GloFAS ensemble streamflow predictions
Results from a 2-year verification period

F Pappenberger, L. Alfieri, E. Dutra, and F. Wetterhall

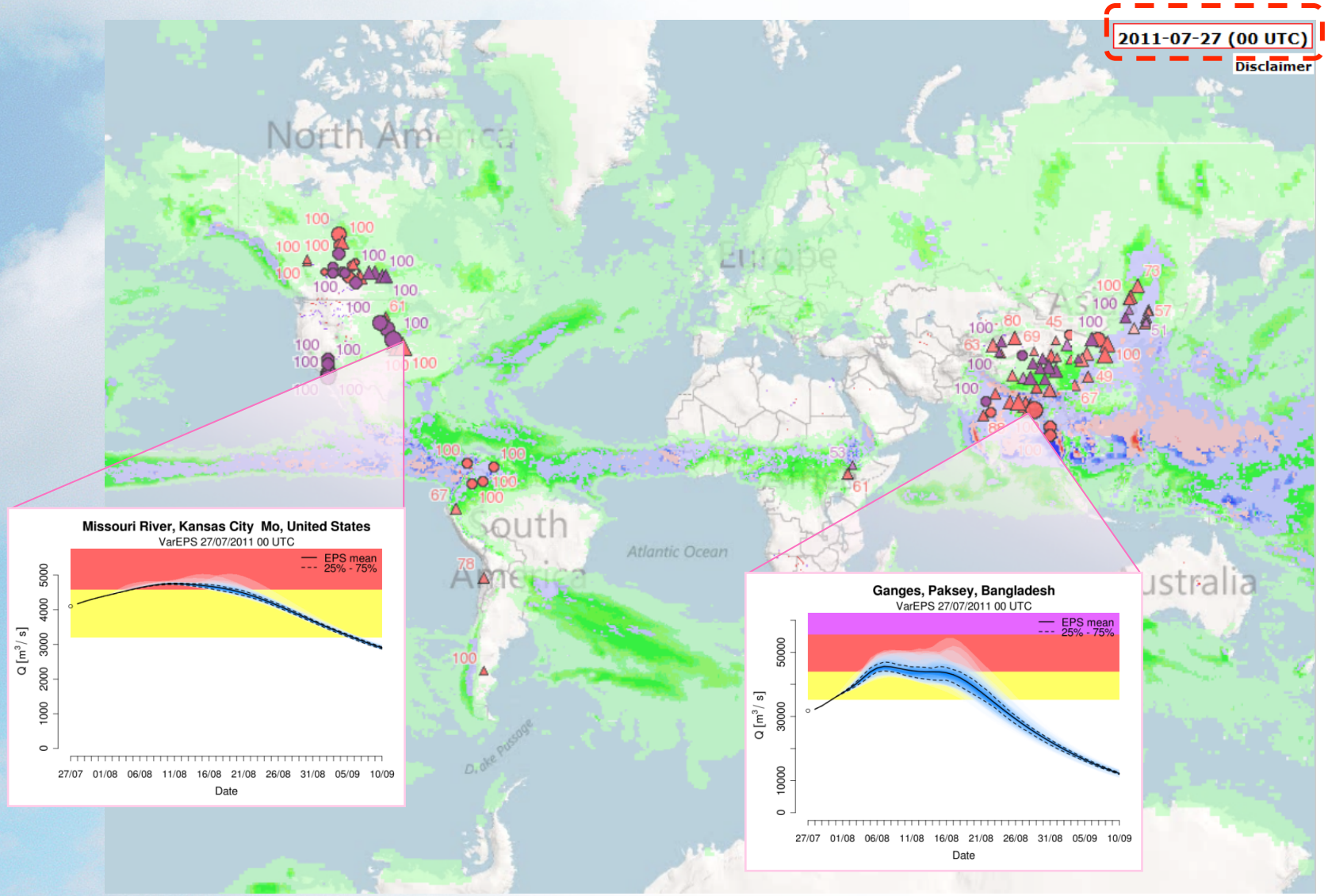
European Centre for Medium-Range Weather Forecasts

P. Burek and J. Thielen

*European Commission - Joint Research Centre*F. Pappenberger

Florian.pappenberger@ecmwf.int

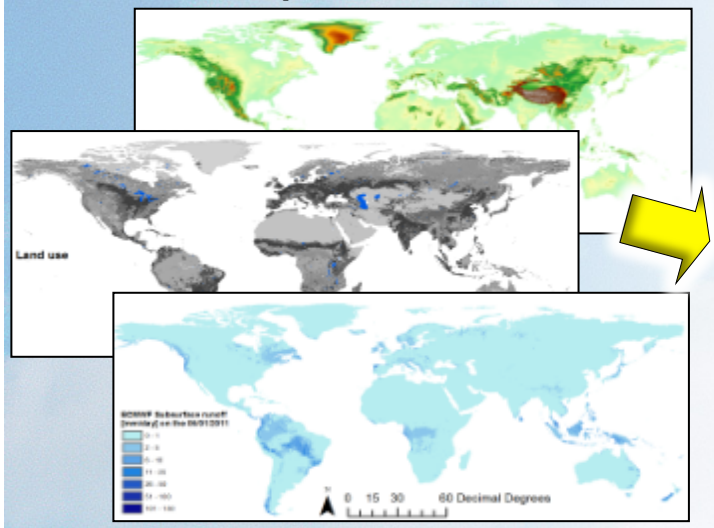
The Global Flood Awareness Systems

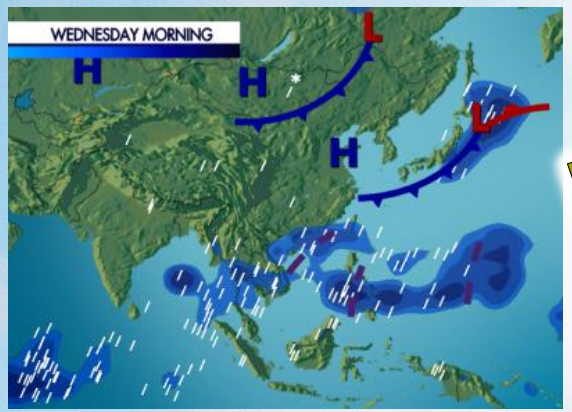


System overview

Input data

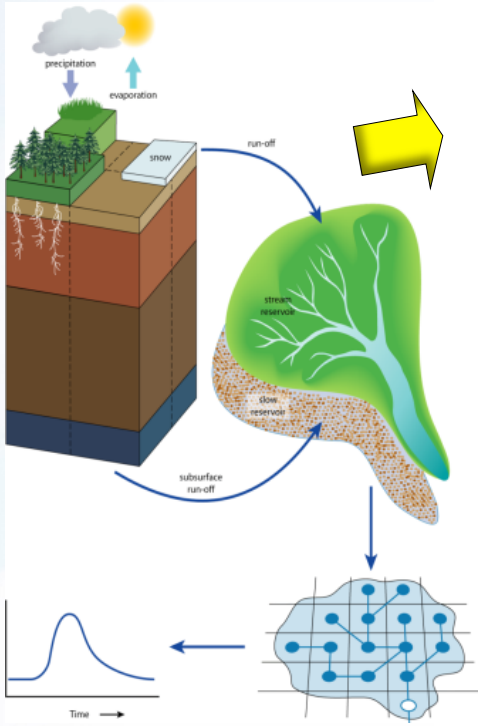
Global spatial information





Weather observations/ predictions

Hydrological model

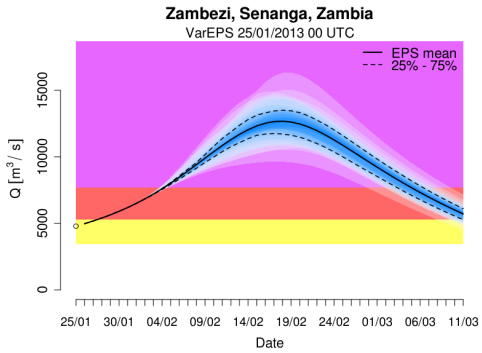


Grid resolution: 0.1°(~ 10 km)

Temporal resolution: 1 day

Output

River flow forecast



Flood warning

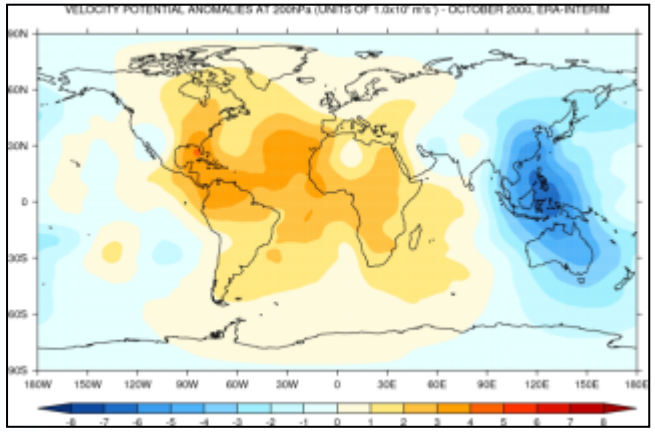
Meteorological input data

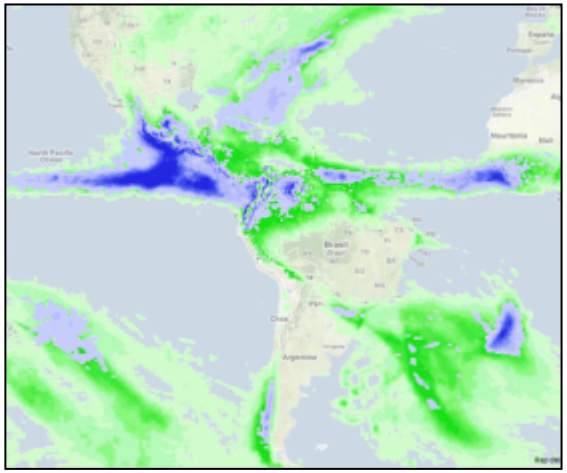
Ensemble forecasts
ECMWF - VAriable Resolution Ensemble Prediction System (ENS)

- **51 ensemble members**
- **15-day forecast horizon**
- **Resolution: ~ 32 km for the first 10 days, ~ 65 km from day 11 onward**

Long term climatology - validation
ERA Interim (ECMWF)

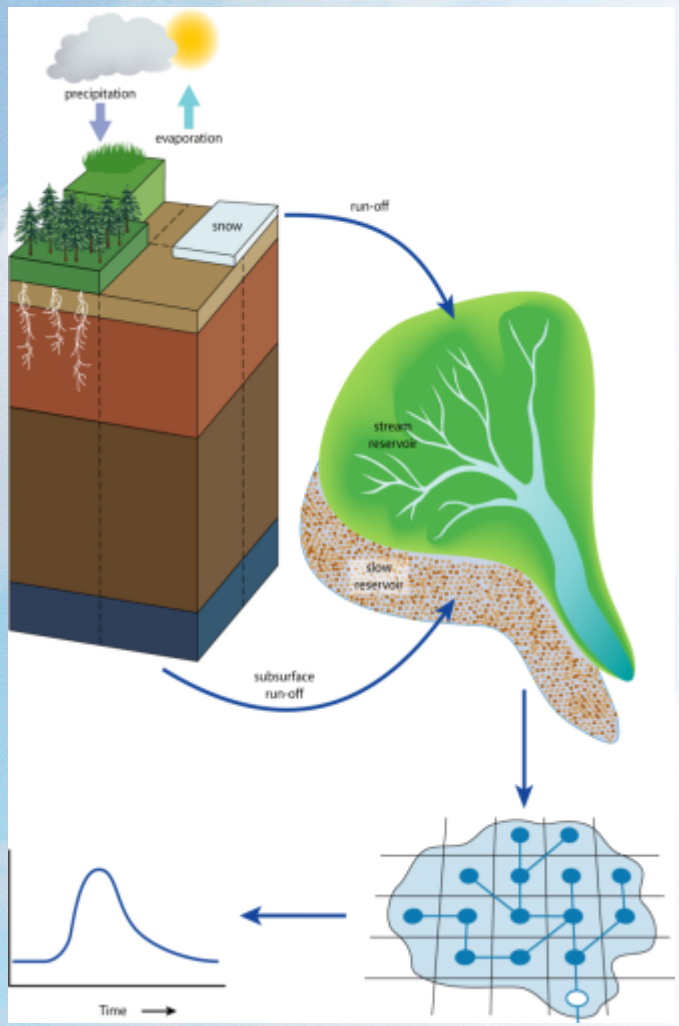
- **ECMWF global atmospheric reanalysis**
- **Available from 1/1/1979 - 31/12/2010**
- **Resolution: ~ 79 km**





% of VarEPS members exceeding 50 mm (green) and 150 mm (blue) in 10 days on the 01/07/2011

Hydrological Models



A combination of:

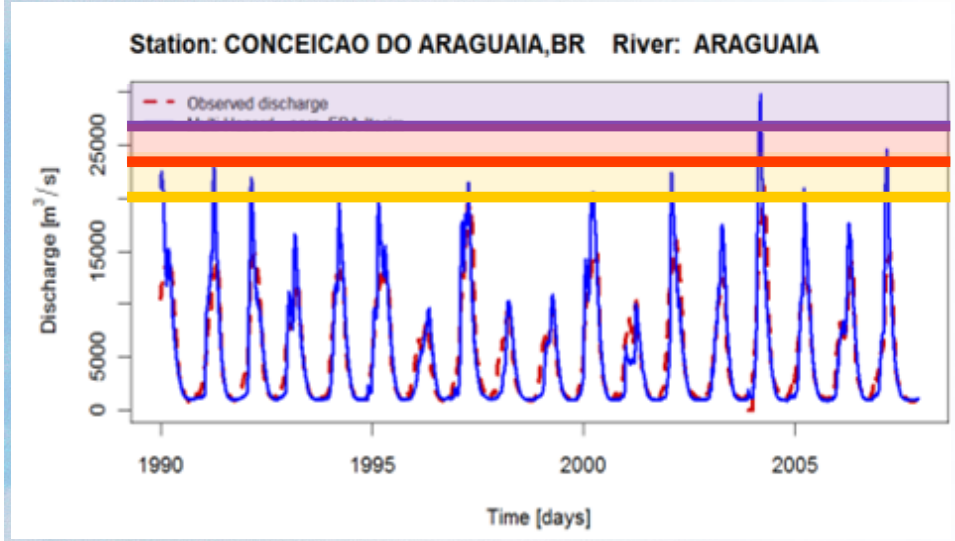
HTESSEL (ECMWF)
(Hydrology Tiled ECMWF Scheme for Surface Exchange over Land)
- **Surface heat and evaporation**
- **Soil water budget**

Output: surface runoff
subsurface runoff

LISFLOOD (JRC)
- **Groundwater**
- **Routing (kinematic wave)**

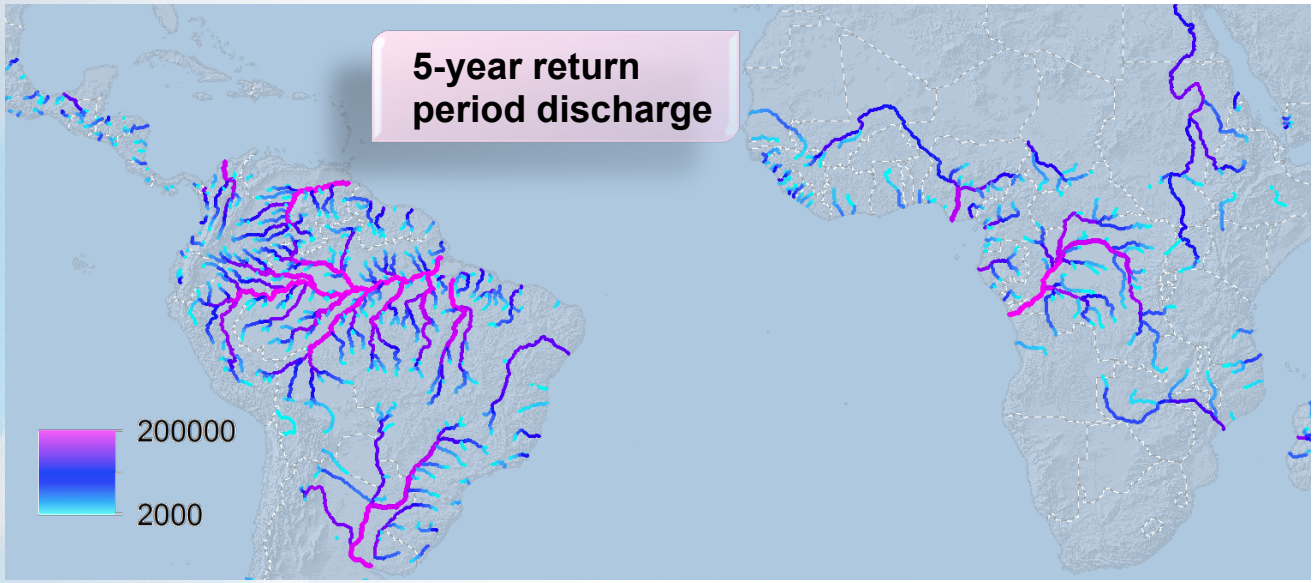
Output:
- 51 ensemble streamflow predictions (4D)
- Threshold exceedance maps (RP=2, 5, 20 years)

Alert thresholds



For each grid point, three alert thresholds are derived from the long term simulation (1990-2010) through extreme value fitting

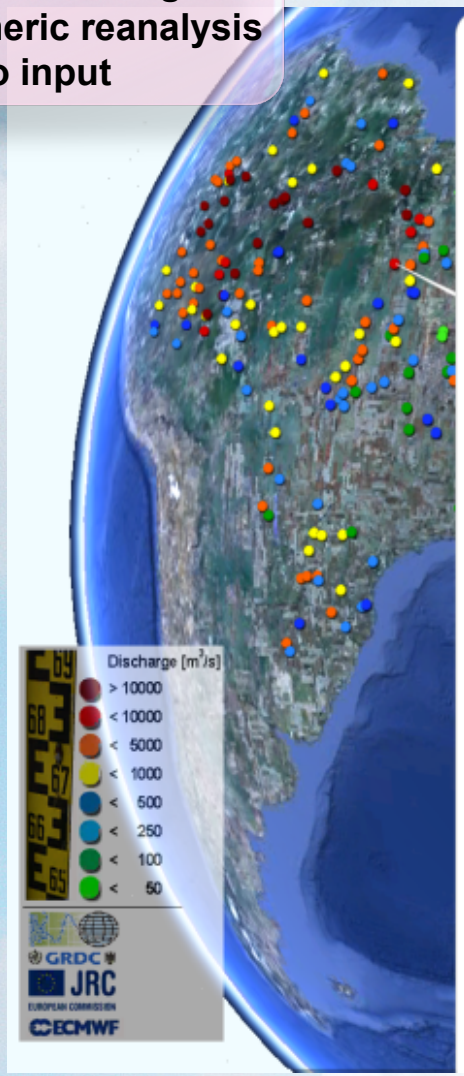
- **Severe alert = 20-year return period**
- **High alert = 5-year return period**
- **Medium alert = 2-year return period**

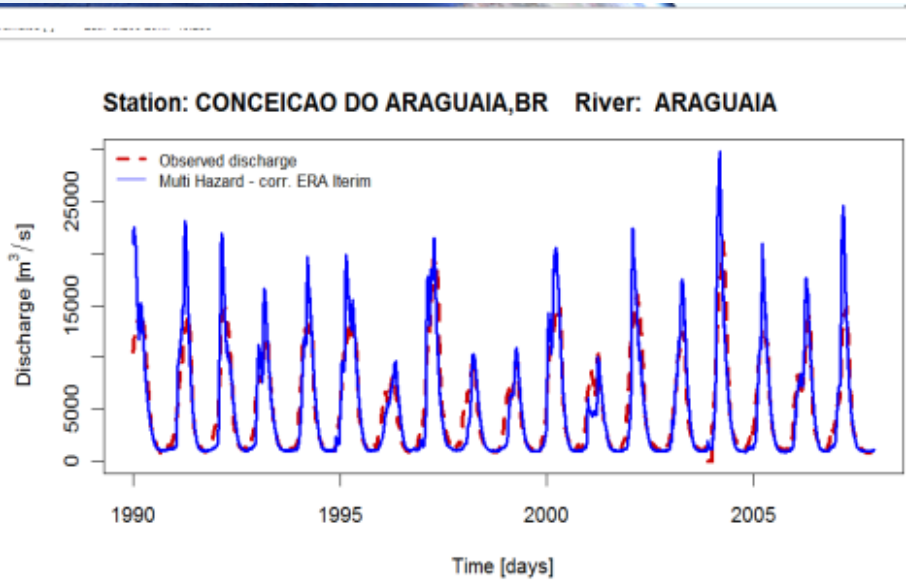


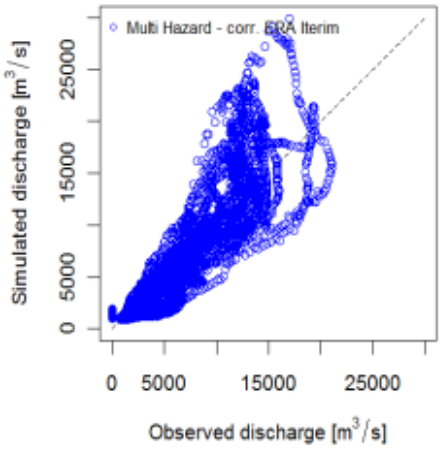
Long term run 1990-2010

Streamflow simulations with ERA-Interim global atmospheric reanalysis as meteo input

Comparison with observed discharge data







Statistics - Multi Hazard March 2011

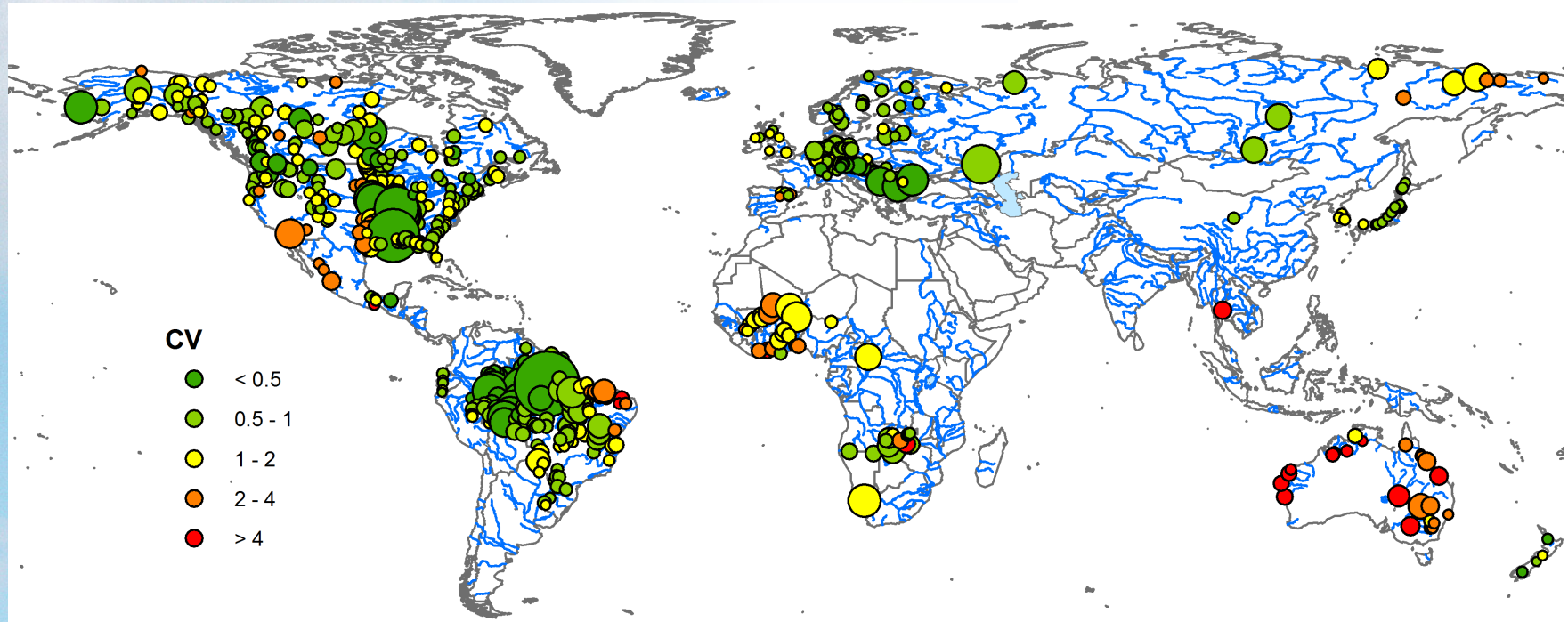
	Obs.	corr ERA I.
NS		0.735
Pearson		0.909
RMSE		2380.1
MAE		1385.1
ME		-37.5
Mean	5159	5184
95 %	13973	17565
99 %	18413	22252
Max	21076	29881

NS: Nash-Sutcliffe
Pearson: Pearson correlation
RMSE: Root mean square error
MAE: Mean absolute error
ME: Mean error

Observed vs. simulated discharge

620 river stations:

- **≥ 5 years of daily data**
- **Difference between measured and modeled upstream area ≤ 10%**
- **No significant water regulation or errors in the obs (visual check)**

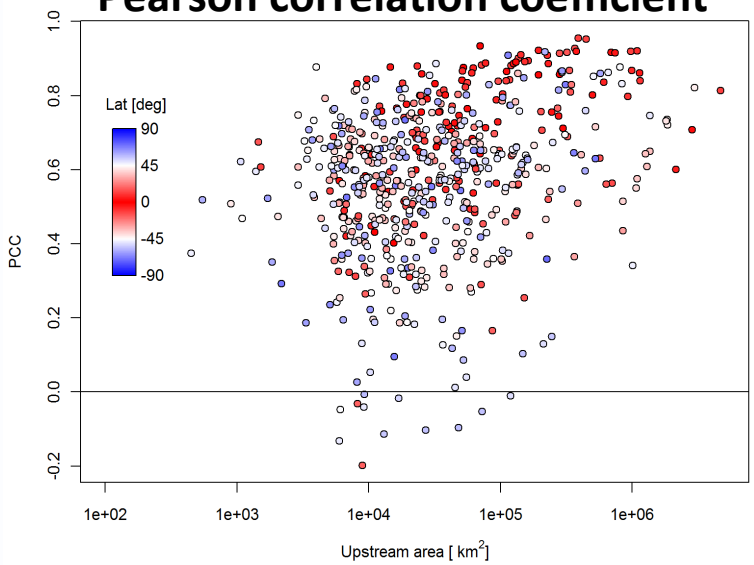


Dimensionless scores to enable comparison at different locations

Observed vs. simulated discharge

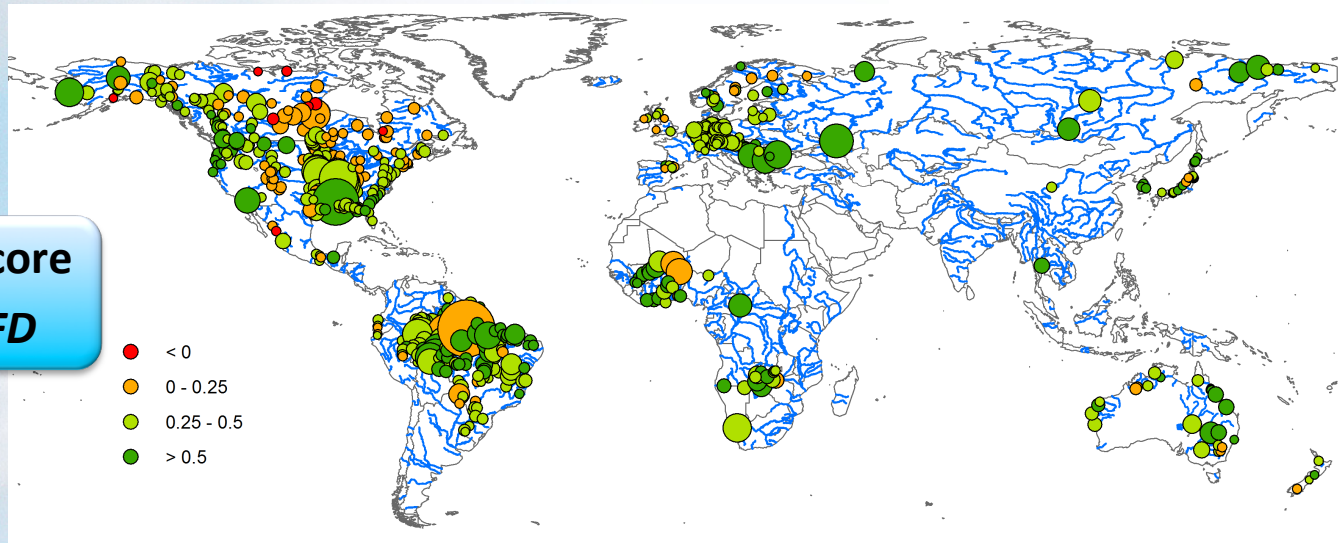
- Best correlations in large river basins in inter-tropical latitudes
- Scale issues
- Modeling issues:
  - — snow-related processes
  - — arid regions

Pearson correlation coefficient



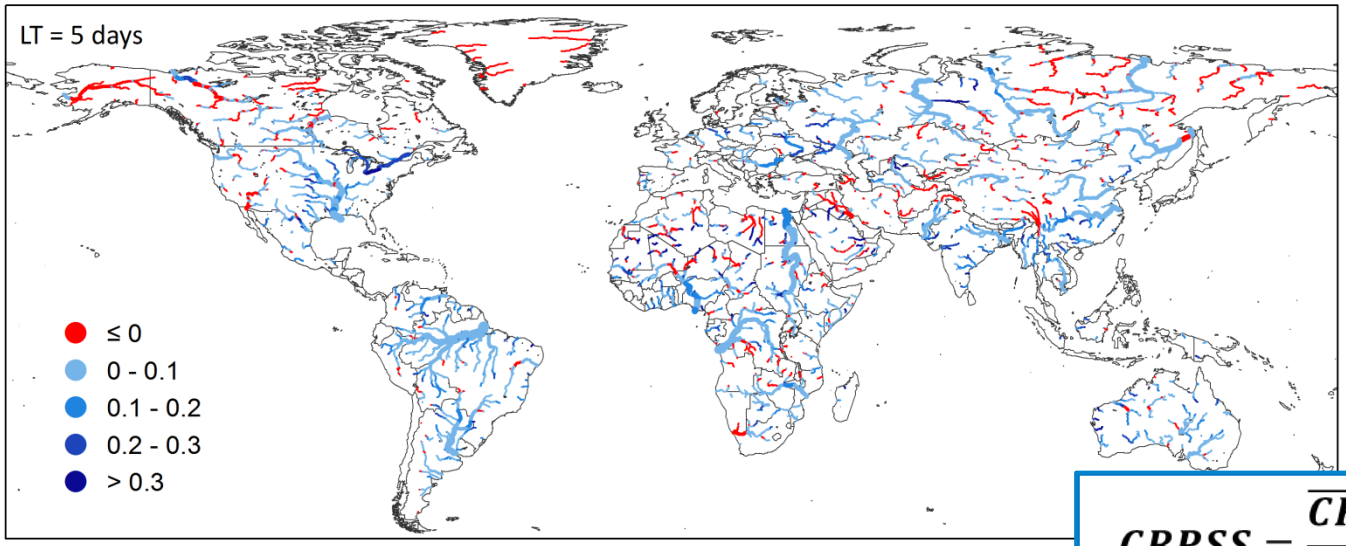
Peirce's skill score

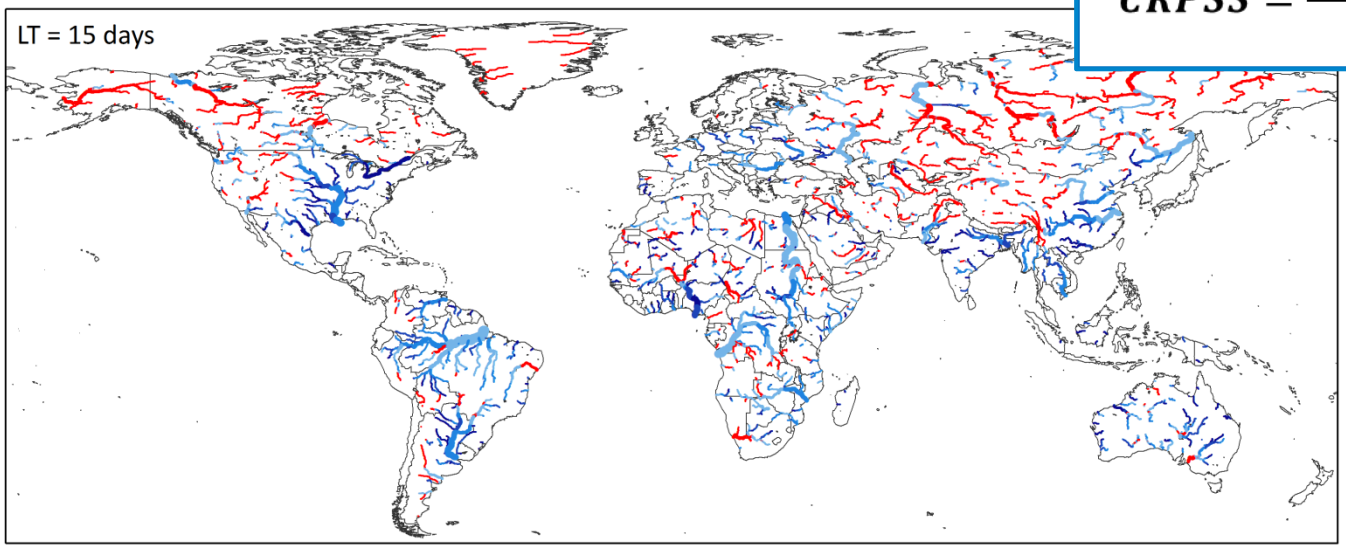
PSS=POD-POFD



Performance of ensemble forecasts

1. Quantitative performance (CRPSS)





2 years of daily forecasts (2009-2010)

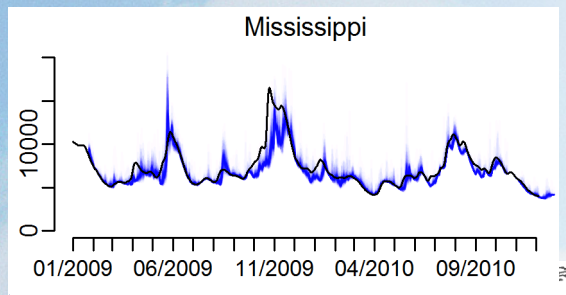
$$CRPSS = \frac{\overline{CRPS_{ref}} - \overline{CRPS_{forecast}}}{\overline{CRPS_{ref}}}$$

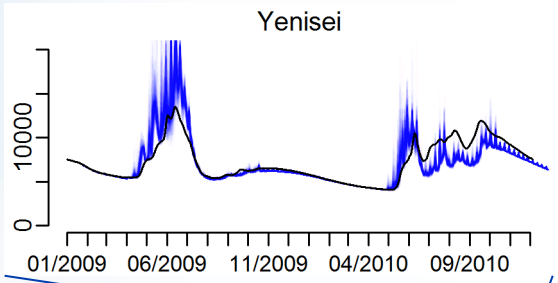
Reference = persistent forecast

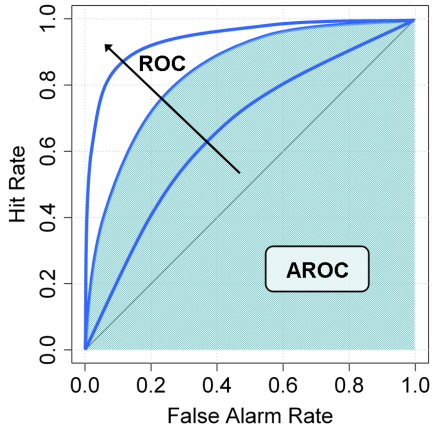
Performance of ensemble forecasts

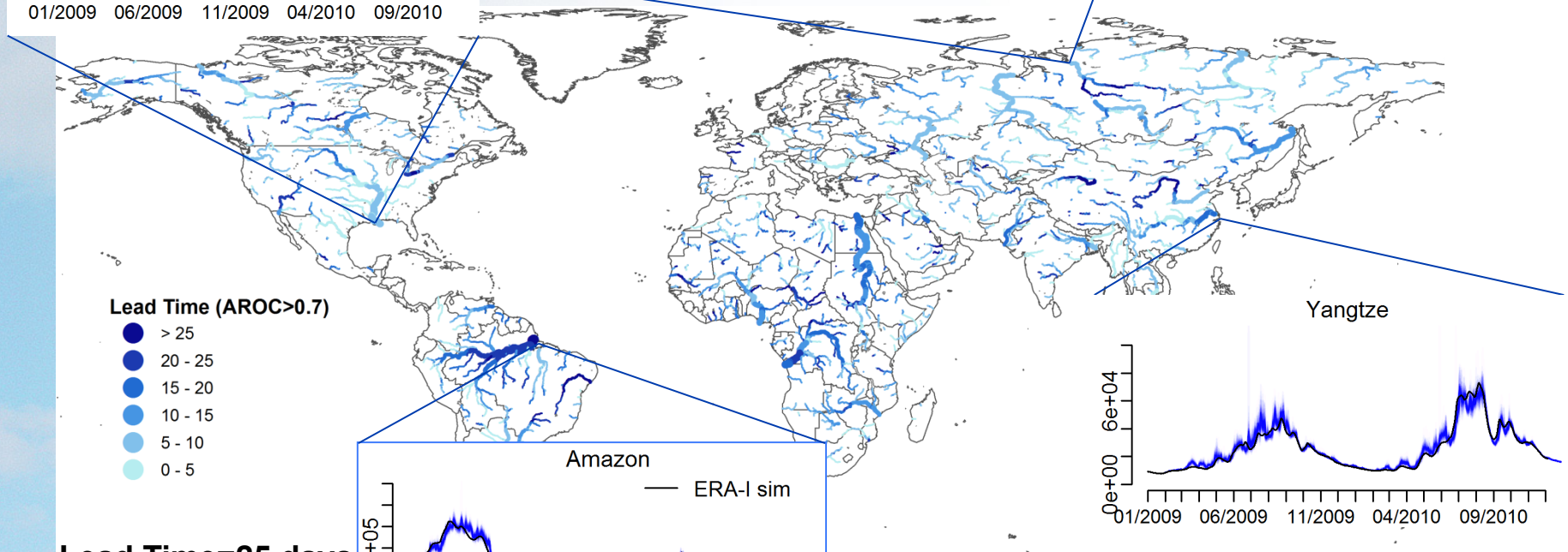
2. Threshold exceedance analysis (AROC)

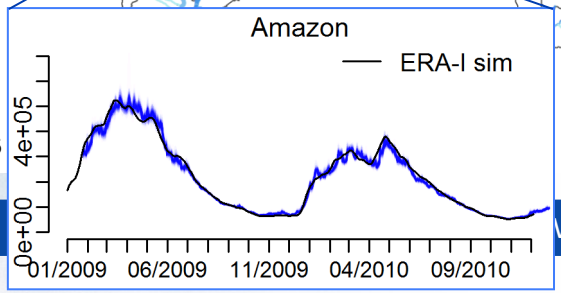
Threshold = 90%



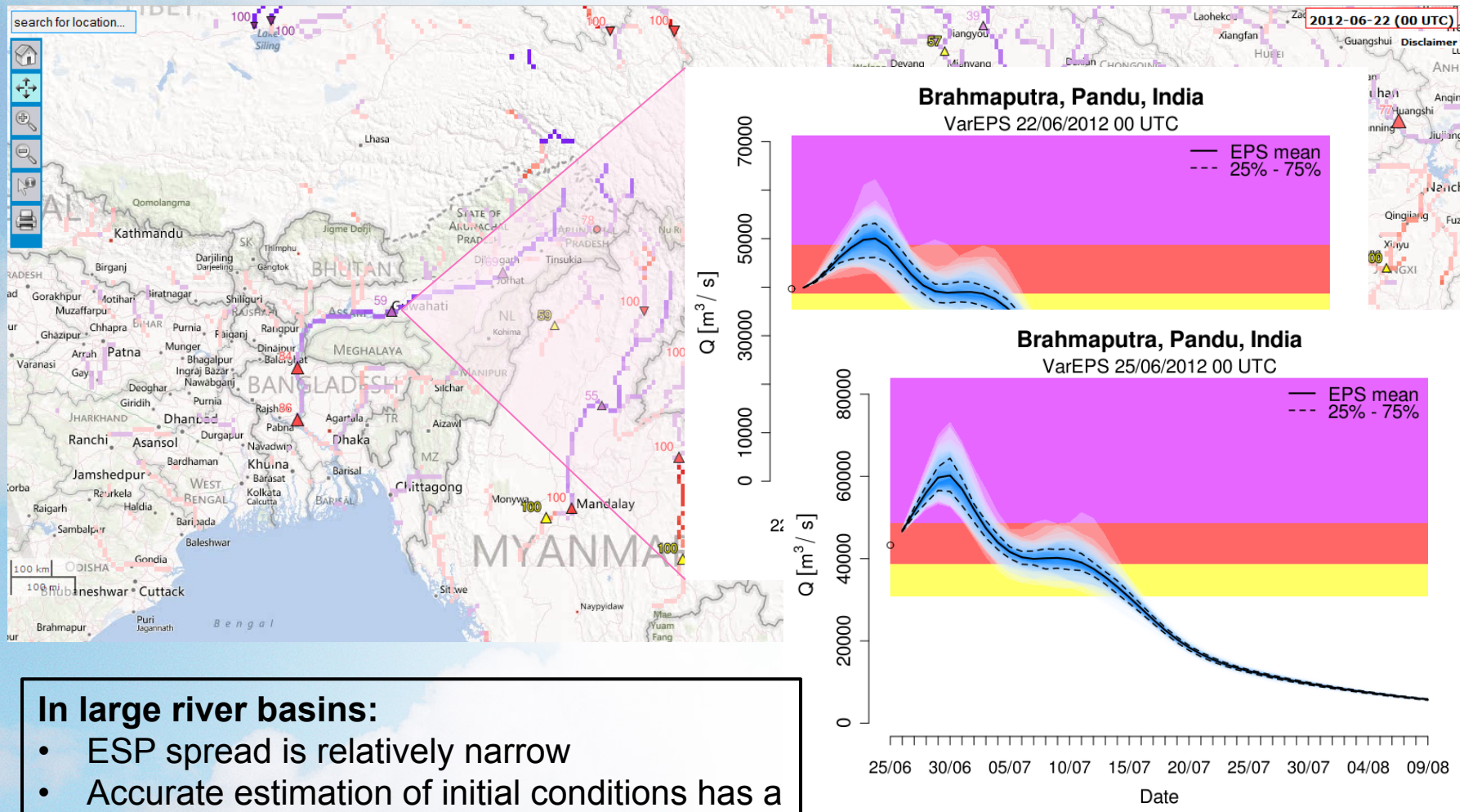








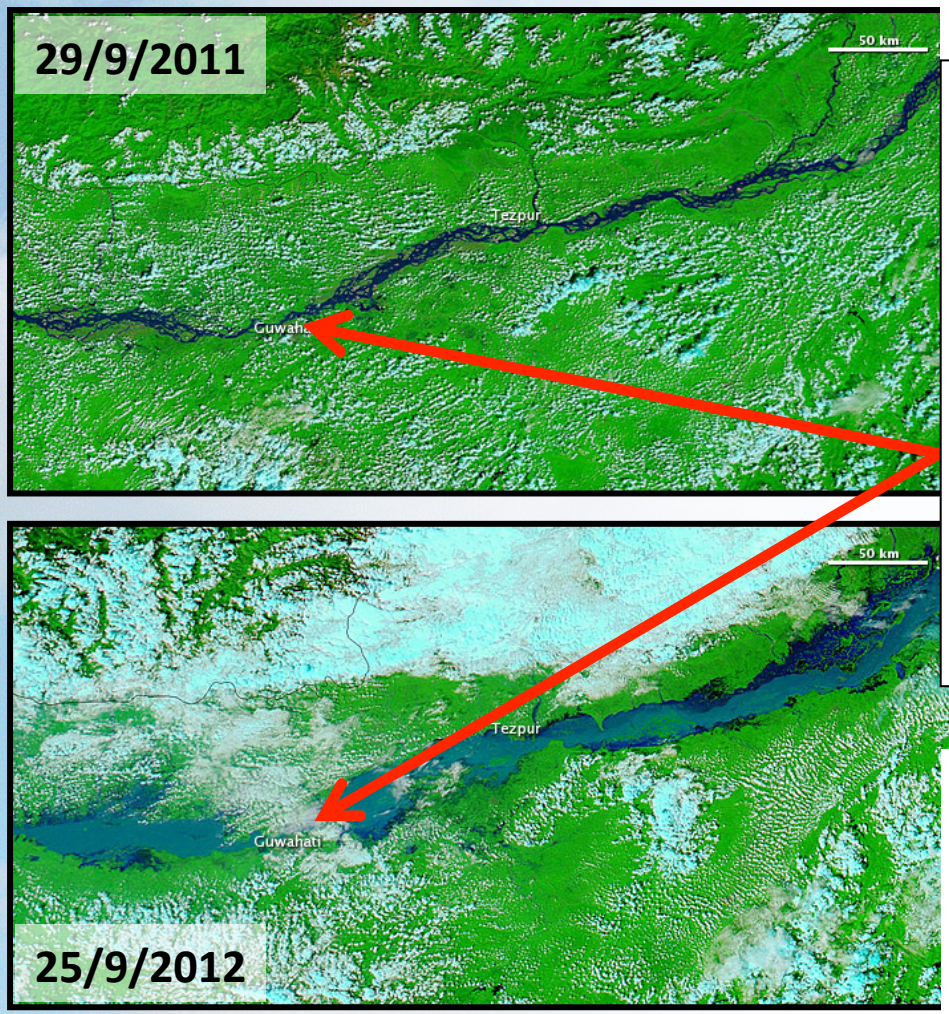
Assam floods - June 2012

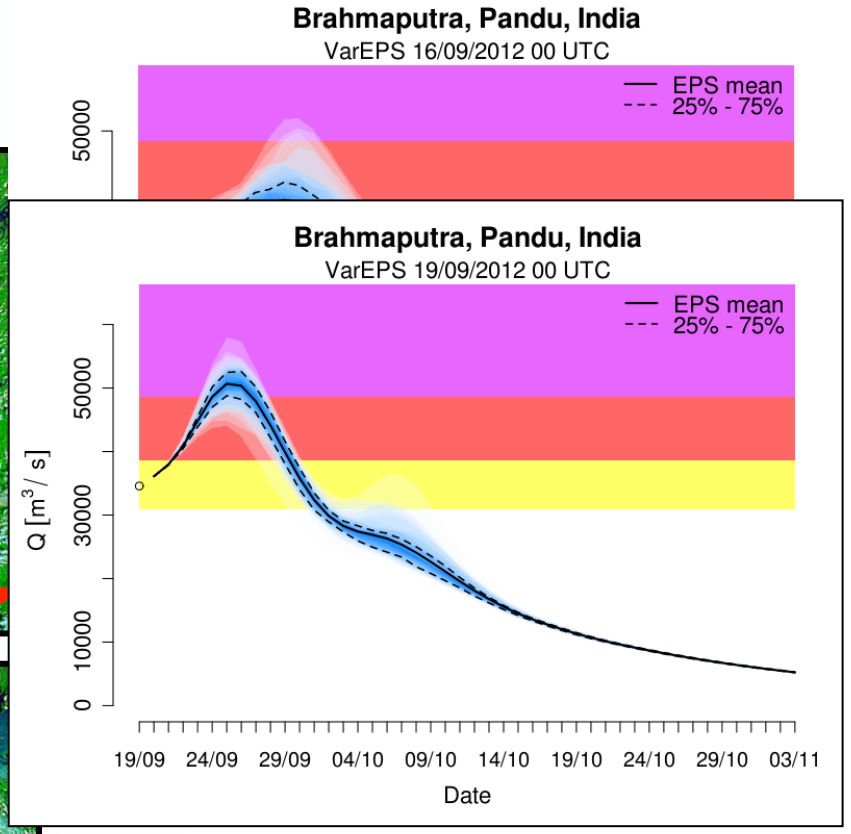


In large river basins:

- ESP spread is relatively narrow
- Accurate estimation of initial conditions has a key role

Assam floods – September 2012

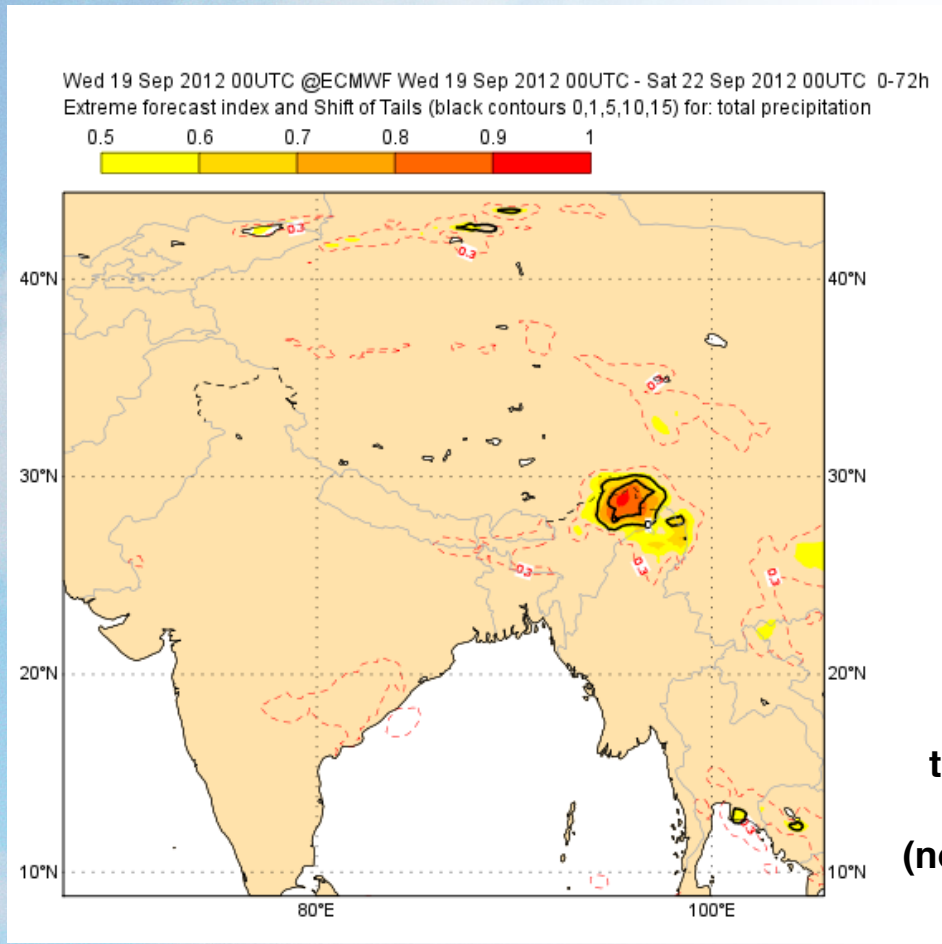




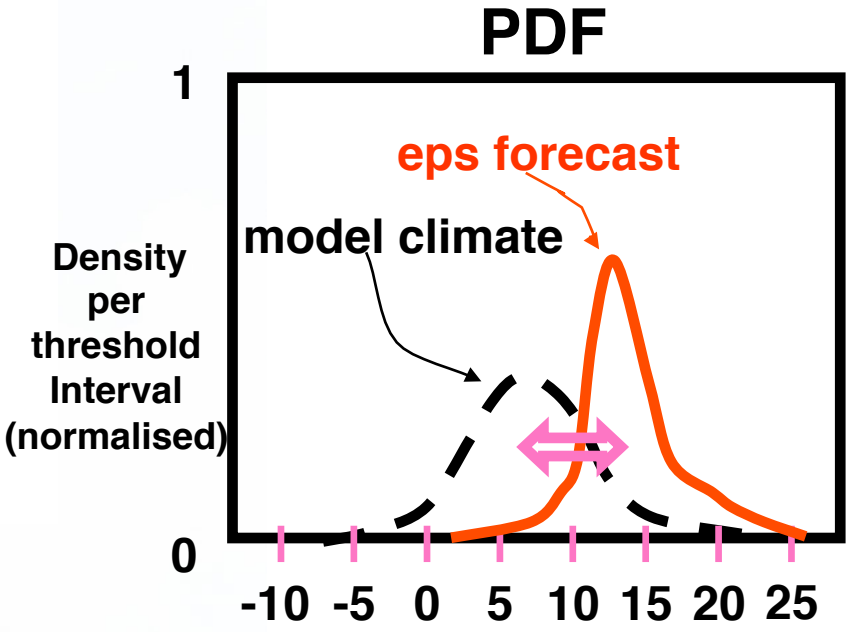
Severe Alert Level

Forecast Day	15	16	17	18	19	20	21	22	23	24	25	26	27	28
15/09/2012									2	2		2		
16/09/2012										2	6	6	4	
17/09/2012										4	2			
18/09/2012									25	43	33	16		
19/09/2012									45	80	75	47		

Assam floods – Extreme Forecast Index



Extreme Forecast Index (EFI) is designed to detect extremes of EPS forecast variables, in comparison to past forecasts for the same season (±2 weeks)



Nigeria floods 2012

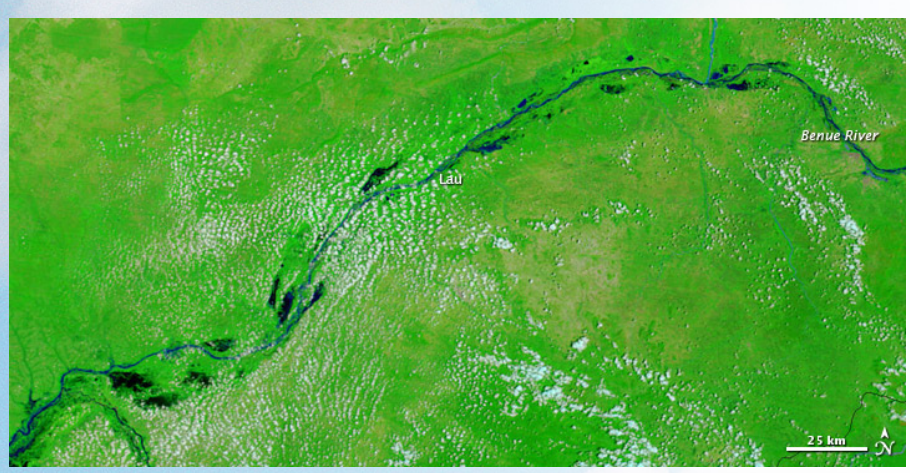
July-October 2012

Series of seasonal floods/flash floods after heavy tropical rain caused 363 people killed, over 2,100,000 displaced.

Date	Location	Description	Type	Toll
02-Jul	Lagos, coast of Nigeria	heavy rain on many Nigerian coastal and inland cities	Flash flood, surface water floods	
mid-July	Ibadan	torrential rain	heavy rain, flash flood	3 killed
end-July	Jos, Plateau state	heavy rainfall caused Lamingo dam to overflow	dam overflow, river floods	≥ 39 killed
mid-August	Plateau state	floods had destroyed homes and washed away roads and bridges, hampering rescue efforts	flash floods	≥33 killed, ≥12,000 affected
end-August to early September	along the Benue River	Water released from the Lagdo dam (Cameroon)	dam overflow, riverine flood	≥30 killed, ≥120,000 affected
early October	Niger delta	Large areas flooded in the Niger delta	flood + storm surge	3 killed, 300,000 homeless

Nigeria floods 2012

Flooding from the release of water from Lagdo Dam (Cameroon) was blamed for 30 deaths in Nigeria*.

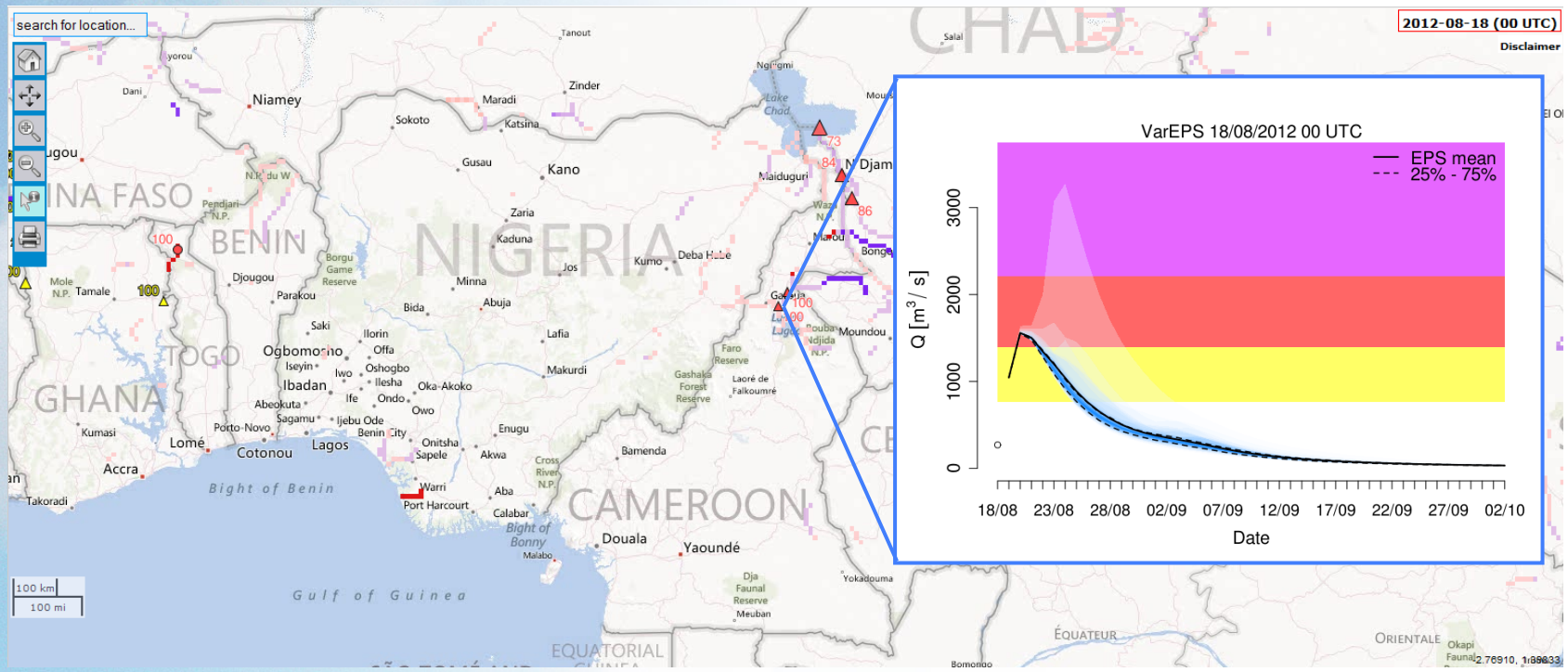


23/9/2009

8/9/2012

*Agence France-Presse. (2012, September 9) Thirty dead in Nigeria flood, 120,000 displaced.

Water inflow from Cameroon

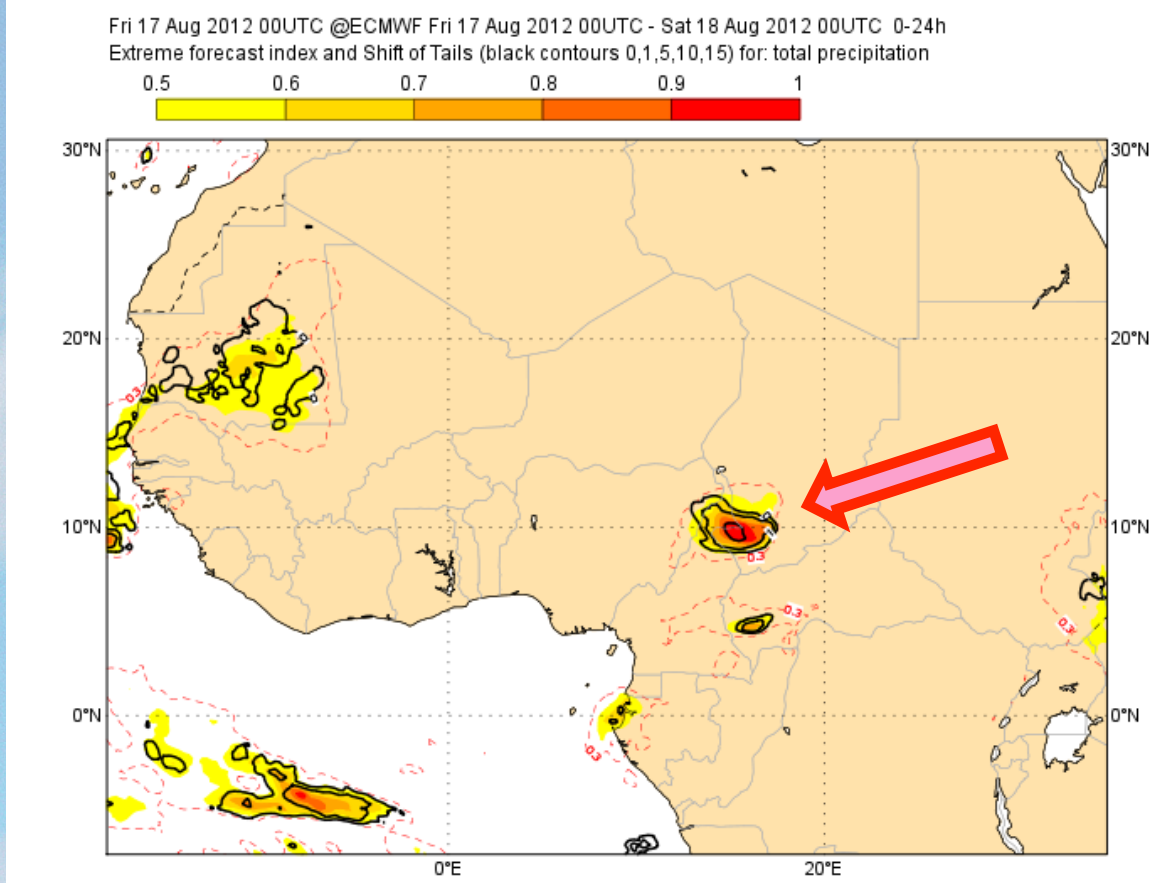


Limitations:

- Flash floods/surface water flooding are outside the system limits of predictability, as their space-time scales are typically below the resolution of the input data and of the hydrological model

- Operating rules of artificial reservoirs cannot be included, though they can significantly affect the streamflow conditions

Extreme forecast Index (EFI)



Strong signal of EFI on 1-day forecasts in the upper Benue (Cameroon) with very short predictability

Pros

- Fast indication (EFI is stored in MARS)
- Free from hydrological uncertainty
- Shows the area affected by the extreme

Cons

- No info on flood timing
- No hydrological processes
- More prone to false alarms

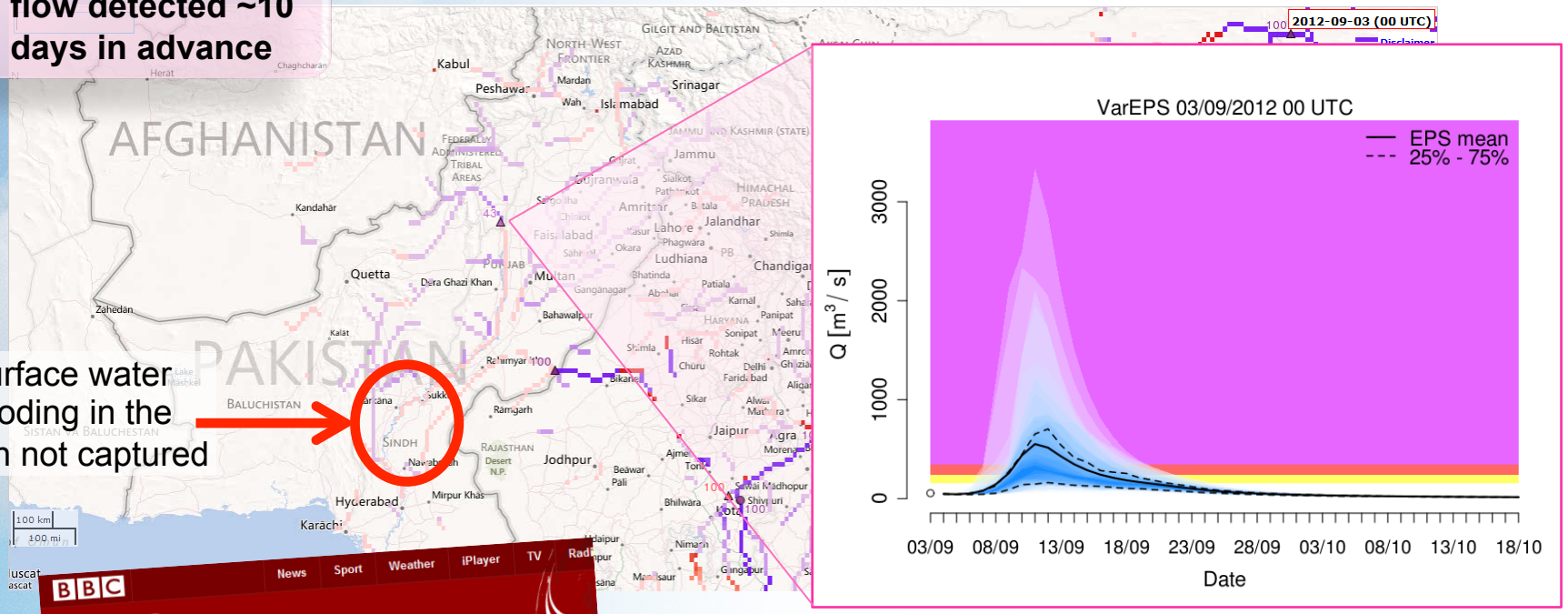
Aggravating effects

- Nigeria is the most populated country of Africa (high vulnerability)
- Poor rainfall/discharge gauging networks (BusinessDay, 18/10/2012)
- Cholera outbreak had also occurred in August, with 65 cases recorded (The Botswana Gazette, 10/9/2012)
- farmlands of rice, maize and other crops have been destroyed by the floods, bringing food security threat. (AllAfrica, 15/10/2012)
- Dangerous animals, including crocodiles, snakes and hippos, have found their way into homes and communities in central Nigeria (BBC, 3/10/2012)
- Landslides

Pakistan flood Sept 2012

Forecast peak flow detected ~10 days in advance

Ensemble streamflow predictions



Surface water flooding in the Sindh not captured


BBC NEWS ASIA

10 September 2012 Last updated at 18:56

Flooding in Pakistan kills at least 78 people in three days

At least 78 people have died in floods in Pakistan in the last three days, officials say.

They say that Khyber Pakhtunkhwa province and Pakistani-administered Kashmir are the worst hit regions, accounting for more than 60 deaths.

Hundreds of tents have been sent to these areas as part of relief efforts.

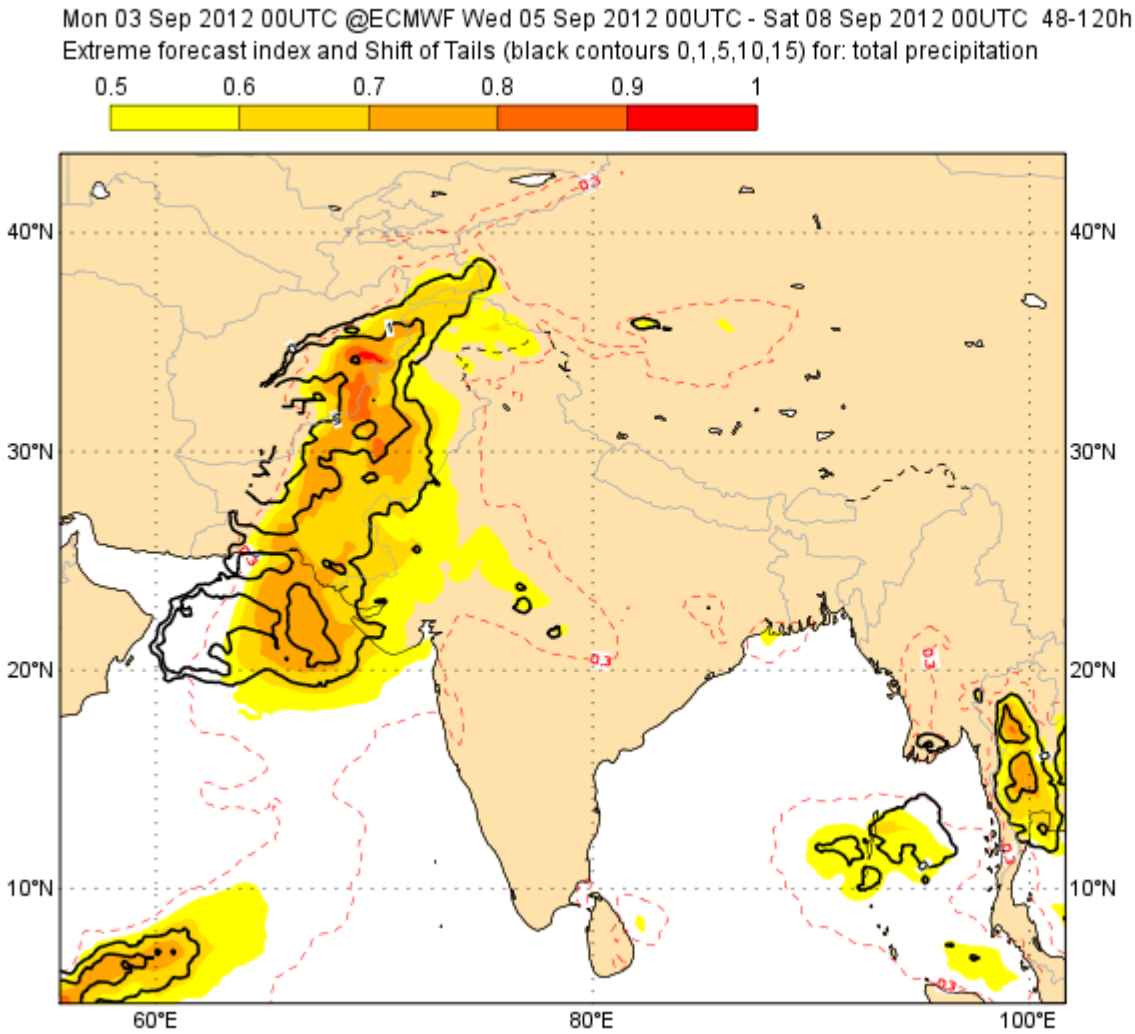
Probability of exceeding the 20-year alert threshold

Forecast persistence

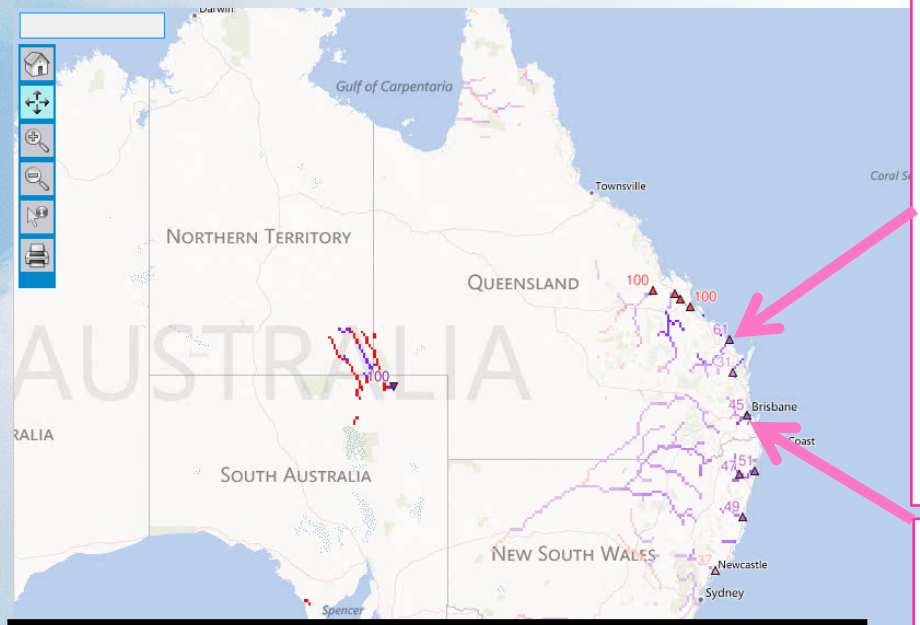
Severe Alert Level

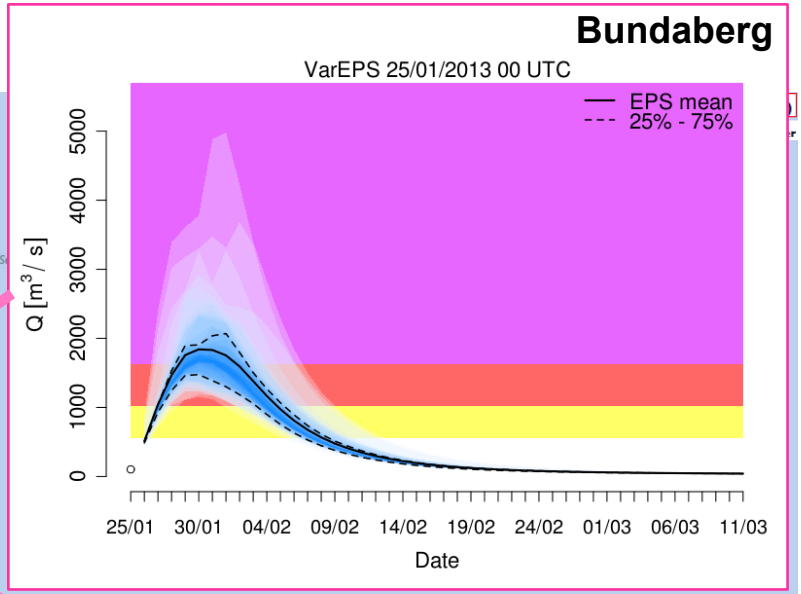
Forecast Day	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
30/08/2012									4	10	16	14	20	16	12	8	6	6	4	2				
31/08/2012								2	8	20	29	31	31	22	18	16	14	12	6	4	2			
01/09/2012									6	24	33	41	37	31	22	18	6	2	2	2				
02/09/2012									14	33	39	37	31	27	18	16	16	10	8	4	2			
03/09/2012									6	14	39	43	39	37	33	27	24	18	12	6				

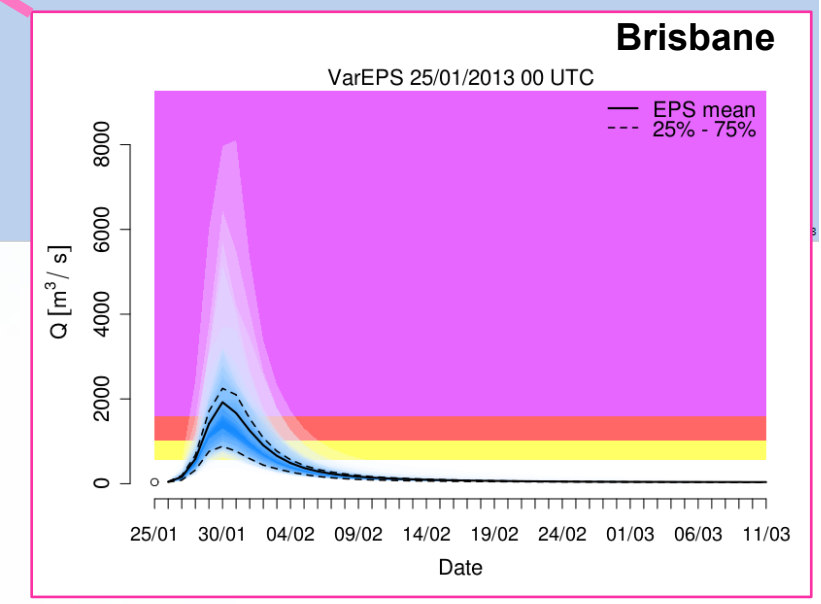
EFI Pakistan



Floods in Australia Jan 2013







Conclusions

Strengths

- Ensemble streamflow predictions globally on a daily basis
- Skillful detection of hazardous events with forecast horizon as long as 1 month in large river basins

Potential developments

- Model calibration
- Coupling with vulnerability maps
- Coupling with 2D hydraulic simulations

Limitations

- Scale issues - fit for basins >10,000 km^2 (**no flash floods**)
- Need for hydrological **calibration**
- Quality of **initial conditions** is crucial to detect extremes
- No floodplain storage modelled (affect timing of floods)
- GloFAS produces hazard maps, risk depends on **vulnerability**

More details in *Alfieri et al., HESSD, 2012*

Florian.pappenberger@ecmwf.int