The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

Global Climate Modeling at the Abdus Salam International Centre for Theoretical Physics

Fred Kucharski

All presented results with contributions from
Filippo Giorgi, Annalisa Bracco, Jin-Ho Yoo, Franco Molteni, Martin P. King, Erika Coppola and Juergen Kroeger

Outline:

Talk will present an overview over the global modeling activities at the ICTP

1. **Uncoupled AGCM integrations (2-tier) to understand Climate Variability in the 20th century and its potential changes in the 21st century**

2. **Regionally coupled/pacemaker experiments (1.5-tier) for Asian Monsoon**

3. **Conclusions**

i. 2-Tier approach

1) AGCM uncoupled simulation (ICTP AGCM 8 lev):

Simulation of 20th century variability in 50-yr and 130-yr in ensembles forced globally by HadISST (1870-2002), in the context of the "Climate of the 20th Century" (C20C) project. 25 members of 130-year integrations and 100 members of 50-year integrations.

2) Climate change simulations with the high resolution NASA FVGCM

ICTP AGCM stand-alone model: GCM of intermediate complexity

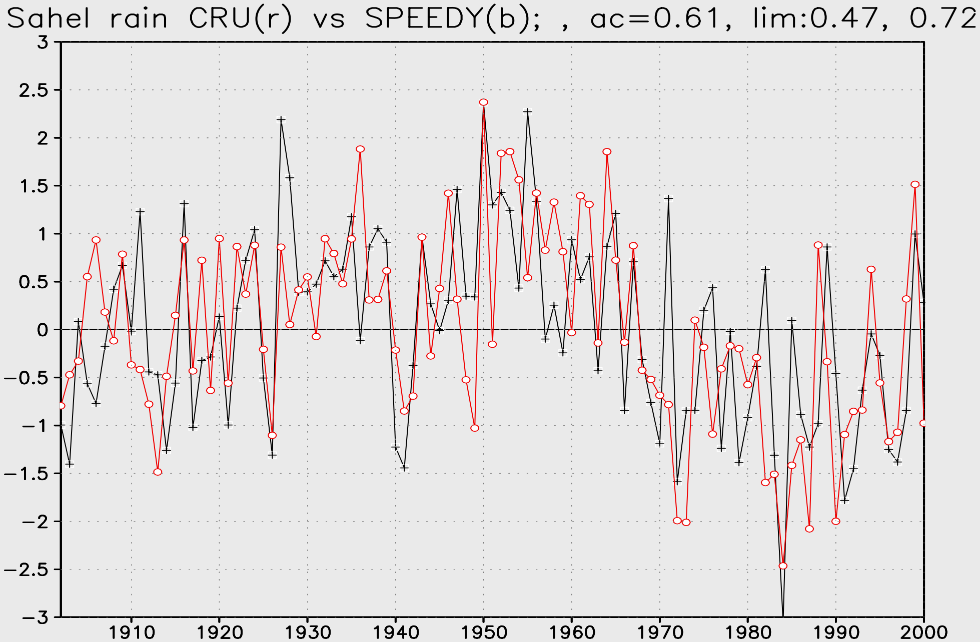
- Spectral dynamical core (Held and Suarez 1994)
- Truncation currently at T30 (~3.75x3.75 degrees)
- 5, 7 or (recently) 8 vertical levels
- Variables: Vor, Div, T, log(ps) and Q
- Physical parameterizations of
  - Convection (mass flux)
  - Large-scale condensation (RH criterion)
  - Clouds (diagnosed)
  - Short-wave radiation (two spectral bands)
  - Long-wave radiation (four spectral bands)
  - Surface fluxes of momentum and energy (bulk formulas)
  - Vertical diffusion
- Land-temperature calculated in simple model of 1-m soil layer
- Mixed-layer option

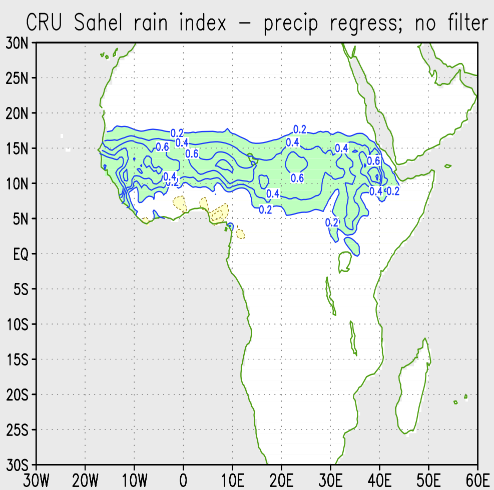
Results from C20C ensembles :

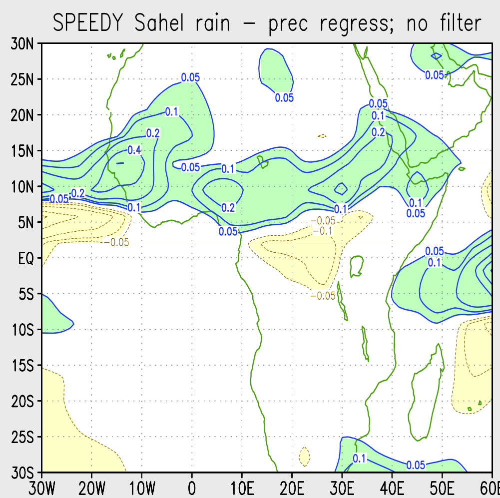
a) Sahel rain

(unpublished, but there is a lot of literature already)

Seasonal means
of Sahel rainfall
(15W to 37.5E,
 12.5N to 17.5N)
in JJAS:
Standardized
time series and
regression patterns
Corr(1yr) = 0.61
Corr(11yr) = 0.94



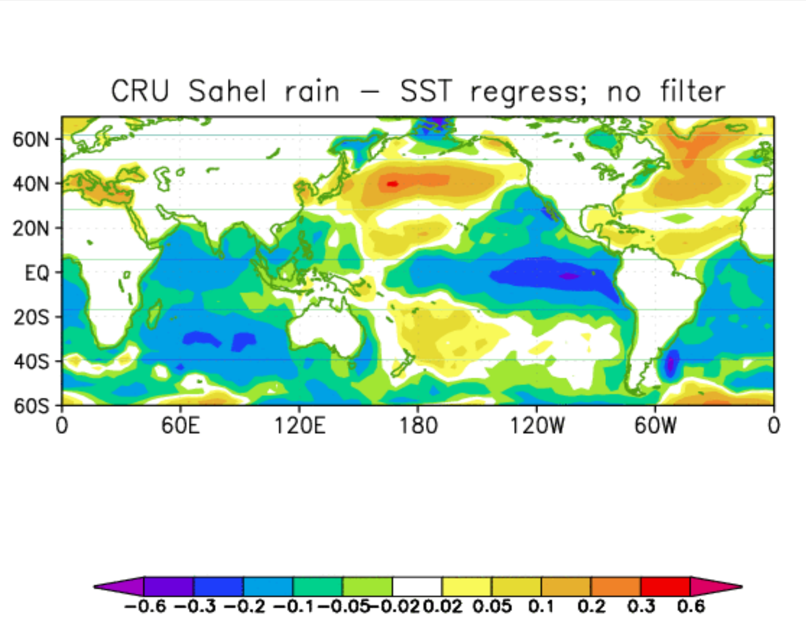




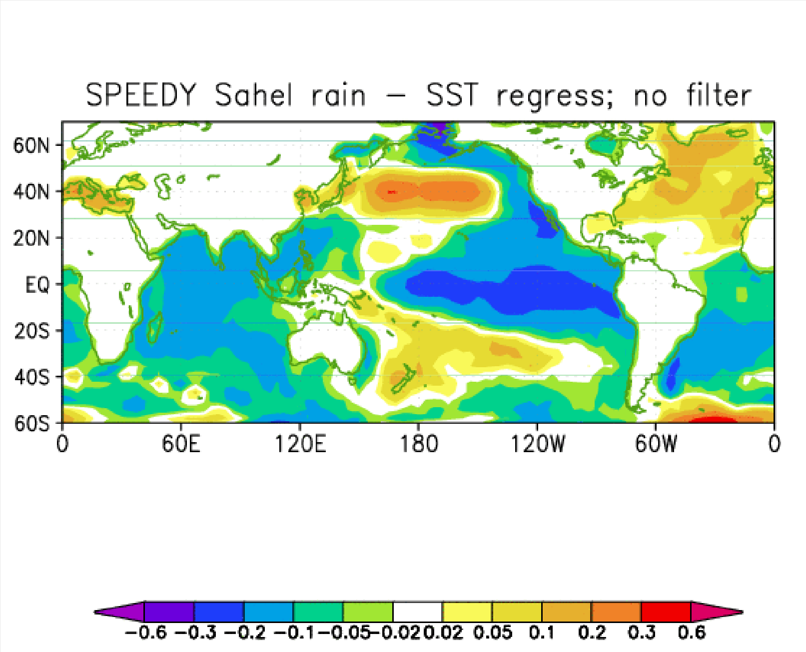
CRU **SPEEDY**

SST regression (K)

CRU



SPEEDY

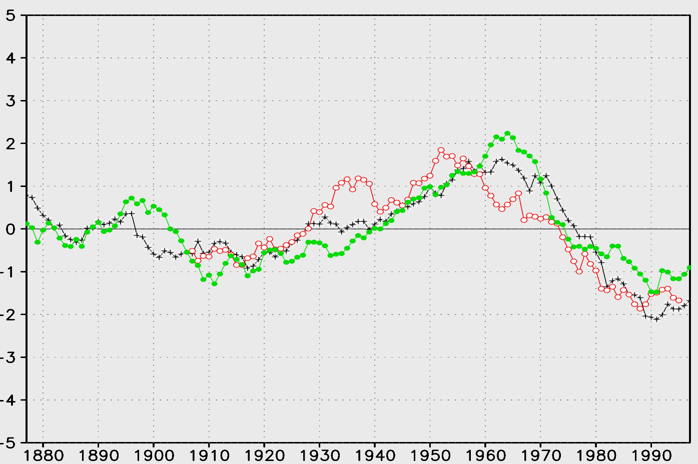


Results from C20C ensembles:

b) Decadal Indian monsoon rain

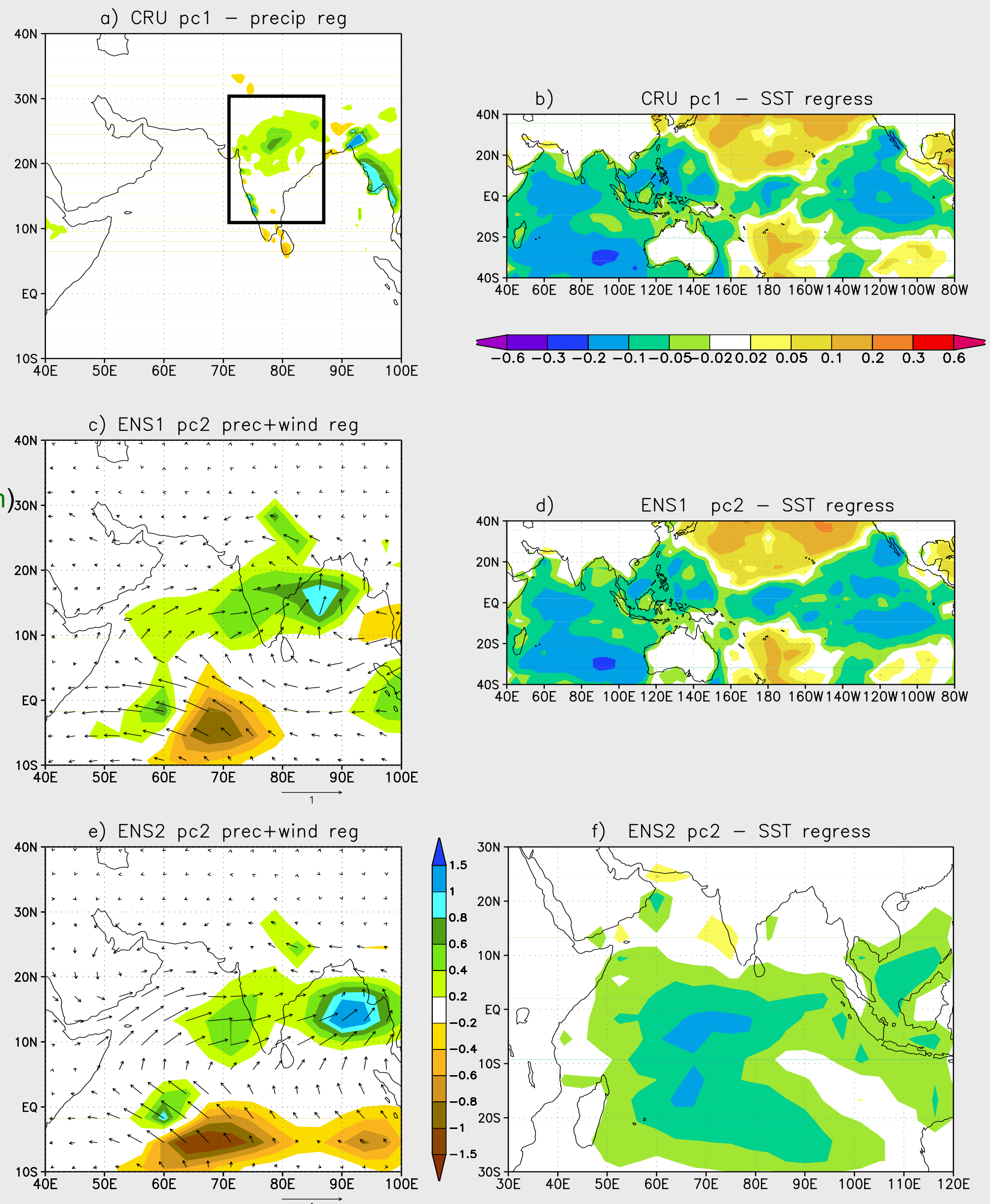
(11-year JJAS mean 70E to 85E, 10N to 30N)

PCs from CRU (red), SPEEDY (black), SPEEDY_IO (green)



Corr(pc1_cru,pc2_sp) = 0.85
Corr(pc1_cru,pc2_spio) = 0.70

EOFs of decadal Indian rain, PCs regressed onto SSTs (Kucharski et al. , GRL, 2006)



CRU EOF1

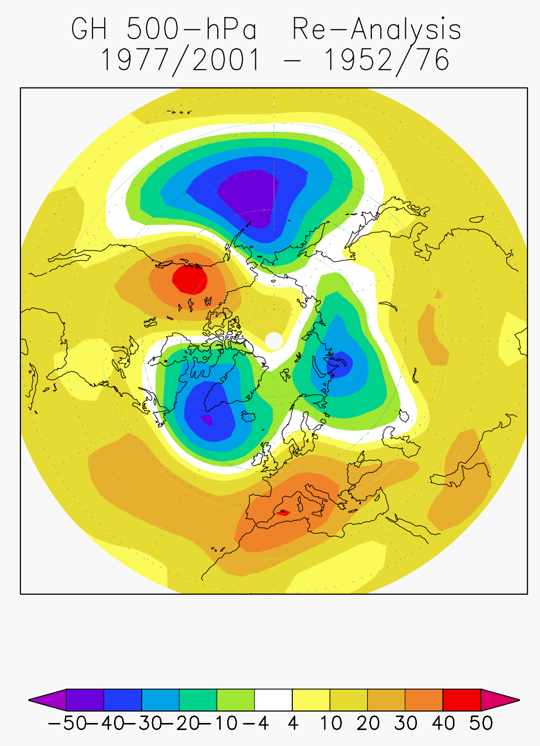
SPEEDY EOF2

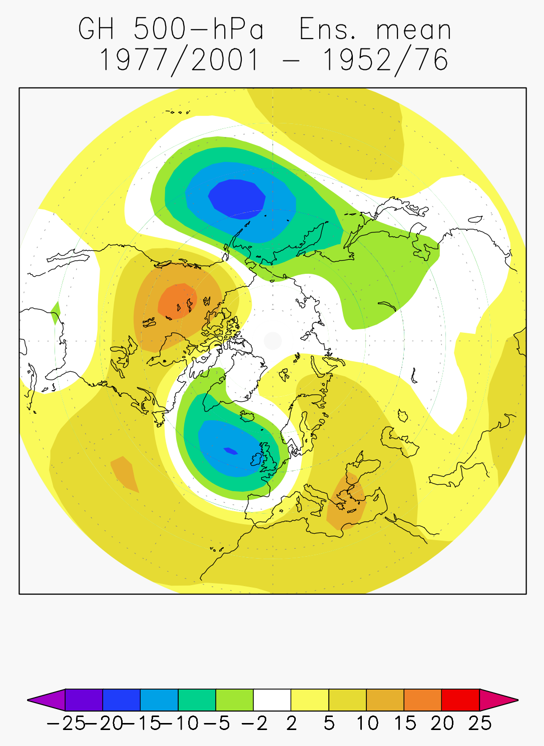
SPEEDY EOF2 Forced in Indian Ocean only

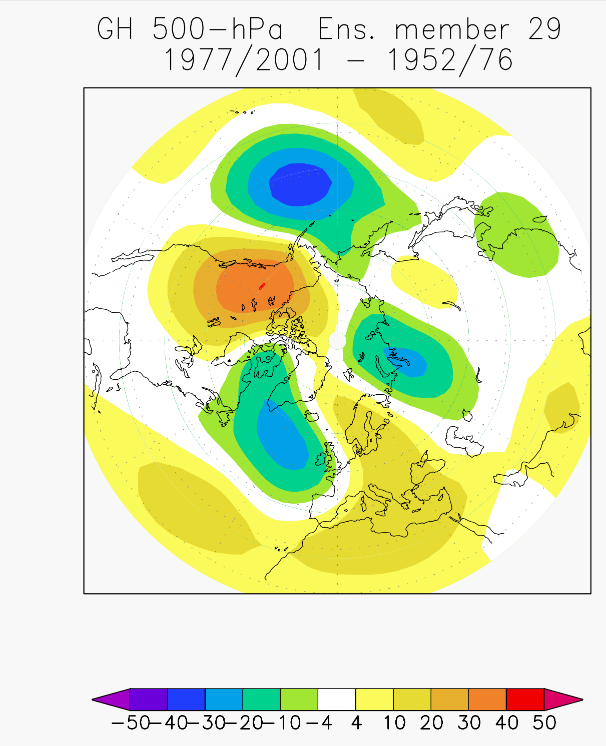
Results from C20C ensembles:
c) Extratropical climate trends

500 hPa height trend ***(1977/2001 – 1952/76)*** **in:**

Re-analysis | **Ens. Mean** | **Single exp.**



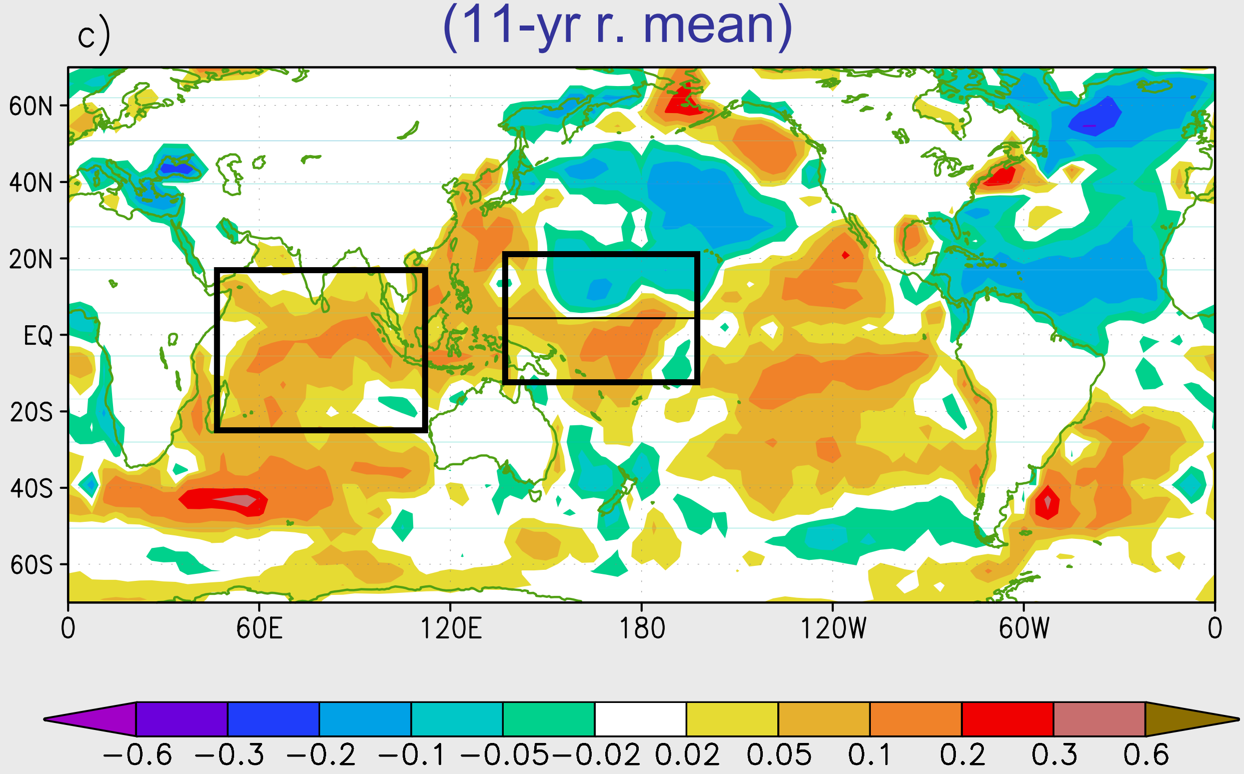




Results from C20C ensembles:
d) Decadal NAO-western tropical Pacific interaction

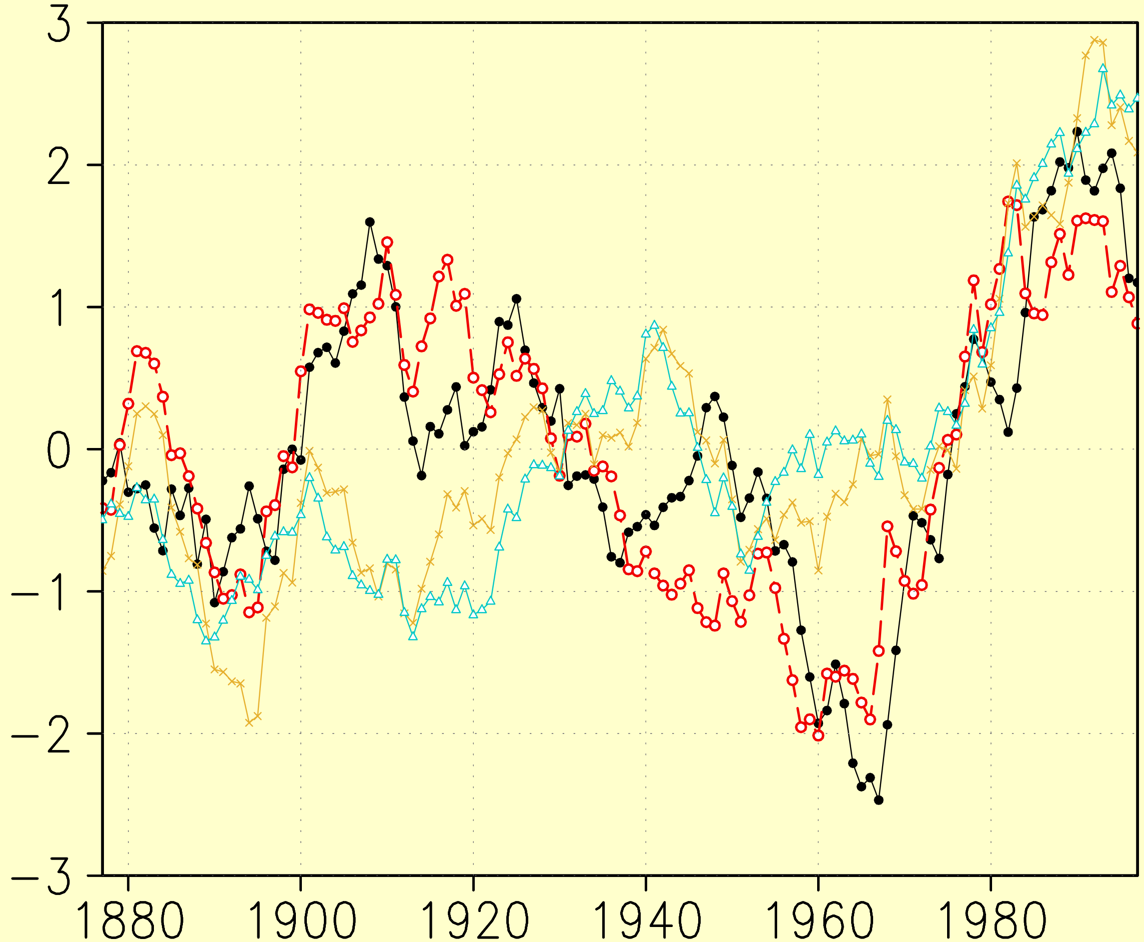
(Kucharski et al., Clim. Dyn., 2006)

Regression of SST onto decadal NAO index
(11-yr r. mean)



HadISST 1870-2002 from Hadley Centre (Rayner et al. 2003)

Decadal NAO index vs. tropical SST indices

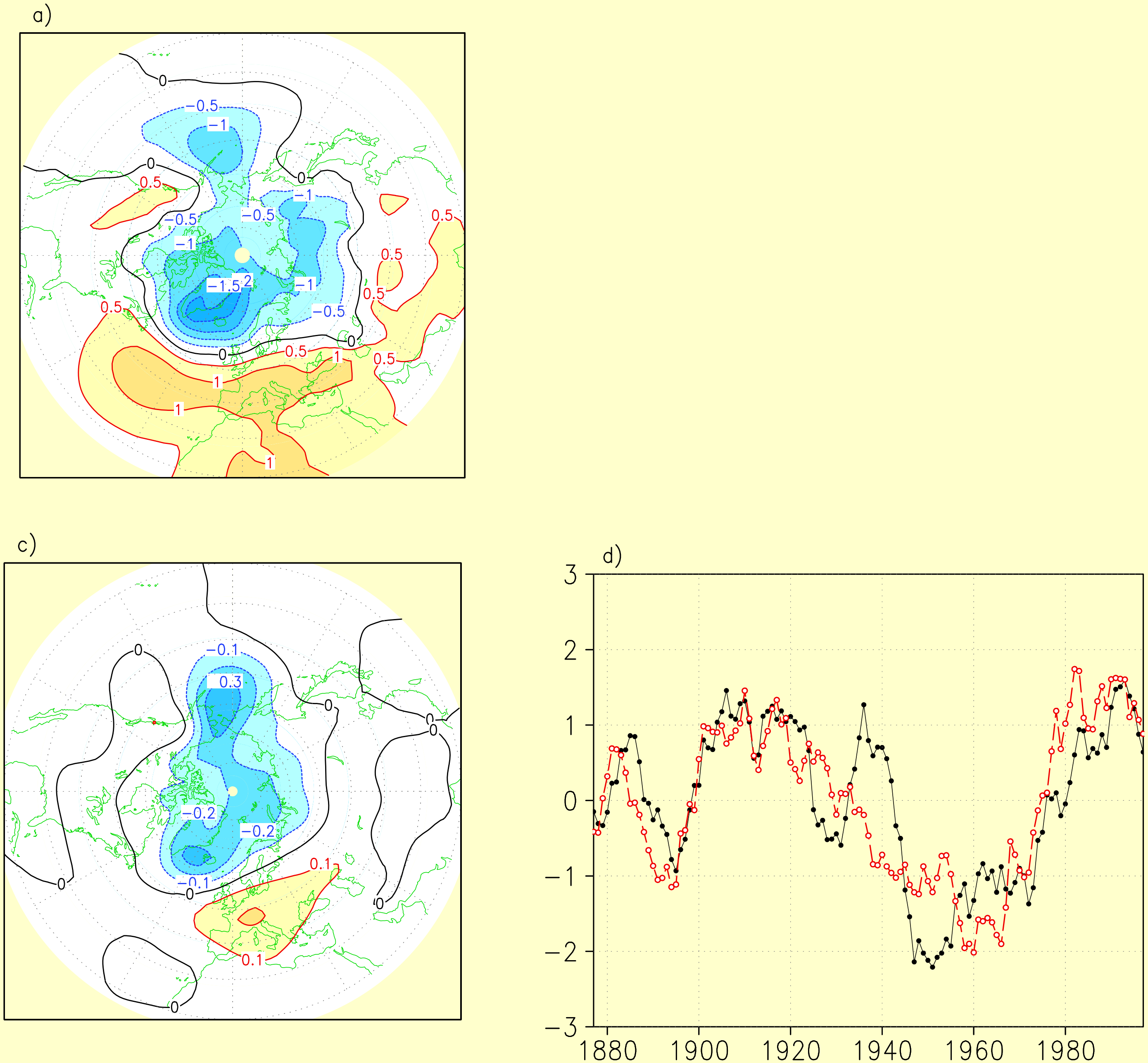


West. Trop. Pacific gradient
[12S - 4N] – [8N - 20N]
(cc = 0.82)

West. Trop. Pacific Southern box
(cc = 0.52)

Indian Ocean box,
20N - 20S
(cc = 0.43)

Niño 3.4
(cc = 0.36)



PC-2 vs.
WTP SST gradient
[12S - 4N] –
[8N – 20N]
cc = 0.78

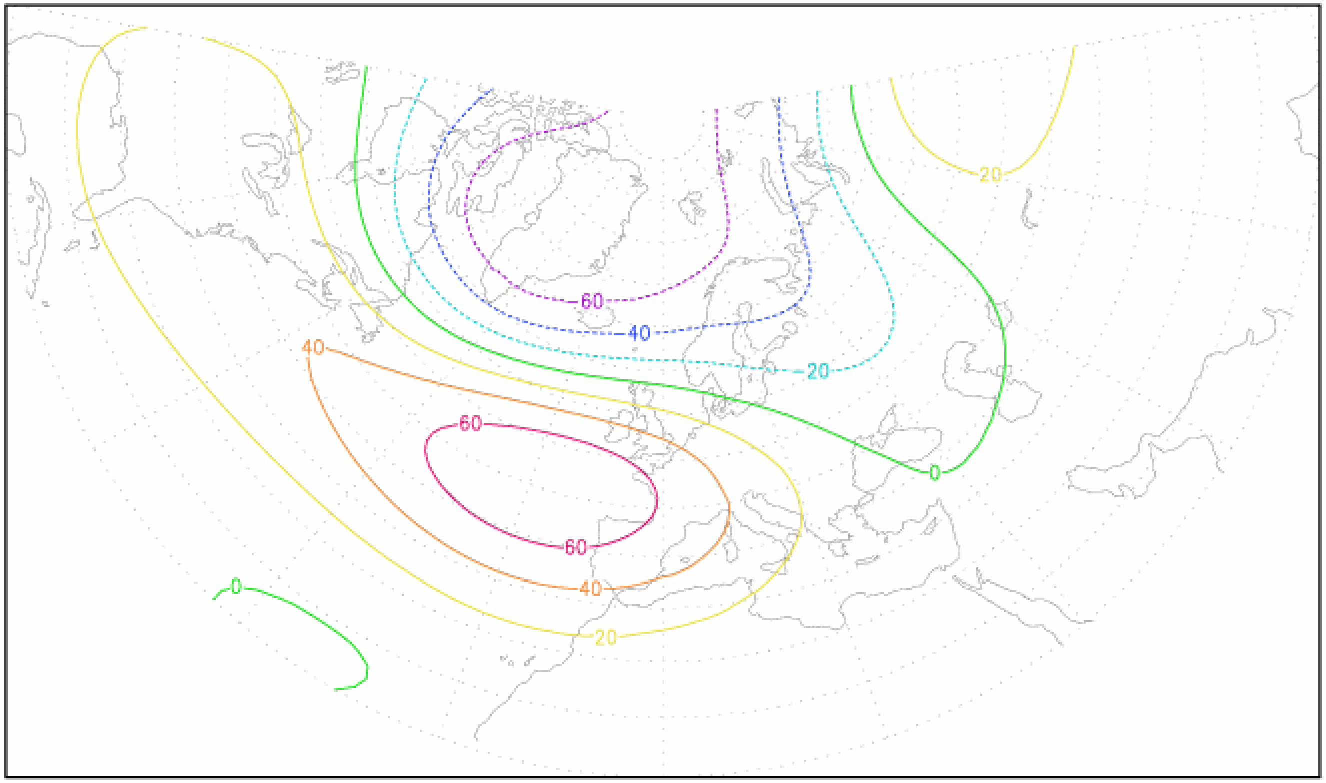
Bimodality of the North Atlantic Oscillation in simulations with greenhouse gas forcing (Coppola et al. GRL, 2005)

FVGCM integrations

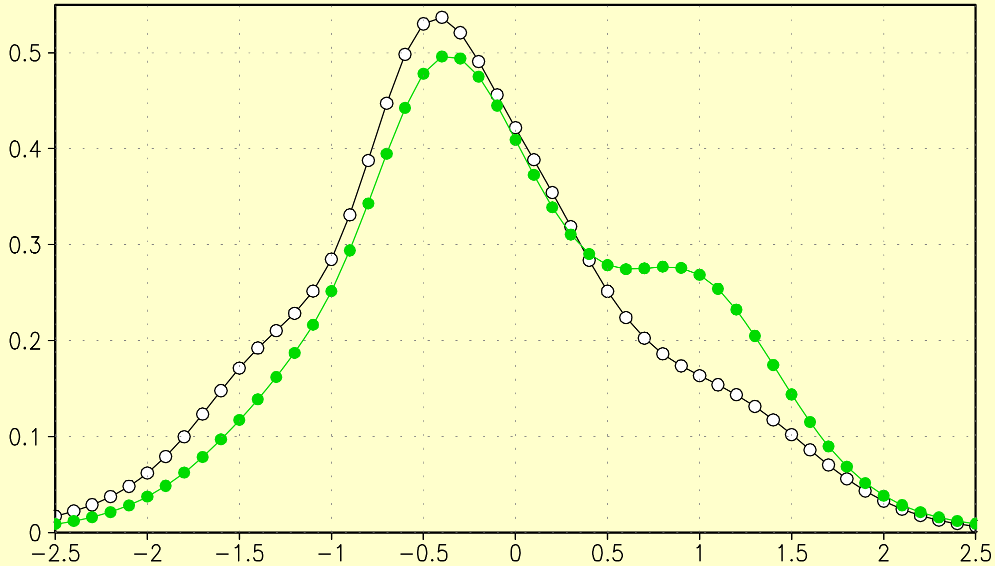
Finite Volume General Circulation Model (NASA FVGCM) time-slice Experiments within the PRUDENCE project

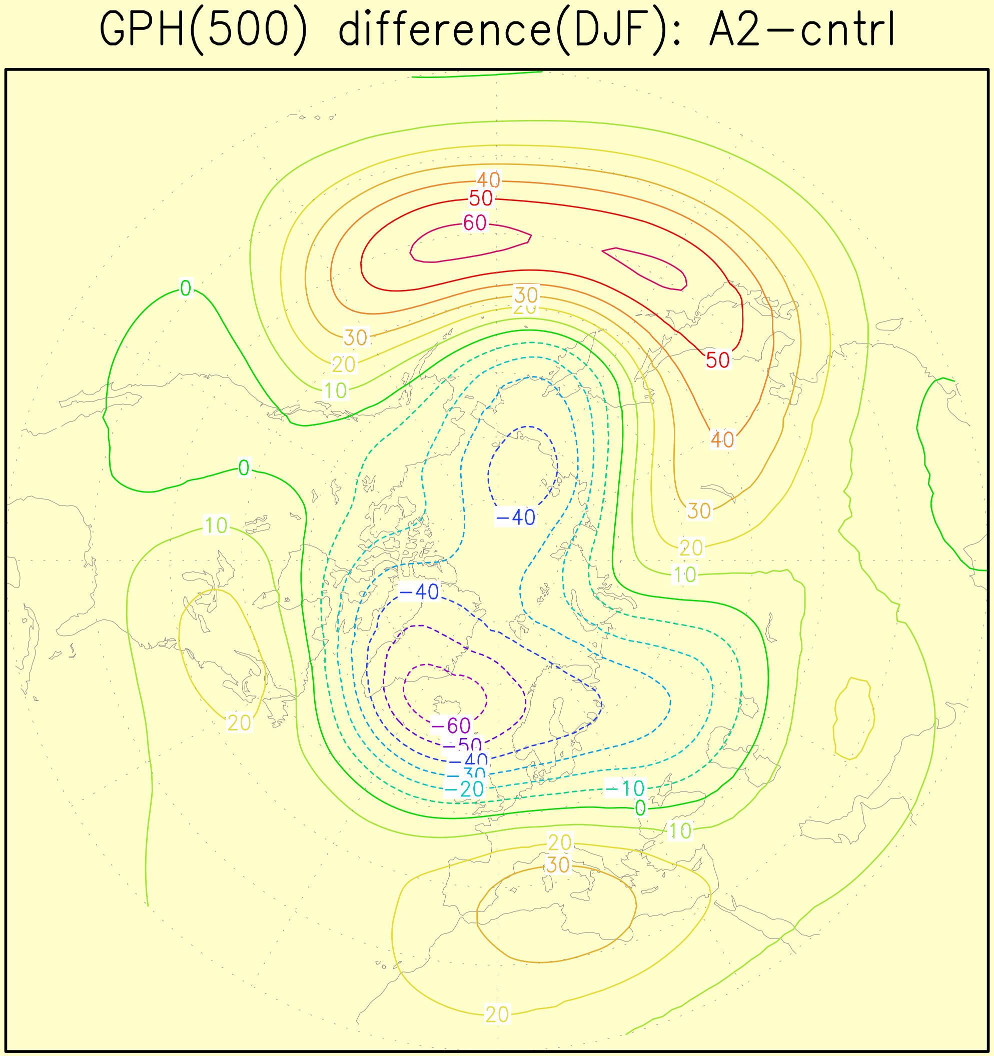
- Physical parameterizations from NCAR CCM3
- High resolution (1.25x1 degree, 18 levels) time-slice experiments
- 2 Ensemble members as control (1960-1990):
  - different initial conditions;
- 2 Ensemble members for A2 scenario (2070-2100):
  - different initial conditions
- All data (6 hourly output, daily diagnostics) stored (8 Tbite)
- Forcing SSTs from coupled HadCM3 model
- Additionally CO2 and aerosol forcing

1 EOF(DJF) of GPH500: cntrl+A2



PDF comb PC: cntrl=circle; A2=dot





Bimodal NAO related to a mean shift in 500 hPa height

The increase of height in the Pacific region projects onto the negative phase of PNA (Wallace and Gutzler).

Corti and Palmer (1997) showed that the NAO is more sensitive to baroclinic perturbation when the PNA index is negative.

ii. 1.5-Tier approaches

2) Comparison of ENSO-Monsoon relationship in different experimental set-ups (within ENSEMBLES Project)

Using observed SST outside the Indian Ocean region, but

a) **SPEEDY-MICOM inside Indian Ocean/western Pacific region (1.5-tier)**

a) **1-d mixed-layer in Indian Ocean/western Pacific (1.5-tier), or**

a) **Observed SST everywhere (2-tier)**

A) Results from coupling of MICOM in the Indian Ocean: ENSO-Monsoon teleconnection (Bracco et al., Clim. Dyn., 2006)

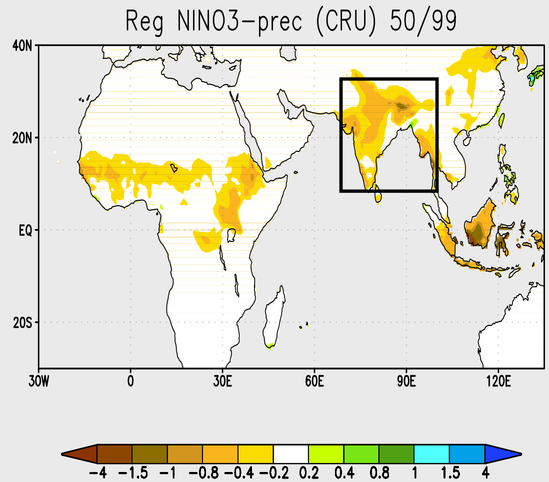
Along the lines of Kirtman, Kang…….

Regression of NINO3 onto JJAS rain

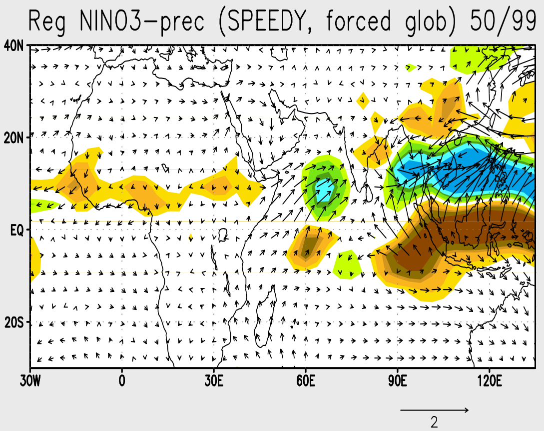
Indian Monsoon rain:
Mean rain in land-points of box:
70-95E, 10-30N

Corr(CRU,speedy_glob) = 0.29
Corr(CRU, speedy_iomxl) = 0.50
Corr(CRU,speedy_iocoup) = 0.63

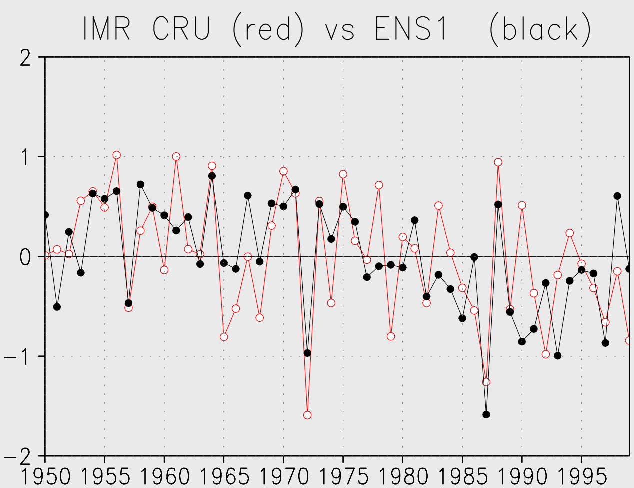
CRU



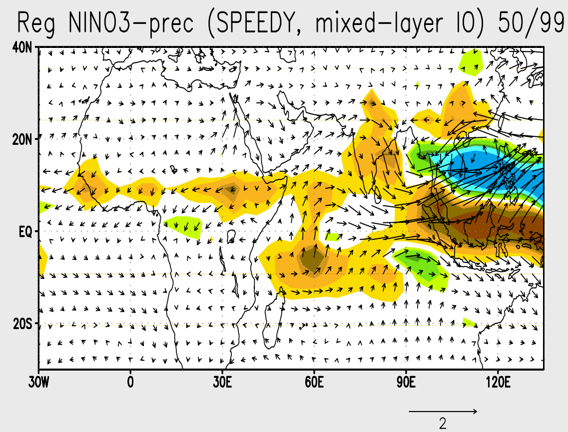
SPEEDY (forced glob)



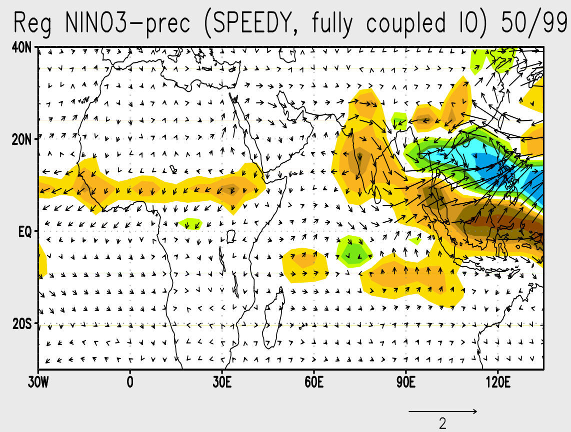
Timeseries of IMR: SPEEDY (IO coupled) vs CRU



SPEEDY (IO mixed-layer)

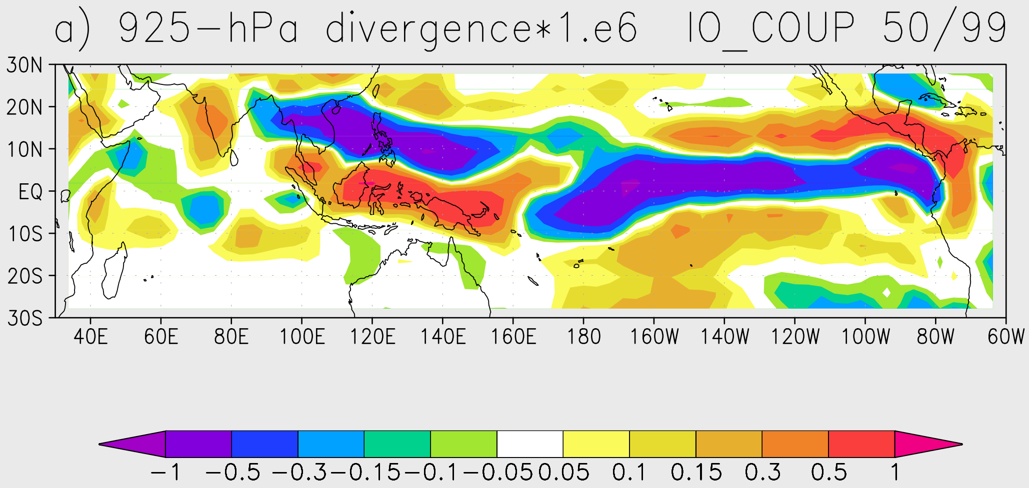


SPEEDY (IO coupled)

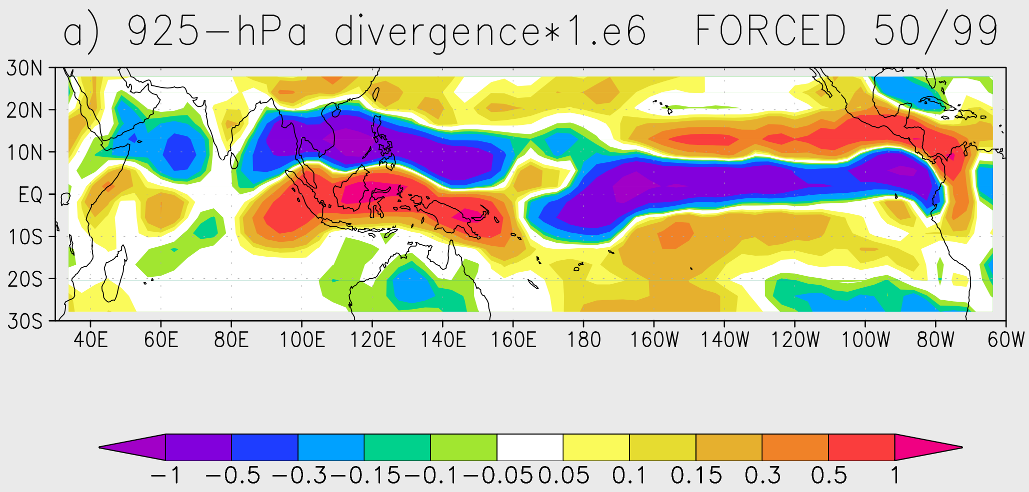


925-hPa wind Divergence

IO_coup

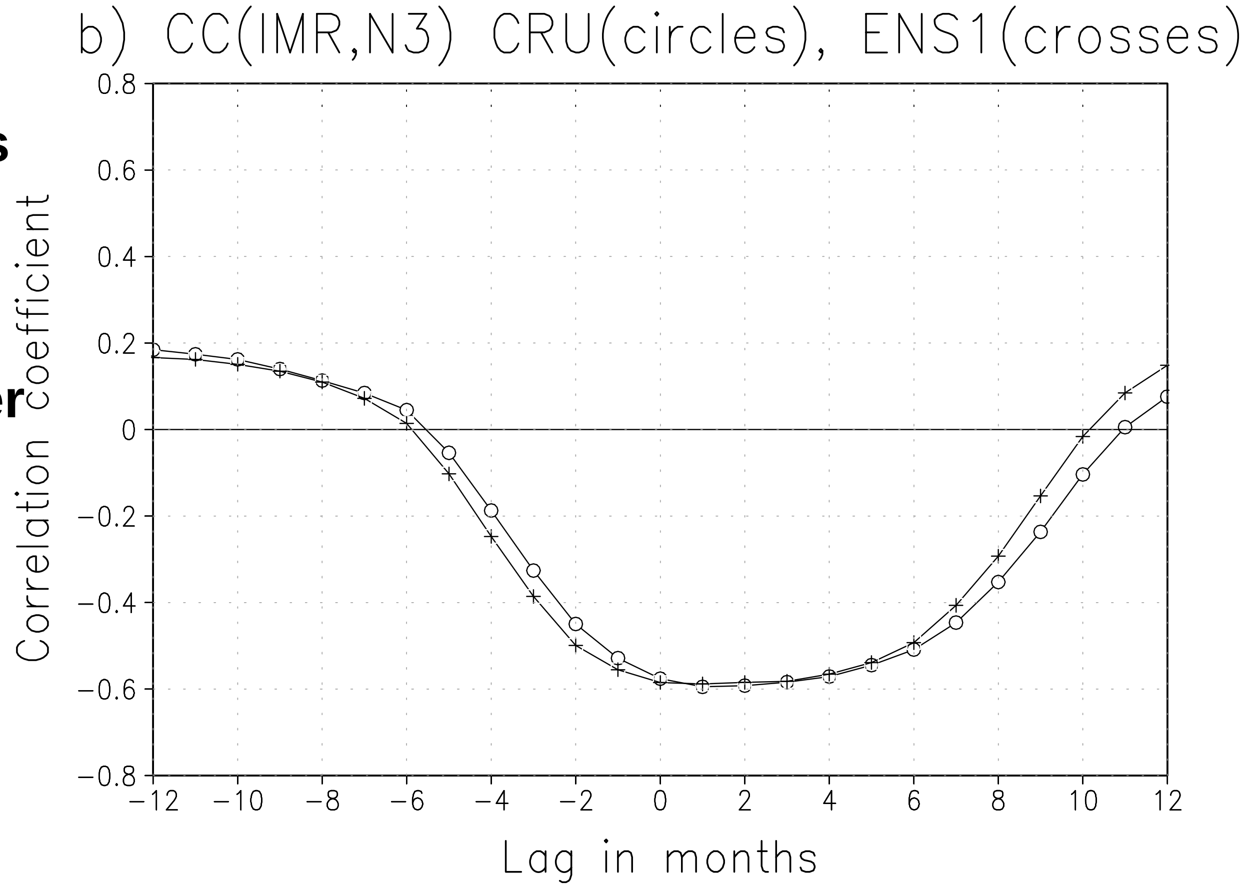


forced



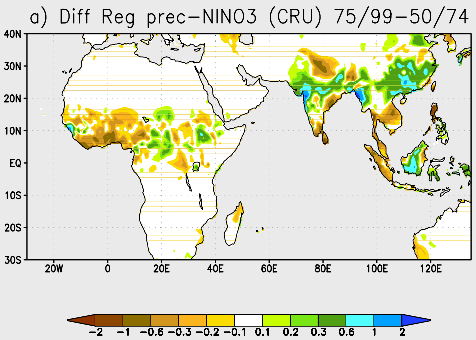
Lagged correlation between IMR (JJAS) and 4-month average NINO3 index for IO_coup

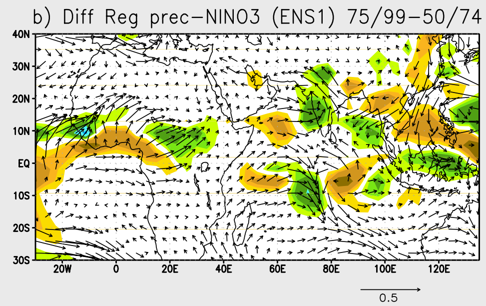
Support for Goswami's Hypothesis the that IMR leading ENSO is do to phase locking of ENSO in autumn/Winter

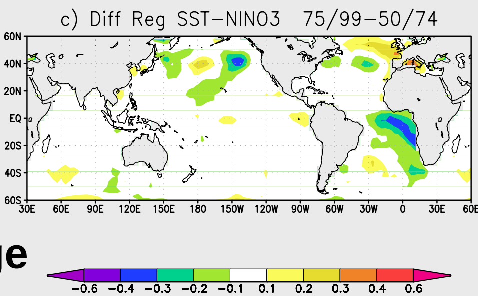


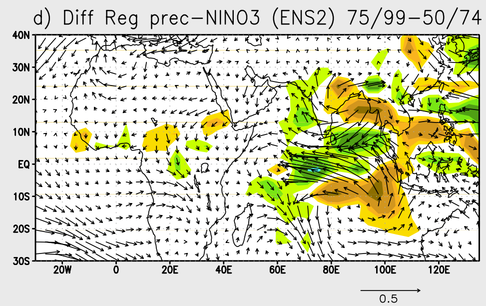
B) Results from coupling of MICOM in the Indian Ocean: Change of ENSO-Monsoon Teleconnection and changes in the Tropical Atlanitc

(Kucharski et al., J. Climate, subm.)

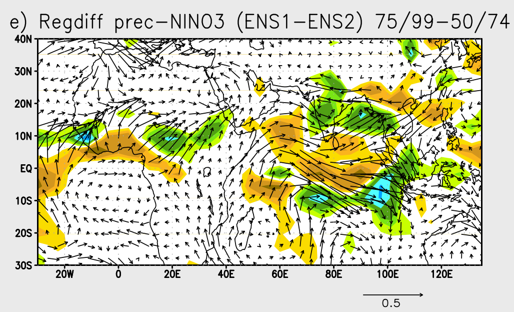








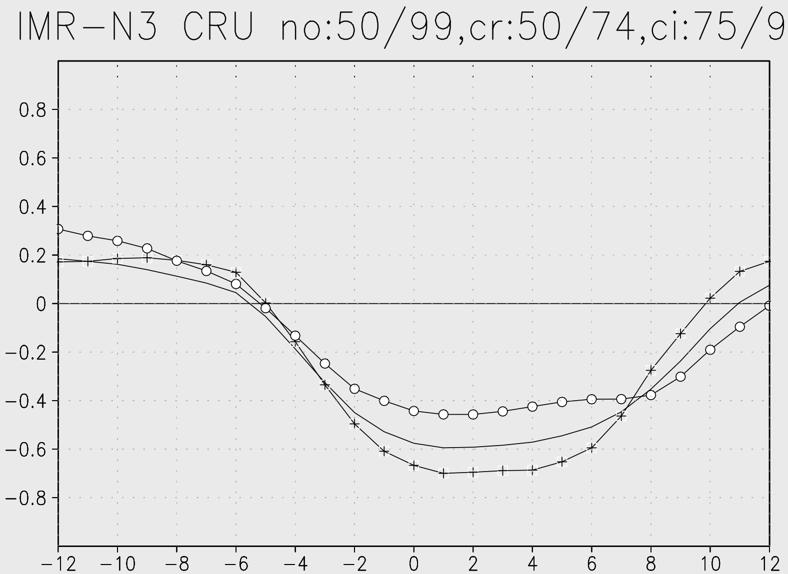
	1950-1974	1975-1999	Change
CC(CRU,NINO3)	-0.69	-0.45	0.24
CC(ENSM,NINO3)	-0.79	-0.51	0.28

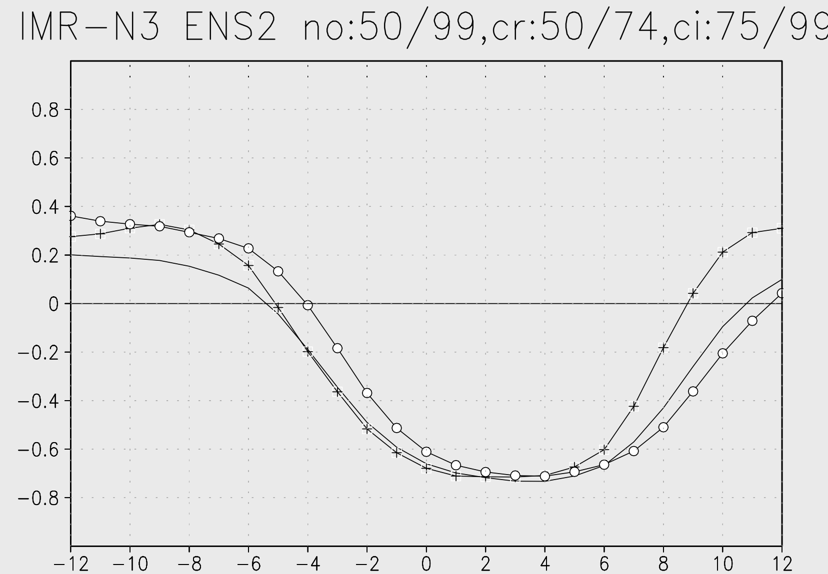


Change of ENSO-Monsoon relationship very similar in model and observation

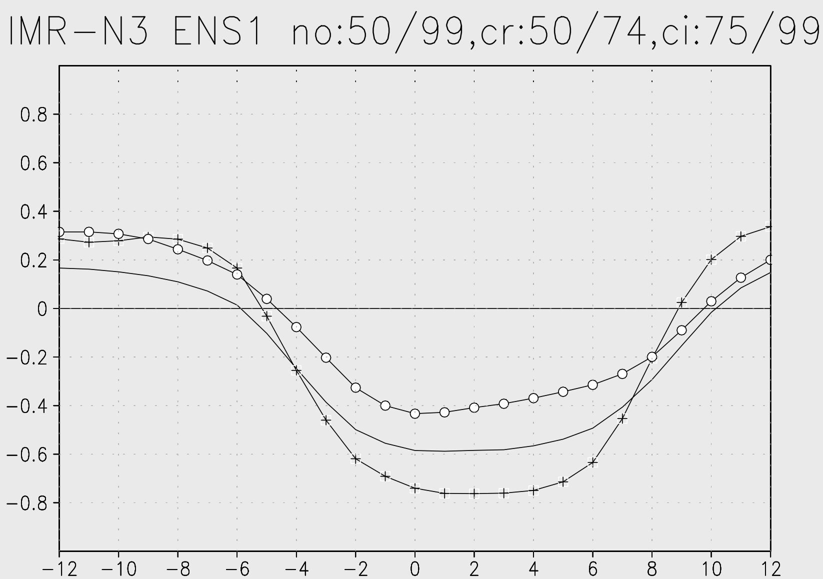
JJAS IMR and lagged 4-month mean NINO3 index

CRU





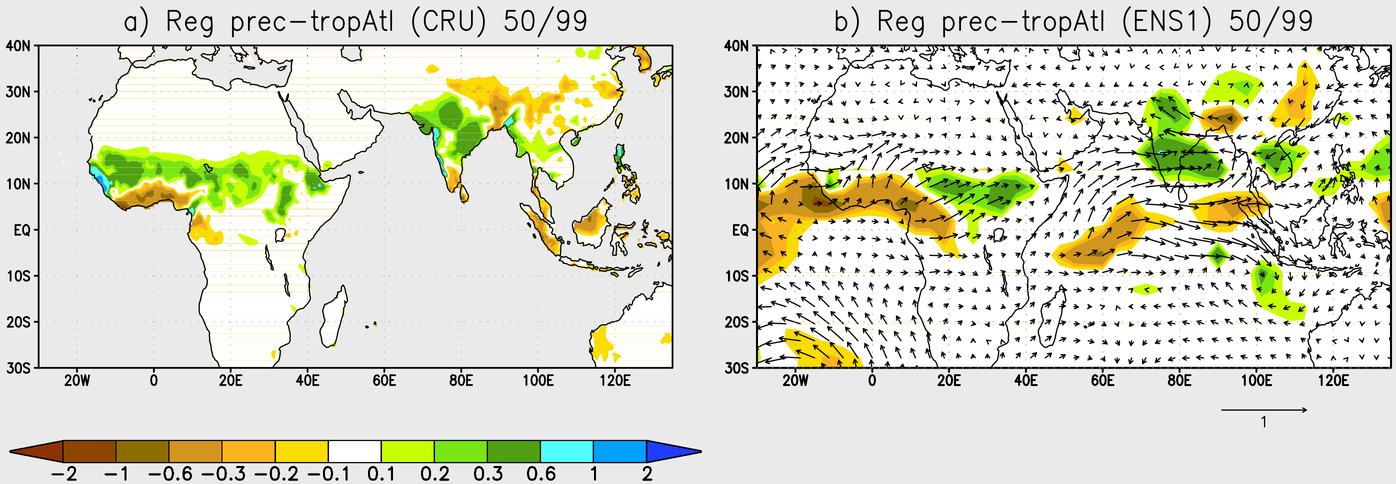
ENS1
IO_coup



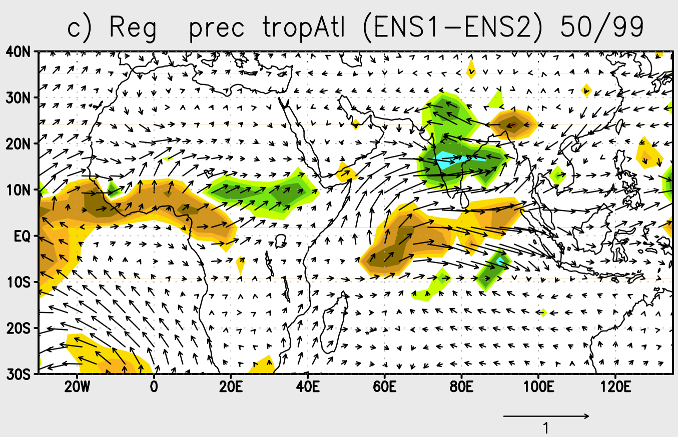
ENS2
No-ATL
IO_coup

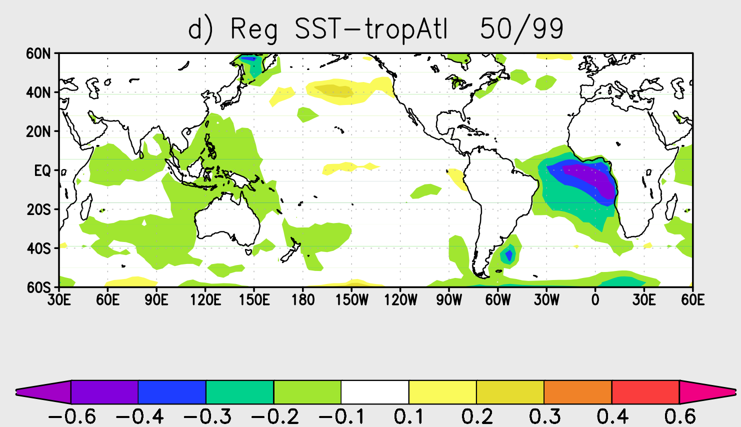
B) Results from coupling of MICOM in the Indian Ocean: Change of ENSO-Monsoon Teleconnection and changes in the Tropical Atlanitc

Tropical Atlantic Index: Average negative SST in box 30W-20E, 20S-0N



Difference between ENS1 and ENS2

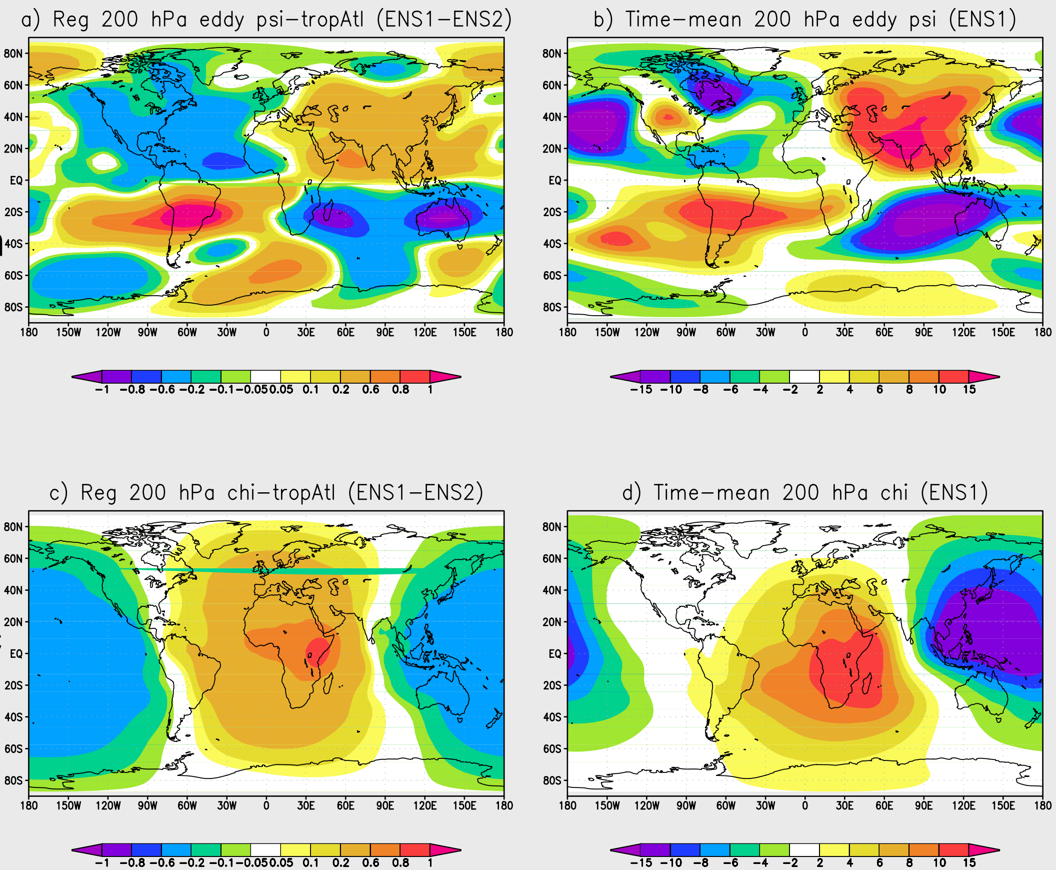




B) Results from coupling of MICOM in the Indian Ocean: Change of ENSO-Monsoon Teleconnection and changes in the Tropical Atlanitc

Response to heating in tropical Atantic: Regression of Tropical Atlantic Index onto 200 hPa eddy streamfunction

Response to heating in tropical Atantic: Regression of Tropical Atlantic Index onto 200 hPa velocity potential



Conclusions

- **Globally SST-forced (2-tier) experiments can be useful to investigate many issues of climate variability (e.g. Sahel rain variability, decadal Indian monsoon Variability, extratropical flow changes)**

- **Asian monsoon variability can be realistically modeled using a regional coupling strategy, i.e. coupling only in the Indian Ocean/western Pacific region. This may be Referred to as 1.5-tier approach.**

- **Important statements
Regarding interdecadal changes in the ENSO-monsoon Relationship are possible using the 1.5-tier approach.**

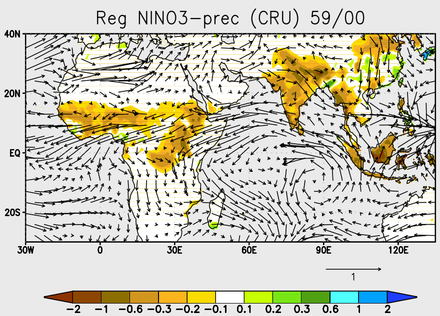
C) Demeter hindcast experiments:

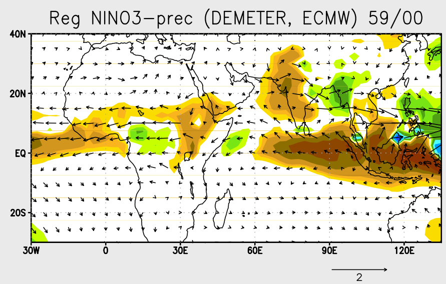
SST outside Indian Ocean prescribed by DEMETER data (for MJJASO; 9-member ensemble means) or HadISST (for NDJFMA), inside the Indian Ocean, a simple mixed-layer. Data from 3 centers (with longest integrations) compared with speedy results.

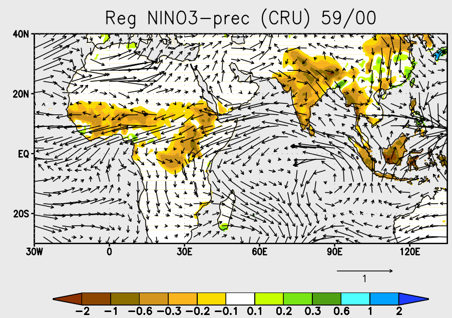
As before IMR defined over land points in region 70-95E, 10-30N. Correlations are evaluated over the period 1959-2000.

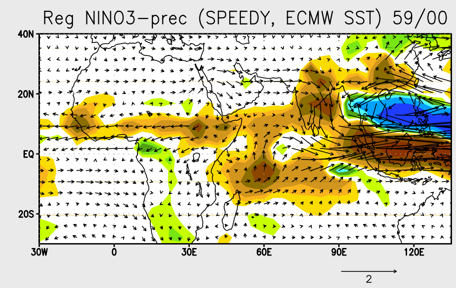
	Demeter (9 member ens means)	SPEEDY re-run MXL (6 members each)	SPEEDY re-run GLOB (6 members, 2-tier)	NO-ATL (6 members)
	Corr(R,CRU)			
ECMW	0.28	0.40		
METF	0.39	0.50	0.12	0.23
UKMO	0.33	0.49		
Multim ENS	0.41	0.49		

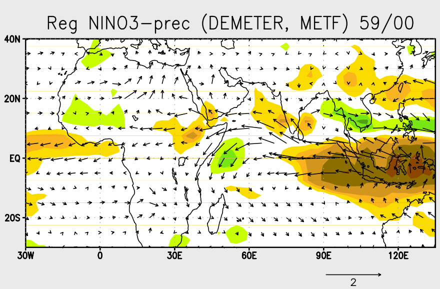
C) Demeter hindcast experiments: NINO3 Regressions

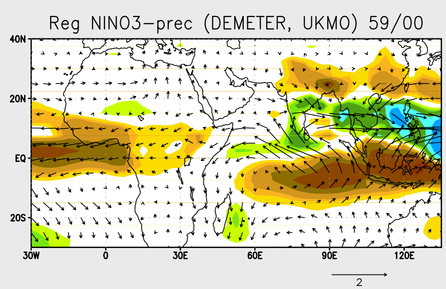


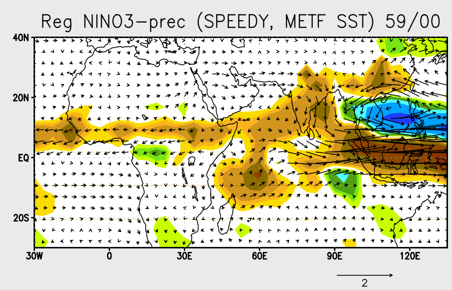


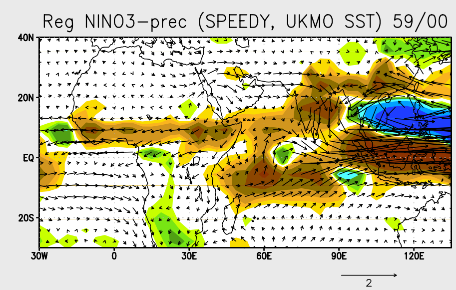


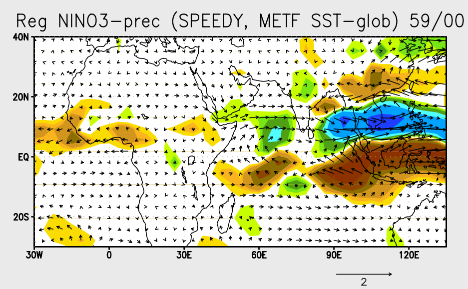


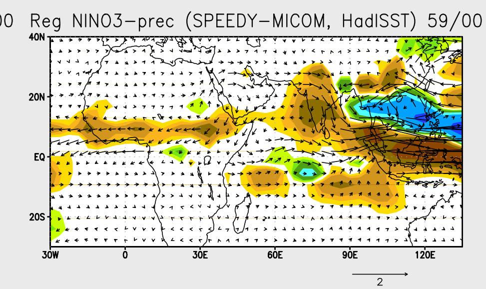












Future plans:

- Continue DEMETER hindcasts, hopefully with coupled model
- Looking into other regions, e.g. Amazon…
- Phd student working on application of bayesian method to Monsoon prediction, combining observed ENSO-Monsoon relationship with modeling results.

The SST-anomaly coupled model:

surface fluxes over the ocean are computed from both corrected SST (→ SPEEDY) and uncorrected SST (→ MICOM)

Near-surface atmosphere : ---------------------------

SST*: Clim + MICOM anomaly: --------------

SST: full MICOM SST : ---------------------------

The SST-anomaly coupled model:

SST anomalies are defined w.r.t. the average MICOM SST in an initial spin-up period *t**

For $t \leq t^*$:

$$SST^*(t) = Clim + \alpha(t) \left(SST - \{SST\}_{t0,\, t-1} \right)$$

$$\alpha(t0) = 0, \quad \alpha(t^*) = 1$$

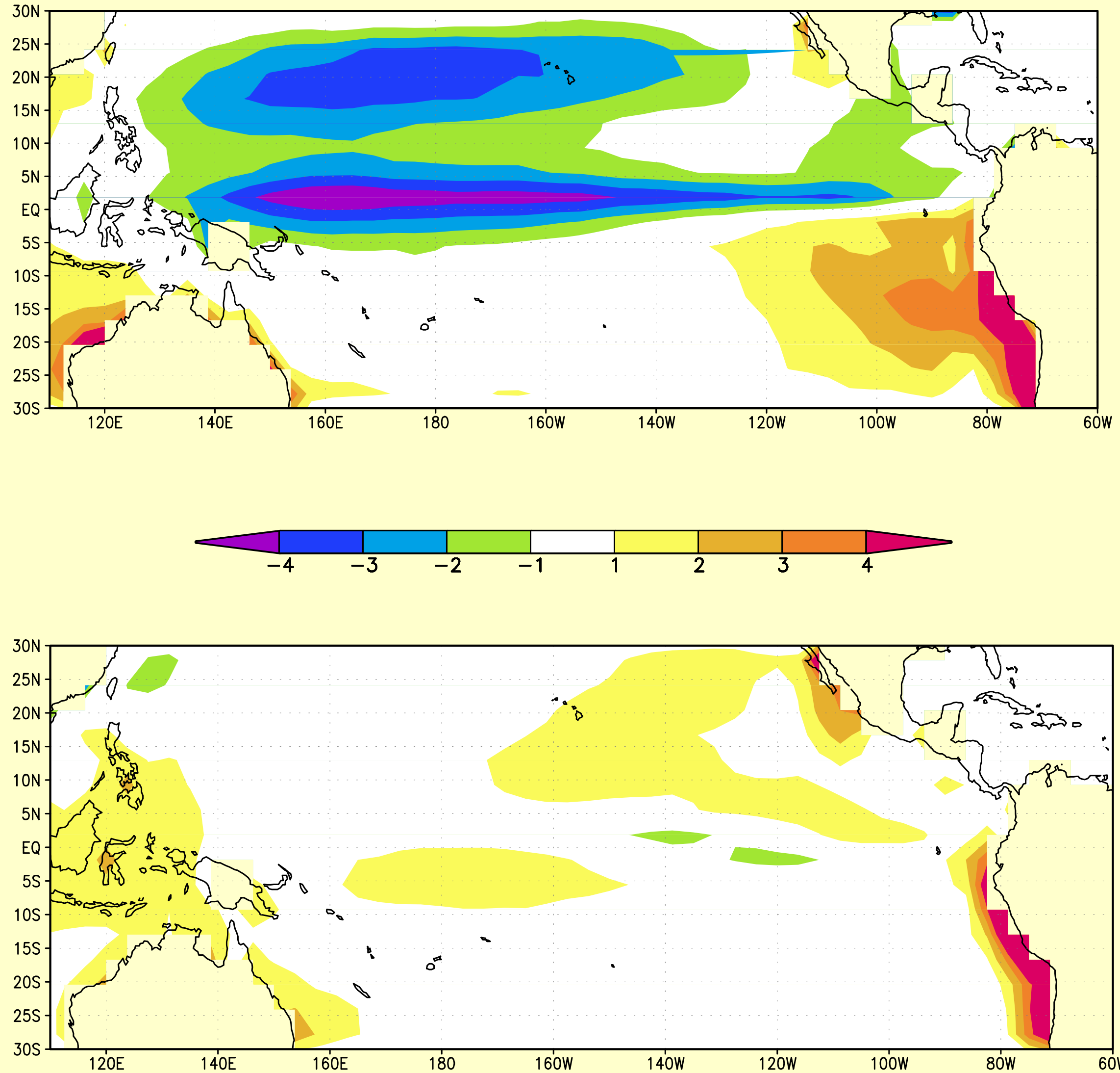
For $t > t^*$:

$$SST^*(t) = Clim + \left(SST - \{SST\}_{t0,\, t^*} \right)$$

Mean error of ocean model SST in fully-coupled vs. anomaly-coupled model (DJF):

Fully-coupled

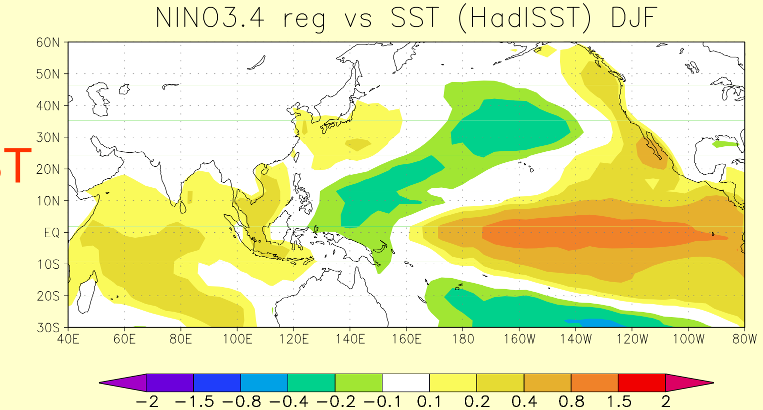
Anomaly-coupled



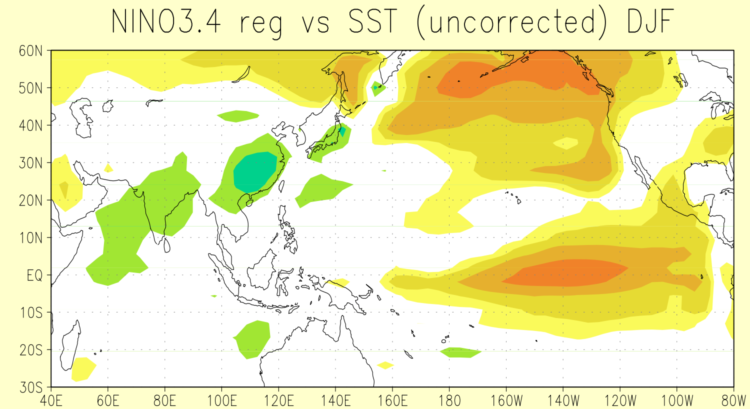
ENSO in fully-coupled vs. anomaly-coupled model:

regression of
ocean-model SST
vs. Nino3.4 in DJF

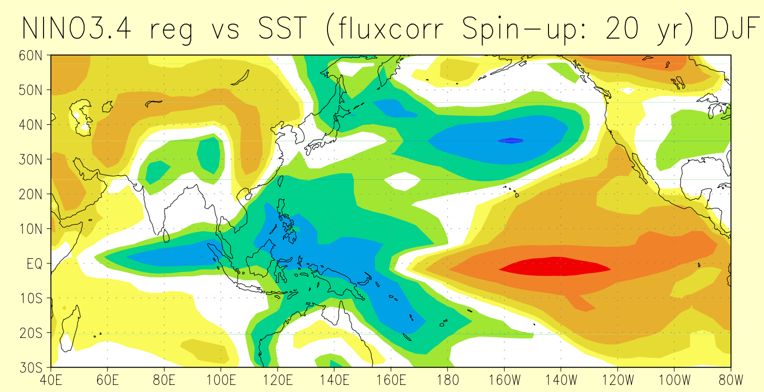
HadISST



Fully-coupled:
σ (nino3.4) = 0.74



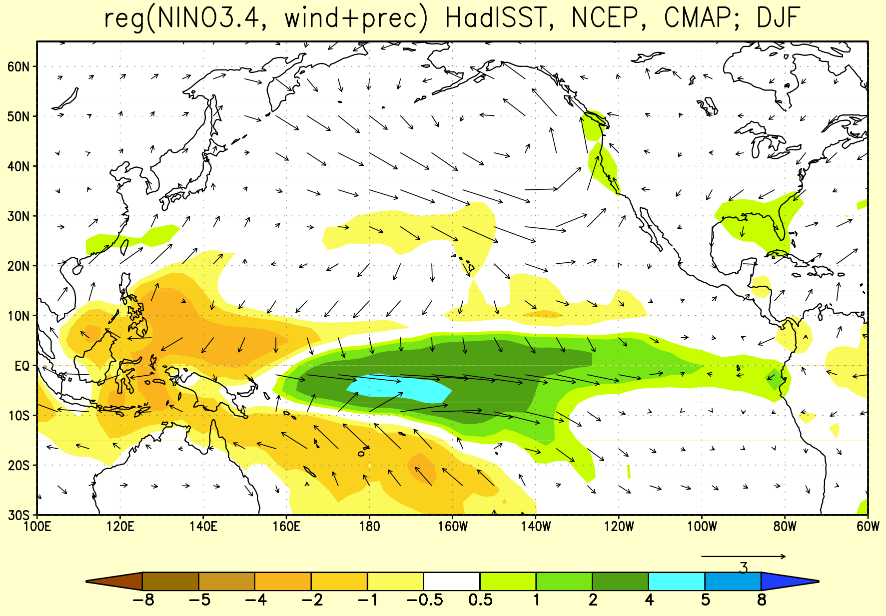
Anomaly-coupled:
σ (nino3.4) = 1.4



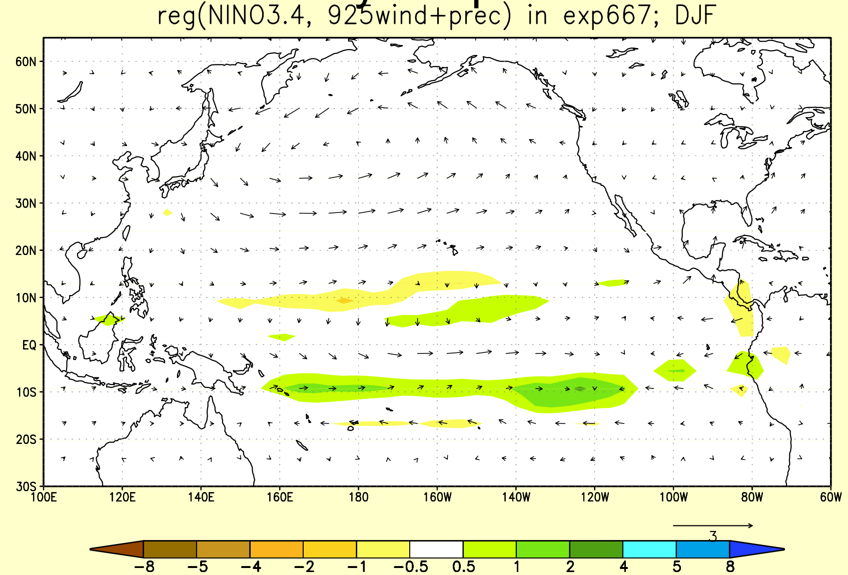
ENSO in fully-coupled vs. anomaly-coupled model:

regression of precipitation and wind vs. Nino3.4 in DJF

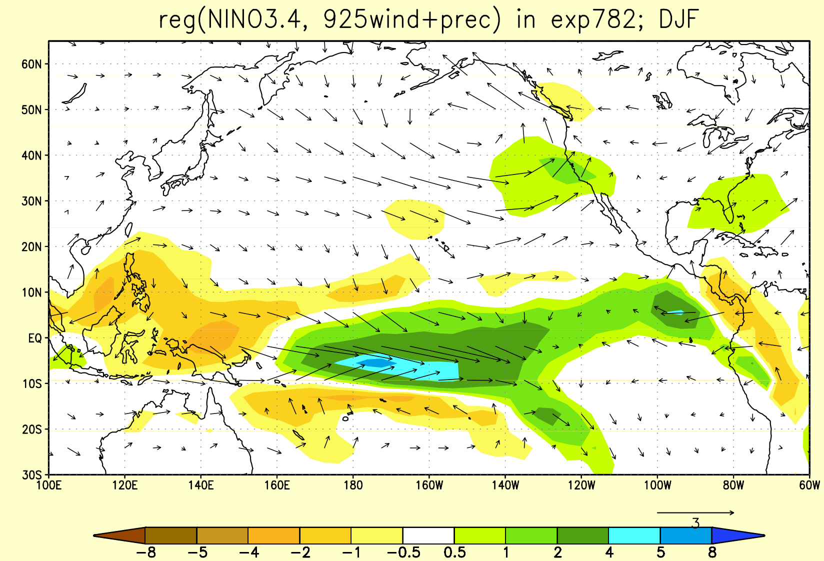
CMAP



Fully-coupled



Anomaly-coupled



Clim. Dynamics & Pred. : research topics

AGCM uncoupled simulation (SPEEDY 8 lev):

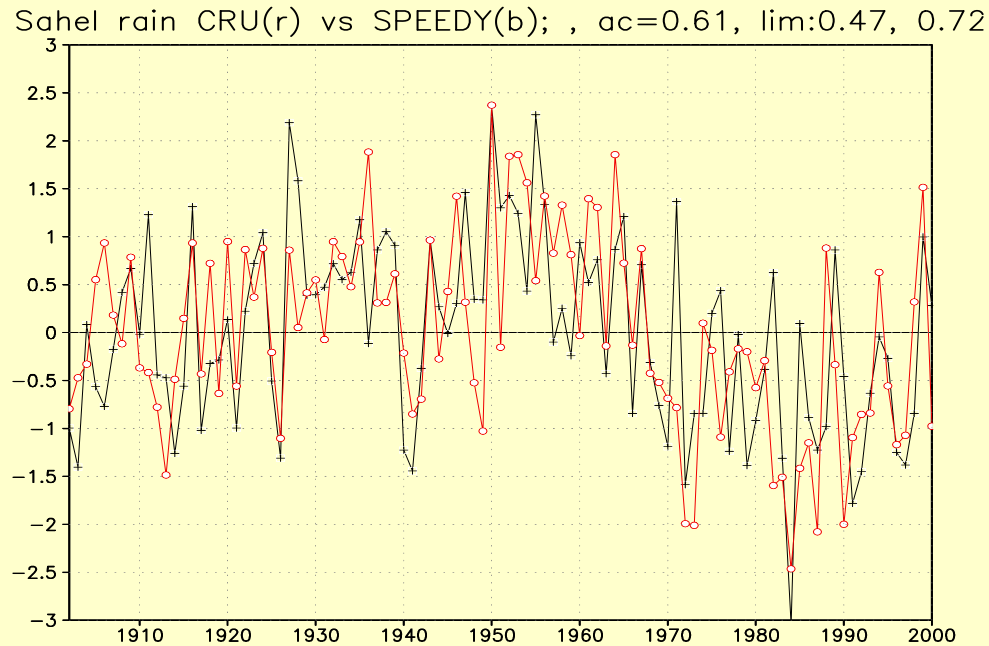
- Simulation of 20th century variability in 50-yr and 130-yr in ensembles forced by HadISST (1870-2002), in the context of the "Climate of the 20th Century" project *[Kucharski, Molteni, Yoo, Bracco]*
- 130-yr ensembles with prescribed SST in specific regions to investigate NAO decadal variability *[Kucharski, Molteni, Bracco]*
- Response to tropical SST anomalies in idealized geographical settings (e.g. aqua-planet, zero-topography) *[King, Kucharski]*
- Variability induced by land-sea thermal contrast in NH winter *[Molteni, Kucharski]*

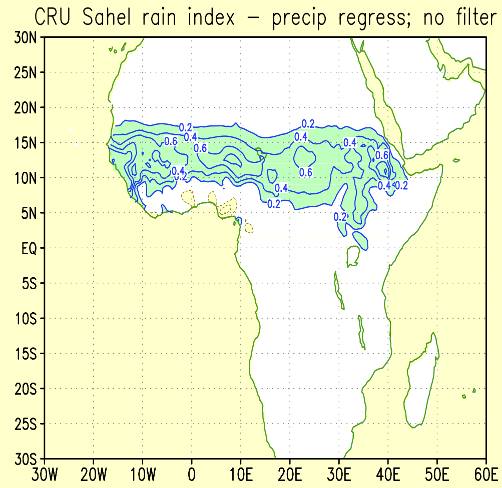
Results from C20C ensembles :
a) Sahel rain

Seasonal means of Sahel rainfall (15W to 37.5E, 12.5N to 17.5N) in JJAS: Standardized time series and regression patterns

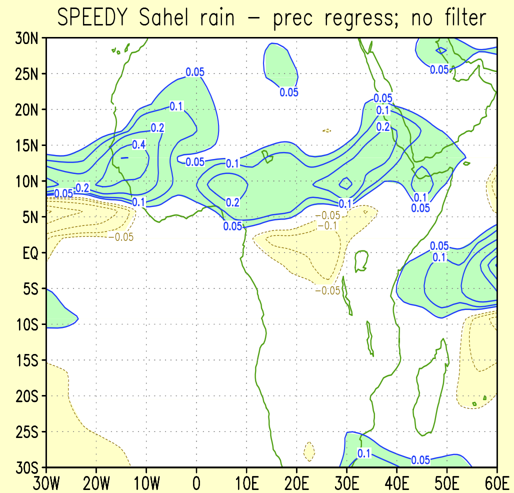
Corr(1yr) = 0.61

Corr(11yr) = 0.94





CRU



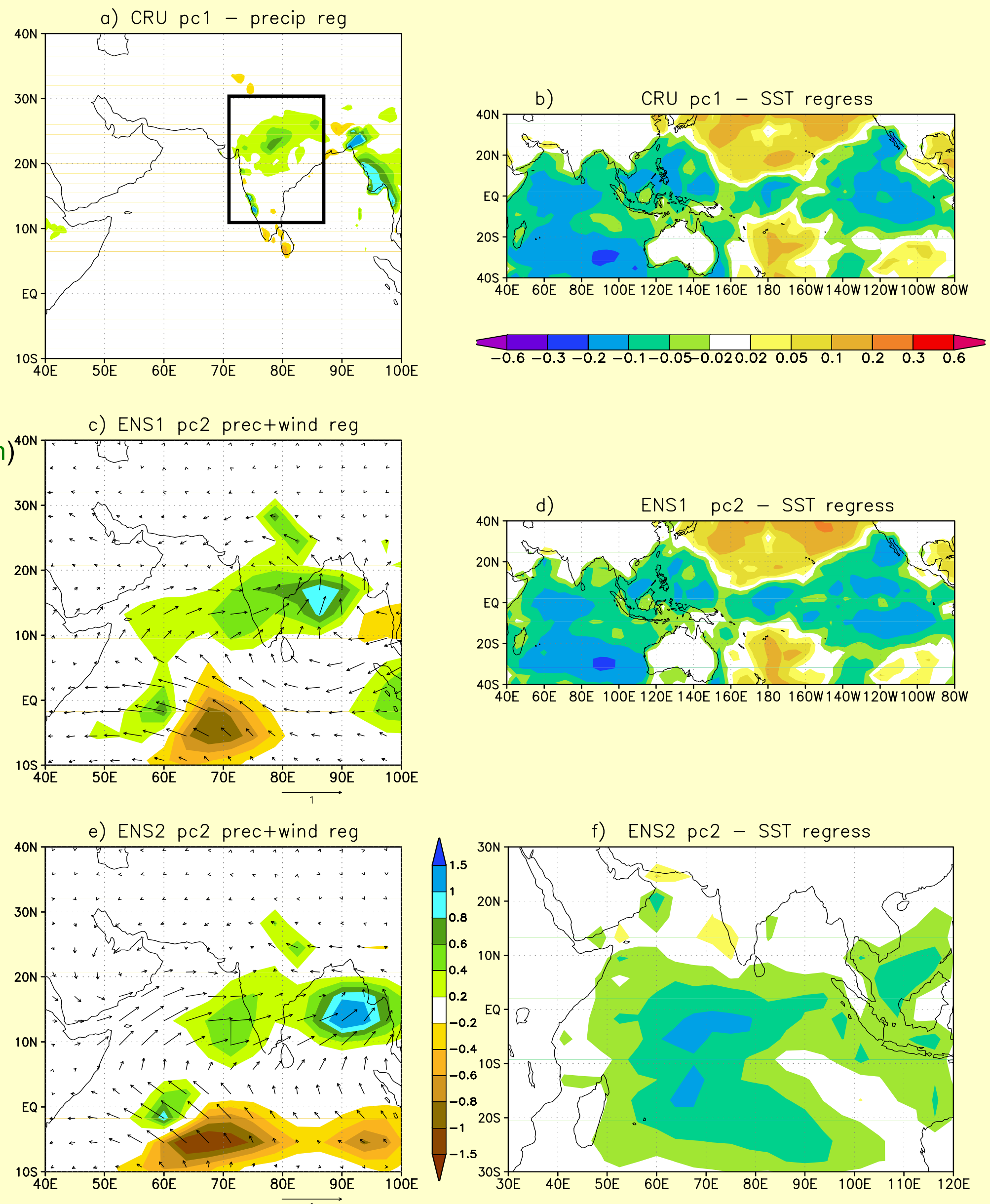
SPEEDY

Results from C20C ensembles:

b) Decadal Indian monsoon rain

(11-year JJAS mean 70E to 85E, 10N to 30N)

EOFs of decadal Indian rain, PCs regressed onto SSTs

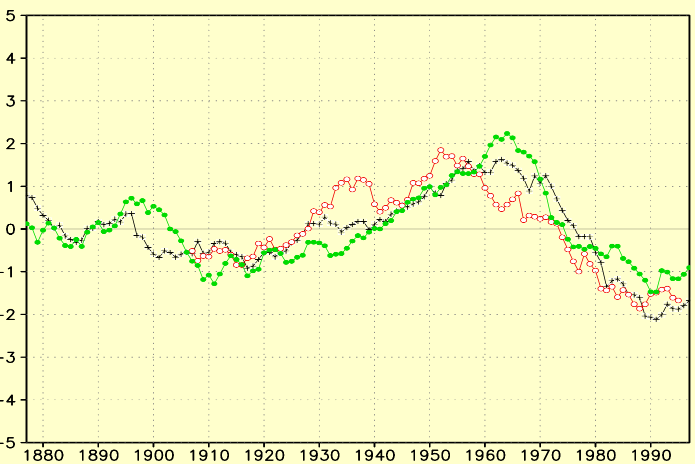


CRU EOF1

SPEEDY EOF2

SPEEDY EOF2 Forced in Indian Ocean only

PCs from CRU (red), SPEEDY (black), SPEEDY_IO (green)

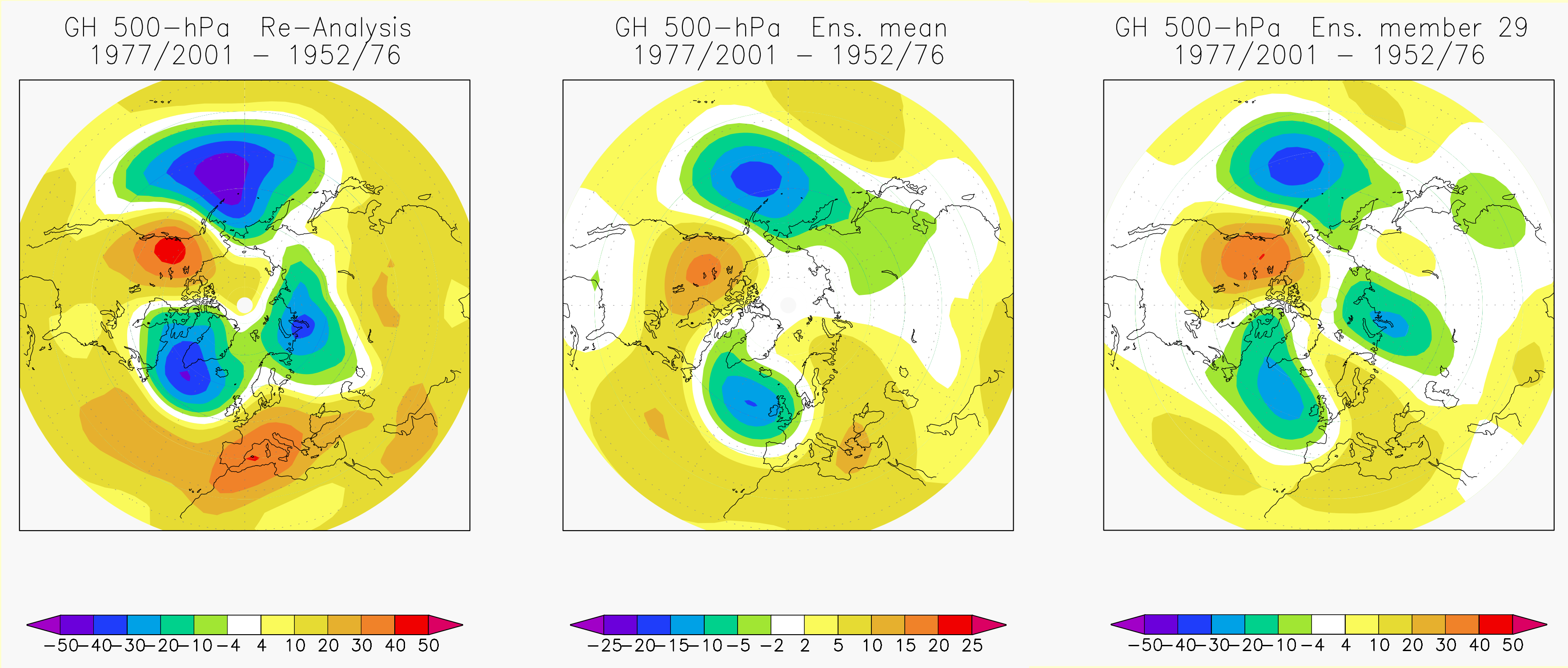


Corr(pc1_cru,pc2_sp) = 0.85
Corr(pc1_cru,pc2_spio) = 0.70

Results from C20C ensembles:
c) Extratropical climate trends

500 hPa height trend *(1977/2001 – 1952/76)* in:

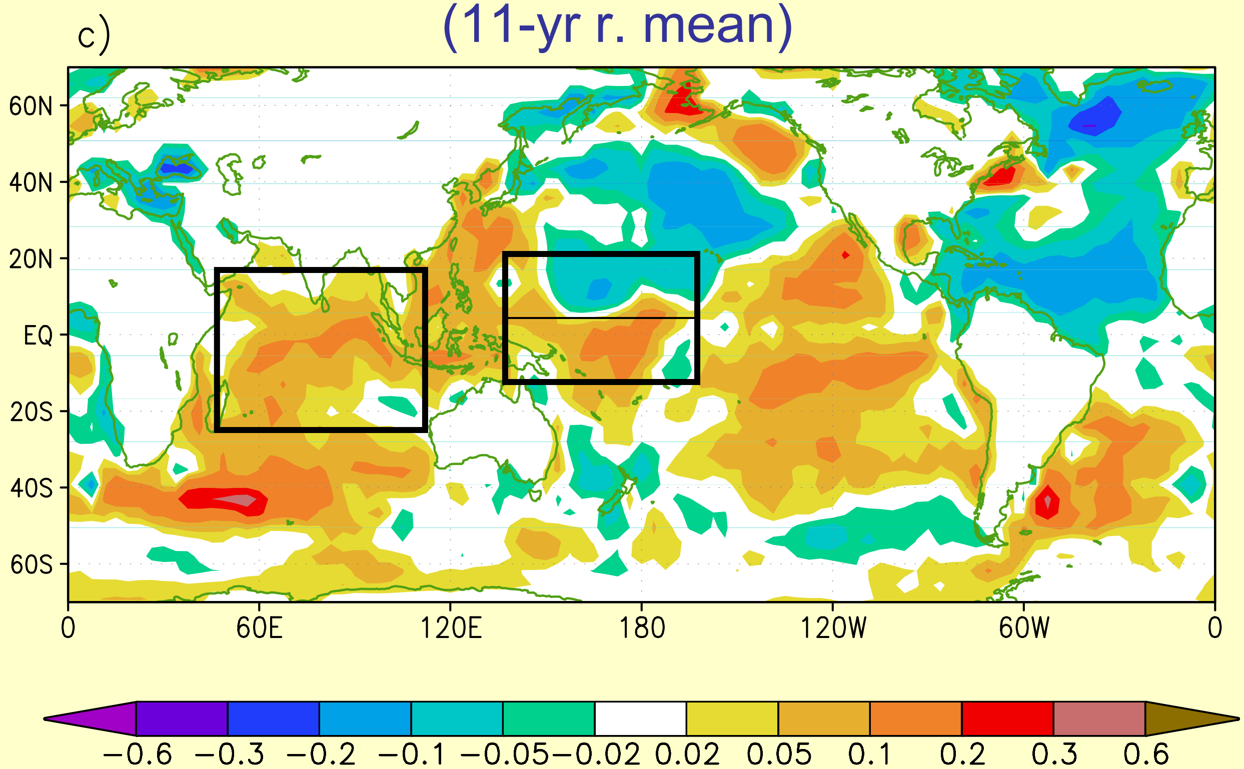
Re-analysis **Ens. Mean** **Single exp.**



Results from C20C ensembles:

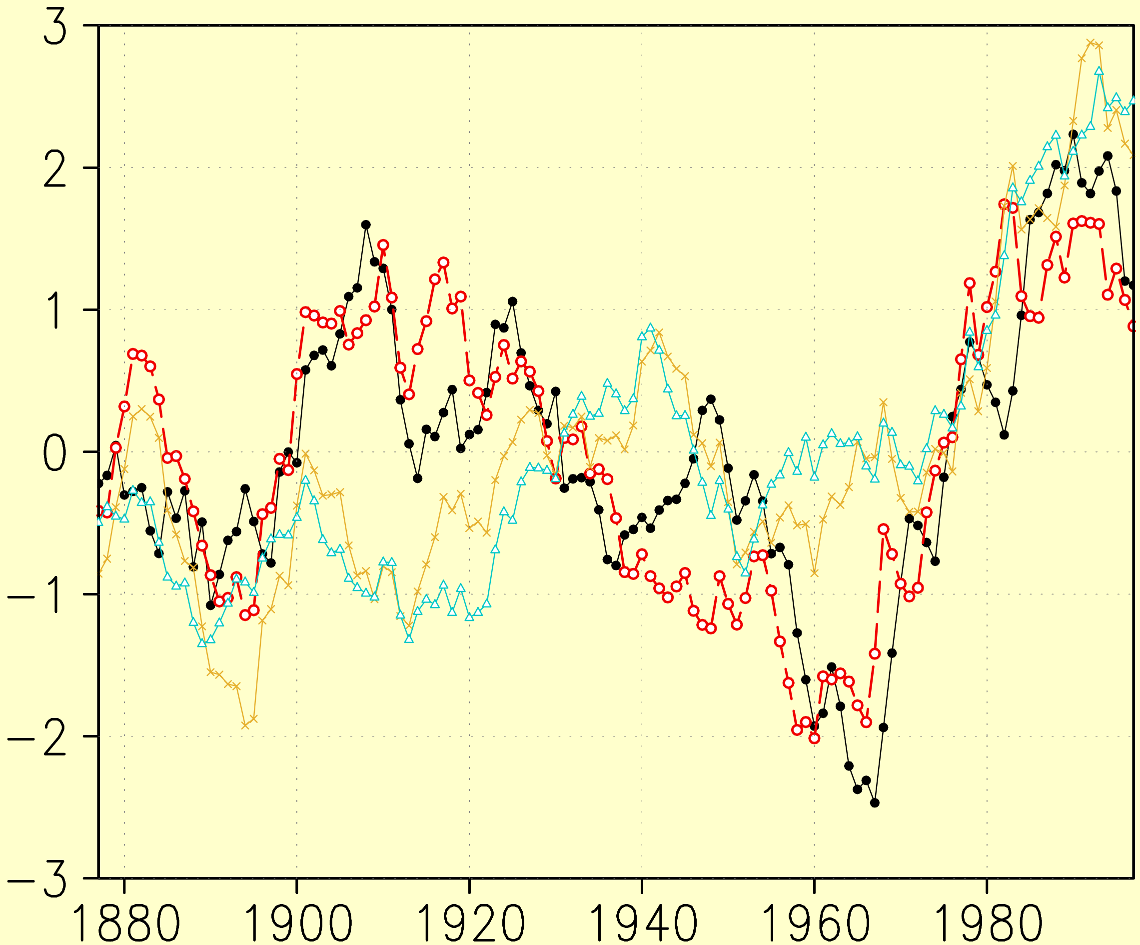
d) Decadal NAO-western tropical Pacific interaction

Regression of SST onto decadal NAO index
(11-yr r. mean)



HadISST 1870-2002 from Hadley Centre (Rayner et al. 2003)

Decadal NAO index vs. tropical SST indices



West. Trop. Pacific gradient [12S - 4N] – [8N - 20N] (cc = 0.82)

West. Trop. Pacific Southern box (cc = 0.52)

Indian Ocean box, 20N - 20S (cc = 0.43)

Niño 3.4 (cc = 0.36)

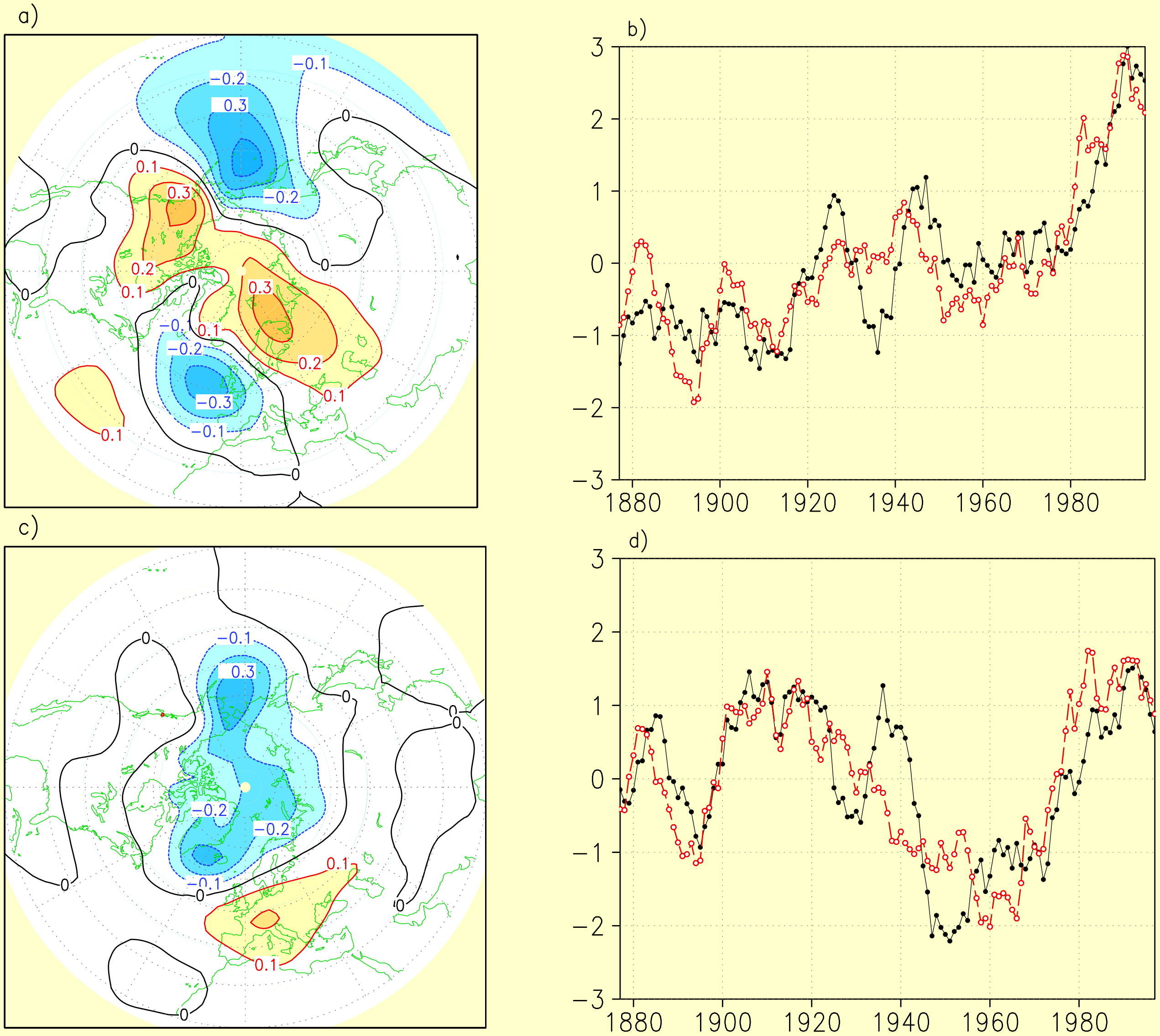
SPEEDY "one-basin" ensembles, 1870-2002

- Prescribed SST from HadISST dataset in :
  Western Tropical Pacific (WTP): 18 members
  Indian Ocean (IND) : 10 members
- 50-m slab ocean model driven by anomalous heat fluxes in the North Atlantic
- Climatological SST elsewhere

Diagnostics of forced decadal response:

- EOFs and PCs of ensemble mean/11-year run.-mean fields of SLP ; PC regression maps

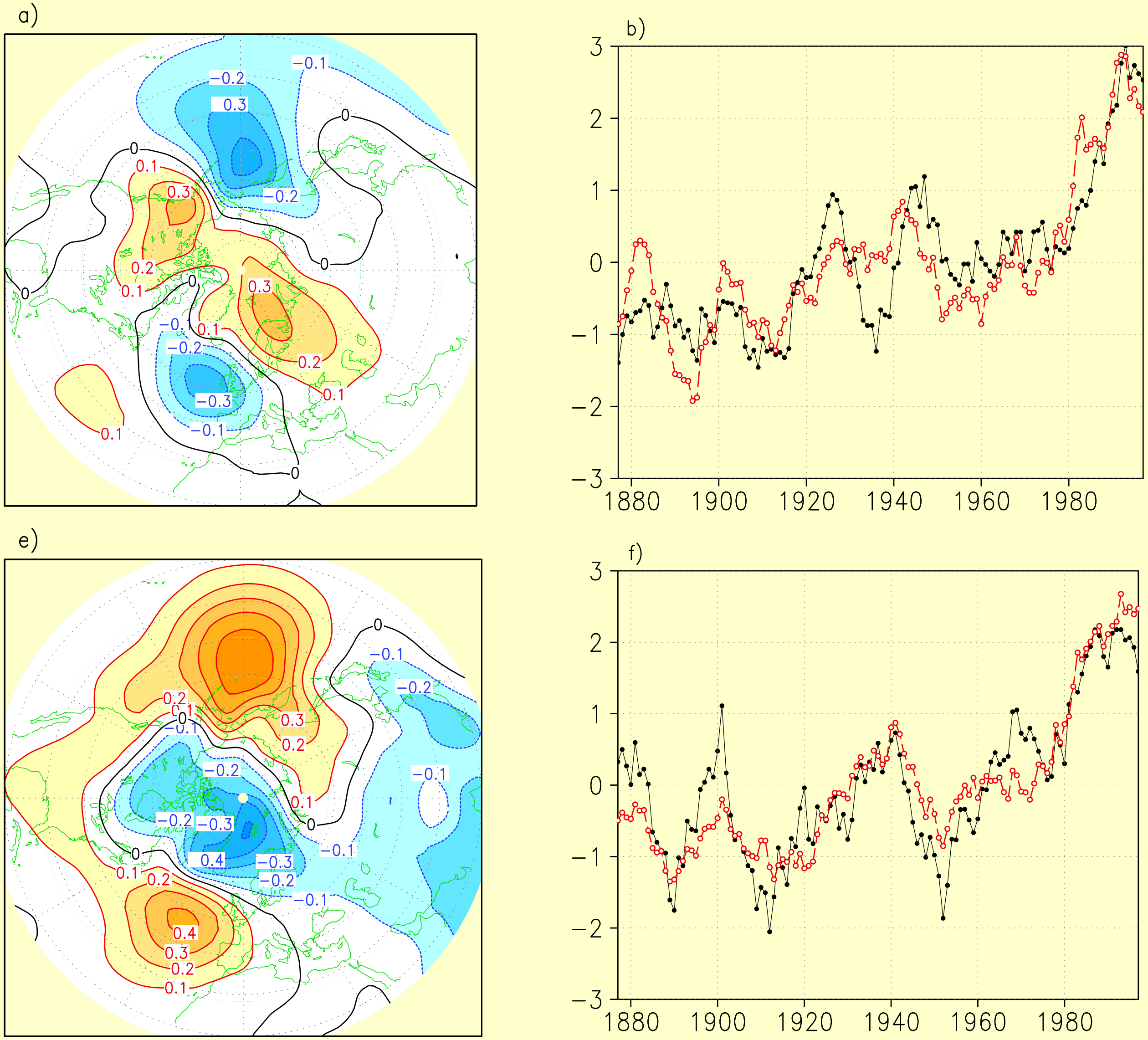
EOFs/PCs of ens.mean 11-yr SLP (W.Trop.Pac.)



PC-1 vs.
WTP SST
southern
box
[12S - 4N]
cc = 0.85

PC-2 vs.
WTP SST
gradient
[12S - 4N] –
[8N – 20N]
cc = 0.78

1st EOF/PC of ens.mean 11-yr SLP (WTP vs IND)



PC-1 WTP

vs.

WTP SST southern box [12S - 4N]

cc = 0.85

PC-1 IND

vs.

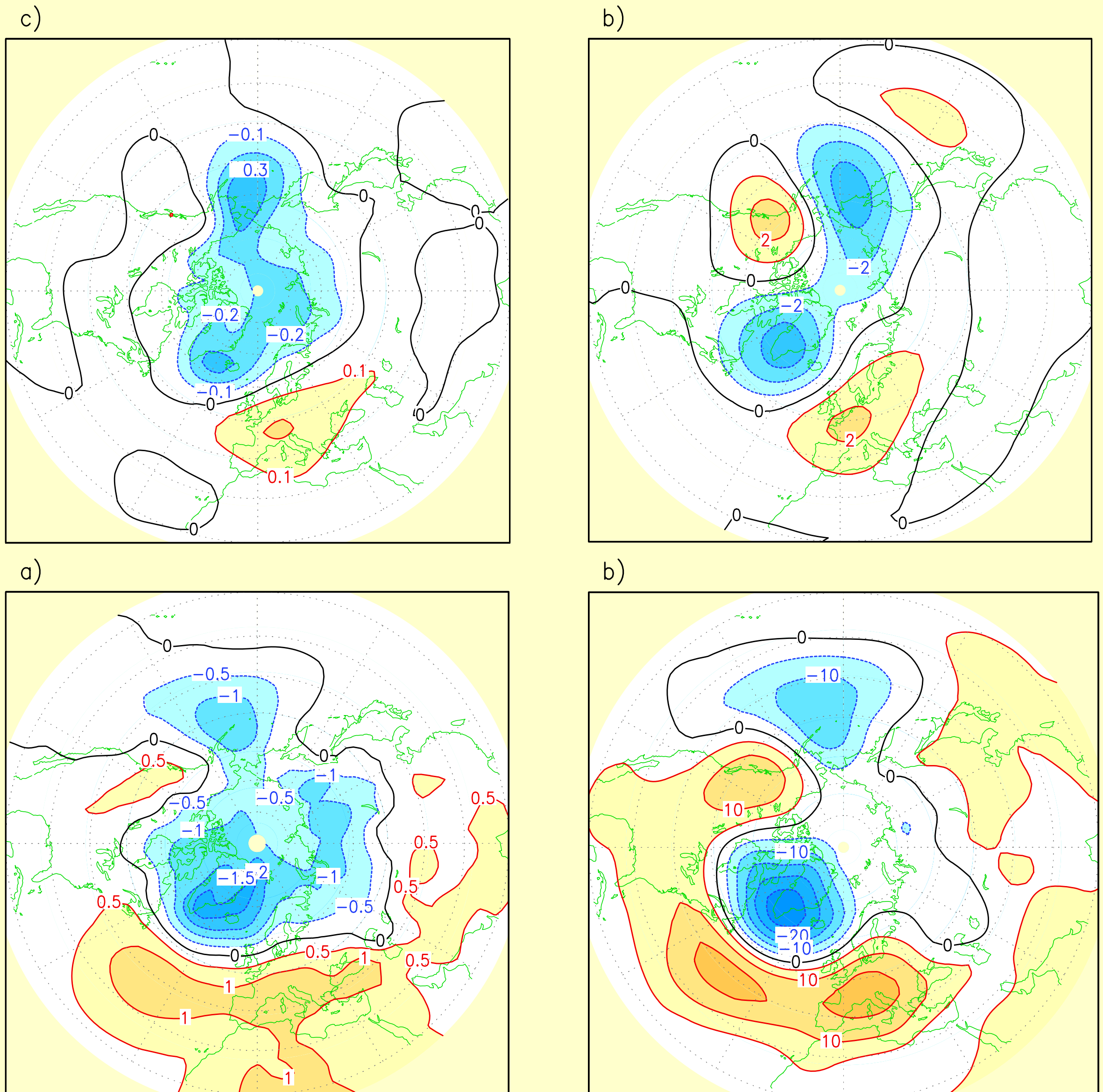
Indian Oc. SST box [20S – 20N]

cc = 0.88

Regres. (SLP) | Regres. (Z 500)

WTP PC-2

Hurrell NAO index



Computer resources

- IBM Linux cluster based on 2.4 GHz Intel Xeon (2-proc. nodes): 1 master node, 2 storage nodes (~ 1TB), 12 computing nodes.
- 4 comp. servers based on dual-proc Intel Xeon (2.4 and 3.0 GHz)
- 4 comp. servers based on dual-proc AMD Opteron (64-bit, 2.2 GHz)
- Internal data server (4-proc Sun V440 + EMC RAID storage, ~5 TB)
- External data server (2-proc Opteron + ~4 TB RAID system; ftp + GrADS DODS server)
- Computer resources on CINECA and ECMWF systems