



**1849-38**

**Conference and School on Predictability of Natural Disasters for our  
Planet in Danger. A System View; Theory, Models, Data Analysis**

*25 June - 6 July, 2007*

**Forecasting the occurrence of extreme tropical rainfall anomalies with  
ensemble seasonal prediction systems**

Franco Molteni  
*European Centre for Medium-Range Weather Forecasts  
Reading, U.K.*



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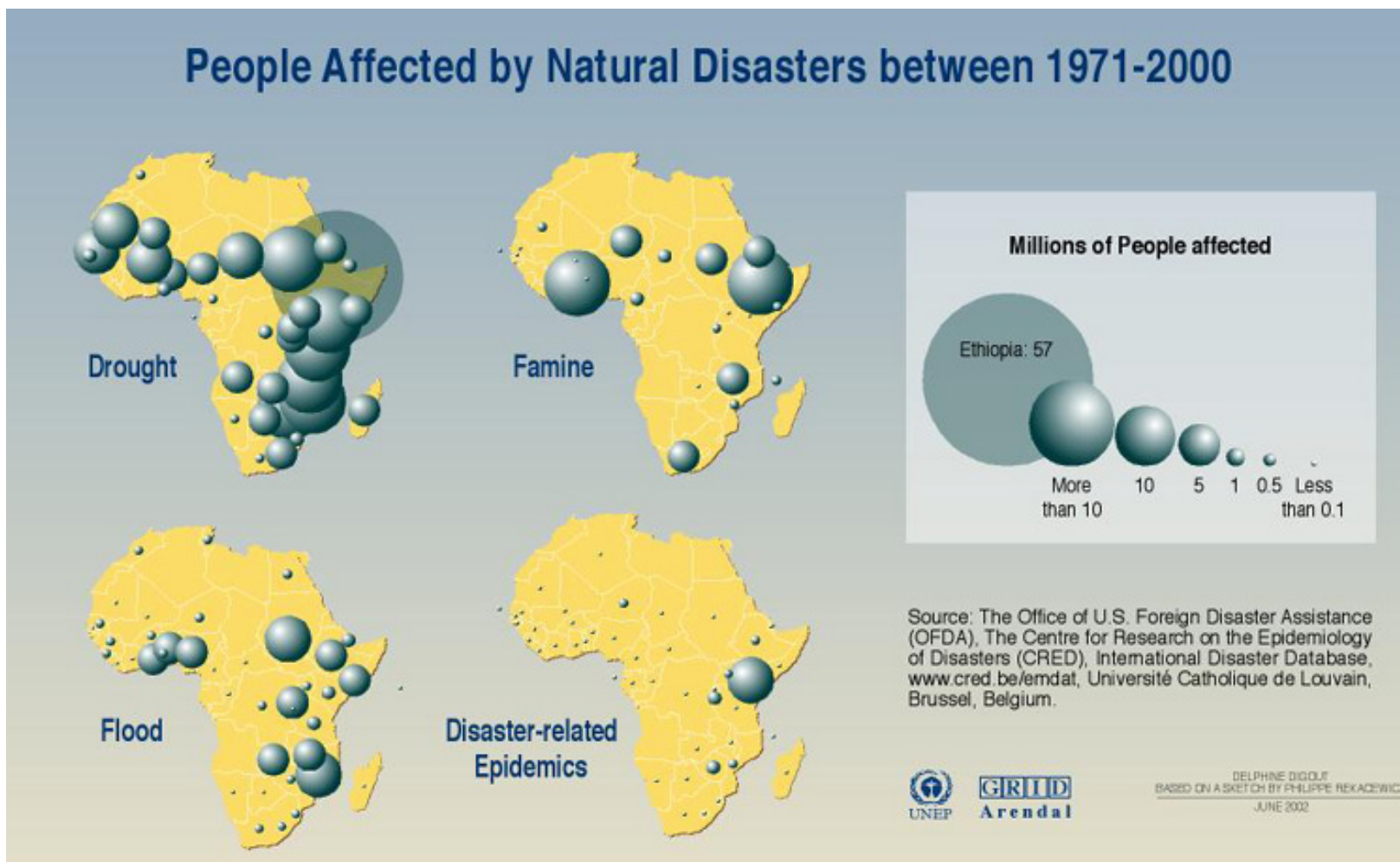
# Forecasting the occurrence of extreme tropical rainfall anomalies with ensemble seasonal prediction systems

Franco Molteni

European Centre for Medium-Range Weather Forecasts

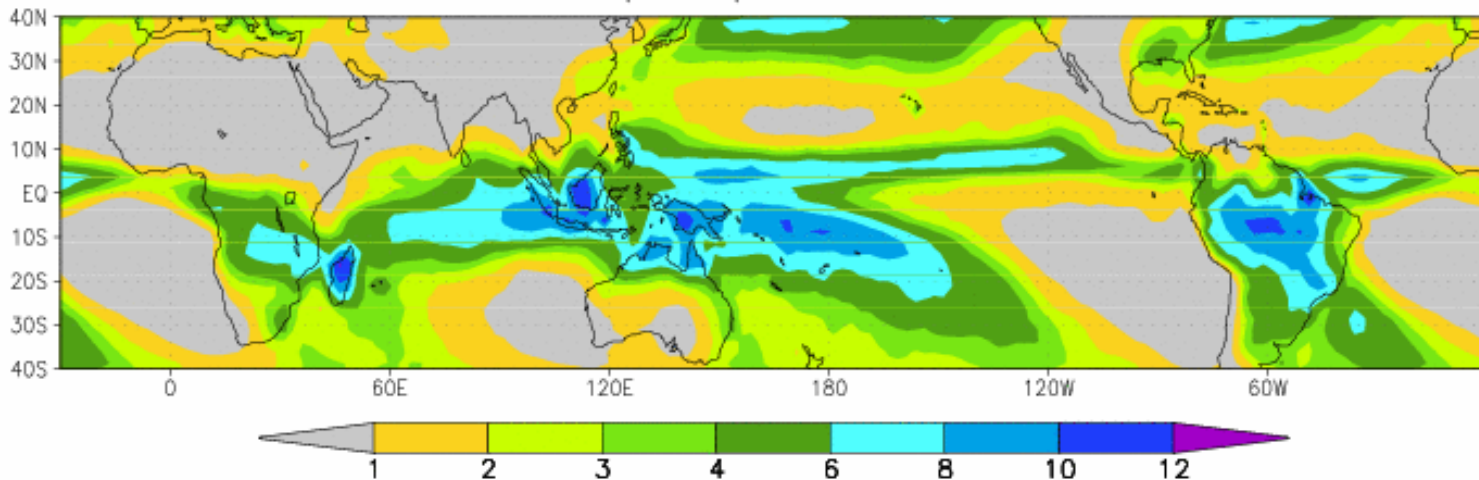


# Rainfall anomalies and natural disasters

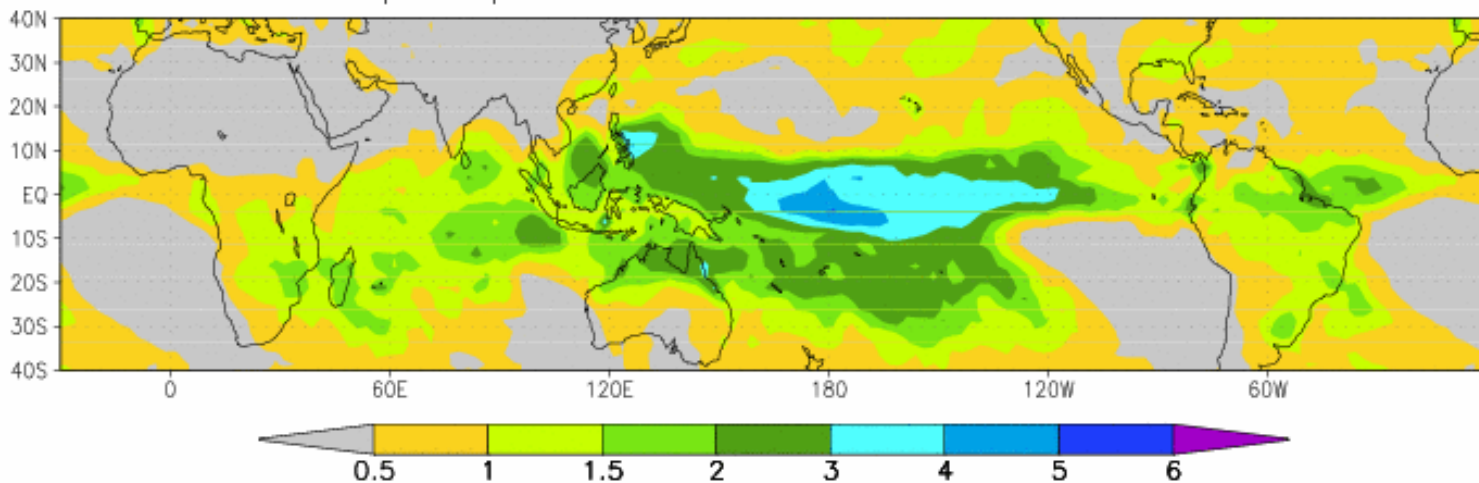


# GPCP rainfall climatology: DJF 1981-2005

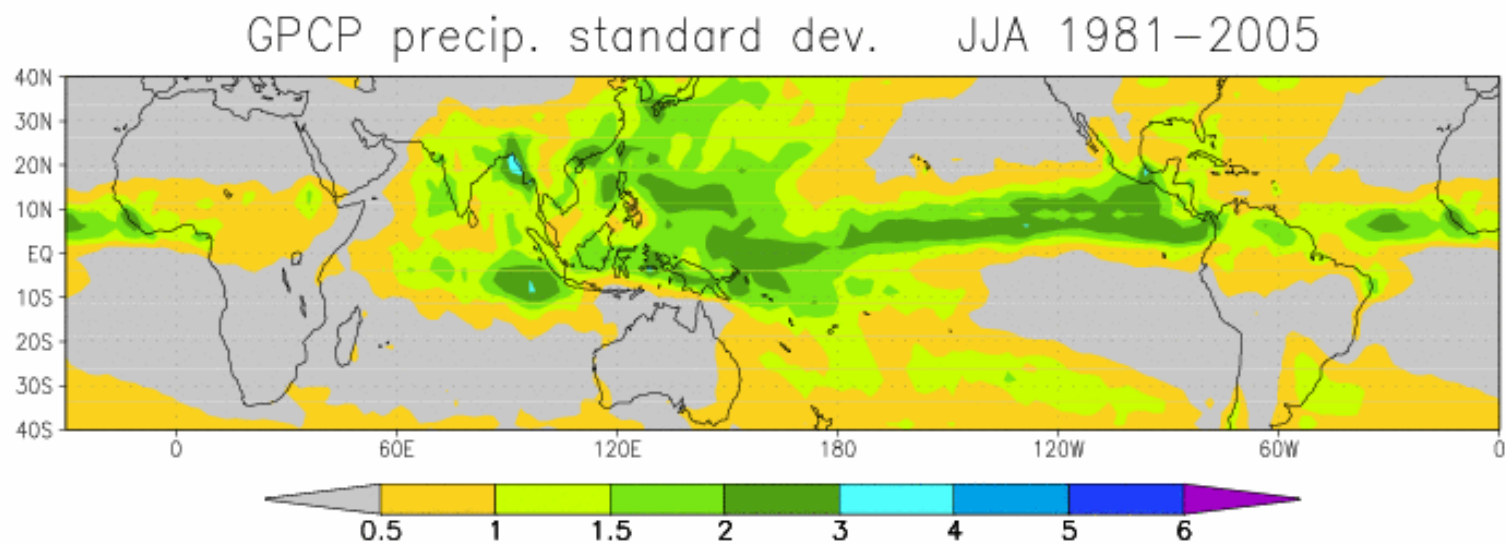
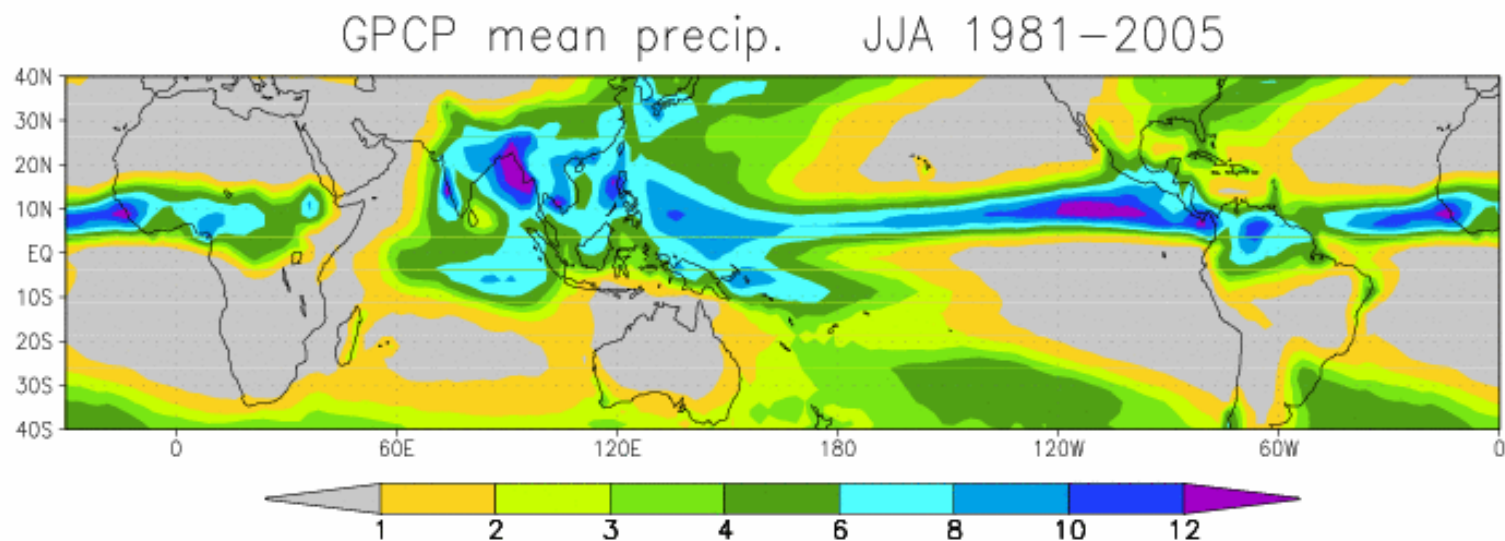
GPCP mean precip. DJF 1981-2005



GPCP precip. standard dev. DJF 1981-2005

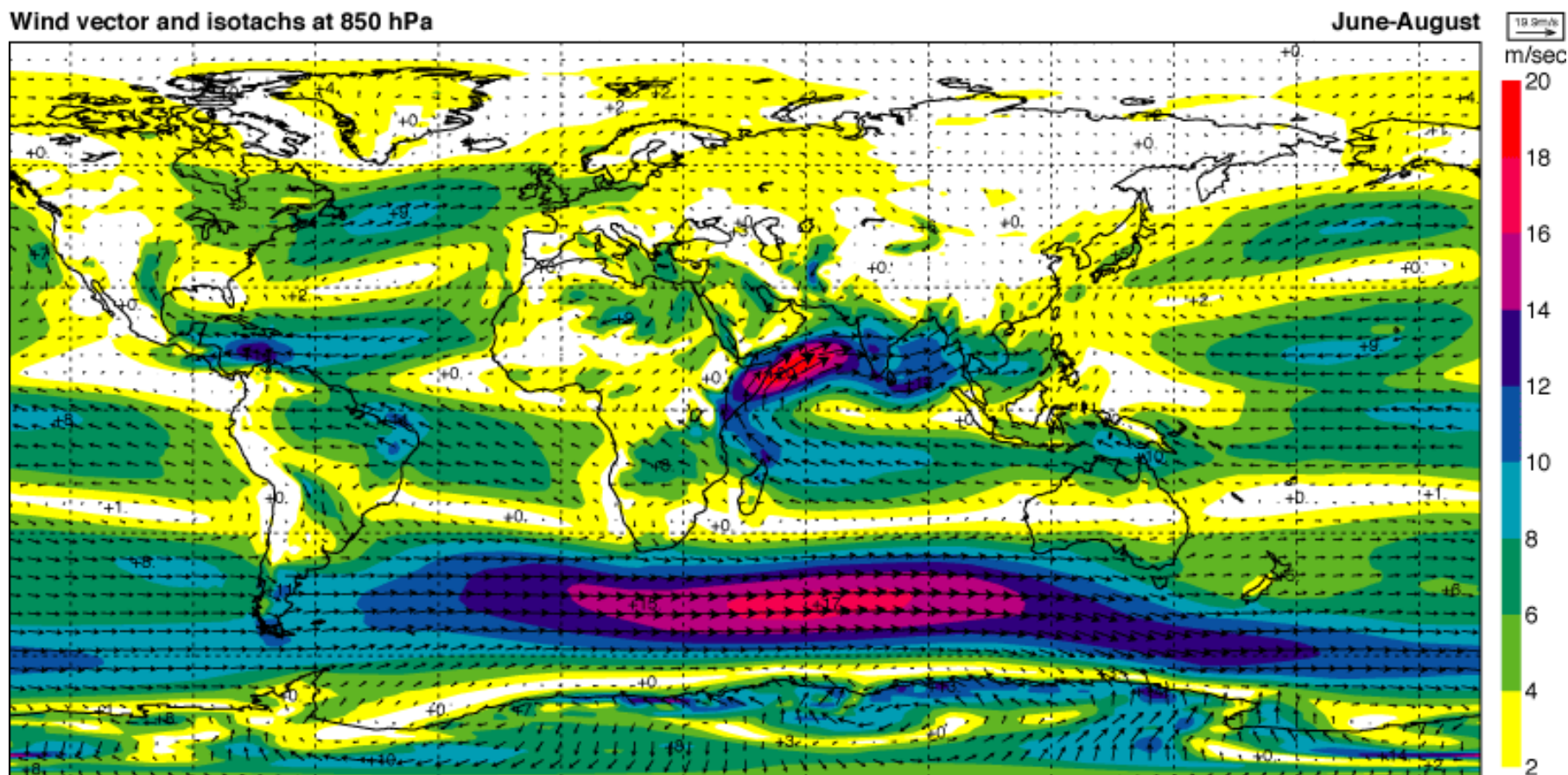


# GPCP rainfall climatology: JJA 1981-2005



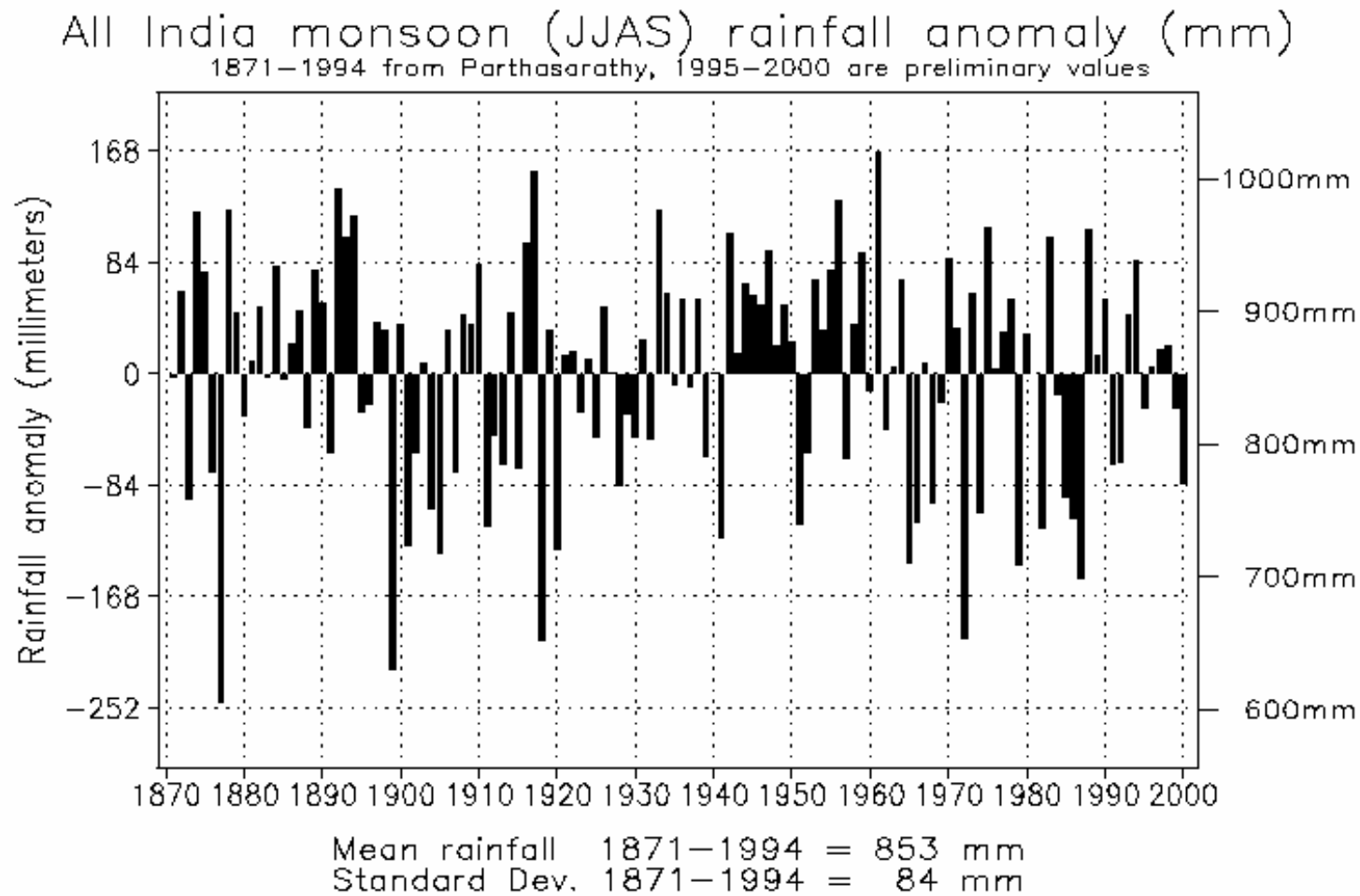


# Era-40 climatology of 850-hPa wind in JJA



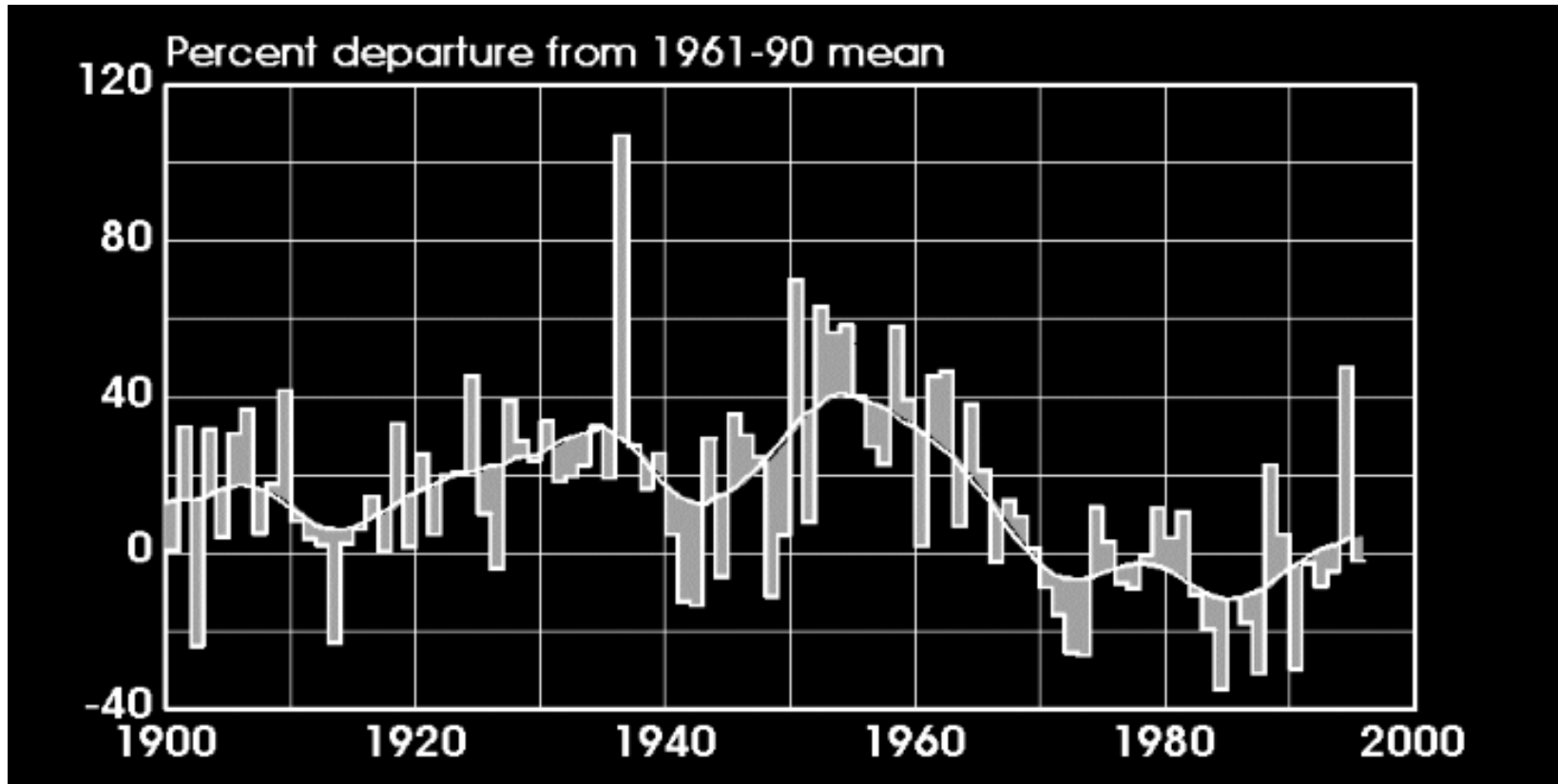


# Variability of all-India rainfall (JJAS)



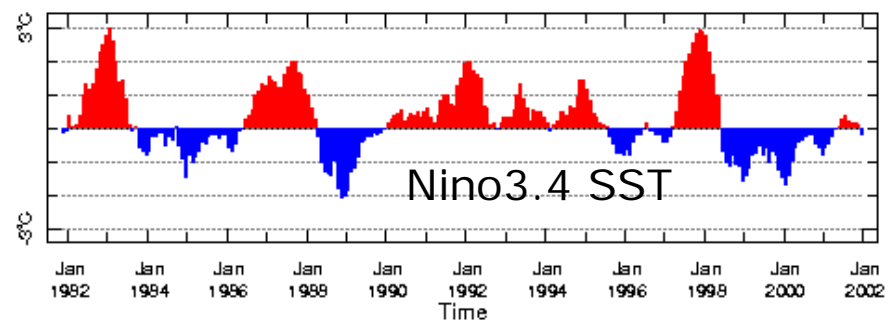
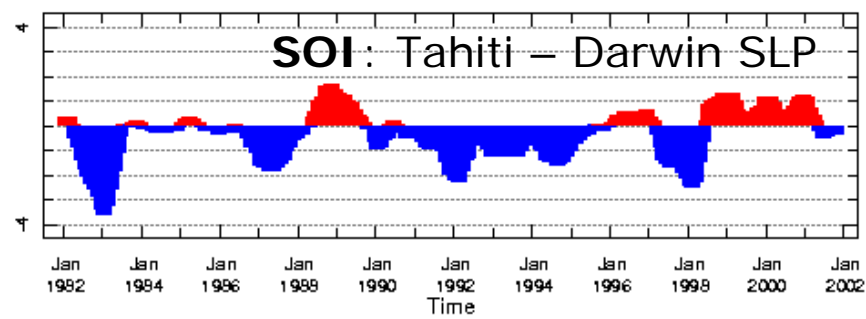
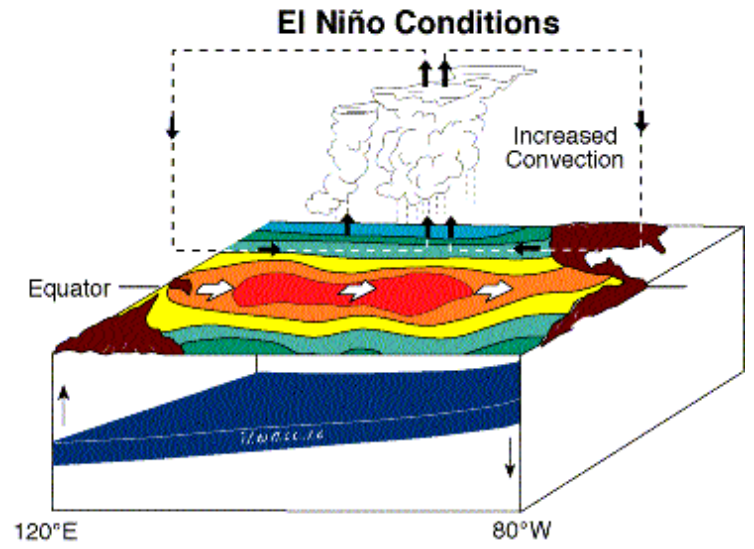
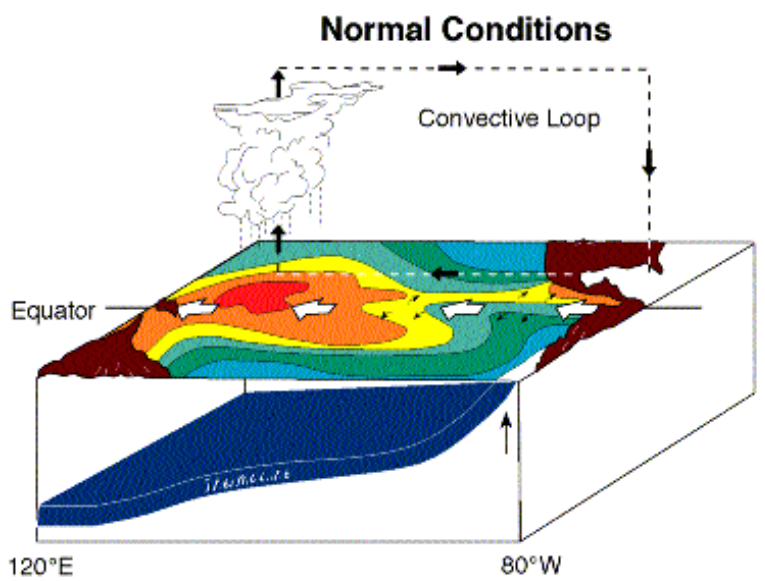


# Variability of Sahel rainfall (JJAS)



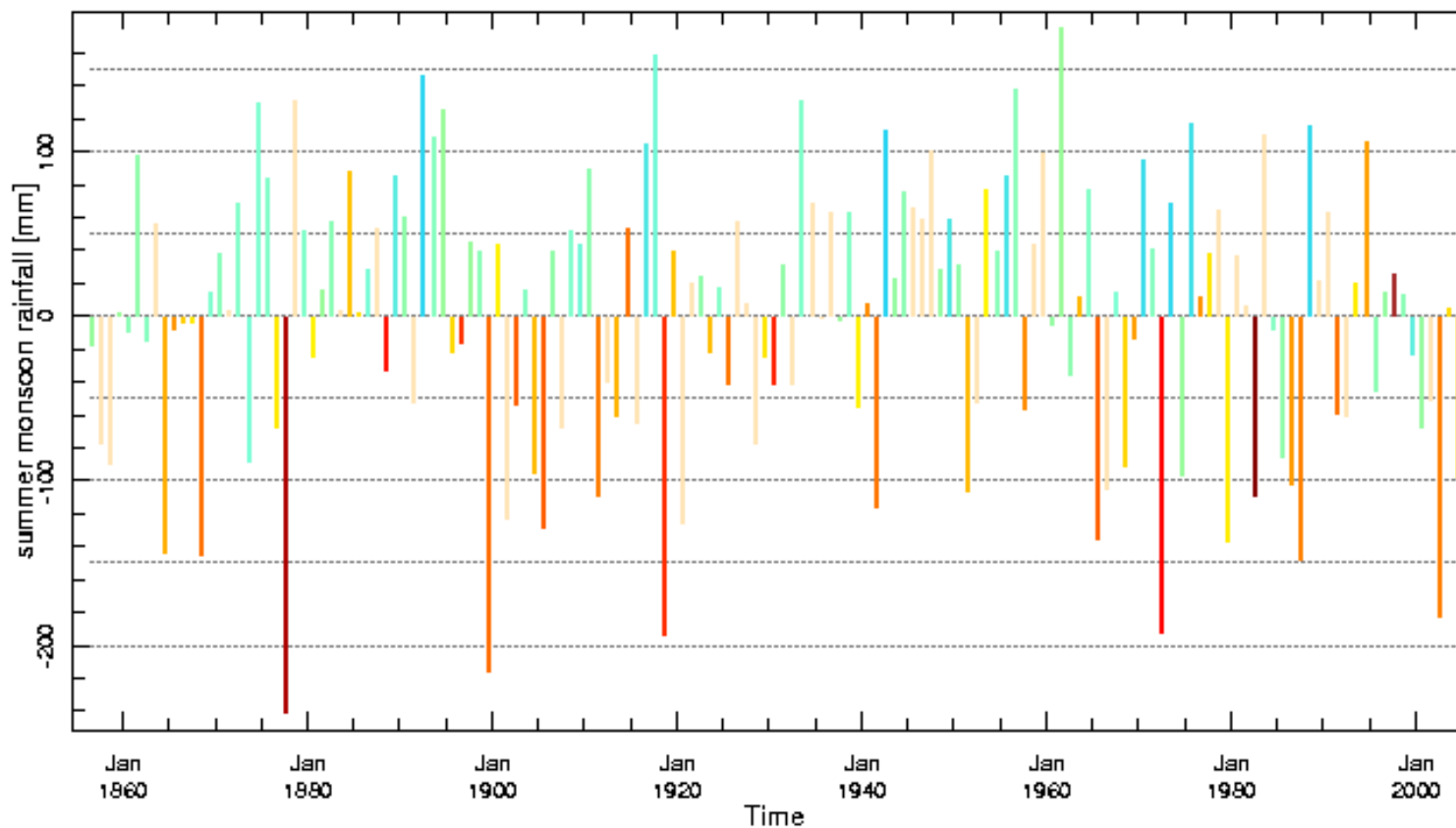


# Coupled variability: El Niño – Southern Oscill.





# All India rainfall and ENSO phase



El Niño

La Niña



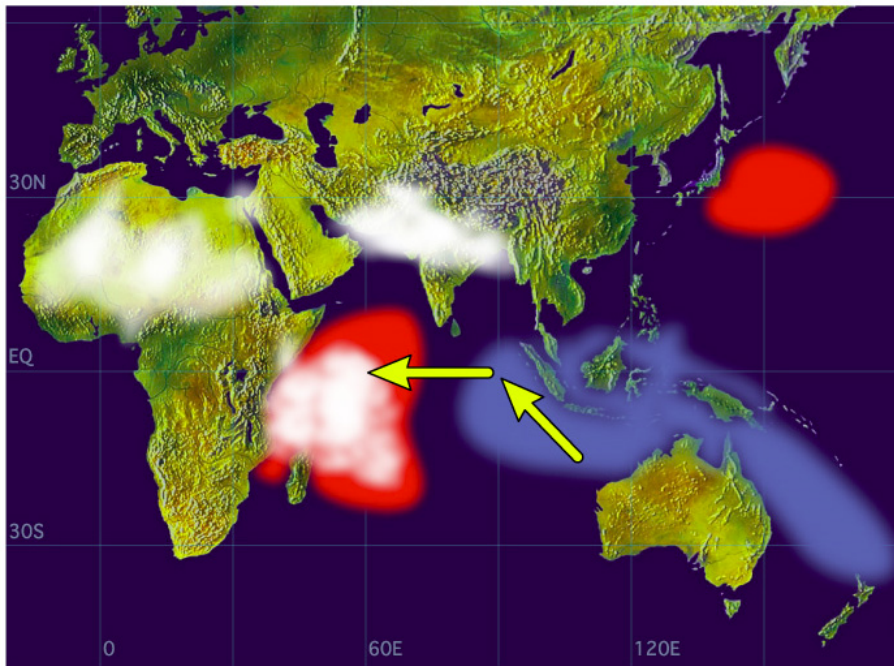
# Coupled variability in the Indian Ocean

## The Indian Ocean Zonal Mode (or I.O. Dipole)

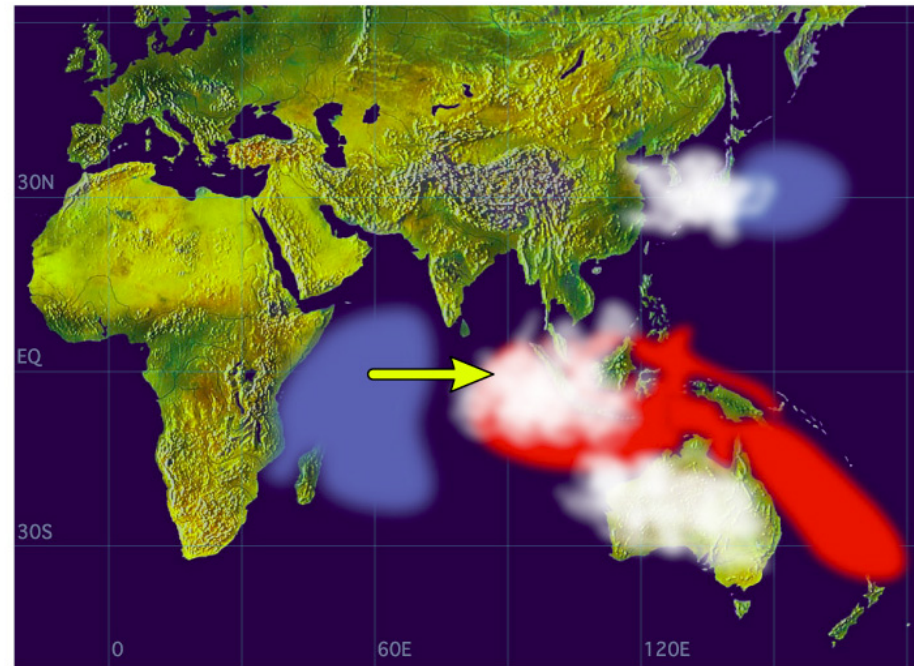
Saji et al. (1999), Saji and Yamagata (2003)

Webster et al. (1999)

Positive Dipole Mode

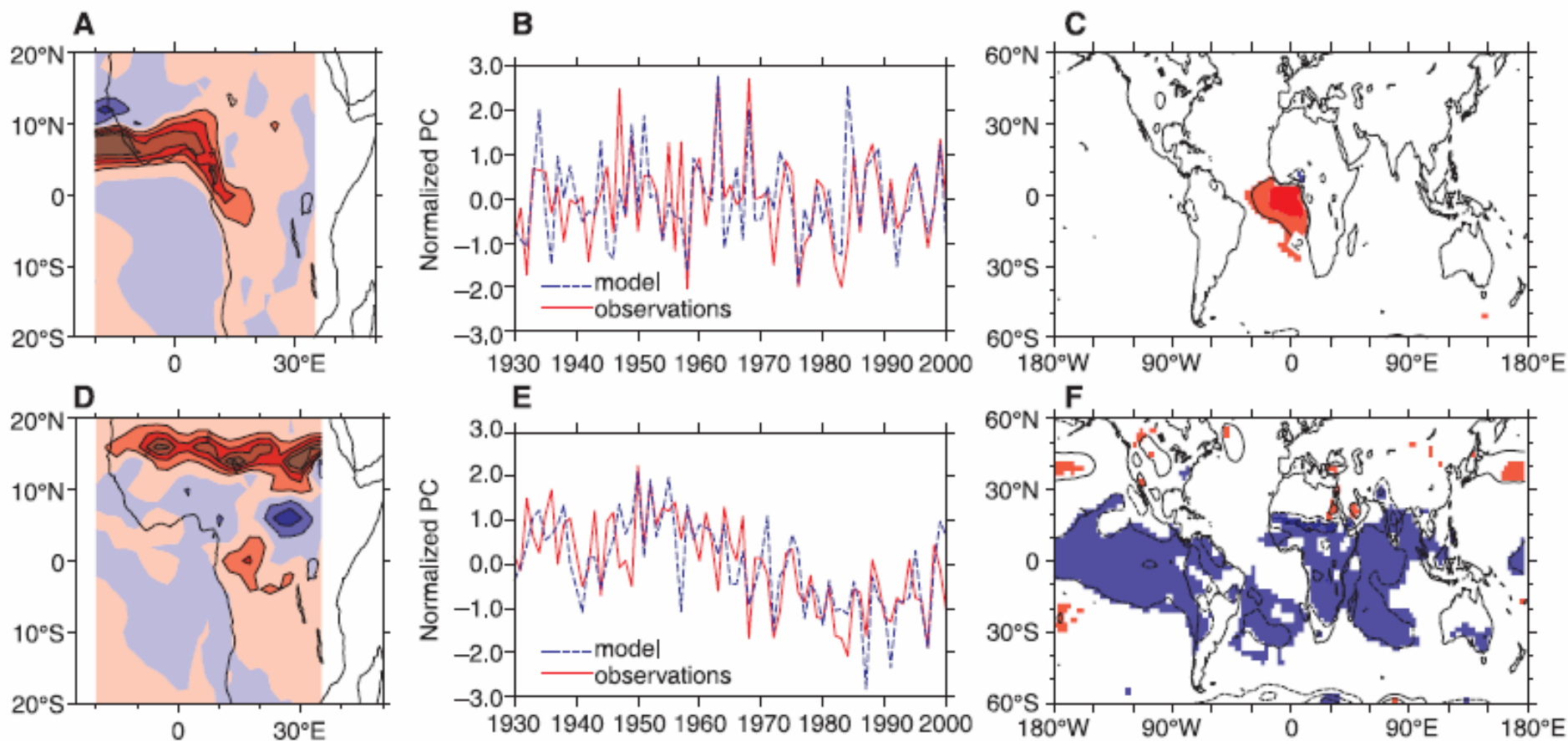


Negative Dipole Mode



# West African rainfall and trop. Atlantic SST

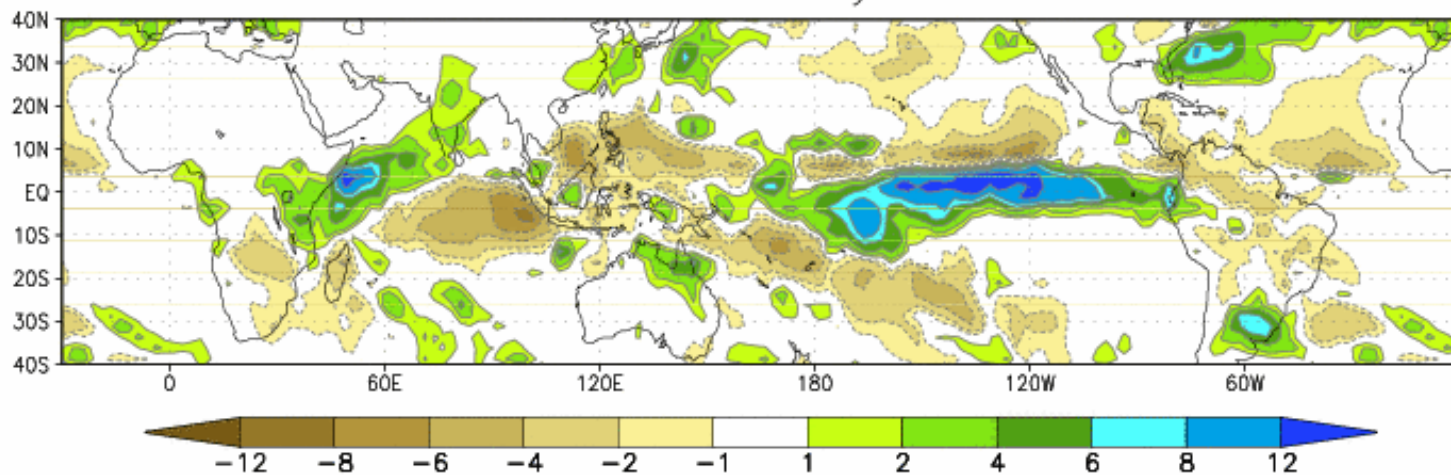
Giannini et al., Science 2003



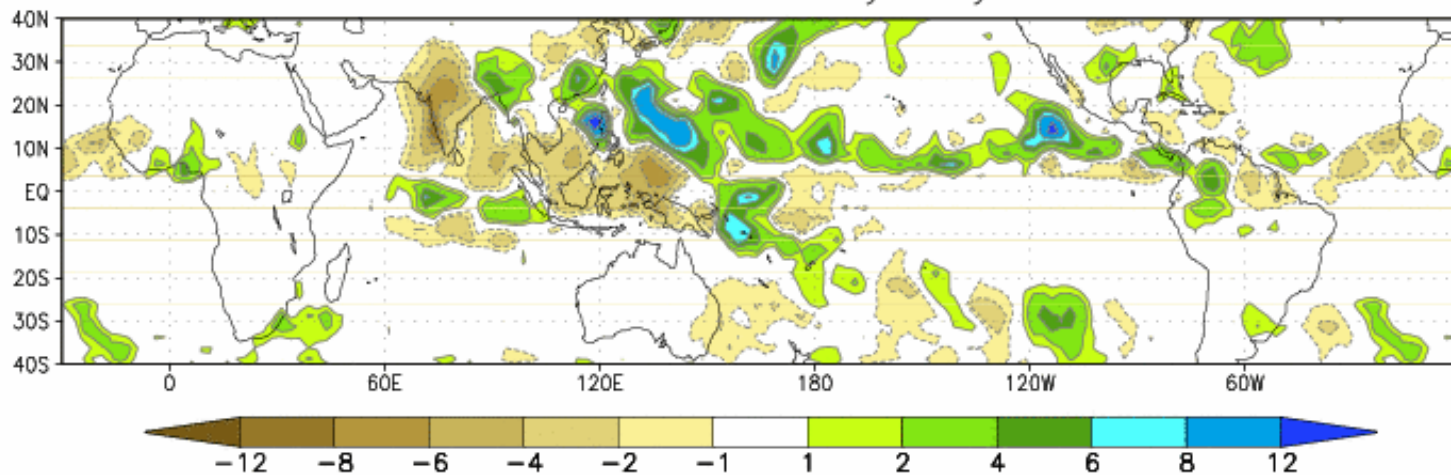


# Rainfall anomalies in Dec. 1997 and July 2002

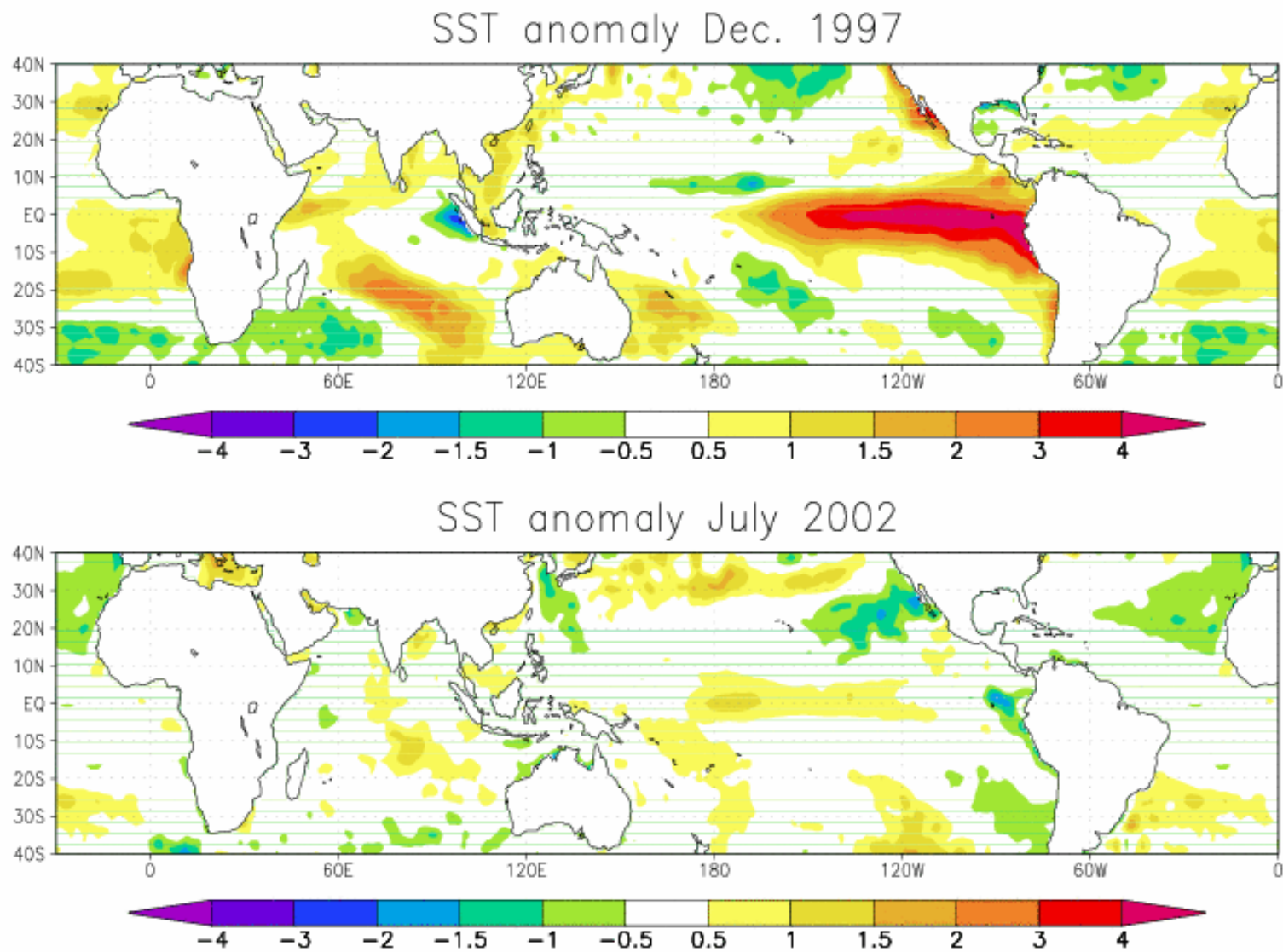
GPCP rainfall anomaly Dec. 1997

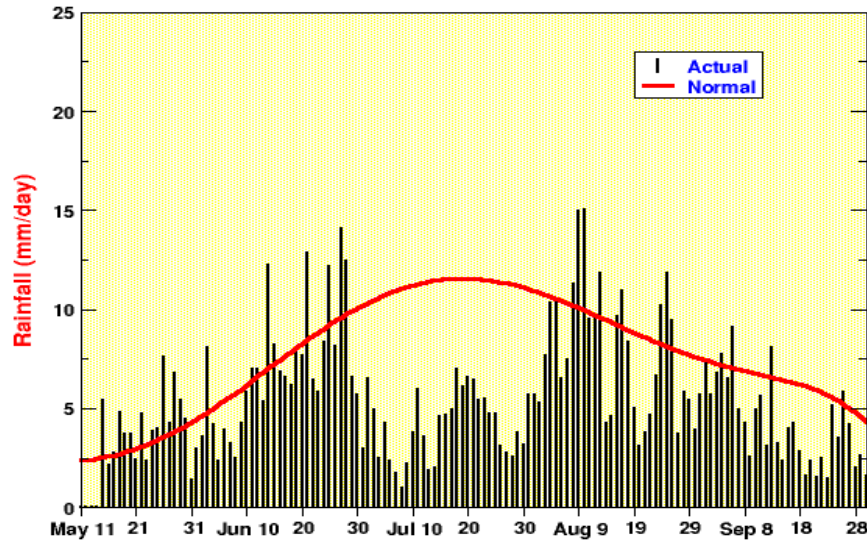


GPCP rainfall anomaly July 2002



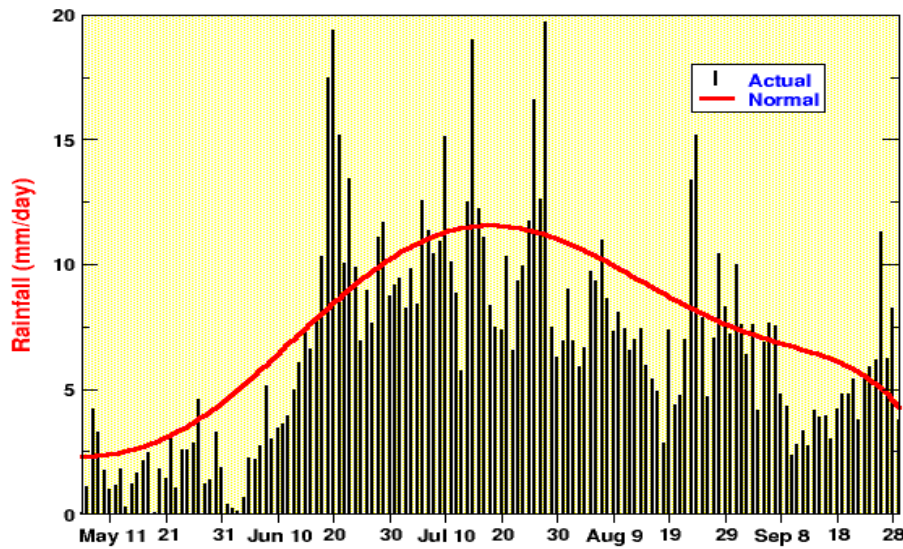
# SST anomalies in Dec. 1997 and July 2002



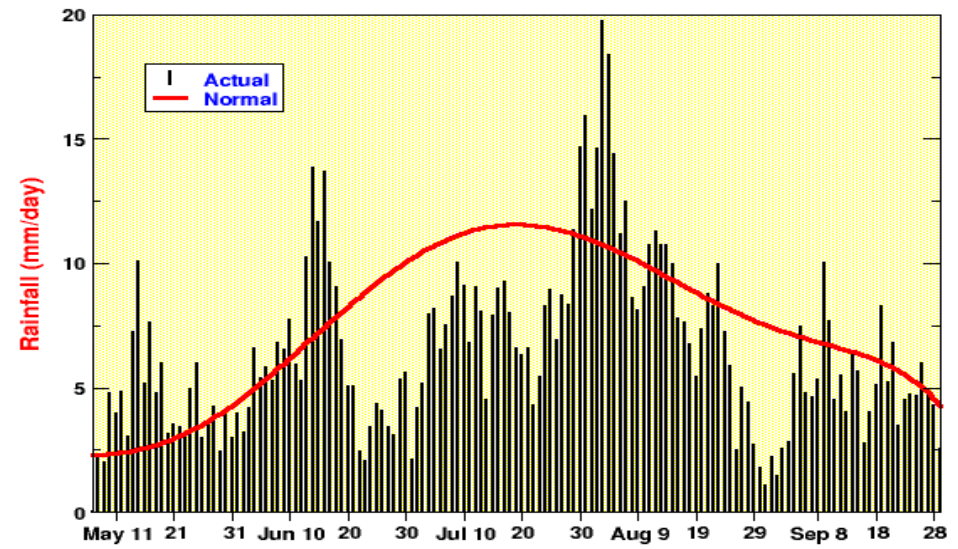


2002

## All-India Rainfall time-series (May-September)

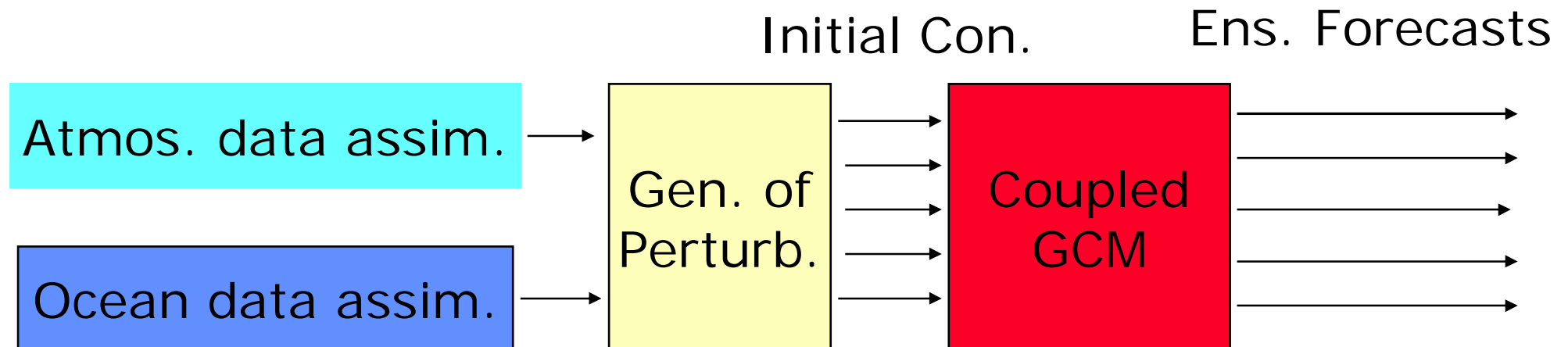
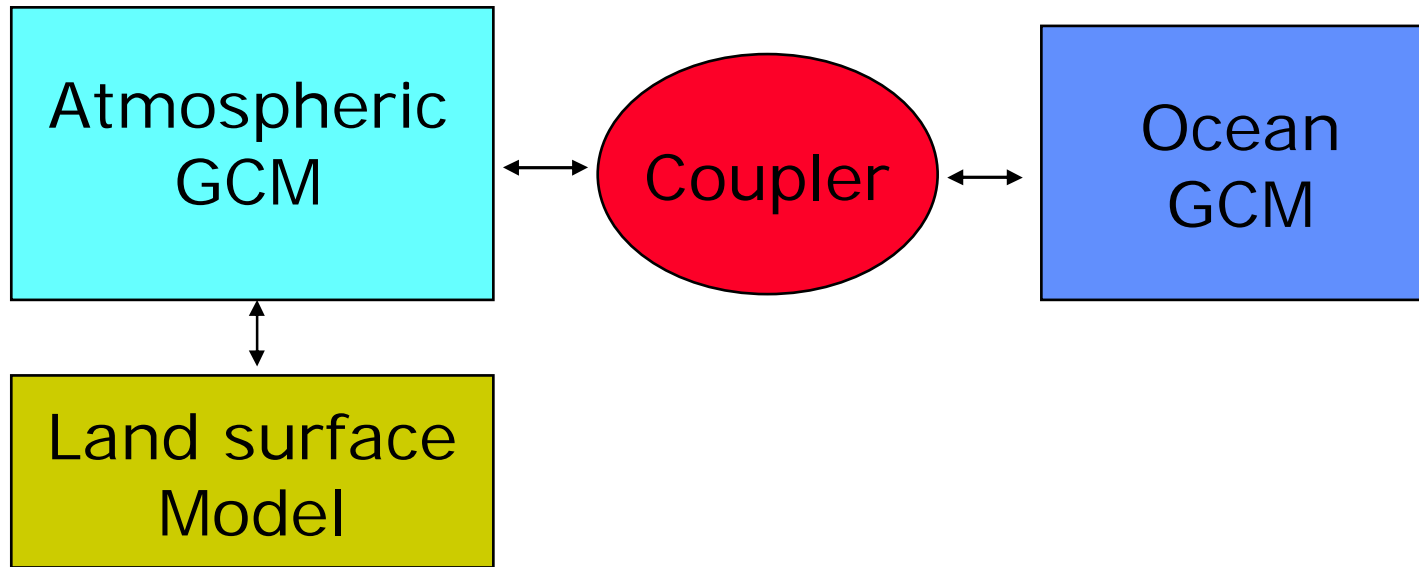


2003



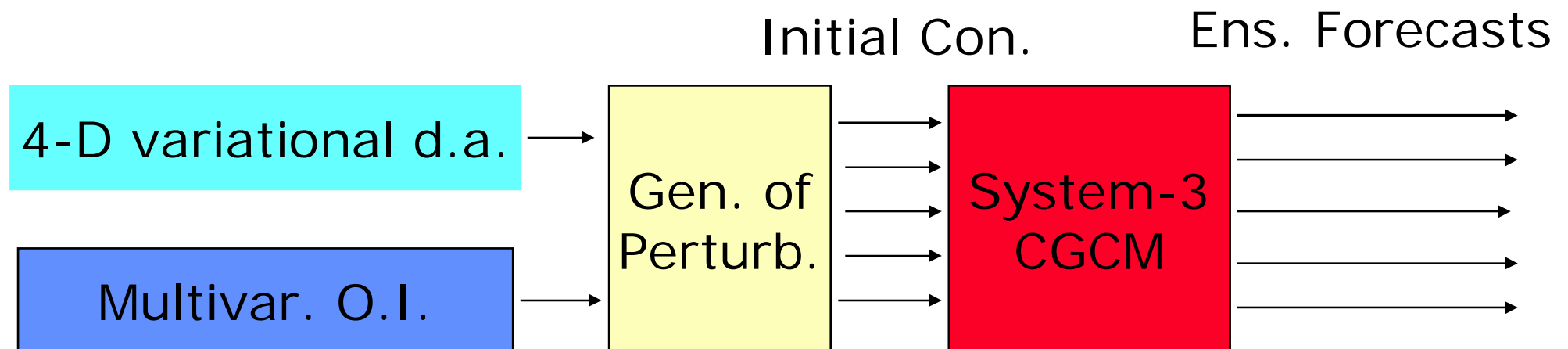
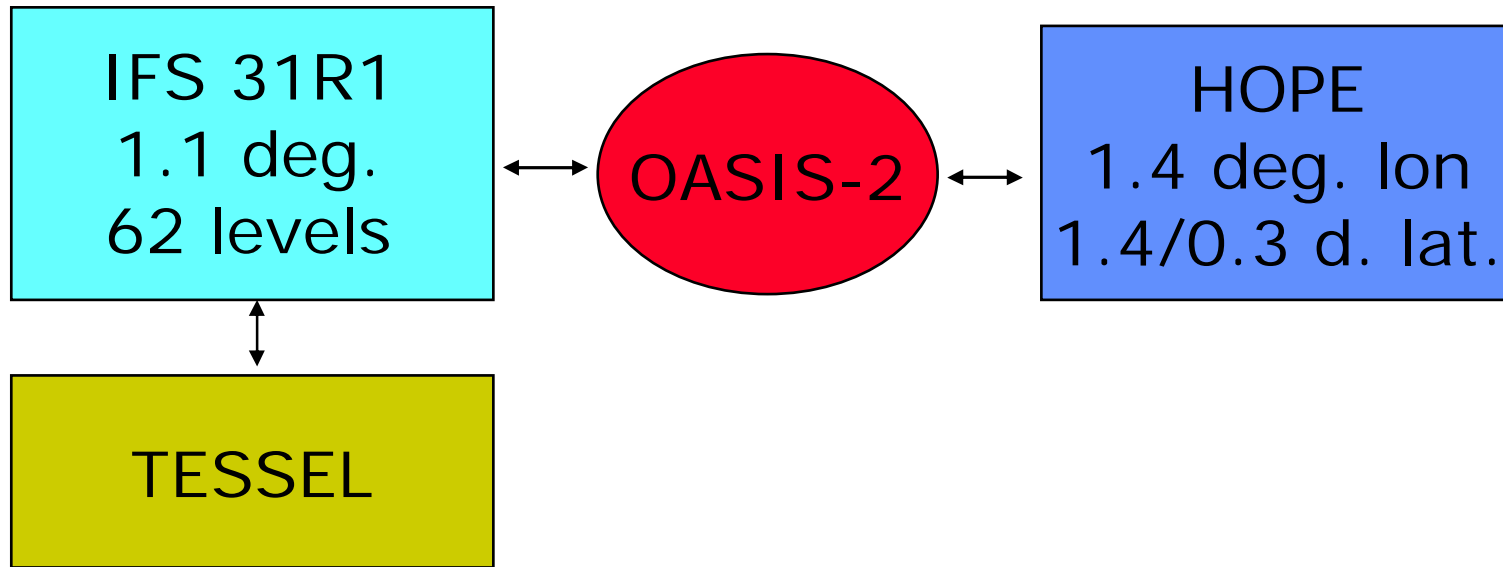
2004

# Ensemble predictions with coupled GCMs





# ECMWF Seasonal forecast system (Sys-3)

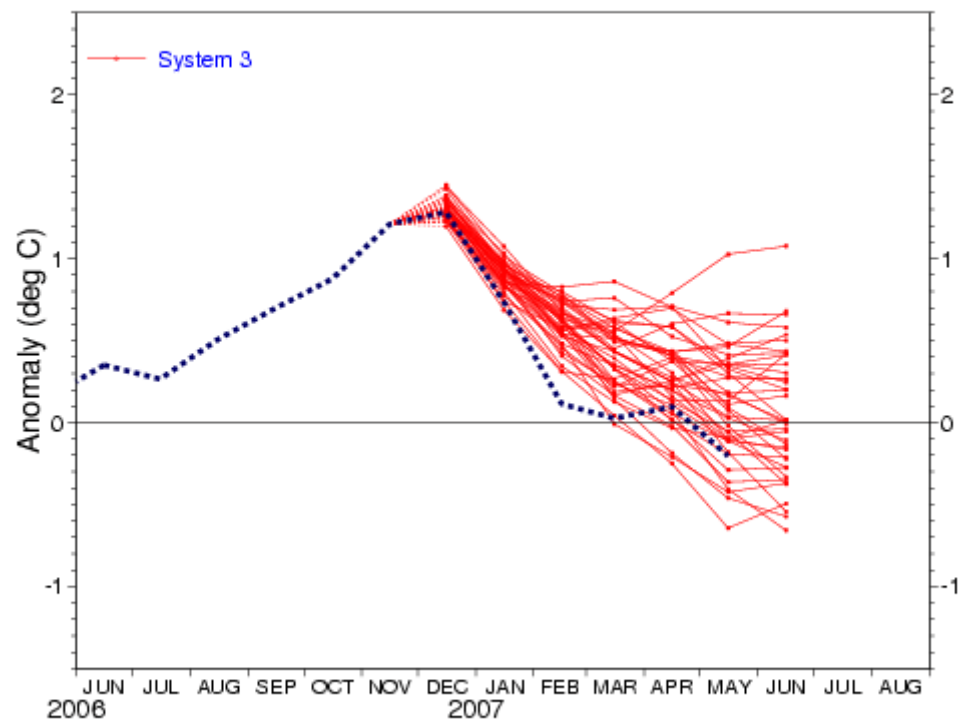




# Example: "plumes" of El Niño indices

NINO3.4 SST anomaly plume  
ECMWF forecast from 1 Dec 2006

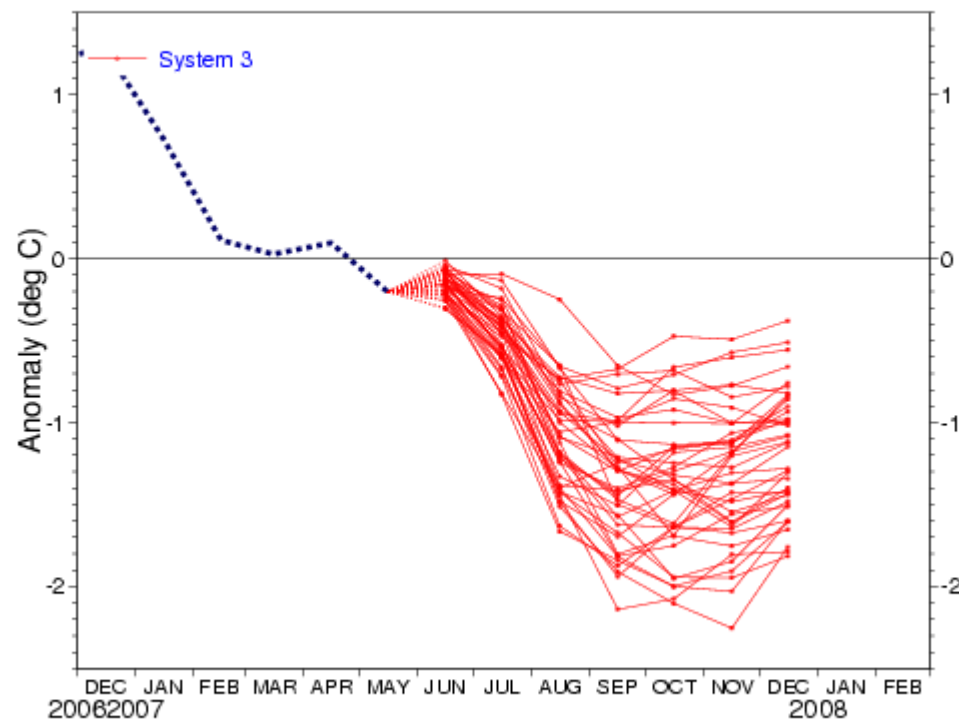
Monthly mean anomalies relative to NCEP adjusted OIv2 1971-2000 climatology



Produced from real-time forecast data

NINO3.4 SST anomaly plume  
ECMWF forecast from 1 Jun 2007

Monthly mean anomalies relative to NCEP adjusted OIv2 1971-2000 climatology



CEK Forecast issue date: 15 Jun 2007





## Partition of variability in an ensemble of time-evolving atmospheric fields

$$\mathbf{A}(t', k, m)$$

$t'$  = time within year,  $k$  = year index,  $m$  = ensemble member index

Anomaly:  $\mathbf{A}'(t', k, m) = \mathbf{A}(t', k, m) - \mathbf{A}_{cl}(t')$

Seasonal mean anomaly:  $\mathbf{A}_s(k, m) = \{ \mathbf{A}'(t', k, m) \}_{t'}$

Ens./seas. mean anomaly:  $\mathbf{A}_{es}(k) = \{ \mathbf{A}'(t', k, m) \}_{t', m}$

Total variability:  $\text{var} [\mathbf{A}'(t', k, m)]$

Interannual variability:  $\text{var} [\mathbf{A}_s(k, m)]$

Intraseasonal variability:  $\text{var} [\mathbf{A}'(t', k, m) - \mathbf{A}_s(k, m)]$

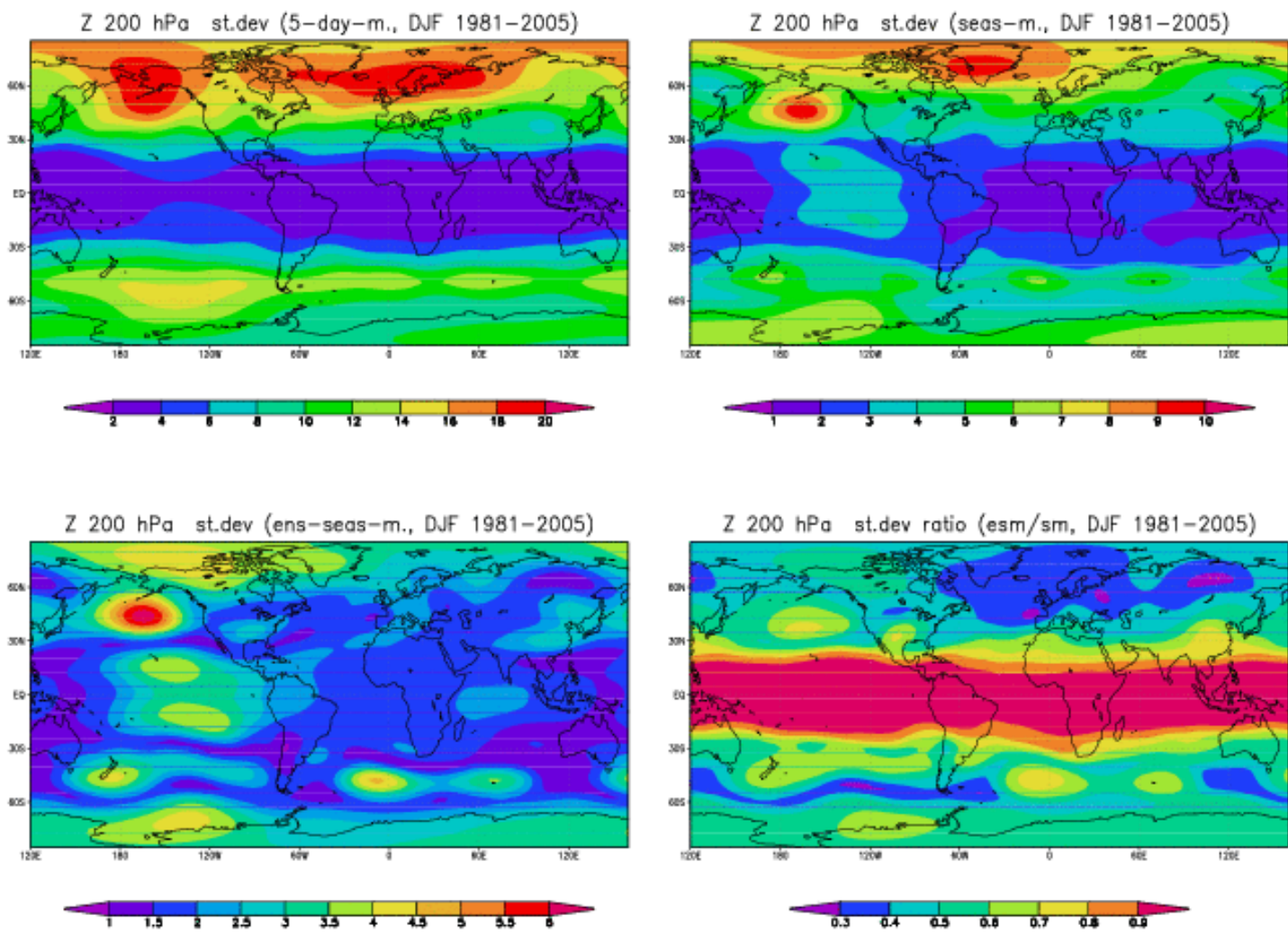
Forced/coupled variability:  $\approx \text{var} [\mathbf{A}_{es}(k)]$

Internal variability:  $\approx \text{var} [\mathbf{A}'(t', k, m) - \mathbf{A}_{es}(k)]$

Perfect-model anomaly cor. =  $\{ \text{var} [\mathbf{A}_{es}(k)] / \text{var} [\mathbf{A}_s(k)] \}^{1/2}$

# Variab. of Z 200hPa in DJF from ECMWF hindcasts

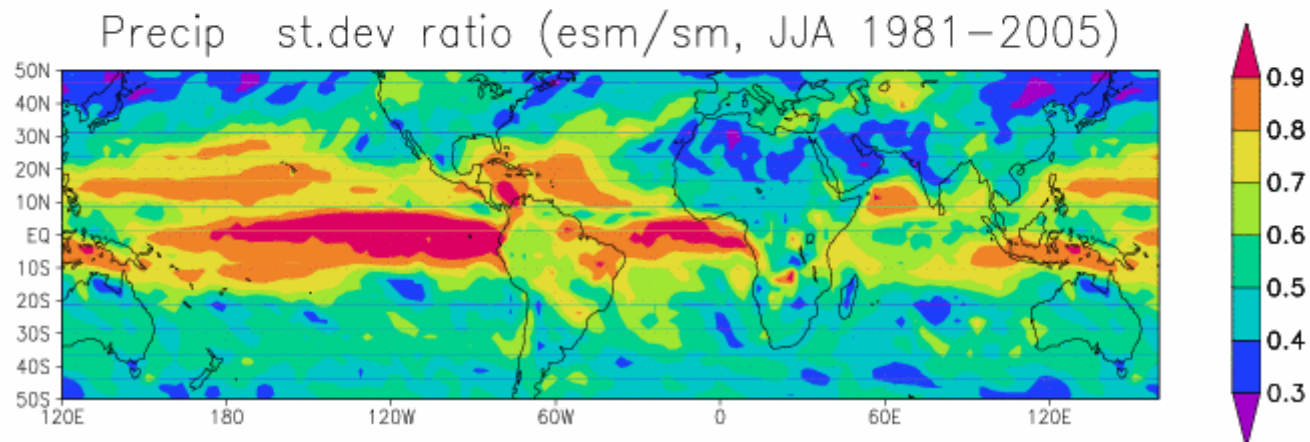
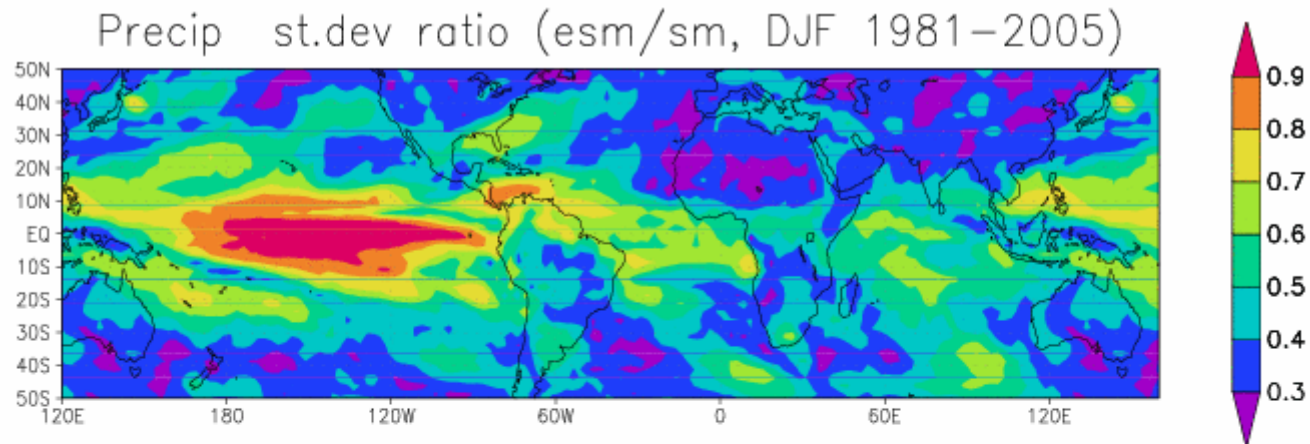
System-3 11-member ensembles, init. on 1 nov. 1981/2005



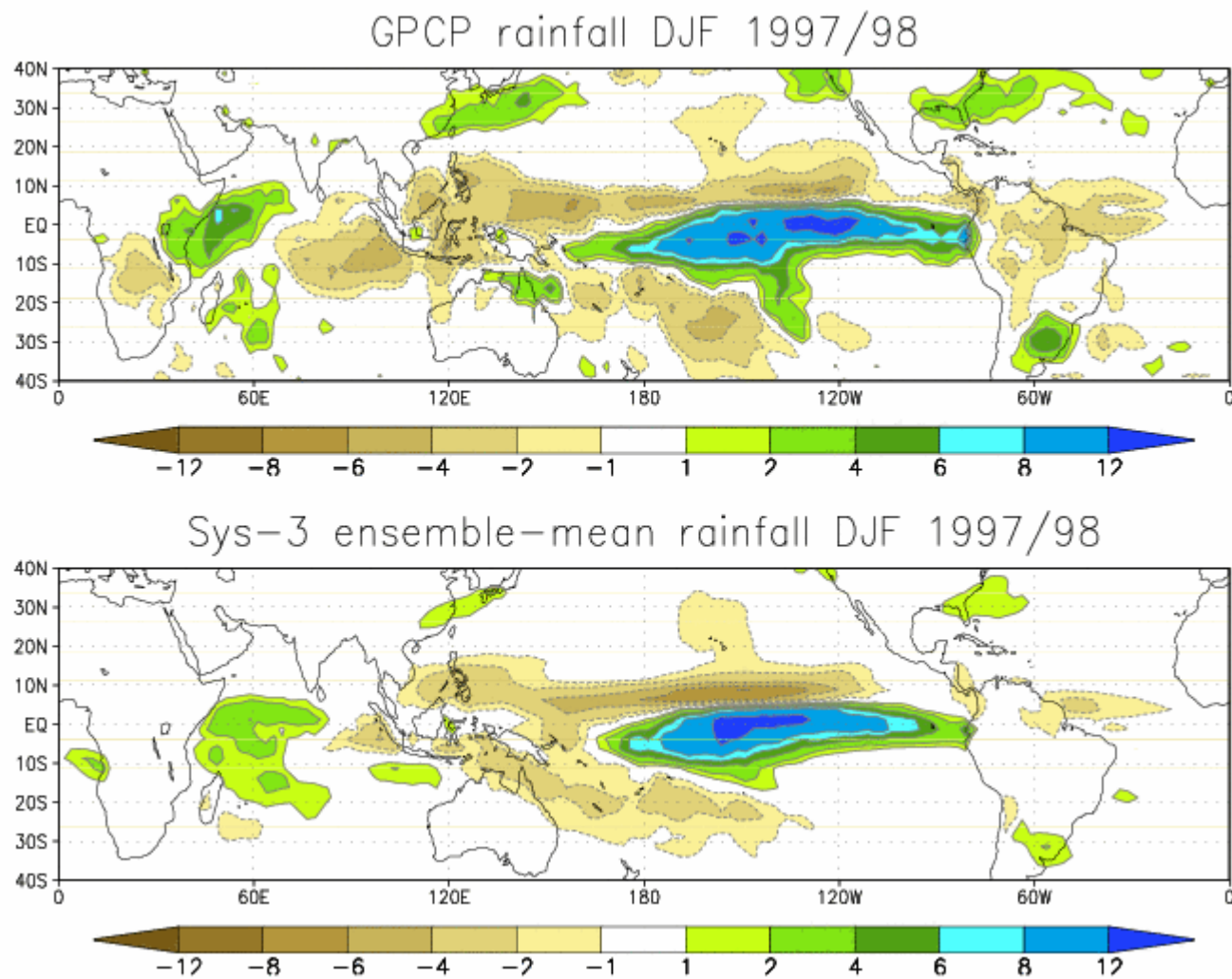


# Variability of rainfall from ECMWF hindcasts

S-3 11-member ensembles, init. on 1 may/nov. 1981/2005



# A "real" prediction: observed vs. ens.mean anomaly

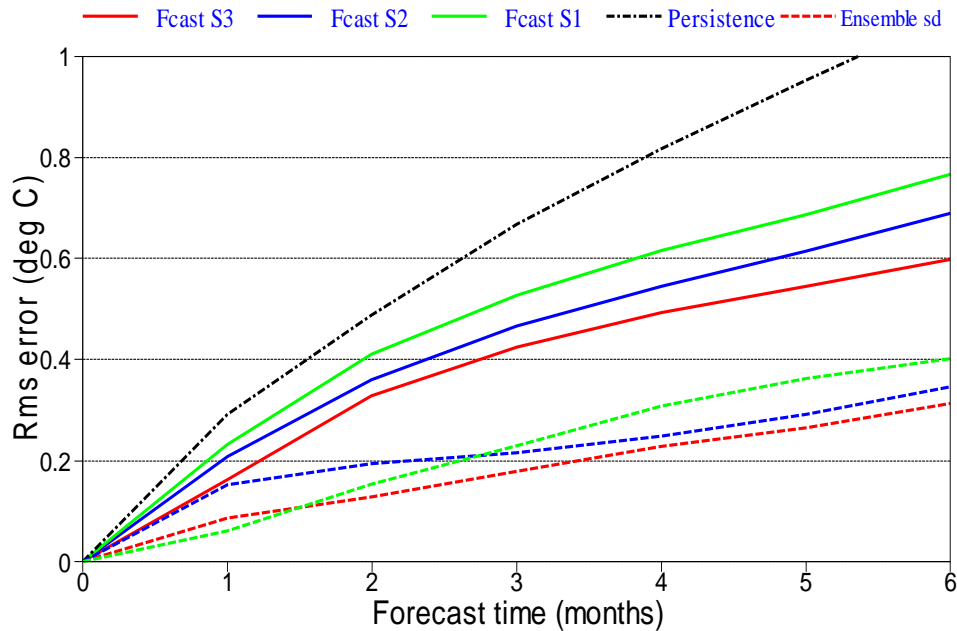




# Predictive skill for of the Nino3.4 index

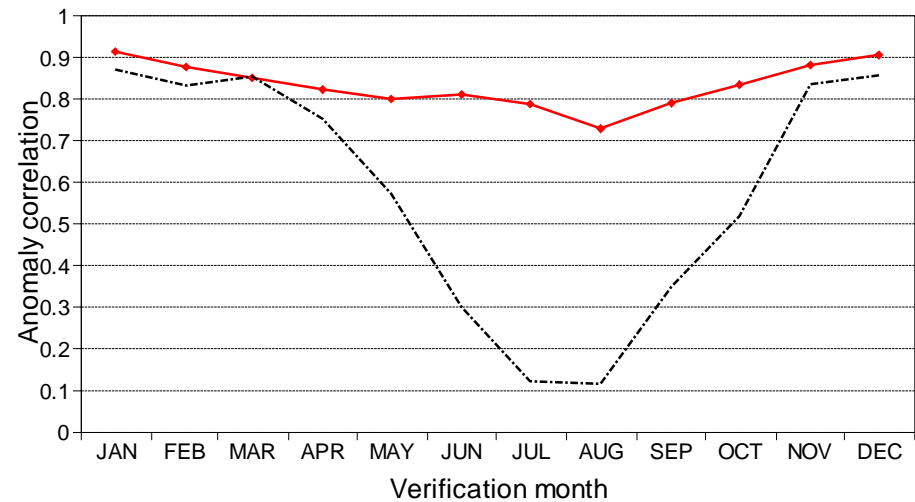
## NINO3.4 SST rms errors

192 start dates from 19870101 to 20021201  
Ensemble sizes are 5 (0001), 5 (0001) and 5 (0001)

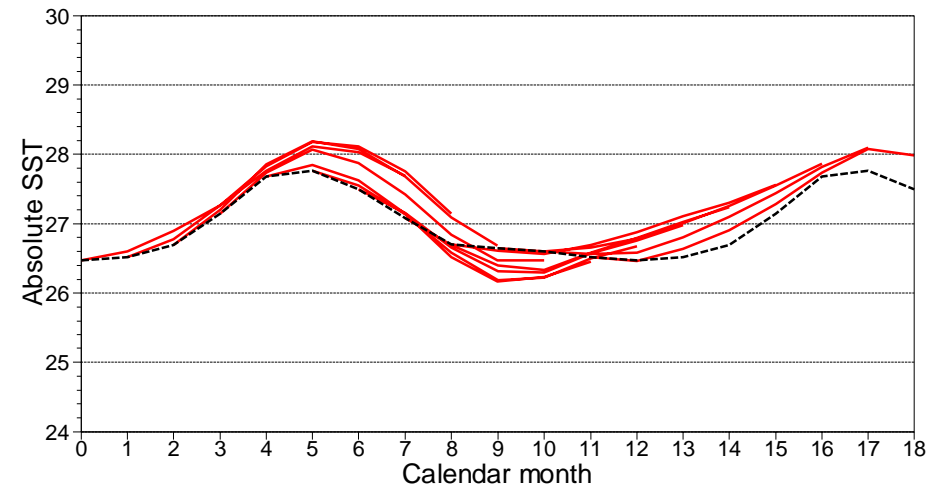


## NINO3.4 SST anomaly correlation at 5 months

wrt NCEP adjusted OIv2 1971-2000 climatology

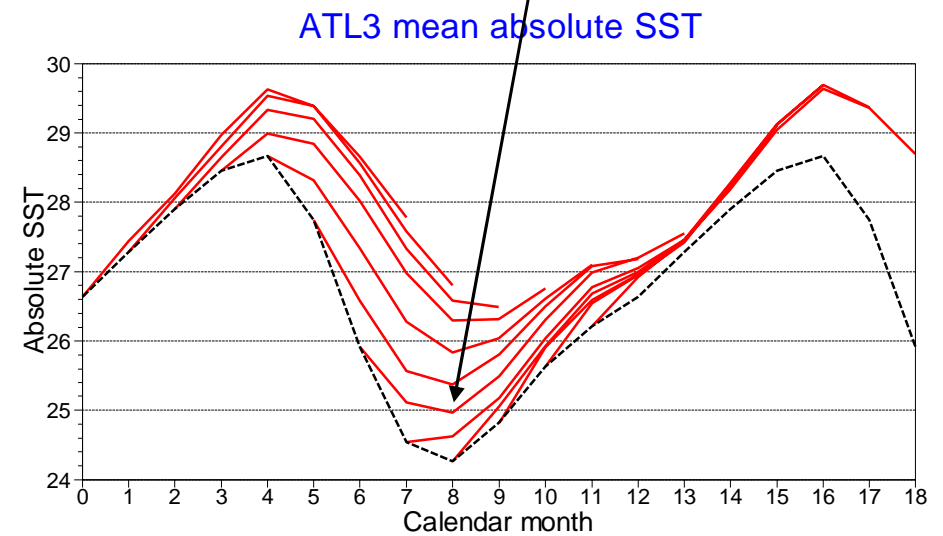
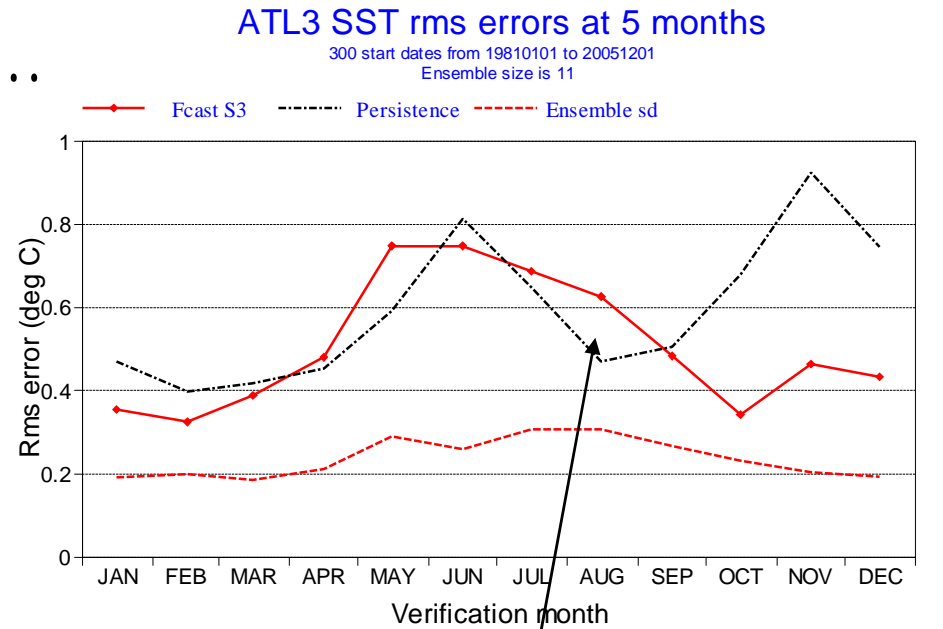
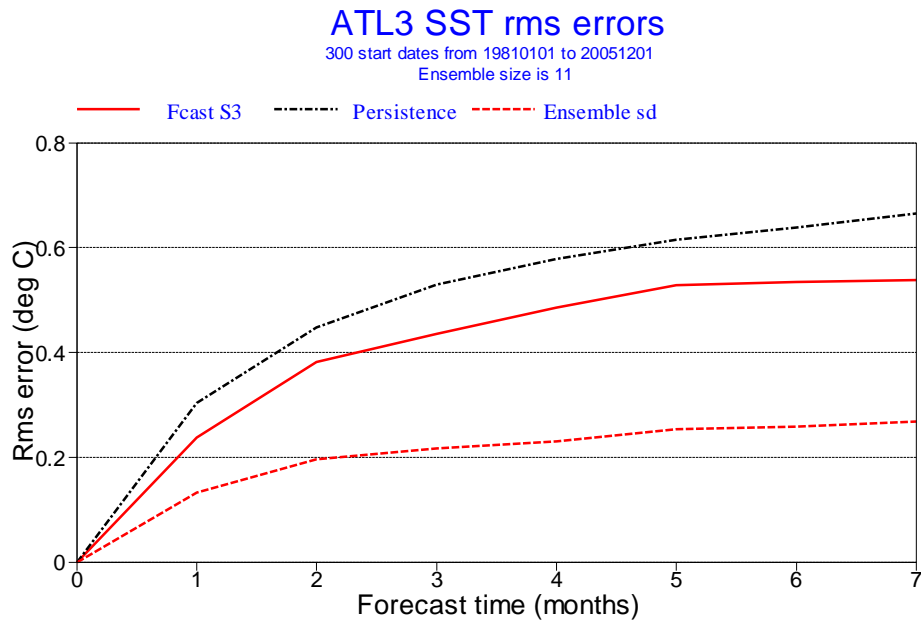


## NINO3.4 mean absolute SST





# But in the eq. Atlantic ...



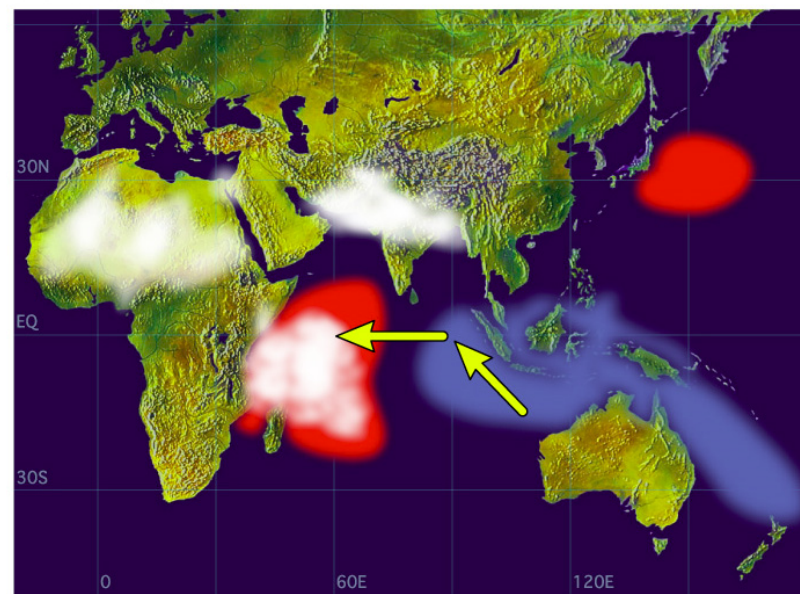


# The role of feedbacks from heat/moisture fluxes

Tropical convection tends to occur over warm SST and warm-and-wet land surface, but it induces a number of feedbacks:

- Convective clouds decrease solar radiation at the surface
- Anomalous divergent winds tend to increase evaporation to the east/west of the convective region when the climatological near-surface winds are easterly/westerly
- The strength of the feedback depends on the heat capacity of the “interactive” surface layer and the phase of the day

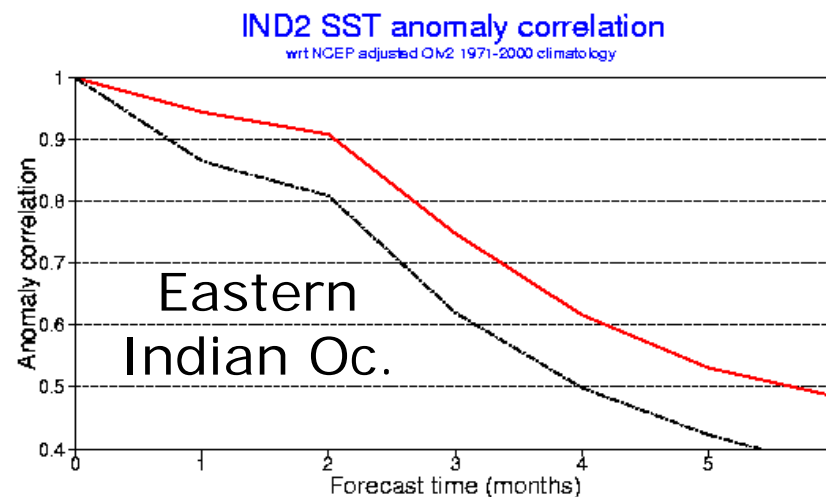
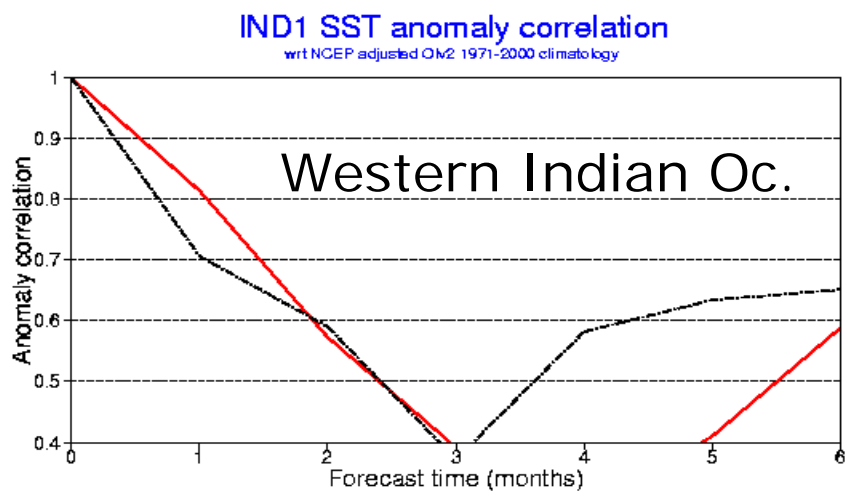
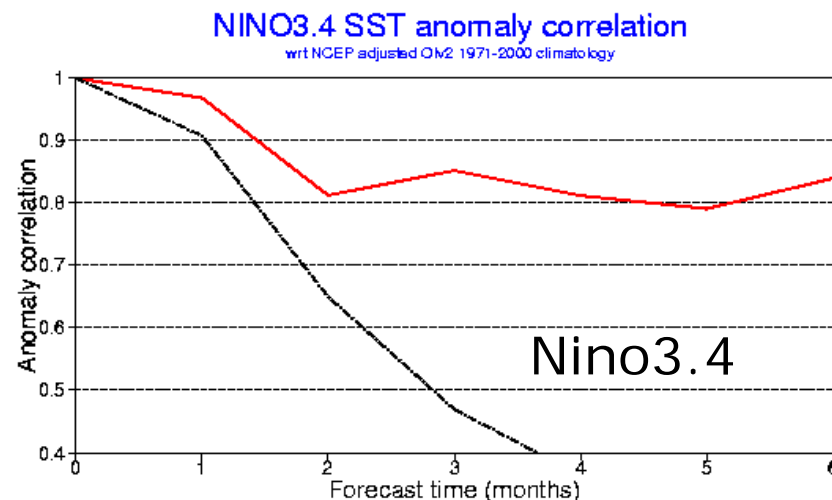
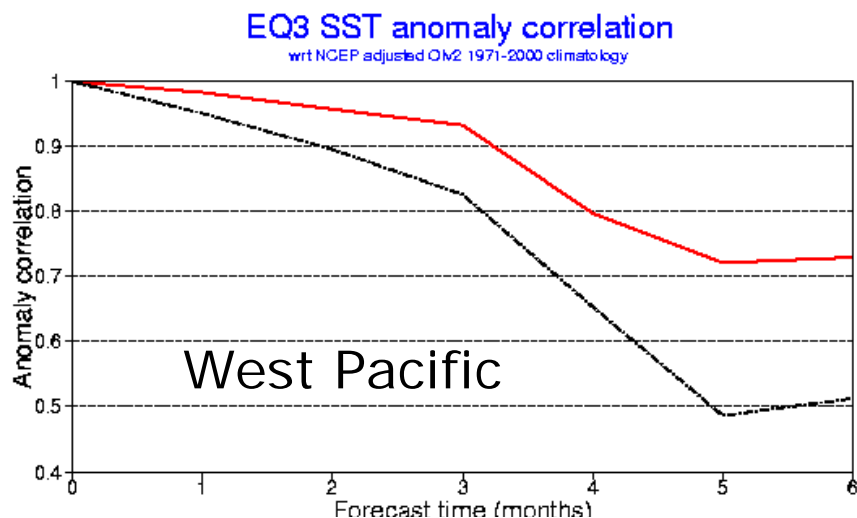
Positive Dipole Mode





# Skill of tropical SST forecasts for NH summer

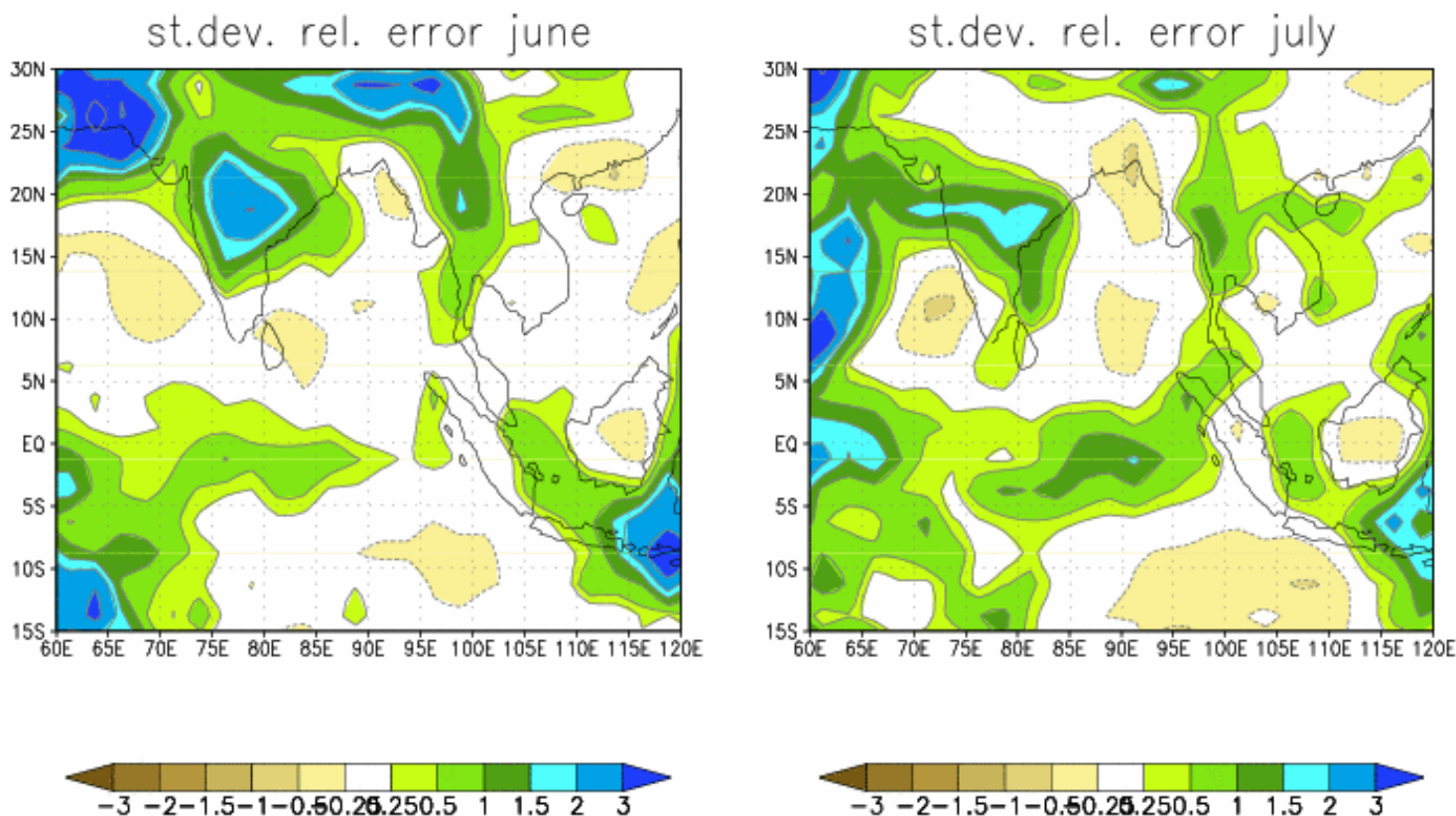
Anomaly correlation of area-averaged SST (---S3 --- pers.)



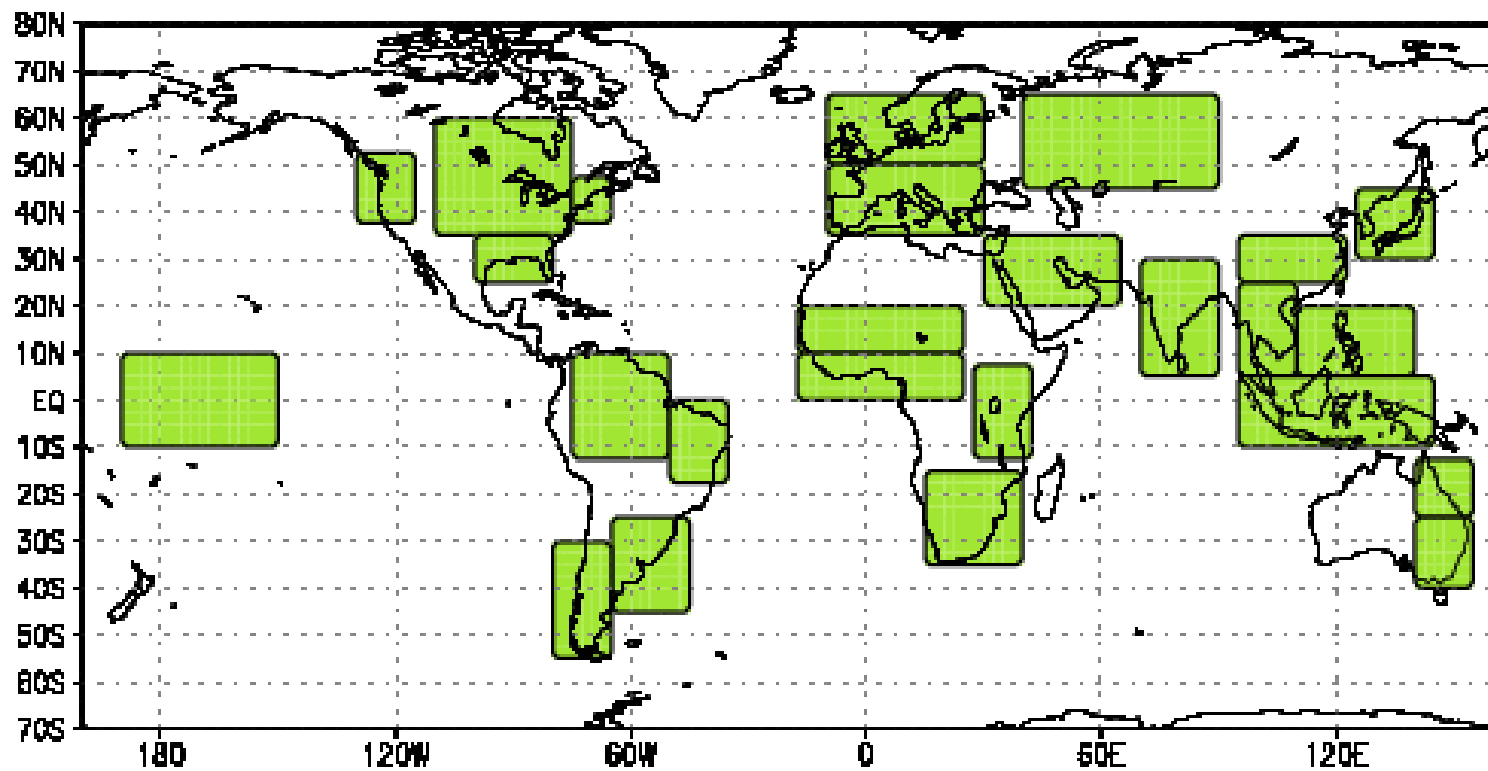


# Errors in rainfall variability (standard dev.)

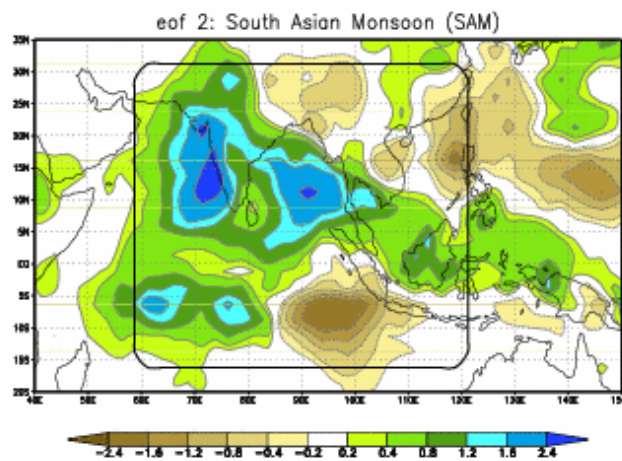
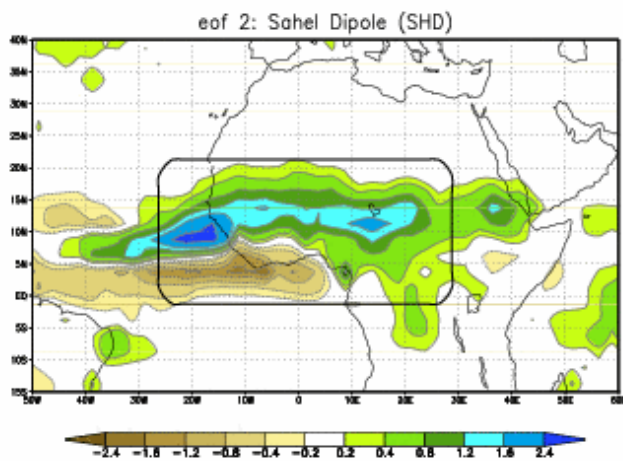
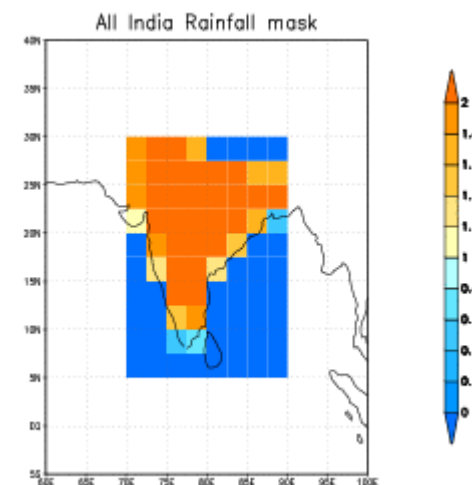
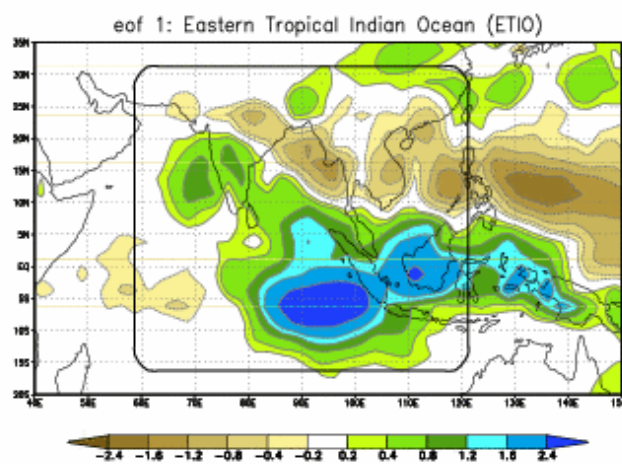
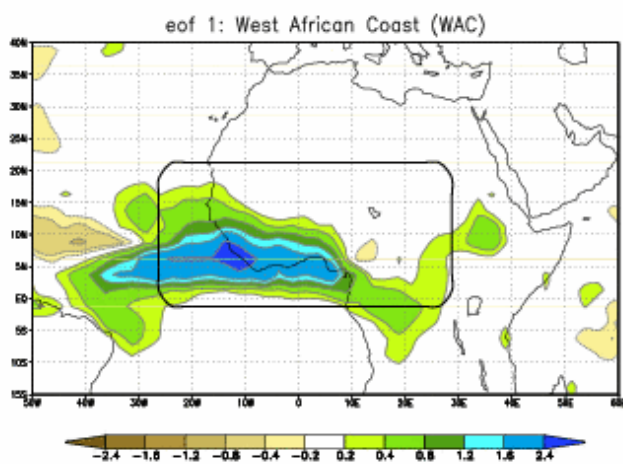
$$[\text{SD (Sys-3)} - \text{SD (GPCP)}] / \text{SD (GPCP)}$$



# Sys-3 products: area-averages of 2mT and rainfall



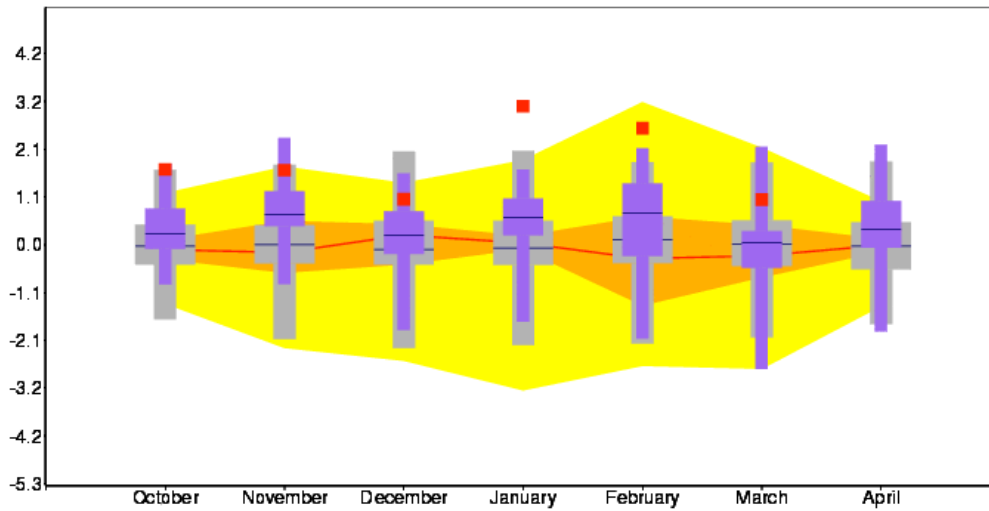
# Sys-3 products: monsoon ind./ teleconnections



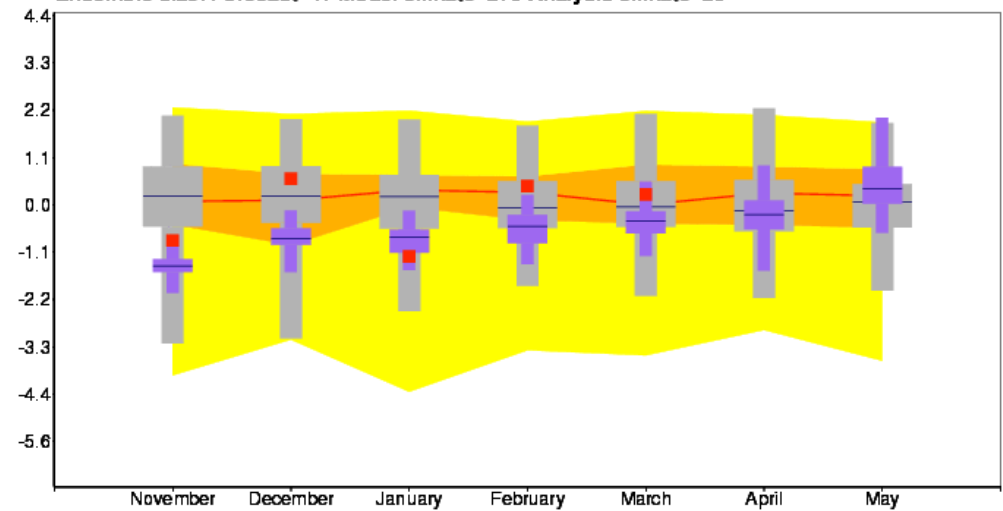


# Time series from ECMWF Sys-3: climagrams

2m temp. anomalies (K) latitude= 50.0 to 35.0 longitude= -10.0 to 30.0  
Forecast initial date: 20061001  
Ensemble size: Forecast=41 Model climate=275 Analysis climate=25



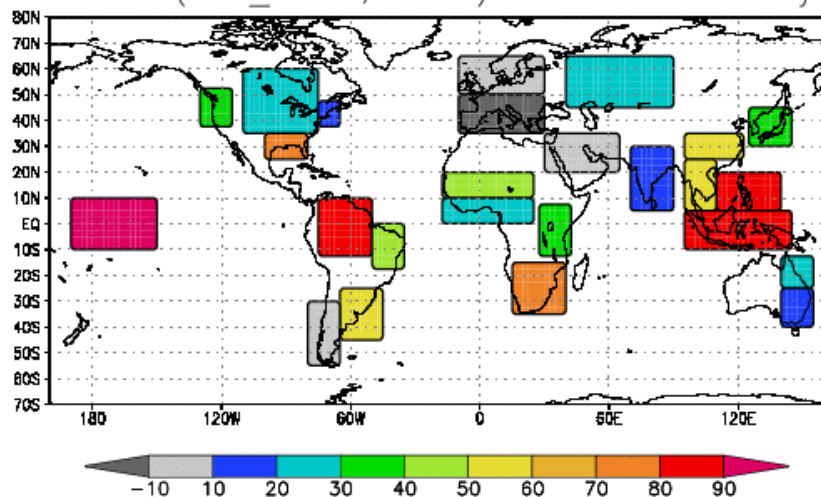
Equatorial Southern Oscillation  
Forecast initial date: 20061101  
Ensemble size: Forecast=41 Model climate=275 Analysis climate=25



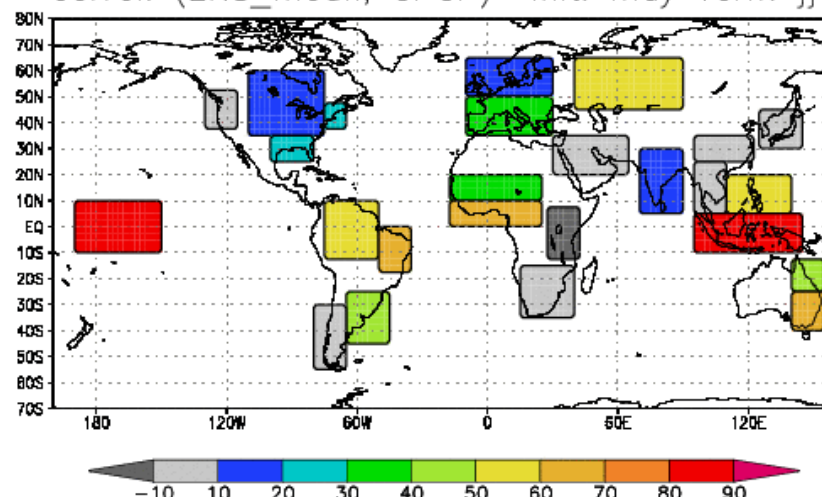


# Anomaly correlation of seasonal-mean rainfall

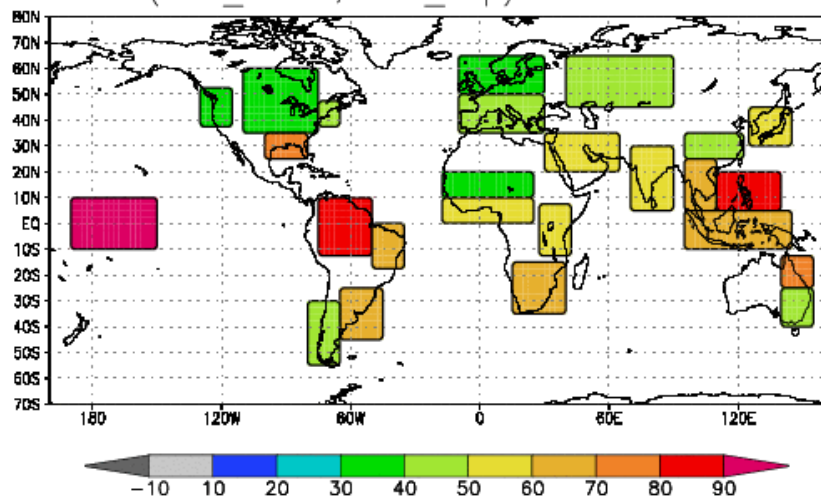
correl. (ENS\_mean, GPCP) Init: nov Verif: djf



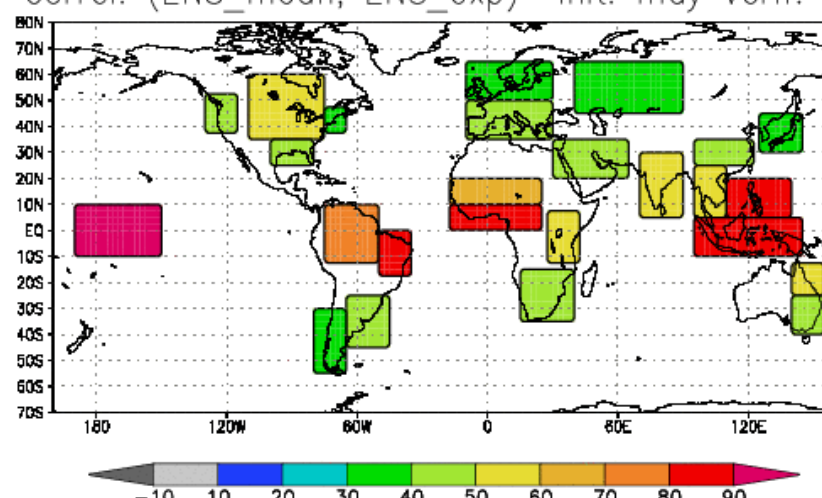
correl. (ENS\_mean, GPCP) Init: may Verif: jja



correl. (ENS\_mean, ENS\_exp) Init: nov Verif: djf



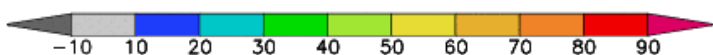
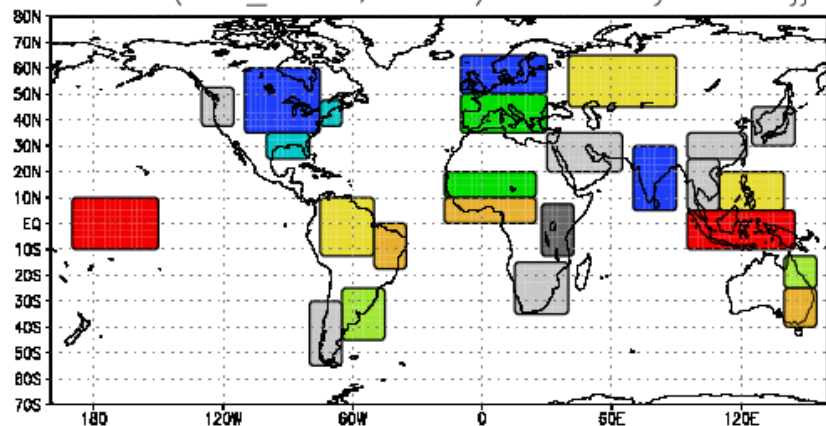
correl. (ENS\_mean, ENS\_exp) Init: may Verif: jja



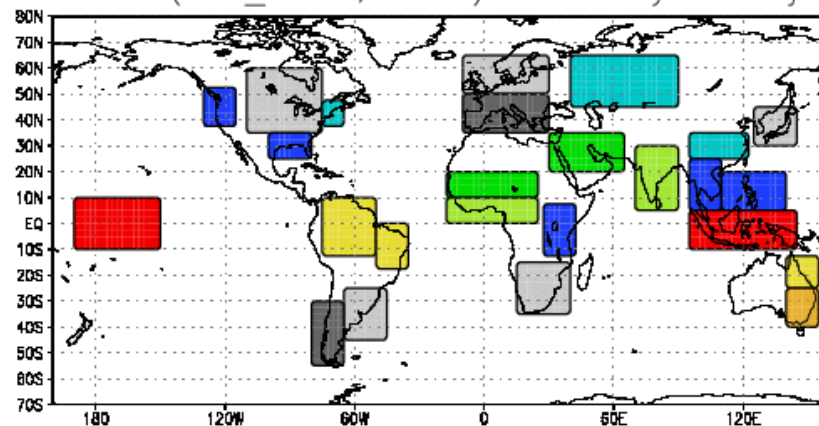


# Anomaly correlation of seasonal-mean rainfall

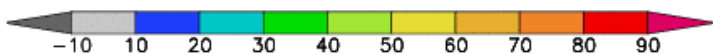
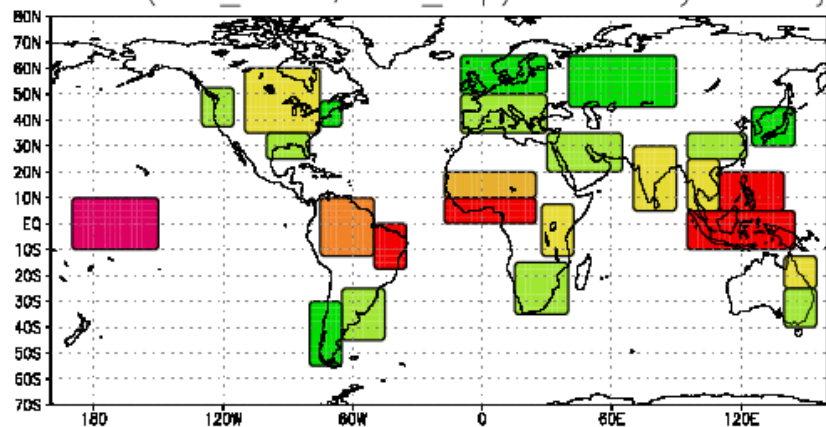
correl. (ENS\_mean, GPCP) Init: may Verif: jja



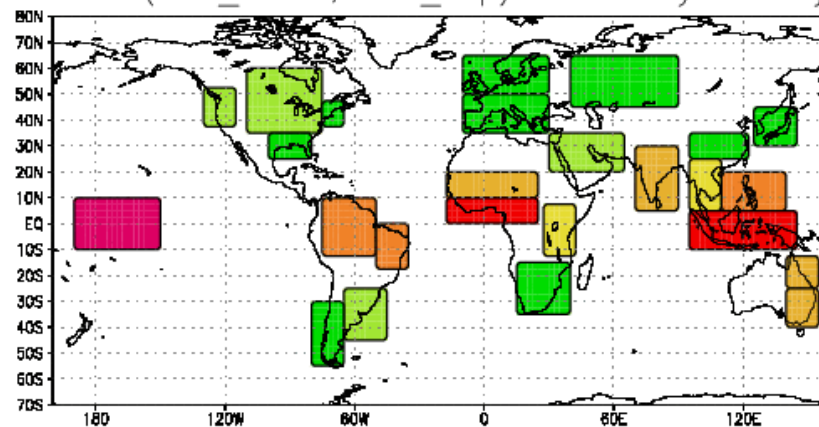
correl. (ENS\_mean, GPCP) Init: may Verif: jas



correl. (ENS\_mean, ENS\_exp) Init: may Verif: jja



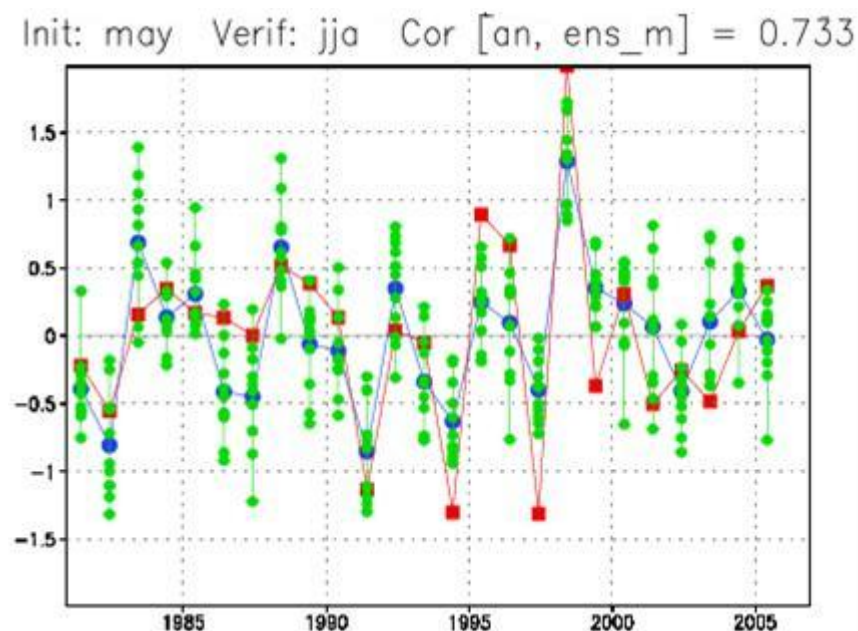
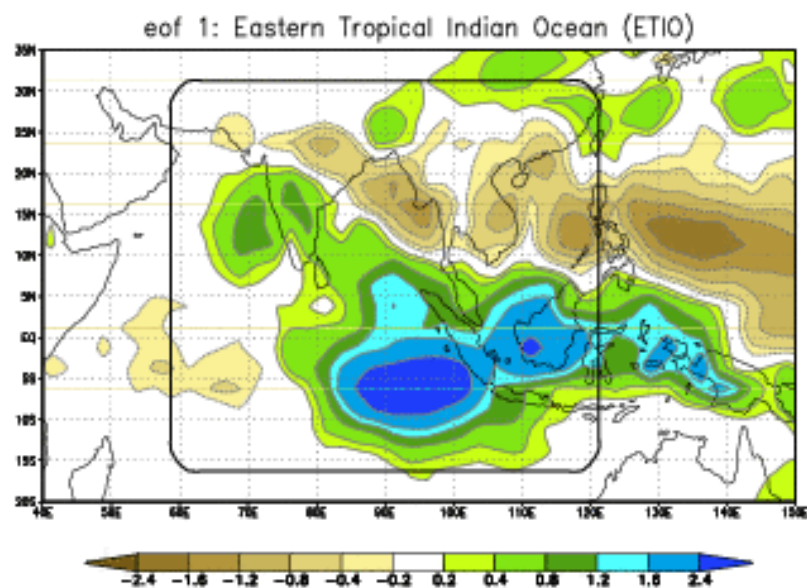
correl. (ENS\_mean, ENS\_exp) Init: may Verif: jas





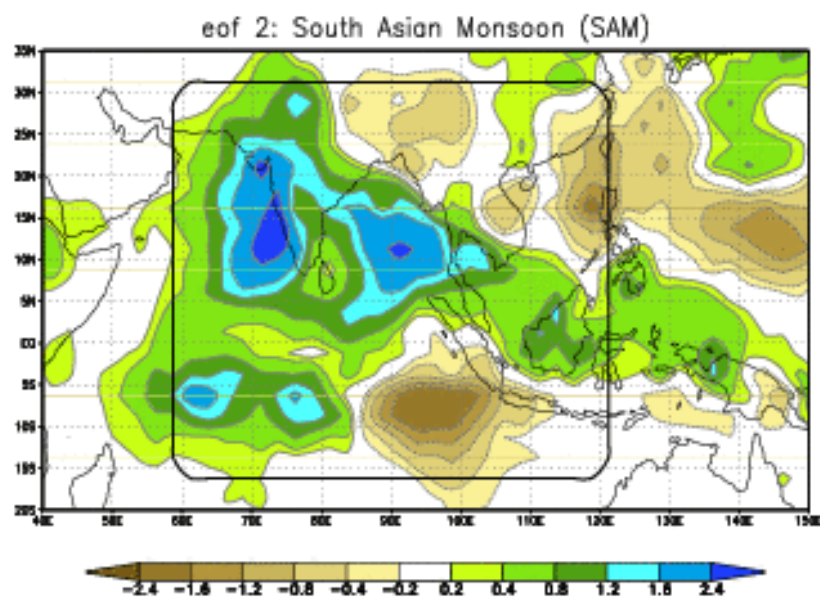
# Predictability of teleconnection/EOF indices in S-3

## Rainfall: East. Tropical Indian Ocean pattern (JJA)

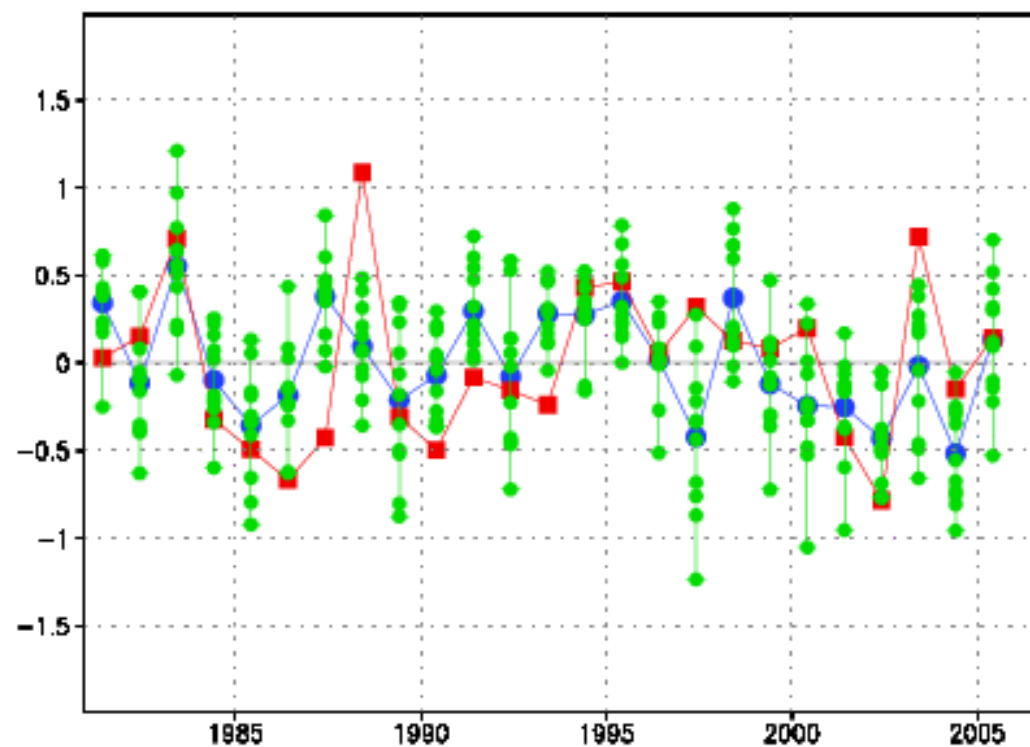


# Predictability of teleconnection/EOF indices in S-3

## Rainfall: South Asian monsoon pattern (JAS)

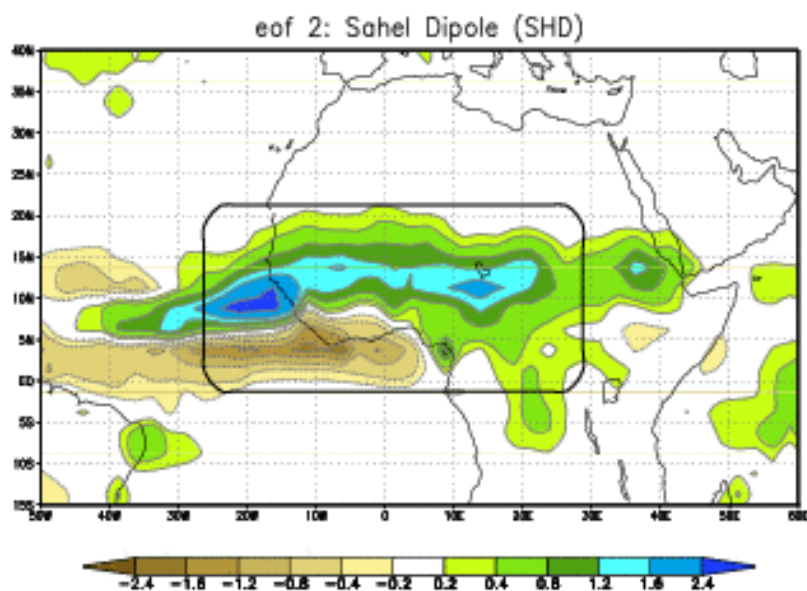


Init: may Verif: jas Cor [an, ens\_m] = 0.411

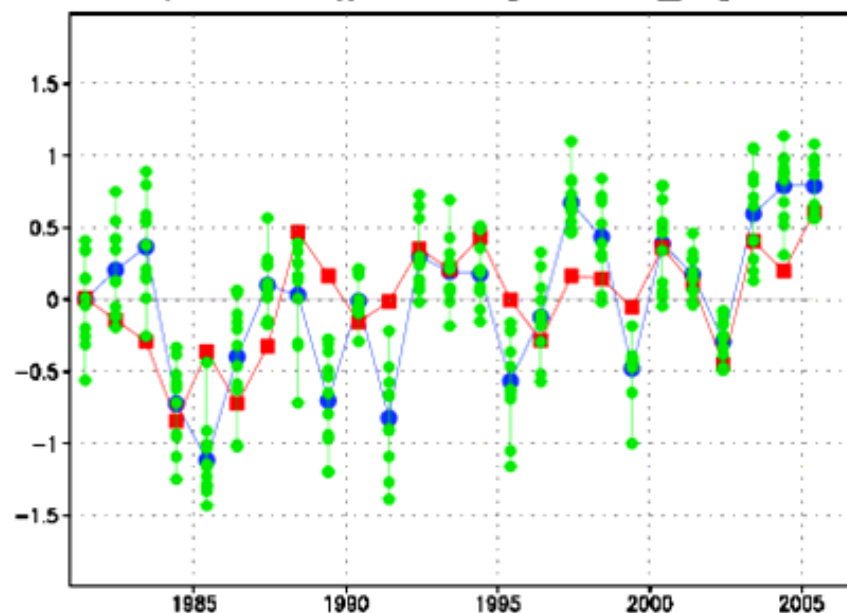


# Predictability of teleconnection/EOF indices in S-3

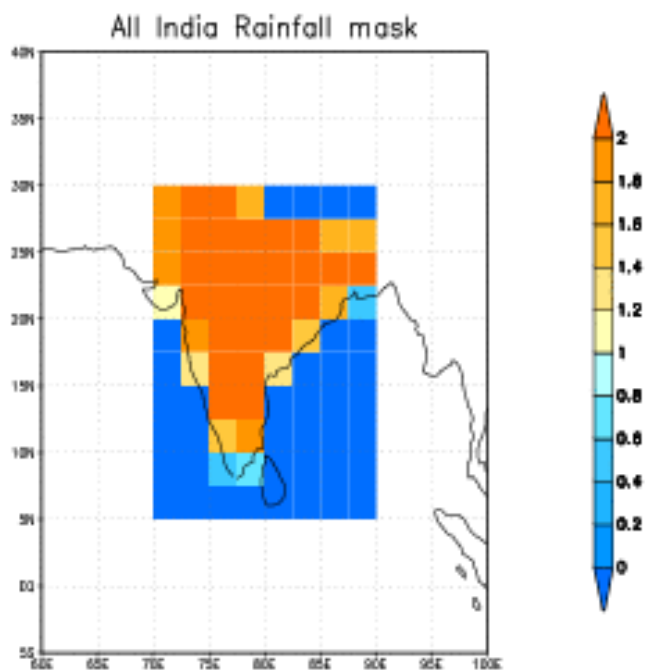
## Rainfall: Sahel / Guinea coast dipole (JJA)



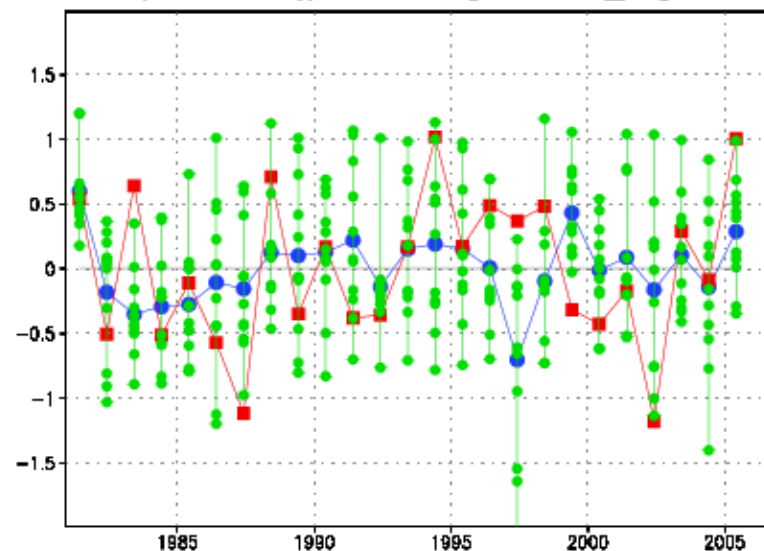
Init: may Verif: jja Cor [an, ens\_m] = 0.580



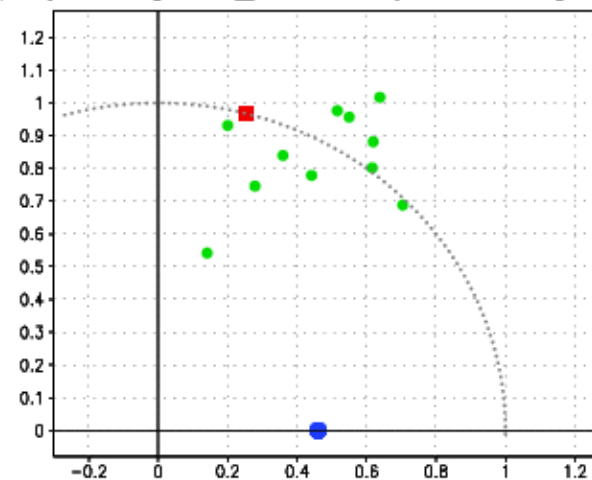
# Predictability of AIR in S-3: a case study - JJAS



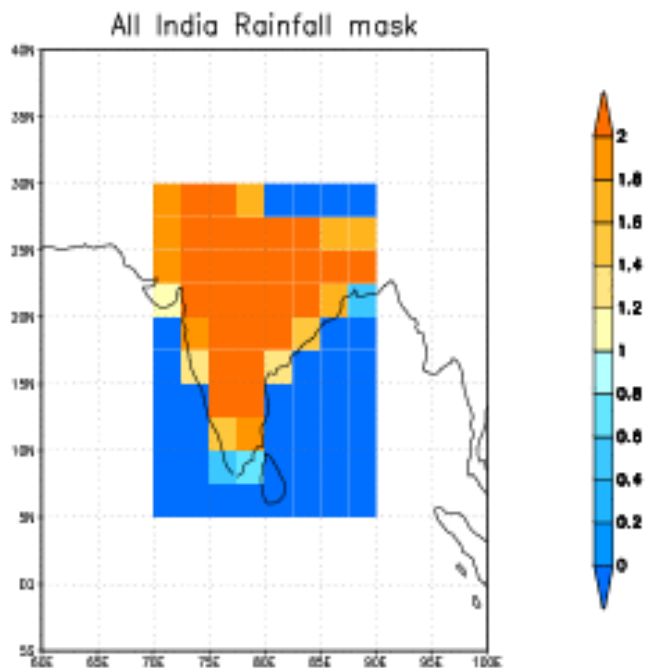
prec average in air [70/90 ; 5/30]  
 Init: may Verif: jjas Cor [an, ens\_m] = 0.254



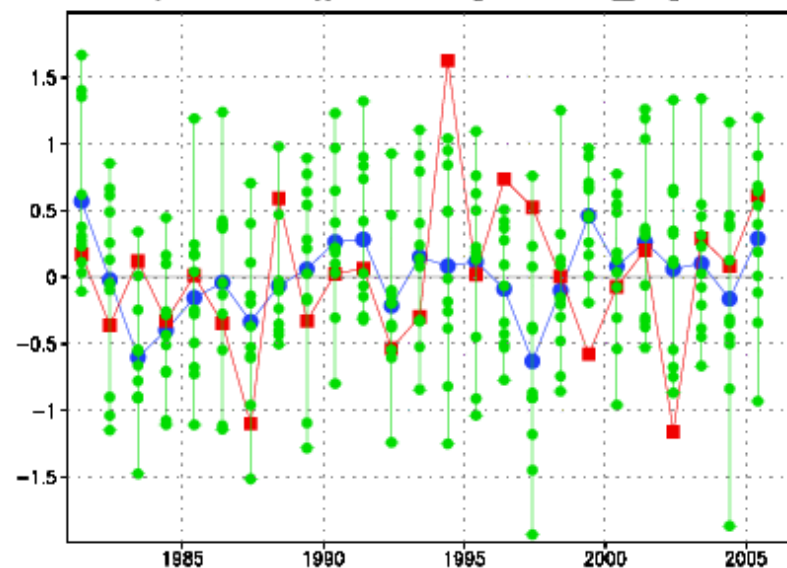
Ensemble anomalies normal. by analysis rms anomaly  
 x = proj. along ens\_m t.s. ; y = orthogonal comp.



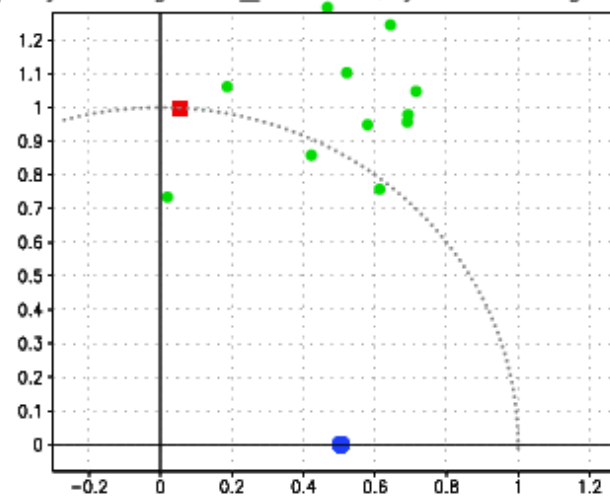
# Predictability of AIR in S-3: a case study - JJA



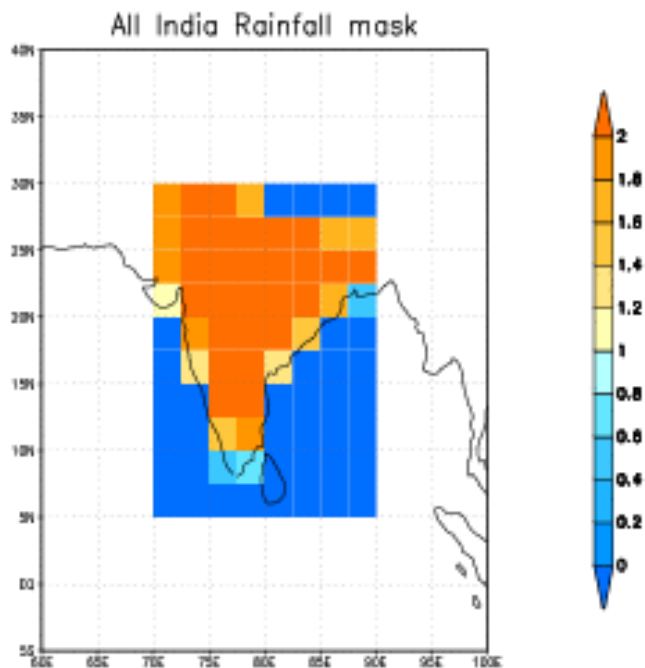
prec average in air [70/90 ; 5/30]  
Init: may Verif: jja Cor [an, ens\_m] = 0.054



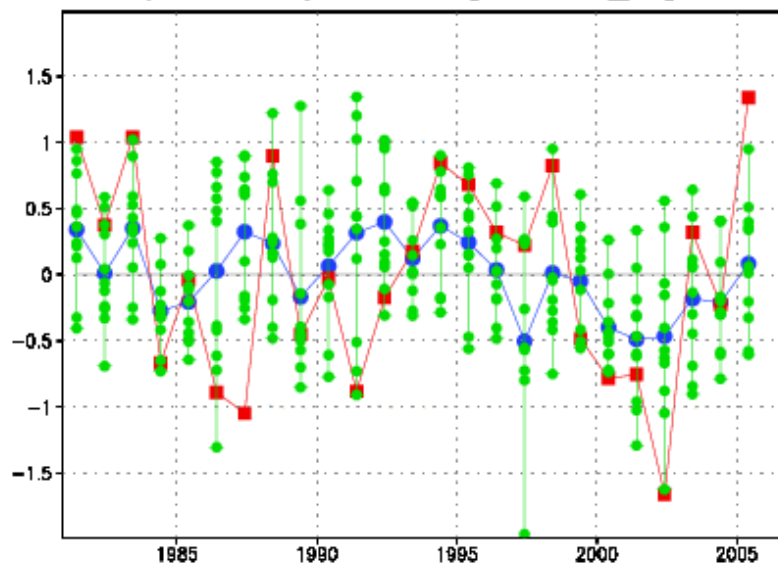
Ensemble anomalies normal. by analysis rms anomaly  
x = proj. along ens\_m t.s. ; y = orthogonal comp.



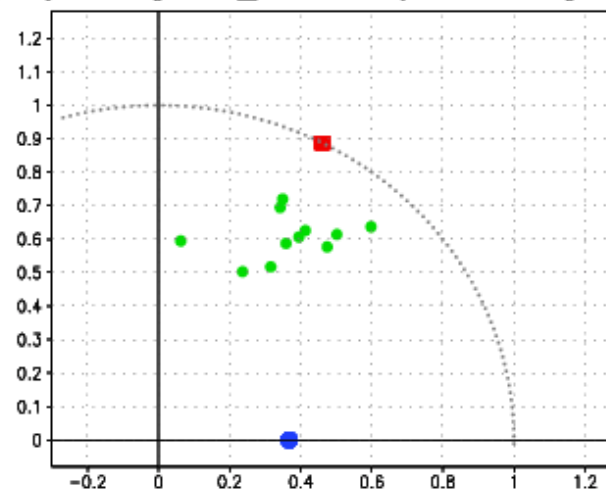
# Predictability of AIR in S-3: a case study - JAS



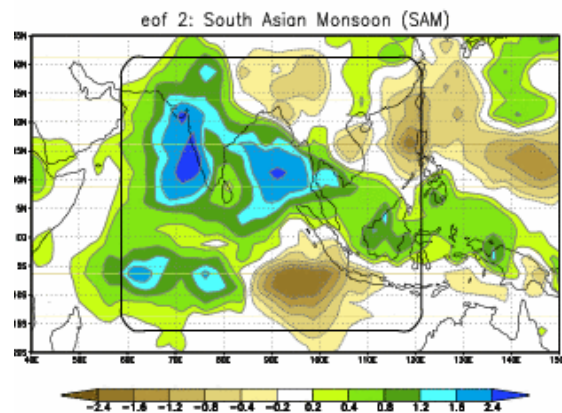
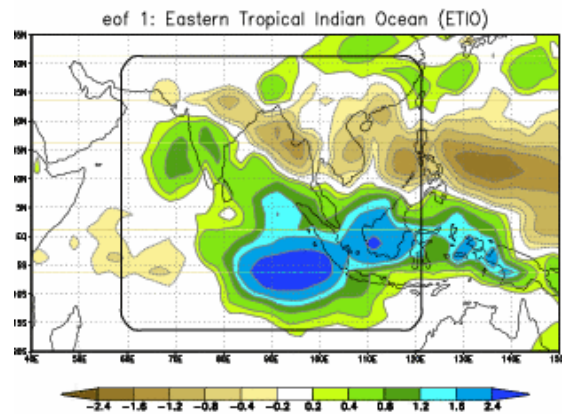
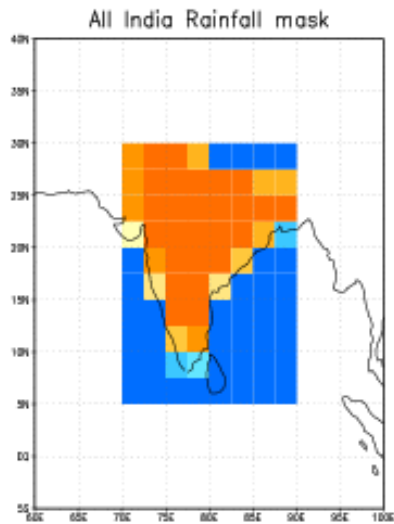
prec avobsge in air [70/90 ; 5/30]  
Init: may Verif: jas Cor [an, ens\_m] = 0.460



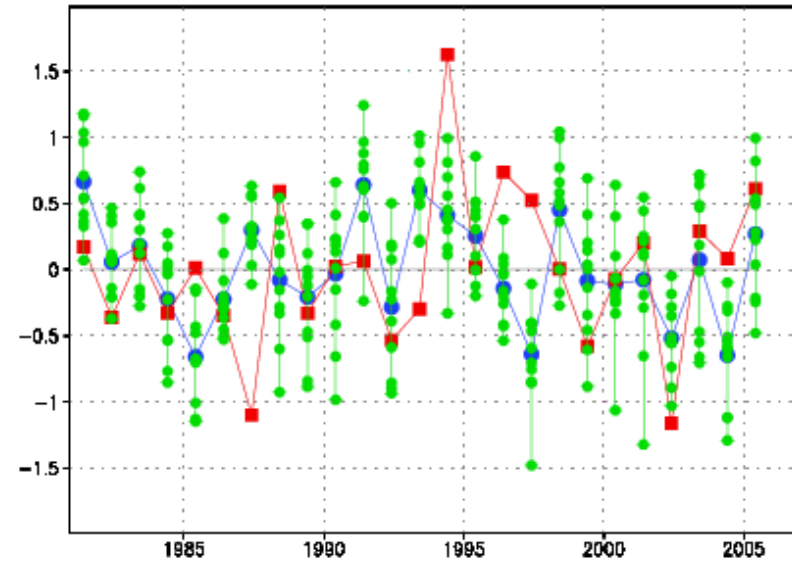
Ensemble anomalies normal. by analysis rms anomaly  
x = proj. along ens\_m t.s. ; y = orthogonal comp.



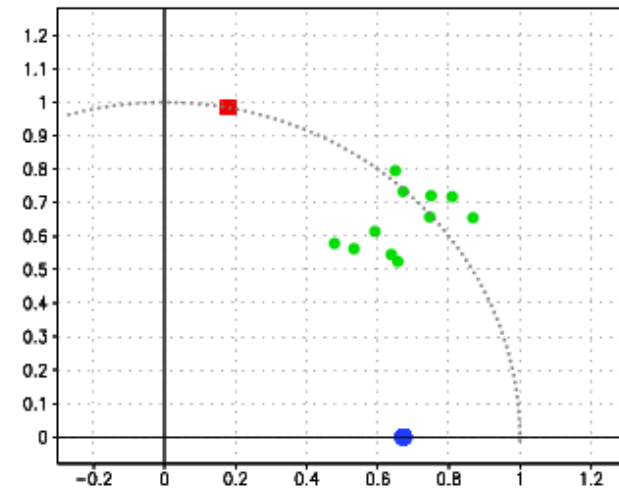
# Predictability of AIR in S-3: EOF filtered JJA



prec projection on air [60/120 ; -15/30]  
Init: may Verif: jja Cor [an, ens\_m] = 0.178

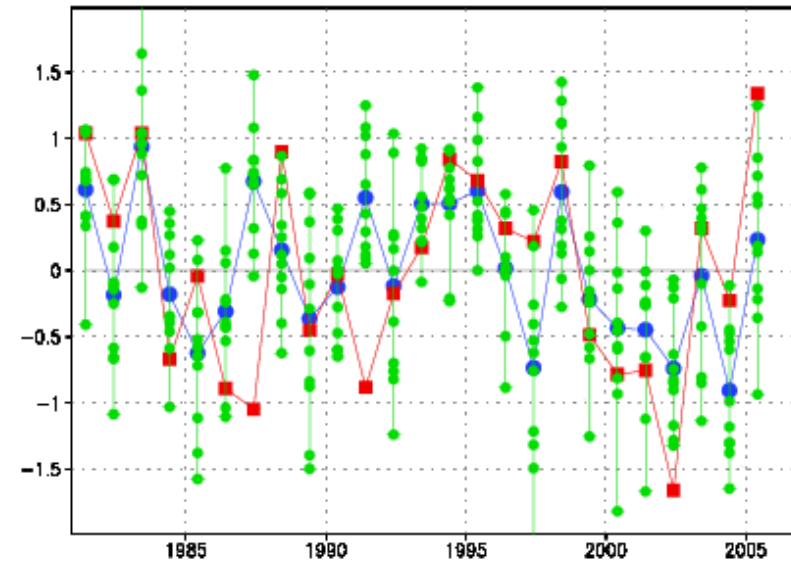
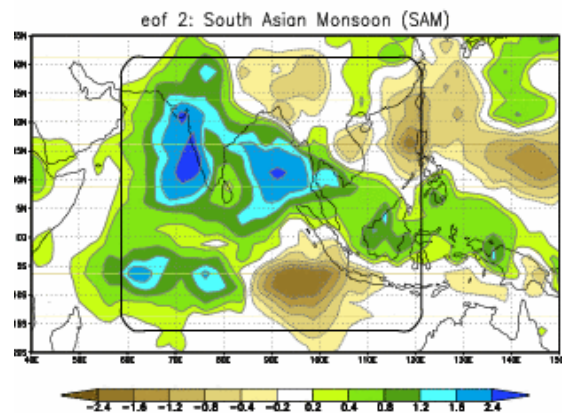
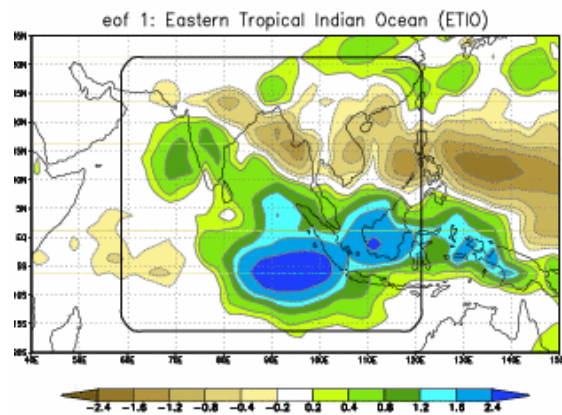
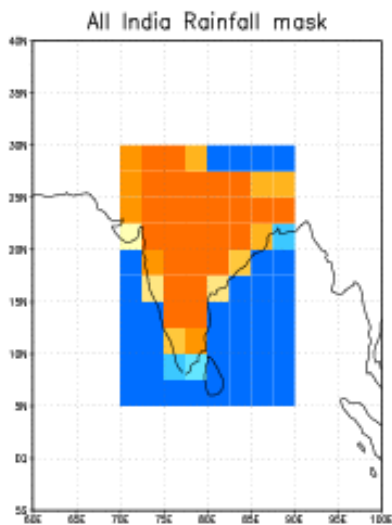


Ensemble anomalies normal. by analysis rms anomaly  
x = proj. along ens\_m t.s. ; y = orthogonal comp.

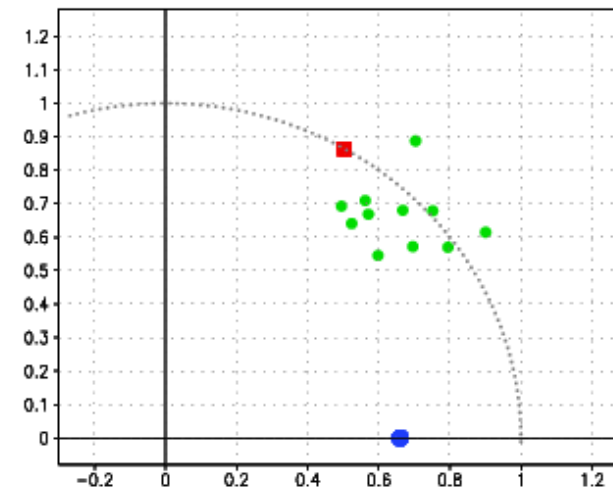


# Predictability of AIR in S-3: EOF filtered JAS

prec projection on air [60/120 ; -15/30]  
Init: may Verif: jas Cor [an, ens\_m] = 0.504



Ensemble anomalies normal. by analysis rms anomaly  
x = proj. along ens\_m t.s. ; y = orthogonal comp.







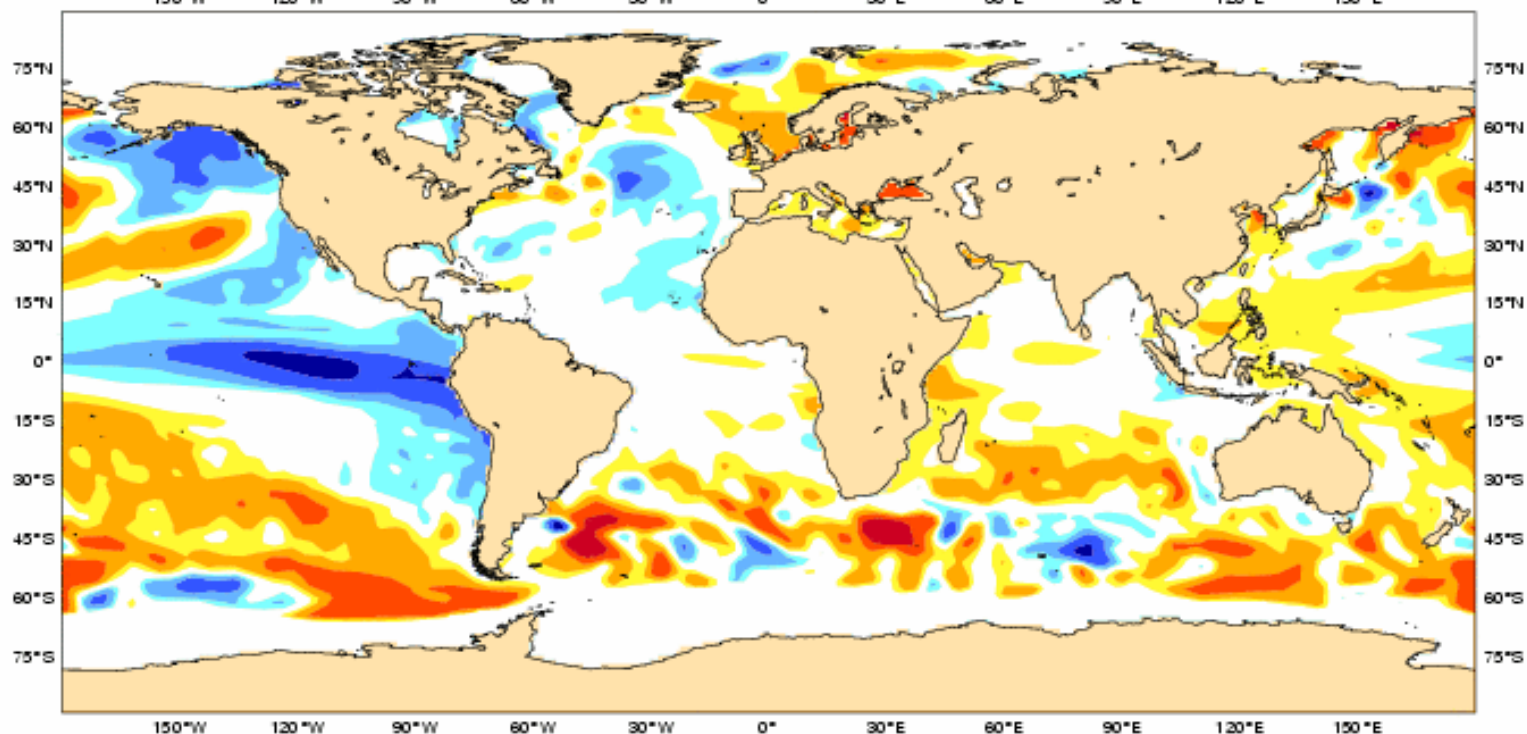
# Prediction of SST anomalies in JAS 2007

ECMWF Seasonal Forecast  
Mean forecast SST anomaly

Forecast start reference is 01/08/07  
Ensemble size = 41, climate size = 275

System 3  
JAS 2007

No significance test applied



Forecast issue date: 15/08/2007

ECMWF



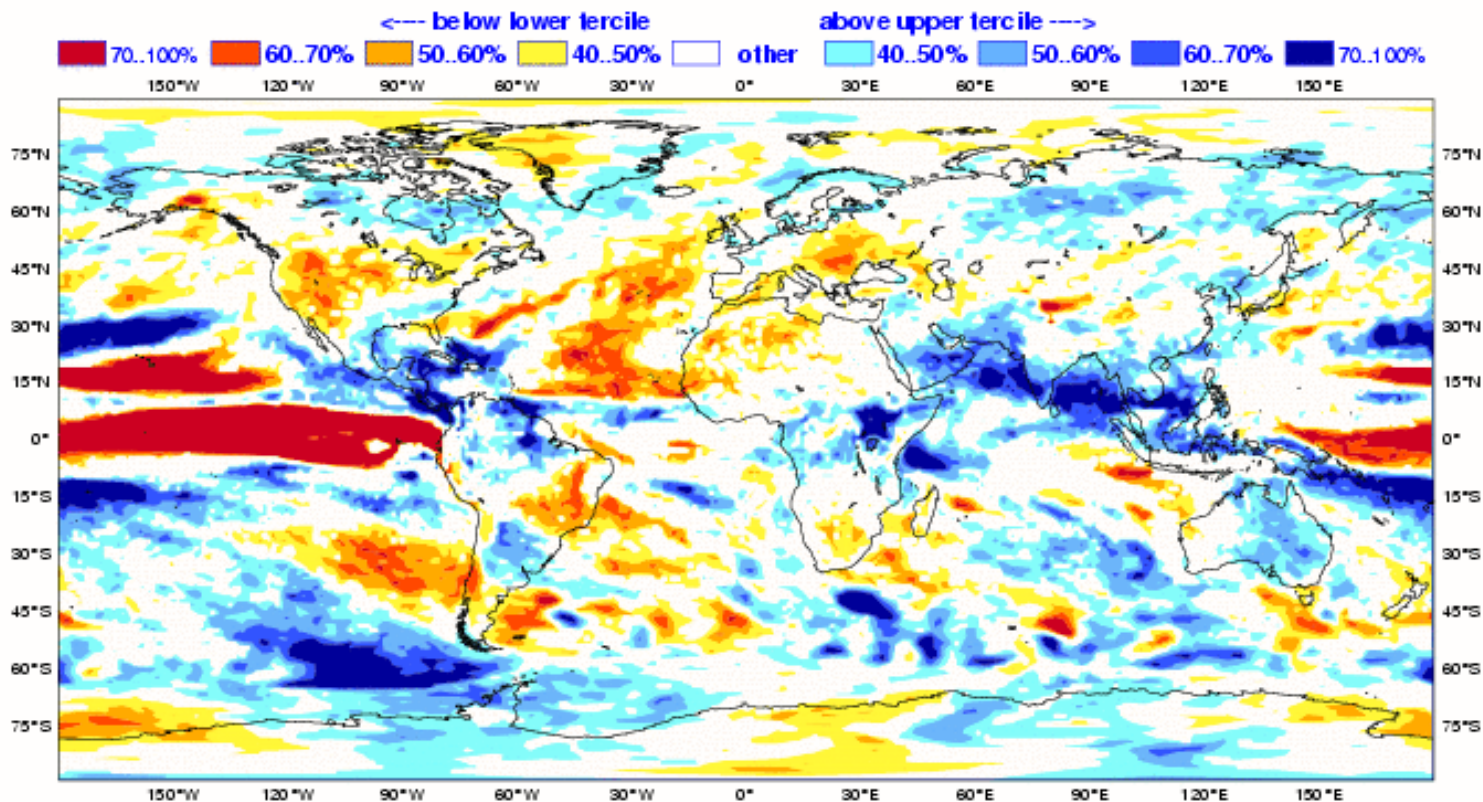
# Prob. of rainfall tercile categories in JAS 2007

ECMWF Seasonal Forecast  
Prob(most likely category of precipitation)

Forecast start reference is 01/08/07  
Ensemble size = 41, climate size = 275

System 3  
JAS 2007

No significance test applied

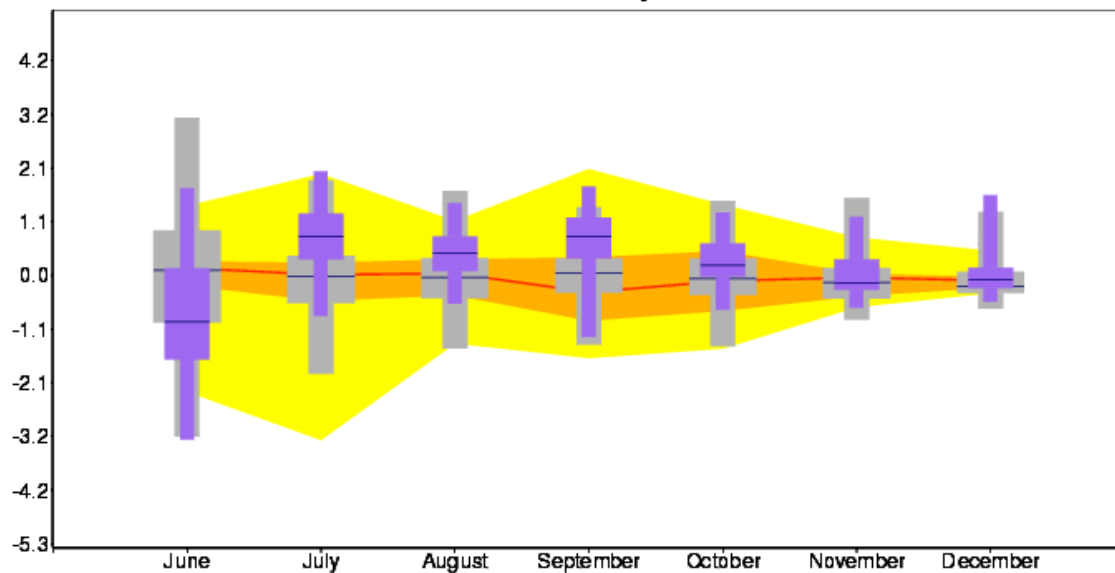


Forecast issue date: 15/08/2007



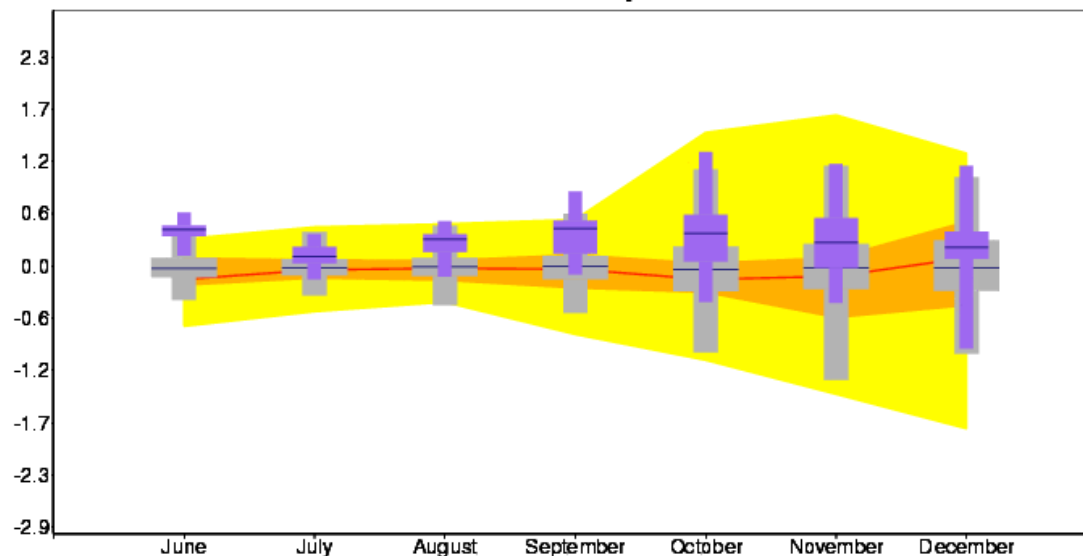


# Indian and East African rainfall



All India rainfall

East Africa rainfall





# Conclusions

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- Extreme tropical rainfall anomalies are often associated with significant SST anomalies, but the role of internal atmospheric variability and land-surface processes cannot be neglected.
- SST predictions with CGCMs are reasonably good for the ENSO phenomenon, but predictive skill over the tropical Indian and Atlantic Ocean is still relatively low in NH summer.
- Difficulty in getting the correct rainfall variability over land.
- Predictive skill for seasonal rainfall is generally good around the Pacific and over tropical S. America, lowest along the coast of the Indian Ocean (especially in early summer).
- Predictions for regional teleconnection indices are usually better than for area-averages, and can be exploited to extract signal over land.



## The seasonal forecast System-3 (implem. March 07)

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- **COUPLED MODEL (IFS + OASIS2 + HOPE)**

- Recent cycle of atmospheric model (Cy31R1)
- Atmospheric resolution TL159 and 62 levels
- Time varying greenhouse gasses.
- Include ocean currents in wave model

- **INITIALIZATION**

- Includes bias correction in ocean assimilation.
- Includes assimilation of salinity and altimeter data.
- ERA-40 data used to initialize ocean and atmosphere in hindcasts
- Ocean reanalysis back to 1959, using ENACT/ENSEMBLES ocean data

- **ENSEMBLE GENERATION**

- Extended range of back integrations: 11 members, 1981-2005.
- Revised wind and SST perturbations.
- Use EPS Singular Vector perturbations in atmospheric initial conditions.

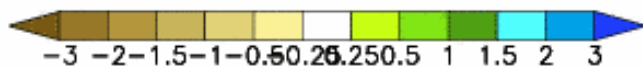
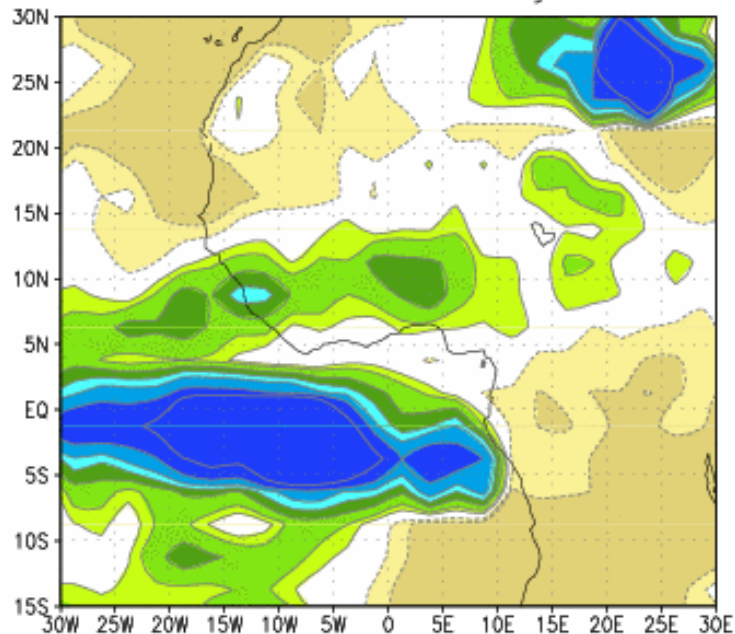
- **Forecasts extended to 7 months (to 13 months 4x per year).**



# Errors in rainfall standard deviations

$$[\text{SD (Sys-3)} - \text{SD (GPCP)}] / \text{SD (GPCP)}$$

st.dev. rel. error june



st.dev. rel. error july

