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The Meteorological Observatory at Neumayer Stations (GvN and NM-II) Antarctica

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Abstract: Since March 1981 a meteorological observatory program is carried out at Georg von Neumayer Station (GvN, 70°37'S, 8°22'W) continuously. On 16 March 1992 the program was extended and transferred to the new Neumayer Station (NM-II, 70°39'S, 8°15'W) in a close neighbourhood of the former one. Today, the meteorological observatory of NM-II is an integral part of many international networks, mostly associated with the World Meteorological Organization (WMO). The data from NM-II help to close significant gaps in the global weather and climate observing networks. NM-II takes part in the Global Telecommunication System (GTS), the Global Climate Observing System (GCOS), the Global Atmospheric Watch (GAW), the Network for the Detection of Atmospheric Composition Change (NDACC, formerly NDSC), and the Baseline Surface Radiation Network (BSRN). Three-hourly synoptic observations, daily upper air soundings including weekly ozone profiling, and substantial surface radiation measurements are the main parts of the measurements. Additionally, the meteorological observatory of NM-II evolved more and more into the meteorological forecast centre for the whole Dronning Maud Land. Meanwhile, data from 25 years are measured and archived in a carefully validated and post processed form in the Meteorological Information System at the Alfred Wegener Institute (MISAWI). Within this publication, the observatory will be described and some results from the long-term measurements will be presented.

Zusammenfassung: Seit März 1981 wird an der Georg-von-Neumayer-Station (GvN, 70°37'S, 8°22'W) kontinuierlich ein meteorologisches Observatoriumsprogramm durchgeführt. Am 16. März 1992 wurde das Programm erweitert und in die in der Nachbarschaft errichtete neue Neumayer Station II (NM-II, 70°39'S, 8°15'W) überführt. Das meteorologische Observatorium von NM-II ist heute ein integraler Bestandteil vieler, meist mit der World Meteorological Organization (WMO) verbundener internationaler Netzwerke. Die Daten von NM-II tragen dazu bei, wesentliche Lücken im globalen Wetter- und Klimabeobachtungsnetz zu schließen. NM-II ist Bestandteil des Global Telecommunication Systems (GTS), des Global Climate Observing Systems (GCOS), des Global Atmospheric Watch (GAW), des Network for the Detection of Atmospheric Composition Change (NDACC, vormals NDSC) und des Baseline Surface Radiation Networks (BSRN). Alle drei Stunden durchgeführte synoptische Beobachtungen, tägliche Radiosondierungen mit wöchentlichen Ozonsondenprofilierungen sowie umfangreiche bodennahe Strahlungsmessungen machen den Hauptteil der Messungen aus. Zusätzlich hat sich das meteorologische Observatorium von NM-II nach und nach zum Wettervorhersagezentrum für das gesamte Dronning-Maud-Land entwickelt. Mittlerweile sind die sorgfältig validierten und nachprozessierten Daten von 25 Jahren Observatoriumsbetrieb im Meteorologischen Informationssystem des Alfred-Wegener-Instituts (MISAWI) archiviert. In dieser Publikation wird das Observatorium beschrieben und einige Ergebnisse aus den Langzeitmessungen dargestellt.

Introduction

Antarctica is a continent of superlatives, especially from the climatologically point of view. It is the most isolated continent, completely surrounded by the only circumpolar ocean current of the Earth. It is the highest, driest as well as the coldest continent. More than 98 % of its surface is covered by snow and ice.

The general circulation of the whole atmosphere is mainly driven from the temperature difference between the equatorial and the polar regions, resulting from the differential absorption of solar energy. Without the knowledge of the Antarctic climatology the general circulation of the whole atmosphere cannot be understood. Thus, meteorological observatories in Antarctica have a fundamental importance, not only for Antarctica but for the whole world. Antarctica is frequently regarded to be very sensitive to anthropogenic induced climate changes. The ozone depletion – firstly observed in Antarctica – is one well known example. Also the collapse of parts of the Larsen Ice Shelf in 1995 and 2002 is frequently regarded as a result of global climate changes.

Despite the fact that Antarctica belongs to the "motors" of our climate system and its sensitivity to climate changes, only very few meteorological measurements are available. From no other continent less data exist. Only the oceanic regions face a comparable problem. To reduce this problem, the World Meteorological Organization (WMO) strongly recommends that any research station established in Antarctica should run a

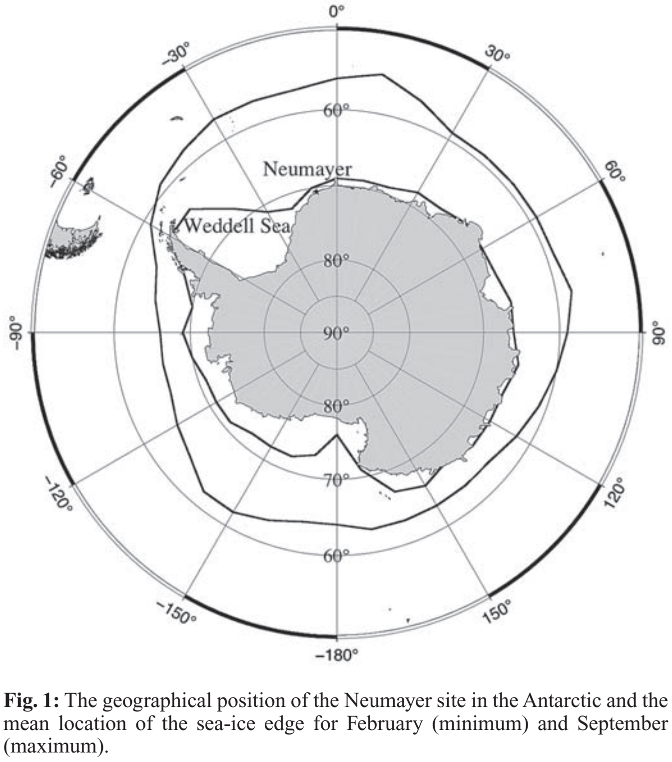

Fig. 1: The geographical position of the Neumayer site in the Antarctic and the mean location of the sea-ice edge for February (minimum) and September (maximum).

Abb. 1: Die geographische Position der Neumayer-Stationen in der Antarktis sowie die mittlere Lage der Meereisausdehnung im Februar (Minimum) und September (Maximum).

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meteorological observatory. The obtained data should be delivered without delay into the Global Telecommunication System (GTS), the worldwide data backbone of any national weather service agency. Georg von Neumayer Station (GvN; marked as Neumayer in Fig. 1) became part of the GTS from its very beginning on. Meanwhile the successor, Neumayer Station II (NM-II) is member in many world wide weather and climate monitoring networks. They are mostly organised or associated with programs founded by the WMO such as:

• The Global Telecommunication System (GTS).

The aim of the GTS is to transfer in real time standardized synoptic surface weather observations and upper air soundings. The data are mainly used from a variety of meteorological agencies worldwide for weather forecasts products. The data from Neumayer within the GTS are tagged with the WMO number 89002.

• The Global Climate Observing System (GCOS).

It was established to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users.

• The Network for the Detection of Atmospheric Composition Change (NDACC, formerly NDSC)

This network was established to study the temporal and spatial variability of atmospheric composition and structure in order to provide early detection and subsequent long-term monitoring of changes in the physical and chemical state of the stratosphere and upper troposphere.

• The Baseline Surface Radiation Network (BSRN).

The objective of the BSRN is to provide worldwide observations of short- and long-wave surface radiation fluxes to monitor their changes with the best methods currently available, to provide data for the validation and evaluation of satellite-based estimates and to produce high quality observational data for comparison to global climate model (GCM) calculations and for the development of local regionally representative radiation climatologies.

• The Global Atmospheric Watch (GAW).

The main goal of the GAW program is to produce high quality data of selected atmospheric parameters and to make these data available to the scientific community. The parameters are focussed on chemical constituents as well as on meteorological measurements.

Most of these goals cannot be achieved by using unmanned automatic weather stations. Despite the amazing technical progress, permanently manned stations will be needed at least within the next 25 years to run highly sophisticated observatories in a remote and harsh environment such as Antarctica.

HISTORY OF THE METEOROLOGICAL OBSERVATORY AT NEUMAYER STATIONS (GVN, NM-II)

Since the very beginning of the Georg von Neumayer Station (GvN) in March 1981 three-hourly synoptic observations have been performed continuously and transferred without delay into the GTS via short-wave communication. In March 1982 surface energy budget measurements started. Upward and downward short- and long-wave radiation fluxes, turbulent heat fluxes in the atmospheric boundary and the heat fluxes within the snow are measured continuously. From 1983 on daily upper air soundings have been launched. The data were transferred without delay into the GTS via a satellite-based data-collecting platform (DCP).

In March 1992 the GvN observatory was transferred – without interrupting the measurements – into the new Neumayer Station II (NM-II), built in the very vicinity of the former one. The surface radiation measurements were extended to meet the high quality standards of the Baseline Surface Radiation Network (BSRN). Furthermore, the weekly ozone sounding measurements – started in 1985 at the nearby Georg Forster Station (70°46'S, 11°41'E) – were transferred to GvN. The Neumayer site obtained the status of a complementary NDSC station.

During the last decade the infrastructure of the observatory improved significantly. The measurements were automated wherever possible. The observatory program could be extended further although the personal had to be reduced from two to one meteorologist. A satellite image receiving station was installed for the online reception of pictures (visible and infrared) from the NOAA- and DMSP-satellites. Due to the highly sophisticated scientific and logistic infrastructure of the station, which since 1999 includes a worldwide communicationsystem via a permanent data link, NM-II became the weather forecasting centre of the Dronning Maud Land. The full forecast service, especially essential for the growing air operations, is carried out during the summer months from specialists of the German Weather Service (DWD).

TECHNICAL ASPECTS OF THE METEOROLOGICAL OBSERVATORY

Measuring site

The whole Neumayer Station II (NM-II) is buried completely below the snow surface. Only the entrance towers, some antennas and exhaust pipes are visible (Fig. 2). Most of the meteorological sensors are installed 75 m southeast of the easterly entrance tower. Even the rarely occurring winds from north-westerly directions are not disturbed by the station. Directly north of the meteorological tower all radiation sensors are mounted. The horizon is nearly free of obstacles. Shadows from the meteorological lattice tower are rather unimportant and reach the radiation measurements only during sunny polar day nights. The snow surface is modulated by so called sastrugies, giant snow ripples created during blowing snow events. The surface gently inclines towards the station.

Data acquisition

Close to the sensors all analogue signals get digitized every fifth second by a data logger (CR7, Campbell Scientific, USA) positioned in an isolated waterproof box above the snow surface. The CR7 works autonomously, performs the analogue/digital conversion and the 1-minute averages or maxima of all data. Every minute the results are transferred serial into the station. Common mode reduction (very important since the whole station has no defined electrical earth potential) is realized by differential measurements and opto-electronic couplers. Due to carefully shielded cables interferences with the local short-wave transmitter and other sources of electrical noise are excluded. Power failures are minimized

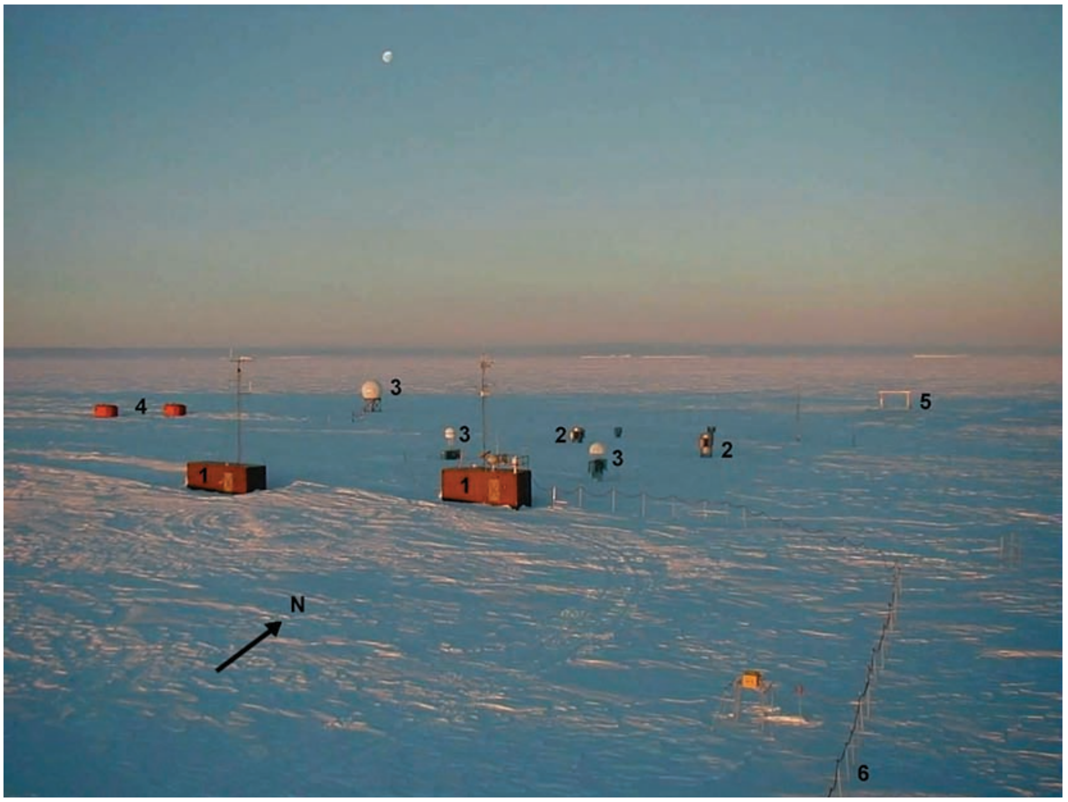

Fig. 2: View over Neumayer Station II from the 15 m high meteorological tower. The whole station is buried below the snow. Only the entrance towers (1), exhaust pipes (2), antennas (3), emergency huts (4), garage entrance (5) and the cables (6) toward the meteorological measuring site are visible.

Abb. 2: Blick auf die Neumayer-Station II vom 15 m hohen meteorologischen Mast. Die gesamte Station ist im Schnee/Firn verborgen. Nur die Eingangstürme (1), Lüfterrohre (2), Antennen (3), Rettungshütten (4), die Garageneinfahrt (5) und die Kabelkette (6) zum Messplatz der Meteorologie sind zu erkennen.

by uninterruptible power supply units (UPS). The digitized data from the CR7, as well as all other measurements already obtained directly digital are collected by a terminal server (Lantronix ETS 16PR, USA). The terminal server transfers the whole dataset into the computer network of NM II. Workstations (SUN, USA) are used to post process the data. They get automatically visualized online, validated to a certain extent, archived, and distributed to any user worldwide via the internet.

Instrumentation for the synoptic observations

The synoptic observations are carried out every three hours. They include measurements of air temperature (at 2 m and 10 m height), air pressure (values are reduced to mean sea level), wind vector (at 2 m and 10 m height), dew point temperature (at 2 m height), clouds (cloud amount, type and height), horizontal visibility, present and past weather, snowdrift and whiteout. The full program is carried out at 0, 9, 12, 15, 18, 21 UTC. During night-time at 3 and 6 UTC the synoptic observations are performed automatically. Thus, no visual observations are available. All data are generally coded (FM12-SYNOP) and transferred directly into the GTS via mail using a permanent data link. Additionally, they are available from
<http://www.awi.de/MET/Neumayer/latest_obse.html>. All datasets covering a whole year of synoptic observations are published at PANGAEA, e.g., KÖNIG-LANGLO (2005).

Temperature measurements at 2 and 10 m height are carried out with PT-100 platinum resistance sensors with an accuracy of 0.1 °C (Thies 2.1265.10.000, Germany). The thermometers are ventilated artificially and are double protected against radiation. The dew point temperature is measured with two hygrometers (Vaisala, HMP233, Finland) mounted in naturally ventilated radiation shields at a height of 2 m. The hygrometers are permanently checked against each other. The relative humidity is calculated using the dew point temperature and the artificially ventilated temperature measurements to minimize radiation errors during calm and sunny days. The resulting accuracy is about 5 %.

Surface air pressure is detected by using three quartz systems (Digiquartz, 215-AW002, USA). The Digiquartzes are permanently checked against each other. They are installed inside the station but connected to a pipe, which ends outside the station at a depth of about half a meter below the snow surface. Thus, influences due to wind induced pressure fluctuations or effects caused by the air-conditioning inside the station are eliminated. For the reduction of the air pressure to mean sea level an instrument height has to be determined. Due to tidal movements of the whole Ekström Ice Shelf and its more or less isostatic movements with respect to snow accumulation and basal melting the instrument height has an uncertainty of about 4 m. Compared with this uncertainty (~0.5 hPa) other errors in the pressure measurements can be neglected.

The wind vector is determined at 2 and 10 m height by a combined instrument consisting of a cup anemometer and a wind vane (Thies 4.3323.21.002, Germany). All axes are heated. Ultrasonic anemometers have been tested several times. But they failed during blowing snow events. Cloud base heights below 12000 feet are measured using a ceilograph (LD-WHX 05, Impulsphysik, Germany). Bases above 12000 feet are estimated visually. Visibility is automatically measured by a visibility sensor (Vaisala, FS11, Finland).

Instrumentation for the daily upper air soundings

Once daily (about 10:45 UTC) a radiosonde is launched to measure vertical profiles of air pressure, temperature, relative humidity and the wind vector. The resulting TEMP message is transferred into the GTS via a permanent data link and into internet at <http://www.awi.de/MET/Neumayer/nrt_temp>. All upper air soundings are published at PANGAEA with full height resolution of up to 25 m, see KÖNIG-LANGLO (2006). The upper air soundings are carried out with RS92-SGPW radiosondes (VAISALA, Finland). They directly measure air pressure, air temperature and relative humidity. The wind vector is determined with the aid of the GPS navigation system, the height information is calculated using the hydrostatic approximation. Helium filled balloons (TOTEX 600 g, 800 g, Japan) are taken to obtain an ascent velocity of about 5 m s^{-1}. Typically, two hours later the balloons burst at heights between 25 and 37 km. To reach such height levels also during wintertime when the stratosphere is extremely cold, the balloons are pretreated by heating and oil dipping. All balloons were filled inside an inflation shed equipped with a sliding door 3 m wide and 4 m high (Fig. 3). During strong wind conditions (>20 m s^{-1}), only 350/600 g balloons can be launched with a reasonable chance of success. The data reception and evaluation is carried out by a DigiCora III MW31 (VAISALA, Finland).

Fig. 3: The balloon filling hall at Neumayer Station II.

Abb. 3: Die Ballonfüllhalle an der Neumayer-Station II.

Instrumentation for the weekly ozone soundings

Normally, one ozone sonde is launched every week to measure the vertical ozone profile through the troposphere and the lower stratosphere. For the ozone soundings an ozone sonde (ECC-6AB, Science Pump Corporation, USA) is connected via an interface to a RS92 radio sonde. The ozone is measured by pumping air through a chemical solution and using the principal of iodide redox reaction to release electrons. 1500 g TOTEX balloons are used for these ascents. The DigiCora III is able to handle the data reception and evaluation of both, the normal RS92 radio sonde and the ozone sonde at the same time.

Instrumentation for the surface radiation measurements

The following radiation quantities are measured every fifth second and stored together with all other meteorological measurements described below in form of one minute averages:

- global (solar) radiation with glass-filter (305-2800 nm)
- global radiation with OG1-filter (530-2800 nm)
- global radiation with RG8-filter (695-2800 nm)
- uv radiation (300-370 nm)
- diffuse sky radiation (305-2800 nm)
- direct solar radiation (305-2800 nm)
- reflected solar radiation (305-2800nm)
- downward long-wave radiation (4-50 µm)
- upward long-wave radiation (4-50 µm)
- sunshine duration. (yes / no)

Nearly all radiation sensors are ventilated with slightly preheated air (Eigenbroth, FRG) to minimize hoar frost problems and zero offset effects during cloud- and windless conditions. The radiation measurements are carried out with:

- 5 pyranometers (CM11, Kipp & Zonen, Netherlands) for global radiation (glass, OG1-, RG8-filter), diffuse sky radiation and reflected solar radiation,
- 1 normal incidence pyrheliometer (NIP, Eppley, USA) for direct radiation,
- 1 uv-meter (TUVR, Eppley, USA) for broadband uv radiation,
- 2 pyrgeometers (PIR, Eppley, USA) for upward and downward long-wave radiation,
- 1 photoelectric sunshine detector (Solar 111b, Haenni and Cie., Switzerland).

The normal incidence pyrheliometer is mounted on a sun tracker (SCI-TEC 2AP, Kipp & Zonen, Netherlands), which follows the azimuth and elevation direction of the sun automatically. The diffuse sky radiation is obtained using a shadow disk pointed from the tracker (see background of Fig. 4). From the pyrgeometers the thermopile output, one body temperature and three dome temperatures are recorded separately. All instruments are calibrated at the World Radiation Centre, Davos Switzerland. After one year of operation the sensors get exchanged with newly calibrated ones.

Together with the radiation data one-minute averages of the surface air pressure, relative humidity (2 m), air temperature (2 m and 10 m) and the wind vector (2 m and 10 m) are recorded. The minimum value of the ceilometer record within a 1 min. interval is taken as cloud base height. Data are available below <http://www.awi.de/en/infrastructure/stations/neumayer_station> or from the World Radiation Monitoring Centre, ETH Zürich, Switzerland.

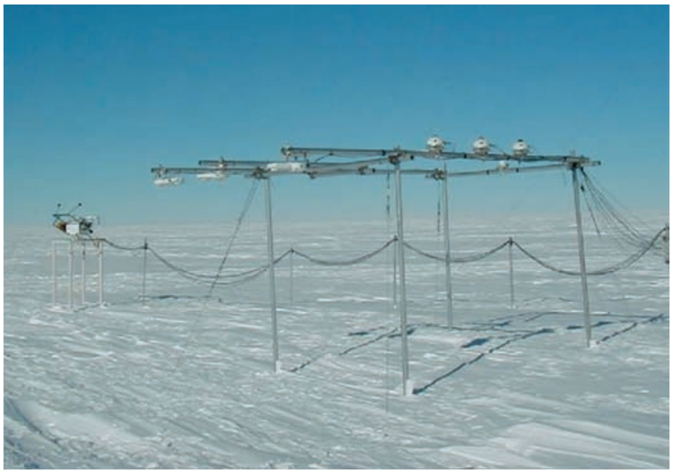

Fig. 4: The radiation sensors at Neumayer Station II. In the background the sun tracker is visible.

Abb. 4: Die Strahlungssensoren an der Neumayer-Station II. Im Hintergrund ist der Sonnenfolger zu erkennen.

SELECTED RESULTS

Meanwhile, time series from data of up to 25 years are available from the Neumayer site. Within this chapter some results from the long-term measurements will be discussed. For a better interpretation first the general climatologically conditions at Neumayer will be presented briefly.

General climatological conditions at Neumayer stations

The sea-ice extent around Antarctica has a pronounced annual cycle with a minimum in February and a maximum in September (Fig. 1). During summertime the coastlines at Neumayer are sometimes ice free. In wintertime the area between the coastline and the sea-ice edge – frequently more than 1000 km away – includes a few percent of cracks, leads and polynyas not covered by sea ice. The sea ice, as well as the open-water patches, are an important source for many aerosols measured at Neumayer.

The station's annual course of the sun elevation (without refraction) from Neumayer is shown in Figure 5. The maximum incidence angle is 42.8° at 22 December. The sun stays permanently above the horizon from 19 November to 24 January (polar day) and permanently below the horizon from 19 May to 27 July (polar night).

Owing to the low sun elevations at high latitudes and the high albedo of snow and ice the surface radiation balance of Antarctica is mostly negative, which means that the ground loses more energy by radiation than it gains. Corresponding to the radiation balance, the cooling of the lower atmosphere is faster in high than in middle latitudes, which induces a meridional temperature gradient through the mean troposphere, which varies with season and reaches equinoctial maxima in March and September. To a large extent this gradient controls the number and strength of the depressions which move in eastward direction around Antarctica in a circumpolar trough at approximately 65 °S. This trough can be depicted as a continuous belt surrounding Antarctica where pressure is minimum on average. North of 65 °S, westerly surface winds are predominant, while south of 65 °S, easterlies surface winds prevail. The Neumayer site is situated at the southern edge of this low-pressure belt. Thus, the mean sea level pressure at Neumayer is comparably low. Strong easterly winds associated with cyclonic disturbances are common. Only few cyclonic disturbances penetrate into the interior of Antarctica.

The surface circulation over most parts of the Antarctic continent is dominated by katabatic effects, initiated by a horizontal density gradient due to a slope between the cold air neighbouring the surface and the relatively warmer upper air. At Neumayer the katabatic winds are typically during high pressure regimes associated with clear skies and negative radiation balance. Since the Ekström Ice Shelf slopes only gently upward to the south, the katabatic winds have a south-north orientation and stay always below 10 m s^{-1}.

Surface station climatology

The annual averaged temperature at the Neumayer site is -16.1 °C. The day-to-day temperature variations are largest during winter, when the temperature variations between the air masses from the interior of Antarctica and the surrounding ocean are most pronounced (Fig. 6). An additional reduction of the temperature variations in summer results from some minor melting processes, which tend to constrain near surface

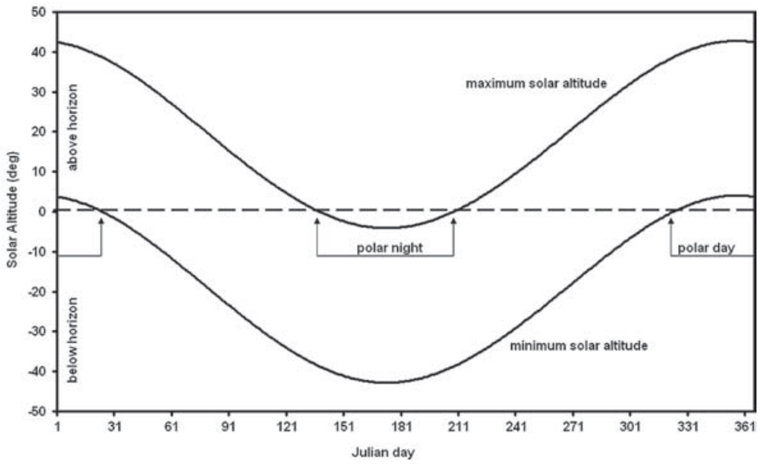

Fig. 5: Annual cycle of the maximum of the solar elevation at Neumayer calculated after IQBAL (1983).

Abb. 5: Jahresgang der maximalen Sonnenhöhe bei Neumayer berechnet nach IQBAL (1983).

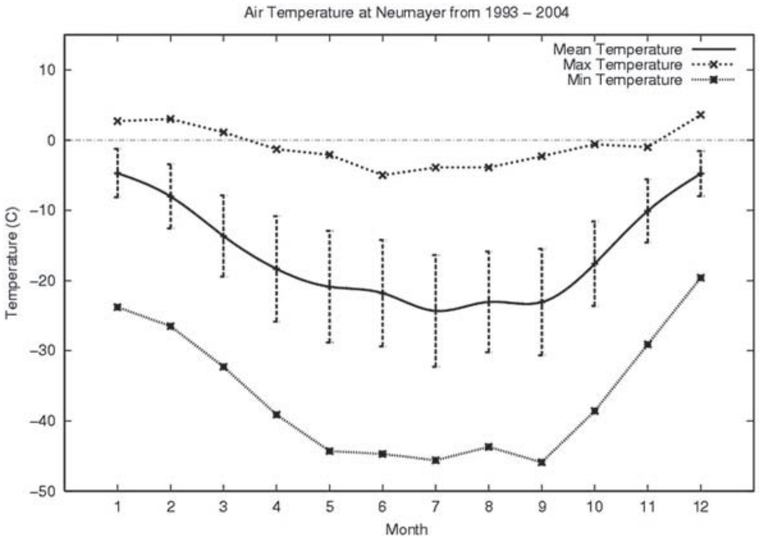

Fig. 6: Monthly mean, maximum and minimum values of air temperatures from Neumayer. Mean temperature values are plotted with standard deviation with respect to the three-hourly synoptic observations.

Abb. 6: Monatliche Mittel, Maxima und Minima der Lufttemperatur bei Neumayer. Die mittleren Temperaturen sind mit den Standardabweichungen aus den drei-stündlichen synopticschen Beobachtungen dargestellt.

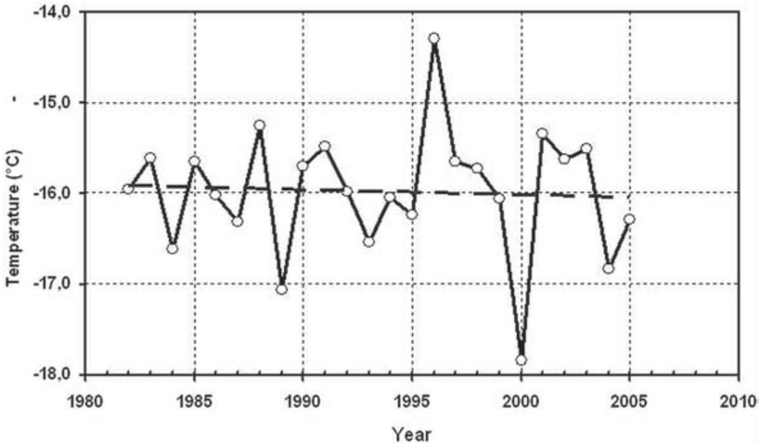

Fig. 7: Time series of the annually averaged air temperature at Neumayer stations 2 m above the snow surface.

Abb. 7: Zeitserie der Jahresmittel der Lufttemperatur an den Neumayer-Stationen 2 m über der Schneeoberfläche.

air temperatures to 0 °C. Within the last 25 years remarkable year-to-year temperature variations were measured but no significant trend can be observed (Fig. 7). This finding is in contrast to measurements at the Antarctic Peninsular where a significant warming took place, but it is typical for the majority of all other Antarctic stations.

Neumayer is a rather windy site with an averaged wind speed of 9 m s^{-1}. Severe easterly storms are common. They can reach wind velocities well above 30 m s^{-1}. Only during summer blizzards are less frequent. Drifting and blowing snow events are common at Neumayer. This makes meteorological and air-chemistry measurements to be a rather complicate task. Frequently, precipitation events are hidden behind severely blowing snow events. Drifting or blowing snow is reported in 40 % of all visual observations. Depending on the surface conditions, snow begins to drift at wind speeds of 6-12 m s^{-1} (Fig. 8). If the saltated snow reaches heights above the eye level of the observer, the phenomenon is called blowing snow which gets reported in 20 % of all observations from Neumayer. Drifting and blowing snow events are restricted to synoptic disturbances, which are connected mainly with the advection of air masses from the east.

The surface wind observations are performed with a wind speed resolution of 1 knot (0.5144 m s^{-1}) and a resolution of the wind direction of 10°. The two-dimensional frequency distribution (Fig. 9) is based directly on these observations

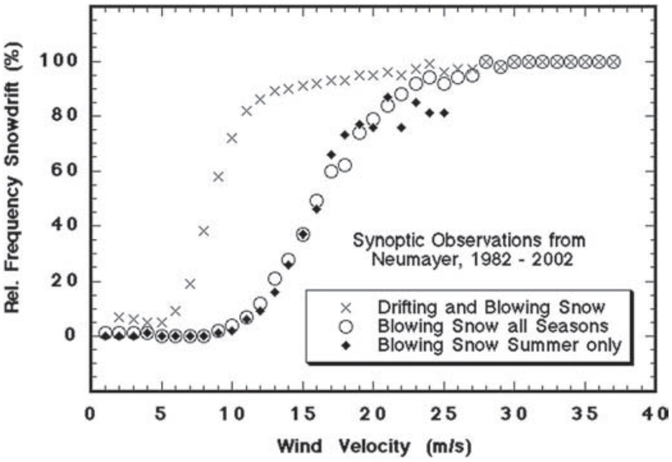

Fig. 8: Accumulated frequency distribution of snow-drift observations at Neumayer stations versus wind velocity 10 m above the snow surface.

Abb. 8: Akkumulierte Häufigkeitsverteilung von Schneedriftbeobachtungen bei Neumayer in Abhängigkeit von der Windgeschwindigkeit 10 m über der Schneeoberfläche.

with wind speeds exceeding 2.5 knots. Certain wind directions are correlated with rather distinct wind speeds. Two combinations occur most frequently at Neumayer: The synoptic disturbances are responsible for the maximum at 90° and 25 knots, the katabatic flows for the combination around 180° and 10 knots. The medium strong westerly winds are associated with

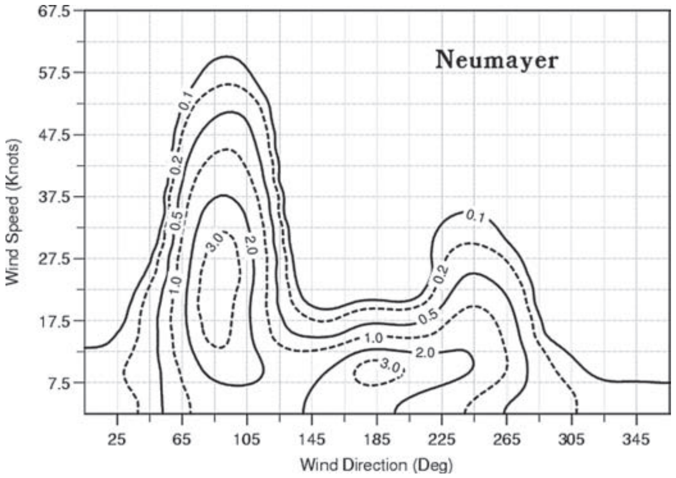

Fig. 9: Two-dimensional frequency distribution of wind speed and wind direction in percent of all observations with a wind speed exceeding 2.5 knots. The class widths are 5 knots and 20°, respectively.

Abb. 9: Zweidimensionale Häufigkeitsverteilung der Windgeschwindigkeit und der Windrichtung in Prozent aller Beobachtungen mit einer Windgeschwindigkeit über 2,5 Knoten. Die Klassenweiten betragen 5 Knoten sowie 20°.

super geostrophic flows resulting from a high-pressure ridge north of Neumayer. Northerly winds hardly occur.

Since the Neumayer site is located at the southern edge of the circumpolar low-pressure belt surrounding whole Antarctica the mean sea-level pressure of the station is just 986.5 hPa. According to VAN LOON at al. (1984a, 1984b) a half-year cycle in the pressure data with minima during spring and autumn should exist. To a certain extend this cycle is detectable in the full dataset, but mostly hidden behind synoptic disturbances if only single years are regarded. Precipitation events occur all year around. In very rare cases during summer, drizzle and rainfall are possible. Most of the precipitation is due to slight to moderate fall of snowflakes, while showers seldom occur. Drifting and blowing snow make the quantification of the amount of precipitation impossible. Only the annual averaged accumulation rate of about 340 mm water equivalent can be obtained.

The annually averaged total cloud amount at Neumayer is 5.1 octa. During darkness, the total cloud amount can only be observed while the moon or stars are visible. Therefore, the tendency toward lower total cloud amounts during winter is questionable. The mean annual sunshine duration accumulates to 1430 hours. The lowest annual sunshine hours were recorded 1983 (1134 hours) while the highest value was reached in 2003 (2047 hours). The overall tendency is towards a significant increase of the sunshine duration.

All data from the synoptic observations from the Neumayer site are stored within MISAWI. Via internet <http://www.awi.de/met/en/infrastucture/stations/neumayer_station> they can be obtained interactively. More detailed analyses of the synoptic observations from distinct years are published from by GUBE-LENHARDT et al. 1986, GUBE-LENHARDT 1987, HELMES 1989, KÖNIG-LANGLO 1992, KÖNIG-LANGLO et al. 1996, KÖNIG-LANGLO et al. 1998 and SCHMIDT et al. 1994.

Upper air soundings

The prevailing easterly surface wind dominates the troposphere just within the lowest 2 km. Only between November and February do easterlies exist at any higher levels (Fig. 10). During the rest of the year, a pronounced circumpolar cyclonic vortex, with westerly winds increasing with height, is well established. This vortex is strongest within the stratosphere but also present in the troposphere above 5 km (Fig. 11). The whole upper air climatology of Antarctica is governed by this vortex. In the stratosphere the flow is driven by horizontal temperature gradients that are maintained by radiative heating and cooling. During the austral summer, the Antarctic stratosphere receives more solar radiation than lower latitudes and thus becomes relatively warm, generating a weak easterly circulation. From February onward, as solar heating decreases,

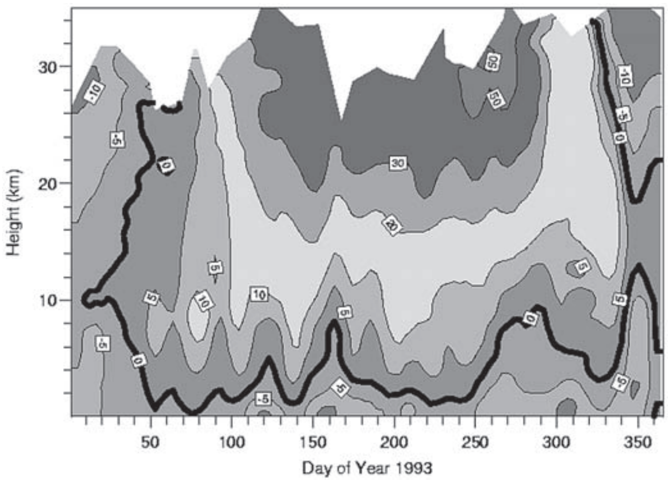

Fig. 10: Time-height section of zonal wind in m s^{-1} from daily radiosonde soundings in 1993 at Neumayer. Positive values denote wind from west to east; negative values denote wind from east to west.

Abb. 10: Höhen-Zeit-Schnitt des Zonalwindes in m s^{-1} aus Radiosondierungen 1993 im Bereich Neumayer. Positive Werte bedeuten Winde von West nach Ost, negative Werte bedeuten Winde von Ost nach West.

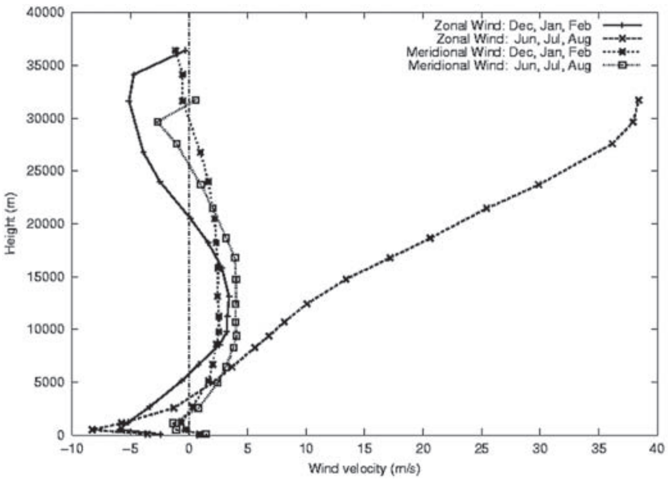

Fig. 11: Mean summer (December, January, February) and winter (June, July, August) profiles of zonal and meridional wind components from Neumayer 1983-2005.

Abb. 11: Mittlere Sommer (Dezember, Januar, Februar) und Winter (Juni, Juli, August) Profile zonaler und meridionaler Windkomponenten im Bereich Neumayer 1983-2005.

the Antarctic stratosphere cools rapidly, and an intense westerly vortex develops until the stratosphere warms once again in the austral spring.

The meridional components of the upper air wind field are comparable weak (Fig. 12). At Neumayer a mean meridional transport is hardly observed (Fig. 11). Meridional advection takes place only during events associated with cyclonic disturbances, which affect all height levels of the atmosphere at the same time. These disturbances can occur in all seasons, and they create southerly as well as northerly winds. The only remarkable advection from lower latitudes takes place above 30 km in November each year, when the upper part of the circumpolar vortex vanishes and sudden stratospheric warming takes place.

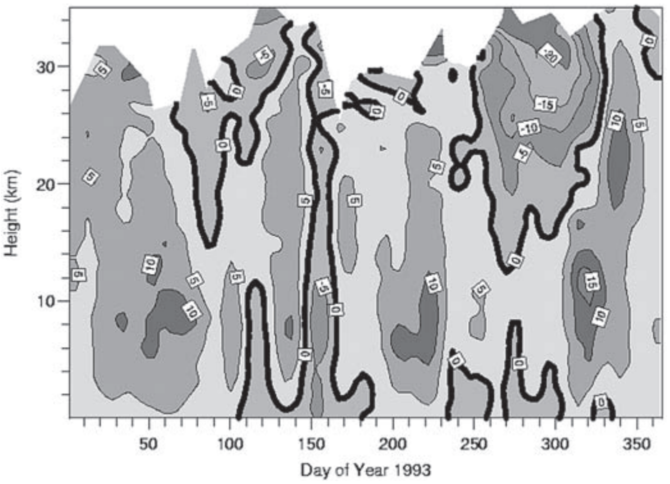

Fig. 12: Time-height section of meridional wind in m s-1 from daily radiosonde soundings in 1993 at GvN station. Positive values denote wind from south to north; negative values denote wind from north to south.

Abb. 12: Höhen-Zeit-Schnitt des Meridionalwindes in m s-1 aus Radiosondierungen 1993 an GvN. Positive Werte bedeuten Winde von Süd nach Nord, negative Werte bedeuten Winde von Nord nach Süd.

While the circumpolar vortex exists, it isolates its interior efficiently from any significant transport of warm air masses from the lower latitudes. The stratospheric winter temperatures inside the vortex – where no solar absorption takes place during polar night – drop frequently below -80 °C (Figs. 13, 14). The coldest ever measured temperature at Neumayer was -96.9 °C at August 23 2003 in a height of 16033 m. Neumayer is normally surrounded by this vortex and cold stratospheric winter temperatures are predominant. In rare cases, the vortex dynamically breaks down during winter (1988, 2002) and much warmer air masses exist above Neumayer.

Recent publications denote a significant warming of the Antarctic winter troposphere (TURNER et al. 2006). The authors analysed long-time radiosonde measurements of nine Antarctic stations covering the whole continent. The data from Neumayer, which have not been taken into account in this

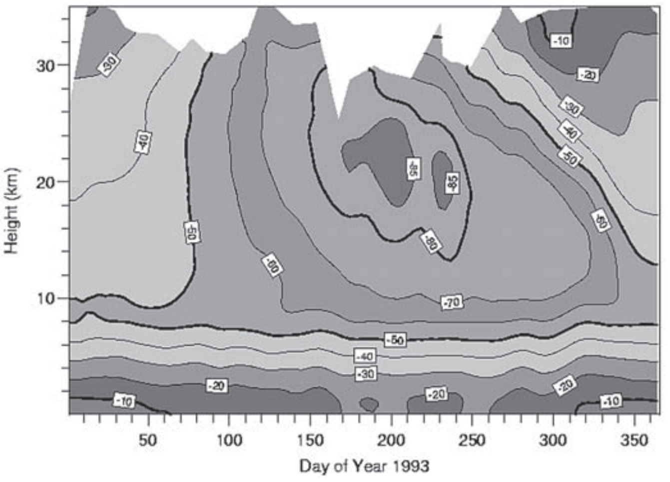

Fig. 13: Time-height section of temperature from daily radiosonde soundings in 1993 at Neumayer Station II.

Abb. 13: Höhen-Zeit-Schnitt der Temperatur aus den täglichen Radiosondierungen von 1993 bei Neumayer-Station II.

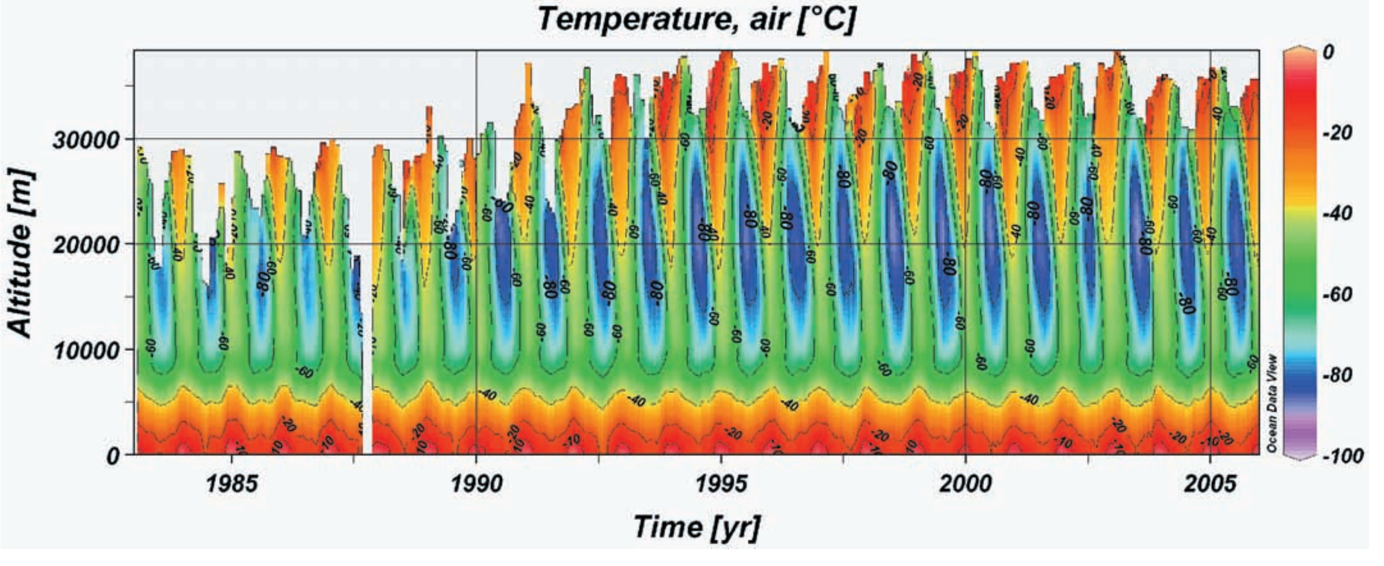

Fig. 14: Time-height section of temperature from daily radiosonde soundings from 1983 to 2005 at Neumayer stations.

Abb. 14: Höhen-Zeit-Schnitt der Temperatur aus den täglichen Radiosondierungen von 1983 bis 2005 an den Neumayer-Stationen.

publication, show a comparable trend, but vice versa (Fig. 15). The winter cooling at Neumayer can be observed in the whole troposphere down to 2 m above ground. Thus, at this moment it seems to be questionable whether the proposed warming of the Antarctic winter troposphere is significant for whole Antarctica.

Surface inversions are a common phenomenon at Neumayer. They are created by radiative cooling typically during anticyclonic conditions. During wintertime the surface inversions can reach heights up to about 2 km. Only from November to February, when short-wave radiation gains more than compensate the long-wave radiative cooling of the surface inversions are rare and are mainly restricted to heights of less than 1 km. During stronger cyclonic events they may vanish completely. The difference between the temperatures at the surface inversion tops and the surface reach values up to 25 K. At Neumayer 75 % of all soundings show an inversion strength of at least 1 K and a minimum height of 50 m. Thus, although surface inversions are a common feature, they are no persistent barrier against vertical air mass exchange, even during wintertime.

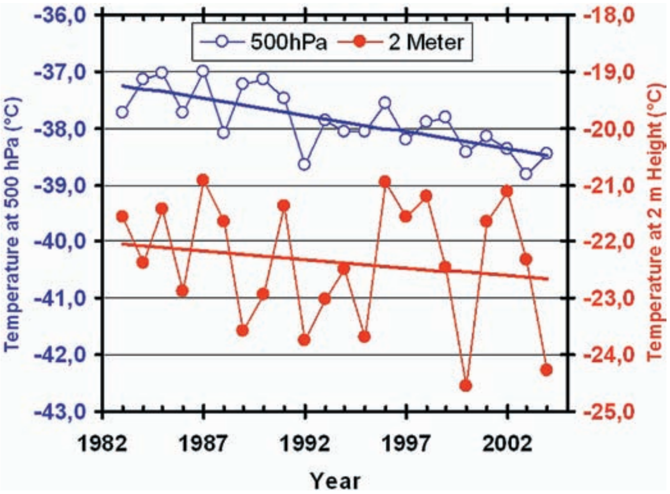

Fig. 15: Time series of the averaged winter (April–September) air temperature of the 2 m (red) and 500 hPa (blue) levels above Neumayer stations.

Abb. 15: Zeitserien der gemittelten Lufttemperatur im Winter (April bis September) in der 2 m (rot) sowie 500 hPa-Ebene (blau) an den Neumayer-Stationen.

Ozone soundings

While the polar vortex is established, the advection of ozone rich and warm air from lower latitudes into the stratosphere of Antarctica is strongly reduced. Thus, during polar night, when no solar uv-radiation can get absorbed from the ozone layer, the stratosphere cools down to temperatures below -78 °C which allows the formation of polar stratified clouds. With the increasing meridional temperature gradient across the polar vortex the wind velocities of the vortex increase. This thermal wind has mean zonal values well above 50 m s-1 and lead to a further separation of the air masses inside the vortex.

After the Antarctic winter, when the sun rises above the horizon and polar stratified clouds are frequent, the solar radiation has the potential to destroy ozone molecules very efficiently. This happens normally during the first half of September. Afterwards, the ozone layer within the whole vortex is severely depleted or locally destroyed completely. The area with a vertically integrated ozone amount of less than 200 Dobson is called ozone hole. The ozone hole frequently covers the total area within the stratospheric vortex. The worldwide increasing anthropogenic CFC concentration led to an increasing ozone depletion.

The decreasing ozone concentrations in the Antarctic stratosphere lead to a diminished absorption of uv-radiation. Thus, the warming of the Antarctic stratosphere during spring is reduced. The isolating polar vortex – a thermal wind – resists longer and the possibility for polar stratified clouds leading to further ozone depletion is rising. This positive feedback mechanism ends when the stratosphere gets warm enough that polar stratified clouds cannot exist any longer. The temperature gradient across the polar vortex becomes weaker till the vortex loses its isolating character and warm, ozone rich air from lower latitudes can penetrate into the Antarctic stratosphere. This happens normally during November. In rare cases the stratospheric vortex is dynamically unstable and gets destroyed during winter. Comparable high temperatures and high ozone concentrations during the following spring are the consequences.

In 1992 a weekly ozone sounding programme (started in 1985 at the near by Georg Forster Station) was transfered to Neumayer Station II. Both stations are situated comparably within the area normally surrounded by the Antarctic stratospheric vortex. The measurements contribute to the "Global Atmospheric Watch" (GAW) as well as to the "Network for the Detection of Stratospheric Change" (NDSC). As can bee seen clearly (Fig. 16) the ozone layer above the Forster/Neumayer stations shows a pronounced annual cycle. High ozone partial pressures are measured at altitudes around 20 km from December/January till end of August. This ozone originates from lower latitudes while the polar stratospheric vortex did not exist. Later, it stays more or less without mayor concentration changes inside the isolated vortex. From January to August the ozone layer descents about 3 km. The prevailing katabatic winds at the surface of Antarctica, leading to a mass transport out of the area of the polar vortex, are the reason. During Antarctic spring (September to November) the ozone layer vanishes more or less completely. Within the troposphere the ozone partial pressure is comparable constant with time and height. Close to the surface an annual variation with maxima during polar night and minima during polar day is evident.

The ozone layer during Antarctic spring shows remarkable inter-annual variations as well as an overall reduction of the ozone partial pressure with time. If the time series from the Neumayer site gets extended with the measurements taken from the near-by Georg Forster Station these effects are even more pronounced (Fig. 17). The ozone reduction is strongly correlated with a cooling of the stratosphere. Corresponding variations or a significant trend during other seasons could not be ascertained. From 1985 till 1989 a biannual oscillation of the spring ozone concentrations is evident. It is strongly correlated with the temperature in the height of the ozone layer. LABITZKE et al. (1992) explained this behaviour as dynamically induced from the quasi-biannual oscillation of strato-

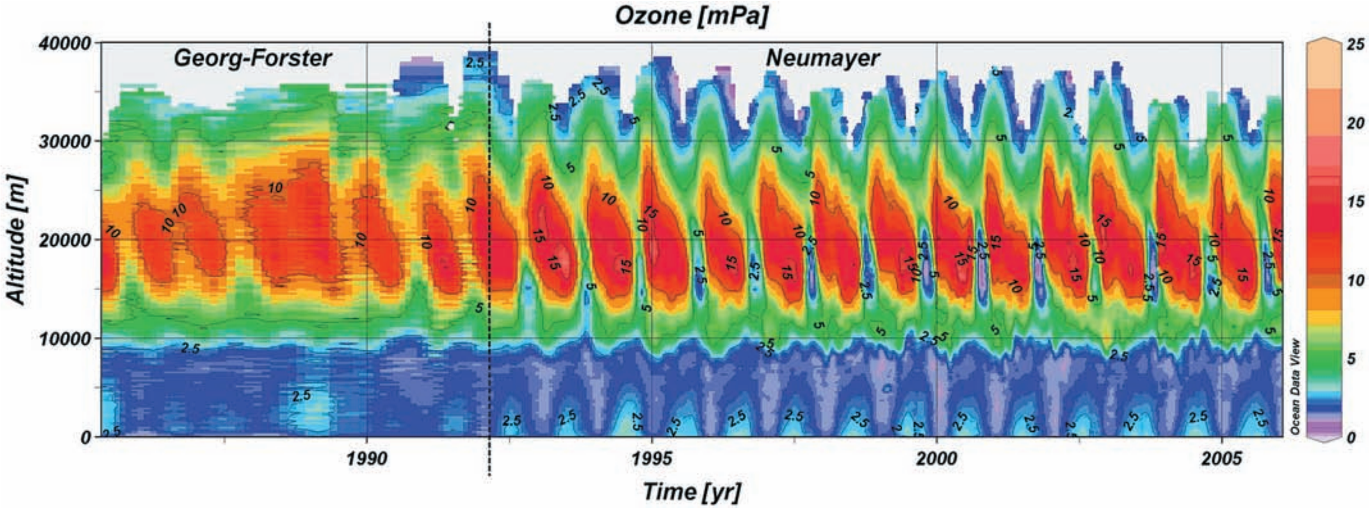

Fig. 16: Time-height section of ozone partial pressure above Forster/Neumayer Station II from 1985 to 2005.

Abb. 16: Höhen-Zeit-Schnitt des Ozonpartialdrucks über Forster/Neumayer Station II von 1985 bis 2005.

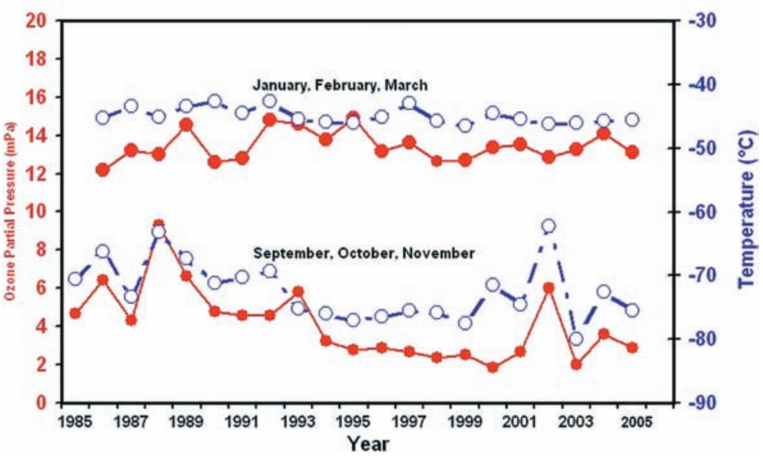

Fig. 17: Time series of seasonally averaged ozone partial pressures (solid red line) and temperatures (dotted blue line) in the 70 hPa level above Georg Forster Station and Neumayer Station II.

Abb. 17: Zeitserie des jahreszeitlich gemittelten Ozonpartialdrucks (durchgezogene rote Linie) und der Temperatur (gestrichelte blaue Linie) in der 70 hPa-Ebene über den Stationen Georg-Forster und Neumayer II.

spheric wind above the equator. In the nineties, no biannual oscillation of the spring ozone concentration was measured any longer. The data show a more or less continuously reduction of the ozone concentration and a cooling of the air around 70 hPa. CRUTZEN et al. (1986) explained this kind of behaviour as a chemically effect with respect to the worldwide rising anthropogenic CFC concentrations.

Between 2001 and 2004 the springtime ozone concentrations measured above an altitude of 20 km were rising again. This finding was obvious in the data from NM-II as well as from the Polar Ozone and Aerosol Measurement satellites (POAM). This effect was discussed as the beginning of the recovery of the "ozone hole" after the worldwide ban of nearly any CFC product. Recent results (HOPPEL et al. 2005) from NM-II support the assumption that the recovery of the ozone hole does not take place yet. Especially, the very high temperatures and ozone concentrations during spring 2002 could be explained as a result from a dynamically break down of the Antarctic stratospheric vortex during winter. Although the CFC concentrations in the troposphere are significantly falling and start to fall in the stratosphere the recovery of the ozone layer will most probably not take place within the next decade.

As a third contribution to the changes in the polar ozone layers solar activities are discussed. As an example Sinnhuber et al. (2006) found a strong correlation between the negative ozone anomalies and the flux of energetic electrons in the radiation belt, which is modulated by the eleven-year solar cycle. These findings suggest a previously unrecognized mechanism by which solar variability impacts on climate through changes in polar ozone.

Radiation measurements

The averaged surface radiation fluxes at the Neumayer site (Fig. 18) are denoted positive if the surface gains energy. Positive fluxes contribute to warm the atmospheric boundary layer or snow, evaporate or sublimate snow, or melting processes. Energy losses, associated with cooling, freezing or condensation, are denoted negative. With an averaged global radiation flux of 118 W m^{-2} Neumayer receives a comparable high energy input from the sun, but due to the high albedo of the snow surface (84 %) 99 W m^{-2} gets reflected without contributing as local energy input. The remaining net short-wave radiation flux of 19 W m^{-2} is very small. Low surface temperatures are the consequence.

Caused by wind snow surfaces tends to create ripples, so called sastrugies. They have a height scale of up to 1 m and a length scale of about 10 m. During direct sunshine they can

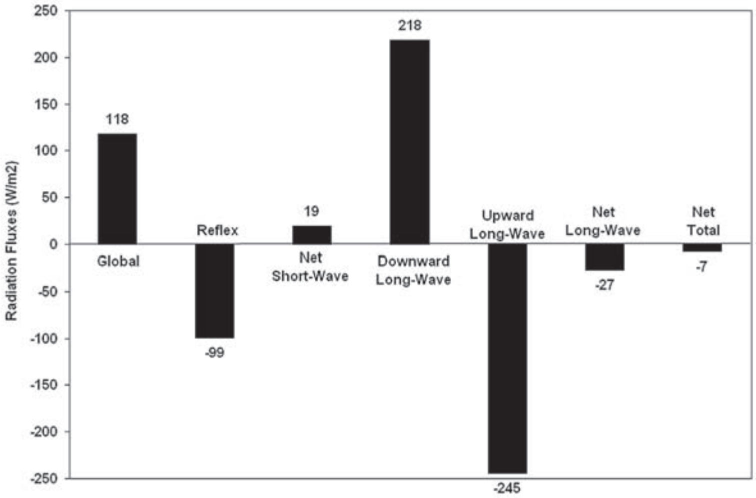

Fig. 18: Mean surface radiation fluxes at Neumayer stations from 1983 to 2005.

Abb. 18: Mittlere Strahlungsflüsse am Boden bei den Neumayer-Stationen von 1983 bis 2005.

influence instantaneous albedo measurements significantly. Especially during low solar elevations they case shadows or act as focussing disks. Sastrugies make instantaneous clear sky albedo measurements to a rather questionable task. Fortunately, daily averages are still quite unaffected from sastrugies and no problems remain if the global radiation is totally diffuse. Albedo measurements at stations with a permanent snow surface, such as an ice shelf, suffer from a second problem. Drifting snow tends to get accumulated with respect to the prevailing wind direction behind the sensors. Even behind delicate platforms (see Fig. 4) the snow surface becomes inclined. This process may take years till it reaches equilibrium. At Neumayer the prevailing easterly winds lead to a daily cycle in the albedo measurements during direct sunshine. Monthly averaged albedo values are quite constant. They only show a slight tendency towards lower value during summer caused by higher solar elevations and some seldom occurring melting events. During overcast days the averaged albedo is 86 %, the averaged clear sky albedo is 5 % less.

The snow surface emits the average upward long-wave radiation flux of 245 W m^{-2}. This corresponds to a black body radiation of -16.8 °C which is very close to the average air temperature of -16.1 °C in 2 m height. The black body approximation holds nearly perfect for the snow surface at Neumayer. Thus, the upward long-wave radiation flux can be used to determine the surface temperature quite accurately. In the average the downward long-wave radiation fluxes is 218 W m^{-2}. This is significantly lower than the averaged thermal emitted upward long-wave radiation flux from the surface and results in an overall net long-wave radiation flux of -27 W m^{-2}. The downward long-wave radiation flux depends strongly on clouds. During clear sky situations the flux can be parameterized with the Stefan-Boltzmann radiation law, the 2 m air temperature and an empirically derived effective atmospheric emissivity of 0.765 (KÖNIG-LANGLO et al. 1994). Skies totally obscured by opaque clouds lead to an effective atmospheric emissivity of about unity and a net long-wave radiation flux of about zero at the snow surface.

The energy gains from the short-wave budget normally exceed the net long-wave energy losses. The overall net total radiation is only -7 W m^{-2}, which is more than one order of magnitude less compared with the single fluxes. In the long-time average the net total radiation has to be compensated by atmospheric advection processes. Small positive monthly averaged net total radiation fluxes are observed only in November, December and January (Fig. 19). During the rest of the year negative net total radiation fluxes exist. Within the 25-years average they never fall below -21 W m^{-2}. The stabilizing negative feedback mechanism between the surface temperature and the net total radiation prevent more negative net total radiation fluxes.

The mean annual diffuse sky radiation is 76 W m^{-2} at Neumayer. In relation to the mean annual global radiation the relative mean annual diffuse sky radiation is 62 %. In the average the sun shines at Neumayer 1429 hours per year which is 33.2 % of the theoretically possible sunshine duration. The relative sunshine duration is comparable constant throughout the whole summer. Neumayer becomes more and more sunny. While the relative sunshine duration was frequently below 30 % at the beginning of the measurements, values about 40 % are nowadays common.

The daily averaged measured global radiation fluxes vary only within rather distinct limits from the corresponding extraterrestrial insolation calculated after IQBAL (1983), (Fig. 20). The upper envelope of the data points obviously present cloud free days while days totally obscured by opaque clouds led to

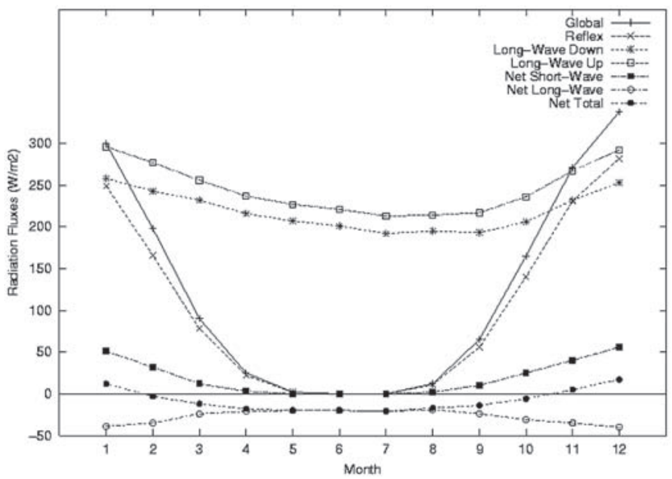

Fig. 19: Annual cycle of mean monthly averaged surface radiation fluxes at Neumayer stations from 1983 to 2005.

Abb. 19: Jahresgang der mittleren Monatsmittel von Strahlungsflüssen am Boden der Neumayer-Stationen von 1983 bis 2005.

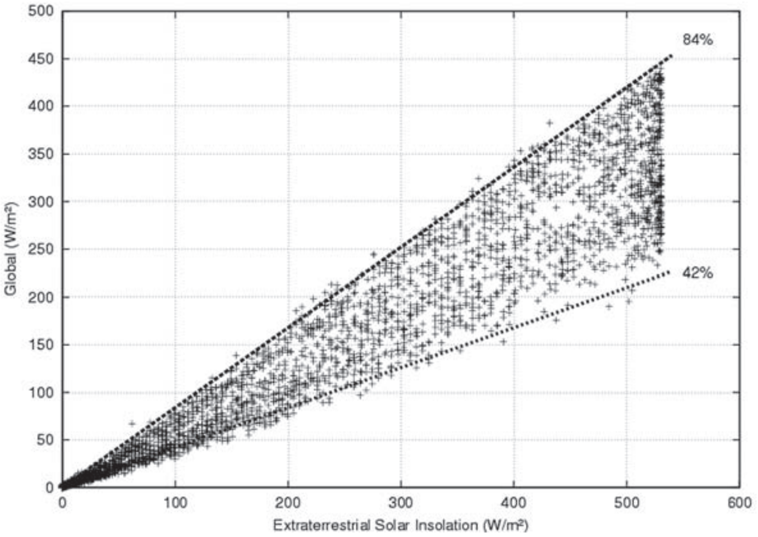

Fig. 20: Scatter plot of the daily averaged global radiation *versus* the daily averaged extraterrestrial insolation at Neumayer stations from 1983 to 2005.

Abb. 20: Scatterplot der täglich gemittelten Globalstrahlung in Abhängigkeit der täglich gemittelten extraterrestrischen Einstrahlung an den Neumayer-Stationen von 1983 bis 2005.

results at the lower envelope. Both envelopes are more or less linear. At totally cloud free days up to 84 % of the extraterrestrial insolation reaches the ground at Neumayer. This extremely high value denotes that rayleigh extinction above Neumayer dominates the extinction caused by aerosols. Even during totally cloudy days at least 42 % of the extraterrestrial insolation is measured as global radiation at Neumayer. In other regions of the world clouds influence the global radiation much more. This small cloud forcing at Neumayer is a result of the high mean albedo of the permanently snow covered Ekstrøm Ice Shelf. Multi-reflection between the snow surface and the cloud ceiling compensate significant parts of the cloud extinction processes.

The determination of trends in the mean radiation fluxes is one goal of the Baseline Surface Radiation Network (OHMURA et al. 1998). This is a rather difficult task since the measurement accuracy is in the order of possible signals. Only carefully performed and homogenized long-time measurements may be used for such kind of trend analysis. WILD et al. (2005) analysed data from Neumayer and found a remarkable increase in the global radiation between 1993 and 2002. This trend is in good agreement to the increasing sunshine duration at Neumayer and the reduced downward long-wave radiation fluxes. Most probably a change from opaque low clouds toward more transparent high clouds took place at Neumayer during the last decades. The reason for this change is unclear yet. A local change in the atmospheric circulation pattern around Neumayer may be one reason.

Meteorological forecast centre

During the summer season the meteorological observatory at Neumayer Station II (NM-II) offers a detailed and individual weather forecast service for all activities in Dronning Maud Land. This service is performed in close cooperation between the AWI and the German Weather Service (DWD). The increasing flight activities (Fig. 21) within the Dronning Maud Land and especially the intercontinental air link between Cape Town and Novolazarevskaja (DROMLAN) made the establishment of this service mandatory. NM-II Station was chosen for the

Fig. 21: The Dronning Maud (Queen Maud) Land and the typical flight routes within the DROMLAN air network.

Abb. 21: Darstellung der typischen Flugverbindungen im Queen Maud (Dronning-Maud) Land im Rahmen des DROMLAN-Flugnetzes.

forecast service due to its central position within the Dronning Maud Land, its good communication facilities including a permanent satellite data link (128 kb, Intelsat), and the modern infrastructure of the meteorological observatory.

The forecasts base on special model outputs from the European Centre for Medium-Range Weather Forecasts (ECMWF), the Antarctic Mesoscale Prediction System (AMPS) and the Global-Model of the German Weather Service (GME). New outputs are available twice a day. They are used to cover a forecast period up to one week. For short-term forecasts and flight-following activities the satellite picture receiving station from NM II (HRPT, SeaSpace) is of great importance. Up to 20 satellite passes can be obtained daily (NOAA 12, 14, 15, 16, 17, 18 DMSP 12, 13, 14, and 15). Visual as well as infrared pictures get geocoded automatically on a variety of masters covering the synoptic scale (2500 x 5000 km, Fig. 22) down to local scale with a spatial resolution up 500 x 500 m at any place in the Dronning Maud Land (Fig. 23).

All information from the GTS including the three-hourly synoptic observations and daily upper air soundings are available via the permanent data link at any time. Information from surrounding automatic weather stations transponding via ARGOS but not included into the GTS get extracted automatically from the digital NOAA-satellite data stream received at NM-II.

Due to many previous voyages on board of the German RV "Polarstern" the summer forecasters from NM-II are well experienced with the typical weather phenomena of Antarctica and its surrounding oceans. The forecaster can be reached during summer at any time from all DROMLAN members by mail, fax, telex, phone, and by short-wave communication. Typically, more than 1000 forecasts get performed in one summer season for about 20 different field parties, ships, stations and especially aircrafts. It is obvious, that this service contributes considerably to the increase the safety of the ambitious projects going on in the Dronning Maud Land. Furthermore, it helps to reduce weather induced idle times of expensive flight operations to a minimum. During winter no official forecast service is available. Nevertheless, the wintering meteorologist is able to give certain weather advices on request for all NM-II activities and the surrounding stations.

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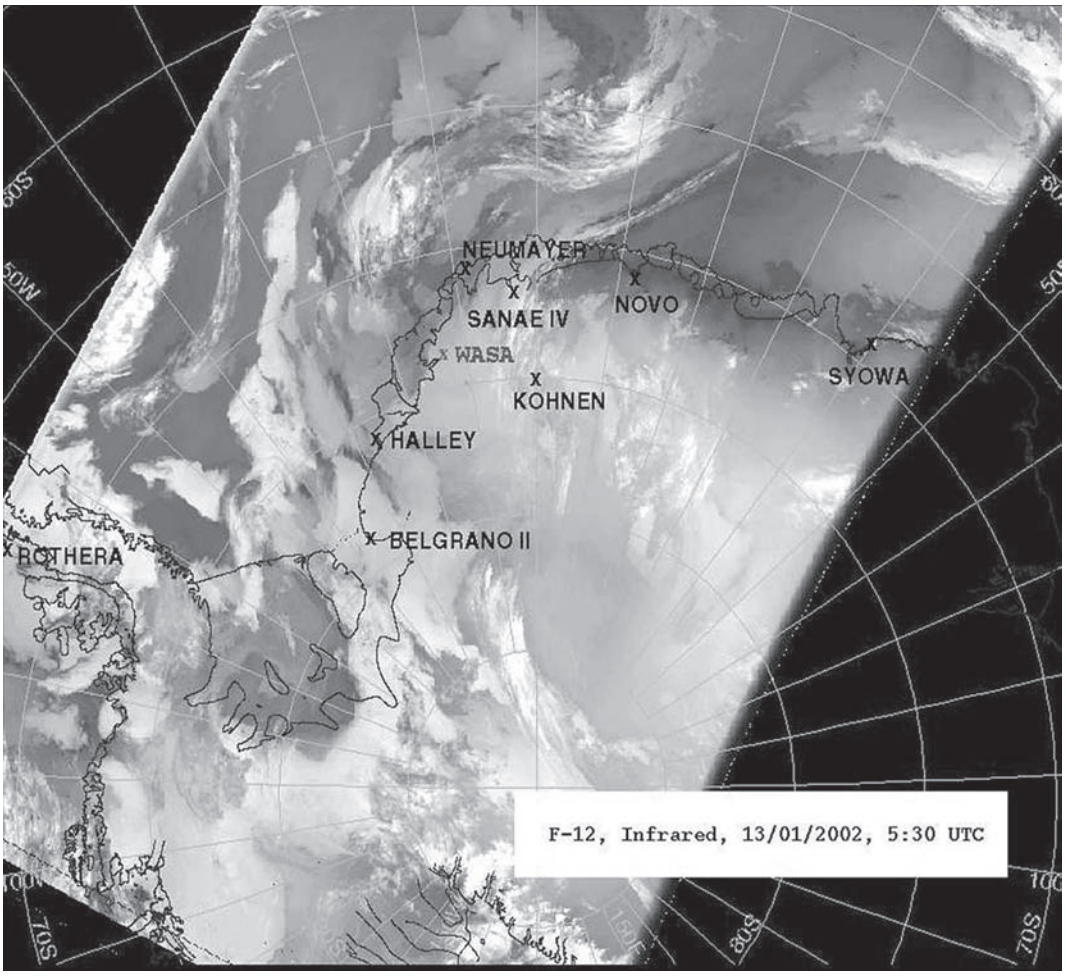

Fig. 22: Example of a full scale satellite picture received and processed at Neumayer Station II.

Abb. 22: Beispiel eines auf der Neumayer-Station II empfangenen und prozessierten großskaligen Satellitenbildes.

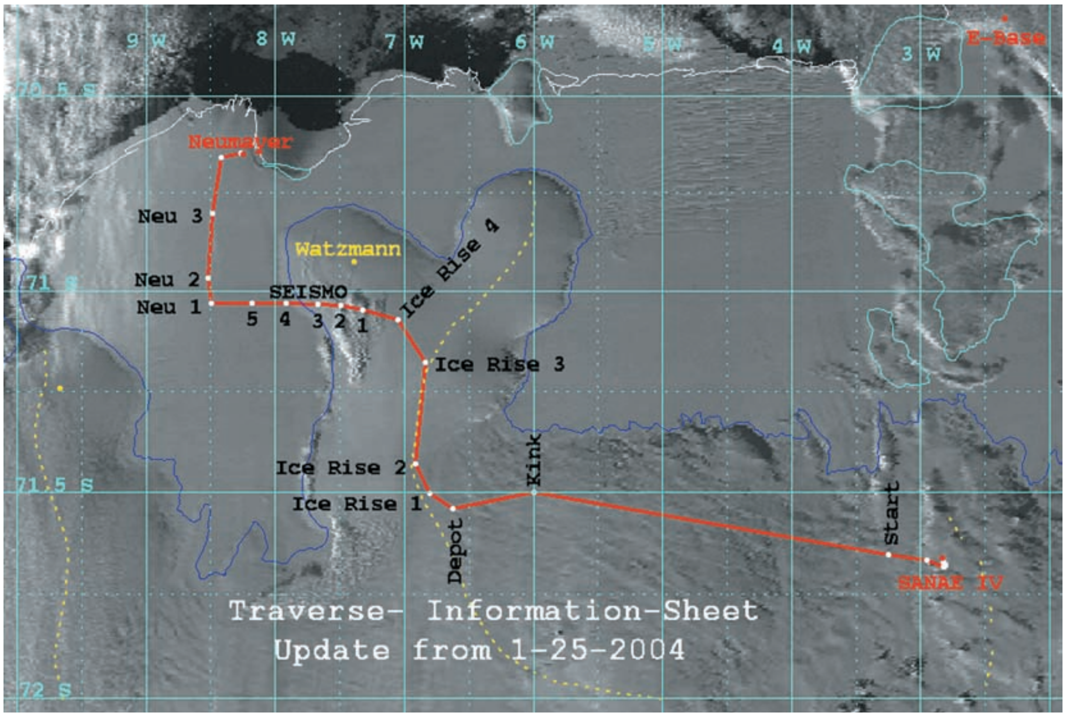

Fig. 23: Example of a local scale satellite picture received and processed at Neumayer II.

Abb. 23: Beispiel eines auf der Neumayer-Station II empfangenen und prozessierten lokalskaligen Satellitenbildes.

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