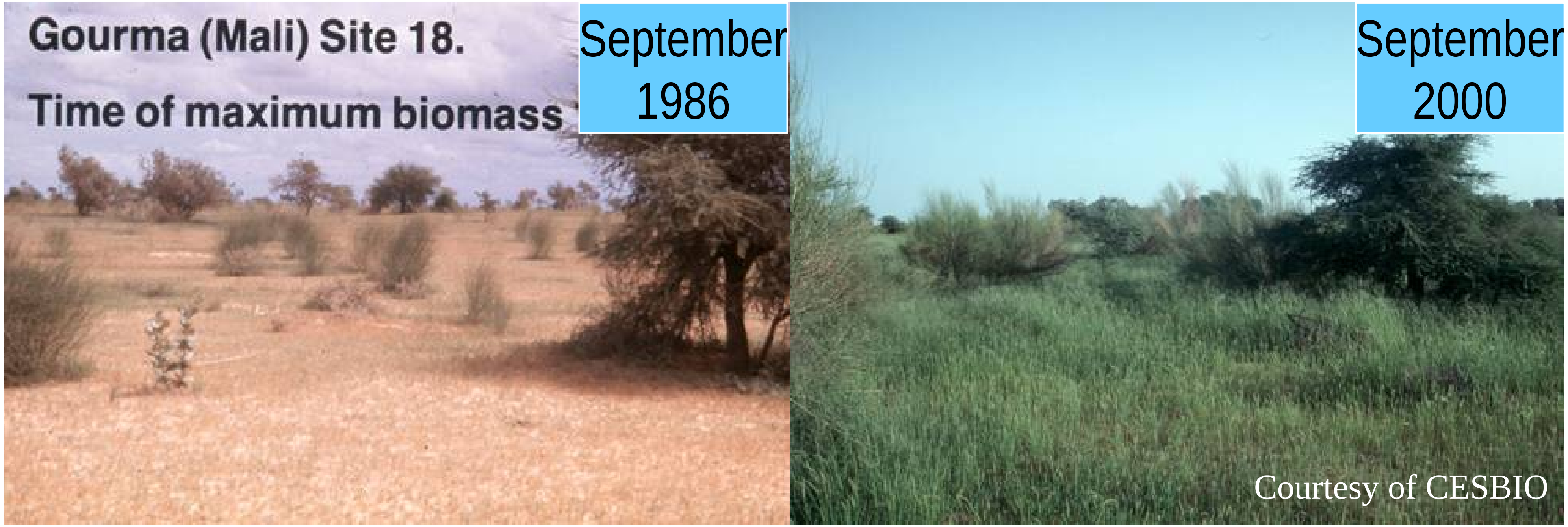
Climate variability and predictability at the seasonal timescale

Land surface versus ocean influence



Hervé Douville
S. Conil, B. Decharme, Y. Peings
Météo-France/CNRM

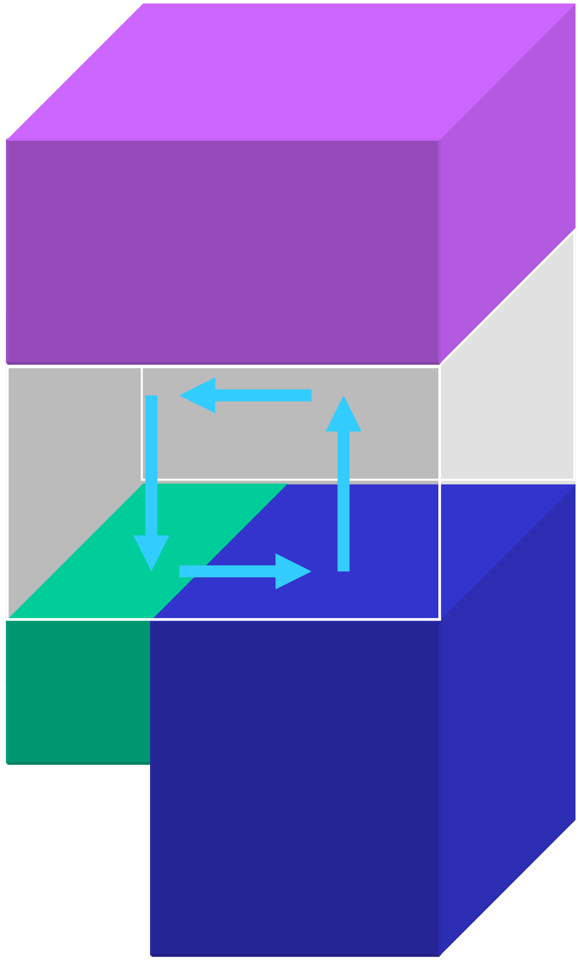
From weather to climate prediction

Troposphere has no deterministic predictability beyond a few weeks, but interacts with « external » factors that are themselves more or less predictable:

1. Ocean
2. Land
3. Stratosphere
4. Radiative forcings

⇒ feasibility of long-range climate prediction

(i.e. Palmer and Anderson 1994)

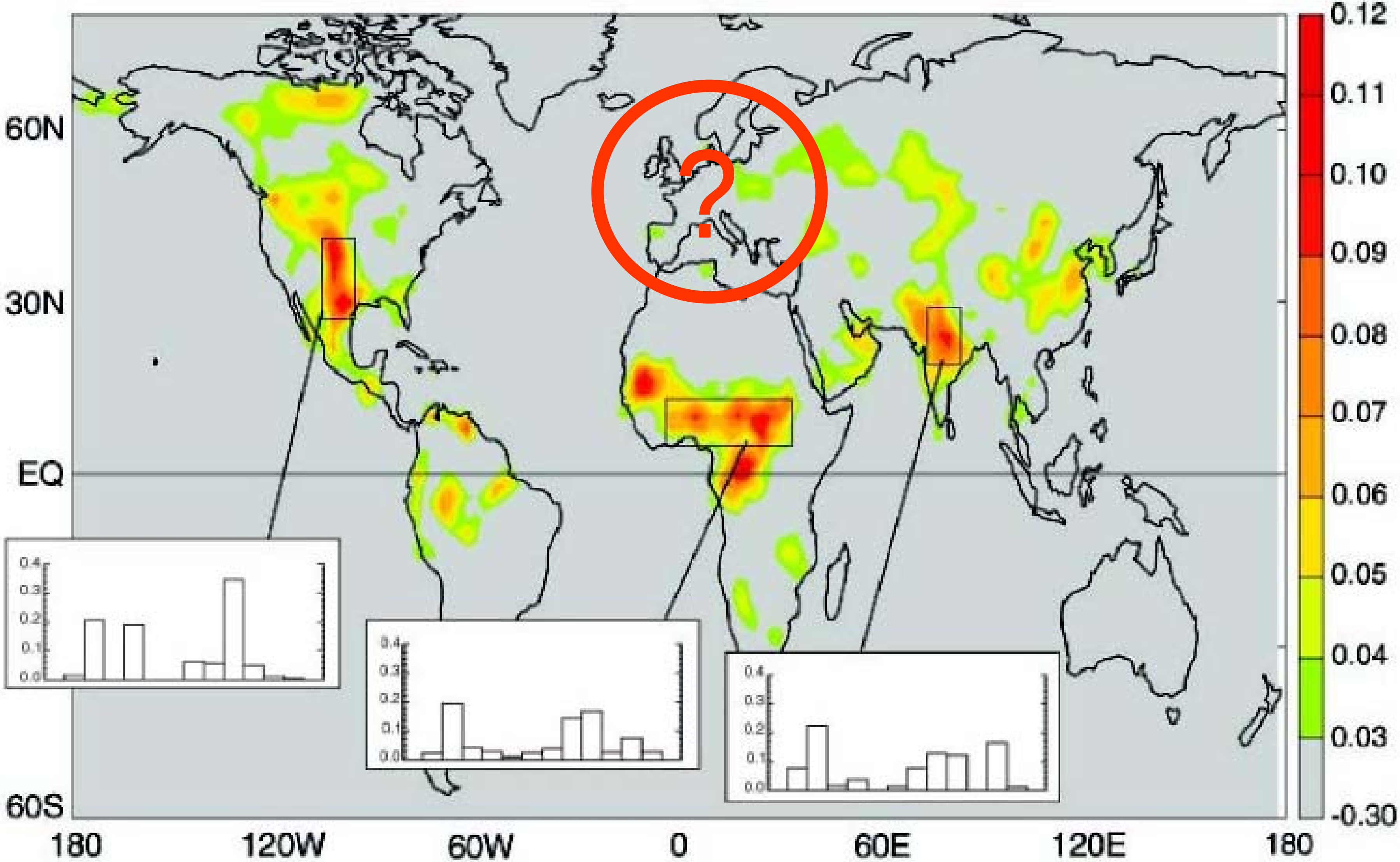


Land-atmosphere coupling in climate studies
A brief (not comprehensive !) history

- *Sir Blanford (1884)*
  Remote snow influence on the Indian summer monsoon
- *S. Manabe (1969, 1975)*
  Bucket model and massive irrigation sensitivity experiment
- *J. Charney (1975)*
  Surface albedo feedback and desert dynamics
- *J. Walker et P. Rowntree (1977), J. Shukla et Y. Mintz (1982)*
  Soil moisture feedback and precipitation
- *H. Lettau et al. (1979), A. Henderson-Sellers et A. Gornitz (1984)*
  Climate consequences of tropical deforestation
- *R. Gallimore et J. Kutzbach (1996), N. De Noblet et al. (1996)*
  Feedbacks due to vegetation dynamics (paleoclimate studies)
- *P. Sellers et al. (1995)*
  Carbon cycle feedbacks (climate change studies)

The GLACE intercomparison project

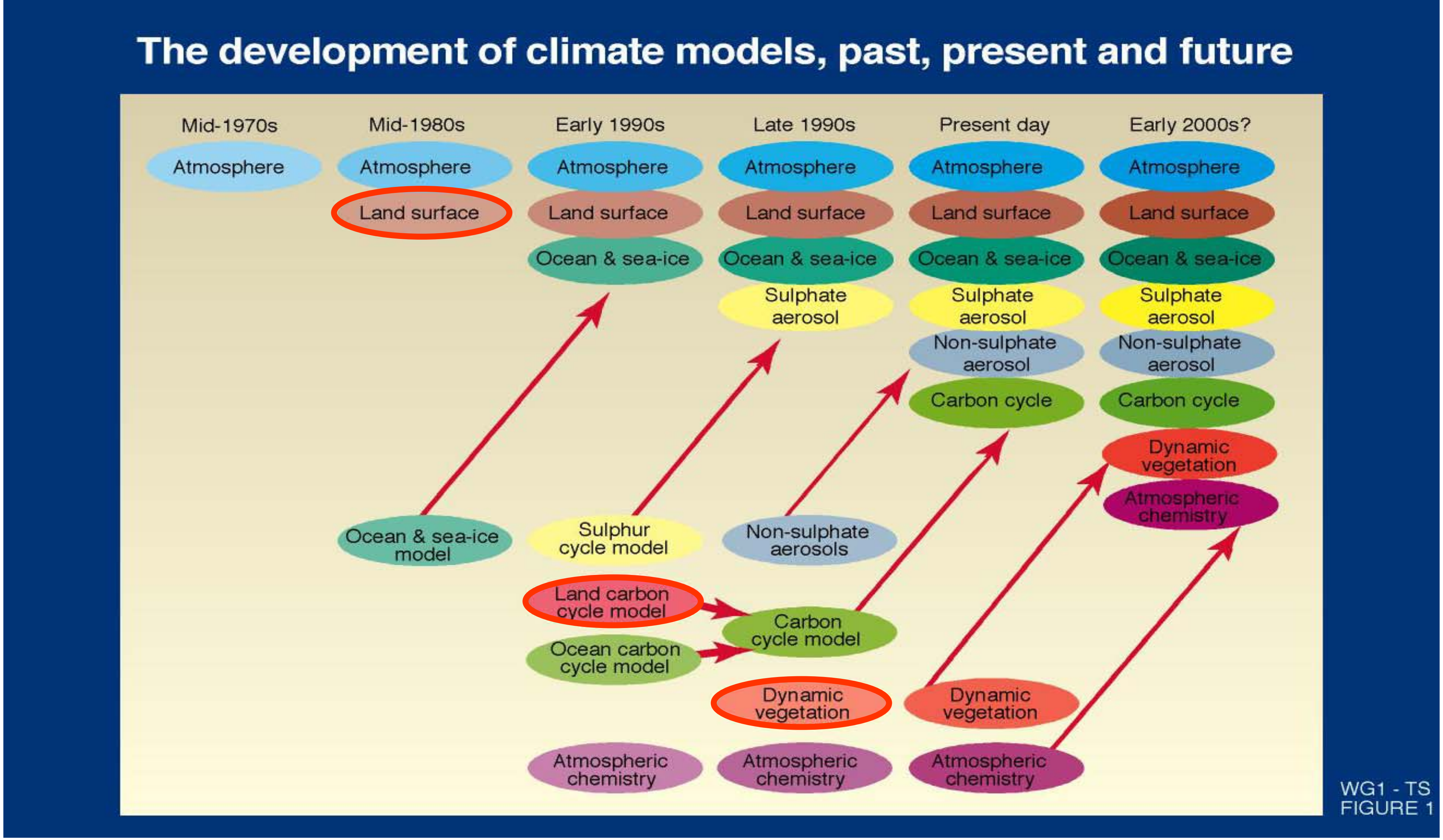
(Koster et al. 2004)



Relevance of land-atmosphere coupling for climate *predictability*: At least 3 conditions

- ✓ Land surface anomalies must have a *significant* impact on atmospheric variability
- ✓ Land surface anomalies must be *predictable* at the selected timescale (using statistical and/or dynamical tools)
- ✓ *Real-time* global analyses must be available to initialize the relevant land surface variables

The development of climate models
(IPCC TAR, 2001)



Land surface versus ocean boundary conditions: Differences and similarities

- Less than 30% of the Earth surface
- Described with 1D-models (advection can be neglected)
- No strong sensitivity to initial conditions

- 100 % of inhabited areas and of freshwater resources
- River routing, migration of vegetation species
- Vegetation dynamics (as a simple chaotic system)

- Strong high-frequency variability (including diurnal cycle)
- Strong spatial variability (topography, soil and vegetation properties, snow, surface and subsurface waters)

- Wind and radiation effects on the high-frequency variability of sea surface temperature
- Precipitation effect on surface salinity
- Meso-scale eddies

Improvement of Land Surface Models: Development of subgrid hydrology

ISBA-SGH

Precipitation

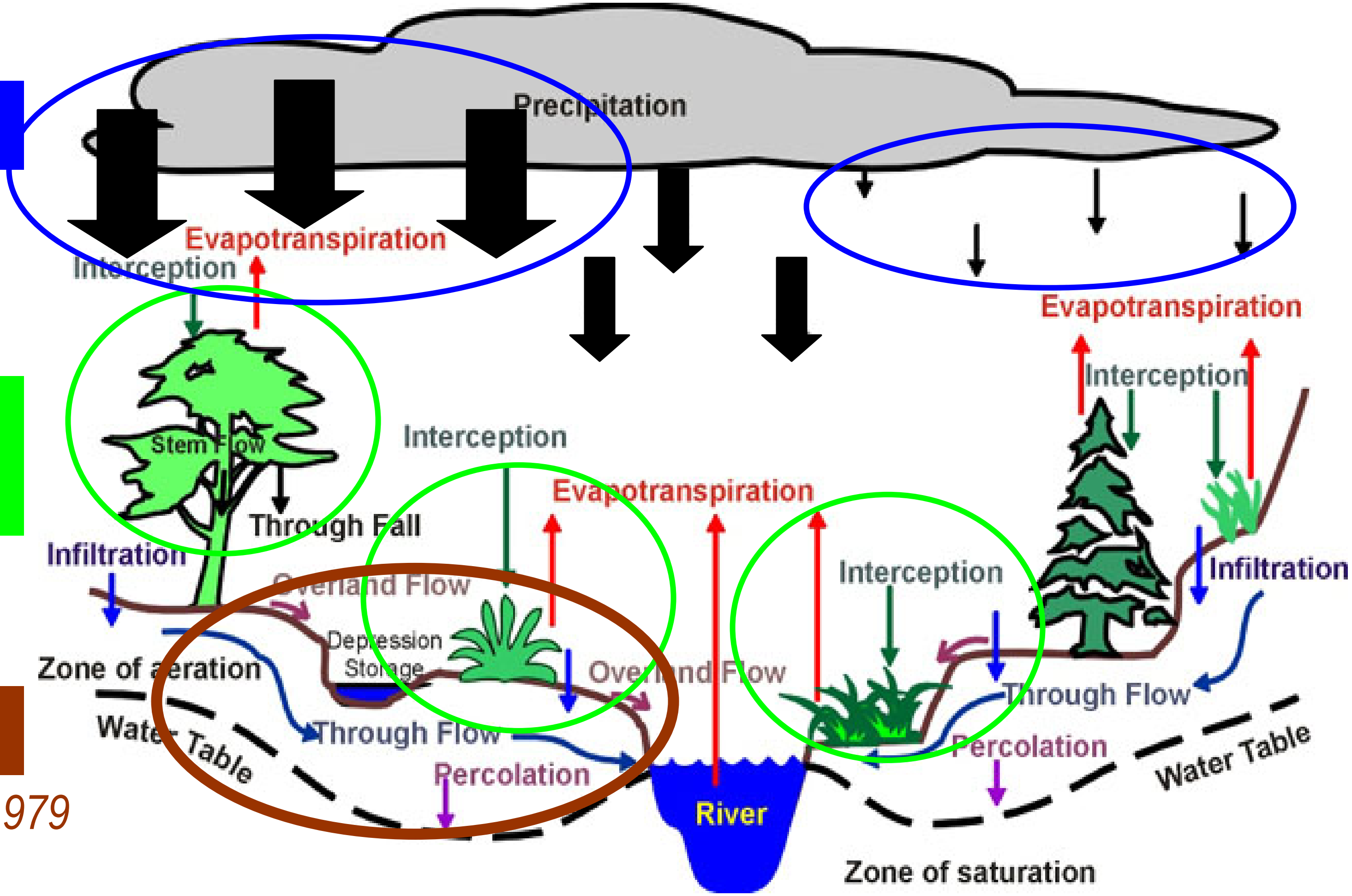
Entekhabi and Eagleson 1989

Vegetation and soil properties

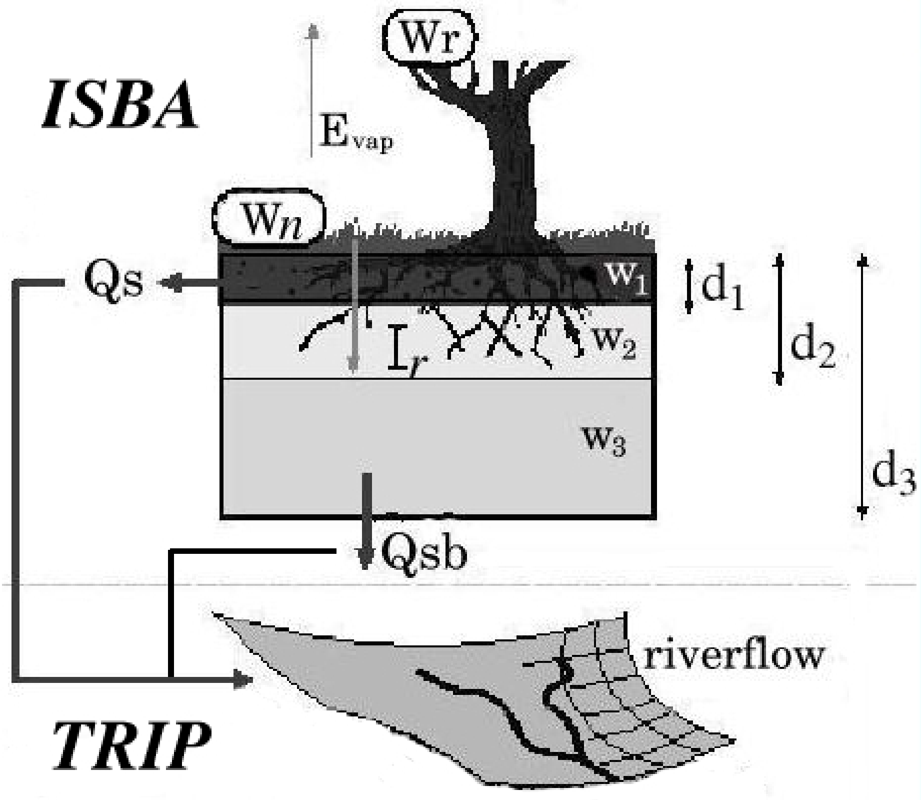
Koster et al. 1992

Topography

Beven and Kirby 1979

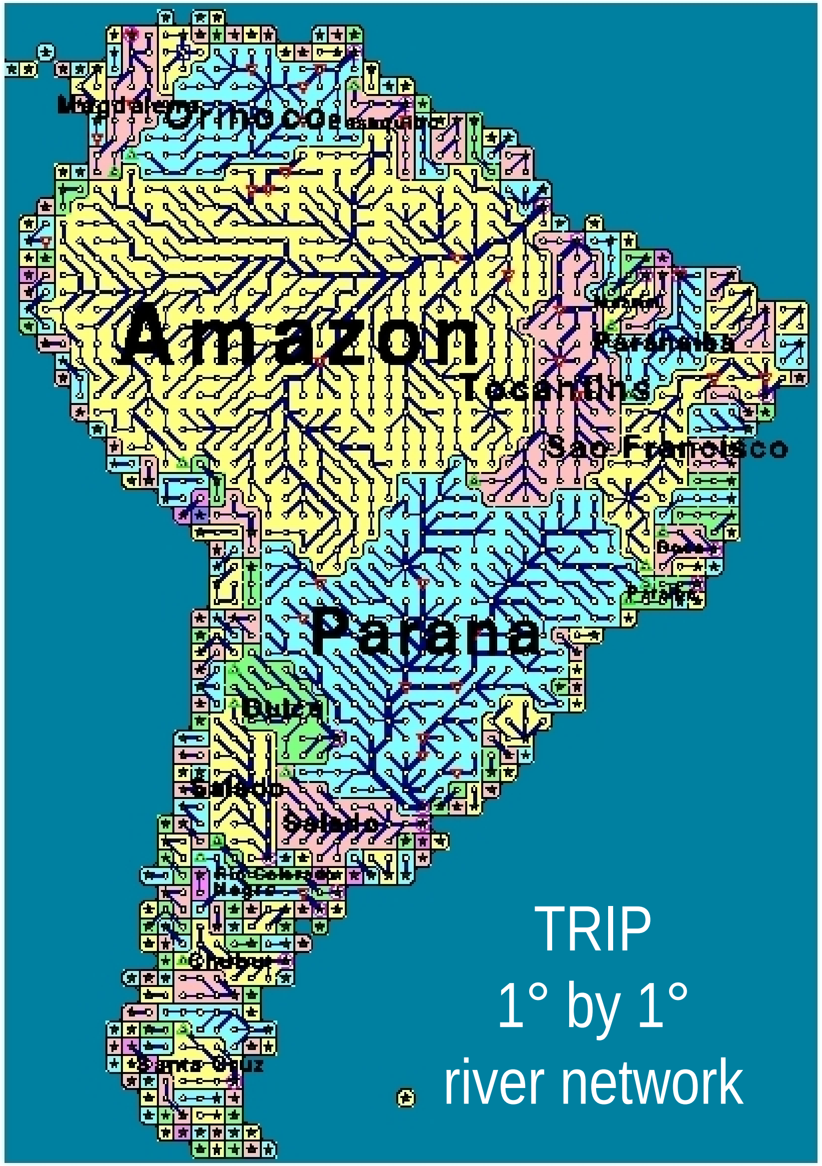


Basin-scale validation of Land Surface Models



$$\frac{\partial S}{\partial t} = Q_{in} - Q_{out}$$

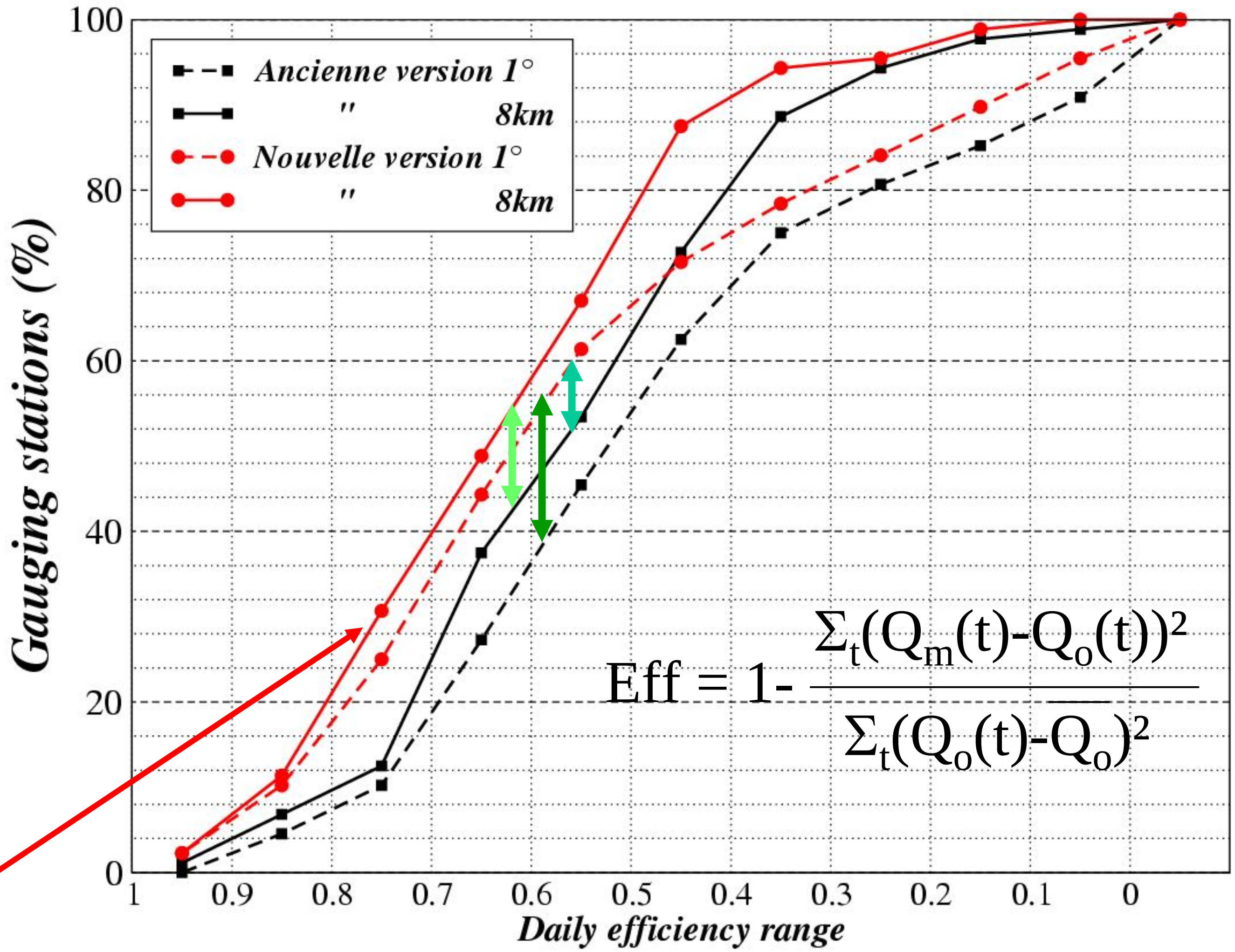
Inflow *Outflow* $Q_{out} = \frac{v}{L} S$



Impact of subgrid hydrology on daily river discharges (Rhône river basin)

Cumulative efficiency distribution of daily river discharges at 1° versus 8km over the Rhône (88 gauging stations)

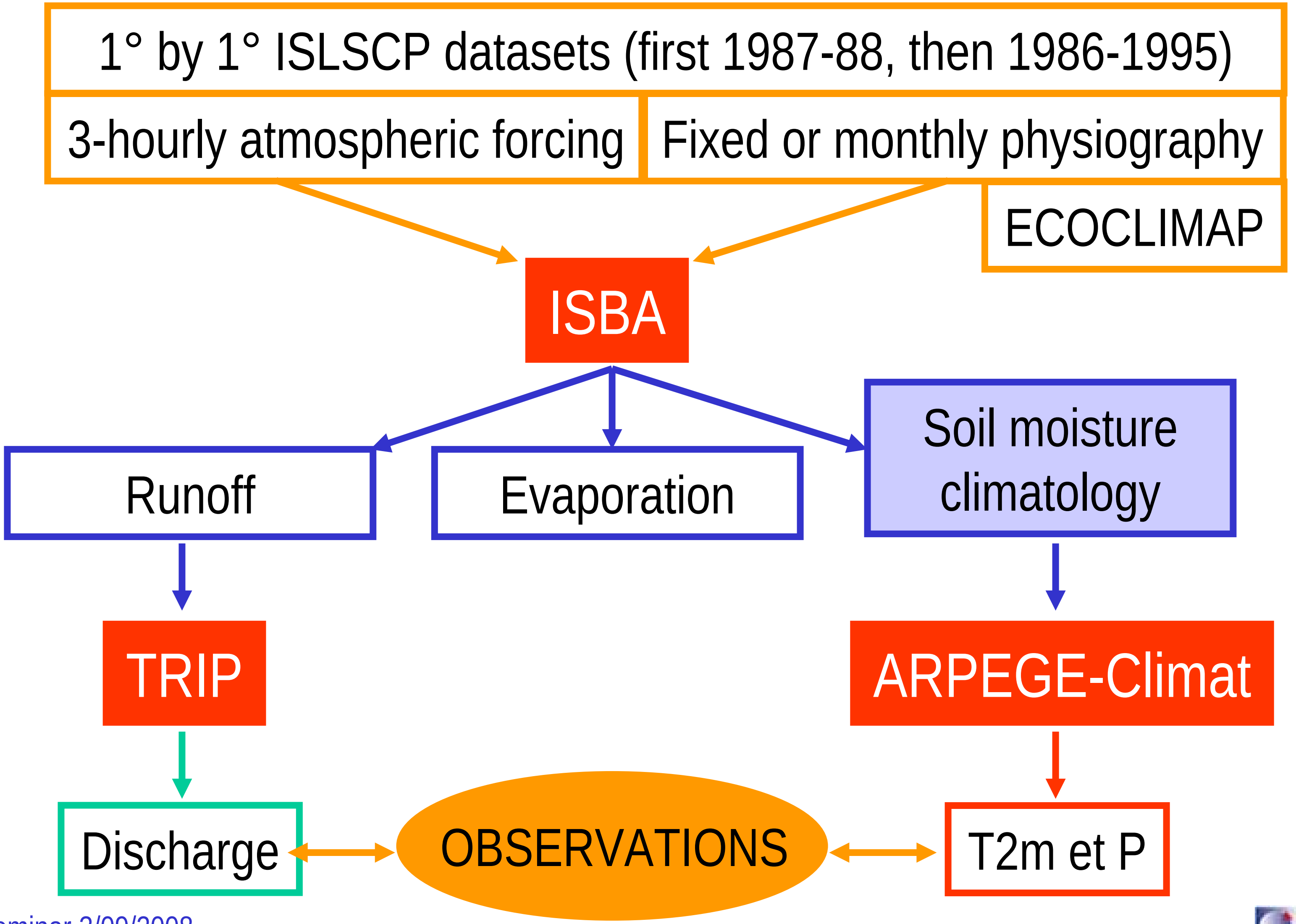
Comparison between the standard ISBA model and ISBA-SGH



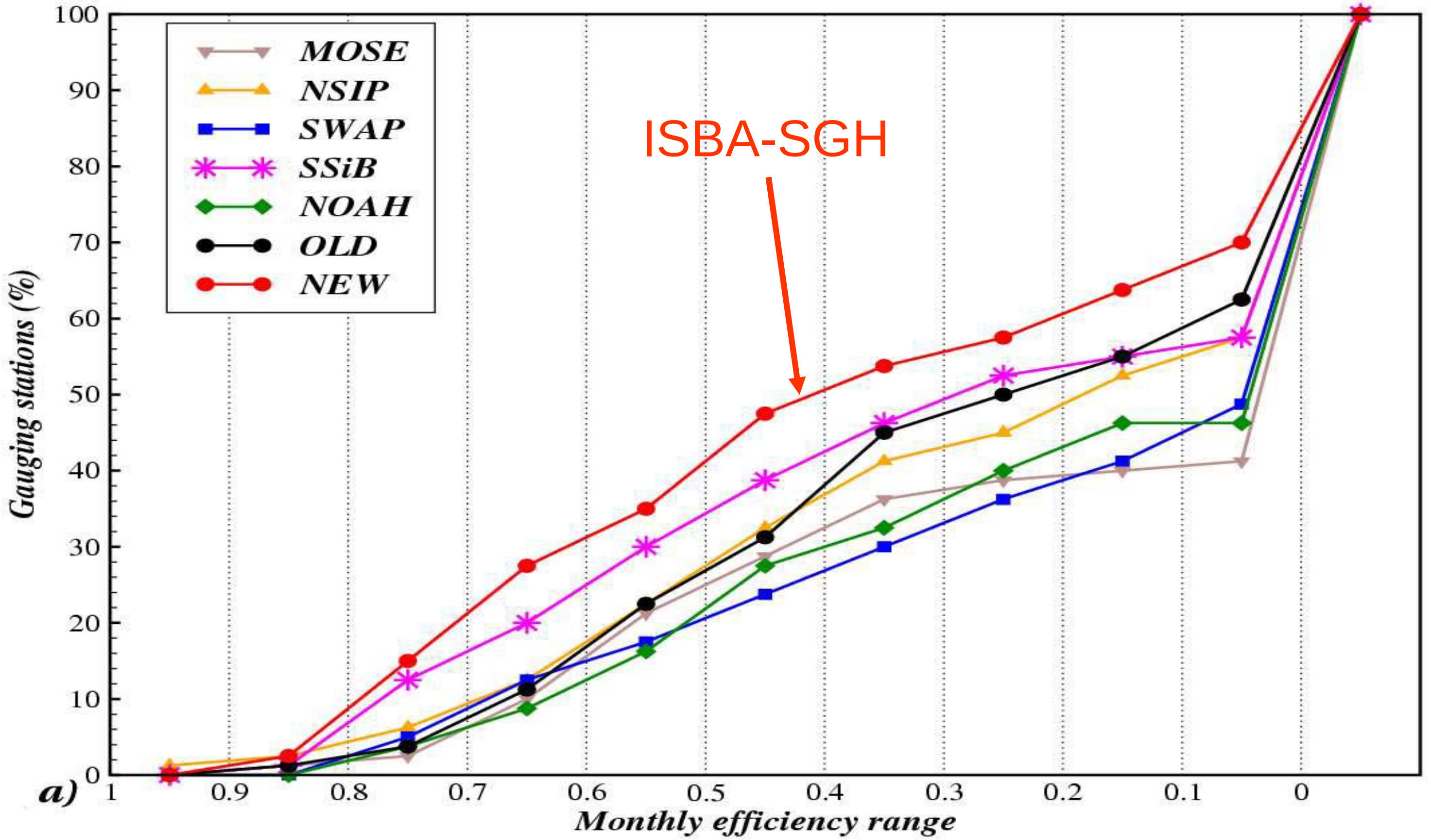
$$\mathrm{Eff} = 1 - \frac{\Sigma_t (Q_m(t) - Q_o(t))^2}{\Sigma_t (Q_o(t) - \overline{Q_o})^2}$$

Decharme and Douville 2006

Global intercomparison of Land Surface Models: The Global Soil Wetness Project



Results of GSWP-2 (1985-1996): Comparison of monthly river discharges



Cumulative efficiency distribution of monthly river discharges at 80 worldwide gauging stations

(Decharme and Douville 2007)

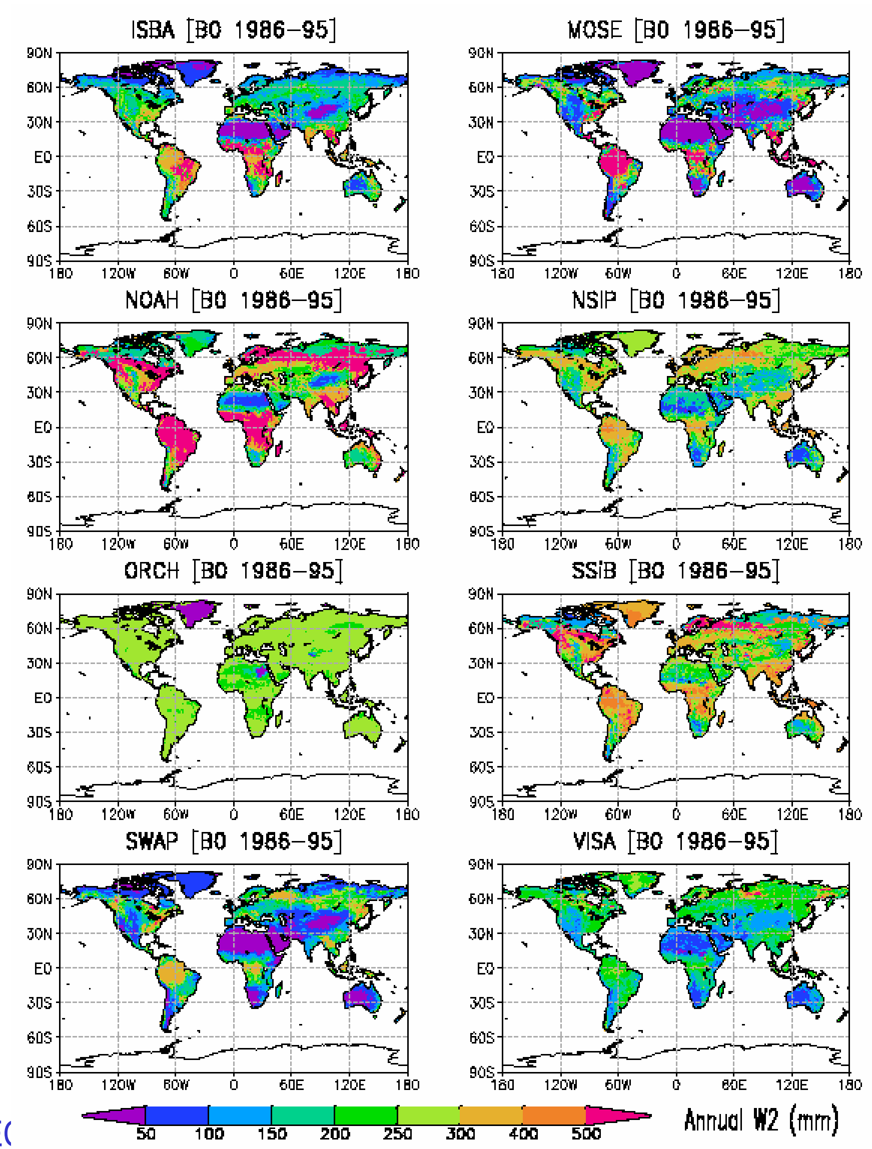
Background

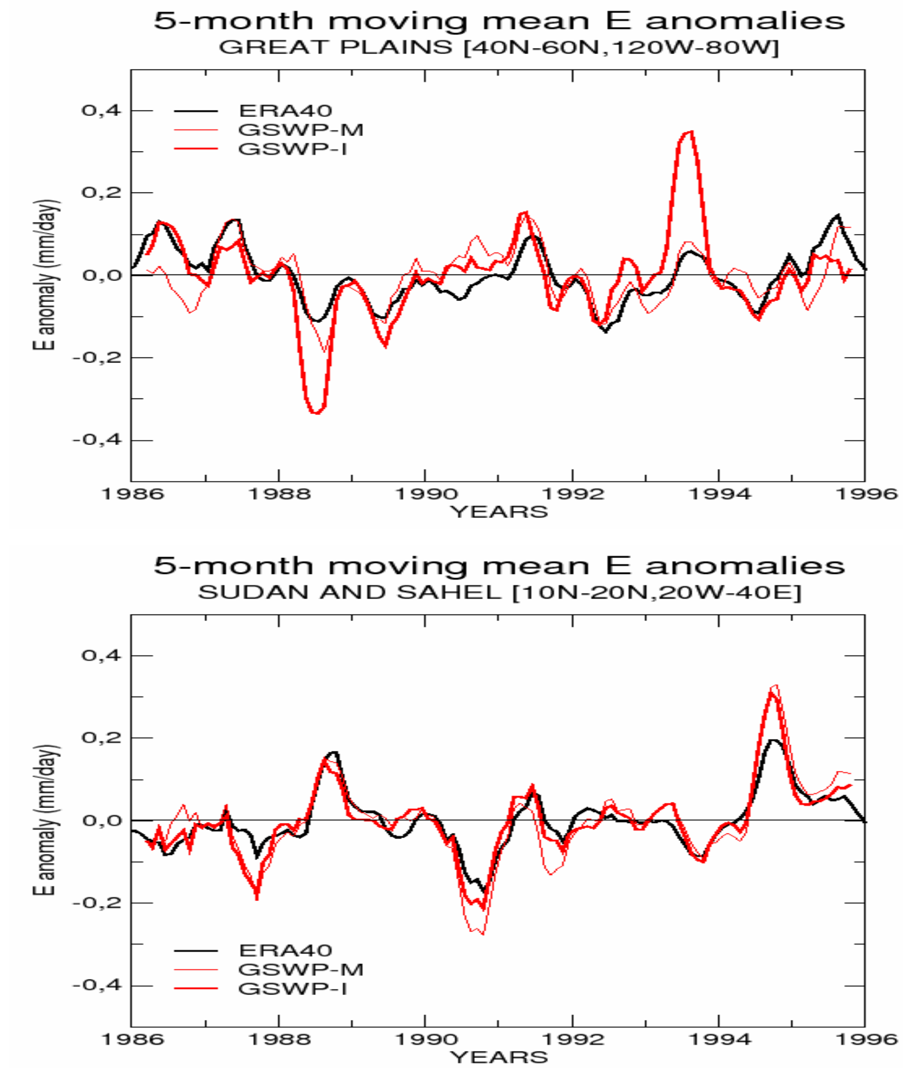
LSM & Data

L-A coupling

Issues

Results of GSWP-2 (1986-1995) : Comparison of root zone soil moisture





Summary

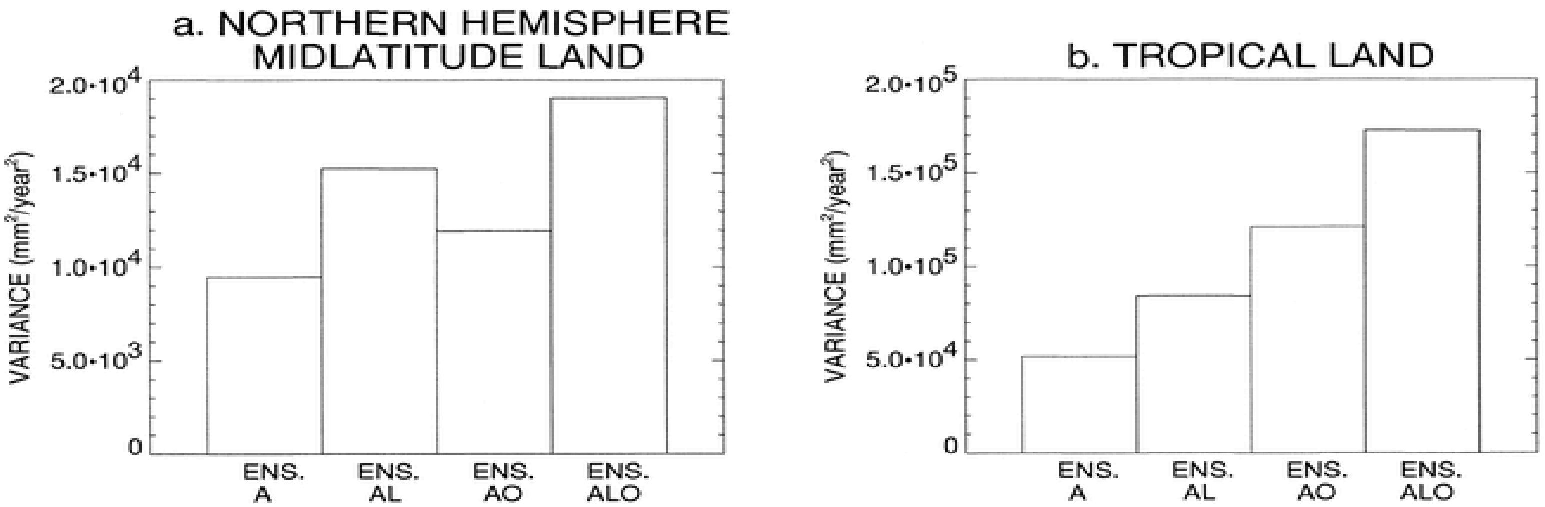
- ✓ Early LSM developments have focused on improving the one-dimensional structure of the soil-snow-canopy system;
- ✓ Basin-scale validation studies have emphasized the role of subgrid hydrological processes and the parametrization of runoff;
- ✓ Over recent years, land surface models have emerged as independent models that can be used in both off-line and on-line (coupled to the atmosphere) simulations;
- ✓ Recent developments include carbon cycle, interactive phenology, vegetation dynamics, floodplains, groundwater, soil freezing and permafrost, etc...
- ✓ Off-line intercomparisons still show large uncertainties and the need of better constraining the models.

Background
LSM & Data
L-A coupling
Issues

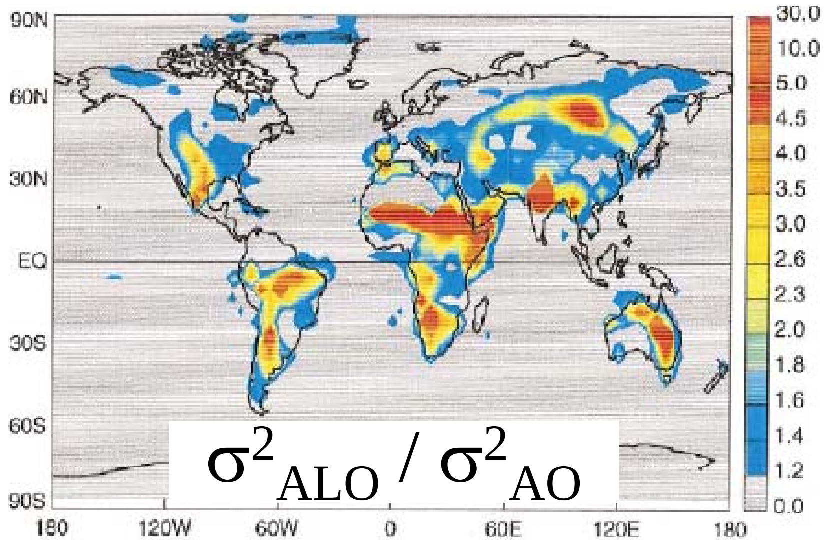
Ocean vs Land Variability: Annual Precipitation

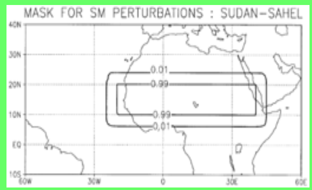
(Koster et al. 2000)

Variance of annual P



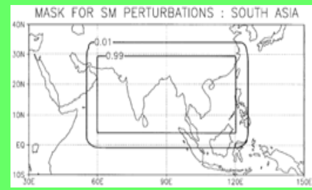
Control experiment ALO
A: Atmosphere
L: interactive Land hydrology
O: Observed monthly SST
16x45=720-yr simulations





A « dynamical » feedback

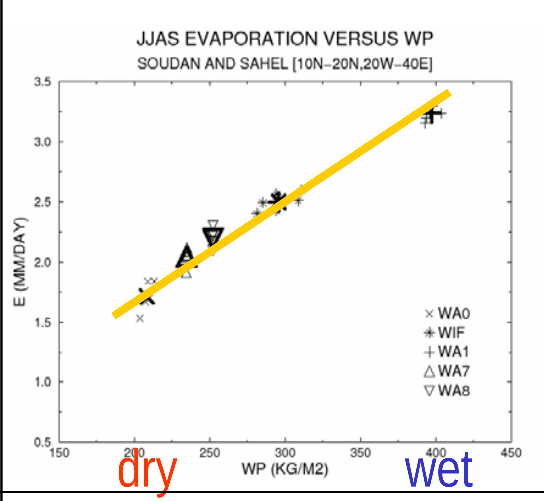
(Douville et al. 2001)



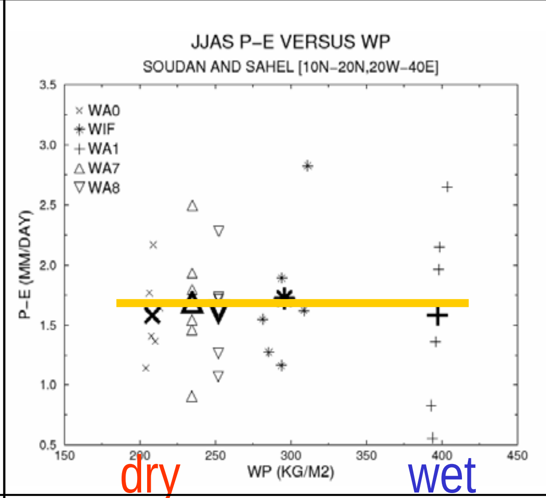
Anom. | E | P-E | P

Sahel

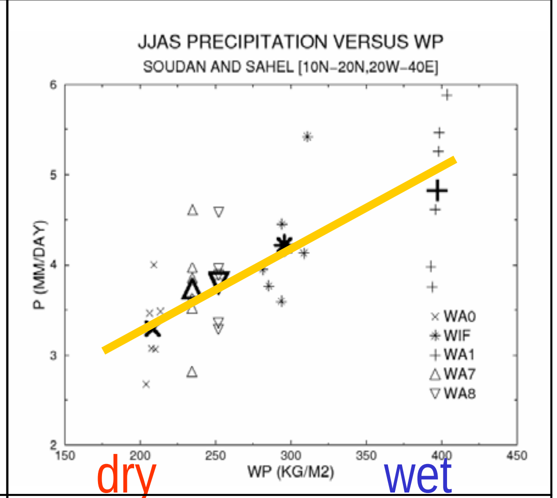
E



P-E

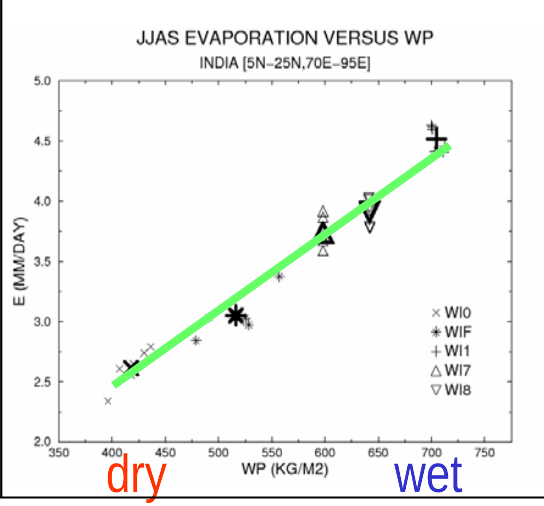


P

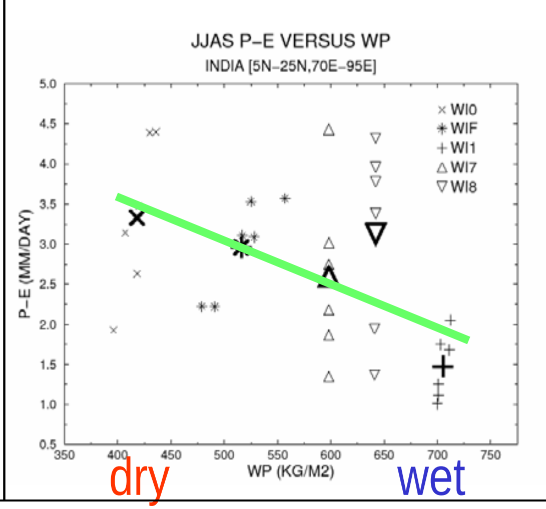


South Asia

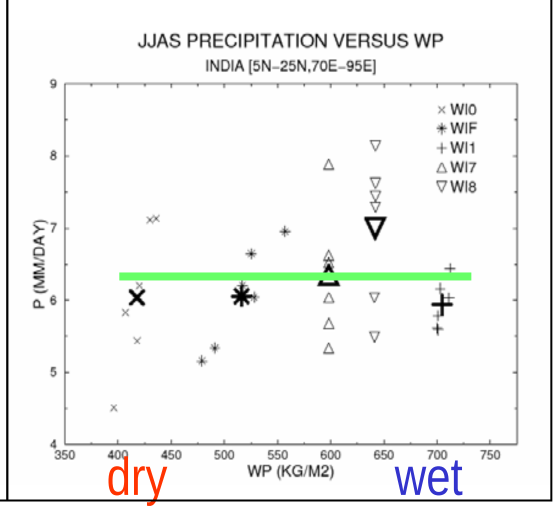
E



P-E



P



Soil moisture or snow mass nudging of the CNRM atmospheric GCM towards GSWP-2

- ✓ Ensembles of 10-member AMIP simulations from 1986 to 1995
- ✓ Nudging towards the GSWP-2 reanalysis to prescribe « realistic » boundary (or initial conditions) for soil moisture or snow mass
- ✓ Five 10-year ensembles:
  - FF: Control experiment (interactive land surface hydrology)
  - GG: Nudging towards GSWP-2 soil moisture
  - GC: Same as GG, but with climatological SSTs
  - HH: Nudging towards GSWP-2 snow mass
  - HC: Same as HH, but with climatological SSTs
- ✓ Two ensembles of seasonal hindcasts:
  - GF: Same as GG, but no nudging after the end of May
  - HF: Same as HH, but no nudging after the end of March

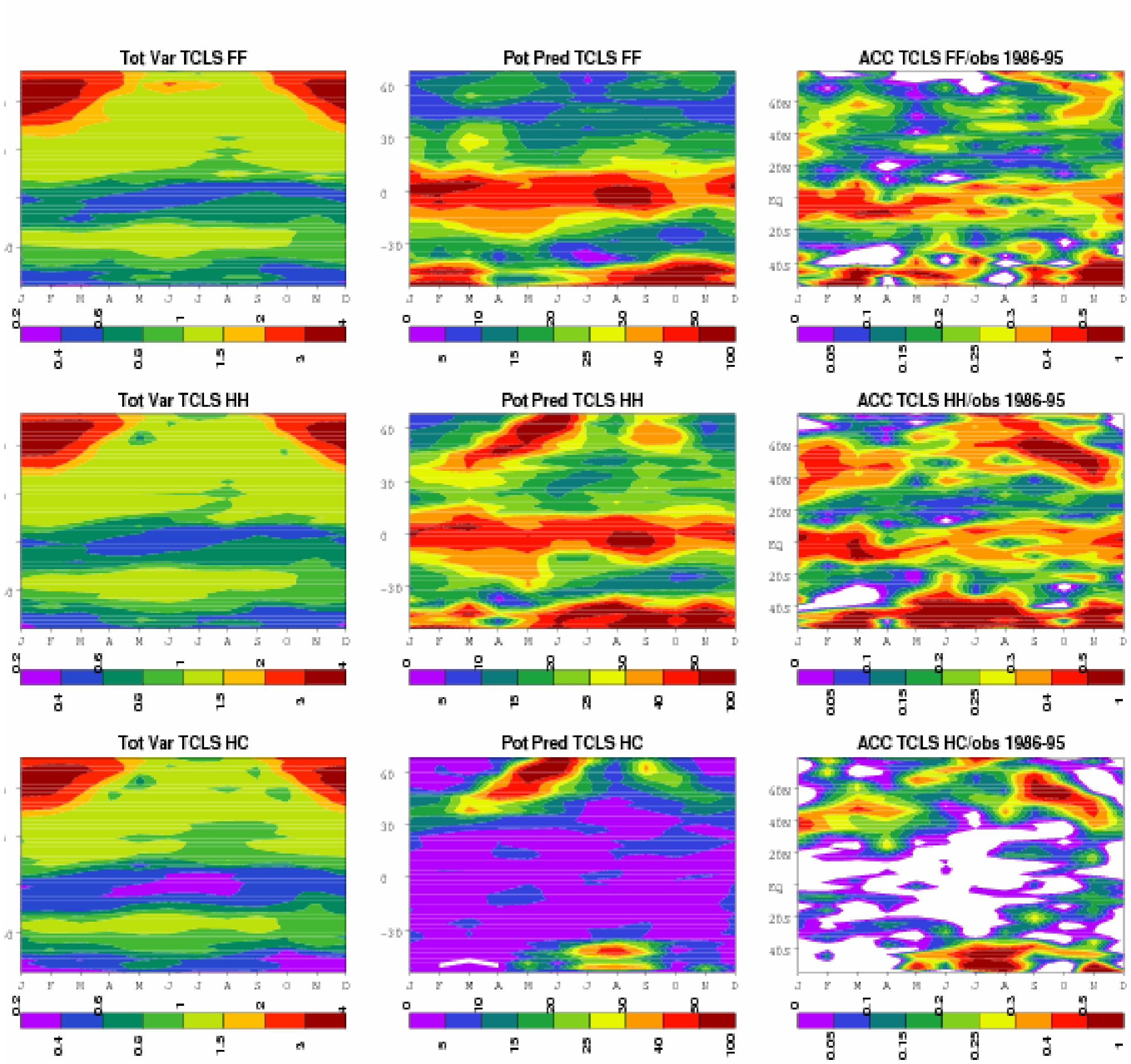
Zonal mean annual cycle of PP (ANOVA) and EP (ACC)

Monthly Screen-Level Temperature (Land only)

Control
No nudging
Obs. SST

Nudging
Obs. SST

Nudging
Clim. SST



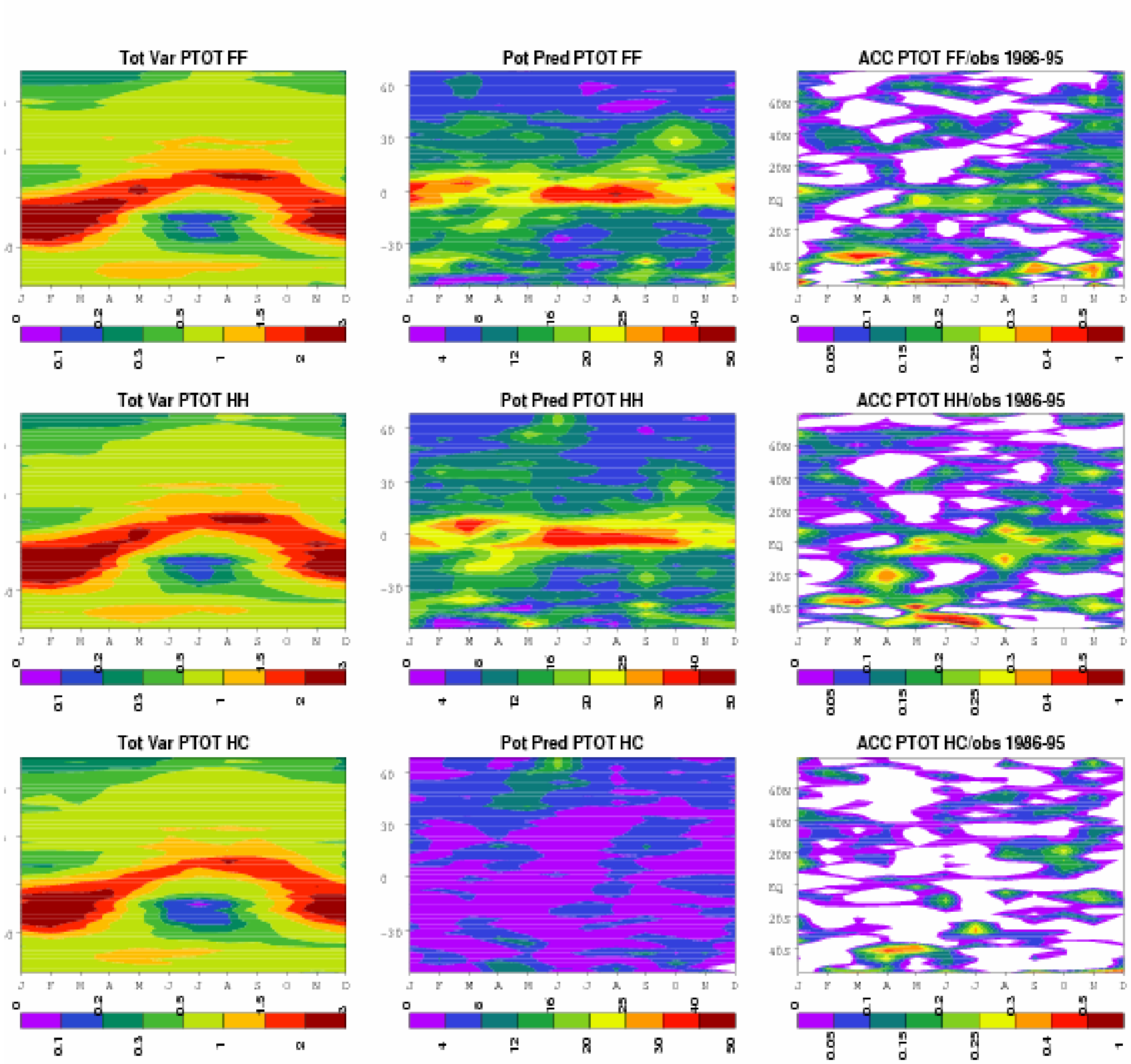
Zonal mean annual cycle of PP (ANOVA) and EP (ACC)

Monthly Precipitation (Land only)

Control
No nudging
Obs. SST

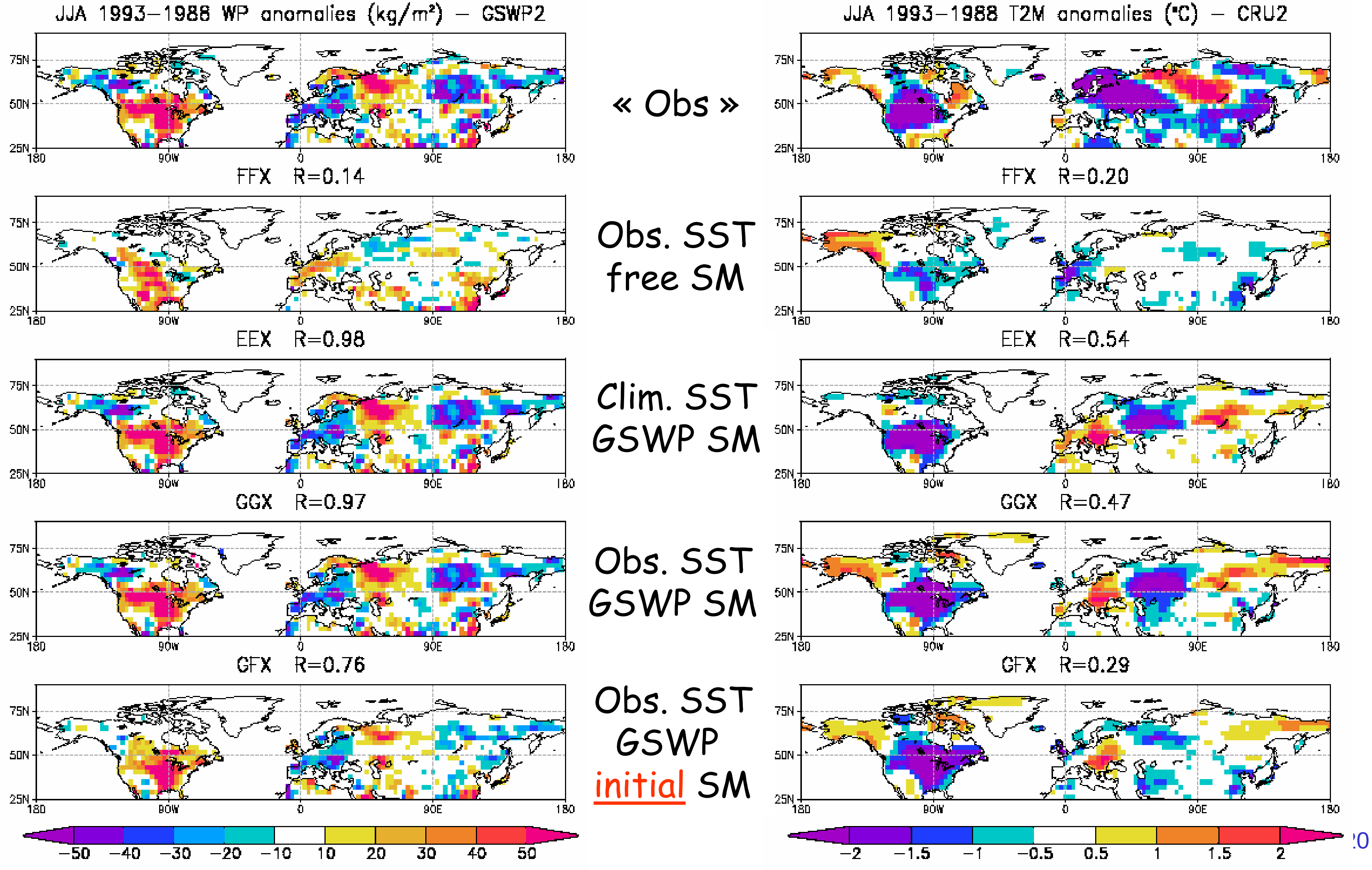
Nudging
Obs. SST

Nudging
Clim. SST



US case study: JJA 1993 versus JJA 1988

(Conil et al. 2007, Conil et al. 2008)



Global evaluation of soil moisture predictability
Dynamical (GF) versus statistical forecasts

Fraction (%) of grid points where each model is the best at predicting soil moisture *(Conil et al. 2008)*

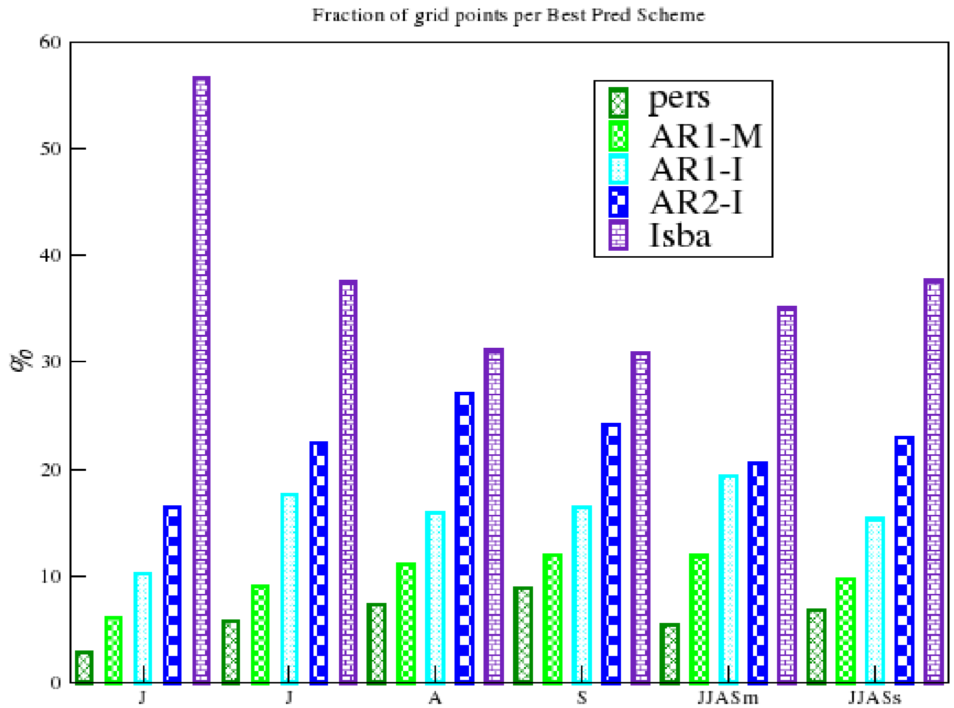


FIGURE 3: Number of grid points where each SM prediction model appears to be the best predicting scheme (Fraction of the total land grid points). The fraction of points where each model is the best is evaluated for each month June, July, August and September, showing the evolution with the lead-time but also for the overall season using monthly means (JJASm) and seasonal means (JJASs).

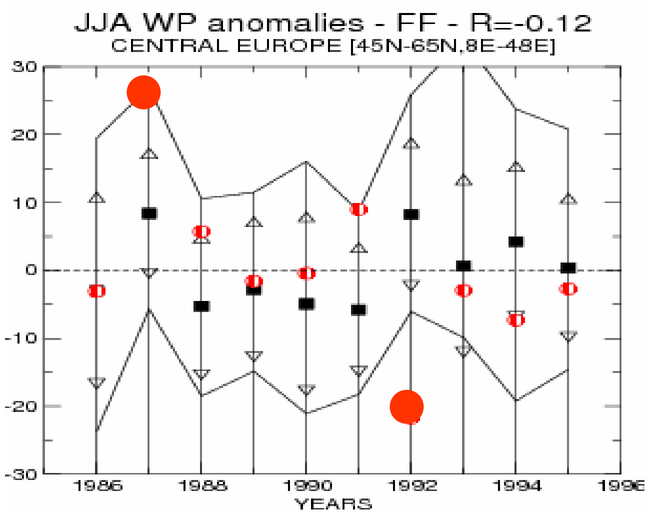
No horizontal dynamics => possible to combine dynamical and statistical methods

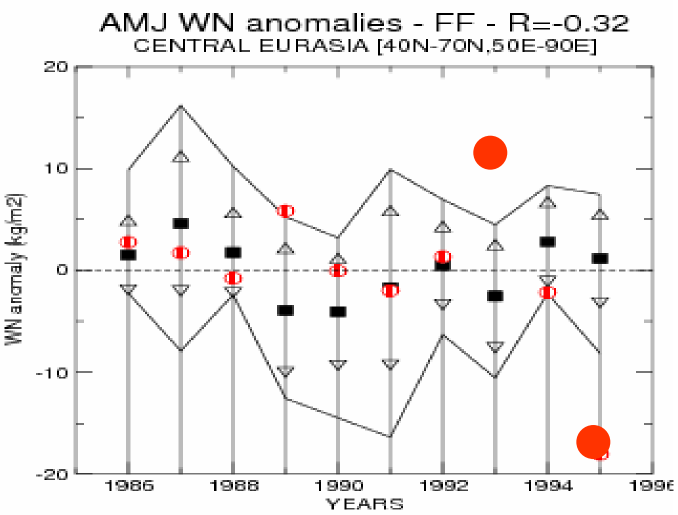
Eurasian case studies

(Conil et al. 2007, Conil et al. 2008, Douville 2008)

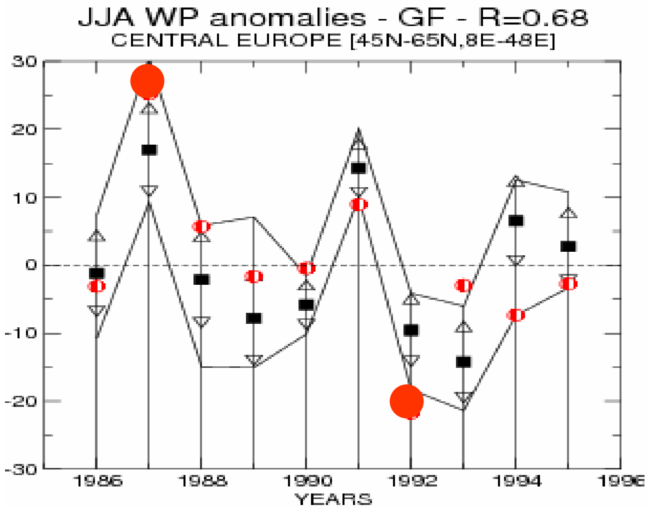
Soil moisture | **Snow mass**

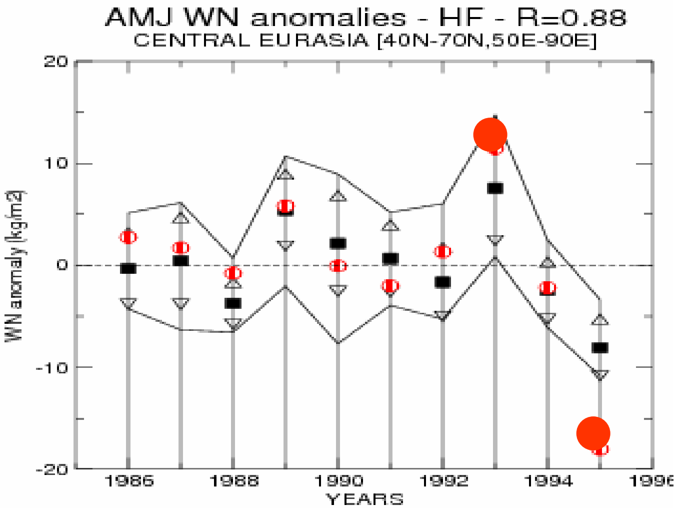
Control experiment no nudging (random initial conditions)





Hindcasts initialized from the nudged experiments





Background

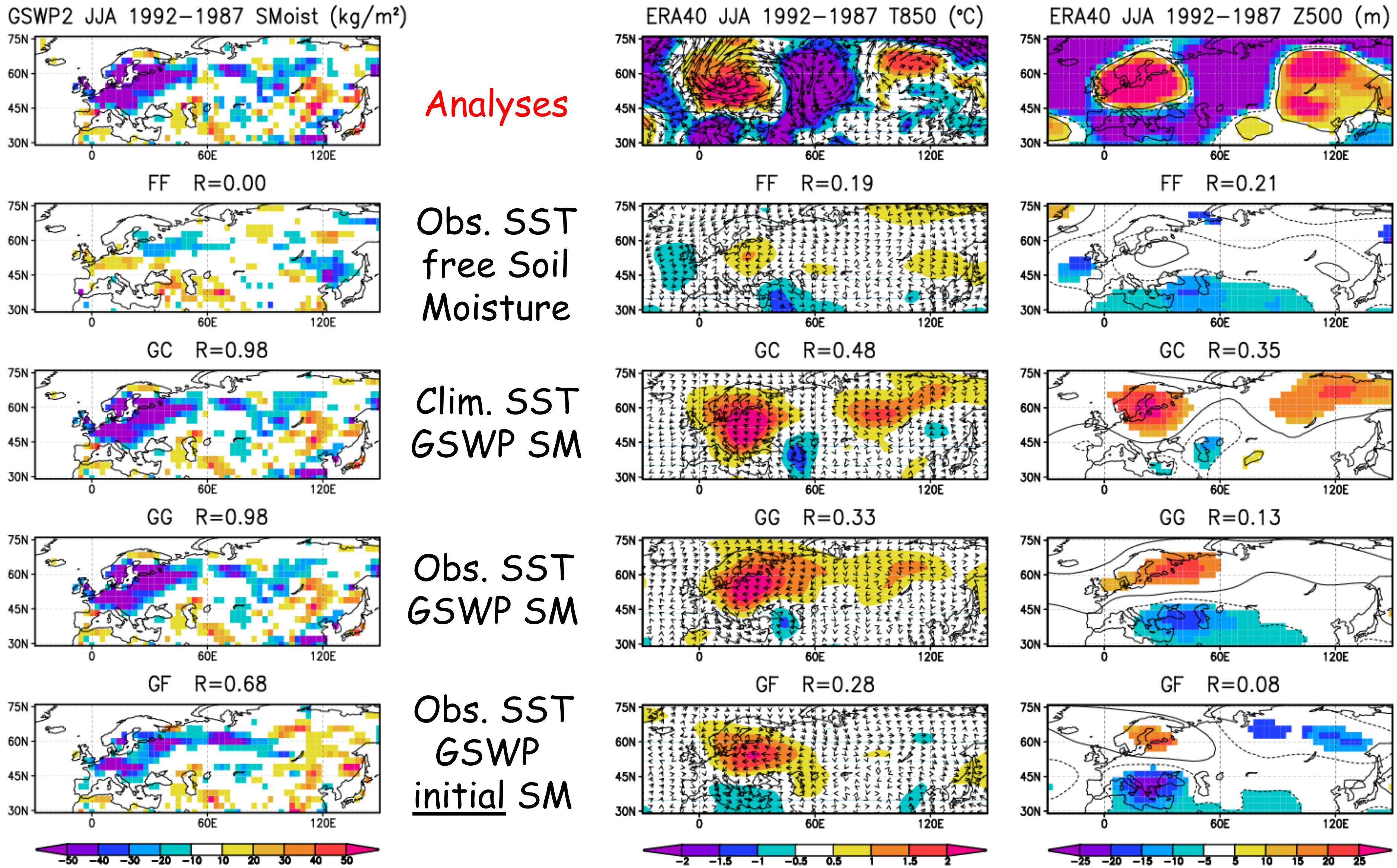
LSM & Data

L-A coupling

Issues

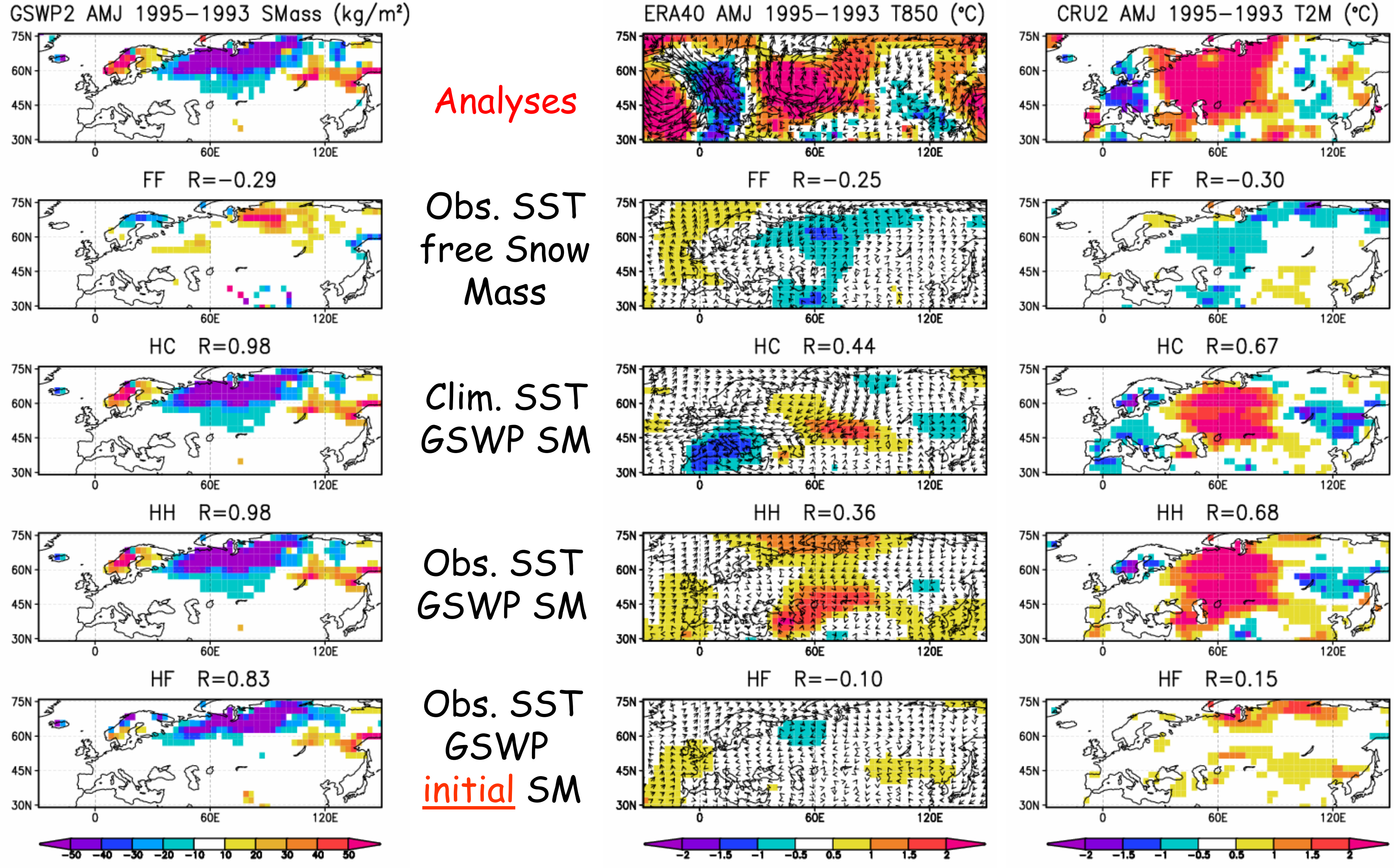
Eurasian case study 1: JJA 1992 versus JJA 1987

(Conil et al. 2007, Conil et al. 2008, Douville 2008)



Eurasian case study 2: AMJ 1995 minus AMJ 1993

(Douville 2008)



Summary

- ✓ Soil moisture and snow mass anomalies show persistence and are predictable at the monthly to seasonal timescale;
- ✓ Soil moisture mainly contributes to predictability in the summer mid-latitudes (including over Europe);
- ✓ Snow mass also shows significant impacts, mostly on springtime low-level temperatures;
- ✓ Both contributions do not amount to simple changes in the surface energy budget, but also possibly involve large-scale dynamical and cloud feedbacks;
- ✓ Both contributions should not be neglected given the weak SST impact on extratropical predictability in spring and summer.

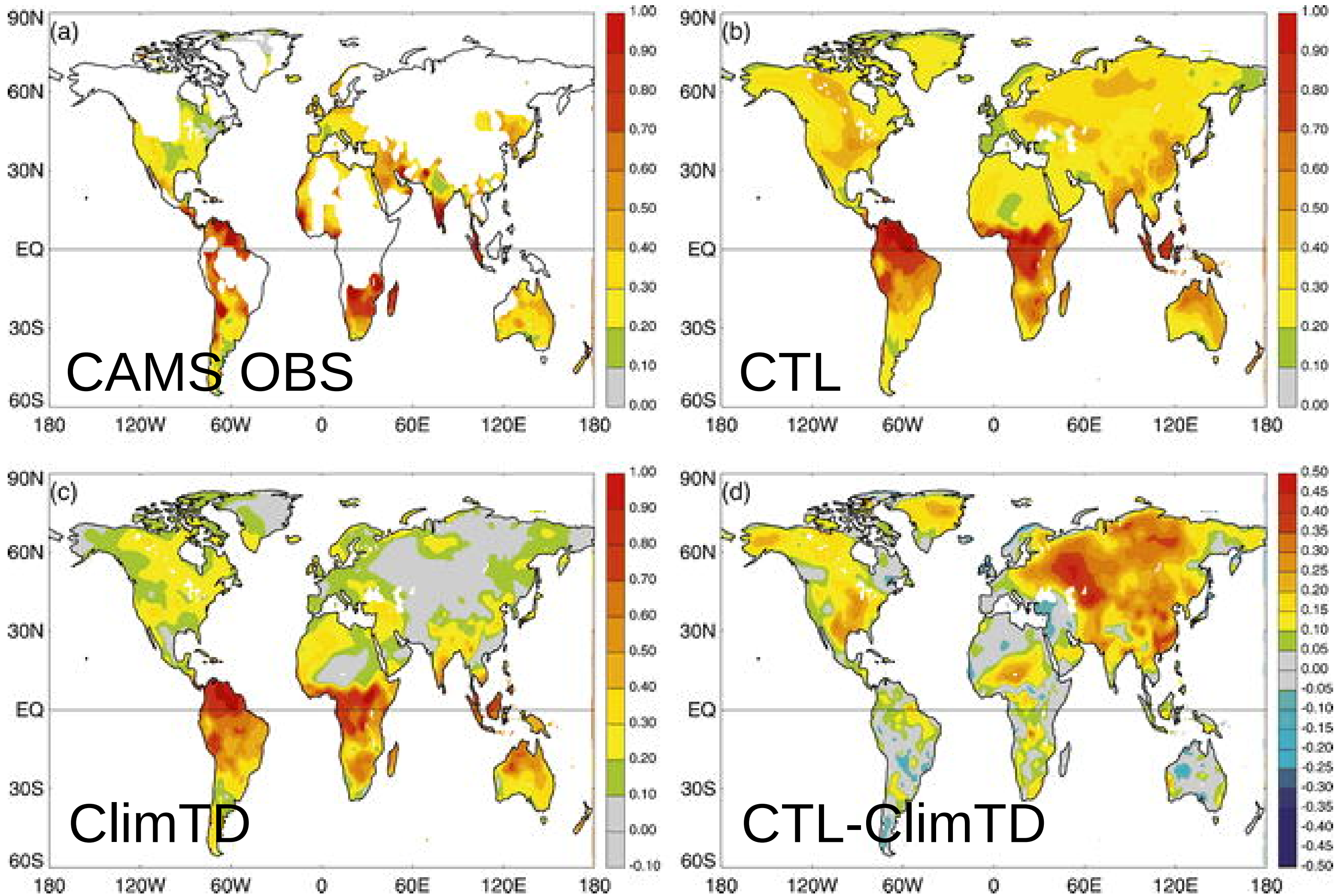
1. Need of model intercomparison
The GLACE-2 project *(R. Koster)*

- Series 1:
  - 60-day forecasts using realistic (GSWP-2) land surface initial conditions
  - Start dates ranging from April 1 to August 15
  - 10-member ensembles
  - If possible, realistic atmospheric initial conditions
  - Prescribed monthly observed SSTs
- Series 2:

  Same as 1 but using « random » land surface initial conditions
- Optional:
  - Coupled instead of prescribed SSTs (ECMWF-KNMI contribution)
  - Extension to cover the 1950-2000 period ?
  - Austral summer forecasts ?

2. Look for other land surface contributions ? Impact of deep soil temperature on Tair persistence

DJF



Mahanama et al. 2008

1-month-lag autocorrelation of Tair

Background

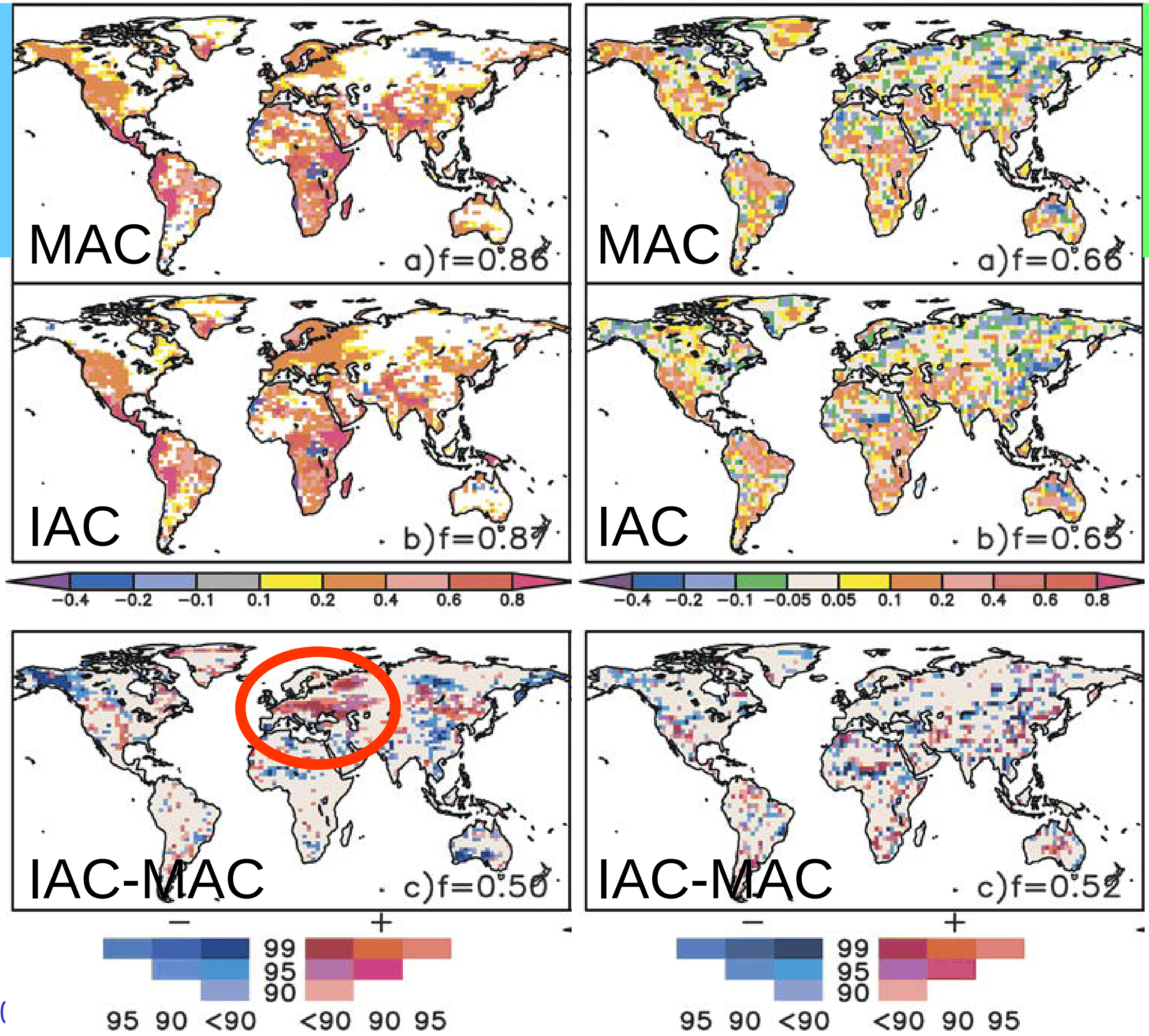
LSM & Data

L-A coupling

Issues

2. Look for other land surface contributions ? Impact of vegetation variability on Tair and Prec

monthly Tair ACC



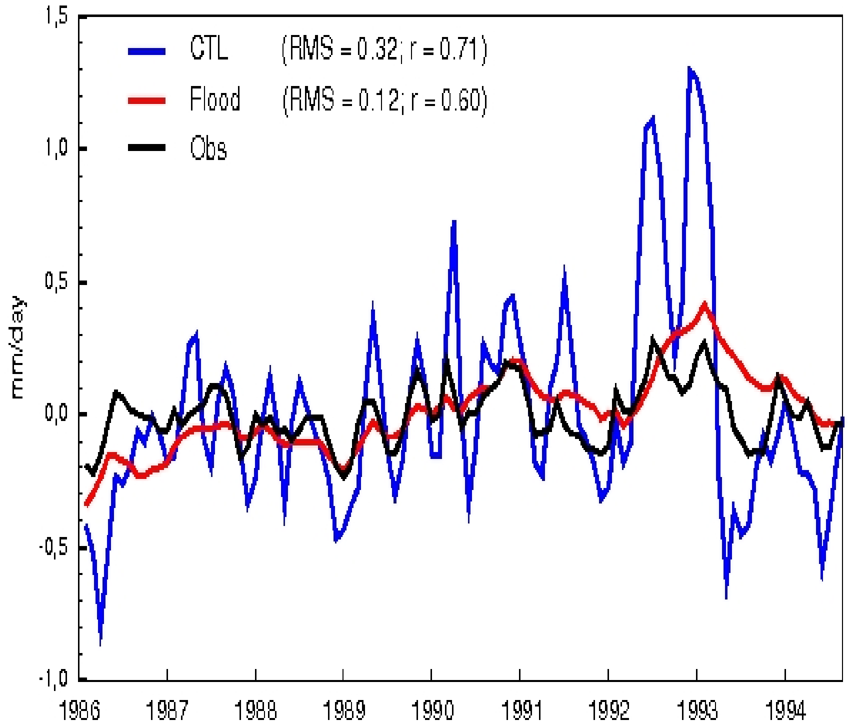
monthly Prec ACC

Gao al. 2008

2. Look for other land surface contributions ?

Groundwater and floodplains

Groundwater convergence and land-atmosphere coupling
(Bierkens and van den Hurk 2008)



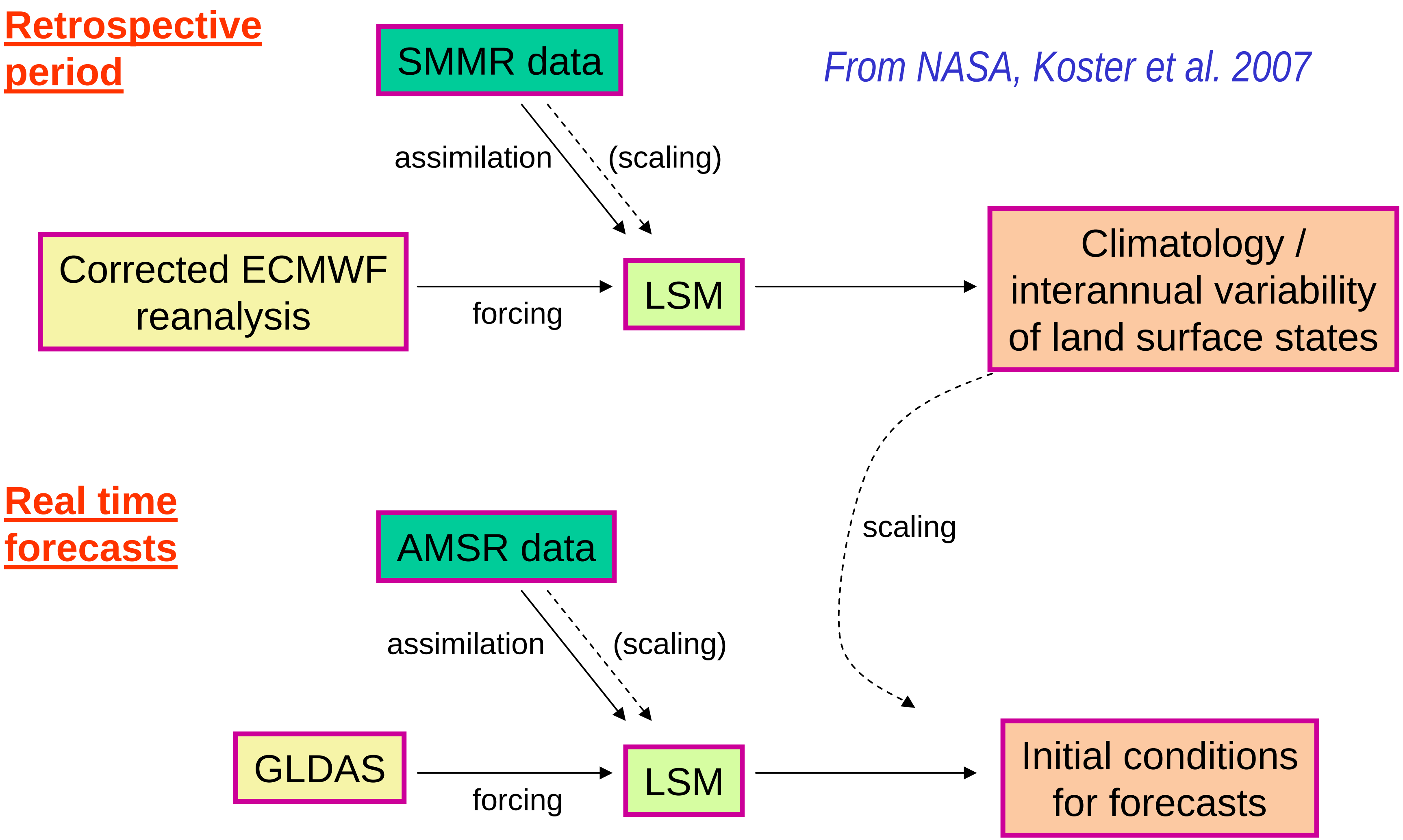
Monthly discharge anomalies of the Parana river at Timbues
(Decharme et al. 2008)

3. Need of land surface climatologies

- ✓ Soil moisture (surface and/or deep)
  - ✓ Regional networks of in situ measurements (SMDB)
  - ✓ Satellite data: IR, passive and active microwave
  - ✓ On-line land surface (re)analyses (ERA40)
  - ✓ Global off-line simulations: GSWP, GLDAS, …
- ✓ Snow (depth and/or cover)
  - ✓ Continental climatologies of situ measurements
  - ✓ Satellite data: visible, passive and active microwave
  - ✓ On-line land surface (re)analyses (ERA40)
  - ✓ Global off-line simulations: GSWP, GLDAS, …
- ✓ Total mass variation (surface and subsurface): GRACE

3. Need of land surface climatologies (semi) off-line assimilation of satellite observations

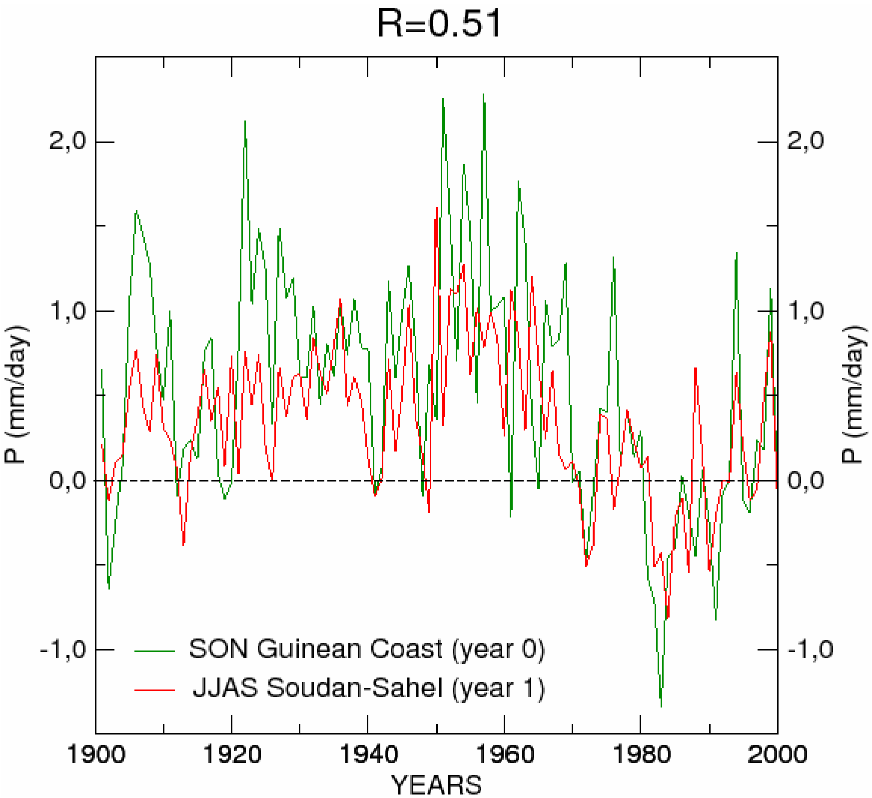
From NASA, Koster et al. 2007

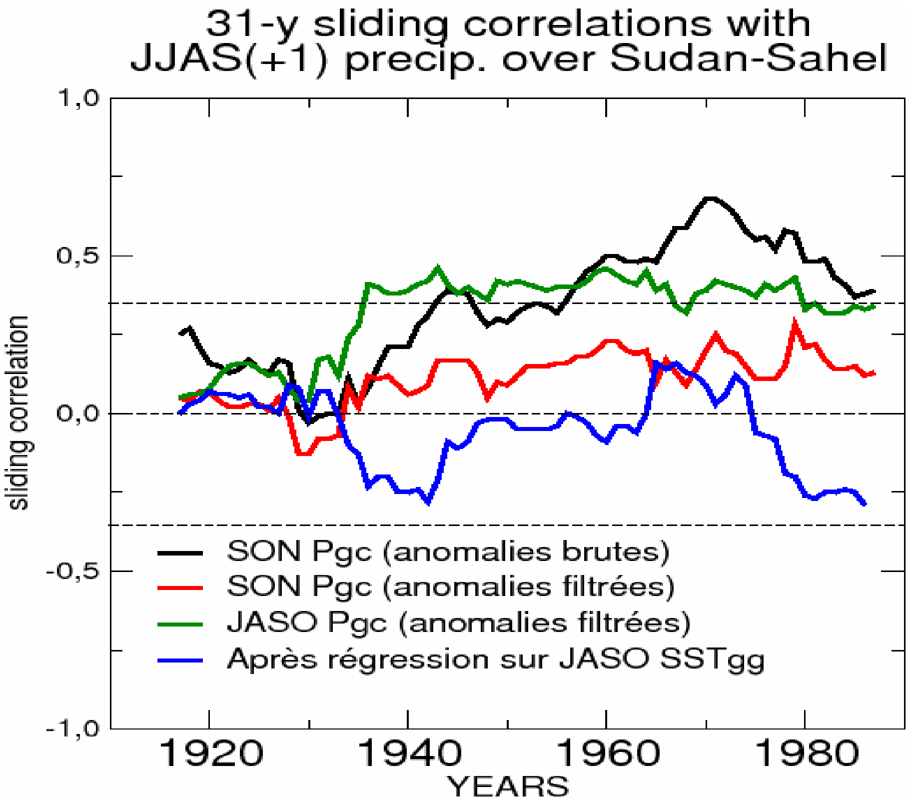


4. Regional issues: West African monsoon

(Douville et al. 2007)

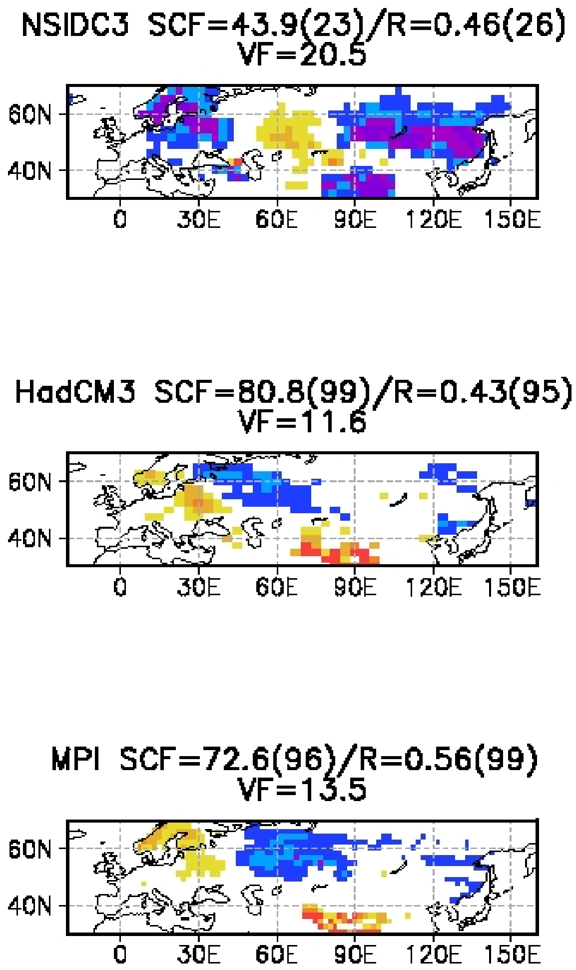
- Strong land-atmosphere coupling over the Sahel *(i.e. Douville et al. 2001, Koster et al. 2004)*
- Apparent relationship between Sahelian rainfall and the former 2nd rainy season over the Guinean Coast *(Landsea et al. 1993, Phillippon et Fontaine 2002)*

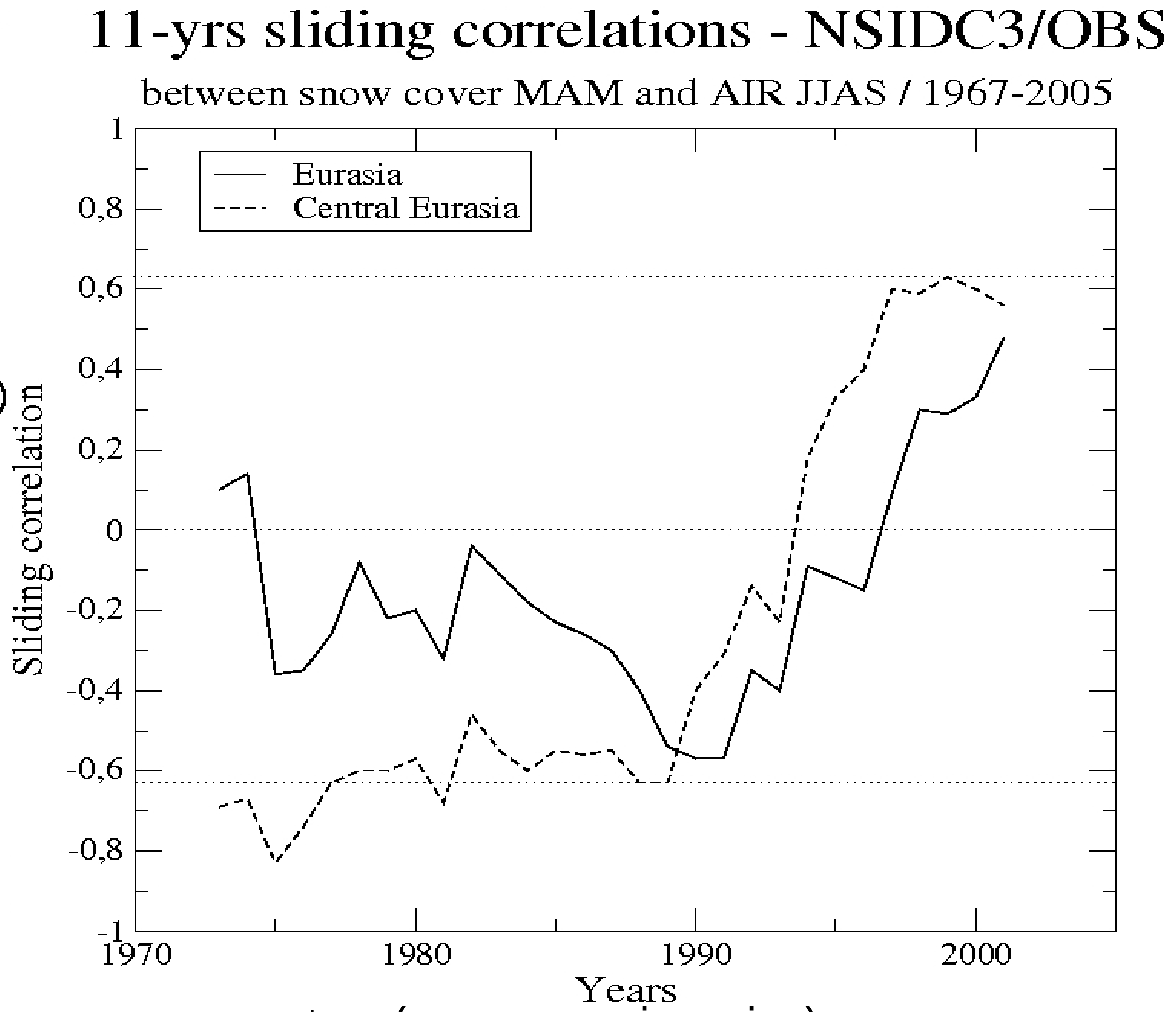




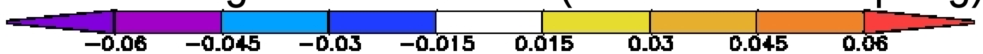
4. Regional issues: Snow-monsoon relationship

(Peings and Douville 2008)





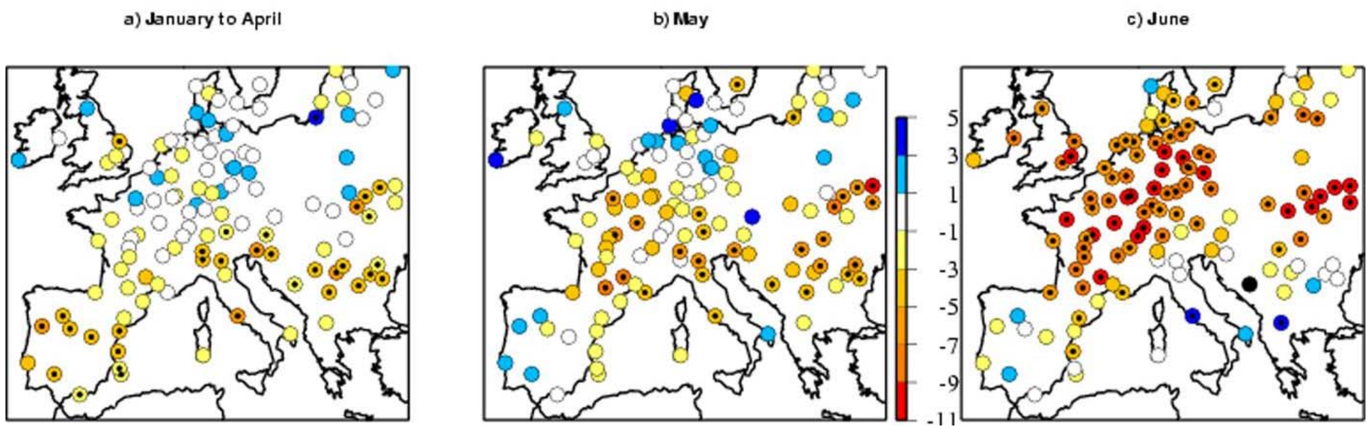
MCA homogeneous vectors (snow cover in spring)



4. Regional issues: Heat & drought over Europe

(Vautard et al. 2007)

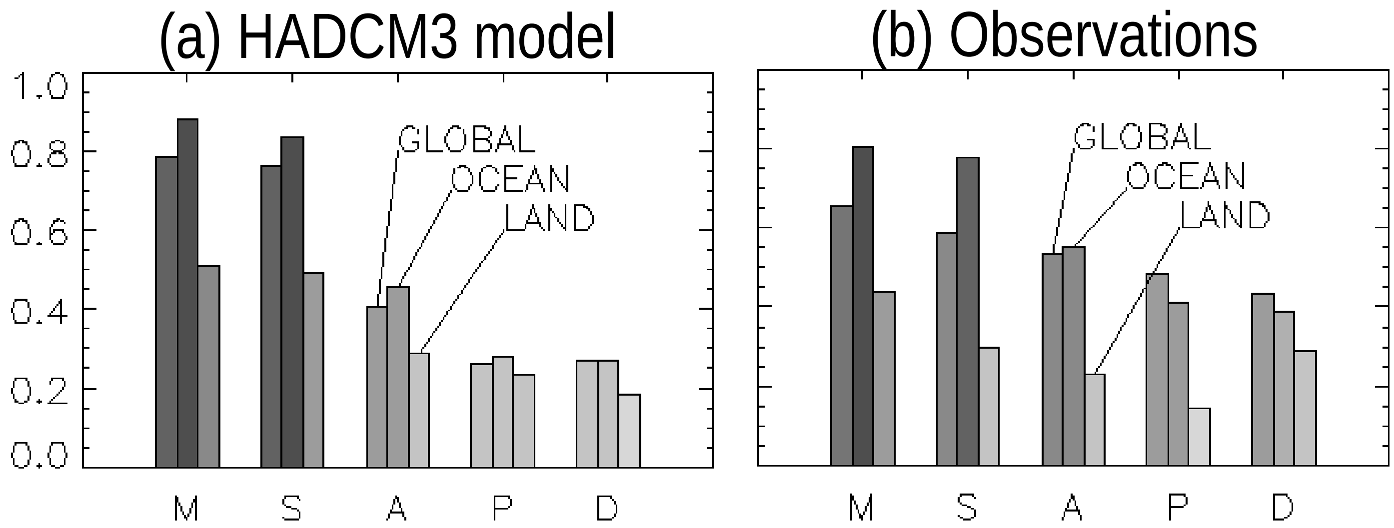
- Weak *(Koster et al. 2004)* or strong *(Schär et al. 1999)* land-atmosphere coupling over Europe ?
- Impact of soil moisture initial conditions on the predictability of summer heat waves *(Ferranti and Viterbo 2006, Conil et al. 2008)*
- Wintertime precipitation as a precursor of summer heat and drought waves over Europe *(Vautard et al. 2007)*



Rainfall frequency anomalies for the 10 hottest summers

5. Beyond the seasonal timescale ?

Lag-1 autocorrelation of surface air temperature at monthly to decadal scales *(Collins 2002)*



- NB: No variability in land cover and land use in HADCM3
- Possible influence of natural vegetation *(i.e. Zeng et al. 1999)* and land use change *(i.e. Taylor et al. 2002)* on multi-decadal climate variability ?

Summary

- ✓ GLACE-2 will provide a multi-model evaluation of the benefit of « improved » land surface initialization in 2-month forecasts;
- ✓ Improved land surface data assimilation systems are needed to provide real-time initial conditions;
- ✓ None study combines all potential sources of land surface memory (including wetlands, groundwaters, permafrost and vegetation);
- ✓ Possible impacts on the predictability of extreme climate events should be also explored (=> larger ensembles);
- ✓ Remote impacts of snow anomalies (Indian summer monsoon but also winter North Atlantic Oscillation) are still a matter of debate;
- ✓ Possible influence beyond the seasonal timescale ?

Too much emphasis on land-atmosphere coupling ?

- ✓ « Land-atmosphere interactions are perhaps the most obvious example of the need to improve the representation of climate system interactions and their potential to improve forecast quality » (WCRP position paper on seasonal prediction, 2008)

- ✓ « Model errors, particularly in the Tropics, continue to hamper seasonal prediction skill » … including in the northern extratropics and not only in winter !

The French IRCAAM Project
Experiment design *(Douville et al. 2008)*

SST / ERA40	Climatology (1971-2000)	Observed Year YY
Free ITCZ No nudging	1x30 years CtCl	30xMJJAS CtYY
Nudged ITCZ Year YY	30xMJJAS YYCl	30xMJJAS YYYY

→ 3D nudging of U,V,T,Q [15°S-25°N]

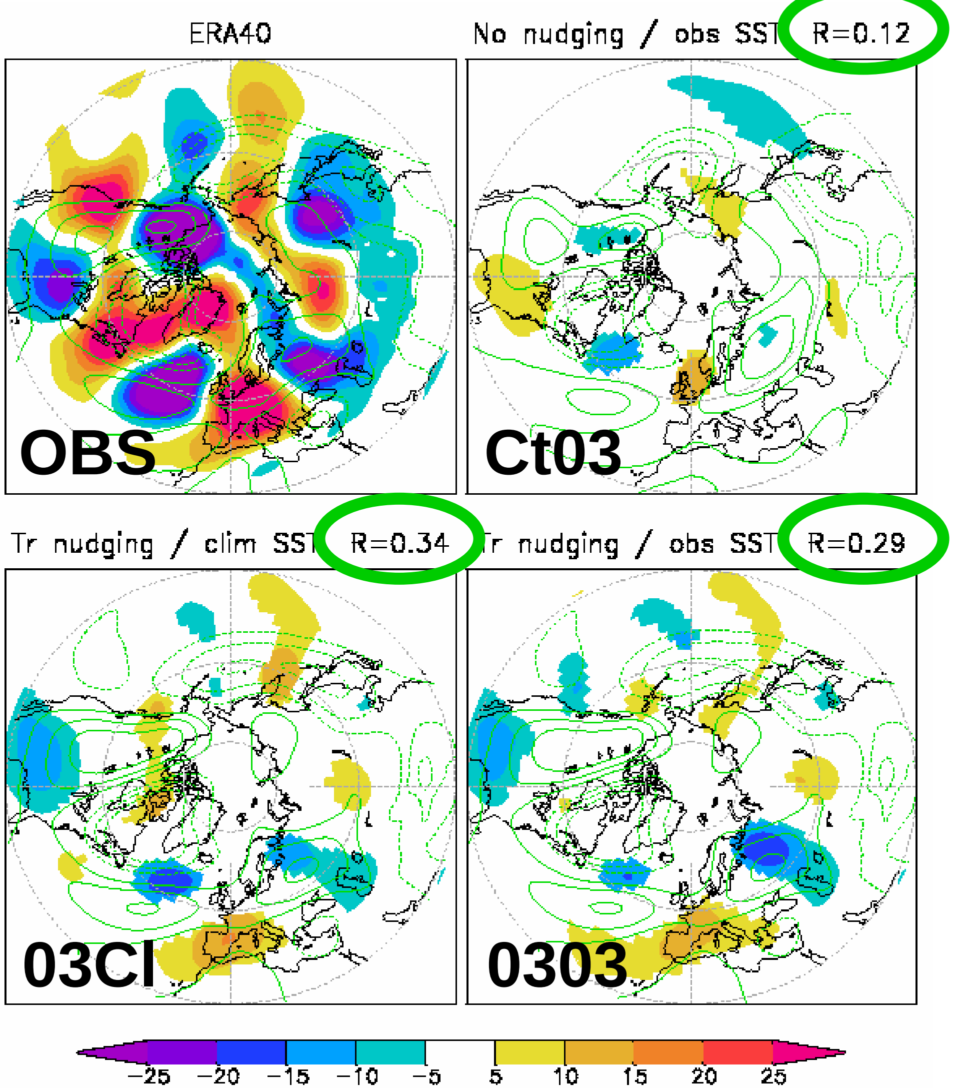
Impact of tropical nudging (case studies): JJAS northern hemisphere stationary waves

ERA40 anomalies

No nudging and observed SST

Tropical nudging and climatol. SST

Tropical nudging and observed SST



Z500* anomalies (m) and climatology

The French IRCAAM Project
Preliminary conclusions and prospects

- ✓ Tropical SST is the main source of seasonal predictability, but is probably *misused* given systematic errors in the model response (diabatic heating profile, upper-troposphere divergent circulation, Rossby wave propagation) to the oceanic forcing;
- ✓ Extratropical SST is a very limited source of predictability (at least in the summer hemisphere), but could contribute to amplify the stationary wave anomalies;
- ✓ Next step: compare the relative influence of land surface and oceanic feedbacks (coupling with an oceanic mixed layer model)