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# COASTAL SEA LEVEL AND THE LARGE-SCALE CLIMATE STATE:

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## AN OVERVIEW OF STATISTICAL AND DYNAMICAL DOWNSCALING EXERCISES

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## BACKGROUND

- Global climate models decidedly envisage a climate change due to the increasing concentrations of greenhouse gases in the atmosphere. These models agree on an overall warming in the ocean and in the atmosphere. Evidence is now available that this anthropogenic climate change is presently happening (Hegerl et al., 1994).
- The ocean warming will lead to an increase of the volume of the ocean - which will be accompanied with an increase of sea level.
- The climate models simulate sea level on the large-scale, but have little skill in simulating coastal sea level, since the coast is nothing but a discontinuity in models; also the regional details are poorly resolved. Present-day climate models are assembled from fully 3-dimensional dynamic models of the atmosphere, the ocean and the sea-ice; typical horizontal resolution:  $5^\circ \times 5^\circ$  latitude  $\times$  longitude; skillful simulation on horizontal scales  $> 2000\ km$ ; results for grid points are formally available but are of little value.
- Some highly simplified models, such as CLIMAPS, are sold with the promise to yield small-scale information about coastal sea level. Such products, however, operate with strong assumptions; they produce maps of sea level vulnerability depending only on the global mean sea level rise and the local land sinking/rising rates.

# OUTLINE

- Recent results from the MPI climate model with respect to sea level rise.
- What is a “coast” in a climate model ?  
What is the spatial resolution of present climate models?
- The concept of a “downscaling” strategy: Abandon local GCM data; Use of models which relate the reliable model-generated large-scale information to small-scale information.
- Downscaling coastal sea level.  
**Examples:**
  - Two cases of statistical downscaling: Winter means along the coast of the Baltic Sea, 1905 - 71 (Heyen, 1994), and along the coast of Japan, 1958 - 1988 (Cui et al., 1994).
  - First results from an example of dynamical downscaling: A simulation with a regional model of the North Sea and the Baltic Sea. (From Kauker)
- References:
  - Heyen, H., 1994: Downscaling der monatlichen Anomalien des Luftdruckfeldes über dem Nordatlantik auf die Wasserstände in der Ostsee. Diplomarbeit Hamburg 1994, 68 pp.
  - Cui, M., H. von Storch and E. Zorita: Coastal sea level and the large-scale climate state: a downscaling exercise for the Japanese Islands. Tellus 46, 1994 (in press)

double click. View detail may be selected after plotting any of the four variables available under View coast. You may *not*, however, View detail before you View coast.

You are now familiar with the Sea Level Menu. Select Exit to return to the Main CLIMAPS Menu where you should choose Tables.

### Vulnerability

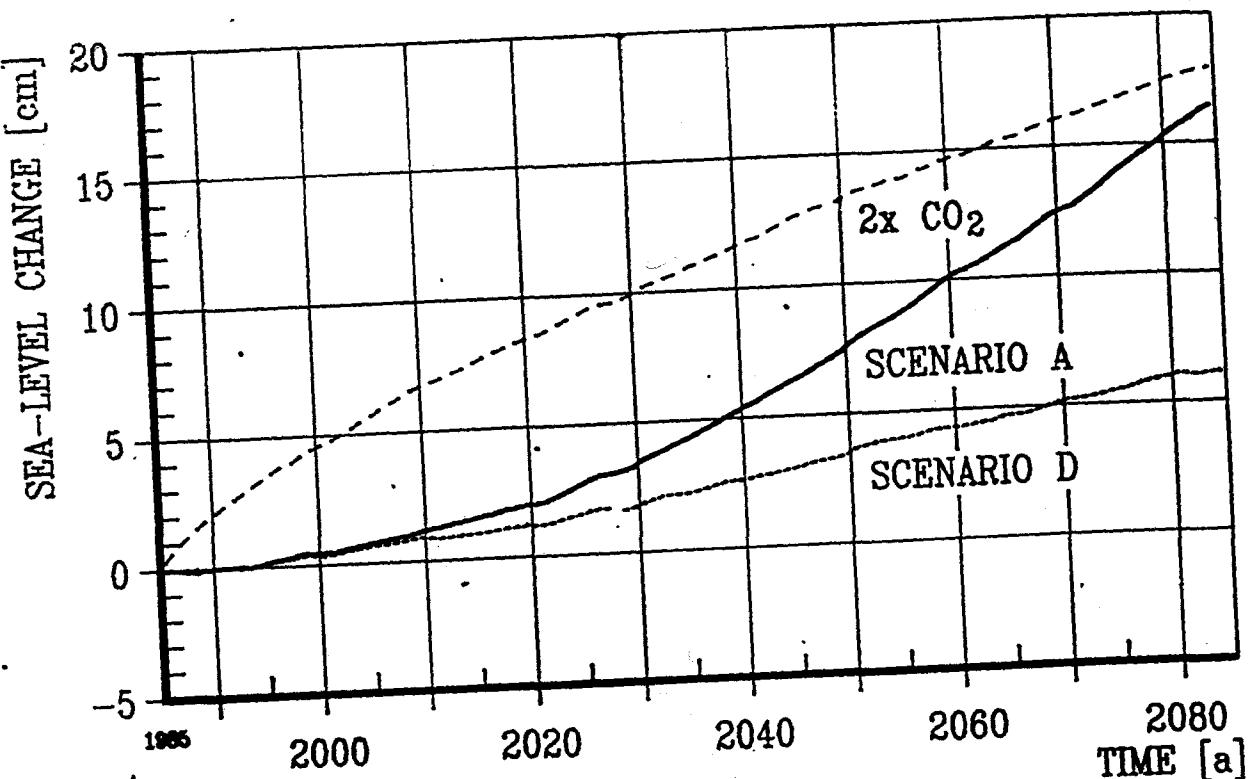


Country : UK	Coastline : 369 kms		
Latitude : 58.25°N	Vulnerability : U Low		
Longitude : 6.58°W	Year : 2100		
ULM (cms) : 2.2			
dMSL(cms) : (11.8)(43.3)	00 00		
Net MSL(cms) : (-9.6)(41.1)	00 00		
Shoreline Character (%)	Shoreline Defence (%)	Vulnerability Category (%)	
Rocky 99	Protected 1	U Low 85	
Sandy 9	Natural 99	Low 8	
Mud 2		Medium 16	
Artificial 1		High 5	
		U High 1	
		??? 2 kms	

Figure 6.6: Sample output from the View detail option in the Sea Level Menu of CLIMAPS.

## 6.7 The Tables Menu

You are now in the Tables Menu which enables you to view and save tabular output for chosen impact indicators for the EC countries calculated for selected years. The tabular data will appear on screen as well as being dumped into an ASCII file named CLIMAPS.OUT in the CLM sub-directory on your hard disk.



031ULCa

### SEA LEVEL CHANGE

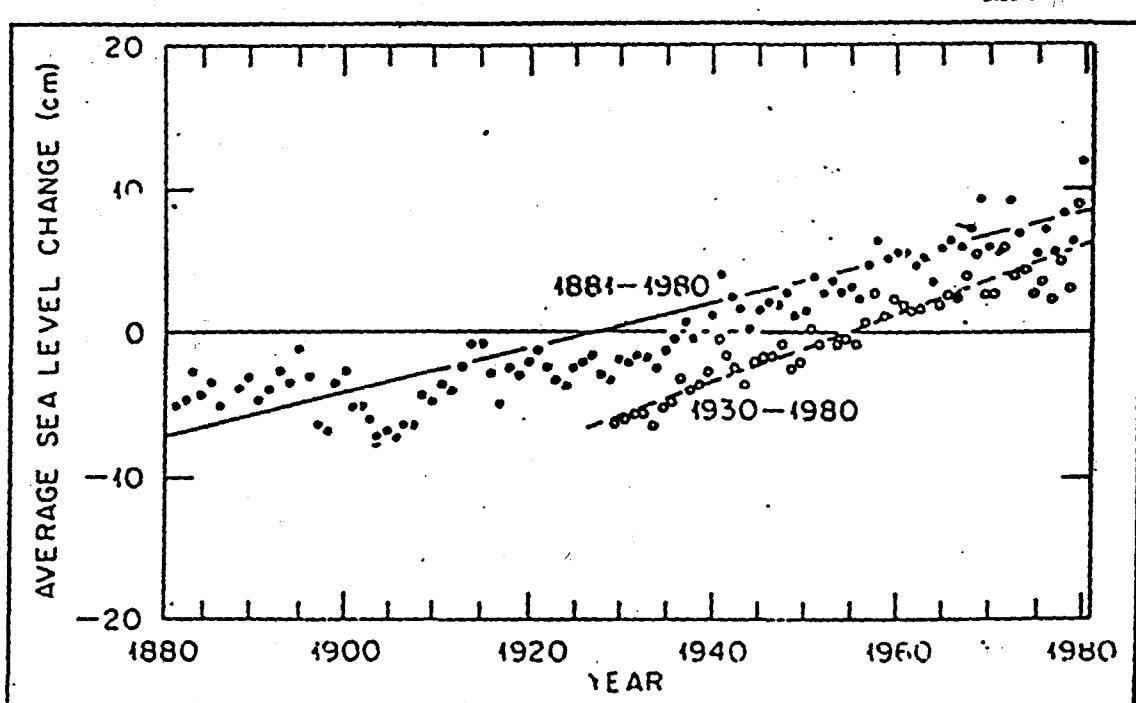
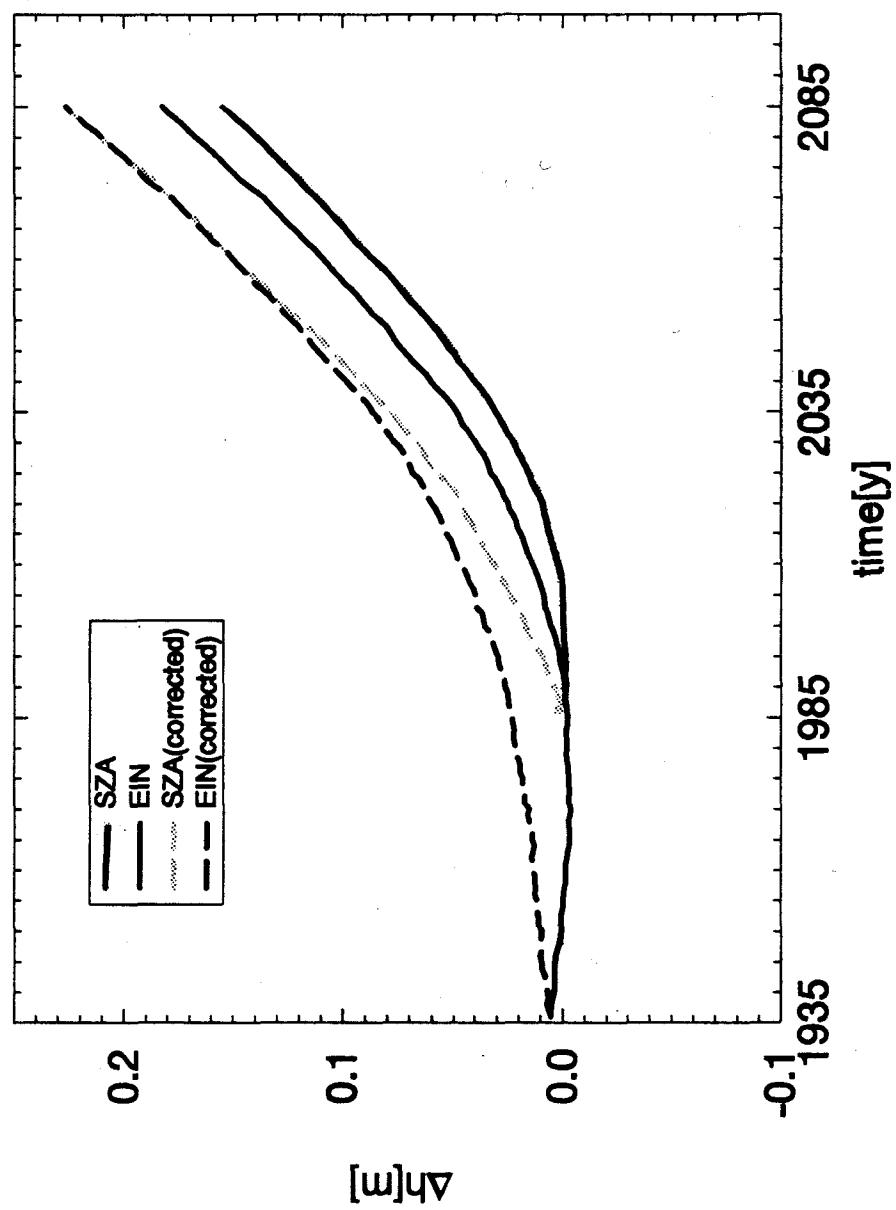
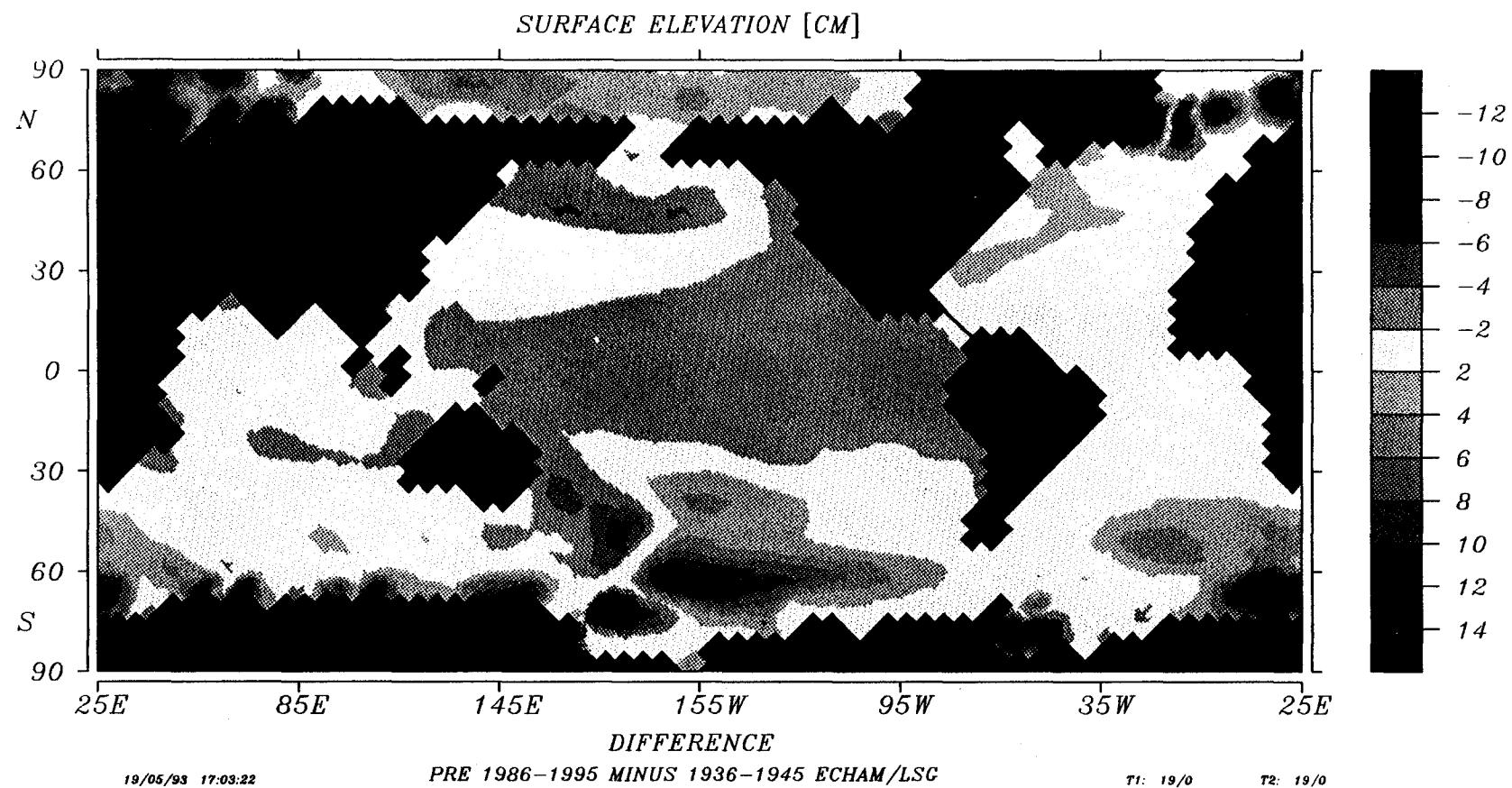


Figure 1. Estimates of overall average sea level change for two periods, 1881 to 1980 and 1930 to 1980. (Reprinted from Barnett, 1984, Journal of Geophysical Research, Vol. 89, No. C5, p. 7987, with permission from the American Geophysical Union.)

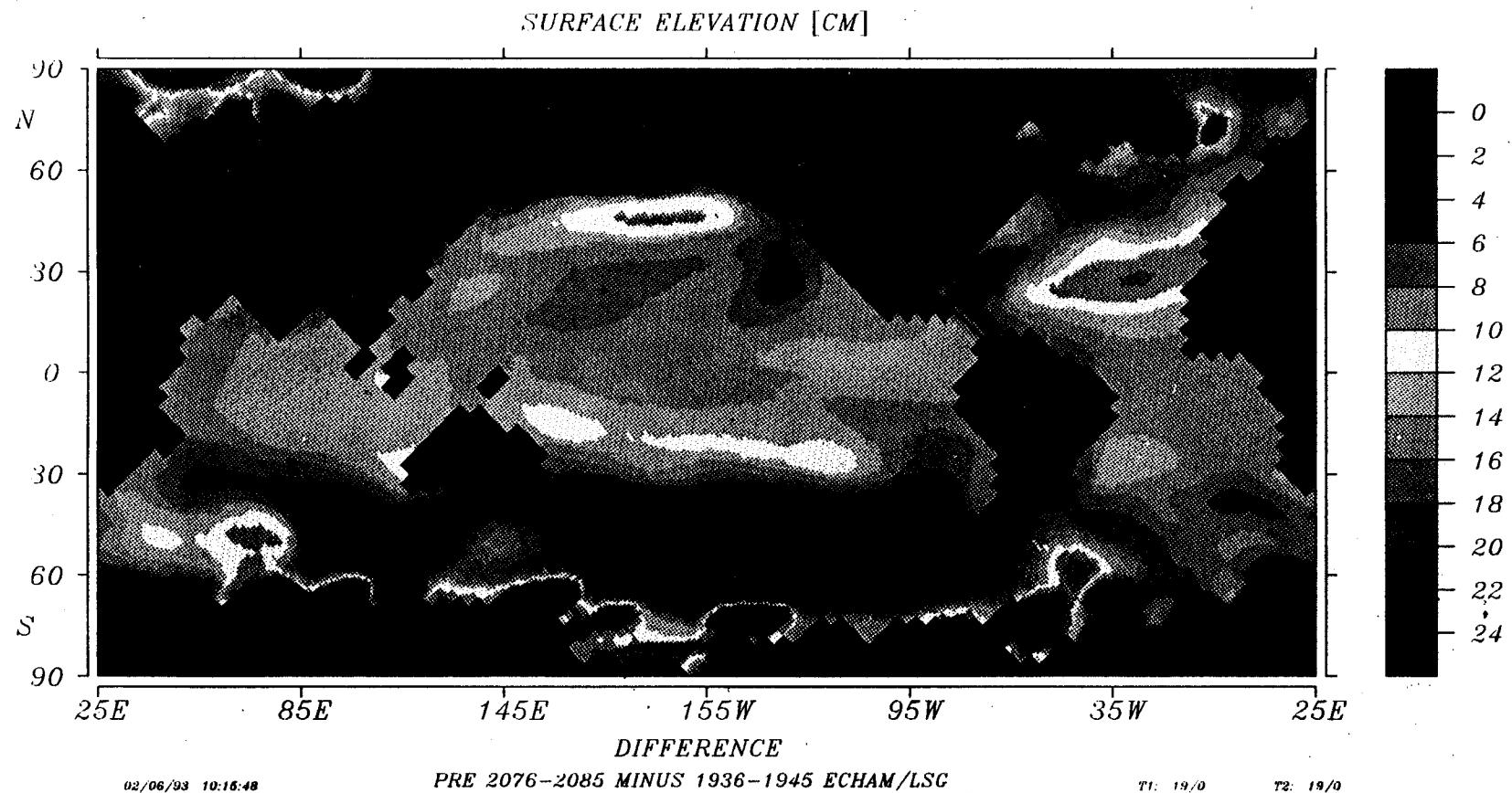
*Global mean sea level change  
(Cubasch et al., 1994)*





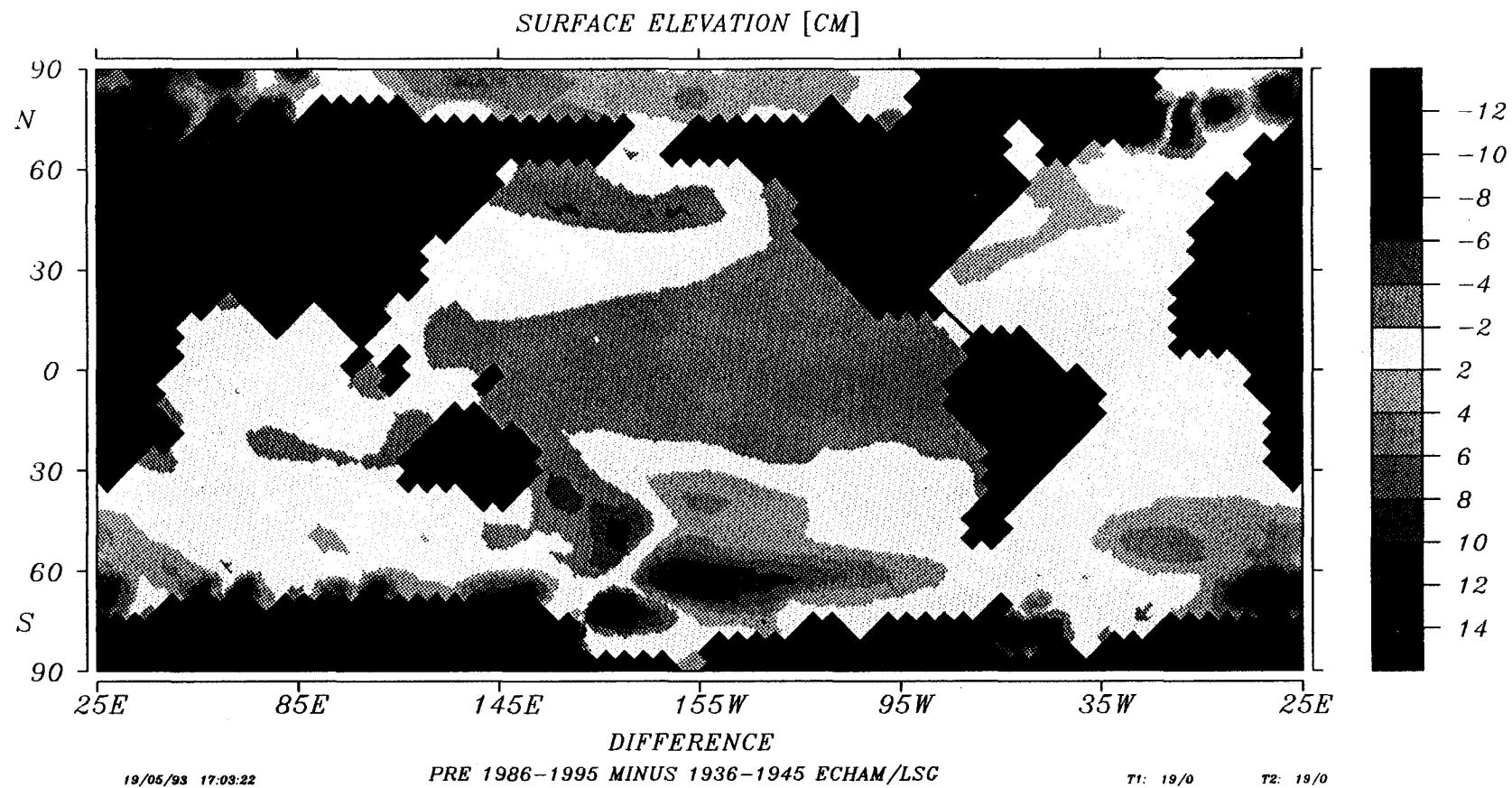
"1986-1995" minus "1936-1945"  
thermal expansion only  
 $\text{CO}_2$ -forcing only

from Cubasch et al., 1994



"2076-2085" minus "1936-45"  
*thermal expansion*  
 $\text{CO}_2$ -forcing (Scenario A) only

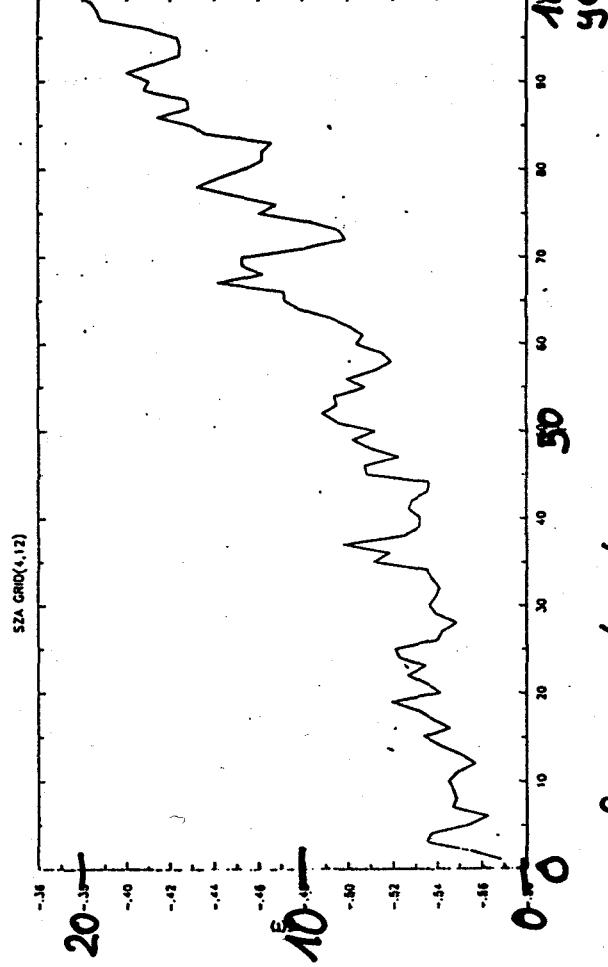
from Cubasch et al., 1999



"1986-1995" minus "1936-1945"  
thermal expansion only  
 $\text{CO}_2$ -forcing only

from Cubasch et al., 1994

from Kauker (1993, unpubl.)



Directly derived change of sea level  
at 4 grid points "representing" the "North Sea"  
in the coupled LSG / EC3A climate model. Response to Scenario A.

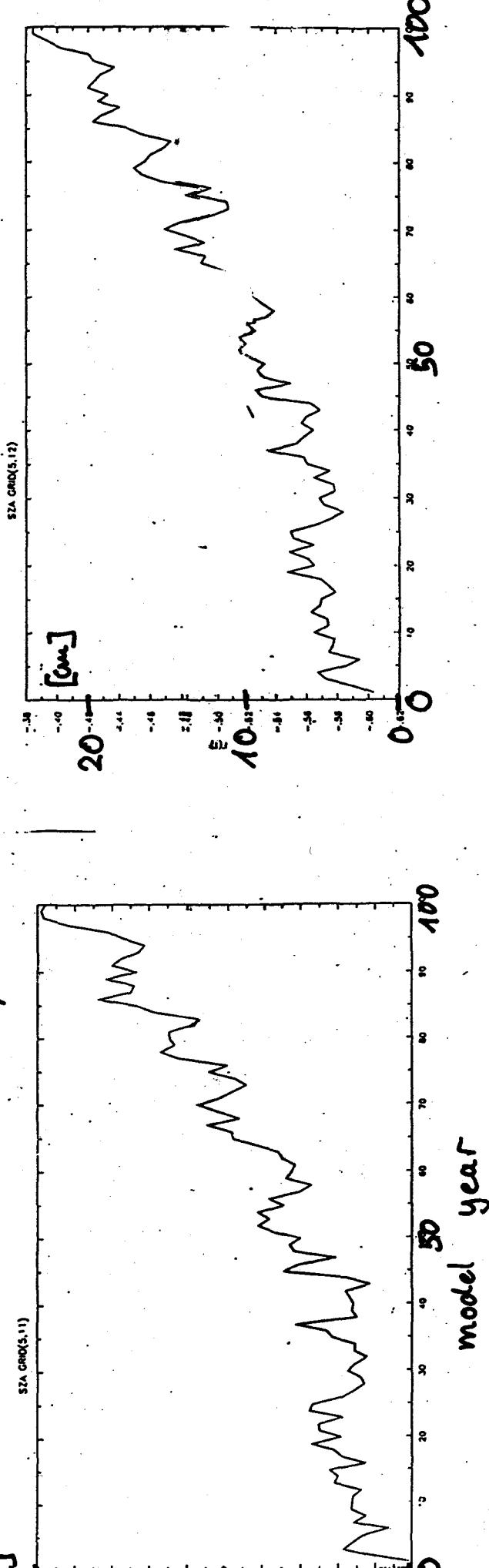
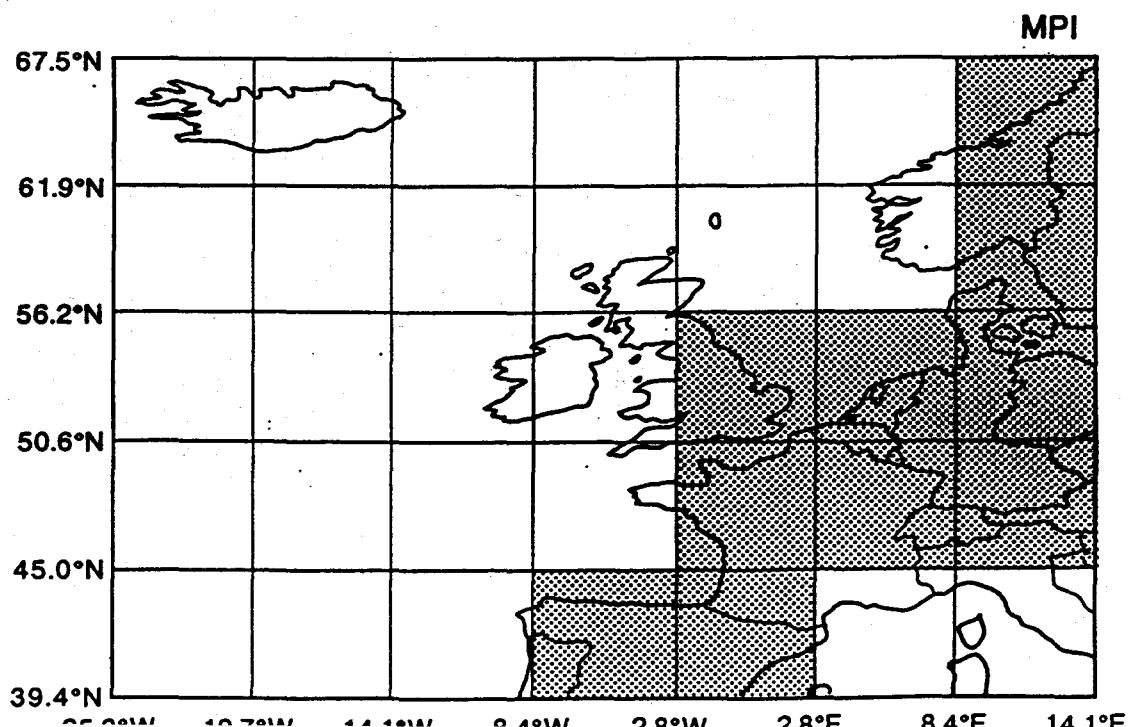
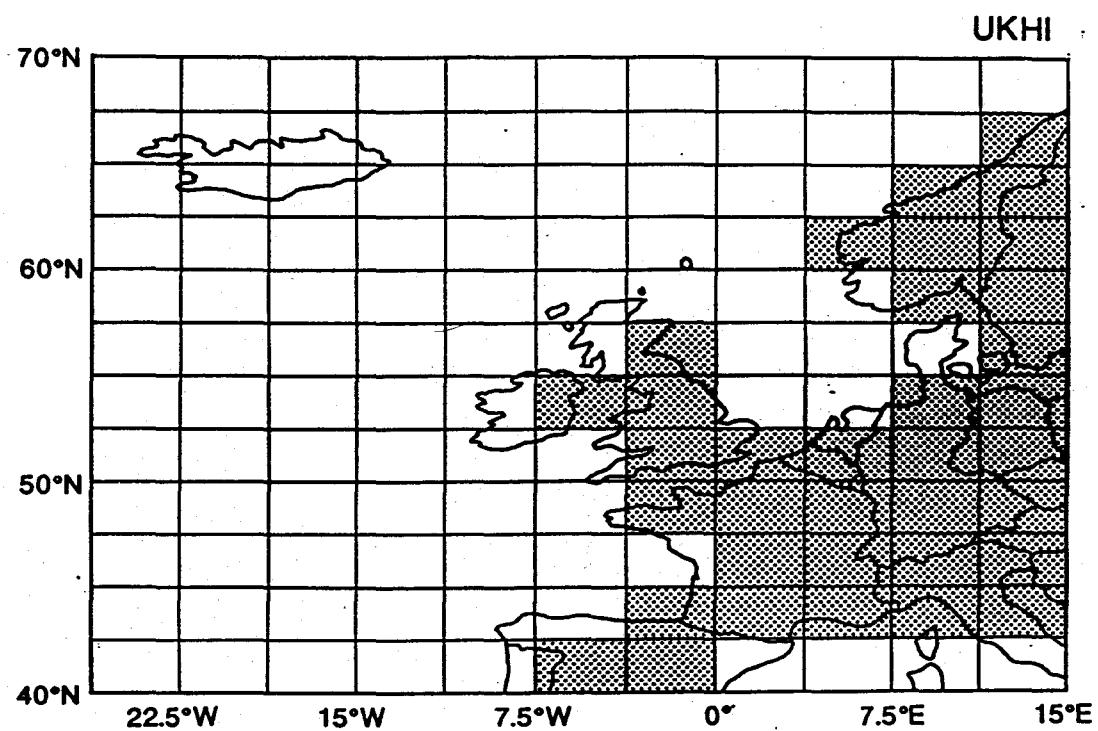


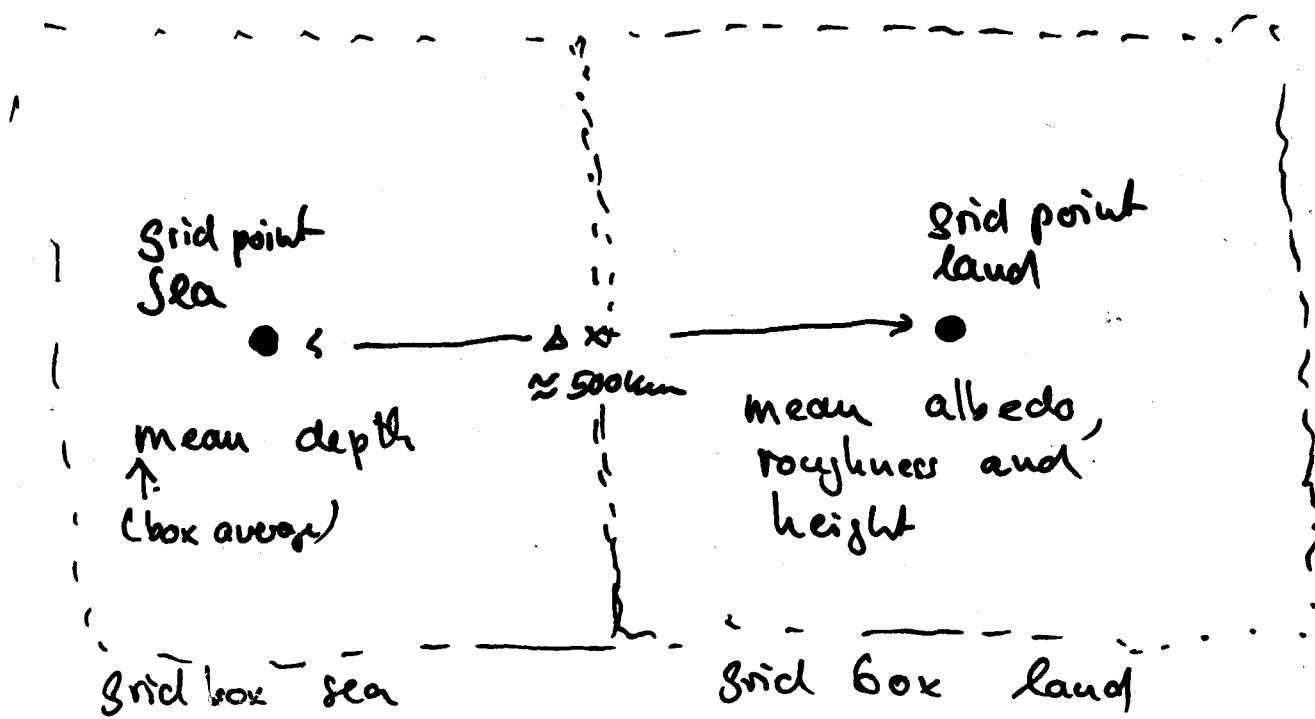
Figure 8.4

Horizontal resolution for two standard climate models  
(from Briffa, 1994)



# What does a climate model know about Coast

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$\Rightarrow$  Coast = Contrast in some  
box-averaged properties.

Shelf sea model result  
driven with observational data

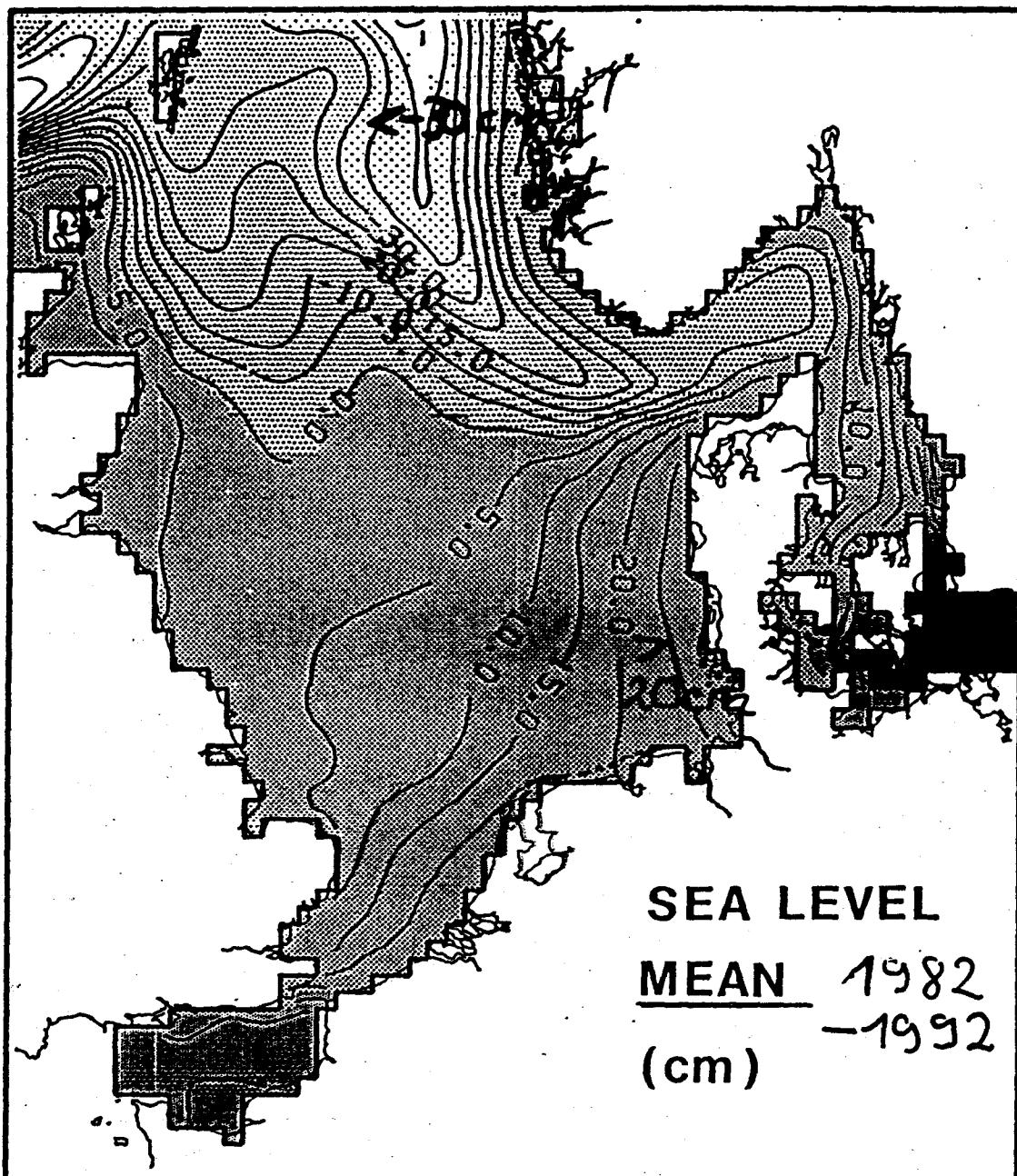


Fig. 4a: Mean sea level of the North Sea due to 3-hourly atmospheric forcing.  
Calculated with a three-dimensional baroclinic shelf sea model.  
Averaged over the period 1982 to 1992. (Pohlmann)

# **DOWNSCALING for LOCAL SEA LEVEL**

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- **The General Strategy** - dynamical and statistical models
- **Factors Controlling Local Sea Level:** The large scale thermal and dynamical state of the ocean, the regional atmospheric forcing, tectonic processes.

## MODEL DESIGN

Identify regional climate parameter(s),  $R$

Find large-scale climate parameter  $L$  which

- controls  $R$  through  $R = \mathfrak{F}(L, \vec{\alpha})$  with parameters  $\vec{\alpha}$  to be specified.
- is well simulated by a climate model.

Use samples  $(R, L)$  from historical data to find  $\vec{\alpha}$  such that

$$\|R - \mathfrak{F}(L, \vec{\alpha})\| = \min$$

Validate choice of  $\vec{\alpha}$  with independent historical data.

## MODEL APPLICATION

Get  $L$  from climate model output

Calculate  $R = \mathfrak{F}(L, \vec{\alpha})$

Use  $R$  as forcing function for impact model.

# **DOWNSCALING for LOCAL SEA LEVEL**

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- **The General Strategy** - dynamical and statistical models
- **Factors Controlling Local Sea Level:** The large scale thermal and dynamical state of the ocean, the regional atmospheric forcing, tectonic processes.

# The “downscaling” model $\mathcal{F}$

- Expand  $R$  and  $L$  :

$$R(t) = \sum_i \rho_i(t) \vec{r}_i$$

$$L(t) = \sum_i \lambda_i(t) \vec{l}_i$$

with fixed “patterns”  $\vec{r}_i$  and  $\vec{l}_i$  and time dependent coefficients  $\rho_i(t)$  and  $\lambda_i(t)$ .

The patterns are fitted to the data such that the coefficients  $\rho_i$  and  $\lambda_i$  are optimally correlated. The technique to get these optimally correlated patterns is named Canonical Correlation Patterns.

- Then there are good regression equations

$$\rho_i = \alpha_i \cdot \lambda_i$$

and the downscaling model writes

$$\mathcal{F}(L) = \mathcal{F}(\lambda_i; \alpha_i) = \sum_i \alpha_i \lambda_i \vec{r}_i = \tilde{R}$$

# **Example: BALTIC SEA**

- **Regional Parameter  $R$ :**

- Sea level at 14 stations along the coast of the Baltic Sea;
- Detrended data (to avoid land sinking/rising signals);
- Mean annual cycle subtracted;
- Seasonal means (DJF) from 1905 - 1972.

- **Large-scale parameter  $L$ :**

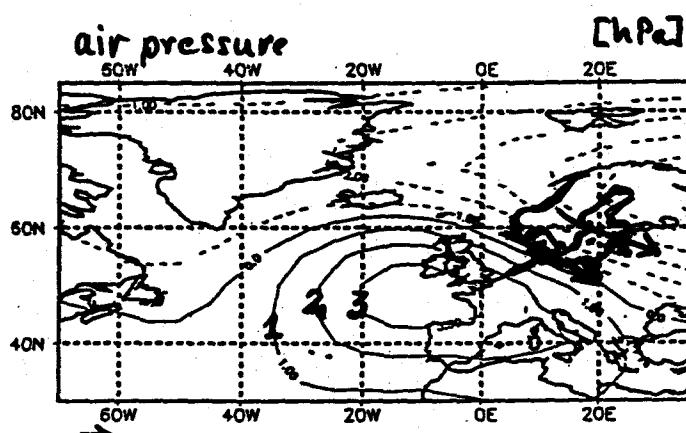
- North Atlantic sea level pressure  $70^{\circ}W - 35^{\circ}E \times 30^{\circ}N - 85^{\circ}N$
- Mean annual cycle and trend subtracted.
- Seasonal means (DJF) from 1905 - 1972

- **Fit of CCA-model** with data from 1951-70.

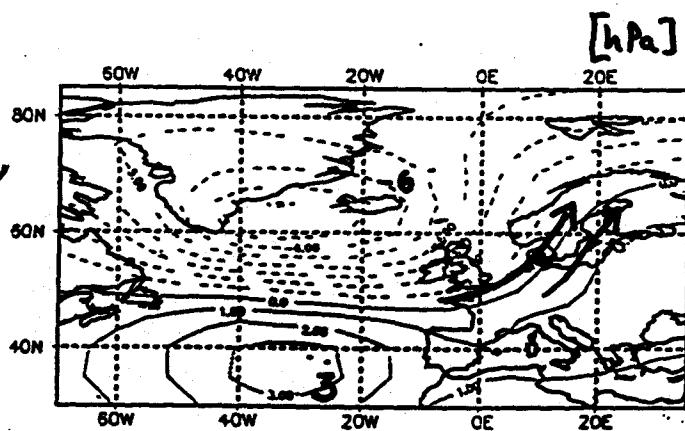
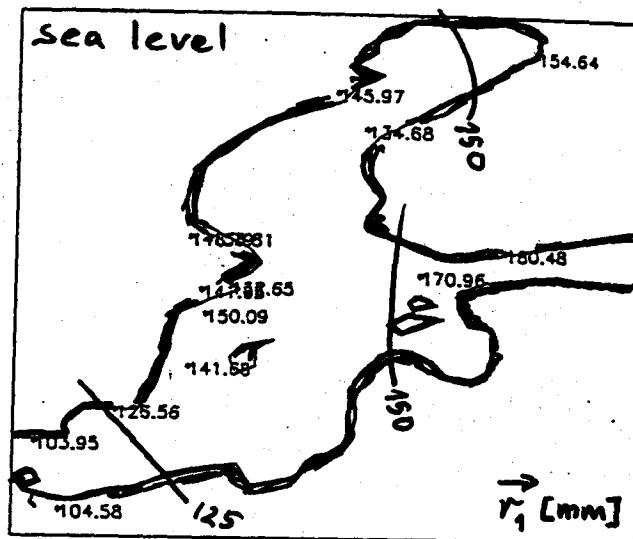
Abb.8a) Die ersten beiden Musterpaare der CCA Luftdruck-Wasserstand für die Anpassungsperiode 1951-70. Verwendet wurden die Wasserstandsdaten der 14 Stationen.

~~Gegenüber der mit 26 Stationen durchgeführten CCA (Abb.5a) sind die Muster und Korrelationen praktisch sehr ähnlich, die 14 Stationen enthalten damit die gleichen grundlegenden Informationen über den Ostseewasserstand: (Erklärte Luftdruckanomalien: 10%, 30%, erklärte Wasserstandsanhomologien: 83%, 8%, Korrelationen: 0.81, 0.56).~~

Die weiteren Ergebnisse beruhen auf dieser CCA.



Korrelation of  
coefficients  $\lambda_1$  and  $s_1$ : 0.81



$\vec{l}_2$   
Correlation of  
coefficients  $\lambda_2$  and  
 $s_2$ : 0.56

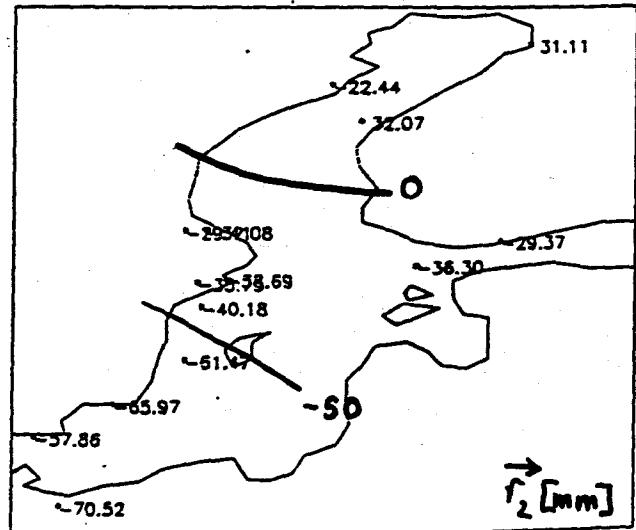
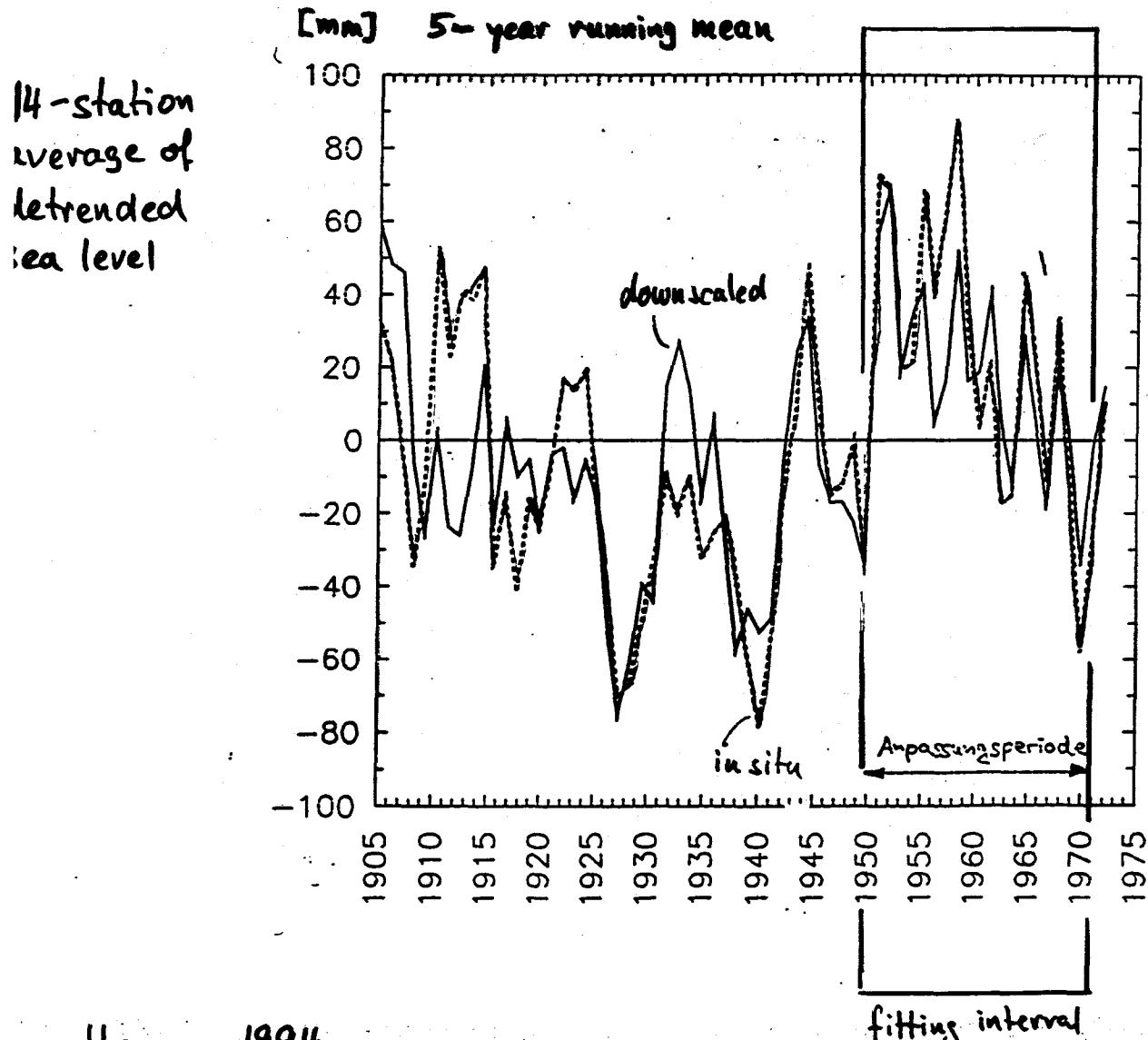


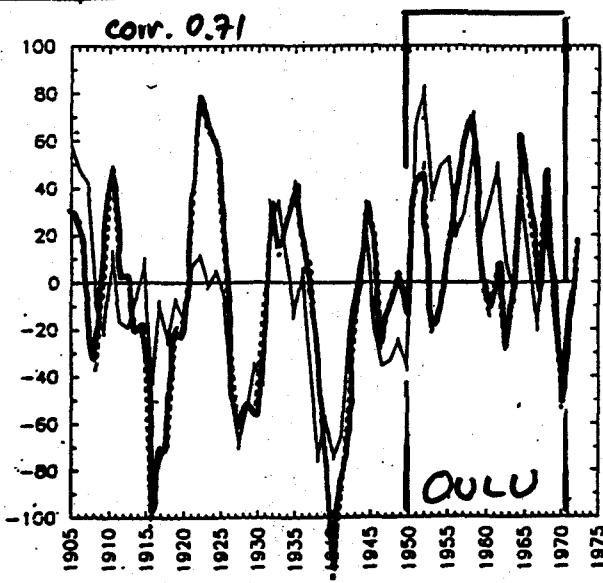
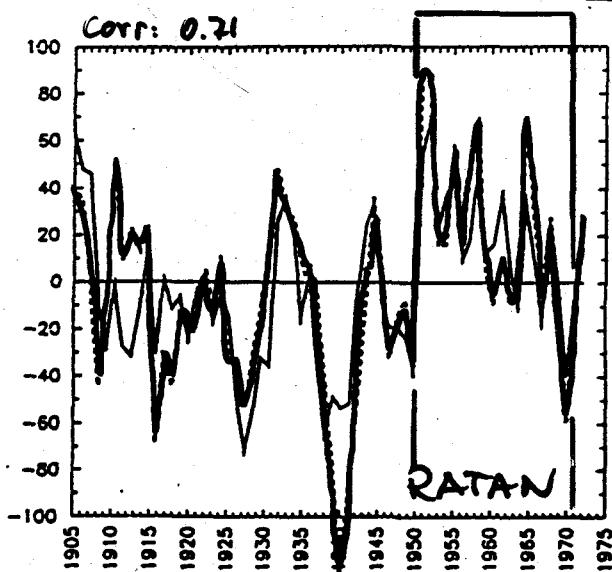
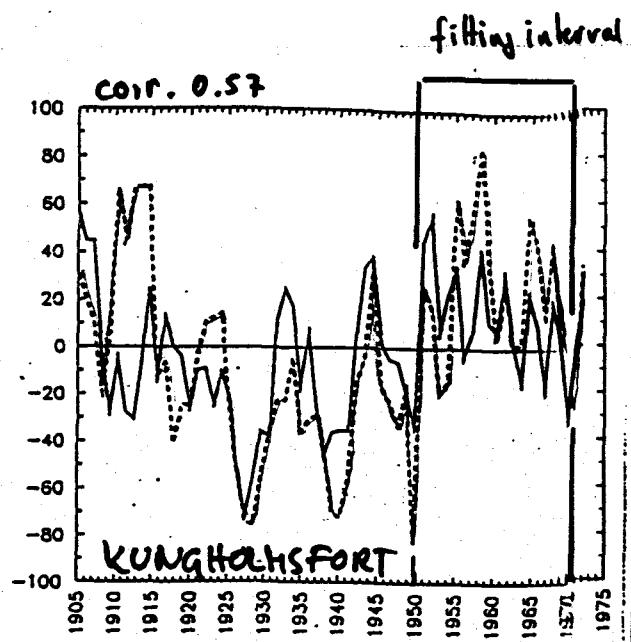
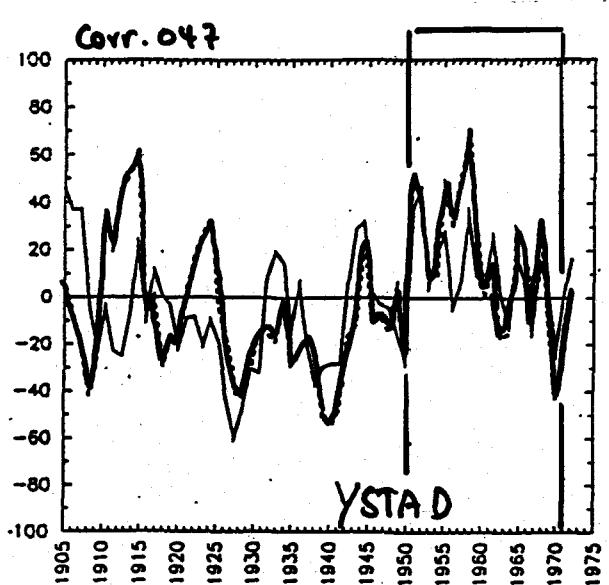
Abb.9a) Abgebildet ist das Downscaling der trendlosen Luftdruck- auf die Wasserstandsanomalien für den Zeitraum 1905 - 71.

Die errechneten Wasserstandsanomalien in mm (—) wurden saisonal, über die Stationen und mit einem 5-jährigen laufenden Mittel gemittelt. Zum Vergleich sind auch die beobachteten Anomalien dargestellt (---).

Man beachte, daß das Downscaling-Modell mit trendlosen Daten aus den Jahren 1951-70 erstellt wurde. Die Beobachtungen weisen ganz offensichtlich neben den kurzperiodischen, monatlichen und jährlichen Anomalien auch längerperiodische Anomalien auf der Zeitskala von Dekaden auf, die ausgezeichnet wiedergegeben werden. Die schlechte Übereinstimmung von Modell und Beobachtungen zu Anfang unseres Jahrhunderts hängt vermutlich mit ungenauen Luftdruckdaten in diesem Zeitraum zusammen.



— : downscaled sea level / detrended.  
 — : in situ sea level

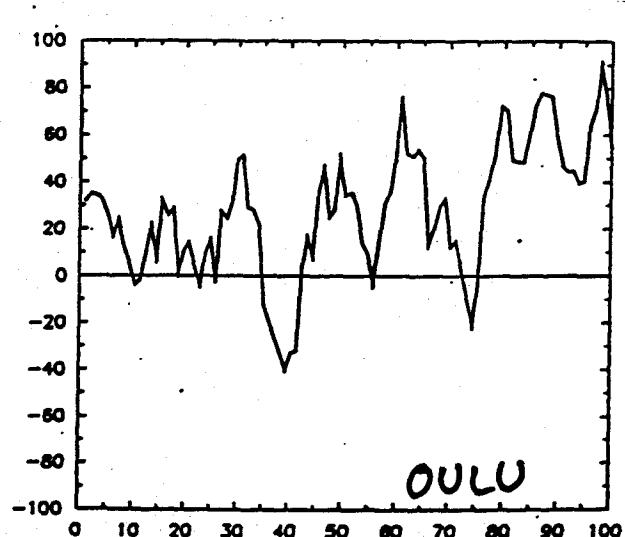
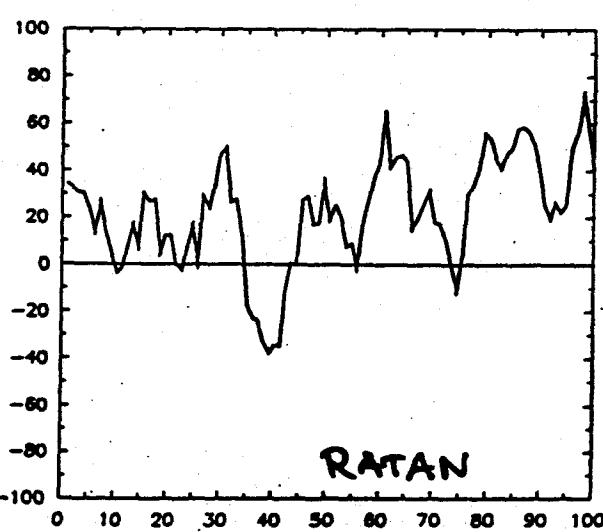
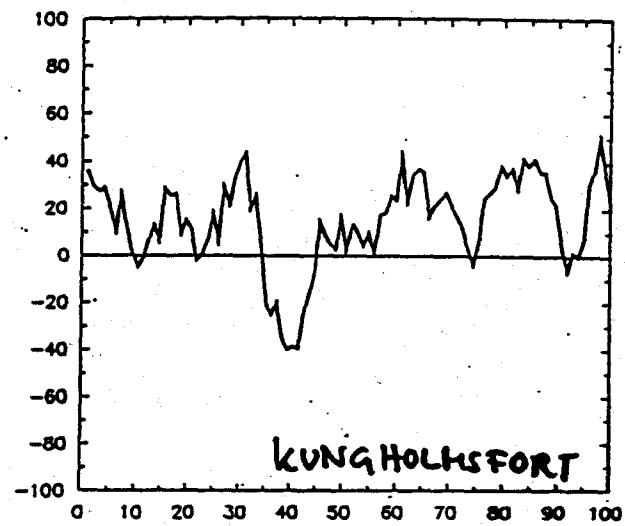
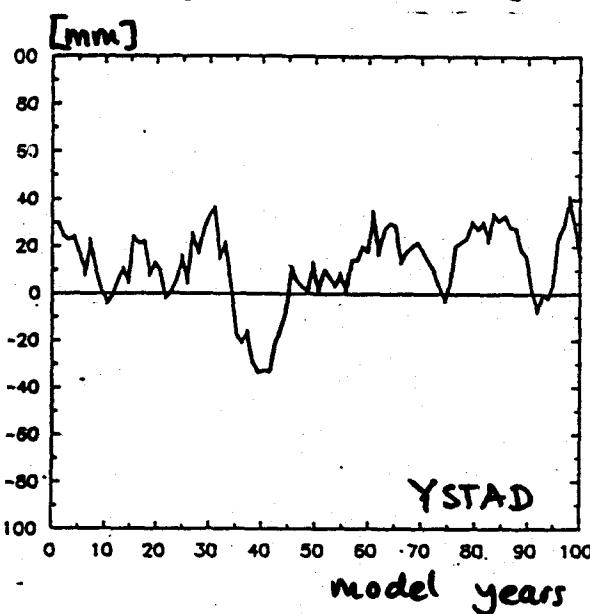


Die durchgezogene Linie (—) stellt die aus dem Luftdruckfeld abgeleiteten, die gestrichelte Linie (—) die beobachteten Wasserstands-anomalien dar.

Die Korrelation zwischen dem Modell und den Beobachtungen beträgt für die einzelnen Stationen 0.47, 0.57, 0.71, 0.71 .

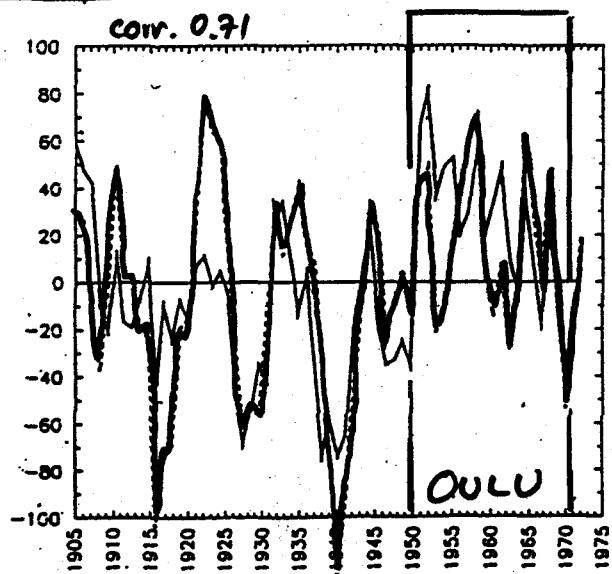
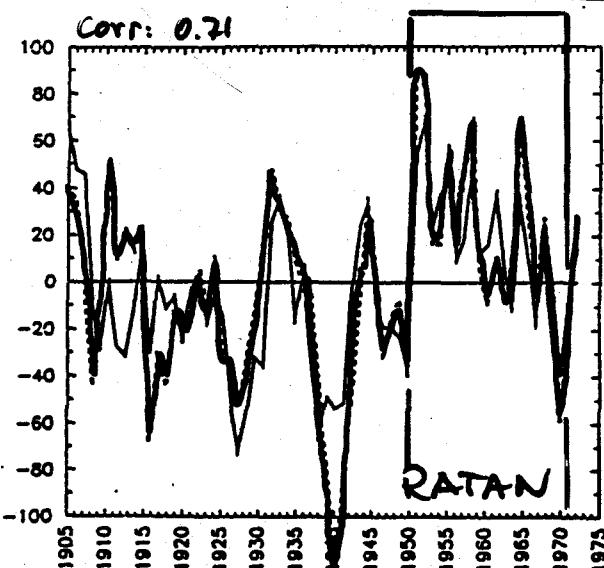
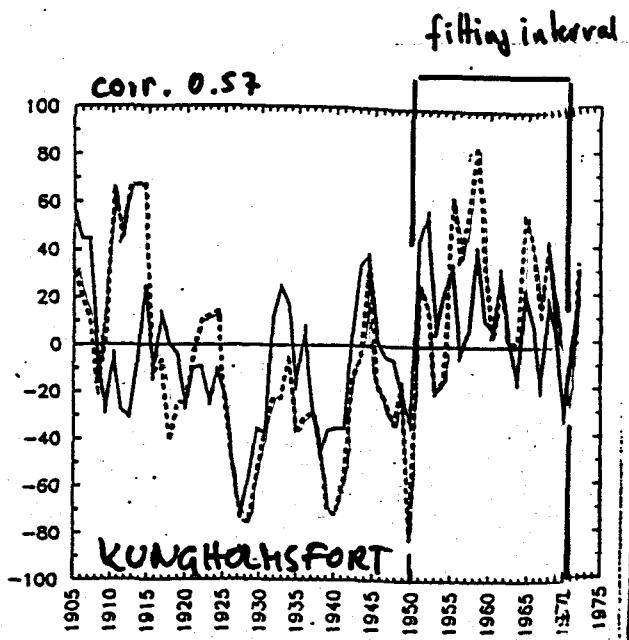
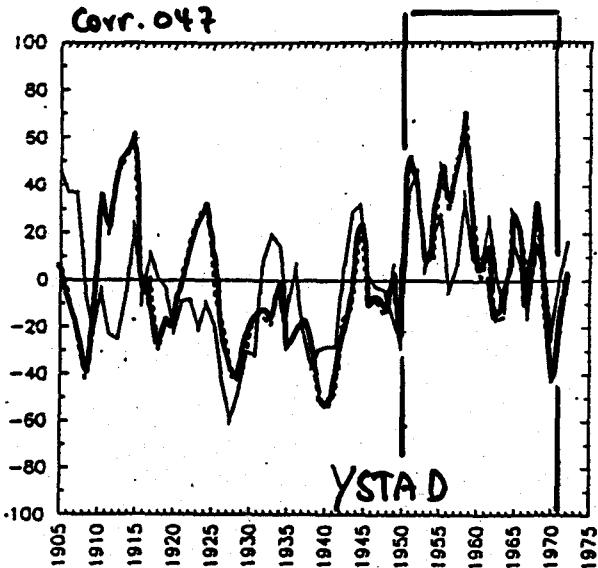
Sea level rise according  
to the "downscaled" scenario A

Abb.11) Ergebnis des Downscalings für "Scenario A";



Die Kurve stellt die aus dem Luftdruckfeld ermittelten Wasserstandsano-  
malien in mm dar, saisonal und durch ein 5-jähriges laufendes Mittel  
gemittelt. Die x-Achse zeigt die Jahre des Klimamodellaufs.

— : downscaled sea level / detrended.  
 — : in situ sea level



Die durchgezogene Linie (—) stellt die aus dem Luftdruckfeld abgeleiteten, die gestrichelte Linie (—) die beobachteten Wasserstands-anomalien dar.

Die Korrelation zwischen dem Modell und den Beobachtungen beträgt für die einzelnen Stationen 0.47, 0.57, 0.71, 0.71 .

# Example: JAPANESE COAST

- **Regional Parameter  $R$ :**

- Sea level at 15 stations along the coast of the Japanese Islands;
- Detrended data (to avoid land sinking/rising signals);
- Mean annual cycle subtracted;
- Seasonal means (DJF) from 1958 - 1988.

- **Large-scale parameter  $L_{SST}$ :**

- Sea surface temperature in the area  
 $125^{\circ}E - 150^{\circ}E \times 25^{\circ}N - 45^{\circ}N$ .
- Mean annual cycle and trend subtracted.
- Seasonal means (DJF) from 1958 - 1988

- **Large-scale parameter  $L_{SLP}$ :**

- Sea surface temperature in the area  
 $115^{\circ}E - 80^{\circ}W \times 20^{\circ}N - 60^{\circ}N$ .
- Mean annual cycle and trend subtracted.
- Seasonal means (DJF) from 1958 - 1988

- **Fit of CCA-model with all data.**

- All data smoothed by 25-months running mean filter to suppress El Niño related variability.

Figure 3: Distribution of tide gauges from which data are used in the present analysis. The numbers refer to Table 1.

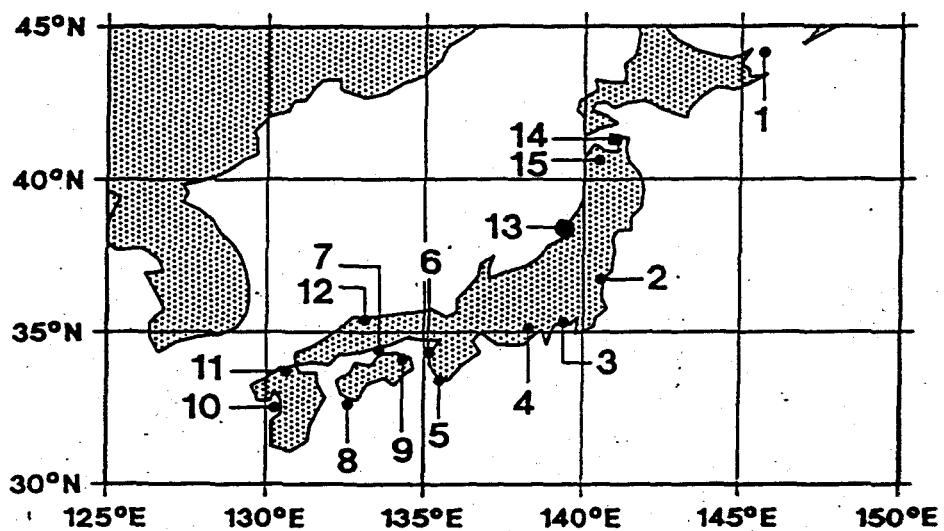


Figure 4: Time series of monthly mean sea level at Nezugaseki (station 13). The abrupt change in July 1964 is due to an earthquake.

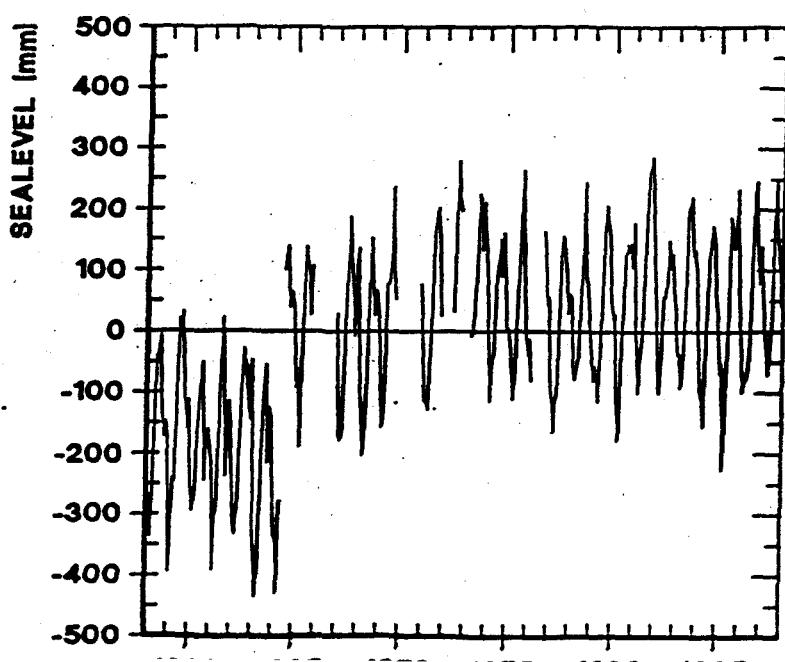


Figure 5: First EOF of the filtered monthly mean sea level at the 15 stations (listed in Table 1 and shown in Figure 3) derived from 30 years of data (1958 - 1987).  
 Top: Pattern in dimensionless units.  
 Bottom: Coefficient time series in mm.

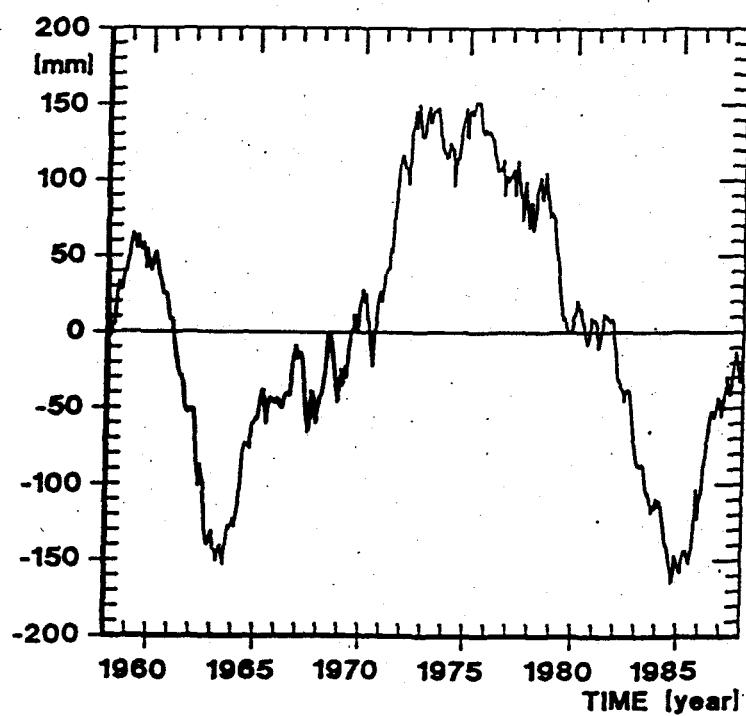
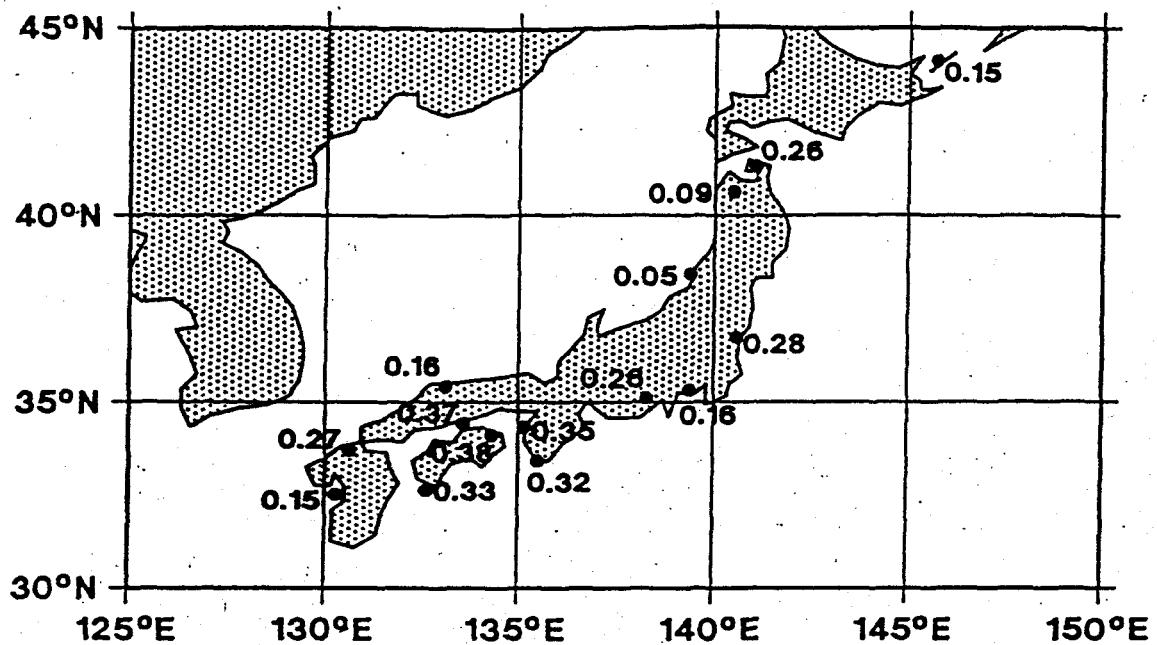


Figure 9: 1st pair of canonical correlation patterns  $\bar{p}_2^{(1)}$  and  $\bar{q}_2$  of the joint analysis of Japanese sea level and regional sea-surface temperature. Units: mm and °C.

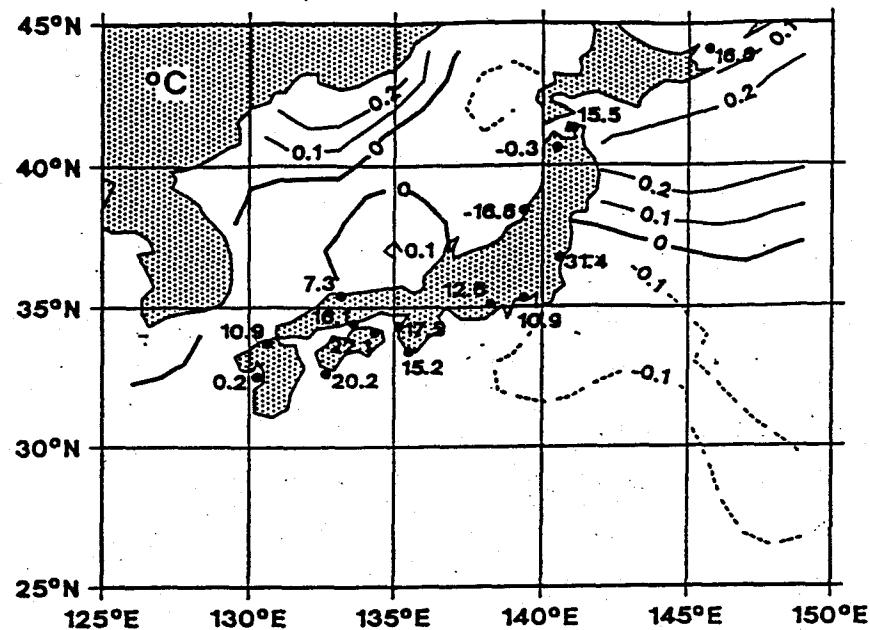
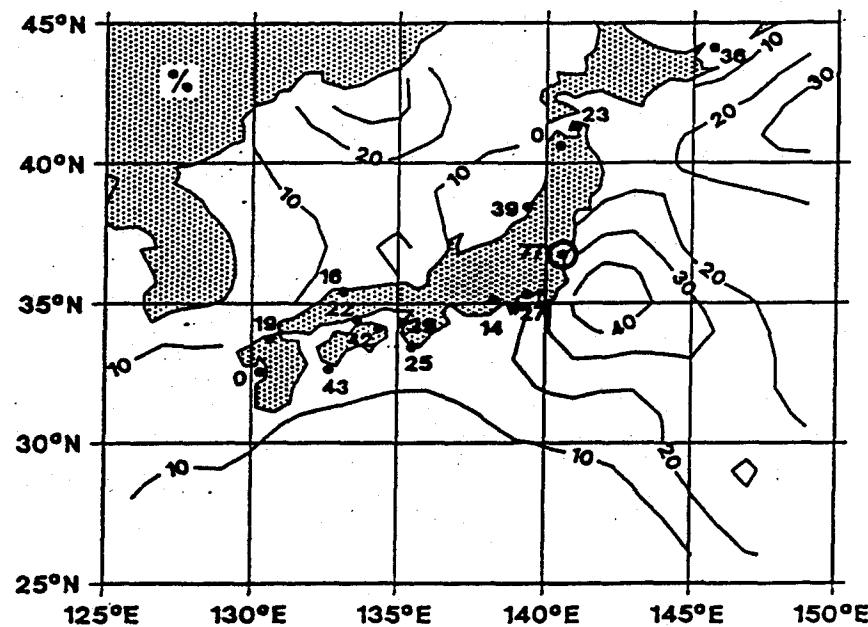
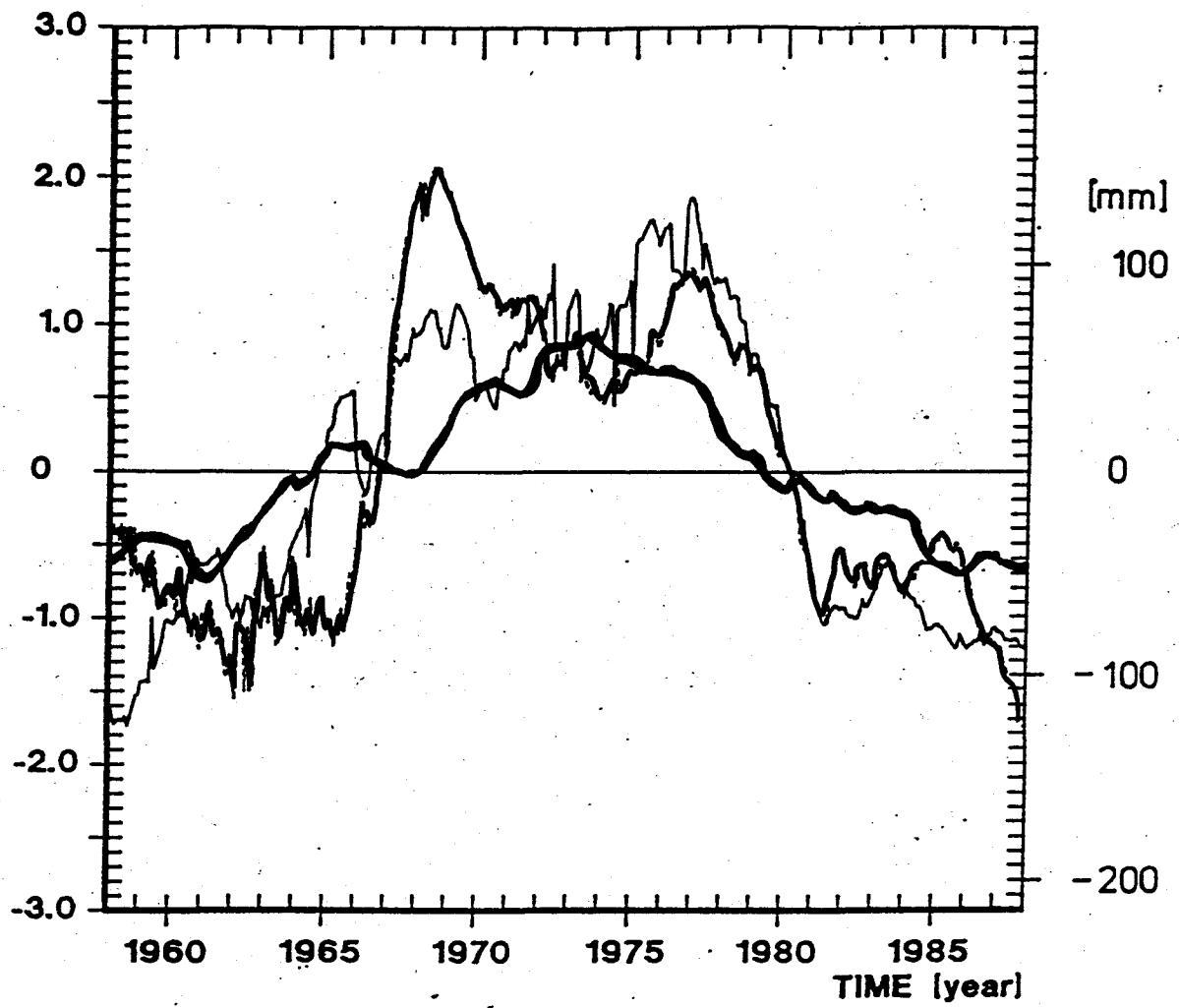


Figure 10: Percentages of local variance accounted for by the 1st pair of canonical correlation patterns of the joint analysis of Japanese sea level and regional sea-surface temperature. Units: %. Station 2, for which the local sea level time series is shown in Figure 11, is marked by a circle.



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Figure 11: Time coefficients  $\alpha_1(t)$  and  $z_1(t)$  of the first pair of canonical correlation patterns derived in the joint analysis of sea level (continuous line) and regional sea-surface temperature (dashed line). The time series are normalized to standard deviation 1. As heavy line the time-filtered sea level anomalies at station 2 (for the location, see Figure 10), at the northeast coast is shown for comparison.

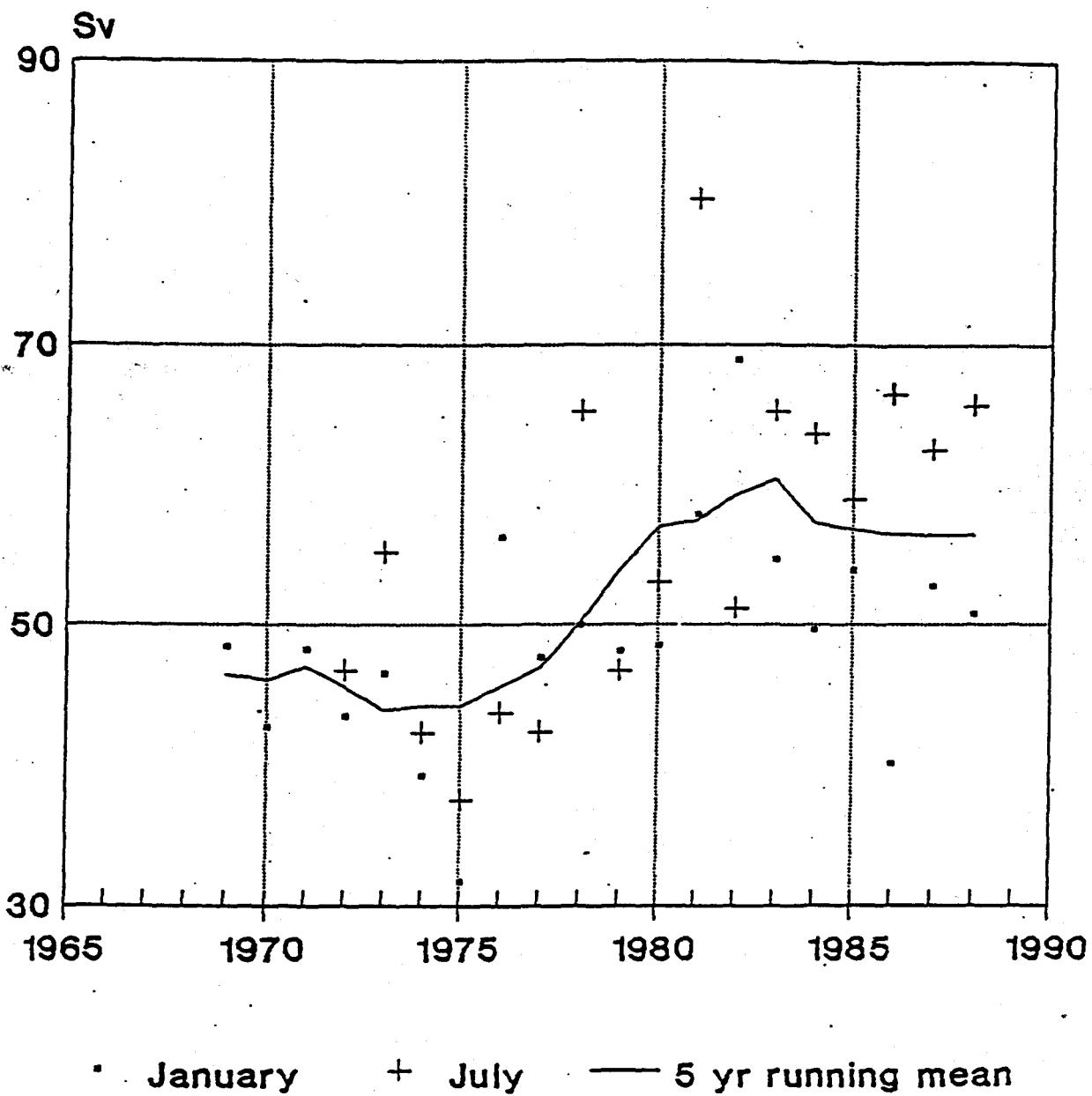


— : station 2

— : time coefficient  $z_1(\text{SST})$

— : time coefficient  $\alpha_1$  (sea level)

Figure 20: Time series of the transport of the Kuroshio compiled by Qiu and Joyce (1992) from hydrographic data. The symbols represent July and January mean values whereas the continuous line is the 5-year running mean of the annual means formed as averages of the January and (when available) July values.



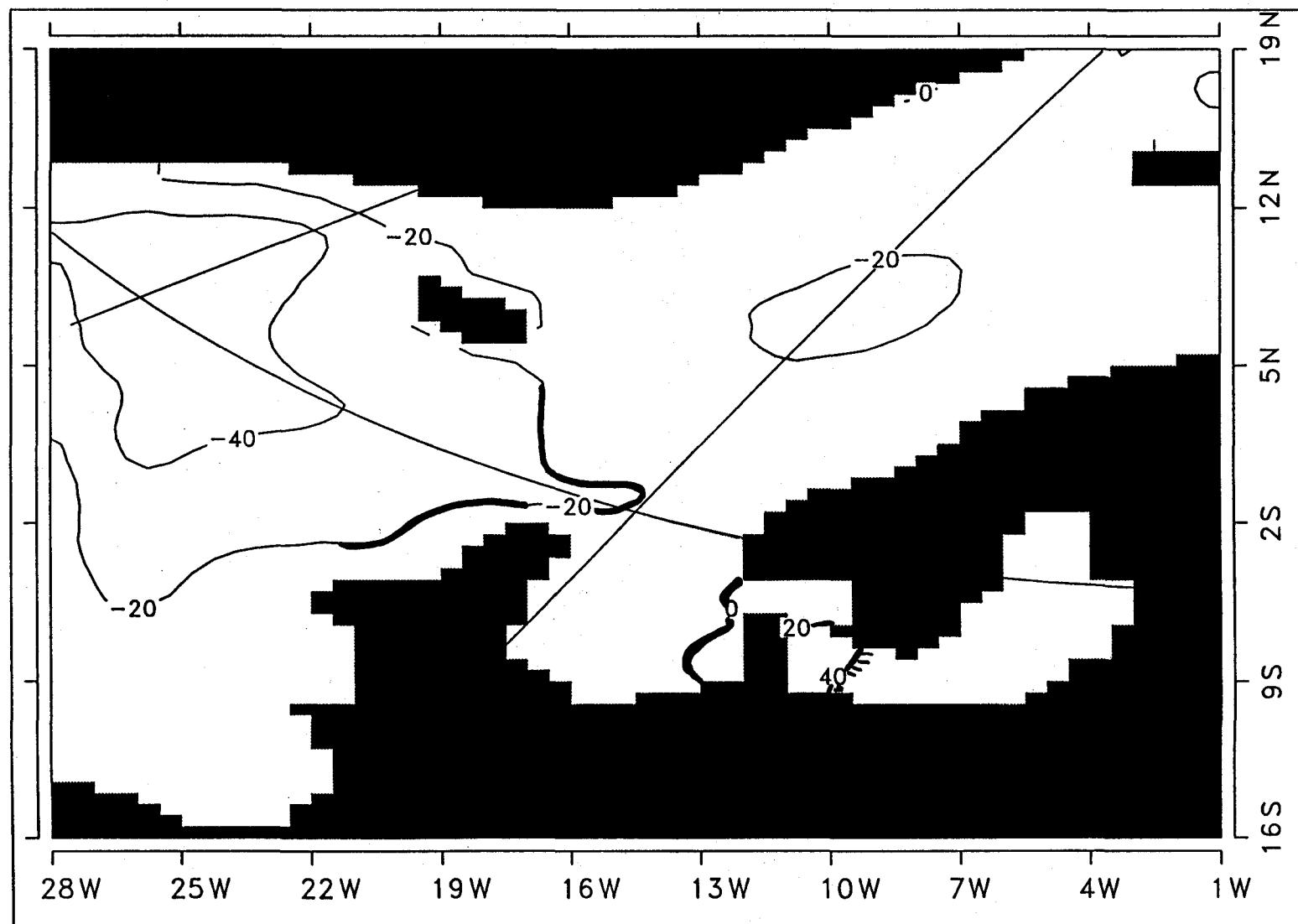
# Dynamical Downscaling for the North Sea

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- **Idea:** Run a regional ocean model of North Sea and simulate the effect of changing atmospheric forcing and a changing state of the North Atlantic.
- **Actual Set-up:** The ocean model used is Oberhuber's (1993; J. Phys. Oceano.) isopycnic ocean model which covers the North Sea and the Baltic Sea as key areas and the Northern North Atlantic with a uniform resolution of approximately 50 km.  
At present this preliminary model is tested and tuned. A first run over several years has been made.
- **Ideal Set-up:** At a later stage the model will be run with non-uniform resolution, with a high resolution of approximately 10 km in the key area and 50 km in the Atlantic.

## SEA SURFACE ELEVATION

DEPTH=0000 01AUG 006



REFERENCE LINE: 0    UNIT: cm  
CONTOUR INTERVAL: 20

MIN=-52    MEAN=-14  
MAX=57    STDV= 20

from Kauker

LABEL: Josef M. Oberhuber [ DKRZ ]

DATE: 04/28/94

TIME: 17:30:32

JMO-GRAFICS

# Conclusions

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- Climate models predict a rise of the sea-level, as a consequence of the thermal expansion of the sea water. This effect competes with other effect such as deposition and release of water on glaciers.
- Impact-wise is not sea level in general of interest but coastal sea level. Present day models are not good in simulating the coastal sea level, because of limited spatial resolution and the idealization of the coast.
- Downscaling techniques are useful to derive statistics of coastal sea level from large-scale oceanic or atmospheric variables. Since some large-scale variables are (relatively) well observed in the past 100 years, and (potentially) reliably simulated by climate models, such downscaling techniques may be used to reconstruct past regional variations and to estimate regional aspects of future changes.
- Statistical downscaling procedures can be implemented whenever homogeneous observations are available; dynamical approaches have the advantage that they are able to reproduce regional aspects without extensive observations.
- More work is needed - in particular with respect to the dynamical downscaling approach.