The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

**2050-6**

# Targeted Training Activity: Predictability of Weather and Climate: Theory and Applications to Intraseasonal Variability

***27 July - 7 August, 2009***

## Ensemble predictions at ECMWF: From one day to one month

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# Ensemble predictions at ECMWF:

# From one day to one month

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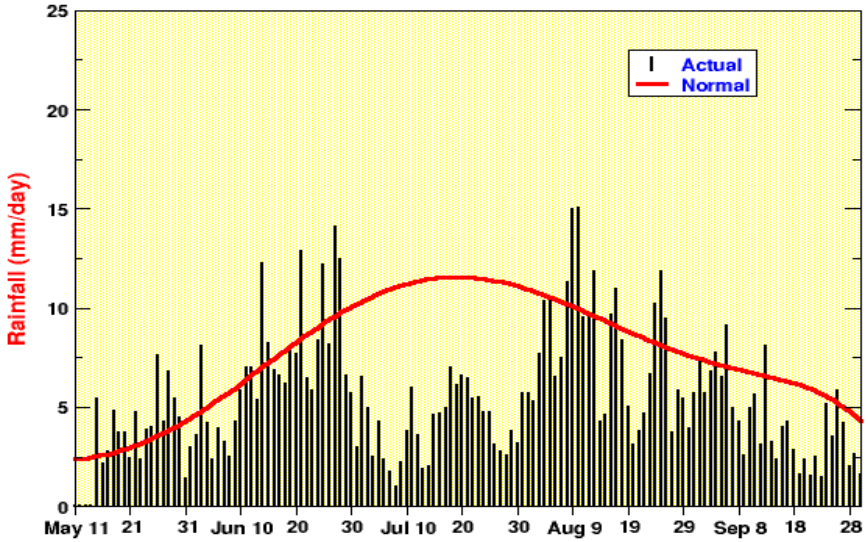
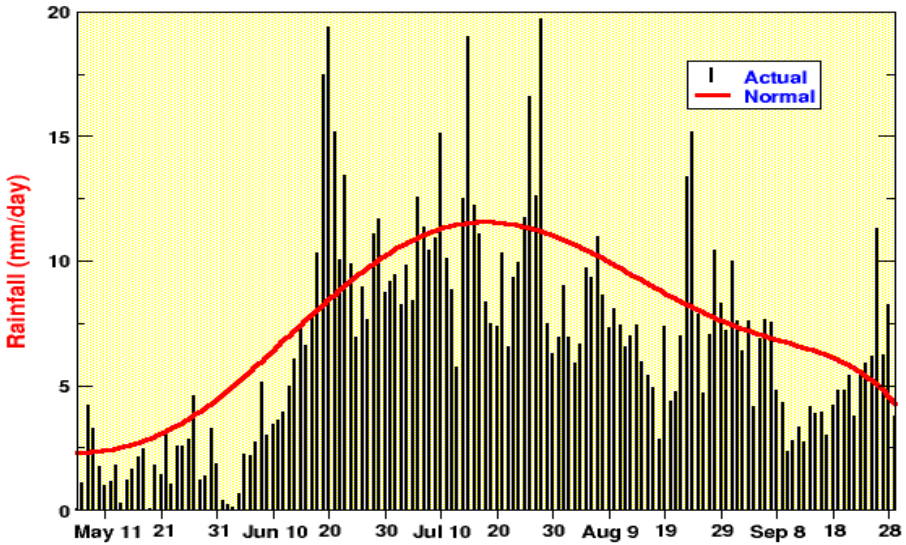
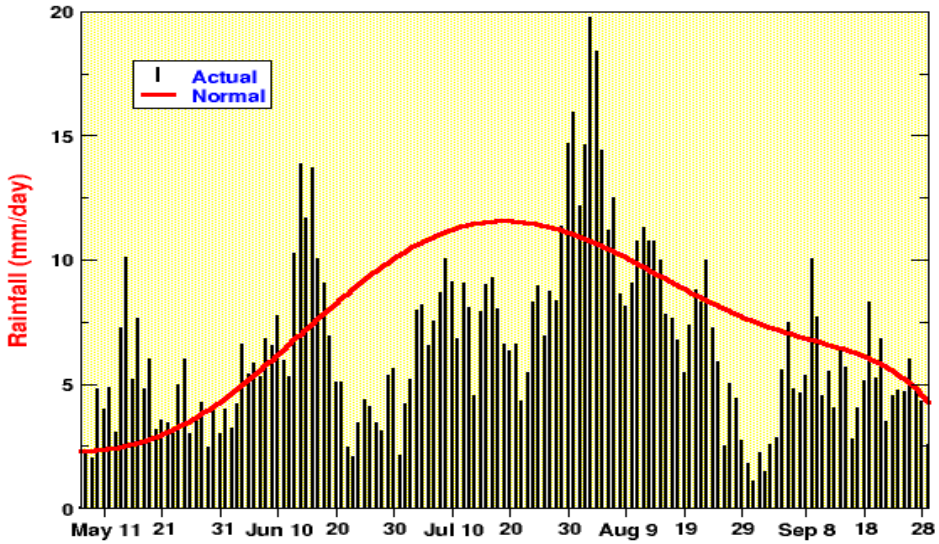
# All-India Rainfall time-series (May-September)




2002

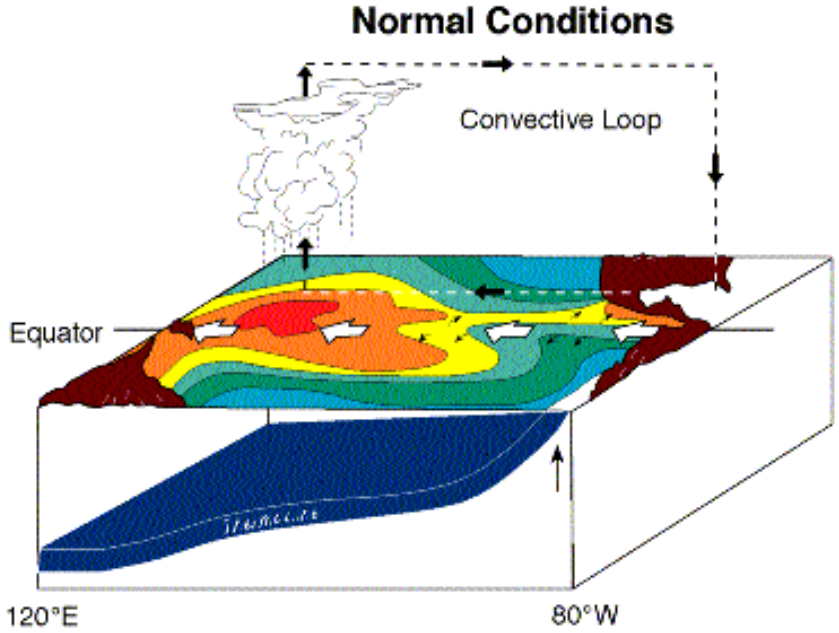


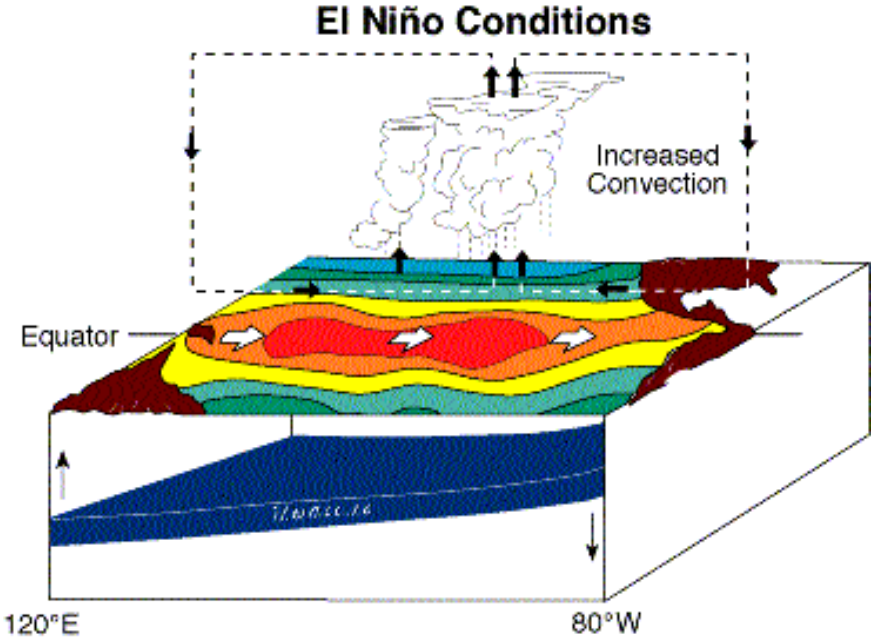

2003

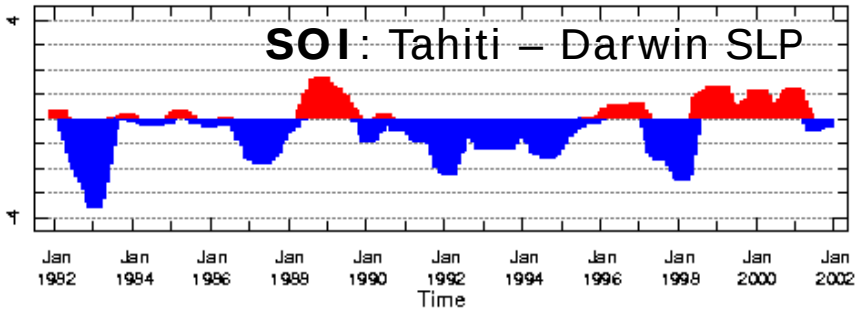


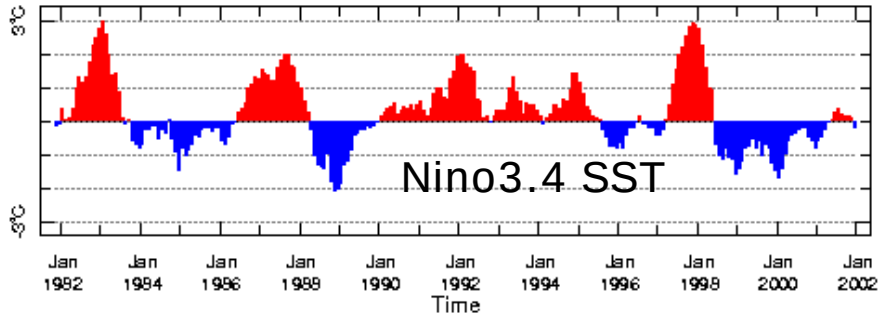

2004

# The El Niño – Southern Oscillation (ENSO)



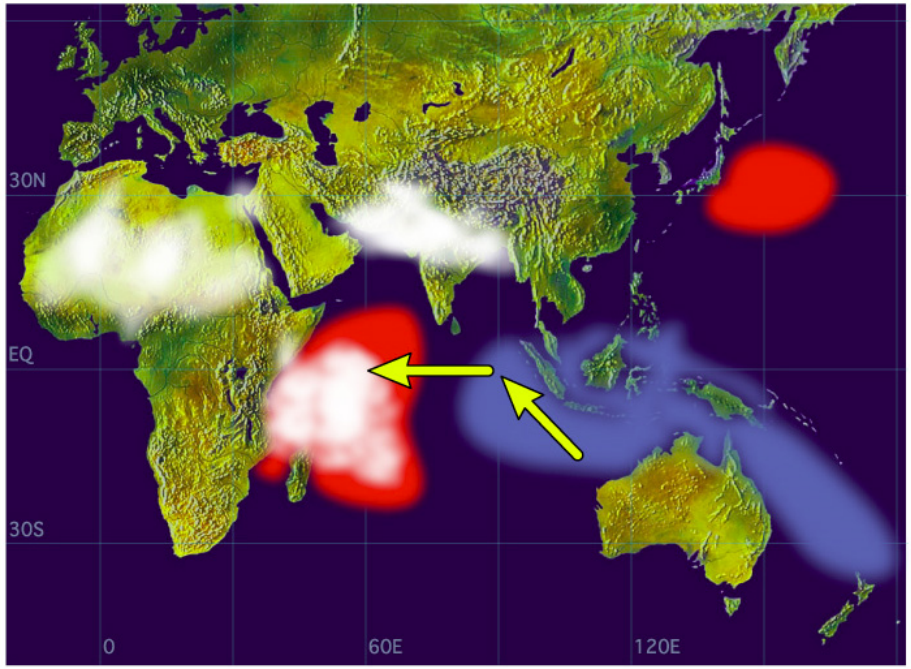



# The Indian Ocean Zonal Mode (or I.O. Dipole)

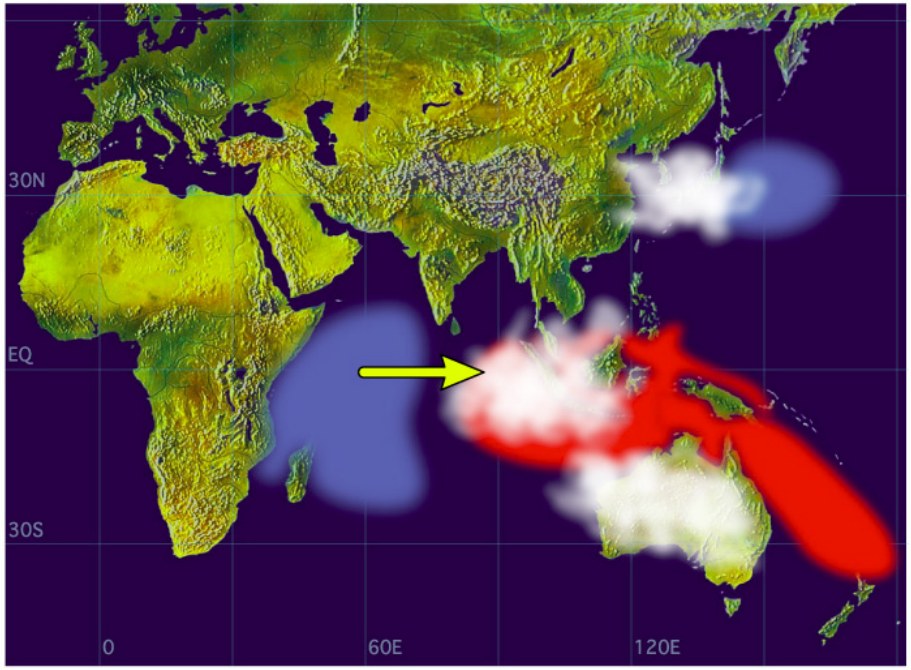
Saji et al. (1999), Saji and Yamagata (2003)

Webster et al. (1999)

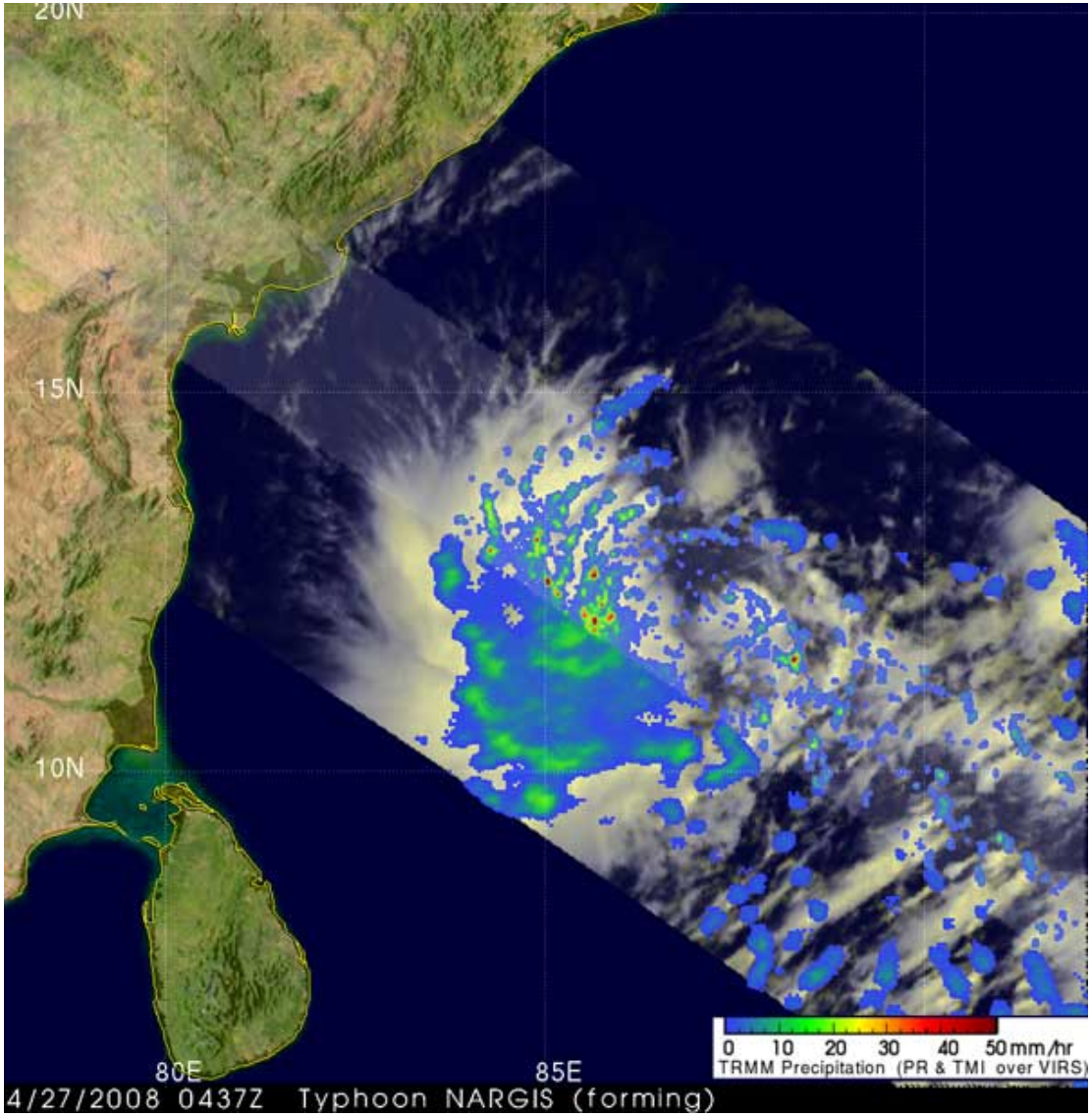
Positive Dipole Mode




Negative Dipole Mode



# Tropical storms and typhoons in the Indian Ocean



# Stochastic-dynamic prediction: the Liouville equation

Given a dynamical system:

$$d_t \boldsymbol{X}(t) = \boldsymbol{\Phi}\,(\boldsymbol{X}(t),\, \boldsymbol{F})$$

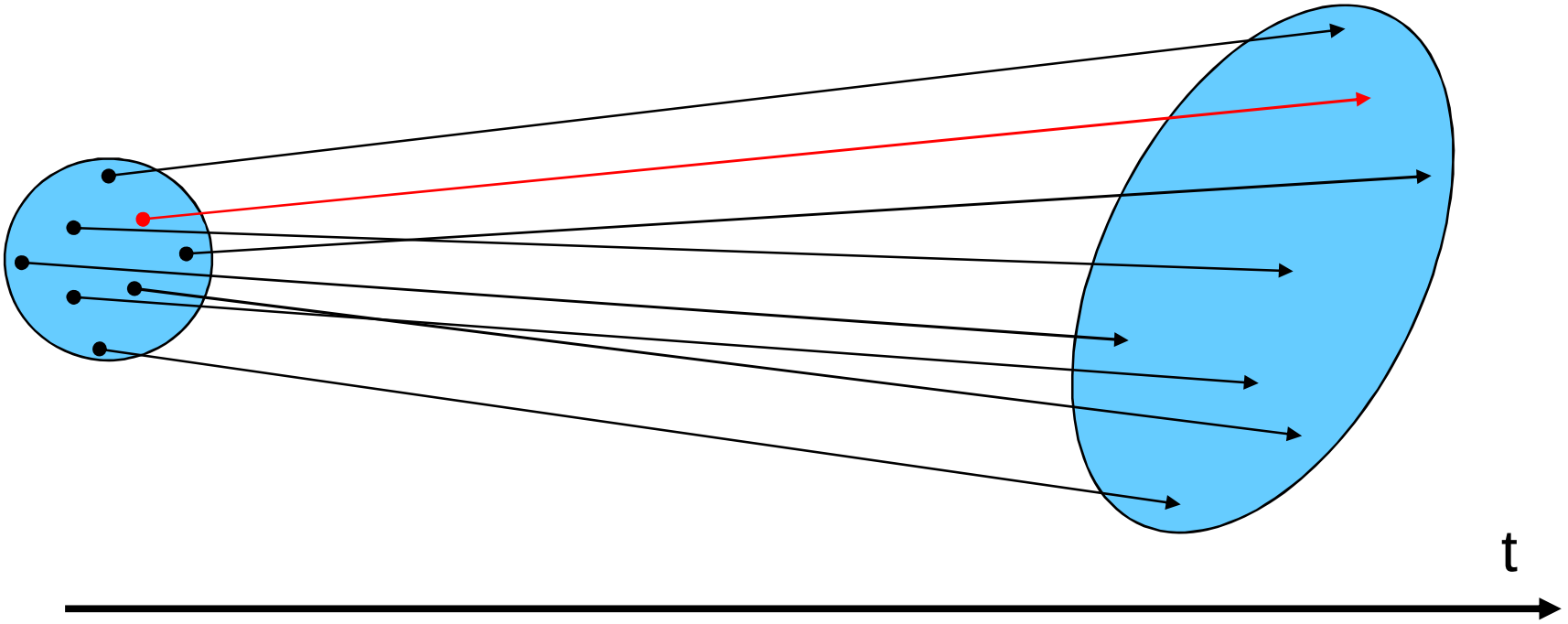
where $\boldsymbol{X}(t)$ is the state vector of the system and $\boldsymbol{F}$ a vector of forcing terms, the evolution of the PDF of the system $\rho(\boldsymbol{X}, t)$ is given by the Liouville equation (Gleeson, 1970; Ehrendorfer 1994):

$$\partial_t\, \rho(\boldsymbol{X}, t) + div\, [\rho(\boldsymbol{X}, t) \cdot \boldsymbol{\Phi}(\boldsymbol{X}, \boldsymbol{F})] = 0$$

In practice, the Liouville equation cannot be solved for climate predictions because of the large numbers of degrees of freedom

# The ensemble approach to stochastic-dynamic prediction

In ensemble prediction, the PDF at initial time is represented by a finite sample of initial states, and the dynamical evolution of each of those states is predicted using a deterministic model



# The ECMWF Ensemble Prediction System

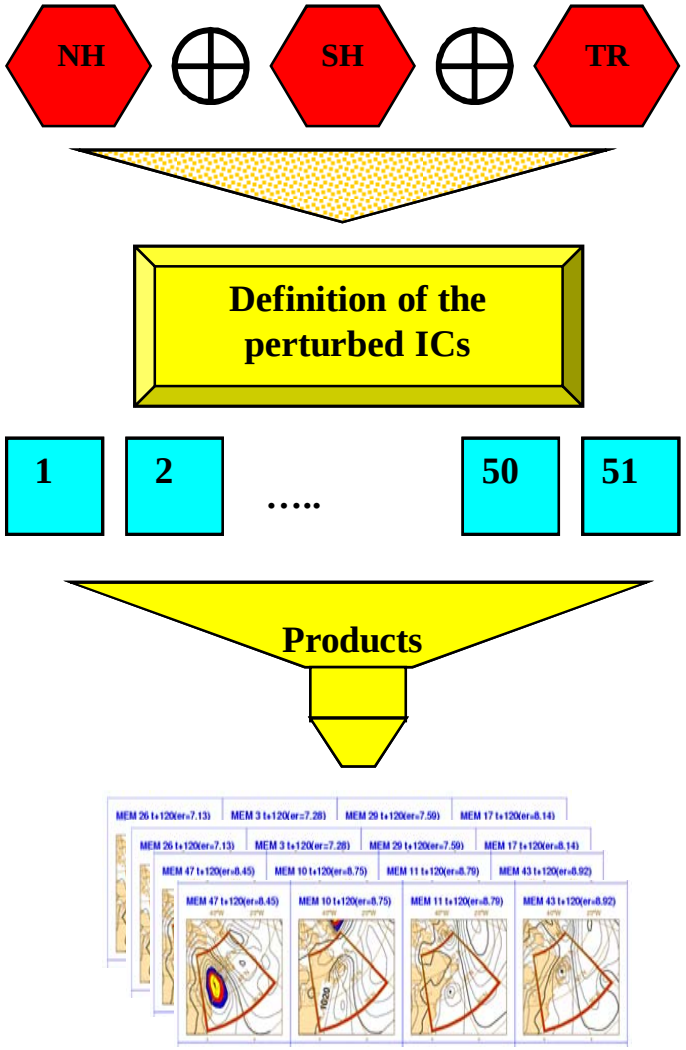
The Ensemble Prediction System consists of 51 forecasts run with variable resolution:

- $T_L$399L62 (~50km, 62 levels) from day 0 to 10
- $T_L$255L62 (~80km, 62 levels) from day 10 to 15.

The EPS is run twice a-day, at 00 and 12 UTC.

Initial uncertainties are simulated by perturbing the unperturbed analyses with a combination of the fastest-growing singular vectors of the T42L62 tangent-linear model , computed to optimize total energy growth over a 48h time interval (OTI).

Model uncertainties are simulated by adding stochastic perturbations to the tendencies due to parameterized physical processes.



# Initial perturbations: singular vectors

- Non-linear dynamical system:

  $dX/dt = \mathbf{N}(X)$

- Linearize the evolution of X along a prescribed trajectory

  $X(t) = X_0(t) + X'(t)$ : *basic-state trajectory + perturbation*

  $X'(t_2) = \mathbf{L}(t_1,t_2)\, X'(t_1)$ : *linear "propagator" for X'*

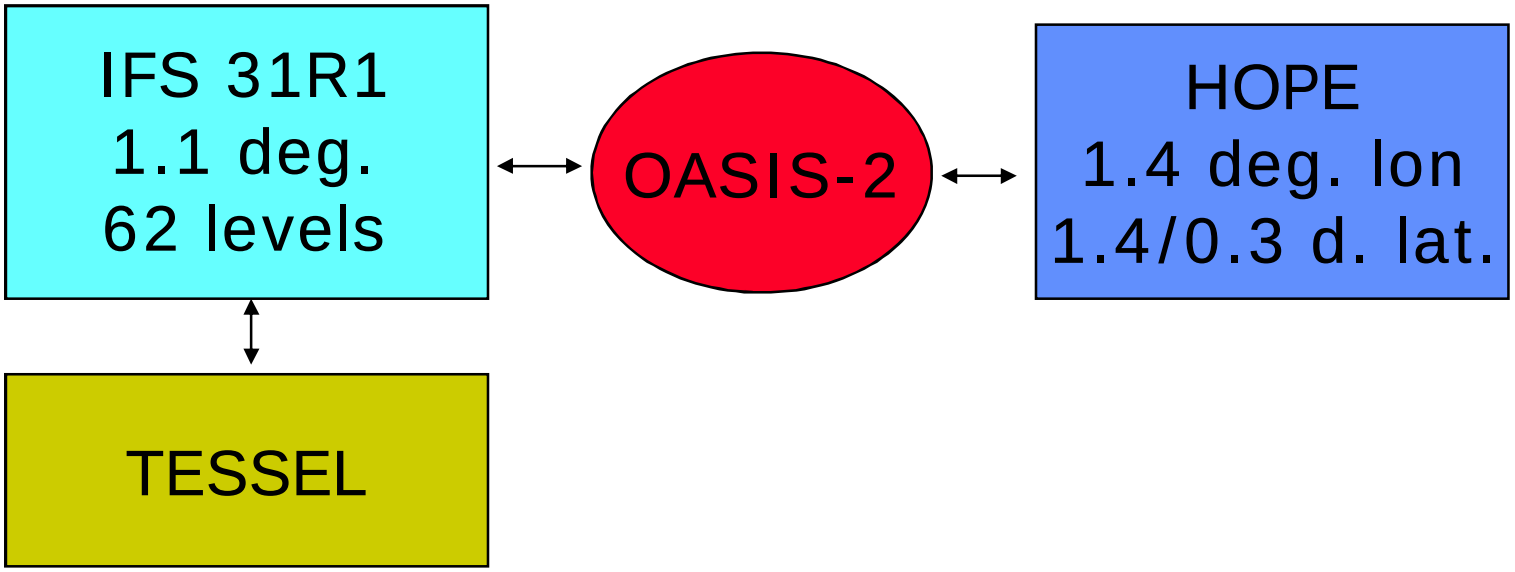
- Given an inner product <,> for the perturbation vector X', compute singular vectors U and V, such that

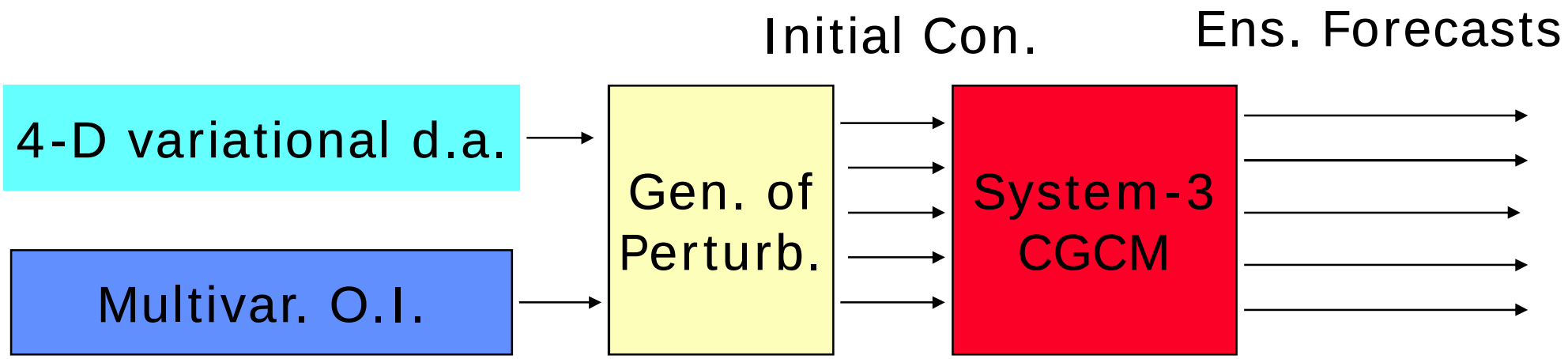
  $V = \mathbf{L}\, U$

  $< V, V > / < U, U > = \max$

  $< V, V > = < \mathbf{L}\, U, \mathbf{L}\, U > = < U, \mathbf{L}^* \mathbf{L}\, U >$

# ECMWF Seasonal forecast system (Sys-3)

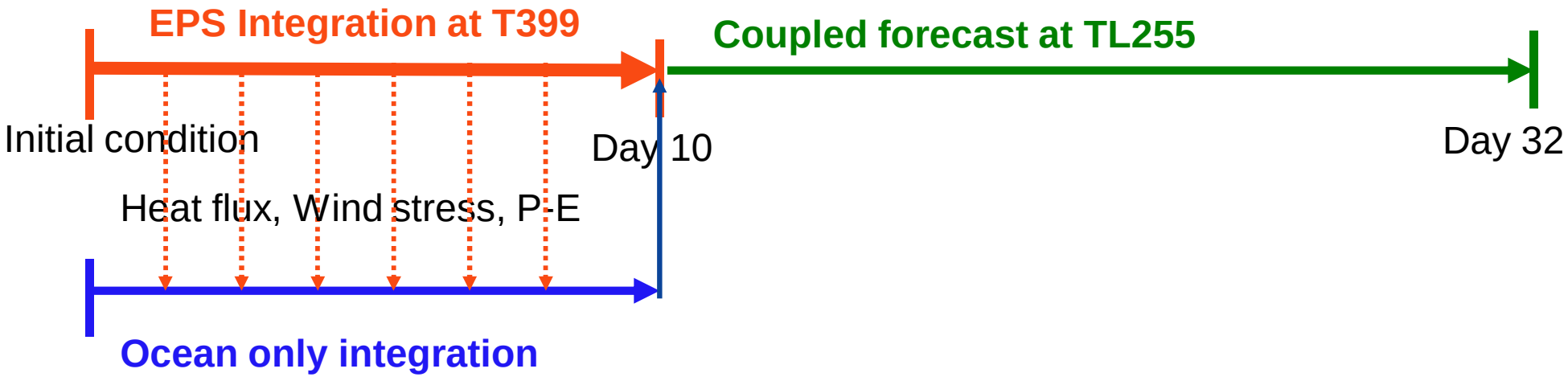


# Unified EPS/monthly system

**Previous TL159 monthly system:**

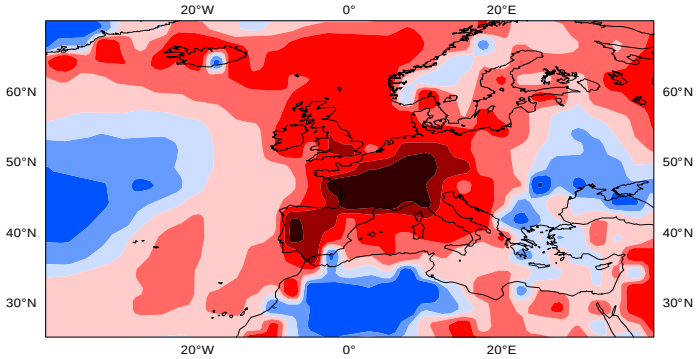

**Current 32-day EPS/monthly system:**



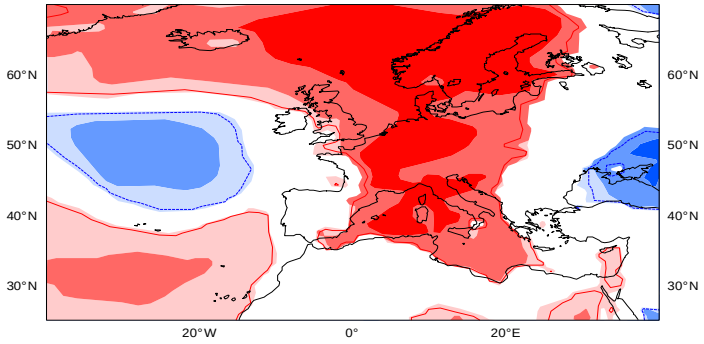
# EPS-monthly hindcast: summer 2003 heat wave

Forecasts started on 23 July 2003 for 2mT anomalies for 3-9 August 2003 (fc day 12-18): impact of model cycle and upgrade to 32-day VAREPS.

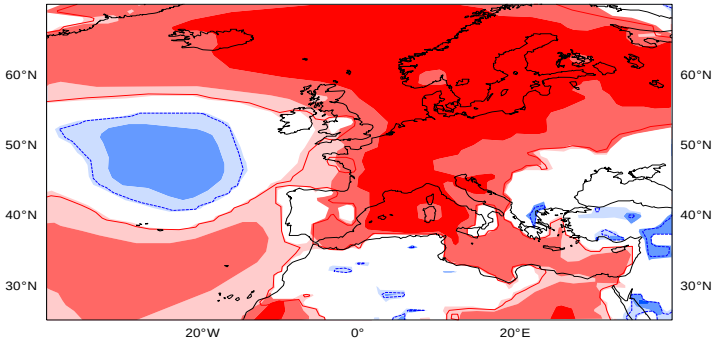
a) Analysis



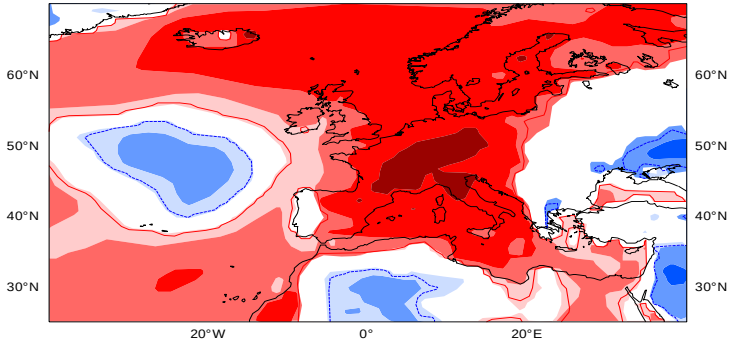

b) Operational MOFC




c) MOFC CY31R2




d) VAREPS CY31R2




< -6deg | -6.. -4 | -4.. -2 | -2.. -1 | -1.. 0 | 0.. 1 | 1.. 2 | 2.. 4 | 4.. 6 | > 6

# Use of re-forecasts for calibration

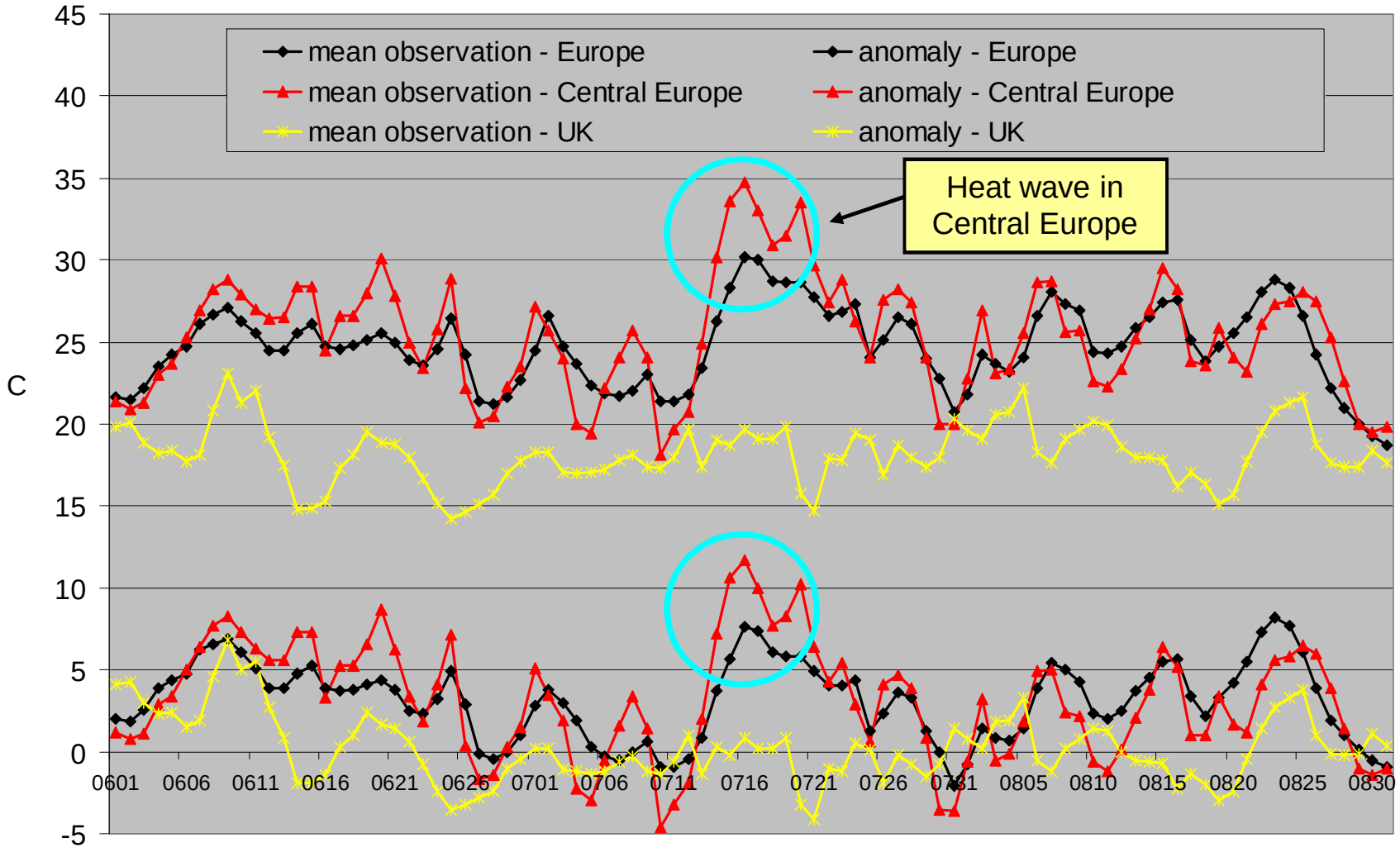
With the implementation of the unified 32d EPS-Monthly forecast system, a new re-forecast suite is run operationally. These re-forecasts can be used as training data to calibrate both medium-range and monthly forecasts.

The suite runs once a week and produces re-forecasts for the last 18 years (to be extended to 20y) on the respective operational date, and with 5 ensemble members.

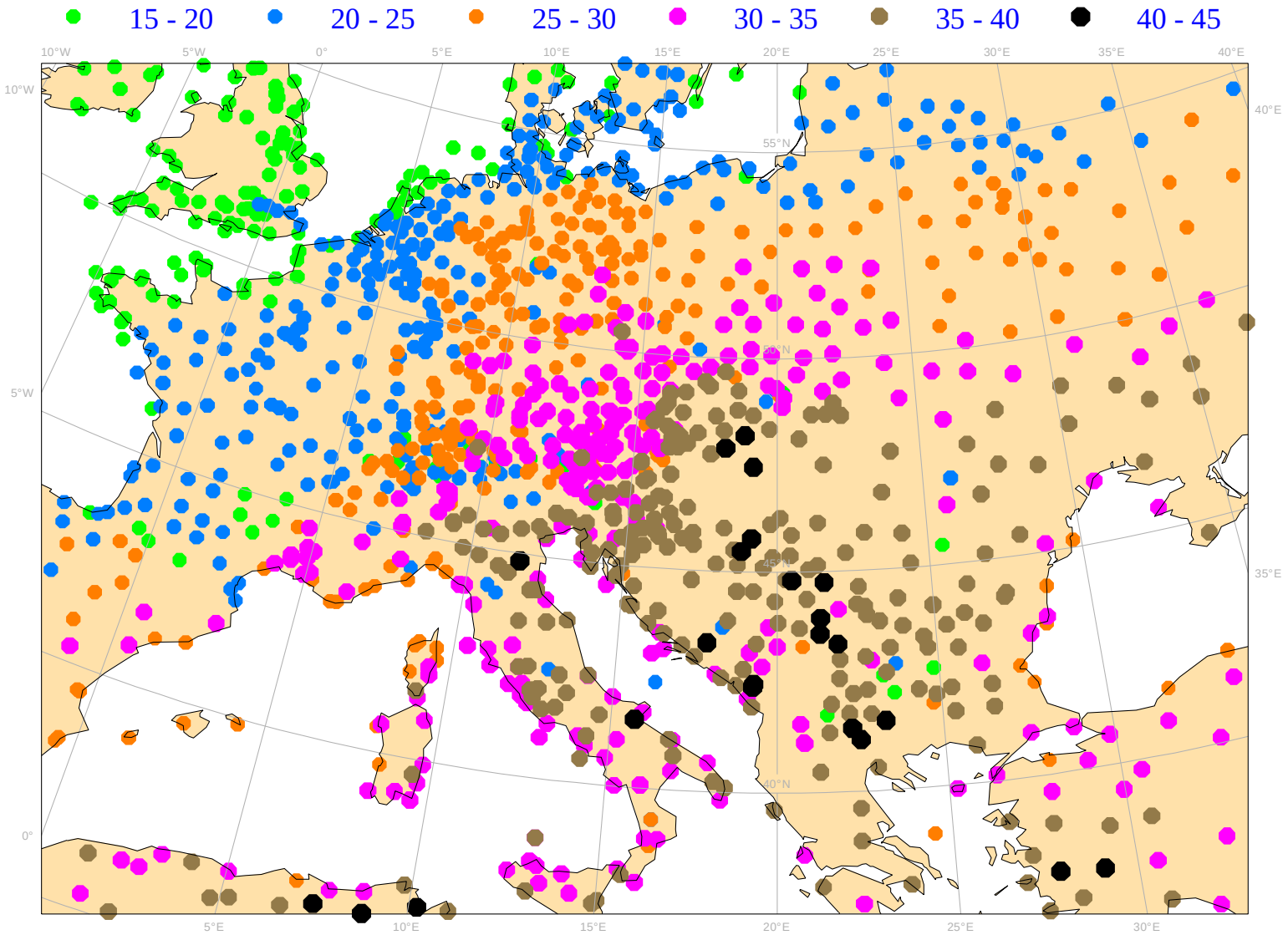
Results of calibration tests indicate that:

- ECMWF forecasts can be improved through calibration
- The main improvement is due to bias correction (60-80%), but advanced methods lead to better calibrated ensemble spread, thus adding some extra improvements, in particular at early lead times
- Improvements occur mainly at locations with low skill

# Daily max. 2m temp. anomalies JJA 2007



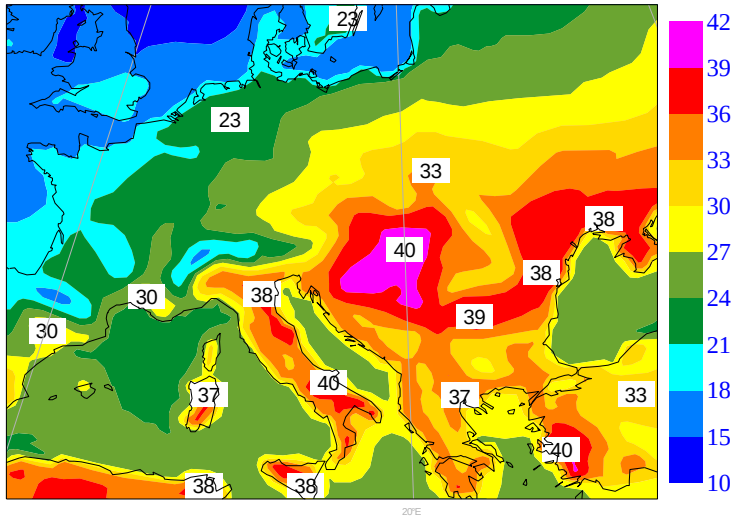
# Heat wave in central and S.-East. Europe: 20 July



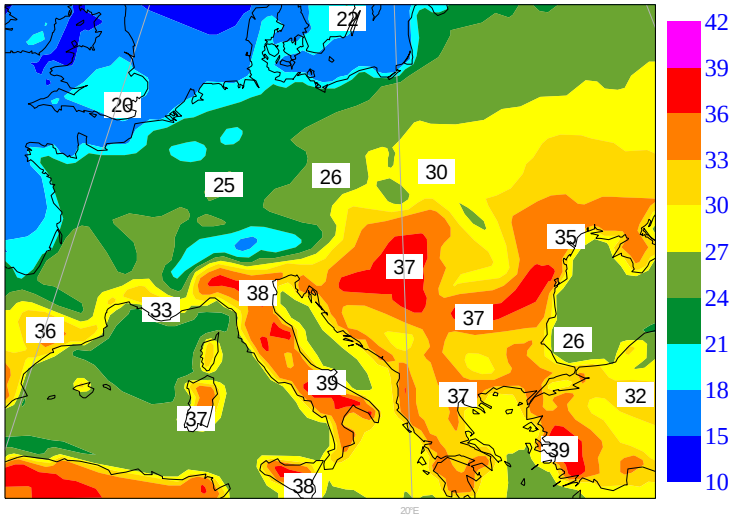
# EPS Day-5 and day-10 forecast for 20th of July

D5

EPS mean, 2m max temp, VT:20070720, t+120

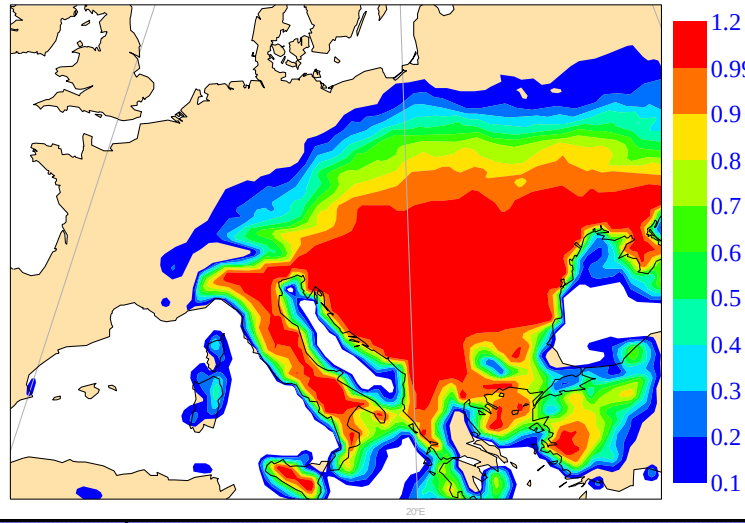



EPS mean, 2m max temp, VT:20070720, t+240

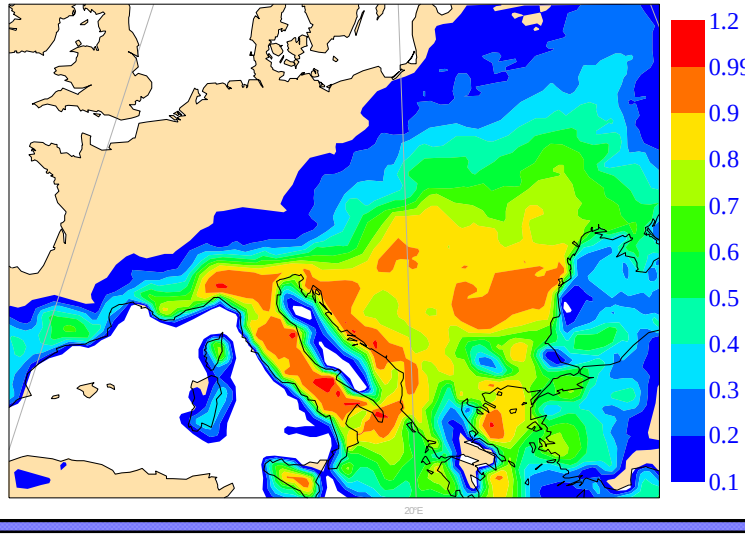



D10

EPS prob, 2m max temp gt Q95, VT:20070720, t+120

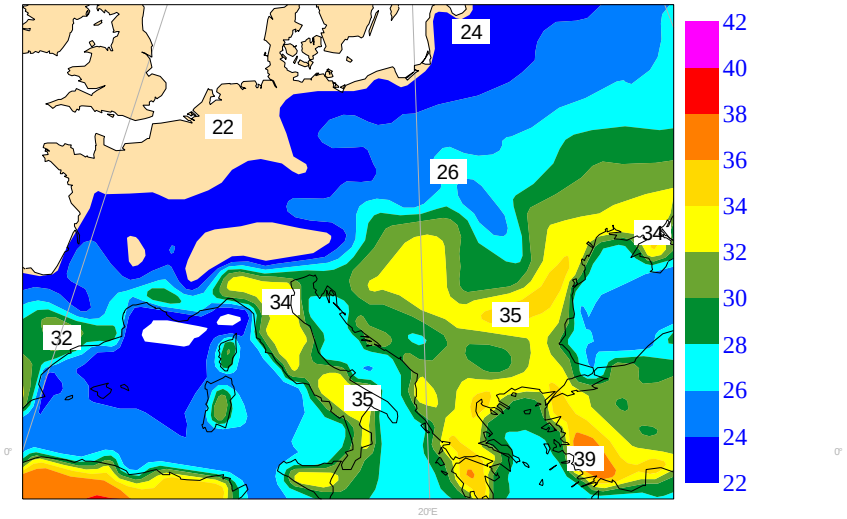



EPS prob, 2m max temp gt Q95, VT:20070720, t+240

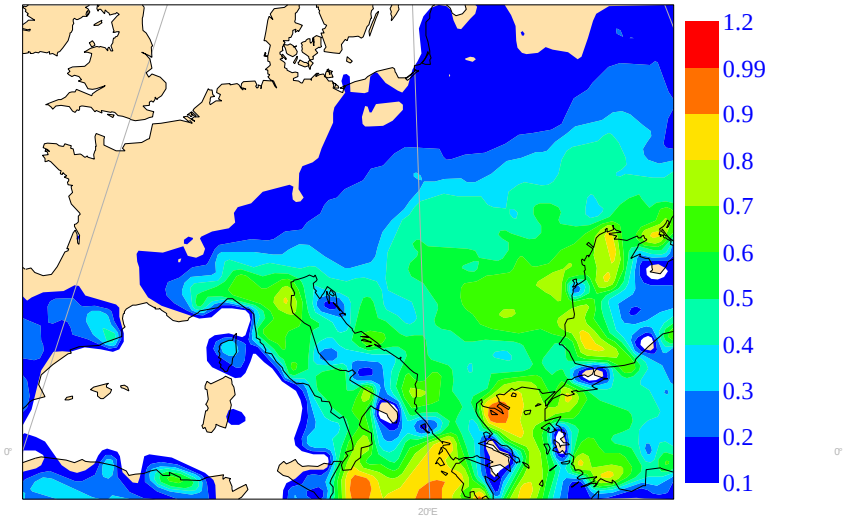


# EPS Day-15 forecast for 20th of July

EPS mean, 2m max temp, VT:20070720, t+360




EPS prob, 2m max temp gt Q95, VT:20070720, t+360



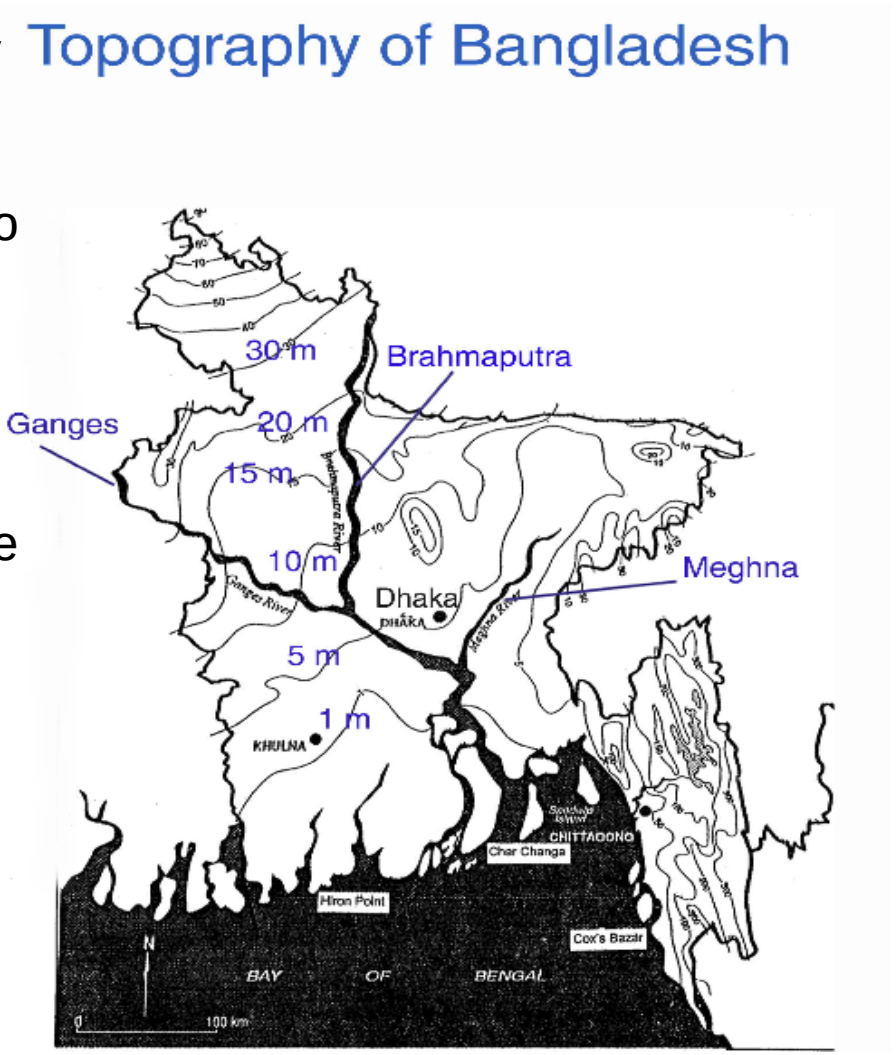

**D15**

# Flood predictions in Bangladesh (CFAB)

In 2000, The Georgia Institute of Technology started the Climate Forecast Applications for Bangladesh (CFAB) project, with the aim to investigate the feasibility of medium-range to seasonal forecasts of river discharge and flood alerts to Bangladesh.

The project has important societal benefits, also in view of the potential impact of climate change on Bangladesh: a 5m raise in sea-level would flood ~30% of the country, affecting ~ hundred million people.

The project has been sponsored by USAID and uses ECMWF medium-range and seasonal ensemble forecasts to drive hydrological models.




*(Source: T Hopson, P Webster)*

# Flood prediction in Bangladesh (CFAB)

CFAB has designed and developed a three-tier system:

- **SEASONAL OUTLOOK:** "Broad brush" probabilistic forecast of rainfall and river discharge. Updated each month. Produced out to 6 months, currently most useful skill out 3 months

- **20-25 DAY FORECAST:** Forecast of average 5-day rainfall and river discharge 3-4 weeks in advance. Updated every 5 days

- **1-10 DAY FORECAST:** Forecast of rainfall and precipitation in probabilistic form updated every day. Considerable skill out to 5-days. Moderate skill 5-10 days.

*(Source: T Hopson, P Webster)*

# Flood prediction in Bangladesh (CFAB)

Damaging Floods:

- early floods in May, June
- above-normal peak floods in July, August
- late floods extending in September

Recent severe flooding: 1974, 1987, 1988, 1997, 1998, 2000, 2004 and 2007

- 1988: 3/4 of country inundated, 1300 people killed, 30 million homeless, $1 billion in property loss
- 1998: 60% of country inundated for 3 months, 1000 killed, 40 million homeless, 10-20% total food production lost
- 2004: flooding in Brahmaputra basin killed 500 people, displaced 30 million for 3 weeks, 40% of capital city Dhaka (10 million people) under water

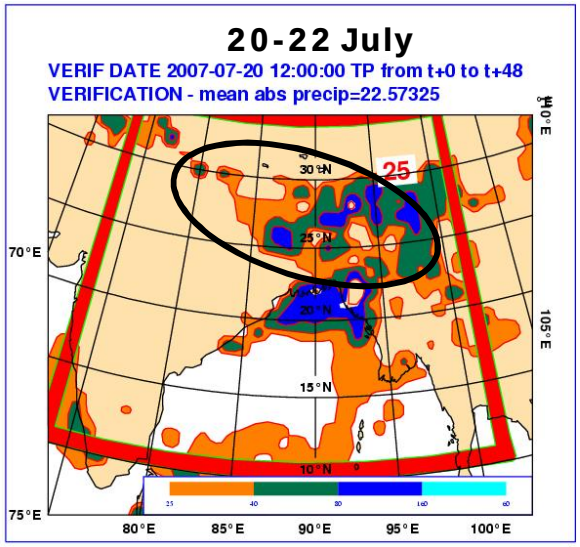
*(Source: T Hopson, P Webster)*

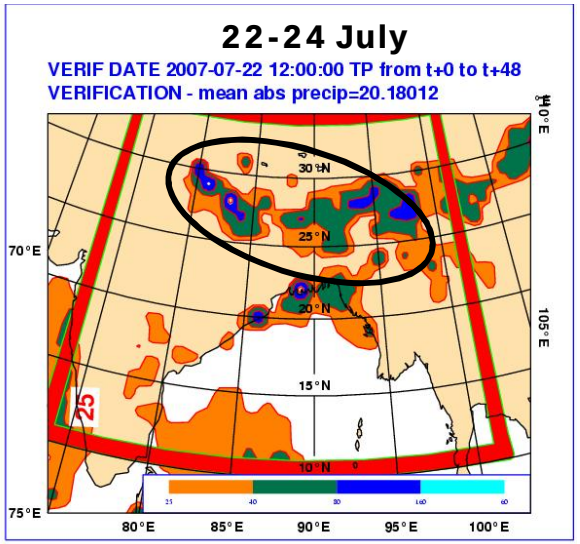
# July/August 2007 floods in Bangladesh

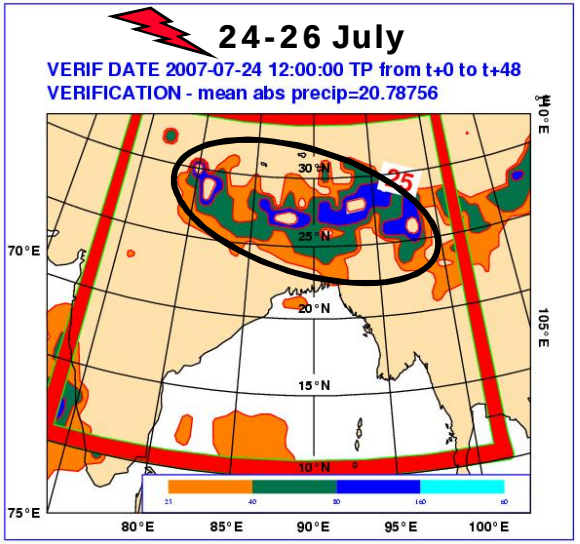
"Seven people had died and thousands have been forced to leave their homes in Bangladesh because of worsening floods. Officials said that nearly half a million people remained marooned in seven flood-hit districts in the country's north west and in the south." (8 August 2007, from *http://news.bbc.co.uk*).

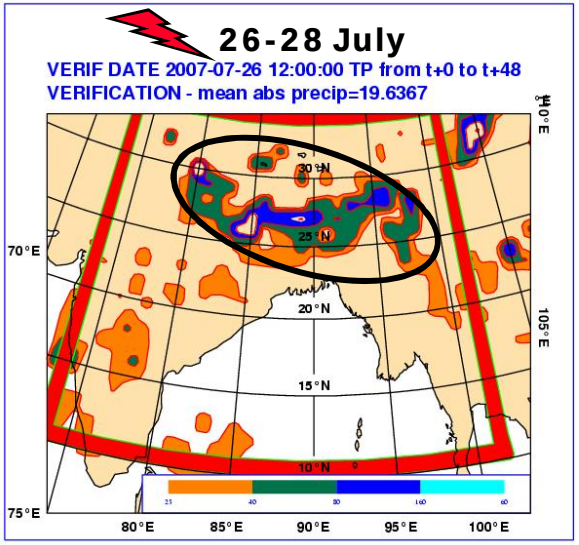
# July/August 2007: floods in Bangladesh

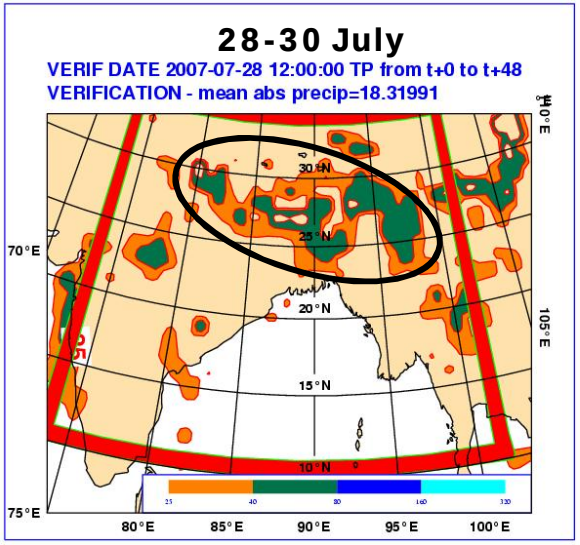
In July/ August 2007, the floods were linked to intense precip. towards the end of July, notably from 24 to 28 July.

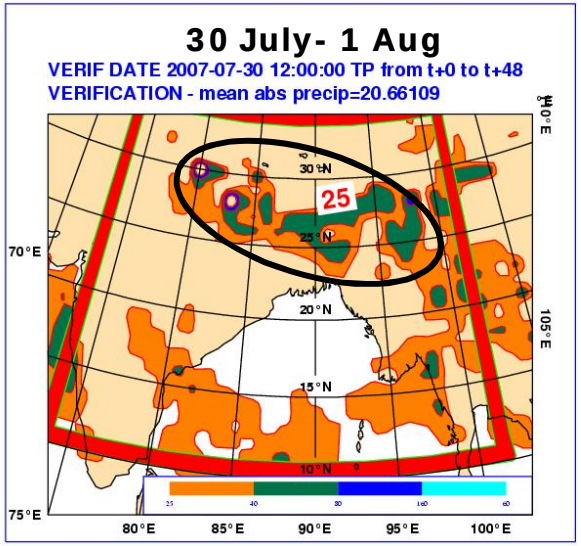


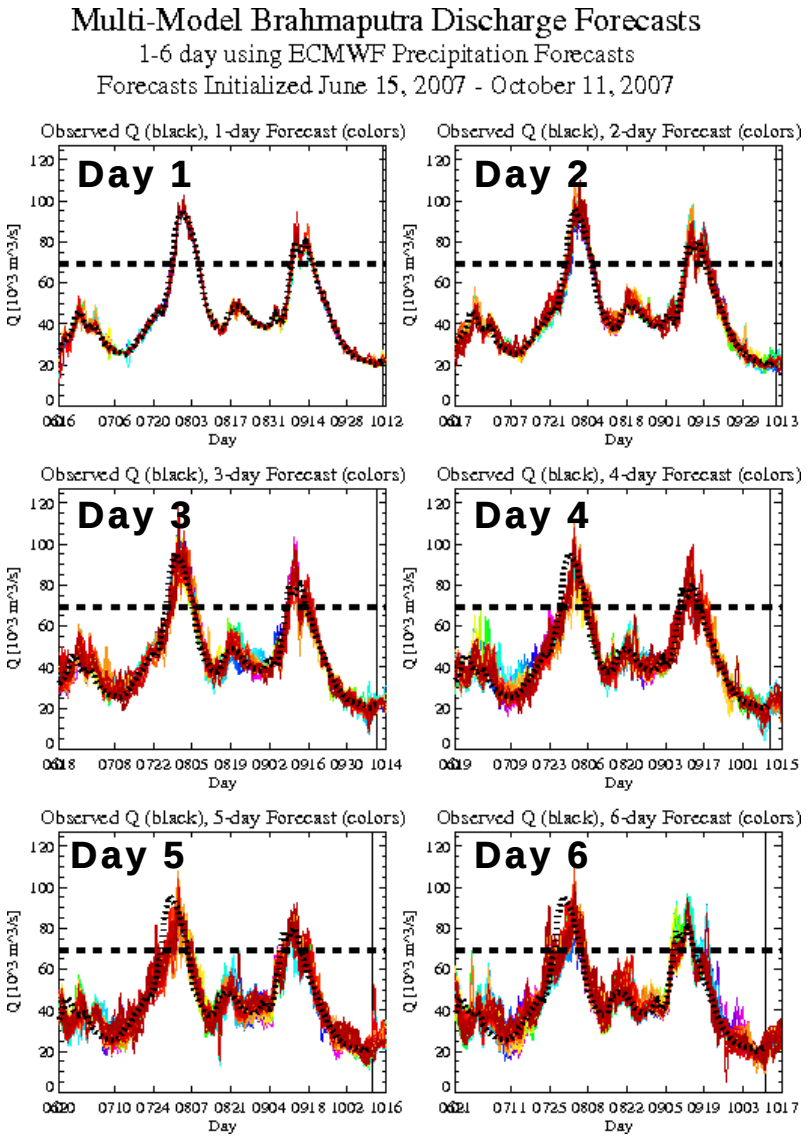



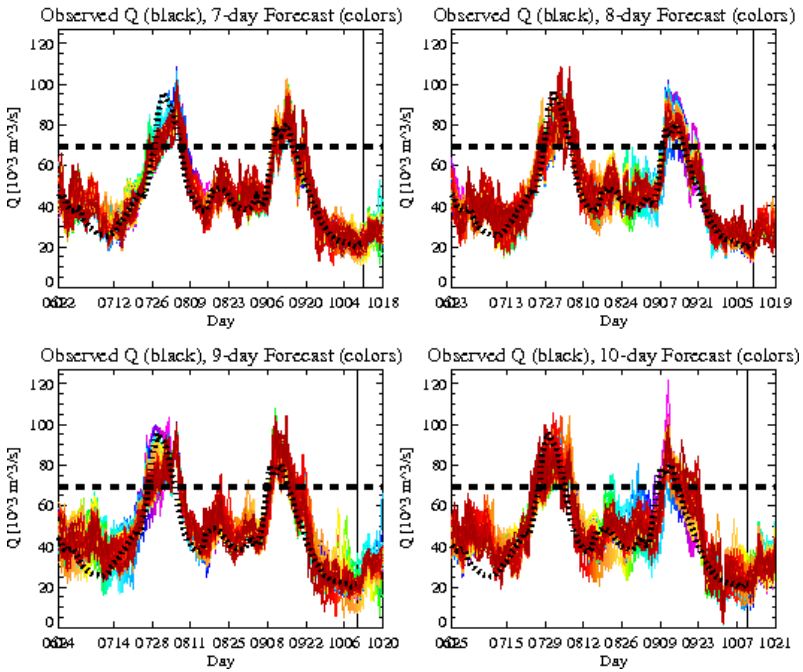



# 2007 floods in Bangladesh: fc. for the Brahmaputra

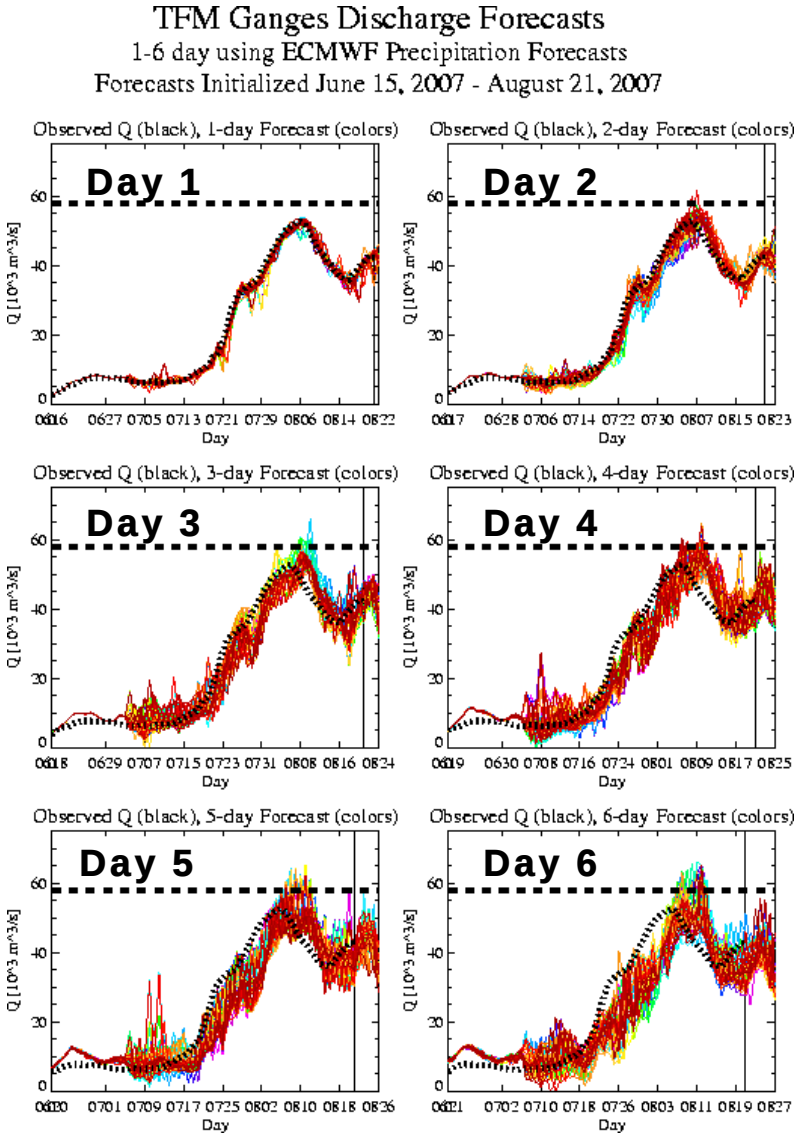


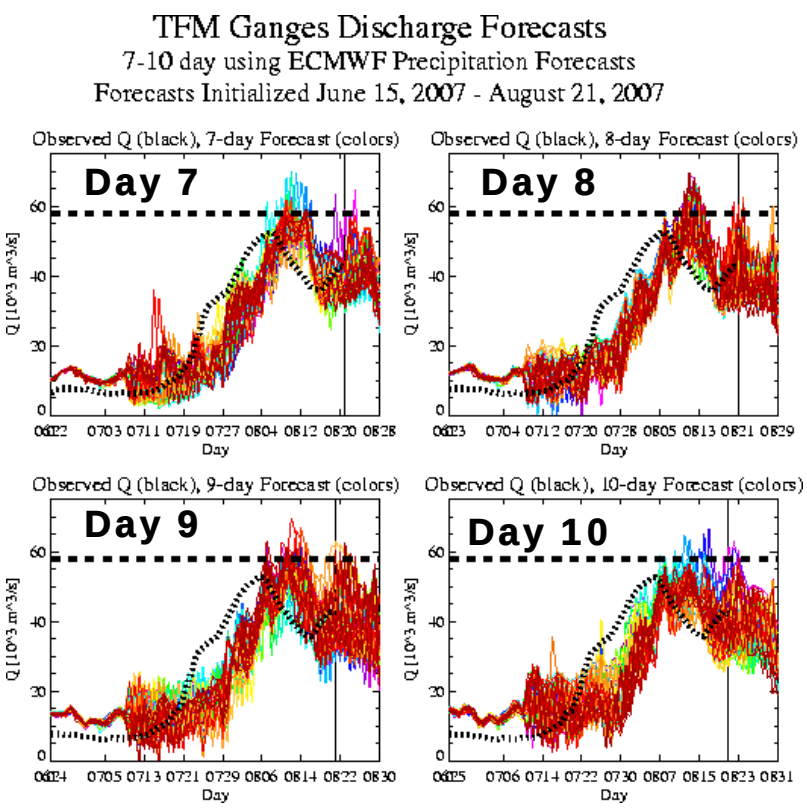




1-10 day forecasts (coloured lines) and observed (black dotted line) discharge of the Brahmaputra river at Bahadurabad (from *http://cfab.eas.gatech.edu/shortterm/*)

*(Source: T Hopson, P Webster)*

# 2007 floods in Bangladesh: fc. for the Ganges




1-10 day forecasts (coloured lines) and observed (black dotted line) discharge of the Gange river at Hardinge Bridge (from *http://cfab.eas.gatech.edu/shortterm/)*

*(Source: T Hopson, P Webster)*

# 2.2 2007 floods in Bangladesh

*"… thank you very much for your efforts on 1-10 days flood forecasting for major rivers in Bangladesh. We were able to inform the people in advance and on 25th July we started communicating the information to as many people as possible about the certainty of exceeding danger levels along the Brahmaputra …*

*… The local partners, NGO networks and DMC members were advised to inform to the poorest of the poor especially people living in river chars …*

*… The forecast was of great value to the people in Rajput union and many other locations along the Brahmaputra river to undertake the preparatory measures in advance. The 10 days forecasts helped the FFWC engineers immensely to give advance information and they were confident to face the press …"*

(extract from a letter sent from the Asian Disaster Preparedness Centre to Georgia Tech)

*(Source: T Hopson, P Webster)*

# Asian monsoon onset exp. with EPS-monthly

- EPS configuration with cycle 31r2
- 45-day integration from 15 May to end of June 1991-2007

Verification of all-India rainfall vs. GPCP data

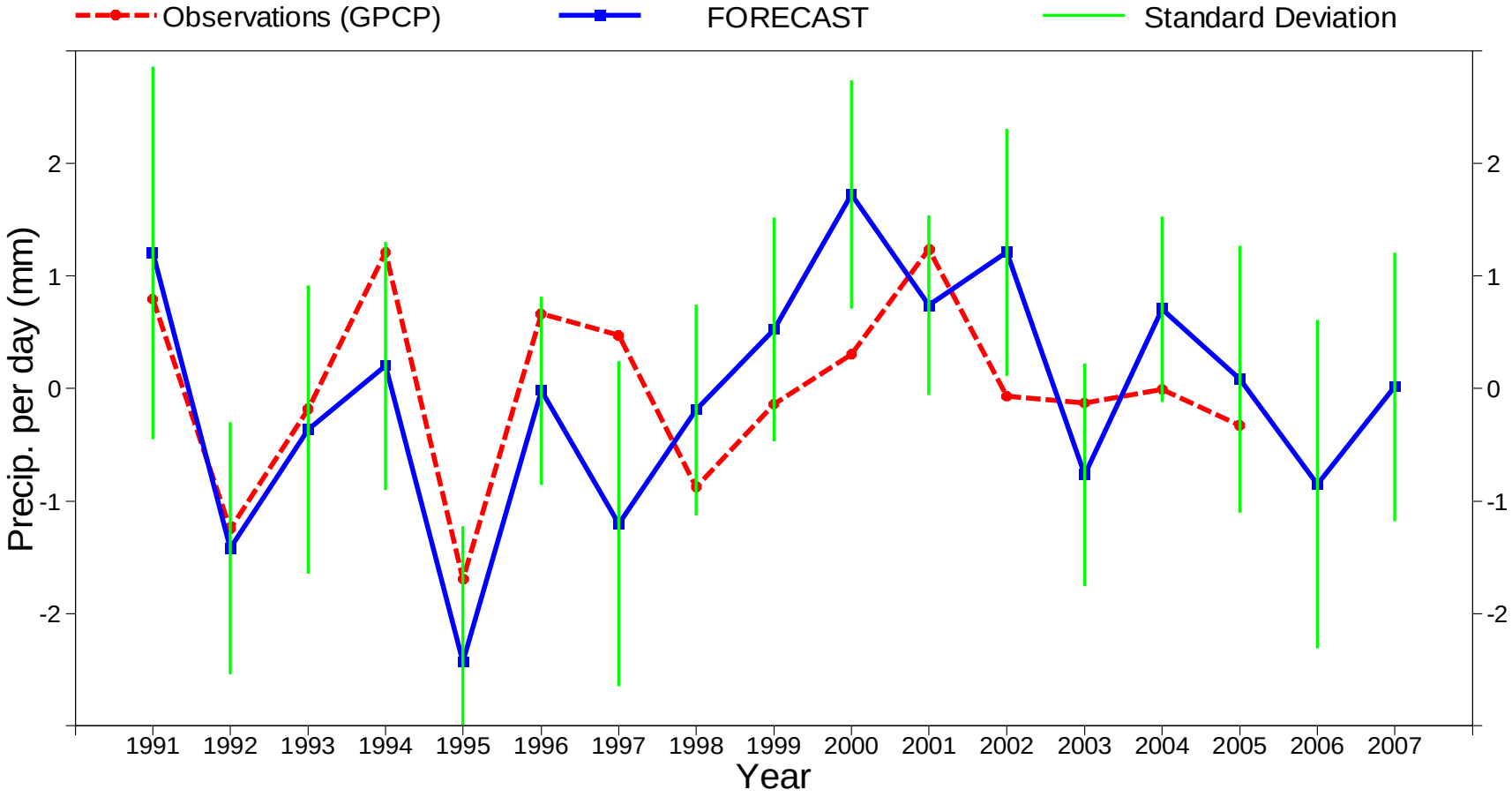
- June mean rainfall
- Pentad-mean rainfall

# Monsoon onset in India: EPS-monthly fc.

ECMWF Monthly Forecast
June Precip over India (70-85E,5-30N)
Forecast start reference is 15/05/yyyy
Calibration period = 1991-2005
Ensemble size = 10 (real time =140)

CC = 0.62

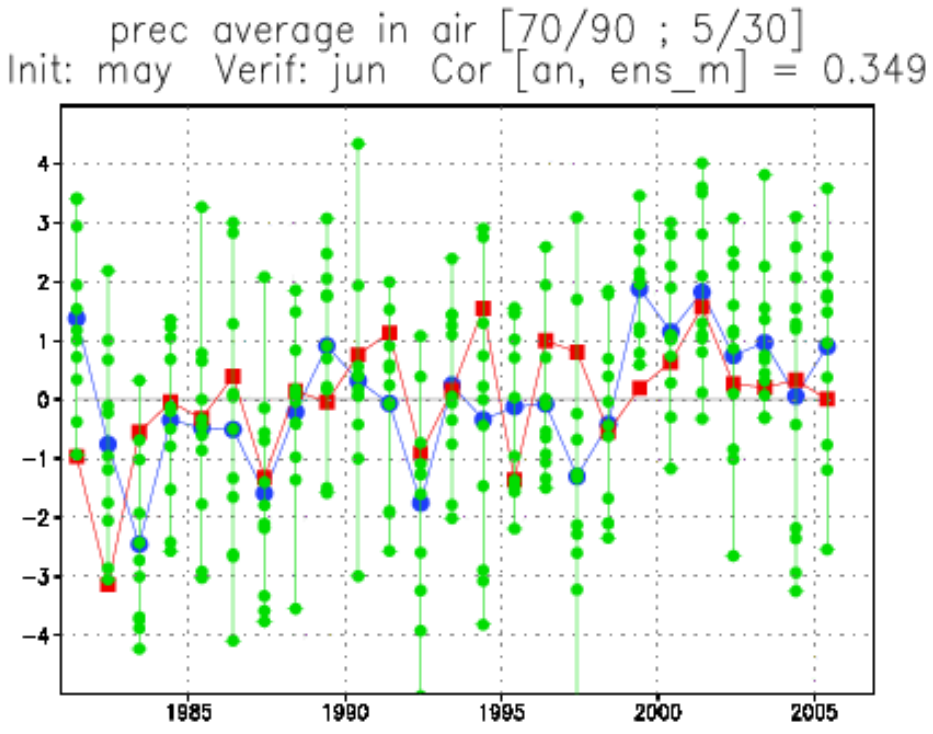
Correlation= 0.62( 0.99)
RMS Error= 0.88( 0.83)

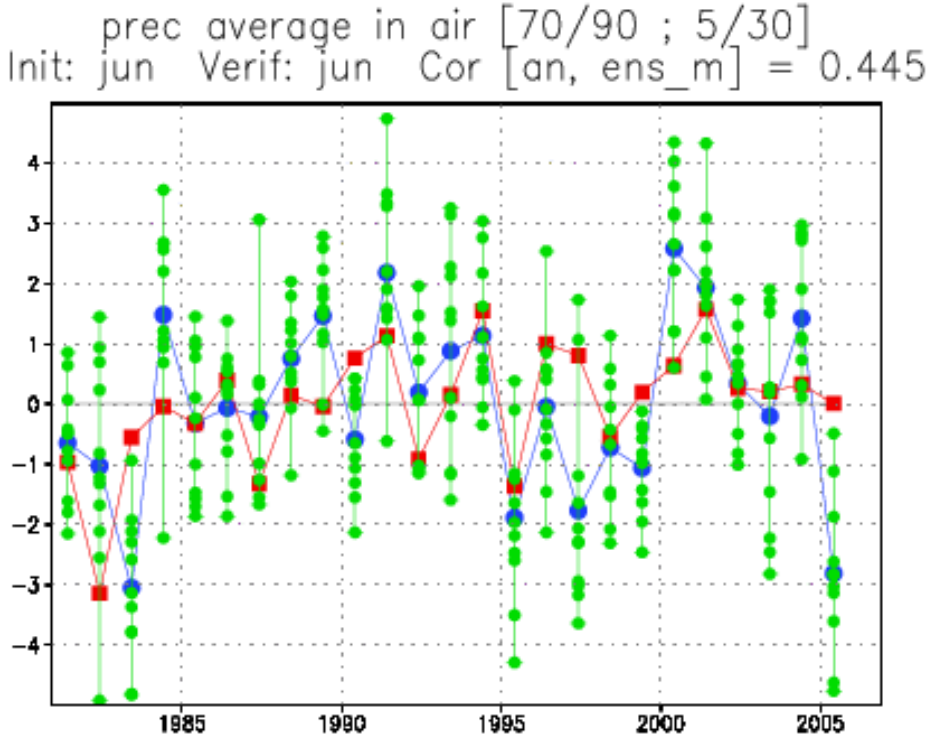


# Monsoon onset in India: seasonal fc. for June

1-month-lead fc.
cc = 0.35

0-lead fc.
cc = 0.45



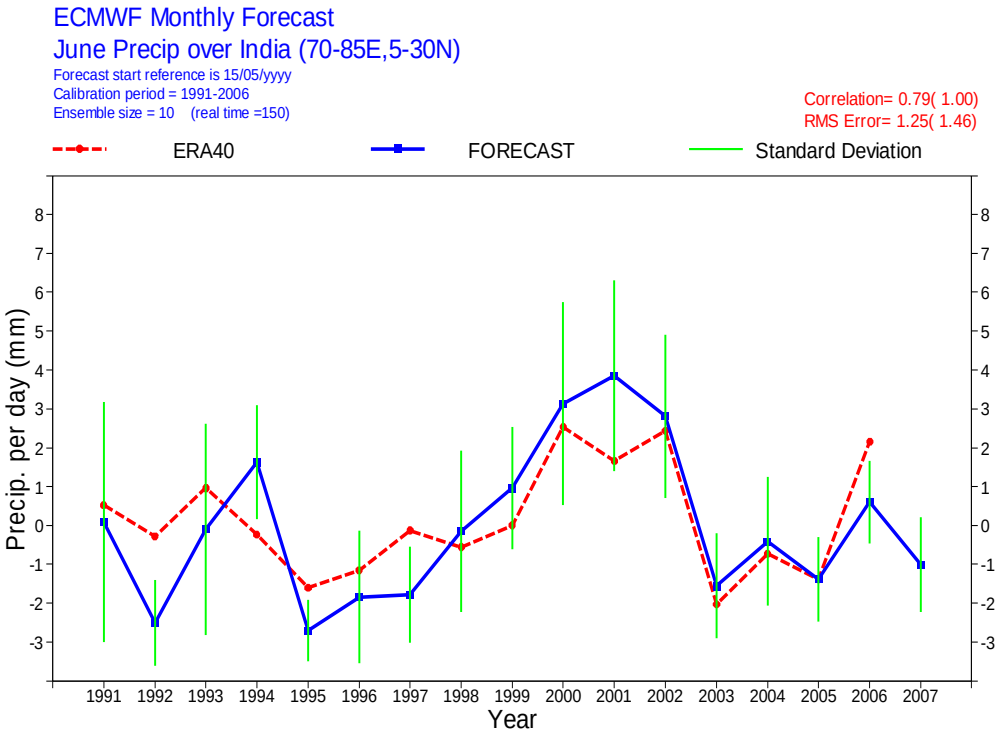




Forecast anomaly amplitude is ~ 2 x obs. !

# Monsoon onset predictions: early June pentads

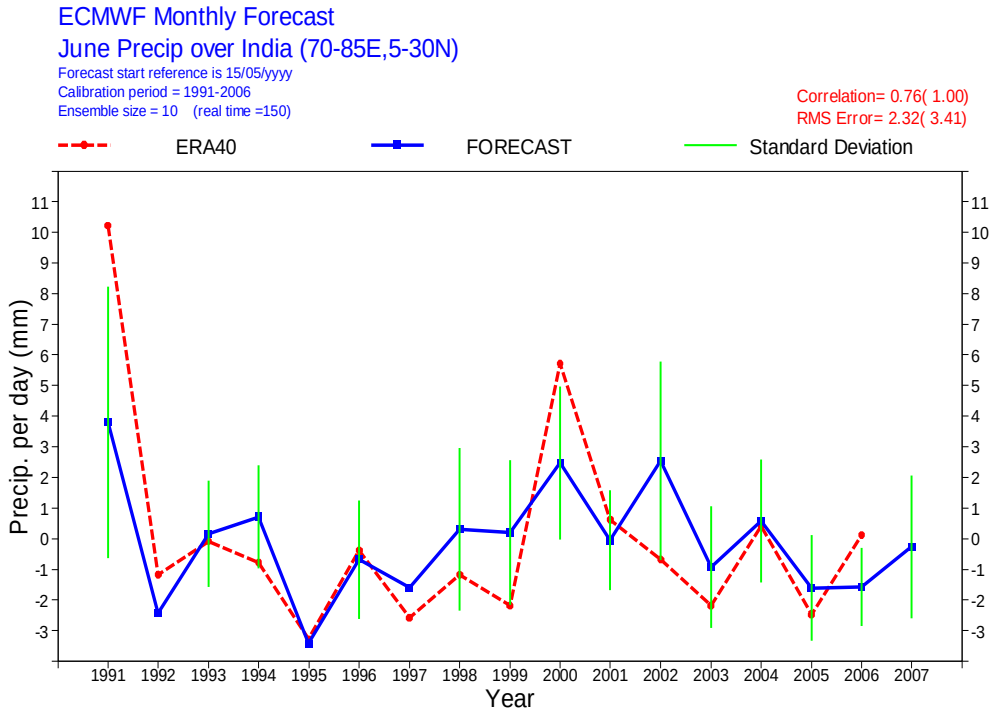
## Day 16-20: 1-5 June

CC = 0.79



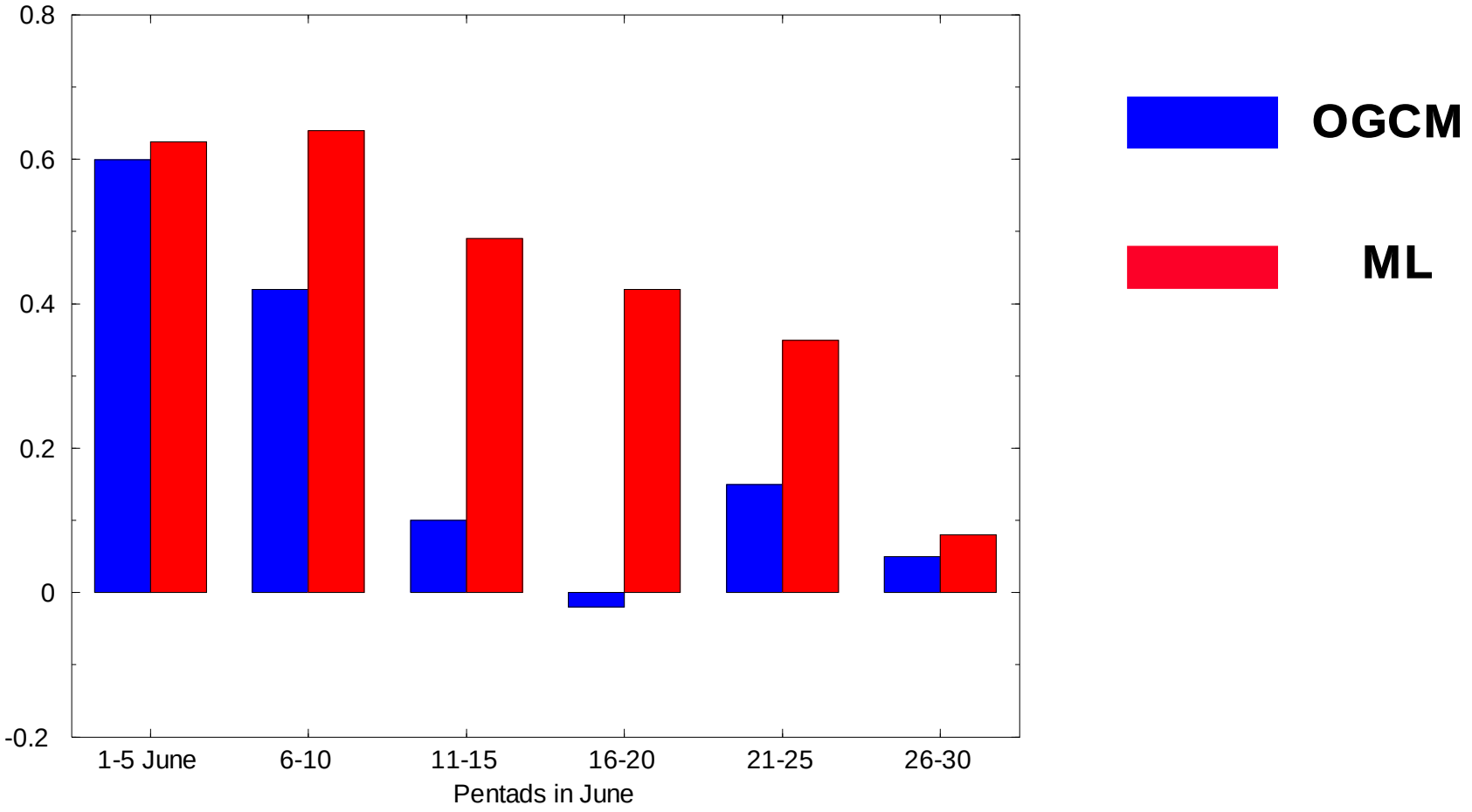

## Day 21-25: 6-10 June

CC = 0.76

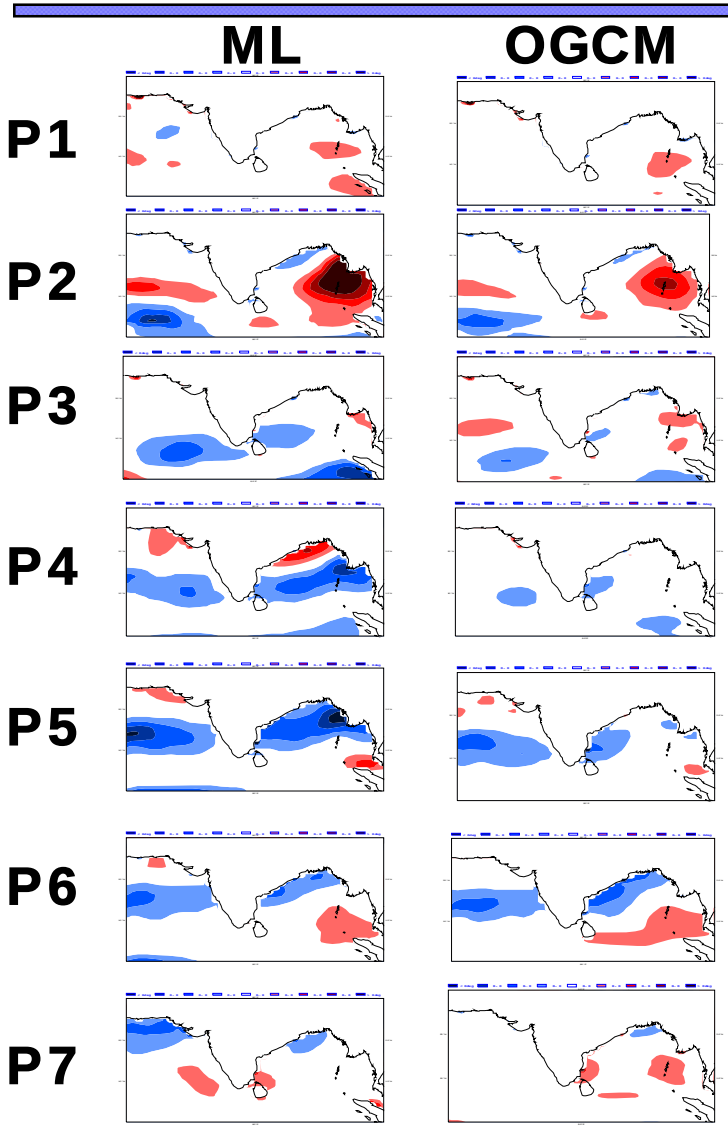


# Mixed-layer model vs. OGCM coupled to T159 IFS

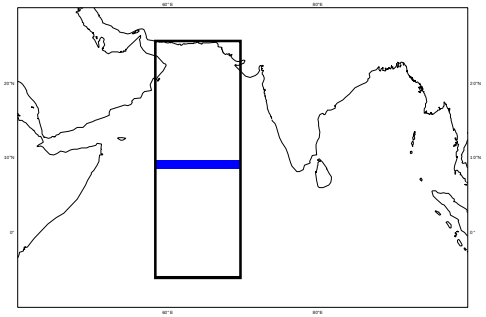
## Correlation with IMD station data – 1991 -2007

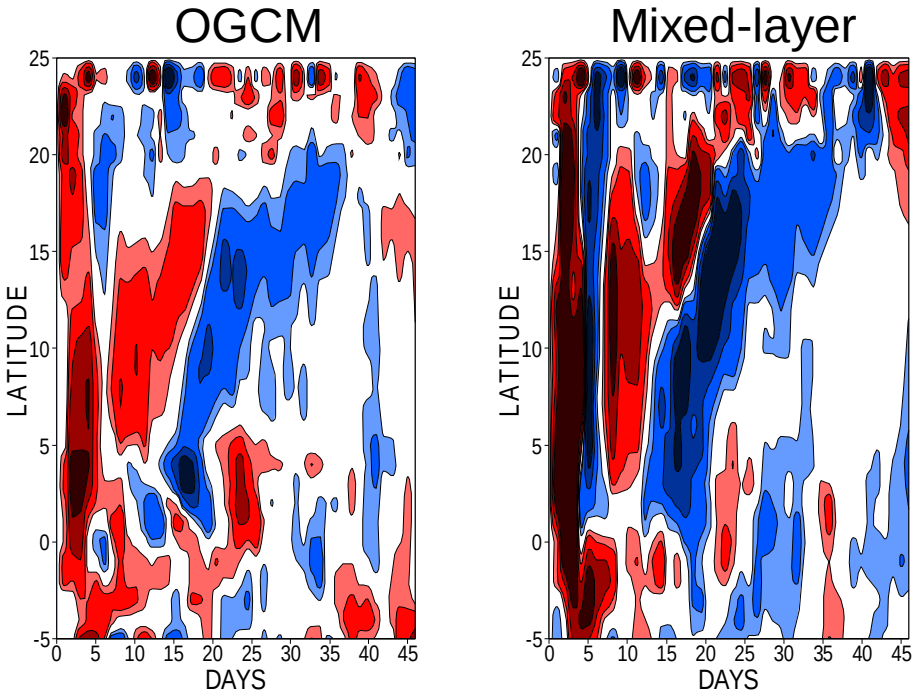


# SST Evolution - 1994



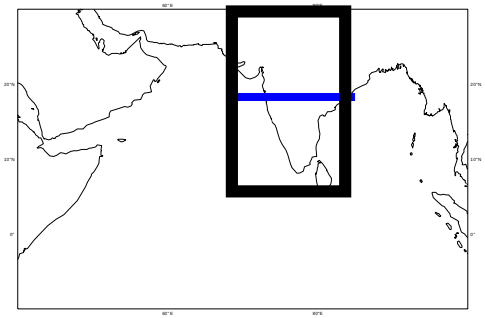

## SST Tendencies



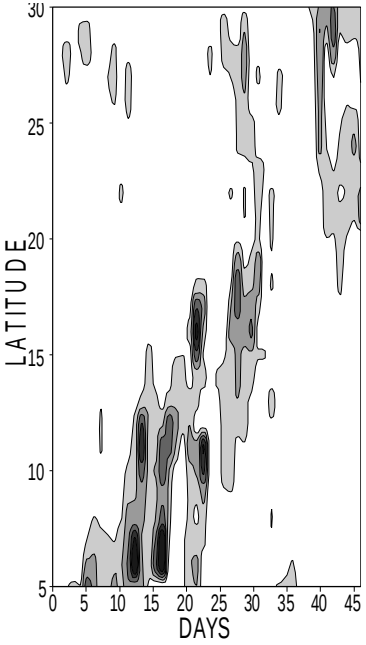


# Precipitation averaged between 70E and 85E

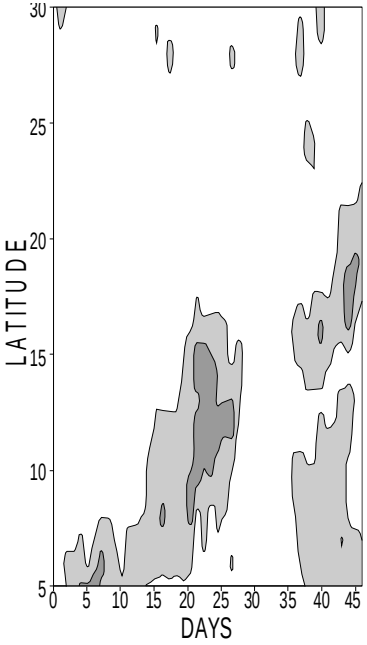
**1994**



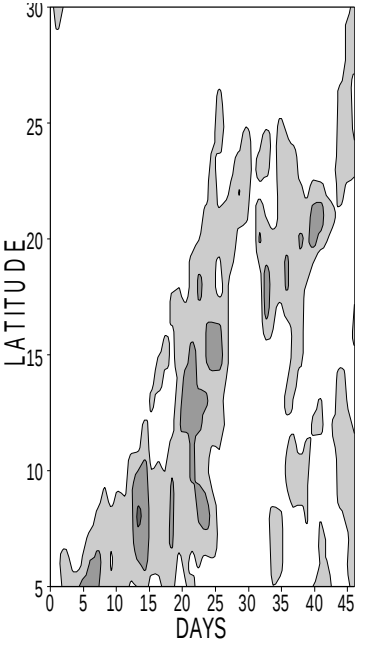
Analysis




OGCM




ML



# Conclusions

- The EPS-monthly system represents an important step towards combining the advantages of high-resolution forecasts at medium range with those of coupled simulations of low-frequency intra-seasonal variability.
- Probabilistic predictions of temperature and precipitation in the medium-range (up to day 15) have useful skill up in both tropical and extra-tropical regions.
- The use of re-forecast sets can substantially increase the value of calibrated forecast products for regional applications.
- Rainfall predictions from the EPS-monthly system show useful skill at the beginning of the South-Asian monsoon season, on both monthly and pentad time-scales. The skill is enhanced by an accurate representation of ocean mixed-layer variability.