Predictability of Monsoons in CFS

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Simulation of Monsoons by NCEP CFS

Forecast Skill and Predictability

•Simulation of monsoon rainfall and low level winds

•Forecast skill of CFS on daily time scale
- Spatial correlation (anomaly correlation) and temporal correlation

•Predictability of CFS on daily time scale
- Lorenz analysis

•Growth rate of forecast errors and predictability errors
- Lorenz formula

•Predictability and forecast errors based on initial conditions in active and break phases

•Predictability based on ENSO and ISO modes

•South Asian Monsoon and South American Monsoon

CFS Retrospective Forecasts

Model

Atmosphere GFS, Ocean GFDL MOM3
AGCM horizontal resolution: 2.5 x 2.5 degrees
OGCM Zonal: 1degree, meridional: 1/3 degree (10S-10N)
Full coupling (50°N-65°S); once a day; no flux correction
Sea ice from observed climatology
Land model from Mahrt and Pan

Retrospective Forecasts

15 ensemble members:
15 atmosphere initial conditions and 3 ocean initial conditions each month

9-month long forecasts from each initial condition 1981-2005

Analysis includes:

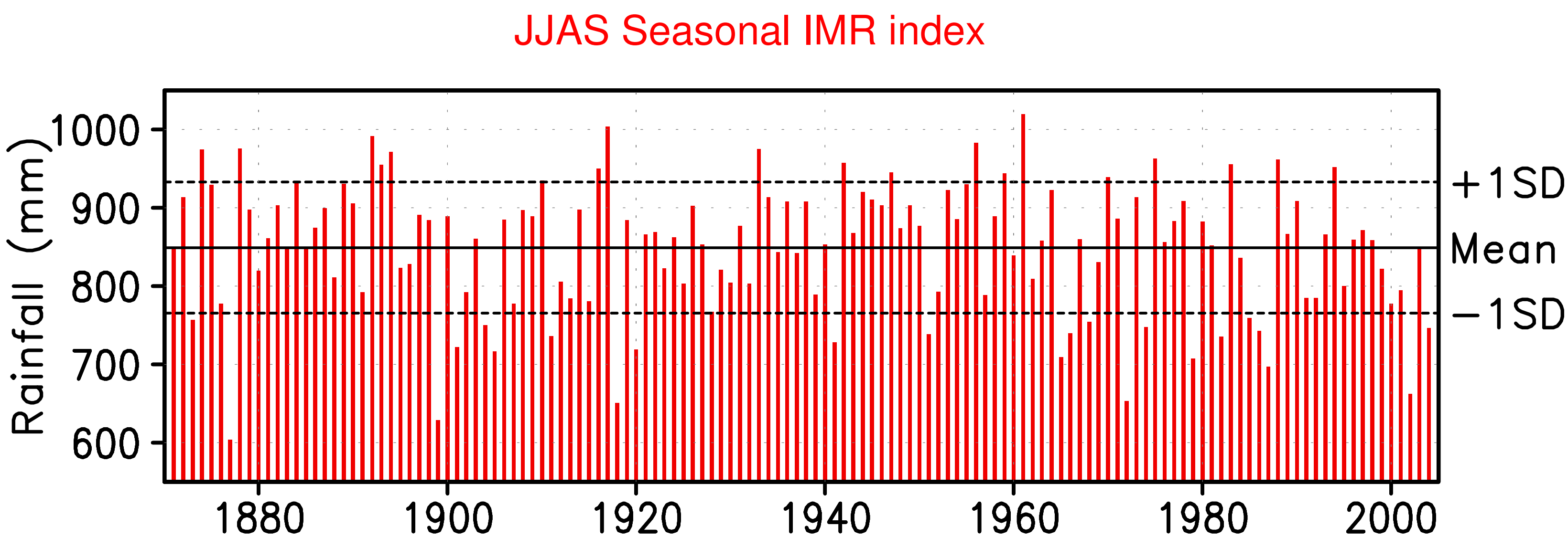
May initial conditions
June initial conditions
July initial conditions
August initial conditions
November initial conditions

South Asian Monsoon

Interannual Variability of Indian Monsoon

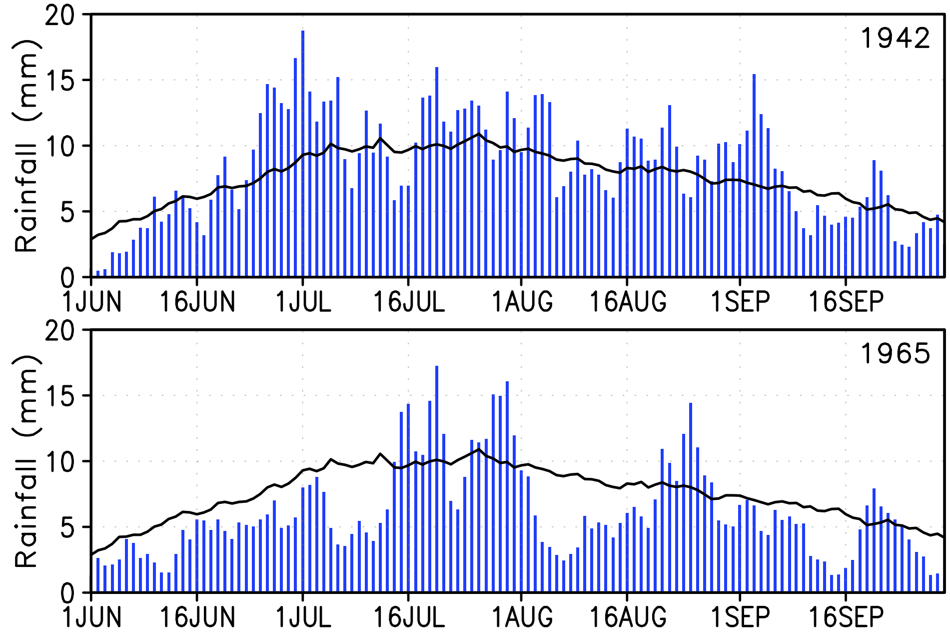
The long-term mean of JJAS seasonal Indian monsoon rainfall (IMR) index (rainfall area averaged over India) is 852 mm (about 7 mm/day).
The standard deviation is 83 mm (about 0.7 mm/day), about 10% of the long-term mean.

The JJAS seasonal mean of rainfall exhibits a pronounced interannual variability.
There are several flood (above-normal rainfall) years and several drought (below-normal rainfall) years, crossing 1 standard deviation.
There were 18 flood years and 22 drought years during 1871-2004.



Intraseasonal Variability of Indian Monsoon

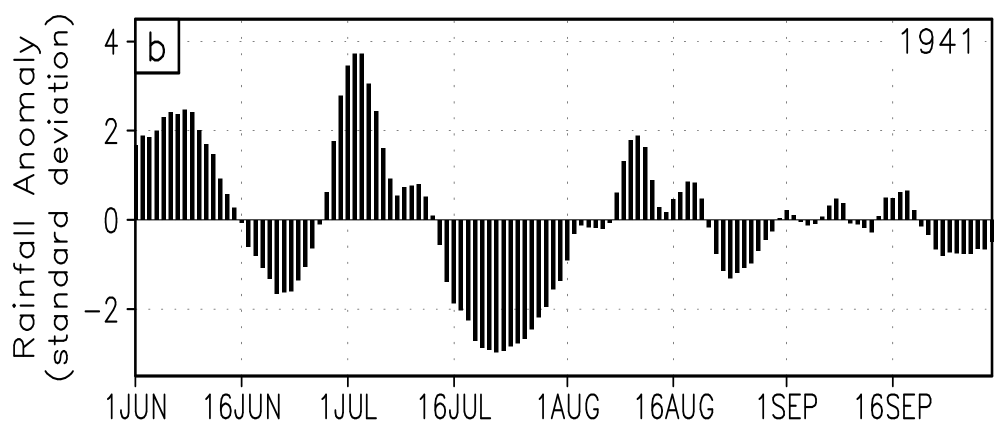
Daily IMR index



Intraseasonal variability consists of active and break phases which for a period ranging from a few days to a few weeks.

Total IMR index for
strong monsoon year 1942 and
weak monsoon year 1965

Anomaly for 1941



South Asian Monsoon Climatology

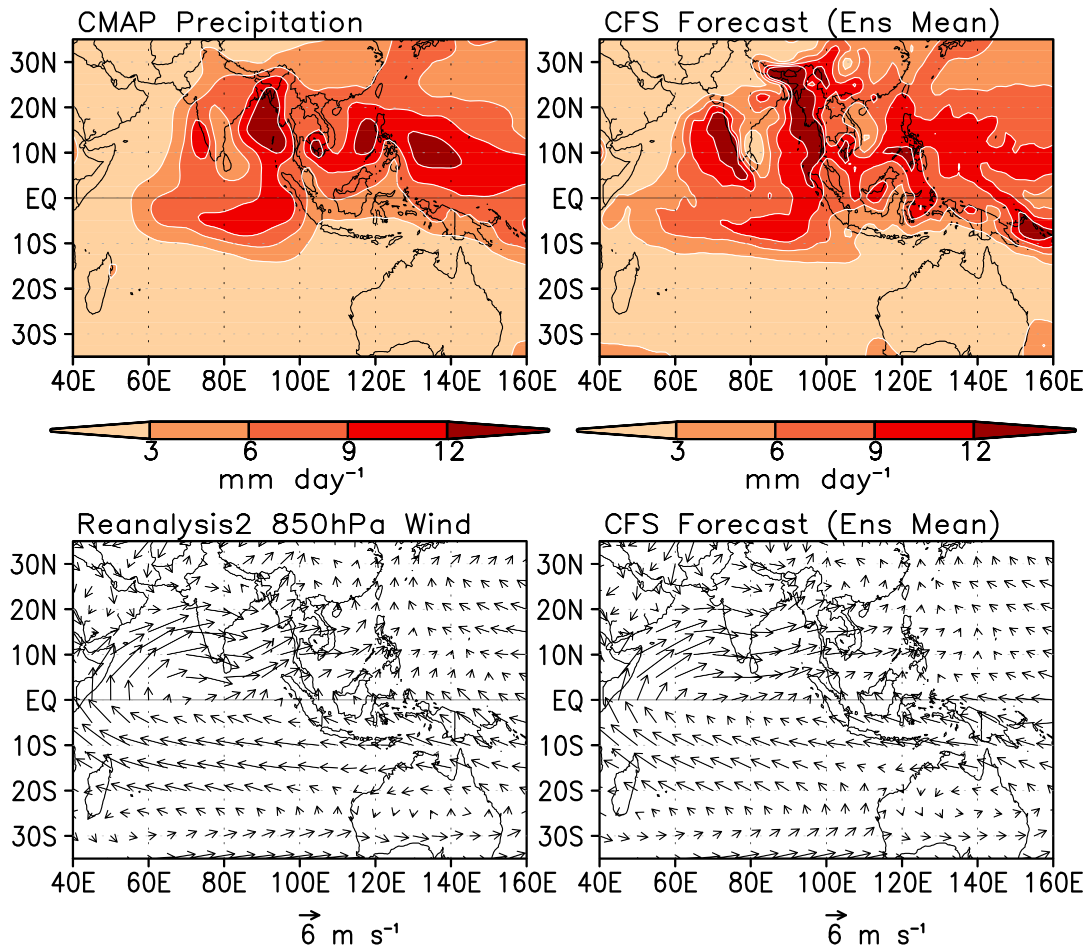
JJAS climatology of ensemble mean

Precipitation:

- Compared with CMAP rainfall
- General spatial structure is fairly well simulated
- Overestimation along west coast and Bay of Bengal
- Underestimation over central plains

850hPa horizontal wind:

- Compared with Reanalysis2 wind
- Well simulated in both magnitude and direction of the winds



Annual Cycle

Annual Cycle of daily climatology

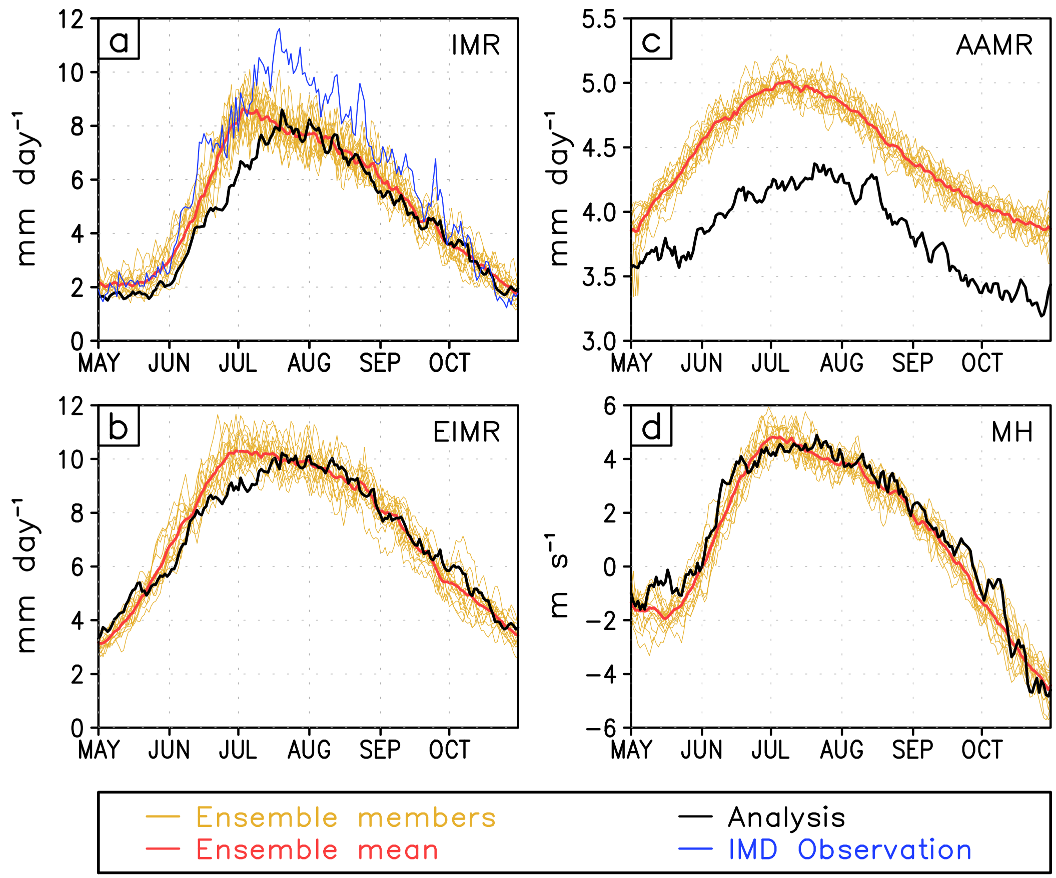
IMR (Indian Monsoon Rainfall) index:
area average of rainfall over the land region of India

EIMR (Extended Indian Monsoon Rainfall) index: area average of rainfall over (70°E-110°E, 10°N-30°N)

AAMR (Australia-Asia Monsoon Rainfall) index: area average of rainfall over (40°E-160°E, 40°S-40°N)

MH (Monsoon Hadley) index: area average of meridional wind shear (850 and 200hPa) over (70°E-110°E, 10°N-30°N)

IMR, EIMR and MH indices are well simulated.

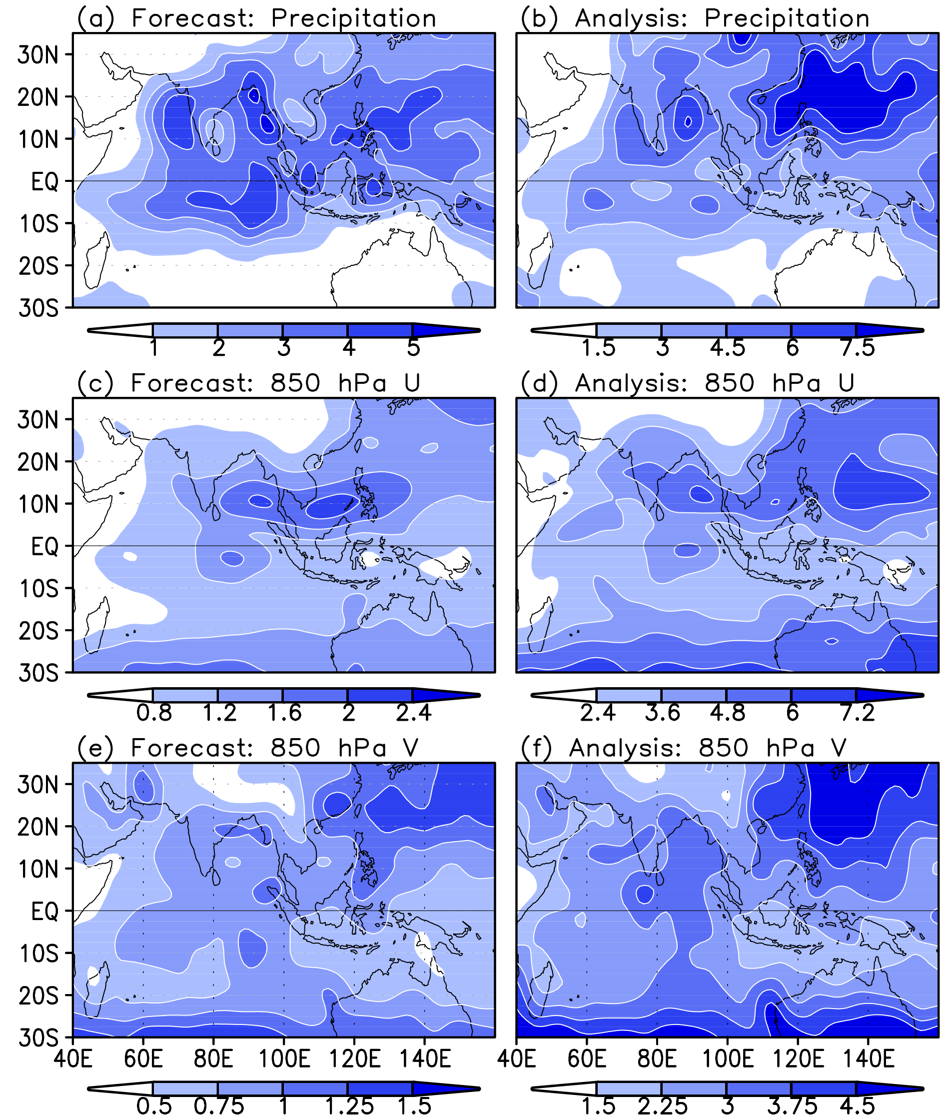


Standard Deviation

Standard deviation of daily anomalies for JJAS season

The standard deviation of precipitation is slightly higher over India and equatorial Indian Ocean.

The standard deviation of 850hPa winds are fairly well simulated.



Anomaly Correlation of Precipitation

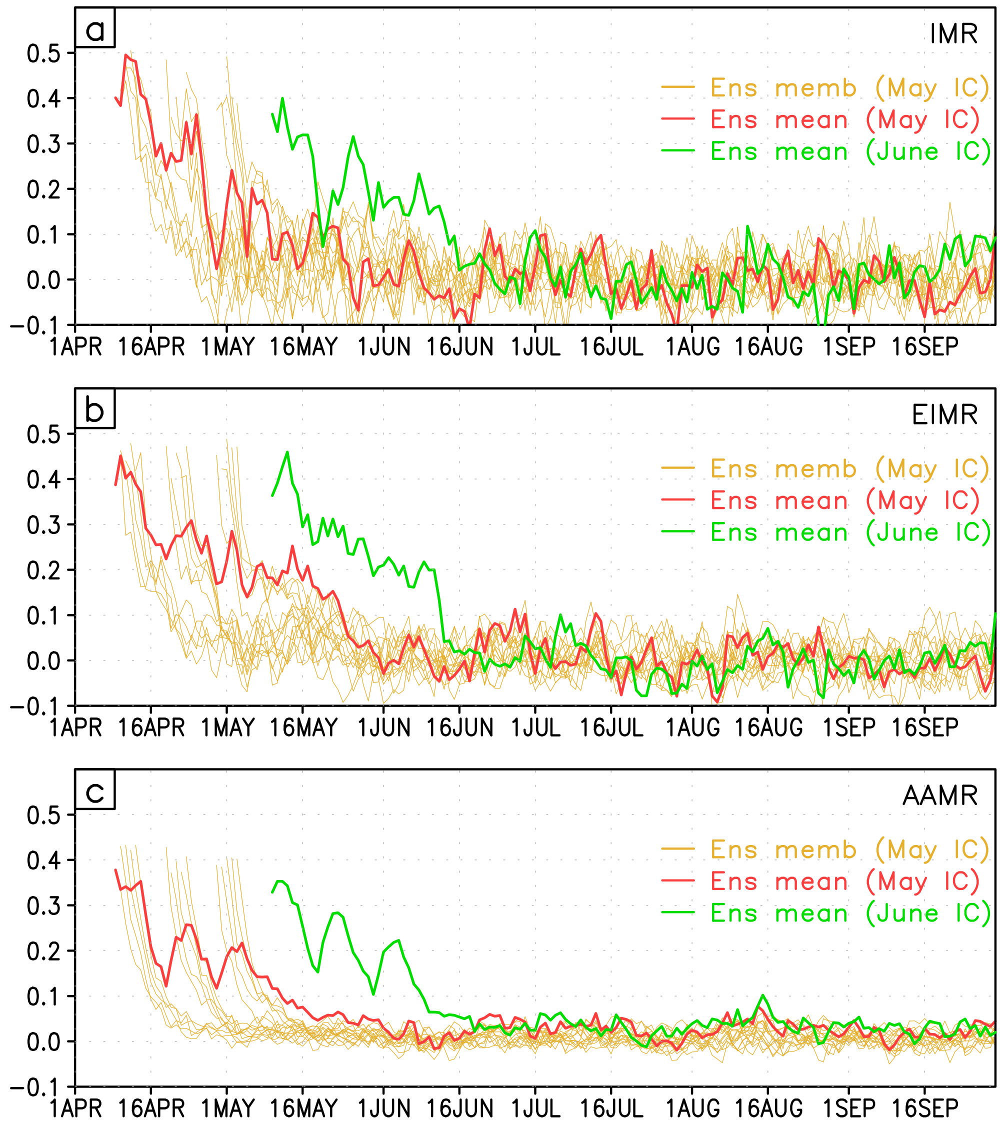
Anomaly correlation of daily precipitation

Spatial correlation between forecast and analysis in three regions

- IMR
- EIMR
- AAMR

The correlation decreases rapidly and takes about a month to reach zero correlation.

No difference between forecasts from May and June initial conditions.



Anomaly Correlation of 850hPa Zonal Wind

Anomaly correlation of daily 850hPa zonal wind

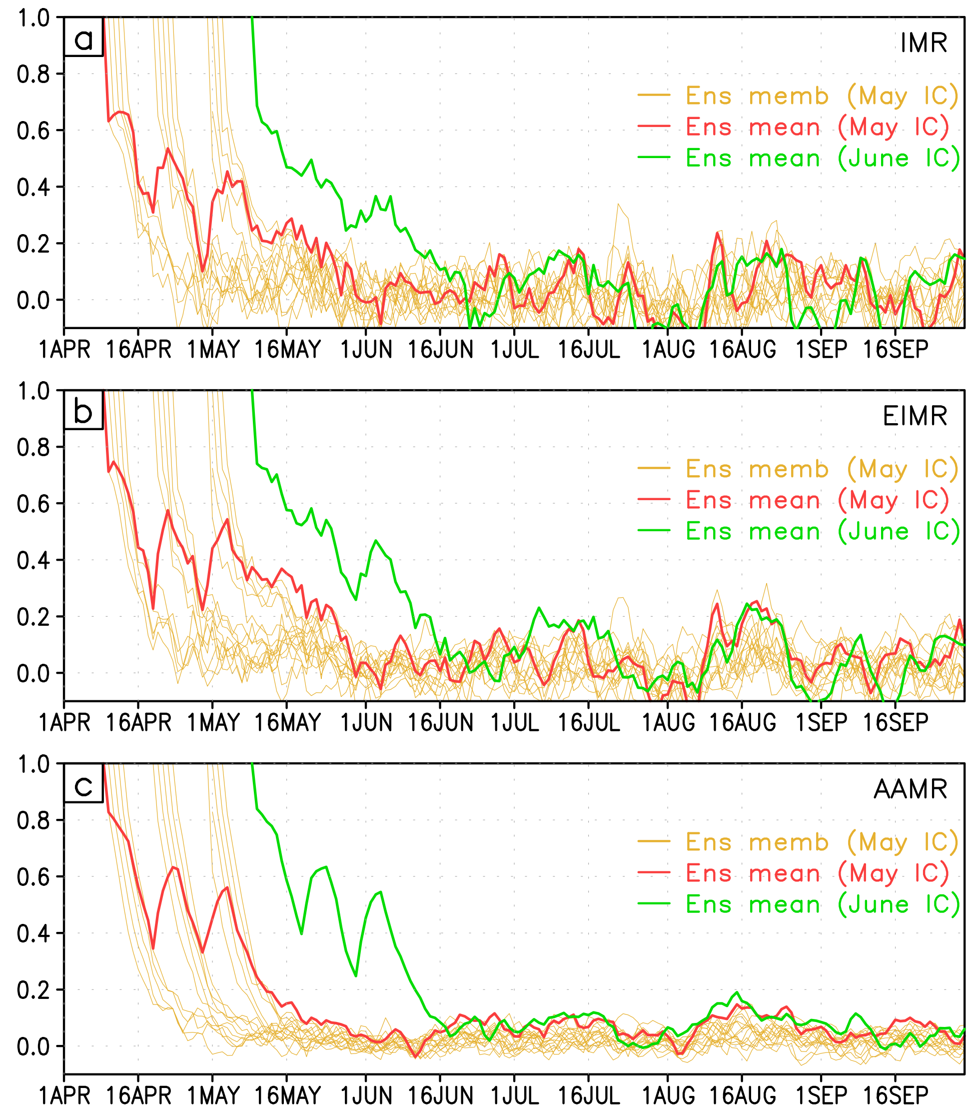
Spatial correlation between forecast and analysis in three regions

- IMR
- EIMR
- AAMR

The correlation decreases rapidly and takes about a month to reach zero correlation.

Similar to the correlations of precipitation forecasts.

No difference between forecasts from May and June initial conditions.



Temporal Correlation of Precipitation

Temporal correlation of daily rainfall

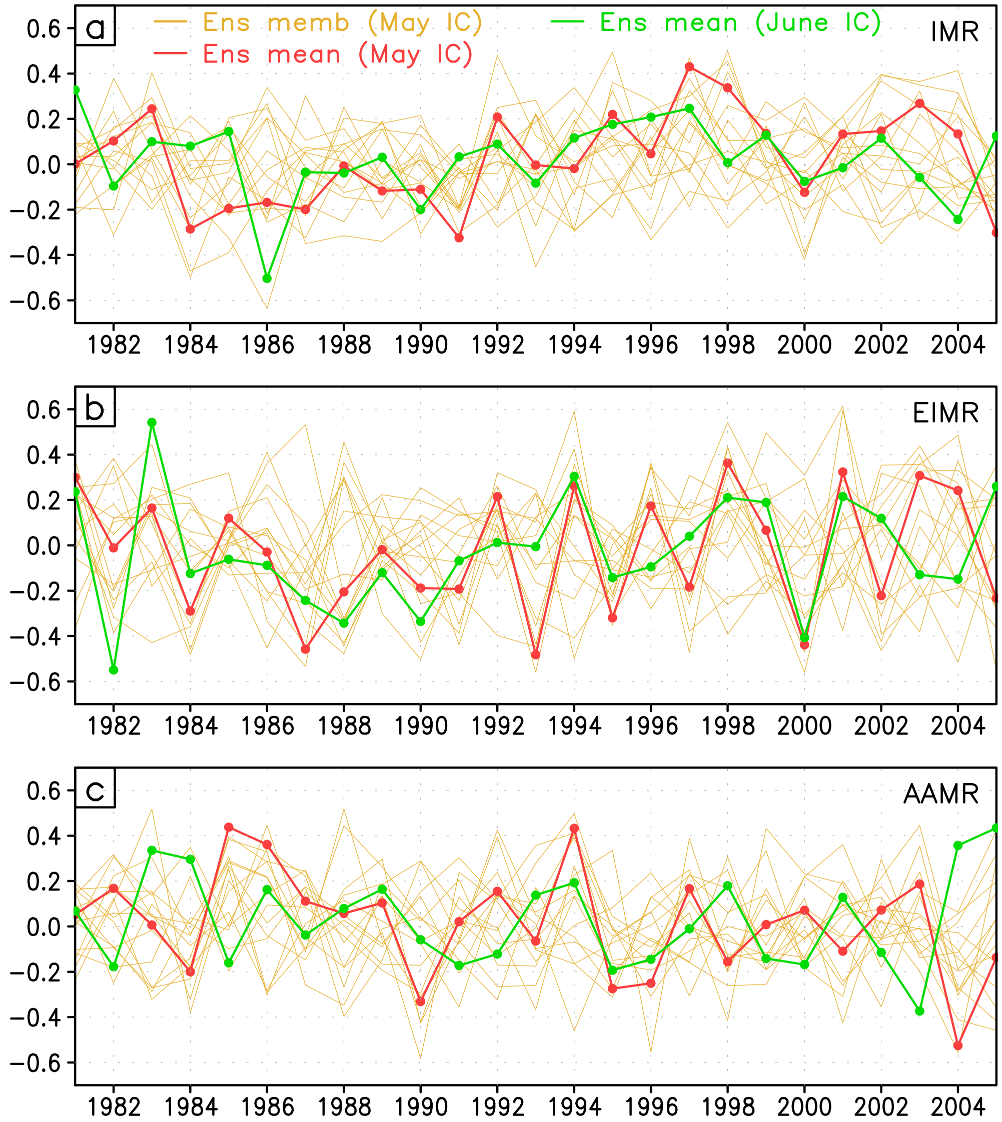
Correlation of daily rainfall anomaly indices for each JJAS season between forecast and analysis.

May IC and July IC

IMR: Low correlation

EIMR: Some ENSO years have moderate correlations.
Similar behavior of several ensemble members.

AAMR: Low correlation



Temporal Correlation of 850hPa Zonal Wind

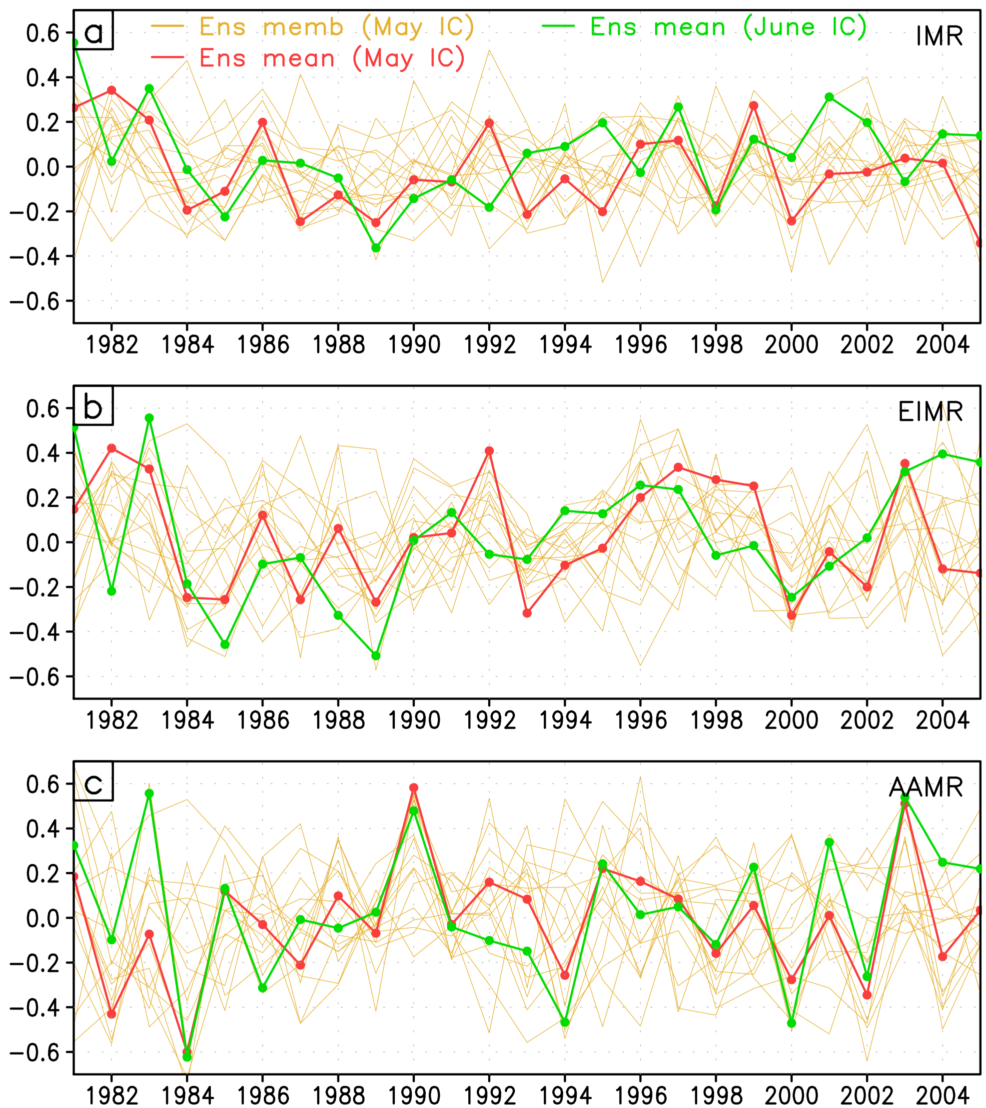
Temporal correlation of daily 850hPa zonal wind

Correlation of daily 850hPa zonal wind anomaly indices for each JJAS season between forecast and analysis.

May IC and July IC

The correlation values are slightly higher compared to rainfall correlations.

AAMR index has much higher correlation.



Forecast Error Growth

Growth of daily forecast errors

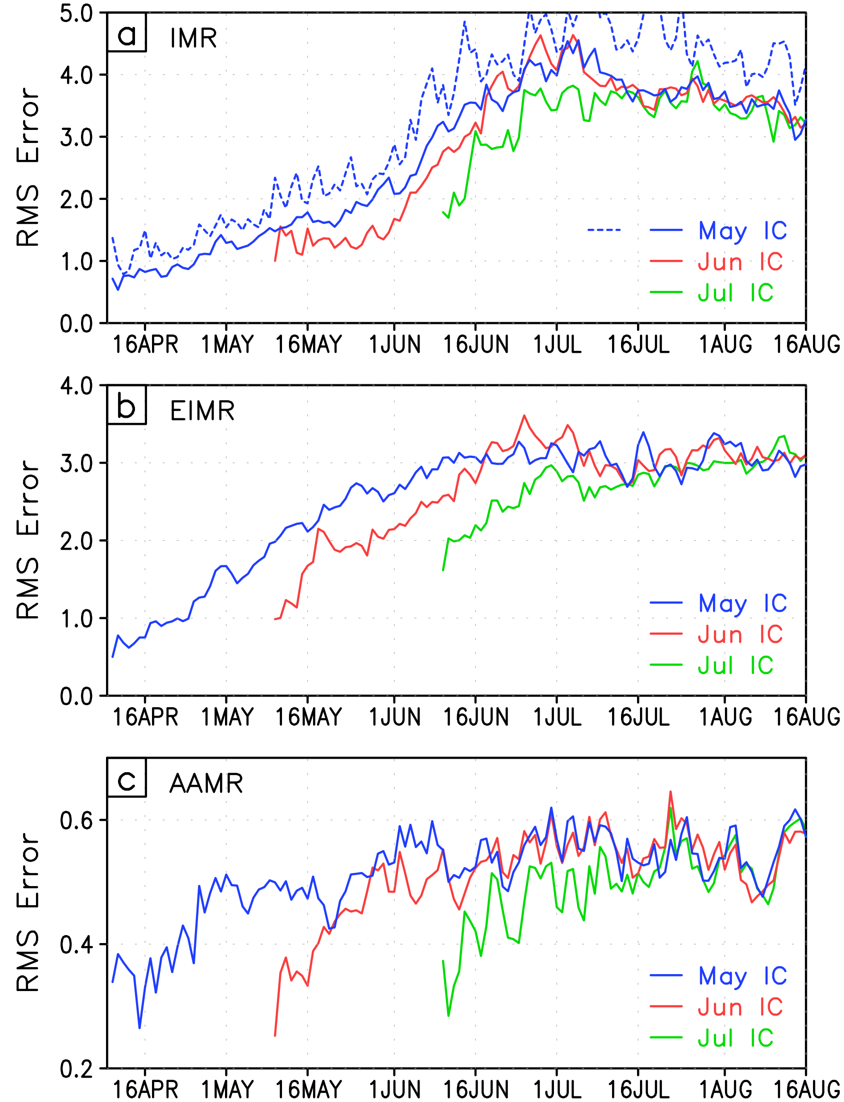
Forecast error is the difference between forecast and analysis.

(For May IC IMR, the forecast errors are also shown with respect to IMD observed rainfall – dashed curve)

RMS error using all ensemble members.

The growth rate is similar for all three ICs (estimates of growth rate will be provided later).

All three ICs reach the saturation point at the same time of the season because of differences in the size of the initial errors.



Forecast Error Growth for May IC

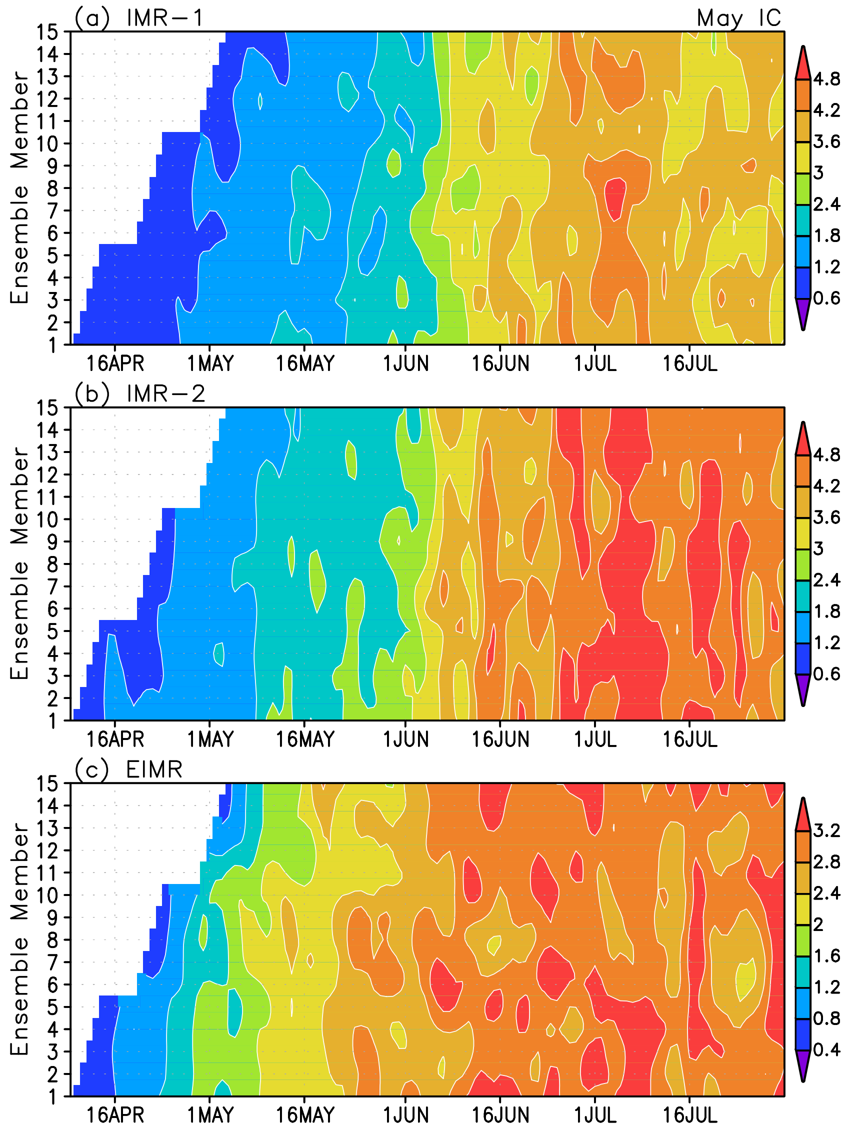
Forecast error of individual ensemble members: May IC

IMR-1: error with respect to IMD rainfall

IMR-2 and EIMR: error with respect to analysis

The initial errors are small.

Both IMR EIMR, the saturation is reached at the same time of the year.



Forecast Error Growth for July IC

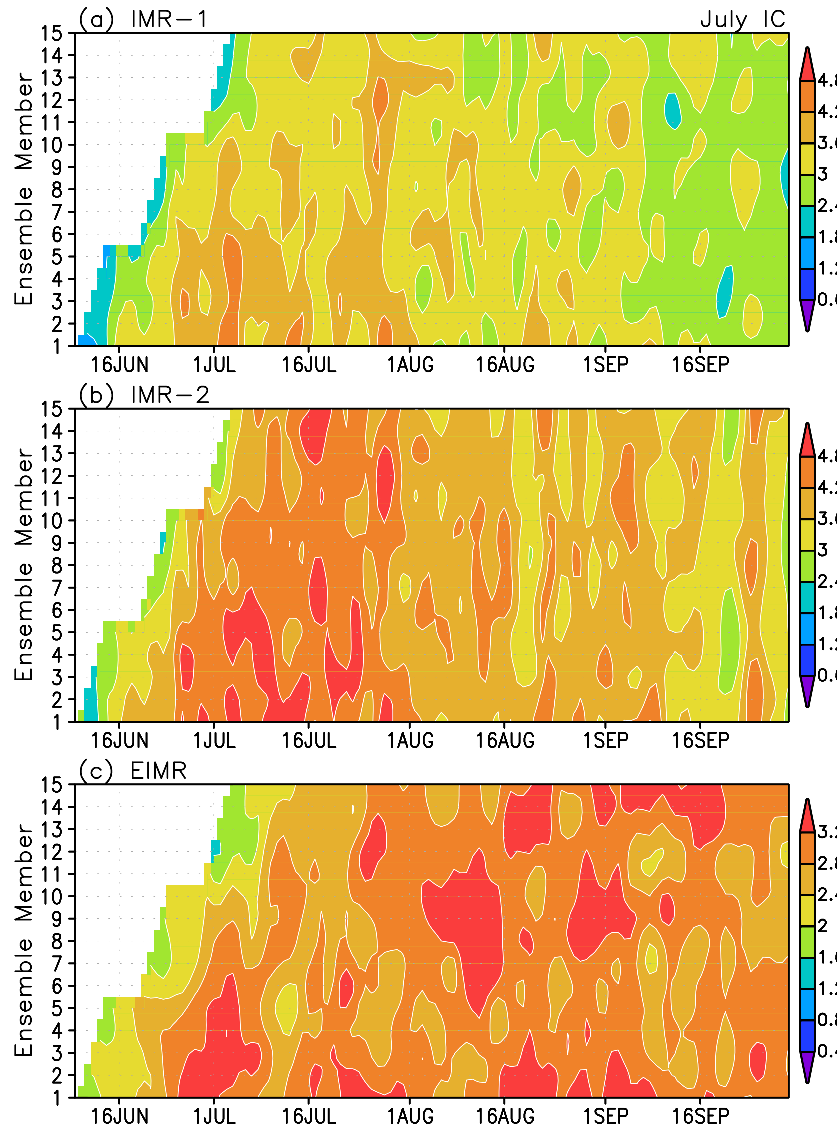
Forecast error of individual ensemble members: July IC

IMR-1: error with respect to IMD rainfall

IMR-2 and EIMR: error with respect to analysis

The initial errors are larger compared to May ICs.

Both IMR EIMR, the saturation is reached at the same time of the year.



Lorenz Analysis of Predictability for May IC

Lorenz error analysis for May IC

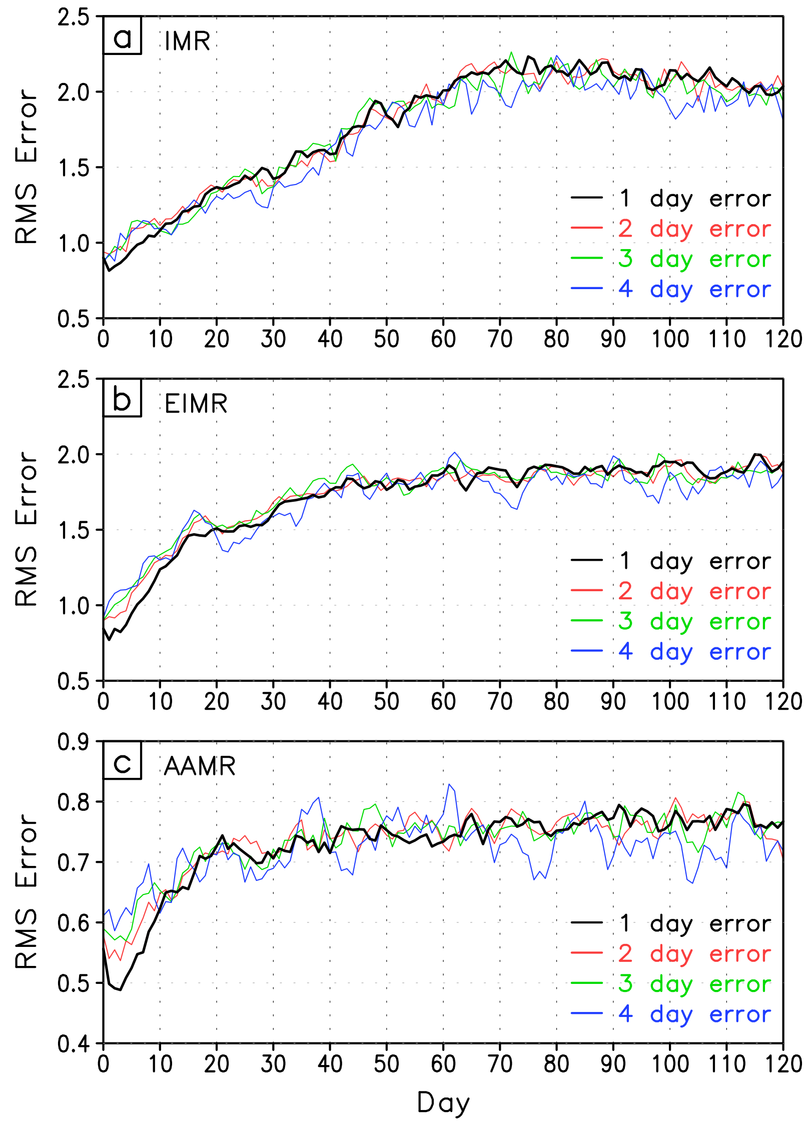
Two forecast integrations starting on successive days are considered for 1-day error. The difference between the two forecast for each day provides the evolution of 1-day initial error.

Similar error evolutions are found for 2-day, 3-day and 4-day initial errors.

These errors are used for finding the predictability of the model

RMS errors for IMR, EIMR and AAMR are plotted using all ensemble members.

IMR has the slowest error growth.

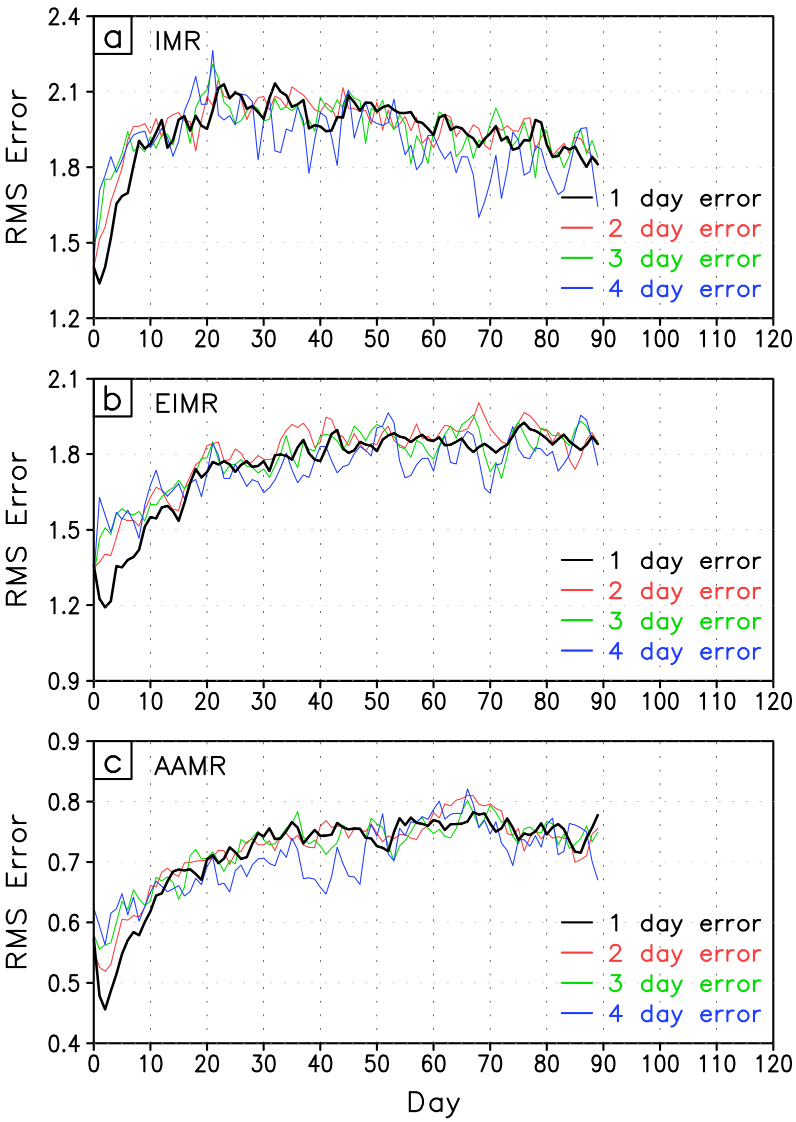


Lorenz Analysis for July IC

Lorenz error analysis for July IC

The initial errors are larger compared to May IC for each index.

The size of the initial errors also show more differences from 1-day error to 4-day error.



Error Growth Rate

Growth rate of errors using Lorenz's formula

An approximate formula can be fitted to the error curve. If E is the mean error, the exponential growth is given by the equation

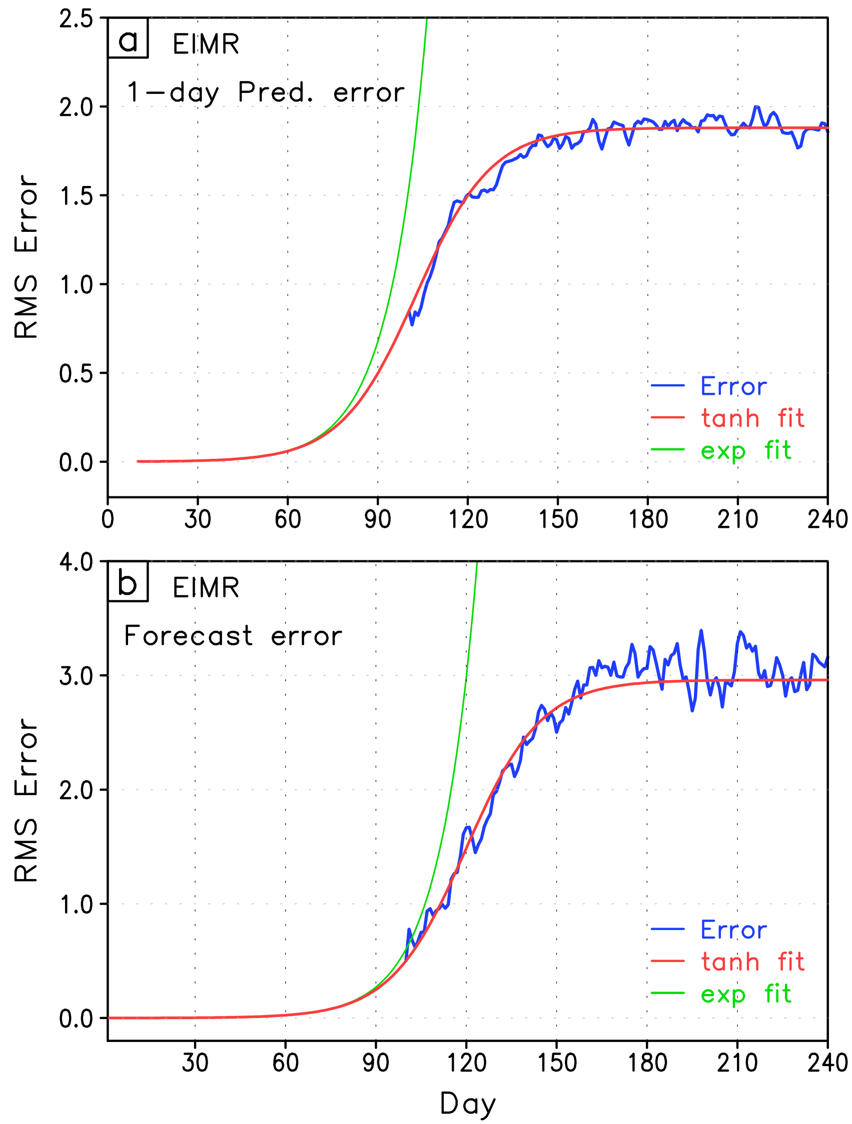
$$\frac{dE}{dt} = \lambda_1 E$$

The errors do not grow forever. The modified error equation is

$$\frac{dE}{dt} = \lambda_1 E - sE^2$$

where s is so chosen that $E_s = \lambda_1/s$ is the saturation value of E. The solution involves a *tanh* function.

The doubling time of the small errors is $t_d = (\ln 2)/\lambda_1$



Error Growth Rate

Growth rate of errors using Lorenz's formula

Estimates of <u>doubling time</u> of errors

Forecast errors

IMR: 5-6 days

EIMR: 8-9 days

AAMR: 6-7 days

Predictability errors (1-day errors)

IMR: 14 days (May IC), 4 days (July IC)

EIMR: 9 days (May IC), 7 days (July IC)

AAMR: 5 days (May (IC), 5 days (July IC)

Forecast Errors from Active and Break Phases

Forecast errors initiating from different phases of the intraseasonal variation

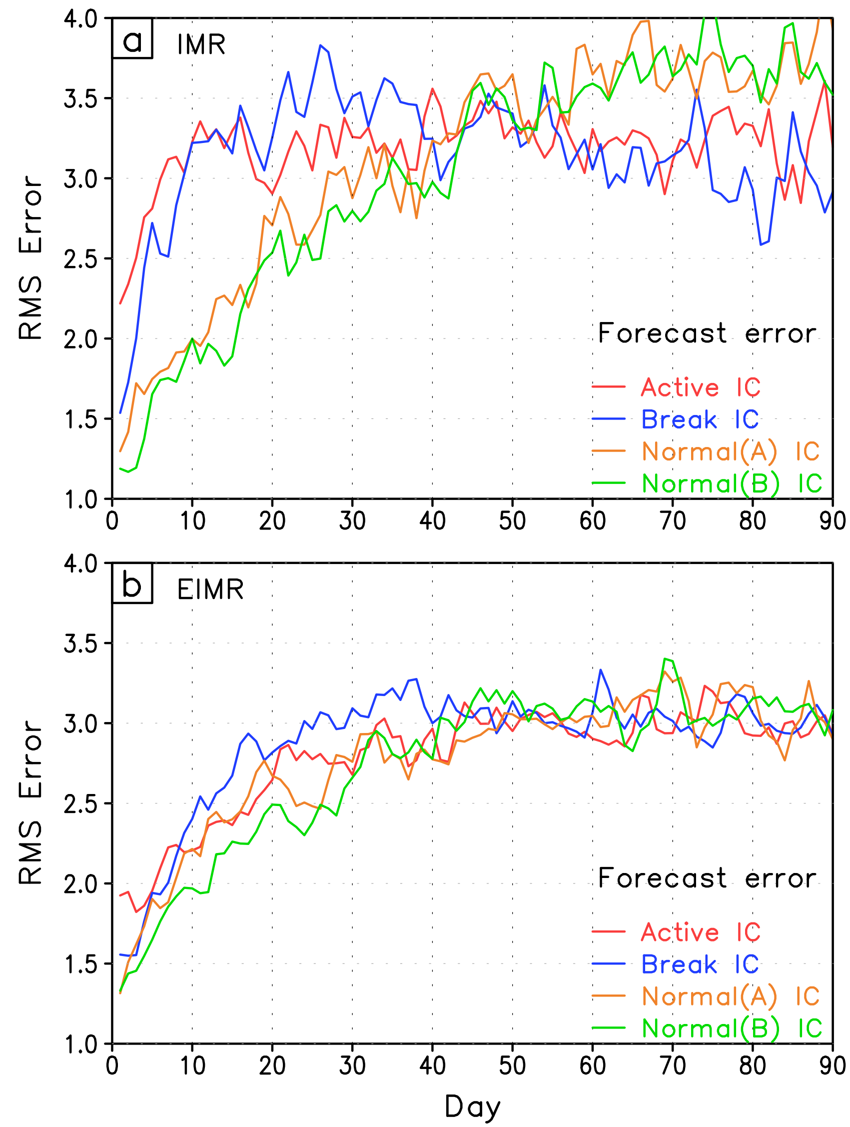
RMS errors of IMR and EIMR indices

Forecasts are initiated in four different phases:

Peak active phase
Peak break phase
Normal phase (going to active phase)
Normal phase (going to break phase)

EIMR has same growth for all phases.

IMR has faster growth rate for forecasts starting from active and break phases compared to those starting from normal phases.



Predictability Errors from Active and Break Phases

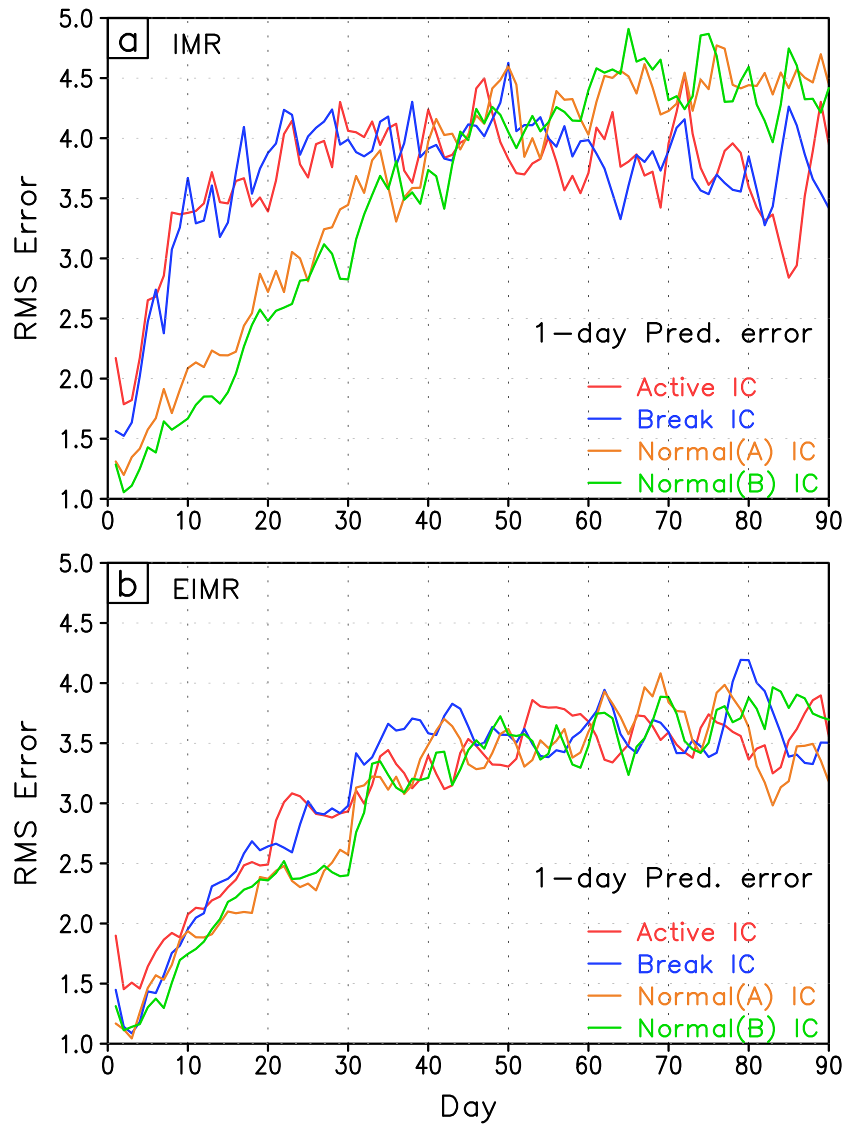
Predictability errors (1-day initial errors) initiating from different phases of the intraseasonal variation

RMS errors of IMR and EIMR indices

Doubling time of errors (using Lorenz formula):

IMR:
Active and Break IC: 2 days
Normal IC: 9 days

EIMR:
Active and Break IC: 7-8 days
Normal IC: 7-8 days



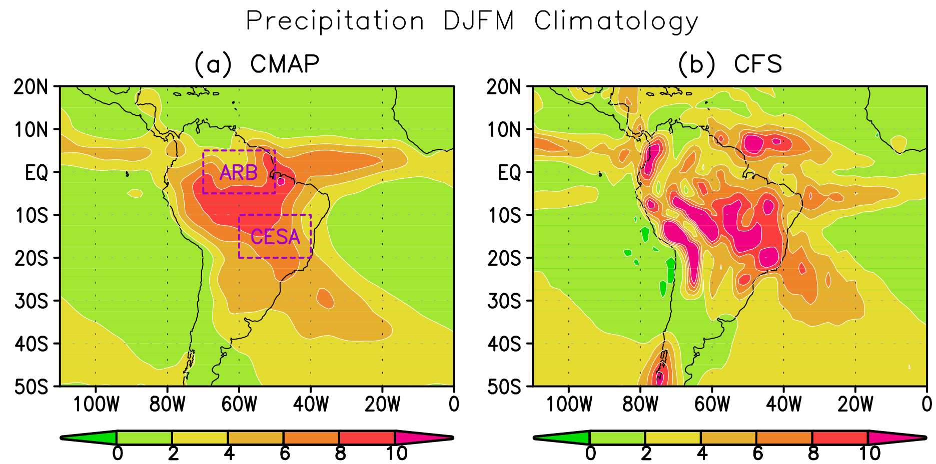
South American Monsoon

South American Monsoon Climatology

Climatology of Precipitation

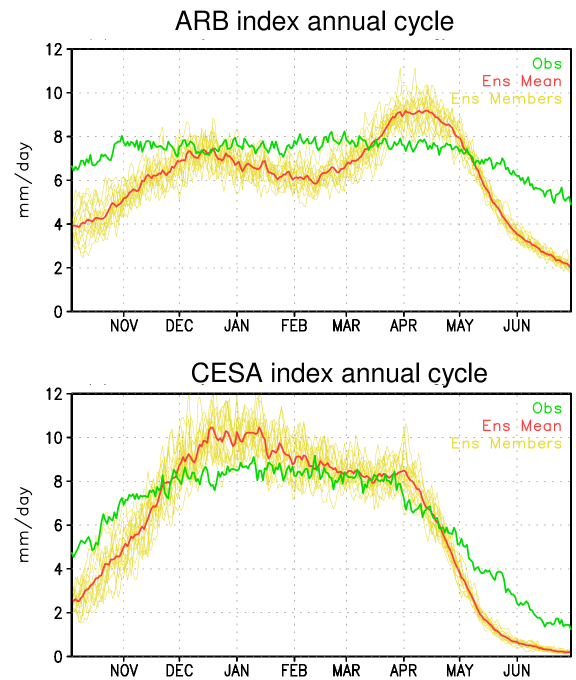
DJFM Climatology:

- Compared with CMAP rainfall
- Less rainfall over ARB
- More rainfall over CESA



Annual cycles of ARB and CESA indices:

CESA index is better simulated than ARB index

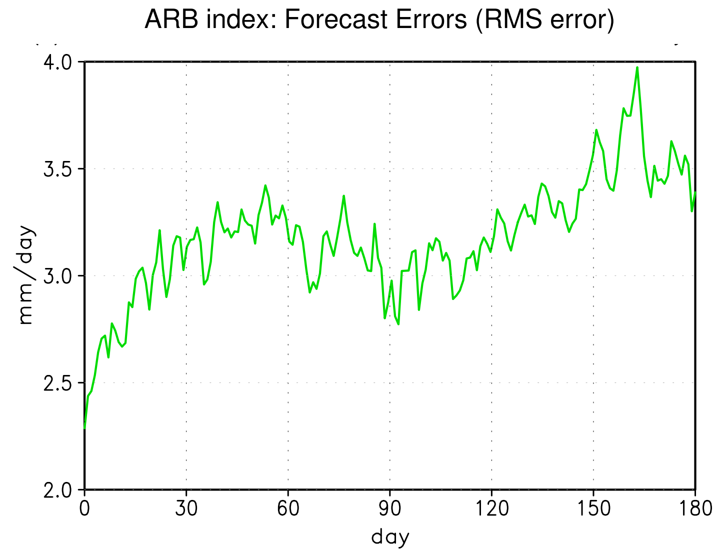


Forecast Error Growth Rate

Growth rate of errors
Forecast errors

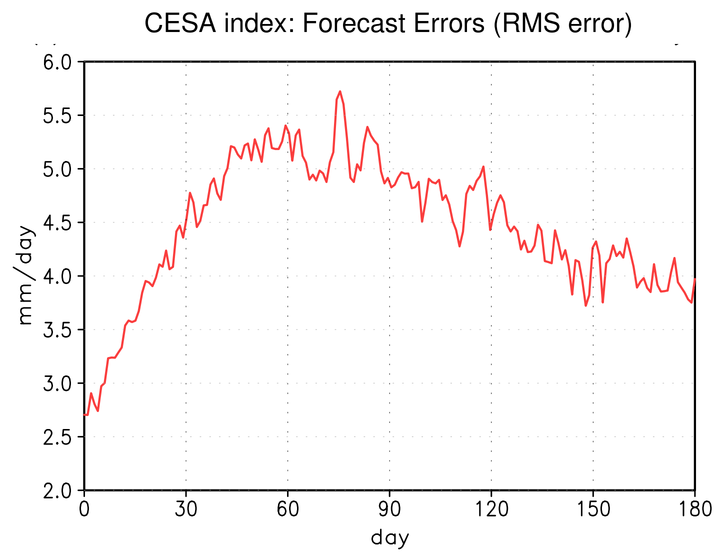
RMS errors for ARB index

Lorenz error formula:
doubling time $t_d = 6$ days



RMS errors for CESA index

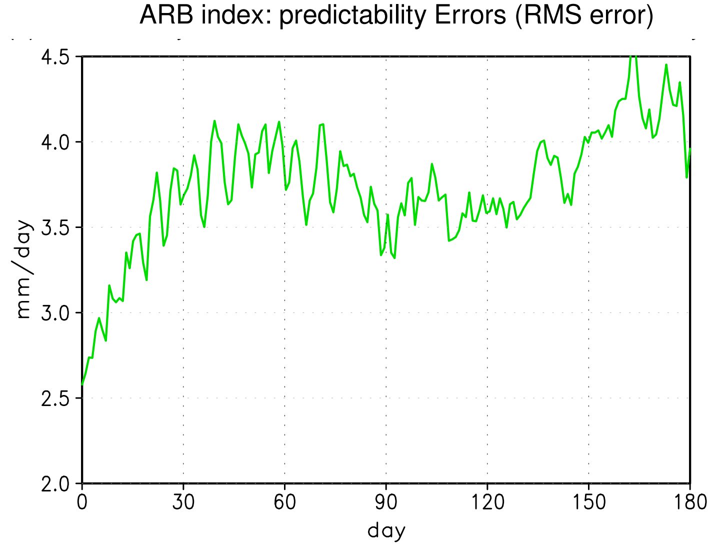
Lorenz error formula:
doubling time $t_d = 9$ days



Predictability Error Growth Rate

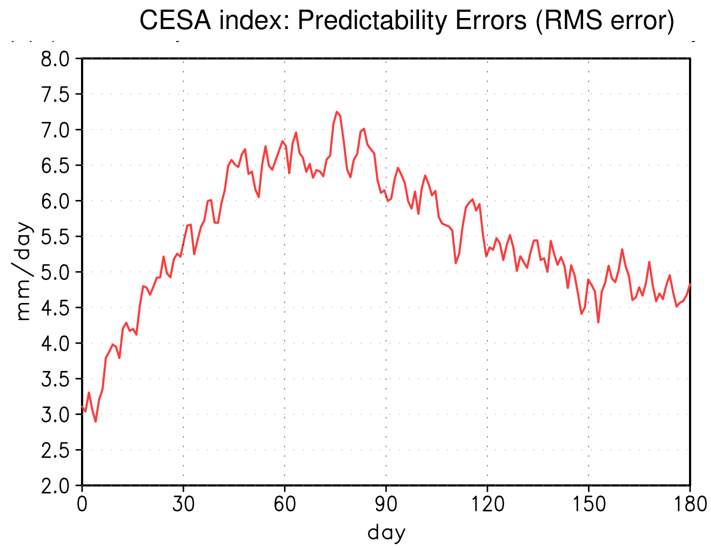
Growth rate of errors
Predictability errors

RMS errors for ARB index



Lorenz error formula:
doubling time $t_d = 6$ days

RMS errors for CESA index



Lorenz error formula:
doubling time $t_d = 9$ days

MSSA of South American Monsoon

Multichannel singular spectrum analysis (MSSA) of daily data was performed over the monsoon region to obtain different modes of variability

Oscillatory and persisting components in the form of RCs were obtained from the EOFs and PCs

South American Monsoon:

Daily OLR anomalies over 110°W-0°, 50°S-10°N
All days of the year 1981-2005
Lag window: 120 days at one day interval

Modes:

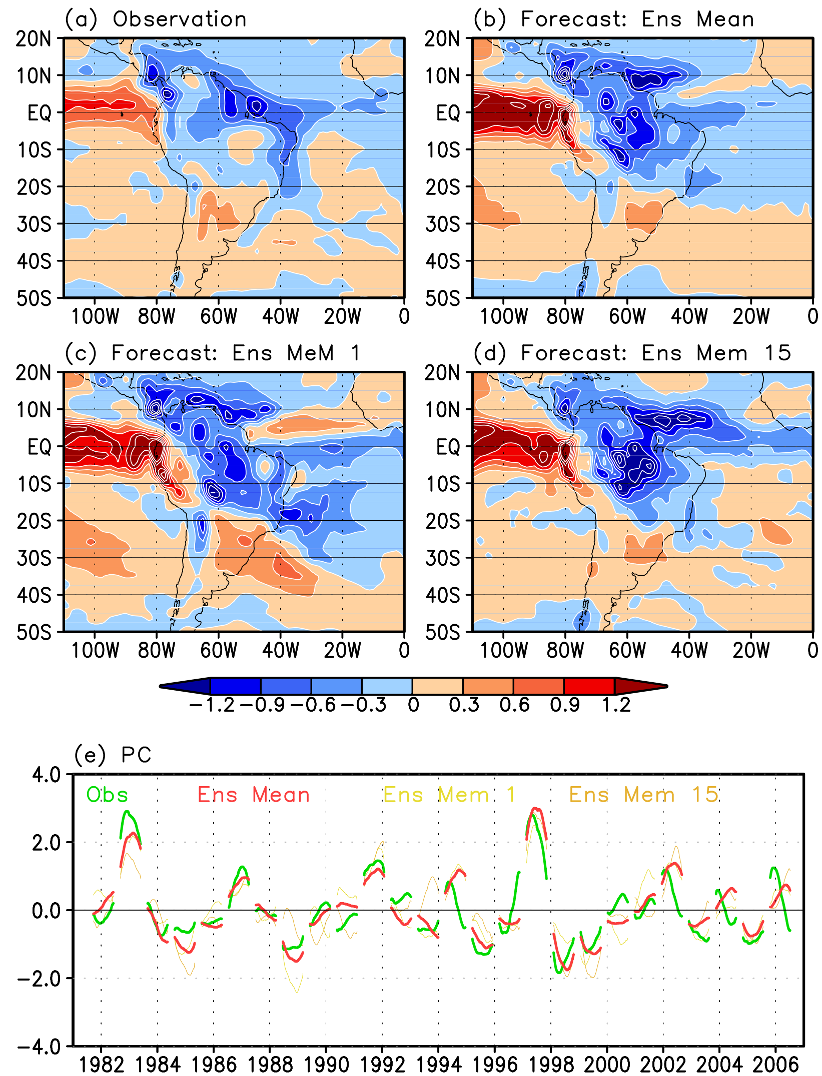
ENSO mode
Oscillatory mode (55-day period)

ENSO Mode

ENSO mode from MSSA

The spatial structure is fairly well captured

The daily variability and interannual variability are also well simulated



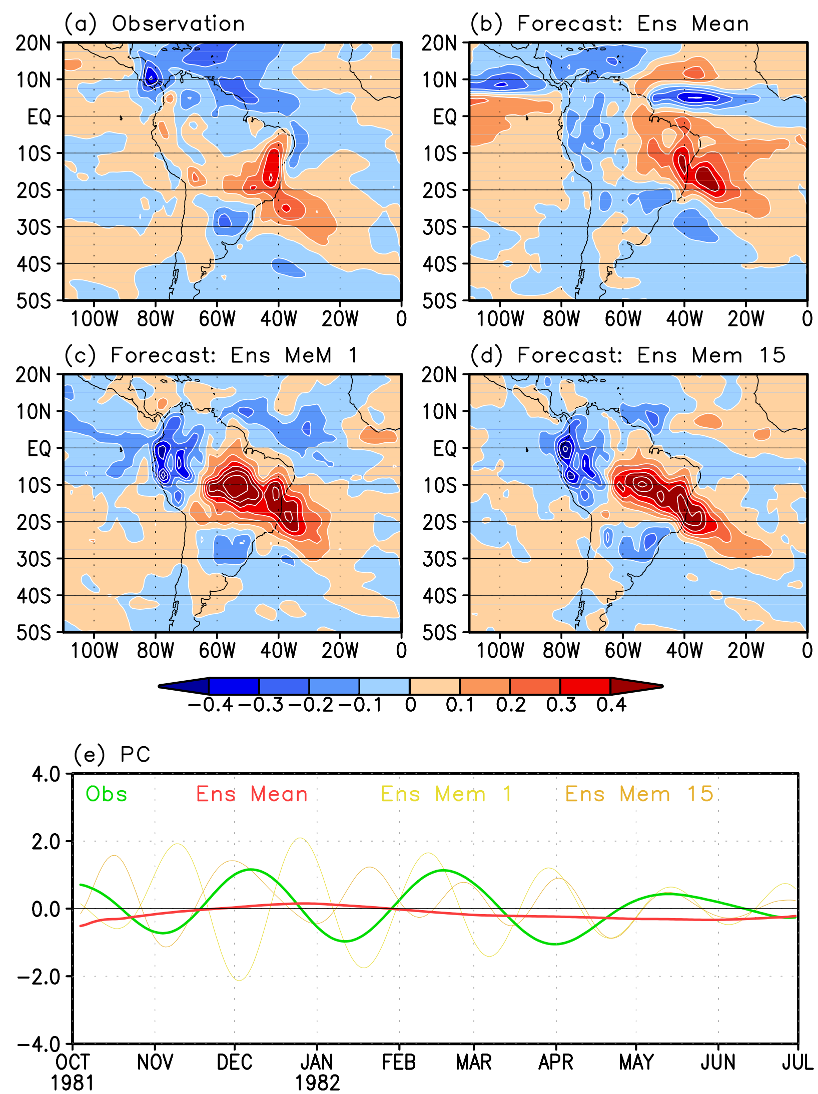
Intraseasonal Oscillatory Mode

Oscillatory mode from MSSA

Intraseasonal oscillation
Period: 55 days
Northeastward propagation

Model simulates the oscillation with northeastward propagation

Phases are mixed up

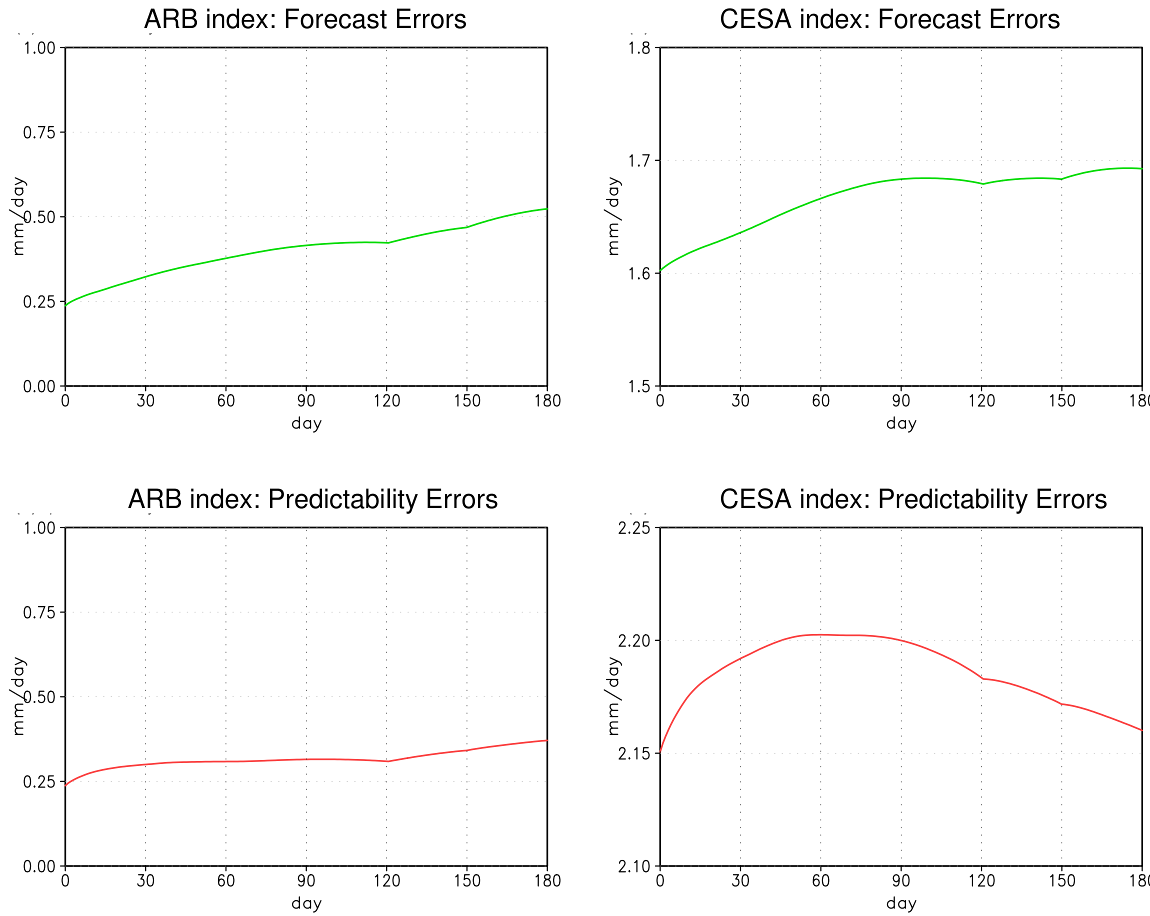


Error Growth of ENSO Mode

ENSO Mode
Growth rate of errors

ARB index and CESA index
Forecast errors and
Predictability errors
RMS errors

Slow growth for both indices

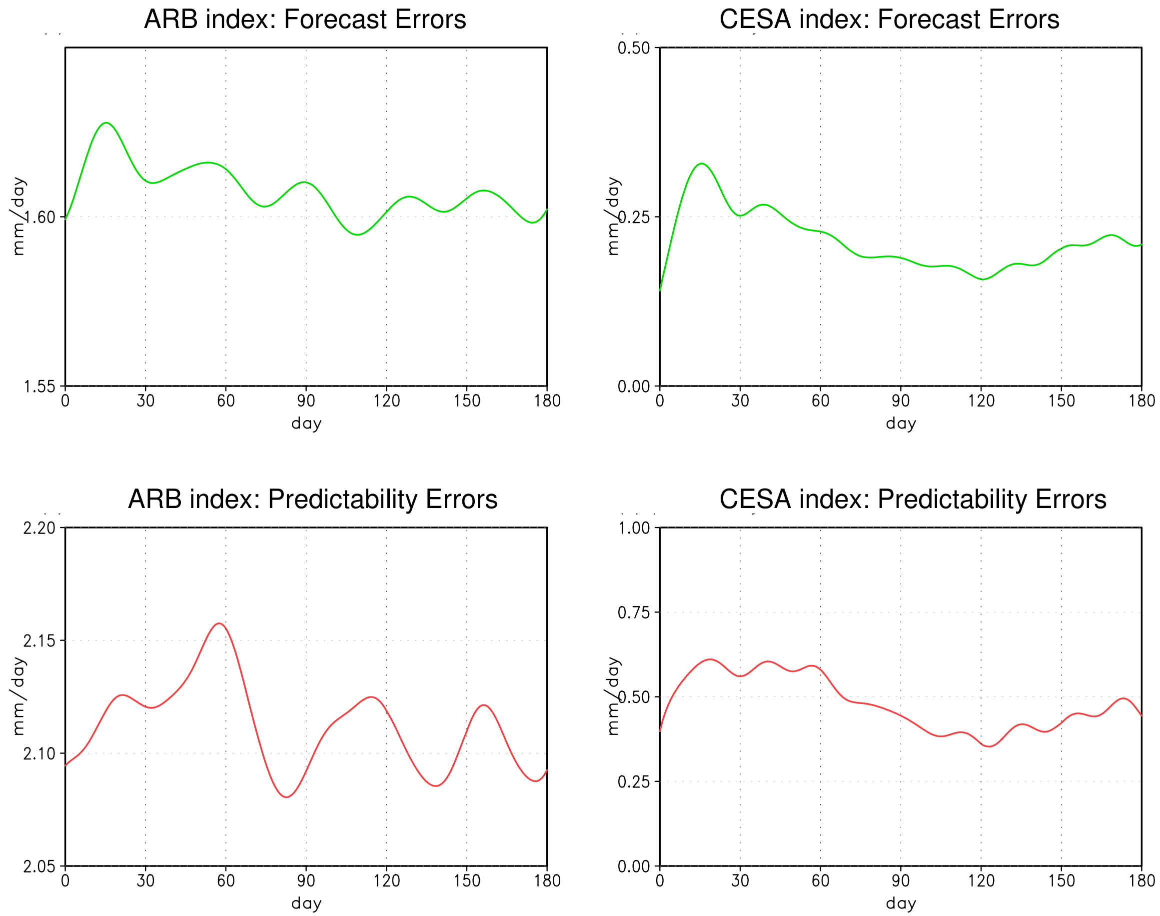


Error Growth of Intraseasonal Mode

Intraseasonal Mode
Growth rate of errors

ARB index and CESA index
Forecast errors and
Predictability errors
RMS errors

Oscillatory growth rate



Conclusions

•Climatology and annual cycle of precipitation and low level winds are fairly well simulated

•Doubling time of forecast errors are in the range of 5-9 days

•Doubling time of predictability errors are in the range of 4-14 days

•The errors of forecasts initiated from active and break phases grow faster only for IMR index

•ENSO modes grow slowly

•Intraseasonal oscillatory modes have phases mixed up