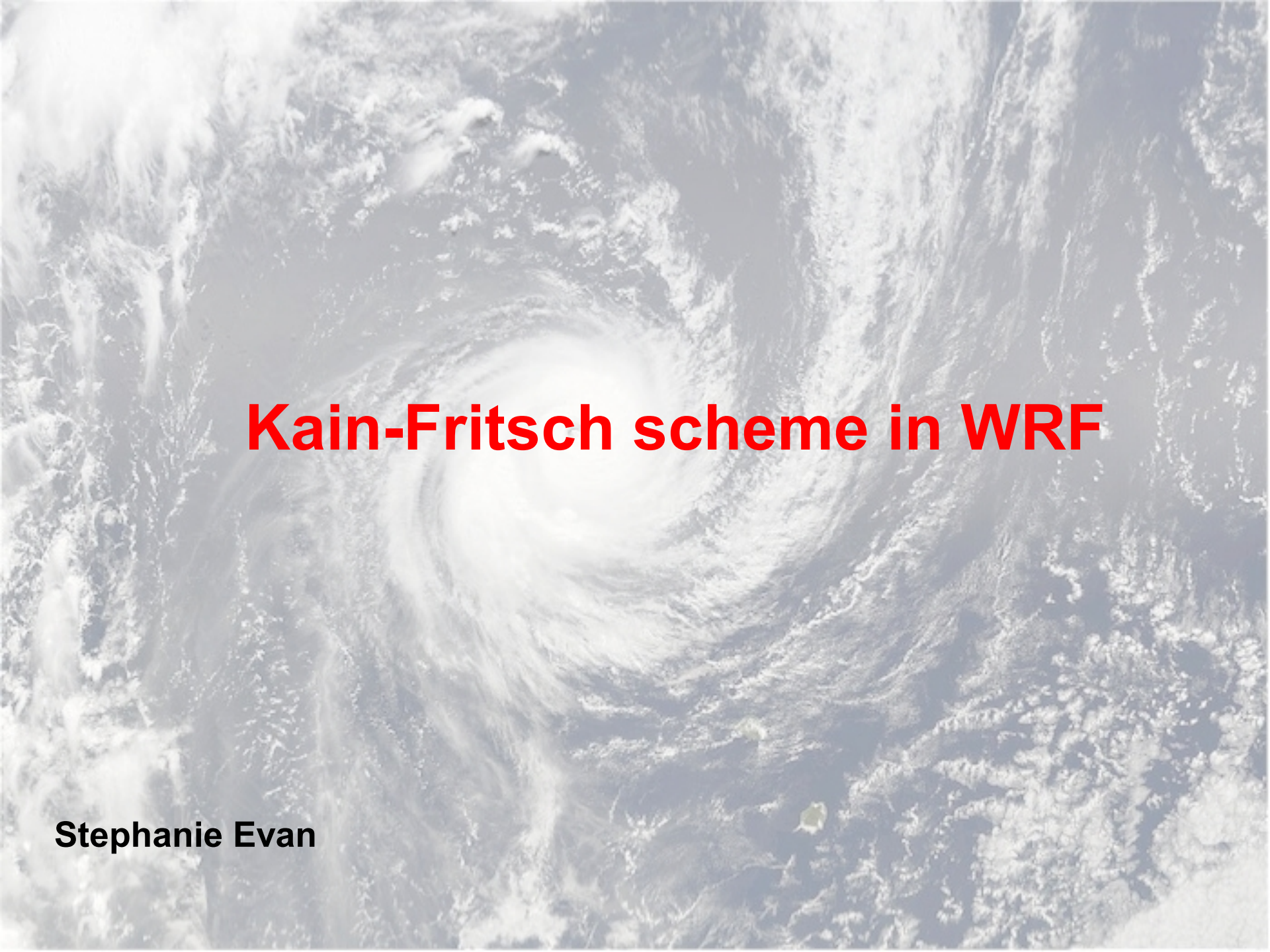


Kain-Fritsch scheme in WRF

Stephanie Evan

Moist Convection

Moist convection alters the environment in two different ways:

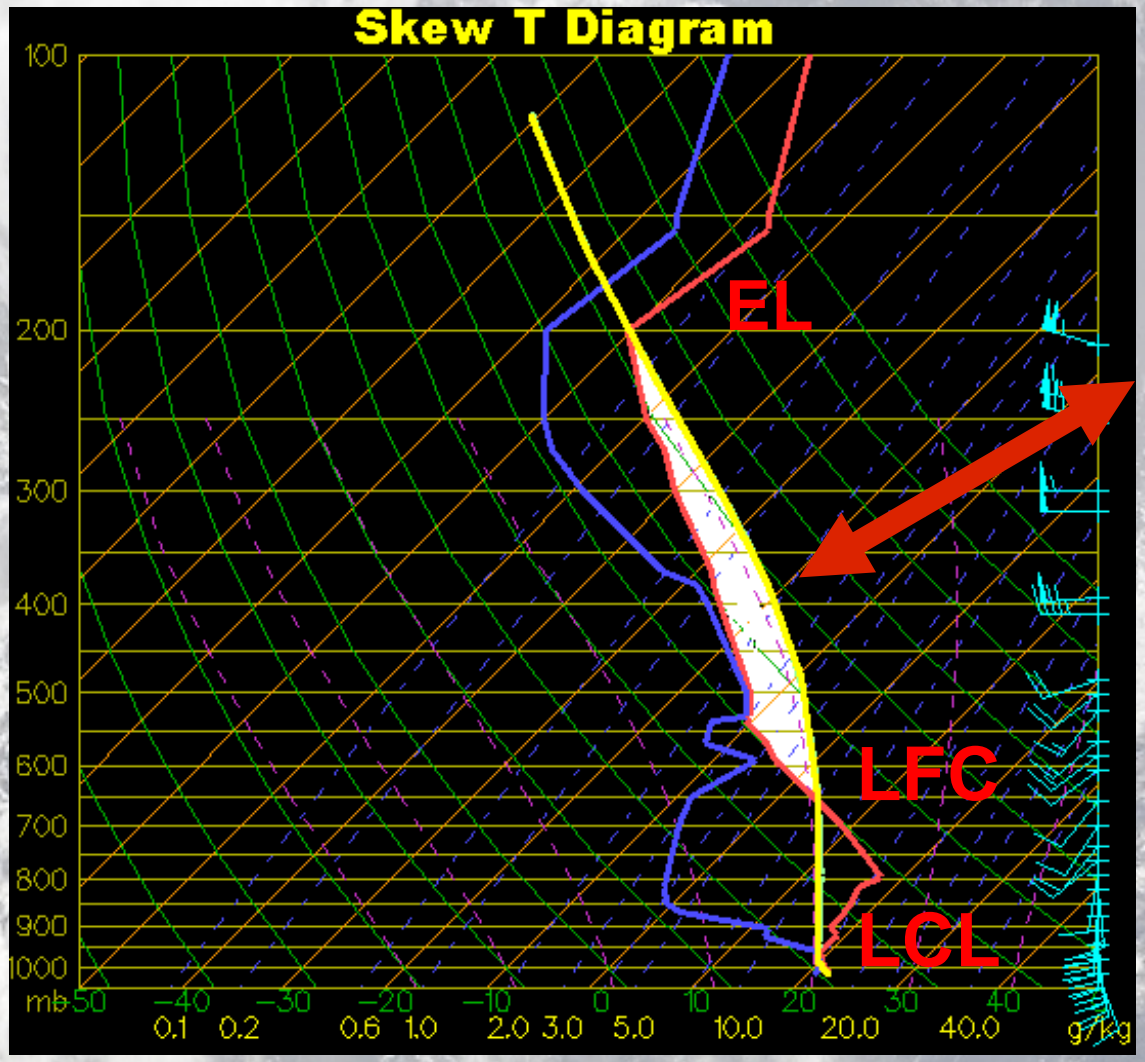
- **Deep convection associated with strong updrafts and precipitation acts to warm and dry the environment (precipitation removes water vapor from the atmosphere)**
- **Shallow convection produces no net warming or drying because water vapor is not removed from the atmosphere but is important for the radiative budget.**

Convective parameterization

- A technique used in numerical modelling to predict the collective effects of convective clouds that may exist within a single grid element as a function of larger-scale processes and conditions.
- Implicit parameterization: represents the effects of subgrid scale processes on the grid variables.

A convection scheme :

- predicts convective precipitation
- changes vertical stability
- generates and redistributes heat
- removes and redistributes moisture
- makes clouds



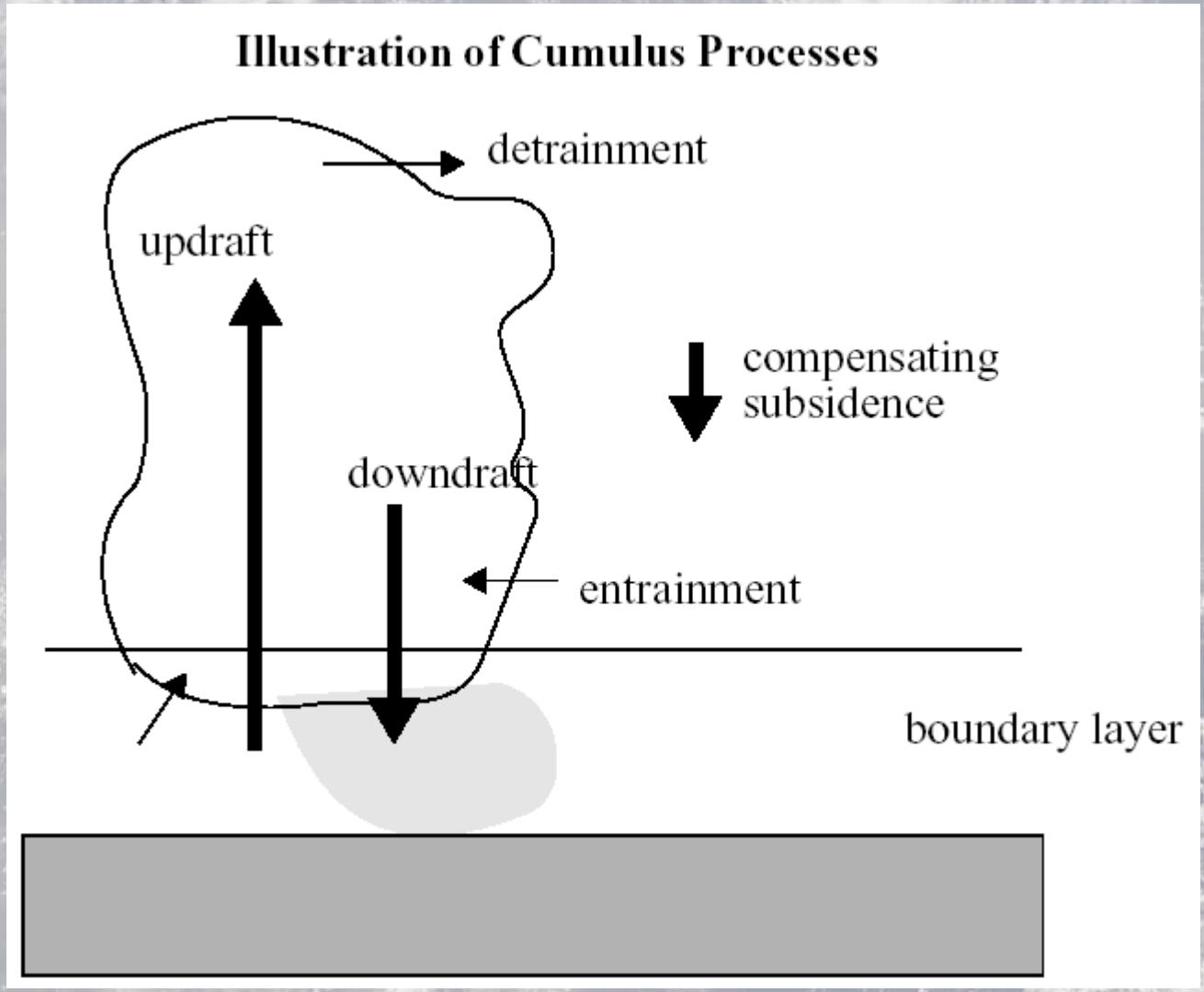
Convective Available Potential Energy :

$$\text{CAPE} = g \int_{LFC}^{EL} \frac{\theta(z) - \overline{\theta(z)}}{\overline{\theta(z)}} dz$$

Convective Inhibition :

$$\text{CIN} = -g \int_{LCL}^{EL} \frac{\theta(z) - \overline{\theta(z)}}{\overline{\theta(z)}} dz$$

Mass-Flux scheme



Formulation of the convective parameterization.

Anthes (1977), the heating tendency due to subgrid - scale convective processes can be expressed as :

$$\left.\frac{\partial \bar{\theta}}{\partial t}\right|_{conv} = \frac{L}{\pi}\frac{\partial \bar{q}}{\partial t} - \frac{\partial \overline{\omega'\theta'}}{\partial p}$$

π : Exner's function = $c_p (p/p_0)^{R/C_p}$

$\frac{\partial \bar{q}}{\partial t}$ is the rate of phase change of water substance (kg/kg)

L is the latent heat released during phase change of a unit mass of water substance (J/kg)

$$\left.\frac{\Delta\overline{\theta}}{\Delta t}\right|_{conv} = \frac{1}{\Delta p}[(\omega_{u2}+\omega_{d2})\overline{\theta_2} - (\omega_{u1}+\omega_{d1})\overline{\theta_1}$$

$$+ (\varepsilon_u+\varepsilon_d)\overline{\theta m} - \delta_u\theta_{um} - \delta_d\theta_{dm}]$$

$$\left.\frac{\Delta\overline{q_v}}{\Delta t}\right|_{conv} = \frac{1}{\Delta p}[(\omega_{u2}+\omega_{d2})\overline{q_{v2}} - (\omega_{u1}+\omega_{d1})\overline{q_{v1}}$$

$$+ (\varepsilon_u+\varepsilon_d)\overline{q_{vm}} - \delta_u q_{vum} - \delta_d q_{vdm}]$$

Liquid water detrainment from convective clouds supplies moisture to the resolvable scale :

$$\left.\frac{\Delta\overline{q_c}}{\Delta t}\right|_{conv} = -\frac{\delta_u q_{lum}}{\Delta p}$$

U: Updraft
D: Downdraft
qc: cloud water
qv: water vapor
qlum: mean updraft liquid water mixing ratio in a layer

Major components of the KF scheme

- Convective Updraft:
  - Removes high θe from lower troposphere, transports it aloft.
  - Generates condensate

- Convective downdraft:
  - Starts 150-200mb above cloud base.
  - Deposits low θe air in subcloud layer.
  - Assumed to be saturated above cloud base, RH decreasing linearly (10%/km) below cloud base

- Compensating subsidence:
  - Compensates for any mass surplus or deficit created by updraft and downdraft.

- Precipitation:
  - Updraft generates condensate and dump condensate into environment
  - Downdraft evaporates condensate at a rate that depends on RH and depth of downdraft
  - Leftover condensate accumulates at surface as precipitation.

Entrainment rate (kg/s) at which the environmental air mixes into an updraft over a pressure interval dp :

$$\delta M_e = -\frac{0.03\delta p M_{u0}}{R}$$

R is the updraft radius (m) and M_{u0} is the mass flux at the cloud base.

This equation specifies the rate at which environmental air flows into the turbulent mixing region at the edges of an updraft.

Variable cloud radius :

$$R = \begin{cases} 1000 & W_{KL} < 0 \\ 2000 & W_{KL} > 10 \\ 1000(1 + W_{KL}/10) & 0 \le W_{KL} \le 10 \end{cases}$$

Dependence of R on larger-scale forcing, R depends on the magnitude of vertical velocity at the LCL.

Variable entrainment/detrainment.

Function which defines how often the various subparcel mixtures are created (mixing between updraft air and environmental air).

$$f(x) = \frac{1}{0.97\sigma\sqrt{2\pi}}\left[e^{-(x-0.5)^2/2\sigma^2} - e^{-4.5}\right]$$

x : from 0 to 1, fraction of environmental air mixed in the subparcels.

f(x) is used to determinate the total rate at which these subparcels (after mixing) are entrained into the updraft (if buoyancy > 0) or detrained into the environment (if buoyancy < 0).

Search for USL starting at the surface k=0 until depth=60hPa
T, q and T_{LCL} and q_{LCL} are computed
$T_{LCL} + \delta Tvv$ compared to Tenv (Buoyancy > 0 or Buoyancy < 0)
$\delta Tvv = k[w_g - c(z)]^{1/3}$

if $T_{LCL} + \delta Tvv < Tenv$

k=k+1 make a new search
T, q and T_{LCL} and q_{LCL} are computed
$T_{LCL} + \delta Tvv$? Tenv

if P < 300mb
go to next grid point

if $T_{LCL} + \delta Tvv > Tenv$

Convection activated, parcel is released with T_{LCL} and vertical velocity
$w_p = 1 + 1.1[(Z_{LCL} - Z_{USL})\ \delta Tvv / Tenv]^{1/2}$

Determine cloud top as the highest model level at which $w_p > 0$

$Z(top) - Z_{LCL} > Dmin$?
Dmin=4000 if $T_{LCL} > 20C$
Dmin=2000 if $T_{LCL} < 0C$
$Dmin = 2000 + 100T_{LCL}$ if $0 \leq T_{LCL} \leq 20$

Shallow Convection

Deep Convection
stop when 90% of CAPE removed

w_g is an approximate running - mean grid - resolved vertical velocity

c(z) is a threshold vertical velocity given by :

$$c(z) = \begin{cases} w_0 (Z_{LCL} / 2000) & \text{if } Z_{LCL} \leq 2000\text{m} \\ w_0 & \text{if } Z_{LCL} > 2000\text{m} \end{cases}$$

$$w_0 = 2\text{cm s}^{-1}$$

```
!...CHECK TO SEE IF CLOUD IS BUOYANT USING FRITSCH-CHAPPELL TRIGGER
!...FUNCTION DESCRIBED IN KAIN AND FRITSCH (1992)...W0 IS AN
!...APROXIMATE VALUE FOR THE RUNNING-MEAN GRID-SCALE VERTICAL
!...VELOCITY, WHICH GIVES SMOOTHER FIELDS OF CONVECTIVE INITIATION
!...THAN THE INSTANTANEOUS VALUE...FORMULA RELATING TEMPERATURE
!...PERTURBATION TO VERTICAL VELOCITY HAS BEEN USED WITH THE MOST
!...SUCCESS AT GRID LENGTHS NEAR 25 km.  FOR DIFFERENT GRID-LENGTHS,
!...ADJUST VERTICAL VELOCITY TO EQUIVALENT VALUE FOR 25 KM GRID
!...LENGTH, ASSUMING LINEAR DEPENDENCE OF W ON GRID LENGTH...
!
      IF(ZLCL.LT.2.E3)THEN
        WKLCL=0.02*ZLCL/2.E3
      ELSE
        WKLCL=0.02
      ENDIF
      WKL=(W0AVG1D(K)+(W0AVG1D(KLCL)-W0AVG1D(K))*DLP)*DX/25.E3-WKLCL
      IF(WKL.LT.0.0001)THEN
        DTLCL=0.
      ELSE
        DTLCL=4.64*WKL**0.33
      ENDIF
```

Conversion of condensate to precipitation- Cloud glaciation.

Ogura and Cho (1973) : condensate (liquid/solid) removed from the updraft in a layer dz given by :

$$\delta r_c = r_{co}(1 - e^{-c_1 \delta z / w})$$

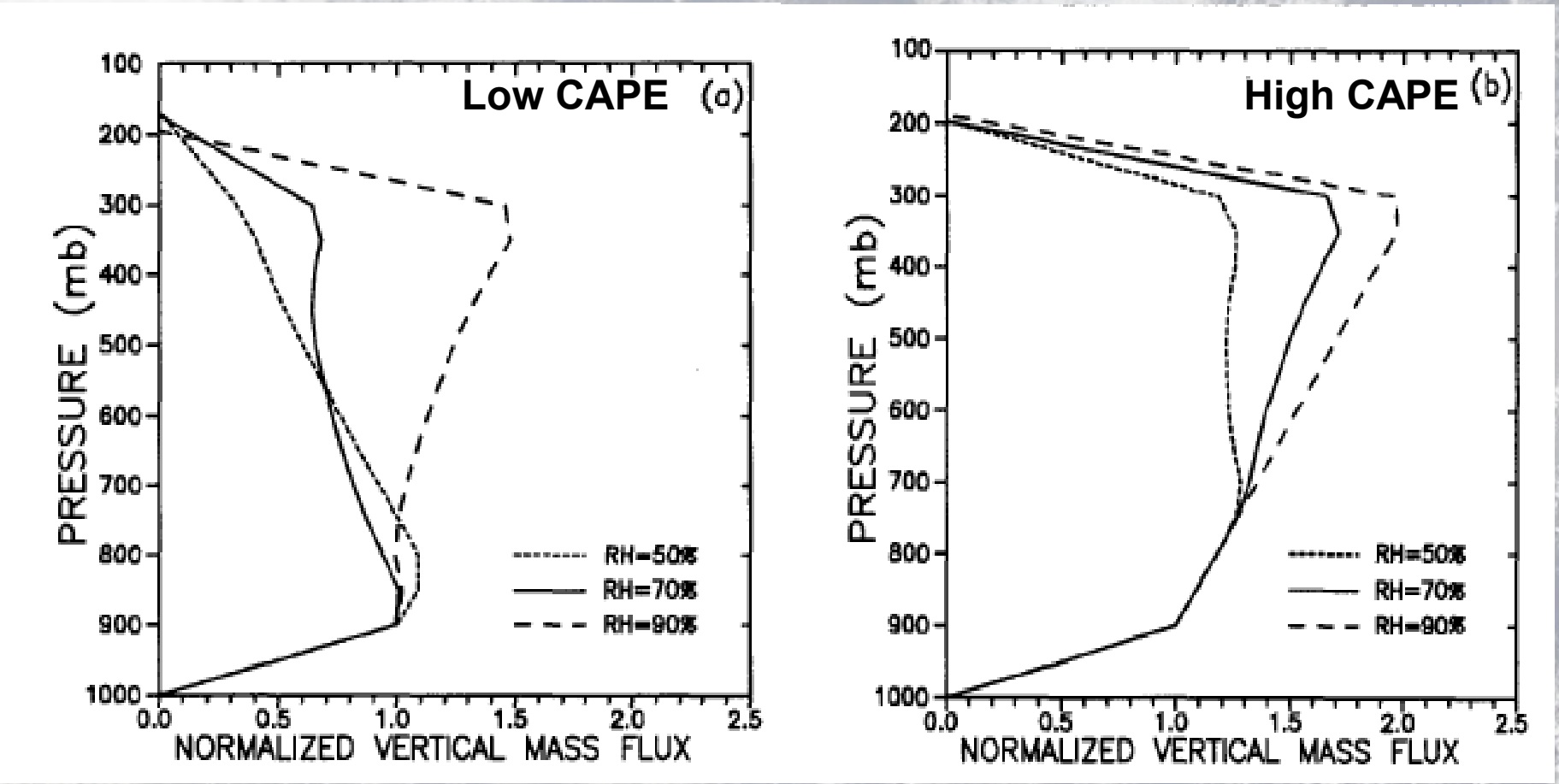
r_{co} : concentration of condensate at the bottom of the layer.

c_1 : rate constant

w : mean vertical velocity in the layer

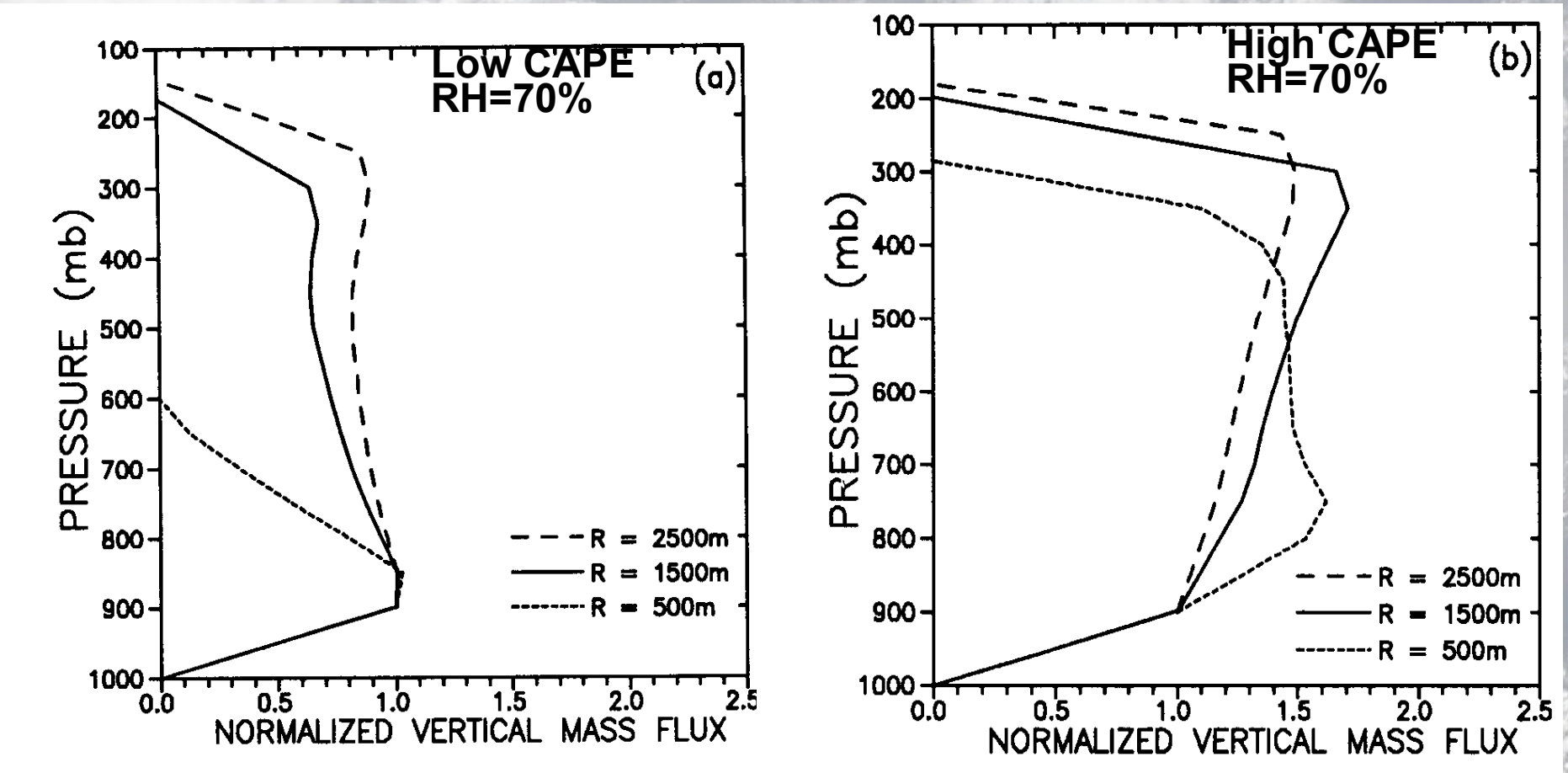
Glaciation processes are parameterized by assuming a linear transition from θe with respect to liquid water to θe with respect to ice from 268K to 248K.

Sensitivity to RH (Kain and Fritsch, 1990)



KF scheme is sensitive to the environmental RH. Vertical mass flux can vary by more than a factor of 2 in upper levels as the RH is varied from 50% to 90%.

Sensitivity to cloud radius (Kain and Fritsch, 1990)



Difficult to estimate cloud size.

Sensitive to the inverse radius entrainment relationship.

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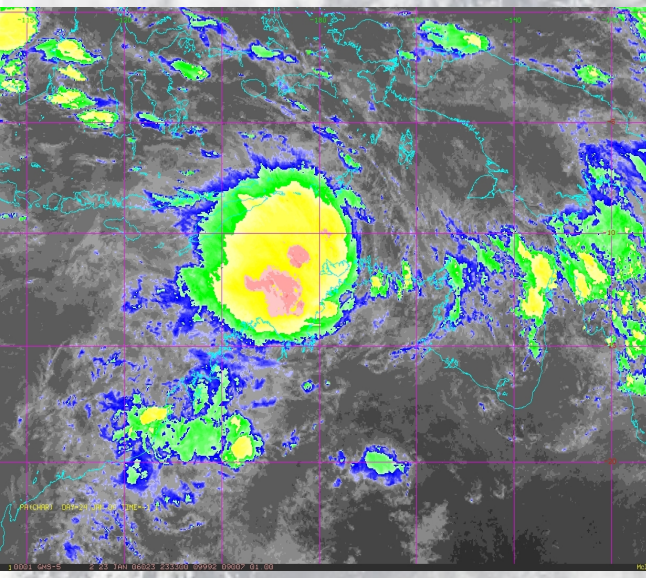

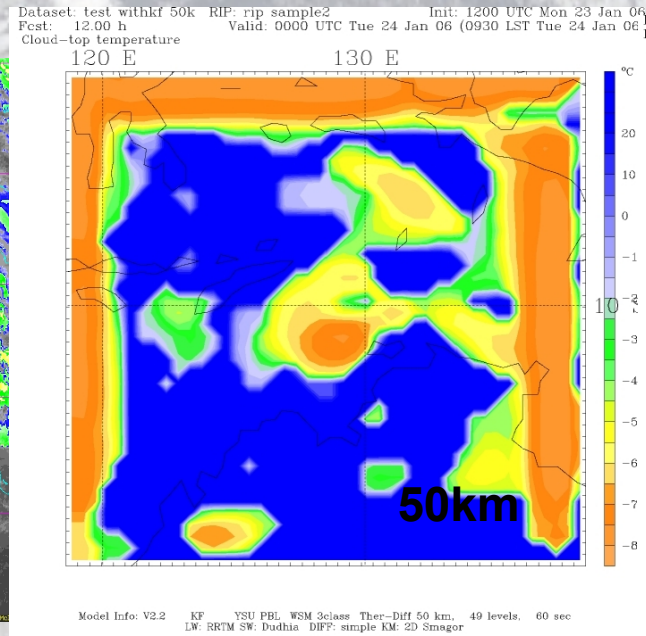

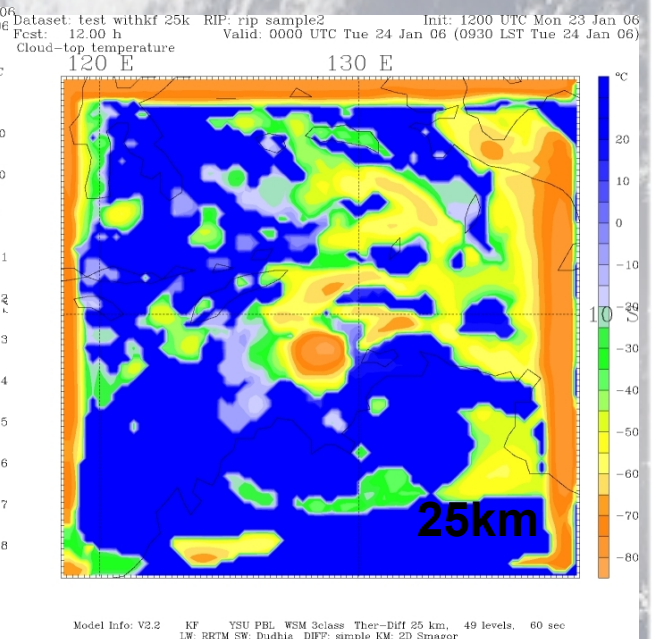

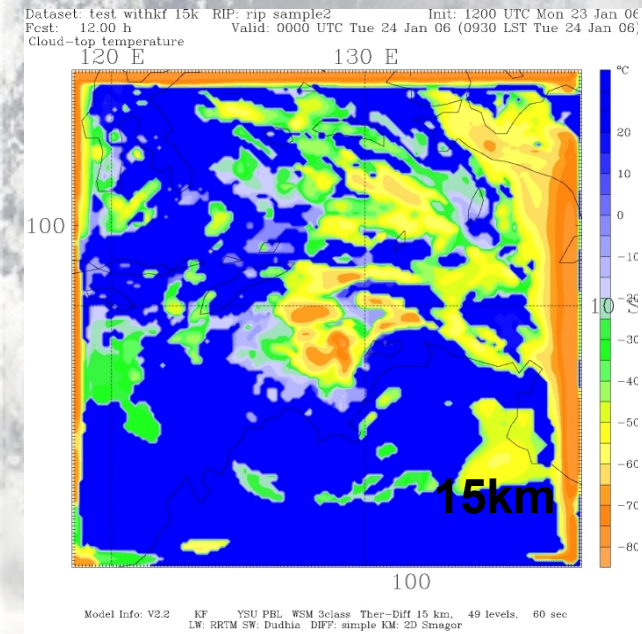

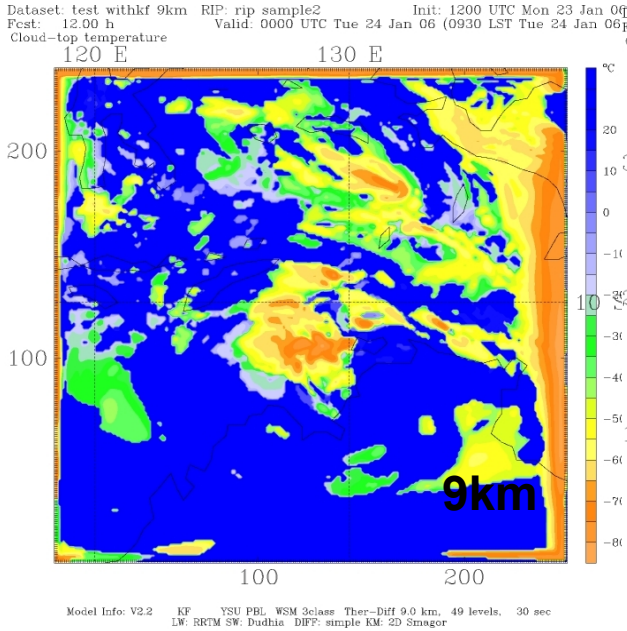

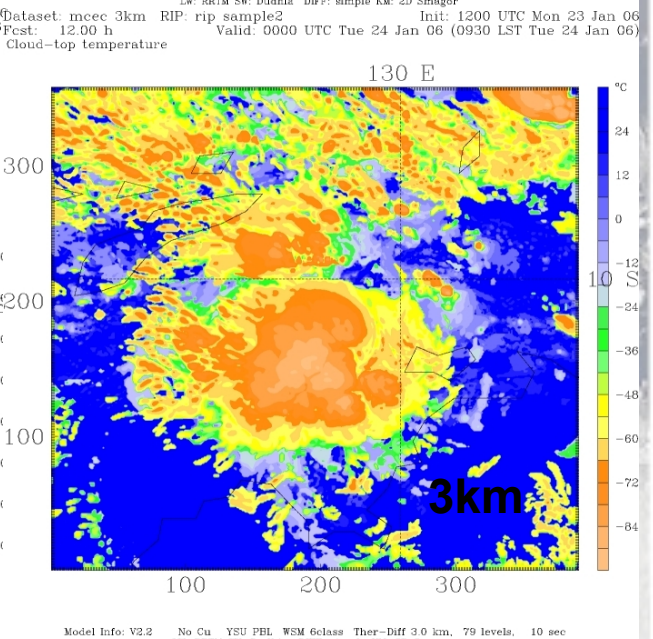

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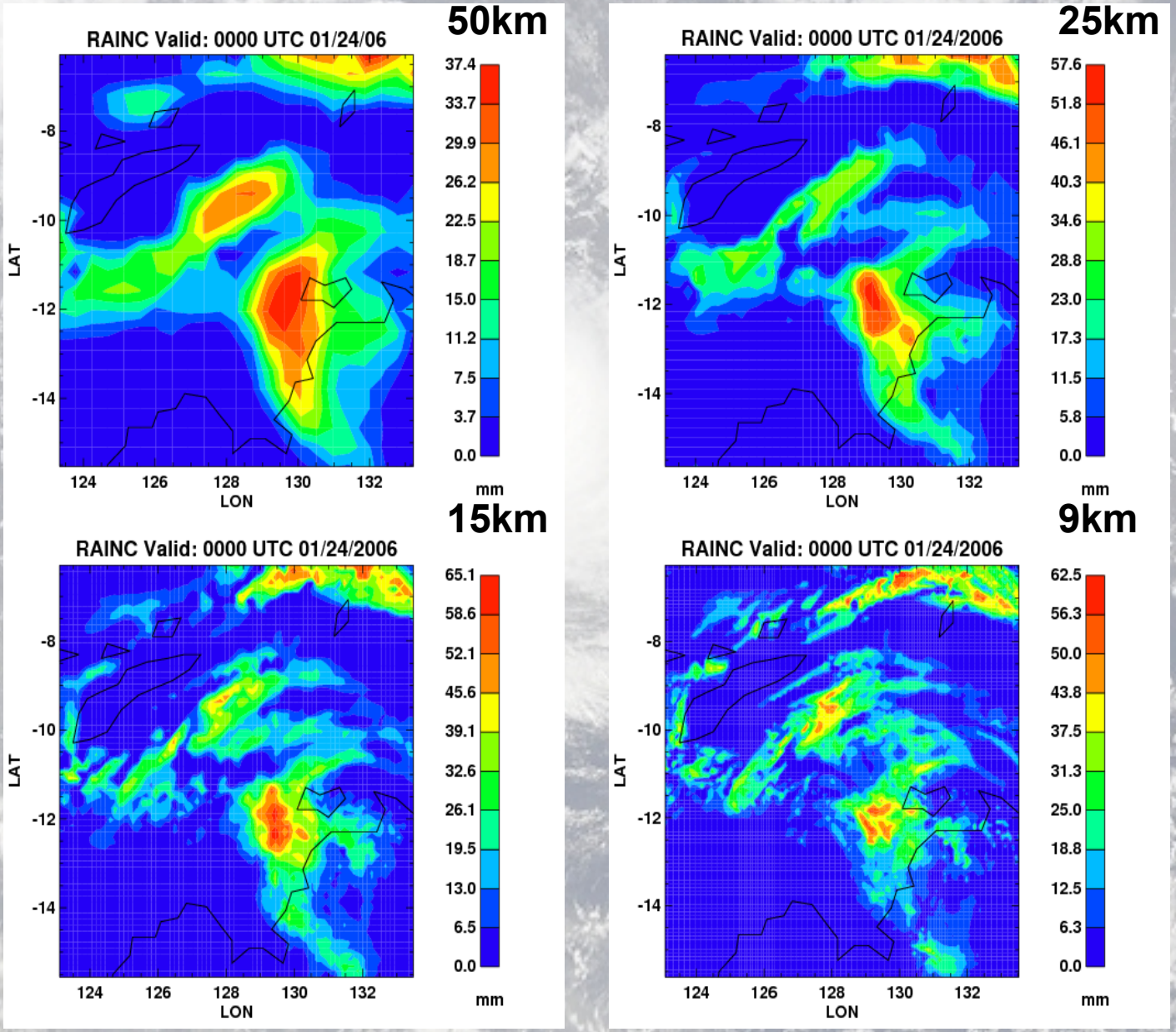
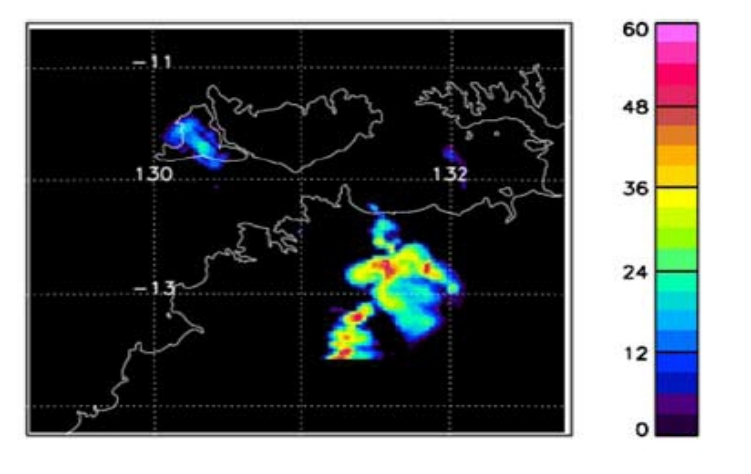
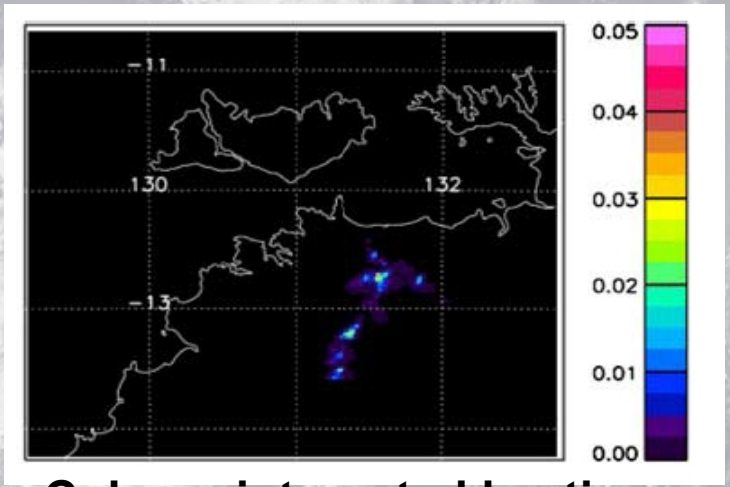


Alexander et al., 2004

- 7-hour period on 17 November 2001.
- model is a dry version of a three-dimensional (3-D) mesoscale cloud resolving model with horizontally uniform background wind and stability fields.
- The model is forced with a spatially and temporally varying heating field representative of the convective latent heating in the area. This heating field is derived from radar reflectivity.

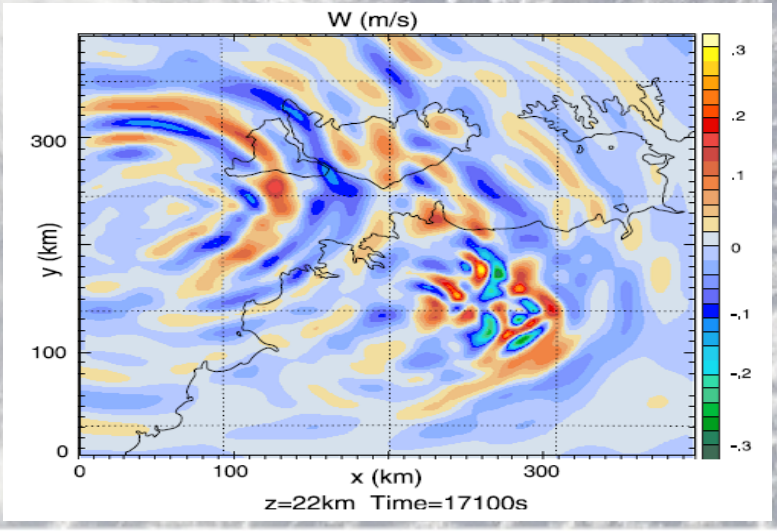


Radar Reflectivity at 8km (17 November 1730 LT)



Column integrated heating (K/s) for the same time

W at 22km at 1715 LT



Conclusions

- KF scheme is 1-D Entraining/Detraining cloud model derived from the Fritsch-Chapell cumulus scheme.
- The scheme includes a downdraft in the cloud model.
- Has been used with the most success at grid lengths near 25km.
- More suited for midlatitude environment.
- More than 8 tunable coefficients.

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