Berichte
zur Polar-
und Meeresforschung

588
2009

Reports
on Polar and Marine Research

Selected Contributions on Results of Climate Research in East Germany (the former GDR)

Edited by
Peter Hupfer and Klaus Dethloff

HELMHOLTZ
GEMEINSCHAFT

ALFRED-WEGENER-INSTITUT FÜR
POLAR- UND MEERESFORSCHUNG
In der Helmholtz-Gemeinschaft
D-27570 BREMERHAVEN
Bundesrepublik Deutschland

ISSN 1866-3192

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* Anschrift / Address

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D-27570 Bremerhaven
Germany
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Editor in charge:
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Die "Berichte zur Polar- und Meeresforschung" (ISSN 1866-3192) werden ab 2008 ausschließlich elektronisch als Open-Access-Publikation herausgegeben (URL: http://epic.awi.de).

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Ber. Polarforsch. Meeresforsch. 588 (2009)
ISSN 1866-3192

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Preface

This issue of the “Reports on Polar and Marine Research” is devoted to a topic of recent science history. In the German Democratic Republic (GDR), existing from 1949 to 1990, sciences, and among them geosciences, were quite well developed. This applies also to the meteorology, first and foremost conducted by the State Meteorological Service, but pursued as well at universities, research institutes of the Academy of Sciences, and other institutions. Climatology had been well promoted already since 1945. It was founded on a good balance between basic research and application of climatological know-how for public benefit. The potentiality of a global climatic change, upcoming due to anthropogenic influence upon the atmosphere was recognized rather early. Numerous papers dealt with recent climatic variations in the region. Even in 1990, the final year of the GDR, a national climate research programme was set up.

In the present volume, selected results are described which focus on both, topics of the physically oriented basic research and on problems of climatic variations in different time scales. It should be emphasized that in accordance with modern climatology also geologists and geographers are involved in this restrospection.

The contributions to this report, including numerous references, do not claim for completeness. But they will give a distinctive view on the climate research in the eastern part of Germany during the existence of the GDR.

In 1992 the Alfred Wegener Institute for Polar and Marine Research (AWI) established the AWI research unit Potsdam and extended successfully evaluated peri-glacial and atmospheric research topics, thereby continuing the very long geophysical research traditions on the Telegrafenberg Potsdam.

Polar Regions are highly sensitive regions to global change. Processes in polar regions, connected with a variety of feedbacks, like sea-ice albedo, vegetation and cloud-water vapour feedbacks introduce implications on the global scale and can influence sea level changes.

During the last years the main research topics of AWI transformed to the understanding and quantification of recent climate variability and change in the north and south polar regions through physical, chemical and biological investigations of key processes in ocean, atmosphere, cryosphere, shelf systems and permafrost areas by means of field studies, experimental work and modelling.

The authors are therefore grateful to the Alfred Wegener Institute for Polar and Marine Research (AWI) in the Helmholtz Association for including this volume in their “Reports” series.

Special thanks are due to Mrs. Beate Leutert, AWI Potsdam, for final editing of the papers.

Peter Hupfer and Klaus Dethloff

Climate Research in the German Democratic Republic – an Overview

Wolfgang Böhme[1]

Leibniz Society of Sciences Berlin

Main stages of the climate research

Continuity and built-up (since 1945)

After World War II, primarily it was very important in the east of Germany just as in western Germany to carry on the observational networks like climate, the precipitation, and the phenological ones, including their personal and material basis. This was the duty of the countries' weather services, in the course of which the Meteorological Observatory Potsdam, which exercised the function of the country's weather services for Berlin and Brandenburg, had a guiding function from the very beginning.

Climatological investigations, being possible only in a modest size, dealt with the fulfilment of requirements of the country concerned, or for instance, with the treatment of data from the years before and of war time. Research, ordered by the Hydrometeorological Service of the Soviet Military Administration (SMA), played a positive role in all the existing weather services because it improved the personnel and, over all, the material conditions for research and the people engaged in research. Later developments could early be recognized. Consequently, the weather service of the state Saxony-Anhalt concentrated its research, among others, on problems of surface humidity and to the relations of weather character and agricultural yields (see DWD 2007, section 11.1).

As projected, climate related research was developed especially at the observatories in Potsdam (mainly radiation measurement and heat balance), Lindenberg (aeroclimatology), Wahnsdorf (atmospheric chemistry), Warnemünde (among others radiation, later transferred to Kühlungsborn: radio-wave emission, ionosphere), Greifswald (among others agricultural climatology, and climatology of weather characteristics, existing up to 1957) and at the radiation research station Gotha, which was founded 1948 and existed up to the early 1960s.

Including the country weather services, in 1950 the uniform Meteorological Service of the GDR (Meteorologische Dienst der DDR = MD) was founded. The territorial competence continued with the new offices (Offices for Meteorology resp. Offices for Meteorology and Hydrology) for the countries, respectively for the 1952 created districts (Bezirke) being then the administrative authorities. The climate, respectively hydrological research remained at these offices in a relatively small size.

In the years from 1951 to 1964, the MD was called Meteorological and Hydrological Service with tasks corresponding to those of the Hydrometeorolocigal Service in the USSR. At the end of this phase the departments for hydrology at the offices for meteorology were transformed into research departments, by which during the whole further existence of the MD extensive hydrometeorological investigations have been made, which to a substantial degree can be attached also to the field of climate research.

[1] I am grateful to my colleagues E. Freydank, M. Hendl, P. Hupfer, H.-D. Piehl and J. Taubenheim for comments and completions, cf. also W. Böhme et al. (2007)

The Main Office for Climatology (HAK = Hauptamt für Klimatologie), which was established in 1952, became the leading institution for climatology. To its defined tasks there belonged climate research, regional climatology, and phenology. Already in the year 1953, a large-scale climatic atlas for the GDR was published on the basis of the averages 1881/1891 – 1930 (using the volume of tables 1939 to the "Klimakunde des Deutschen Reiches") and in supplements of the averages 1901-1950 (see also DWD 2007, section 9.8).

In more detail, we enter into the Institut für Großwetterforschung (IGF; Institute for large-scale weather research), because the investigations carried out there have a direct significance also for up-to-date climate research. This institute was established in 1953 by Horst Philipps (1905–1962): Up to the years of the war, Philipps was a co-worker in the research institute for long-range weather forecast, which was situated in Bad Homburg v.d.H. (1929–1945) and was managed by the founder of the Large-Scale Weather Research, F. Baur (1887–1977). This activity inspired Philipps to the foundation of the new institute in Potsdam. At the beginning, the IGF had three fields of work (Wege 2002): (1) theoretical meteorology (mainly radiation theory, energy balance, energetic of meteorological processes, (2) combined climatological and statistical investigations (large scale weather situations and their changes, tables of multiple correlation, anomalies of air pressure and temperature for pentads and months), (3) synoptic investigations (individual cases, circulation in the middle troposphere, 5-day smoothed weather maps of the 500 hPa-surface). Philipps succeeded in joining scientists in this institute, who had already successfully done climatological studies on weather characteristics. Due to the limited availability of data, this led to the fact, that the elements of order for further studies on weather characteristics regarded mainly the "Großwetterlagen" (general weather situations; Flohn & Hess 1949, Hess & Brezowsky 1952). In this field Hans Maede (1909–1988) was very active; he became known for his dissertation on the rainy situations at the southern Baltic Sea, he defended 1952 in Greifswald (Maede 1954), and for many further publications (Maede 1953 a,b,c; 1954 and 1955 a,b). Günter Grünewald and Martin Teich (1911–2003). Günter Grünewald and Martin Teich (1911-2003) belonged also to the group of scientists, which had been active in the field of climatological studies on weather characteristics. Grünewald was engaged in Central European rapid changes of weather characteristics (Grünewald 1955, 1959), whereas Teich (1955) investigated another problem, namely the interaction of Central European high pressure areas with the general circulation of the northern hemisphere.

Further studies of Maede (1956, 1957a, 1959, 1960, 1961, 1963/65) did not preliminary regard the problem of mean range forecasts, but were designed more generally and lead then to dealing with the fundamental question on the possibility of mean range forecasts on a statistical basis, for instance by the use of tables of multi-correlations (Maede 1962). In the case of the fulfilment of additional conditions the results had been encouraging. Böhme (1965) underlined at the same time, that a combination of statistical and numerical procedures may be especially useful. Further investigations by Teich (1955, 1957, 1959, 1960), were more strongly directed towards the problem of mean range forecasts, but often naturally addded new knowledge to climatological questions. It should be very interesting to check the different relations (and their stability) on spatial and temporal relations found by these scientists by means of data of the last 40 to 50 years and to use the results for present-day questions.

In this connection, I should like to underline that in the surrounding of this group further scientists (e.g. Böer 1954, Heyer 1954, 1955, Heckert 1955, Wiechert 1960, Wörner 1968) have been engaged in this special climatological field.

Later on, in connection with the preparation of the introduction of the numerical weather prediction, in the IGF a paper was prepared to objectify the definition of the general weather situation (Barg & Böhme 1962) which may be of climatological interest, too. In this connection, proposals were made by the IGF (a.o. Barg 1966) to investigate the extension of the quasi-biennial oscillation (QBO) of the general circulation. In resulting papers Böhme (1967, 1969) could show, that the QBO is not limited to the tropics, but has a global extension and that it is present also in the frequency of blocking situations in mid-latitudes. Further proofs for the existence of the quasi-biennial oscillations in mid-latitudes can be found in Sprenger & Schminder (1967), and Barg (1969/1970).
For investigations concerning the atmospheric circulation see also the chapter "General Circulation of the Atmosphere".

The papers on spatial and temporal distribution of the incoming radiation (part I) are of outstanding climatological importance, the outgoing one and the radiation balance at the sea level of Bernhardt and Philipps (1958, 1966 a.o.) which later were supplemented (see also section "Climate related Radiation Research"). As his last contribution, Philipps published an extensive paper on the theory of the daily variation of the temperature near the ground. This paper is not only a valuable contribution to the climate theory, but has also current importance with respect to the testing of modern numerical models, as it covers processes in the transit region between ground and atmosphere (Philipps 1962, 1964). After the death of Philipps, Fritz Bernhardt (1897–1982) became Chief of the IGF. In the year 1971, the IGF was incorporated into the Potsdam Central Weather Office as its Theoretical Department.

As in the early years of the GDR, work of climatolocigal importance was barely done at the Academy of Sciences, climate research was developed at university institutes in relatively broad fields, but only with a modest volume. That concerned institutes which educated graduated meteorologists (Diploma – Meteorologists): in Leipzig by W.Hesse (1915–1979) with regional and agricultural climatology, and in Berlin by Johannes Hoffmeister (1894–1974) with regional climatology. At the Dresden Technical University (TU) climatology was developed by Herman Pleiß with regional and forest climatology, in Eberswalde by Friedrich Kortüm (1912–1993) with forest climatology, in Rostock by Adolf-Friedrich Bauer with agricultural and orographical climatology, and in Jena by Horst-Günther Koch (1911–1981) with regional climatology. Moreover, work on regional climatology started again at geographical institutes, for the time being in Greifswald and Halle. This concerned the habilitation paper of Reinhard (1950) and the dissertation of Kliewe (1951).

Harmonized basic and practice-related research (since about 1955)

In the meteorological service (MD), the research work at the HAK was concentrated in the first place on the investigation, systematisation and interpretation of atmospheric states and processes for the description of the climate in the GDR (a.o. MHD 1955, Böer & Lorenz 1956, Antonik and Börr 1962): beside the publication of the climate atlas of the GDR, as already mentioned, this resulted in detailed local and regional climatologies (e.g. Böer 1960, Antonik 1961, MD 1971, see also the chapter "Global Climatic Classification"). In connection with this, there had been a series of investigations devoted to the spatial and temporal distribution of the air temperature, which can be taken as an indirect measure for the heat balance and proved to be a means for the delimitation of different climate regions (Antonik et al. 1963/65, Böer 1963/65, 1966). Furthermore, conceptional and methodical work was done for the measurement and processing of data as well as for the distribution of information, which should be seen in connection with the development of the network of meteorological stations (see for instance MD 1987, Wege 2002). In cooperation with the

Workshops of the Academy of Sciences, the Instrument Office developed an automatic meteorological station (Baumgart and Höhne 1969/70). About 40 specimens of the first generation were introduced in the MD network in the period from 1970 to 1981. After 1981 a further developed generation followed.

In the MD great importance was allotted to the development of the applied climate research, which means research concerning practical application of climatological data. This was shown in the foundation of three research institutes (see DWD 2007, sections 11.1, 11.2, and 6) within the MD: a research institute for agricultural meteorology in Halle, another one for bioclimatology in Berlin-Buch, and the third one for hydrometeorology in Berlin-Mitte, which all operated branch-offices or research stations. Besides these institutes, the HAK continued to be the most important institution for the development of applied climate research. In the year 1959, on the initiative of Wolfgang Böer (1920 – 1971), whose activities in the GDR enduringly promoted climate research in several fields, a working sphere "Technical Meteorology" had been established, at the beginning as a working group and later on as a department for technical meteorology (DWD 2007, section 11.3), that gained structure-determining importance. Besides this new direction, the HAK had the Department Basis and Information and the Department Network. In about 1970, the target of a "comprehensive meteorological service of the national economy" by the institutions of the MD for all parts became the permanent principle that could evidently be realized successfully. By this it is understood that in each case all climate and other data had to be prepared, represented, and interpreted in such a way, that the individual sectors of economy were enabled to take into account the influences of weather and climate to their advantage and the avoidance of detriments.

Within the MD, the present Meteorological Main Observatory Potsdam (MHO, Körber 1993), the Aerological Observatory Lindenberg (Dubios 1993, Neisser 2005) and the Meteorological Observatory Wahnsdorf (Herrmann et al. 1991) continued to be research centres. The Greifswald Observatory was closed in the second half of the 1950s, whereas the Observatory Kühlungsborn, which had specialized in the physics of the high atmosphere, was incorporated by E.A. Lauter (1920–1984) into the Heinrich Hertz Institute of the Academy of Sciences in 1968 (since 1969 with the common name "Central Institute for Solar-Terrestrial Physics").

Within the MD, the MHO was of the greatest importance for the fundamental questions of climate research. The focal points represented there had been radiation measurement and radiation theory, ozone, investigation of the heat balance and the turbulence and, later on, climate-diagnostic research. The traditional research field concerned radiation, including the careful continuation of the longest radiation series of the world (in the 1980s these series were submitted to an extensive homogeneity check by K. Behrens). To this belonged the development of new instruments for radiation measurement and to safeguard the calibration of instruments of other institutions of the whole world with the Potsdam standards. Later, as a special focal point, radiation theory belonged to the research programme of the MHO which was of importance in connection with the developing exploitation of satellite data.

As far as the focal point heat balance is concerned, we refer to the chapter "Interaction between the Atmosphere and the underlying Surface". The measurement of total ozone, that was resumed on K.-H. Grasnick's initiative (1916–2000), was a profile line of this observatory (see also the chapter "Long-term Measurements of Atmospheric Ozone"), that since 1974 had become a regional ozone centre of the Regional Association VI of WMO. At the Meteorological Observatory Wahnsdorf the ozone near the ground has been a focal research point for many years.

At the universities also capacities for climate research were growing. At the Geophysical Institute of the Leipzig University research oriented towards climate was developed in connection with the delivery of the directorship to K. Schneider-Carius (1896 – 1959, see Börngen et. al. 2003). His paper on the climate, its definition and its presentation, which still is worth reading today, was published posthumously (Schneider-Carius 1961). At this institute the Geophysical Observatory specialized on the physics of the high atmosphere and therein on long-time measurements of the wind in the lower ionosphere (see Schminder 1992 and also DWD 2007, section 2.6.1.1). In the year 1957, at the same institute, the Maritime Observatory Zingst was established, which also served as a basis for climatologically important investigations (Hupfer et. al. 2006, see also chapter "Marine climatic variations of the Baltic Sea"). In the Area Geophysics, into which since 1971 essential parts of the Geophysical Institute had been included, experimental aerosol studies were established (see also section "Experimental Investigation of Atmospheric Turbidity in Leipzig") and different measurements of the city's air were performed on top of the very tall university building in the framework of a "City Observatory".

Led by J. Hoffmeister, the Berlin Humboldt University became the centre for regional climate research. Later, a focal point was formed for the development and application of statistical methods to the analysis of time series, to which in course of time further climatological themes were associated, which the working group "Climate Research" dealt with. Research started within the boundary layer and a number of aeroclimatological investigations had been carried out (see section "Aeroclimatology").

The Institute for Agricultural Meteorology at the Leipzig University carried out experimental and statistical investigations (see section 11.1.2.4). Institutions for agricultural meteorology existed also at the universities in Halle (DWD 2007, section 11.1.2.3) and Rostock (DWD 2007, section 11.1.2.1). At the TU Dresden, in Tharandt, a measurement area "Wildacker" was started, which allowed detailed water balance and forest-meteorological investigations (see also DWD 2007, section 9.6). At the Institute for Forestry Meteorology of the Forest Science Faculty of the Berlin Humboldt University in Eberswalde, besides the legendary lysimetric measurements, mainly investigations were performed concerning the heat- and water-balance of the forests in the flat country of northern Germany. After the closure of this faculty in 1965, the investigations have been continued by the Academy of Agricultural Sciences.

At the geographical institutions of several universities and high schools climatological investigations were also made, however, with a very limited personal capacity. These investigations mainly concentrated on questions to the climate classification (Berlin Humboldt University), such as regional climatology (Berlin Humboldt University), in the beginning also the Greifswald University and Pedagogical High School Potsdam, and on investigations of orographical climatology (Pedagogical High School Potsdam, Dresden Technical University, Berlin Humboldt University). In the year 1962, for the first time the book "Witterung und Klima" (Weather situations and climate) of Ernst Heyer (1912 – 1987) appeared, who taught at the Pedagogical High School Potsdam. Originally, morphological research related to the Quaternary, as focal point research of some geographical universities and high school institutions as well as of technically related ones, led to insights into the climate history mainly of the Pleistocene and the Holocene (see chapter "On the Development of the Landscape and Climate in recent geological History").

As to be seen from DWD 2007, section 3.2, for paleoclimatology no separate institution had existed there. Related work was often developed on private initiative. The extraordinary great number of drillings, done for prospecting purposes as well as the great number of open-cast workings for brown coal provided, in principle, optimal research conditions which in a united Germany could be used in an ordered way.

In these years in the Academy of Sciences extensive investigations were done into the processes in the middle and high atmosphere (see DWD 2007, section 2.6.1). Due to the requirements of the statistical specification of the data gathered, in 1969 the well-known textbook "Statistical Interpretation of Geophysical and Meteorological Data" by J. Taubenheim was published. Important contributions to the coupling between troposphere and stratosphere were presented by the investigation of atmospheric gravity waves (see also section "Experimental Investigations of Atmospheric Gravity Waves"). At the observatory Kühlungsborn, a group was created under the guidance of G. Schmitz who did climate and circulation modelling for special questions. At the Institute for Physical Hydrography C.Weikinn (1888–1966) was given the possibility of continuing his voluminous collection of proofs for the history of weather and climate and of publishing the results.

The oceanographic investigations performed by the "Institut für Meereskunde" (about: Institute for Oceanography), led by K Voigt (1934-1995), besides the Baltic Sea, concerned mainly the Atlantic Ocean (see section "Atlantic Exploration and Climate") at which the investigations on the buoyancy and the research on the equatorial systems of currents had deserved special emphasize. Solar processes had been studied at the Observatory for Solar Radio Astronomy near Potsdam.

On the way to a national research programme (since 1980)

After numerous discussions also in the GDR on a possible forthcoming climate change and connected consequences, the first world climate conference, which had come up in 1979 at Geneva and in which a delegation of the GDR took part, can be taken as the landmark, for adjusting climate research to the global environmental problem "climate". This statement concerns academic teaching, continued education of the scientists, who are active or interested in climate research, as well as the selection of the research tasks. Due to the international evolution, ozone research gained an increased importance (compare with section "Long-term measurements of Atmospheric Ozone"). The research and development themes, which were important with respect to climatic variability and climatic change, and to the investigation of the climatic system, were concentrated at the MHO that took the lead in this field.

A stronger support was given to climatic modelling, being at that time still in its infancy. It was mainly developed at institutions of the Academy of Sciences. However, because of limited computational recourses, a much more rapid development of this direction of research in the Federal Republic of Germany was impossible.

The research at the universities took up these new challenges by a stronger proceeding to the questions concerning the investigation of the climate variability and by analysing global climatic problems (ENSO; see DWD 2007, section 2.8). This was promoted by research studies which had become possible then in the USA and the FRG. The Institute for Oceanographic Research Warnemünde took part with its ships in the great projects of the World Climate Programme (WCP). Although the targets of these enterprises in the first line had been of oceanographic nature, yet they added to the knowledge on the role the ocean plays within the climate system. A universal centre of gravity was the diagnostics of the climate of the territory with modern statistical methods including scientific historic considerations (Bernhardt 1984, 1985, 1987, 1990).

A representative publication of a book on the climate system, in which numerous climate investigators of the GDR and the USS took part, had been started and was published in 1991 (Hupfer 1991). Originally, this publication was earmarked as an “Address of GDR-climatologists on the climate problem”.

In the second half of the 1980s, the new evolution in the field of climate research was marked by efforts to create a national climate research programme. As already mentioned, in the beginning of 1986, in connection with the international development the guidance of the climate research in the MD was transferred from the Main Office for Climatology (HAK) to the Meteorological Main Observatory (MHO), at which climate diagnostics also became concentrated. The director of the MHO, Ilse Spahn, was charged with the preparation of the climate research programme. She was supported by a working group which was led by P. C. Werner and consisted of scientists of the institutions engaged in climate research. The first representative on paleoclimatology included was K.-D. Jäger.

A Commission on Climate and Ozone Research established in 1989 had the task to examine the draft of the programme and to confirm it. Under the direction of W. Böhme, to this commission there belonged nine members of the MD, four of the universities, three of the Academy of Sciences, and five of other institutions. In January 1990, the passed programme was handed over to the Minister for Nature and Environmental Protection and Water Management. Due to the quick political development, however, this programme could not be implemented. Nevertheless, 16 years later, the programme still appears quite modern. It contains four cardinal points: the development of scenarios for extreme realizations of the climate variability for the country, the investigation of the natural climate variability by climate diagnostic methods, the development of climate modelling, and the realization of research for the closing of gaps in the understanding of partial processes in the climate system of the Earth.

So to speak, this programme gives the final point to the climate research in the GDR, the themes of which have been furthered to a large extent after the unification of the German state and they were included in the German Climate Research Programme (GSF 1992).

International cooperation

In general and as well as in the GDR, there existed the fundamental conviction, that international cooperation in meteorology and, by this, also in climatology is of very high and indispensible value. Scientific ideas and questions, in general, can be led to realization, respectively clarification and through this to a success only if agreement is early reached on the scientific procedures, which include especially measurement, control and interpretation procedures. In this way, all nations may have a benefit. In this sense, Böhme (1973) had underlined, appreciating the international conference of meteorologists in Leipzig in 1872 as the “birthday of the international cooperation in meteorology”, that the cooperation between representatives of meteorological institutions on the basis of equal rights and in accordance with the experiences made, relieves these bodies of political disputes and enables them to concentrate on scientific problems.

In essence, the international cooperation in the field of atmospheric sciences proceeded in two different ways. On the one hand, the GDR was correct and constructively endeavoured to take actively part in the relevant scientific international organizations and in common international activities. At corresponding meetings and also at international conferences and congresses smaller delegations of leading and mostly competent scientist took part. To this category belong also international comparisons of instruments as well as calibrations of instruments, which took place under the auspices of the World Meteorological Organisation (WMO). Within the last ten years of the existence of the GDR an exchange of scientists began, although numerically small, with the USA, the FRG and other western countries.

On the other hand, also in the field of climate research, cooperation mainly existed with the USSR and the other socialist countries. Although tourist traffic and the trade of goods were not free of bureaucratic hindrances, joint projects were successfully developed and realized in the frame of various organizational forms. Outstanding instances are common expeditions of different kind, experiments for the measurement of turbulence and coastal experiments and, last but not least, the cooperation in the field of remote sensing of geophysical information. In principle, this kind of cooperation was well developed and of mutual advantage.

Following the tradition of the International Polar Years (1.IPY 1882/83, 2.IPY 1932/33), the "year" 1957/58 was carried out as the International Geophysical Year (IGY) which then was followed by the year of the International Geophysical Cooperation 1959 (IGC), and later (1964/65) by the International Year of the Quiet Sun (IQSY). The participation of scientists of the GDR (see also Böhme & Körber 1984) at the IGJ/ IGC and at the IQSY was initiated and furthered by Horst Philipps, the director of the MD at that time, in cooperation with Hans Ertel (1904–1971) at that time Vice President of the German Academy of Sciences (DAW). Philipps, who was the President of the coordinating National Committee for Geodesy and Geophysicy at that time, presented at the Meeting (which then had still an all-German character) of the Meteorological Society in the GDR in October 1960 at Eisenach the welcome address by Hans Ertel, in which he said: "this meeting of meteorologists should show, that even in a time of utmost globally political tensions, the continuity of the research and of the exchange of scientific experiences will be preserved by the intelligent and ready to help position of all participants concerned. The meteorological science is called to the solution of great tasks in the service of the whole mankind…" And Philipps continued "The boom following after 1945 and the progress (which puts all expectations in the shadow) in all disciplines of the natural and technical sciences had led to the growing recognition, that there is a need for optimal mastering of tasks which stand before sciences. On example par excellence is given by the International Geophysical Year`" (Philipps and Ertel 1961). In these international activities scientists of many institutions of the MD, the DAW and the universities took part. The cooperation was realized on expeditions, by programmes of observatories, and in the form of the interpretation of the high quantity of data gathered. Of the expeditions are only mentioned here the German USSR Tienschan expedition in 1958 with its measurements of the heat balance on glaciers, and the oceanographic expdeditions on the RV "Michael Lomonossov" to the Atlantic, in which groups of German scientists took part (Hupfer 1958).

A successful cooperation with the USSR took place within the scope of Antarctic research that ultimately culminated in the establishment of the GDR station "Georg Forster". The first participation of GDR scientists started with the Fifth U.S.S.R. Antarctic Expedition (SAE) 1959/61. The meteorological / climatological studies done had a relatively minor volume, nevertheless, the glaciological and geological investigations contributed to an improved knowledge of the climate system (see DWD 2007, sections 2.9.1 and 2.9.2). J. Kolbig (1933–1999) had performed already ozone measurements near the ground in Mirny (Kolbig 1965).

In a comparable way, the cooperation in the fields of remote geo-reconnaissance and space research with the USSR and the other socialist countries was developed in which numerous institutes of different activities participated. Since the 1970s a substantial expansion of the data basis for climatological investigations, too had resulted in the use of meteorological satellites in an international scope. I. Spahn in a paper, which was read at the German Aviation and Space Flight Congress in 1992, drew the attention to the activities in the framework of the Interkosmos Cooperation, to the contribution of the GDR, and to existing problems.

Beside the Interkosmos activities, the cooperation also was developed in the scope of the Committee on Space Research (COSPAR). In the 1960s and the 1970s the targets of the international cooperation in the field of meteorology with its World Weather Watch (WWW) and the Global Atmospheric Research Programme (GARP) were oriented by using new technological means to the improvement of the observing system for the numerical weather prediction and to a better understanding of the atmospheric circulation. At that time, more precisely from 1966 to 1980, W. Böhme cooperated in the working group 6 (Cosmic Meteorology) of COSPAR in the preparation of GARP.

In the frame of the Council for Mutual Economical Support (RGW, COMECON) at the beginning of the 1970s there existed an intensive cooperation in the field of the programme "World Ocean". Besides oceanographical activities, for the first time complex multilateral coastal experiments were performed, which were dedicated to the dynamics, including the transport of matter and the interaction between sea and ocean in the immediate proximity of the coast. The first experiment of this kind took place at the Maritime Observatory Zingst of the Leipzig University in the year 1973 (Druet et al. 1975; Hupfer et al. 2006). Further experiments were carried out at the Polish coast and in Bulgaria.

A useful cooperation and furthering science was developed in the frame of the Commission of the Academies of Socialist Countries on the Field of Planetary Geophysics (KAPG). Taking into account the level of the research achieved in the world, themes for common research were formulated and results had been exchanged. The broadly designed palette of themes covered also problems of modern climate research, as well as the solar-terrestrial relations concerning the earth atmosphere. To the activities in the KAPG, see Foken & Bernhardt (1994) and Taubenheim (2003).

An active cooperation of different intensity was given in the international scientific organisations, as the International Union for Geodesy and Geophysics (IUGG) with its technically related Associations. One example for it is the atlas on the elements of the water balance of the Central and East European socialist countries, which was created within the scope of the International Hydrological Programme (IHP) of the IAHS at which the responsibility to the complex theme of evaporation (Freydank et al. 1983, 1986) was given to the GDR. An important concern was the participation in the World Climate Programme (WCP). In the middle of the 1970s, also in connection with results of the GARP, it became more obvious that human activities have a growing global influence on the climate. This was the background to convene the First World Climate Conference in 1979 and to initiate the WCP (WMO 1980), including its sub-programmes and especially the World Climate Research Programme WCRP (WMO 1981). Detailed information is given in Böhme & Golicyn (1991). Within the WMO a working group, respectively a group of reporters of the Commision for Atmospheric Sciences (CAS) dealt with the WCRP. This group was led by W. Böhme in the period 1979 to 1990 (see also TABA 1998). At the Second World Climate Conference 1990 he, too was charged with the guidance of the "Task Group 10" for the theme

"The World Climate Programme: Overview and Future", which had to prepare recommendations for future priorities of the WCP and its components. The eleventh WMO Congress in spring of 1991, in principle, accepted the recommendations of the Second World Climate Conference. They form part of the background of the United Nations Framework Convention on Climate Change (UNFCCC) which was adopted by the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992.

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Sun, Radiation and Clouds

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Solar-terrestrial processes

After the end of the war the investigation of variable energy turnover processes at the active regions of the solar surface and the solar atmosphere could proceed from the results and experiences gathered with the optical observations of the sun at the Potsdam astronomical institutes (Astrophysical Observatory, Einsteinturm, Sternwarte Babelsberg) during the preceding decades. Since 1947 these institutes hade been incorporated into the "Deutsche Akademie der Wissenschaften zu Berlin (German Academy of Sciences at Berlin). At the beginning of the fiftieth of the 20th century both the Potsdam Astrophysical Institute and the Heinrich-Hertz-Institut für Schwingungsforschung of the Academy started nearly simultaneously the measurement of the spectrum of the solar radio wave radiation. Both, (1) the uninterrupted registration since that time and (2) the internationally distributed documentation of the data of the solar radio emission in order to trace those long- and short-term solar activity variations that may be of interest for the climate system of the earth, form an essential contribution of the GDR to the International Geophysical Year (IGY) 1957/58 and to its numerous succeeding international programmes, as well as for the cooperation in the Commission for Planetary Geophysical Research (KAPG) of the Academies of Socialistic Countries (see Taubenheim 2003). In 1969 the Central Institute for Solar-Terrestrial Physics (ZISTP) of the Academy of Sciences of the GDR had been formed. Herewith the work in the field of radio astronomy had been combined with that of the solar observatory Einsteinturm. The investigations concerned mainly the radiation of radio-bursts, the solar noise-storms and variations connected with solar active regions in the scale of days and weeks (see for instance Krüger 1979; A. Boehme 1989, 1990; Aurass et al. 1978). The studies of solar-terrestrial processes of the atmosphere of the earth in the ZISTP were concentrated towards the effects of the solar activity in the layers of the middle and high atmosphere that were ionized by the solar ultra-violet and Roentgen radiation (see section 2.6.1). In 1984, in connection with a transformation of the Heinrich-Hertz-Institute for Atmospheric Research and Geomagnetism, the solar-physical investigations altogether were given to the Potsdam Central Institute for Astrophysics. After the winding-up of the Academy of Sciences these investigations were carried on by the Astrophysical Institute Potsdam (AIP), which belongs since 1992 to the Leibniz Community.

In the habilitation paper of W. Böhme (1969), in which as a main result could be shown, that the quasi-biannual oscillation (QBO) is not limited to the tropics, but has a global character (Böhme 1967 a, b), as a further essential result clear hints were found, that coherent connections exist between a quasi biannual variation of the solar activity and oscillations of the general circulation of the earth's atmosphere. This became very distinct with the comparison of the monthly time series of the middle heliographic latitude of the sun-spots and of the frequency of meridional circulation types of the atmosphere over Central Europe. Further, it was remarkable, that the time series of the relative number of the sun-spots do almost not show such behaviour. In this paper it was discussed in detail, which processes are at work between sun and earth. It proved to be most probable, that a combination of the variation of the intensity of the solar corpuscle radiation with the variation of the intensity of the solar ultra-violet radiation is important. By the way it could be shown, that a prognostic relation which was empirically derived by W. Böhme (1959) and which connects the atmospheric circulation at a given day t_L with the circulation which occurs on the average at the day t_A of the general year (in the sense of a meteorological singularity) can be explained by the existence of a quasi 26-month cycle.With the further pursuance of this theme after 1990 in connection with investigations for the generalisation of the application of the term “remote effects” by W. Böhme (2004a) he draw the attention to the fact that the (1) course of meteorological monthly time series (for instance of the series of the deviation of the monthly mean temperature from the long-time average) and (2) the course of the series of the Southern Oscillation Index (SOI) as well as (3) the course of the monthly time series of the geomagnetic index aa relative frequently have a similar behaviour with respect to their temporal structures, W. Böhme (2004b). The index a characterizes the intensity of the geomagnetic disturbances in the belts which join both the circumpolar aurora belts in the directions to the equator. This supports the conclusion, that the solar-terrestrial relations (at least the kind, which is discussed here) are connected with the corpuscle radiation. The frequency of the simultaneous occurrence of similar sequences of state in different series is used as a measure of the similarity of the temporal structures. This can be seen in the simultaneous appearance of equal distances of analogies in the discussed different temporal series. The use of this behaviour in meteorological time series may be especially fruitful because one can trust, that as is known from complex dynamical systems with the ability for self-organization, spatial structures of a larger scale in the atmosphere are connected, at the same time, with larger temporal scales; this means that the mentioned larger scale structures will have longer lifetimes and normally higher predictabilities. Similar relations may be valid for the interplanetary space, at least for the part near the Sun and the Earth. The expected relations (regarding lifetime and predictability) show already up, as was already mentioned (Böhme 1993 a, b) with strong volcanic eruptions, at which the large scale spatial disturbances, generated by the eruption, astonishingly have a lifetime of many years, although their amplitudes are often an order of magnitude smaller than the amplitudes of the spatially smaller scale “noise”.

Climate related radiation research

The Meteorological Main Observatory in Potsdam of the Meteorological Service was the centre of the meteorological radiation research in the GDR.

Critically evaluated long-term measurements and records were edited and extensive homogeneity checks performed (K. Behrens). Based on these data, quite different projects have been investigated. The results have been published in numerous papers. Summarizing overviews on the radiation research in general as well as on the measurements in Potsdam had been given by Foitzik and Hinzpeter (1958) and Hinzpeter (1953). Later Spänkuch (1985) discussed the role of the radiation processes within the climate system on Earth.

Climate-related analyses of radiation data measured in Potsdam since 1937 demonstrated that the sunshine duration and the direct solar radiation had decreased within this time spread. In contrast to these findings, the diffuse sky radiation and the ratio of sky radiation to global radiation had increased.

These tendencies might mainly be explained by the increase of both, opaque deep clouds and middle height clouds. This variation in the cloudiness corresponds to synchronous changes of the atmospheric circulation. Comparing the years 1937/40 and 1986/89 the ratio of direct solar radiation to sunshine duration decreased by about 0.3 % per year. Furthermore, it is of interest that in almost all months before 1960 this ratio was continuously above the long-term average of the years 1937/89. After 1960 this value was lower than that average with only few exceptions (Schöne et al. 1990).

Götschmann (1960), Zerche (1969) and others published papers about spatially compared variations of the sunshine duration.

Discussions about the influence of aerosol particles on the climate (see also v. Hoyningen-Huene, within this volume) are mainly founded on models related to their optical properties. Within this context the change of the short wave planetary net radiation has been ascertained as a function of the turbidity on the base of empirical relations between global radiation and turbidity. In dependence on season, place and turbidity factor these investigations resulted in an estimation of maximal heating rates of 0.2 to 0.5 K/d in the troposphere (Spänkuch). The global radiation follows a non-linear function decreasing with the turbidity.
But the measurements made in Potsdam did not allow educing that a significant difference exists for the decrease of the global radiation for air mass types with different aerosol (Spänkuch and Schöne 1961). The raising of the turbidity factor by one unity refers, with regard to its influence on the global radiation, to a factor of 2 to 3 tenth for the increase of cloudiness.

Regarding aerosol research associated with the participation in polar research it should here be referred to Leiterer and Sakunov (1989) as well as to the summarizing paper by Böhme und Mundt (1990).

H. Wörner, Meteorological Observatory Potsdam, compared measurements of the radiation balance for the meridian 10° E in the period between IGY/IGC (1957/59) and IYQS (1964). He could present that both parameters, global and net radiation had increased during the International Geophysical Year (with intensive and more powerful solar activity) compared to the International Year of Quiet Sun. According to Wörner, these effects can primarily be interpreted by large-scale circulation variations between the observational periods.

The global calculations and estimations of radiation components and net radiation conducted by Bernhardt and Philipps (1958, 1966 and others) had been of extraordinary importance for the climate research and were presented in form of hemispherical maps, meridional sections, isopleths diagrams as well as tables for every month and the annual average. The following list of parameters had been taken into account by the work mentioned above: the extraterrestrial radiation, the Rayleigh radiation, the direct solar radiation in consideration of the turbidity and cloudiness resp., the diffuse sky radiation and both, the global and net radiation, whereas the latter is defined as the difference between global and reflected radiation. In the second part (1966) of the papers approximated calculations of the long-wave radiation fluxes had been pursued which were performed in dependence on given vertical distributions of air temperature, moisture and CO_2 concentration resp.. Results are accessible for distributions of the atmospheric back radiation, the effective emitted radiation and last but not least the net radiation.

The results of this fundamental work are absolutely comparable with corresponding calculations from Albrecht, Budyko and others. But unfortunately they did not find the same acceptance. The reason should be found probably in the employment of German language and/or because the publication was realized in a relatively nameless journal.

The early work done by Bolz and Falckenberg (1949) had been proved to be of considerable climatological importance because it deals with the determination of the atmospheric back radiation Q_G on the base of measurements conducted in Warnemünde at the Baltic Sea coast. The findings have been cited very often. The mean values of the back radiation are calculated

by a special form of the well-known Ångström formula suitable for the application in the Northern coastal area of Central Europe.
Without consideration of the cloudiness the formula can be expressed as follows:

$$Q_G = \sigma T_L^4(0.820 - 0.250 \cdot 10^{-0.95 \cdot e}) \qquad \text{cal cm}^{-2}\ \text{min}^{-1}$$

with σ = Boltzmann constant, T_L = surface air temperature in K and e = vapour pressure of air near the surface in hPa.
For the influence of clouds Bolz (1949) has developed a factor for the formula mentioned above:

$$(1 + kC^{2.5})$$

with C = cloud cover ($0 < C < 1$) and k = coefficient, depending on the cloud species. On the average k is 0.22.

Containing numerous data for radiation and cloudiness, the data manual of the Meteorological Service, Ser. B, No. 3, was very valuable for practical climatological works. Included can be found also radiation data received from inclined surfaces. Such measurements have been carried out in Potsdam and formulas for the calculation of the different properties had been developed (for example Schöne and Busch 1986). These data were required especially for investigations in the area of the urban climate or microclimate (compare Junghans 1967).

Based on the relatively commonly available data of sunshine duration formulas for calculation of the global radiation were developed with practical benefit. Hinzpeter (1953, 1958), Matzke (1953) and others have made studies on this topic. For application in the area of the West Pomerianian coast of the Baltic Sea Foken and Foken (1979) developed a formula to estimate the daily values of the global radiation.

Further investigations for the calculation of the global radiation on GDR territory were given by v. Schönermark et al. (1973). Based on data of the global radiation data acquisition network Schöne and Behrens (1989) investigated the spatial variability of the daily sums of global radiation for the same territory. Except for Potsdam, evaluations of radiation data from other stations had been presented, an example is the paper of Matzke (1953) for Greifswald.

Clouds as components of the climate system

Investigations into cloud physics and climatology were stimulated doubtlessly in the GDR by Süring's well-known monograph of 1950, the author of which has described the actual knowledge of the first post-war years in the supplemented third edition.

Bernhardt, 1960, 1961 has treated morphological, synoptic and climatological characteristics of low clouds, cloud microphysics included. The study was based on the boundary layer conception by Schneider-Carius, 1953 and extended references, including data from aerological observatories and aircraft weather reconnaissance stations obtained during the pre-war and war time. Following, theoretical investigations have been carried out on the influence of diabatic, radiative especially, processes on isolated clouds on the one hand (Bernhardt, 1962), and on the determination of the height of low cloud bases from surface parameters on the other hand (Bernhardt, 1967). Cloud structures to be seen from satellite pictures were related to boundary layer types (Werner et al., 1976) and to vertical moisture profiles (Schubert et al., 1976). Structures of convective cloud fields have been simulated by means of cellular automats in the unpublished diploma thesis by Friedrich, 1989.

Numerical thermodynamic models have been applied to problems of technical meteorology by Graf, 1982, and to the determination of the height of convective cloud tops by Teubner, 1988. Finally, moist convection parameterization approaches were developed by Hellmuth and Pethe, 1988, with regard to the hydrological cycle, general circulation and climate.

Spänkuch, 1985 has discussed the role of clouds for radiative processes in the frame of a review paper on radiation and climate. Other special investigations into clouds as components of the climate system were dedicated to radiative properties of cirrus clouds as derived from Meteor-28 Fourier spectrometer measurements (Spänkuch and Döhler, 1985) and to climatic effects of changing cloudiness on polar ice (Vogel, 1985).

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Long-Term Measurements of Atmospheric Ozone

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Column ozone measurements

Instruments and data

A basic fundament for later worldwide systematic measurements of atmospheric ozone – triatomic oxygen – was laid by Gordon Miller Borne Dobson (1889 – 1976) in the twenties of the last century by constructing a Fery spectrograph in his laboratory in Oxford, and using it to measure spectral direct solar ultraviolet radiation in the ozone absorption bands to derive the column ozone amount in a vertical air column of air from the Lambert-Bouger law (Dobson 1966). The first series of his ozone spectrographs manufactured in Oxford were used in 1926/27 at 6 European stations – among them the Aeronautical Observatory Lindenberg founded by Richard Aßmann in 1905 (Steinhagen 2005) – to measure column ozone, and get a first pattern of the spatial ozone distribution. Another approach to measure the ozone variability in space and time again was discussed at the second International Ozone Conference at Oxford in 1936, and the decision taken to measure ozone at 15 European sites for a period of at least two years (Brönnimann et al. 2003). One of those sites was the Meteorological Observatory Potsdam that had commenced operation in 1893. The ozone instrument determined for Potsdam, Dobson spectrophotometer No. 9, arrived at its destination shortly before World War II in summer 1939. Due to technical problems and the non-availability of spare parts from the manufacturer in Great Britain, it took until September 1941 to take the instrument into routine operation (Hoelper 1949). Maria Dorfwirth took regular ozone measurements from the roof of the Potsdam Observatory by March 12, 1945 (Körber 1993). That first record of ozone measurements at Potsdam was later analyzed and published by Hans Hinzpeter (1921 – 1999) (Hinzpeter 1952).

The resumption of ozone measurements at the Potsdam Observatory after World War II, and their integration in international research programmes was in no small part due to the activities of Karl-Heinz Grasnick (1916 – 2000). He and his colleagues succeeded in re-installing available radiation instruments, modernising them, developing new instruments such as broad-band UV filter radiometers, and having them manufactured in the Observatory's machine shop during the 1950s. On the occasion of the International Geophysical Year in 1957/58, atmospheric column ozone measurements were resumed with a Hoelper spectrometer (Grasnick 1963) which had already been used to measure diffuse ultraviolet sky radiance at Potsdam in the 1930s by Schloemer (1938).

Modernisation of Dobson spectrophotometer No. 9, which became then No 64, and installation of a second new Dobson instrument No 71 manufactured by R. and J. Beck Ltd., London, improved the instrumental equipment for ozone measurements. Günter Skeib, director of the Meteorological Observatory Potsdam at that time, and Christian Popp took one of the Dobson instruments to the Antarctic station Mirny at 66.5° Southern latitude, and performed ozone measurements under extreme climatic conditions from November 1959 to April 1961 (Skeib & Popp 1961). Due to a tragic occurrence, Ch. Popp did not return from that expedition. A regular daily column ozone record started at Potsdam in January 1964. The ozone data were submitted to the World Ozone Data Center (WOUDC 2005) and the results of these early measurements published by K.-H. Grasnick in several papers (see references by Feister 1985, and Körber 1993).

Grasnick was also one of the scientists initiating regular ozone soundings with balloon-borne ozone sondes, which provide the vertical ozone distribution from the ground up to the middle stratosphere (> 30 km). An ozone sonde was added once to three times per week to the regular 6 hourly launches of radiosondes at the Lindenberg Observatory from December 1974 onwards (Leiterer et al. 2001. Between 1974 and 1992, ozone sondes of the type OSE (Rönnebeck & Sonntag 1976) were used, and the results of soundings analysed (Feister et al. 1985, 1986). The OSE sonde type was also tested under extreme weather conditions at the Antarctic station Novolasarevskaya from 1975 to 1977 (Gernandt 1979) and used for regular ozone soundings from 1985 to 1992 at the Georg Forster station in the ‚Schirmacher Oasis‘ (at 70° 40‘ S) (Gernandt 1979, 1987, 1990; Gernandt et al. 1987, 1989; Feister et al. 1989). Ozone soundings with this type of ozone sonde were performed by Peter Plessing and Eckehard Peters during ship expeditions on the Indian Ocean (Feister et al.1981).

At the meeting of the Regional Association VI (Europe) of the World Meteorological Organization WMO in Bukarest in 1974, the Meteorological Observatory Potsdam was nominated to serve as a Regional Ozone Center of Region VI (Europe). Dobson spectrophotometer No 71 was used from 1974 onwards as one of the reference instruments of Region VI, but that status was transferred to the modernised Dobson instrument No. 64 in 1981. The Regional Standard Dobson instrument was calibrated several times by the World Standard Dobson instrument in Boulder (USA) and it served as a reference instrument at the Dobson intercomparison campaigns in Potsdam in 1979 and in 1988 (Grasnick et al.1991; Feister et al. 1991).

Selected ground-based ozone measurements taken during overpasses of the USSR METEOR satellites over Potsdam were used as ‘ground truth’ data to check and improve the performance of remote sensing algorithms that had been applied to derive atmospheric ozone from satellite-based Fourier spectra of the terrestrial upwelling infrared radiation (Feister 1982, 1983, 1986). Potsdam column ozone data were also used as a data base for studies of ozone variations and their connection to atmospheric circulation and solar cycle variations (Grasnick and Entzian 1977; Entzian & Grasnick 1981, 1984).

An improvement in the instrumentation for ozone measurements at Potsdam became available in May 1987, when a Brewer spectrophotometer of the type MKII (single monochromator, No. 030) was installed that takes ozone measurements automatically several times per day. Its ozone data were compared with Dobson ozone as well as column ozone values derived from a filter instrument of the type M124 (Feister 1991). The latter instrument type had been in operational use at many sites in the USSR ozone network.

A second, new type of Brewer instrument (MKIII, No. 118) which as a double monochromator with improved performance and the capability of measuring UV spectra of global irradiance both in the UV-B and part of the UV-A region, was installed in 1996. It was not only applied to measure spectral UV irradiance, but also used to measure column ozone to enhance the reliability of measured data. The additional automatic Brewer instruments helped to avoid data loss, when - as a consequence of reduced staff – the frequency of manual Dobson ozone measurements had to be reduced to be performed on workdays only from July 2000 onwards.

In the beginning of the 90s, after the Potsdam Observatory had become part of Deutscher Wetterdienst, the responsibility of the Regional Ozone Center was transferred to the Meteorological Observatory Hohenpeissenberg, where column ozone measurements had been taken since 1967 with Dobson instrument No 108, and ozone research carried out for many years (Wege 1996, Winkler, 2006). Dobson Regional Reference Instrument No 64 was moved from Potsdam to Hohenpeissenberg as well. Column ozone measurements were continued at Potsdam with the remaining Dobson instrument No 71 and the Brewer instruments to provide data relevant for climate monitoring, and as an input to the analysis of measured solar UV irradiance and aerosol optical depths.

The record of ozone measurements taken at the Potsdam Observatory for more than three decades was re-evaluated for instrument calibrations and changes, and the re-evaluated ozone data re-submitted to the WOUDC in the middle of the nineties (Spänkuch et. al. 1999). In addition to addressing relevant issues of instrument use, their characteristics, and calibrations over the whole time period, external data sources such as the temperatures of the lower stratosphere – as it is highly correlated to column ozone - served as ancillary data in ozone data evaluation.

The ozone measurements at Potsdam ceased to be taken at the end of April 2003 after almost 40 years of record, when the Potsdam Observatory was closed by Deutscher Wetterdienst, and the tasks of the WMO Regional Radiation Center as well as its staff were transferred to the Lindenberg Observatory (Spänkuch 2000). The instrumentation for ozone measurements was transferred from Potsdam to the Meteorological Observatory Lindenberg in May 2003, where a Brewer instrument (No 78) had been in operation since 1992.

Long-term column ozone variations

In correspondence to ozone records of other mid-latitude sites, the Potsdam ozone data record from 1964 to 2003 shows that the natural seasonal ozone change, which is due to large scale atmospheric circulation with minimum values in autumn and maximum values in spring, is superimposed by multi-annual and long-term ozone variations. The latter can be seen more clearly in the 12monthly running mean values of ozone where the seasonal variation is removed (Fig. 1).

The first time period of measurements in the early 60s is characterized by low ozone values, which similarly occur in ozone records at other mid-latitude sites. It may to a certain extent have been caused by a high frequency of nuclear bomb testing shortly before the 'Limited' or 'Partial Test Ban Treaty' that was signed on August 5, 1963 by the United States of America, Great Britain and the USSR, and that came into effect on October 10, 1963. The large eruptions of the Mt. Agung volvano (Bali, Indonesia; 8.34° S, 115.5° E) on March 17 and May 16, 1963 (e.g. Robock, 2000) may have been another possible cause of the low ozone values observed at Potsdam in 1964.

From the beginning of the 1970s onwards, a long-term gradual ozone decrease became more and more evident. The trend in column ozone derived from annual averages over the period from 1964 to 2002 of -(1.0 ± 0.40) % per decade is somewhat smaller than the trend of -(2.09 ± 0.49) % per decade for the shorter period from 1970 to 2002 (Fig. 2). Looking at the trends of monthly column ozone which are shown in Table 1 for the period 1964–2002, and in Table 2 for the period 1970–2000, it can be seen that the strongest significant ozone decreases of -2.8 to -3.6 % per decade occur between 1970 and 2002, or –1.7 to –2.6 % per decade between 1964–2002 in spring and early summer (March to June). A major cause of the negative ozone trends, which have been similarly observed at other mid- and high-latitude sites as well, is attributed to the anthropogenic production and the release of trace gases such as fluoro-chloro-carbons that accumulate in the middle atmosphere and destroy ozone by chemical reactions (WMO 2003).

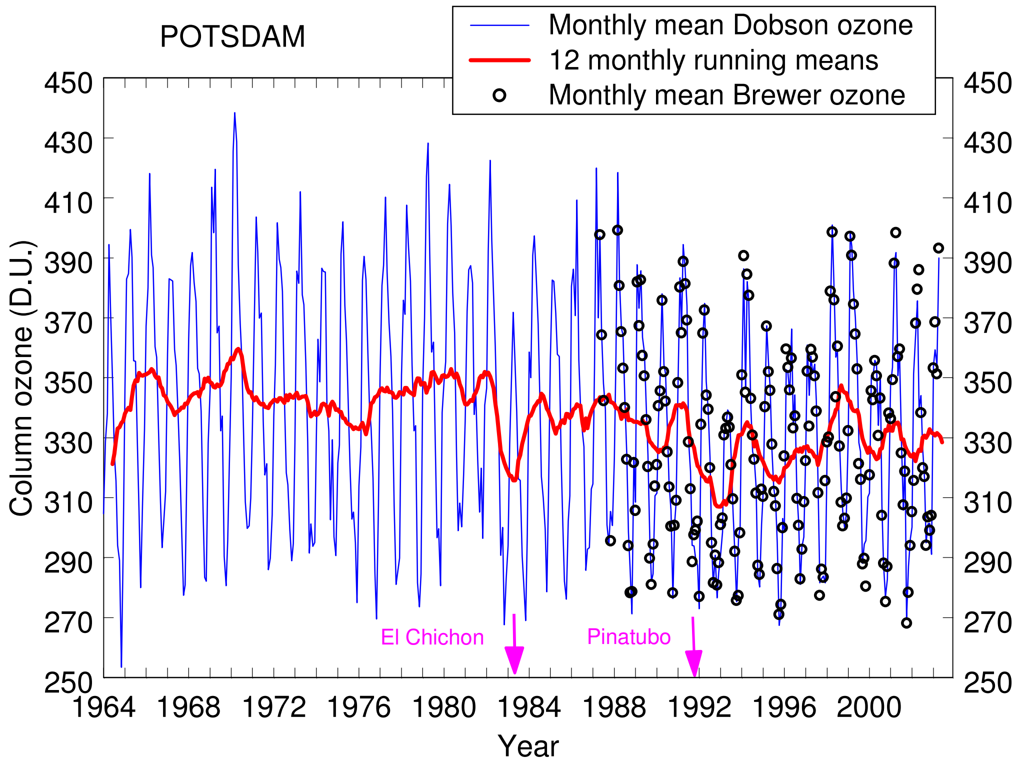

Fig. 1: Monthly averages of column ozone and 12-months running mean values derived from Dobson ozone measurements at Potsdam in the period from January 1964 to April 2003 (lines). Monthly ozone averages derived from Brewer ozone data for the period 1987 to 2003 are shown as circles.

Table 1: Average values and trends with standard deviations and relative trends of column ozone at Potsdam for monthly and annual means in the period from 1964 to 2002. Significant changes are shown in gray.

	Mean (D.U.)	Trend (D.U. / year)	Trend (% / decade)
JAN	331.71	-(0.8412 ± 0.3149)	- (2.54 ± 0.95)
FEB	363.87	-(0.7267 ± 0.3672)	-(2.00 ± 1.01)
MAR	380.52	-(0.8896 ± 0.3473)	-(2.34 ± 0.91)
APR	387.81	-(0.9991 ± 0.2573)	-(2.58 ± 0.66)
MAY	371.36	-(0.7647 ± 0.2011)	-(2.06 ± 0.54)
JUN	357.07	-(0.5937 ± 0.1843)	-(1.66 ± 0.52)
JUL	340.15	-(0.4147± 0.1805)	-(1.21 ± 0.53)
AUG	322.12	-(0.4645 ± 0.1356)	-(1.44 ± 0.42)
SEP	300.79	-(0.2550 ± 0.1681)	-(0.85 ± 0.56)
OCT	290.08	-(0.2242 ± 0.1862)	-(0.77 ± 0.64)
NOV	287.84	+(0.0476± 0.1801)	+(0.17 ± 0.63)
DEC	304.78	-(0.3193 ± 0.2226)	-(1.04 ± 0.73)
YEAR	336.51	-(0.5370 ± 0.1361)	-(1.60 ± 0.40)

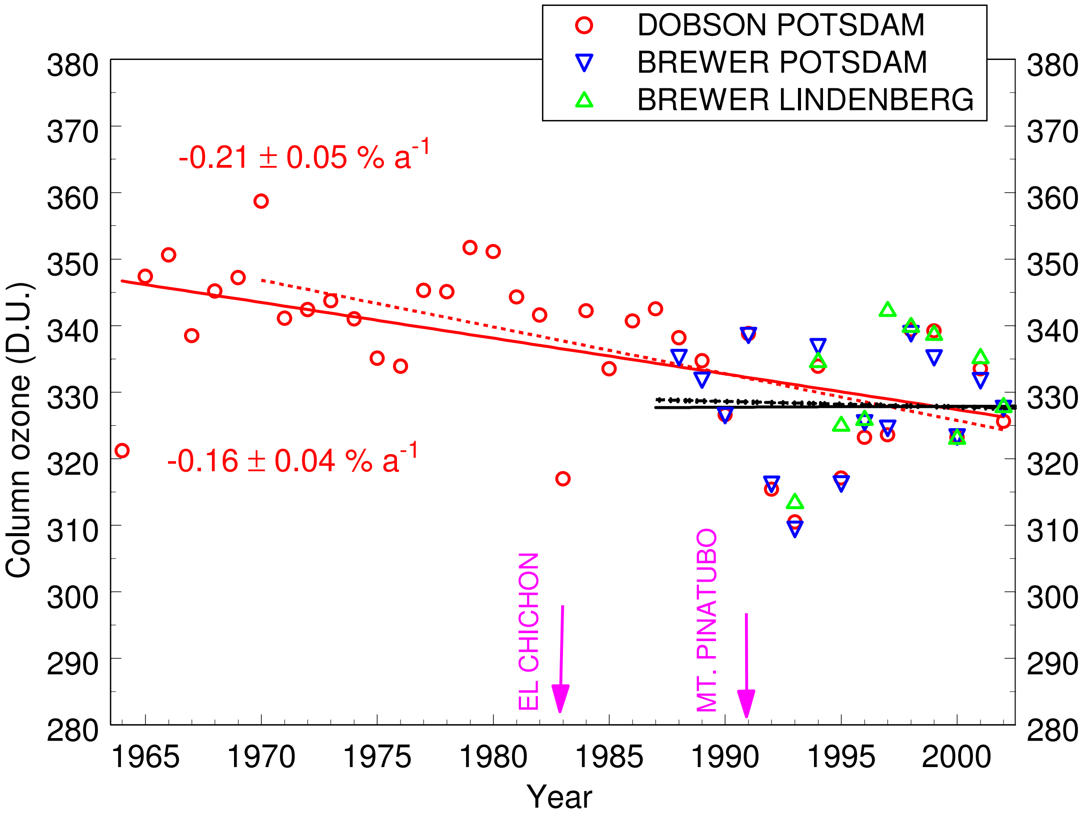

Fig. 2: Annual averages of column ozone over Potsdam from measurements by Dobson spectrophotometers (1964 – 2002) and Brewer spectrometers (1987 to 2002). In addition, annual averages of Brewer ozone data are shown for Lindenberg (1992 to 2002: which is about 73 km from Potsdam

A sustainable reduction in the production and release of trace gases harmful to atmospheric ozone has been effected by the Montreal Protocol on Substance that Deplete the Ozone Layer, which was signed in 1987 and went into force in 1989. Further steps to strengthen the Montreal Protocol were agreed on in the 1990s. Natural causes such as globally effective volcanic eruptions of El Chichon in Mexico in 1982, and Mt. Pinatubo in the Philippines in 1991 have significantly contributed to multi-annual ozone variations.

The smaller the ozone amount in a vertical column of air is, the more solar radiation in the UV-B (280 – 315 nm) region reaches the earth's surface. Due to the seasonal cycle of maximum solar elevation reached at a certain geographical location, the annual dose of solar radiation at the ground is mainly determined by monthly doses of the summer months. This is even more true for ultraviolet radiation than for radiation in the visible region because of the absorption of UV radiation on its inclined way through the stratospheric 'layer' of highest ozone concentration. Past large volcanic eruptions did lead to ozone decreases also in the summer months and thus to increasing UV radiation doses at the ground. For example, in the summer months of the years 1992 through 1995 after the eruption of Mt. Pinatubo, column ozone values at Potsdam were about 4% to 7% below their long-term averages. As a result of the reduced ozone, the annual doses of erythemal (‚skin reddening and sunburn') radiation over Potsdam without the effect of variable cloudiness were estimated to have been enhanced by 8% from 1992 to 1995 (Feister & Grewe 1995; Feister et al. 2002).

Table 2: Average values and trends with standard deviations and relative trends of column ozone at Potsdam for monthly and annual means in the period from 1970 to 2002. Significant changes are shown in gray.

	Mean	Trend (D.U. / year)	Trend (% / decade)
JAN	328.84	-(0.8119 ± 0.4061)	- (2.47 ± 1.23)
FEB	361.06	-(0.6707 ± 0.4690)	-(1.86 ± 1.30)
MAR	379.59	-(1.3174 ± 0.4288)	-(3.47 ± 1.13)
APR	386.55	-(1.3896 ± 0.3275)	-(3.59 ± 0.85)
MAY	370.73	-(1.1102 ± 0.2498)	-(2.99 ± 0.67)
JUN	357.14	-(1.0071 ± 0.2256)	-(2.82 ± 0.63)
JUL	339.64	-(0.5753 ± 0.2287)	-(1.69 ± 0.67)
AUG	320.88	-(0.5241 ± 0.1763)	-(1.63 ± 0.55)
SEP	300.81	-(0.4199 ± 0.2251)	-(1.40 ± 0.75)
OCT	291.19	-(0.6001 ± 0.2336)	-(2.06 ± 0.80)
NOV	287.98	+(0.0298± 0.2075)	+(0.10 ± 0.72)
DEC	302.38	-(0.0386 ± 0.2774)	-(0.13 ± 0.92
YEAR	335.57	-(0.7029 ± 0.1661)	-(2.09 ± 0.49)

Brewer instrument No 078 had been installed at the Lindenberg Observatory in 1992 (Nagel & Leiterer 1995) mainly for the purpose of complementing the ozone soundings performed at the site since 1974. Now, the parallel records of ozone measurements (Dobson and Brewer at Potsdam, Brewer at Lindenberg) provide a chance to compare the differences which result from small-scale spatial ozone variations and uncertainties of the sites' instruments.

The relative standard deviation of daily mean ozone values at Potsdam, i.e. the natural ozone variability, is 13% to 14% (Table 3). Comparing Brewer ozone between Potsdam and Lindenberg in the period from January 1, 1993 to April 27, 2003 shows only small differences of 0.61 ± 3.3 %. The correlation coefficient between Potsdam Brewer and Lindenberg Brewer ozone for all types of measurements (direct sun and zenith sky) is 0.970, and is thus close to the correlation coefficient between Potsdam Brewer and Potsdam Dobson ozone (Table 4).

Table 3: Daily maximum and minimum values, averages and standard deviations of column ozone from Dobson and Brewer measurements at Potsdam

	DOBSON 1964 – 2003	BREWER 1987 – 2003	DOBSON 1987 – 2003
Number	12,031	4,827	5,338
Minimum (D.U.)	206.1	195.0	206.1
Mean (D.U.)	337.0	328.4	329.1
Maximum (D.U.)	535.6	511.0	535.6
Standard deviation STD (D.U.)	47.9	43.5	45.4
Relative STD (%)	14.2	13.4	13.8

Table 4: Relative average differences, relative mean square differences σ and correlation coefficients R of column ozone from Dobson and Brewer measurements at Potsdam (a) and from Brewer measurements at Lindenberg and Potsdam (b)

	(a) Dobson Potsdam – Brewer Potsdam (May 6, 1987–Apr. 27, 2003)	(b) Brewer Lindenberg – Brewer Potsdam (Jan. 1,1993–Apr. 27, 2003)
Number	4,452	2,825
Mean rel. difference (%)	0.19	0.61
σ (%)	3.26	3.35
R	0.972	0.970

Fig. 3 shows a scatter-plot of column ozone values measured at Potsdam and Lindenberg over the period from January 1, 1993 to April 27, 2003. The values at the two sites are close to the ideal regression line with very small systematic deviations. It must be noted that the individual differences between daily ozone values at Potsdam and Lindenberg are not only due to uncertainties of the measurement, but it has been shown that larger differences on some days might have been caused by meteorological conditions such as air mass changes and different observation times. Those larger non-frequent differences can be studied in detail for the individual situations using all the available information at the site (Brewer, Dobson and satellite-based ozone).

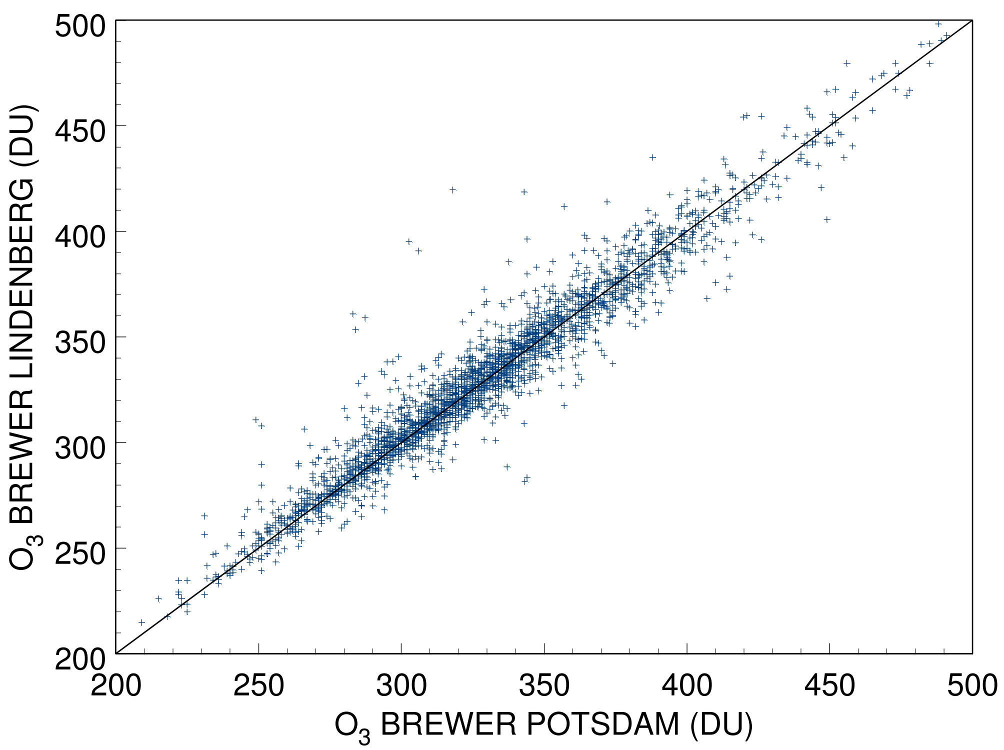

Fig. 3: Column ozone from Brewer measurements at Potsdam (abscissa) and Lindenberg (ordinate) in the period from January 1, 1993 to April 27, 2003

The Potsdam ozone record has been compared with ozone records of neighboring European sites at latitudes close to that of Potsdam, i.e. Hradec Kralove in the Czech Republic (Vaniček et al. 2003), Belsk in Poland (Krzyscin 2006) and Uccle in Belgium (DeBacker et al. 2005). They show similar inter-annual and long-term ozone variations over the period of comparison as the Potsdam ozone record (Fig. 4) in spite of their spatial distances to Potsdam (Hradec Kralove 298 km, Belsk 531 km and Uccle 622 km). The similarities between inter-annual and long-term variations at the neighboring sites are an additional hint to the long-term stability of the Potsdam ozone record.

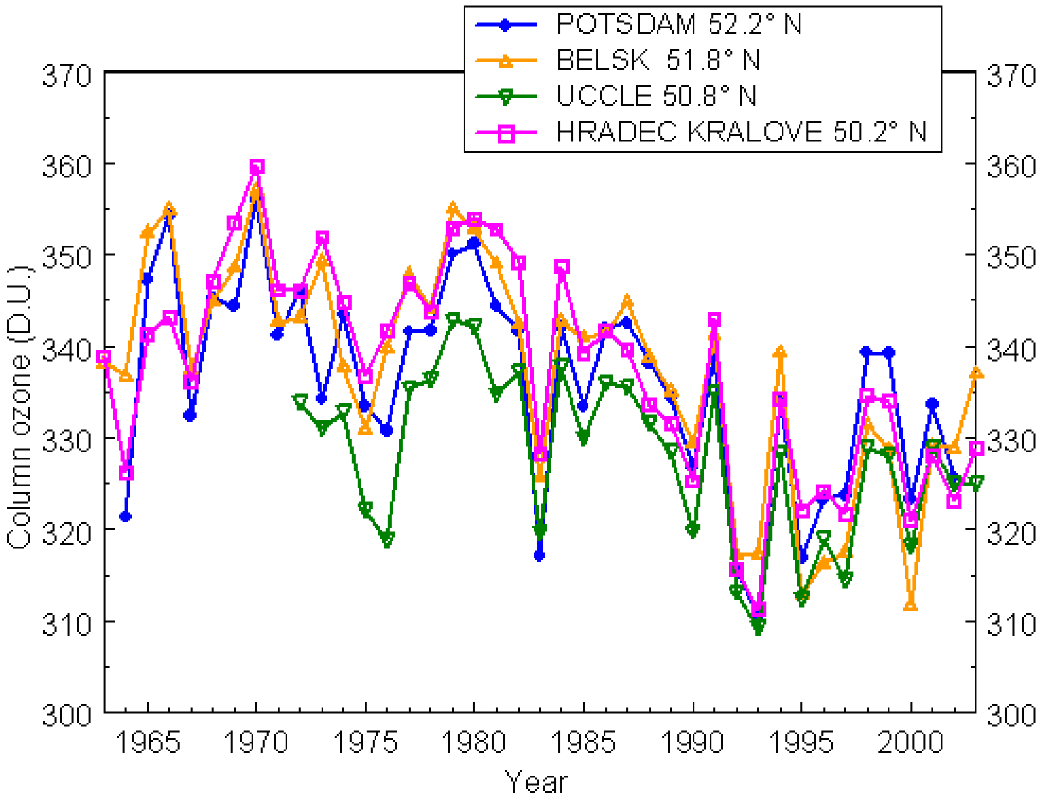

Fig. 4: Annual mean values of column ozone from Dobson ozone measurements at Potsdam (52.36° N, 13.08° E) Hradec Kralove (50.18° N, 15.83° E) Belsk (51.84° N, 20.79° E) and Uccle (50.80° N, 4.35° E) in the period 1964 to 2002.

Column ozone measurements taken at the Meteorological Observatory Potsdam over almost four decades can be used as a data base to describe state and variability of atmospheric ozone at that site. The data base has been used in addition to other meteorological parameters as an input to re-construct long-term variations of solar UV radiation for past time periods, where solar UV radiation measurements are not available (e. g. Feister et al. 2002, Koepke et al. 2006, Feister and Junk 2006, Junk et. al. 2007). The distance between Potsdam and Lindenberg of 73 km, which is small compared to large scale variations of column ozone, the use of comparable types of instruments at the two sites for more than ten years, and the small deviation between the two records, which should be further studied in more detail, give rise to the hope that the column ozone measurements at Lindenberg may be considered as a continuation of the ozone record that had started at Potsdam in 1964.

Ozone near the surface

It was in 1952, when F. Teichert (1905 – 1986) at the Meteorological Observatory Wahnsdorf near the city of Dresden started monitoring air constituents including dust, chemical compounds of precipitable water, and the concentration of ozone near the Earth's surface. Wolfgang Warmbt expanded the surface ozone measurements by initiating a first network of sites. An overview on the activities was given by Herrmann et al. (1991) on the occasion of the 75th anniversary of the Meteorological Observatory Wahnsdorf. Despite the observed phenomenon of photochemical smog in the Los Angeles area, there was consensus among most scientists at that time that the source of surface ozone is of natural origin, as it is transported from its stratospheric source region to the lower troposphere by turbulent transport, and chemically destroyed at the Earth's surface.

A larger network of sites was set up soon, where surface ozone was measured manually 4 times a day at 01, 07, 13 and 19 hours Central European Time with instruments manufactured at the Wahnsdorf Observatory to provide data on ozone variations in space and time, and to study the ozone source hypothesis. Seven sites (Dresden-Wahnsdorf, Fichtelberg, Kaltennordheim, Brocken, Lindenberg, Boltenhagen and Arkona) were measuring surface ozone in 1956, and in 1974 there were already 10 sites measuring surface ozone. Longest surface ozone records are available from Wahnsdorf, Fichtelberg and Arkona (Fig. 5). An automatic instrument, the 'Ozonograph' was developed by Mrose and Warmbt (1974) on the basis of the iodometric principle to take quasi-continuous measurements, and its new design, the 'Ozonograph II' installed at the network sites in 1981/1982 to improve data coverage with 24 hours operation and stored 30 minute ozone averages. Due to the interfering effect of sulphur dioxide (SO_2) to the iodometric method, surface ozone measurements were affected at the sites with high ambient SO_2 concentrations, before a chromium trioxide filter was introduced into the network in 1971/1972 to remove the SO_2 effect (Warmbt et al. 1974). In the long-term ozone record, the SO_2 effect was noticed as an artificial downward step-change in ozone concentration at the time of introducing the filters. The low atmospheric SO_2 concentrations at Arkona prevented a disturbing effect of SO_2 on the ozone measurements at that site (Feister and Warmbt 1987). Both diurnal and annual ozone variations at the different sites of the network showed patterns reflecting their distance to sources of ozone precursors, i.e. higher average values with smaller variability at the mountain sites such as Fichtelberg mountain, and smaller average values with higher variability, and higher peak values during summer photosmog episodes at the sites closer to urb,an areas such as at Dresden-Wahnsdorf.

In the early years of measurements, the ozone concentrations measured were quite low. There was no concern about any possible consequences of ozone changes for the biosphere and for climate. Despite some attempts, at that time, to blame ozone research as a type of ‚hobby research', the involved scientists maintained their conviction, and they were fortunately allowed to continue their studies and carried on their monitoring programs. When in 1970/1971 P. J Crutzen (Crutzen 1970) – years later in 1995 honored by the Nobel prize for his excellent work in atmospheric chemistry (Crutzen and Taba 1998) – and H. S. Johnston (Johnston 1971) published papers on the role of nitrogen oxides and oxygen-hydrogen compounds in the ozone chemistry of the troposphere and lower stratosphere, and their important role for the ozone budget in the lower atmosphere, and after observations of a new type of plant damage in parts of Western Europe, in the Northeastern US, in Canada, and in the southern part of Norway, that were ascribed to photochemical smog with high ozone concentrations, the efforts of the scientists who had started surface ozone monitoring in a network two decades earlier were recognized and acknowledged. Also at that time, the known role of tropospheric ozone as a greenhouse gas and its potential increasing effect on climate were pointed out. It was the time when 'meteorology' became more and more widely accepted as 'the science of physics *and chemistry* of the atmosphere'. One of the worldwide longest ozone monitoring networks that was set up by the Meteorological Observatory Wahnsdorf at a time, when it was generally believed that human activities would not affect the atmospheric ozone budget on a regional or even global scale, did finally find international recognition. Detailed descriptions on the methods of measurement, the instruments applied in the network, and results of measurements were published by Teichert & Warmbt 1956; Warmbt 1962, 1964, 1966, 1979; Grasnick & Warmbt 1973; Feister and Warmbt 1987; Feister et al. 1989. Surface ozone was also measured aboard ships on the ocean (Warmbt 1965), on the Antarctic continent (Warmbt & Kolbig 1978), and in mountainous regions (Warmbt 1980). Other atmospheric trace gases relevant for the Earth's climate were monitored by other institutions, as was discussed by Böhme and Mundt (1991).

The increase in surface ozone concentration was about 2% per year by 1989 (Renner and Rolle, 1989). As is shown in Fig. 5 for the coastal site Arkona on the northernmost tip of the Rügen island, which has probably been least affected by anthropogenic local and regional air pollution sources among all sites, the ozone concentration showed an intermediate period of decrease in the first half of the 1980ies, but increased again after 1986, as at other network sites. The long-term increase in surface ozone was observed in other networks as well (Attmannspacher 1976; Attmannspacher et al. 1984; Logan 1985; Oltmans and Komhyr 1986; Hov et al. 1986; Volz and Kley 1988; Staehelin et al. 1994) in Europe and North America, but did not occur at all remote sites with long-term observation records (Lefohn et al. 1992). From the available records of surface ozone measurements at remote sites, it was concluded in the beginning of the 1990ies that world-wide monitoring of surface ozone at remote locations be continued and expanded (Lefohn et al. 1992).

Natural processes such as variations of atmospheric circulation that affect cloudiness and therefore the amount of solar UV radiation reaching the lower atmosphere and influencing photodissociation of atmospheric trace gases, and also anthropogenic causes such as the high concentrations of volatile organic compounds and nitrogen oxides that serve as precursors of the photochemical ozone production in the lower atmosphere were discussed as potential sources of enhanced ozone concentrations. Several studies with atmospheric chemistry models confirmed that the long-term increase in ozone concentrations in the troposphere and near the ground in regions of the Northern hemisphere could have been the result of increasing photochemical ozone production due to increased emissions of nitrogen oxides and hydrocarbons by anthropogenic activities (e.g. Isaksen and Hov 1987; Crutzen 1988; Crutzen and Zimmermann 1991; Renner and Rolle 1991). On the other hand, it was also shown from ozone data measured in the network, and those meteorological parameters, which are related to the production, destruction and transport of ozone in the lower atmosphere, that long-term variations of cloudiness and thus changes in the photoactinic UV flux should not have been the main cause of increasing values of surface ozone (Feister and Balzer 1991) even though the enhanced amount of UV radiation transmitted to the troposphere as a result of stratospheric ozone decrease by accumulating fluorochlorocarbons may have affected the oxidizing capacity of the lower atmosphere by additional OH radical production, as well as effects to other radical concentrations, and may thus have slightly reduced the tropospheric ozone increase (Fuglestvedt et al. 1994).

The variation of surface ozone in space and time was analyzed and evaluated from a statistical analysis of ozone data measured in Europe such as daily variation, averages, percentiles, frequency of exceeding thresholds etc. by a joint study with the Norwegian Institute of Air Research in the framework of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP) (Feister and Pedersen 1989; Feister et al. 1990).

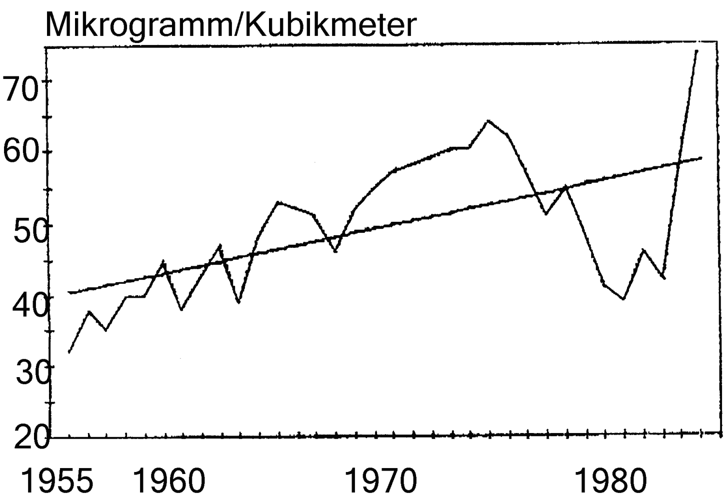

Fig. 5: Annual mean values of surface ozone concentration at Arkona on the Rügen island (Baltic Sea coast) from 1955 to 1990. Also shown is the linear trend. The overall percentage change was 37.5 %

Conclusions

Is there something to be learned from that history of ozone measurements at Meteorological Observatories? There is probably broad consensus that we can always learn from history. In this particular instance, it may be the enthusiastic commitment and the continued efforts of the early pioneers, including scientists and engineers dealing with those observations and analyses of ozone data, who have not been cited here. They did contribute to improve our understanding of nature, and to gain knowledge that is a prerequisite for measures to avoid or mitigate harmful side-effects of the activities of man-kind to the environment. Any reproaching actions of the authorities and others who at times criticized the efforts of the early ozone researchers as a type of 'hobby' have fortunately not been hardened into administrational decisions and actions to cut those projects.

On the other hand, we must not forget that an occupation performed by a person as if it is done like a 'hobby' has also a big advantage: If a scientist does consider his or her work as a ‚hobby', i.e. an ‚interest or activity outside regular occupation and pursued for pleasure', it can be expected that the person will try to do his/her best possible to perform the study and keep interested in the subject, even if it may not always be in line with generally accepted scientific target issues, and may thus not be generally acknowledged by the scientific community, and sometimes even criticized by the authorities. But doing work simply like a 'hobby' misses one important aspect needed to qualify it as a motivation for scientific atmospheric research: It does not necessarily include its relevance for life on Earth, the preservation of ecological balance, and its benefit for the societies. The history of long-term ozone measurements and their results have shown that the ideas and the continued efforts of the scientists who started that type of work in the 1950ies were right, and that the results were finally proven to be useful to us.

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Experimental Investigation of Atmospheric Turbidity in Leipzig

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Introduction

The relative increased turbidity of the atmosphere over the territory of former GDR, connected with high impacts of trace substances and atmospheric pollutants had different effects: It yielded a significant decrease of global radiation, especially a significant UV radiation, of view ranges, of contrasts in satellite imaginary and remote sensing data and so on. An estimate of radiative forcing by aerosols, using changes in global and diffuse sky radiation yields values of more than –12 W/m² (more than fourfold of climatologic assumptions at the beginning of the 80s of the 20th century. This was the reason for efforts to investigate atmospheric turbidity within environmental research at the Meteorologischer Dienst (MD) of GDR, Observatory Lindenberg by U. Leiterer and M. Weller (today German Weather Service), the Institute of Cosmos Research (IKF) of Academy of Science by G. Zimmermann (today DLR) and by the author at the University of Leipzig (UL, later Leipzig Institute of Meteorology, LIM) by the group for Environmental Research led by Chr. Hänsel. The focus was there on analysis of aerosol particle size distribution by investigations of turbid atmospheric media (von Hoyningen-Huene and Spänkuch, 1979, Spänkuch and von Hoyningen-Huene, 1983) and on experimental determination of spectral properties of aerosol-caused turbidity for a further analysis (Leiterer and Weller, 1983a, b).

Also at IKF and UL sun photometers with wedged interference filters have been developed, yielding spectral sun radiance within the range of 0.35 – 1.10 µm with 40 to 90 spectral channels and band widths of 8 – 15 nm, c.f. von Hoyningen-Huene et al., 1991. Results on different measurement campaigns are given for urban conditions in Leipzig, von Hoyningen-Huene, 1984, different locations, Hänsel et al., 1986, Atlantic, von Hoyningen-Huene & Raabe, 1987. The different groups had different foci: The MD group was focussed on the climate effect, the IKF group was interested in atmospheric correction of remote sensing data of ocean colour, and the UL group in the environmental pollution of urban areas. In all groups the investigations have been continued after reunification of Germany in different projects of the successor institutions. Thus, the sun photometer measurements of UL gave a time series of aerosol optical thickness from 1982 – 1996, which is being continued since 2000 within the AERONET framework at the Institute of Tropospheric Research (IfT) Leipzig (Holben et al. 1998, Mattis et al, 2004).

Method

For the time series of aerosol optical thickness between 1982 and 1996 sun photometers of the ASP type (Atmosphere Spectral Photometer) with wedged interference filters, built by the University of Leipzig have been used, von Hoyningen-Huene et al., 1991. Within this time 3 different instruments ASP-1, ASP-2 and ASP-3 (4 – 6 are of the type ASP-3) with the same basic concept, however, several technical improvements were available, giving 40 – 90 spectral channels between 0.35 and 1.10 µm. About 40 channels have been calibrated by the Langley-plot method for the determination of optical thickness $\delta(\lambda)$ from solar direct radiation measurements $i(\lambda)$ with the extraterrestrial solar intercept $io(\lambda)$

$$\delta(\lambda) = \frac{1}{M(z)} \ln \frac{i_0(\lambda)}{i(\lambda)},$$

where M(z) is the air mass factor, determined by Kasten & Young, 1989 for the solar zenith distance z. The aerosol optical thickness $\delta_{AER}(\lambda)$ has been derived by correction for Rayleigh scattering $\delta_{RAY}(\lambda)$ (Fröhlich & Shaw, 1980, Bucholtz, 1995) and ozone absorption $\delta_{OZONE}(\lambda)$ within the Chappius band, using ozone absorption coefficients, given by *WMO, 1995*

$$\delta_{AER}(\lambda) = \delta(\lambda) - \delta_{RAY}(\lambda) - \delta_{OZONE}(\lambda).$$

Spectral regions with water vapour absorption have not been considered.

Since within the time period from 1982 until 1996 three different instruments with different channel structure and numbers of channels had been used, the measurements of spectral aerosol optical thickness needed to be homogenized. By instrument inter-comparisons and inter-calibration measurements the comparability of the data between the different instruments and measurement periods had been established. Thus, the error of $\delta_{AER}(\lambda)$ for the measurements in Leipzig is estimated with 0.03.

As a general reference wavelength for δ_{AER} the wavelength $\lambda = 0.55\ \mu m$ has been selected. For the characterization of the spectral behaviour of $\delta_{AER}(\lambda)$ Angström spectral slope parameter α of Angström's power law parameterisation $\delta_{AER}(\lambda) = \beta\, \lambda^{-\alpha}$ has been used.
Since within the time period measurements with different time regime have been made, daily averages of $\delta_{AER}(\lambda)$ have been determined.

The measurement place of most data was at the roof top of the building of the LIM.

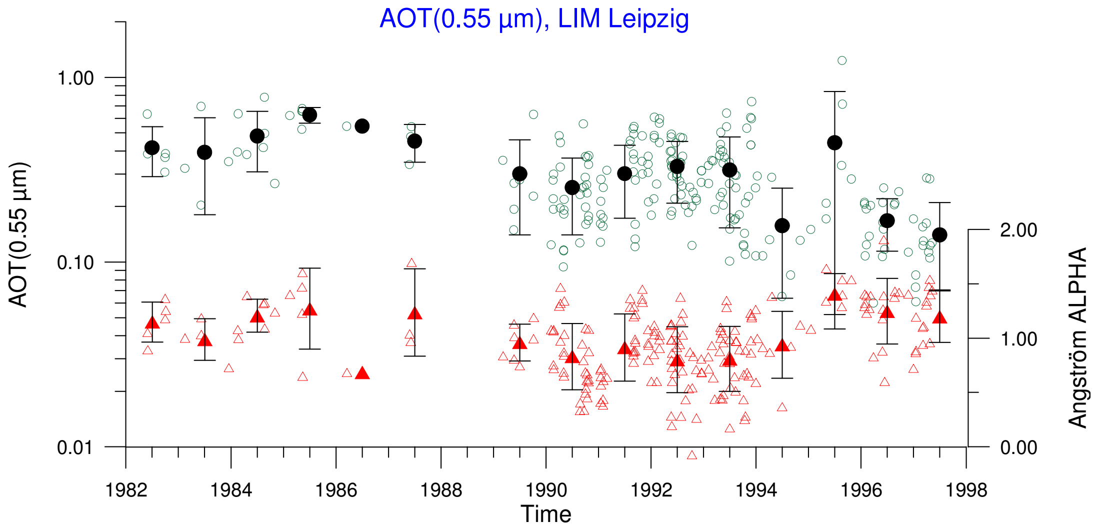

Fig. 1: Time series of the optical thickness of aerosol for 0.55 µm (full circles) for Leipzig, measured with ASP-sun fotometers of the Leipzig University, and the α-parameter by Ångström derived from the spectral course (triangles)

Results and discussion

The time series of aerosol optical thickness $\delta_{AER}(\lambda = 0.55\ \mu m)$, obtained by the method described in section 2, is presented in Fig. 1. Also Angström α-parameter is shown in Fig. 1. Unless some data losses in 1986 and 1988 a clear trend of decrease of aerosol turbidity of

Leipzig can be recognized. A linear fit through the time series of aerosol optical thickness over the whole time period gives a decrease of aerosol optical thickness of $\Delta\delta_{AER}(0.55\ \mu m)$ = 0.019/year. The main decrease was after 1990, especially 1993/1994. It is obvious, that $\delta_{AER}(0.55\ \mu m)$ dropped from 0.4 … 0.5 within the 1980-th to 0.15 … 0.20 within the middle of the 1990s, which is a reduction of about 50 %.

During GDR times in the 1980s no advective caused increases of turbidity by desert dust transports or large forest fire events could be observed. Now such events in the measurements of Leipzig are suspicious. In the 1980s the turbidity was caused mainly by local sources. Thus, strong advective air mass exchanges lead to a decrease of the turbidity.

Within the years 1991-1992 the aerosol optical thickness of Leipzig contains additionally the effect of the stratospheric aerosol of the volcanic eruption of Mt. Pinatubo. Its maximum effect increased the aerosol optical thickness of 0.1. The consideration of this additional global turbidity effect will more highlight the turbidity reduction within the region.

The consideration of the spectral behaviour of the aerosol optical thickness enables conclusions on modifications of the main optical equivalent size distribution. The spectral slope in terms of the Angström α-parameter has probably the opposite trend. A first look of the whole data set shows almost no tendency. It is visible that the stratospheric aerosol of Mt. Pinatubo yields a significant decrease of Angström α. This is visible in 1991 – 1993. If one considers the Pinatobo effect, one obtains an increase of Angström α, which is then really visible from 1995 until the end of the series. Indirectly one can observe here a change of formerly domination coarse aerosol to a relatively increased fine fraction of aerosol.

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Interaction between the Atmosphere and the Underlying Surface

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This chapter includes investigations of processes of the atmospheric boundary layer and the interaction between the atmosphere and the underlying surface - land and water surfaces. Most of the investigations were not made in a climatological context, but they are highly relevant for climate modelling and understanding of climatological processes. After an introduction of the terminus Boundary-Layer climate, relevant studies of this topic in the former GDR are presented.

Boundary-Layer climate

The terminus boundary-layer climate, the climate of the lowest kilometre of the atmosphere, is not very well decribed, because the temporal and spatial classification of the climate is more focussed on horizontal scales (Hupfer, 1989). Climatological investigations in aerology often did not include the atmospheric boundary layer because radio sounding of the boundary layer is very expensive and the layer near the surface is excluded. Measurements within the 10-50 m thick surface layer are in the typical range of climatological measurements, but in this chapter of boundary-layer processes the focus will be orientated on the determination of turbulent fluxes of sensible and latent (evapotranspiration) heat. The available measurements were made during short-term experiments, which did not fulfil the typical “climatological” scale, although they were the basis upon which climatology of the evaporation in the territory of the GDR could be presented (Richter, 1984).
The conference ”Meso-Meteorology“, held in Castle Reinhardsbrunn near Friedrichroda from December 8 to 11 (Abhandl. Meteorol. Dienst DDR, Nr. 141, 1989), was remarkable for the presentation of a boundary-layer climatology of the GDR. This conference opened the way to a future mesoscale orientation of future meteorology, as well as for the weather forecast and for the climatology.

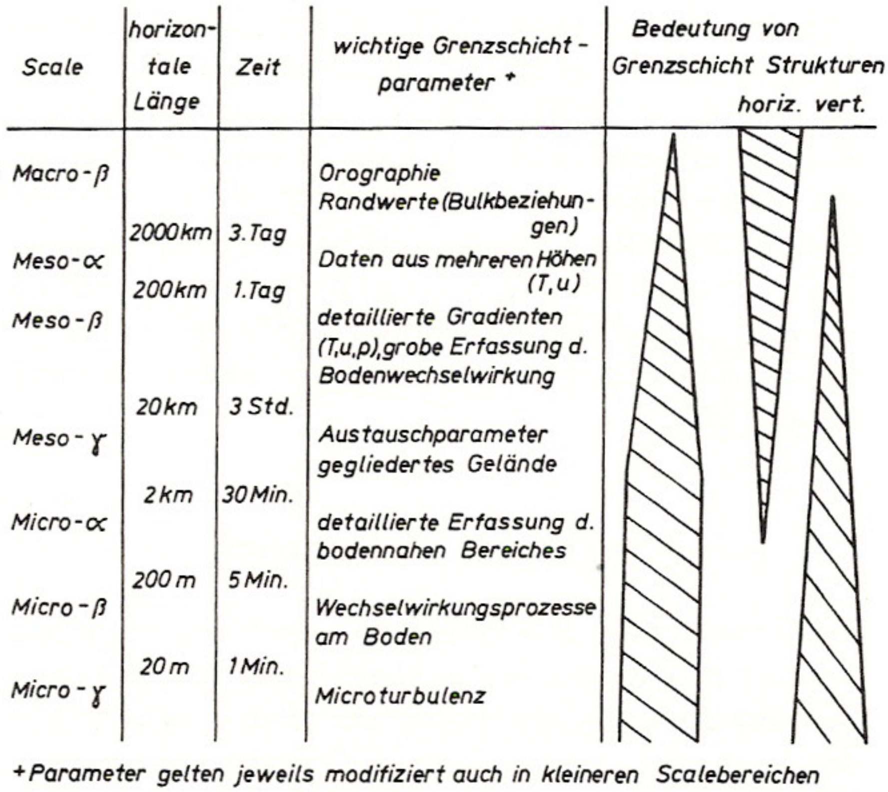

Fig. 1: Scales of boundary-layer processes (Foken, 1987; Foken, 1989), translation of important phrases: wichtige Grenzschichtparameter: important boundary layer parameter; Bedeutung von Grenzschicht-Strukturen, horiz., vert.: importance of boundary layer structures, horizontal, vertical; Orographie, Randwerte (Bulk-beziehungen): orography, marginals (bulk approach); Daten aus mehreren Höhen: data from different heights; detaillierte Gradienten, grobe Erfassung der Bodenwechselwirkung: detailed gradients, pure application of surface interaction; Austauschparameter im gegliederten Gelände: exchange parameters in heterogeneous landscape; detaillierte Erfassung des bodennahen Bereiches: detailed coverage of the near surface layer: Wechselwirkungsprozesse am Boden: interaction processes near the surface; Microturbulenz: micro-turbulence; Parameter gelten jeweils modifiziert auch in kleineren Scalenbereichen: parameters are valid in modified form also for lower scales.

Mesometeorology means a new orientation of meteorological measurements with more attention to vertical fluxes in the boundary layer (Fig. 1). This was the start of a development which became reality in Germany about 10 to 20 years later. Therefore, it may be interesting to investigate this nucleus of boundary-layer climatology. In the following sections this investigation is done for the boundary layer and the turbulent fluxes near the surface.

Climatology of vertical boundary-layer processes

Early aerological investigations in the context of this description of the vertical structure of the atmospheric boundary layer were measurements made in 1950-1951 with a 80-m-lift at the Aerological Observatory Lindenberg (Rink, 1953). But the available analysis unfortunately did not permit climatological or boundary-layer meteorological conclusions.

First investigations of boundary-layer climatology were focussed on the upper part of the boundary layer and the inversion layer. Investigations of the geostrophic drag coefficient, the ratio of the surface and geostrophic wind and an important parameter to characterize the shear included the whole boundary layer. These investigations were based on carefully made analyses of radio sounding profiles over Lindenberg and showed variations within the daily cycle (Bernhardt, 1975, see also Bernhardt, this issue, 52 - 579). Some special boundary-layer soundings were made in the 1980s near Greifswald to investigate possible internal boundary layers near the Baltic coast in the region of the former atomic power station Greifswald-Lubmin. No report about these measurements is available.

Besides short-term experiments at tall towers, mostly in Czechoslovakia (Table 1), systematic investigation of the wind shear between 30 and 60 m were done at the 60 m shear-wind tower of the Berlin-Schönefeld airport (Graebe, 1984) in the period from March 13, 1980 to December 31, 1983. The measurements were continued up to 1990 only for operational purposes. The main aim was the determination of the frequency of wind shears and the identification of situations of possible wind shears, which are risky to the landing of aircrafts. In the period of investigation, within the height interval between 30 and 60 m, 15548 two minute intervals with wind shear ≥ 3,0 m s^{-1} (Table 2) were found. Additionally, the dependence of wind shear on the weather situation was investigated. About 36 % of strong shear-wind situations were found under low wind conditions with inversion and only 18% for high wind conditions.

Table 1: Short-term boundary-layer experiments using tall towers

Year	place	Scientific goal	Reference
1980-1983	Airport Berlin-Schönefeld, GDR	Wind shear	Graebe (1984)
1985	Tusimiče near Kaden, Czechoslovakia	Calibration of sodar technique	Keder et al. (1989)
1986	Kopisty near Most, Czechoslovakia	Calibration of sodar technique, exchange processes in a heterogeneous industrial area	Pretel (1988)
1987	Juliusruh, Rügen, GDR	Calibration of sodar technique	Neisser et al. (1990)
1989	Jaslovske Bohunice, Czechoslovakia	Control of the monitoring system of the atomic power station	Zelený and Foken (1991)

Table 2: Cumulative frequency of wind shear between 30 and 60 m (2-minutes-interval in the period 1980–1983 at the airport Berlin-Schönefeld according to Graebe (1984).

Wind shear in m s^{-1}	≥ 3.0	≥ 3.5	≥ 4.0	≥ 4.5	≥ 5.0	≥ 3.5	≥ 6.0	≥ 6.5
Number of cases	15548	4279	1136	362	115	43	24	4

At the conference of the Meteorological Society of the GDR in 1986 mentioned above, the direction that a meso-scale meteorology needs the development of ground based remote sensing technique was shown/demonstrated (Foken, 1987; Foken, 1989). In 1983 a project management led by Peters and Foken started to develop the sodar technique. This technique was developed at the Heinrich-Hertz-Institute of the Academy of Sciences of the GDR. The first device was a vertical sodar to measure the backscatter intensity (Gronak and Kalaß, 1986). The version of a doppler sodar was finished after 1989 but thereafter no longer used in the GDR. To use the vertical sodar in the network of the meteorological service a special weather code was developed (Foken et al., 1987). The first operational application was in winter 1985/86 at the weather bureau in Leipzig. The height distribution of the inversion is shown in Table 3. In the following years a network of vertical sodar devices was installed. They were used to observe the inversion height for a better forecast of inversion situations. A further application was the determination of the cloud base for military aircrafts. In winter 1989/90 a network of six civil and five military stations (Foken et al., 1997, see Fig. 2) was installed. Consequently, information regarding the inversion height was available every hour especially in the industrial areas in the south of the GDR. Still, in winter 1990/91 the network was switched off by the German Meteorological Service and only the devices at Potsdam und Leipzig-Schkeuditz worked “illegally” some years longer. Only in 2005, 15 years later in reunified Germany, was a network of six wind profiles installed for a continuous observation of the atmospheric boundary layer and for meso-meteorological application.

Table 3: Percentile frequency of the height distribution of ground inversion (thickness) and free inversions (lower base) in winter 1985/86 in Leipzig (Foken et al., 1997).

Thickness or height in m	00 – 49	50 – 99	100 – 149	150 – 199	200 – 249	250 – 299	300 – 349	350 – 399	> 400
Surface inversion	15.9	28.0	18.2	12.1	6.8	3.8	3.8	1.5	9.8
Free inversion	19.7	30.3	17.8	6.6	4.0	1.3	4.0	2.6	19.7

Fig. 2: Vertical sodar network in winter 1989/90 (Foken et al., 1997)
●: civil station with real-time communication
○: civil station without communication
■: military station with real-time communication

Turbulent fluxes in the surface layer

Immediately after the Second World War the ideas of Albrecht (1940) about the investigation of the heat budget of the Earth were revived. This was mainly done at the Meteorological Main Observatory at Potsdam of the Meteorological Service of the GDR. According to the character of research at this observatory, investigations were mainly done in campaigns and not made under climatological points of view. But they were used to generate long-term measuring programmes at other institutions.

Under the leadership of Skeib, investigations of the heat budget of the near surface layer in Potsdam were started, first with a forest climate station (Heckert, 1955). At the Aerological Observatory Lindenberg, the micro-aerological measurements by Rink (1953) were also a contribution to this research topic.

The modern era of turbulence research at Potsdam began with the procurement of the first modern sonic anemometer in 1968 at the Meteorological Main Observatory (Beyrich and Foken, 2005). A huge number of national and international experiments were done in the following 20 years (Table 3). There were three main focusses, which were partly realized in cooperation with other institutes. Parallel measurements on a raft at lake “Stechlinsee” were made in 1977 and 1983 together with the Research Institute for Hydrometeorology of the Meteorological service of the GDR to update parameterizations for the calculation of evaporation (Richter, 1984).

The contacts to the Research Institute for Agrometeororology of the Meteorological Service of the GDR at Halle-Kröllwitz and its research station Müncheberg were very intensive. At both places a profile measuring program of wind, temperature and humidity to calculate the sensible and latent heat flux.there was running. These measurements were compared with direct turbulence technique with the eddy-covariance method in 1976 and 1984 at Halle-Kröllwitz and in 1978, 1979 and 1982-84 in Müncheberg (Fig. 3). Not only a remarkable measuring methodical paper resulted from this (Koitzsch et al., 1988), but also a data set for a computer-based agriculture advice system for sprinkling and harvest forecast (Forschunsgzentrum, 1985). Unfortunately, this data set was not investigated under climatological focusses.

Furthermore, a system for the routine determination of turbulent fluxes with measurements of temperature, wind and humidity at two levels was developed (Foken, 1991) and in 1985 successfully applied at the Berlin-Schönefeld Airport (Fig. 4, Richter and Skeib, 1991). The method was based on theoretical investigations by Skeib and Richter (1984) and was included into a possible meso-meteorological network (Foken, 1989). The strong recommendations for a homogeneous measuring field, the manpower and the missing application of the data were reasons that this technique was not used in the routine network. This was only possible from 1998 on at the Meteorological Observatory Lindenberg with an updated measuring technique (Beyrich and Foken, 2005).

Table 3: Short-term experiments with direct turbulence measurements

Zeitraum	Ort	Zweck	Quelle
1971-1975	Potsdam, Schlaatz	Turbulence and profile measurements, long-term measurements	Gerstmann (1973)
1973	Zingst	Air-sea interaction in the coastal zone Küstenbereich, Experiment EKAM	Mücket and Gerstmann (1975)
1976, 1984	Halle-Kröllwitz	Intercomparison with measurements of the Agrometeorological Research Institute	Wendling et al. (1980)
1977, 1983	Stechlinsee	Intercomparison with measurements of the Hydrometeorological Research Institute	
1978, 1979, 1982, 1983, 1984	Müncheberg	Intercomparison with measurements of the Agrometeorological Research Institute, research station Müncheberg	Koitzsch et al. (1988)
1981	Tsimlyansk, Soviet Union	International turbulence intercomparison experiment, determination of universal functions, ITCE-81	Tsvang et al. (1985)
1985	Berlin-Schönefeld Airport	Test of parameterization equations	Foken (1991)
1987	Tautenburg	Investigation of astro-climate	Foken et al (1990)
1988	Kursk, Soviet Union	Turbulence experiment in heterogeneous areas, KUREX-88	Tsvang et al. (1991)
1990	Brocken, Harz mountains	Test of turbulence devices, measurements in sloppy terrain	Richter et al. (1990)
1990	Töravere/Tartu, Soviet Union (Estonia)	Turbulence measurements at a sudden change of surface roughness TARTEX-90	Foken et al. (1993)

Fig 3: Sonic anemometer and Lyman-alpha-hygrometer of the Meteorological Main Observatory Potsdam during intercomparison measurements at Müncheberg (photo: Th. Foken).

Fig. 4: Mast for the parameterization of turbulent fluxes of the Meteorological Main Observatory at Potsdam, consisting of anemometers at three and psychrometers at two heights, during measurements at the Berlin-Schönefeld Airport in 1985 (photo: Th. Foken).

Energy exchange measurements above ice and in mountain regions

This topic was already reviewed by Foken (1999) on the occasion of the 70th anniversary of the first German-Soviet-Pamir expedition in 1928 by Finsterwalder and the second 30 years later in 1958. When scheduling the International Geophysical Year in 1958-1959, research activities were focussed on ice regions. Supported by Prof. Boulanger (Moskau), Prof. Philipps (Potsdam) and also Prof. Finsterwalder (Munich) the second expedition was planned (Skeib and Dittrich, 1960). The meteorological investigations were made by Skeib (1961; 1962) in 1958 on the Tujuksu glacier near Alma-Ata.

The main focus of the investigations by Skeib (1962) on the Tujuksu glacier were measurements of the radiation balance. The net radiation could be parametrized depending on the albedo. To determine the evaporation wind velocity, temperature und water vapour pressure were measured at heights of 25, 50, 100 and 200 cm and the fluxes were calculated with the logarithmical wind profile. The measurements made from July 12 to September 05, 1958, showed the energy input to the glacier by net radiation and sensible heat flux except for a residual of 4 %, are transferred to ablation and evaporation (Fig. 5). Because of their more than monthly measuring periods they are also relevant to describe the climate of this region.

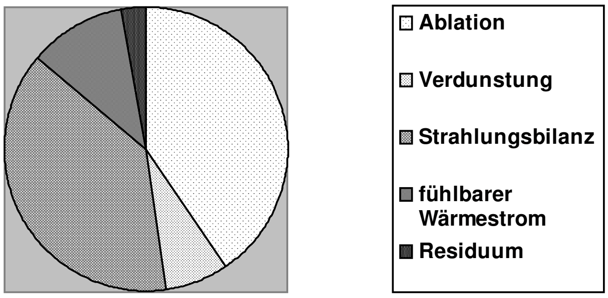

Fig. 5: Energy and water balance of the Tujuksu glacier from July 12 to Sept. 05, 1958 (runoff 113 cm) according to Skeib (1962), Ablation: ablation; Verdunstung: evaporation; Strahlungsbilanz: net radiation; fühlbarer Wärmestrom: sensible heat flux; Residuum: residual.

The Pamir expedition was a test of similar measurements in the years 1959-61 at the Soviet Antarctic station Mirni by Skeib (1968). Both expeditions were one of the first modern measurements of the heat budget of ice and snow regions. Nevertheless, the sonic anemometer technique was at this time not available and therefore the results are limited. Preparations for a new Antarctic expedition for energy exchange measurements were done at the end of the 1980s with sensor tests on Brocken Mountain (Richter et al., 1990), but the experiment took place four years later in 1994 (Foken, 1996).

Air-Sea interaction

There were only a few investigations into the interaction between the atmosphere and the ocean conducted in the former GDR. These were large scale studies of processes of the system ocean-atmosphere, based on the North Atlantic, the Caspian Sea, the Western Baltic Sea and the coastal area of the Baltic Sea near Zingst. But the air-sea interaction as a climate problem was always a topic of high relevance (Hupfer, 1982; Hupfer, 1985).
Michelsen (1989) investigated the effects of global and regional anomalies of the system ocean-atmosphere in the cold water upwelling regions of the Eastern Atlantic, which were mainly investigated by the Institute of Ocean Research, Rostock-Warnemünde. It was found that the seasonal variability is very large and determines the interannual variability. The discovered delay of one year of the parallelism of currents of the East Atlantic to the ENSO years in the Pacific was found to be insignificant because of the data availability. Hagen and Schmager (1991) investigated the relationship between anomalies of the air pressure at the surface in the North Atlantic and European region with anomalies of the sea surface water temperature (SSTA). It was shown that the interannual variations of the zonal averaged SSTA in the subtropical and tropical ocean is influenced by ENSO processes with a delay time of some months due to the anomalies of the air pressure at the surface in the mean latitudes. In cooperation with an international working group, the proposal of the creation of "Phantom Weather Vessels" in this region, which are met continuously by tankers, followed (Dickson, 1977). Harno (1981) evaluated SST observations of weather vessels in the North Atlantic and tried to find a relationship between the change of the SST and the atmospheric circulation. Continuing this direction of research, Schumann (1985) checked the hypothesis by Nikolajev, that in Europe weather relevant changes of the circulation due to SSTA in the North Atlantic depend an the phase difference of the long temperature and pressure wave in the middle troposphere. Hupfer (1988) evaluated long-term SST measurements of the ICES areas in the Northern Atlantic with statistical methods and found as a result the effect of the global

warming in the 20th century in this area of the ocean as well as a corresponding phase relation to the air temperature.

Hupfer (1970) summarized existing problems and the results of maritime meteorology in the Western Baltic Sea at the end of the 1960s. Sturm (1969) presented a first extensive investigation of the heat budget of this area on the basis of measurements of the light vessel “Fehmarnbelt”. The results were a basis for the evaluation of the water temperature and the heat exchange between the Belt Sea and Kattegat during the year. Monthly maps of the sensible heat flux between the atmosphere and the ocean in the region between the North Sea and the Baltic Sea on the basis of Danish light vessels were calculated and published by Helbig und Hupfer (1970).

Hupfer und Schubert (1966) determined on the basis of data of the light vessel “Gedser Rev” the conditions for the generation of sea and evaporation fog over the Baltic Sea and found a close relation to the air-sea interaction. Using data of the station Warnemünde from 1946 to 1970, Tiesel and Foken (Tiesel and Foken, 1987) investigated the energetic conditions for the generation of sea fog due to advection of cold air above the warm sea (sea smoke). Sea smoke is possible for high sensible heat fluxes and free convective conditions, with low wind and lower fluxes.

Since 1963 the main focus of the research activities of the Maritime Observatory of the Leipzig University had been investigations into the “Air-sea interaction in the coastal zone” (Hupfer et al., 2006). Based on the investigations of the heat budget of the coastal zone of the Baltic Sea and the transformation of the components of the heat budget in the zone between land and sea (Hupfer, 1974a) and the water temperature field in shallow water (Hupfer, 1974b) the variation of the wind field depending on the surface conditions were a main focus of research. The micro-structure of internal boundary layers was determined over land and sea by Hupfer et al. (1976). The increase of the drag coefficient with increasing distance to the coast line was calculated by Hupfer (1978) for off-shore winds. An extensive study about the internal boundary layer was presented by Raabe (1981). Most of these extensive investigations, not reported here in detail (Hupfer, 1984; Hupfer and Raabe, 1994), were done within complex international coastal experiments (e.g. Druet et al., 1975). Within these studies the density effect on turbulent fluxes was also investigated (Bernhardt and Piazena, 1988).

In the coastal zone of the Baltic Sea near Zingst as well as on an oil platform in the Caspian Sea near Baku, extensive measurements of the molecular sublayer over the ocean had been made since 1972 with a self-made temperature drop probe (Hupfer et al., 1975). The sensible heat flux could be determined from the temperature gradient of the 1 mm thick sublayer. The variation of the thickness depending on the wave phase is presented in Fig. 6. The study of the dynamic of this layer (Foken et al., 1978) was used for the development of an energy exchange model including molecular and turbulent transport processes (Foken, 1979).

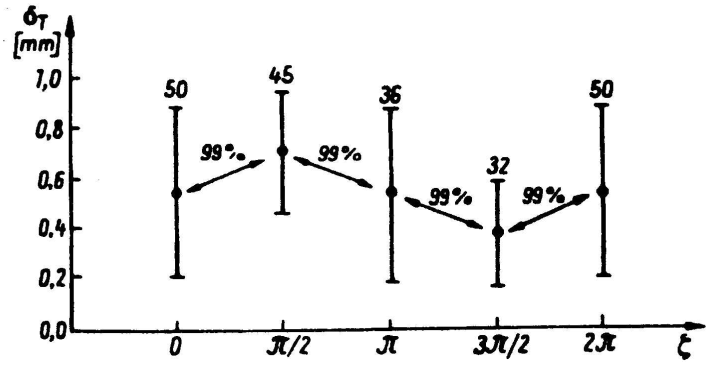

Fig. 6: Averaged heights of the molecular sublayer for temperature depending on the windward (3π/2) and lee (π/2) site of a wave. The measured differences are statistically significant (Foken et al., 1978).

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Aeroclimatology

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Favourable preconditions existed in the GDR for aeroclimatological investigations applicable in the fields of aeronautical meteorology and of air pollution dispersion calculation, for instance (Sonderheft, 1965, e. g.). The Meteorological Service possessed a rather dense radiosounding network with up to four stations at the time and, further, the productive observatory at Lindenberg rich in tradition (see Dubois, 1993). Well-known representatives of classical aerology were working in the GDR, as Reinhard Süring (1866-1950), Paul Dubois (1903-1994), and Max Robitzsch (1887-1952). The latter had been encouraged to write a textbook of aerology, instead of which an extended handbook came out (Hesse, 1961) in which Flohn, 1961 has published a section on aerological climatology and treated boundary layer inversions, the tropopause and maximum wind speed levels among others. Schneider-Carius (1896-1959) was appointed to a chair at the university of Leipzig in 1955 (see Börngen et al., 2004) and made the first move for the later boundary layer research in the GDR by his well-known monograph (Schneider-Carius, 1953).

Aeroclimatological research in the GDR at the beginning was focussed on the climatology of inversions in the lower troposphere. Bernhardt, 1967 has composed in a review paper recent publications on the climatology of inversion layers all over the world and reported on diploma works, dealing with frequency, height and spatial distribution of boundary layer inversions within surface pressure systems (cyclones and anticyclones). The results had been obtained from radiosoundings made at the stations Greifswald, Lindenberg, Dresden-Wahnsdorf, and Wernigerode during the period 1957-1963 (Figs. 1, 2). Further remarkable results were presented by Kirchner, 1967 and Friedel, 1967 in the same connection.

month

Fig. 1: Mean annual variation (1957-63) of the frequency of low inversion layers ("peplopauses") up to 1000 and 500 m, resp., above radiosonde stations Lindenberg (full lines), Wernigerode (dashed lines), Greifswald (dash-dotted lines) and Dresden-Wahnsdorf (dotted lines); after Bernhardt, 1967, data from Friedel, 1966, and Schminke, 1964.

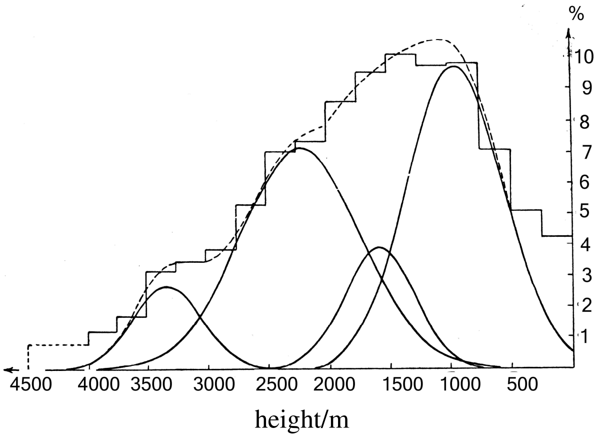

Fig. 2: Decomposition of height distribution (step curve) of lower tropospheric inversion layers (peplopauses) above radiosonde station Lindenberg (1967-63) into normal distributions with sum curve (dashed line); after Bernhardt, 1967, data from Schminke, 1964.

In these papers, the considered inversion layers have been selected by characteristics of the so called "peplopause" as described by Schneider-Carius ("peplopause" means a capping inversion at the top of a normal or convective type boundary layer as well as a ground based inversion in case of an inversion type boundary layer). Later, in view of applications, for example to evaluate the barrier effect of inversion layers for turbulent exchange and air pollution dispersion, this selection was not made furthermore. Bernhardt and Helbig, 1982 have reported on the climatology of inversion layers in the lower troposphere, based on routine (operational) radiosonde data from the decade 1961-70 which were gathered in special data storage. From these data, usual inversion characteristics were derived, as frequency and mean annual variation of occurrence of ground based as well as of elevated inversion layers, but also mean values and one- and two-dimensional frequency distributions of inversion height, thickness and temperature increase. Furthermore, also inversion wind-roses (relating wind directions with inversion parameters) were presented, parameters characterizing the barrier effect of inversion layers were calculated and, finally, the persistence of inversions was described and modelled (see also Bernhardt et al., 1978). Some parts of aeroclimatological data store for the radiosonde station Greifswald was published in the handbook "Klimadaten der DDR" by Helbig, 1988.

Radar sounding of radiosonde balloons made it possible to determine the real ascent velocity by angular position and distance measuring. In this way, Helbig, 1977 studied the deviation of the real ascent velocity from that deduced from pressure registration in time to evaluate, for example, the accuracy of height determination of significant levels by previous methods.

Helbig, 1982, 1987 was able to verify the influence of an urban area on temperature and wind fields in the lower troposphere by comparison of 12-UTC-radiosoundings carried out at the stations Lindenberg and Berlin-Tempelhof during the period 1974 to 1976.

Bernhardt, Klose and Pethe, 1982, have summarized the results of some diploma and other graduation works[1] on derivation and parameterization of boundary layer heights and mean vertical wind profiles by use of specially processed radiosoundings at GDR stations (Greifswald, Lindenberg from October 1974 until September 1975; see also Tran Duy-Binh,

[1]Cited diploma works and dissertations made at the Humboldt-University in the field of meteorology can be found now in the library of the Institute of Meteorology of the Free University Berlin.

1977, 1979, e. g.). Handschack, 1982 has presented characteristic non-dimensional vertical wind profiles in dependence on boundary layer and synoptic parameters based on aerological data of the same kind.

Wind profile data obtained by another special data processing procedure (1335 profiles from station Lindenberg, see Klose and Hübel, 1983) were used by Klose, 1988a, together with temperature and humidity profiles to characterize statistically layers of maximum wind speed in the lower troposphere. Low level jets were studied and modelled in detail by Klose, 1988b, 1989.

Great attention has been dedicated to the behaviour of the wind vector at inversion layers. For example, wind speed and direction at the inversion base and top as well as wind shear within the inversion layer were processed statistically by use of GDR-radiosoundings (1961-1966), and relations between inversion and maximum wind speed layers were found by Mix, 1981a. Mix 1981b has included these results into an extended review paper and compared the empirical findings with theoretical considerations. Detailed information on the wind field modelling in stratified boundary layers can be found in publications by Mix, 1982 and Albert et al., 1988 with further references.

In such a way, aeroclimatological investigations into the lower tropospheric wind profile, especially near inversion layers, were connected with the development of theoretical approaches and with modelling of such phenomena. On the other hand, wind profile data from routine (operational) radiosoundings (Lindenberg, 1962-64) were also used to determine empirically the geostrophic drag coefficient (Dittmar and Emmaus, 1971). This way, a climatological description of this fundamental parameter of dynamic surface-air interaction was obtained in dependence on boundary layer characteristics, season, and time of day (Bernhardt, 1975, Rüffer, 1976). Mean values of the geostrophic drag coefficient deduced by this ageostrophic method were included into the table presented by McBean, 1979 (Appendix II). Contributions from GDR to boundary layer physics and climatology published during the period 1986-90 are listed in a bibliography compiled by Foken and Bernhardt, 1994 for a survey of KAPG[2] activities in the field of atmospheric boundary layer research.

Radiosounding data have been used also for climatological studies of the upper troposphere. Kasper, 1976, for example, has presented a contribution to climatology of jet streams over the territory of GDR based on a special data processing of radiosonde observations at Dresden-Wahnsdorf, Greifswald, and Lindenberg from January and July months during the period 1961-70. Lindenberg radiosounding data have been used by Werner, 1983 for an analysis of long period (1957-80) thickness change of some relative topographies and by Görsdorf, 1985 for studies of tropospheric-stratospheric compensation and changing tropopause height. Investigations of the latter kind were continued at the Humboldt-University up to the closure of the Meteorological Institute (Benz, 1996, Berger, 1996).

Earlier, Matzke 1960, had already used radiosounding data from Greifswald station to calculate correlations between interdiurnal changes of air pressure and temperature following classical investigations in the field of statistical aerology (see Schneider-Carius, 1953, paragraph 312, e. g.) and considerations on the "location" of atmospheric pressure changes (that means, the level of air mass flow divergence).

[2]KAPG means the former Commission of the multilateral scientific cooperation of the Academies of Sciences of socialistic countries for the complex problem "Planetary Geophysical Phenomena".

Some aspects of climatology of the free atmosphere were treated by use of mountain station data. This way, Bernhardt, 1962 has discussed subsidence processes in the lower troposphere, their diagnosis and their mean diurnal and annual variations from long time meteorological observations at Brocken and Fichtelberg stations.

Finally, some contributions to aeroclimatology were based on data from the pre-war and war time or on data from outside of GDR, resp. Höhn, 1949a, b, c, for example, has presented annual variations of absolute and relative topographies as well as horizontal pressure and temperature gradients, heat fluxes and mass flows in the troposphere over some European stations for the period 1935-44. Bernhardt, 1960 has described some features of the climatology of low clouds over Central Europe on the basis of published synoptic observations, kite and captive balloon ascents as well as of aircraft weather reconnaissance flight data from the war and pre-war time. Barg and Herzog, 1970 have carried out harmonic analyses of temperature and geopotential fields for selected isobaric surfaces in the lower stratosphere (monthly mean maps for the period 1949-53) and calculated, among others, kinetic energy of zonal and meridional geostrophic wind components and corresponding meridional momentum and enthalpy fluxes as well.

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General Circulation of the Atmosphere

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Introduction

"The character of weather and climate is a global one. As to their local or regional occurrence, both are determined by the interaction of location and circulation-based factors." (Bernhardt et al., 1984, p. 55)

Although the studies on circulation treated here deal with analyses of observation data and parameters derived, they do not consider the dynamic modelling of flow conditions. The investigations can be subdivided into two groups: a) investigations for considering climate variations and trends on the basis of circulation and b) investigations for explaining changes of meteorological parameters or conditions influenced by the atmosphere (e.g. coastal sea level) in the subscale range (from dot to region) with circulation being the cause. For the description of the circulation patterns, integral parameters were preferred for the investigations described hereafter that characterise a situation by only one or a few parameters. These were on the one hand mostly grosswetterlagen (GWL) according to Hess/Brezowsky and circulation forms according to Dzerdzeevskij as well as, on the other hand, indices like gradients, vorticity measurements (eddy parameter, vorticity index parameter VAI), circumpolar zonal indices and North Atlantic oscillation (NAO) derived from air pressure and/or geopotential fields.

The goal of the often statistically based investigations consisted in estimating the frequencies, periodicities and persistencies as well as the classification of periods with a typical circulation behaviour (e. g. zonal, meridional, cyclonal and anti-cyclonal) and the description of circulation variabilities in the annual course.

Some investigations examine in more detail the causes of a certain circulation behaviour. In the following, publications on ground-level wind fields will only be considered if they are within the context of large-scale streamings.

The following chapters are more subdivided into the subject-matter of research and the method and less chronological. Due to the scope of the subject-matter "circulation" and the fact that literature in which streaming conditions are only marginally considered, compared to the investigation of other meteorological events, is not considered here, there might definitely be gaps in the list of publications on circulation.

Analysis of circulation

Grosswetterlagen and circulation forms

In an earlier publication (Wiese, 1953), the grosswetterlagen defined by Baur (1947) are used to investigate the effects of climate rhythms and fluctuations on the flow conditions of the river Saale. This correlation is especially associated with singularities in the annual course. The classification of Baur was continued and supplemented by Hess and Brezowsky (1952). They define 29 patterns and a transition situation that describes the flow conditions over

Western and Central Europe. These are available as daily value series as of 1881. The circulation forms of Dzerdzeevskij et al. (1946), however, characterise the daily conditions on the entire Northern Hemisphere since 1899 on the basis of 41 types. Numerous analyses of both data series were carried out by Olberg and his colleagues as well as by students whom he supervised. Thus, frequency analyses for individual grosswetterlagen and grosswetterlagen groups and/or circulation forms are, for instance available mostly in connection with the description of typical circulation types by Olberg (1977a) and Schubert (1990). The authors could demonstrate that a "circulation turn" took place in the 1930s which could also be detected in other climate elements (Hupfer, 1991). Besides the frequency analysis, the investigations on the persistence behaviour were another focus: Graf (1974), Quellmalz (1975), Olberg et al. (1976), Graf (1977) and Olberg (1977b). Their most essential results summarised by Olberg can be found in Bernhardt et al. (1984). In the basic work of Olberg from 1977b regarding the problem of persistence, the duration and transition probabilities were described with the maintenance number of Bartel and/or the Poisson distribution that served to distinguish three periods for the zonal and meridional circulation forms according to Dzerdzeevskij: 1899-1916, 1917-1950 and 1951-1972. Moreover, the long-known phenomenon in meteorology, i.e. that the probability for the termination of a condition does not monotonously grow with time, could be proven. This statistical behaviour of the circulation regime was interpreted as an occurrence of self-organization in the atmospheric motion sequence (Bernhardt et al., 1984).

The search for periodicities was and is a large field in climate analysis. Hence, the methods of spectral analysis and filtering were also applied to circulation data. A 26-month-period for the meridional circulation forms of Hess/Brezowsky was proven by Böhme (1967). A similar period was found by Schönermark (1982) in the coefficient series of the eigenvectors for the frequencies of the circulation forms of Dzerdzeevskij. Moreover, she was able to statistically secure additional periods (8, 12 and 24 years).

Other authors who were dealing with the spectral analysis of circulation were, amongst others: Roloff and Schlegel (1981) who investigated the meridional circulation forms of GWL as well as the precipitation series according to Baur by means of the maximum entropy spectral analysis and bandpass filtering. One highlight in the field of spectral analyses is the publication of Olberg and Schönermark (1981) where the authors, on the basis of the meridional circulation of Hess/Brezowsky, proved that the periodicities are not stable, that they occur and vanish or that they are subject to a frequency shifting. Hence, it becomes evident that medium-term predictions or even climate predictions are not possible by means of period observations. The analysis of periods can therefore at the most only contribute to interpret the climate system behaviour.

Some publications exist on the different occurrence of individual circulation patterns in the annual course. Gerstengarbe and Werner (1987), for instance, investigated the changes in the occurrence of normal weather conditions according to Baur on the basis of grosswetterlagen. They were able to demonstrate that the annual courses of the frequencies of individual conditions are instationary in time so that normal weather conditions are partially only to be considered as a temporary event and that a massive adjustment of the conditions occurred in the 1930s (see above). Graf (1977) detected a differentiated seasonal behaviour and a temporal variation of it for the circulations forms.

The detection of relationships to meteorological parameters in the subscale range is always a basic aspect in circulation investigations. There are, amongst others, two publications of

Hupfer (1962a, b) that deal with the changes in air temperature in Central Europe and/or sea-climatic conditions in the Belt Sea.

Already in 1954, Böer who examined the correlation between grosswetterlagen and extreme deviations in the monthly mean temperature committed himself to the occurrence of extreme situations that is today more than ever a topical problem. Later on this was followed by Marx (1973) who was able to identify correlations between grosswetterlagen und high precipitation sums in Germany.

Circulation indices

In many cases, the results from investigations on circulation indices correspond with the ones on grosswetterlagen and circulation forms. In contrast to the studies presented in 2.1, the following studies often refer not only to climate but also to weather prediction.

An area-wide vertical sounding of the atmosphere started after World War II. As a consequence, studies were published in the 1950s already in which the large-scale circulation conditions were statistically evaluated not only on the ground but also in the altitude. The study of Grünewald (1955) who investigated the medium tropospheric circulation of the Northern Hemisphere with regard to weather changes in Europe and the study of Teich (1955) the focus of which were the medium tropospheric high pressure areas are to be mentioned here as an example. In the publication of Barg and Herzog (1970), higher spheres were studied a little later which analysed the condition of the lower stratosphere.

Barg (1966) was able to prove an almost two-years-fluctuation based on parameters of soil air pressure in Northwest Europe and one year later, Böhme was able to prove this on the basis of grosswetterlagen (see Chap. 2.1). In 1969, Böhme published a comprehensive study on the theory of this quasi-two-years' cycle of the circulation behaviour.

In parallel to the afore-mentioned investigations, investigations were not only carried out internationally but efforts were also made in the GDR to derive parameters from air pressure and geopotential fields that characterize circulation and allow for establishing a relationship to subscale weather conditions. These activities were closely connected with the name Maede (1955, 1956, 1957, 1959, 1961, 1964a, 1964b). The goal of these studies were less targeted on climate research but primarily to improve weather forecasts in the medium range. For this purpose, the multiple correlation method was mostly used to develop "maintenance-" and/or "turnover prognoses" (anticyclonic <-> cyclonic). But with these parameters derived by Maede (zonal and meridional wind as well as the eddy parameter for different grid widths and the 1000 and 500 hPa area, similar also Gregor, 1988) and other published parameters like the difference in the air pressure Azores – Island (see also North Atlantic Oscillation – NAO), the vorticity area index – VAI (Olson et al., 1977), the catalogue of blocking patterns (Montalto et al., 1971) or the circumpolar zonal index (described inter alia in Emmrich, 1991), climatological analyses, similar to those described in Chapter 2.1, were carried out after sufficiently long series were available. For the parameters of Maede and for VAI, comprehensive studies were made by Werner (1982, 1983a, 1983b) regarding the mean conditions, the variances, the persistence, the periodicity, the trends and the coherence between the parameters of the 500- and 1000-hPa area. These statistical characteristics are often subject to strong temporal changes so that also here the quasi-periodic fluctuations do usually not prove to be persistent. Some few examples of other publications should shine a light on the spectrum of research on circulation:

Using the vorticity area index of Maede (1967), Graf and Gräfe (1979) were able to establish a correlation between weather situations in higher layers and surface wind and precipitation in the Berlin area, similar to Maede (1967) for temperature in Potsdam and precipitation in the GDR.

Using the VAI, Werner (1983b) confirmed the persistence behaviour of circulation as described by Olberg (see above). Moreover, he found some correlations between vorticity area index and weather in Central Europe.

By means of the rotation spectral analysis (Werner, 1983a), it could be shown that the main axis position of the geostrophic wind over Central Europe has an N-S-orientation at lower frequencies, whereas at higher frequencies, there is an orientation from NE to SW. The wind vector is almost linearly polarised in a period range of 2 to 126 days.

Graf and Funke (1986) analysed the catalogue of blocking situations and, regarding frequencies, they found a period of two years and a more frequent occurrence of El Niño years.

Additional investigations on the general circulation of the atmosphere:

Within the framework of climate observations, only relatively few investigations were made for the complex circulation and air masses. For example, Heyer (1962) and his study on the climate of the State of Brandenburg should be mentioned here.

The studies of Böhme (1954, 1955, 1956) that are strongly based on the theory of fluid dynamic deal with thermally determined circulation taking the monsoon and the coupling of troposphere and stratosphere via momentum exchange as an example.

Entzian and Lauter (1982) analysed the dynamics of spring change of the stratospheric circulation (here 30 hPa-level and 1958 - 1980) over the Northern Hemisphere. This change is quite variable from year to year (differences up to 50 days). They found out that, in higher latitudes, this change began on average on the 110th day (1960s) with a move to the 90th day in the 1970s. This was an indicator for today's generally known circulation change in the 1970s which coincides with the beginning of the second phase of global warming.

In the second half of the 1980s, correlations between the circulation in the Atlantic-European area and other events in the climate system were more intensively investigated as for example the correlation with ENSO events (Schaefer, 1987; Graf, 1988).

The genetic climate classification

Within the framework of geographic climate classification, the introduction of the genetic climate classification by Hendl (1963) is a milestone despite some few ancestors. Hendl assumes that the climate characteristics of a region are predominantly influenced by the circulation conditions. Hence, a genetic classification can be reached by representing the climate types by *regionally specifically* formed types of parts of the atmospheric circulation. The genetic classification allows to give information on the causes for the spatially varying formation of climate which is ad hoc not possible with an effective classification.

Resume

Since the beginning of the 1950s, investigations on circulation have almost continuously been made by numerous researchers, the majority of which were members of the Humboldt-Universität zu Berlin or the Meteorological Service of the GDR. Time series analyses were the focus for these studies for which mostly state-of-the-art methods were used that were partially self-developed. Attention was paid to the fact that these series were long and up-to-date. In most of the cases, Central Europe was the region under observation. Numerous studies dealt with the theory of the dynamics of the atmosphere with only a few mentioned here since the larger part needs to be attributed to the development of models (see chapt. "Modelling of Aatmosheric and Climate Processes").

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Global Climatic Classification

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The climatic classification of Hendl

Beginning in the late fifties of the past century Hendl tried to work out a global climatic classification of the genetic type on the basis of the atmospheric circulation and her spatial differentiation. A first draft had been published in 1960, a somewhat improved version with extended accompanying text followed in 1963.

At first Hendl determined 3 kinds of *zonal climates*, using the distribution of first order structures of atmospheric circulation. Distinguishing between large-area-circulations of trade wind or monsoon type with high constancy on the one hand and macroturbulent circulations with travelling eddy systems (cyclones) on the other hand Hendl obtained *tropical* and *extratropical zonal climates*. For the separation of these main zonal climates the mean positions of the axes of the margin-tropical high pressure belts during the extreme months had been used. Because the axes of the high pressure belts take different latitudinal positions in the extreme months over the eastern parts of the oceans and over the adjacent land areas, a *subtropical zonal climate* could be defined, with seasonal change between tropical circulation structure in summer and extratropical circulation structure in winter. Of equal hierarchical order with the zonal climates an *azonal parautochthonous plateau climate* comprises plateau areas being to a large extent orographically shielded from external influences by high mountain ranges at their margins.

For the further subdivision of the zonal climates into climatic types have been taken into consideration: (1) the annual or seasonal continuity of tropical large scale currents and their (continuous or seasonally variable) state of stratification as well as their hygro-thermal properties, (2) the occurrence of extratropical cyclonic eddies of the polar front type or the Arctic/Antarctic front type, (3) orographically induced windward or leeward effects in limbs of circulation.

The distribution of the zonal climates and the climatic types both on the continents and on the oceans is illustrated on a coloured world map; see the enclosed black and white version of this map.

A brief survey of the classification with an attempt to translate the name of the climatic types into English terminology can be found in the following table 1.

Table 1: Genetic climatic system of Hendl 1963

T	Tropical zonal climate
T-1	Continental core trade wind climate
T-2	Maritime core trade wind climate
T-3	Alternating core trade wind climate with summertime maritime margin-type trade wind period
T-4	Equatorial trade wind convergence climate
T-5	Maritime windward trade wind climate
T-6	Maritime leeward trade wind climate

T-7	Monsoon climate
T-8	Windward monsoon climate with enhanced summer precipitation by orographic lifting
T-9	Windward monsoon climate with enhanced winter precipitation by orographic lifting
TZ	Subtropical zonal climate
TZ-1	Alternating core trade wind climate with wintertime cyclonic period
TZ-2	Alternating core trade wind climate with wintertime windward cyclonic period
Z	Extratropical zonal climate
Z-1	Temperate cyclonic climate
Z-2	Subpolar cyclonic climate
Z-3	Polar cyclonic climate
Z-4	Monsoon type cyclonic climate
Z-5	Windward cyclonic climate
Z-6	Leeward cyclonic climate
P	(Azonal) parautochthonous plateau climate

Note: The abbreviations in a letter and number combination refer to the marking in the enclosed world map (see Fig. 2)

Some additional explanations concerning the climatic types and their demarcation as well as the properties of the utilized circulation limbs may be useful.

The core trade wind currents are characterized mainly by a high frequency of free subsidence inversions or stability layers round the year in the lower troposphere. Typical for continental core trade wind currents are low water vapour pressure and extremely rare low cloudiness, whereas in maritime core trade wind currents, high water vapour pressure, and very frequent low cloudiness (mainly of the Sc and Cu hum type) below the inversion layer are present. Both core trade wind currents are very poor in precipitation because of their stable stratification. Regarding these findings two *core trade wind climatic types* have been established; their boundaries are given by the borderlines of adjacent climatic types.

Table 2: Mean frequency of the trade wind inversion in the western parts of tropical oceans (after Gutnick, 1958, Emon, 1948)

Location	Frequency (%)	Period
	Jan. Apr. July Oct.	
Caribbean Sea: Swan Island 17°24'N. 83°56'W.	92 75 24 34	1951-1953
Mozambique Channel: Toliary (Madagascar) 23°21'S. 43°41'E.	3 24 72 26	7.1943-2.1945

A third trade wind climatic type is connected with a seasonally different structure of the mean high pressure belts at the margins of the tropics. Whereas in winter these high pressure belts are developed more zonally, they show in summer a more cellular structure with concentration in the eastern parts of the oceans (see Fig. 1). Therefore over the western parts of the tropical oceans (and adjacent continental areas) maritime trade winds of the core type are developed in winter, whereas in summer maritime trade winds of a different character are developed there, which have been termed margintype trade winds by Hendl (1963). Within this latter trade wind type the frequency of subsidence inversions or stability layers is much lower (see some examples in table 2), owing to the longer way with gradually diminishing subsidence processes from the source regions in the form of the high pressure cells over the eastern ocean parts. So the margin-type trade winds are characterized by considerable precipitation from frequent clouds of the Cu con and Cb type, occasionally also connected with tropical cyclones. The climatic type has been termed initially as *maritime alternating trade wind climate,* later on (more precisely) as *alternating core trade winds climate with summertime maritime margin-type trade wind period*. Because the frequency of subsidence inversions is seldom given, the isoline of mean 75 % wind constancy in midsummer was chosen as a substitute boundary against the core trade wind climatic type; the real boundary should be defined by the isoline of 50 % frequency of subsidence inversions in midsummer. (A research paper by Neiburger et al. 1961 showed a satisfactory approximation between a 50 % isoline of subsidence inversion frequency in midsummer and the isoline mentioned before in the case of the tropical North Pacific Ocean.)

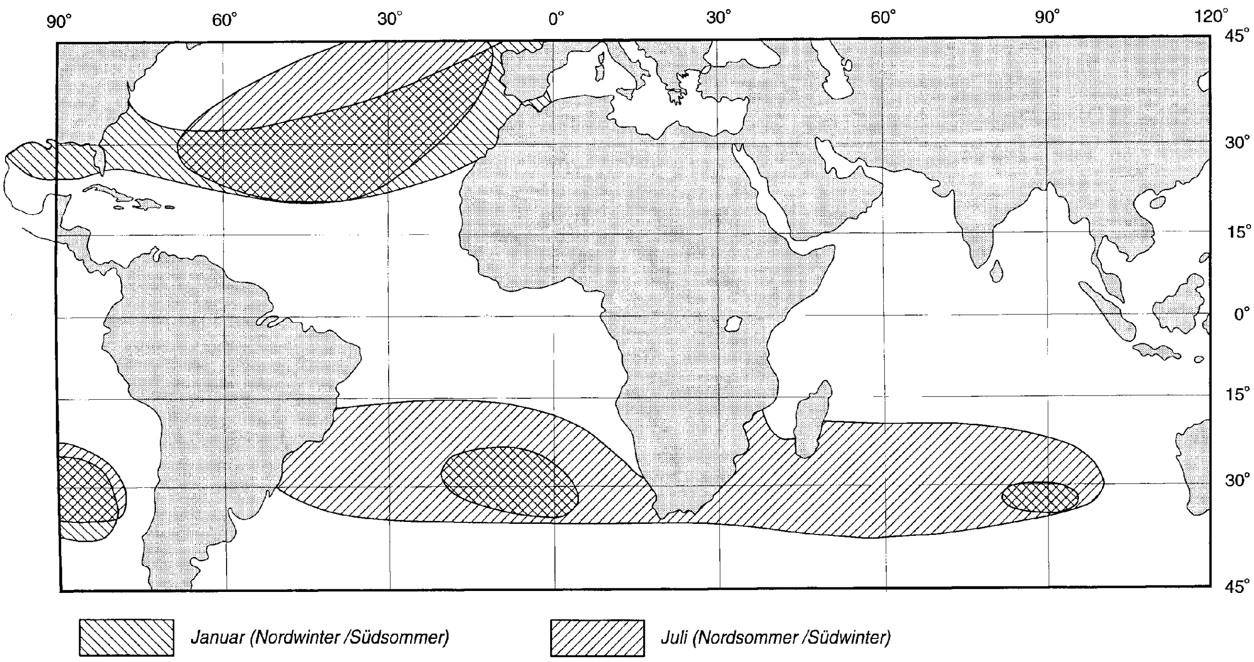

Fig. 1: Core areas of the high pressure regions at the margins of the tropics with mean pressure values ≥1020 hPa during the extreme seasons (after Hendl 1997 on the base of monthly pressure maps in Atlas Okeanov II 1977)

An *equatorial trade wind convergence climate* is to be found only over the central parts of the Pacific and the Atlantic Ocean, where the maritime core trade winds of the Northern and the Southern Hemisphere converge round the year in a rather narrow belt covering a small meridional range of mean monthly positions of the intertropical convergence (ITC). The continuous water vapour transport into the convergence belt and the forced ascent result in high Cb towers and in abundant precipitation.

Where high mountains are reaching into the maritime variants of the trade winds, for example the mountain ranges of Central America and the Antilles or the central range of Madagascar, the currents are forced to quasi-permanent orographic lifting on the windward sides. Because of the high water vapour pressure in the currents the windward flank of the mountain obstacles obtain abundant precipitation. In this way a *maritime windward trade wind climate* is developed between the mountain foot and the mountain crest.

On the other hand a *maritime leeward trade wind climate* is developed in the rear of mountain obstacles by orographic subsidence processes. Here the precipitation is strongly diminished in the case of core trade winds (owing to their stable stratification) and is more weakly diminished in the case of margin-type trade winds (because of their reduced stability and the occasional influence of tropical cyclones). The leeward boundary of this climatic type against other climatic types follows the extent of the rain shadow effect in the rear of the mountain barriers.

The *monsoon climate* is characterized by a pair of tropical currents with directional change between winter and summer. The winter monsoon is identical with the stable stratified core trade wind of the (station's) own hemisphere, the opposite summer monsoon is a transformed trade wind from the other hemisphere with unstable stratification and high water vapour pressure as a rule. Consequently the monsoon climate can be bounded by the mean January and July positions of the ITC, changing the hemisphere between the extreme months. The low cloudiness of the winter monsoon is of a typical core trade wind type, the cloudiness of the summer monsoon is mainly of an intense convective type in the afternoon and early evening with considerable precipitations from Cb clouds.

When the summer monsoon is directed against a mountain barrier, the current is influenced intensively by orographic lifting causing abundant summer precipitation at the windward slopes of most mountain ranges under monsoon climate. Therefore a special *windward monsoon climate with enhanced summer precipitation by orographic lifting* has been defined between mountain foot (or coast line in the case of coastal mountains) and mountain crest.
Again under monsoon climate conditions the case is occurring also, that slopes of mountains are in a leeward position to the summer monsoon. Here, therefore, the winter monsoon will be forced to orographic lifting producing enhanced winter precipitation in this way. Tropical cyclones are able to expand the rain period into autumn. For such a climate the term *windward monsoon climate with enhanced winter precipitation by orographic lifting* is suitable. It will also be distributed between mountain foot (or coast line respectively) and mountain crest. During summer the precipitation is diminished considerably due to orographic subsidence processes.

The *subtropical climatic types* are bounded by the mean January and July positions of the axes of the margin-tropical high pressure belts. The positions of these axes differ considerably between January and July only in the eastern parts of the oceans and the adjacent land areas. The wintertime weather is dominated by moving extratropical cyclones with frontal precipitation (orographically increased at the western flanks of mountains), whereas in the summer months core trade winds prevent precipitation processes largely.

The extratropical regions poleward of the mean July axeś positions of the margin-tropical high pressure belts are the domain of moving cyclonic eddy systems with highly variable air currents of different properties and mainly frontal precipitation. At first a differentiation into climatic types was possible by using the mean January and July positions of the Arctic resp. Antarctic front; they were determined at that time chiefly according to a publication by

Chromov (1950), approximately connecting the individual frontal sections. Equatorward from the arctic/antarctic front position polar front cyclones dominate, whereas within the poleward lying areas Arctic resp. Antarctic front cyclones are the main type of moving eddy systems. The vast areas, dominated by polar front cyclones, have been identified with a *temperate cyclonic climate*, those with Arctic/Antarctic front cyclones with a *polar cyclonic climate*. A *subpolar cyclonic climate* on the northern continents is to be found between the mean January and July positions of the Arctic front.

Though moving cyclonic eddies occur everywhere in the extratropics, there are some obvious differences between the temperate and the polar cyclonic climate. At first the air masses within the temperate cyclonic climate show on the average a significant higher water vapour content than the air masses within the polar cyclonic climate; hence with frontal upgliding processes inside of polar front cyclones considerable more precipitation will be associated than with those of Arctic/Antarctic front cyclones. Further: Within the polar cyclonic climate the polar night of high winter causes a continuous negative net radiation with very low air temperature, whereas during midsummer (in spite of considerable insolation) melting processes at the surface of the oceanic ice pack fixate the temperature at 0°C. (The surfaces of the high ice shields of Greenland and the Antarctic cannot be heated up to the melting point because of the high snow albedo of about 0,9.) On the Arctic coast regions and Islands (Canadian Archipelago etc.) at last the midsummer rise of temperature is limited strongly by the energy consumption for evaporation processes. The polar cyclonic climate is therefore characterized both by a cold winter and a cold summer, whereas within the temperate cyclonic climate a more or less cold winter is followed by a temperate to warm summer.

On the eastern side of important mountain and plateau areas in the Northern Hemisphere midlatitudes the definition of a *monsoon type cyclonic climate* became necessary. Though influenced by moving cyclonic eddy systems round the year, these regions are characterized by a sharp alternation between a cold winter with only insignificant frontal precipitation and a warm to hot summer with rich frontal and convective rainfall. As the main causes of this seasonal variation had been ascertained (1) in winter the predominance of degenerated polar front cyclones from westward situated source areas with orographically diminished weather effects, but with frequent outbreaks of polar air in their rear, (2) in summer the dominance of fresh cyclones and extensive convection centres supported by an inflow of very humid maritime air masses from low (subtropical) latitudes following the general pressure gradient into the heated continental areas. The mean January positions of 500 hPa trough lines could be used as suitable eastern boundaries of this climatic type; the western boundaries are always orographically determined.

Where high mountain ranges of large meridional extent are reaching into the atmosphere of the extratropics, they will cause a *windward cyclonic climate* on their western flank and a *leeward cyclonic climate* on their eastern flank.

The former (windward) climatic type is characterized by orographical intensification of frontal upgliding processes and by the retardation of the frontal travelling velocity. Both effects are the cause of increased and prolonged cloudiness and precipitation round the year, in quantitative dependence on the height of the mountain ranges and their distance from the water vapour supplying oceans. As borderlines have been used the mountain foot line (in the case of coastal mountains the coast line) and the mountain crest line.

The latter (leeward) climatic type is characterized by descending processes with weakening effects on the cyclone-internal fronts and with diminishing effects on the associated cloudiness

and precipitation. Only a considerable interdiurnal variability of air temperature (as a result of frequent air mass change) shows indirectly the cyclone activity. This climatic type is bounded by the crest line of meridional mountain barriers to the west and the mean (western) borderline of areas with new cyclone formation or regeneration to the east.
For further information see Hendl (1963) and Hendl (1966 b).

The climatic classification of Kupfer

In 1950 Flohn proposed to base a genetic climatic classification on the prevailing zonal wind component in the low troposphere. His proposal was limited to 7 zonal climates, 4 with constant prevailing zonal component round the year and 3 with seasonally alternating prevailing zonal component (see table 3).

Because the zonal climates of Flohn had been represented only schematically on an ideal continent, Kupfer (1954) tried to determine their distribution (with partially modified terms, see table 3) on a world map, but only for the continents.

Table 3: Zonal climates of the earth after Flohn (1950) and equivalent zonal climates after Kupfer (1954)

Zonal climate after FLOHN	Zonal climate after KUPFER
TT Innertropical climate TP Margin tropical climate	TT Permanent moist innertropical climate TP Periodic moist innertropical climate
PP Subtropical dry climate PW Subtropical winter rain climate	PP Trade wind climate PW Subtropical climate
WW Moist temperate climate	WW climate of the planetary frontal zone
EW Subpolar climate EE Highpolar climate	WE Subpolar climate EE Polar climate

Note: The designation of the zonal climates by letters refer to the prevailing zonal wind component, with the first letter for summer and the second letter for winter. Distinguished are innertropical westerly winds T, tropical easterly winds P, extratropical westerly winds W and polar easterly winds E.

Some of the zonal climates were classified by supplementary climatic types. These climatic types are characterized either by a pluvioclimatic description (moist east coast and dry west coast respectively inland type of the trade wind zonal climate, winter and spring rain type of the subtropical zonal climate, permanent moist and periodic moist type of the innertropical zonal climate) or they are completely undefined and therefore designated on the map by some occasional letters (sea climate, land climate and transition climate type of the planetary frontal zone climate). A summer moist east coast type of the planetary frontal zone climate is also mapped without information about limiting conditions.

The climatic classification of Neef

Neef (1956) published a wall map of climatic zones for use at higher instructional institutions, accompanied by a short commentary. According to Neef the map should give insights into the basic formation of the earth climates. Restricted to the continents, the mapped climates are entirely without (boundary) definitions. Terms indicating the climate formation processes are also missing to a large extent.

Distinguished are at first 7 kinds of climatic zones: polar zone, subpolar zone, temperate zone, subtropical zone, trade wind zone, zone of tropical alternating climate, equatorial zone. Of same rank is a climate of highlands. The temperate zone is subdivided fivefold according to hygrothermal aspects: (moist) sea climate of the west sides (of the continents), transition climate, summer warm continental climate, cool continental climate, east side climate. A winter rain climate of the west sides and an east side climate are the climatic limbs of the subtropical zone. The trade wind zone is divided into a dry and a moist trade wind climate, the latter with a differentiation into rainy outward sides and drier inland slopes.

Other contributions with relevance to global climatic classification

Surveys of purposes, history and procedures of global climatic classification with detailed discussions of classification examples are available in contributions by Hendl (1984) and especially Hendl (1991). They are complemented by summary tables and by maps. The same points of view apply to a comparative study by Hendl (1966 b) of genetic climatic classifications.
Further papers by Hendl (1964 and 1966 a) contain an areal measurement of the climatic types on the world maps after Köppen and Geiger and after Hendl. The quantitative results are also reprinted in Hendl (1991).

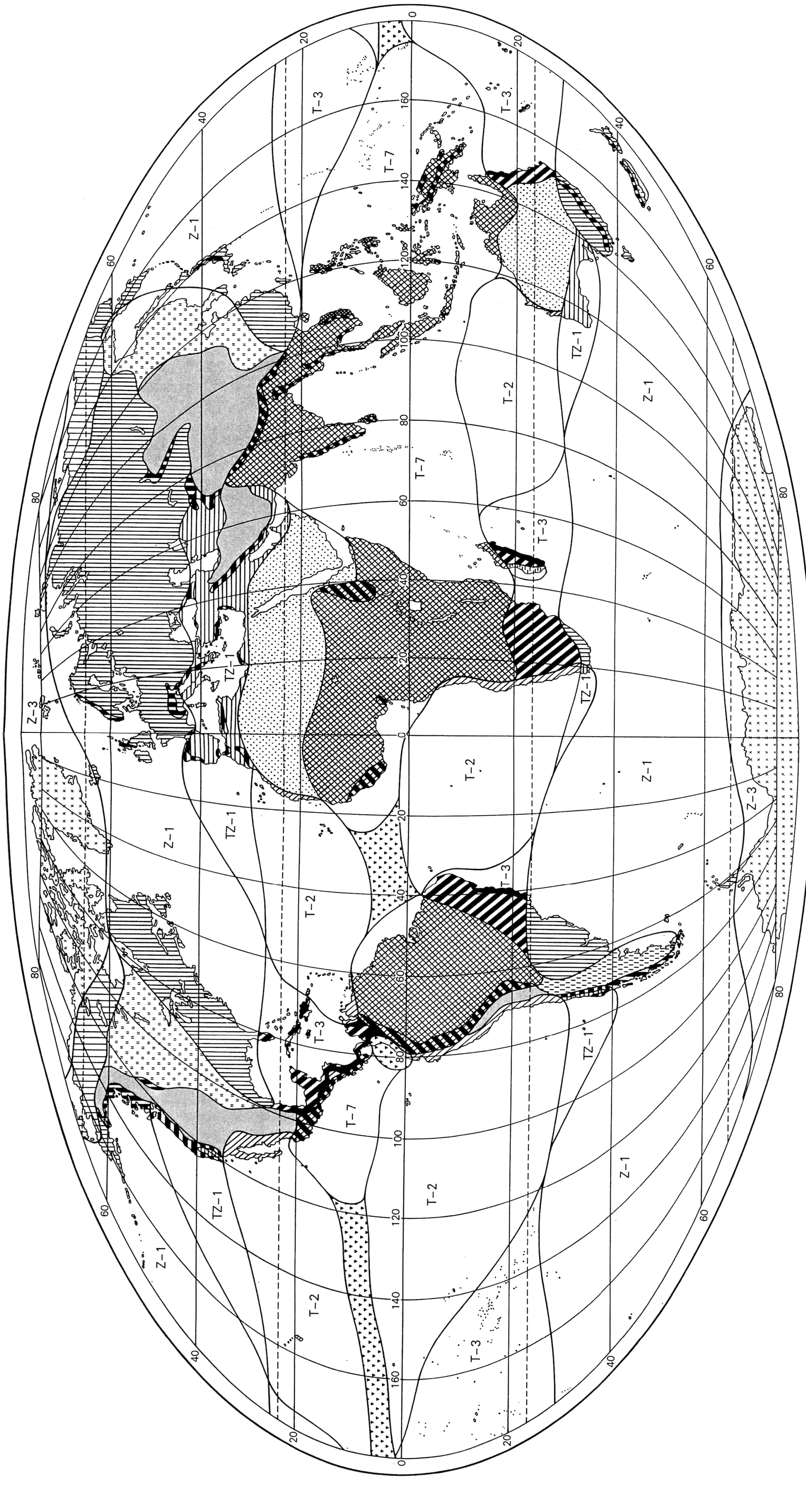

Fig. 2: Genetic climatic types after M. Hendl, 1963

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Experimental Investigations of Atmospheric Gravity Waves

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Introduction

In the mid-20th-century research activities have been focused on coupling processes of different layers of the lower and upper atmosphere. In this respect atmospheric gravity waves play a substantial role for the dynamic coupling from below and contribute significantly to the energy and momentum transfer in the lower and middle atmosphere (Hines, 1960, Gossard/Munk, 1954, Gossard, 1962). The Heinrich-Hertz-Institute (HHI) of the German Academy of Science in Berlin - Adlershof carried out an extensive monitoring programme of the mesosphere and ionosphere at the observatories Kühlungsborn, Neustrelitz and Juliusruh (Rügen Island). Initiated by the director of HHI at the time, E.A. Lauter the HHI started an experimental programme of the detection and characterization of gravity waves in the upper atmosphere about 1967. The results of the measurements at the HHI observatories were a suitable basis for analysing gravity waves.

The present paper summarizes the main steps of this programme.

Identifications of gravity waves in the mesosphere

The first analyses concerning high-atmospheric waves described wave-like structures in noctiluced clouds (Auff´m Ordt, 1973). These cirrus-like clouds consist of ice and aerosols and are concentrated in heights of 80-85 km. The clouds can be observed in summer in latitudes between approx. 50 and 65 degrees north after sunset (-6 to -16 degrees). From 1967 to 1972 stereo-photogrammetric analyses were carried out at three measuring stations on the two islands Hiddensee and Rügen in the Baltic Sea. During 28 nights noctilucent clouds could be observed and wave-like structures were found on cloud pictures of 12 nights. The analysed wave parameters showed great variations (wave length: 6 - 30 km, period: 5 - 30 min, phase velocity: 10-50 m/s). Due to the large range in the wave parameters the analysed correlation between the phase velocity and the stream fields in the upper troposphere was not significant. In the daytime photographic pictures were made of stratospheric condensation trails of aircrafts at two of the three observing stations. Unfortunately, it was not opportune for the HHI administration to interpret such flying pattern of military jets on the border between the former western and eastern political blocks, so that there are no results about these interesting soundings in the lower stratosphere.

The so-called phase-height measurements were identified as a better method for systematic studies of gravity waves in the mesosphere. Long-wave recordings of the French transmitter Allois (160 kHz, 1030 km distance) and of the Slovak transmitter Brasov (155 kHz, 1360 km distance), were made at the observatory Kühlungsborn (Lauter/Entzian, 1966). Normally the phase-height records show regular changes of the phase-height as a result of the daily variations of ionosphere structure. Parts of these recordings are affected by superimposed fluctuations of the phase difference, which could be interpreted as fluctuations of the reflection height with periods from about 5 to about 6o minutes. The hypothesis was established that these high-periodic variations occur during the passage of gravity waves. In order to verify this hypothesis a correlation was sought with potentially meteorological sources of gravity waves in the lower atmosphere (Brodhun et al., 1974). At first all records were excluded with strong solar radiation events at the same time. Then ray-tracing model computations were undertaken in order to evaluate the emission regions of possible sources in the lower atmosphere. Propagation times and paths were computed for gravity waves with different periods (8 to 40 minutes) and different phase velocities (15 to 40 m/s). The computations showed horizontal propagation distances from 70 to 550 km and propagation times from 1 to 10 hours. For this large range of parameters the statistical analyses reveal jet streams and cold fronts as possible sources of the wave-like variations in mesospheric measurements. The results showed clearly that for further investigations about gravity waves in the upper atmosphere it is very important to know the wave emission characteristics and not only the location of possible sources in the lower atmosphere. Using these characteristics a much better correlation between gravity waves in the mesosphere and their sources in the lower atmosphere can be achieved. Especially reflection and / or absorption processes can be taken into consideration during the propagation of waves through the tropo-, strato- and mesosphere.

Investigations of gravity waves with ground-based pressure measurements

In order to get more detailed data about the gravity wave field in the troposphere a special pressure sensor was developed and installed at the HHI. The troposphere gravity wave signal is strongly influenced by local and turbulent pressure fluctuations and by synoptic pressure variations. Therefore, many problems exist for reliable and stable measurements of the waves in the lower atmosphere. The developed sensor was a capacitor microphone with a measuring interval from 1 sec to approx. 6o min period. Frequencies above 1 Hz were eliminated by a „Helmholtz-resonator" as container for the sensor (acoustic low pass). The acoustic high pass was realised by the dimension of the volume behind the microphone membrane and by the diameter of the capillary of microphone (3db-decrease in the filter characteristic at approx. 0.00055 Hz).

From 1973 to 1980 different measuring campaigns were carried out with this new microphone pressure sensor. Data interpretation was concentrated on frequency of occurrence and on amplitude distribution of the waves (Bull/Neisser, 1976). Further investigations described the correlation of the waves with the occurrence of cold fronts (Brodhun et al., 1976) and with the troposphere inversion regime (Hotzler, 1976). In cooperation with the Academy of Science of Bulgaria a field campaign was carried out near the Vitoscha Mountains in the vicinity of Sofia in 1978. The results demonstrated special characteristics for the occurrence and for the parameters of waves in the lee region of the mountains (Neisser/Dubois, 1981, Bull et al., 1981).

The different campaigns with a single sensor station showed the necessity to install a stationary network for gravity wave measurements in the lower atmosphere (sec also Gossard/Hooke, 1975). In summer 1982 at the observatory Juliusruh (Rügen Island) a network was installed consisting of an array of three microbarographs (Fig. l). The type of the sensor was the same as above mentioned. The measuring data were transmitted by radio from the stations 2 and 3 to the central station 1. The pressure fluctuation records were processed by a microprocessor system, numerically filtered and spectrally analysed. Analyses of cross-correlation, spectral density, phase spectra and coherence spectra were performed, which allowed the determination of frequency of occurrence of gravity waves, amplitudes, phase velocities, directions of propagation and wave lengths as function of frequency (Neisser et al., 1983, Bull et al.,1984, Stangenberg, 1986).

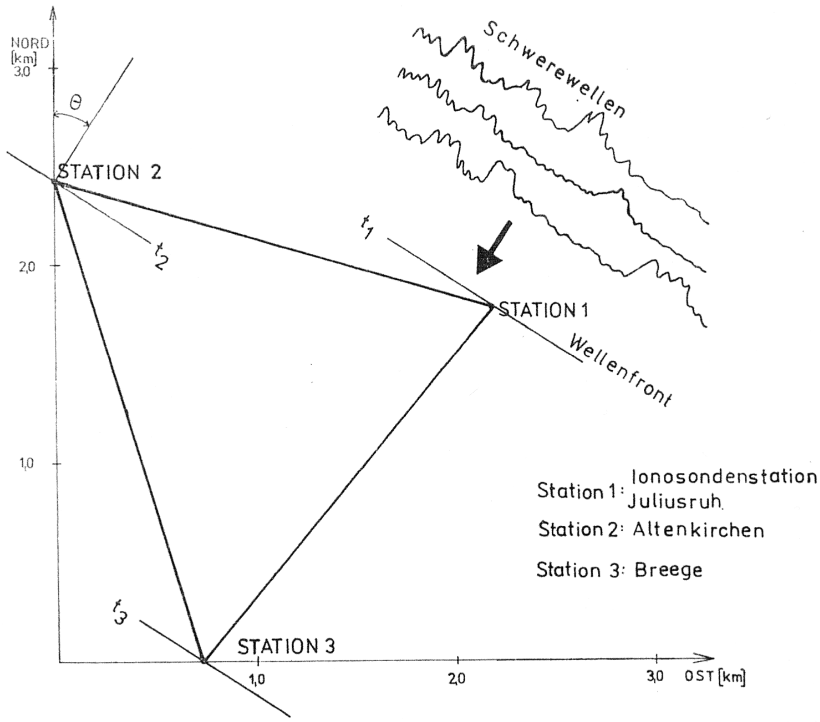
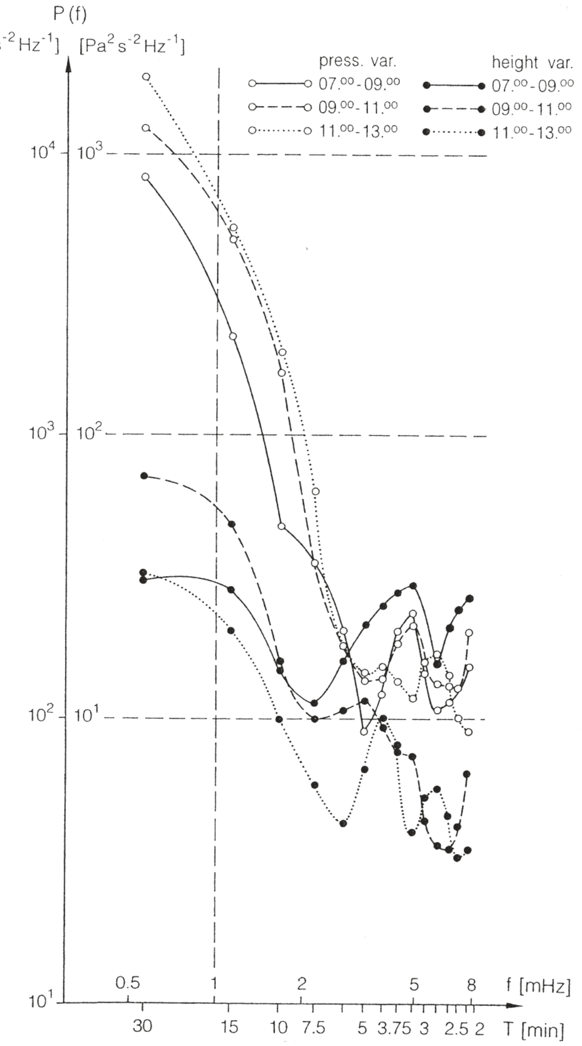


Fig. 1: Geometry of the microbarograph network in Juliusruh (Rügen island in operation: 1982 to 1991) Station 1: central station near by the observatory

The first statistical results of continuous records and of moving cross-spectral analysis yielded a 92 % frequency of occurrence of waves with significant coherence, mean rms amplitude of 3.3 Pa and a mean phase velocity of 33m/s (Bull, 1985). The mean wave amplitudes show only a small diurnal cycle. A moderate diurnal variation of the coherence behaviour was observed in autumn in accordance with the diurnal variation of the occurrence of temperature inversions. Special meteorological analyses (upper-air topographies, vertical cross sections, weather maps) and radiosonde soundings from the station Greifswald (distance to the network approx. 60 km) were examined for corresponding time intervals to determine the existence of high-tropospheric jet streams and the existence of dynamically instable wind-shear layers (Neisser, 1985). Comparisons of wave characteristics and the parameters of jet streams showed a significant increase of the amplitudes and of the velocities of the gravity waves for time intervals with dynamically instable shearing layers in the upper atmosphere (defined by a Ri-number smaller than 1.0). The correlation between the phase velocity vectors of waves and the wind vectors in the height region of the minimum of Ri-number was highly significant. This showed that many of the possible sources of gravity waves, especially in winter, lie rather near to the jet stream. The observed characteristics of jet stream generated waves showed a broad range of instable wave modes. The gravity wave measuring network was working at the station Juliusruh up to 1991.

Analyses of gravity waves in SODAR records

Gravity waves are also important for many micro- and mesoscale processes in the Planetary Boundary Layer (PBL). The waves interact with different processes typical for the PBL like turbulence, diffusion, local flows, inversions and act as trigger mechanism for convection, condensation and thunderstorm processes.



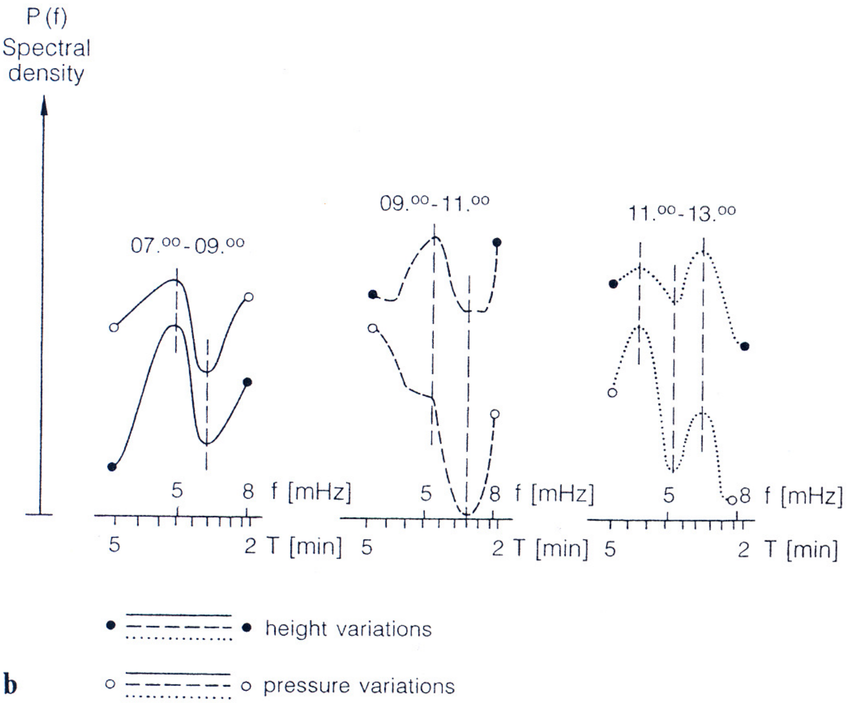
a

Fig. 2: JULEX - 87, 26.05.1987, 07.00 -13.00 T, Synchronously measured spectra:

- Height variations of SODAR structures (filled circles)
- Pressure fluctuations derived from microbarograph network (open circles)

a) Period range: 30 - 2 min

From 1986 to 1989 investigations of gravity waves in the PBL were carried out by means of acoustic remote sounding systems (SODAR) at the HHI. SODAR-soundings make it possible to observe the gravity waves synchronously for different height levels in the PBL. But in contrast to direct measurements with a microbarograph the SODAR measurements require the presence of sufficiently intensive turbulence blobs as tracer. Sometimes the waves themselves produce the tracer. Therefore, some restrictions exist for the interpretation of occurrence of gravity waves by means of SODAR records. The investigation of gravity waves was carried out during the following international PBL - experiments:
KOPEX-86 in the northern Bohemia (Czech),
JULEX-87 at the observatory Juliusruh (Rügen island),
JABEX-89 at the meteorological station Jaslovske Bohunice (Slovakia) near a nuclear power station.



b

b) cut-out for period range: 5 - 2 min

During KOPEX-86 (Neisser et al., 1988) and JABEX-89 (Bull/Neisser, 1991, 1993) networks were installed using three SODAR antennas dislocated in a triangle with distances between 4oo and 1200 m and transmitting vertically. Correlation and spectral analyses were carried out for the continuously measured profiles of the backscatter intensity and the vertical wind component. The results of the analyses showed gravity waves with periods from 2 to 30 minutes and wavelengths between 2 and 20 km. In many cases the propagation vectors correspond with the wind vectors in the PBL. Therefore, it was concluded that SODAR soundings are principally suited for a continuous monitoring of gravity wave structures in the whole range of the PBL.

For the better understanding of many processes in the PBL it is important to differentiate between turbulent and wave-like structures in the streaming field of PBL, especially for the modelling of the transport of air pollutions. Synchronous measurements of the fluctuations of vertical wind component and of the fluctuations of pressure were made in a common experiment with the Meteorological Observatory Potsdam (Meteorological Service of the GDR) during JULEX-89. A detailed analysis of the coherence spectra, co-spectra and quadrature-spectra for the two parameters showed, that in principle it is possible to separate turbulent and wavelike structures (Neisser et al., 1990).

Furthermore a comparison was carried out between the displacement spectra of SODAR structures and the spectra of pressure fluctuations during JULEX-89. Fig. 2a presents the spectra for three measuring intervals showing the spectral density of periods from 2 to 30 minutes. In Fig. 2b the minima and maxima of the two different spectra only for the short-periodic range from 2 to 5 minutes are shown. For these periods, typical for processes in the PBL, the coincidence of the spectra is very good. From this comparison the conclusion was derived, that both spectra were manifestations of the same wave process (Bull/Neisser, 1993).

Activities alter the unification of Germany

At the end of 1989 a cooperation focusing on the measurements of gravity waves in the troposphere was started by the Institute of the Physics of Atmosphere of the DLR (Oberpfaffenhofen) with the HHI. In the frame of a DFG-project (joint management by Th. Hauf and J. Neisser) in 1991/92 the HHI installed a microbarograph array with four pressure sensors in the lee of the AIps, 4o km southwest of Munich. The main components were the same as in the HHI network in Juliusruh. But the sensor electronics and the data processing were improved (Hauf et al, 1996). The new network was working for approx. five years. Especially during the mesoscale experiment CLEOPATRA of the DLR the data from the network were used for investigations of the interaction between convection processes and gravity waves (Finke, 1995).

On the initiative of the Institute for Meteorology and Climatology of the University Hannover a further network of the HHI-type was started at the Meteorological Observatory Lindenberg of German Weather Service in 1998. The scientific concept of this network was the combination of the measurements with special results of the monitoring programme of the observatory Lindenberg, e.g. profiles of virtual temperature and of vertical wind velocity measured by the first European 482 MHz wind profiler with RASS (Böhme et al., 2004).

The many years of experiences of the HHI (Academy of Sciences in Berlin-Adlershof) in investigating gravity waves have found a successful continuation and extension in these cooperations.

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Atlantic Exploration and Climate

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Ocean circulation and climate

Areas of coastal upwelling occupy less than 1% of the world ocean, but they provide more than 90% of worldwide fish landings and are of exceptional importance for the international economy, Cushing (1982). Four of them are forced by subtropical north- and south-east trade winds off the continental west coasts, Fig. 1. These persistent winds generate broad eastern boundary currents with core velocities of about 0.3 m/s, which are represented by the California Current and the Humboldt Current

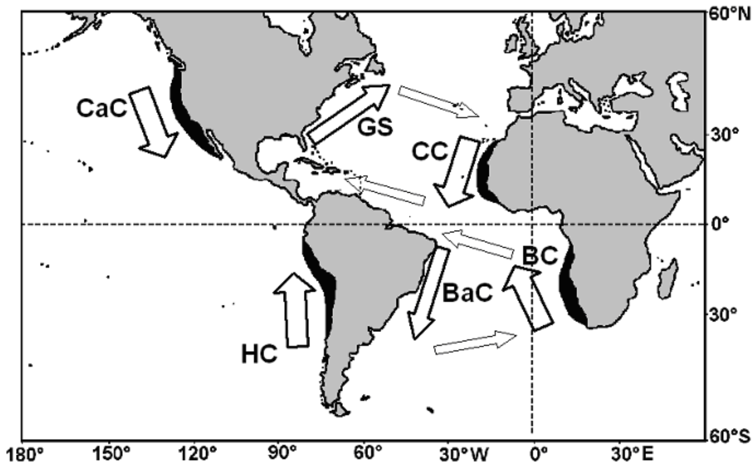

Fig. 1: Subtropical upwelling areas (black) within the system of eastern boundary currents of the basin-scale gyre circulation given by arrows representing the California Current (CaC) and the Humboldt Current (HC) in the eastern Pacific, as well as the Canary Current (CC), the Gulf Stream (GS), the Benguela Current (BC), and the Brasil Current (BaC) in the Atlantic.

in the eastern North/South Pacific and the Canary Current and the Benguela Current in the eastern North/South Atlantic. Within the oceanic top layer of several decametres, these wind-driven currents convey cold water from the horse to equatorial latitudes to form the eastern branch of the respective anticyclonic gyre on the basin scale, Krümmel (1907). Off the continental east coasts, the poleward western boundary currents are forming the western branch of these gyres steered significantly through the continental slope. In the Atlantic Ocean, these narrow current systems are represented by the Gulf Stream in the north and the Brazil Current in the south. Associated core velocities frequently exceed 1 m/s, Sverdrup et al. (1942). Dwelling exemplarily in the North Atlantic, the subtropical gyre is closed by the westward North Equatorial Current. It feeds great water portions from the Canary Current into the Caribbean source area of the Gulf Stream. Finally, the anticyclonic subtropical gyre is closed by the eastward Azores Current between 30° and 40°N. However, the resulting net volume transport of these eastern and western boundary currents is controlling the remaining

Fig. 2: Research vessel (r/v) 'Alexander von Humboldt' was owned by the Academy of Sciences of the former GDR (1970-1991).

flux of heat and freshwater from equatorial to Arctic regions, cf. Oort and von der Haar (1976). Following Broecker (1991), established internal pressure gradients between high and low latitudes maintain the overall thermohaline circulation (THC). It conveys saline and warm near-surface water towards Arctic latitudes, but cold and lesser saline deep water towards low latitudes. Vertically, this THC is mainly closed in the Greenland Sea by sinking dense water. Resulting thermohaline characteristics of the southward spreading deep water are given by those of the North Atlantic Deep Water, Sverdrup et al. (1942). It crosses the equator in the West Atlantic Basin to reach Antarctic zones, Wüst (1935). Concerning the northward near-surface branch of the inter-hemispheric THC, the equatorial system of zonal currents acts like a barrier. Consequently, the mass deficit due to downward convection in the Greenland Sea can only be partly compensated and remaining meridional pressure gradients maintain the thermohaline overturning circulation on a certain level. Associated spatiotemporal changes in the strength of theses pressure gradients modify the inter-hemispheric heat transport to influence net heat fluxes from the ocean towards the atmosphere. Via wind-driven currents, the underlying meridional redistribution of heat affects the climate state, especially on the decadal scale. Among other things, this results from large differences in the heat capacity of air and water as well as from the basic difference between the velocity of oceanic currents and winds, Grötzner et al. (1998). Consequently, the strength of trade winds and the intensity of coastal upwelling fluctuate along African west coasts on comparable time scales, Bakun (1990). Looking for climatic wind patterns over tropical and subtropical zones of the Atlantic by inspecting climate atlases, it becomes clear that the Inter Tropical Convergence Zone (ITCZ) separates the north-east trade wind (NET) from the south-east trade wind (SET) in the vicinity of the geographical equator. However, the meteorological equator of the ITCZ intersects the geographical equator in the equatorial West Atlantic and crosses the West African coastal zone between 7° and 15°N. Consequently, the equatorial westward component of the SET maintains positive anomalies of the sea level in the west and negative anomalies in the east. Associated internal pressure gradients sustain the mentioned system of eastward equatorial undercurrents feeding thermohaline properties of the South Atlantic Central Water, as described in Sverdrup et al. (1942), towards the Gulf of Guinea as well as into poleward undercurrents of coastal upwelling areas off Northwest and Southwest Africa all year round.

Coastal upwelling

Beside the native Baltic Sea, the Institute for Marine Research (IfM) of the former GDR Academy of Science focussed its hydrographic research activities on the spatio-temporal variability in coastal upwelling areas off Northwest and Southwest Africa. Related field campaigns were assigned to the so-called 'applied hydrography' and co-ordinated by the former Institute for Sea Fishery Rostock-Warnemuende. Starting with the rediscovery of the Atlantic Equatorial Undercurrent by the former director of the IfM, cf. Voigt (1961), the system of eastward equatorial under currents also got some research priority. These research activities were assigned to the so-called 'basic hydrography' and supervised by the former president of the GDR Academy. Details of related cruise arrangements are discussed in more detail by Brosin (1996). Outside the Baltic Sea, all research activities of the IfM were carried out onboard of the r/v 'A. v. Humboldt', Fig. 2. These field campaigns started in 1970 and ended in 1983, Table 1. Each hydrographic station was sampled by using the classical Nansen bottles. Each of them was equipped with (pressure) unprotected and protected thermometers to control actual measuring horizons in the vicinity of recommended so-called UNESCO standard depths. Salinity, dissolved oxygen, and different nutrients were determined finally in the ship laboratories.

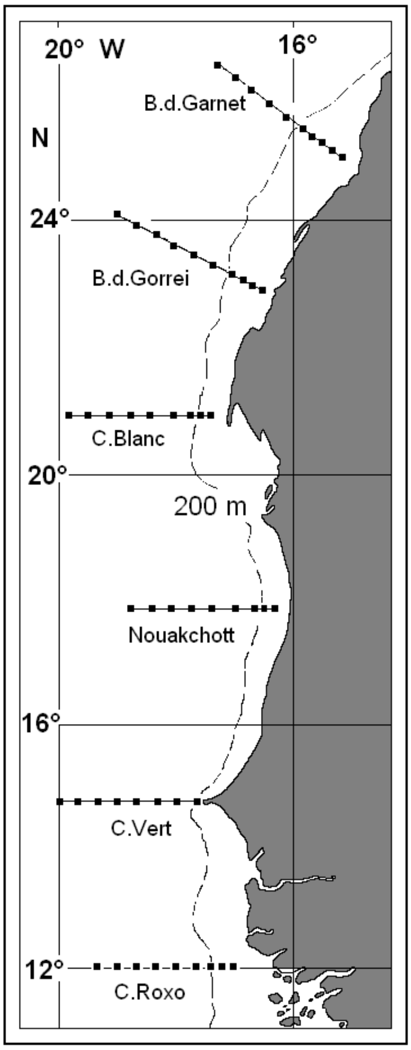

Fig. 3: Hydrographic standard stations of the r/v 'A. v. Humboldt' to investigate coastal upwelling off Northwest-African coasts with a station spacing of 10 nm over the continental shelf, but 20 nm further offshore during 1970-1983 as adopted from Schemainda et al. (1975); named transects point to given landmarks such as Bahia de Gorrei (B. d. Gorrei) and Cape Blanc (C. Blanc).

Table 1: Cruises of the r/v ‚Alexander von Humboldt' into the equatorial Atlantic Ocean and coastal upwelling zones off Northwest and Southwest Africa during 1970-1983; the associated frame programmes are explained in more detail in the text.

No.	Cruise Time	Programme
1	01 July - 23 November 1970	IfM
2	23 March - 25 June 1971	IfM
3	16 September - 17 December 1971	IfM
4	07 June- 07 September 1972	CINECA
5	16 November 1972 - 18 April 1973	CINECA
6	26 April - 18 July 1974	CINECA
7	25 July -09 September 1974	GATE
8	28 January -14 April 1976	IfM
9	21 September -17 December 1976	IfM
10	01 April-11 July 1979	FGGY
11	14 September - 20 December 1979	IfM
12	07 September - 25 December 1982	IfM
13	26 February - 10 May 1983	IfM

Hydrographic stations generally followed given standard transects with an offshore length of about 300 km, Fig. 3. The station spacing varied between 20 nm further offshore and 5 nm outside the 12 nm covering coastal zone (1 nm = 1.852 km). Resulting sections aligned normal to the isobath of 200 m. The validated data sets were distributed, via hard copies, without any costs for interested institutions of riparian countries. This was the first step towards an international scientific co-operation under the umbrella of the CINECA programme (Cooperative Investigations of the Northern Part of the Central Atlantic, UNESCO 1969-1978). An own CTD probe, which was named OM-75, could be developed during the mid 1970s, Möckel (1980). Its underwater unit opened a continuous profiling of conductivity (C)/salinity, temperature (T), and pressure/depth (D). During the following years, related standard sensors could be completed with a sufficient measuring accuracy through those for sound speed and dissolved oxygen. For example, the measured and the computed sound velocity have been compared on-line at each station to control the electronic stability of the CTD sensors. This progress in the measuring techniques accomplished the base for the international exchange of obtained data sets. Thus, own results were more and more involved into the so-called CUEA research programme (Coastal Upwelling Ecosystem Analysis) co-ordinated by the USA as part of the UNESCO-International Decade of the Ocean Exploration (1971-1980). Beginning with the first hydrographic station, all hydrographic profiles were accompanied by standard meteorological observations. Due to logistical reasons, the sampling of zoo- and phytoplankton has been performed only at selected stations. Altogether, the resulting data sets should provide the base to answer two questions:

- Which general dynamics are controlling the process of coastal upwelling in the offshore-depth plane?
- Which consequences result from the seasonal migration of the NET for the meridional distribution of the bio-productivity providing the feeding ground of commercially landed fish?

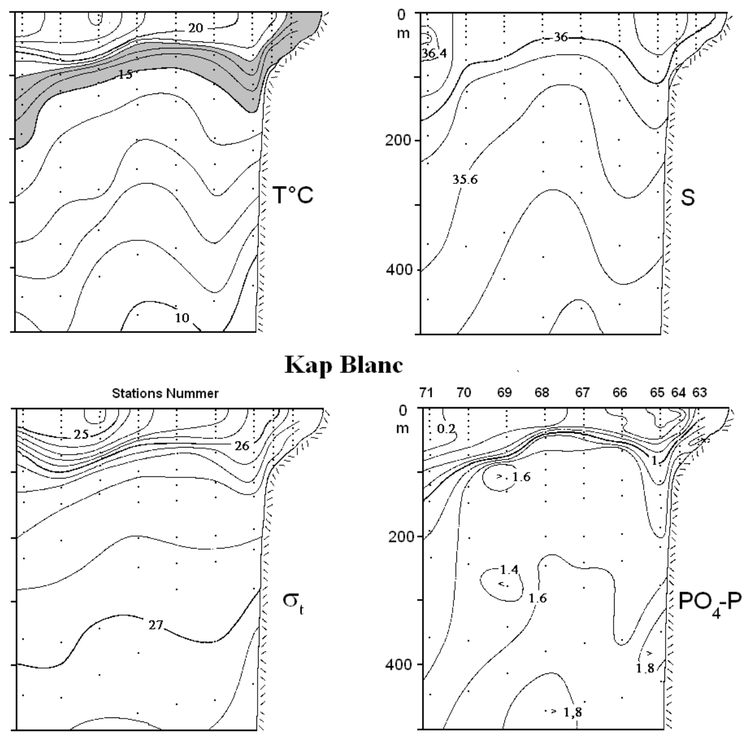

Fig. 4: Vertical distribution of temperature (T), salinity (S), density (σ_t), and phosphate (PO4-P) measured along the zonal Cape Blanc section, see Fig. 3, during 2 - 4 September 1970; cold upwelling water is climbing shallow shelf areas with temperatures between 15° and 18°C (grey).

Fundamental results

Concerning the first question, it was well known that the climatic belt of the NET covers about 1.500 km between its northern and southern boundary along the Northwest African coast and that its climatic velocity is about 6 m/s. The resulting alongshore wind-stress produces, via the deflecting Coriolis force, an offshore mass transport within near-surface layers, Ekman (1905). Thus, a one-sided divergence zone is formed along the coast line. It is accompanied by a certain mass deficit, Smith (1968). Consequently, cold, poorly oxygenated, but nutrient rich water compensates partly this mass deficit via onshore motions in layers between 80 and about 120 m depth, Fig. 4. Over the continental shelf, the upwelled water intersects the sea surface and forms a belt of cold water following the coastal geometry. Here, the sea surface temperature (SST) is several °C colder than in the open eastern Atlantic. For the principal understanding of the embedded on-offshore circulation, a conceptual model was created during the early 1970s, Hagen (1974). It was able to accumulate basic characteristics of all subtropical zones of coastal upwelling, independently of the given coastal geometry, Fig. 5. In general, it simply describes the development/maintenance of two circulation cells on the offshore-depth plane. The primary cell occupies the shallow coastal zone with coldest SSTs. It only affects an offshore scale of some ten kilometres. Towards the open ocean, this cold water belt is bounded by a relative sharp frontal zone at the sea surface. The position of this front zone is dynamically trapped over steepest on-offshore gradients in the shelf topography. Therefore, it was also called shelf-break frontal zone. Here, the upward displacement of the seasonal pycnocline intersects the sea surface and generates strong offshore gradients in the hydrography. In the open East Atlantic, the pycnocline separates warm near-surface water from cold water of intermediate layers. Because the exchange of water properties takes place mainly on such isopycnal surfaces, it became clear that all subtropical upwelling regions sensitively react on spatiotemporal changes of the wind forcing, which are controlling the net upward flux of carbon dioxide from the ocean into the atmosphere. Thus, the trades redistribute this atmospheric intake on the hemispheric scale. On the oceanic side, however, this surface frontal zone separates nutrient rich onshore water of the primary upwelling zone from nutrient poor offshore water of the secondary upwelling zone. Shoreward of the front, the upwelled cold water is heated by the solar radiation. The resulting mixed water of the euphotic zone is well oxygenated via wind induced stirring. This provides optimal conditions for an exceptional growing of phytoplankton/zooplankton and establishes best feeding grounds for commercially landed fish species, Postel et al. (1995). Concerning the Ekman offshore transport in quite mixed near-surface layers, the surface frontal zone acts like a barrier along the continental slope. Immediately off the front zone, the resulting current convergence generates downward motions oxygenating intermediate layers and the on-offshore circulation cell of the primary upwelling zone is closed. This relative narrow zone of downwelling sufficiently explained the frequently observed enrichment of plankton and fish along the landside of the surface front. Along its offshore flank, however, the barrier-effect of the surface front produces a small divergence zone. Associated upwelling feeds water from layers above the pycnocline into near-surface layers. However, this upwelled water is poor in nutrient and a significant biological reaction can be missed at all.

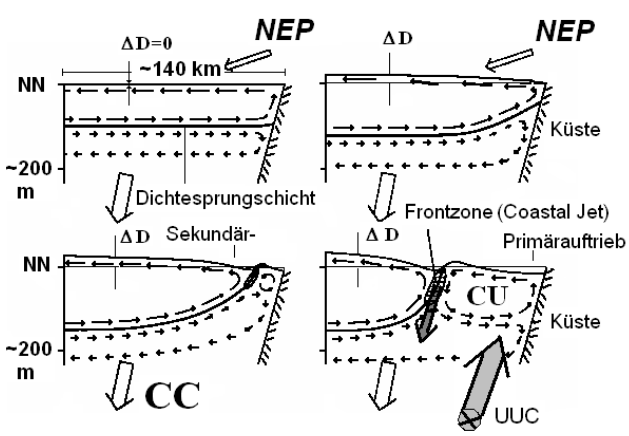

Fig. 5: Schematic describing the development of the coastal cross circulation in subtropical upwelling areas with a meridional coast as derived from observations carried out in the Canary Current regime (CC) off Northwest Africa by Hagen (1974); the north-east trade wind (NET=NEP) generates an offshore mass transport within well mixed near-surface layers to produce, with respect to the standard sea level NN, a zone of negative anomalies ΔD) in near-shore zones; due to zonal differences in the hydrostatic pressure, the seasonal pycnocline inclines the sea surface along the shelf edge and forms a frontal zone with the embedded southward coastal jet; con-and divergences of the surface current are producing down- and upwelling belts closing the primary (CU) and the secondary circulation cell on both sides of the frontal zone; meridional differences in the offshore transport maintain internal pressure gradients steering the poleward upwelling undercurrent (UUC) in intermediate depths off the continental slope.

Ekman (1905) already pointed out that the Ekman offshore transport involves a strict dependence of the given latitude. For constant alongshore winds, this transport increases towards lower latitudes due to the decreasing Coriolis frequency. Consequently, Yoshida (1967) overcame the two-dimensional approach of the offshore-depth plane and included alongshore pressure gradients to describe three-dimensional upwelling patterns with positive sea level anomalies in the north and corresponding negative anomalies in the south. Thus, meridional pressure gradients maintain a poleward ‘upwelling undercurrent (UUC)’ within several hundred metres depth, just off the continental slope. The UUC must be considered to be a dynamical ingredient of each subtropical system of coastal upwelling. Consequently, it could be also observed in the Namibian upwelling area, Hagen et al. (1981). Due to its geostrophic adjustment with the surrounding mass field, this undercurrent is easily visible through downward inclining isopycnal surfaces off the intermediate continental slope, Fig. 4. On both hemispheres, the UUC conveys thermohaline properties of the so-called South Atlantic Central Water (SACW) up the latitude of about 24°, cf. Hughes and Barton (1974) and Shannon (1985). The SACW is rich in nutrients, but relative poor in dissolved oxygen. For instance, moored current meter strings deployed off Cape Blanc (21°N) revealed an overall core speed of the UUC between 0.05 and 0.15 m/s, Mittelstaedt et al. (1975). Its importance for the transformation of thermohaline properties in upwelled water was already realized during the early 1980s. Across the intermediate continental slope, upper levels of the UUC feed their SACW into the cross circulation cell of the primary upwelling belt. Beside the received observational evidence, this could be also confirmed by the aim of different versions of diagnostic circulation models. Legitimate preconditions about lateral and vertical mixing conditions provided numerical solutions of the equation of motion over coarsely resolved bottom topography with a grid resolution of one degree. Resulting circulation patterns came close to observed dynamical topographies of the mass field. The regional runs started with results of climatic solutions computed on the basin scale. The latter originated from climatic fields of the water density and the wind and delivered the necessary boundary conditions for regional case studies in the Northwest African upwelling area. Thus, one objective was focussed on the spreading of the SACW within the UUC off Senegal and Mauritania, Fig. 6. Further model versions used much narrower numerical grids and emphasized the role of submarine plateaus and canyons to form eddy-like circulation patterns on the meso-scale, Hagen and Gurina (1985). All modelling efforts were supervised by A. Sarkisyan of the Shirshov Institute of Oceanography/Moscow. Based on the obtained results and retrospectively analyzed hydrographic data sets of the 1960s, which were available from the international data centres for the tropical/ subtropical Atlantic, it could be shown that the source area of the SACW of the UUC takes place in the eastward North Equatorial Undercurrent (NEUC), Fig. 7. Consequently, it came to a close interlocking between the so-called ‘fundamental research’ about the system of eastward equatorial counter currents and the ‘applied research’ in the Northwest African coastal upwelling during the early 1980s, Fig. 8.

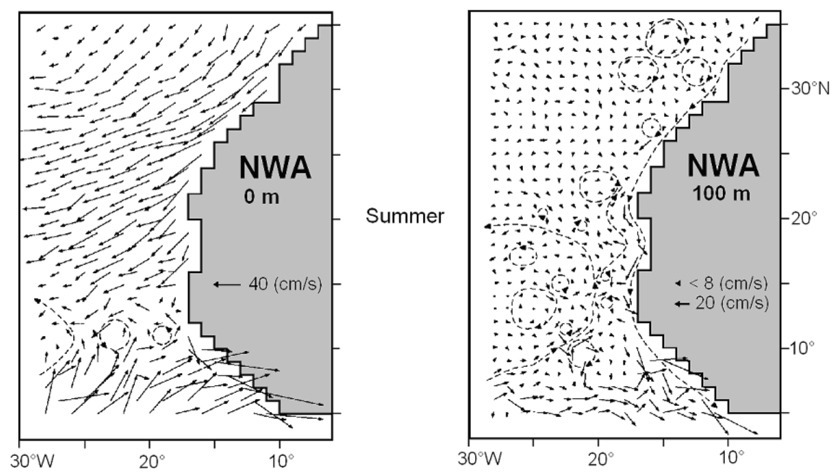

Fig. 6: Current arrows at the sea surface and at 100 m depth obtained from diagnostically analyzed data of summer season density fields in the central East Atlantic according to Demin et al. (1981); broken lines indicate persistent current branches and associated eddy-like structures.

The equatorial current system

During the 1970s, the IfM participated in the international Atlantic Tropical Experiment (GATE) as well as in the First Global Experiment (FGGE) planned under the umbrella of the Global Atmospheric Research Programme (GARP). Activities focussed on the better understanding of the dynamics in the system of eastward equatorial undercurrents of the Atlantic Ocean, Fig. 9. Joint field campaigns focussed on variations in core speed and horizon of the equatorial undercurrent, Lass and Hagen (1980). On the climate scale, the south-east trade wind pushes a hill of warm water into the equatorial West Atlantic. This generates positive sea level anomalies in the equatorial West Atlantic, but negative anomalies in the Gulf of Guinea. Established internal pressure gradients provide the driving force for the entire system of eastward counter currents on both sides of the equator with significant fluctuations on the year-to-year scale, Lass et al. (1983).

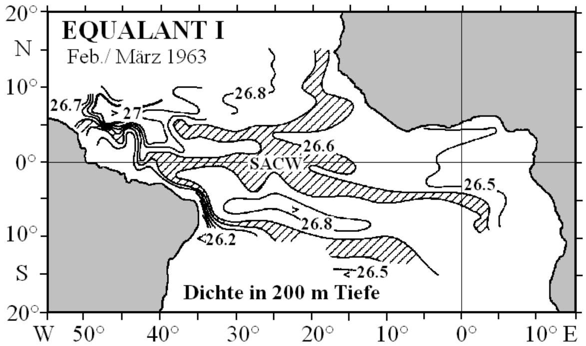

Fig. 7: By Hagen and Schemainda (1984) reconstructed distribution of the water density (σ_t units) resulting from first measurements of the international programme for the exploration of the equatorial Atlantic (EQUALANT) during February/March 1963; the density range of the South Atlantic Central Water (SACW) is hatched; in comparison with Fig. 8, 9 , the obtained patterns suggest that the SACW of the Equatorial Undercurrent (EUC) ascended into shallower layers in the east of about 14°W and that of the South Equatorial Undercurrent (SEUC) and the North Equatorial Undercurrent (NEUC) reached the eastern flanks of locally trapped cyclonic eddies named the Angola Dome in the south-east (12°S, 4°E) and the Guinea Dome in the north-east (12°N, 22°W); both persistent features were considered to be the source areas feeding their SACW into the poleward upwelling undercurrent (UUC) to reach higher latitudes, immediately off the continental edge.

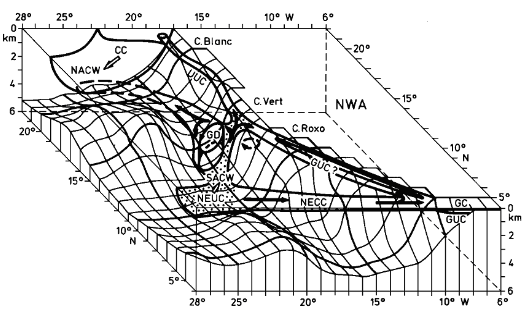

Fig. 8: Scheme of Hagen and Schemainda (1984) derived from results of the applied diagnostic circulation model for the description of topographically steered pathways of the intermediate eastward spreading of the South Atlantic Central Water (SACW, dots); the superficial layers of the south-westward Canary Current (CC) convey North Atlantic Central Water towards lower latitudes; in contrast, the dissemination of the SACW starts in the North Equatorial Undercurrent (NEUC) and passes the eastern flank of the cyclonic Guinea Dome (GD) to reach the upwelling undercurrent (UUC) at higher latitudes; at the sea surface, the North Equatorial Counter Current (NECC) propagates much further eastward and continues as Guinea Current (GC) along the Gulf's zonal coast; only poor observational evidence was retrieved for a continuous recirculation from the westward Guinea Undercurrent (GUC) into the UUC.

Spatiotemporal variability, subinertial waves, and marine productivity

Furthermore, it became clear that the eastward North Equatorial Counter Current (NECC) of near-surface layers continues downward to form the North Equatorial Undercurrent (NEUC) flowing in several hundred metres depth. The latter conveys the thermohaline properties of the SACW towards the regionally trapped Guinea Dome (12°, 22°W), which is greatly in geostrophic balance and rotates cyclonally all year round, Fig. 8.

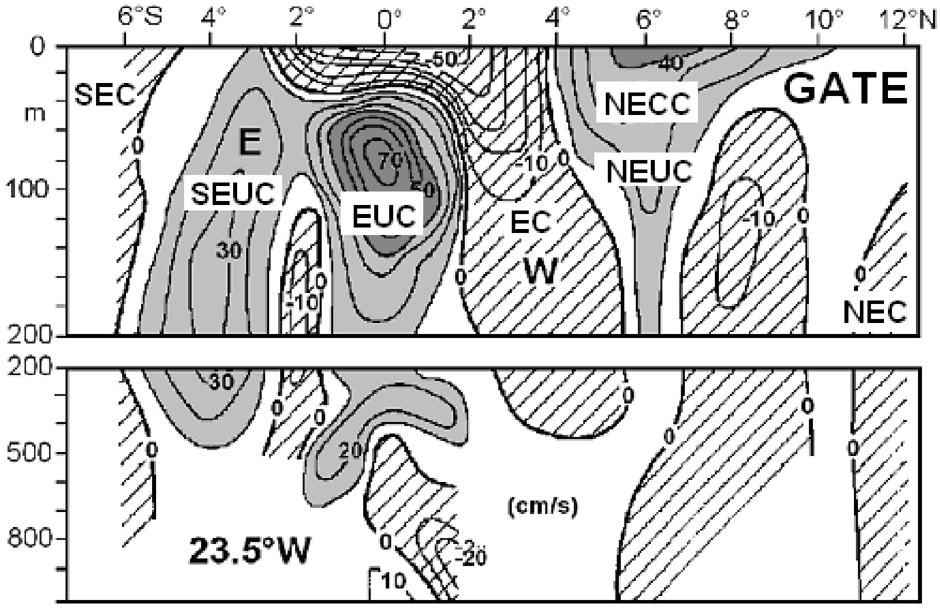

Fig. 9: Depth and speed (cm s-1) of eastward (grey) and westward current cores (hatched) of equatorial currents observed at 23.5°W during GATE (26 June – 19 September 1974) by Düing et al. (1980); the notation is: SEC=South Equatorial Current, SEUC= South Equatorial Under Current, EUC= Equatorial Under Current, EC= Equatorial Current as northern branch of the SEC, NECC= North Equatorial Counter Current, NEUC= North Equatorial Under Current, and NEC= North Equatorial Current.

The second question focussed on the seasonality in intensity of coastal upwelling and related consequences for the biological productivity off Northwest Africa. Hitherto, two further aspects entered the existing paradigm so far. The first of them regarded the so-called ‘remote forcing’ of the Northwest African upwelling due to the dynamical connection between the NEUC and the UUC. The second one was given through year-to-year changes in the strength of the north-east trade wind producing corresponding anomalies in the meridional displacement of the actual upwelling centre. For both cases, it was assumed that the seasonal cycle in the alongshore wind component provides the most energy rich signal in the spectrum of upwelling variability. In other words, the compilation of a characteristic seasonal cycle should be possible by using monthly measurements of different years. Thus, it could be shown for the first time that Northwest African upwelling reaches its northernmost position in August and its southernmost position in February, Schemainda et al. (1975). Concerning an effective biological productivity all the year, it became clear that sufficient feeding grounds for commercially used fish are located in the shelf zones between 19°N and about 24°N, Fig. 10. This was the base of first recommendations for seasonal commitment of the national fishing fleet. However, there was an unexplained peak in the biological productivity southward of the southern border of the north-east trade wind (15°-19°N) during the nonupwelling season. It occurred sporadically on the year-to-year scale and could be feasibly explained by corresponding changes in the intake of SA CW into the shelf areas via related

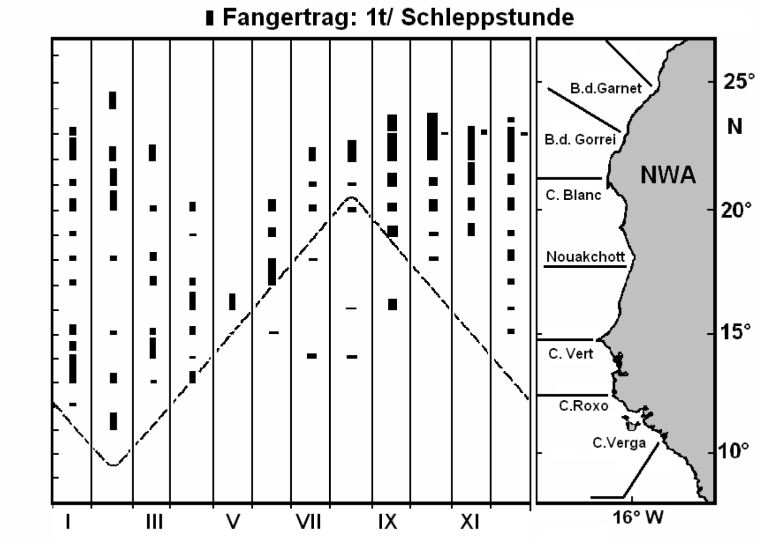

Fig. 10: Seasonal cycle in the meridional distribution (dashed line) of actual fish landings (metric tonnes per hour) compiled monthly (Roman numbers) from catches of different years off Northwest Africa (NWA) according to Schemainda et al. (1975); the hydrographic transect off Cape Verga shown in the very south of the right panel was not a regular section of the observational programme shown in Fig. 3.

fluctuations in the strength of the UUC and the NEUC. This means, however, that such years reflect an enhanced export of nutrients from the UUC into shallow shelf zones to accelerate regionally the biological production off the coasts of Mauritania and Senegal.

During the 1980s, the UUC was considered to be a persistent ingredient of seasonally forced planetary Rossby waves. Such wave types involve extended meridional wave crests of the magnitude of 1000 km off the West African coast, Hagen and Schemainda (1989). They are forced by the seasonal cycle in the wind-stress curl and propagate slowly westward to cross the subtropical/tropical North Atlantic in a few years, Hagen (2005). Within intermediate layers, they export thermohaline properties of the SACW towards the open North Atlantic, Fig. 11. Reaching the coasts of South America under relaxed trade winds, they may trigger eastward travelling equatorial Kelvin waves, Hagen (2001). Thus, a huge hill of equatorial warm water attains the Gulf of Guinea after 2-3 months. Here, it splits up into two branches propagating poleward to suppress coastal upwelling off Northwest and Southwest Africa. Spatio-temporal structures of associated mass field anomalies in the cold upwelling belt could be sufficiently explained by the linear theory of barotropic continental shelf waves on the multi-day scale, Hagen (1981). On the monthly scale, it became clear that the observed spectra of current fluctuations in equatorial zonal currents mainly reflect properties of equatorially trapped waves, Fennel et al. (1987). Unfortunately, corresponding results must be missed for the year-to-year scale due to the gap of adequate data sets. However, it became clear that the annual intensity of coastal upwelling exhibits exceptional strong and relaxed 'years'. Among other things, this could be engaged by interannual fluctuations of cold water areas derived from remotely sensed satellite images of the sea surface temperature, La Violette (1974), as well as from corresponding changes in annual landings of commercially caught fish, Sedykh (1978). Concerning involved quasi-cycles, Hagen and Schmager (1991) reported a three-year-cycle affecting the entire subtropical North Atlantic Ocean.

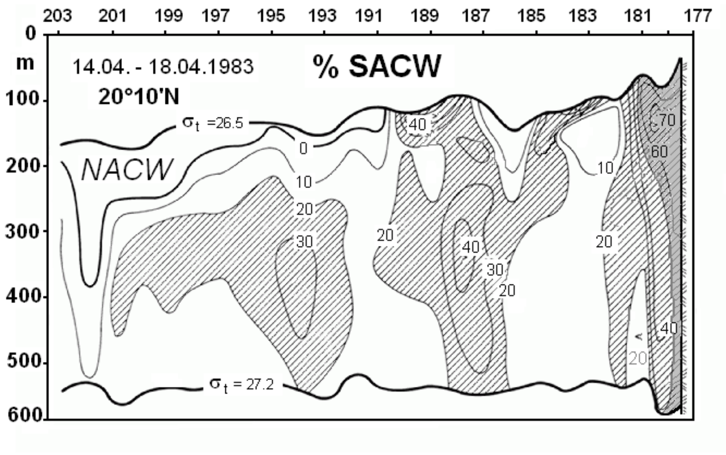

Fig. 11: Zonal distribution of the South Atlantic Central Water (SACW, 30% SACW corresponds to 70% NACW) between two selected isopycnal surfaces (σ_t=27.2 means 1027.3 kg m-3) beginning with station 177 in the east and the predominant station spacing of 20 nm further offshore along the zonal section off Cape Blanc (20°10'N, see Fig. 3) during April 1983, Hagen and Schemainda (1987); the core of the actual upwelling undercurrent (UUC) exceeded 70% SACW between 100m and 150m depth (18°W); the second SACW core reached values greater than 40% at about 350 m depth, while the third core still reached more than 30% SACW around 400 m depth; the averaged zonal distance between these three SACW cores was estimated to be 260 km; concerning the working hypothesis about seasonally forced planetary Rossby waves propagating slowly westward, the second SACW core corresponds to the UUC of the previous years and so on.

Large-scale processes in atmosphere and ocean

To obtain somewhat more insight into associated dynamics, Michelchen (1989) gathered long-term series of meteorological standard parameters such as wind, sea level air pressure, dry/ wet air temperature, sea surface temperature (SST), and salinity measured at coastal stations along the Northwest African coast. On this base, he could show that opposite anomalies in the SST usually characterise the interannual reaction along meridional African coasts in the north and the zonal coast of the Gulf of Guinea in the south. Thus, it became evident that the sign of equatorial SST anomalies in the Gulf well reflects thermal conditions in the Benguela upwelling off Namibia, especially on the interannual scale. The cross-correlation between different long-term series suggested the following scenario: Global changes in the heat flux between ocean and atmosphere increase the core pressure of the anticyclone in sea level air pressure over the central South Atlantic. This enhances the air pressure gradient towards the equatorial belt of low air pressure and cyclones over South Africa to accelerate not only the south-east trade wind (SET), but also the resulting Benguela upwelling. Synchronously, the SET achieves extremely northern latitudes in the eastern Atlantic and intensifies the south-west monsoon over the Gulf of Guinea. This causes coastal upwelling with decreasing SSTs along the Gulf's northern coast. Consequently, there is a positive correlation between the anomalies of the SST observed along the zonal coast of the Gulf of Guinea and along the meridional coast off Namibia. However, these data sets also suggested that the core pressure of the Azores High simultaneously decreased over the eastern North Atlantic. The strength of the north-east trade wind (NET) relaxes to produce decreasing coastal upwelling in the Canary Current regime off Northwest Africa. This, however, causes a negative correlation between associated anomalies in the SST and those observed along the zonal coast of the Gulf of Guinea on the year-to-year scale. Such a situation, which is characterised by a relaxed NET and an intensified SET, coincides with an enhancement of westward winds along the equator. This accelerates transports in the westward South Equatorial Current and establishes exceptional differences in sea level with positive anomalies in the West and negative anomalies in the equatorial East Atlantic. Associated internal pressure gradients increase to intensify transports in the system of eastward equatorial counter-currents. Concerning a given interval of time, much more SACW is conveyed towards the equatorial East Atlantic. It reaches the near-surface layers in the east of about 10°W. Here, it is well heated by the solar radiation on its pathway towards the Gulf. Consequently, the seasonal pycnocline declines to greater depths due to the increasing hydrostatic pressure within the upper layers, O'Brien (1978). Thus, along the Gulf's northern coast, upwelling favourable winds convey relatively warm water from layers above the pycnocline towards the sea surface. Steered by meridional pressure gradients between the Gulf of Guinea and the Namibian upwelling area, the equatorial near-surface water spreads southward to restrict the Namibian upwelling regionally. In literature, this phenomenon is called 'Benguela Nino' in analogy to that what is happening under similar circumstances in the equatorial East Pacific. The arrived warm surface water releases enhanced heat fluxes between ocean and atmosphere. Heated air masses gradually reduce the meridional gradients in sea level air pressure between the anticyclone over the South Atlantic and the equatorial low pressure belt beneath the ITCZ. Thus, the strength of the SET decreases and a self-regulating oscillation is established to produce quasi-rhythmic fluctuations in the SST on the interannual/ decadal scale, Gu and Philander (1997). This scenario assumes that observed changes in the strength of the Atlantic trade winds partially originates from corresponding fluctuations in the trades over the central Pacific Ocean because the latter provides the largest reservoir of the so-called oceanic warm water sphere influencing the water-air heat fluxes, Hagen (1989). For instance, the analysis of monthly long-term series (1892-1999) of the dry air temperature, the sea level air pressure, and the precipitation recorded at the St. Helena Island (16°S, 5.7°W) in the South Atlantic clearly exhibited quasi-cycles of 30-40, 12-17, and 3-9 years, Feistel et al. (2003). The shortest of them points to the well known El Nino cycle detected in the equatorial East Pacific, Rasmusson (1984), see annex.

Research continuity under changed conditions

In Warnemuende, the investigation of the impact of climate changes on associated changes in annual fish landings in subtropical coastal upwelling areas could be continued after the reunification of Germany in 1991, cf. Schwartzlose et al.(1999) and Hagen (2003). For instance, under the umbrella of the international World Ocean Circulation Experiment (WOCE), several hydrographic field studies could be carried out to study the intermediate spreading of the SACW within poleward undercurrents off Northwest Africa and the Iberian Peninsula, cf. Hagen et al. (1994) and Stöhr et al. (1997). Among other things, it could be shown that the expected consistency of the poleward undercurrent is frequently disrupted on its pathway across the Gulf of Cadiz. Instancing the undersea plateau off Cape Ghir (31°N), other research topics focussed on the topographically controlled westward extension of so-called upwelling filaments, Hagen et al. (1996).

The former 'Institute for Marine Research Warnemuende (IfM)' was legally closed in December 1991. In January 1992, it was replaced through the newly founded 'Institute for Baltic Sea Research Warnemuende (IOW)' at the Rostock University. Beside the native Baltic Sea and based on rendered results of the former IfM, the field activities of the IOW shifted more intensely towards the exploration of the Benguela upwelling during the 1990s. Thus, the r/v 'A. v. Humboldt' could continue the upwelling exploration, Lass et al. (2000), and results of single field campaigns could be ranked by year-to-year changes in the overall upwelling intensity, Hagen et al. (2001). In summary, it can be assessed that the r/v 'A. v. Humboldt' wrote a noticeable history in the exploration of the system of equatorial zonal currents/undercurrents and meridional currents/undercurrents in the areas of coastal upwelling off Northwest and Southwest Africa. Due to the aged constitution of this ship, it has been discharged and disposed into its 'second homeland', Africa, in 2004.

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Annex:

Teleconnections

During the beginning 1980s, the topic of El Nino-Southern Oscillation (ENSO) was studied somewhat more intense by H. F. Graf of the Meteorological Institute of the Humboldt University Berlin. Intergovernmental agreements enabled productive working stays at the National Center of Atmospheric Research (NCAR) in Boulder/ USA as well as at the Max-Planck-Institute of Meteorology in Hamburg/FRG. The achieved understanding inspired interested students. Joint efforts exhibited that a cooling of the northern troposphere is frequently coupled with an enhanced southward displacement of the Intertropical Convergence Zone (ITCZ), Graf (1986). On the hemispheric scale, such a cooling mirrors the changed radiation budget in both the troposphere and the stratosphere. Strong volcanic eruptions inject aerosol clouds into the stratosphere. The stratospheric meridional circulation accumulates enhanced aerosol concentrations at Arctic latitudes. Here, the overall temperature of the stratosphere increases via intense absorption of the solar radiation. Synchronously, the tropospheric temperature decreases due to shading. Thus, the meridional gradients in sea level air temperature are strengthened between high and low latitudes. This establishes increasing gradients in sea level air pressure, which accelerate the tropospheric zonal circulation and shift the ITCZ somewhat southward. Analysing different long-term series, it became clear that such globally acting processes influence the development of ENSO events in the equatorial Pacific Ocean. The inspection of 78 strong volcanic eruptions, which occurred during the 19th and 20th centuries, clearly showed that only six of them left any ENSO signature, cf. Graf (1988) and Graf (1991).

Obtained insights into the dynamics of interannual fluctuations in the system 'Tropical Ocean and Global Atmosphere (TOGA)' provided the base for a working hypothesis studies focused on a dynamical link between circulation anomalies of the northern Hemisphere and fluctuations in the zonal 'Southern Oscillation' of the equatorial Pacific, Kirchner (1986). In this context, it became evident that the Asiatic monsoon plays a key role and that its strength significantly depends on the degree of snow coverage at mid-latitudes. For instance, anomalies of the 500 hPa geopotential surface over Asia significantly correlate with those of the Southern Oscillation, but with a lag of about one year, Graf (1989). On the monthly scale, it could be shown that the frequency of cyclonic anomalies exceeding two times the underlying standard deviation in the relative vorticity of winds at the 500 hPa level of the northern Hemisphere increase during pre-ENSO winters, cf. Schube (1989) and Oestreicher (1990). As already mentioned, associated winter cooling of Arctic latitudes accelerates the zonal circulation conveying maritime air masses towards Siberia to release heavy snowfall. In general, these findings were supported by the international literature describing the analyses of other data sets and derived scenarios of climate models.

The most important conclusion pointed to the observational evidence for a persistent energetic link between ENSO-like anomalies in the atmospheric circulation of equatorial latitudes and the sequence of certain atmospheric circulation types over the North Atlantic/European sector. Furthermore, some observational evidence was worked out for a certain feedback mechanism. It originates at mid-latitudes of the northern Hemisphere and propagates equatorward to contribute to the triggering of Pacific ENSO events, Schaefer (1987). For instance, such a regenerating feature is sufficiently reflected through a well developed trough in sea level air pressure over the western North Atlantic. It influences wind and precipitation in subtropical/ tropical latitudes as well as in mid-latitudes, Graf (1988). Considering related weather types and evaluating the catalogue of associated blocking situations over the North Atlantic sector, Graf and Funke (1986) detected a quasi two-year cycle. Without any doubt, there was an increasing frequency of such blocking situations during the so-called ENSO years. These studies were continued during the late 1980s to understand observed changes in the atmospheric circulation of the Atlantic-European sector somewhat more in detail.

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Freunde, bedenket euch wohl, die tiefere, kühnere Wahrheit
Laut zu sagen: sogleich stellt man sie euch auf den Kopf.
[Gefährliche Nachfolge, aus Goethe`s „Xenien und Votivtafeln"]

On the Development of the Landscape and Climate in Recent Geological History – A Brief Cross-Section on the Activities in Central Germany of Palaeoclimatic Research in the German Democratic Republic

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In place of a foreword: An argumentative reflection

For decades, we have been exposed to a debate on climate involving extensive sections of the public sphere while generating heretofore unknown confusion. The information this debate feeds on has been highly simplified, causing the public to almost lose sight of the natural course of climate development. Admittedly, people are beginning to accept the idea that humans - otherwise not particularly sensitive about the way they deal with the Earth - might just have something to do with erratic weather patterns that were previously put down to the "natural" course of things. No more than one or two newspapers have been bold enough to query whether a cold summer might be a sign of new Ice Age. In any event, the upside is the fact that some journalists have finally recognised that the Ice Age was located in the past.

Previously, conventional wisdom was using climate and weather as terms for light conversation. Now they are the subject matter of serious discussions that are shifting the accent in a different direction. It has become the fashion to blame whatever happens - be it rain, snow, fog, if there is too much ozone or too many clouds, whether it is too hot or too cold, too dry or too wet - on humans. Common sense fades in the background and findings gathered over millions of years fall to the wayside of a creeping/vibrating or even galloping/pulsating climate development; sometimes they are even ignored altogether.

Geologists carrying out field observations for empirical research can only shake their heads when they are witness to such one-sidedness. But, even for climate specialists among scientists, it is a daunting task to comprehensibly explain the highly convoluted issues of climate development to policymakers and other stakeholders. This is the reason why many take refuge in simplifications to illustrate the foremost issues in climate policy. The community of international climate researchers who regularly publish their findings in the reports of the UN's Interstate Panel on Issues of Climate Change (IPCC) concurs totally that any potentially imminent anthropogenous climate change will have to deem a modulation in the natural climate development of emerging on all timelines.

To at least convey a feeling of the eternally vibrating and pulsating progress of climate on the Earth in the Caenozoic Era to our students, we focus their view on the behaviour of mountain glaciers in the Alps and the progress of the climate that have been frozen in the sentiments and structures of Central and North Germany for more than 50 million years. It is the glaciers of the Alps that give us a visual impression of the minor and major steps that climate development has taken in its deglaciation phase for the last 18,000 years (Furrer 2001). No one who has stood on the moraine of the Moteratsch Glacier from 1850 several dozen meters high and seen the progress from 1900, 1920 and today would dream of asserting that the retreat from 150 years ago might have been triggered by human behaviour at a time when there were neither gasoline engines nor diesel motors, not to mention large-scale power stations. But some people might have come up with the idea that the modern age is apparently witnessing a climate that is changing with and without the participation of the human race. At the same time, an anthropogenous contribution to the acceleration in the rise in temperature gradient cannot be ruled out. Indeed, it is even probable.

The awe-inspiring artificial explorations and dense network of drill holes are unique anywhere in the world. They have provided evidence in the last 50 years that the Caenozoic North German depression and the central depression it leads into is among the foremost archives of Earth's history, climate and processes in one of the most agitated epoch of its entire history in terms of climate. The strata often unfold before your eye like the pages of a book with the prime features being alternating oceans and mainland from the farthest reaching Tertiary to the Quaternary closest to us, the present. The climatic panorama undulates in tranquil oscillations of more than 50 million years from the subtropics, the "greenhouse climate" of the Palaeocene and Eocene Eras, to warm moderate climates and finally to the moderate beech climate of the Pliocene and the early Quaternary Eras, to then enter into the central and recent Quaternary Era alternating its frequency and amplitude. Steppes and frost spread at an early stage, most likely in the lower Quaternary while the guiding endogenous impulse for sedimentation in the formation of sediment is almost completely separated from the climactic impulse 500,000 years ago. Long periglacial periods with wide valleys drowning in the congelifract and apparently brief interglacial episodes are followed by a period of three short inland ice invasions preceded by long periglacial sections and subsequent brief deglaciation phases culminating in brief drastic phases of preheating (interglacial episodes).

Every visit to one of the major lignite mines is from the first step on a tour through the climate of the last thousands and millions of years with its excesses at the beginning of the Elsterian Drift (Figure 1), the maximum inland ice development in Central Europe, arguably the entire Earth. The glacial deposits reflect the climatic conditions of 10,000 years while the thick periglacial deposits of rivers and wind reflect the climatic conditions of 100,000 years and the intermediate complete sequences of interglacial episodes (Fig. 2) reflect the climatic conditions of another 10,000 years. It is an extremely high-resolution document of the vegetation, and sometimes even the fauna or the sequence of isotopes bound in the lime.

The thick layers of glacial, periglacial and limnic genesis often lying like boards over one another that we pass through on our journey through the history of the earth and the climate are akin to the major path of nature exposing the great steps that climate has taken. The minor path, the three-step that man has experienced and continues to experience in the entire postglacial period is stunningly mirrored in the banded clay of the Quaternary Era and annual rings of the thousands of residues of trees that have come to light from the Tertiary and Quaternary piled up in as much as nine layers of seasons on top of one another for more than 50 million years. Trees from 50, 35 or 20 million years ago, or those 300,000 years ago (Holstein Interglacial Episode), 200,000 (the early Saalian Ice Age), 120,000 (Eemian Interval) or 5,000 (Holocene), we can read "fat" and "lean" years from the thickness of the annual rings, although we are far from verifying gradients in the "minor climatic progress" of faraway times. Perhaps they will reach that of the present, maybe they will be far above it. What a terrible decision: wrought by natural or humans?

In any event, palaeoclimatic research in Central Germany provides evidence that everything that has happened in prior periods has apparently existed several times before: climate changes on all levels, ranging from the subarctic to the subtropic in the last 5000 years with maximum natural mean temperature fluctuations ranging from 1° to 2°C.

A brief historical outline

Central Germany, with its 21 major active mines in the lignite industry in existence until the end of 1990 (along with the German region of Lusatia) is one of the best explored regions on the face of the Earth. 50 million years of the geological history have been brought to light in these mines over a several tens of kilometres of face mining including at certain places more than 100 m of exposure depths. Beyond this, there is yet another sheer inexhaustible regional geoarchive that can be used for a wide variety of aspects of georesearch and that has been included in various sets of geological maps (such as Lithofacies Quaternary Maps) with the far in excess of 200,000 exploration drillings carried out by the lignite industry west of the Elba River before 1990 and other geozones (such as groundwater, stones and earth), not to mention the estimated 50,000 drillings (many which are deep drilling) sunk by WISMUT AG exploring for uranium ore that reach back to the pre-Tertiary Era (Eissmann 1994a, 1999). Altogether, Central Germany under the government of the German Democratic Republic offered the best conceivable conditions for far-reaching geoscientific exploration on the development of the landscape and climate of more recent Caenozoic geological history, meaning palaeoclimatic research in the broadest possible sense the word; this took place in a region reflecting the crucial phenomena of the more recent global climate development.

Notwithstanding these extremely favourable conditions in particular for the Caenozoic floor, various aspects of palaeoclimatic research (i.e., studies targeting statements on the changes in the landscape and the climate over space and time) were never the mainstream focus of geoscientific activities. Instead, the thrust of this research, just like the entire state-guided georesearch in the German Democratic Republic, was subordinate to the priorities of exploring raw materials. And, even in the work of the Society for Geological Sciences of the German Democratic Republic, palaeoclimatic research never became an independent focus of research until the political changes of 1990; palaeoclimatic issues were a component of various task forces (such as the Quaternary Geology Task Force or the Lignite Task Force). This is the reason why one would have been hard put to find studies or interpretations with a palaeoclimatic thrust in the publications on older geological formations in Central Germany (the Precambrian and the Palaeo- and Mesozoic Eras; such as Watznauer 1967: Ordovician Emery Rock as Read Earth Weathering Formation; Katzung 1961, Schulz 1969: Ordovician Leather Slate as a Glacimarine Deposit; Neumann 1974: Cordierit Gneises of Granulite Mountains as Palaeo-Weathering Formations).

In contrast, the very voluminous studies in applied research, particularly for exploring, extracting and processing lignite, touched upon a wide range of aspects and findings in palaeoclimatology. Beyond this, the explorations on the stratigraphic structure of explored unconsolidated ground needed for mining work had to provide insights into the natural changes in the landscape of Central Germany in space, time and climate. The totality of geological field findings brought to the fore (such as bedding conditions including the structure and characteristics of sediment such as grain size and hydrogeological parameters in the spectrum of rubble), the findings of methods applied in biostratigraphy (pollen analysis and macroflora), mineralogy and geochemistry (clay minerals, carbonate or organic carbon) and some dating techniques (radiocarbon or magnetostratigraphy) were on an international research level considering the outstanding initial geological conditions. This meant that today there is a sound stratigraphic structure for the Caenozoic sequence of unconsolidated ground in Central Germany reflecting the changes in the landscape of the last 50 million years caused both by facial and climatic phenomena.

Central Germany has far more than 100 Caenozoic strata to be differentiated, making it a key region for studying phenomena in the transition from the mainland to the oceans and (the Tertiary Era; Eissmann 1968, 2002a) and also the transition from the glacial to the periglacial period (the Quaternary Era; Eissmann 2002b). A study of the strata in the major explorations not only reveals the Earth's global trend towards cooling off since the beginning of the Tertiary Era, the meso- to fine-scale climate fluctuations are also documented in the stratigraphic sequence such as the occurrence on various temporal levels of characteristic sediment types (such as deposits from glaciers and melting water, fluvial sediments of meandering or braided river systems, organogenous sediments, Eissmann 1975, 1990) and weathering formations (kaolin, red loams and soils) that are linked to specific climatic conditions, due to the effectiveness of various geological processes dependent upon the climate in the stratigraphic sequence (such as deposits from glaciers and melting water: glacitectonics, glacihydromechanical scourings in the form of subglacial channels; gravitative sediment foundations due to the deterioration of permafrost over large areas: diapirism (Figure 3) and collapsed structures (Figure 4); underground leaching or subrosion forming local coal pots (known as "cauldrons") and postgenetic basins ("holes") whose partially climate-dependent genesis has not been entirely explained; Eissmann 1967, 1978, 1984, 1987), due to the constant-level proof of sediment structures specific to climates, milieus and events (such as permafrost indicators in the form of pseudometamorphoses of ice wedges (Figures 5 and 6), involution and drip layers (Figure 7), cryoturbations, Eissmann 1981; strata types as facial indications; features of bioturbation; non-glacial gravitative sag structures to a certain extent as a result of seismic events including floods and storm tides), and due to numerous specific climate-sensitive findings of fauna (such as deposits of the Quaternary from the Ice Age and interglacial periods: residues of large mammals: Kahlke R.-D. 1994, Mania et al 1990, Kahlke H.-D. 1985; molluscs and ostracodes: Fuhrmann 1973; in marine sediments of the Tertiary Era: Müller 1983) and flora (such as laurophyllic/palaeotropic and arctotertiary macroflora in Tertiary deposits: Mai and Walther 1978, 1983, 1985; pollen spectrums of the Tertiary consequences and Quaternary interglacial periods, Krutzsch 1967, Erd 1973) in the Tertiary and Quaternary sequence of sediments.

The warm climate at the end of the Cretaceous Age continued on into the later Tertiary almost without change (Figure 8). Intensive weathering covers (forming kaolin as much as 100 m thick; Figure 9) and palaeotropic evergreen residues of flora in the Palaeocene to the Middle Eocene Eras also bear witness to a subtropic climate at our latitudes that only begin cooling off at the beginning of the Middle Eocene Era (approximately 51 million years ago) and distinctly in the transition from the Eocene to the Lower Oligocene Eras (38 million years ago). The latter is among the most important temperature declines in the Tertiary Era and can be felt in the pattern of vegetation from an increase of the arctotertiary leaf throwing flora. In contrast, there are slight periods of warming up in the higher Lower Oligocene and Middle Oligocene Eras. A temperature decline in the upper Oligocene is followed by a temperature increase continuing far into the deep Miocene Eras (the “optimum Miocene climate”) that briefly interrupts the general trend of a temperature drop. Then, in the Middle Miocene, there is a phase of cooling off followed by re-warming and another distinct cooling off in the Late Miocene. The climate levels off to the constantly moderate atmosphere of the Pliocene Era that evidences a remarkable cooling off period towards its end and the beginning of the Swift climate change that is typical for the Quaternary (Eissmann and Hänsel 1991; Figure 10). This can be seen in the almost textbook meshing of Quaternary sediments of glacial facies (banded clay, ground moraines and glacifluvial sediments) and periglacial facies (river gravel, muds and loesses) with intermediate interglacial deposits (peats, muds and limnic carbonates). At least four alluvial terraces developed between the Younger Tertiary and the first Elsterian Drift inland ice cover that bear witness to cold climate. The most recent of these free gravel bodies on Nordic rocks meshes with glacilimnic deposits (banded clay) of the Elsterian Drift while interglacial periods from before the Elsterian Drift have been detected at several points in Central Germany and two major ice advances can be proven to have taken place with minor ice edge oscillations from the Elsterian Drift and Saalian Ice Age. The Holstein Interglacial Episode and Eemian Interval are handed down with complete sequences of sediments and vegetation (cool, moderately warm and cool). The Weichselian Ice Age in Central Germany is a period when thick periglacial sediments were formed (gravel, muds, covers of debris and loesses) so that it left behind a wide range of glacial and periglacial sentiment deformations and climate marks (Eissmann 1994b; Figure 11).

The knowledge base briefly sketched out here is essentially based on the lithographic/geological and palaeofloristic phenomena, the latter of which were particularly accelerated by the macrofloristic work of D.H. Mai (Natural History Museum of the Humboldt University of Berlin) and H. Walther (previously Dresden State Museum for Mineralogy and Geology; now the Dresden State Museum for Natural History Collections), and with spore and pollen studies carried out by W. Krutzsch (Central Geological Institute of Berlin), which was continued in more recent times by H. Blumenstengel. To be sure, the main platform for the knowledge base available at the beginning of the 90s on the change in climate and landscape over time were the lithological/geological findings of exploratory lignite work outlined in the 60s and 70s of the past century by the Leipzig Outer Office of VEB Geologische Forschung and Erkundung Freiberg, headed up by the senior author (L. Eissmann). A major portion of these findings were summarised and published at the beginning of the 80s in the work at the Geophysics Faculty of the Physics Department of the Leipzig-based Karl Marx University. Then, a dozen, 5-day and one to 1 1/2 hour papers including a day of excursions of expert courses in postgraduate ongoing education (that were called "Unconsolidated Ground Seminars") on "Dislocations in the Upper Supracrustal Formation of Central Europe", some taking place on September 24-28, 1984, April 8-12, 1985 and May 4-8, 1987; in reunified Germany after the wall came down) made possible to showcase the knowledge base on the development of climate and landscape of Central Germany to a broader audience of hands-on experts and college teachers.

These findings bearing witness to the more recent history of the climate were supplemented by analyses and observations on the causes and functional mechanisms of climate change that were a component of the spectrum of research carried out by the Physics Department of the Leipzig-based Karl Marx University starting in the mid-70s (C. Hänsel). And these findings were also quoted in a whole series of postgraduate ongoing courses of education at the Geophysics Faculty, a case in point being September/October of 1980 and 1982 in courses on "Advancements and Tendencies in the Development of the Geological Sciences (Stocktaking from 1980)" (course directed by G. Olszak and A. Berthold) and "New Global Tectonics II" (course directed by R. Lauterbach) with papers on the issues of "The Possibilities of Terrestrial Causes for Changes in Palaeoclimatics" and "Continental Drift and Global Climate Changes". Both of these research complexes on palaeoclimatology from the Geophysics Faculty of the Leipzig-based Karl Marx University have been described in edited book collections (Hänsel 1975, Eissmann and Hänsel 1991, Junge and Eissmann 2003).

Modern geochemical methods (such as radiometric dating and stable isotopes) were only applied to the Caenozoic unconsolidated ground sequences of Central Germany for palaeoclimatic and palecological statements starting in the mid-80s. This was particularly based upon cooperation between the Geophysics Faculty of the Karl Marx University arising from personal contacts between Leipzig and the Central Institute for Isotope and Radiation Research Leipzig of the Academy of Sciences of the German Democratic Republic. This produced absolute statements on the age of Weichsel glacial (“lower terrace”) and Holocene river sediments in the catchment area of the White Elster and Mulde Rivers (Hiller et al 1991). This was the first time that subfossil woods and organogenous horizons were radiocarbon dated (^{14}C) for Central Germany and it provided an enhanced stratigraphic structure for the climate while supplementing the age data for this most recent Quaternary time period for the Lusatian region available at the end of the 60s (Cepek 1967).

This was also the time when the foundation was laid for the beginning of systematic palaeoclimatic studies in the Quaternary Era of Central Germany and the Lusatian region on a isotopic/geochemical basis. When the academic community was re-oriented in Eastern Germany due to reunification, these palaeoclimatic studies for Central Germany that were carried out unofficially in the German Democratic Republic on personal/private initiative were given a new and official platform. The Academy of Sciences of the German Democratic Republic was dissolved pursuant to the Reunification Treaty, which then led to the closure of the Leipzig-based Central Institute for Isotope and Radiation Research by the end of 1991. This is why a Palaeoclimatology Task Force was established within the Academic Integration Programme set up by the German federal government under the direction of the junior author (F.W. Junge). This research group carried out geochemical-palaeoclimatic studies (such stable isotopes and radio carbon) for Central Europe (Central Germany and Lusatia) and then Eastern Europe (Russia and Poland). This was initially in collaboration with the new Institute for Geophysics and Geology set up at the university in 1993 with KAI e.V. in the period when it was supported by the Academic Integration Programme and later it became an organisational unit of the University of Leipzig. The initial findings of this work was presented at the Conference of the German Quaternary Association (DEUQUA) in Leipzig in 1994 and then published in greater detail nationally and internationally in subsequent years. The focus of this work was studies on limnic sediments to resolve questions of climate variability with transitions from the interglacial to the glacial (the Late Glacial to Holocene Periods: for instance, Böttger et al 1998, 2002; the Eem to the Early Weichsel Periods: for instance, Böttger and Junge 1994, Böttger, et al 2000; Figures 12 and 13), papers on the dynamics of glaciers (for instance, Junge and Böttger 1994, Junge 1998) and the climate stratigraphic structure of the Weichsel Ice Age and its transition into the Holocene Period (for instance, Kühner et al 1999, Hiller et al 2004).

This focus of research work was then included in the curriculum of the newly established course of study of geology in 1992 under the direction of the senior author at the Institute for Geophysics and Geology at the University of Leipzig with lectures on „General and Historical palaeoclimatology” (a minor subject area to 1995 and part of the diploma course of study of geology from 1995). Some of these palaeoclimatic issues passed over into the range of research topics of the University of Leipzig, Umweltforschungszentrum Leipzig-Halle GmbH and Leipzig-based Saxon Academy of Sciences when the Palaeoclimatology Task Force was dissolved starting in July/1997 and the co-workers moved onto other research institutes. Logically, palaeoclimatic research issues have been continued since then in these institutions in the form of institutional collaboration (such as Hempel et al 2005, Junge et al. 2005). They still constitute a component of the projects on palaeoclimatic research supported by the German federal government (“Terrestrial Palaeoclimatology”, directed by B. Frenzel, Stuttgart-Hohenheim (Frenzel 2004); “DEKLIM-EEM”, directed by F. Sirocko, Mainz (Sirocko et al 2004)).

Research papers on archaeology or analysing the natural region provided other usable palaeoclimatic findings in Central Germany in the 60s to 80s including a whole series of pedological-geodynamic papers written at the Leipzig Institute for Geography and

Geoeconomy of the Academy of Sciences of the German Democratic Republic (previously the Institute for Regional Studies to 1968 and the Geographic Institute of the German Academy of Sciences in Berlin from 1968-76) (Hönsch et al. 1995). The most notable were the pioneering papers on the spread and genesis of loess in North-West Saxony (for instance, Neumeister 1964, 1969, Richter 1964, Altermann et al. 1978). There were also numerous studies at the foremost archaeological excavation points in Central Germany that targeted reconstructing the landscape and life realm of humans. The most notable of these research issues mostly carried on in the German Democratic Republic by the Halle Prehistorical Museum (D. Mania, V. Töpfer), the Berlin Institute for Prehistory and Early History of the German Academy of Sciences (K.D. Jäger) and the Weimar-based College of Architecture and Building Construction (W. Steiner) were the papers of Mania (1990: Bilzingsleben), Mania and Töpfer (1971: Geiseltal; 1973: Harzvorland), Jäger (1978: Prehistory and Early History of Central Germany) and Steiner (1984: Weimar-Ehringsdorf).

Issues of palaeoclimatic research were included and still are included in the research papers of the long-term studies on “Quaternary Geology-Palaeoclimatology” (the section is directed by M. Krbetschek, Freiberg) and “Pollutant Dynamics in Catchment Areas” (the section was directed by An. Müller and by L. Zerling to 2001, since 2001 by junior author). Some of them were established in the 80s and are now attached to the Leipzig-based Saxon Academy of Sciences that the senior author directs. The project initiated on “Quaternary Geology-Palaeoclimatology“ focuses on the age classification of Quaternary sediments of the Early and Middle Pleistocene Eras for issues of Quaternary stratigraphy and classifying palaeoclimatic and archaeological findings (Fuhrmann 1999, Tinapp 2002). Finally, the study and geochemical analysis of the Holocene meadow sediments in the catchment area of the Saale and White Elster Rivers (Müller et al 2003) also grappled with issues of more recent climatic history in the project on “Pollutant Dynamics in Catchment Areas” set up in 1987 (the Territorial Environmental Research Task Force to 1991).

In addition to the palaeoclimatic papers named here, most of which focused on Central Germany, Leipzig-based academics from the Leipzig-based Central Institute for Isotope and Radiation Research of the Academy of Sciences were also active in Antarctic research in the 80s with palaeoclimatic studies. The Antarctic research of the German Democratic Republic organised by the Central Institute for Physics of the Earth of the Academy of Sciences of the German Democratic Republic was logistically integrated in the programmes of the Soviet Antarctic Expeditions and their essential thrust was towards complex geological- and bioscientific studies in the Schirmacher Oasis and Wohlthat Massif of the Central Queen Maud Land (the east Antarctic). A whole series of academics from the Leipzig-based Central Institute for Isotope and Radiation Research spent the winter or were involved in summer expeditions (such as 1984/85: 30th Soviet Antarctic Expedition; 1986: 31st Soviet Antarctic Expedition) and the laboratory of the German Democratic Republic in the area of the Soviet Novolazarevkaya Station carried out these activities that had been expanded since 1987 to become the “Georg Forster” Base Station of the German Democratic Republic. Bormann and Fritzsche (1995) have recorded a general description of the research findings generated by the Central Queen Maud Land. Of the papers on palaeoclimatology, it is particularly the isotope studies on the current and historical history of glaciation (Hermichen 1995) and studies on the late Quaternary glacial history that have been highlighted for the first time by precision-lithological 14C-dating of lithified stomach oils (“Mumijo“) of snow petrels of a wide variety of positions (brooding locations) in the Undersea Oasis (Wand 1995, Hiller et al. 1988, Wand and Hiller 1987). The latter showed that the Undersea Oasis has been continually free of ice in the last 8,000 years. That means that brooding colonies and therefore areas free of ice must have also existed in this area in the time period of the last glacial maximum ice (between 13,000 and 33,000 years before today).

Final remarks or the region of terrestrial classification of the Ice Age

The climate behind us with its infinite variety of rocks, morphology and world of living organisms is cast in the sediment from where it is waiting to be awakened to life. North Germany and its adjacent Central Germany, are like hardly any other region on the Earth in the way they have opened up their bowels to the oceans of the world for millions of years so that it could penetrate to the hill country; but also to the Scandinavian domestic iron in the last 500,000 years that also advanced as far. And uncounted rivers and brooks moved towards the ocean and domestic ice from the south and east. This model of collision and collusion of the evolutionary and revolutionary forces of earth formation and reformation changing its face in succeeding episodes is what makes up the North and Central Germany and this is the reason why it has become one of the great stages upon which more recent geological history has played and has even become a Shakespearian stage that is the incarnation of the pinnacle of Ice Age dynamism and performance.

In the 20s/30s, the foremost researcher of the Quaternary Period, Wolfgang Soergel, described Central Germany (the area of the Saale/Ilm Rivers (Soergel 1924) as the region of the "complete classification of the Ice Age". Today, this "classification" has been so completely underscored by findings that it is difficult to make the cornucopia material comprehensible. This is a challenge that will be left up to the commitment of a whole new generation of researchers.

The fact that the global scientific community has hardly taken any notice of this storehouse of knowledge can hardly be attributed to a dearth of explicative literature. Furthermore, this knowledge is made easily available in one compact space in the thick sequences of settlements of three glaciation periods in a unique and wholly verifiable manner. Beyond this, it has that accessed many times and has been involved in global structures akin to a series of worldviews. It is more likely that this is due to ignorance in relation to old Europe, a lack of interest or willingness to invest the effort, and perhaps also the incapability to imagine how rich the demanding and many layered legacy of nature could be. And, perhaps it is due to the German language – one almost hates to put it black on white - even the desire to set up a barrier to calm the scientific conscious in global, even Eurocontinental research into recent geological history including its climate.

In the final analysis, this is a challenge that still has to be met. It is at least as important, if not more so, than the cost-intensive ocean research because it serves the purpose of enlightening us as to the history of our climate and the specific impact it has on hard ground where the main activities of human history have been taking place for hundreds of thousands of years and will continue to play a role for millennia.

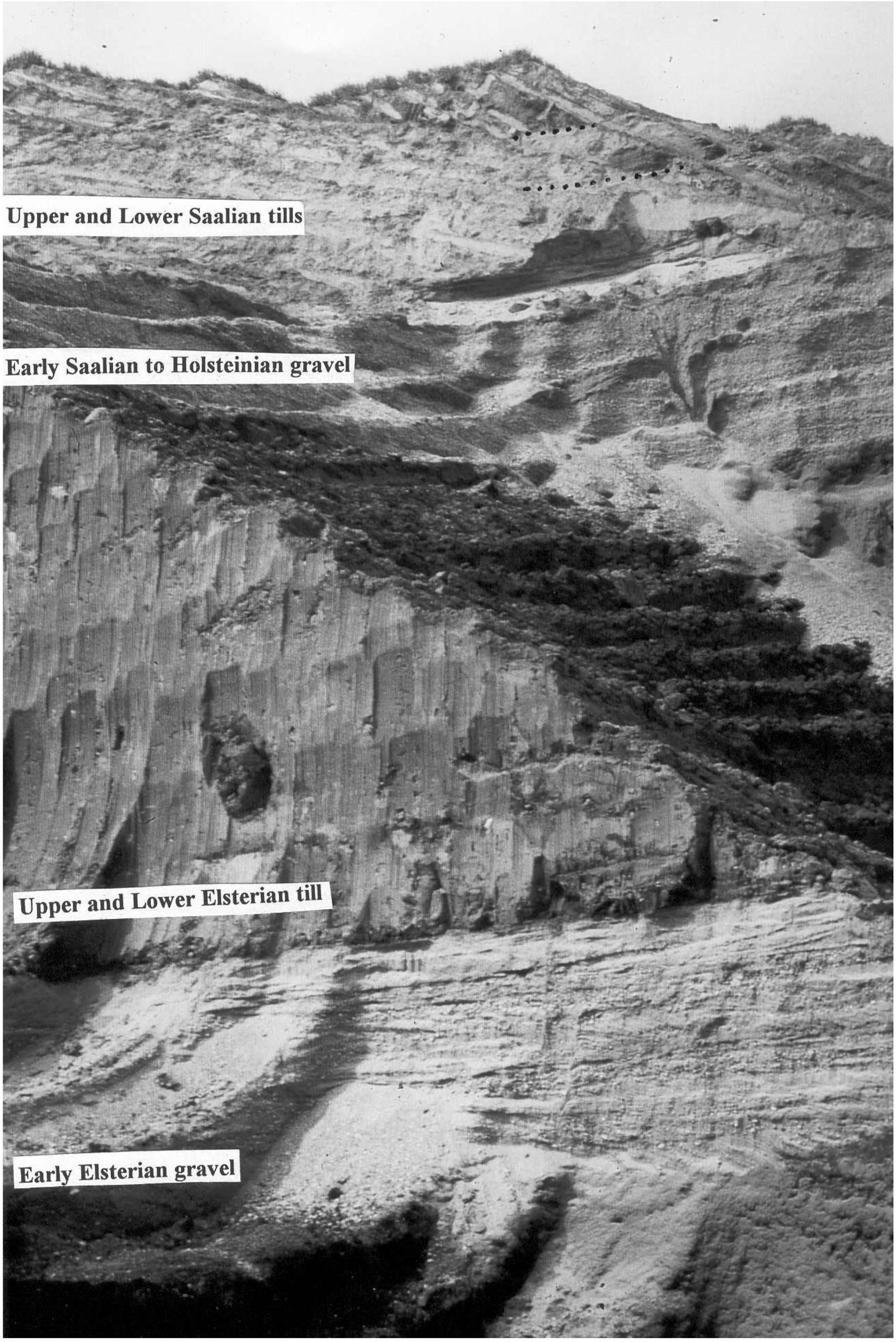

Fig. 1: The main steps in the development of Central Germany reflected in the sentiments of the Quaternary sequence. South West Delitzsch Mine, head slope in the area of Zwochau, 1994.

From the Elsterian Drift Periglacial (Early Elsterian gravel) over thick glacier deposits (Upper and Lower Elsterian till) of the Elsterian Drift, thick periglacial deposits with ice wedges of the Saalian Ice Age in the form of river gravel (Early Saalian to Holsteinian gravel), above that the ground moraines of two ice advances of the Saalian Ice Age (Upper and Lower Saalian till), on the surface of the gravelly layer and sandy loess from the Weichsel Ice Age.

Fig. 2: When studying the classical Eemian interglacial period sequence in the Gröbern Mine during the conference of the German Quaternary Association in Leipzig, 1994.

Over Saalian ground moraine and sand of the late Saalian Ice Ages of a fully concordant transition of a complete Eemian interglacial sediment sequence into a Weichsel Ice Age sequence of sediments from three stadials (steppes-tundra landscape) and two interstadials (taiga formation).

Fig. 3: Coal diapirism as an indicator of the deterioration of permafrost over large areas. South Profen Mine, 2005.

Diapiric ascent of lignite ("mollisoldiapirism") when the ground ice thawed in the late Saalian Ice Age due to water saturation and supersaturation including varying overburden loads. The coal ascended (seams III+IV) with symmetrical rim sycline formation in the early Saalian Ice Age river gravel (main terrace) of the White Elster River, partially into the older Saalian ground moraine and late Saalian Ice Age sediments.

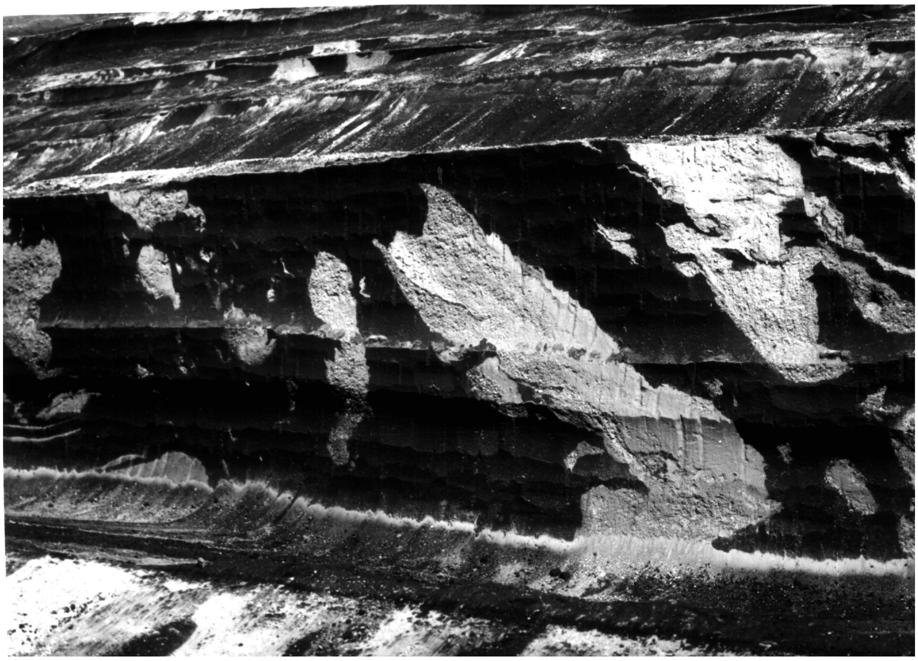

Fig. 4: Autoplastic (solikinetic) settling structures ("giant drop ground") as an example of ground collapse with the deterioration of thick permafrost formations. Mücheln Mine; photograph by Linke.

Saalian Ice Age river gravel (sand and gravel) sank in irregular, strip- and nest-shaped bodies into the lower level of the Geiseltal lignite saturated with water in the process of thawing when the 100 m thick permafrost ground of the Saalian and Weichsel Ice Age thaws over large areas. The level of the face in the foreground is approximately 10 m.

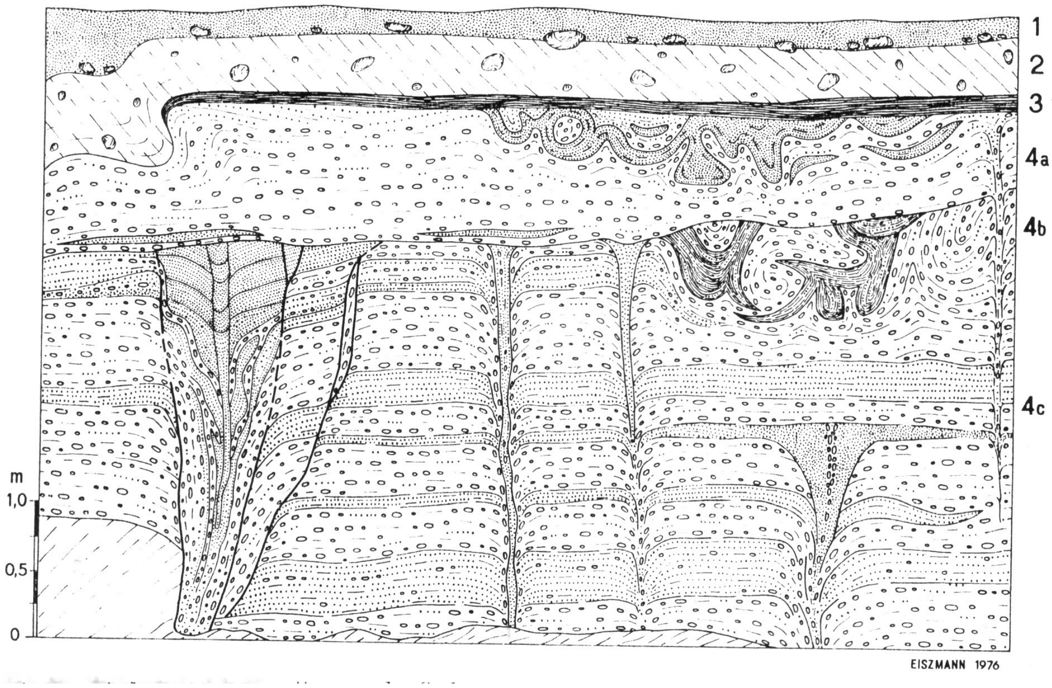

Fig. 5: Early Saalian glacial main terrace of the Saale River with three generations of fossil ice wedges and two generations of cryoturbation phenomena. Lochau Gravel Pit (in the County of the Saale River).

These typical former ice wedges and frost cracks developed in several phases including cryoturbation phenomena from the Early Saalian glacial bear witness to major fluctuations in climate changes in the periglacial period before the second autonomous inland ice cover (Saalian Ice Age). Above it is banded clay from Böhlen-Lochau, older ground moraine from the Saalian Ice Age, a gravelly layer with wind-shaped pebbles and sandy loess from the Weichselian Ice Age.

Explanations on Figure 5:

1 – Weichselian glacial sandy loess with a gravelly layer; 2 - 1. Saalian ground moraine; 3- banded clay from Böhlen-Lochau; 4 – early Saalian glacial main terrace of the Saale River: 4a – upper gravel; 4b – residues of the cryoturbation horizon of Markkleeberg (relicts of them in the left-hand trench-shaped pseudometamorphosis of ice wedges); 4c – lower gravel

Fig. 6: Permafrost indicators: pseudometamorphosis of ice wedges in the early Pleistocene terrace of the Saale River. North Golpa Mine. 1979.

The numerous intraformational pseudometamorphoses of ice wedges to be found in the early glacial river gravel prove that they developed under permafrost. Wedge- and column-shaped permafrost structures previously filled with ice are gradually filled with sediment with the swelling process from the roof hanging and from the side progressing symmetrically from outside to inside. Thawing ice causes the overlying strata to crumble away in steps partially symmetrically. The structure of the ice wedge previously filled with ice is completely replaced with sediment at the end of the thawing process. This brings about a pseudometamorphosis of ice wedges that lasts longer than geological periods and bears witness to the previously predominant conditions of the permafrost ground.

Fig. 7: Indicator of seasonal deterioration of permafrost: Brösener drip ground. Peres Mine. 1979.

The thawing layer (mollisol) visible above the permafrost (border visible due to the basis of the drops) in the seasonal Elsterian Drift, with a drip ground that probably developed with earth vibrations.

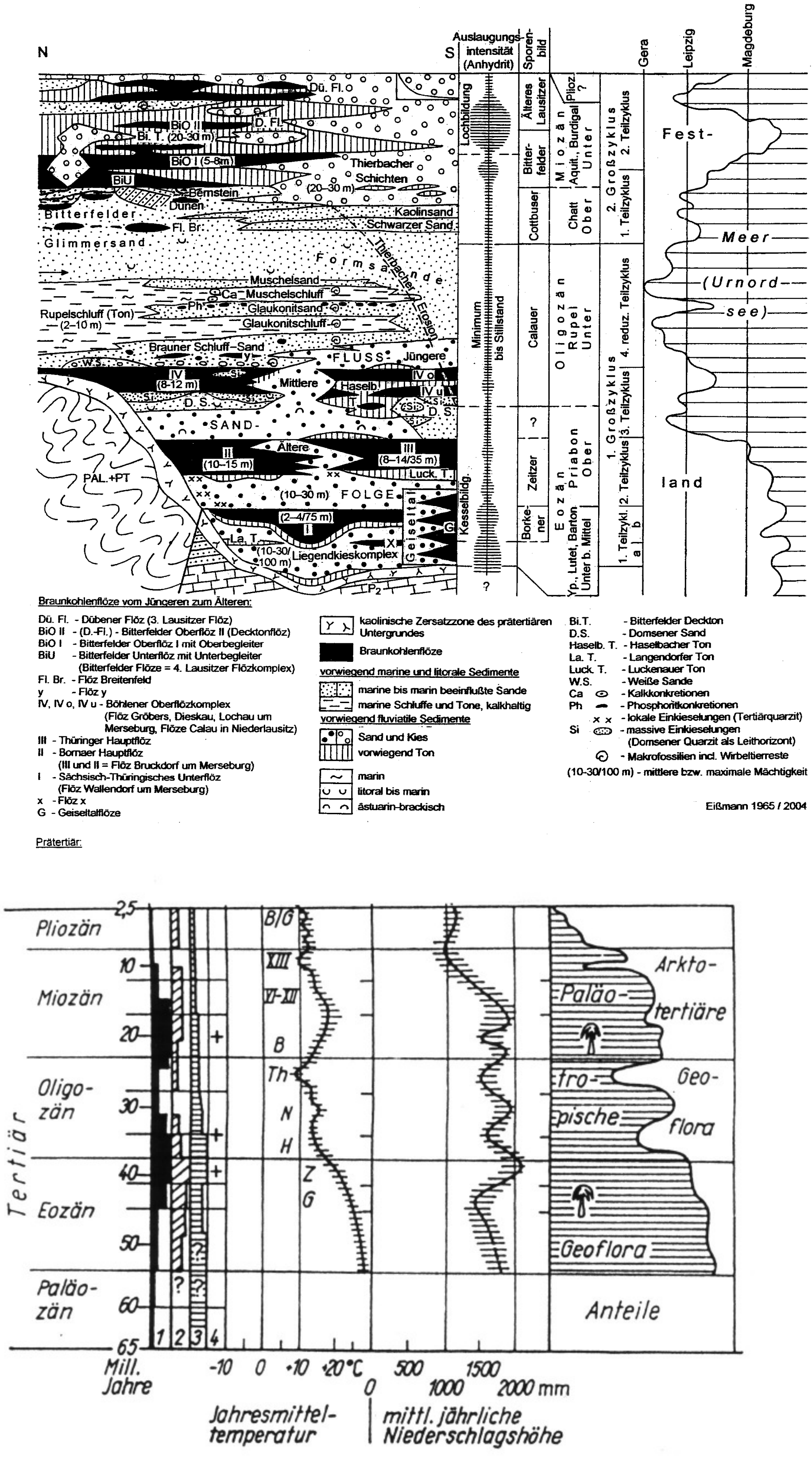

Fig. 8: Sediment (top) and climate progress (bottom) of the Tertiary Era in Central Germany.

The Tertiary sediment sequence in Central Germany has an epirogenously guided change in river deposits, peat sediments (coal), marine sediments and various phases of climactic and hydrodynamic leaching intensity of the pre-Tertiary subgrade (subrosion). Its inventory allows a reconstruction of the climate progress in the Eocene through Miocene Eras primarily based upon floristic findings. The flora and inorganic climate indicators point to a climate in this period with great precipitation that is moderately warm and has longer cooler sections (Lower Oligocene, Upper Oligocene, Upper Miocene) and warmer sections (Middle Eocene, Middle Oligocene, Lower Miocene; Eissmann 2005, Eissmann and Hänsel 1991).

Explanations on Figure 8 (bottom):
Flora: G – Geiseltal, Z – Zeitz, H – Haselbach, N – Nerchau, Th – Thierbach, B – Brandis, VI to XIII – Lusatian flora zones Vi to XIII;
B/G – Berga, Gerstungen;
Intensities: 1 – coal formation, 2 – subrosion, 3 – siallitic weathering (mostly kaolinisation), 4 – silification (quarzite formation)

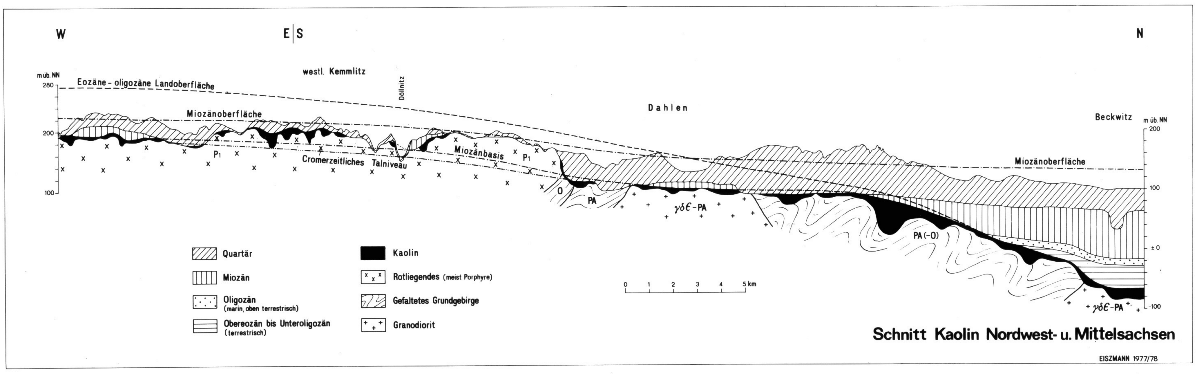

Fig. 9: Geological section of Beckwitz in the area of Torgau, Germany (Northern Saxon lowland) after the Kemmlitz region in the area of Mügeln, Germany (Northern Saxon hilly region/granulite mountains).

The various pre-Tertiary rocks of the lower subgrade ranging from porphyry over quarzites, greywackes to granodiorites and granulites are covered by a thick layer of kaolin. This is the result of intensive chemical weathering of solid rocks on the surface in times of subtropic climate changes (the Upper Cretaceous to the early Tertiary). The layer of kaolin that has been in erosive dissolution since the Upper Miocene originally covered the entire southern hilly region and hill country.

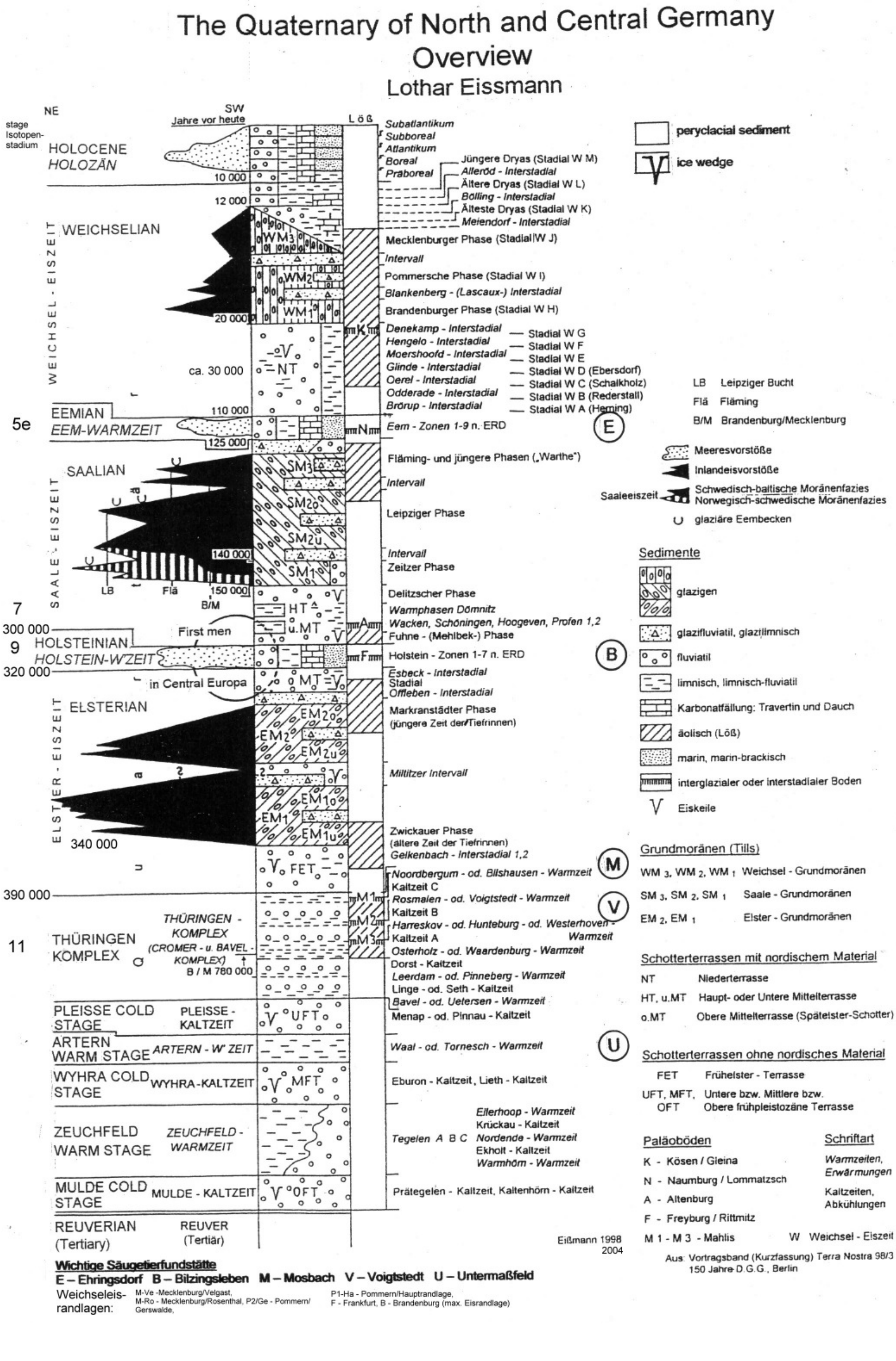

Fig. 10: The Quaternary of North and Central Germany in the overall view of its sediments, phenomena and processes as an expression of climate pulsation.

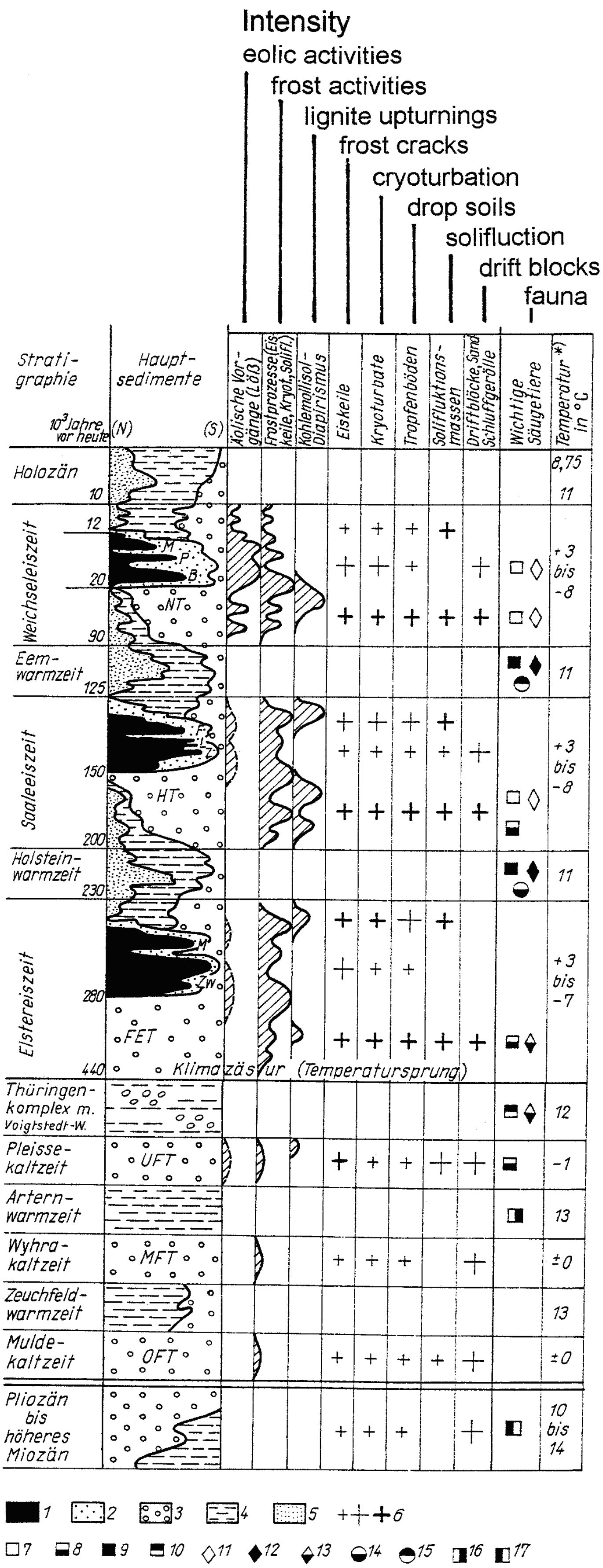

Fig. 11: Simplified structure of the Quaternary Era in the North German lowland, Saxony and Thuringia with the attempt at an estimate of intensity and frequency of periglacial processes and phenomena.

Explanations on Figure 11:

1 ... domestic ice or ground moraine, 2 ... primarily melting water sediments, 3 ... river sediments, 4 ... ocean and river sediments, 5 ... ocean sediments, 6 ... rarely or frequently or very frequently, 7 ... mammonteus primigenius, 8 ... mammonteus trogontherii, 9 ... palaeoloxodon antiquus, 10 ... archidiscodon meridionalis, 11 ... coelodonta antiquitatis, 12 ... dicerorhinus kirchbergensis, 13 ... dicerorhinus etruscus, 14 ... homo erectus, 15 ... homo neandertalensis ehringsdorfensis, 16 ... hippopotamus, 17 ... mastodon;

Abbreviations in temporal sequence:
M – Mecklenburg, P – Pommeranian, B – Brandenburg, L – Leipzig, Z – Zeitz, M – Markranstädt, Zw – Zwickau icing stage,
NT – lower terrace, HT – main terrace, FET – early Elsterian terrace, UFT – lower early Pleistocene terrace, OFT – upper early Pleistocene terrace,
presumed mean annual temperature (with reference to the high glacial to interglacial periods in the ice ages and with reference to the optimum climate in the interglacial periods).

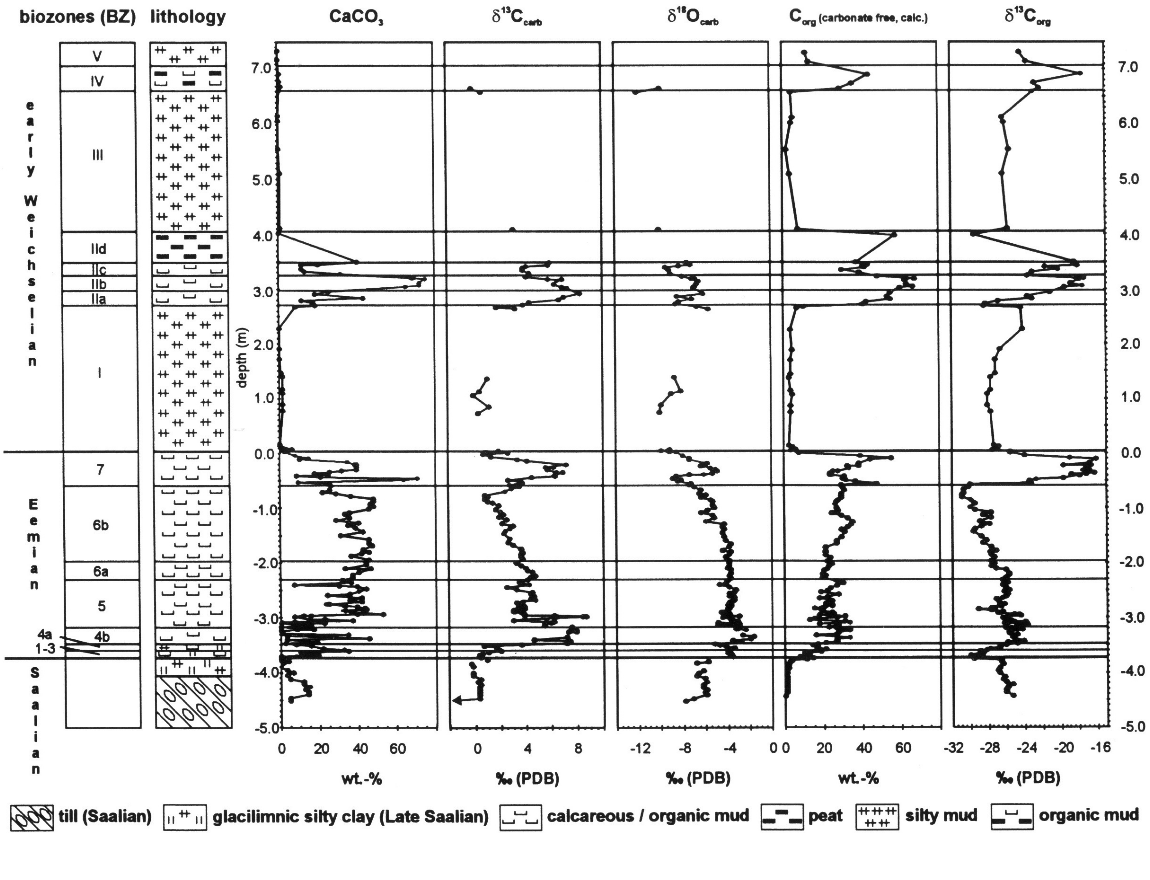

Figure 12: Geochemical findings of the Eemian - Early Weichselian sequence of Gröbern, Germany (according to Boettger and Junge)

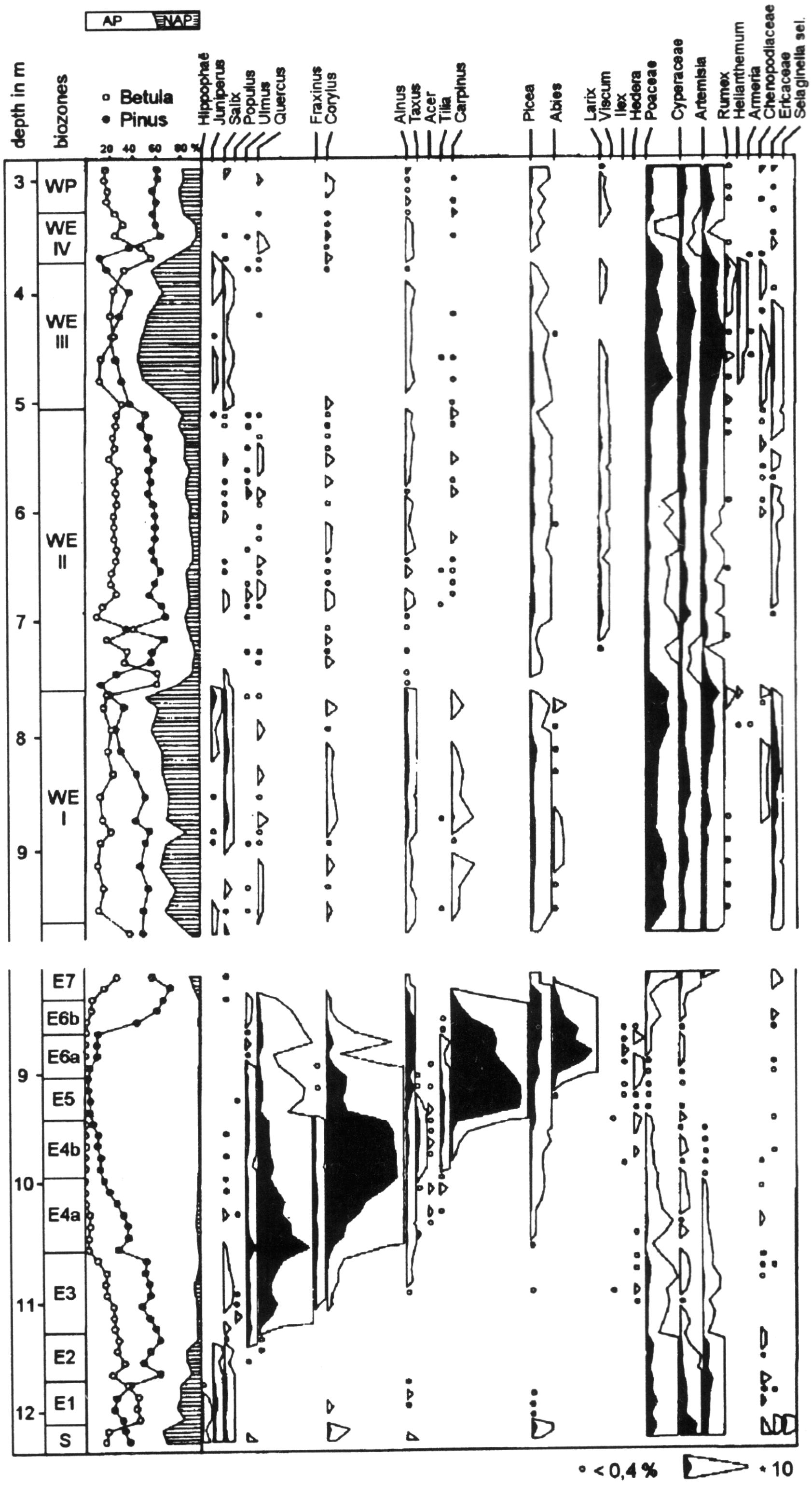

Fig. 13: Vegetation development of the Eemian - Early Weichselian sequence of Gröbern, Germany (pollen finds according to Litt)

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Development of Climate and Environment in the Coastal Region of Western Pomerania since the Late Weichselian

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Methodology of geosciences and concept of interdisciplinarity determining coastal research

During 4½ decades between 1945 and the German reunification the experts of physical geography employed at the Greifswald University have focussed their activities in geosciences to investigations related to the development of coastal regions and the adjacent areas of Weichselian Glaciations in Western Pomerania. These activities have continued previous research in the southern Baltic area. The coastal zone of Mecklenburg following towards west has been taken into consideration by similar work of Th. Hurtig (1954, 1957) and his scholars at the Rostock University. However, up from 1952 geography is no longer present at the Rostock University.
Up from the same year at Greifswald the concept of physical geography has been enlarged by items of geoecology and system theory, but this topic exceeds the realm of the present paper. During the early fifties a methodical enlargement of the Greifswald geographical institute took place by the new establishment of a laboratory for sedimentary analyses by physical geographers. This installation was the first extension like that in Germany and took as examples larger geographical laboratories in neighbouring countries like that of J. P. Bakker in Amsterdam or that of L. Kádár at Debrecen.
At the beginning the laboratory installation at Greifswald had been registered sceptically and moreover was faced with critical considerations insisting on the supposition of experimental activities unrelated to geogaphy. Nevertheless, these activities have been continued at Greifswald and on top of it they have been used for the purpose of laboratory education of students.
Additionally, the preconditions of special investigations by means of pollen and diatom analyses have been created by W. Janke. A further enlargement and modernization of the laboratory was enabled 1960 by reconstruction of the institute. Moreover, this reconstruction has permitted an additional methodical supplementation related to geochemical examinations of coastal sediments by R. LAMPE, supported by two (then disposable) laboratory technicians. Beyond these innovations the field-work has been supported by a simple mobile lab, and a minor research ship has made possible examinations in the bodden waters.
Among first results of manifold analytical procedures reliable chronometrical and palaeoclimatological records could be provided by means of investigated coastal sediments. The presentation and explanation of these results has been published by common papers of the participating experts (a. o. Kliewe and Janke 1978, 1982, 1991). In this context the interdisciplinary cooperation of physical geography with other geosciences has proved to be necessary and useful. Especially geology, geophysics, geochemistry, geobotany, and (prehistoric) archaeology have been involved. These cooperations are reflected also by publications (a. o. Kliewe and Lange 1968; Kliewe and Lauterbach 1955/56; Kliewe and Rast 1979; Gramsch 1978; Gramsch and Kliewe 2005).

International research cooperation

The interdisciplinary cooperation of geosciences in the inland Baltic regions has been supplemented by international contacts and cooperations with neighbouring coastal countries. Such relations have been and still are indispensable for international exchange of ideas as well as competition. Nevertheless, their realization had been complicated under GDR conditions, at least with reference to western countries. On the other hand, an effective and successful coordination of work had been tried and tested with reference to the adjacent Polish coastal country. This cooperation has been subdued to the concept of „Research to the Upper Quaternary and its utilization" in the northern regions of both countries. This aim has been the general topic of 7 bilateral field-conferences with included workshops during the years from 1971 to 1989. They took place in regular intervals of 3 years as a rule, and with alternating choice of location. Parts included were lectures, excursions, working teams and reports, and last but not least, closing sessions passing common resolutions. Detailed documentations concerning course and results of these conferences were published in university journals of both countries (Greifswald, Toruń, Poznań: Kliewe, Galon et al. 1983; Kliewe, Billwitz et al. 1987; Kozarski 1992 a. o.). The preparing and coordinating teams a. o. consisted of R. Galon †, J. Szupryczinski and W. Niewiarowski (all of them from Toruń,) as well as St. Kozarski † (from Poznań), Poland, and of H. Kliewe (Greifswald), J. F. Gellert † (Potsdam) and H. Schulz † (Berlin), and later of K.-D. Jäger (Halle/Saale) and W. Janke (Greifswald), Germany.

The activities at the Greifswald University relating to coastal research have not been of less importance within the framework of the International Union for Quaternary Research (INQUA), including commissions and subcommissions. The regional competency with regard to investigations concerning the Baltic Sea has been overtaken by the previous INQUA-Subcommission on Shorelines of Northwestern Europe. The writer of this contribution was elected member of this subcommission in 1961 on the occasion of the INQUA Congress in Warsaw, and he became president for two terms of office from 1968 to 1977. Afterwards, from 1977 to 1980 he was acting vice-president. This body of INQUA has comprised representatives from 13 countries, covering Northwestern Europe from Iceland to Russia and from Norway to France. Since 1967 and especially during the author's term of office symposia and field-conferences were prepared and realized in the previous GDR (Warnemuende), in the Netherlands, in France, Wales, Scotland, Poland and Sweden. During this period 3 common monographs could be compiled and published which became regional standard-works. They dealt with „The Quaternary History of the Baltic", „The Quaternary History of the North Sea" and „The Quaternary History of the Irish Sea". These publications had brought together the level of knowledge of that time concerning the coastal and sea areas of Northwestern Europe including the shorelines displacement connected with world-wide sea level rise (Gudelis and Königsson 1979; Oele et al. 1979; Kidson and Tooley 1977). The writer's membership in this subcommission has enabled the participation in the exchange of experiences with reference to sea level oscillations and shoreline displacements. Included was the use of results by way of comparison as well as contributing own findings from the coastal region of Western Pomerania.

Spatial and tectonic integration of the investigated area

According to shape and features of landscape the coastal zone of Western Pomerania claims a special and independent position in the regional context of the southern Baltic coast. A remarkable change of forms depends on direction, course, and exposition of the coast as well as the size of the offshore marine area and climate conditions.

The regional variation of the shape is due to the coastal dynamics from west to east, from Jutland to the eastern Baltic: The western part of the southern Baltic coast comprises the firth coast (*Förden*) of eastern Jutland as well as the large bay coast (*Großbuchtenküste*) of Holstein and western Mecklenburg and the equilibrium coast (*Ausgleichsküste*) of Mecklenburg as far as to the bodden coast of Western Pomerania including the subsequent islands of the Oder estuary in Poland. Eastward this change of forms is continued by the equilibrium coast of eastern Pomerania as far as to the lagoon and spits coast (*Haff-* and *Nehrungsküste*) of the eastern Baltic area (Kliewe 2004 b). With reference to the bodden coast of Western Pomerania the term bodden equilibrium coast is appropriate. Processes of equilibrating by removal and accretion have reshaped decisively previous bays of the Baltic Sea during Holocene, especially with reference to the Fischland-Darß-Zingst peninsula and to the Islands of Hiddensee, Ruegen, Usedom, and Wolin.

As an additionally important perception may be stated that during the Late Weichselian exclusively the regions surrounding the southern Bight of the Baltic Sea have suffered from the last advance of inland ice belonging to the ice current of the Oder glacier. Relics are the marginal zones of the so-called Ruegen or coastal squadron („Rügen- or Küsten-Staffel“) covering the north-eastern half of Ruegen Island as well as the central regions of the Islands of Usedom and Wolin situated in the region of the river mouth. The deeply scraped glacier tongue basins have provided foregoing shapes of later bodden chains as well as of lake groupings on the islands. The depths of the scrapings were of such an extent that later following deposits of the Littorina transgression having thicknesses between 5 and 15 m could be accumulated and preserved there.

Following to initially autonomous stages of development of waters during Early Holocene the southern parts of the Baltic Sea have been connected immediately with the ocean during ca. 8 millenia until the present time. Consequently, during these millenia the Baltic Sea has shared all the oscillations of the ocean level. The connection from the Atlantic Ocean to the Baltic inland sea has been ensured by the Danish waterways of Great and Little Belt as well as Øresund. Thus, the Littorina transgression could penetrate in stages into the deep hollows of the coastal region remaining from the glacial past. There the penetrating sea has left its deposits.

The melting inland ice had led to unload Scandinavia by removing the earlier ice cap of a few kilometers’ thickness followed by isostatic equilibrating movements of the Earth’s crust. Lifting of northern Europe has been accompanied by synchronous lowering of the adjacent marginal bulge in present northern Germany and Poland. Several researchers suppose that this equilibration in consequence of glacial isostasy ended several millenia ago. The axis of these isostatic movements takes its course from northern Jutland via southern Skåne to southern Latvia and is situated quite near the TEISSEYRE-TORNQUIST line (Ekman 1988; Grünthal and Katzung 2004).

In Western Pomerania the most approximation to the mentioned axis is provided by the Island of Ruegen for it is spread widely to north. Thus, this island is situated near to the zero line of equilibrating movements. Vertical crust movements are approximated to zero in this region (Grünthal and Katzung 2004). Recently on both sides of this axis vertical crust movements had an effect, towards southwest with an increasing tendency to lowering. Within the limits of the Wismar Bight sites of the Later Mesolithic period (Dietrich and Liebsch 2006; Lembke 2005; Lübke 2005; Lübke and Terberger 2005) in sea depths down to 8 m are archaeological evidences of the actual investigation programme dealing with „Sinking coasts“ of the southern Baltic Sea. On the other hand, on the Island of Ruegen artefacts have been found near to the actual water surface. They prove a preferred region, where vertical crust movements in the Holocene sea sand areas (on spits, in German Nehrungen) of Ruegen and Usedom are excluded and observed oscillations of sea level correspond to those of the ocean without isostatic falsification.

The investigations at the southern Baltic coast have resulted in a documentation of alternating water levels of the Baltic Sea. This documentation has permitted evidences related to the history of climate not only of regional but also of global significance. The reason is that rising in the world-wide eustatic curve reflects processes of melting inland ice covering polar and adjoining regions as well as glaciers in higher mountain altitudes. This means that the southern area of the small inland sea called Ostsee shares immediately as well as actively the global record of sea level oscillations occurring in the oceans of the world.

Selected markings related to time and climate in the coastal areas of Western Pomerania

Due to the explained methodical preconditions as well as due to a consequence of interdisciplinary and international cooperation a large number of new results have expanded our knowledge related to the development of landscape in Western Pomerania. Mainly there are markings with reference to time and climate deduced from the examination of coastal deposits. In the following, selected items are presented point by point. In this context, consequences of climatic development and accompanying phenomena respectively changes are the focus of attention.

a) Concerning course and system of marginal zones of the northern inland ice cover during the Weichselian Kliewe and Janke (1972) have provided general maps covering the young moraines in their entirety. Already previously comparing the glacial morphology Reinhard (1962) had published a map of the former northern districts of the GDR, incorporating contributions of H. Kliewe and other experts. A joint presentation of marginal zones across the lower course of the Oder River to the northwestern region of Poland has been provided by an additional map of Kliewe and Kozarski (1979). The so-called Mecklenburg stage of the Weichselian provided with a separate ground moraine has been introduced by Eiermann (1984). This stage can be subdivided in substages in consequence of advances and stops of the inland ice. Their sequence in Western Pomerania reaches from the Rosenthal substage to the substage of northern Ruegen and eastern Usedom. The development of the substages and especially of the latter has been discussed controversely. Among others, Rühberg (1995) has given special emphasis to dead-ice, whereas others, among them W. Schulz (1998) and the author of this contribution (Kliewe 1957; 1960) focus on pushing. Apparently, both of them have taken effect in succession. Later on, the morainic landscape shaped by the Mecklenburg stage and especially the region of coastal substages became the sphere of activity caused by Holocene modifications. In this context a monograph related to the genesis of the so-called Haffstausee (at present a large sandy plain south of the actual Szczecin lagoon) provided by Bramer (1964) is worth mentioning.

b) Extensive examinations of drilled samples from the coastal regions by means of pollen analyses and their evaluation – especially by E. Lange and W. Janke (Lange et al. 1986; Kliewe and Janke 2006 a. o.) – have included the LateWeichselian, too. From the viewpoint of climate history, these ca. 5 millenia (approximately 15000 to 10200 years BPconv) are characterized by repeated alternation of first warm phases and relapses of cold. Consequently, a repeated change of vegetation took place – alternating between woodland and open grounds (cf. tab. 3.1).

A first warm phase, named after the site of Meiendorf, respectively after the shrub ***Hippophaë***, was characterized by annual mean temperatures of ca. 12° - 14° C.

Numerous high growing specimens of sallow thorn (***Hippophaë rhamnoides*** L.) are proved with reference to this period.
A second phase of warming has been the Allerød. During this period already birchwoods containing pine trees have existed. The optimum of warming has changed them to pinewoods containing birch trees.
Among the relapses of cold, the Oldest Dryas period (Dryas I) represents a transitional time leading from the melting inland ice at first to conditions poor in vegetation but rich in sharp-edged frost detritus and subsequently to lichens and mosses as well as finally to grasses and herbs. Another relaps of cold was Dryas II, but shorter and weaker. On the contrary, the last relaps of cold (called Dryas III) has proved to be a striking and effective cold period with tundra, permafrost, solifluction and increasing wind effects (ventifacts and inland dunes) also in Western Pomerania. During this period the inland ice sheet could advance once more to central Sweden and to southern Finland, where the marginal zone of Salpausselkä is clear evidence. Common investigations in cooperation with prehistorians have exemplified in case of Ruegen Island how stoneage hunters have grappled with the alternation of cold steppe and woodland during the late Weichselian.
About 10200 $BP_{conv.}$ (= 11902 BP_{cal} according to www.calpal-online.de, maintained by U. Danzeglocke 2005) the definite warming and afforestation has introduced the beginning Holocene into the coastal area.

c) Fine-grained pyroclastic deposits of the final maar eruption at the lake Laacher See in the Eifel area have provided a special climatic marker and temporal key horizon at about 11200…11065 $BP_{conv.}$ resp. 12880 BP_{cal} (Litt, Schmincke and Kromer 2003). The tephra layer contains not only small particles of pumice but also fragments of sanidin, augit, plagioclase a. o. Layers of pumice ash have been preserved mostly under hydromorphic conditions of ground depressions, for instance in the case of so called „Crednersee“ in the cliff of Mukran north of Saßnitz (Kliewe 1969, 1995). There a pumice layer included in a sequence of Allerød peat layers did not exceed a thickness of 3-5 mm. For a while, this exposure in the northern part of Ruegen Island has been evaluated to be the northernmost evidence of an eolian deposition from a cloud of dust that most probably was moved widely towards northeast by winds from southwest. This interpretation includes the supposition of a cyclonal period during this part of Late Weichselian in the Baltic region. In the meantime, in addition relics of pumice have been proved on the Island of Bornholm and in the Gotland Sea. Moreover, traces of pumice have been evidenced by means of microscopic analysis of samples from the coastal regions of NW Poland (Kozarski and Nowaczyk 1995), where the sites of discovery at Warnowo and Niechorze may be mentioned. The tephra may have covered the whole territories of Mecklenburg and Western Pomerania, providing a key horizon and a palaeoclimatic marker.

d) Since the publication of SAURAMO (1954) the problem of the Ancylus Lake is a matter of controversial debate with reference to the pre-Littorina development of the Baltic Sea. Moreover, regarding the coastal regions of Western Pomerania the chronological and spatial position still is unsolved.
Aiming at a special record of the Littorina transgression drillings have been put into position on the sandy spits of the Islands of Usedom and Ruegen. An unexpected result was the occurrence of a pre-Littorina sequence of sediments with a thickness up to 10 m and in some cases even more. These deposits contain a mollusc fauna with ***Ancylus fluviatilis*** (O. F. MÜLLER), ***Bithynia tentaculata*** L. and ***Theodoxus fluviatilis*** (L.). On top of this, an assemblage of diatoms has to be mentioned with ***Ellerbeckia***

(Melosira) arenaria (MOORE) CRAWFORD, ***Cymatopleura elliptica*** (BRĖBISSON) W. SMITH, ***Cocconeis placentula*** EHR., ***Navicula radiosa*** KÜTZING a. o., i. e. species characterizing the Ancylus Lake in supposed great extension within the basin of the Baltic Sea. The continuing discussions with reference to interpretation and positioning of the water body reach from a southern margin of a supposed great lake (Kliewe and Reinhard 1960; Kolp 1986; Björck 1995) to the assumption of an adjacent smaller water of Late Weichselian age (Lemke 1998). One cannot exclude the presumption that the fresh-water deposits underlying the spits can be traced back to previous lakes without or with merely temporary contact to any great lake.

e) Longitudinal and transversal sequences of drillings carried out on the Island of Usedom and in addition on the Islands of Ruegen and Hiddensee aimed at a special analysis of the Littorina transgression. These investigations have permitted a subdivision by 3 main phases which have been separated by phases of regression or at least stagnation (tab. 3.2).The organogenous sediment layers of the early Littorina transgression have been object of laboratory analyses and radiocarbon datings. The examinations have provided a significant new discovery elucidating the extremely rapid eustatic sea level rise of the Baltic Sea in the course of the first main phase of Littorina transgression (7900-5700 BP). The mean order of magnitude has amounted to 0.9 m during each century. In the beginnings of this first main phase even 2.5 m per century have been obtained. However, the mean amount has been decreased to 0.3 m per century during the final space of time (Kliewe and Janke 1982; Kliewe 2004 b).
Without essential coast equilibrating the sea has penetrated into the glacier tongue basins of the young morainic landscape as well as into the lower courses of coastal rivers. Thus, a landscape marked by islands and peninsulas has come into being. This has happened during the Middle Holocene, i. e. more precisely the Atlanticum, comprising the climatic optimum of the Holocene. Characteristic features were continuing increase of maximum temperatures and of mean precipitation values. The left remains of Scandinavian inland-ice caps as well as the polar ice sheets and the mountainous glaciers have suffered from intensified thawing.
Both components – as climatic optimum as eustatic sea level rising – and their consequences have inspired also the research related to the Baltic inland sea to contributions to global problems and their solution. Due to the almost realized absence of tides the Baltic Sea is really suitable for this purpose.

f) Apparently, the regressions of the Littorina Sea have taken place in the same periods of time as the comparatively dry periods of the Central European inland (Hageman and Jäger 1992; Jäger 2002). The regression at the top of the Littorina period (5700 to 5300) is already recorded by the eustatic curve published by Kliewe and Janke 1982. Later investigations have been related to the bodden waters of Western Pomerania as well as to spits (Janke and Lampe 2000). These investigations confirm the mentioned regression period and correspond to the estimation supposing that this regression of the Littorina maximum respectively of the Late Atlanticum, i. e. between 5800 and 5000 BP, has been by far the most significant one. The lowering of sea level during that interval has amounted to several meters. A possible reason can be assumed with reference to processes of neotectonic lifting.
Moreover, during the same period the Island of Ruegen has been occupied by the so-called Lietzow group of the Younger Mesolithic, proved by excavations at the sites Lietzow-Augustenhof and Lietzow-Buddelin (Gramsch 1978; Kliewe 2000). The previous population consisting of fishermen as well as hunter-gatherers living in sites

adjacent to bights of the Baltic Sea and also to inflowing brooks was faced with the necessity of adaptation to the changing water levels.
Frequently, datings of sites by means of ^{14}C provide significant temporal markings not only for the respective period of prehistory but also for the relevant developmental phase of the Baltic Sea.

g) During the subsequent long time of the 2nd and 3rd main phases of Littorina transgression and likewise during the period after the Littorina transgression lasting until the present (cf. table 2), i. e. a space of time comprising more than 5 millenia, merely minor oscillations of the sea level took place. The variability has been restricted to a range between ca. -1 m and NN or not much more, i. e. the tolerance has had an order of magnitude of somewhat more than 1 m only. This is the long space of time for the equilibration of coasts including the development of spits and bars and the shape of beach ridges and dunes (Kliewe and Janke 1991). Resuming a long course of time has been required by oscillating and ending changes of the water level. Gaps and problems related to their precise record and dating have existed until the present. The actual coastal research dedicates increasing attention to these topics.

Table 1: Changes of climate and landscape during the Late Weichselian in Western Pomerania (according to KLIEWE 2004 a)

Chronology (Years BP_{conv})	Phases of climate development	Vegetation
11000-10200	Younger tundra period (Dryas	Open cold step
12000-11000	Allerød Interstadial	Pine and birch (Pinewood shared by birch)
12200-12000	Older tundra period (Dryas II)	Open vegetation (Cold step respectively shrub tundra)
12700-12200	Meiendorf Interstadial	Shrubs of *Hippophaë*
15000-12700	Oldest tundra period (Dryas I)	Open vegetation (Frost detritus, cold step)

Table 2: Stages of transgression and regression of the Littorina Sea in the coastal regions of Western Pomerania (according to Kliewe and Janke 1982)

Chronology (Years BP_{conv})	Littorina stages
3000-2000	3rd main stage of transgression
3900-3000	Stage of persistence respectively regression (Late Littorina retardation)
5300-3900	2nd main stage of transgression
5700-5300	Stage of regression (Top Littorina retardation)
7000-5700	1rst main stage of transgression
7300-7000	Early Littorina stage of retardation
7900-7300	Initial stage of transgression

h) The actual climatic situation and subdivision of Mecklenburg and Western Pomerania were object of previous investigations. The distinction of actual climatic regions composing the territory of the federal land of Mecklenburg and Western Pomerania has been aimed by the doctoral thesis of Kliewe (1951). As a basis he took actual mean values (Maede 1949 a, b). The investigation has elucidated a double trend of regional variation of climatic elements, on the one hand according to the degree of continentality from west to east, on the other hand from north to south. In this context along the coast a strip of land characterized by typical coastal climate has covered a breadth of approximately 20 km. Typical features are there the cool, dry and sunny so-called „Baltic Sea spring“ („Ostsee-Frühling“) and a soft „Baltic Sea autum“ („Ostsee-Herbst“). A similar regional climatic subdivision has been proposed by Reinhard (1962) in the text volume of the atlas related to the northern districts of the previous GDR. In the map collection of the same atlas he has published valuable coloured maps related to climatic elements as well as to phenological data. A detailed chapter dealing with the climatic situation in Mecklenburg and Western Pomerania has been presented by Hurtig (1957) within the context of his „Physical Geography of Mecklenburg“.

The limited inland sea called Baltic Sea has indeed great worries and problems (Hupfer 1984). But on the other hand, a great chance consists in sharing problems and investigations related to global oscillations of the world-wide ocean level with immediate and unadulterated contributions based on the development of the equilibrating bodden coast of Western Pomerania during the latest 8 millenia.

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Climatic Changes During the Last 10 000 Years in Central Europe

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Introduction

Unfortunately, the availability of data records based on instrumental measurements related to conditions and changes of the global atmosphere during the past is restricted to very few centuries only (v. Rudloff 1967). Beyond that, the evaluation of written documents as well as the message of pictorial evidence with reference to weather, atmospheric conditions and climatic situations covers a range of other few centuries once more. On the whole, all the chances of looking at the climatic past by means of man-made proofs date back to not more than one millennium.

Climate reconstruction related to 10 Holocene millennia

Beyond that restricted era each trial of past climate reconstruction depends on the interpretation of proxy data provided by Earth sciences, biological disciplines and other natural sciences. Altogether the investigation of the climatic development during the last millennia is faced with the same type of methodical problems as all palaeoclimatic records related to the geological past in general.

Additional complications distinguish the access of precise datings from this period, for with reference to the recent events the demands to time resolution are exceptional ones. In this context the completion of own capacities for radiocarbon datings in the previous GDR may be mentioned (a. o. Kohl 1961, 1970, 1977; Quitta and Kohl 1976). Especially pollen analyses related to the late Weichselian and Holocene of Central Europe could make use of resulting ^{14}C datings (cf. p. ex. Kohl 1970). Precise dating of all available evidences with regard to the climatic development of Central Europe during the latest millennia is required mainly by the trial of gathering tendencies or rhythms governing the past. Any discovery of such rules may contribute to deducing prognostic statements. In this respect the available data base has been amplified considerably by palynological investigations in Eastern Germany. Their results have served to reconstructions of temperature development during the latest millennia. Another convincing methodical procedure for this purpose has been provided by palaeomalocology using fossil malacofaunas from well secured stratigraphical positions with precise datings.

The palaeoclimatic interpretation of fossil malacofaunas have based on the methodical rules of documentation and analysis of Czech experts (a. o. Ložek 1964). The extensive experiences of their successful application in the neighbouring country could be used and amplified by investigations mainly in Central Germany (Mania 1973, p. 128) Independently from results of pollen analysis, palaeomalacological investigations have enabled the reconstruction of mean temperature and precipitation values with regard to level and changes in the course of the last 10 000 years (cf. Table 1).

Magnitude and oscillations of annual mean temperatures

Moreover, Mania (1973) has compared the determined annual mean temperature and precipitation values of the middle Holocene (the so-called Atlantic period about 8000 - 6000 years ago) with actual ones. Concerning the development of temperatures he has considered mean values of the complete year (annual values) as well as those of individual months in summertime (July) and wintertime (January). Regarding the precipitation, the comparison is restricted to past and present mean annual values (cf. Table 2).

Table 1: Annual mean values of air temperature near the Earth surface in Central Germany during the Holocene (Postglacial) according to Mania (1973, p. 128)

<table>
<tr><th>Units of stratigraphical subdivision, revised by Jäger (2007)</th><th>Annual mean values of temperature according to Mania (1973)</th></tr>
<tr><td>Subrecent</td><td rowspan="2">8 - 9 °C</td></tr>
<tr><td>Subatlanticum</td></tr>
<tr><td>Subboreal</td><td rowspan="2"></td></tr>
<tr><td>Epiatlanticum</td></tr>
<tr><td>Atlanticum</td><td>≈ 11 °C</td></tr>
<tr><td>Boreal</td><td>9 - 10 °C</td></tr>
<tr><td>Praeboreal</td><td>5 - 6 °C</td></tr>
</table>

Table 2: Approximate annual mean values of air temperature near the Earth surface as well as of precipitation during the so-called Atlantic period (Holocene hypsithermal) in Central Germany (catchment area of the Saale River and of the middle course of the Elbe river, adopted from Mania 1973, p. 128).
The values related to the Atlantic period are derived from palaeomalacological investigations of Holocene deposits. The comparative values related to the 20th century are deduced from meteorological measurements

Averages		Comparative values 20th century	Approximate values during the Atlantic period
Air temperature °C	year	8 ... 9	≈ 8 ... 11
	July	16 ... 18	≈18 ... 20
	January	-3 ... -1	≈- 1
Precipitation mm	Year	450 ... 650	≈ 550 ... 700

However, in consequence of the year of publication (1973) the annual comparable mean values cannot represent that period of reference (1961/90 respectively 1971/2000) that is conventional standard at present.

Conditions and oscillations of water supply and annual mean values of precipitation

Specific items of research in eastern Germany during the second half of the 20th century have consisted in the investigation of conditions and changes of the natural water balance in Central Europe during the Holocene. The observed changes depend on the alternating amount of precipitation as well as on the magnitude of evaporation due to temperature values.

The available discoveries are based on observations of Holocene stratigraphy in karstified limestone regions of the Central European highlands zone. Mainly the stratigraphical sequences of this realm are composed by chemical deposits due to the sedimentation from hard water (Jäger, 1987a, p. 800) in inland waters (Jäger, 1965). This category of waters comprises flowing ones (as rivers and streams, brooks, and creeks), just as lakes and marshes as well as springs (in German *Binnengewässer* according to Thienemann, 1955, p. V). In limestone regions the sedimentary sequences of Quaternary and especially of Holocene age are dominated by deposits of calcium carbonate or here and there of calcium sulphate. Their origin from inland waters justifies their name (summarizing fresh-water lime deposits, in German *Binnenwasserkalke*; Jäger, 1965). In detail a distinction is recognizable between fresh-water carbonates and fresh-water sulphates (Schulze, 1980).

In Central Europe widespread limestone rocks of different geological age (a. o. Palaeozoic, Jurassic, Triassic muschelkalk) enable the widespread occurrence of young fresh-water lime deposits in different regions, especially in the Central European highland zone (a. o. Franconia, Swabia, Thuringia, Bohemia, Moravia and - beyond this cramped realm - southern Slovakia). Sometimes the thickness of the sedimentary sequences reaches or even exceeds 10 m (Jäger, 1987a, p. 802) reflecting the changing sedimentation conditions of several millennia (Fig. 1). The carbonatic quality of these deposits favours the preservation of conchylia, i. e. remains of the exterior skeletons of molluscs (in the inland shells of snails and mussels), and the thickness of layers and sequences enables the pursuit of changing compositions of preserved malacofaunas from layer to layer. The changing annual mean temperature values in the course of time are reflected by the changing composition of faunal assemblages succeeding one by one in the investigated sequences (cf. Mania, 1973).

Frequently, the sequences of Holocene fresh water lime deposits are subdivided by buried soils. Their occurrence is of great significance for the palaeoclimatic interpretation as well as for the chronological correlation of the investigated sequences (Jäger, 1987a, p. 801). In particular the carbonatic layers represent sediments from the hard water of superficial inland waters and consequently periods of water covering the respective site, whereas the buried humus horizons testify previous terraneous soils of subaeric ground surfaces occupying dry sites (Jäger, 1987a, p. 802). These horizons provide comparatively frequent archaeological datings. The discovered findings evidence as the interpretation of the buried humus horizons (giving proof of temporary dryness occupying the site) as the periods in question.

Fig. 1: Sequences of Holocene fresh-water lime deposits (calcereous tufa) with integrated buried humus horizons of previously superficial rendzina soils.

The whitish sedimentary carbonate layers have been deposited under water temporarily covering the sedimentation area.
On the other hand, the blackish intermediate horizons represent previous soiil formation of subaeric surfaces originating during periods of dryness in the same area.
Exemplary site: Pennickental near Jena-Wöllnitz, Thuringia (adopted from Jäger, 2007, Fig. 5)

Moreover, the method of datings by means of archaeological objects favours the chronological comparison and correlation of results from different partial regions of Central Europe.

A widespread synchronism of alternating evidences reflecting superficial waters and dry conditions succeeding each other on the same site has been stated by different publications of participating disciplines during the period under review (a. o Jäger, 1970, 1987a). Nevertheless, a detailed presentation and discussion of the respective observations and results has been submitted subsequently (Jäger, 2002a, 2007; cf. Fig. 2).

Moreover, another synchronism links this alternation of comparatively drier and humid conditions in the Central European inland Holocene with the alternation of regressions and transgressions occurring at the North Sea coasts of north western Central Europe (Hageman and Jäger, 1992). This means that the succession of moisture supply and its fluctuations in the Central European inland during the Holocene can be synchronized with contemporaneous oscillations of the eustatic sea level curve of the world-wide ocean.

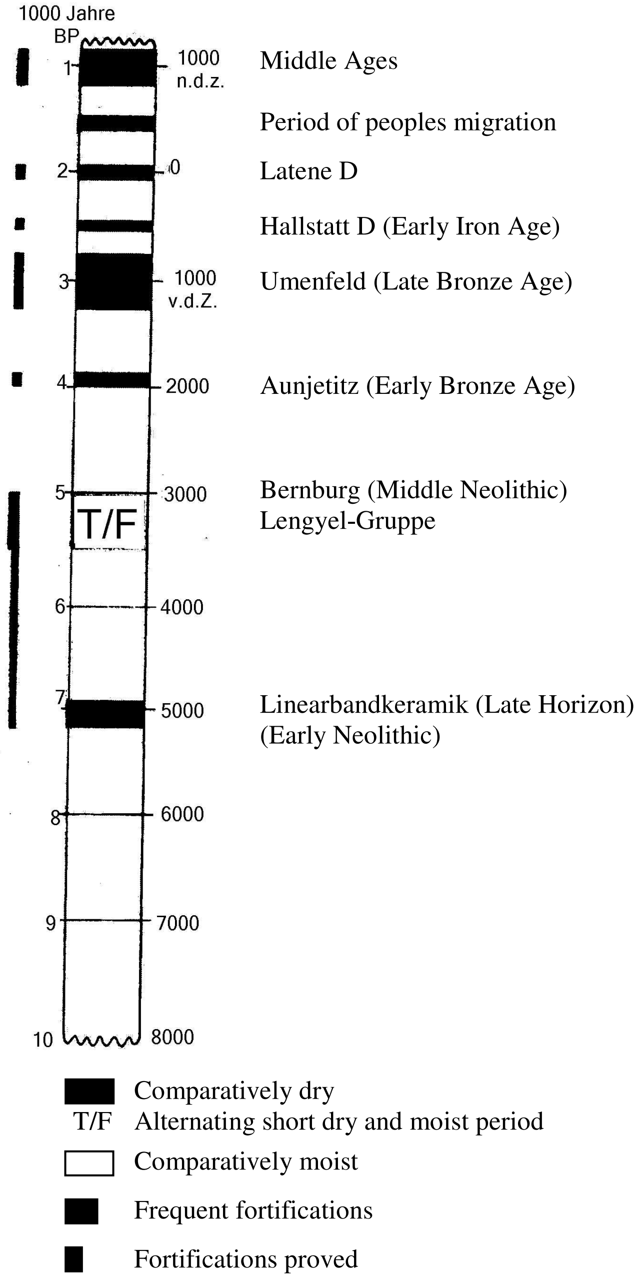

Fig. 2: Alternation of moisture and dryness in the course of Holocene in Central Europe as deduced from the stratigraphical subdivision of sequences composed by Holocene fresh-water lime deposits (cf. Fig. 1).

The chronological is based on archaeological datings of discovered objects from buried soils (adapted from Jäger, 2002 a, p. 34, Fig.1)

In the inland such fluctuations are reflected not only by the stratigraphical subdivision investigated by means of sequences of fresh-water lime deposits.
A comparable record has been provided by the application of pollen analysis to peat sequences of bogs, fens, and moors. H. Müller (1969) has proved changing proportions of genera representing shrubs and trees from different sites and reflections to water supply have. Moist ones have been required by the alder (genus *Alnus*) and dry conditions by the pine (genus P*inus*).

Minimum values of water supply during comparatively dry periods in the course of Holocene

Related to the degree of decrease with regard to annual mean values of precipitation up to now merely pointers were available. In this context a still unpublished doctoral thesis of J. Schulze (1980) at the Greifswald University is noteworthy, for in Holocene sequences his study has evidenced repeatedly a temporary deposition of fresh-water lime sulphate layers in interior Thuringia as well as in Bohemia. A first dating of such accumulations could be obtained by means of pollen analysis (E. Lange 1965) in interior Thuringia at the site of Nägelstedt (previously district of Bad Langensalza, at present Unstrut-Hainich-Kreis) in the riverside of river Unstrut. A significant statement of this investigation was the occurrence of beech (genus *Fagus*) immediately below the sulphatic layer with a percentage of more than 36 %. This means that the beech (*Fagus silvatica **L***) already has left behind the top of mass spreading in interior Thuringia during any time before the accumulation of the sulphatic layer (Lange 1965, p. 8 and 25). In the mean-time radiocarbon datings are available related to the process of beech penetration into interior Thuringia due to sites in adjoining regions (M. Schäfer, 1996, p. 197). Due to these datings the sulphatic accumulation approximately 1000 BC (respectively about 3000 BP) may be assumed. On this condition the accumulation took place in the course of an extraordinarily dry period of the Holocene in Central Europe according to the stratigraphic sequences of carbonatic fresh-water lime deposits (Fig. 2).

Actually, in Thuringia as well as in Bohemia or elsewhere in Central Europe the accumulation of the fresh-water lime calcium sulphate deposits is unknown. However, in more distant warm and dry regions as e. g. in interior Anatolia, sites of actual comparable deposition are evidenced. The conditions of previous sulphate accumulation in the Thuringian Holocene p. ex. 3000 years ago may be better understandable by means of a comparison with the actual climatic situation at present sites of comparable accumulation. Such comparison to the comparable sites in Anatolia has been carried out by J. Schulze, (1980, table 33, cf. Jäger, 2007, Table 3). The result is valid for the time being with regard to a very limited time span approximately about 1000 BC, i.e. about 3000 years ago. For this period a reduction of mean annual precipitation values in Central Europe has to be expected. If compared with the actual precipitation supply in Central Europe (period of reference between 1961 and 1990 or between 1971 and 2000 AD) the degree of reduction amounts to more than 20 % (Table 3).

Consequence of oscillating water supply related to landscape, land use, and settlement patterns

By means of such comparisons the dimension of fluctuations of water balance as in Holocene Central Europe as well as in partial regions is recognizable. Fluctuations of such great dimension have been reflected by the features of landscape equipment as well as by land use and settlement conditions (Jäger, 2008). Consequently, traces of changing landscape equipment and use provide suitable proxy data related to previous (or more concretely ancient) climatic conditions. Their critical investigation and documentation have started already during the second half of the 20th century.

Table 3: Comparison of annual mean precipitation and air temperature values at previous and present sites with underwater accumulation of fresh-water sulphate deposits. Data for Dachwig according to Lange (1965, p. 4, Fig. 1) and for Eskişehir according to Schulze (1980, Table 33)

Site	Annual mean values	
	Precipitation Mm	Air Temperature °C
Dachwig near Erfurt, Thuringia, fossil	462	8.5
Eskişehir, Anatolia actual	374	10.5
Difference Anatolia - Thuringia	- 88	+ 2.0

Their existence may be exemplified by numerous evidences of water level oscillations as proved in cases of Central European inland waters, especially in the young morainic areas of the circumalpine regions (known since Keller 1854) as well as of the circumbaltic belt (Jäger, 1987b, 2001; Prehn 1987; G. Christl 1988 and numerous still unpublished investigations of the eighties of the last century).

Moreover, the course of prehistoric settlement in Central Europe reflects manifold impacts of climatic circumstances and changes (actually comprising Jäger, 2008). Noteworthy are several remarkable synchronisms.

Concurrent events during the comparatively dry episodes (cf. Fig. 2) are low water levels of many inland waters with archaeologically dated "lake dwellings" (in German *Pfehlbauten*, cf. Keller 1854) and archaeological finding sites more or less deeply below the actual water table (cf. a. o. recently in northern Germany G. Christl, 1988) on the one hand. On the other hand, the penetration of human settlement into higher altitudes of mountainous regions in Central Europe took place simultaneously (e. g. Erzgebirge, i.e. Ore Mountains in Saxony and Bohemia: A. Christl 1989). Additional concurrent events are preference periods of cave use (Walther, 1985) in karstified limestone areas (Jäger, 2003) and phases of population displacement and migration. In their consequence the number of contemporaneous prehistoric fortifications had increased (in German so-called *Burgenhorizonte* according to Neumann, 1954). On the whole, the distribution pattern of prehistoric settlement sites had changed due to the succession of climatic oscillations.

Summarizing retrospect

However, an interdisciplinary connection, correlation, and interpretation of all the relevant observations obtained by several sciences and humanities have started during the period under review. In the period following an enhanced documentation has been commenced and continued the preceding work, in some cases supported by an extended data base (cf. actually 2008).

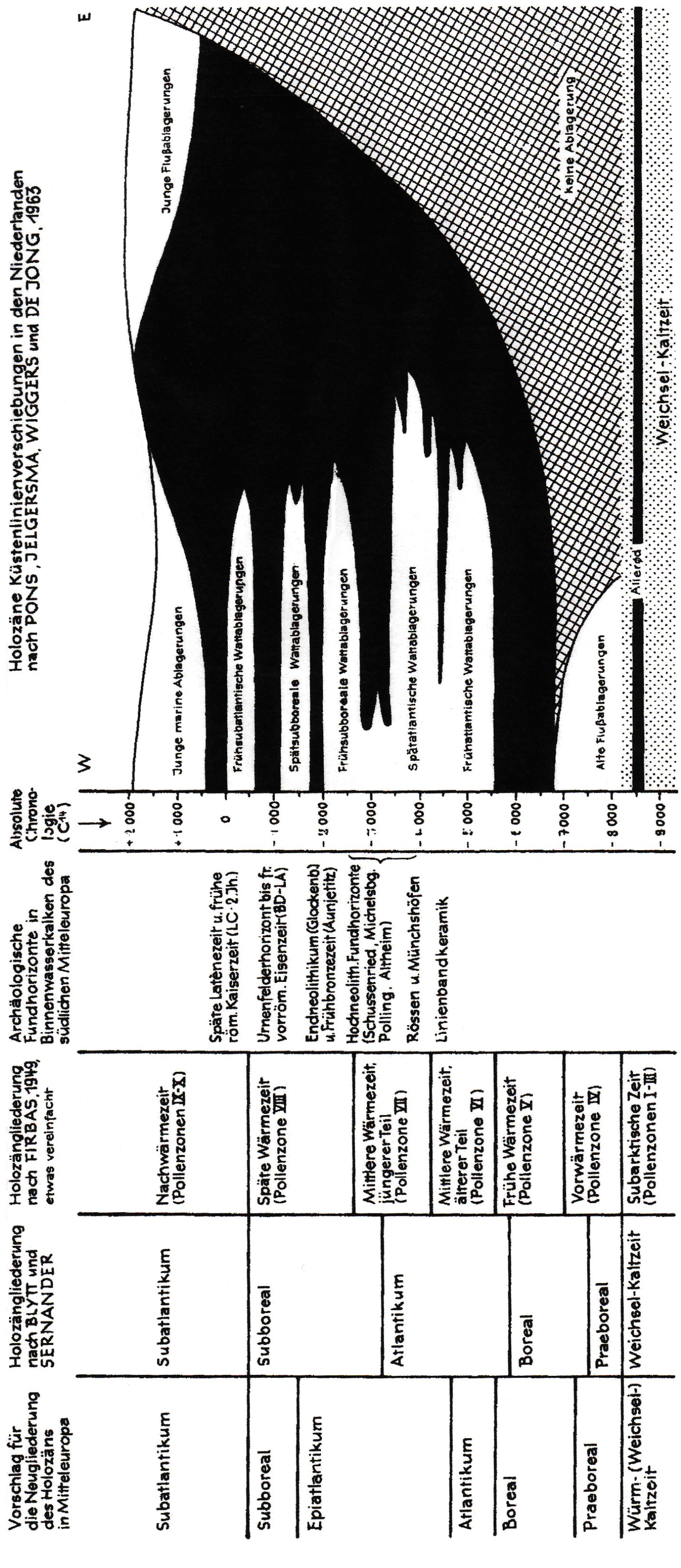

Fig. 3: Stratigraphical correlation of shorelines displacement (alternations of transgressions and regressions) in the coastal belt of the Netherlands with environmental changes (alternation of moist and dry conditions) in interior Central Europe according to the subdivision of fresh-water lime sequences (cf. Fig. 2).

The chronological scale is based by archaeological and radiocarbon datings (adopted from Hageman and Jäger, 1992, p. 165)

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Historical Climatology

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The historical climatology of the pre-instrumental period is based on the use of chronicles, annals, leaflets, newspapers, diaries, weather reports, city and church archives, economic records, memoirs, personal and official correspondence, and other pieces of printed matter. In this connection, reference can be made to the lifework of C. Weikinn, who has compiled man-made sources from beginning of the new era until 1850 AD. However, the author himself was able to publish only the hydrographic part until 1750 AD (Weikinn, 1958, 1960, 1961, 1963; see also Schröder, 1968). The volumes, the first of which was reviewed in detail and appreciated by Knoch, 1959 contain chronologically arranged reports on floods, low water levels, droughts, river, lake and sea icing in the European region. Each volume is supplemented by a geographical index and a list of sources in alphabetical order.

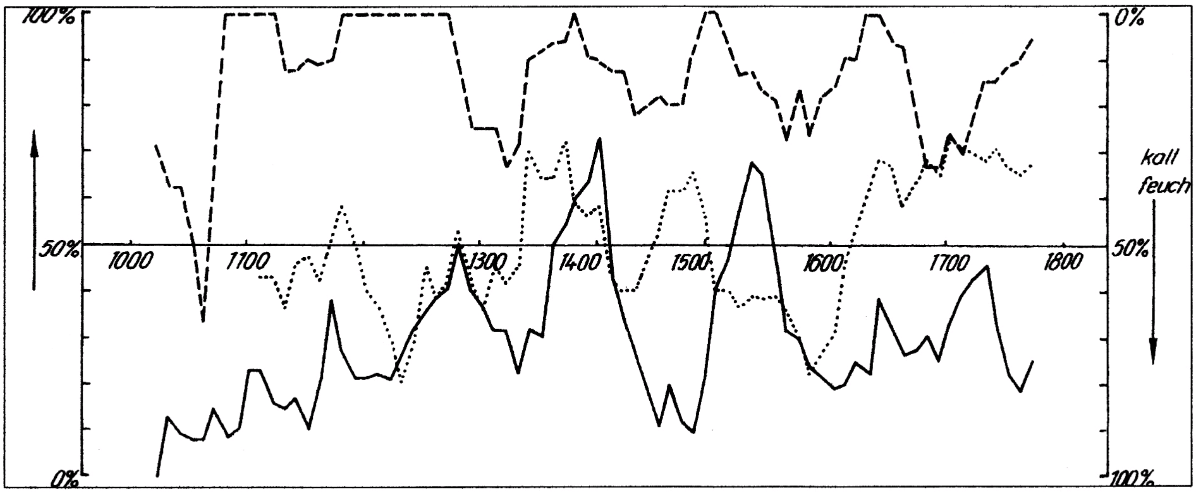

Fig.1: Frequency of reports on significant weather events (warm or dry summer seasons, mild winter seasons) as percentage of all reports in Hennig's, 1904 compilation for the period 1000-1800 AD; fifty-year running means, after Bernhardt and Mäder, 1987. Dashed: temperature, summer; dotted: wetness; summer; full: temperature, winter. Arrow upwards: warm, dry. Arrow downwards: cool, wet

The volumes 5 and 6 of Weikinn's work, the manuscripts of which were finished to a large extent when the author died, have been commendably edited recently by Börngen, Tetzlaff, 2000, 2002. A data collection for part two (meteorology) is not yet treated. Weikinn himself has also reported separately on hailstorms during the period 1100-1400 AD, on droughts from 1500 to 1850 AD and, finally, completing a survey given by Marx, 1966 on floods in the Eastern Ore Mountains (östliches Erzgebirge) during the historical period (Weikinn, 1965/66a, b, 1966/67 a, b).

Bernhardt and Mäder, 1987 have used the compilation published by Hennig, 1904 to present statistics of reports on warm/cool and dry/wet summer as well as on mild/severe winter seasons for consecutive periods covering ten and fifty years, resp., from 1000 to 1800 AD in the European (mainly the Central European) region (see also Bernhardt, 1991). Considering the well known shortcomings of the data source, which were discussed also by the authors at the beginning of their paper, only a simple frequency calculation of the compiled reports has been made. Nevertheless, a clear time structure can be seen for example during the so-called "Little Ice Age", which covers also periods of hot/dry summer seasons and periods of changing thermal continentality. Such results have been precised with a lot more details since that time in extensive investigations by Brázdil, Glaser, and Pfister, for instance.

The long time variation of the frequency of reports on warm or dry summer and mild winter seasons is presented for fifty-year running means in fig.1

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Regional Climatology and Recent Climate Variability

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Introductory remarks

The problem to describe research in the fields of climate variability and regional climatology in the GDR does not consist in finding suitable literature but in the question on how to narrow down this complex of topics. Each investigation of time series, no matter for which meteorological parameter, also provides information about climate variability and possible climate changes and/or the climate of the region in which data was measured. From this point of view, all other chapters provided more or less detailed information on the climate variability and the characteristics of regional climate events. In the following, both terms should thematically be narrowed down. Literature research was therefore aligned in such a way as to compile those studies that a priori had the goal of investigating certain questions in the fields mentioned or by which, besides the original purpose, important new knowledge about climate variability and regional climate characteristics was elaborated. The general catalogue of Deutscher Wetterdienst in Offenbach on the one hand and on the other hand the one of the library of the Nutzergemeinschaft (community of users) of the Science Park Albert Einstein in Potsdam which also comprises the entire catalogue of the library of the Meteorological Service of the GDR served as the basis for literature research.

When selecting the studies on climate variability, attention was paid to the fact that either temporal and/or spatial climate changes for individual or several meteorological parameters were investigated. As to questions regarding regional climatology, emphasis was put on the climatological description of individual regions in the GDR or the GDR as a uniform area. After reviewing more than 1000 citations, 73 of them were finally left over which provided a good overview of the research work done in this field. This selection, however, should not be regarded as complete. It might even be that some studies or other were not included since the catalogues that were available have unfortunately not been complete and/or since it was not possible to fall back on parts that have not yet been electronically recorded.

A first valuation of the 73 selected studies showed that regional climatology is represented much stronger with 45 studies than climate variability with only 28 studies. This is especially due to the fact that the topic "climate changes" was less considered in international research until the end of the 1970s in contrast to its growing importance as of the 1980s. This could also be proven by the fact that 14 out of the 26 studies were published on climate variability alone in the ten years between 1980 and 1989. This demonstrates on the other hand that scientists from the GDR did follow the developments made in international research and collaborated in finding solutions to upcoming problems.

It is not astonishing that regional climatology was most important in the GDR. On the one hand, one was endeavoured, for sure also politically motivated, to create an independent research profile, on the other hand, it was hardly possible to do regional-climatological research directly or via co-operations in other parts of the world.

But there is also another reason why scientists primarily concentrated on the GDR as the area of investigation - that is the base data. After World War II, the network of meteorological stations was quite quickly extended so that relatively long observation series were available as of the 1960s already. Since the Meteorological Service put great emphasis on continuous and homogeneous measurements, the quality of the data available for scientific investigations was quite high.

The systematic approach, i. e. the application of appropriate statistical methods to describe the regional climate and its variability, has changed a lot in the course of time. Besides the general development in the research landscape, the introduction of computers plays an important role in this respect, since they allowed for the first time the analysis of large data amounts using challenging statistics. Although methods to describe the distribution structure were still the main instrument for the analysis at the beginning, factor analysis, spectral analysis and its advancements as well as discriminant and cluster analysis came to the fore in the aftermath.

It is still to be noted that in the first decade of the GDR the number of published research studies is still small compared to the following decades which is to be attributed primarily to the problems of reconstruction during the first post-war years.

With a few exceptions, all studies appeared in journals that were published in the GDR. The "Zeitschrift für Meteorologie" of the Meteorological Society of the GDR plays an important role here as well as scientific papers of the Meteorological Service of the GDR where more than half of all the studies were published.

Regional climatology

Within the framework of investigations on regional climatology, there are a number of studies that deal with the problems of certain regions within the GDR. The two most comprehensive and certainly most important studies in this field are "Das Klima von Sachsen" (Goldschmidt, 1950) and "Das Klima des Landes Brandenburg" (Heyer, 1962).

Already in his introduction, Goldschmidt drew attention to the problems of climate research that today are still valid and are presently intensifying within the framework of a global view. Inter alia, he pointed out that the meteorological stations are often located in places that are only to some extent representative for their surroundings, that the number and sampling of measurements is too low and that no valid climatology can be derived from an examination of individual meteorological parameters. Here, the concept of a complex approach appears for the first time. In his study, he then attempts, even though only empirically, to meet this requirement. The occurrence of extreme weather events is also considered here. An example are the periods with a continuous succession of ice days ($T_{max} < 0°C$) in Leipzig since 1830 (see Table). Besides these extremes, also local characteristics are discussed as for example the climate of the Elbe valley basin, the foehn influence in the Erzgebirge or the thermal situation in Elbsandsteingebirge. A digression about the characteristics of the climate in urban centres(!) concludes the investigations on the climate in Saxony.

Other studies like "Das Föhngebiet des Harzes" (Hentschel, 1953), "Wetter und Klima des Fichtelberges" (Pleiss, 1961) or the bioclimatic investigations in the area of Bad Berka (Zenker, 1964) have only local importance.

Table 1: Non-interrupted period of ice days (Tmax < 0°C) for Leipzig 1830 – 1947. By: J. Goldschmidt, "Das Klima von Sachsen", Abh. Meteor. Dienst DDR, 3 (1950).

Duration in days	Start and end	Remarks
53	20.01.1947-13.03.1947	
47	16.12.1847-31.01.1848	without 12th January 1948
35	04.01.1838-07.02.1838	
29	19.12.1860-16.01.1861	
28	25.01.1929-21.02.1929	without 5th February 1929
26	15.01.1917-10.02.1917	
23	01.01.1893-23.01.1893	
22	29.12.1863-19.01.1864	
21	09.12.1840-29.12.1840	
15	12.12.1946-26.12.1946	
15	29.12.1946-12.01.1947	

This is also true for a number of studies that deal with the climatology of different places. Naturally, two places, although close to each other, play an important role, Berlin and Potsdam; Berlin due to its characteristics as an urban centre where urban-climatic effects are especially emphasised (currently again a top issue) and Potsdam due to its worldwide unique series of measurements. The contributions of Bahr and Böer made to the climate of Berlin were published in 1966 and 1971, respectively; the most comprehensive and informative study "Das Klima von Berlin", however, only in 1990, considerably written by Hupfer who is also the publisher. This comprehensive book with 288 pages is even today still a benchmark on the issue of climate for the Berlin region. The data of the Potsdam secular station were used in numerous investigations. The first more comprehensive climatological analysis is based on the work of Böer (1960) and Antonik (1961). In 1963, Branicki summarised the climatic observations of the records of the 1960s at the Meteorological Observatory and published them at the Institute for Meteorology and Geography of the Free University of Berlin since he had left the GDR in 1961 taking his documents with him.

Within the framework of regional-climatic investigations, a number of meteorologists were engaged in studying the behaviour and/or distribution of individual meteorological parameters within the area of the GDR. One important representative of this group is Reich who studied the role of precipitation. Besides many other investigations, his standardisation and regionalisation of the precipitation climate needs to be especially accentuated within this context (1985). Moreover, Reich was one of the first who used multivariate methods instead of the usual standard methods applied so far in statistical evaluation (1985,1986).

On the basis of 60 precipitation stations within the area of the GDR, Reich attempted in his study of 1985 to classify them into areas with a uniform precipitation behaviour. He used a hierarchic cluster method for which the parameters were created by a main component analysis. Depending on the number of groups used, he received as a result different numbers of area units. As an example, the area distribution is represented in Fig. 1 with 11 groups and 24 area units. The attempt shows that the area distributions generated in such a way are less satisfying. This should, however, not be attributed to the method used but to the fact that the precipitation distribution within the area of the GDR is much more structured than it can be expressed by the 60 stations. Thus, it could be proven that statements as to the spatial structuring of individual meteorological parameters are also a function of the existing density of stations.

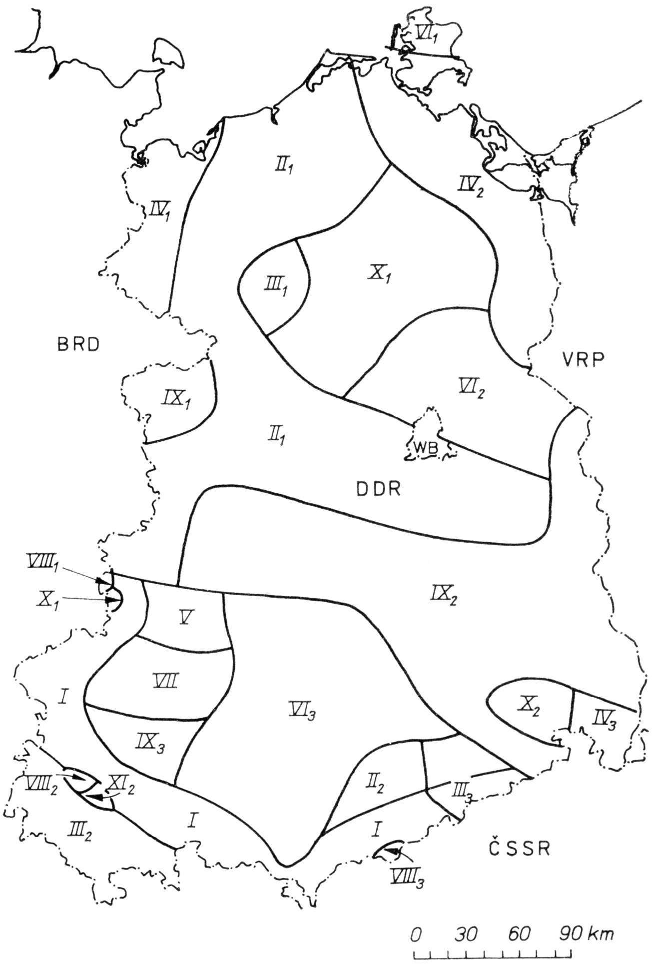

Fig. 1: Regions of the GDR with homogeneous precipitation patterns. From: T. Reich, Z. Meteor., 35 (1985), p. 15-25.

Within the context of precipitation investigations, the study of Marx (1973) needs to be mentioned that deals with the spatial distribution of extreme precipitation for the GDR as well as for the Federal Republic of Germany. Further important studies are (Zerche, 1967) in the field of temperature, (Zerche, 1969; Wagner, 1974) in the field of sunshine duration, (Zerche and Klinker, 1970) in the field of relative air humidity and (Fojt, 1974) in the field of snow cover. In this context, the study of Richter, published in 1966, on the humidity balance of the atmosphere within the area of the GDR needs to be mentioned.

The use of special statistical methods to solve appropriate questions is another category in the investigation of regional-climatic phenomena. The introduction and further development of the maximum entropy spectral analysis in climatology by Olberg (1983) should be especially highlighted within this context.

The shifting maximum entropy spectral analysis (MESA) is used in this analysis. This means that the MESA is calculated for a defined window which is slidingly shifted over the time series. Thus, a temporally dissolved spectrogram is obtained as it is shown for the precipitation series of the station Potsdam in Fig. 2. It can be seen that the emerging periods have a length of 2, 5 and 11 years. At this point of time, the knowledge is not new. New however is the fact that individual periods do not occur constantly over the entire investigation period which could be proven with this method! This means however that results of spectral analyses are only valid for the respectively selected investigation period and have no universality! (a fact that even today is often still ignored!).

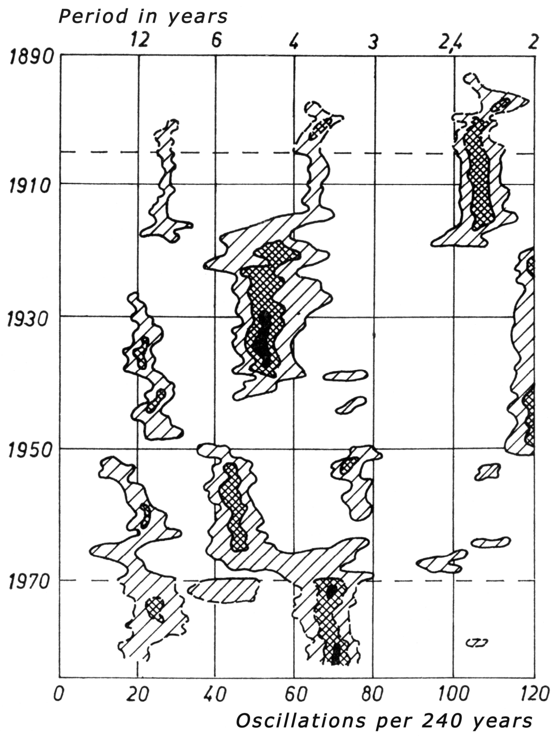

Fig. 2: Spectogram of the precipitation data series of the station Potsdam. By: M. Olberg, Z. Meteor. 33 (1983)5, p. 281-285

In 1984, Gerstengarbe showed in an investigation that the complex approach of several meteorological parameters by means of a modern multivariate statistical method leads to a significant gain of information when regionalisation is done from climatological perspectives. In the following year, Tremmel (1985) put the problem of homogenising time series up for discussion. Taking the measurements of precipitation in Saxony as an example, she illustrated which problems can occur in this context – a complex of issues that has not yet satisfyingly been solved.

Although the studies presented so far were more or less always oriented to a specific problem of regional climatology, investigations were also carried out to approach this topic from a general perspective.

The studies of Böer, Hendl and Hupfer were path-breaking in this respect. Böer dealt in his study (1966) with the problem of regional climate classification and suggested on this basis in the same year to divide the GDR into areas with a uniform macroclimate.

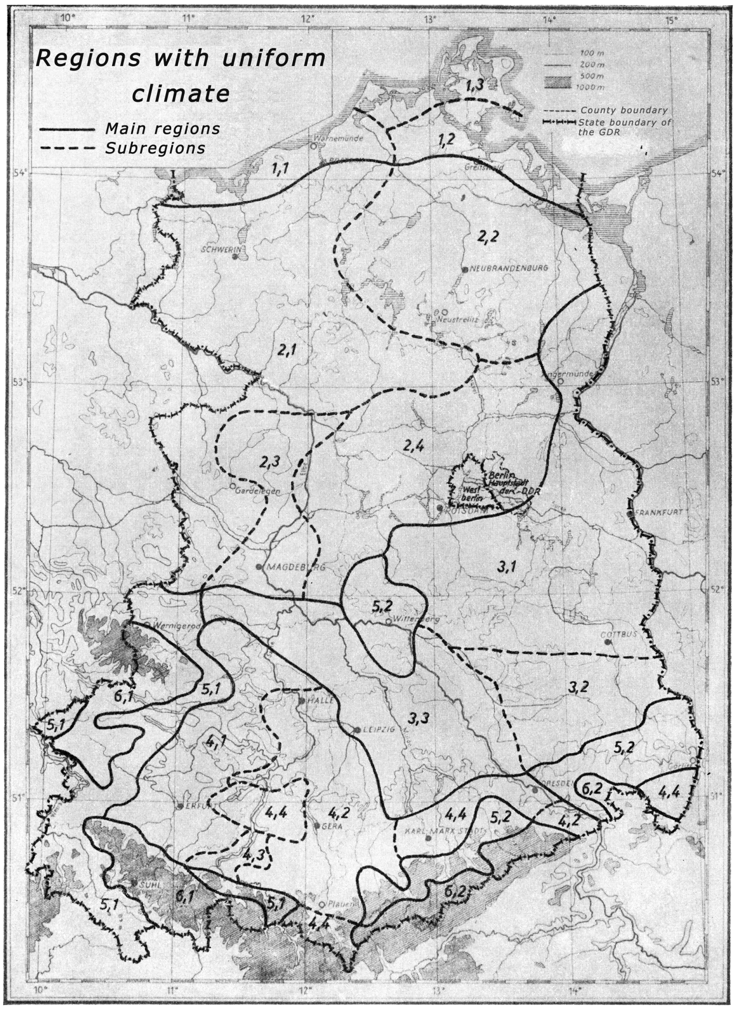

Fig. 3: Regions with homogeneous climate within the GDR. By: W. Boer, Z. Meteor.,17 (1966) 9-12, p. 267-275

Precipitation and air temperature served as output parameters for Böer for the climate classification of the GDR. All stations in the investigation period were used whose monthly values were available for the period 1901 – 1950. By comparing the climate diagrams for air temperature and precipitation, areas with similar behaviour as to the occurrence of meteorological parameters could be identified and defined as a macroclimatic uniform region. Although the approach of Böer has a strong subjective component according to today's standard, the finally defined area classification (see Fig. 3) shows a logical structure in the climatological sense.

Also in 1966, Hendl drew up an outline of the climatology of German landscapes that is still used today. This work has be complemented by approaches of Hupfer relating to the climate on the mesoscale that he summarised in a paper that was however published in 1989 only.

In this paper, Hupfer was able to prove that only the combined use of routine data, field investigations, model calculations and different combined methods allows for satisfying statements on the meso-climatic scale that are also of high practical and interdisciplinary importance (Fig. 4). Based on this knowledge, two types of meso-climates are defined: that of corresponding space and time-scales and that of the great time-scale. The factors necessary to prove the meso-climate are presented and discussed.

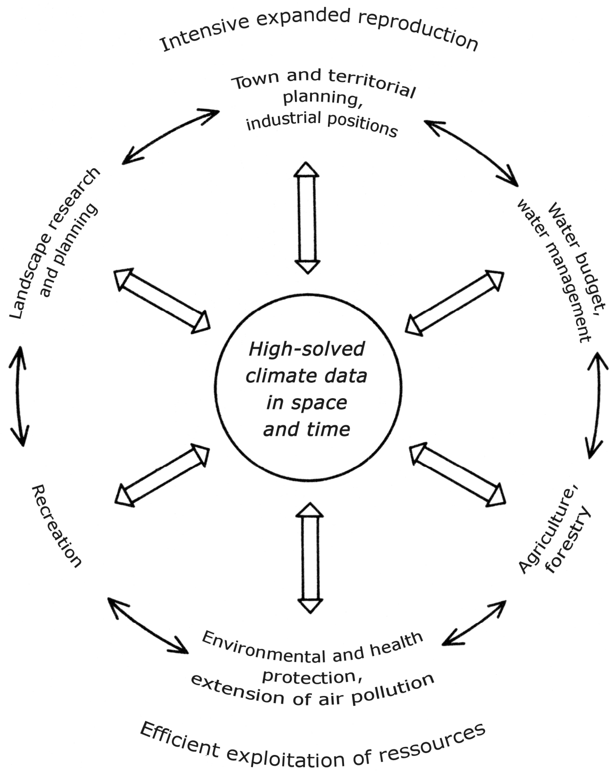

Fig. 4: Practical and inter-disciplinary significance of spatial high resolved climate data. By: P. Hupfer, Abh. Meteor. Dienst DDR Nr. 141(1988), p. 181-192

All in all, it has to be noticed that the work of the scientists who dealt with regional climatology has always been up-to-date. Unfortunately, there was no notable exchange of scientists from other countries and regions during GDR governance (except for Heyer, 1979). Although today many studies mentioned here are no longer valid since the base data is a different one or since the potentials for high-complex evaluations have significantly improved due to the rapid progress made in computer technology, many findings from the methodical approaches developed can even today still be used advantageously.

Recent climate variability

It has already been mentioned that each temporal and/or spatial investigation always provides a statement on climate variability. It would go beyond the scope of this chapter if this item was discussed as broad as defined here. Hence, we will confine ourselves to some important studies which from the outset had the goal to provide a contribution to describe recent climate variabilities.

Only four out of the 26 studies selected exceed the boundaries of the GDR. One under these conditions exotic study is the one of Gellert that was published in 1955 already and dealt with precipitation fluctuations in the highlands of South-West Africa.

One characteristic of this study needs to be mentioned, i.e. the inclusion of tree ring analyses to prove periodicities in the precipitation behaviour. In Fig. 5 it is proven that dendrochronology is not an invention of the last two to three decades but was already applied effectively before.

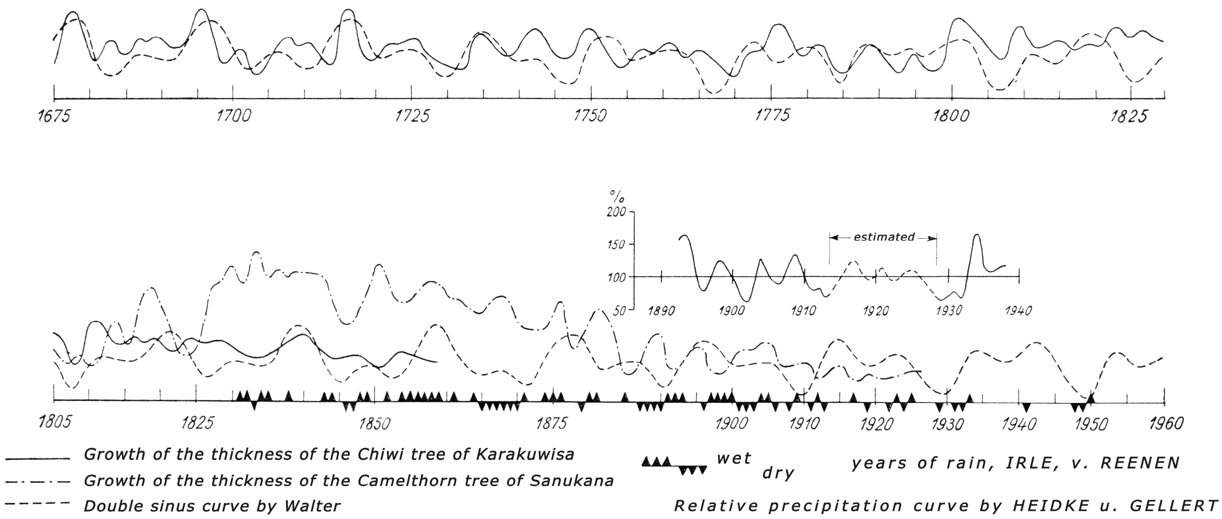

Fig. 5: Diagram of the precipition periods in the highland of South West Africa on the basis of treering measurement. By: J.F. Gellert, Abh. Meteor. Dienst DDR Nr. 32 (1955).

Further studies are on the one hand the attempt of Olberg (1981) to describe the statistical structure of climate fluctuations in Central Europe as well as on the other hand the study of Schönermark (1983) on the variability of temperature in the Atlantic-European area.

Such as in the analysis of climate at the station Potsdam, Olberg used the shifting maximum entropy spectral analysis to prove climate fluctuations. This enabled him to prove that the meridional circulation forms according to Hess/Brezowsky showed different, for some periods between 1881 und 1978 significant period lengths (see Fig. 6). Hence, evidence is provided for the first time that the meridional and definitely also the zonal and mixed circulation forms are changing their internal character in the course of time and that different climatic conditions can be expected in Central Europe with the same circulation patterns.

The fourth study originating from Hänsel (1975) is more general and on 98 pages gives a good review about the forms of appearance and the causes of climate changes. It has to be noted that even today most of the facts compiled in this book are still valid even though the problem of the anthropogenic influence on the climate development is naturally not yet dealt with. All other studies deal with investigations that are restricted to the area of the GDR.

Seven selected publications show that research focussed on the analysis of precipitation. The studies of Antonik and Böer in the 1960s that especially focus on the effects of extreme events (intense and continuous rain) with regard to their temporal occurrence have to be noted in this context. Reich (1985 and 1986) continued these investigations and complemented them by adding a question by then hardly discussed, namely the occurrence of dry periods and how these can endanger individual regions in the GDR. With regard to the presently on-going climate changes and the fact that the Eastern part is the driest region in Germany, the latter studies are still of high significance in current research. Regionally limited studies on precipitation were carried out by Böer (1964) for the Northern German lowlands and Kortüm for the secular station Potsdam.

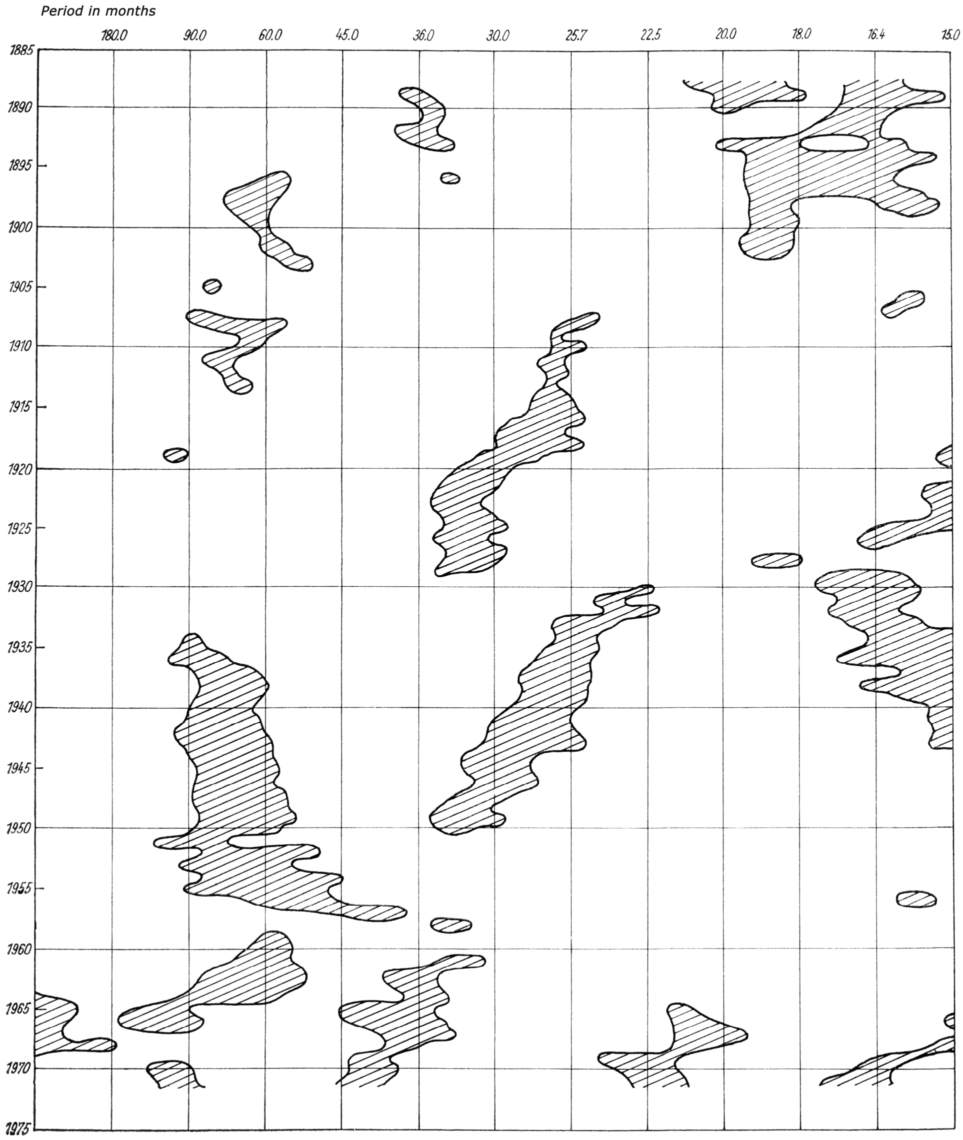

Fig. 6: Spectogram of the meridional circulation by Hess/Brezowsky. By: M. Olberg, M. v. Schönermark, Z. Meteor. 31 (1981)6, p. 370-374.

Further meteorological parameters that were investigated with regard to recent climate variations are temperature, wind, global radiation as well as evaporation. Antonik (1966) showed that the daily temperature fluctuations are not constant in space and time. By means of statistical filter methods, Olberg was able to prove in 1973 that the wind components are subject to temporal variations and Kortüm published in 1974 a time series analysis of the annual sums of global radiation of Potsdam for the period 1893-1972.

In his study, Kortüm interprets time series to be realisations of a random process to obtain climate-relevant statements by empirically determining the characteristics of this random process. Furthermore, he pointed out that the global radiation in combination with precipitation considerably determines the climatic moist conditions of sites that are far from ground water. The development trend of the annual sums of global radiation (see Fig. 7) illustrates the instationary character of this parameter.

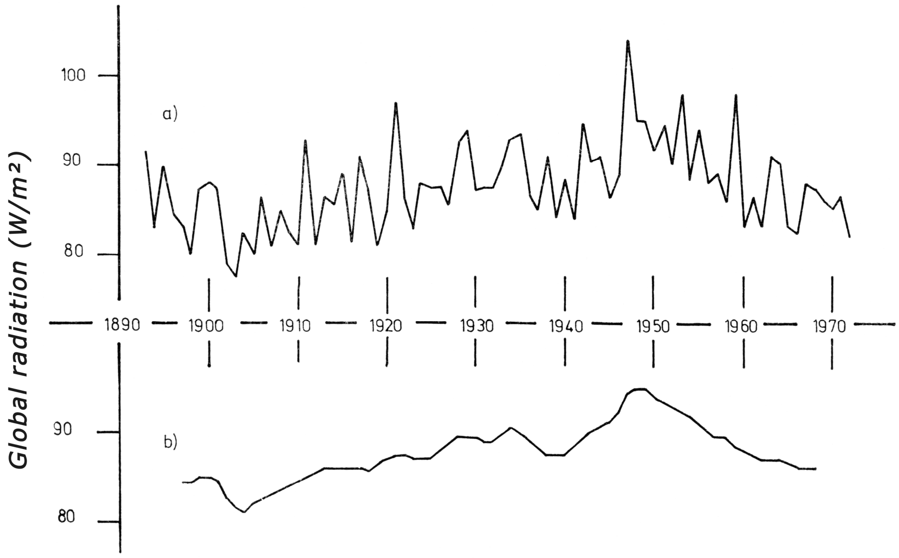

Fig. 7: a) Annual sum of the global radiation, Potsdam, 1893-1972; b) smoothed course By: F. Kortüm, "Zeitreihenanalyse der Jahressummen der Globalstrahlung, Potsdam, 1893 – 1972", Z. Meteor., 24, 3-8, 1974, p. 259-261.

In 1982, Richter presented for the first time a statistical analysis of the evaporation level of open water surfaces for the area of the GDR that has until then been unique in this form.

A more complex approach to describe climate variations was followed by Hupfer and Thiele. In 1967, Hupfer already established a connection between the drift of ice conditions at the southern coast of the Baltic Sea and recent climate fluctuations. Supervised by Hupfer, Thiele wrote his diploma thesis in 1987 in which the temporal variability of winter in the Berlin area was classified. Another publication of Hupfer that is based on this preliminary work was published in 1989 und describes the recent climate fluctuations in the Berlin area.

The basis of this study is the famous Berlin temperature series for which data is available since 1766. Similar to the temperature series of the secular station Potsdam, the authors found out that the Berlin data correspond also well with the course of the mean temperature of the Northern Hemisphere. Besides temperature as such, parameters derived such as summer days, ice days and cold sum are also investigated and the results are discussed. In the analysis of the cold sums, the authors point out to a fact that even today is often ignored: the specification of return intervals that assume stationarity when instationary processes exist. Fig. 8 shows that the probability for the occurrence of a cold sum of 400 K - 600 K for a return interval of 40 years has the same secured probability than for a return interval of 240 years. For a practical application, however, this is a completely absurd statement. Due to the importance of the investigation results, it is unfortunate that only restricted audiences were reached since the article was published only in the journal "Zeitschrift für Meteorologie".

In 1988, a research project on climate dynamics was completed at the Humboldt-Universität zu Berlin that had been supervised by Hupfer and Chmielewski. For the first time the authors combined climate variability to be observed in the area of the GDR with large-scale up to global processes that caused and/or influenced climate variability.

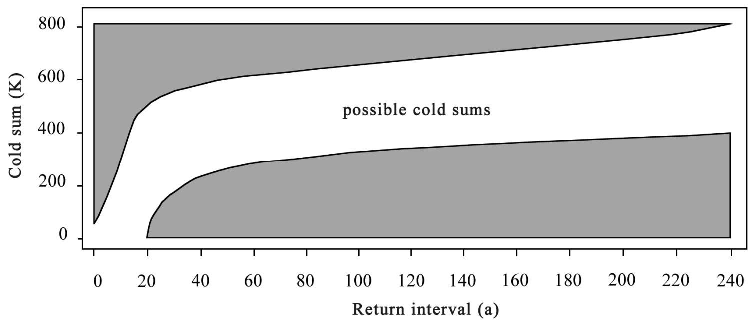

Fig. 8: Relation between boundary values and return intervalls of the cold sums for Berlin suburban regionBy: P. Hupfer, R. Thiele, “Beitrag zur Kenntnis der Klimaschwankungen im Berliner Raum”, Z. Meteor., 39, 6, 1989, p. 327-337.

Table 2: Measure (M) for the definition of standard value periods in % of the period length. By: F.-W. Gerstengarbe and P.C. Werner, Z. Meteor.,36, 4, 1986, p. 272-275

Period (a)	*M* (%)					
	T	T_{MIN}	T_{MAX}	U	RR	P
10	20	50	40	30	60	50
15	47	47	47	20	60	47
20	40	55	50	20	55	50
25	40	44	48	28	56	60
30	33	37	40	30	63	70

T - Daily mean of the air temperature
T_{MIN} - Daily minimum of the air temperature
T_{MAX} - Daily maximum of the air temperature
U - Daily mean of the relative humidity
RR - Daily sum of precipitation
P - Daily mean of the air pressure

In this research study that involved a number of other scientists, the characteristics of the dynamics of climate relating to the area of the GDR were investigated. The proof of long-lasting fluctuations of the climatological main elements, the correlation between the growth conditions of cultivated plants with proven climate fluctuations as well as the influence of ENSO-events on the circulation regime in the Atlantic-European area were the foci here. This research study should serve as a basis for a long-term estimation of weather and climate anomalies to be expected.

Finally, two studies of Gerstengarbe, Werner should be mentioned in which they could prove that due to climate variability, the normal value periods defined by the WMO have only a temporally quite restricted validity depending on the meteorological parameter (1986) and that the normal weather conditions of Baur that are highly and often quoted in public are today mostly not or only marginally valid due to the climate changes to be observed (Tab. 2).

Due to the instationarity of climate, Gerstengarbe/Werner suggested to reconsider the problem of using normal value periods as a source of information for climatological statements. They proved in their study that the stability of parameters derived from a normal value period primarily depends on the position of the period in the course of time as well as on the length of the periods regarding their intended use. A measure is defined that indicates the percentage of the period length after which the normal value period needs to be recalculated in order to secure statistical stability. As an example, Fig. 2 shows the measures for the station Potsdam, several meteorological parameters and different period lengths.

Even though the number of studies available on the topic "recent climate variability" is restricted, it could be shown that their theoretical approaches can fully be applied even in current investigations and that on the date of their publication they reflected the current state of knowledge in the respective field of research. The same is true for the knowledge attained which can be used as a basis for current research projects.

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Recent Climate Changes

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Early investigations

The PhD Thesis (Leipzig University) by Wiese (1949, published only four years later (Wiese 1953) on rhythms and changes of climate including their impact on the water transport by the Saale river was the first East German original publication on the problem of recent climatic change. Equally, this hydro-climatic study was a first contribution to learn the consequences of long-term variations of the climatic elements (surface air temperature, precipitation and height of the snow cover) on hydrological processes. Shortly after that, the paper by Flach (1951) followed on the peculiarities in the hydro-meteorological course of the winter in Middle Germany including an evaluation of the long-term variation of surface air temperature and precipitation.

Gellert (1955) published his results on the changes of precipitation in the Highland of South-West-Africa, achieved already before World War II. In the same year a review by Kortüm (1955) was published, which summarized the knowledge on recent global climatic change at that time.

Then followed a study by Götschmann (1960) on the increase of the sunshine duration and the corresponding variations of the number of days without sunshine as well as the number of days with anticyclonic weather for eight German stations. This paper was worked out as a diploma thesis under the guidance of K. Schneider-Carius at the Leipzig University.

An important milestone in the development of these investigations was the work by Böer (1960), presenting a careful evaluation of the wind measurements at the secular station of the Meteorological Observatory Potsdam (in operation since 1893). On this base seasonal changes of the atmospheric circulation have been identified, for example the “circulation turnover” about 1930. The author showed that the variations of the circulation are strongly connected with corresponding changes of surface air temperature, global radiation and rainfall, resp. (see Table 1).

Wusselt (1962) published an extensive analysis of long-term changes of the mean values as well as the extreme values of the surface air temperature (year, season and month) together with corresponding data of the cloud cover as well as of the atmospheric circulation (“Großwetterlagen”) for the station Jena in Thuringia (Fig. 1). The results have been compared by correlation analyses with those of several other European stations.

A first study on marine climatic fluctuations in the period 1901/60 in the Baltic Sea has been published by Hupfer (1962). The results were cited also in textbooks and monographs (see Neumann and Pierson 1966, v. Rudloff 1967). This investigation is different to others by the inclusion of oceanographic data like sea temperature, salinity and sea level as well as of all available climate elements including parameters of atmospheric circulation. It has been shown, that these properties are strongly correlated.

In this way, the effects of the first global warming in the 20th century (see Hupfer and Tinz 2006) could be shown in detail for the area under investigation. Thereby several impacts of the climatic changes in the sea as well as in the atmosphere have been discovered (s. Chmielewski and Hupfer in this volume).

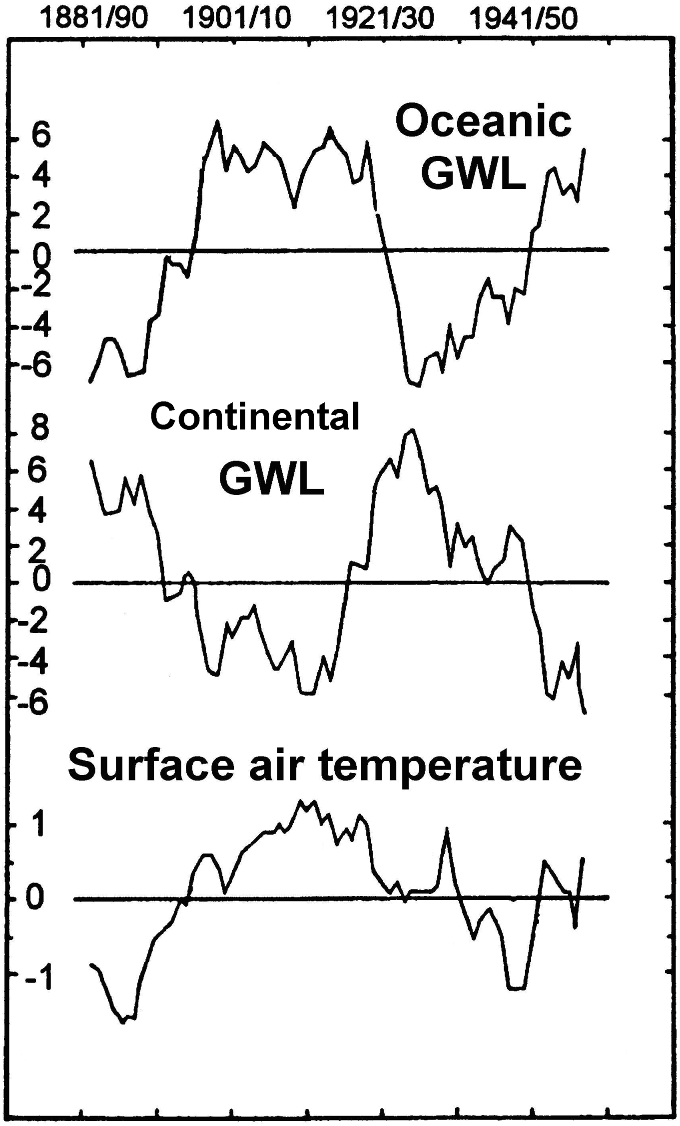

Fig. 1: Secular changes of frequency of selected combinations of circulation types ("Großwettertypen") and the variation of the mean winter temperatures for the period 1881 - 1957 in Jena (11-yearly sliding averages), (after Wusselt 1962)

Development and application of statistical methods

Together with investigations into the recent climatic changes and other climatological problems statistical methods have been developed or fitted by scientists at the Meteorological Service (Gerstengarbe, Werner, Lehmann and others), at the Academy of Sciences (Taubenheim, Stellmacher and others) and at the Humboldt-University Berlin (Olberg with colleagues and students). For research as well as education the monograph "Statistical evaluation of geophysical and meteorological data” (in German) by Taubenheim (1969) provided a valuable tool over many years.

Table 1: Comparison of mean values of the wind components measured in Potsdam and other elements for the periods 1896-1929 and 1930-1954 (summer) as well as 1896-1924 and 1925-1954 (winter) resp. Underlined and double underlined Δ-numbers have an error probability of 5 % and 0,1 % resp. significantly different from zero (Böer 1960)

	Wind /m s^{-1}		Mean surface air temperature /°C	Sum of global radiation /cal cm^{-2}
	N-component	E-component		
Summer (May – September):				
Average 1896-1929	-0,11	-1,63	15,3	1912
Average 1930-1954	-0,14	-1,27	16,2	2016
Δ	-0,03	0,36	0,9	104
Winter (September – February):				
Average 1896-1924	-1,45	-1,80	1,1	-
Average 1925-1954	-1,34	-1,12	0,8	-
Δ	0,11	0,68	-0,3	-

An imperative condition for every statistical treatment of data series are tests of homogeneity (Fig. 2). Appropriate methods for homogeneity checks and for the examination of the structure of time series have been summarized by Stellmacher (1982), who applied and tested those at numerous examples of meteorological and hydrological time series. Time series of water flow in the run-off areas of the Spree River, of the seston content in the lake Müggelsee, of cold sums of Berlin, Rostock and Dresden as well as of precipitation in Saxony have been analyzed. The review presented in Fig. 2 schematically shows the necessary steps for application of such methods.

Methods of time series analysis have been especially developed or used in fitted form by M. Olberg and his students and co-workers. These methods allow determination of both periodical and quasi-periodical components of oscillations within the sample under consideration. Further, these methods are able to discover the non-stationarity of such significant oscillations being included in the stochastic process. To this end, special methods of numerical filtering have been used as well as autoregressive spectral estimate procedures like the Maximum-Entropy-SEM in a sliding variant especially. In this connection multi-channel spectral estimate methods (SEM) have proven useful for the climate diagnostics. The overview presented in Fig. 3 shows various methods. By their use numerous climatological problems could be cleared. Our knowledge on the oscillations characterizing a considerable number of climate processes could be expanded. As an example the monthly contributions to the 2- to 4...6-yearly oscillation have been studied containing in the rainfall time series for Central Europe after Baur as well as in the series of monthly numbers of “Großwetterlagen” after Hess and Brezowsky. Both by use of SEM and harmonic analysis a quasi-80-yr oscillation could be found in numerous climatological time series. Non-persistent periods apart from the annual and daily variations could be observed in many cases (Fig. 4). For summaries of the mentioned methods see the monograph by Olberg and Rákóczi (1984) as well as Olberg (1984a).

In more recent investigations on numerical band pass filtering (Olberg 1988b), using modified harmonic band filter sets temporal changes in the spectral behaviour of meteorological data series could be shown, too. This method is a reasonable completion of SEM. With the aid of a set of filter weights the data are filtered in several frequency bands, and the results are displayed in a time-frequency diagram. With this procedure, however, non-significant spectral density values are suppressed, such that only the amplitudes exceeding a given spectral level are shown.

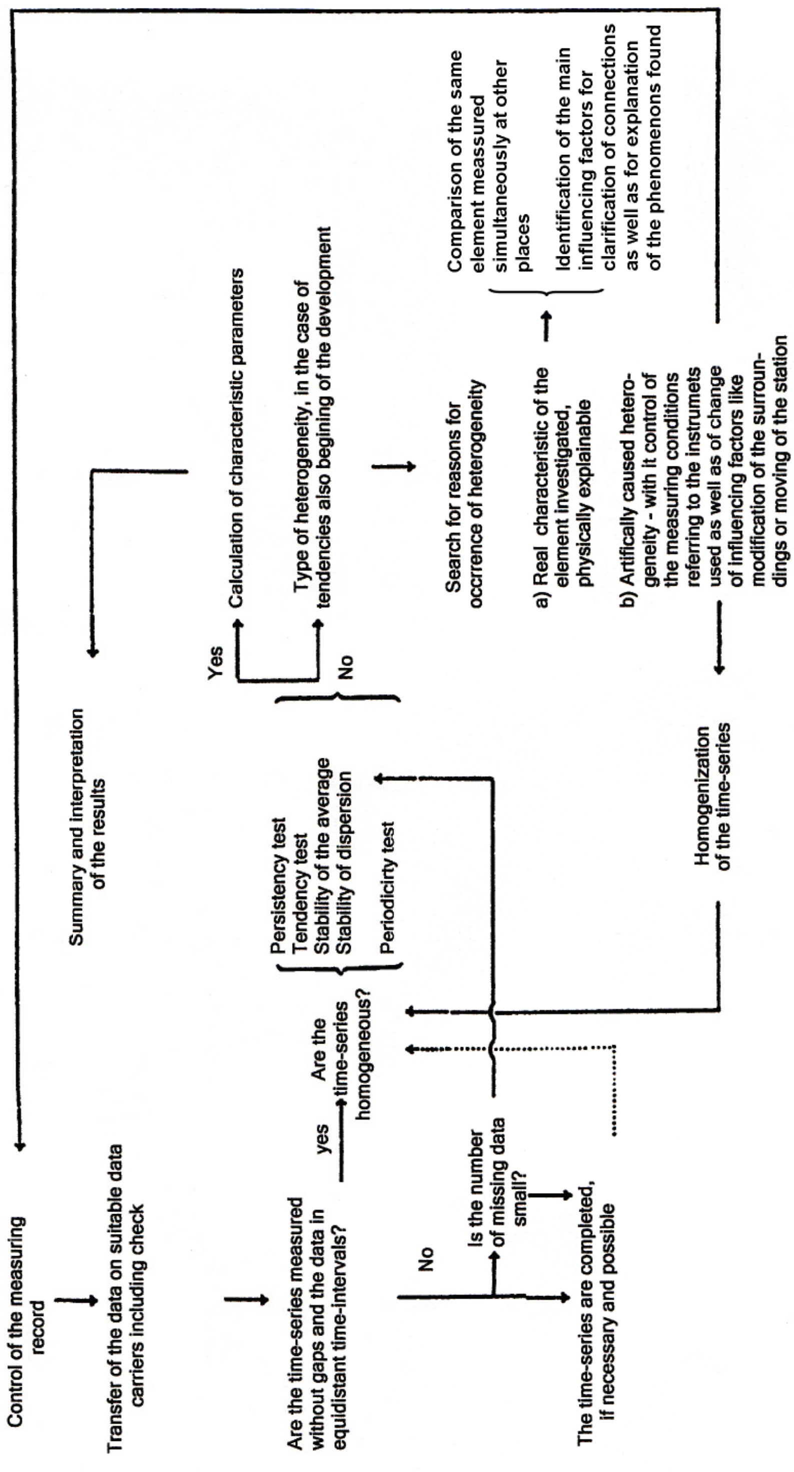

Fig. 2: Scheme of checking (Stellmacher 1982)

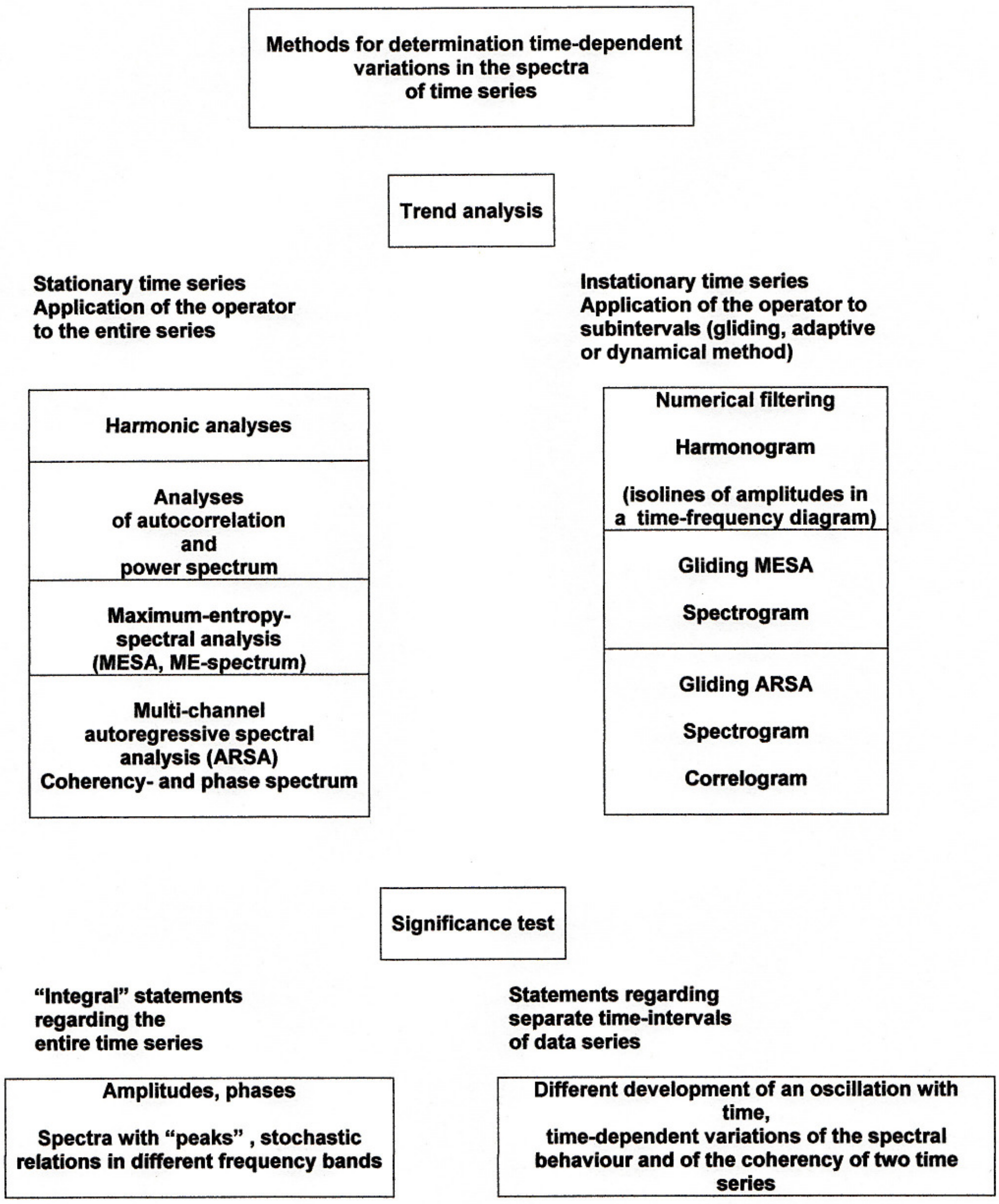

Fig. 3: Methods of time series analysis as an overview (after Olberg)

For the statistical assessment of time series having large spectral contributions near the Nyquist-frequency, a model spectrum is needed which deviates from the usual red or white model spectra. For this case a coloured model spectrum has been developed applicable to discrete data (Olberg 1989), which can be adjusted to an empirical spectrum by least-square fitting.

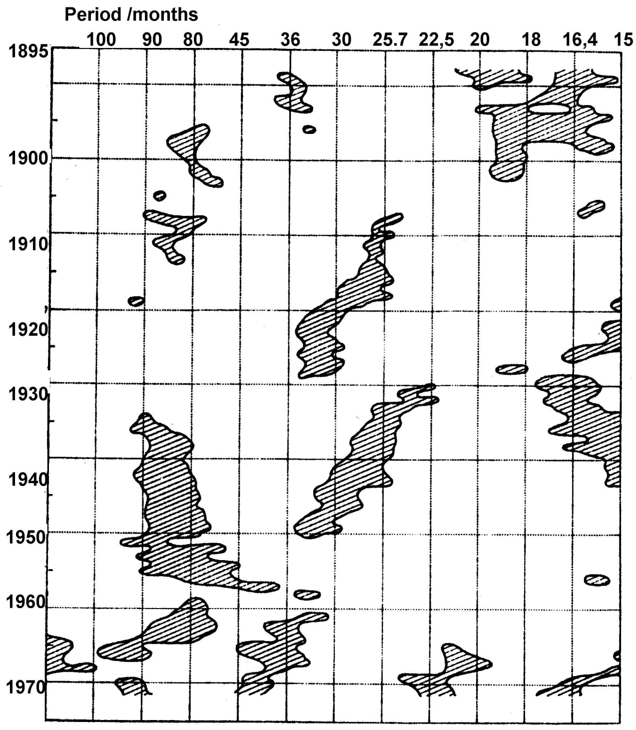

Fig. 4: Spectrogram of the meridional circulation after Hess/Brezowsky (Olberg and v. Schönermark 1981)

Gerstengarbe and Werner (1987a, b; 1989a, b, c; 1990) have presented methodical contributions especially with regard to the statistics of extreme values, to the validity of normal periods in climatology and to the time variability of climate characteristics in the spatial meso-scale. It has been shown, that the classical methods of extreme-value statistics frequently used in climatology to predict the probability of occurrence of extreme events are not adequate for the solution of climatological problems. An improved methodology has been developed. Normal periods have also to be considered critically, since the choice of any reference period may lead to a wrong interpretation because of a scale incompatibility.

Further, A. Lehmann carried out investigations into the empirical determination of persistence characteristics and into their modelling for stationary conditions. This work was done in co-operation with the Geophysical Main Observatory in Leningrad (now St. Petersburg).

Problems of climate definition, the role of climate diagnostics in the framework of climate research as well as the proof of climate changes have been discussed by Bernhardt (1987, 1990). By this he summarized results of climate research at the Meteorological Institute of the Humboldt University of Berlin, which were directed primarily on the application of modern methods of multi-dimensional statistics and spectral analyses of time series, for instance factor analysis/natural orthogonal functions or sliding maximum-entropy spectral estimations).

J. Taubenheim, besides his above-mentioned monograph (Taubenheim 1969b) and a contribution to correlation techniques (Taubenheim 1958a, b), has published a number of further papers on statistical treatment of time series. The topics were on the influence of autocorrelation (persistency) on sample estimates, correlation and test procedures

(Taubenheim 1969a, 1974a, b), on the detection of discontinuities in time series (Taubenheim 1989) and on the determination of statistical characteristics by auto-synchronization (Taubenheim and Feister 1975) .

Paths to the climate impact research

In awareness of a coming anthropogenic climate change, regional climate diagnostic investigations have been increasingly carried out in view of the preparation of the analysis of consequences of the climate variations during the 20th century and in future (see Chmielewsky and Hupfer, in this volume).

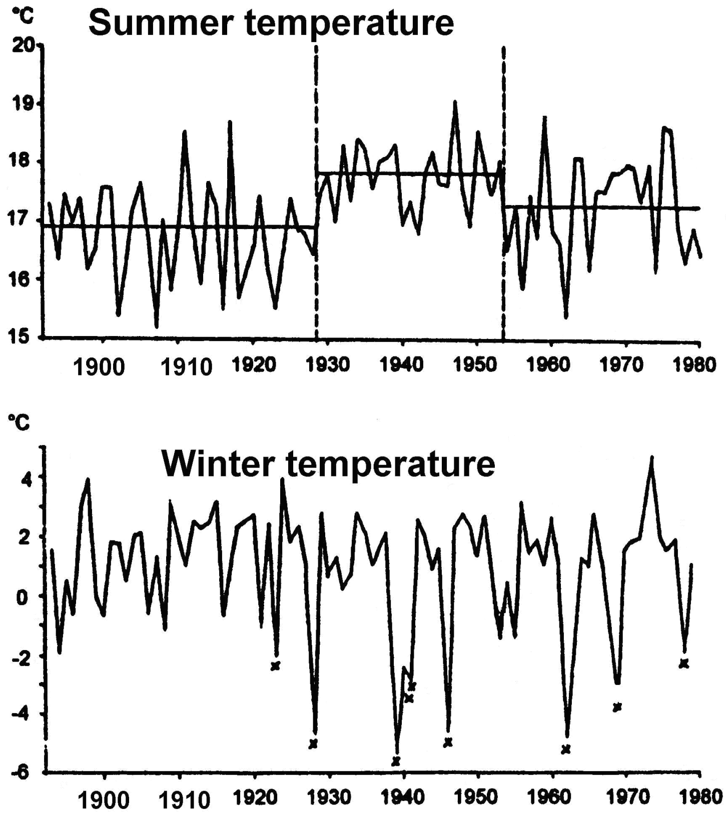

Fig. 5: Mean air temperatures in summer (not smoothed) with averages for individual intervals (above) and winter temperatures (not smoothed) for Potsdam (Kleber 1986). x = severe winter

Under processing and careful examination of 70- to 90-yearly time series of daily values of surface air temperature, rainfall, amount of clouds, wind speed as well as the snow cover conditions at the meteorological stations Schwerin, Potsdam, Halle, Jena and Wahnsdorf (near Dresden), G. Helbig (1991) has reported on the results of his investigations into regional climate dynamics. This work was based on findings (Kleber 1986) which for the first time had studied the recent regional climate variations in a more complex way, not only on the base of averages of the conventional climate elements. Starting with the long-term course of the annual variations of surface air temperature, three 25- to 35- yearly periods each could be delimited from each other. Between these time intervals, there are statistically significant differences regarding the climate parameters used.

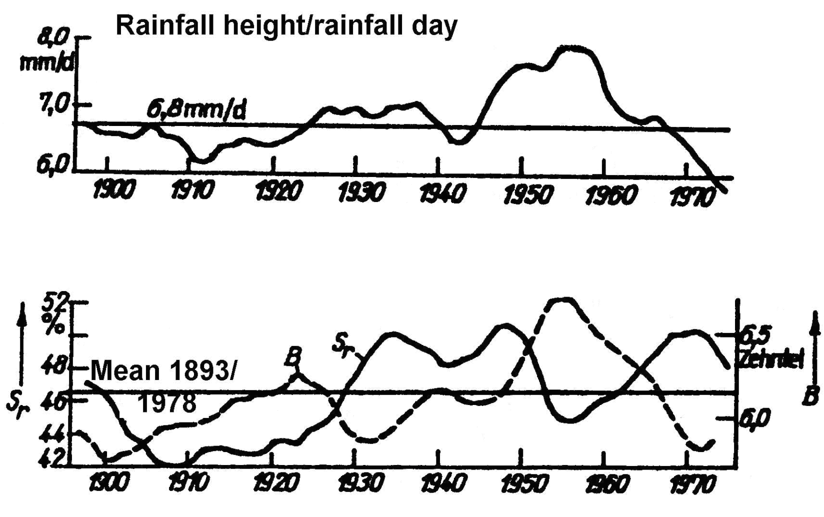

Fig. 6: Mean height of precipitation/precipitation day (≥ 1 mm), relative sunshine duration (——) as well as amount of clouds (----) (below) in summer in Potsdam. The curves are 11-yearly weighted smoothed. (Kleber 1986)

The time intervals can be characterized as maritime (up to 1928), continental (up to 1954) and mixed (after 1954), respectively. In the area under investigation the secular warming proved for the entire Northern Hemisphere (cf. Hupfer and Tinz 2006) lasted up the end of the 1940s, with the strongest temperature increase in spring and summer. The annual temperatures show an increase of about 1 K (statistically significant). There are clearly defined differences in the development of the climate characteristics in winter and summer. In the long-term course of the summer temperatures distinct level shifts ("jump-like") have been recognized, timely coinciding with the transition to another climate period as mentioned above (Fig. 5). The summer temperatures fluctuated around the mean values of the respective period. The interannual temperature variability is significantly higher in the period of cool summers at the beginning of the century. The warm summers during the continental time interval (1929-1954) are characterized by a great number of summer days and hot days resp. (by about 30 %), a low frequency of rainfall as well as a greater daily variation of air temperature. The winter temperatures showed fluctuations around the relatively constant mean value during the entire period under consideration. Strong negative anomalies of winter temperatures are to be seen in connection with a more frequent occurrence of severe winters happening in certain time intervals. But the winters with "normal" temperatures have been distinctly milder (see also Fig. 6). The investigated variations correspond to the climate changes in the European area known from literature. Fig. 7 shows the transition of the "Little Ice Age" to the present warm period on the basis of decadal means of the cold sums in Berlin.

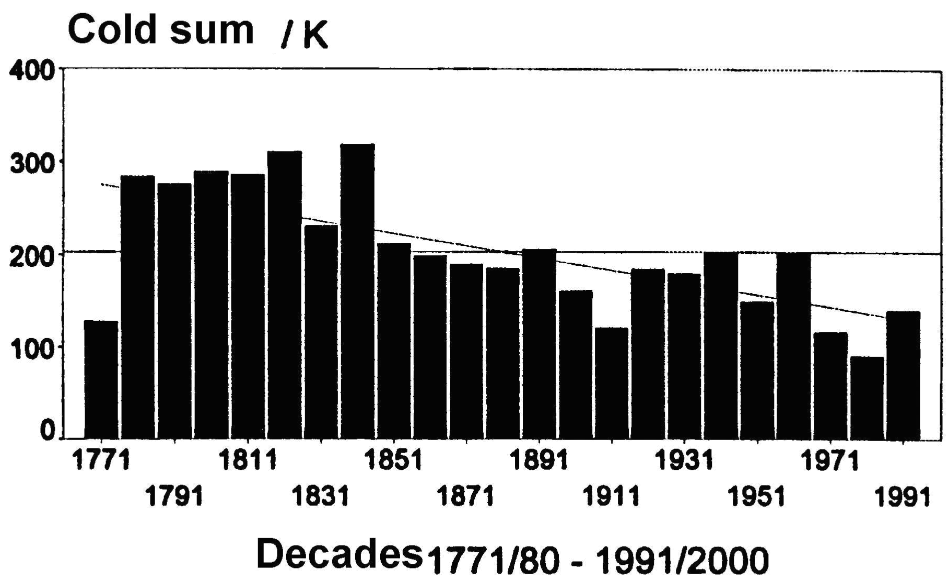

Fig. 7: Decadal cold sums for Berlin. Indrawn is the linear trend and the position of the average

Analyses of frost endangering, especially in the case of barfrost, of snow conditions, of data characterizing the vegetation period, of heat sums, of precipitation sums as well as of the detailed course of extreme summers and winters, resp., gave good insights into the nature of climate variations in Eastern Germany (Fig. 5 and 6).

Anthropogenic climate influence existed in the GDR especially by the development of urban climates characterized by a significant warming and by modifications of most climate elements (Helbig 1987, Hupfer and Chmielewski 1990). Rather drastic anomalies could be observed near large industrial plants (Mahrenholz 1986).

The investigation of some agroclimatically important properties revealed on the annual and monthly scale a strong correlation with the corresponding courses of the main climate elements. Especially the potential evaporation after Trc/Ivanov as well as the climatic water balance, this is the difference between precipitation and potential evaporation, show considerable variations. The changes are different in the individual months (Hupfer and Korzynietz 1990).

Gerstengarbe and Werner (1987) attended to the analysis of the temporal and spatial structure of extreme events, which are of special importance for the climate impact research. Extremes are a significant indicator of climate variations, because in the case of a climate change the frequency of extreme, spatially large-scale weather anomalies show an increasing tendency. This is possible also with opposite signs of the anomalies in far apart situated areas.

A methodology to define extreme events has been developed on statistical basis. It could be shown, that the frequency of the occurrence of such events for the region Central Europe was strongly coupled with those hemispheric averaged meteorological elements describing the behaviour of the extreme events (Fig. 8). In individual cases the occurrence of an extreme event can be definitely inverse to the mean course.

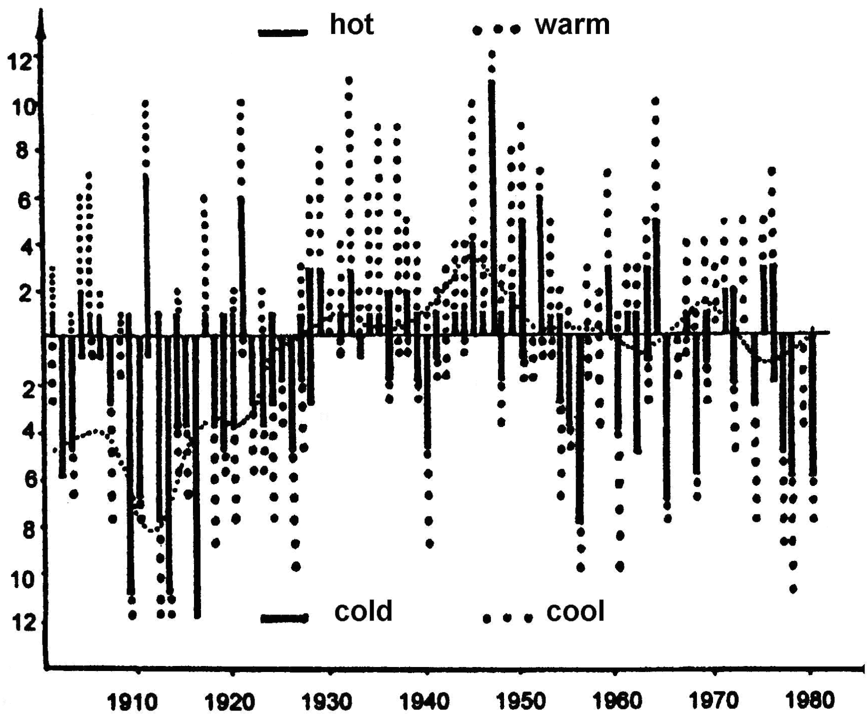

Fig. 8: Number of European stations with hot or warm as well as cold or cool summers compared with the smoothed course of the hemispheric annual mean value (points, no scaling) (Gerstengarbe and Werner 1987)

Trends in the middle atmosphere

Global atmospheric dynamics, constituting the climate system, extends with height beyond the tropopause into the strato- and mesosphere. In this region, named the Middle Atmosphere, the lower fringe of the ionosphere is reached, where a fraction of the atmospheric gas is ionized by the high-energy part of the Sun‘s radiation spectrum, and consequently, space and time variations in structure and dynamics of the air affect the properties of the atmosphere as an electromagnetic medium. This can be detected and monitored by means of observations of the propagation of ‘radio-frequency‘waves, emitted from technical sources (e.g., radio stations), or from natural sources (e.g. the ‘atmospherics‘ produced by lightning discharges). Such observations can be carried out at ground-based stations in a continuous mode, not dependent on rocket and/or balloon launching schedules. Approaches in this direction were developed already soon after the end of World War II by research groups of the GDR Meteorological Service (Observatory of Ionosphere Research at Kühlungsborn at the Baltic Sea coast) and of the Heinrich Hertz Institute of the GDR Academy of Sciences. In 1968, these two groups were integrated in the Central Institute of Solar-Terrestrial Physics (in 1984 renamed into Heinrich Hertz Institute of Atmosphere Research and Geomagnetism) of the Academy of Sciences.

The basic technique applied for monitoring the ionized upper mesosphere made use of radio waves in the frequency range around 200 kHz, which are transmitted from commercial radio broadcasting stations over distances of several hundred kms. In this case, the reflection height of the waves is between about 70 and 95 km, to be measured by comparing the phase of the reflected wave with that of the ground-propagated wave. The observed variations of the reflection height can be interpreted in terms of variations of the height profile of electron density vs. isobaric levels (Lauter 1974, Entzian et al. 1976, Lauter et al. 1984). The validity of this method of evaluation was confirmed by comparison with rocket measurements of electron densities (von Cossart et al. 1986). Beginning with the International Geophysical Year (IGY) 1957/58, the observations were complemented by a spaced-receiver configuration, which allowed the determination of speed and direction of the wind-driven movement of the electron density inhomogeneities at the reflection level (Sprenger and Schminder 1967, Sprenger and Lysenko 1972), thus revealing the characteristics of the wind field in the upper mesosphere and lower thermosphere. This method was then adopted and further improved by the Geophysical Observatory of the Leipzig University (a comprehensive survey of results has been given by Schminder 1995).

The results of the continuous observational programmes were regularly published in Data Bulletins (generally monthly) and forwarded to the international Geophysical Data Centers installed and continued since the IGY. The data also provided the base of contributions to further subsequent international cooperation programmes, in particular, the international Middle Atmosphere Program (MAP) which was inaugurated in the 1980s by the ICSU Scientific Committee of Solar-Terrestrial Physics (see, e.g. Taubenheim 1984). As the measuring techniques and schedules were continuously sustained over more than 30 years, and were partly taken over and carried on by successor institutions after 1990, they are a highly valuable data source for the study of climate shifts, as the length of these data series allows their clear distinction from other long-period influences (e.g., quasi 11-year solar activity cycle, El-Nino oscillation etc.).

In particular, the following two aspects of recent climate change in the height region of the middle atmosphere could be established:

(1) Advance of the ‘spring changeover‘date (Entzian and Lauter 1982, Entzian et al. 1984). A prominent feature of the dynamics of the middle atmosphere is the strong eastward zonal wind which over the Northern winter hemisphere forms a circumpolar cyclonic vortex spanning both stratosphere and mesosphere. Though temporarily disturbed by Stratwarm effects, this vortex usually re-stabilizes, until it breaks down in spring with the final stratospheric warming, and reverses into westward direction. The calendar date of this changeover can be well identified each year from the records of meteorological rocket and balloon networks. In the ionized region of the upper mesosphere, the transition from winter to summer conditions is characterized by the electron density passing through a well-pronounced minimum at a distinct calendar date. In Fig. **9**, the date of the final stratospheric wind reversal at the 30 hPa level (dots, full lines), derived from mid-latitude rocket and balloon data, is plotted together with the date of upper mesospheric ionization minimum (open circles, broken lines), observed at Kühlungsborn, for each year of the period 1958-1982. Although the correlation between both series is not very close in detail, their general trend (indicated by a straight line) clearly suggests that the date of spring changeover in the middle atmosphere has advanced by about half a month over the 25-year period of observations.

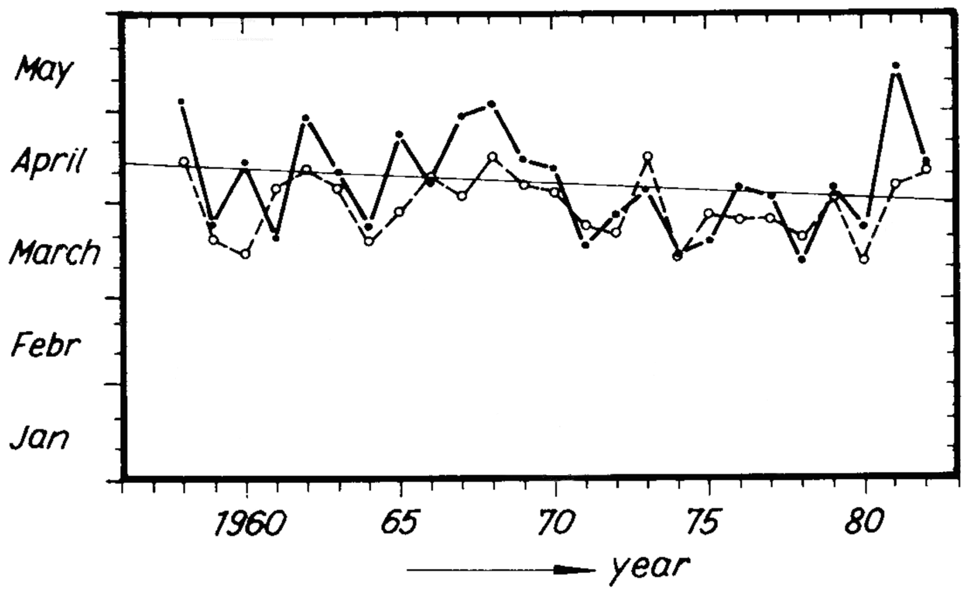

Fig. 9: Date of zonal wind reversal at the 30 hPa level (full dots) and date of ionization minimum in the lower ionosphere (open circles) (Entzian et al. 1984)

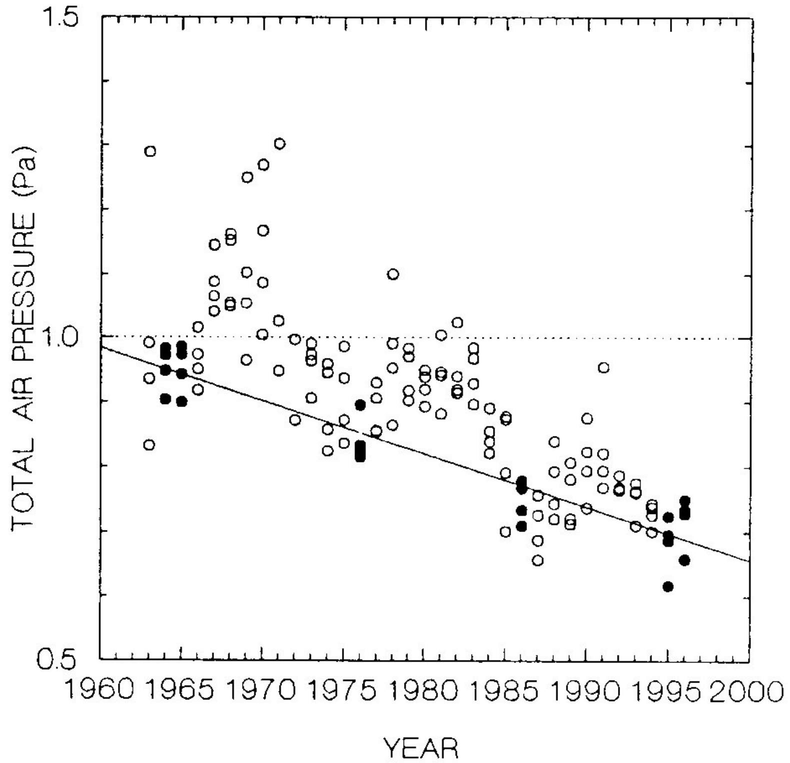

Fig. 10: Monthly mean summer (MJJA) values of air pressure at 81.8 km height over Central Europe, 1963-1995 (Taubenheim et al. 1997)

(2) Steady temperature decrease of the mesosphere since 1963 (Taubenheim et al. 1990, 1997). As already pointed out above, variations of radio wave reflection heights at the lower fringe of the ionosphere can be evaluated in terms of air pressure variations (see, e.g., Taubenheim and von Cossart 1987). From a time-series of daily reflection height data, started in 1963 at Kühlungsborn and continued till 1995, monthly mean values of air pressure at the altitude of 81.8 km were derived for the summer months May, June, July and August. These are presented in Fig. 10. As expected, this exhibits an 11-year variation which obviously results from the interplay between the solar-cycle variation of the incoming ionizing radiation with the decadal variation of mesospheric temperature already well known from rocket data (von Cossart and Taubenheim 1987). In order to separate this from a long-term climatic change of interest here, however, those months in which the sun was completely free of sunspots, such that the incoming ionizing radiation flux can be regarded to be at its (constant) minimum level, are marked by filled dots. Now, the straight line drawn through these points can be assumed to represent a pure long-term climate change, which can be attributed to a steady temperature decrease of the atmosphere between 50 and 80 km at a linear rate of –0.6 °K per year.

Anthropogenic climate modification

Bernhardt and Kortüm, (1976) have published an extended survey on the impact of human activities on the atmosphere based on more than 230 references in German, English, and Russian languages and following a lecture given at a conference held in Potsdam, 1973 by the Meteorological Society of GDR. Intended as well as inadvertent human influences on Earth's surface properties, on atmospheric matter and energy balances from local to global scales were considered by the authors (see Figs. 11 and 12).

Problems of climate changes and their effects on the mankind-environment interaction were discussed (Bernhardt 1978, 1981, e. g.) in a scope from solar-terrestrial and upper atmospheric physics (Bernhardt and Lauter 1977) to climate and climate changes in Atlantic-European maritime and continental regions (Bernhardt, Hupfer and Lauter 1986; Hupfer 1988). Special attention was paid to the urban climate and to the climate of industrial agglomerations (Helbig 1987, 1988) taking into account mainly the temperature, but also the precipitation regime (Graf 1982).

Worldwide studies on the climatic implications of a nuclear war ("nuclear winter") were noted and discussed in the GDR with great attention causing the Meteorological Society of GDR to publish a statement (Z. Meteor. 1984: 34, p. 65) similar to a preceding statement published by the American Meteorological Society (Bull. Amer. Meteor. Soc. 1983: 64, p. 302).

Further reference relating to mankind-atmospheric environment relationships can be made to Hupfer et al. (1991), chapter 6.

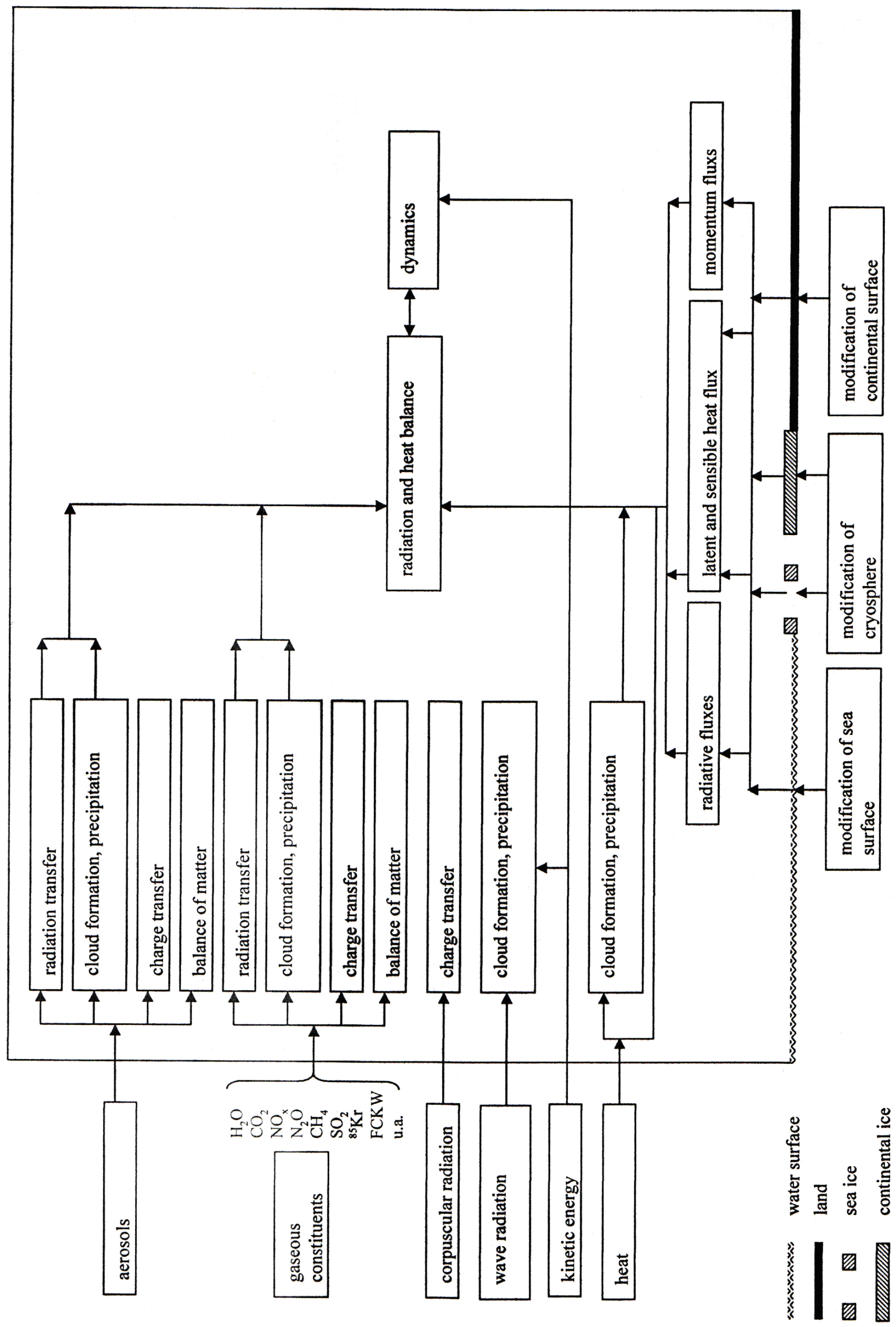

Fig. 11: Schematic diagram of anthropogenic impacts on the climatic system, (changed and supplemented by Bernhardt and Kortüm 1976)

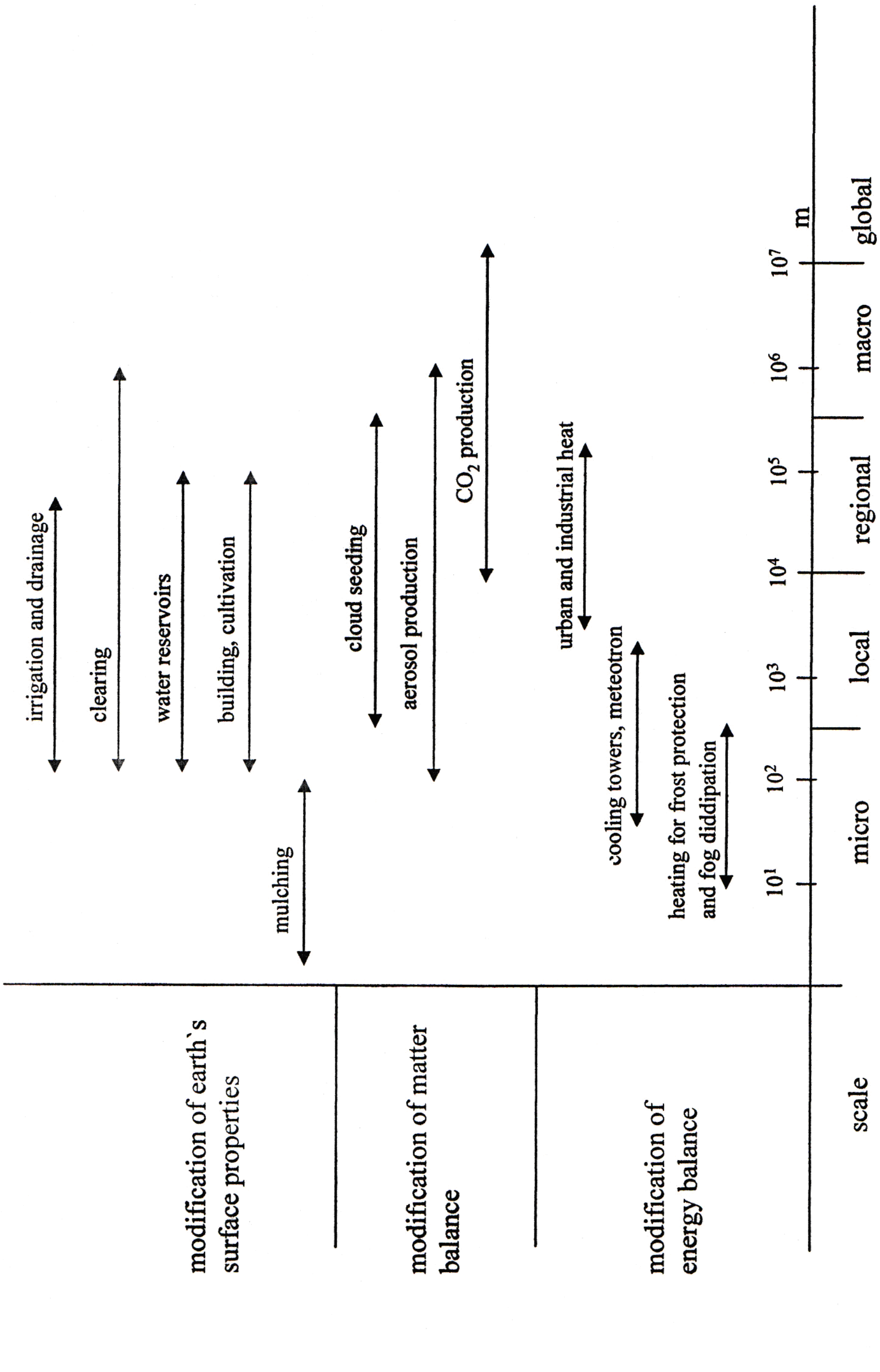

Fig.12: Characteristic scales of selected anthropogenic impacts on the climate system (slightly changed by Bernhardt and Kortüm, 1976)

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Marine Climatic Variations of the Baltic Sea

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Air-sea interactions are the main cause of variations in oceanographic parameters of seas in time scales ranging from years to centuries. On decadal time scales, variations in atmospheric circulation over the northern Atlantic Ocean and Europe govern fluctuations in the water exchange between the North Sea and the Baltic. The Baltic Sea is sensitive to climatic changes in the Atlantic-European sector and reacts relatively quickly by considerable variations in basic oceanographic properties like water temperature, salinity and oxygen content, in particular in the central Baltic deep water (e.g. Hupfer 1962, 1975, Matthäus 1984). The inflow of highly saline water into the Baltic Sea, especially the occurrence or absence of major Baltic inflows (MBIs) (Börngen et al. 1990, Matthäus & Franck 1992, Matthäus 2006), is closely connected with variations in the atmospheric circulation.

The Institute of Marine Research (IMR) of the Academy of Sciences (1958 – 1991) and its preceding marine institutions in Warnemünde (the Baltic Sea Observatory, 1952 – 1957; the Hydro-Meteorological Institute, 1957 – 1958; both institutions belonging to the Marine Hydrographic Service) dealt with marine climatic variations since the 1950s. The investigations based on data measured and compiled by the Warnemünde institutions and annual assessments of the Baltic Sea environment published by the IMR since 1969. Moreover, data sets of both the observations of light vessels in the transition area between the North Sea and the Baltic and the measurements compiled in the frame of the International Council for the Exploration of the Sea (ICES, since 1902) and the Helsinki-Commission (HELCOM, since 1979) were included in the investigations.

In the 1950s, investigations on long-term variations of oceanographic parameters of the Baltic Sea like water temperature, salinity and oxygen content started. Using ship-borne observation data measured since the late 19th century, a characterization of the long-term variations of these parameters including mean trend calculations were carried out at 10 stations of six deep basins of the Baltic proper (Matthäus 1978, 1979, 1983c, Nehring & Matthäus 1991). Moreover, long-term trends of the in-situ-density (Matthäus 1983a), of the variability of the Baltic primary halocline (Matthäus 1980) and of the vertical stability of the thermohaline stratification in the Gotland Deep (Matthäus 1983b) were analysed based on the same data set. The causes of the most significant and serious stagnation period from 1977 to 1992 observed so far in the deep water of the eastern Gotland Basin were of special interest (Matthäus 1987b, 1990).

Up to the mid-1970s, a regional different mean increase in temperature and salinity of the deep water and a decrease in oxygen content have been observed (cf. Figs. 1 and 2). These secular trends were superimposed by variations of shorter periods. From the 1950s to the early 1990s a significant decrease in temperature and salinity could mainly be analysed in the eastern Gotland Basin (cf. Fig. 1) but - compared with the total trend - a faster mean decrease in oxygen content was observed (Matthäus 1979, 1983c). Between 1900 and 1980, the primary halocline of the Gotland Deep was lifted by 5 – 6 m, on average, and the isohalines were lifted by 11 m (9 PSU; PSU = Practical Salinity Unit ≈ ‰) and 52 m (12 PSU) (Matthäus 1980)

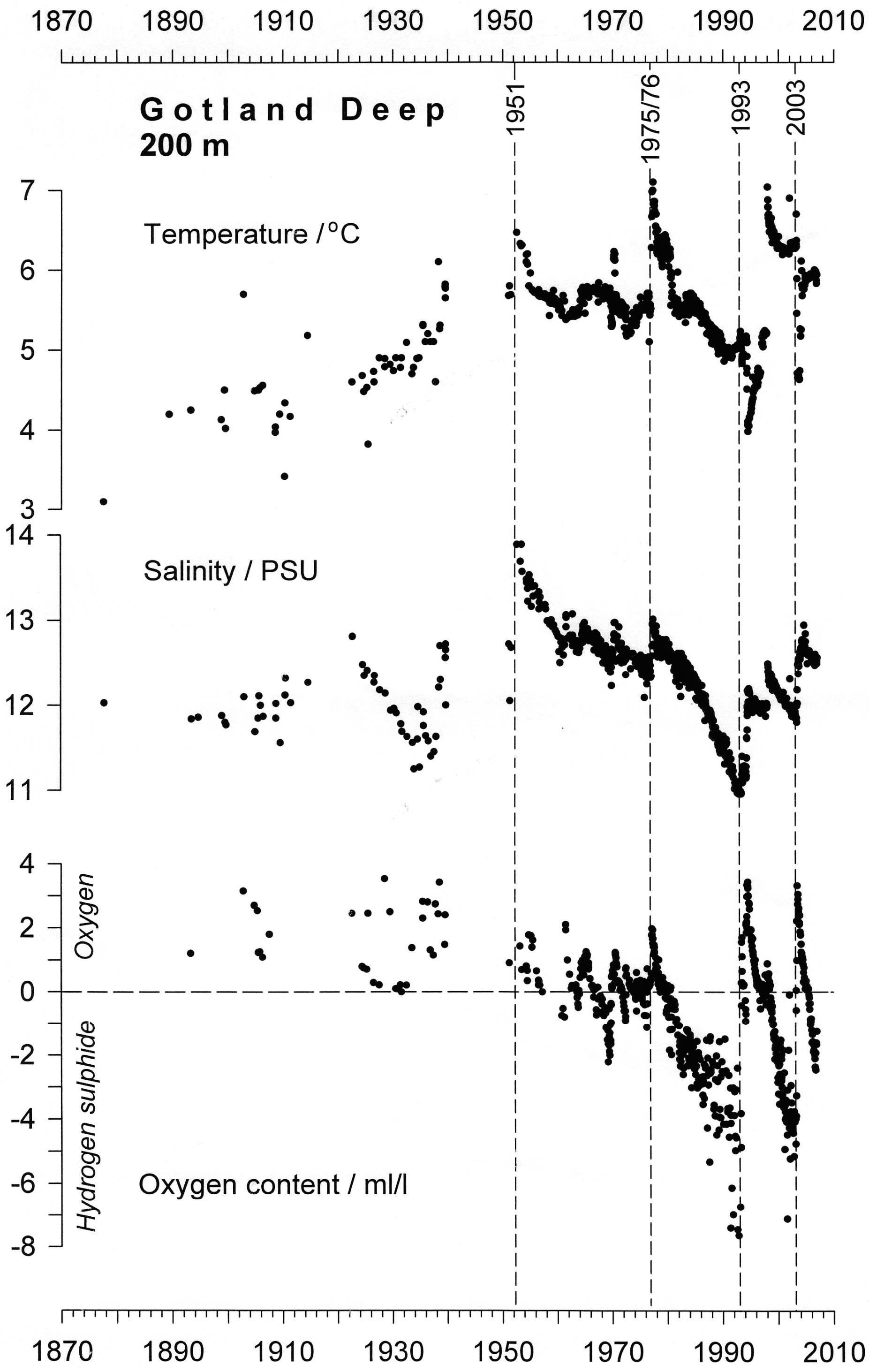

Fig. 1: Long-term variations of water temperature, salinity, oxygen and hydrogen sulphide concentrations in the deep water of the eastern Gotland Basin (Gotland Deep). Selected effective MBIs are marked by hatched lines. Hydrogen sulphide converted into negative oxygen equivalents

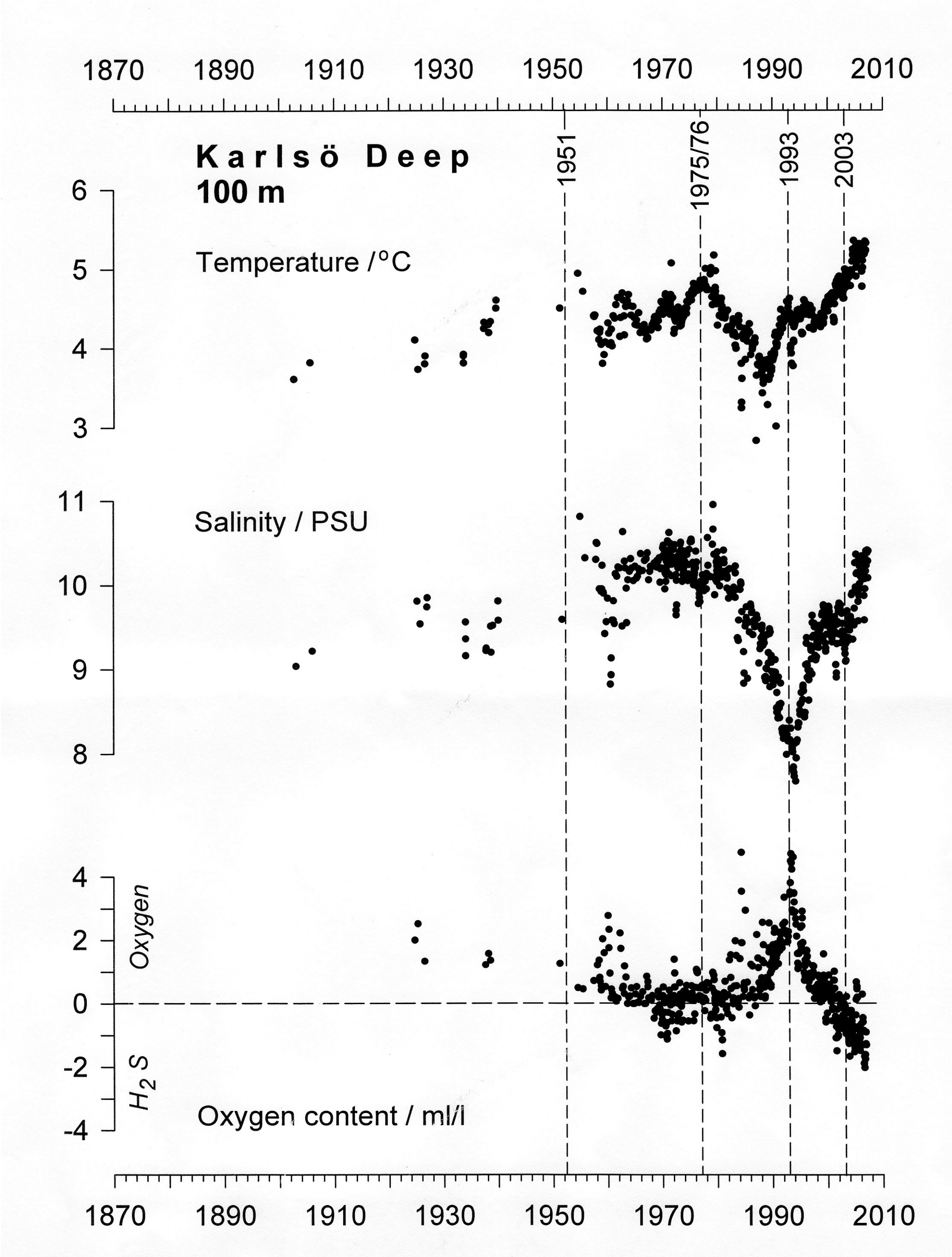

Fig. 2: Long-term variations of water temperature, salinity, oxygen and hydrogen sulphide concentrations in the deep water of the western Gotland Basin (Karlsö Deep). Selected effective MBIs are marked by hatched lines. Hydrogen sulphide converted into negative oxygen equivalents

For the same period, a significant decrease in stability of stratification was analysed in the 100 – 150 m layer of the Gotland Deep (Matthäus 1983b).

During the last three decades of the 20th century, the conditions in the central Baltic deep water changed drastically (Matthäus 1987b, 1990). During the late 19th and the first three quarters of the 20th century, major inflows renewed the deep water more or less regularly (cf. Fig. 3) and salinity and oxygen concentration increased temporarily (Figs. 1 and 2). Stagnation periods of several years occurred between the MBIs and both salinity and oxygen content decreased and the formation of considerable concentrations of hydrogen sulphide was observed.

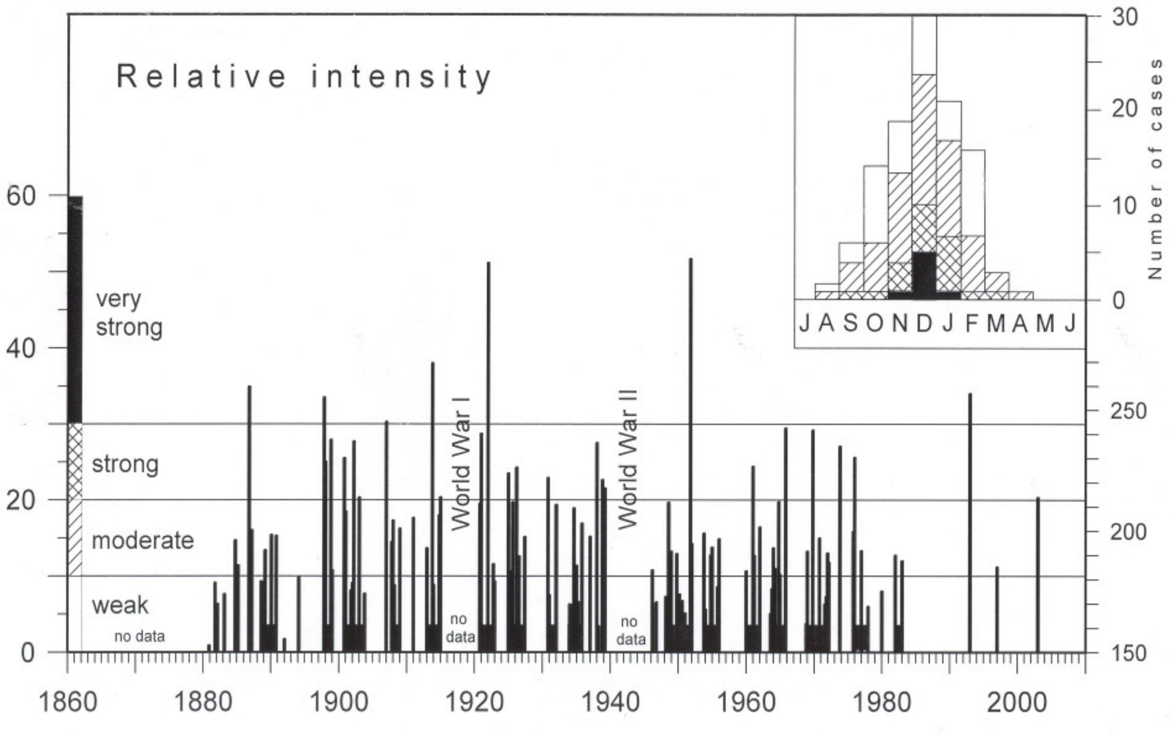

Fig. 3: Major Baltic inflows between 1880 and 2007 (1897 – 1976 analysed by Matthäus & Franck 1992) and their seasonal distribution (upper right) shown in terms of their relative intensity. Intensities were re-assessed (Fischer & Matthäus 1996) and the time series supplemented and updated (Matthäus 2006). Black boxes at the time axis: MBIs arranged in clusters

In the mid-1970s, a serious stagnation period started and lasted about 16 years in the eastern Gotland Basin. This stagnation was longer than each stagnation interval observed during the 20th century. A considerable decrease in temperature and salinity was recorded in the deep water of the entire central Baltic (cf. Figs. 1 and 2) and a drastic decrease in oxygen concentration was observed in the eastern central basin (cf. Figs. 1 and 2). The period started with the highest temperatures (7.4 ºC) and led to the formation of the highest concentrations of hydrogen sulphide ever measured at near-bottom levels of the Gotland Deep (cf. Fig. 1). The salinity and density values observed at the end of the period were the lowest on record. The stagnation period led to a mean decrease of about 2 ºC in temperature, 2 PSU in salinity and 9.5 ml/l in oxygen concentration (and a corresponding increase in H_2S concentration) at the 200 m level of the Gotland Deep. Compared to that, the oxygen concentration in the deep and bottom layers of the western Gotland Basin increased during the stagnation period (cf.

Fig. 2). This was probably due to the increasing advection of oxygenated water passing the stagnating deep water of the eastern Gotland Basin immediately below the halocline. On the other hand, decreasing density and stability of stratification in the western Gotland Basin favoured vertical mixing.

The IMR Warnemünde has performed the monitoring studies – including investigations in marine climatic variations – in the frame of the HELCOM. The institute took an active part in the international „Assessments of the State of the Marine Environment of the Baltic Sea" produced by HELCOM every five years (HELCOM 1981, 1986, 1990). Moreover, the IMR participated in joint Baltic research programmes since the 1960s like the Cooperative Synoptic Investigation of the Baltic in August 1964 (Matthäus 1987a), the International Baltic Year (IBY) 1969/1970 (Anonymous 1968), the Baltic Open Sea Experiment (BOSEX-77) in September 1977 (Kullenberg 1984) and the Patchiness Experiment (PEX-86) in April/May 1986 (Dybern & Hansen 1989). These studies and research programmes supplied further basic information on variations in marine climatic changes.

In the late 1950s, the IMR Warnemünde started investigations on MBIs. In the beginning, causes and effects of individual events were investigated. Schemainda (1957) studied the oceanographic variations in the Bornholm Basin after the very strong MBI in November/December 1951 based on observations of the German and Polish Fisheries Research Institutes.

Francke and Nehring (1971) investigated the meteorological and oceanographic conditions which generated the MBI in February 1969 (cf. also Nehring & Francke 1971). Later, Nehring and Francke (1973) studied the effects of the MBIs of February and October/November 1969 in the central Baltic deep water. The renewal process in the different basins is described by means of the variations in hydrographic (salinity, oxygen) and nutrient conditions (phosphate, nitrate, silicate). For the first time, the effect of a MBI in the central Baltic was studied in detail by a 5-day anchor station in the Gotland Deep in October 1969 (Nehring et al. 1971). During the turnover process, quick alternations between oxic and anoxic conditions accompanied by considerable variations in the concentrations of chemical parameters were observed within three hours.

In 1976, Francke et al. (1978) presented first information on the strong inflow event in 1975/1976. They reported on the current conditions at the permanent buoy station at the eastern slope of the Darss Sill, which was installed in 1973 by the IMR (Müller 1974, Francke 1982). Moreover, they informed on the variations in oceanographic conditions of the central Baltic between autumn 1975 and April 1976. The inflow covered a period of four months interrupted by outflow periods. Strong inflow was observed from the end of September 1975 and reached peak values in October and December 1975 and January 1976. A detailed description of the inflow event and its effects in the central Baltic deep water was given by Nehring and Francke (1978).

Using the same inflow event, Francke and Hupfer (1980) studied current, wind, sea level and salinity conditions in the Darss Sill area. Based on measurements at the permanent buoy station at the Darss Sill, they analysed the currents in the surface and bottom layers in December 1975 and January 1976. Lass and Schwabe (1990) examined the dynamics of the mass and salt transports resulting from this MBI. They found that the system Kattegat – Baltic Sea has a geostrophic controlled water exchange in the Belt Sea which linked the two sea areas. The advection of salt water through the Belt Sea occurs mainly in a river-like form without much exchange with water from the neighbouring bights.

Nehring and Francke (1980) reported on the increasing inflow activity in the second half of 1976 which culminated in November/December 1976 in a moderate MBI. This inflow process was traced by the IMR research vessel "Professor Albrecht Penck" and caused an exceptional increase in temperature in the central Baltic deep water reaching more than 7 ºC (cf. Fig. 1).

In the 1960s, Wolf (1972) started with statistical analysis of MBIs. Between 1950 and 1968, he identified 20 events by means of a quantitative definition of MBIs based on the duration of the inflow and the mean salinity of the inflowing water at the Darss Sill.

In the 1980s, detailed statistical analyses were carried out. During the 80-year period from 1897 to 1976, a total of 90 MBIs could be identified on the basis of specific salinity and stratification criteria at the Darss Sill (Franck et al. 1987, Matthäus & Franck 1992). The events were analysed with respect to various parameters. Based on the 90 identified cases the intensities, the properties of the inflowing water (temperature, salinity, density, oxygen content) and their seasonal variation (Matthäus & Franck 1988) were investigated. The sea level conditions associated with MBIs were studied in detail in each complete inflow process by using the sea level difference Kattegat/Baltic Sea and the Baltic sea level variations during selected relevant periods (Franck & Matthäus 1992). Later, the investigations were carried on (Matthäus 1995, Fischer & Matthäus 1996, Schinke & Matthäus 1998).

MBIs were recorded more or less regularly up to the mid-1970s (Fig. 3). Since that time, their frequency and intensity have decreased. The abiotic environmental conditions changed drastically culminating in the two most significant stagnation periods in the eastern Gotland Basin from 1977 – 1992 and from 1995 - 2002 ever observed in the Baltic Sea (cf. Fig. 1). During the last 20 years, only three MBIs were recorded (cf. Fig. 3).

Based on a total of 43 MBIs identified at the Darss Sill in the post-war period between 1945 and 1976, Matthäus and Franck (1989) studied the salinity conditions in the Kattegat deep water at four light vessels for the 30-day periods preceding the MBIs. They concluded that positive salinity anomalies in the Kattegat deep water are not a necessary precondition for MBIs. The anomalies ranged between –5 and +3 PSU in the central Kattegat and between –5 and +5.5 PSU in the southern Kattegat. Even strong inflows occurred after both positive and negative anomalies. This was supported by investigations carried out by Lass and Schwabe (1990). They found that the monthly means in bottom salinity of the Skagerrak and Kattegat had no significant positive anomalies during four months before the strong MBI 1975/1976 started.

A total of 113 major inflows had been identified between 1880 and 2007, excluding the two world wars, 90 of that between 1897 and 1976 (cf. Fig. 3). All MBIs have occurred between the end of August and the end of April. The seasonal frequency distribution (Fig. 3, top right corner) shows that such events are most frequent between October and February (90 %). MBIs have their maximum intensity and duration between November and January and are less common in August/September and in March/April. Major events have never been recorded between May and mid-August. MBIs usually occur in clusters (21 cases, distance between individual events <1 year), but some have been isolated events (11 cases). Most clusters had durations of several years the longest being recorded lasted from 1948 to 1952. The longest periods without MBIs before the late 1970s lasted for three years (1927/1930, 1956/1959), but ten years passed without a major event between February 1983 and January 1993 (cf. Fig. 3). Using a MBI classification according to their intensity into weak, moderate, strong and very strong (cf. Fig. 3), about 75 % of all events can be characterized as weak and moderate.

Inflow processes linked to major events start with a precursory period of 22 days followed by the main inflow period of 10 days, on average. During the precursory period, water with a relatively low salinity is transported back from the transition area into the Baltic Sea followed by the inflow of highly saline water (≥17 PSU). During the whole inflow process, the Baltic sea level increases by an average of 59 cm (i.e. 38 cm during the precursory period, 21 cm during the inflow period). The Baltic Sea level can vary between –60 cm and +65 cm. The volumes of highly saline water entering the Baltic Sea during MBIs are >100 km^3 during very strong events and <100 km^3 during weak events (Matthäus & Franck 1990).

Major Baltic inflows cause an increase in salinity and oxygen concentration of the central Baltic deep water below the permanent halocline. Temperature and oxygen concentration of the water penetrating during MBIs correspond to the seasonal values of these parameters in the near-surface water of the sill areas. Therefore, intensive events between August and early December generally raise the temperature in the Baltic deep water while inflows from January to April reduce it. A major improvement in the oxygen conditions of the central Baltic deep water can generally be expected by intensive events in the cold season between January and April.

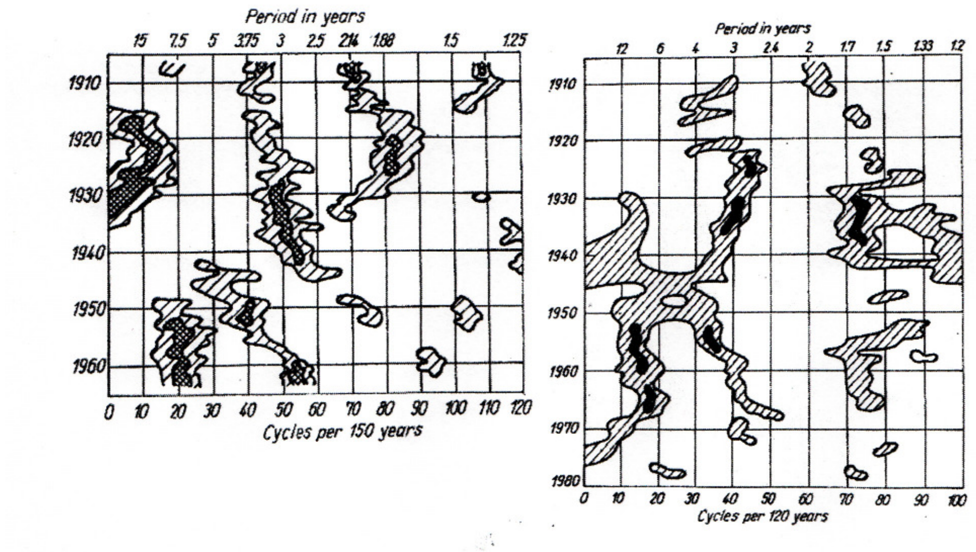

Fig. 4: Maximum-entropy spectrograms of time series of salinity at the 15 m level of l/v "Lappegrund" 1(left) and of meridional circulation over the North Atlantic (right) (hatched: significant areas) (Börngen et al. 1990).

The Geophysical Institute (Working Group Oceanology) of the Leipzig University and – since 1979 – the Department of Meteorology and Geophysics of the Humboldt-University Berlin dealt – among others – with marine climatic fluctuations of the Baltic Sea (Hupfer 1962, 1975) and meteorological and oceanographic time series in order to identify characteristic correlates with MBIs (Börngen 1978, 1983, Börngen et al. 1990). They found that the absence of MBIs since the mid-1970s could be attributed to variations in the meridional circulation over the North Atlantic, whereas the quasi-regular occurrence seems to be connected with the existence of a three-year oscillation of the meridional circulation.

Börngen (1978) estimated energy and coherence spectra of salinity at the 15 m level of the Danish light vessels "Lappegrund" and "Gedser Rev", meteorological (meridional circulation over the North Atlantic, zonal circulation over the Baltic) and oceanographic factors (Baltic sea level). Later he included further meteorological and oceanographic parameters and used the factor analysis and band-pass filtering (Börngen 1983). The analyses performed yielded evidence of a period of three years – especially since 1930 – in the 15 m level salinity, in the meridional (North Atlantic) and zonal circulation (Baltic) and in the sea level. These results are in fairly good agreement with the correlation found by Dickson (1971, 1973).

Börngen et al. (1990) analysed the long-time data sets used by Börngen (1978, 1983) by spectral correlation applying the Fourier Transformation. They found distinct relationships in the period range of about three years. They supposed that the occurrence and strength of MBIs seem to be determined by corresponding temporal variations in the meridional (North Atlantic) and zonal component (Baltic sea region) of the atmospheric circulation and of the Baltic sea level. That could be confirmed by the determination of the maximum-entropy spectrum for the salinity at the 15 m depth of the two l/v "Lappegrund" and "Gedser Rev" and the meridional circulation over the North Atlantic. A maximum-entropy spectral analysis was carried out in order to find out temporal changes of the spectral behaviour of the two time series (Fig. 4).

The river runoff to the Baltic Sea, one of the parameters influencing salinity, was subject to a detailed statistical analysis during the period 1921 – 1970. The results were discussed in connection with recent variations in climate and atmospheric circulation (Hupfer et al. 1984).

Finally, it could be shown that the water exchange dynamics and, consequently, the salinity conditions of the Darss-Zingst-Bodden chain – a landlocked coastal area in the southern Baltic Sea – react very sensitively to variations in atmospheric circulation (Hupfer 1992).

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Modelling of Atmospheric and Climate Processes

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Developments and main research lines

The modelling activities with respect to atmospheric dynamics and climate started in 1968 at the Central Institute for Solar-Terrestrial Physics of the Academy of Sciences of the GDR in Kühlungsborn under the leadership of G. Schmitz. In the research task "Physics of the high Atmosphere" these were driven by the interest of the director of the institute, E. A. Lauter (1920-1982) to understand the influence of dynamical processes of the lower and middle atmosphere on the ionosphere of the Earth. Since 1968 they had become part of the Interkosmos cooperation in Cosmical Meteorology. From 1974 until 1984 an experimental research direction "Ionospheric Laboratory" and a theoretical Laboratory "Physics of the Strato- and Mesosphere" existed in the institute part Kühlungsborn (Böhm et al. 1993).

Until 1984, the main research questions focused on the vertical propagation of planetary waves from the troposphere into the strato- and mesosphere and the interaction of these wave disturbances with the zonally averaged state. The interaction between tropo- and stratosphere was investigated through the analyses of hemispheric pressure maps, the computation of momentum and heat fluxes during stratospheric warmings, and the development of linear planetary wave propagation models. A further task was to study the dependence of the zonally averaged state on the momentum and heat fluxes and the diabatic heat source. This research delivered internationally accepted contributions to the structure and dynamics of the strato- and mesosphere.

In 1984, the institute was restructured as Heinrich Hertz Institute of Atmospheric Research and Geomagnetism (HHI), but the modelling activities remained at Kühlungsborn in the new section "Atmospheric Research". The cooperation with the meteorological service was extended and new research questions became important. These concerned the physical and chemical processes in the atmospheric boundary layer, with its strong influence on human life, the climate dynamics and climate variations as environmental factor, the outstanding ozone problematics and the development of acoustic and optical atmospheric remote sensing techniques.

From 1984, with the new orientation of the HHI a stronger focus on the environmental important lower atmospheric layers started. Following this topic, the modelling activities focused more on climate modelling of the tropo- and stratosphere. In this context cooperation with the Institutes of Atmospheric Physics and of Numerical Mathematics of the Academy of Sciences in Moscow was been developed.

As a result of insufficient computer resources a hierarchy of climate models from simple energy balance models over statistic-dynamical models to low-order models have been developed. At the end of the eighties the group started with the construction of a complex model for the long planetary waves of the atmosphere. The dynamical and physical blocks for a spectral model of large-scale anomalies of the atmosphere were developed. Further data

analyses of planetary wave activity in different winters were carried out and it was shown, that these depend on anomalies of the ocean sea surface temperatures.
Internationally accepted contributions to energy balance models were delivered (Dethloff & Peters 1982). A simple instability model of the middle atmosphere of the Venus was created as part of the indirect soundings of the Venus atmosphere with an infrared Fourier spectrometer (Dethloff 1988, Schäfer et al. 1990).

Selected results of the dynamics of large-scale atmospheric disturbances

The mean atmospheric circulation is determined by ultra-long waves excited by the land-sea distribution and the orography. The variability of these waves determines the atmospheric circulation variations and the climate variability on time scales of weeks. Forcing anomalies of external parameters and interactions with the baroclinic waves and the zonal mean averaged wind can excite these variations. The aim of the out work carried out was to determine the averaged zonal circulation and the stationary ultra-long waves in dependence on the external forcing and the mean impact of transient processes on the basis of a simplified complex climate model.

The main idea behind these time independent models was, to consider the circulation in the zonally-symmetric case as well as in the stationary wave case as driven by given forces, which have been computed based on observations. These models were extended into the stratosphere, to ensure the free energy propagation of the ultra-long waves from the troposphere. The yearly averaged zonal mean circulation of the tropo- and stratosphere was computed by Dethloff & Schmitz (1982). The momentum and heat fluxes were based on long-term observations, whereas the diabatic heating source was taken from other model studies. The model described the circulation in tropo- and stratosphere compared to observations and allowed to discuss especially the influence of the heat fluxes on the circulation cells. In the upper stratosphere transports by gravity waves become important, as they are not sufficiently covered by the model. In this context it was shown, that the parameterization of zonally averaged transports (Schmitz & Dethloff 1984) on the basis of potential vorticity transports is insufficient.

The standing waves have been described by a quasi-geostrophic model of the Northern Hemisphere (Schmitz & Grieger 1982, Grieger & Schmitz 1982). On the basis of this model the impact of the variability of zonal wind in the lower stratosphere on the amplitude and phase of ultra-long waves in the troposphere was investigated. Fluctuations in the phase of the waves around 15 degrees longitude occurred in the 500 hPa level which is consistent with observations.

This linear model was used to compute the ultra-long waves forced by the diabatic heat source, the orography and the transient fluxes. These fluxes were computed on the basis of the FGGE data set and spectrally separated between the baroclinic wave part and the long wave part (Schmitz et al. 1987, Dethloff et al. 1987).

Fig. 1 shows the importance of the mean impact of the transient fluxes compared to the other forcing factors. The model does not include a feedback with the transient processes, which of course limits the model results. In middle latitudes the interplay and coupling between external forcing anomalies and impacts with changes in the transient processes cannot be separated. The strength of this coupling has been investigated with analyses of the extended Eliassen-Palm fluxes, if the correlation of anomalies of sea surface temperatures determines the geopotential in the middle troposphere (Schmitz et al. 1989).

Further investigations were carried out for the coupling of ultra-long and baroclinic waves. The main idea was to investigate the dynamical feedback between ultra-long and baroclinic waves. For this purpose, a three layer model on a spherical Earth with 20 degrees of freedom was used, that includes orography and a diabatic heating with respect to a zonally-symmetric and long wave state. The interesting question was to detect multiple equilibria states, whose existence strongly depends on the heat source. There are no multiple equilibria states for a realistic heat source distribution. After the inclusion of an additional vorticity forcing multiple stationary states appeared which can be changed through feedbacks with baroclinic waves. Simple parameterizations of the mean impact of baroclinic waves are not sufficient to allow the transitions between these multiple states (Rinke et al. 1990). The atmospheric variability sensitively depends on the latitudinal structure determined by the heat source and is less sensitive with respect to longitudinal temperature disturbances. This aspect may be important for the development of blocking situations (Dethloff & Schmitz, 1992).

Research under new conditions

Parts of the research programme have been continued and extended under new conditions in the Leibniz Institute of Atmospheric Physics Kühlungsborn at the University Rostock (www.iap-kborn.de) and in the Research Unit Potsdam of the Alfred Wegener Institute for Polar- and Marine Research (www.awi.de).

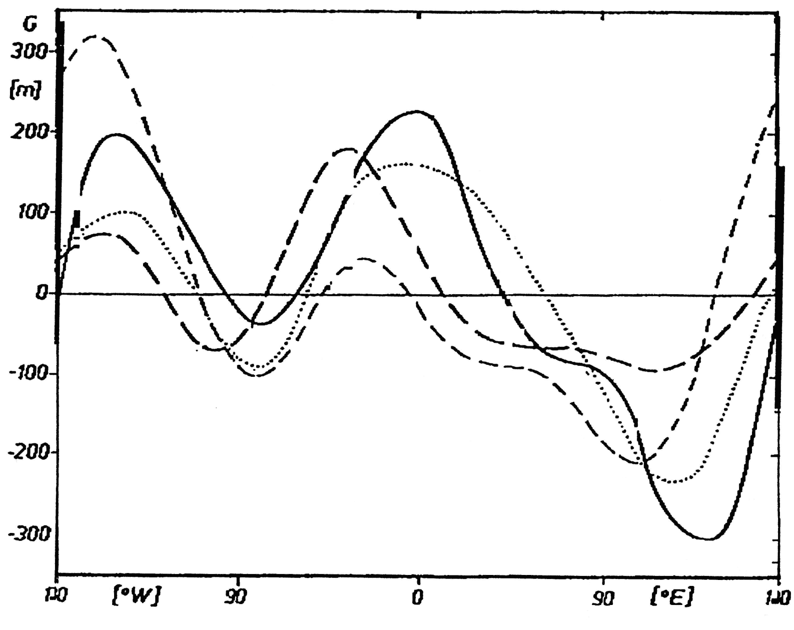

Fig. 1: Comparison of the zonally averaged geopotential anomalies at 60° N at the 200 hPa level. (…) results from a linear quasi-geostrophic model externally forced with orographically induced vertical motions (---), diabatic heating source (---) and mean transient vorticity fluxes.

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Climate Modelling in Martialic Contexts

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The circumstances under which climate research in the German Democratic Republic (GDR) became interested in, and familiar with, global three-dimensional climate modelling are coincidental. The are borne both in a chance encounter within a framework of cooperation between the Academies of Sciences (AS) of the GDR and the USSR in controlled nuclear fusion research (CTFR), and in the fact that the modelling challenges in CTFR and climate research are not too dissimilar. Among the hosting institutes were the Central Institute for Electron Physics of the GDR AS (ZIE, Berlin) and the Computing Center of the USSR AS (CCAS, Moscow).

In tradition of the *Vernadskij* school of environmentalist's thinking in the USSR, there was also a model system GEA developed since the mid-1970s at the CCAS in order to foster understanding of man's interaction with the environment (Moiseev et al., 1985). As a central brick to GEA, a physically reasonably detailed and spatiotemporally sufficiently resolved General Circulation Model (GCM) was needed which was effective enough to be run under the conditions of limited computational resources. Supported by the Oregon State University (OSU), the two-layer tropospheric GCM of the RAND Corporation (Gates et al., 1971) was adapted to coarse horizontal resolution (Aleksandrov & Gates, 1981). When coupled with a local (one•dimensional; 1D) thermodynamic model of the upper oceanic mixed layer (Reznyanskij & Trosnikov, 1980), matched this the envisaged purpose and became known then as "CCAS model". The GCM is a version of the renounced *Mintz•Arakawa* model (Arakawa et al., 1968) of the University of California at Los Angeles (UCLA), spread over the world to seed a number of climate model families in effect (Edwards, 2000).

Customary model climate evaluations and sensitivity studies within the GEA context (Aleksandrov et al., 1983; Aleksandrov & Stenchikov, 1985; e.g.) became interfered with an unexpected application of this coupled atmosphere-ocean model: studies on *nuclear winter*, the anticipated severe climatic disturbance following nuclear war (Aleksandrov & Stenchikov, 1983). This 'baptism of fire' to the CCAS model was meant as a contribution to the Washington conference "The world after nuclear war" (October 31 and November 1, 1983; Ehrlich et al., 1984) and turned out to be one of the two early three•dimensional (3D) studies on the climatic effects of massive atmospheric smoke loads due to the large fires after a nuclear exchange (Thompson et al., 1984). By virtue of a CCAS visit within the CTFR framework, copies of the Aleksandrov & Stenchikov (1983) preprint found their way to Berlin. They triggered a sound effort of the GDR Physical Society to inform the scientific public (Carl, 1985) and an ad-hoc ZIE/CCAS agreement in February 1985 to launch a joint study during a three-months stay in Berlin planned under the CTFR scheme (Stenchikov & Carl, 1985).

This common work was the first CCAS model study that combined mobile aerosols with a smoke residence parameterization which included washout by the GCM's rains. *Self-consistent* formulations like this are a prerequisite of inquiries into potential climatic *regimes* and their preservation or qualitative change due to the action of *feedbacks*. A 'minimum' disturbance was studied without minimizing the problem, conditions were traced for the southern hemisphere to become inflicted, and the *transient* response was explored for hints to the type of 'post-nuclear' climate relaxation and its possible pathways (Carl & Stenchikov, 1988). This comprised closer views on the *complexity* of the acute phase of the disturbance and its subsequent evolution (Svirezhev & Carl, 1990). Given the annual mean model climate used to match the available computational resources, though, the important issue of monsoon response was unfortunately not touched at that time.

To focus on a more qualitative, conceptual line of research, the CCAS model became completely regenerated in Berlin in 1988/89, using modern principles of software engineering (Carl, 1988) to make it a flexible tool of dynamic systems analysis ("CCAS-B"). This decision was also made with a view on first experiences since 1987 of the model's use beyond the specific *nuclear winter* context. The Meteorological Institute of the Humboldt University at Berlin exploited the chance of a tractable GCM being available in Berlin to offer its students a brief introduction to 3D climate modelling including a certain (yet very preliminary trial of) training. The urgent need, within this context, of flexible diagnostics was a major drive of the model regeneration. Though the demands on computational resources were very limiting to this approach, the *nuclear winter* GCM studies (which were continued as a single-person initiative in cooperation with the CCAS) added thus an option to climate research and education in the GDR.

The regenerated model's delicate and sensitive *monsoon climate* emerged as a surprise when an attempt was made in 1991 to foreshadow potential climatic effects of the Kuwait oil well fires, using the GCM for the first time in a mode of diurnal and annual cycle forcing (Carl, 1991). The systems analytical approach experienced an unexpectedly clear confirmation at this occasion, far beyond the martialic problem which brought forth these features: the GCM's boreal summer monsoon circulation emerges as a result of a structural instability of the annual cycle of planetary circulations. The (topological) circle blows up into a torus segment the minor cross section of which carrying the monsoons' intraseasonal *active•break cycle* (Carl, 1992).

Based on such a qualitatively advanced understanding of the GCM's climate, and on a new hardware now, these dynamics could be explored in detail (Carl, 1994; Tschentscher et al., 1994; Carl et al., 1995). A decisive step was their projection on the system's integrals of motion (interhemispheric mass displacements, relative angular momentum, e.g.) which provides a clear view on the GCM's intraseasonal attractor sets in the back of its seasonal climatic evolution. Beginning in 1994, GCM training courses were conveyed within a three years' pilot phase at the Humboldt University in a close contact to these conceptual research studies.

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Climate Impact Research: First Steps

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Introduction

Like in other countries, also in the GDR, studies on the impact of recent climate changes were only imade to a relatively small extent. The idea that recent and relatively weak climate variations already existed was still too new and too strange to be an interdisciplinary research topic. In spite of this, first remarkable results on the impact of climate change on coastal processes have been found already in the 1960s. Investigations into climate impacts on vegetation and on crop production in the territory of the GDR started about in 1985, when the climate began to change and the anthropogenic influence was recognised. A survey of results and some approaches in the filed of climate impact research was given by Hupfer (1991) and Chmielewski and Hupfer (1991). After 1990 these studies could be continued without any cutbacks or delays and were inserted into the German Climate Research Programme.

Processes in the Belt Sea and at the coast of the Baltic Sea

In generell, there is agreement, that coastal zones are very sensitive to climate change. This is valid for the Baltic Sea and its coastal zone. The first global warming in the 20th century, which was probably not strongly anthropogenically influenced and was observed in the 1930s and 1940s, is known as the “Warming of the North Polar Region”. Today, this topic is still subject to scientific research (cf. Hupfer and Tinz 2006). Global warming was accompanied by changes of the general atmospheric circulation and had distinct effects on the Baltic Sea and on the coast of Mecklenburg-Vorpommern.

Compared to the period 1901/30, the Baltic See showed statistically significant changes in sea temperature and salinity in the period 1931/60 (see Matthäus, in this volume). Since atmosphere and ocean are coupled components of the climate system, these climate variations are no real impacts, but an integral part of the climate change itself (Hupfer 1962a).

The sea-climatic changes which occurred in the Baltic Sea and the Belt Sea resp. during the past decades are not only of great significance for meteorology and oceanography, but also for biological conditions with consequences for the fishery. Warming and increase of salinity at the surface and in deeper layers had measurable effects on flora and fauna in the Baltic See. Marine species moved into the inner parts of the Baltic Sea, and their number increased in the different sea regions. New species of both zooplankton and phytoplankton appeared in that time, especially after 1930. Also the fauna near the bottom has spread out eastwards. This change of species was a clear signal of sea-climatic variations. A strengthening of the salty inward flowing deep current in the Belt Sea is coupled with the occurrence of more frequent marine species. The stock of fishes showed corresponding changes. The observed decrease of salinity in the 1950s had already fatal consequences on the stock of cod (*gadus gadus*). The spawning space had been immediately reduced because of decreasing salinity as well as of corresponding changes of water density depending on temperature and salinity (Schemainda 1956, 1960).
Up to the end of the 1950s, the sea level at the gauge-station Warnemuende showed a mean increase of about 1 mm/y. This effect was different in the individual months and was the result of changes in the atmospheric circulation. Compared to the period 1901/30 days with

storm surges (sea level ≥ 100 cm above normal) in 1931/60 were more frequent by 41 %. On the other hand, the number of days with storm-caused low water (sea level ≥ 100 cm below normal) was decreasing by 38 %. These changes in sea level were also related to variations in the general circulation of the atmosphere.

The greater frequency of storm surges corresponds to a strengthened attack of the marine forces on the coast. The accelerated abrasion at the flat coast between Warnemuende and Hiddensee since about 1930 temporally coincided with a change of the atmospheric circulation. At the same time the zonal circulation has decreased. In the case of predominant meridional circulation the coastal variations were opposite (Hupfer 1965).

The Belt Sea is included in those large regions with a long-term increase of both air temperature and sea temperature. Here, the increase of the annual mean temperatures took place essentially in summer and autumn. One of the consequences of the warming of air and water was a considerable elongation of the bathing season (a bathing day is defined by a sea surface temperature near the shore line at the 08 CET of ≥ 15 °C). For the coast of the GDR the bathing season during 1931/60 on the average was 2-3 weeks longer than in the period 1901/30. The growth of the number of bathing days has been considerably greater in late summer than at beginning of the season - in the early summer.

According to observations on the number of days with ice as well as on the dates of both the first and last occurrence of ice at seven selected stations along the GDR coast, it was possible to define the so-called ice season. On the basis of these data the long-term course of the ice conditions for the winters 1903/04 to 1962/63 had been investigated (Hupfer 1967). A strong relationship between the variation of the ice conditions and those of zonal circulation, air temperature, and sea temperature and coldness sum has been shown. The real long-term changes of the sea ice conditions are obvious if the normal ice winter (86 % of all cases) and the aperiodically occurring strong ice winters are separately investigated (Fig. 1).

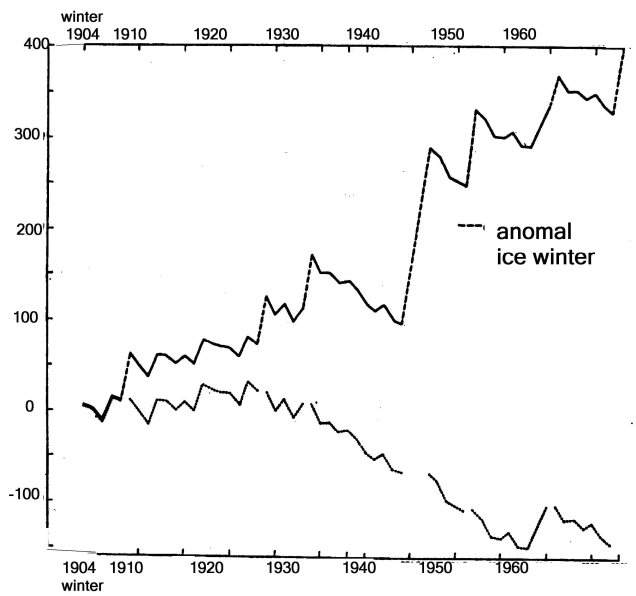

Fig. 1: Sum-curves of anomalies of the reduced ice-sum for the GDR-coast. Upper curve: all ice winters, reference period 1904/33 with exception of the strong ice winter 1909, 1924 and 1929. Lower curve: normal ice winter, reference period 1904/33 (Hupfer 1967)

According to this, the normal ice winters in the decades 1924 - 1953 were distinctly milder than in the time before and later. In contrast, the part of strong ice winters at the entire ice-sum had been greater in the period 1931/60.

Vegetation and plant production

The first paper dealing with this problem was written as diploma under the guidance of Walter Hesse (1915 - 1980). It focussed on variations of phenological phases of crops as well as on corresponding changes in the growing season length (Conrad 1959).

Later, research was carried out, in essence, by F.-M. Chmielewski and students at the Berlin Humboldt University, partly in co-operation with the Meteorological Service and other institutions.

Hechler (1988) had investigated, whether recent climate variations have had an impact on the flora in Central Europe. For this study a large number of phenological data was used, which were observed, processed, and archived in the Meteorological Service. In this study almost 100-yearly phenological time-series of wild plants have been related to climate variations.

Methodically, three approaches have been chosen: case studies, regression or correlation analyses as well as investigations into the temporal variations. The results showed a strong relation between the course of temperature and the plant development, especially strongly revealed in spring. In contrast to this, the findings for autumn are less clear. Mild winters, but also warm spring months led to an early timing of the phenological phases and contrary. The plants investigated react especially sensitive to extreme deviations from the mean values. Since such reactions exist in all climatically different periods, a clear relationship between the phenological development and the climate period, defined by Kleber (1986), is not probable for all phases. One of the consequences is that the use of conventional phenological data does not allow general conclusions.

The beginning, end and length of the growing season, defined as the time within the year when surface air temperatures are permanent ≥ 5 °C, showed distinct variations during the 20th century (Kleber 1986). Comparisons of changes in the duration of the growing season on one hand and crop yields of a long-term field experiment “Eternal Rye trial” in Halle/Saale on the other hand, showed that the yield is high (low) in the case of a long (short) growing season (Fig. 2). This can be traced back to the fact that after mild or short winters, winter cereals generally show a higher number of tillers. Those could be effective for a high crop density and can influence positively the yield. Such effects are of economic importance in agriculture (Chmielewski 1990).

Phenological observations allow to study on the impact of climate variations on natural processes. The influence of inter-annual climate fluctuations on phenological events is undisputed. To study these relationships, comprehensive investigations on the phenological phases of the winter rye in the North Western part of the GDR have been carried out. For these investigations phenological data from natural regions (area-means), but also meteorological elements, calculated for individual phenological stages, and data of the duration of developmental periods were used.
It could be shown, that the timing of a phenological event mainly depends on the timing of the preceding phenological phase as well as on the climatic conditions between both phases. The positive correlation between all phenological phases after the beginning of the growing season indicates a preservation tendency of the plant development within the year. The consequence

is that in years with an extremely delayed or advanced plant development in spring, the anomalies during the course of the year will be reduced, because the subsequent development is faster or slower than normal. This depends on the meteorological conditions during the developmental stages and on the internal preparedness of a plant for the formation of a phenophase. For this, to a certain extent plants are physiologically able to compensate the effect of climate fluctuations.

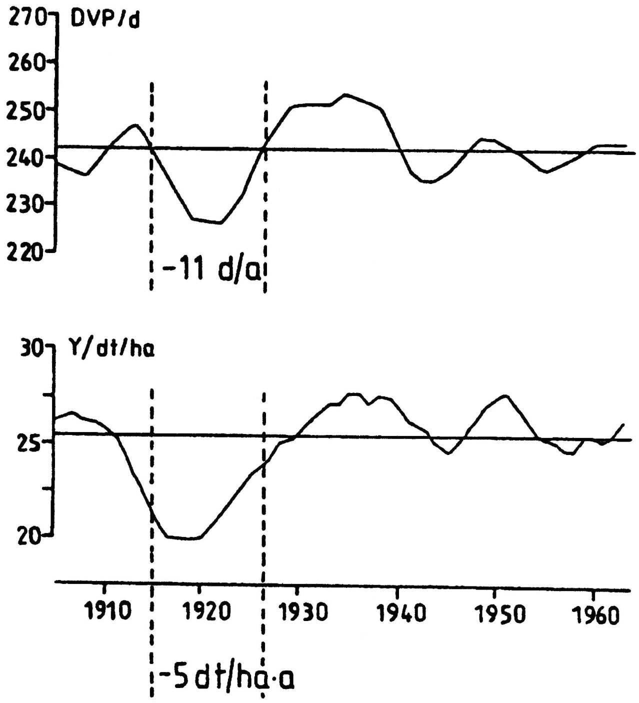

Fig. 2: Variations in the duration of the growing season (DVP, above) and in crop yields of the long-term field experiment "Eternal Rye trial" in Halle (Y, below) (Chmielewski 1990)

The duration of phenological stages is mainly influenced by the air temperature. With statistical methods (e.g. correlation and regression analysis) it was possible to estimate the timing of phenological events, using the onset of the preceding phenological phase and the mean air temperature (annual deviation from the average 1951/80) in the following stage. Hereby, phenological forecasts were possible, which are important for the planning of field works and the harvest.

Considering the long-term course of air temperature in the investigation area as well as the dependence of the plant development on air temperature, a "Pheno-temperaturenomogramme" has been constructed. Herewith, an estimation of the phenological phases is possible. In this nomogramme the starting time can freely be chosen, and the timing of a phenological event can be estimated using observed temperature data or forecasts. This way it is possible to estimate the timing of consecutive phenophases within a year. The mean forecast error of this method was between 3 - 5 days (1951-1986). This value is smaller than the standard deviation of the phenological events within the investigation area.

With the data of the above mentioned "Eternal Rye trial" it was also possible to show that the long-term changes of air temperature and rainfall during the growing season are related to variations in the atmospheric circulation since the end of the 19^{th} century, which have influenced both the height of yields and their variability. The yield variability can be characterized by the term “risk of the agricultural production” (Fig. 3).

The relationships between climatic variations and yield fluctuations must be studied in regard to the recent climate period. For the thermally continental influenced time intervals (1879-1997, 1929-1954 for Halle/Saale) the correlation coefficient between the mean air temperature in May and June and the crop yields was essentially stronger (statistically significant) than in the maritime period 1898-1928. In contrast to both continentally influenced periods, for the maritime interval even positive correlation coefficients between air temperature and grain yield have been found. In the maritime interval the height of precipitation is negatively and in both continental periods positively correlated with the anomalies of the yields. The investigations showed also that the annual yield fluctuations are influenced by the variability of the atmospheric circulation across Central Europe (Fig. 3).
The results of this research have been used later for the development of yield models, in which all relevant climate elements were considered.

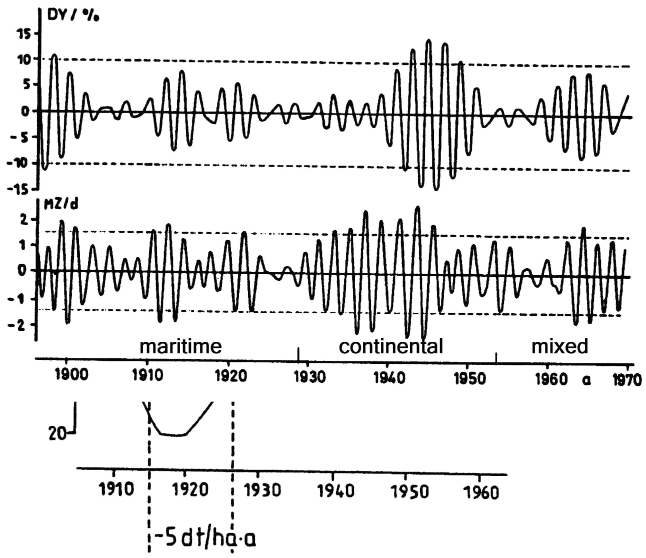

Fig. 3: Filtered time-series of yield anomalies (DY) and the number of days with meridional circulation patterns (MZ) in the frequency range of the biennial oscillation (Chmielewski 1990; Chmielewski and Hupfer 1991)

Concluding remarks

The main topics presented here only in short concerning the first investigations on the climate impact in the GDR could be continued after 1990 also at the Berlin Humboldt University with partially expanded objectives. As an example, changes in the region of the German sea coasts have been investigated in the frame of the Federal/Countries Programme “Climate change and coast” in the second half of the 1990s, on the base of a lot more data than formerly (Hupfer et al. 1998, Die Küste 1999, Hupfer et al. 2003, Tinz und Hupfer 2006). Climate impacts in further economically important sectors have been studied. Beside agriculture, sectors as forestry, medicine, energy and water industry were included in the studies (Moldenhauer 1994).
The research in the field “climate change and agriculture” is continuously carried out at the Faculty of Agriculture and Horticulture at the Berlin Humboldt University. Main topics were the water consumption of field crops, the sensitivity of the yields to weather and climate as

well as the growth of these plants under changed climate conditions. The phenological studies were also continued and were focused on the impact of climate change on the individual plant development and growing season.

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Published in:

Deutscher Wetterdienst, Reihe "Geschichte der Meteorologie in Deutschland" Nr. 8
ISBN 978-3-88148-421-3

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