Operational Flood Forecasting using Ensemble Weather Forecast- A Review

Presented By

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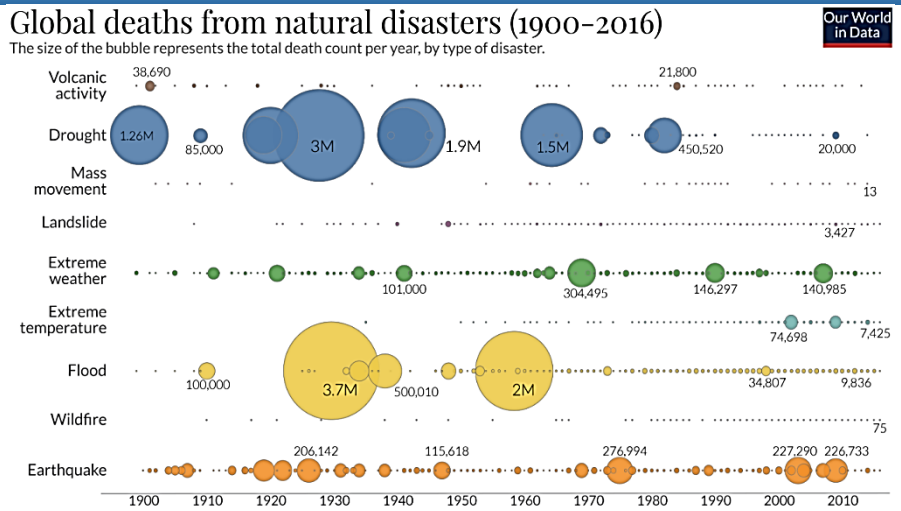
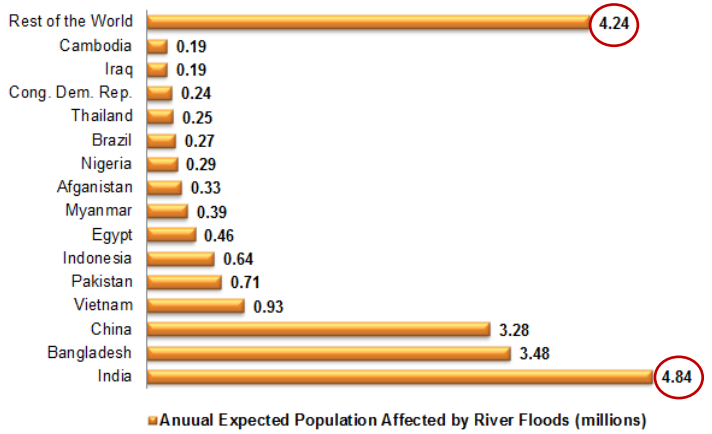
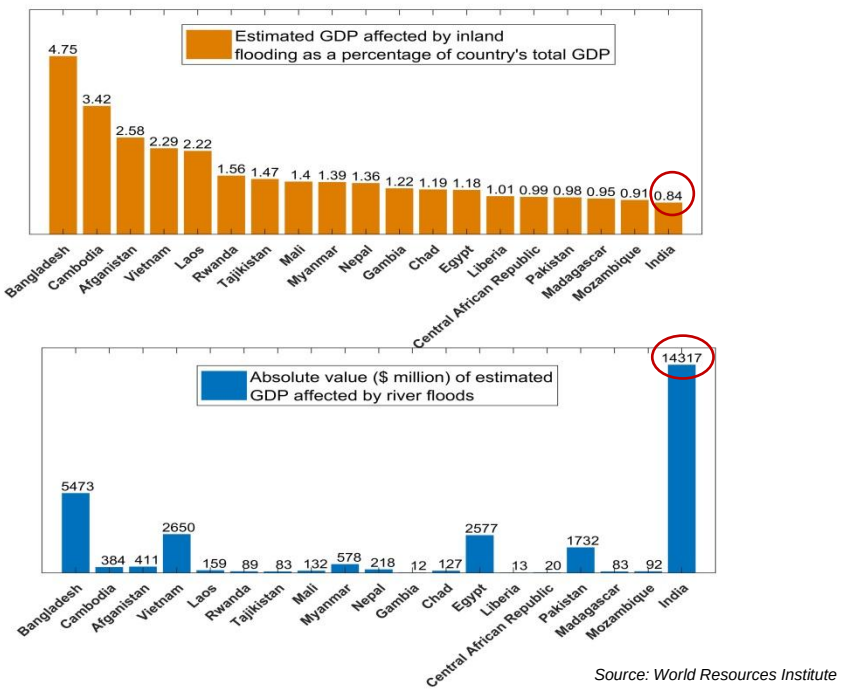
Flooding: A Global Challenge



Source: OFDA/CRED International Disaster Database



Source: World Resources Institute



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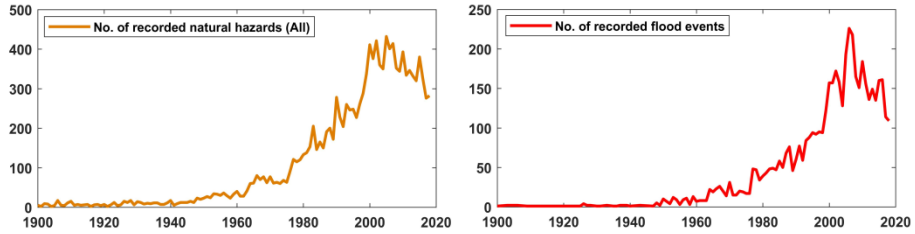
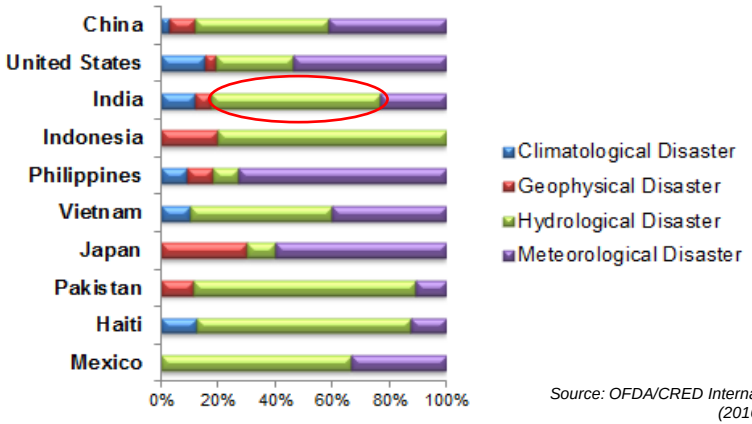


Source: OFDA/CRED International Disaster Database (2019)



Source: OFDA/CRED International Disaster Database (2016)

Flood Forecasting in India

Most of the techniques formulated for real-time flood forecasting in India, are based on-

Statistical, and

Deterministic approach.

Flood Forecasting Methods Presently Used in India are

Statistical correlations using gauge to gauge;

Gauge-discharge data;

Multiple coaxial correlations using gauge, rainfall, and antecedent precipitation index (API) data

The models like HEC-HMS, and MIKE-11 are being used by CWC, for hydrologic (rainfall-runoff) and hydrodynamic modelling for flood forecasting.

At present, CWC is issuing flood alerts with 3-day lead-time.

Limitations in the Present FF Techniques

Major Limitations:

- ✓ Lead-time of Deterministic forecasting is very short i.e. up to 72 hrs (i.e. 3 days).
- ✓ Predicting the flood for a lead-time of >72 hrs with the present FF techniques doesn't give satisfactory results.
- ✓ Errors in the observations (input), model structure, model parameters, and initial conditions, are not quantified.
- ✓ Deterministic techniques don't integrate meteorological models with hydrological models to generate flood forecasts.

Need of the Hour

- The techniques that integrates fine-scale weather forecast models with high-resolution distributed hydrological models to generate reliable flood forecasts are needed to be adopted.
- Also,
  i. identifying the source of uncertainty,
  ii. focusing on the cascading nature of uncertainties through the flood modelling system, and
  iii. quantification of uncertainty

is of primary importance in operational flood forecasting

Motivation

Limitations of Existing Flood Forecasting Systems in India (provided by CWC)

- Lead time is 12 to 36 hours
- Provide only single deterministic forecast
- Precipitation inputs from rain gauge networks

Advantage of using NWPs

- Provide ensemble forecasts
- Increase in lead time

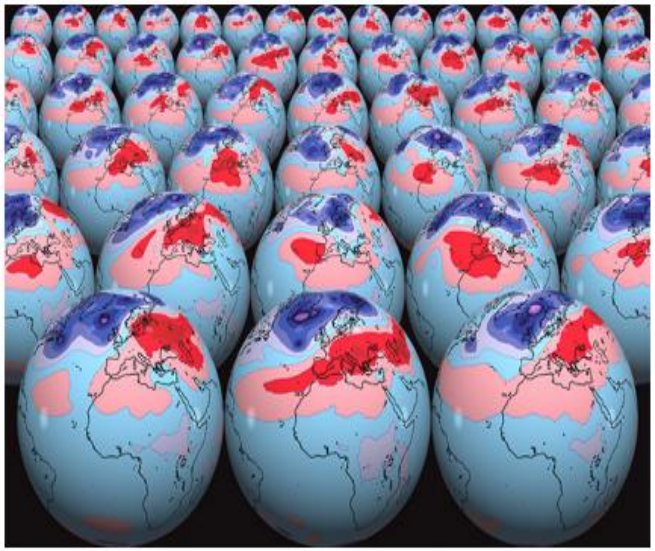
Deterministic vs. Ensemble

Deterministic Model

- Single forecast from one forecast model or method using a single set of initial conditions
- Deterministic runs usually have more skill than any individual ensemble member due to superior resolution

Ensemble Model

- Collection of “member” forecasts verifying at the same time created from:
  - Different but equally viable initial conditions
  - Different forecasting methods and/or models that statistically represent nearly all forecast possibilities
- Ensemble mean can be more skillful than a higher-resolution deterministic run, especially beyond ~3 days



Source: Blake & Bernnam (2016)

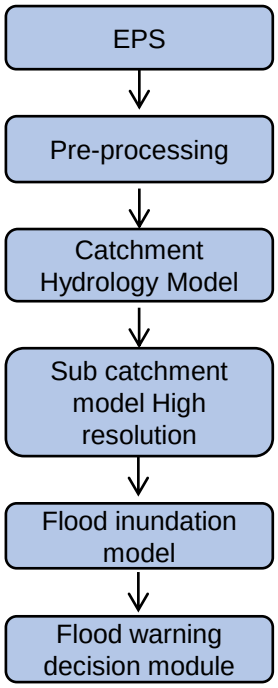
Ensemble Flood Forecasting, Why?

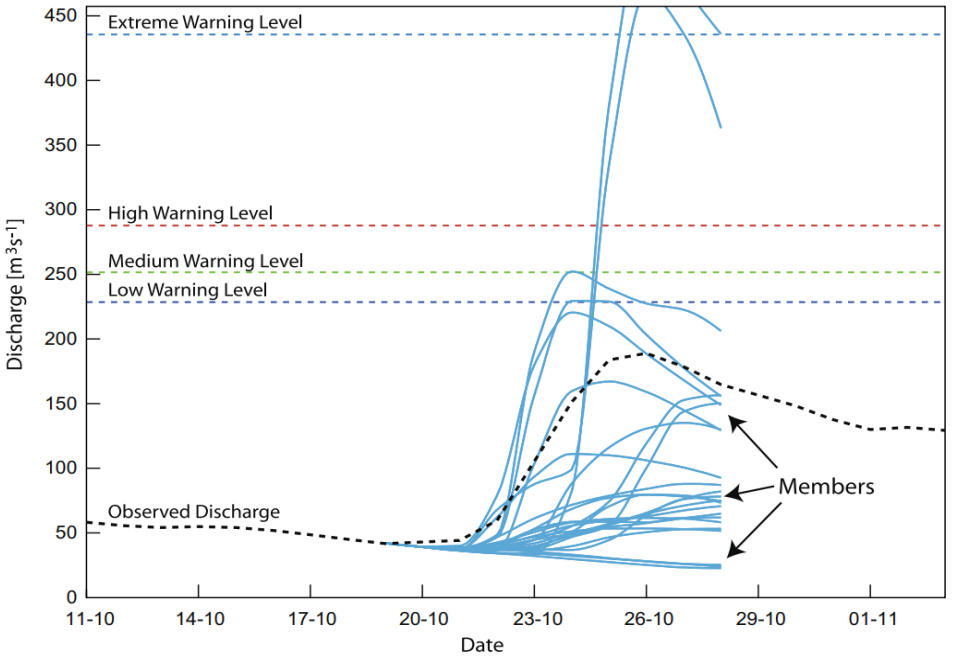
Reason	Reference
Operational and research flood forecasting systems around the world are increasingly moving towards using ensembles of Numerical Weather Predictions (NWPs), known as Ensemble Prediction Systems (EPS), rather than single deterministic forecasts, to drive their flood forecasting systems	***Cloke & Pappenberger, 2009***
The use of meteorological ensembles to produce sets of hydrological predictions increased the capability to issue flood warnings	***Balint et al., 2006***
The hydrological ensemble predictions have greater skills than deterministic ones	***Roulin, 2007***
The use of EPS in hydrological forecasting proved to be of great added value to a flood early warning system, as the EPS-based forecasts showed in general higher skill than the deterministic-based ones	***Bartholmes et al., 2009***
Even if the flood peak is first forecast with an error of one or two days [...] and is underestimated [...], the information given by the ensemble forecast can be of use for flood warning or water management agencies	***Regimbeau et al., 2007***
A list a large number of case studies and long term evaluations showing the added value of EPS.	***Cloke & Pappenberger , 2009***

Ensemble Flood Forecasting, What?

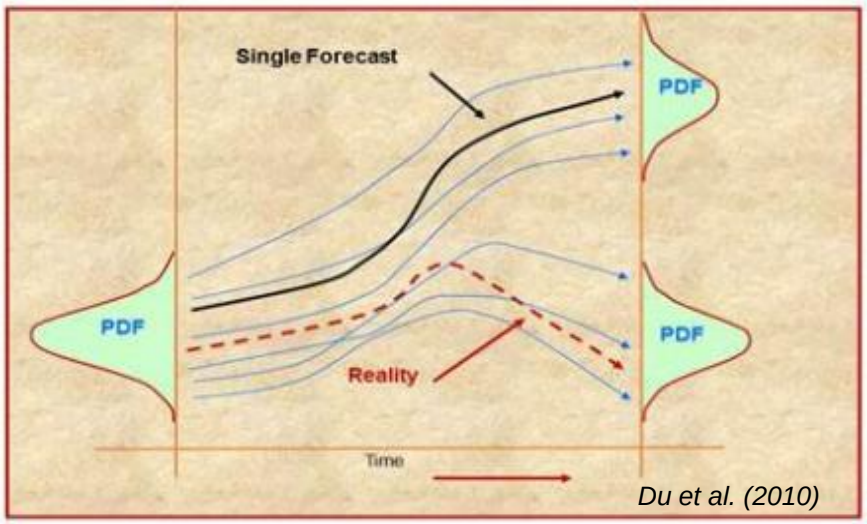
This usually involves using EPS as input to a hydrological and/or hydraulic model to produce river discharge predictions, often supported by some kind of Decision Support System.

- Multiple inputs (EPS), multiple-model
- Probabilistic predictions
- Take into account uncertainty



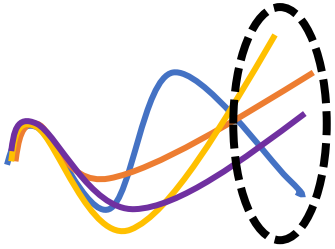


Cloke & Pappenberger (2009)



Du et al. (2010)

Forecasting Chain in Ensemble Flood Forecasting

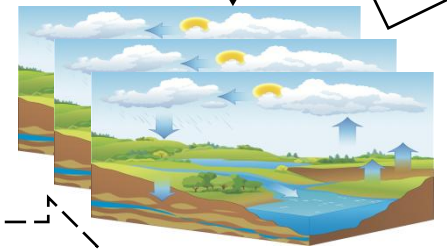


EPS

Multi-model

Hydraulics

Pre-Processing
Downscaling,
Bias correction, etc.



Hydrology

Post-Processing
Threshold exceedance
(members, probability, etc.)

Feedback to the model

Warning

Flood Watch

Flood Warning

Severe Flood Warning

Verification with the real scenario

Potential for Medium range (2-15 days lead time) Early Flood Warning

Source: Cloke (2009)

Users of EPS

Forecast Center	Ensemble NWP input
European Flood Alert System (EFAS) of the European Commission Joint Research Centre	ECMWF, COSMO-LEPS
Georgia-Tech/Bangladesh project	ECMWF
Finnish Hydrological Service	ECMWF
Swedish Hydro-Meteorological Service	ECMWF
Advanced Hydrologic Prediction Services (AHPS) from NOAA	US National Weather Service (NOAA)
MAP D-PHASE (Alpine region)/Switzerland	COSMO-LEPS
Vituki (Hungary)	ECMWF
Rijkswaterstaat (The Netherlands)	ECMWF, COSMO-LEPS
Royal Meterological Institue of Belgium	ECMWF
Vlaamse Milieumaatschappij (Belgium)	ECMWF
Météo France	ECMWF and Arpege EPS
Land Oberoestereich, Niederoestereich, Salzburg, Tirol (Austria)	Integration of ECMWF into Aladin
Bavarian Flood Forecasting Centre	COSMO-LEPS

Various centers (mainly in Europe) use EPS mostly from European Centre for Medium-Range Weather Forecasts (ECMWF) to drive hydrological ensemble prediction systems *Cloke & Pappenberger (2009)*

EPS in Hydrology-A Global Review

European Flood Awareness System (EFAS)

- Inputs from European Centre for Medium-Range Weather Forecast
- Lisflood Hydrological Model – forecasts daily discharge up to 15 days in advance
- Operational from 2012

Hydrologic Ensemble Forecasting System – US National Weather Service

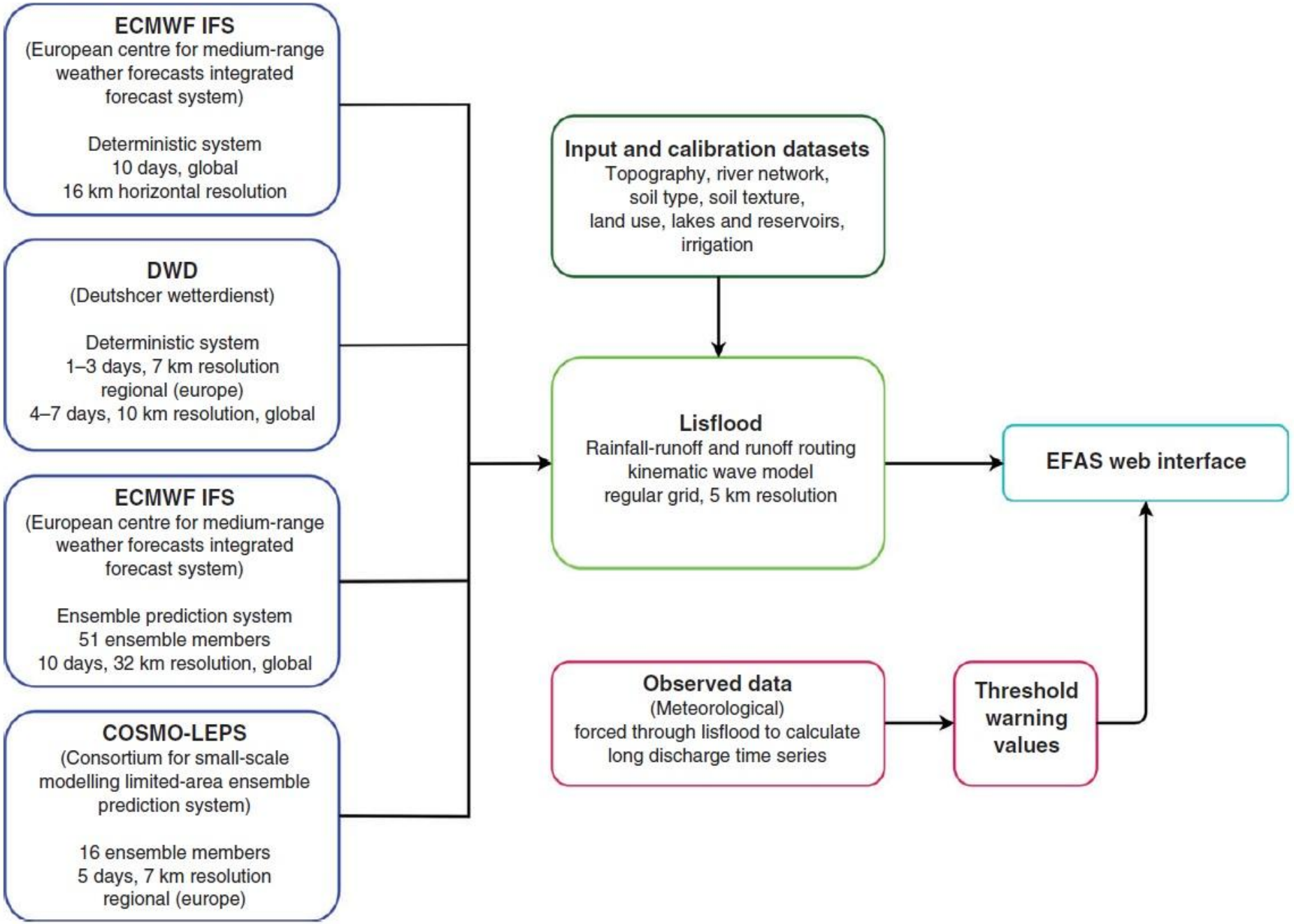
- Uses ensemble weather forecasts from Climate Forecast System of NCEP & Global Ensemble Forecast System

Flood Early Warning System for Po River (FEWSPo)

- Uses meteorological inputs from several models
- Forecasts flood 5 days in advance
- Also forecasts droughts 3 months in advance

Global Flood Awareness System (GloFAS)

- Developed by Joint Research Centre of European Commission and ECMWF
- Provide flood warning maps over global domain



Components of the European Flood Awareness System (EFAS).

Scientific Issues to be Addressed

- **How can the ensemble forecasts of weather and climate made by NWPs be used reliably to develop short range to medium range flood forecasting systems?**
- **How to downscale/ disaggregate the EPS forecasts to hydrological scale in Hydrological Ensemble Prediction Systems (HEPS)?**
- **How well do the existing hydrological models perform in predicting high floods?**
- **How can uncertainties (meteorological inputs, parameter uncertainty and spatial and temporal uncertainties caused due to downscaling) be represented in the hydrological ensemble prediction?**
- **How to effectively disseminate the probabilistic flood forecasts from HEPS to the end users?**

Key Challenges in Ensemble Flood Forecasting

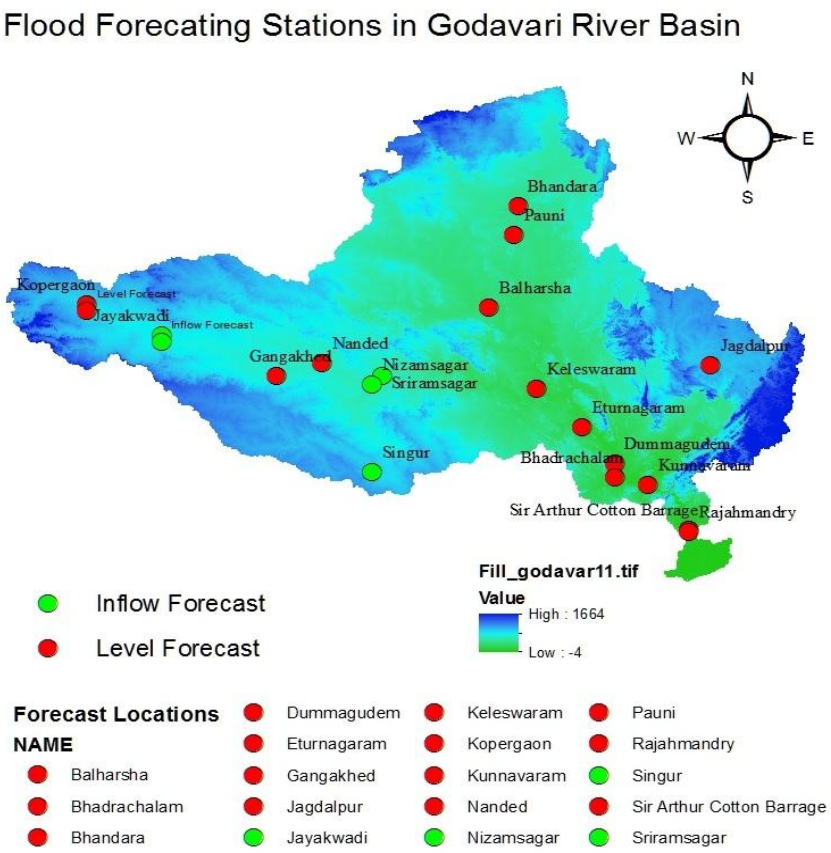
Challenge 1	• **Improvement of NWPs with more number of ensembles**
Challenge 2	• **Understanding the total uncertainty**
Challenge 3	• **Analysis of more case studies**
Challenge 4	• **Installation of enough computer power**
Challenge 5	• **Learning how to use it in an operational setting**
Challenge 6	• **Communicating the uncertainty & probabilistic forecasts**

Source: Cloke & Pappenberger (2009)

Short and Medium Range Flood Forecasting System for Godavari River Basin using Ensemble Weather Forecast

- To develop a flood forecasting system by coupling high resolution hydrological models with fine scale meteorological models. The ensemble precipitation forecasting models will be integrated with distributed hydrological model to provide flood forecast. Godavari basin will be used as a pilot study area
  - To identify suitable pre-processing techniques for downscaling/ disaggregating the ensemble weather forecasts from NWP to Hydrological Scale
  - To develop a multi-model hydrologic system for flow forecasting in a river basin
  - To integrate the weather forecasting system with hydrologic system to develop an ensemble flood forecasting system
  - To develop methodologies and models for communicating the probability flood forecasts to different levels of decision-making mechanisms

GODAVARI BASIN



Summary

- There is clearly the need both for more theoretical development of flood forecasting systems and a convincing all encompassing strategy for tackling the cascading of uncertainties in an operational framework.
- EPS are increasingly tested and applied for operational flood forecasting for early warning.
- EPS based forecasts allow earlier detection of floods and provide early warning. Decision making for Civil Protection based on EPS remains difficult.
- Uncertainty of EPS based flood forecasts can be reduced significantly through the use of threshold exceedance, persistency criterion and post-processing.
- A pilot study on developing an Ensemble Flood Forecasting System for River Godavari is being undertaken by NITW

Take Home Message

- In flood forecasting there is no one-size fits-all.
- Integration of different systems and methods is a major challenge.
- Any system does not have to be perfect but suitable.

Source: Pappenberger (2010)

References

- Balint, G., Csik, A., Bartha, P., Gauzer, B., Bonta, I., 2006. Application of meterological ensembles for Danube flood forecasting and warning. In: Marsalek, J., Stancalie, G., Balint, G. (Eds.), Transboundary Floods: Reducing Risks through Flood Management. Springer, NATO Science Series, Dordecht, The Netherlands, pp. 57–68.
- Bartholmes, J., Thielen, J., Ramos, M., Gentilini, S., 2009. The European flood alert system EFAS – Part 2: statistical skill assessment of probabilistic and deterministic operational forecasts. Hydrology and Earth System Sciences 13 (2), pp.141–153.
- Blake, E.S., Brennan, M.J., 2016. Ensemble prediction systems (Presentation).
- Cloke, H.L., Pappenberger, F., 2009. Ensemble flood forecasting: a review. Journal of Hydrology 375(3–4), pp. 613–626.
- Cloke, H.L., 2009. Ensemble flood forecasting (Presentation).
- Debarati, G.S., 2016. Annual disaster statistical review 2016.
- Du, J., Deng, G., 2010. The utility of the transition from deterministic to probabilistic weather forecasts: verification and application of probabilistic forecasts. Meteorological Monthly, 36(12), pp. 10-18.
- Pappenberger, F., 2009. Application in hydrology and real-time flood forecasting (Presentation).
- Regimbeau, F.R., Habets, F., Martin, E., Noilhan, J., 2007. Ensemble streamflow forecasts over France. ECMWF Newsletter 111, pp. 21–27.
- Roulin, E., 2007. Skill and relative economic value of medium-range hydrological ensemble predictions. Hydrology and Earth System Sciences 11 (2), pp. 725–737.
- Ritchie, H., Roser, M., 2019. "Natural Disasters". Published online at OurWorldInData.org.

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Thank You