Status of monsoon prediction

Dr Andy Turner

Part II

Outline: part II

- Decadal time scales & the global monsoon
- Linking interannual and intraseasonal time scales
- Societal need for subseasonal prediction
- Challenges ahead

Monsoon prediction

DECADAL VARIABILITY & THE GLOBAL MONSOON

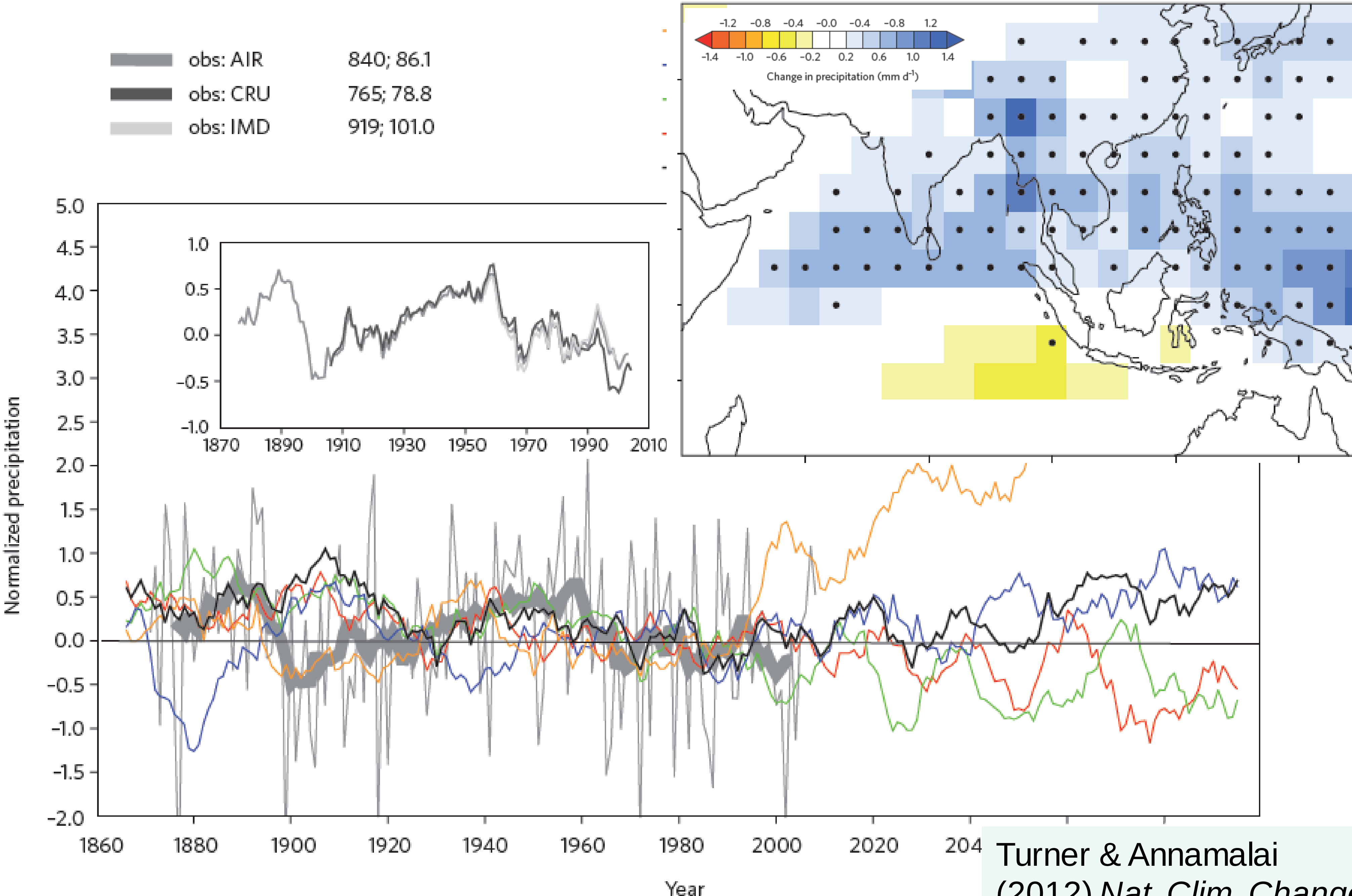
Introduction

- The regional monsoons, perhaps as part of the global monsoon, exhibit important decadal variations with potential large socio-economic impacts
- Recent studies have highlighted interdecadal variability in:
  - The various regional monsoons
  - Features embedded in the monsoon, such as tropical cyclones and monsoon depressions
  - The strength of monsoon teleconnections, impacting the prospect for seasonal prediction

Decadal outline

- Context: anthropogenic greenhouse gas forcing and the role of aerosol
- Decadal drivers of the Asian monsoon
- Coherent drivers of the global monsoon
- Modulation of teleconnections

Anthropogenic greenhouse forcing…



Turner & Annamalai (2012) *Nat. Clim. Change*

...and the role of aerosol

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- Sulphate aerosols causing negative trends in 20th century South Asian monsoon (Bollasina *et al.*, 2010, *Science*) or early withdrawal of EASM (Guo *et al.*, 2013, *ACP*)?
- Black carbon EHP strengthening early monsoon rainfall (Lau *et al.*, many studies!) or Asian Brown Cloud (Ramanathan *et al.*, 2005)
- We can't ignore anthropogenic drivers when measuring observed decadal variability in the monsoon

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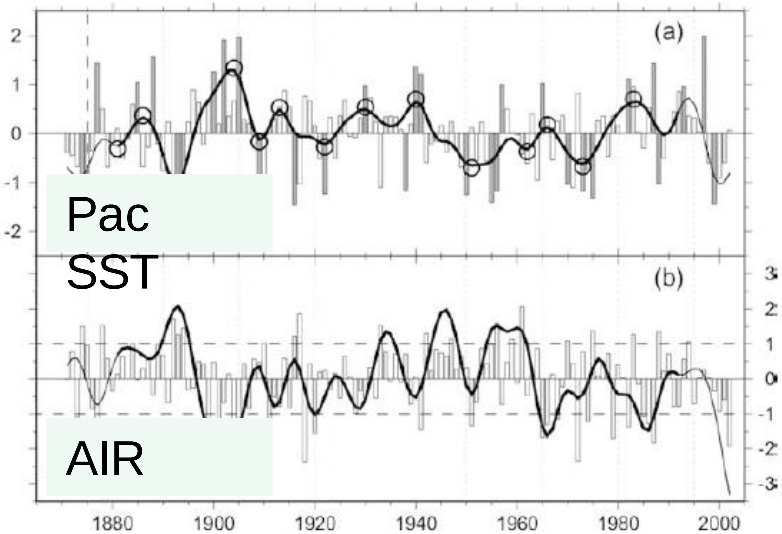
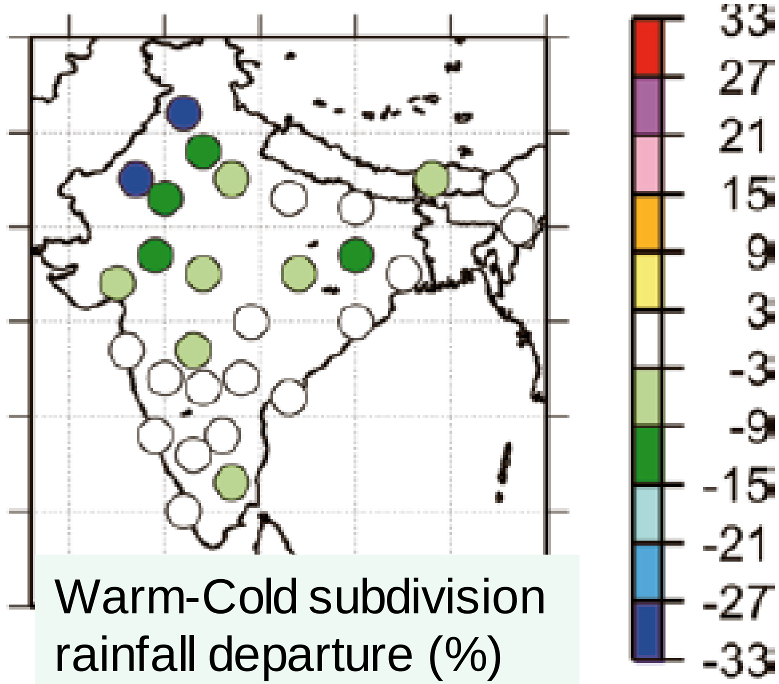
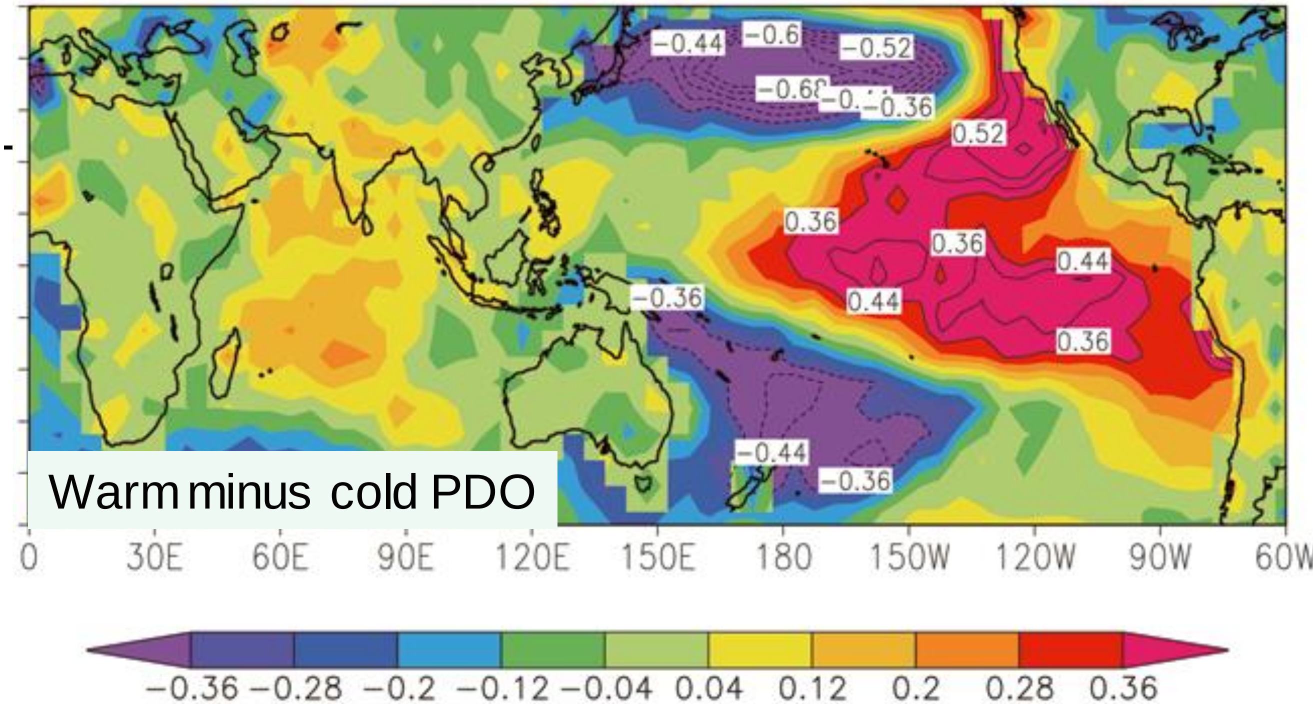
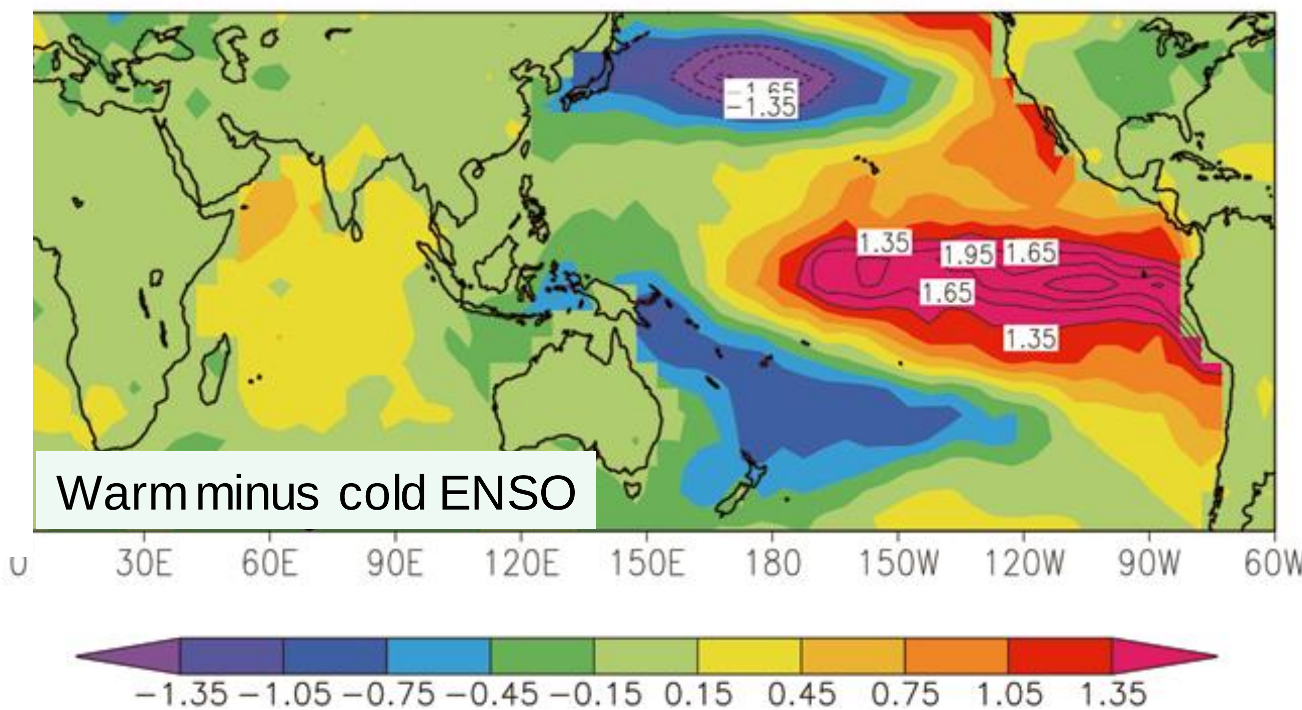
The PDO as a driver









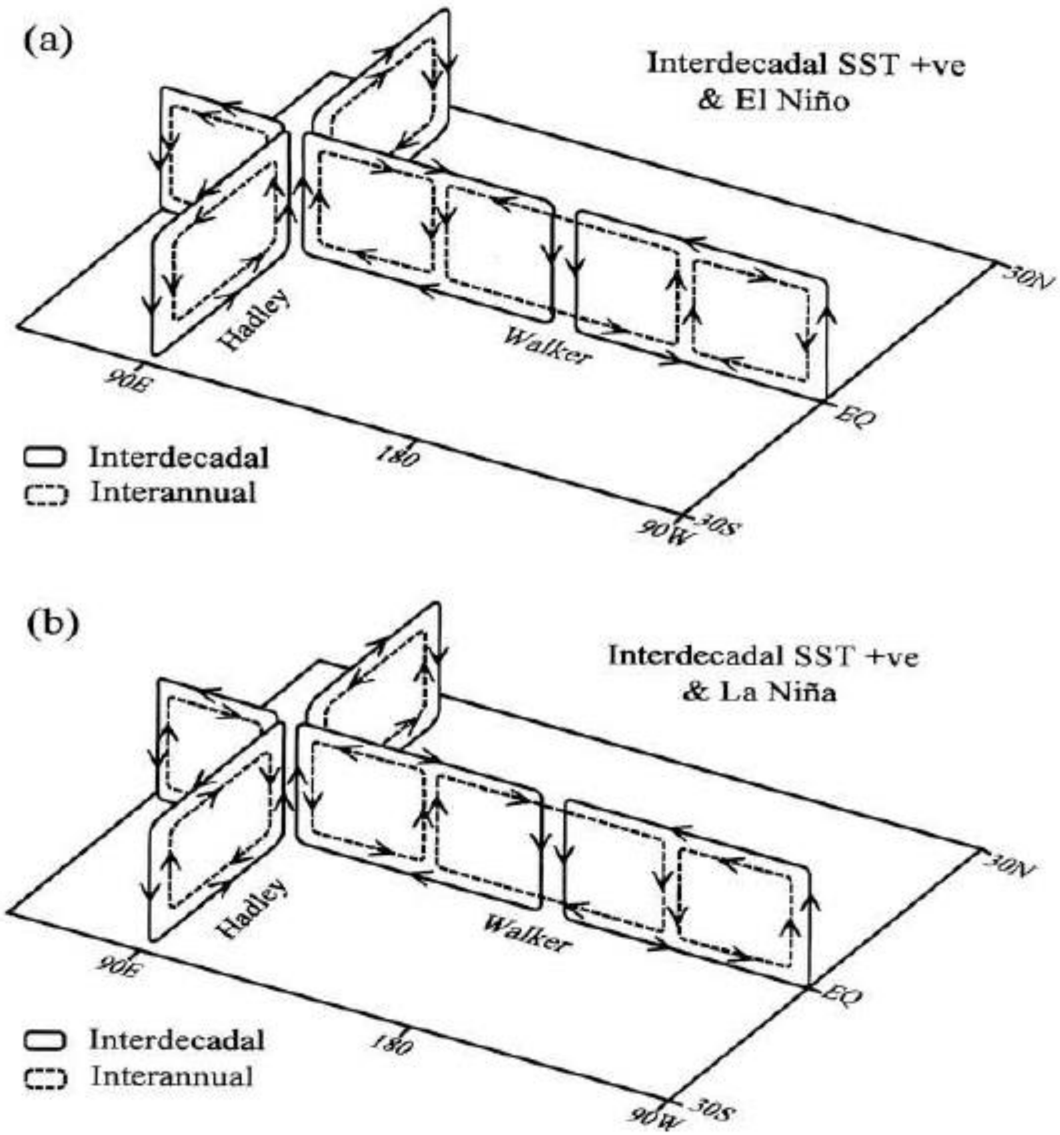
Krishnan & Sugi (2003) *Clim. Dyn.*

Pacific Decadal Variability and the teleconnection

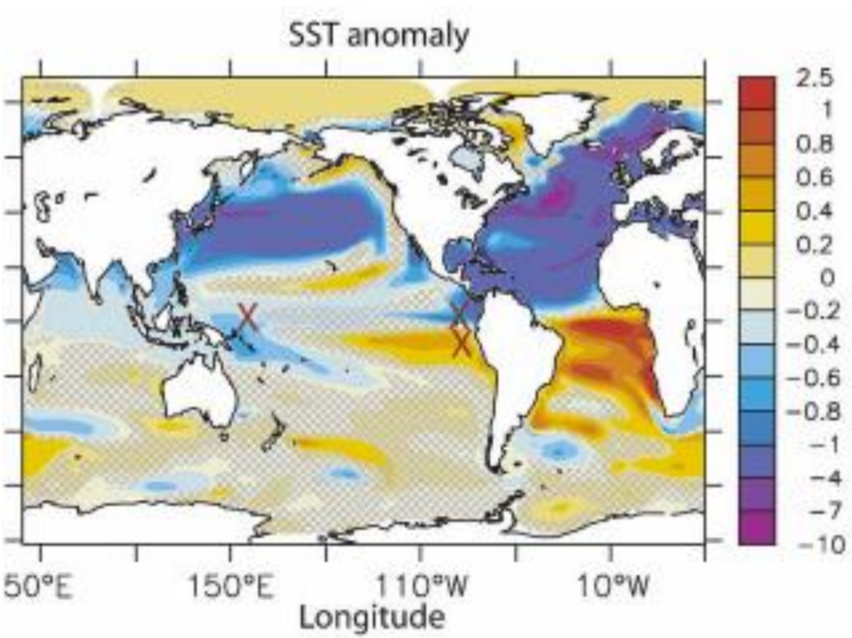
Combination of ENSO and decadal Pacific impacts on monsoon in a Walker Circulation framework:

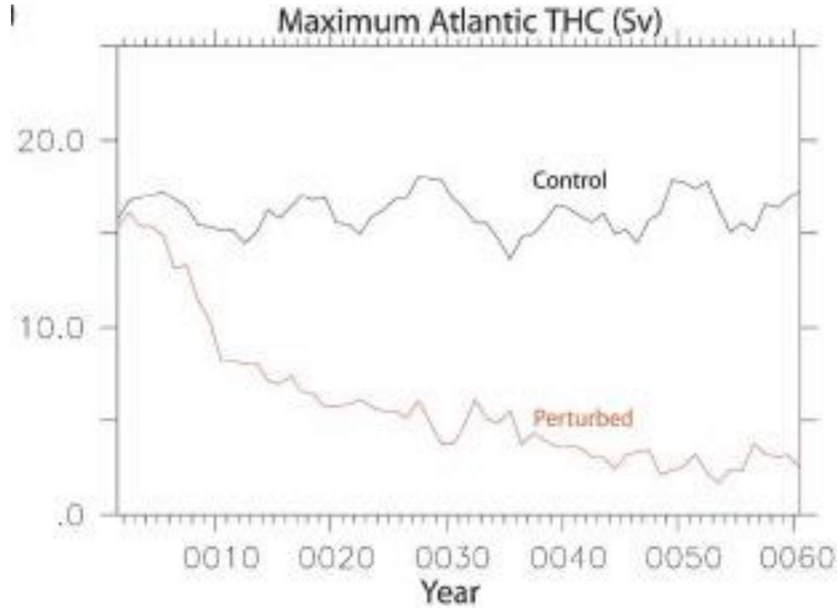
- PDO may affect monsoon-ENSO teleconnection in addition to direct impact on mean state

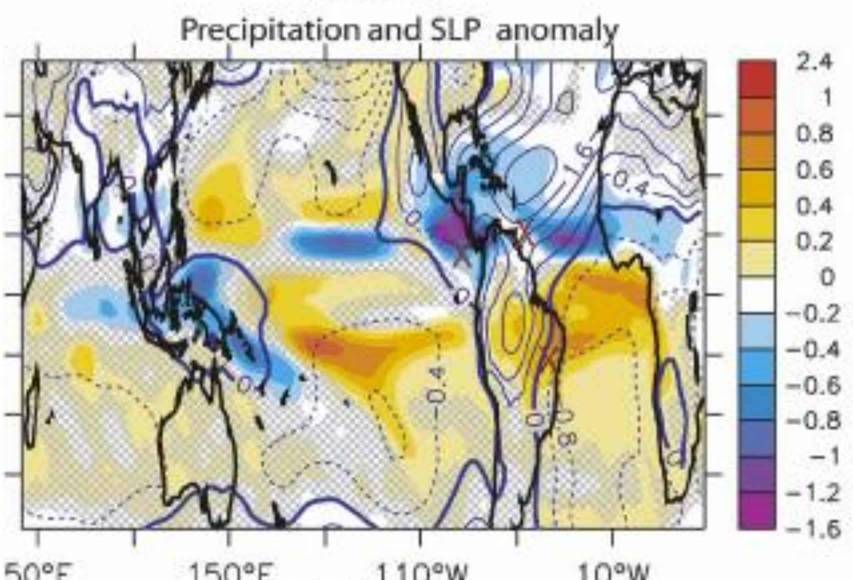
Krishnamurthy & Goswami (2000)



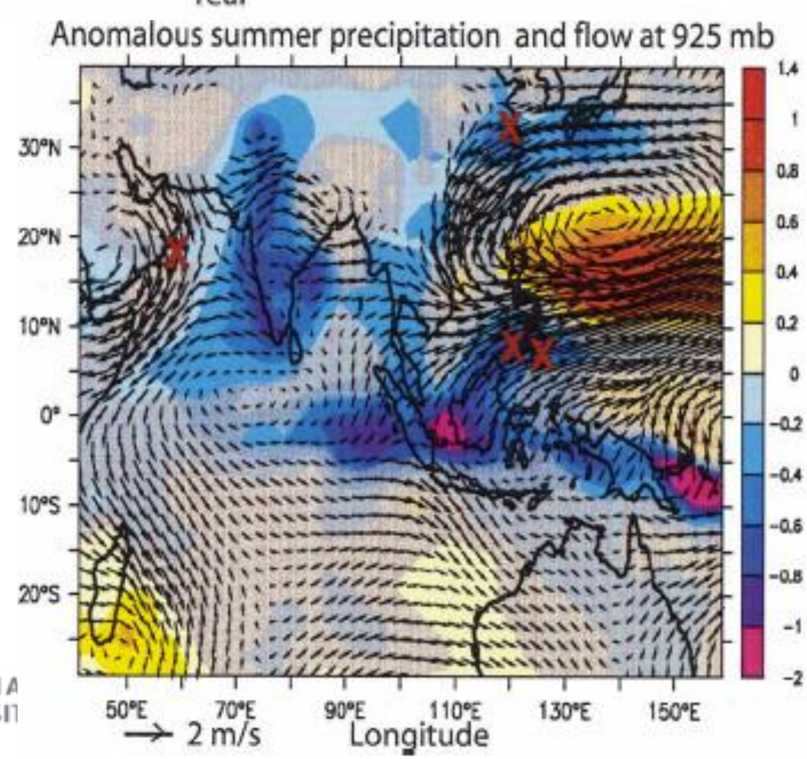
The AMO as a driver #1 hosing exps.







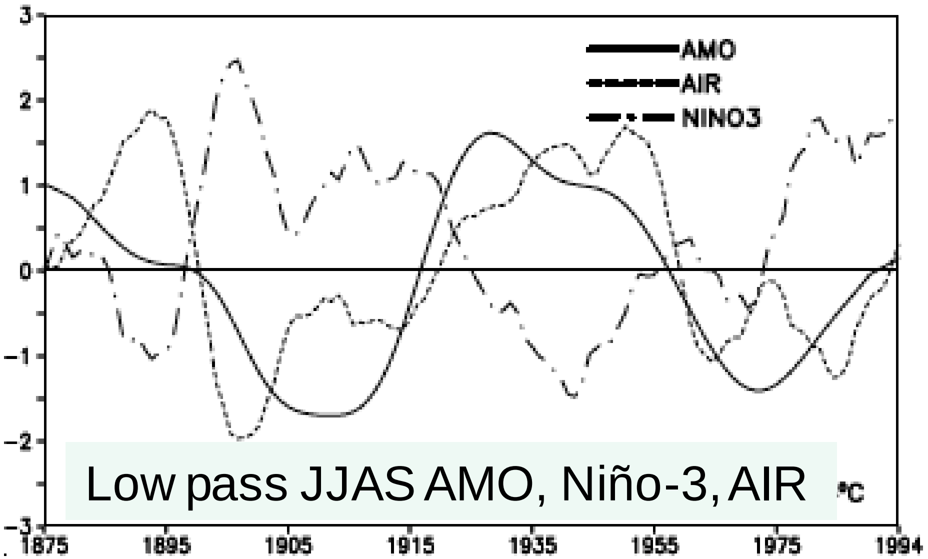
Warning:
blue=dry in
rain plots



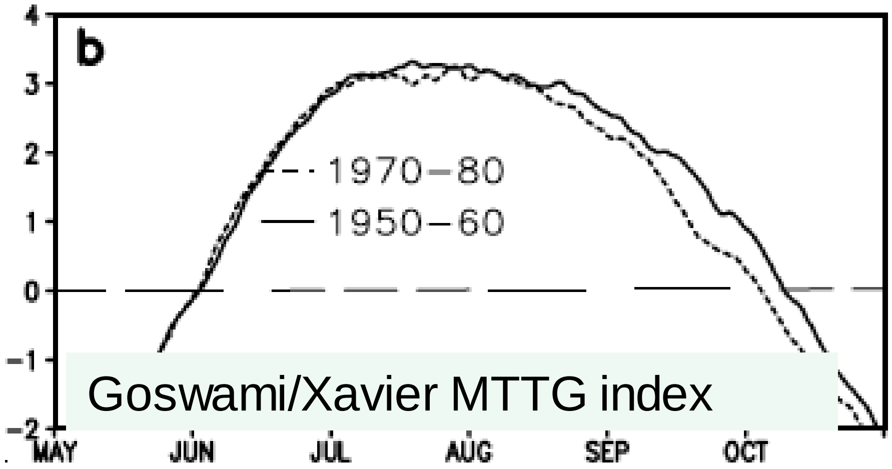
Zhang & Delworth (2005) *J. Clim.*

The AMO as a driver #2 observations

- Alteration of Tropospheric Temperature gradient (longer season in warmer AMO period)
- AMO+ → corresponding warming over Eurasia



Low pass JJAS AMO, Niño-3, AIR



Goswami/Xavier MTTG index

Goswami *et al.* (2006) *GRL*

Atlantic multi-decadal variability: via the Pacific

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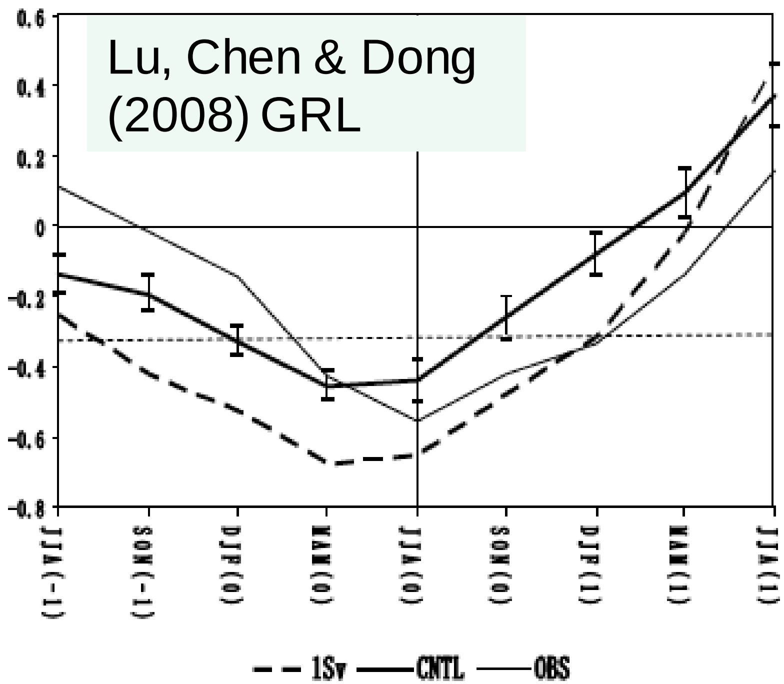
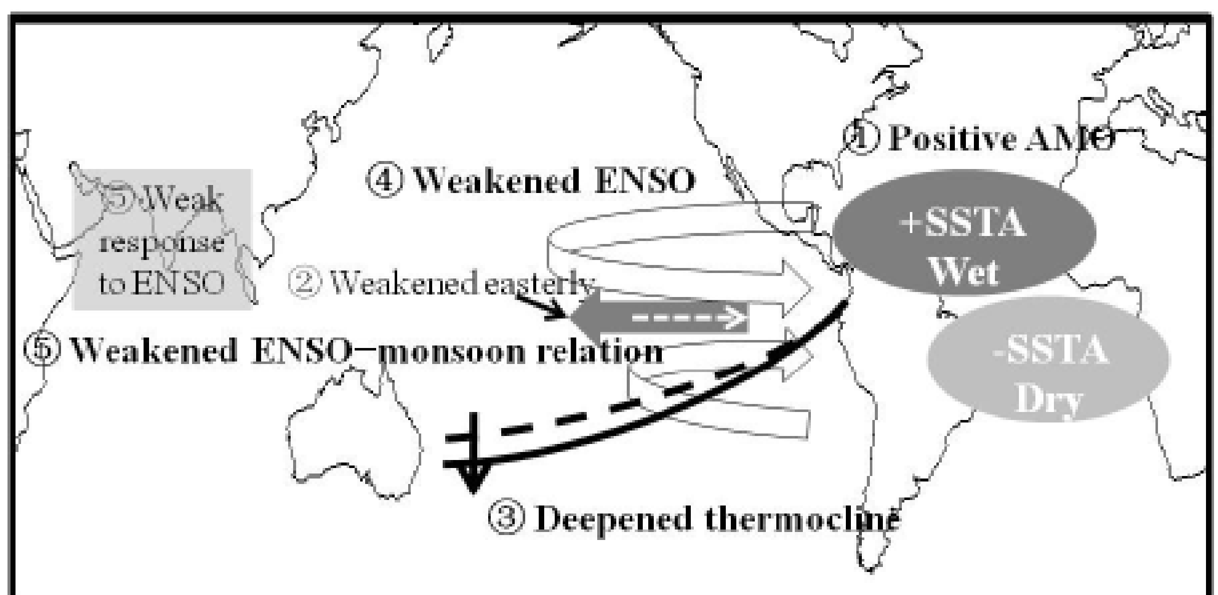
- NAtl freshwater flux → weakened THC (c.f. water hosing earlier in Zhang & Delworth; cooler NAtl SST) → stronger ENSO variance → stronger teleconnection with monsoon
- Long integration analysis composites on AMO± show AMO+ weakening the Pacific trades, deepening the thermocline and damping ENSO

Chen et al. (2010) JGR-

Lu, Chen & Dong (2008) GRL





Tropical Atlantic modulation of the monsoon-ENSO teleconnection

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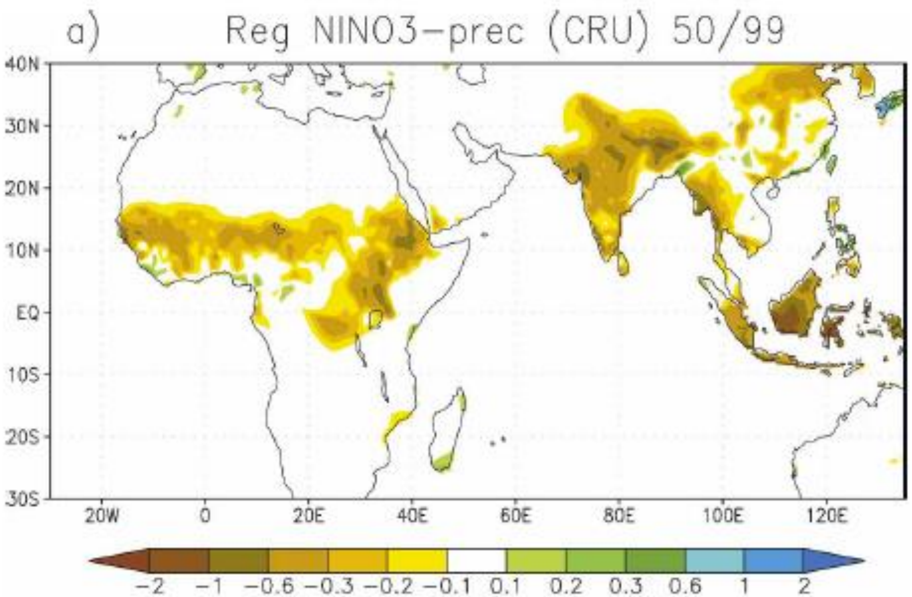
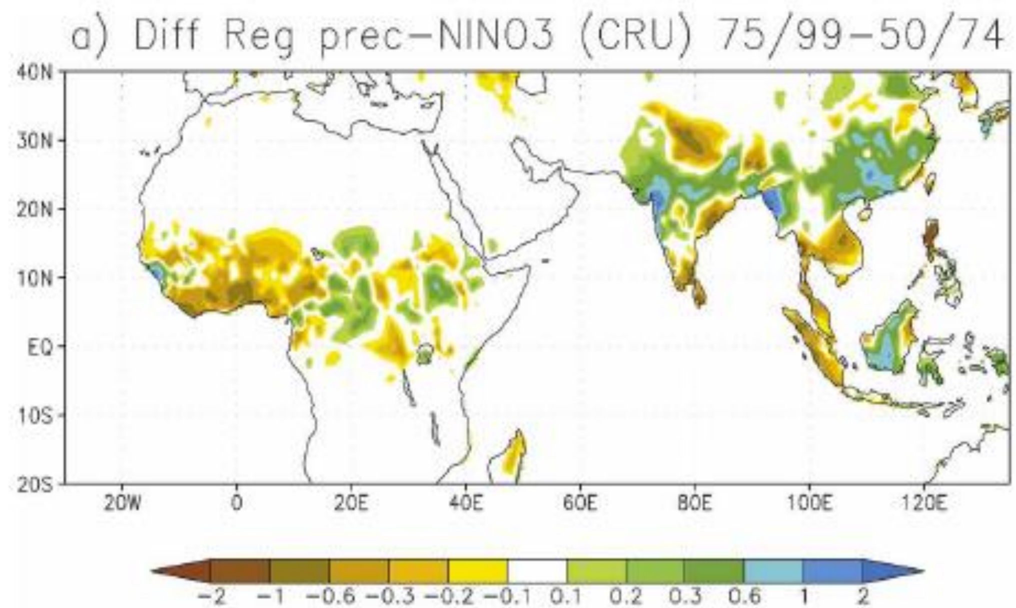
- Going back to the weakening teleconnection from earlier: JJAS Niño-3 regressions of rainfall



Long-term regression with Nino-3

Change in the regression to the recent period



Kucharski *et al.* (2007) *J. Clim.*

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Tropical Atlantic modulation of the monsoon-ENSO teleconnection

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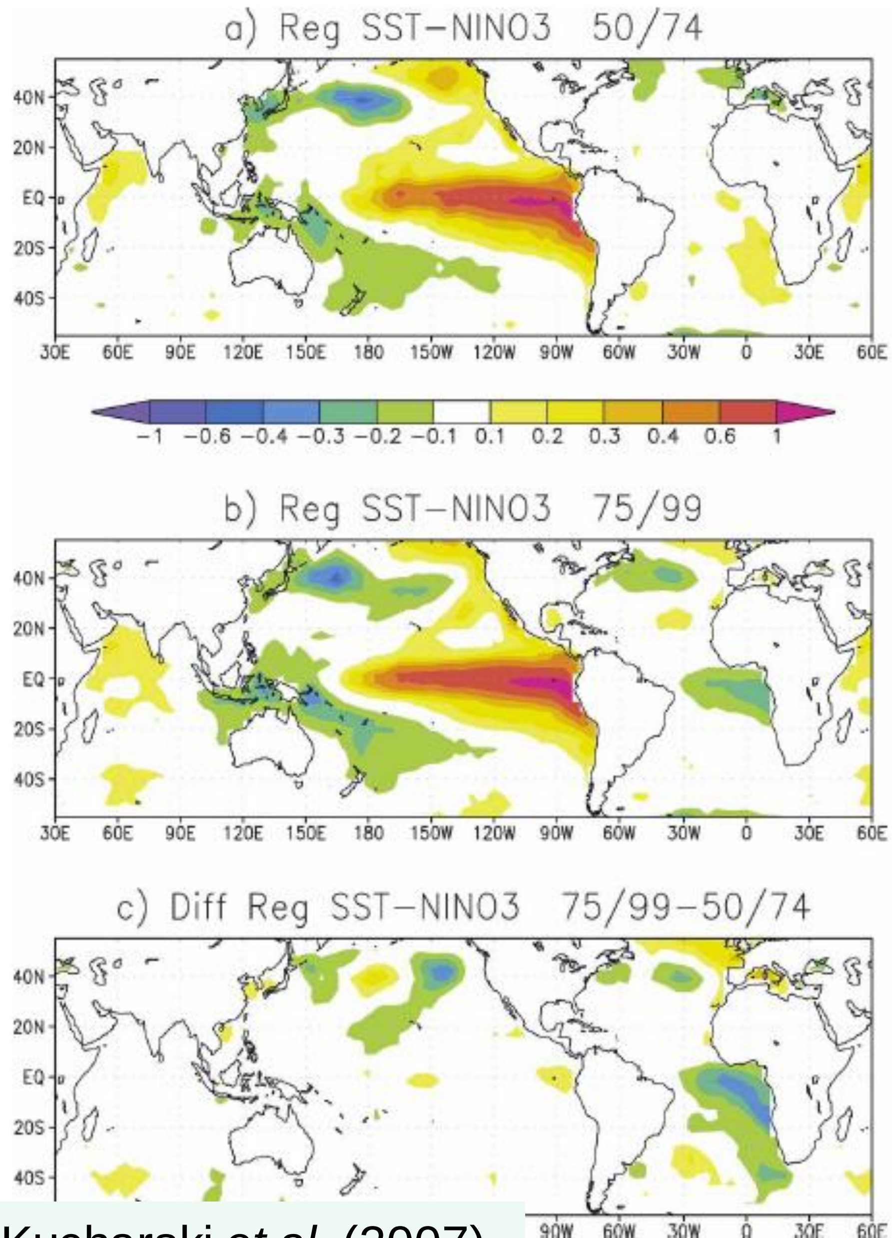

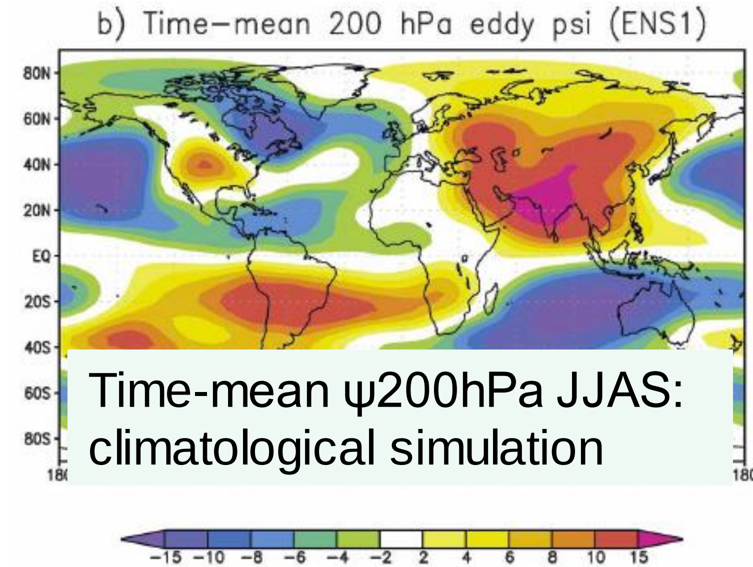

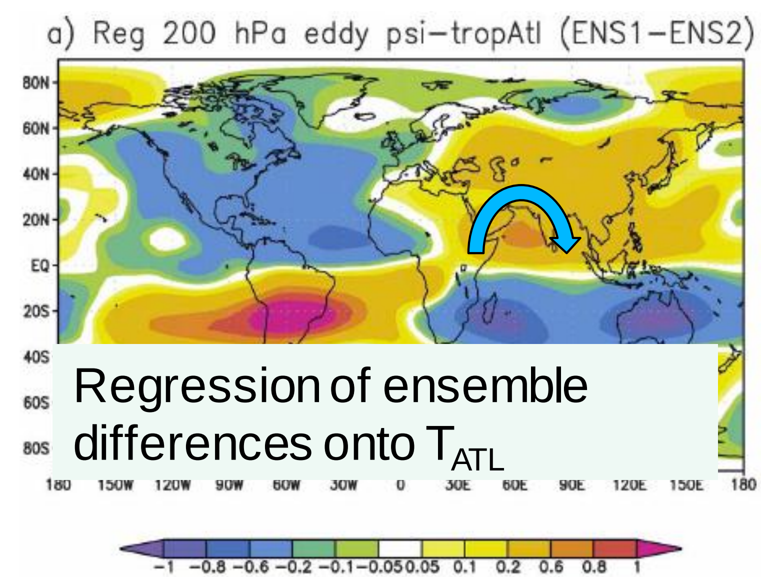

AGCM coupled in IndOc/WPAC

TATL cooling during El Nino weakens teleconnection to monsoon

Kucharski *et al.* (2007) *J. Clim.*

Coherent drivers of the global monsoon

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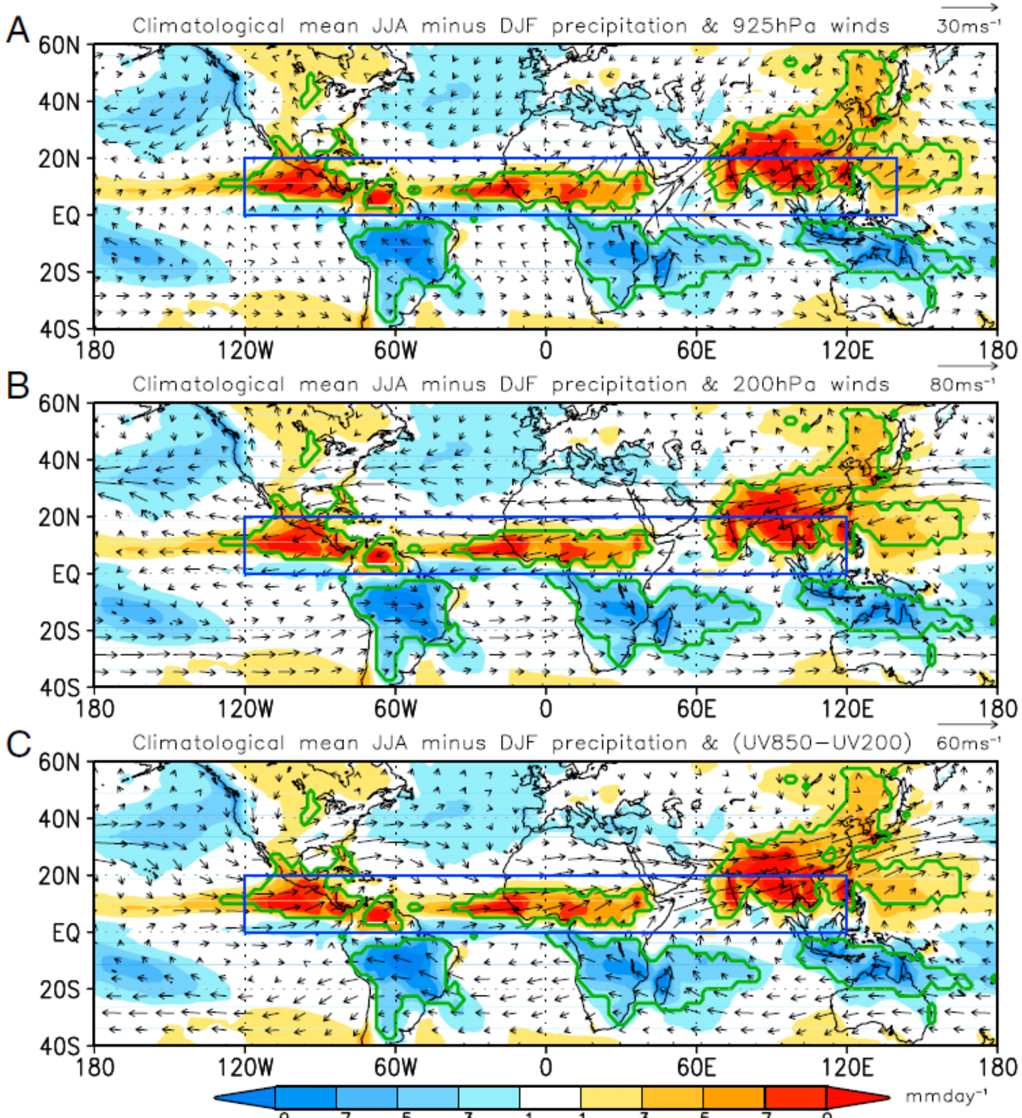
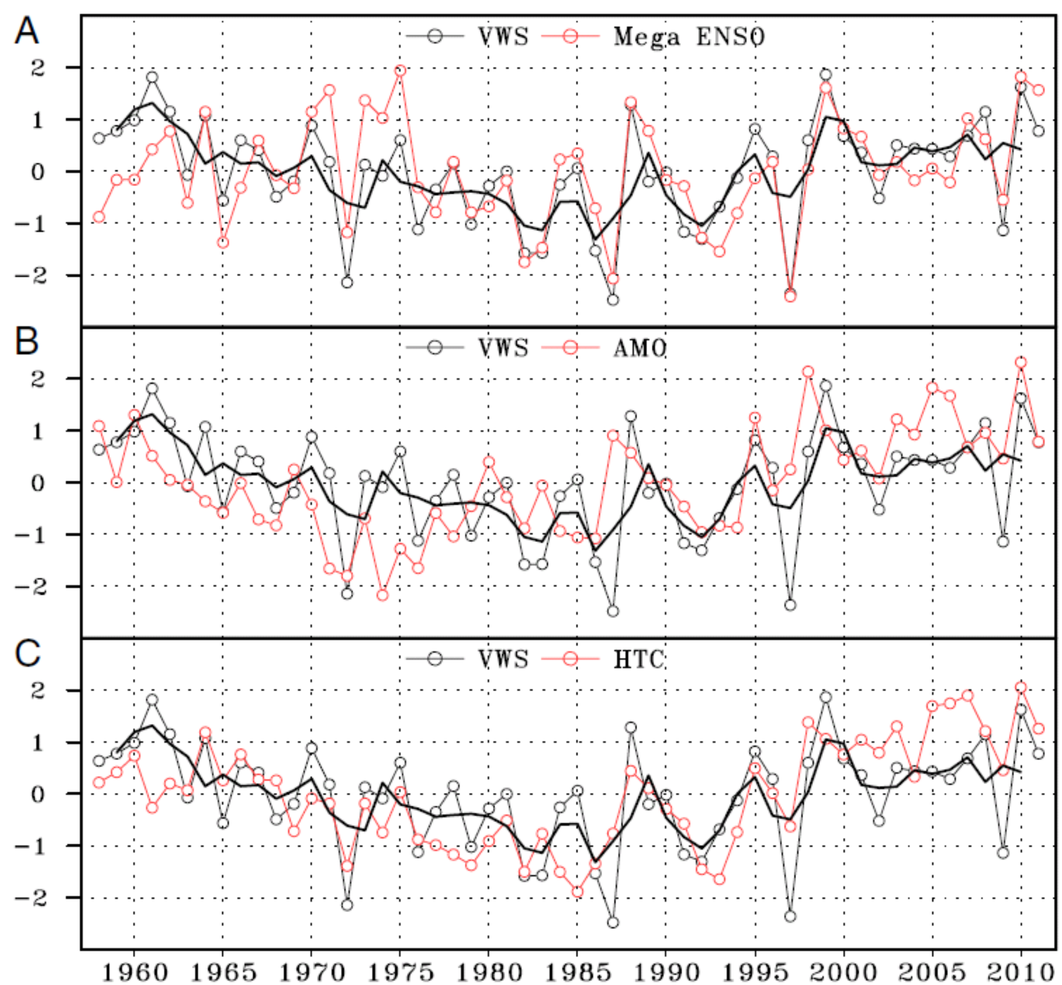
- Northern tropics <u>wind</u> shear as an index for NHSM
- Varies on decadal time scales with IPO/AMO/HTC





Wang *et al.* (2013) PNAS

Coherent drivers of the global monsoon

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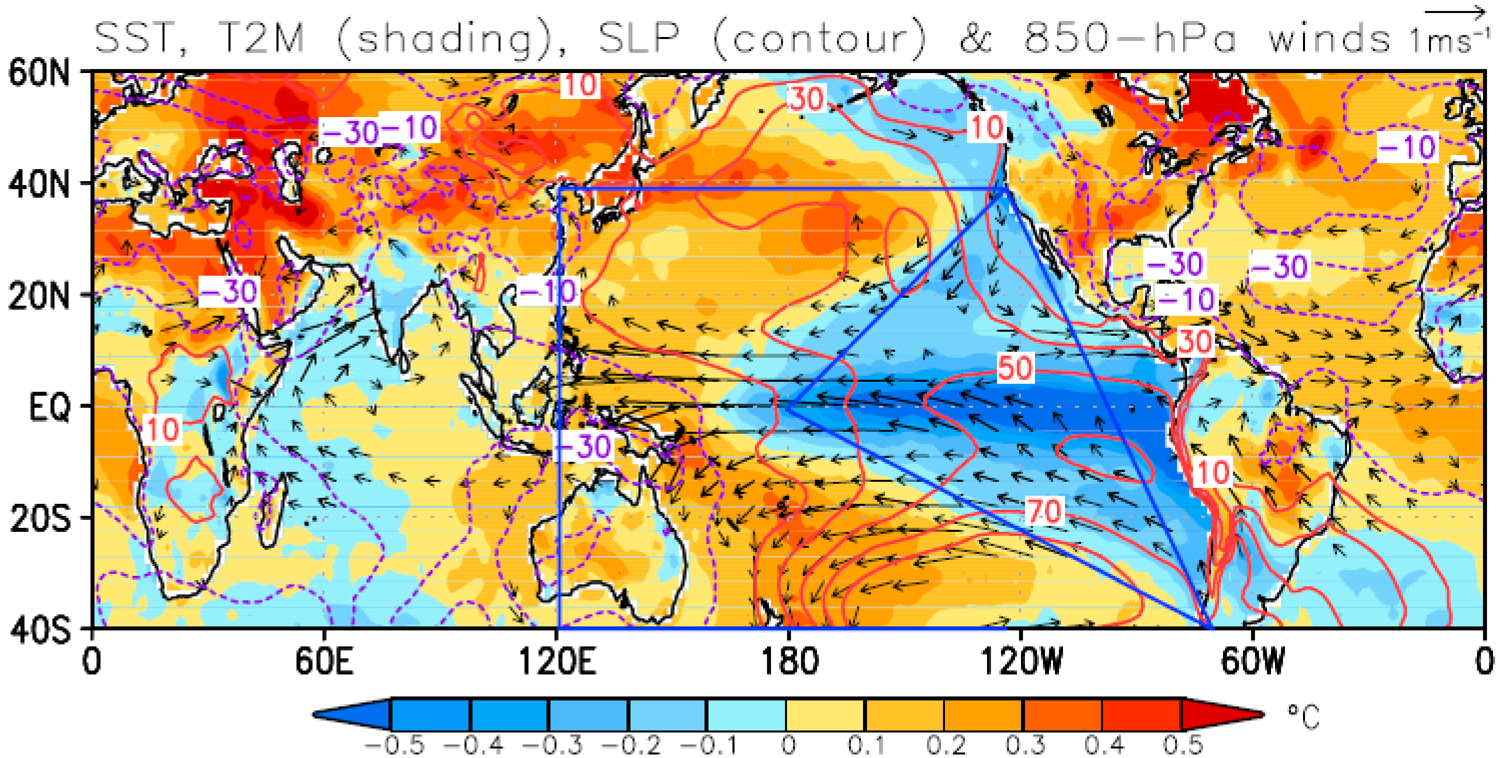
The mega-ENSO / IPO

Wang *et al.* (2013) PNAS



- Potentially added value here: anthropogenic global drivers (climate sensitivity and hemispheric thermal contrast)
- Addition of internal decadal modes (AMO, PDO)

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Prediction opportunities offered by decadal hindcasts: the Indian Ocean?

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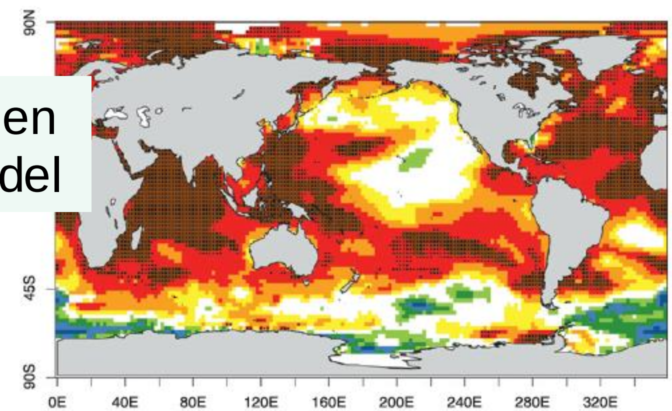
Initialised decadal hindcasts in CMIP5

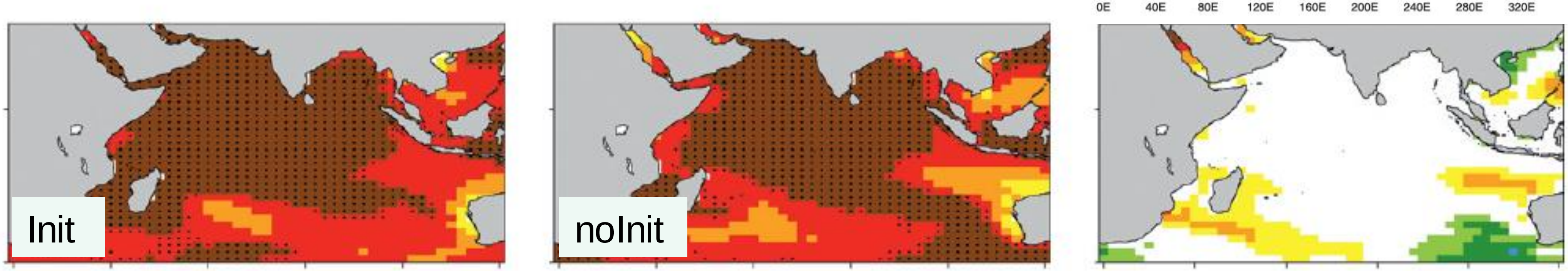
- Kim et al. (2012, *GRL*) 10-year hindcasts every 5 years from 1960: “all models show high prediction skill for surface temperature up to 6–9 years over the Indian Ocean” (7mods)
- Comparison in Guemas *et al*. (2013, *GRL*) between initialized and uninitialized runs suggests no added bonus for initialization in Indian Ocean (5mods).

b) Forecast times : 6-9 years



Correlation between observed and model

b) CMIP5. 6-9 years



Opportunities offered by decadal hindcasts: the decadal modes

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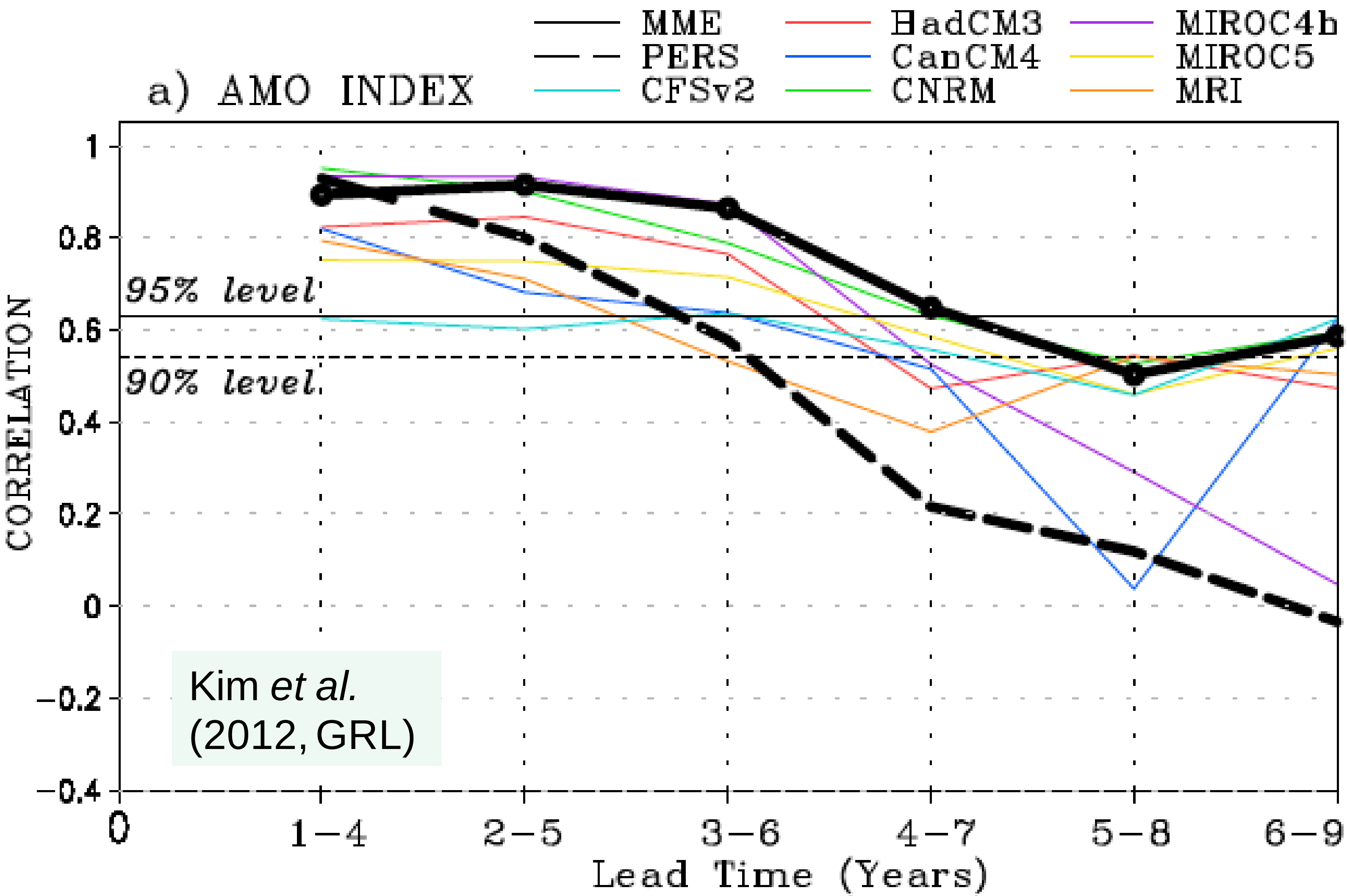
Reasonable skill for AMO out to 4-7 years ahead, but not for PDO.



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Decadal prediction outlook

Modulation of the mean South Asian monsoon

- Internal decadal modes (AMO, PDO) may tell us something about long-term monsoon variability but need to be considered against external drivers (GHG, aerosol)
- Comparison with the global monsoon can be considered if used with caution

Modulation of teleconnections by decadal drivers may prove more useful: PDO, AMO, tropical Atlantic

- Real mileage will lie in understanding relationships between decadal drivers and ISV/synoptic variability
- Utilize decadal forecasts

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Monsoon prediction

LINKING TIME AND SPACE SCALES

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Space and time scales in the monsoon

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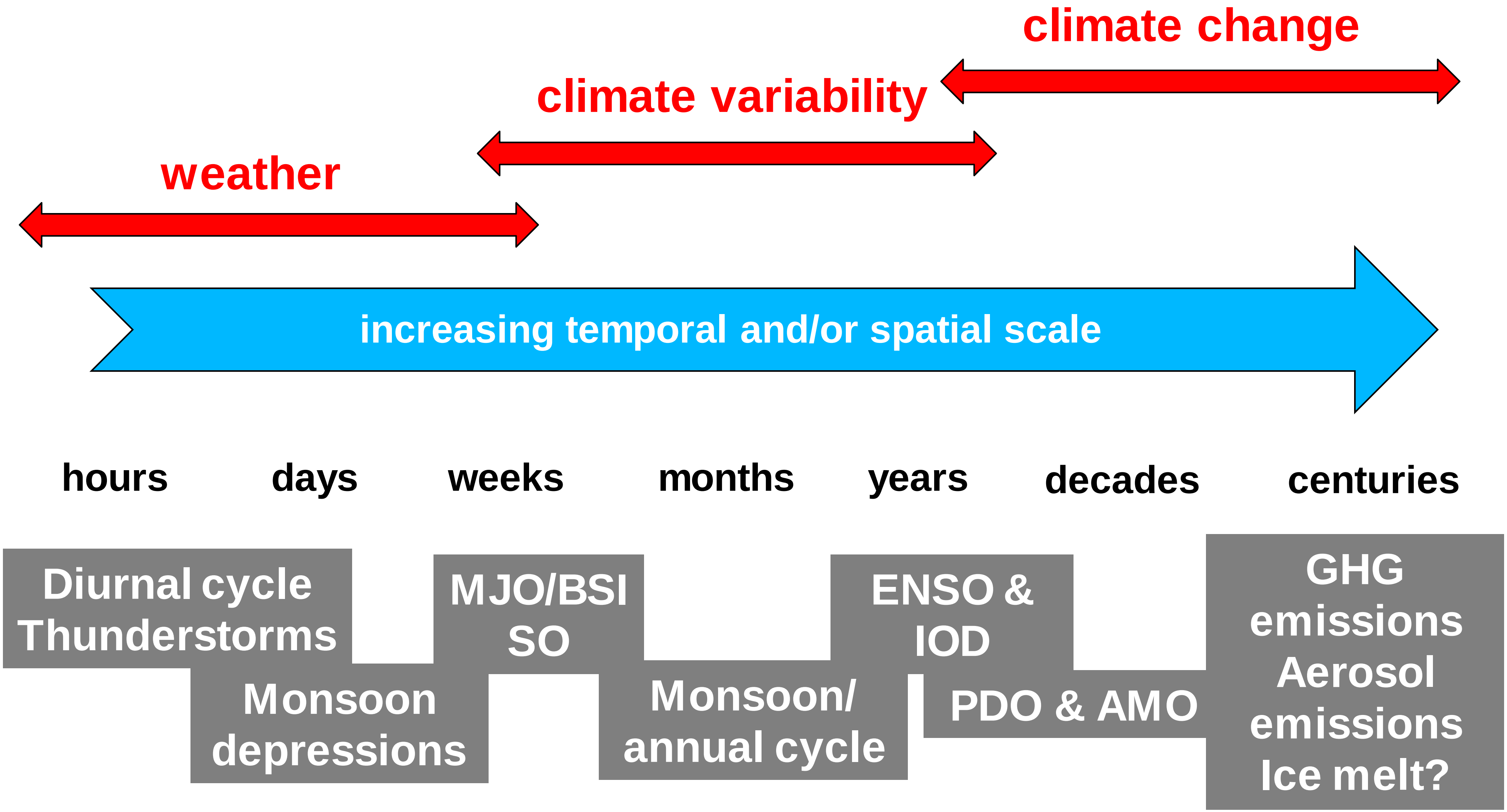

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Monsoon prediction

LINKING INTERANNUAL & INTRASEASONAL SCALES

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Palmer's vision of the monsoon as a Lorenz attractor

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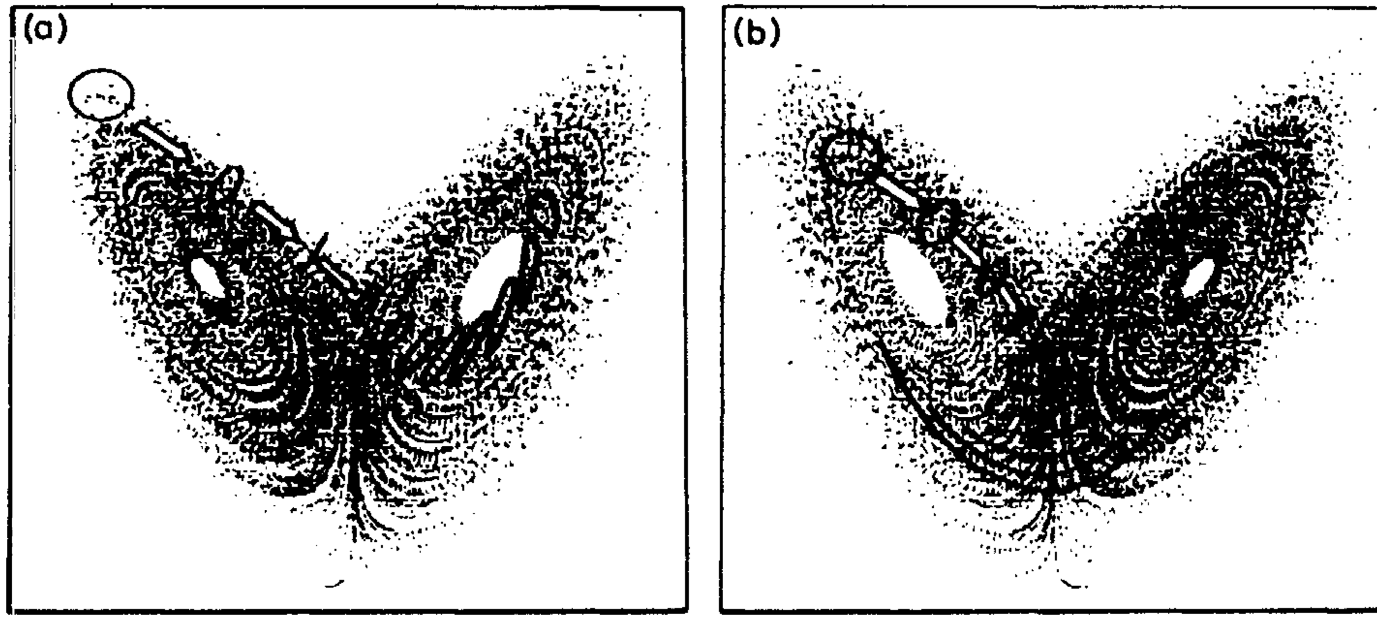
- Monsoon with active and break regimes
- Can boundary forcing predispose the system to spend more time in either regime?

Proc. Indian natn. Sci. Acad., **60**, A, No. 1, 1994, pp. 57-66.

CHAOS AND PREDICTABILITY IN FORECASTING THE MONSOONS

T N PALMER

ECMWF Shinfield Park, Berkshire RG2 9A-X, Reading, England



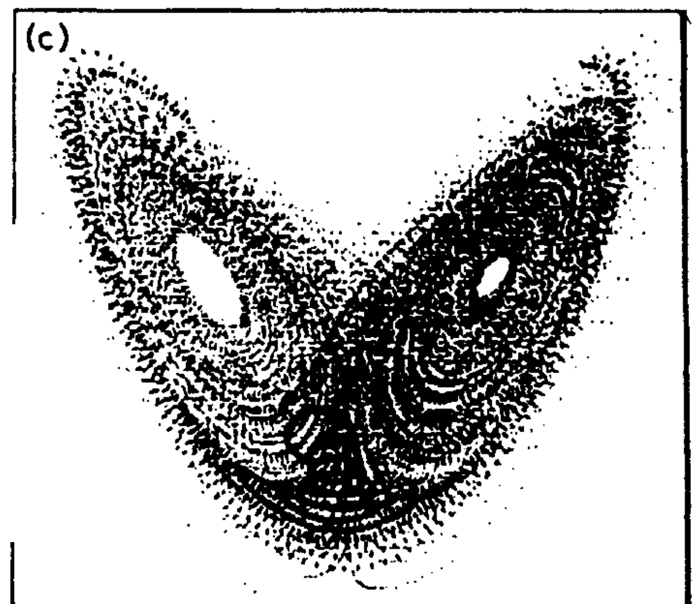


Fig 1 Phase-space evolution of an ensemble of initial points on the Lorenz attractor, for three sets of initial conditions, superimposed on the Lorenz attractor

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Palmer's vision of the monsoon as a Lorenz attractor

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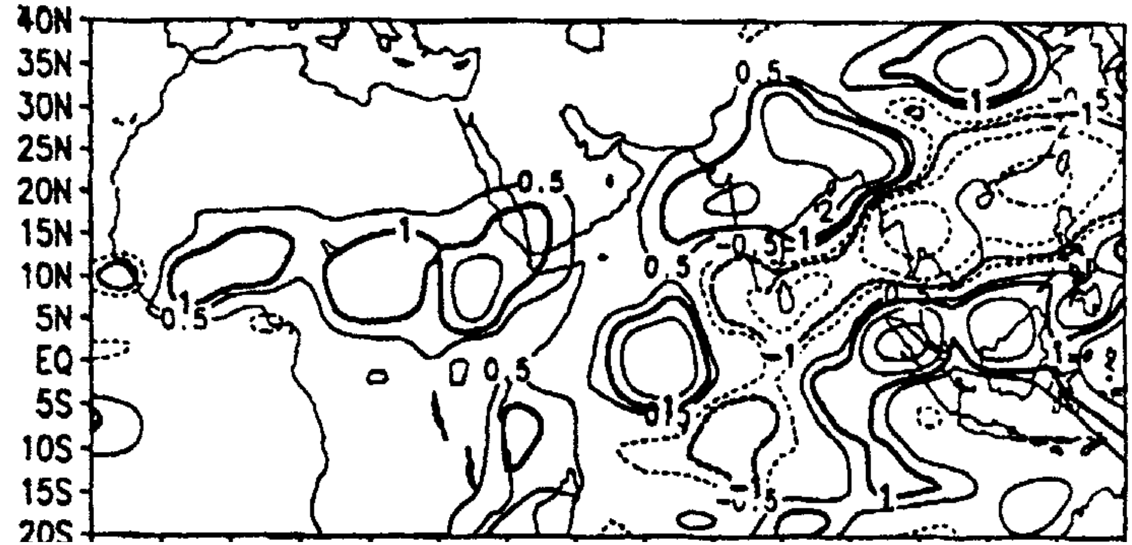
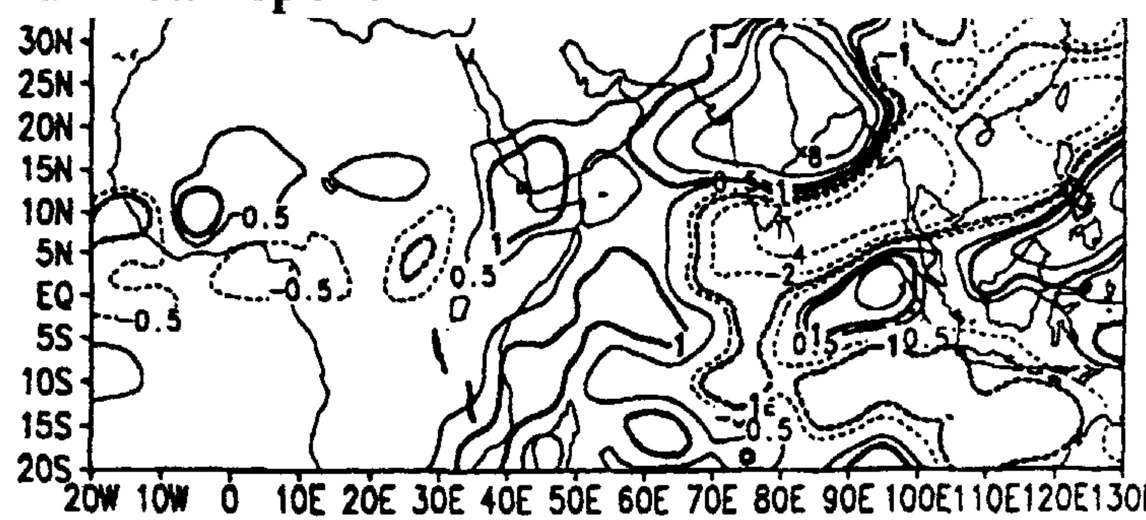
Palmer's COLA model picture shows resemblance between IAV and ISV patterns of monsoon rainfall

COLA Ensemble JJA 88-87 Precip (mm/day)



One of the principal testable hypotheses of such a paradigm is that the patterns of interannual fluctuations in monsoon rainfall, should correspond to patterns associated with the active and break spells.



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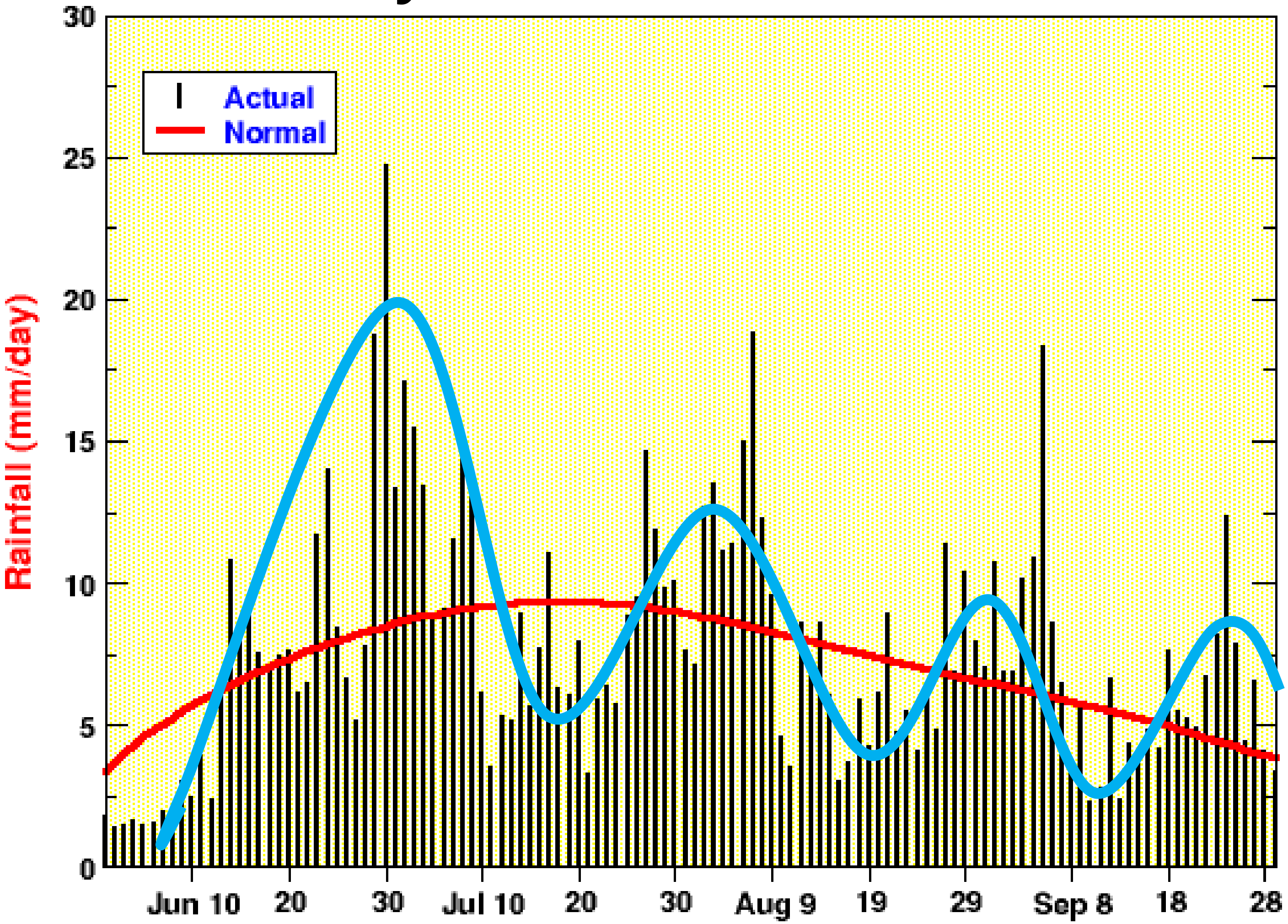
Indian monsoon: intraseasonal variability

Daily All-India Rainfall 2007



Sum of active and break events giving some contribution to seasonal mean rainfall

Comparison of monsoon variation on ISV, IAV time scale

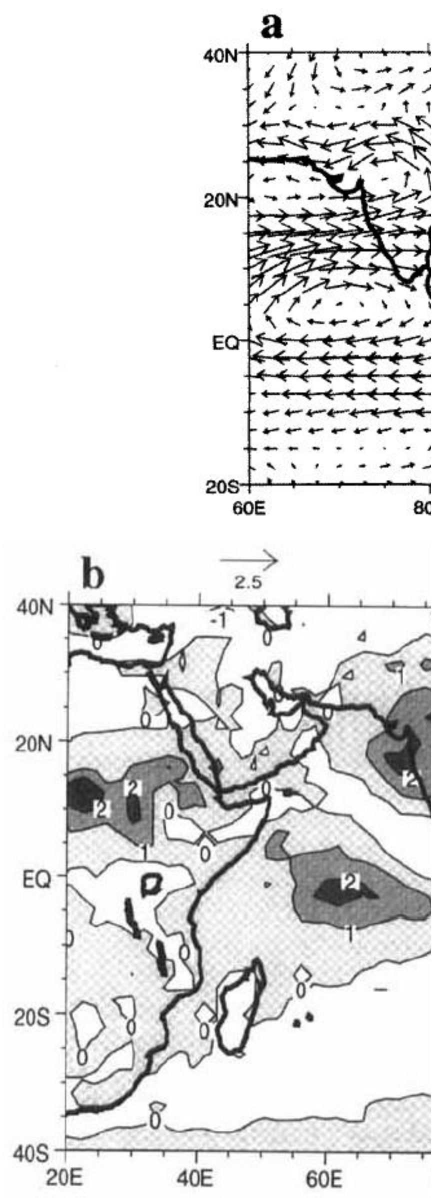
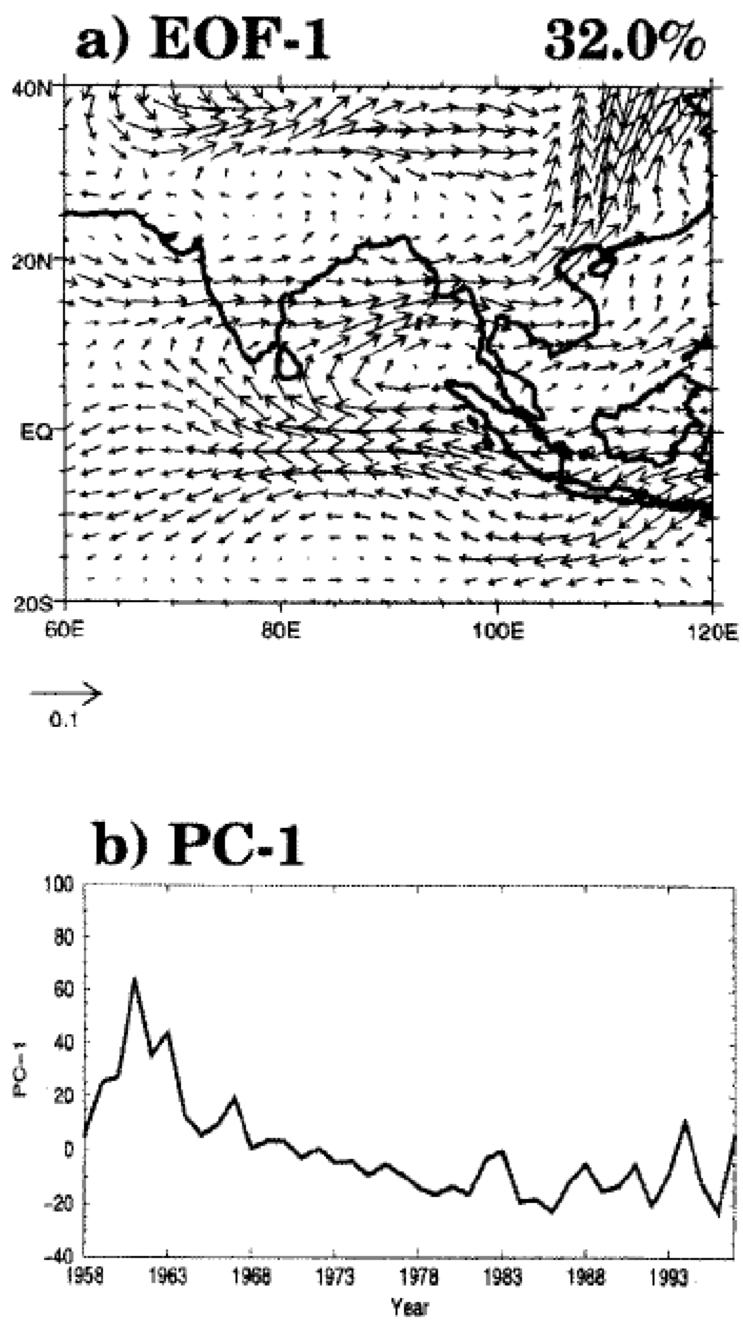
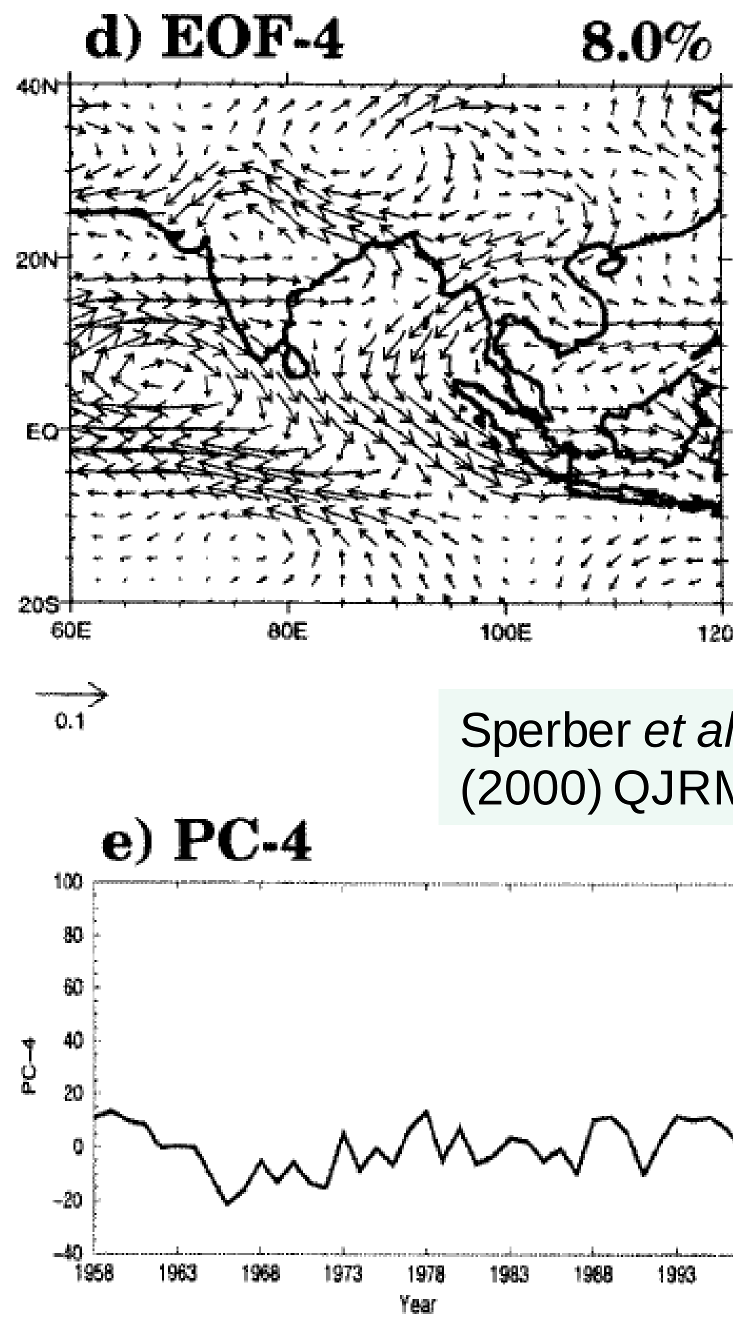


Figure 3. Difference of seasonal mean (June
(mm day^{-1}) based on strong–weak years of all
thresholds to define extreme years. In (b) neg





Sperber *et al.* (2000) QJRMS

Comparison of monsoon variation on ISV, IAV time scale

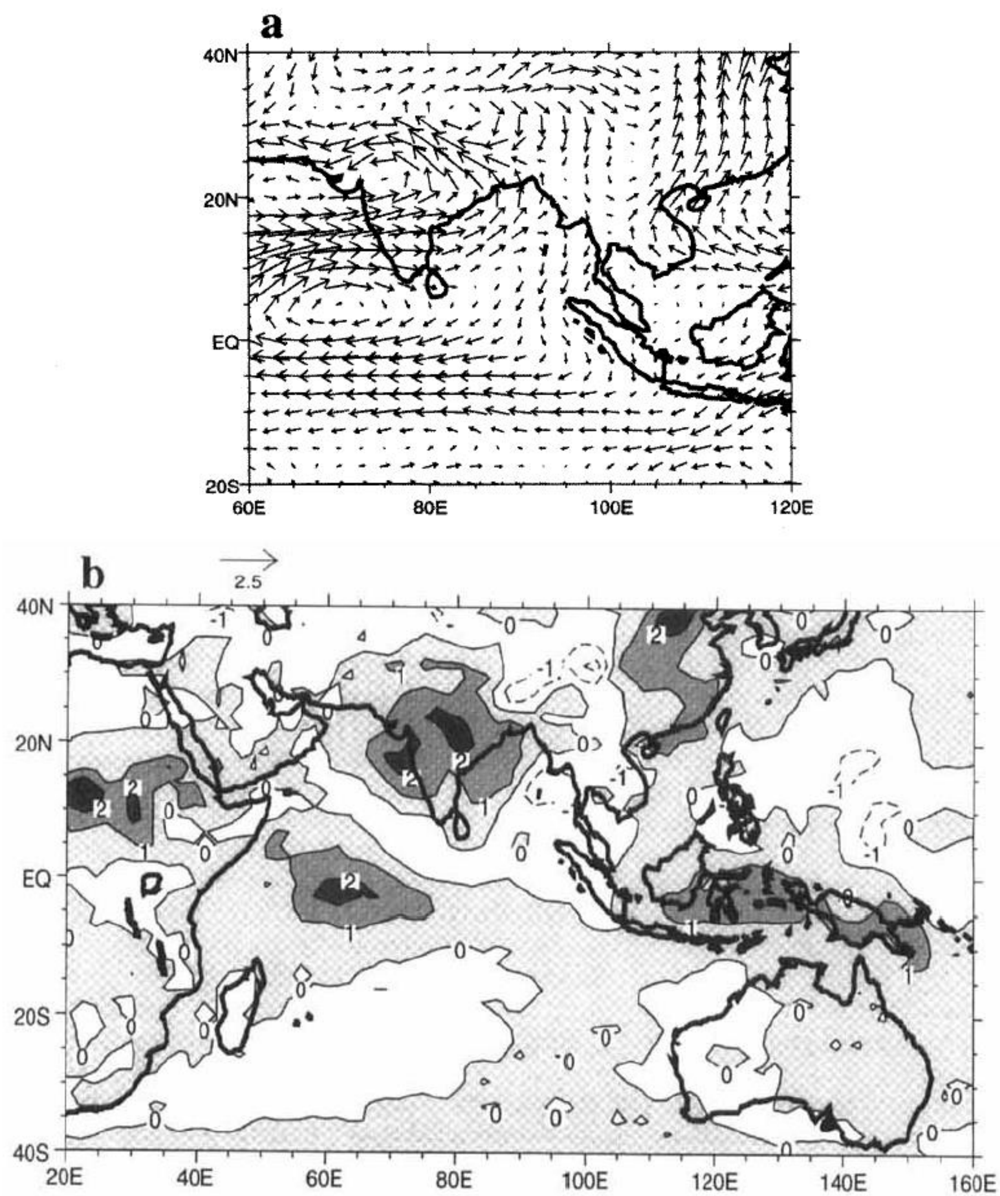
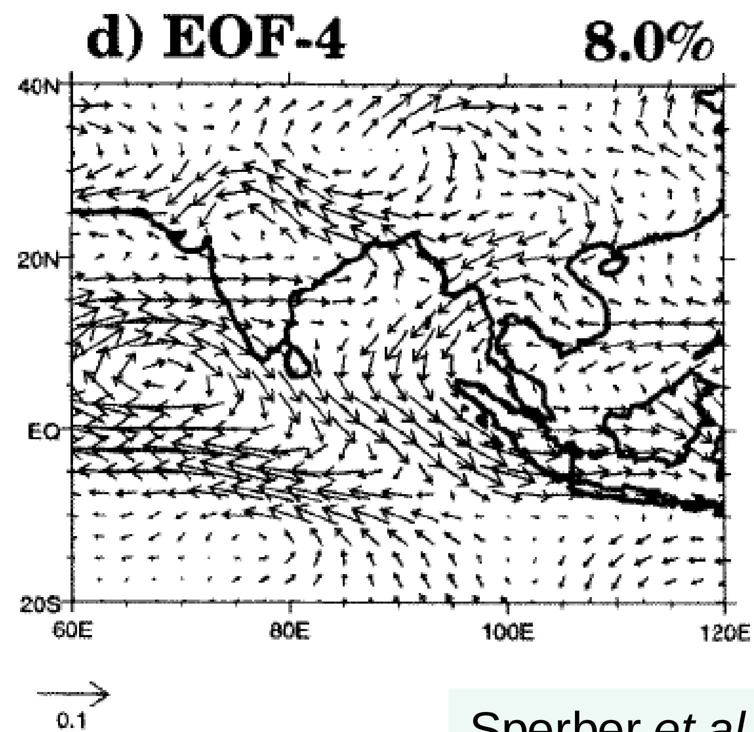
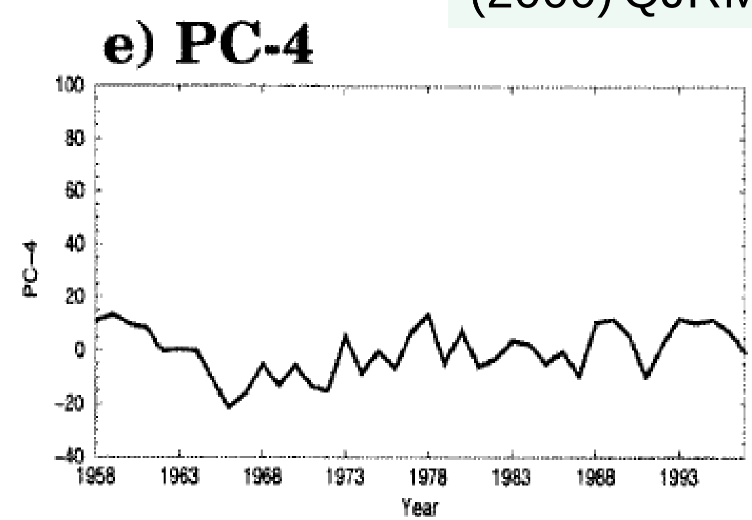


Figure 3. Difference of seasonal mean (June–September) composites of (a) 850 hPa wind, and (b) rainfall (mm day^{-1}) based on strong–weak years of all-India rainfall in Fig. 2(b) using 0.5 and −0.5 standard-deviation thresholds to define extreme years. In (b) negative contours are shown dashed and positive values are shaded progressively.



Sperber *et al.* (2000) QJRMS



Comparison of monsoon variation on ISV, IAV time scale

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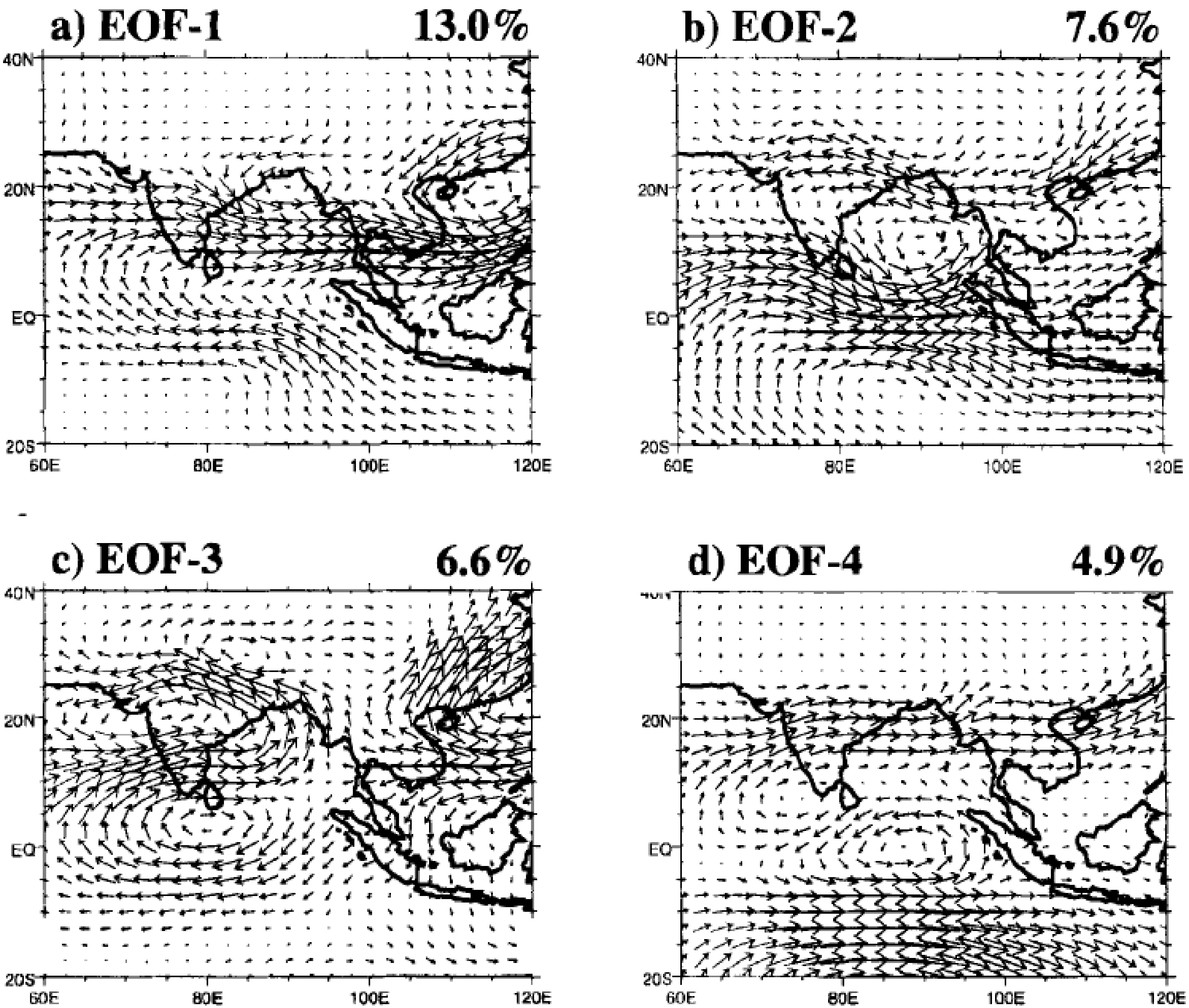
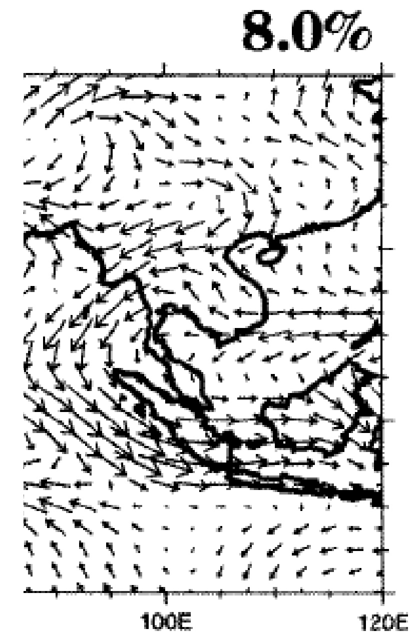
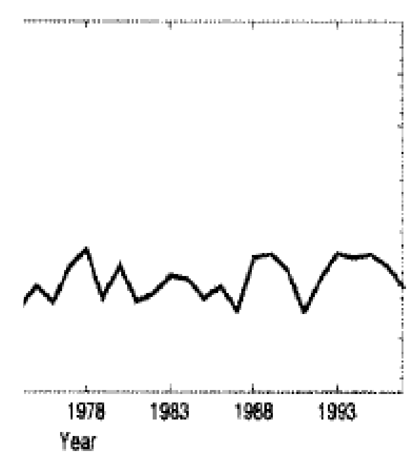
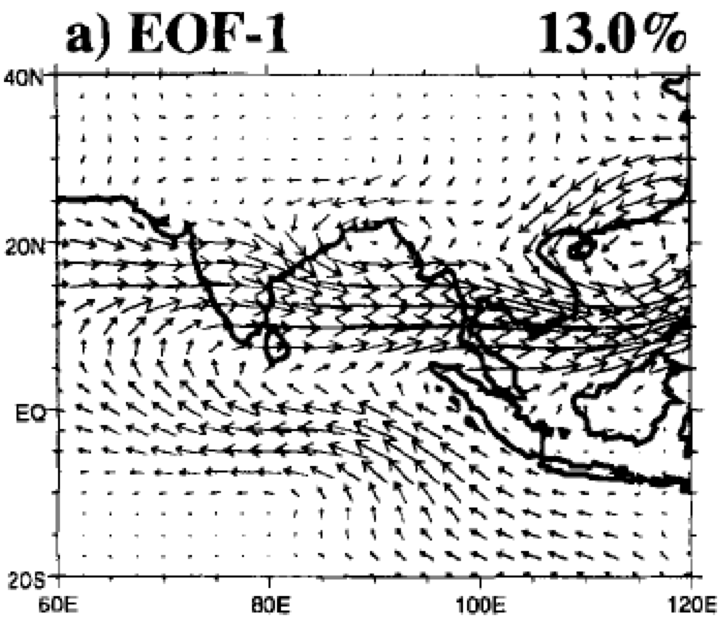


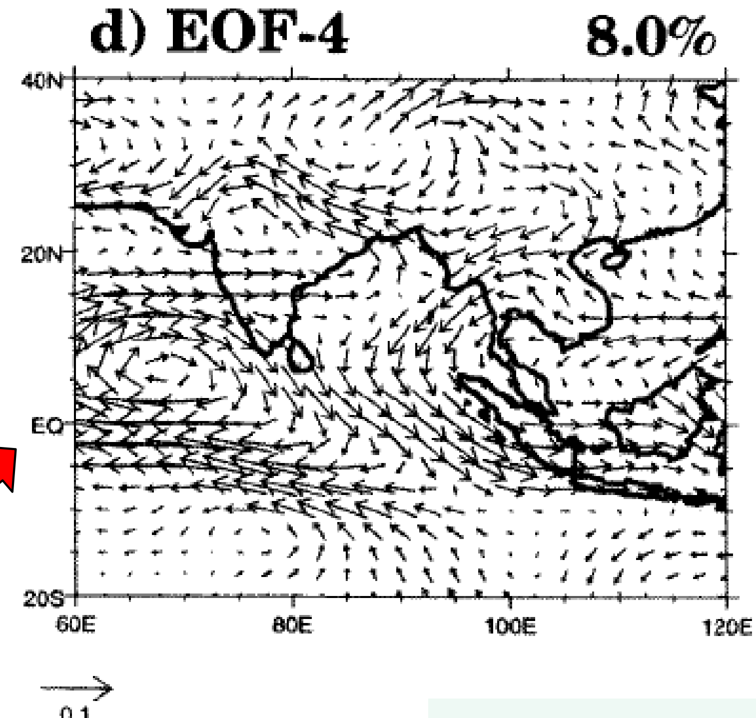


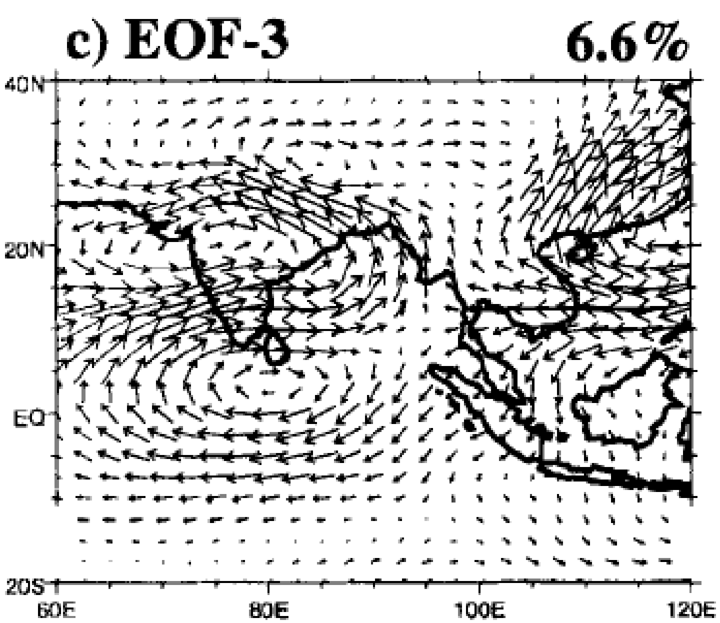
Sperber *et al.* (2000) QJRMS



Comparison of monsoon variation on ISV, IAV time scale



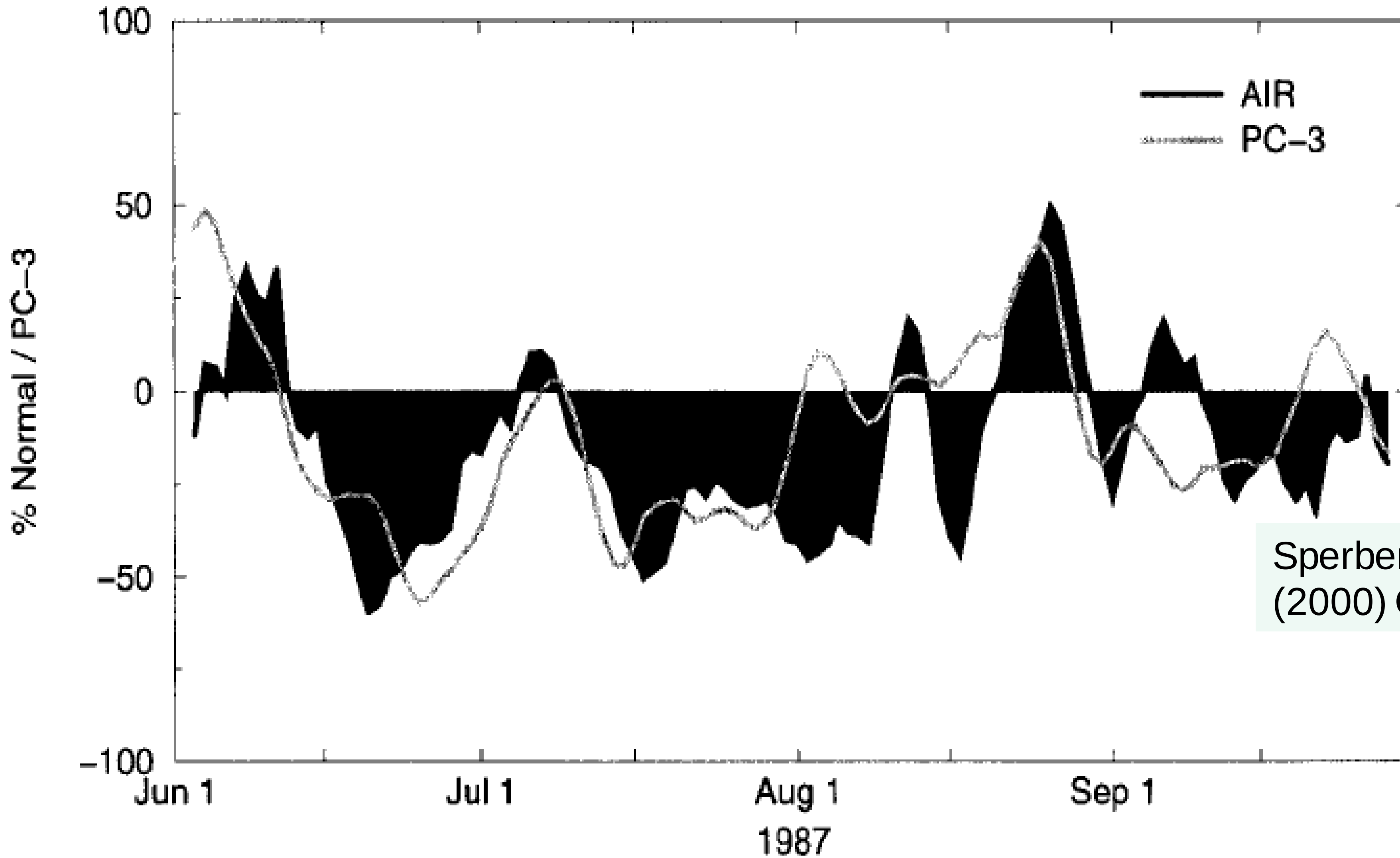




Sperber *et al.* (2000) QJRMS

Resemblance suggesting than an element of the ISV can rectify onto the IAV

Co-variation of daily Indian rainfall and PC3



Sperber *et al.* (2000) QJRMS

ISV vs. IAV

PDFs constructed from the daily PC-time series

- The daily PC3 mode more/less prevalent under different seasonal mean rainfall conditions

Sperber *et al.* (2000) QJRMS

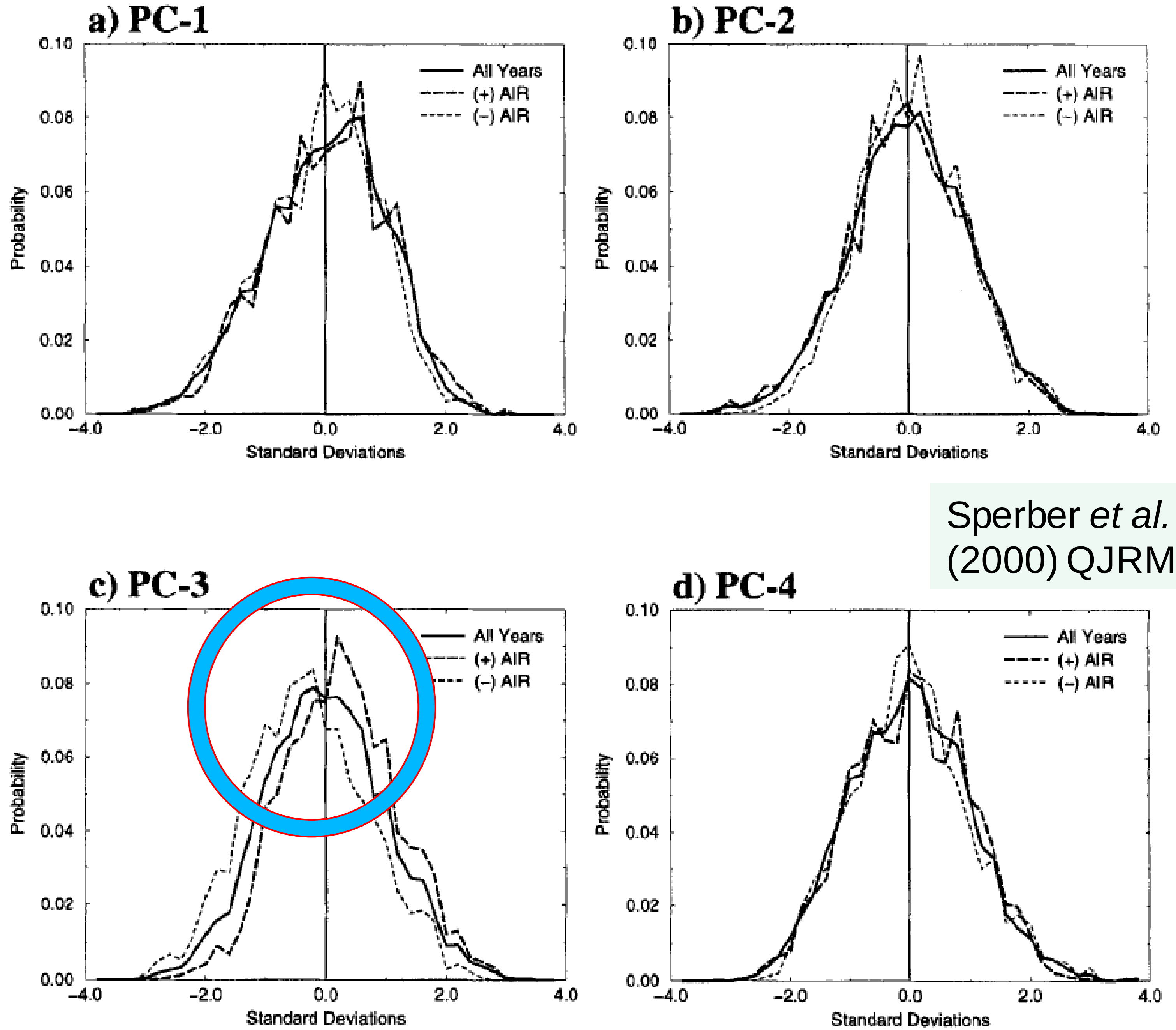


Figure 10. Probability distribution functions (PDFs) of the principal component (PC) time series of EOFs 1–4 given in Fig. 6. Each of the PC time series was standardized before calculating the PDFs. The solid line is the PDF based on all years of data. The thick dashed line is the PDF for years when the observed all-India rainfall (AIR) was above normal ($\geqslant$0.5 standard deviation in Fig. 2(b)), and the thin short-dashed line is the PDF for years when the observed AIR was below normal ($\leqslant -0.5$ standard deviation in Fig. 2(b)). A vertical reference line at 0.0 standard deviations is also given.

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Linking intraseasonal and shorter time scales (monsoon depressions)

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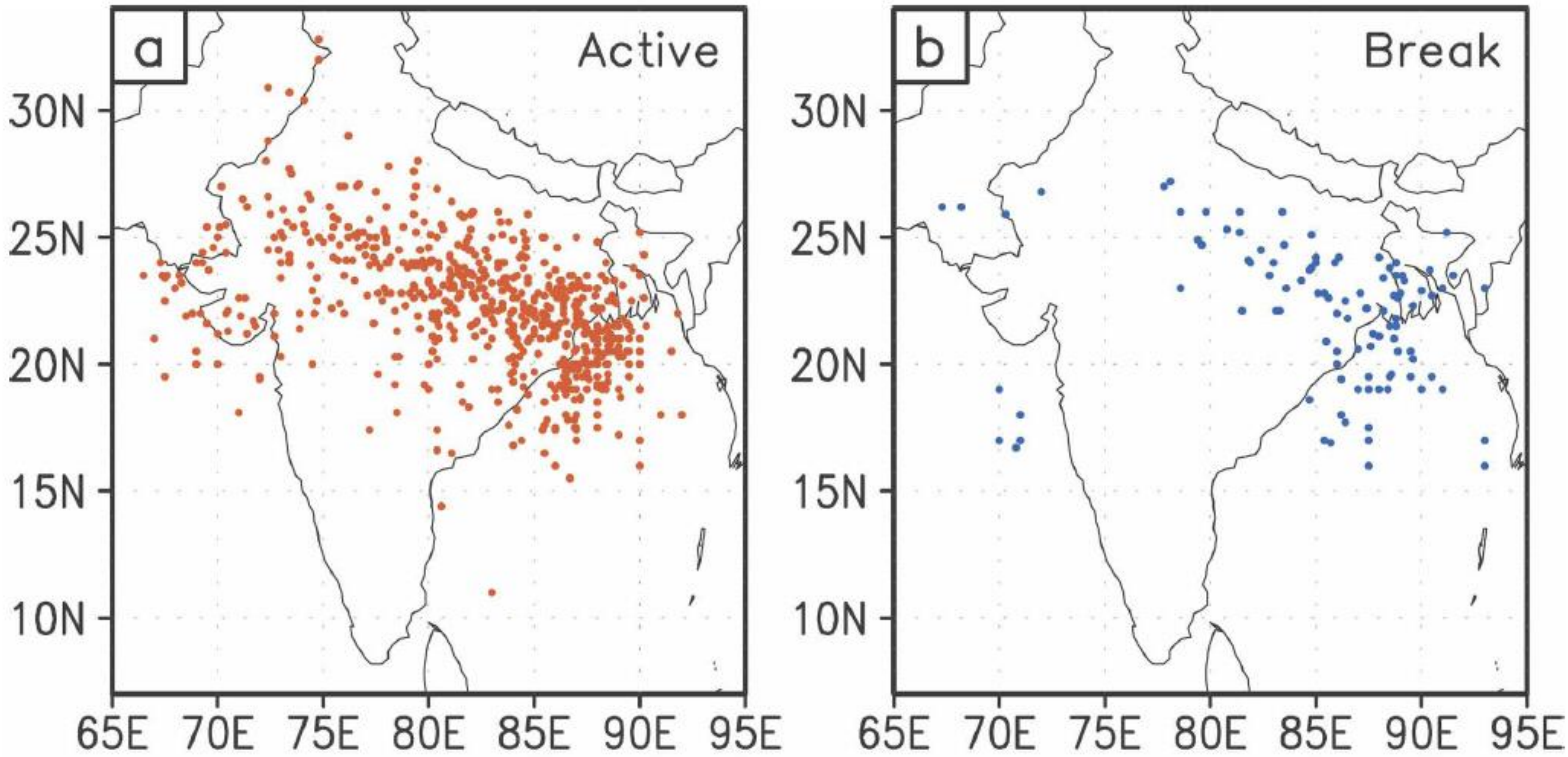

FIG. 2. (a) Active phase composite (red dots) and (b) break phase composite (blue dots) of depression-days. Each dot represents the location of the depression for a day (or depression-day). The composites were constructed for all active and break days during JJAS 1901–70. (c) Lagged active phase composites (red) and lagged break phase composites (blue) of depression-days for the period JJAS 1901–70. Lag 0 corresponds to the midpoint of each active or break phase.

From Krishnamurthy & Shukla (2007) *J. Clim.*

Monsoon prediction

SOCIETAL NEED FOR SUBSEASONAL PREDICTION & CHALLENGES AHEAD

Indian monsoon: intraseasonal variability

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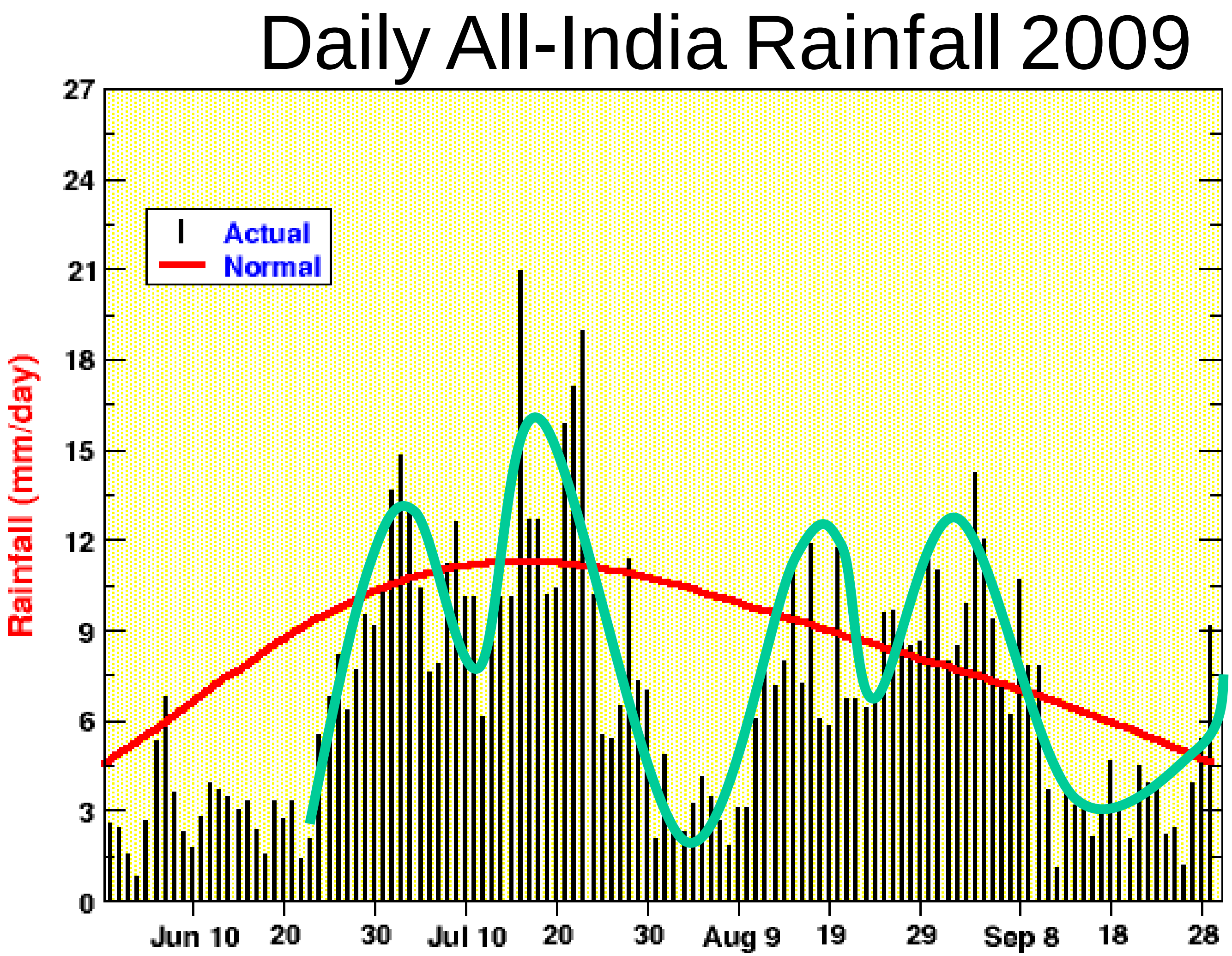

In 2009, several breaks contribute to the worst monsoon in decades

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Indian monsoon: intraseasonal variability in 2009

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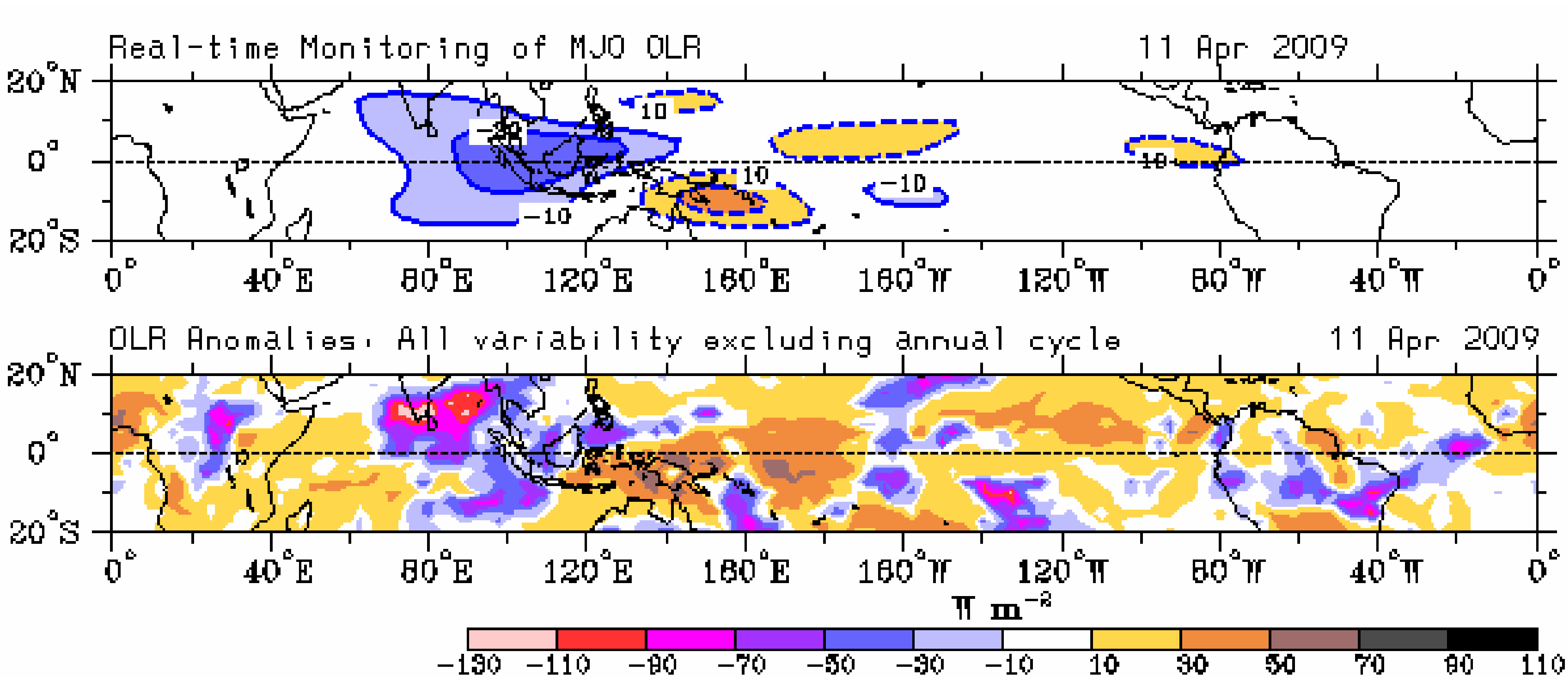
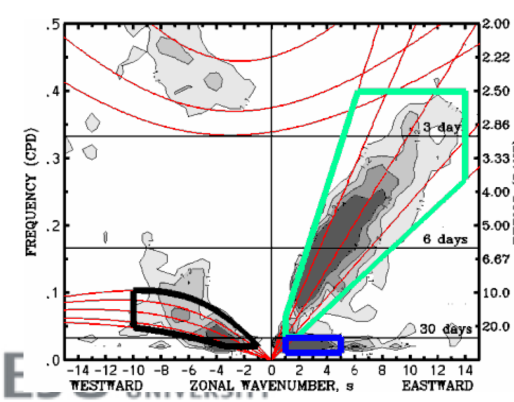
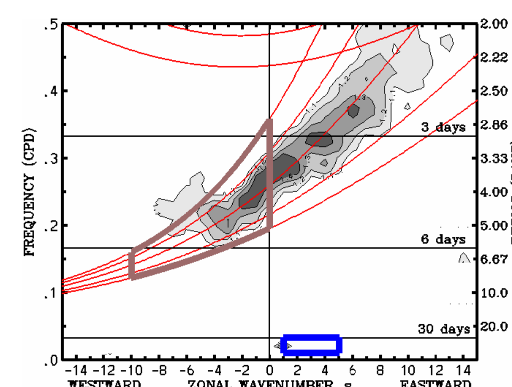


'MJO' mode by filtering in the zonal wavenumber / frequency domain, Wheeler & Weickmann (2001)





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Indian monsoon: series of breaks contributing to reduced seasonal total

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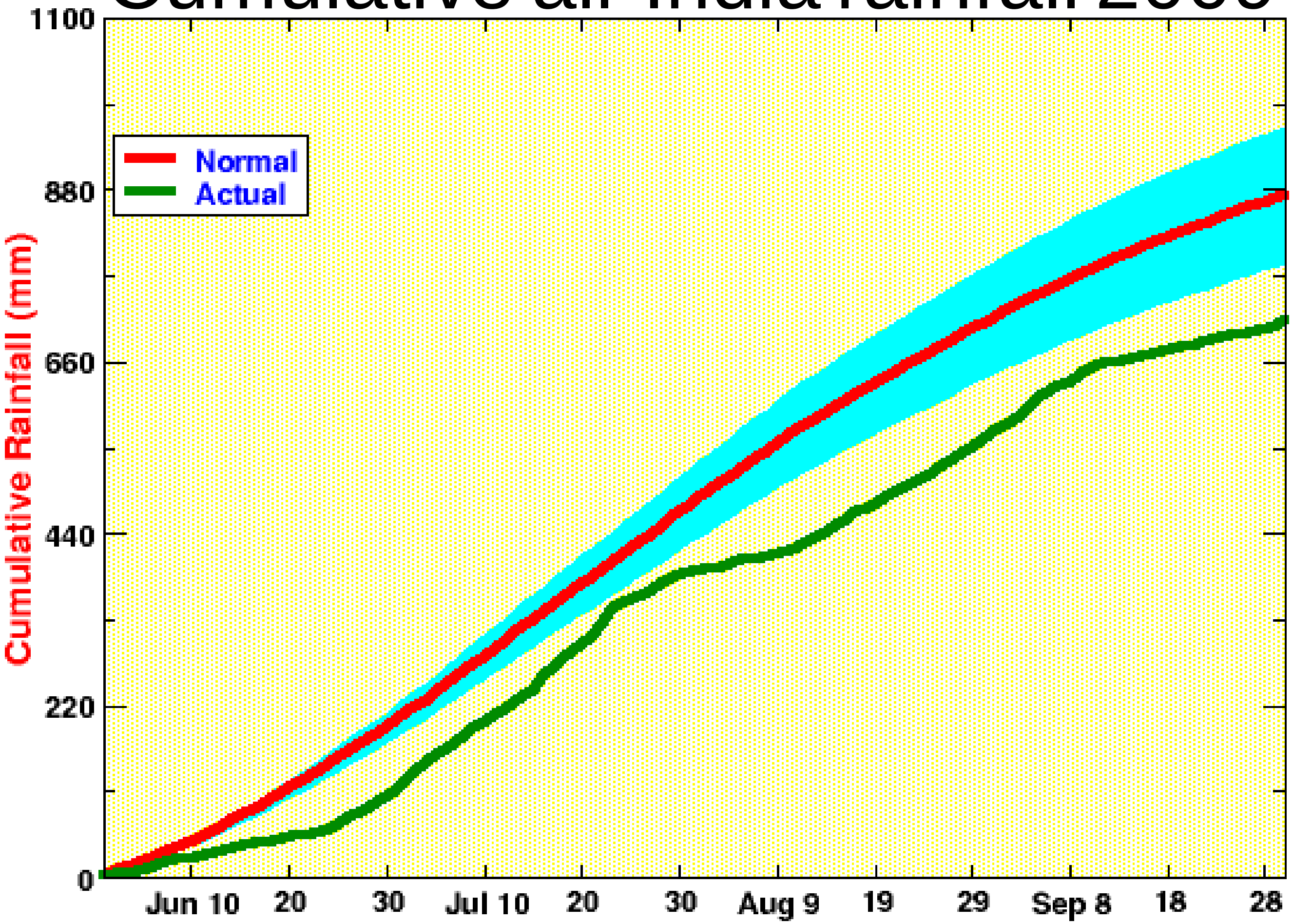
Cumulative all-India rainfall 2009



In 2009, several breaks contribute to the worst monsoon in decades

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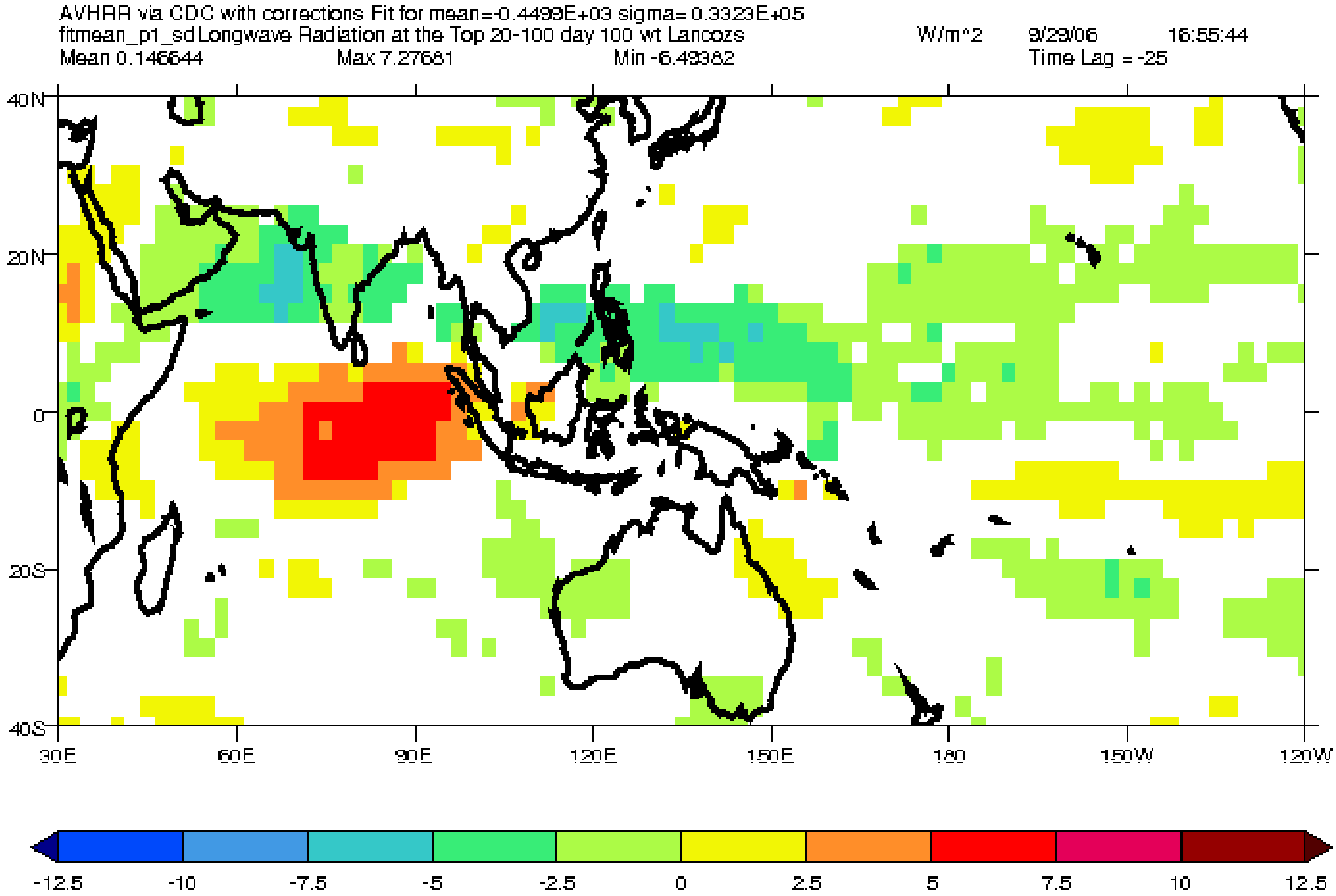
Active-break cycle: animation

A composite cycle of monsoon intraseasonal variability, courtesy Ken Sperber, PCMDI, USA



Example current subseasonal predictability

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Abhilash *et al.* (2014)

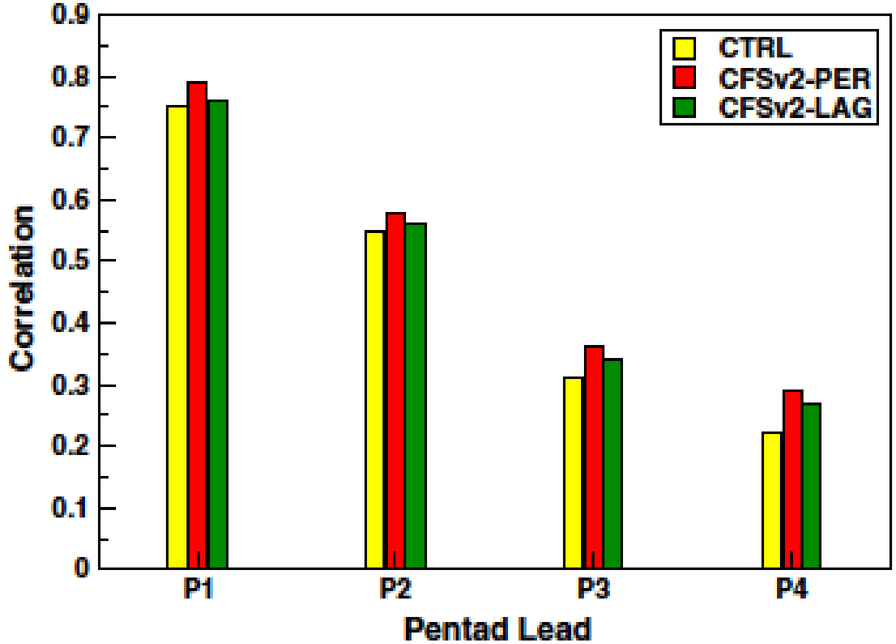

Fig. 1 Correlation coefficients between pentad mean observed and predicted area-averaged rainfall anomalies over Central India for the control and ensembles from CFSv2 perturbation experiments and lagged ensembles from NCEP CFSv2 reforecast. The correlation has been calculated for 24 pentads during summer monsoon (JJAS) for 9 years (2001–2009)

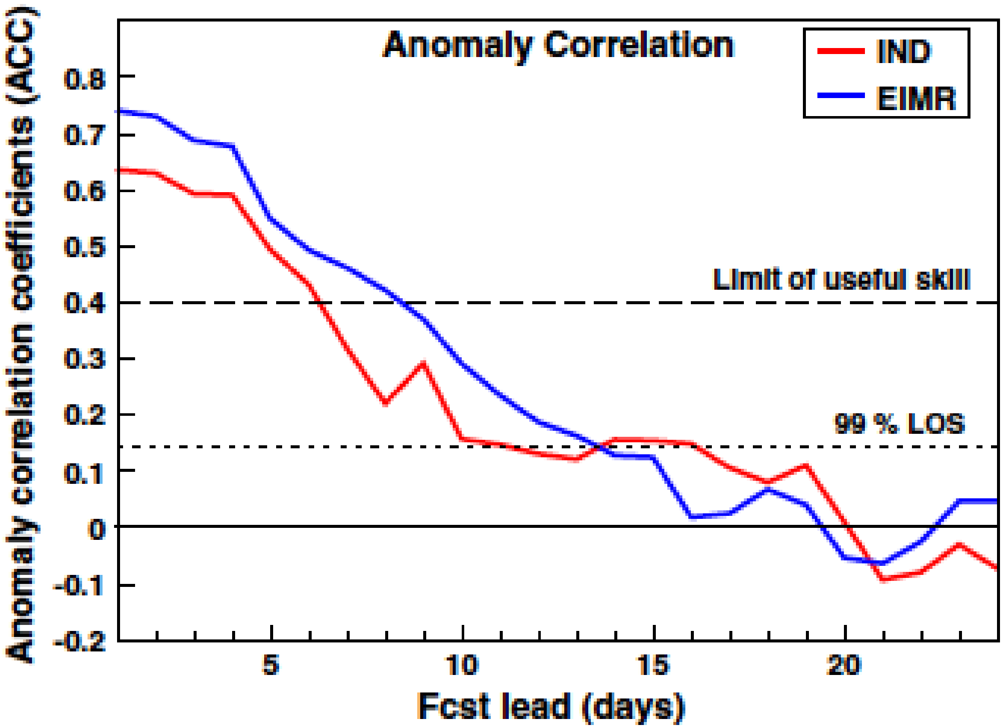

Fig. 7 Anomaly correlation coefficient (ACC) of the area-averaged rainfall over MZI and EIMR region as a function of forecast lead in days

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BSISO in the Met Office GloSea5 model

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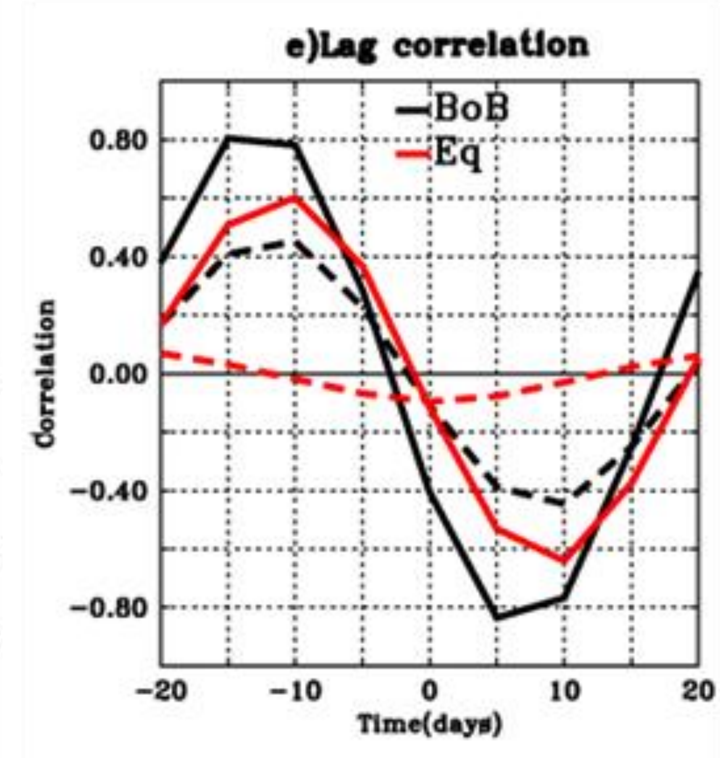
The GloSea5 coupled initialized seasonal forecast model shows good representation of quadrature relationship between intraseasonally filtered SST and precipitation over the Bay of Bengal (black curves, comparing solid observation and dashed model lines)

Air-sea interaction over the equatorial Indian Ocean is poor (red curves)



Boreal summer sub-seasonal variability of the South Asian monsoon in the Met Office GloSea5 initialized coupled model. A. Jayakumar, A. G. Turner, S. J. Johnson, E. N. Rajagopal, Saji Mohandas and A. K. Mitra. *Climate Dynamics*, 2016

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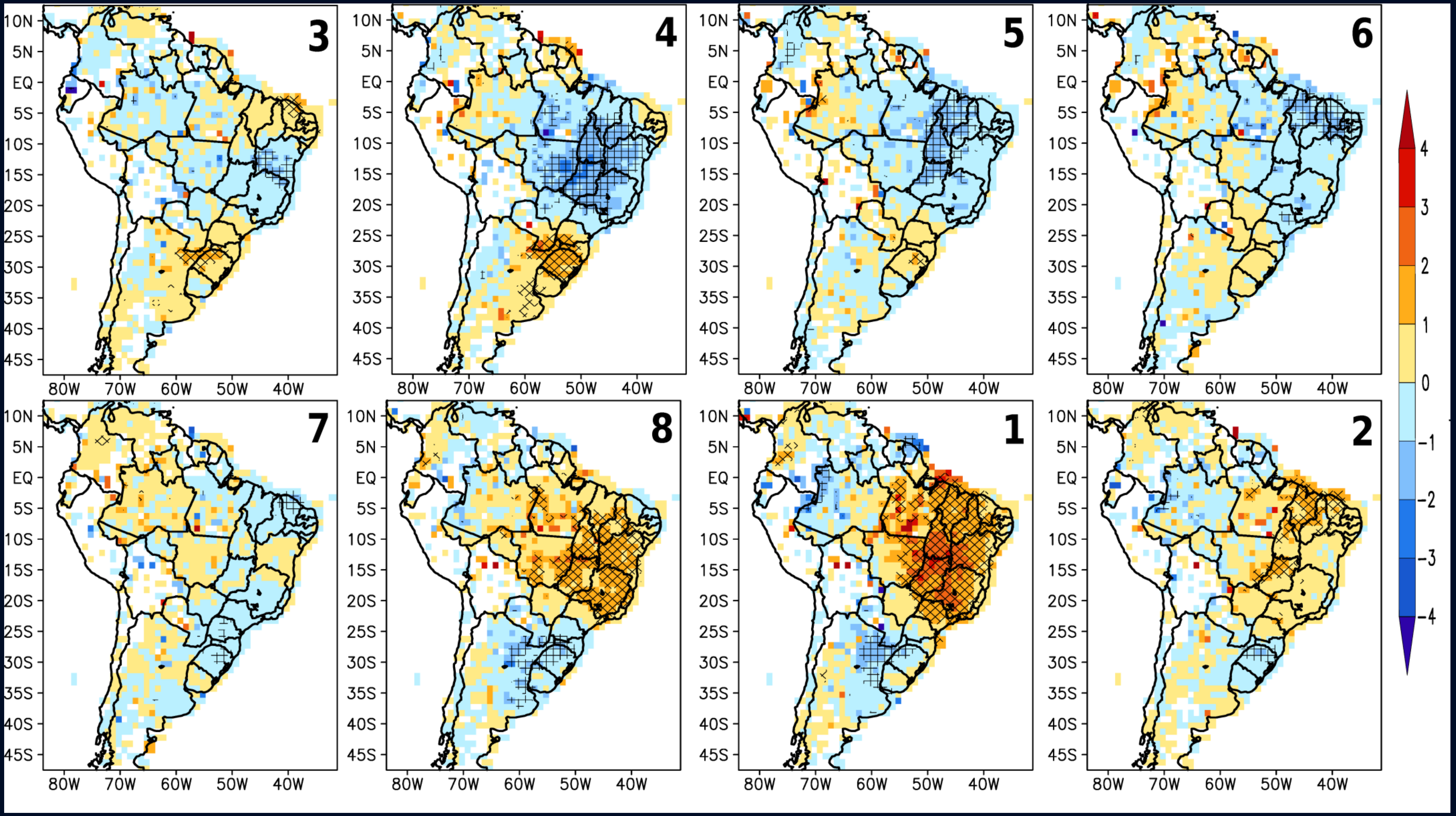
Courtesy:
Alice Grimm
(2016)

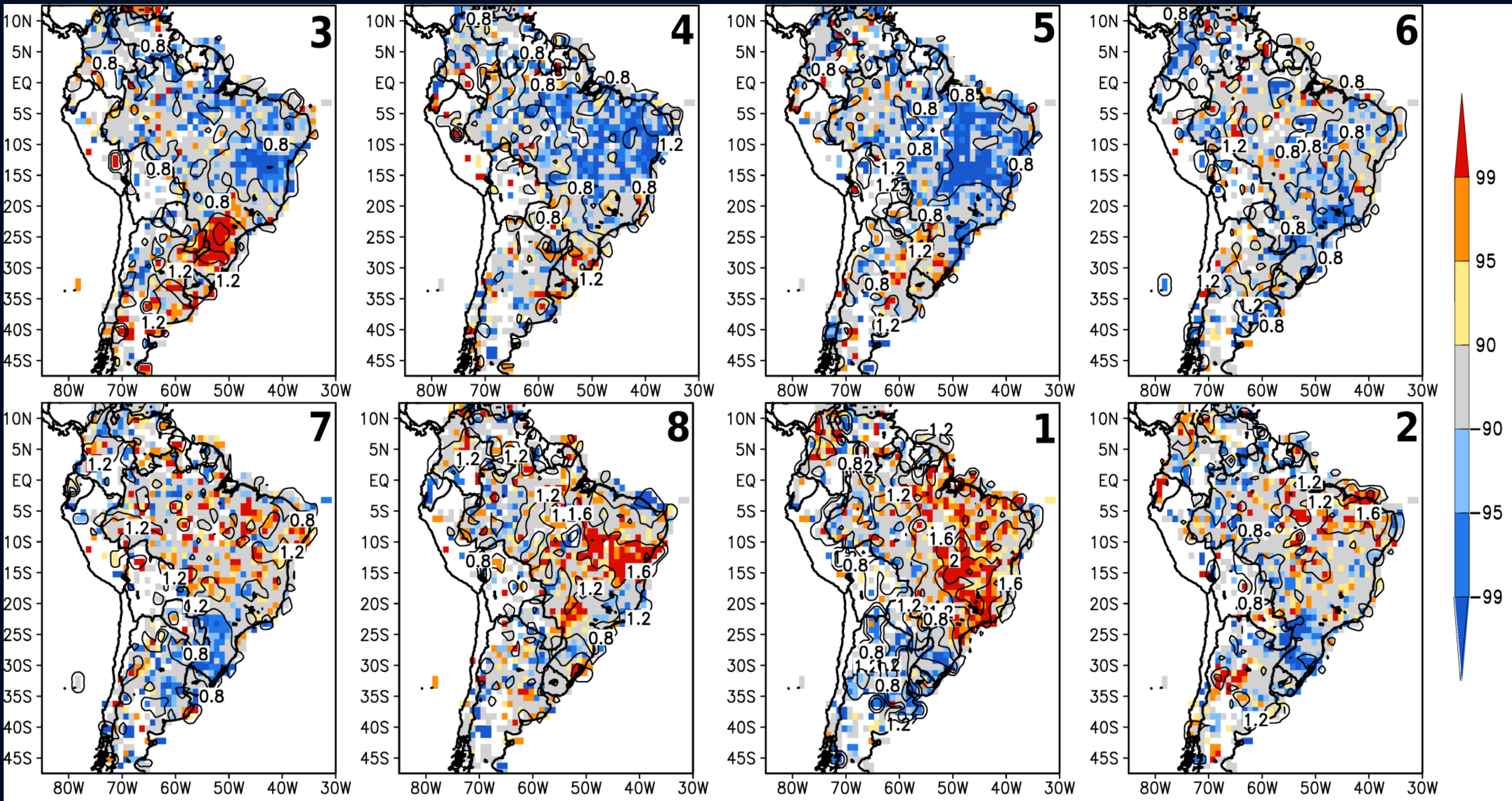
South America summer MJO-related daily precipitation anomalies



In central-east South America there is up to 4 mm more daily precipitation on average during phase 1 of MJO.

Courtesy: Alice Grimm (2016)

South America summer MJO-related anomalies in frequency of extreme events



In central-east South America there are twice more extreme rainfall events in MJO phase 1. In southeast South America, they increase by a factor 1.6 in phase 3.

Mid-latitude interactions as another driver on subseasonal time scales

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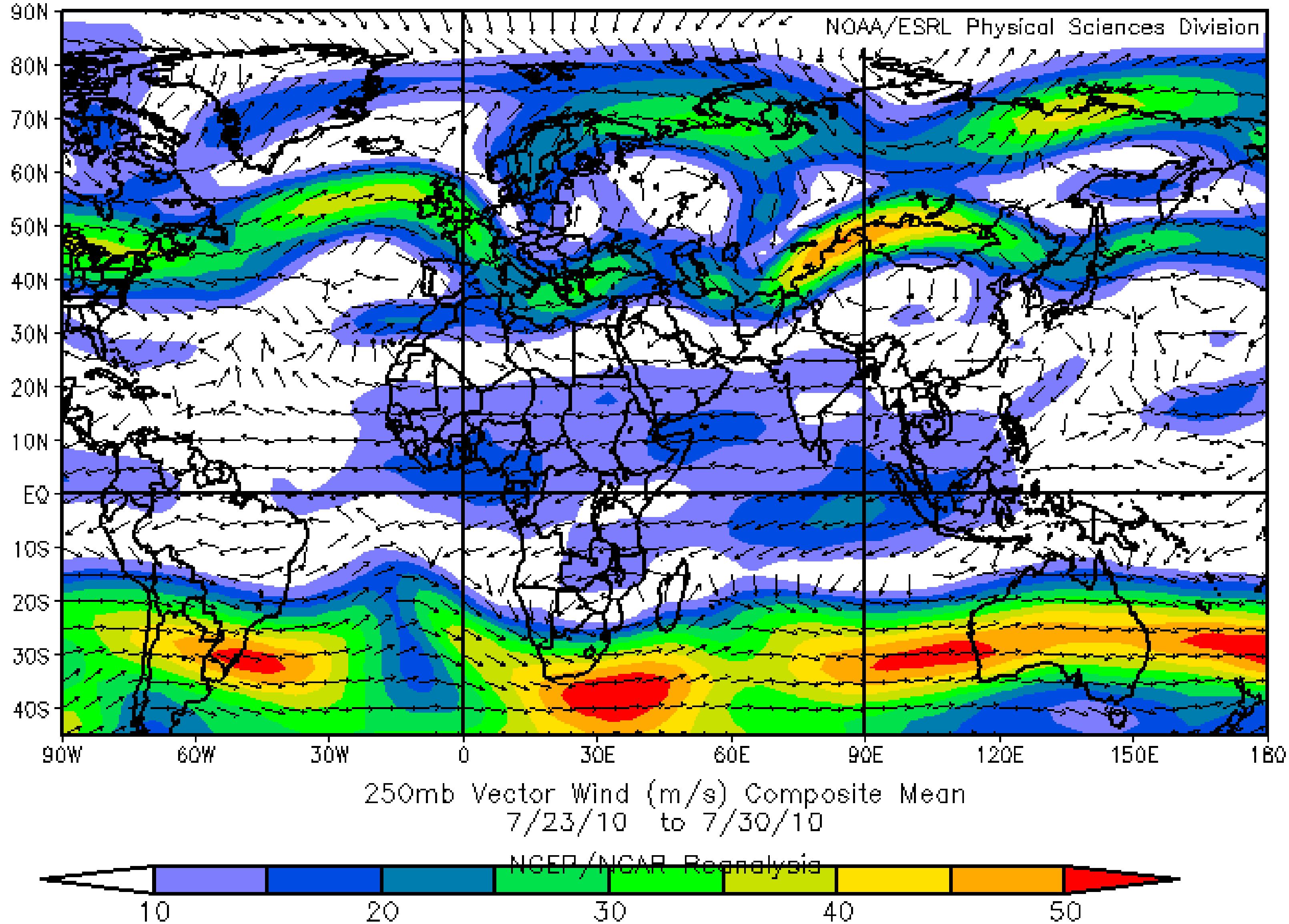
Case of the Pakistan floods, July/August 2010



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Large biases that develop rapidly

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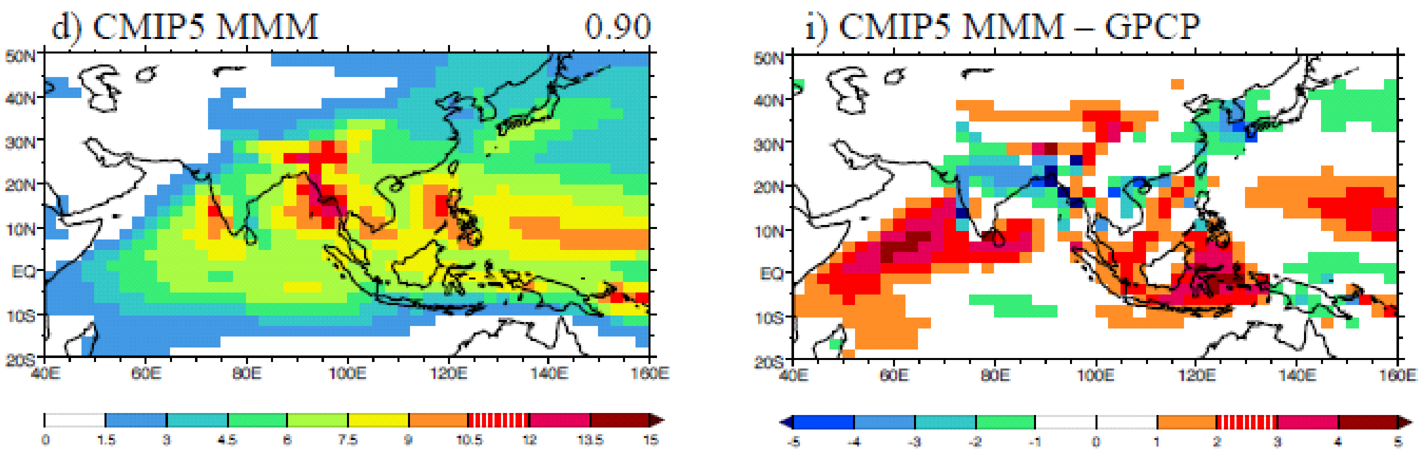
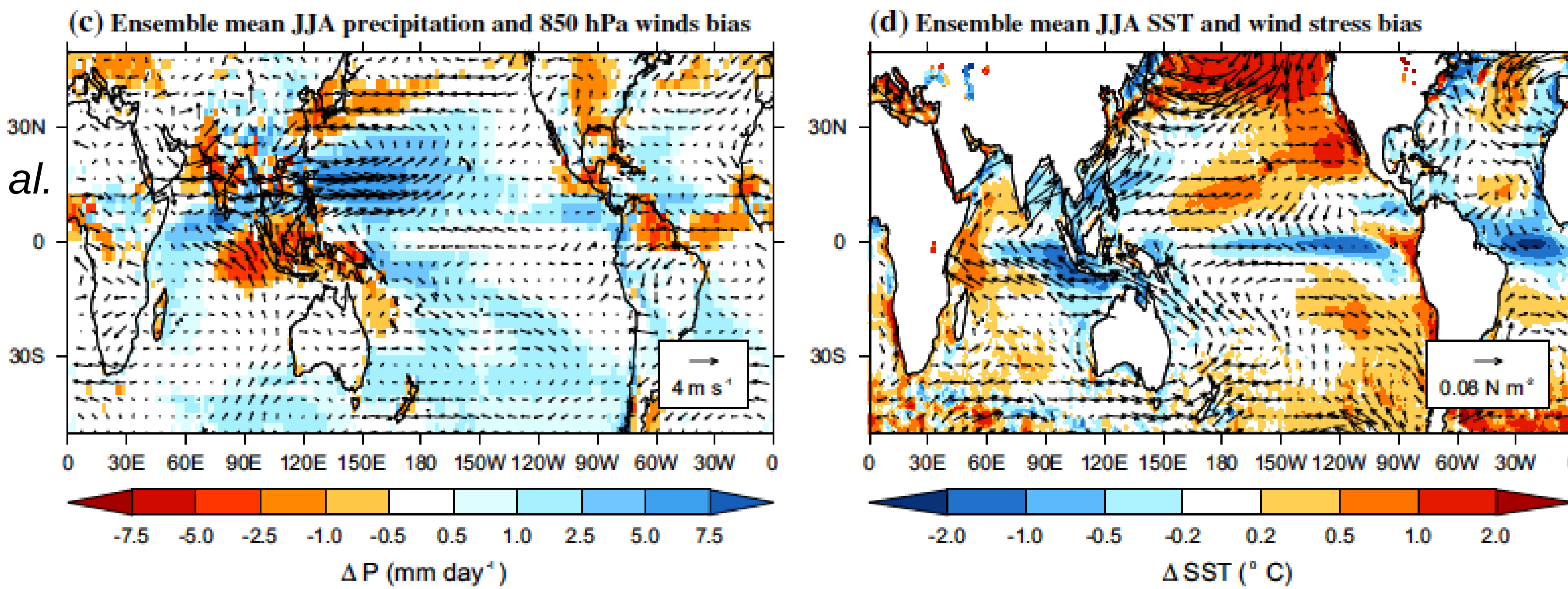


See Sperber *et al.* (2013) *Climate Dynamics*

Johnson *et al.* (2016) *Climate Dynamics*



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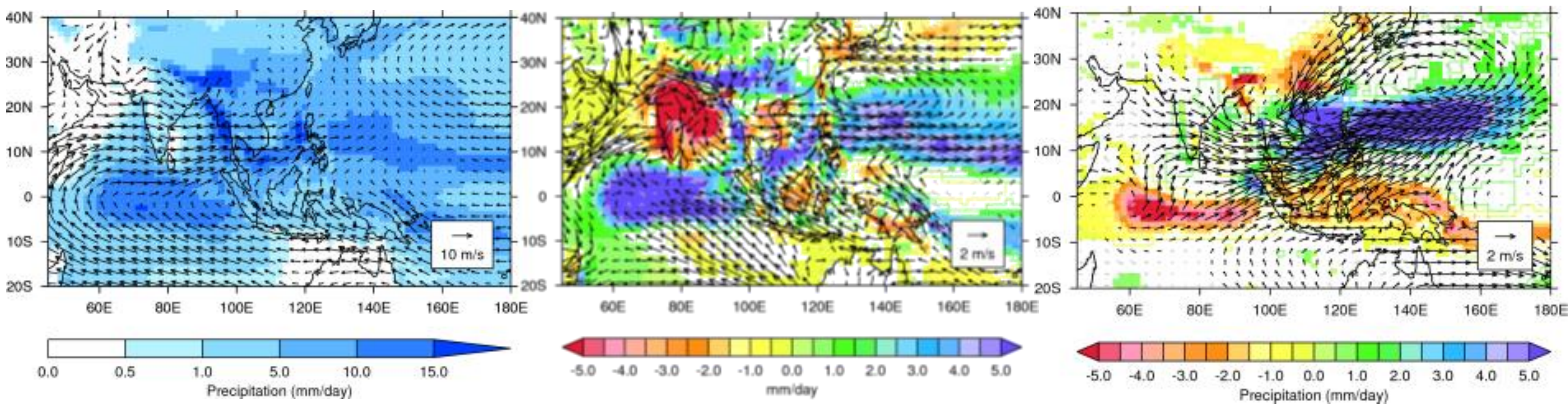
Large uncertainty in parametrizing tropical convection

UM JJAS precipitation and 850 hPa circulation	Bias: GPCP and ERA Interim	Mid-level and Deep Entrainment increased by a factor of 1.5



- Increasing the convective entrainment rate tends to improve ISV (e.g. Klingaman *et al*.; Hirons *et al*., 2012; Del Genio *et al*., 2012)

- Increasing convective entrainment globally decreases several biases while increasing others (Kim *et al.* 2011): WEIO versus India versus WNP/Maritime Continent

Bush et al. (2014, *QJRMS*)

The S2S database as a resource

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S2S Database - Models and Specs

	Time range	Resolution	Ens. Size	Frequency	Re-forecasts	Rfc length	Rfc frequency	Rfc size	Volume per cycle	Volume of reforecast per update
BoM (ammc)	d 0-60	T47L17	33	2/week	fix	1981-2010	6/month	33		6 TB
CMA (babj)	d 0-45	T106L40	4	daily	fix	1994-April 2014	daily	4		
EC (cwao)	d 0-35	0.6x0.6 L40	21	weekly	on the fly	past 15y	weekly	4		
ECMWF (ecmf)	d 0-46	T639/319 L62	51	2/week	on the fly	past 20 years	2/week	11		
ISAC-CNR	d 0-32	0.75x0.56 L54	40	weekly	fix	1981-2010	6/month	1		
HMCR	d 0-63	1.1x1.4 L28	20	weekly	fix	1981-2010	weekly	10		
JMA (rjtd)	d 0-34	T159L60	50	2/week	fix	1979-2010	3/month	5	3.8 Gb	900 Gb
KMA (rksl)	d 0-60	N216L85	4	daily	on the fly	1996-2009	4/month	3		
Meteo-France (lfpw)	d 0-60	T255L91	51	monthly	fix	1993-2014	monthly	15		6.75 Go/start date
NCEP (kwbc)	d 0-44	T126L64	16	daily	fix	1999-2010	day	4		
UKMO (egrr)	d 0-60	N216L85	4	daily	on the fly	1996-2009	4/month	3		

Slide courtesy Paul Dirmeyer GMU/COLA

S2S Database

- Now 10 models out of 11 in some form - content varies greatly though
- Web page to generate near-real-time S2S forecast plots (maps and indices): http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/
  - 6 S2S models available on the plot page (BoM, CMA, NCEP, UKMO, ECMWF, JMA) every Thursday starting from 7 January 2016.

Slide courtesy Paul Dirmeyer GMU/COLA

Example S2S maps available

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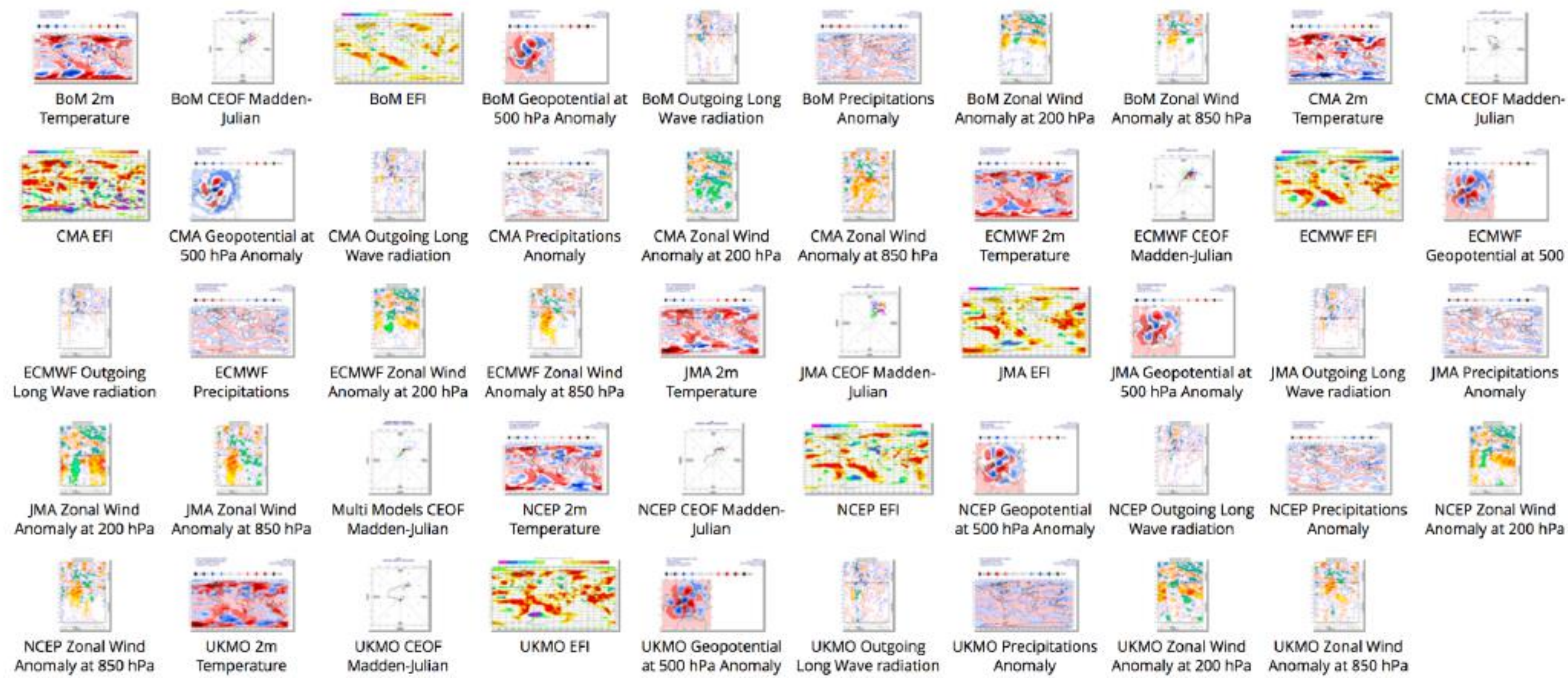
Sub-seasonal to seasonal forecast

Please visit the S2S Product page in ECMWF at http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/

49 matching items

No filters currently applied



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Summary

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- Potential for prediction on a number of different time and space scales for the monsoon
- Some evidence of skill at these different scales
- Numerous challenges
  - Convective parametrization
  - Coupled model drift from initialization, introducing coupled biases
  - Detailed analysis needed for process understanding
  - Detailed observations needed to challenge the representation of these processes in models (chiefly for ISV time scales)

End of part II

Thank you!

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