Status of monsoon prediction

Dr Andy Turner

Part II
Outline: part II

- Decadal time scales & the global monsoon
- Linking interannual and intraseasonal time scales
- Societal need for subseasonal prediction
- Challenges ahead
Monsoon prediction

DECADAL VARIABILITY & THE GLOBAL MONSOON
The regional monsoons, perhaps as part of the global monsoon, exhibit important decadal variations with potential large socio-economic impacts.

Recent studies have highlighted interdecadal variability in:

- The various regional monsoons
- Features embedded in the monsoon, such as tropical cyclones and monsoon depressions
- The strength of monsoon teleconnections, impacting the prospect for seasonal prediction
Decadal outline

- Context: anthropogenic greenhouse gas forcing and the role of aerosol
- Decadal drivers of the Asian monsoon
- Coherent drivers of the global monsoon
- Modulation of teleconnections
Anthropogenic greenhouse forcing...

...and the role of aerosol

- Sulphate aerosols causing negative trends in 20th century South Asian monsoon (Bollasina et al., 2010, Science) or early withdrawal of EASM (Guo et al., 2013, ACP)?

- Black carbon EHP strengthening early monsoon rainfall (Lau et al., many studies!) or Asian Brown Cloud (Ramanathan et al., 2005)

- We can’t ignore anthropogenic drivers when measuring observed decadal variability in the monsoon
The PDO as a driver

Introduction


Warm minus cold PDO

Warm-Cold subdivision rainfall departure (%)

Warm minus cold ENSO
Combination of ENSO and decadal Pacific impacts on monsoon in a Walker Circulation framework:

PDO may affect monsoon-ENSO teleconnection in addition to direct impact on mean state

Krishnamurthy & Goswami (2000)
The AMO as a driver #1 hosing exps.

Warning: blue = dry in rain plots

The AMO as a driver #2 observations

- Alteration of Tropospheric Temperature gradient (longer season in warmer AMO period)
- AMO+ → corresponding warming over Eurasia

Goswami et al. (2006) GRL

Goswami/Xavier MTTG index
Atlantic multi-decadal variability: via the Pacific

- NATl freshwater flux → weakened THC (c.f. water hosing earlier in Zhang & Delworth; cooler NATl SST) → stronger ENSO variance → stronger teleconnection with monsoon

- Long integration analysis composites on AMO± show AMO+ weakening the Pacific trades, deepening the thermocline and damping ENSO

Chen et al. (2010) JGR-

Lu, Chen & Dong (2008) GRL
Going back to the weakening teleconnection from earlier: JJAS Niño-3 regressions of rainfall

Long-term regression with Nino-3

Change in the regression to the recent period

Tropical Atlantic modulation of the monsoon-ENSO teleconnection


Regression of ensemble differences onto $T_{\text{ATL}}$

Time-mean $\psi^{200\text{hPa}}$ JJAS: climatological simulation

AGCM coupled in IndOc/WPA C

TATL cooling during El Nino weakens teleconnection to monsoon
Coherent drivers of the global monsoon

- Northern tropics wind shear as an index for NHSM
- Varies on decadal time scales with IPO/AMO/HTC

Wang et al. (2013) PNAS
Coherent drivers of the global monsoon

The mega-ENSO / IPO

- Potentially added value here: anthropogenic global drivers (climate sensitivity and hemispheric thermal contrast)
- Addition of internal decadal modes (AMO, PDO)

Wang et al. (2013) PNAS
Prediction opportunities offered by decadal hindcasts: the Indian Ocean?

Initialised decadal hindcasts in CMIP5

- Kim et al. (2012, GRL) 10-year hindcasts every 5 years from 1960: “all models show high prediction skill for surface temperature up to 6–9 years over the Indian Ocean” (7mods)

- Comparison in Guemas et al. (2013, GRL) between initialized and uninitialized runs suggests no added bonus for initialization in Indian Ocean (5mods).

b) Forecast times: 6-9 years

Correlation between observed and model
Opportunities offered by decadal hindcasts: the decadal modes

Reasonable skill for AMO out to 4-7 years ahead, but not for PDO.

Kim et al. (2012, GRL)
Decadal prediction outlook

Modulation of the mean South Asian monsoon

- Internal decadal modes (AMO, PDO) may tell us something about long-term monsoon variability but need to be considered against external drivers (GHG, aerosol)

- Comparison with the global monsoon can be considered if used with caution

Modulation of teleconnections by decadal drivers may prove more useful: PDO, AMO, tropical Atlantic

- Real mileage will lie in understanding relationships between decadal drivers and ISV/synoptic variability

- Utilize decadal forecasts
Monsoon prediction

LINKING TIME AND SPACE SCALES
Space and time scales in the monsoon

- **Diurnal cycle**
- **Thunderstorms**
- **Monsoon depressions**
- **Monsoon/annual cycle**
- **ENSO & IOD**
- **PDO & AMO**
- **GHG emissions**
- **Aerosol emissions**
- **Ice melt?**

Increasing temporal and/or spatial scale:
- **Hours**
- **Days**
- **Weeks**
- **Months**
- **Years**
- **Decades**
- **Centuries**

**Climate variability**

**Climate change**
Monsoon prediction

LINKING INTERANNUAL & INTRASEASONAL SCALES
Palmer’s vision of the monsoon as a Lorenz attractor

- Monsoon with active and break regimes
- Can boundary forcing predispose the system to spend more time in either regime?

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CHAOS AND PREDICTABILITY IN FORECASTING THE MONSOONS

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ECMWF Shinfield Park, Berkshire RG2 9A-X, Reading, England

Fig 1 Phase-space evolution of an ensemble of initial points on the Lorenz attractor, for three sets of initial conditions, superimposed on the Lorenz attractor
Palmer’s vision of the monsoon as a Lorenz attractor

Palmer’s COLA model picture shows resemblance between IAV and ISV patterns of monsoon rainfall.

One of the principal testable hypotheses of such a paradigm is that the patterns of interannual fluctuations in monsoon rainfall, should correspond to patterns associated with the active and break spells.
Indian monsoon: intraseasonal variability

Daily All-India Rainfall 2007

Sum of active and break events giving some contribution to seasonal mean rainfall
Comparison of monsoon variation on ISV, IAV time scale

Differences of JJAS-mean monsoons based on strong minus weak years

Next will show seasonal mean EOFs

Sperber et al. (2000) QJRMS

Figure 3. Difference of seasonal mean (mm day$^{-1}$) based on strong–weak years of all thresholds to define extreme years. In (b) neg
Comparison of monsoon variation on ISV, IAV time scale

Figure 3. Difference of seasonal mean (June-September) composites of (a) 850 hPa wind, and (b) rainfall (mm day$^{-1}$) based on strong-weak years of all-India rainfall in Fig. 2(b) using 0.5 and --0.5 standard-deviation thresholds to define extreme years. In (b) negative contours are shown dashed and positive values are shaded progressively.

Sperber et al. (2000) QJRMS
Comparison of monsoon variation on ISV, IAV time scale

Sperber et al. (2000) QJRMS
Comparison of monsoon variation on ISV, IAV time scale

Resemblance suggesting than an element of the ISV can rectify onto the IAV

Sperber et al. (2000) QJRMS
Co-variation of daily Indian rainfall and PC3

Sperber et al. (2000) QJRMS
PDFs constructed from the daily PC-time series

- The daily PC3 mode more/less prevalent under different seasonal mean rainfall conditions

Figure 10. Probability distribution functions (PDFs) of the principal component (PC) time series of EOFs 1–4 given in Fig. 6. Each of the PC time series was standardized before calculating the PDFs. The solid line is the PDF based on all years of data. The thick dashed line is the PDF for years when the observed all-India rainfall (AIR) was above normal ($\geq 0.5$ standard deviation in Fig. 2(b)), and the thin short-dashed line is the PDF for years when the observed AIR was below normal ($\leq -0.5$ standard deviation in Fig. 2(b)). A vertical reference line at 0.0 standard deviations is also given.

Sperber et al. (2000) QJRMS

Fig. 2. (a) Active phase composite (red dots) and (b) break phase composite (blue dots) of depression-days. Each dot represents the location of the depression for a day (or depression-day). The composites were constructed for all active and break days during JJAS 1901–70. (c) Lagged active phase composites (red) and lagged break phase composites (blue) of depression-days for the period JJAS 1901–70. Lag 0 corresponds to the midpoint of each active or break phase.
Monsoon prediction

SOCIETAL NEED FOR SUBSEASONAL PREDICTION & CHALLENGES AHEAD
In 2009, several breaks contribute to the worst monsoon in decades.
Indian monsoon: intraseasonal variability in 2009

'MJO' mode by filtering in the zonal wavenumber / frequency domain, Wheeler & Weickmann (2001)
In 2009, several breaks contribute to the worst monsoon in decades.
Active-break cycle: animation

A composite cycle of monsoon intraseasonal variability, courtesy Ken Sperber, PCMDI, USA
Example current subseasonal predictability

Abhilash *et al.* (2014)

Fig. 1 Correlation coefficients between pentad mean observed and predicted area-averaged rainfall anomalies over Central India for the control and ensembles from CFSv2 perturbation experiments and lagged ensembles from NCEP CFSv2 reforecast. The correlation has been calculated for 24 pentads during summer monsoon (JJAS) for 9 years (2001–2009)

Fig. 7 Anomaly correlation coefficient (ACC) of the area-averaged rainfall over MZI and EIMR region as a function of forecast lead in days
BSISO in the Met Office GloSea5 model

The GloSea5 coupled initialized seasonal forecast model shows good representation of quadrature relationship between intraseasonally filtered SST and precipitation over the Bay of Bengal (black curves, comparing solid observation and dashed model lines)

Air-sea interaction over the equatorial Indian Ocean is poor (red curves)

South America summer
MJO-related daily precipitation anomalies

In central-east South America there is up to 4 mm more daily precipitation on average during phase 1 of MJO.

Courtesy: Alice Grimm (2016)
In central-east South America there are twice more extreme rainfall events in MJO phase 1. In southeast South America, they increase by a factor 1.6 in phase 3.
Mid-latitude interactions as another driver on subseasonal time scales

Case of the Pakistan floods, July/August 2010
Large biases that develop rapidly

See Sperber et al. (2013) *Climate Dynamics*

Johnson et al. (2016) *Climate Dynamics*
Large uncertainty in parametrizing tropical convection

- Increasing the convective entrainment rate tends to improve ISV (e.g. Klingaman et al.; Hirons et al., 2012; Del Genio et al., 2012)

- Increasing convective entrainment globally decreases several biases while increasing others (Kim et al. 2011): WEIO versus India versus WNP/Maritime Continent

Bush et al. (2014, QJRMS)
## The S2S database as a resource

### S2S Database - Models and Specs

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*Slide courtesy Paul Dirmeyer GMU/COLA*
The S2S database as a resource

S2S Database

- Now 10 models out of 11 in some form - content varies greatly though
- Web page to generate near-real-time S2S forecast plots (maps and indices): http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/
  - 6 S2S models available on the plot page (BoM, CMA, NCEP, UKMO, ECMWF, JMA) every Thursday starting from 7 January 2016.

Slide courtesy Paul Dirmeyer GMU/COLA
Example S2S maps available

Sub-seasonal to seasonal forecast

Please visit the S2S Product page in ECMWF at http://www.ecmwf.int/en/research/projects/s2s/charts/s2s/
Summary

- **Potential** for prediction on a number of different time and space scales for the monsoon
- Some evidence of skill at these different scales
- Numerous challenges
  - Convective parametrization
  - Coupled model drift from initialization, introducing coupled biases
  - Detailed analysis needed for process understanding
  - Detailed observations needed to challenge the representation of these processes in models (chiefly for ISV time scales)
End of part II

Thank you!

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