Performance of high resolution ensemble prediction system in predicting extreme events over Indian region

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Ensemble Methods in Modelling and Data Assimilation (EMMDA), 24-26 Feb 2020
Outline

• The backdrop: Increasing trend of extreme rainfall events
• The Kerala heavy rain events of 2018 & 2019 and its forecast
• New Approaches (Dycore)
• Summary
Unfortunately, we expect to see much extreme #weather throughout 2020 and the coming decades, fuelled by record levels of heat-trapping #greenhouse gases in the #atmosphere.
Increasing Trend of Extreme Rain Events Over India in a Warming Environment

Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data

A threefold rise in widespread extreme rain events over central India
(a) Temporal variation of frequency of very heavy rainfall events ($R \geq 150$ mm/day) over central India (thick solid line) and its smoothed variation (thick solid line) for the period 1901–2004. (b) Smoothed variation of frequency of very heavy rainfall events over central India and SST anomalies over the Equatorial Indian Ocean. The smoothing has been done to remove the sub-decadal fluctuations using a 13-point filter [IPCC, 2007].

Fig. 3. Temporal variation (1951 to 2000) in the number ($N$) of (A) heavy ($R \geq 100$ mm/day, bold line) and moderate ($5 \leq R < 100$ mm/day, thin line) daily rain events and (B) very heavy events ($R \geq 150$ mm/day) during the summer monsoon season over CI. The statistical significance of the trends (dashed lines) was calculated as in Fig. 2.

Goswami et al. 2006
Flowchart of GEFS

GDAS
EnKF – GSI Hybrid Data Assimilation System

Analysis (Control)

Tropical Storm Relocation (if storm is present)

Centering of the perturbations on the ensemble control analysis (Distributes the spread around analysis instead of Ensemble Mean)

20 Perturbed members

Forecast:

21 members runs for 192 hrs (8 days)
GFS Semi-Lagrangian T1534 (approx 12 km at equator); L64 vertical resolution.

The stochastic total tendency perturbation (STTP) to enhance model uncertainty

POST PROCESSING
240 hr (10 days) forecast
Resolution: 0.125°x0.125°
6 hr interval
Products: 21 members, Ensemble mean, Ensemble Spread

Flowchart of GFS

GDAS
EnKF – GSI Hybrid Data Assimilation System

Analysis (Control)

Forecast:

GFS Semi-Lagrangian T1534 (approx 12 km at equator)
L64 vertical resolution, runs for 240 hrs (10 days)

POST PROCESSING
240hr (10 days) forecast
Resolution: Regular grid and Gaussian grid at different resolutions
0.125°x0.125°

The Global (Ensemble) Forecast Model
## About GEFS and GFS V14 Model physics

<table>
<thead>
<tr>
<th>Physics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection</td>
<td>Revised Scale Aware Simplified Arakawa-Schubert (RSAS) and mass flux based SAS shallow convection scheme</td>
</tr>
<tr>
<td>Microphysics</td>
<td>Zhao-Carr-Moorthi microphysics formulation for grid-scale condensation and precipitation</td>
</tr>
<tr>
<td>Gravity Wave Drag</td>
<td>Orographic gravity wave drag, mountain-drag and stationary convective gravity wave drag</td>
</tr>
<tr>
<td>PBL</td>
<td>Hybrid Eddy Diffusion Mass flux turbulence/vertical diffusion scheme</td>
</tr>
<tr>
<td>Radiation</td>
<td>Solar radiation and IR based on RRTM (originally from AER, modified at EMC) with Monte Carlo Independent Column Approximation (McICA). Cloud fraction for radiation computed diagnostically from prognostic cloud condensate</td>
</tr>
</tbody>
</table>
IC 7 June 2018 00Z: forecast valid for 10 June 2018 00Z (+72h forecast)

Control run shown as

Initial Condition

Analysis

Forecast Uncertainty of different ensemble members

Probability of Rainfall > 6 cm/day

Observed Rainfall

GEFS SL T1534 Probabilistic Quantitative Precipitation
IC 2018060700 Day-3 Forecast valid for 00Z/10JUN2018
Probability of > 6 cm/day rainfall

70E

15N

20N

70E
Application of High resolution GFS model for Solar and Wind Energy Forecast

Initial Condition for Fog Forecast Experiment

Heavy rainfall forecast

Initial Condition for Solar and Wind energy forecasting

Initial Condition for hydrological modeling

Cyclogenesis, track and intensity prediction with 3 to 4 days lead time

APPLICATIONS OF HIGH RESOLUTION (12 km) GFS MODEL

District & block level forecast for agricultural applications
GEFS 12km ensemble based forecast strike probability.

IMD - Observation
AC00 - control run
AEMN-Ensemble Mean
---- Ensemble members
Tropical Cyclone VAYU strike probability and Intensity

2019 Tropical Cyclone Intensity
Storm: N0219 (VAYU)

2019 Tropical Cyclone Tracks
Storm: N0219 (VAYU)
Probability (%) of storm passing within 65nm during next 72h

Forecasts: Beginning 2019061300

Map showing the 2019 Tropical Cyclone Tracks.
THE KERALA DELUGE AUGUST 2018

Ref: CWC Report, Sept, 2018
<table>
<thead>
<tr>
<th>Period</th>
<th>Normal Rainfall (mm)</th>
<th>Actual Rainfall (mm)</th>
<th>Departure from normal (%)</th>
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</thead>
<tbody>
<tr>
<td>June, 2018</td>
<td>649.8</td>
<td>749.6</td>
<td>15</td>
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<tr>
<td>July, 2018</td>
<td>726.1</td>
<td>857.4</td>
<td>18</td>
</tr>
<tr>
<td>1-19, August, 2018</td>
<td>287.6</td>
<td>758.6</td>
<td>164</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1649.5</strong></td>
<td><strong>2346.6</strong></td>
<td><strong>42</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Districts</th>
<th>Normal Rainfall (mm)</th>
<th>Actual Rainfall (mm)</th>
<th>Departure from Normal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerala State</td>
<td>1701.4</td>
<td>2394.1</td>
<td>41</td>
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<tr>
<td>Alappuzha</td>
<td>1380.6</td>
<td>1784</td>
<td>29</td>
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<tr>
<td>Kannur</td>
<td>2333.2</td>
<td>2573.3</td>
<td>10</td>
</tr>
<tr>
<td>Ernakulam</td>
<td>1680.4</td>
<td>2477.8</td>
<td>47</td>
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<tr>
<td>Idukki</td>
<td>1851.7</td>
<td>3555.5</td>
<td>92</td>
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<tr>
<td>Kasaragode</td>
<td>2609.8</td>
<td>2287.1</td>
<td>-12</td>
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<td>Kollam</td>
<td>1038.9</td>
<td>1579.3</td>
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<tr>
<td>Kottayam</td>
<td>1531.1</td>
<td>2307</td>
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<tr>
<td>Kozhikode</td>
<td>2250.4</td>
<td>2898</td>
<td>29</td>
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<tr>
<td>Malappuram</td>
<td>1761.9</td>
<td>2637.2</td>
<td>50</td>
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<tr>
<td>Palakkad</td>
<td>1321.7</td>
<td>2285.6</td>
<td>73</td>
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<tr>
<td>Pathanamthitta</td>
<td>1357.5</td>
<td>1968</td>
<td>45</td>
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<tr>
<td>Thiruvananthapuram</td>
<td>672.1</td>
<td>966.7</td>
<td>44</td>
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<tr>
<td>Thrissur</td>
<td>1824.2</td>
<td>2077.6</td>
<td>14</td>
</tr>
<tr>
<td>Wayanad</td>
<td>2281.3</td>
<td>2884.5</td>
<td>26</td>
</tr>
</tbody>
</table>
Districts in Kerala:

1. Kasargode
2. Kannur
3. Kozhikode
4. Wayanad
5. Malappuram
6. Palakkad
7. Thrissur
8. Ernakulam
9. Idukki
10. Kottayam
11. Alappuzha
12. Pathanamthitta
13. Kollam
14. Thiruvananthapuram
The merged lightening & satellite cloud top temperature operational product is a joint collaboration of IMD, IITM & IAF
ENS weekly TP fc over India for 20180813-0819

Slide borrowed from Roberto Buizza, ECMWF
Rainfall (mm/day) time series over Kerala during 06-19Aug from GFS T1534

2018

2019
Rossby wave filtered anomaly of rainfall from 1 Aug to 31 Aug 2018
24 hr Forecast Rossby wave filtered anomalous rainfall

120 hr FCST
Vertically integrated moisture convergence and tendency of precipitable water vapour daily (mm/day)

Following Yanai et al. (1973), the traditional WVB equation may be expressed in the following form:

\[ \frac{1}{g} \frac{\partial}{\partial t} \int_{S}^{T} q dp + \frac{1}{g} \int_{S}^{T} \nabla \cdot q V dp = E - P. \]  

\[ \text{dPW} \quad \text{MFD} \]

Where, \( q \) is specific humidity, \( p \) is atmospheric pressure, \( V \) is the horizontal wind vector, \( g \) is the acceleration due to gravity, \( S \) and \( T \) indicate the land/ocean surface and an upper integration limit, respectively, \( E \) is the surface evaporation rate, \( P \) is precipitation, \( \text{dPW} \) is the time change of atmospheric water vapor (precipitable water, PW), and MFD is the horizontal moisture flux divergence.

Tendency in PWV is governed by source (moisture convergence) and Sink (Precipitation) terms. Tendency term is relatively small, giving an indication that moisture convergence is balanced by precipitation up to a large extent.
GEFS Probabilistic forecast for Kerala heavy rain during August 2018 and 2019

Threshold~Clim +1sd

Clim+2sd

Clim+3sd

Better skill in 2019 in general is achieved by sorting out/resolving initial condition issues in 2018
New Approach of Dycore in GFS
Update in Dynamic Core: Spectral Cubic Octahedral grid

Conventional Spectral grid:
- Not scalable
- I/O
- Artificial diffusion damping
- Negative tracer

Improvements: ....
Strong reduction of spurious grid-scale rainfall events (LSP)

Figure (adopted from ECMWF News Letter 146) demonstrates that the octahedral mesh (right) has a locally more uniform dual-mesh resolution than the mesh (left).

Numerical simulation of an idealised baroclinic instability, conducted using IFS model on both the mesh showed the octahedral grid results in higher accuracy and substantially reduced unphysical flow distortions accuracy mainly as the approach depends on the underlying mesh which defines the shape of the elementary volumes around which the computations are made (ECMWF New Letter, No. 146, 2015).
96 hour forecast

GFS Tco 765: Rainfall (cm/day)
valid for 03Z09AUG2019 (IC=00Z05AUG2019)

GFS T1534: Rainfall (cm/day)
valid for 03Z09AUG2019 (IC=00Z05AUG2019)

IMD-GPM: Rainfall (cm/day)
IC=03Z09AUG2019
Day 1 to Day 5 forecast valid for 2019080900
Summary

• The way forward is the probabilistic forecast of extremes

• The heavy rain of Kerala of 2018 and 2019 appear to be influenced by westward propagating Rossby wave phase and large scale moisture convergence resulting extremely heavy rain.

• Models show fidelity in capturing the Rossby wave propagation but limited fidelity in moisture convergence.

• Percentile based forecast provide better forecast guidance with longer lead time

• Tco shows promise in improving the rainfall forecast over western Ghat
Thank You !