

The Global and Regional Climate Systems

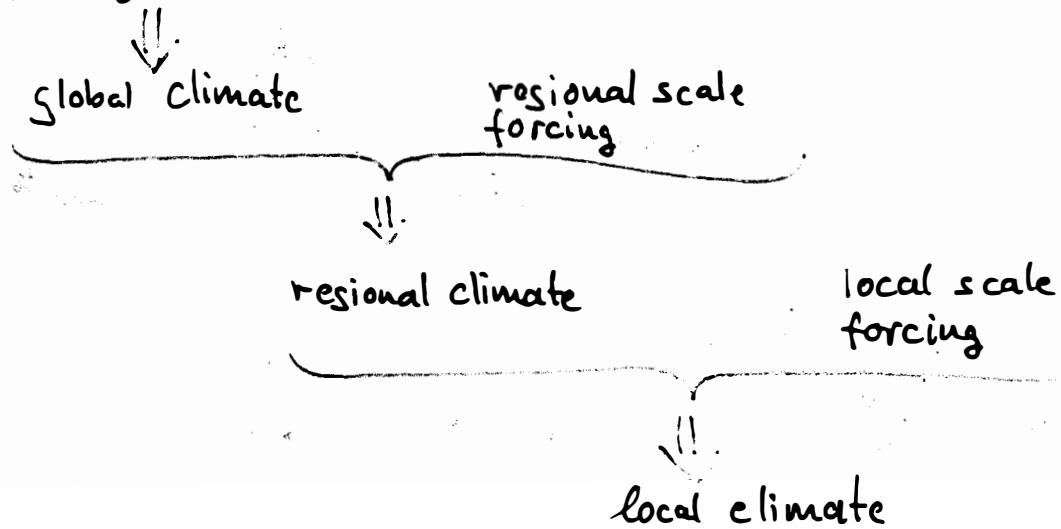
Haus von Storch, GKSS

- the formation of the global climate
- the formation of the regional climates
- the rôle of local processes for the formation of the global climate

Main Conclusions

a) global climate $\neq \sum_{\text{regions}}$ regional climates

b) planetary scale
forcing



c) statistics of local features, and not details of specific localized features, matter for the formation of the global climate

Historical note

Köppen's (and others) applied view
of mapping the climate of the earth

Hadley's (and others) theoretical view
of understanding major features of global climate.

Question:

$$\text{global climate} \stackrel{?}{=} \sum_{\text{regions}} \text{regional climates}$$

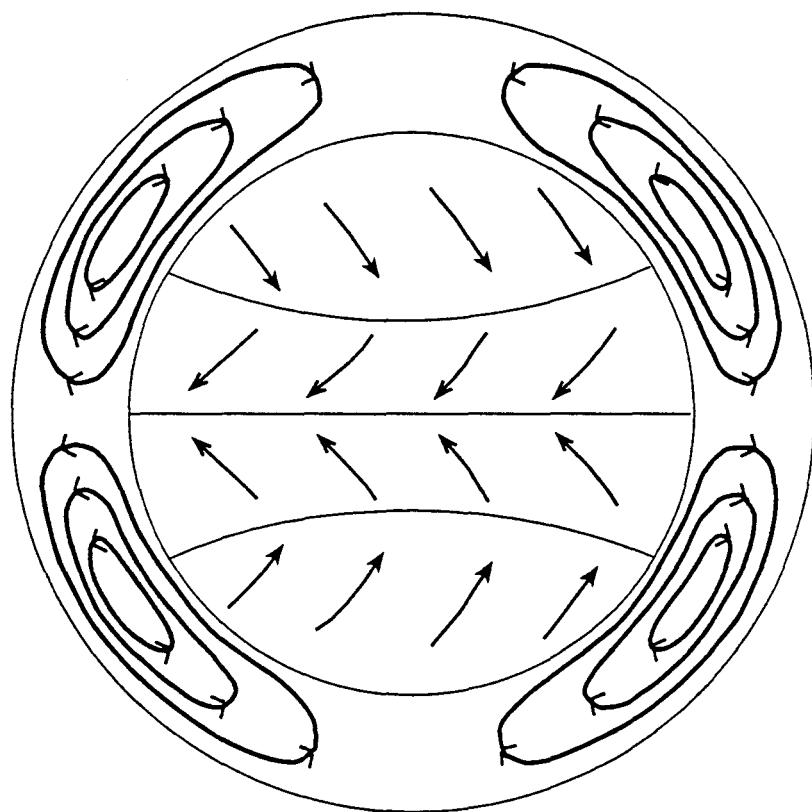
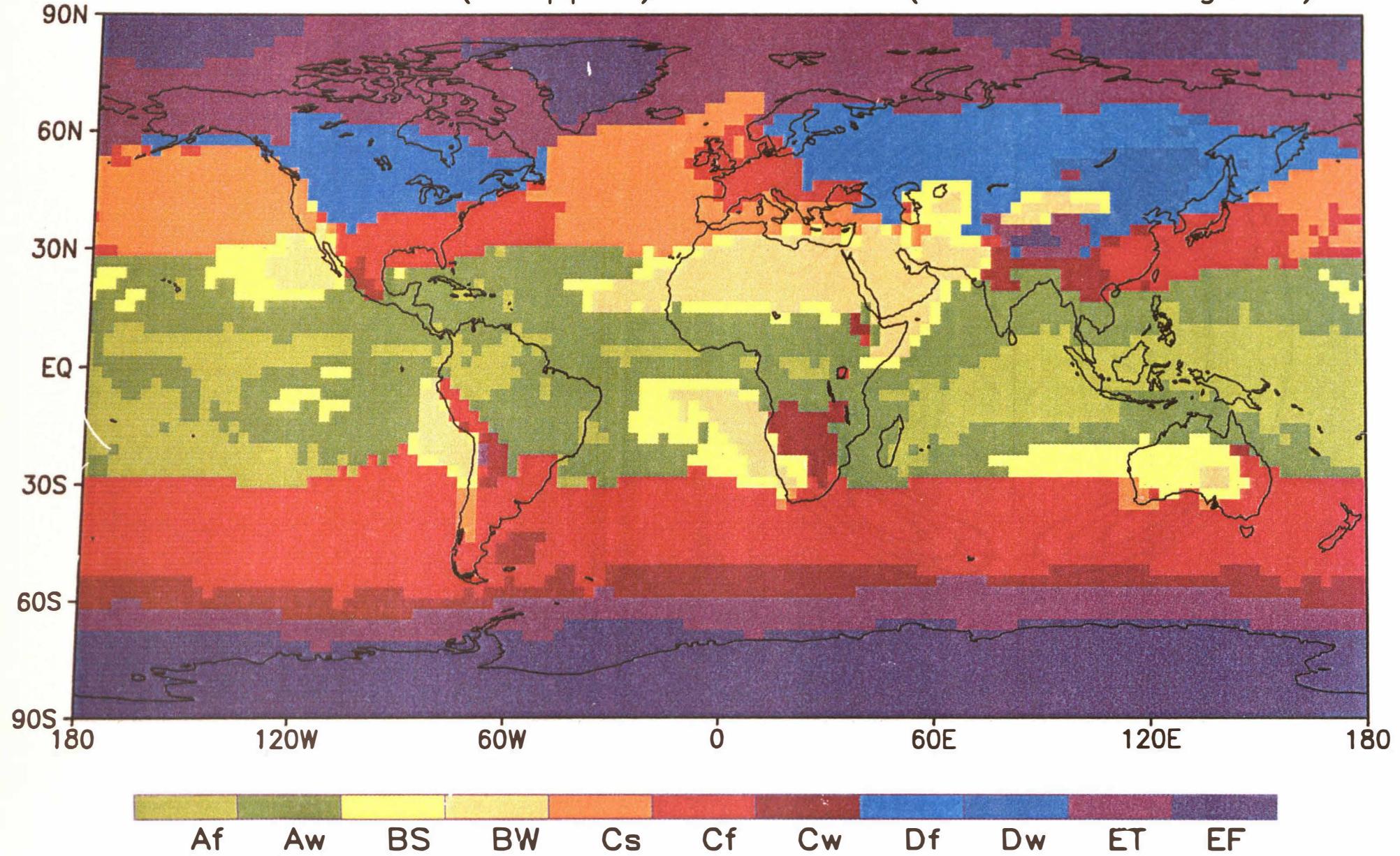


Figure : A schematic representation of the general circulation of the atmosphere as envisioned by Hadley (1735).

Lohmann, 1993

Climate Zones (Koeppen) from Obs. (Jones and Legates)



The Formation of the Global Climate

Energy Balance Models

Emergence of Planetary Scale
Atmospheric State from a State
of Rest

EBMs

$$R_{\text{incoming}} = R_{\text{outgoing}}$$

$$R_{\text{sw}} = \alpha R_{\text{sw}} + R_{\text{lw}}$$

$$R_{\text{lw}} = k \sigma T^4$$

σ : constant

$$\Rightarrow T_{\text{eq}} = \left[\frac{(1-\alpha) R_{\text{sw}}}{k \sigma} \right]^{1/4}$$

k = transmissivity
of the atmosphere

$$k = 1 \quad (\text{no atmosphere}) : \quad T_{\text{eq}} \approx -4^\circ\text{C}$$

$$k = 0.64, \alpha = 30\% \quad T_{\text{eq}} \sim 15^\circ\text{C}.$$

\Rightarrow We can determine the global mean temperature without knowing the (details of) regional temperatures.

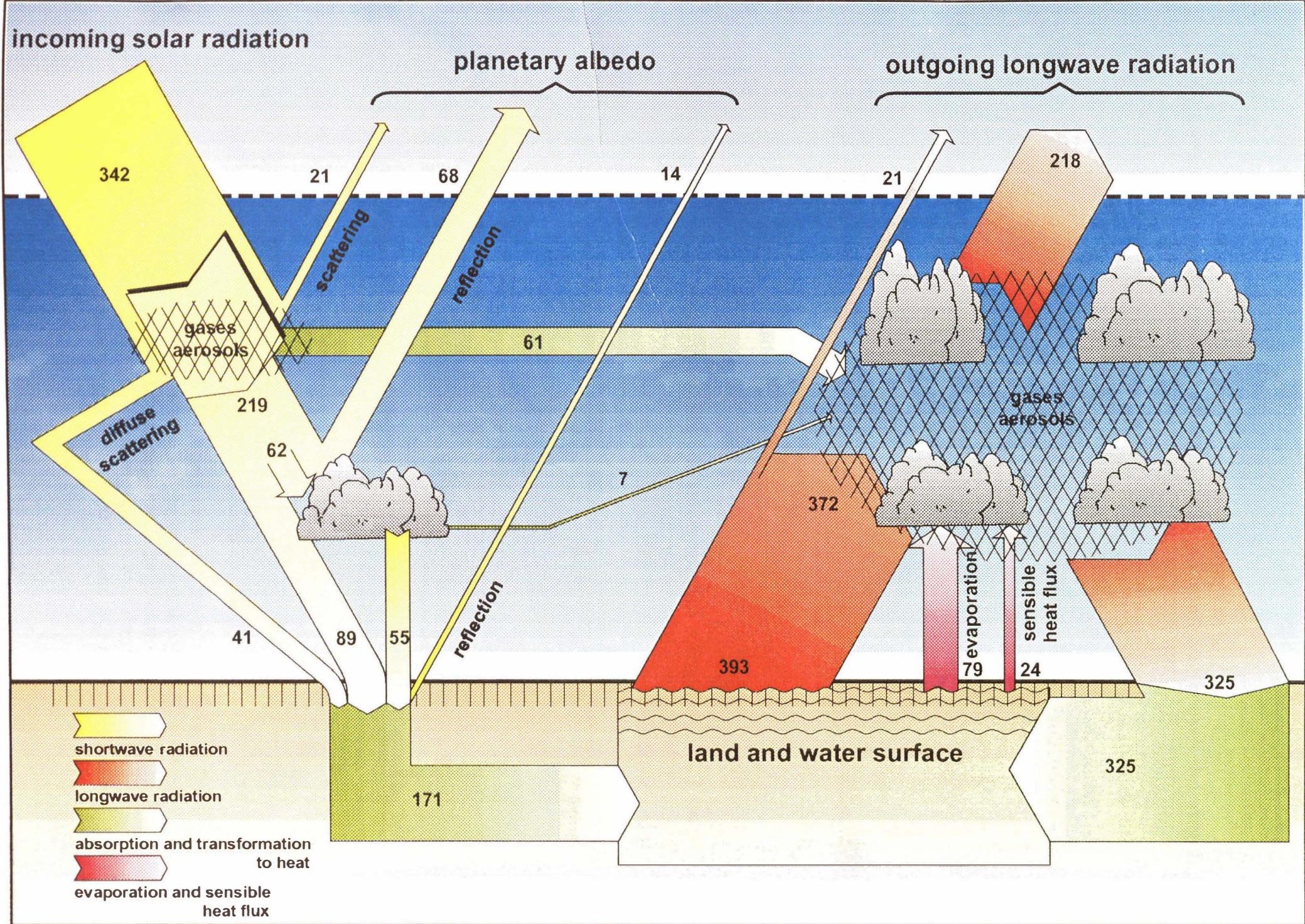


Figure 1.4: Assumed nonlinear dependency of albedo α upon the global mean temperature. From von Storch et al. (1998)

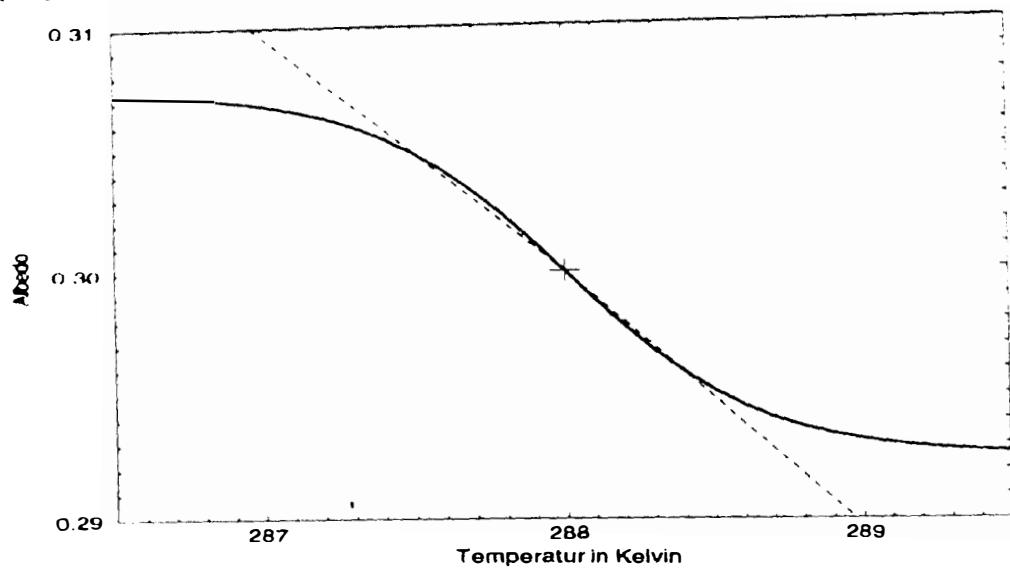
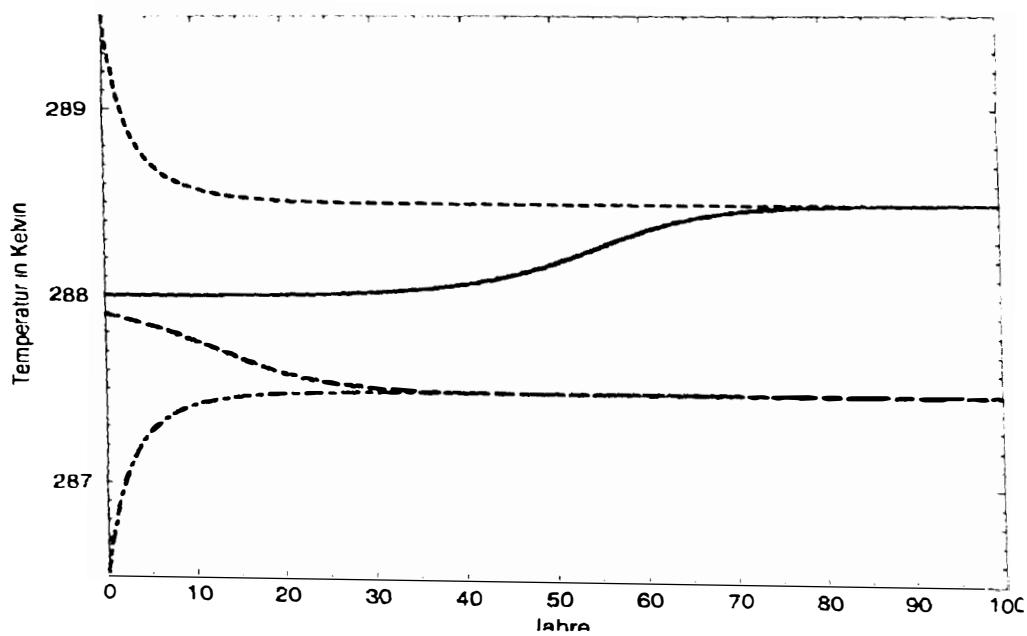


Figure 1.5: Convergence towards stable equilibrium solution of the Energy Balance Model (1.4) with temperature dependent albedo. From von Storch et al. (1998)



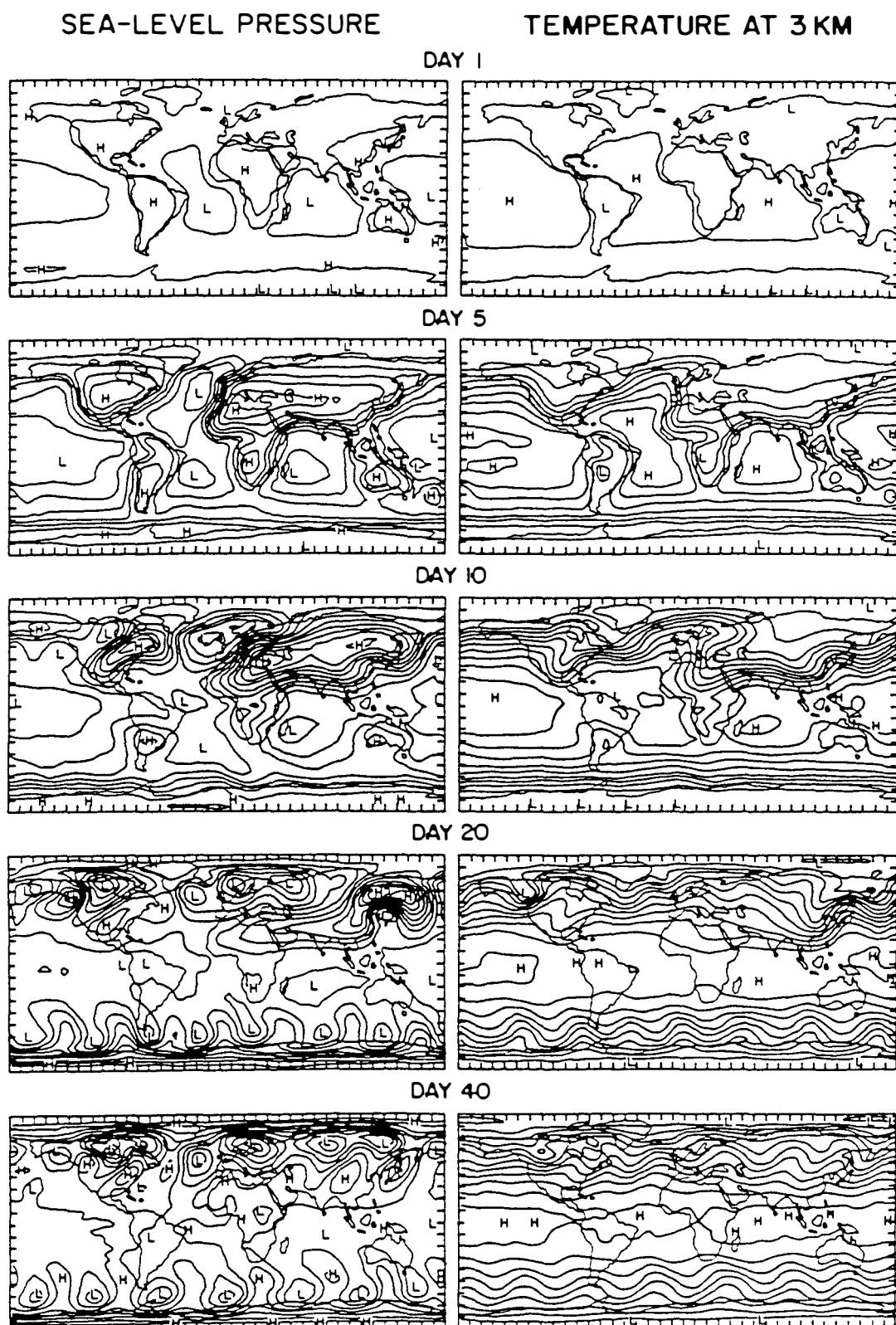


Fig. 5.1 Time sequences of sea level pressures and 3 km temperatures from a perpetual January simulation of a two-layer atmospheric GCM starting at rest with a 240 K isothermal atmosphere. The pressure contours are drawn at intervals of 4 mb and the temperature contours at intervals of 5 K. The contour lines on day 1 are at 1000 mb and 245 K. [From Washington (1968).]

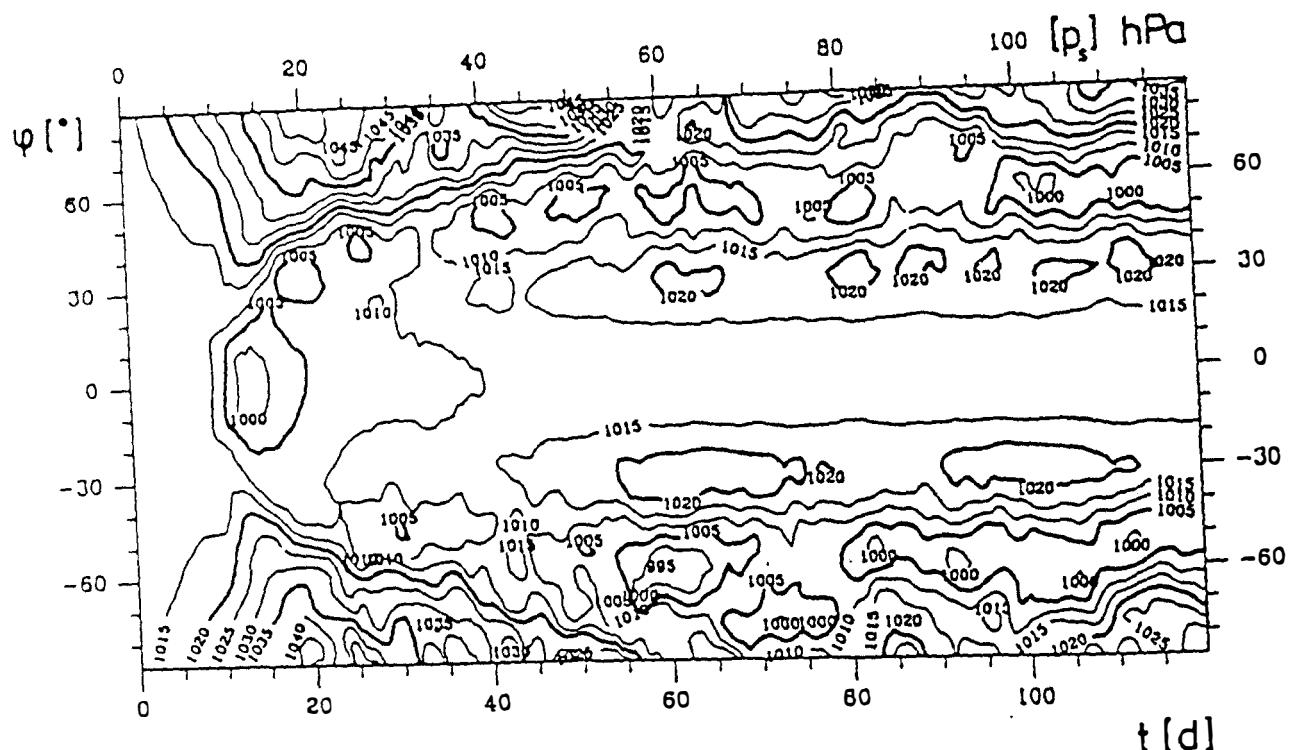
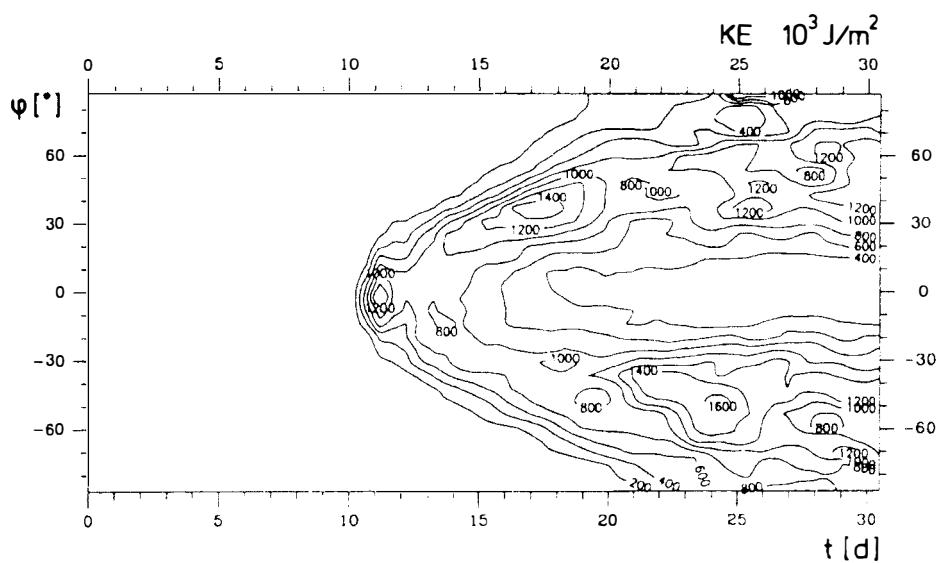
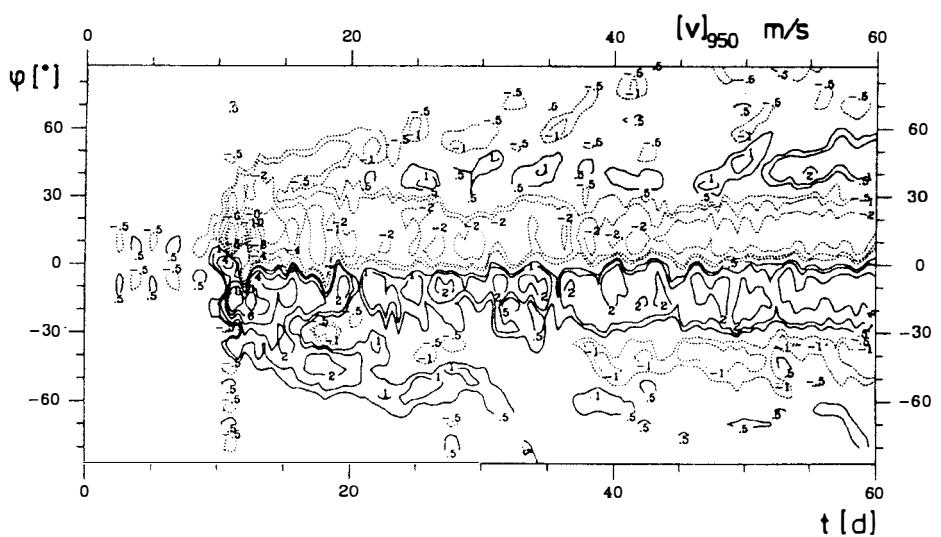
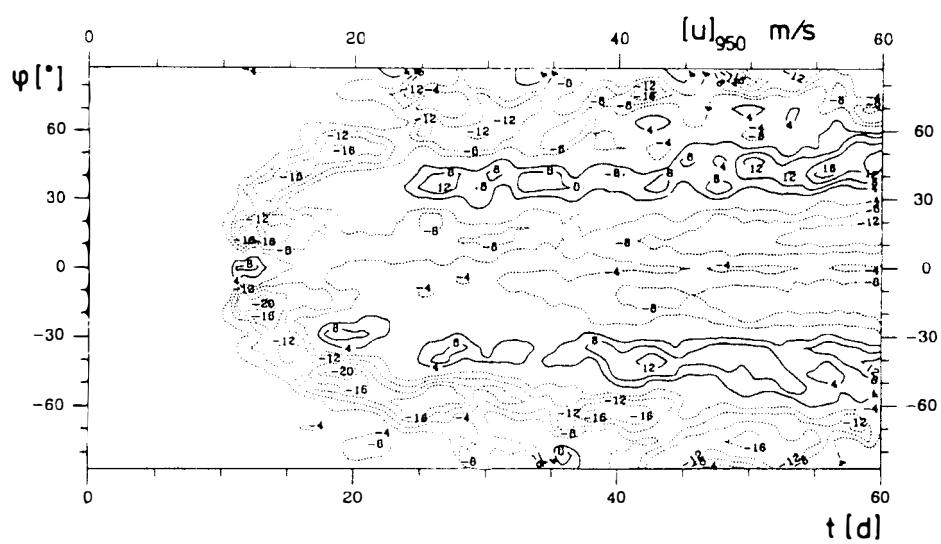


Abb. 2. Zeitliche Entwicklung des zonal gemittelten Bodendrucks als Funktion der geographischen Breite. Isolinienabstand 5 hPa.

Fig. 2. Latitude-time diagramme of the zonally averaged surface pressure; spacing 5 hPa.



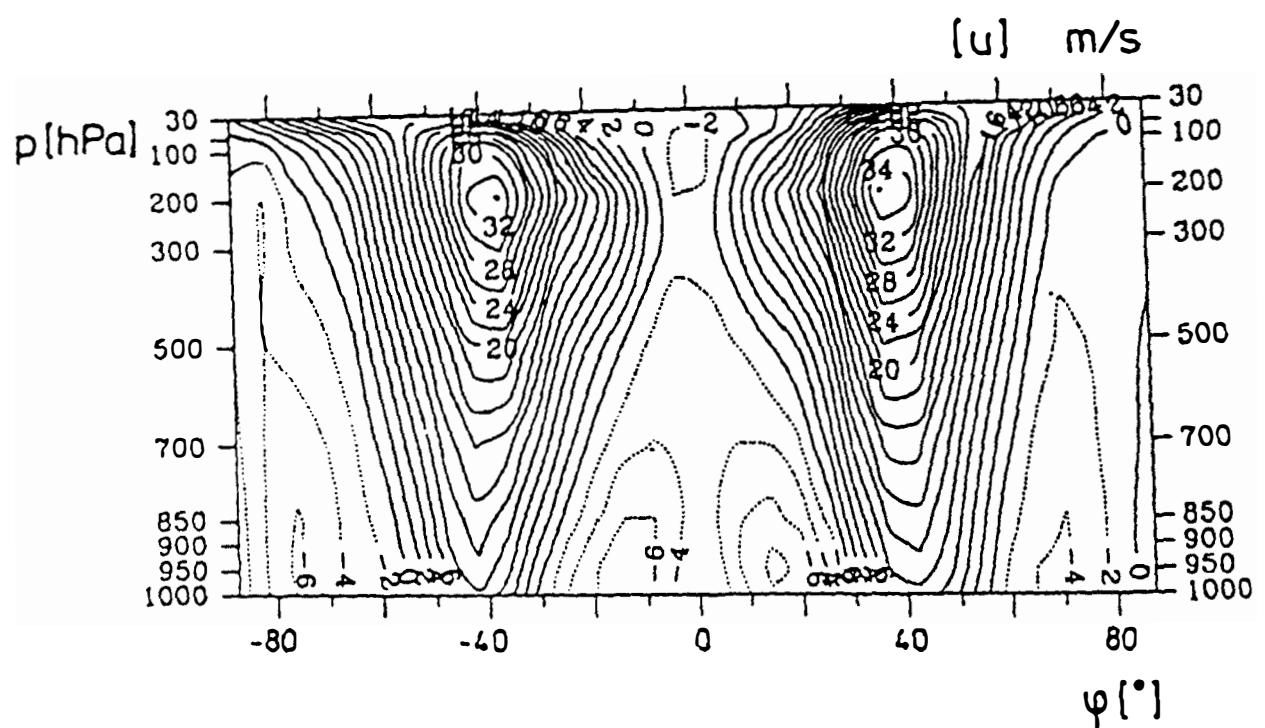


Abb. 5. Meridionalschnitt der Zonalwindverteilung im Mittel des 4. Monats. Ostwindgebiete sind gestrichelt, Isolinienabstand 2 m/s.

Fig. 5. Latitude-height cross section of the zonal wind averaged over month 4. Areas with easterly winds are stippled, spacing of isolines 2 m/s.

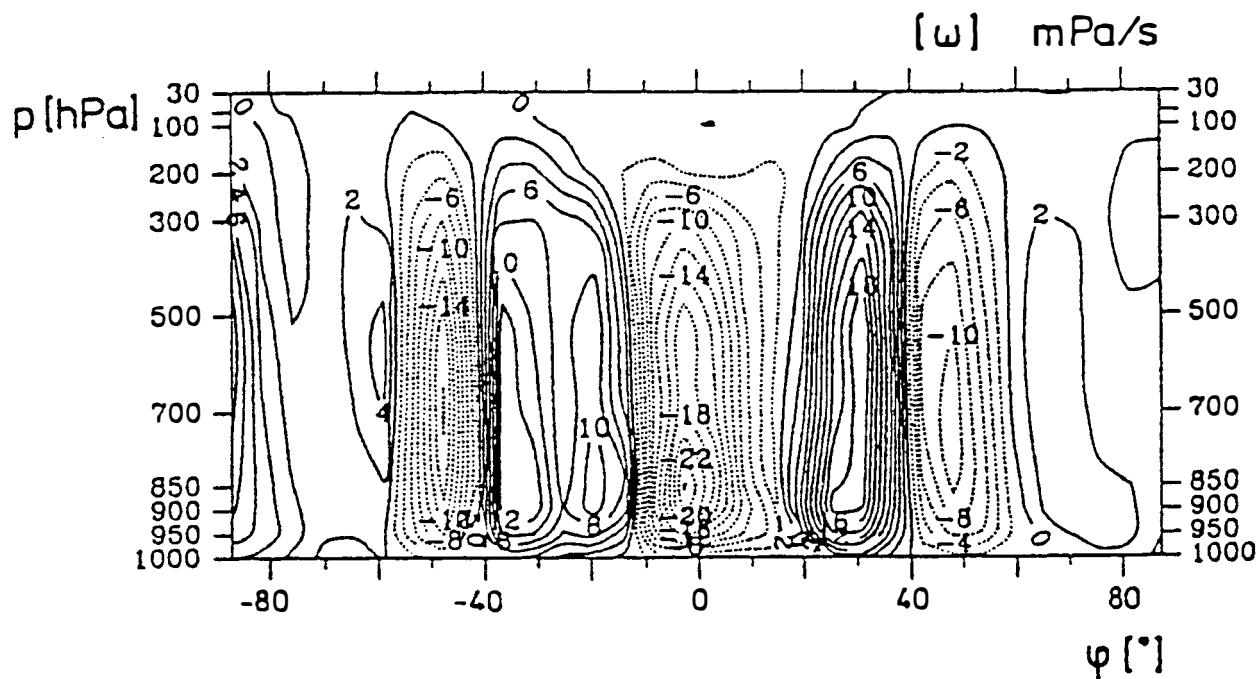
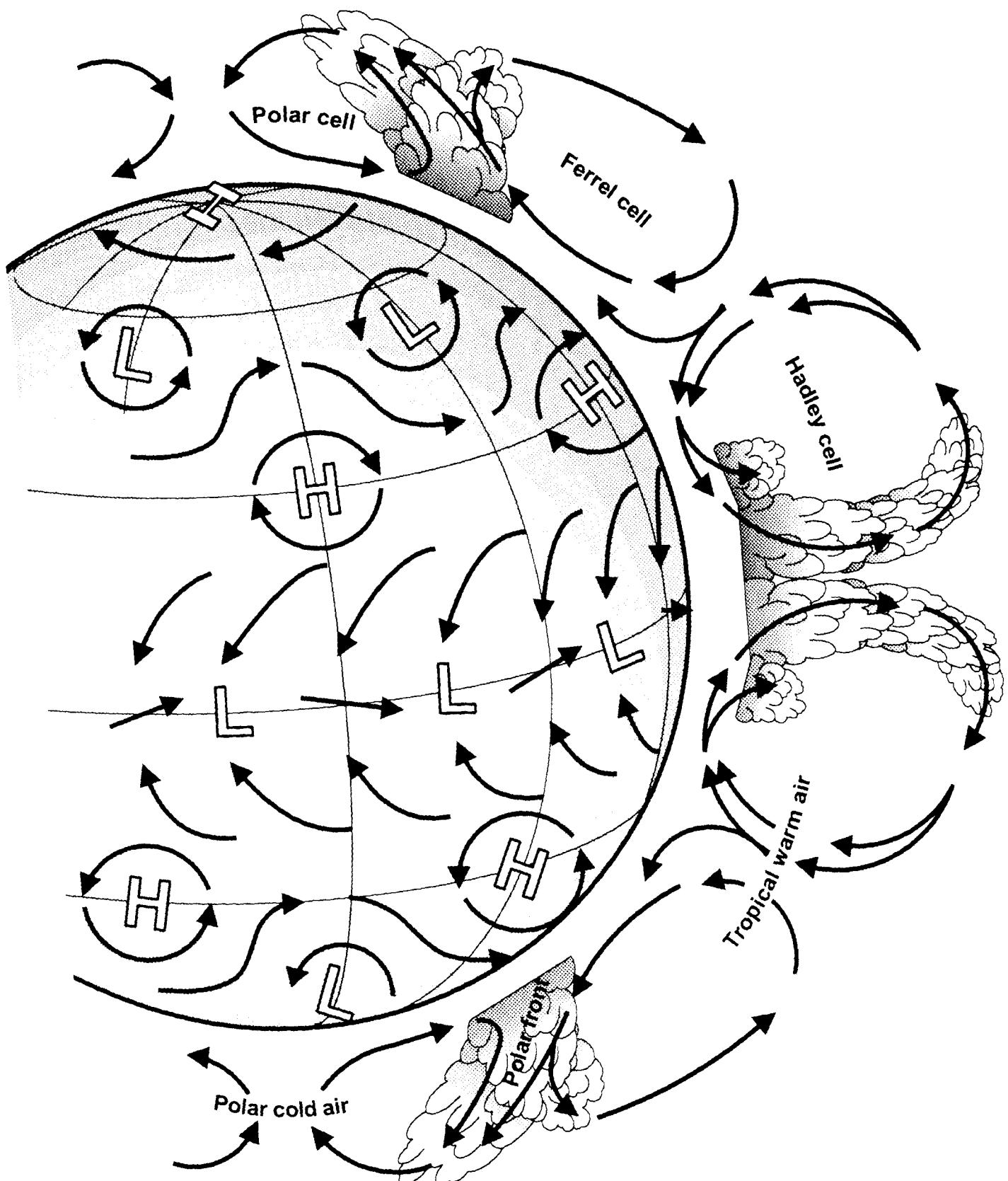


Abb. 6. Meridionalschnitt des Vertikalwindes im Mittel des 4. Monats. Gebiete mit aufsteigender Bewegung sind gestrichelt. Isolinienabstand $2 \cdot 10^{-1} mPa/s$.

Fig. 6. Latitude-height cross section of the vertical p -velocity averaged over month 4. Areas with ascending motions are stippled, spacing $2 \cdot 10^{-1} mPa/s$.



obs win (dly) mean 500mb geopotential-1980s (m)

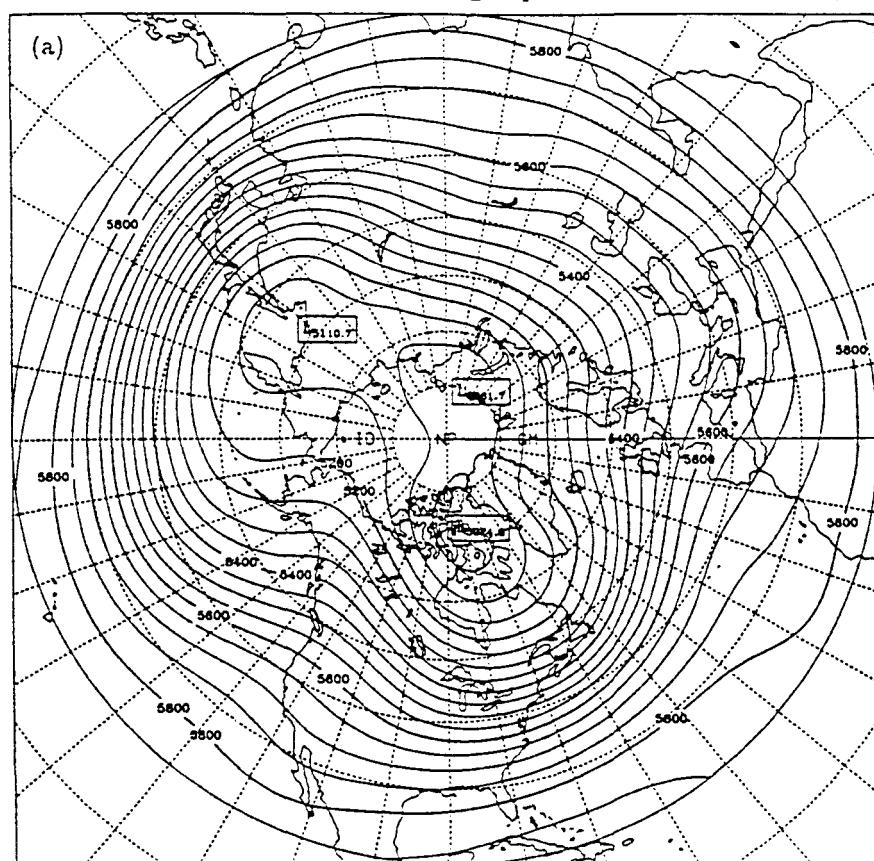


FIG. 8. Winter mean geopotential height at 500-hPa for (a) NMC observations, (b) CCM1, and (c) CCM2. The winter mean is an average over December, January, and February (for the 1980s for observations and over ten years of model simulation for models).

Risbey & Stone, 1996

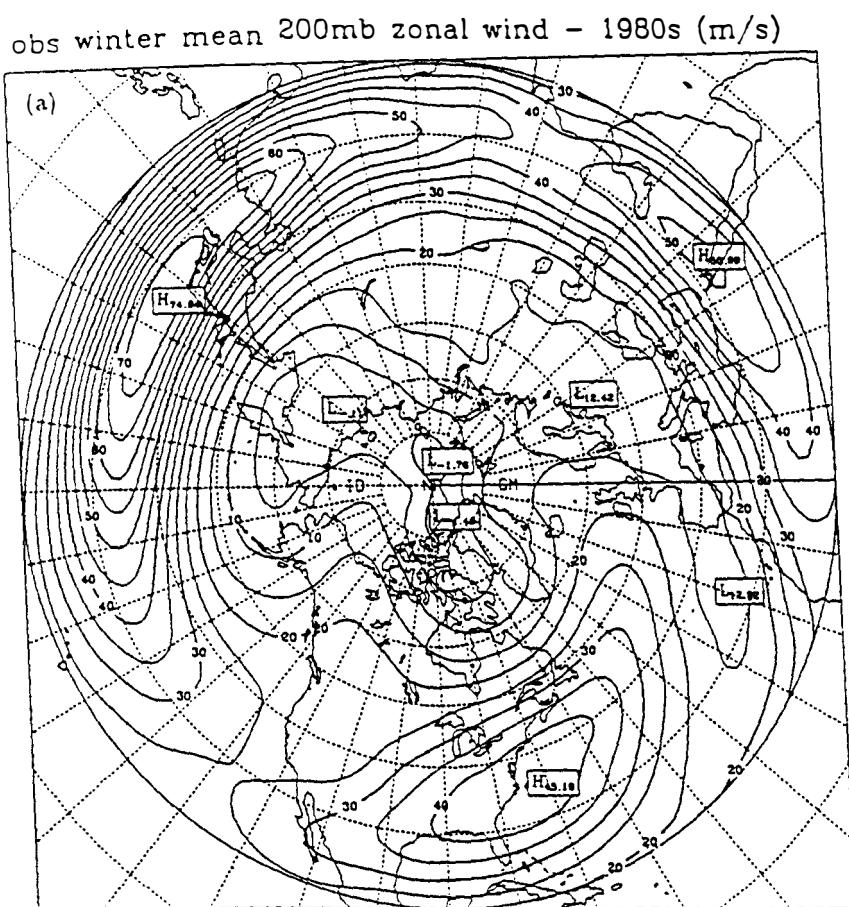


FIG. 6. Winter mean zonal wind at 200 hPa for (a) NMC observations, (b) CCM1, and (c) CCM2. The winter mean is an average for December, January, and February over the 1980s for observations and over ten years of model simulation for models.

Risbey & Stone, 1996

obs win bandpass rms 500mb geoptl-1980s (m)

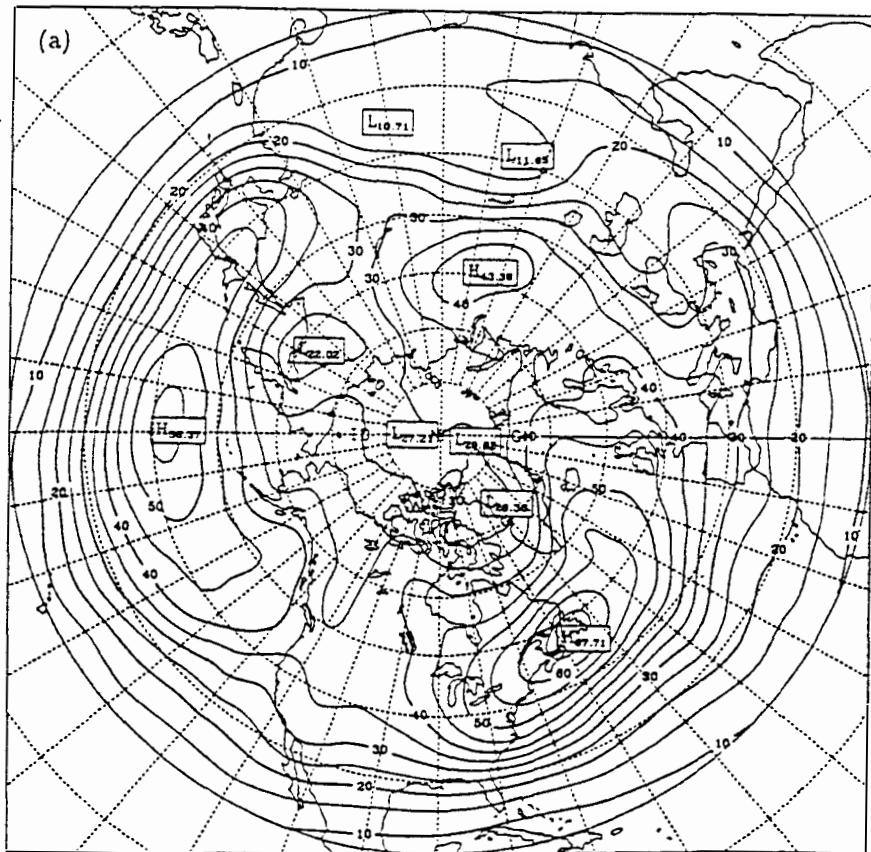


FIG. 9. Winter-mean bandpass filtered rms geopotential height at 500-hPa for (a) NMC observations, (b) CCM1, and (c) CCM2. The winter mean is an average for December, January, and February over the 1980s for observations and over ten years of model simulation for models. The filtering retains periods in the range between 2.5 and 6 days.

Risbey and Stone, 1996

Conclusion

Physicists' view

$$\text{global climate} = f(\text{global forcing, planetary scale features})$$

is write and

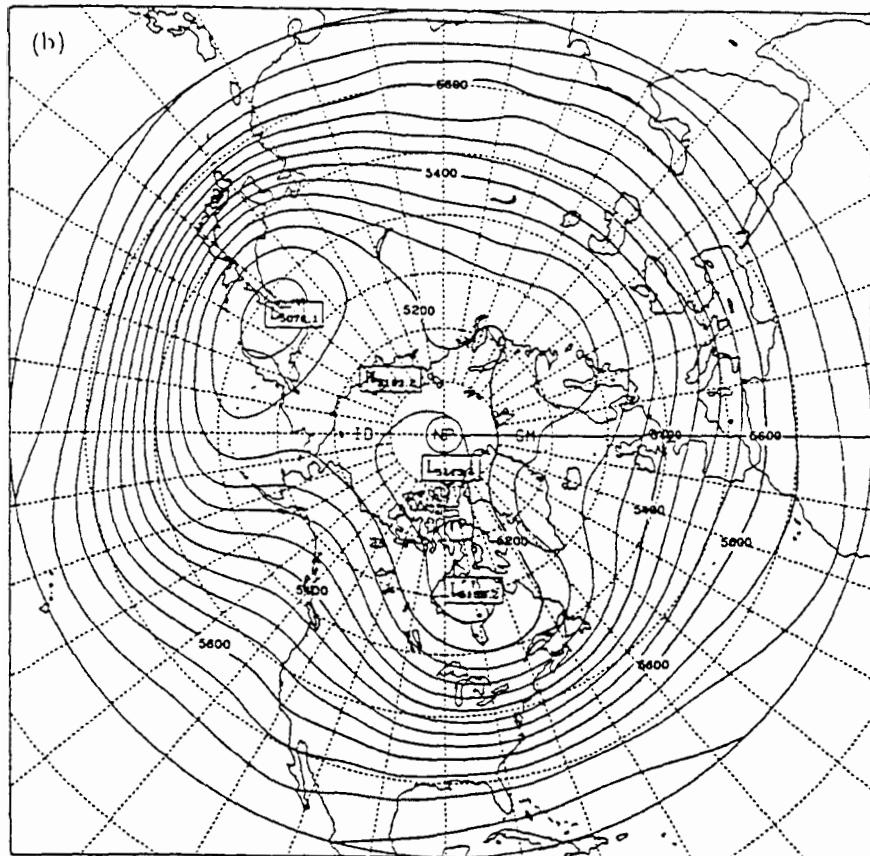
$$\text{global climate} = \sum_{\text{regions}} \text{regional climate}$$

is inadequate.

⇒ Therefore General Circulation Models (GCMs) with limited spatial ~~area~~ resolution (e.g. $6^\circ \times 6^\circ$ longitude x latitude) can simulate the global climate.

⇒ The success of GCMs on the planetary scale does not imply their success on the regional scale.

ccm1 win (dly) mean 500mb geopotential-1980s (m)



ccm2 win (dly) mean 500mb geopotential-1980s (m)

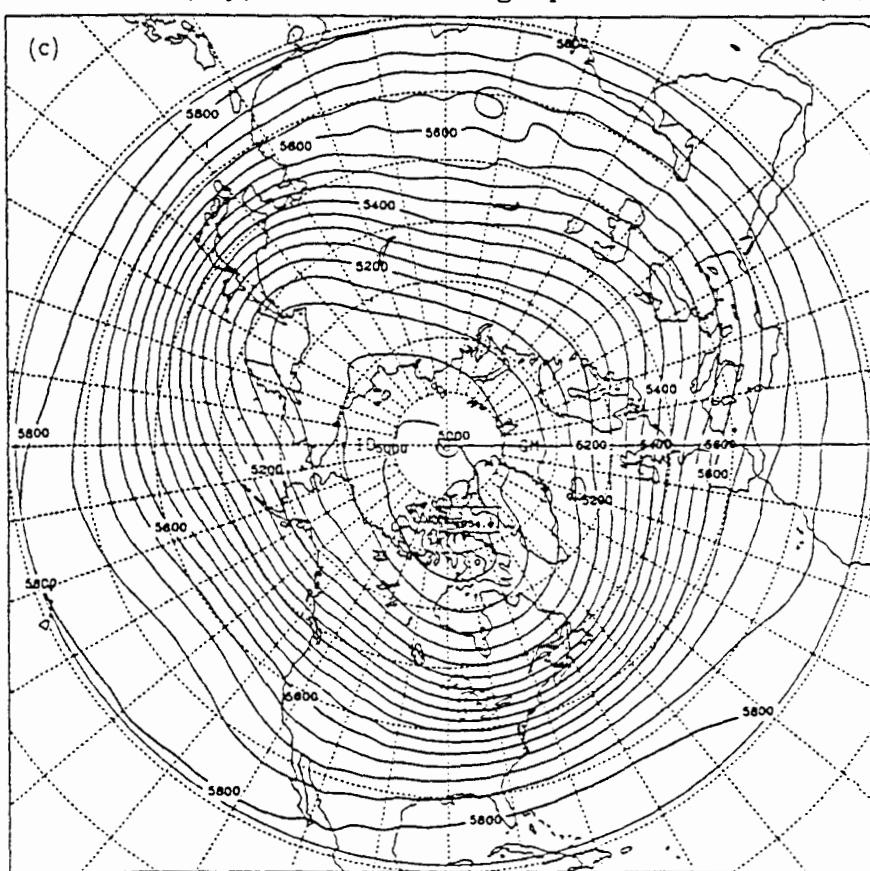


FIG. 8. (Continued)

The Formation of Regional Climates

- o Case: Sacramento Valley
a synoptic analysis
- o Conditional Statistical Models
Canonical Correlation Analysis
and Redundancy Analyses as a tool
for specifying conditional means
- o Cases: Romanian precipitation
and North Atlantic wave height statistics

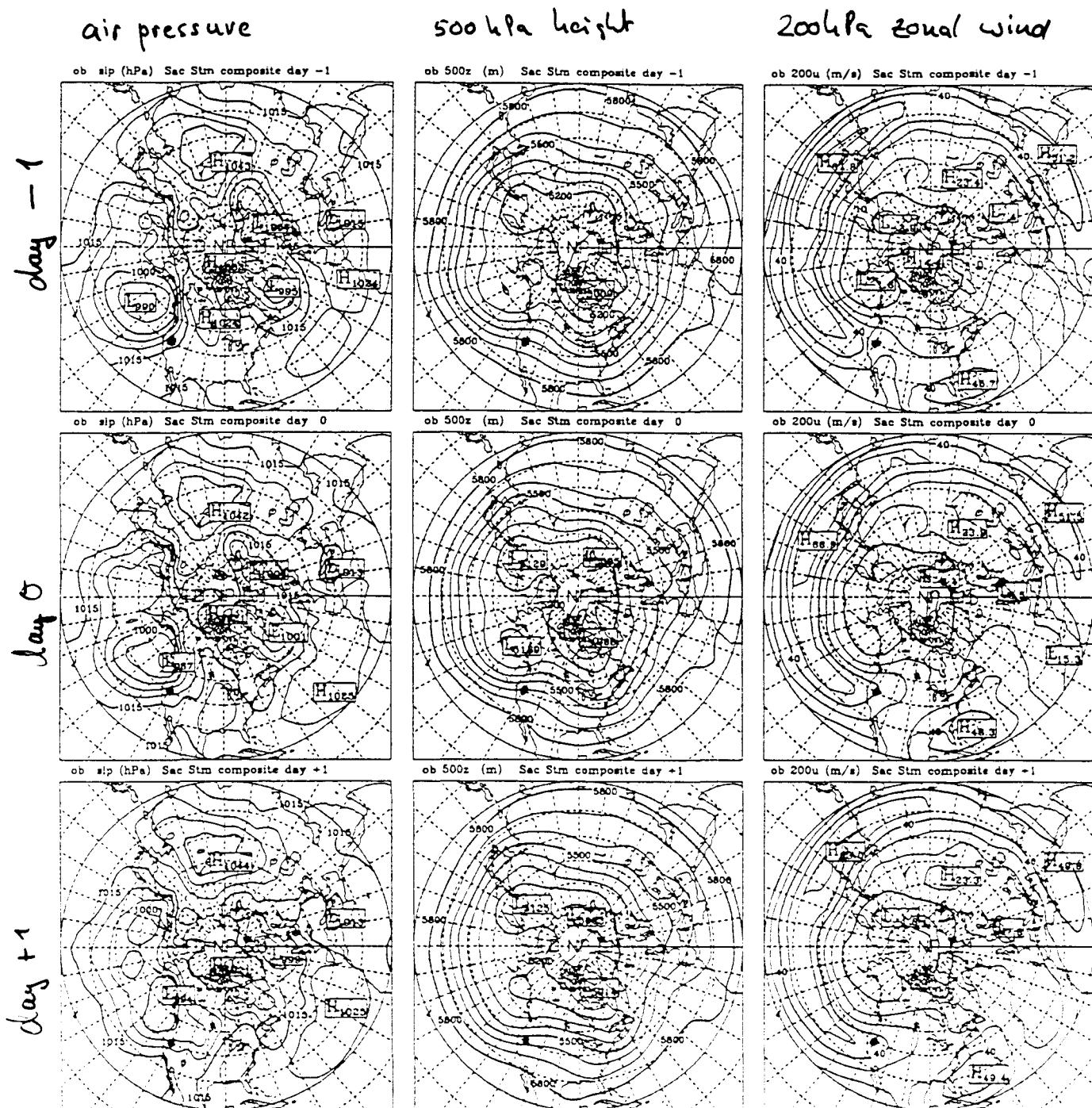


FIG. 10. Composite Sacramento Basin storm patterns for NMC observations. The left column is sea level pressure, the middle column is 500-hPa geopotential height, and the right column is 200-hPa zonal wind. The top row is for the day before the precipitation maximum, the middle row is for the day of the precipitation maximum, and the bottom row is for the day after the precipitation maximum.

Risbey & Stone, 1991

- approximate location
of region with precipitation events
(Sacramento Valley)

1. The General Nature of Weather Forecasting. The general problem of forecasting weather conditions may be subdivided conveniently into two parts. In the first place, it is necessary to predict the state of motion of the atmosphere in the future; and, secondly, it is necessary to interpret this expected state of motion in terms of the actual weather which it will produce at various localities. The first of these problems is essentially of a dynamic nature, inasmuch as it concerns itself with the mechanics of the motion of a fluid. The second problem involves a large number of details because, under exactly similar conditions of motion, different weather types may occur, depending upon the temperature of the air involved, the moisture content of the air, and a host of local influences.

Victor Starr, 1942

Conditional Statistical Models

local parameter X
 large-scale parameter G

$$f_X(x) = \int f_{X|G=g}(x) f_G(g) dg$$

Then

$$E(X) = E_g(E_x(X|G))$$

$$\text{Var}(X) = \text{Var}_g(E_x(X|G)) + E_g(\text{Var}_x(X|G))$$

Example: Regression $X_t = \mu_0 + \beta G_t + N_t$
 N_t and G_t independent
 N_t white (red) noise)

then ~~$E_x(X|G)$~~ $E_x(X|G) = \mu_0 + \beta G$
 $E(X) = \mu_0$ if $E(G) = 0$

and $\text{Var}_g(E_x(X|G)) = \beta^2 \sigma_g^2$
 ~~$E_g(\text{Var}(X|G))$~~ $E_g(\text{Var}(X|G)) = E_g(\mu_0 + \beta G_t + N_t - \mu_0 - \beta G_t)^2$
 $= \sigma_u^2$

$$\Rightarrow \sigma_x^2 = \underbrace{\beta^2 \sigma_g^2}_{\text{externally induced}} + \underbrace{\sigma_u^2}_{\text{internal uncertainty / variability}}$$

in the case of global / regional climate,
we formulate the model

$$\vec{x}_t \sim P(\vec{\alpha}_c, \vec{x}_{t-1})$$

$$\alpha_t = F(\vec{G}_t)$$

with \vec{x}_t regional state vector

\vec{G}_t planetary scale state vector

P probability distribution with parameters $\vec{\alpha}$

F functional dependence

in the following cases, we assume that x_{t-1} is
not of importance such that our model

$$\vec{x}_t \sim P(F(G_t))$$

In case of regression

$$x_t = \mu + N_t$$

N_t white noise

$$\mu = \mu_0 + \beta G_t$$

$$\Rightarrow x_t = \mu_0 + \beta G_t + N_t$$

$$\alpha = (\mu) = F(G_t) = \mu_0 + \beta G_t$$

Canonical Correlation Analysis and Redundancy Analysis

$$\vec{G}_t \approx \sum_{j=1}^J g^j(t) \vec{p}_j^G \quad \text{planetary scale } \}$$

$$\vec{X}_t \approx \sum_{j=1}^J x^j(t) \vec{p}_j^X \quad \text{regional scale } \}$$

J small
(filter operation)

with the regression links

$$x^j(t) = r_j g^j(t) + \text{noise}$$

and x^j independent of all g^k with $k \neq j$.

Then

$$E(\vec{X}|\vec{G}) = \sum_{j=1}^J r_j g^j(t) \vec{p}_j^X \quad \left| \begin{array}{l} \text{planetary - regional} \\ \text{scale estimate link!} \end{array} \right.$$

if

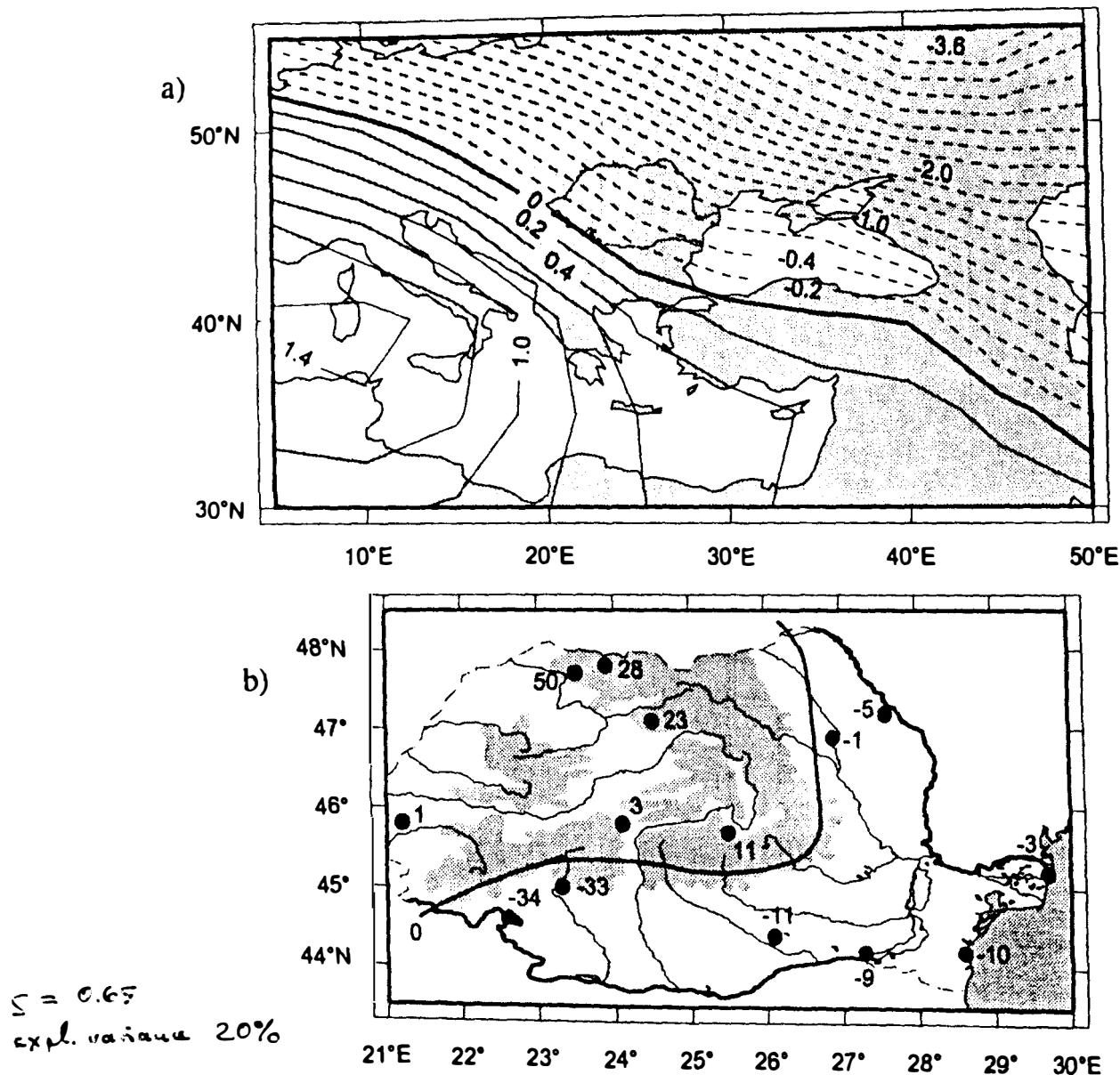
$$G_t = \vec{p}_j^G \quad \text{then} \quad X_t \approx \vec{p}_j^X$$

CCA determines patterns $(\vec{p}_j^G, \vec{p}_j^X)$ such that correlations between g^j and x^j are maximum

RDA determines patterns such that the expected error $[X - E(X|G)]^2$ is minimum.

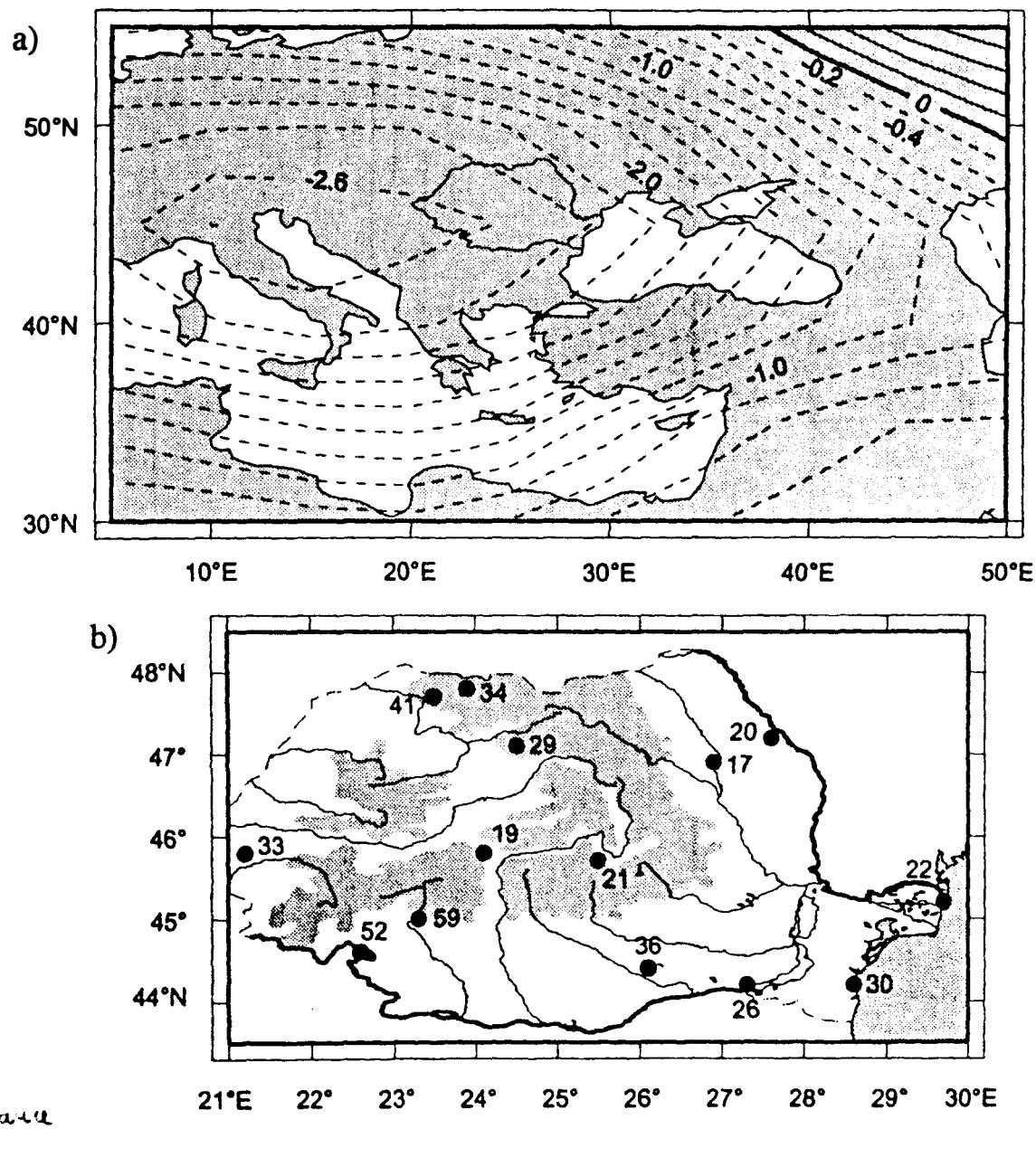
Practically, similar results

Figure 8: The patterns of the second canonical pair of the winter mean SLP (contour 0.2 mb) and total winter Romanian precipitation (contour 5 mm). Continuous lines mark positive values, and dashed lines negative values.



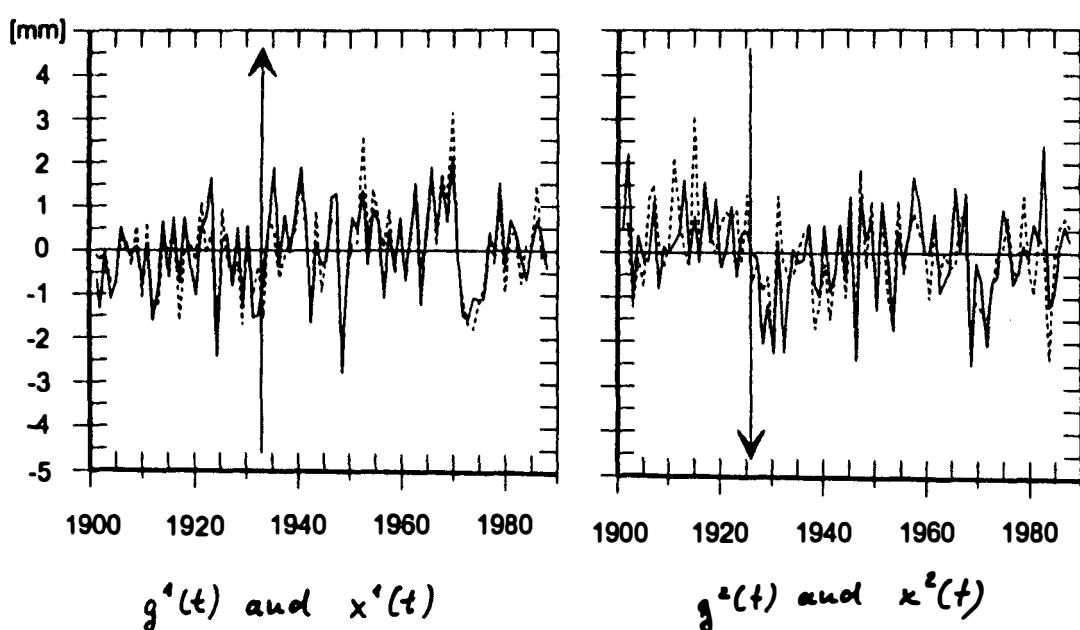
CCA Case: Romanian precipitation

Figure 7: The patterns of the first canonical pair of the winter mean SLP (contour 0.2 mb) and total winter Romanian precipitation (contour 5 mm). Continuous lines mark positive values, and dashed lines negative values.



Busuioc & von Storch, 1996

Figure 9: Normalised time components of the first (a) and second (b) CCA patterns of SLP anomalies (continuous line) and Romanian precipitation anomalies (dashed line).

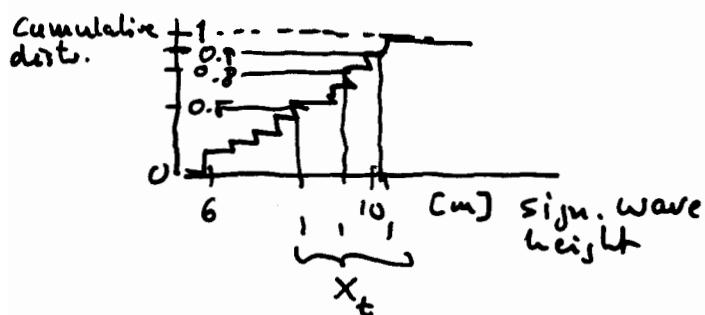


Busuioc & von Storch, 1996

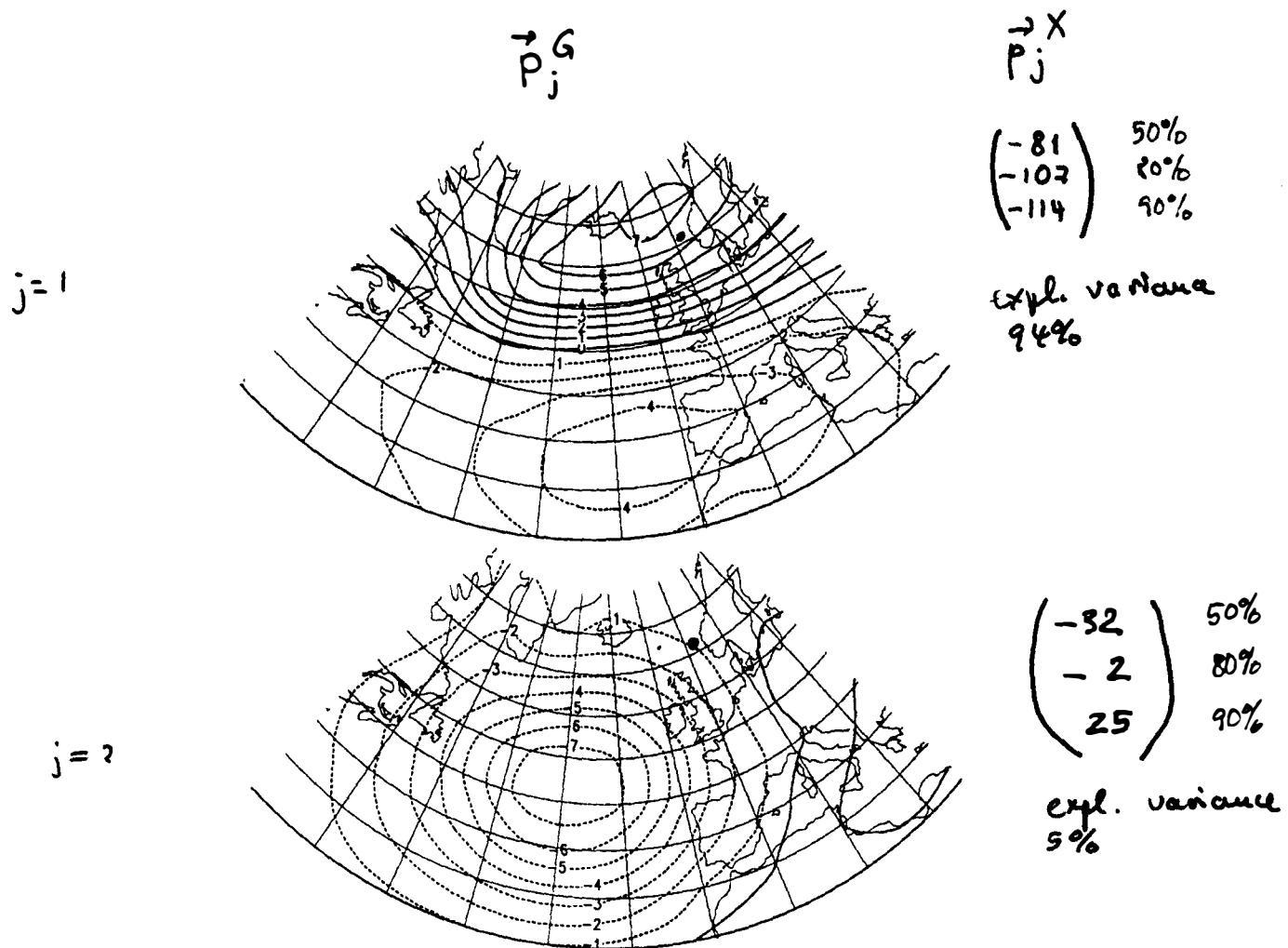
RDA case

G_t = North Atlantic
monthly mean air pressure field

\vec{x}_t = intramonthly percentiles
of significant wave height
at oil field Brent 6/N, 2E.

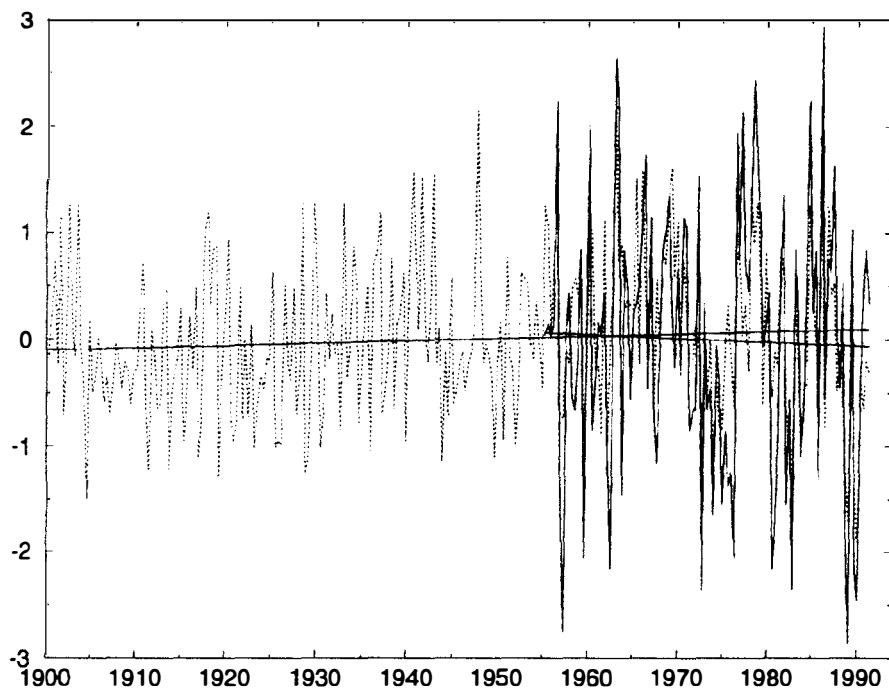


The vectors G_t and x_t are centered, i.e.
anomalies relative to a long term mean
are derived.

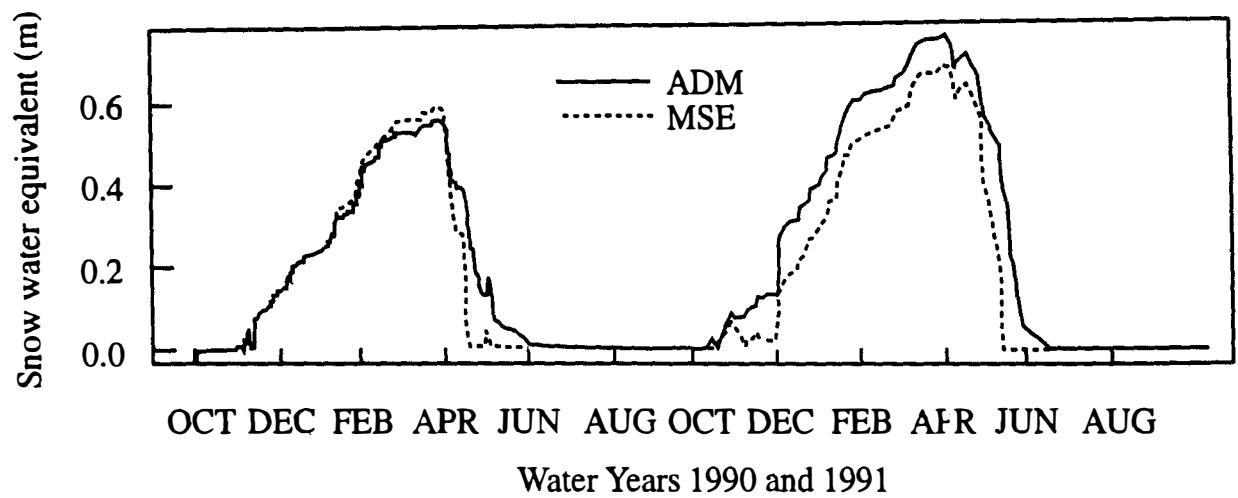


• Brent

First two monthly mean air pressure anomaly distribution identified in an Redundancy analysis as being most strongly linked to simultaneous variations of intramonthly quantiles of significant wave height at Brent (61°N , 1.5°E). The anomalies of the quantiles at that position are listed in Table 1.1



Reconstructed (continuous line) and hindcasted (dashed line; 1955-94) anomalies of 90% quantiles of significant wave heights at "Brent" (61°N, 1,5°E). The straight lines represent the trends ~~of the last 40 years~~ in the hindcasted and reconstructed data. Units: m.



Arola and Lettenmaier: aggregated and mean models

ccm1 winter mean 200mb zonal wind - 1980s (m/s)

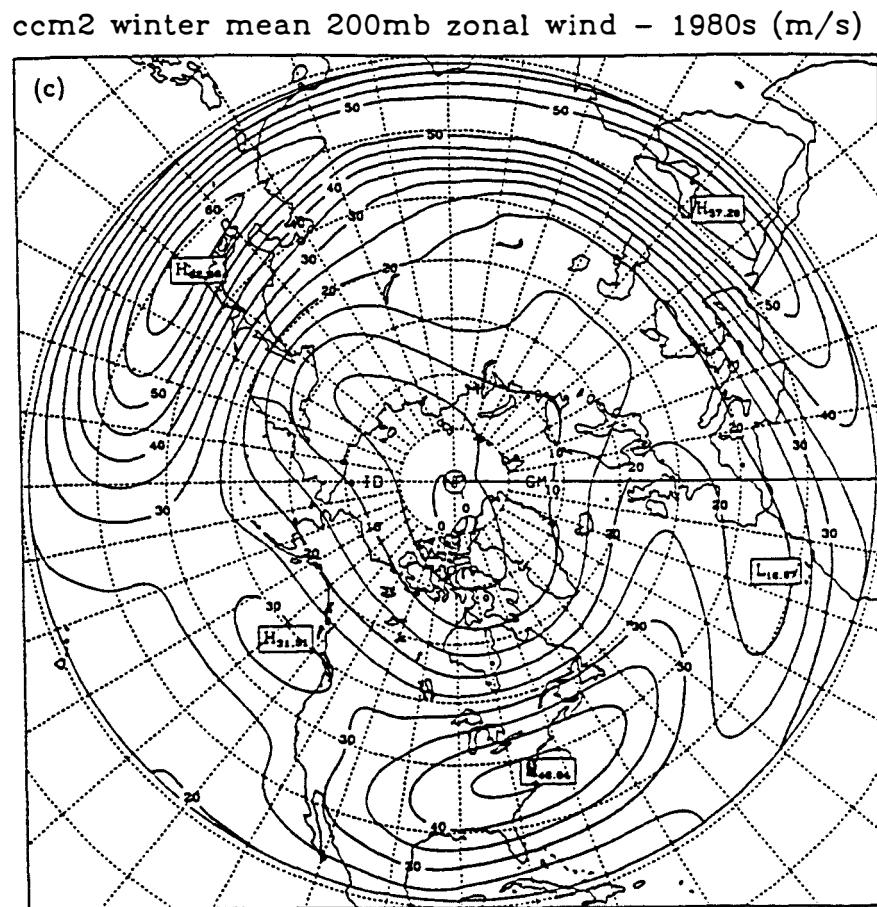
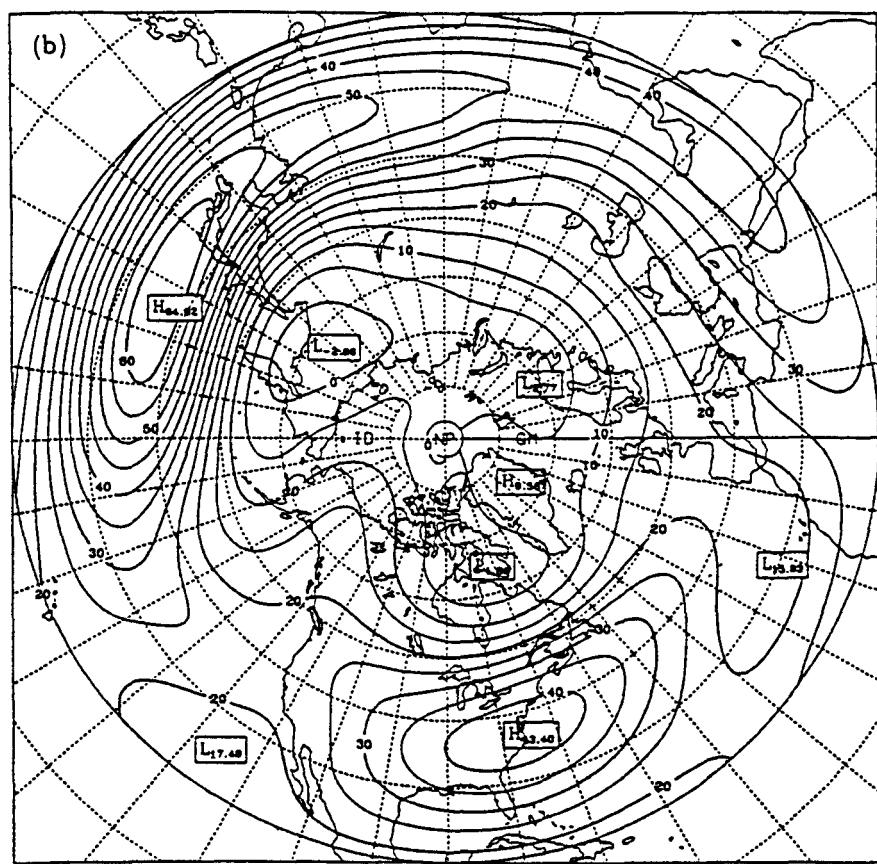


FIG. 6. (Continued)

Conclusion

regional climate = f' (planetary scale climate,
regional features)

is a valid model.

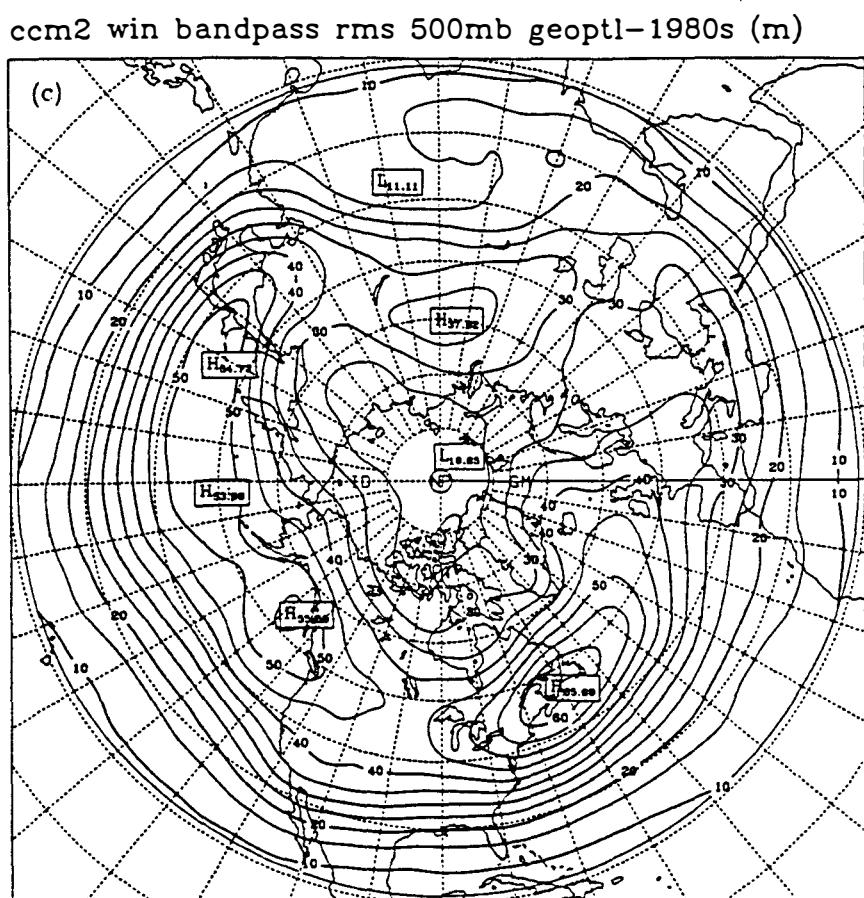
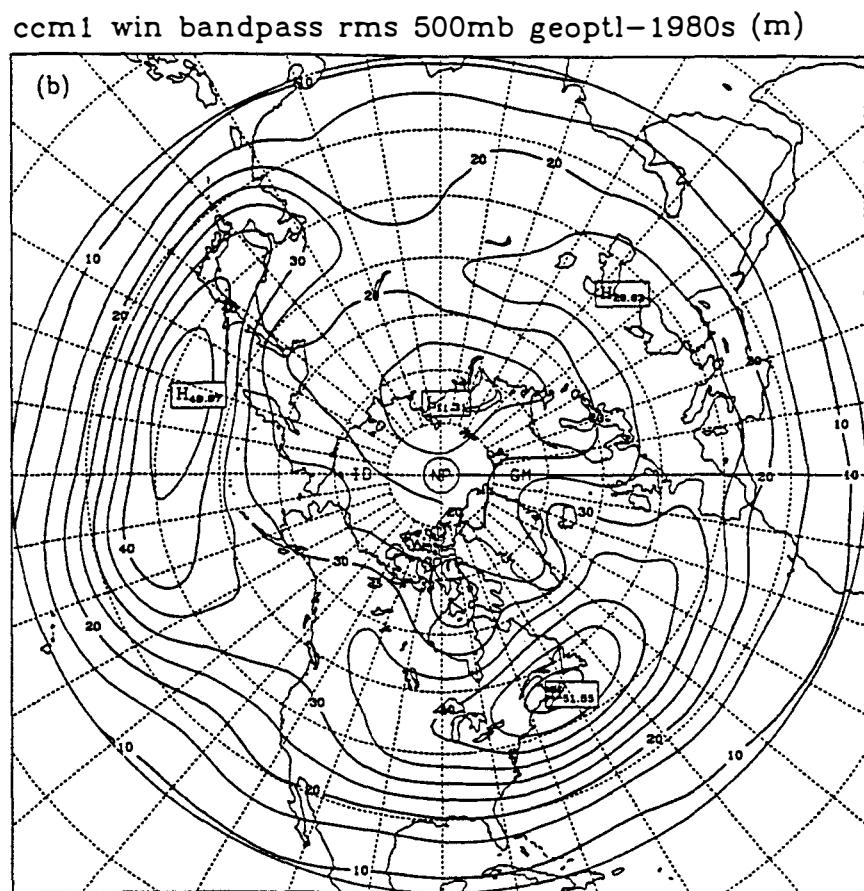
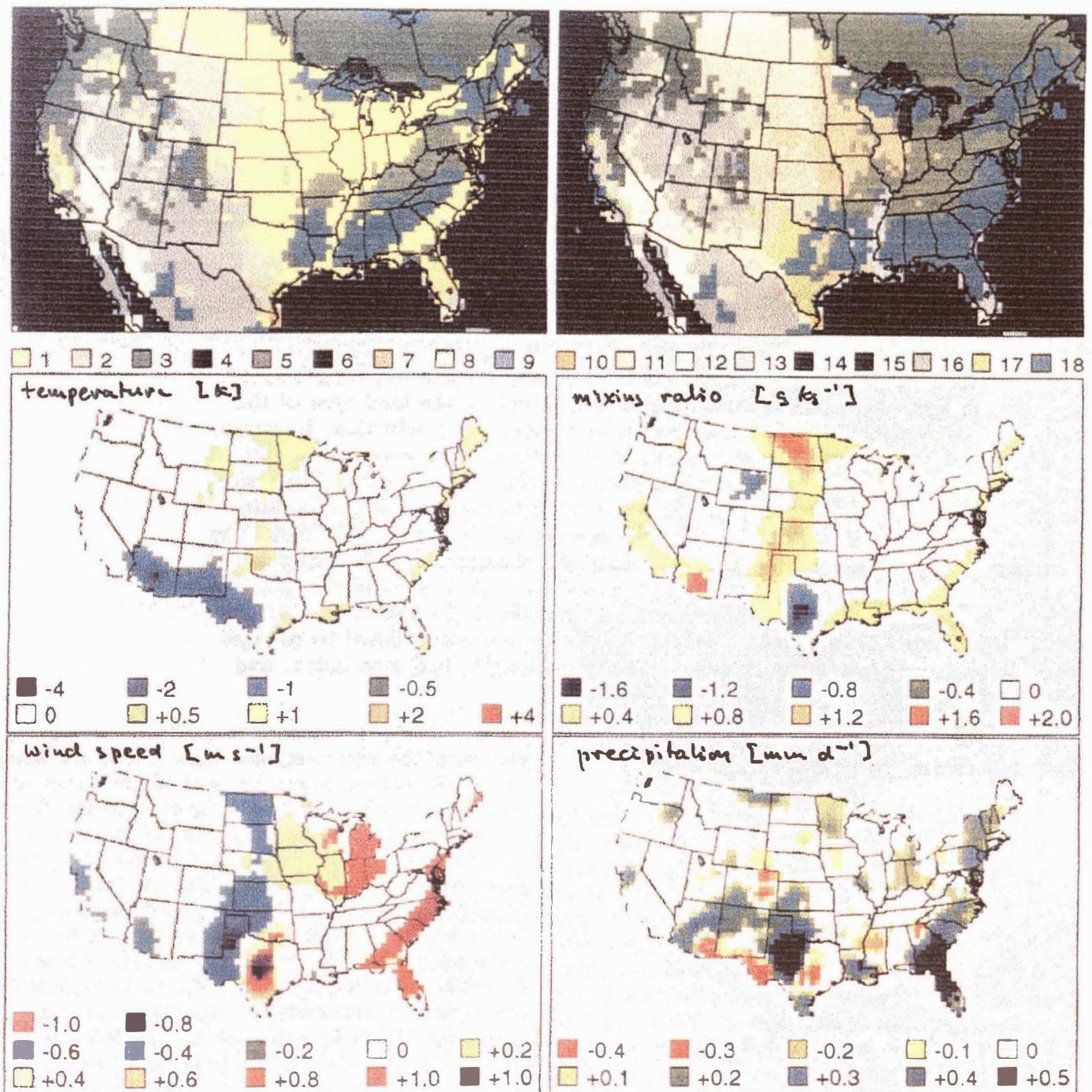


FIG. 9. (Continued)

The rôle of local processes for the global climate

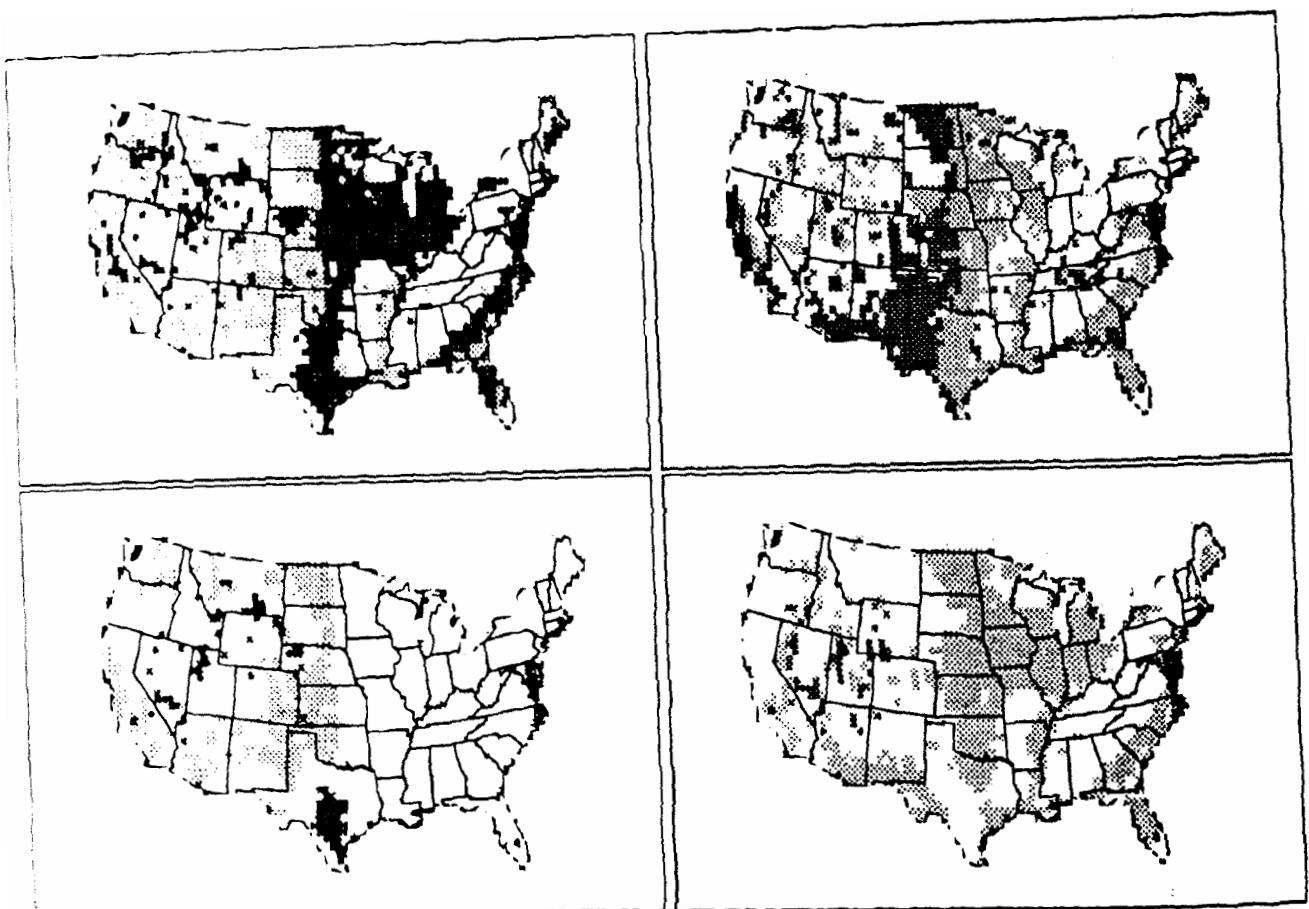
÷

- o a numerical experiment on the climatic effect of large-scale changes of land-use
- o the concept of parameterizations
 - the conventional approach; example
 - the randomized approach; EBM demonstration



Copeland et al., 1996

- 1: crop /mixed farming
- 2: short grass prairie
- 7: tall grass prairie
- 3,5: forests
- 18: mixed woodlands

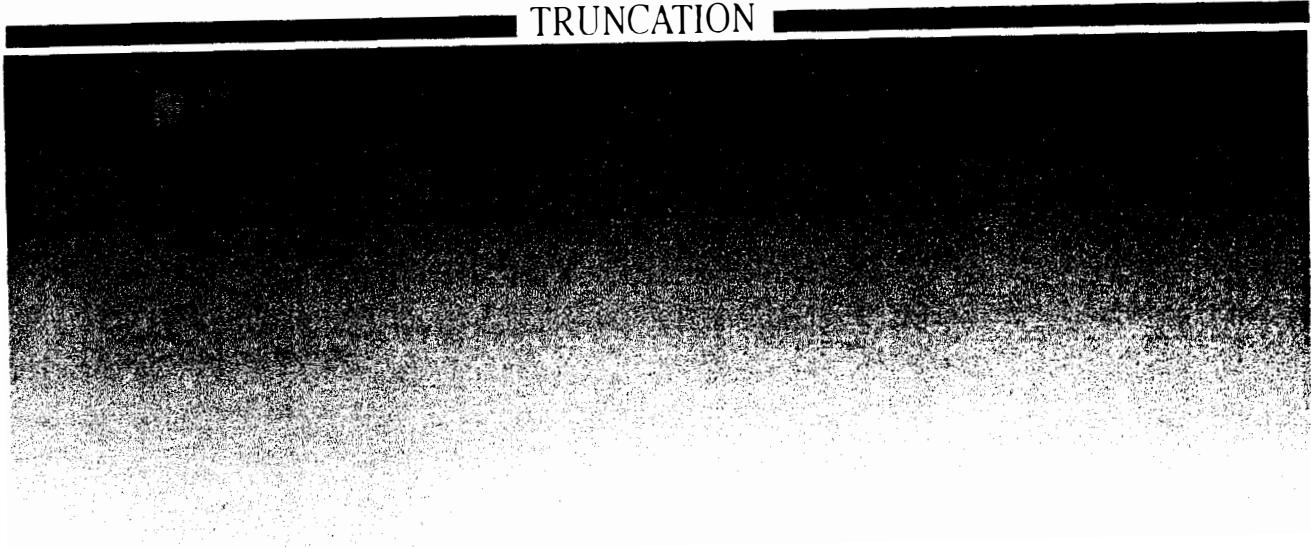


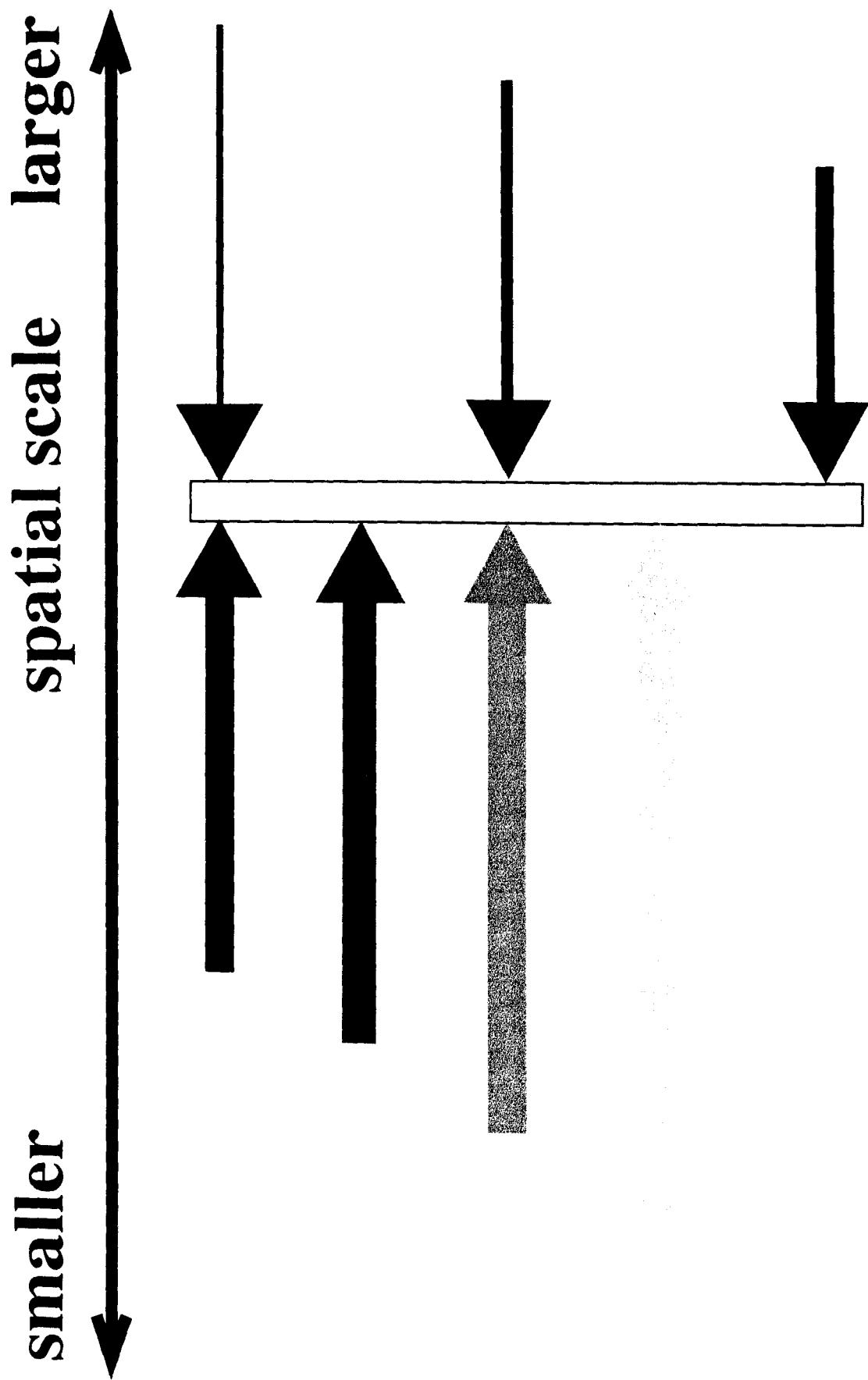
Differences (current-natural) in vegetation parameters used in the simulations. (upper left) Roughness length, (upper right) albedo,(lower left) leaf area index, and (lower right) fractional coverage. The sign of the chage is shown as follows: dark grey is a decrease, white is no change, and light grey is an increase in the parameter value.

FEW degrees of freedom
DETAILS matter
described by dynamical
models

Many DGFs,
Statistics matter
not completely resolved by dynamical models

TRUNCATION





The Local modifying the Global - PARAMETERIZATIONS of sub-grid scale processes

Let's consider a climate model

$$\frac{\partial \phi}{\partial t} = R(\phi)$$

and a spatial truncation $\phi = \bar{\phi} + \phi'$

Then

$$(*) \quad \frac{\partial \bar{\phi}}{\partial t} = R_{\Delta x}(\phi) = R(\bar{\phi}) + R'(\phi')$$

Equation (*) is not closed and cannot be integrated.

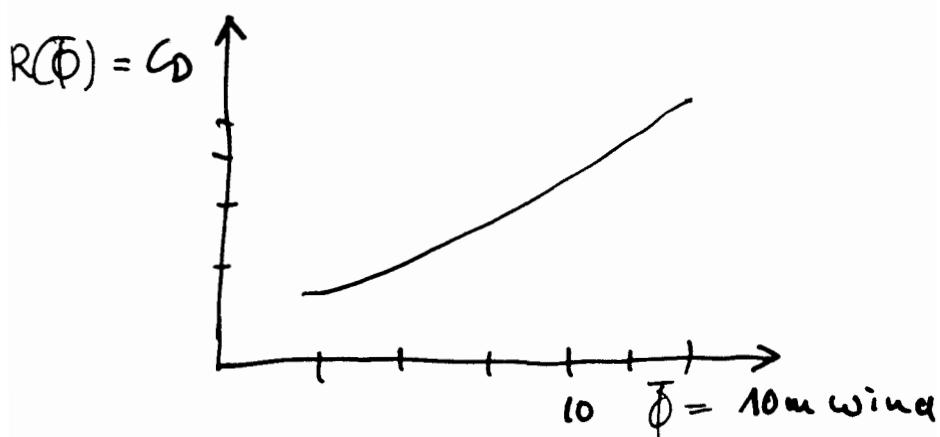
Options

(a) $R'(\phi') = 0$ in many cases done

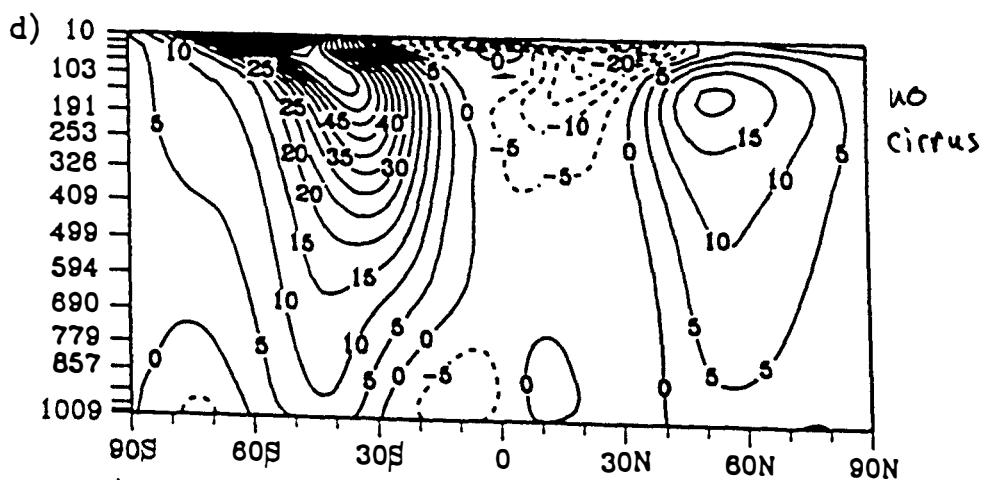
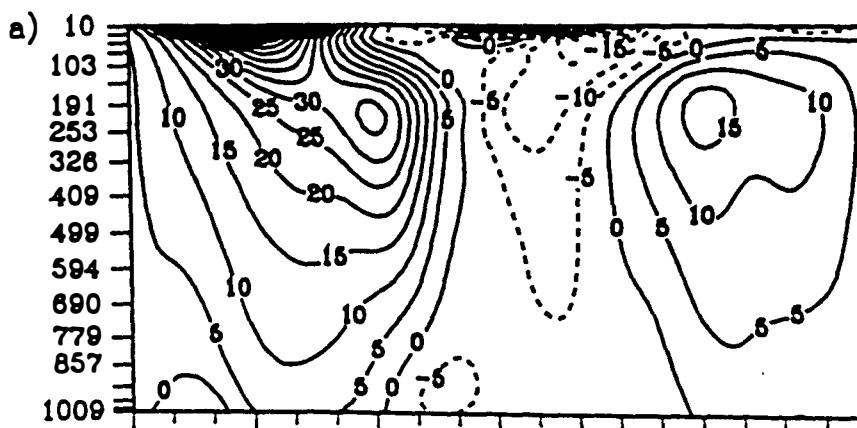
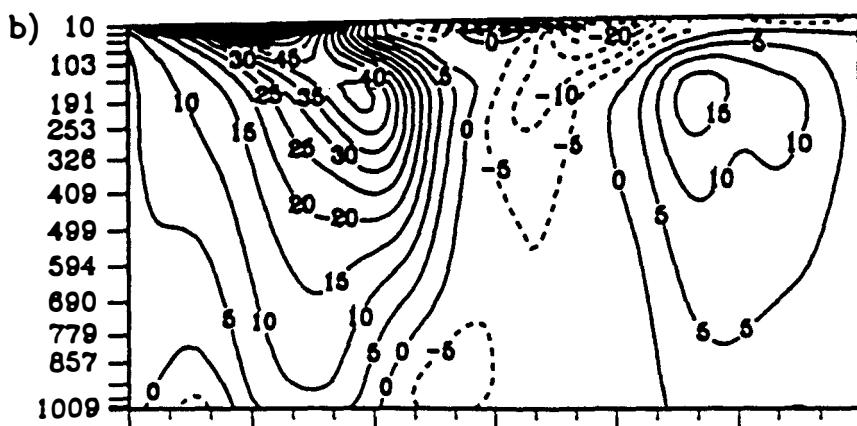
(b) $R'(\phi') = Q(\bar{\phi})$ called "parameterization"

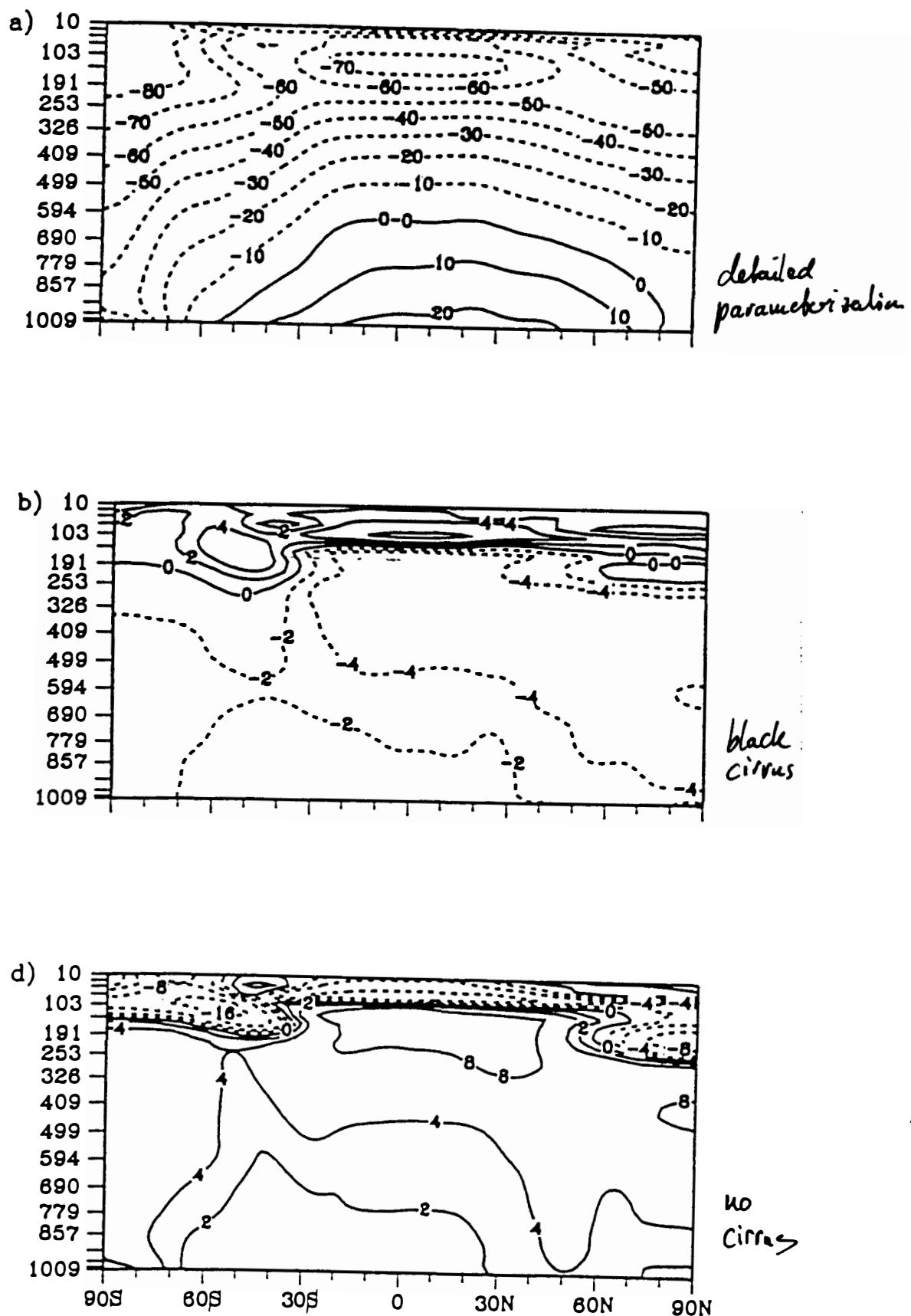
This ansatz implies that all variability on sub-grid scales unrelated to the resolved scale dynamics, $\bar{\phi}$, is irrelevant.

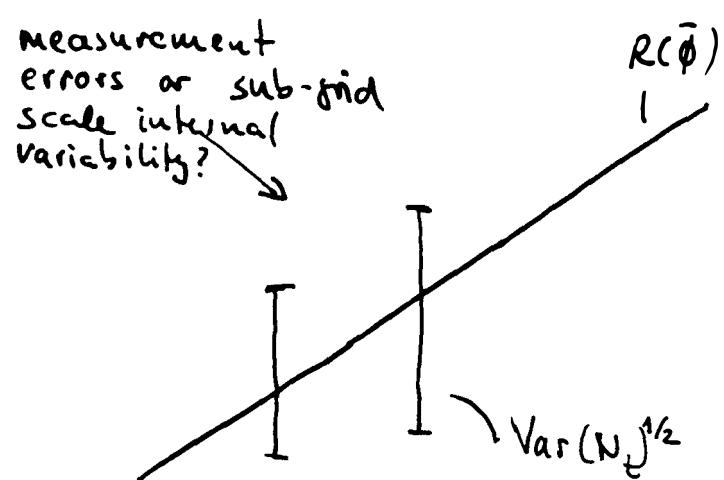
Example

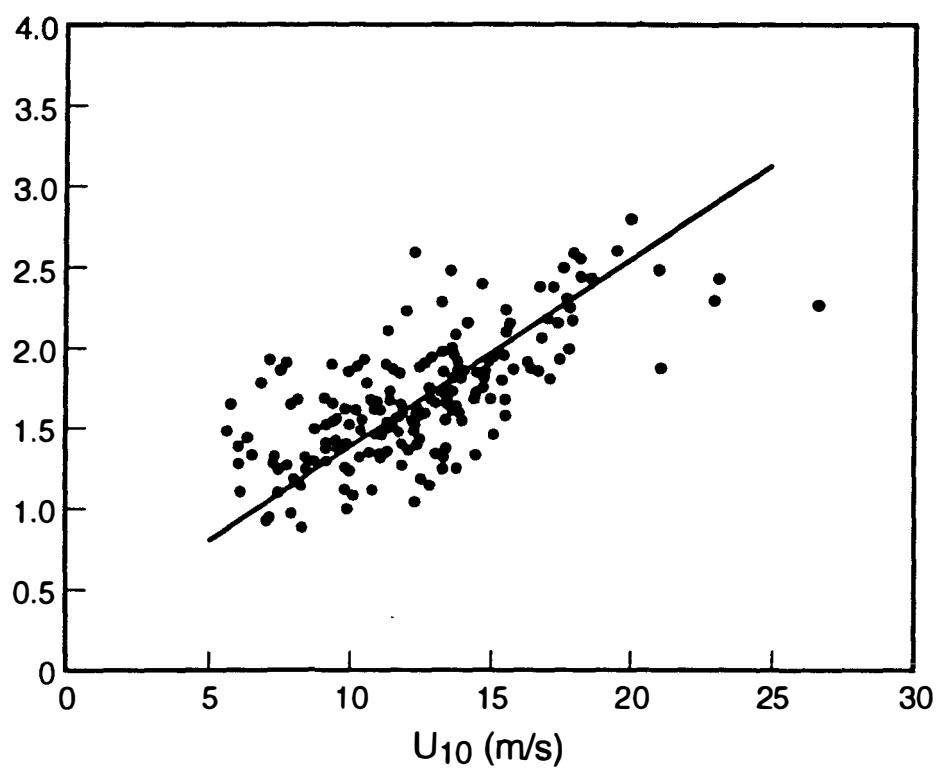


Different parameterizations of Cirrus clouds









c) randomised parameterization

$$R'(\phi') \sim \mathcal{P}(\vec{\alpha})$$

$$\vec{\alpha} = \mathcal{F}(\bar{\phi})$$

$$\Rightarrow R'(\phi') \sim \mathcal{P}[\mathcal{F}(\bar{\phi})]$$

$$\text{and often: } = Q(\bar{\phi}) + N,$$

with N independent of $\bar{\phi}$
and adequately distributed.

(**) is a randomized parameterization as it returns different values for the same resolved scale state.

[It is formally identical with the randomized downscaling, with $\bar{\phi} \neq G$.]

DOES IT MATTER .!?

A demonstration with an Energy Balance Model

$$\frac{\partial \bar{T}}{\partial t} = c_w [S + L]$$

↑ short wave radiation; \bar{T} = global mean temp

option b) conventional

$$S = \bar{S} = (1 - \alpha) S_0, \quad \alpha \text{ a function of } \bar{T}.$$

$$L = \bar{L} = b \bar{T}^4$$

$$\Rightarrow \frac{d\bar{T}}{dt} = \alpha(1 - \alpha(\bar{T})) S_0 + b c_w \bar{T}^4$$

two stable solutions, no "real" variability
after initial adjustment phase.

option c) randomized

$$S = \bar{S} + S_0 N_t$$

$$N_t \sim \mathcal{N}(0, 5\%)$$

two dynamical equilibria, full spectrum
of variability, stationary dynamics
Considerably richer than option b.

... this of course just Hasselmann's stochastic climate
model ...

Yes, it matters, at least in certain situations.
Nonlinearity is not a needed ingredient.

Abschnitt 5.5: Nichtlinearität und Zufall

Abbildung 5.7: Oben: Langfristverhalten des EBMs bei temperaturabhängiger Albedo (aus Abbildung 5.6).

Mitte: Die Häufigkeitsverteilung des Ergebnisses.

Unten: Als Vergleich das Langzeitverhalten des EBMs bei konstanter Albedo.

