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SECOND AUTUMN WORKSHOP ON MATHEMATICAL ECOLOGY

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"Climate Modeling - Lecture Notes"

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These are preliminary lecture notes, intended only for distribution to participants.

Climate Modeling Basics

Conservation laws (ie, 1st principles) applied to fluids:

- ENERGY ($T_A, T_O, \rho v^2$ ...)
- MOMENTUM ($\vec{v}_A, \vec{v}_O$)
- MASS ($\rho_A, \rho_{H_2O}, \rho_{CO_2}, \rho_{O_3}$, ...)

Boundary Conditions

- Solar radiation ($S = S(t,$ ...
- Geography (Land) Part of Cl...
- Composition (depends on time frame)

1

Climate Modeling Methods

(semi-empirical in real world -- i.e., bye-bye 1st principles!)

Solving the equations

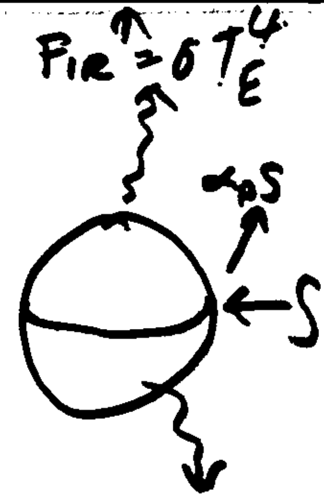
- Analytically (very simple systems)
- Numerically (discretization)
  - grid points
  - orthogonal functions
  - time steps

  (can make spurious waves or mixing problems)

Parameterization (sub-grid scale)

- radiation
- convection
- clouds
- rain
- runoff
- evaporation
- orography
- storms (depends on scale)
- Aerosols
- ⋮

Radiation Energy Balance



$Q_{in} = Q_{out}$ (equilibrium)

Solar absorbed = outgoing IR

$$\frac{S}{4}(1-\alpha_p) = \sigma T_E^4 \quad (T_E \approx 255 °K)$$

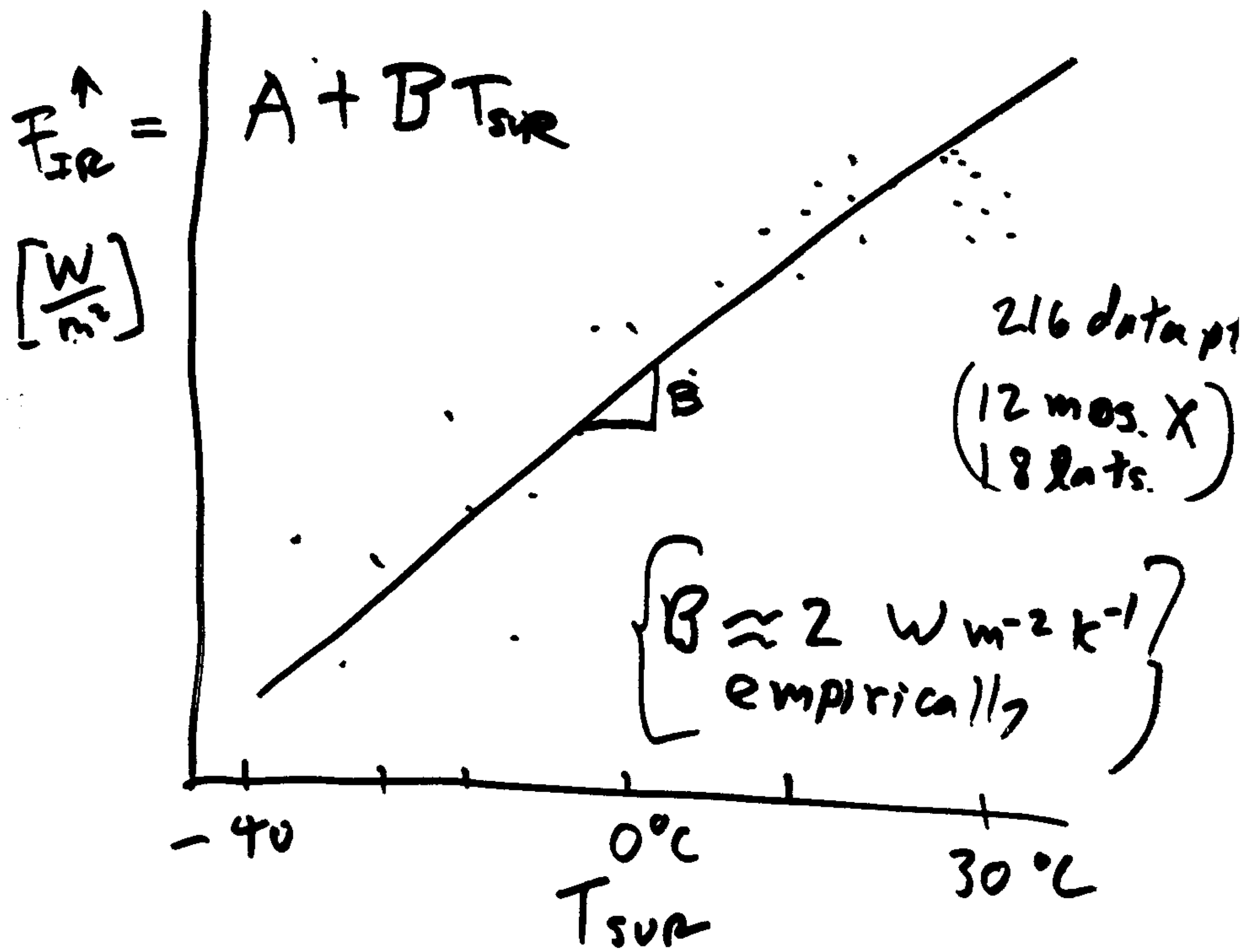
Sensitivity Parameter $\beta_E = \frac{S \partial T_E}{\partial S} = \frac{T_E}{4} \sim 65 °K$

$\Rightarrow$ if $\frac{\Delta S}{S} \sim 0.01$ then $\Delta T_E \sim 0.65 K$

but, $T_E = 255 K$, while $T_{SUR} \approx 288 °K$

(ie, "Greenhouse Effect")

Need $F_{IR}^{\uparrow} = f(T_{SUR}, \text{composition})$



Warren + Schneider, JAS (1979)

Water vapor - Greenhouse effect Feedback

Solar absorbed = IR emitted

$$\frac{S}{4}(1-\alpha_p) = A + B T_{sur}$$

Sensitivity parameter $\quad \beta_{sur} = \dfrac{S(1-\alpha_p)}{4B}$

B ← IR Radiation Damping Coefs

for $\alpha_p \sim 0.3$

$B = 2\ W/m^2/K$

$\Rightarrow \beta_{sur} \approx 120\,°K \quad (2 \times \beta_E)$

Albedo – Temperature Feedback

$$\frac{S}{4}\left[1 - \alpha_p(T)\right] = A + BT$$

eg, if: $\alpha_p = g + f\,T_{sur}$

Sensitivity parameter $\beta = \dfrac{S(1-g)}{4B + fS}$

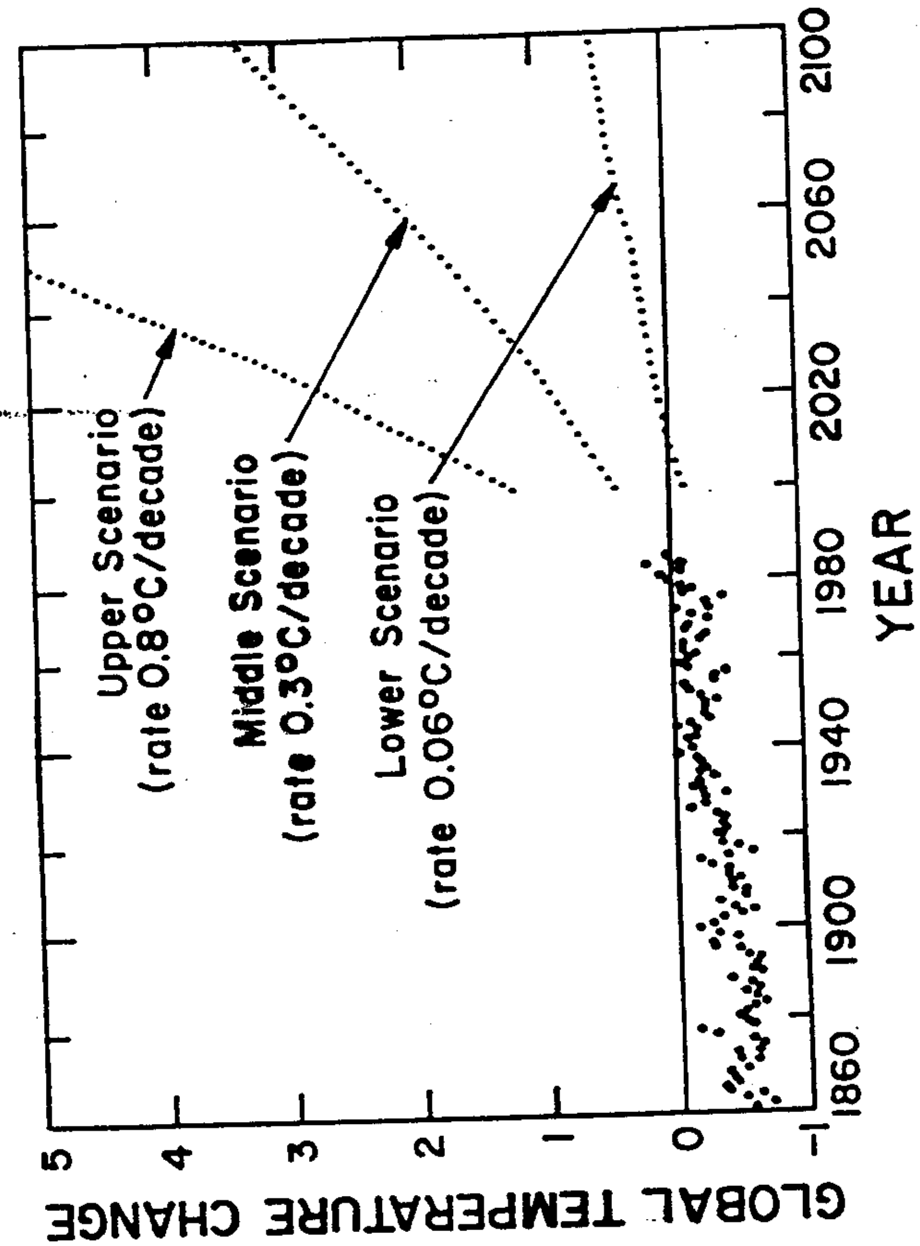
if $f < 0$, <u>positive</u> feedback

$f > 0$, <u>negative</u> feedback

if $f = -0.01$ ie $\Delta T = -1K \Rightarrow \Delta\alpha_p = 0.0$

then $\beta \sim 500°K$

Figure 1



Upper Scenario
(rate 0.8°C/decade)
Middle Scenario
(rate 0.3°C/decade)
Lower Scenario
(rate 0.06°C/decade)
GLOBAL TEMPERATURE CHANGE
-1
0
1
2
3
4
5
YEAR
1860
1900
1940
1980
2020
2060
2100

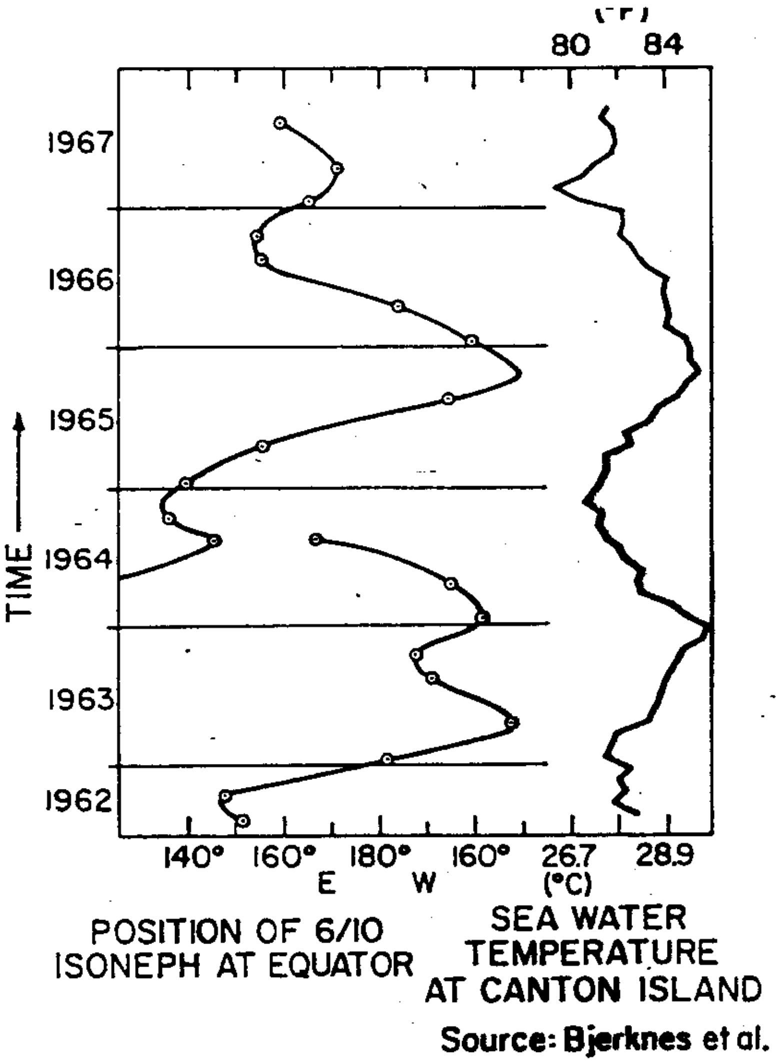


FIG. 3. Position of 0.6 isoneph of cloudiness versus sea surface temperature at Canton Island (from Bjerknes *et al.*, 1969). The figure shows more cloudiness when sea surface temperatures are warmer.

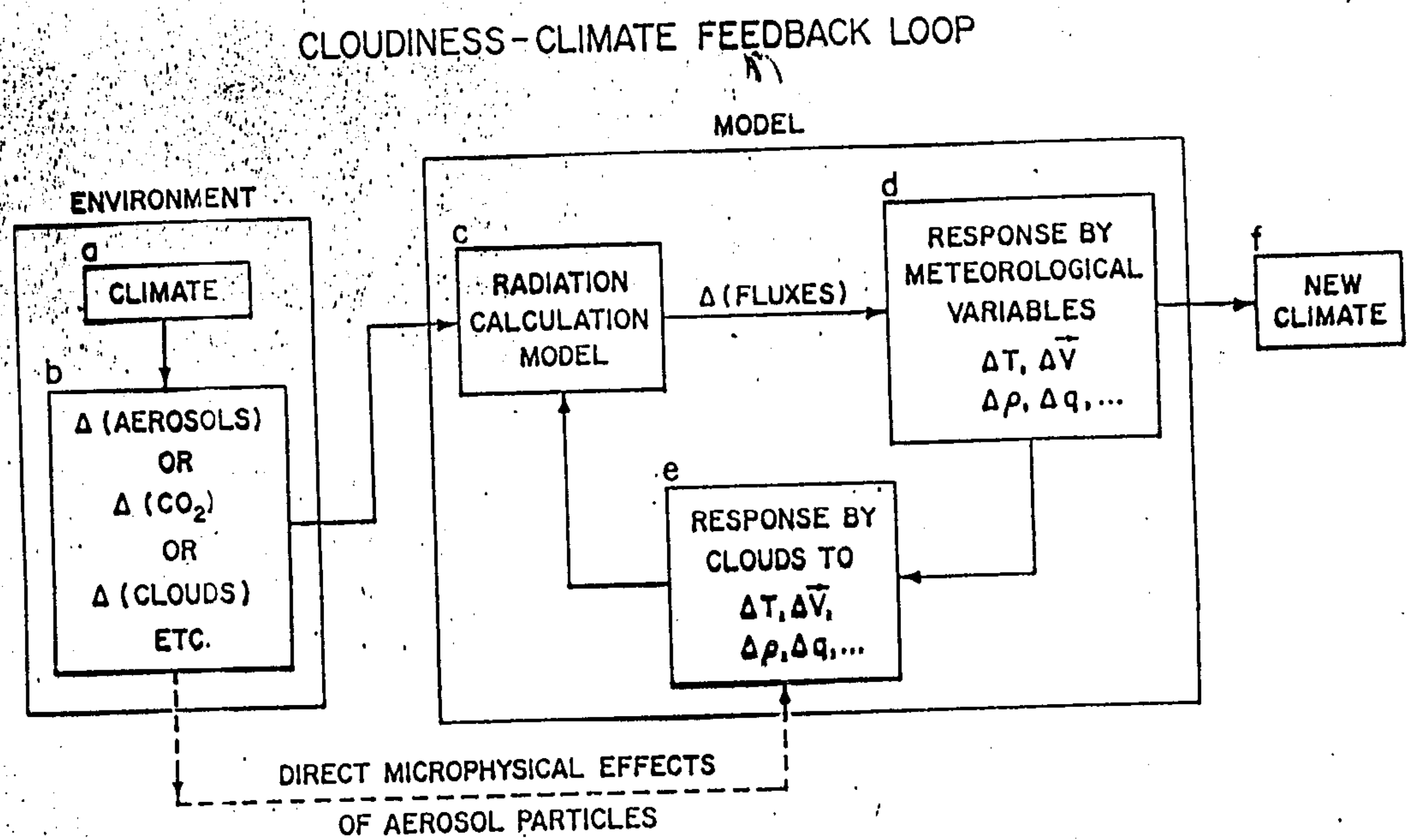


FIG. 1. Flow chart illustrating the possible role of cloudiness as a climatic feedback mechanism. The arrows represent the order in which calculations would be made by a climate model attempting to predict the effect of changes in environment (e.g., $\Delta(CO_2)$ on the climate).

SCHNEIDER (1972)

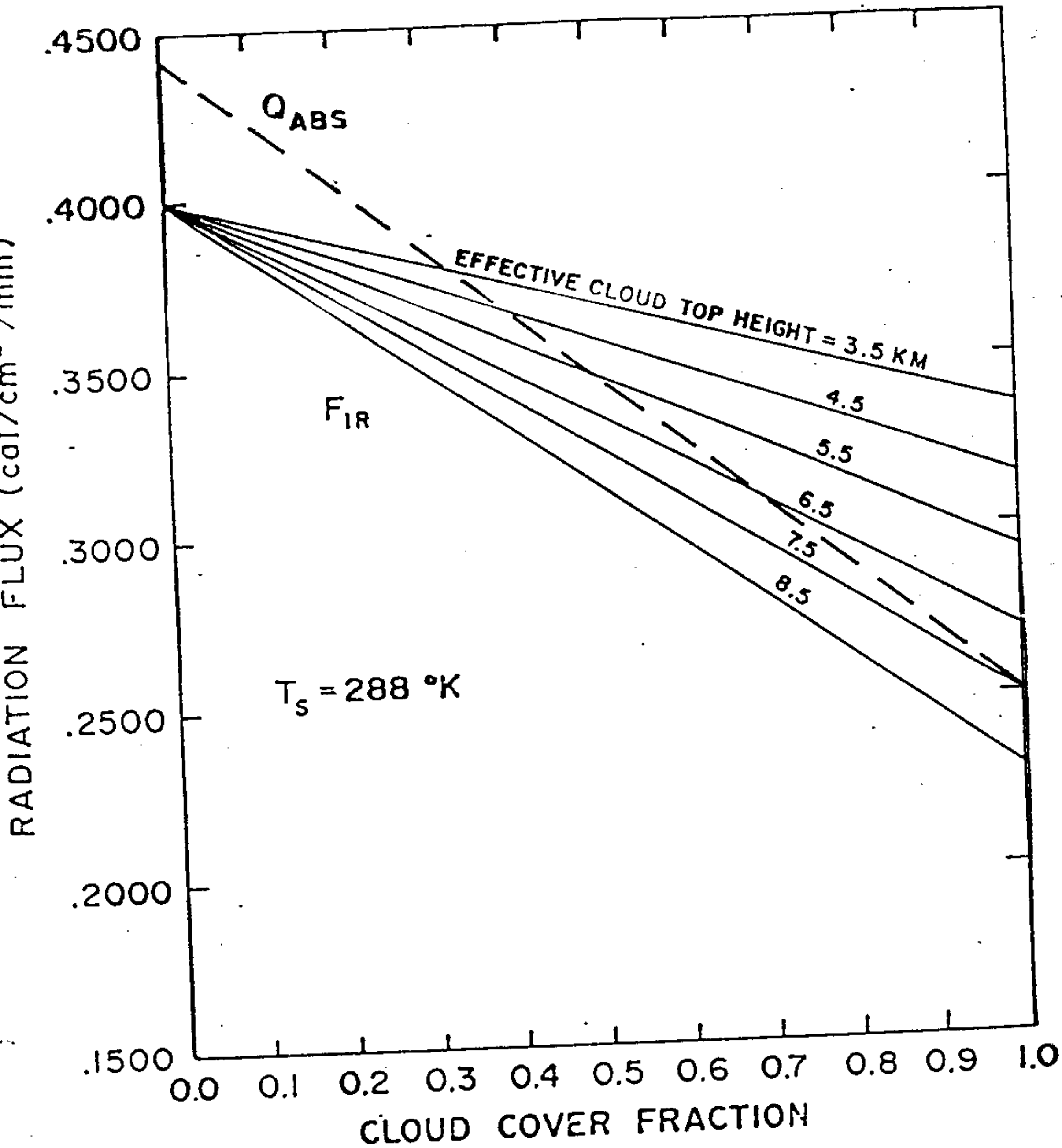


FIG. 2. The infrared flux to space, F_{IR}, emitted from the earth-atmosphere system (described in Table 1) and the absorbed solar energy, Q_{ABS}, as a function of amount of cloud cover and for several values of effective cloud top height.

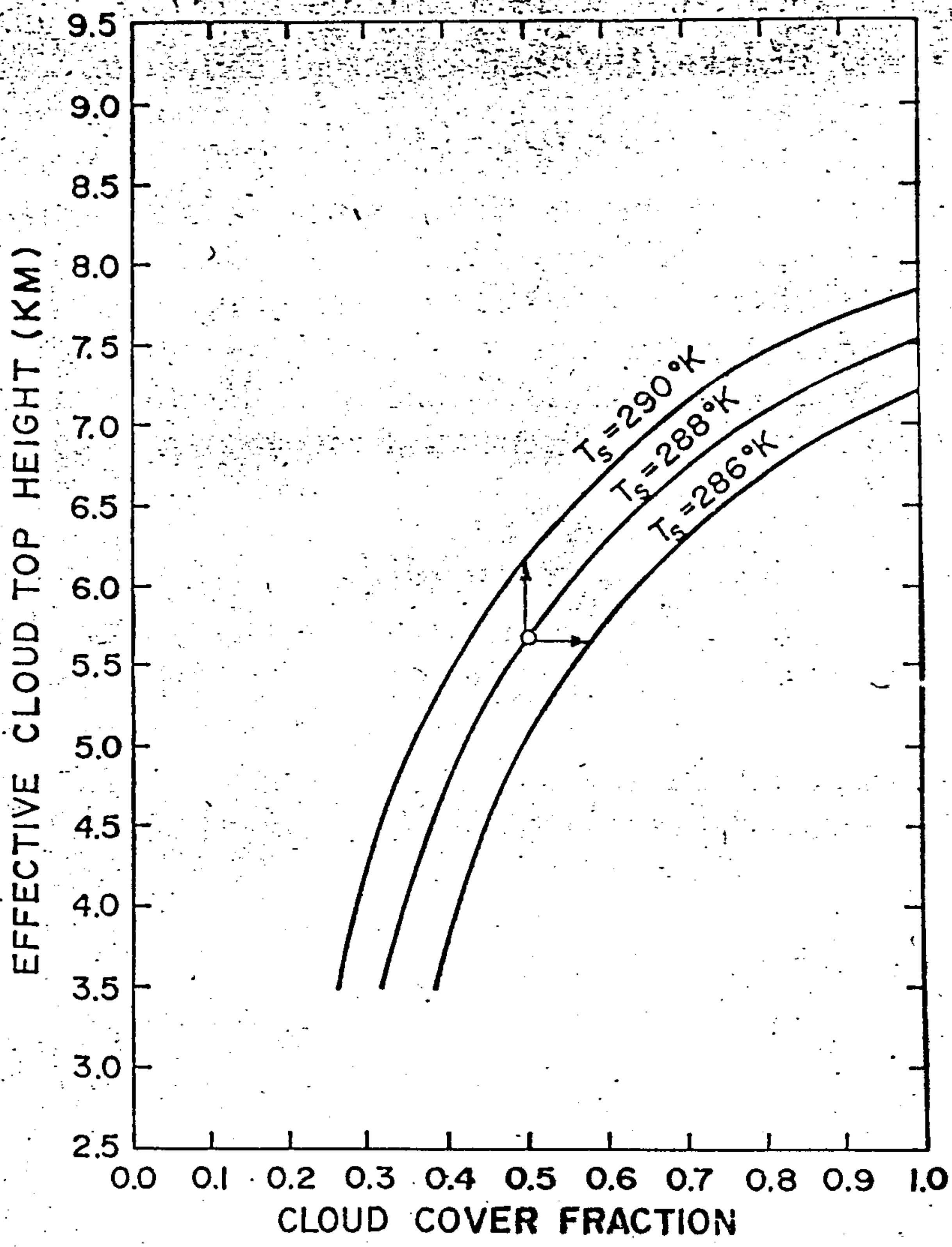
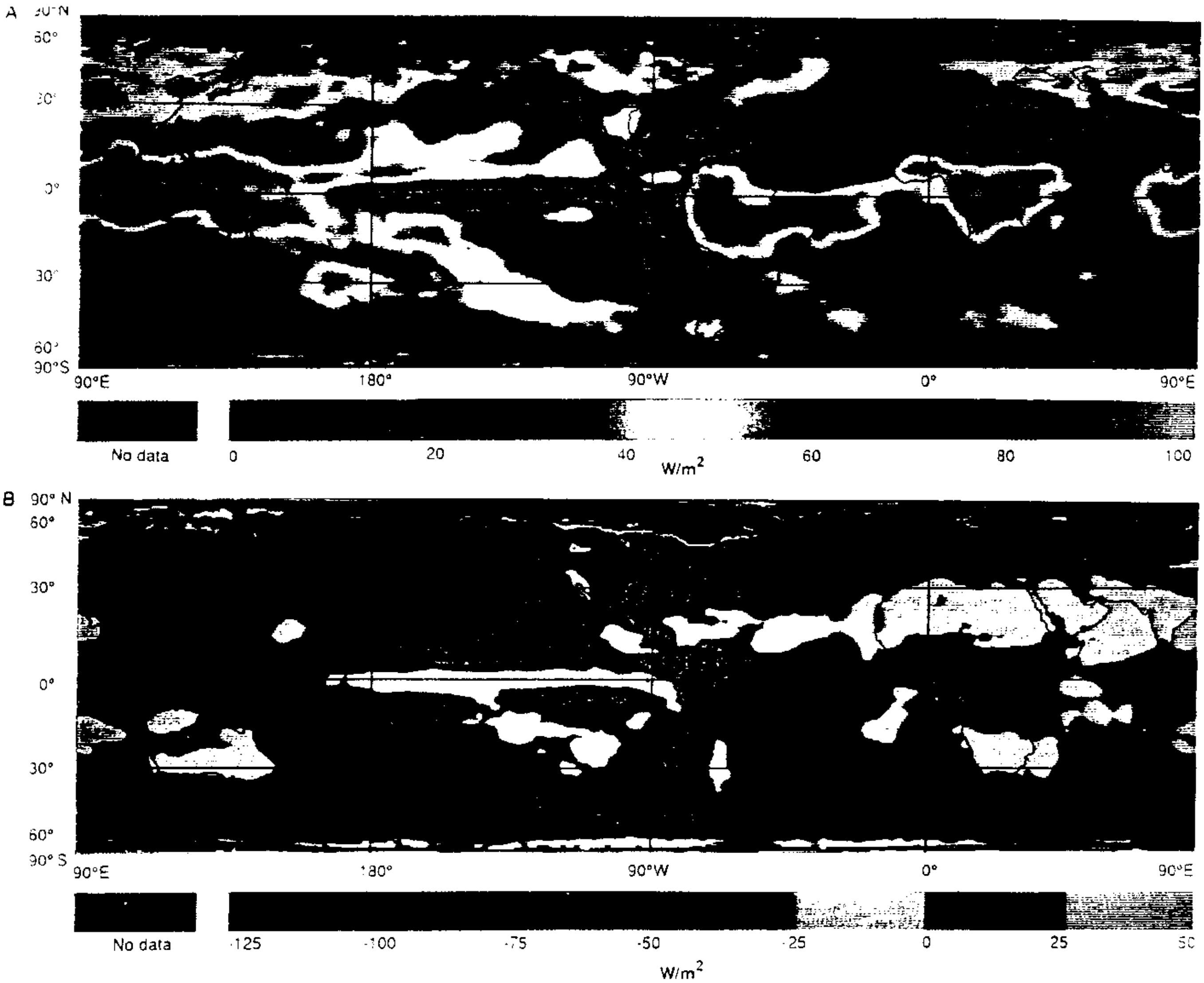
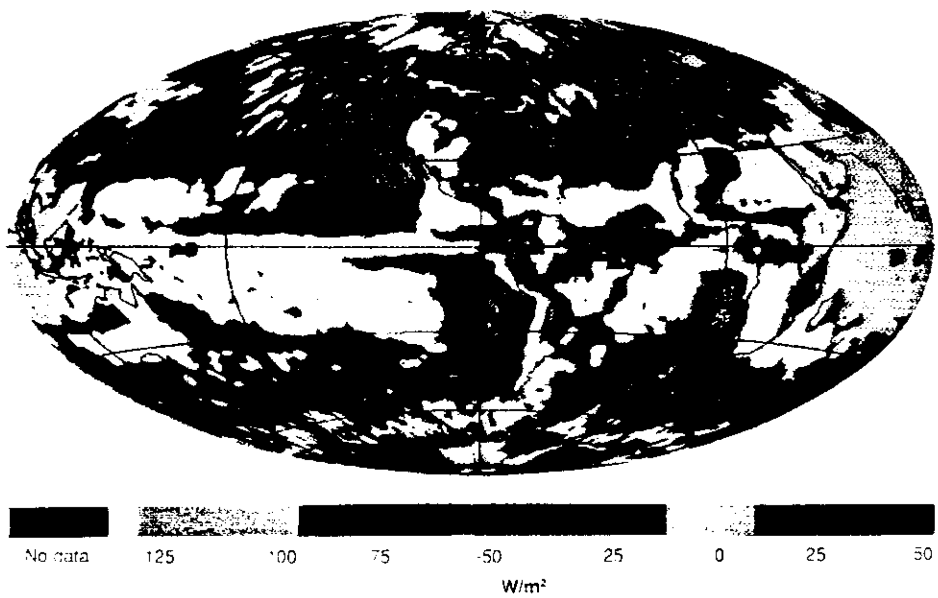


FIG. 3. A cross-plot of the intersections on Fig. 2 of the Q_{ABS} curve with the various F_{IR} curves for three values of surface temperature. Each curve represents a locus of the possible equilibrium values of cloud top heights and cloud cover amounts that are consistent with a constant value of surface temperature.



The LW (**A**) and SW (**B**) cloud forcing for April 1985. The uncertainties in the estimated values are about ± 10 W/m^2. Estimates over snow-covered regions may potentially have larger uncertainties because of difficulty in distinguishing clear from cloudy regions over the bright snow-covered regions



Net (C_{LW} + C_{SW}) cloud forcing for April 1985. The positive values of cloud forcing, including those seen in North America and in the polar regions, do not exceed 25 W/m²

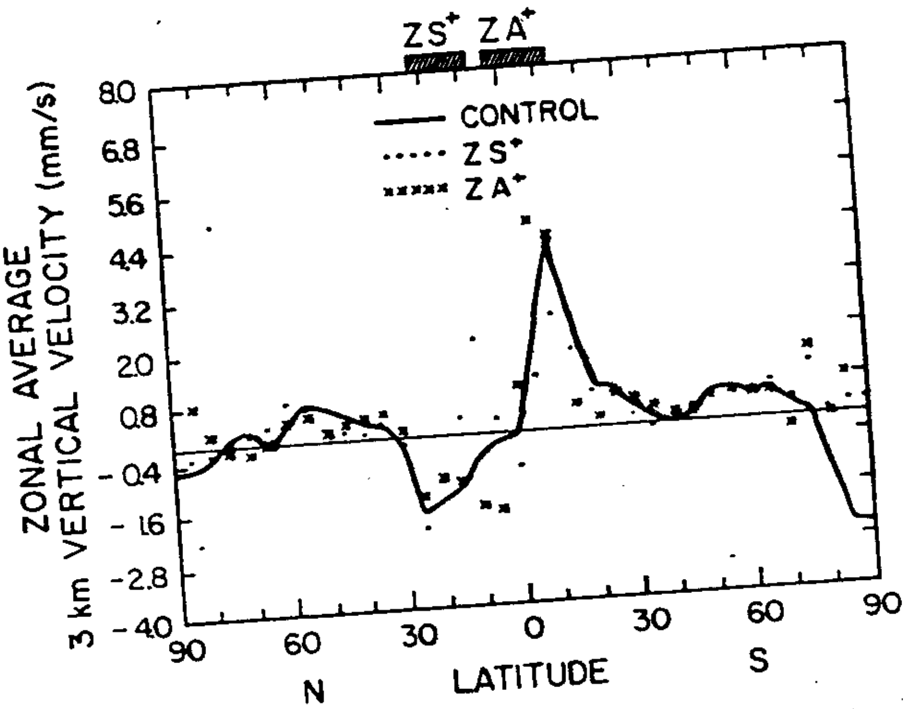


FIG. 5. Thirty-day mean zonal average vertical velocity for control and strip experiment ZS+ and ZA+. The creation of local direct cells by the +2 K strips of surface temperature anomaly superimposed on the January vertical velocity graph is evident in each strip experiment. The prescribed change region is cross-hatched for each experiment.

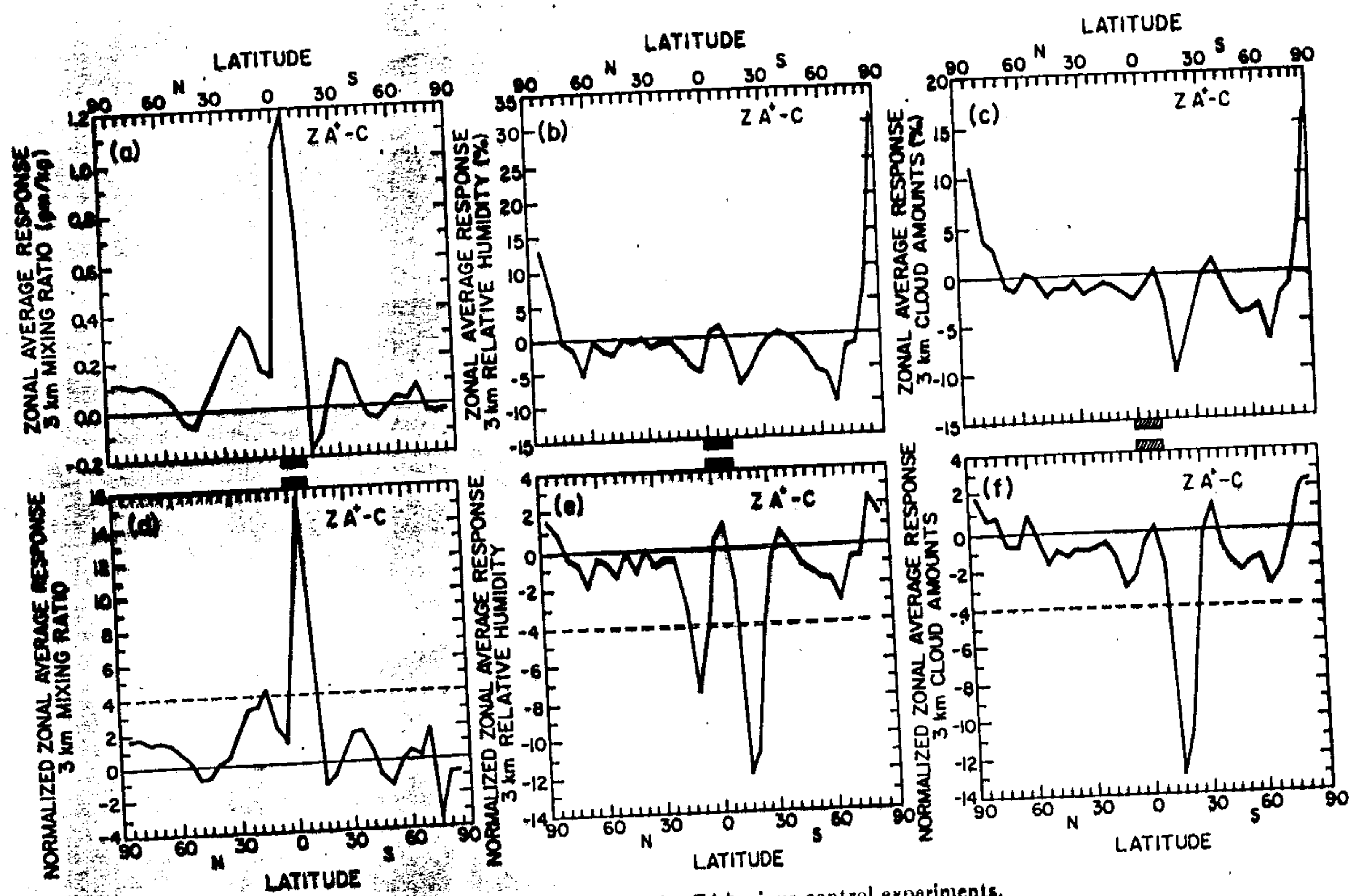


Fig. 7. As in Fig. 6 except for ZA^+ minus control experiments.

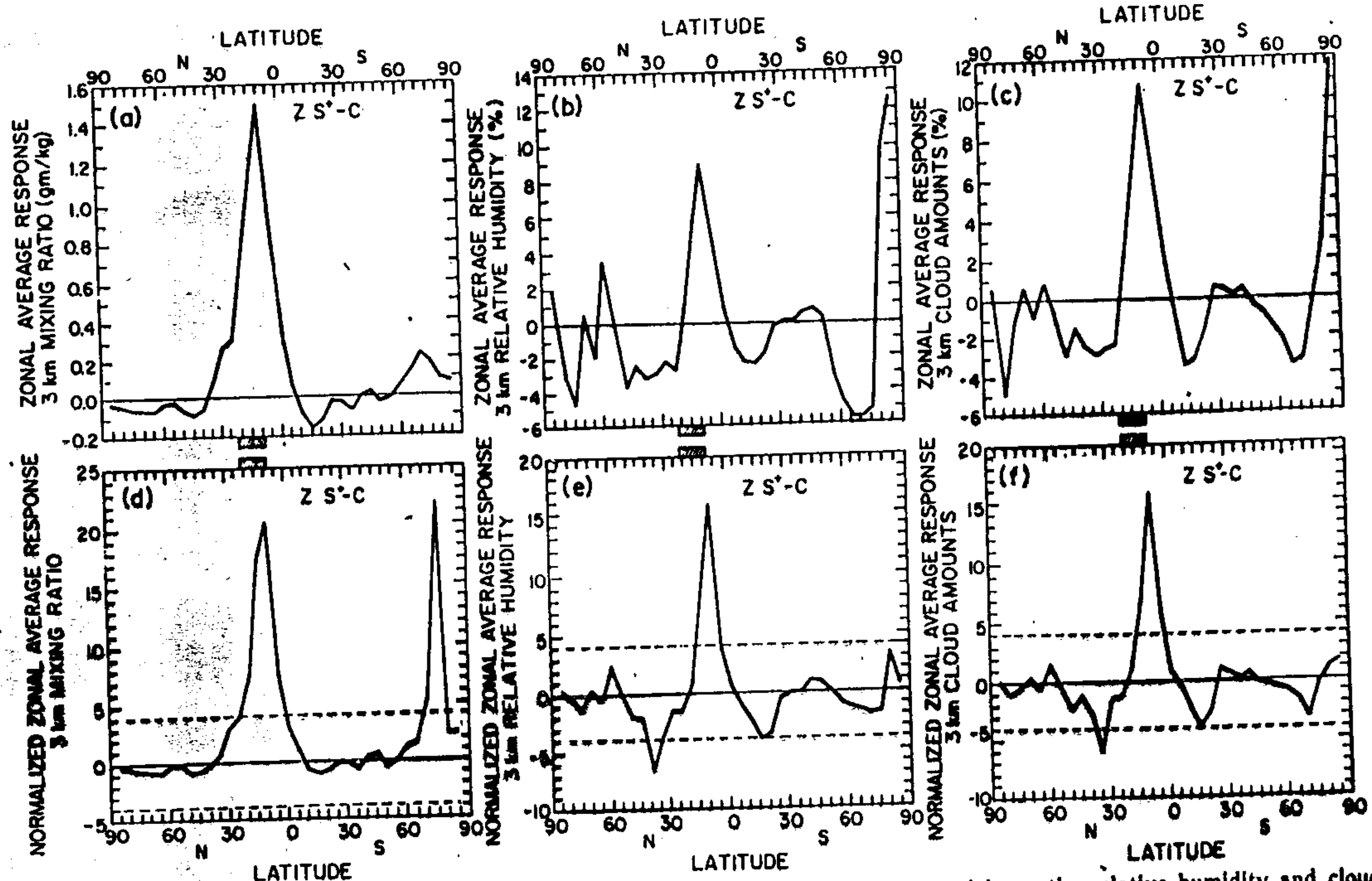


FIG. 6. Thirty-day mean zonal average response and normalized response for 3 km mixing ratio, relative humidity and cloud amounts for ZS^+ minus control experiments. The dashed line in each normalized response plot indicates the 5% significance level. The prescribed change region is cross-hatched.

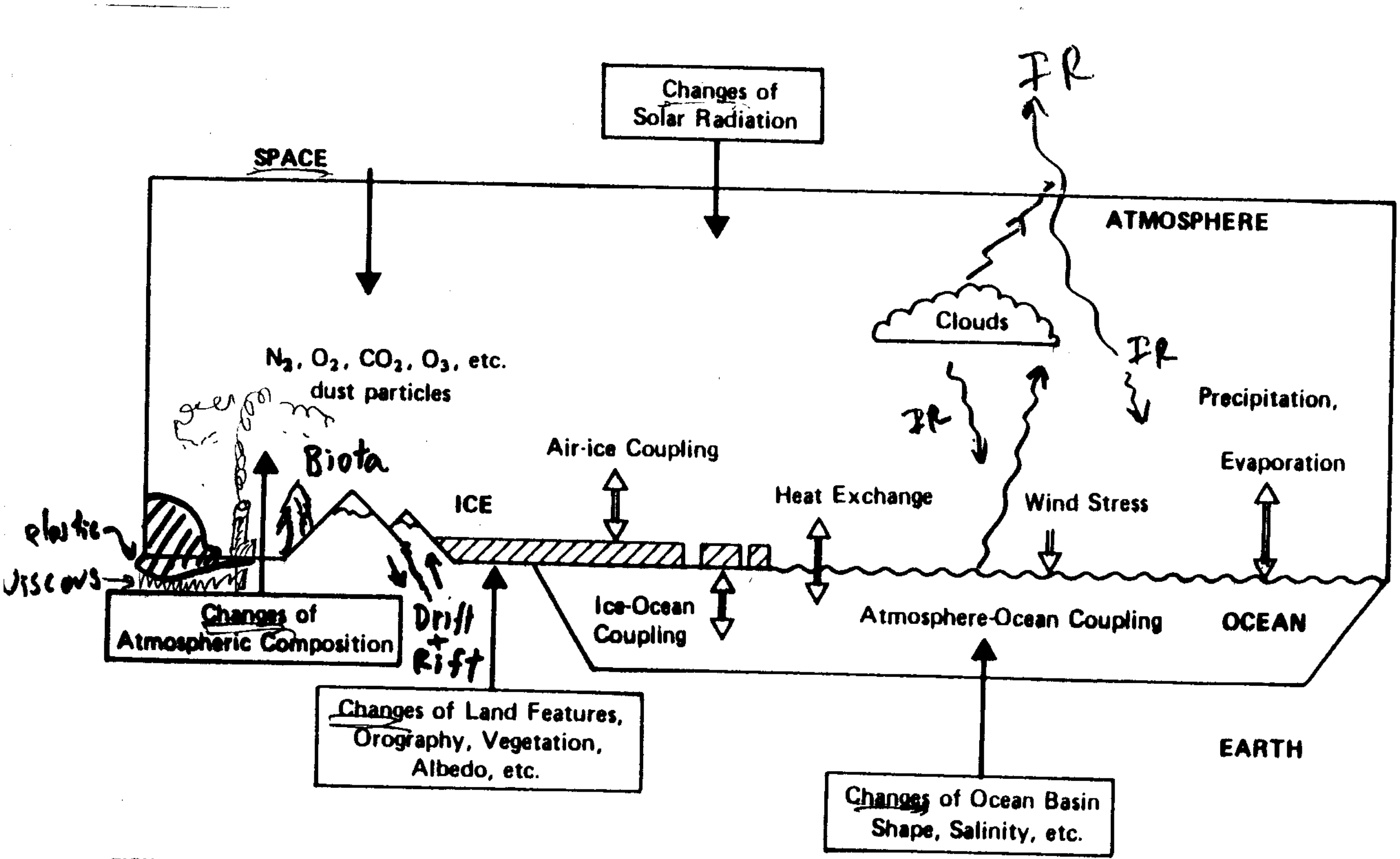


FIGURE 3.1 Schematic illustration of the components of the coupled atmosphere–ocean–ice–earth climatic system. The full arrows (⟶) are examples of external processes, and the open arrows (⟹) are examples of internal processes in climatic change.

NAS (1975)

ON THE PROBLEM OF MULTIPLE TIME SCALES IN CLIMATE MODELING

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Man's Impact on Climate

Proceedings of an International Conference held in Berlin
June 14–16, 1978

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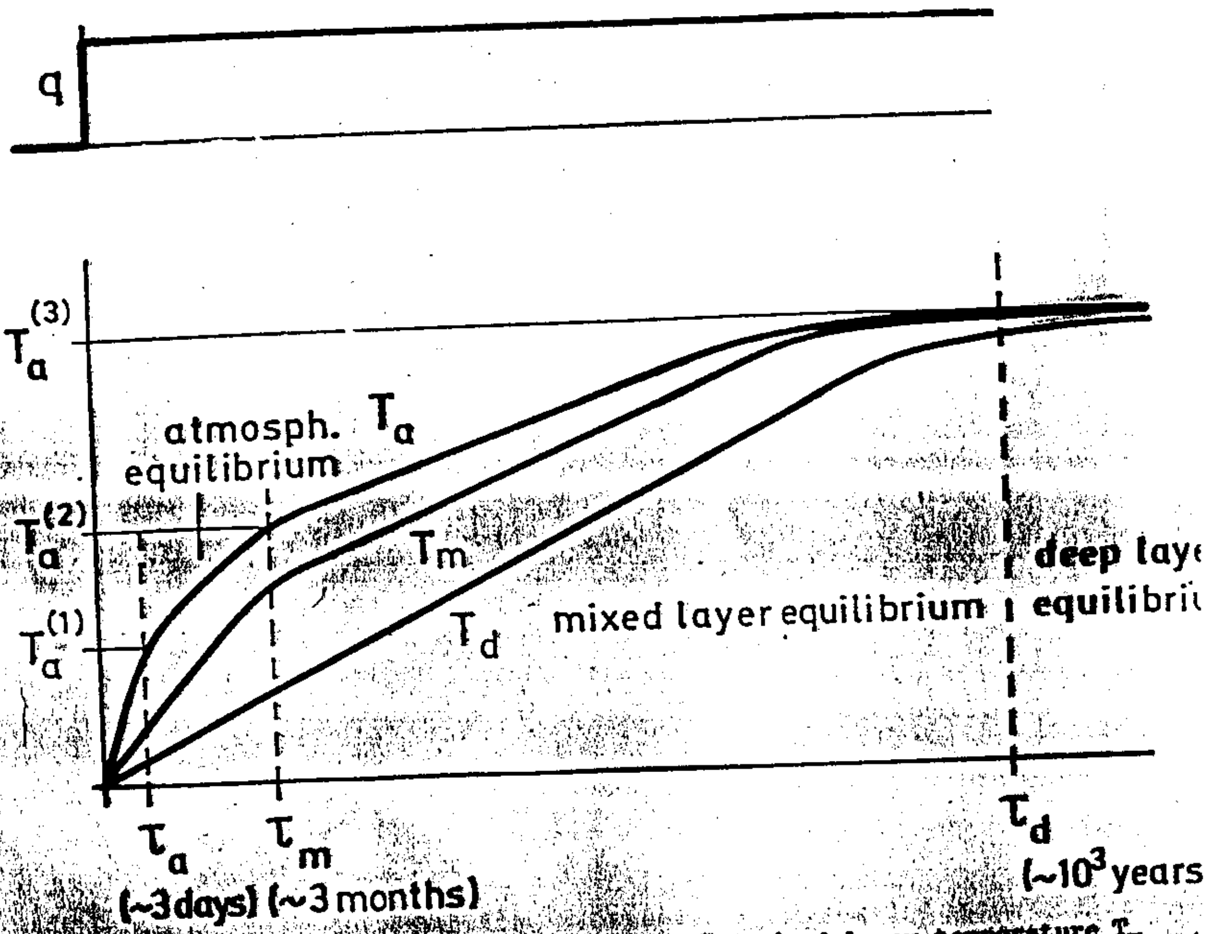
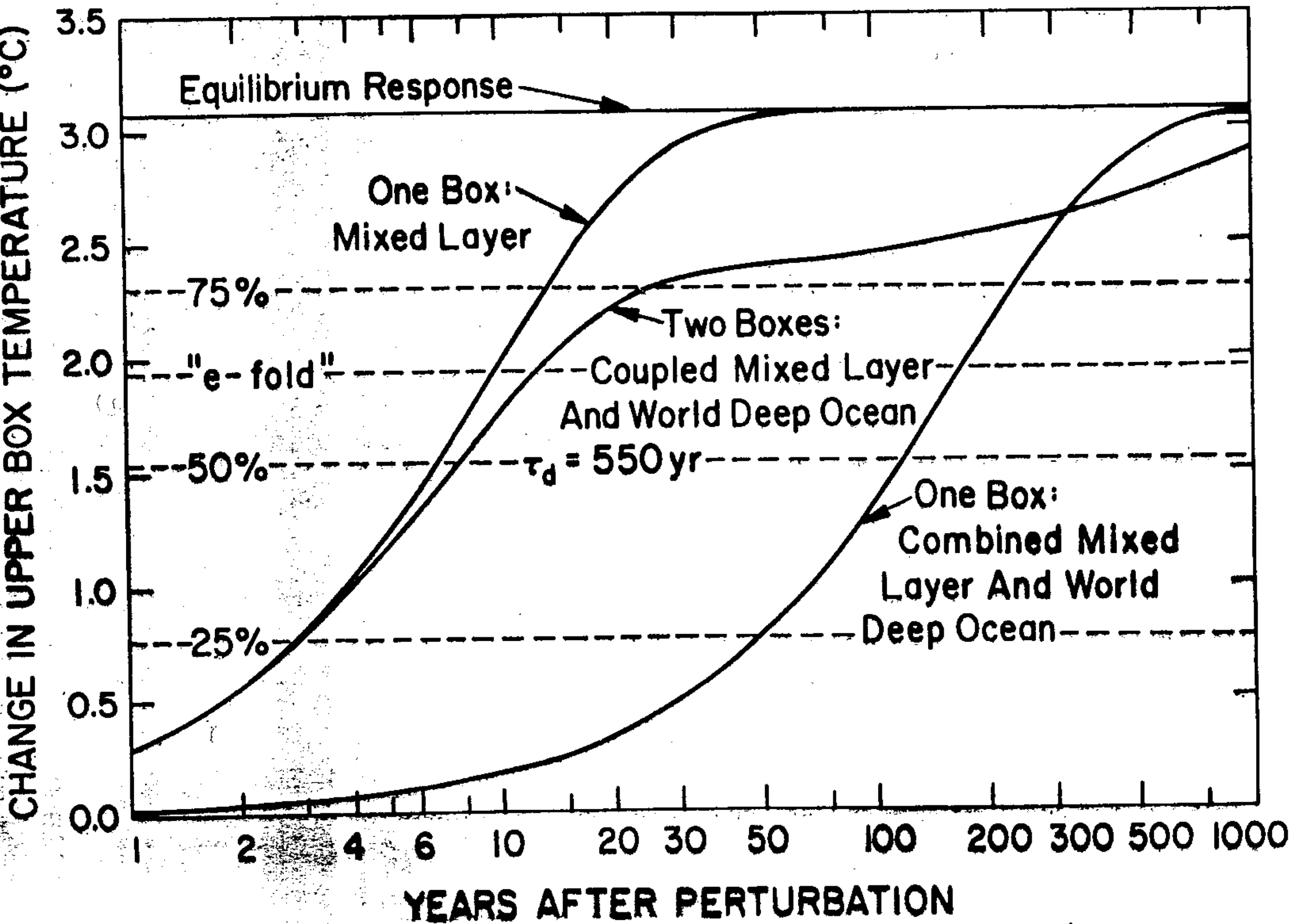
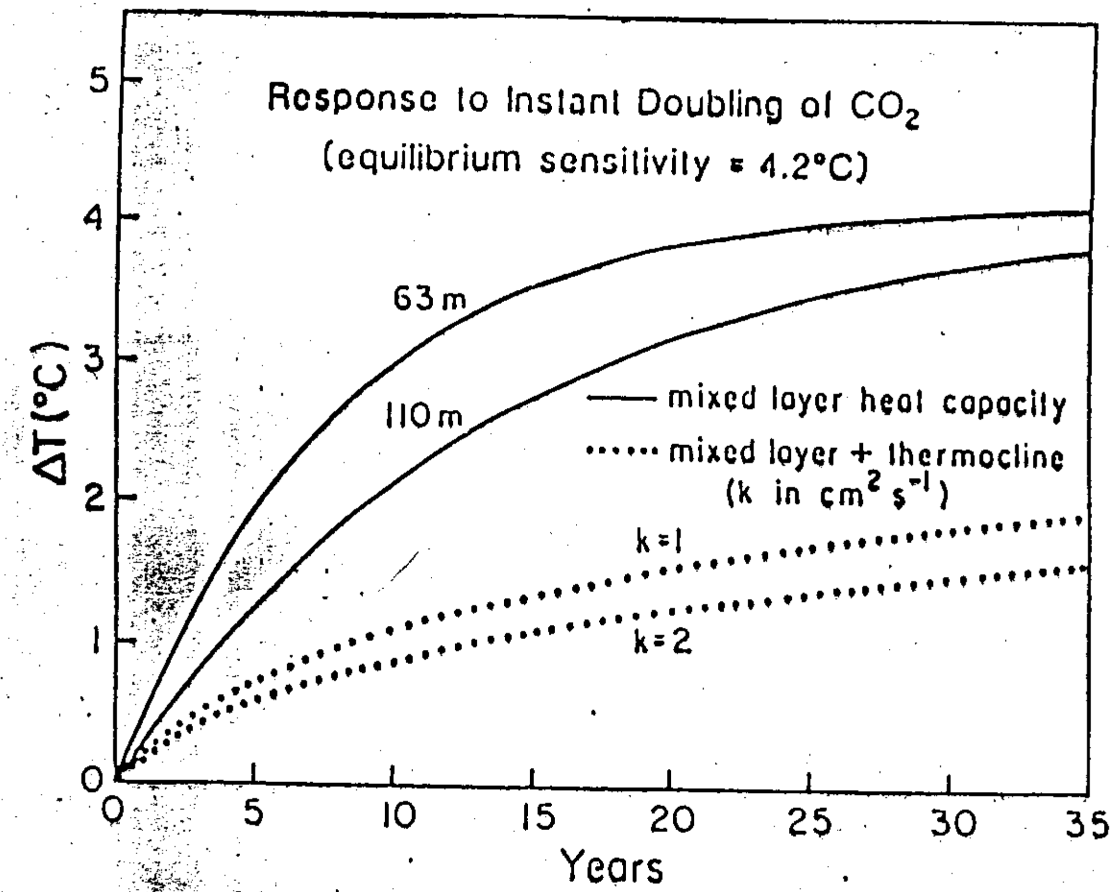


Fig. 2. Response of the atmospheric temperature T_a, mixed-layer temperature T_m and deep-ocean temperature T_d to a step-function change in heating q (schematic).

RESPONSE OF THE TWO-BOX MODEL TO A STEP FUNCTION CO_2 DOUBLING AT YEAR ZERO



Schneider & Thompson (1981) JGR



Transient response to step function doubling of atmospheric CO_2 from 315 ppm to 630 ppm, computed with three representations of the ocean. The 63 m mixed layer corresponds to the mean mixed layer depth in the GISS 3-D experiments; 110 m is the global-mean annual maximum mixed layer depth obtained from global ocean data. (Hansen, J. E. and Takahashi, T. (eds.), Climate Processes and Climate Sensitivity, American Geophysical Union, Washington, D.C., 1981)

Climate Response Times: Dependence on Climate Sensitivity and Ocean Mixing

Abstract. *The factors that determine climate response times were investigated with simple models and scaling statements. The response times are particularly sensitive to (i) the amount that the climate response is amplified by feedbacks and (ii) the representation of ocean mixing. If equilibrium climate sensitivity is 3°C or greater for a doubling of the carbon dioxide concentration, then most of the expected warming attributable to trace gases added to the atmosphere by man probably has not yet occurred. This yet to be realized warming calls into question a policy of "wait and see" regarding the issue of how to deal with increasing atmospheric carbon dioxide and other trace gases.*

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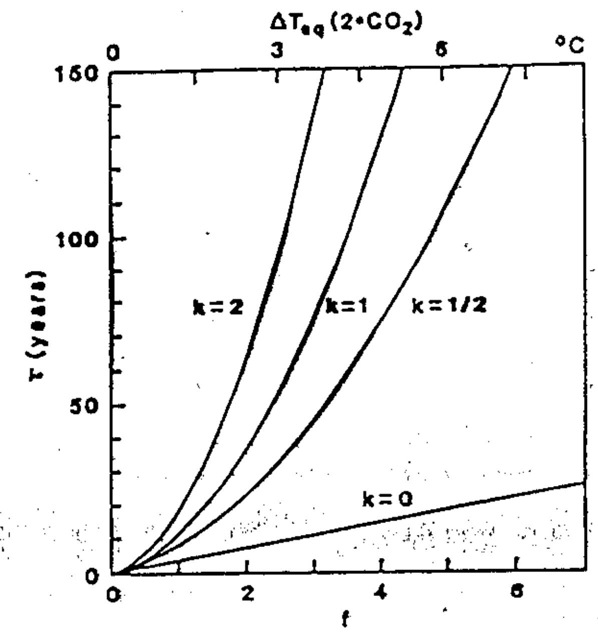


Fig. 1. Ocean surface response time (time to reach $1 - e^{-1}$ of equilibrium response) for the 1-D box diffusion ocean model as a function of climate feedback factor, f, or climate sensitivity to doubled CO_2, $\Delta T_{eq}(2 * CO_2)$ (k is the vertical diffusion coefficient in square centimeters per second; the mixed-layer depth $d_0 = 100$ m). Results depend strongly on k, as illustrated, but only slightly on d_0 for the cases in which $k \geq 0.5$ cm^2 sec^{-1}. Calculations are based on Eqs. 9 and 10, with an instant doubling of CO_2 from 300 to 600 ppm.

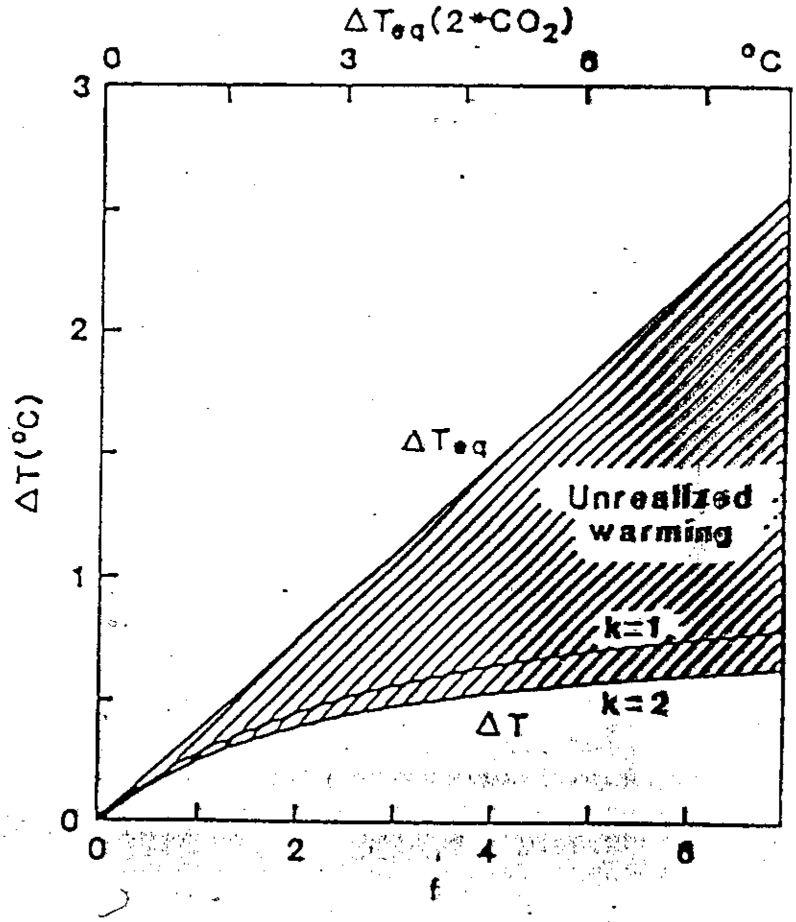
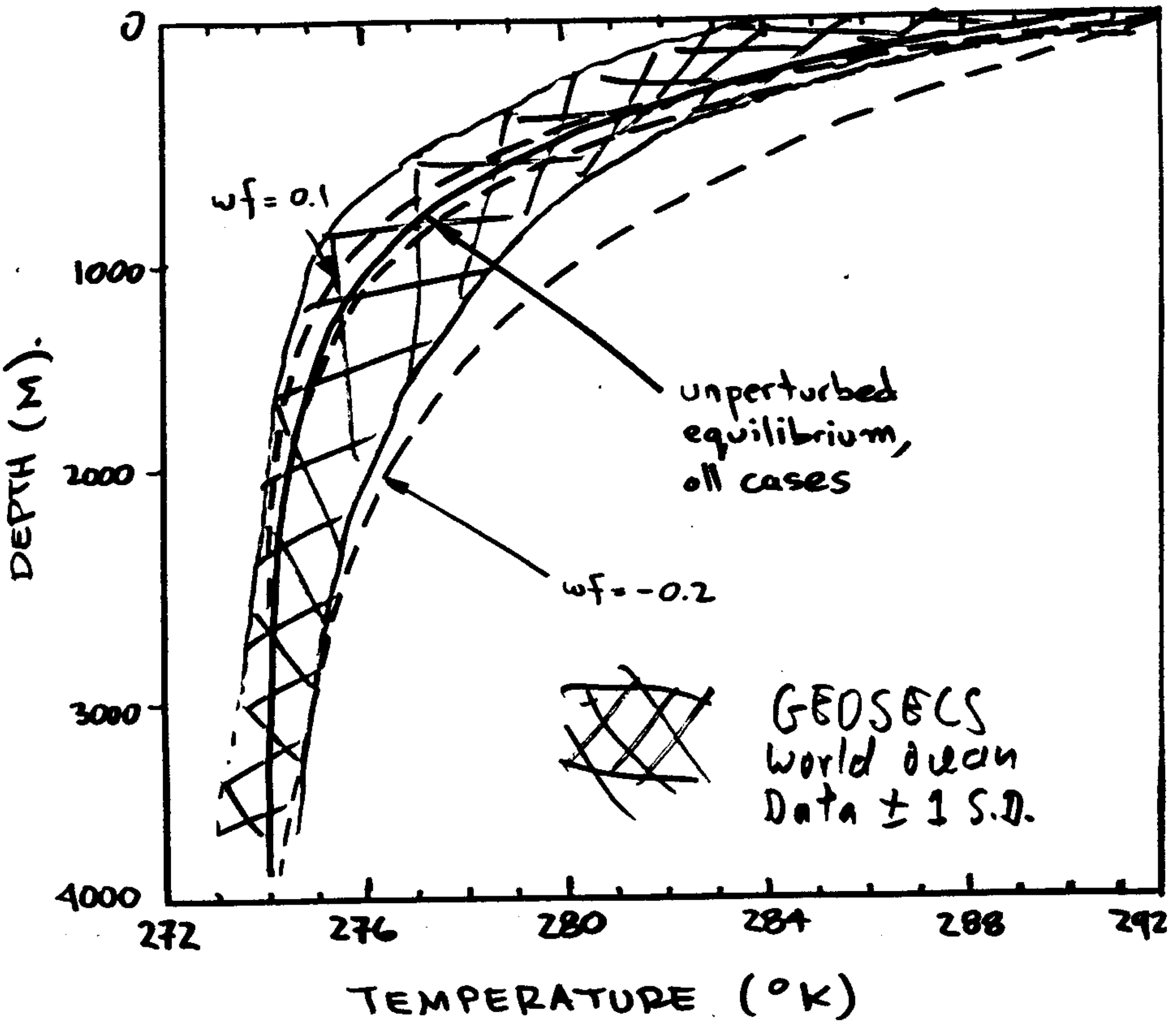
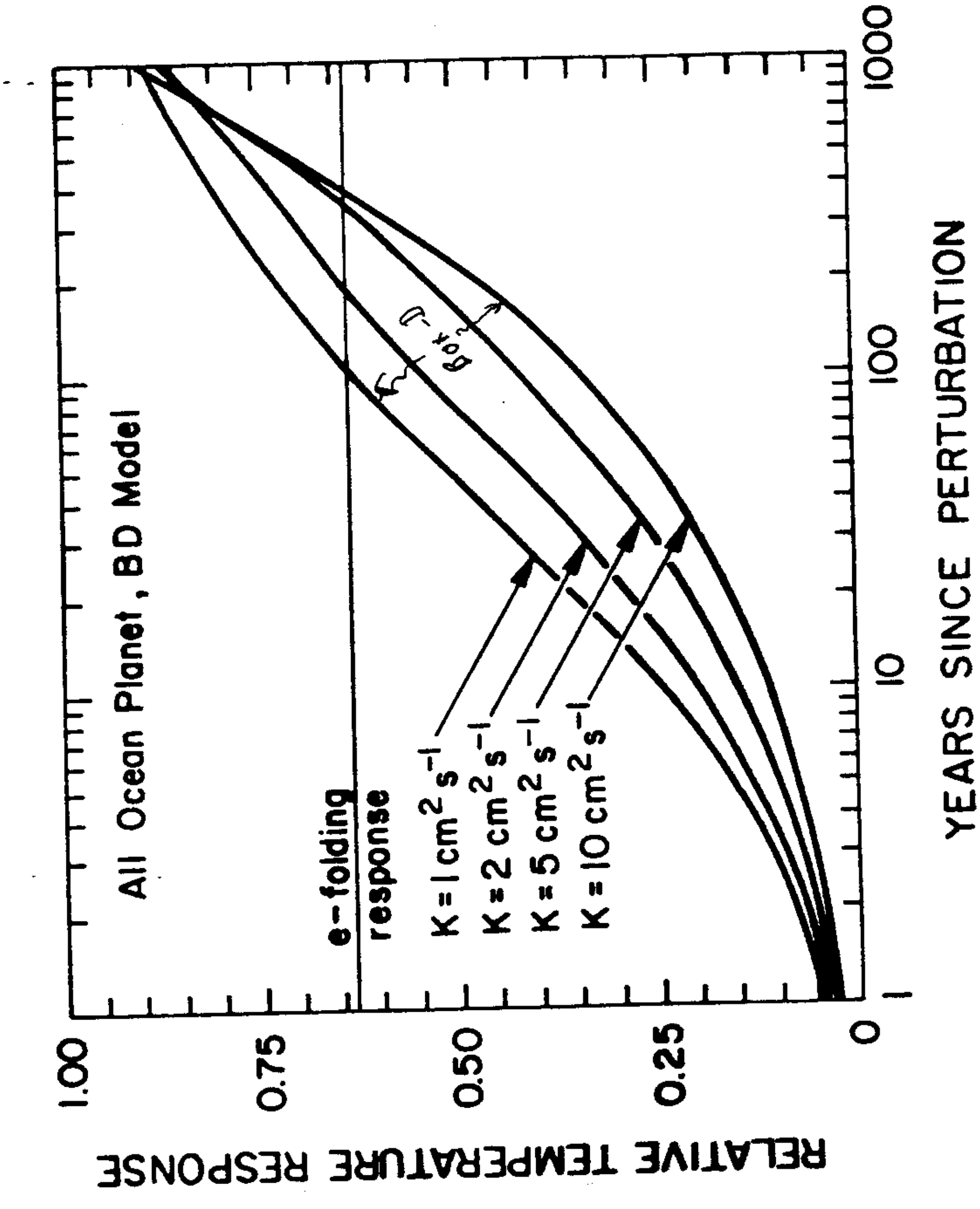


Fig. 2. Ocean surface warming (ΔT) and the equilibrium warming (ΔT_{eq}) due to CO_2 added to the atmosphere in the period 1850 to 1980 for the 1-D box diffusion ocean model as a function of f or $\Delta T_{eq}(2 * CO_2)$.

*

DEEP OCEAN TEMPERATURE PROFILE





All Ocean Planet, BD Model
e-folding response
K = 1 cm² s⁻¹
K = 2 cm² s⁻¹
K = 5 cm² s⁻¹
K = 10 cm² s⁻¹
RELATIVE TEMPERATURE RESPONSE
YEARS SINCE PERTURBATION
1.00
0.75
0.50
0.25
0
1
10
100
1000

Fig 1.

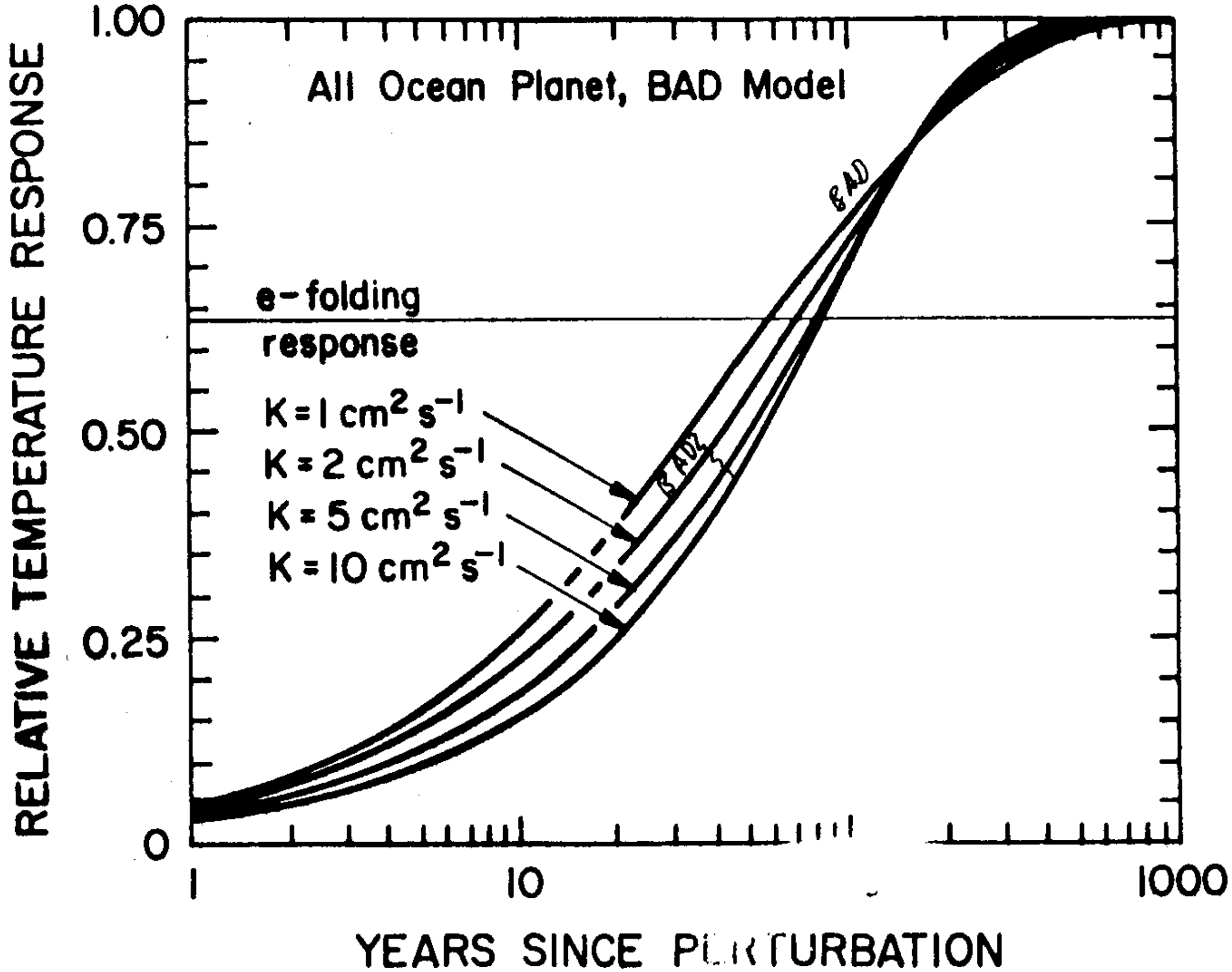
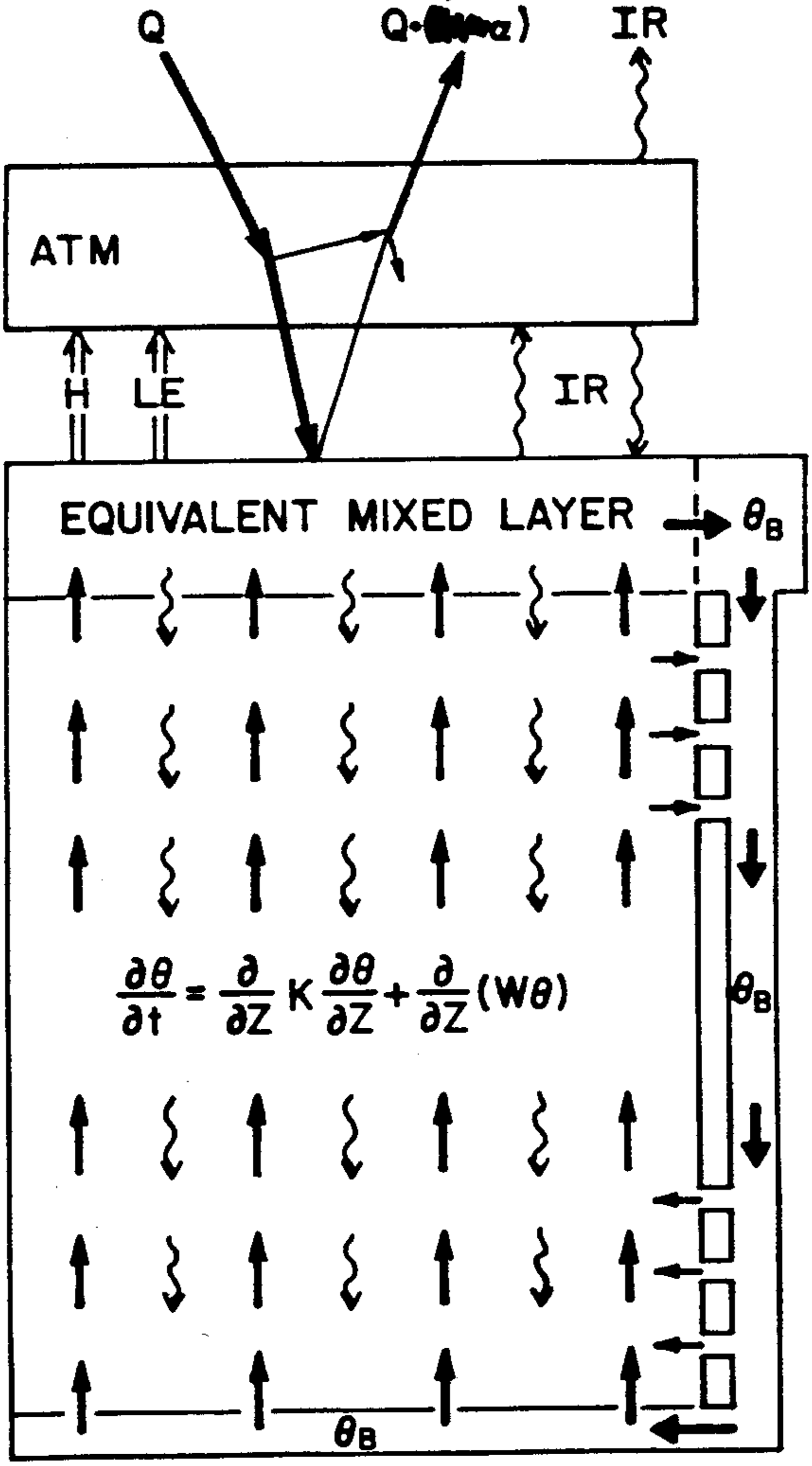


Fig. 2.

Harvey + Schneider

Box-Advection-Diffusion (BAD) Model
(Munk, 1960; Hoffert et al, 1980)



Source (This fig): Harvey & Schneider (1985) JGR

Box-Advection-Diffusion (BAD) Model