A two dimensional modeling of the West African Monsoon annual cycle

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4th AMMA Conference – 2-6 June 2012, Toulouse

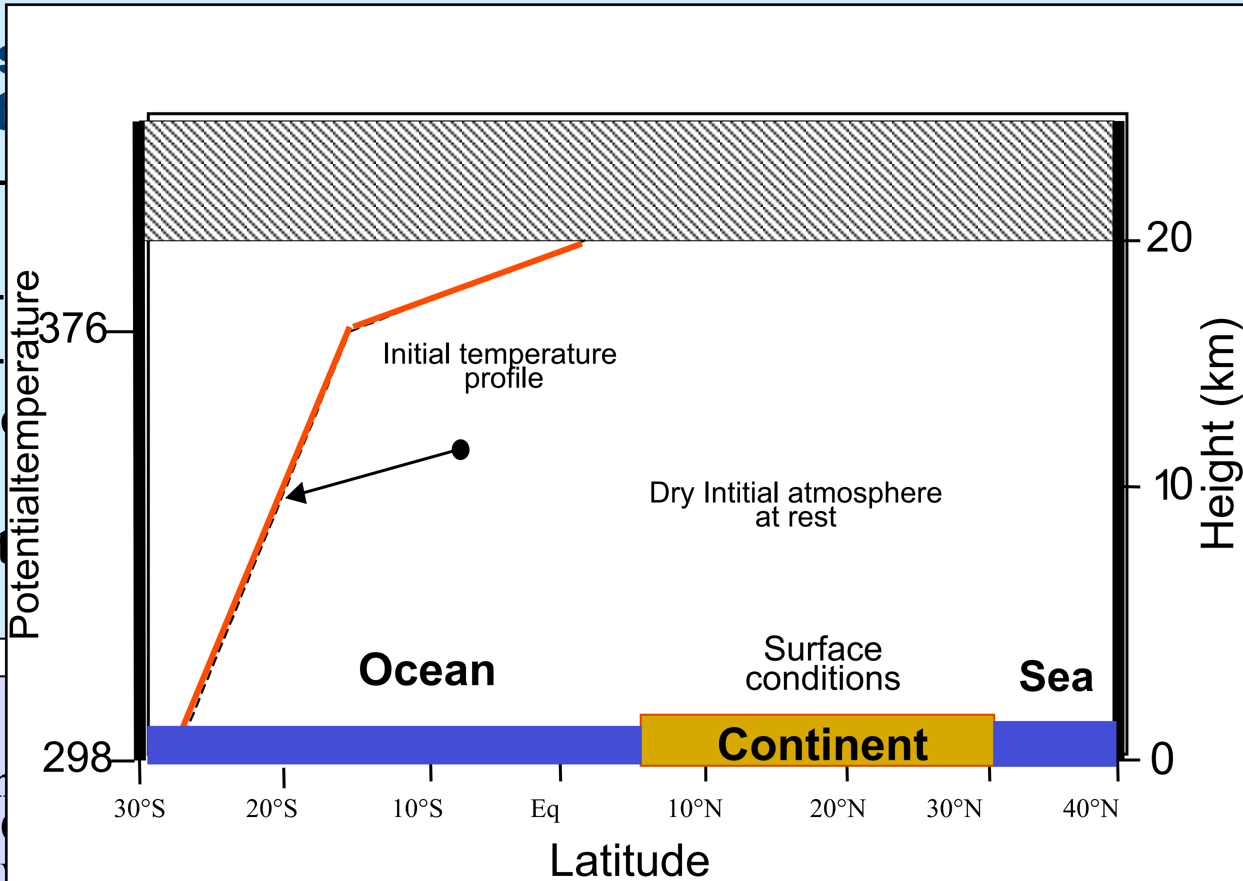
Introduction

The Wes … **lot of open quest**

- … 07, Thorncroft et al.
- …
- … ocean)

➔ **Interac**

Object … **during the**



Approach:

- **Assur** … et al. 1997, Privé and Plumb 20(
  - …
- Use the 2D framework defined in Peyrillé and Lafore (2007): PL07

Introduction

The West African monsoon annual cycle still raises a lot of open questions :

- Northward movement of the ITCZ
- Monsoon jump
- Intraseasonnal variability (zonal modes)

➔ **Processes and scales interactions difficult to quantify**

Objective : Better quantify the effects of different processes during the annual cycle

Questions addressed :

- **Can we represent a correct annual cycle using a 2D framework ?**
- **Can we analyse some key mechanisms like the ITCZ northward migration?**
- **Is there some intraseasonal signal without any waves or zonal modes ?**

Outline

1. Introduction
2. Methodology
3. Results:
   - Seasonal cycle
   - Humidity budget
4. Conclusions

Methodology

Numerical tool: 2D Meridional-vertical framework base on Meso-NH (Lafore et al. 1998)

- **SST are prescribed** from a 1979-2002 mean annual cycle averaged over (10W-10 E) from Reynolds data but can be coupled using an oceanic mixed layer model
- **Continent** : (10E-10W) zonal average meridional profiles are used

- Full physical package (radiation, cloud, convection, interactive continent):
  => No simplified physics
- Convection is parameterized (horizontal grid : 100 km)

- **Necessary for the 2D model:**
  - Meridional transport (eddies) of temperature and zonal momentum
  - **Advective forcing** (ventilation) : new formulation
  - Large scale feedback

Advective forcing defined in PL07

$$-\left\langle \overline{\vec{V}.\vec{\nabla}\alpha}^{z} \right\rangle = -\left\langle \overline{v}^{z}\frac{\partial \overline{\alpha}^{z}}{\partial y} \right\rangle - \left\langle \overline{w}^{z}\frac{\partial \overline{\alpha}^{z}}{\partial z} \right\rangle - \left\langle \overline{u}^{z}\frac{\partial \overline{\alpha}^{z}}{\partial x} \right\rangle - \left\langle \overline{u'\frac{\partial \alpha'}{\partial x}}^{z} \right\rangle - \left\langle \overline{v'\frac{\partial \alpha'}{\partial y}}^{z} \right\rangle - \left\langle \overline{w'\frac{\partial \alpha'}{\partial z}}^{z} \right\rangle$$

zonal mean total advection

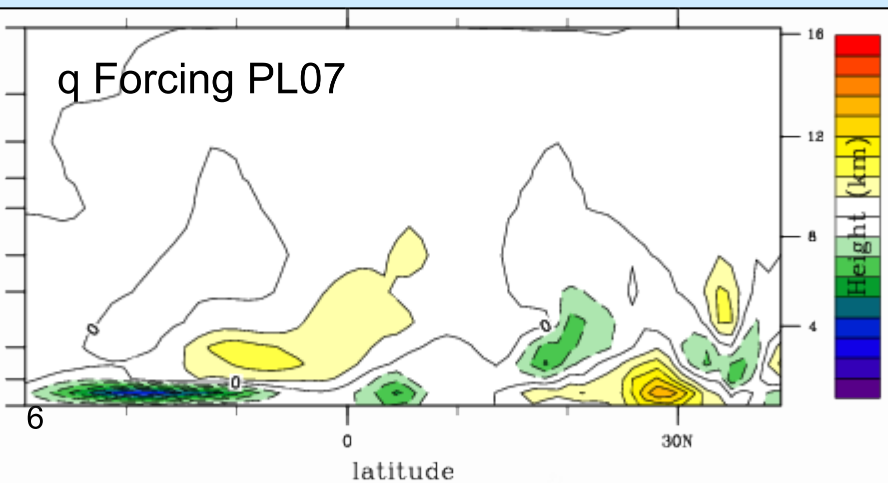
2D term assuming
- **$\partial/\partial x=0$**
- **$U' = \alpha' = 0$**

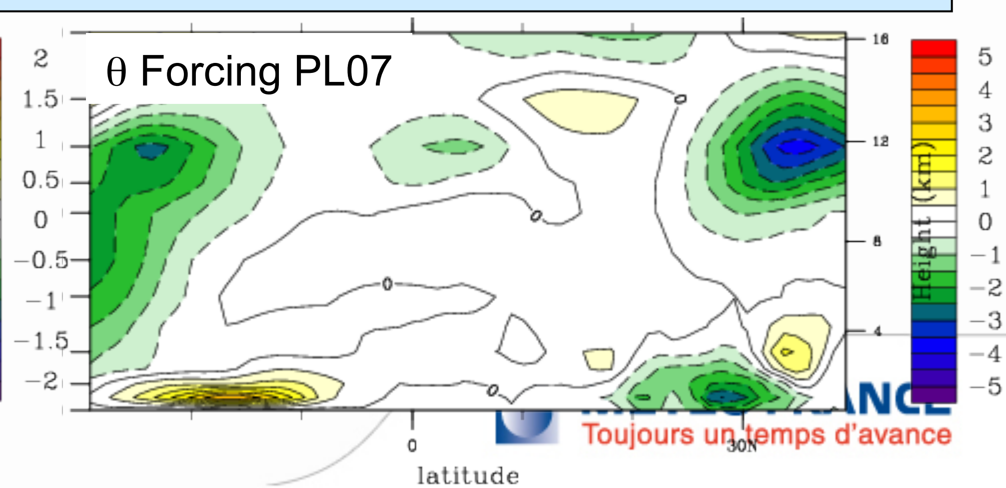
Missing terms in 2D :
- Fluctuations
- Zonal advection

$\overline{\alpha}^{z}$ **:** zonal average operator

Previous Method :
- **Missing terms** estimated from reanalyses
- Parameterized with an analytical formulation over the continent and in the low levels only

Underlying hypothesis:
- **No temporal variations of the forcing**
- **The zonal mean flow is well handled in 2D → not correct, only its non divergent part**



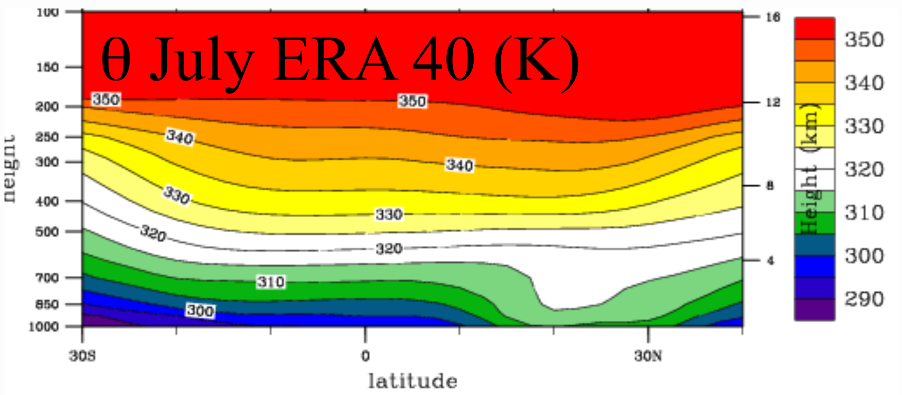


New approach for the advective forcing

Two-step methodology:

1. Retrieval of advective tendencies :

- **1st simulation**: θ and q relaxed towards monthly reanalysis cross section (ERA40), τ= 3 days
  → Corresponding tendencies (∂θ/∂t) and (∂q/∂t) are stored



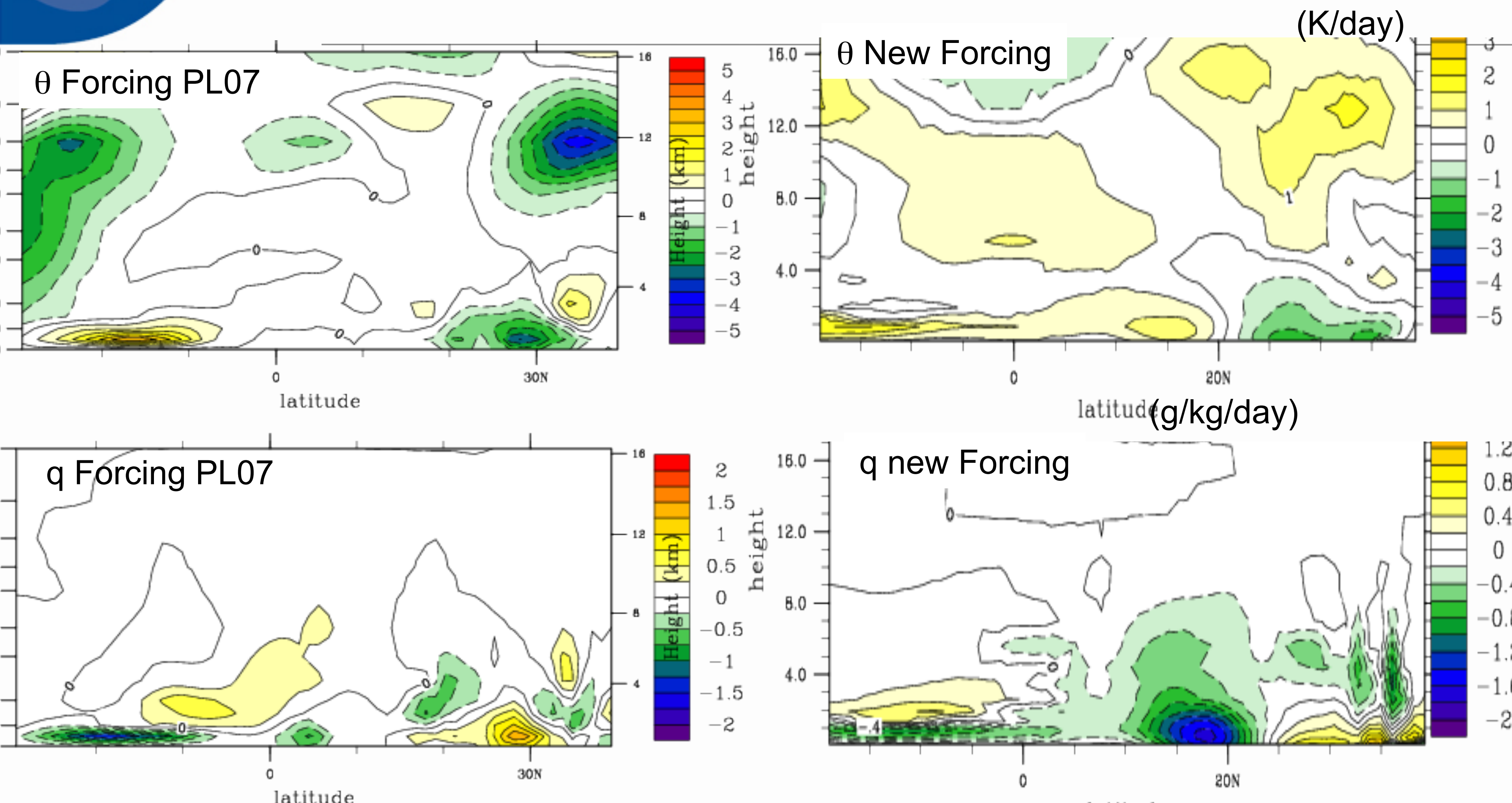
2. Prescribe these tendencies as an external forcing term in the 2D model : New Forcing

Advantage:

- We get what needs to be included in 2D to get the right mass field
- No assumption on what the 2D model can represent or not

How does it compare to the previous formulation?

Comparison of the forcing



- Cooling / mostening dipole north of the Heat Low seen in both forcing
- **Warming/ drying on southern flank of the Heat Low**

➔ linked to the 2D hypothesis : Acts as a blocking

Large Scale Feedback : a new component

Interactions of West Africa with Tropics

- MJO, tropical waves (Kelvin, …)
- Other monsoons…

} Large scale signature on θ field
Janicot et al. 2007

Slow-drift of simulations over several years (mass adjustment)

→ **Relaxation of the mean tropical $\theta(z)$ profile (τ=5 days) towards a climatological profile**

New Forcing : Missing advections + large scale feedback

Long integration are then performed (4 years) :

→ equilibrium regime typical of a climatological monsoon is obtained

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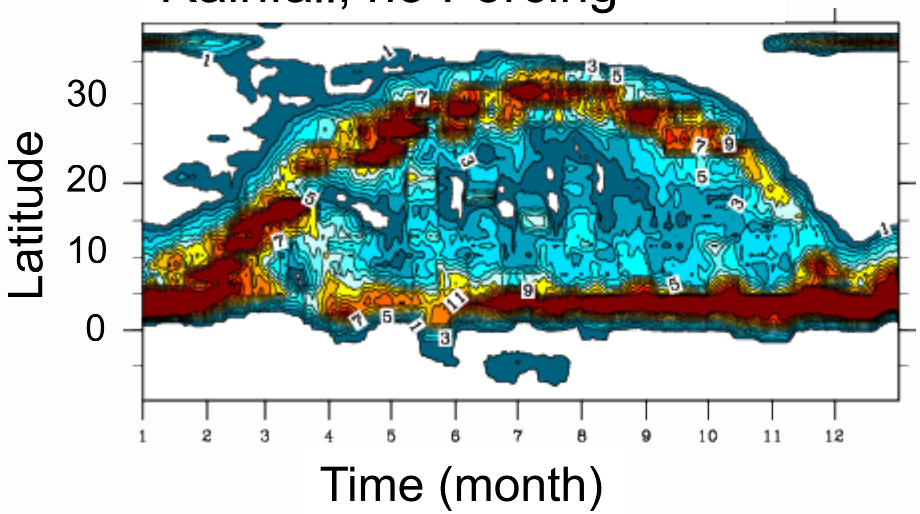
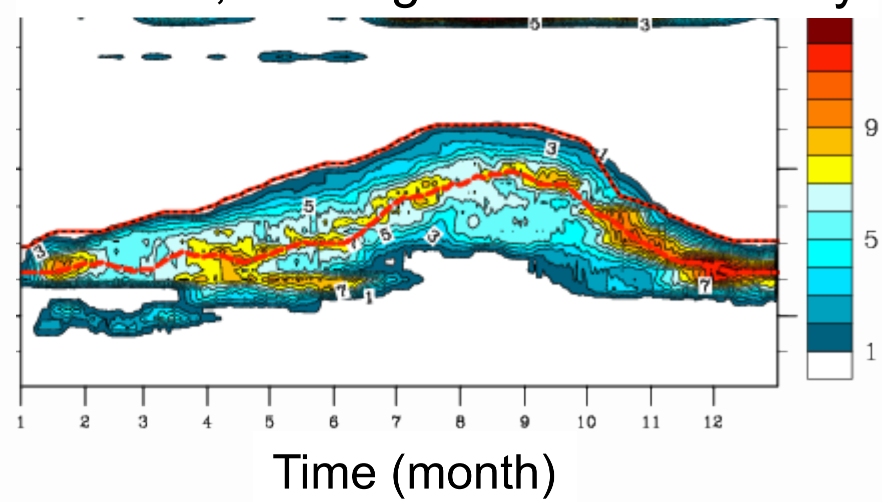
Toujours un temps d'avance

Impact of the forcing

Rainfall, no Forcing

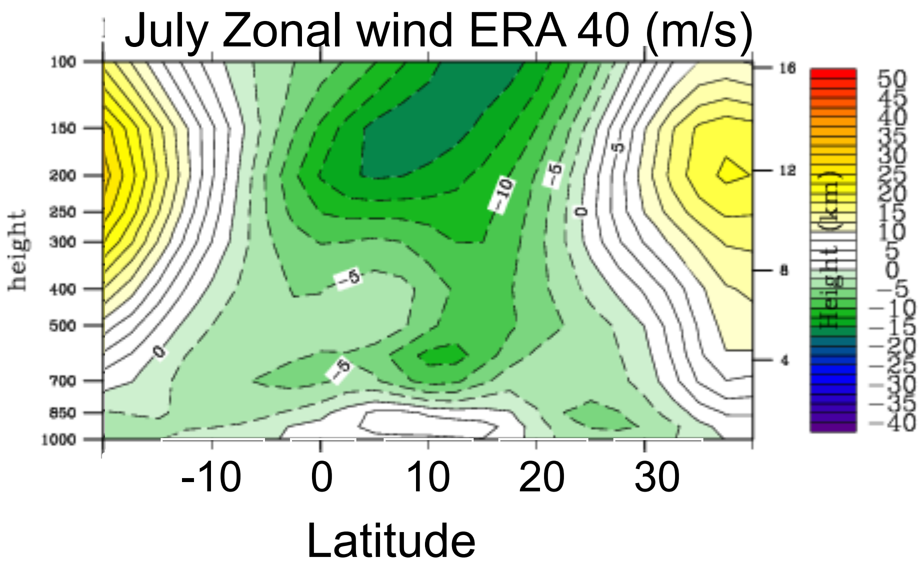


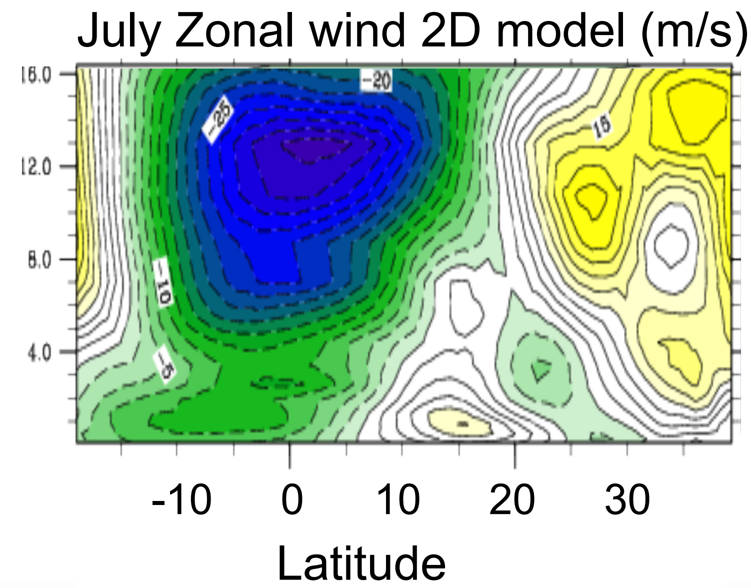
Rainfall, Forcing included mm/day



Large scale advections are of prime importance for blocking the monsoon propagation

Idealized annual cycle





Correct magnitude and location of rainfall maxima

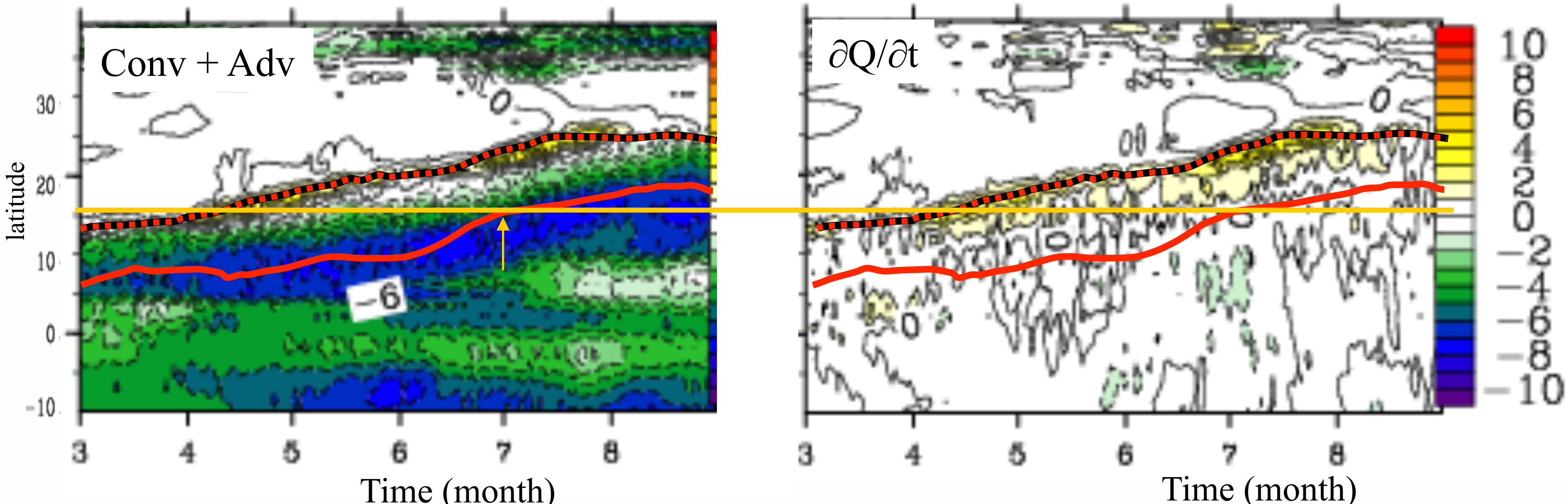
Basic zonal wind structures (Jets, low level flow) are reproduced in the 2D model

→ the basic key elements of the monsoon are in the 2D model

Evolution of precipitable water

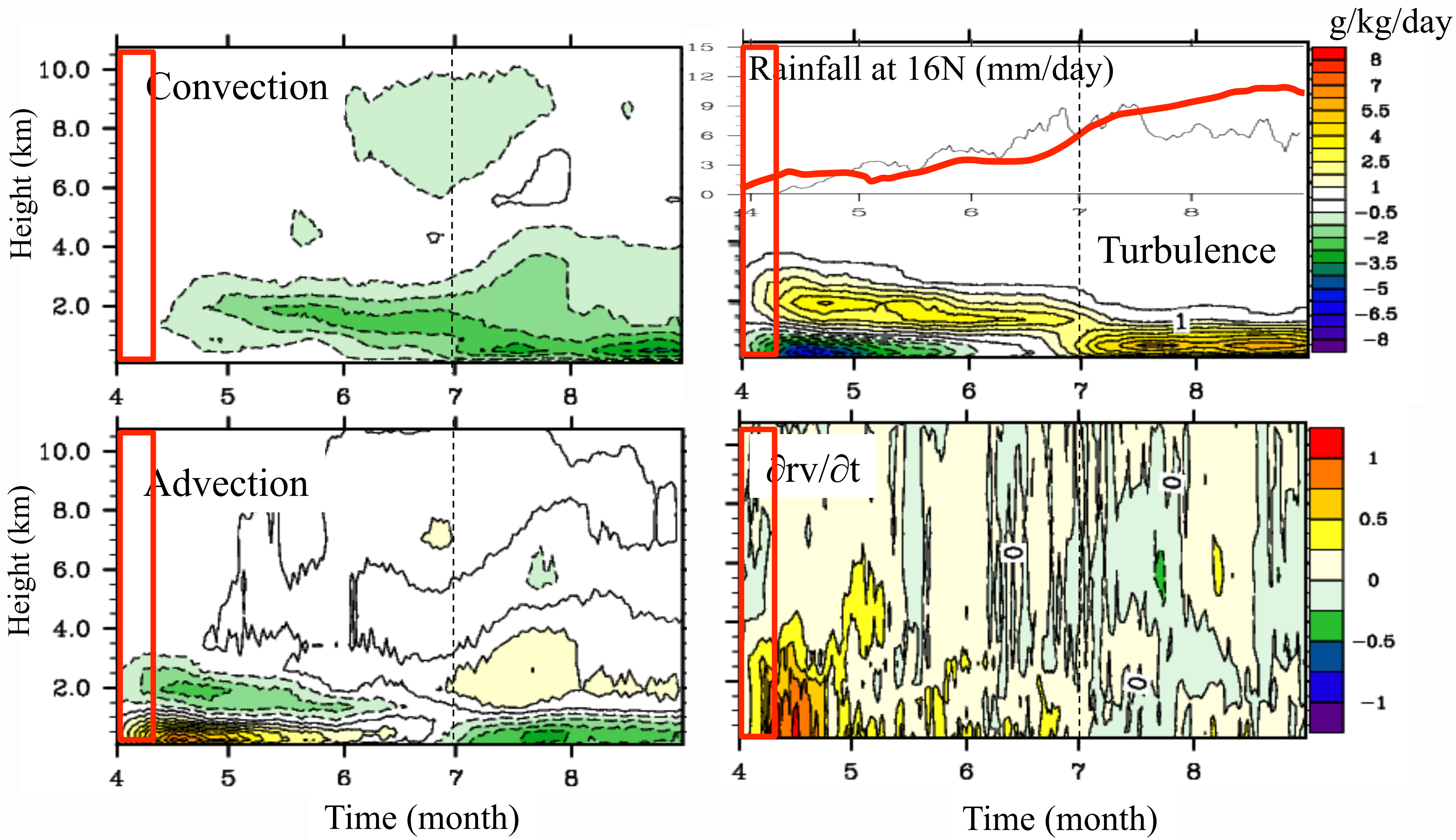
Evolution of the integrated water vapour:

$$\int_0^{Ztop} \frac{\partial Q}{\partial t} dz = -div\left(\int_0^{Ztop} Q.V\,dz\right) + \int_0^{Ztop} \frac{\partial Q}{\partial t}^{Conv} dz + \int_0^{Ztop} \frac{\partial Q}{\partial t}^{Turb} dz$$



Humidification ahead of the rainband made by advections

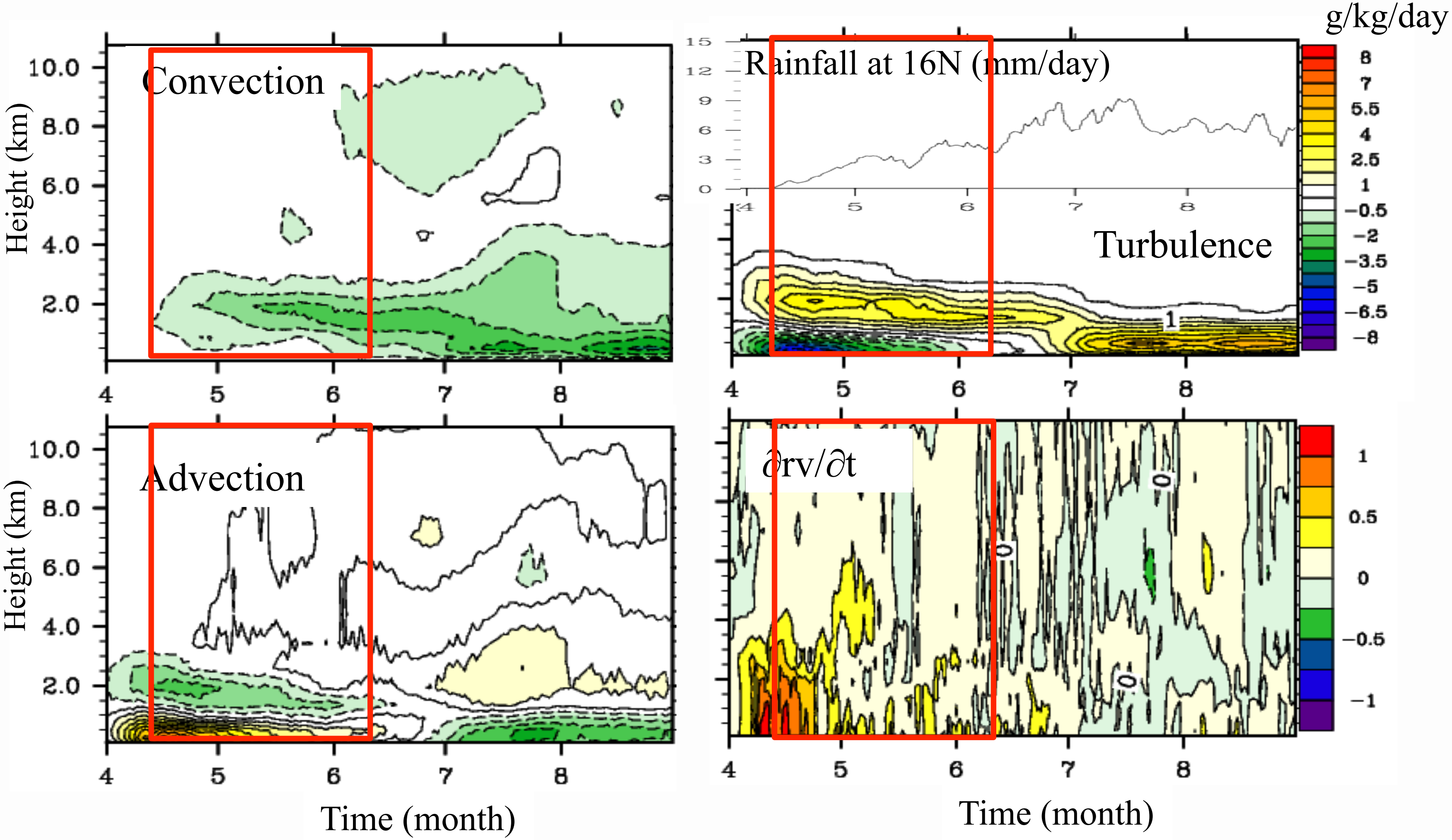
Vertical structure of humidity budget :
1- dry phase (10 days)



Humidification: low level advection and turbulent fluxes (vertical redistribution)

Drying by the return Harmattan flux

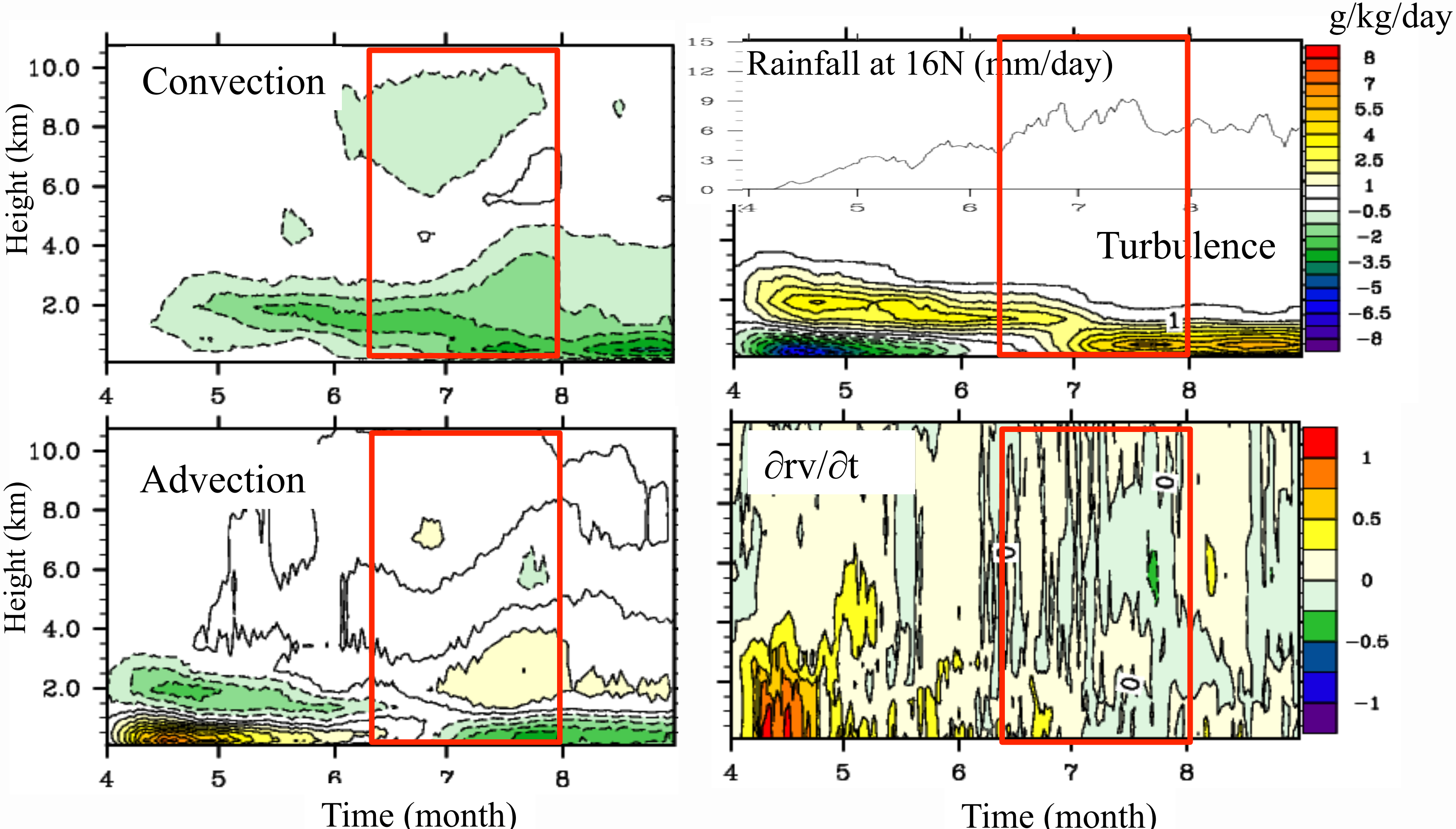
Shallow convection precipitating phase 2 - (50 days)



Increased Humidifiation in the lower layers :

Acceleration of the monsoon flow + significant role of turbulence

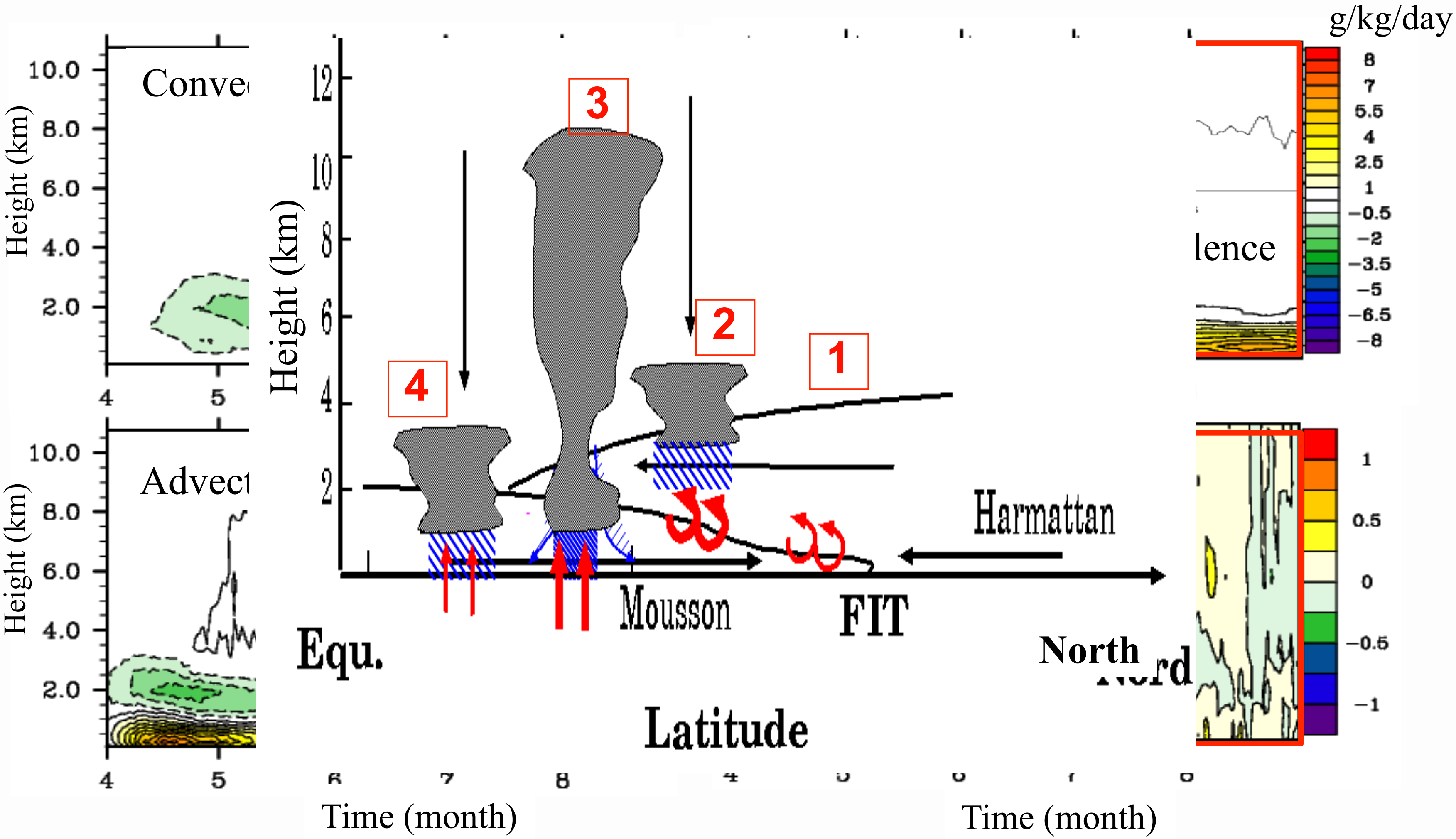
3 - Deep convective regime (50 days)



Humidification by vertical advection and turbulence

Drying by the monsoon flow

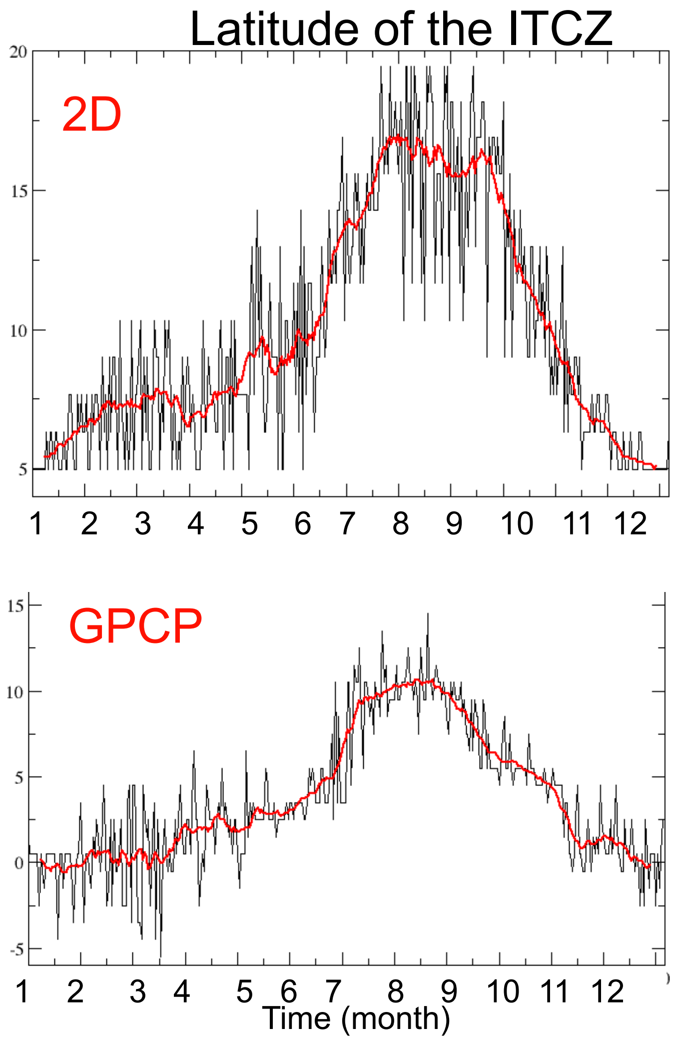
4 - Post ITCZ regime (30 Days)

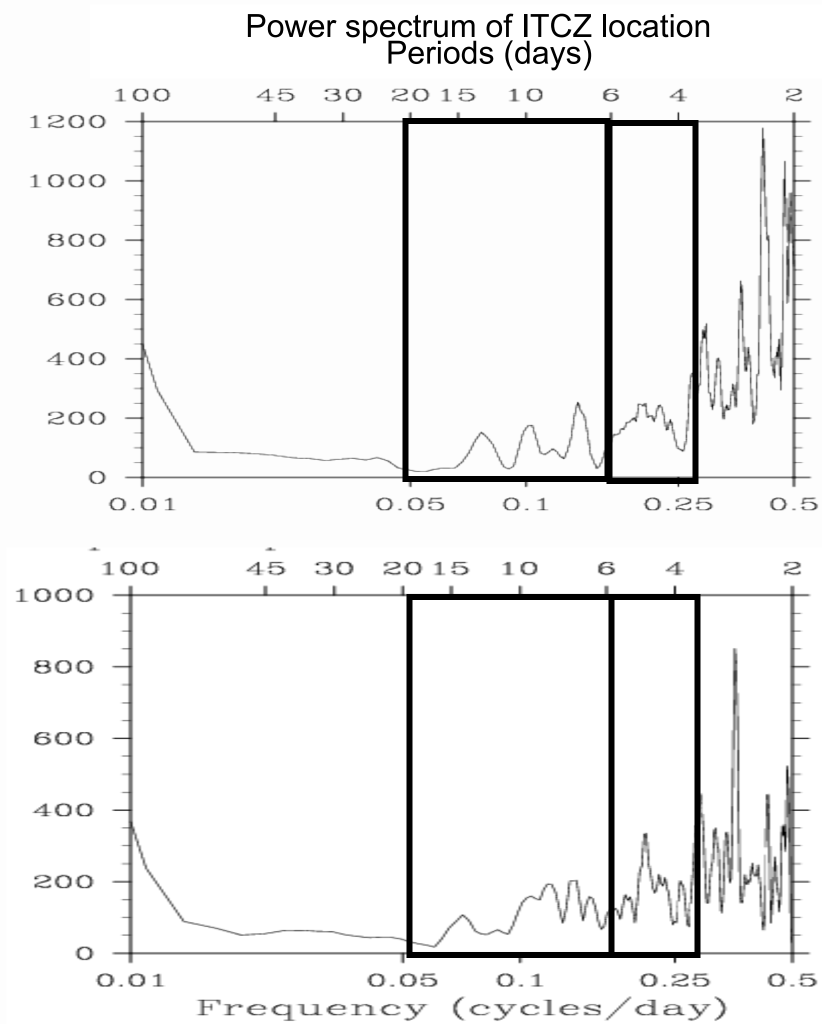


Low level advections drying while the return flow moistens
turbulence helps maintaining deep convection

Is there some intra-seasonal signal in the 2D model?

1. Thorncroft et al. Mentionned the ITCZ goes northward pregressively, step by step





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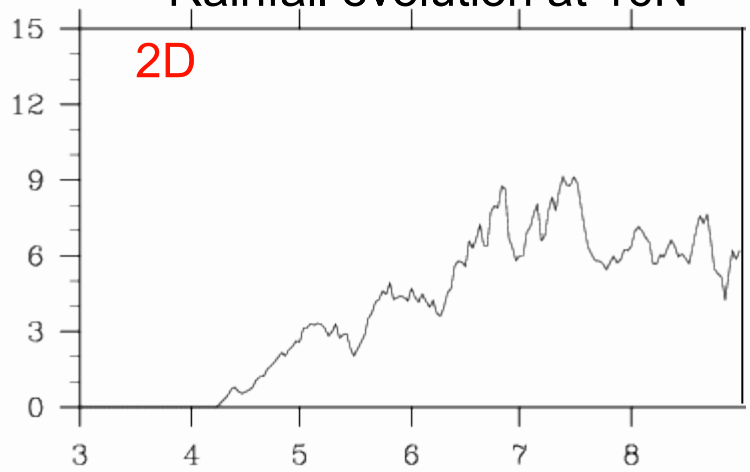
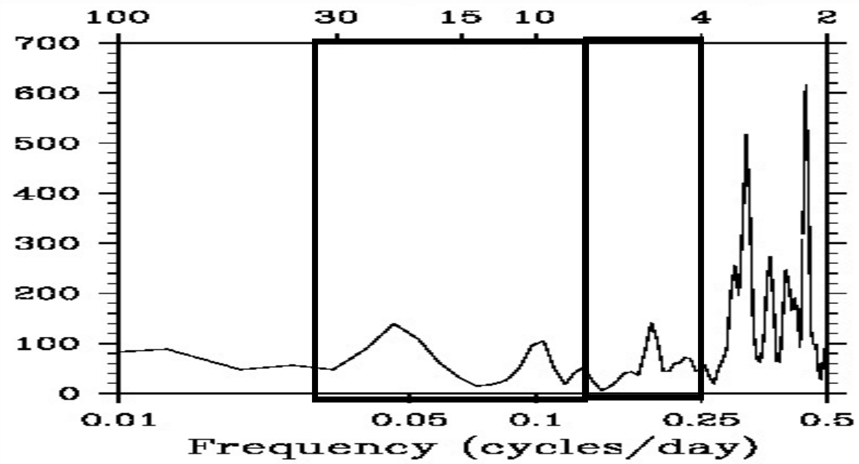
Rainfall evolution at 16N





There is some source of intraseasonal variability in the 2D model
=> Needs more investigation (role of the surface, forcing…)

Conclusions

- **The 2D model is able to mimic the West African Monsoon annual cycle**
    - **Advective forcing + Large Scale relaxation**

- **Mechanism of monsoon northward migration :**
    - Trasition from dry, shallow moist and deep convective regime
    - Turbulent transport is a key in 1st step
    - → **Consistent with Hagos and Cook (2007), Thorncroft et al (2011)**

➔ The 2D model is a suitable tool to analyse the annual cycle

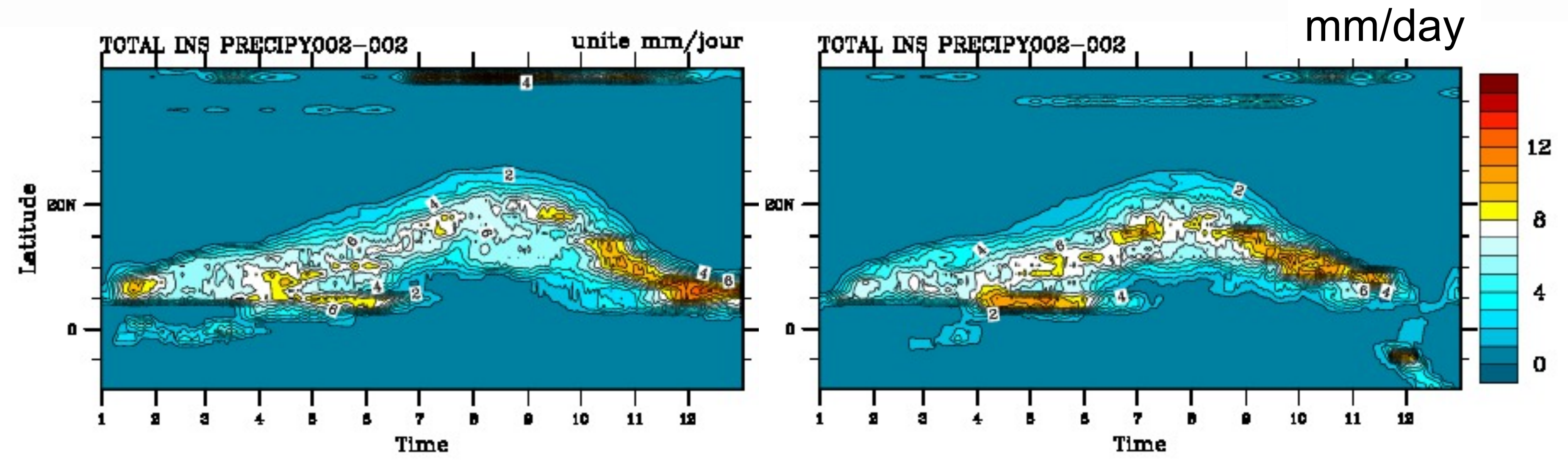
➔ Can be used to test ideas on a simplified monsoon

Future work

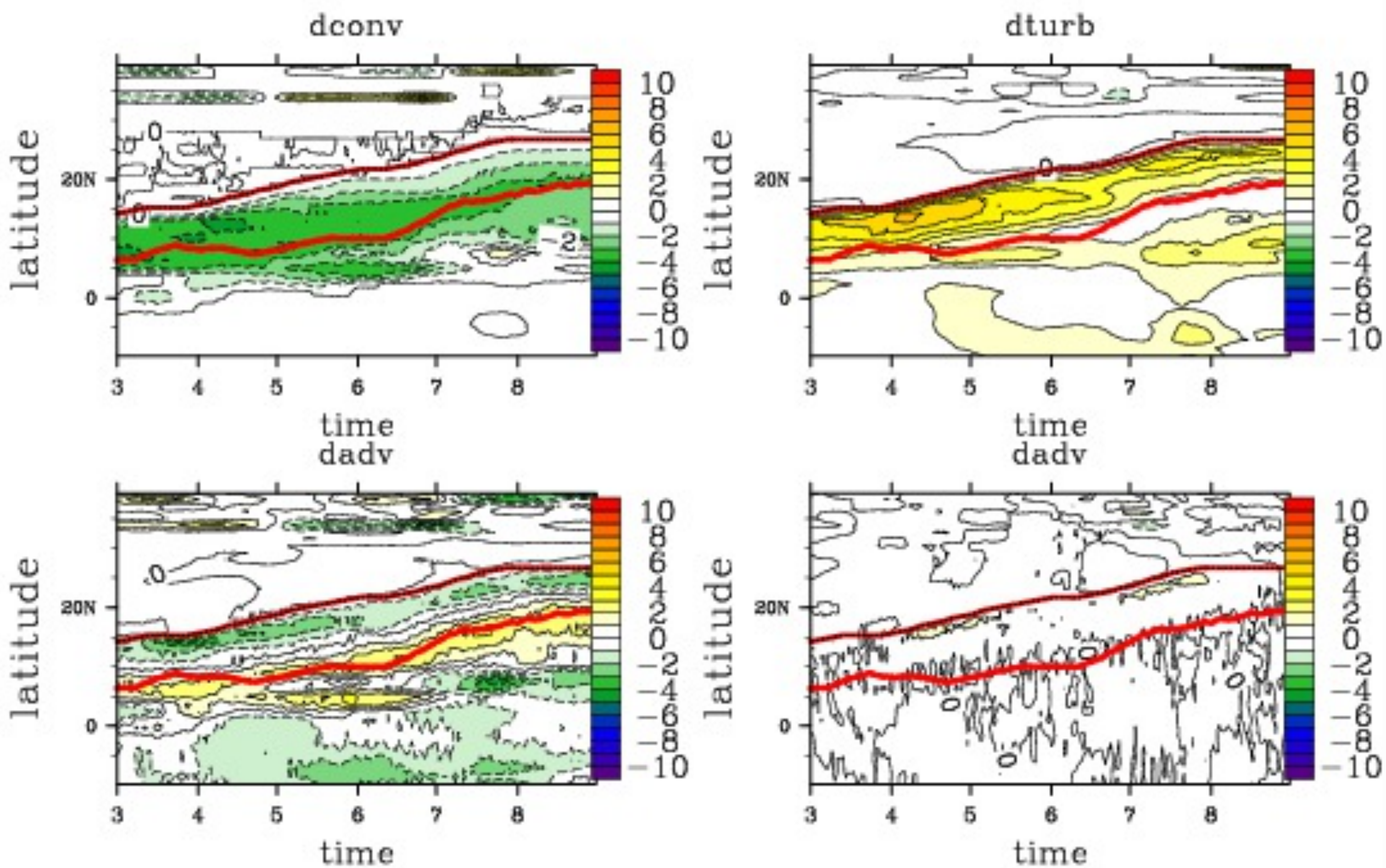
- **Investigation of the role of coupling :**
  Ocean – atmosphere → regulation of the system, ?
  Interactive **vegetation** → impact on ITCZ northward migration ?
- **Intraseasonal variability :**
  Include in the 2D model an oscillatory corresponding to observed modes of varaibility
  (forcing terms or relaxation)

First simulations with ocean-atmosphere coupling

1. SST initialized with Levitus climatology (colder than Reynolds)
2. Ocean Mixed layer Model : turbulent vertical mixing is the key process



First simulations look good and are not dramatically different



dconv
dturb
dadv
dadv
latitude
time
20N
0
10
8
6
4
2
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−4
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−10