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Land-surface atmosphere interactions over tropical regions

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Land atmosphere feedbacks in tropical regions

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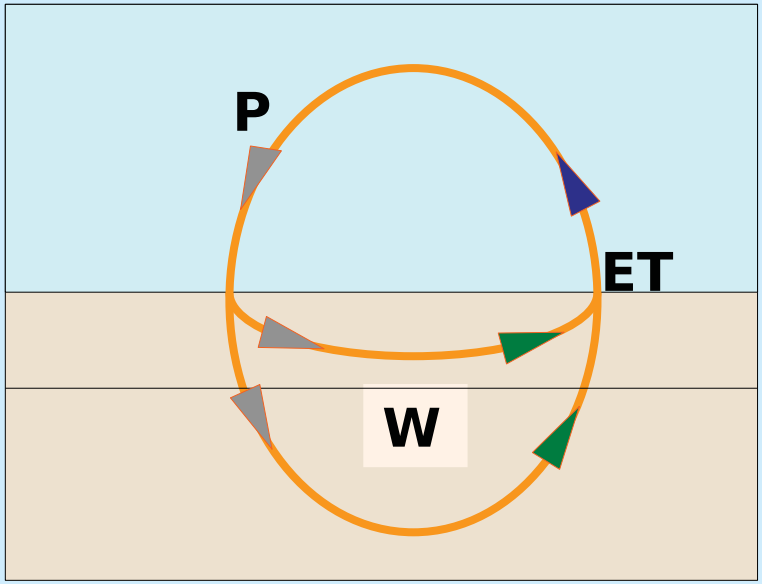
With contributions from Chris Taylor, Thierry Lebel, Randy Koster and Paul Dirmeyer

- What are the characteristics of tropical climate which make them key regions for land/atmosphere feedbacks ?
- At what scales are these feedbacks likely to act.
- New ideas being developed within AMMA on the processes governing the surface atmosphere feedback.
- The AMMA results open new doors in this field of research.

Surface atmosphere Feedback Loops

Arid regime:
E is very sensitive to soil wetness variations, but the dry atmosphere is mostly unresponsive to small inputs of water vapor.



Humid regime:
Small variations in E affect the conditionally unstable atmosphere, but deep-rooted vegetation is not responsive to soil wetness variations.

W→ET

ET→P

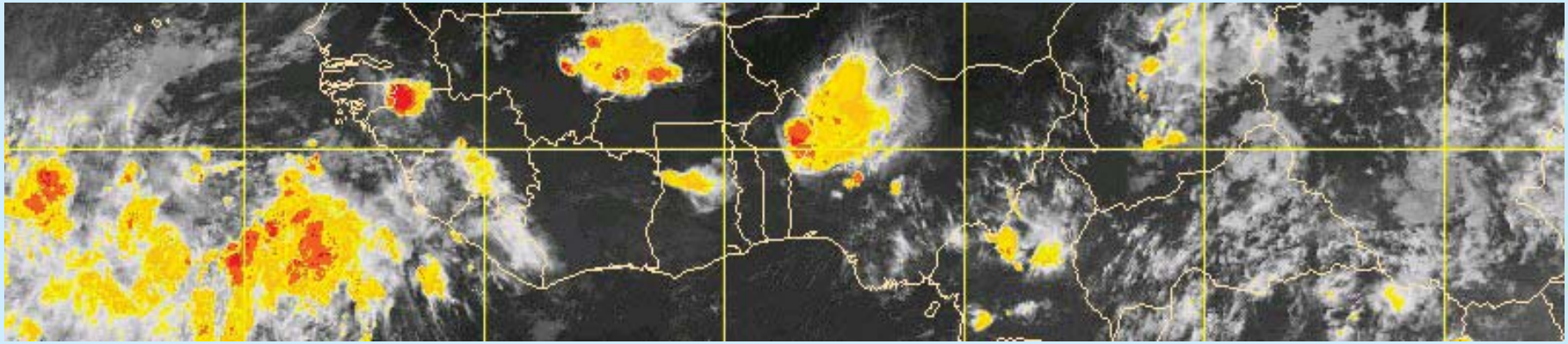
In between, soil wetness sensitivity and conditional instability both have impacts

Arid

Humid

West Africa as an example

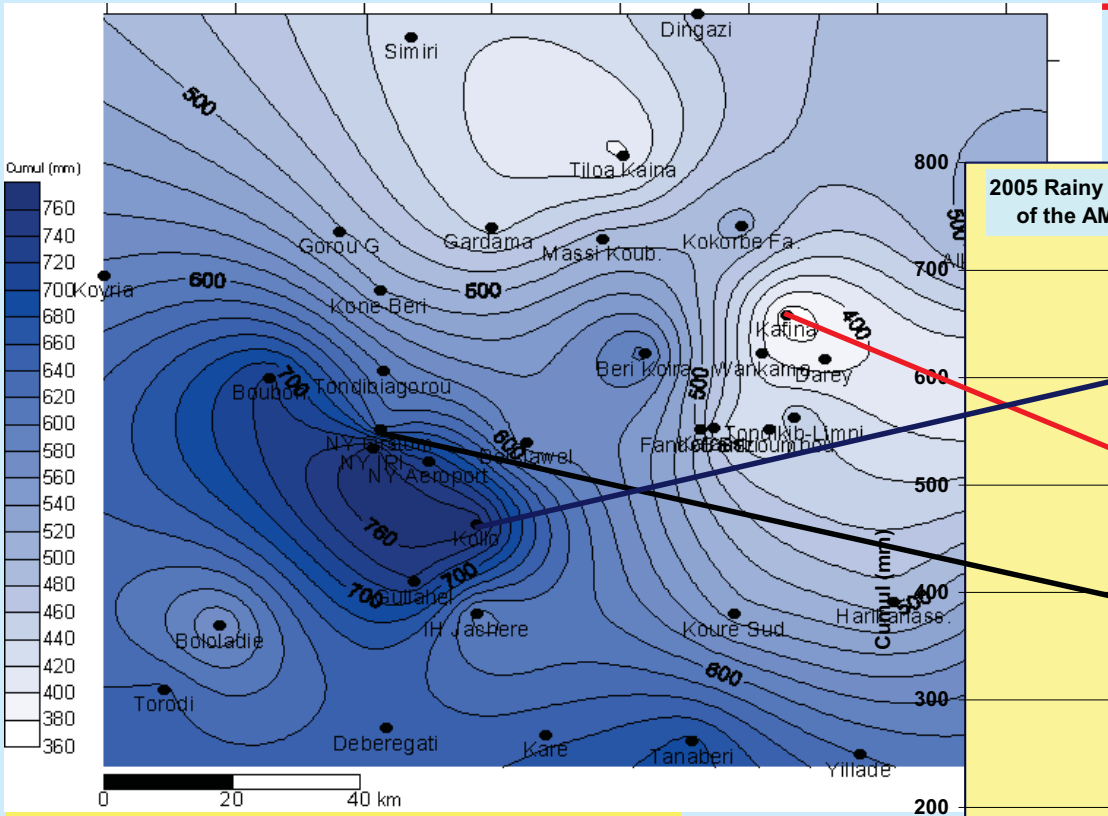
Convective systems bring the rain in West Africa while moving from East to West.
The Sahelian region has 10 to 20 systems per year.

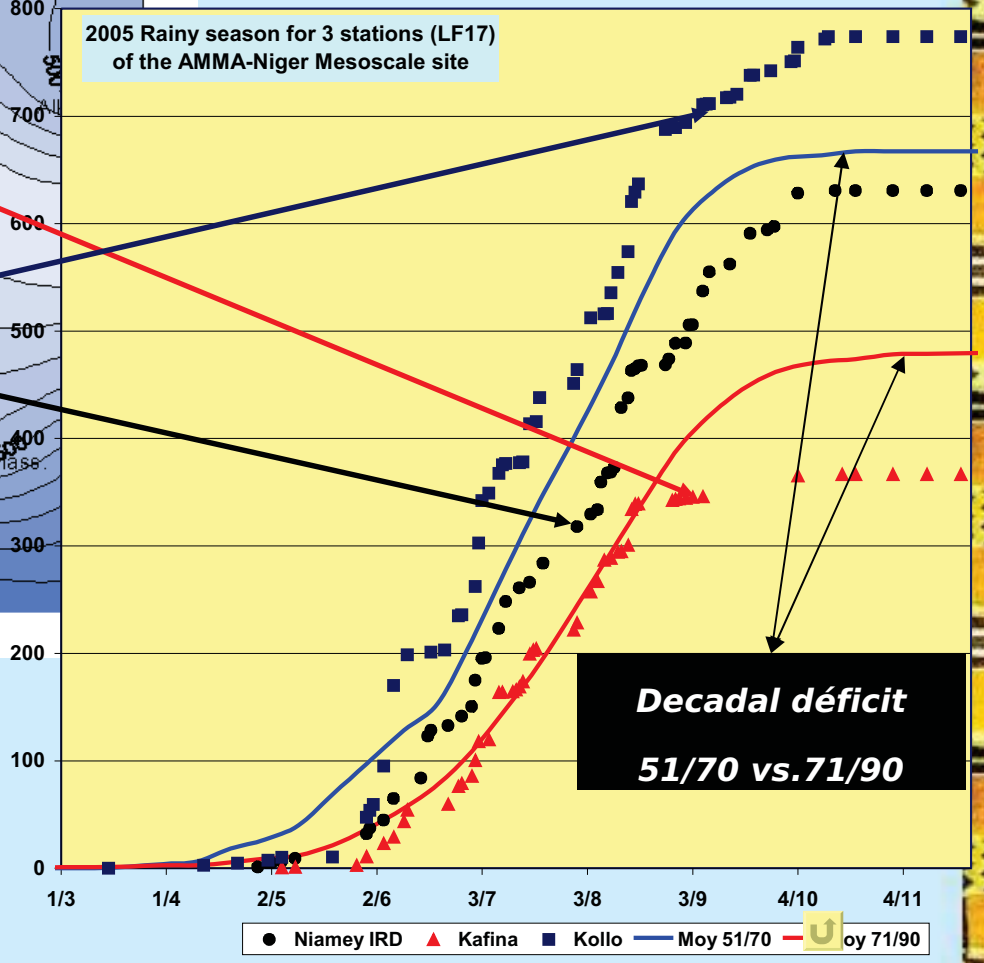


These characteristics of the water cycle have a strong impact on land surface processes :

- rainfall is intense.
- The contrast is strong between processes during and after the rain events.
- Vegetation responds quickly.

The Rainy season has a marked spatial variability





Source: C. Bailleul, L. Descroix

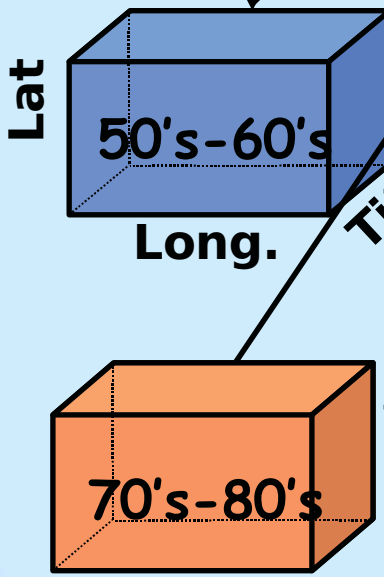
2005 Rainy Season, Niger meso site

The inter-annual variability of total rainfall

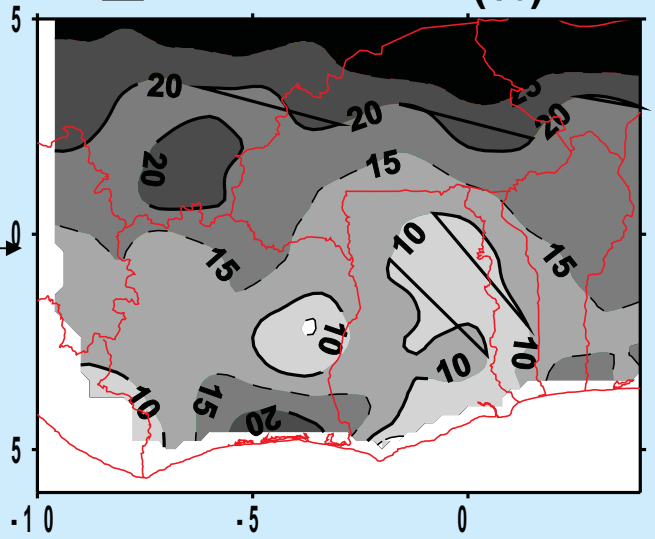
Total rainfall can be decomposed into a succession of events :

$$P = f(p,n)$$

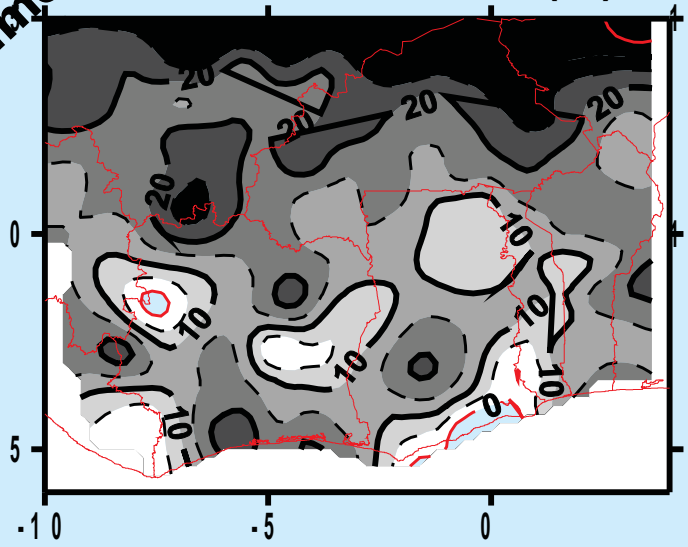
$$\Delta P = (P1 - P2) / P1$$



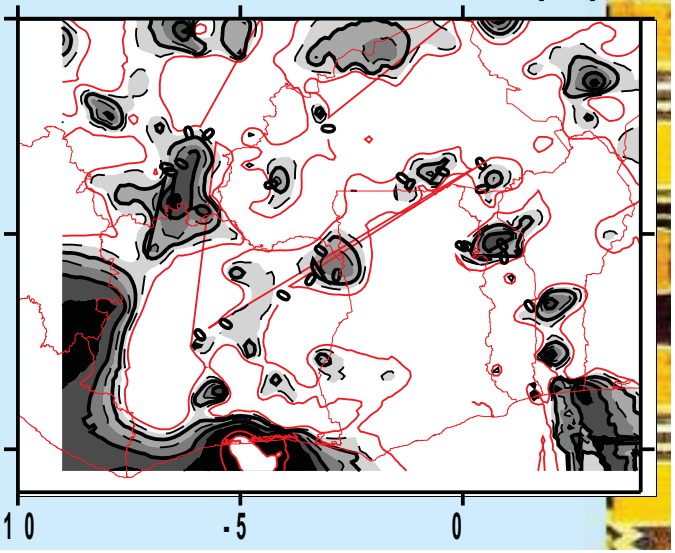
Δ Total Rainfall (%)



Δ Number of events (%)



Δ Mean event rainfall (%)



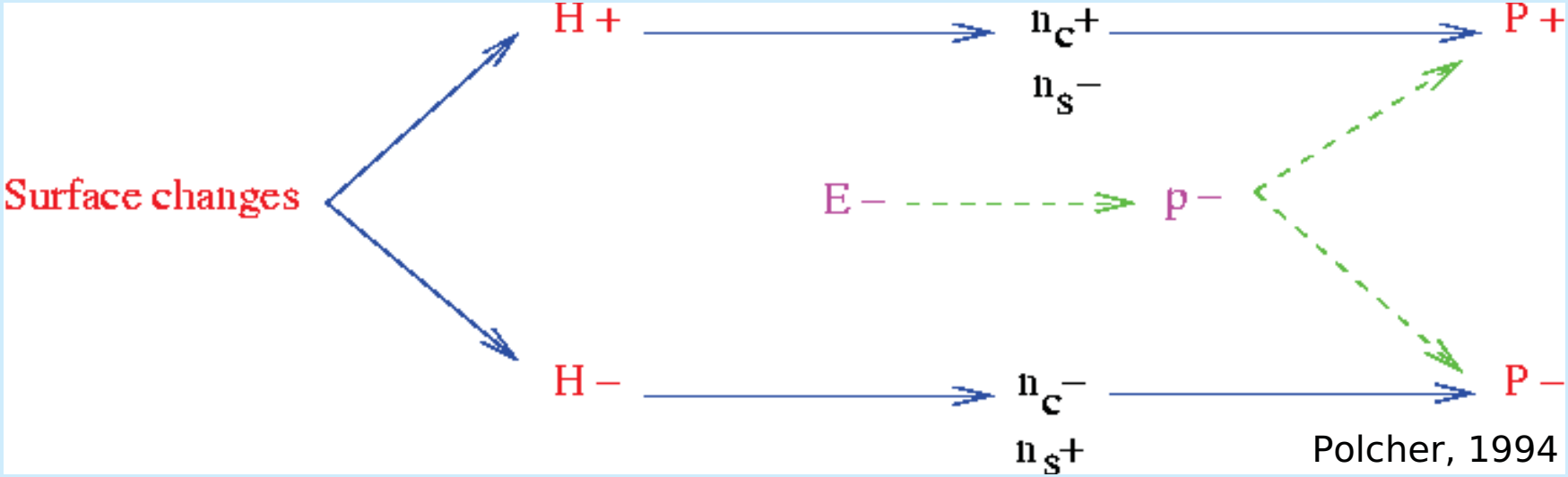
Deforestation experiments with GCMs have shown that the impact on precipitation is also dominated by the change in the number of events.

⟶An analysis of the land atmosphere interactions on a synoptic scale is thus essential.

An analysis of tropical deforestation experiments

All models which have performed deforestation studies used different changes in surface properties. We can play through them with one GCM.

It demonstrates that with this uncertainty only, a deforestation leading to a reduced moisture convergence as well as one with an increase can be obtained.



The approach also allows to propose a mechanism to explain the sensitivity of the model and test it.

Strong indications that the coupling is active at the synoptic scale

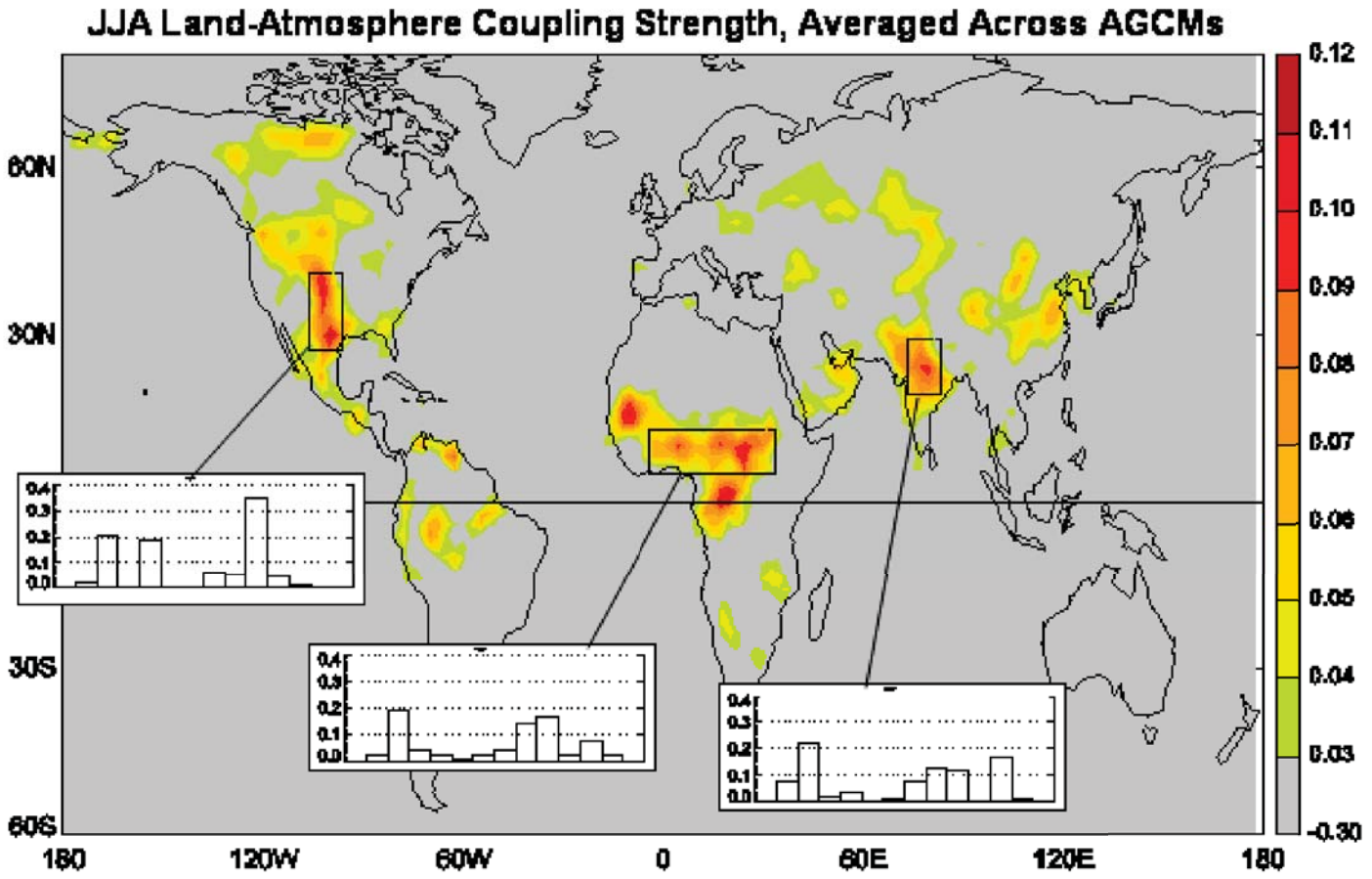
- It is highly unlikely that the triggering and life cycle of the convective systems are insensitive to the surface conditions.
- The high spatial contrasts generated by tropical rain events at the surface has the potential to induce local atmospheric circulations.
- The rapid changes from dry to wet will lead to non-linear responses of the surface and exacerbate contrasts.

- In 1975 J. Charney emitted the hypothesis that in West Africa the coupling could modify the regional climate.
- A number of modeling studies confirmed this potential.
- Most analysis of these experiments were carried out at the monthly scale and thus have probably missed the underlying processes.

Measuring the coupling strength in an ensemble of models

Koster et al. (2004)

The coupling strength is measured by the impact of surface processes on the coherence of an ensemble of seasonal forecasts.



The GLACE project showed that while the 12 participating models differ in the land-atmosphere coupling strength for precipitation some regions have a stronger coupling.

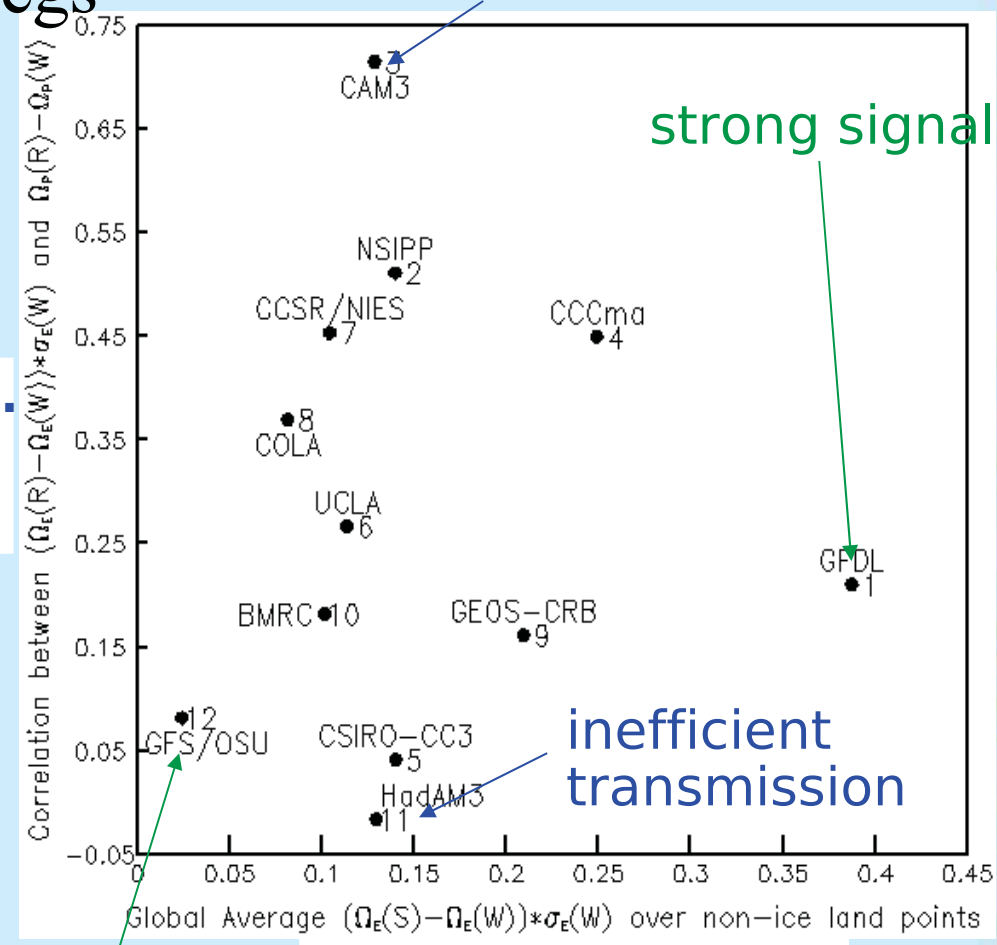
Coupling Segments in GCMs

Guo et al. J. Hydromet, 2005

Land-Atmosphere coupling has been broken down between legs of the hydrologic cycle:

- **soil wetness => E**
- **E => precipitation**

Signal Transmission to Precip.
(Corr Between ET Signal and P Coherence)



Signal In Evaporation

ΔΩ times Evap StdDev

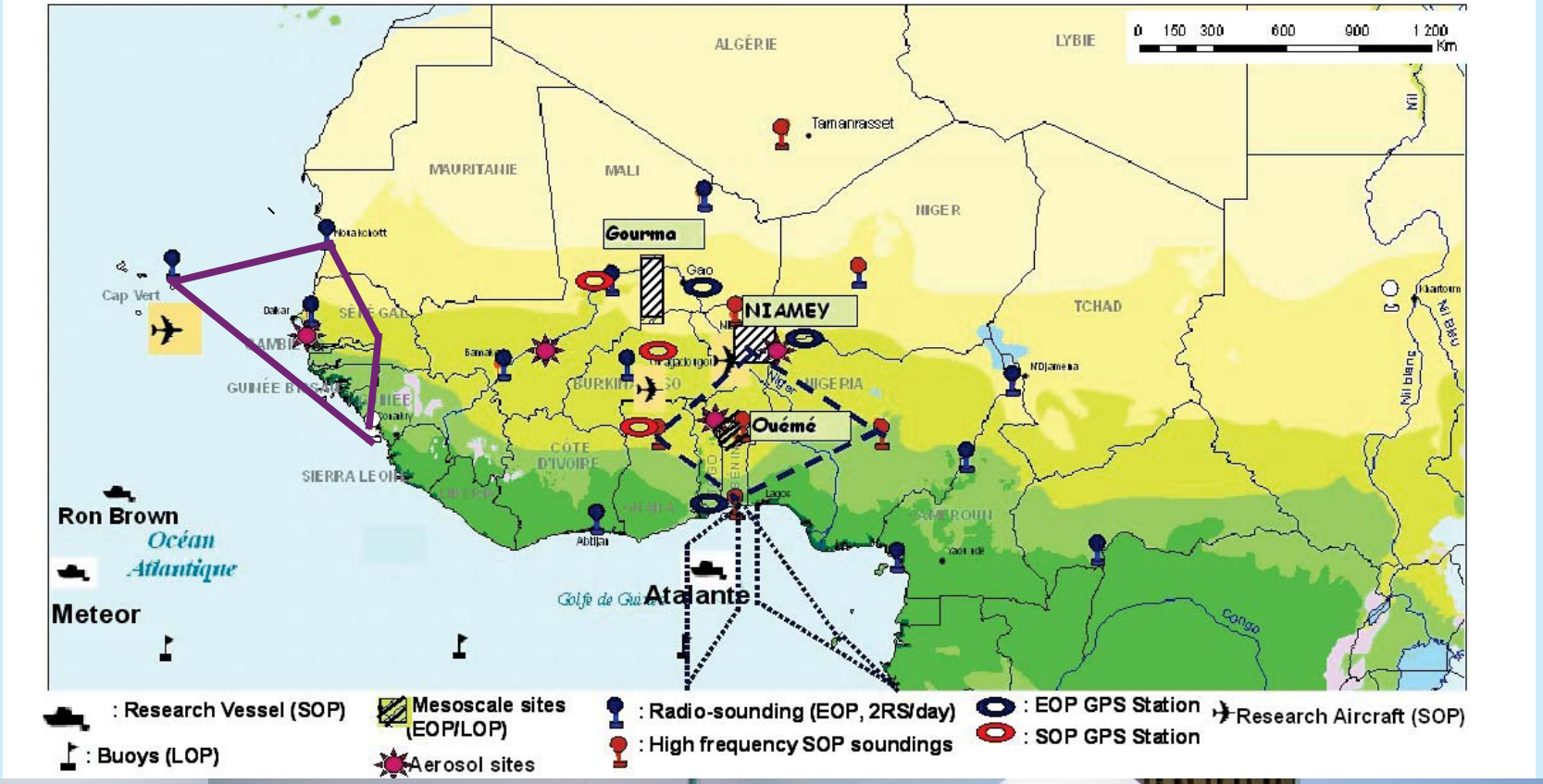
Surface atmosphere interactions have been at the core of the AMMA project *(African Monsoon Multidisciplinary Analysis)*

From the start of the project it was felt that surface atmosphere interactions (and land-surfaces in particular) are key to understand a number of geophysical phenomenons in West Africa :

- The dramatic decrease in rainfall in the 70's and 80's.
- The initialization of weather to seasonal forecasts in the region.
- The triggering and evolution of convective systems.
- Climate and land-use changes and their impact on water resources.

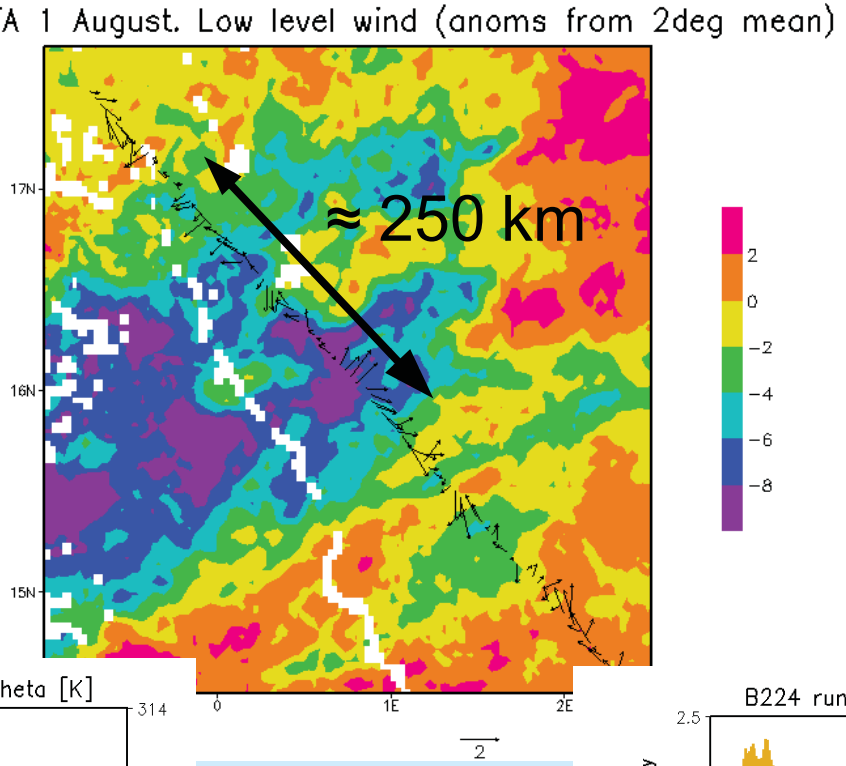
AMMA was thus designed with the objective of better understanding the land atmosphere coupling in West Africa.

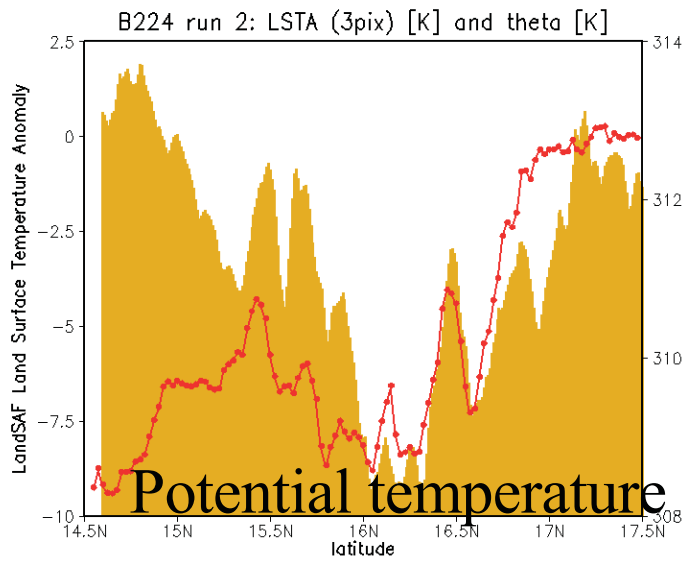
Observational network for the Extended Observing Period (2005-07)



Surface moisture anomalies impact low level atmospheric conditions

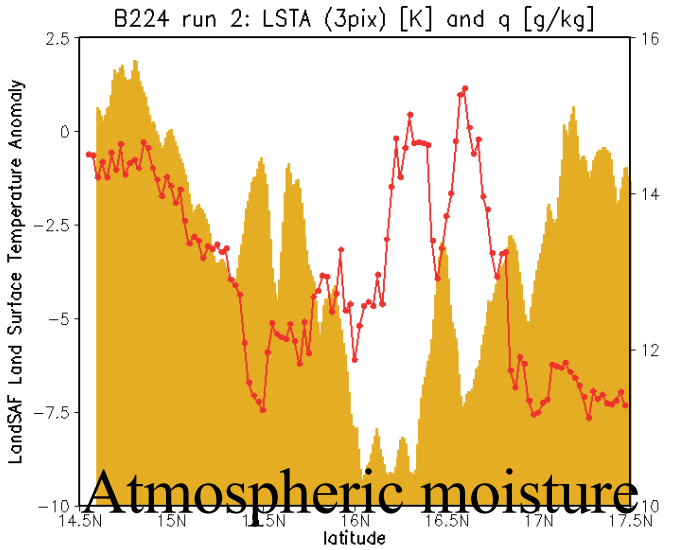
Convection on the 31th of July 2006 left a trace on surface temperature.





Potential temperature

Boundary layer conditions on the aircraft track.

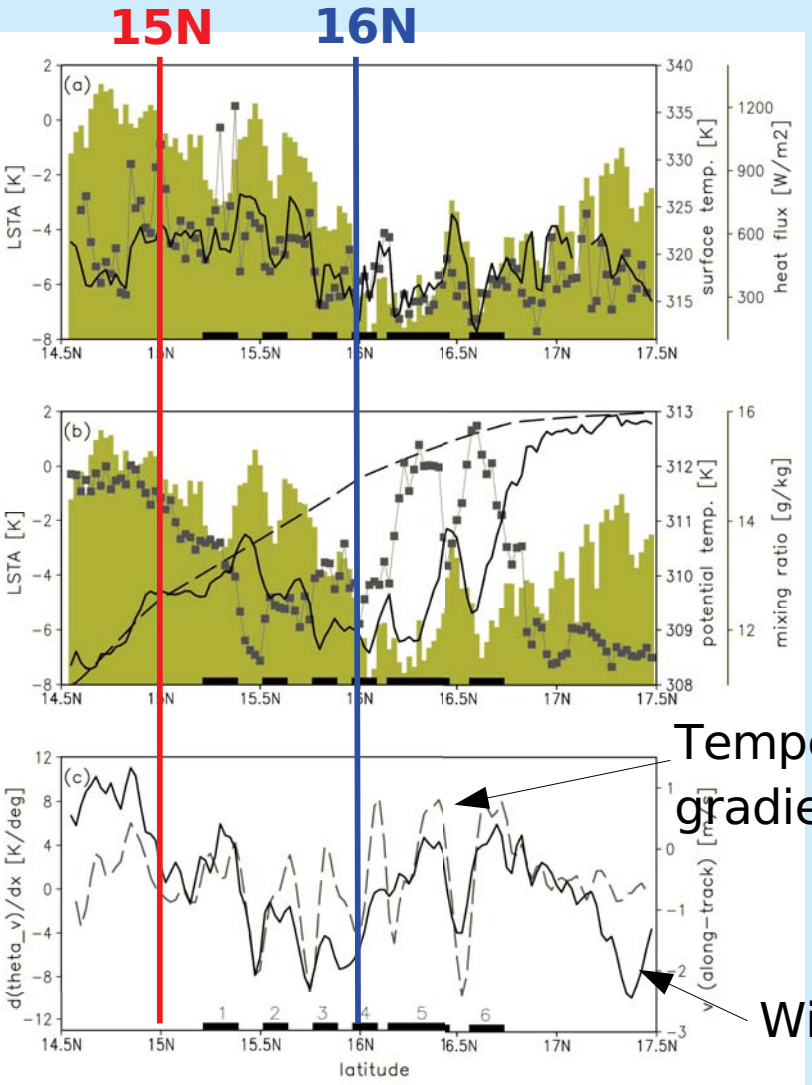


Atmospheric moisture

Impacts on the atmospheric dynamics

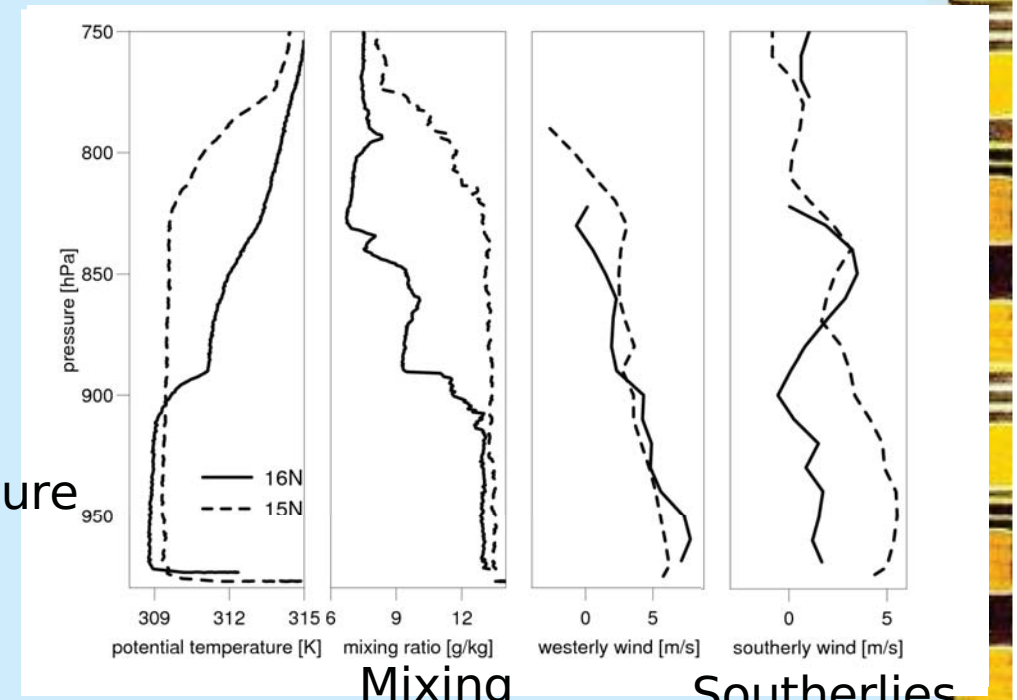
Taylor et al. (2007)

The moist patches modify the structure of the PBL and induce divergent circulations.



Temperature gradient

Wind



Potential temperature

Mixing ratio

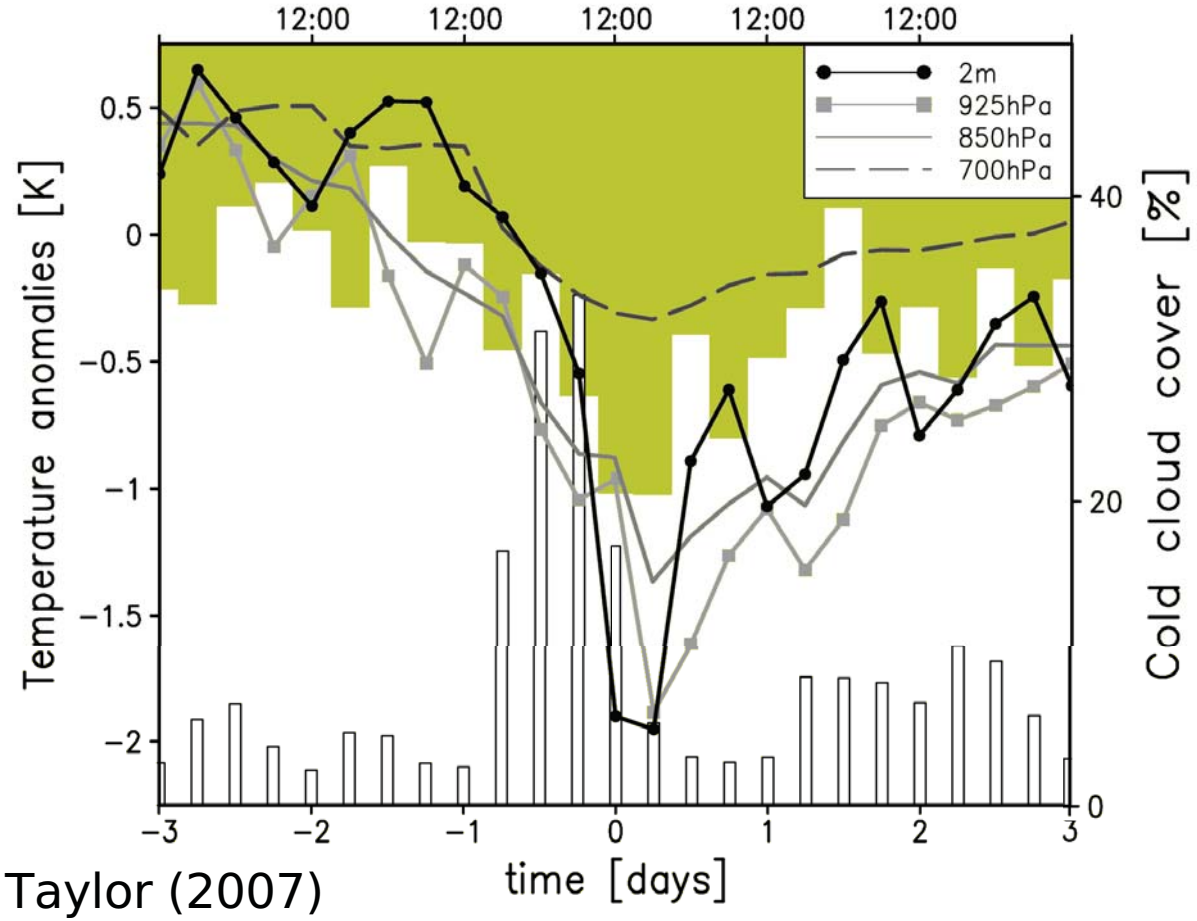
Westerlies

Southerlies

Impacts of wet spots at the larger scale

Using remote sensed soil wetness anomalies (microwave polarization) and meteorological analysis products over 9 wet seasons, composites of the atmospheric response to wet patches can be constructed.

- The impact of wet patches is consistent with in-situ observations.
- A rainfall event modifies the PBL temperature for 3-4 days.
- The cool high seems to be a robust feature.



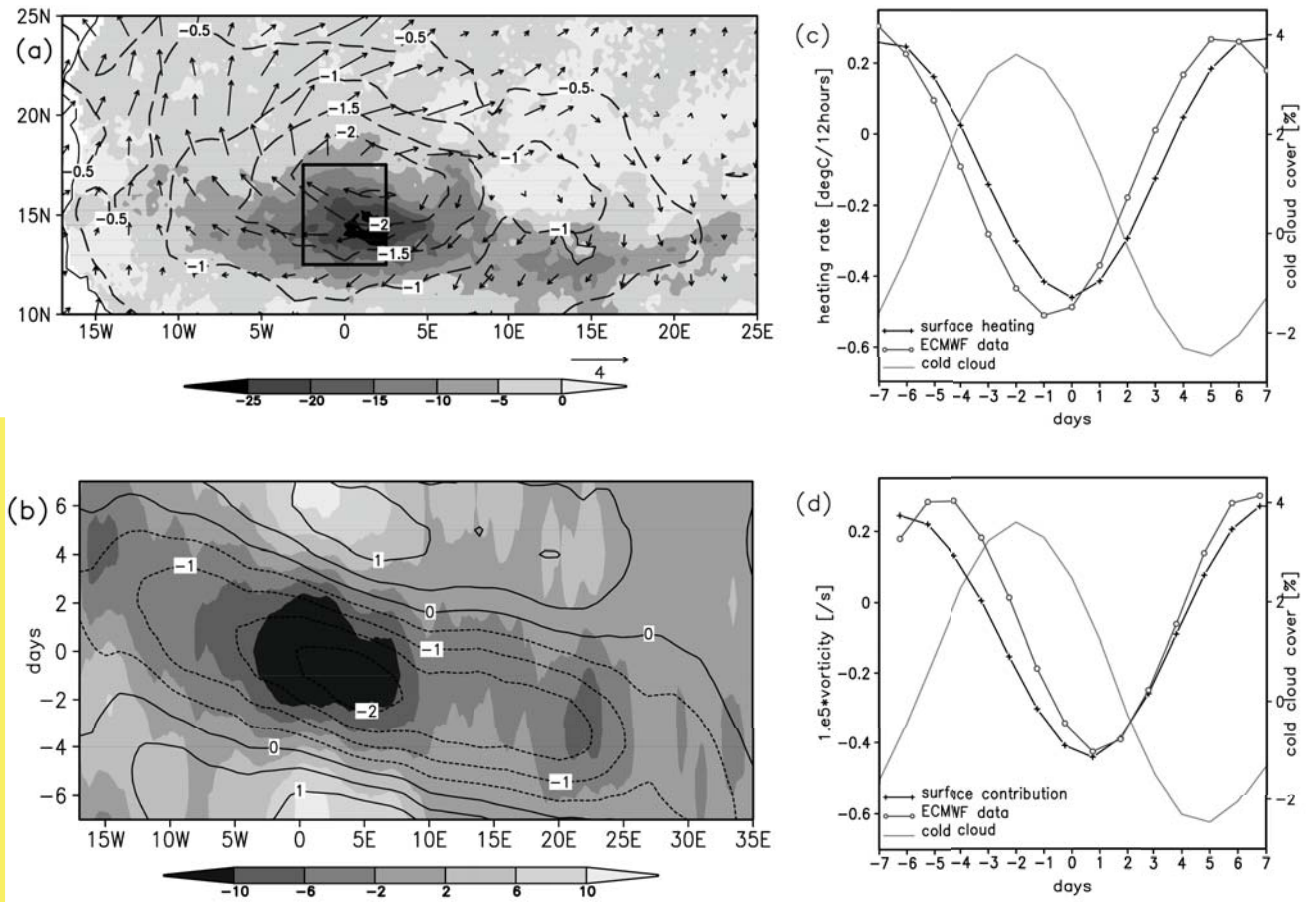
Taylor (2007)

The impact of the cool high on the circulation

The cool high induces a low level vortex which increases the southerlies in front of the wet patch and might help propagate the system.

The intensity of the cool high is controlled by the preceding rain distribution and the surface processes .

These dynamical structures are similar to those associated with the intra-seasonal fluctuations of rainfall (Janicot and Sultan (2001))



The next steps ...

These new hypothesis on the coupling between land-surfaces and the atmosphere offer new opportunities to advance our understanding.

- The AMMA data sets will be used to test these ideas further.
- Their potential to explain some of the characteristics of the West African monsoon needs to be explored.
- Are models able to reproduce the relationships explained by these mechanisms ?
  - Do convection permitting regional models represent these effects ?
  - Can RCMs or GCMs simulate this type of land-surface atmosphere feedbacks ?

Some questions are already raised by these new ideas on the feedback

- Should the cool high favor the propagation of the rain systems then this should lead to a more or less homogeneous seasonal rainfall pattern ... but at which scales ?
- A deforestation which decreases evaporation and increases sensible heat flux reduces the cool high ... and the propagation of systems ?
- On the contrary a land use which would increases evaporation should strengthen the cool high !

Only with models which correctly reflect our understanding of the land atmosphere coupling will we be able to explore these questions and provide answers for the precipitation in the tropical regions.

Conclusion

- Modeling studies of land/atmosphere interactions have been limited by our lack of confidence in their sensitivity. Still these exercises have been helpful to
  - show the limits of our understanding, and
  - develop new methods for diagnosing the feedbacks.
- New remote sensed and in-situ observations have permitted a more theoretical understanding of the land/atmosphere feedbacks.
  - In contract to model results these ideas can be tested.
- These new hypotheses need to be refined and used to validate the sensitivity of our models
  - This process should lead to a higher confidence in our modeling capabilities and their potential for their application :
    - Weather and seasonal forecasts – surface initialization,
    - Anthropogenic climate change - land-use impact.

Thank you to all who have made AMMA possible

Founding agencies:

African agencies :

Supporting agencies :

Partners :

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Direction de la Météorologie Nationale

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Centre de Recherches Hydrologiques

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