Overview of current developments in land surface modeling

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Why do land surface processes matter for environmental forecasting ?

People live on land and thus :

- Modify the land-surface properties and processes,
- They are directly affected by weather/climate processes near the surface.

Land surface and climate processes are not independent and thus need to be considered together. All 3 major cycles need to be represented :

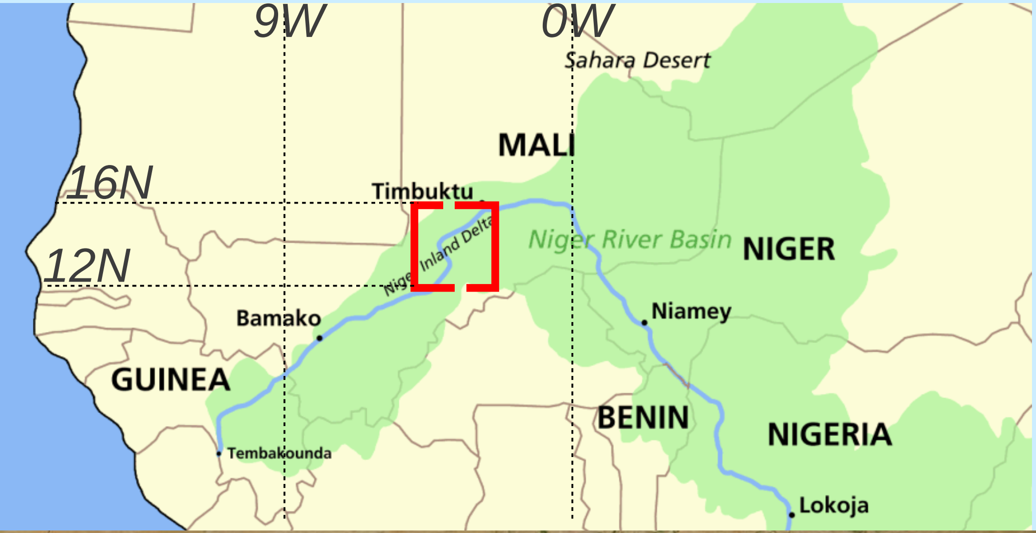
- The water and energy cycles
- The carbon cycle
- The chemical cycles

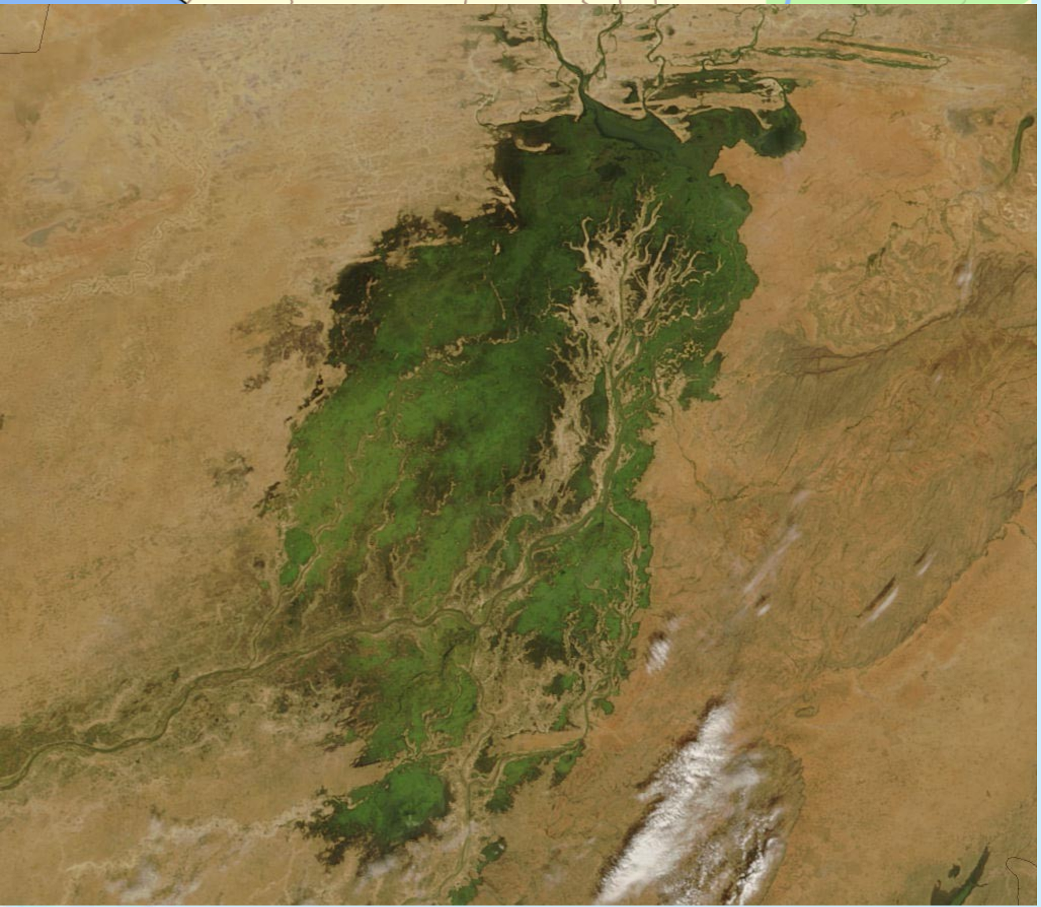
Contrary to the atmosphere or the oceans, on the continents these 3 cycles are tightly coupled and affected by human activities.

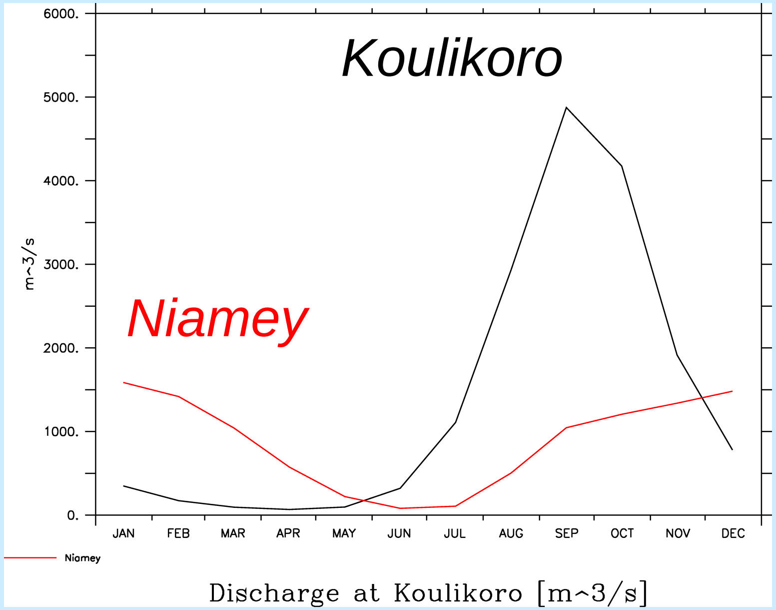
Outline

- Current status of our knowledge on surface/atmosphere coupling.
- Climate determines to a large extent the state of the surface.
- Impact of human activities on the continental water cycle.
- Representing the carbon cycle and the control exerted by humans.
- Extending models to other components of the biogeochemical cycles.
- Some more philosophical considerations on land surface model developments.

Regional scale wetness anomalies





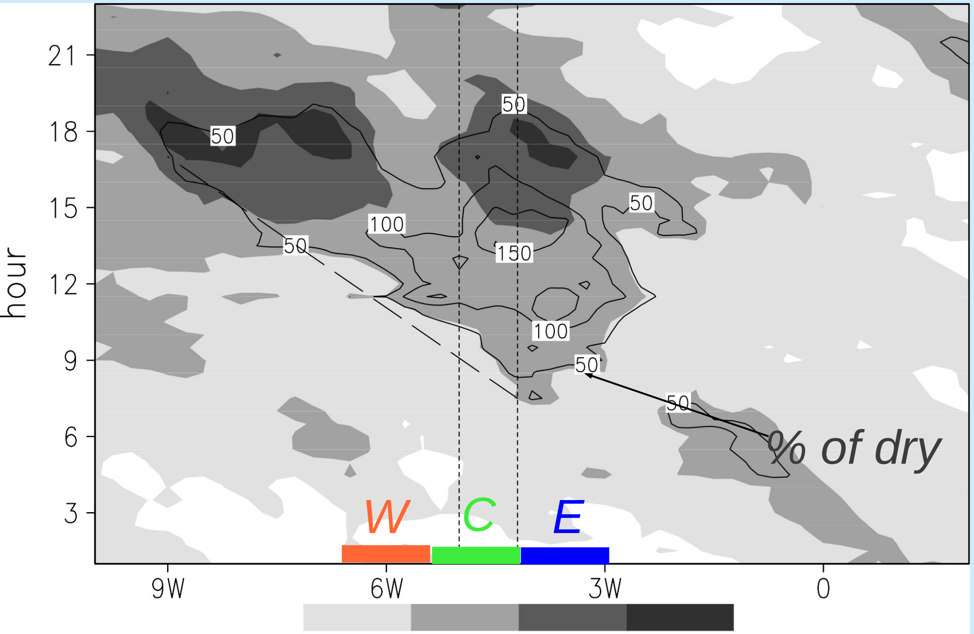


In order to determine the role of the delta in generating rain 24 years of meteosat data (for August and September) were used.

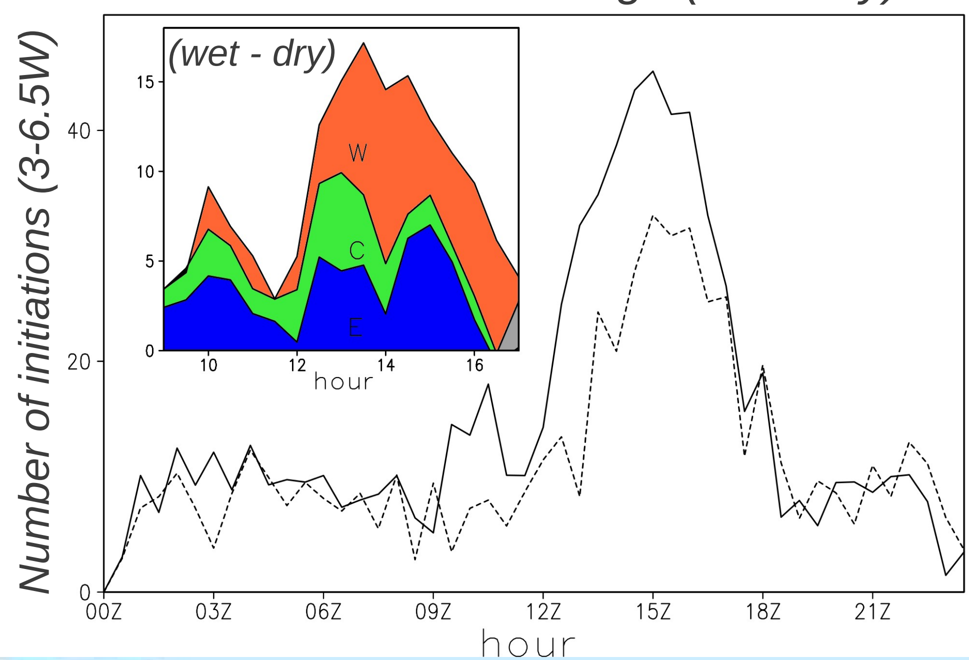
Using the morning warming rates the data was split in years with large and small wetlands (wet/dry years).

[Taylor, 2009]

Initiation of convection in the Niger delta.



Cold cloud cover change (wet - dry)

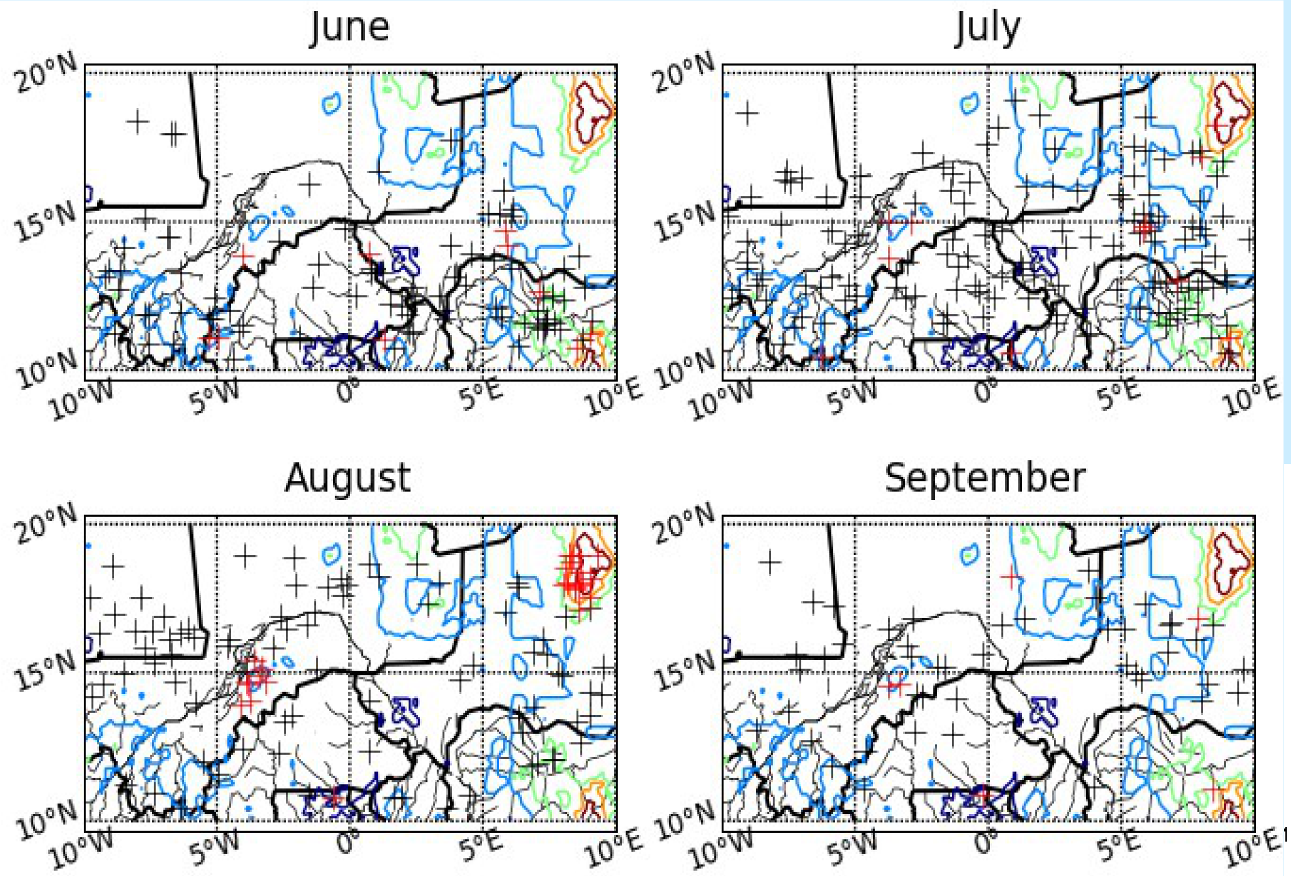


- During wet years more cold clouds are observed in the vicinity of the delta.
- The clouds propagate West at 17ms^{-1}.
- The increase in high clouds occur in the afternoon.
- The increase in initiations is maximum to the West of the delta.
- This is consistent with a wetland breeze opposing the background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

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

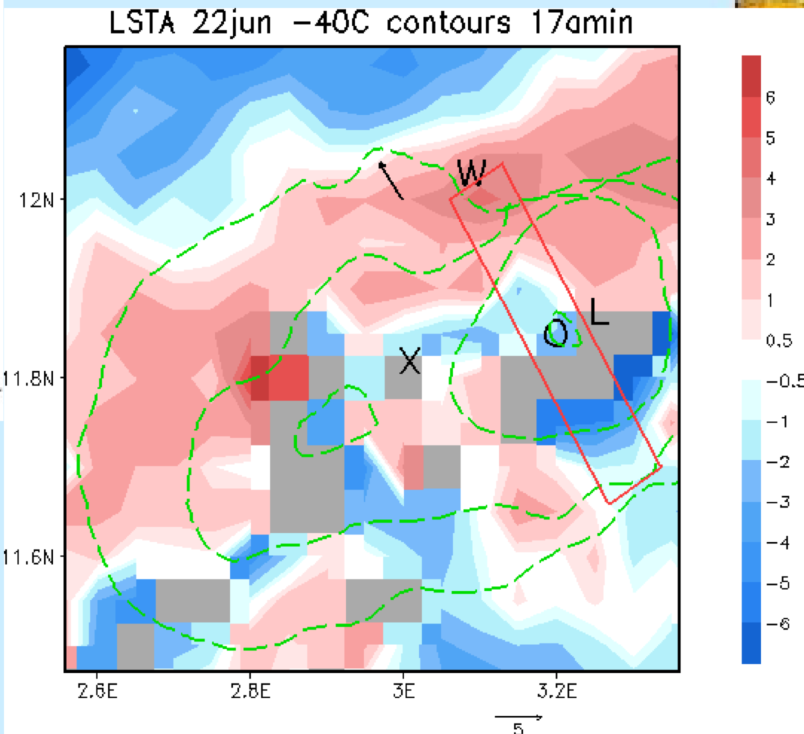
Initiation of convection during 2006

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.)

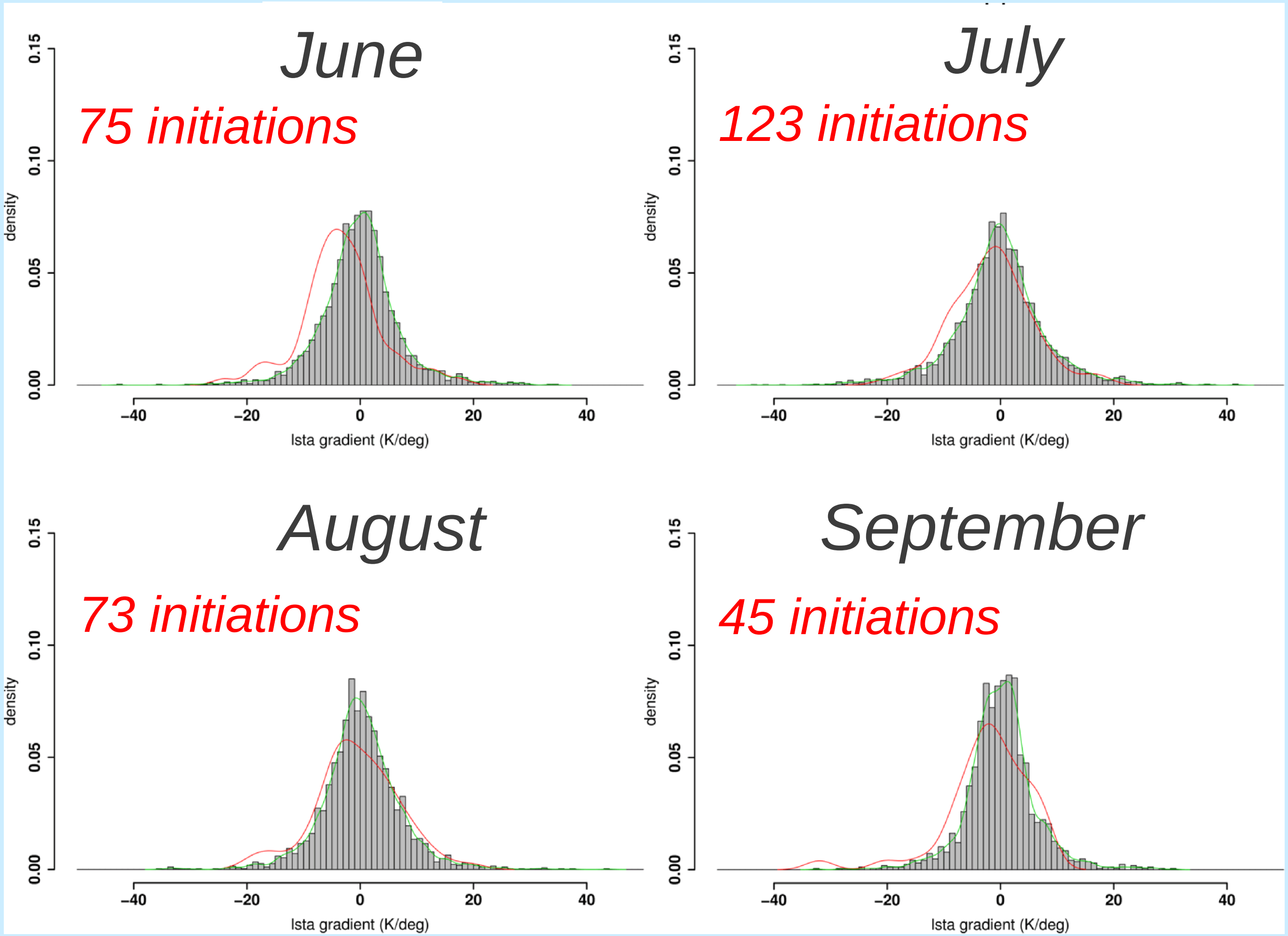
Taylor et al. 2011



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.



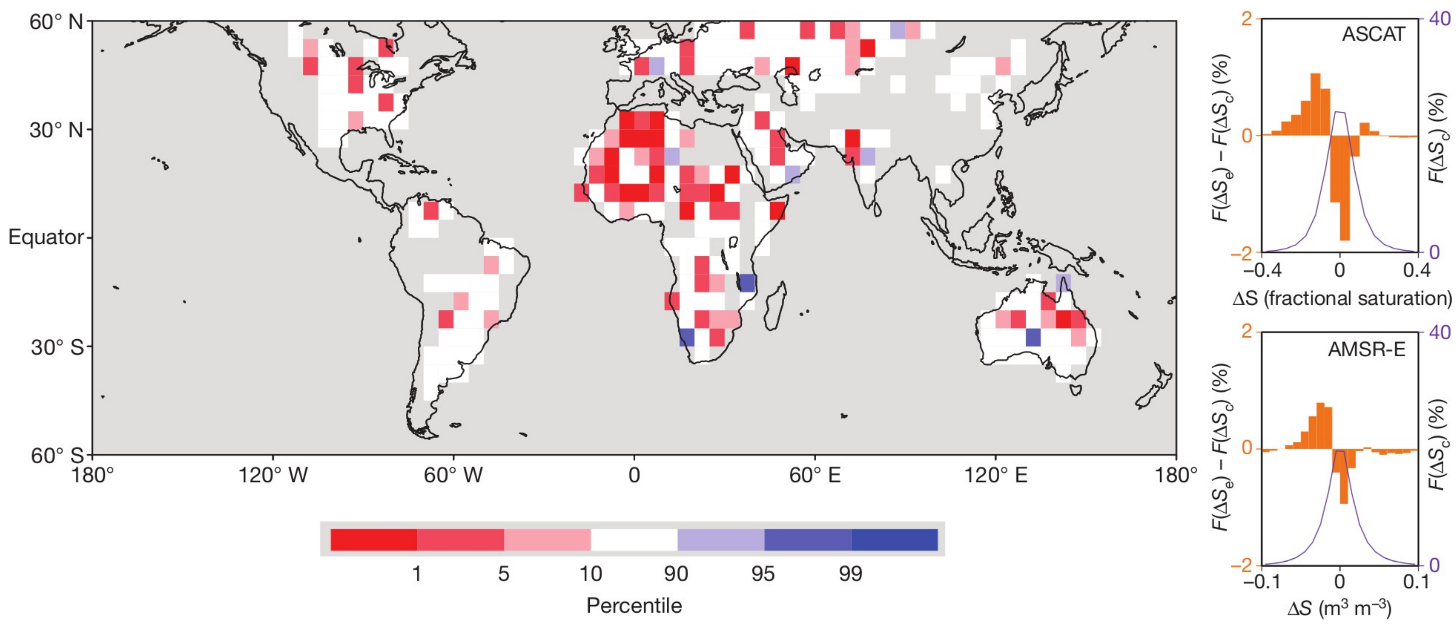
Maximum initiation when :

- 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.

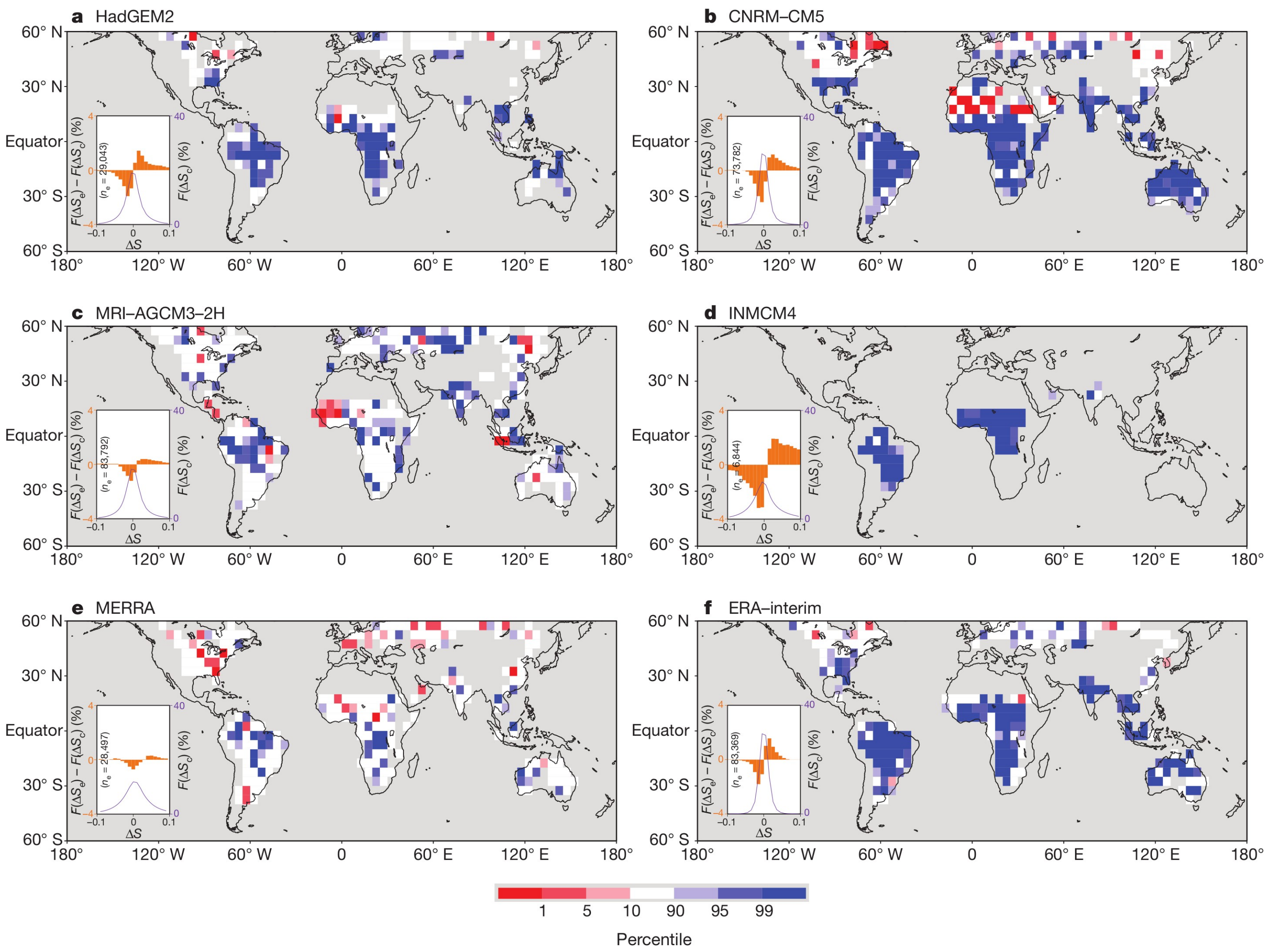
Generalization to afternoon rains

• Once an afternoon rain event is detected on a 0.25°x0.25° grid box, the non precipitating adjacent region is identified.
• The gradient of preceding soil moisture between these 2 regions is computed (Δse)
•This gradient is compared to a control sample of gradients (Δsc)



Taylor et al. 2012

How do GCMs locate the afternoon rain ?



The same methodology is applied to 3h output of GCMs and the ERA-Int re-analysis.

Most models favour daytime rainfall over the wetter areas. This is a fundamental flaw in the sensitivity of the models to surface processes.

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Water and Global Change

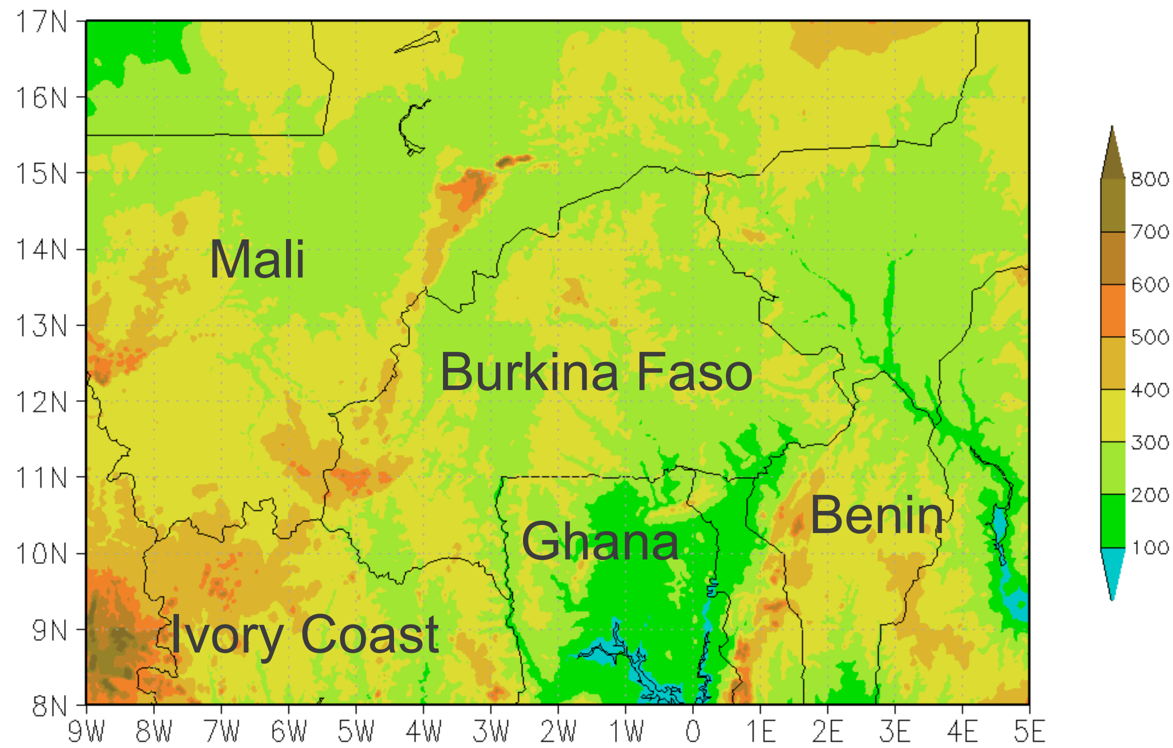
Some models do show some sensitivity to soil moisture gradients

Model setup:

- COSMO model 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:

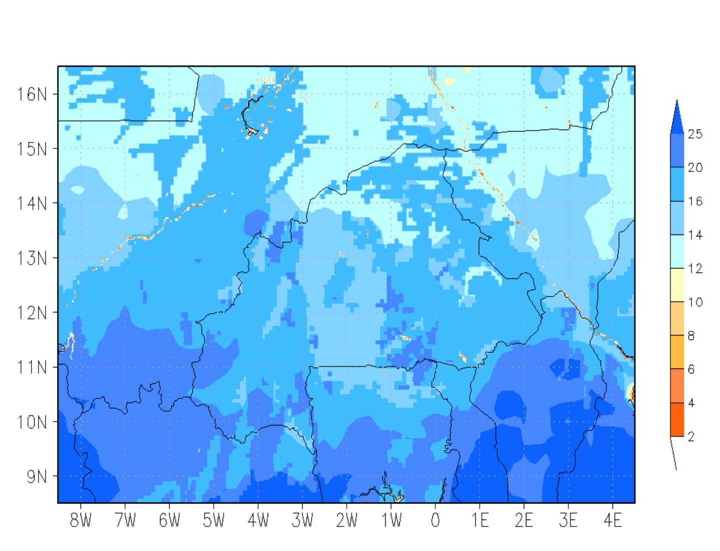
- Operational analyses from ECMWF
- Initiated on 11 June 2006 at 00 UTC



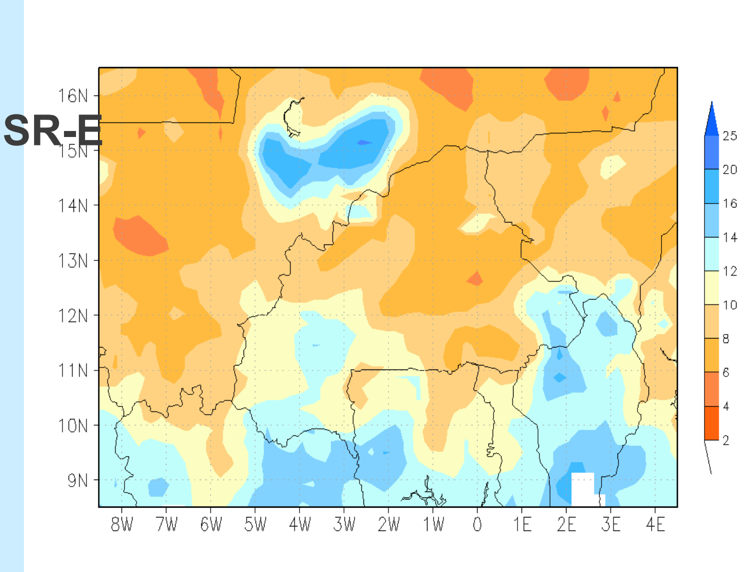
[Gantner & Kalthoff, 2010, Adler et al., 2011]

Soil moisture conditions for model initialisation

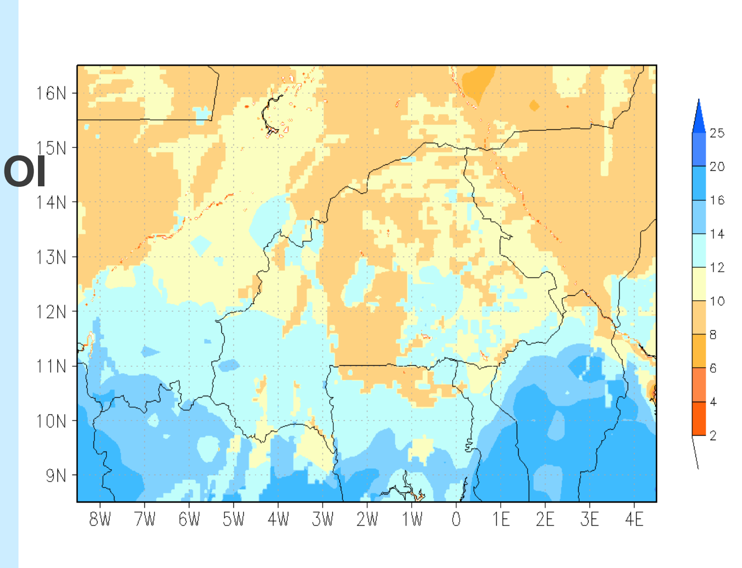
MOI



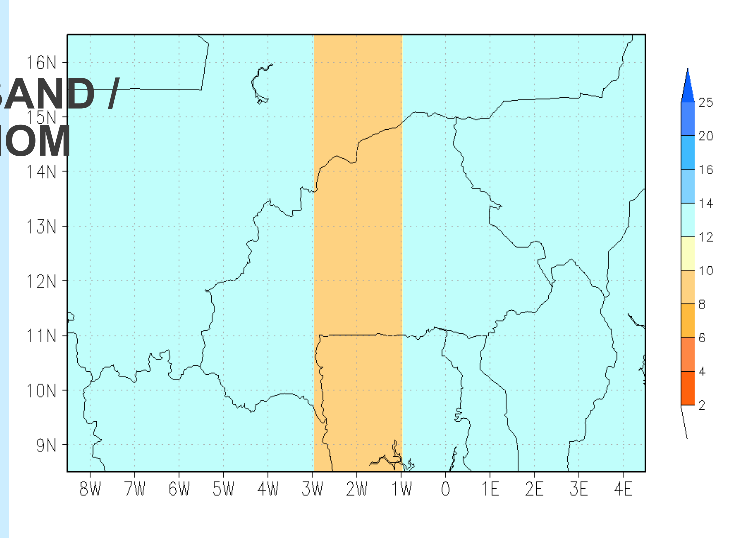
AMSR-E



CTRL
65% of MOI

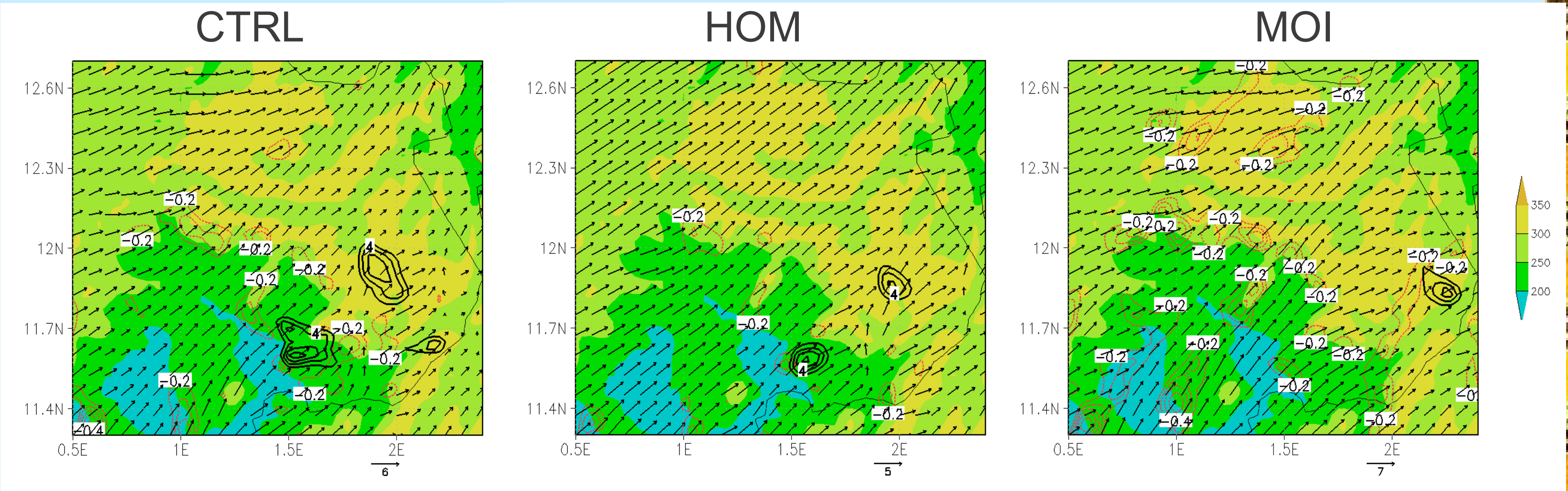


BAND / HOM



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.***

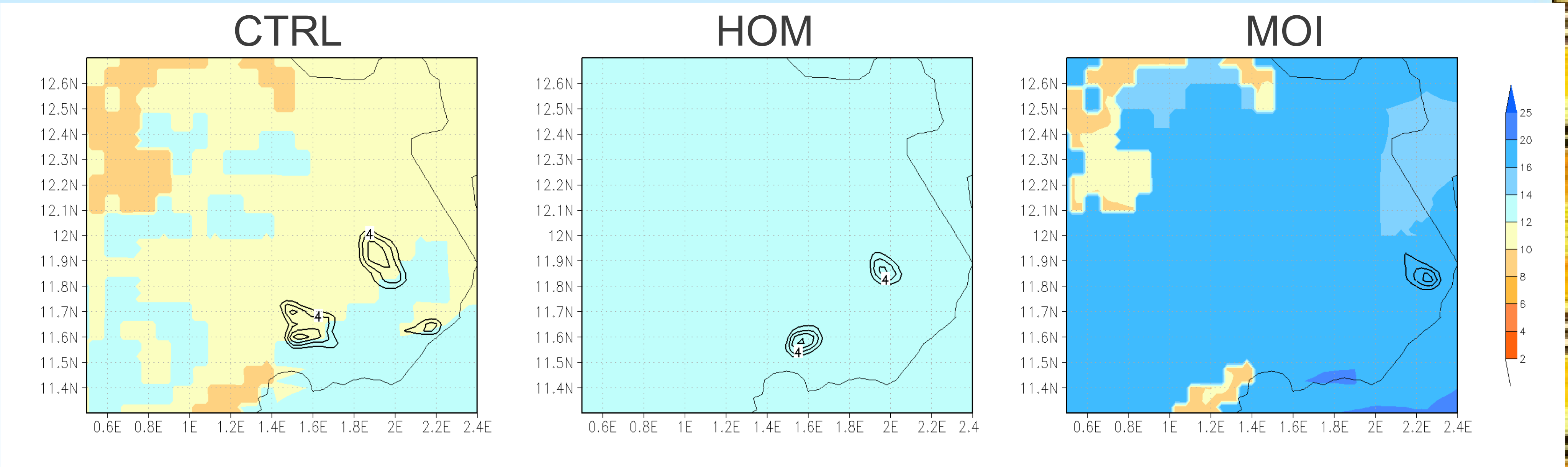
Model results: initiation of convection



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.

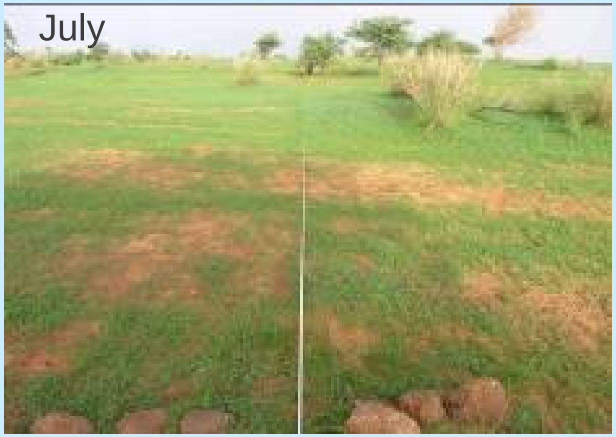
What to conclude from our poor knowledge on surface/atmosphere interactions ?

The large uncertainty about process governing surface/atmosphere interactions should not affect our ambitions for Land Surface Model (LSM) development.

The LSMs also play other roles in climate/weather models :

- Monitor and predict the continental water cycle and its extremes (droughts and floods)
- Monitor and predict vegetation states.
- Monitor and predict the evolution of carbon sources and sinks
- Monitor and predict chemical concentrations and air quality.

Climate also determines the state of the surface



- As the weather changes with seasons so does the state of the surface.
- This modifies land surface processes.
- Climate anomalies produce variations in surface characteristics.

In the Sahel :

- 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.

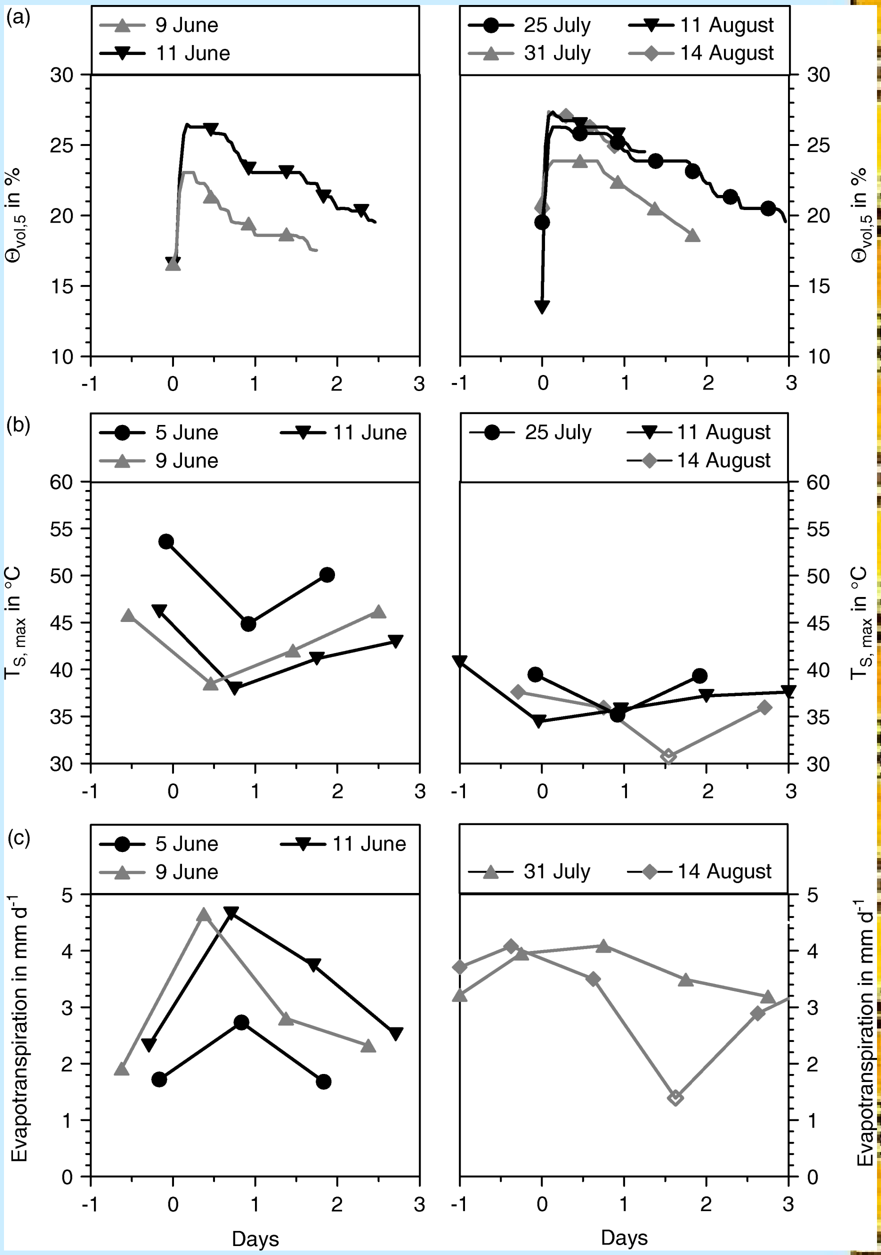
Impact on the surface fluxes

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.

How far can these evolutions of the surface processes be taken into account without a Dynamic Global Vegetation Model (DVGM) ?

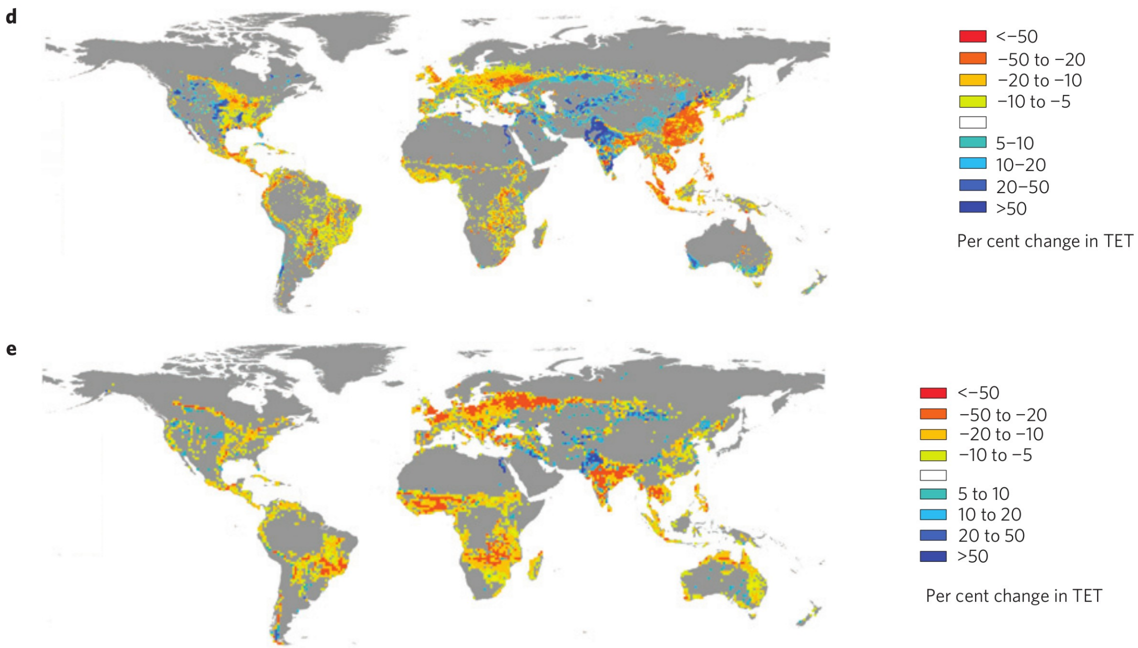
This goes hand in hand with a representation of the CO_2 cycle.



[Schwendike et al., 2010]

The impact of human activities on surface process

GIS methodology



Land surface model

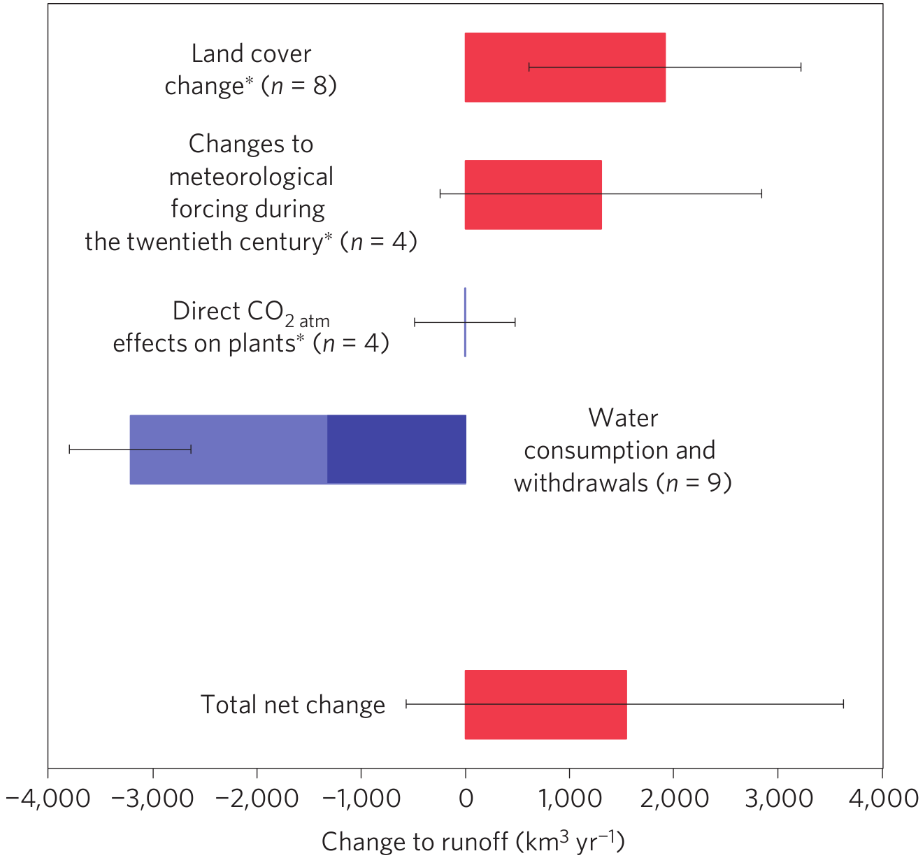
The impact of anthropogenic land cover changes on evaporation can be evaluated by comparing it to what a potential vegetation would have evaporated.

- Databases of evaporation measurement over different biomes and climates can be re-assembled.
- Or the land cover change is imposed on a LSM.

It is consistently found that land cover change has reduced ET by about 5%.

Sterling et al. 2012

How do human activities affect the runoff from continents ?

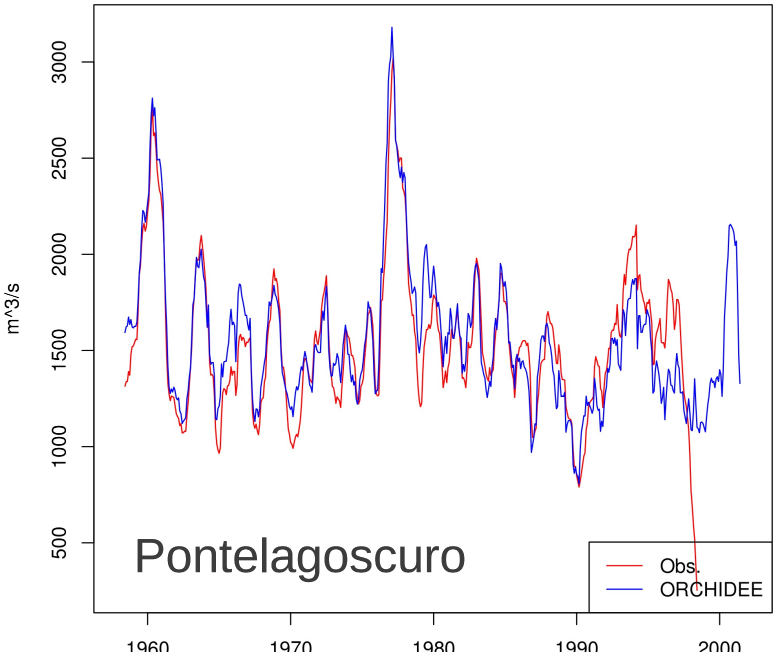


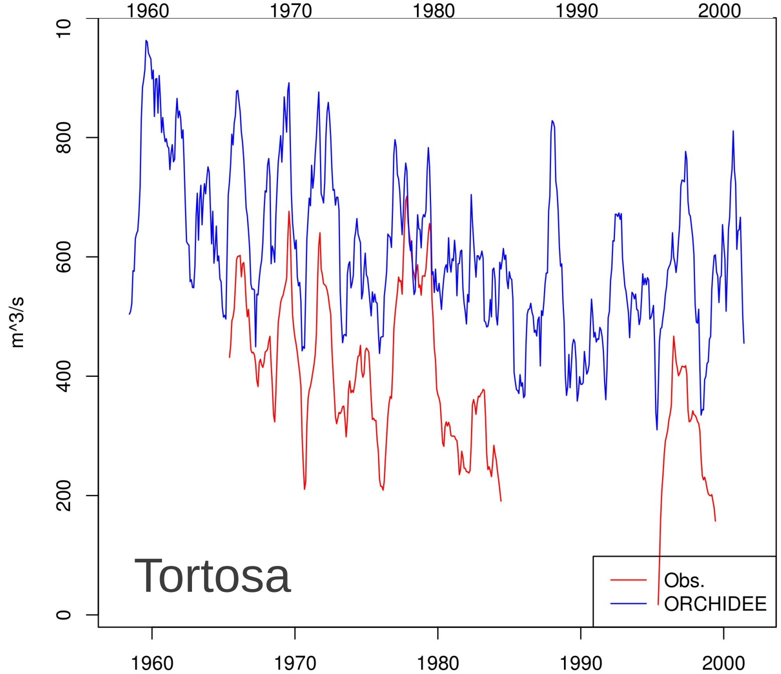
Sterling et al. 2012

Reviewing various studies an evaluation is given of the most likely impact of human activities on discharge from continents. Land cover change tends to increase river discharge.
Water consumption does not compensate.

These studies are limited to the sustainable water cycle, i.e. without considering water mining !

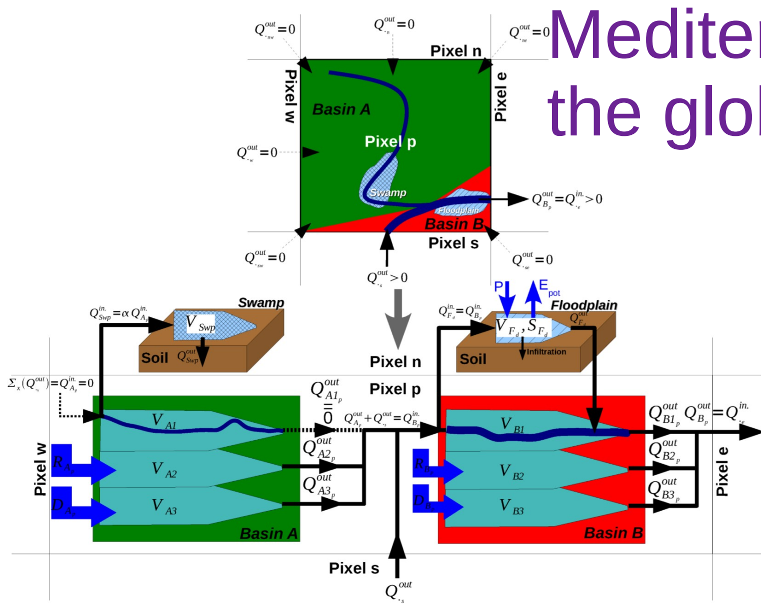
River discharge is altered by human activities



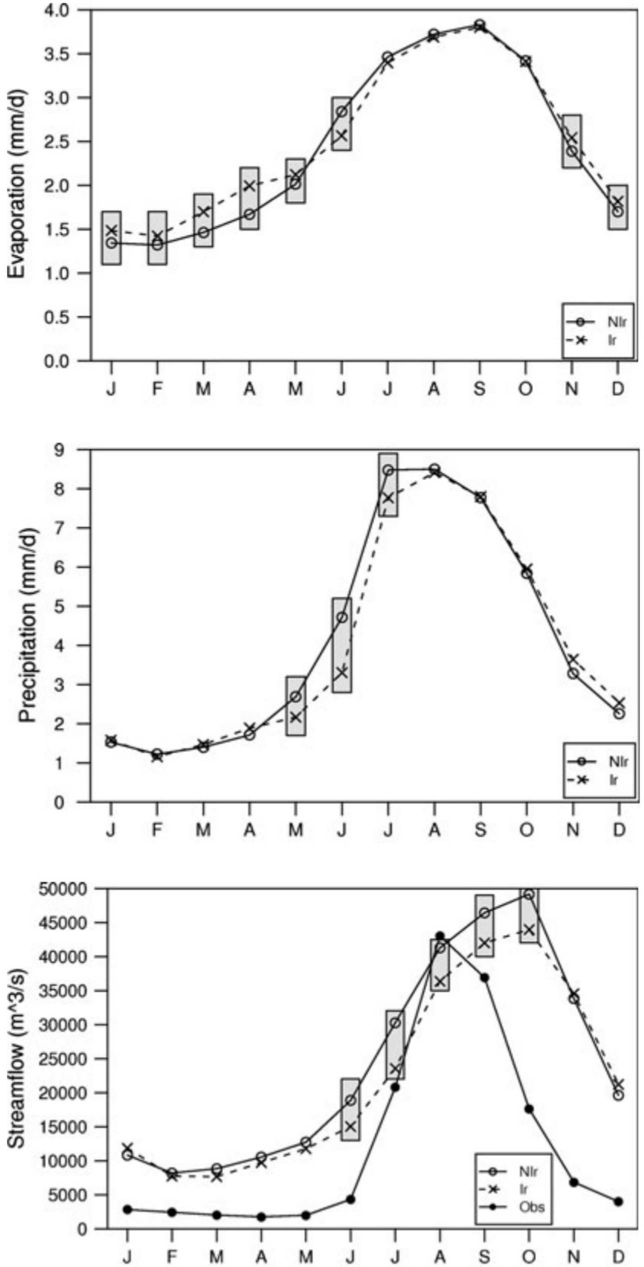


- This model represents well the inter-annual variability of the discharge of the Po at Pontelagoscuro.
- On the other hand it is unable to reproduce the trend in the Ebro at Tortosa.

What is the impact of human activities on the Mediterranean sea or the global sea level ?



The impact of irrigation on the regional water cycle



Integrating irrigation into the LSM allows to evaluate its impact on the water cycle.

The region considered here is the Indian Peninsula :

- Irrigation increases evaporation during the dry season.
- The GCM predicts a delayed onset of the monsoon. This is seen in the rainfall as well as the dynamic fields.
- The discharge of the Ganges-Brahmaputra is reduced by a combined effect of water abstraction and delayed onset of the monsoon.

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Guimberteau et al. 2012

Water impoundments by reservoirs and groundwater usage

The global water cycle cannot be simulated without considering man-made storage of water in reservoirs and the pumping of ground water.

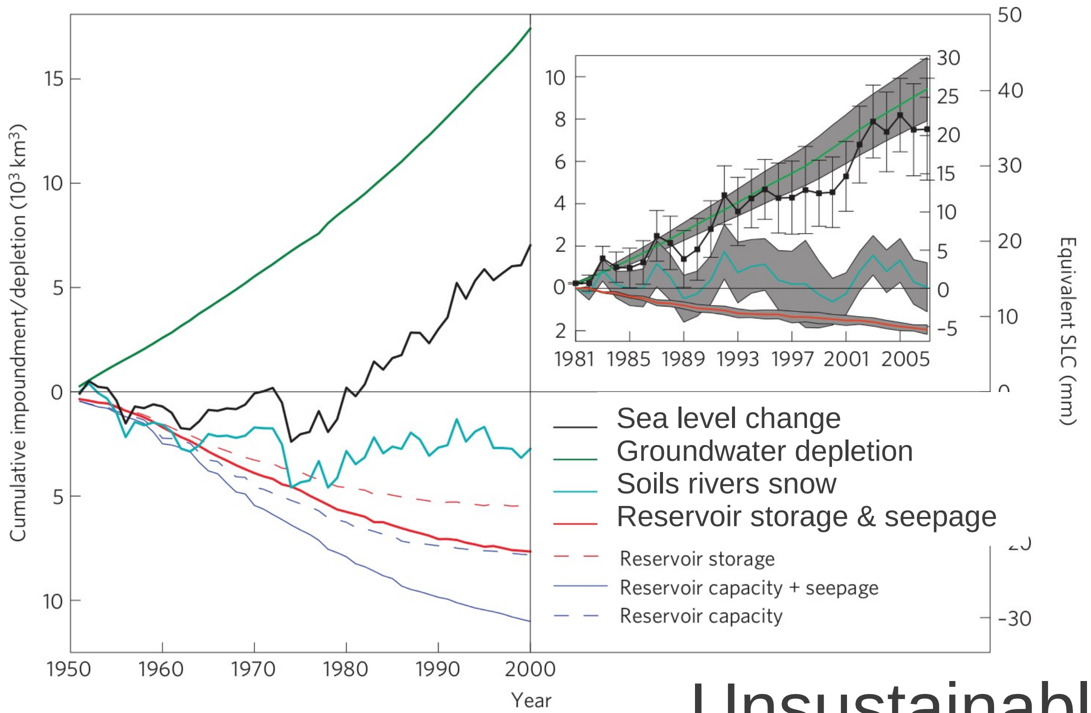
The LSMs need to be extended in order to add reservoirs and groundwater abstraction.

This requires to include in LSMs :

- Regulation mechanisms for reservoirs dedicated to hydro-power
- Regulation of reservoirs used for irrigation
- Seepage from reservoirs and sedimentation
- Groundwater usage estimations based on demand

Hypatia Nassopoulos et al. 2012

Estimating sea-level changes due to human intervention



Pokhrel et al. 2012

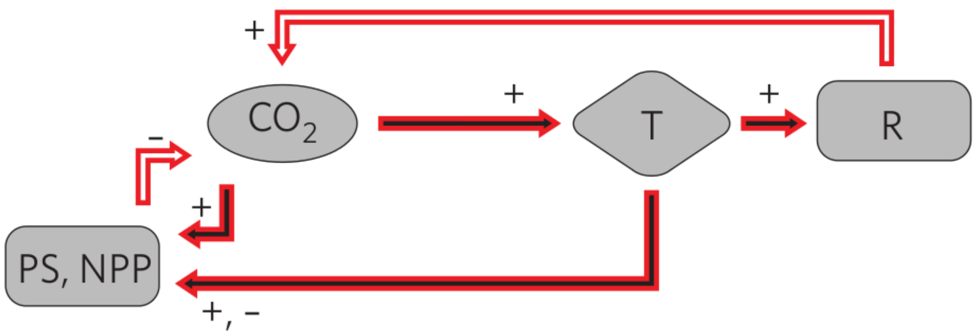
Thermal expansion and melting ice caps explain a large part of the sea level rise. Out of the observed 1.8 mm/y, 0.7 mm/y are still unexplained !

Unsustainable groundwater usage has been increasing. It dominates the other humans impact on the continental water balance.

This LSM attributes 0.77 mm/y of sea level change to the continental water cycle as modified by humans.

Modeling the carbon cycle

- The carbon cycle is a key element of climate change and the continents is one of its main sinks.
- Because of efforts to regulate carbon emissions quantifying sources and sinks has become a major endeavor.
- Processes driving the CO2 uptake by vegetation are small scale in nature.



R : Respiration
PS : Photosynthesis
NPP : Net primary productivity

Net Ecosystem Productivity : NEP = NPP - R

Humans also control the evolution of the vegetation

The usage and control humans exerts on ecosystems modifies the capacity of plants to accumulate [CO_2] :

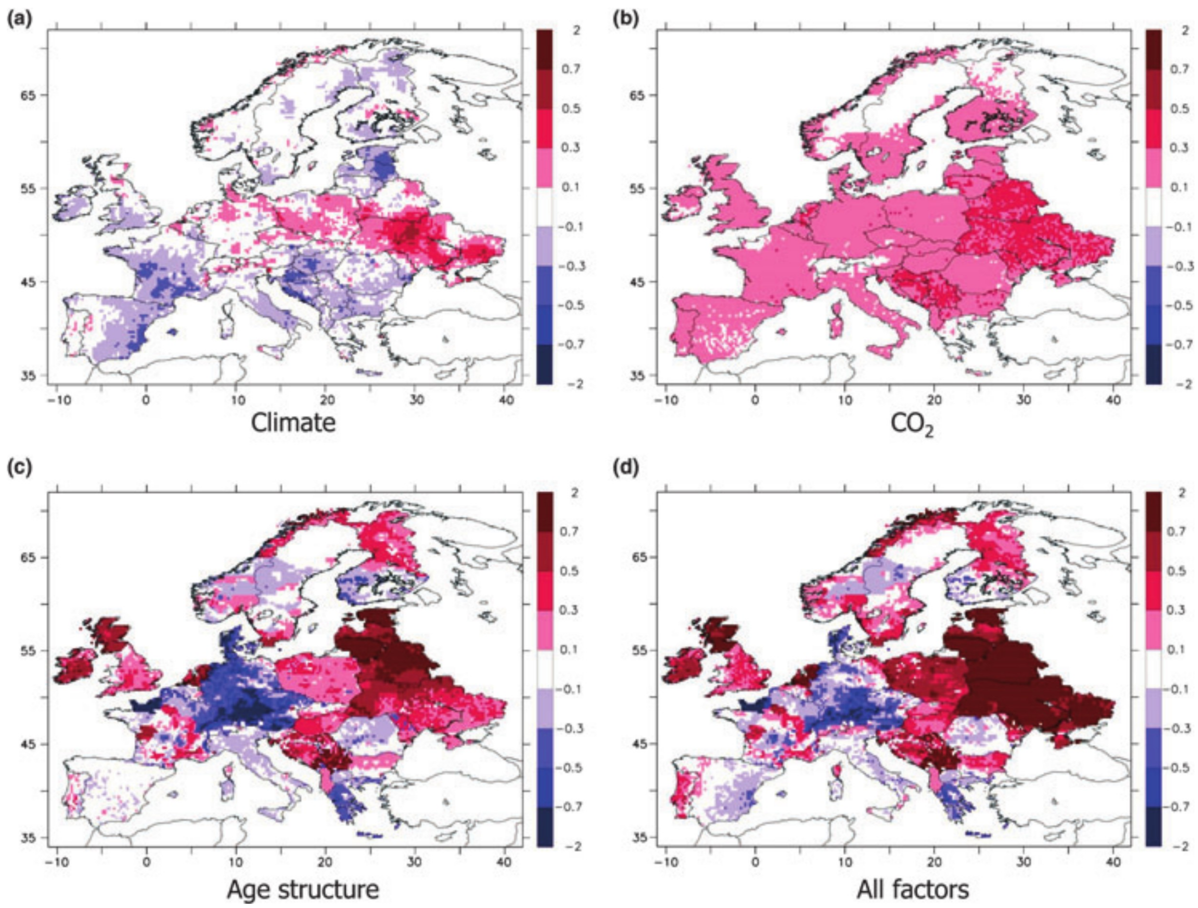
- Deforestation
- Agriculture
- Forest management
- Modification of wetlands.

Quantifying the evolution of the continental carbon sink needs to take into account these processes.

LSMs thus require some form of representation of :

- Land use and land cover changes
- Crops
- Forest management

The evolution of the carbon sink in European forests



A LSM is used to estimate the role of various processes in the CO2 storage of forests over the 1950-2000 period.
A major challenge for a forest management module is the ageing of the forests.

Contributions to NEP

The model estimates that forest management is the dominating factor in determining the sign of NEP.

Bellassen et al. 2011

Introducing the nitrogen and methane cycles

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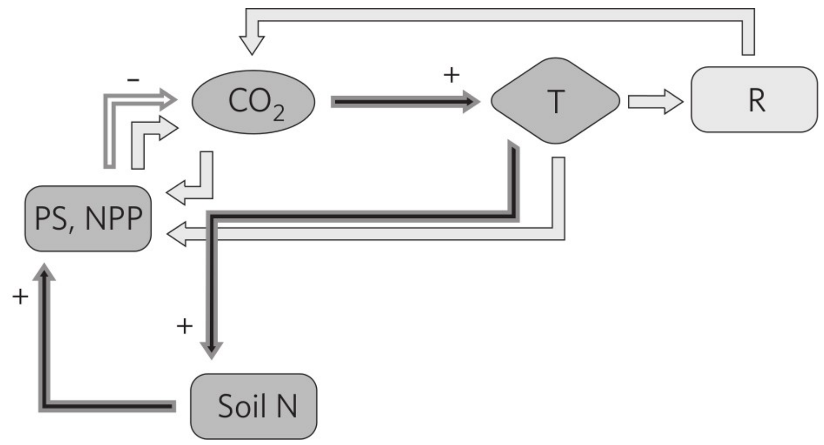
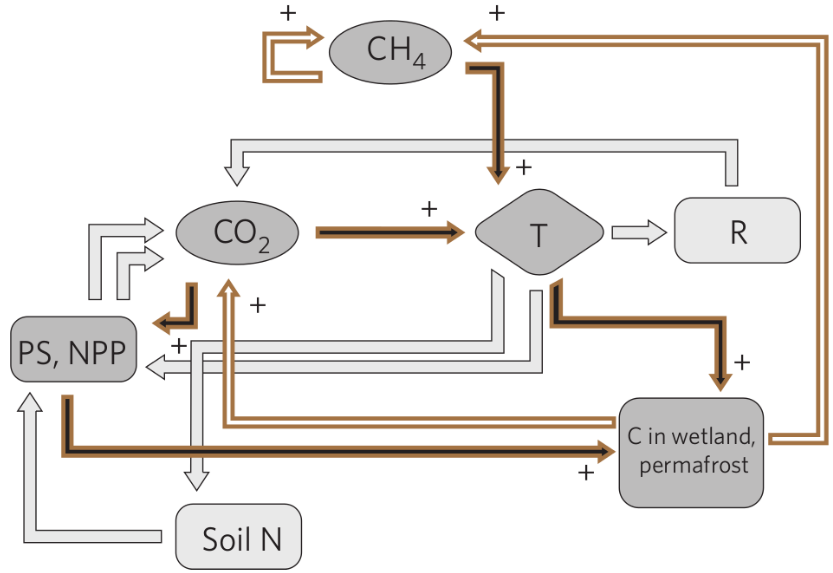


Nitrogen is an essential element for photosynthesis and plant growth.
Global warming could increase its availability

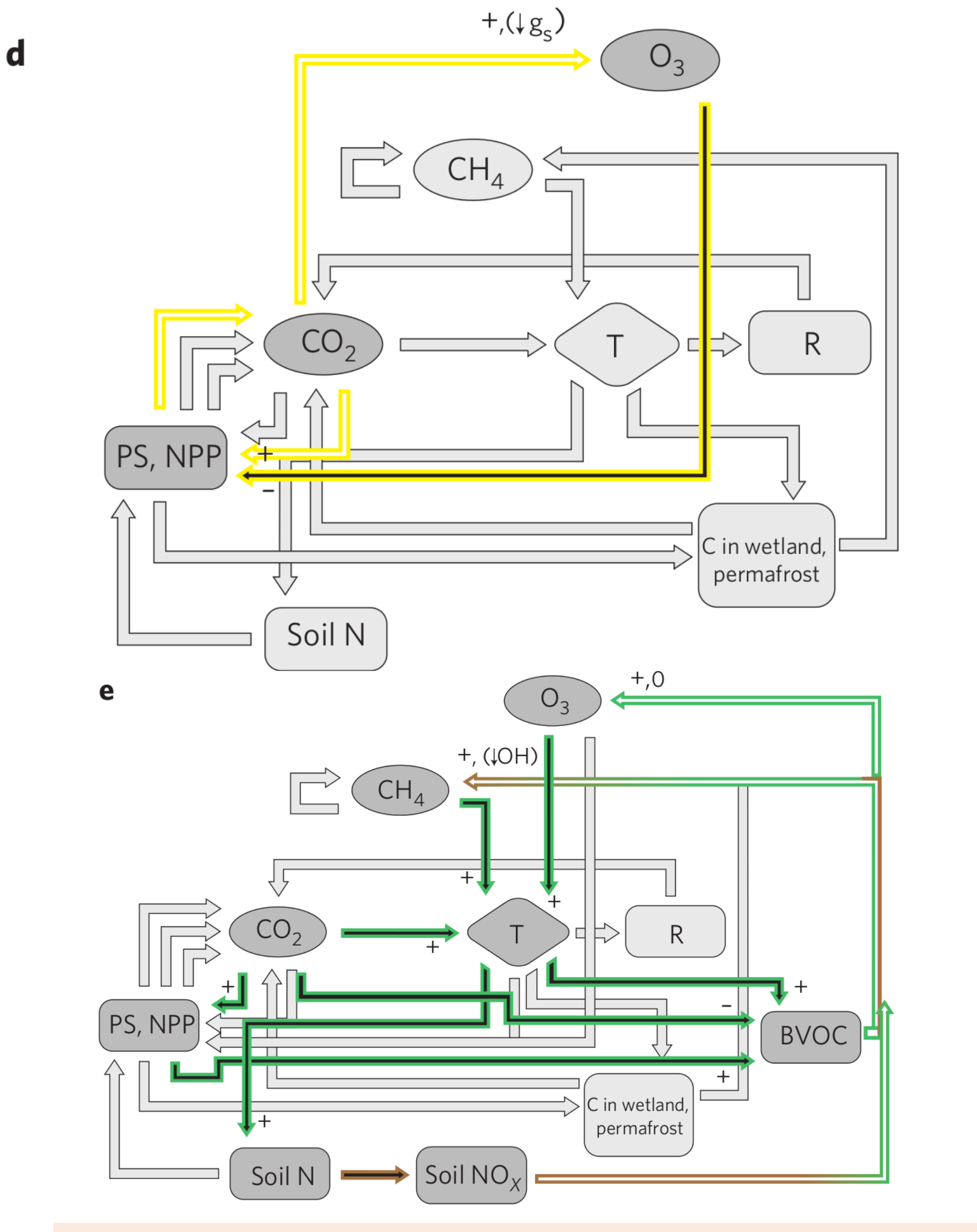
c



Arneth et al. 2010

Warmer temperatures will enhance methane release from wetlands.
Thawing of permafrost will liberate stored CO_2 and CH_4.
More rain and flooding could mitigate the effect.

Ozone and volatile organic compounds



- Air pollution produces tropospheric ozone which is toxic for plants.
- It is estimated to reduce transpiration by 3 to 16%
- Plants are also emitters of volatile organic compounds (isoprene !)
- Thus vegetation processes are key in air quality monitoring and prediction.

… and then we have biogenic aerosols.

On the conceptual nature of LSMs

We dot not have the luxury of having a closed theory for describing continental processes. Thus concepts from various research fields are integrated in LSMs. These concepts are not always compatible.

Potential evaporation :

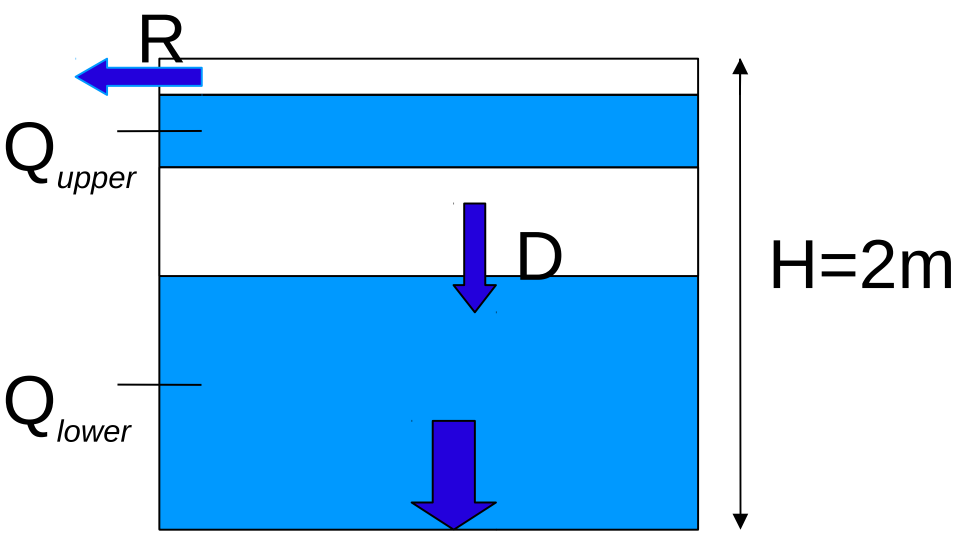
- Fick's law of diffusion : originates in the turbulence community.
- Penman-Monteith originates in the ecophysiology community.

Vegetation classes can be defined differently :

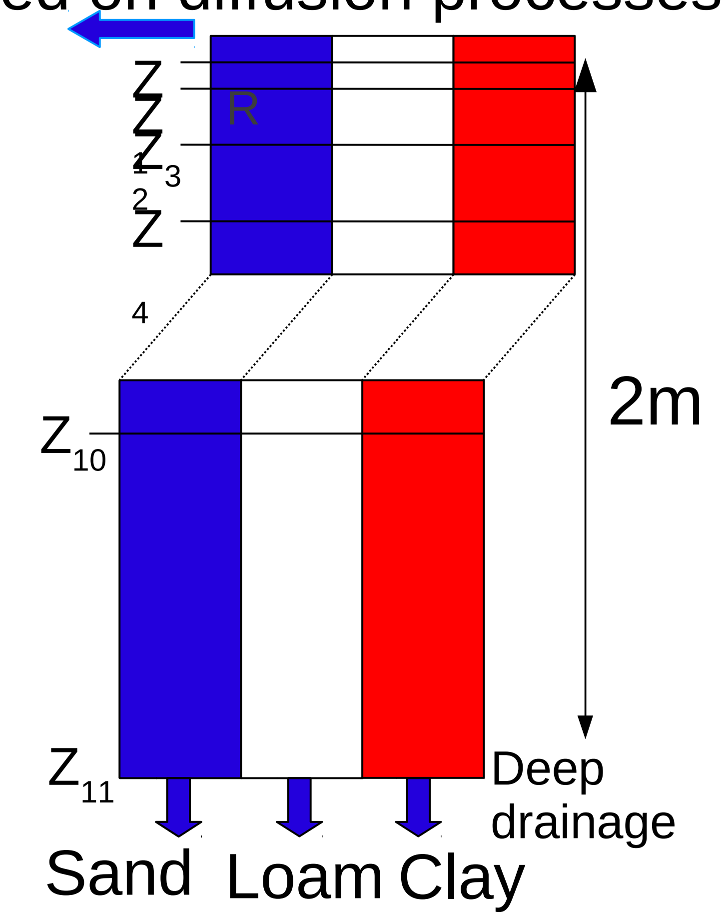
- Biomes or ecological units (geography)
- Plant functional types based on physiological and phenological criteria.

Soil moisture : another conceptual variable

Simple 2 layer scheme



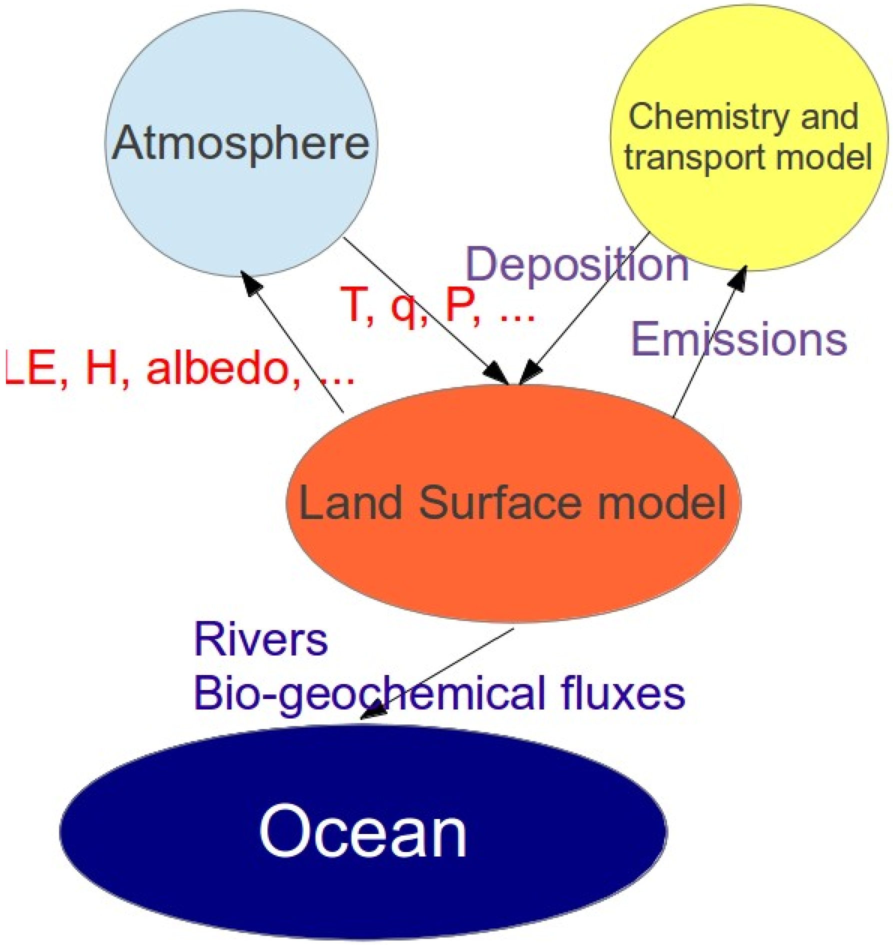
Based on diffusion processes



These choices determine the parametrisation of :

- Soil moisture stress
- Bare soil evaporation and infiltration
- Freezing and soil respiration
- ...

Coupling LSMs with the other components



LSMs interact with all other components of Earth System models !

Off-line simulations are needed for the evaluation but also offer space for rich studies.

Implementation of the LSM as a "subroutine" of the GCM/RCM is not practical anymore.

Coupling software is already in use for atmosphere/ocean exchanges.

OASIS has made progress in the past year and might be a good candidate for managing the LSM coupling.

Conclusion

- Land surface models have become truly multidisciplinary tools. Their development require teams with very diverse competences.
- Their applications are multiple from the local to the global scales. But their development is always based on small scale observations.
- They have to take into account the human impact on the natural systems. We need to know how our environmental footprint interacts with weather events and climate change.
- LSMs will help us better manage our impact on the environment !
- Data assimilation in LSMs will be a major challenge as the sources of observations are diverse and often only indirectly related to the processes.

What if surface gradients are key for the surface/atmosphere interactions ?

How have humans influenced rain generating systems :

- Water reservoirs, river regulation and ground water usage.
- Agricultural practices modifying surface properties
- Irrigated area
- Landscape modifications with contrasts between preserved forests and agricultural areas ?

All these activities will determine the way the surface responds to rainfall events and imprints heterogeneities on the surface fluxes and the atmosphere.

Do these gradients offer some predictability potential ? … in which regions and for which seasons ?