The Abdus Salam
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Energy Agency

Spring Colloquium on
'Regional Weather Predictability and Modeling'
April 11 - 22, 2005

1) Workshop **on Design and Use of Regional Weather Prediction Models,** *April 11 - 19*

2) Conference on **Current Efforts Toward Advancing the Skill of Regional Weather Prediction. Challenges and Outlook,** *April 20 - 22*

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Cumulus Parameterization

Sin Chan Chou
CPTEC/INPE
Brazil

Strada Costiera 11, 34014 Trieste, Italy - Tel. +39 040 2240 111; Fax +39 040 224 163 - sci_info@ictp.it, www.ictp.it

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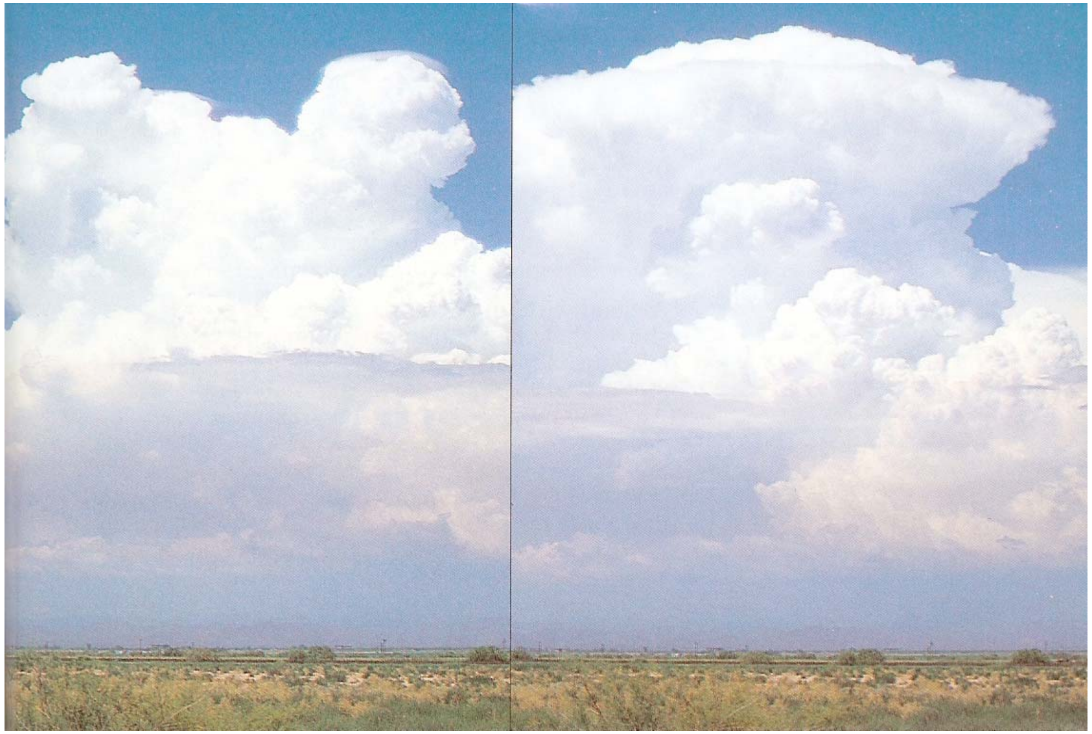
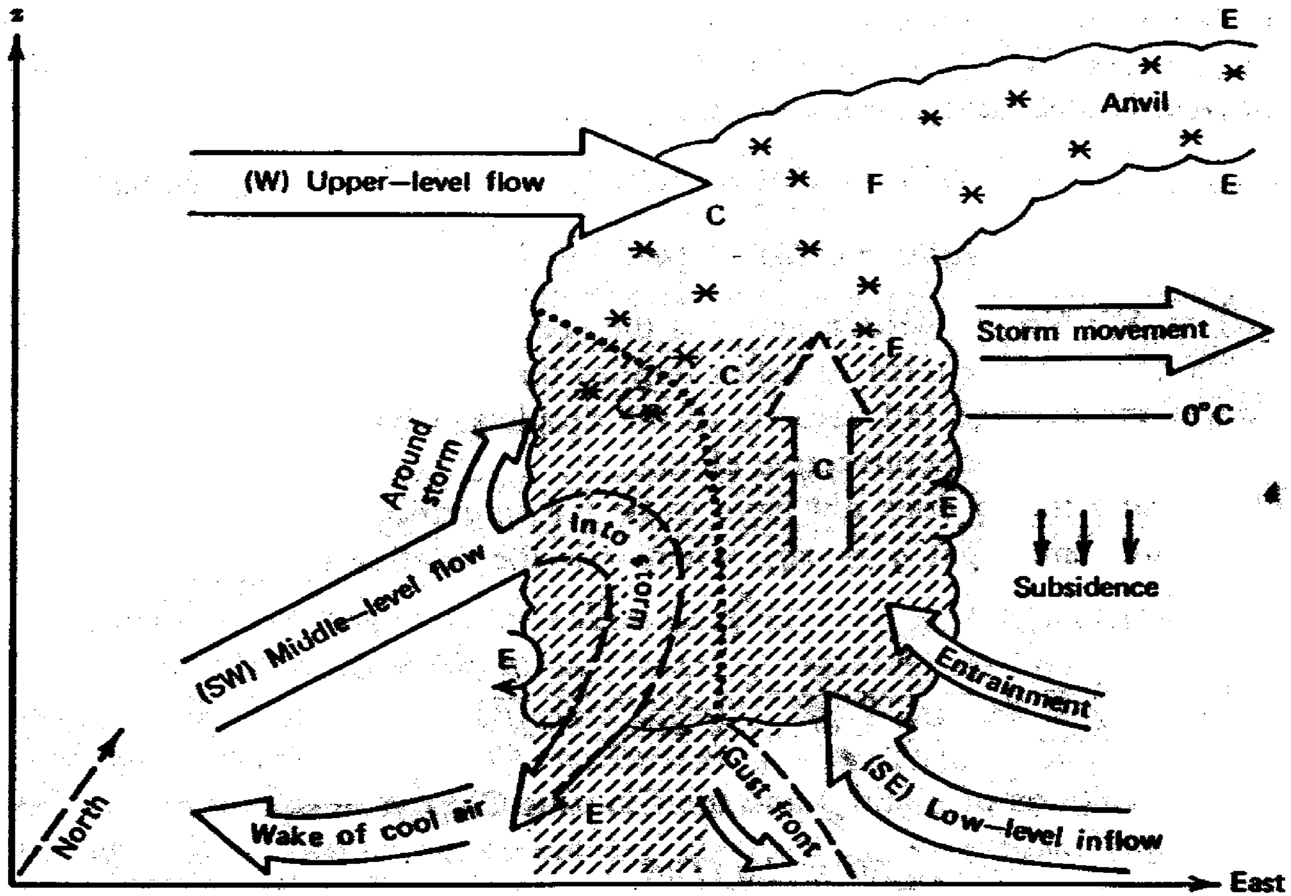
Sin Chan Chou

CPTEC/INPE
chou@cptec.inpe.br

CUMULUS CLOUDS

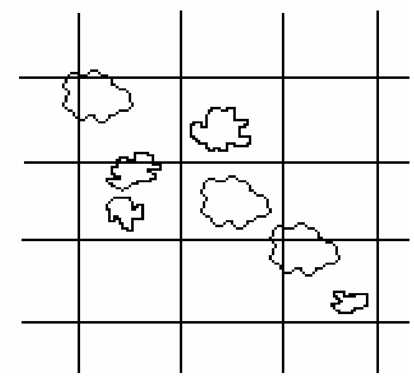


CUMULUS PARAMETERIZATION



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.

General assumption:

- This area is assumed to be large enough to contain the cluster or the ensemble of clouds, but still regarded as a small fraction of the large scale model, the grid size.

Parameterization effect:

- Model temperature and moisture profiles are altered by scheme due to the parameterized convective fluxes and precipitation.

Equations of heat, moisture and continuity

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

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

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

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

Therefore the contributions from the cumulus convection to the large scale moisture and heat are:

$$\left(\frac{\partial\overline{\theta}}{\partial t}\right)_{cu} = -\frac{1}{\overline{\rho}}\frac{\partial}{\partial z}\overline{\rho}\,\overline{\theta^{`}w^{`}} + \frac{L}{c_p\overline{\pi}}(c-e)$$

$$\left(\frac{\partial\overline{q}}{\partial t}\right)_{cu} = -\frac{1}{\overline{\rho}}\frac{\partial}{\partial z}\overline{\rho}\,\overline{q^{`}w^{`}} - (c-e)$$

Cumulus parameterization schemes are designed to represent the convective fluxes and the associated condensation or evaporation.

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)

Convective adjustment

•Large scale precipitation, sometimes called stratiform precipitation, can be considered a type of convective adjustment in the sense that the environment profile is adjusted to a near-saturated state under stable conditions to convection.

•Every grid point is checked for supersaturation and when this occurs, the adjustments, δT and δq, are calculated for a near saturated condition by solving iteratively the system:

$$-L\delta q = c_p \delta T$$

$$q + \delta q = q_s(T + \delta T, p)$$

• the adjustments are applied level by level.

Betts-Miller-Janjic

- The Betts-Miller scheme (Betts and Miller, 1986) uses reference profiles of T and q to relax the model profiles in convective unstable conditions.

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

- Treats deep and shallow convection:

1. Determine type of cloud

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

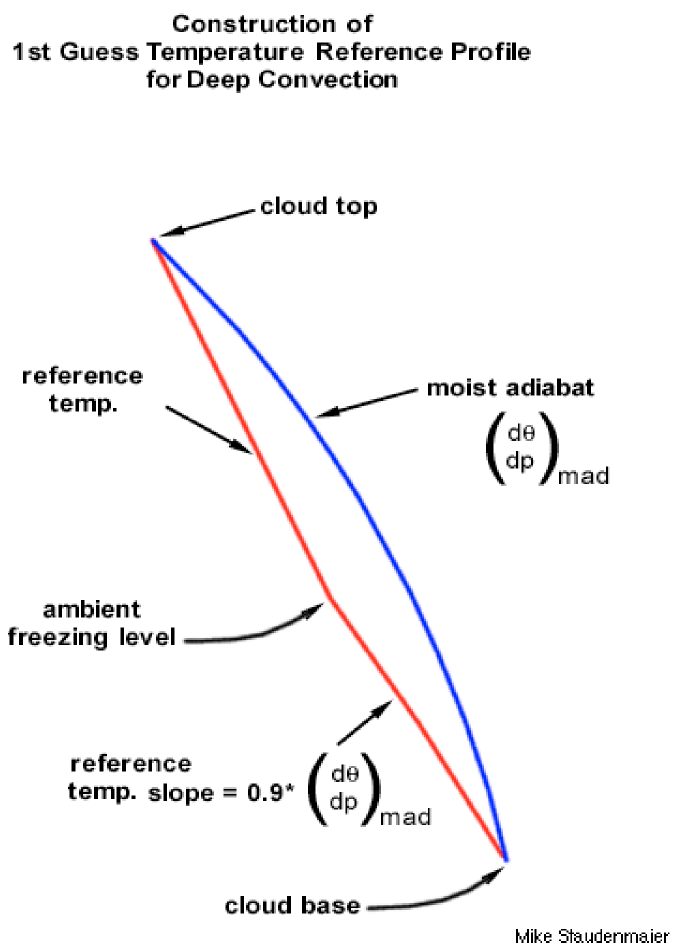
2. Determine reference profiles

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

Make sure enthalpy is conserved

Deep Convection

Temperature Reference Profile



To draw the temperature profile 3 levels are important:

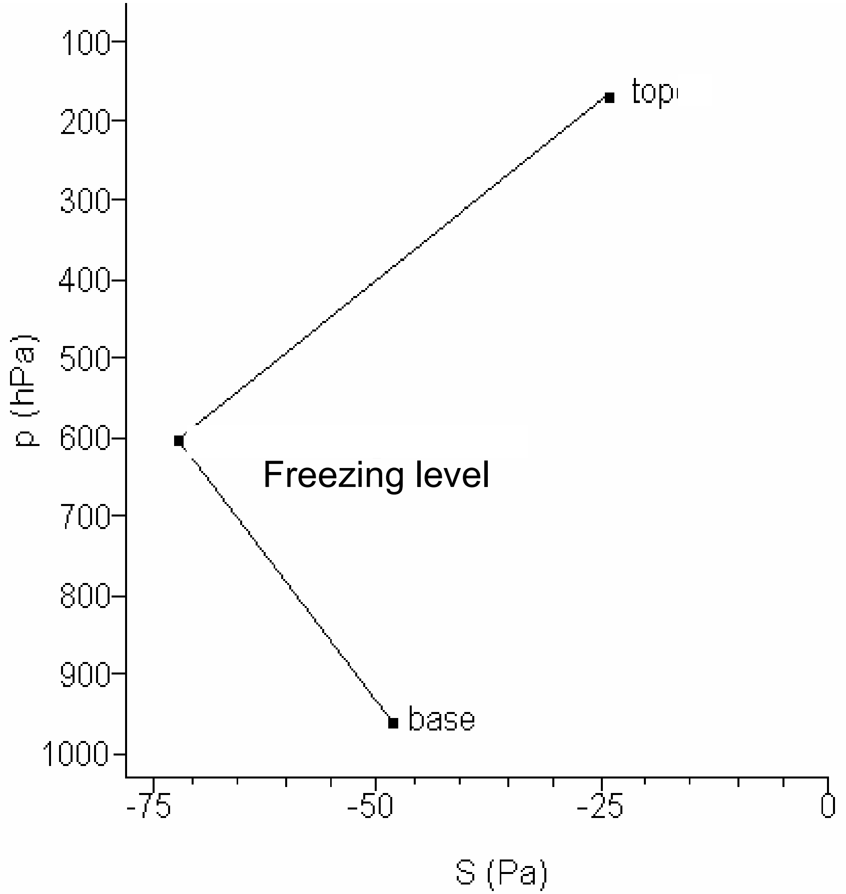
- cloud base
- freezing level
- cloud top

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_s - 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

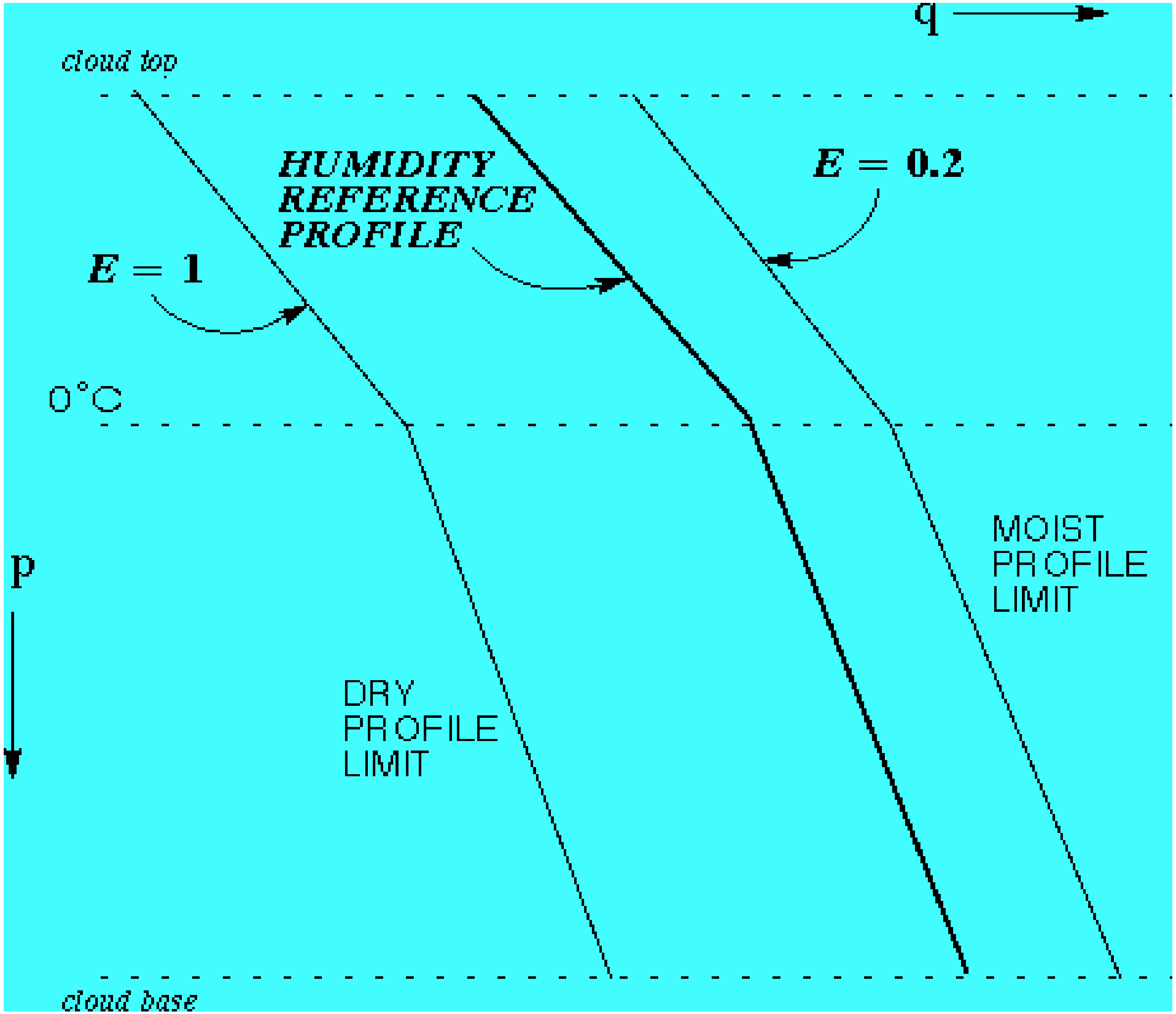
- Eficiency related to the precipitation production
- Dependent on cloud entropy.
- Eficiency varies from 0.2 to 1.0
- Modifies reference profiles
- Modifies relaxation time

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

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

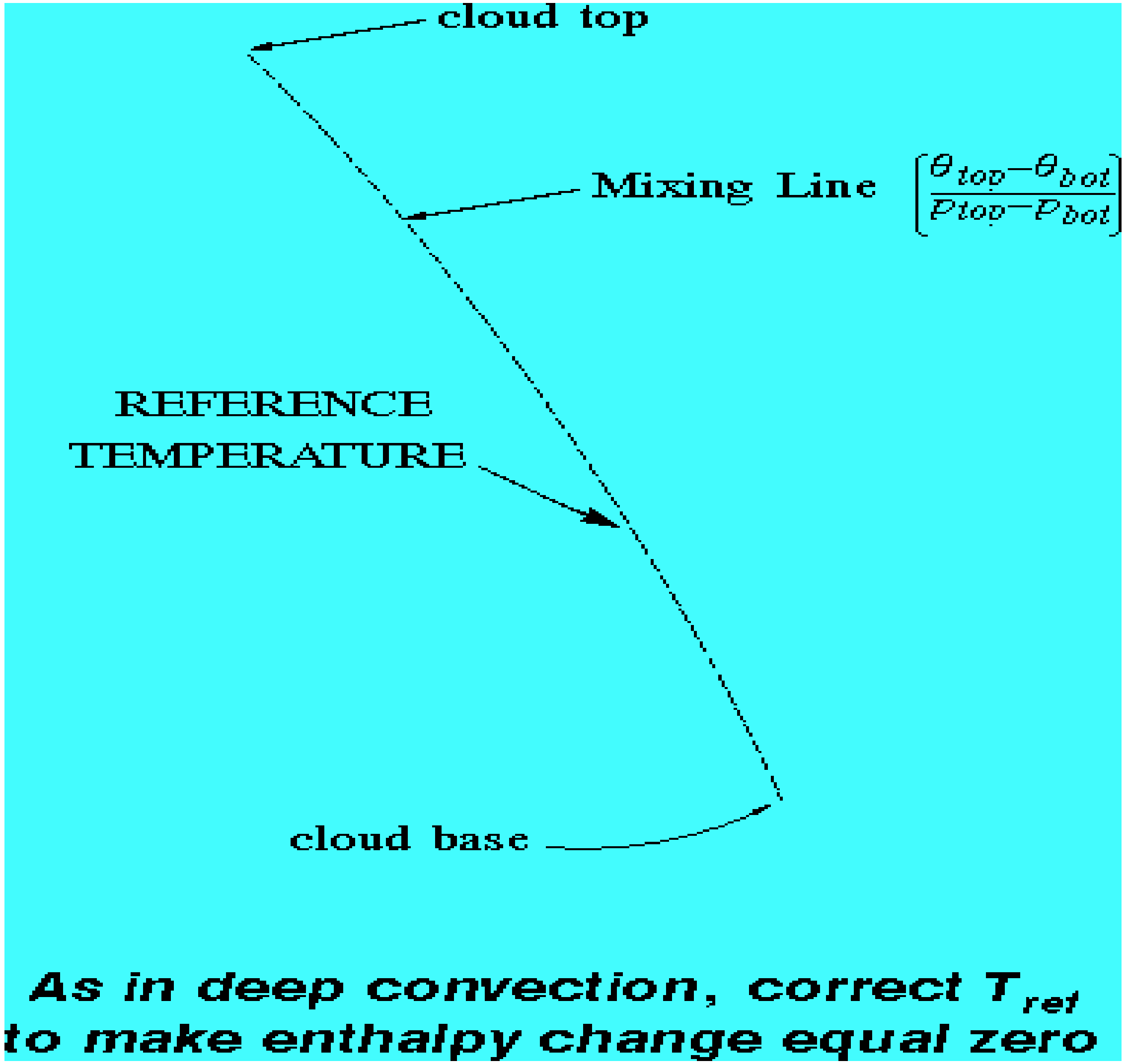
$$0.7 \le F \le 1.0 \;\; for \;\; 0.2 \le E \le 1.0$$

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

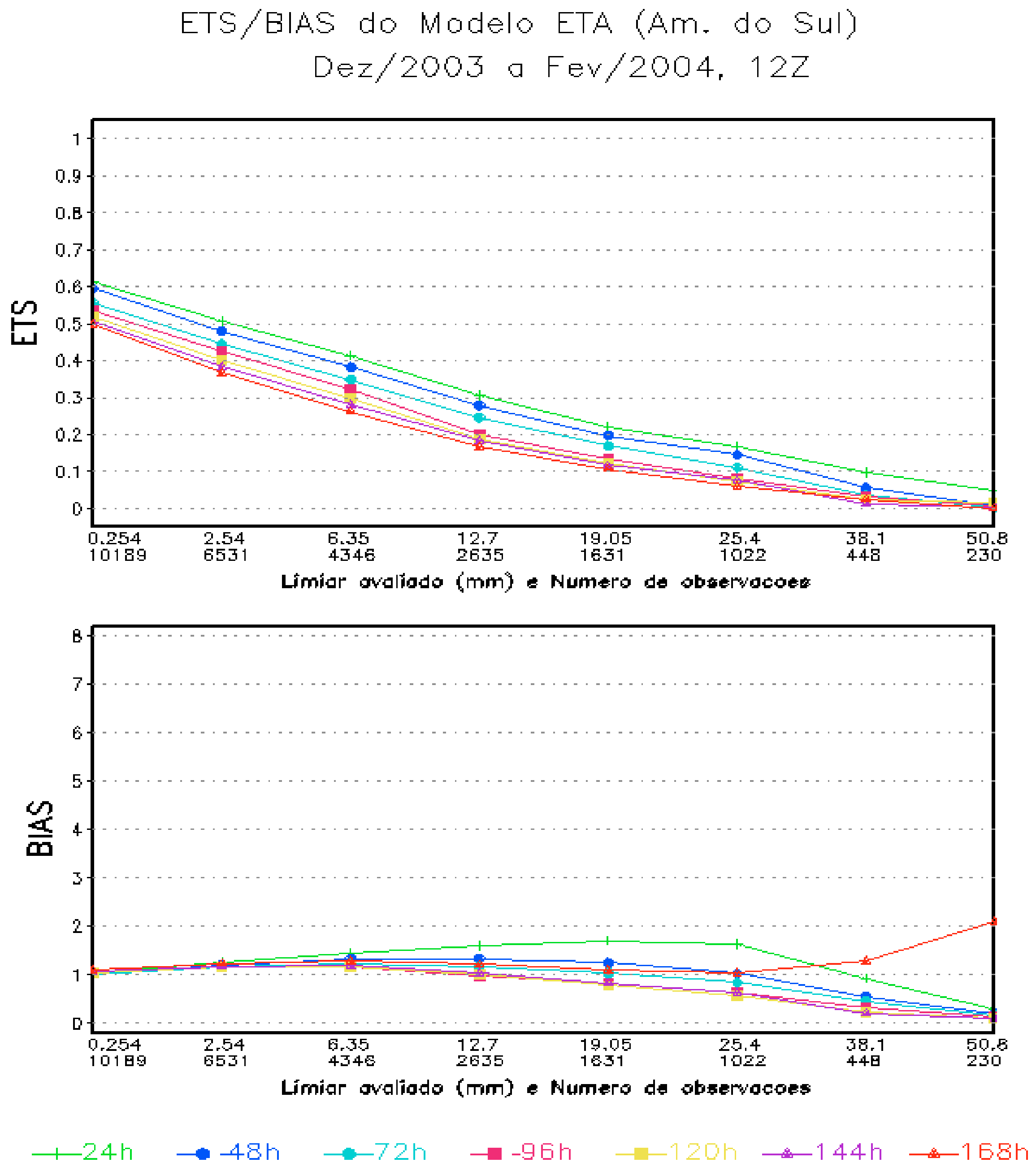


- Applied to points where cloud depth is larger than 10hPa and smaller than 290hPa
- At least two layers
- swap points: negative precipitation and entropy in deep convection points.

$$ETS = \frac{H - CH}{F + O - H - CH}$$

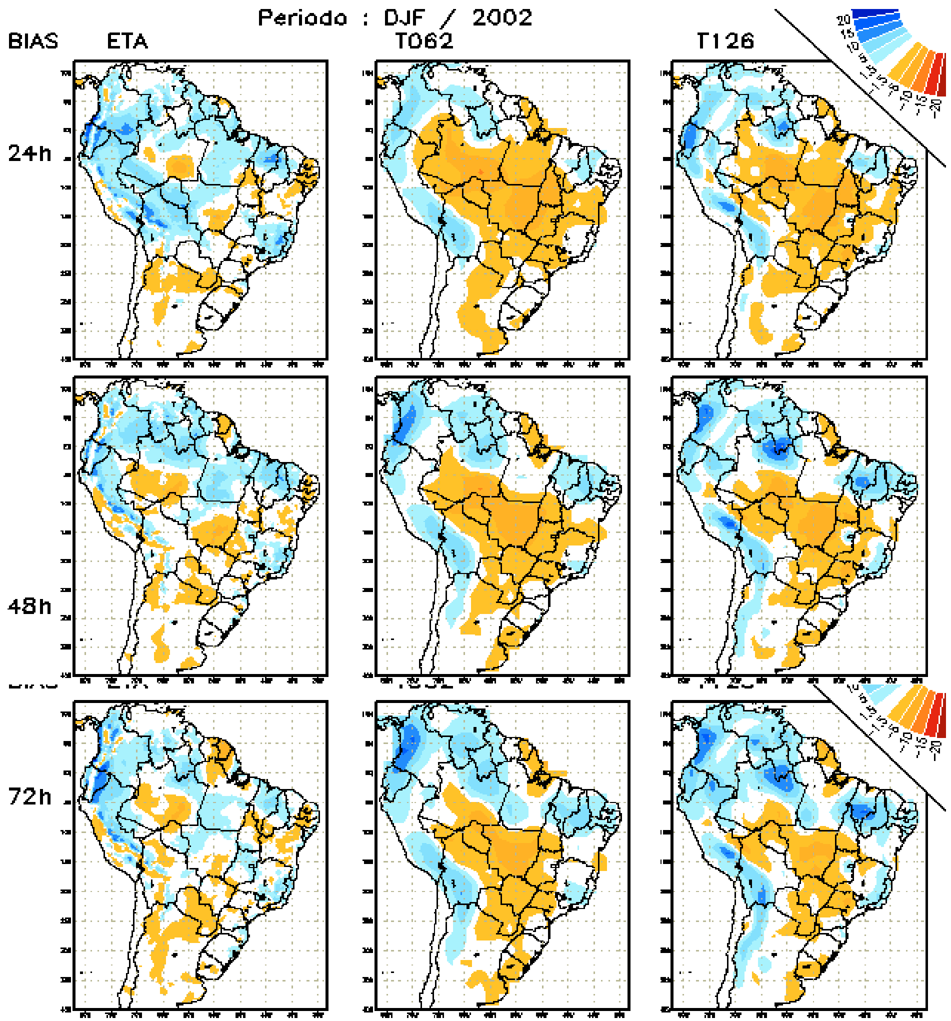
$$CH = \frac{F \times O}{N}$$

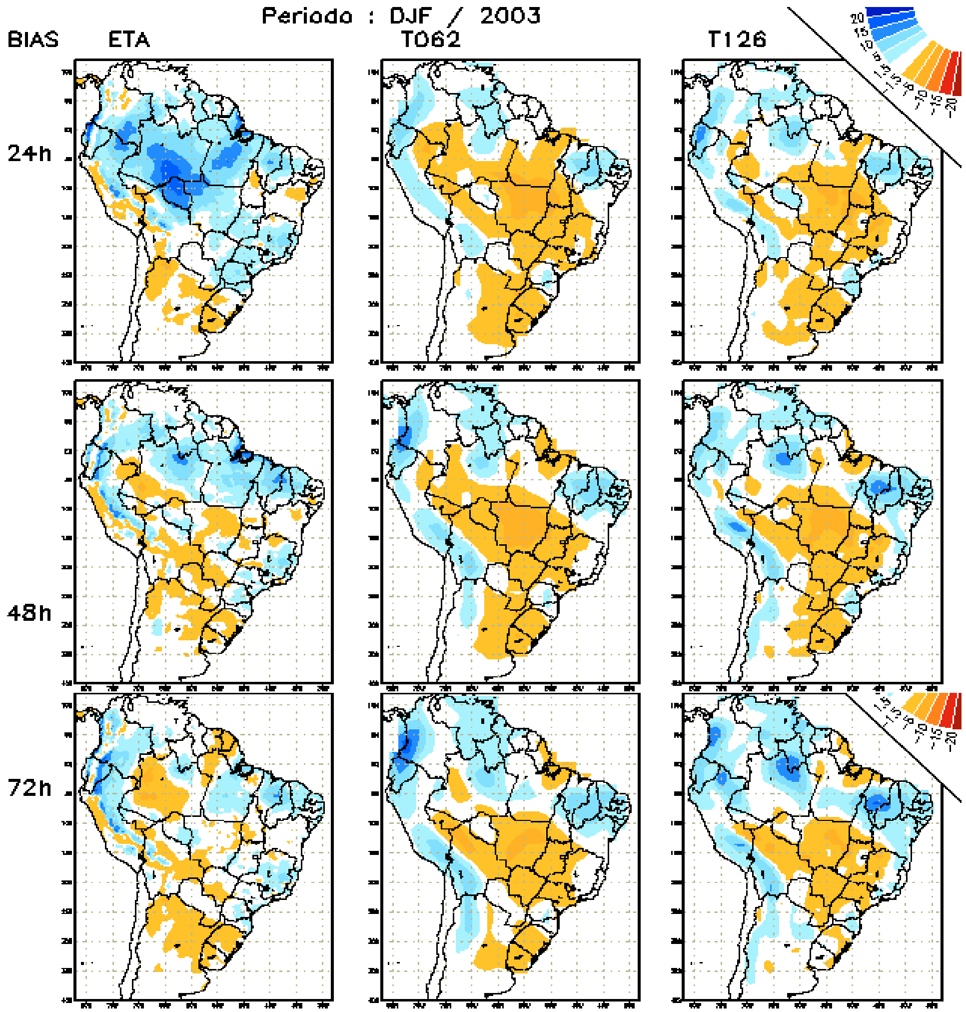
$$BIAS = \frac{F}{O}$$



F = No. de pts previstos acima do limiar
O = No. de observaoces acima do limiar
H= No. pts de acertos
CH = No. de pts por acertos aleatorios

DJF – 2002/2003





Mass Flux Scheme

- The single component of the cloud is not treated individually but as bulk effects produced by an ensemble of clouds.

- The large scale area average mass flux, $\overline{M}$, is assumed to contain an environment part, represented as M_e, and a cloudy part, M_c, which represents the contribution from all clouds.

$$\overline{M} = M_c + M_e$$

- The clouds occupy a fractional area σ, and the environment $1-\sigma$

- Vertical mass fluxes can be rewritten as

$$\overline{\rho}\,\overline{w} = \sigma \overline{\rho} w_c + (1-\sigma)\overline{\rho} w_e$$

Mass Flux Scheme

• The observed $\overline{w}$ is generally small, which implies that the strong ascent within the cloud is compensated by the descent between clouds.

From the assumption that $\sigma << 1$, and that $\overline{w} \sim 0$, we have then

$$\overline{\rho}\,\overline{s'w'} \approx \sigma\,\overline{\rho}\,w_c(s_c - s_e) = M_c(s_c - s_e)$$

s : dry static energy

Mass Flux Scheme

A cloud model is necessary to give values of M_c and s_c

Based on the mass conservation and assuming steady state

$$\frac{\partial \rho \omega_c}{\partial z} = E - D$$

E and D are the entrainment and detrainment rates

$$\frac{\partial M_c}{\partial z} = E - D$$

Extension to other typical cloud conservative properties:

$$\frac{\partial (M_c s_c)}{\partial z} = E\bar{s} - Ds_c$$

In a moist atmosphere:

$$\frac{\partial (M_c s_c)}{\partial z} = E\bar{s} - Ds_c - L\rho c$$

Mass Flux Scheme

The conservation of water substance can be split into vapour, q, and liquid, l, phases.

$$\frac{\partial (M_c q_c)}{\partial z} = E\bar{q} - Dq_c - \rho c$$

$$\frac{\partial (M_c l)}{\partial z} = Dl + \rho c - \rho k l$$

k is the rate of conversion of liquid water into precipitation.

By writing the convective eddy transports in the flux form, the energy conservation in the column is assured.

Mass Flux Scheme

The contribution from cumulus activity to the large scale heat and moisture are thus,

$$\left(\frac{\partial\overline{\theta}}{\partial t}\right)_{cu} = -\frac{1}{\overline{\rho}}\frac{\partial\left[M_c(\theta_c-\overline{\theta})\right]}{\partial z} + \frac{L}{c_p\overline{\pi}}(c-e)$$

$$\left(\frac{\partial q}{\partial t}\right)_{cu} = -\frac{1}{\overline{\rho}}\frac{\partial\left[M_c(q_c-\overline{q})\right]}{\partial z} - (c-e)$$

Observations show that cloud mass flux is larger than the vertical mass flux forced by large scale convergence.

The representation of cloud mass flux from large scale convergence is not enough to reproduce the warming in cloud free area. There is need for an explicit representation of mass transports, or of other quantities, within the cloud.

KAIN-FRITSCH CONVECTION PARAMETERIZATION

- Based on Fritsch-Chappell Scheme
- Based on Mesoscale Convective Systems
- Mass Flux Type
- Cloud Model to estimate the convective mass fluxes

CLOSURE:

$$\frac{dw}{dt} = g\left(\frac{T_u - T}{T}\right)$$

$$\frac{1}{2}w^2 \,|_{ETL} - \frac{1}{2}w^2 \,|_{LFC} = \int_{LFC}^{ETL} g\left(\frac{T_u - T}{T}\right) dz = CAPE$$

ETL: Equilibrium Temperature Level
LFC: Level of Free Convection

All CAPE in the column is removed within t_c

Trigger Function:

$$T_u - T + \Delta T \begin{cases} > 0 \Rightarrow unstable \\ \le 0 \Rightarrow stable \end{cases}$$

$$\Delta T = c_1 w_{LCL}^{\frac{1}{3}}$$

Updraft:

$$\frac{\partial M_u}{\partial z} = \varepsilon_u - \delta_u$$

$$\frac{\partial M_u \theta_u}{\partial z} = \varepsilon_u \theta_u - \delta_u \theta_u + L(c - e)$$

$$\frac{\partial M_u q_u}{\partial z} = \varepsilon_u q_u - \delta_u q_u - L(c - e) - R$$

$$\frac{\partial M_u l}{\partial z} = -\delta l + R + L(c - e)$$

Downdraft:

LFS: Level of Free Sink

Mixture of saturated updraft air and environment air

$$\frac{\partial M_d}{\partial z} = \varepsilon_d - \delta_d$$

$$\frac{\partial M_d \theta_d}{\partial z} = \varepsilon_d \theta_d - \delta_d \theta_d - Le$$

$$\frac{\partial M_d q_d}{\partial z} = \varepsilon_d q_d - \delta_d q_d + Le$$

ε and δ: gaussian distribution

Tendencies:

$$\left.\frac{\partial \theta}{\partial t}\right|_{con} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left[(M_u + M_d)\theta + (\varepsilon_u + \varepsilon_d)\theta - (\delta_u + \delta_d)\theta_u\right]$$

$$\left.\frac{\partial q}{\partial t}\right|_{con} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left[(M_u + M_d)q + (\varepsilon_u + \varepsilon_d)q - (\delta_u + \delta_d)q_u\right]$$

$$\left.\frac{\partial u}{\partial t}\right|_{con} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left[(M_u + M_d)u + (\varepsilon_u + \varepsilon_d)u - (\delta_u + \delta_d)u_u\right]$$

$$\left.\frac{\partial v}{\partial t}\right|_{con} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left[(M_u + M_d)v + (\varepsilon_u + \varepsilon_d)v - (\delta_u + \delta_d)v_u\right]$$

Flux form: Conservation of moisture and energy

$$\frac{\Delta T}{\Delta t} = \frac{T_p - T}{t_c}$$

$$\frac{\Delta q}{\Delta t} = \frac{q_p - q}{t_c}$$

$$t_c = \frac{\Delta x}{V}$$