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Upstream Satellite Remote Sensing for River Discharge Forecasting: Application to Major Rivers in South Asia

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National Center for Atmospheric Research

Outline

I. Bangladesh Problem

II. Climate Forecast Applications for Bangladesh

   a) Weather-based flood forecasting

III. DFO-JRC satellite-derived flood prediction

   a) Estimating flood wave celerity

   b) Discharge forecasting

IV. Ongoing and Future Assimilation Work

   a) Multi-model approach

   b) Transforming forecasts to flood extent maps

Asia

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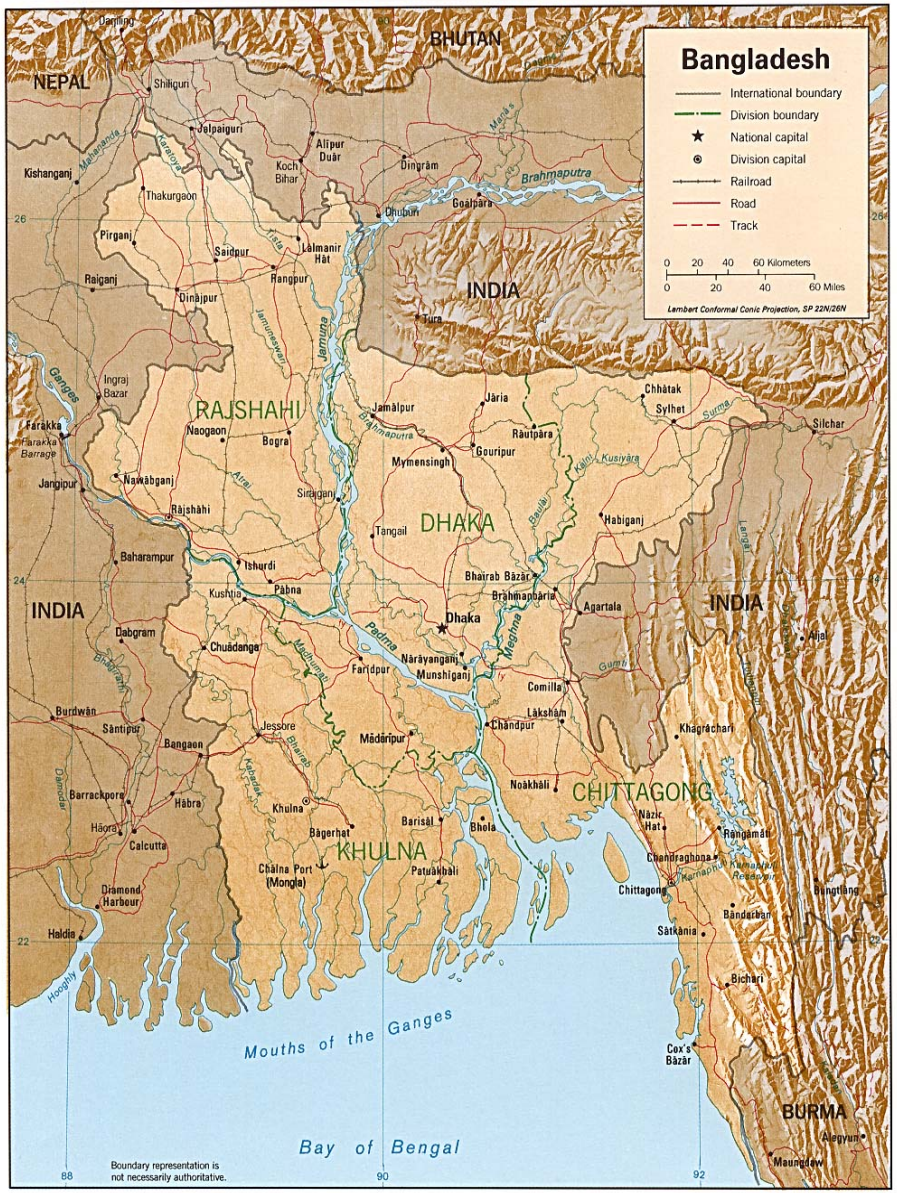


Base 802491 (544488) 5-96

Case Study: Bangladesh River Flooding

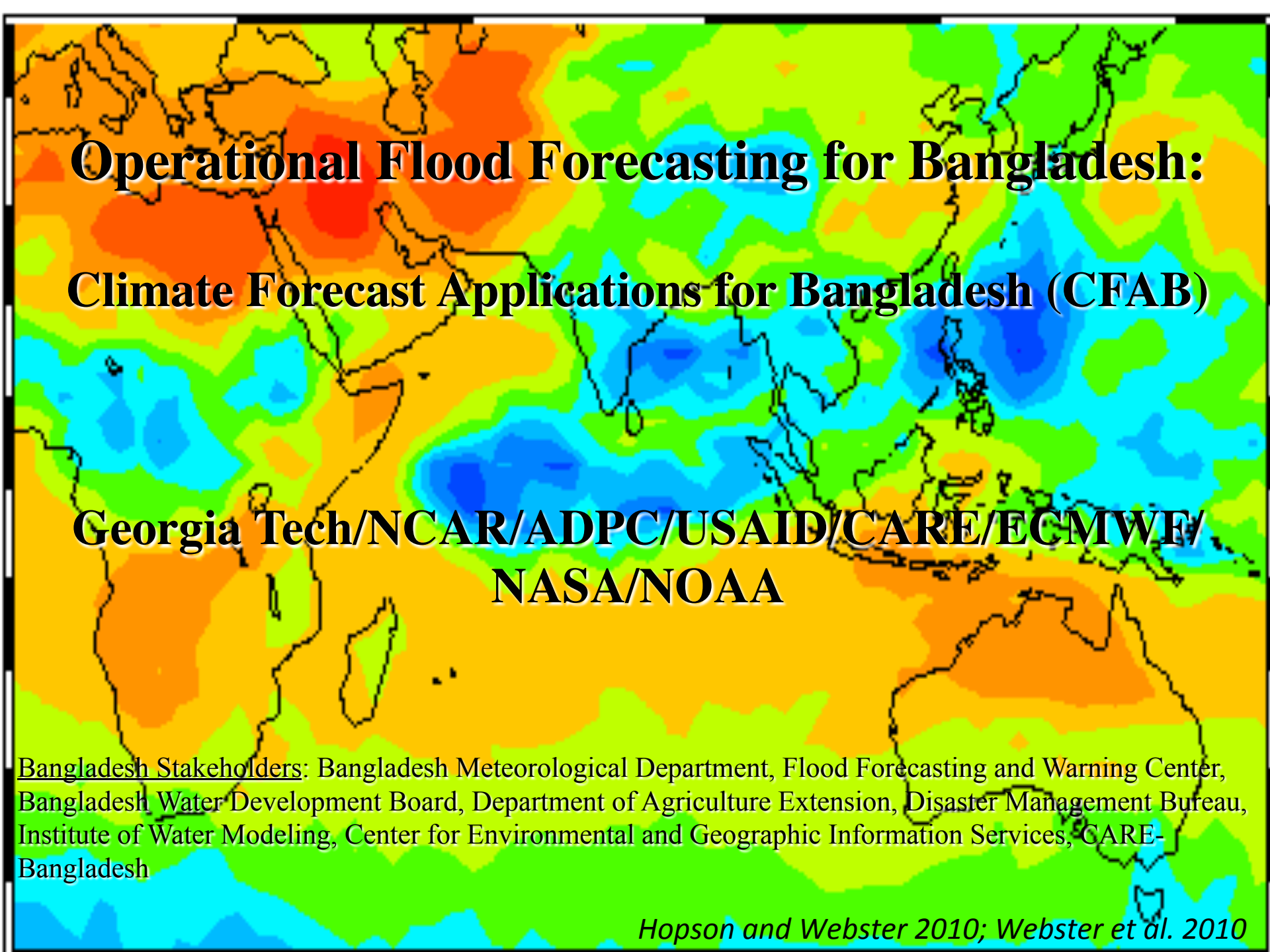
Damaging Floods:

- **large peak or extended duration**
- **Affect agriculture: early floods in May, late floods in September**

Recent severe flooding: 1974, 1987, 1988, 1997, 1998, 2000, 2004, and 2007

- **1998: 60% of country inundated for 3 months, 1000 killed, 40 million homeless, 10-20% total food production**
- **2004: Brahmaputra floods killed 500 people, displaced 30 million, 40% of capitol city Dhaka under water**
- **2007: Brahmaputra floods displaced over 20 million**

(World Food Program)



Operational Flood Forecasting for Bangladesh:

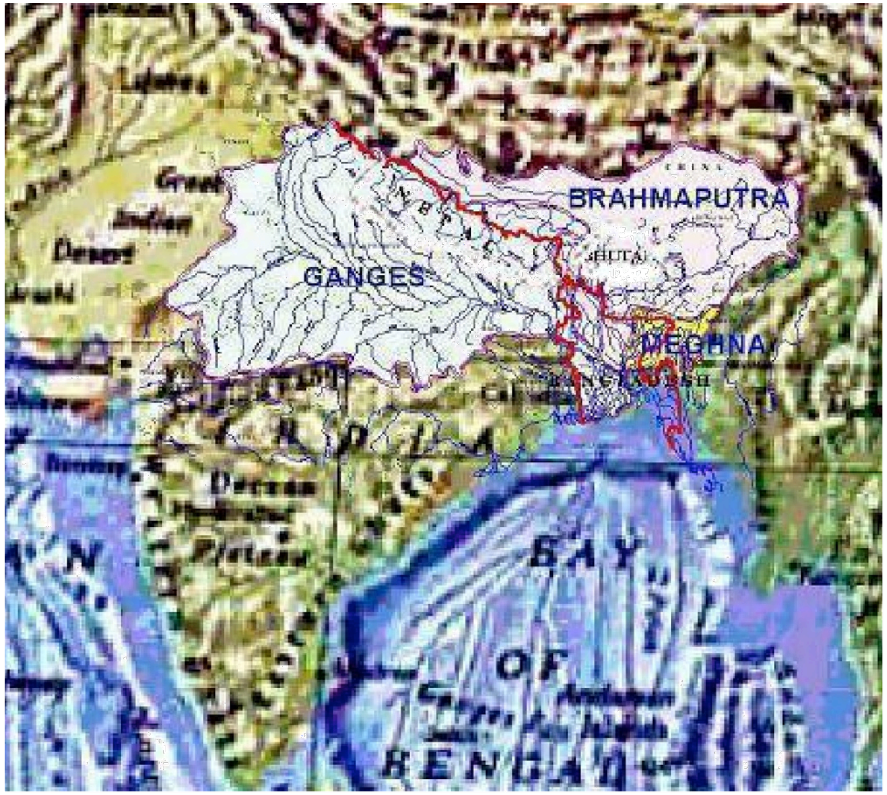
Climate Forecast Applications for Bangladesh (CFAB)

Georgia Tech/NCAR/ADPC/USAID/CARE/ECMWF/ NASA/NOAA

Bangladesh Stakeholders: Bangladesh Meteorological Department, Flood Forecasting and Warning Center, Bangladesh Water Development Board, Department of Agriculture Extension, Disaster Management Bureau, Institute of Water Modeling, Center for Environmental and Geographic Information Services, CARE-Bangladesh

Hopson and Webster 2010; Webster et al. 2010

CFAB Project: Improve flood warning lead time



Problems:

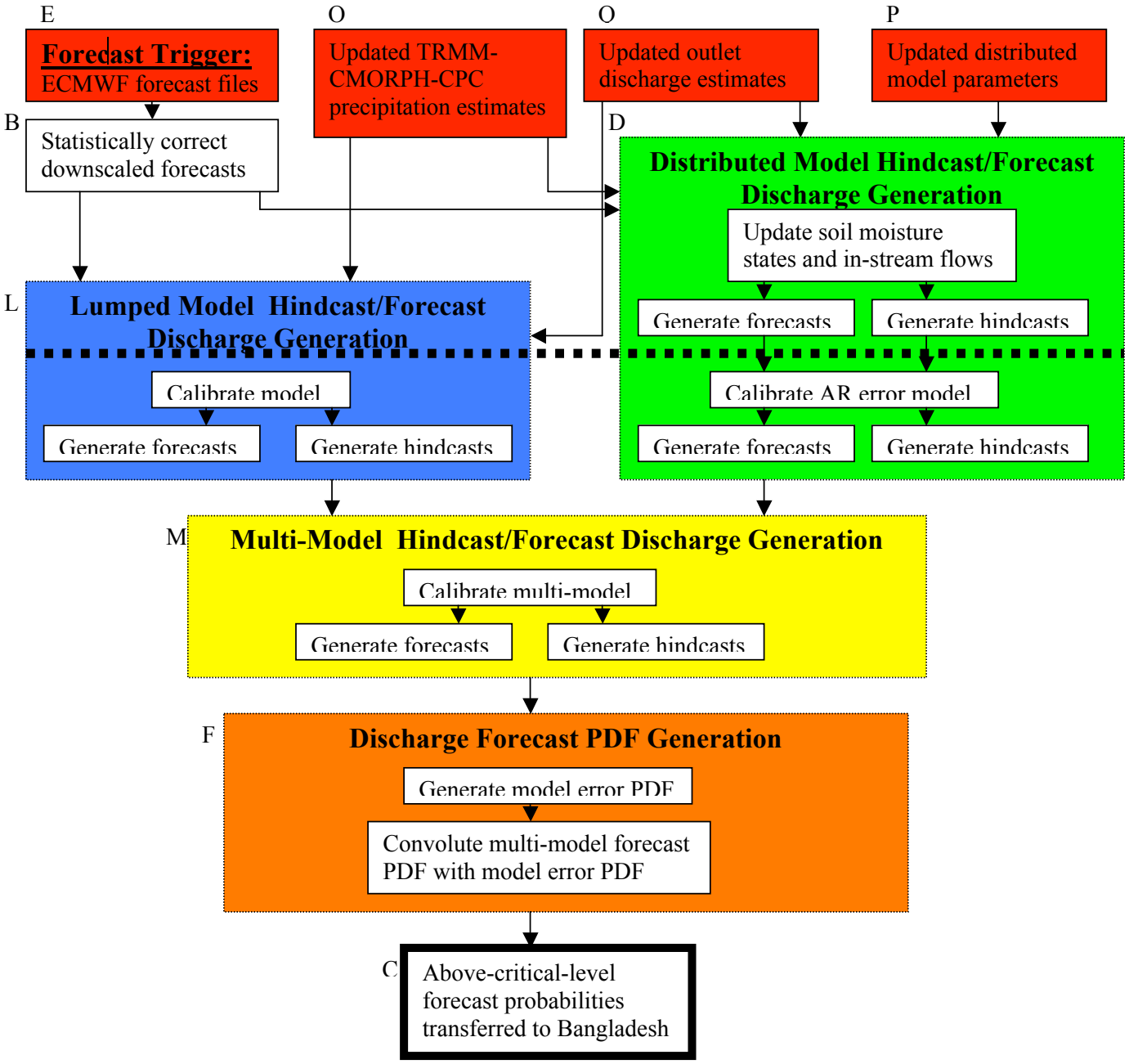
1. Limited warning of upstream river discharges

2. Precipitation forecasting in tropics difficult

Assets:

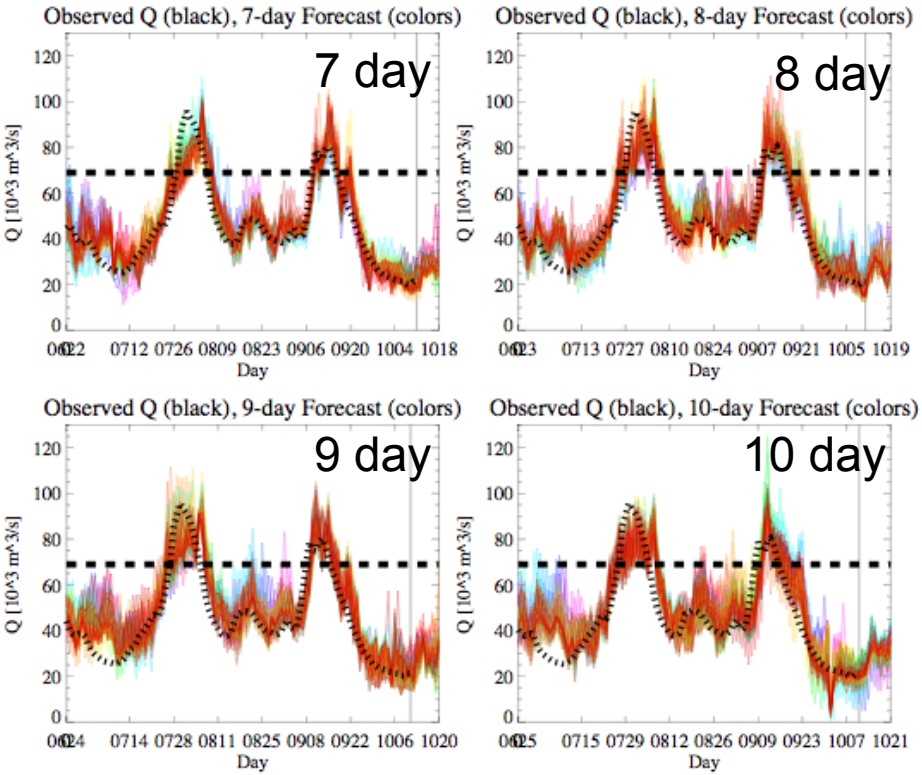
1. good data inputs: weather forecasts, satellite rainfall
2. Large catchments => weather forecasting skill "integrates" over large spatial and temporal scales
3. Partnership with Bangladesh's Flood Forecasting Warning Centre (FFWC)
   => daily border river readings

Daily Automated Operational Flood Forecasting Sequence

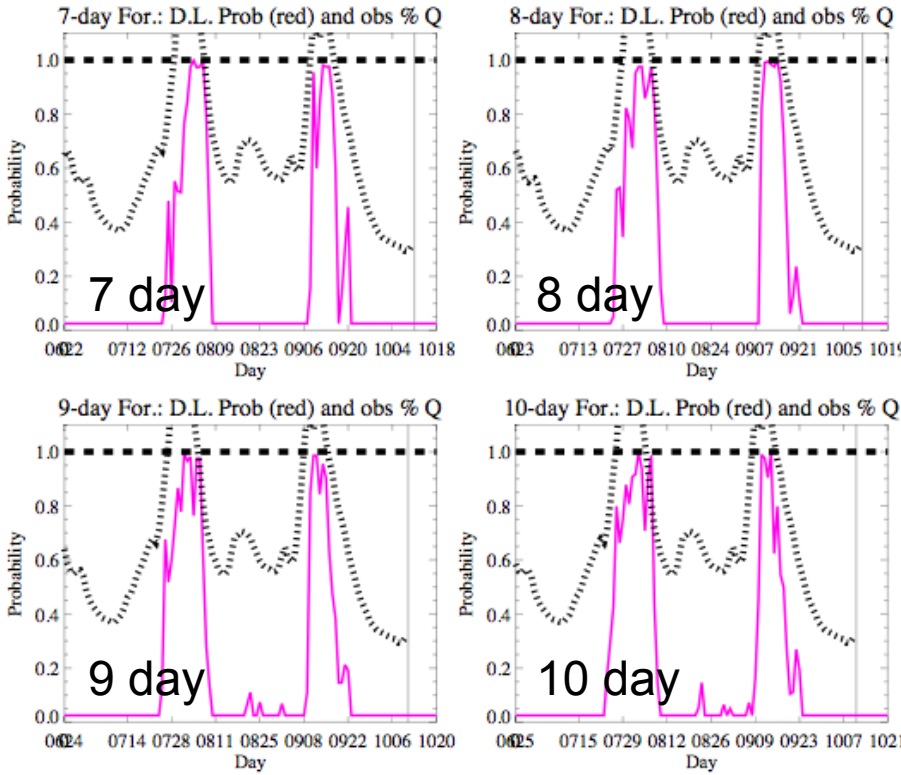


2007 Brahmaputra Ensemble Forecasts and Danger Level Probabilities

7-10 day Ensemble Forecasts



7-10 day Danger Levels



Skill Score Verification

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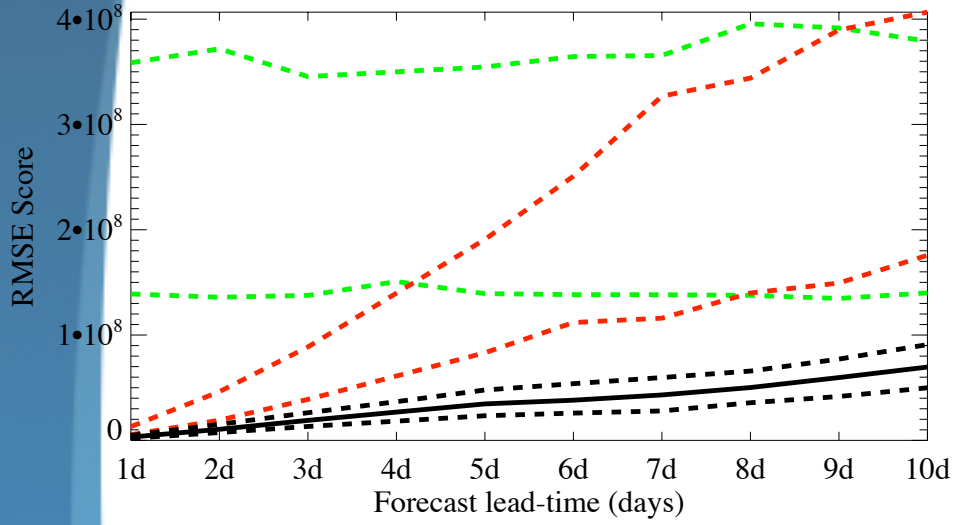
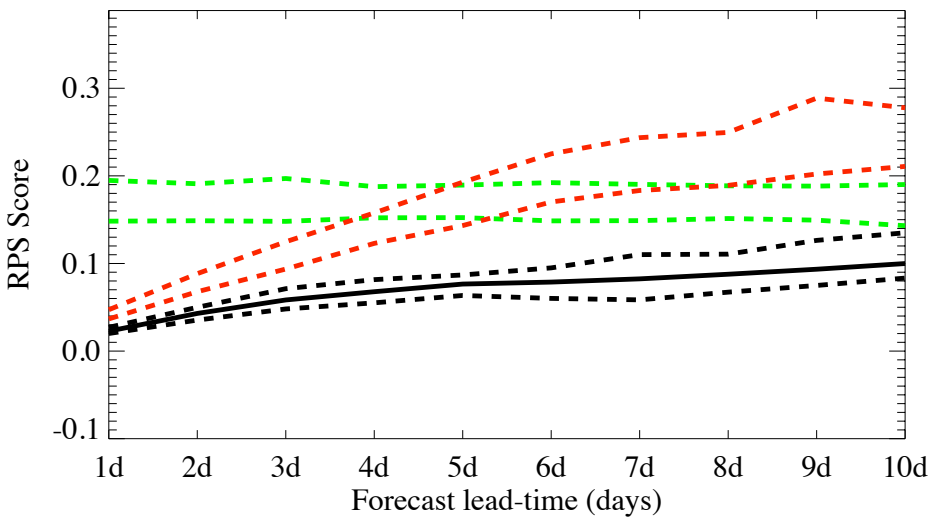
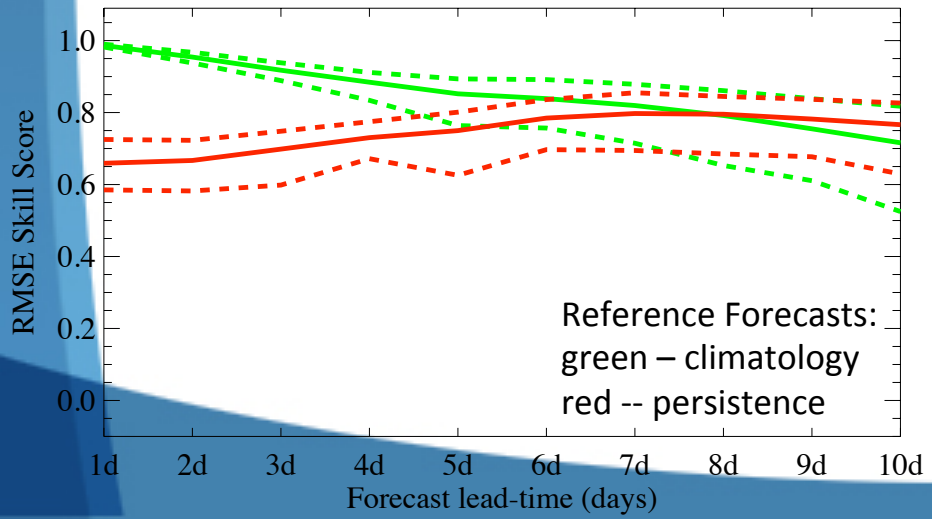
RMSE Score



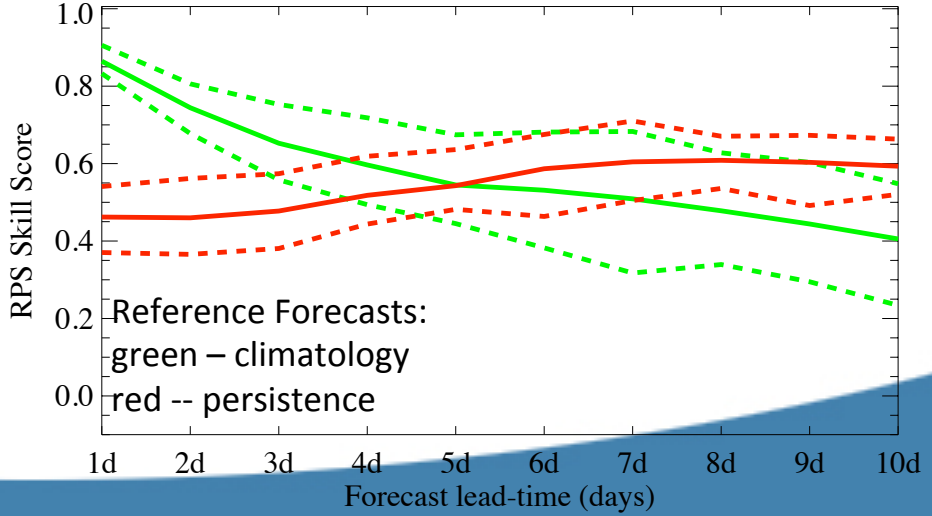
CRPS Score



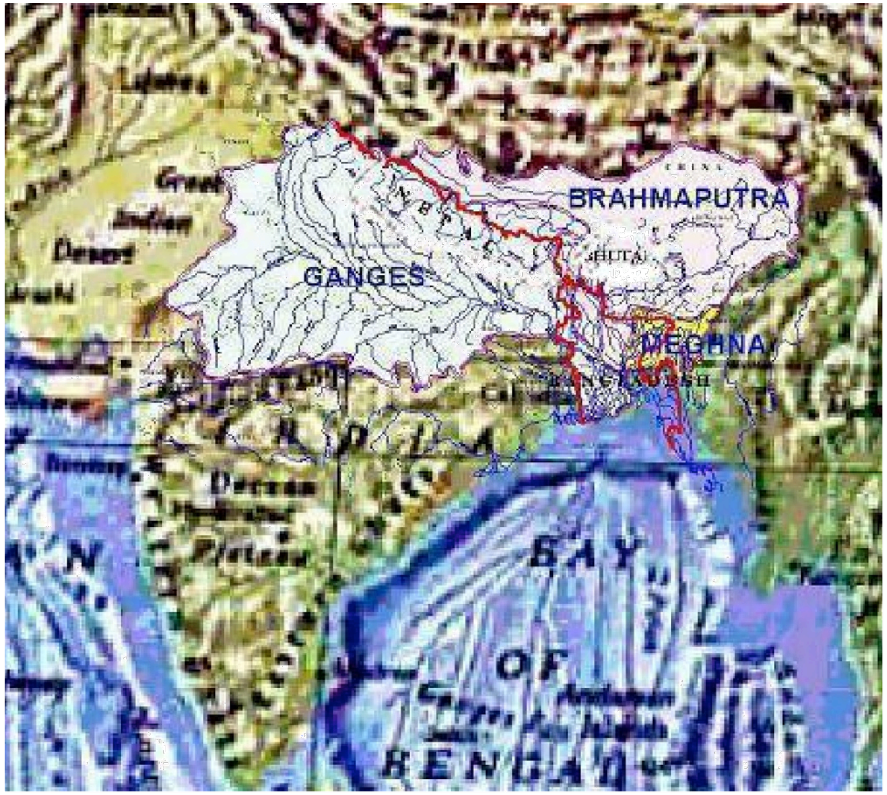
RMSE Skill Score



CRPS Skill Score



CFAB Project: Improve flood warning lead time



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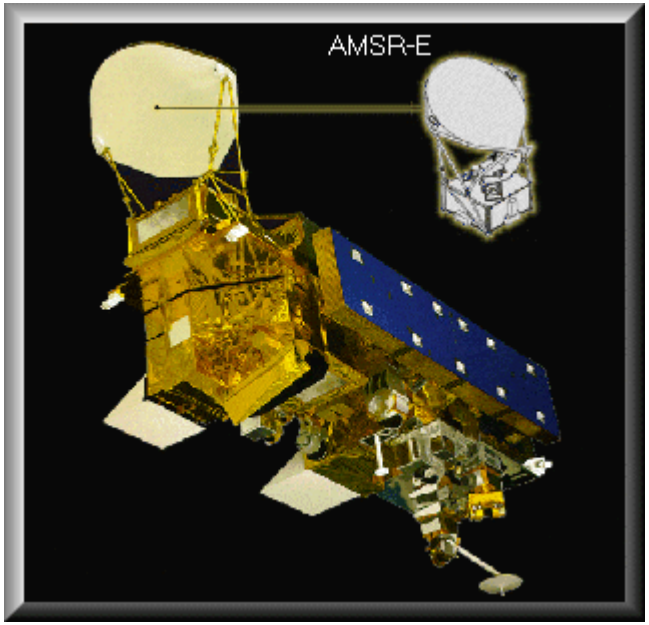
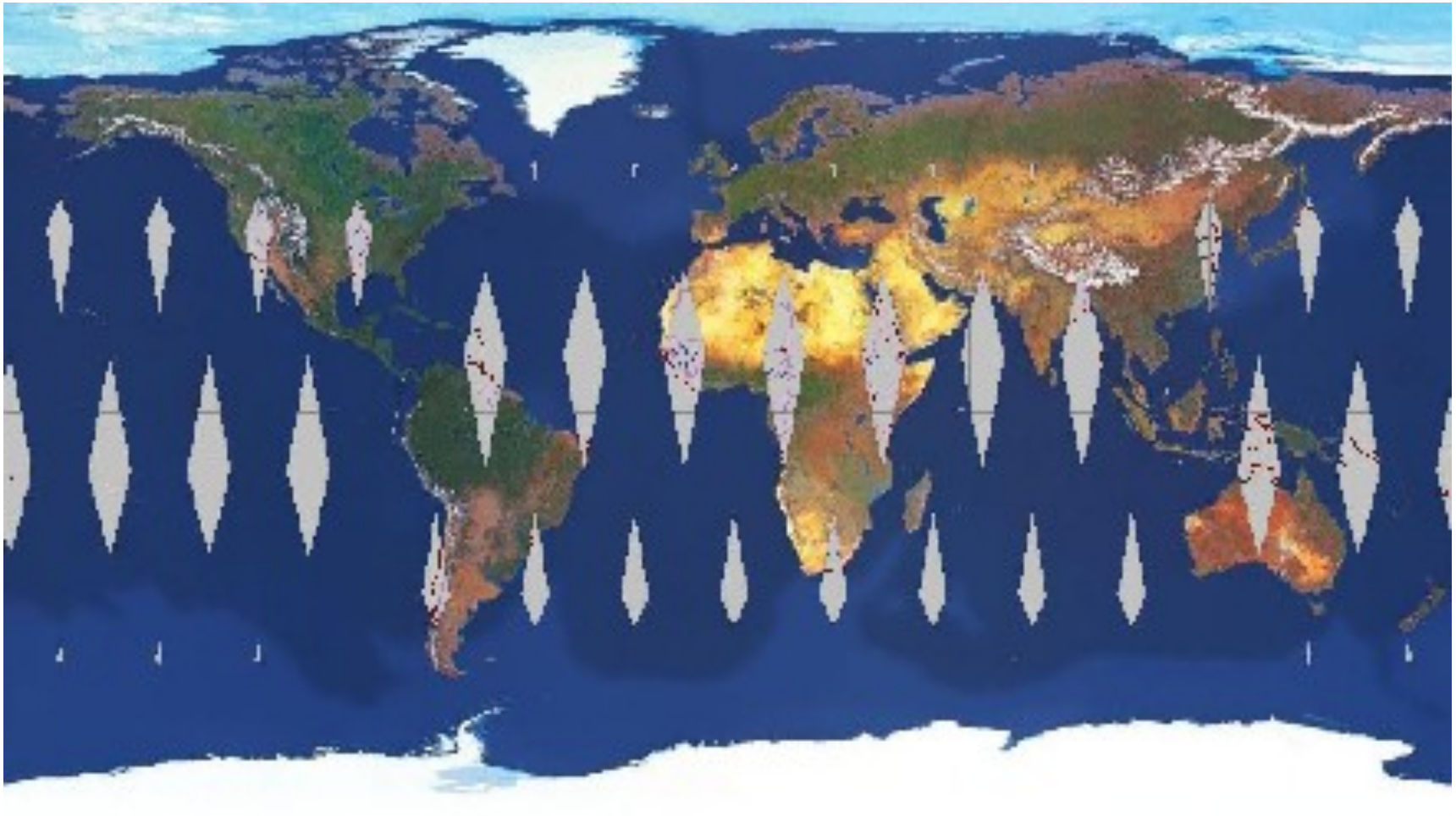
Objective Monitoring of River Stage and Flow: Satellite-based Passive Microwave Radiometer

-- Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) & NASA TRMM (Future: Global Precipitation Measurement System)
-- Utilizing 36-37Ghz (unaffected by cloud)
-- pixel size ~20km
-- ~2day complete global coverage (night-time brightness temperatures)
-- data range: 1997 to present



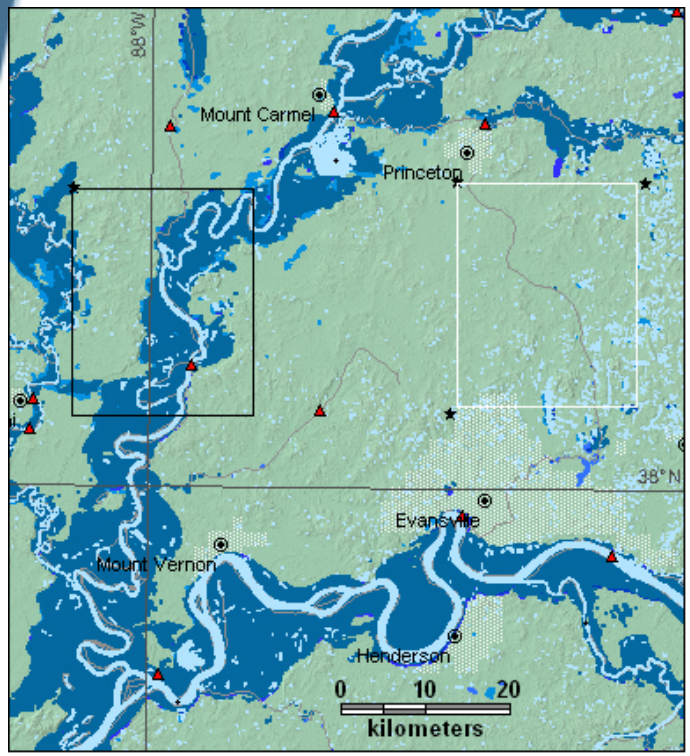
Other Approaches: satellite altimeter-derived water level (and discharge derived through rating curve):
e.g. Birkett, 1998; Alsdorf *et al.* 2000; Jung *et al*. 2010, Papa et al. 2010, Alsdorf *et al*. 2011, Biancamaria *et al.* 2011

One day of data collection
(high latitudes revisited most frequently)



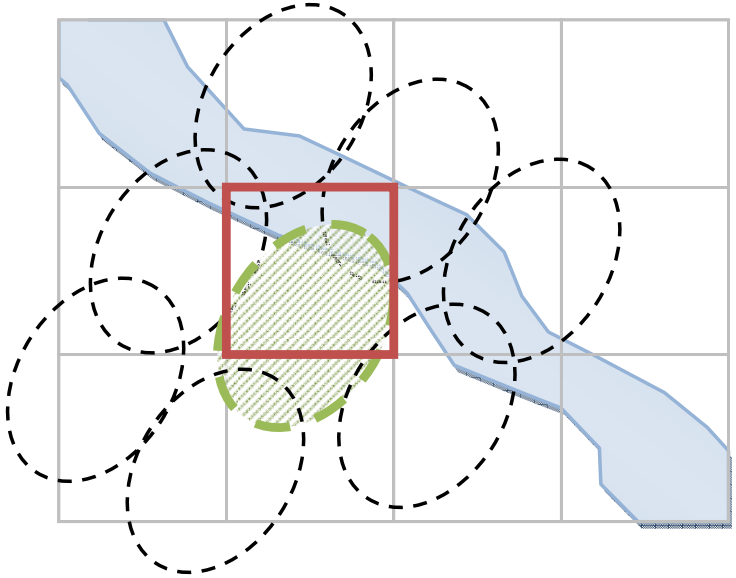
=> On average, global coverage 1-2 days

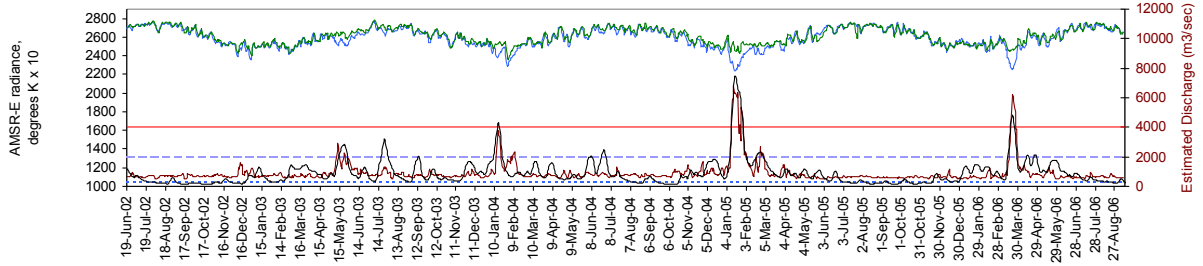
Example: Wabash River, Indiana, USA



Black square shows measurement pixel.
White square is calibration pixel.

GDACS, JRC
Gridded Approach



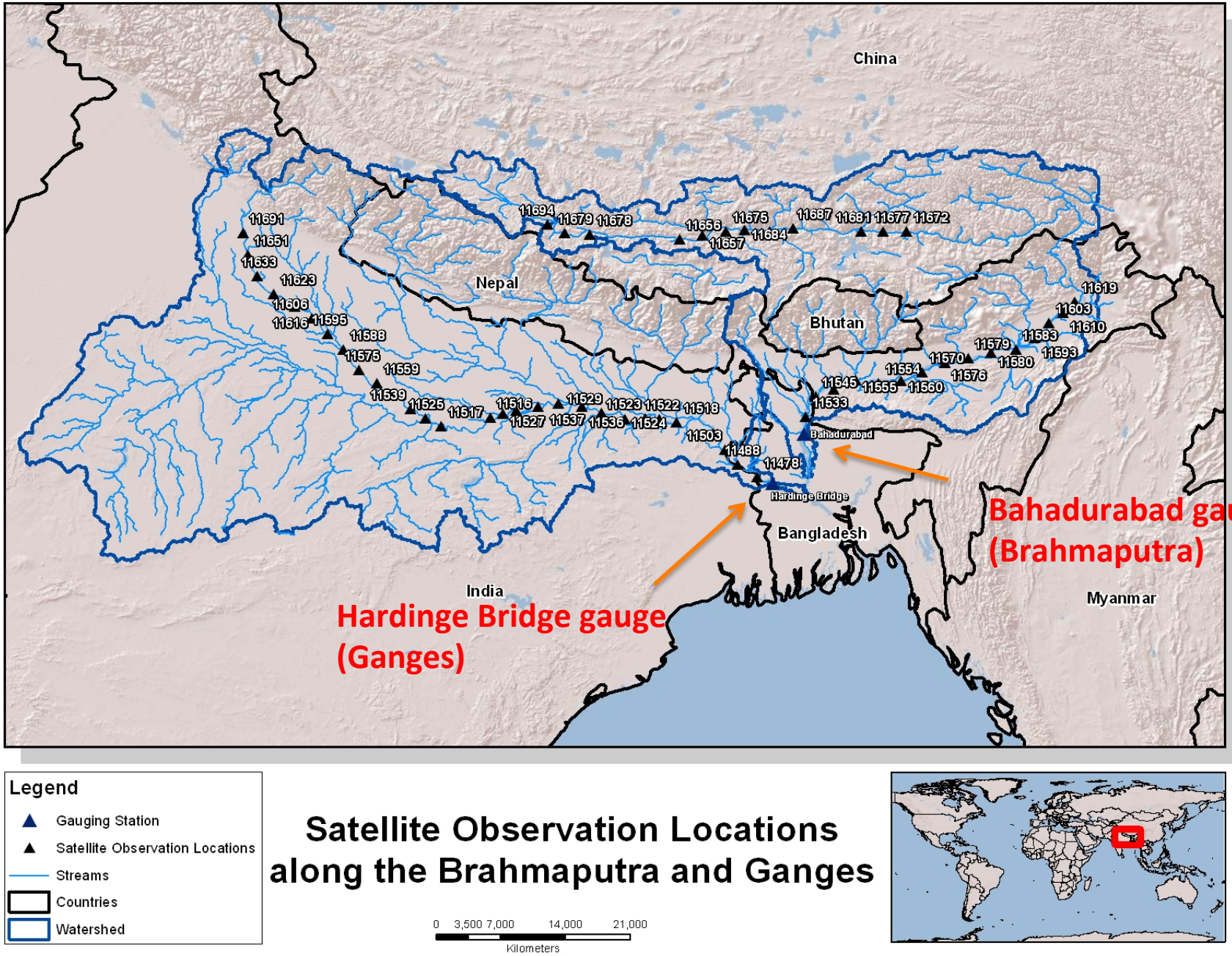


De Groeve, et al, 2009, 2010

=> Use "M/C" ratio

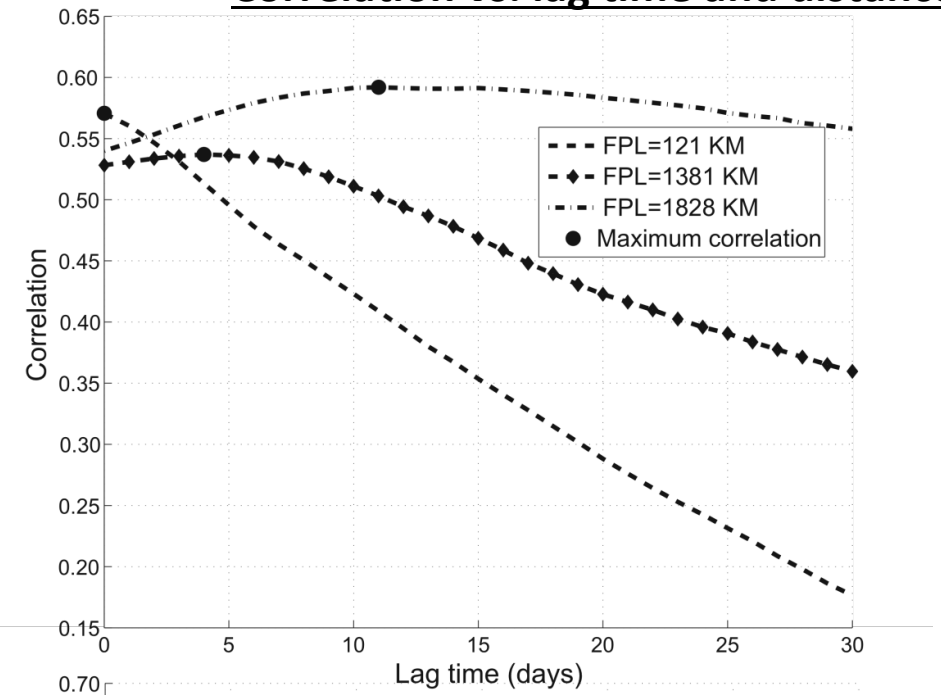
$$s = \frac{M}{C} = \frac{T_{b,measurement}}{T_{b,calibration}}$$

Brakenridge, et al, 1998, 2005, 2007

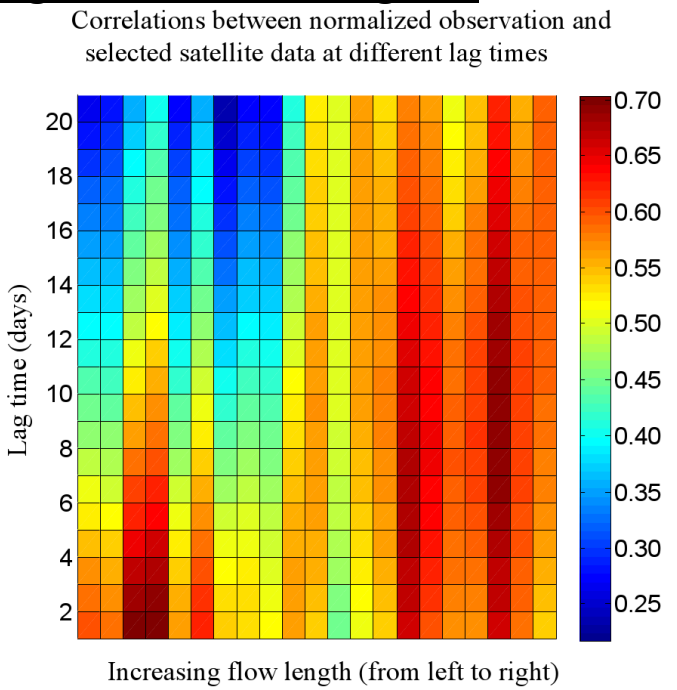


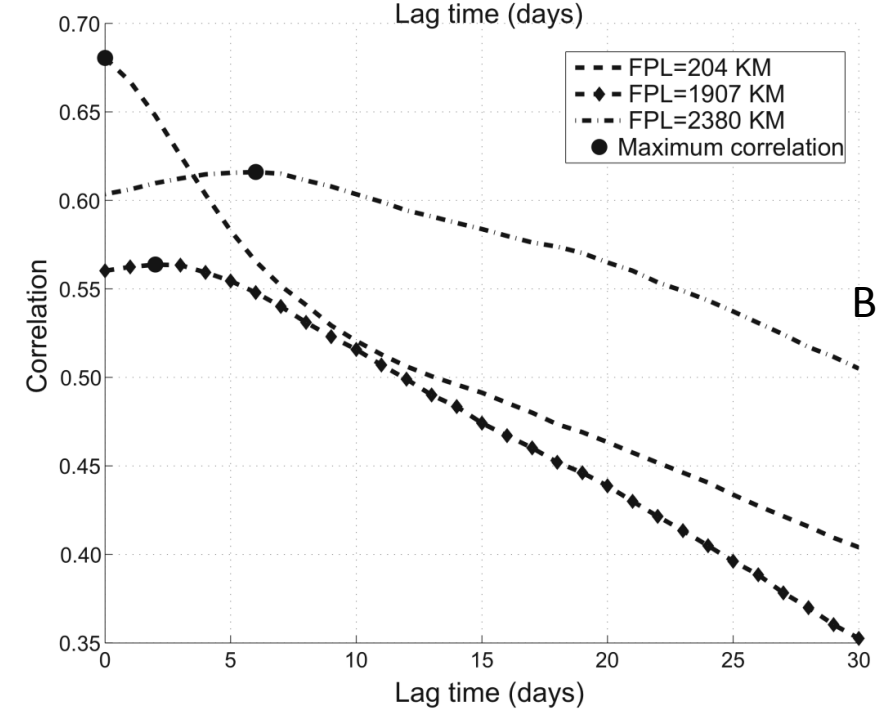
Hirpa et al. 2013

Correlation vs. lag time and distance between Gage Q & satellite signals

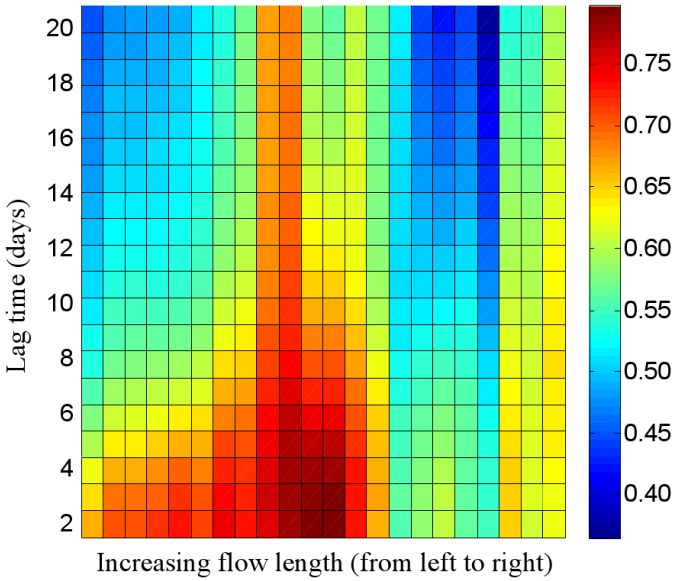


Ganges

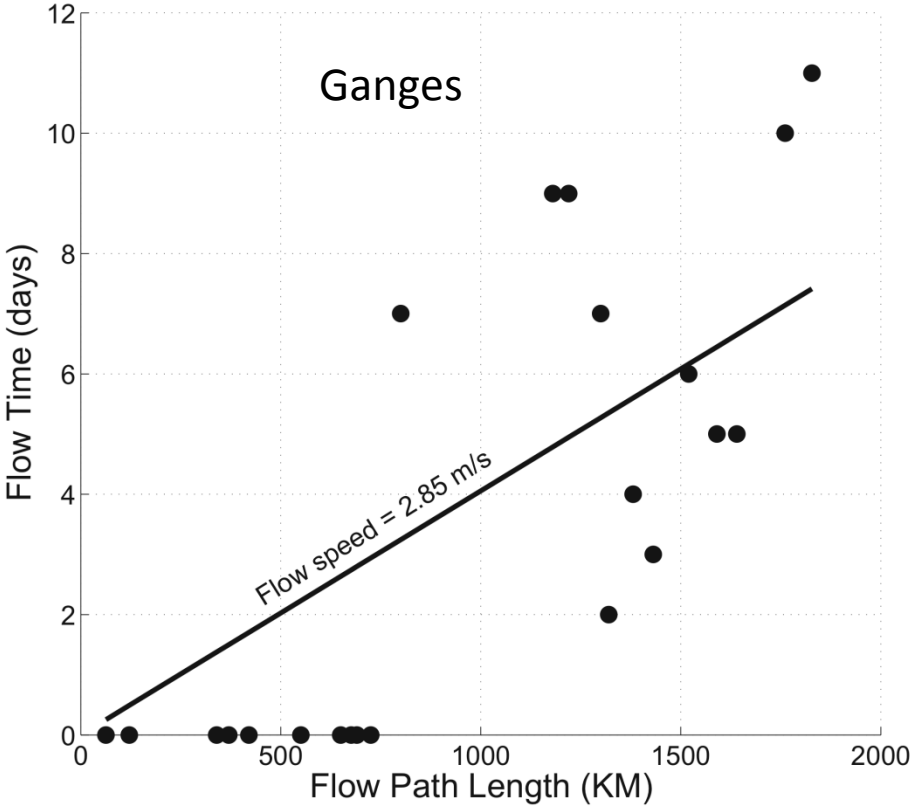


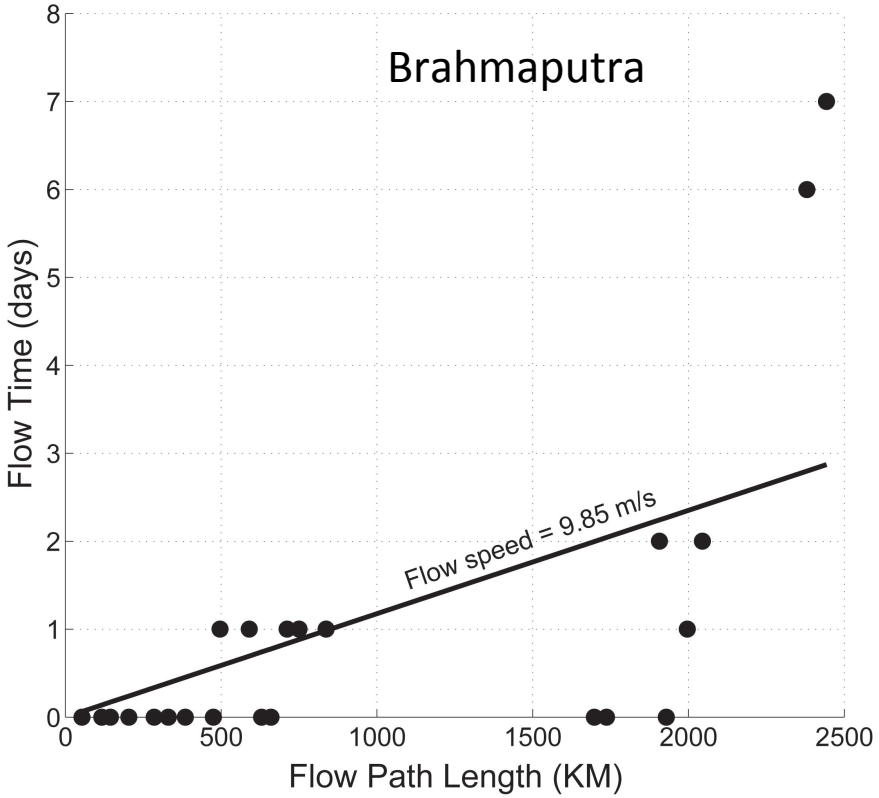


Brahmaputra



Estimating the kinematic wave celerity





Assumptions (large): hydraulic parameters homogenous; rainfall predominantly upper-catchment; wave speed variation with depth lower-order; dynamic wave effects lower-order (confirmed through rating curve analysis – not shown), etc.

Independent analysis: Kleitz-Seddon Law for kinematic wave celerity *c*: $c = \frac{1}{W}\frac{dQ}{dy}$

W channel top-width, *Q* discharge, *y* the river stage.

Brahmaputra at Bahadurabad: $4m/s < c < 8m/s$; Ganges at Hardinge Bridge: $2m/s < c < 6m/s$.

Generation of Nowcasts and Forecasts

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Regressor and model selection procedure:

i) Correlate all variables with gauged observations

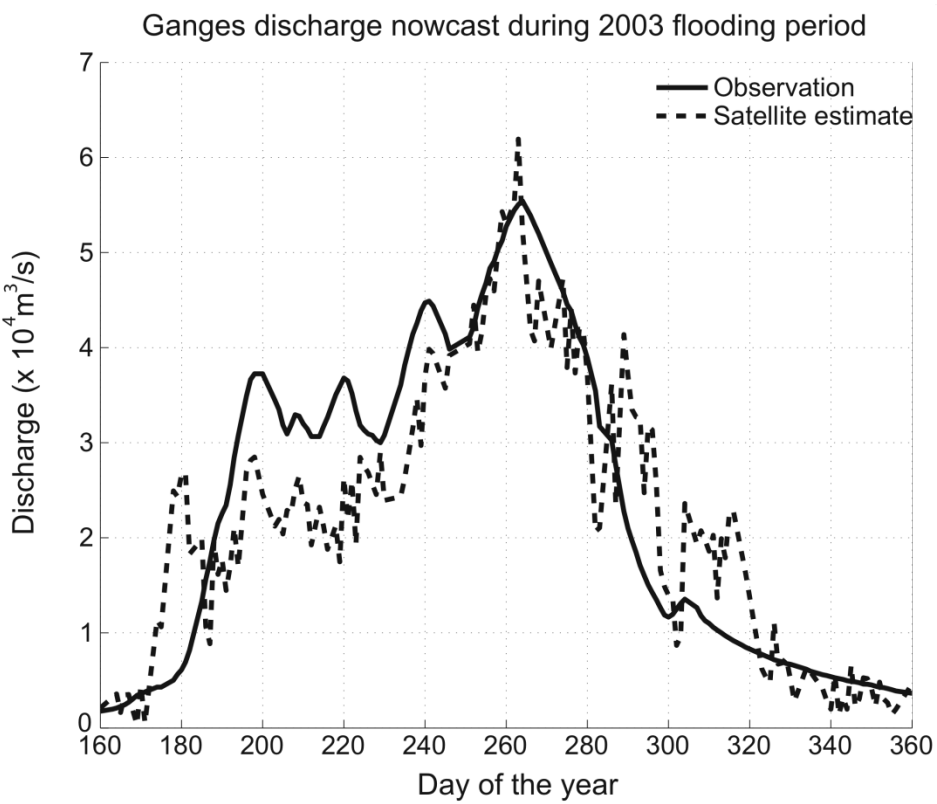
ii) Sort in decreasing level

iii) Select using step-wise forward-selection using K-fold cross-validation and RMSE cost function

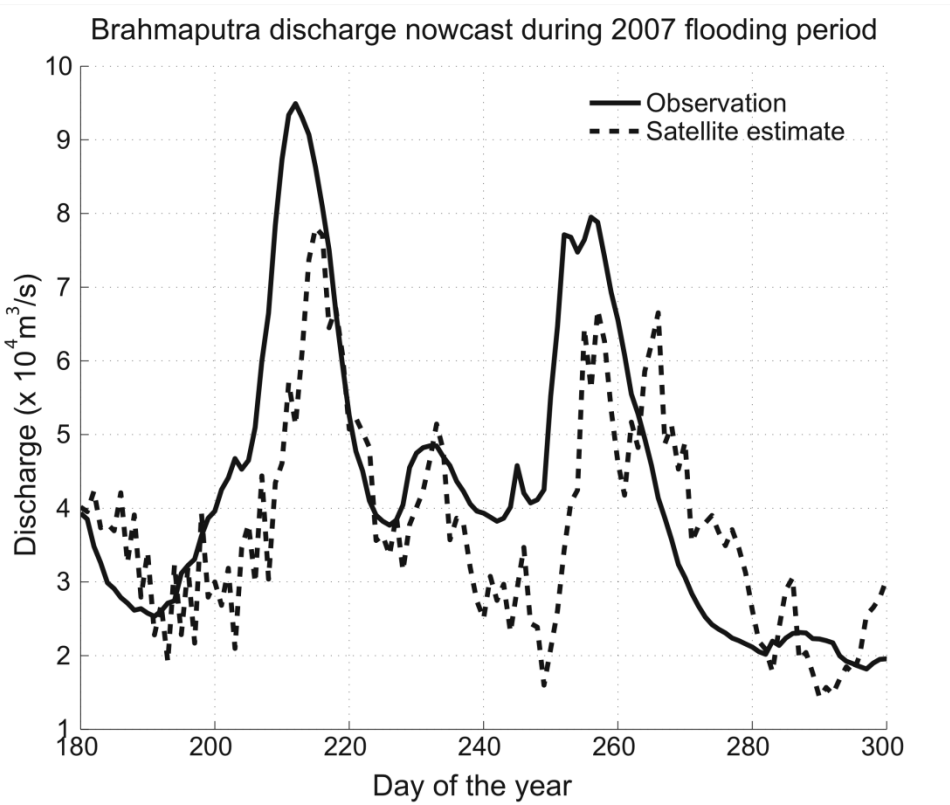
iv) Repeat ii) – iii) for all lead-times

Discharge estimation "Nowcasting"

Ganges 2003

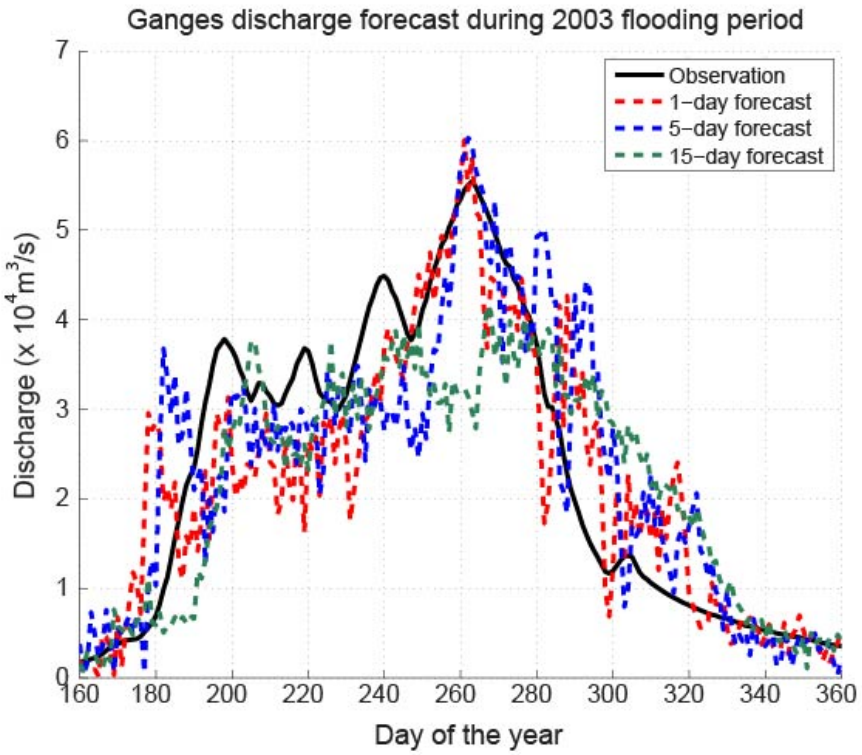


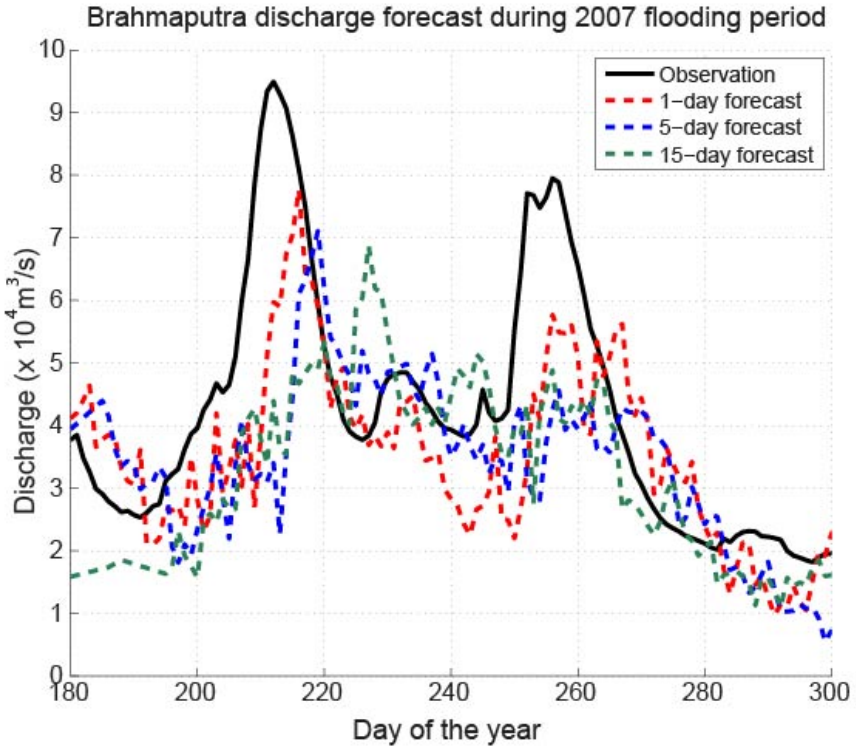
Brahmaputra 2007



Hirpa et al. 2013

1-, 5-, 15-day Forecasts





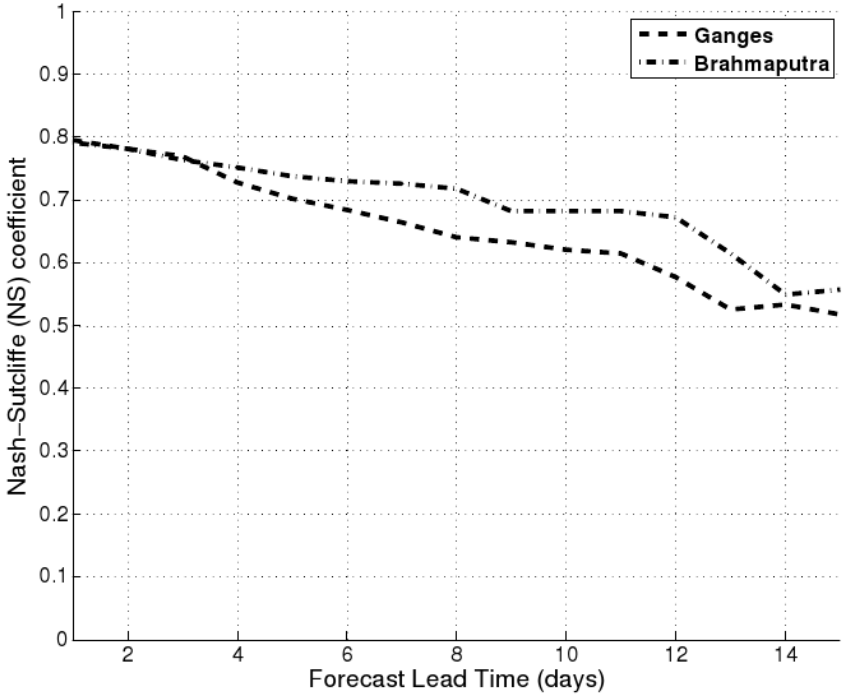
Hirpa et al. 2013

Skill Scores

$$SS = \frac{A_{forc} - A_{ref}}{A_{perf} - A_{ref}}$$

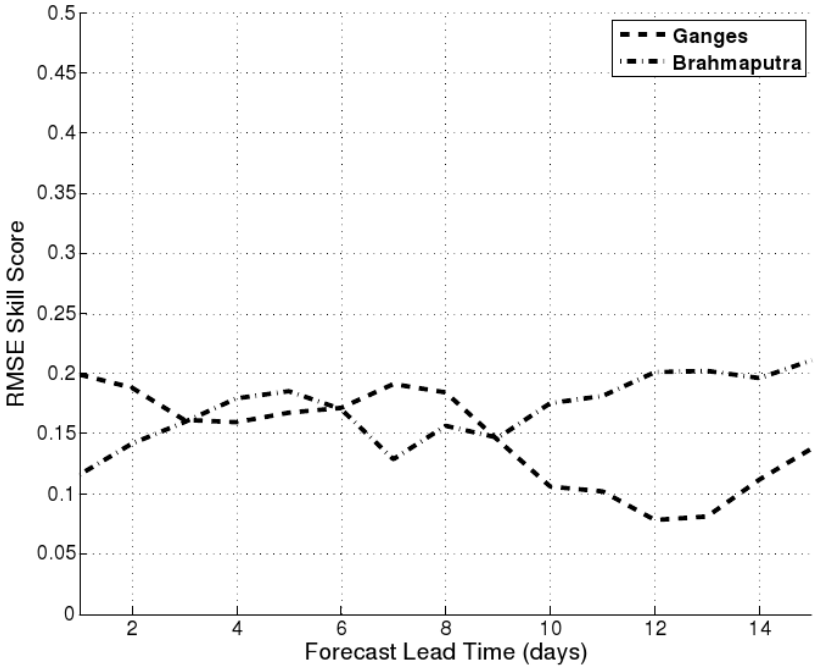
Nash-Sutcliffe efficiency
(fraction of variance explained):

-- 80% (1-day) to 55% (15-day) explained

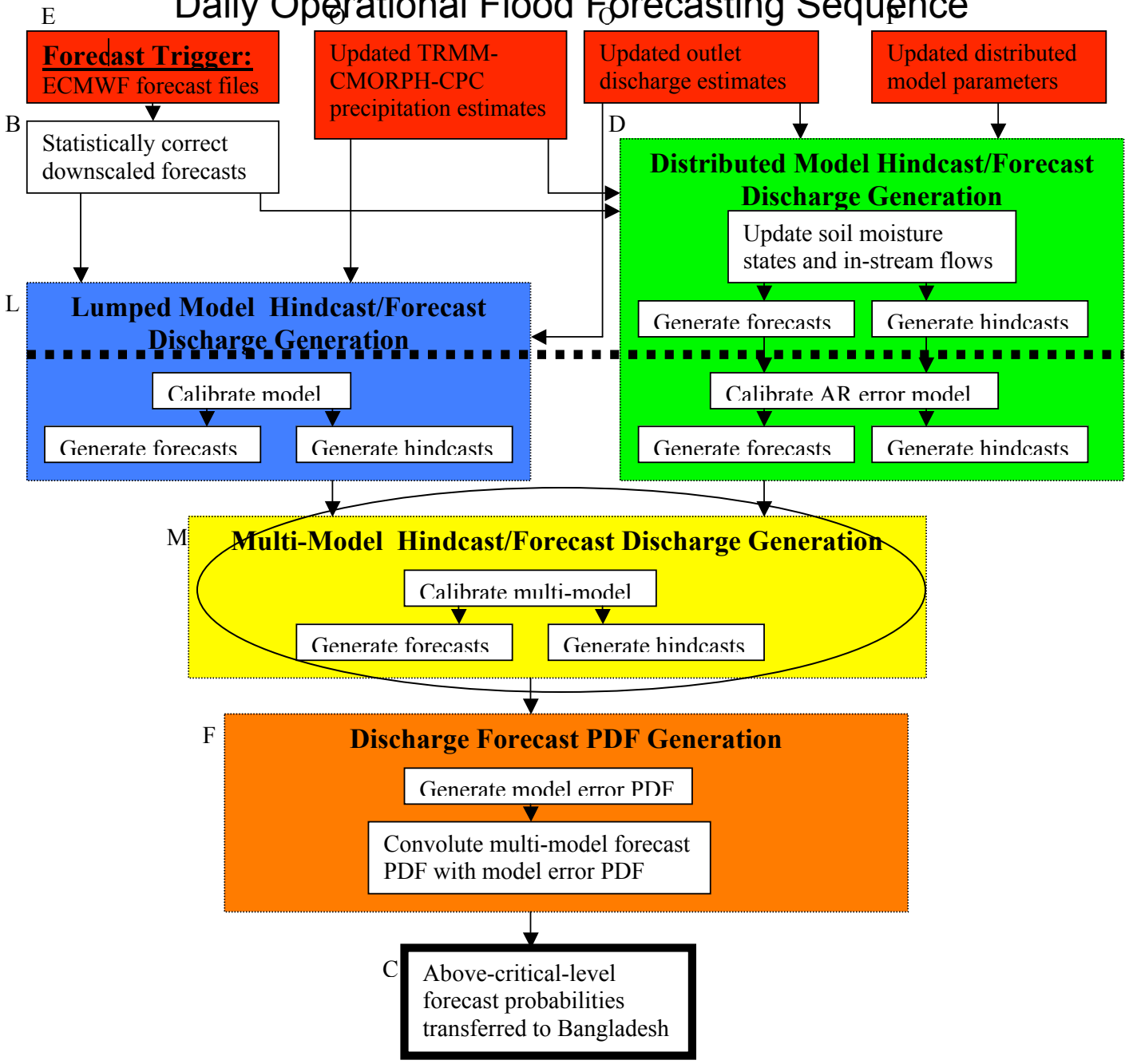


Now, generate a forecast including "persistence":

-- satellite information improves forecasts by 10-20% at all lead-times



Daily Operational Flood Forecasting Sequence



Discharge Multi-Model Forecast

Multi-Model-Ensemble Approach:

- Rank models based on historic residual error using current model calibration and "observed" precipitation

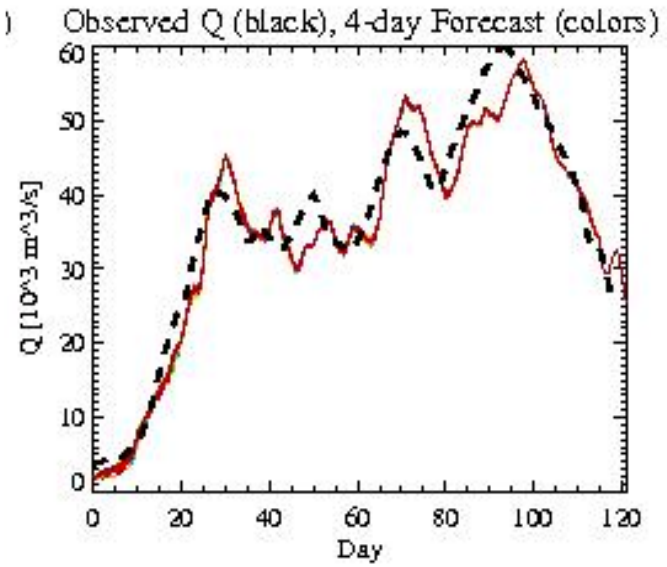
- Regress models' historic discharges to minimize historic residuals with observed discharge

- To avoid over-calibration, evaluate resultant residuals using Akaike Information Criteria (AIC)

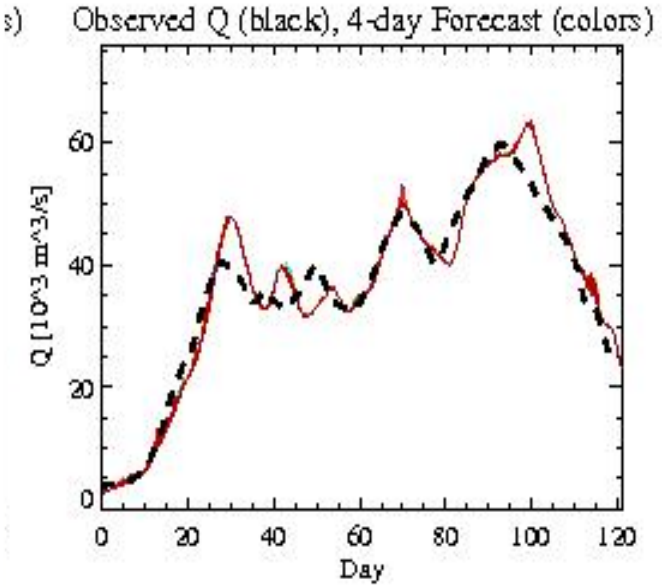
- If AIC minimized, use regression coefficients to generate "multi-model" forecast; otherwise use highest-ranked model => "win-win" situation!

2003 Model Comparisons for the Ganges (4-day lead-time)

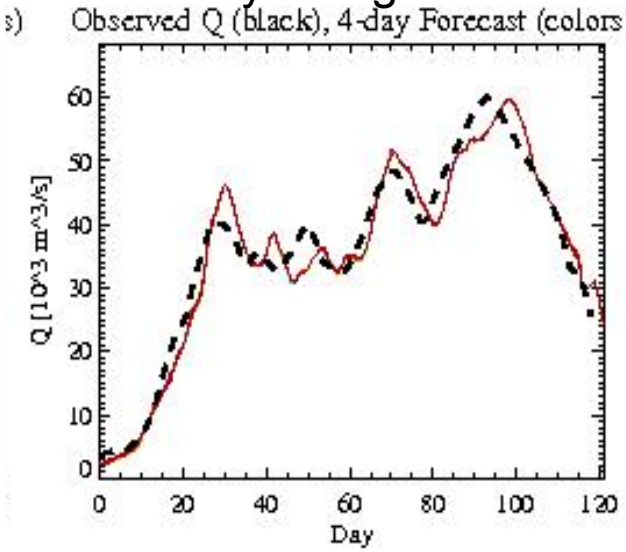
hydrologic lumped model



hydrologic distributed model



Resultant Hydrologic multi-model



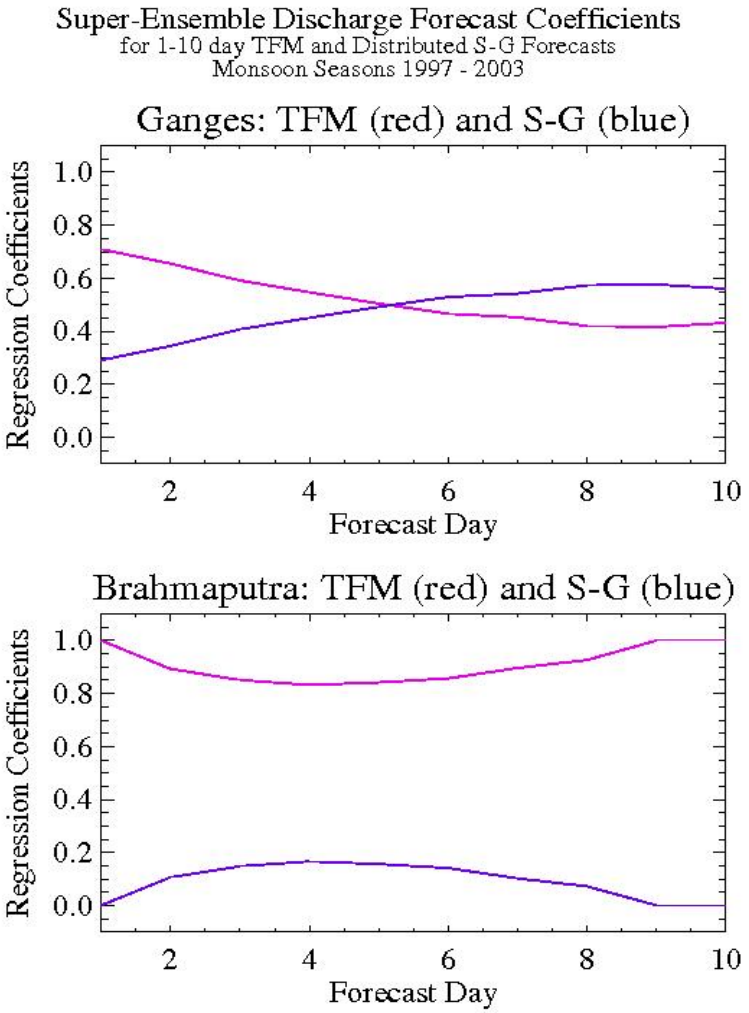
Multi-Model Forecast Regression Coefficients

- Lumped model (red)
- Distributed model (blue)

- Significant catchment variation
- Coefficients vary with the forecast lead-time
- Representative of the each basin's hydrology

-- Ganges slower time-scale response

-- Brahmaputra "flashier"



=> Same approach, but additional blending with DFO-JRC Forecasts

Data Blending and Assimilation

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- Forecast blending – multi-model approach
- Model calibration: Parameter estimation in "ungauged" catchments
- Data assimilation: Updates to hydrologic model states
- Transform forecast discharge (flood peak discharge) into inundation extent maps

Transforming discharge into inundation maps

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DFO Archived History of Inundation

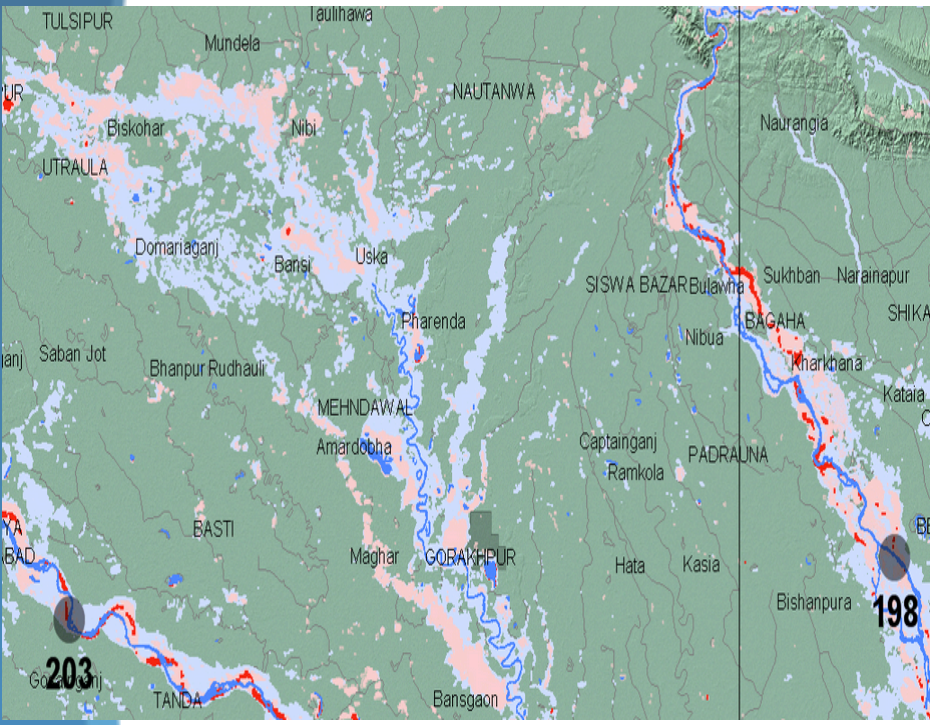


Figure 6. The DFO record of flooding in this portion of the Ganges Basin is shown as light blue (2000 to 20111), light red was flooding in the 10 days prior to map update date, and red was current flooding. The numbers indicate River Watch discharge measurement sites. This is a small subscene of the complete Surface Water Record display for this region.

DFO Archived History of Inundation

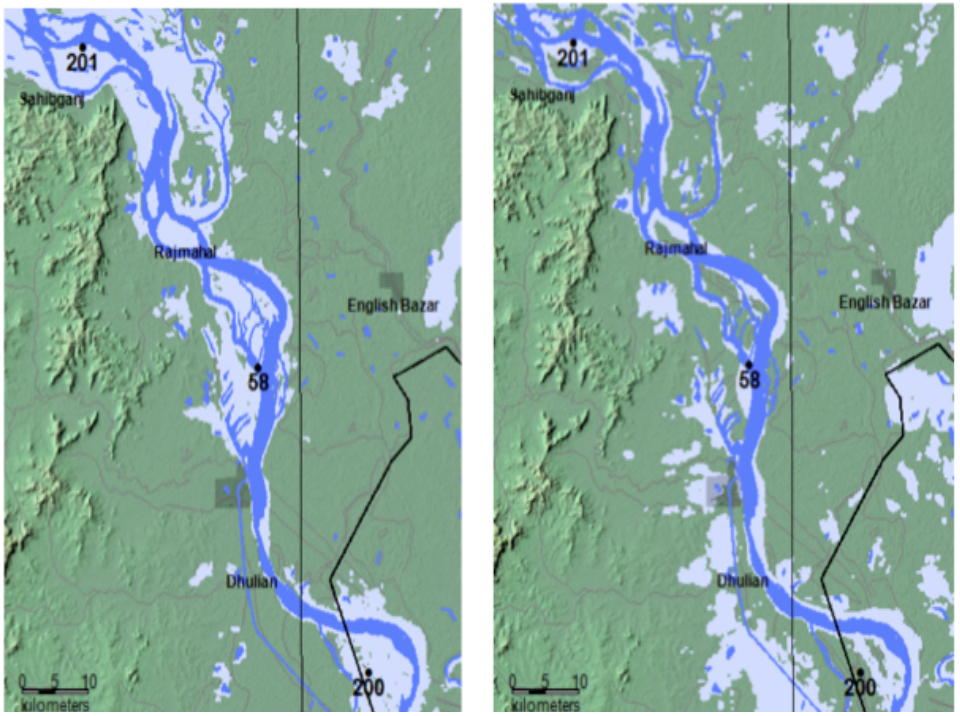


Figure 7. Left: MODIS imaging and mapping of 2003 flooding along the Ganges River between river measurement sites 200 and 201. At site 200 (uncalibrated) peak discharge was 8500 m3/sec.

Right: mapping of 2004 flooding. The uncalibrated peak discharge here is only ~3500 m3/sec.

Approach:

- Predicted model flow compared with historic model flow
- Corresponding hindcast dates used to extract imagery

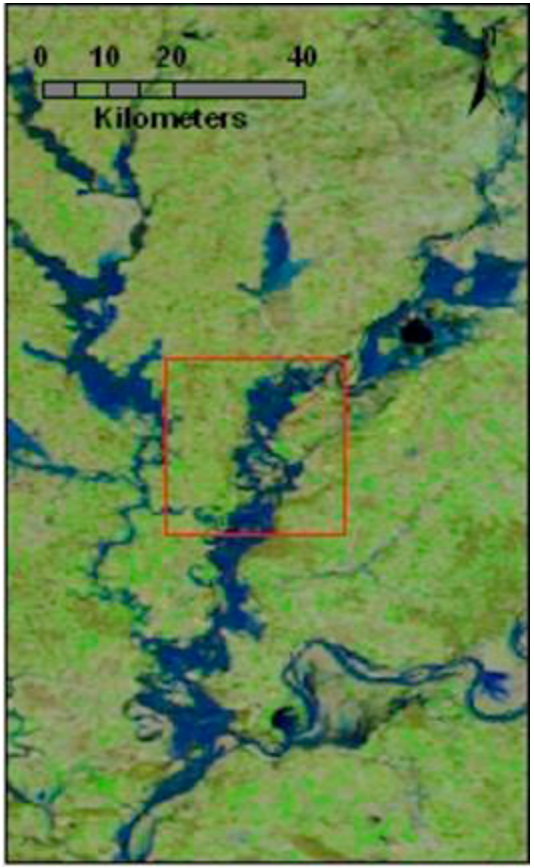
Thank You!

References:
Hopson and Webster 2010, *JHM*
Hirpa et al. 2013, *RSE*
Contact: hopson@ucar.edu

MODIS sequence of 2006 Winter Flooding

2/24/2006 C/M: 1.004

3/15/2006 C/M: 1.029



3/22/2006 C/M: 1.095

Site 98, Wabash River at New Harmony, Indiana, USA