Probabilistic predictions of monsoon rainfall with the ECMWF Monthly and Seasonal Forecast Systems

Franco Molteni, Frederic Vitart, Tim Stockdale, Laura Ferranti, Magdalena Balmaseda

European Centre for Medium-Range Weather Forecasts, Reading, U.K.
Why monsoon rainfall?

... and why south Asian monsoon rainfall in particular?

- The variability of Asian summer monsoon rainfall, particularly over India, is originated by the super-position of seasonally-coherent SST forced signals and intra-seasonal variabilities with quasi-periodic (MJO-like) and chaotic components.

- Increasingly frequent claims are made in scientific meetings/literature that monsoon rainfall can be better predicted by statistical methods than by dynamical, GCM-based ensemble forecasts.
P. K. Xavier (LMD, Paris) and B. N. Goswami (IITM, Pune) :

A promising alternative to prediction of seasonal mean all India rainfall

... The theoretically achievable skill for seasonal prediction of rainfall being barely useful, there is a need to explore alternative strategies ... we propose here that predicting the phases of the monsoon sub-seasonal oscillations 3-4 weeks in advance is such an alternative strategy. .. Using an empirical model, it is demonstrated that ... useful predictions of monsoon breaks 3 weeks in advance could be made.

... 21 year hindcasts from DEMETER project (ECHAM4-OPA8.1) ... for most years, there is hardly any correspondence with with observed EIMR (from CMAP).
P. K. Xavier (LMD, Paris) and B. N. Goswami (IITM, Pune) :

A promising alternative to prediction of seasonal mean all India rainfall

Analogue-based prediction of pentad OLR principal comp.

\[ \text{OLR}(x, y, t+\tau) = \sum_{k=1}^{K} \text{EOF}_k(x, y) \times \text{PC}_k(t_0 + \tau). \]

Figure 6. a. Spatial and temporal correlations between observations and predictions over Central India at different lead times. b. Temporal correlations between predictions and observations from active and break initial conditions at different lead times.
GPCP rainfall climatology: JJA 1981-2005

GPCP mean precip.  JJA 1981–2005

GPCP precip. standard dev.  JJA 1981–2005

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Rainfall anomalies in Dec. 1997 and July 2002
Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems

SST anomalies in Dec. 1997 and July 2002

[SST anomaly maps for Dec. 1997 and July 2002 showing temperature anomalies across the globe]
All-India Rainfall time-series (May-September)

2002

2003

2004
Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems

ECMWF Seasonal forecast system (Sys-3)

IFS 31R1
1.1 deg.
62 levels

OASIS-2

HOPE
1.4 deg. lon
1.4/0.3 d. lat.

TESSEL

4-D variational d.a.

4-D variational d.a.

Multivar. O.I.

Gen. of Perturb.

System-3
CGCM

Initial Con.
Ens. Forecasts

Multivar. O.I.

Gen. of Perturb.

System-3
CGCM

Initial Con.
Ens. Forecasts
The seasonal forecast System-3 (implem. March 07)

• COUPLED MODEL (IFS + OASIS2 + HOPE)
  • Recent cycle of atmospheric model (Cy31R1)
  • Atmospheric resolution TL159 and 62 levels
  • Time varying greenhouse gasses.
  • Includes ocean currents in wave model

• INITIALIZATION
  • Includes bias correction in ocean assimilation.
  • Includes assimilation of salinity and altimeter data.
  • ERA-40 data used to initialize ocean and atmosphere in hindcasts
  • Ocean reanalysis back to 1959, using ENACT/ENSEMBLES ocean data

• ENSEMBLE GENERATION
  • Revised wind and SST perturbations.
  • Use EPS Singular Vector perturbations in atmospheric initial conditions.

• Forecasts extended to 7 months (to 13 months 4x per year).
Planned unified VAREPS/monthly system

Present TL159 monthly system:

Coupled forecast at TL159

Initial condition

Future 32-day VAREPS/monthly system:

EPS Integration at T399

Initial condition

Heat flux, Wind stress, P-E

Ocean only integration

Coupled forecast at TL255

Day 10

Day 32
Products from Sys-3: ‘tercile summary’

ECMWF Seasonal Forecast
Prob(most likely category of precipitation)
Forecast start reference is 01/06/07
Ensemble size = 41, climate size = 275

<--- below lower tercile

above upper tercile --->

Forecast issue date: 15/09/2007

No significance test applied
Climagrams: area-averages of 2mT and rainfall
Climagrams: monsoon indices / teleconnections

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
All India Rainfall: “climagram” from 1 May 2007
Rms error of forecasts has been systematically reduced (solid lines) ...

.. but ensemble spread (dashed lines) is still substantially less than actual forecast error.
Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Eastern Indian Ocean

IND2 SST rms errors
300 start dates from 19810101 to 20051201
Ensemble size is 11

Fcast S3  Persistence  Ensemble sd

IND2 mean absolute SST

Eastern Indian Ocean
Anomaly correlation of seasonal-mean rainfall

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Anomaly correlation of seasonal-mean rainfall

corr. (ENS mean, GPCP) Init: may Verif: jja

corr. (ENS mean, GPCP) Init: may Verif: jas

corr. (ENS mean, ENS_exp) Init: may Verif: jja

corr. (ENS mean, ENS_exp) Init: may Verif: jas
Errors in rainfall standard deviations

\[ \frac{[SD \ (Sys-3) \ - \ SD \ (GPCP)]}{SD \ (GPCP)} \]
Predictability of teleconnection/EOF indices in S-3

Rainfall: East. Tropical Indian Ocean pattern (JJA)
Predictability of teleconnection/EOF indices in S-3

Rainfall: South Asian monsoon pattern (JAS)
Predictability of teleconnection/EOF indices in S-3

Rainfall: Sahel / Guinea coast dipole (JJA)
Predictability of AIR in S-3

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems

JJAS CC = .25

JAS CC = .46

prec average in air [70/90 ; 5/30]

Init: may Verif: jjas Cor [an, ens_m] = 0.254

 Init: may Verif: jas Cor [an, ens_m] = 0.460
Predictability of AIR in S-3: EOF filtered JAS

Prec projection on air [60/120 ; -15/30]
Init: may Verif: jas Cor [an, ens_m] = 0.504

CC = .50
Predictability of AIR in S-3: EOF filtered JAS (2)

Unfiltered
CC = 0.46

EOF proj.
CC = 0.59

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Predictability of East Africa short rains: EOF filtered OND

Unfiltered
CC = 0.04

EOF proj.
CC = 0.39
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.!
Asian monsoon onset exp. with VarEPS-monthly

- VarEPS 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: VarEPS-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)

Observations (GPCP)  FORECAST  Standard Deviation

CC = 0.62
Correlation= 0.62( 0.99)
RMS Error= 0.88( 0.83)
Anomaly correl. of pentad rainfall over India

Correlation EM/GPCP

Indian Precip

Correlation

Pentads

Monthly Forecast

Persistence of pentad -1

Persistence of pentad 1

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Monsoon onset predictions: early June pentads

Day 16-20: 1-5 June  
CC = 0.79

Day 21-25: 6-10 June  
CC = 0.76

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Conclusions (1)

- SST predictions from the ECMWF seasonal forecast system-3 show higher skill than those from previous system, particularly in the tropical Pacific and eastern Indian Oc., but western Indian Oc. and tropical Atlantic are still not better than persistence in NH summer.
- Substantial model errors affect rainfall variability over tropical land.
- Predictive skill for seasonal rainfall is generally good over the Pacific and tropical S. America, poor along the coast of the Indian Ocean in early summer. Skill for All-India Rainfall increases in the latter part of the monsoon season.
- Seasonal forecasts over land can be improved by exploiting teleconnections with adjacent ocean regions.
Conclusions (2)

- Predictions from the VarEPS-monthly forecast system show useful skill at the beginning of the South-Asian monsoon season, even on a pentad time-scale.

- If a minimal amount of statistical post-processing is performed, and information from monthly and seasonal forecast systems are used on the appropriate scales, the skill of dynamical predictions of monsoon rainfall from the ECMWF systems compare favourably with that of purely statistical schemes.
Products from Sys-3: “plumes” for El Nino indices

NINO3.4 SST anomaly plume
ECMWF forecast from 1 Sep 2007
Forecast issue date: 15 Sep 2007

NINO3.4 SST anomaly plume
ECMWF forecast from 1 Aug 2007
Forecast issue date: 15 Aug 2007
New products from Sys-3: ocean reanalysis

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
Equatorial Atlantic

ATL3 SST rms errors
300 start dates from 19810101 to 20051201
Ensemble size is 11

ATL3 mean absolute SST

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
ECMWF Seasonal Forecast
Tropical Storm Frequency
Forecast start reference is 01/06/2007
Ensemble size = 41, climate size = 176

**Forecast mean**  **Standard deviation**  **Climate mean**

Not Significant
Significant at 9%

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
EUROSIP seasonal fc of tropical storms (from 1st June)
Can we predict rainfall over tropical continents?

Predictions of monsoon rainfall with ECMWF monthly and seasonal fc. systems
ACC for seasonal-mean prec.: DJF from 1 Nov

Anomaly Correlation Coefficient for CodOecmE0001S003M001 with 11 ensemble members
Precipitation
Hindcast period 1981-2005 with start in November and averaging period 2 to 4
Black dots for values significantly different from zero with 95% confidence (1000 samples)
ACC for seasonal-mean precip.: JJA from 1 May

Anomaly Correlation Coefficient for CodOecmfE0001S003M001 with 11 ensemble members
Precipitation
Hindcast period 1981-2005 with start in May and averaging period 2 to 4
Black dots for values significantly different from zero with 95% confidence (1000 samples)
ACC for seasonal-mean 2m-T: DJF from 1 Nov

Anomaly Correlation Coefficient for CodOecmF0001S003M001 with 11 ensemble members
Near-surface temperature
Hindcast period 1981-2005 with start in November and averaging period 2 to 4
Black dots for values significantly different from zero with 95% confidence (1000 samples)
ACC for seasonal-mean 2m-T: JJA from 1 May

Anomaly Correlation Coefficient for CodOcme0E0001S003M001 with 11 ensemble members
Near-surface temperature
Hindcast period 1961-2005 with start in May and averaging period 2 to 4
Black dots for values significantly different from zero with 95% confidence (1000 samples)