Use of Bayesian Model Averaging to determine Uncertainties in River Discharge and Water Level Forecasts

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Content

- Water level forecasts in The Netherlands
- Historical overview
- FEWS NL
- Dealing with uncertainties
- Application of BMA in FEWS NL


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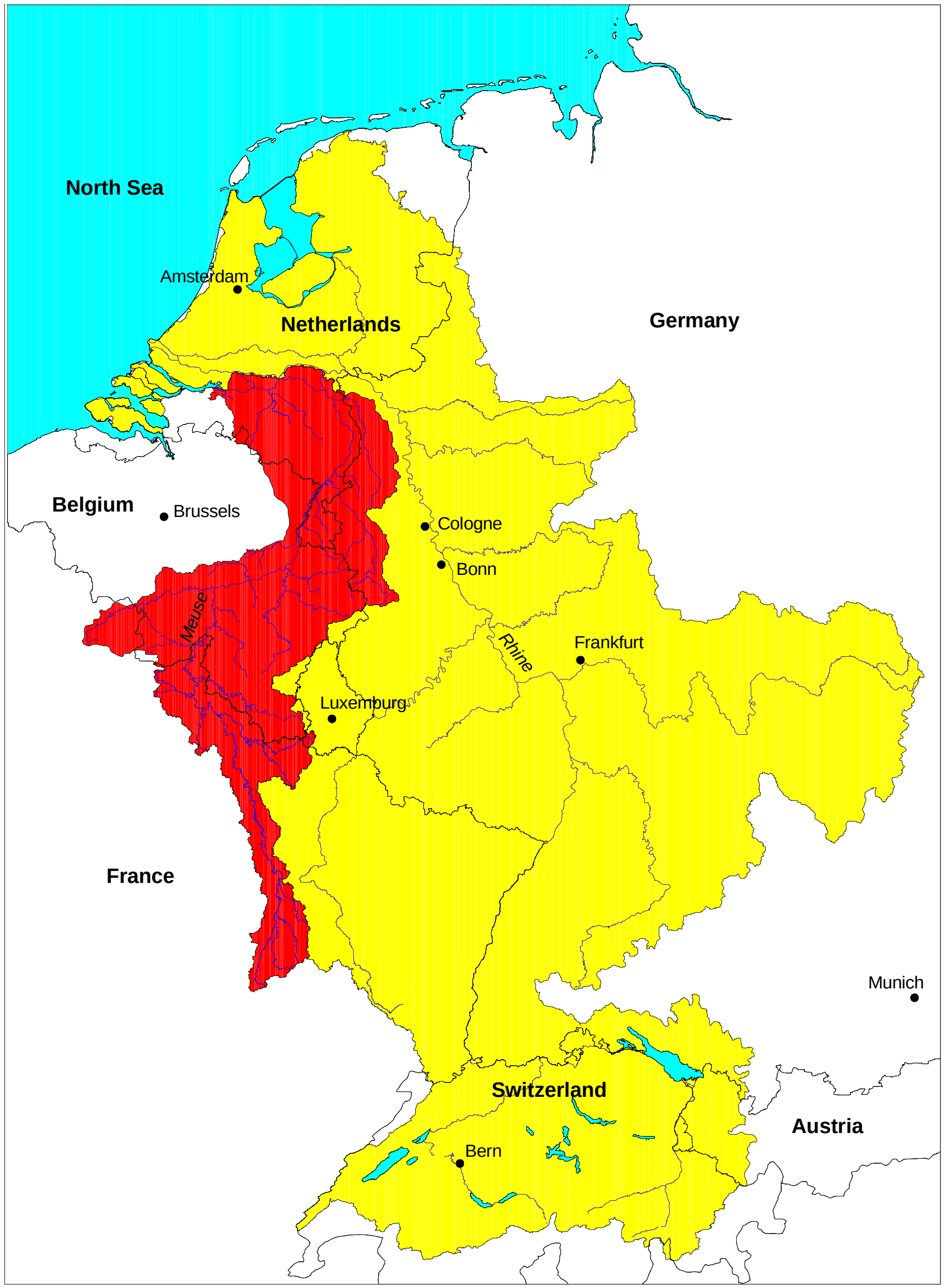
Importance of water level forecast

- 25% of the country below sea level
- 60% of the country potentially threatened by floods
- 9 million people in the endangered zone
- 65% of the GNP is earned in this part of the country
- Potential economic damage of floods estimated at appr. 1,200 billion Euro
- Preparation time for evacuation of a larger area is about 2,5 – 3 days

When do we make forecasts?

- Daily forecast every day (365 d/y) for navigation and river management
- Flood forecasts when the water level comes above a warning level and further rise expected.
  At least twice a day. For navigation, population and flood management
- Low flow forecasts when the discharge comes below the low flow criterion.
  Up to once a week. Indicative medium range forecast.
  For navigation, agriculture, ecology, availability of cooling and drinking water



North Sea
Amsterdam
Netherlands
Germany
Belgium
Brussels
Cologne
Bonn
Meuse
Rhine
Frankfurt
Luxemburg
France
Munich
Switzerland
Austria
Bern

Characteristics

	Rhine	Meuse
Basin area	185.000 km^2	36.000 km^2
Length	1,320 km	935 km
Type	snow + rain	rain
Q mean	2,300 m^3/s	230 m^3/s
Q max	13,000 m^3/s	3,000 m^3/s

Historical overview of the development of forecasting systems

- till January 1999: statistical model LOBITH based on multiple linear regression
- input: water levels, discharges, observed and forecasted precipitation
- output: water level forecasts for the gauging station Lobith for the next 4 days

Why an other approach?

- After the floods of 1993 and 1995 international agreements were made to extend the lead time of reliable forecasts
- Improvement of the existing model did not lead to the desired result
- Expected changes in the basin ask for a more physical way of modelling

Development of FEWS NL

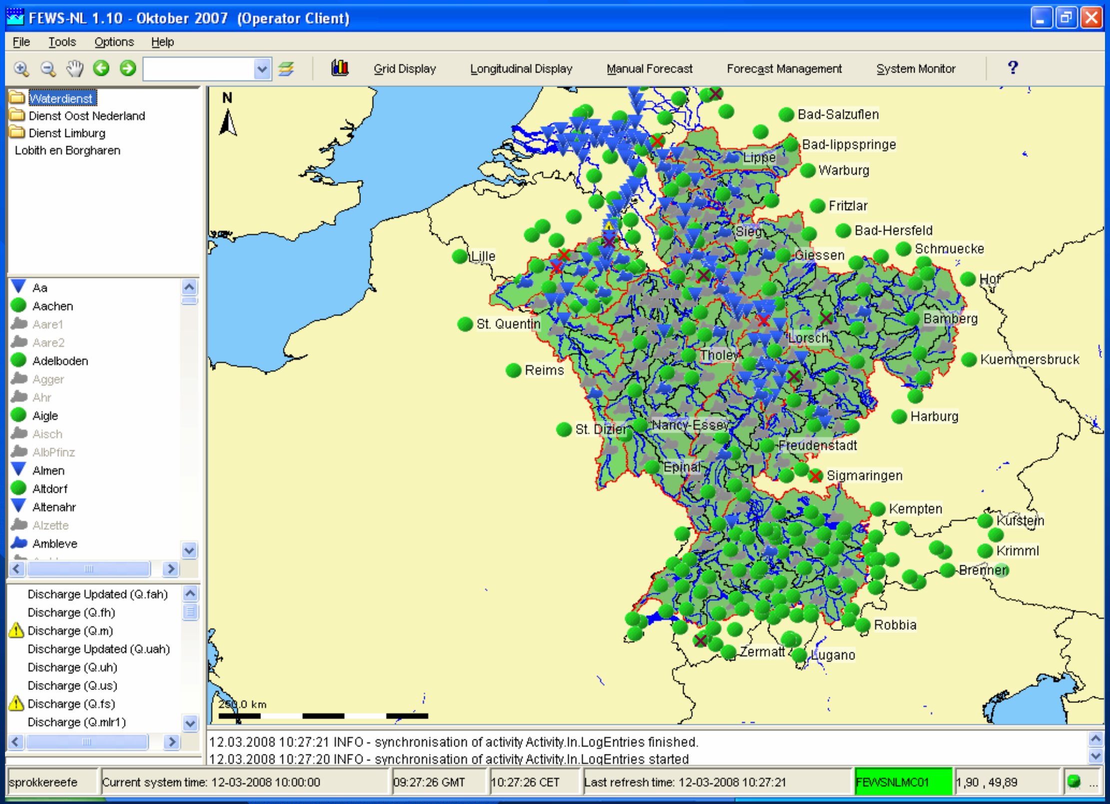
- Start of the project in 1996
- Financed by 2 EU frame work projects
- Cooperation with BfG (D) and FOEN (CH)
- Contracts to Deltares (formerly Delft Hydraulics) and SMHI

New aspects

- Combination of hydrological and hydraulic models
- Medium range forecasts (4 – 10 days)
- Introduction of multiple weather forecasts
- Use of ensemble weather forecasts
- Client server / multi user
- Rhine and Meuse in one application
- Simulation for the entire basin
- Improvement through data assimilation techniques

Observations

- Water stages from appr. 60 gauges
- Precipitation and air temperature at more than 600 stations



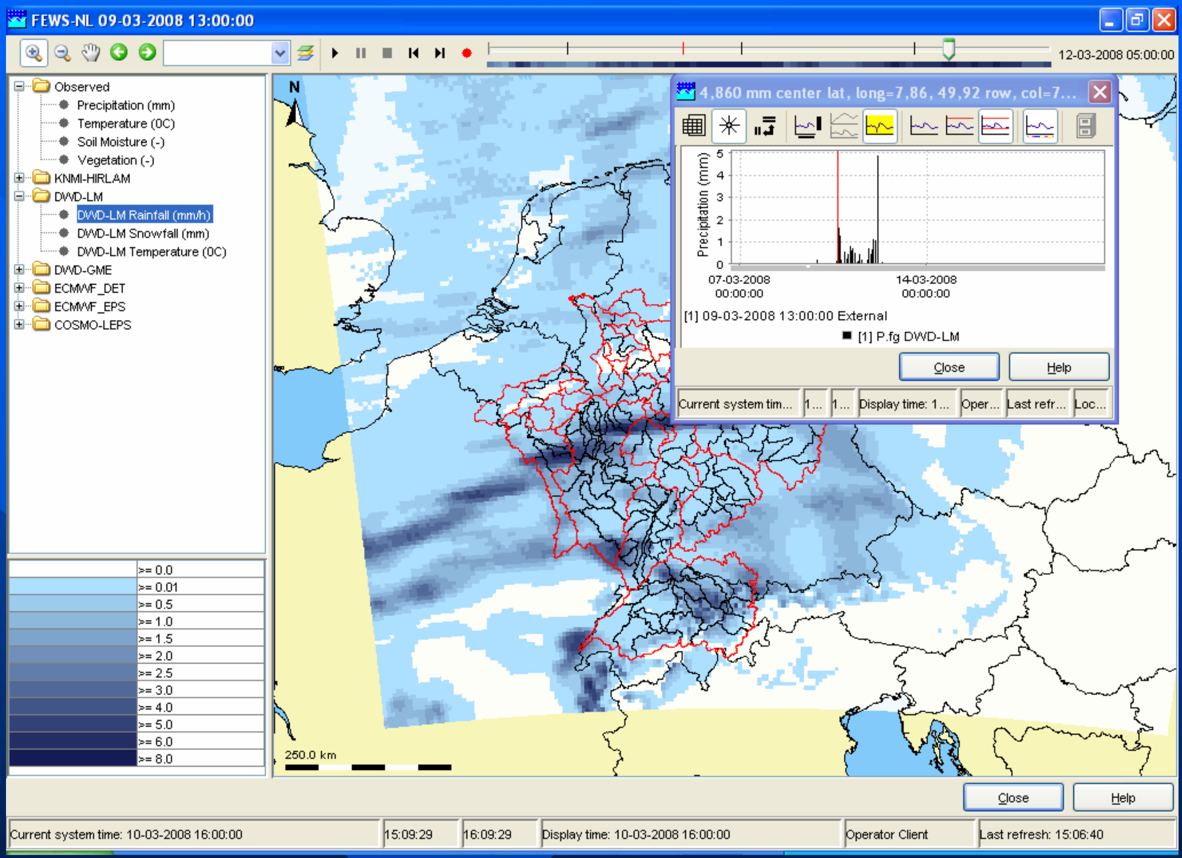
Planned

- Data from precipitation radar
- Observed soil moisture
- Potential evaporation

Weather forecast data

Numerical Weather Prediction grids

- KNMI-HIRLAM
  - 48 hrs lead time
- DWD-LM2
  - 78 hrs lead time
- DWD-GME
  - 174 hrs lead time
- ECMWF deterministic
  - 240 hrs lead time
- ECMWF ensemble
  - 240 hrs lead time
  - 51 ensemble members
- COSMO LEPS
  - 160 hrs lead time
  - 16 ensemble members

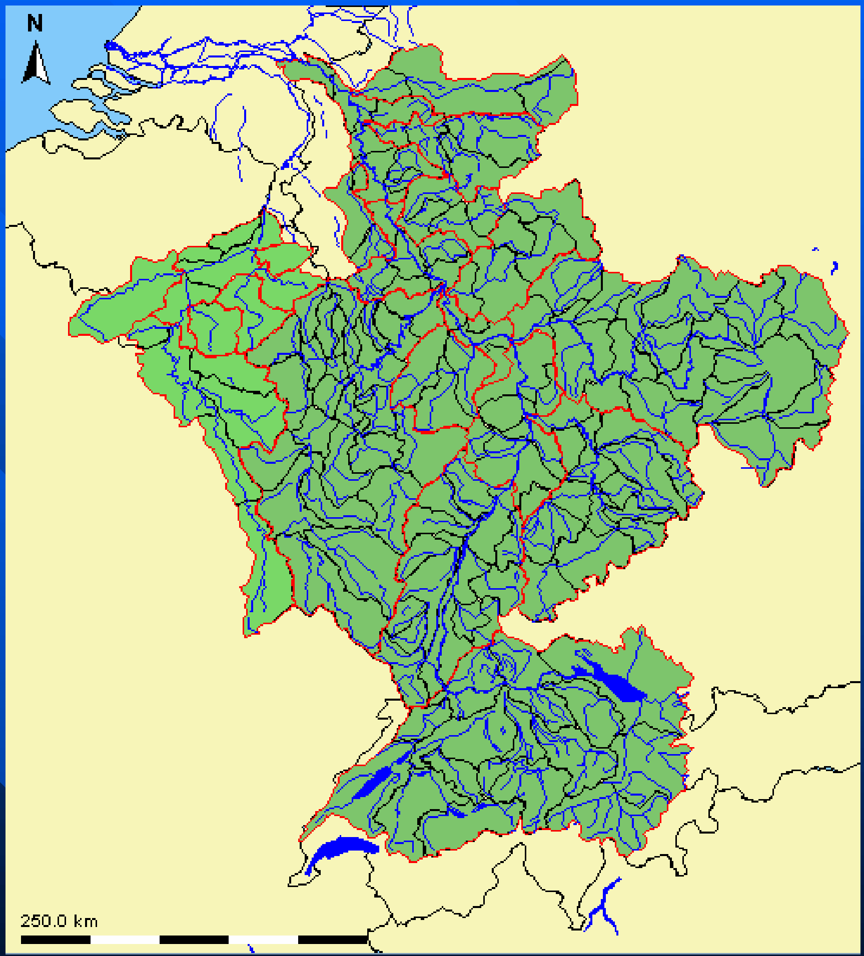


LM2 Forecast: 09-03-2008 13:00 UTC

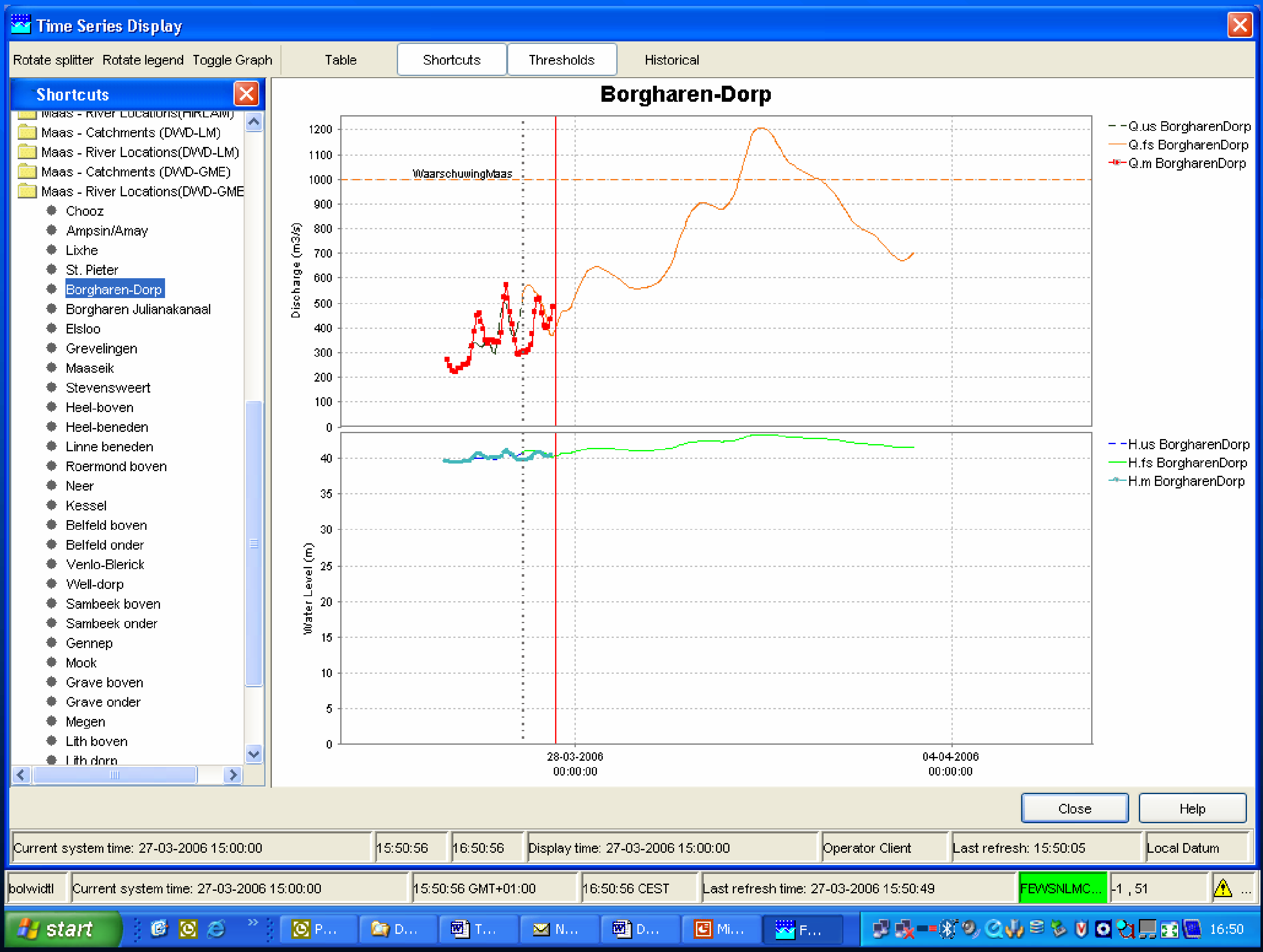
Forecasting Models

HBV Hydrological Model
- ⇔ Rhine 134 catchments
- ⇔ Meuse 15 catchments

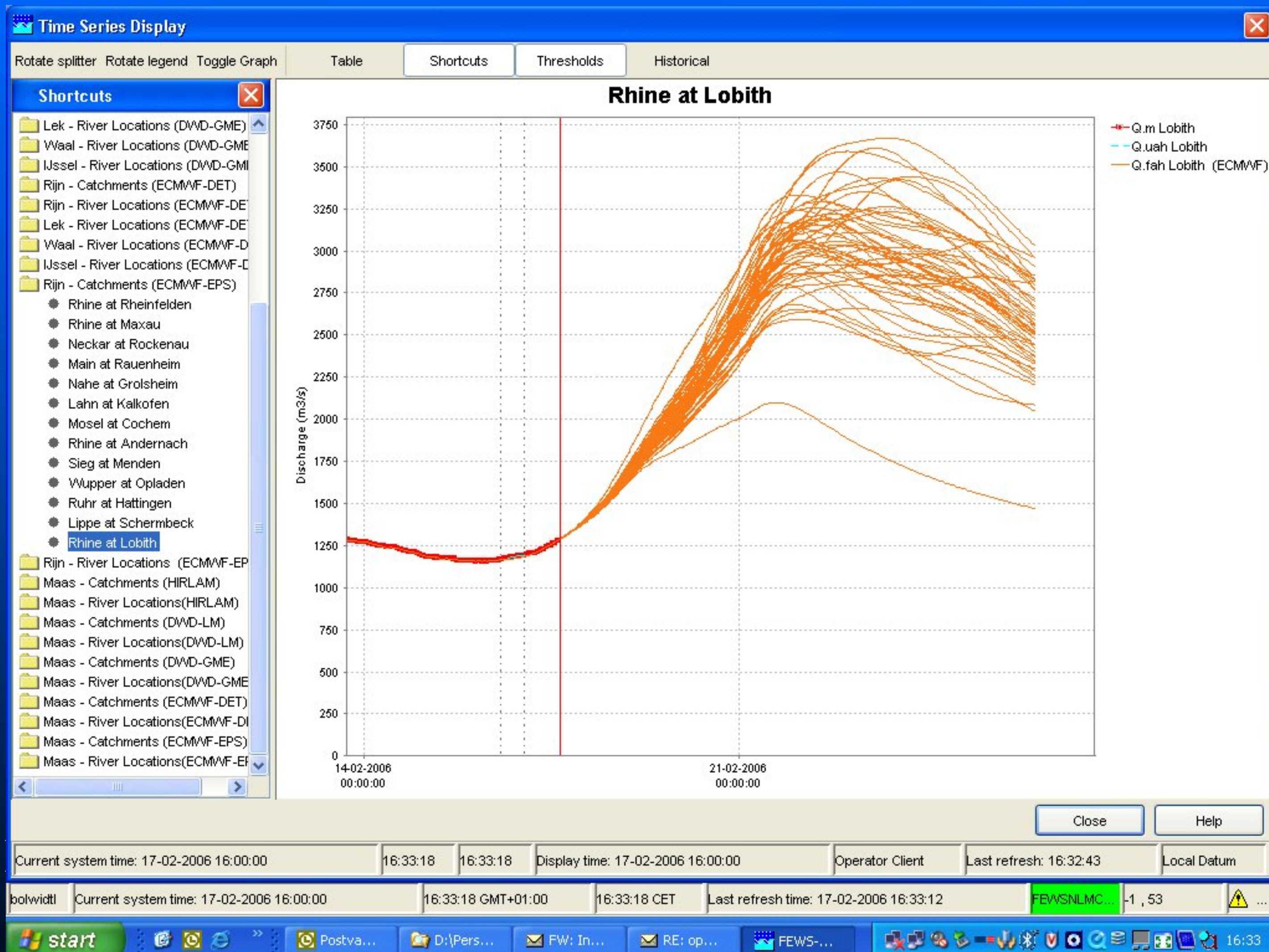
Sobek hydraulic model
- ⇔ Rhine Maxau-Lobith
- ⇔ Meuse Chooz-Borgharen



Forecasting results deterministic



Forecasting results probabilistic



What to do with all the information?

- 71 different water level/discharge forecasts
- Information about the (un)certainty of the forecasts
- But the spread in the ensemble members cannot be translated directly into uncertainty
- Ensembles need to be calibrated to correct errors in the probability distribution

Calibration of competing forecasts with Bayesian Model Averaging (BMA)

- Correction of spread and bias on the basis of historical time series
- Generation of overall forecast probability distribution through weighted average of individual forecast probability distributions
- Weights represent model performance in training period

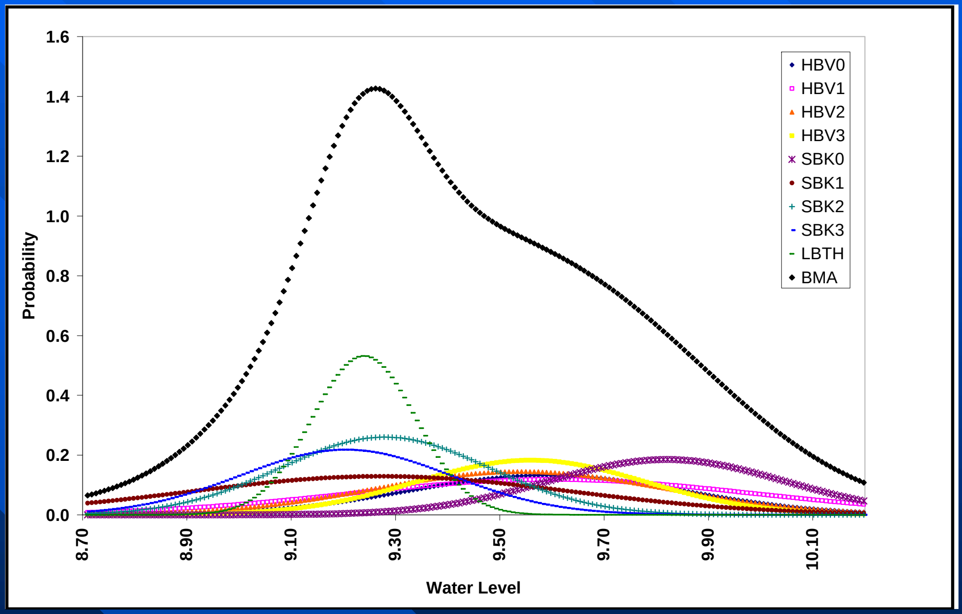
[Ref.: Hoeting, Madigan, Raftery & Volinsky in Statistical Science 14, pp 382-417 (1999)]

Application of BMA in FEWS NL (1)

The overall forecast probability is a combination of:

- the spread between the individual forecasts and

- the observed uncertainty of each individual forecasts in the training period



Application of BMA in FEWS NL (2)

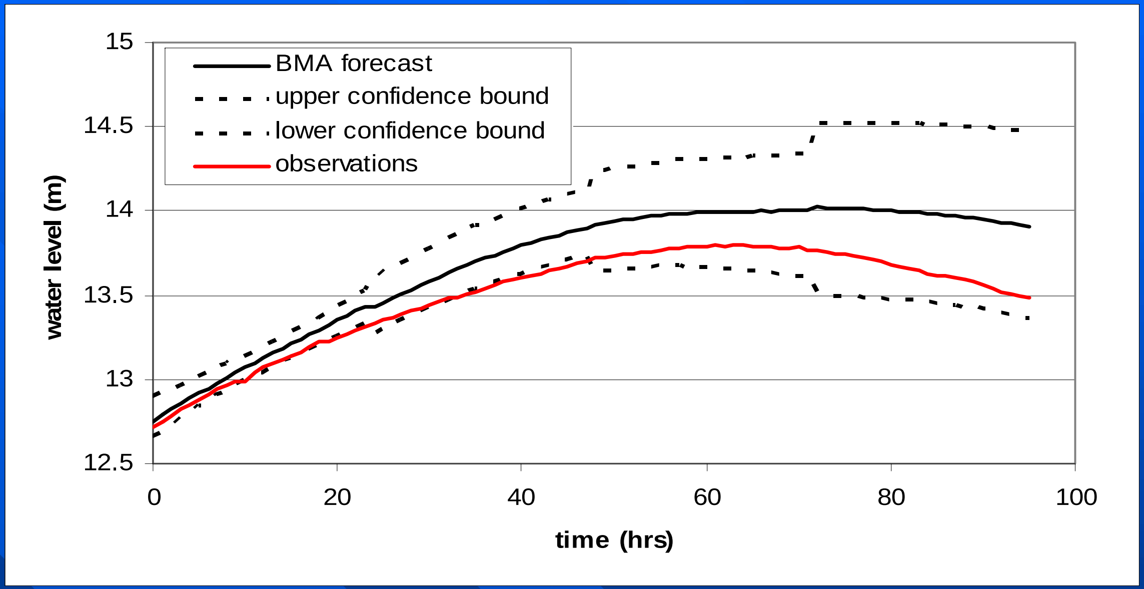
Forecast	Meteorological input	Hydrological/ hydraulic model	RMSE (24-48 hrs)	RMSE (48-72 hrs)	RMSE (72-96 hrs)
1	HIRLAM	HBV	0.252	0.329	0.428
2	ECMWF	HBV	0.249	0.313	0.379
3	DWD-LM	HBV	0.249	0.302	0.347
4	DWD-GME	HBV	0.249	0.306	0.345
5	HIRLAM	HBV/SOBEK	0.196	0.258	0.381
6	ECMWF	HBV/SOBEK	0.196	0.250	0.340
7	DWD-LM	HBV/SOBEK	0.195	0.238	0.314
8	DWD-GME	HBV/SOBEK	0.195	0.239	0.303
9	LobithW (statistical model)		0.176	0.250	0.366
BMA mean forecast			0.179	0.235	0.307

RMSE of the individual forecasts and the BMA mean forecast for different lead times.

Application of BMA in FEWS NL (3)

BMA forecasts can be used to calculate a confidence interval.

Example with 10% upper and lower bounds



Conclusions and outlook

- BMA is a promising method that produces probabilistic forecast, which can be used to calculate a confidence interval
- In the investigated period (2007) BMA mean forecast generally resulted in a lower RMSE compared to the individual forecasts
- BMA was consistently optimal
- Further investigations will be performed to optimize the method

All models are wrong, some are useful
[George Box, 1979]

Thank you very much for you attention