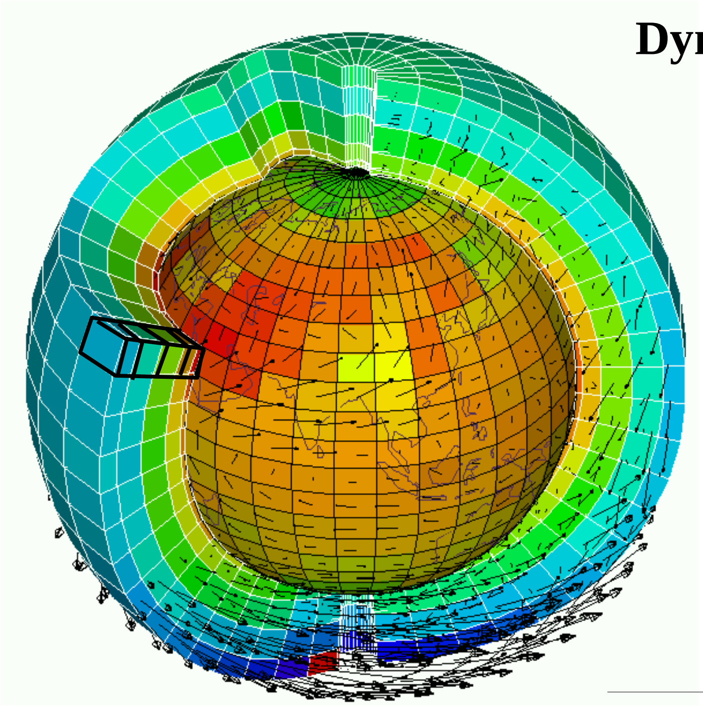
Model physics part II
Water vapor and clouds

LMDZ Training – January 2026

J-B Madeleine and the LMDZ team

Reminder of the context (given yesterday)



Dynamical core : primitive equations discretized on the sphere

- Mass conservation

  $D\rho/Dt + \rho\,\mathrm{div}\underline{U} = 0$
- Potential temperature conservation

  $D\theta / Dt = Q / Cp \;(p_0/p)^{\kappa}$
- Momentum conservation

  $D\underline{U}/Dt + (1/\rho)\,\underline{\mathrm{grad}}p - \underline{g} + 2\,\underline{\Omega} \wedge \underline{U} = \underline{F}$
- Secondary components conservation

  $Dq/Dt = Sq$

Parameterizations purpose : account for the effect of processes non resolved by the dynamical core

→ **Traditional « source » terms in the equations**

- *Q* : Heating by radiative exchanges, thermal conduction (neglected), condensation, sublimation, **subgrid-scale motions (turbulence, clouds, convection)**
- *F* : Molecular viscosity (neglected), **subgrid-scale motions (turbulence, clouds, convection)**
- *Sq* : condensation/sublimation (q= water vapor or condensed), chemical reactions, photo-dissociation (ozone, chemical species), micro physics and scavenging (pollution aerosols, dust, ...), **subgrid-scale motions (turbulence, clouds, convection)**

Temperature tendencies

Part II

Basic facts about parametrizations I

– Each parametrization : (1) works almost independently of the others ; (2) depends on vertical profiles of u, v, w, T, q and on some interface variables with the other parametrizations ; (3) ignores the spatial heterogeneities associated with the other processes (except for some processes in the deep convection scheme).

– The total tendency due to sub-grid processes is the sum of the tendencies due to each process :

$$\boxed{\begin{aligned} S_T = (\partial_t T)_\varphi &= \boxed{(\partial_t T)_{\rm eva} + (\partial_t T)_{\rm lsc}} + (\partial_t T)_{\rm diff\ turb} + \boxed{(\partial_t T)_{\rm conv}} \\ &+ \boxed{(\partial_t T)_{\rm wk}} + (\partial_t T)_{\rm Th} + (\partial_t T)_{\rm ajs} \\ &+ \boxed{(\partial_t T)_{\rm rad}} + (\partial_t T)_{\rm oro} + (\partial_t T)_{\rm dissip} \end{aligned}}$$

In the model, the total tendency of T for example is $\partial_t T_{\rm dyn} + \partial_t T_{\rm param}$ = `dtdyn + dtphy`, where :

```
dtphy = dteva + dtlsc + dtvdf + dtcon +
        dtwak + dtthe + dtajs +
        (dtswr + dtlwr) + (dtoro + dtlif) + (dtdis + dtec)
```

Specific humidity tendencies

Part II

Basic facts about parametrizations II

– Similiarly, the total tendency of a given tracer q writes :

$$\boxed{\begin{aligned} S_q \;=\; (\partial_t q)_\varphi \;&=\; \boxed{(\partial_t q)_{\mathrm{eva}} + (\partial_t q)_{\mathrm{lsc}}} + (\partial_t q)_{\mathrm{diff\ turb}} + \boxed{(\partial_t q)_{\mathrm{conv}}} \\ &+ \boxed{(\partial_t q)_{\mathrm{wk}}} + (\partial_t q)_{\mathrm{Th}} + (\partial_t q)_{\mathrm{ajs}} \end{aligned}}$$

In the model, the total tendency of q is therefore

$\partial_t q_{\mathrm{dyn}} + \partial_t q_{\mathrm{param}} = \mathtt{dqdyn} + \mathtt{dqphy}$, where :

$\mathtt{dqphy} = \boxed{\mathtt{dqeva} + \mathtt{dqlsc}} + \mathtt{dqvdf} + \boxed{\mathtt{dqcon} + \mathtt{dqwak}} + \mathtt{dqthe} + \mathtt{dqajs}$

Subroutine structure

physiq_mod.F90 structure - I

Initialization (once) : *conf_phys, phyetat0, phys_output_open*

Beginning *change_srf_frac, solarlong*

Cloud water evap. *reevap*

Vertical diffusion (turbulent mixing) *pbl_surface*

Deep convection *conflx* (Tiedtke) or *concvl* (Emanuel)

Deep convection clouds *clouds_gno*

Density currents (wakes) *calwake*

Strato-cumulus *stratocu_if*

Thermal plumes *calltherm* and *ajsec* (sec = dry)

Large scale clouds *calcratqs*

Large scale and cumulus condensation *fisrtilp*

Diagnostic clouds for Tiedtke *diagcld1*

Aerosols *readaerosol_optic*

Cloud optical parameters *newmicro* or *nuage*

Radiative processes *radlwsw*

In blue : subroutines and instructions modifying state variables

physiq_mod.F90 structure - II

Orographic processes : drag *drag_noro_strato* or *drag_noro*

Orographic processes : lift *lift_noro_strato* or *lift_noro*

Orographic processes : Gravity Waves *hines_gwd* or *GWD_rando*

Axial components of angular momentum and mountain torque : *aaam_bud*

Cosp simulator *phys_cosp*

Tracers *phytrac*

Tracers off-line *phystokenc*

Water and energy transport *transp*

Outputs

Statistics

Output of final state (for restart) *phyredem*

Effect of subrid-scale transport

Coupling with surface

Clouds and radiation

Architecture of the physical scheme

Procedure / Subsection	Input variables	Other outputs
	↺ Updated variables	
2.1. Evaporation	$\theta\ q_v\ q_l\ q_i$	
	↺ $\theta\ q_t\ (q_l = q_i = 0)$	
2.2. Local turbulent mixing	$\theta\ q_t$	
	↺ $\theta\ q_t$	
2.3. Deep convection	$\theta\ q_t\ ALE\ ALP$	$q_c^{in,cv}$ $P_{l,i}^{cv}\ d\theta_{dw}^{cv}\ dq_{t,dw}^{cv}$
	↺ $\theta\ q_t$	
2.4. Deep convection PDF	$q_t\ q_c^{in,cv}$	α_c^{cv}
2.5. Cold pools (wakes)	$\theta\ q_t\ d\theta_{dw}^{cv}\ dq_{t,dw}^{cv}$	$ALE^{wk}\ ALP^{wk}\ \theta_{env}^{wk}\ q_{t,env}^{wk}$
	↺ $\theta\ q_t$	
2.6. Shallow convection	$\theta_{env}^{wk}\ q_{t,env}^{wk}$	$(s_{th}\ \sigma_{th}\ s_{env}\ \sigma_{env})^{th}\ ALE^{th}\ ALP^{th}$
	↺ $\theta\ q_t$	
2.7. Large-scale condensation	$\theta\ q_t\ (s_{th}\ \sigma_{th}\ s_{env}\ \sigma_{env})^{th}$	$q_c^{in,lsc}\ \alpha_c^{lsc}$ $P_{l,i}^{lsc}$
	↺ $\theta\ q_v\ q_l\ q_i$	
2.8. Radiative transfer	$q_c^{in,lsc}\ \alpha_c^{lsc}\ q_c^{in,cv}\ \alpha_c^{cv}$	
	↺ θ	

- **GREY TERMS :** Heating and mixing by moist processes `(ex : dtcon, dqcon, dtlsc, dqlsc)`
- **BLUE TERMS :** Cloud water content and cloud fraction used for radiative calculations `(ex : lwc, rnebcon)`

CAREFUL : clouds are evaporated/sublimated at the beginning of each time step (~15 min), but vapor, droplets and crystals are prognostic variables. In other words, **clouds can move but they can't last for more than one timestep** (meaning that for example, crystals can't grow over multiple timesteps).

Picture by Oleg Artemyev taken from the ISS

Fundamental process

- Clausius-Clapeyron equation :

$$\frac{1}{e_{\mathrm{sat}}}\frac{\mathrm{d}e_{\mathrm{sat}}}{\mathrm{d}T} = \frac{L}{R_{\mathrm{vap}}T^2}$$

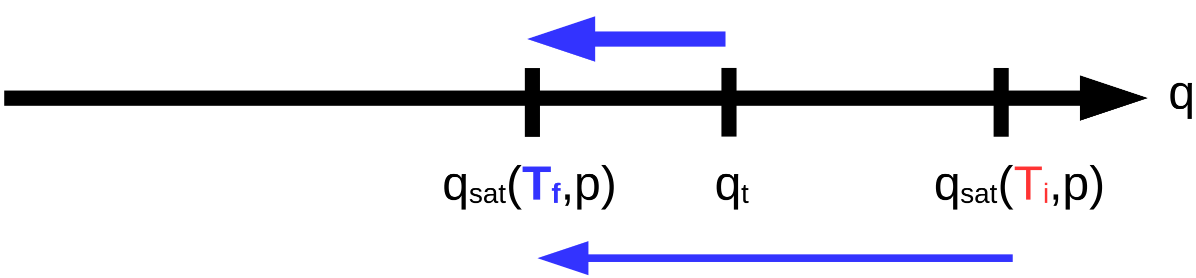
T	0°C	20°C
e_{sat}	6.1 hPa	23.4 hPa
q_{sat}	$3.7\ \mathrm{g\ kg^{-1}}$	$14.4\ \mathrm{g\ kg^{-1}}$

- Saturation mass mixing ratio :

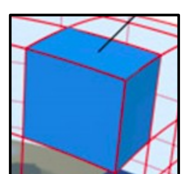
$q_{sat}(T,p) \simeq 0.622\,\frac{e_{sat}(T)}{p}$, where $e_{sat}(T)$ grows exponentially with temperature

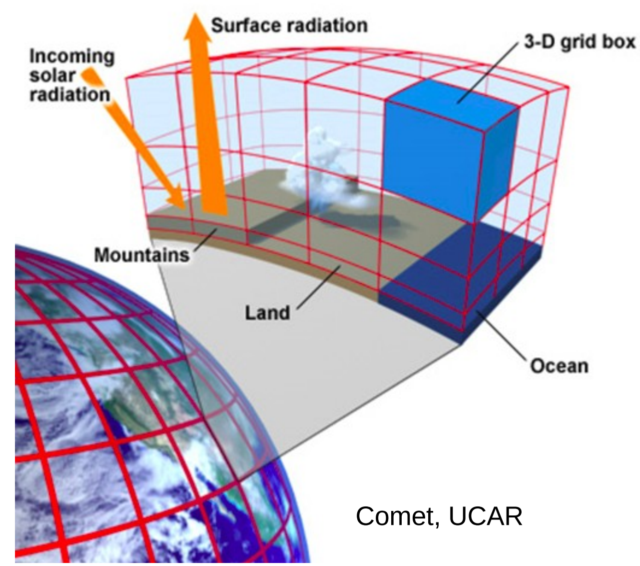
- Clouds form when an air parcel is cooled :

$q_c = q_t - q_{sat}(T_f,p)$



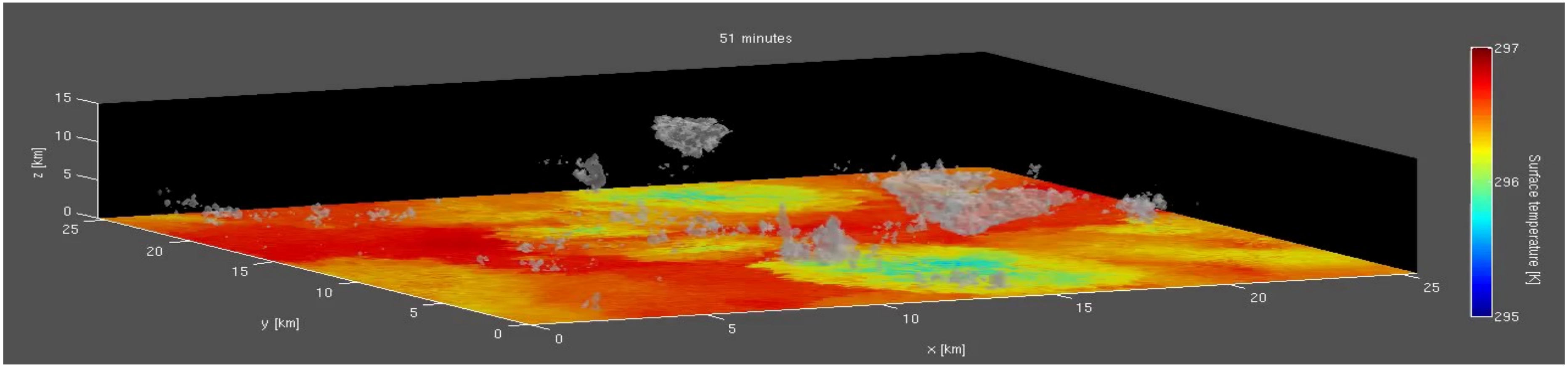
- But clouds do not look like that :





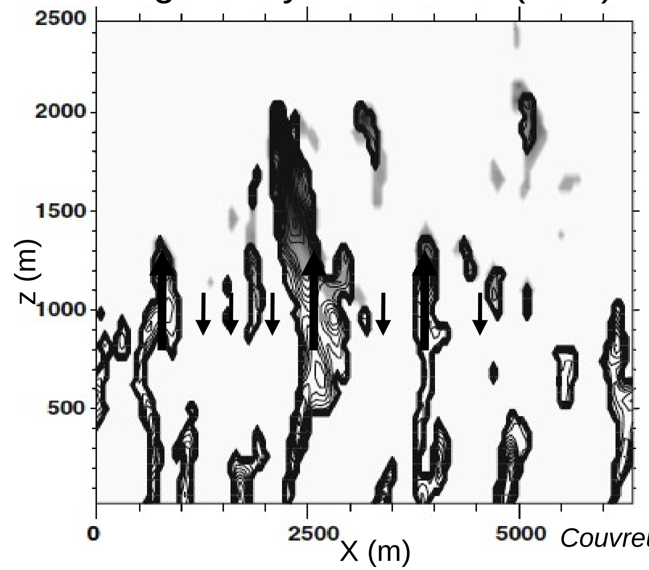
Comet, UCAR

Many processes in one grid cell



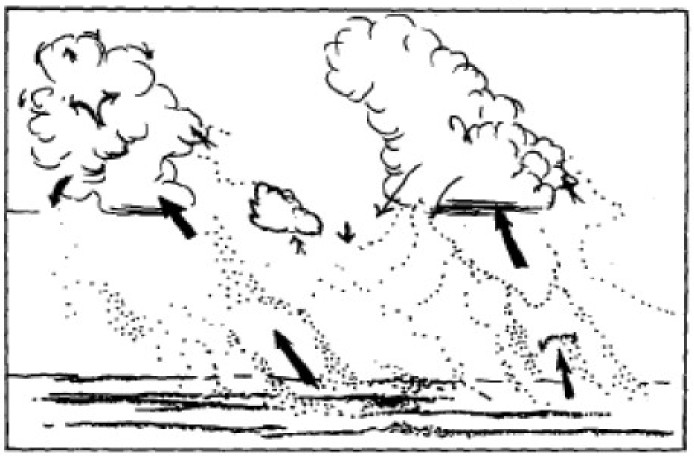
Around 8 hours of simulation by a **Cloud Resolving Model (CRM)** – C. Muller, LMD

Thermals in a
Large-Eddy Simulation (LES)



Couvreux et al., BLM, 2010

Conditional sampling of thermals based on a tracer emitted at the surface.

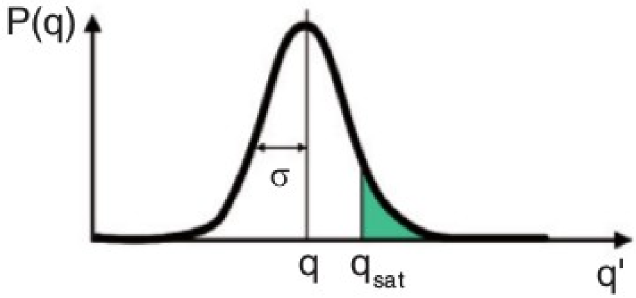


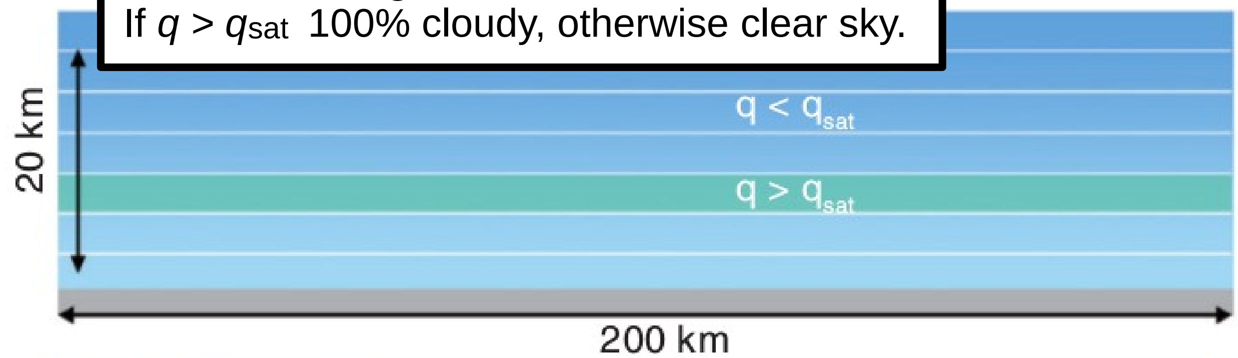
(b)

Lemone et Pennell, MWR, 1976

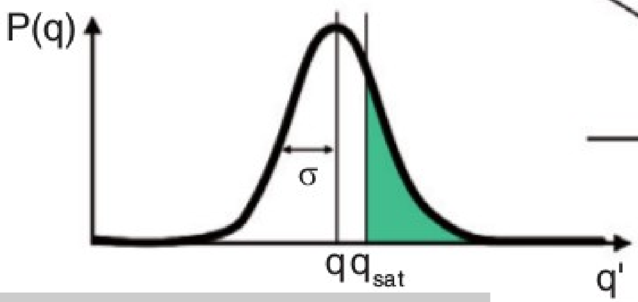
Statistical cloud scheme 1/2

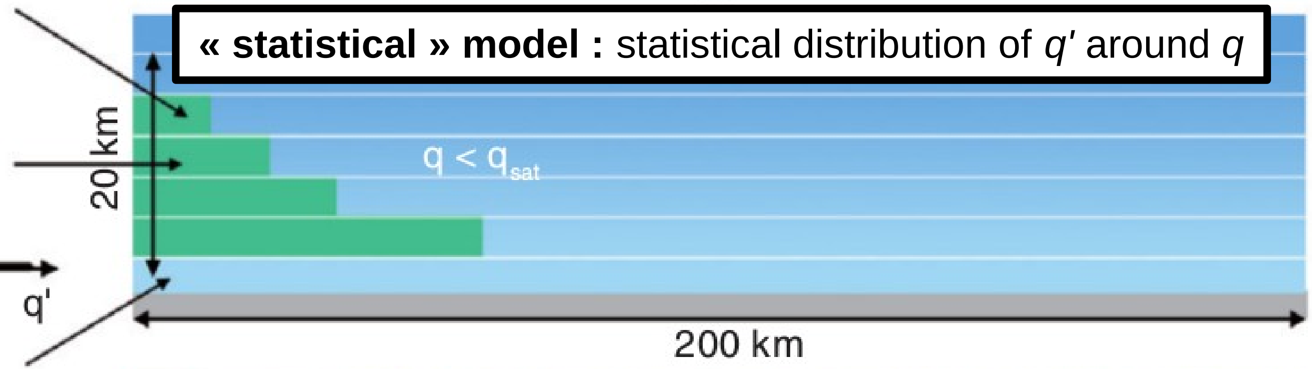
« all or nothing » model :
If $q > q_{sat}$ 100% cloudy, otherwise clear sky.



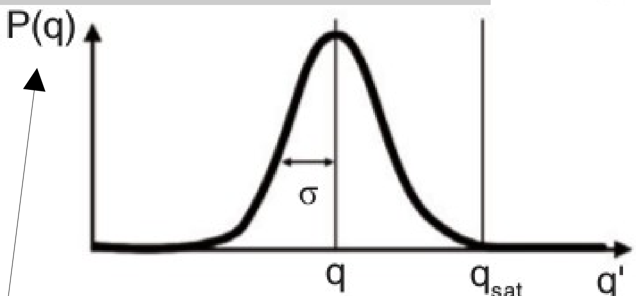


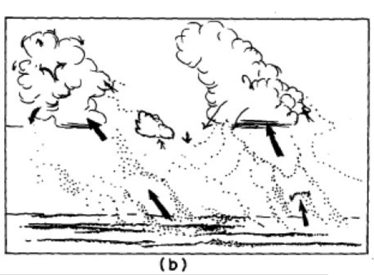
« statistical » model : statistical distribution of q' around q

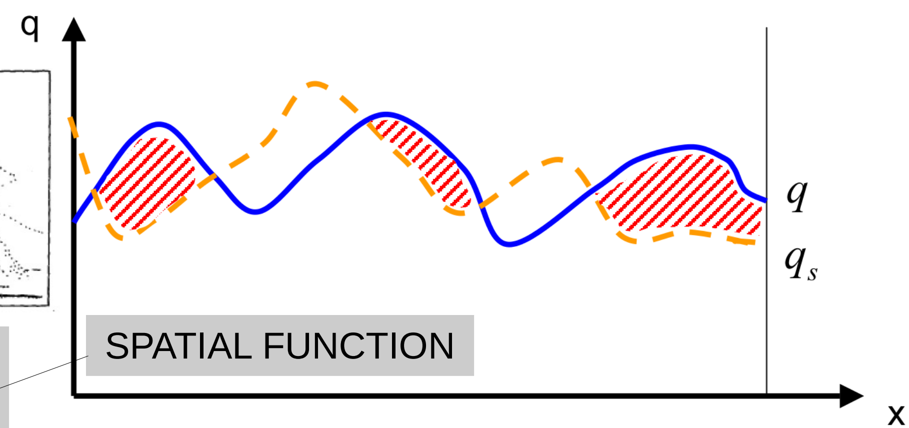




PROBA. DENSITY FUNCTION



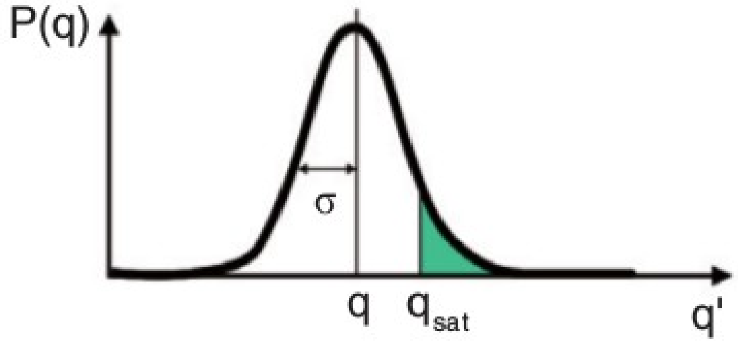


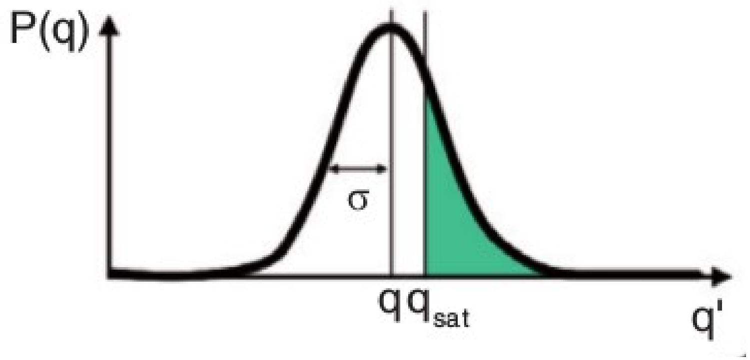


SPATIAL FUNCTION

ergodicity (statistical stationarity) : for turbulent flow, the property of having the spatial, temporal and ensemble averages all converge to the same mean (AMS dictionary)

Statistical cloud scheme 2/2





Mean total water content :

$$\bar{q} = \int_0^{\infty} q \; P(q) \; dq$$

Domain-averaged condensed water content :

$$q_c = \int_{q_{sat}}^{\infty} (q - q_{sat}) P(q) dq$$

Cloud fraction :

$$\alpha_c = \int_{q_{sat}}^{\infty} P(q) dq$$

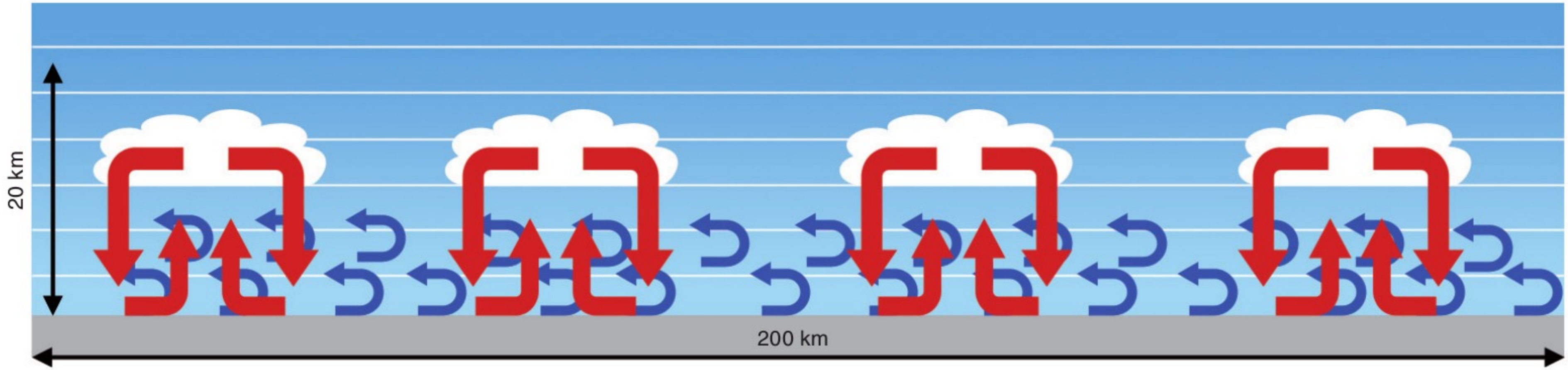
In-cloud condensed water content :

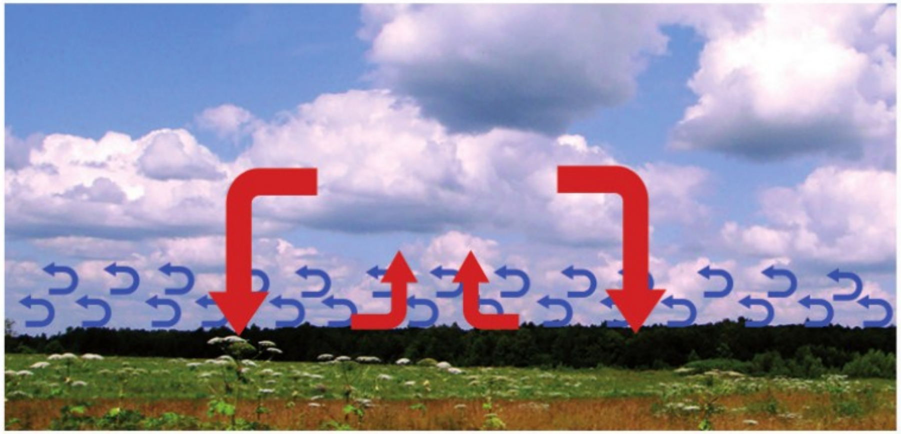
$$q_c^{in} = \frac{q_c}{\alpha_c}$$

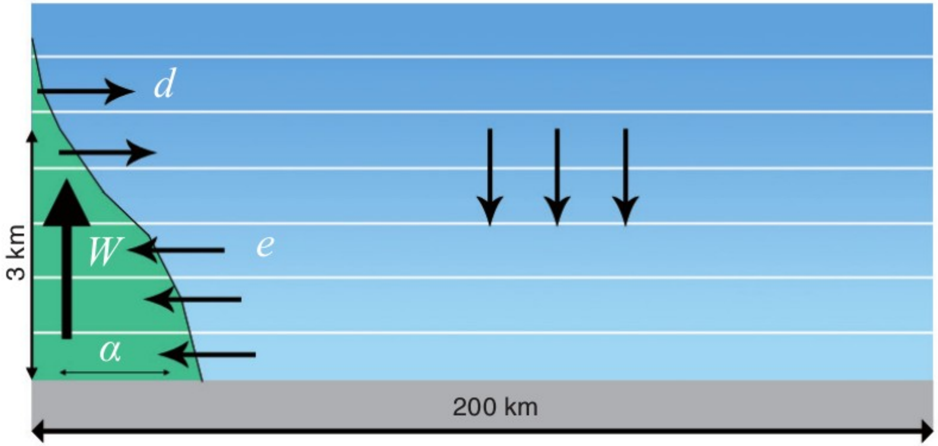
The goal of a cloud scheme is therefore to compute q_c^{in} and the cloud fraction based on the different physical parameterizations.

Clouds over the southern ocean with the Antarctic ice sheet in the distance (Thomas Pesquet, ISS)

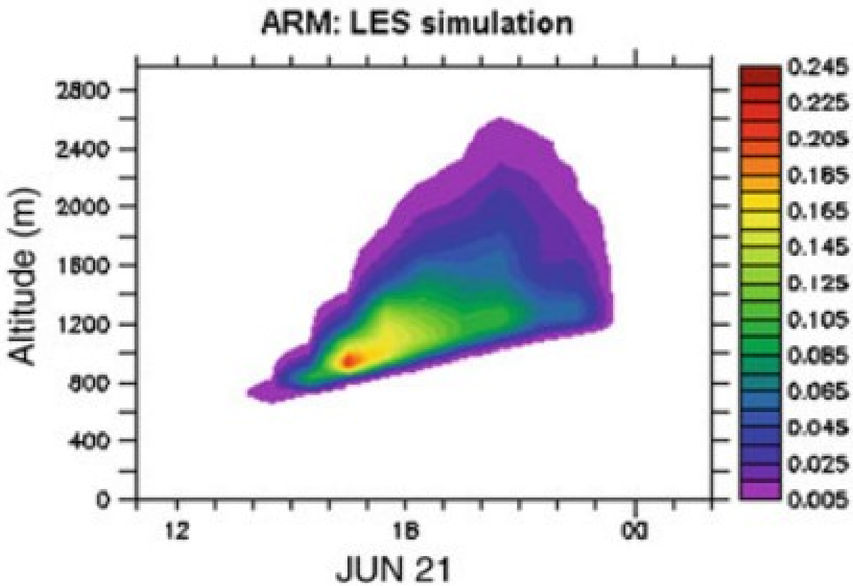
Shallow convection 1/2

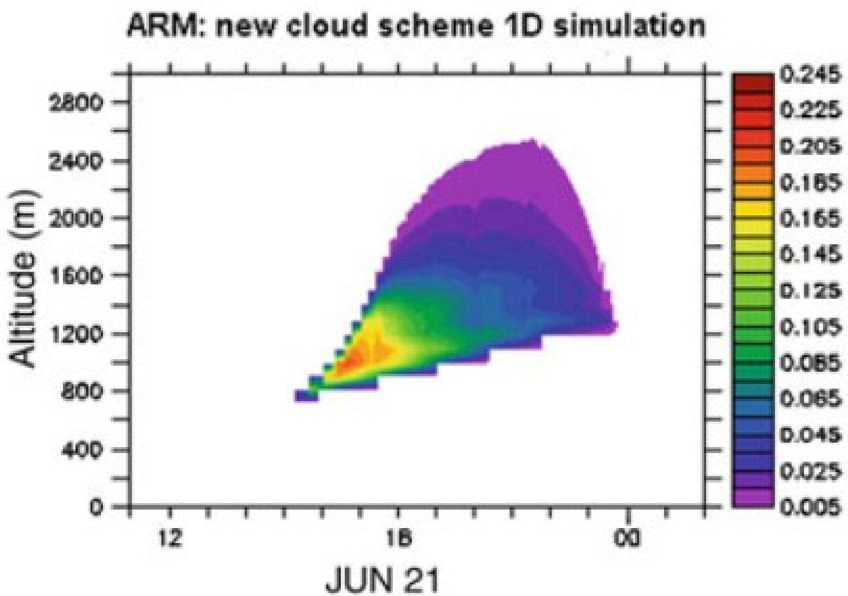




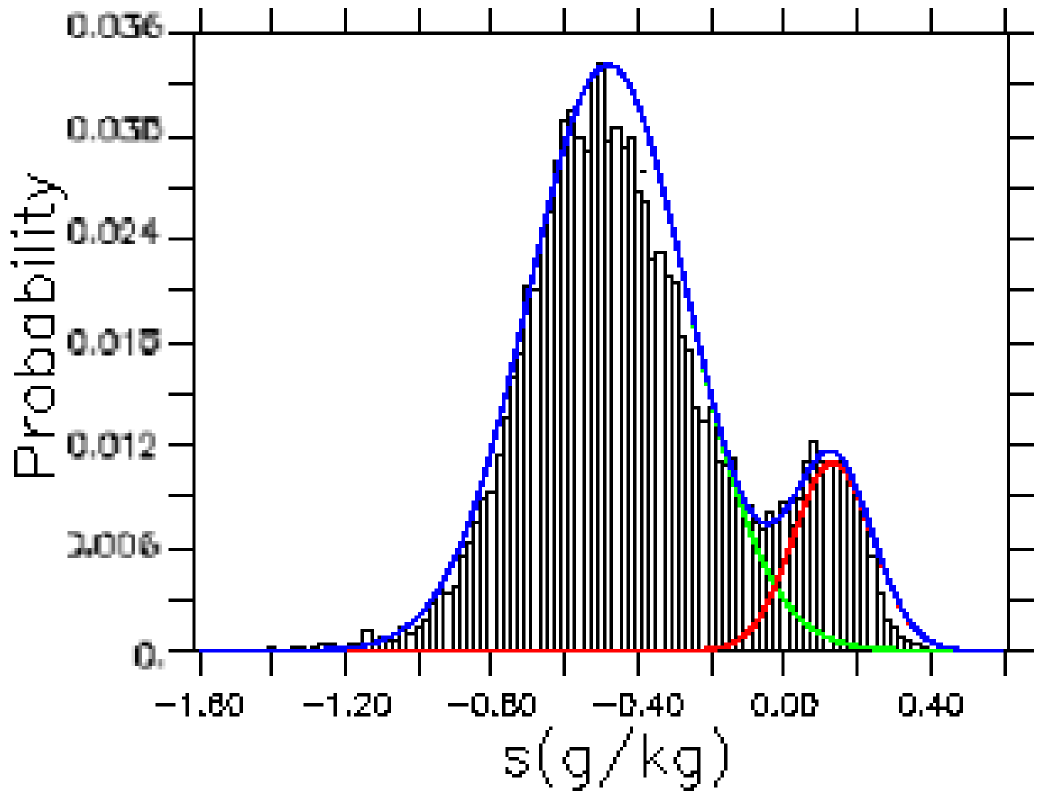


Shallow convection 2/2





[Jam & al., BLM, 2013]

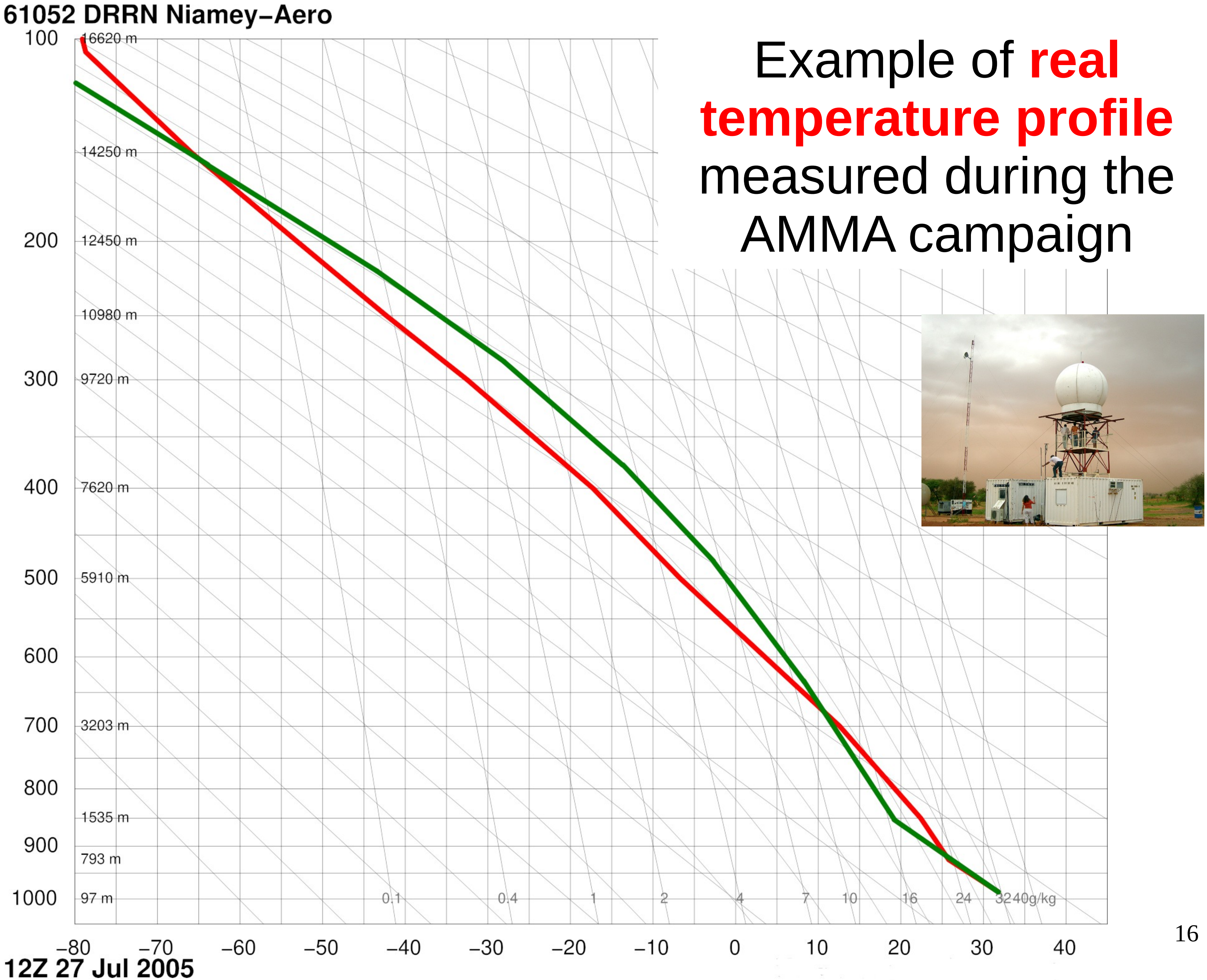


q_c^{in} and the cloud fraction can be computed following :

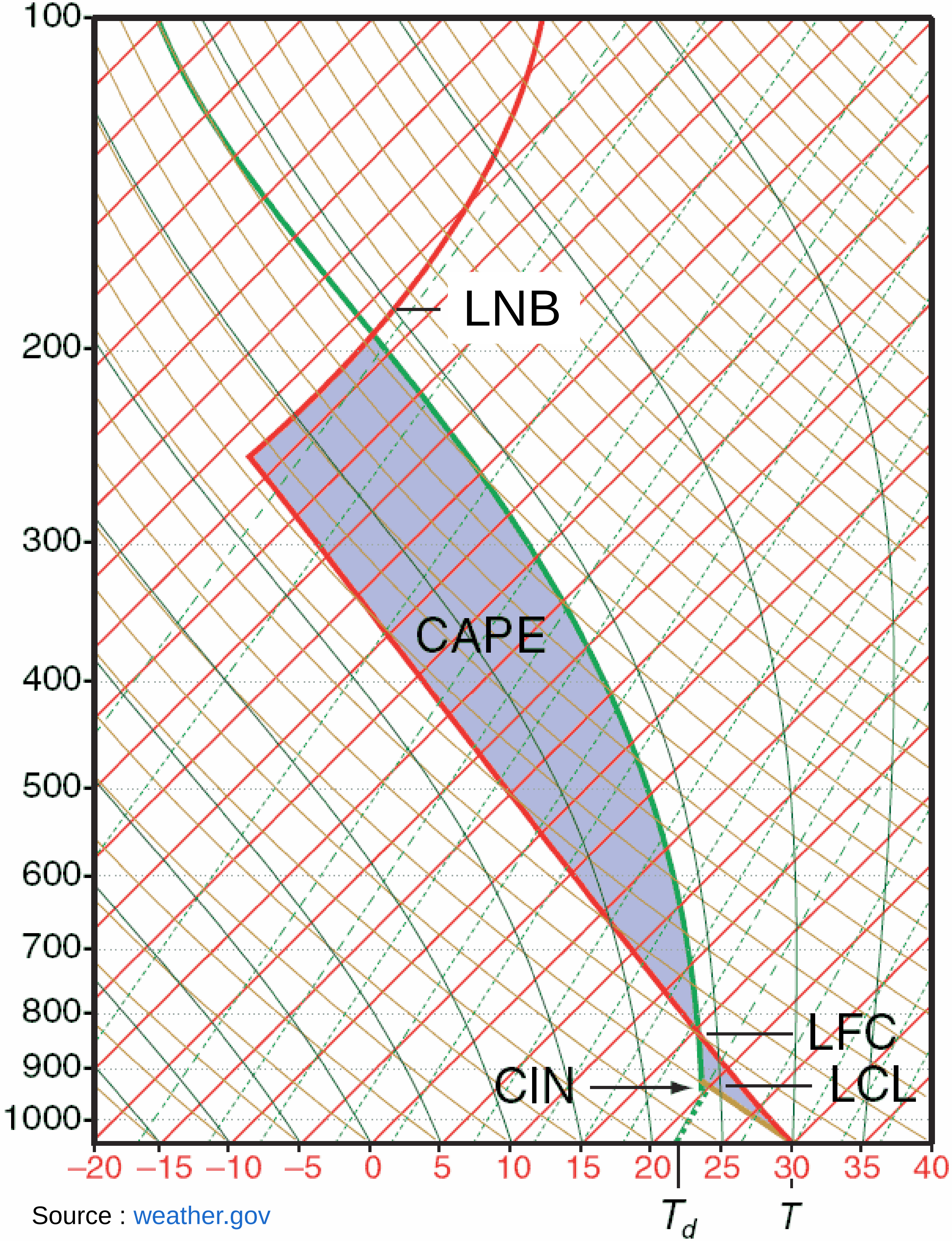
$$q_c^{in} = \int_0^\infty s\,Q(s)\,ds \qquad \alpha_c = \int_0^\infty Q(s)\,ds$$

International Space Station

Example of **real temperature profile** measured during the AMMA campaign



Theory



Main variables shown on a skew-T diagram :

Red profile : Environment
Green profile : Adiabatic ascent

LCL : Lifted Condensation Level
LFC : Level of Free Convection

CIN : Convective INhibition
CAPE : Convective Available Potential Energy

CAPE = (J/kg) $$\int_{z_{LFC}}^{z_{LNB}} \boxed{g\left(\frac{T}{T_{env}} - 1\right)} \cdot dz$$

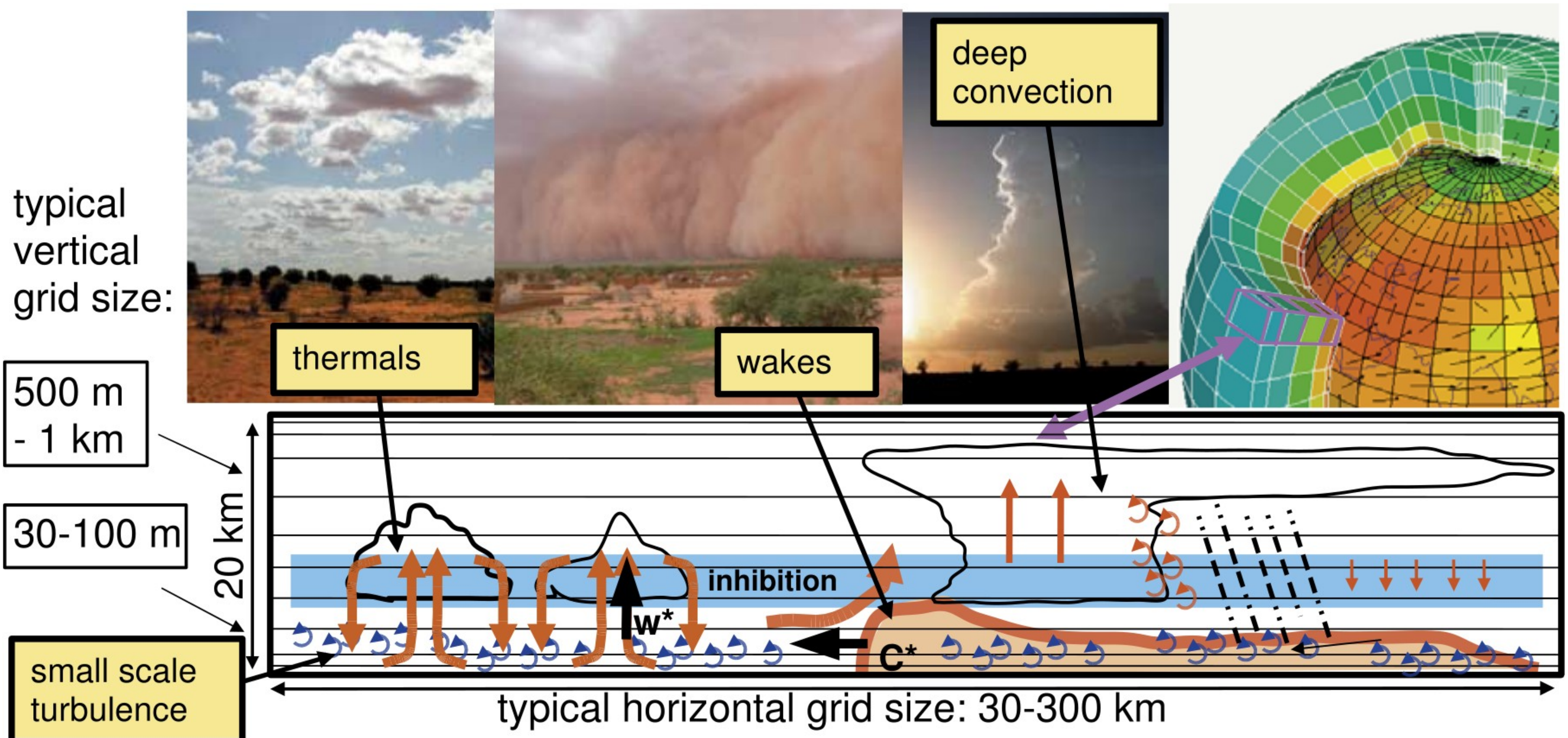
Buoyancy (N/kg)

$$E_c = \frac{1}{2} \cdot w^2$$ and therefore :

$$\boxed{\text{CAPE} = \Delta_{LFC \to LNB} E_c}$$

LMDZ framework

Source : Rio et al., 2009



$$\mathrm{ALE}^{\mathrm{th}} = w_*^2/2$$

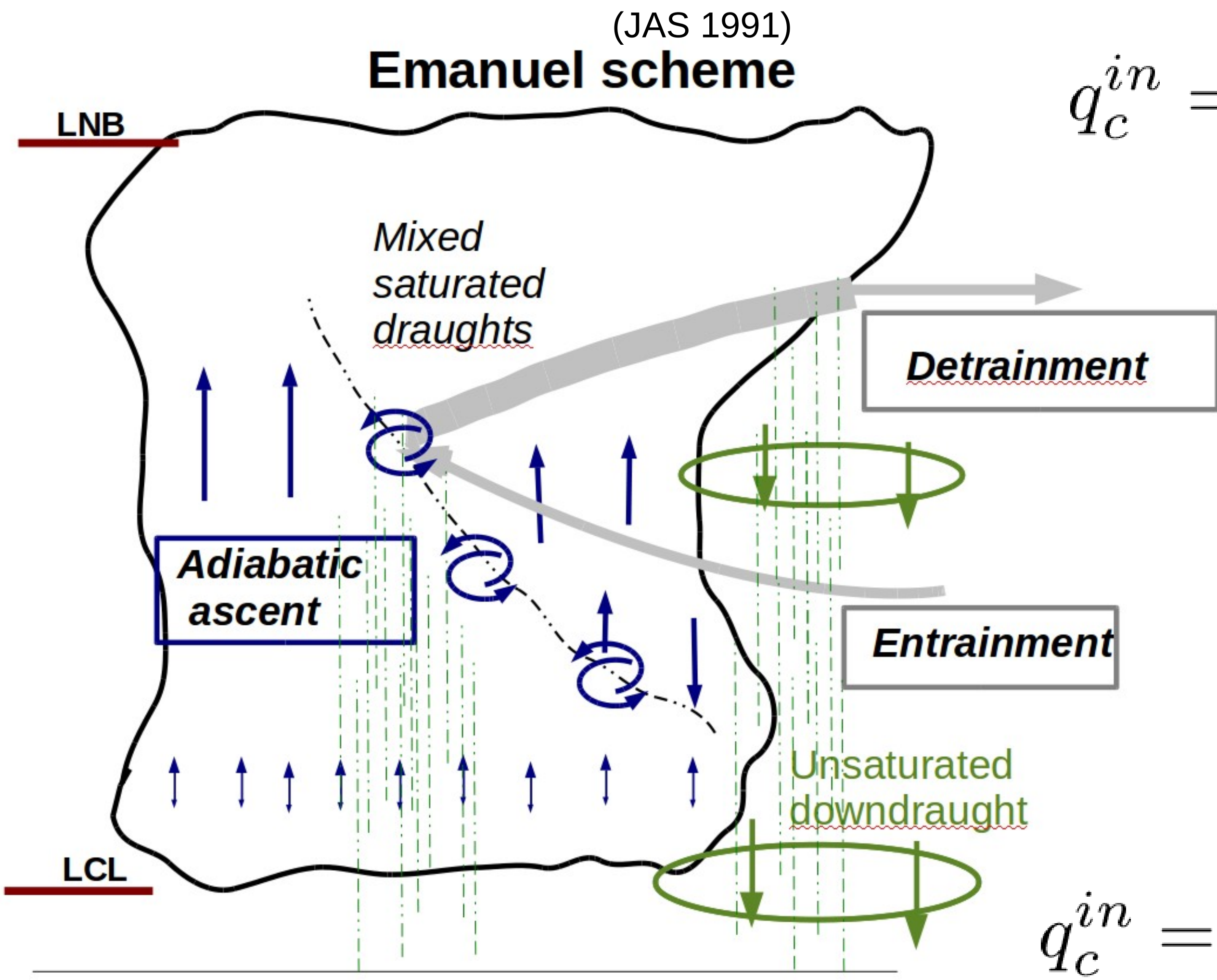
$$\mathrm{ALE}^{\mathrm{wk}} \simeq C_*^2$$

Deep convection is triggered :

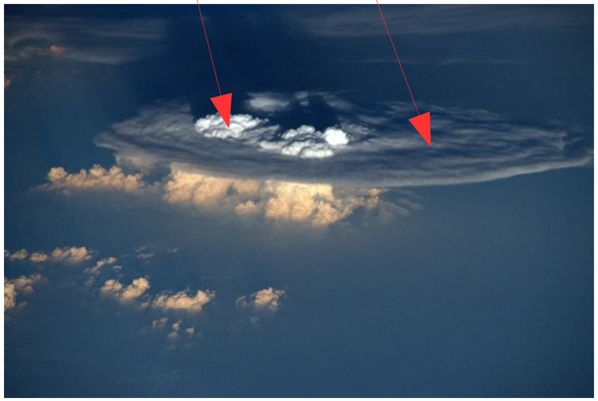
IF : $\max(\mathrm{ALE}^{\mathrm{th}}, \mathrm{ALE}^{\mathrm{wk}}) > |\mathrm{CIN}|$

AND **AND IF** : at least one cloud reaches a given threshold size (stochastic triggering scheme, Rochetin et al., 2014)

Deep convection cloud scheme



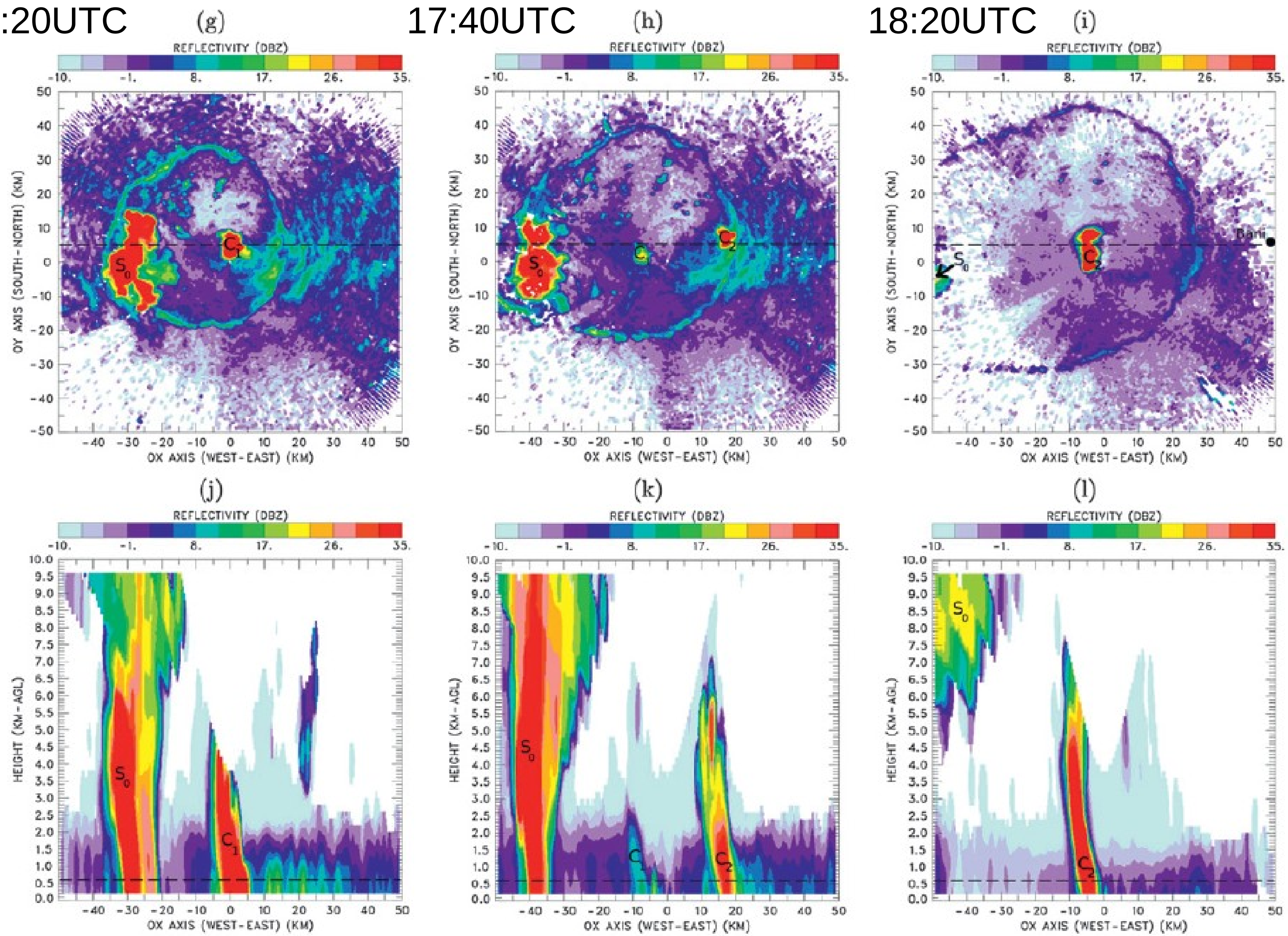
$$q_c^{in} = \frac{\sigma_a\, q_{ca} + \sigma_m\, q_{cm}}{\sigma_a + \sigma_m}$$



$$q_c^{in} = \frac{\frac{M_a}{\rho\, w_a}\, q_{ca} + \frac{\tau\, M_t\, g}{\delta p}\, q_{cm}}{\frac{M_a}{\rho\, w_a} + \frac{\tau\, M_t\, g}{\delta p}}$$

q_c^{in} is computed by the deep convection scheme and $\bar{q}$ is known → cloud fraction is found

Cold pools in Niamey (July 2006)



Lothon et al., MWR, 2011

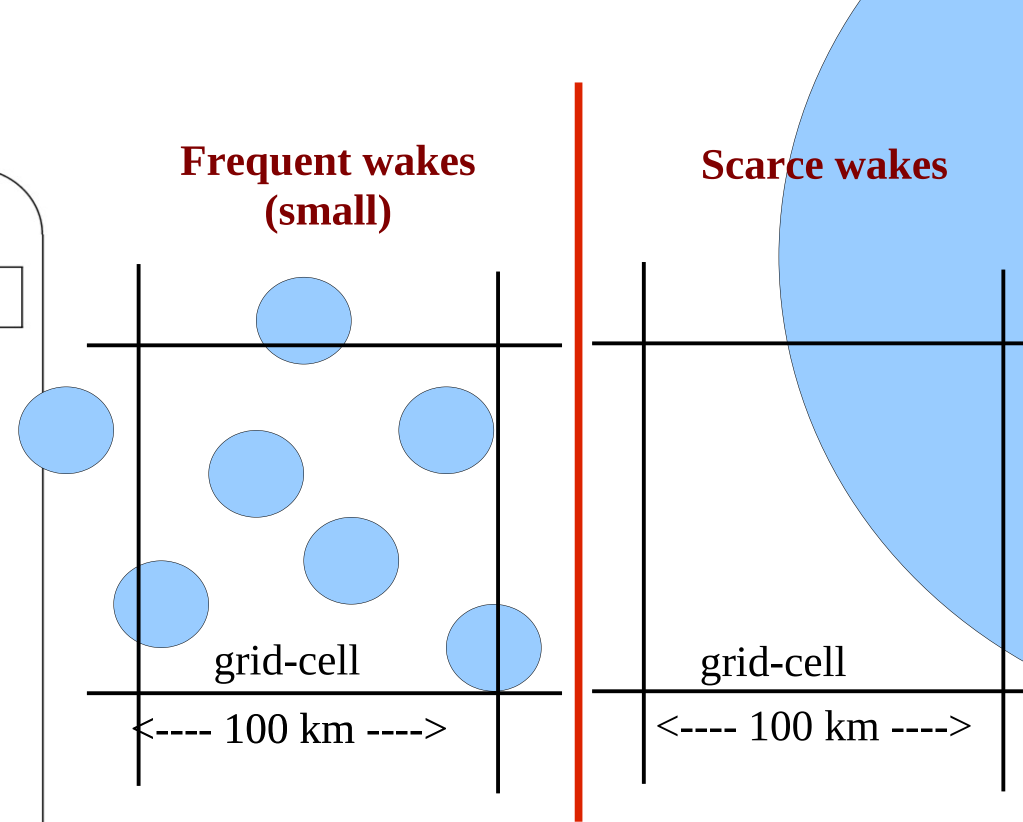
Cold pools (wakes)

The density current (wake) parametrization

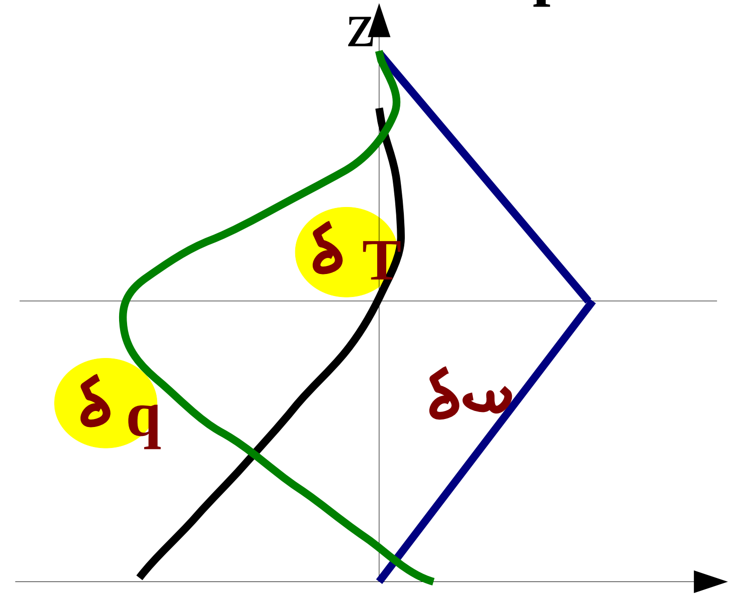
(Grandpeix and Lafore, JAS, 2010 ; Grandpeix et al., JAS 2010)

- Representation of a part of an infinite plane where identical cold pools (radius r, height h) are scattered with an homogeneous density $D_{\mathbf{wk}}$.
- State variables : (i) surface fraction covered by the wakes $\sigma_w = \frac{S_w}{S_t}$ ($\sigma_w = \pi r^2 D_{\mathbf{wk}}$), (ii) temperature and humidity differences (resp. $\delta\theta(p)$ and $\delta q(p)$) between wake and off-wake regions.
- Spreading speed : C_* such that $C_*^2 \simeq$ WAPE (WAke Potential Energy) ; $WAPE = \int_{p_{top}}^{p_{surf}} R_d \delta T_v \frac{dp}{p}$
- Evolutions of $\delta\theta$ and δq profiles are given by conservation equations of mass, energy and water taking into account vertical advection, turbulence and phase changes.
- Turbulence and phase change terms are assumed to be given by the deep convection scheme.
- $\delta\omega$ profile is linear between the surface and the wake top (no mass exchange through the wake boundary) ; it goes back to 0 linearly between the wake top and an arbitrary altitude (about 4000 m).

Grandpeix & Lafore, JAS, 2010



Wake differential profiles



Importance of deep convection

Manabe, Smagorinsky & Strickler, 1965

December 1965

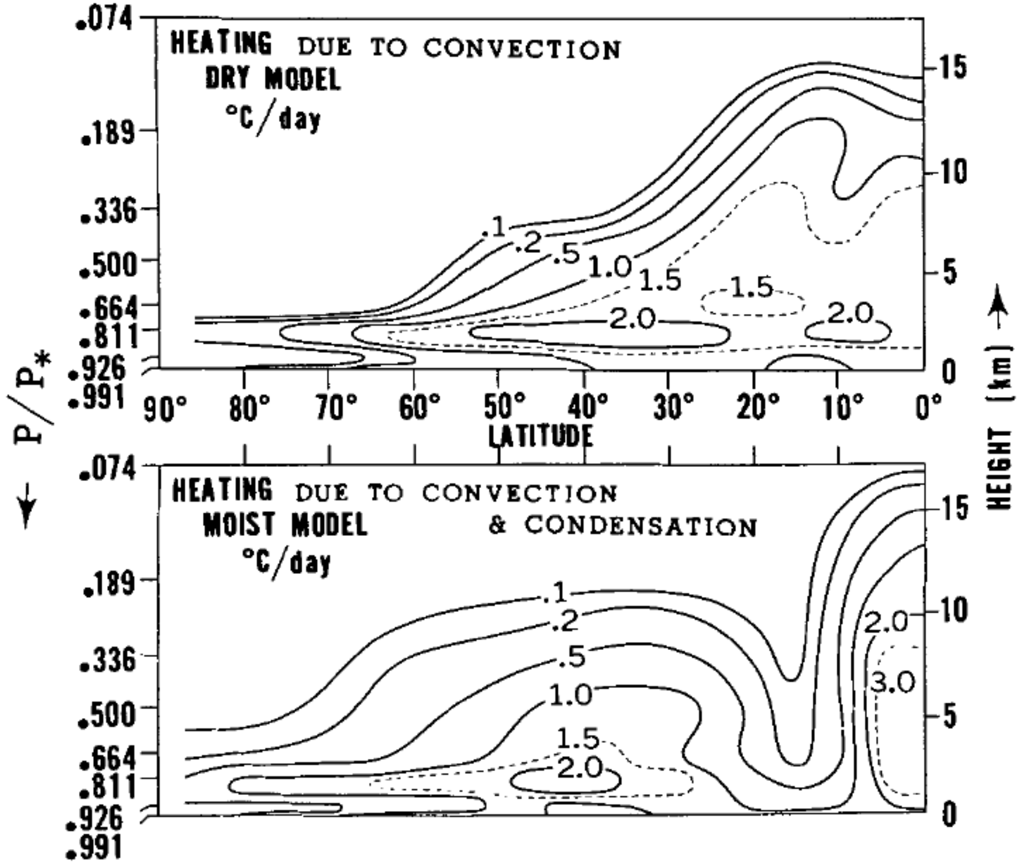
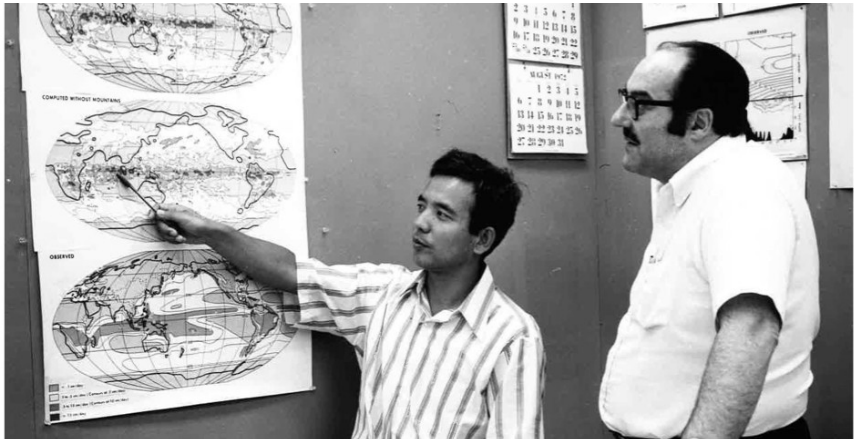
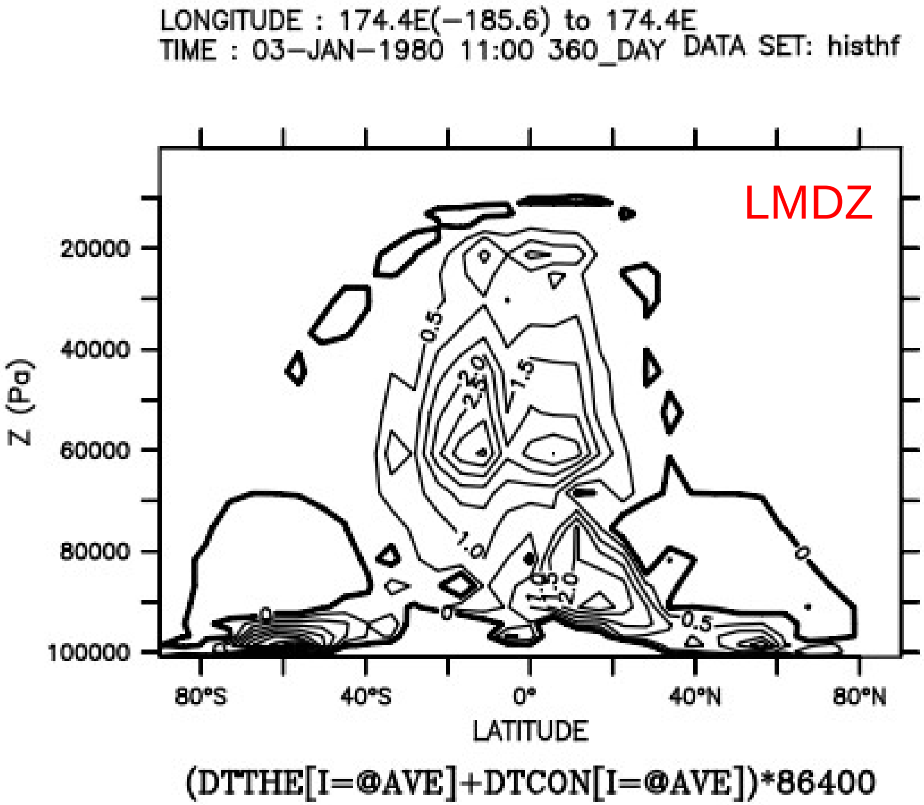


FIGURE 12C1.—In the upper part of the figure the latitude-height distribution of the rate of the net temperature change in °C./day caused by the sensible heat from the earth's surface and the moist convective adjustment in the dry general circulation model. In the lower part, that caused by the heat of condensation, the sensible heat flux from the earth's surface, and the vertical heat flux due to convection is shown for the moist model.

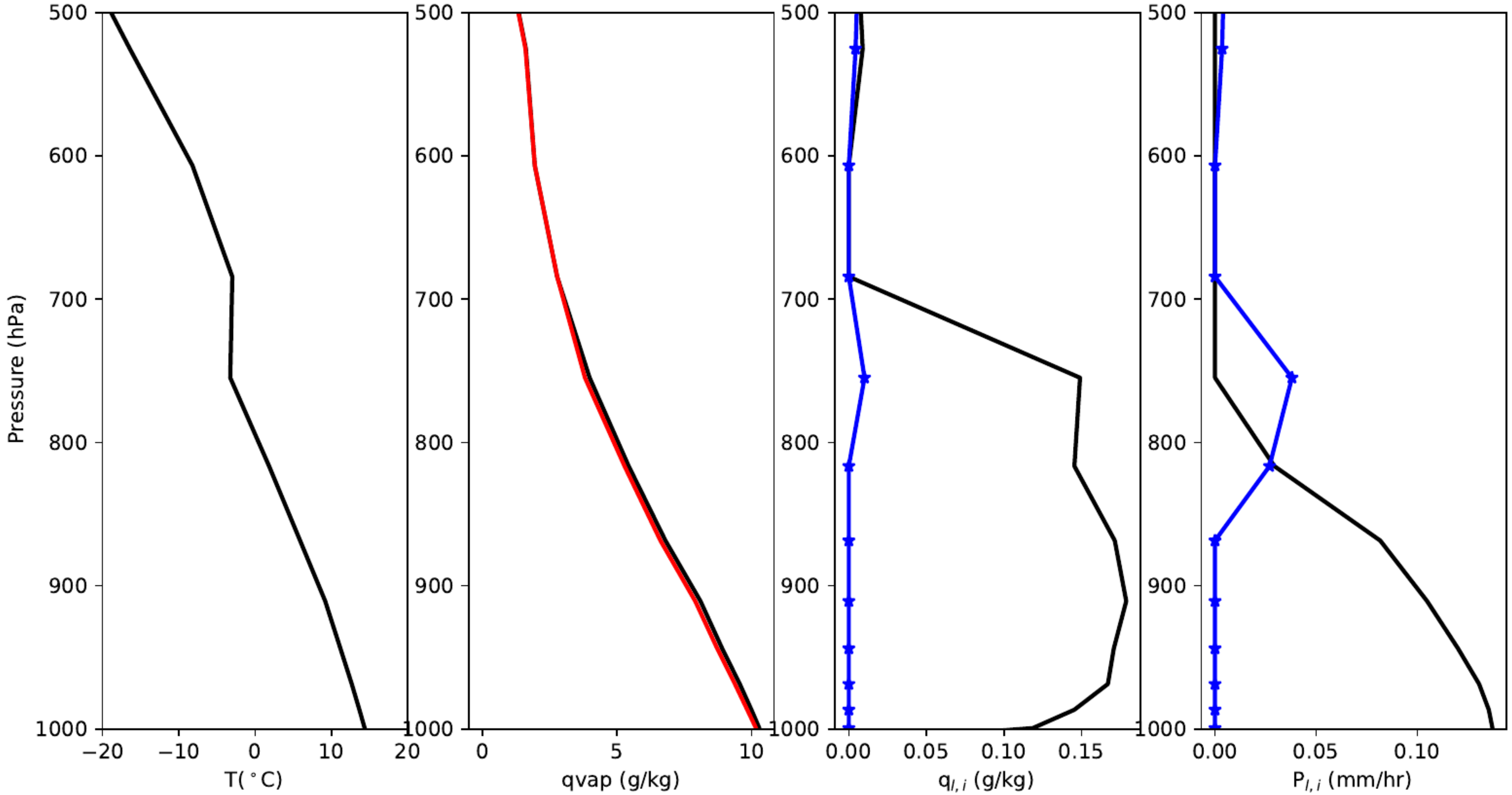




International Space Station

Large scale condensation 1/3

Temperature, water vapor, clouds and precipitation over one timestep



1 **REEVAPORATION** 2 **CLOUD FORMATION** 3 **PRECIPITATION**

Large scale condensation 2/3

- Rain/snow is partly evaporated in the grid below (parameter controlling the evaporation rate) :

$$\frac{\partial P}{\partial z} = \beta[1 - q/q_{sat}]\sqrt{P}$$

1 REEVAPORATION

2 CLOUD FORMATION

If there is shallow convection

q_c^{in} and the cloud fraction can be computed following :

$$q_c^{in} = \int_0^{\infty} s\,Q(s)\,ds \qquad \alpha_c = \int_0^{\infty} Q(s)\,ds$$

If there is no shallow convection

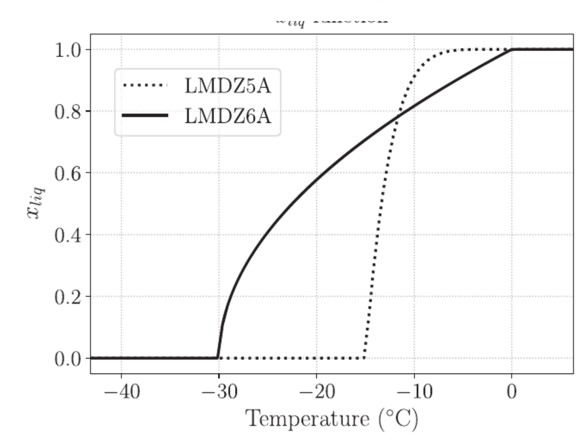
q_c^{in} and the cloud fraction can be computed following :

$$q_c = \int_{q_{sat}}^{\infty} (q - q_{sat}) P(q) dq \qquad \alpha_c = \int_{q_{sat}}^{\infty} P(q) dq$$

Log-normal distribution of total water q_t using a prescribed variance $\sigma = \xi q_t$

In both cases, cloud phase is parameterized using a simple function of temperature :

$$x_{liq} = \left(\frac{T - T_{min}}{T_{max} - T_{min}}\right)^n$$



Large scale condensation 3/3

3 PRECIPITATION

- A fraction of the condensate falls as rain (parameters controlling the maximum water content of clouds and the auto-conversion rate)
- For clouds, it corresponds to a sink term written as :

$$\frac{dq_{lw}}{dt} = -\frac{q_{lw}}{\tau_{convers}}\left[1 - e^{-(q_{lw}/clw)^2}\right]$$

[Kessler 1969, Sundqvist 1988]

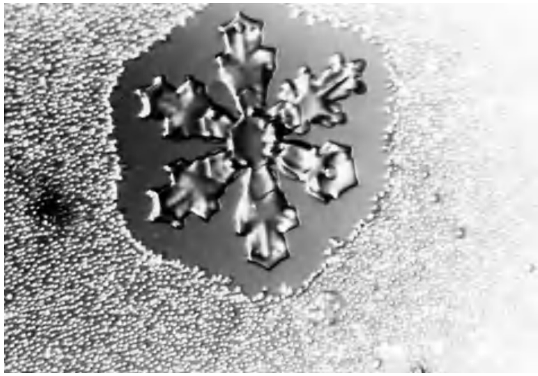
- Another fraction is converted to snow ; the corresponding sink term for ice clouds depends on the divergence of the ice crystal mass flux :
- This fraction depends on the same temperature function as clouds → rain can be created below freezing
- When this occurs, the resulting liquid precipitation **is converted to ice.**
- When freezing, rain releases latent heat, which can potentially bring the temperature back to above freezing. If this is the case, a small amount of rain remains liquid to stay below freezing.

$$\frac{dq_{iw}}{dt} = \frac{1}{\rho}\frac{\partial}{\partial z}(\rho w_{iw} q_{iw})$$

$$w_{iw} = \gamma_{iw} w_0$$

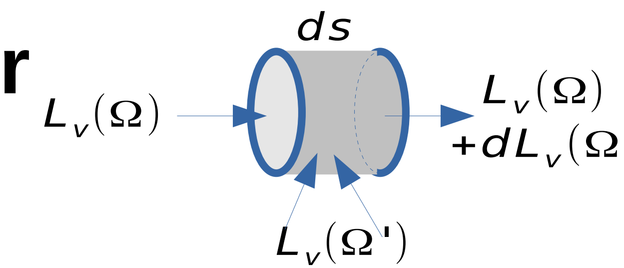
$$w_0 = 3.29(\rho q_{iw})^{0.16}$$

[Heymsfield, 1977; Heymsfield & Donner, 1990]



Growth of an ice crystal at the expense of surrounding supercooled water drops [Wallace, 2005]

Parameterization of radiative transfer



Radiative transfer : well known equations ...
Giving the evolution of luminance along a line of sight:

$$\frac{dL_\nu(\Omega)}{ds} = -\kappa_\nu L_\nu(\Omega) + \kappa_\nu B_\nu(T) - \sigma_\nu L_\nu(\Omega) + \sigma_\nu \frac{1}{4\pi} \int_{4\pi} P(\Omega', \Omega) L_\nu(\Omega') d\Omega'$$

absorption — **emission** — **Scattered in other directions** — **Scattered from other directions**

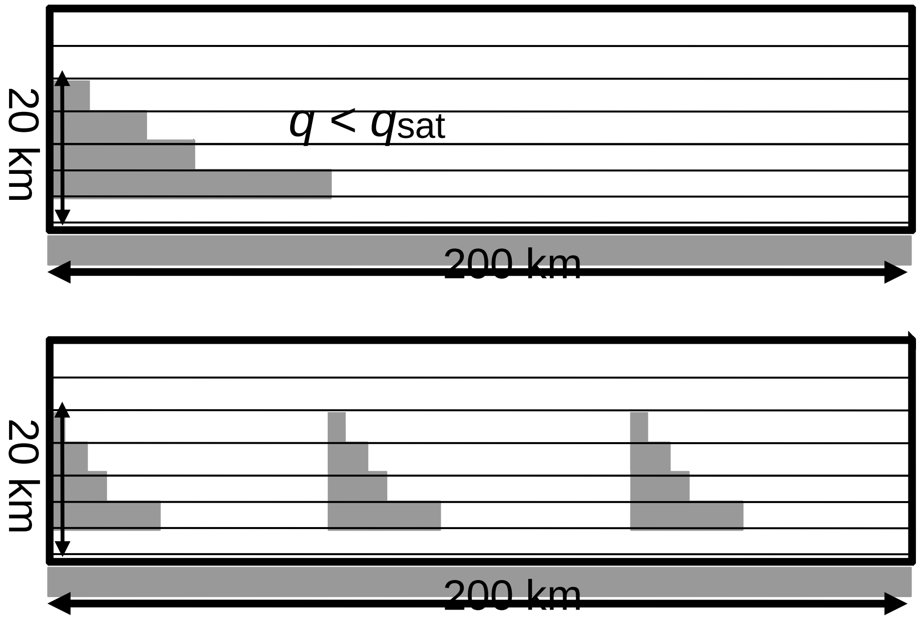
(see Part I)

Solving the radiative transfer equation requires :

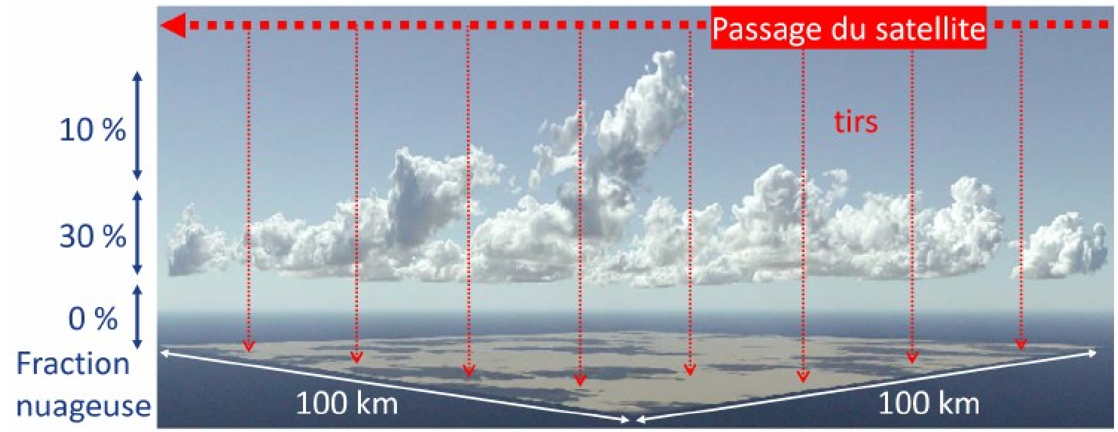
- ***q****$_{rad}$* to compute the optical depth ;
- **Cloud droplet and crystal sizes** to compute the optical properties ;
- The cloud fraction **α** to compute the heating rates in the clear-sky (1-α) and cloudy (α) columns.

$$q_{rad} = q_c^{in,\,cv} \alpha_c^{cv} + q_c^{in,\,lsc} \alpha_c^{lsc}$$

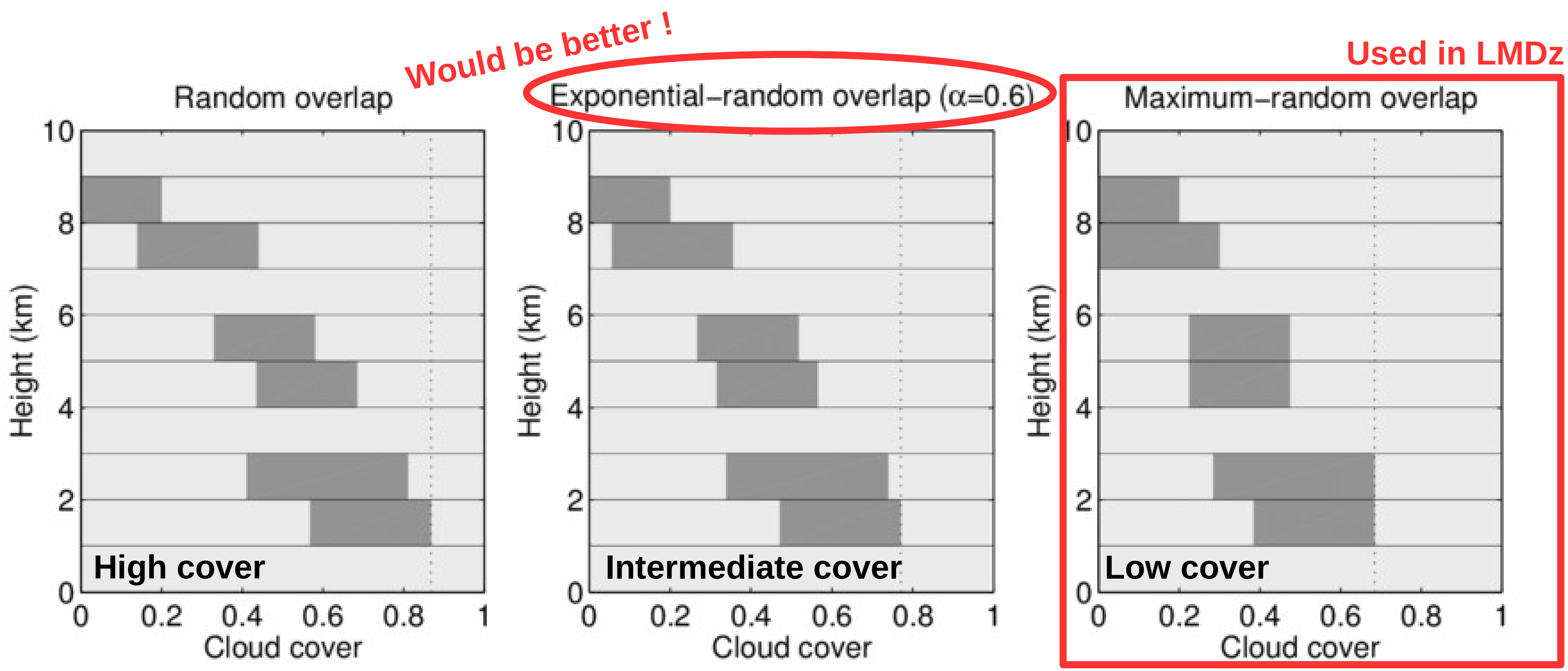
$$\alpha_c = \min\left(\alpha_c^{cv} + \alpha_c^{lsc},\, 1\right)$$



CF versus height is known, but radiation also needs to know the total cloud **cover ;** we therefore parameterize the **cloud overlap**



[Justine Charrel 2025]



[Radiation parameterization and clouds, Hogan, 2009]

Radiative forcing

LW radiative forcing

Positive : clouds reduce the LW outgoing radiation

Annual mean : +29 W m^{-2}

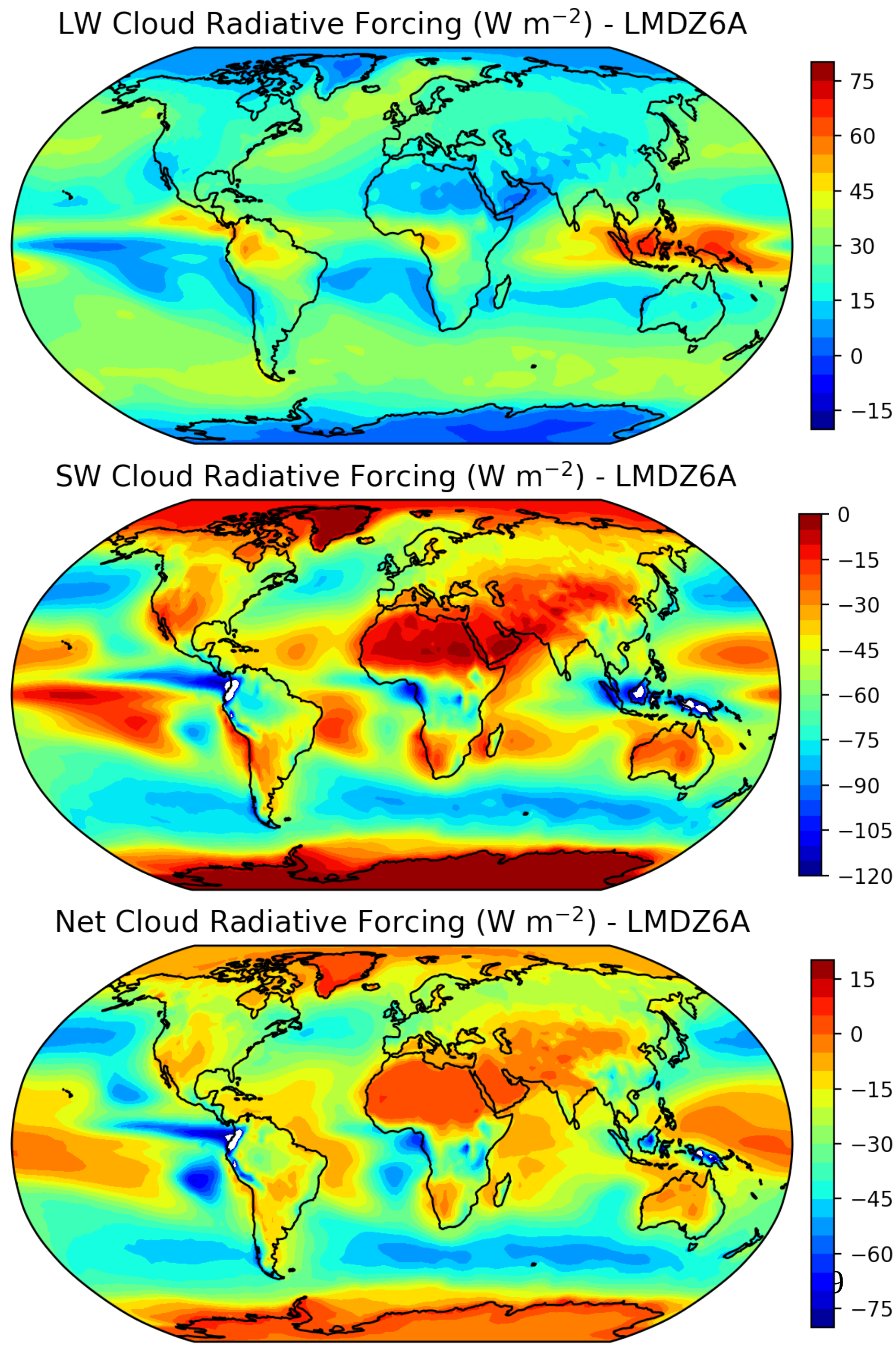
SW radiative forcing

Negative : clouds reflect the incoming SW radiation

Annual mean : -47 W m^{-2}

Net forcing : **Cooling**

Annual mean : -18 W m^{-2}



Clouds and precip : toward LMDZ v.7

- **Improved reevaporation** (Ludovic Touzé-Peiffer 2021 PhD thesis p117)
- **Prognostic variances for cloud PDFs** (Louis d'Alençon)
- **Mixed-phase clouds** (Lea Raillard)
- **Supersaturation** with respect to ice in high clouds (A. Borella)
- **New ice precipitation scheme** (Lea Raillard & friends)
- **Tuning of the ecRad radiative transfer scheme** inside LMDZ using LES simulations (Maëlle Coulon-Decorzens)

- **New radiative transfer scheme ecRad** ECMWF (Abderrahmane Idelkadi et al.)
  - McICA (Monte-Carlo Independent Column Approximation, Pincus et al. 2005) → subgrid scale heterogeneities
  - SPARTACUS (3D effects at cloud sides, Hogan et al., 2016)

Useful links and references

- **On the general LMDZ v.6 cloud scheme :**
  - Madeleine et al. 2020 : https://doi.org/10.1029/2020MS002046
  - Supplementary material : https://zenodo.org/record/3942031
- **On the deep convection scheme :**
  - Grandpeix et al., 2004 : https://doi.org/10.1256/qj.03.144
  - Rio et al., 2009 : https://doi.org/10.1029/2008GL036779
- **Process animations :**
  - Satellite animation using the SEVIRI instrument : http://pmm.nasa.gov/education/videos/water-vapor-animation
  - Animations of updrafts and triggering of deep convection over the mountains of Arizona : https://animations.atmos.uw.edu, sections 15.1 and 16.5
  - Animation of the cloud field in high resolution LMDZ simulations : https://lmdz.lmd.jussieu.fr/pub/Training/Presentations/202601/video_LMDZ.mp4
  - Time lapse video of cold pools : https://lmdz.lmd.jussieu.fr/pub/Training/Presentations/202601/video_wakes.mp4

Supplementary technical information

Cloud variables in LMDZ

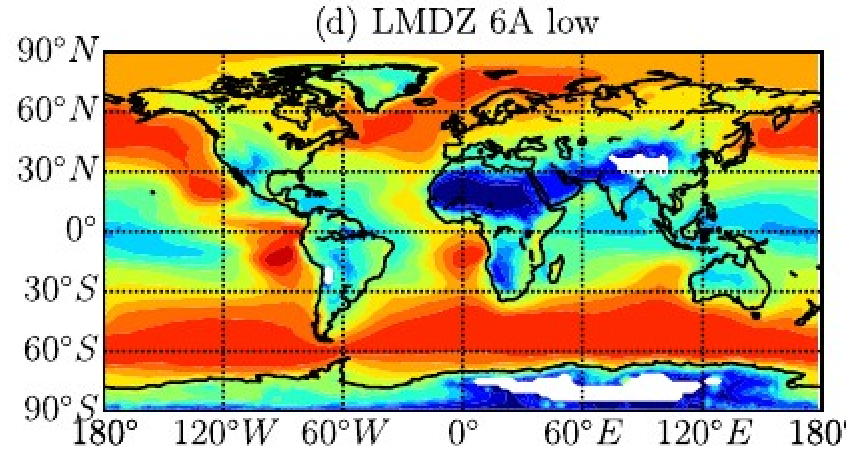
prw (2D) : Precipitable water (kg/m^2)
pluc/plul (2D) : Convective/lsc rainfall (kg/m^2/s)
snow (2D) = surface snowfall (kg/m^2/s)
lwp (2D) : Cloud liquid water path (kg/m^2)
iwp (2D) : Cloud ice water path (kg/m^2)

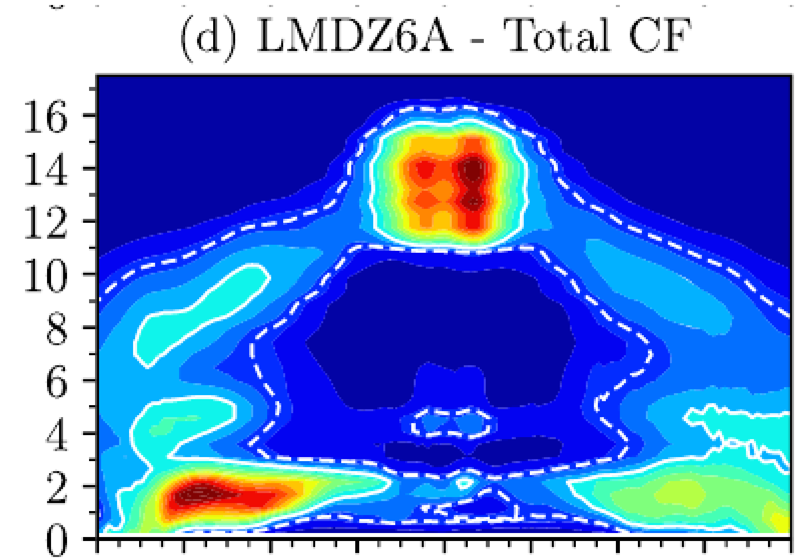
ovap (3D) : water vapor content (kg/kg)
oliq (3D) : cloud liquid water content (kg/kg)
ocond (3D) : cloud liq+ice water content (kg/kg)

pr_lsc_l (3D) : lsc rain mass fluxes (kg/m^2/s)
pr_lsc_i (3D) : lsc snow mass fluxes (kg/m^2/s)

rneb (3D) : cloud **fraction** (%)
cldh (2D) : High-level cloud **cover** (%)
cldm (2D) : Mid-level cloud **cover** (%)
cldl (2D) : Low-level cloud **cover** (%)
cldt (2D) : Total cloud **cover** (%)

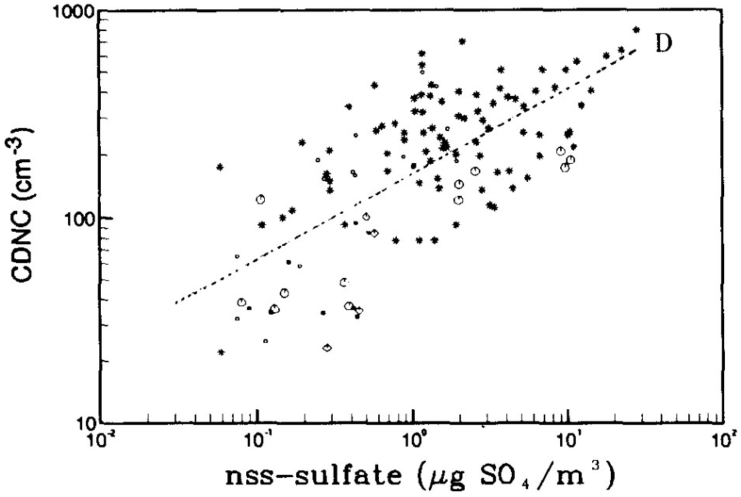
low-level clouds = below 680 hPa or ~3 km
mid-level clouds = between 680 and 440 hPa
high-level clouds = above 440 hPa or ~6.5 km





Optical properties of liquid clouds

$$\mathrm{CDNC} = 10^{1.3 + 0.2\log(m_{\mathrm{aer}})}$$



Link cloud droplet number concentration to soluble aerosol mass concentration (Boucher and Lohmann, Tellus, 1995)

N = CDNC

$$r_3 = \left(\frac{l\,\rho_{\mathrm{air}}}{(4/3)\,\pi\rho_{\mathrm{water}}N} \right)^{1/3}$$

$$r_{\mathrm{e}} = \frac{\int r^3 n(r)\,\mathrm{d}r}{\int r^2 n(r)\,\mathrm{d}r}$$

$$r_{\mathrm{e}} = 1.1\ r_3$$

Size-dependent computation of cloud optical properties (Fouquart [1988] in the SW, Smith and Shi [1992] in the LW)

Optical properties of ice clouds

Optical properties are computed using Ebert and Curry [1992], based on the computed crystal sizes.

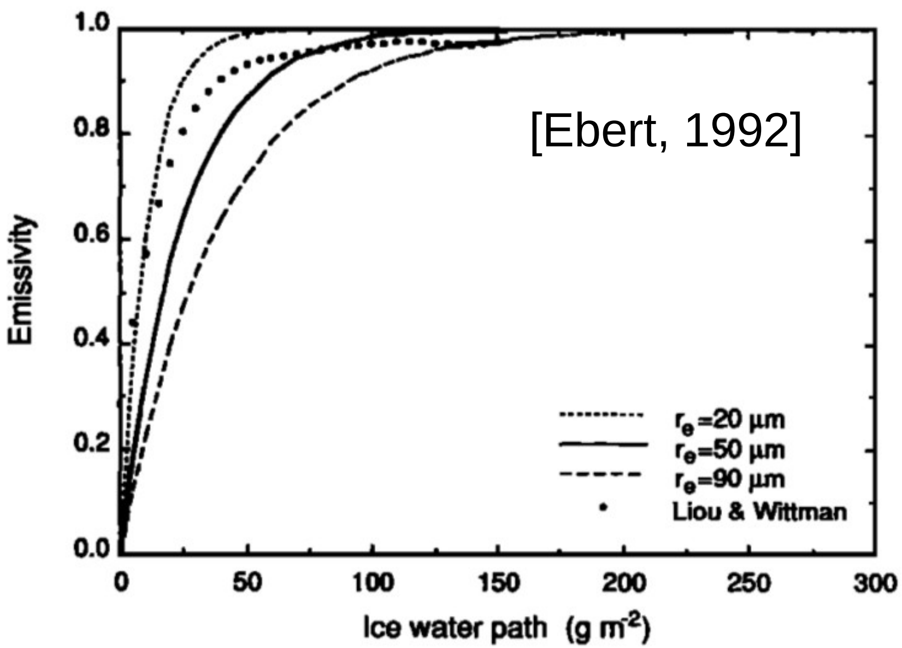
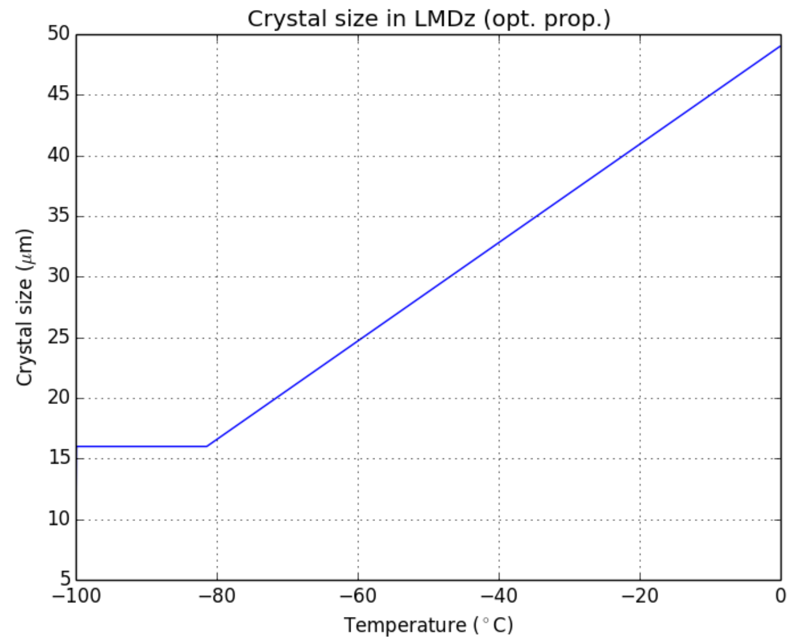


Fig. 5. Cirrus infrared emissivity for r_e = 20, 50, and 90 μm as a function of ice water path. The solid circles represent values computed using the parameterization of *Liou and Wittman* [1979].



Crystal sizes follow
r = 0.71T + 61.29 in µm
[Iacobellis et Somerville 2000]
with r_{min} ~ 10 µm (tuneable)
for T < -81.4°C *[Heymsfield et al. 1986]*

Shallow cumulus clouds

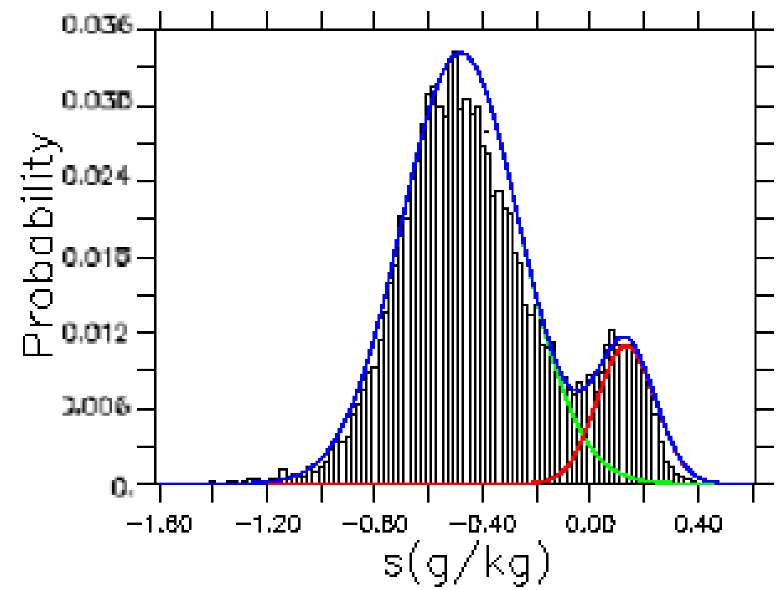
Bi-Gaussian distribution of saturation deficit s:

$$Q(s) = (1-\alpha_{th}) f(s, s_{env}, \sigma_{env}) + \alpha_{th} f(s, s_{th}, \sigma_{th})$$

One mode for thermals : s_{th}, σ_{th}

One mode for their environment : s_{env}, σ_{env}

[Jam & al., BLM, 2013]

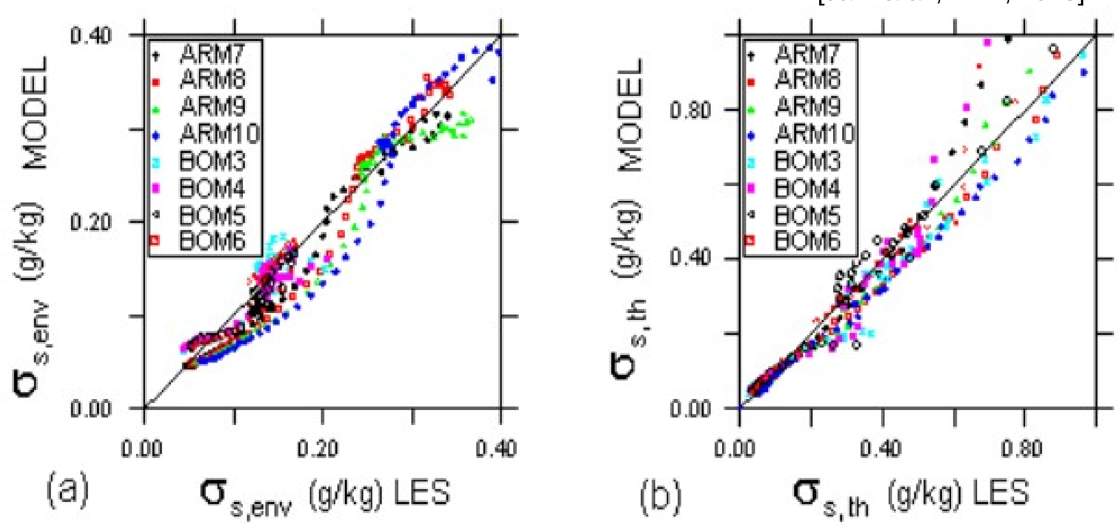


S_{env}, s_{th}, and α are given by the shallow convection scheme, and the distribution's variances are parameterized following :

$$\sigma_{\mathrm{s,env}} = c_{\mathrm{env}} \frac{\alpha^{\frac{1}{2}}}{1-\alpha} (\overline{s}_{\mathrm{th}} - \overline{s}_{\mathrm{env}}) + b\, \overline{q}_{t_{\mathrm{env}}}$$

$$\sigma_{\mathrm{s,th}} = c_{\mathrm{th}}\, \alpha^{-\frac{1}{2}} (\overline{s}_{\mathrm{th}} - \overline{s}_{\mathrm{env}}) + b\, \overline{q}_{t_{\mathrm{th}}}$$

[Jam & al., BLM, 2013]



q_c^{in} and the cloud fraction can be computed following :

$$q_c^{in} = \int_0^{\infty} s\, Q(s)\, ds \qquad \alpha_c = \int_0^{\infty} Q(s)\, ds$$

Tuning parameters

$$\frac{\partial P}{\partial z} = \beta[1 - q/q_{sat}]\sqrt{P}$$

coef_eva=0.0001

$$\frac{dq_{lw}}{dt} = -\frac{q_{lw}}{\tau_{convers}}\left[1 - e^{-(q_{lw}/clw)^2}\right]$$

cld_lc_lsc=0.00065
cld_tau_lsc=900

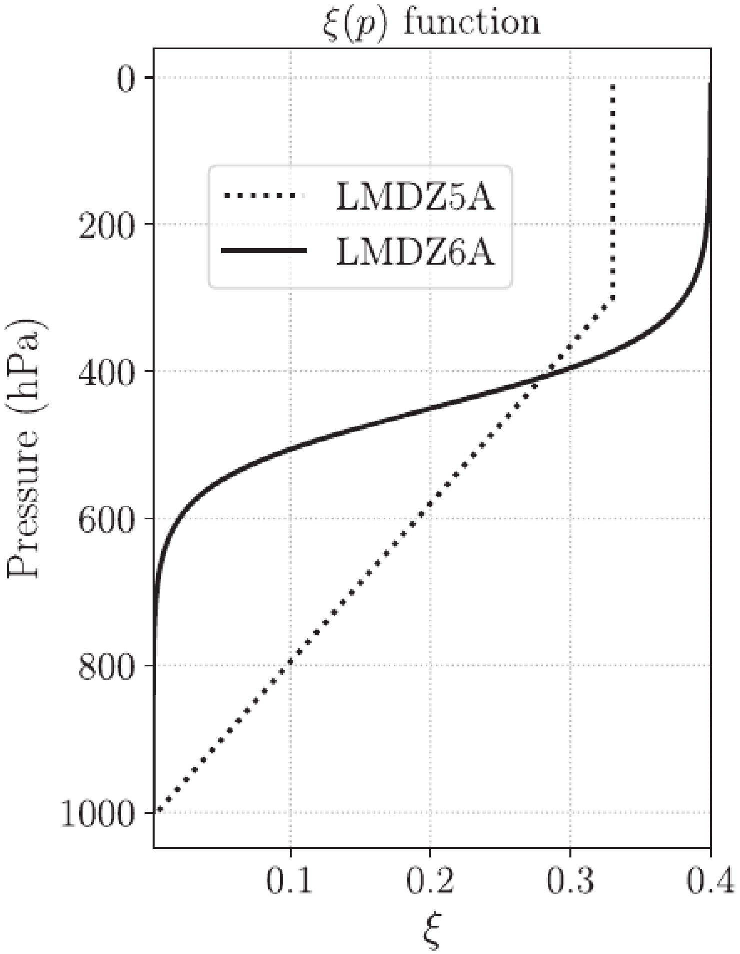
$$\frac{dq_{iw}}{dt} = \frac{1}{\rho}\frac{\partial}{\partial z}(\rho w_{iw} q_{iw})$$

$$w_{iw} = \gamma_{iw} w_0$$

ffallv_lsc=0.8

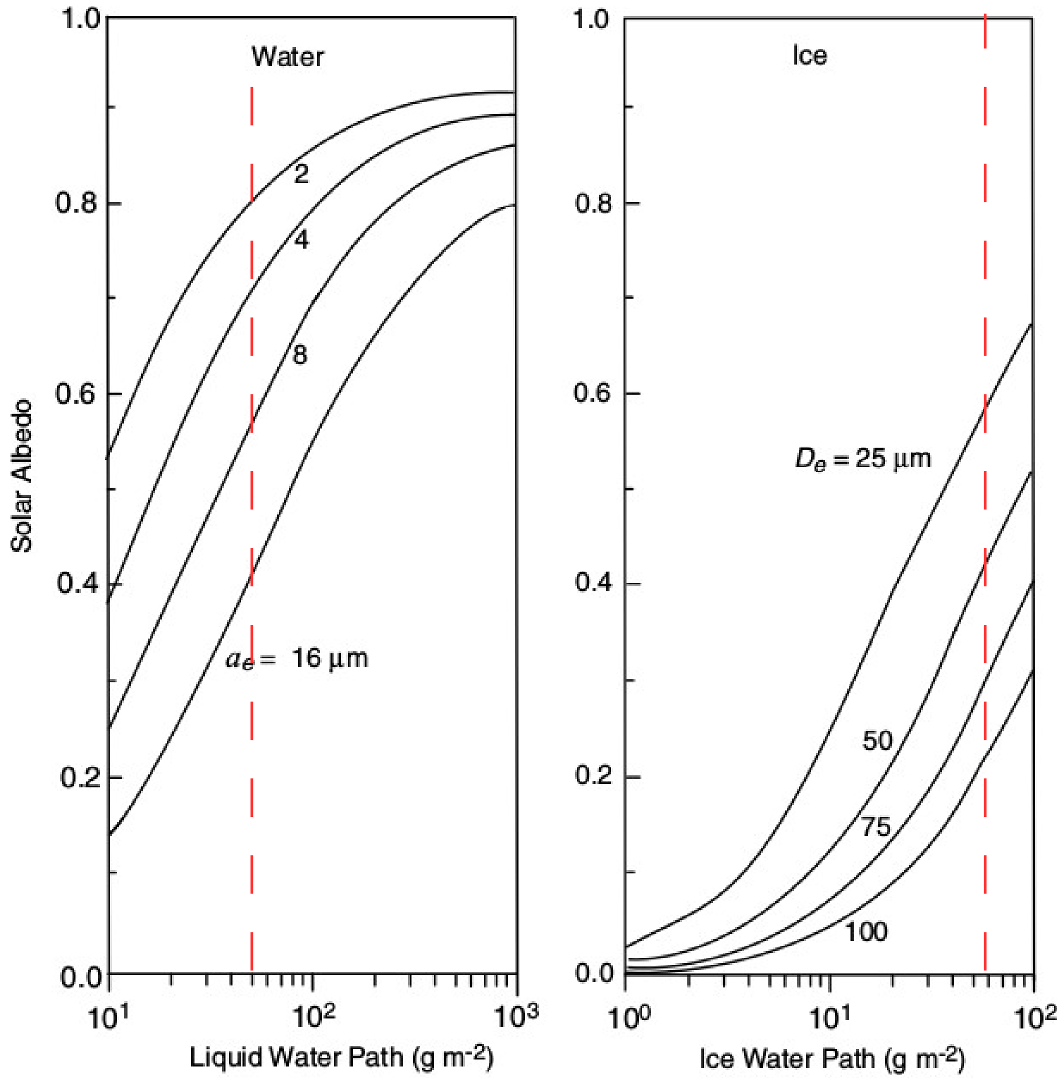
$$\sigma = \xi q_t$$

ratqsp0=45000
ratqsdp=10000
ratqsbas=0.002
ratqshaut=0.4



Importance of cloud phase

- Clouds reflect sunlight (negative forcing, cooling) and emit in the infrared (positive forcing, warming) ;
- For the same water content, liquid clouds reflect more sunlight than ice clouds ;
- <u>For liquid clouds :</u> if the cloud water content increases, there is a negative forcing (reflection dominates) ;
- <u>For ice clouds :</u> if the cloud water content increases, the forcing depends on the size of the crystals.



[Liou 2002]

Précision sur les sorties

- L'eau nuageuse que voit le rayonnement n'est pas la même que l'eau nuageuse utilisée dans la physique et la dynamique. Lors de la conversion en précipitation dans fisrtilp, c'est une moyenne de l'eau restante dans le nuage PENDANT la précipitation qui est stockée dans radliq pour le rayonnement, et non l'eau restante À LA FIN du pas de temps, qui elle est utilisée dans la physique et advectée par la dynamique. (C'est un choix qui peut être discuté.) Du coup, il est facile de se perdre et de voir des incohérences dans les sorties entre l'eau qui sort du rayonnement et celle qui sort de la physique.
- Pour résumer, sont écrites ci-dessous les variables qui sont égales avec entre parenthèses le nom de la routine correspondante ou "netcdf" quand il s'agit des sorties :
- Rayonnement : xflwc(newmicro) + xfiwc(newmicro) = cldliq(physiq) = radliq(fisrt) = lwcon(netcdf) + iwcon(netcdf)
- Physique / dynamique : ql_seri(physiq) + qs_seri(physiq) = ocond(netcdf)
- Attention cependant : radliq(fisrt) /= ocond(netcdf) autrement dit : lwcon(netcdf) + iwcon(netcdf) /= ocond(netcdf) (ce qui n'est pas du tout évident)
- Si on enlève la moyenne faite par fisrtilp lors de la conversion en précipitation, on obtient bien l'égalité entre l'ensemble des variables. Ci-contre un exemple de profils des différentes variables. Cette moyenne tend à augmenter l'eau nuageuse transmise au rayonnement. Comme il s'agit d'une moyenne sur le pas de temps plutôt qu'une eau restante à la fin du pas de temps, elle tend donc, a priori, à faire des nuages plus brillants. Cette moyenne remonte à Le Treut et Li (1991), où le pas de temps physique du modèle était d'une demi-heure contre 15 min actuellement.