Instituto Nacional de Pesquisas Espaciais

Parametrização de chuva e nuvens

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Deep convection cloud structure

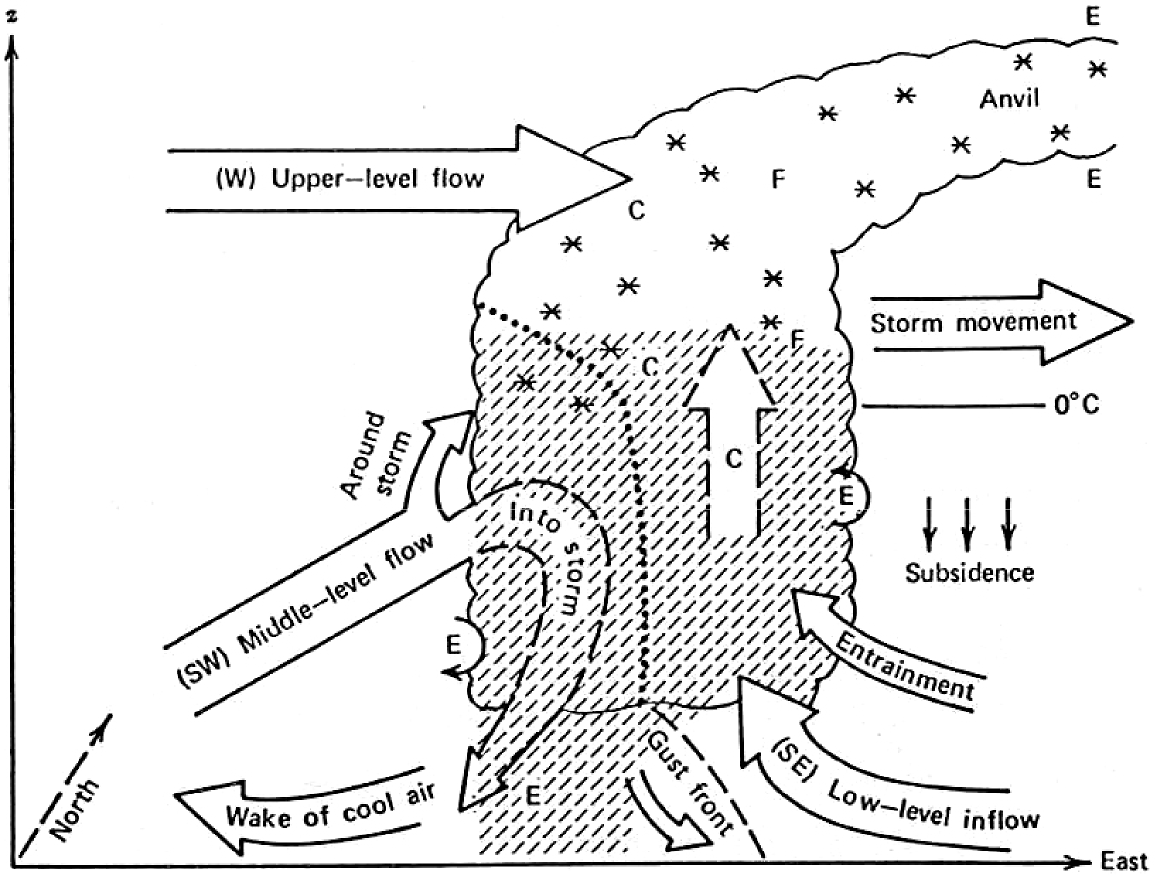
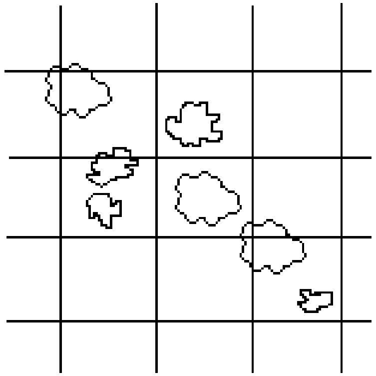


Figure 9-1 Schematic diagram of a mature thunderstorm. (*After Anthes, 1978.*) *C* refers to condensation; *E*, evaporation; and *F*, freezing. Letters in arrows refer to wind direction. (From R. A. Anthes, H. Orville, and D. Rayword. Chapter XIX of *The Thunderstorm: A Social Scientific and Technological Documentary*. E. Kessler, ed. University of Oklahoma Press, 1978.)

The need for cumulus parameterization

*Convective clouds can organise in clusters and show their collective effects in model grid-box.



*Large-scale destabilizes the environment >>> cumulus parameterization scheme acts to remove the convective instability

*The upward fluxes of heat, moisture and momentum in the cloud can be seen by means of an area average over the equations of mass continuity and heat energy.

*Up to which resolution should the parameterization act in a model? No clear agreement.

Médias

- Os movimentos atmosféricos existem em várias escalas espaciais. Em um modelo numérico há processos resolvidos pela grade do modelo e outros processos “sub-grade”.

- Há necessidade de descrever os processos **resolvidos** pelo sistema de observações e aqueles **não-resolvidos** e designados por perturbação (“eddy”).

- Para identificar as propriedades estatísticas de um sistema, utiliza-se médias.

•1 Média no volume da grade (Grid-volume averaging):

$$\boxed{\phi = \overline{\phi} + \phi'}$$

Variável composta por uma média resolvida e uma perturbação

'–' se refere à média na grade do modelo

ϕ' perturbação subgrade

$$\boxed{\overline{\phi} = \int_t^{t+\Delta t}\int_x^{x+\Delta x}\int_y^{y+\Delta y}\int_z^{z+\Delta z} \phi\, dz\,dy\,dx\,dt \,/(\Delta t \Delta x \Delta y \Delta z)}$$

Δx, Δy, Δz são as dimensões da grade do modelo e Δt o passo de tempo.

$$\boxed{\overline{\overline{\phi}} = \overline{\phi}} \qquad \boxed{\overline{\phi'} = 0}$$

$$\boxed{\overline{\frac{\partial u}{\partial t}} = \frac{\partial \overline{u}}{\partial t}} \qquad \boxed{\overline{\frac{\partial u}{\partial x}} = \frac{\partial \overline{u}}{\partial x}}$$

$$\boxed{\overline{\phi' \overline{u}} = 0} \qquad \boxed{\overline{\phi' w'} \neq 0}$$

$$\overline{T' w'} \neq 0$$

A média do produto da correlação das perturbações resulta em valor diferente de zero!!

Equations of heat, moisture and continuity

$$\frac{\partial\bar{\theta}}{\partial t}+\overline{\nabla.\theta\mathbf{v}}+\frac{\partial\bar{\theta}\bar{w}}{\partial z}=\frac{Q_R}{c_p\bar{\pi}}+\frac{L}{c_p\bar{\pi}}(c-e)-\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}\overline{\theta`w`}$$

$$\frac{\partial\bar{q}}{\partial t}+\overline{\nabla.q\mathbf{v}}+\frac{\partial\overline{qw}}{\partial z}=-(c-e)-\frac{1}{\bar{\rho}}\frac{\partial}{\partial z}\bar{\rho}\overline{q`w`}$$

$$\overline{\nabla.\mathbf{v}}+\frac{\partial\bar{w}}{\partial z}=0$$

These subgrid terms need to be parameterized because their effects contribute to model grid scale

The vertical eddy fluxes are due mainly to the cumulus convection and turbulent motions in the boundary layer.

Effects of cumulus convection on large scale thermodynamic fields

$$Q_1 \equiv \frac{\partial \bar{s}}{\partial t} + \bar{v} \bullet \nabla \bar{s} + \bar{\omega} \frac{\partial \bar{s}}{\partial p} = Q_R + L(\bar{c} - \bar{e}) - \nabla . \overline{s'v'} - \frac{\partial}{\partial p} \overline{s'\omega'}$$

Q_1: Apparent Heat source

$$Q_2 \equiv -L\left(\frac{\partial \bar{q}}{\partial t} + \bar{v} \bullet \nabla \bar{q} + \bar{\omega} \frac{\partial \bar{q}}{\partial p} \right) = L(\bar{c} - \bar{e}) + L\nabla . \overline{q'v'} + L \frac{\partial}{\partial p} \overline{q'\omega'}$$

Q_2: Apparent Moisture sink

Assume horizontal fluxes are negligible compared to vertical fluxes

$$\boxed{Q_1 - Q_R - Q_2 = -\frac{\partial}{\partial p} \overline{h'\omega'}}$$

Eddy (sensible and latent) heat fluxes
h is the moist static energy

$$\frac{c_p}{g} \int_{p_t}^{p_s} (Q_1 - Q_R) dp = LP + H_s$$

Verify against sfc observations

$$\frac{c_p}{g} \int_{p_t}^{p_s} Q_2 dp = L(P - E)$$

Yanai et al., 1973
Yanai and Johnson, 1993
Fig 4.1, Fig 4.3, F4.17

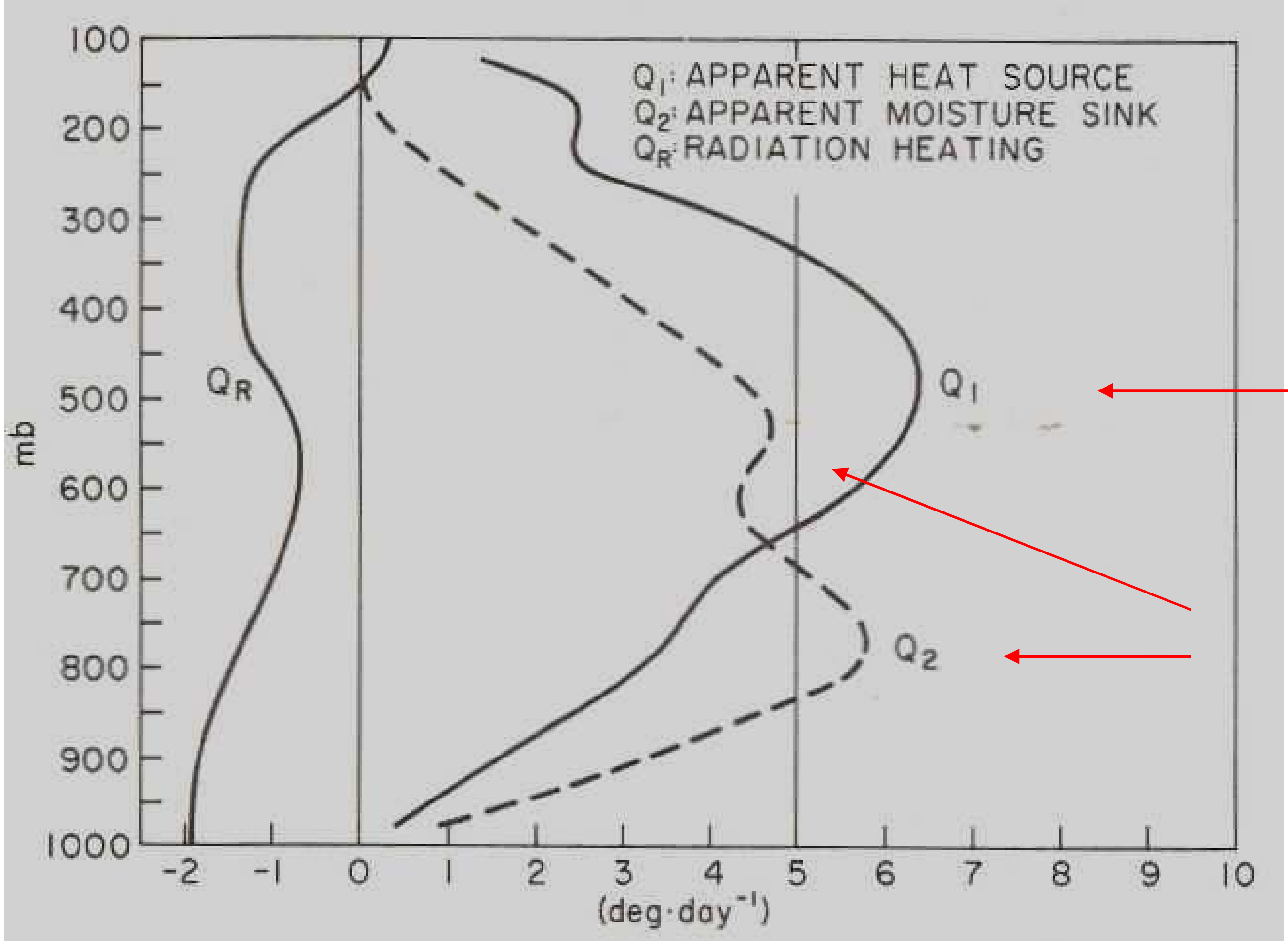


FIG. 4.1. The mean apparent heat source Q_1 (solid) and moisture sink Q_2 (dashed) over the Marshall Islands. On the left is the radiational heating rate given by Dopplick (1972) (from Yanai et al. 1973).

~5°C/dia,
~400-500 hPa

~4°C/dia,
~500 hPa,
~800 hPa

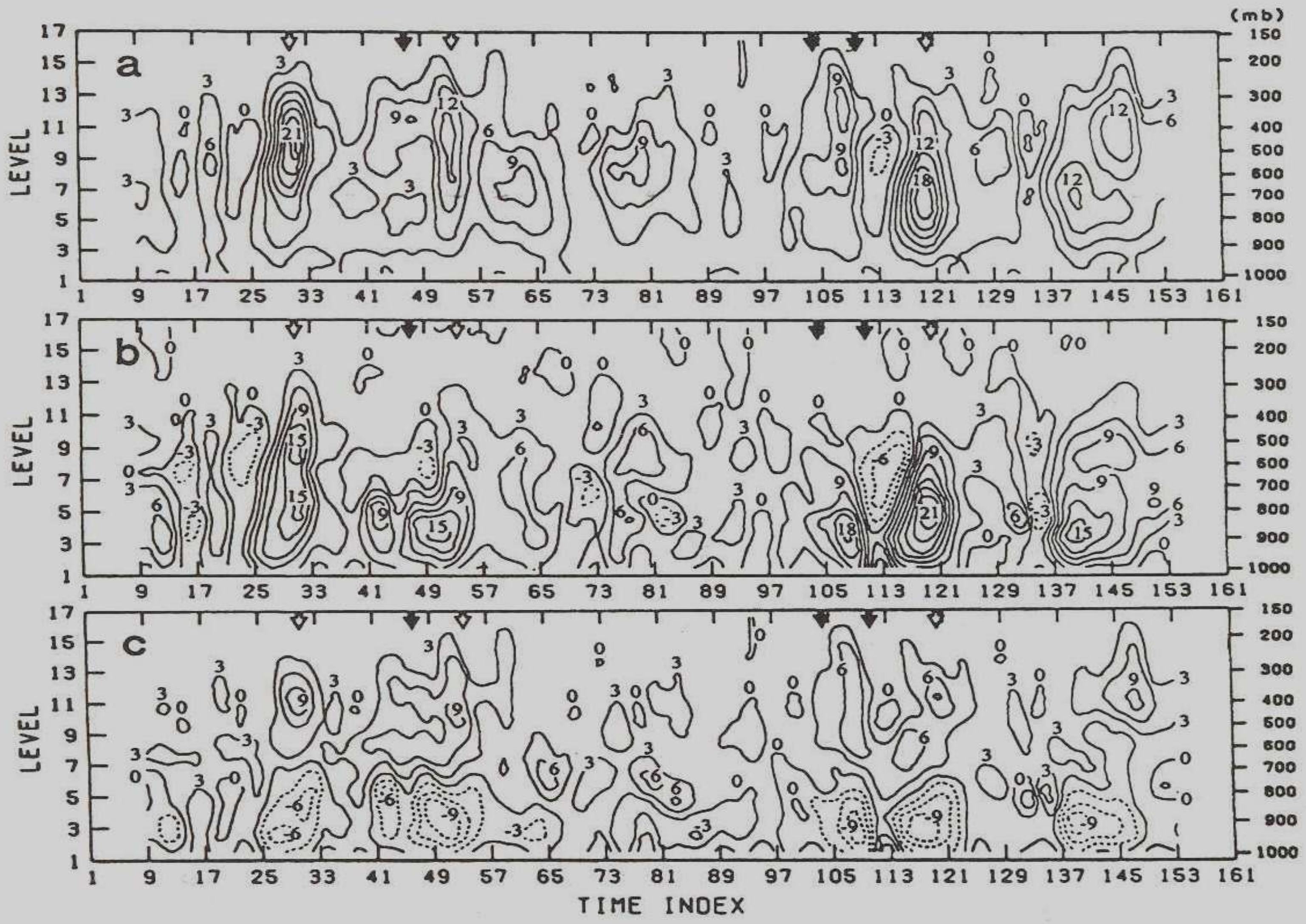


FIG. 4.3. Time–height sections of the observed (a) $Q_1 - Q_R$, (b) Q_2, and (c) $Q_1 - Q_2 - Q_R$, averaged over the 3° × 3° area at the center of the GATE network during a period from 0000 UTC 31 August (index 9) to 0000 UTC 18 September 1974 (index 153). Units are kelvins per day (from Cheng and Yanai 1989).

Q_1

Q_2

Q_1-Q_2-Q_R

warming

cooling

$$\boxed{Q_1 - Q_R - Q_2 = -\frac{\partial}{\partial p}\overline{h'\omega'}}$$

Downward motion

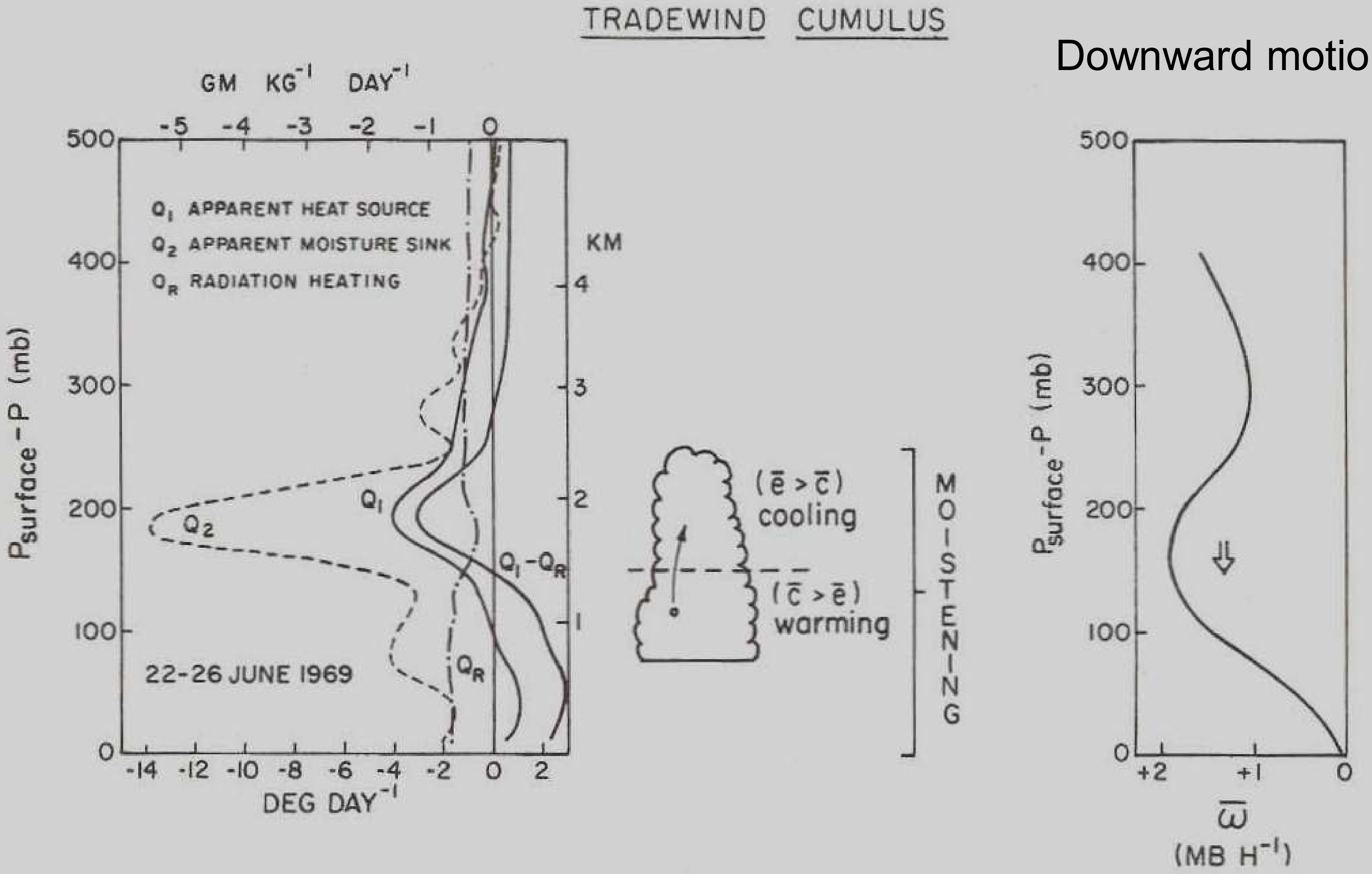


FIG. 4.17. (Left) The observed Q_1, Q_2, Q_R, and $Q_1 - Q_R$ for the undisturbed BOMEX period 22–26 June 1969 (from Nitta and Esbensen 1974). (Center) Schematic of trade-wind cumulus layer showing effects of condensation and evaporation on the heat and moisture budgets. (Right) Mean vertical p velocity $\bar{\omega}$ over budget area.

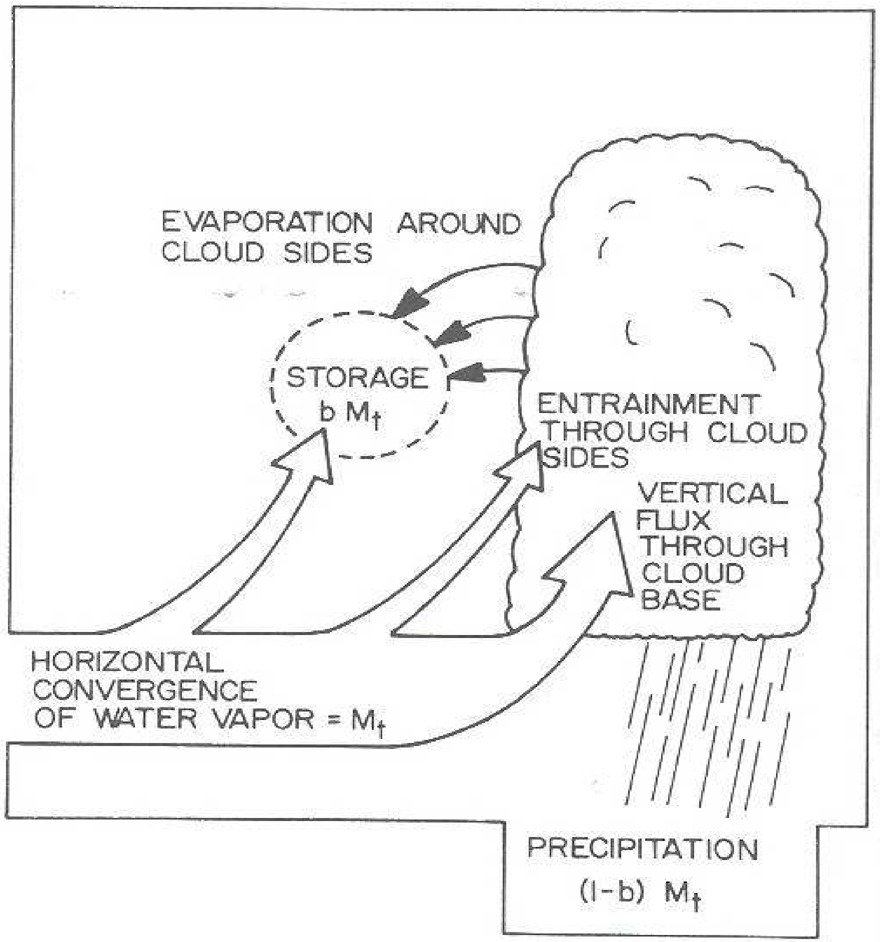
Types of convective scheme:

Adjustment: Betts-Miller (1986), Janjic (1994)

Kuo: Kuo (1974)

Mass-flux: Arakawa-Schubert (1974), Fritsch-Chappell (1980), Tiedtke (1989), Grell, Kain-Fritsch (1993)

The Kuo Convective Parameterization Scheme



Betts-Miller-Janjic Scheme

- The Betts-Miller scheme (Betts and Miller, 1986) uses reference profiles of T and q to relax the model profiles in convective unstable conditions. Profiles derived from campaigns GATE, VIMEX, etc

- The reference T and q profiles are based on observational studies of convective equilibrium in the tropics.

- Treats deep and shallow convection.

- (Modification by Janjic, 1994)

1. Determine type of cloud

- Parcel lift: determine cloud base and cloud top
- Check: cloud depth > 290 hPa: deep convection, else shallow convection.

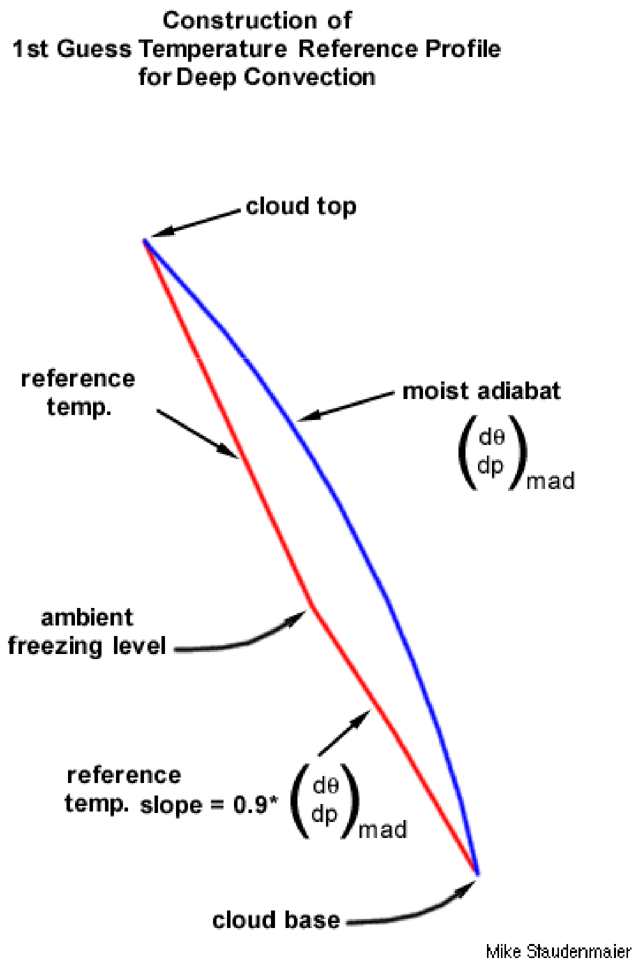
2. Determine reference profiles

$$\int_{base}^{top} (c_p \Delta T - L\Delta q) = 0$$

Make sure enthalpy is conserved

Deep Convection

Temperature Reference Profile



To draw the temperature profile 3 levels are important:

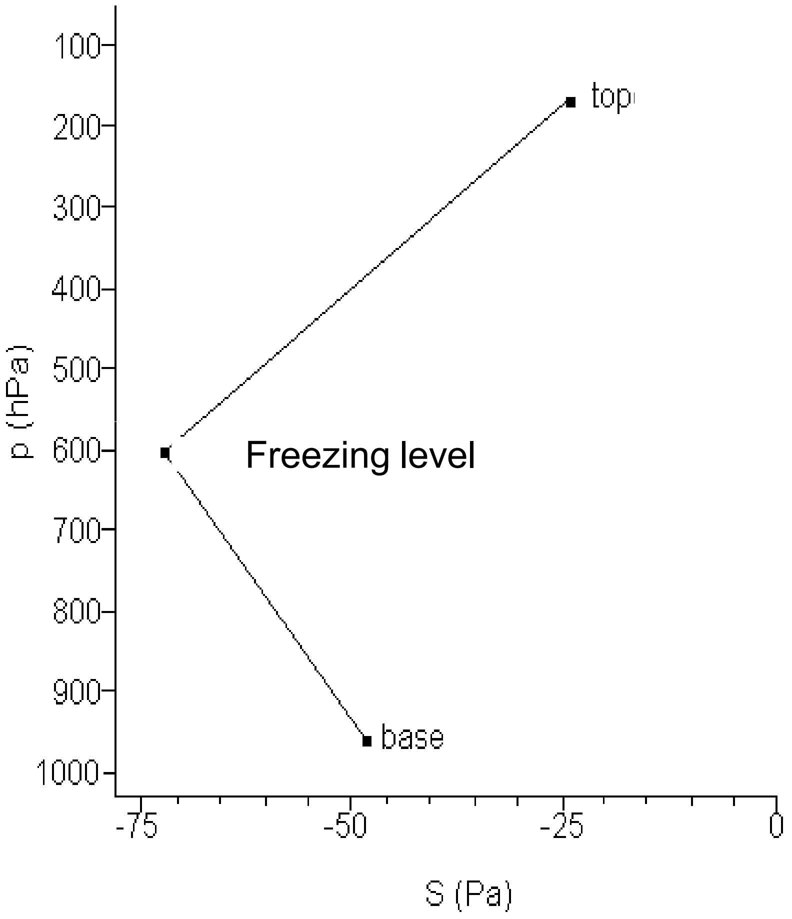
- cloud base
- freezing level
- cloud top

Some instability is left in the lower part of the cloud.

Profile is linearly interpolated from the freezing level to the cloud top

Deep Convection

Moisture Reference Profile



DSP= p_{sat} - p

Deficit saturation pressure (DSP) is defined at the 3 levels.

•cloud base:	DSPb
•freezing level:	DSP0
•cloud top:	DSPt

Values are linearly interpolated between the levels

$$T_{new} = T_{old} + \frac{\Delta t_{cnv}}{\tau}\left[T_{ref} - T\right]$$

$$q_{new} = q_{old} + \frac{\Delta t_{cnv}}{\tau}\left[q_{ref} - q\right]$$

$$\Delta t_{cnv} = 4 * \Delta t$$

$$\tau = 3000s$$

$$P = \frac{1}{\rho_w g}\frac{\Delta t_{cnv}}{\tau}\sum_{base}^{top}(q_{ref} - q)(p_s - p_t)$$

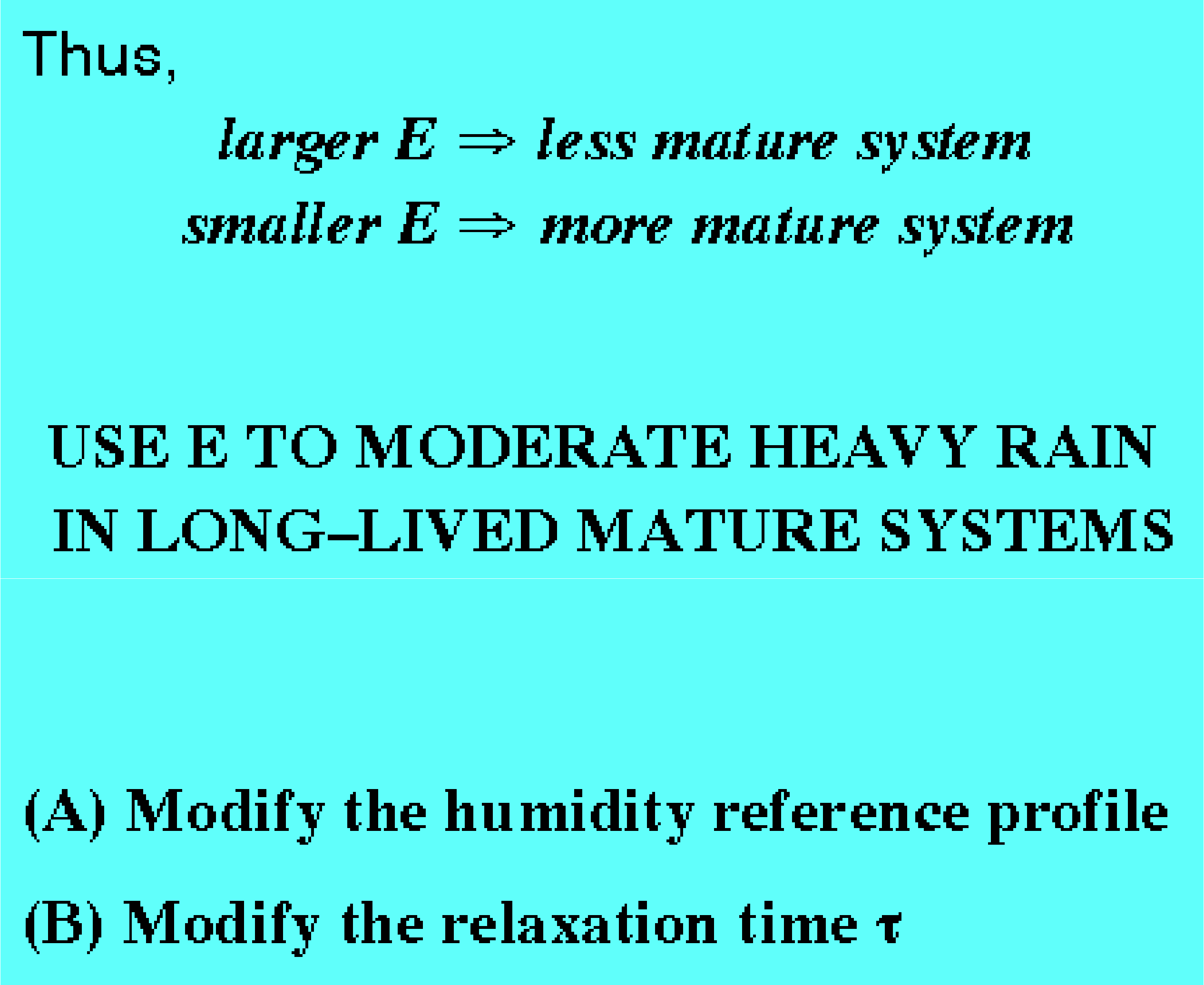
1. Cloud Eficiency

- Eficiency related to the precipitation production
- Proportional to the cloud column "entropy" change, per unit precipitation produced.
- Eficiency varies from 0.2 to 1.0
- Modifies reference profiles
- Modifies relaxation time

$$\tau' = \frac{\tau}{F(E)}$$

$$F(E)\ is\ linear$$

$$0.7 \le F \le 1.0\ for\ 0.2 \le E \le 1.0$$



Thus,

larger E ⇒ less mature system

smaller E ⇒ more mature system

USE E TO MODERATE HEAVY RAIN IN LONG–LIVED MATURE SYSTEMS

(A) Modify the humidity reference profile

(B) Modify the relaxation time τ

$$T_{new} = T_{old} + \frac{\Delta t_{cnv}}{\tau}\left[T_{ref} - T_{old}\right] F(E)$$

$$q_{new} = q_{old} + \frac{\Delta t_{cnv}}{\tau}\left[q_{ref} - q_{old}\right] F(E)$$

$$OR$$

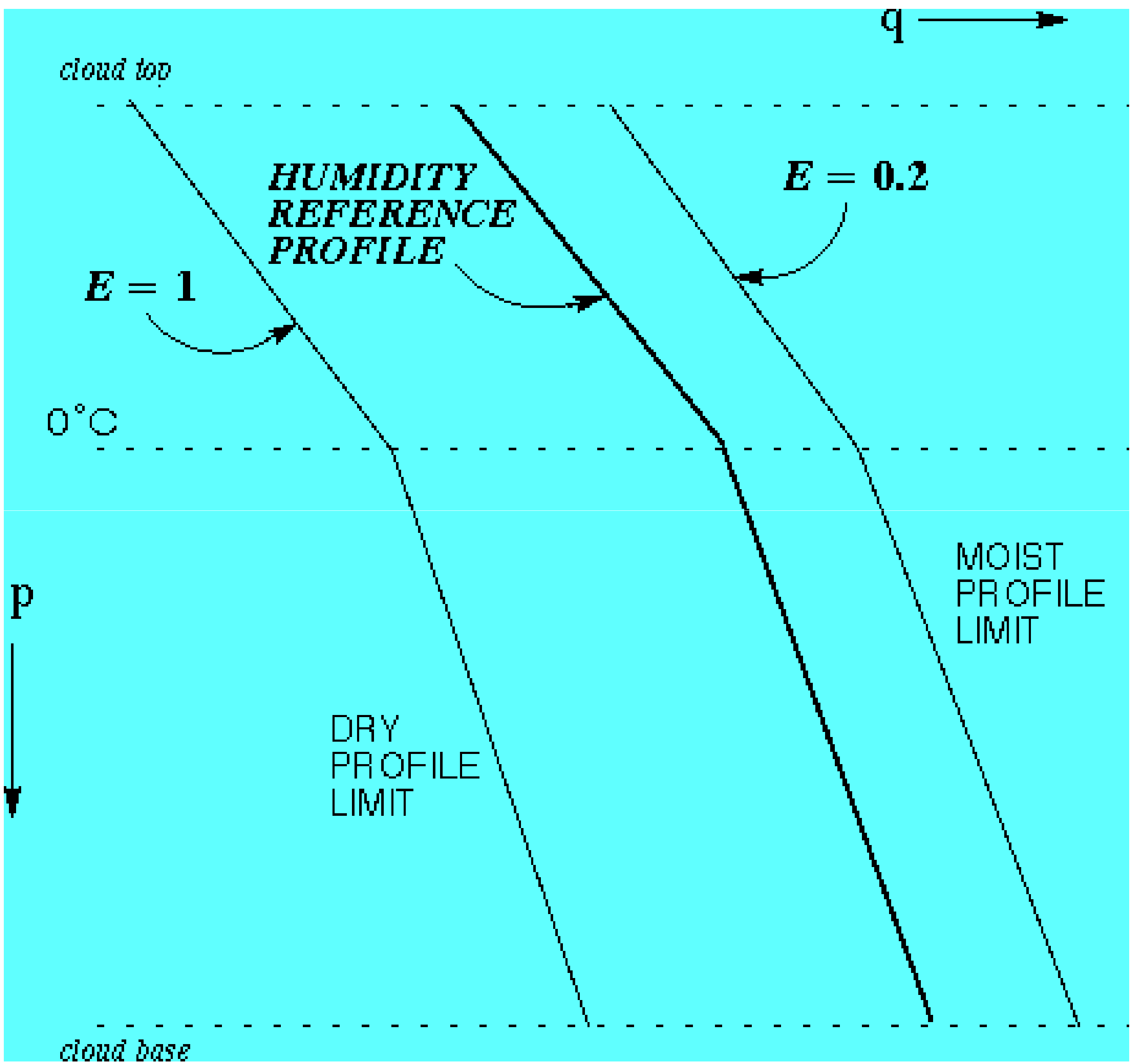
$$T_{new} = T_{old} + \frac{\Delta t_{cnv}}{\tau'}\left[T_{ref} - T_{old}\right]$$

$$q_{new} = q_{old} + \frac{\Delta t_{cnv}}{\tau'}\left[q_{ref} - q_{old}\right]$$

where

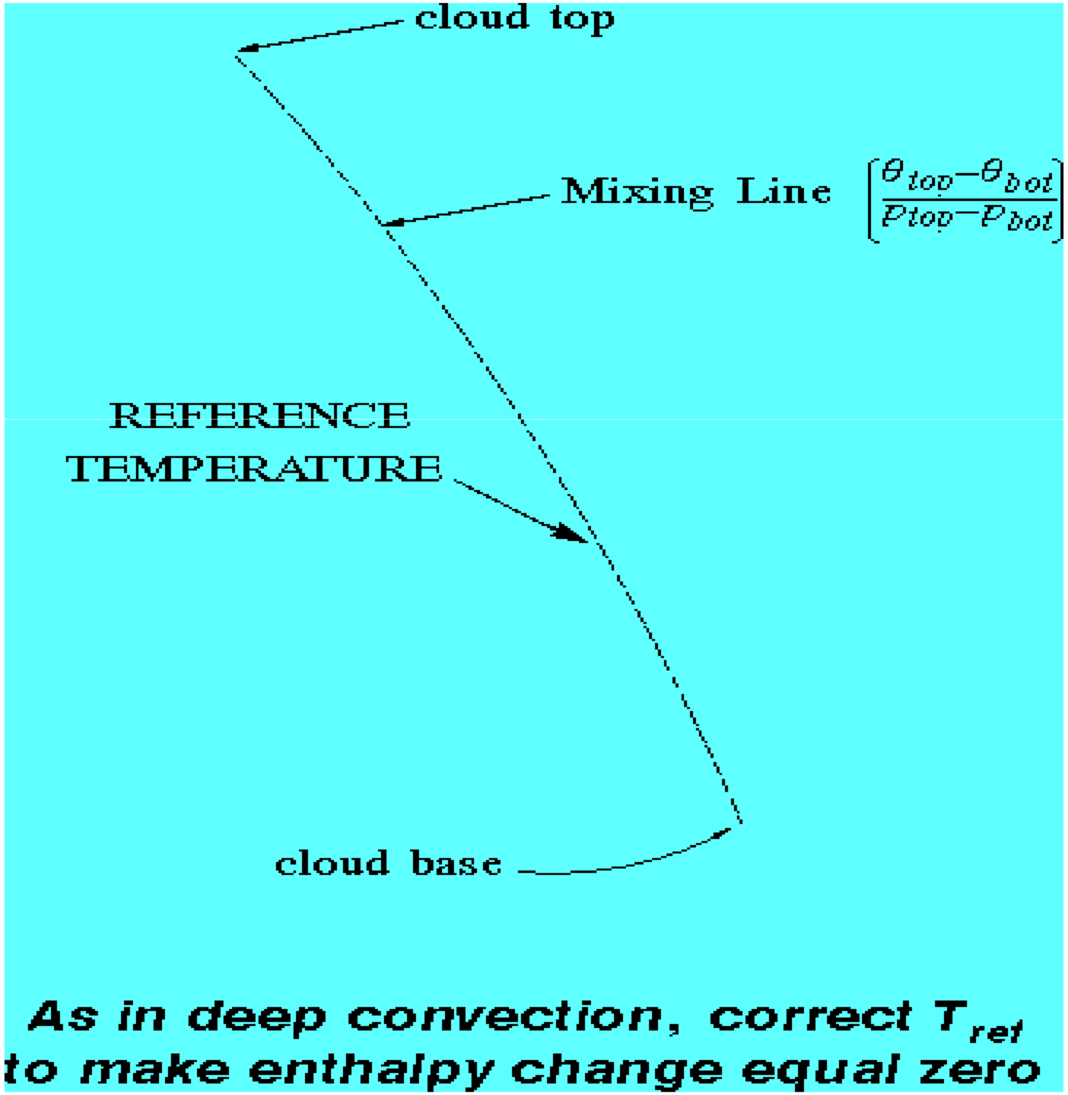
$$\tau' = \frac{\tau}{F(E)}$$

Fefi, fss


q
cloud top
HUMIDITY
REFERENCE
PROFILE
E = 0.2
E = 1
0°C
MOIST
PROFILE
LIMIT
p
DRY
PROFILE
LIMIT
cloud base

Shallow Convection

Temperature Reference Profile



As in deep convection, correct T_{ref} to make enthalpy change equal zero

- Applied to points where cloud depth is larger than 10hPa and smaller than 290hPa
- At least two layers
- swap points:
  - precipitation < 0
  - entropy change < 0

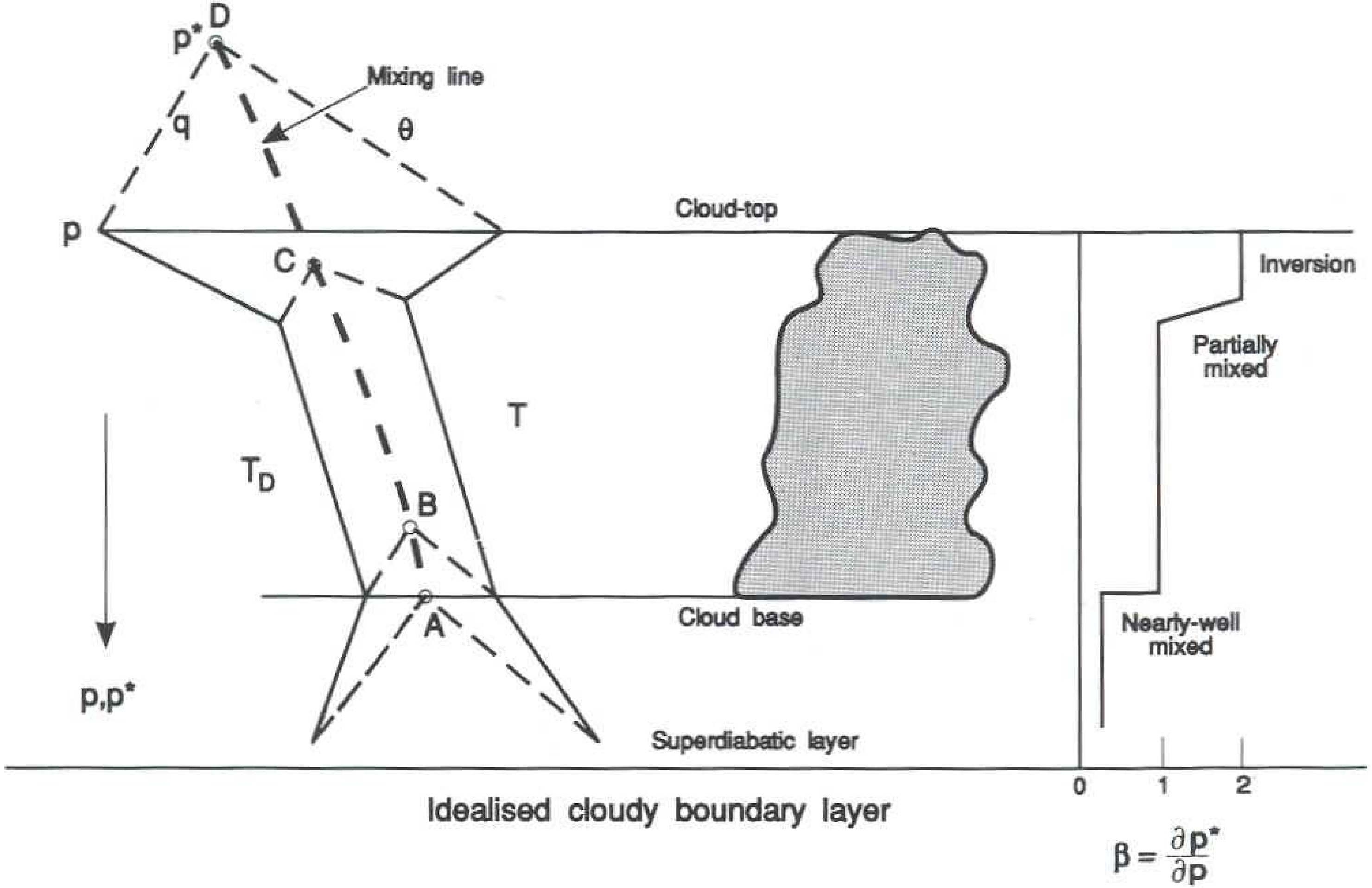


FIG. 9.1. Relationship between mixing line, temperature, and dewpoint, and a mixing parameter β for an idealized convective boundary layer. The light dashed lines are lines of constant potential temperature θ and mixing ratio q (from Betts 1986).

There are two stratagems to reducing the model's ability to do heavy convection.

If the model wishes to rain hard while changing the environment not too much, efficiency will be low.
The code limits E to be between 0.2 and 1.

1. Reduce the relaxation time
2. FSS: Slow profiles or wet profiles

fss = factor multiplying dsp’s over sea
fefi = function of cloud efficiency

fss = factor multiplying dsp’s over sea
fefi = function of cloud efficiency

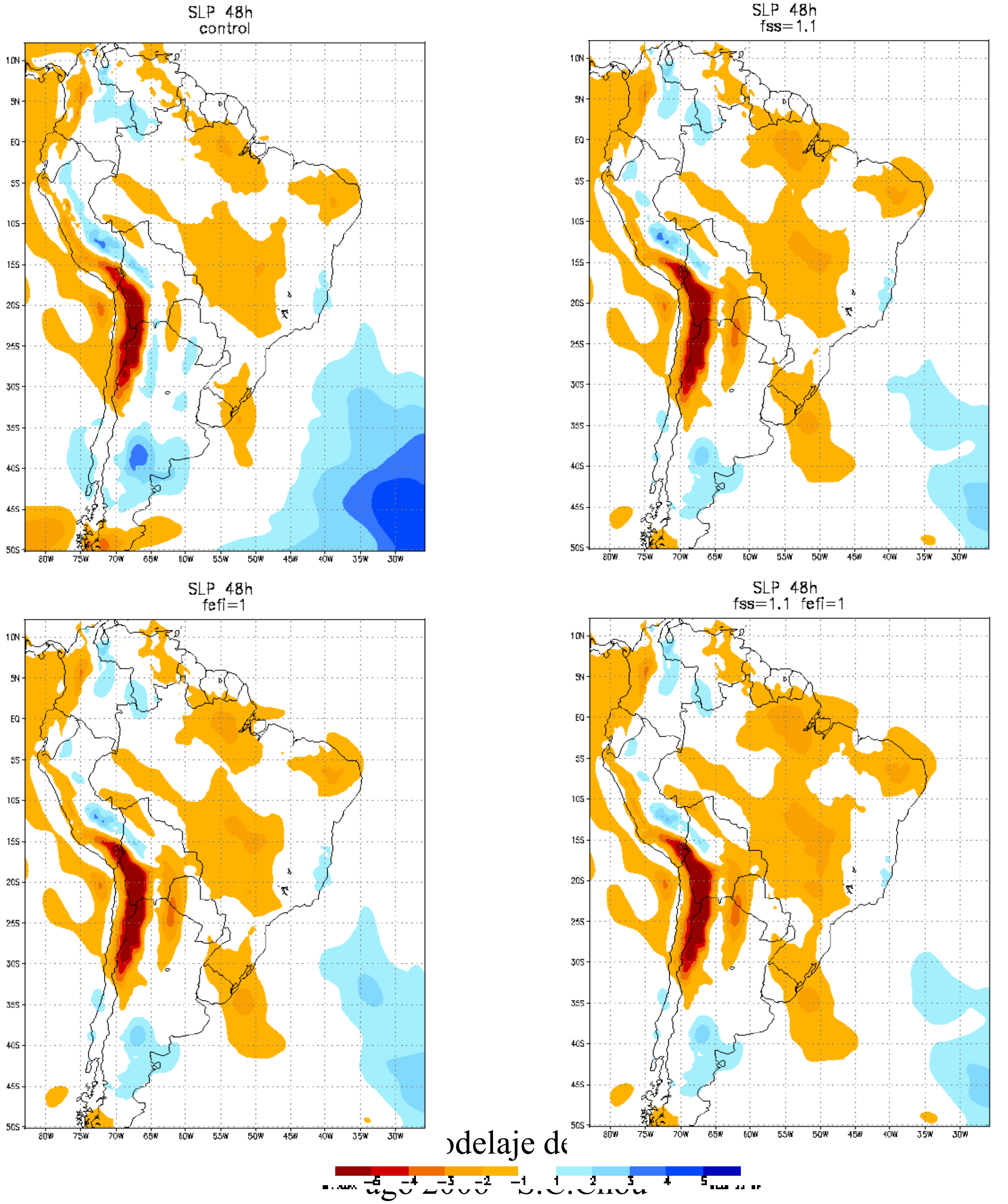
Experiments	
Control	fss=0.85 and fefi= f(E)
Exp. 1	fss=1.1 and fefi= f(E)
Exp. 2	fss=0.85 and fefi=1
Exp. 3	fss=1.1 and fefi=1

Period: 20/01/2002 to 30/01/2002

Where E is the parameter called Cloud Efficiency

Control

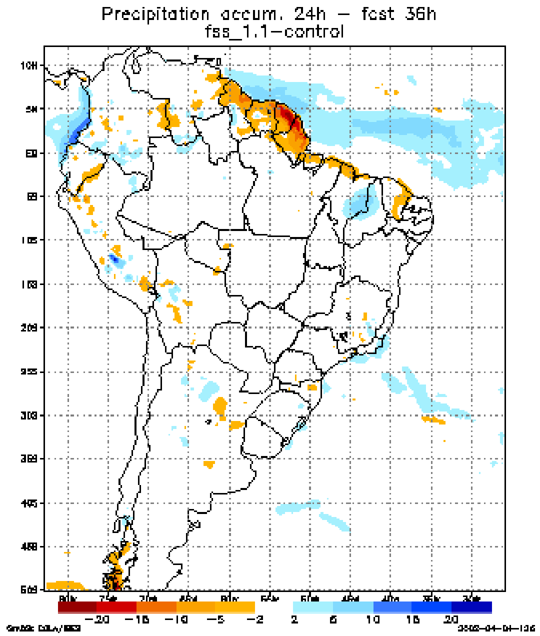
Exp. 1

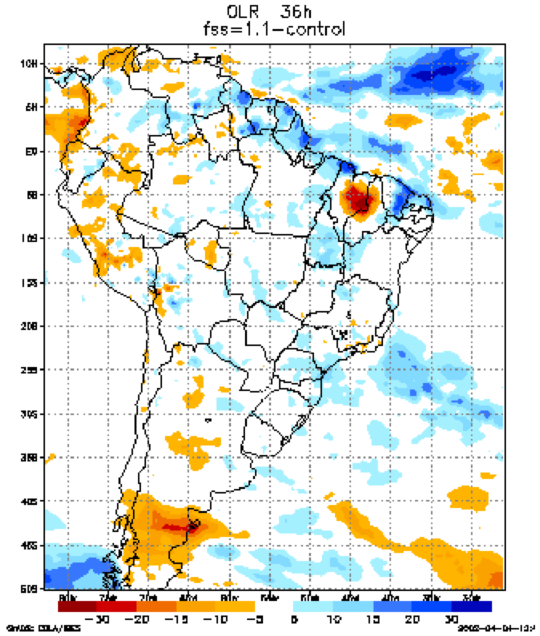


Exp. 2

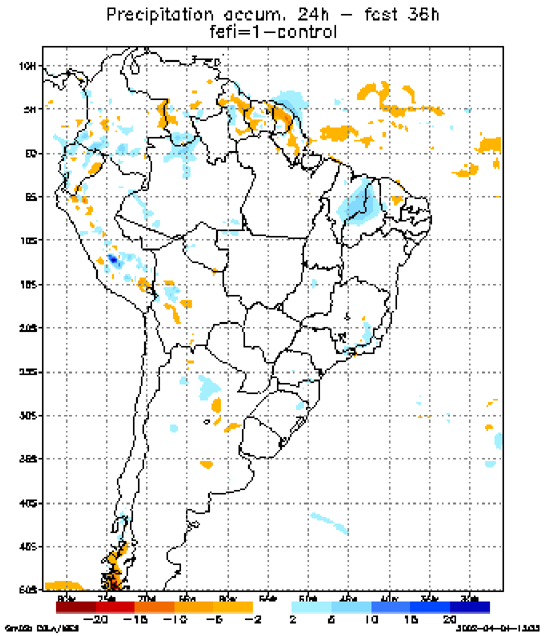
Exp. 3

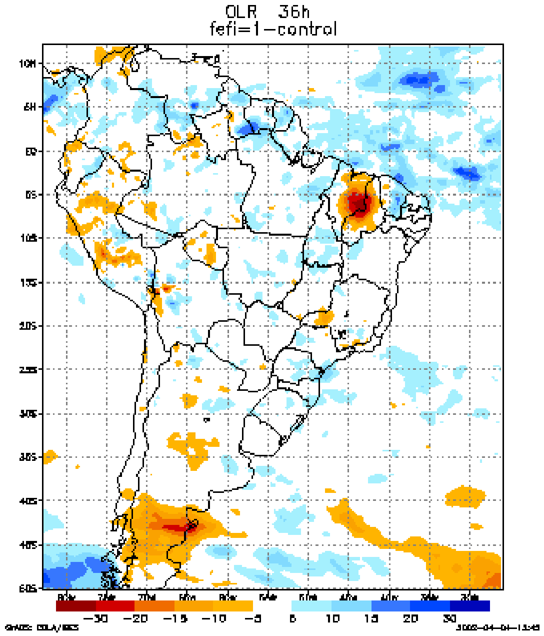
Exp. 1



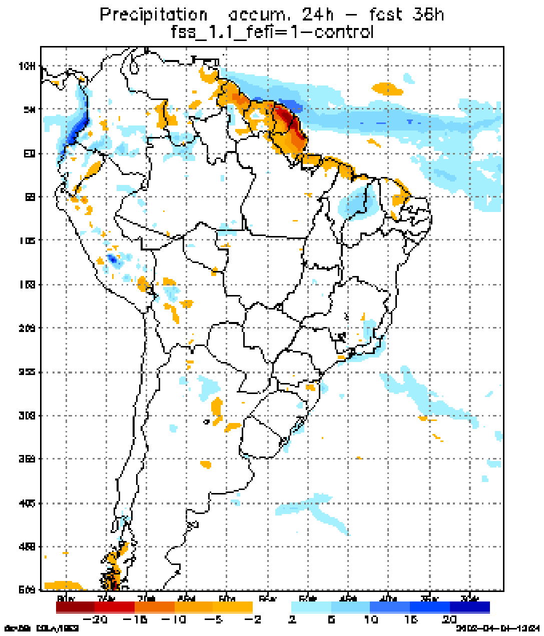


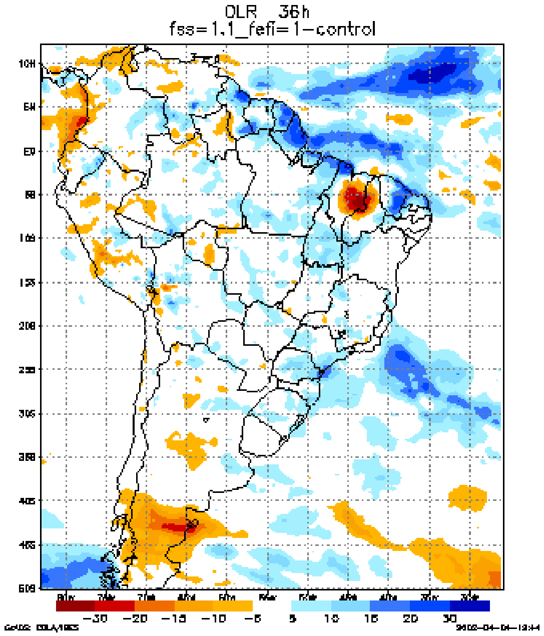
Exp. 2





Exp. 3





•Enhanced ITCZ rain, but had small impact on extratropical rain.

•Reduced positive bias in extratropical SLP, but increased slightly in the tropics.

•Reduced errors in the 250 mb zonal wind in the extratropics.