Boundary layer control of air-sea fluxes and SST in the tropics

Or :
Role of convective bounrary transport of moisture and momentum by organized structures in the convective boundary layer (CBL)

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1/ Atmospheric origin of the Eastern Tropical Ocean systematic warm biases

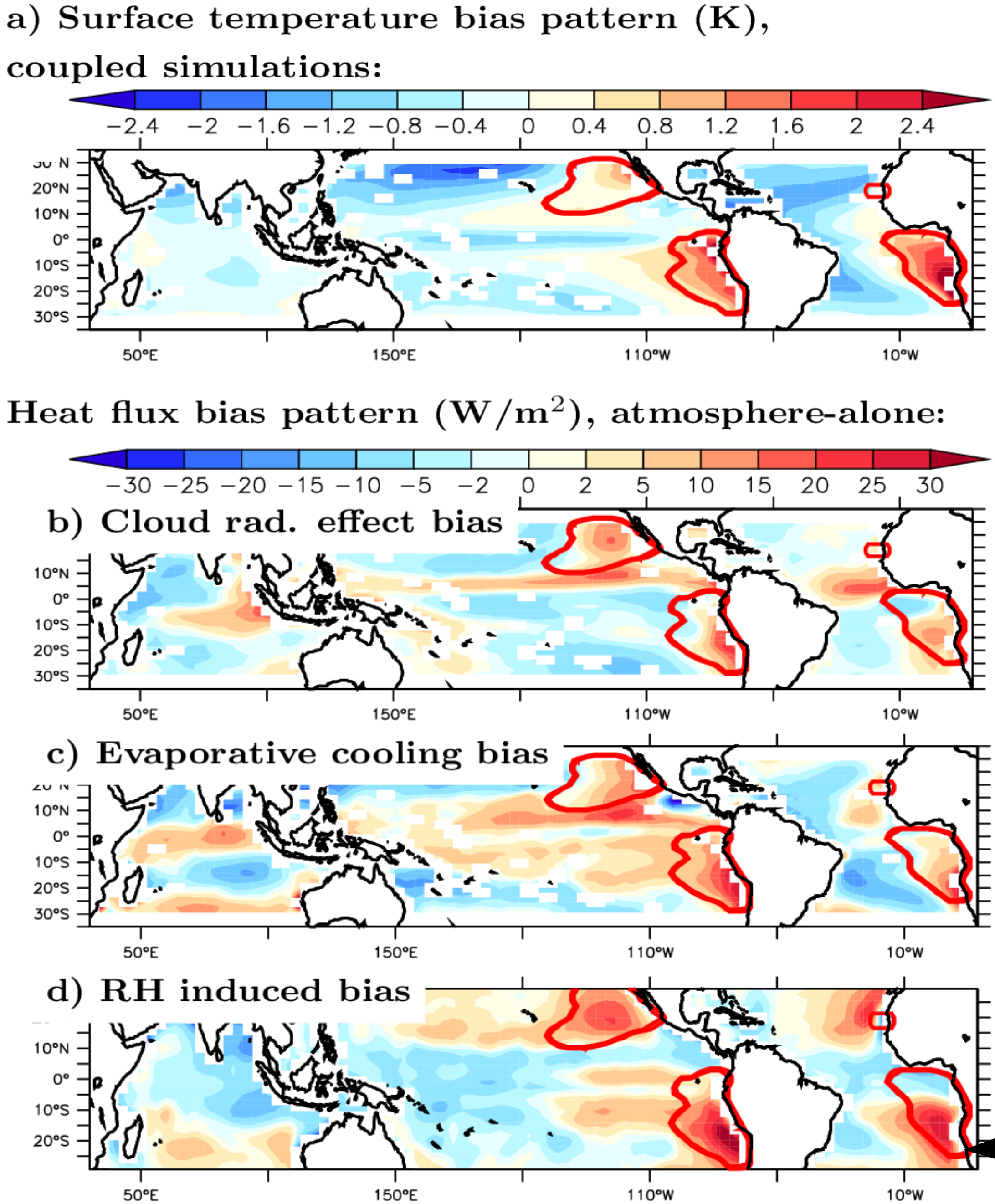
2/ Boundary layer convective transport controlling near surface humidity

3/ Boundary layer convective transport controlling momentum and dust lifting

4/ Toward inclusion of gustiness in the surface drag computation

1/ Atmospheric origin of the Eastern Tropical Ocean systematic warm biases

Hourdin et al, 2015, GRL



SST biases (K)
Coupled to ocean (historical)

CMIP5 multi-model mean

Heat flux biases (W/m2)
Forced by SSTs (amip)

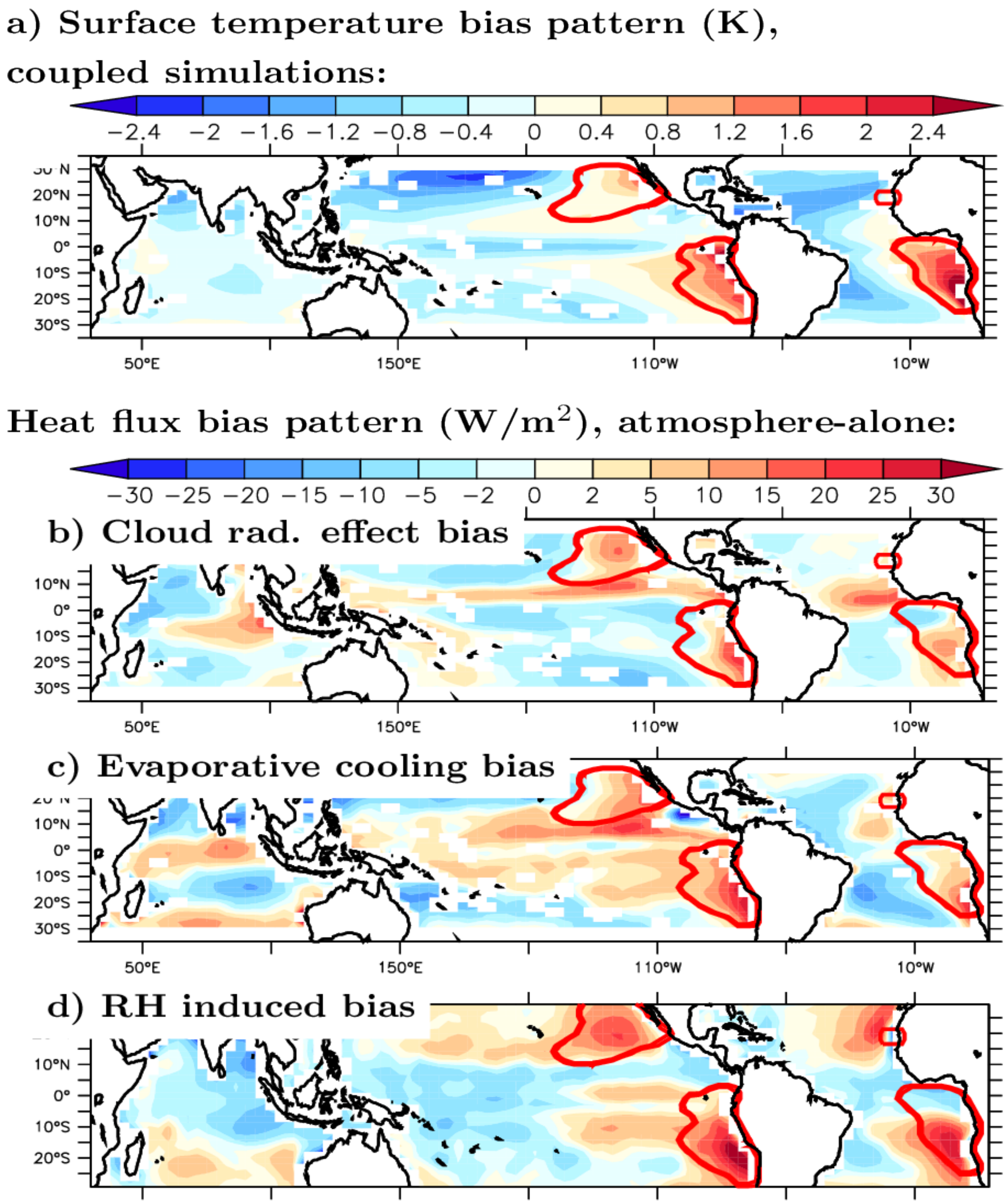
RH bias with respect to Da Silva obs

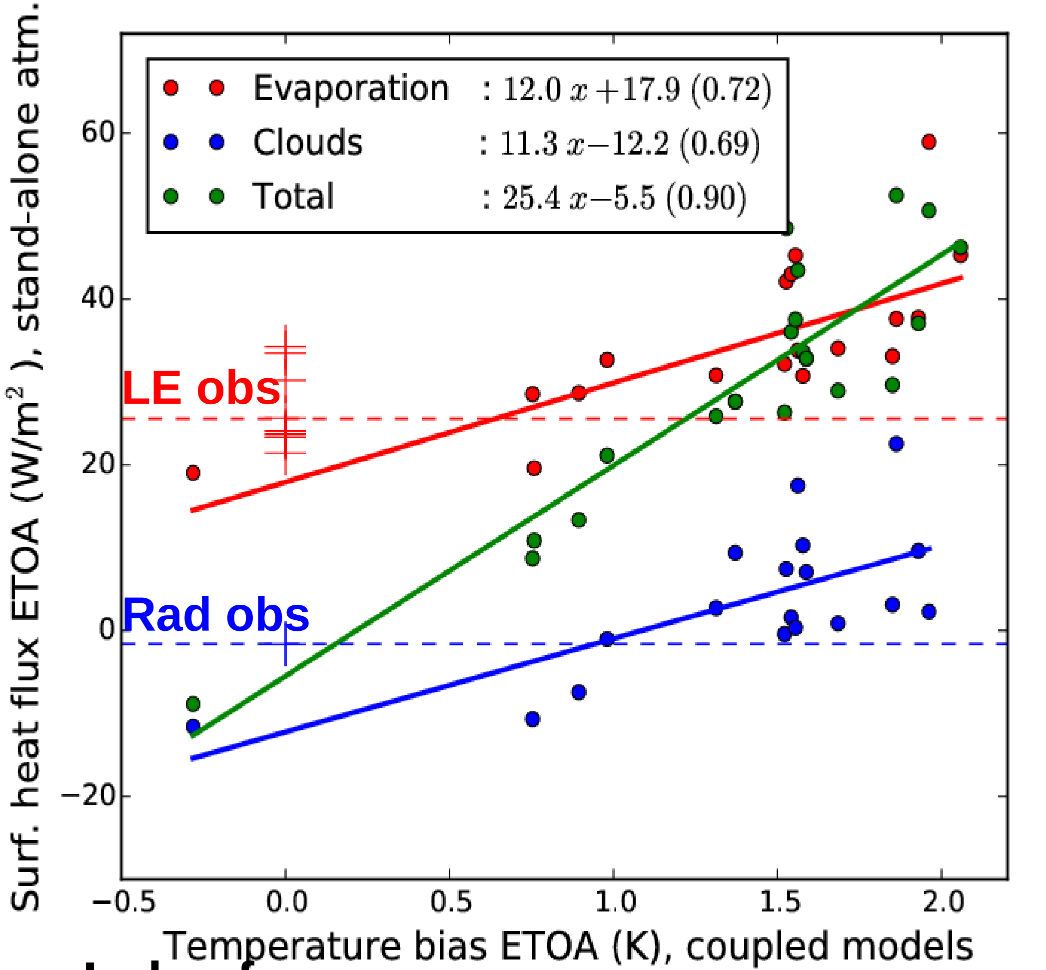
$$\delta LE = -L\rho C_D \|V\| q_{sat}(T_a)\,\delta RH_2$$

Latent heat flux LE :

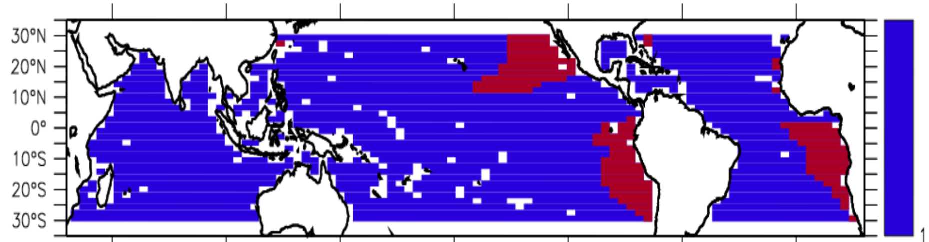
$$LE = L\rho C_D \|V\| (q_{sat}(T_s) - q_a) \longrightarrow LE = L\rho C_D \|V\| \left[\frac{\partial q_{sat}}{\partial q}(T_s - T_a) + q_{sat}(T_a)(1 - RH)\right]$$

1/ Atmospheric origin of the Eastern Tropical Ocean systematic warm biases





Index for
Eastern Tropical Ocean Anomaly



→ Strong warm biases in coupled models are assiociated with overestimated radiative fluxes and/or underestimated evaporative cooling

→ Underestimated evaporation due to overestimated near surface RH in terms of ETOA

1/ Atmospheric origin of the Eastern Tropical Ocean systematic warm biases

Bias decomposition

δLE

$$LE = L\rho C_D \|V\| \left[\frac{\partial q_{sat}}{\partial q}(T_s - T_a) + q_{sat}(T_a)(1 - RH)\right]$$

IPSL-CM5A-MR | **CNRM-CM5**

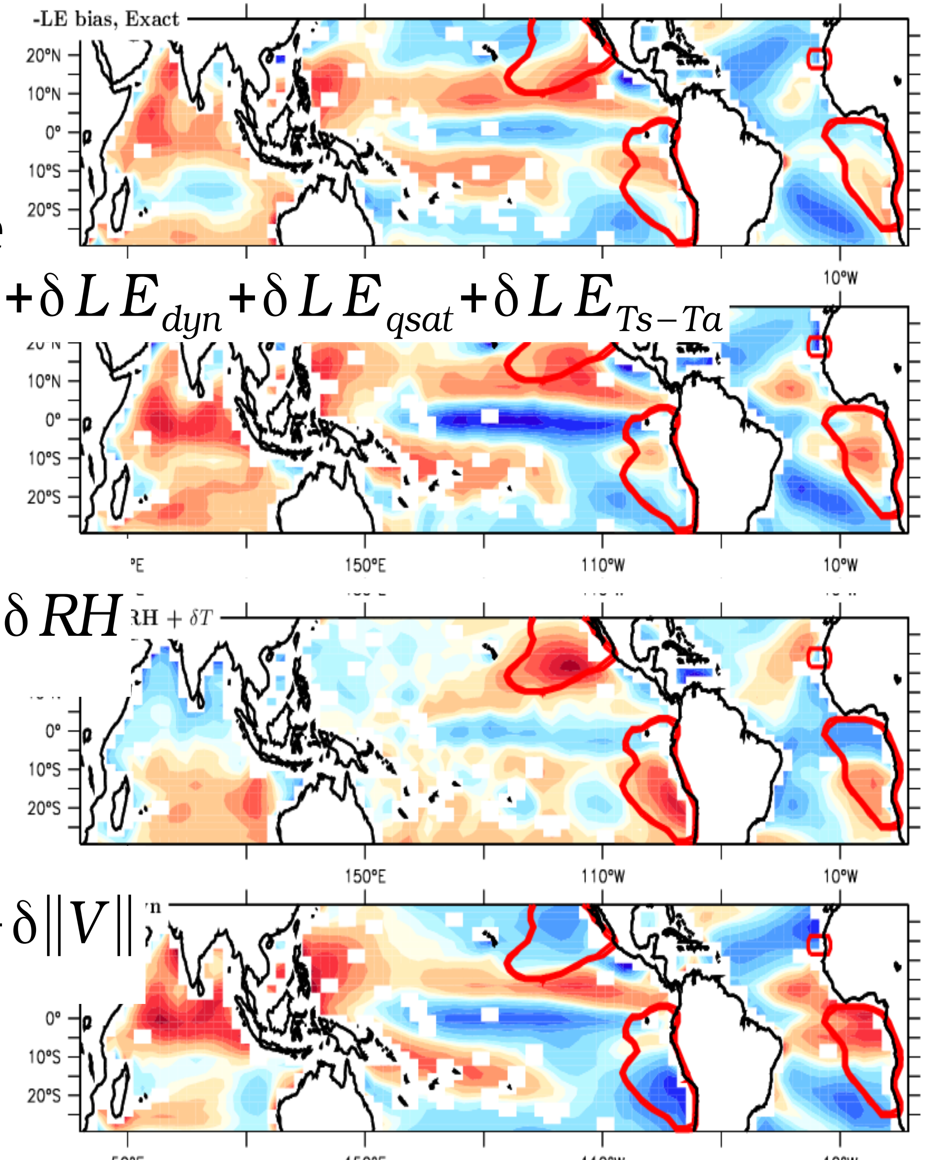
Exact

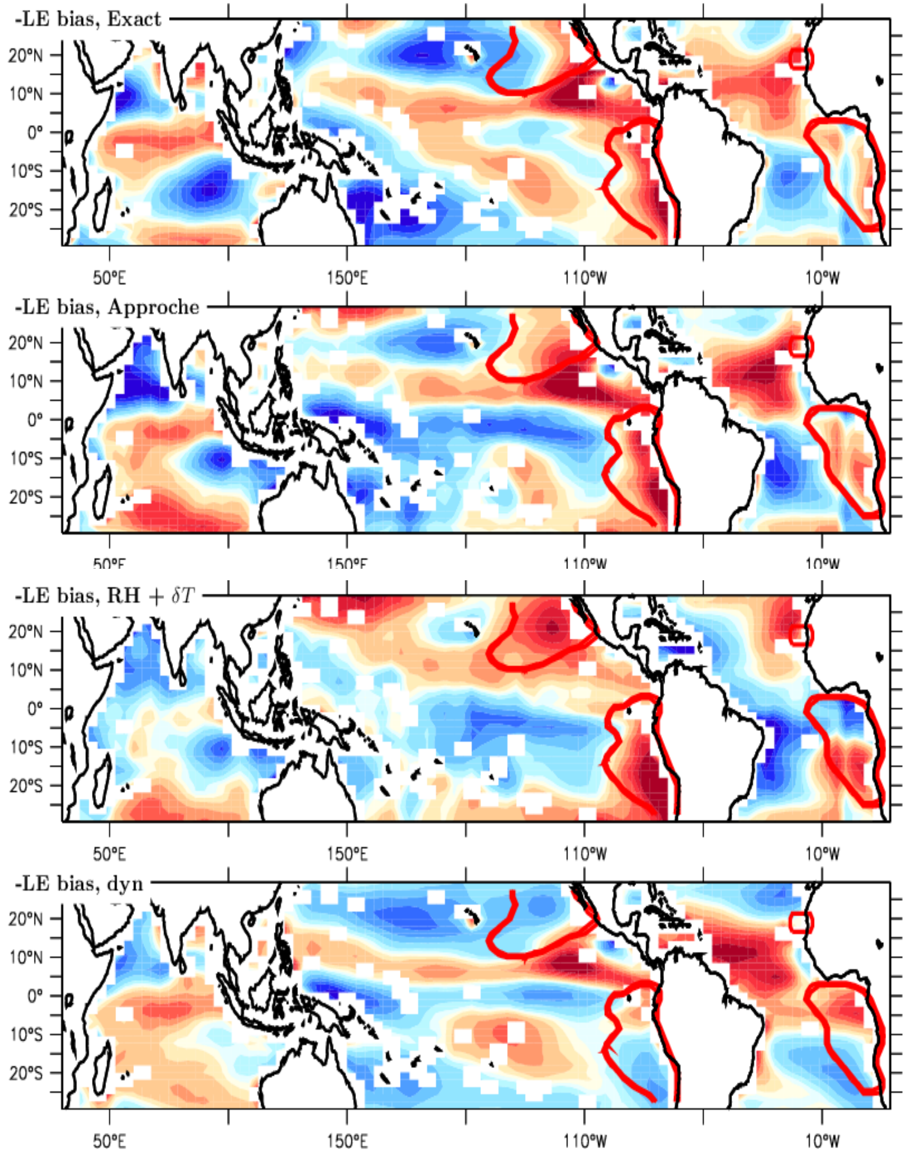
Approximate

$$\delta LE = \delta LE_{RH} + \delta LE_{dyn} + \delta LE_{qsat} + \delta LE_{Ts-Ta}$$

$$\delta LE_{RH} = \frac{\partial LE}{\partial RH}\delta RH$$

$$\delta LE_{dyn} = \frac{\partial LE}{\partial \|V\|}\delta \|V\|$$





→ Evaporative biases (RH) dominate East-West contrasts and are quite systematic

→ Dynamical contribution is more zonal and variable from model to model

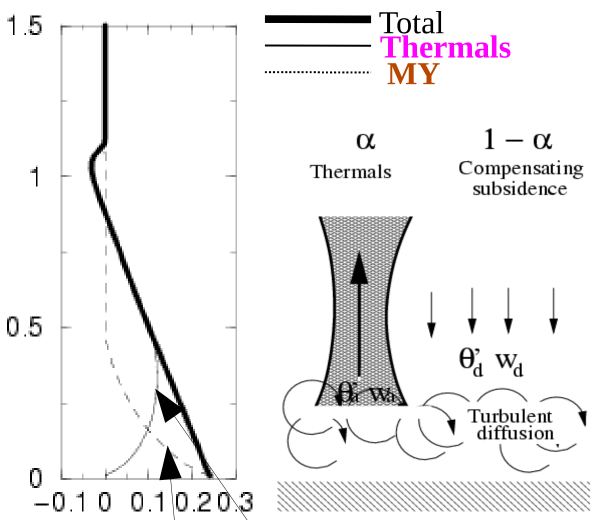
The “thermal plume model”

Hourdin et al., 2002, JAS
Similar to the EDMF approach introduced at about the same time by Siebesma and collab.
Rediscovering a proposition by Chatfield and Brost 1987

Combination of a TKE scheme (Mellor and Yamada MY, Yamada 1983) and mass flux scheme of the orgfanized structures of the convective boundary layer

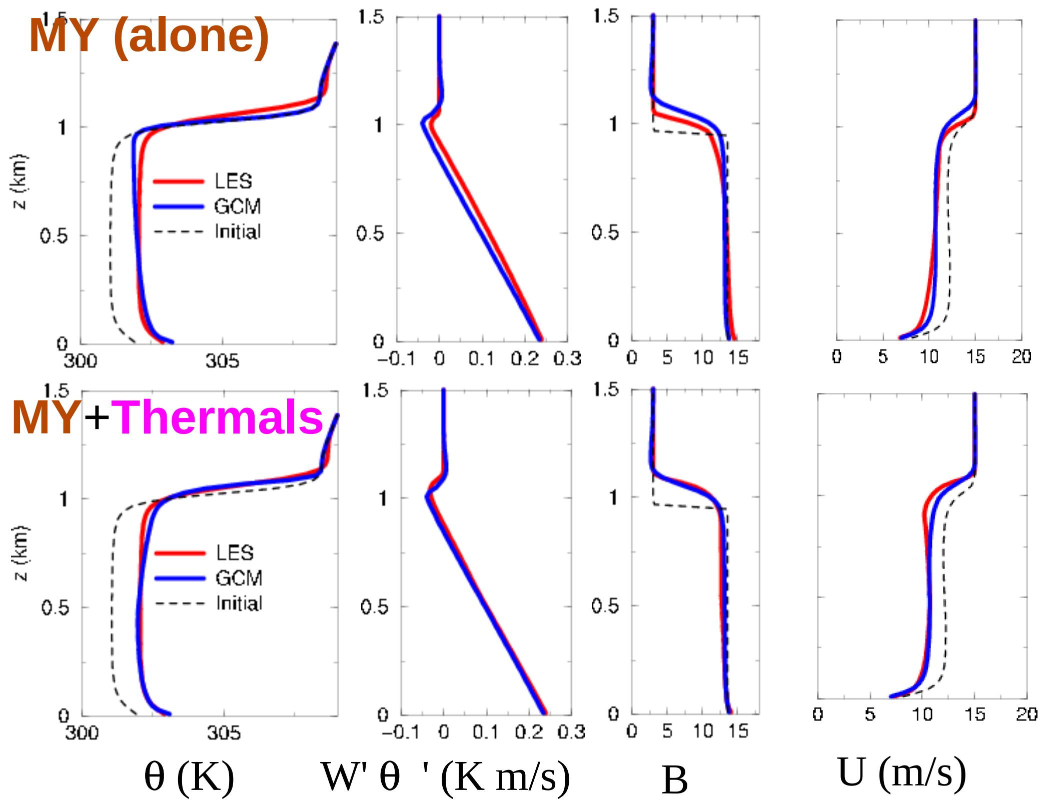
Comparison with large eddy simulations with the NCAR model, Moeng et al, 1992, Ayotte et al. 1999.)
Idealized convective boundary layer

Forcing : surface heat flux $\overline{w'\theta'}_0$=0.24 Km/s
geostrophic wind u=10m/s



MY+Thermals

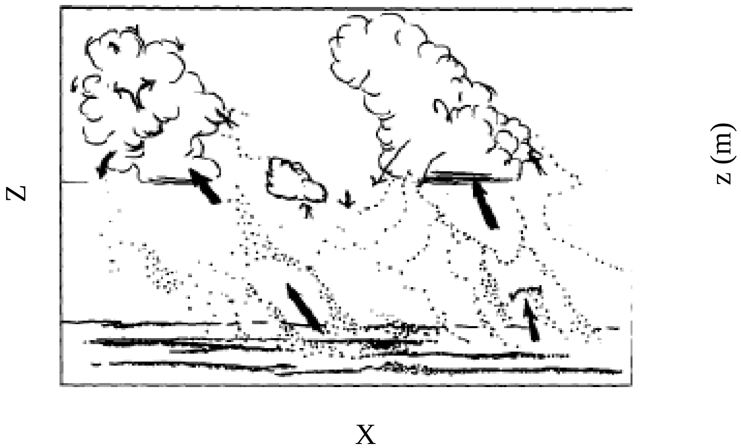
$$\overline{\rho w'\phi'} = -\rho K_\phi \left(\frac{\partial \phi}{\partial z} - \Gamma_\phi\right) + \hat{f}\left(\phi_a - \phi\right)$$

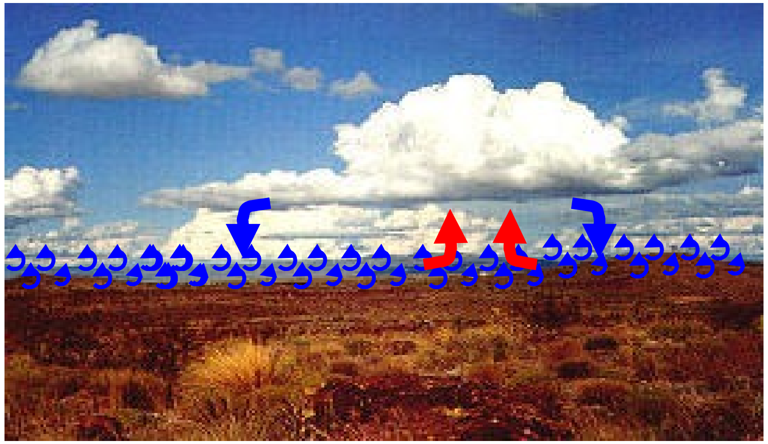


2/ Boundary layer convective transport controlling near surface humidity

Extension to cumulus clouds :
Rio et al., 2008, JAS
Couvreux et al., 2010, Rio et al. 2010, BLM

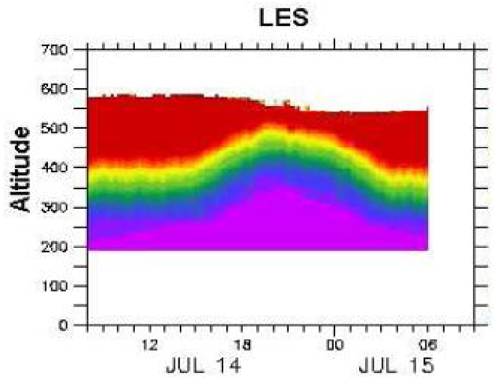
LeMone and Pennell, MWR, 1976



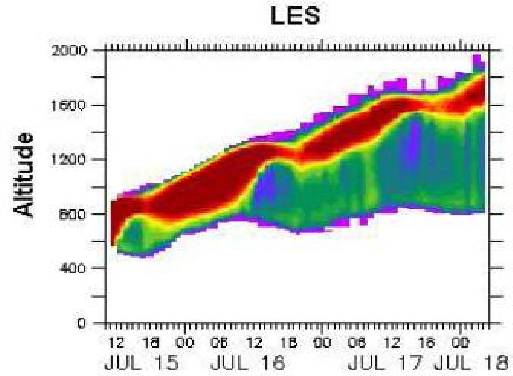


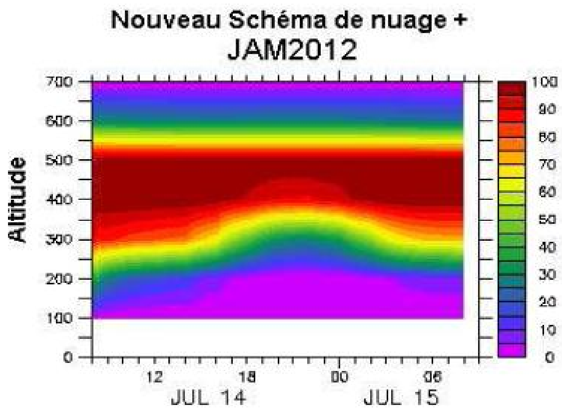
Jam et al, 2013, BLM :
Modification of detrainment to get stratocumulus
1D/LES evaluation of cloud cover

Fire test case | **Sandu** « transition case »

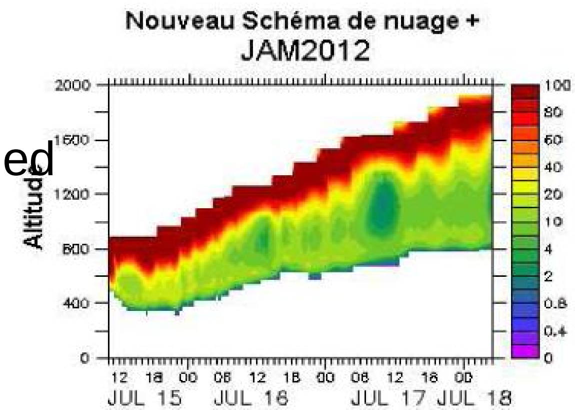


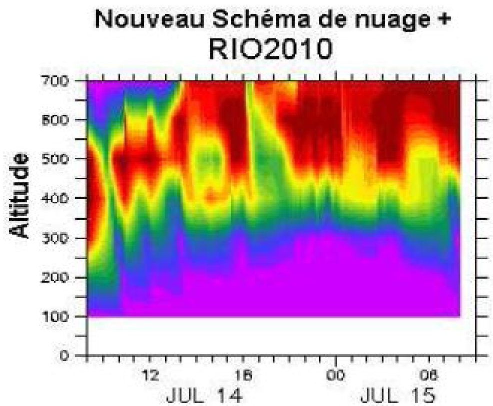
LES





Modified





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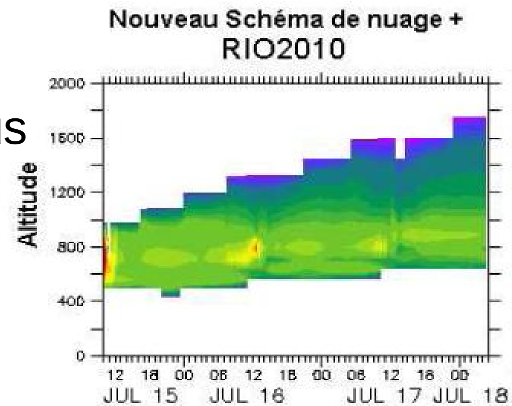


2/ Boundary layer convective transport controlling near surface humidity

Results from atmospheric simulations forced by climatic sea surface temperature (amip)

- Red arrow: activating thermal plumes
- Blue ellipse: ETO region
- Green arrow: Detrainement modifié

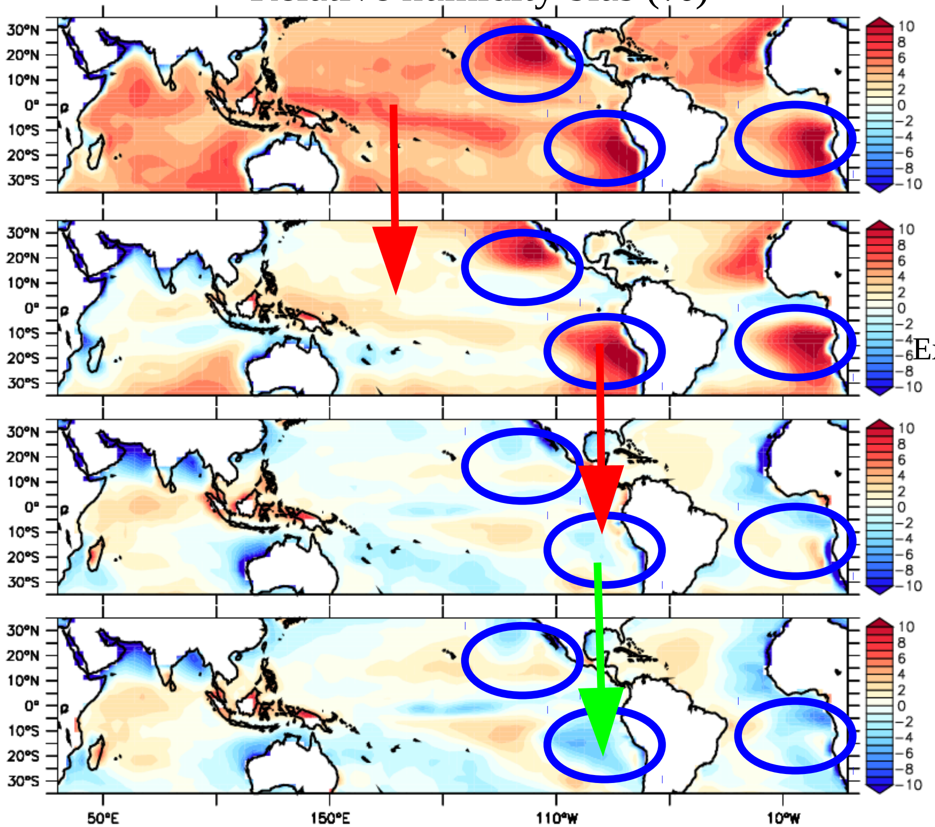
Observations

Da Silva

Calipso GOCCP

Total cloud cover (%)

Relative humidity bias (%)

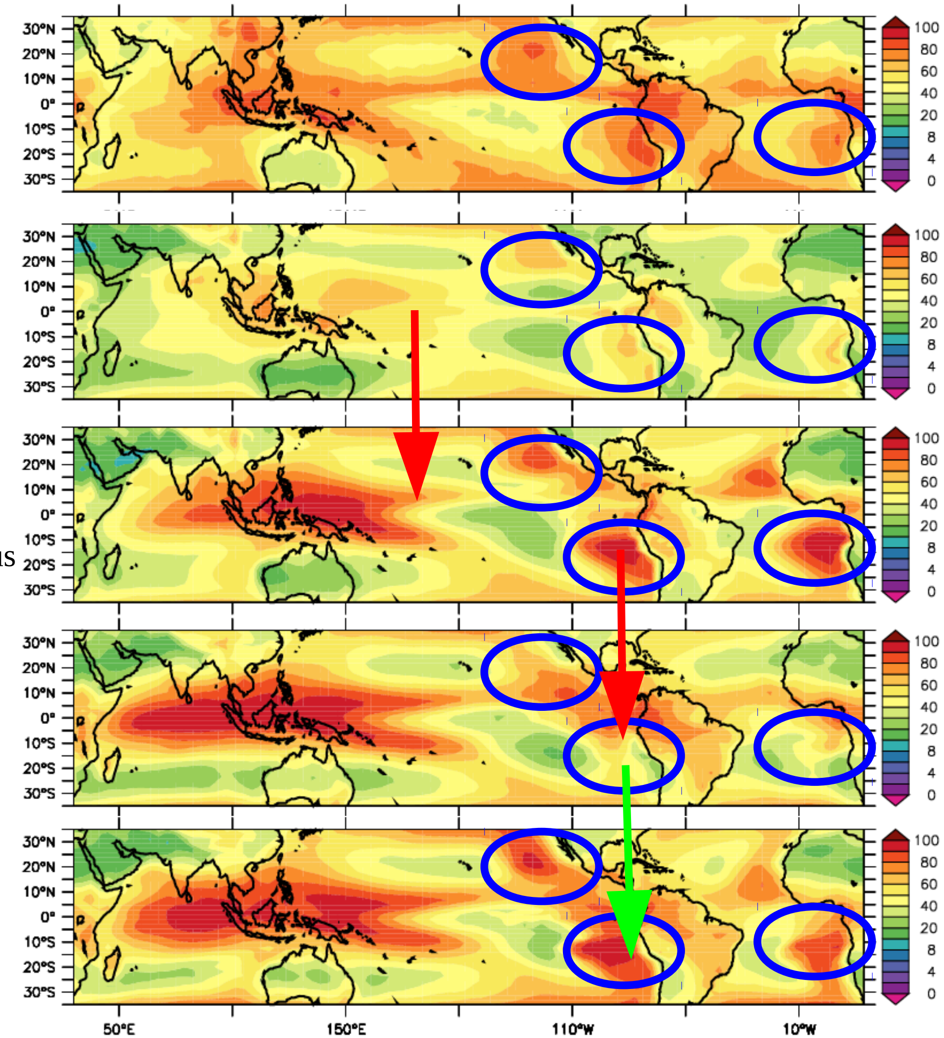


LMDZ5A
(or IPSL-CM5A)
No thermals

LMDZ5B
Thermals activation
Except for strato-cumilus

LMDZ6.0
Thermals activation
everywhere

LMDZ6.1
Thermals activation
Everywhere + special
Treatment for strato
Cumulus clouds



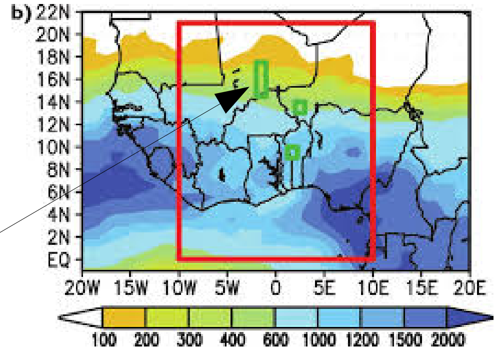
→ **Convective boundary layer transport dries the surface**

→ **Subtile : you need convective transport without destroying strato-cumulus**

2/ Boundary layer convective transport controlling near surface humidity

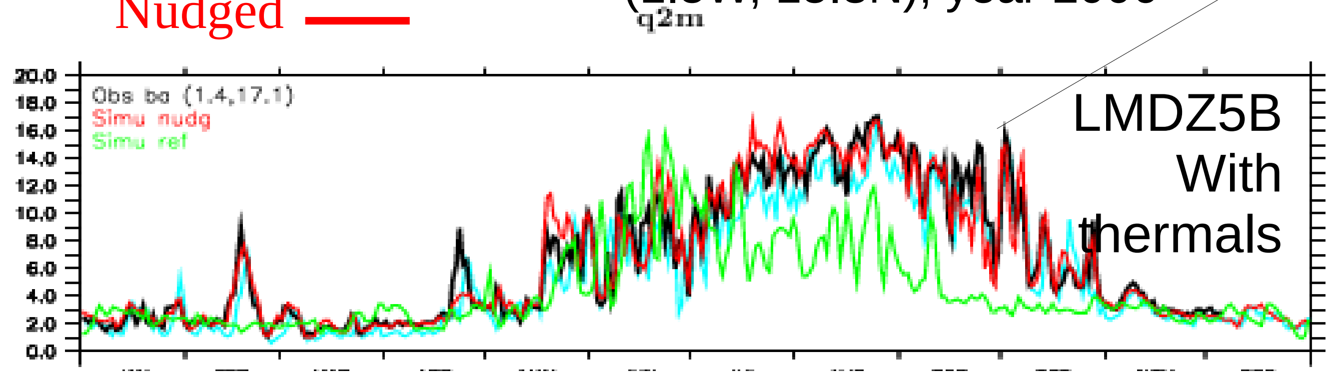
$$\frac{\partial X}{\partial t} = M(X) + \frac{\partial X^a - X}{\tau}$$

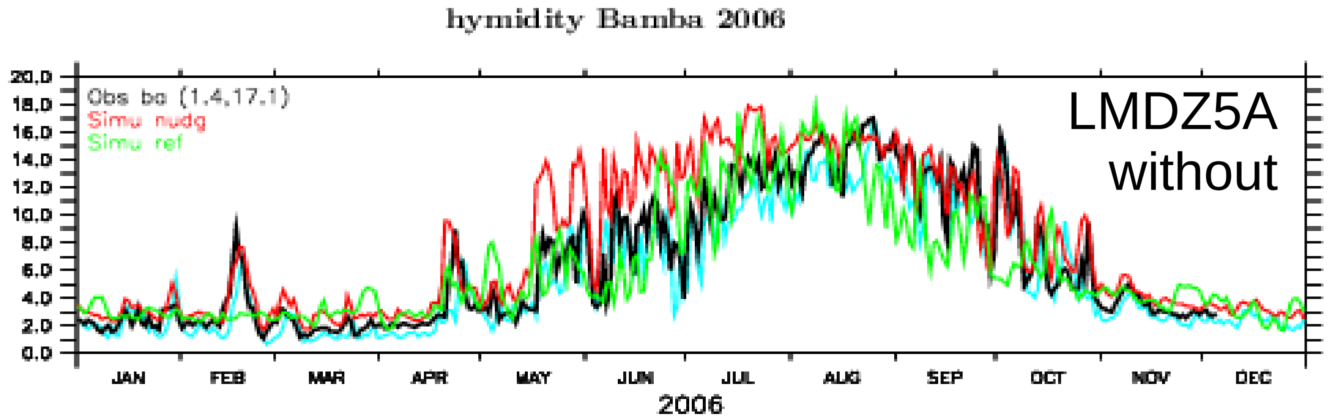
Control of near surface humidity over Sahel
LMDZ simulations nudged by ERA-I winds
τ = 6 hours



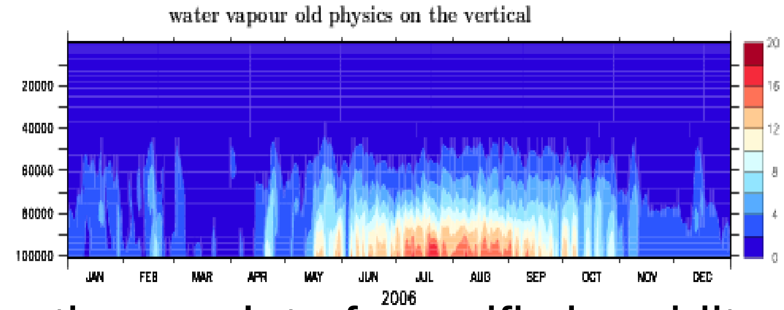
Obs
ERAInterim
Free
Nudged

Direct comparison of the model (300 km resol) 2m specific humidiy, with AMMA-Catch site obervations Bamba (1.5W, 15.3N), year 2006



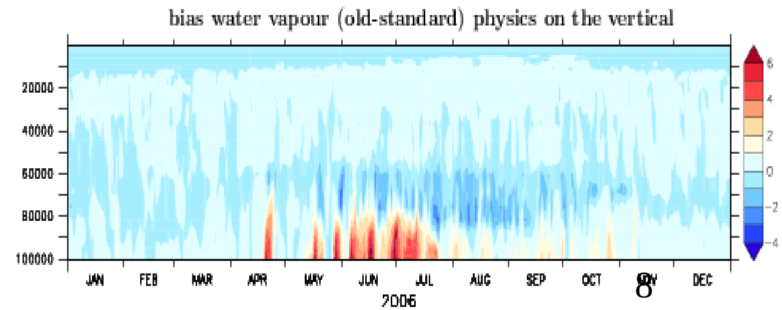


LMDZ5A



time-z plot of specific humidity

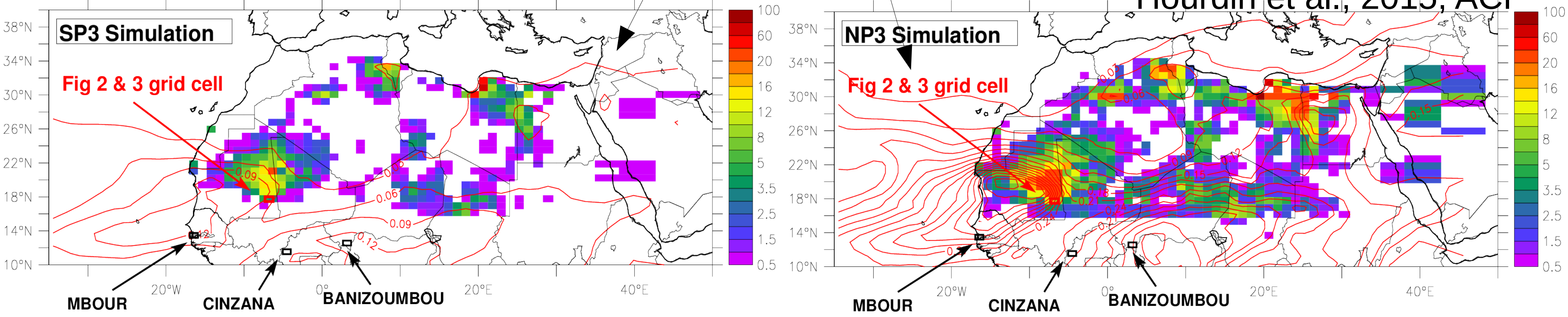
LMDZ5B-LMDZ5A



→ **Convective boundary layer transport dries the surface**
→ **Nudging allows to learn from direct comparison with site observations**

Impact of the new parametrization on dust emissions (version with interactive dust)
Simulations with standard (A) and new (B) physics (with thermals)

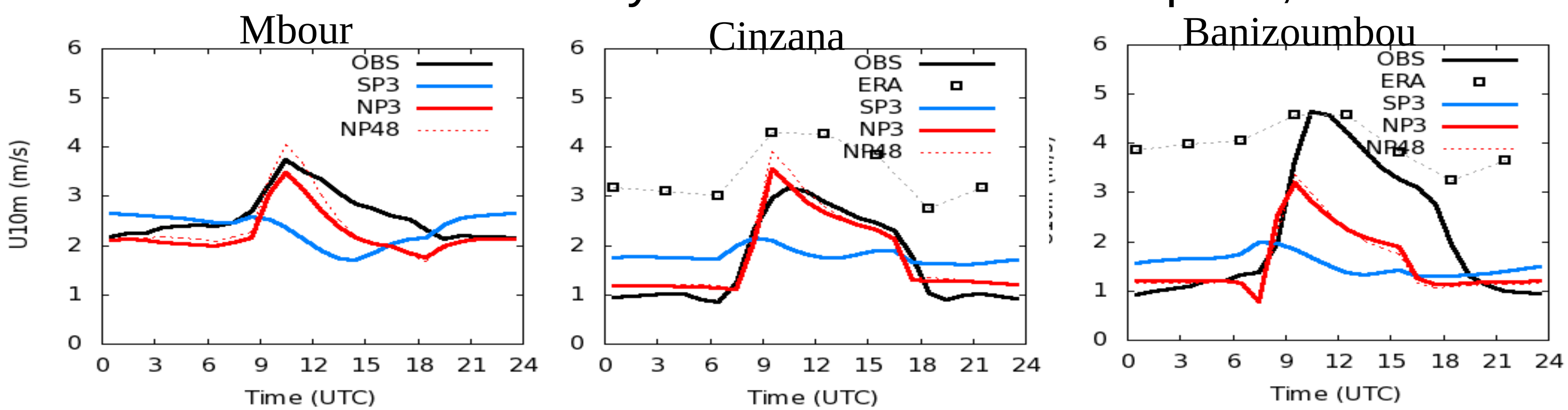
Hourdin et al., 2015, ACP



Dust emissions Mars 2006, µg/m²/s, simulations nudged with ERA-I winds

Non linear wind dependency of emission : $F_h = \frac{K \rho_a}{g} U^{*3} \left(1 - \frac{U^{*Th}}{U^*}\right) \left(1 + \frac{U^{*Th}}{U^*}\right)^2$

Mean diurnal cycle of near 10m wind speed, m/s



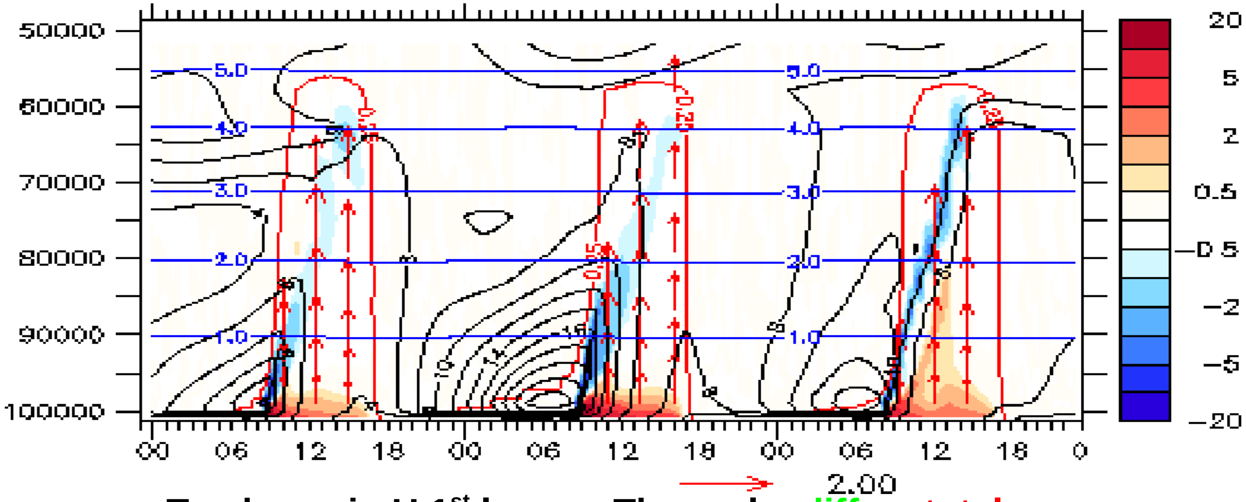
Standard without LMDZ5A

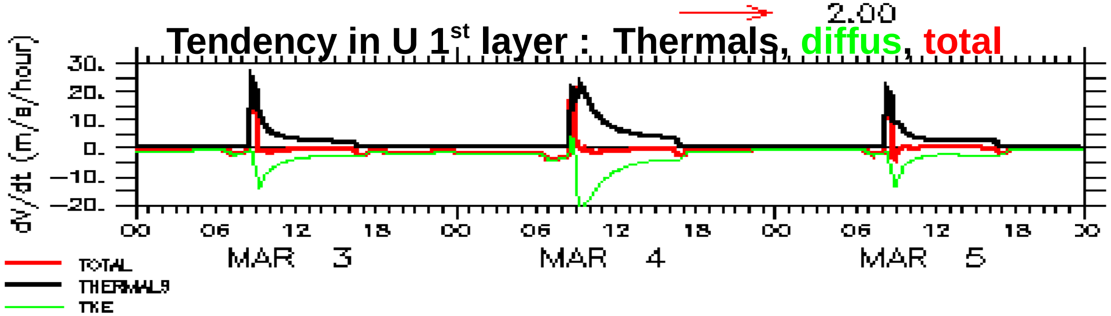
New with thermal plume model LMDZ5B

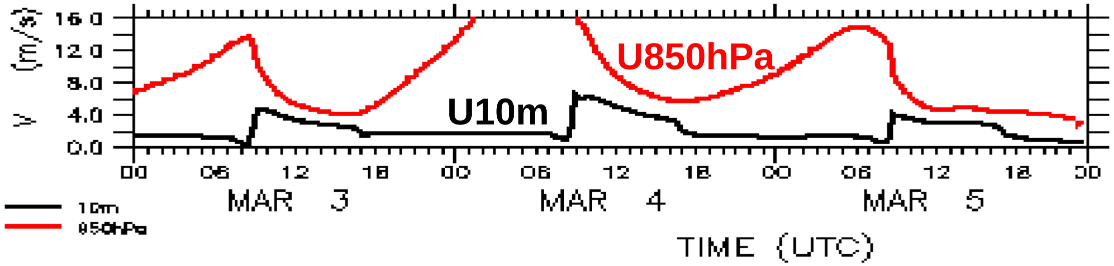
→ The new physics reinforce emissions by reinforcing the morning wind max
→ Diurnal cycle of wind speed improved, even compared to ERA-I used for nudging

3/ Boundary layer convective transport controlling momentum and dust lifting

Colors : « thermal plume » tendency (non local transport) in ||V|| (m/s/day)
Black contours : ||V|| (m/s)
W in thermal plumes (red arrows)







Plume conservation equations

$$\frac{\partial f}{\partial z} = e - d, \quad f = \rho \alpha w$$

$$\frac{\partial f \hat{c}}{\partial z} = e c - d \hat{c}$$

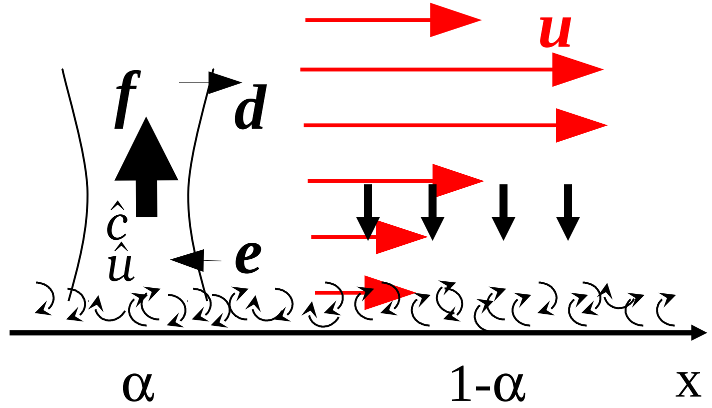
$$\frac{\partial f \hat{u}}{\partial z} = e u - d \hat{u} + C(u - \hat{u})$$

Pressure drag plume / environment

Vertical transport of momentum

$$\frac{\partial \rho u}{\partial t} = -\frac{\partial \left(\overline{\rho w' u'}\right)}{\partial z}$$

$$\overline{\rho w' c'} = -\rho K z \frac{\partial u}{\partial z} + f(\hat{u} - u)$$



Vertical wind speed ~ 1 m/s

→ subsidence 10 cm/s

→ advective time 2000s / 200m

4/ Toward inclusion of gustiness in the surface drag computation

Increase of surface fluxes by meso-scale circulations, issued from Toga-Coare experiment (Redelsperger et al., 2000)

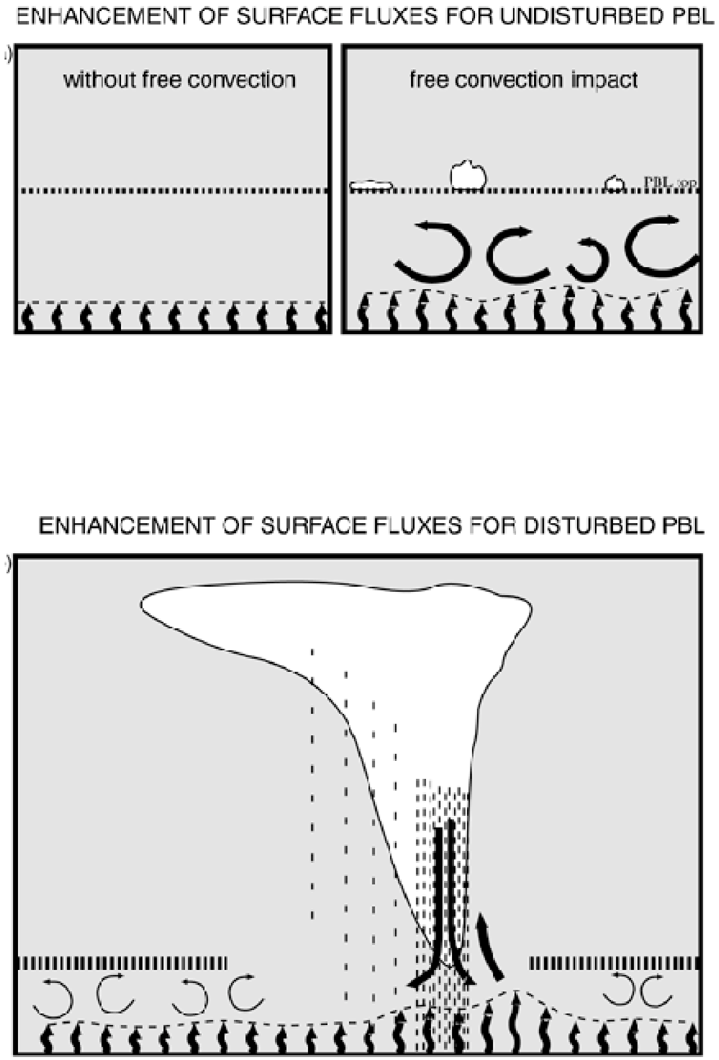
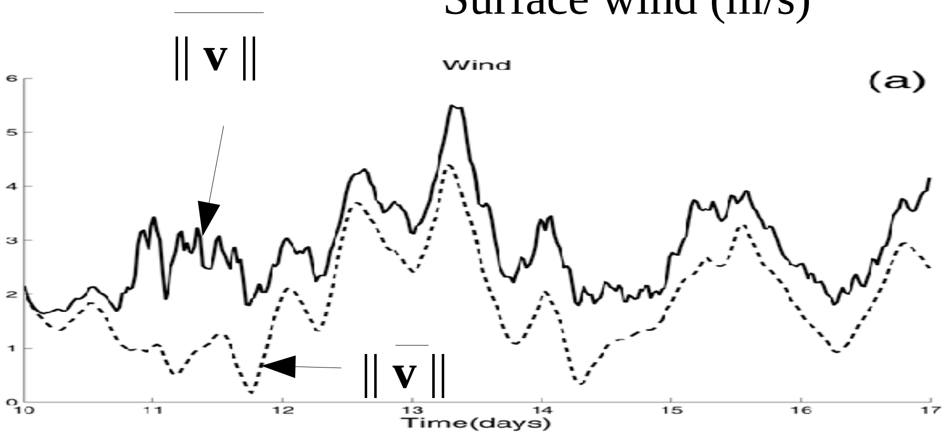
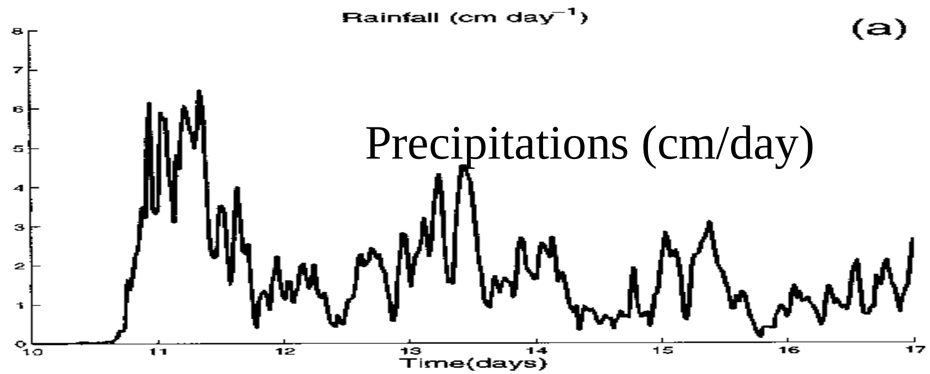
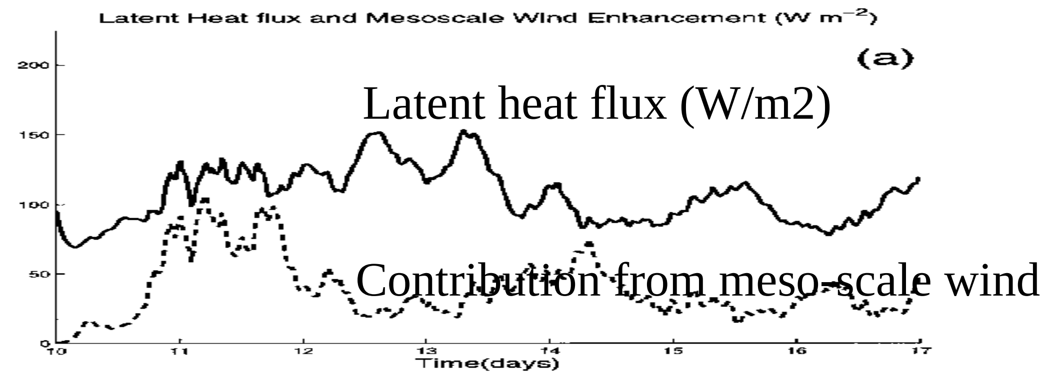


FIG. 1. Enhancement of surface fluxes for (a) undisturbed convective boundary layer and (b) disturbed boundary layer.

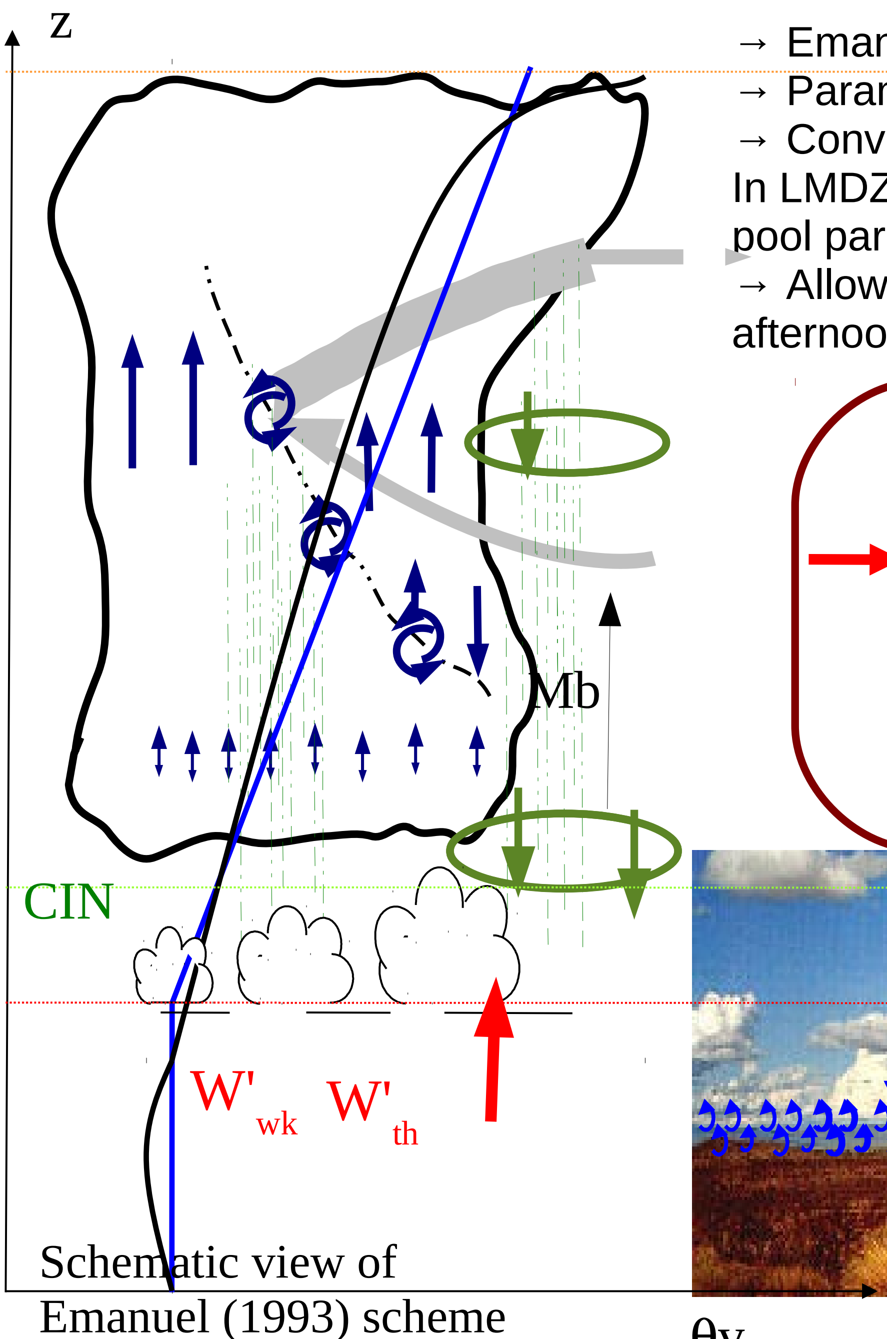






4/ Toward inclusion of gustiness in the surface drag computation

"New Physics" : thermal plumes + cold pools + convection controlled by sub-cloud processes

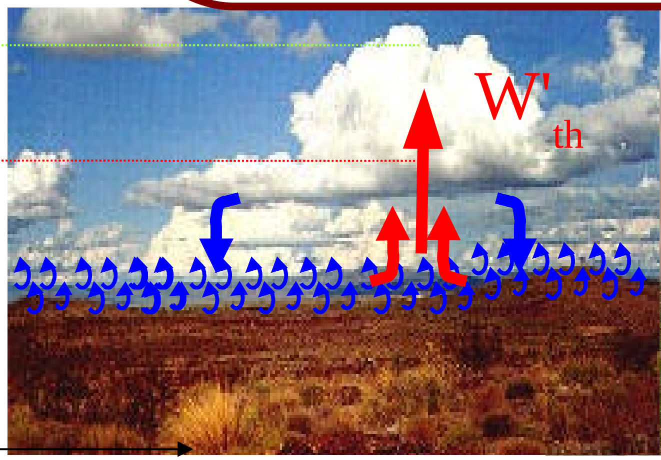


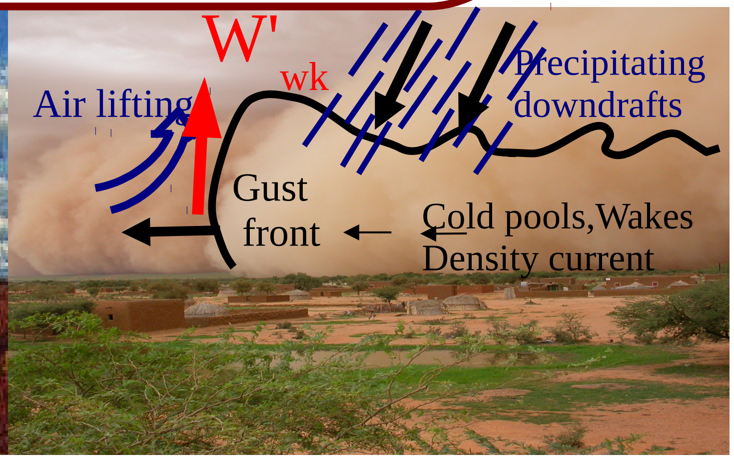
Schematic view of
Emanuel (1993) scheme
Deep convection

→ Emanuel scheme for deep convection
→ Parameterization of cold pools or wakes (Grandpeix and Lafore 2010)
→ Convective closure and trigering based on sub cloud processes
In LMDZ : we use estimations of W' coming from thermal plumes and cold pool parametrization (Catherine Rio, Phd)
→ Allows to shift the diurnal cycle of deep convection with a max in late afternoon (Rio et al., 2009, GRL)

K: Available lifting energy
ALE in J/kg, scaling with w'^2.
→ **Triggering** : max (ALE_{th},ALE_{wk}) > |CIN|

P: Available lifting power
ALP in W/m², scaling with w'^3.
→ **Closure** : MB=f(ALP_{th}+ALP_{wk})





4/ Toward inclusion of gustiness in the surface drag computation

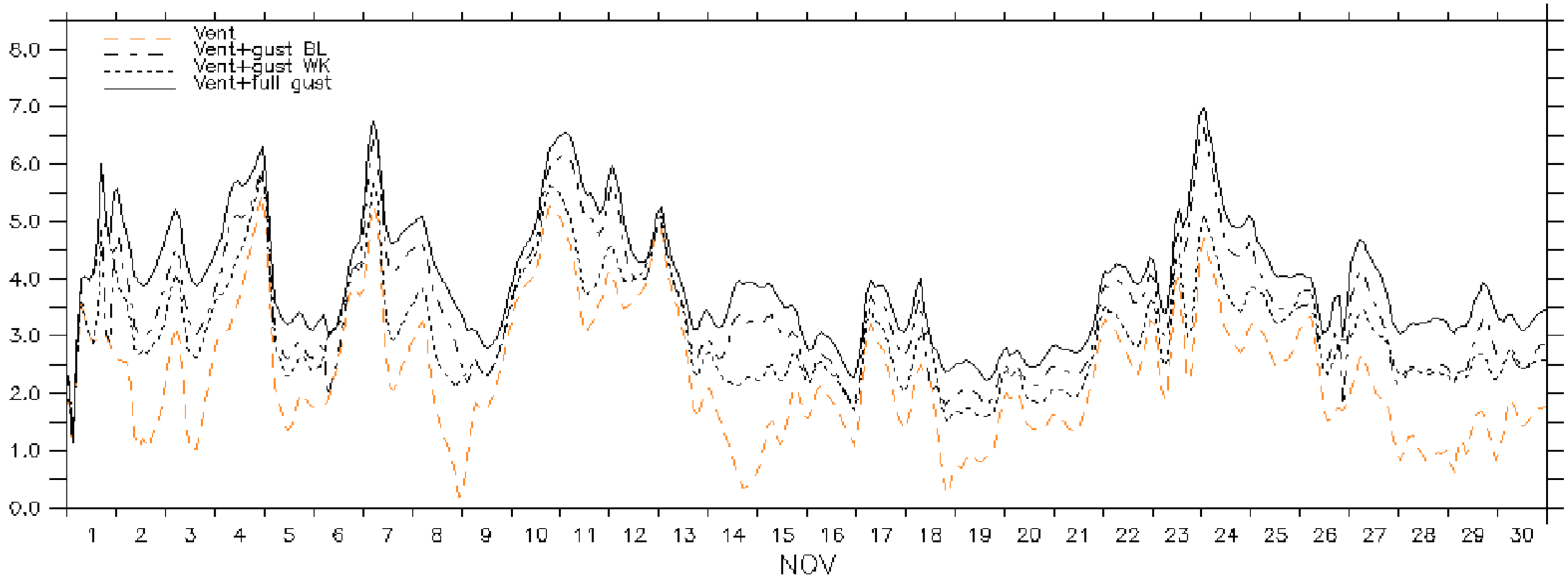
$$U_{eff}^2 = U_{10m}^2 + \beta^2 \zeta \, 2ALE_{thermals} + \alpha \, 2ALE_{cold\ pools}$$

ALE = Available lifting energy, scaling with w'^2

- LMDz_gust (f_gust_bl=0.845, f_gust_wk=0.2)

Wind (U10m)
Wind + gust thermals
Wind + gust cold pools
Wind + total gust

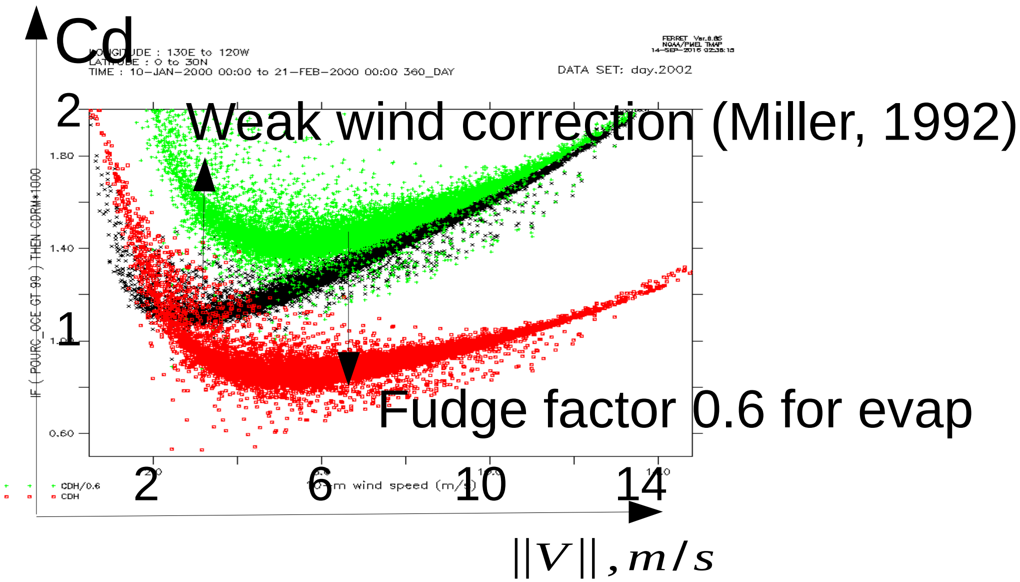
Ueff
m/s

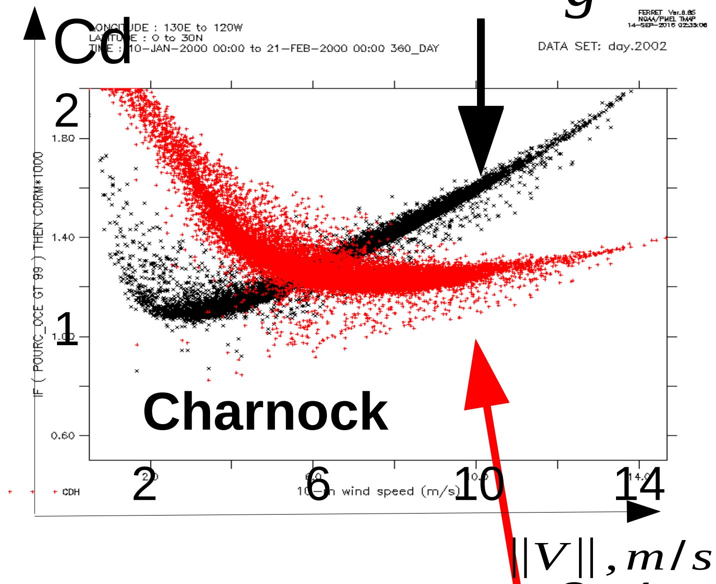


Cd : drag coef

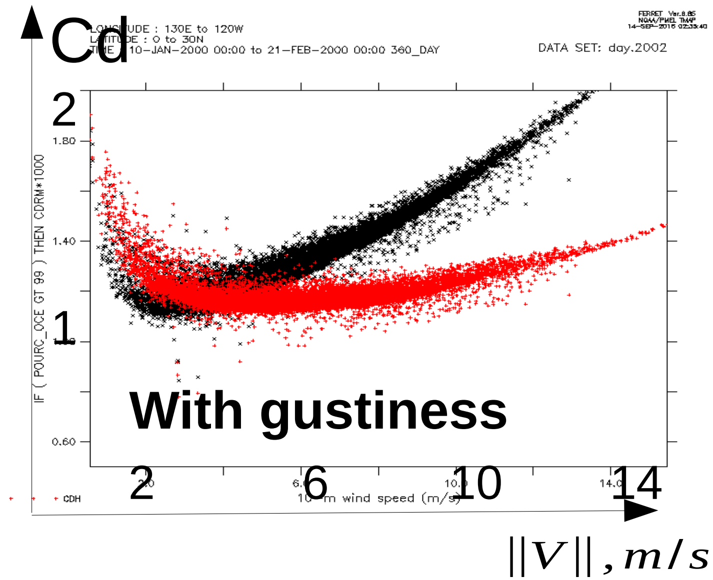
Cq : Exchange coef for moisture

$$Z0_m = 0.018\frac{u_*^2}{g} + \frac{0.11*14e\text{-}6}{u_*}$$





$$Z0_h = \frac{0.4*14e\text{-}6}{u_*}$$

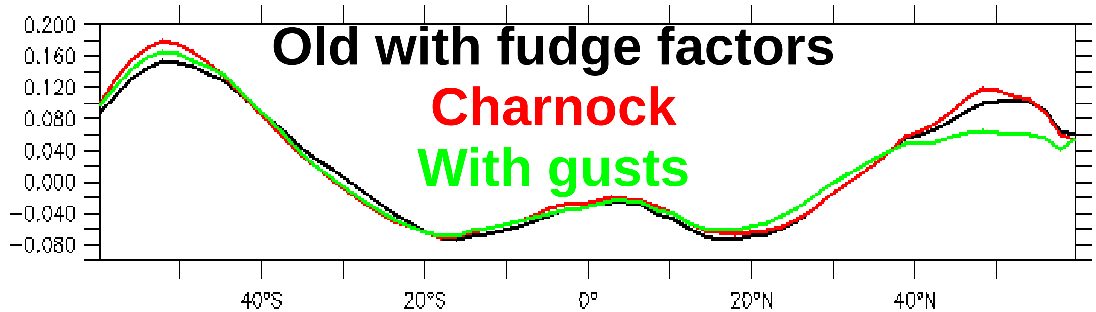


Old formulation :
z0h=z0m
Correction of Cq for weak winds
+ thresholds (min) on wind speed

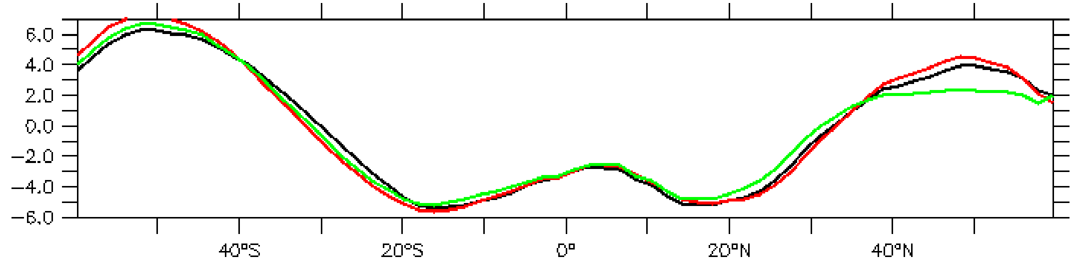
Diagnostic computed over the North Pacific ocean from one month of daily data

Very very very … preliminary results : Impact on forced-by-SST simulations
1-year & zonal averages over oceans

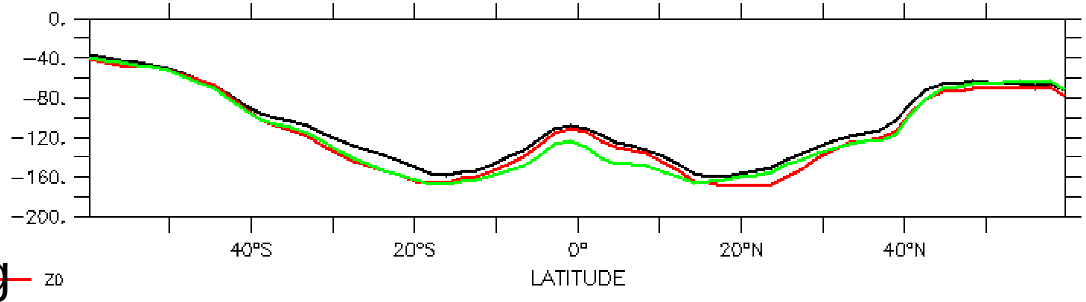
Zonal wind stress (N/m2)
Not much except in the northern mid latitudes



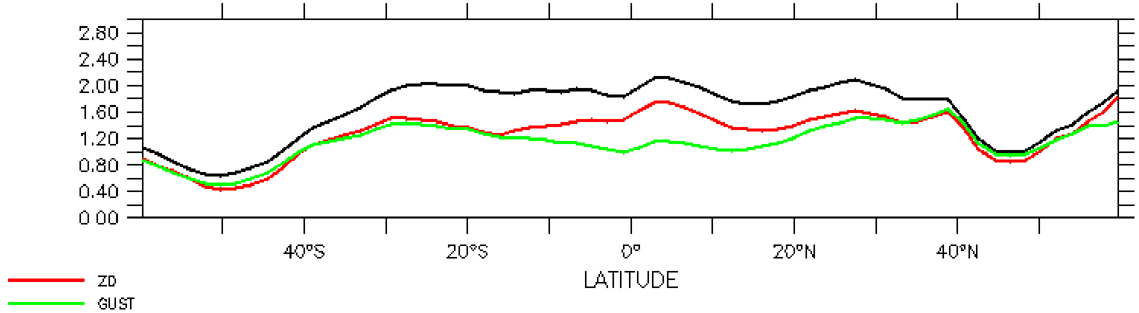
Near surface zonal wind (m/s)
same



Latent heat flux LE (W/m²)
Non neglectalbe
Change of 4 W/m² of the global energetic balance at TOA → retuning



Ts-T2m (K) :
strong. Divided by 2 in tropics...



→ very very preliminary results → I should rather have slept

Concluding remarks

SST biases and evaporation

- SST biases strongly correlated to evaporation biases in forced-by-SST simulations
- Eastern Tropical Oceanic warm biases : RH related. Systematic.
- As strong as cloud effect (not excluding a contribution from direct drag effect on SSTs)
- Wind induced latent heat biases as strong but more variable and zonal

Parametrization of non local transport by boundary layer convection

- Dries the surface. Important for evaporation.
- Important for a good representation of the diurnal cycle of wind over continents and dust lifting
- Involved in the stress / U10m issue discussed in this workshop ?

Work on air-sea drag

- Must include improvement of boundary layer processes
- Get drags and wind stress right for good reasons, i e with good representation of boundary layer processes and near surface variables (RH, wind, Ts-T2m, correlations)
- For wind stress : impact often hidden by compensation to satisfy the momentum budget
- Strong impact on evaporation requires retuning the model energetics

Link with observations / methodology issues

- Lacking reliable climatology : 2m RH and T, near surface wind, fluxes, vertical profiles ...
- Are we sure that scatterometer winds are OK in terms of mean wind speed ? Are they used correctly ? Are they scale issues ? Link with gustiness ? U or Ueff ?
- Nudging can be useful for sensitivity studies to model parametrization and model inter-comparisons (Annelize van Niekerk), and direct use of in-situ observations