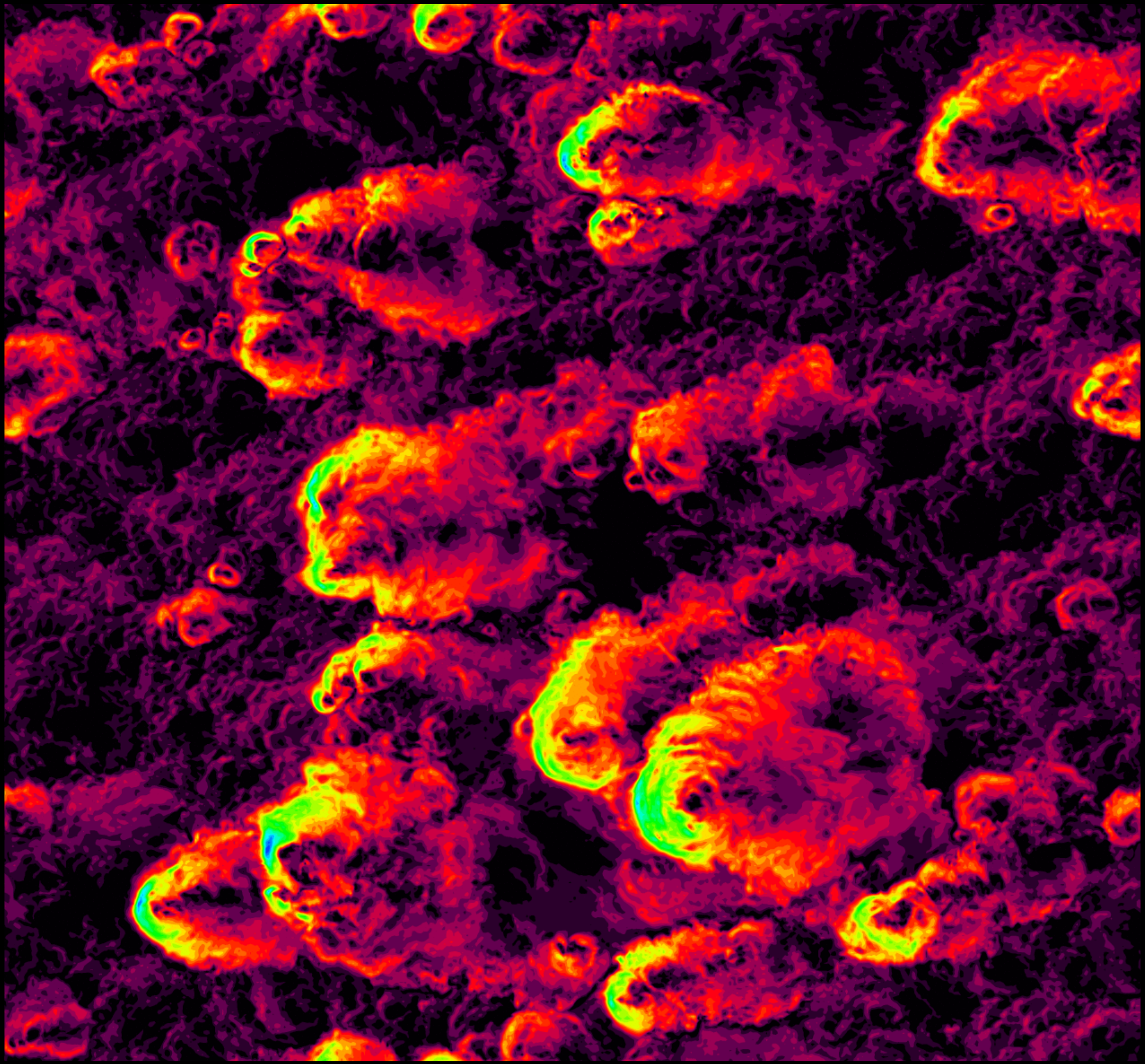
Large Eddy Simulation (LES) & Cloud Resolving Model (CRM)

Françoise Guichard and Fleur Couvreux



Cloud-resolving modelling : perspectives

Improvement of models, new ways of using them, renewed views

And also trementous increase in computing power
more resolution and/or larger domain size and time integration

CRMs in GCMs (Randall et al. 2003)
Global CRM (NICAM, Tomita et al. 2005)

High-resolution regional simulations (CASCADE UK project) MJO, Monsoon...
couplings between convective and larger-scale circulations

LES over very large domains, grey zone (Pier & colleagues)
parametrization issues

DNS to study convective BL (Jonker et al.), stratocumulus entrainment (ask Bjorn)

Basic cloud and climate related issues

Diurnal cycle over land, deep convection and cold pools

Direct numerical simulation (DNS) of the convective boundary layer (Source : Harm Jonker)

Academic frameworks to address basic climate issues

Climatic feedbacks associated with low clouds

CGILS Zhang et al. (2013), Bretherton et al. (2013)

exploring the impact of idealized climate change perturbations (LES & SCM)

LES : 10 to 20 day runs, quasi-equilibrium state.

negative cloud feedback well-mixed coastal stratus/stratocumulus regime

positive feedback for shallow cumulus and stratocumulus regime

Subtle compensating effects

Weak temperature gradient

prescribing a mean temperature profile rather than mean vertical velocity

Sobel and Bretherton (2000)

Formulated within a CRM (Raymond et al. 2005)

$$w_{\mathrm{D}} = \frac{E_\theta}{(\partial\bar{\theta}/\partial z)}$$

Ongoing activity CRM, SCM

Convective radiative equilibrium

Kerry Emanuel's lecture yesterday, address climate issues

Convective-Radiative Equilibrium

90's : CRMs, sensitivity of mean column to SST

10's : sensitivity of rain intensity (Muller et al. 2011), to CO_2 increase (Romps 2010), aggregation (Jeevanjee and Romps 2013,...)

*New emphases **:** shallow clouds, cold pools, consideration of domain size*

See summary, comparison Of CRE-type CRM studies in Tao et al. (1999)

TABLE 1. Summary of previous cloud-radiation modeling studies. The general setup for each study is given along with some of the model characteristics and treatments used to parameterize the radiative effects. The case used in each study is also given.

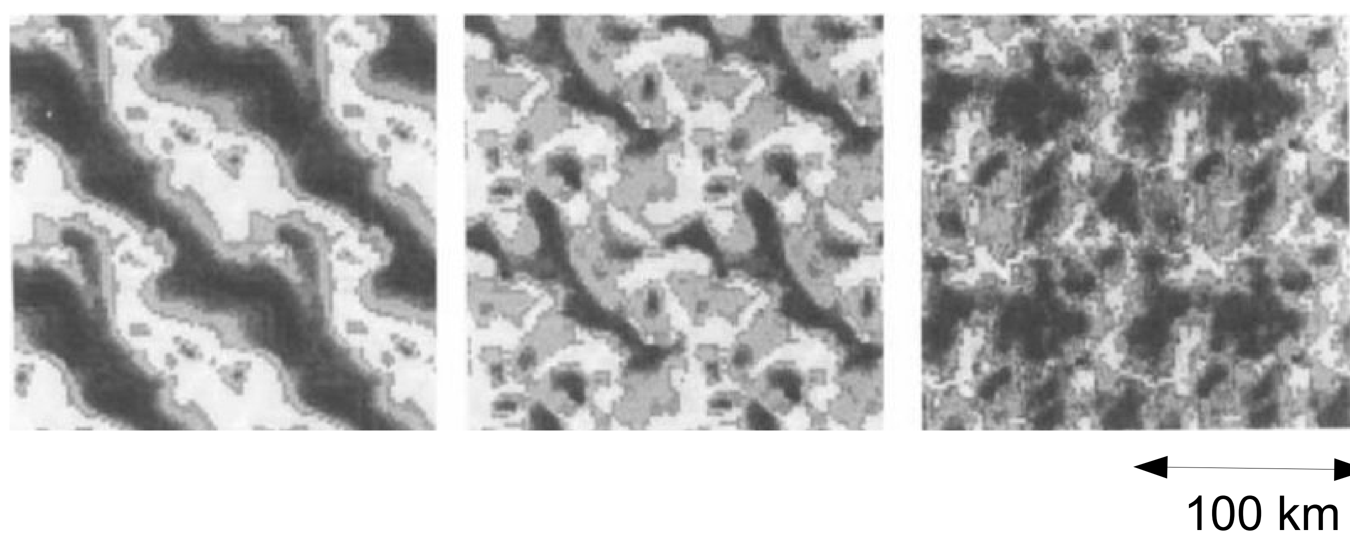
	Model	Domain (dx)	Large-scale forcing	Integration time (days)	Case
Nakajima and Matsuno (1988)	2D No ice	512 km (1000 m)	Constant radiative cooling	2.5	East Atlantic
Islam et al. (1993)	3D	60 × 60 km² (2000 m)	Constant radiative cooling	4	West Indies
Held et al. (1993)	2D 3 ice	640 km (5000 m)	Cloud-radiative forcing	42	Tropics
Sui et al. (1994); Lau et al. (1993); Lau et al. (1994)	2D 3 ice	768 km (1500 m)	Large-scale velocity and radiative forcing	52	West Pacific
Randall et al. (1994)	2D 3 ice	256 km (2000 m)	Radiative forcing	100	East Atlantic
Grabowski et al. (1996)	2D 2 ice	900 km (1000 m)	Large-scale velocity and radiative forcing	25	West Pacific
Robe and Emanuel (1996)	3D No ice	60 × 60 km² (2000 m)	Constant radiative cooling	6–30	West Indies
Tompkins and Craig (1998)	3D 3 ice	100 × 100 km² (2000 m)	Cloud-radiative forcing	70	Radiative–convective equilibrium
Xu and Randall (1999)	2D 3 ice	512 km (2000 m)	Constant forcing in T and Q_V and radiative forcing	29	West Pacific and East Atlantic

Tompkins and Craig (1998)

Organization (mesoscale structuration) of convection.

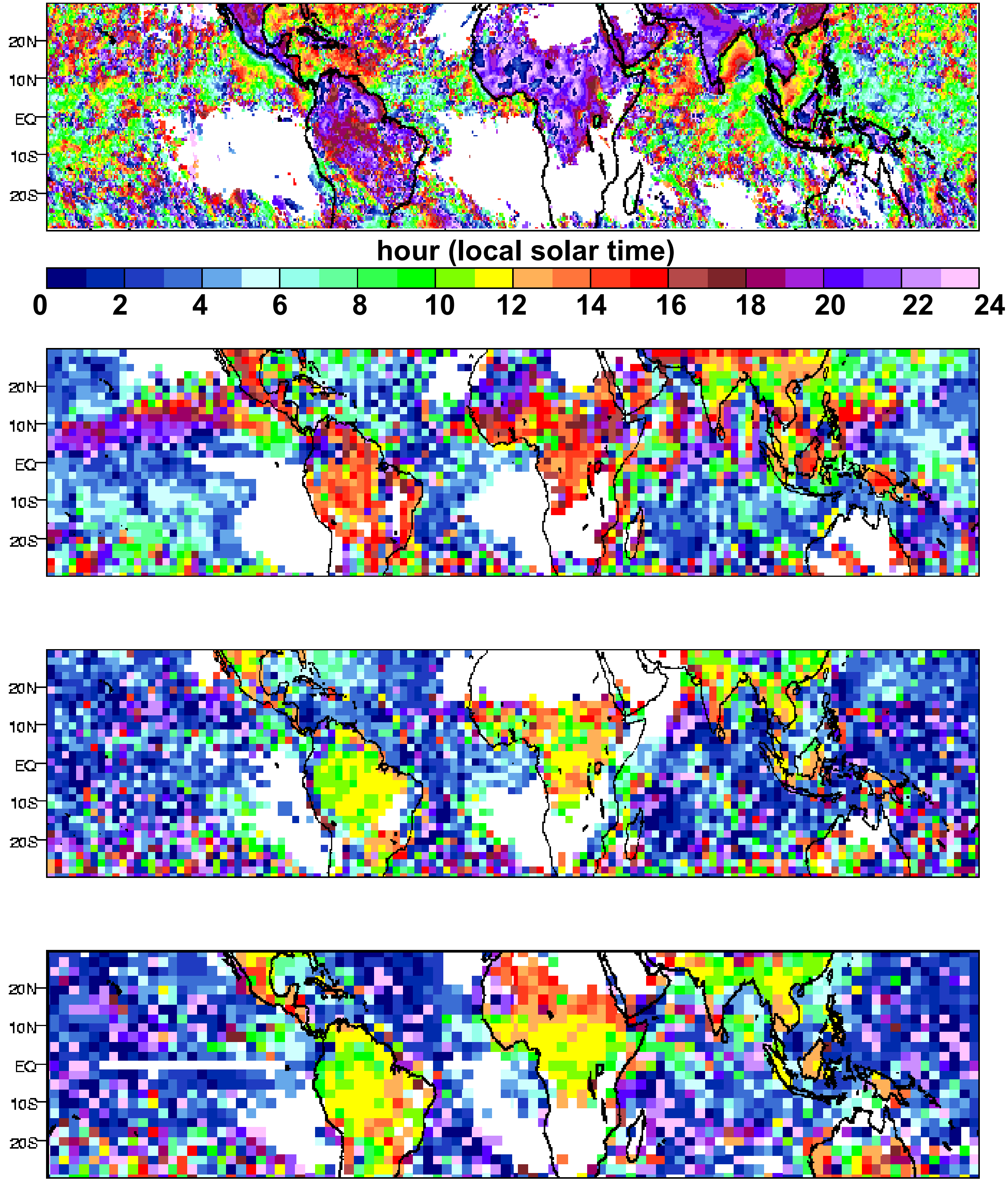
interactions between radiation, convection & surface fluxes involving surface wind feedback.

Impact of horizontally inhomogeneous radiation : longer lasting clouds, enhanced convergence into cloudy region.



Diurnal cycle of convective activity over land

PHASE OF THE DIURNAL HARMONIC IN 3 GCMs



OBSERVATIONS
Yang & Slingo (MWR, 2001)

ARPEGE NWP model
Piriou (2002)

IFS NWP model
Beljaars (2002)

UNIFIED CLIMATE model
Yang & Slingo (MWR, 2001)

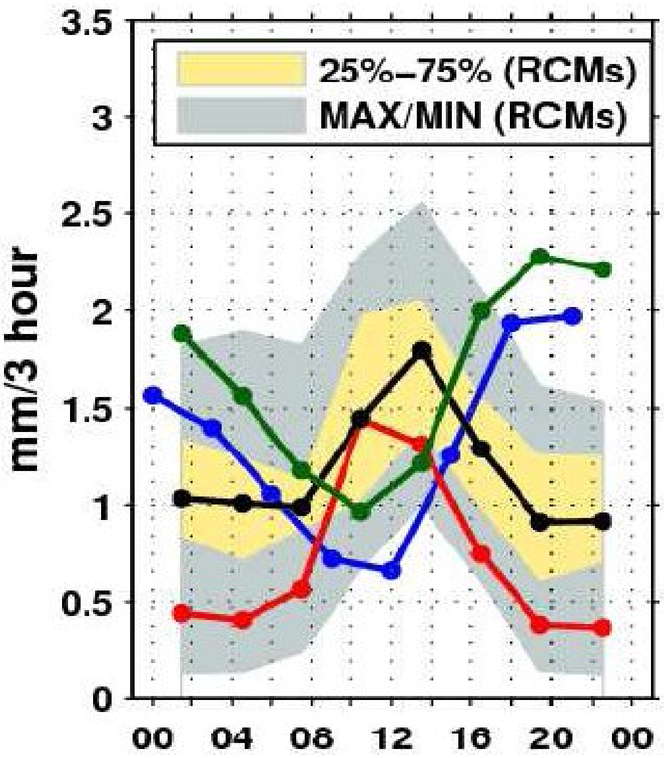
- ***10 years ago : GCMs wrong in the « same way »***

Diurnal cycle of convective activity over land

Progress:
e.g. Hourdin et al. (2013) IPSL model
Improved convective BL, introduction of cold pools, stochastic triggering
Rio et al. (2009, 2013), Granpeix and Lafore (2010), Rochetin et al. (2013)

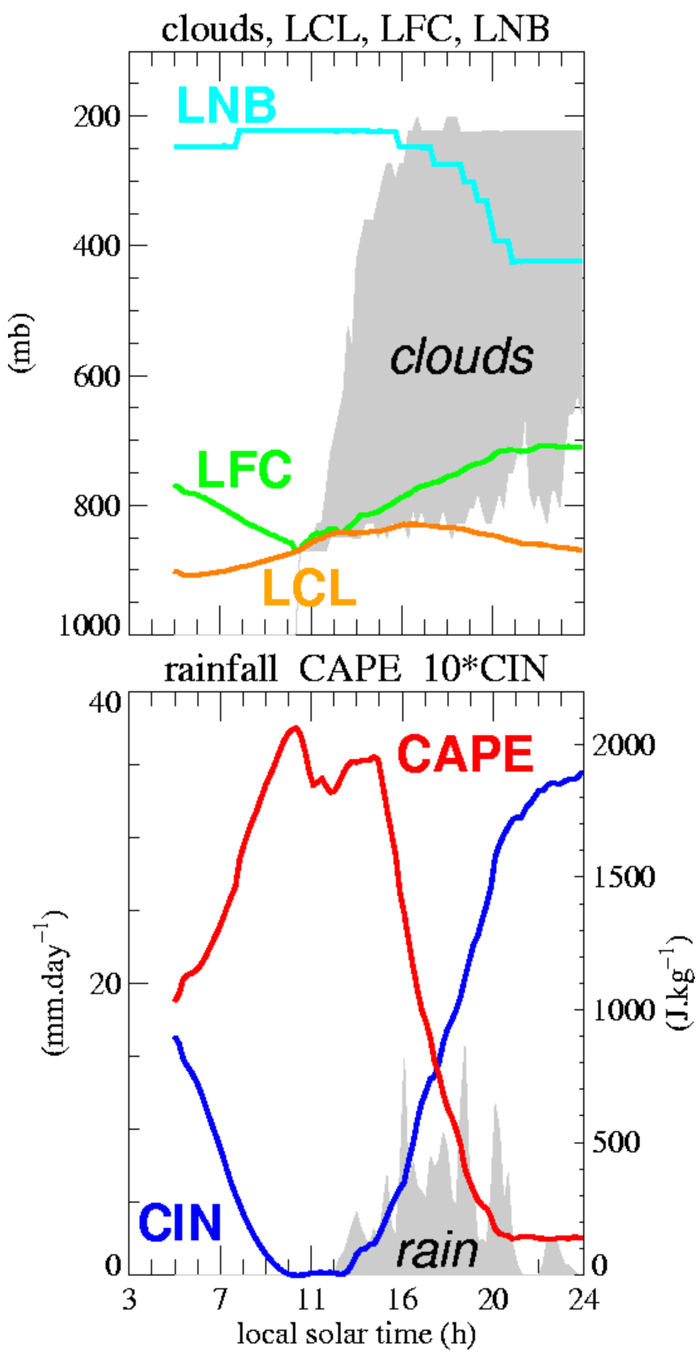
But still an issue in most models, GCM and RCM

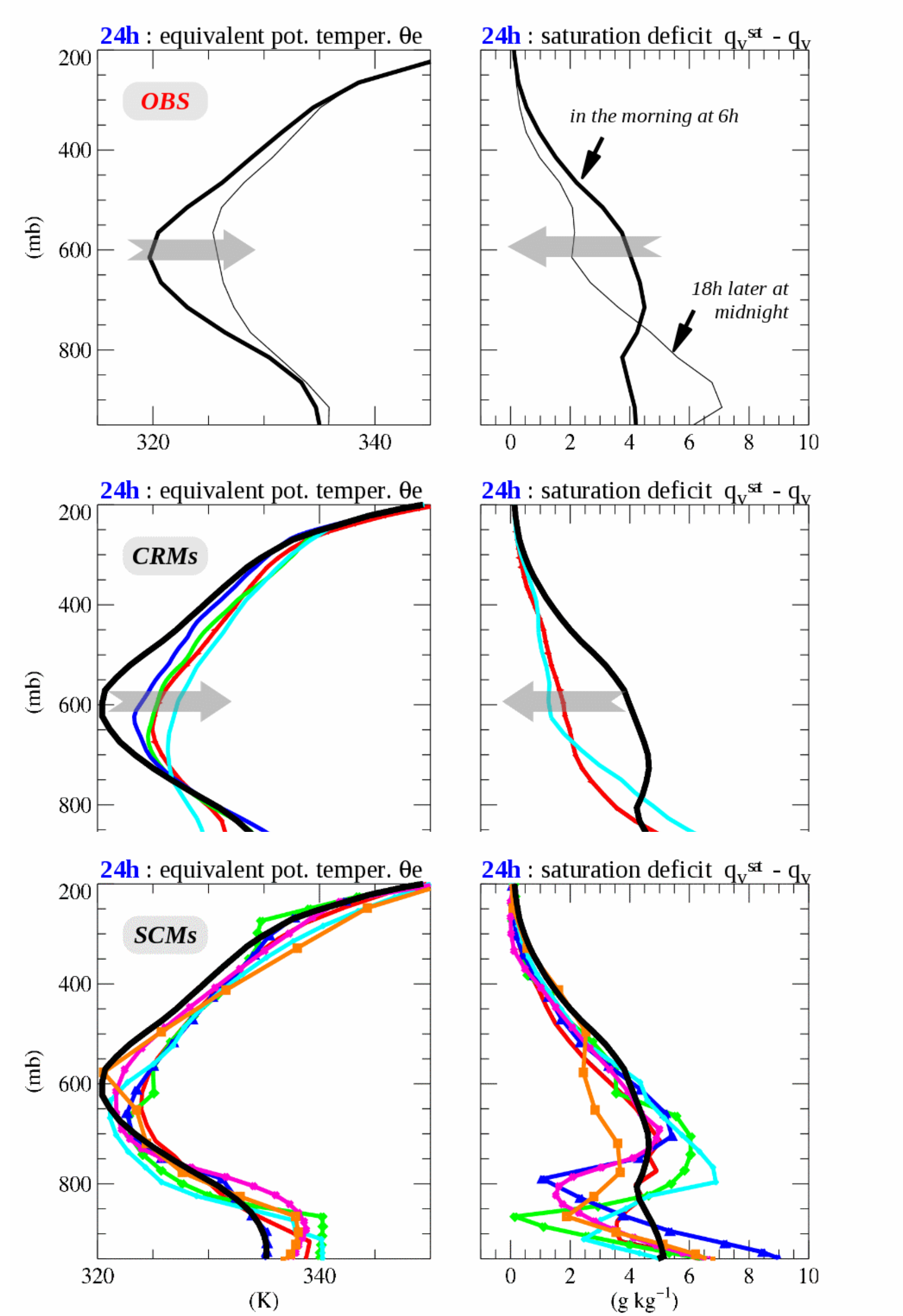
Numerous recent studies
(e.g. in CMIP5 simulations)



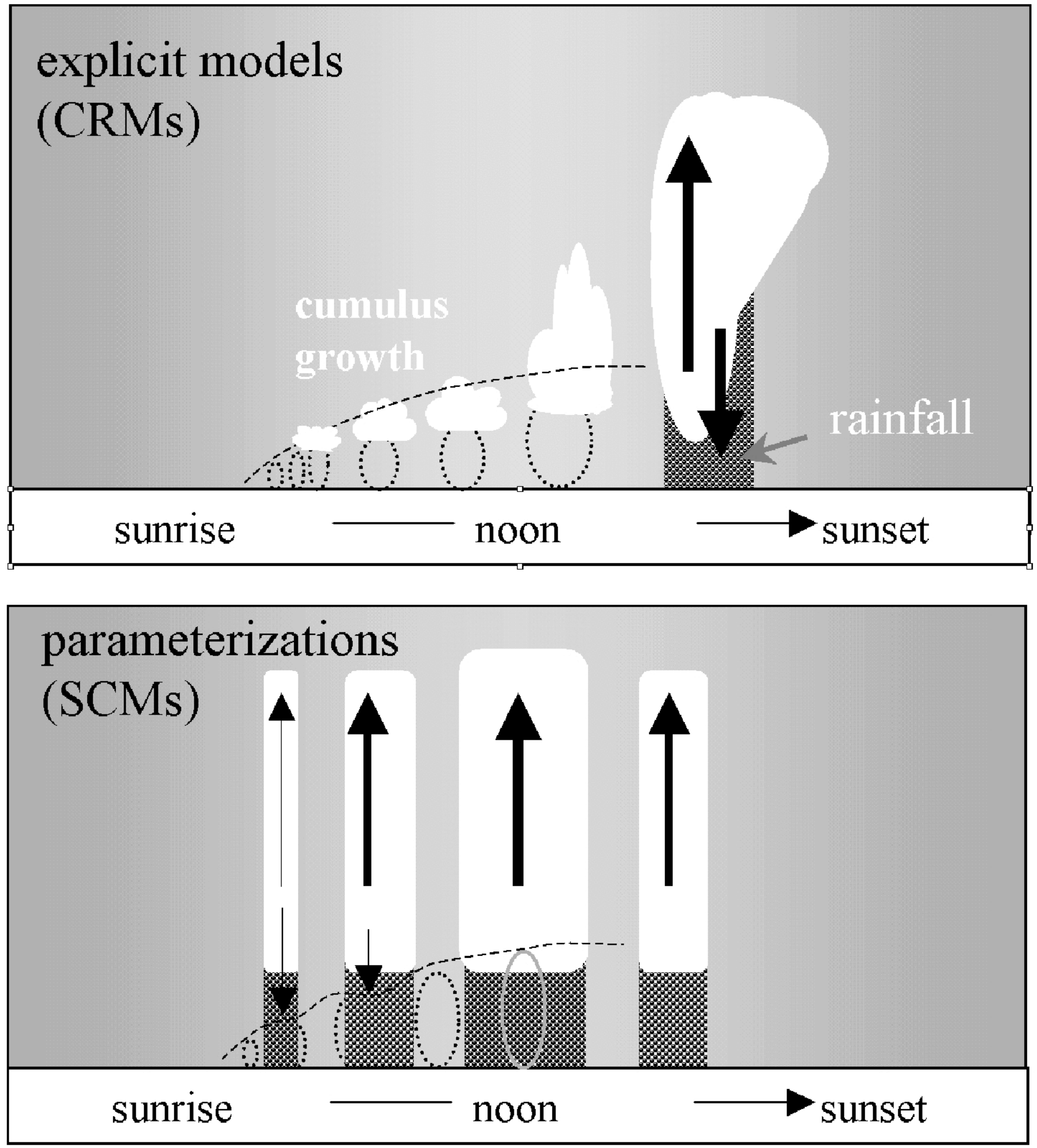
Nikulin et al. (2012)

Deep convective activity over land : local scale considerations





Guichard et al. (2004)

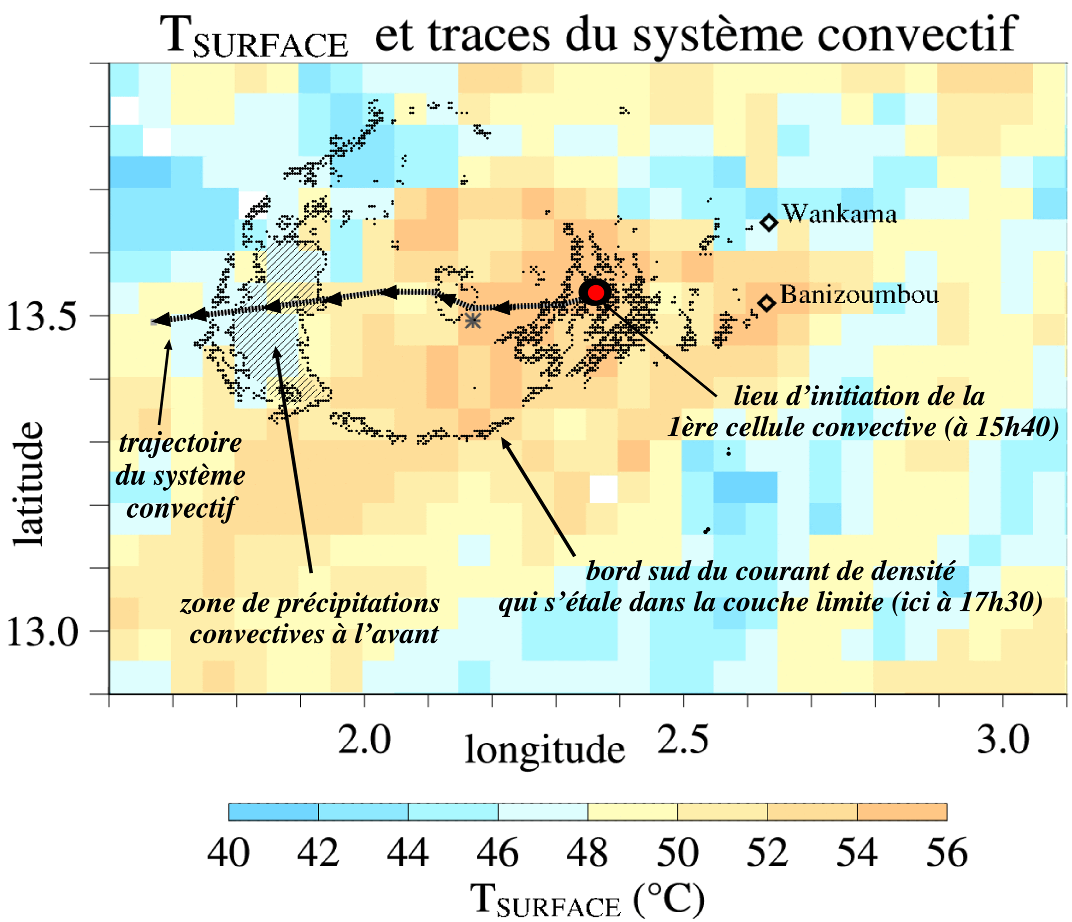


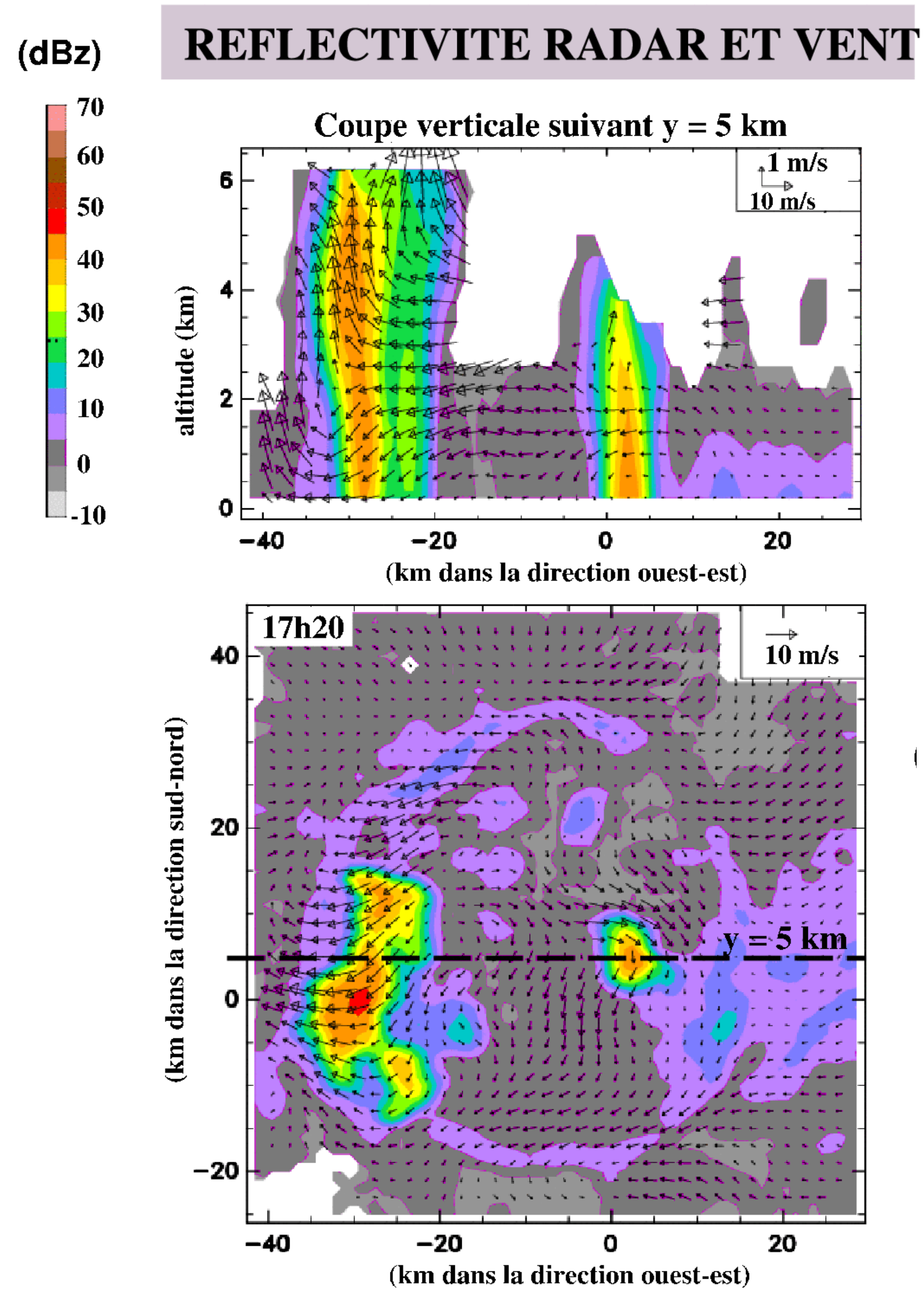
Guichard et al. (2004)

Cf also Hohenegger et al. (2009), with impact on land-atmosphere interactions

Deep convective activity over land : local scale considerations

Importance of cold pools for deep convection development





Lothon et al. (2011), Guichard et al. (2012)

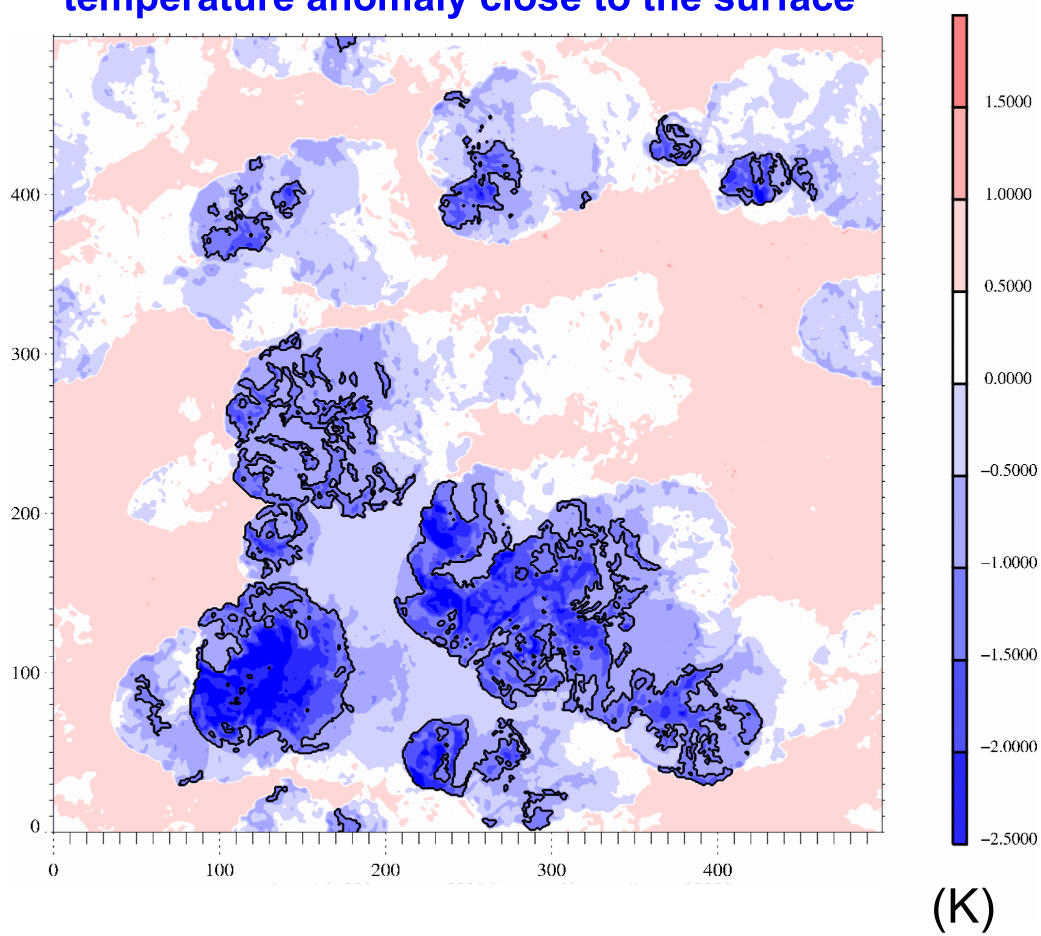
Deep convective activity over land : local-scale considerations

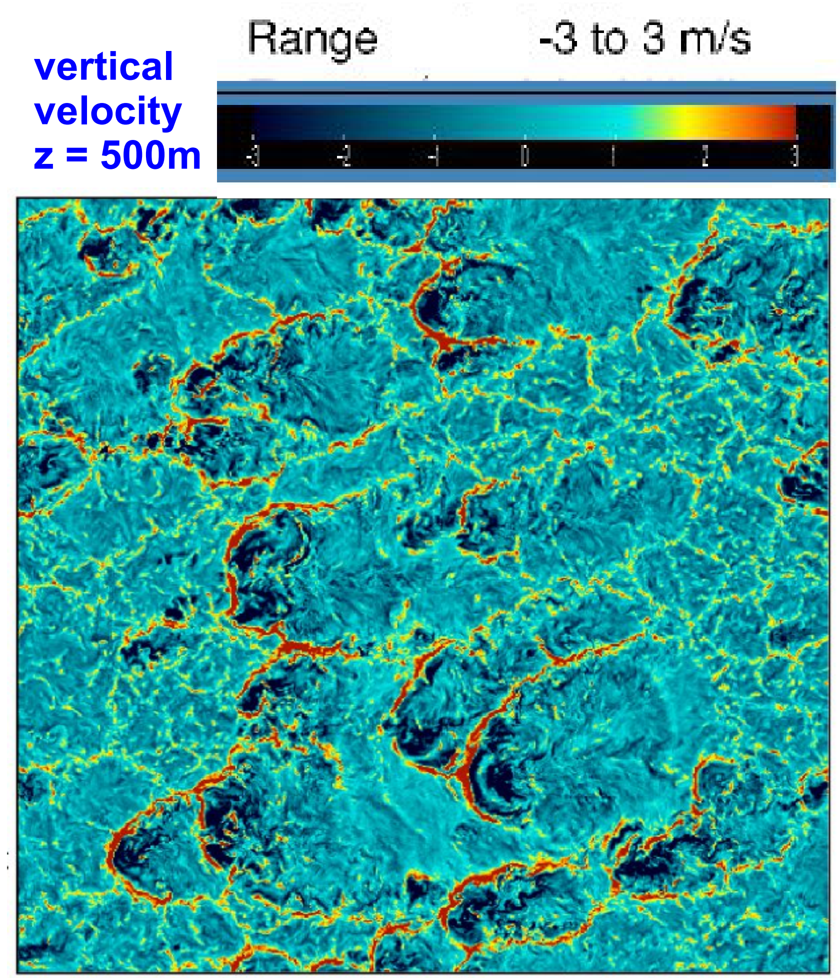
Importance of cold pools for deep convection development

over land — *Khairoutdinov et al. (2006)*
Boing et al (2012), Couvreux et al. (2012)

over ocean — *Tompkins (2000), Zuidema et al. (2013)*

temperature anomaly close to the surface



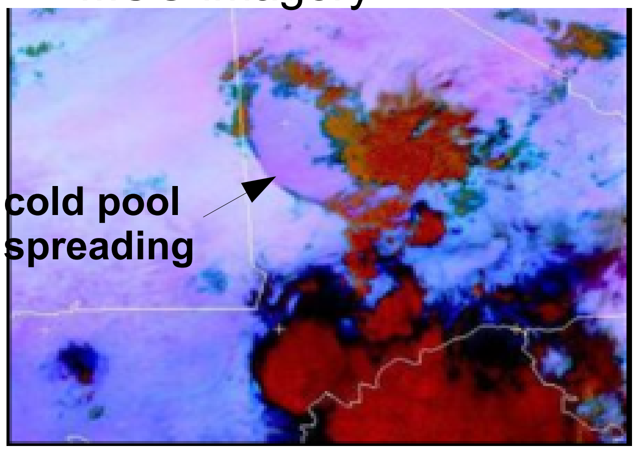


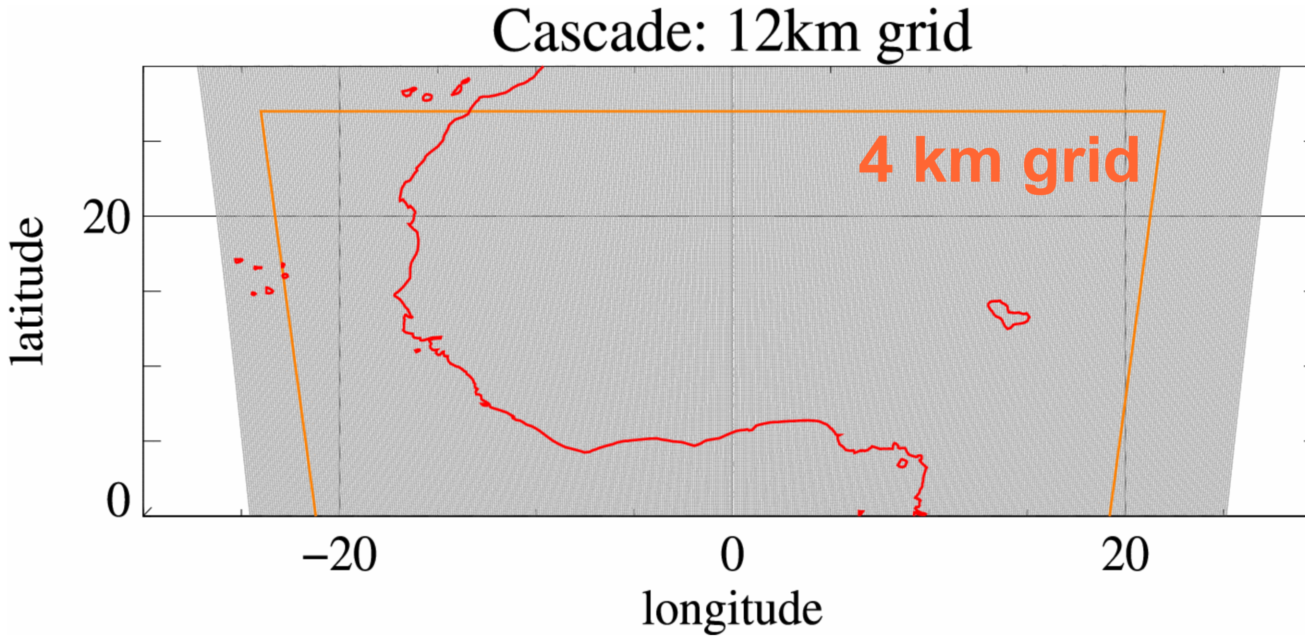
Illustrations from LES runs of the case study presented in Couvreux et al. (2012)

Still numerous questions : e.g. dynamic versus thermodynamic mechanism over ocean, cold pool critical or not to initial deep convection triggering over land in LES/CRM (?)

Diurnal cycle of convective activity over land : interactions with larger scale-motions

MSG imagery



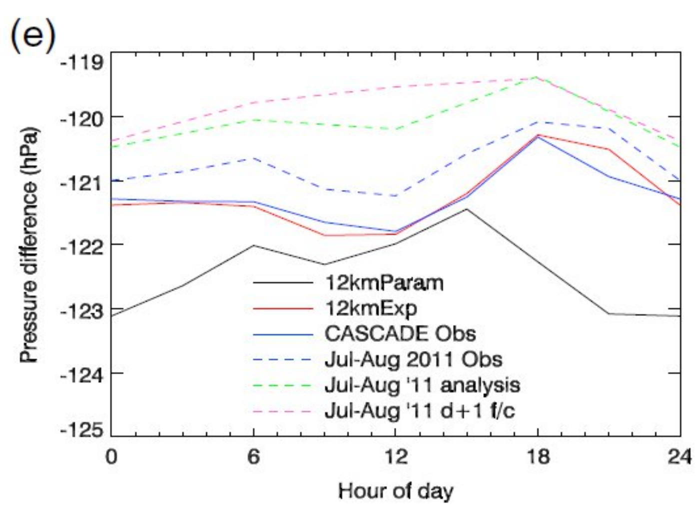


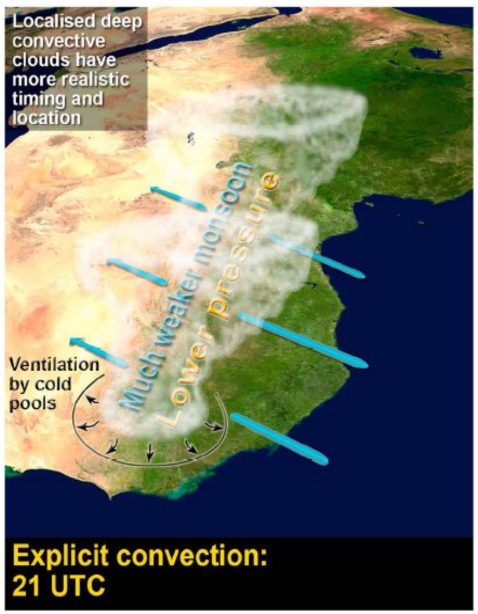
Marsham et al. (2013) : West African monsoon in CASCADE simulations using or not a convection scheme

major change in the monsoon circulation induced by changes in the diurnal cycle of deep convection

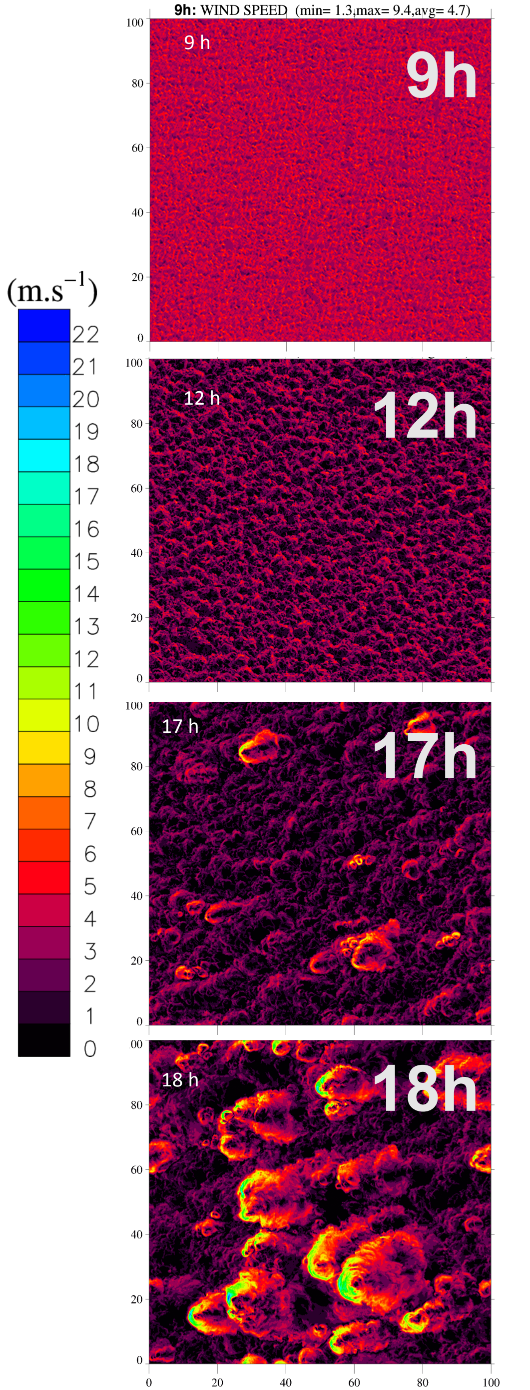
ventilation by cold pools

BL air : weaker horizontal mass flux from monsoon flow, but more mass flux from convectively-generated cold pools



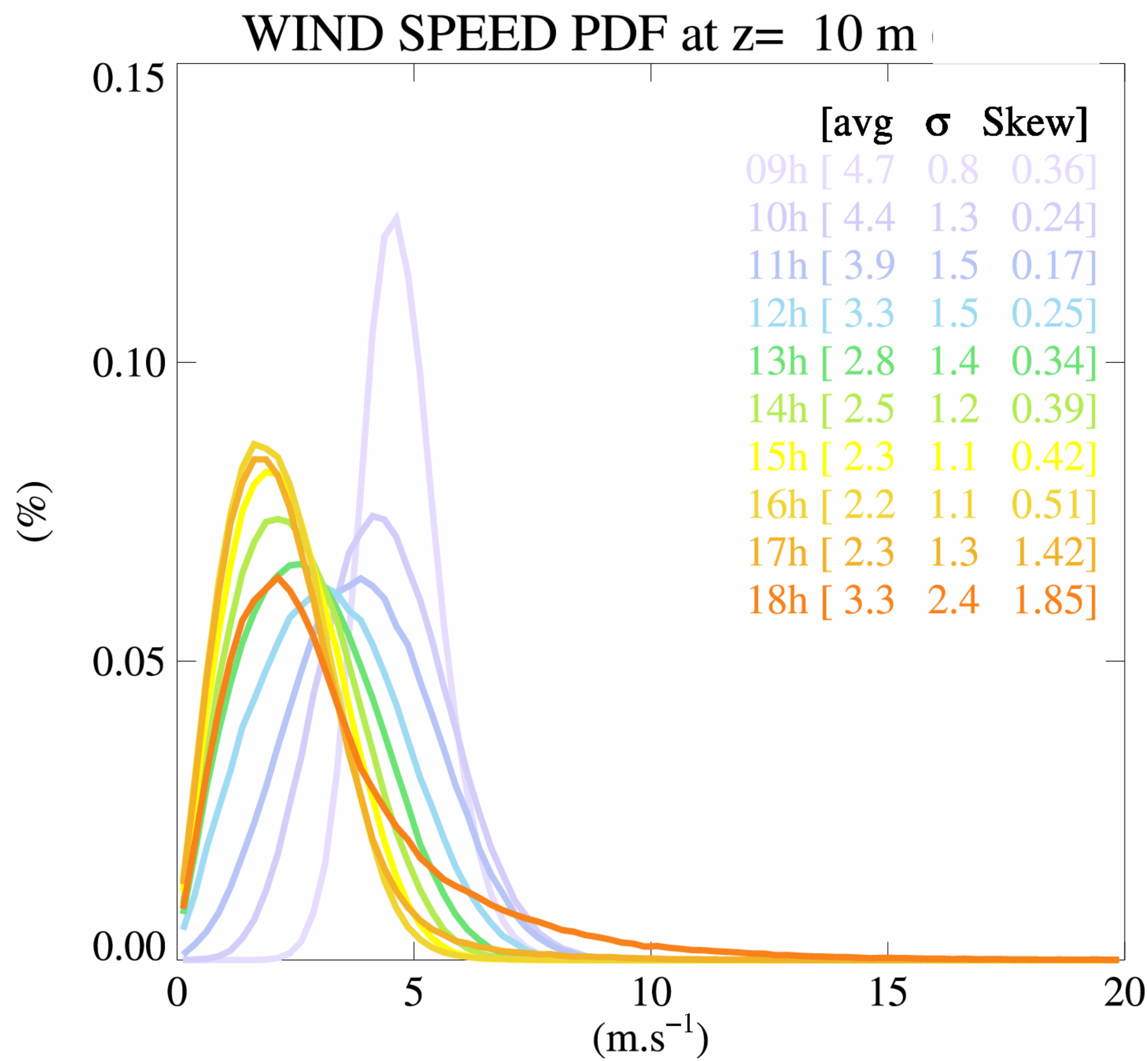


Wind speed at the surface



Further use... wind erosion in the Sahel

(Caviars project, Marticorena et al.,
convectively generated gust front are also critical to dust uplift)

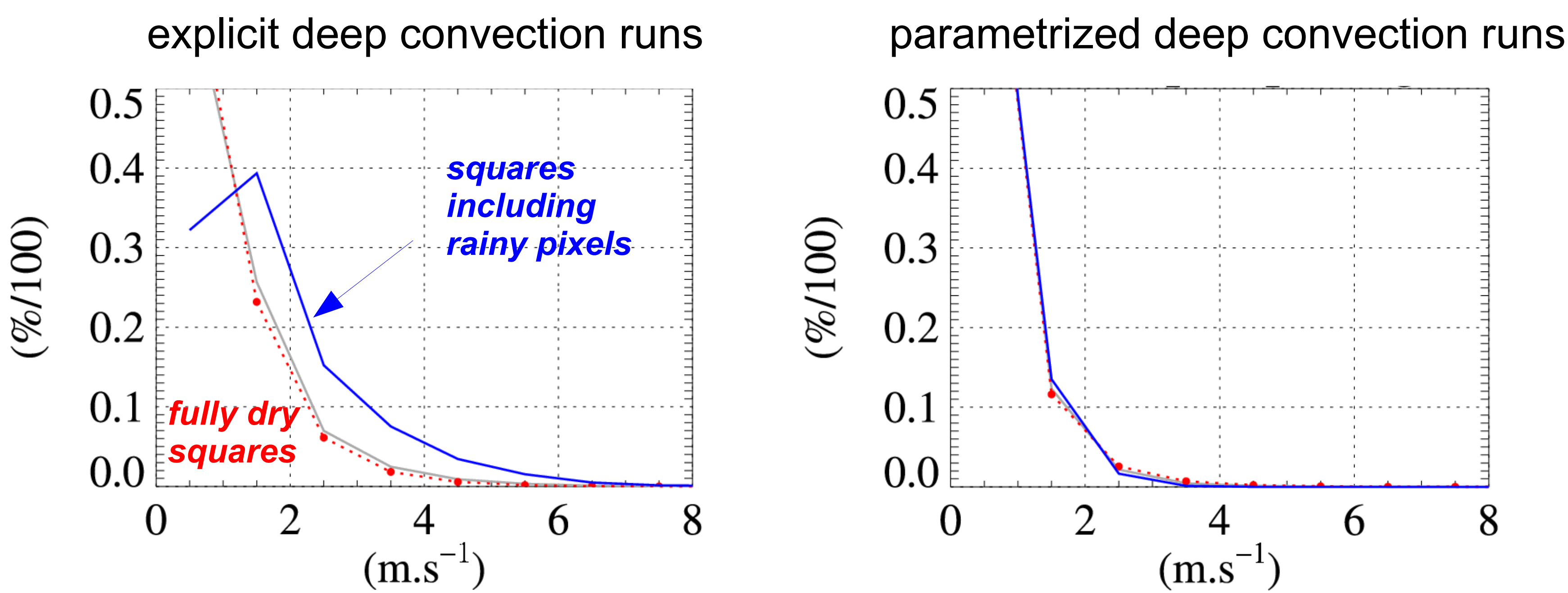


Daytime growth of the CBL : mean wind speed weakens (mixing of upper & lower winds)
Late afternoon : convectively-generated cold pools spread at the surface with strong winds at their leading edges

Δt = 1 h   domaine : 10°W-10°E , 10°N-20°N , 40 days monsoon 2006

Ug computed for 100 km x 100 km squares

PDF of Ug (gustiness) $Ug^2 = U^2 - Uo^2$



(using CASCADE runs outputs provided by Univ. Leeds)

SUMMARY

LES & CRM : specific features

* Fine-scale, limited area models, allowing to simulate explicitely mesoscale dynamics associated with convective clouds.
* These models use parametrizations to represent subgrid processes (turbulence, microphysics, radiative processes).
* Unlike GCMs: explicit coupling between convective motions & physical processes (strength)

Several decades of work to develop these models
Numerous steps of evaluations and intercomparisons
Actively participated to provide new knowledge, understanding on cloud related processes
Start to be used more effectively to guide parametrization development

These models are **not black boxes nor frozen**

Ongoing work to improve them

to make them well suited to answer specific questions

e.g. Surface-atmosphere coupling
land - boundary-layer – convection - cloud interactions
land surface scheme (Patton et al. 2005)
radiative processes (Pincus and Stevens 2013)
Ocean mixed layer model

However, their current capabilities allow now to address major scientific questions involving Interactions among processes operating on a wide range of scale

More computing power makes life easier but great science is also achieve with less

Thank you !

Bonne continuation !

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