African **M**onsoon **M**ultidisciplinary **A**nalyses
Analyses **M**ultidisciplinaires de la **M**ousson **A**fricaine
Afrikanischer **M**onsun: **M**ultidisziplinäre **A**nalysen
Analisi **M**ultidisciplinare per il **M**onsone **A**fricano
Afrikanske **M**onsun : **M**ultidisciplinære **A**nalyser
Analisis **M**ultidiciplinar de los **M**onzones **A**fricanos
Afrikaanse **M**oesson **M**ultidisciplinaire **A**nalyse

Modelling and predictability of weather systems in West Africa : lessons learnt from AMMA

Jan Polcher, LMD/IPSL/CNRS
With contributions from : C. Taylor, S. Bastin, N. Kalthoff, A. Agusti-Panareda, P. Ruti, ...

Sixth Framework Programme

Outline

- Introduction to the climate of West Africa (WA)
- The impact of enhanced atmospheric observations during AMMA on predictability
- Is there a potential for predictability in surface heterogeneities ?
  - Small scale moisture gradients.
  - Cool highs and its impact on African Easterly Waves.
  - The impact of inland wetlands on convection.
- Can models respond to these surface heterogeneities ?

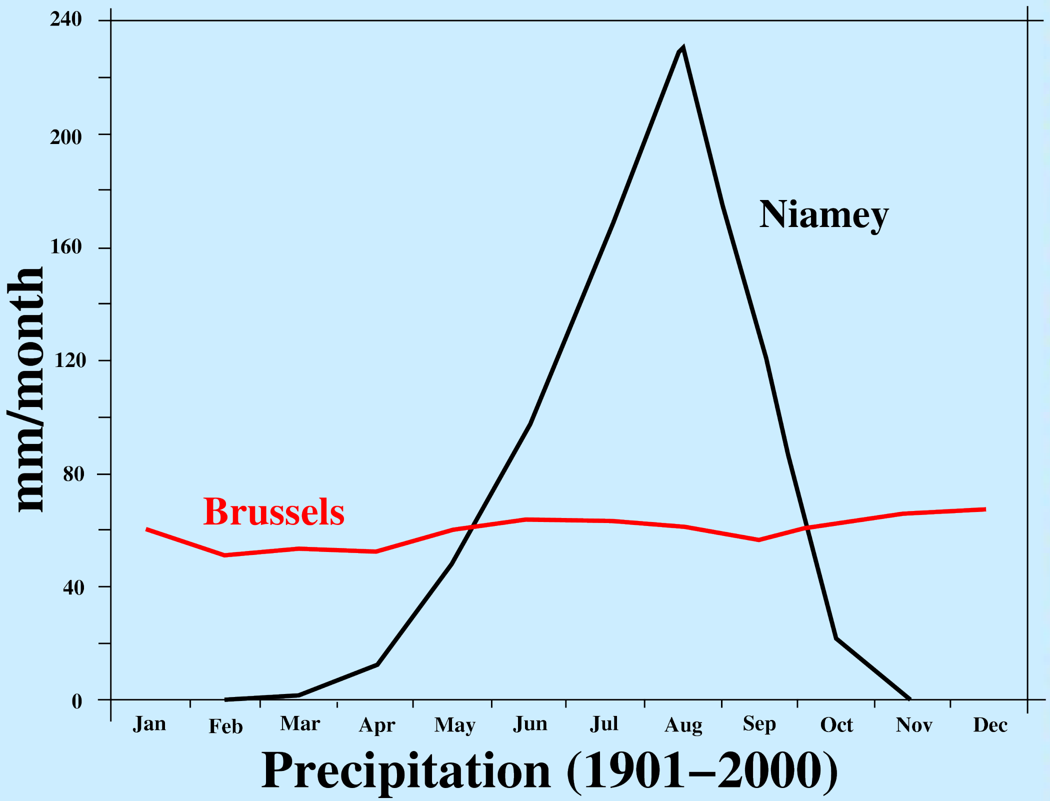
Some characteristics of the West African climate

The annual cycle of precipitation in the tropics is very marked.
The mean annual precipitation for two cities :

- Brussels : 720 mm/year
- Niamey : 708 mm/year

The short rainy season has profound impacts on human activities :

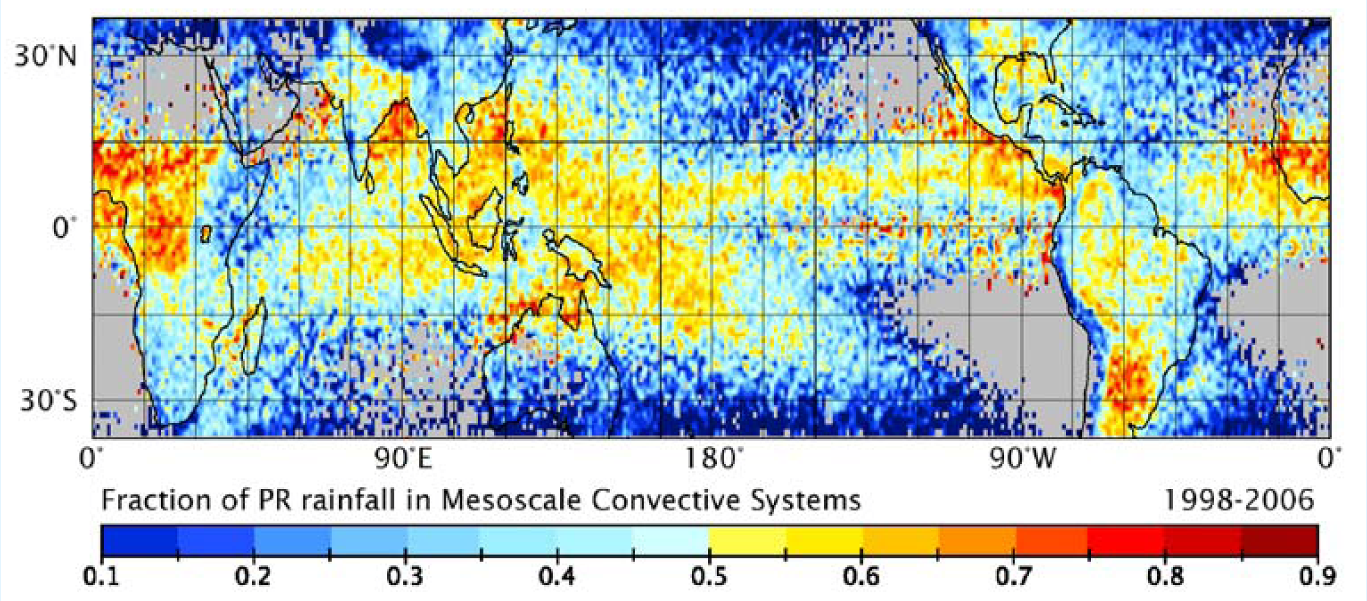
- Agriculture is only possible during the 3 month long rainy season.
- Water scarcity needs to be managed for 9 month of the year.
- High flood risks in Sep.



[New et al. 1999]

Rainfall predictions from medium range to seasonal are thus essential for the development of region.

Rainfall is mostly brought by convection



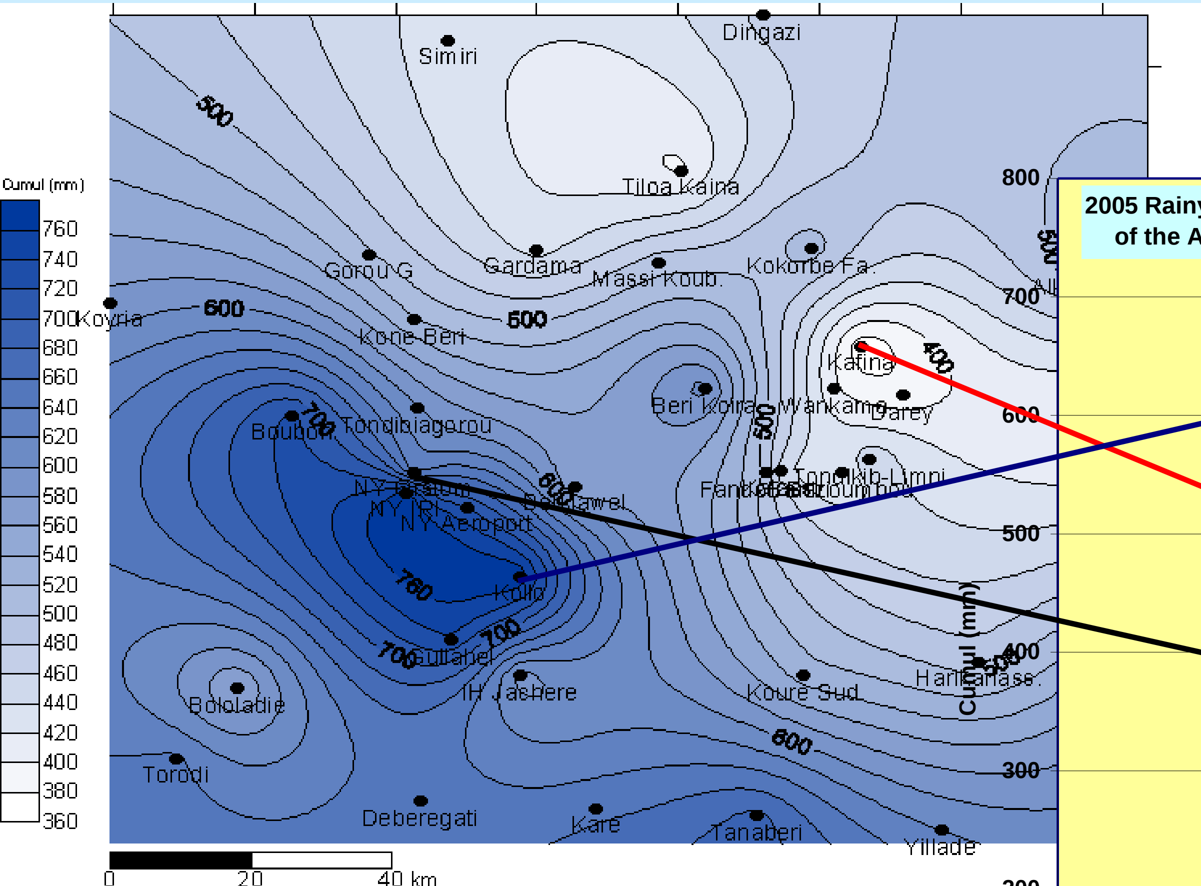
[Tao and Moncrieff, 2009]

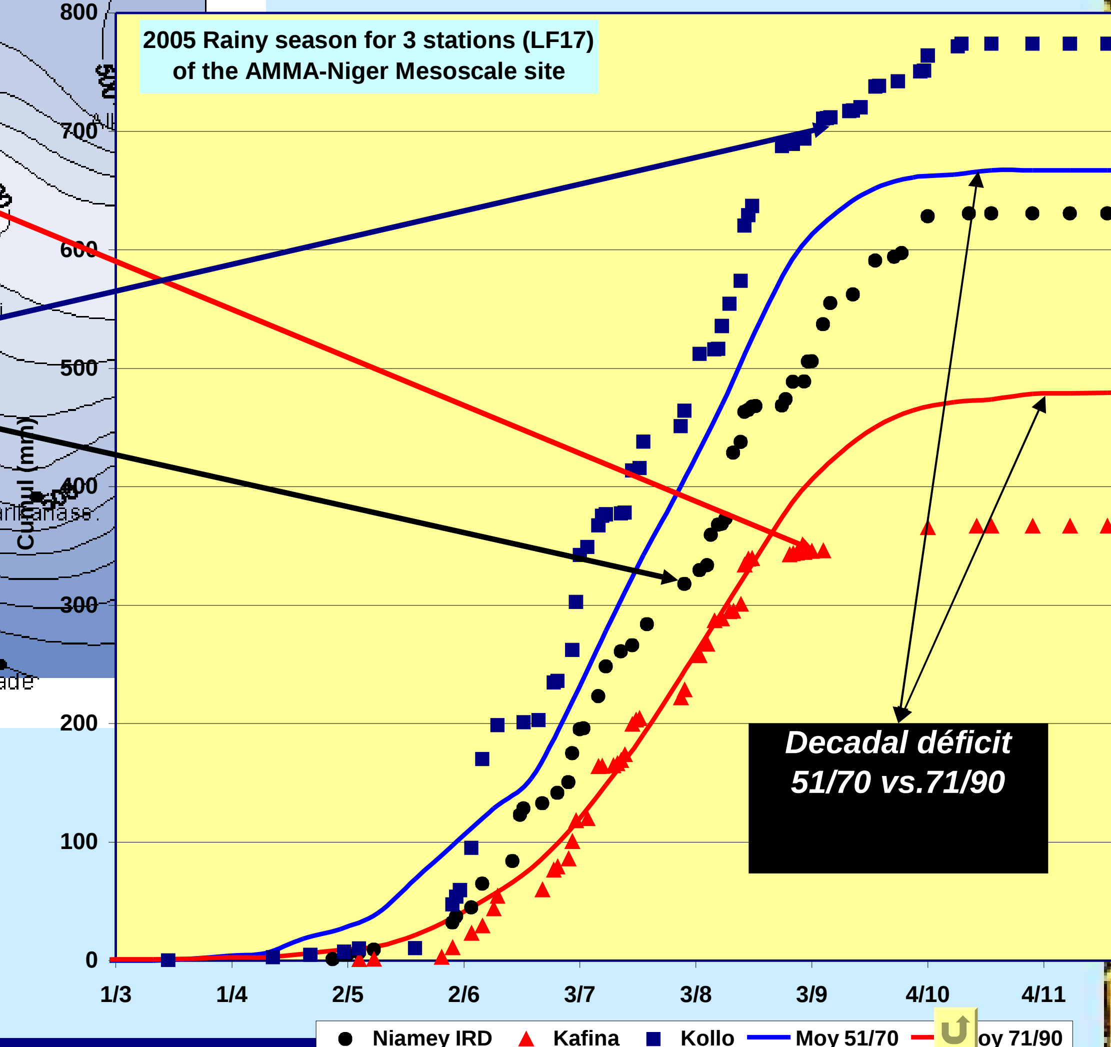
Using TRMM a few feature of WA rainfall can be identified :

- The region has the largest precipitating systems.
- Over 70% of the rainfall in the Sahel originates from systems wider than 100km.
- In Niamey most of the rainfall falls in 15 to 20 days with more than 10mm/d.

This type of rainfall can leave strong contrasts at the surface between wet and dry surfaces.

The strong spatial variability of rainfall

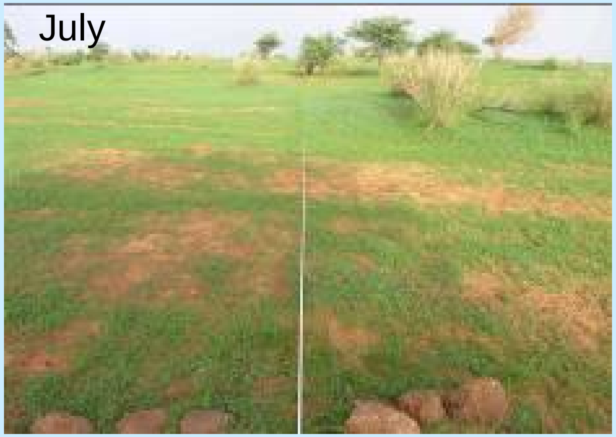




[C. Bailleul, L. Descroix, pers. comm.]

2005 average rainfall over the Niger mesoscale site.

Surface characteristics in West Africa



- May and June the surface energy balance is driven by bare soil evaporation. Runoff and ponding is important.
- July vegetation starts to smooth out evaporation. Role of infiltration increases.
- August and September the vegetation drive the surface processes. The roots extract deeper water.

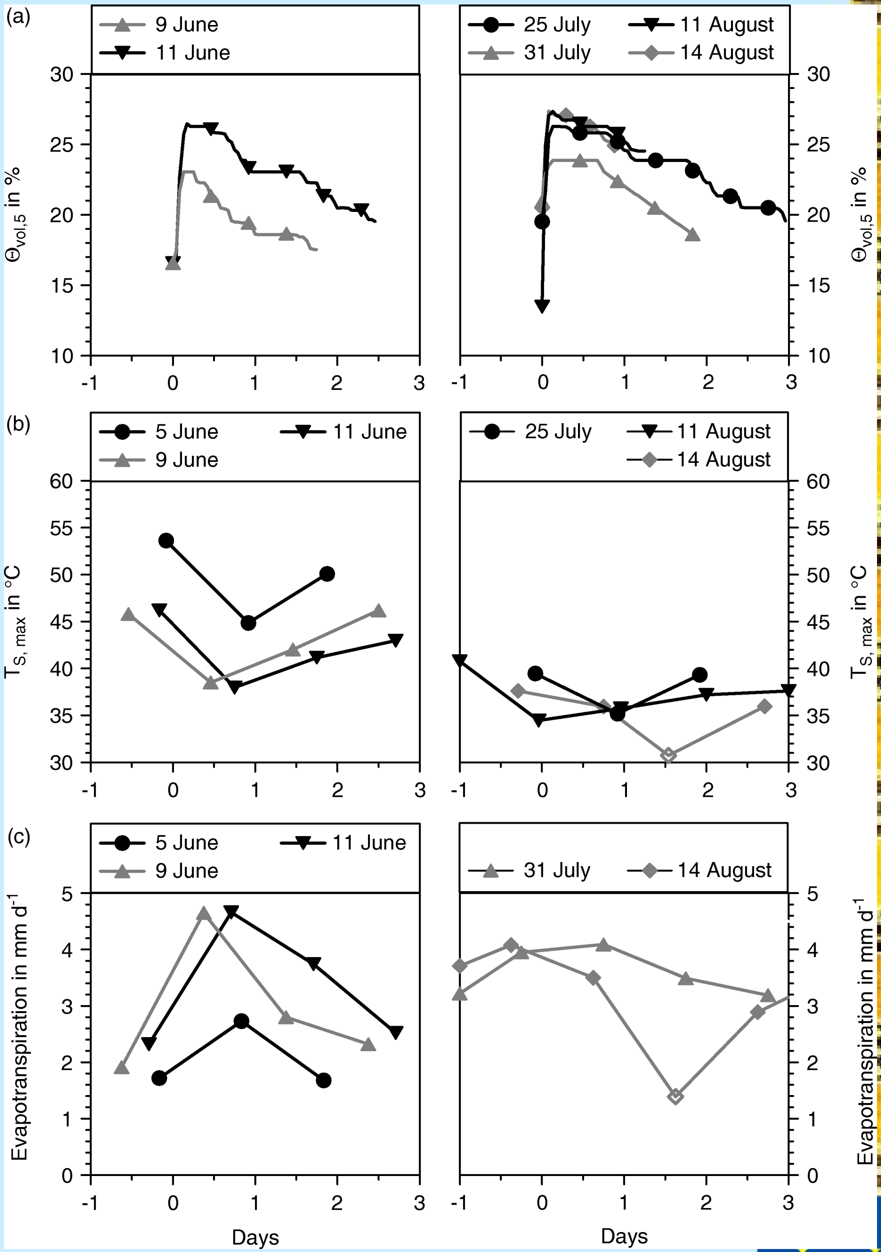
- Early in the the season, spatial structures of soil moisture could offer predictability.
(This is information which can be remote sensed.)
- Later in the season, soil moisture memory is likely to play a more important role.

Observing the evolution of the surface

In June the surface keeps a memory of the last rain event for 2-3 days => Spatial contrasts of surface fluxes between wet and dry patches are maintained.

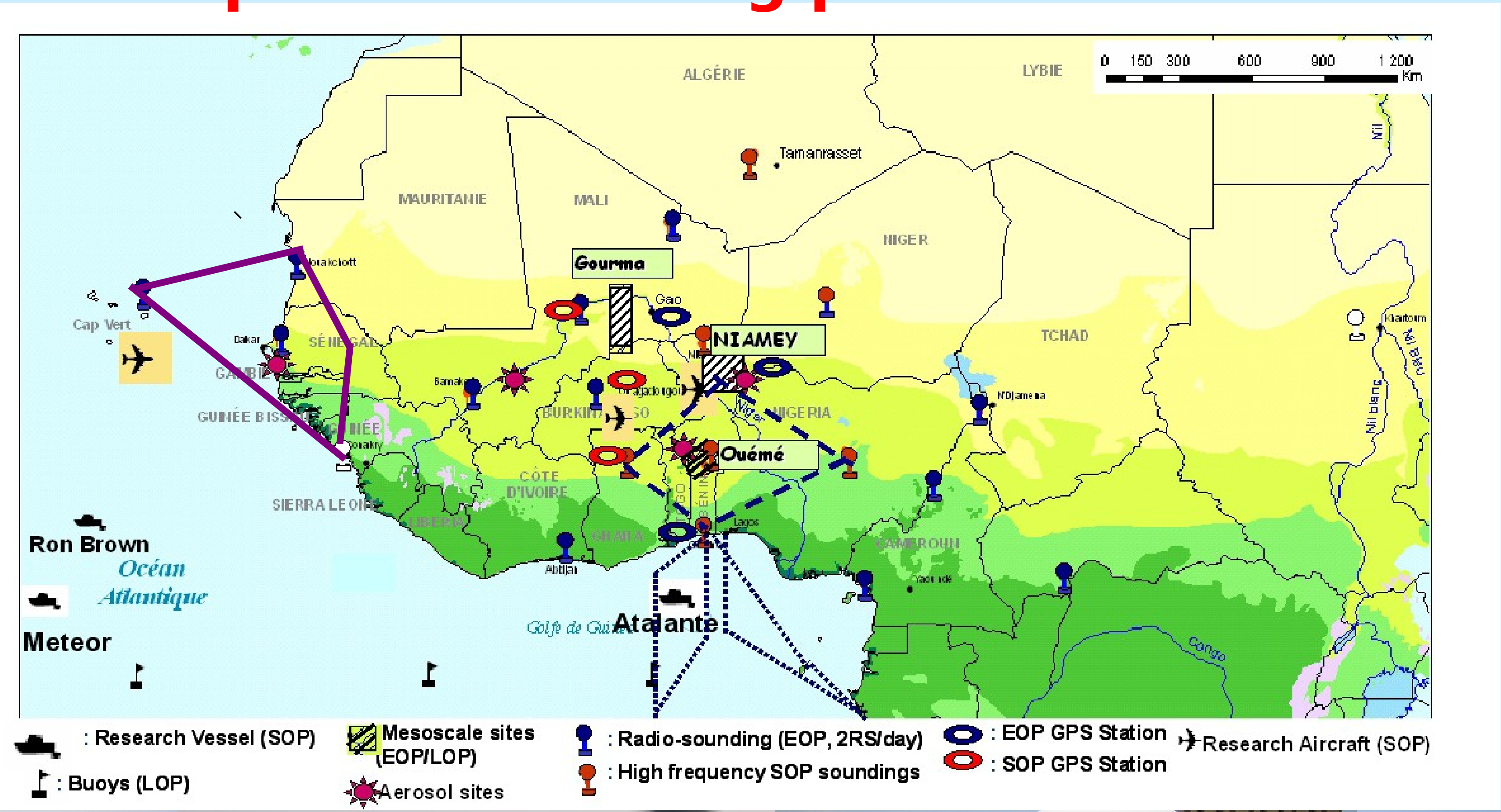
But this evolves through the season as the soil moistens and the vegetation grows.

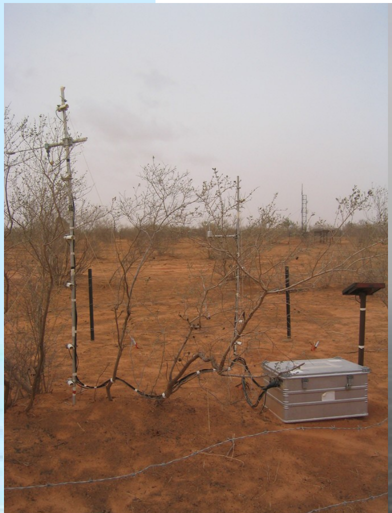
Can RCMs or GCMs, and their associated land surface schemes, represent these processes correctly ?



[Schwendike et al., 2010]

Enhanced Observing networks for 2005-2007
Special observing periods in 2006



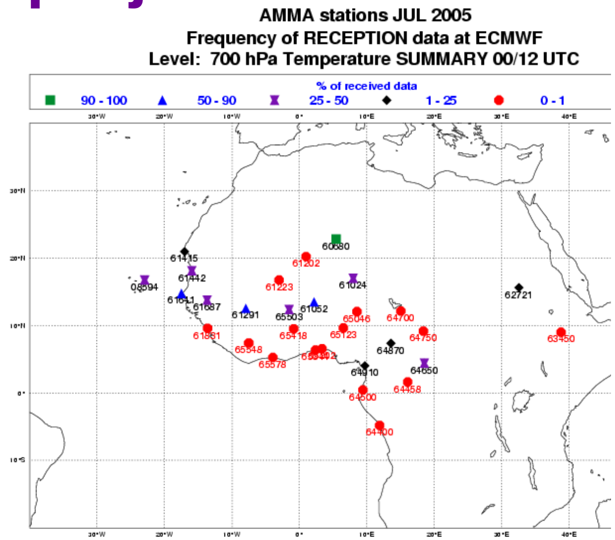


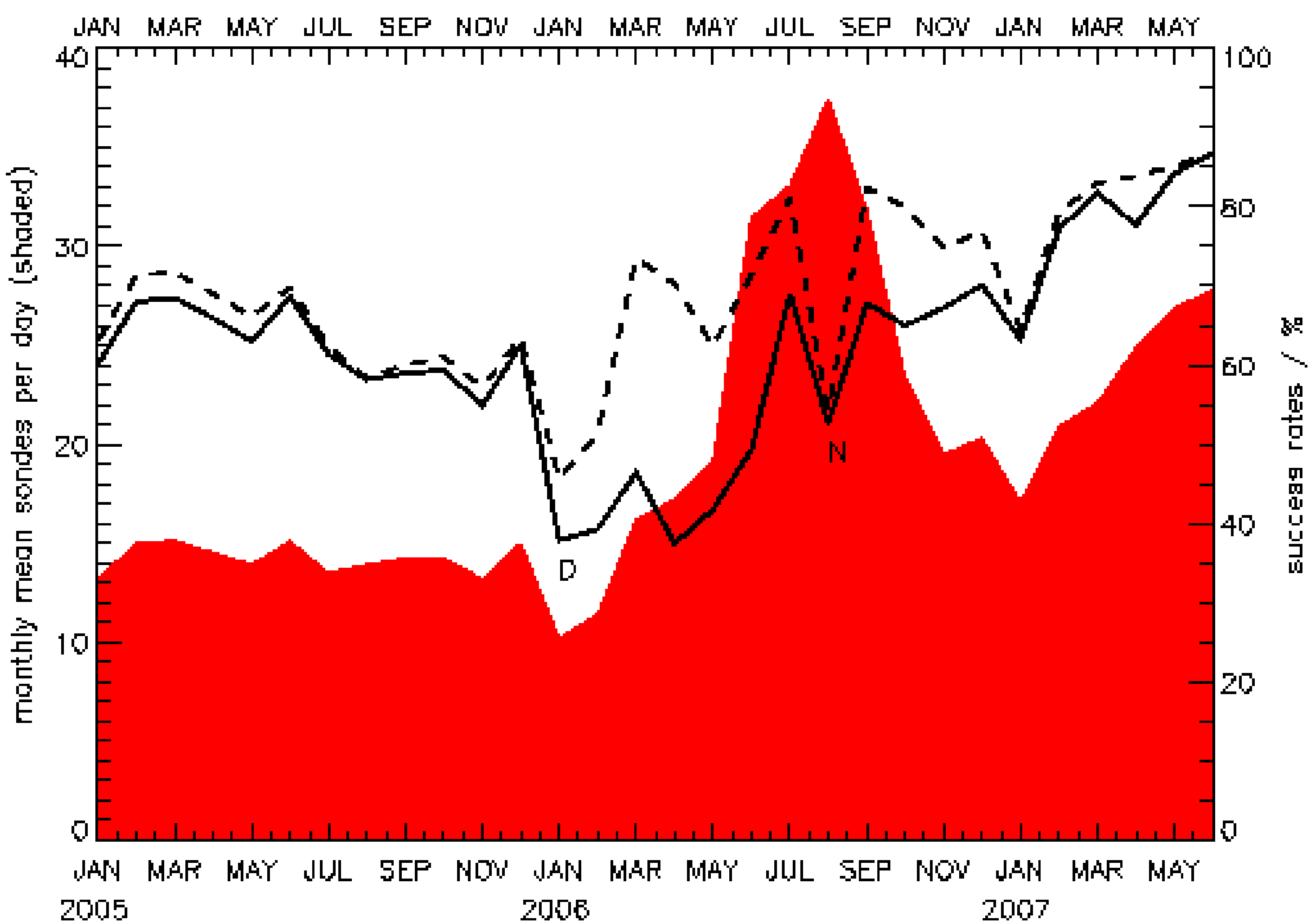
Improved atmospheric observations and their impacts on forecasts

The radio-sounding network upgrade accomplished by AMMA

During 2006 the AMMA research project has demonstrated that West African organizations (ASECNA, GMET, NIMET) can provide the same density of radio-sounding as seen in other regions.

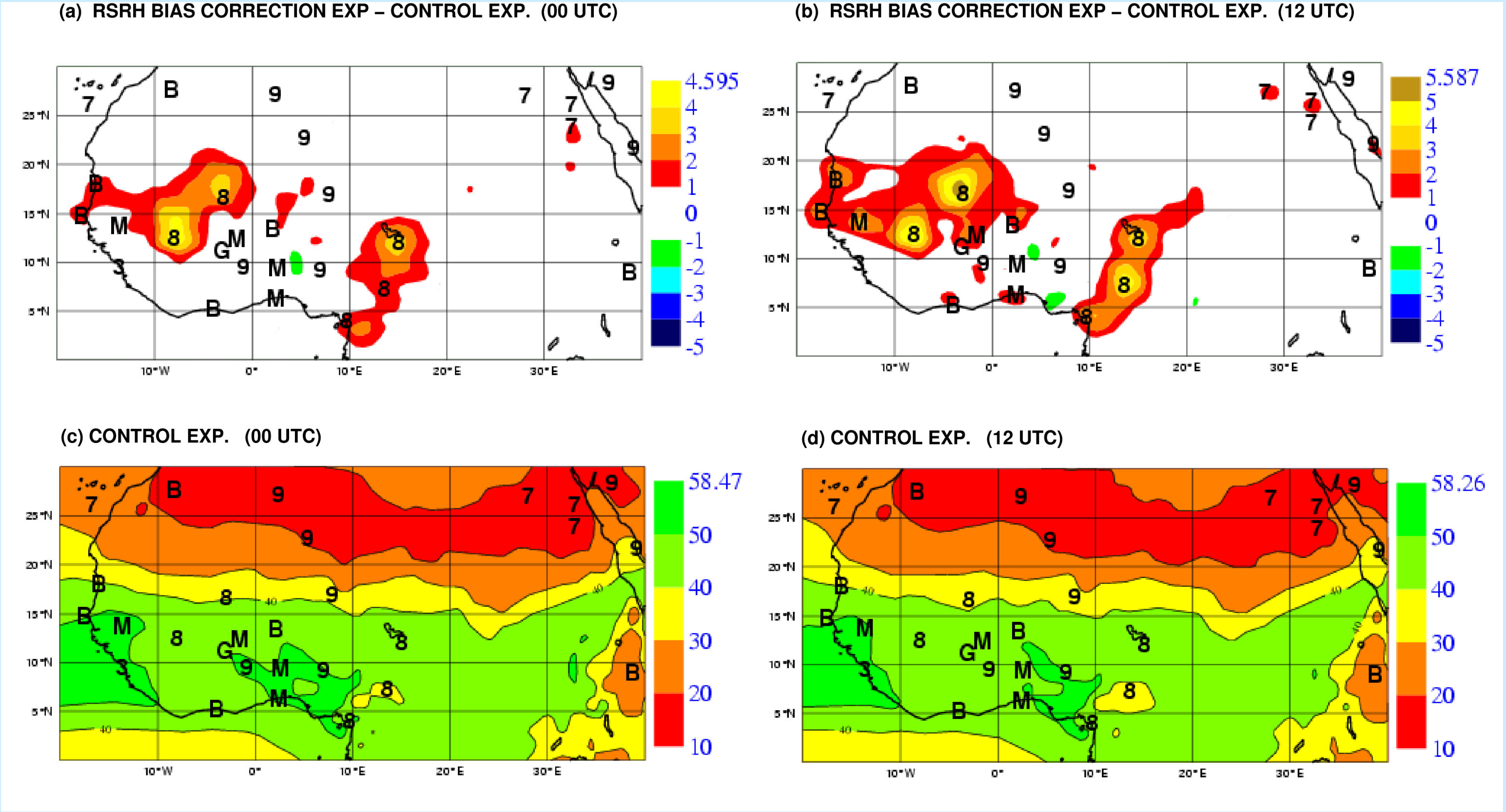
It needs to be ensured that this effort is sustained ...
but this can not be done by research projects !





Bias corrections of humidity

- The GPS stations allowed to verify the precipitable water observed by radio sounding.
- The large diversity of sounds made the correction of biases a difficult task.

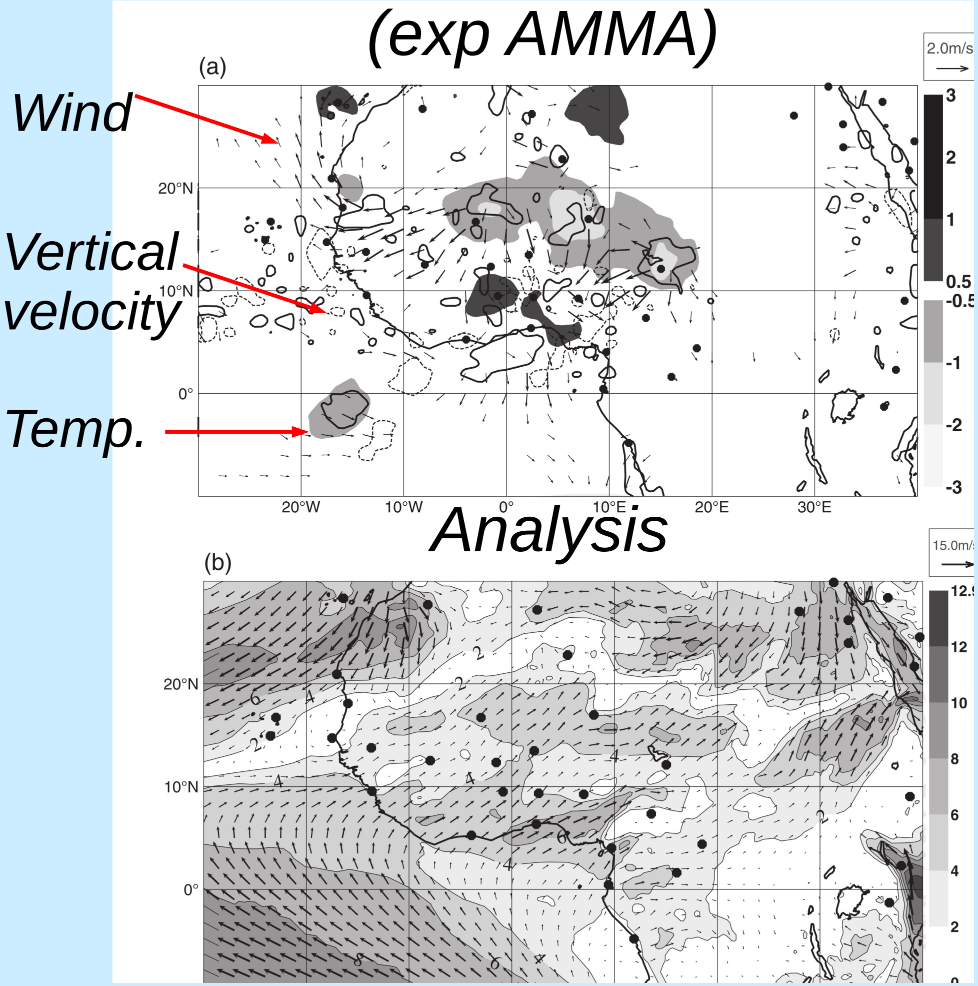


The humidity bias correction was one of the most important contributions to improving the analysis.

[A. Agusti-Panareda et al. 2009, M. Nuret al.2008]

Impact of the AMMA data on dynamic fields

Analysis increments @ 925hPa



[A. Agusti-Panareda et al. 2010]

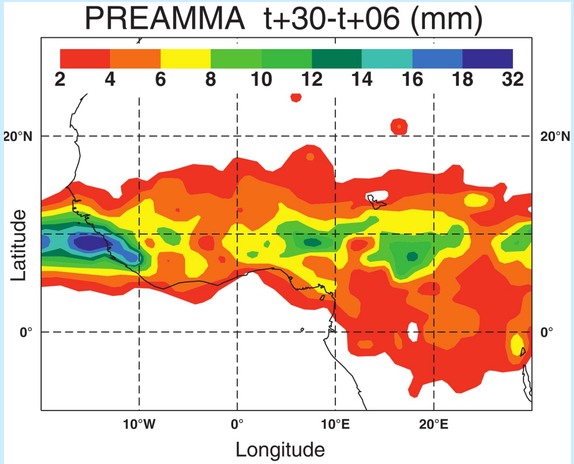
ECMWF conducted a re-analysis for 2006 :

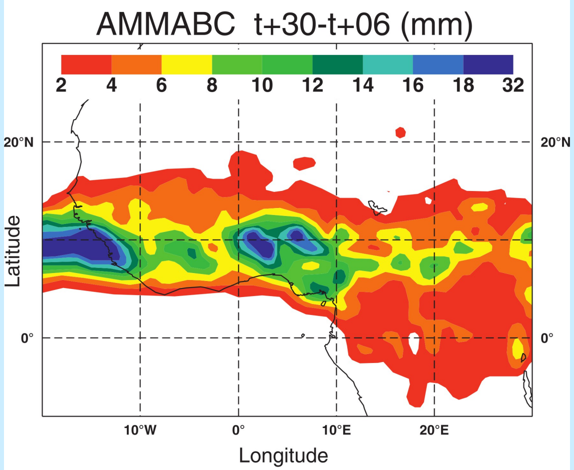
- Analysis of a pre-AMMA radiosounding network
- Analysis of all 2006 soundings at high resolution

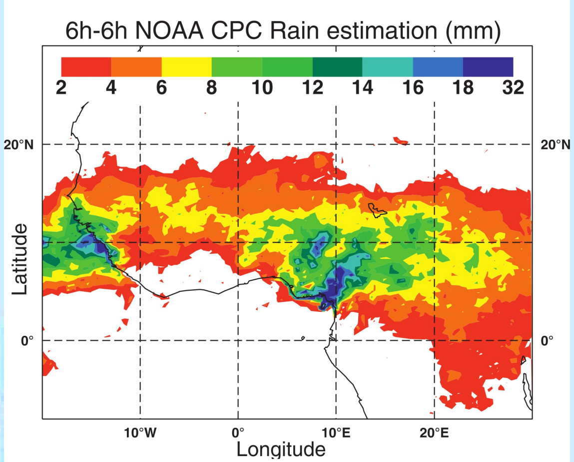
Soundings in data sparse regions (N'Djamena, Agadez and Timbuktu) lead to large temperature increments which induce unrealistic divergent winds.

The model biases are too large or observations too few !

Impact of AMMA data on precipitation forecasts





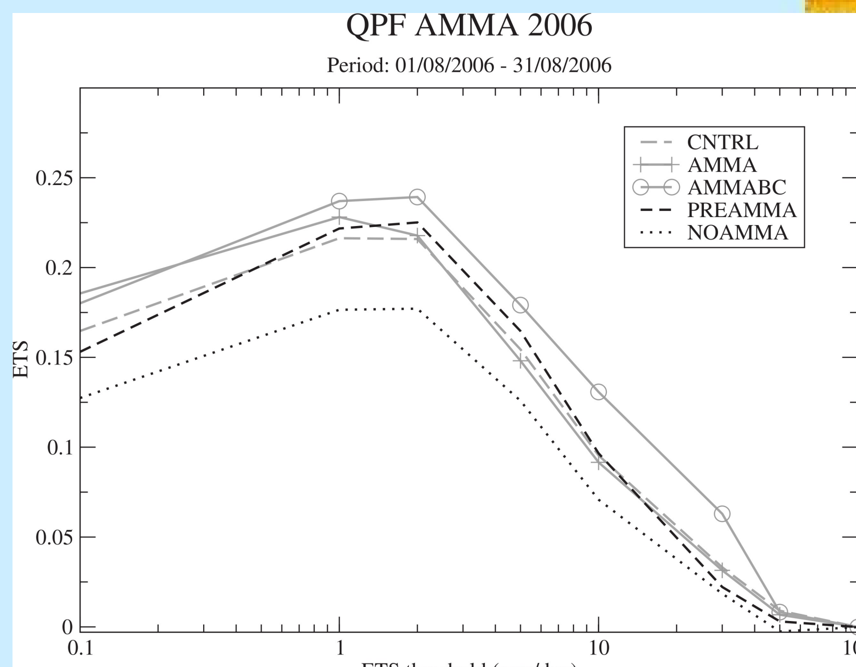


Météo-France evaluated the impact of the AMMA data on the forecasts over the month of August (4 day forecasts starting at 0hUTC).

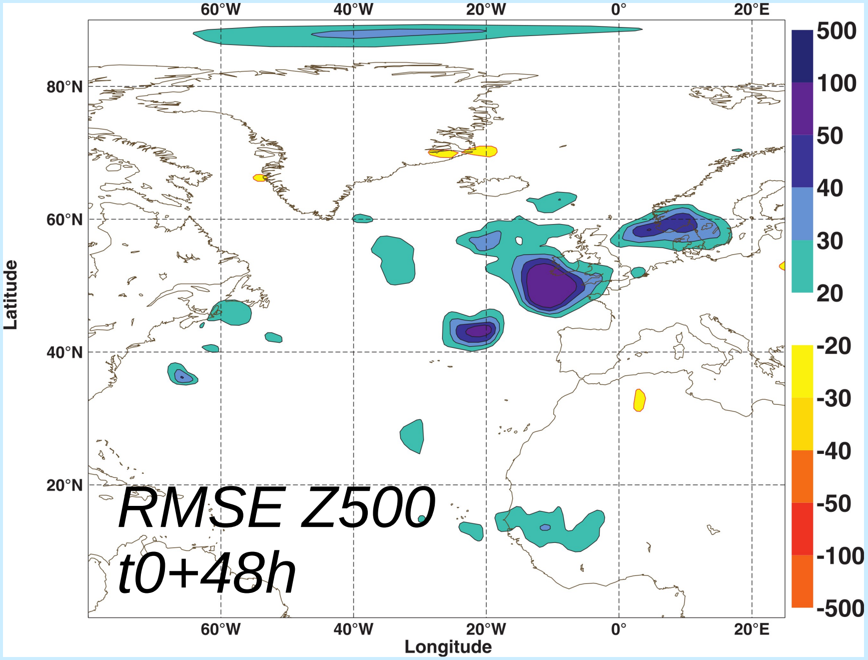
- The model continues to have a southerly placed convergence zone.
- Intense precipitation features are better represented.

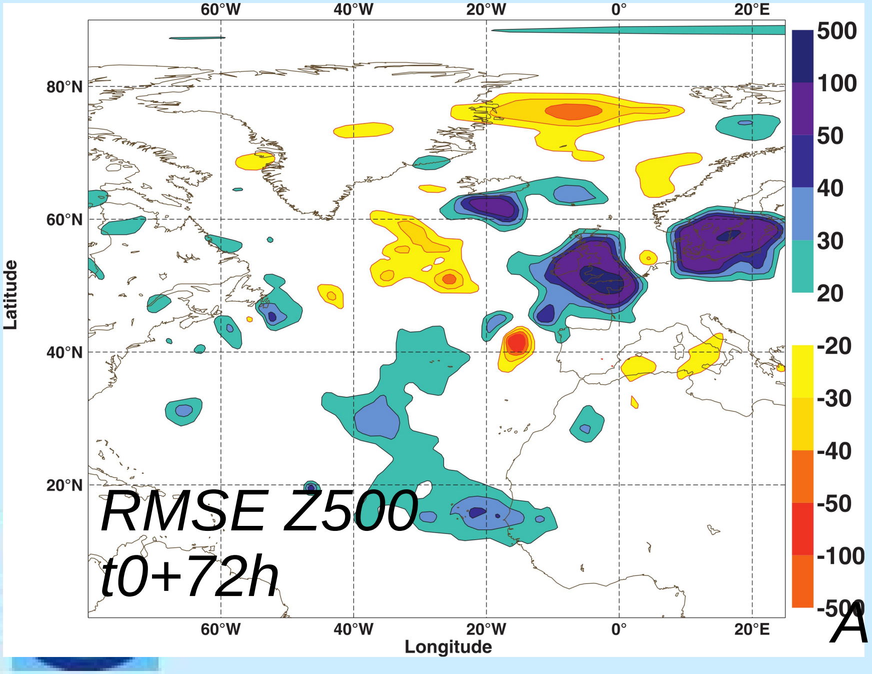
- The equitable threat scores are improved – but score remain weak for intense rainfall events.

[C.Faccani et al. 2010]



Remote impact of improved West African analysis





The improvements in the forecast are advected into the mid-latitudes.
This leads to significant improvement of the Z500 scores after 48 and 72 hours.

Some questions remain :

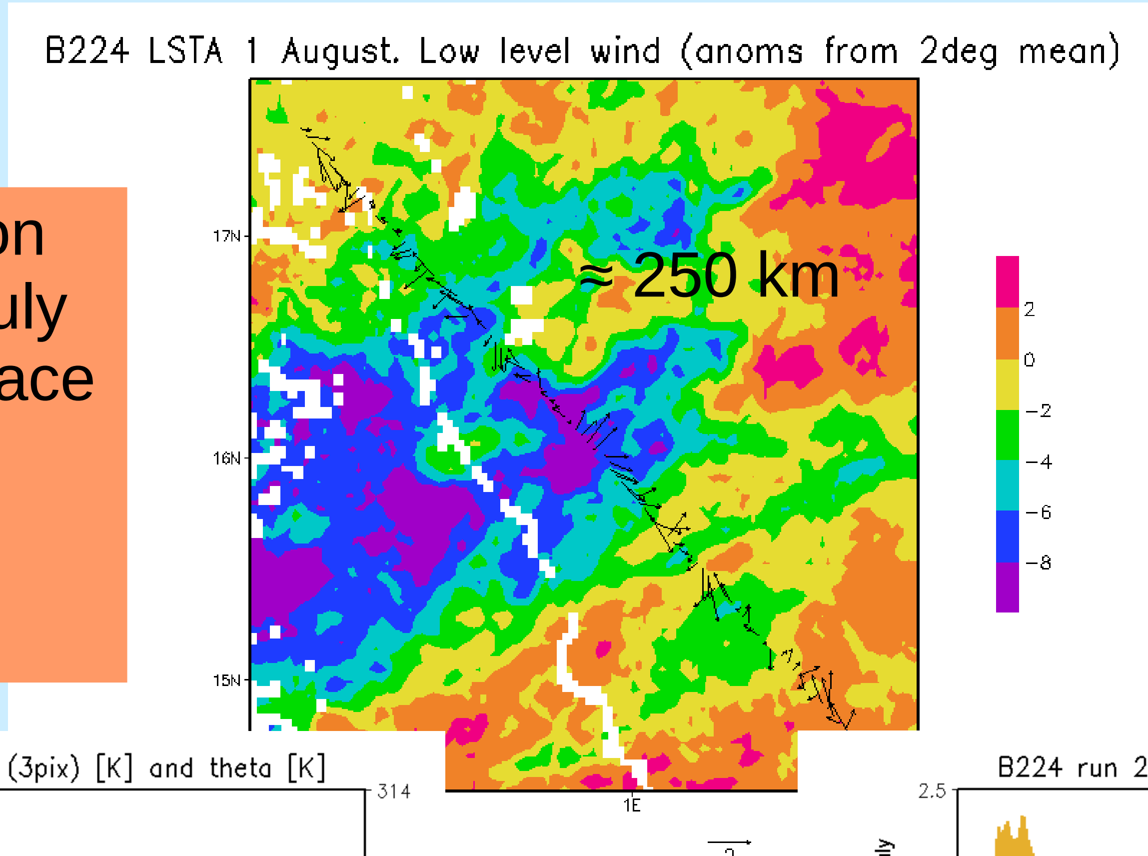
- Does this benefit exist through the entire season ?
- Is this particular to the 2006 conditions ?

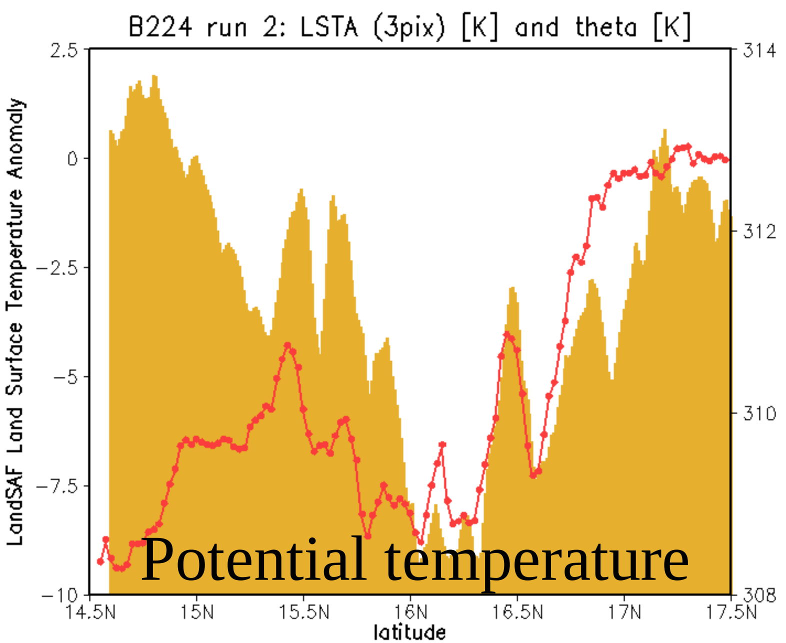
Averaged over the period 1-Aug to 14 Sep

Is there a potential for predictability in surface heterogeneities ?

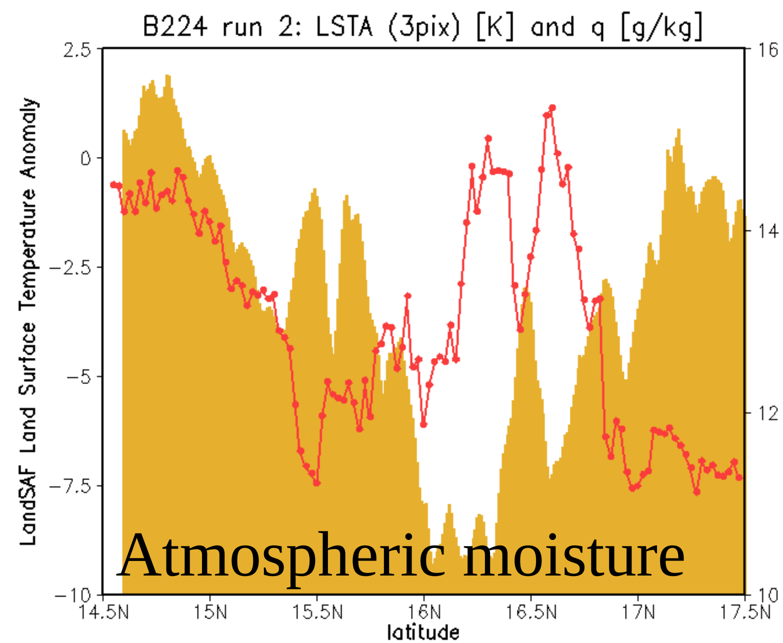
The rôle of small scale soil moisture anomalies

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





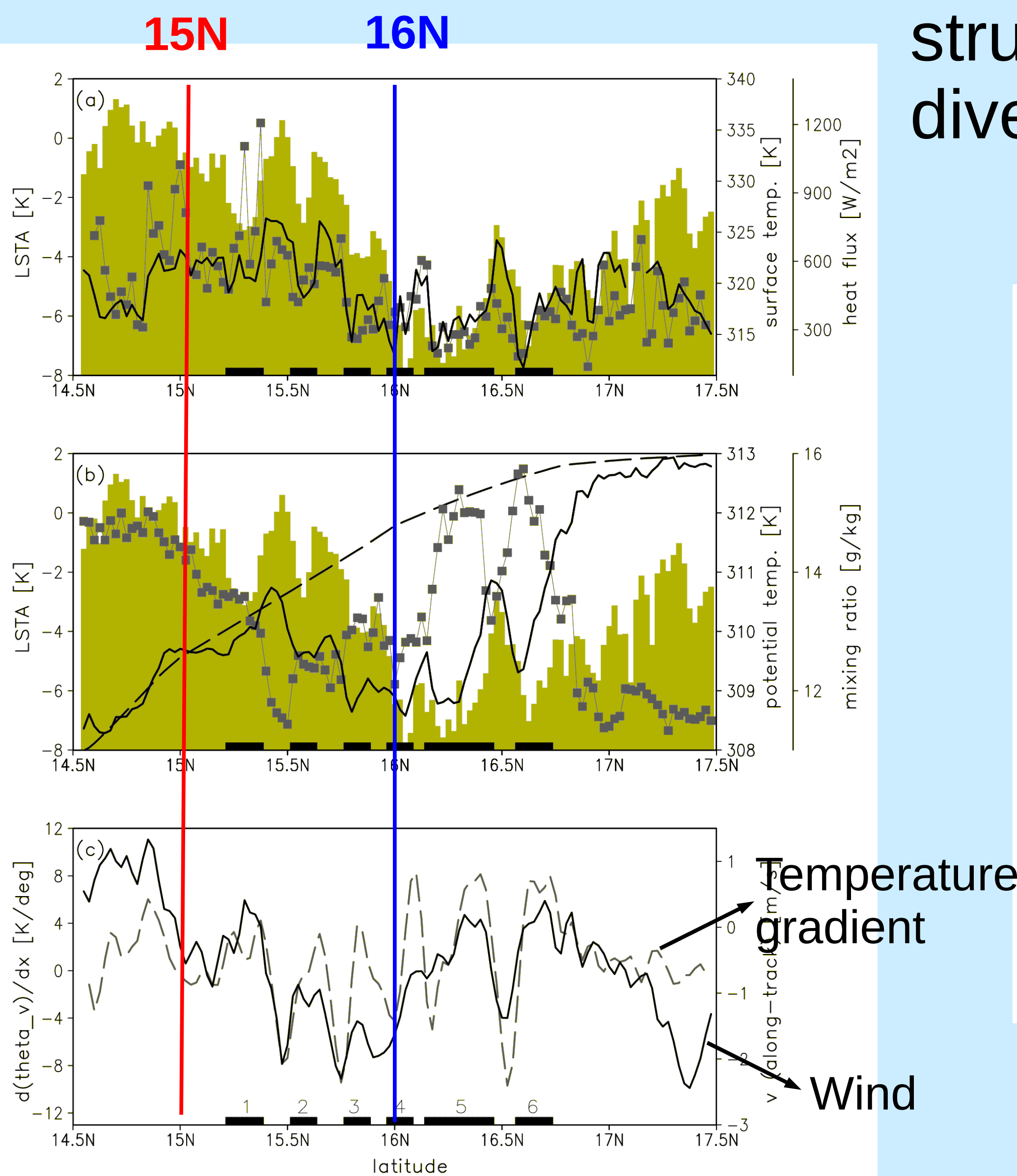
Boundary layer conditions on the aircraft track.

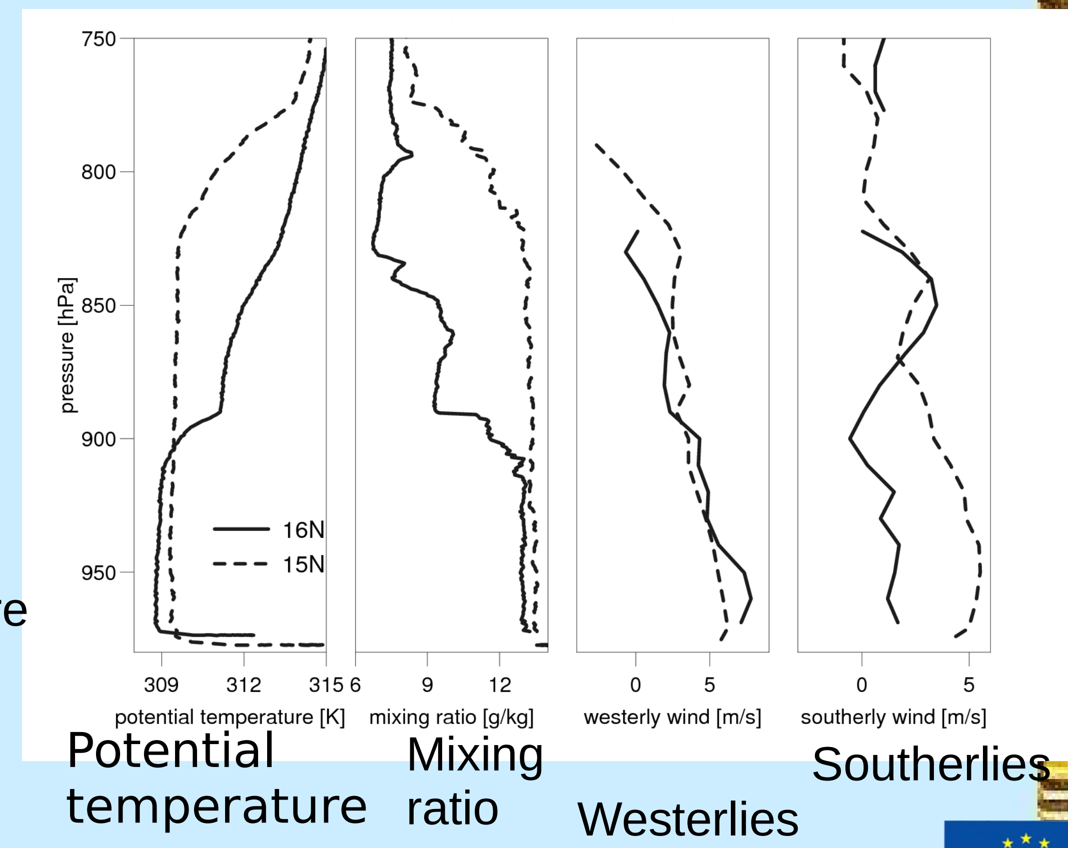


Impacts on the atmospheric dynamics

[Taylor et al., 2007]

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



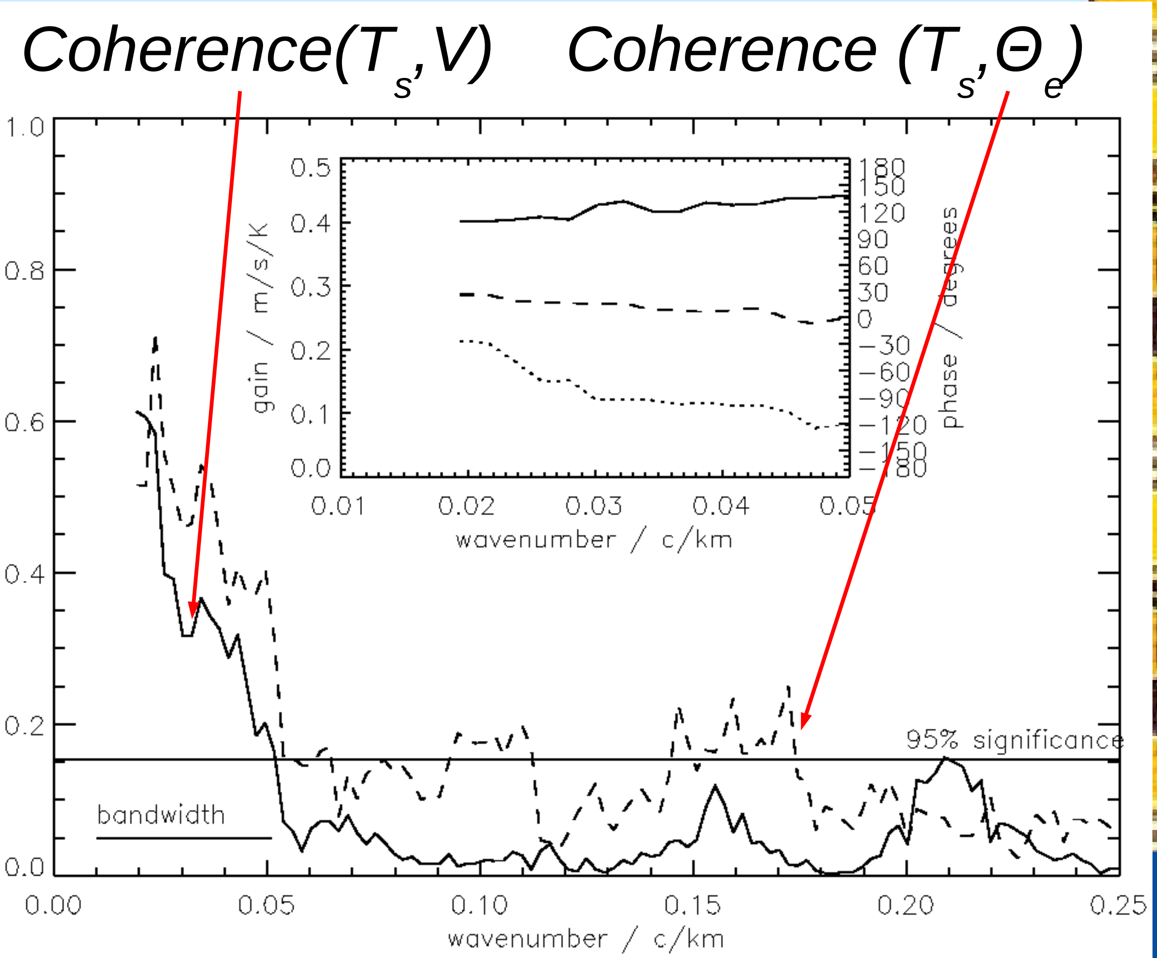


The spatial scales inducing circulations

The spectral coherency analysis allows to identify the spatial scales at which the surface influences the atmosphere.

- 10Km patches and larger generate significant atmospheric structures.
- Θ_e is in phase with surface structures while wind is out of phase.

The analysis of a wider set of flights has shown that the mesoscale circulations (phase and intensity) depend on the background wind



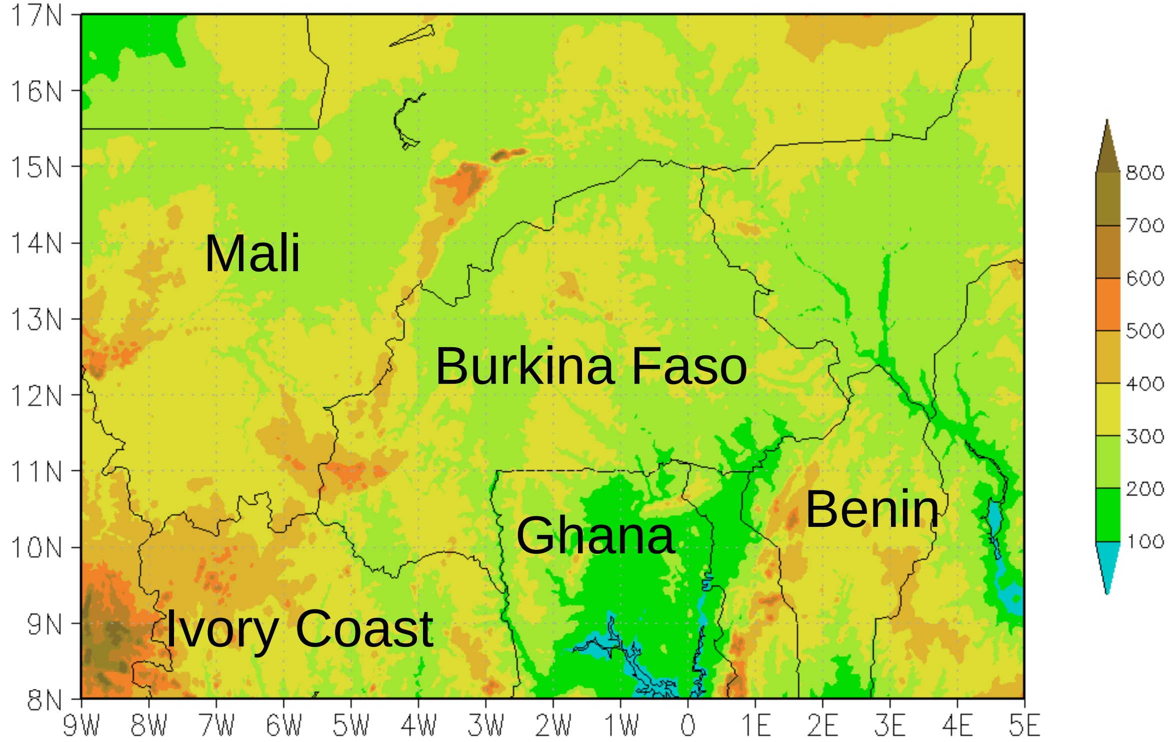
Simulations of the 11th of June 2006

Model setup:

- COSMO model (former LM) from DWD
- Resolution: 0.025 ° (2.8 km)
- No convection parameterisation scheme
- 50 layers in the vertical (up to 28 km)
- Multi-layer SVAT model TERRA_M (7 soil layers)

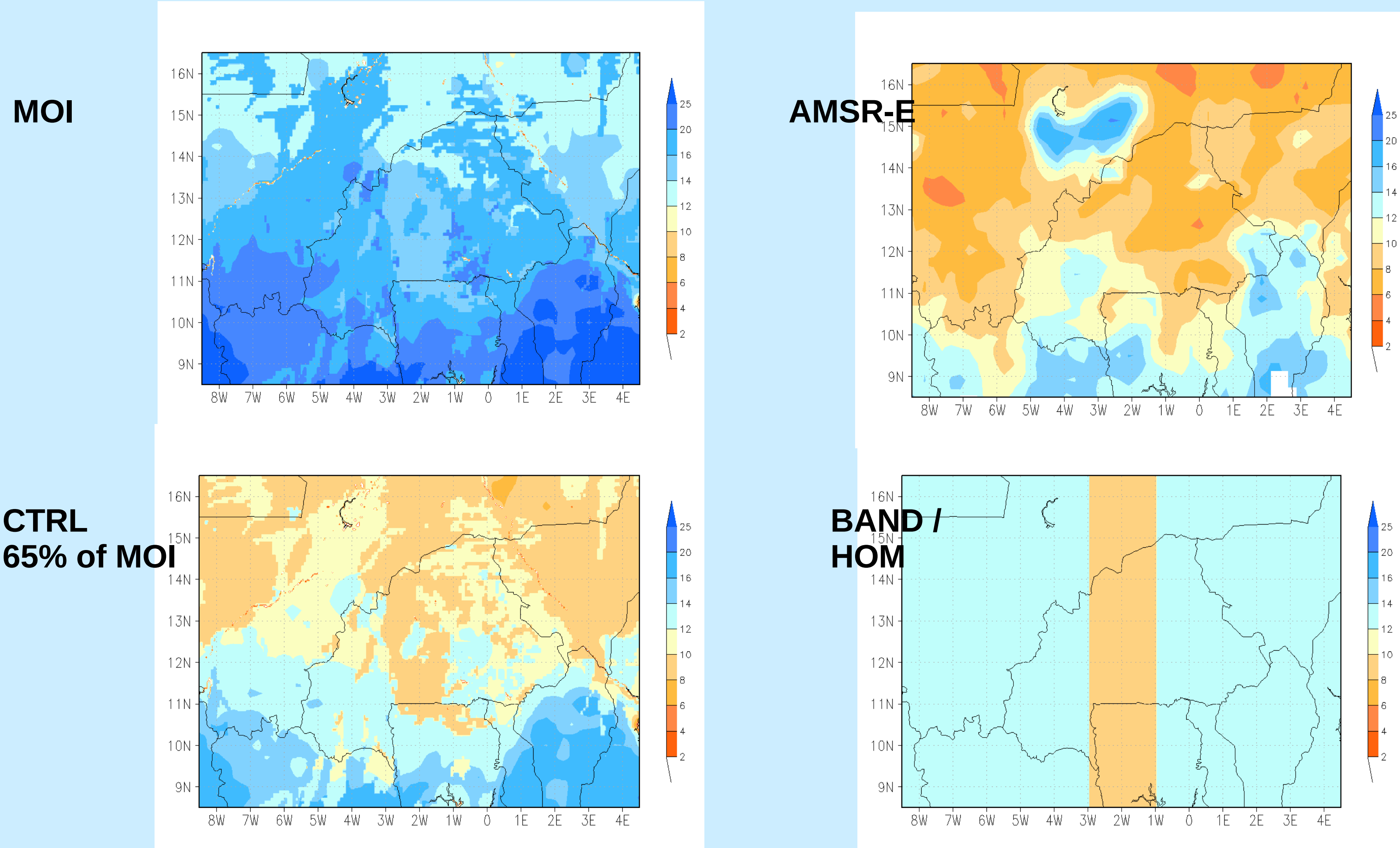
Initialisation and boundary conditions:

- Operational analyses from ECMWF
- Initiated on 11 June 2006 at 00 UTC



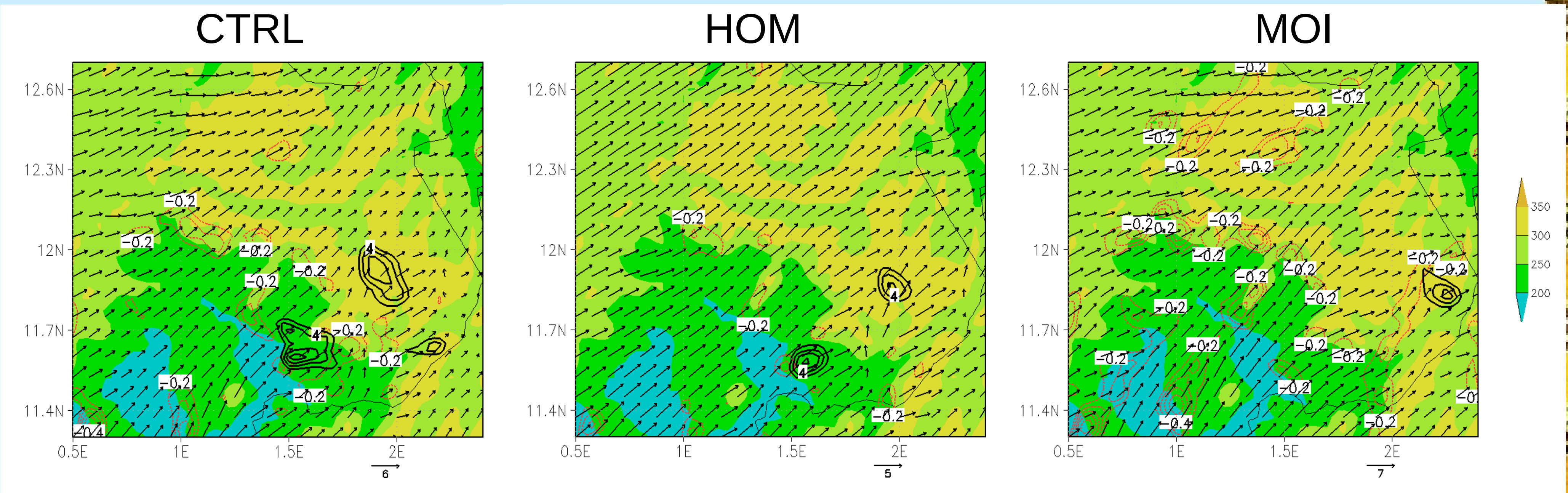
[Gantner & Kalthoff, 2010, Adler et al., 2011]

Soil moisture conditions for model initialisation



COSMO initial volumetric soil moisture in % in the uppermost layer on 11 June 2006 at 0000 UTC for the cases ***MOI****,* ***CTRL****, and* ***BAND/HOM case.***

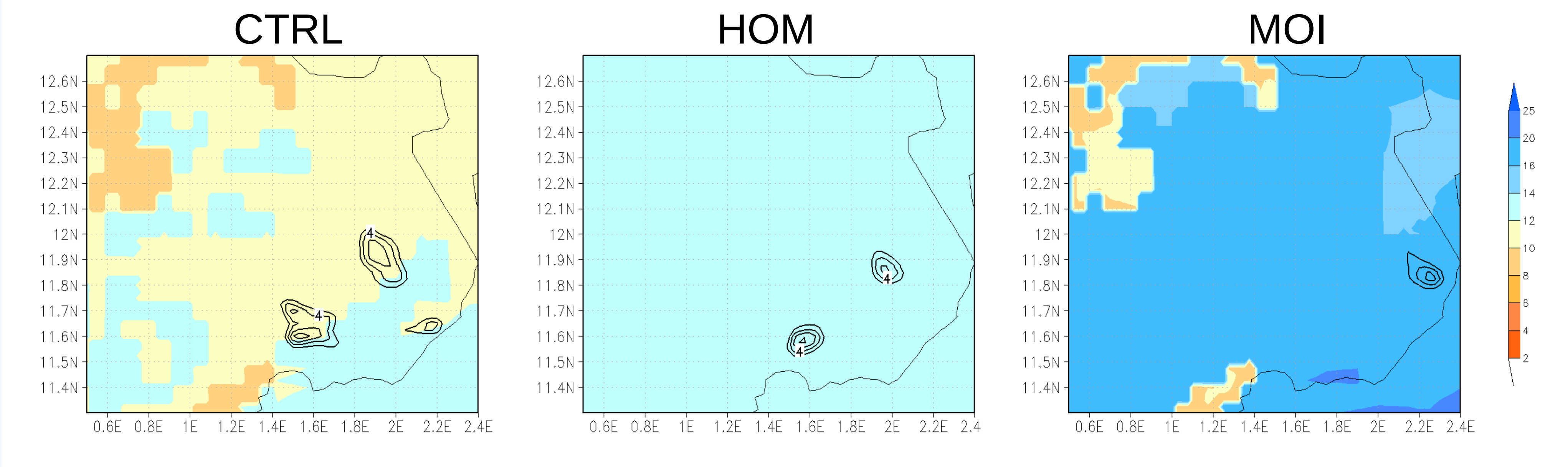
Model results: initiation of convection



Orography *in m,* ***vertical velocity*** *(omega) in Pa s^{-1} averaged between 1200 and 1500 UTC (dotted isolines, interval 0.1, start value 0.2),* ***horizontal wind vector*** *in m s^{-1} at 1700 UTC at 950 hPa, and* ***precipitation*** *in mm h^{-1} (solid isolines) at 1700 UTC on 11 June 2006.*

- The monsoon flow is out of the South West.
- Some precipitating cells developed in the lee of slopes (upward motion)
- But only the surface conditions explain the triggering needed.

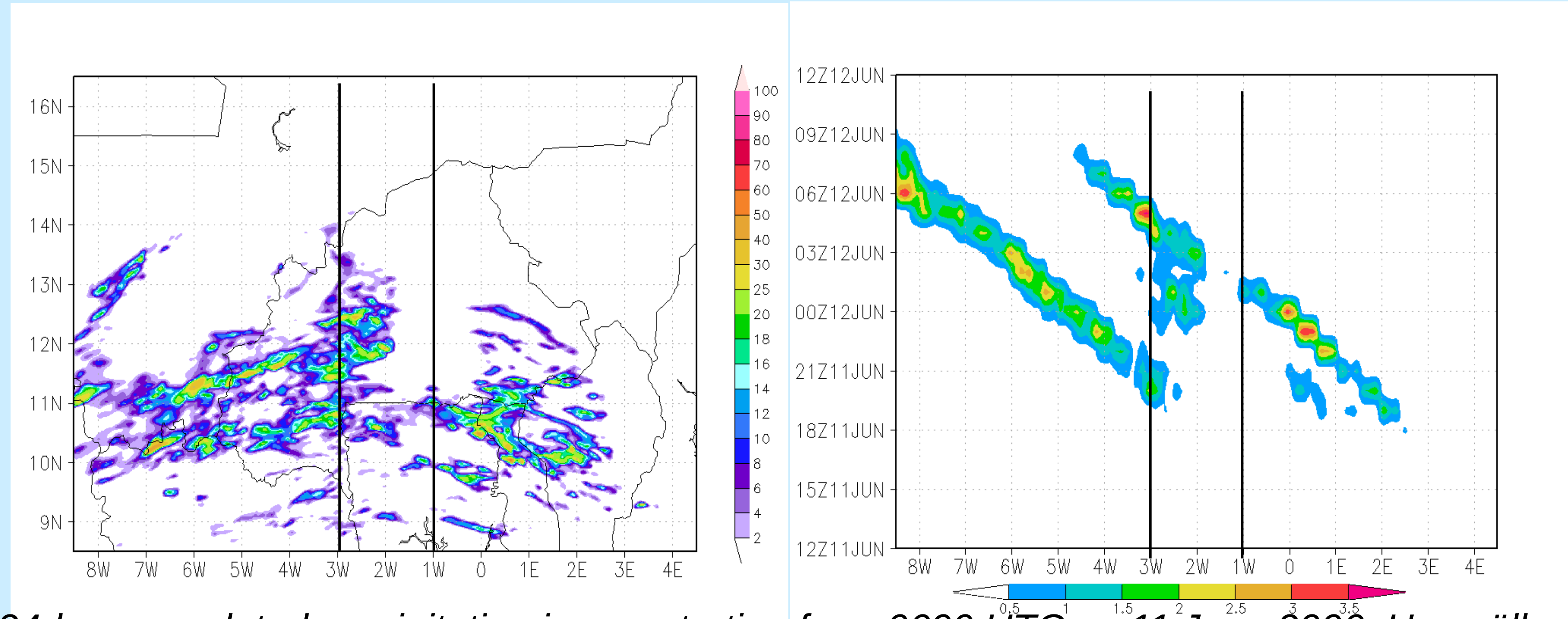
Model results: initiation of convection



***Volumetric soil moisture** in % at 1500 UTC in the uppermost layer and **precipitation** in mm h^{-1} on 11 June 2006 at 1700 UTC.*

- HOM contains the heterogeneities of vegetation
- HOM and MOI are wetter and thus have shallower CBLs and higher CIN.
- Cells developed over dry patches where thermally induced converges destroyed the CIN.
- HOM and MOI developed thermal contrast through vegetation and soil texture heterogeneities.

The impact of a dry spot on a system

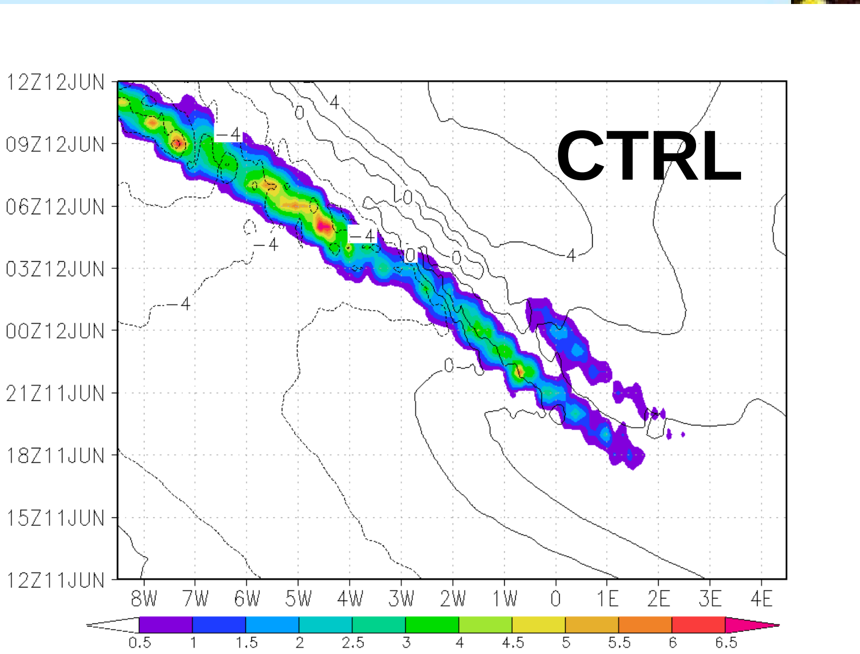


24-h accumulated precipitation in mm starting from 0600 UTC on 11 June 2006 Hovmöller diagram of precipitation in mm h-1 averaged between 10.5 and 13.5 °N

PBL is very high over the drier area => downward mixing of momentum

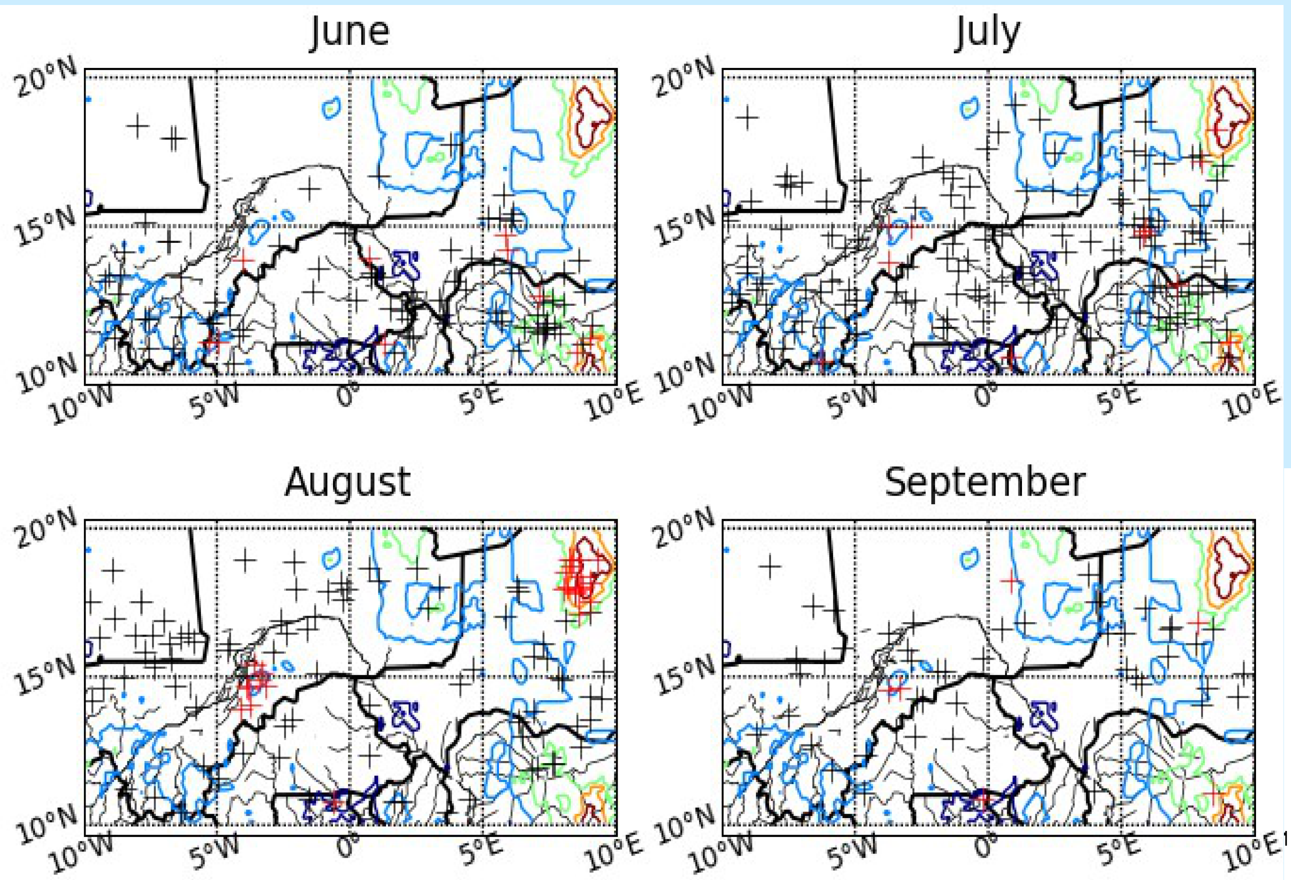
Thermally induced circulation and opposing background winds => convergence zone

 Superposition of both effect => enhanced convergence over the western part of the dry area & triggering of convection



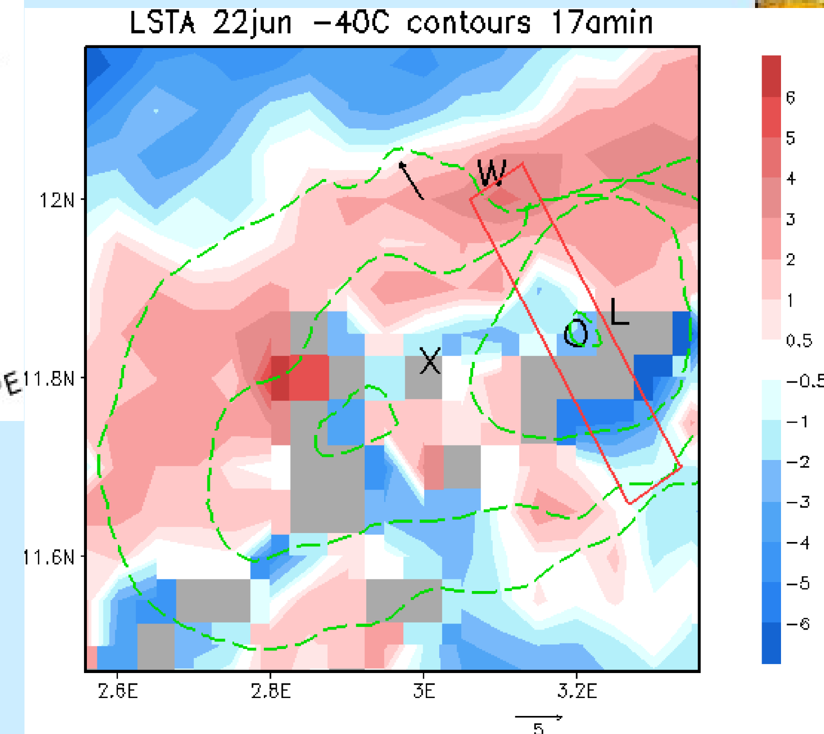
Initiation of convection during 2006

Using the ISIS system of Météo-France and Meteosat images the initial location of storms could be traced back .



(ISIS picks-up most systems around 16Z but first cold clouds are visible 2 hours earlier.)

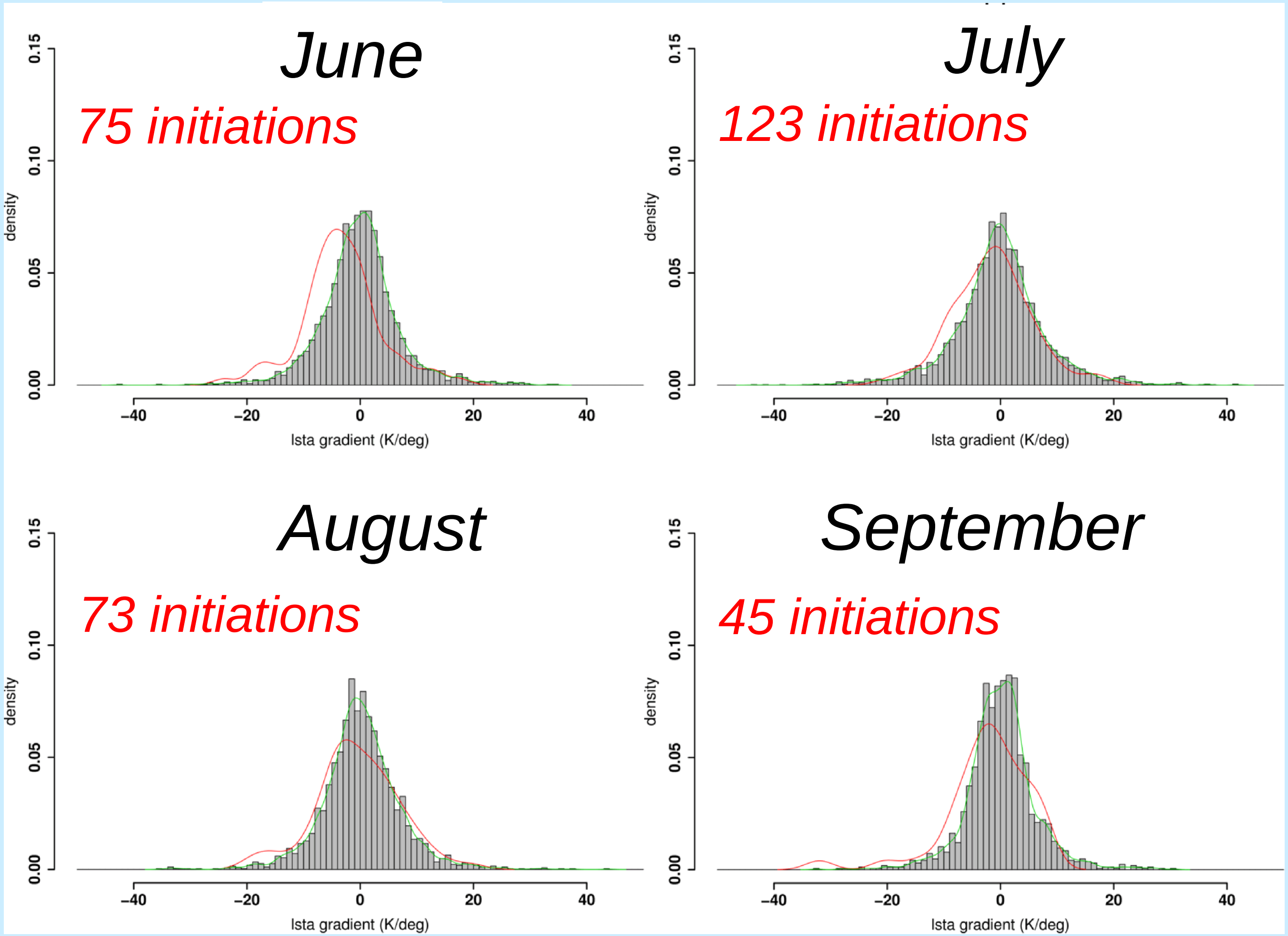
AMMA deliverable D1.3.3.i, Taylor et al.



The locations are then placed on the maps of surface temperature anomalies to compute gradients.

Initiation and temperature gradients

Gradients on randomly chosen points are computed to define a reference distribution.



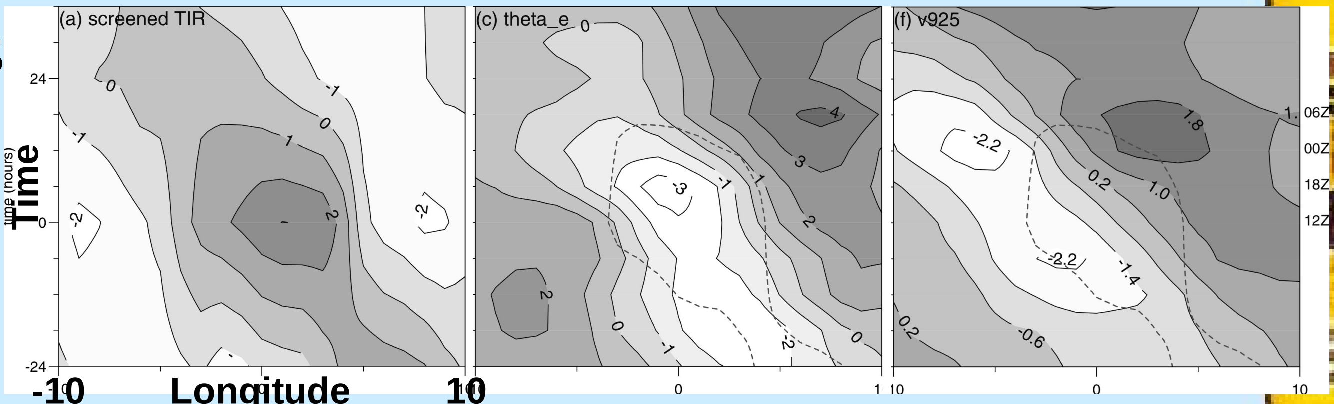
Maximum initiation when :

- T_s gradient is opposite to the direction of background wind.
- Wind opposes the soil moisture induced circulation.
- The length scale of grad. is 40km.

In this region soil moisture gradients enhance initiation of convection by 13% compared to 12% by orography. The role of soil moisture changes during the season.

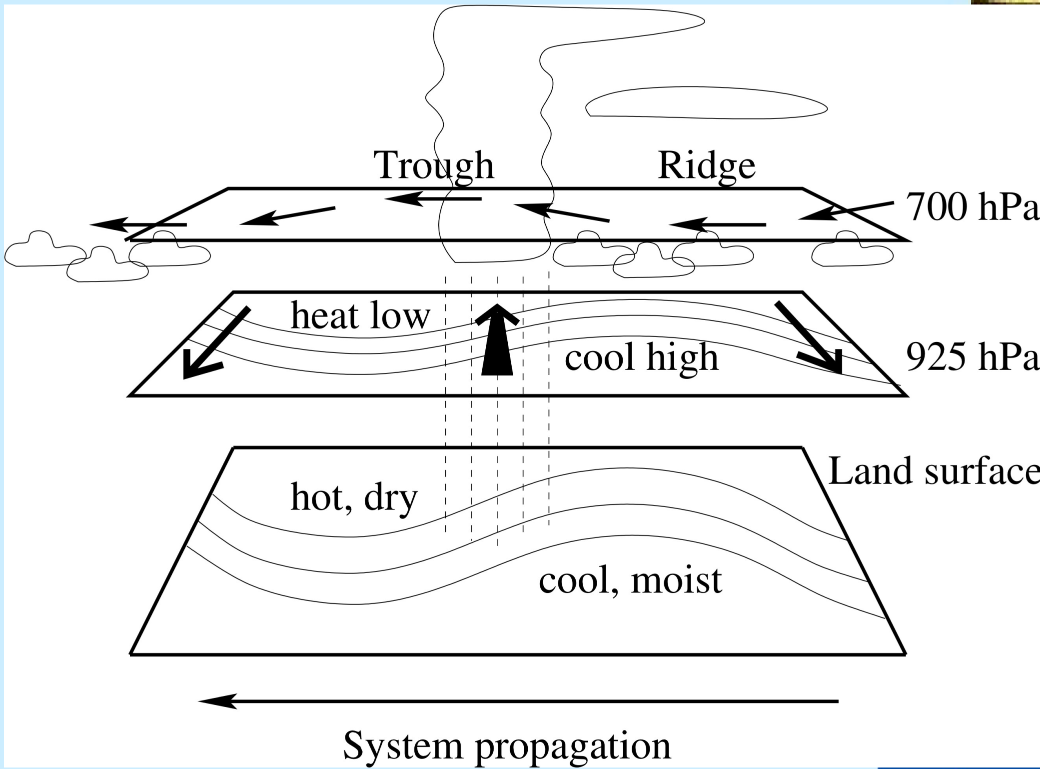
Surface processes and synoptic variability

Compositing anomalies of hot surface temperatures allows to link them to atmospheric features.



Meteosat Obs. *ECMWF Analysis*

- A deep and dry PBL forms over the hot spots.
- A heat low is generates.
- To the East southerlies (@ 925hPa) intensify at 06Z.
- A cool and moist high follows

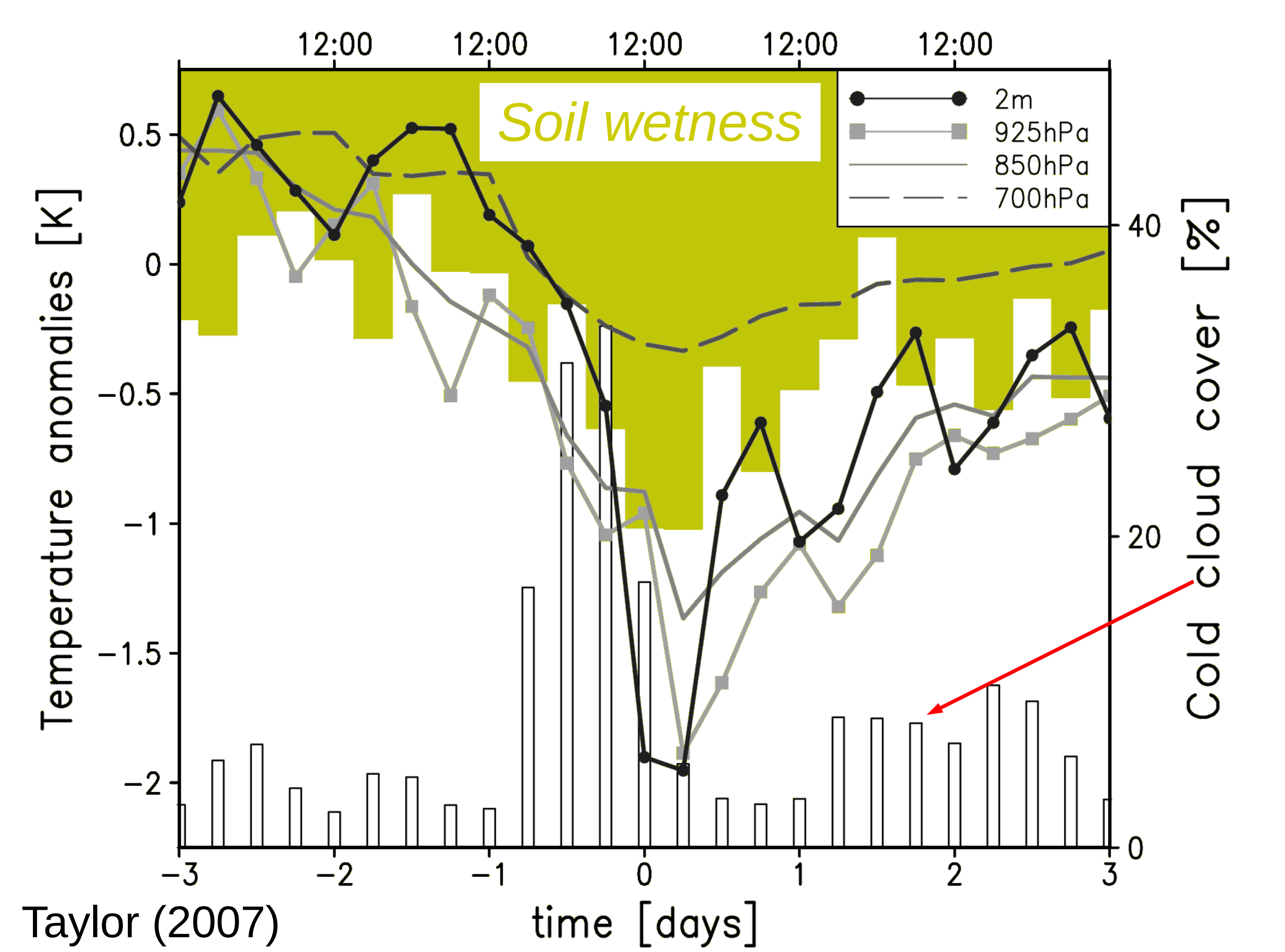


[Taylor et al., 2005]

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 high cloud cover events.
- The wet events modify PBL temperatures for 3-4 days.
- The cool high seems to be a robust feature.



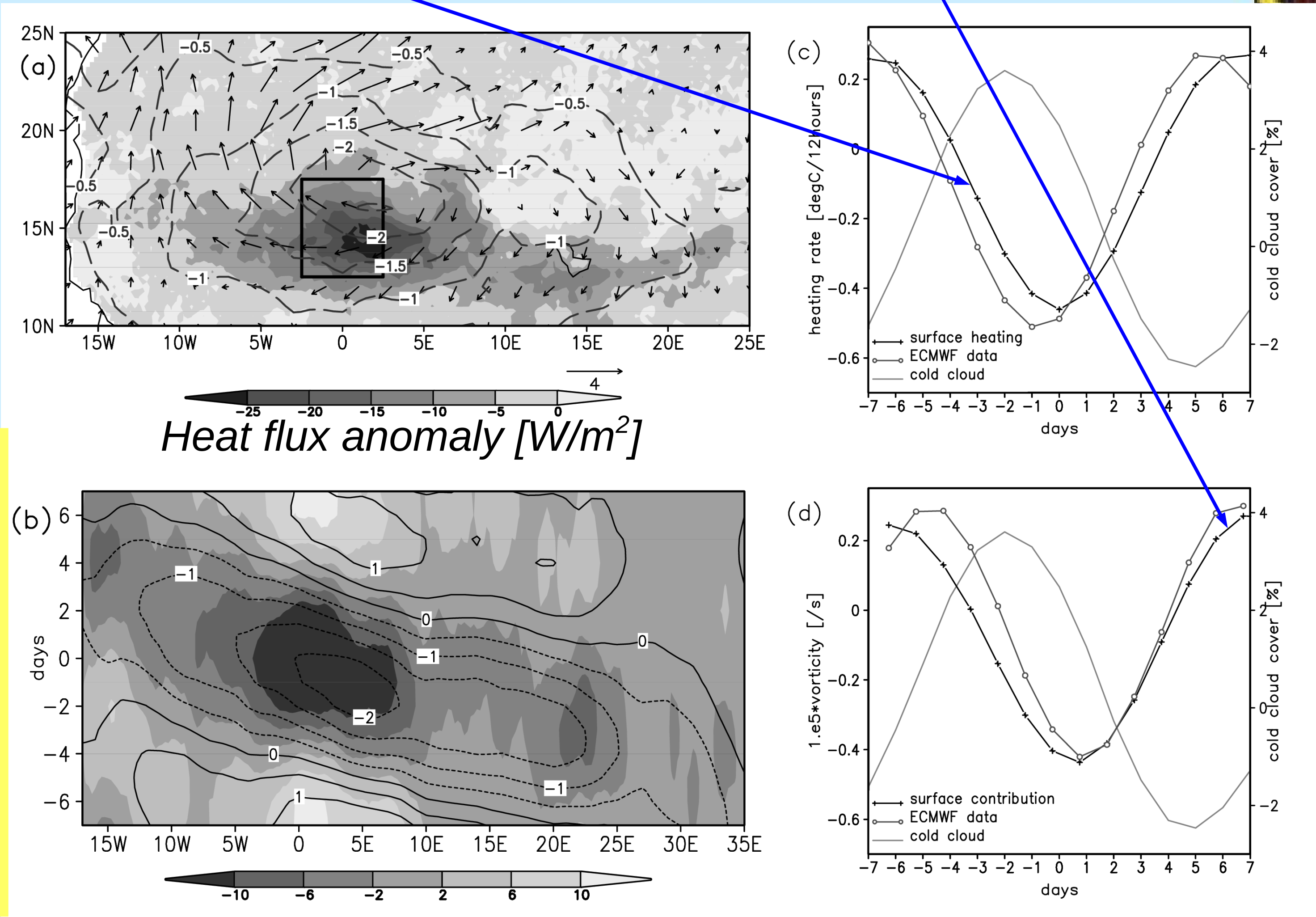
Taylor (2007)

Impact of the cool high on 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.

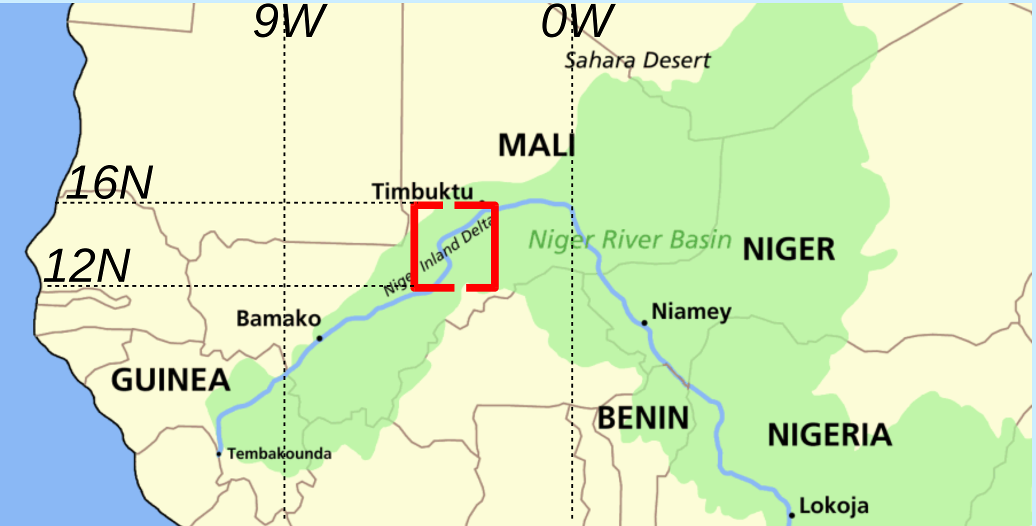
A theoretical model : surface cooling → geostrophic vortex

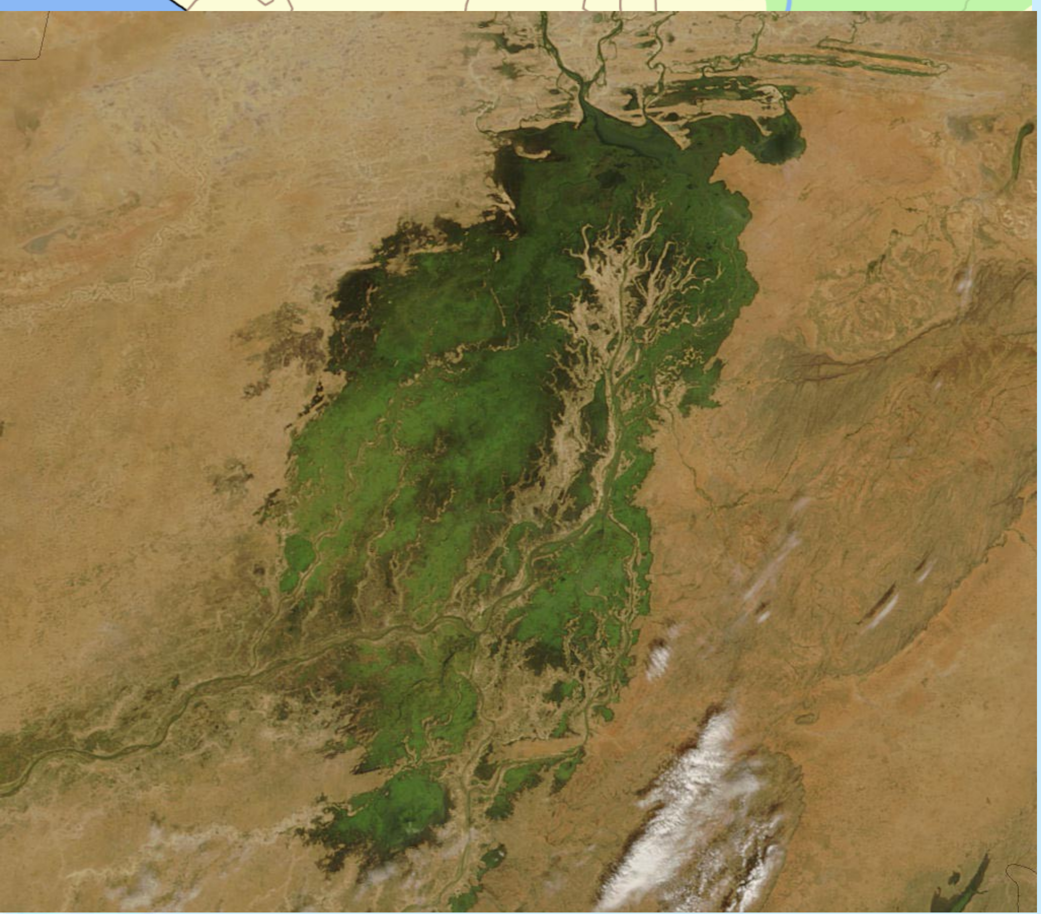
The estimated intensity of the cool high corresponds well to the analysed fields.

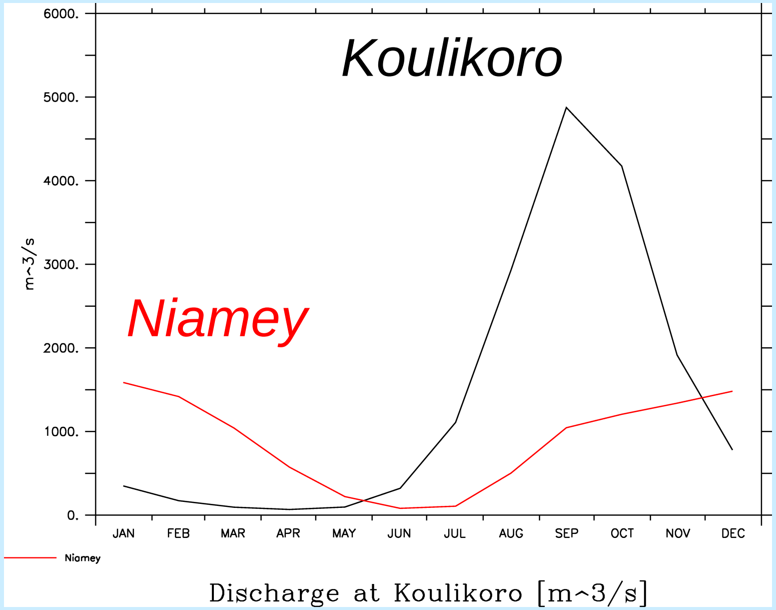


These dynamical structures are similar to those associated with the intra-seasonal fluctuations of rainfall [Janicot and Sultan, 2001]

Regional scale wetness anomalies





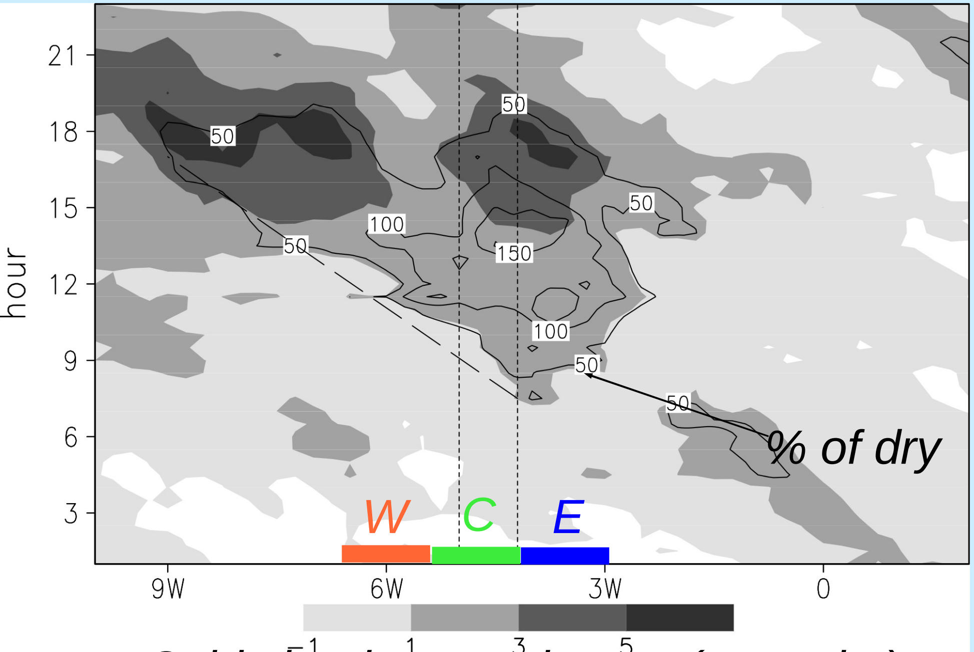


In order to determine the role of the delta in generating rain 24 years of meteosat data (for August and September) were used.

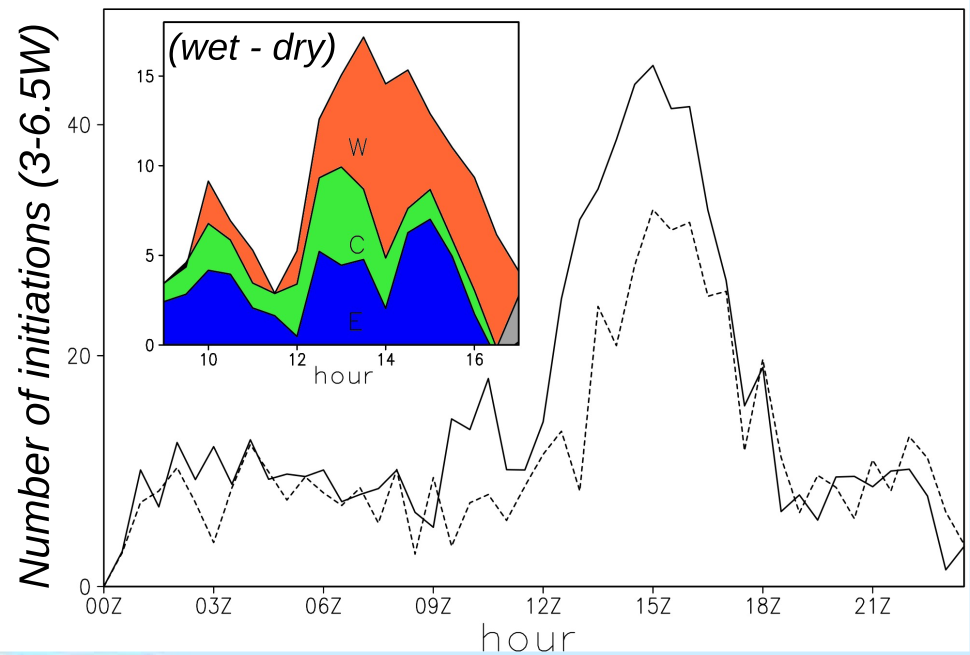
Using the morning warning rates the data was split in years with large and small wetlands (wet/dry years).

[Taylor, 2009]

Initiation of convection in the Niger delta.



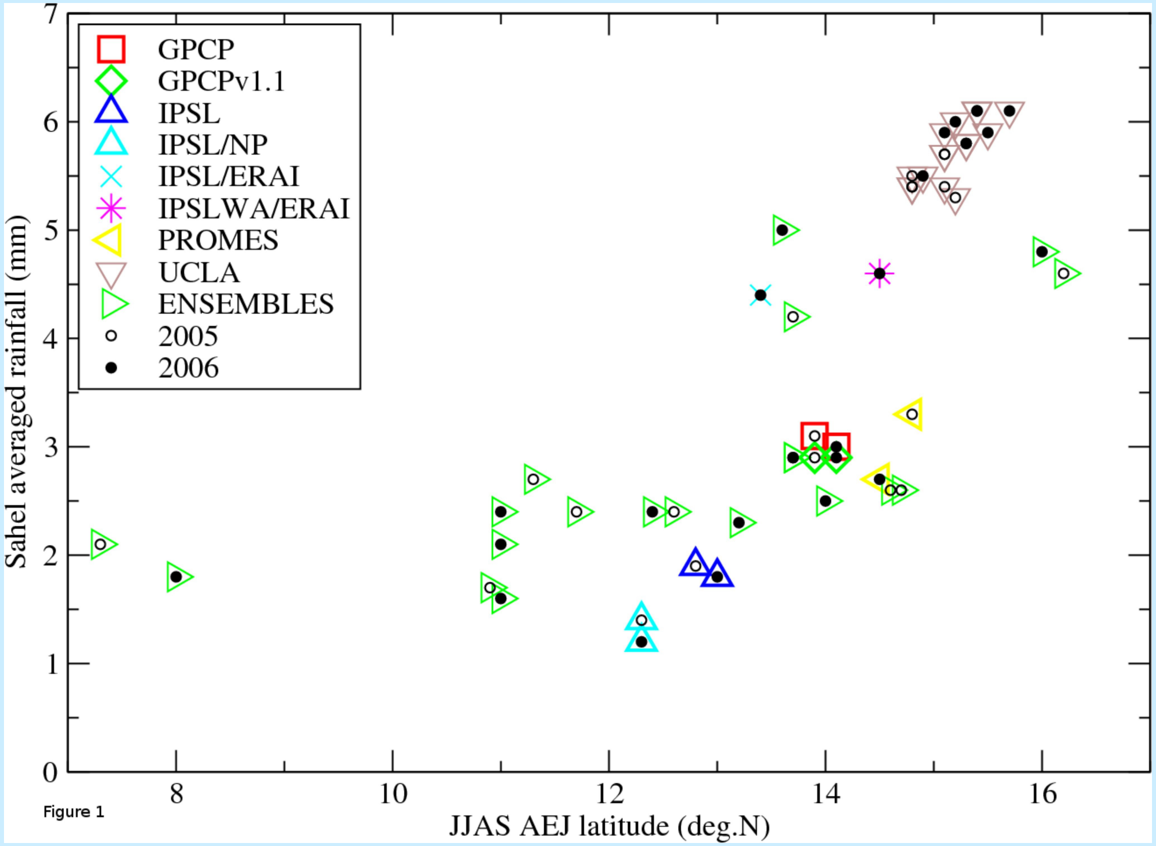
Cold cloud cover change (wet - dry)



- During wet years more cold clouds are observed in the vicinity of the delta.
- The clouds propagate West at 17ms^{-1}.
- The increase in high clouds occur in the afternoon.
- The increase in initiations is maximum to the West of the delta.
- This is consistent with a wetland breeze opposing the background wind (S.W.) and initiating convection.

The inner delta initiates 54% more storms during wet years.

Are models able to exploit this predictability ?



Most model compared in AMMA-MIP were global models, except for :

- PROMES
- ENSEMBLES : RCMs forced by ERA-Interim

- There is an indication that deficiencies in rainfall and dynamics are related.
- All models misrepresent the diurnal cycle of convection.

[Ruti et al., 2010]

Exploiting this predictability is a modeling challenge

- Soil moisture gradients
  - High resolution models are needed.
  - Time constants of bare soil evaporation have to be correct.
  - The phenology of the vegetation needs to be predicted.
- Cool highs
  - The phasing of rainfall and the diurnal cycle is critical for generating the vortex.
- Regional scale land surface anomalies
  - More complete representations of the hydrological cycle are needed.
  - Rivers, lakes, flood plains and irrigated areas need to be able to interact with the atmosphere.

The most immediate challenge for models remains the diurnal cycle of precipitation.

(3-4 hours of strong solar radiation before dusk will erode the surface gradients.)

Conclusions

- A denser radiosounding network increases predictability … but its impact is limited by the systematic biases in models.
- As in most regions where CAPE and CIN are high, the triggering mechanisms are key to predict the initiation of convection.
- A better representation and initialization of land surface are likely to increase predictability in West Africa (spatial structures as well as time scales).
- This would require model improvement in the following areas :
    - A more detailed representation of surface processes and their diversity : phenology, full hydrological cycle.
    - A higher resolution.
    - Diurnal cycle of convection.