Indian Summer Monsoon – An Overview: Structure, Variability, and Predictability

ICTP – TTA, July 31, 2017

Jagadish Shukla

University Professor
Department of Atmospheric, Oceanic, and Earth Sciences (AOES)
Center for Ocean-Land-Atmosphere Studies (COLA)
George Mason University (GMU)

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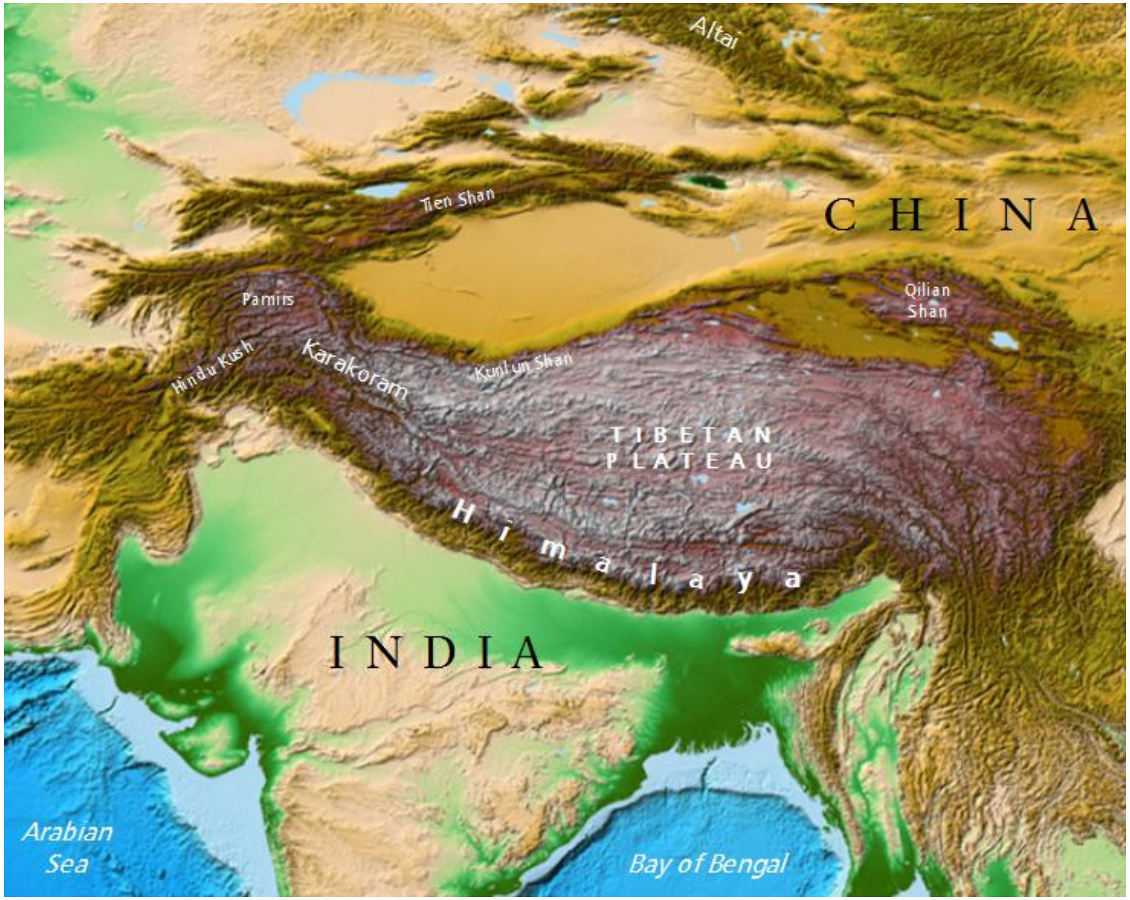
Himalayas

- **(Blanford, Founding Head, IMD- 1875);** **High Himalayan snow cover and deficient Indian summer monsoon**
- **Major drought/famine: 1877, 1899**
- **Walker (Director General, IMD, 1904 -1924)** **Discovered Southern Oscillation**



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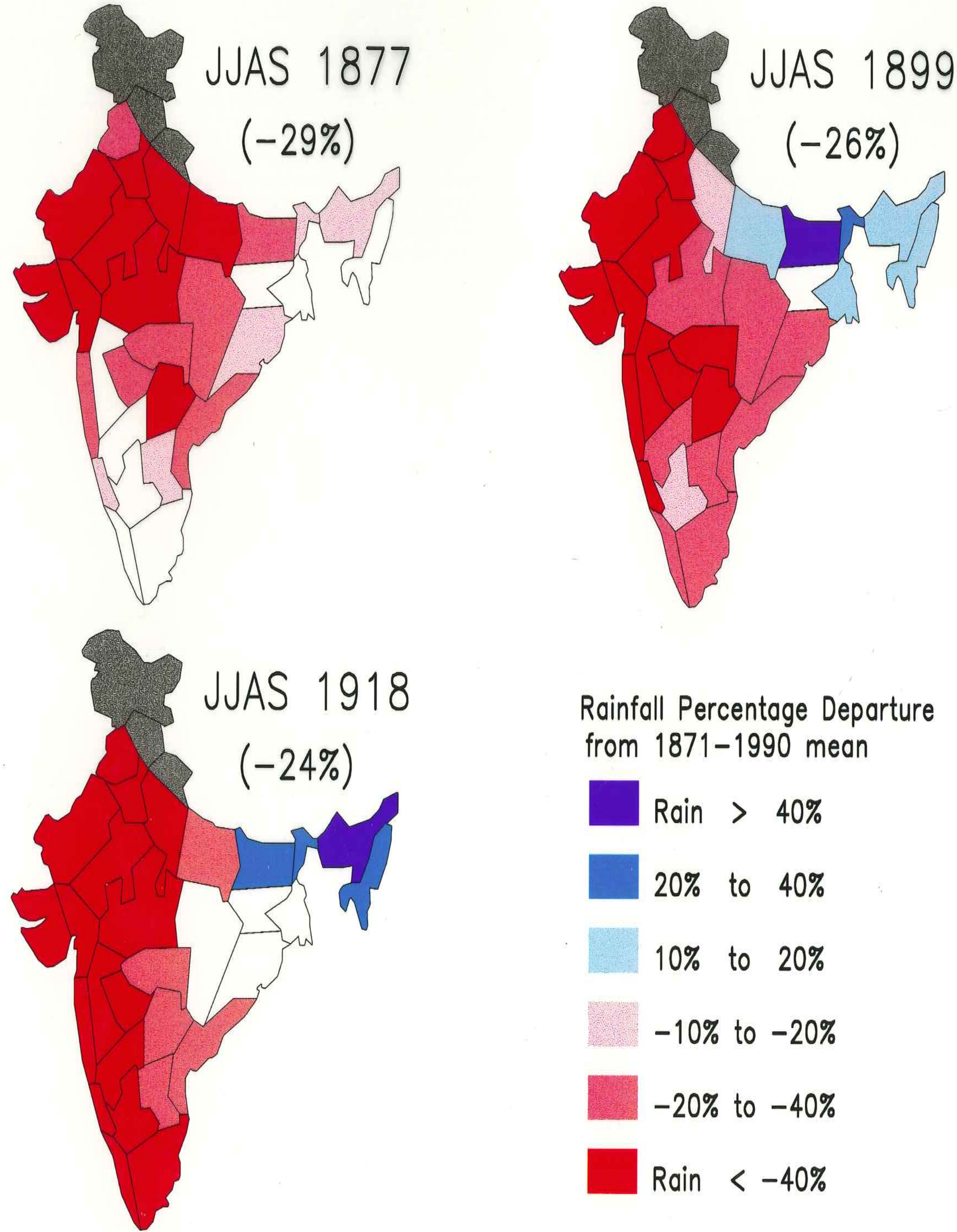
Major Droughts over India

1877, 1899, 1918



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Great Famine of 1876-78 (India)

All India Monsoon Rainfall:	-29%
Drought Area:	670,000 km^2
Estimated Deaths (Wikipedia):	5.5 – 8.2 million
Governance:	British Rule

(Lord Lytton exported food from India to England)

About 13 million people died in China

Late Victorian Holocausts (2001) by Mike Davis
El Nino Famines and the Making of the Third World

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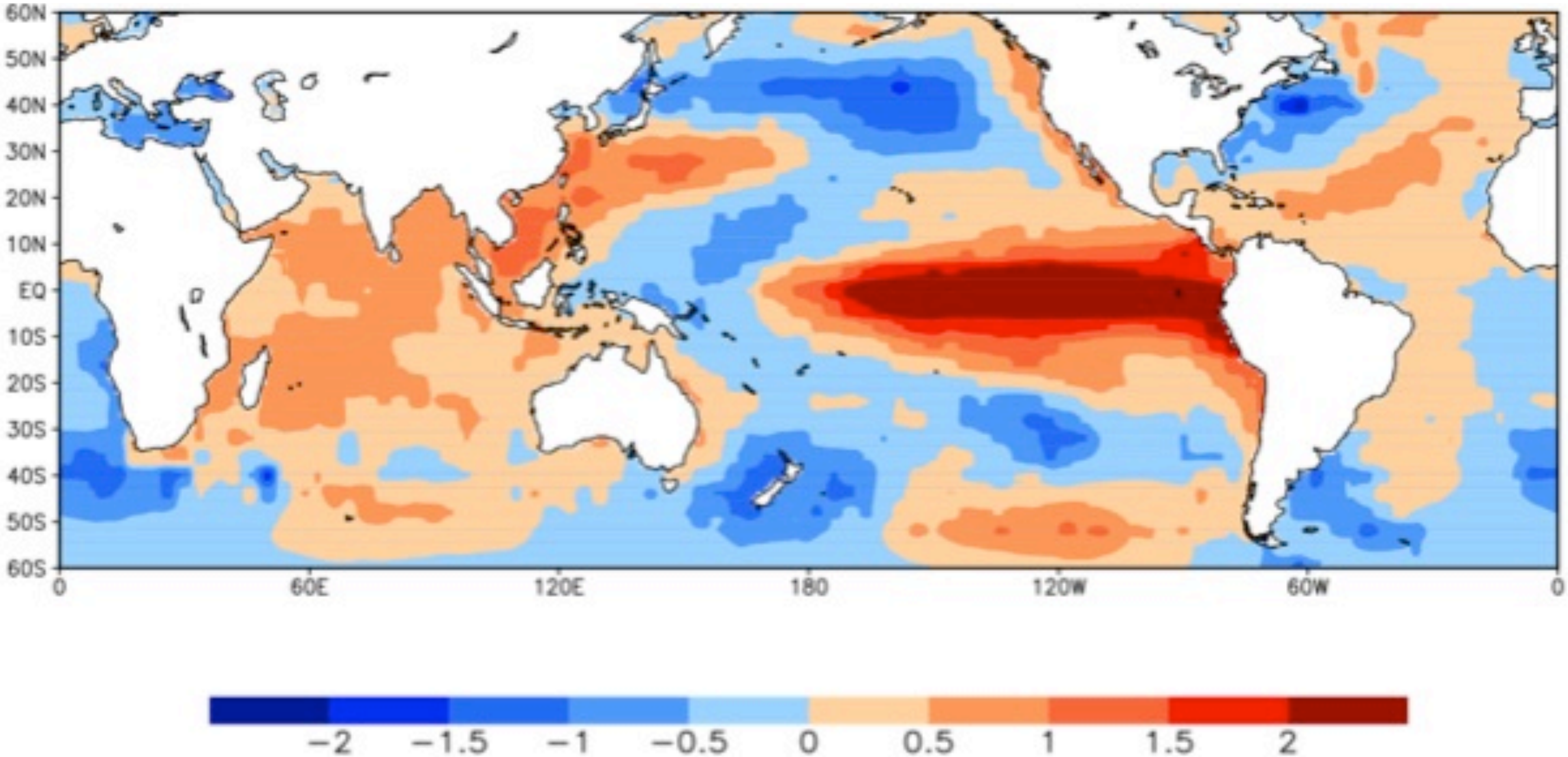
SST Anomaly (°C) for DJF 1877



Courtesy of Lakshmi Krishnamurti

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Outline

1. Structure & Variability of Monsoon
2. Predictability of Monsoon
3. The Tale of Two Monsoons: 1972 & 1997
4. Seasonal Prediction: *Challenges in Bridging the Gap Between Potential Predictability and Skill of Predictions*
5. Prospects for the Future

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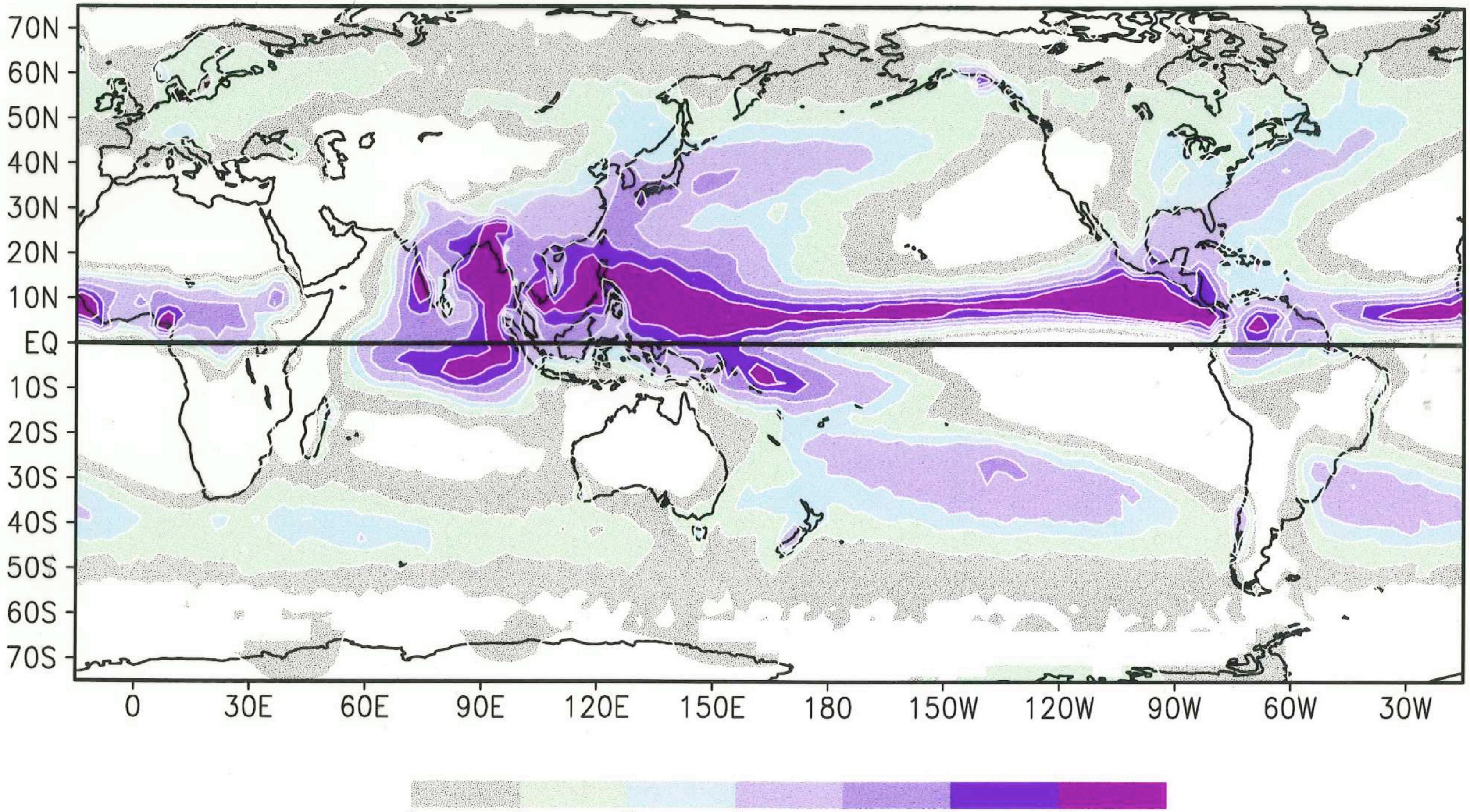
Xie/Arkin JJAS 79–97 Precip Climo (mm/day)



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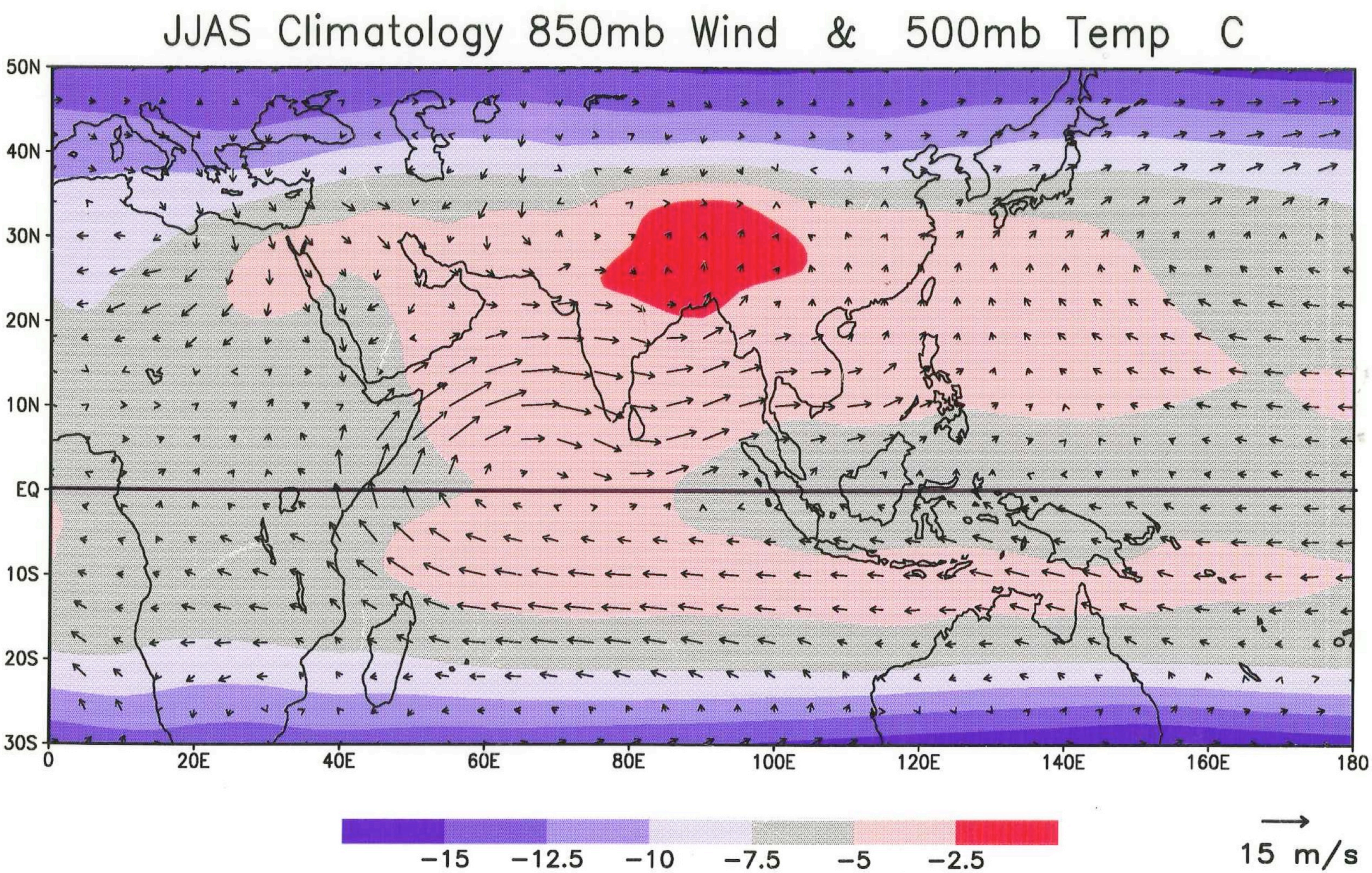

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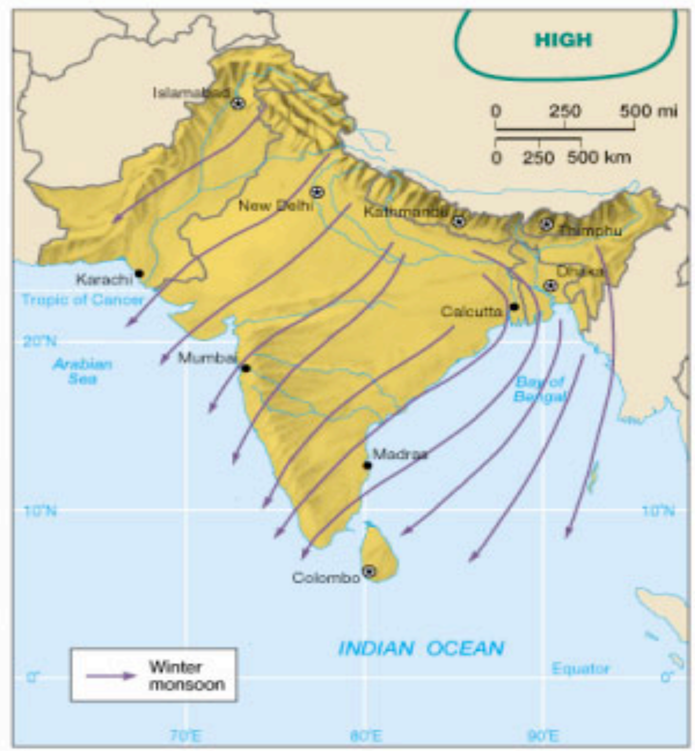
Monsoon

- Monsoon is derived from the Arabic word "Mausim" meaning "season", although generally defined as a system of winds characterized by a seasonal reversal of its direction.

Summer

Winter



Theoretical Explanation of Monsoon

Extension of Axisymmetric Theory of Hadley Circulation to Include Local (land) Forcing

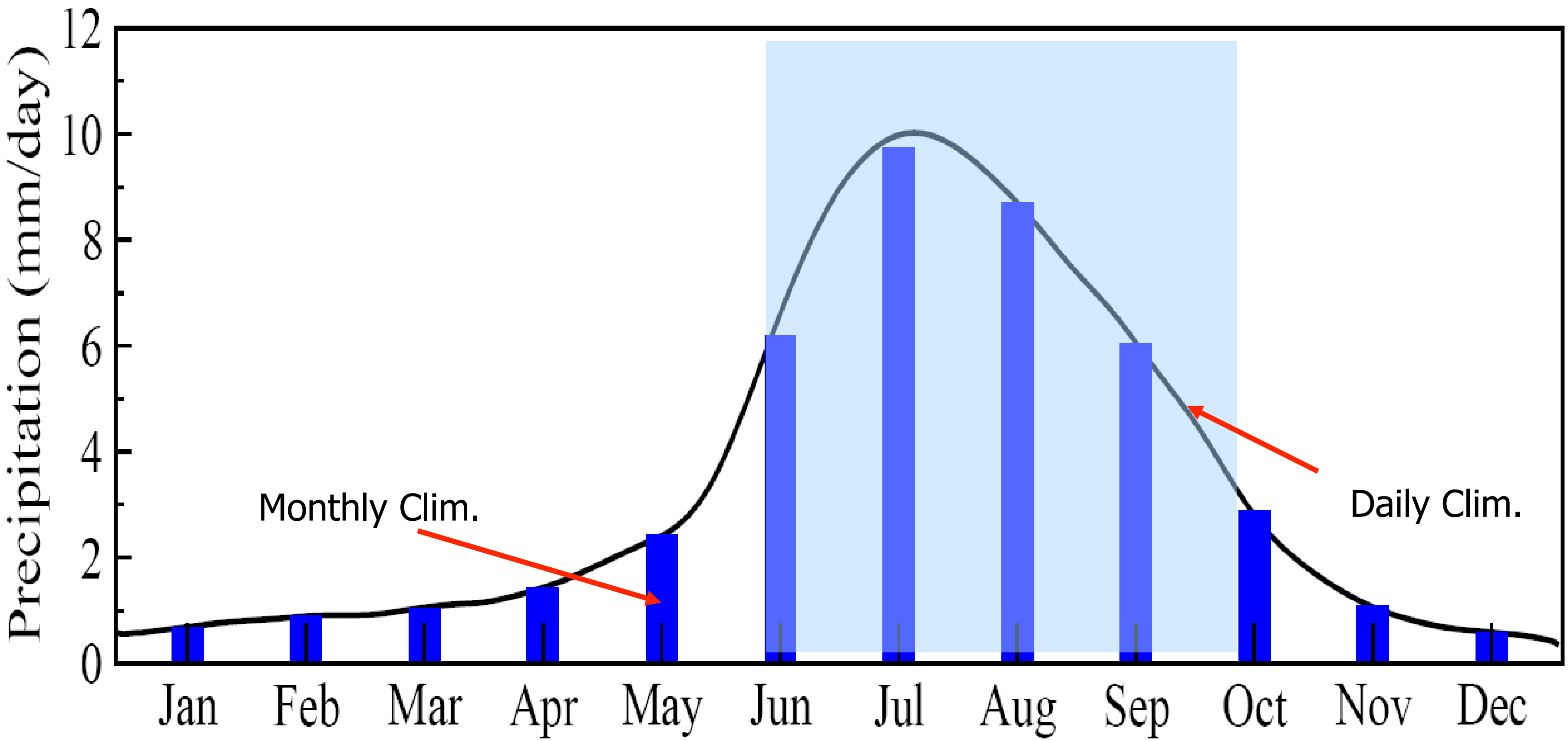
The critical condition for the development of an angular momentum conserving meridional circulation (viz monsoon) is the existence of an extremum of angular momentum in the thermal equilibrium state (**Plumb and Hou, 1992**). **Emanuel (1995)** showed that assuming a moist adiabatic lapse rate, the threshold may be written as:

$$\frac{\partial}{\partial \phi}\left[\frac{\cos^3\phi}{\sin\phi}(T_s - T_t)\frac{\partial s_b}{\partial \phi}\right] = -4\Omega^2 a^2 \cos^3\phi \sin\phi,$$

where ϕ is the latitude, a is the radius of the earth, Ω is the angular velocity of the earth, s_b is the subcloud moist entropy, T_s is the surface temperature, and T_t is the temperature at the tropopause. Zheng (1998) veri-

(Privé and Plumb, 2006 JAS)

Annual cycle of Rainfall over India



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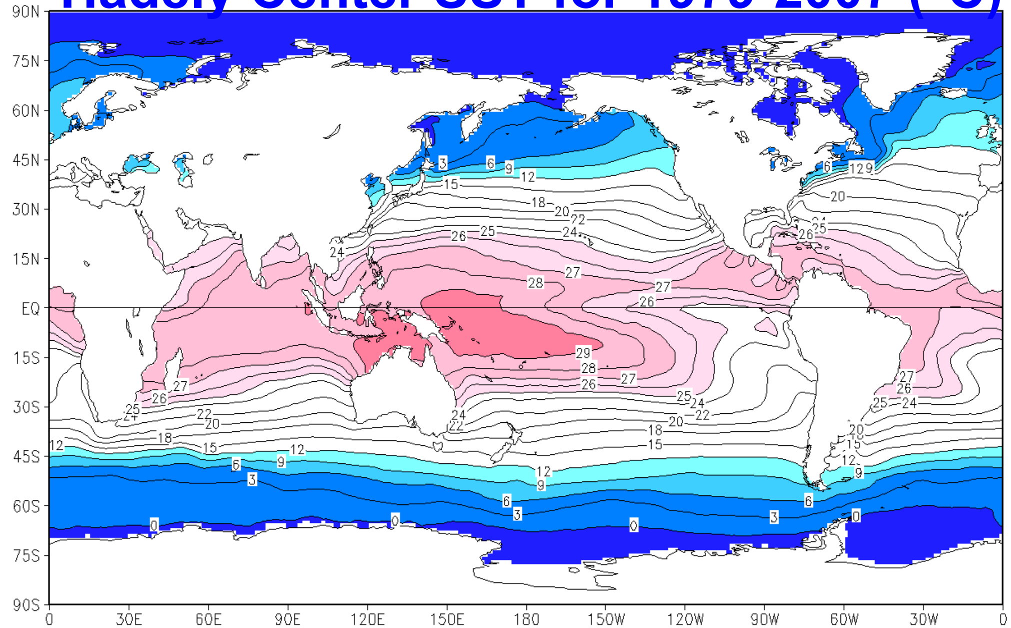
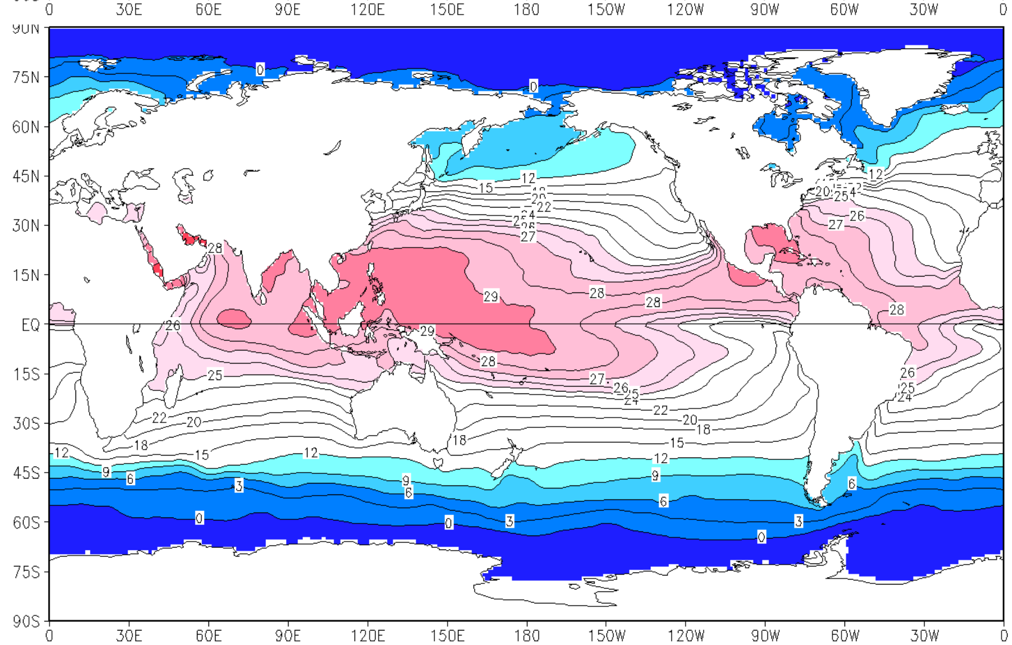
Climatology of Sea Surface Temperature

Hadely Center SST for 1979-2007 (°C)

DJF



JJA



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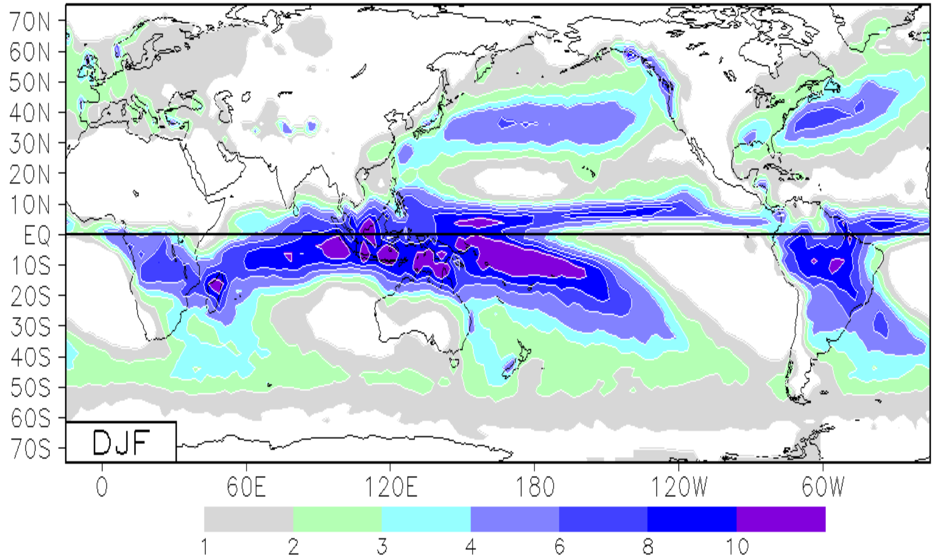
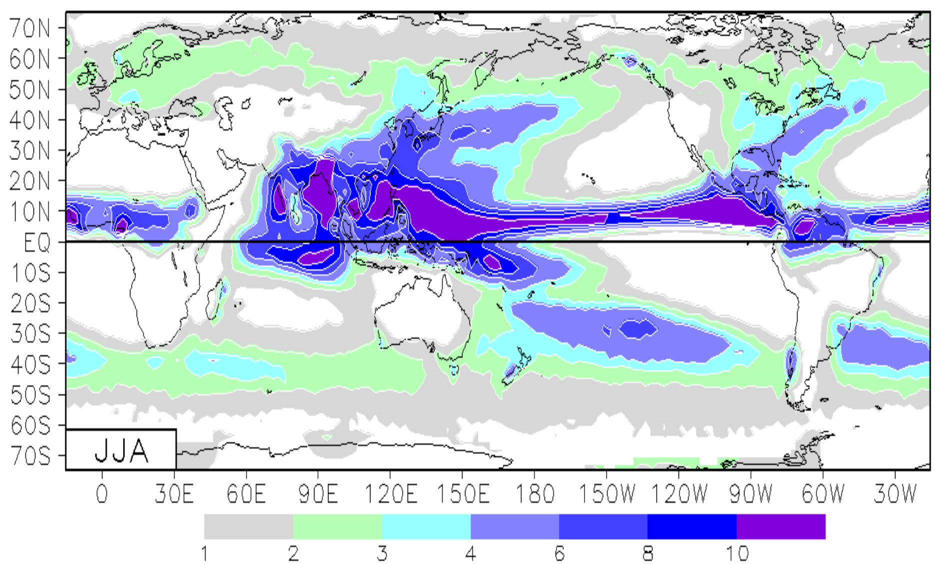
Climatological Precipitation

CMAP Precipitation for 1979-2007 (mm/day)

DJF



JJA



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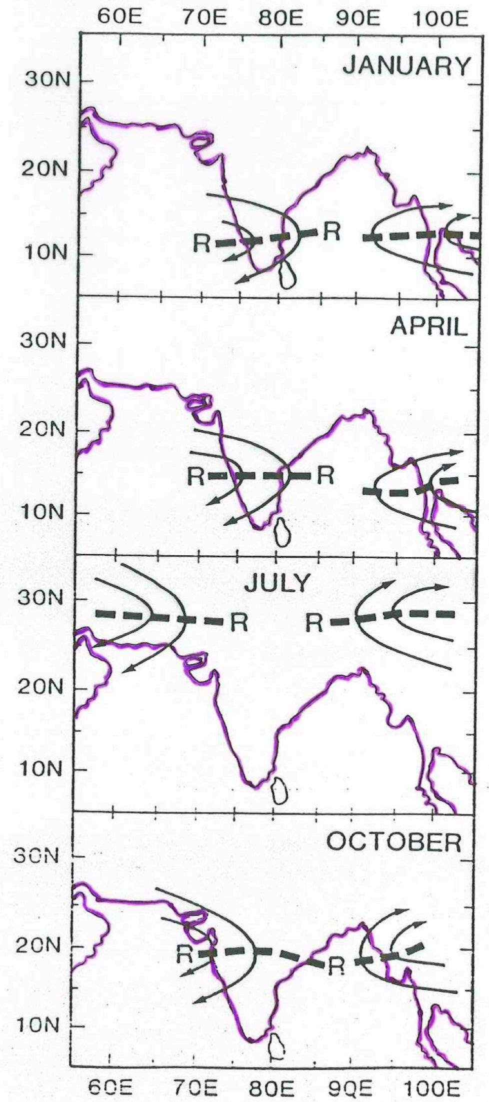
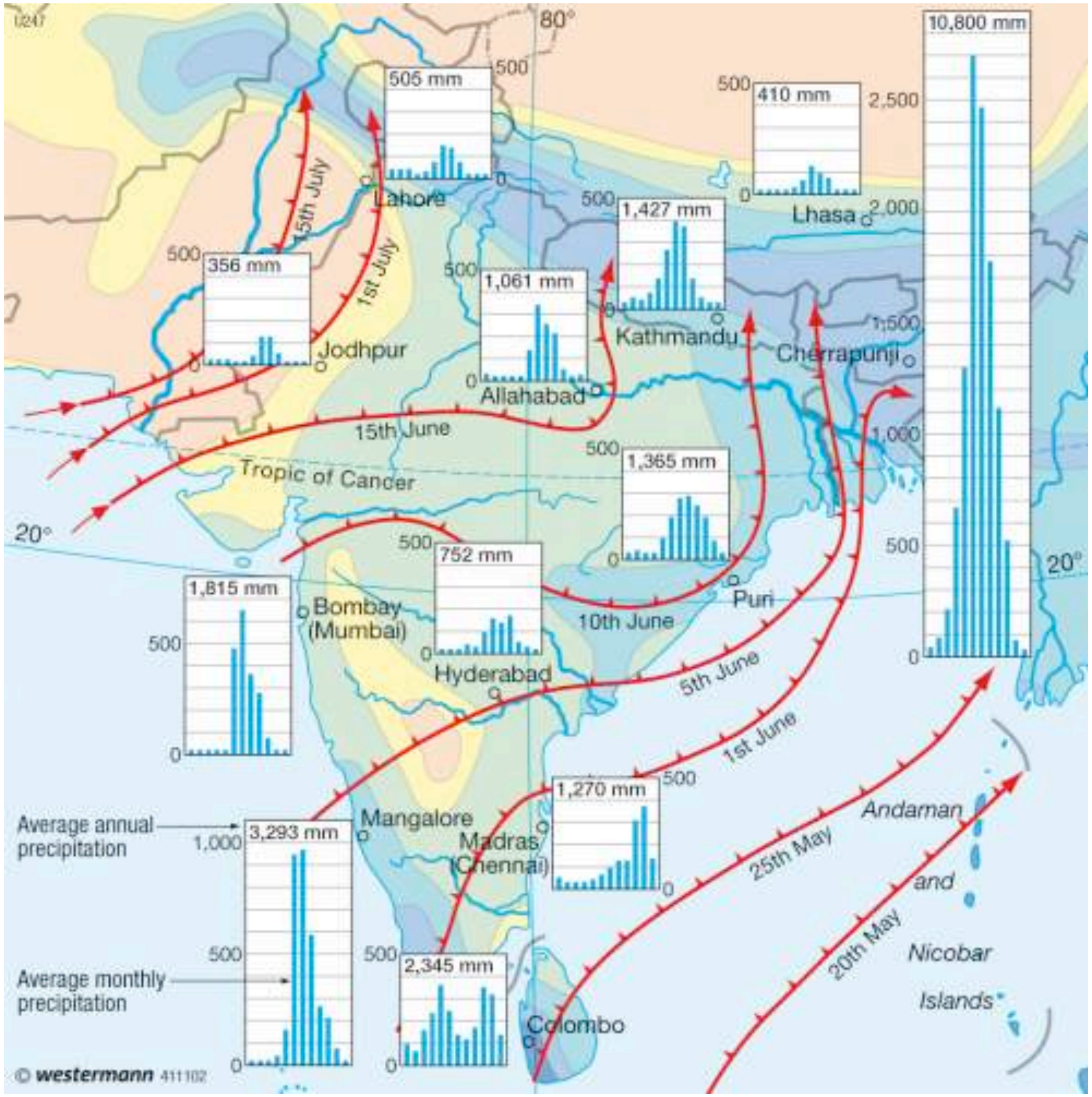


Figure 2. Schematic representation of the climatological monthly mean circulation and location of the ridge (R) at 500 mb during January, April, July and October. Based on actual streamline maps published by the India Meteorological Department (1972).

Onset Dates for Summer Monsoon



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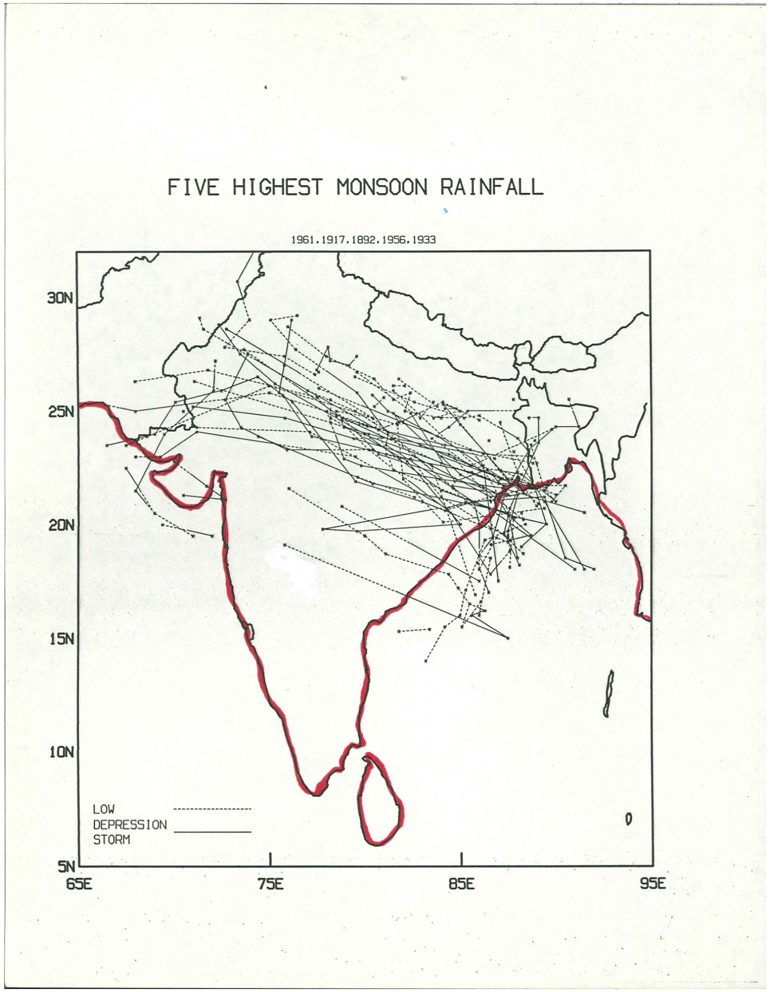
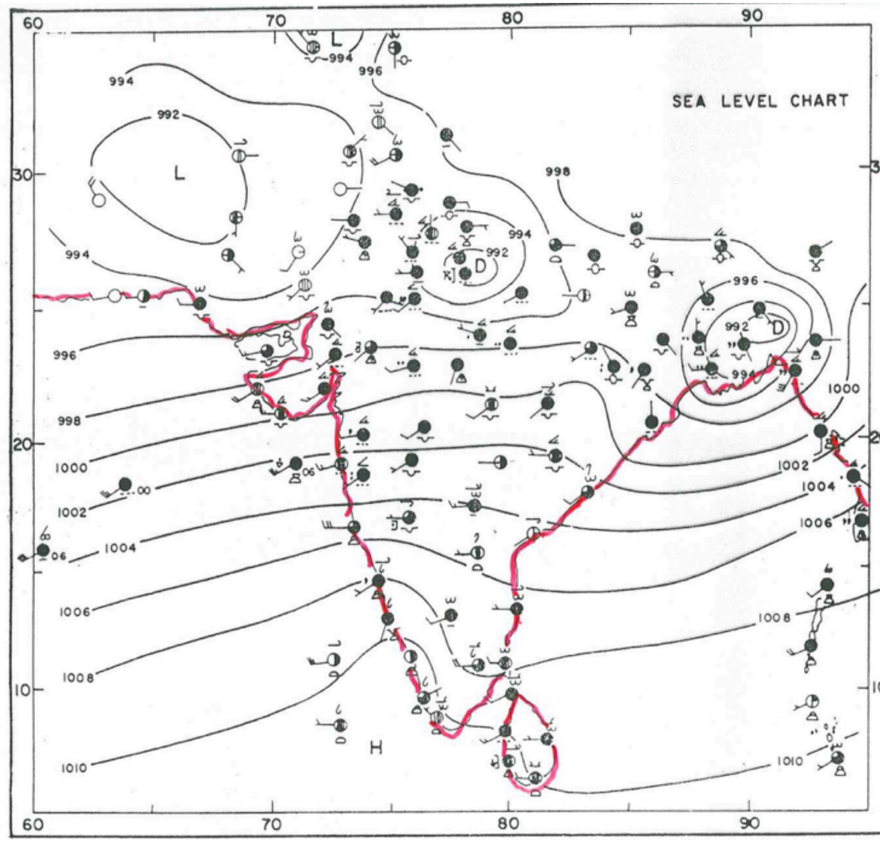
Monsoon Depressions





- Mechanisms of formation, growth, and propagation of depressions
- Contributions to seasonal monsoon rainfall
- Are monsoon depressions changing due to global warming?
- Can climate models simulate depression statistics?

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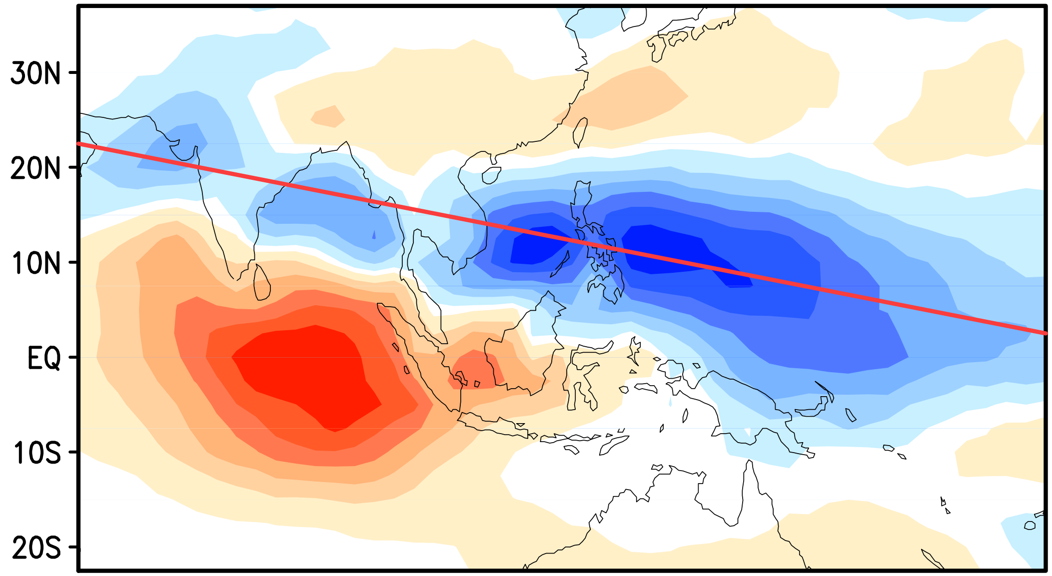
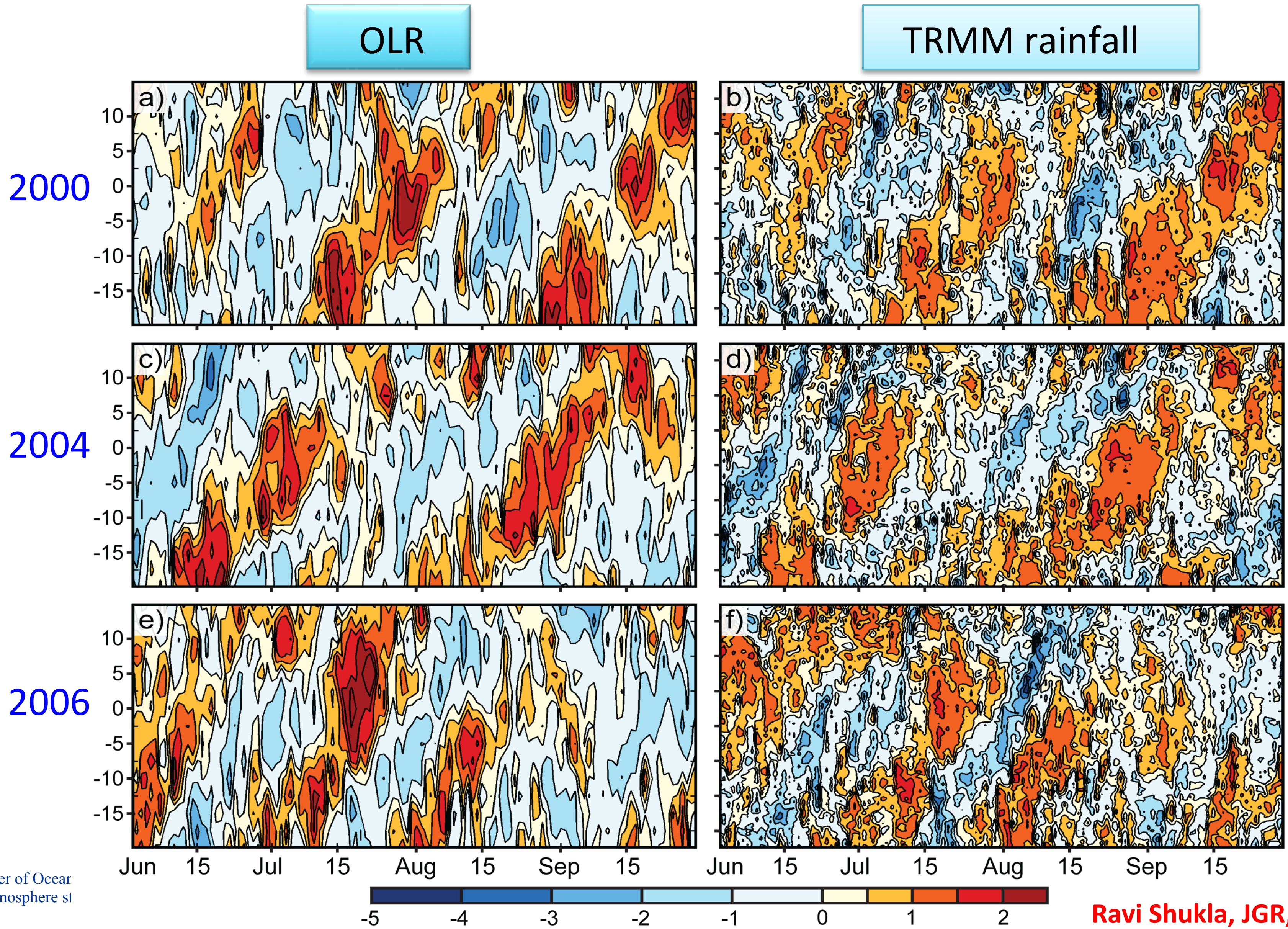
For evidence of the northward propagation: (Time-latitude plots of zonally averaged OLR and TRMM rainfall: based on daily data)

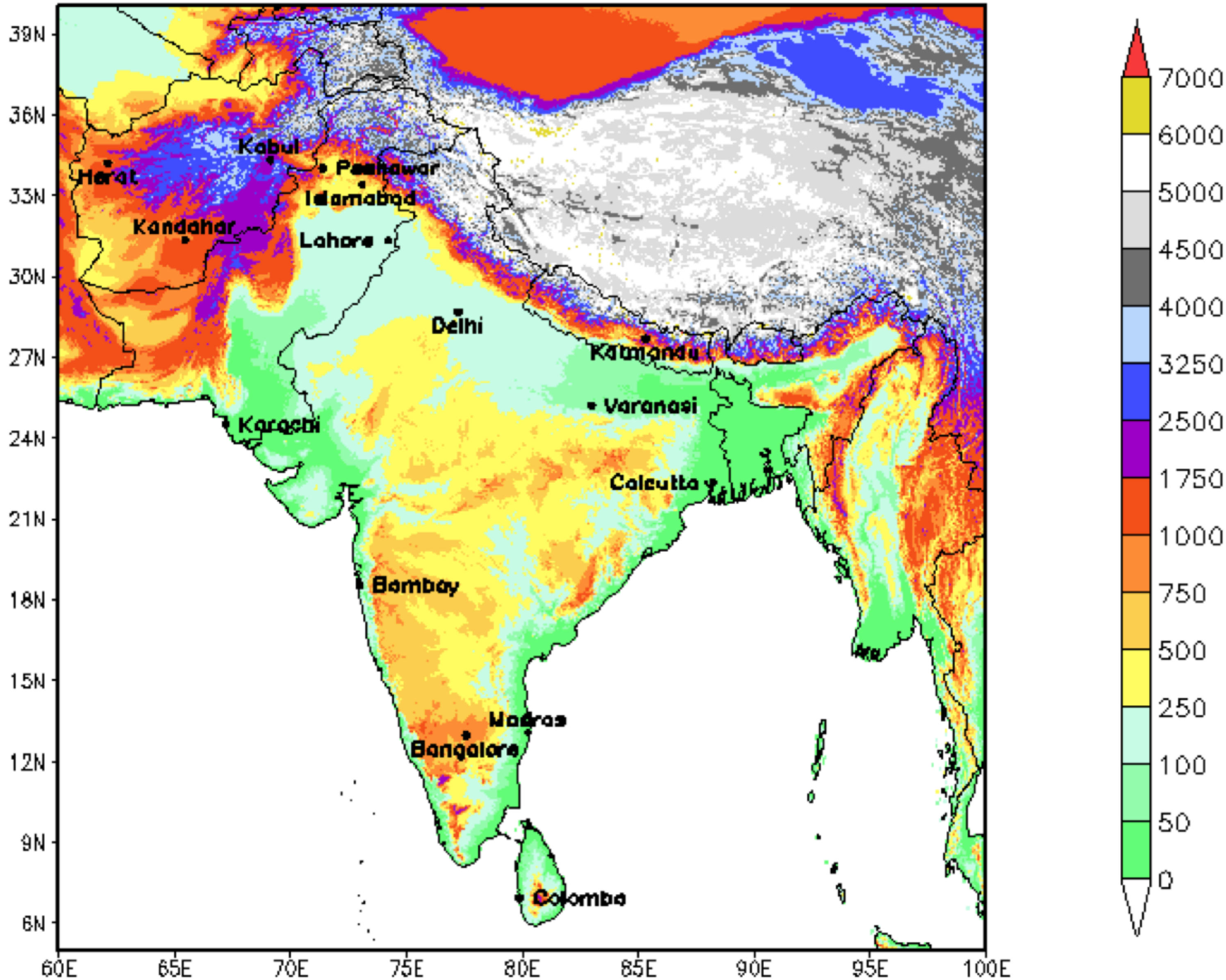


Time-Latitude section of daily JJAS OLR and TRMM Rainfall



Ravi Shukla, JGR, 2014

4 km Topography (m)



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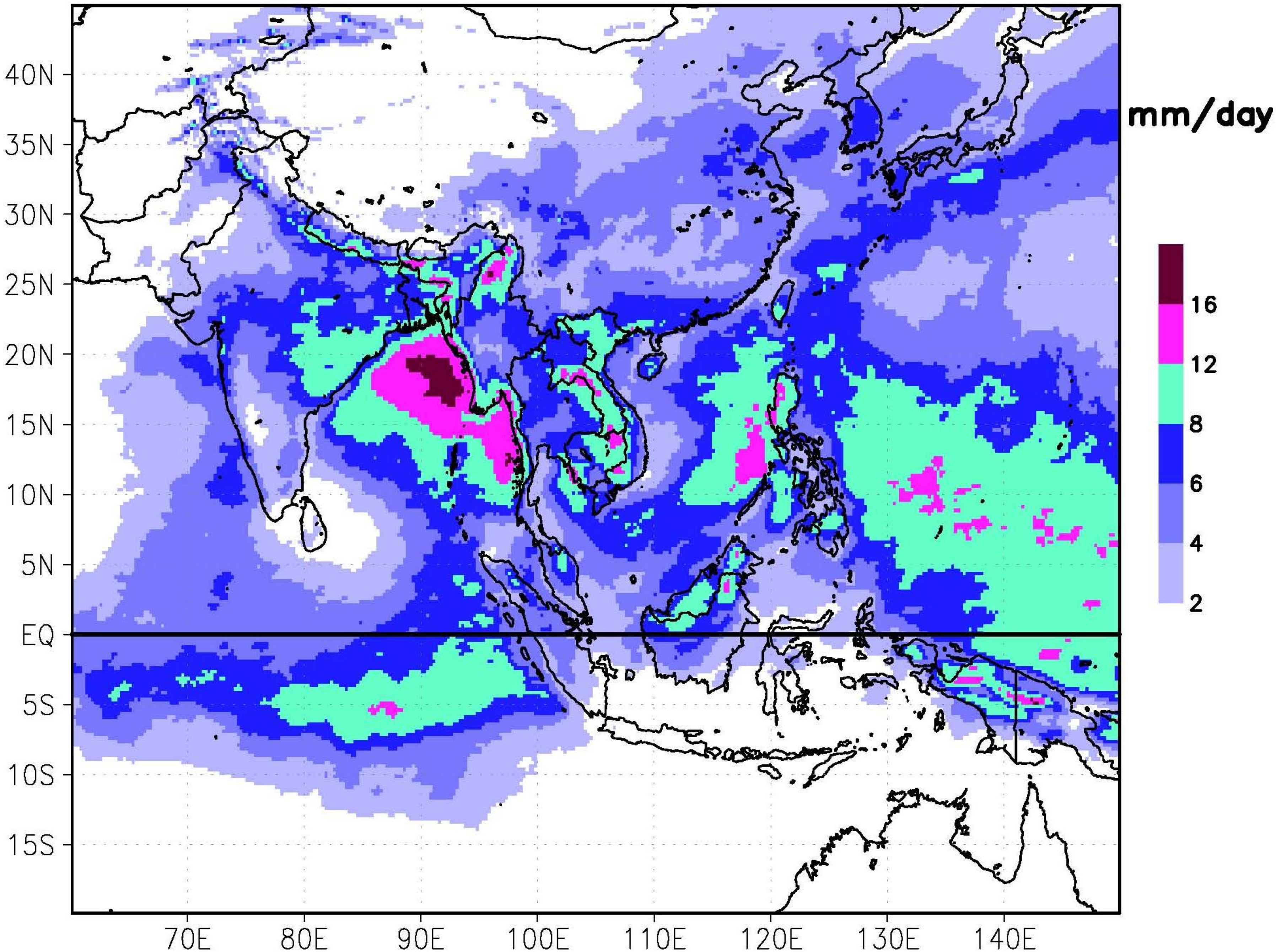
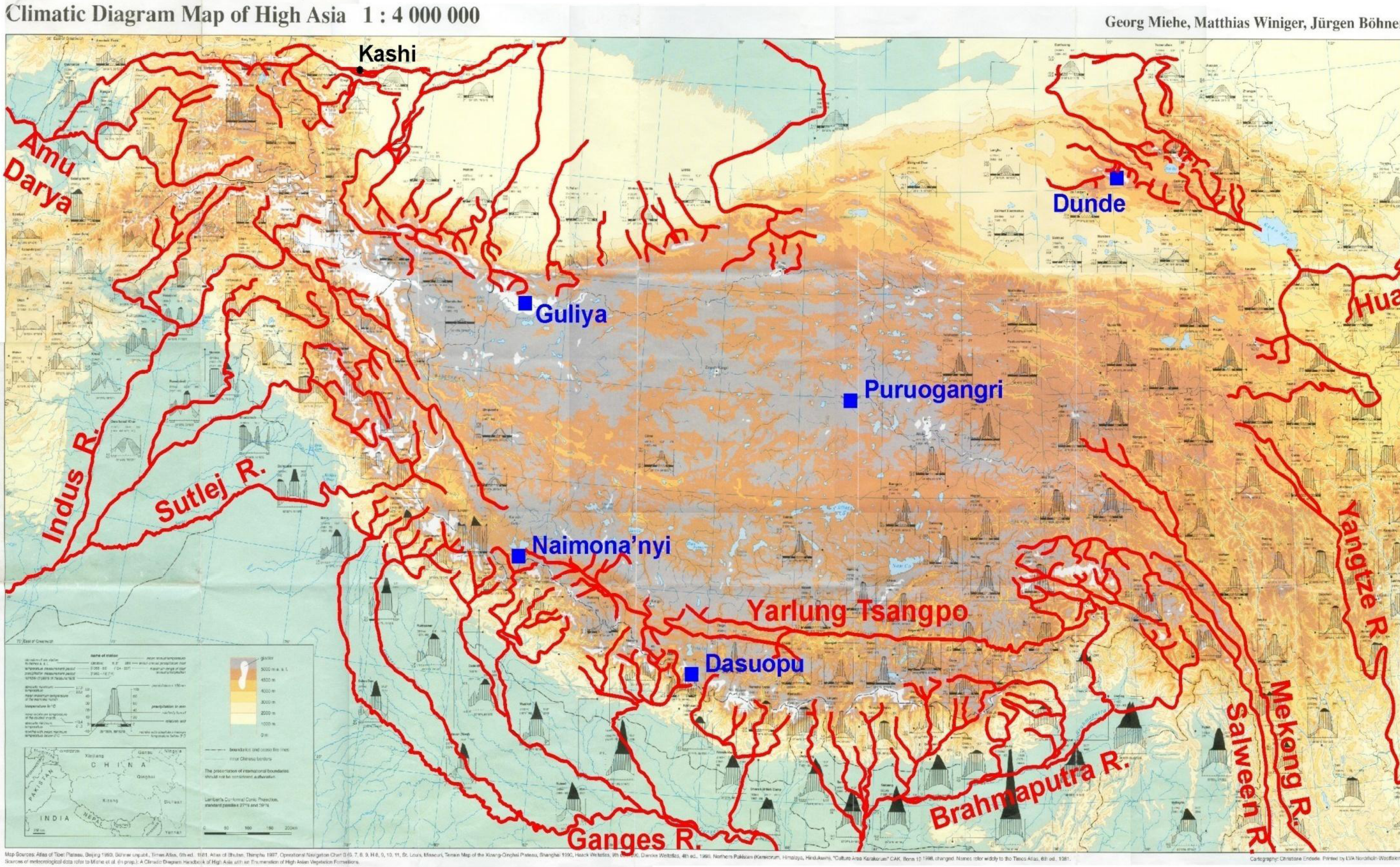
CMORPH OBS Precip Climo JJAS (2003–2006)





Himalayan glaciers store about 12,000 cubic kilometers of freshwater in ~15,000 glaciers and are the lifeline for millions of people (IPCC, 2007)

Predictability and Prediction of Monsoon

Predictability in the Midst of Chaos:

Scientific Basis for Dynamical Seasonal Prediction

Empirical Prediction: *Regression Methods*

Dynamical Seasonal Prediction:
Source of predictability: Dynamical memory of atmos. IC
+ Boundary forcing (SST, SW, snow, sea ice)

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Sources of Predictability (Signal) and Processes Limiting Predictability (Noise)

	Signal	Noise
Weather: 1-10 Days	Initial conditions (IC) of atmosphere; prescribed boundary conditions at Earth's surface (SST, land (L), soil wetness, sea ice, snow, etc.	Turbulence, instabilities, errors in IC's
Intraseasonal Variations: 10 - 100 Days	IC of atmosphere and upper-ocean and land; convection dynamics interaction; A-O interaction	Weather variations
Seasonal to Interannual Variations: 100 – 100 Days	IC of A, O, L, and A-O-L interactions	Weather and intraseasonal variations
Climate Change	Human effects (Greenhouse Gases, land-use changes)	ENSO, decadal and multidecadal variations, volcanoes

Influence of Boundary Condition
(SST, Soil Wetness, Snow, etc.)

$$\underset{\text{Change in Precipitation}}{\delta P} = \underset{\text{Change in Evaporation}}{\overset{20\text{-}30\%}{\delta E}} - \underset{\text{Change in Moisture Flux Convergence}}{\overset{70\text{-}80\%}{\delta \int \nabla \cdot q\vec{V}}}$$

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Change in SST Produces Changes in Evaporation, Precipitation, and Moisture Flux Convergence

$$\Delta \text{ SST} \rightarrow \Delta E, \Delta \tilde{V}, \Delta P$$

$$\boldsymbol{\delta} P = \boldsymbol{\delta} E - \boldsymbol{\delta}\left(\int \nabla \cdot \tilde{V} q \right)$$

Change in Precipitation	Change in Evaporation	Change in Moisture Flux Convergence
	20-30%	**70-80%**

Mechanisms for Boundary-Forced Seasonal Predictability

Large-scale persistent anomalies in SST, soil wetness, snow, etc. create a deep and persistent heat source anomaly (SST); The heat source anomalies in turn force atmospheric circulation anomalies locally and remotely.

Boundary-forced Atmospheric Circulation Anomalies

$$\delta(BC) \xrightarrow{\text{(5-10 days)}} \delta(Q) \xrightarrow{\text{(10-30 days)}} \delta(\text{Circulation})$$

Change in SST Produces Changes in Evaporation, Precipitation, and Moisture Flux Convergence

$$\Delta\, SST \rightarrow \Delta E,\ \Delta\tilde{V},\ \Delta P$$

$$\delta P = \delta E - \delta\left(\int \nabla \cdot \tilde{V} q \right)$$

Change in Precipitation	Change in Evaporation	Change in Moisture Flux Convergence
	20-30%	**70-80%**

Analysis of Variance: F as a measure of predictability

E is ensemble size (e = 1,2,3 - - - E); Y is total years (y = 1,2,3 - - - Y); P is the predicted variable

Measure of predictability is

$$F = E\frac{\hat{\sigma}_S^2}{\hat{\sigma}_N^2}$$

Ratio of Signal and Noise Variance

where

$$\hat{\sigma}_S^2 = \frac{1}{Y-1}\sum_{y=1}^{Y}\left(\overline{P}_y - \overline{\overline{P}}\right)^2$$

Signal Variance

$$\hat{\sigma}_N^2 = \frac{1}{Y(E-1)}\sum_{y=1}^{Y}\sum_{e=1}^{E}\left(P_{y,e} - \overline{P}_y\right)^2$$

Noise Variance

$$\overline{P}_y = \frac{1}{E}\sum_{e=1}^{E} P_{y,e}$$

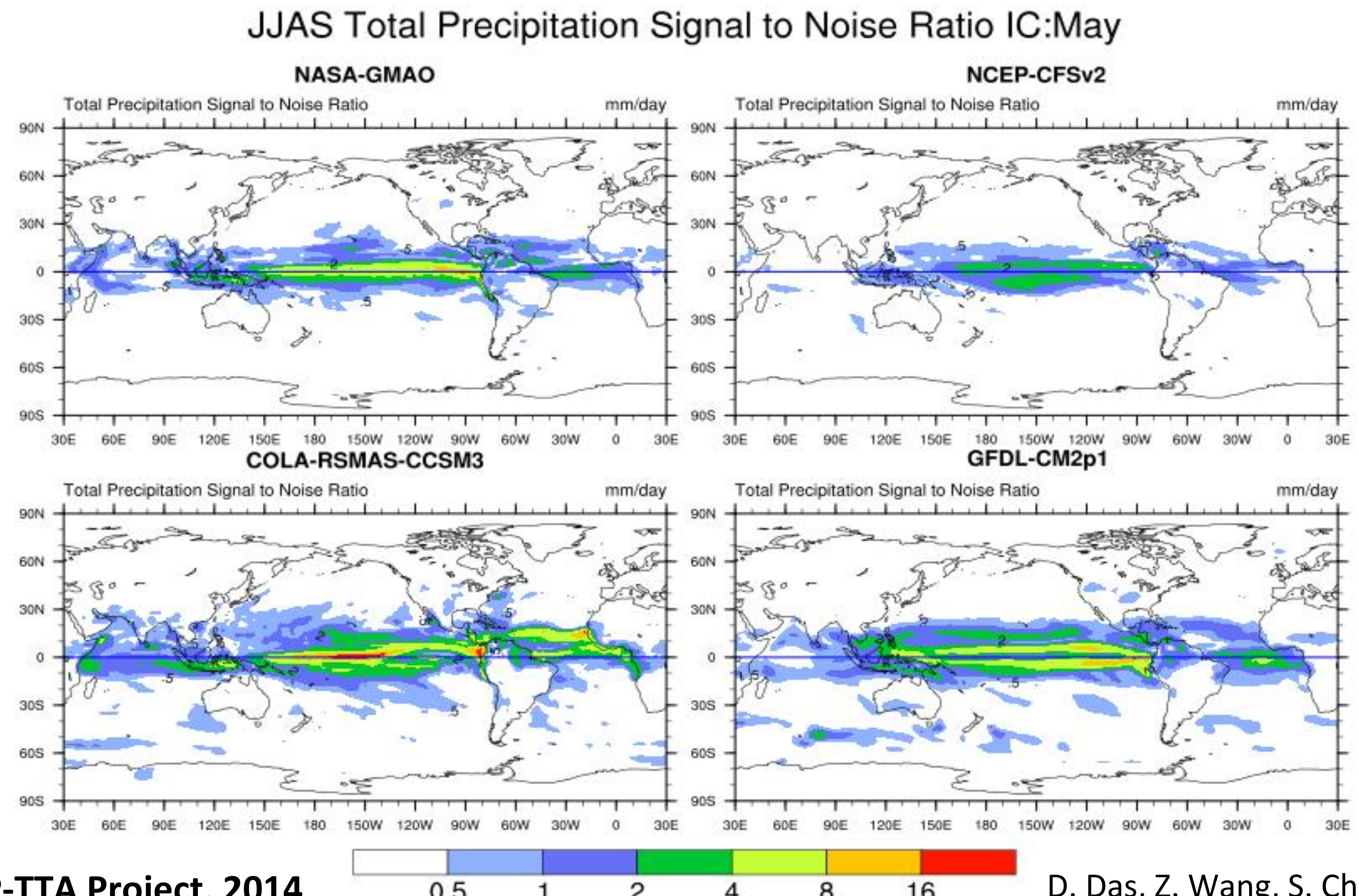
$$\overline{\overline{P}} = \frac{1}{Y}\sum_{y=1}^{Y}\overline{P}_y$$

For samples drawn independently from the same normal distribution, and for $Y = 46$ and $E = 9$, the 5% significance threshold of F is 1.40

Please find the value of F from the F distribution table for a given value of **Y** and **E** for x% significance threshold.

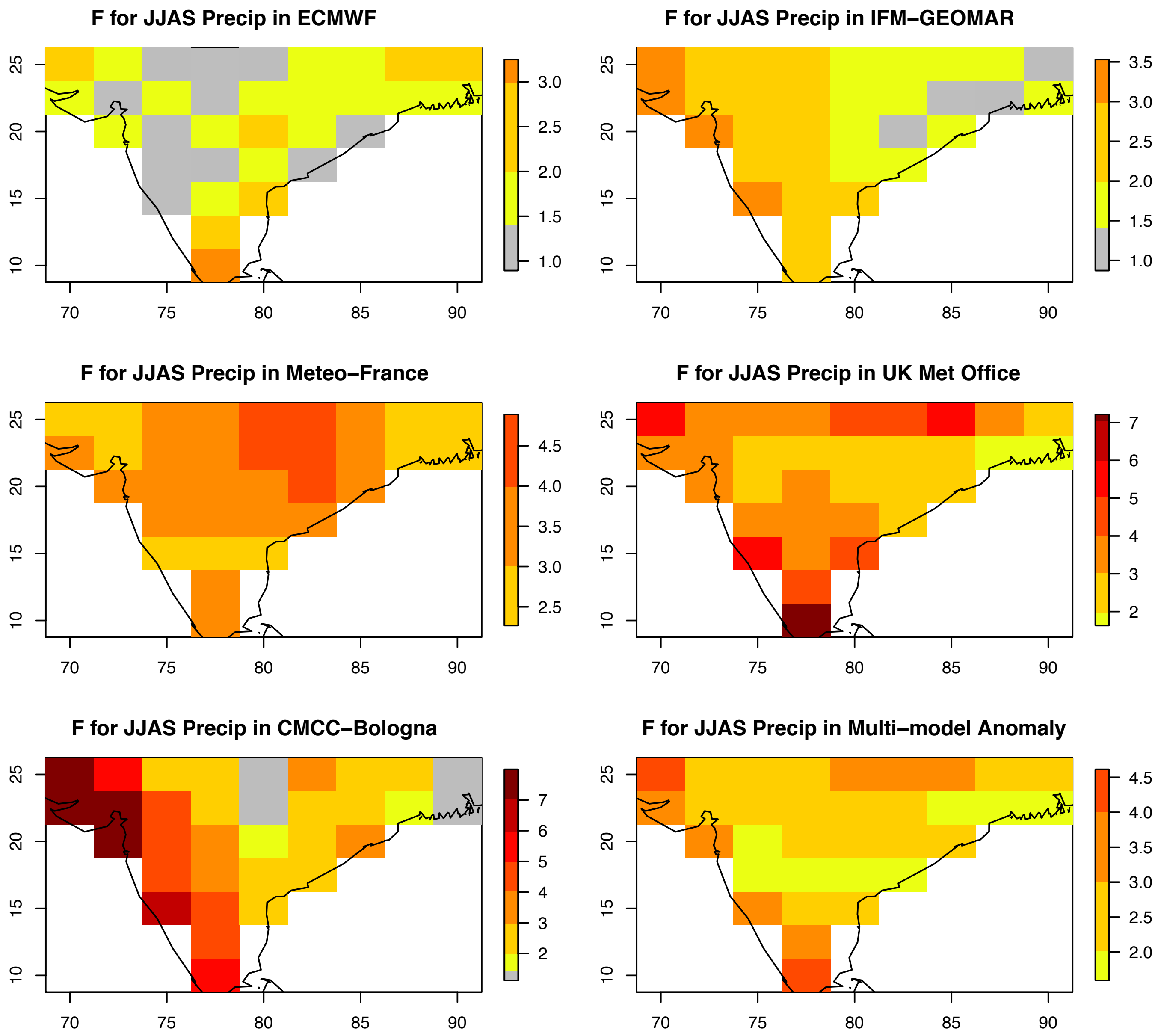
Ratio of Signal to Noise Variance for JJAS Rainfall for Four Climate Models

NASA, NCEP, CCSM3, GFDL



ICTP-TTA Project, 2014

D. Das, Z. Wang, S. Chaudhuri



F-values for JJAS precip. For 46-years and 9 ensemble members the 5% significance is F=1.4. Gray color indicates not statistically significant at 95% confidence interval.

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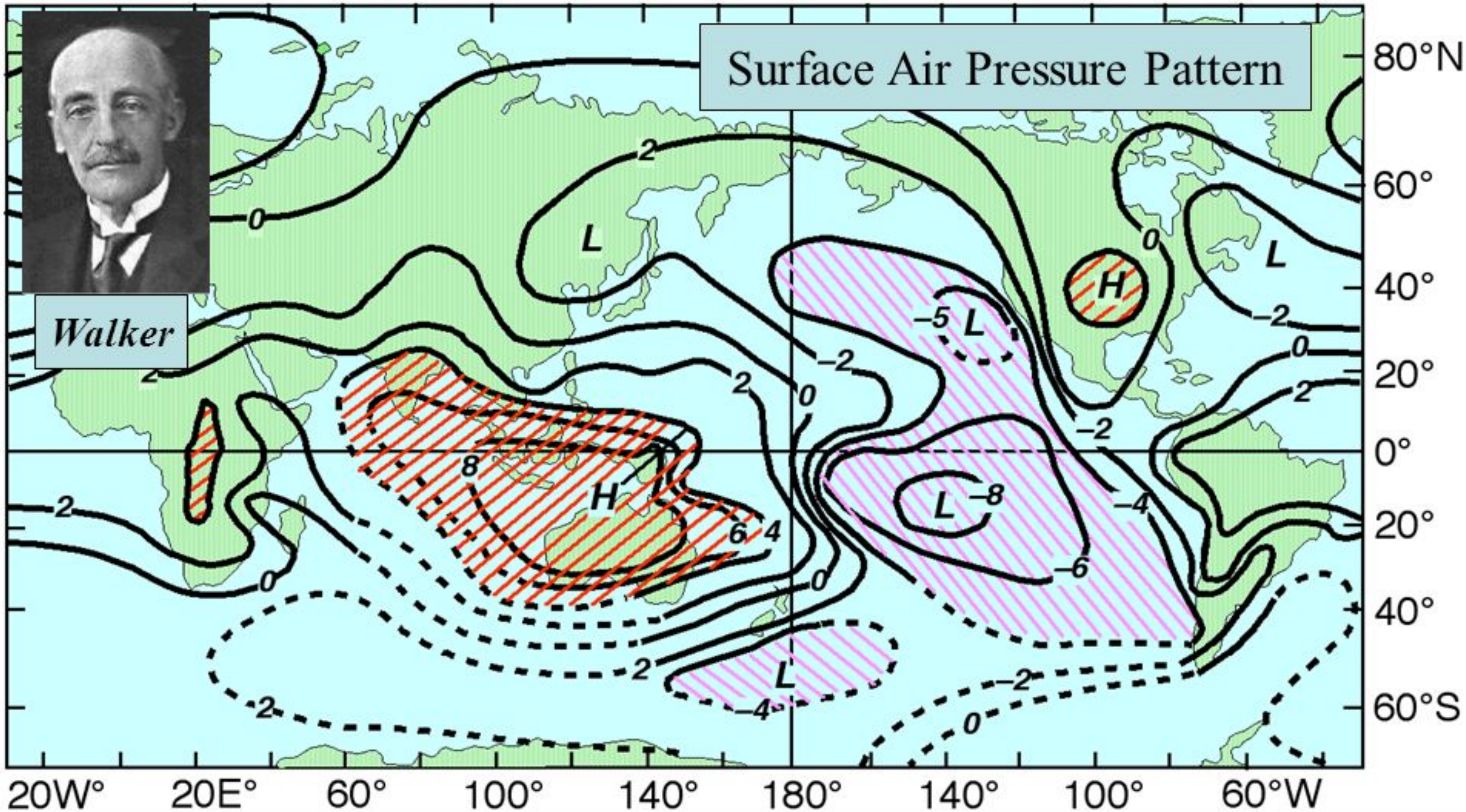
If monsoon has high predictability, why is the skill of operational predictions so low?

The Southern Oscillation



Correlation coefficient with respect to Darwin sea level pressure

Rasmusson, 1984

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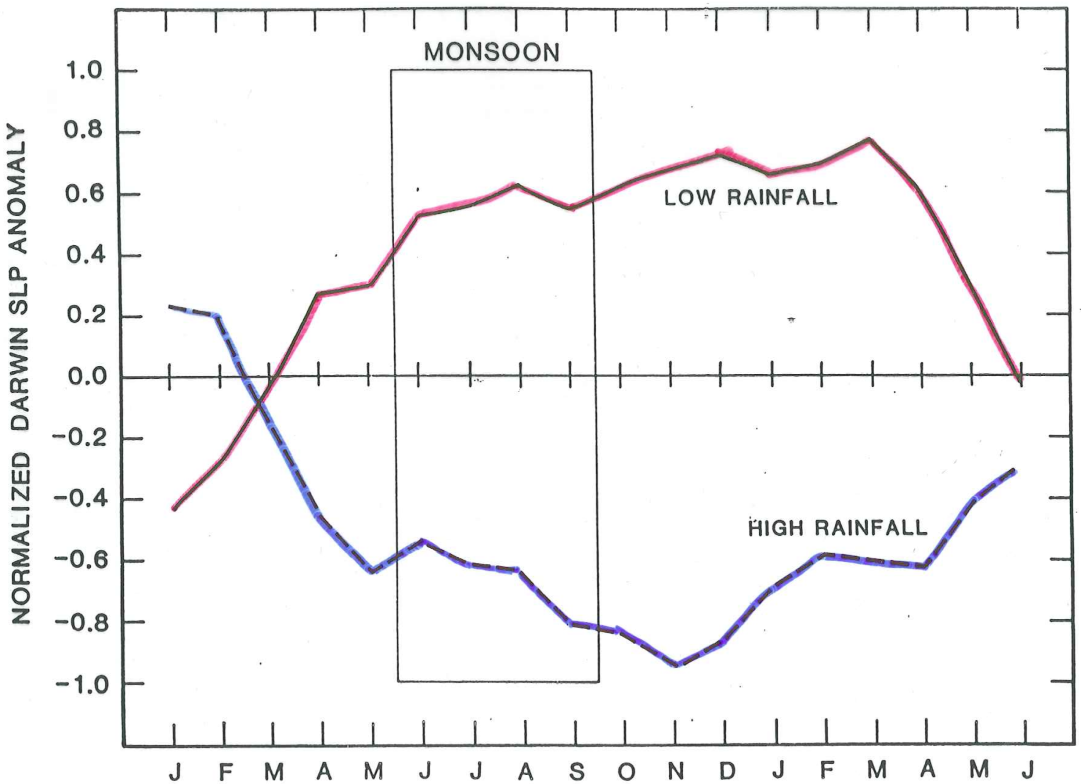
To predict monsoon, we must predict ENSO first

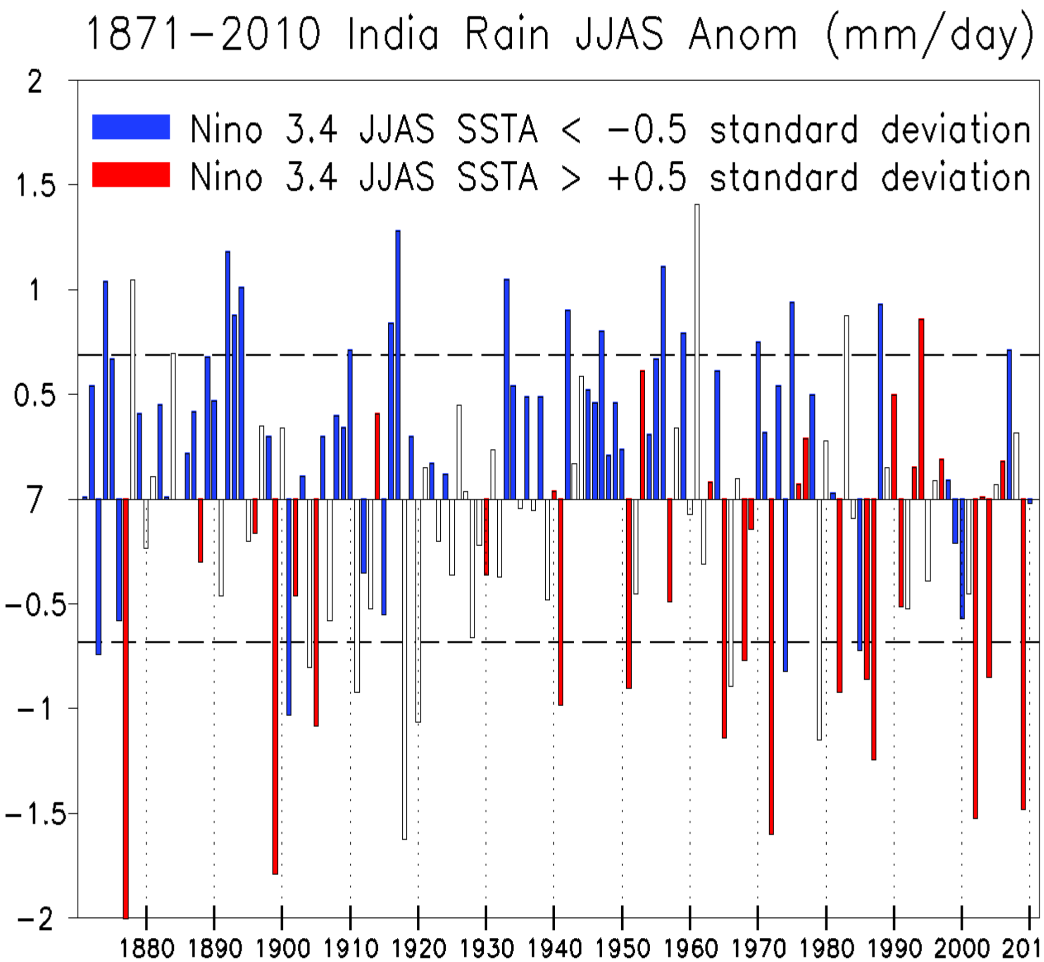
(ENSO has large amplitude after the monsoon season)

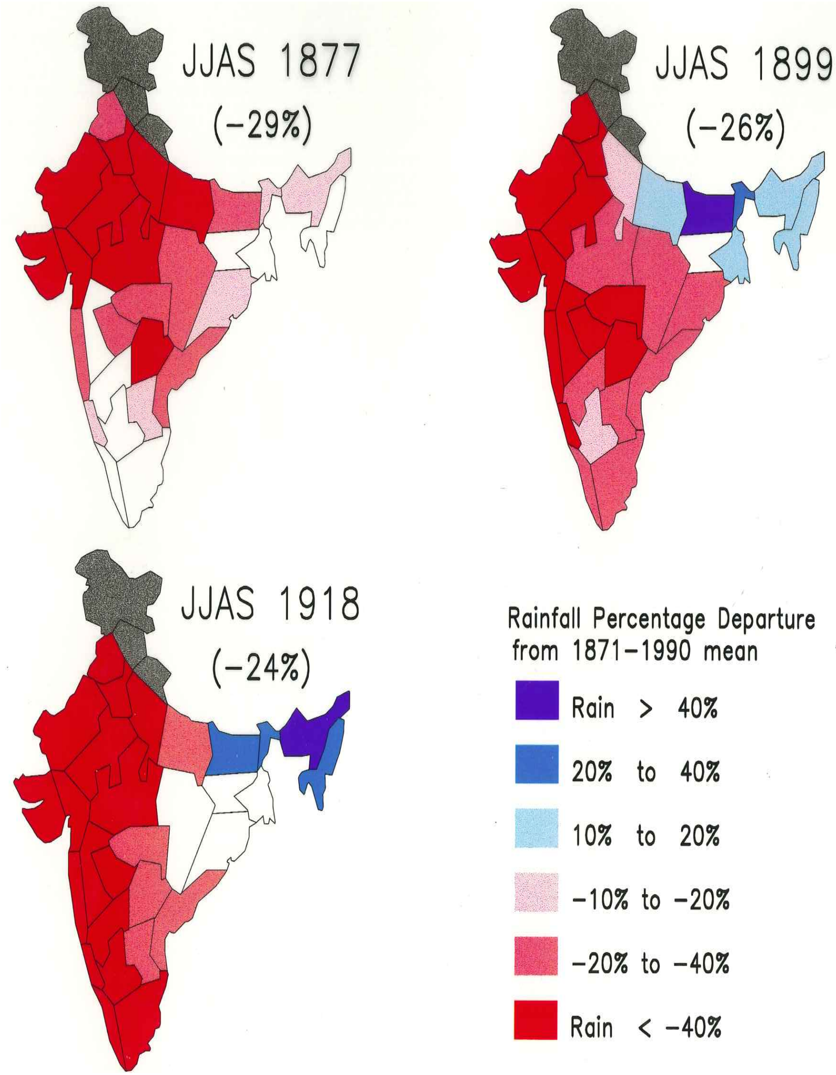


A possible explanation for why Walker's empirical forecasts had no skill

DelSole and Shukla (2012)

- Canonical Correlation Analysis (CCA) for 1880-1959 for May SST & Indian Subdivisional rainfall. (No Skill)
- CCA: May SST and all India rainfall (1880-1959):
- No skill in independent sample for 1960-2005.





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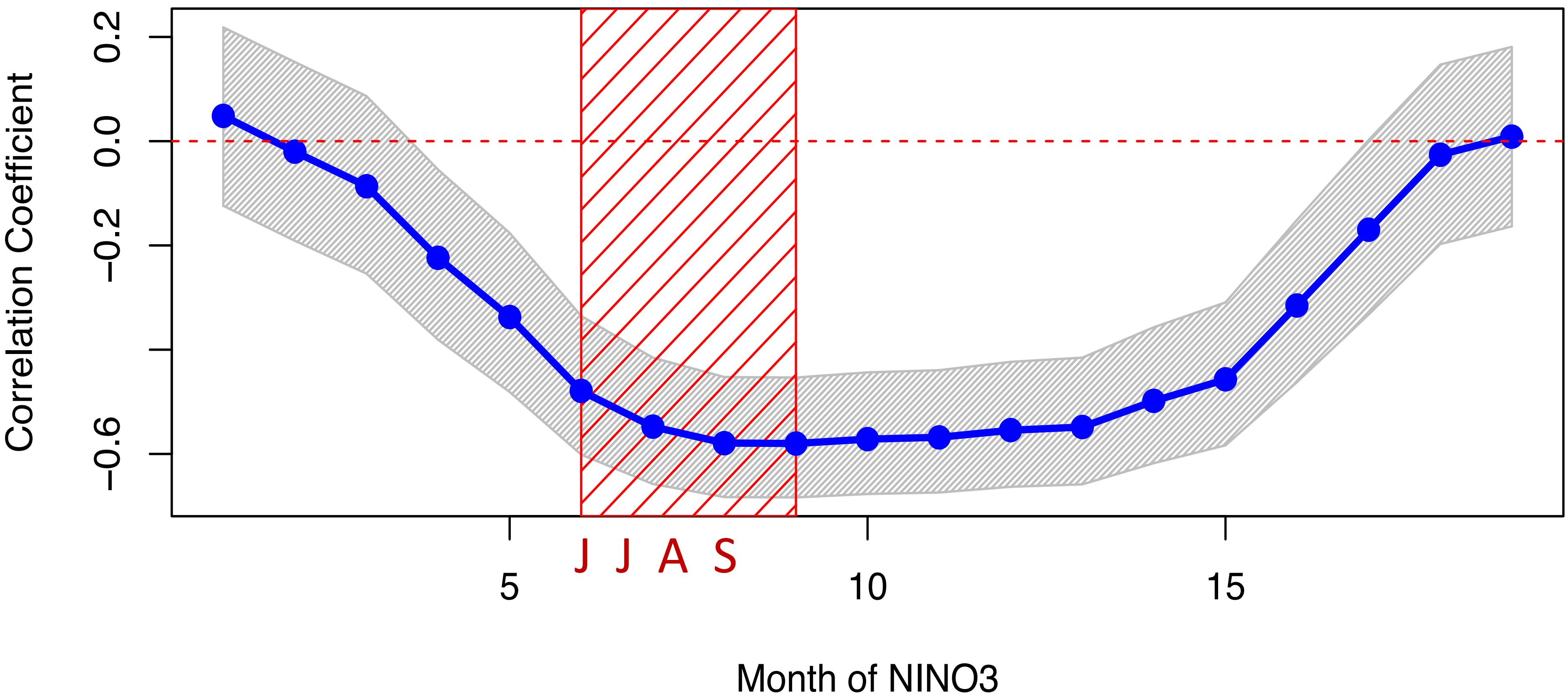
Correlation between NINO3 and All–India JJAS Rainfall
1880–2010



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Reforecasting the ENSO Events in the Past 57 Years (1958-2014)

Bohua Huang[1], Chul-Su Shin[1], J. Shukla[1], Lawrence Marx[1], Magdalena A. Balmaseda[2], Subhadeep Halder[1], Paul Dirmeyer[1], James L. Kinter III[1] **(to appear, J of Climate)**

<table>
<tr><th>Initial Conditions (ICs)</th><th>1958-1978</th><th>1979-2014</th><th></th></tr>
<tr><td>Atmosphere</td><td>ERA-40</td><td rowspan="3">CFSR</td><td rowspan="3">4 members
(The first 4 days of each month)</td></tr>
<tr><td>Land</td><td>NASA GLDAS2</td></tr>
<tr><td>Sea Ice</td><td>CFSR
(January 1, 1979,
April 1, 1979,
July 1, 1979,
October 1, 1980)</td></tr>
<tr><td>Ocean</td><td colspan="2">ORA-S4</td><td>5 members*</td></tr>
</table>

* Perturbed through ocean data assimilation.

20 total ensemble members

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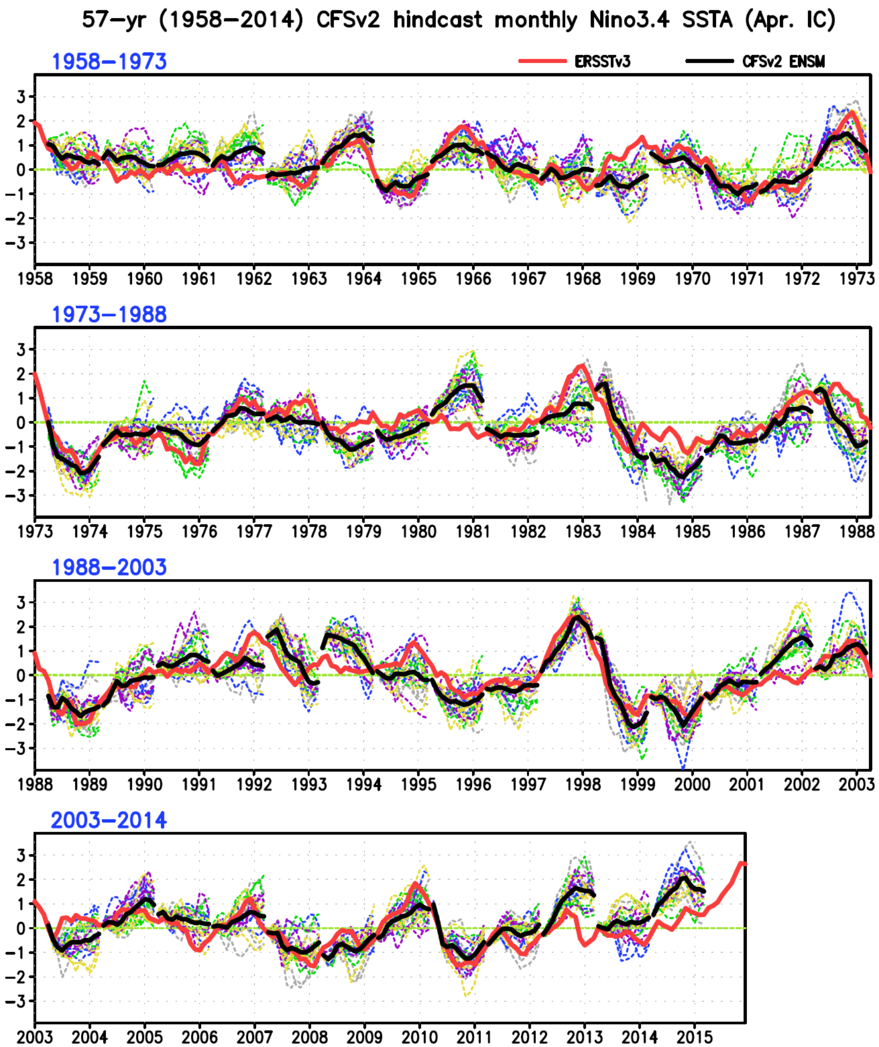
Niño 3.4

57 Years of Reforecasts:

No secular changes in ENSO predictability



Huang et al. 2017

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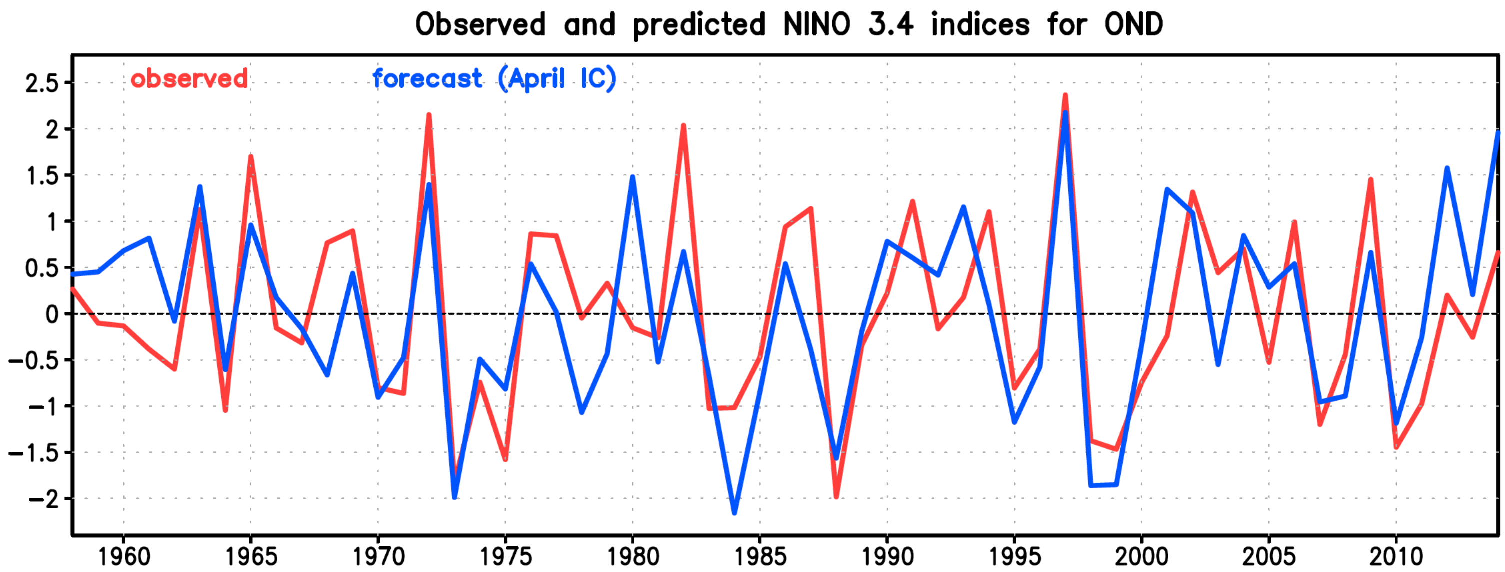
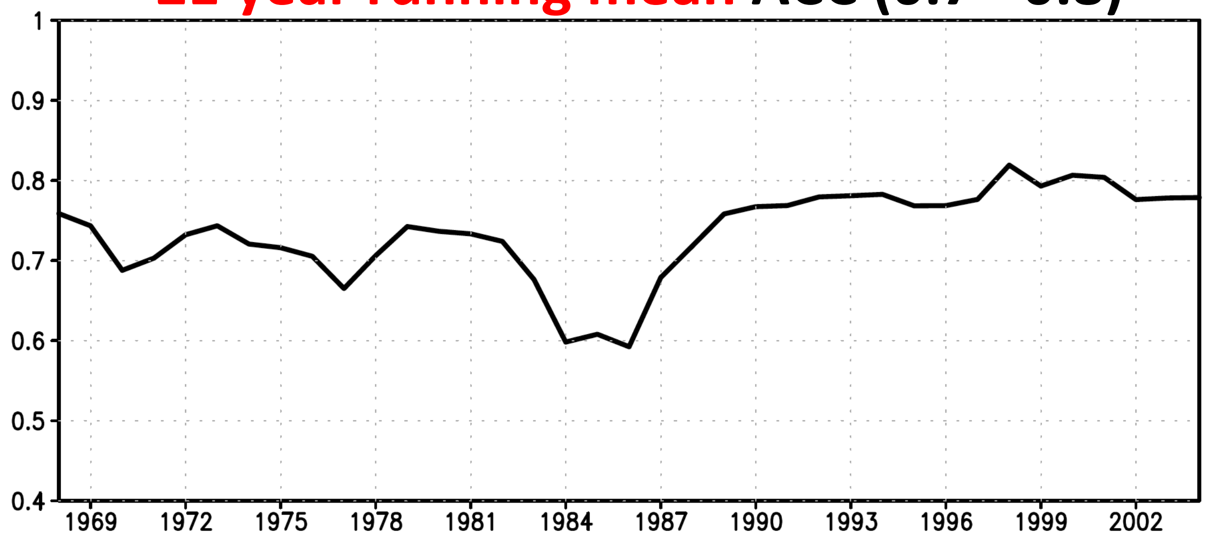
Obs. and Forec. OND Nino 3.4 (April IC)



21 year running mean ACC (0.7 - 0.8)



x-axis label indicates a center year of 21-yr time window

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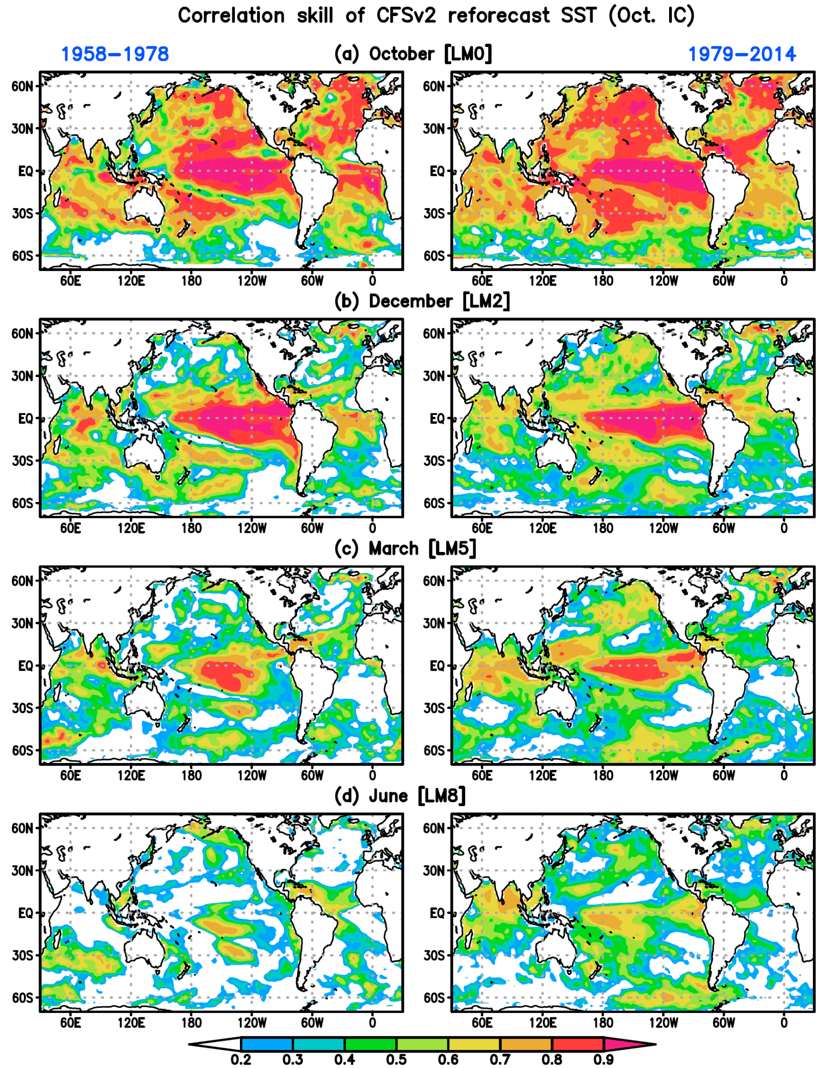
Oct. IC

1958-1978



1979-2014

Verified against ERSSTv3

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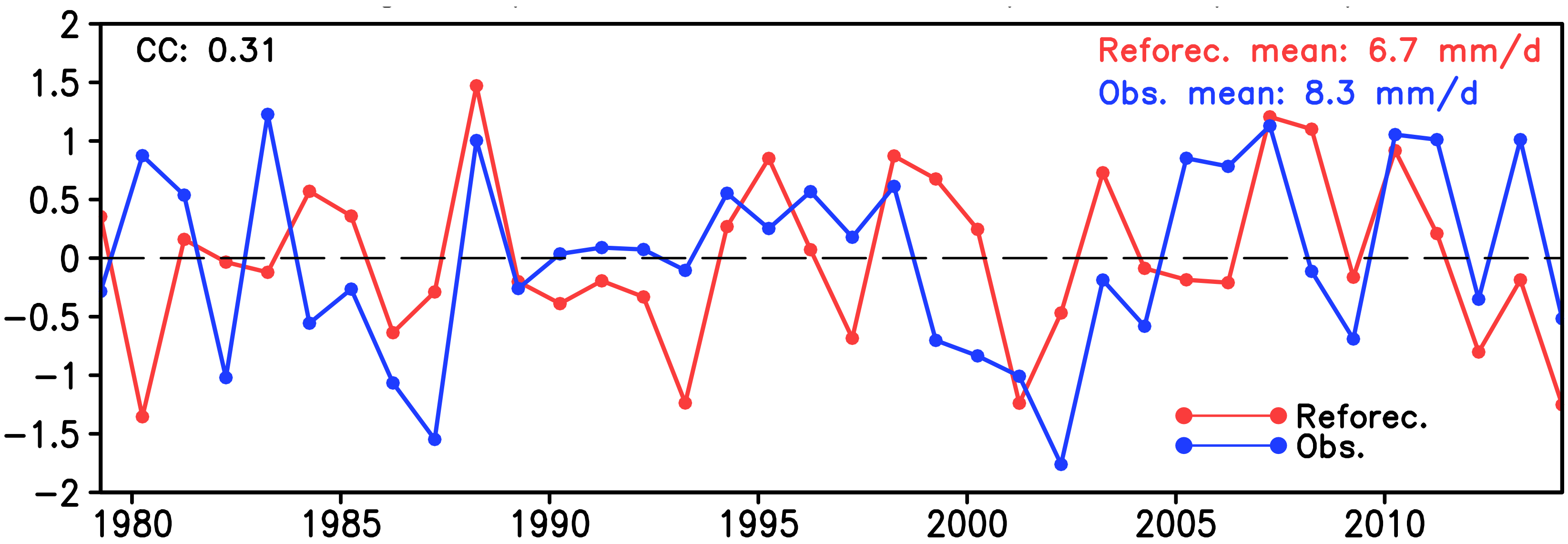
Obs. and Forec. JJAS Precip. Anom. (10-25N, 70-90E)

Obs. Mean: **8.3** mm/d; Forec. Mean: **6.7** mm/d; **ACC = 0.31**



Coupled A-O models now show statistically significant skill in predicting Indian Summer Monsoon rainfall;

But not good enough for many societal applications

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In Spite of Large Biases in Simulated SST, Predictions of SST Anomalies Have Some Skill in Some Cases

Small Skill in Predicted SST is Enough to Give Statistically Significant Skill in Predicted Monsoon Rainfall

That is why statistical models using April/May SST to predict JJAS monsoon rainfall have no skill, but coupled models with April/May initial conditions of A & O have statistically significant skill

Reforecasting 1972-73 & 1997-98 ENSO and Monsoon

ENSO - Monsoon Teleconnections:

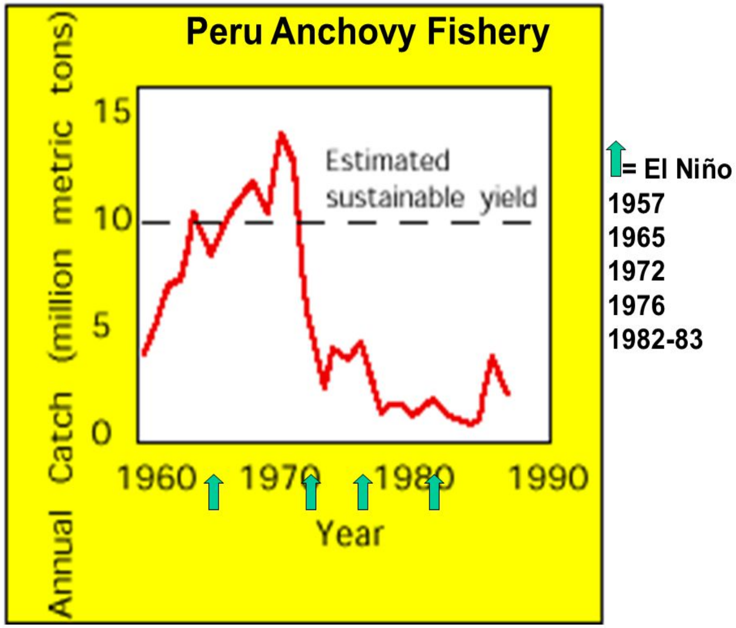
Sometimes they work marvelously,
and sometimes they fail miserably.

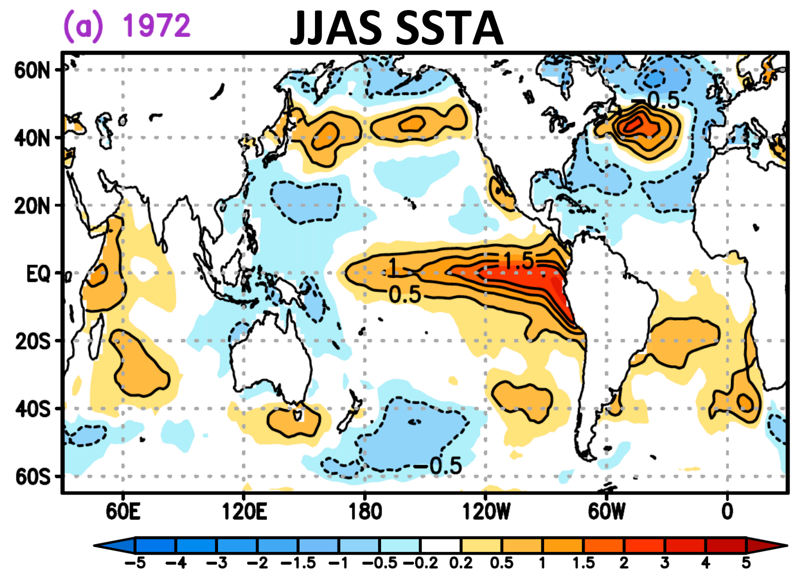
The tale of two ENSOs:

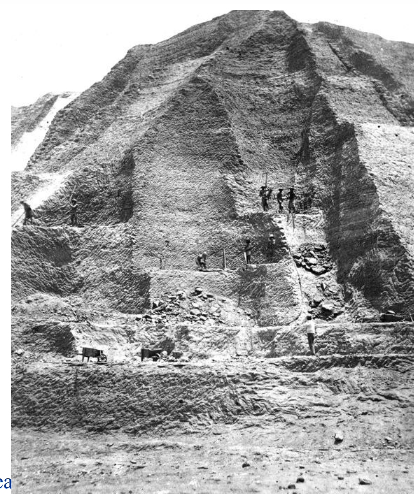
1972 – 1973

1997 – 1998

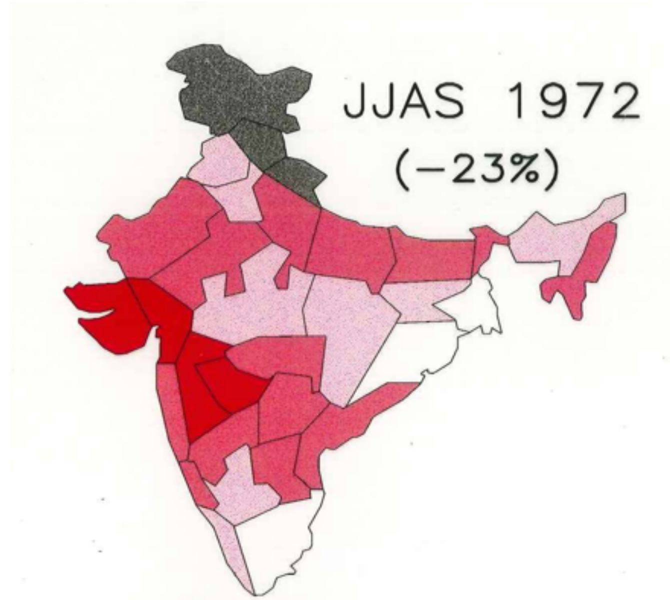
1972-73 El Nino Devastated Peruvian Fisheries; Caused Severe Drought Over India





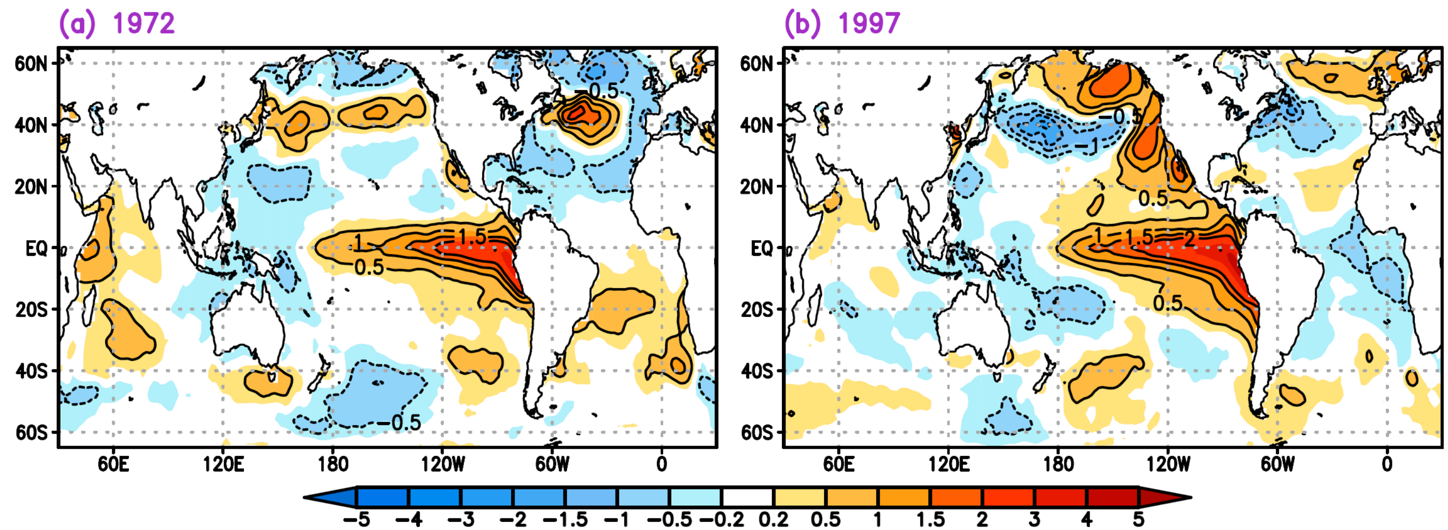


Guano Mountain (1860) in Peru – 60 ft tall

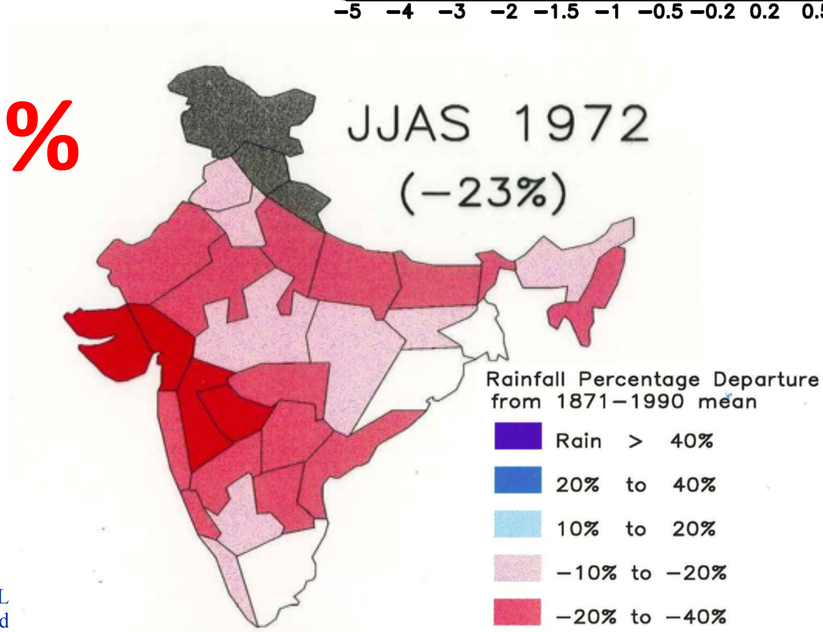


ENSO & ISMR for JJAS 1972 and 1997

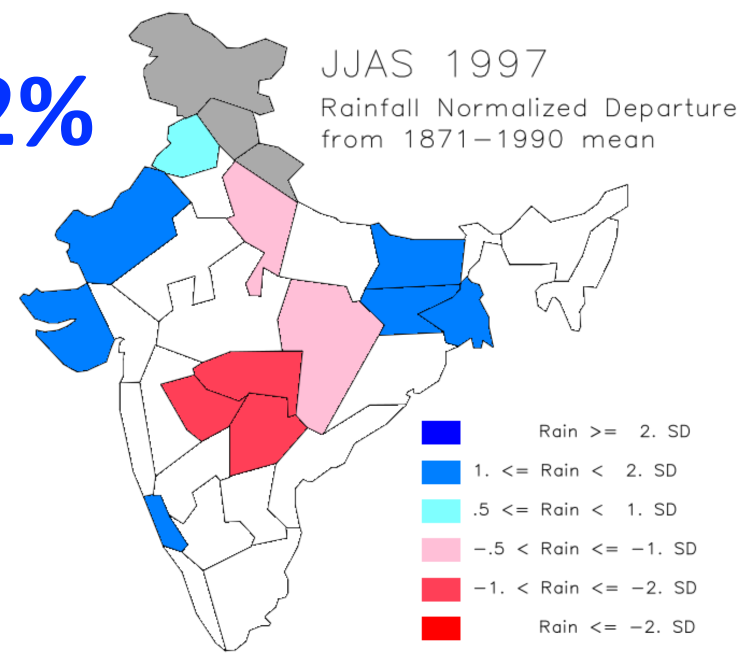
1972 1997



- 23%

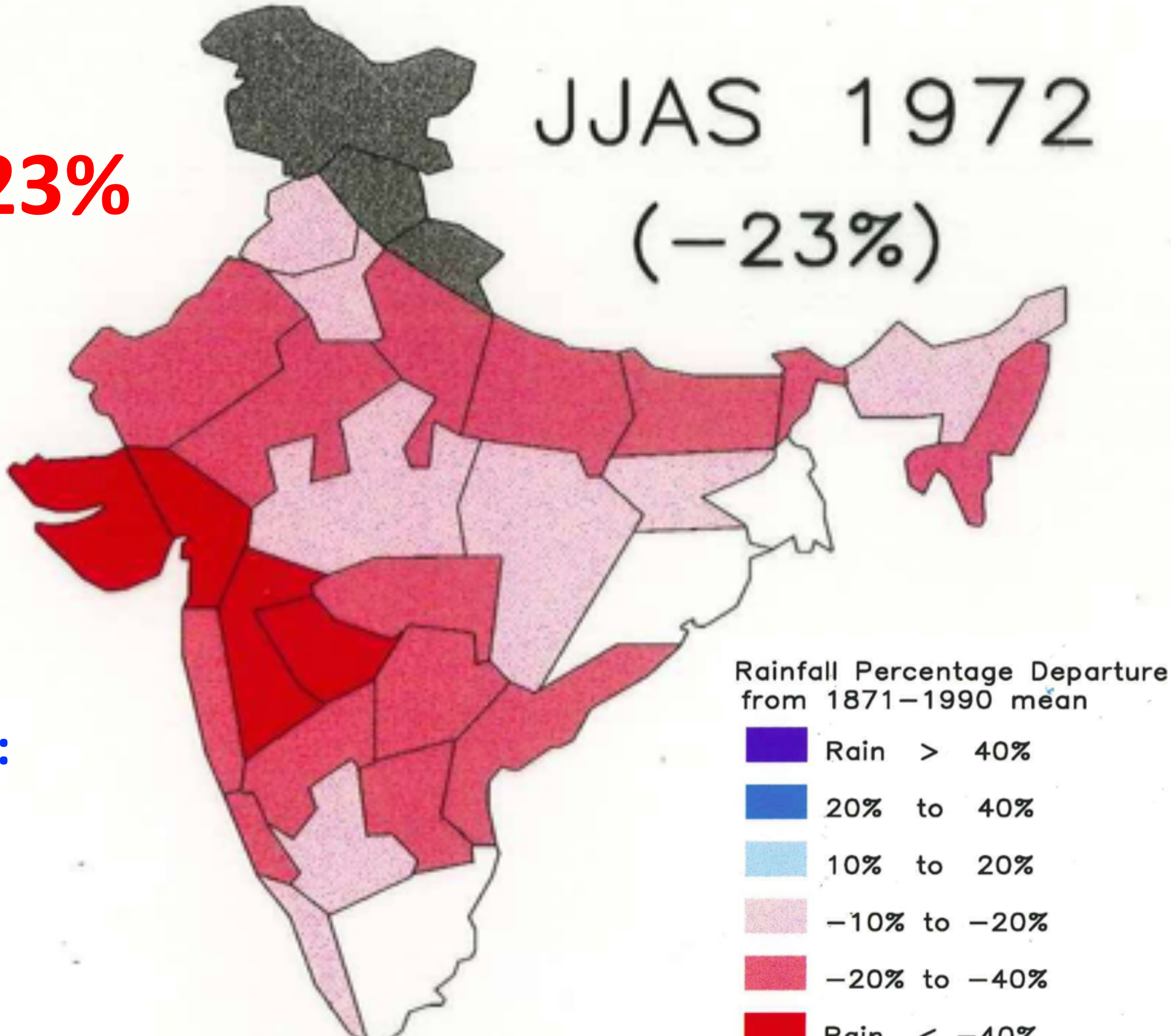


+ 2%



1972 JJAS Rainfall Anomalies Over India

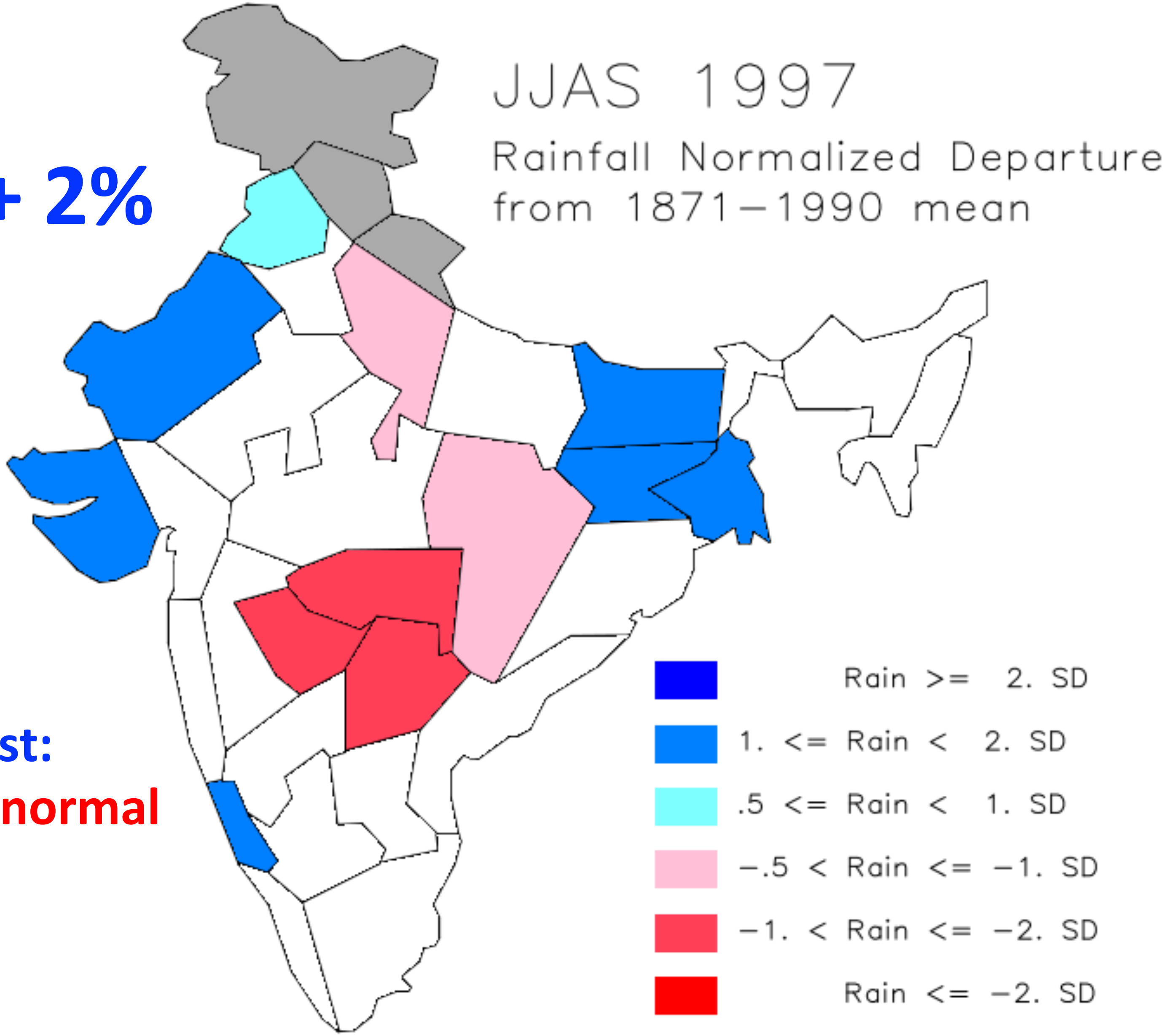
- 23%



Forecast: normal

1997 JJAS Rainfall Anomalies Over India

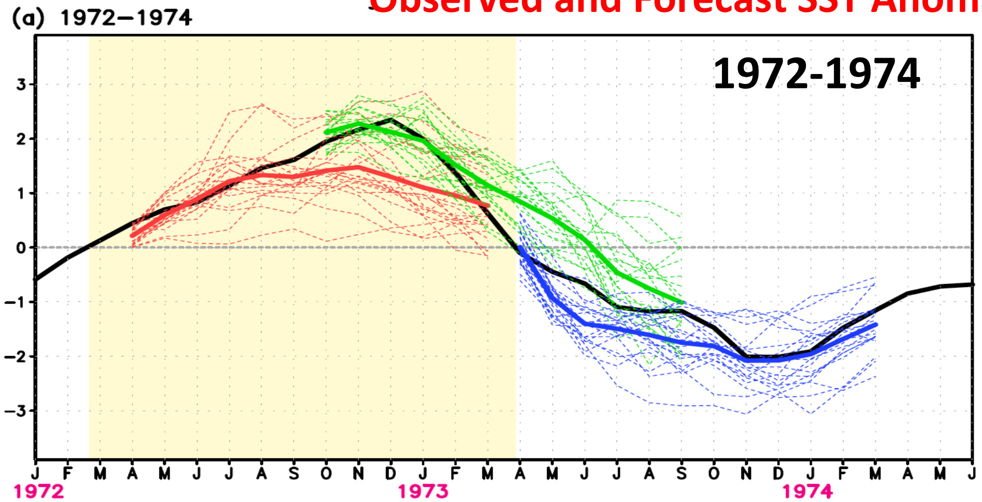
+ 2%

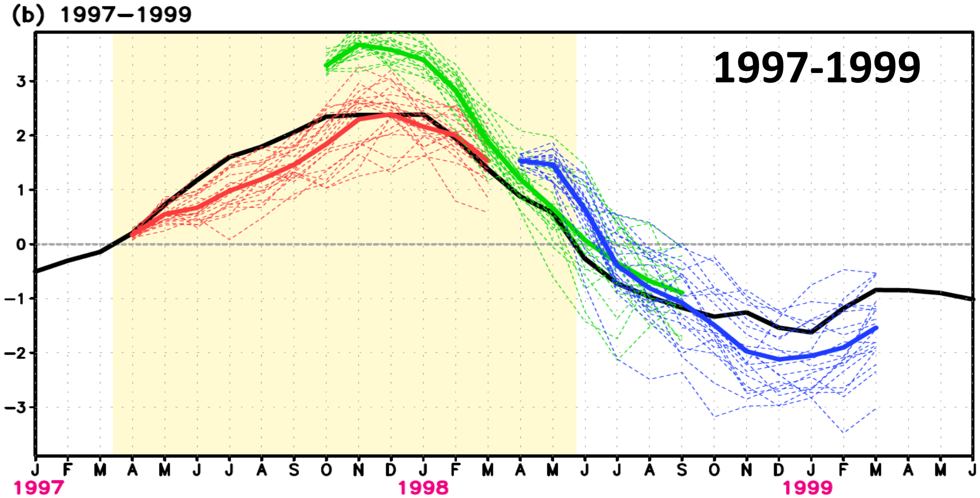


Forecast:
below normal

C

Observed and Forecast SST Anomalies for April and October IC (CFSv2)





Case Studies: Strong Warm Events

Yellow shading indicates the period of each event. The 1972-73 event terminated earlier than the 1997-98 event.

This is an example of rapid drop of skill after March in the earlier period.

Apr Year 0 IC

Oct Year 0 IC

Apr Year 1 IC

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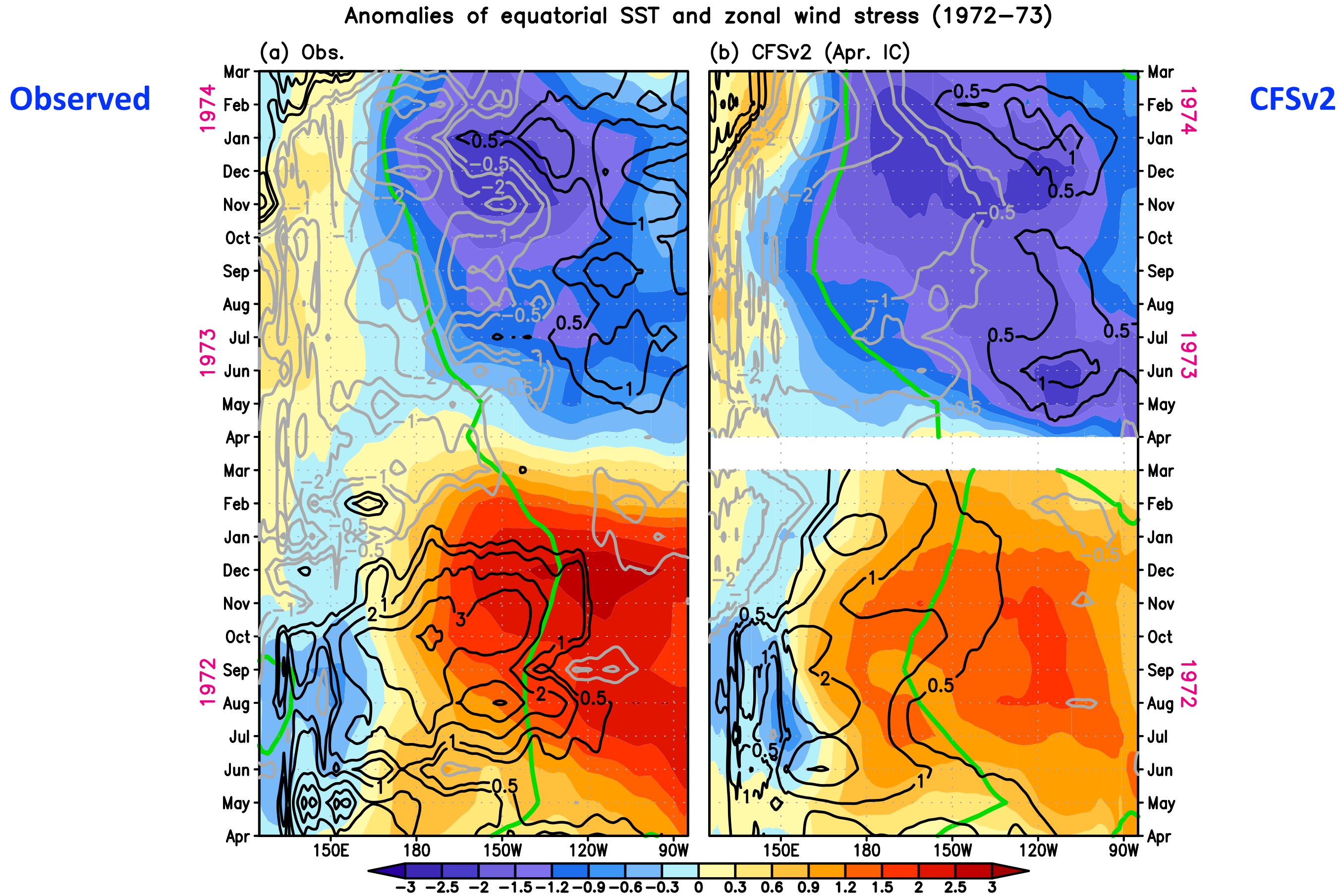
Observed and Predicted SST Anomalies for 1972-74

April IC



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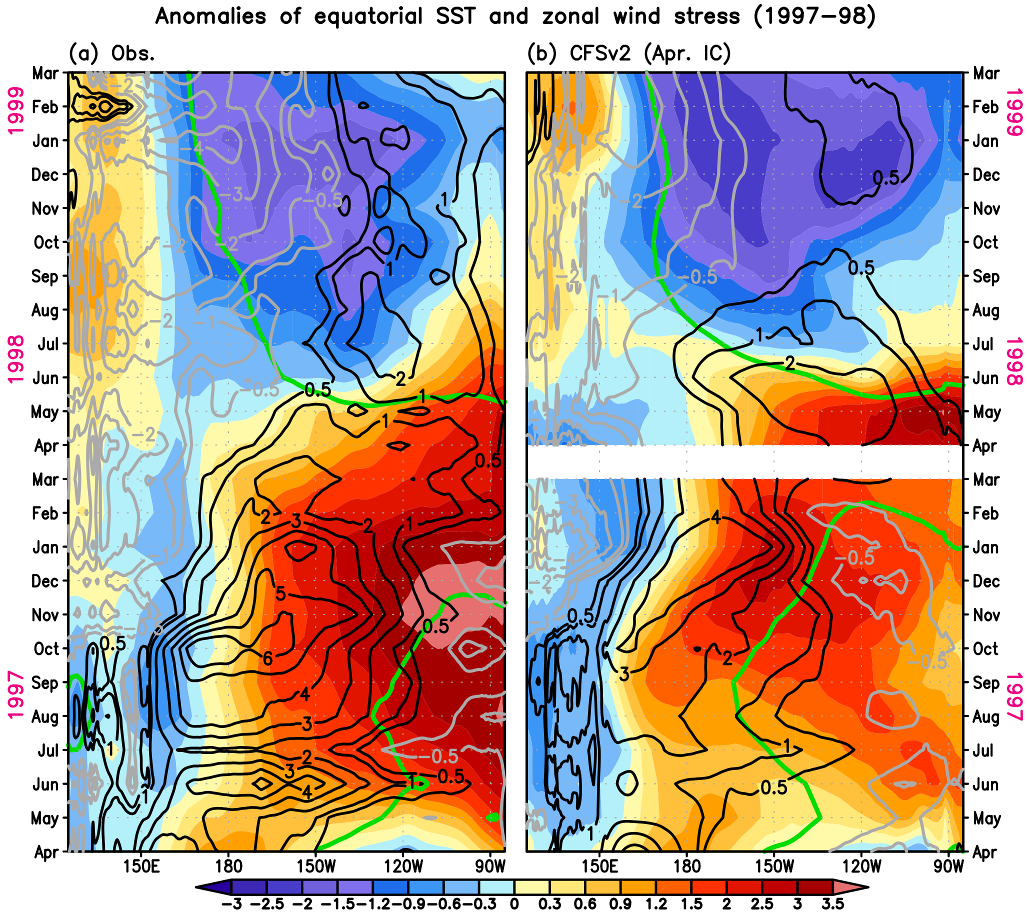
Observed and Predicted SST Anomalies for 1997-99

April IC

Observed

CFSv2



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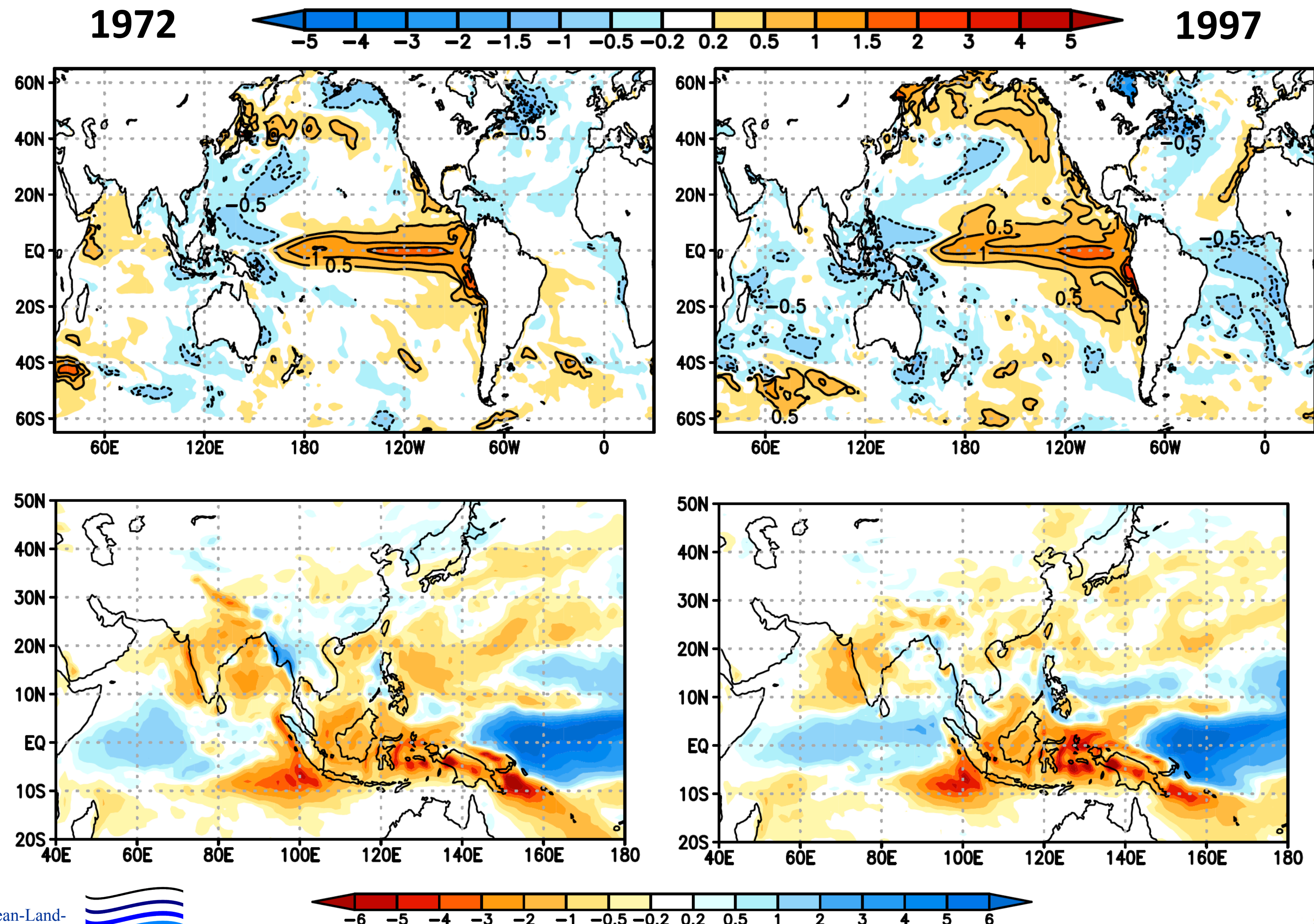
CFSv2 Forecast JJA mean SSTA and Precip. (April IC)



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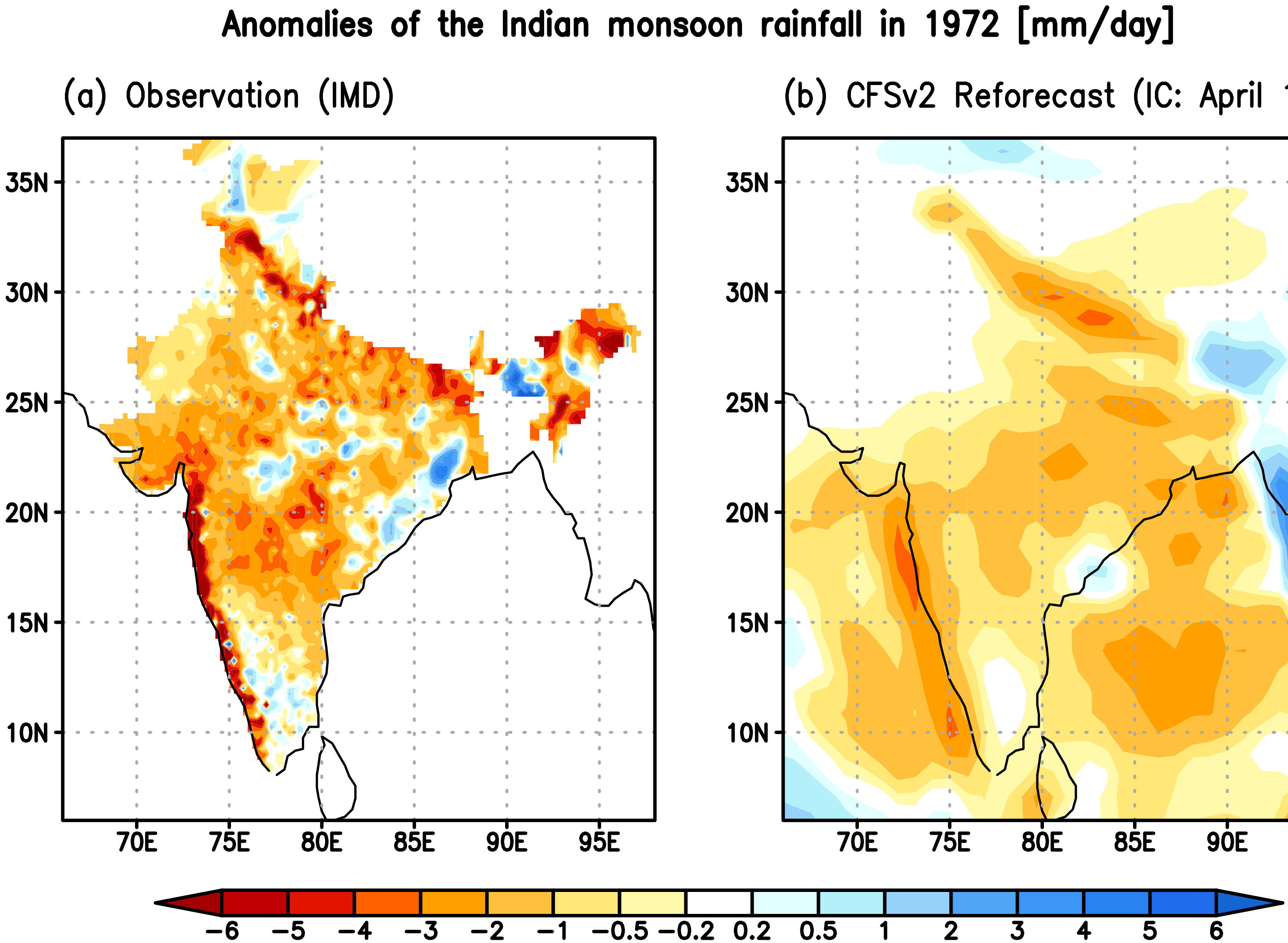
Forecast (April 72, IC) and Observed (IMD) Rainfall Anomalies for JJAS 1972 (mm/day)

Observed IMD Forecast CFSv2



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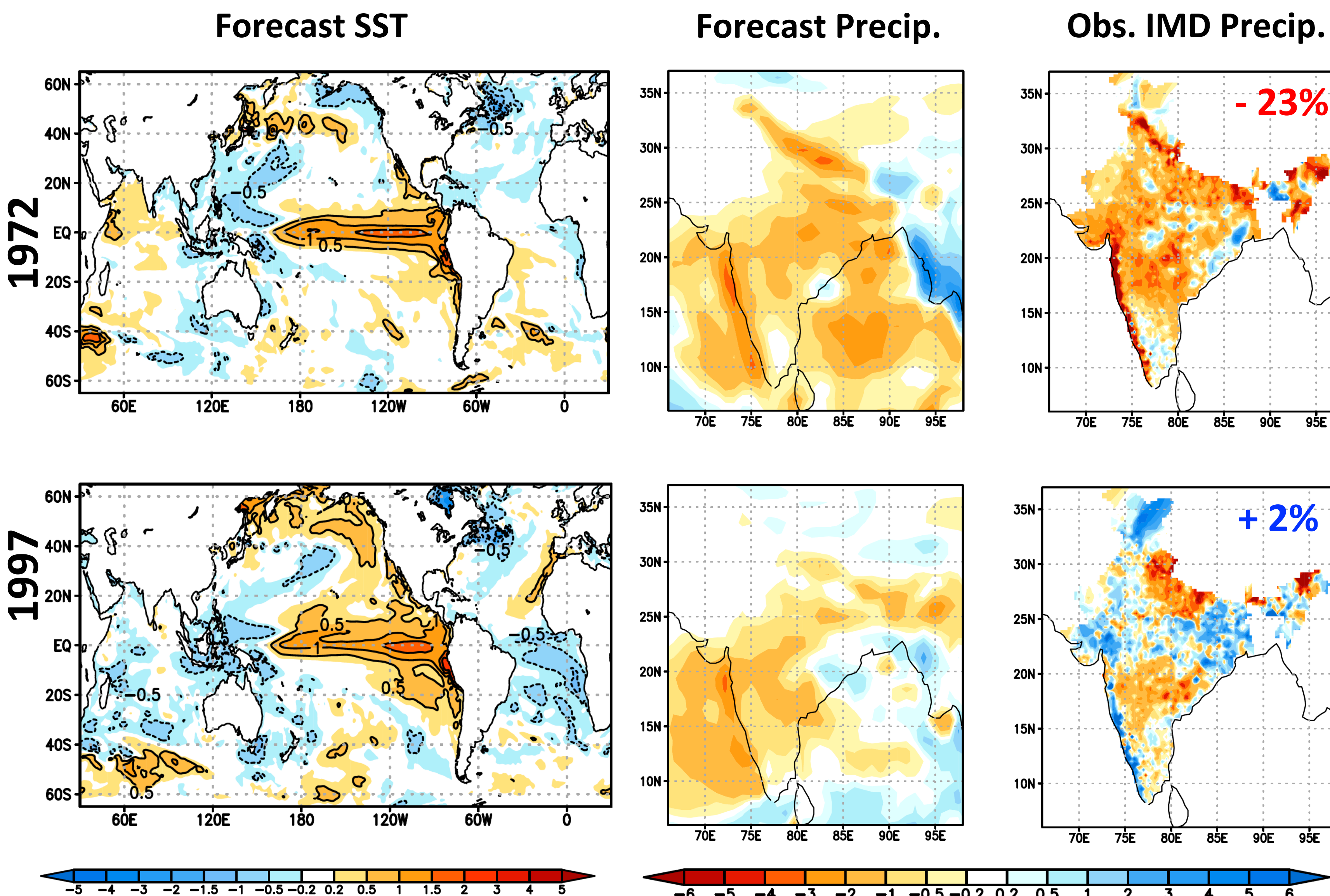
CFSv2 Forecast JJA mean SSTA and Precip. (April IC)



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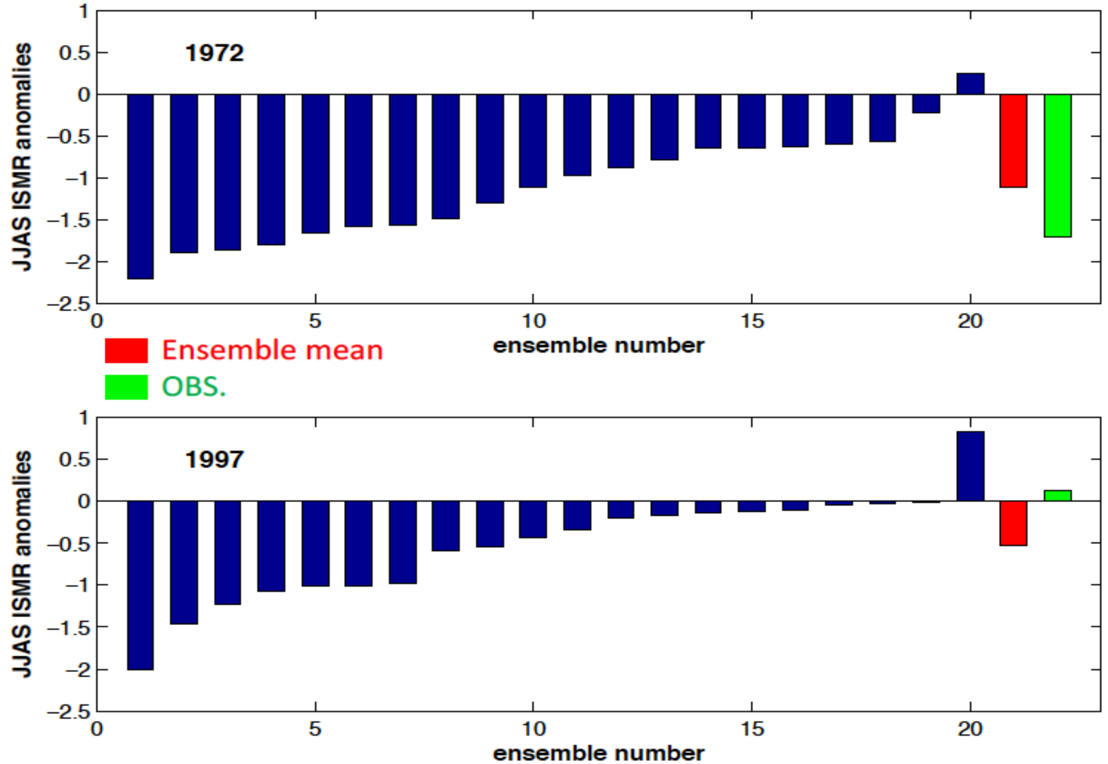
JJAS India Rainfall for 1972 & 1997

Model; ensemble members & ensemble mean; observations



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Challenges in Bridging the Gap Between Predictability and Prediction of Monsoon

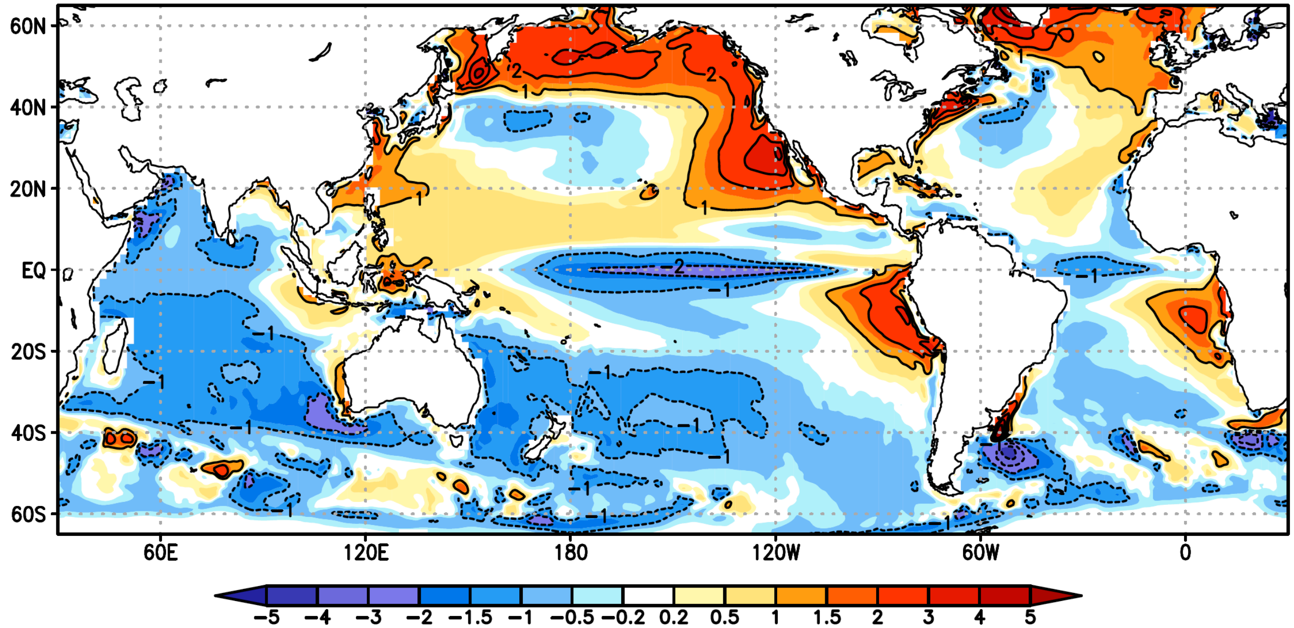
- **Large model biases: improving the fidelity of models**
- **Improving the initial conditions of ocean and land**
- **Realistic simulation of tropical diabatic heat sources (IOD)**

Climate Modelers' Good Luck

- In spite of large systematic errors, climate models can capture part of the short-term climate variability, and therefore can produce a skillful seasonal forecast.

- Puzzle: model errors, although large in amplitude, do not seem to interact strongly with the real signal, and therefore a systematic bias correction can be used to produce seasonal forecasts.

SST Bias in 5 Month Forecasts (CFSv2), 1979-2014, I.C. April, 1



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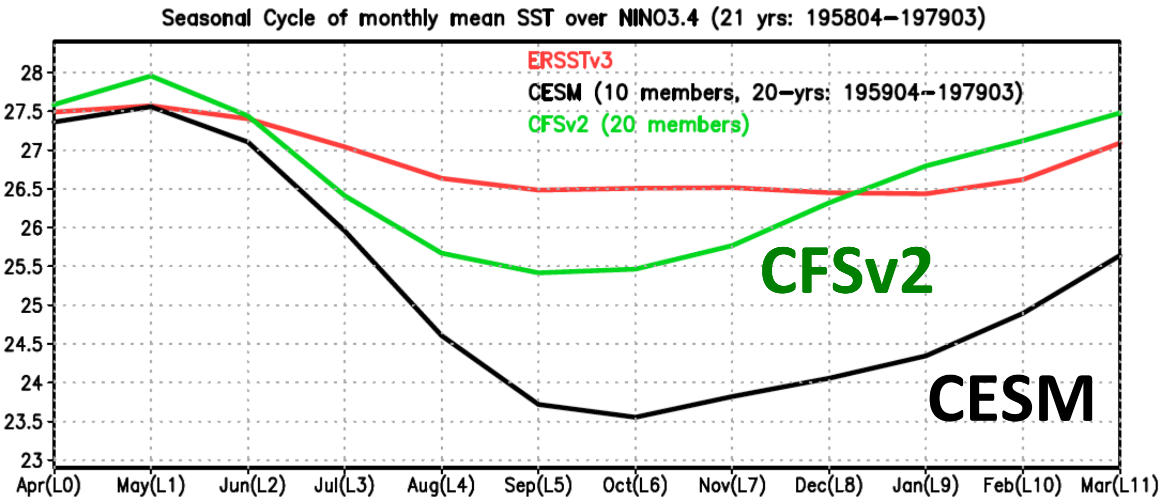

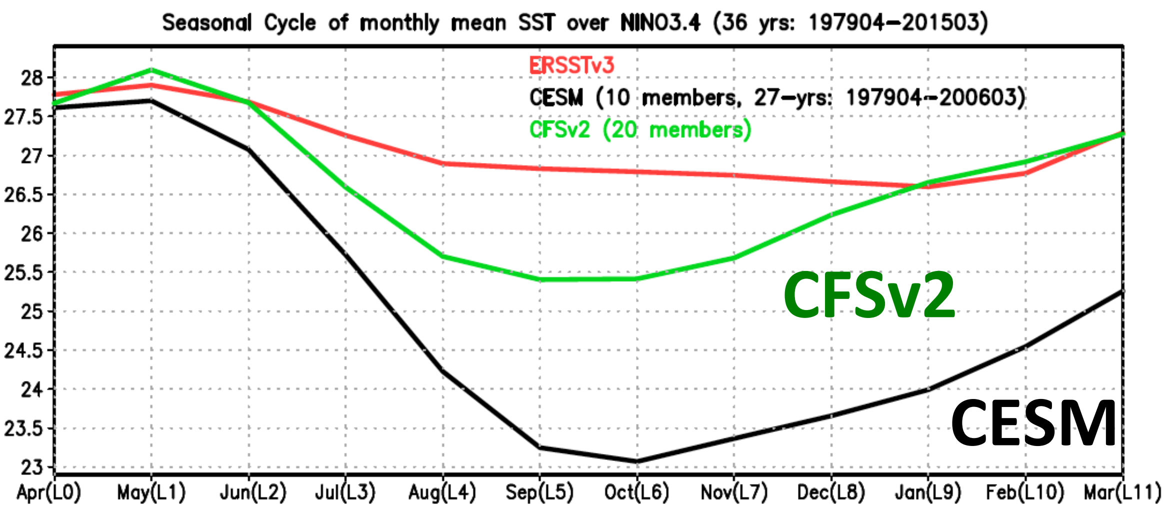

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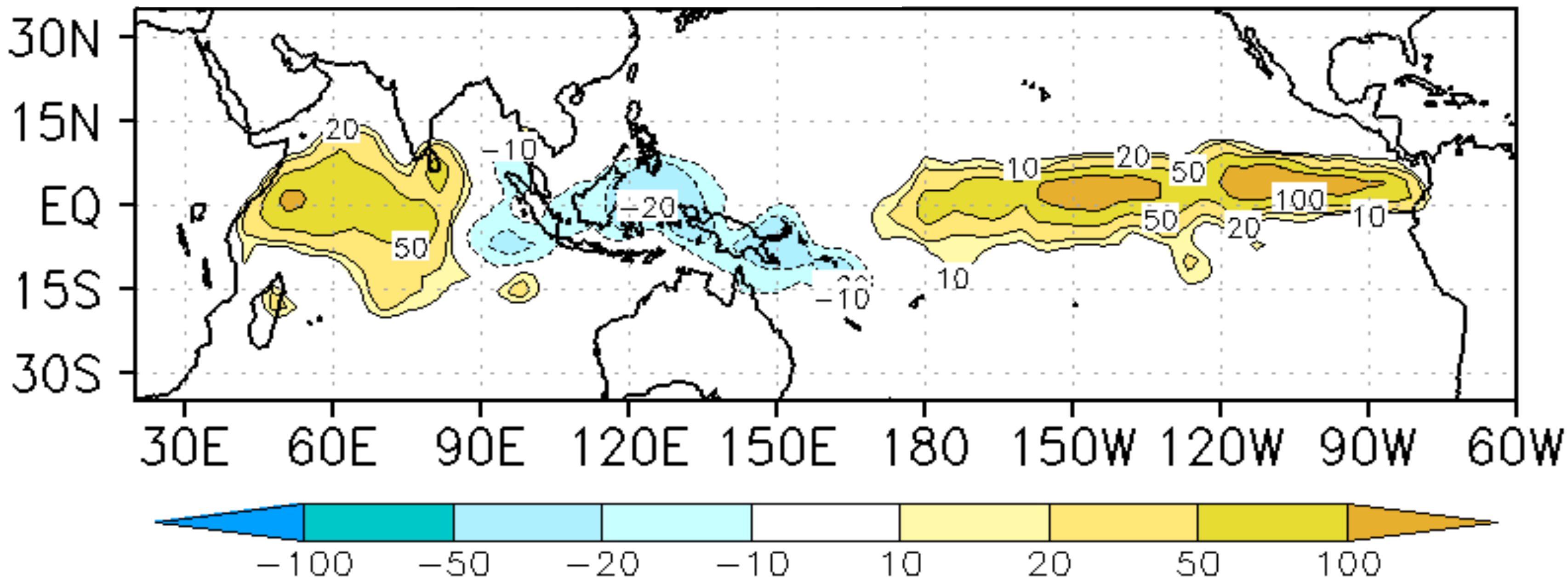
1997 Diabatic Heating Anomaly (W/m^2)

(Based on Observations)



Jang, Y. and D. M. Straus, 2013: Tropical Stationary Wave Response to ENSO: Diabatic Heating Influences on the Indian Summer Monsoon. J. Atmos. Sci., 30, 193-222.

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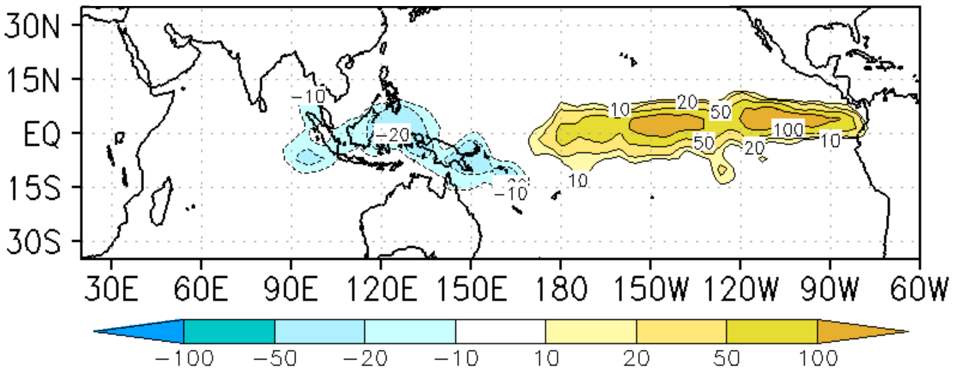
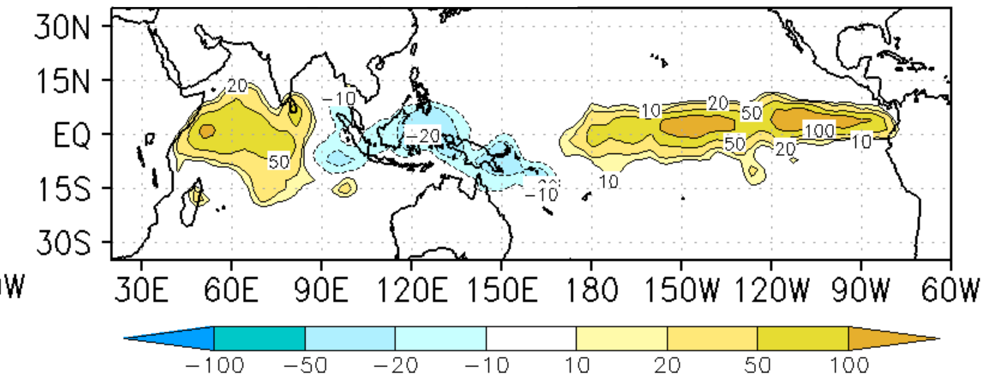
Pacific Only vs. Pacific + Indian Ocean (1997 ENSO)

➢ 1997 Pacific forcing(only) W/m^2



➢ 1997 Pacific + IO forcing W/m^2



The Pacific heating and cooling associated with 1997/98 El Nino produced a weaker monsoon circulation (drought!) over India. However, the superposition of Pacific El Nino and Indian Ocean warming produced a normal monsoon circulation over India.

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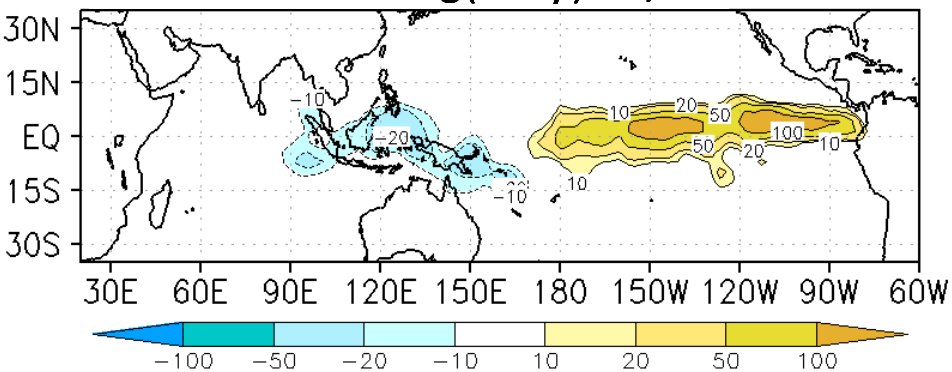
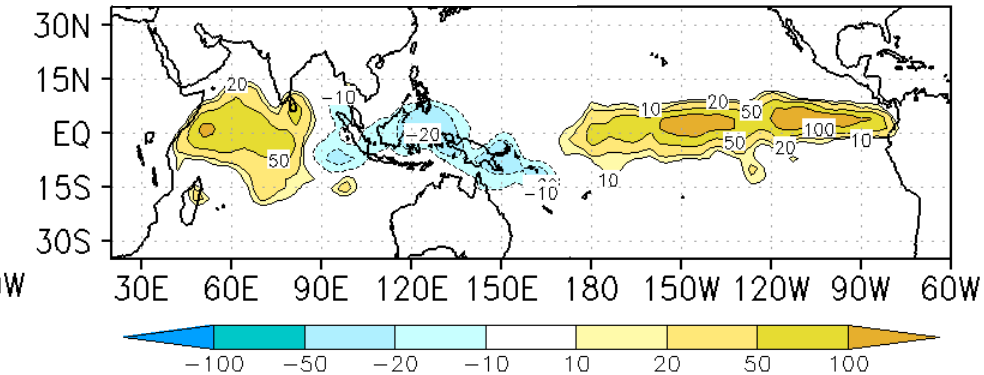
Pacific Only vs. Pacific + Indian Ocean

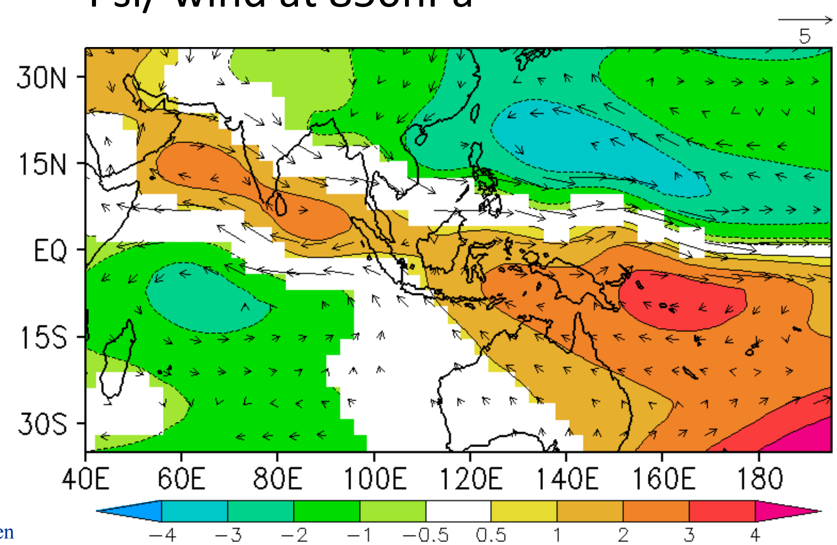
- 1997 Pacific forcing(only) W/m^2



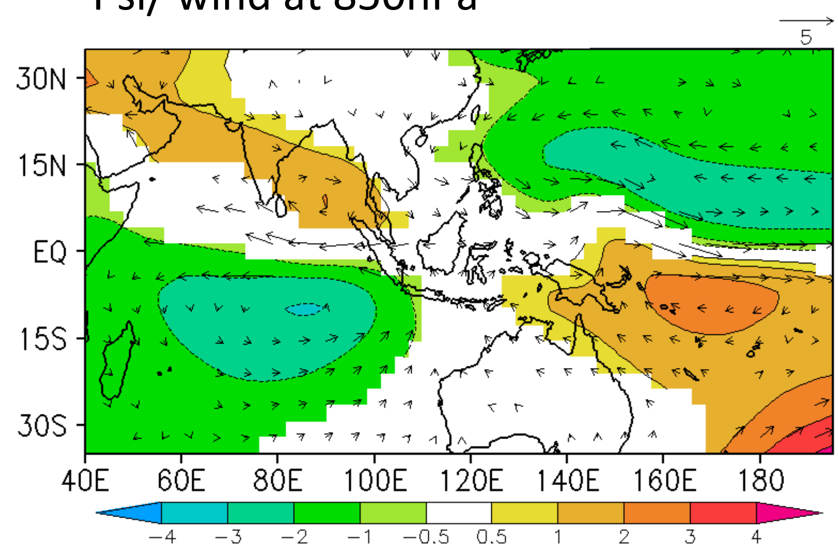
- 1997 Pacific + IO forcing W/m^2



- Response:
  Psi/ wind at 850hPa



- Response:
  Psi/ wind at 850hPa



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Pacific Only vs. Pacific + Indian Ocean 1997 ENSO

• **The Pacific heating and cooling associated with 1997/98 El Nino produced a weaker monsoon circulation (drought!) over India. However, the superposition of Pacific El Nino and Indian Ocean warming produced a normal monsoon circulation over India.**

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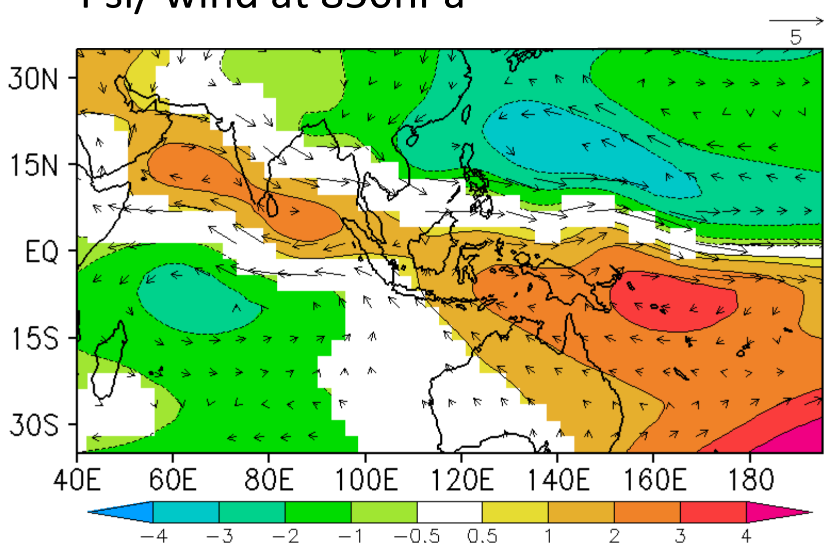

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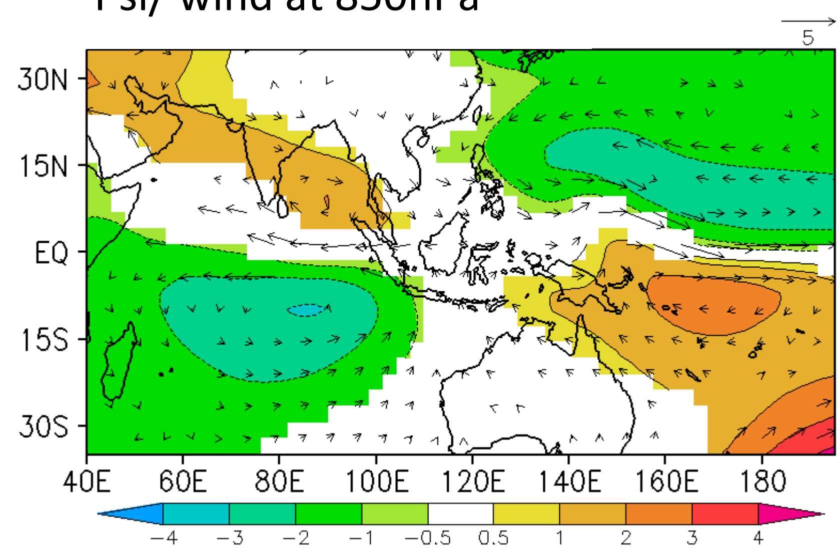

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Some Broad Conclusions & Suggestions

- In spite of large model bias, ENSO has significant predictability. Model biases seem to influence ENSO growth and decay.
- In spite of improved ocean observations during the recent decades, skill is comparable between 1958-78 and 1979-2014.
- Current models and assimilation systems are unable to take full advantage of enhanced ocean observations.
- Need for mechanistic process-based experiments to understand the limitations in predicting characteristics of individual ENSO events and their global impacts (viz monsoons).

Summary

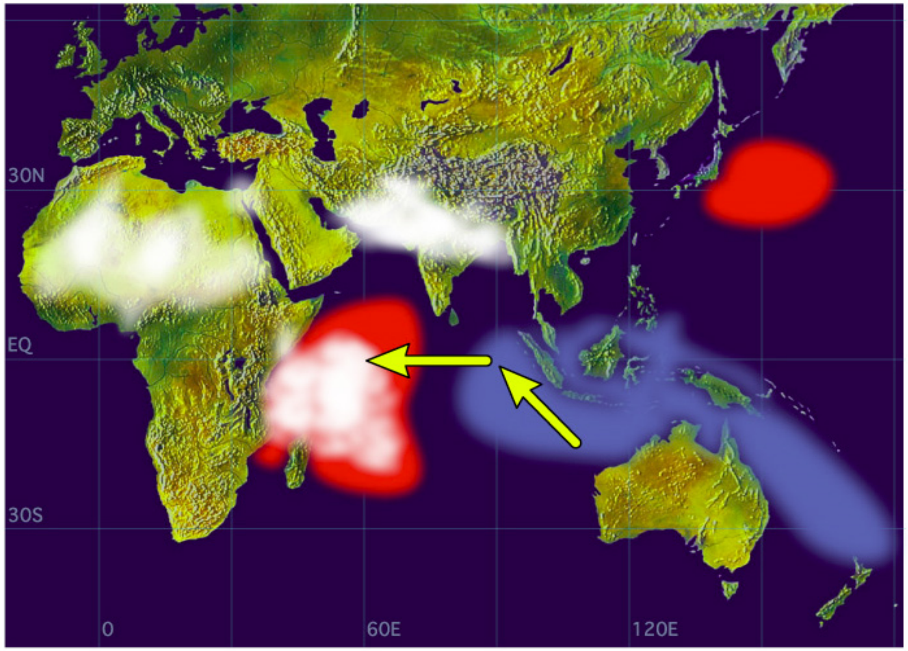
- In spite of large model bias, ENSO has significant predictability
- After 50 years of climate modeling, models have begun to show some skill in prediction of seasonal mean rainfall over India. This skill comes almost entirely from skill in prediction of tropical SST (ENSO).
- Realistic simulation of SST and diabatic heat sources in West-Pacific & IO appear to be important for accurate seasonal mean monsoon rainfall prediction, and intraseasonal variations during the monsoon season.
- The lack of skill in monsoon forecasts is not due to intrinsic limits of predictability.

THANK YOU!

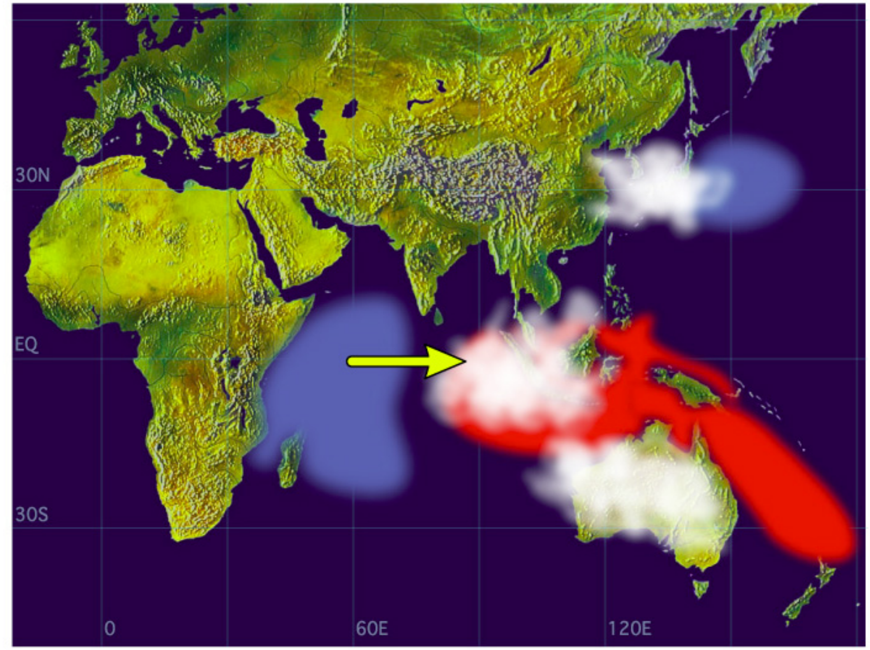
ANY QUESTIONS?

Indian Ocean Dipole

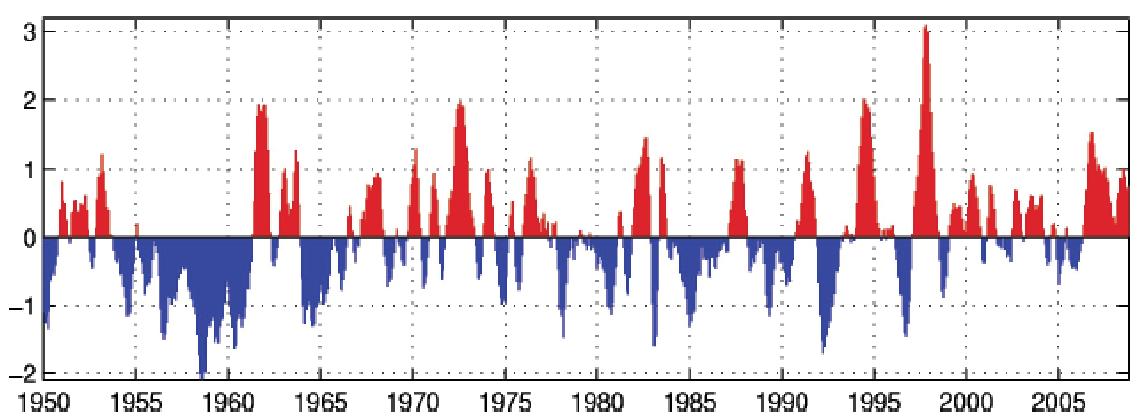
Positive Dipole Mode



Negative Dipole Mode



Dipole Mode Index (DMI)



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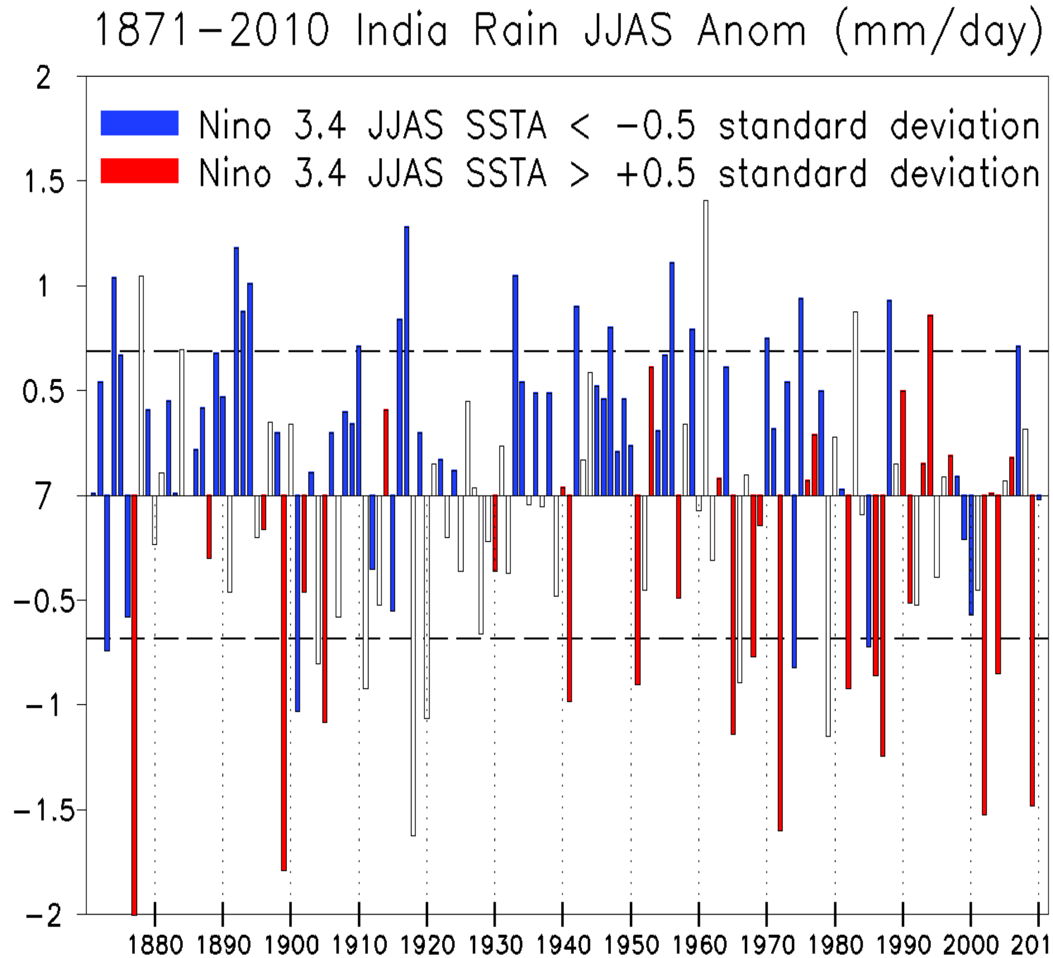
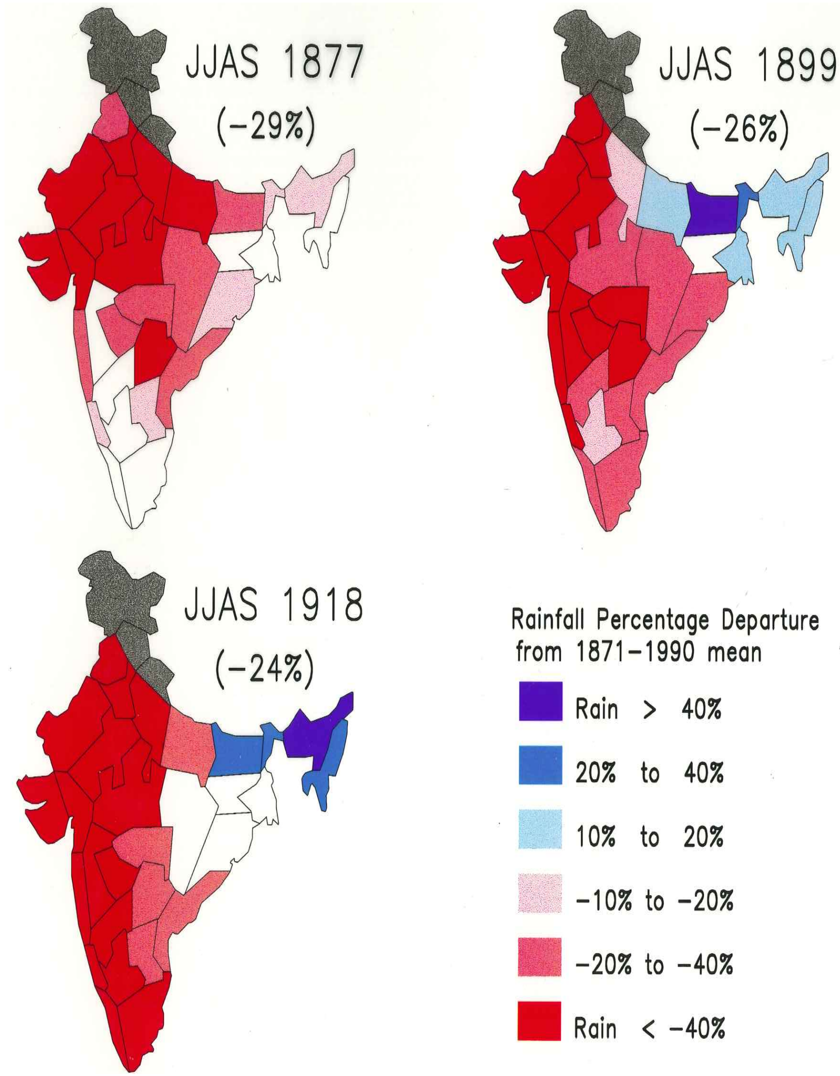
Vinayachandran et al. 2010, IASc





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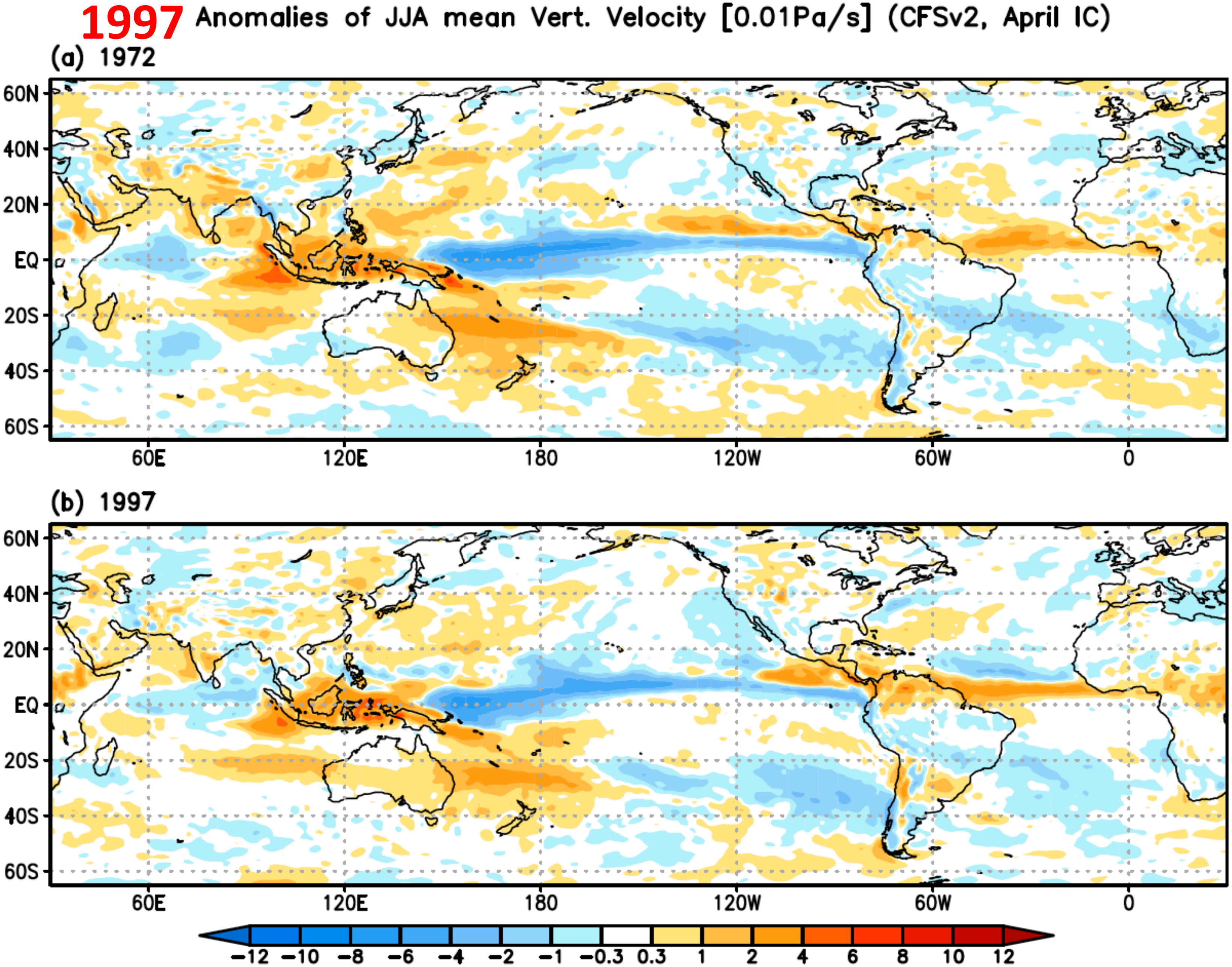
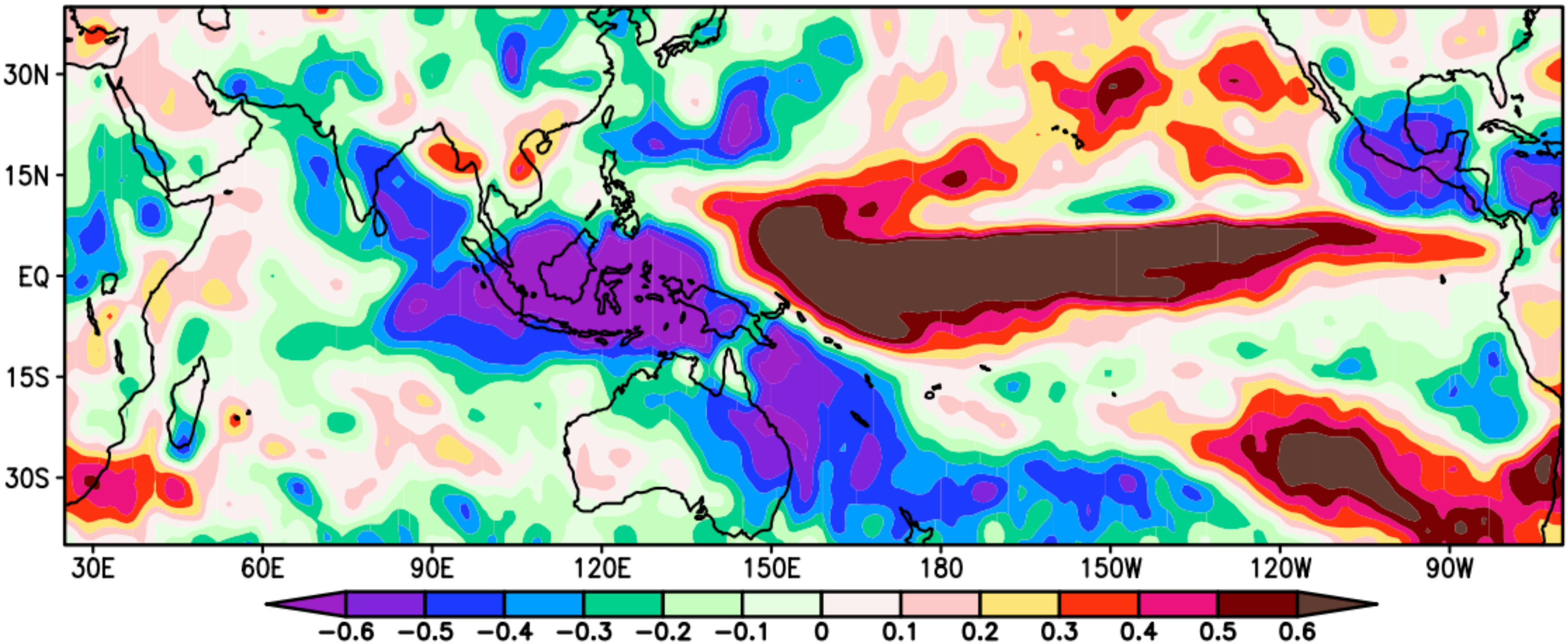
Forecast JJA Vertical Velocity (omega) for 1972 and 1997



1972

1997

Correlation Coefficient between Nino 3.4 SSTA and Observed Precip for JJAS (1981-2010)



Ravi P. Shukla & Huang (2015)

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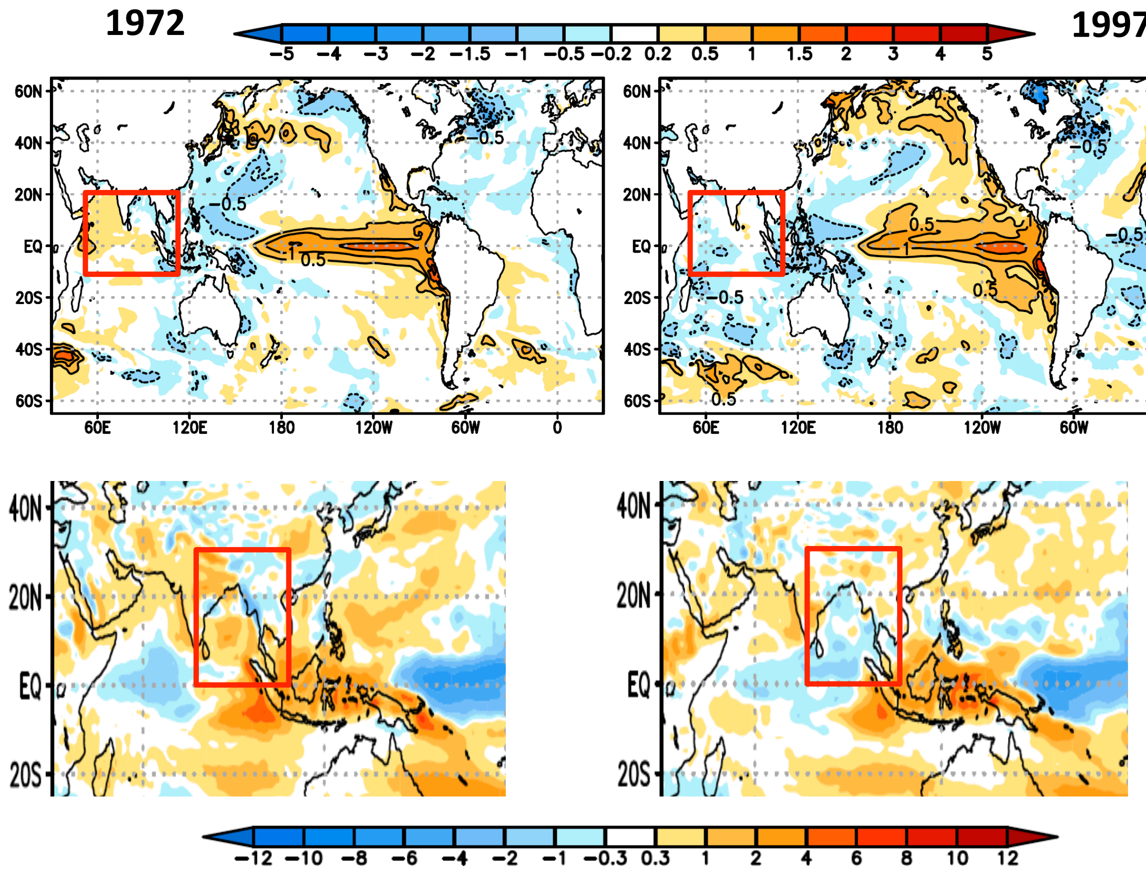
CFSv2 Forecast JJA mean SSTA and Omega (April IC)



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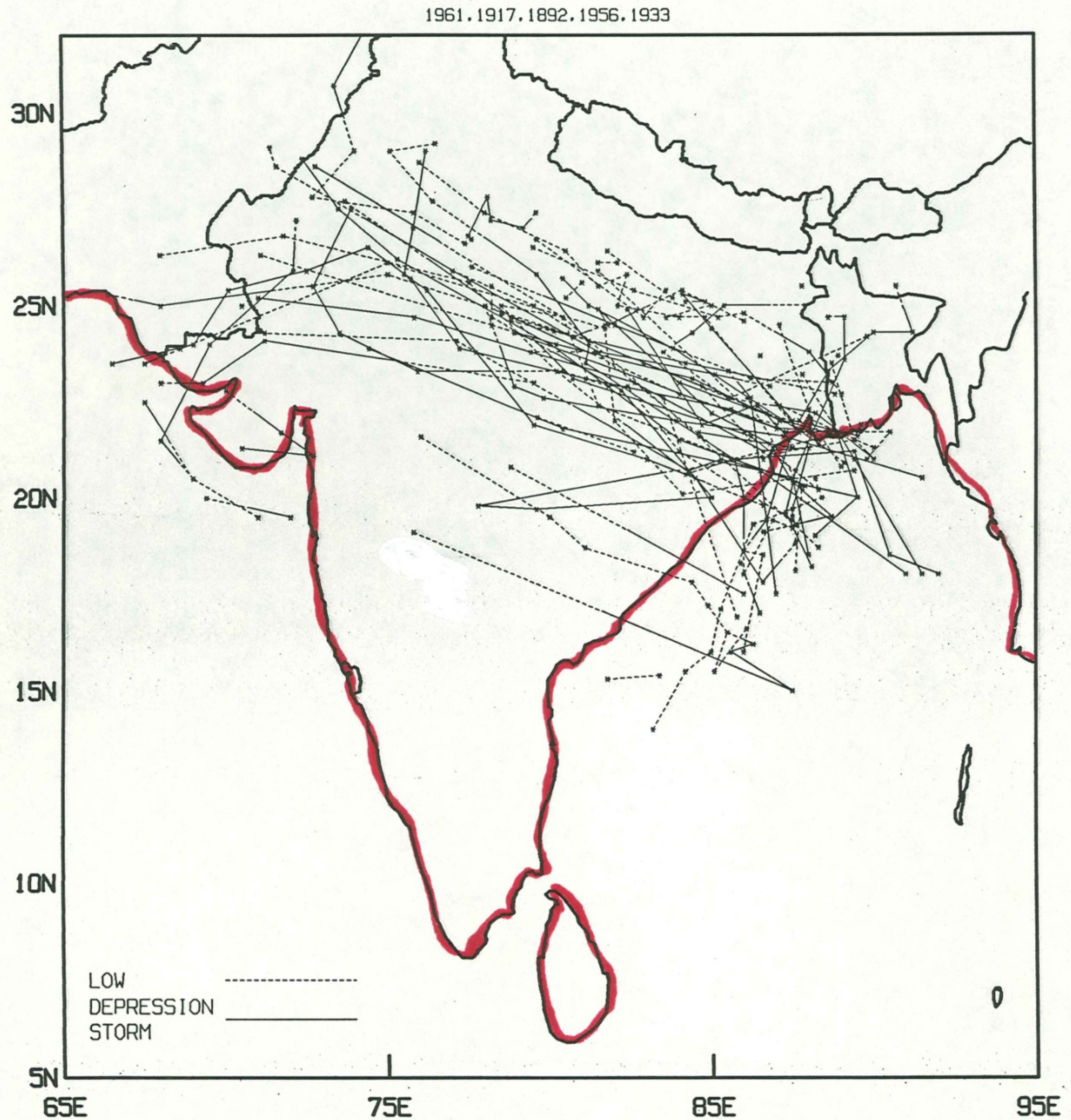
FIVE HIGHEST MONSOON RAINFALL



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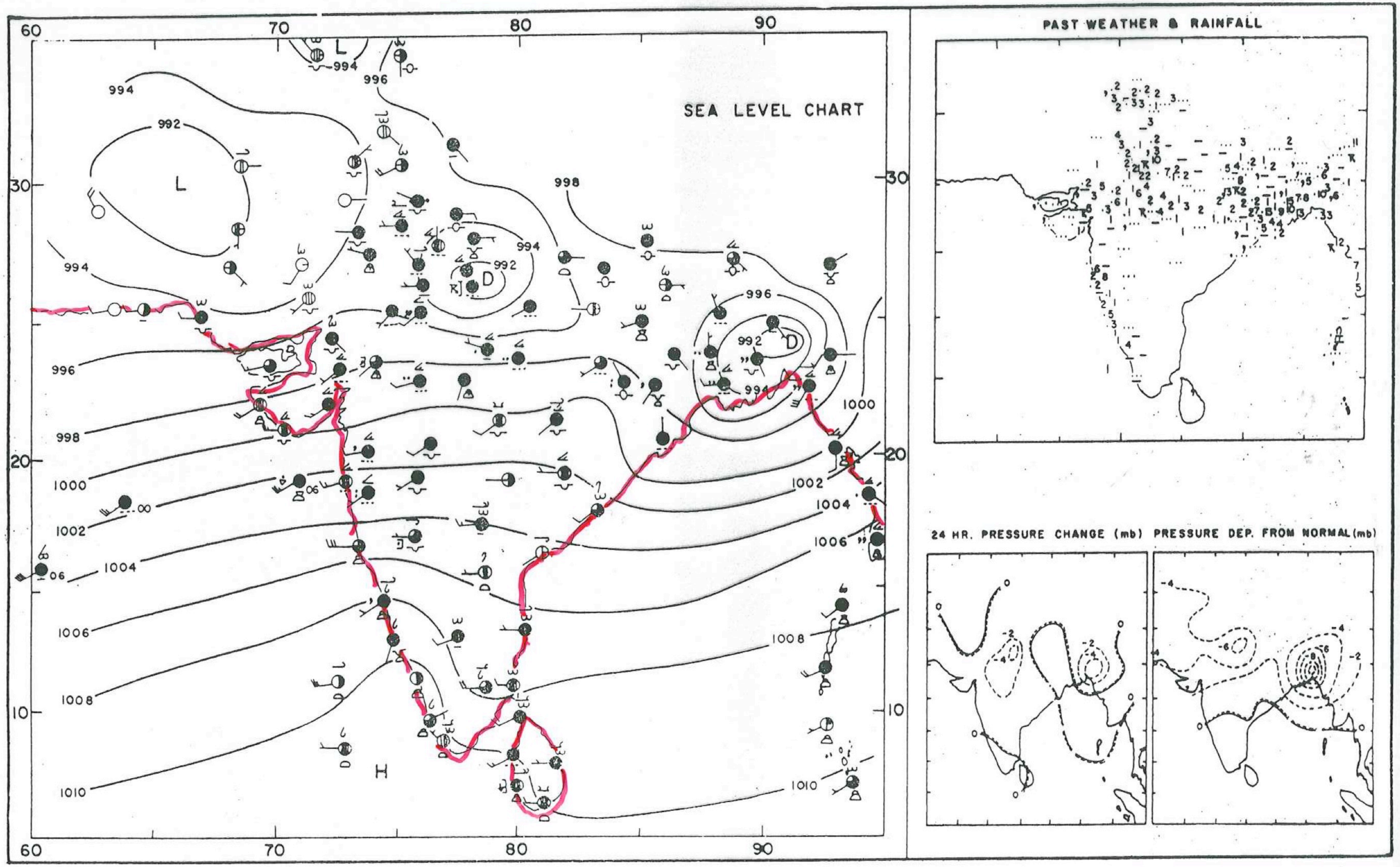
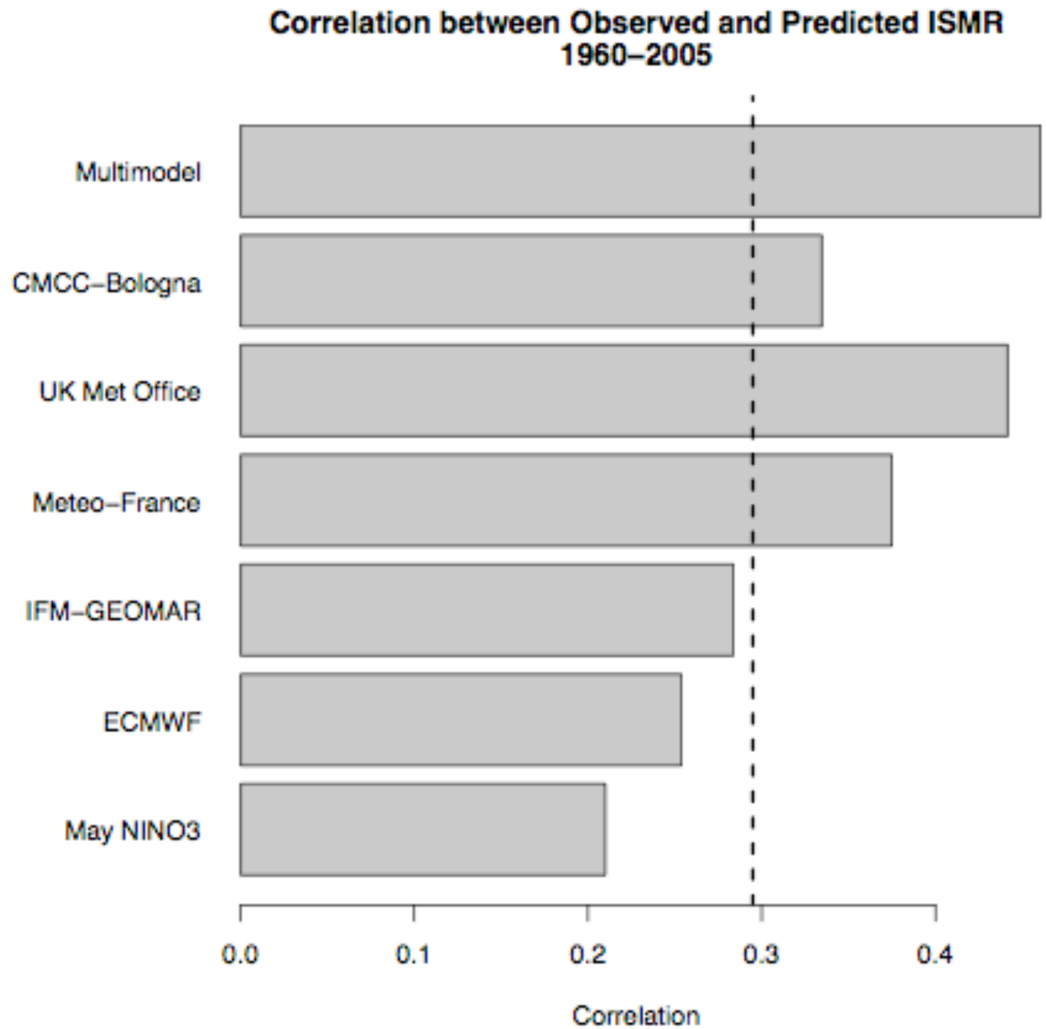


Fig.9.7(h) Synoptic charts 0300 GMT 10 July 1968.



(46 years (1960-2005); Ens.=9)

For 1960-2005 Obs,

CC (April Nino3, ISMR): −0.18

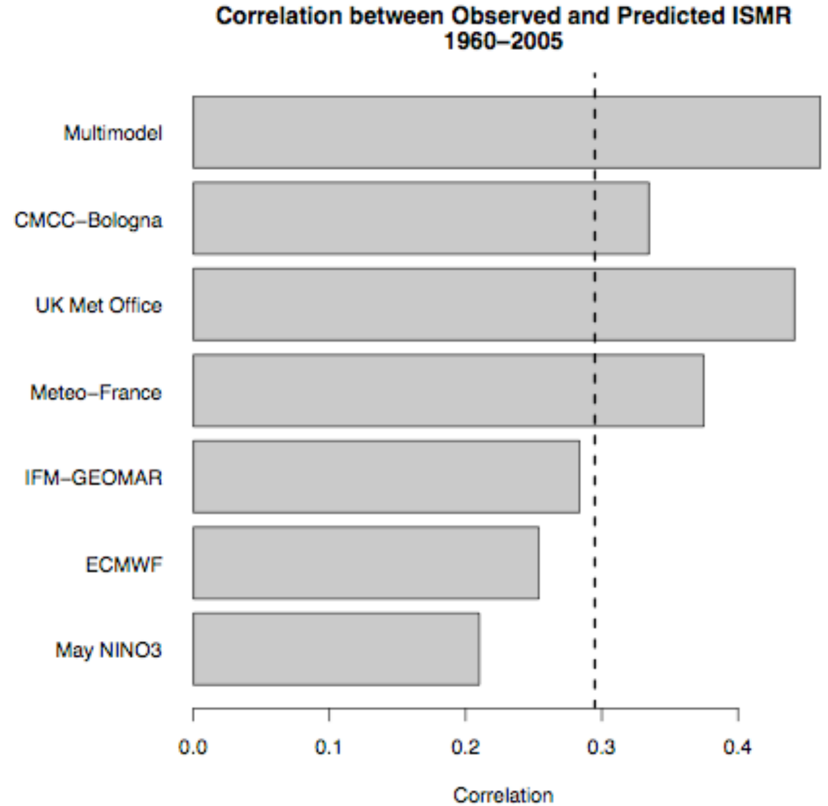
CC (May Nino3, ISMR): −0.21

Correlation between observed and predicted JJAS all-India rainfall for hindcasts in the ENSEMBLES data set for the period 1960-2005. All-India rainfall in dynamical models is defined as the total land precipitation within 70E – 90E and 10N – 25N .

Last row shows empirical prediction using observed May NINO3.

A Breakthrough in Monsoon Prediction (~ 2010)

After 50 years of climate modeling, coupled ocean-atmosphere models began to show some skill in prediction of seasonal mean rainfall over India.



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Summary of Results not shown

- **There is significant unrealized seasonal predictability. (*dilemma*: theoretical predictability of monsoon is high, but prediction skill is low)**

- **Ocean initial conditions import for skillful seasonal prediction.**

- **Realistic Land ICs enhance weekly-monthly predictions (high resolution land rainfall data required)**

- **Model predictability depends on model's fidelity to simulate climate.**

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Predictive Understanding

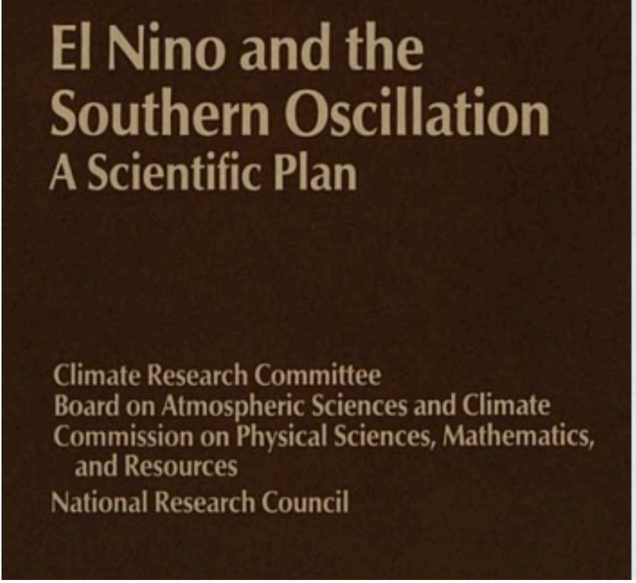
Prediction Skill and Predictability as a Metric of Understanding

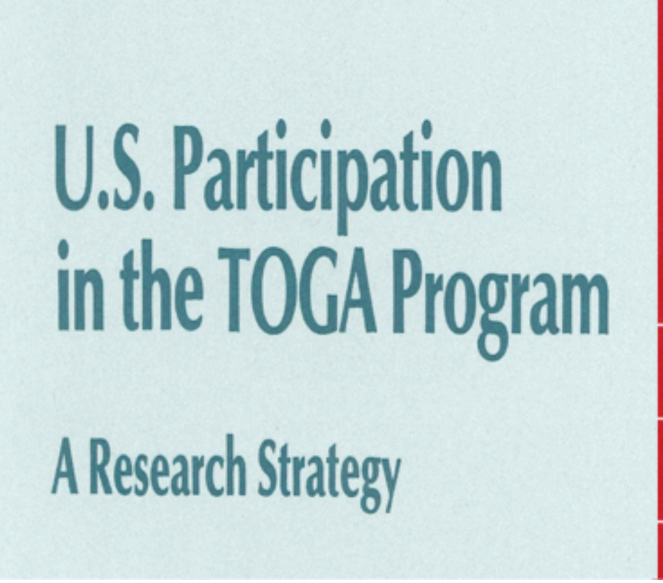
- **To enhance predictive understanding, a vigorous, collaborative, and simultaneous effort is needed for model development, predictability research, and seamless prediction of weather and climate. Diagnostic evaluation and prediction must be an integral part of model development.**

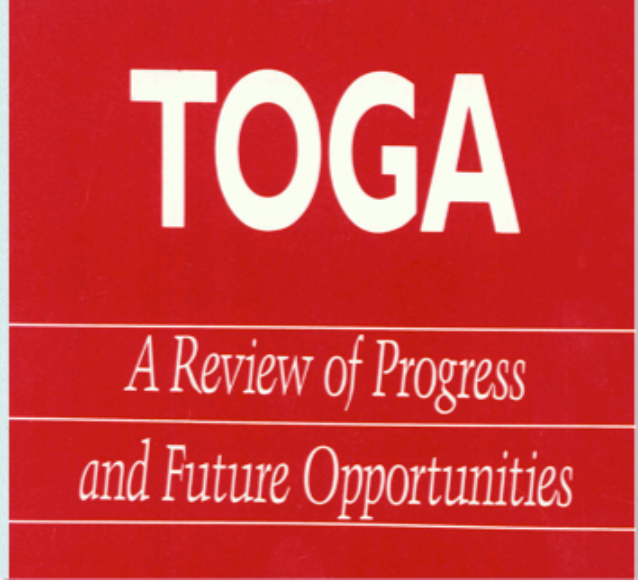
- **A multi-institutional (multinational) enhanced research effort and computational infrastructure is needed to develop the next generation of high fidelity climate models for improved climate predictions.**

- **Advances in NWP did not come by some major theoretical or conceptual breakthrough; it came by comprehensive, persistent, and simultaneous efforts in prediction, model development and predictability research by a team of qualified scientists.**

  (A similar effort for Dynamical Seasonal Prediction is needed.)

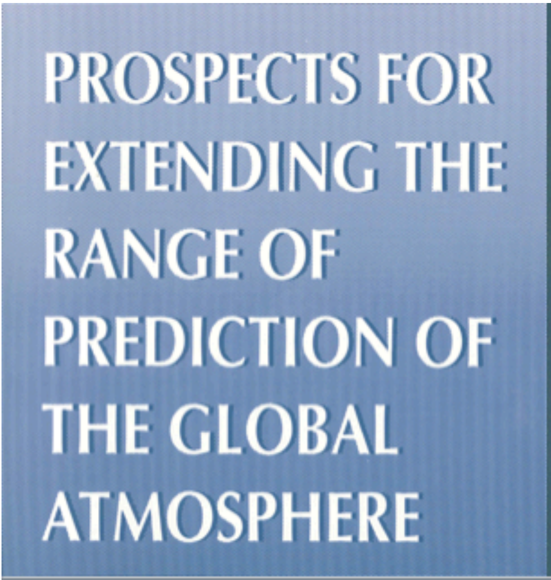


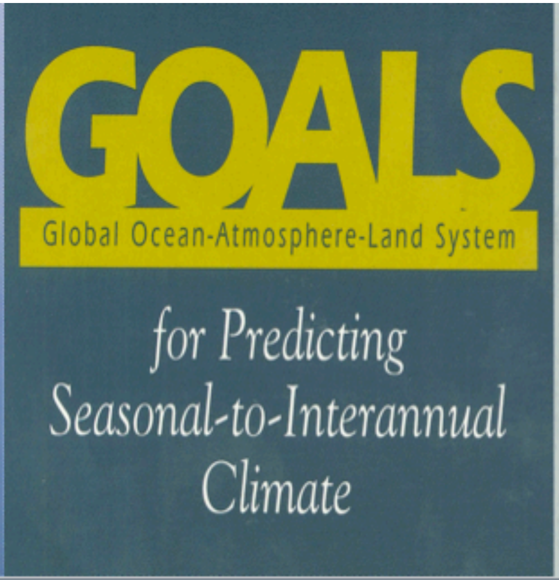


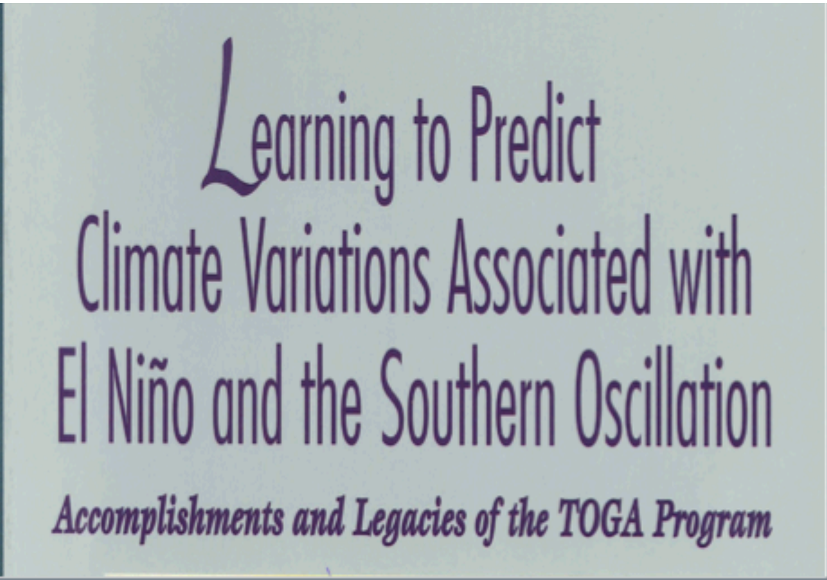


1983 1986 1990

1991 1994 1996







Analysis of Variance: F as a measure of predictability

E is ensemble size (e = 1,2,3 - - - E); Y is total years (y = 1,2,3 - - - Y); P is the predicted variable

Measure of predictability is

$$F = E\frac{\hat{\sigma}_S^2}{\hat{\sigma}_N^2}$$

Ratio of Signal and Noise Variance

where

$$\hat{\sigma}_S^2 = \frac{1}{Y-1}\sum_{y=1}^{Y}\left(\overline{P}_y - \overline{\overline{P}}\right)^2$$

Signal Variance

$$\hat{\sigma}_N^2 = \frac{1}{Y(E-1)}\sum_{y=1}^{Y}\sum_{e=1}^{E}\left(P_{y,e} - \overline{P}_y\right)^2$$

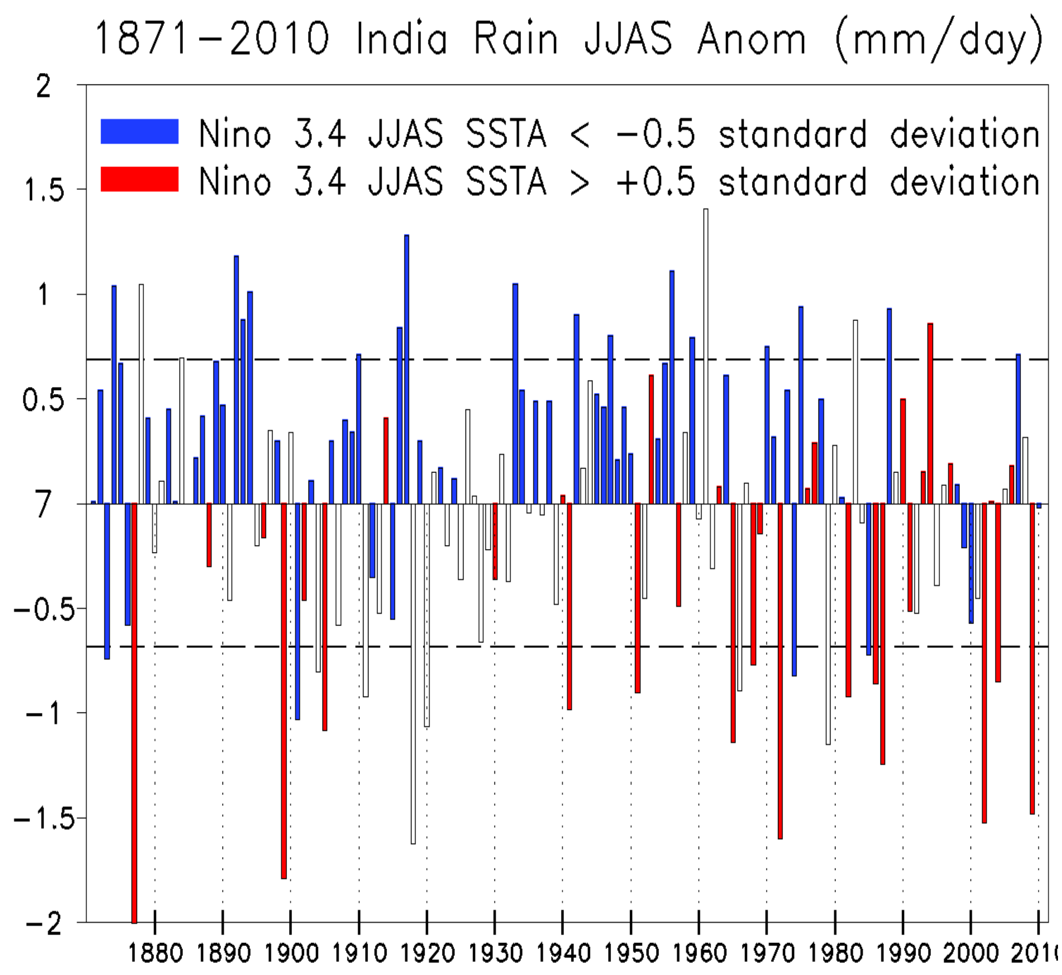
Noise Variance

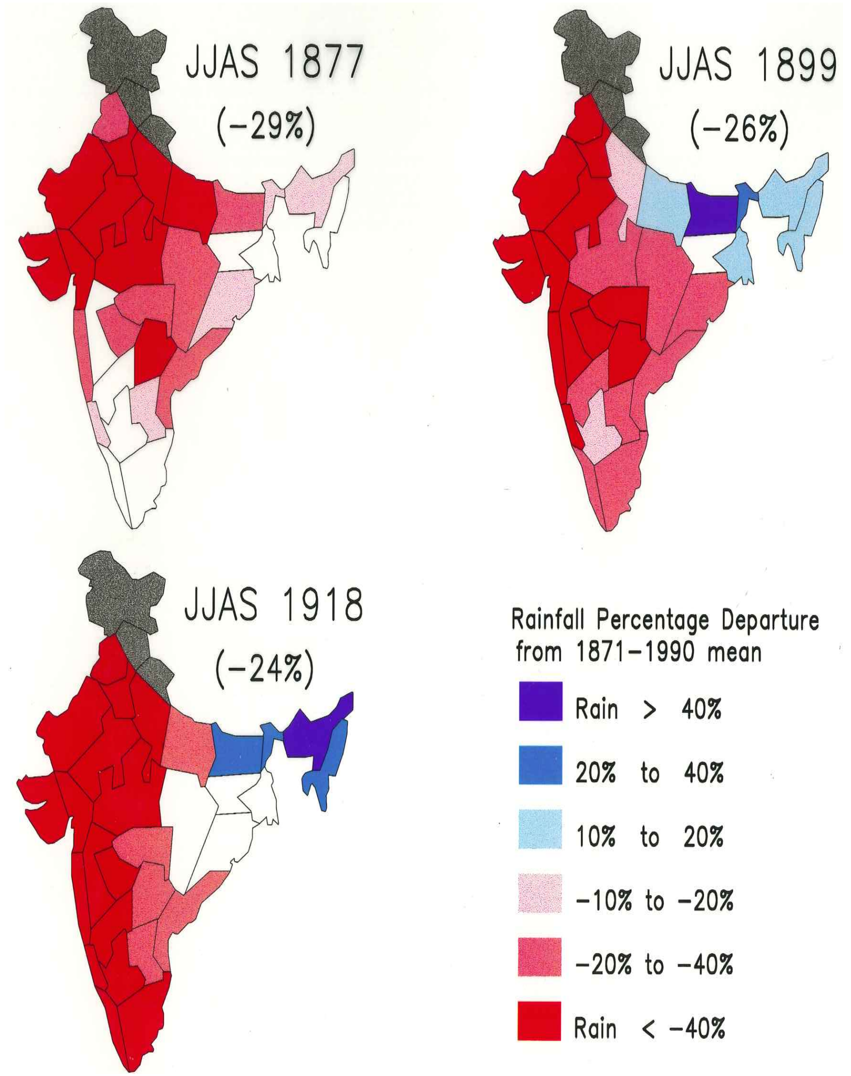
$$\overline{P}_y = \frac{1}{E}\sum_{e=1}^{E} P_{y,e}$$

$$\overline{\overline{P}} = \frac{1}{Y}\sum_{y=1}^{Y}\overline{P}_y$$

For samples drawn independently from the same normal distribution, and for $Y = 46$ and $E = 9$, the 5% significance threshold of F is 1.40

Please find the value of F from the F distribution table for a given value of **Y** and **E** for x% significance threshold.





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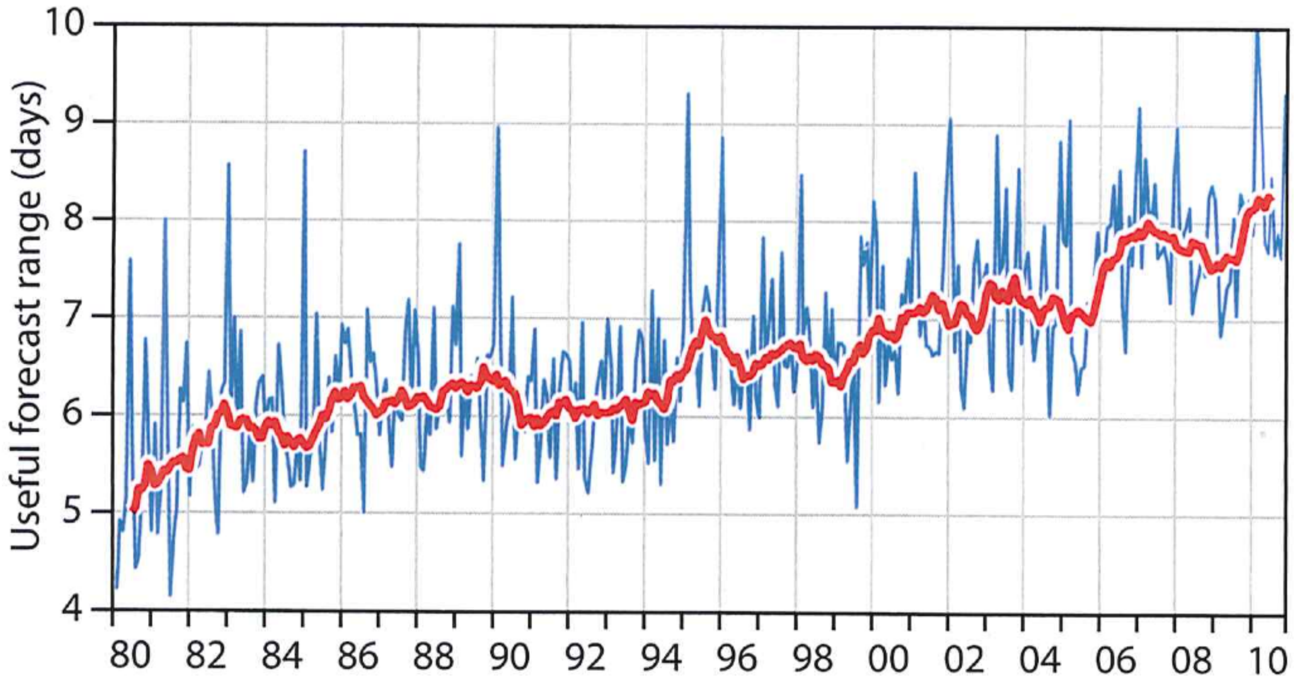
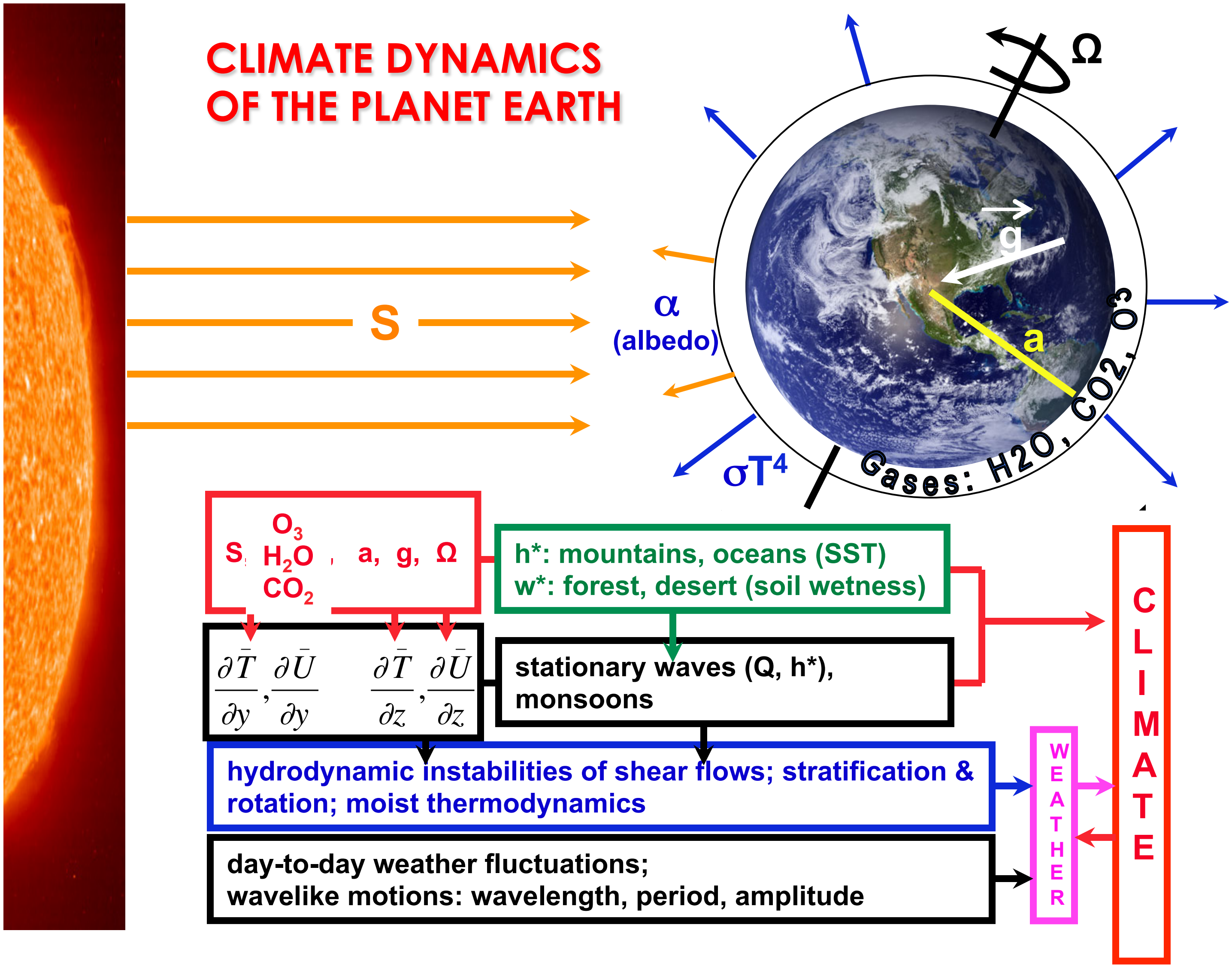
After FGGE: Skill of NWP has steadily improved



After TOGA: No significant improvement in seasonal prediction of regional circulation and rainfall by coupled climate models.

- Inaccurate simulation of non-ENSO heat sources
- Large biases in climate models

CLIMATE DYNAMICS OF THE PLANET EARTH



Sources of Predictability (Signal) and Processes Limiting Predictability (Noise)

	Signal	Noise
Weather: 1-10 Days	Initial conditions (IC) of atmosphere; prescribed boundary conditions at Earth's surface (SST, land (L), soil wetness, sea ice, snow, etc.	Turbulence, instabilities, errors in IC's
Intraseasonal Variations: 10 - 100 Days	IC of atmosphere and upper-ocean and land; convection dynamics interaction; A-O interaction	Weather variations
Seasonal to Interannual Variations: 100 – 100 Days	IC of A, O, L, and A-O-L interactions	Weather and intraseasonal variations
Climate Change	Human effects (Greenhouse Gases, land-use changes)	ENSO, decadal and multidecadal variations, volcanoes

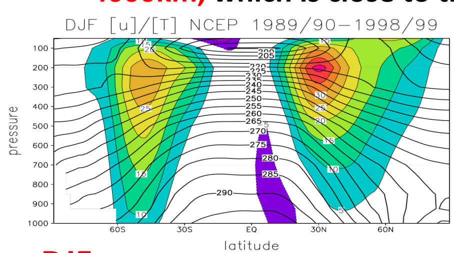
Baroclinic Development:

7.1 Hydrodynamic Instability

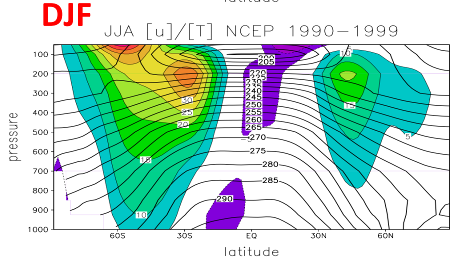
“Specifically, we discuss the role of dynamical instability of the mean flow in accounting for the growth of synoptic-scale disturbances.”

“A zonal-mean flow field is said to be hydrodynamically unstable if a small disturbance introduced into the flow grows spontaneously, drawing energy from the mean flow.”

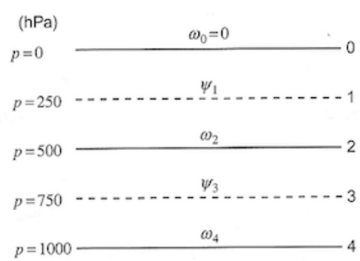
“Under normal conditions of static stability the wavelength of maximum stability is about 4000km, which is close to the average wavelength for mid-latitude synoptic systems.”



DJF



JJA



Arrangement of variables in the vertical for the two-level baroclinic model.

$$\frac{\partial}{\partial t}\left(\frac{\partial \psi}{\partial p}\right) = -\mathbf{V}_{\psi}\cdot\nabla_h\left(\frac{\partial \psi}{\partial p}\right) - \frac{\sigma}{f_0}\omega \qquad (7.3)$$

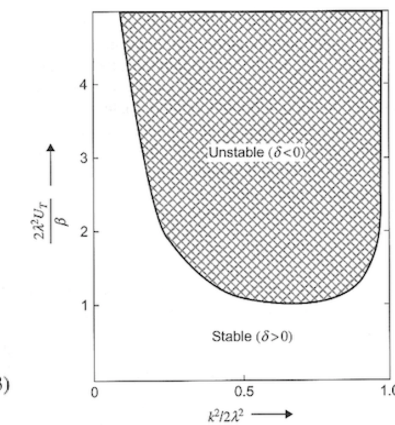


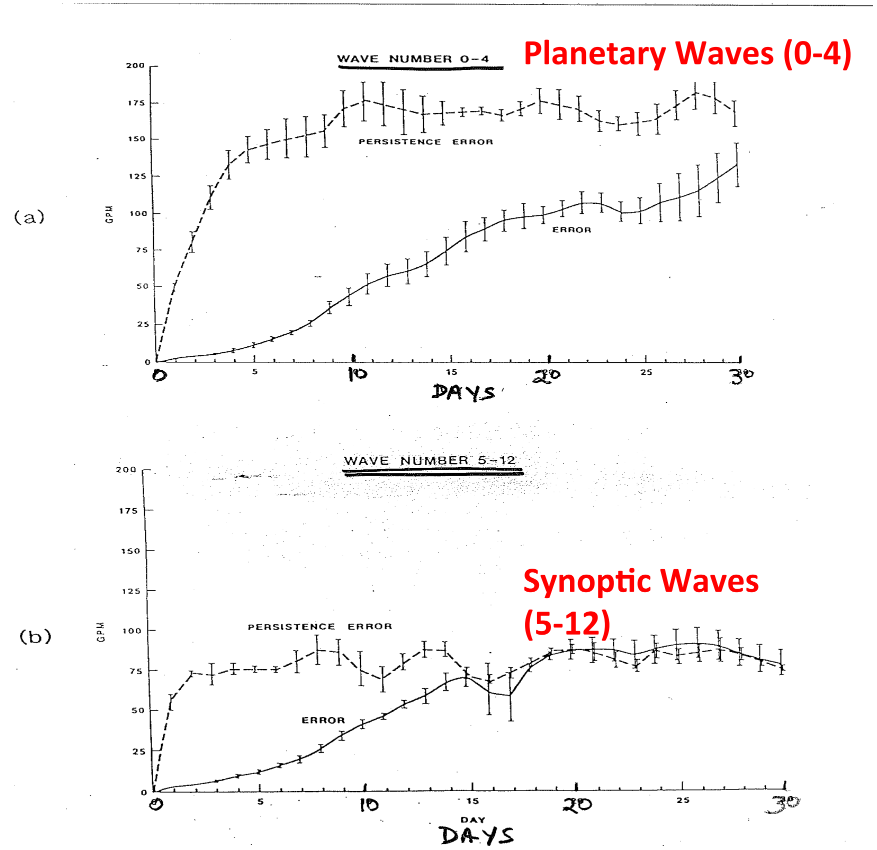
FIGURE 7.3 Neutral stability curve for the two-level baroclinic model.

An Introduction to Dynamic Meteorology by Holton & Hakim (2013)

Dynamical Predictability: Beyond Weather

Predictability of Planetary Waves and Synoptic Waves

1. Largest Variance in Low Frequency Long Waves
2. Longer Predictability for Planetary Waves



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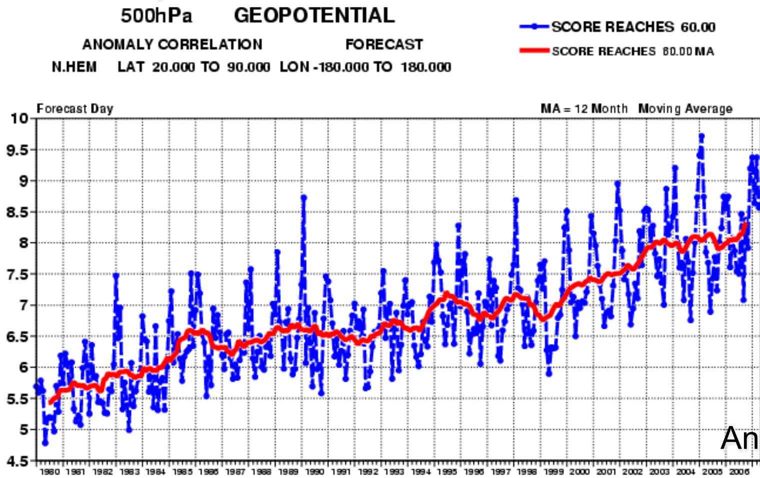
ERA Forecast Verification

Anomaly Correlation of 500 hPa GPH, 20-90N



ERA Forecast Verification

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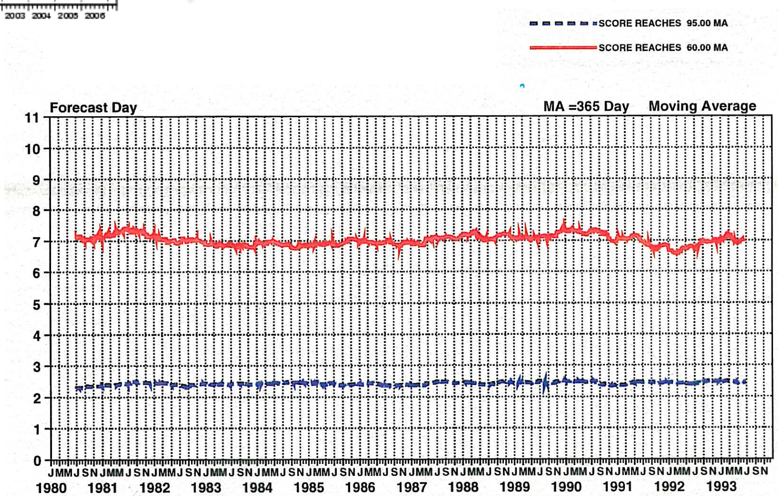
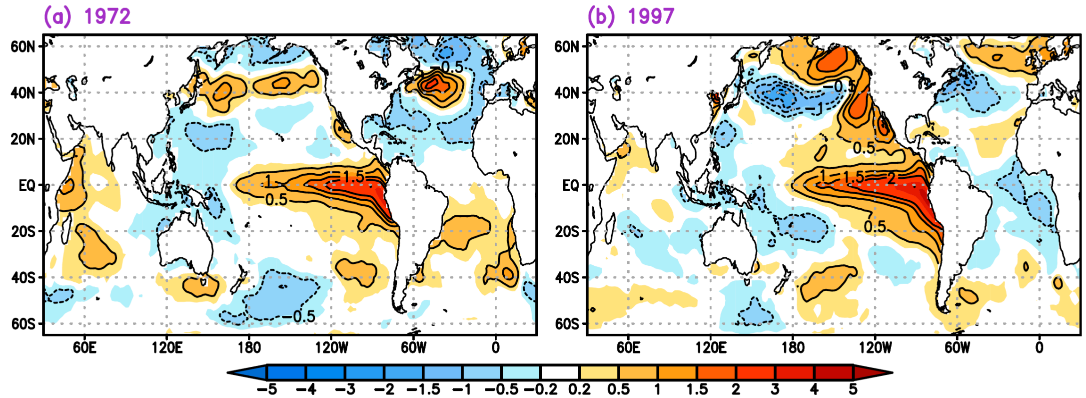


ENSO & ISMR for JJAS 1972 and 1997

1972 **1997**



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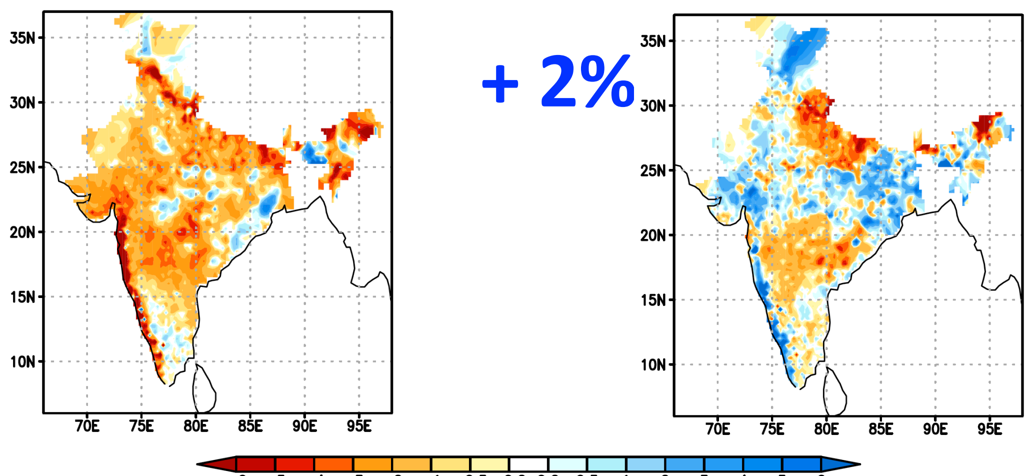

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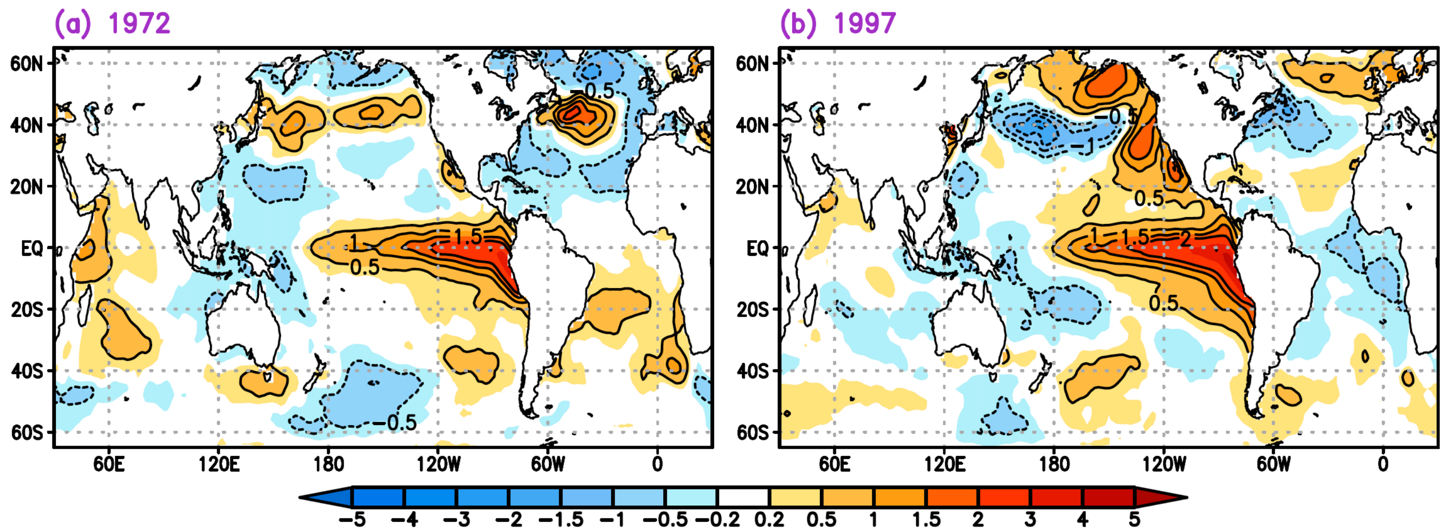
ENSO & ISMR for JJAS 1972 and 1997

1972 | 1997



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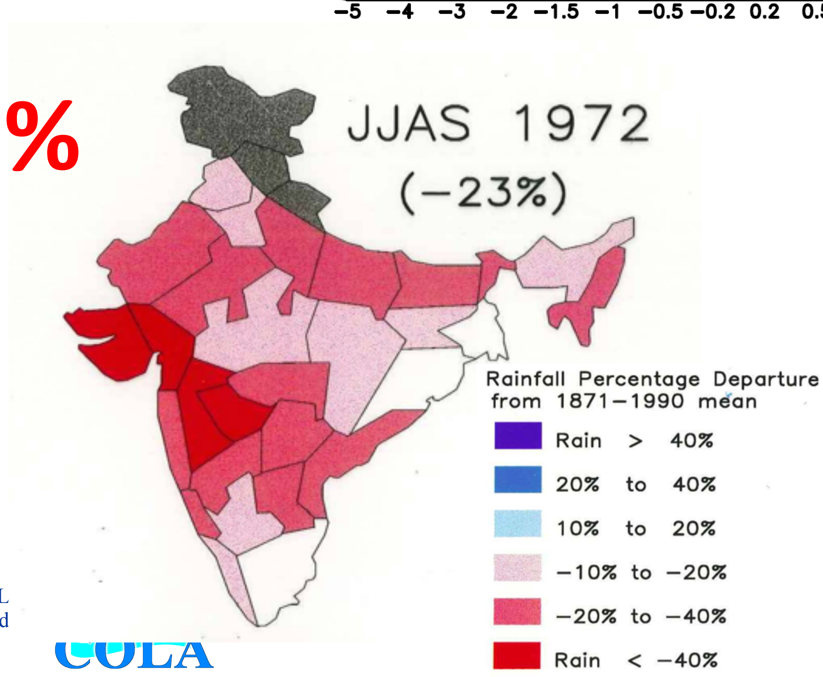

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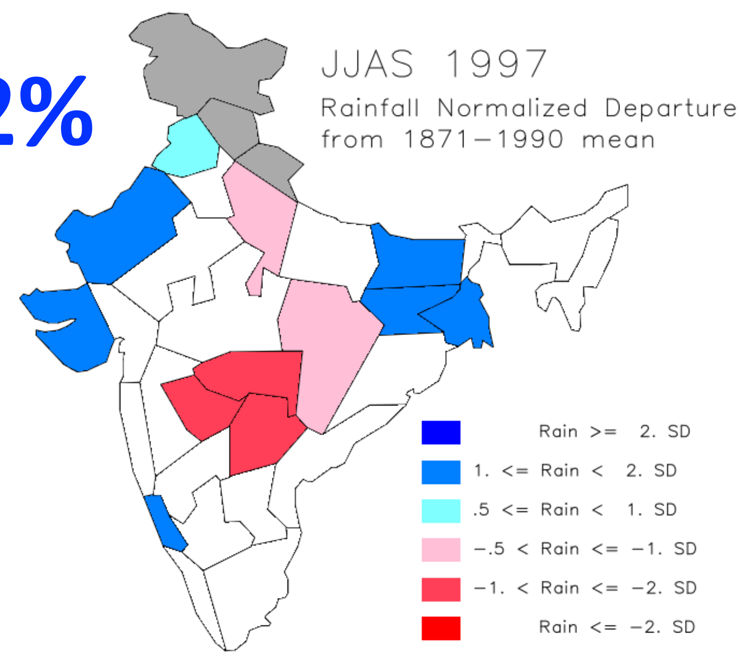
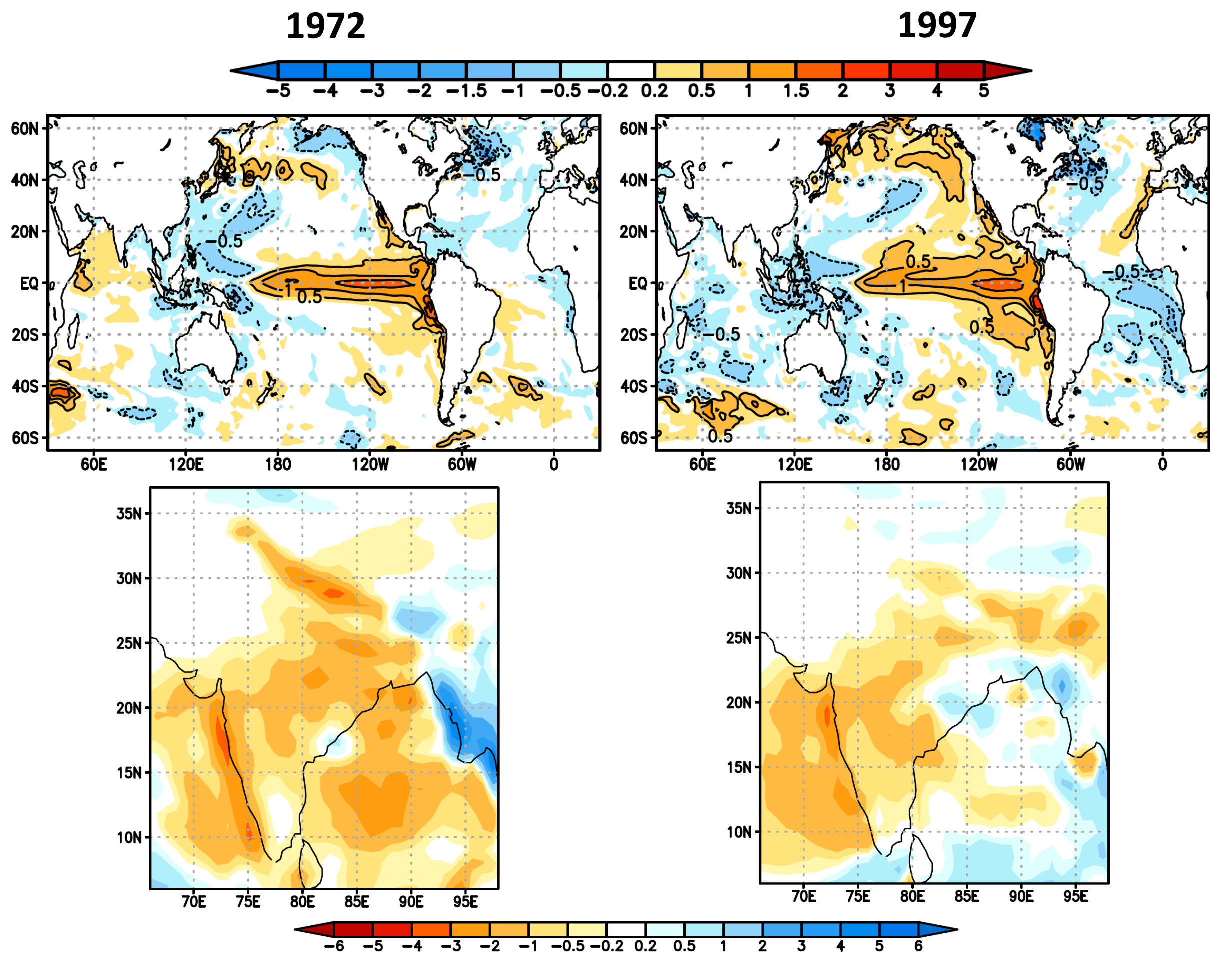


CFSv2 Forecast JJA mean SSTA and Precip. (April IC)



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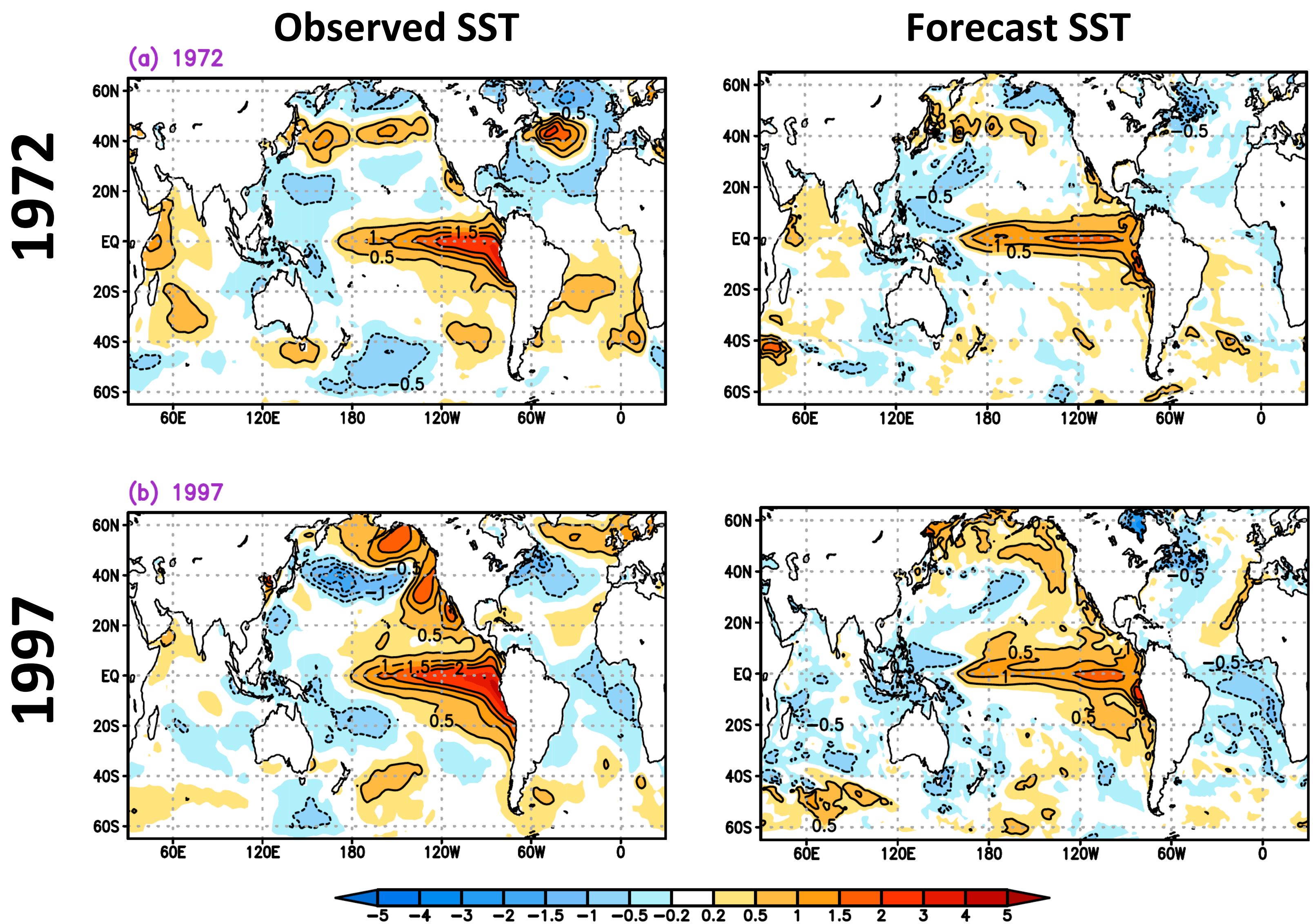
Obs. and Forec. SST Anomalies for JJA (April IC)



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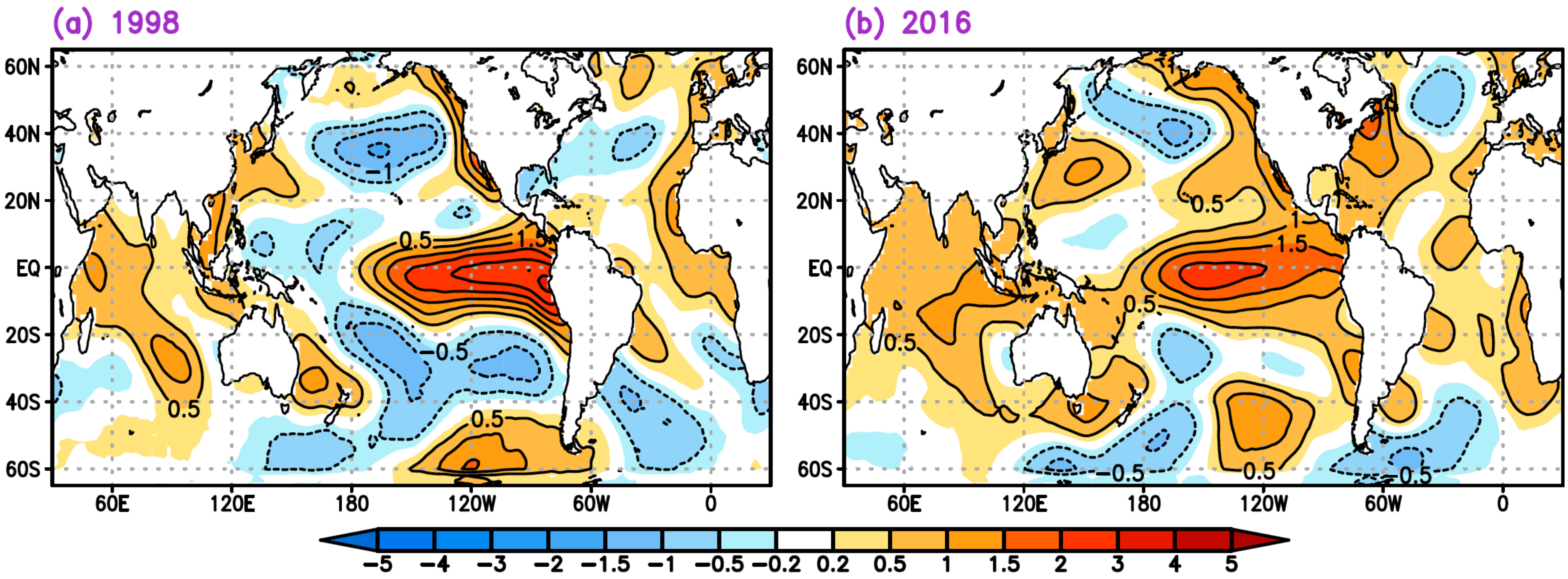
Observed JFM SST anomalies for 1998 and 2016



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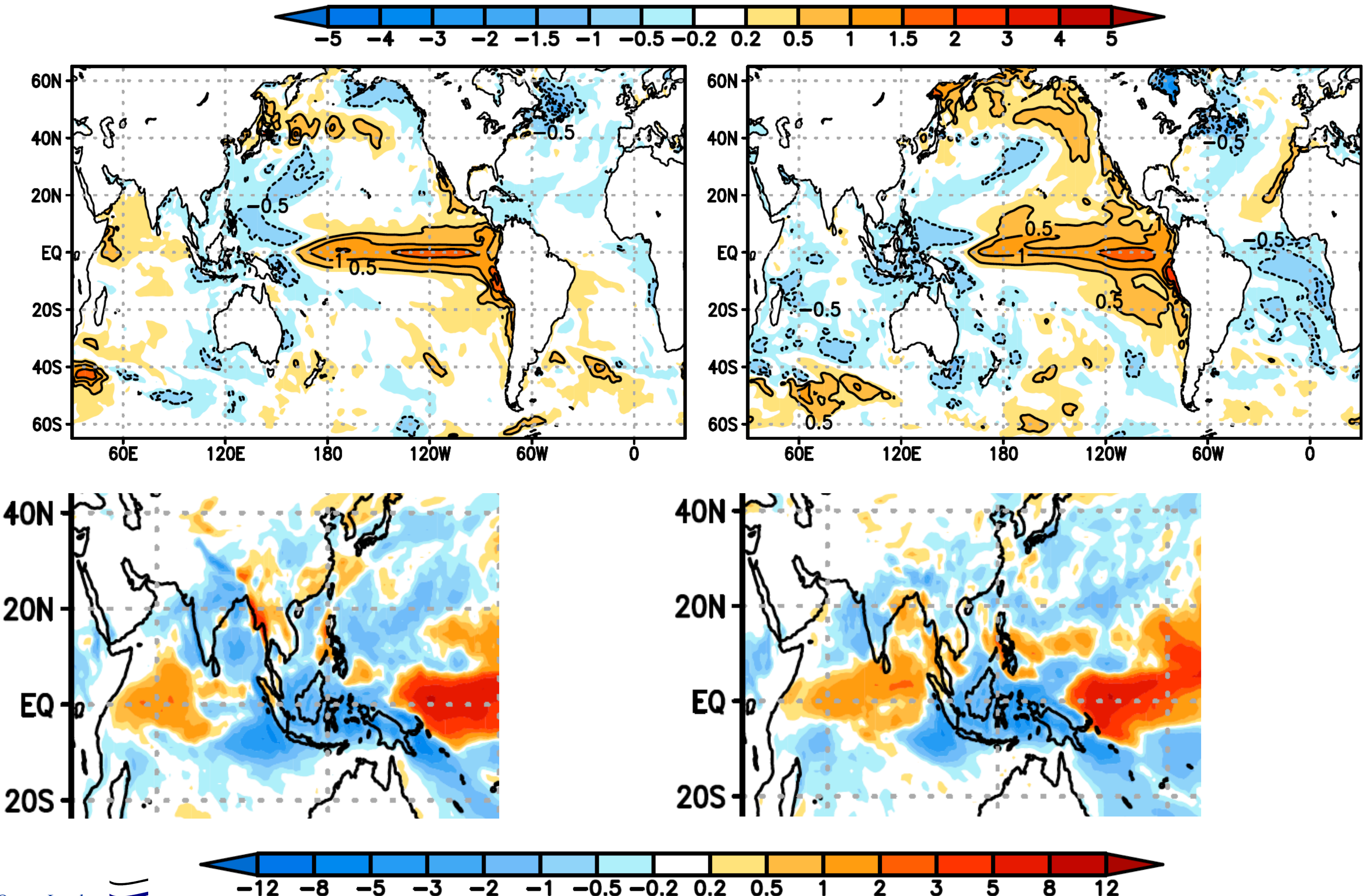
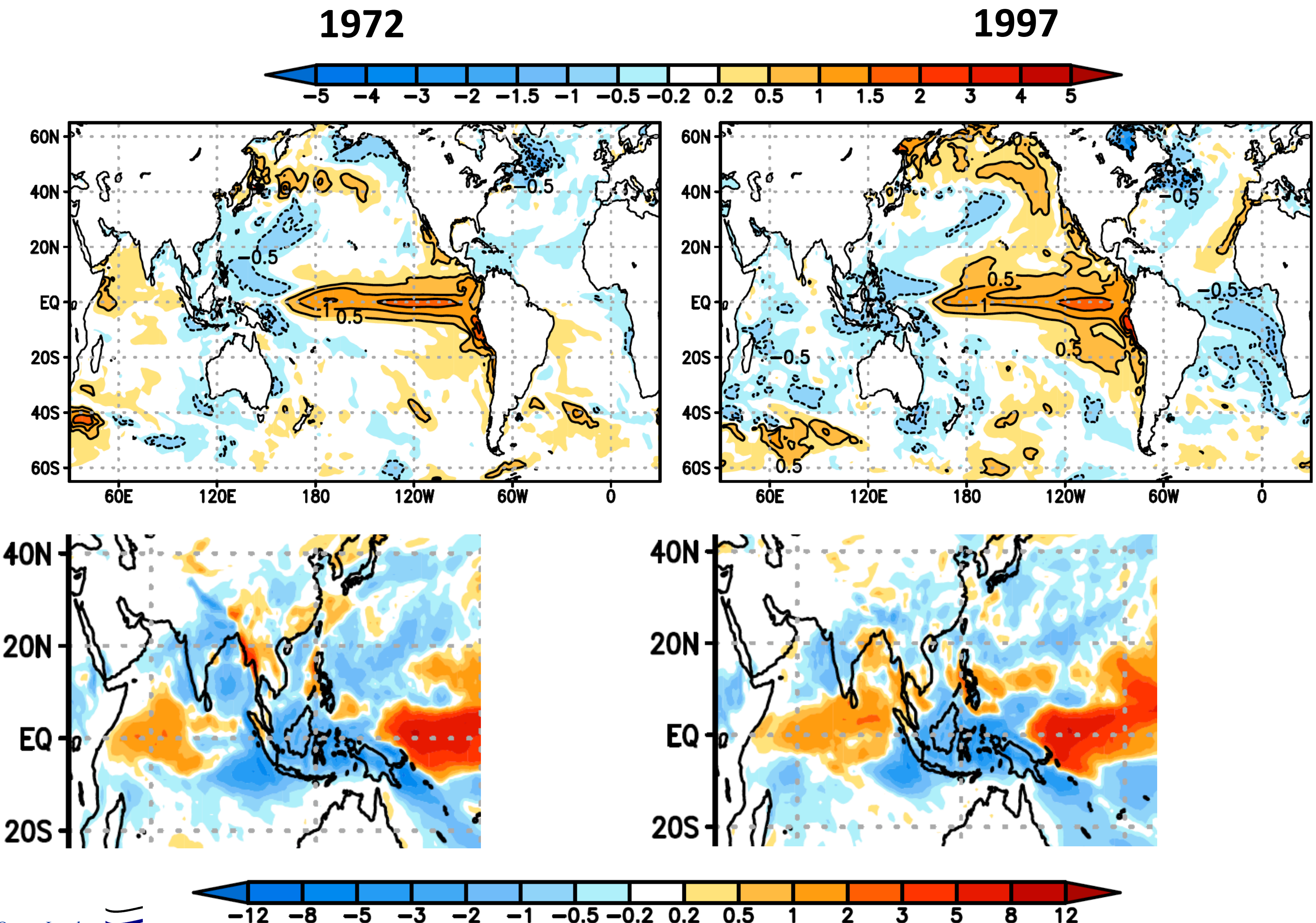
CFSv2 Forecast JJA mean SSTA and Precip. (April IC)

1972 1997



CFSv2 Forecast JJA mean SSTA and Precip. (April IC)



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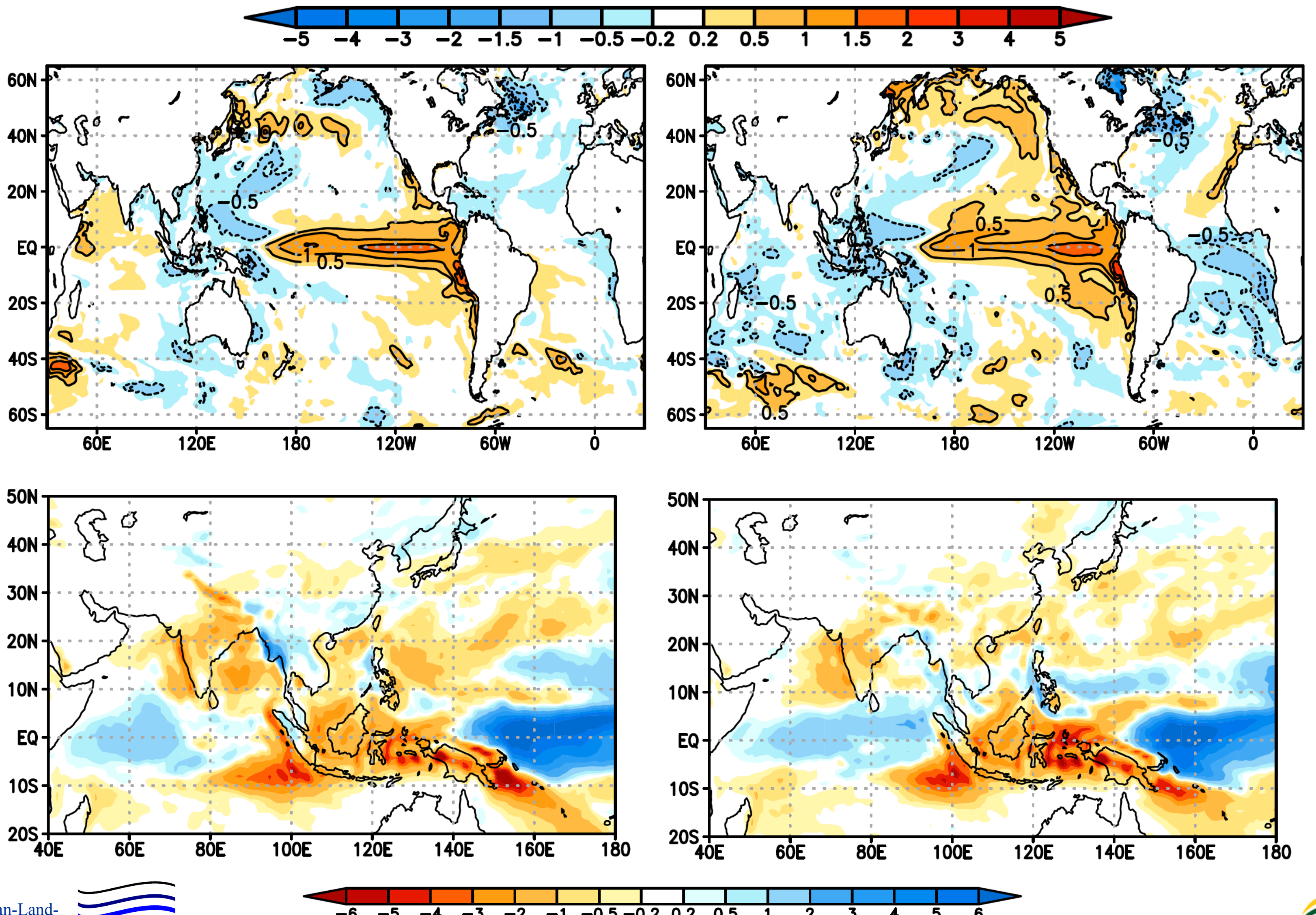
CFSv2 Forecast JJA mean SSTA and Precip. (April IC)

1972 1997



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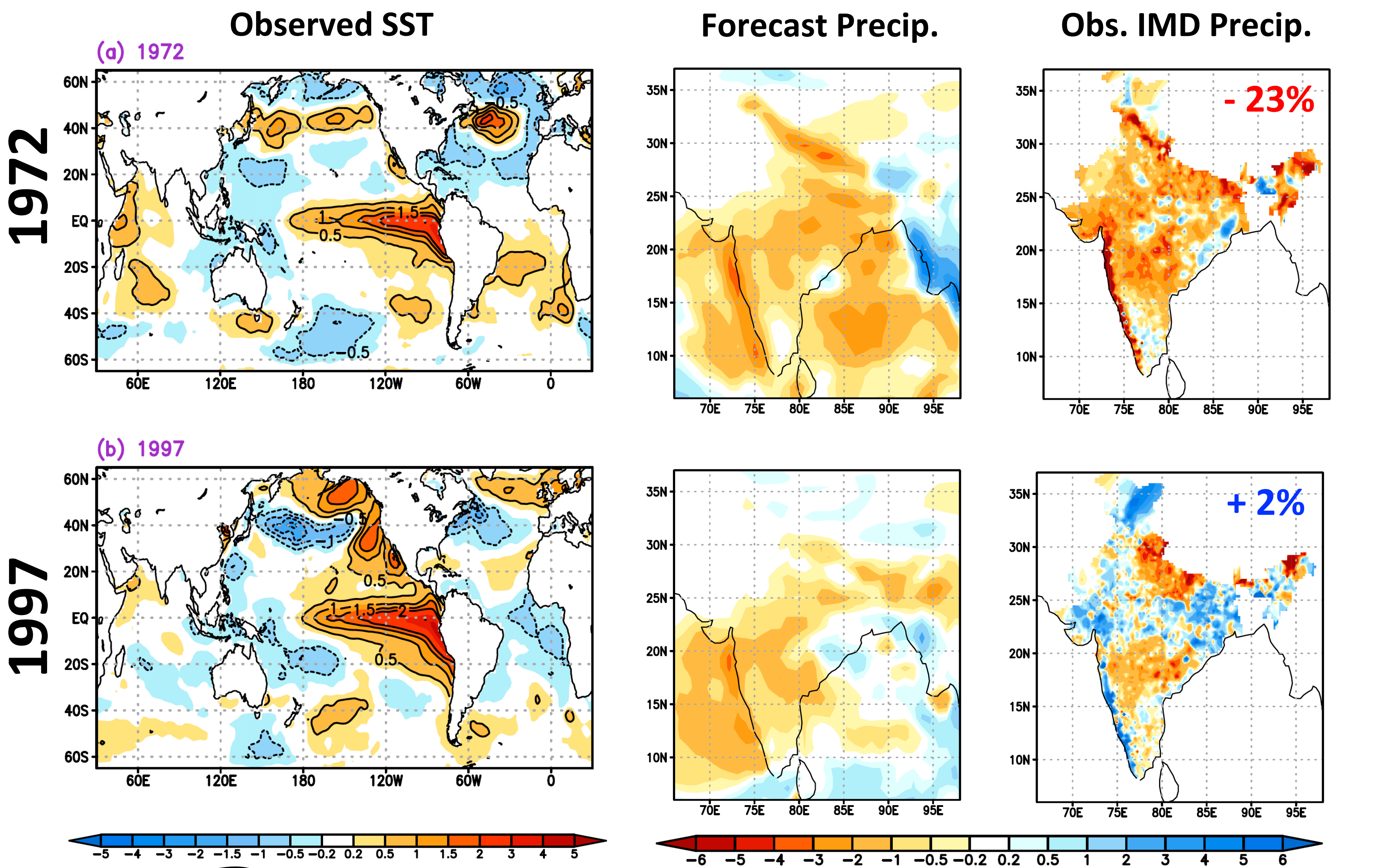
ENSO & ISMR for JJAS 1972 and 1997



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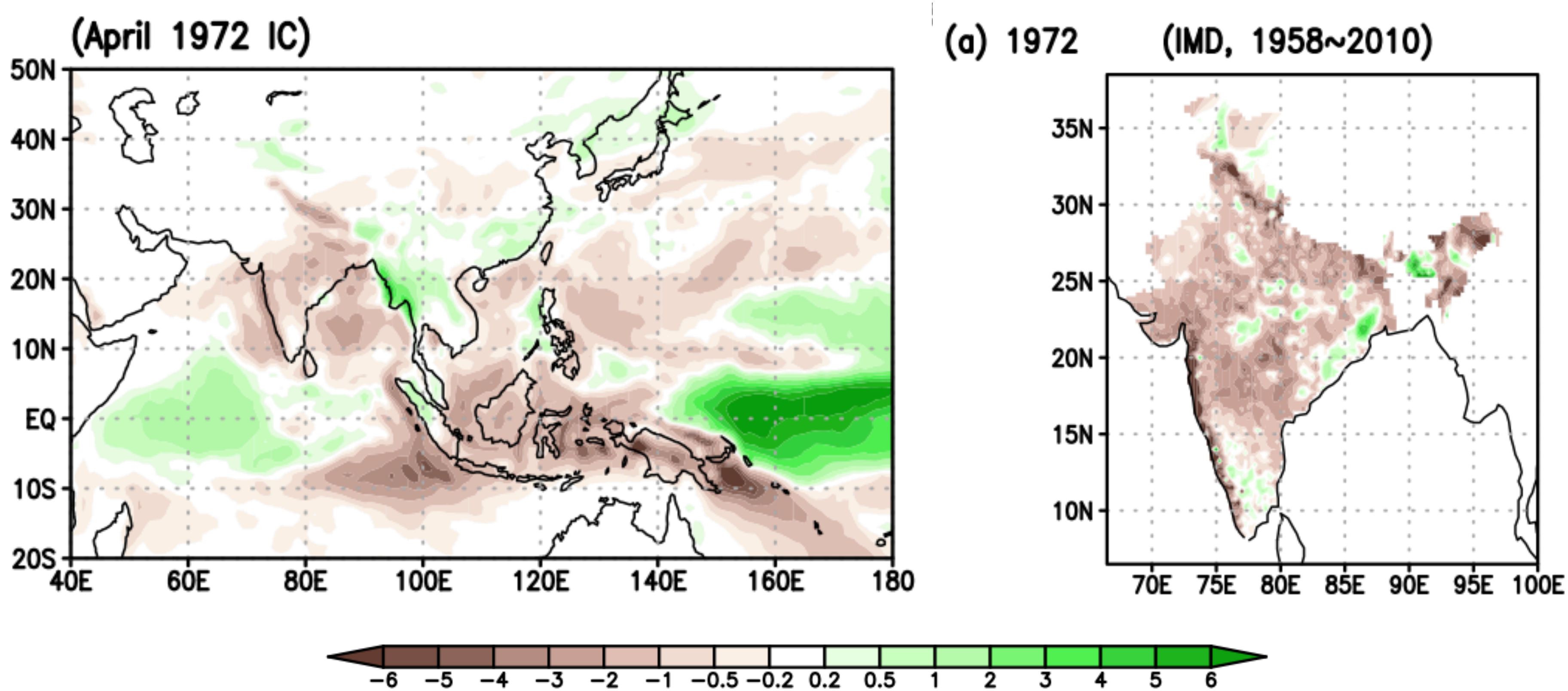
Forecast (April 72, IC) and Observed (IMD) Rainfall Anomalies for JJAS 1972 (mm/day)

Forecast Model Anomaly CFSv2 **Observed Anomaly IMD**



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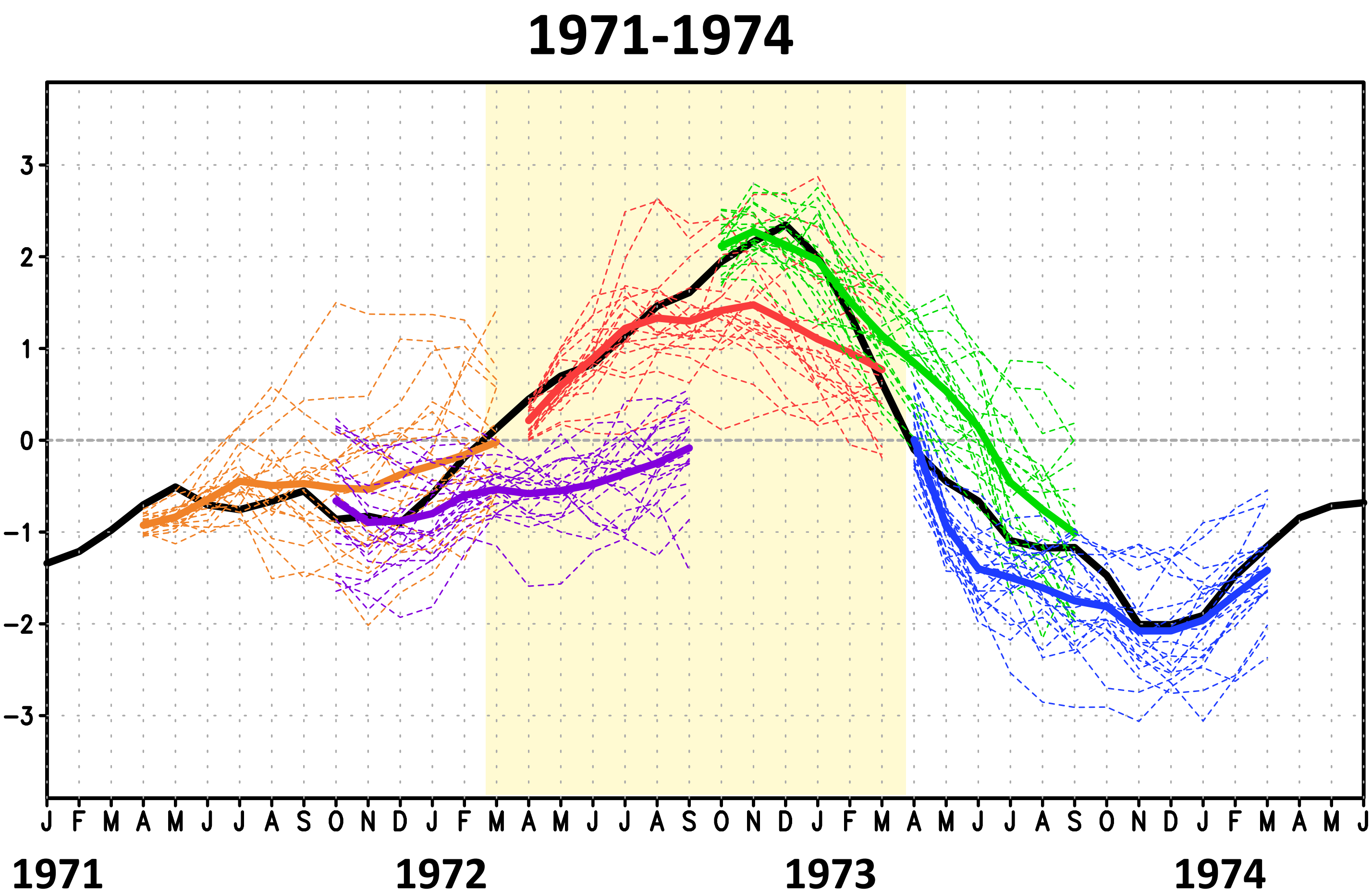
Obs. and Forecast SST Anomalies for April and Oct. IC (CFSv2)



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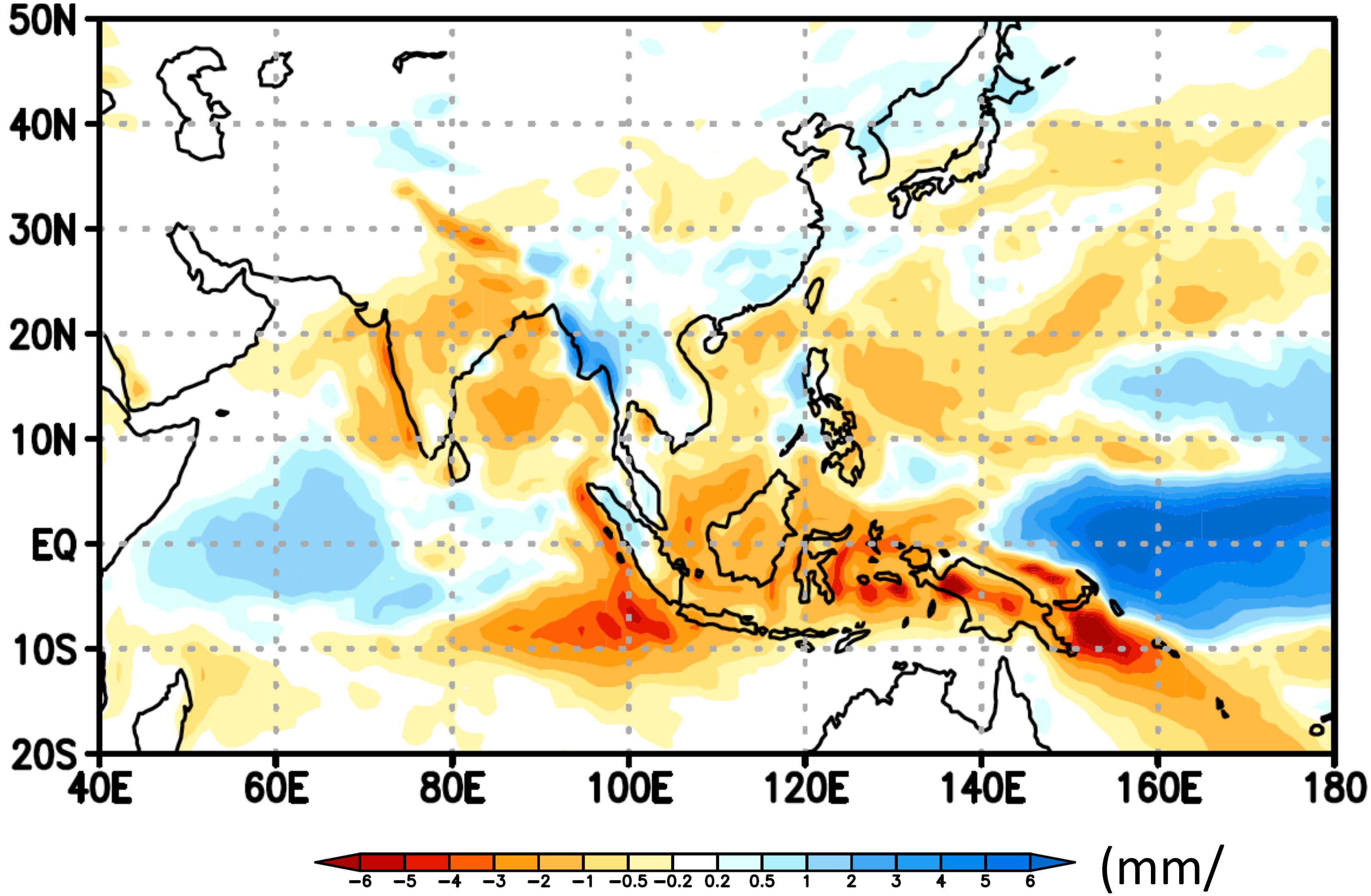
CFSv2 Forecast JJA 1972 mean Precip. anomaly (April IC)



(mm/day)

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