Real-time Global Flood Monitoring and Forecasting Using an Enhanced Land Surface Model with Satellite-based and NWP Forcings

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System is running quasi-globally every three hours at 1/8th degree, and routing is also running at 1km resolution.
DRIVE model
http://flood.umd.edu

Soil, Vegetation (Princeton)
DEM (HydroSHEDS)

MERRA

TRMM + other satellites [TMPA/3B42]

0.25°, 3-hourly

06 August 2013 06 GMT
Routed runoff [mm] based Flood Threshold Map

Threshold = $P_{95} + \delta$

$P_{95}$: 95$^{th}$ percentile value of routed runoff

$\delta$: temporal standard deviation of routed runoff

15-year global hydrology model run using satellite rainfall data.
Example: Detection of Recent Flooding in Pakistan
Flood Detection/Intensity (depth above threshold [mm])

\[ R > P_{95} + \delta \]
and
\[ Q > 10 \text{ m}^3/\text{s} \]

- **R**: routed runoff (mm)
- **P_{95}**: 95th percentile value of routed runoff
- **δ**: temporal standard deviation of routed runoff
- **Q**: discharge (m³/s)
Streamflow [m$^3$/s]
August 10-25, 2013

10 August

15 August

20 August

25 August
Recent Flooding in Indus River, Pakistan (20 August 2013)

Flood Detection/Intensity (depth above threshold [mm])

Streamflow (m$^3$/s)

Flood Detection/Intensity (depth above threshold [mm])

12km Streamflow (m$^3$/s)
Real-time Calculations at 1 km

Streamflow and Water Storage (Routed Runoff + Bank Overflow)

Streamflow (1 km) June-August
Global evaluation TMPA real-time (DRIVE-RT) and research (rain gauge adjusted, DRIVE-V7) [15yrs (1998~), 3-hrly, 1/8° res.]

(1) **Flood event** based evaluation using 2,086 archived flood events by Dartmouth Flood Observatory

(2) **Streamflow** based evaluation at 1,121 river gauges by GRDC, across the globe.

[manuscript available on http://flood.umd.edu/]
Flood event based evaluation

Flooding at a point

\[ R > P_{95} + \delta \]

and

\[ Q > 10 \text{ m}^3/\text{s} \]

\[ R: \text{ routed runoff (mm)} \]
\[ P_{95}: \text{95th percentile value of routed runoff} \]
\[ \delta: \text{temporal standard deviation of routed runoff} \]
\[ Q: \text{discharge (m}^3/\text{s)} \]

Matching floods between simulated and reported

Temporal window: ±1 days

Spatial window: all upstream basin area within ~200 km & ~100 km downstream stem river

Flood detection verification against the Dartmouth Flood Observatory (DFO) flood database over the 38 Well Reported Areas (WRAs) for floods with duration more than 3 days.

<table>
<thead>
<tr>
<th>Metrics</th>
<th>POD</th>
<th>FAR</th>
<th>CSI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metrics averaged over all the 38 WRAs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRIVE-V7RT</td>
<td>0.90</td>
<td>0.73</td>
<td>0.25</td>
</tr>
<tr>
<td>DRIVE-V7</td>
<td>0.93</td>
<td>0.65</td>
<td>0.34</td>
</tr>
<tr>
<td><strong>Metrics averaged over the 20 WRAs with ( \geq 5 ) dam</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DRIVE-V7RT</td>
<td>0.93</td>
<td>0.80</td>
<td>0.19</td>
</tr>
<tr>
<td>DRIVE-V7</td>
<td>0.94</td>
<td>0.73</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Metrics averaged over the 18 WRAs with (&lt;5 ) dam</strong></td>
<td></td>
<td></td>
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<tr>
<td>DRIVE-V7RT</td>
<td>0.87</td>
<td>0.66</td>
<td>0.32</td>
</tr>
<tr>
<td>DRIVE-V7</td>
<td>0.92</td>
<td>0.56</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Better flood detection statistics with “research” (instead of RT) rain, with fewer dams (drop in FAR) and for longer, larger floods

**Bottom line**--For 3-day floods in basins with few dams using RT rainfall:  
POD \( \sim 0.9 \)  \hspace{0.5cm} \text{FAR} \( \sim 0.7 \)
Validation Against Global Flood Events (Dartmouth Flood Observatory)

Example of Well Reported Areas [WRAs] (shaded in yellow) and their corresponding FAR metrics for all floods with duration greater than 1 day
River gauges based evaluation

DRIVE-V7 (12km res.)

1,121 GRDC streamflow gauges
Distribution of the number of gauges with positive monthly and daily NSC metrics for DRIVE-V7 and DRIVE-RT simulation for 2001-2011, respectively.

Better NSC statistics for “research” rainfall indicate potential improvement of streamflow estimations when satellite rainfall improves.
Comparison with GRDC Streamflow Gauges
Nash-Sutcliffe (NSC) Daily and Monthly
Mean annual Relative Error (MARE)

<table>
<thead>
<tr>
<th></th>
<th>Daily NSC</th>
<th>Monthly NSC</th>
<th>Correlation Coeff.</th>
<th>MARE&lt;30%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nd&gt;0</td>
<td>Nd&gt;0.4</td>
<td>Nm&gt;0</td>
<td>Nm&gt;0.4</td>
</tr>
<tr>
<td>Global (~50°S to 50°N) with 1,121 gauges</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>% of gauges</td>
<td>V7</td>
<td>V7RT</td>
<td>V7</td>
<td>V7RT</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>19</td>
<td>60</td>
<td>7</td>
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<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>29</td>
<td>7</td>
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<tr>
<td>Mean metrics</td>
<td>V7</td>
<td>V7RT</td>
<td>V7</td>
<td>V7RT</td>
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<tr>
<td></td>
<td>0.22</td>
<td>0.16</td>
<td>0.39</td>
<td>0.37</td>
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<td></td>
<td>0.52</td>
<td>0.57</td>
<td>0.57</td>
<td>0.54</td>
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<td></td>
<td>-10°S~10°N with 141 gauges</td>
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<td></td>
</tr>
<tr>
<td>% of gauges</td>
<td>V7</td>
<td>V7RT</td>
<td>V7</td>
<td>V7RT</td>
</tr>
<tr>
<td></td>
<td>44</td>
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<td>62</td>
<td>6</td>
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<tr>
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<td>9</td>
<td>6</td>
<td>31</td>
<td>57</td>
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<td>V7</td>
<td>V7RT</td>
<td>V7</td>
<td>V7RT</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.23</td>
<td>0.41</td>
<td>0.36</td>
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<tr>
<td></td>
<td>0.55</td>
<td>0.60</td>
<td>0.58</td>
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Results are positive, but show considerable room for improvement

Tropics show better results than global, indicating problems in cool season, higher latitudes; research precipitation shows generally better results over real-time.

Tropics show lower bias with RT, indicating research procedure to reduce rain bias with rain gauges not working well in tropics where rain gauges are sparse
Evaluation of on-line events

Flood Detection/Intensity (depth above threshold [mm])
09Z18Apr2013

Flood Detection/Intensity (depth above threshold [mm])
09Z02Jun2013

Rainfall (7-day accum.) [mm] 09Z18Apr2013

Rainfall (7-day accum.) [mm] 09Z02Jun2013

Streamflow 12km res. [m³/s]
09Z18Apr2013

Streamflow 12km res. [m³/s]
09Z02Jun2013

(e)

(f)
41% (12) out of 29 gauges with daily NSC>0 with mean of 0.23

Internet source: April 19, 2013, Des Plaines, IL

USGS WaterWatch program http://waterwatch.usgs.gov
Flood Wave Too Fast?

Experiment 1: Example hydrograph with 1 day lag gives better results. Larger rivers may have larger lag.

Experiment 2: Increase of Manning parameter (streambed roughness) to 0.035 (from 0.03) also provides better timing—in this one case.

Further model tuning and calibration will likely improve results.
The last 10-day flood evolution, rainfall, and streamflow simulations (at 1km resolution) for north India (north sub-basins of Ganges) The flood during last week has been reported killing more than 130 people in this area.

http://flood.umd.edu/temp/share.html
<table>
<thead>
<tr>
<th>Country</th>
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<tbody>
<tr>
<td>United States</td>
<td>Austria</td>
<td>Korea, Republic Of</td>
<td>Honduras</td>
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<td>Italy</td>
<td>Germany</td>
<td>Cameroon</td>
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<td>Sweden</td>
<td>South Africa</td>
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<td>India</td>
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<td>Mexico</td>
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</tbody>
</table>

Visitor map in last two weeks

http://flood.umd.edu
Precipitation
Evapotranspiration
Soil moisture
SWE

GPM Ground Validation

https://fcportal.nsstc.nasa.gov/ifloods/

http://flood.umd.edu/IFloods.html
~5-day lead Flood Forecasting

TRMM

GEOS-5

Sep 21, 3:00am

Sep 21, 3:00am

Sep 21, 3:00am

Sep 22, 3:00am

Sep 22, 12:00am

Sep 22, 3:00am

Sep 23, 3:00am
Summary and Future

1. A new version of the Global Flood Monitoring System (GFMS) has been implemented for real-time application using the U. of Washington VIC community Land Surface Model and a new physically based DRTR routing model from the U. of Maryland for more accurate flood calculation and greater flexibility, including 1 km routing. The VIC/DRTR combination is called the Dominant river Routing Integrated with VIC Environment (DRIVE) system.

2. The evaluation of the DRIVE model shows promising performance in retrospective runs vs. observed streamflow records and in flood event detection against global flood event statistics. Results show impact of dams (higher FAR), potential improvement with improved accuracy of satellite precipitation and greater skill with longer floods.

3. High resolution (1 km) routing and water storage calculations will lead to high resolution inundation mapping for comparison with high resolution visible and SAR imagery of floods.

4. For the future we will also:
   - be implementing a “dam module” to try to include the impact of man-made structures on the calculations
   - be implementing the use of forecast precipitation info. from numerical models (adjusted by the satellite estimates) to extend the calculations a few days into the future
Thanks!
(a) POD analysis showing the performance of two different methods, V7 and V7RT, across various numbers of dams in the upstream well reported areas.

(b) FAR analysis for the same methods as in (a).

(c) CSI analysis indicating the effectiveness of the methods in relation to the number of dams.