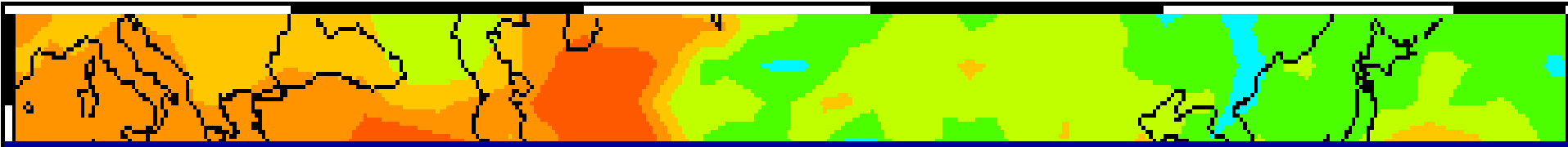


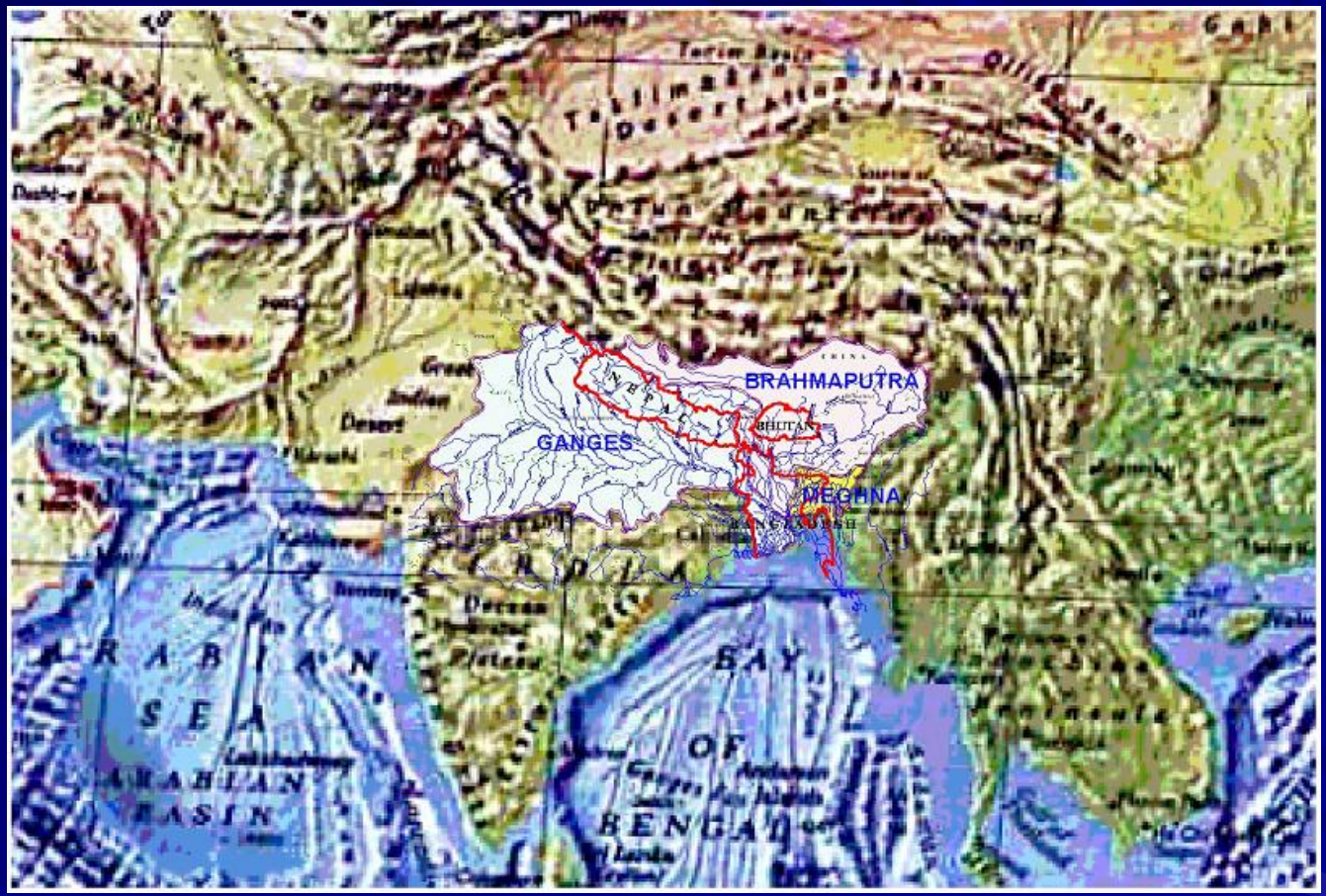
Operational Short-Term Flood Forecasting for Bangladesh:

Application of ECMWF Ensemble Precipitation Forecasts

Tom Hopson Peter Webster

Climate Forecast Applications for Bangladesh (CFAB):
USAID/CU/GT/ADPC/ECMWF

The Climate Forecast Applications Project CFAB



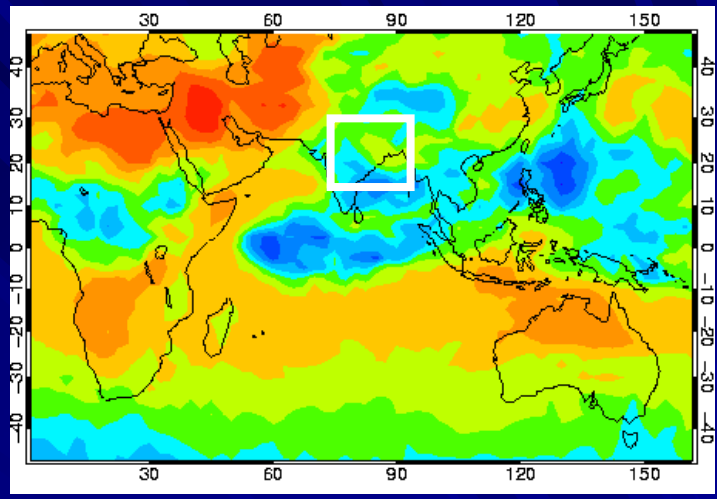
- Bangladesh at confluence of Brahmaputra and Ganges Rivers
- Limited warning of upstream river discharges

CFAB's GOAL: Provide operational upper catchment flood-stage discharge and precipitation forecasts at differing time-scales

=> Utilize good quality daily border discharge measurements

Overview:

Short-term flood forecasting



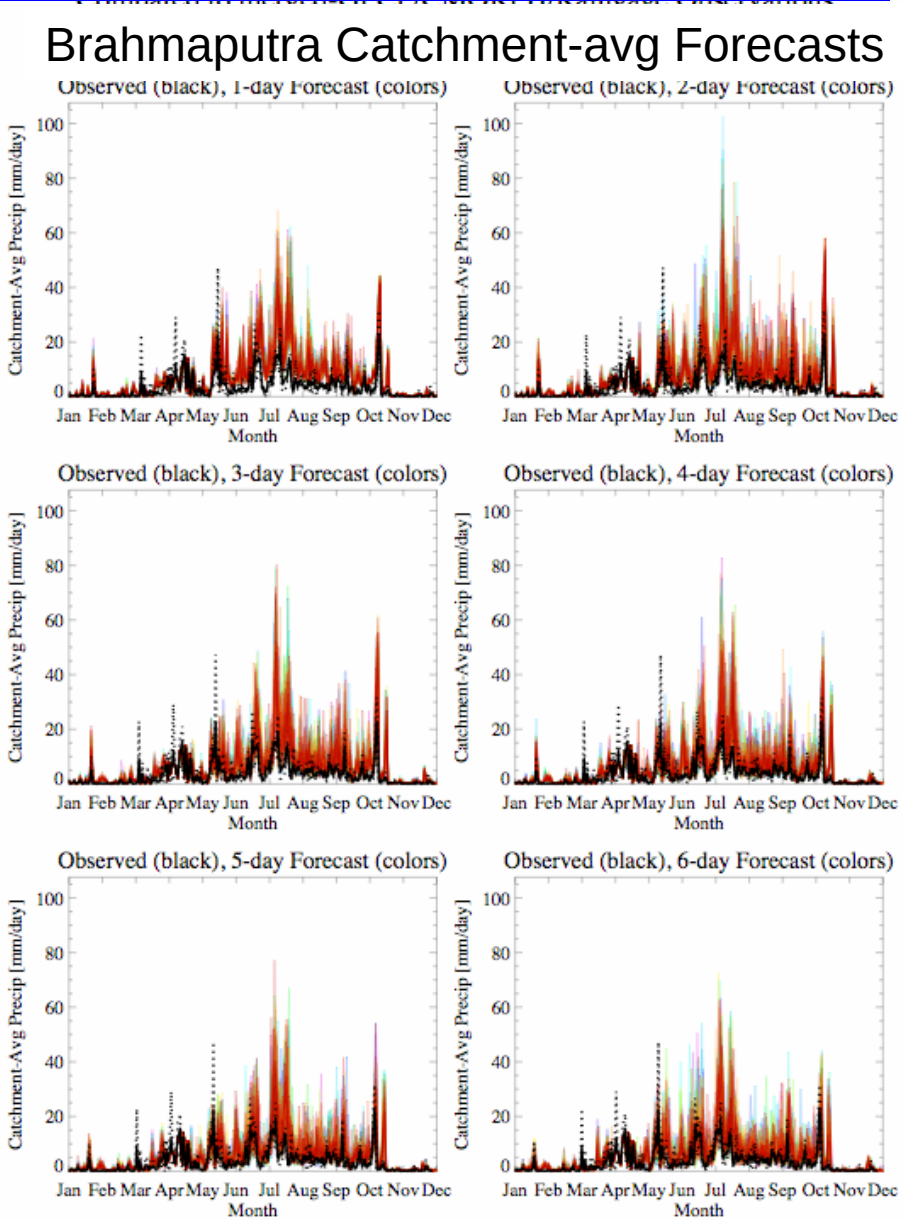
1. Operational ECMWF ensemble precipitation forecast adjustments

2. Multi-Model Ensemble Discharge Forecasting: Combining Catchment-averaged and Distributed Modeling Techniques

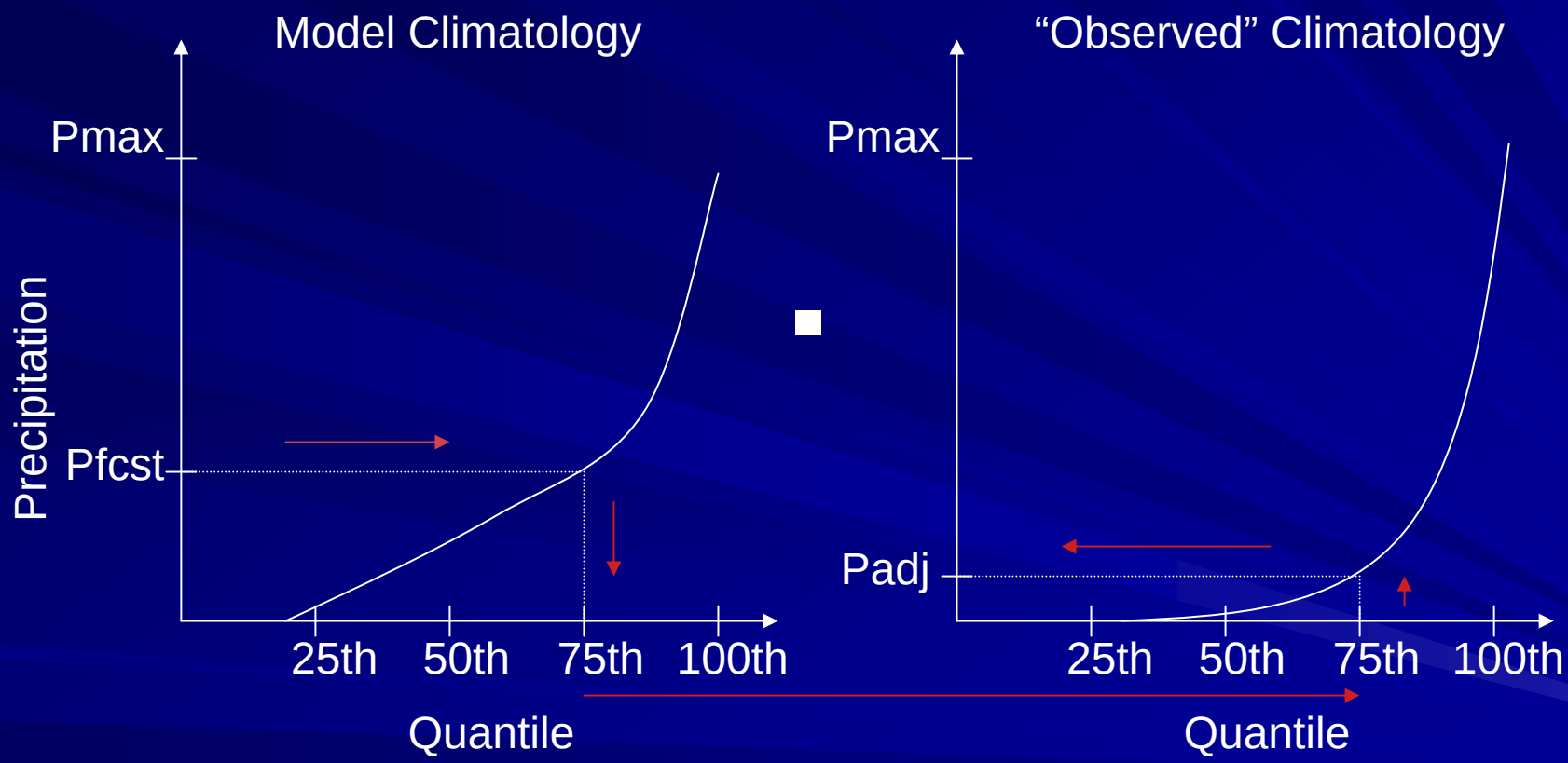
2. “Dressing” Precipitation-derived Discharge Ensembles with Model Error Estimates: “Truer” Discharge Probabilities

ECMWF Ensemble Precipitation Forecast Adjustments -- mapping forecasts from "model-" to "observational-"space

- Hydrology model initial conditions driven by near-real-time GPCP / CMORPH / Raingage precipitation
- Ideally, observations would be statistically "just another ensemble member"
- Approach: calculate historical NWP-climatology PDF and observation-climatology PDF for each grid using a "kernel" method
- For each forecast ensemble, determine its quantile in model-space and extract equivalent quantile in observation-space

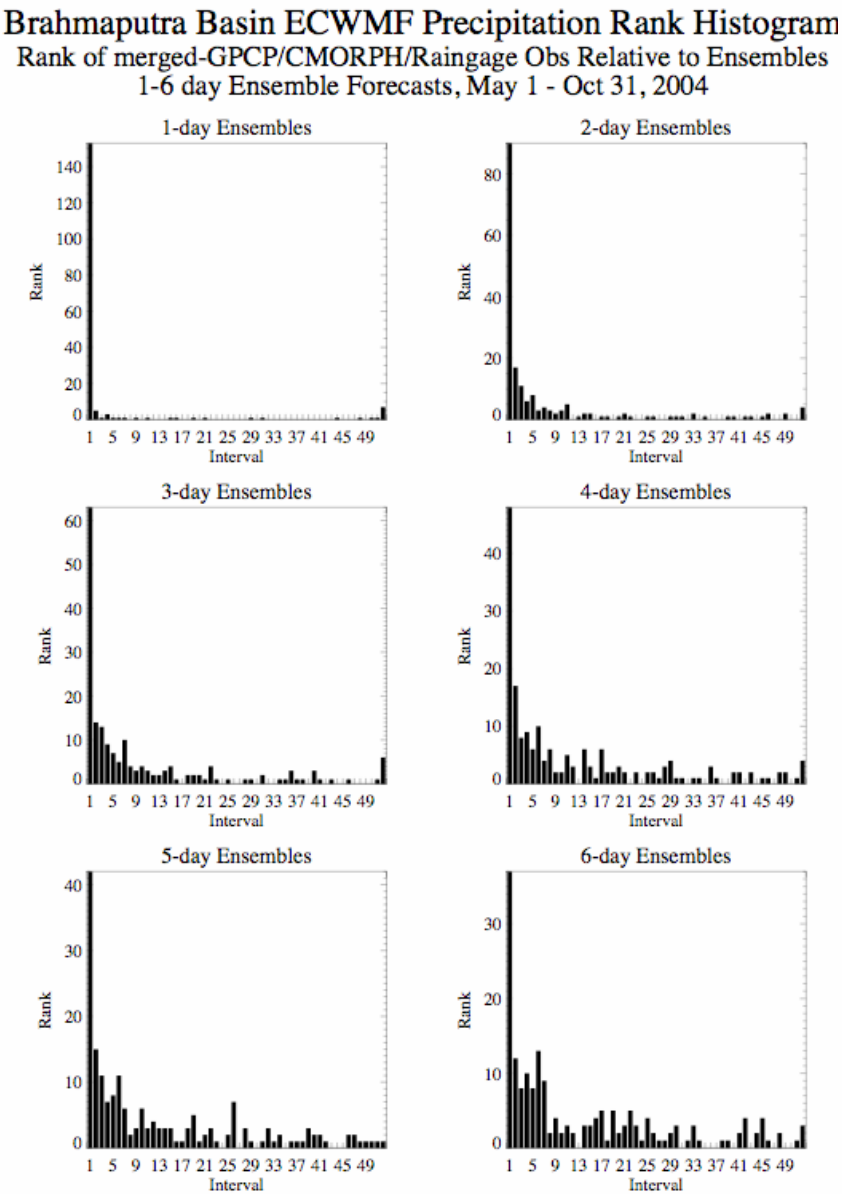


Quantile to Quantile Mapping

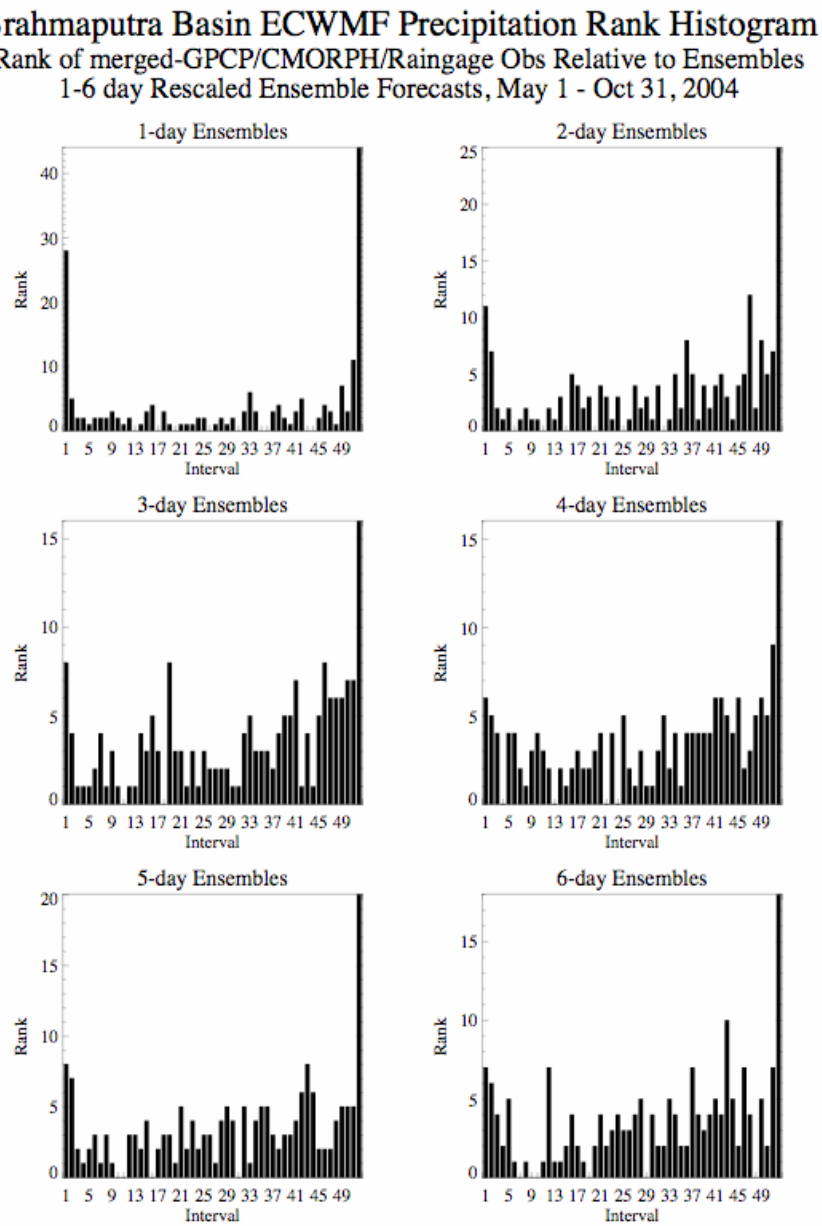


Rank Histogram Comparisons

Original

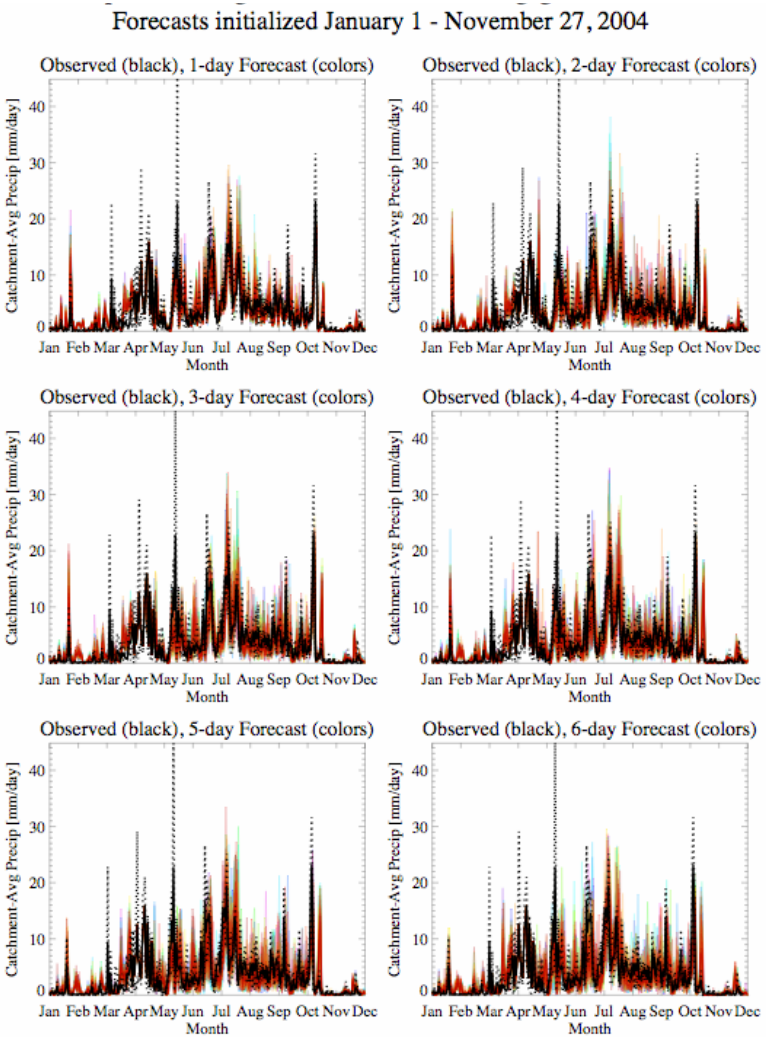


Adjusted



ECMWF Ensemble Precipitation Forecast Adjustments -- mapping forecasts from "model-" to "observational-"space

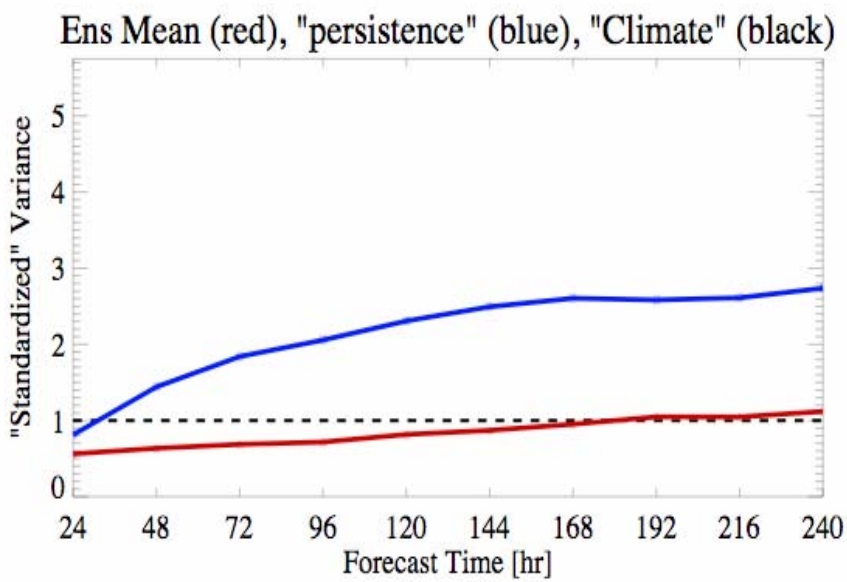
Brahmaputra Adjusted Forecasts



- Benefits:
- --Gridded "realistic" forecast values
--spatial- and temporal covariances preserved

- Drawbacks:
--limited sample set for model-space PDF (2 yrs)
--rank histograms show "under-variance"

Mean-Square-Error of the Ensemble-Mean shows skill out to 7-8 days



Discharge Multi-Model-Ensemble

Krishnamurti (2001): combining (via regression) multiple NWP model outputs significantly improves weather forecasts => apply to 2 discharge models to generate 'multi-model-ensemble' discharge forecasts

Data-Based Modeling (Beven, 2002)

-- Linear Store / Linear Transfer Function Approach.

- Benefits: recalibrate to specific conditions => ;
  maximizes data-assimilation (discharge measurements)
- Drawbacks: basin lumped model; limited slow time-scale response

Distributed Model (Sacramento Model derivative)

-- Subcatchment gridded 2 soil-layer model

- Benefits: ET/soil-storage/water-balance explicitly modeled locally
- Drawbacks: Model recalibration and data-assimilation inflexible

Discharge Multi-Model Forecast

Multi-Model-Ensemble Approach:

• Rank models based on historic residual error using current model calibration and “observed” precipitation

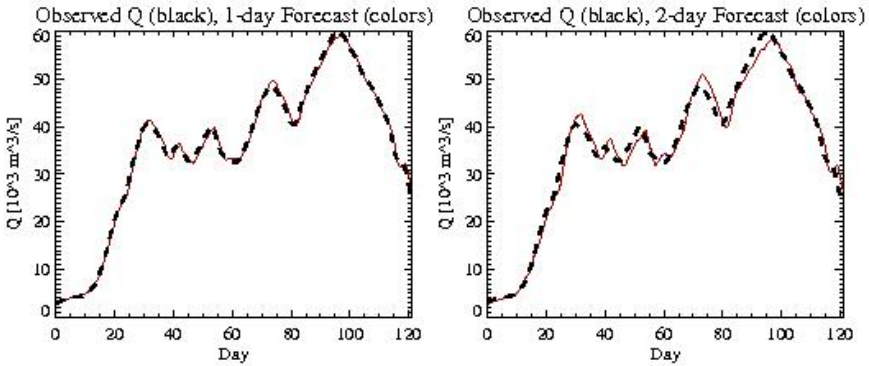
•Regress models’ historic discharges to minimize historic residuals with observed discharge

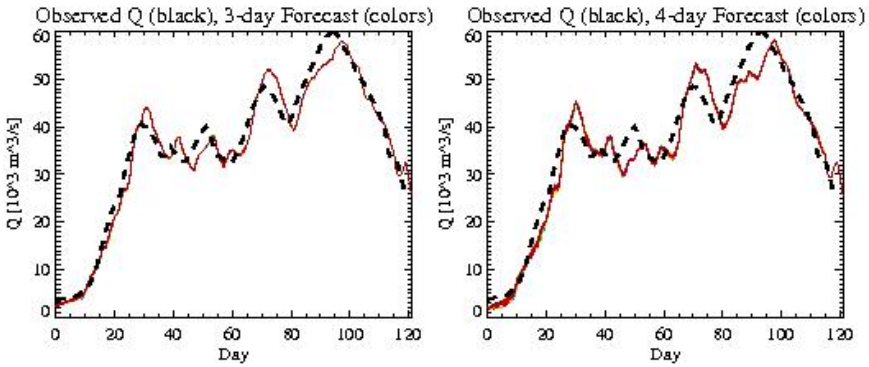
•To avoid over-calibration, evaluate resultant residuals using Akaike Information Criteria (AIC)

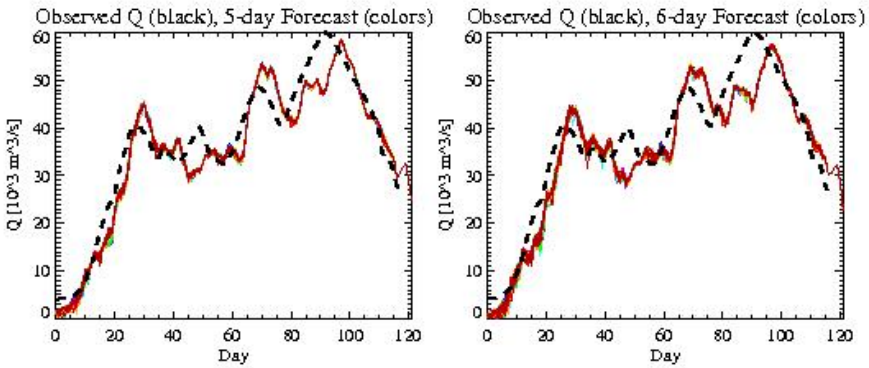
•If AIC minimized, use regression coefficients to generate “multi-model” forecast; otherwise use highest-ranked model => “win-win” situation!

Model Comparisons for the Ganges

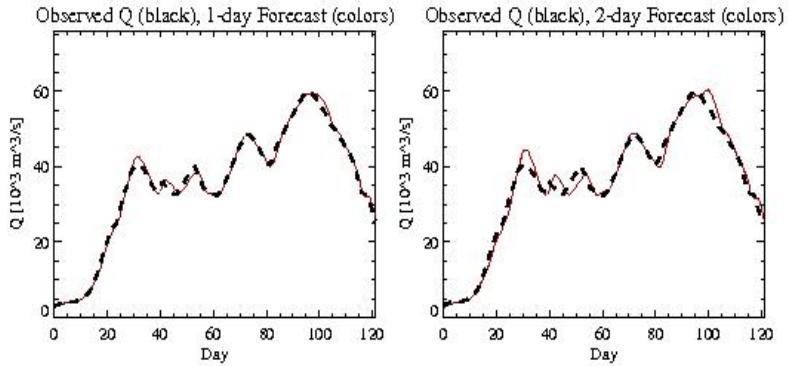
TFM Ganges Discharge Forecasts
1-6 day using ECMWF Precipitation Forecasts
June 15 - October 15, 2003

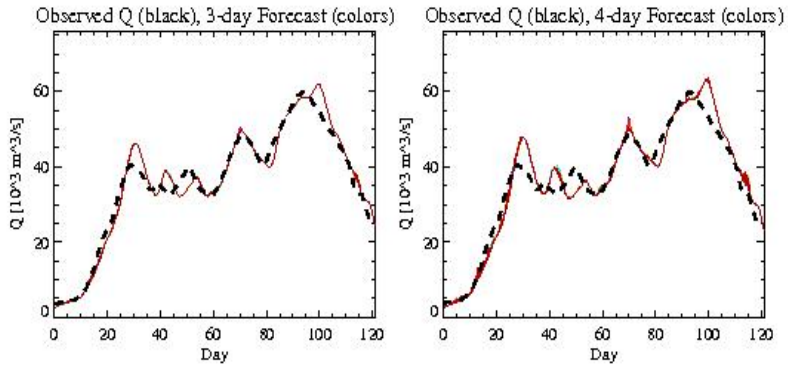


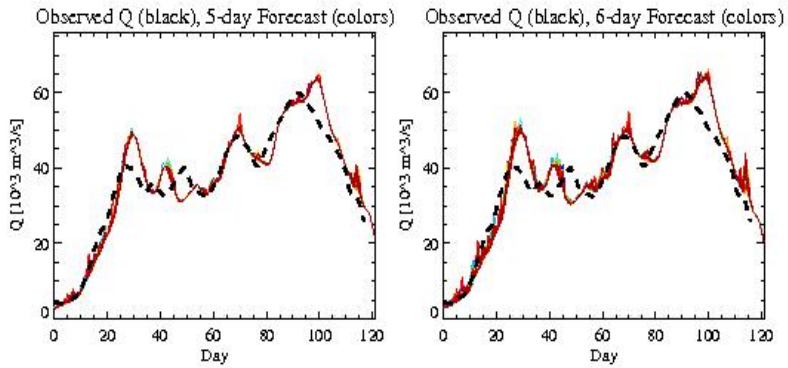




Distributed S-G Ganges Discharge Forecasts
1-6 day using ECMWF Precipitation Forecasts
June 15 - October 15, 2003







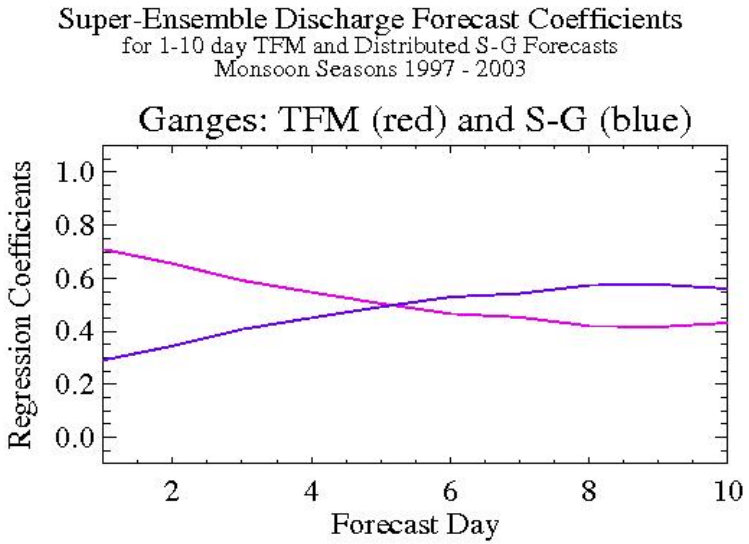
Multi-Model Ensemble Regression Coefficients

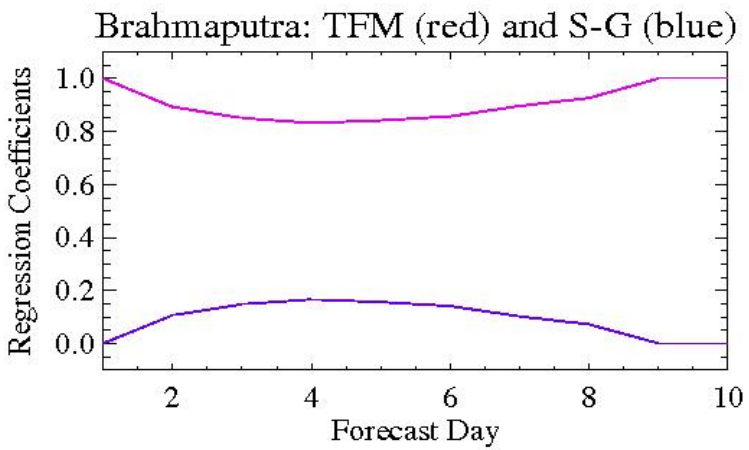
- Lumped model (red)
- Distributed Model (blue)

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

-- Ganges slower time-scale response

-- Brahmaputra "flashier"



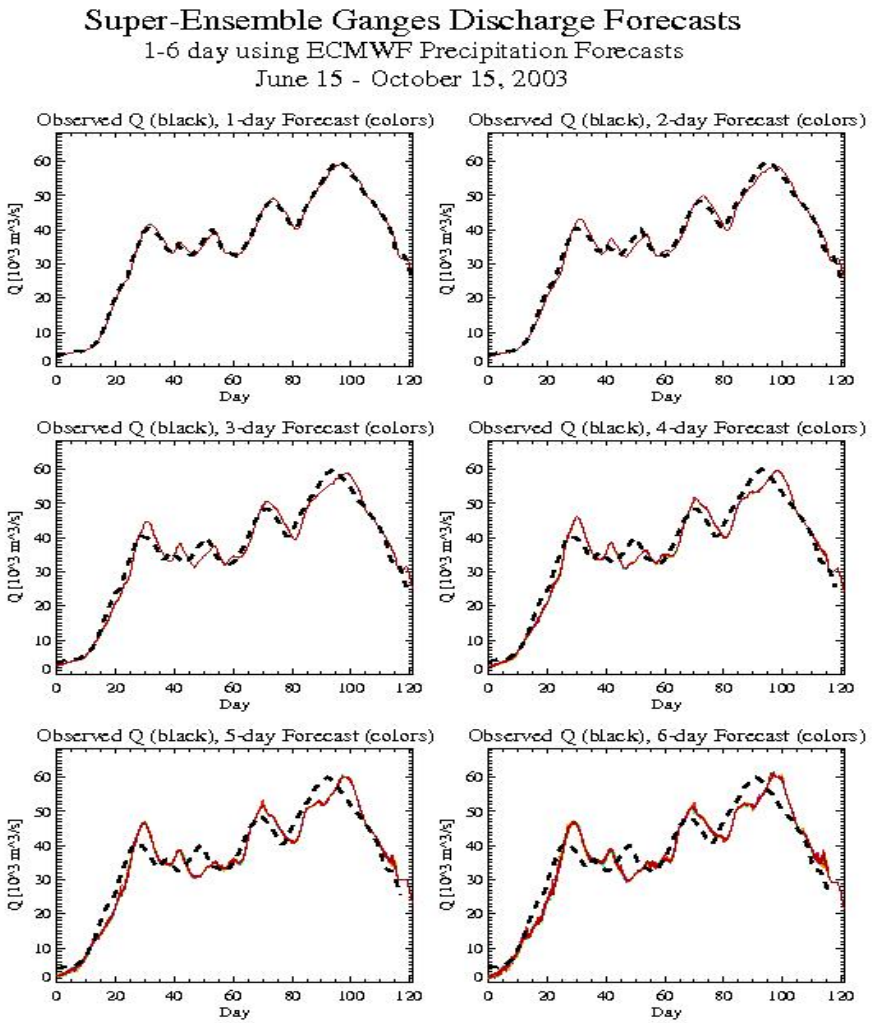


Super-Ensemble Discharge Forecast Coefficients
for 1-10 day TFM and Distributed S-G Forecasts
Monsoon Seasons 1997 - 2003

Multi-Model Ensemble Forecasts

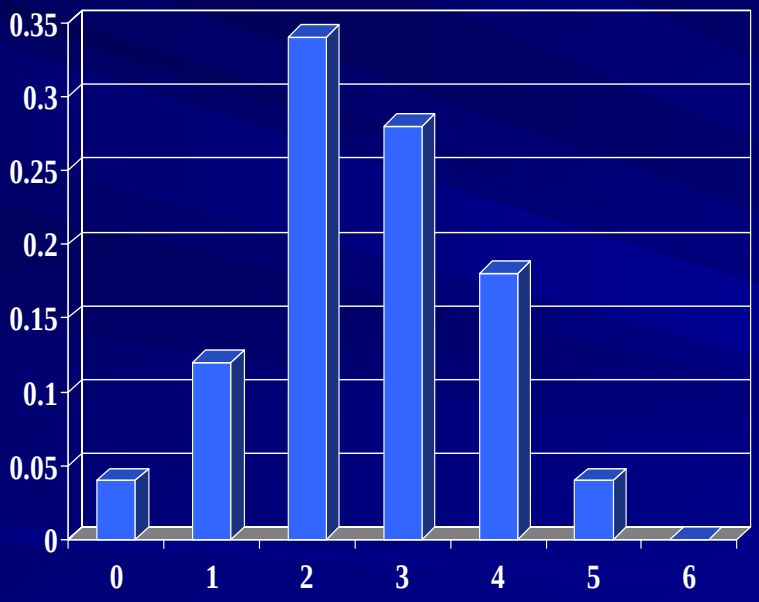
Results:
--show improvements
--compromise between timing (distributed) with amplitude (lumped)
=> use of different error measure in selection process

Future:
-- structure allows incorporating other models
-- KNN technique to select based on current precipitation/discharge conditions

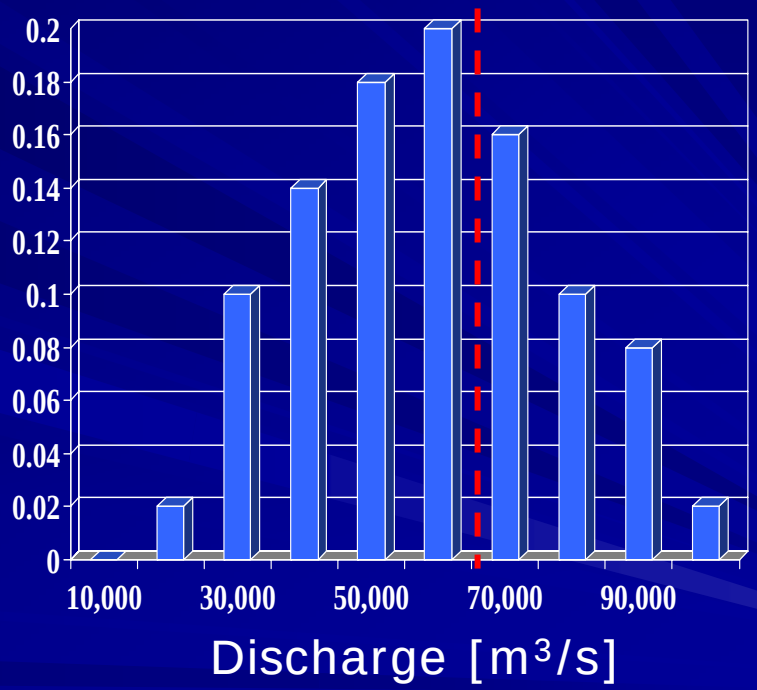


Combining Precipitation (Ensemble) Probability with Model Error: Forecasting "Truer" Discharge Probabilities

Rainfall Probability

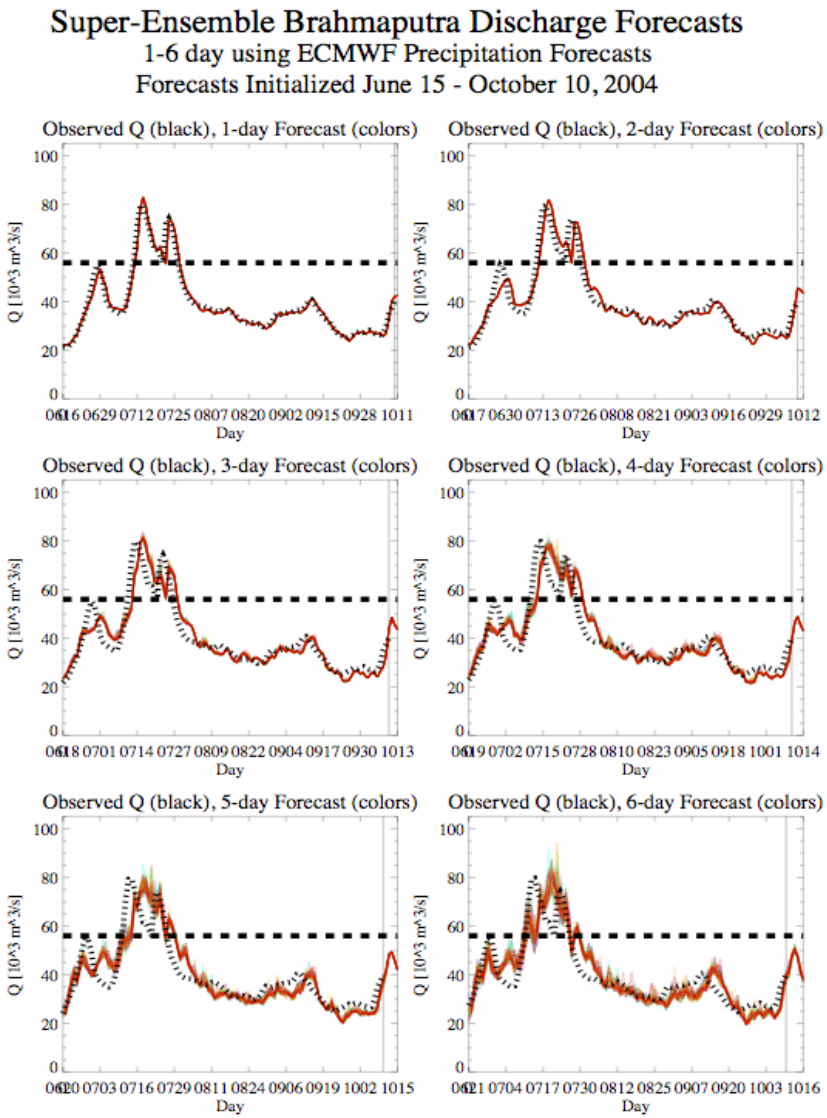


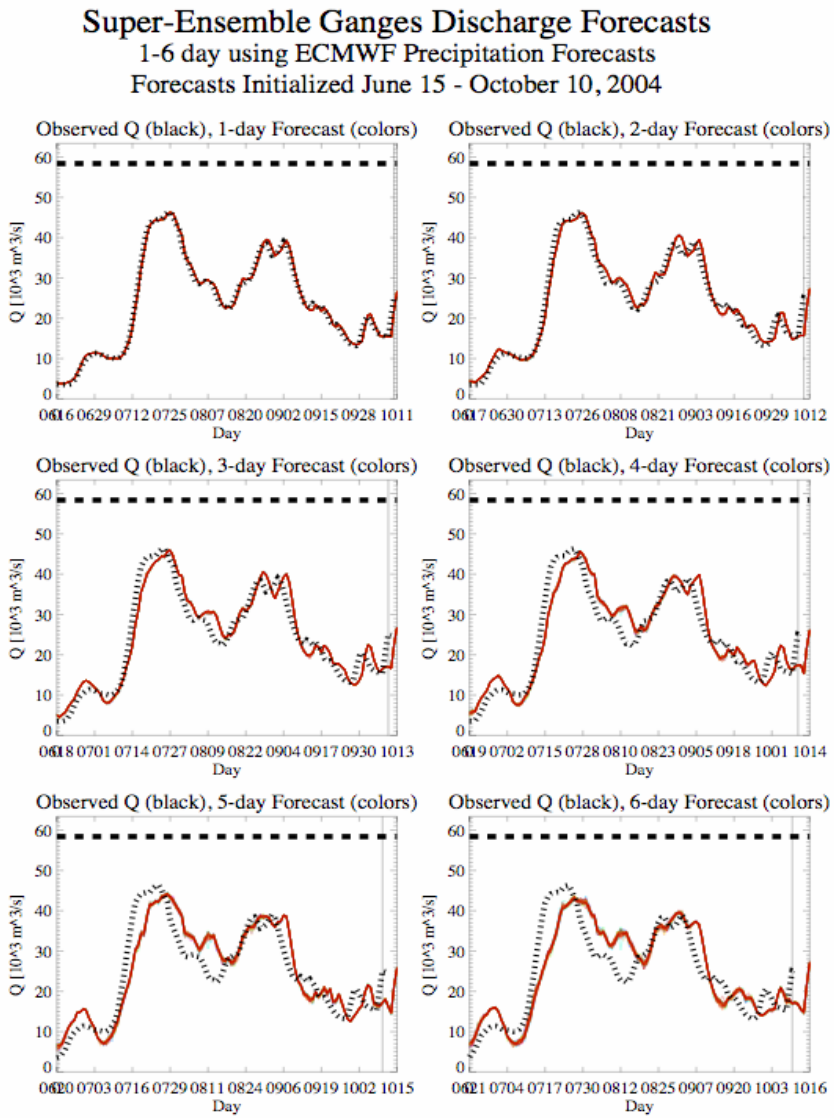
Discharge Probability



Above danger level probability 36%
Greater than climatological seasonal risk?

Relative Significance of NWP Forecast and all Other Model Errors on Final Probabilistic Discharges

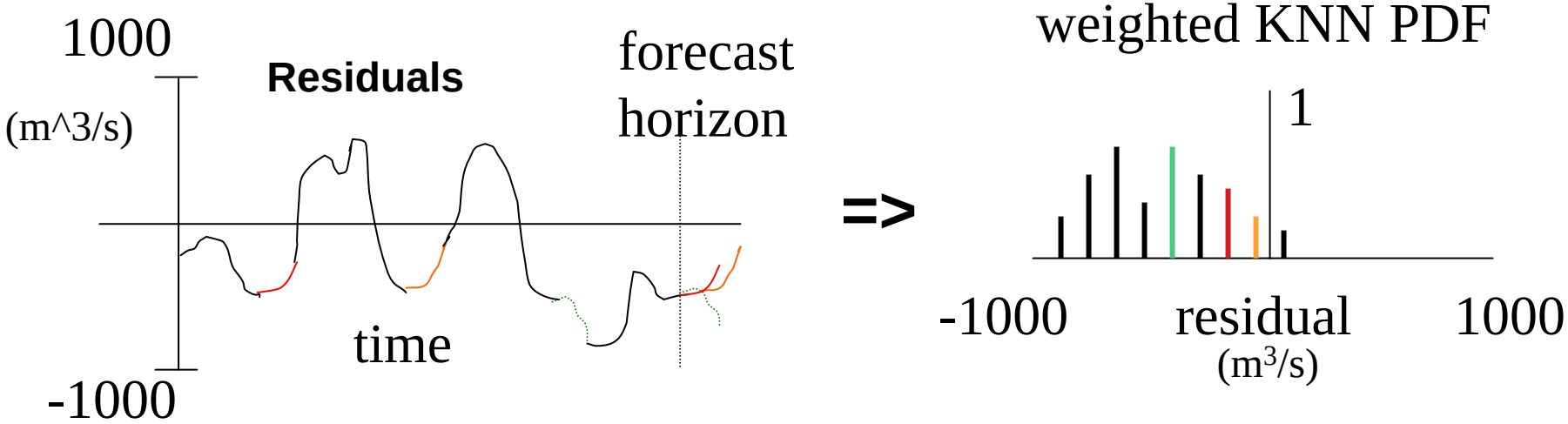




A More Complete Discharge Probability Forecast

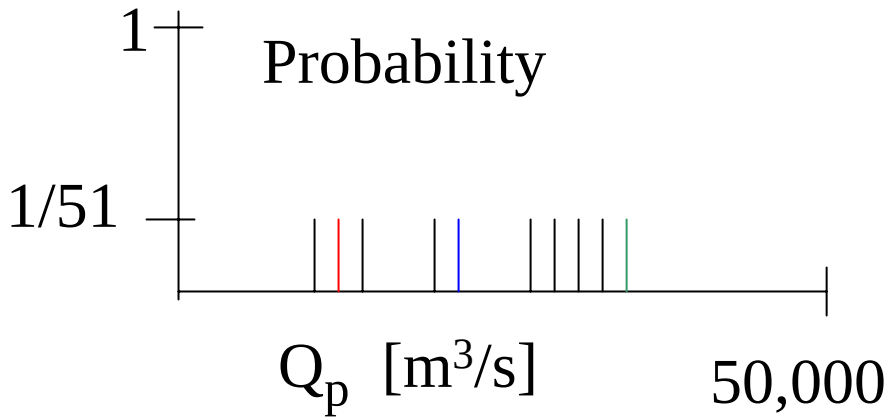
Step 1: generate model error PDF
(discharge model/rating curve/observed precipitation)

- historically generate residual time series for each day's re-calibrated hydrologic model (multi-model) using "observed" precipitation
- use K-Nearest-Neighbor (KNN) technique to select "nearest-neighbor" residuals (selection: values/slope/curvature)
- use Mahalanobis Distance to weight and create model-error PDF



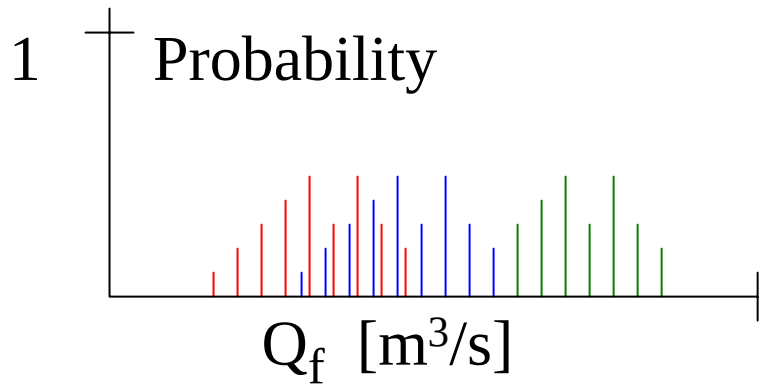
Combining "Model" with Precipitation Error

Step 2: generate precipitation-ensemble-generated discharge PDF



Step 3: combine model error PDF with the above to generate a "new-and-improved" more complete PDF for forecasting:

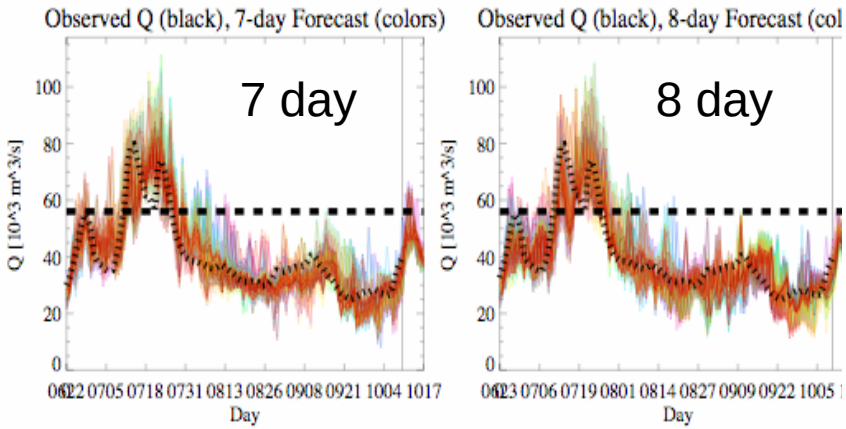
Result

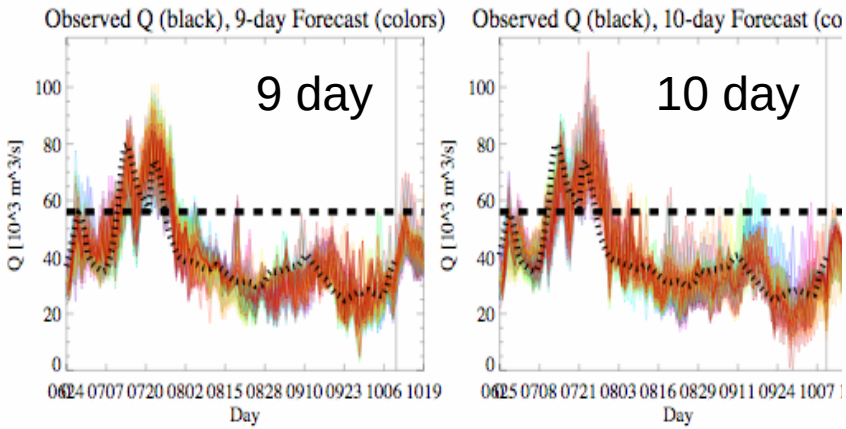


2004 “Corrected” Discharge Forecast Results

Brahmaputra Discharge Ensembles

Observed Q black dot
Ensemble Members in color

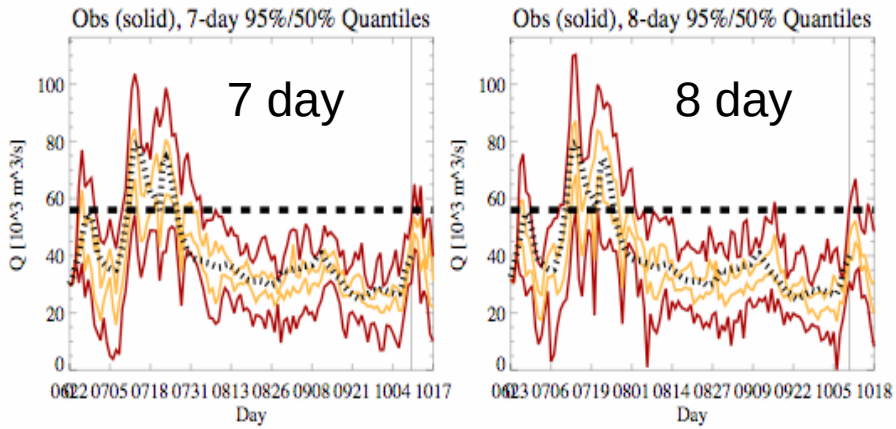


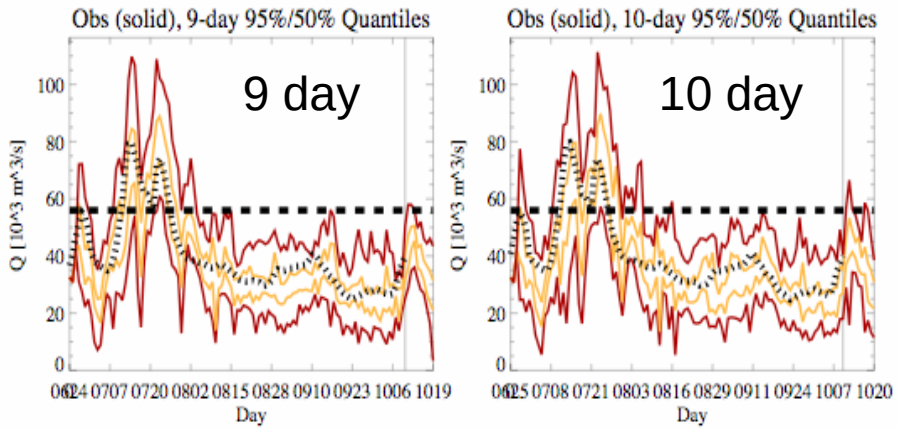


Confidence Intervals

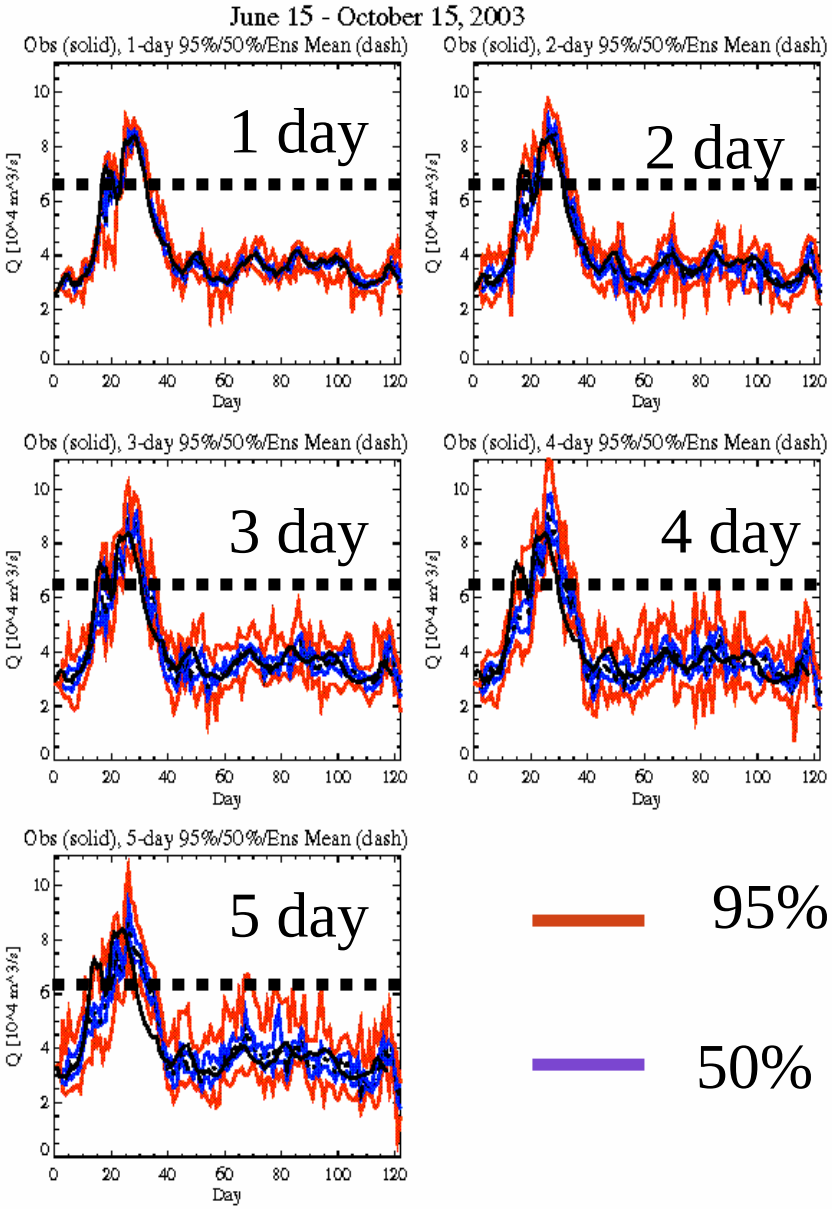
Critical Q black dash

50% 95%

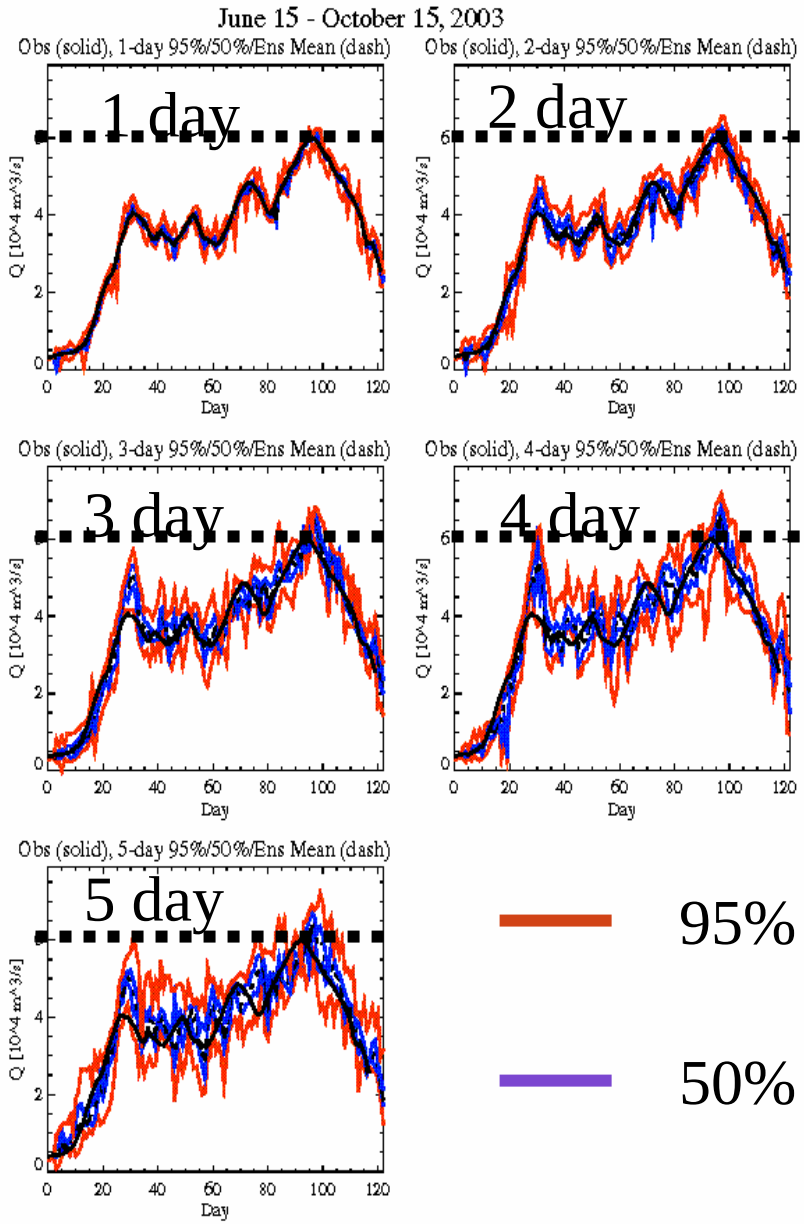




2003 Brahmaputra Flood Probability

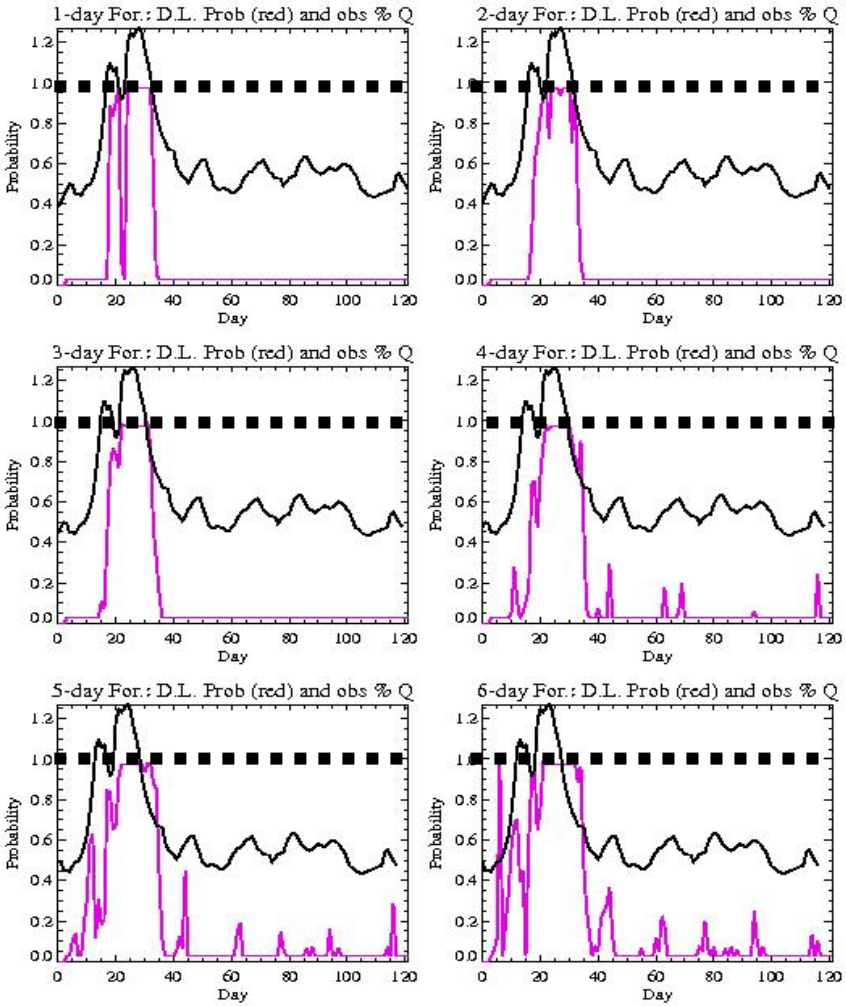


2003 Ganges Flood Probability

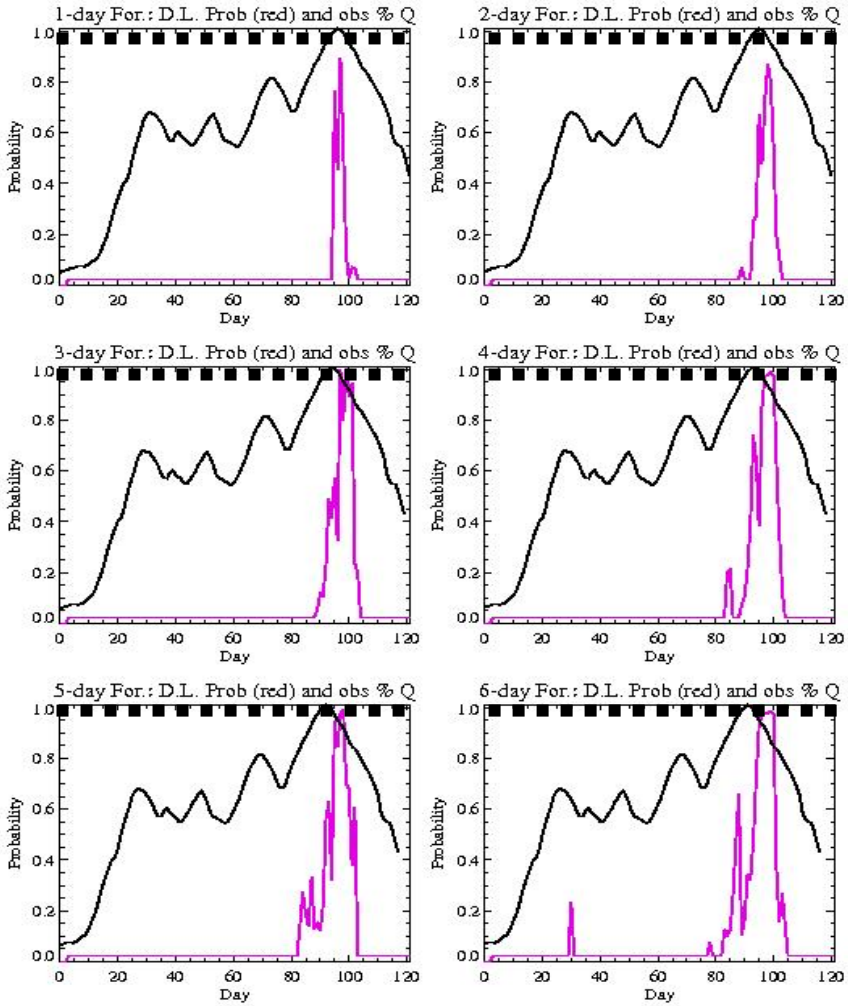


2003 Danger Level Probabilities

Brahmaputra Distributed S-G Danger Level Probabilities
1-6 day using ECMWF Precipitation Forecasts
June 15 - October 15, 2003

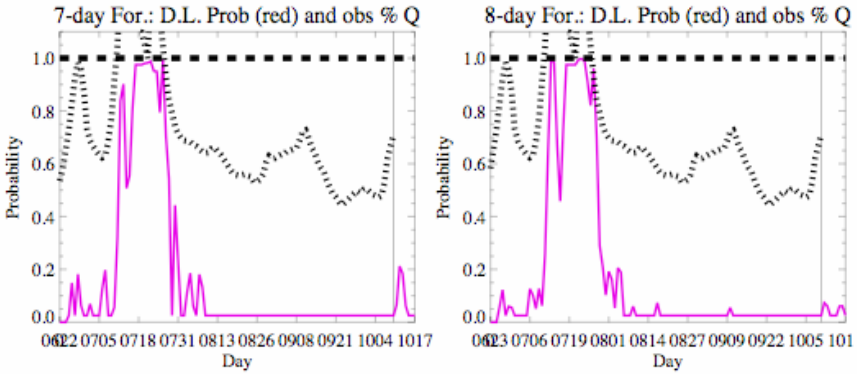


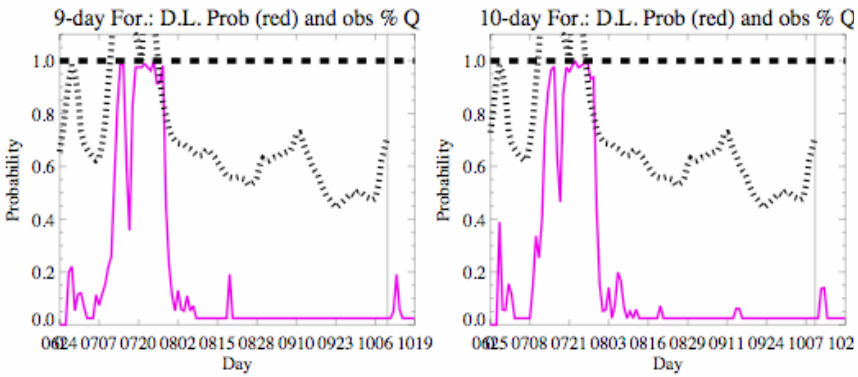
Ganges Distributed S-G Danger Level Probabilities
1-6 day using ECMWF Precipitation Forecasts
June 15 - October 15, 2003



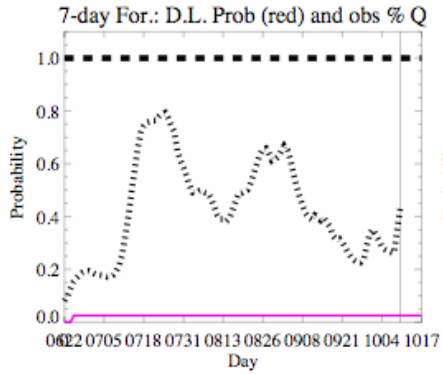
2004 Danger Level Probabilities

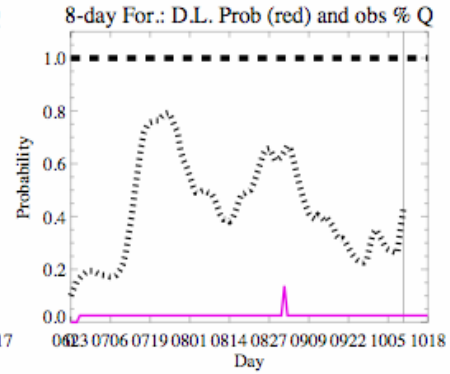
Brahmaputra 7-10 day Forecasts

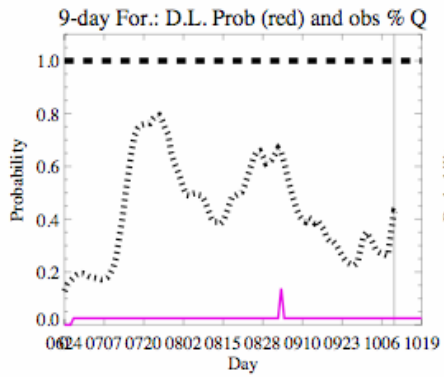


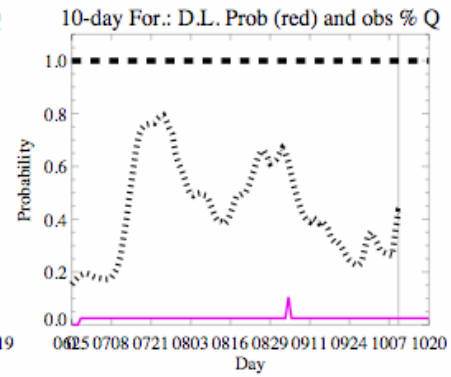


Ganges 7-10 day Forecasts









Conclusions

- Forecasts show good skill out to 7-10 days for the Ganges and Brahmaputra rivers
- 2003: Daily operational probabilistic discharge forecasts “experimentally” disseminated
  -- Multi-model approach implemented
  -- Hydrologic model error corrections
- 2004:
  -- Precipitation forecast corrections operational
  -- Forecasts fully-automated
  -- Forecasts incorporated into Bangladesh flood warning program
  -- CFAB became an institutionalized entity of the Bangladesh federal government
- 2005: Dutch / USAID (local) / CARE
  -- five year funding commitment


Thank You!