LES, CRM : capabilities, sensitivities, evaluation

The decision to perform simulations framed by :

interplay

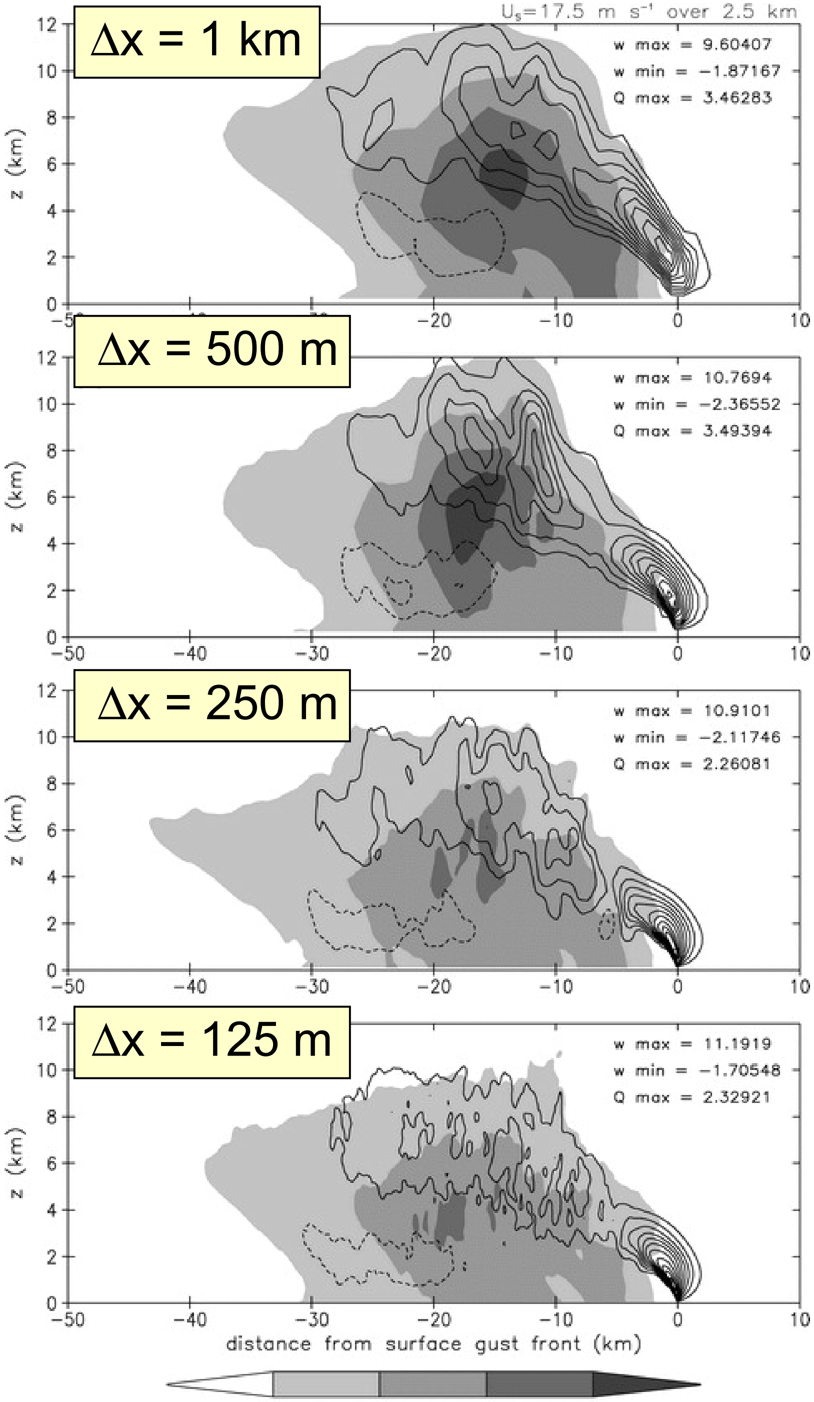
* scientific questions which requires fine-scale modelling
* model capabilities (design, suitable physics & numerics, diagnostics)
* computing power (constrains the focus on specific time & space scales)
* human work, exchanges and motivation

Model capabilities :

examples of sensitivities
suited and unsuited use of observations
model intercomparison (GEWEX GCSS/GASS)

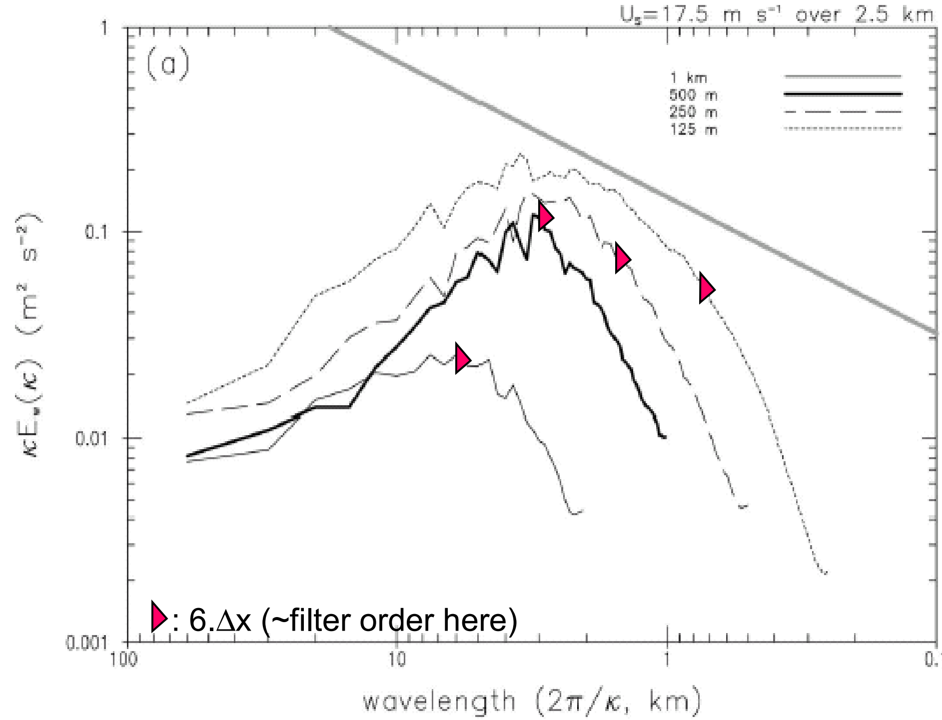
examples of sensitivities : grid size

Vertical velocity and q_r



Bryan et al. (2003)
MCSs *a « turbulent » point of view*

w spectrum at 5 km AGL



innovative at that time (grid size)
note : no cold nor subgrid microphysics

follow on papers

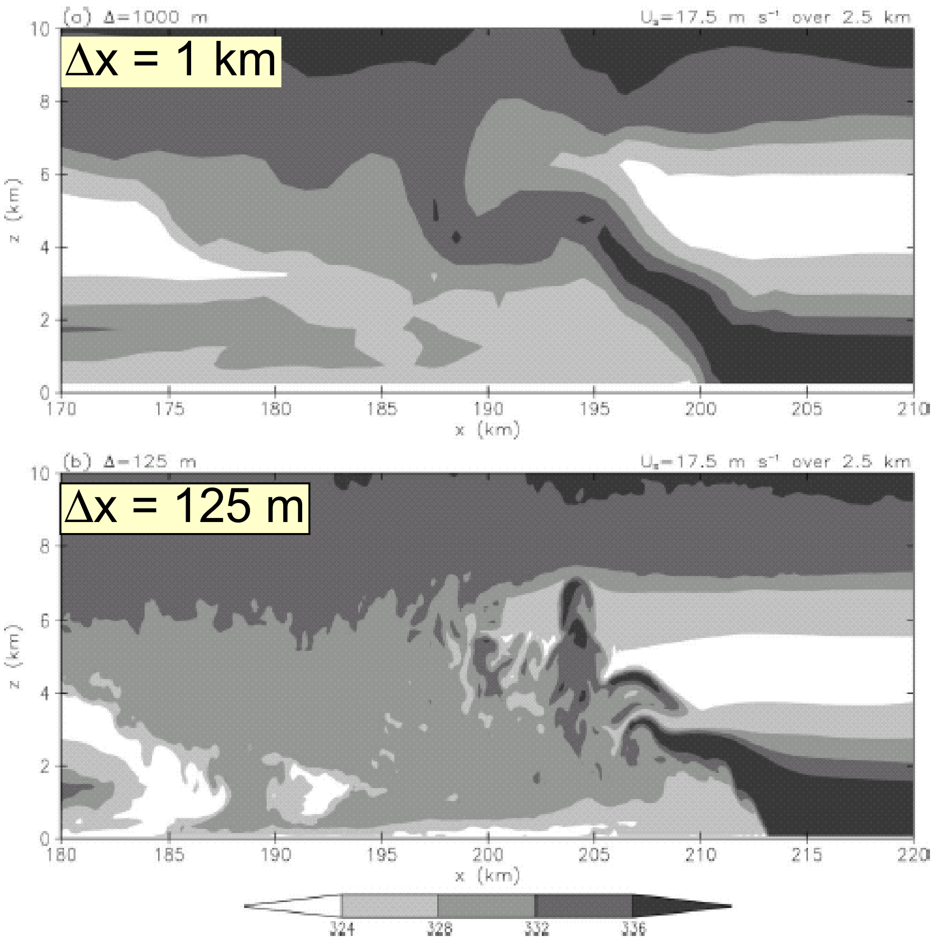
no systematic trends in specific fields as resolution is increased. (vary with environments)

examples of sensitivities : grid size

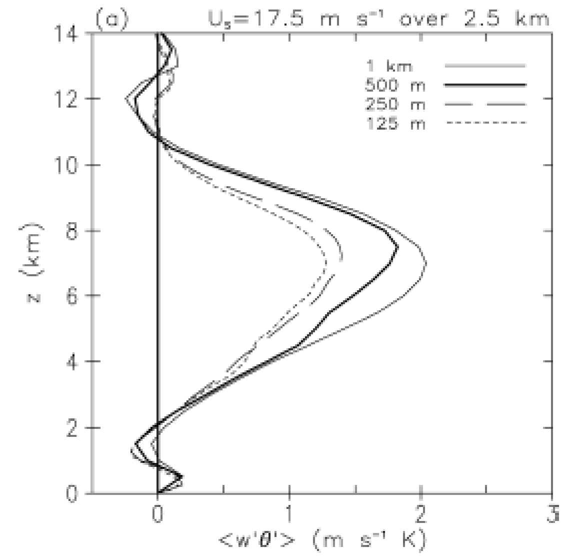
Bryan et al. (2003)

MCSs *a « turbulent » point of view*

θe (x,z) in simulated squall line



buoyancy flux



bulk features

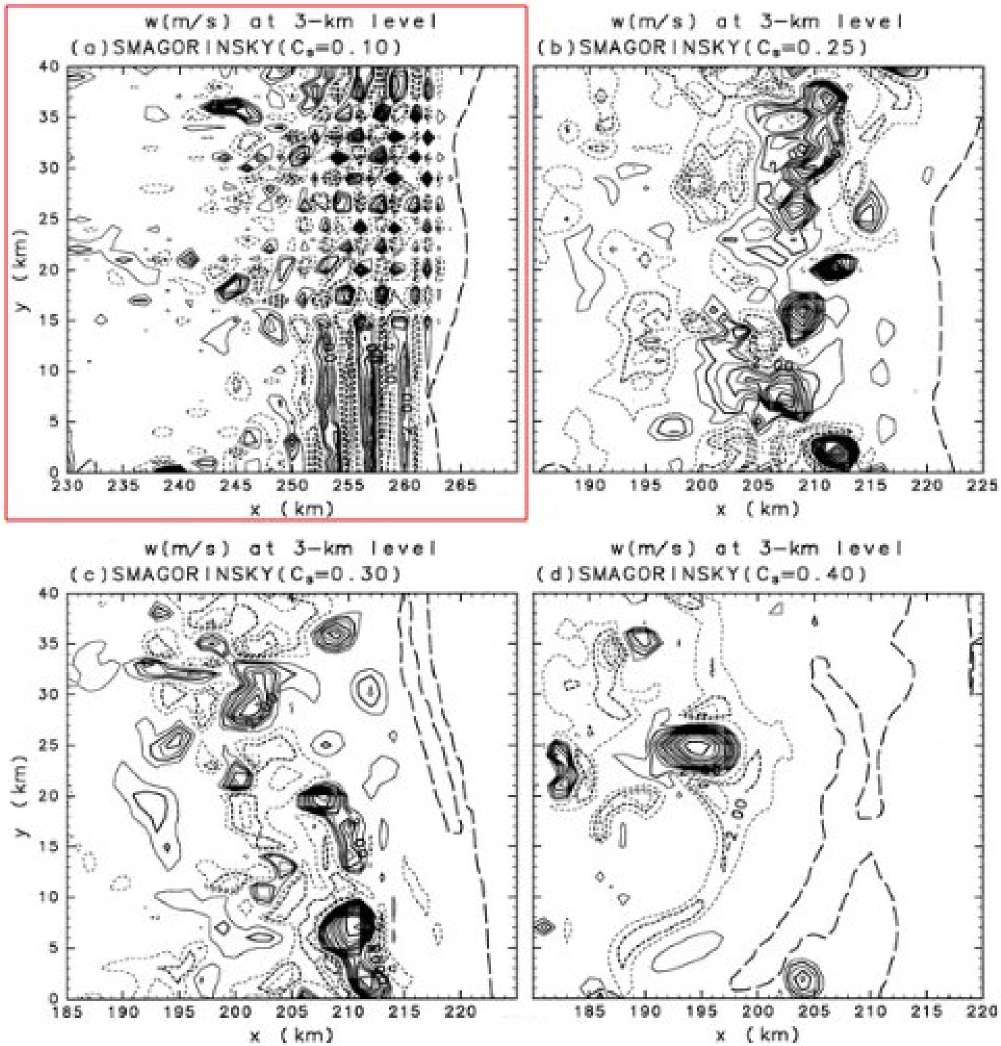
Grid spacing (m)	Rainfall (× 10^9 kg)	Avg x-location of surface gust front (km)
1000	90.9	191.4
500	110.8	198.4
250	105.5	198.2
125	107.1	199.7

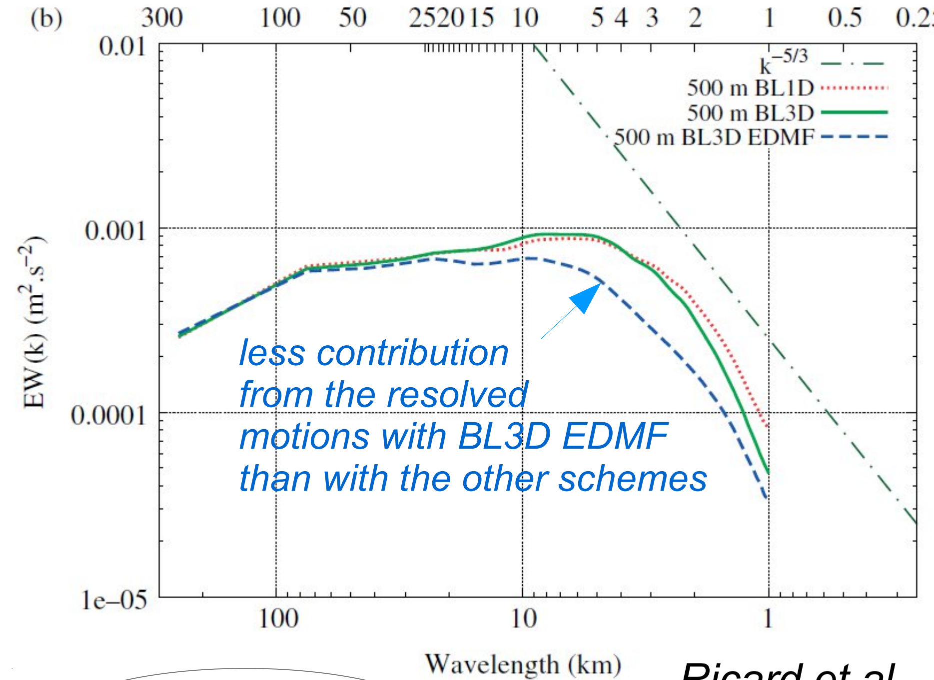
So, 1 km – grid size runs : useful or not ?

depends on your expectations, goals

Grid size ≠ and < résolution

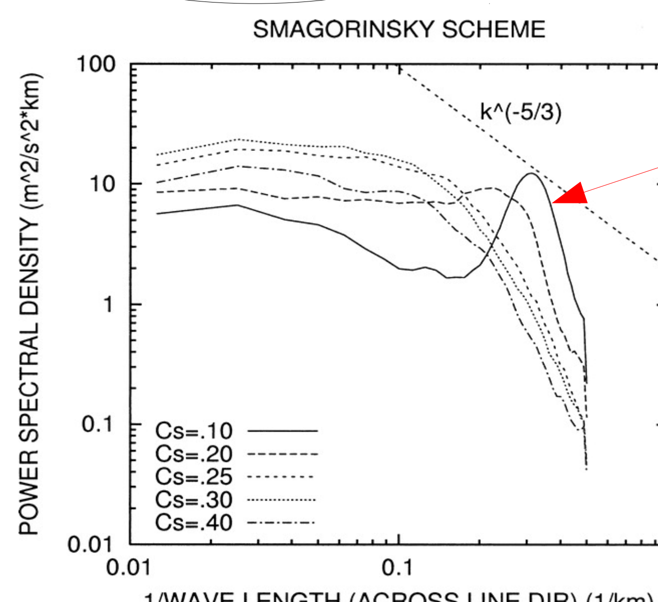
numerical filters and the formulation of subgrid-scale turbulence both affect the resolved motions, especially the structure of the smaller resolved motions (fragile) - to keep in mind when using simulation outputs





Ricard et al. (2013)

vertical velocity spectra



unphysical accumulation of energy at small scale

Takemi and Rotunno (2003)

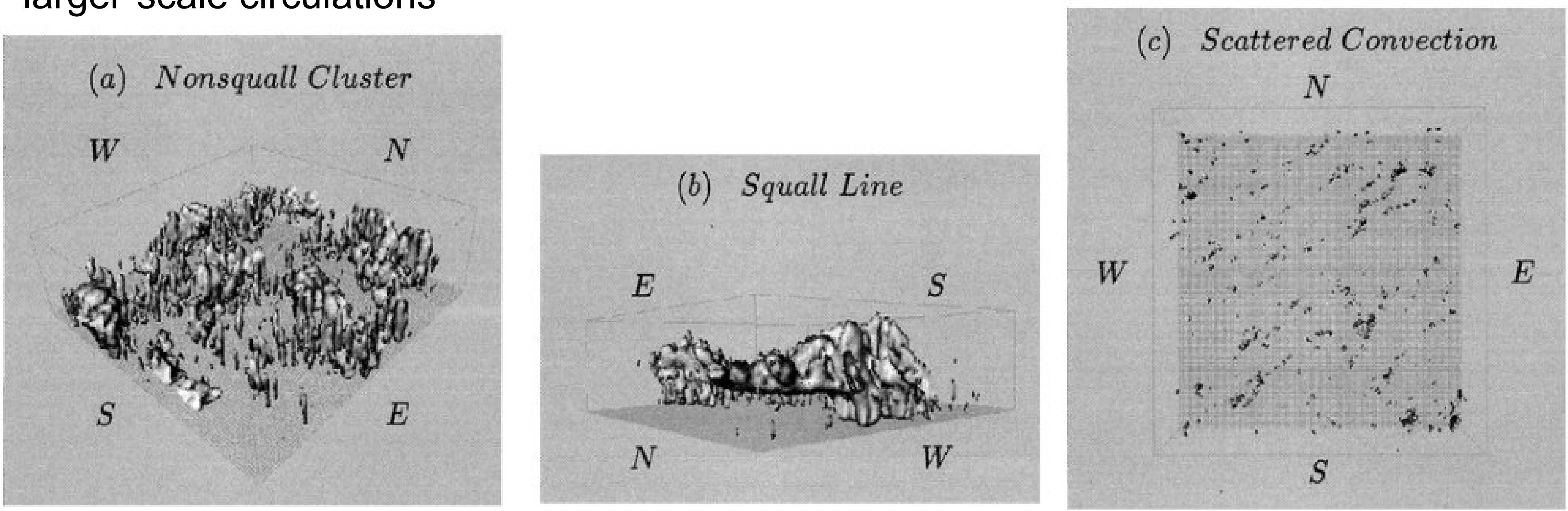
simulating convective activity over tropical oceans

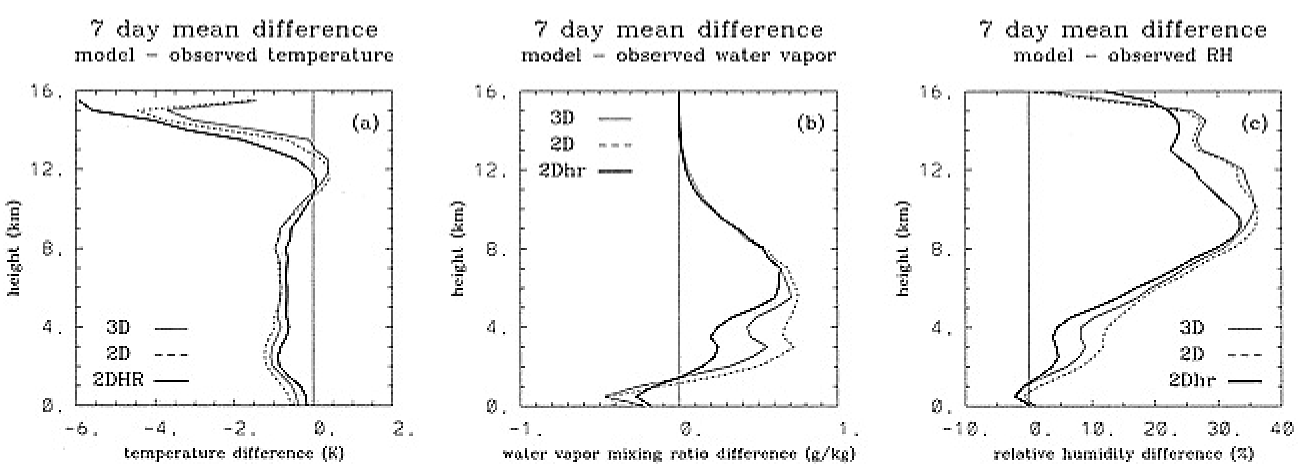
multi-day sequences guided by observations TOGA-COARE/GATE

Xu and Randall (1996), Grabowski et al (1996, 1998)

CRM : use of time varying large-scale advection and nudging of mean-wind towards obs

Challenge in terms of modelling, realism, study the mutual influences of convective and larger-scale circulations





horizontal-mean biases : very small differences between 2D & 3D runs

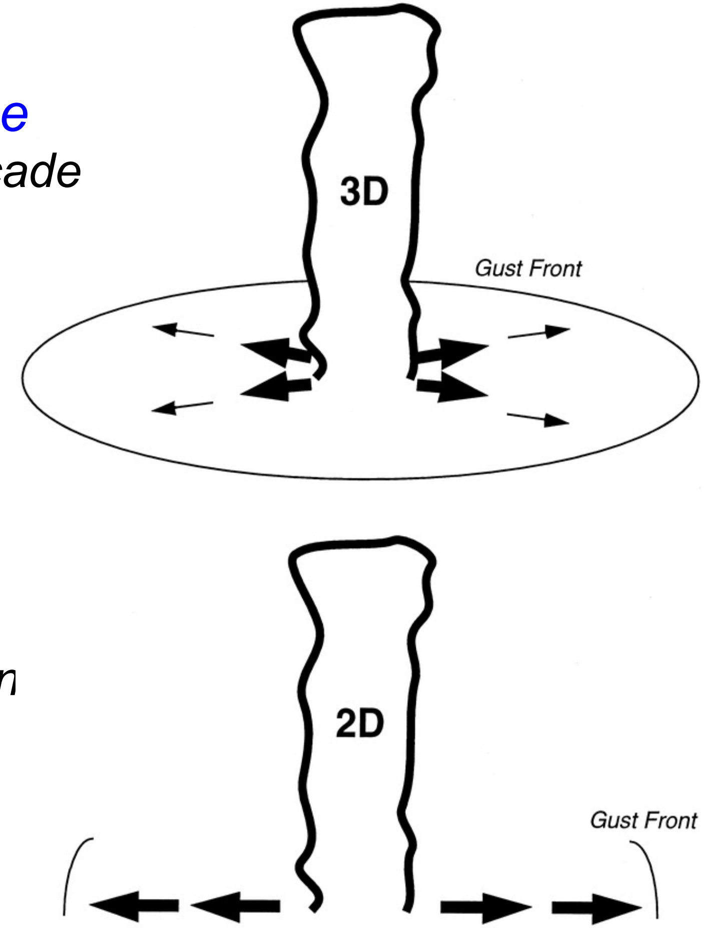
Dimensionality: 2D versus 3D

Basic structural differences between 2D & 3D turbulence
k^{-3} / $k^{-5/3}$ spectra, Nastrom & Gage 1985, stratification, E cascade

Which implications for LES & CRM simulations?

Tompkins (2000) *«...highly 2D organized convection (squall lines) (...) a 2D model can be used. For random or clustered convection, especially in low wind environments (...) highly preferable to use a 3D cloud model. »*

Grabowski (1998)
T,qv, qx fields, 6h mean H, LE, precip : 2D/3D similar evolution
2D: higher temporal variability of domain-averaged quantities.
« as long as high-frequency temporal variability is not of primary importance, low-resolution 2D simulations can be used as realizations of tropical cloud systems in the climate problem and for improving and/or testing cloud parameterizations for large-scale models. »



Tompkins (2000)

Why this apparent potential of 2D runs in some cases?
2D CRM : distorts / misshapes but keeps an explicit treatment of interactions between convective motions and physical processes (+ strong framing by lateral boundary conditons)

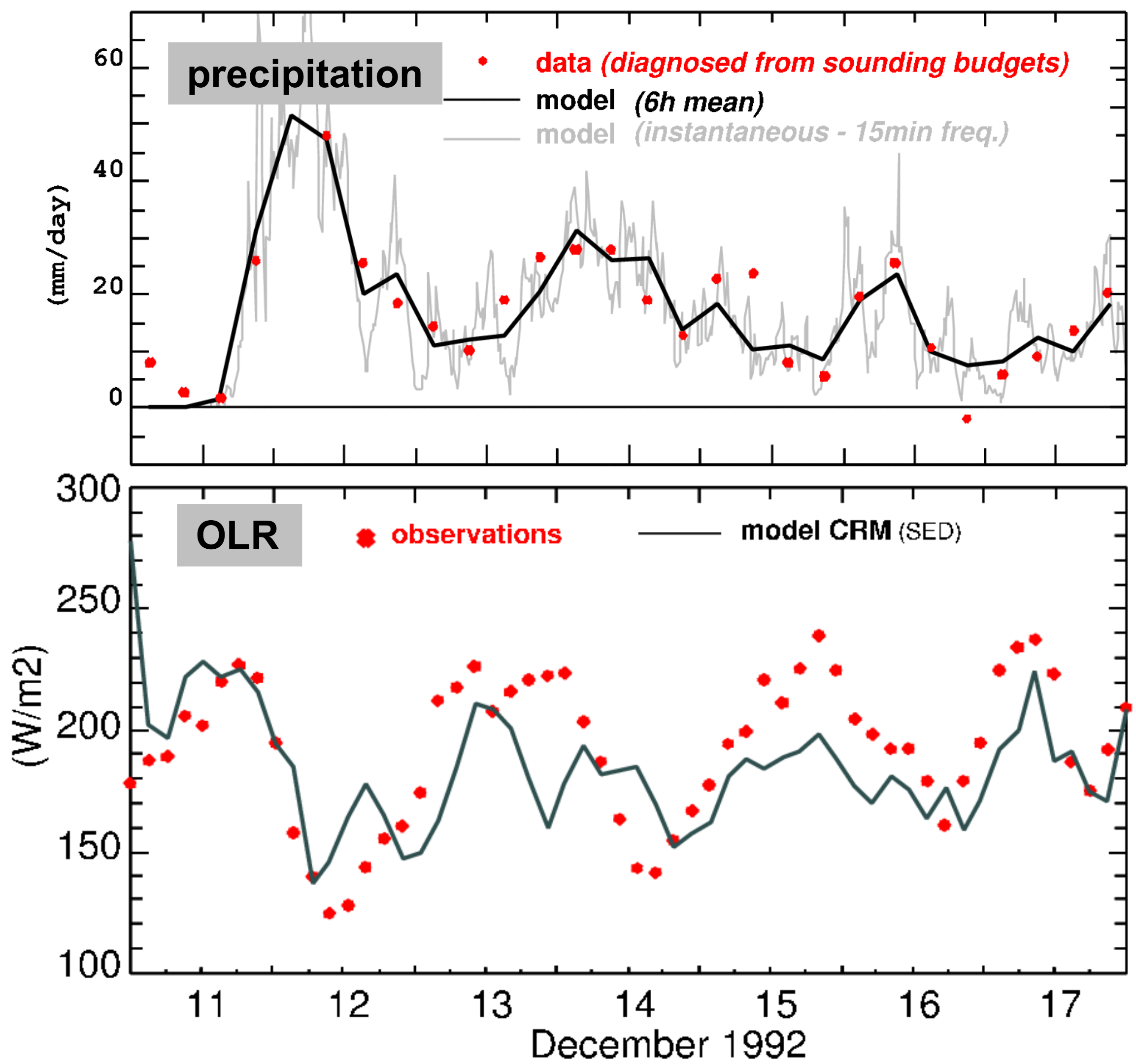
Recall that convective motions, BL thermal, deep cells are highly 3D phenomena

The (ir)relevance of 2D simulations (compared to more realistic 3D simulations) is tight to the purpose of the study.

TOGA-COARE simulations : evaluation and budget analysis

caution with evaluation diagnostics !

(Emanuel and Živković-Rothman 1999)



after some changes to / tuning of ice microphysics

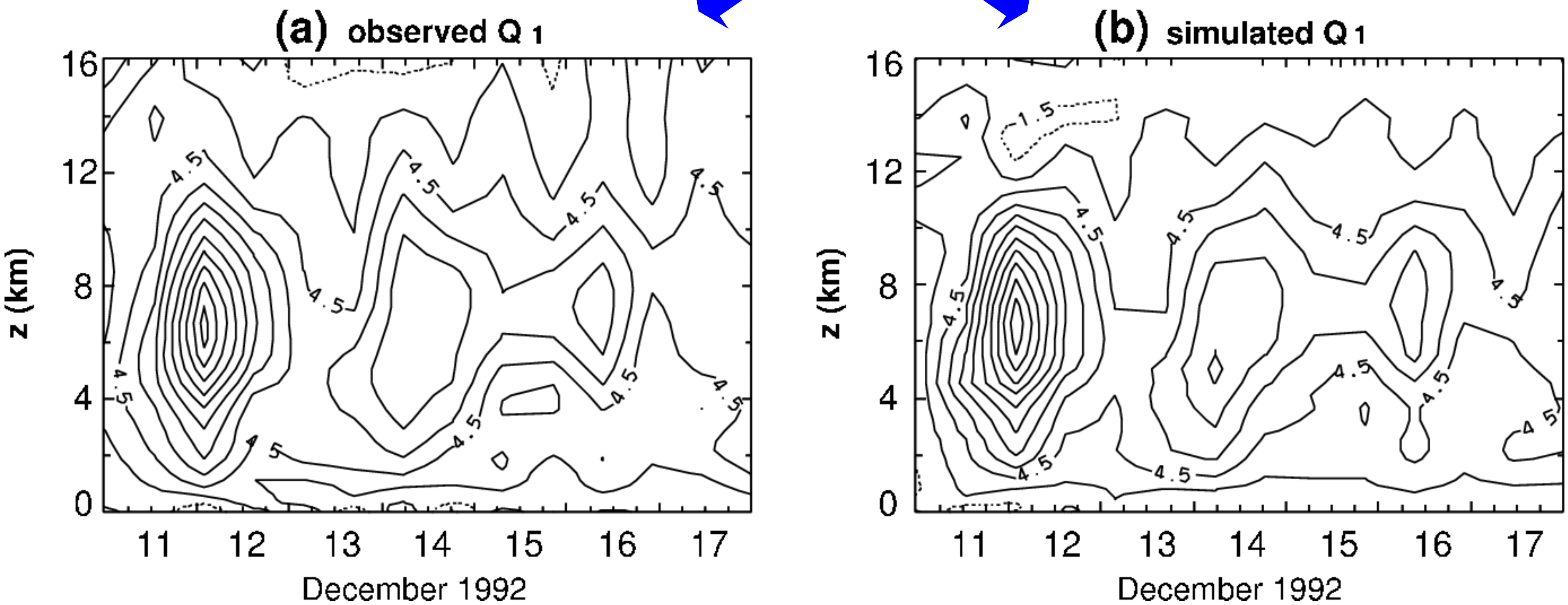
Guichard et al. (2000)

TOGA-COARE simulations : evaluation and budget analysis

tendency | *Large-scale advection* | *convective +turbulence transport* | *microphysics* | *radiative processes*

$$\pi \frac{\partial \bar{\theta}}{\partial t} = -\pi\, \bar{u}_i \left(\frac{\partial \bar{\theta}}{\partial x_i} \right) \underbrace{- \frac{\pi}{\rho} \frac{\partial}{\partial z} \left(\rho \overline{w' \theta'} \right) + Q* + Q_{rad}}_{Q_1}$$

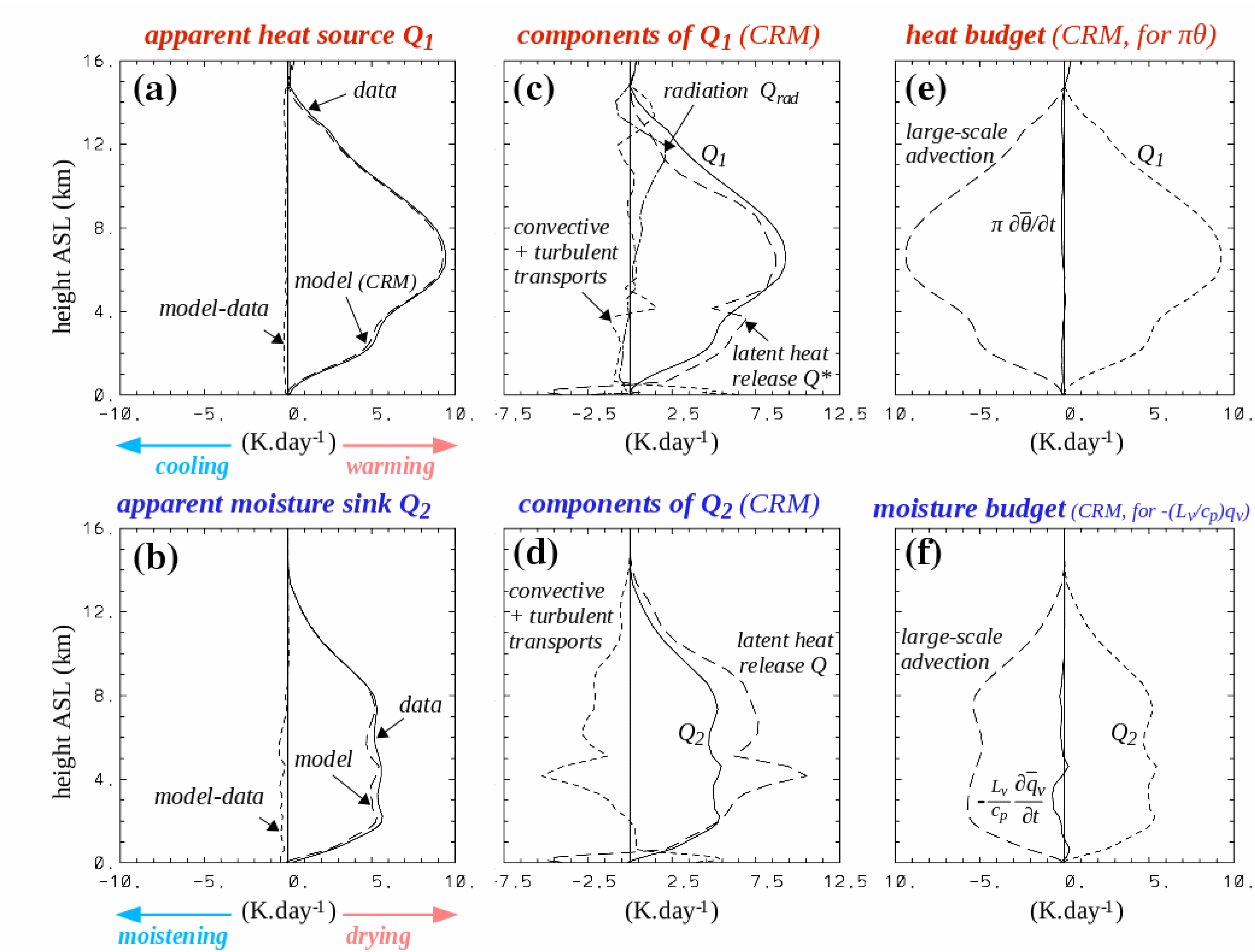
Q_1 *Apparent heat source*



(Lin and Johnson dataset)

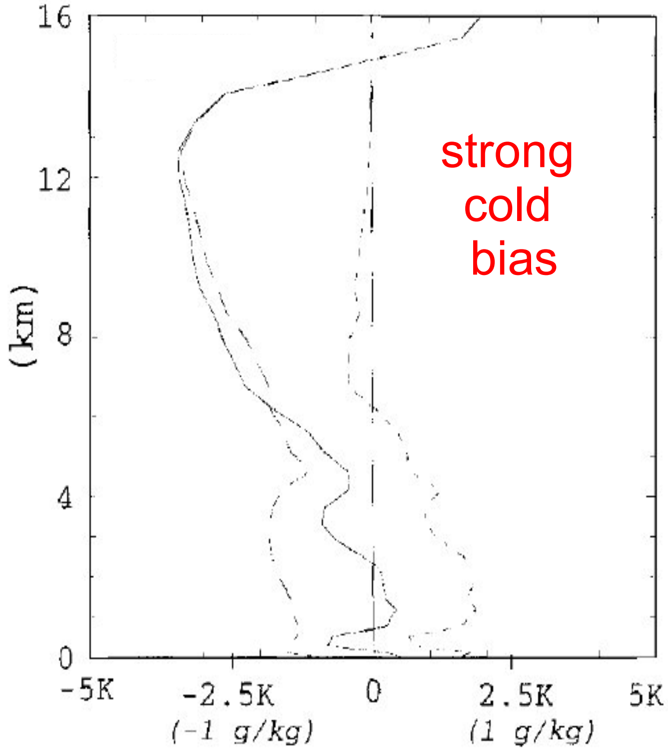
Guichard et al. (2000)

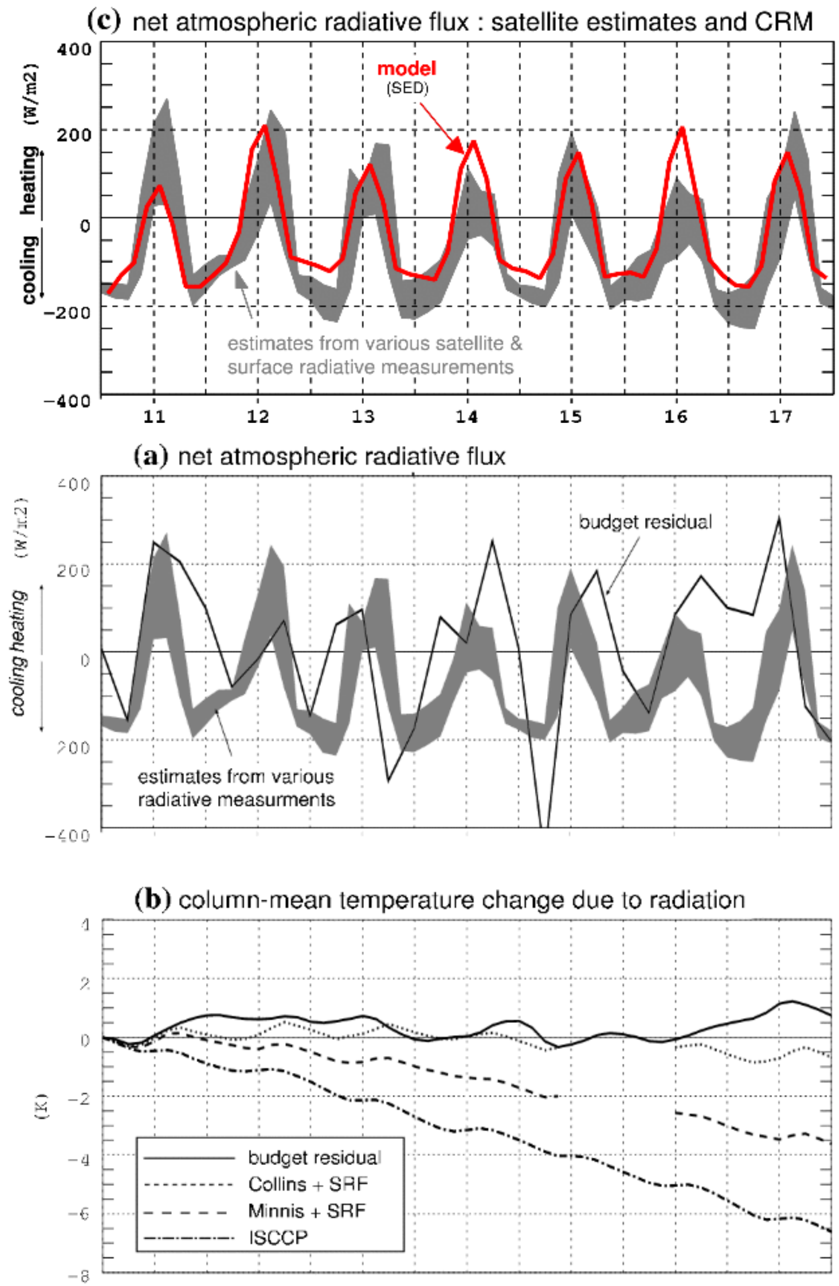
TOGA-COARE simulations : evaluation and budget analysis



Guichard et al. (2000)

TOGA-COARE simulations : evaluation and budget analysis





Vertically integrated θ_e budget

$$c_p \pi \frac{\partial \overline{\theta}_e}{\partial t} + c_p \pi \left\{ \overline{u}_i \left(\frac{\partial \overline{\theta}_e}{\partial x_i} \right) \right\}_{LS} = H + L_v E + F_{rad}$$

an estimate of F_{rad} in observation-derived budgets
(even if implicitely)
cold bias driven by 'large-scale advection'
the evaluation method was wrong (too demanding/obs)

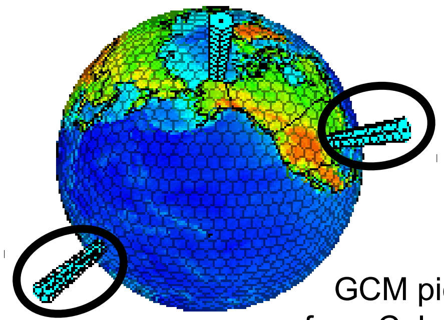
(cf also Emanuel and Živković-Rothman 1999)

Guichard et al. (2000)

LES/CRM model intercomparisons GEWEX (GCSS->GASS), EUCREM, EUROCS

motivation :
assess performance of models (LES & CRM), document state of the art
relevance of using these models for guiding the development of parametrizations in GCMs
especially using SCMs (1D versions of GCMs) - non-observable
(Moncrieff et al. 1997, Randall et al. 2003)

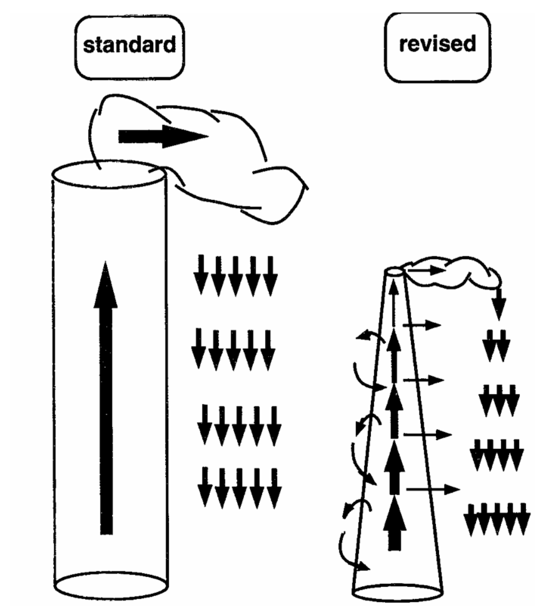
*LES/CRM as **numerical laboratories** ?*
Emphasis on realism of case studies



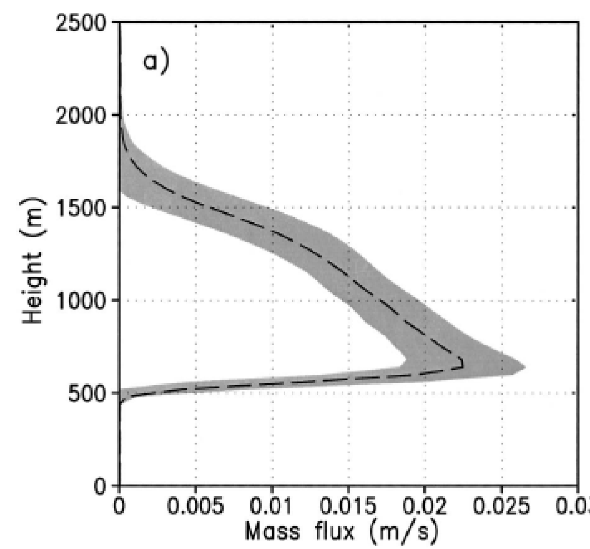
GCM picture
from Colostate

GCSS-> GASS
shallow cumulus (BOMEX, 1969)
shallow cumulus precipitating (RICO)
shallow cumulus diurnal cycle (ARM)
stratocumus (ASTEX)
squall line (TOGA-COARE)
deep convection over land (ARM)
deep convection over land
diurnal cycle (ARM, LBA)
Suppressed phase of
MJO (TOGA-COARE)
...
TWPICE, Artic clouds, CGILS...

A set of test cases
(care in their design, well documented)



Siebesma & Holstlag (1995)

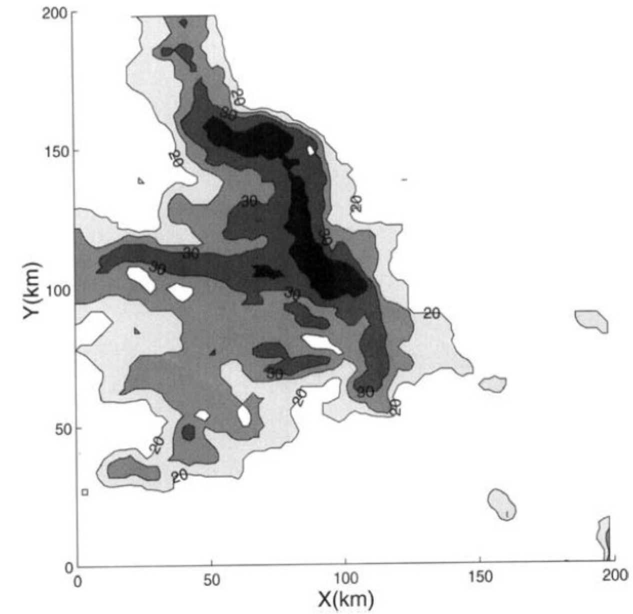


Siebesma et al. (2003)

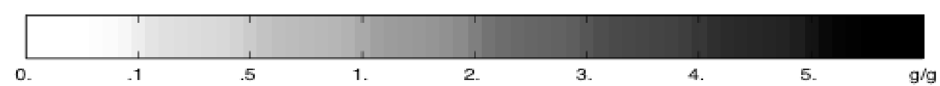
Squall line (TOGA COARE data)

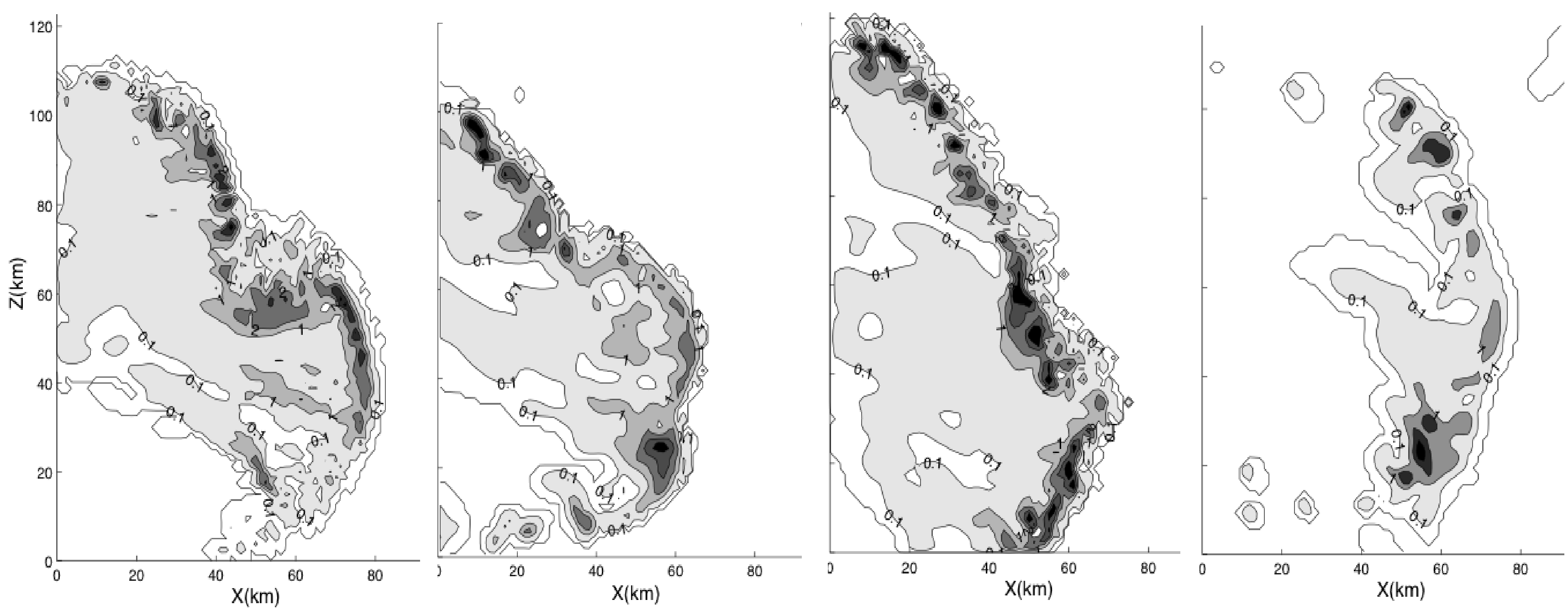
Redelsperger et al. (2000)

Radar reflectivity
At z = 500 m



q_r at z = 1.4 km



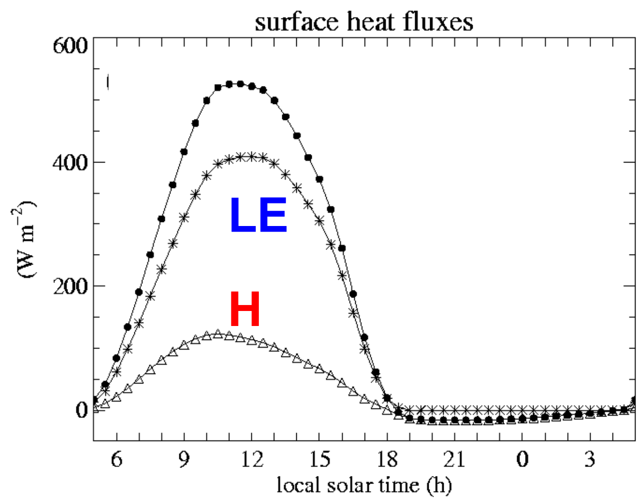


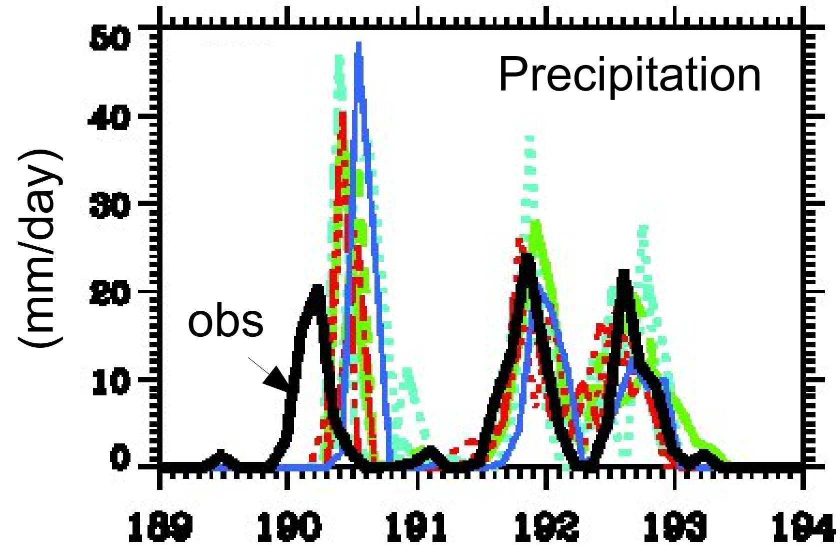
Here, no consideration of variability induced by larger, not resolved, scales of motion ; this could play a role in the delay of the 1st rainfall event (pb for all simulations).

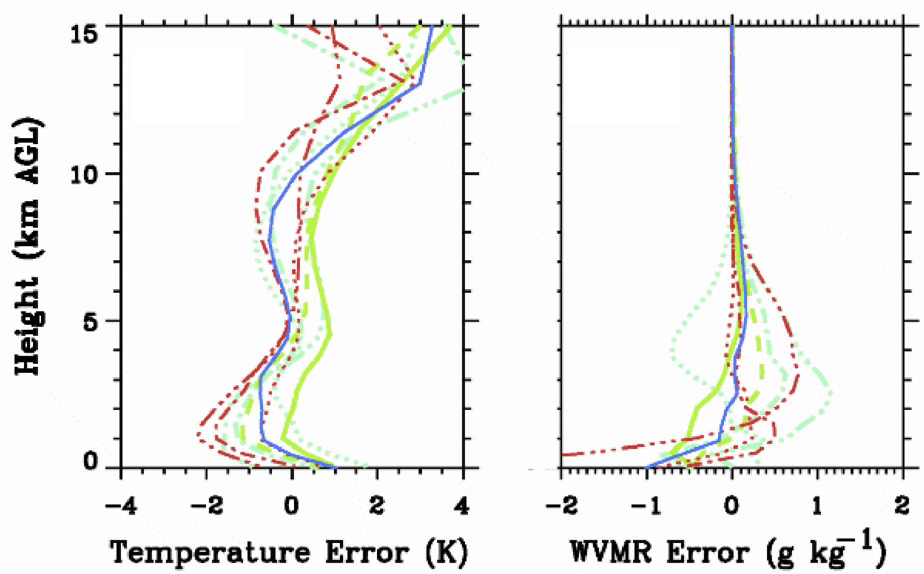
Deep convective activity over land

Xu et al. (2002)

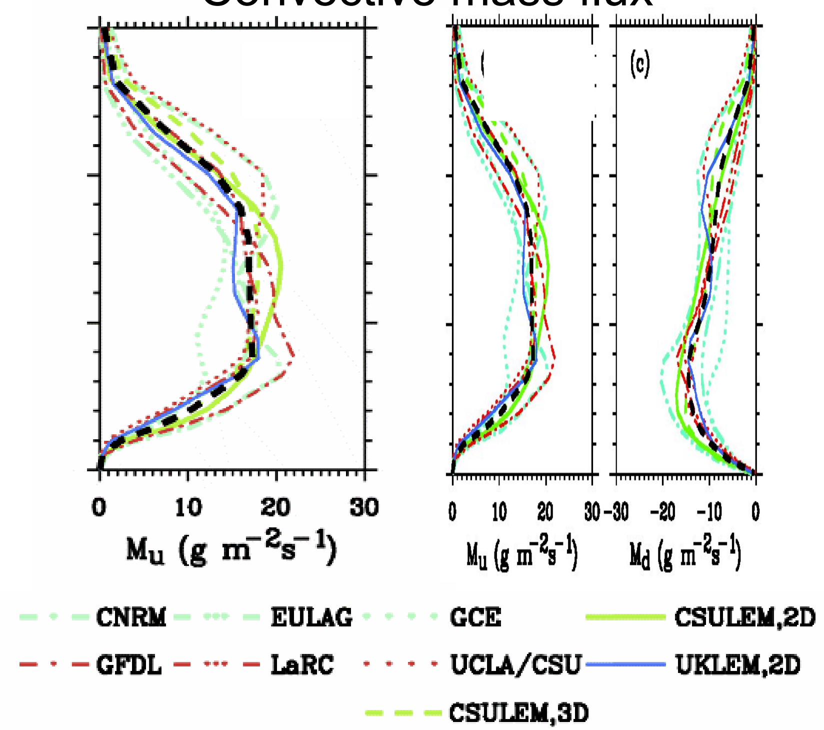
Prescribed surface fluxes





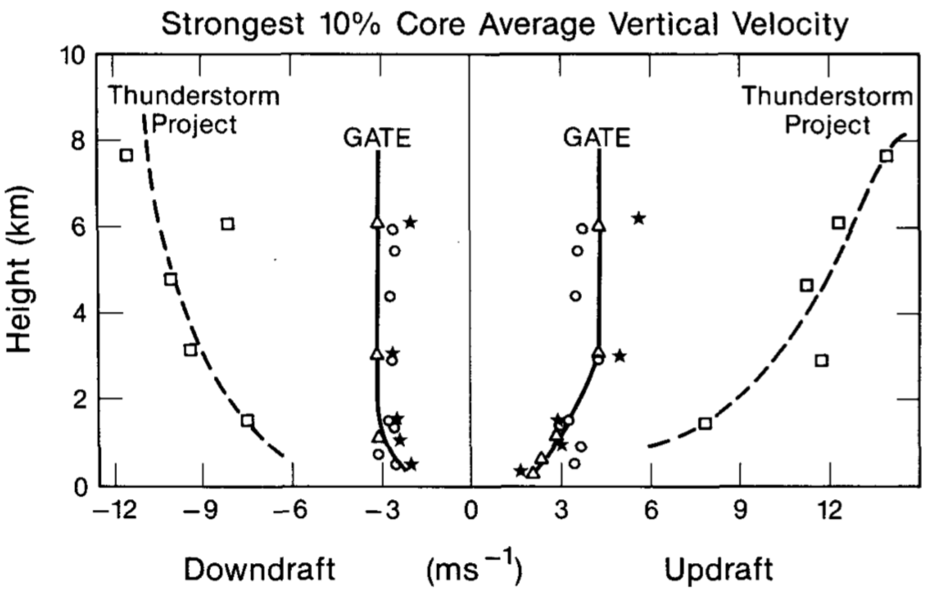


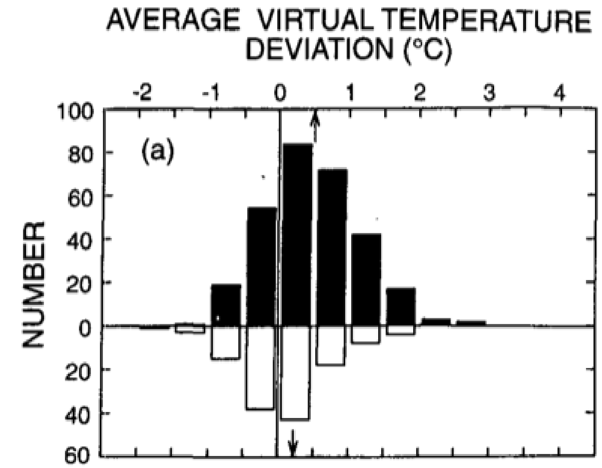
Convective mass flux



convective cells over Tropical ocean : morphology, strength

From a collection of in-situ observations: convective cores are narrow and weak
(in terms of vertical velocity and buoyancy)

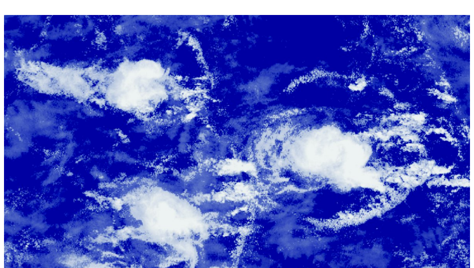




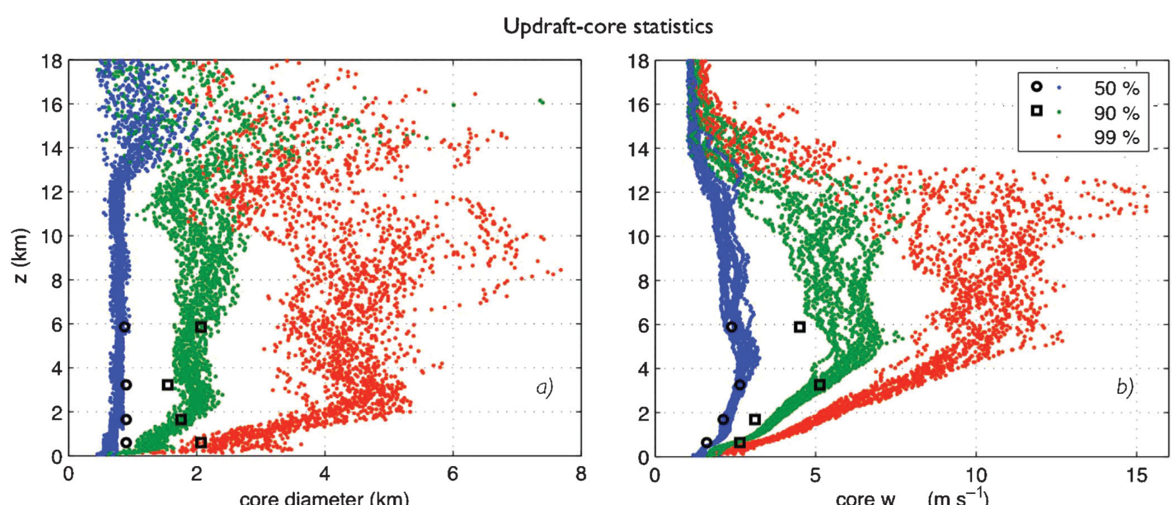
Lemone & Zipser (1980) ,Zipser & Lemone (1980)
Jorgensen & Lemone (1989) , Lucas et al. (1994)

implications : more time for microphysics to operate (formation of warm rain)
possibly related to boundary layer properties (small depth) (?)

Statistics of conv. cores in LES



Khairoutdinov et al. (2009)

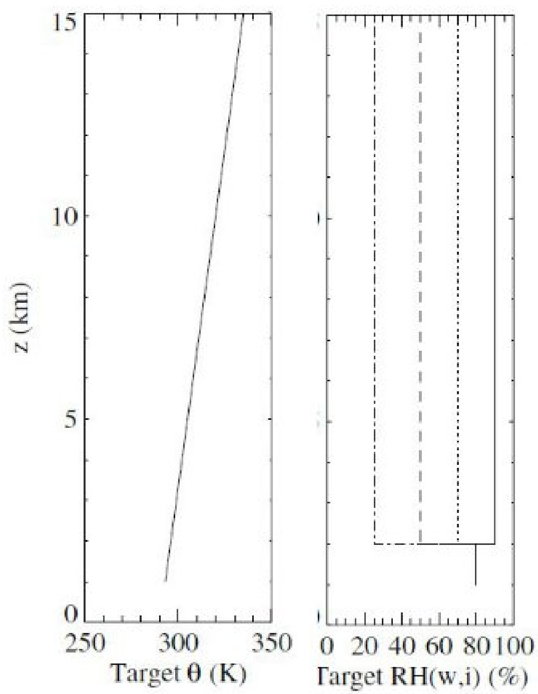


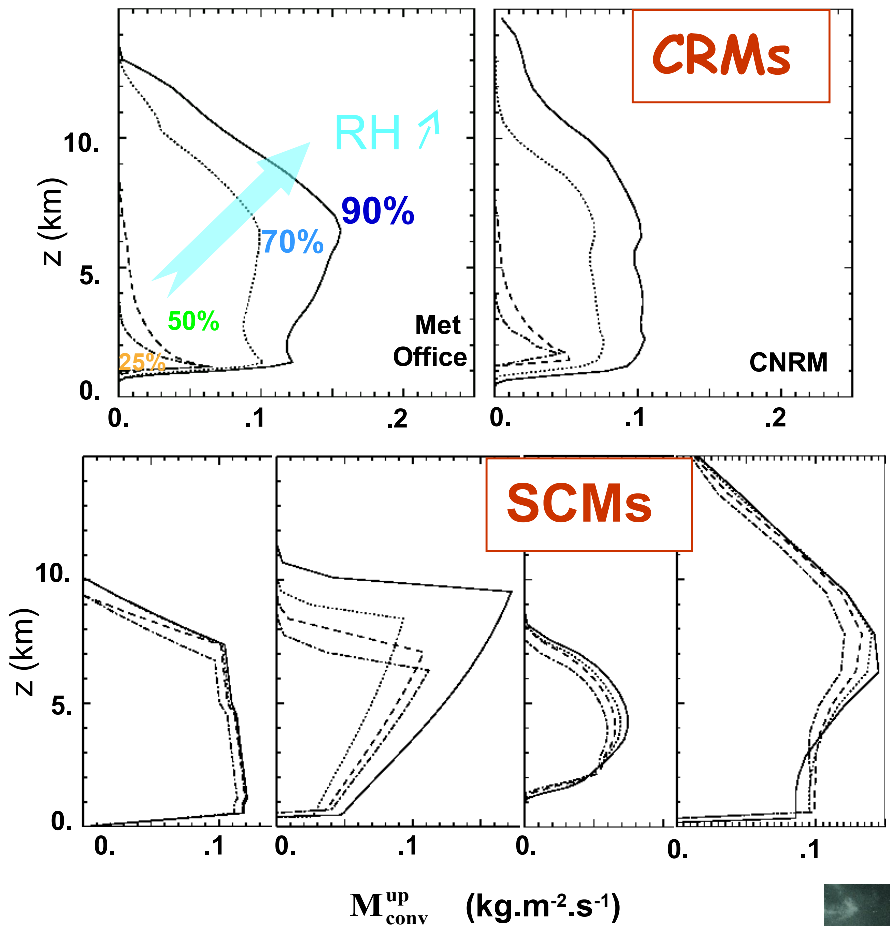
simulation close to observed => worth exploring drivers of conv. cells morphology With LES

Sensitivity to humidity, academic case study

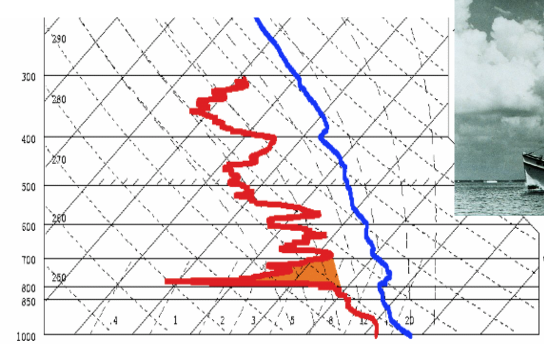
Derbyshire et al. (2004)

nudging to target profiles





weaker sensitivity to tropospheric humidity in SCMs compared to CRM



Relevance to observed
implication for observed convective regimes
sensitivity to dry air intrusions
predominance of congestus
(cloud tops below 10 km)
Further used as to guide development of parametrizations e.g. Derbyshire et al. (2011)

Summary for today

Assessing the quality of LES/CRM results
Sensitivity to grid-size and parametrizations
grid size =/= resolution !
Importance of the design of the set-up (boundary conditions)

Evaluation of simulations : strength of θ_e budget
points to the limits of what obs (or models) can be used for
importance of explicit formulation of (simple) question

GEWEX coordinated work
State of the art 90's-00's
Set of case studies (useful)
Interest and promoted use of LES/CRM for parametrization studies

Much more on convection over ocean
Not much so far over land
(convective param design from / tested with obs over tropical ocean)