Application of satellite based precipitation in Asian-African regions for flood simulation

Oliver SAAVEDRA\textsuperscript{1,2}, Masahiro RYO\textsuperscript{1}, Tomoo USHIO\textsuperscript{3}, Kentaro TAKIDO\textsuperscript{1}, Kazuki TANUMA\textsuperscript{1}, Zuliziana SUIF\textsuperscript{1}, Ryosuke GOMAIBASHI\textsuperscript{1}, Takuji KUBOTA\textsuperscript{4}

\textsuperscript{1} Dept. of Civil and Environmental Eng., Tokyo Institute of Technology, Japan
\textsuperscript{2} Dept. of Environmental Eng., E-JUST, Egypt
\textsuperscript{3} Dept. of Electrical, Electronic and Information Eng., Osaka Univ., Japan
\textsuperscript{4} Earth Observation Research Center, JAXA
Floods in Asia and Africa

Hue city, Vietnam

El-Arish, Egypt

Bangkok, Thailand

Khartoum, Sudan
Floods in Asia and Africa

Flood prevention

In developed countries
- Dam reservoir/Weir
- Embankment
- Dense rain gauge measurement
- Regional forecast system etc.

In contrast …

In developing countries, such countermeasure facilities (HARD) are still poorly implemented due to monetary limitation.
⇒ Importance of system development (SOFT)
Floods in Asia and Africa

System development (SOFT) with satellite products

Short term (per flood event)
Lead time for evacuation act (time)
Detection of hazardous area (space)

Long term (decades)
Analysis of flood characteristics for flood hazard mapping
Objectives

To investigate the applicability of Satellite Based Precipitation (SBP) in combination with local observation network to improve the spatial and temporal resolution of measurements in Asian and African river basins.

To evaluate SBPs from the hydro-meteorological perspective and applicability for flood management
Strategies

We plan to

1) Evaluate of SBP products at selected basins
2) Suggest different correction methods at basin and local scale for different tempo-spatial scales
3) Apply enhanced dataset as input for a hydrological model and compare simulated river discharge
4) Support flood risk assessment under different scenarios

Applications in Asian region
Japan, Vietnam, Thailand, Mekong

in African region
Nile basin, Sinai peninsula
# Test basins in Asia

<table>
<thead>
<tr>
<th></th>
<th>Tone in Japan</th>
<th>Huong in Vietnam</th>
<th>Mekong River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin size (km²)</td>
<td>16800</td>
<td>1500</td>
<td>795000</td>
</tr>
<tr>
<td>Annual rainfall (mm)</td>
<td>1200</td>
<td>2800</td>
<td>2500</td>
</tr>
<tr>
<td>Precipitation Product</td>
<td>GSMap_MVK, GSMap_gauge</td>
<td>GSMap_MVK, GSMap_gauge</td>
<td>GSMap_gauge</td>
</tr>
<tr>
<td>Time step</td>
<td>hh, dd, mm</td>
<td>6h, day</td>
<td>dd, mm</td>
</tr>
<tr>
<td>Eval. approach</td>
<td>POD, FAR, R, Effect of PMW &amp; IR</td>
<td>POD, FAR, R, RMSE, NSE, Bias</td>
<td>Bias</td>
</tr>
<tr>
<td>Qsim with DHM</td>
<td>NA</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Temporal downscaling</td>
<td>NY</td>
<td>OK</td>
<td>NY</td>
</tr>
</tbody>
</table>
Tone River Basin, Japan

Target area of evaluation

Location of Tone River Basin
(Buffered by 7 km)

Area = 16830 km² (Buffered 20560 km²)
No. of Obs. Gauges: 78 stations
Annual average prec = 1300 mm
Monthly Precipitation (Tone)

- Overestimation in summer
- Underestimation in winter

Monthly precipitation [mm]

- Observation
- GSMaP_Gauge
- GSMaP_MVK
Comparison of Average Monthly POD and FAR from 2006-2009

FAR remains relatively stable, but there is an overall improvement on POD.

<table>
<thead>
<tr>
<th></th>
<th>MVK</th>
<th>Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>POD</td>
<td>0.48</td>
<td>0.70</td>
</tr>
<tr>
<td>FAR</td>
<td>0.33</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Annual avg. of POD and FAR
Comparison of Linear Regression in Various Time Scale

Daily Correlation error (R) close to 1 (≈0.95)
Spatial distribution of POD

Overall improvement on POD
Low POD in the northwest: possibly due to snowfall in western Japan
Spatial distribution of FAR

Little difference in comparison of FAR
Distributed Hydrological Model

Precipitation

Discharge

Basin

Sub basin

Flow interval

Soil moisture condition

- Runoff
- Soil condition

Topography
Land use
Soil map
Satellite image

River routine model

Hill slope model

\[ \frac{\partial Q}{\partial x} + \frac{\partial h}{\partial t} = q_L \]
Huong River basin Target area of evaluation

Area = 1500 km²
No. of Obs. Gauges: 8 stations
Annual ave. prec = 2800 mm
Mean Discharge : 100 m³/s
Max Discharge : 5,000 m³/s
Method for temporal downscaling

Huong

\[ P_t = P_{24h} \times \frac{\sum_{i=1}^{4} \frac{MVK_i}{MVK_i}}{\sum_{i=1}^{4} \frac{MVK_i}{MVK_i}} \]

Precipitation [mm/h]

1 6 12 18 24 T [h]

6h

24h

MVK

rain gauge
Sub-daily gauge \( (P_{control}) \)

Distributed hydrological model

6 hourly

calibrated with \( P_{control} \)

Daily gauge

Sub-daily Satellite \( (P_{sat}) \)

GSMaP

MVK

Uniform distribution \( (P_{uni}) \)

Downscale with satellite \( (P_{ds}) \)

Discharge simulation

\[ Q_{control} \]

\[ Q_{uni} \]

\[ Q_{ds} \]

Most realistic simulation (control)

Comparison by indicators and MLR analysis to detect key variables affecting simulation improvement due to downscaling
Simulation results

Huong

18 flood events were targeted. Evaluation indicator (NSE) showed significant improvement: 0.33 $\rightarrow$ 0.63, improved 14 out of 18 flood cases.

How can this method be used?
This temporal downscaling can be used at any basins where have low temporal precipitation data, but are affected by flush floods.

Ryo, Saavedra et al 2014, JHM
• Overestimation in August
• Underestimation in October and November
Precipitation 6-hourly and daily Sep-Nov in 2006-2009

Tendency: underestimation

Accuracy: GSMaP_Gauge > MVK

Log-transformation shows the improvement clearly.

Tendency: underestimation

Accuracy: GSMaP_Gauge > MVK

Log-transformation shows the improvement clearly.
Precipitation evaluation scores

**6 hourly**

<table>
<thead>
<tr>
<th></th>
<th>Gauge</th>
<th>MVK</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>12.7</td>
<td>14.6</td>
</tr>
<tr>
<td>correlation</td>
<td>0.74</td>
<td>0.69</td>
</tr>
<tr>
<td>Bias</td>
<td>-0.29</td>
<td>-0.58</td>
</tr>
<tr>
<td>POD</td>
<td>0.89</td>
<td>0.53</td>
</tr>
<tr>
<td>FAR</td>
<td>0.27</td>
<td>0.16</td>
</tr>
<tr>
<td>TS</td>
<td>0.67</td>
<td>0.48</td>
</tr>
</tbody>
</table>

**daily**

<table>
<thead>
<tr>
<th></th>
<th>Gauge</th>
<th>MVK</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>39.5</td>
<td>47.6</td>
</tr>
<tr>
<td>correlation</td>
<td>0.80</td>
<td>0.76</td>
</tr>
<tr>
<td>Bias</td>
<td>-0.29</td>
<td>-0.58</td>
</tr>
<tr>
<td>POD</td>
<td>0.89</td>
<td>0.58</td>
</tr>
<tr>
<td>FAR</td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>TS</td>
<td>0.81</td>
<td>0.56</td>
</tr>
</tbody>
</table>

*(Threshold amount = 1.0 mm d⁻¹)*
Discharge simulation with three types of precipitation inputs was conducted.

Local rain gauge network > GSMaP_Gauge >> GSMaP_MVK
Discharge simulation with three types of precipitation inputs was conducted.

Local rain gauge network > GSMaP_Gauge >> GSMaP_MVK
Discharge simulation with three types of precipitation inputs was conducted.

Local rain gauge network > GSMaP_Gauge >> GSMaP_MVK

NSE (0~1)
Rain gauge: 0.88
GS_Gauge: 0.56
GS_MVK: 0.20
Discharge simulation with three types of precipitation inputs was conducted.

Local rain gauge network > GSMaP_Gauge >> GSMaP_MVK
## Discharge simulation evaluation scores

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th></th>
<th>2007</th>
<th></th>
<th>2008</th>
<th></th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSE</td>
<td>RMSE</td>
<td>R</td>
<td>Bias</td>
<td>NSE</td>
<td>RMSE</td>
<td>R</td>
</tr>
<tr>
<td>Rain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gauge</td>
<td>Gauge</td>
<td>MVK</td>
<td>Gauge</td>
<td>MVK</td>
<td>Gauge</td>
<td>MVK</td>
<td>Gauge</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>2006</td>
<td>0.93</td>
<td>130</td>
<td>0.97</td>
<td>0.04</td>
<td>0.93</td>
<td>1017</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>0.57</td>
<td>314</td>
<td>0.79</td>
<td>-0.05</td>
<td>0.40</td>
<td>782</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>0.19</td>
<td>432</td>
<td>0.61</td>
<td>-0.57</td>
<td>-0.02</td>
<td>258</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>0.93</td>
<td>258</td>
<td>0.97</td>
<td>0.09</td>
<td>0.88</td>
<td>196</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>0.40</td>
<td>782</td>
<td>0.85</td>
<td>-0.46</td>
<td>0.56</td>
<td>370</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>-0.02</td>
<td>258</td>
<td>0.87</td>
<td>-0.78</td>
<td>0.20</td>
<td>407</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>0.88</td>
<td>1017</td>
<td>0.94</td>
<td>-0.12</td>
<td>-0.02</td>
<td>171</td>
<td>0.97</td>
</tr>
<tr>
<td></td>
<td>0.56</td>
<td>782</td>
<td>0.81</td>
<td>-0.24</td>
<td>-0.18</td>
<td>421</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>258</td>
<td>0.82</td>
<td>-0.64</td>
<td>-0.48</td>
<td>548</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>-0.02</td>
<td>1017</td>
<td>0.82</td>
<td>-0.12</td>
<td>-0.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>0.94</td>
<td>171</td>
<td>0.97</td>
<td>-0.02</td>
<td>0.61</td>
<td>421</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>0.42</td>
<td>196</td>
<td>0.80</td>
<td>-0.12</td>
<td>0.73</td>
<td>548</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>0.61</td>
<td>421</td>
<td>0.73</td>
<td>-0.48</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Graphs

- **2006**
  - Observation
  - Rain gauge
  - GSMaP_Gauge
  - GSMaP_MVK

- **2007**
  - Observation
  - Rain gauge
  - GSMaP_Gauge
  - GSMaP_MVK

- **2008**
  - Observation
  - Rain gauge
  - GSMaP_Gauge
  - GSMaP_MVK

- **2009**
  - Observation
  - Rain gauge
  - GSMaP_Gauge
  - GSMaP_MVK

---

NSE: 0.93
RMSE: 130
R: 0.97
Bias: 0.04

NSE: 0.57
RMSE: 314
R: 0.79
Bias: -0.05

NSE: 0.19
RMSE: 432
R: 0.61
Bias: -0.57

NSE: 0.40
RMSE: 782
R: 0.85
Bias: -0.46

NSE: -0.02
RMSE: 1017
R: 0.87
Bias: -0.78

NSE: 0.88
RMSE: 196
R: 0.94
Bias: -0.12

NSE: 0.56
RMSE: 370
R: 0.81
Bias: -0.24

NSE: 0.20
RMSE: 407
R: 0.82
Bias: -0.64

NSE: 0.61
RMSE: 421
R: 0.80
Bias: -0.18

NSE: 0.34
RMSE: 548
R: 0.73
Bias: -0.48

---

**Discharge simulation evaluation scores**

<table>
<thead>
<tr>
<th>Year</th>
<th>NSE</th>
<th>RMSE</th>
<th>R</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Discharge simulation evaluation scores**

<table>
<thead>
<tr>
<th>Year</th>
<th>NSE</th>
<th>RMSE</th>
<th>R</th>
<th>Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tendency: underestimation
Correlation values do not become worse.
Slope of the regression of MVK reduced more than that of Gauge. → Evaporation
Application in Mekong River Basin

Area = 795,000 km²

No. of Obs. Gauges: 65 stations
Annual prec, Min = 1000 mm
Max = 4000 mm
Mean Discharge : 15,000 m³/s
Max Discharge : 45,000 m³/s

Station Name
1 Chiang Sean
2 Luang Prabang
3 Vientiane
4 Nakhon Phanom
5 Khong Chiam
6 Pakse
7 Kratie
8 Kampong Cham
9 Phnom Penh

Upper region

Middle region

Lower region
Monthly precipitation April – December 2000

Monthly precipitation [mm]

- Observation
- GSMaP_gauge

<table>
<thead>
<tr>
<th>Month</th>
<th>Observation</th>
<th>GSMaP_gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Daily Discharge simulation rain gauge, GSMaP

1. Chiang Sean
2. Luang Prabang
3. Vientiane

Upper region

Discharge \( [m^3/s] \)

Day

Observation Rain Gauge GSMaP
Daily Discharge simulation rain gauge, GSMap

4. Nakhon Phanom

5. Khong Chiam

6. Pakse

Middle region
Daily Discharge simulation rain gauge, GSMAp

7. Kratie

8. Kampong Cham

9. Phnom Penh

Observation
Rain Gauge
GSMap

Lower Region
Findings so far

- We achieved temporal downscaling daily → 6h
- Statistical evaluation, GSMap_gauge > GSMap_MVK
  POD & FAR at Tone and Huong
- Significant improvement of the prec. estimation 10-100 [mm d⁻¹] and slight improvement at intensities (> 100 [mm d⁻¹])
- Timing of rising limbs (rapid increase of discharge, start of flooding) was captured very well.
- Underestimation tendency of peak discharge during floods
- Overall GSMap_MVK ‘s underestimation has been reduced by GSMap_gauge but still some bias can be found even overestimation
- Evaluation seems sensitive on the quality and density of obs prec
Publications


## Schedule

<table>
<thead>
<tr>
<th>JFY</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td>4-6</td>
<td>7-9</td>
<td>10-12</td>
</tr>
<tr>
<td>TRMM &amp; GSMap validation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrological simulations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near real-time applications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Statistical evaluation of TRMM and GSMap against available gauge network at selected Asian and African basins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suggestion of proper correction factors for TRMM and GsMap data set at selected Asian and African basins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Validation of correction factors for TRMM and GsMap data set at selected Asian and African basins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development of enhanced data set for those selected basins</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Applications in African region
Eastern Nile river and Sinai Peninsula

Rainfall at Sinai

High: 220 mm/year
Low: 1 mm/year
Results of Nile River discharge at Sudan

Simulated stream flow using rain gauge at Khartoum st.

ELEVATION

High : 4657
Low : 107

Nile delta

Khartoum
Sudan

TRMM distribution

Rain gauge network
Flood management support system

Input
- Satellite Based Precipitation
- Radar
- Raingauge

Distributed Hydrological Model
Enhanced Precipitation Pattern

Output
- Real-time Inundation Mapping
- Sound Decision Making
Difference in accuracy between PMW and IR

For GSMaP_MVK: values more constant for MWR, alleviation of underestimation for IR + MVK
For GSMaP_Gauge: Stronger correlation for IR + MVK, alleviation of underestimation for PMW
Difference in POD and FAR between PMW and IR (for MVK)

Overall, MWR was better for both POD and FAR
Some resemblance in tendency could be seen between MWR and IR
As expected where POD is low, FAR is high