PROMISE

Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change

Final Report

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Work-package coordinator: Jean-François Royer, Meteo-France CNRM, Toulouse, France

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Participants' information:

No	Institution/ organisation	Street name & number	Postcode	Town/city	Country code	Title	Family name	First name	Telephone number	Fax number	E-mail
3	CNRM (MF)	Av. Coriolis 42	F-31057	Toulouse	FR	Ing. Chef	Royer	Jean-Francois	+33 (0)561079377	+33 (0)561079610	Jean-francois.royer@meteo.fr
3	CNRM (MF)	Av. Coriolis 42	F-31057	Toulouse	FR	Ing.	Douville	Hervé	+33 (0)561079625	+33 (0)561079610	Herve.Douville@meteo.fr
3	CNRM (MF)	Av. Coriolis 42	F-31057	Toulouse	FR	Ing. Trav.	Chauvin	Fabrice	+33 (0)561079667	+33 (0)561079610	Fabrice.Chauvin@meteo.fr
5	ICTP	Strada Costiera 11	I-34014	Miramare (Trieste)	IT	Dr., Senior Scientist	Molteni	Franco	+39 0402240572	+30 040 2240449	Moltenif@ictp.trieste.it
5	ICTP	Strada Costiera 11	I-34014	Miramare (Trieste)	IT	Dr., Senior visiting scientist	Brankovic	Cedo	+39 0402240579	+30 040 2240449	Cedob@ictp.trieste.it
5	ICTP	Strada Costiera 11	I-34014	Miramare (Trieste)	IT	Dr.	Corti (1)	Susanna	+39 0402240572	+30 040 2240449	Cortis@ictp.trieste.it
8	MPG.IMET	Bundesstrasse 55	20146	Hamburg	DE	Dr.	Schnitzler (2)	Karl-Georg	+ 49 40 41173-412	+49 40 41173-298	schnitzler@dkrz.de
8	MPG.IMET	Bundesstrasse 55	20146	Hamburg	DE	Mr	Bader	Juergen	+ 49 40 41173-302	+49 40 41173-298	bader@dkrz.de
8	MPG.IMET	Bundesstrasse 55	20146	Hamburg	DE	Dr.	Latif (3)	Mojib	+ 49 40 41173-248	+49 40 41173-298	latif@dkrz.de
8	MPG.IMET	Bundesstrasse 55	20146	Hamburg	DE	Dr.	Schnur	Reiner	+ 49 40 41173-379	+49 40 41173-298	schnur@dkrz.de
12	UB	6 Bd Gabriel	F-21000	Dijon	FR	Dr.	Fontaine	Bernard	+33 (0)3 80 39 5739	+33 (0)3 80 39 5741	fontaine@u-bourgogne.fr
12	UB	6 Bd Gabriel	F-21000	Dijon	FR	Dr.	Camberlin	Pierre	+33 (0)3 80 39 3821	+33 (0)3 80 39 5741	camber@u-bourgogne.fr
12	UB	6 Bd Gabriel	F-21000	Dijon	FR	Dr.	Philippon	Nathalie	+33 (0)3 80 39 3823	+33 (0)3 80 39 5741	nphilipp@u-bourgogne.fr
12	UB	6 Bd Gabriel	F-21000	Dijon	FR	Dr.	Trzaska (4)	Sylwia	+33 (0)3 80 39 3822	+33 (0)3 80 39 5741	Sylwia.trzaska@u-bourgogne.fr

(1) Dr. Susanna Corti is at ISAC-CNR, Via Gobetti 101, 40129 Bologna, Italy, S.Corti@isac.cnr.it but works for ICTP
(2) Dr. Karl-Georg Schnitzler is at Max Planck Institute for Biogeochemistry, Jena, Germany, but works at MPI for Meteorology.
(3) Prof. Dr. Mojib Latif, is now at Institute for Marine Research, University of Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany, +49-431-600-4050, mlatif@ifm.uni-kiel.de
(4) Dr. Sylwia Trzaska is now at IRI, Columbia University, PO Box 1000, Palisades 10964-8000, NY, USA, syl@iri.columbia.edu

SECTION 3:

3.1 Objectives

The aim of this work-package is to investigate the role of land surface processes and of anomalies in land surface conditions in determining the variability and predictability of monsoon climates. The modelling group at CNRM (MF) has investigated the interannual variability of the African monsoon, particularly the sensitivity of seasonal hindcasts of the monsoon to soil moisture specification. ICTP has studies the global wind patterns and associated snow anomalies over Eurasia, their predictability and influence on large scale monsoon circulation, and analysed the sensitivity of tropical rainfall to soil moisture and evapotranspiration anomalies. MPG.IMET has investigated the role of vegetation feedbacks for the multidecadal Sahelian rainfall variability. The work at CRC-Dijon (UB) was aimed at examining the role of the surface conditions in the variability and predictability of the West African and East African rainy seasons and at assessing the respective roles of the oceanic versus continental surfaces, the main goal being the improvement of the statistical seasonal forecasts for these regions, easy to implement in developing countries.

3.2 Methodology and scientific achievements

CNRM (MF):

Since the early feasibility studies started in 1980's, dynamical seasonal forecasting still shows very limited scores in many areas. Even the upper limit of predictability, derived from atmospheric seasonal hindcasts forced by observed sea surface temperatures (SSTs), seems to be relatively low so that dynamical forecast systems do not necessarily perform better than empirical statistical schemes (Garric, Douville and Déqué, 2002). It is therefore important to take advantage of all possible sources of climate predictability in such dynamical forecasts. Besides SST, the land surface hydrology - snow depth and soil moisture (SM) - also shows some regional anomalies that could persist long enough to affect the atmosphere over several weeks or months. Their potential impact on seasonal predictability is however difficult to assess due to the lack of reliable multi-year climatologies on the global scale. Recently, the Global Soil Wetness Project (GSWP) has investigated the feasibility of producing global soil moisture climatologies by driving land surface models (including the ISBA model of CNRM) with an observed atmospheric forcing. Though limited to a 2-year period (1987-88), this GSWP monthly dataset can be used to relax the deep soil moisture in ensembles of seasonal hindcasts based on the ARPEGE-Climat atmospheric GCM. Such experiments have been first conducted over two boreal summer seasons (1987-88) and have shown that this relaxation not only improves the ARPEGE model's climatology, but also its ability to reproduce some differences between the two seasons (Douville, 2002).

More recently, other ensembles of boreal summer atmospheric hindcasts, spanning a 15-year period (1979-1993), have been analysed (Douville, 2003a). Each ensemble is made up of ten 4-month integrations from June to September (results are averaged only over the last three months) for each season of the 15-year period. In such seasonal hindcasts, especially if the first month is discarded like in the present study, the method used to produce the different members is not very important since the growth of initial errors saturates after only a few weeks. The 15-year ECMWF reanalyses (ERA15) are used to initialize both the atmospheric and land surface variables on 27 May. For each season, the ten members are generated by adding a weak random perturbation to the ERA15 reanalyses through a simple Monte Carlo method. Only the atmospheric prognostic variables are perturbed so that all members of a given season share the same land surface initial conditions. Besides a control experiment using interactive soil moisture (SM) boundary conditions computed by the ISBA land-surface scheme, two sensitivity experiments have been performed with a relaxation of deep SM toward different monthly mean datasets: the ARPEGE climatology (based on the 15 years of the control experiment) and a presumably more realistic climatology (based on the 2 years available from GSWP). The aim is not to capture the observed patterns of interannual variability, but rather to investigate if the reproducibility of seasonal climate anomalies (perfect model approach) is sensitive to different treatments of soil moisture. Both sensitivity experiments indicate that damping the SM variability leads to a clear and robust reduction in surface evaporation and low-level temperature variability over most areas in the tropics and the summer extratropics. Variability in precipitation is not necessarily reduced since the effect of reduced evaporation variability can be offset by an increase in the mean precipitation. Such an increase is however very limited when ARPEGE is relaxed toward its own SM climatology (Fig. CNRM).

Generally speaking, soil moisture seems to have a limited impact on seasonal predictability, especially in the tropics. Moreover, changes in predictability are less homogeneous than changes in variability. For example, SM anomalies appear as a source of predictability over North America, but not over India. Several reasons can be proposed for such a contrast in the regional responses, including the stronger evaporation-precipitation feedback in the interior of the North American continent than over the Indian peninsula. Generally speaking, few tropical areas show a possible influence of SM on predictability at the seasonal timescale. The main exception is the impact found on the predictability of the low-level temperature during the dry season in the southern tropics. In the mid-latitudes, North America shows consistent patterns of decreased predictability of low-level temperature and precipitation in the relaxed SM experiments. In such regions, there is some hope to improve the dynamical seasonal forecasts through a better treatment of the land surface (improved land surface model formulation and/or land surface initialization). Our sensitivity experiments do not allow us to distinguish between the role of initial conditions and boundary conditions of SM, since both are set to climatological values. For this reason, a third ensemble of seasonal hindcasts has been conducted, in which the relaxation is implemented only during the month of June (Douville, 2003b). The results suggest that, in the regions where SM appears as a source of predictability, a large fraction of this extra-predictability originates from the initial conditions of SM. Nevertheless, additional experiments based on other GCMs and on more reliable soil moisture analyses than ERA15 (for example the forthcoming ERA40 or GSWP2 datasets) are necessary to confirm these preliminary results.

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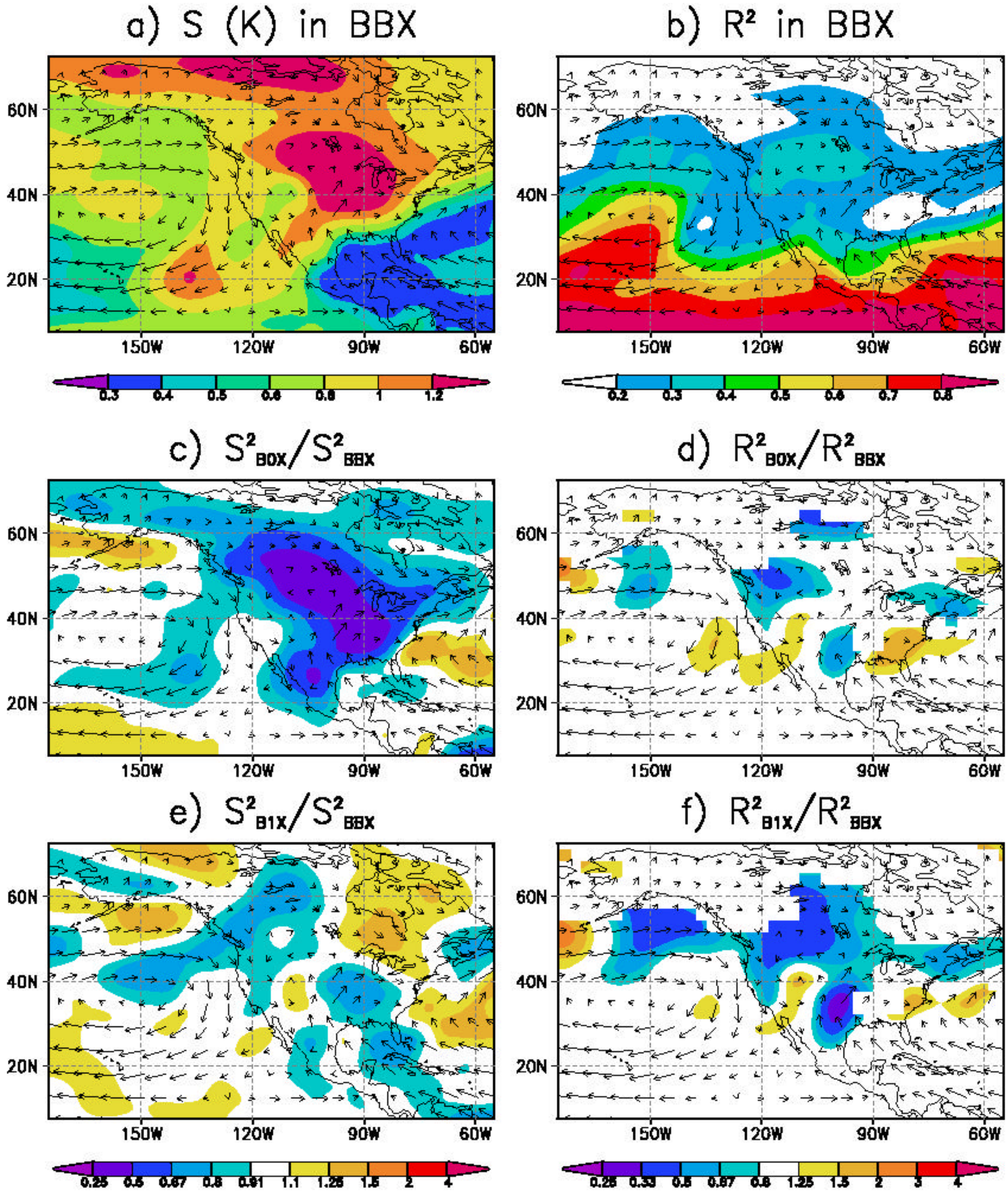

Figure CNRM: ANOVA results for the JAS mean 850 hPa temperature over North America. BBX is the control experiment with interactive soil moisture. B0X and B1X are sensitivity experiments in which the soil moisture variability is damped in the boundary conditions and initial conditions respectively. The vectors show the JAS 850 hPa mean wind in BBX. The colour shading represents: a) Total standard deviation S found in BBX, b) coefficient of determination R2 found in BBX, c) ratio of S2 between B0X and BBX, d) ratio of R2 between B0X and BBX, e) ratio of S2 between B1X and BBX, f) ratio of R2 between B1X and BBX (No shading in d and f if R2< 0.2 in both experiments)

ICTP:

The Global wind patterns and associated snow anomalies over Eurasia, their predictability and influence on large scale monsoon circulation have been studied (Corti, Molteni and Brancovic). Previous diagnostics studies based on model simulations (Corti et al. 2000, Ferranti and Molteni 1999) revealed a link between large-scale snow anomalies over Siberia and anomalies in zonal wind over Eurasia, which (in tropical regions) tend to persist from winter to spring and summer and affect the monsoon circulation over south-east Asia. However, due to the unreliability in the snow-depth re-analyses (both ERA and NCEP/NCAR) over Siberia, to date these model results have not been properly validated against observations. To address this issue, we have used the Historical Soviet Daily Snow Depth dataset (based on observations at 284 World Meteorological Organization (WMO) stations throughout the Former Soviet Union, and made available by the U.S. National Snow & Ice Data Center) together with the 40-year record of NCEP/NCAR re-analyses for upper air fields to investigate the relationship between:

(i) global long-lasting (i.e. persisting from winter to the early summer) tropospheric circulation anomalies;

(ii) tropical SST anomalies (which can determine the flow anomalies (i))

(iii) snow depth anomalies over Eurasia (which may be affected by (ii) through (i));

(iv) the large scale monsoon circulation in the following summer (related to (i)

In the following, a brief summary of the results obtained from such diagnostics is presented.

<u>*Datasets*</u>: The following dataset have been used:

- NCEP/NCAR reanalysis: seasonal means of zonal wind at 200 and 850 hPa in December-February (DJF), March-May (MAM), June-August (JJA), from 1958 to1998.
- Historical Soviet daily Snow depth dataset based on observations at a series of 284 WMO stations through the former Soviet Union (1881- 1995).

<u>*Filters and interpolations*</u>: Snow-depth data (originally daily station data) have been converted into monthly means on a regular 5x5 grid, by averaging the data from all stations reporting for at least 15 days in each month, and located within a 5x5 grid-box centred on each grid point. Furthermore, to perform teleconnection studies between snow depth at the end of winter (i.e. in March) and large-scale circulation parameters, the data have been statistically interpolated to fill the missing values over the period 1958-1995. Since it was found that the best overall coverage was obtained for the 70-year period 1926-1995, the following procedure was adopted:

1. A principal component (PC) analysis was performed on standardised anomalies of March snow depth in the 1926-1995 period, using only stations with more than 80% of available data, and setting the anomaly to zero in missing years.
2. For each time series in the original data with more than 70% of available data, a regression of available data against the first 10 PCs from Step (1) was performed, and the results of the regression was used to fill the missing data for those stations only. In the regression, PCs were re-orthonormalised for the sub-sample of available data at each grid-point, and only those PCs which explained a variance fraction twice as large as explained (on average) by a random time series of the same length were used.
3. Using the filled-up data from Step (2), two further PC analysis were performed as in Step (1), for the periods 1926/95 and 1959/95.
4. Using the regression procedure in Step (2), missing data were re-estimated:
   a) in the 1926/95 period, for all stations with more that 25% of available data, using the first 10 PCs
   b) in the 1959/95 period, for all stations with more that 40% of available data, using the first 10 PCs

<u>*Diagnostic tools*</u>: An EOF analysis was applied to the wind seasonal anomalies from 1959 to 1998 in the sector (40-120°E, 0-90°N) in order to define, for each level and season, a reduced phase space based on the leading modes of variability. A further EOF analysis of the 200-850 wind fields was then performed in the subspace spanned by the 20 leading EOFs of each wind level. This produced a EOF picture of the large-scale vertical structure of the zonal wind. The Eurasian snow depth anomalies associated with the leading circulation patterns were then identified by computing, for each season, the covariance between the wind principal components (associated with the EOFs) and the snow anomaly time series. Finally, the leading variability pattern of March snow depth in the 1959-95 period was defined by an EOF analysis of monthly snow anomalies.

<u>*Results*</u>: Figure ICTP-1 shows the leading EOF of the 200-850 wind seasonal anomalies over the "Asian sector" [i.e. 40-120E; 0-90N]. The DJF upper level anomalies are characterised by zonally-elongated patterns corresponding to a strengthening of the jet at high latitudes (45-70 N), accompanied by weakened westerly winds over north-east China, while a westerly anomaly prevails over south Asia (0-25N). The MAM and JJA upper level patterns are somehow similar to their winter counterpart, but with weaker anomalies. The corresponding patterns at 850-hPa during winter and spring are associated with increasing westerly winds over Siberia while an easterly anomaly is located north of 70N. Apart from this winter/spring equivalent barotropic signal, the most significant anomaly at the lower level is found during the summer when the signal at 200-hPa becomes weaker. The JJA zonal wind anomalies at 850-hPa represent a reduced westerly flow over India and South-East Asia, which indicates a weaker than normal low level Monsoon circulation.

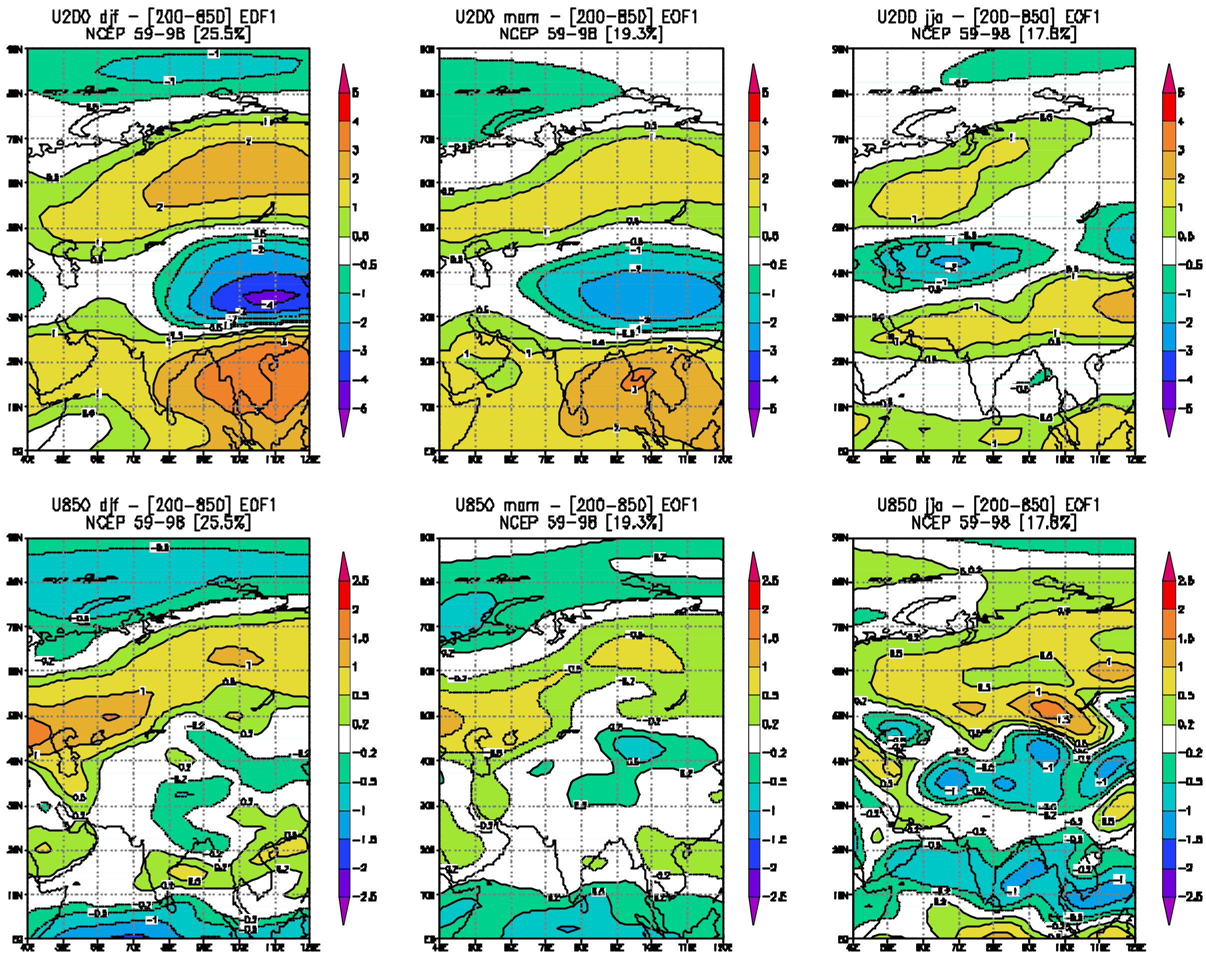

Fig. ICTP-1 Leading EOF1 of the 200-850 zonal wind seasonal anomalies over the 1959-98 period. Left column: DJF; middle column: MAM; right column: JJA. Top row: 200-hPa level. Bottom row: 850-hPa level.

The Eurasian snow depth anomalies in March associated with the leading circulation patterns in winter and summer, together with the leading March snow-depth EOF, are shown in Fig.ICTP-2. All the three patterns are characterised by a positive anomaly over north-west Asia [45-80°E; 40-75°N], which can be interpreted as follows. The correlation pattern between the snow depth anomalies in March and the zonal wind principal components (PCs) during the previous winter (top panel) shows an enhanced snow deposition, caused by the shift in the area of maximum baroclinicity associated with the zonal wind anomaly. This pattern of snow depth spring anomaly, induced by the circulation during the previous winter, in turn may influence the large scale monsoon circulation during the following summer. In particular it may force a weak-monsoon circulation anomaly, as suggested by the correlation pattern in Fig.2 (middle panel). Since the leading snow-depth EOF in March (bottom panel) presents the same kind of anomaly, the time series of the first snow depth PC can be used to quantify the relationship between snow and large scale circulation patterns in different seasons. In this way, it is possible to establish a sort of hierarchy of predictors for the seasonal monsoon circulation.

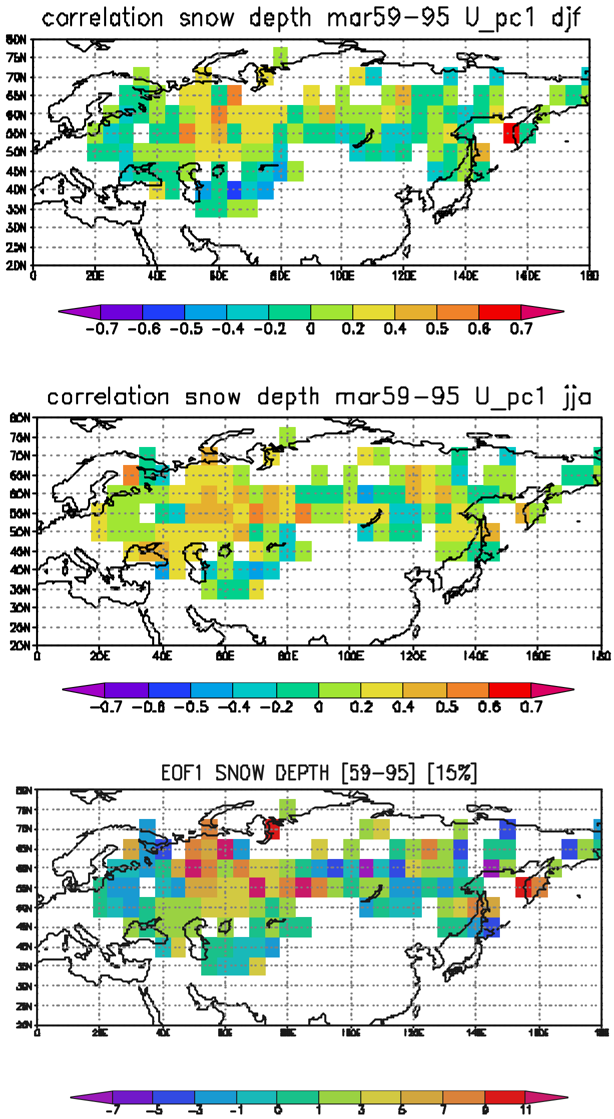

Fig. ICTP-2. Top panel: correlation pattern between DJF zonal wind PC1 and snow depth anomalies in March. Middle panel: the same as below but for JJA zonal wind PC1. Bottom panel: leading EOF of snow depth anomalies in March.

Table 1 – Predictors (rows) vs. predictands (columns) table. Correlation coefficients between Nino3.4, zonal wind PC1 and March snow-depth PC1. Period 1959-98.

CORRELATION COEFFICIENTS [59-98]	SNOW MARCH [59-95]	PC1 U WINTER (DJF)	PC1 U SPRING (MAM)	PC1 U SUMMER (JJA)
NINO3.4 WINTER	10%	53%	29%	26%
NINO3.4 SPRING	17%		53%	33%
NINO3.4 SUMMER				15%
PC1 U WINTER	21%		33%	45%
PC1 U SPRING				27%
SNOW MARCH [59-95]			12%	67%

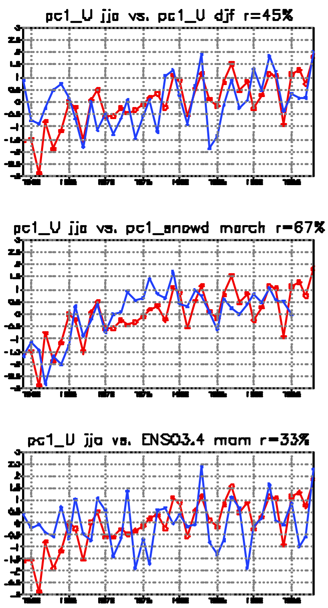

Fig ICTP-3 All panels in red: JJA zonal wind PC1. In blue: top panel: DJF zonal wind PC1; bottom panel: snow-depth PC1 in March; bottom panel: Nino3.4 index in spring.

The results for the 1959-98 period are summarised in table 1, and listed below.

- The leading EOF of Eurasian snow-depth in March and JJA zonal wind are strongly (67%) related, and exhibit a positive trend during the first half of the record.
- The best predictors of the large-scale monsoon circulation during the summer are:
    - March snow-depth over Eurasia (67%)
    - DJF zonal wind (45%)
    - Nino3.4 during the previous spring (33%)

Figure ICTP-3 shows the JJA zonal wind principal components time series, compared to the time series of the three best predictors. The JJA zonal wind PC exhibits a noticeable positive trend, particularly strong during the first half of the record. The same kind of trend characterises the snow depth PC, suggesting that the high correlation index found between the two time series could be mostly due to this common feature of interdecadal variability. (Considering that the two dataset are completely independent, the fact that both snow depth and summer zonal wind present a comparable positive trend may have some interesting implications related to global warming signals, which deserve to be further investigated). In order to find the best predictor of the monsoon circulation over an interannual timescale, the analysis has been repeated focussing on the second half of the record (where the positive trend seems somehow weaker).

Table 2 – Predictors (rows) vs. predictands (columns) table. Correlation coefficients between Nino3.4, zonal wind PC1 and March snow-depth PC1. Period 1977-95

CORRELATION COEFFICIENTS 77-95 (59-98)	SNOW MARCH	PC1 U WINTER (DJF)	PC1 U SPRING (MAM)	PC1 U SUMMER (JJA)
NINO3.4 WINTER	29% (10%)	59% (53%)	54% (29%)	38% (26%)
NINO3.4 SPRING	40% (17%)		67% (53%)	45% (33%)
NINO3.4 SUMMER				32% (15%)
PC1 U WINTER	60% (21%)		47% (33%)	50% (45%)
PC1 U SPRING				7% (27%)
SNOW MARCH			30% (12%)	23% (67%)

From the new results, listed in table 2, a rather different picture emerges:

- The leading snow-depth EOF1 in March is associated (60%) with a global wintertime circulation (DJF zonal wind EOF1) which tends to persist through the following spring up to the summer (50%).
- This kind of circulation is influenced by a boundary forcing arising from ENSO-related SST anomalies during the previous winter (59%)
- The best predictors of the JJA zonal wind EOF1 are:

- DJF zonal wind (50%)
- Nino3.4 during the previous winter and spring (45% - 38%)
- March snow-depth over Eurasia (23%)

References

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Ferranti, L. and F. Molteni, 1999: Ensemble simulations of Eurasian snow-depth anomalies and their influence on the summer Asian monsoon. Q.J.R.Meteorol.Soc., 125, 2597-2610.

Another contribution of ICTP consisted in sensitivity experiments with locally modified land surface. In order to study the impact of locally modified boundary conditions on seasonal time-scale predictability, a series of experiments with a recent version of ECMWF GCM was carried out. The experiments were run in ensemble mode at a relatively high resolution, T159-L40. The model was forced with observed SSTs, and initial conditions were taken from ERA-15. The broadleaf and mixed forests over the northern part of South America were replaced by tall grass. In one set of experiments, albedo was sett to the appropriate value for tall grass (normal albedo), and in the other was forced to a higher value (extreme albedo).

The model response in forcing experiments was compared against control ensemble. The largest response is found in surface and near surface fields over South America. The amplitude of surface warming and the reduction in surface pressure are stronger in the case with extreme albedo than with the normal one. These changes are also seasonally dependent – they are larger in JAS than in JFM. The reduction in local precipitation rate is consistent with increased temperatures and reduced evaporation due to reduced soil moisture. For global precipitation, the model response is confined mostly to the tropics and to relatively smaller spatial scales. Despite such a patchy precipitation pattern, the response is stronger away from the centre of imposed forcing, in the eastern Pacific and in the Indian Ocean, than in the central and western equatorial Pacific. In the northern winter upper-air fields, a coherent wavetrain across the northern hemisphere emerges.

MPG.IMET:

Climate variability on decadal time scales as resulting from feedback processes between the physical climate system and dynamic land vegetation in the Sahel has been studied. Observed rainfall anomalies over the Sahel (defined here as the region between 13-20° N and 15° W to 20° E) during the last five decades show a dramatic drying trend of almost 300mm/year from the fifties to the mid-eighties of the last century. Sea surface temperature (SST) variability and desertification have been proposed as causes for this trend (e.g. Rowell, 1996). However, the physical climate can be controlled to a significant extent by the vegetation distribution, which changes surface albedo and the energy/water budget.

MPG.IMET has investigated the role of vegetation feedbacks for the multidecadal Sahelian rainfall variability during the last five decades using the ECHAM4 atmospheric general circulation model (AGCM) coupled to the simple dynamic vegetation model SVEGE (Zeng et al., 1999, Science, 286, pp 153ff.). This model simulates vegetation growth and loss by a simple functional relationship with plant available soil water (and thus precipitation) and leaf area index, including a relaxation term for vegetation response time. The feedback processes included in the coupled model include changes in albedo, evapotranspiration and surface vegetation cover due to leaf area index changes. Four different ensemble integrations with prescribed observed SSTs were performed: a "control" ensemble with the standard ECHAM4 model using fixed annual climatological vegetation and albedo, an ensemble with ECHAM4 interactively coupled to the SVEGE model, an ensemble of integrations with a fixed but updated annual mean vegetation and albedo that were derived from the ensemble mean of the coupled ECHAM4/SVEGE integrations, and finally integrations with a fixed monthly mean vegetation and albedo also derived from the dynamic vegetation ensemble.

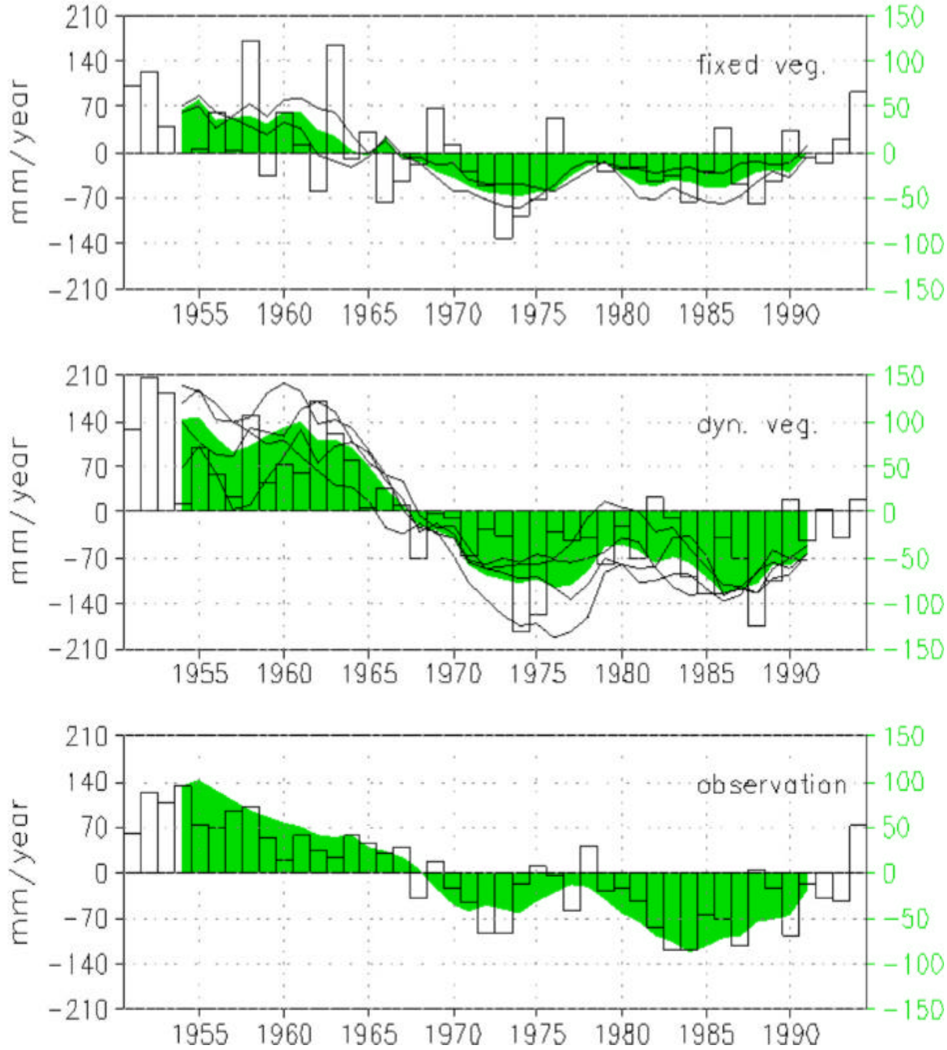

Figure MGP.IMET: Sahel rainfall anomalies relative to the 1951-1994 mean for experiments using fixed (top) and dynamic vegetation (middle), and observations (bottom). Bars: ensemble average of annual means (left axis); solid lines: 7-year running means of single ensemble realizations (right axis); shaded curve: ensemble average of 7-year running means (right axis).

The control simulation forced with observed SST alone is unable to reproduce the amplitude of the Sahelian drying trend from the 1950's to the 1980's. Using the updated vegetation and albedo distribution leads to an improvement over the control run in the simulation of the spatial rainfall pattern in the Sahel and Sahara regions, but still underestimates the amplitude of the multidecadal variability (Fig. MGP.IMET, top). An even better spatial rainfall pattern and a realistic amplitude of multidecadal variability are obtained with the fully interactive vegetation model (Fig. MGP.IMET, middle), which includes three mechanisms not contained in the "fixed vegetation" runs: a variable amplitude of the albedo annual cycle, the interdecadal trend of albedo and the variation of transpiration area (leaf area index). The combination of these processes enhances the SST-induced multidecadal signal by weakening precipitation at the beginning of the monsoon season during dry years through the effects of increased albedo and by enhancing rainfall at the end of the season during wet years through stronger evapotranspiration and convective precipitation related to higher leaf area index. Thus, vegetation responding dynamically to precipitation changes acts as an amplifier for a low-frequency (i.e. interdecadal) signal of SST anomalies.

Neither the control nor the "fixed vegetation" experiments are as persistent with respect to the simulated rainfall as the observations and the dynamic vegetation runs. The dynamic vegetation tends to keep years following wet years to be wet again, and vice versa. Since the dynamic vegetation model uses a vegetation timescale of one month there is little information carried from one year to the next due to vegetation memory. It was therefore further analysed which mechanism is responsible for the improved rainfall persistence in the interactive vegetation experiments. Using lagged correlation analysis between precipitation and leaf area index, it was found that part of the signal of one year's precipitation anomalies in the Sahel region is carried into the following year via the leaf area index information in the coupled atmosphere-vegetation-soil system.

In another study, the effect of mid-Holocene changes in the Earth's orbit and the presence of vegetation, lakes and wetlands in today's Saharan region has been studied. Experiments with ECHAM4 using today's and mid-Holocene insolation and SST forcings emphasize the importance of the changed land surface for the realistic simulation of the "green Sahara". Orbital changes alone were not able to maintain the increased amplitude and northward shift of the West African monsoon. Preliminary results from coupled experiments using the ECHAM5-MPI/OM1 AOGCM suggest a somewhat larger role of the insolation changes.

UB-CRC:

Previous work at CRC-Dijon has shown that statistical forecasts/hindcasts based on the sole standard ocean surface thermal predictors are more useful to predict longer term trends than interannual variability. Furthermore the statistical relationships between traditional SST predictors and rainfall in Africa seem to be unstable on decadal time scales. They seem to greatly depend on the state of the global ocean. The changes in the teleconnections have been successfully reproduced in AGCM sensitivity experiments using ARPEGE-Climat with prescribed specific oceanic boundary conditions (Janicot et al. 2002). The role of the slow warming of the tropical Indian Ocean has been highlighted. On interannual time-scales better statistical forecasts are obtained using more localized low-level atmospheric predictors merging global and regional influences. For West Africa low level Moist Static Energy content (MSE) seems to form a relevant framework. April-to-June meridional patterns of the near surface MSE south of 10°N control the amplitude and timing of the Sahelian July-to-September rainy season (Fontaine and Philippon, 2000). Wetter than normal Sahelian season are usually preceded by stronger than normal MSE gradients during boreal spring. For East Africa useful predictors are related to atmospheric dynamics signals: Indian monsoon and Walker-type circulation for the short rains, Congo basin air mass intrusion and MSE gradient between East Sahel and Ethiopian Mounts for the long rains. For both seasons, significant signals are observed within subtropical stationary waves (Camberlin and Philippon, 2001, 2002). For both regions the NCEP-NCAR Reanalysis atmospheric data were found to be useful for deriving predictors and statistical forecasts with a lead of one season. The real-time statistical forecasts for the 2000 and 2001 Sahelian rainy season were correct. Moreover zonal dynamics and moisture convergence in the reanalyses bear some potential for further improvements of the statistical rainfall forecasts for West Africa (Fontaine et al., 2003).

As far as the continental conditions are concerned, the strong relationship found between Sahelian July-to-September rainfall and the previous September-to-November rainfall amounts over the Guinean Region is of particular interest (Fig. CRC). The hypothesized mechanism for this interseasonal teleconnection involves soil moisture (Philippon and Fontaine, 2002) and is also supported by the rather strong relationship between the development of the vegetation prior to the onset of the monsoon and Sahelian rainfall found in the independent NDVI dataset. The role of the vegetation development on the dynamics of the monsoon has been tested through sensitivity experiments with ARPEGE-Climat (Meteo-France).This model has been found to represent well the seasonal evolution of the West African Monsoon and its interannual variability with a delayed northward shift of the monsoon in wet years, consistent with the observations. The modification of the seasonal cycle of the model vegetation in the Guinean region led to significant changes in the West African monsoon timing and amounts, still less important than global SST impacts. This further supports the possible improvements of dynamical forecasts by better representing the mean and interannual variability of the continental conditions in AGCM.

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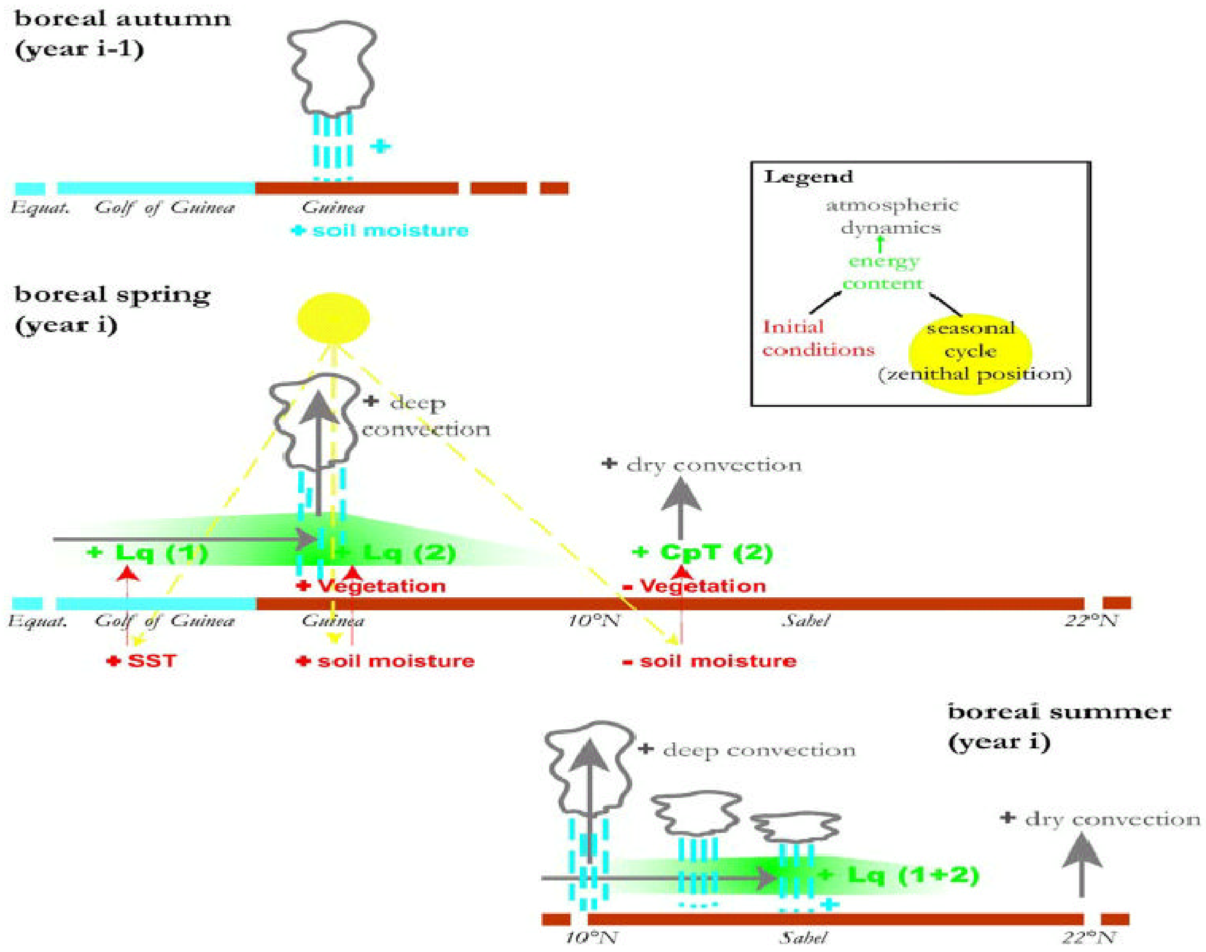

Fig CRC: Schematic view of the mechanisms influencing regional meridional low level gradients of MSE (green shadings) over Atlantic and West Africa with focus on interseasonal persistence (Lq and CpT denote standard latent and sensible energy fluxes). An abnormally high precipitation during autumn over Guinea region leads to stronger MSE gradients between Guinea and Sahel in the next spring, and thus to stronger monsoon over the Sahel in summer.

3.3 Socio-economic relevance and policy implication

Though NCEP atmospheric data may be useful for deriving simple statistical seasonal forecasts with one season lead for West Africa and East Africa on regional scales, the results reported above show the importance of understanding and including the feedbacks between land surface conditions and the atmosphere on regional climate systems, such as the African and Indian monsoon. These feedbacks seem to have the possibility of exerting a long term influence on the development of the monsoon and thus to be a potential source of long-term predictability. Therefore they must be taken into account in any model setup which is to predict seasonal climate variations, as well as for simulating past and future climate, and transitions between different climate regimes. In the future, further improvements of the land surface component and of its initial state by means of suitable measurements of the soil water content, will need to be introduced to produce more accurate climate simulations, which will be of significant value for regional climate change forecasting, and for impact assessment.

3.4 Discussion and Conclusion

During this project the participating groups have performed and analysed numerical simulations documenting the sensitivity of the monsoon to different aspects of land surface processes. The importance of a correct specification of soil moisture for seasonal predictions of Sahel rainfall is confirmed by the sensitivity experiments carried out at MF. Ensemble simulations with SST composites at UB have confirmed the importance of SST patterns in initiating surface anomalies, especially for wet years. A surprisingly high correlation has been found between soil moisture in autumn and the monsoon season of the following year, and a plausible explanation of the various feedbacks involved in this relationship has been proposed. ICTP has investigated the importance of the winter snow cover and carried out ensemble simulations at high resolution over the period 1980-90 using boundary conditions from ERA-15. The simulations with a coupled vegetation model at MGP.IMET have shown the importance of using a dynamic vegetation for enhancing the variability and persistence of rainfall anomalies over the Sahel and Sahara regions. Due to the late availability of the reanalysis ERA-40 several of the planned work had to be carried out on using the shorter ERA-15 data, but will be extended over a longer period.