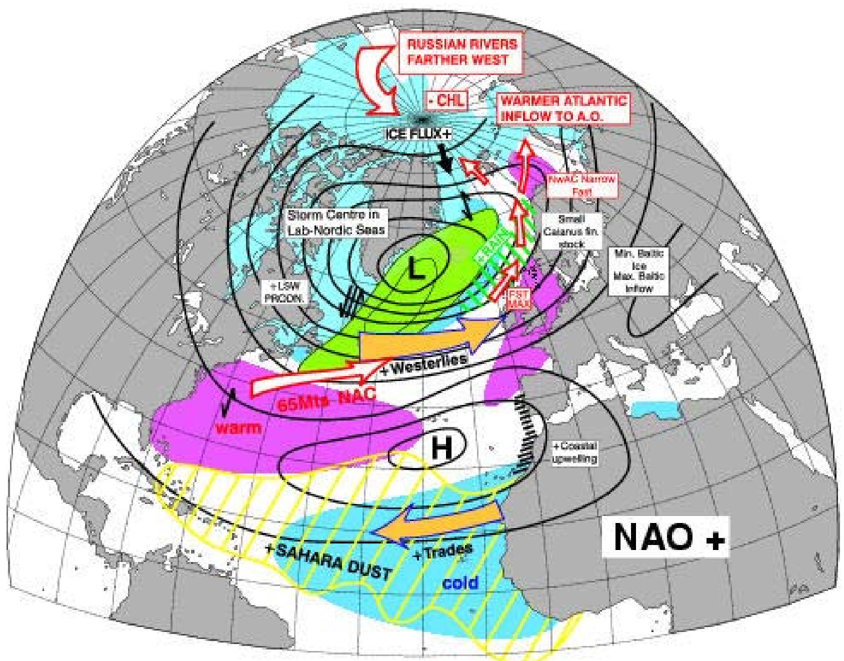
Analysis of spatio-temporal pattern

The Phases of the North Atlantic Oscillation



During the high phase of the NAO westerlies in the North Atlantic are enhanced, resulting in mild and wet winter conditions over Northern Europe. (Courtesy of CEFAS, UK)

AV/D1/99-1

The **North Atlantic oscillation (NAO)**

is a climatic phenomenon in the North Atlantic Ocean of fluctuations in the difference of sea-level pressure between the Icelandic Low and the Azores high.

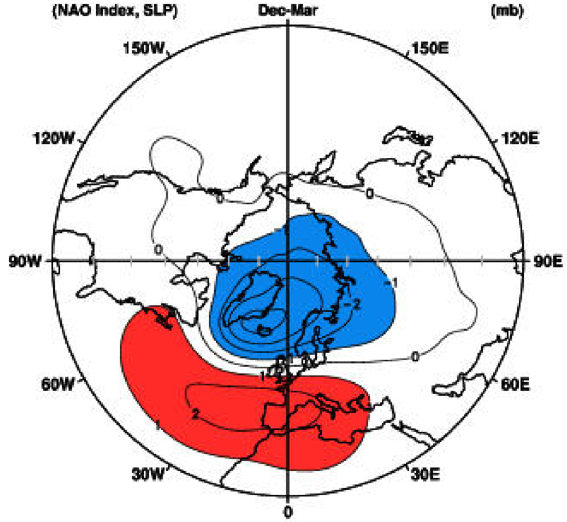
It controls the strength and direction of westerly winds across the North Atlantic

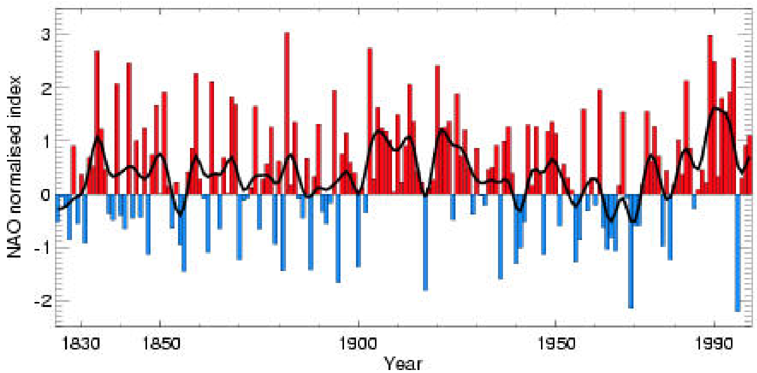
The NAO was discovered in the 1920s by Sir Gilbert Walker. The NAO is one of the most important drivers of climate fluctuations in the North Atlantic and surrounding continents.

Analysis of spatio-temporal pattern

- NAO, ENSO
- Definitions
- Practical work

The North Atlantic Oscillation





Upper panel: Observed Dec-March change in SLP associated with a 1 standard deviation change in the NAO index (after Hurrell, 1995, Science, 269, 676-679).

Lower Panel: Winter (December to March) index or the NAO based on the difference of normalized pressure between Lisbon, Portugal and Stykkisholmur, Iceland from 1864 to 1995. The SLP anomalies at each station were normalized by division of each seasonal pressure by the long-term mean (1864-1995) standard deviation. The heavy solid line represents the meridional pressure gradient smoothed with a low pass filter with seven weights (1,3,5,6,5,3, and 1) to remove fluctuations with periods less than 4 years (after Hurrell, 1995, Science, 269, 676-679, this version: courtesy of T. Osborn, CRU, UEA.

LB/D1/99-1

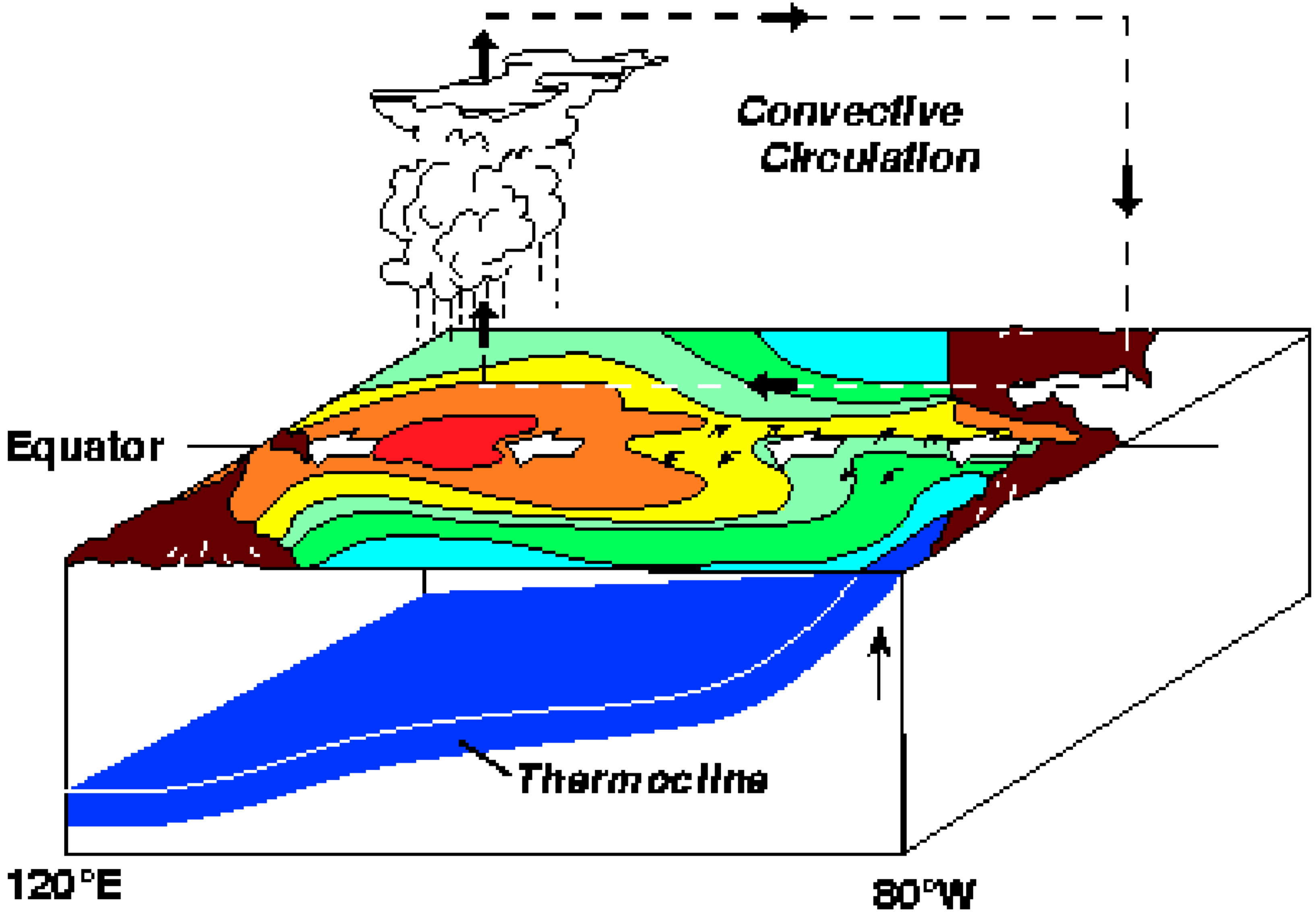
El Niño-Southern Oscillation (ENSO)

El Niño and **La Niña** are important temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean.

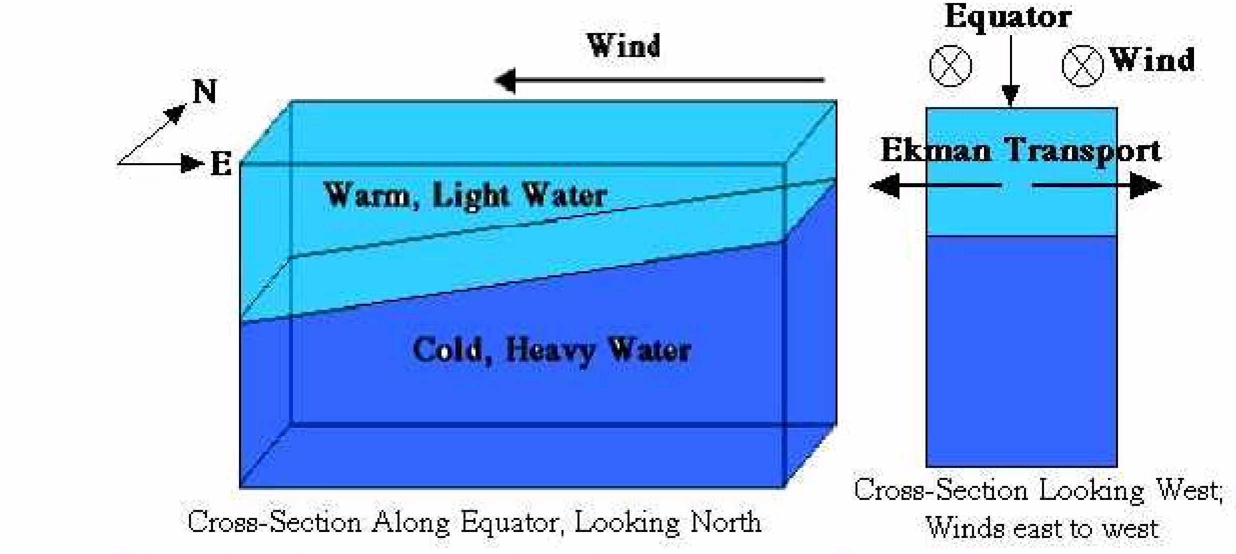
The name El Niño, from the Spanish for "the child", refers to the Christ child, because the phenomenon is usually noticed around Christmas time in the Pacific Ocean off the west coast of South America. La Niña means "the little girl".

These effects were first described in 1923 by Sir Gilbert Thomas Walker from whom the Walker circulation, an important aspect of the Pacific ENSO phenomenon, takes its name. The atmospheric signature, the **Southern Oscillation** (**SO**) reflects the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin.

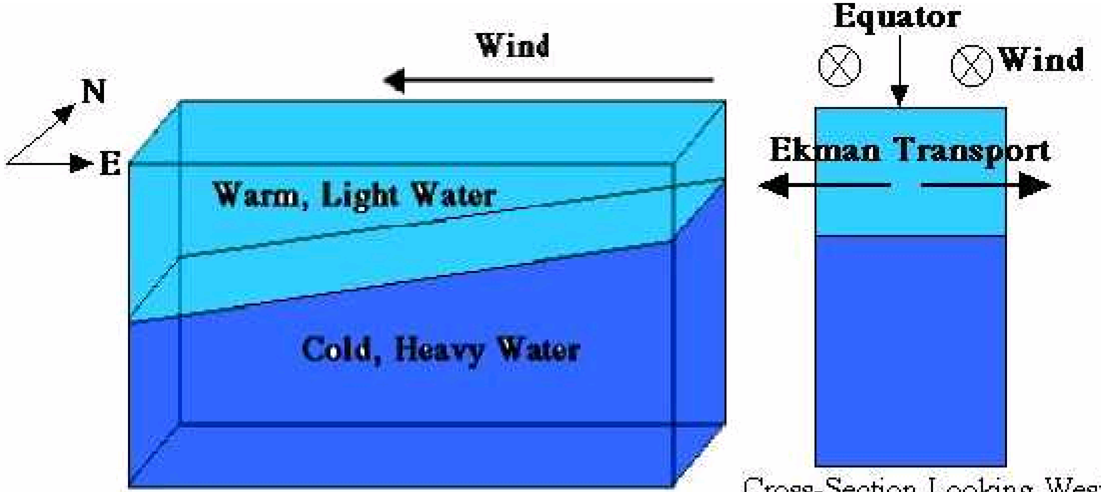
Normal Conditions



Change in the Ekman transport

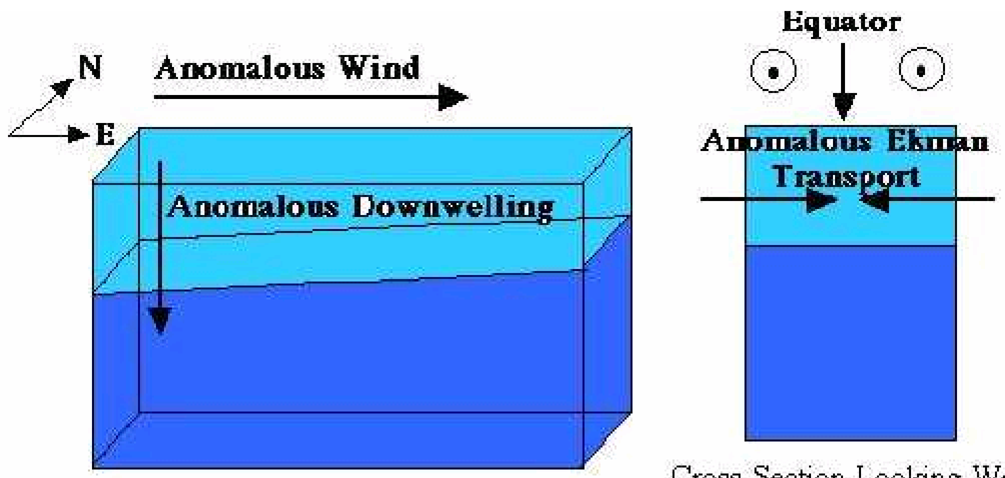


Change in the Ekman transport



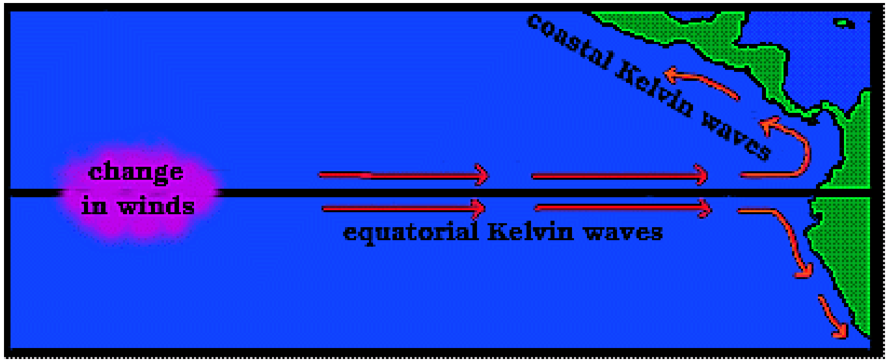
Cross-Section Along Equator, Looking North

Cross-Section Looking West; Winds east to west

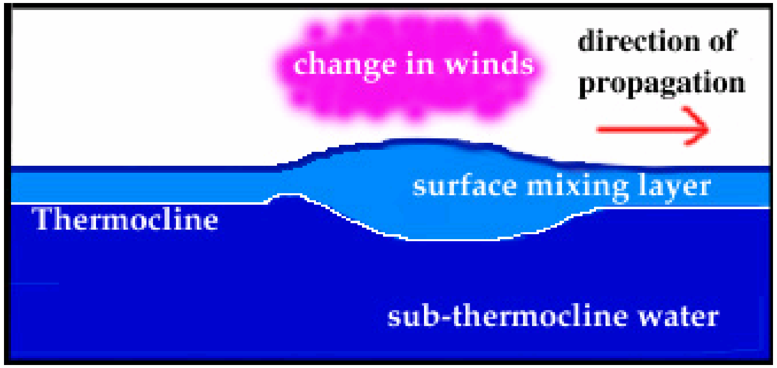


Cross-Section Along Equator, Looking North

Cross-Section Looking West; Anomalous Winds west to east



There are two types of Kelvin waves, coastal and equatorial, and they are both gravity driven and non-dispersive. They are often excited by an an abrupt change in the overlying wind field, such as the shift in the trade winds at the start of El Niño.



The surface waves are very fast moving, typically with speeds of ~2.8 m/s, or about 250 kilometers in a day. A Kelvin wave would take about 2 months to cross the Pacific from New Guinea to Peru.

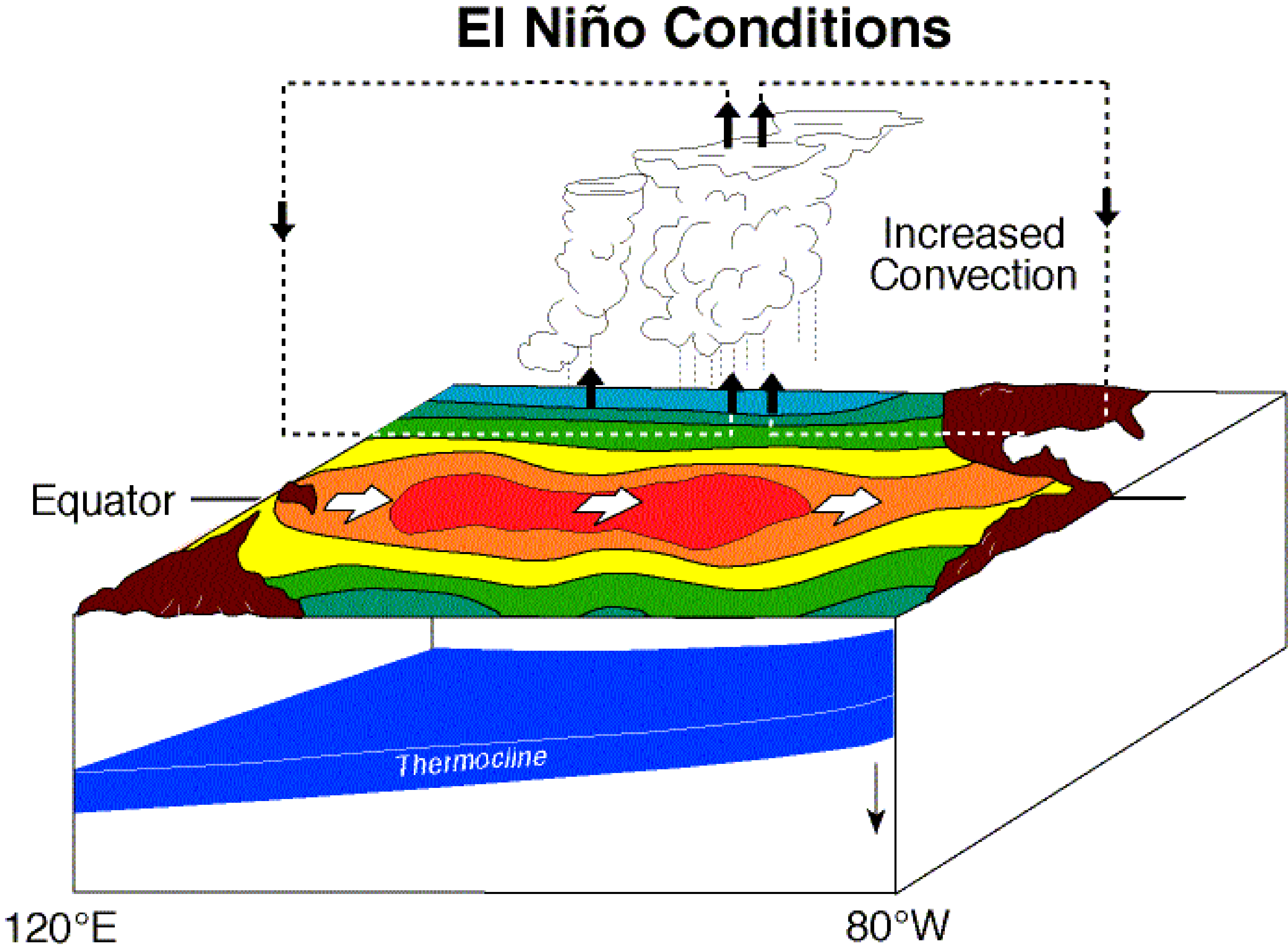
Kelvin wave

A type of low-frequency gravity wave trapped to a vertical boundary, or the equator, which propagates anticlockwise (in the Northern Hemisphere) around a basin. The flow is parallel to the boundary and in geostrophic balance with the pressure gradient perpendicular to the boundary.

The velocity normal to the boundary is identically zero.

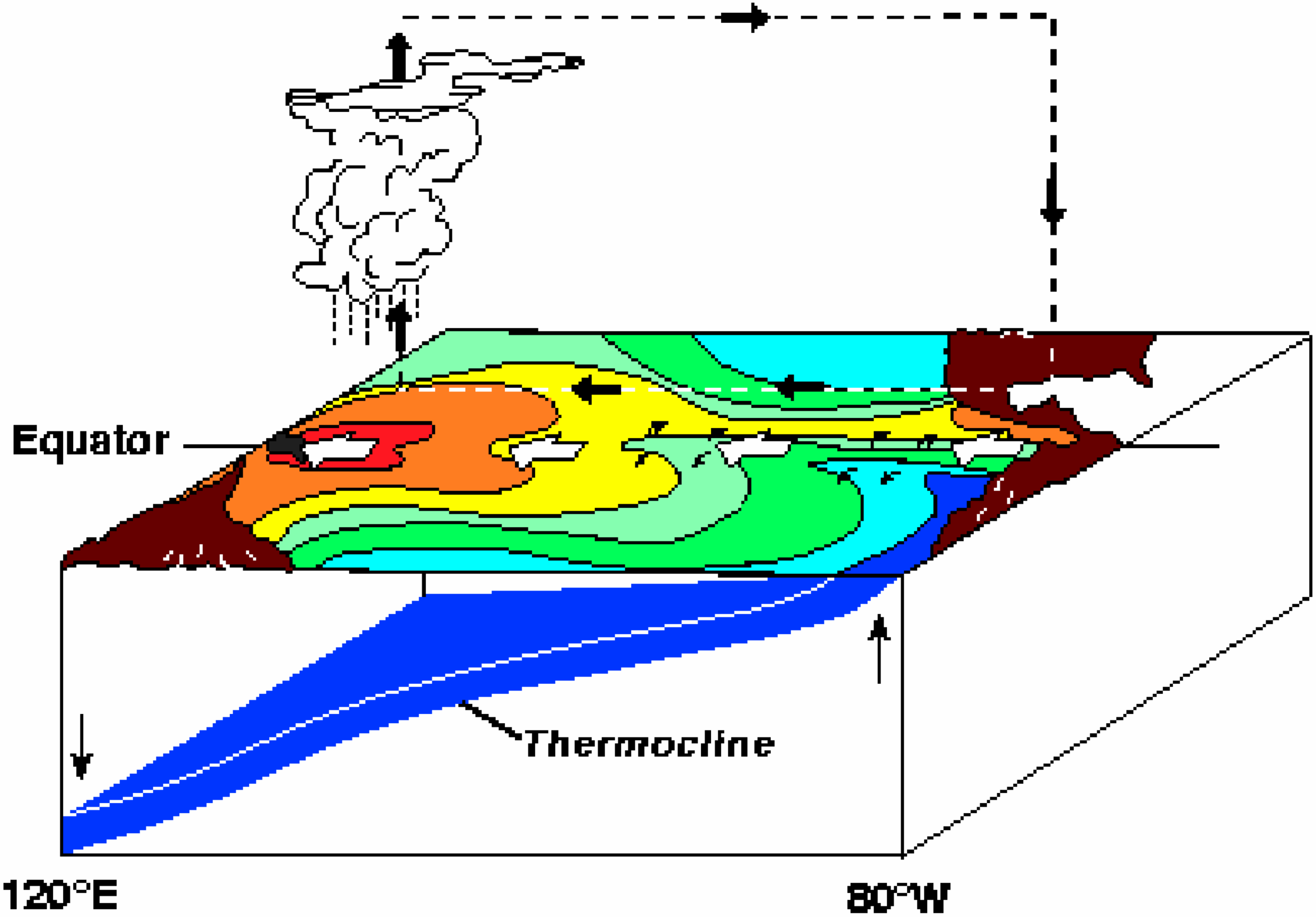
The wave height decreases exponentially from the side wall with an *e*-folding length scale equal to the Rossby radius of deformation

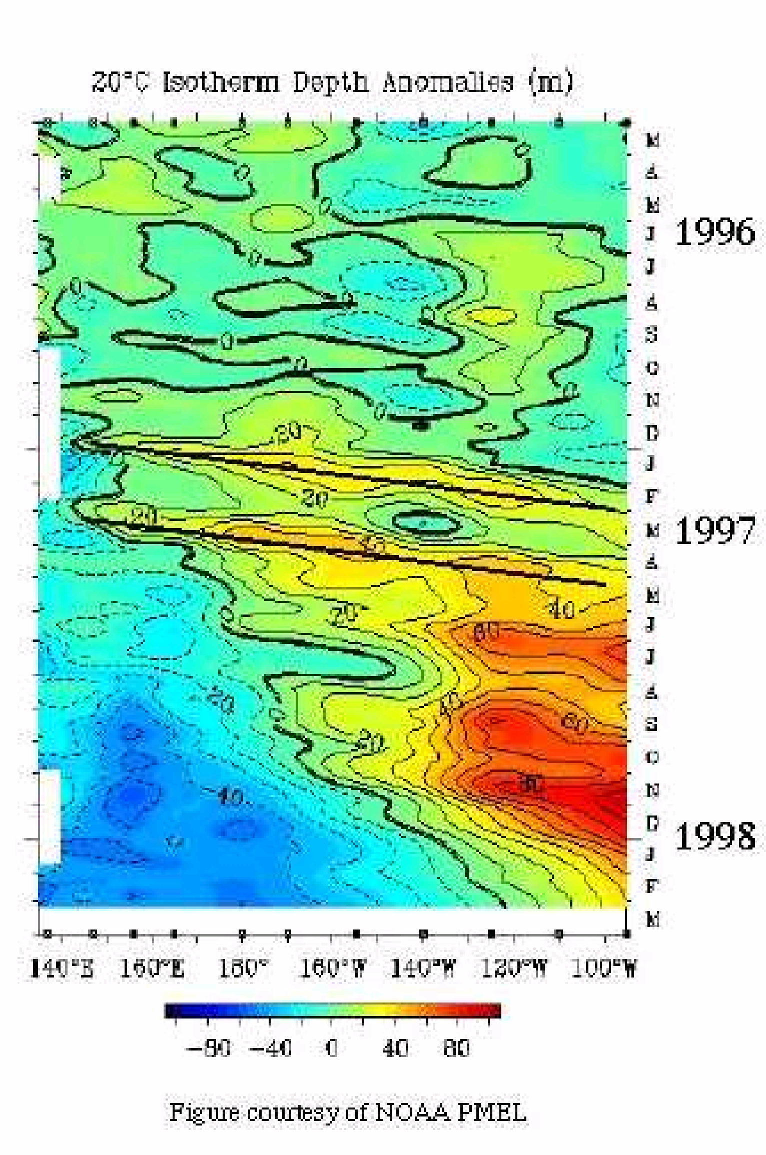
In the shallow water approximation the waves are nondispersive with frequency w = c k, in which *k* is the along-boundary wavenumber $c = (gH)^{1/2}$,



El Niño Conditions
Increased
Convection
Equator
Thermocline
120°E
80°W

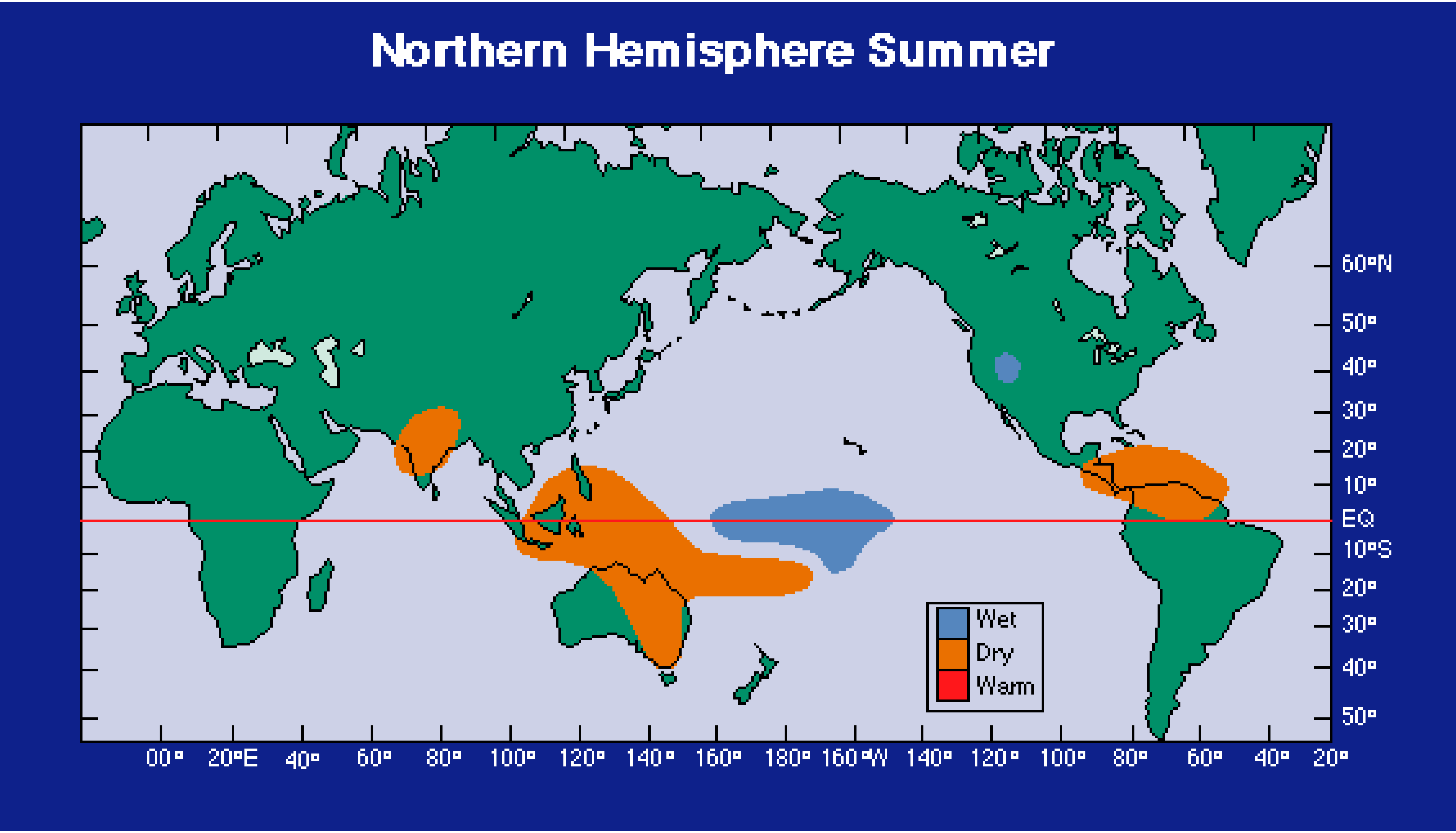
La Niña Conditions

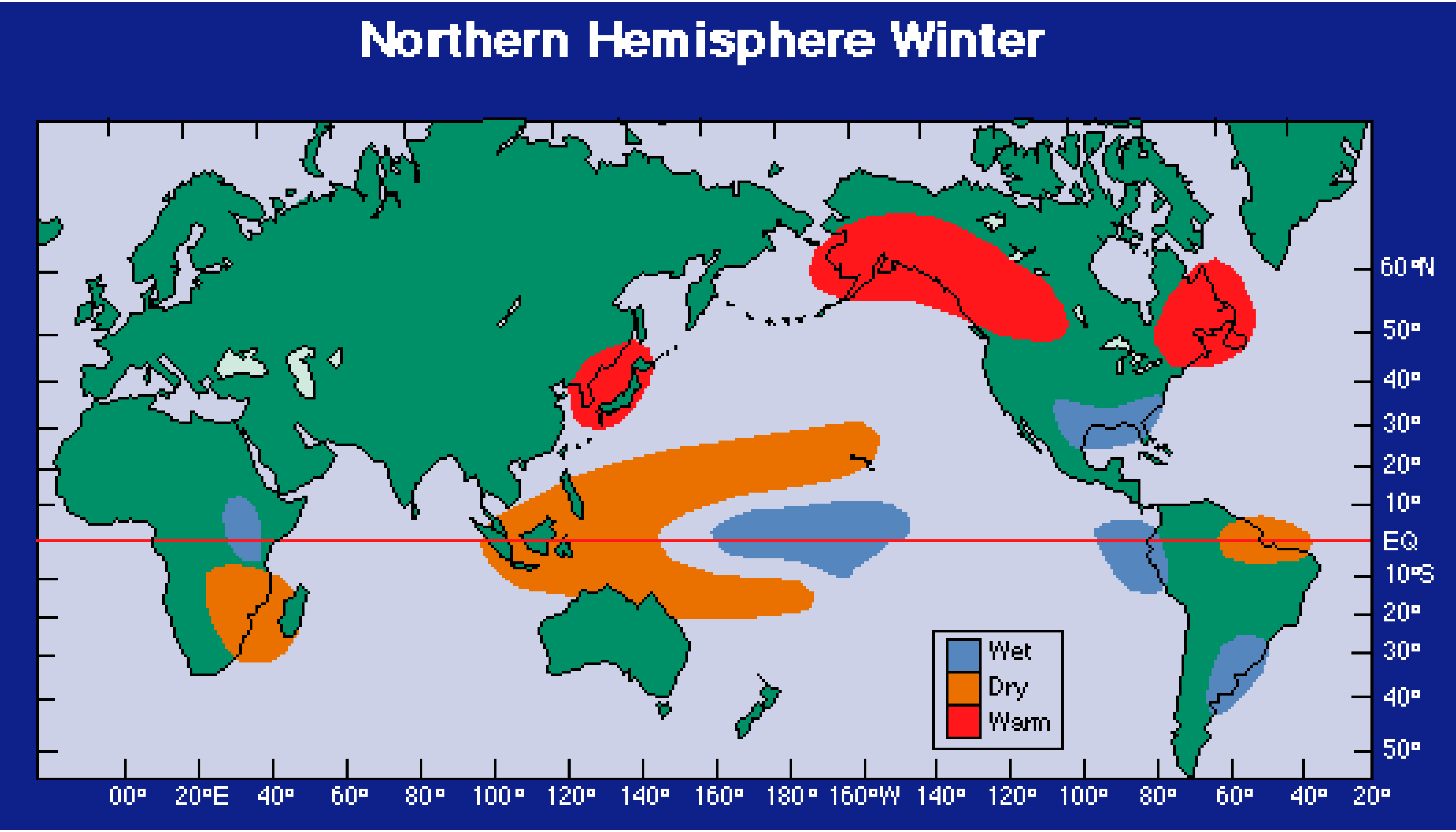




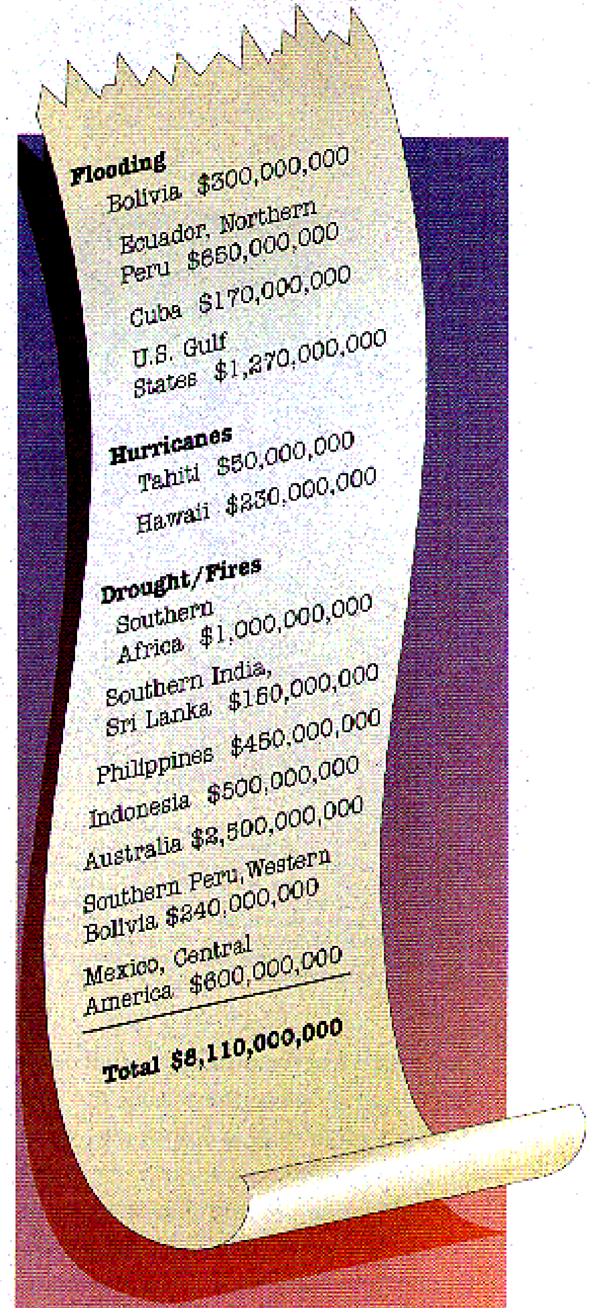
Kelvin waves can cross the Pacific in two months. The amplitude of the Kelvin wave is several tens of meters along the thermocline, and the length of the wave is thousands of kilometers (1 degree of longitude = 111 km)

Eastward movement is indicated by the slope in time from west to east. These waves set up a change in the warm water thickness of the Eastern Pacific beginning in March.


Northern Hemisphere Summer
60°N
50°
40°
30°
20°
10°
EQ
10°S
20°
30°
40°
50°
00°
20°E
40°
60°
80°
100°
120°
140°
160°
180°
160°W
140°
120°
100°
80°
60°
40°
20°
Wet
Dry
Warm

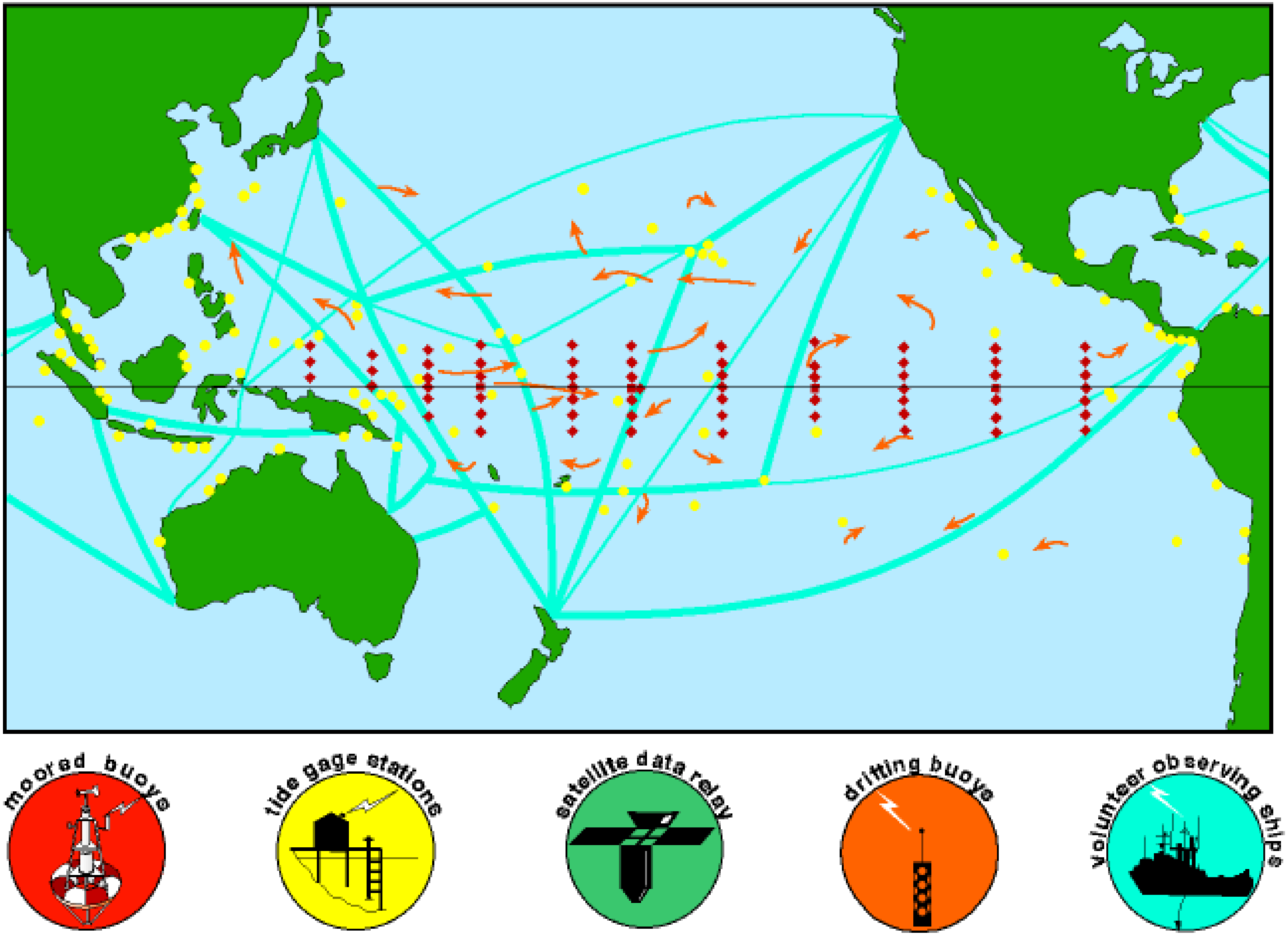


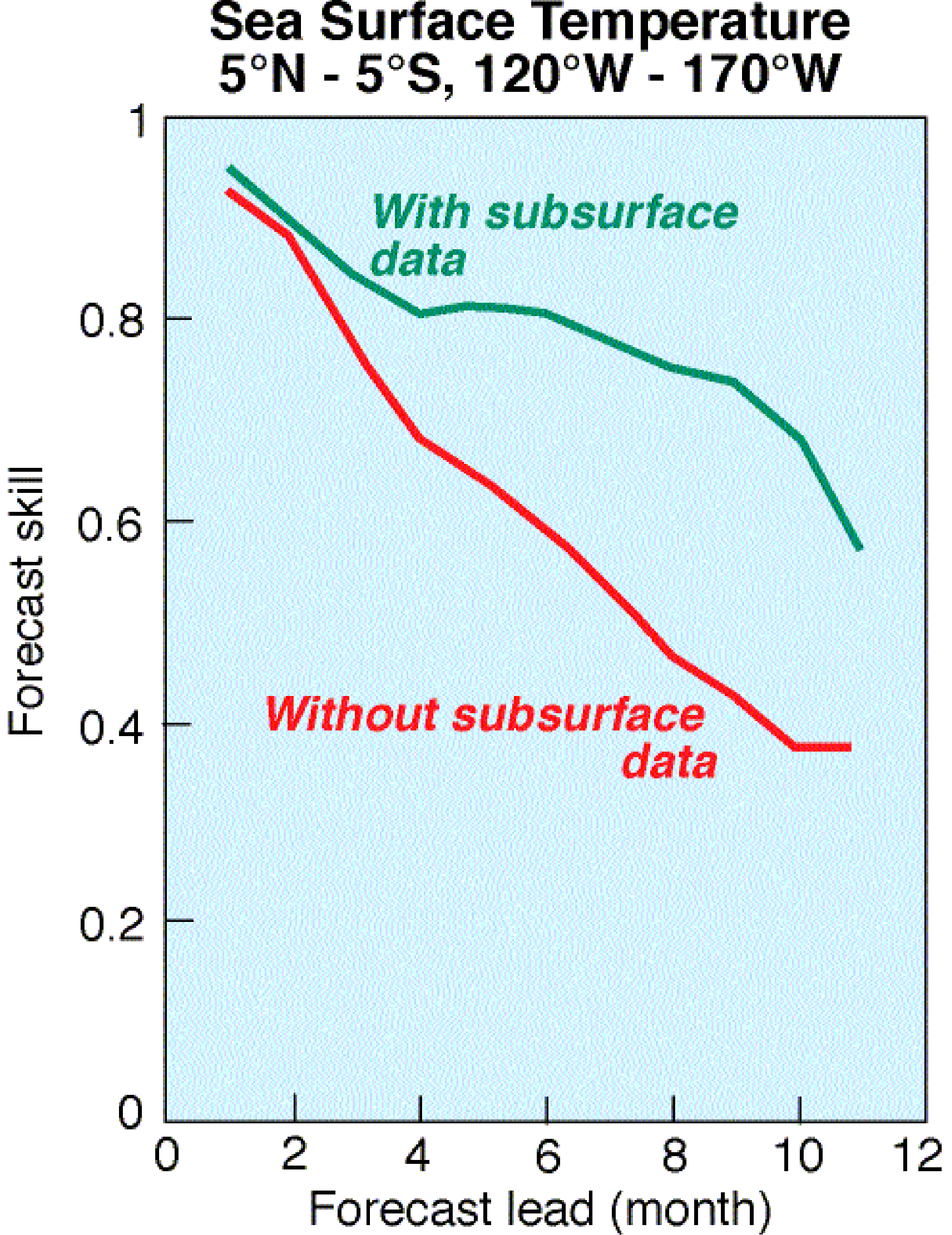
Northern Hemisphere Winter
Wet
Dry
Warm
60°N
50°
40°
30°
20°
10°
EQ
10°S
20°
30°
40°
50°
00°
20°E
40°
60°
80°
100°
120°
140°
160°
180°
160°W
140°
120°
100°
80°
60°
40°
20°



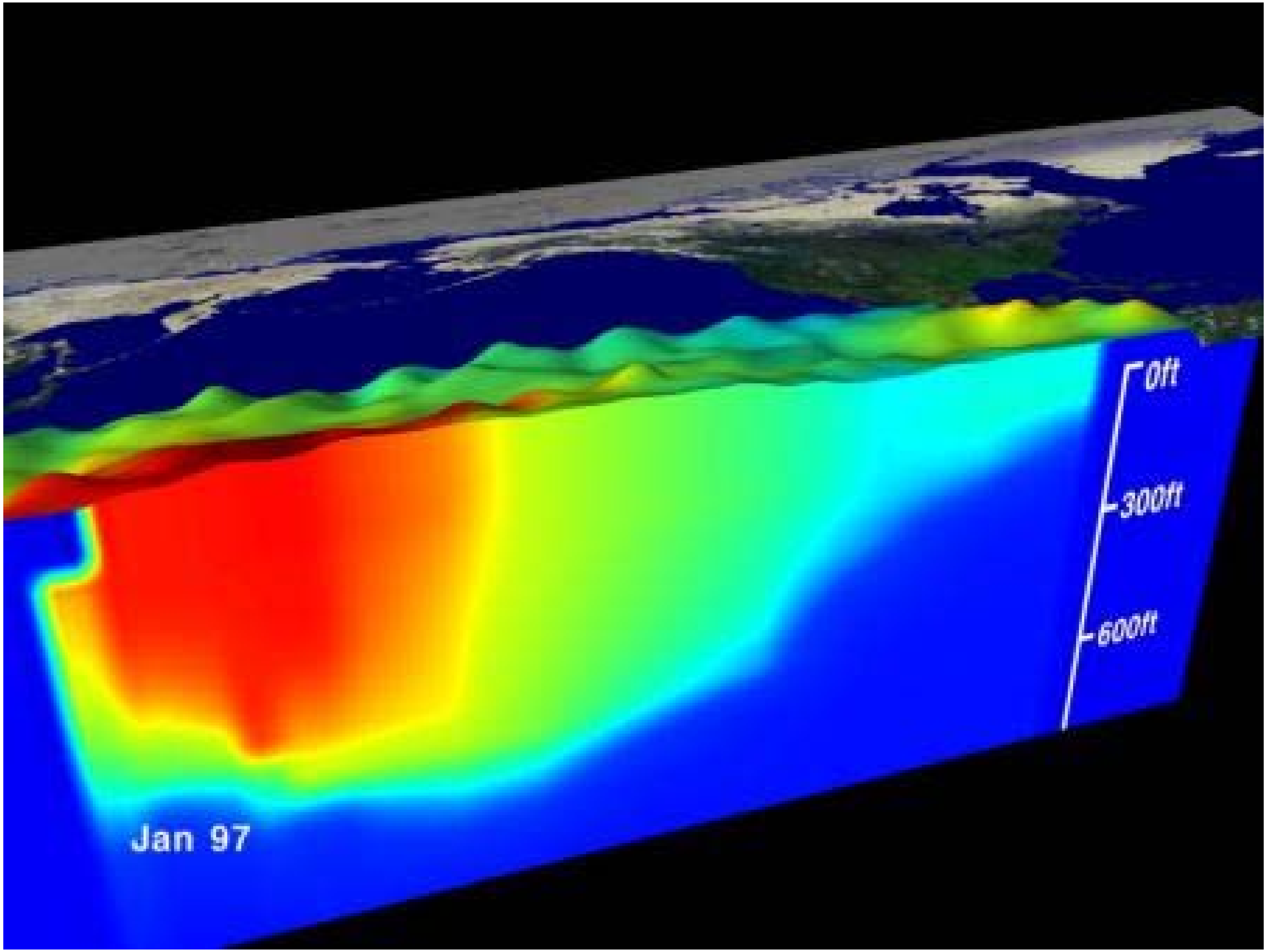
Economic impacts attributed to the 1982–83 El Niño.

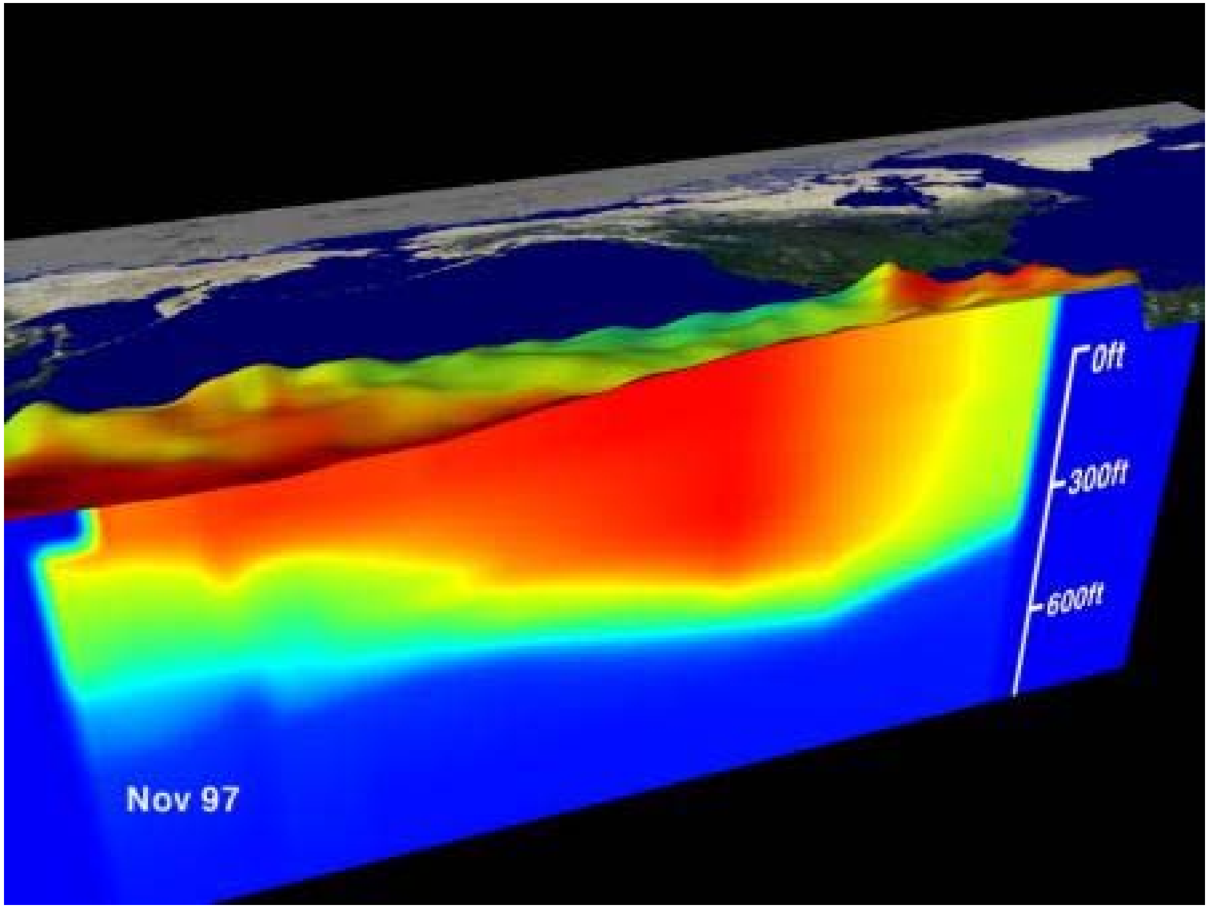
ENSO Observing System

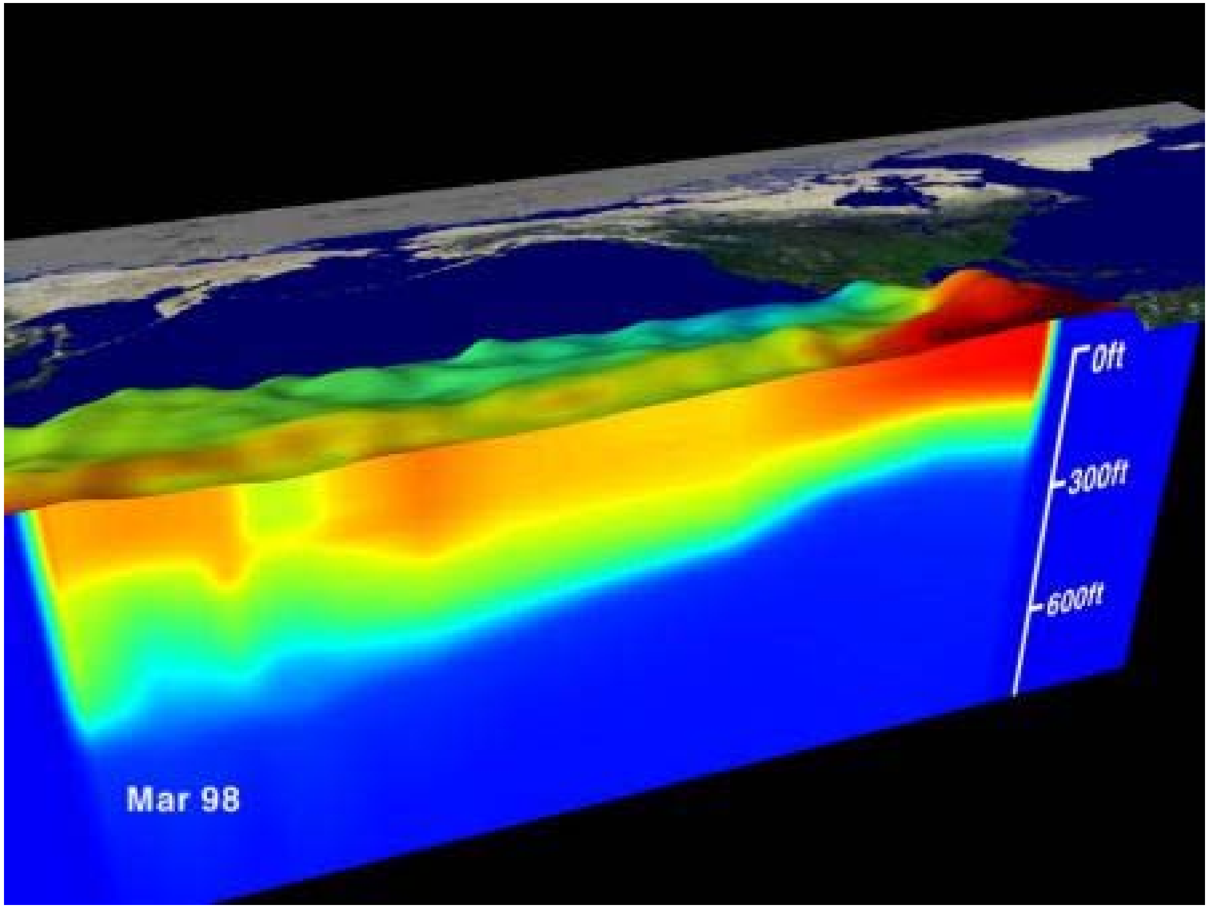


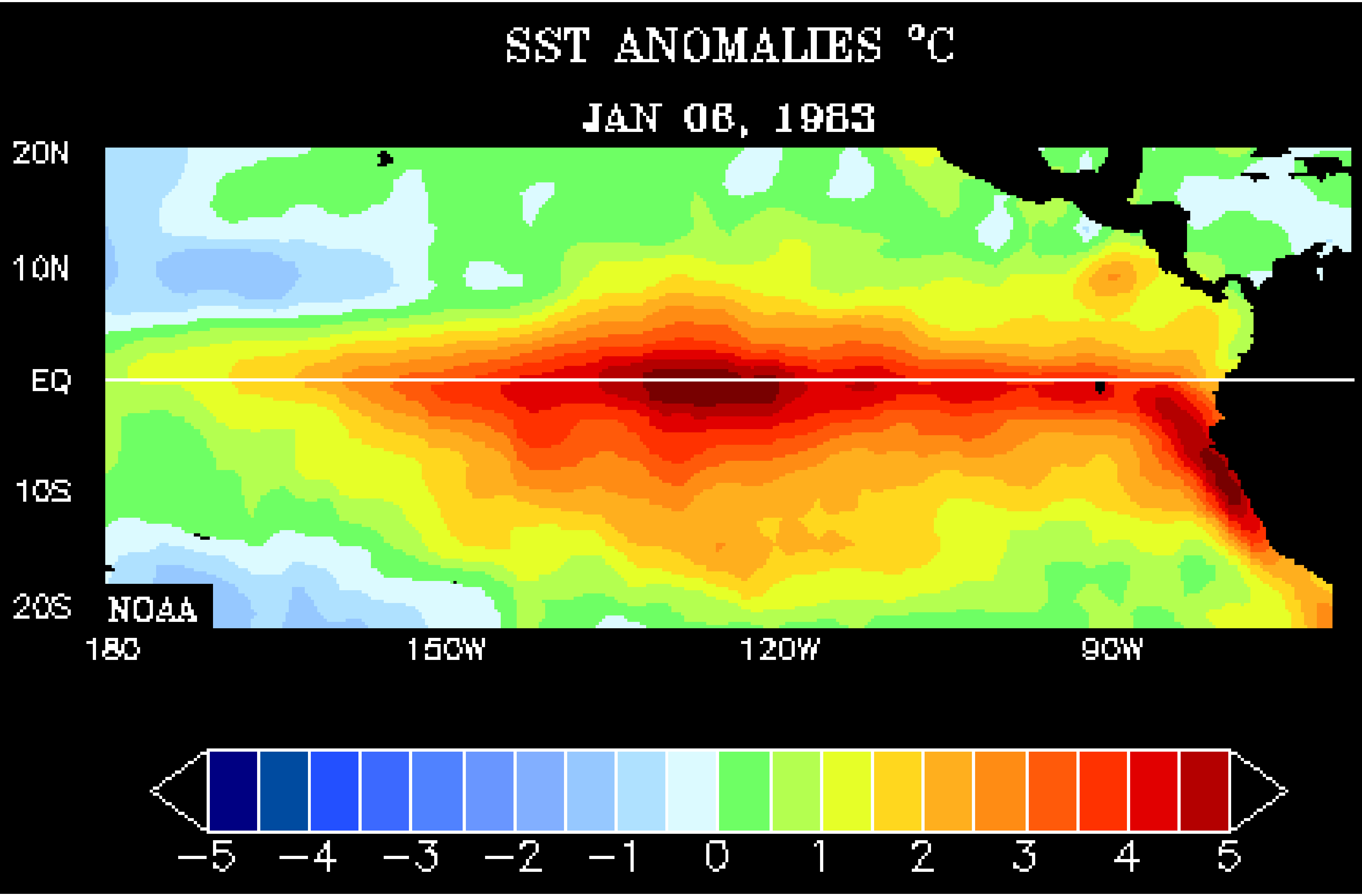


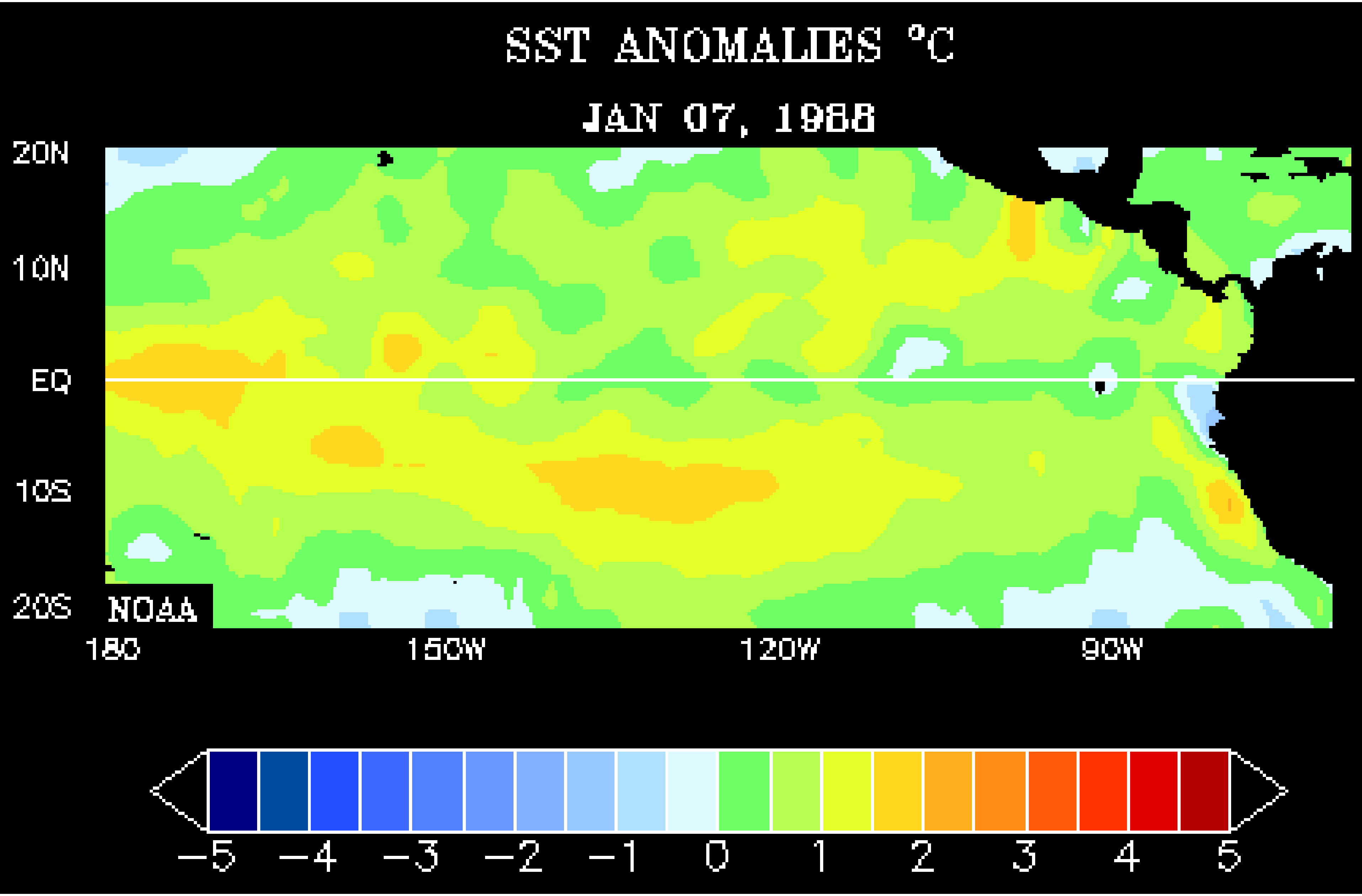
Sea Surface Temperature
5°N - 5°S, 120°W - 170°W
With subsurface data
Without subsurface data
Forecast skill
0
0.2
0.4
0.6
0.8
1
0
2
4
6
8
10
12
Forecast lead (month)


0ft
300ft
600ft
Jan 97

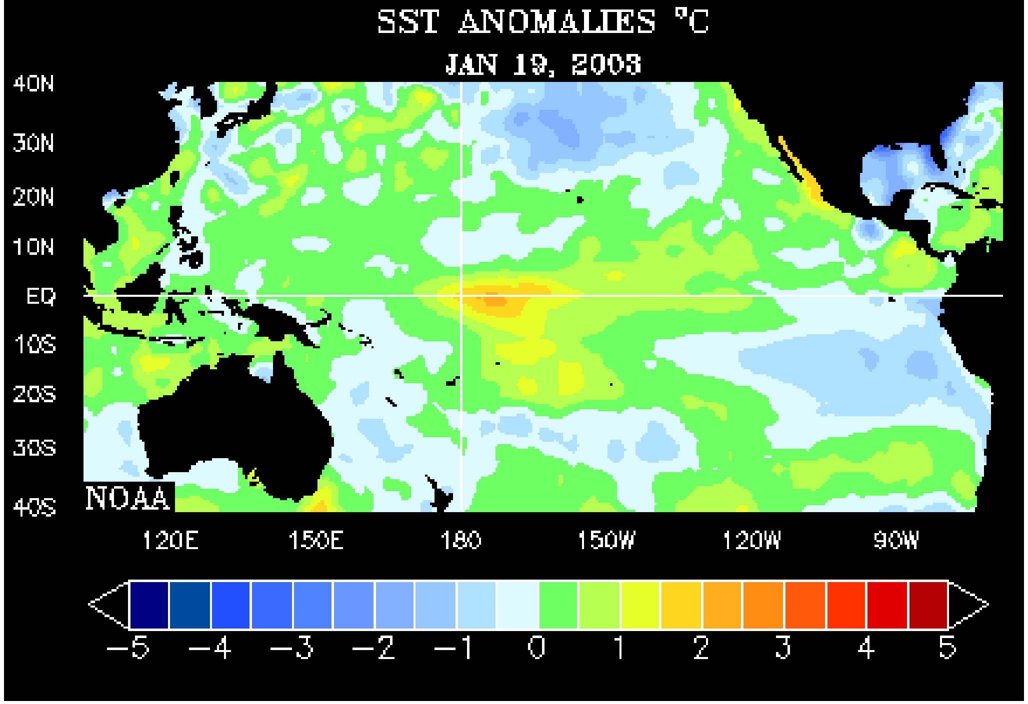

0ft
300ft
600ft
Nov 97


0ft
300ft
600ft
Mar 98

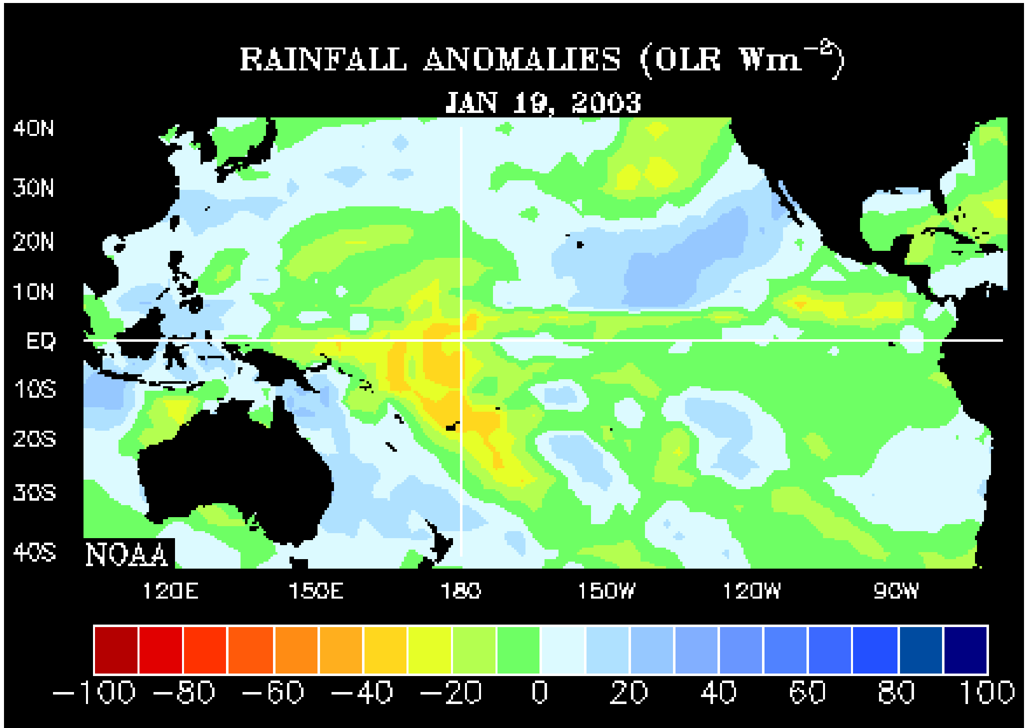

SST ANOMALIES °C
JAN 06, 1983
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5



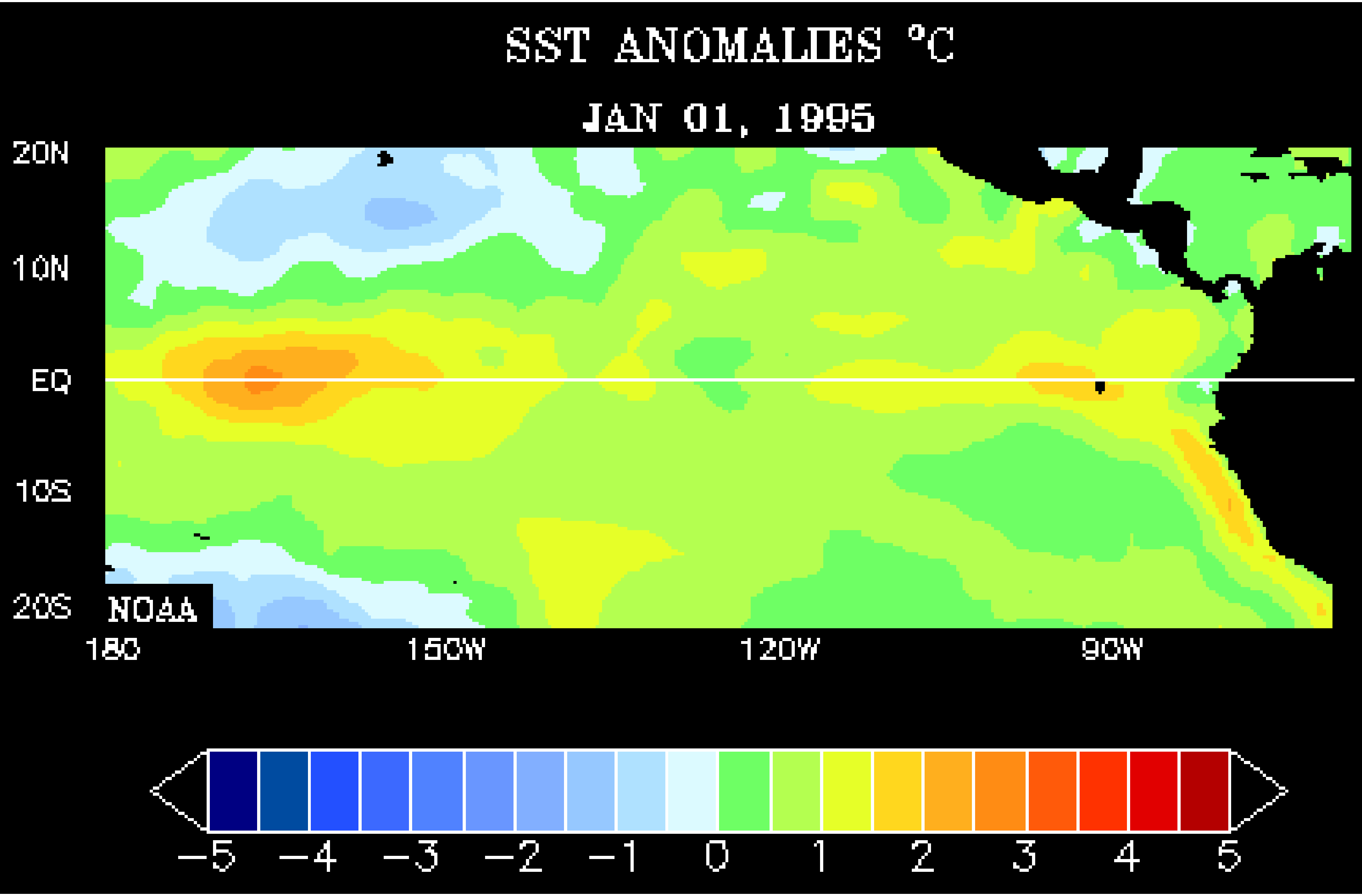
SST ANOMALIES °C
JAN 07, 1988
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
-5
-4
-3
-2
-1
0
1
2
3
4
5

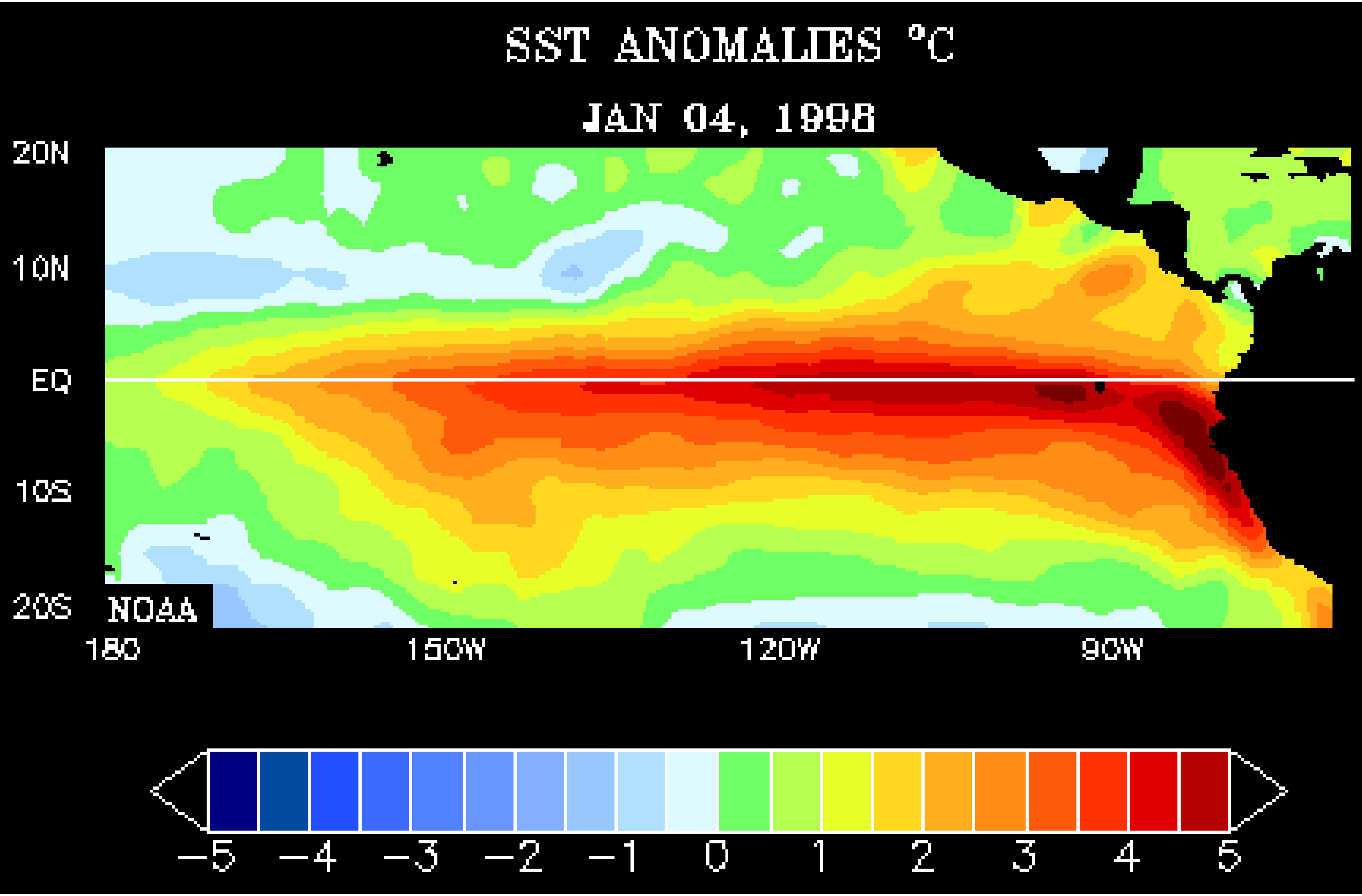


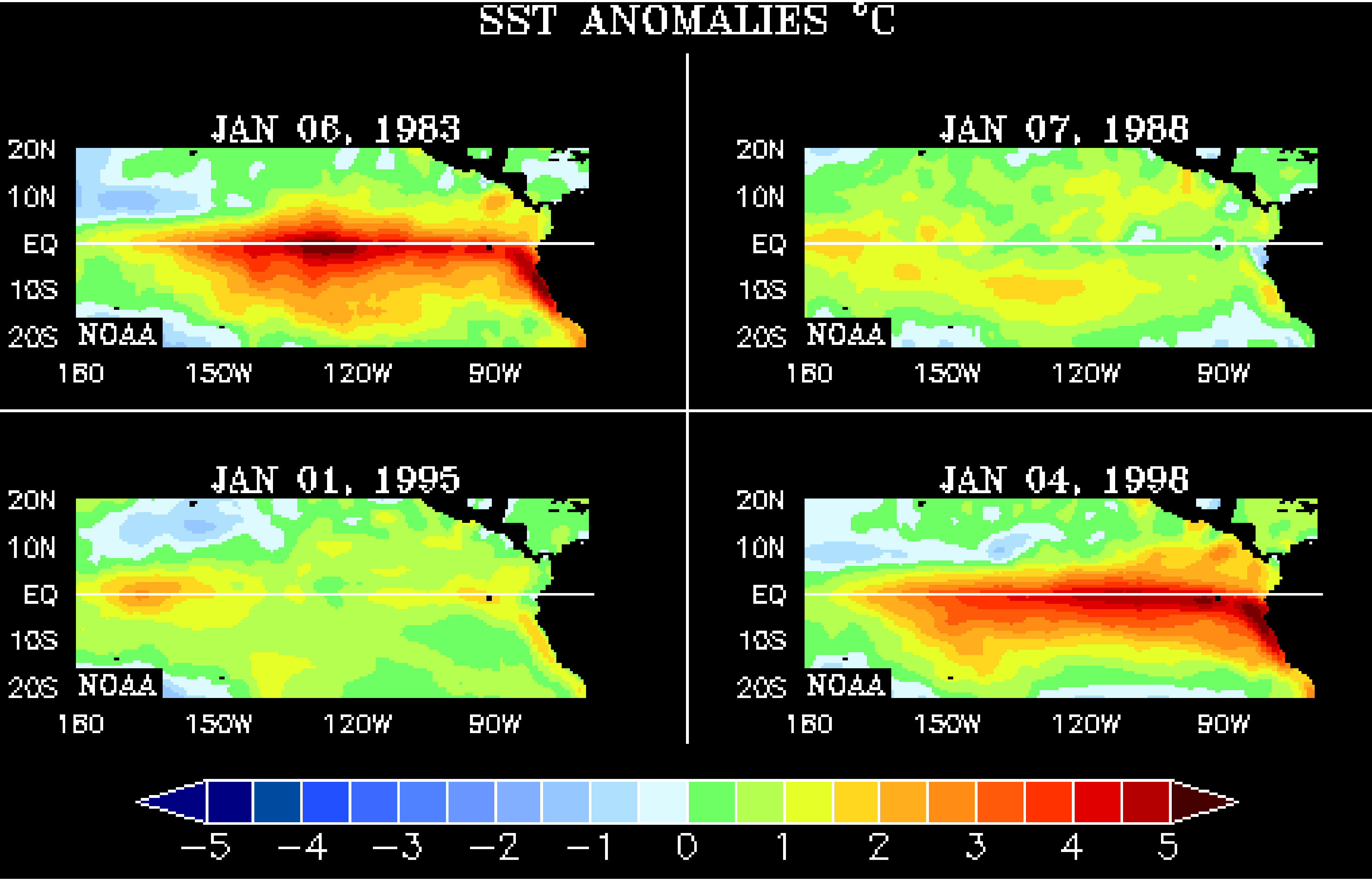
SST ANOMALIES °C
JAN 19, 2003
40N
30N
20N
10N
EQ
10S
20S
30S
40S
NOAA
120E
150E
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5



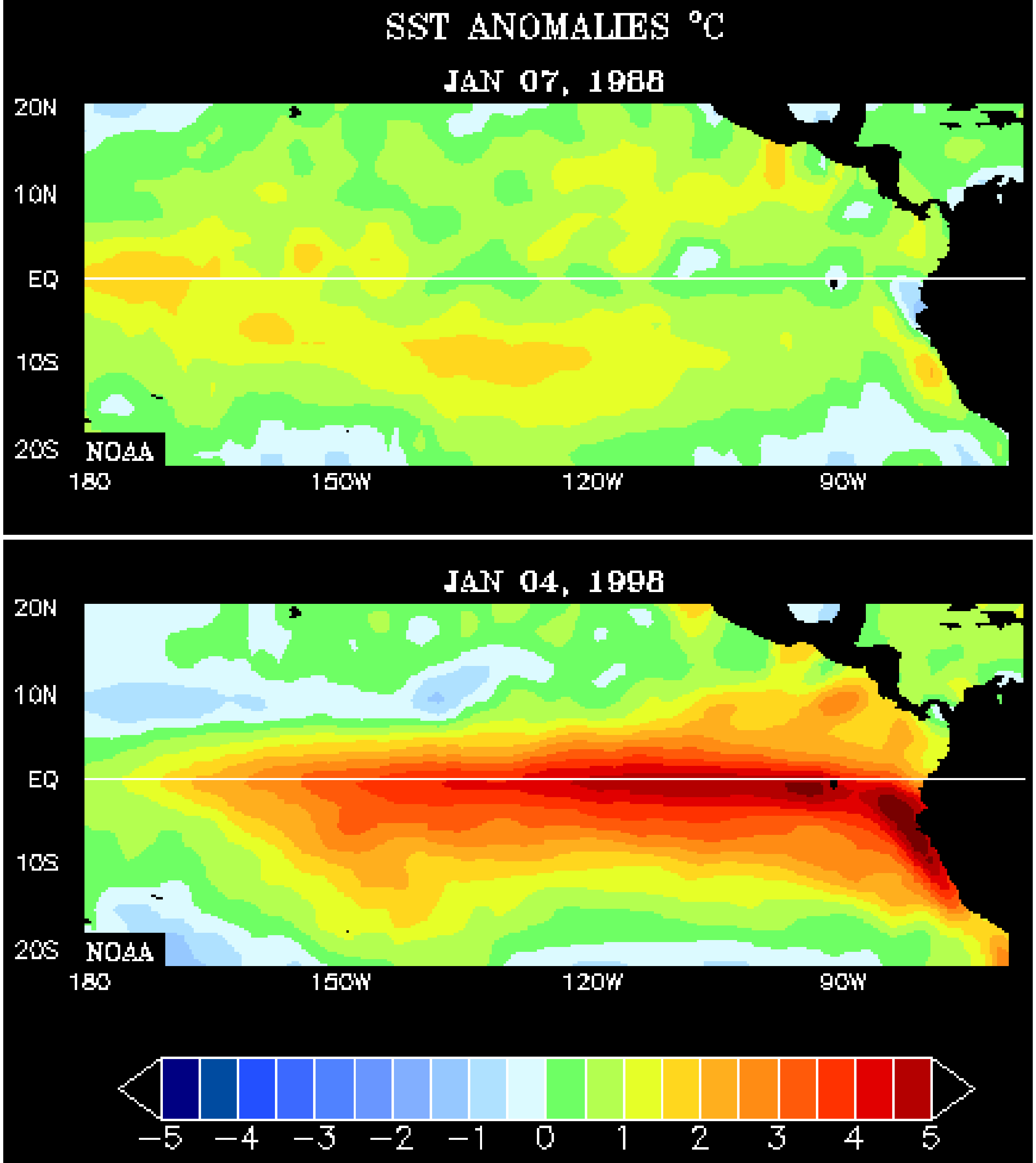
RAINFALL ANOMALIES (OLR Wm^{-2})
JAN 19, 2003
40N
30N
20N
10N
EQ
10S
20S
30S
40S
NOAA
120E
150E
180
150W
120W
90W
−100
−80
−60
−40
−20
0
20
40
60
80
100

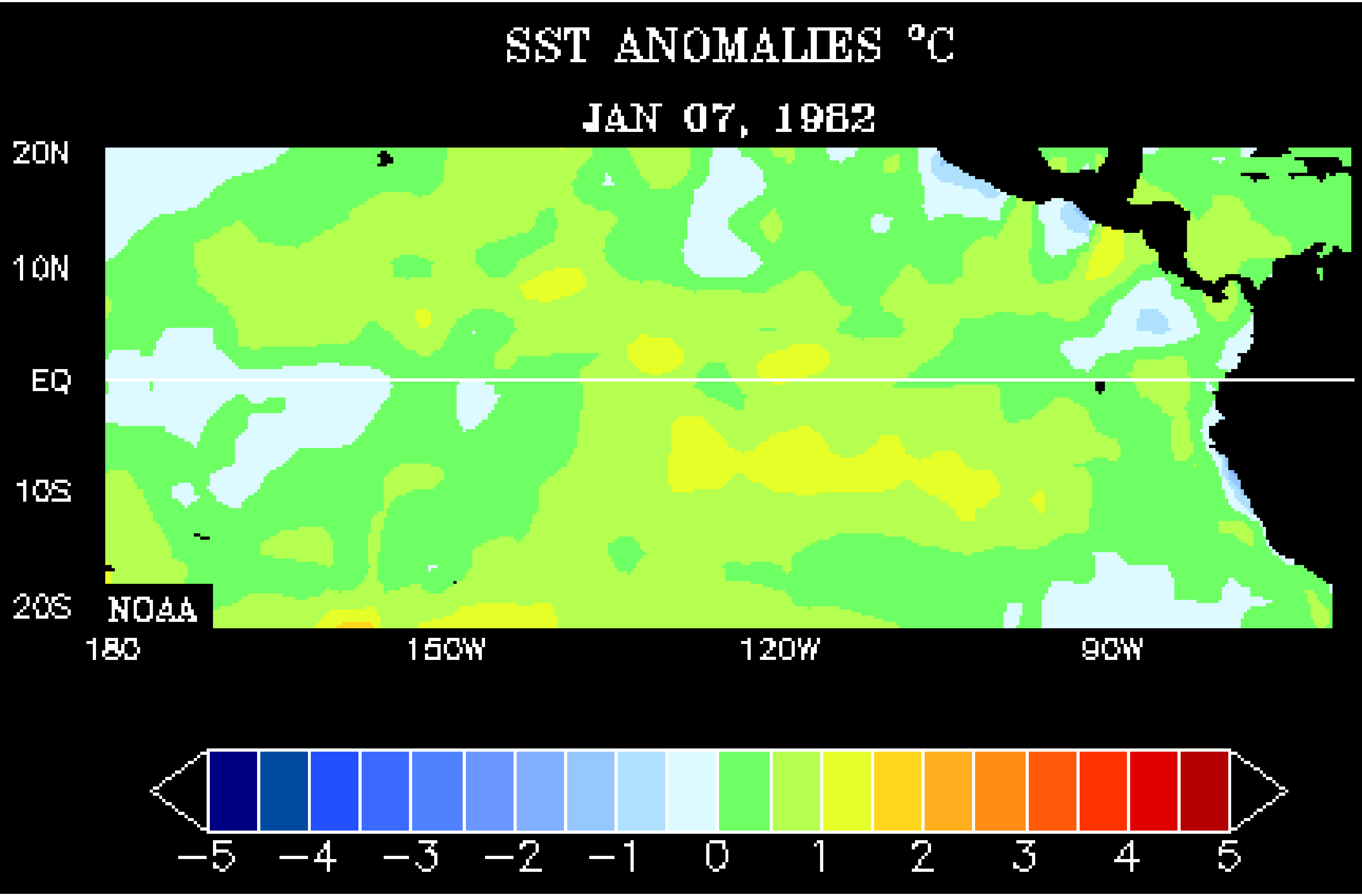

SST ANOMALIES °C
JAN 01, 1995
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5


SST ANOMALIES °C
JAN 04, 1998
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5

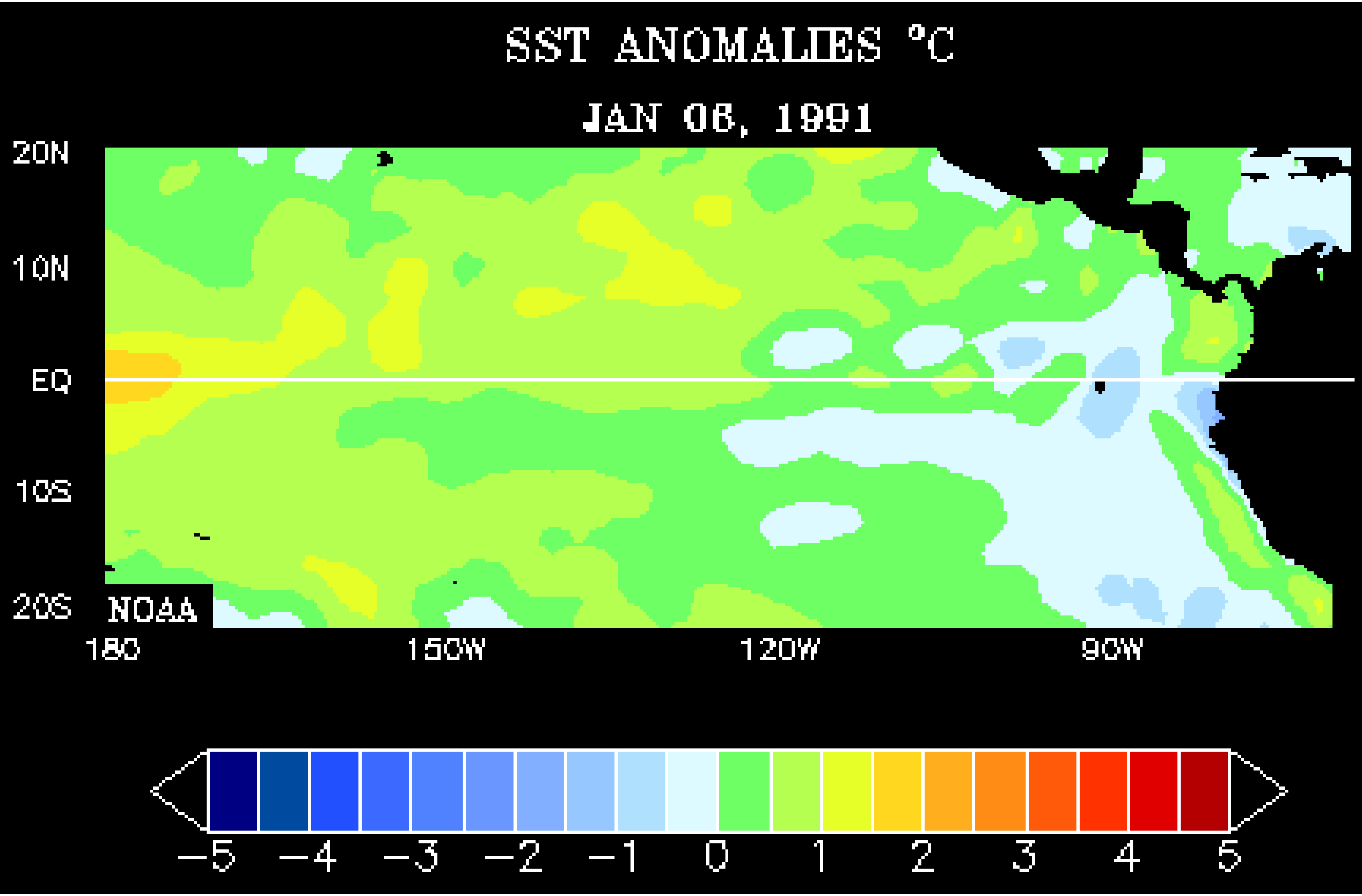


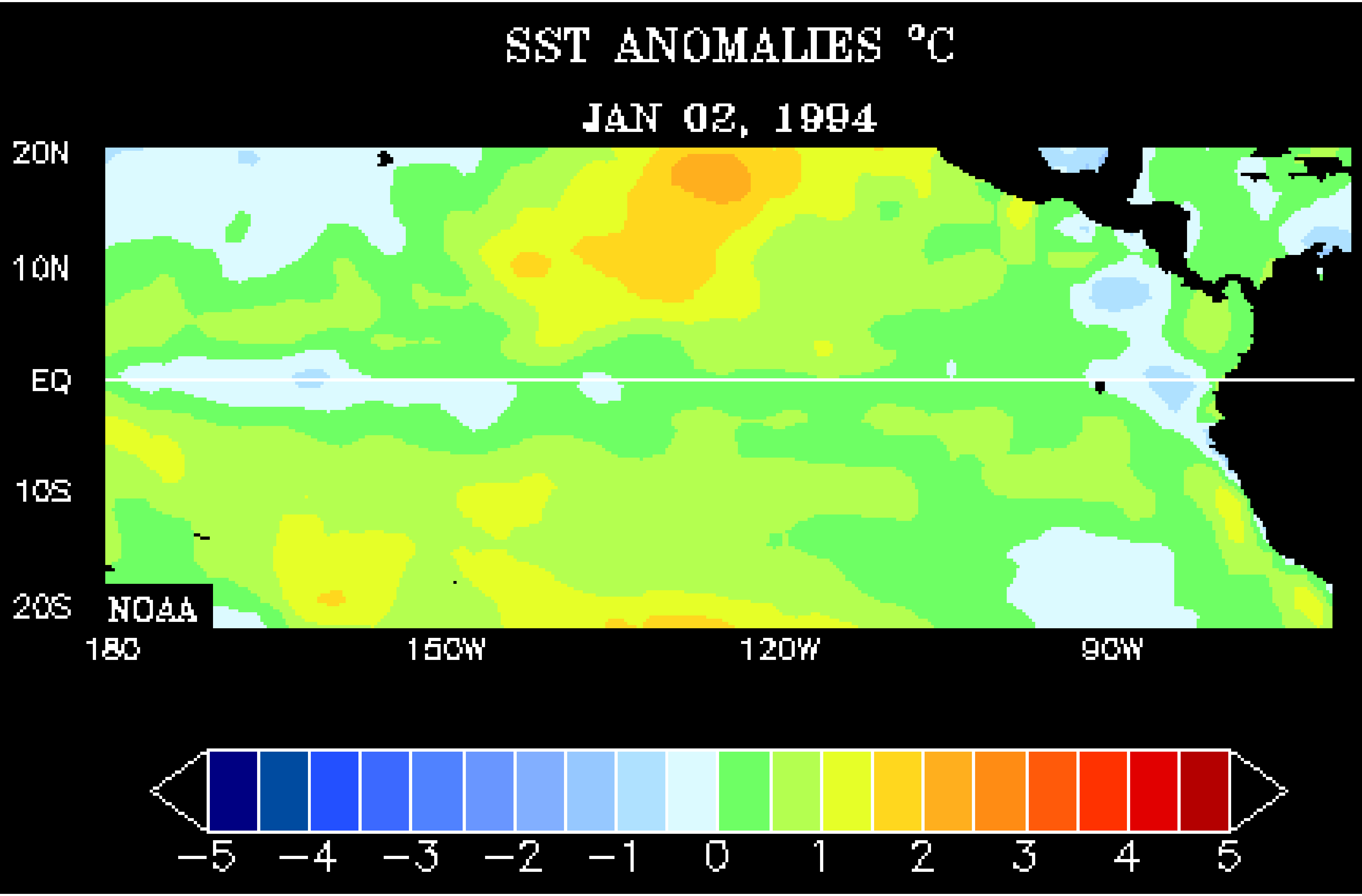
SST ANOMALIES °C
JAN 06, 1983
JAN 07, 1988
JAN 01, 1995
JAN 04, 1998
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5


SST ANOMALIES °C
JAN 07, 1988
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
JAN 04, 1998
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5 −4 −3 −2 −1 0 1 2 3 4 5



SST ANOMALIES °C
JAN 07, 1982
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5


SST ANOMALIES °C
JAN 06, 1991
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5


SST ANOMALIES °C
JAN 02, 1994
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
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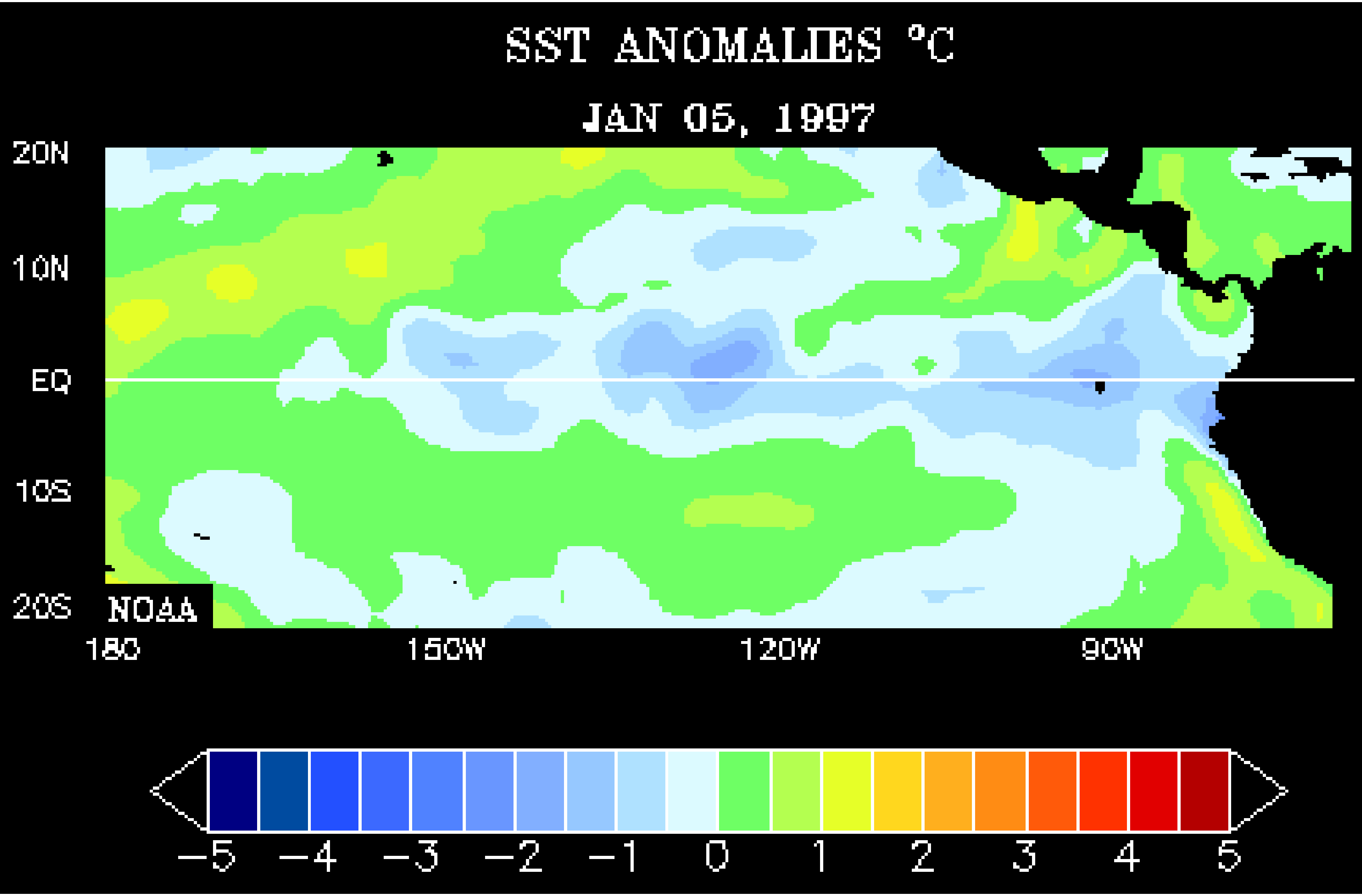
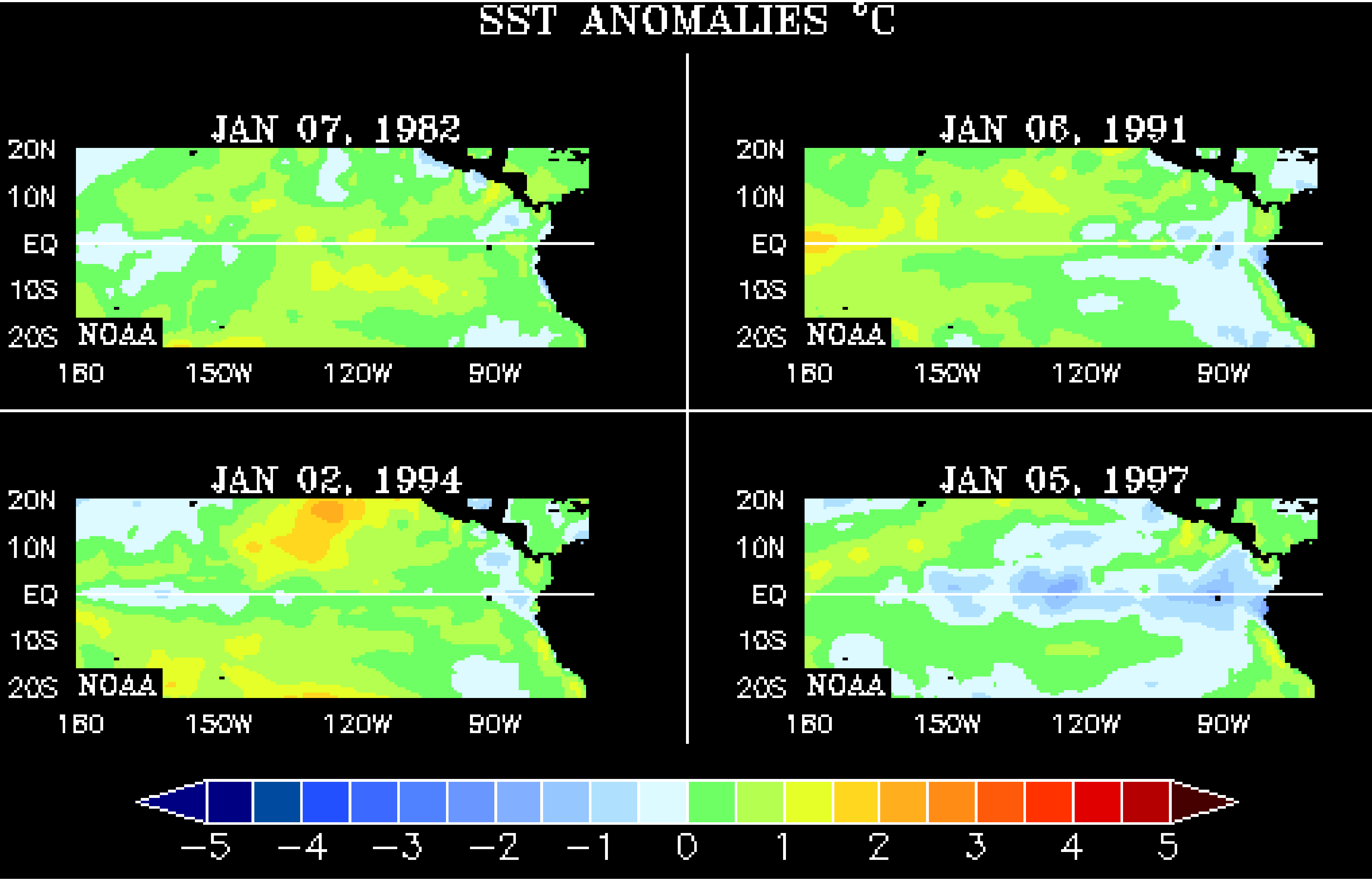
1
2
3
4
5



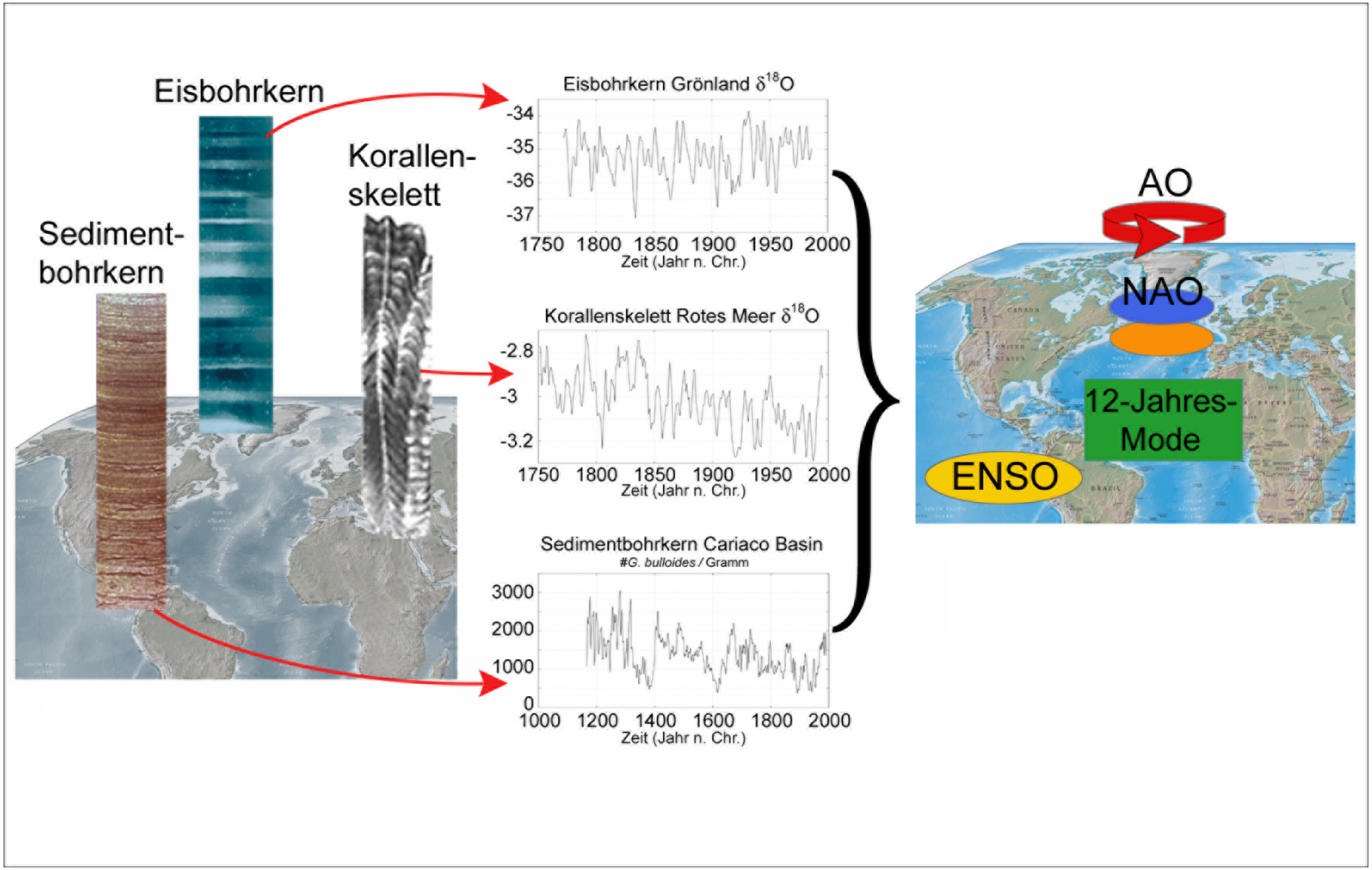
SST ANOMALIES °C
JAN 05, 1997
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5



SST ANOMALIES °C
JAN 07, 1982
JAN 06, 1991
JAN 02, 1994
JAN 05, 1997
20N
10N
EQ
10S
20S
NOAA
180
150W
120W
90W
−5
−4
−3
−2
−1
0
1
2
3
4
5

Upscaling

Interpretation of Proxy Data



Proxy Data

- Aunual, seasonal, etc.
- 18-O, etc.

Instrumental Data

- Daily, Aunual, seasonal, etc.
- Temperature, salinity, precipitation, etc.

Statistic

Covariance (cross, auto)

$$\gamma(\Delta) = E\left((x(t) - \bar{x})\,(y(t+\Delta) - \bar{y}) \right)$$

e.g. coral e.g. meteorol. data

Correlation (cross, auto)

$$\rho_{xy} = \frac{\gamma(\Delta)}{\text{normalized}}$$

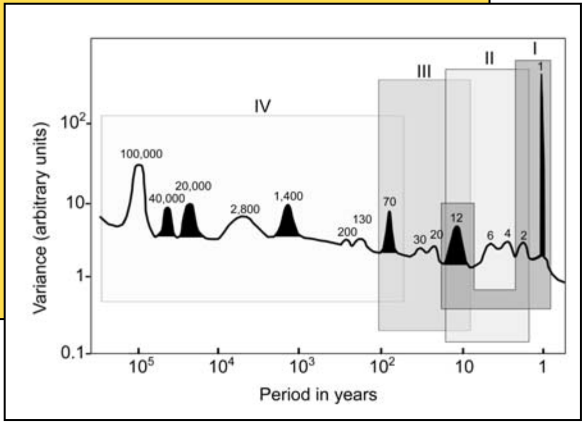
measures the tendency of x (t) and y (t) to covary

Spectrum (cross, auto)

(spectral density)

$$\Gamma(\omega) = \sum_{\Delta=-\infty}^{\infty} \gamma(\Delta)\, e^{-2\pi i \Delta}$$

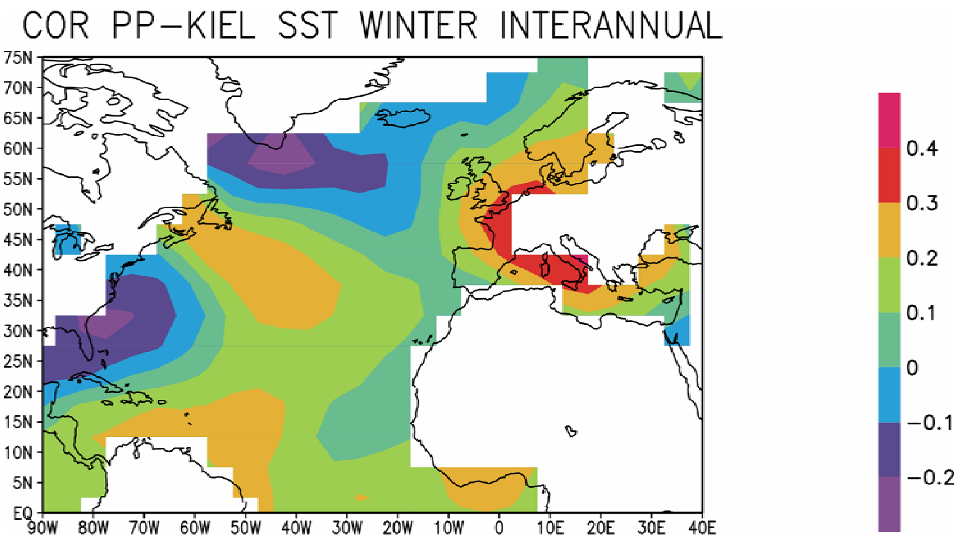
measures variance



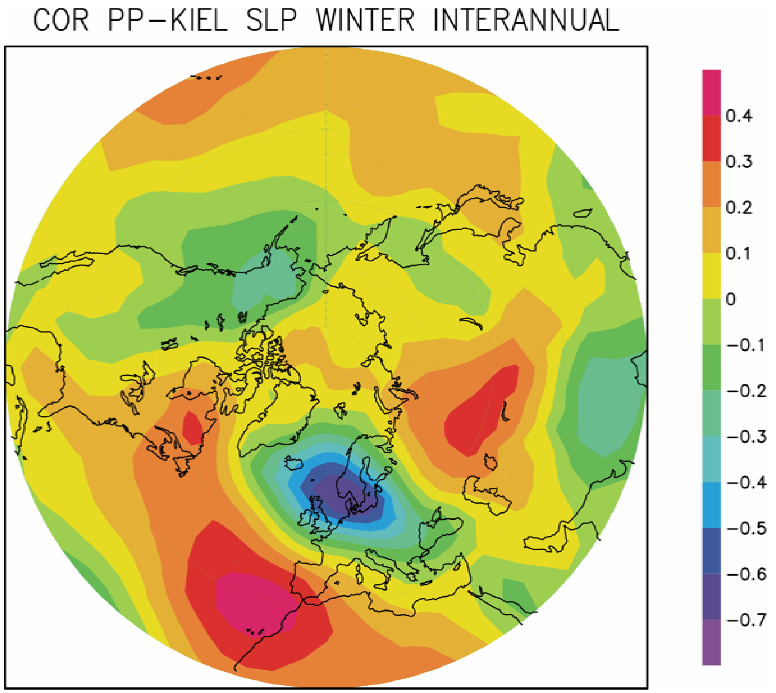
Spatial pattern

- Regression
- Correlation
- Composite maps

Correlation: **Precipitation Kiel**

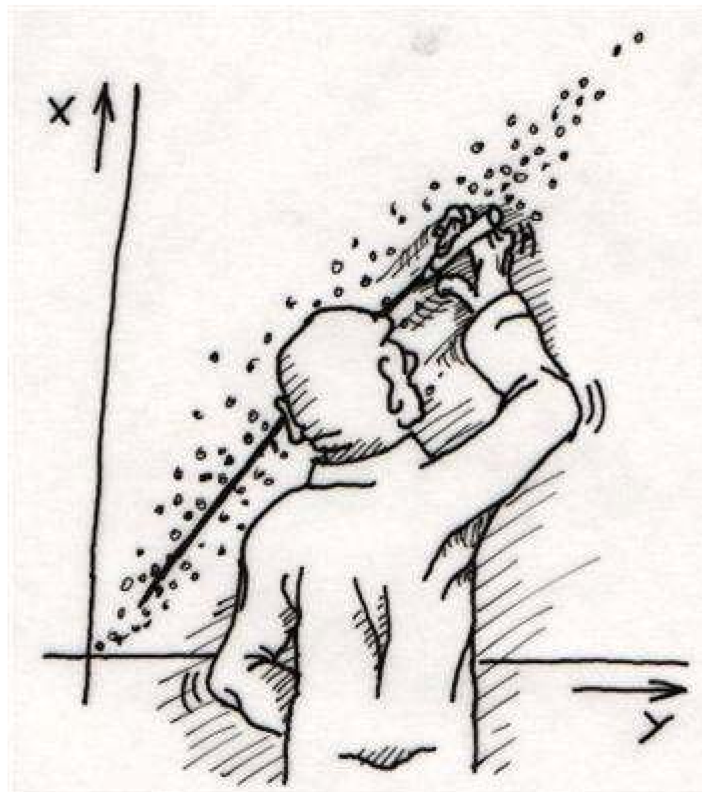


SST



SLP

Regression



Regression

Linear function $f(x) = a\,x + b$

Task: find $f(x)$ given data points $g(x_i)$

Such that $(\,f(x_i) - g(x_i)\,)^2$ is minimal

linear regression

models the relationship between a dependent variable *Y*, independent variables Xp, and a random term *ε*. The model can be written as

$$Y = \beta_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \varepsilon$$

where β1 is the intercept ("constant" term), the βis are the respective parameters of independent variables, and *p* is the number of parameters to be estimated in the linear regression.

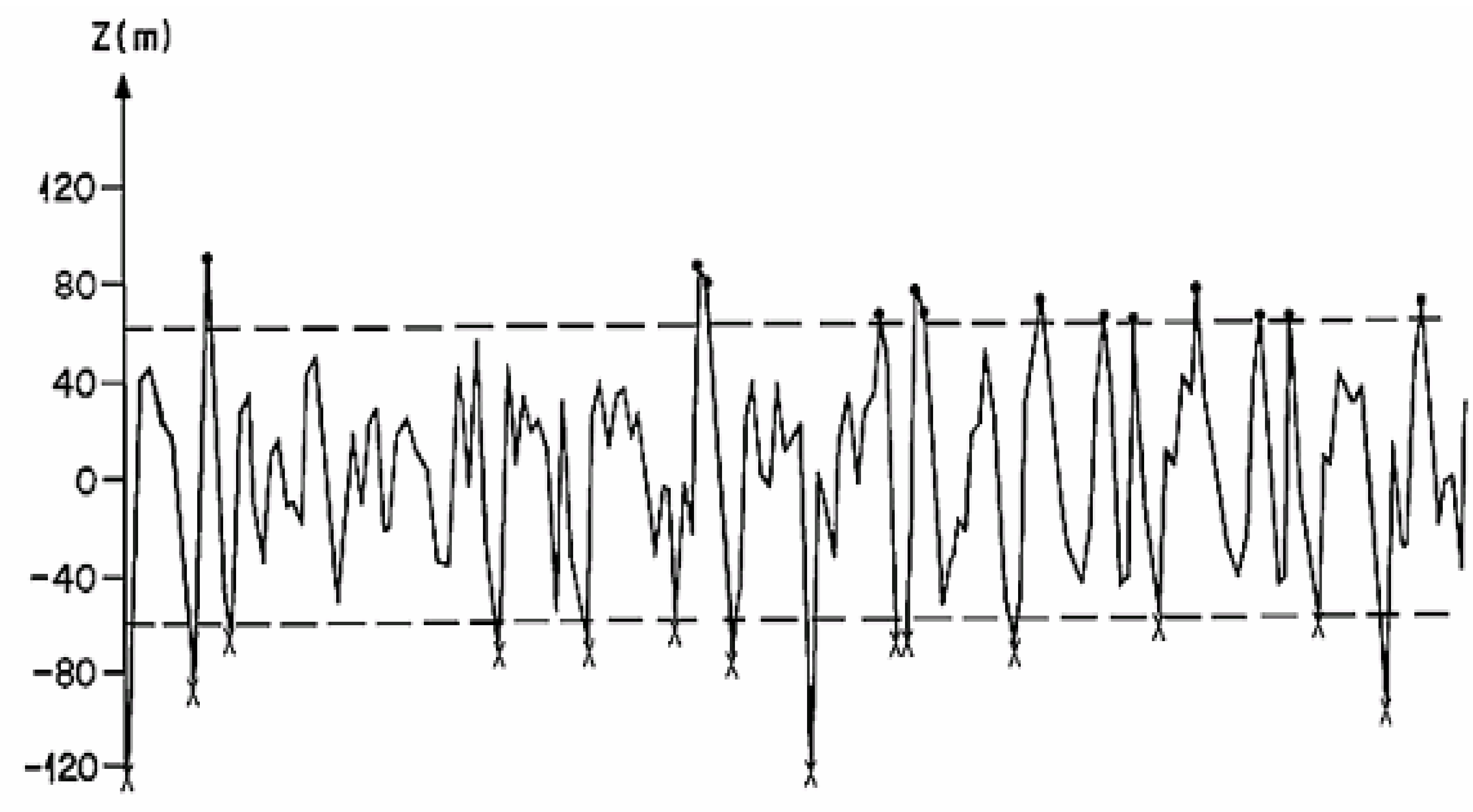
Least-squares analysis

was developed by Carl Friedrich Gauss in the 1820s. This method uses the following assumptions:

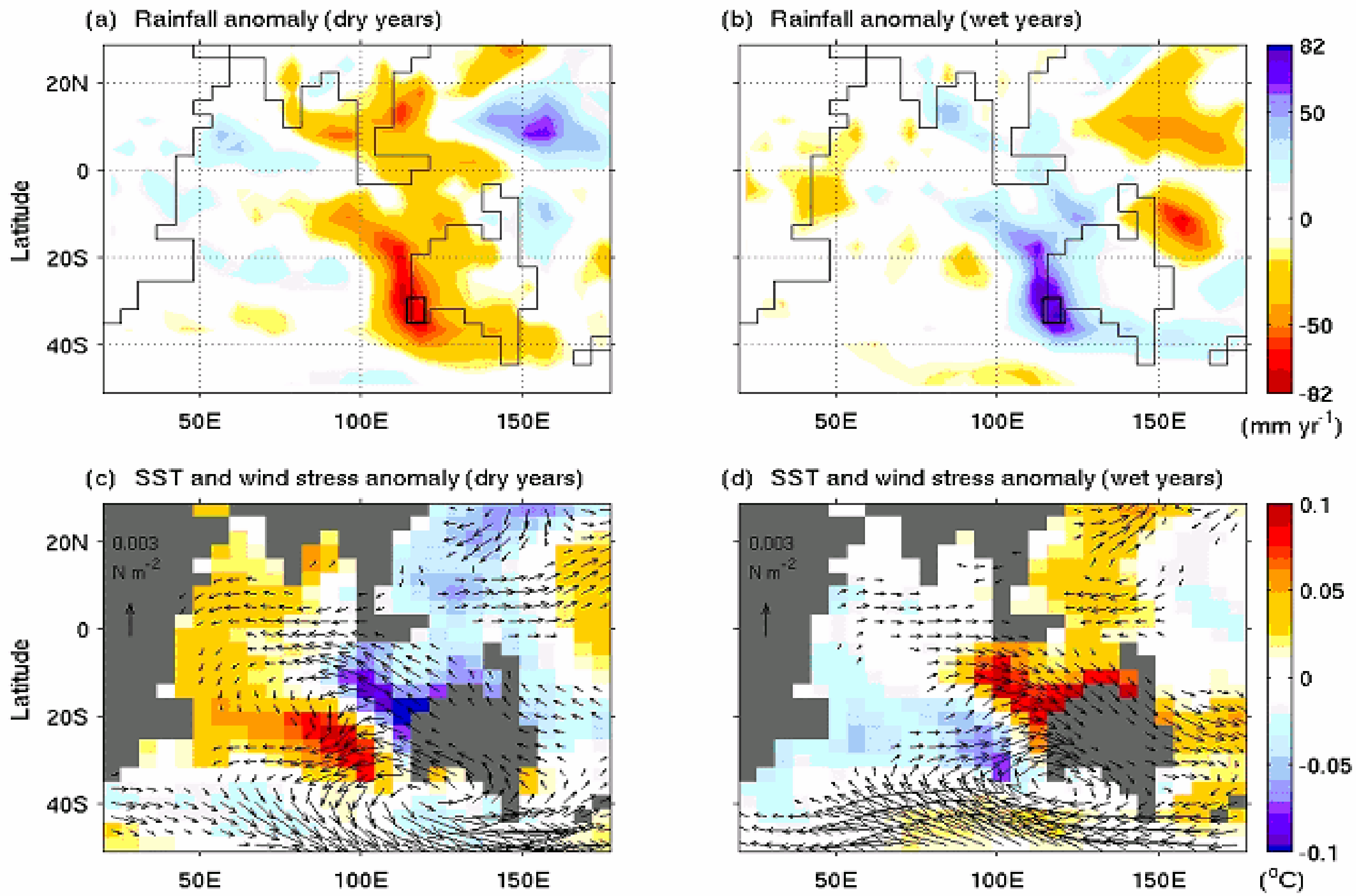
- The random errors ε_i have expected value 0
- The random errors ε_i are uncorrelated
- The random errors ε_i all have the same variance.

Composite Maps

dt.: Kartenzusammenstellung



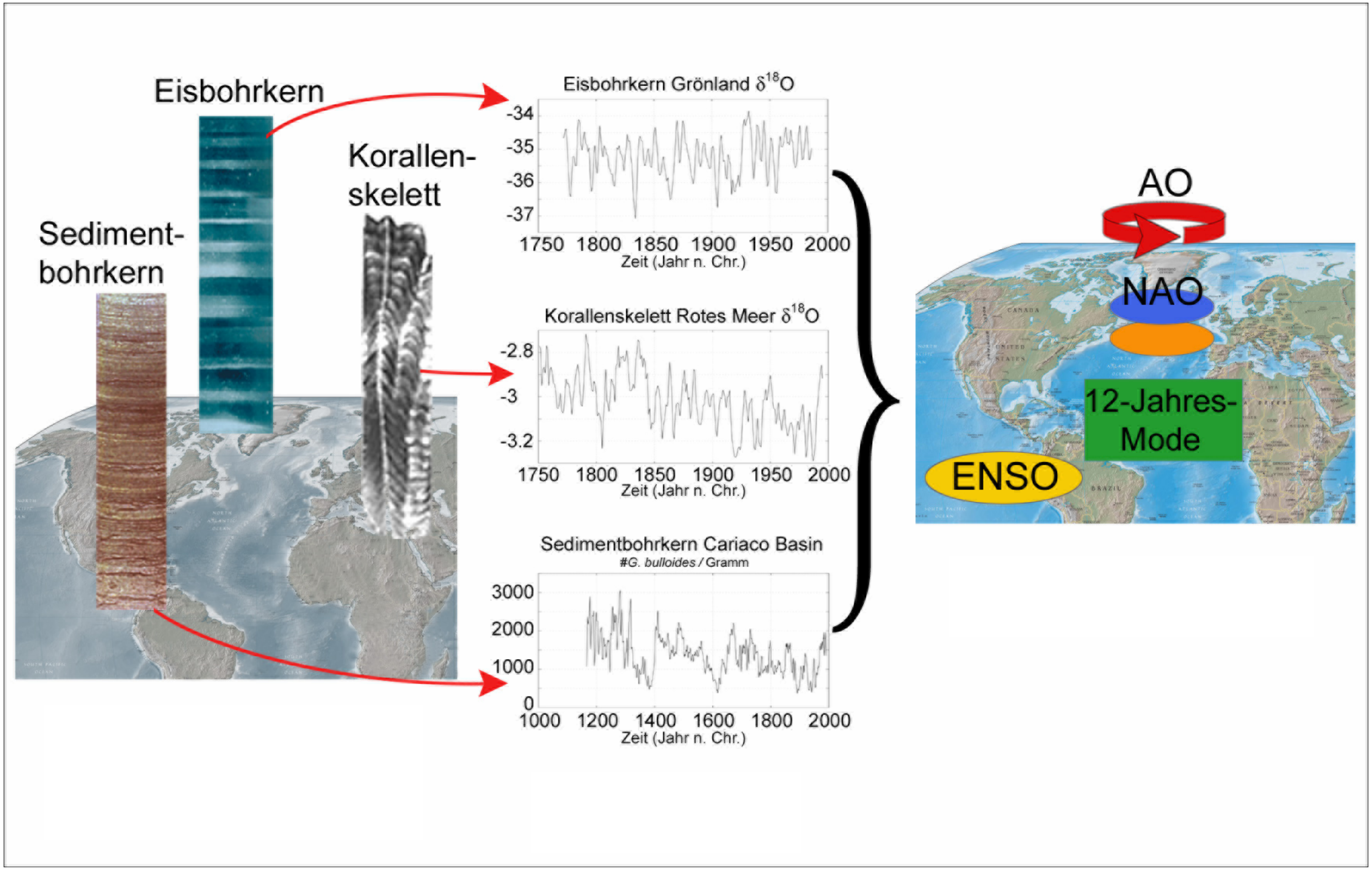
Example



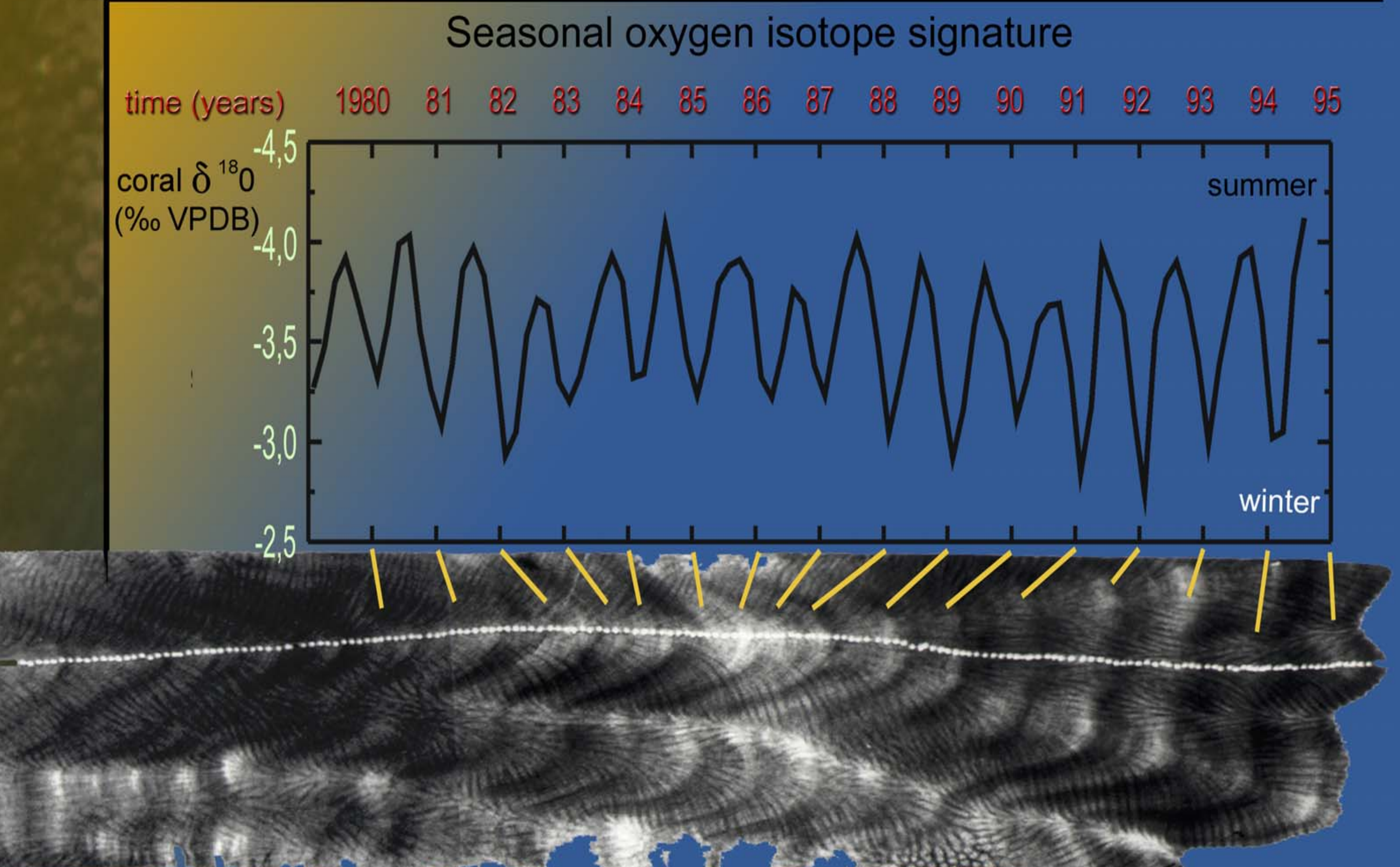
(a) Rainfall anomaly (dry years)
(b) Rainfall anomaly (wet years)
(c) SST and wind stress anomaly (dry years)
(d) SST and wind stress anomaly (wet years)
Latitude
20N
0
20S
40S
50E
100E
150E
82
50
0
-50
-82
(mm yr^{-1})
0.003
N m^{-2}
0.1
0.05
0
-0.05
-0.1
(^{o}C)

Upscaling

Interpretation of Proxy Data



ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



Skeleton of Red Sea coral

Felis et al. Paleoceanography 2000

Statistic

Covariance (cross, auto)

$$\gamma(\Delta) = E\left((x(t) - \bar{x})\,(y(t+\Delta) - \bar{y}) \right)$$

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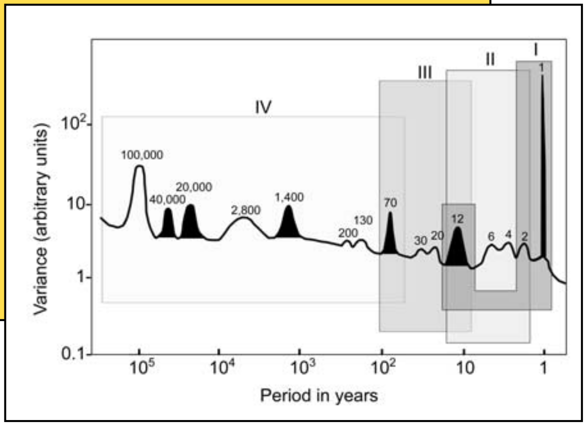
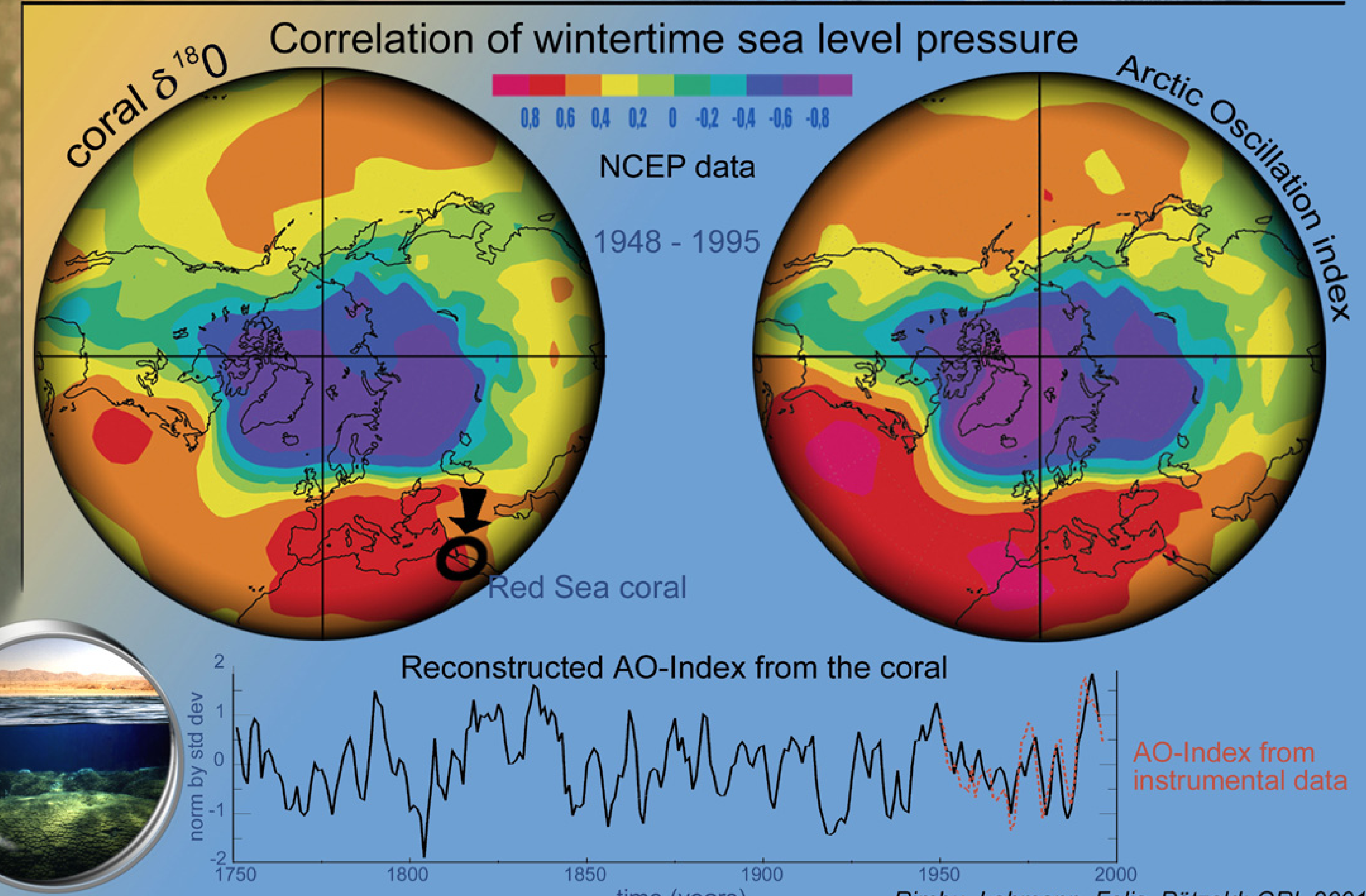
(spectral density)

$$\Gamma(\omega) = \sum_{\Delta=-\infty}^{\infty} \gamma(\Delta)\, e^{-2\pi i \Delta}$$

measures variance

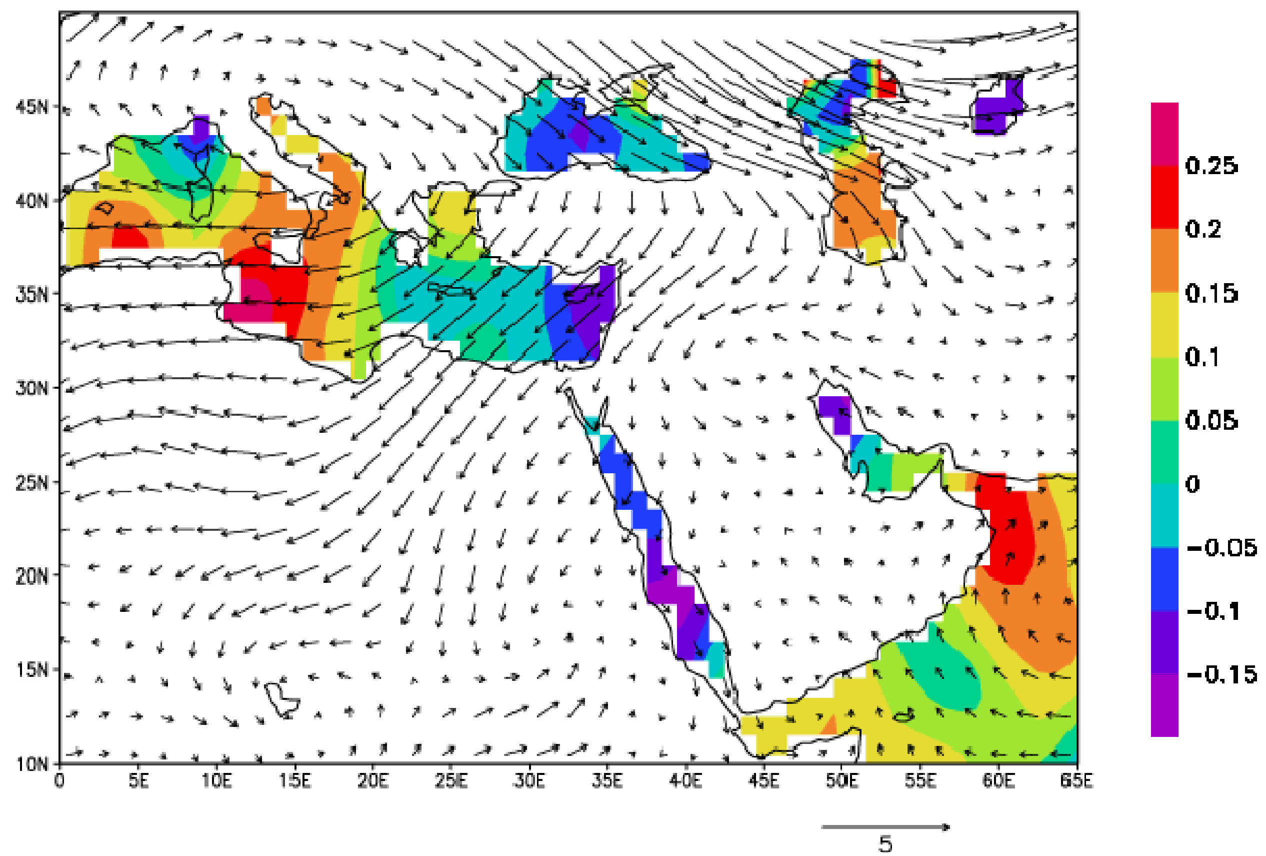


ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



Rimbu, Lohmann, Felis, Pätzold; GRL 2001

ARCTIC OSCILLATION SIGNATURE IN A RED SEA CORAL



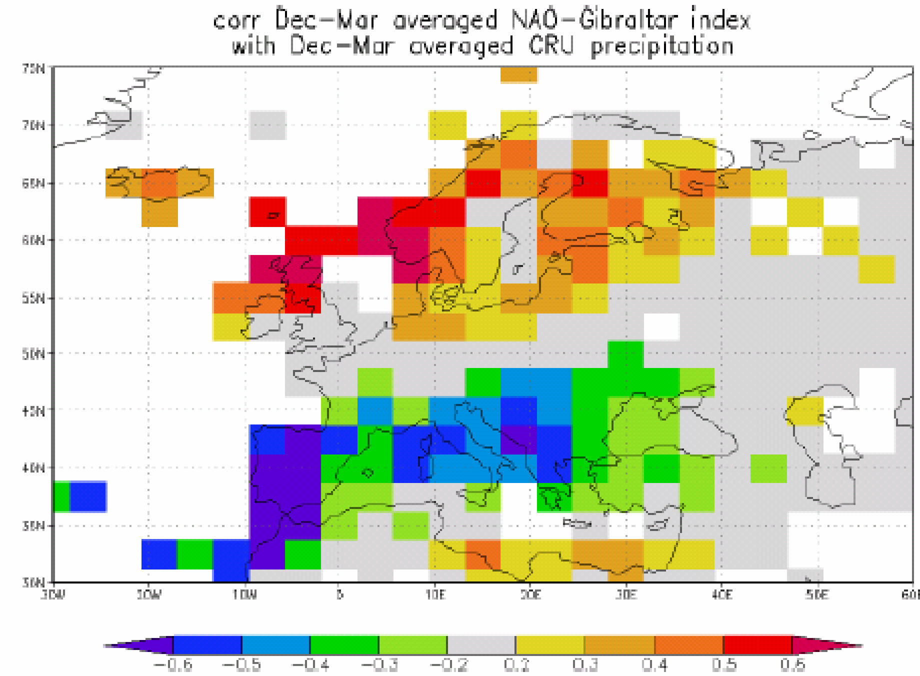
Composite Map of SST [°C] and 925 hPa wind [m/s] for 1948 -1995, January - February

mechanistic understanding

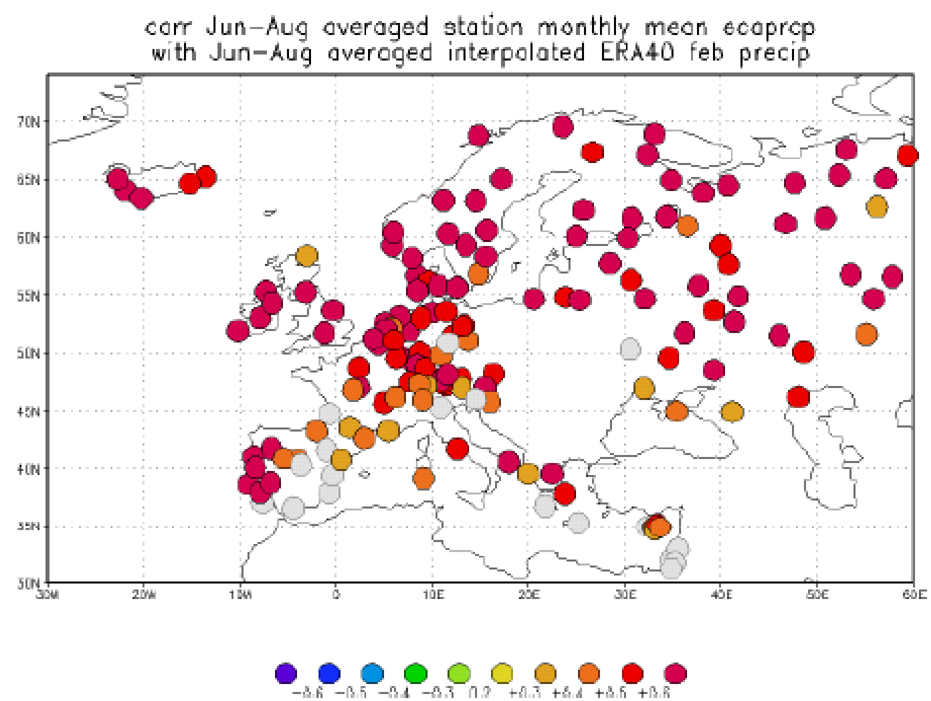
Practical units for Dynamics II 21. May 2007

- Analysis of spatio-temporal pattern
- Open web browser (e.g. mozilla)
- http://climexp.knmi.nl/
- http://kiste.palmod.uni-bremen.de:8080/upsc/ (student mensa)
- Time series (choose one, calculate one)
- Climate of your home town/region (4 seasons)
- Use correlation, regression, composite maps
- Write a report (2-4 pages)

Examples



corr Dec-Mar averaged NAO-Gibraltar index
with Dec-Mar averaged CRU precipitation
-0.6 -0.5 -0.4 -0.3 -0.2 0.2 0.3 0.4 0.5 0.6



corr Jun-Aug averaged station monthly mean ecaprcp
with Jun-Aug averaged interpolated ERA40 feb precip
70N
65N
60N
55N
50N
45N
40N
35N
30N
30W 20W 10W 0 10E 20E 30E 40E 50E 60E