Jun. 23, 2014, ICTP TTA-3, Trieste, Italy

Seasonal Prediction of Asian Summer Monsoon Rainfall with Coupled Models: Problems and Prospects

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Outline

1. Introduction: DSP with 4 Models
(GFDL, NASA, NCAR, NCEP)
2. Influence of Ocean IC
3. Influence of Land IC
4. Quantifying Predictability
5. Model Fidelity and Predictability
6. Summary

Dynamical Seasonal Prediction (DSP)

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

DSP = NWP + IC of Ocean, Land, Atmosphere

- *dynamically coupled and consistent IC*
- *Global ocean (especially upper ocean); sea ice (volume)*
- *Global Atmos. including stratosphere (IC)*
- *Global GHG (especially CO_2, O_3)*
- *Global land (soil moisture, vegetation, snow depth) IC*

Tier 1: Fully coupled models (CGCM) to predict Boundary Forcing

Tier 2: Predict Boundary Forcing separately; use AGCM

- **(NWP=Atmos. IC + SST IC)**

DYNAMIC SEASONAL PREDICTION WITH 4 STATE-OF-THE-ART COUPLED GCMS
(NCEP/CFSV2, GFDL, NCAR, NASA)

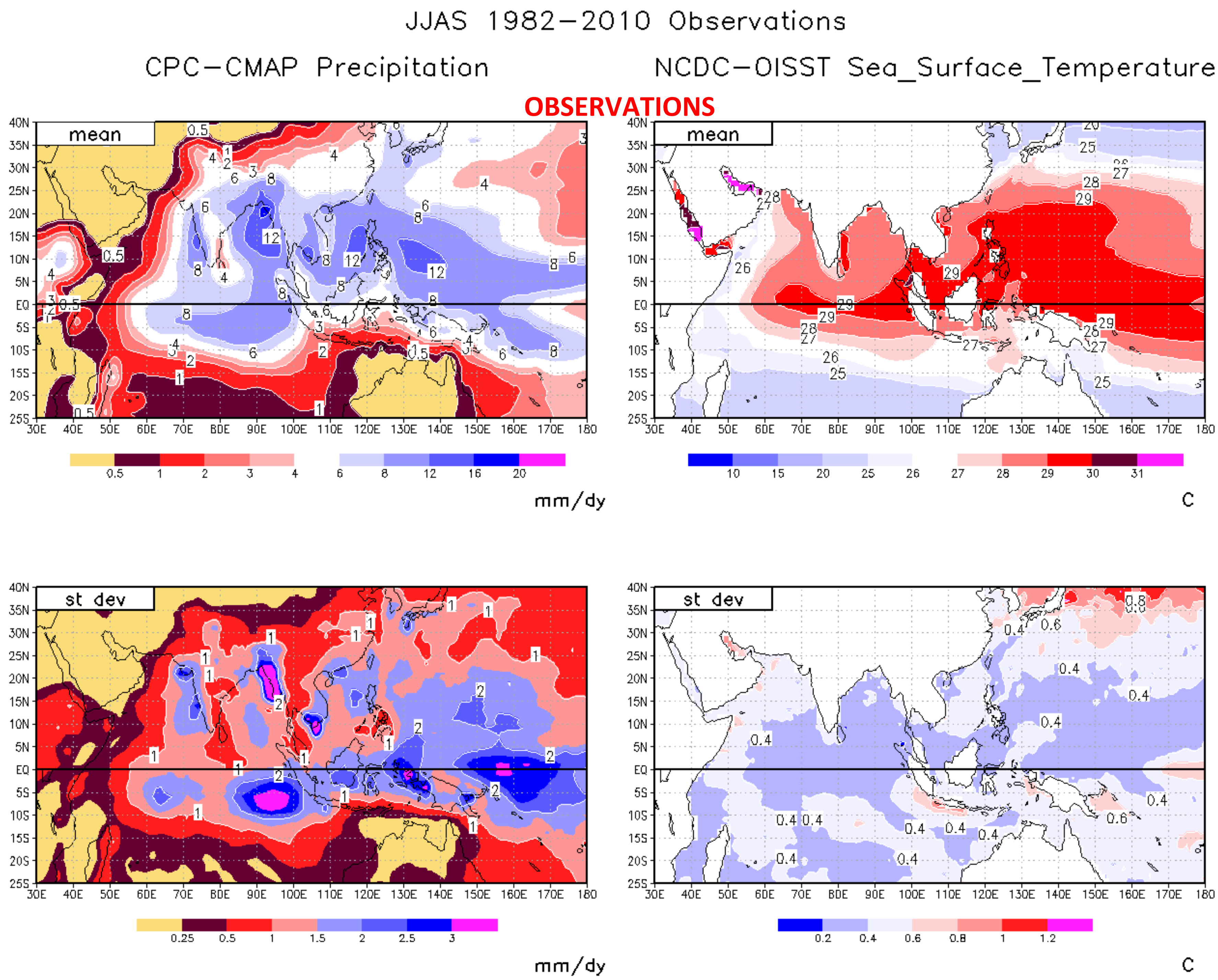
ANALYZE 4 NMME (PHASE I) COUPLED MODELS:
NCEP CFSV2 – 24 ENSEMBLE MEMBERS
GFDL CM2P1 – 10 ENSEMBLE MEMBERS
NASA GMAO – 10 ENSEMBLE MEMBERS
COLA RSMAS CCSM3 – 6 ENSEMBLE MEMBERS

1982-2010 FORECASTS INITIALIZED FROM 01 MAY OBSERVED STATE OF EACH YEAR

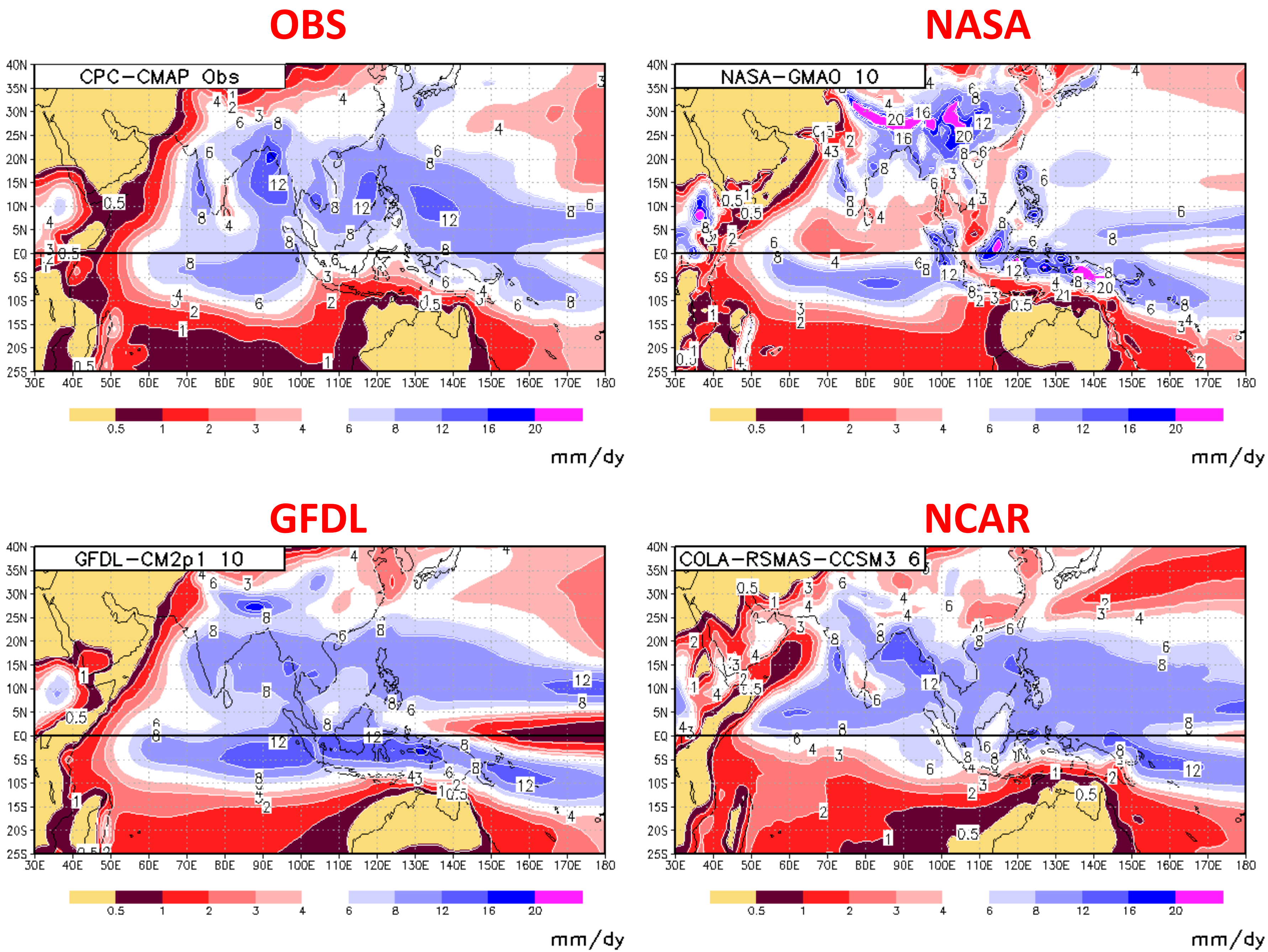
ALL OUTPUT ANALYZED ON 1 DEGREE GRID VERSUS OBSERVATIONS:
NCEP CPC CMAP PRECIPITATION
NCDC OISST SEA SURFACE TEMPERATURE

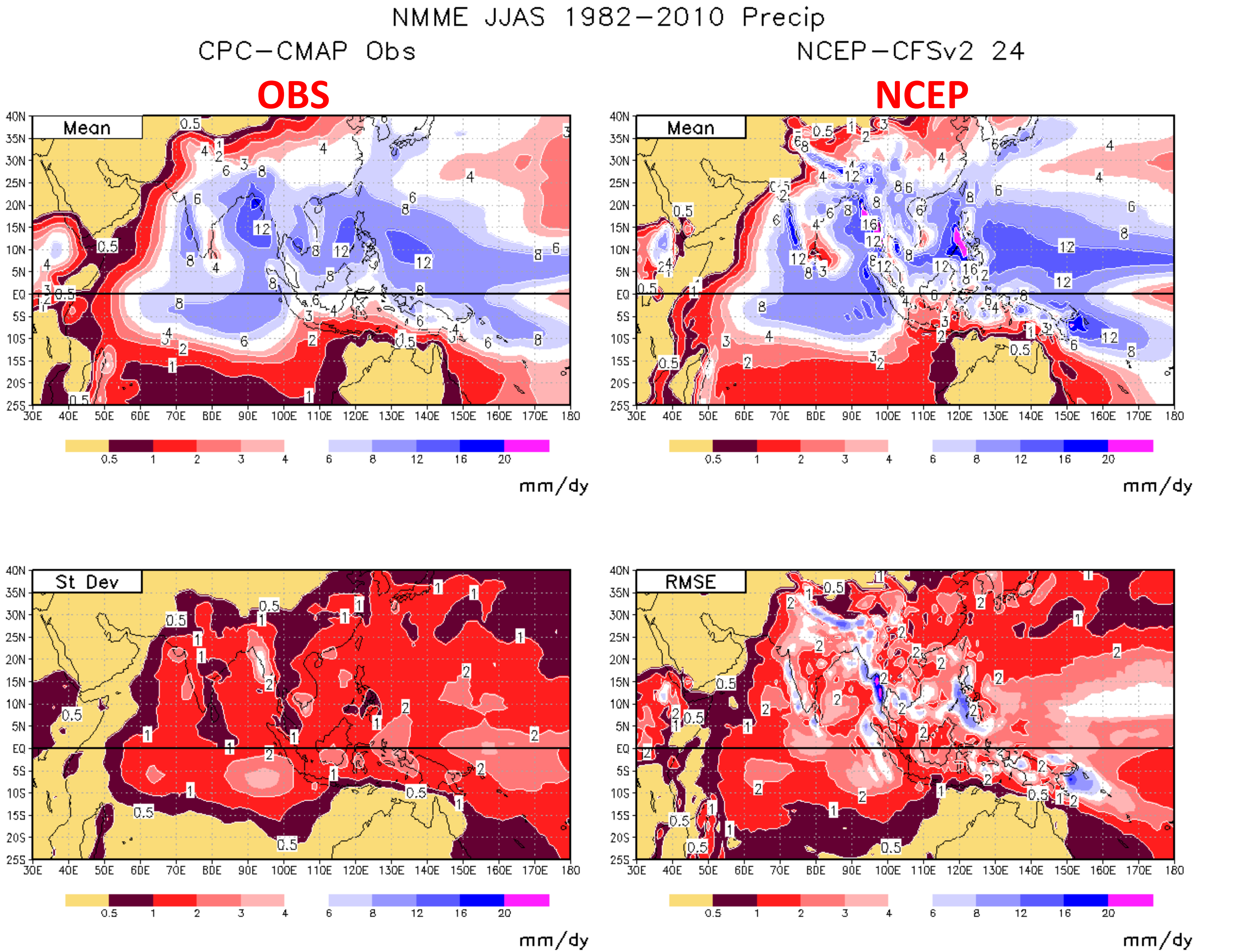
All calculations performed on ensemble mean for JJAS

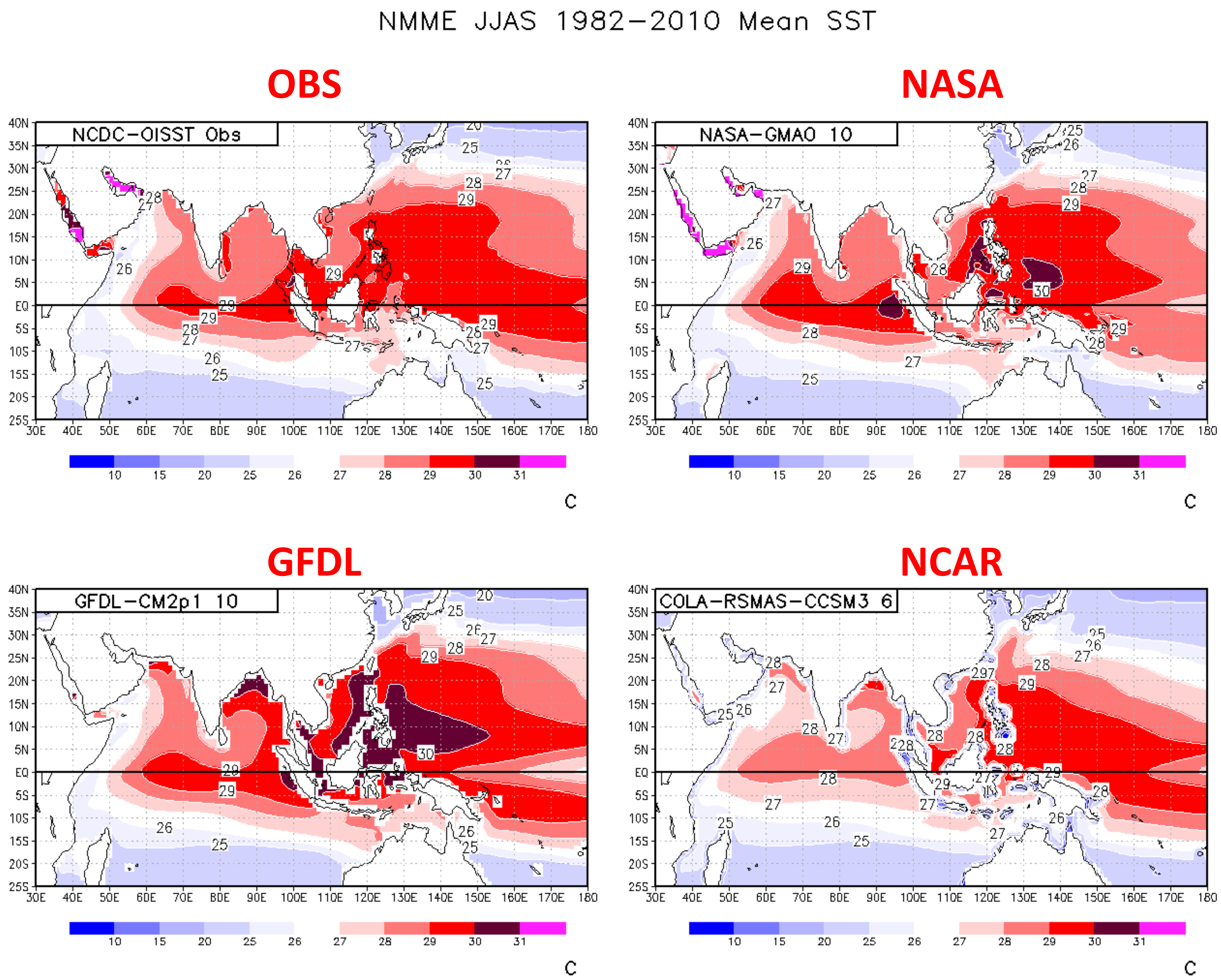
All India Rainfall: Average of Land Points


JJAS 1982–2010 Observations
CPC–CMAP Precipitation
NCDC–OISST Sea_Surface_Temperature
OBSERVATIONS
mean
mean
mm/dy
C
st dev
st dev
mm/dy
C

NMME JJAS 1982–2010 Mean Precip



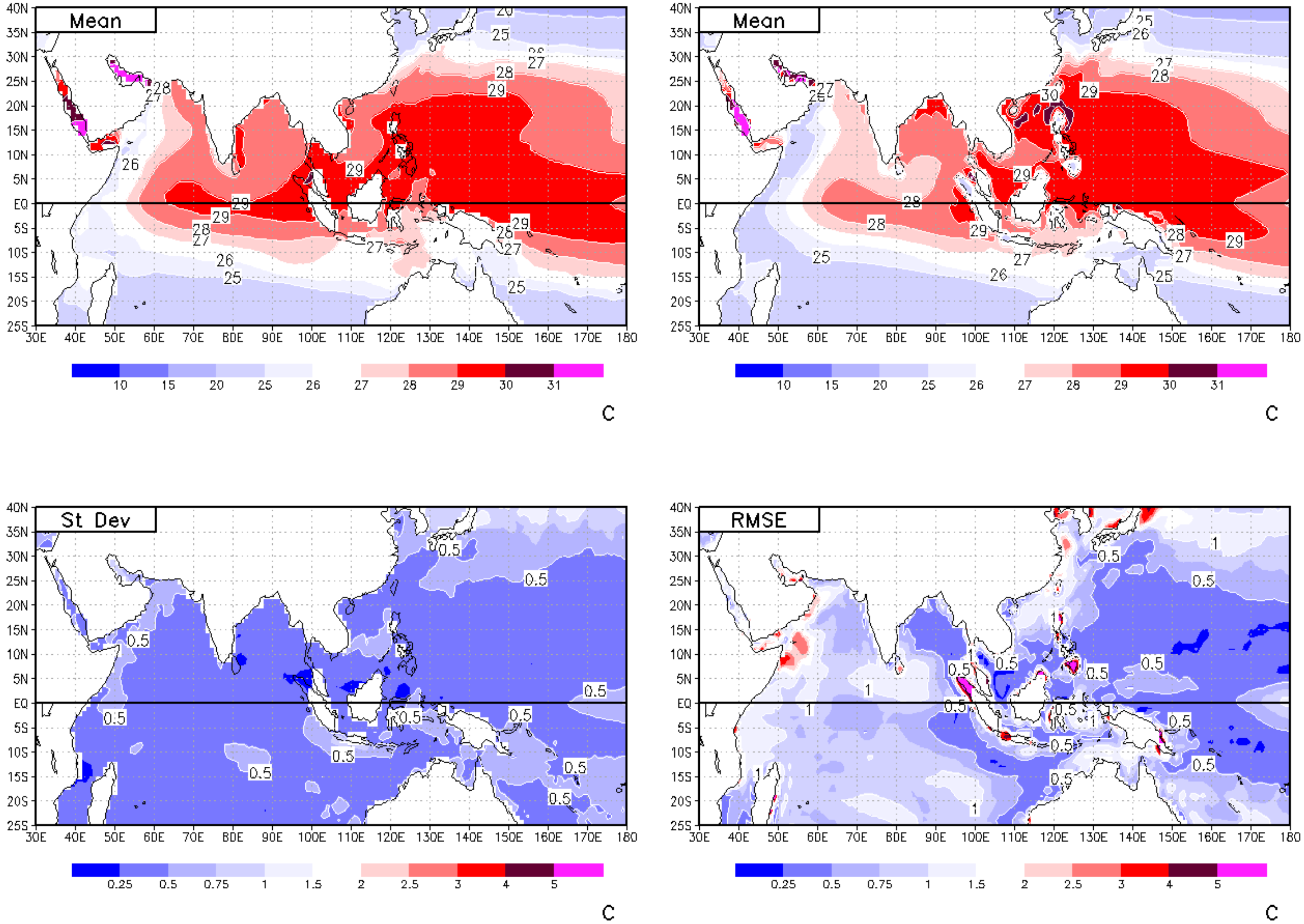

NMME JJAS 1982–2010 Precip
CPC–CMAP Obs
NCEP–CFSv2 24
OBS
NCEP
Mean
Mean
St Dev
RMSE
mm/dy
mm/dy
mm/dy
mm/dy


NMME JJAS 1982–2010 Mean SST
OBS
NCDC-OISST Obs
NASA
NASA-GMAO 10
GFDL
GFDL-CM2p1 10
NCAR
COLA-RSMAS-CCSM3 6
C

NMME JJAS 1982–2010 SST

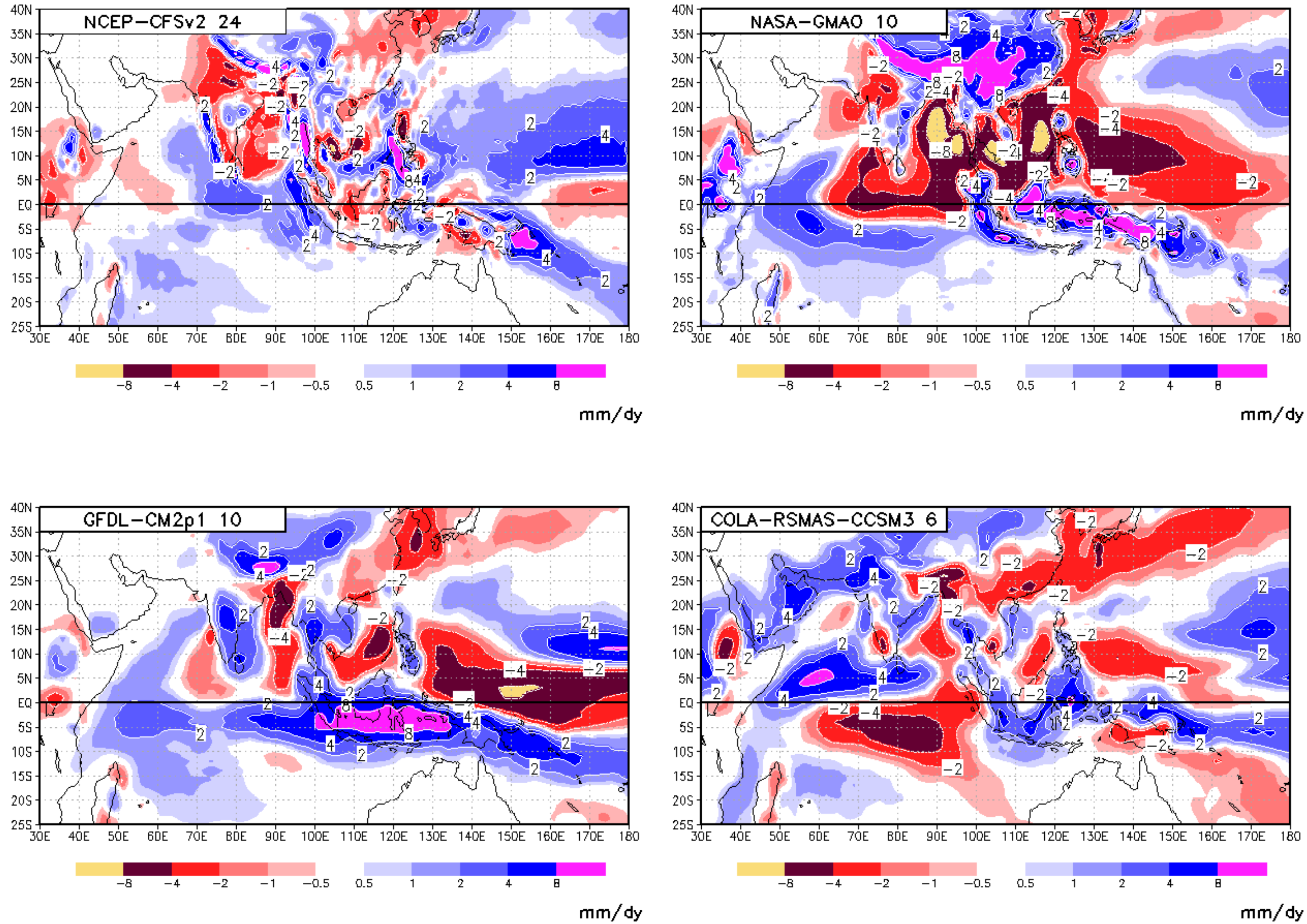
NCDC–OISST Obs | NCEP–CFSv2 24

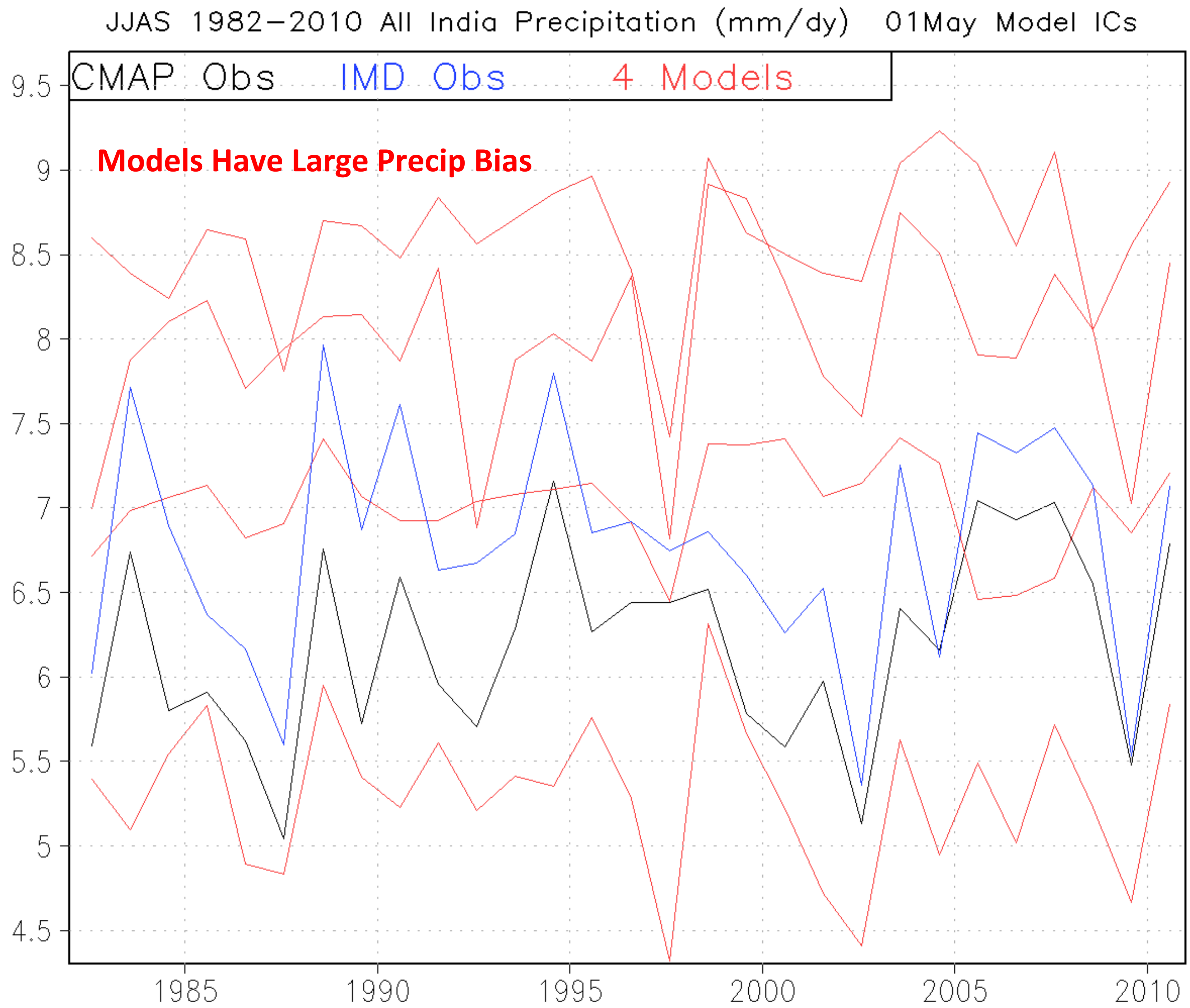
OBS | **NCEP**



NMME 1 May ICS 1982–2010 Precipitation JJAS Mean Bias

PRECIP BIAS

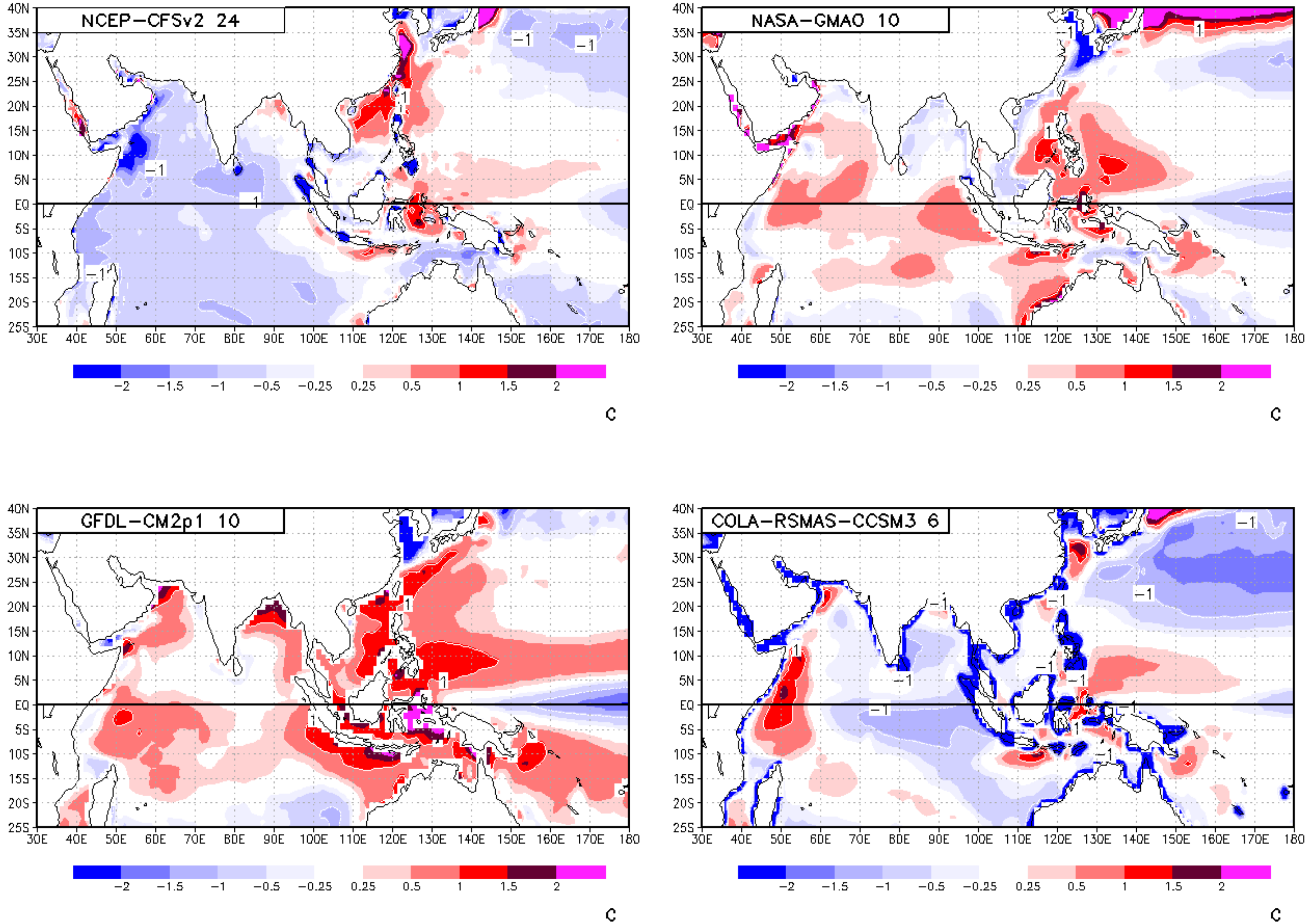




JJAS 1982-2010 All India Precipitation (mm/dy) 01May Model ICs
CMAP Obs
IMD Obs
4 Models
Models Have Large Precip Bias
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
1985
1990
1995
2000
2005
2010

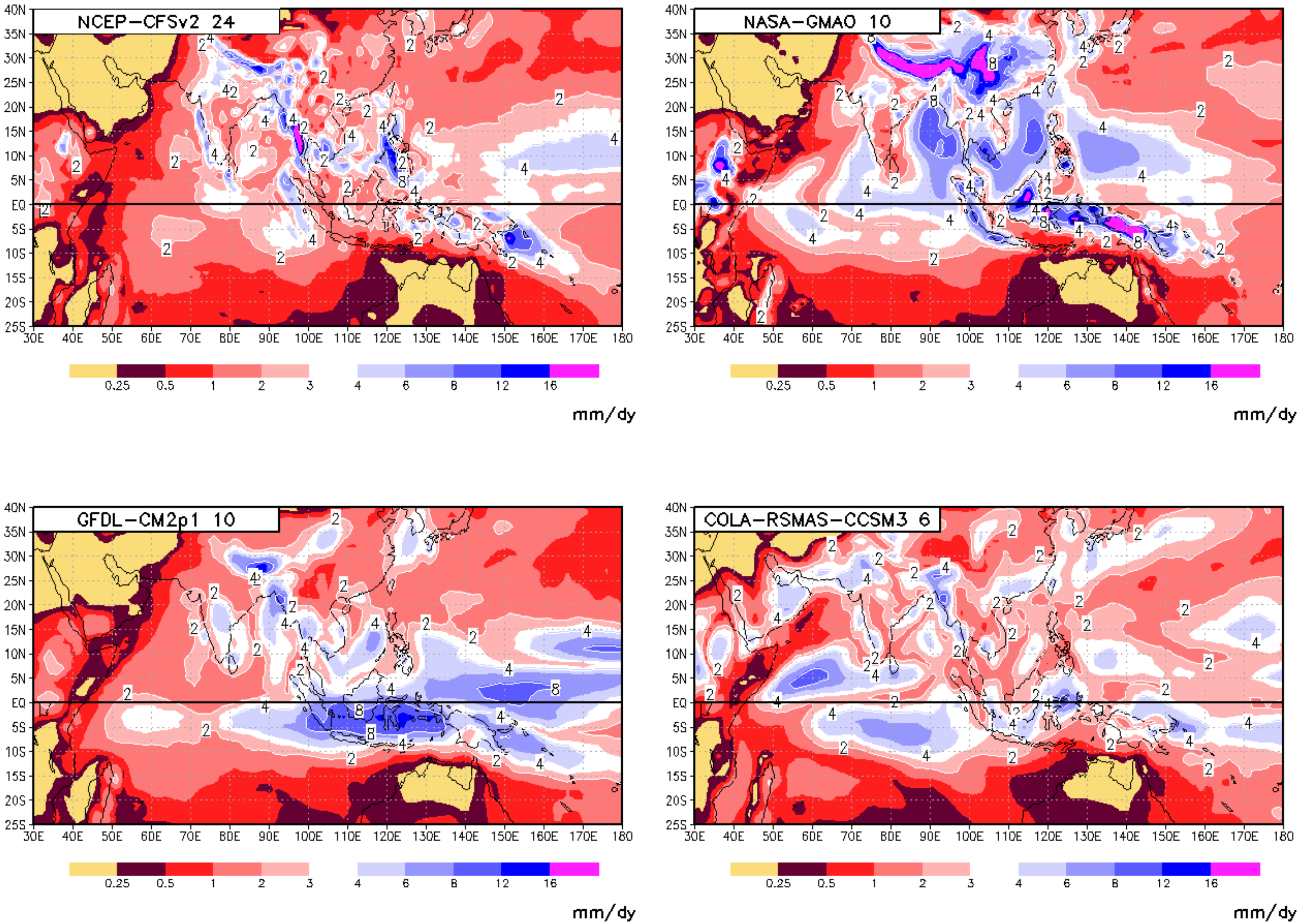
NMME 1 May ICS 1982–2010 Sea_Surface_Temperature JJAS Mean Bias

SST BIAS



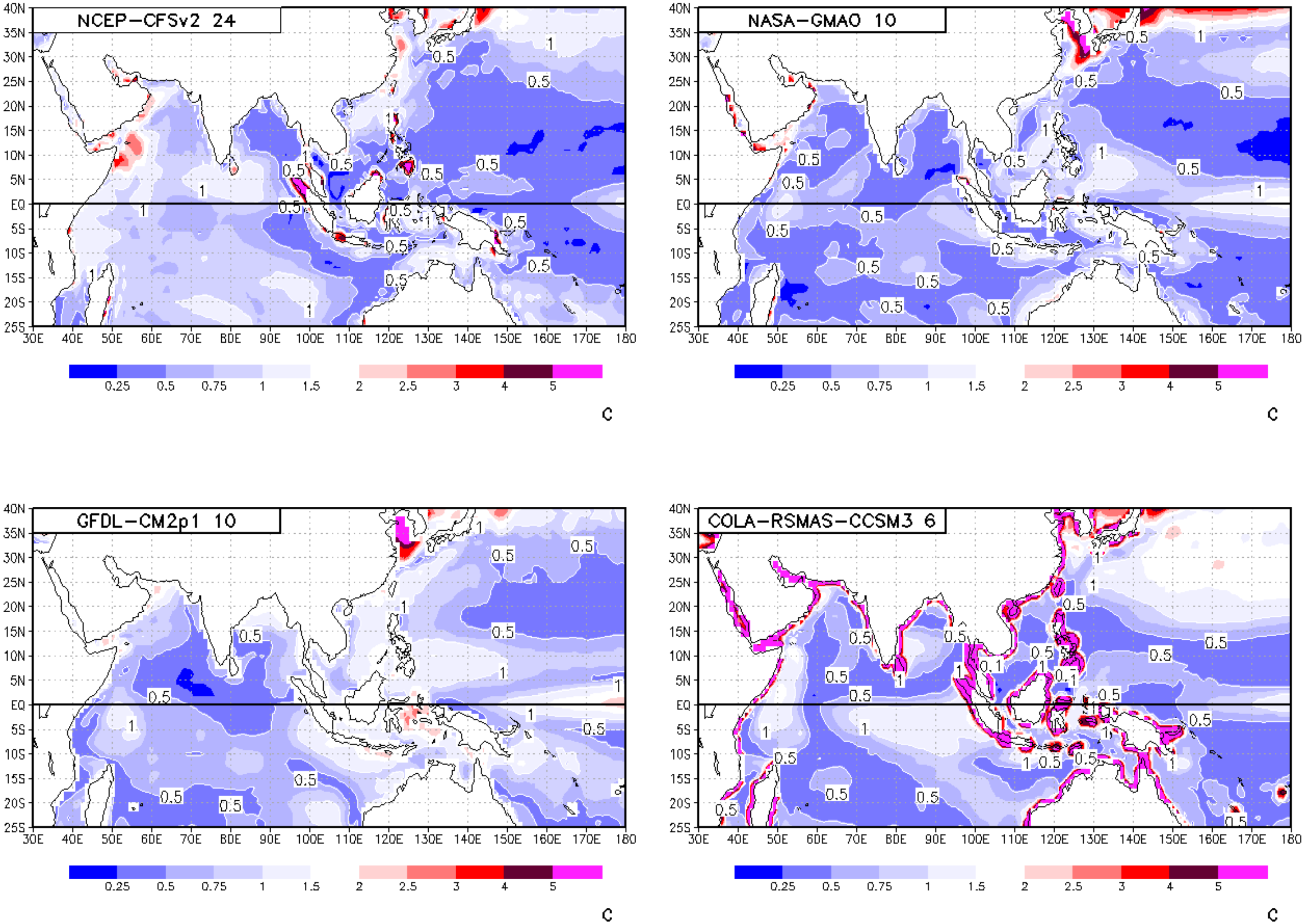
NMME 1 May ICS 1982-2010 Precipitation JJAS Forecast Error (RMSE)

FORECAST PRECIP RMSE



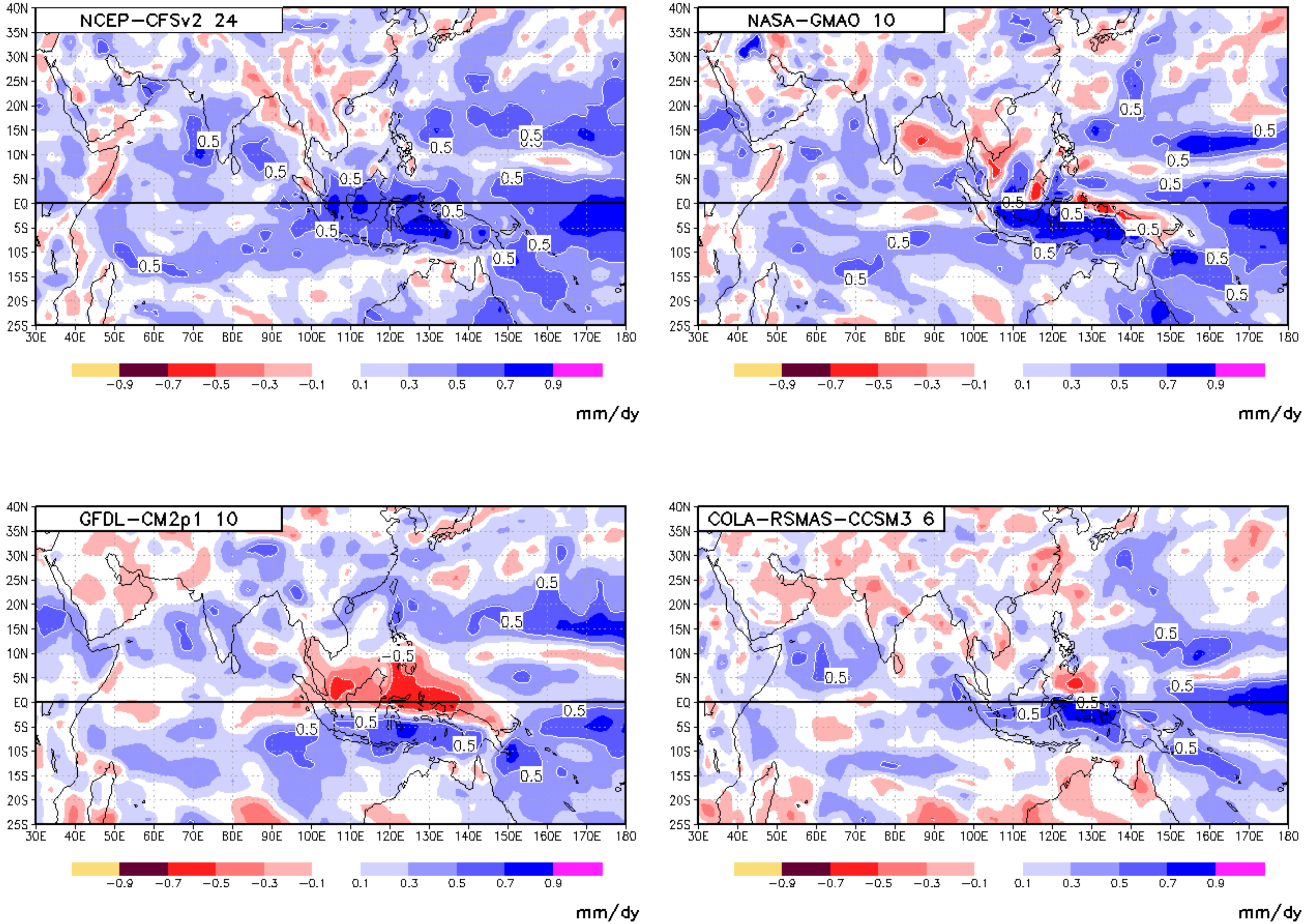
NMME 1 May ICS 1982–2010 Sea_Surface_Temperature JJAS Forecast Error (RMSE)

FORECAST SST RMSE



NMME 1 May ICS 1982–2010 Precipitation JJAS Anomaly Correlation Coefficient

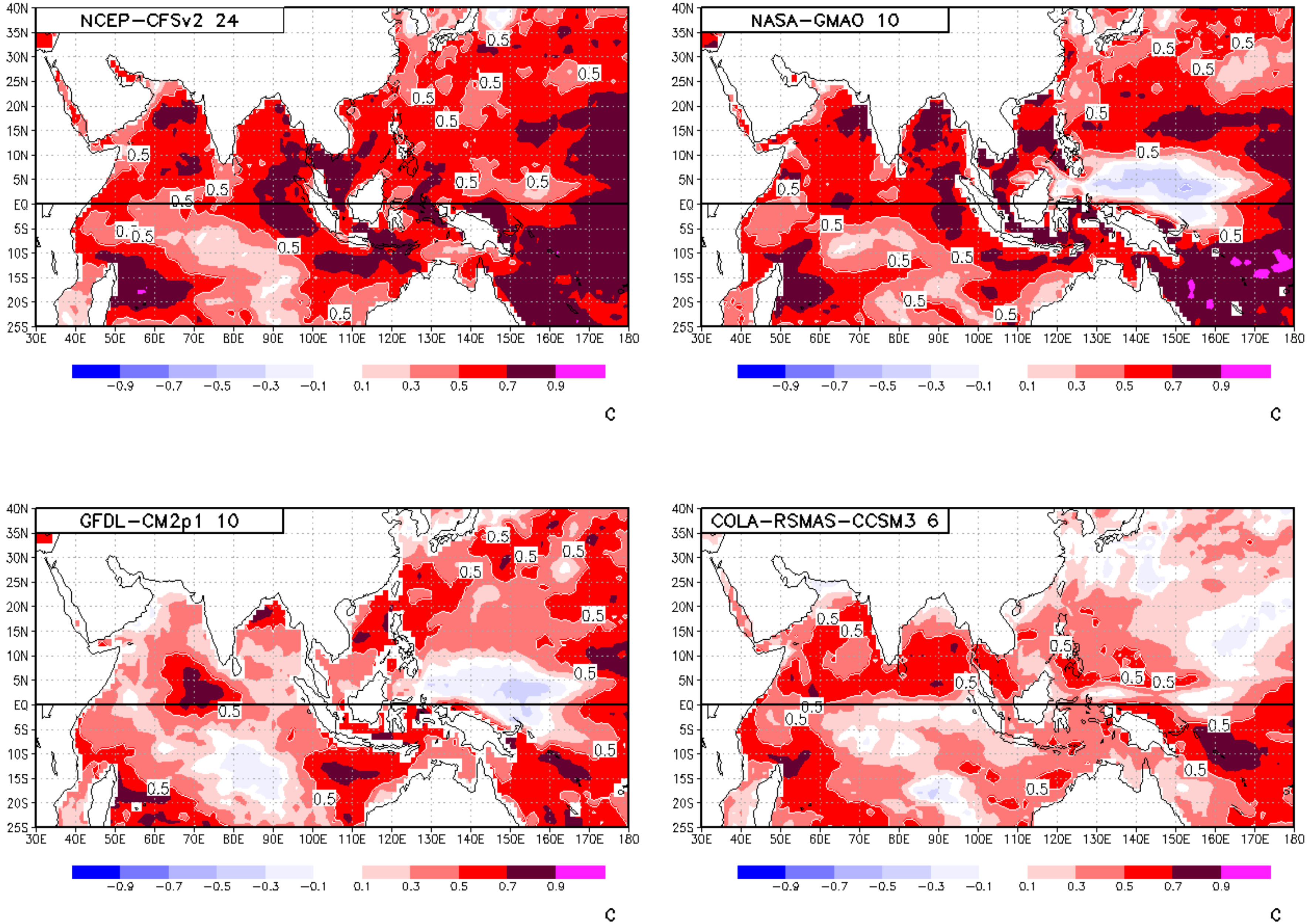
(PRECIP ACC)



NMME 1 May ICS 1982–2010 Sea_Surface_Temperature JJAS

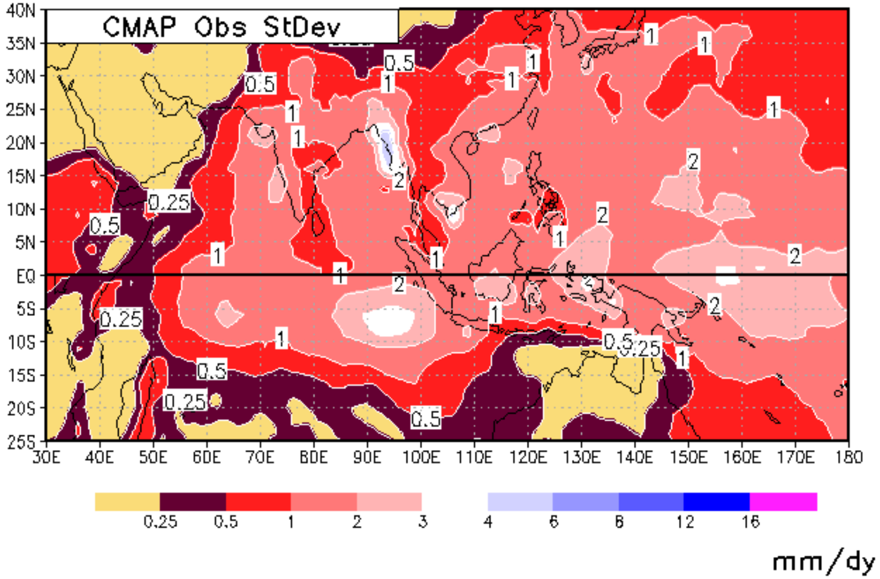
Anomaly Correlation Coefficient

(SST ACC)

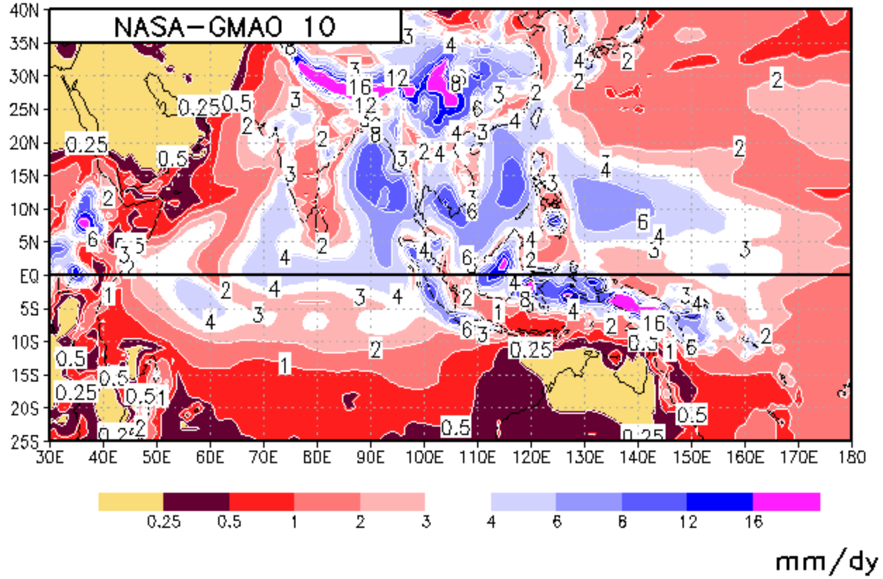


NMME JJAS 1982–2010 RMSE Precip **PRECIP RMSE**

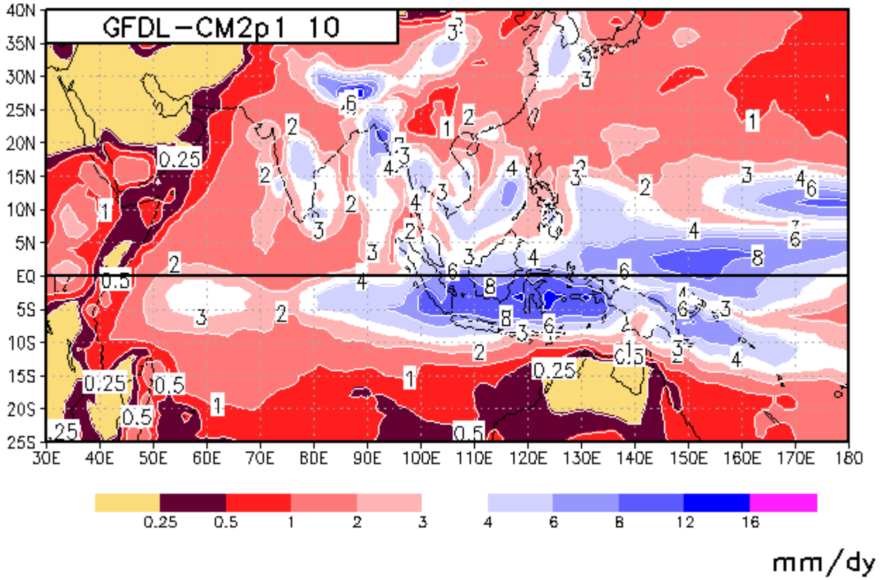
OBS St. Dev



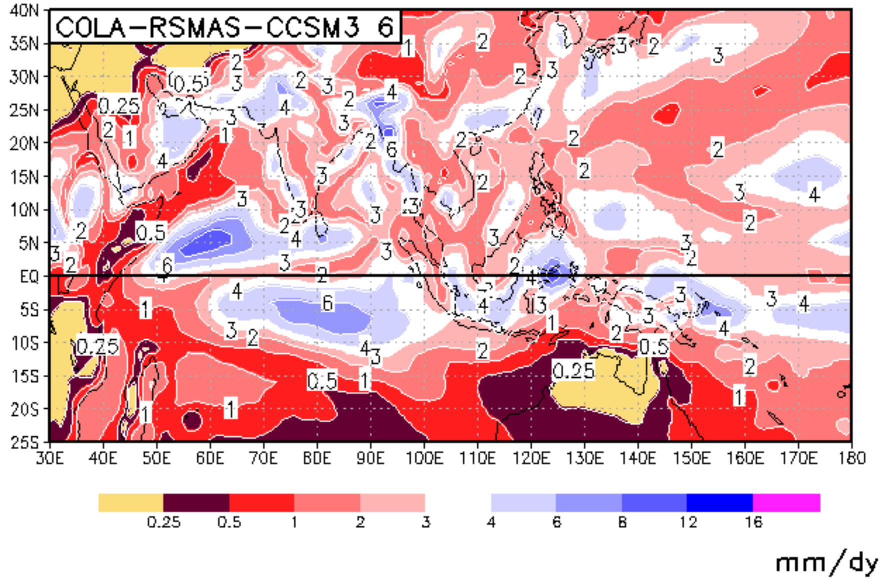
NASA



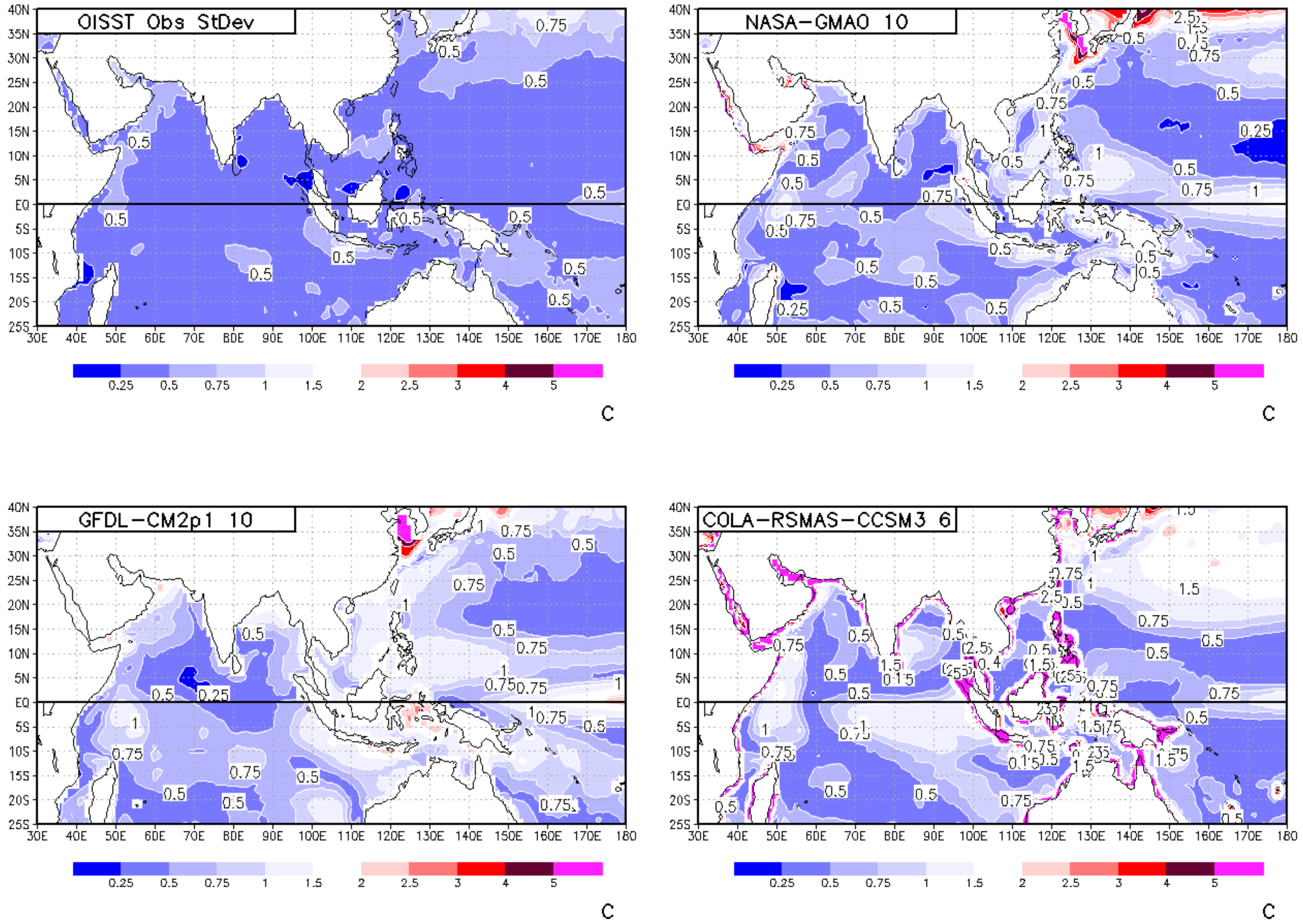
GFDL

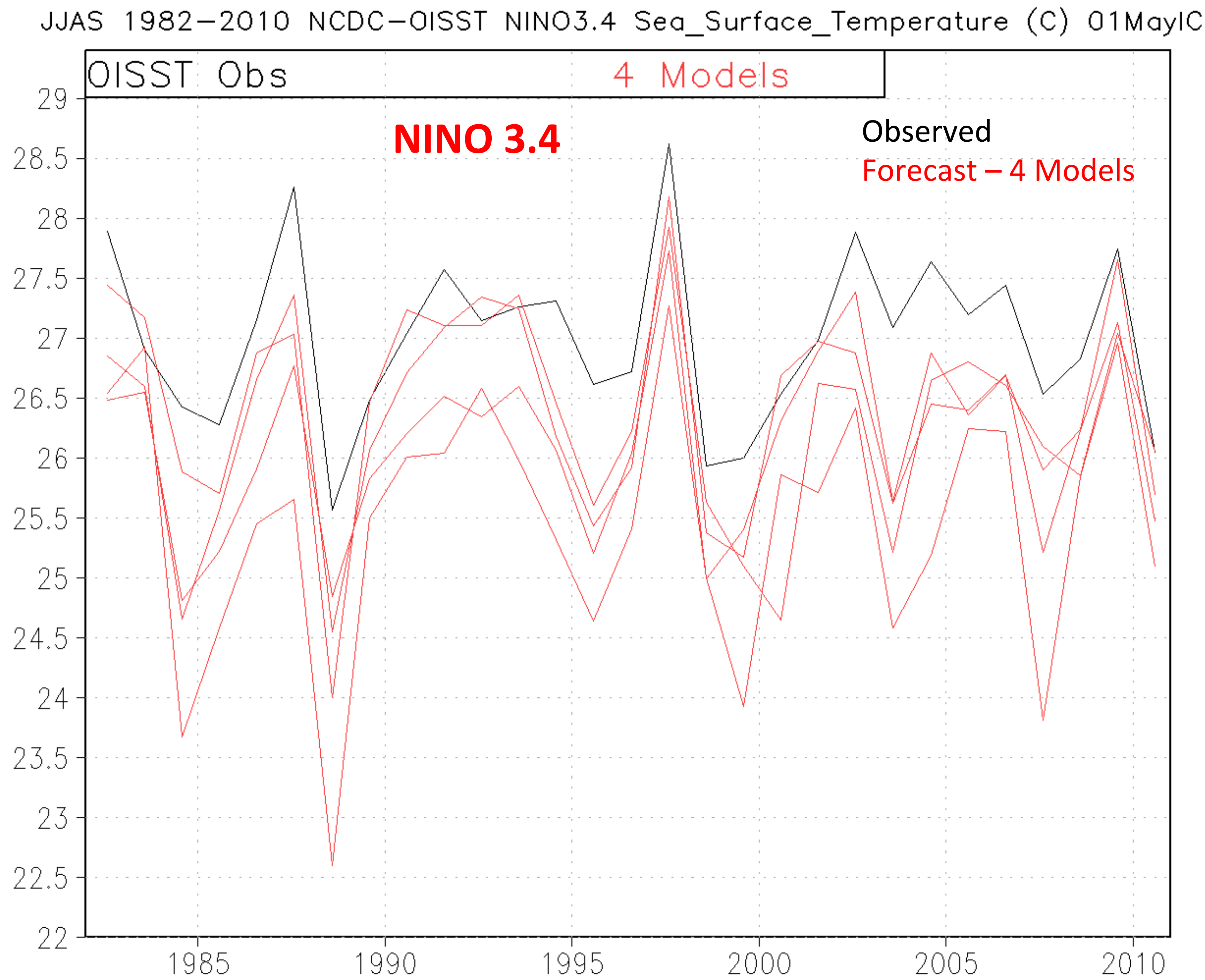


NCAR

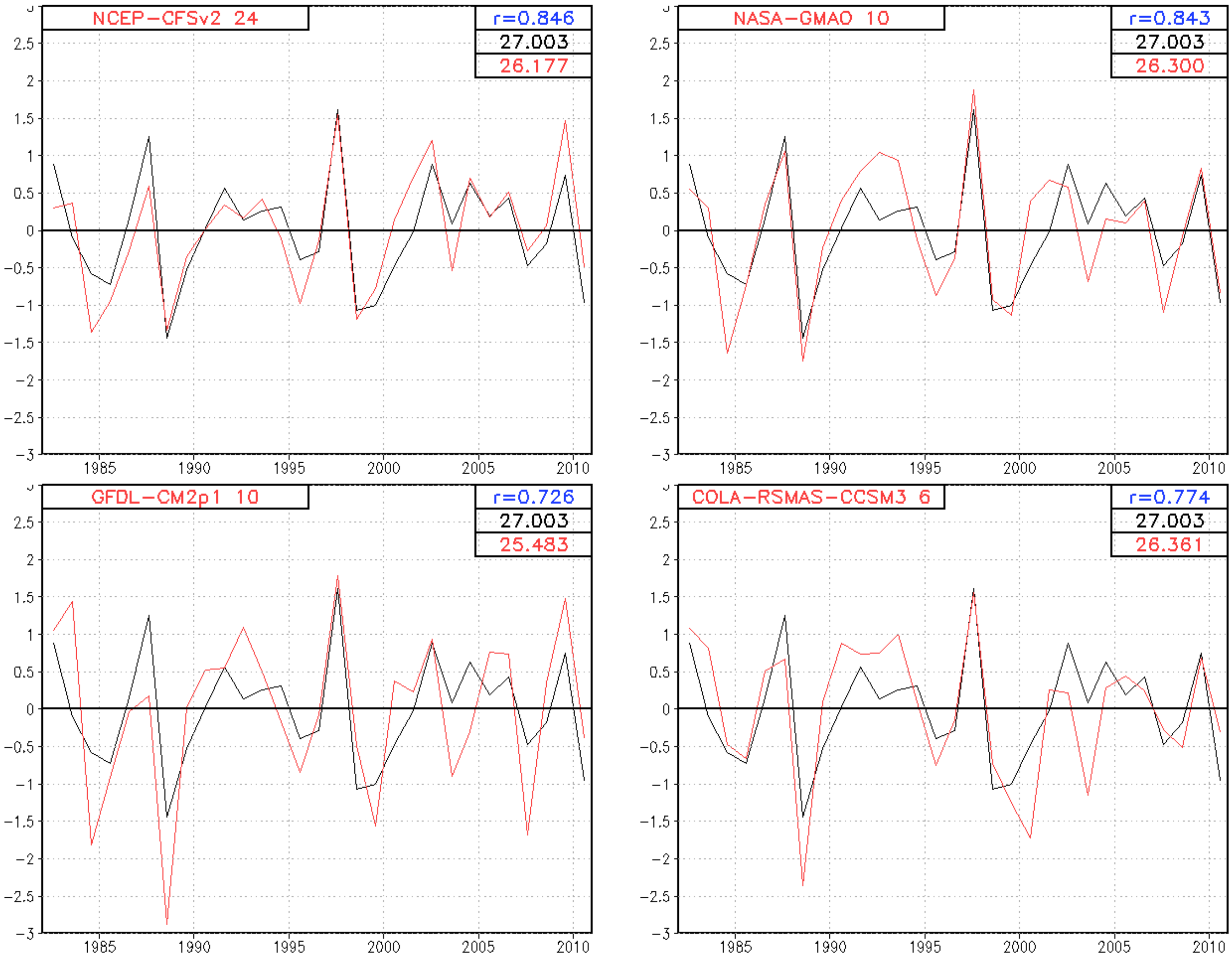


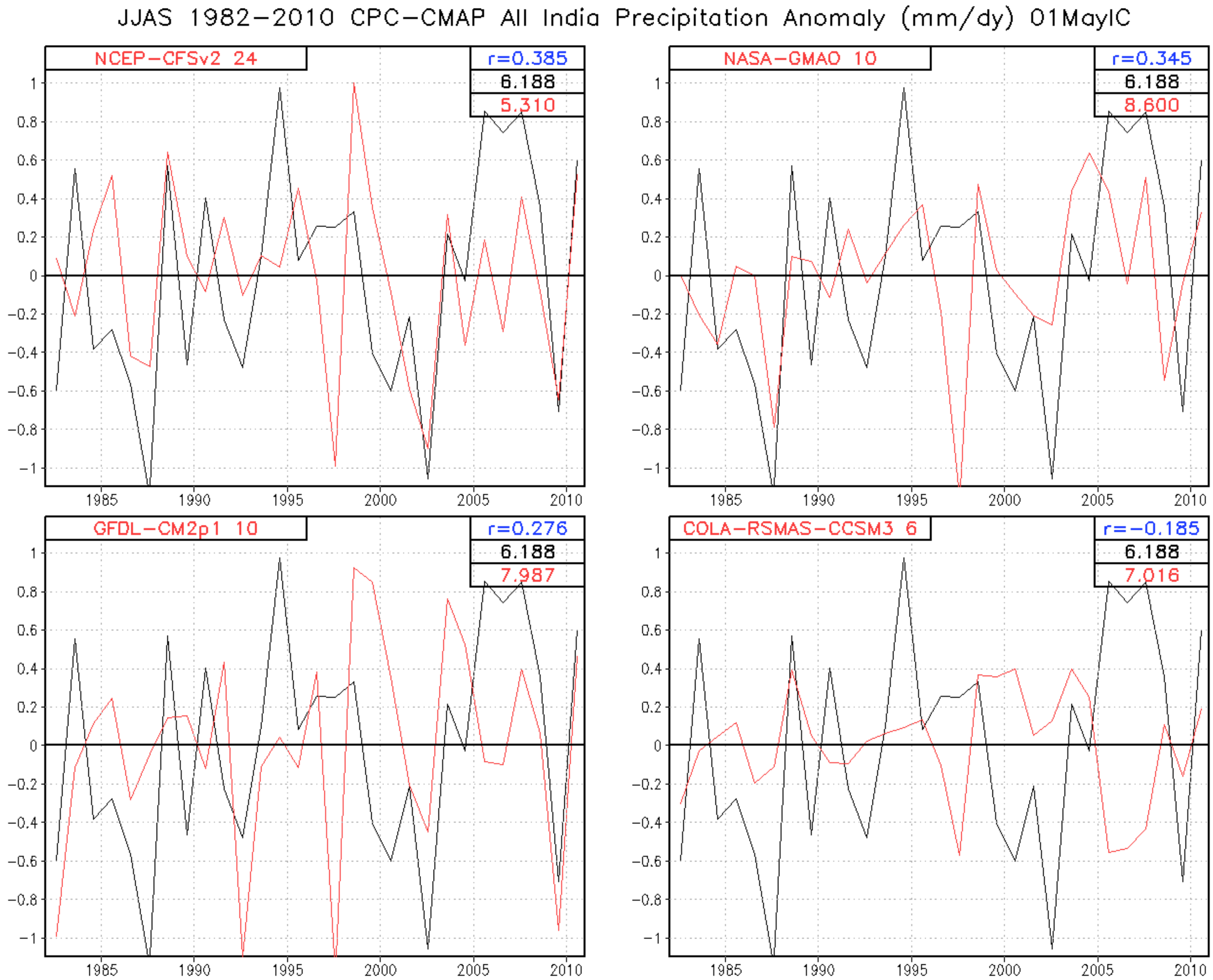
NMME JJAS 1982–2010 RMSE SST




JJAS 1982–2010 NCDC–OISST NINO3.4 Sea_Surface_Temperature (C) 01MayIC
OISST Obs
4 Models
NINO 3.4
Observed
Forecast – 4 Models
29
28.5
28
27.5
27
26.5
26
25.5
25
24.5
24
23.5
23
22.5
22
1985
1990
1995
2000
2005
2010

JJAS 1982–2010 NCDC–OISST NINO3.4 Sea_Surface_Temperature Anomaly (C) 01MayIC





JJAS 1982–2010 CPC–CMAP All India Precipitation Anomaly (mm/dy) 01MayIC
NCEP–CFSv2 24
r=0.385
6.188
5.310
NASA–GMAO 10
r=0.345
6.188
8.600
GFDL–CM2p1 10
r=0.276
6.188
7.987
COLA–RSMAS–CCSM3 6
r=–0.185
6.188
7.016
1
0.8
0.6
0.4
0.2
0
–0.2
–0.4
–0.6
–0.8
–1
1985
1990
1995
2000
2005
2010

CFSv2 Reforecasts

Model

CFSv2 Reforecasts from NCEP
1982-2009

February initial conditions: 20 ensemble members
00Z, 06Z, 12Z and 18Z
Feb 5, 10, 15, 20, 25

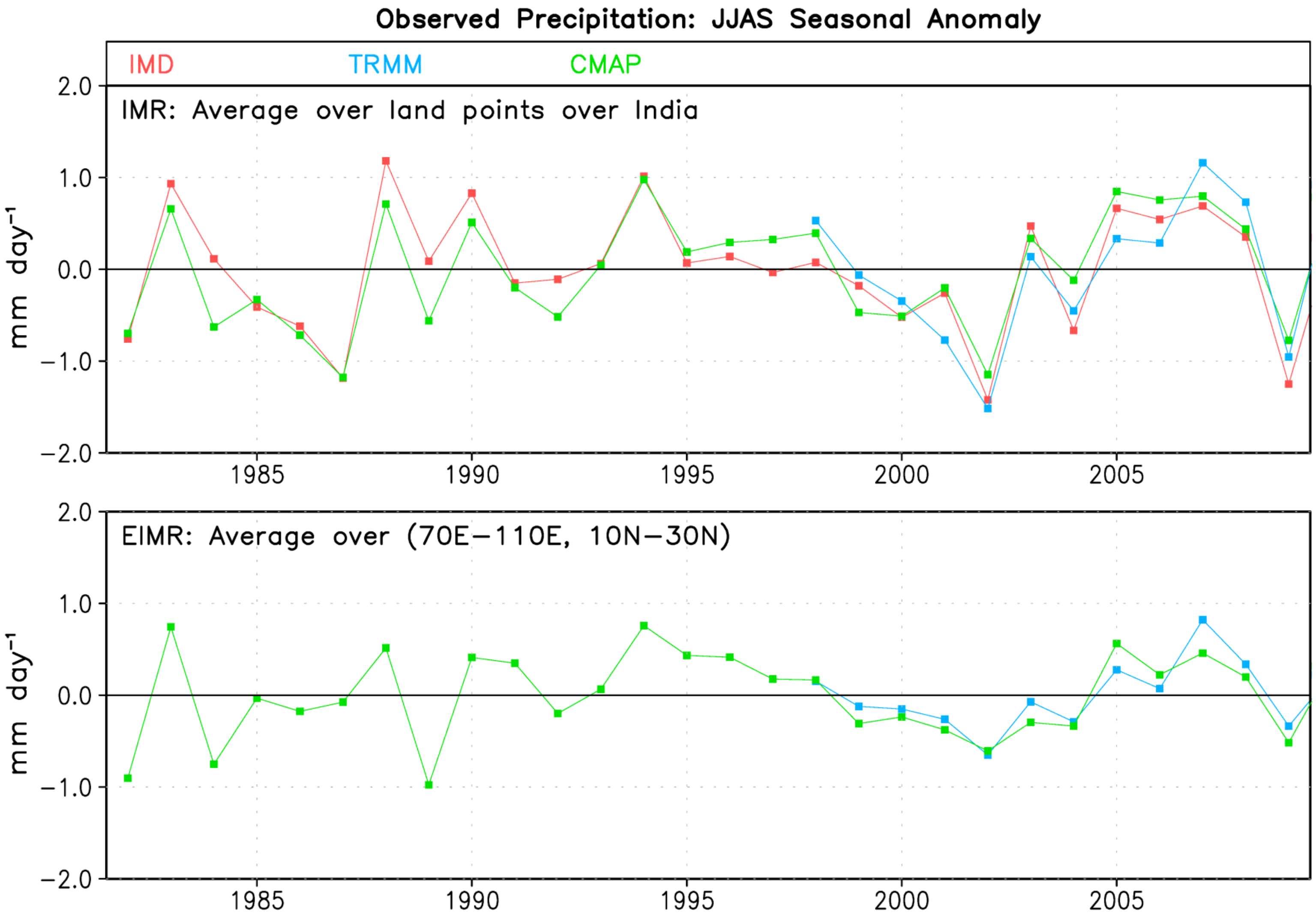
May initial conditions: 28 ensemble members
00Z, 06Z, 12Z and 18Z
May 1, 6, 11, 16, 21, 26, 31

Observation

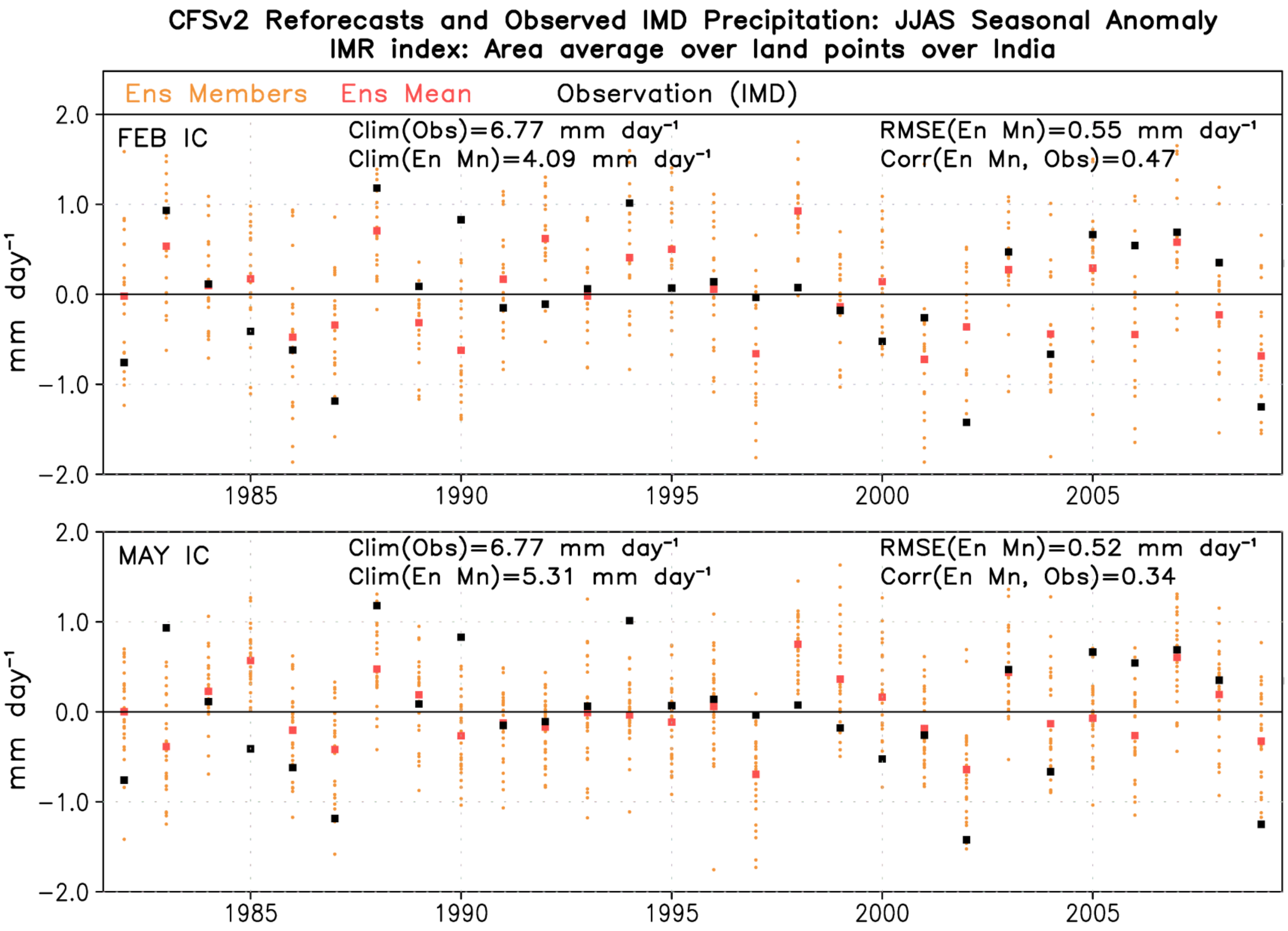
IMD rainfall data 1982-2009
TRMM (version 7) rainfall data 1998-2009

Krishnamurthy, V., 2014: Predictability of the Indian monsoon in CFSv2 on interannual and intraseasonal time scales (in preparation)

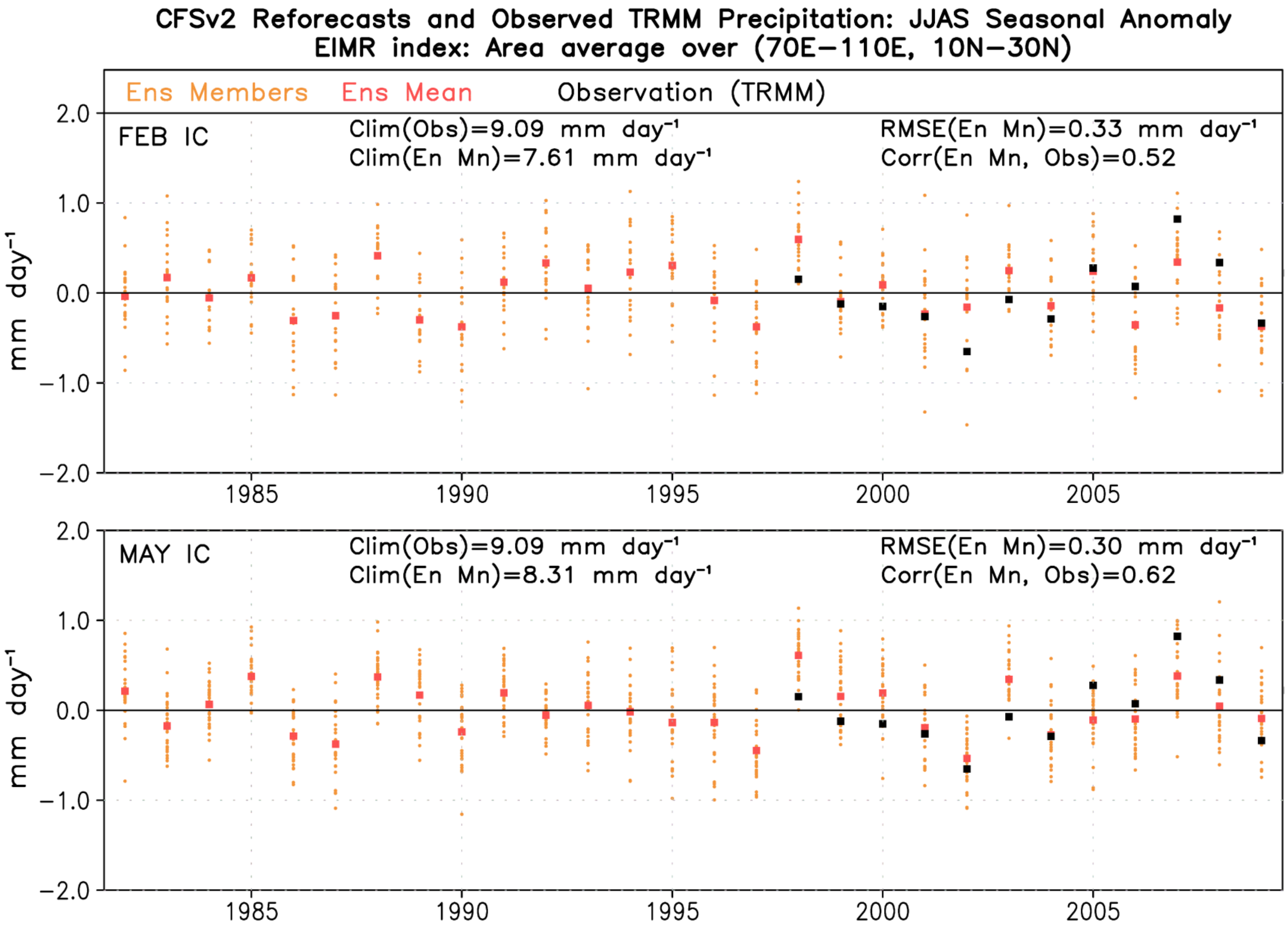
Observations



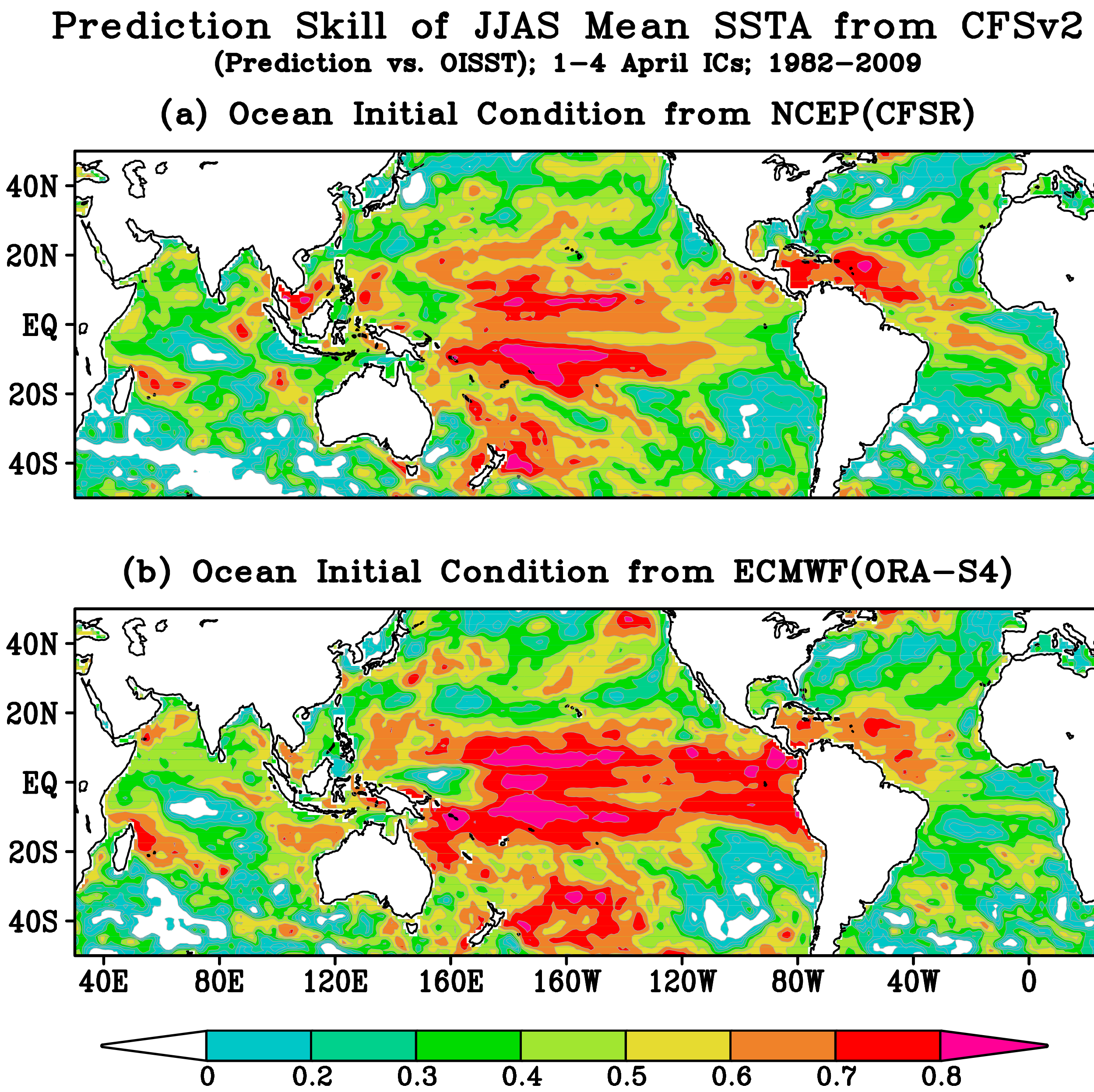
CFSv2 Reforecasts



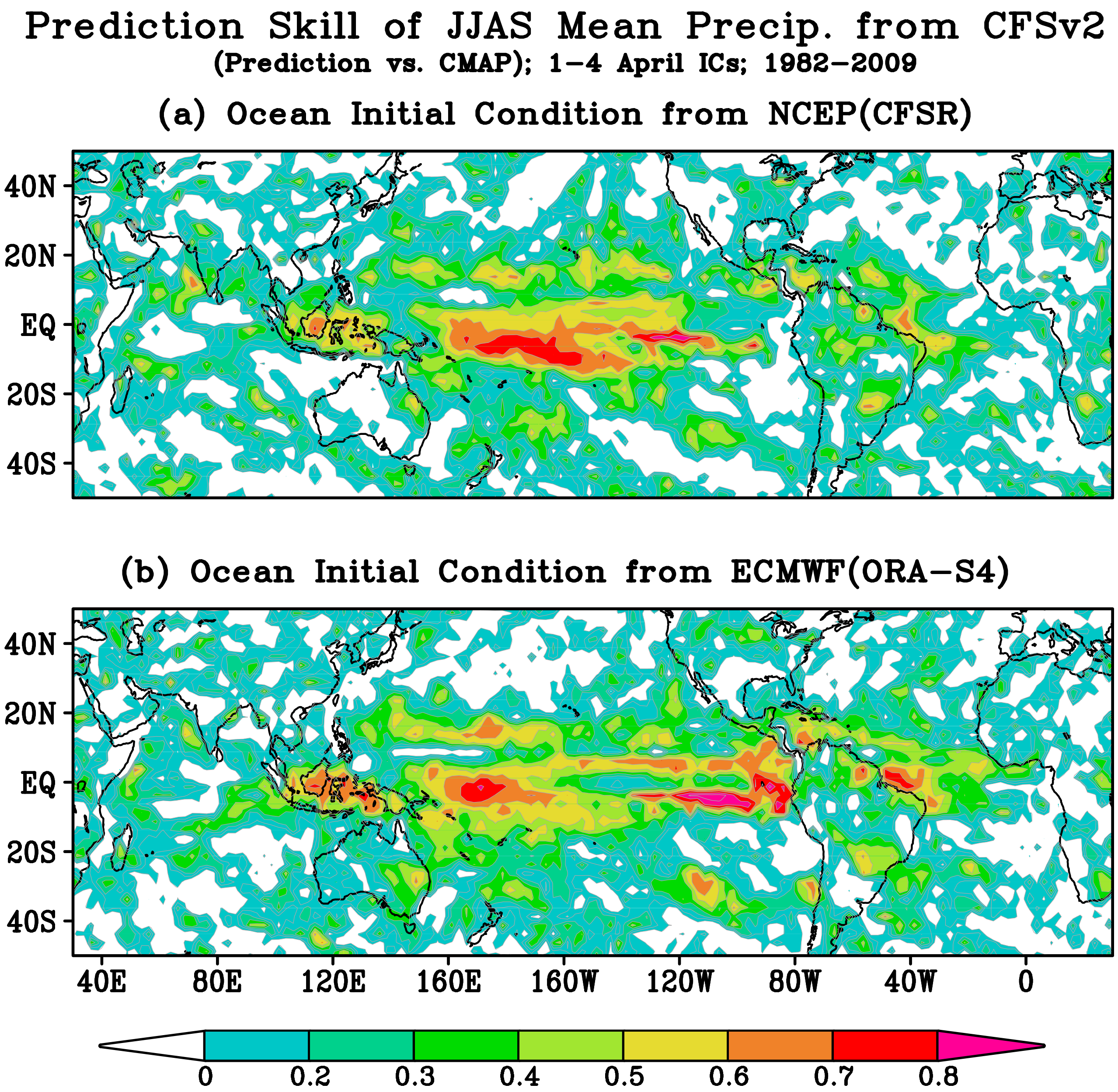
CFSv2 Reforecasts



Impact of Ocean IC on Prediction of JJAS SST



Impact of Ocean IC on Prediction of JJAS Precip.

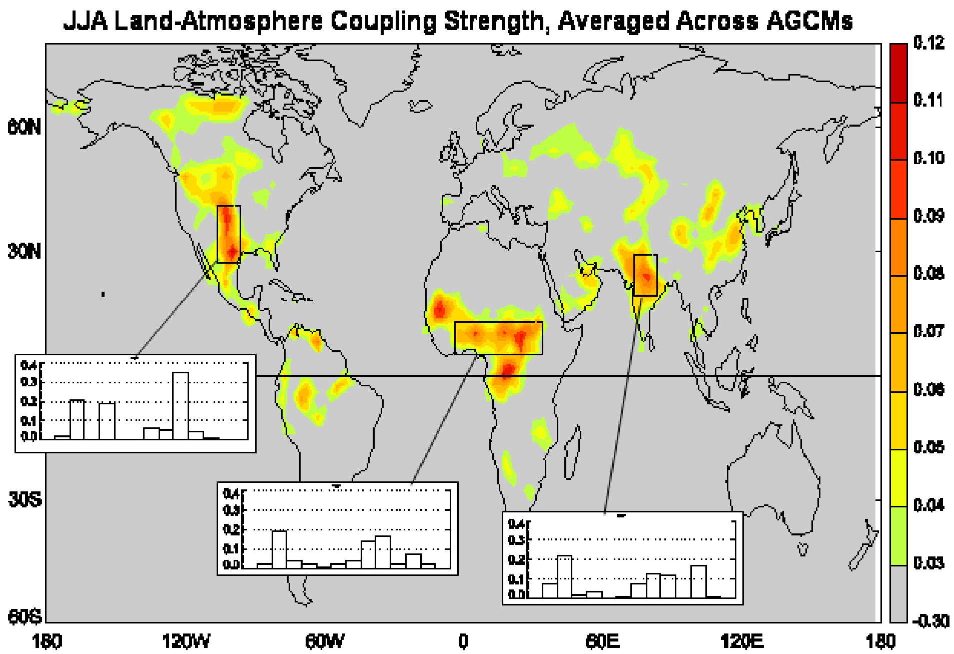


Impact of Land Initial Conditions on Subseasonal to Seasonal Prediction

Thanks: Dirmeyer and Guo

Hot Spots

The **Global Land-Atmosphere Coupling Experiment (GLACE)** : A joint GEWEX/CLIVAR modeling study



- Multi-model results indicate that there are geographic "hot spots" where the atmosphere is responsive to the state of the land surface (soil moisture) = potential predictability.

Koster, et al., 2004: *Science*, 1138-.
Dirmeyer, et al., 2006: *JHM*, 1177-.
Guo, et al., 2006: *JHM*, 611-.
Koster, et al., 2006: *JHM*, 590-.

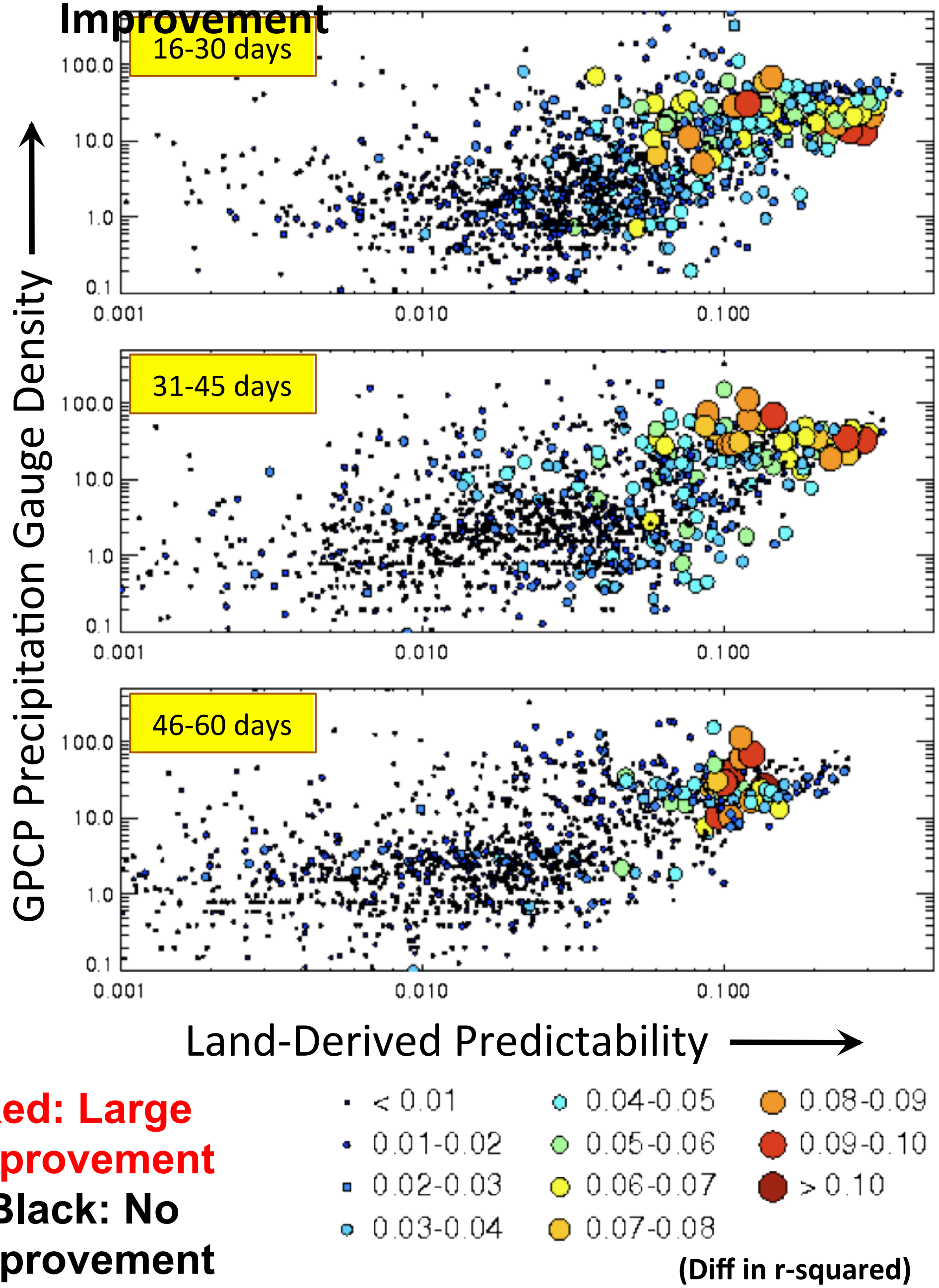
- There have been many subsequent studies using models, analyses and observations that corroborate and help explain this result.

Skill Contributors

- GLACE-2 prediction study (11 GCMs, 1986-1995, forecasts validating during JJA).
- Places that see the greatest skill impact from realistic land surface initialization have high gauge density (good rainfall data to generate initial soil moisture states) and high land-derived predictability (hot spots).

Koster et al., 2011: *JHM*, 805-.

2m Temperature Forecast Skill Improvement



Red: Large Improvement
Black: No Improvement

National Monsoon Mission of India and COLA Joint Research to Enhance Monsoon Prediction

COLA Project: "Ocean-Land-Atmosphere Coupling and Initialization Strategies to Improve CFSv2 and Monsoon Prediction"

- Improve the coupled ocean-land-atmosphere model (CFSv2) performance.
- Better initialization of ocean and land states in the pre-monsoon season to improve forecasts of onset, monsoon season precipitation.
- Better land surface analyses require better timely precipitation data.

The Challenge

Predictability of Asian Summer Monsoon Rainfall is High

but

Prediction Skill is Low

Mechanisms of Seasonal-Interannual Variability

- INTERNAL DYNAMICS
- BOUNDARY FORCING

Atmosphere-Ocean Interaction

Atmosphere-Land Interaction

Atmosphere-Ocean-Land Interaction

(CLIM 710)

Mechanisms of Variability

	Internal	External
Weather:	1. Internal Dynamics of Atmosphere	• Boundary Condition of SST, Soil wetness, Snow, Sea ice, etc.
Climate: (seasonal-decadal)	2. Internal Dynamics of Coupled Ocean-Land-Atmospsphere	• Solar, Volcanoes
Climate Change:	3. Internal Dynamics of Sun-Earth System	• Human effects: (Greenhouse gases, Aerosols, land use changes)

Decadal and multi-decadal variability has contributions from internal dynamics of the coupled climate system and external forcing.

What Determines The Limits Of Weather And Climate Prediction?

- Weather Prediction:
  - Accuracy of observations to describe current weather
  - Realism of physical-dynamical models
  - Chaos: sensitive dependence on initial conditions
- Seasonal Prediction:
  - Weather prediction +
  - Global sea surface temperature, snow, soil wetness, etc.
  - Coupling of ocean-atmosphere-land
  - Power of computers
- Climate change:
  - Weather and seasonal prediction +
  - Human-induced changes in greenhouse gases
  - Deforestation
  - Uncertainty of future population, policy, technology

Sources of Predictability

- Weather: IC (A,L) + SBF
- Intraseasonal: IC (A,O,L) + SBF + AOL Coupling
- Seasonal: IC (A,O,L) + AOL Coupling + SBF
- Decadal: AOLC coupling + EF + IC (AOLC)
- Climate Change: EF + AOLC coupling

IC: Initial Condition, SBF: Surface Boundary Forcing
A: Atmosphere; O: Ocean; L: Land; C: Cryosphere
EF: External Forcing (GHG, solar, volcanoes, Land use etc.)

Dynamical Seasonal Prediction (DSP)

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

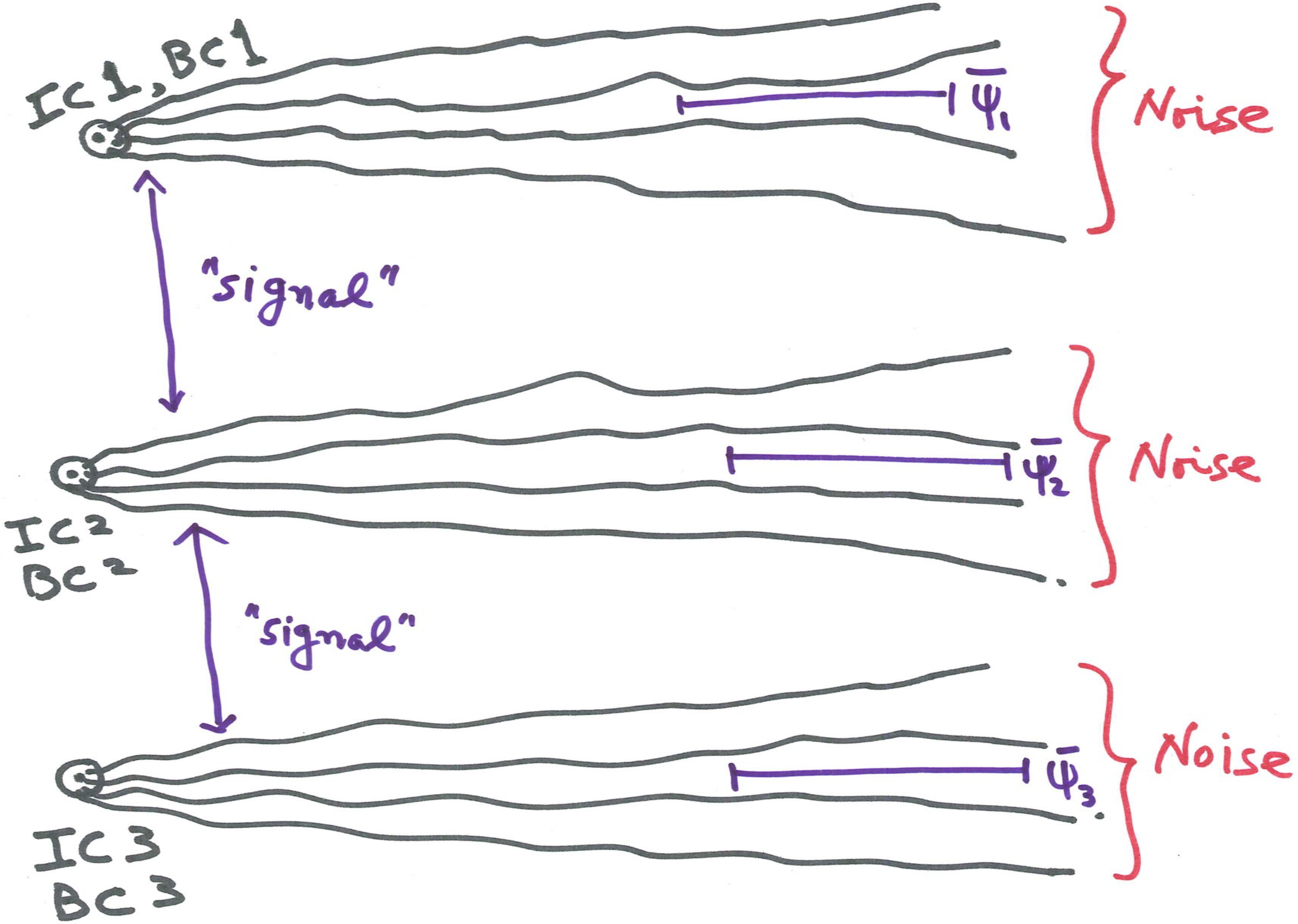
DSP = NWP + IC of Ocean, Land, Atmosphere
- *dynamically coupled and consistent IC*
- *Global ocean (especially upper ocean); sea ice (volume)*
- *Global Atmos. including stratosphere (IC)*
- *Global GHG (especially CO_2, O_3)*
- *Global land (soil moisture, vegetation, snow depth) IC*

Tier 1: Fully coupled models (CGCM) to predict Boundary Forcing

Tier 2: Predict Boundary Forcing separately; use AGCM

- **(NWP=Atmos. IC + SST IC)**

Predictability of Time (Seasonal) Mean



Predictability of "mean":

$$= \frac{\text{Signal Var.}}{\text{Noise Var.}}$$

Analysis of Variance: F as a measure of predictability
5 CGCMs, 46 years, 9 ensembles

Measure of predictability is

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

where

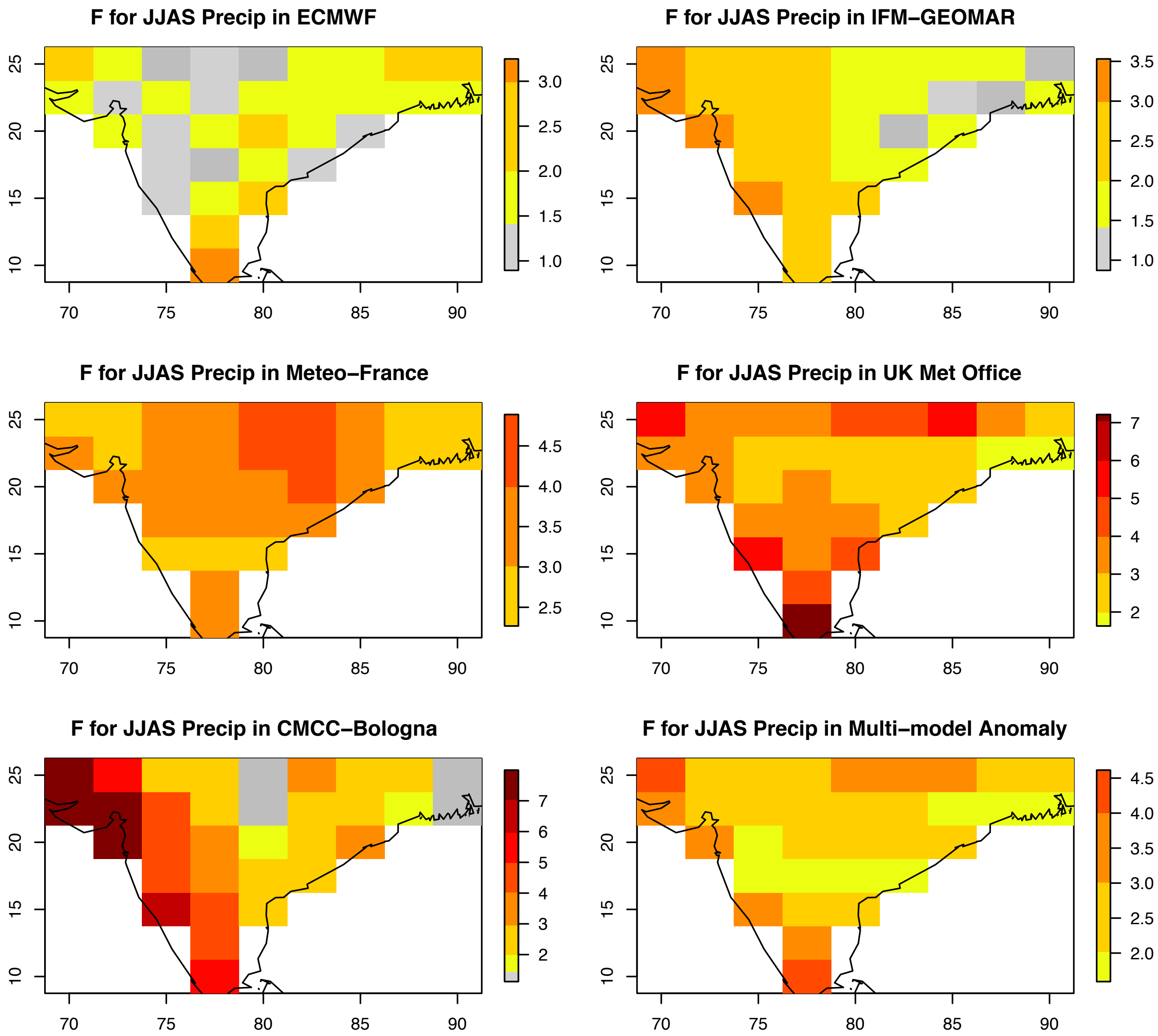
$$\hat{\sigma}_S^2 = \frac{1}{Y-1}\sum_{y=1}^{Y}\left(P_{y,e} - \overline{\overline{P}}\right)^2$$

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

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

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

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



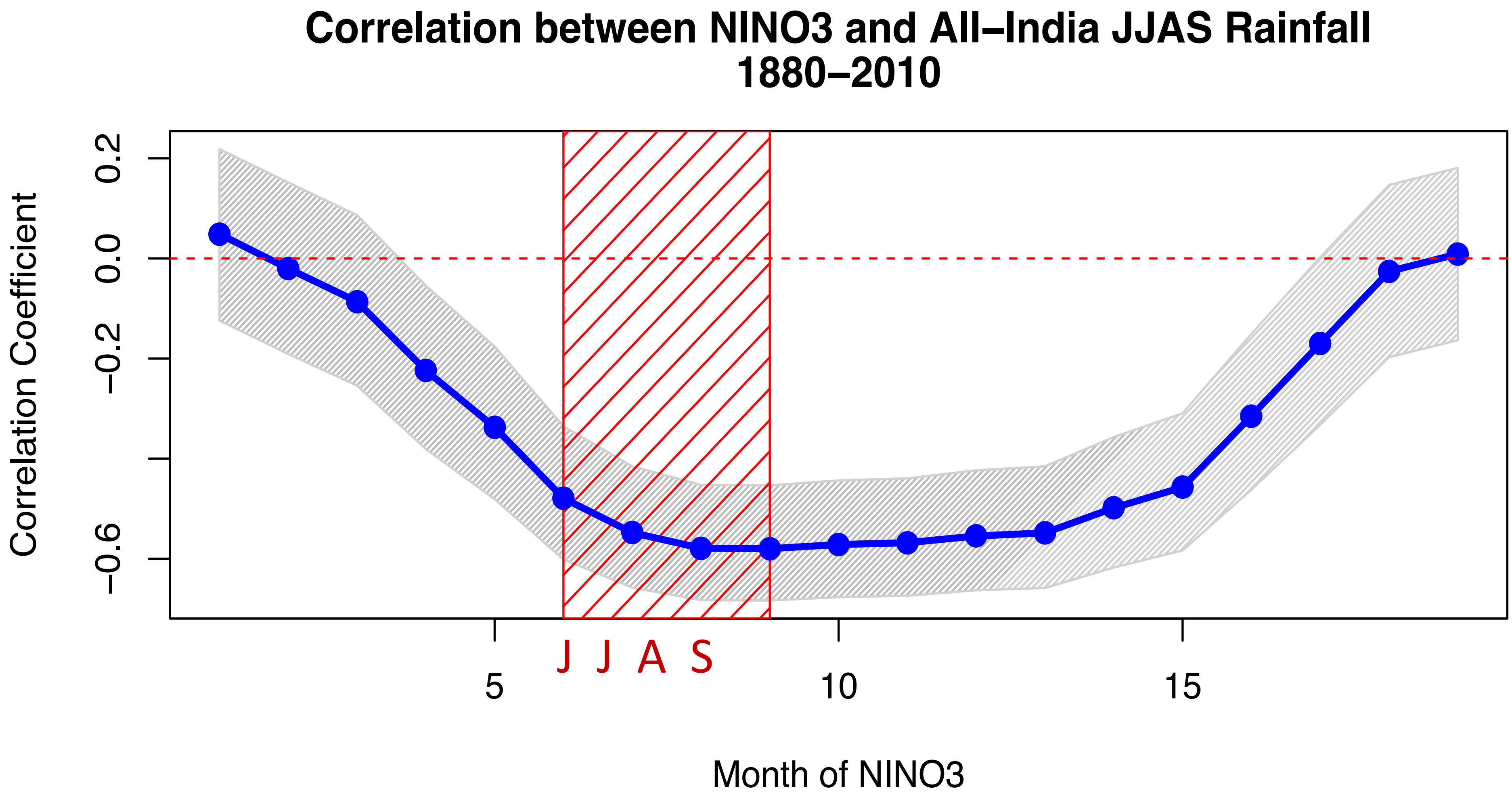
F-values for JJAS precip. For 46-years and 9 ensemble members the 5% significance is F=1.4. Gray color indicates not statistically significant at 95% confidence interval.

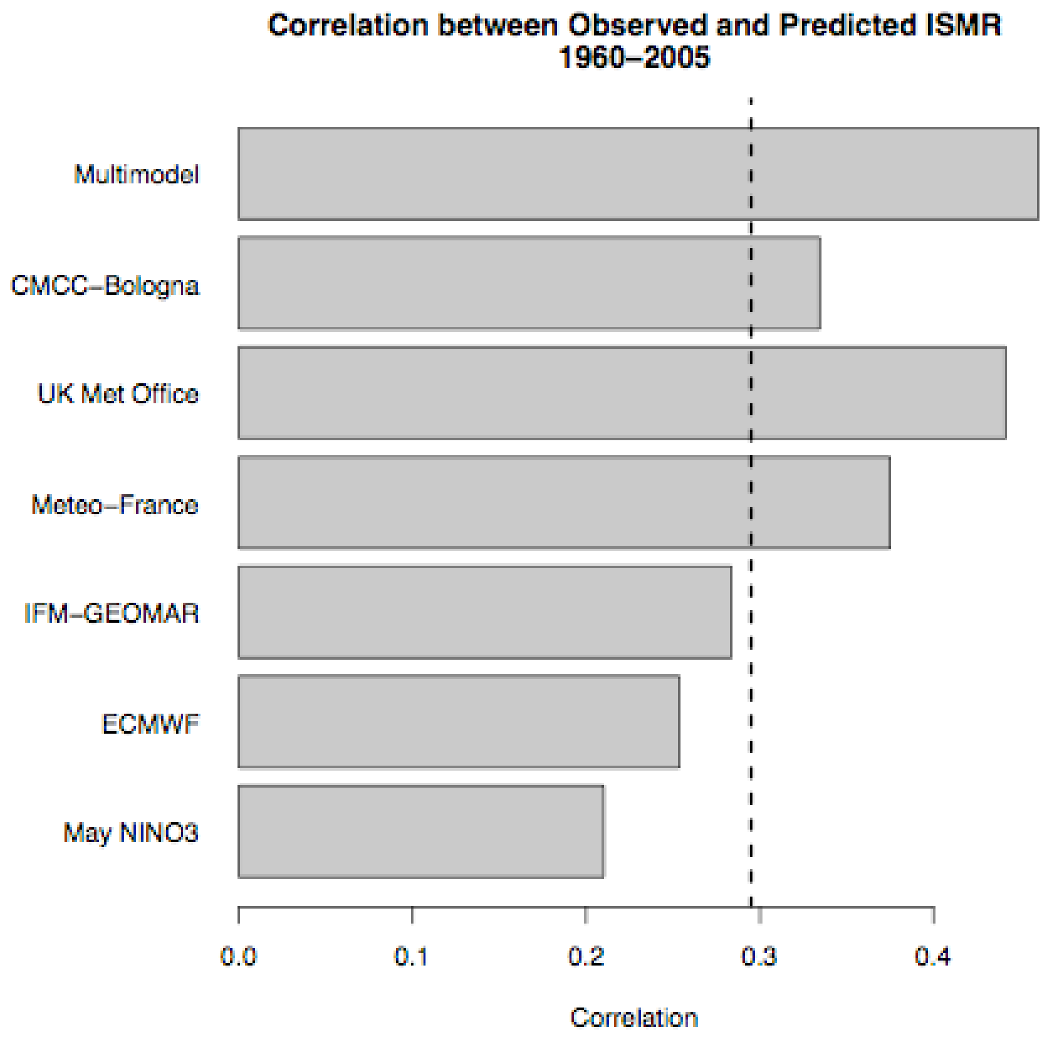
The Challenge

Predictability of Asian Summer Monsoon Rainfall is High

but

Prediction Skill is Low


Correlation between NINO3 and All−India JJAS Rainfall
1880−2010
Correlation Coefficient
−0.6
−0.2
0.0
0.2
5
10
15
J J A S
Month of NINO3



(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.

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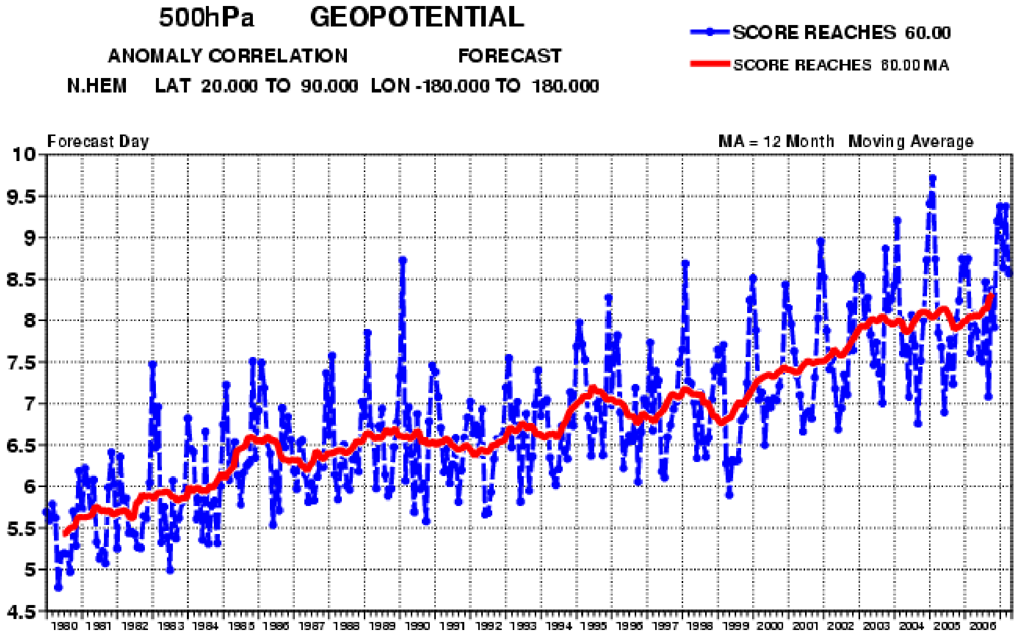
Dynamical Prediction Experience

Model predictability depends on model fidelity

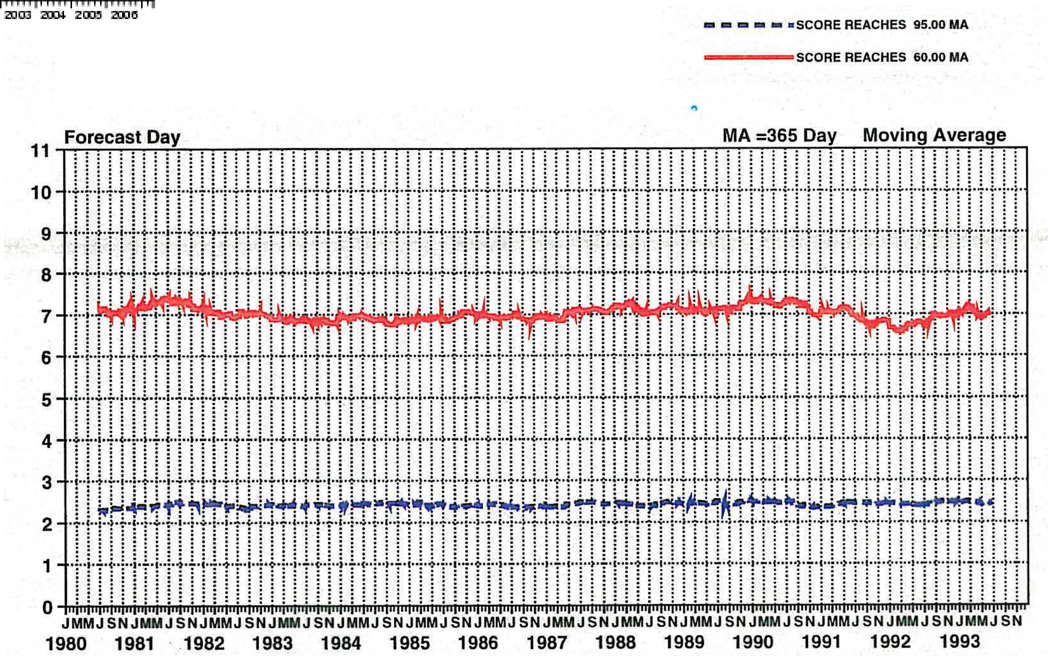
ERA Forecast Verification

Anomaly Correlation of 500 hPa GPH, 20-90N



ERA Forecast Verification

Anomaly Correlation of 500 hPa GPH, 20-90N



Hypothesis

Models that simulate climatology "better" make better predictions.

Definition: Fidelity refers to the degree to which the climatology of the forecasts (including the mean and variance) matches the observed climatology

Testing the Hypothesis: Data

DEMETER Data

- 7 global coupled atmosphere-ocean models
- 9 ensemble members
- 1980-2001 (22 years)
- Initial conditions: 1 February, 1 May, 1 August, 1 November
- Integration length: 6 months

Climate Model Fidelity and Predictability

Relative Entropy: The relative entropy between two distributions, $p_1(x)$ and $p_2(x)$, is defined as

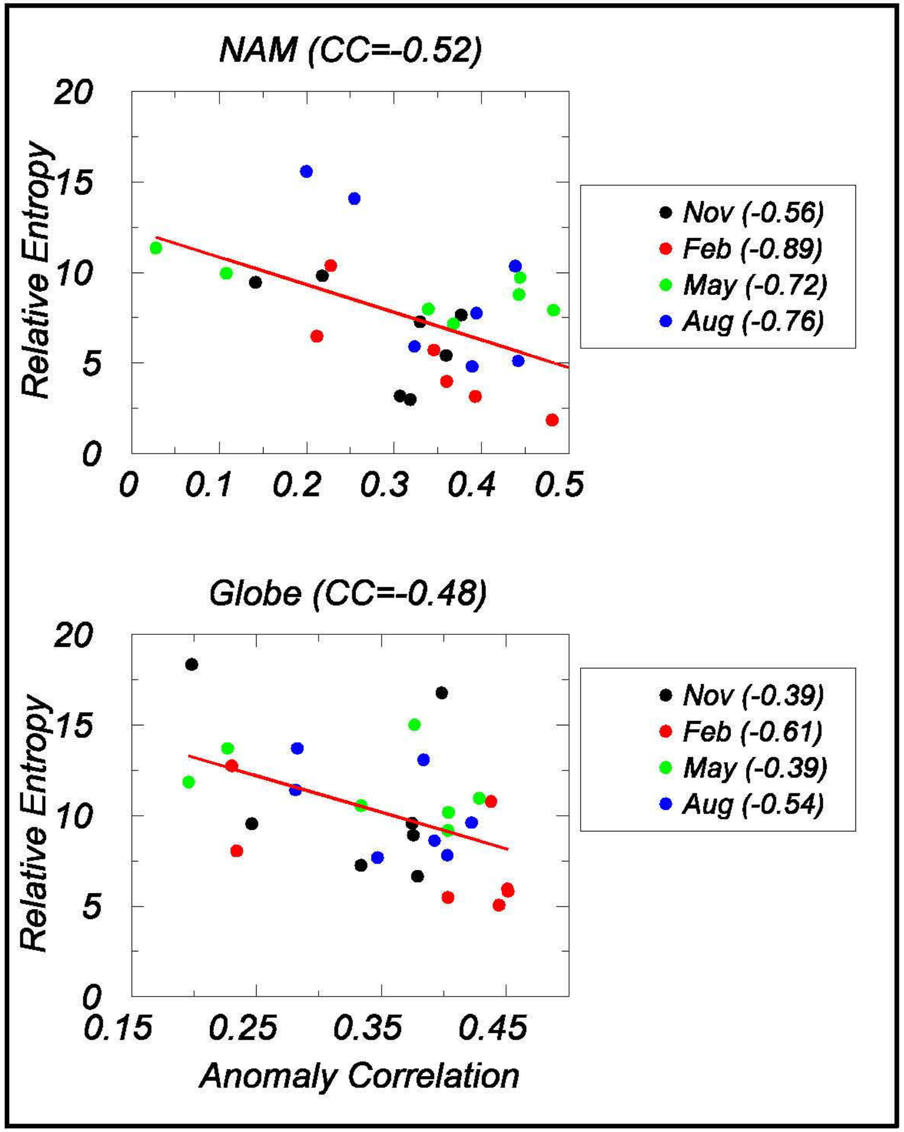
$$R(p_1, p_2) = \int_{R^M} p_1 \log\left(\frac{p_1}{p_2}\right) dx \qquad (1)$$

where the integral is a multiple integral over the range of the M-dimensional vector x.

$$R(p_1, p_2) = \frac{1}{2}\log\left(\frac{|\Sigma_2|}{|\Sigma_1|}\right) + \frac{1}{2} Tr\left\{\Sigma_1 \left(\Sigma_2^{-1} - \Sigma_1^{-1}\right)\right\} + \sum_{k=1}^{4} \frac{1}{2}\left(\mu_1^k - \mu_2^k\right)^T \Sigma_1^{-1} \left(\mu_1^k - \mu_2^k\right) \qquad (2)$$

where μ_j^k is the mean of $p_j(x)$ in the kth season, representing the annual cycle, Σj is the covariance matrix of $p_j(x)$, assumed independent of season and based on seasonal anomalies. The distribution of observed temperature is appropriately identified with p_1, and the distribution of model simulated temperature with p_2.

Fidelity vs. Skill



Fidelity vs. Skill
DEMETER 1980-2001
Seasonal Forecasts

7 models, 4 initial conditions

Lead Time = 0 months

Fidelity and Skill are related.

Models with poor climatology tend to have poor skill.

Models with better climatology tend to have better skill.

Courtesy of Tim DelSole

Dynamical Prediction Experience
(~30 years)

- Weather ≈ 500,000 (30 years X 365 days X 50 centers)
- Seasonal ≈ 5,000 (30 years X 12 months X 15 centers)
- Decadal ≈ 5

Summary

- There is significant unrealized seasonal predictability. **Progress in dynamical seasonal prediction in the future depends critically on improvement of coupled ocean-atmosphere-land models**, improved observations, and the ability to assimilate those observations in coupled ocean-atmosphere models to produce dynamically consistent initial conditions.

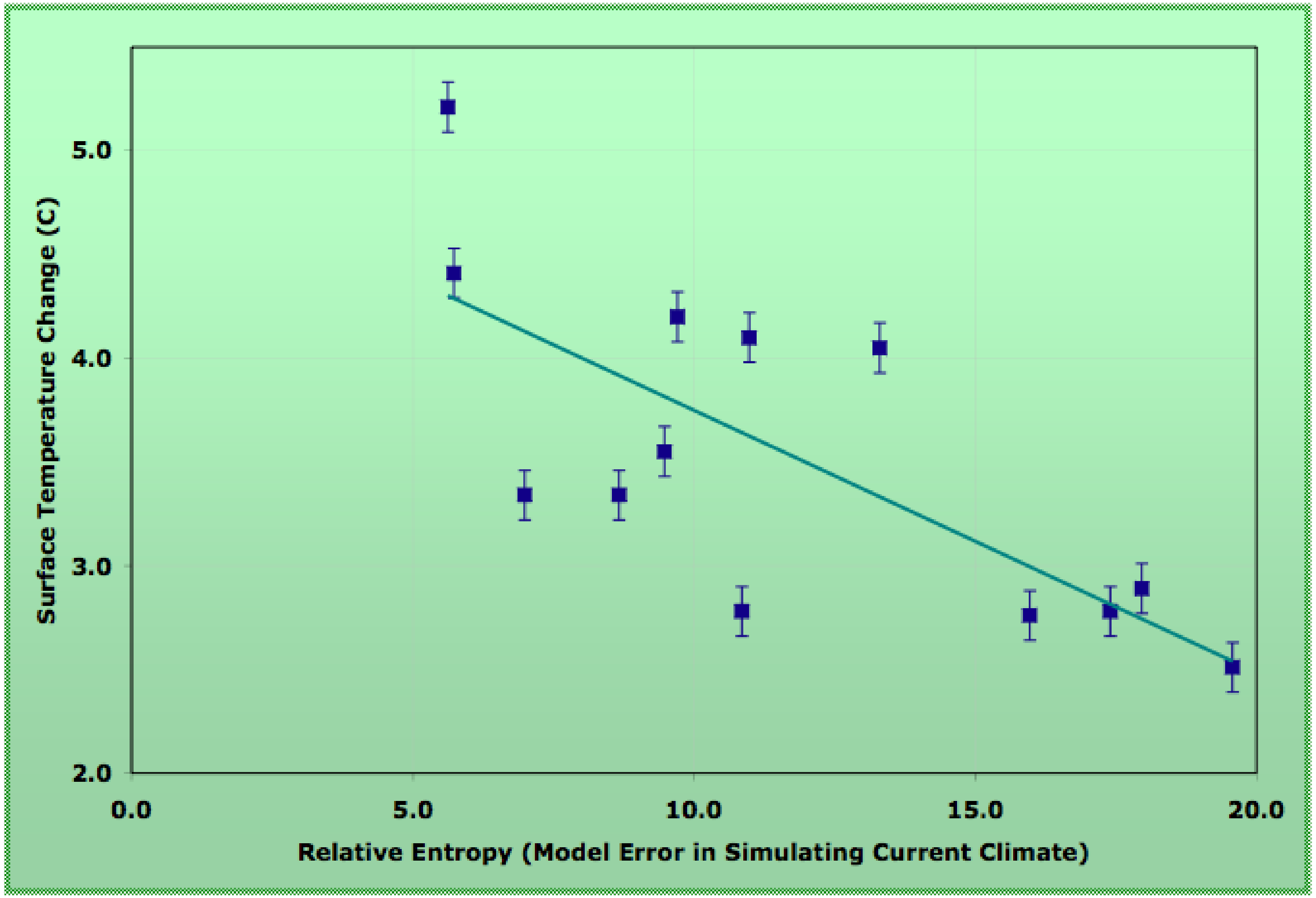
THANK YOU!

ANY QUESTIONS?

Climate Model Fidelity and Projections of Climate Change

J. Shukla, T. DelSole, M. Fennessy, J. Kinter and D. Paolino

Geophys. Research Letters, 33, doi10.1029/2005GL025579, 2006



Model sensitivity versus model relative entropy for 13 IPCC AR4 models. Sensitivity is defined as the surface air temperature change over land at the time of doubling of CO_2. Relative entropy is proportional to the model error in simulating current climate. Estimates of the uncertainty in the sensitivity (based on the average standard deviation among ensemble members for those models for which multiple realizations are available) are shown as vertical error bars. The line is a least-squares fit to the values.