Deltares
Enabling Delta Life

Visualisierung operationeller Daten, Ermittlung und Reduzierung von Vorhersageunsicherheiten, Real Time Control

Visualisation des données opérationelles, détermination et réduction des incertitudes des prévisions, Real Time Control

Martin Ebel

Internationaler LARSIM-Anwenderworkshop Kaiserslautern
22./23. März 2010

Gliederung

- Datenvisualisierung mit Delft-FEWS
- Data Assimilation Tools
  zur Hochwasser-Vorhersage
- Real Time Control Tools –
  operationelle Steuerung von Retentionsräumen

Deltares - WL | Delft Hydraulics

2008 hervorgegangen aus Fusion von

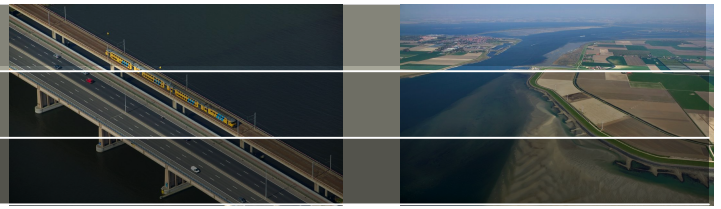
WL | Delft Hydraulics
- Ende 2007: knapp 360 Mitarbeiter
- Schwerpunktaktivitäten
  - Angewandte Forschung in den Bereichen
    Integriertes Wassermanagement, Hochwasser, Dürre, etc.
  - Physikalische Modellierung
  - Spezialisierte Software
  - Expertenberatung fuer Ingenieurunternehmen und staatliche Organisationen

GeoDelft (Geotechnisches Forschungsinstitut)
TNO (Grundwasserabteilung)
RIZA & RIKZ (Forschungsabteilungen niederländischer Fachbehörden)

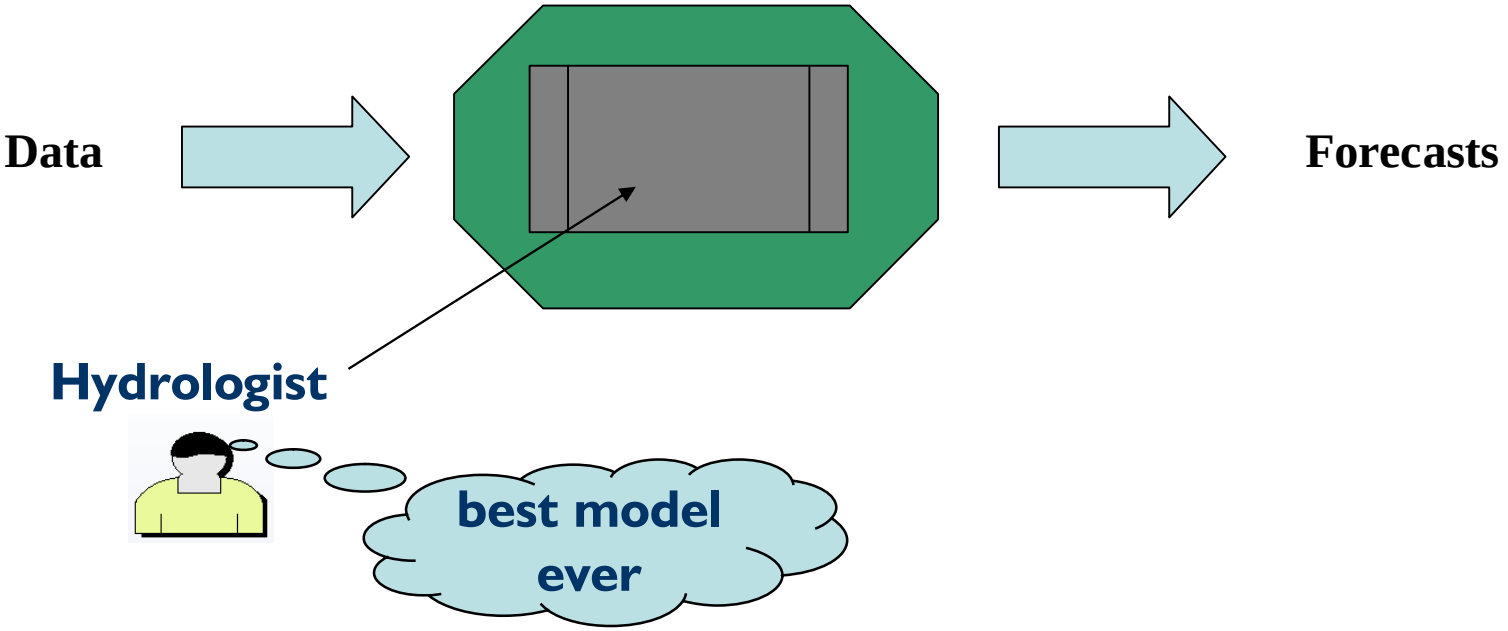
- Not-for-Profit Stiftung
- ca. 900 Mitarbeiter

Forschungs- und Experten-Beratungsinstitut mit hoheitlichen Aufgaben

Why Delft-FEWS ?



Traditionally model centric developments around existing models



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Current trends and challenges…

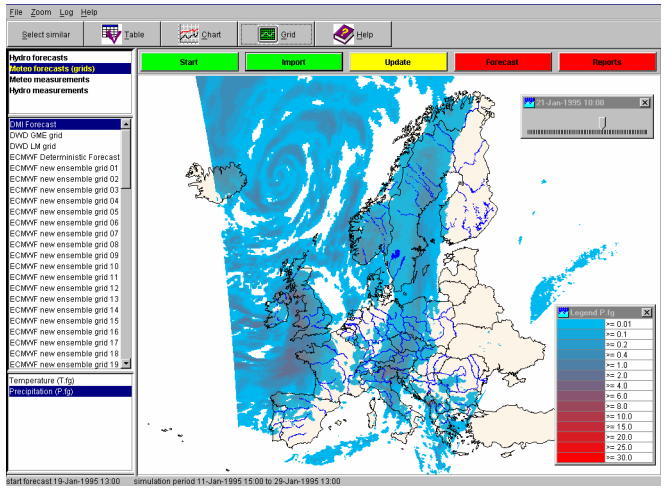
Increasing availability of weather forecast data

- Numerical Weather Prediction
- Radar data

On-line observations (precip., fluvial)

Changing modelling requirements

- *State of the art modelling*
- *model A instead of / plus model B*
- *data assimilation*



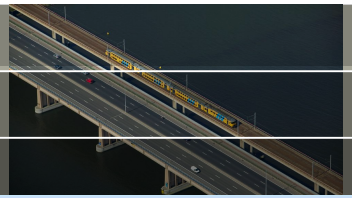
Challenges:

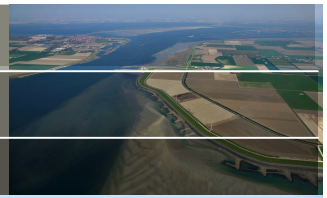
Efficient handling of large datasets

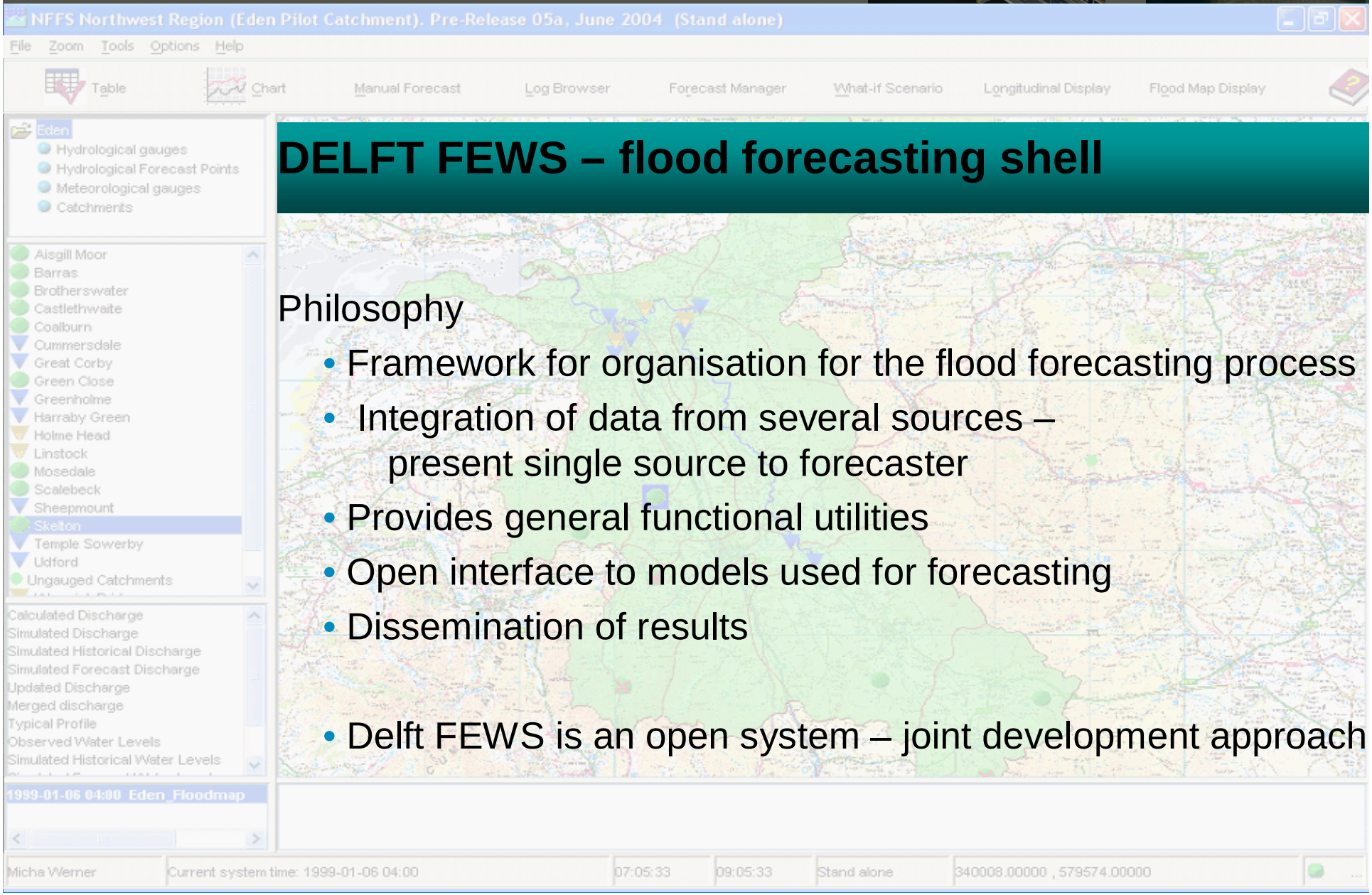
Flexible and open system to enable easy model integration

Working with uncertainties

Data centric approach







DELFT FEWS – flood forecasting shell

Philosophy

- Framework for organisation for the flood forecasting process
- Integration of data from several sources – present single source to forecaster
- Provides general functional utilities
- Open interface to models used for forecasting
- Dissemination of results

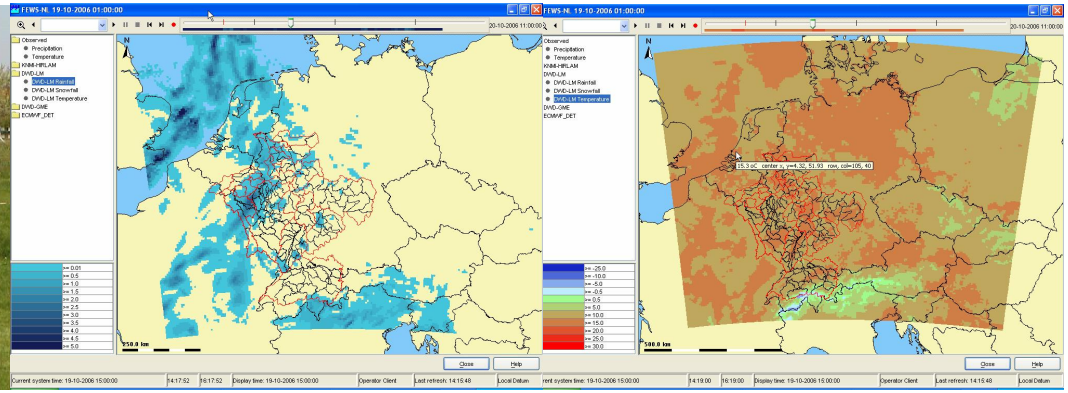
- Delft FEWS is an open system – joint development approach

Integration of data

Interfaces to data sources

- Supports many standards in data exchange formats: xml, ascii, GRIB, NetCDF, many custom made imports (e.g. LUBW SYN-Format), etc.
- Data exchange with HIMS (e.g. WISKI)
- Plugin-technology to extend integration of data formats
- Emerging standards: WaterML – OpenGIS standard for exchange of hydrological data (USGS, NWS, CUAHSI)

list of current import formats:
http://public.deltares.nl/display/FEWSDOC/Available+data+types



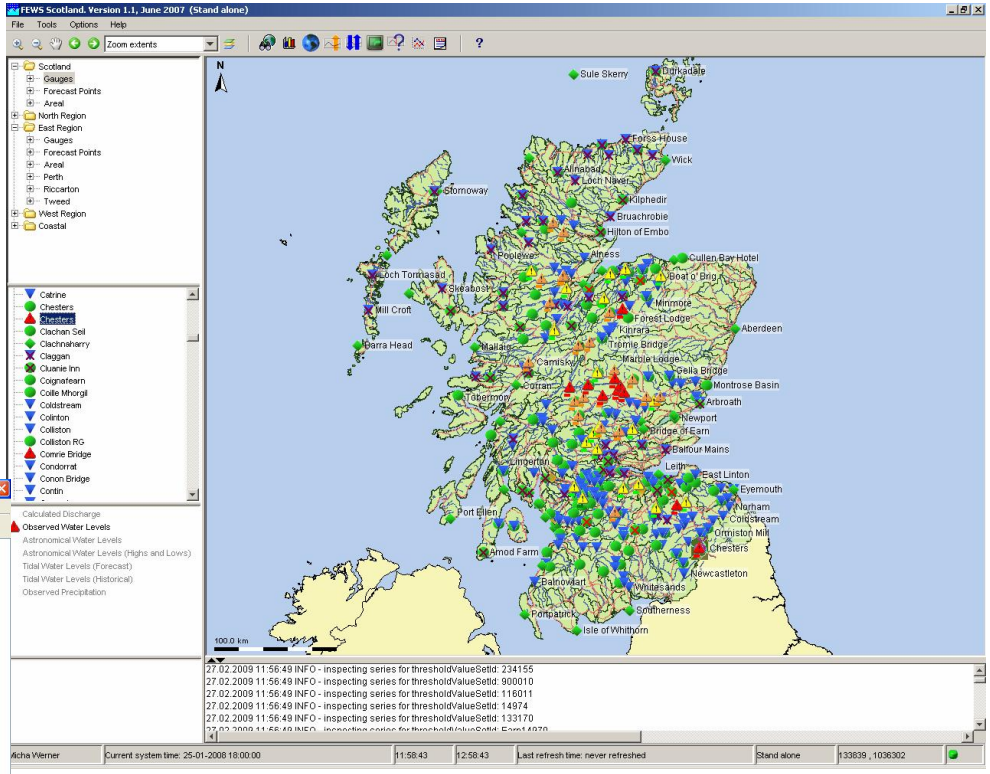
Providing the forecaster an interface to data…

Simple graphical user interface

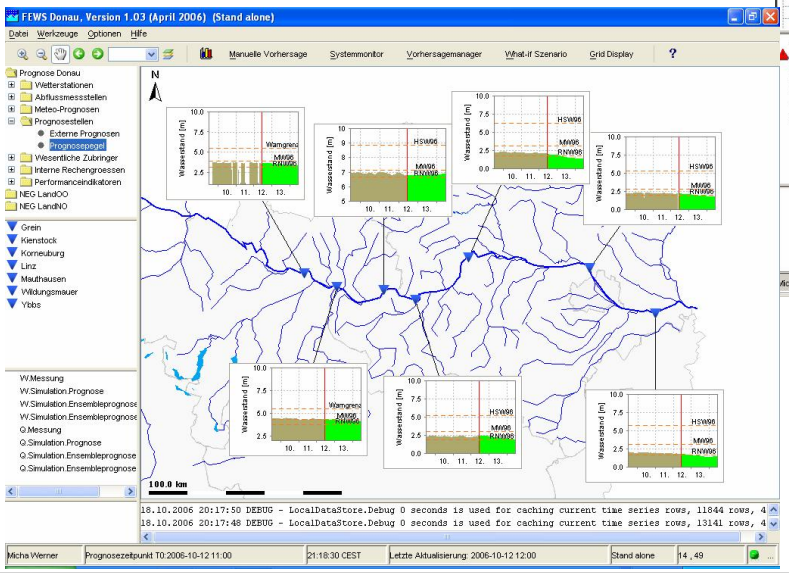
Self explanatory

Key features

- GIS Based
- Overview of data & status



FEWS Scotland – flood status in several catchments, January 2008



FEWS Donau (Austria) – Graphs at key stations

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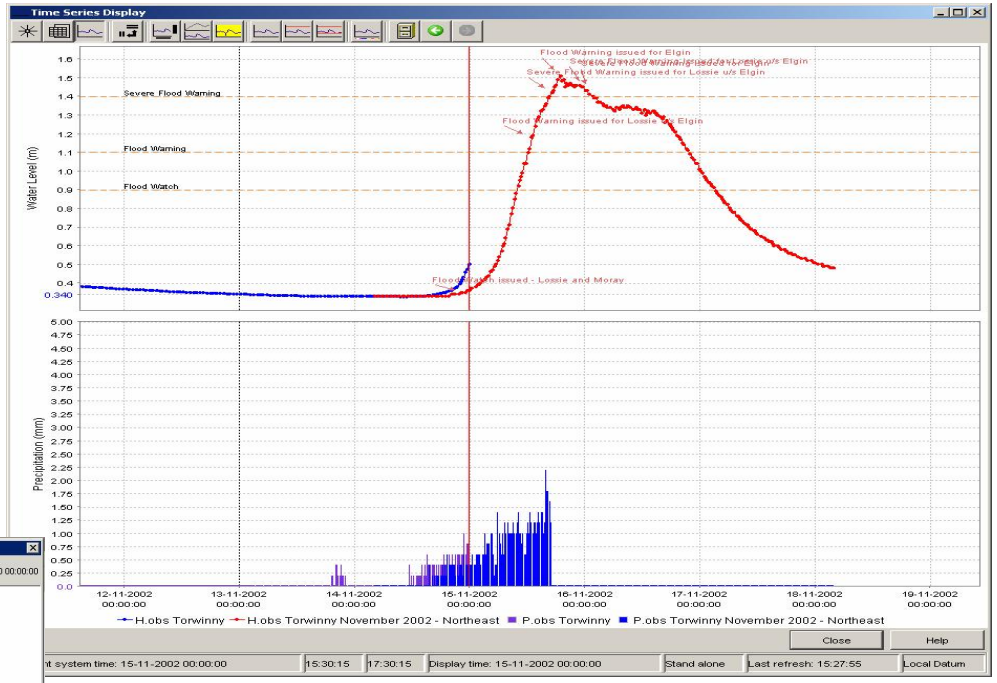
Data visualisation and editing – Graphical data

Powerful graphical tools for viewing time series data

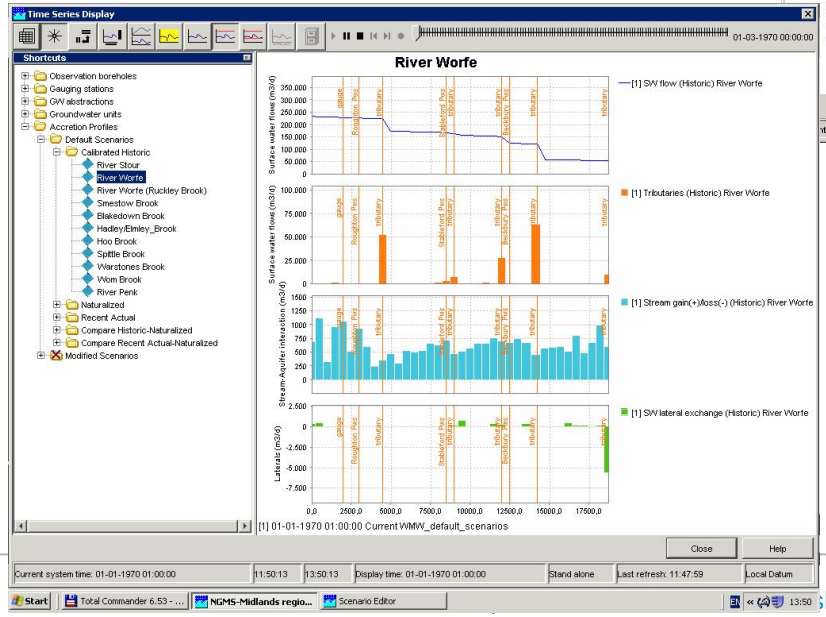
Point time series

Longitudinal profiles (animated)

Editing capabilities –
copy to-from e.g. Excel



Historical event at Torwinny, Scotland



Longitudinal Display

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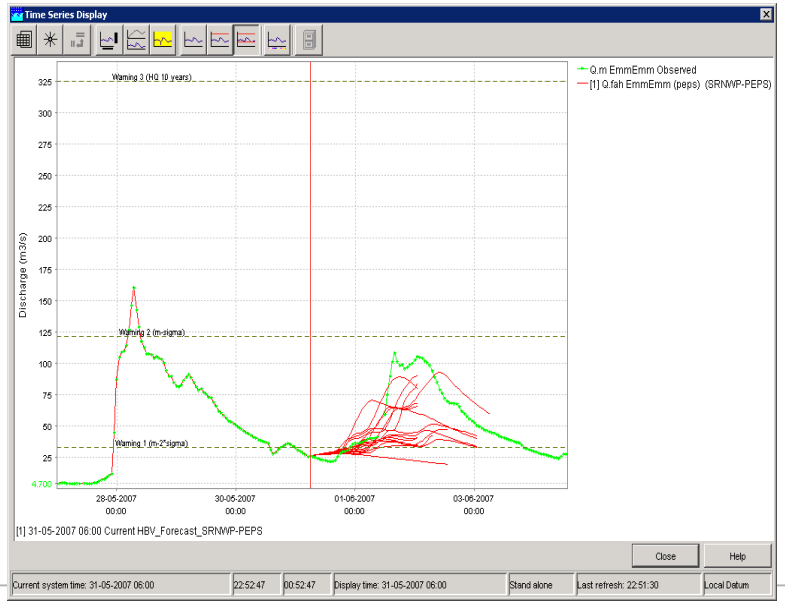
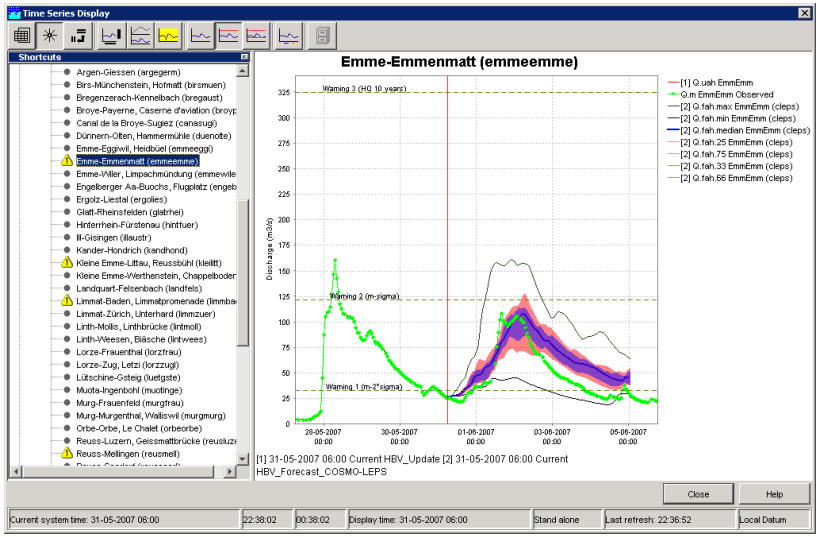
Using and displaying probabilistic data

Delft FEWS database model is inherrently ensemble aware

- Import ensemble data (e.g. ECMWF, COSMO-LEPS)
- Run models for ensemble members
- results
  - statistical summary
  - verification



FEWS-CH:
SRNWP-PEPS Forecast for 31-05-2007 00:00 UTC



FEWS-CH:
COSMO-LEPS Forecast for 31-05-2007 00:00 UTC

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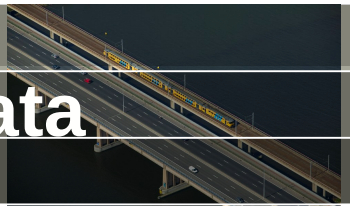
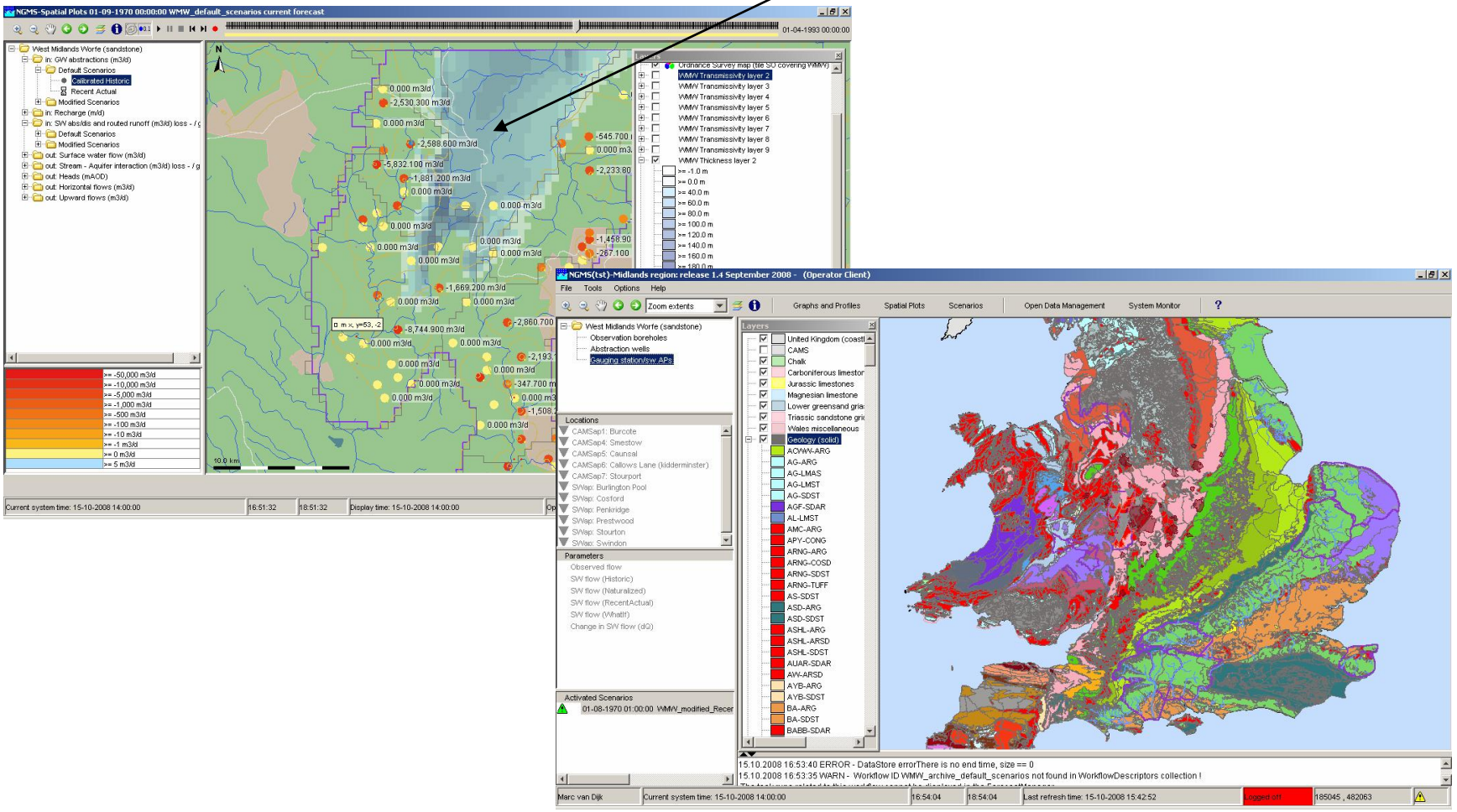
Data visualisation – Spatial Data



Animate Flood Inundation Map



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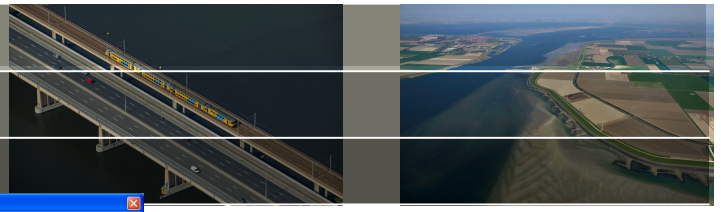
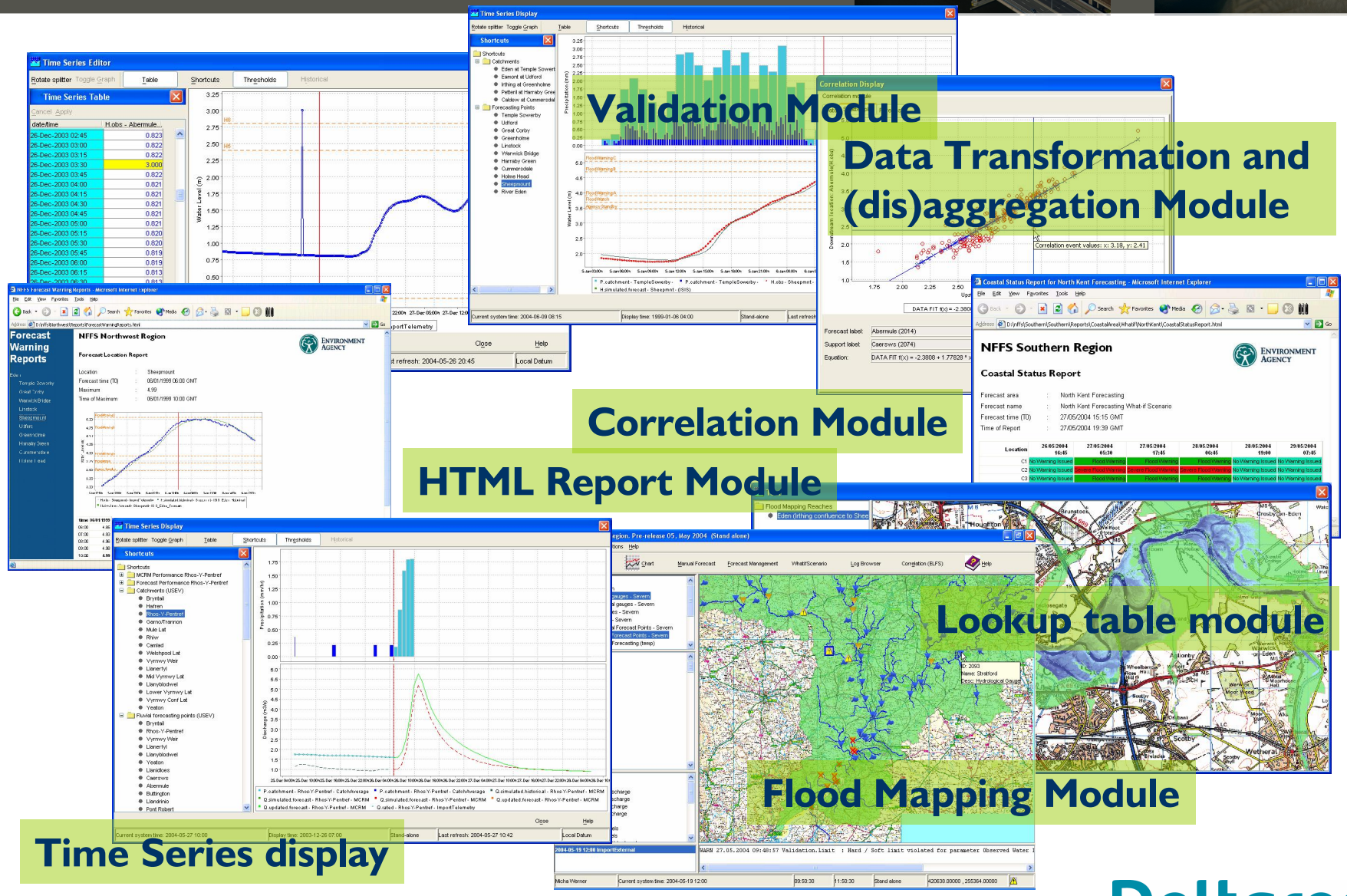
Data Management





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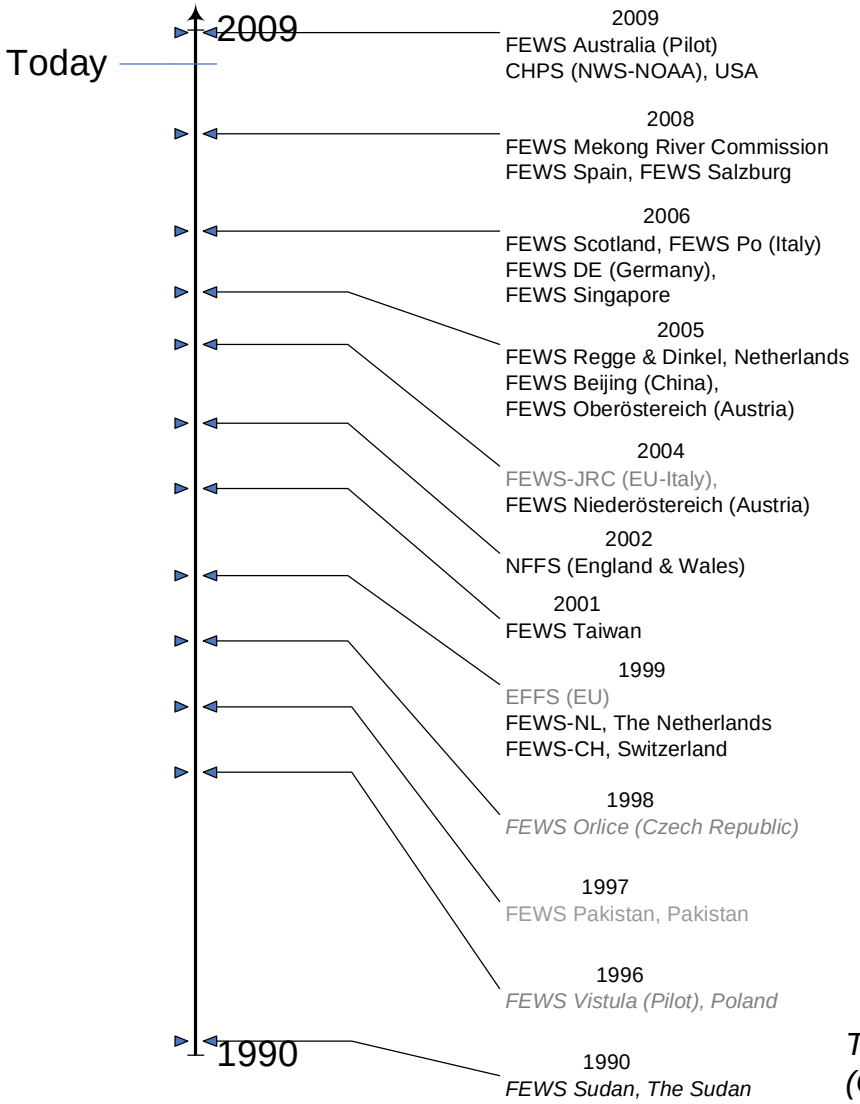
Track record



Timeline of FEWS Implementations
(Grey indicates these are not operational)

Deltares – Delft Hydraulics has extensive track record in operational forecasting

Key Milestones

- FEWS Sudan – 1992
- FEWS Pakistan – 1998
- EFFS – 1999 to 2003
- National Flood Forecasting System (England & Wales) – 2002
- FEWS-Rhine & Meuse (NL, CH, DE) 2003
- FEWS Donau (NOE, OOE), Salzburg
- Community Hydrological Prediction System (CHPS) – NWS-NOAA, USA 2009 – *in development*
- FEWS Australia (Pilot) 2009

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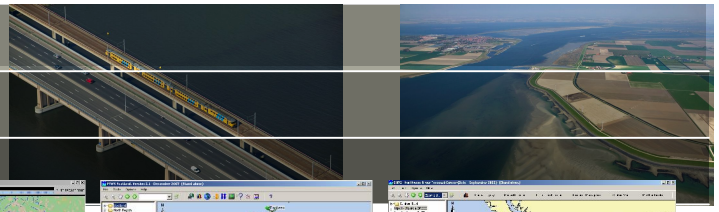
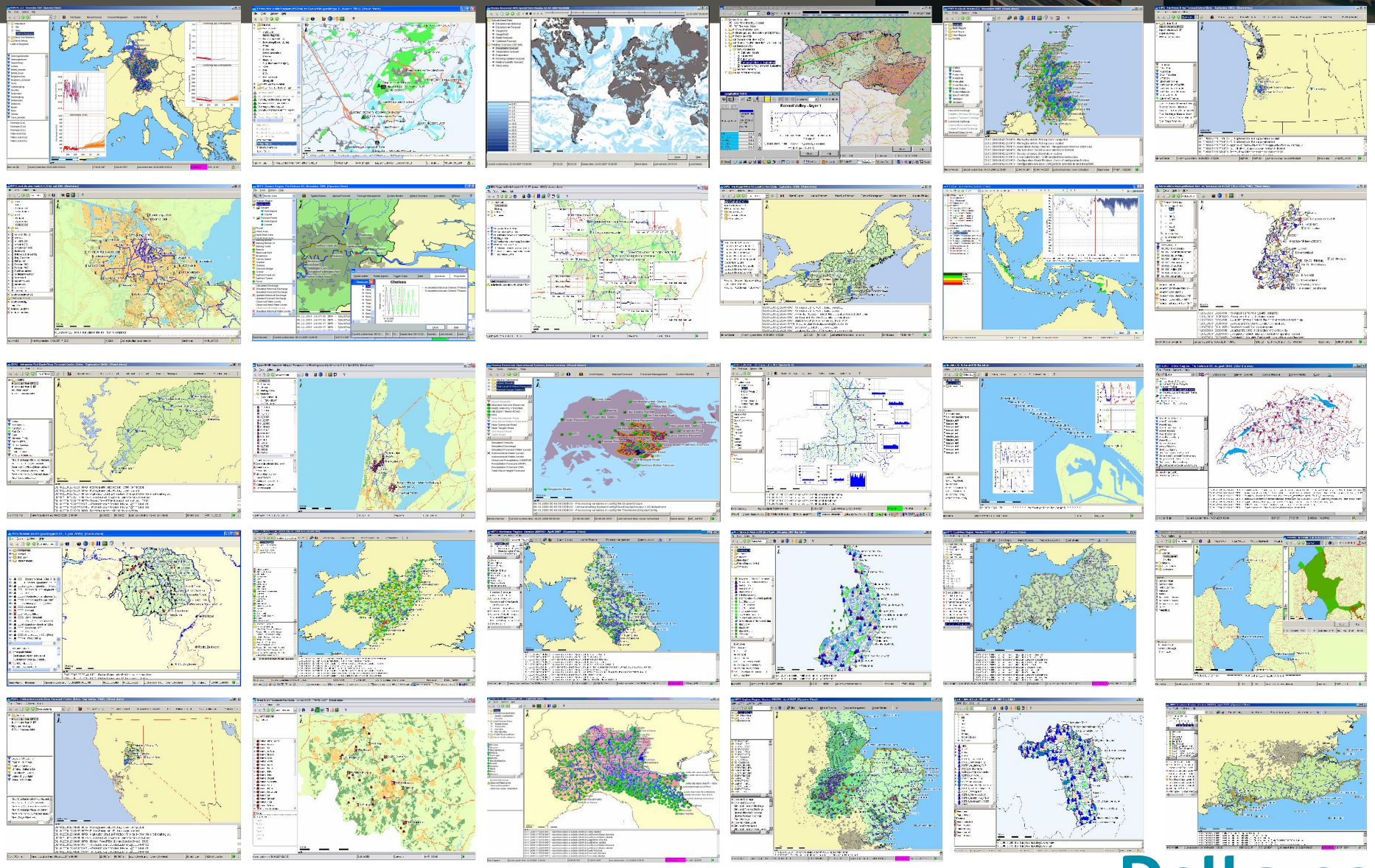
A FEW(S) Demonstrations…





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Uncertainty Estimation

UK Environment Agency Science Report 2009, SR SC080030

Risk-based Probabilistic Fluvial Flood Forecasting for Integrated Catchment Models (Phase 2)

Aim: Develop and test practical probabilistic methods to quantify and reduce uncertainties in fluvial flood forecasts

Tested uncertainty estimation techniques during case studies:

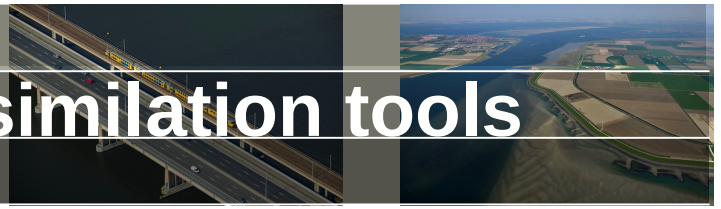
- Forward Uncertainty Propagation methods
  - > for rainfall inputs, rainfall-runoff model parameters, rating curves
- Data Assimilation
  - > adaptive gain, ensemble Kalman Filter
- Forecast Calibration (Conditioning)
  - > quantile regression, Bayesian Model Averaging

Uncertainty Estimation

Table 5.2 Summary of Factsheets and NFFS Configurations

Case Study	Configuration	Factsheet	Type of Method	Method
Upper Calder	C1	C1	FUP	STEPS rainfall forecasts – 2 events in 2008
	C2	C2	FUP	Rainfall inputs
	C3	C3	FUP	Model parameters
	C4	C4	C	Quantile Regressión
	C5	C5	C	Bayesian Model Averaging
Lower Eden	E1	E1	FUP	Rating curve uncertainty
	E2	E2	FUP	Rating curve uncertainty
	E3	E3	R	Existing operational model
	E4	E4	DA	Adaptive gain
	E5	E5	DA	Ensemble Kalman Filter
	E6	E6	R	Emulation of ISIS outputs
	E7	E7	Statistical+DA	Data Based Mechanistic
Ravens-boume	R1	R1	FUP	Rainfall inputs
	R2	R2	FUP	Model parameters
	R3	R3	FUP	Combined inputs
	R4	R4	C	Quantile Regression
Upper Severn	S1	S1	FUP	Rainfall inputs
	S2	S2	FUP	Model parameters
	S3	S3	FUP	Rating curve uncertainty
	S4	S4	DA	Adaptive gain
	S5	S5	DA	To be completed
	S6	S6	C	Quantile Regressión
	S7	S7	R	Emulation of ISIS outputs
	S8	S8	Statistical+DA	Data Based Mechanistic
Other	-	G1	R	Fast Infosets and Binary XML
	-	G2	FUP	Forward Uncertainty Propagation
	-	G3	Statistical+DA	DBM modelling

Development generic data assimilation tools



DATools-openDA

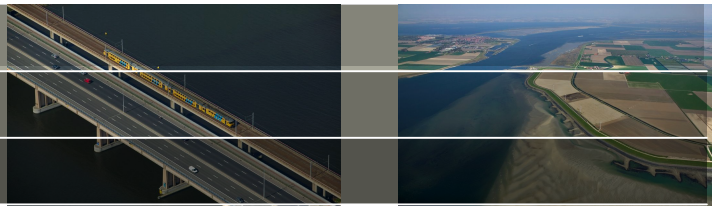
generic (open source)

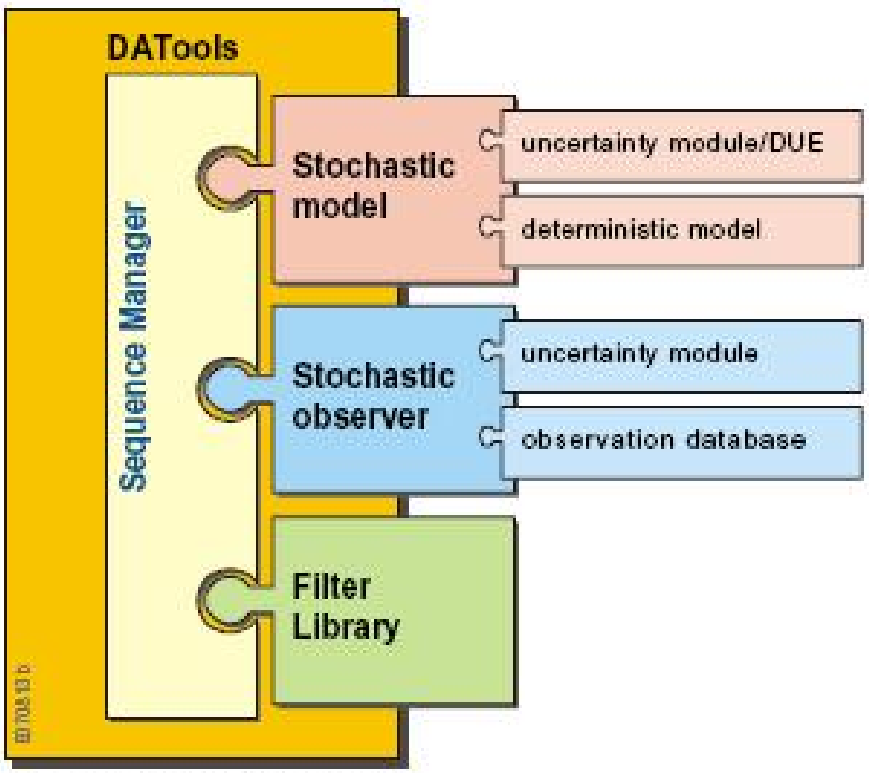
Basic Idea behind:

- costs: the development and implementation of DA methods is very time consuming and therefore expensive;
- incompatible: it is hard to reuse these data assimilation methods and tools for other models than for which they have originally been developed for.

developed for: state updating, calibration, uncertainty analysis

Overview DATOOLS - 1





Basic idea:

adjust the prior estimate of the model states

obtain prior estimates:
stochastic model with specification of input and model uncertainty

adjust prior estimates:
include measurement uncertainty

Filter to choose from:
Ensemble Kalman Filter, Particle Filter

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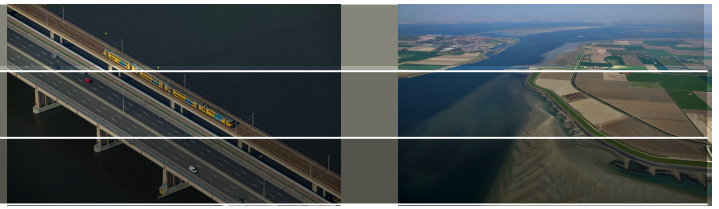
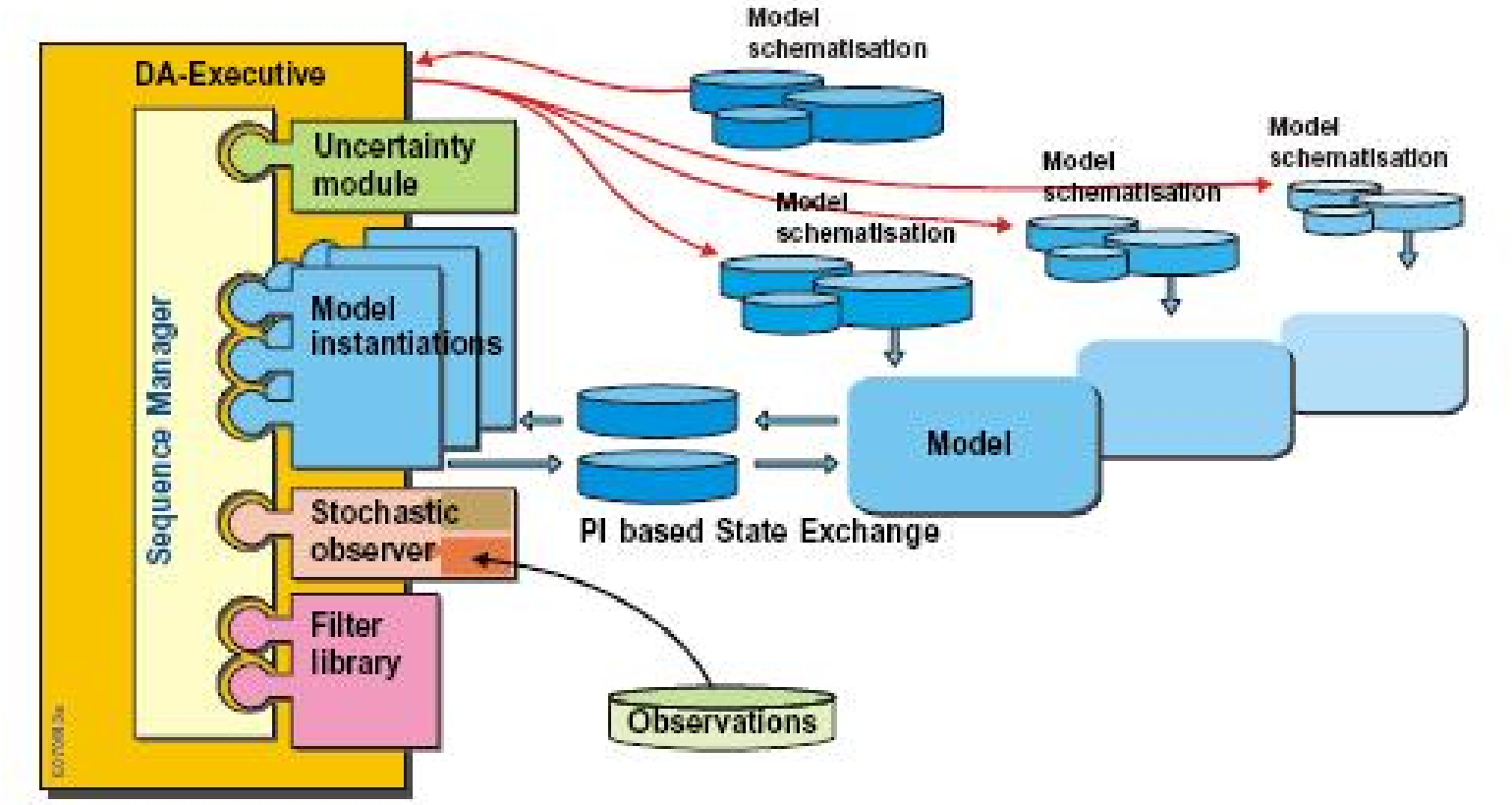
Overview DATOOLS - 2





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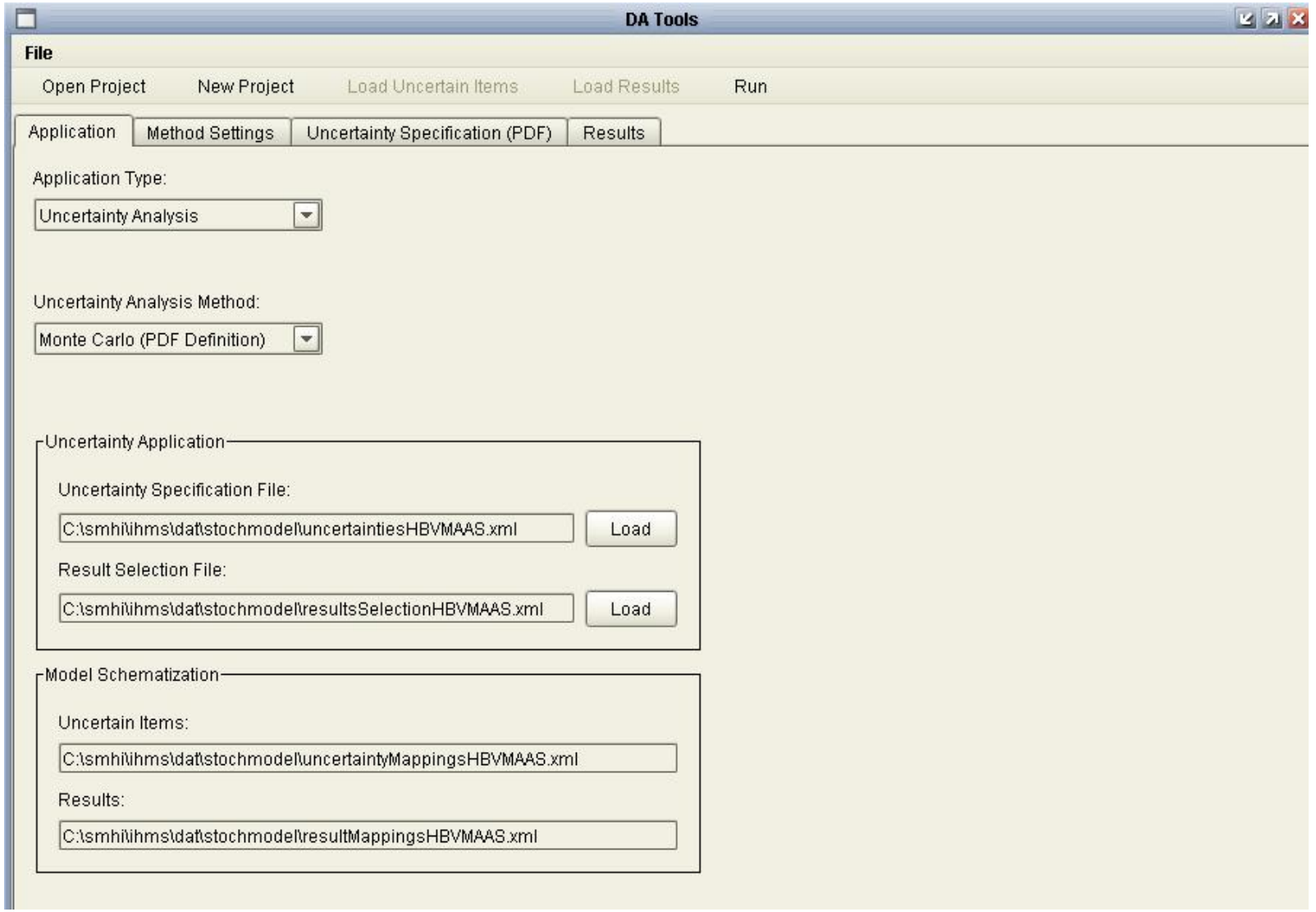
journal homepage: www.elsevier.com/locate/cageo

Application of generic data assimilation tools (DATools) for flood forecasting purposes

Albrecht H. Weerts*, Ghada Y. El Serafy, Stef Hummel, Juzer Dhondia, Herman Gerritsen

Deltares, P.O. Box 177, 2600 MH, Delft, The Netherlands

GUI developments - 1



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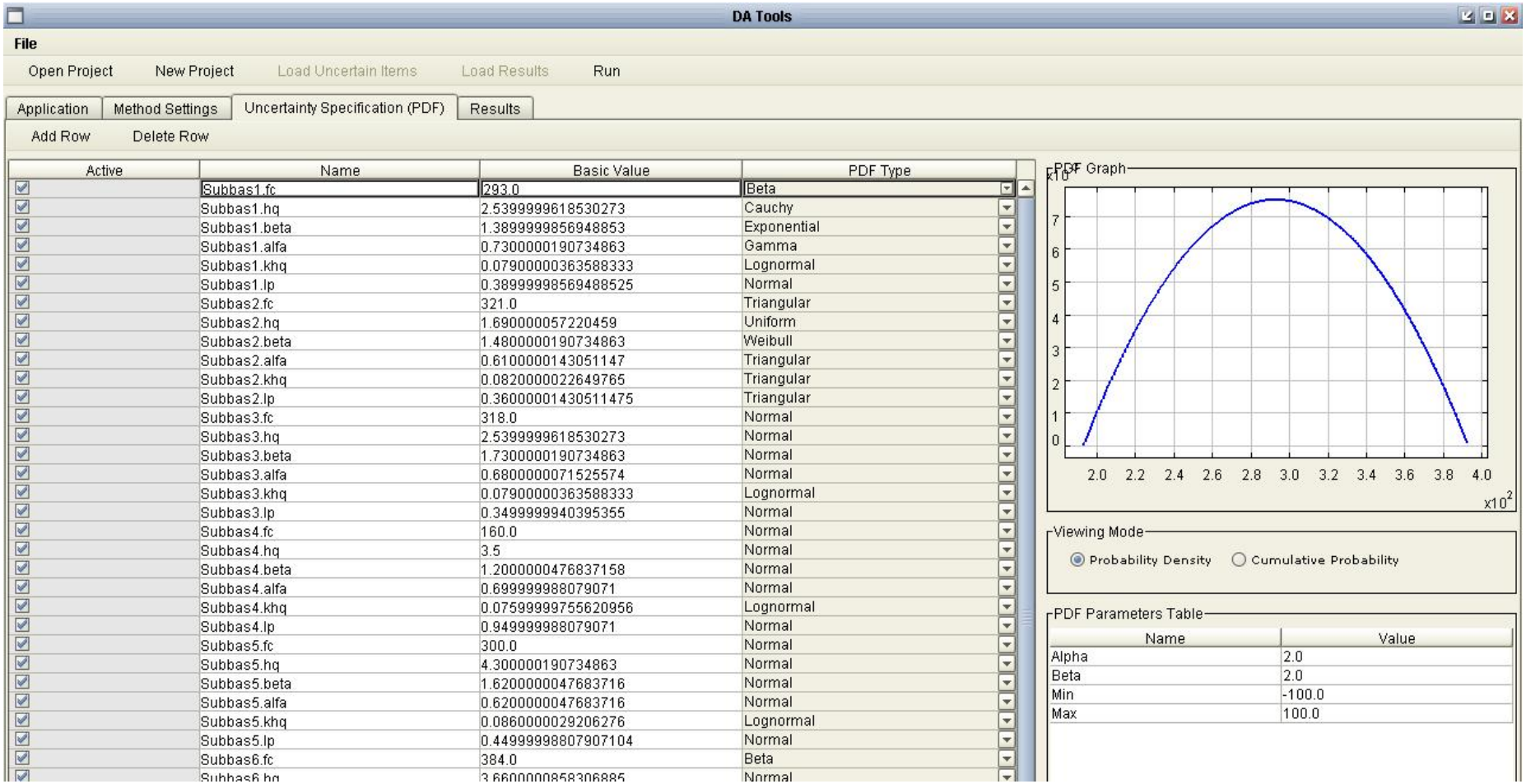
GUI developments - 2



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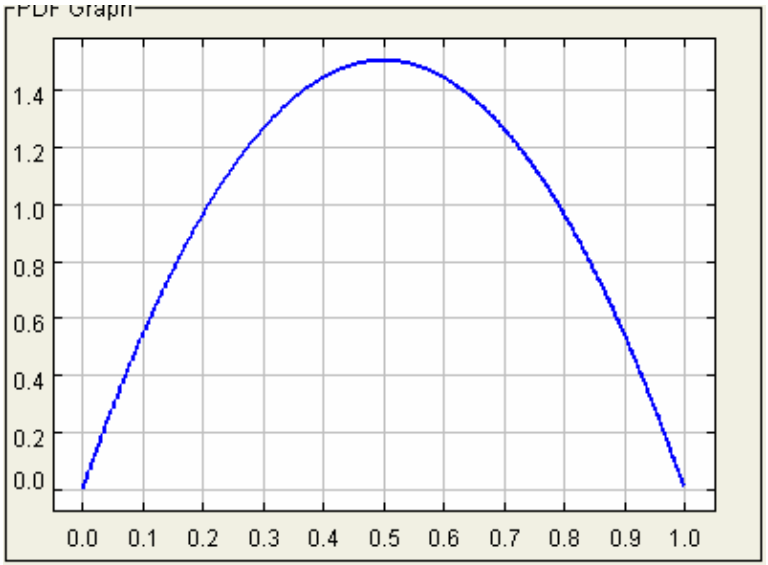
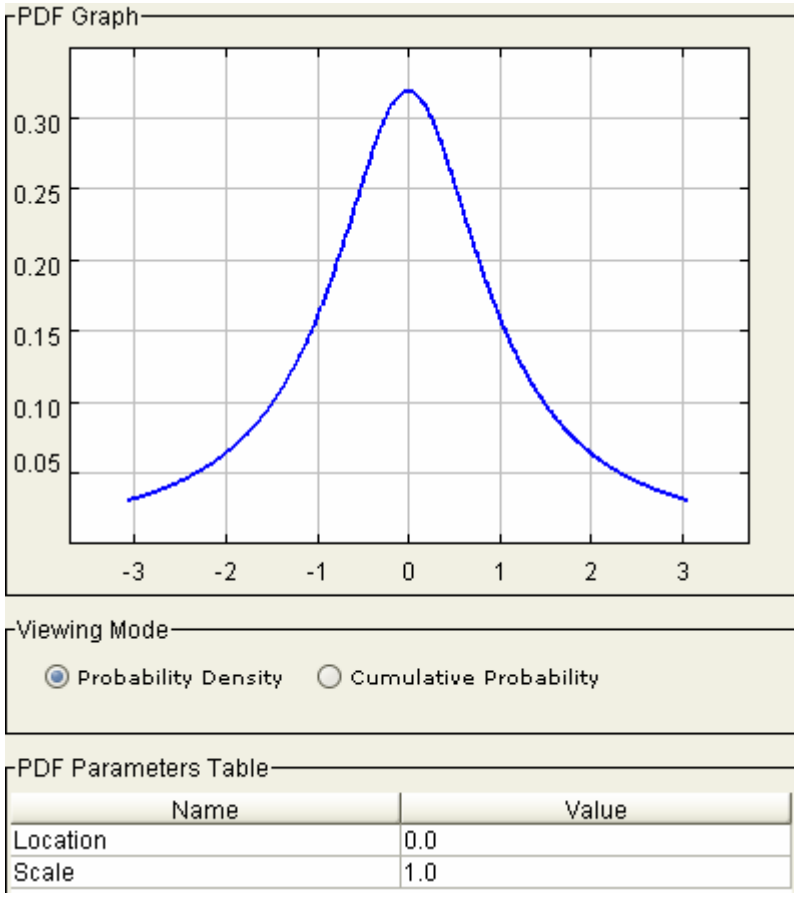
examples of distribution to choose from





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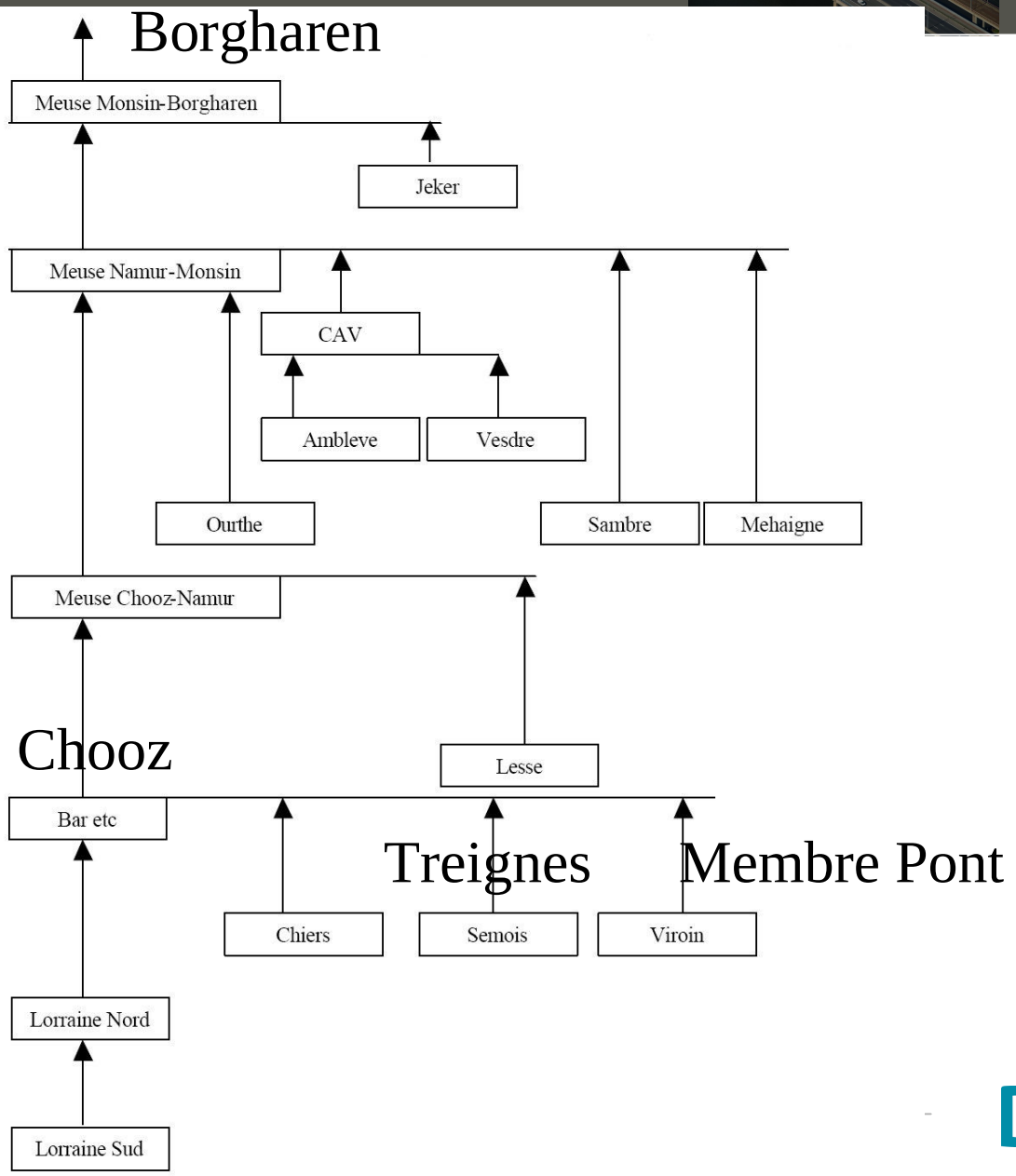
HBV Meuse example



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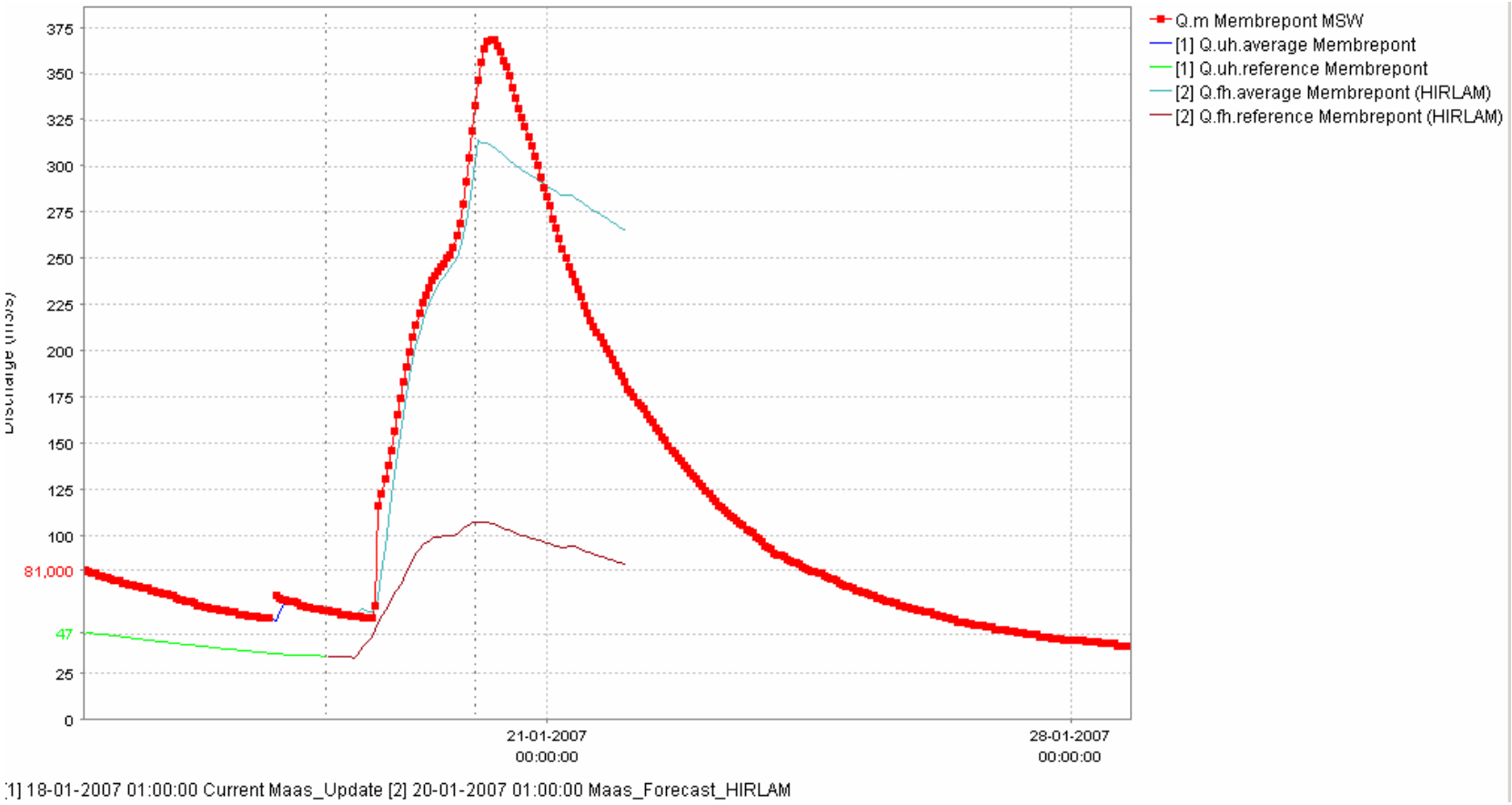
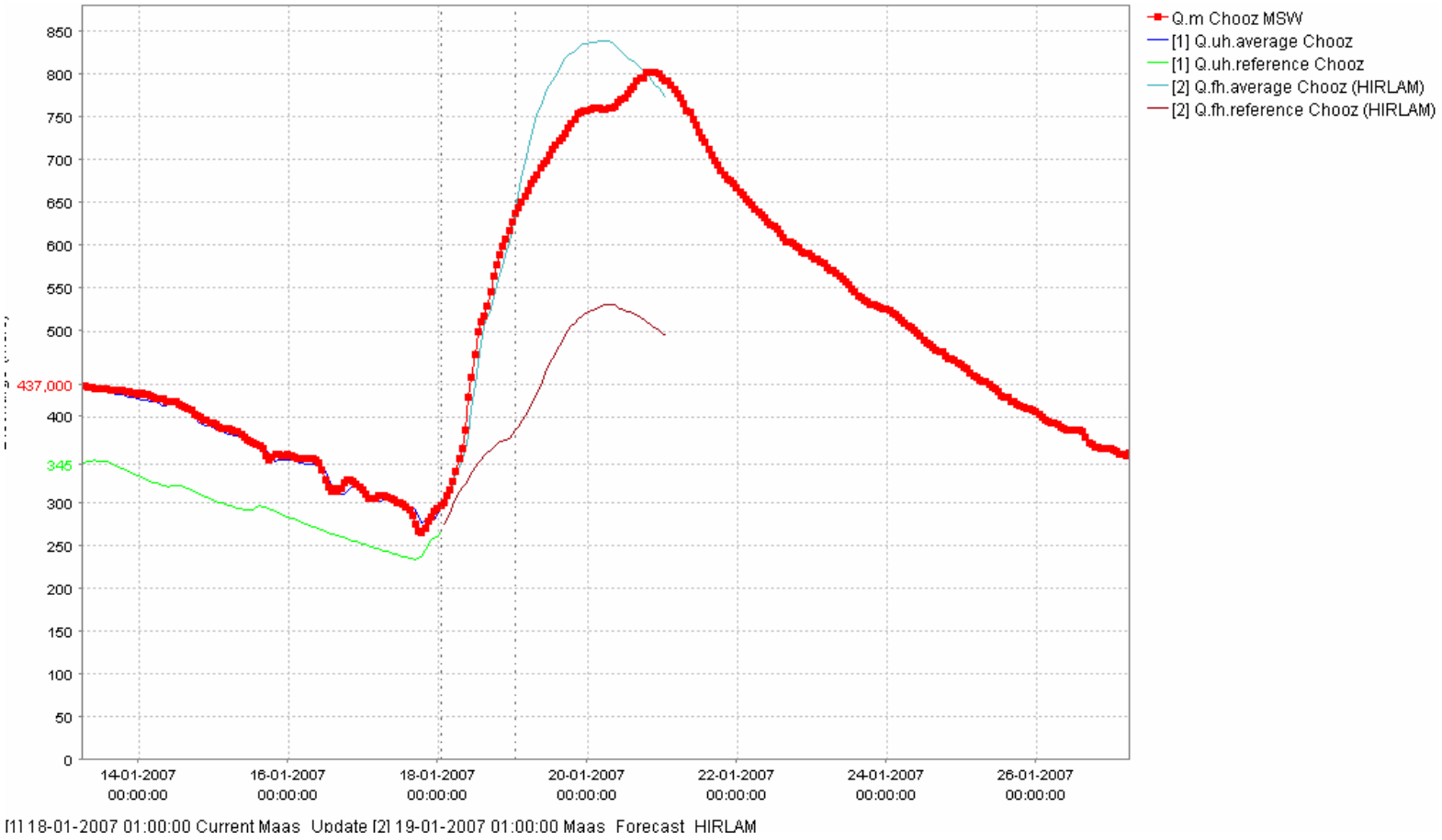
Result of EnKF filtering at Semois (Membre pont) during the forecast 20-01-2007 01:00.



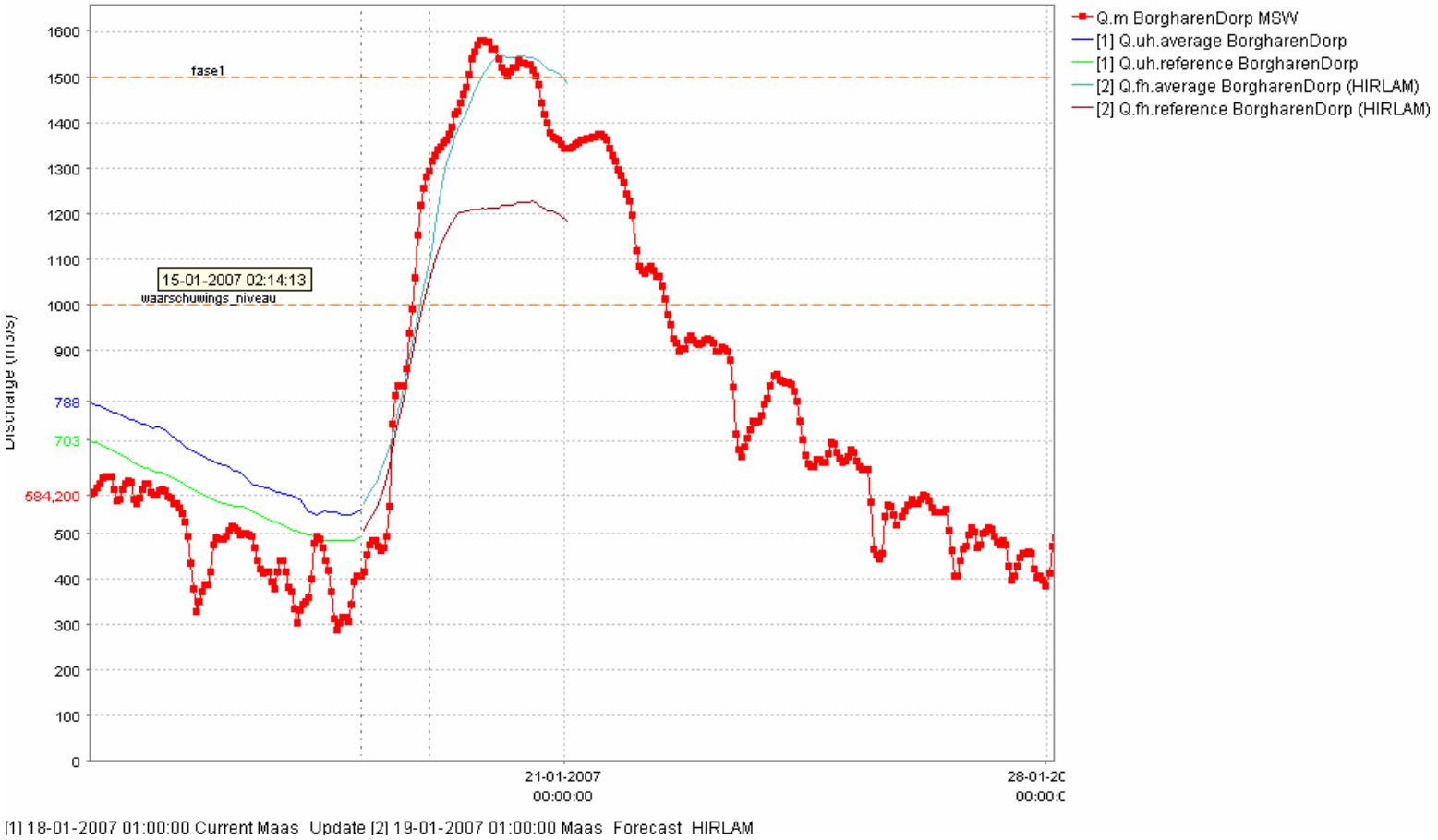
Deltares

Result of EnKF filtering at Bar etc (Chooz) during the forecast at 19-01-2007 01:00.



Deltares

Result of EnKF filtering downstream at Meuse Monsin-Borgharen (Borgharen-Dorp) during the forecast 19-01-



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Updating States SOBEK Model with EnKF

Model consist of +/- 1740 gridpoints

- many lateral inflows (+/- 60)
- tributaries are AR-error corrected when measurements are available
- Measurement Maxau-Lobith:

Speyer, Worms, Mannheim, Mainz, Kaub, Andernach, Bonn, Koln, Dusseldorf, Ruhrort, Wesel, Rees, Lobith

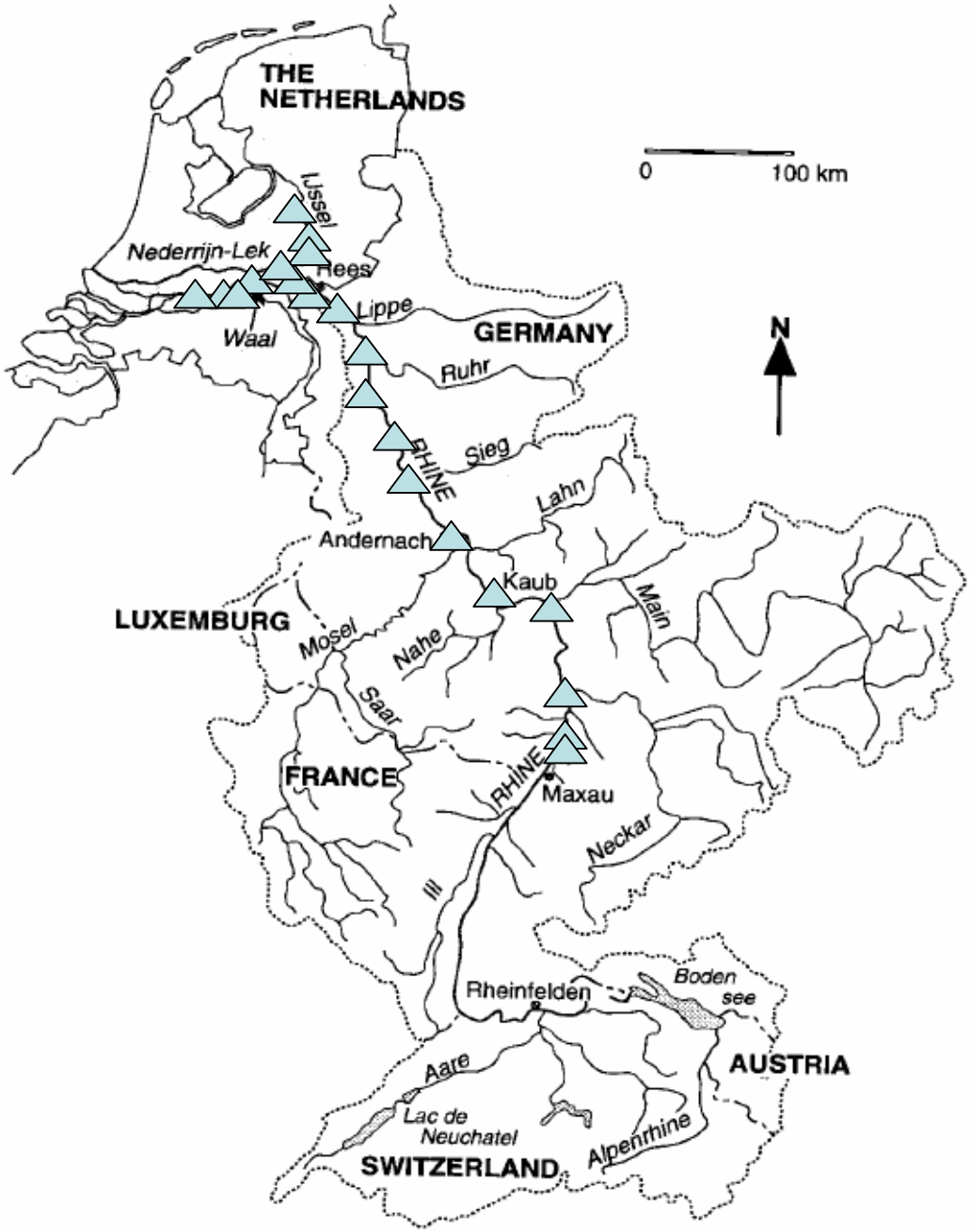
- Measurement Lobith-Rhine branches:

IJssel: Doesburg, Zutphen, Olst, Kateveer

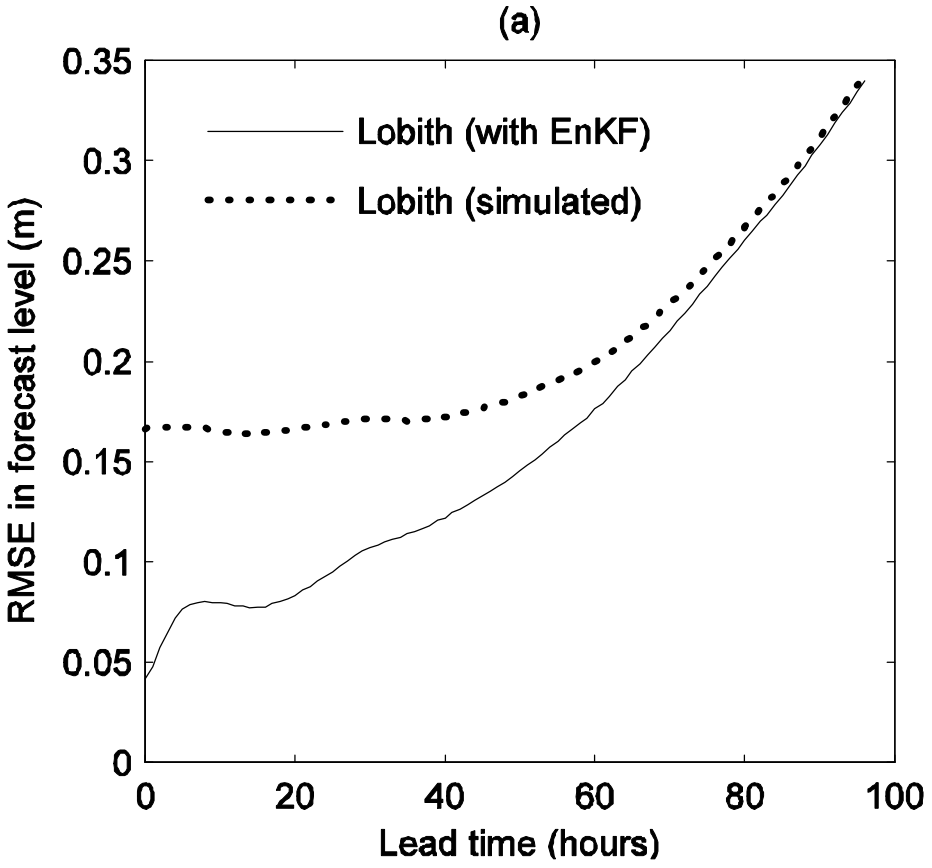
Waal: Nijmegen, Dodewaard, Tiel, Zaltbommel

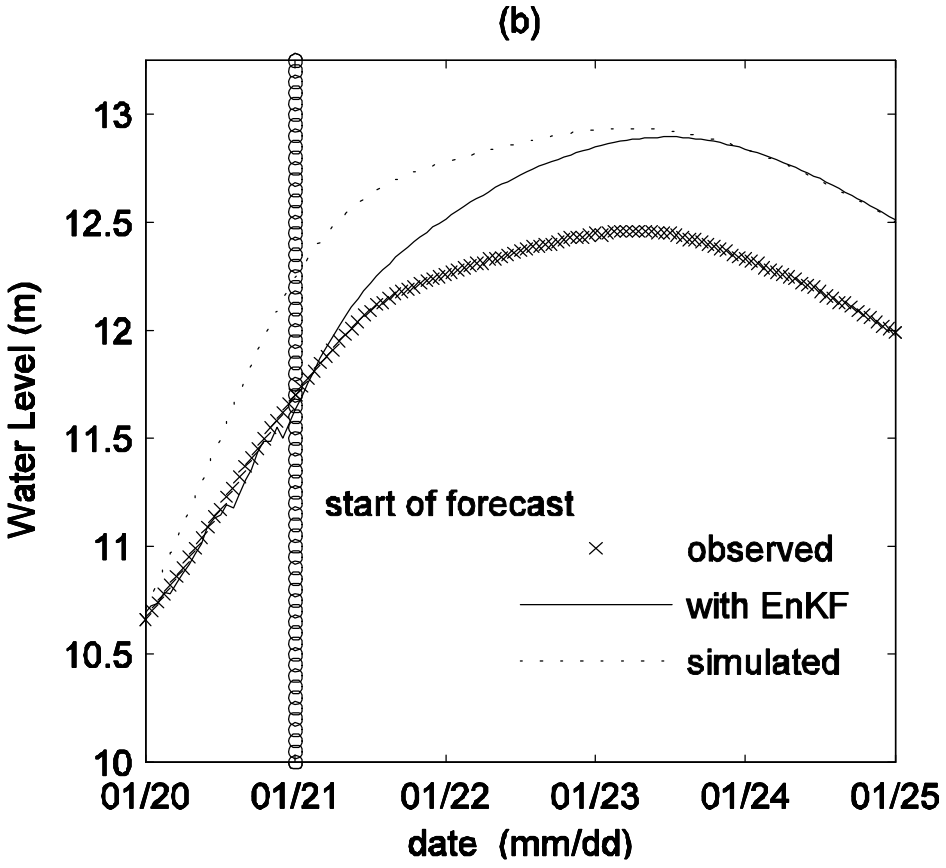
Pannerdensch Kanaal: IJsselkop

Nederrijn: -


THE NETHERLANDS
0
100 km
IJssel
Nederrijn-Lek
Rees
Lippe
Waal
GERMANY
N
Ruhr
RHINE
Sieg
Lahn
Andernach
Kaub
Main
LUXEMBURG
Mosel
Nahe
Saar
FRANCE
RHINE
Maxau
Neckar
Ill
Rheinfelden
Boden see
AUSTRIA
Aare
Lac de Neuchatel
Alpenrhine
SWITZERLAND

Results at Lobith over 2 year hindcast (2006/2007)





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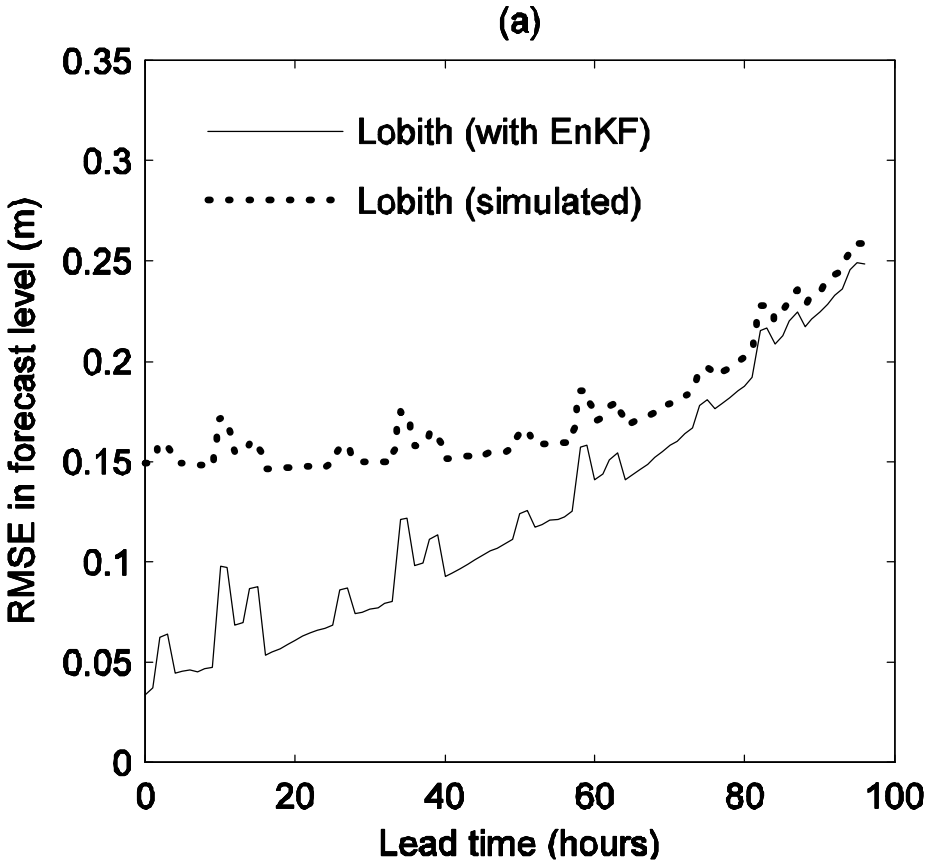
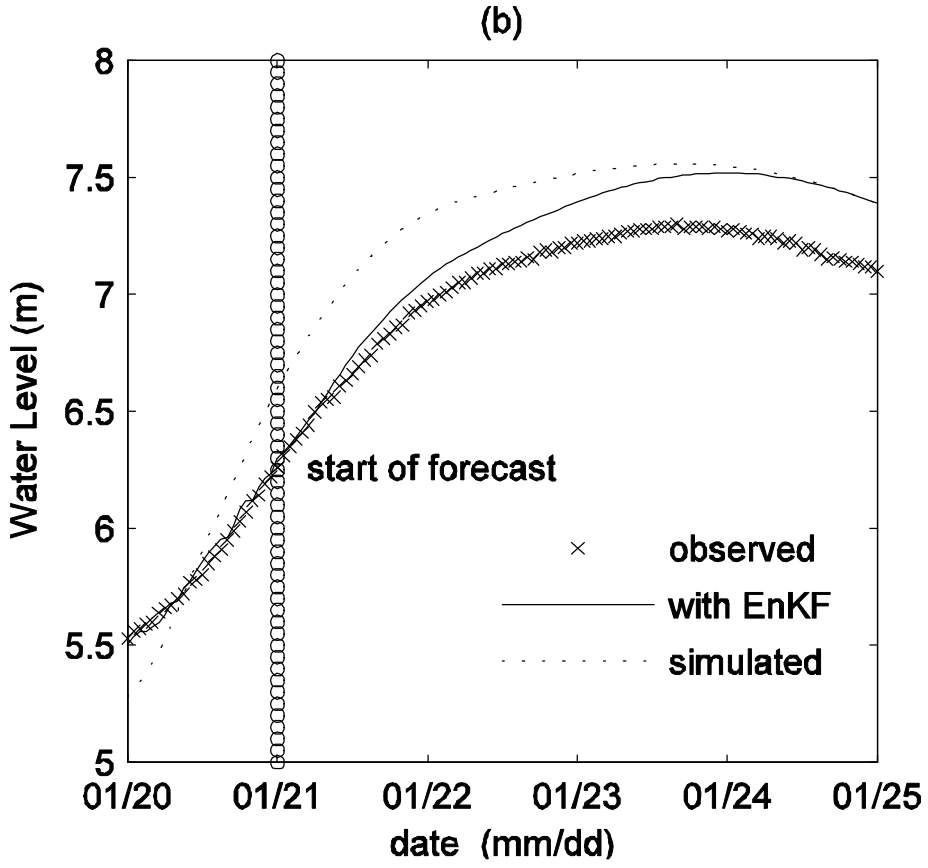
Results at Tiel (Waal) over 2 year hindcast (2006/2007)





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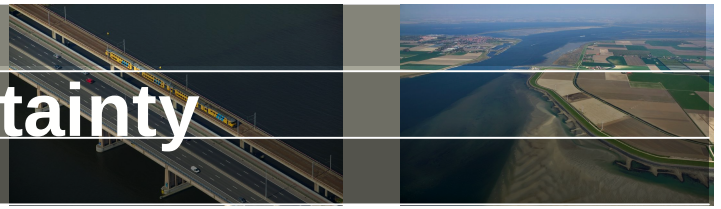
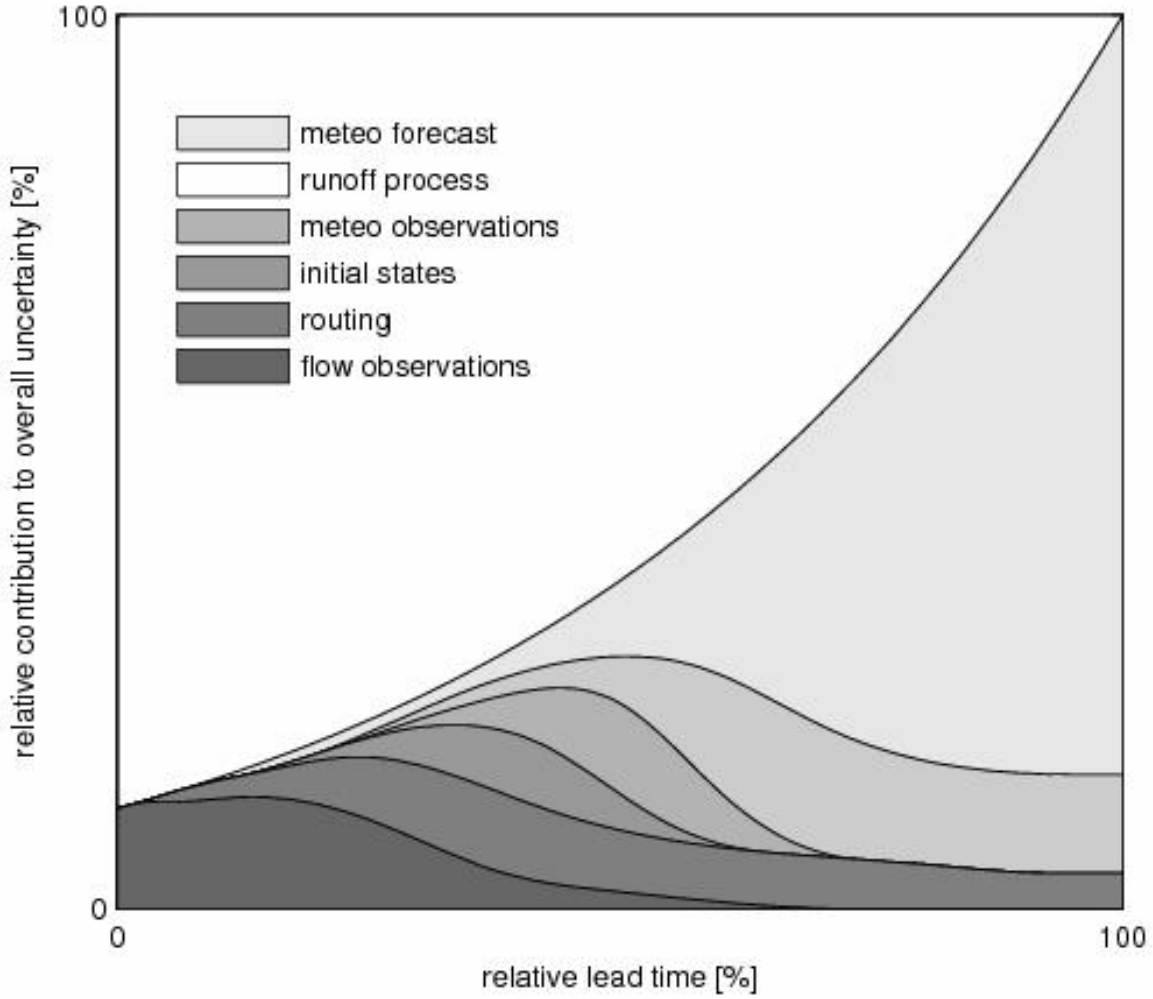
Relative contribution to uncertainty





Dominant source will differ with e.g. lead time

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Post Processing Forecasts

Bayesian Processor of Output

- Condition a single or ensemble forecast using a prior and likelihood (both derived from past performance) to remove of biases etc to derive the predictive uncertainty!!!!

Bayesian Model Averaging

- Merge different forecast into a single forecast based on their past performance (weighing) and derived an uncertainty band

Predictive uncertainty is what we / the forecasters are really interested in!

Uncertainty Estimation

Bayesian Model Averaging (BMA)

- applicable to a set of competing forecasts:
  - > different hydrological / hydrodynamical models
  - > different sets of input data (meteorological ensemble forecasts)

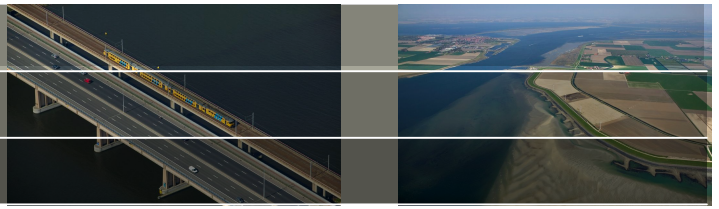
- evaluates the uncertainty of an ensemble forecast in a training period prior to the present forecast
- historical model forecasts are compared with observations
- produces a weighted overall probabilistic forecast with confidence limits
- determines a correction for the bias

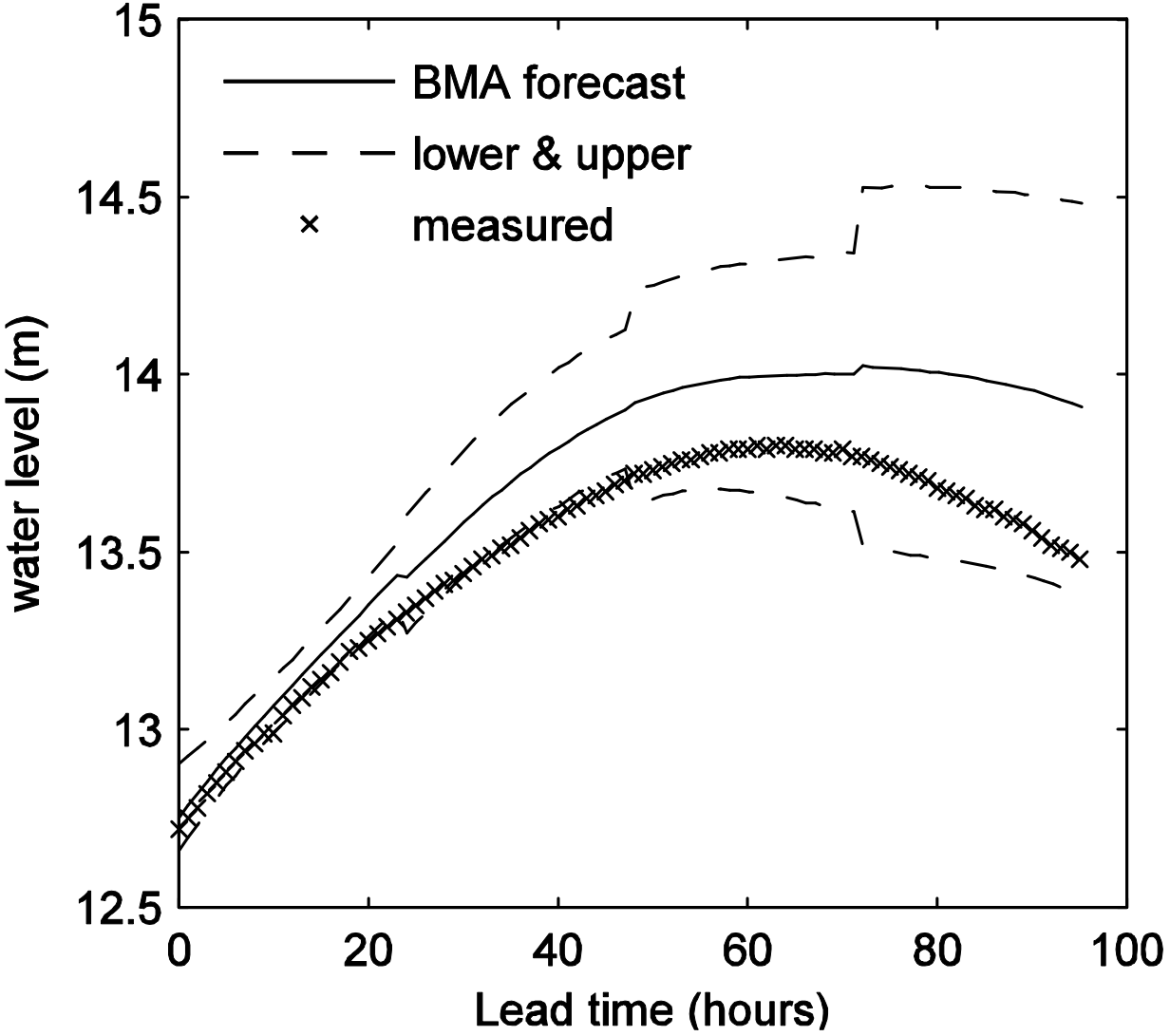
Example BMA

Table 1: RMSE of the individual forecast models and the BMA mean forecast for different lead times, with the lowest RMSE's highlighted in yellow. All calculations used a training period of 28 days.

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

Example BMA





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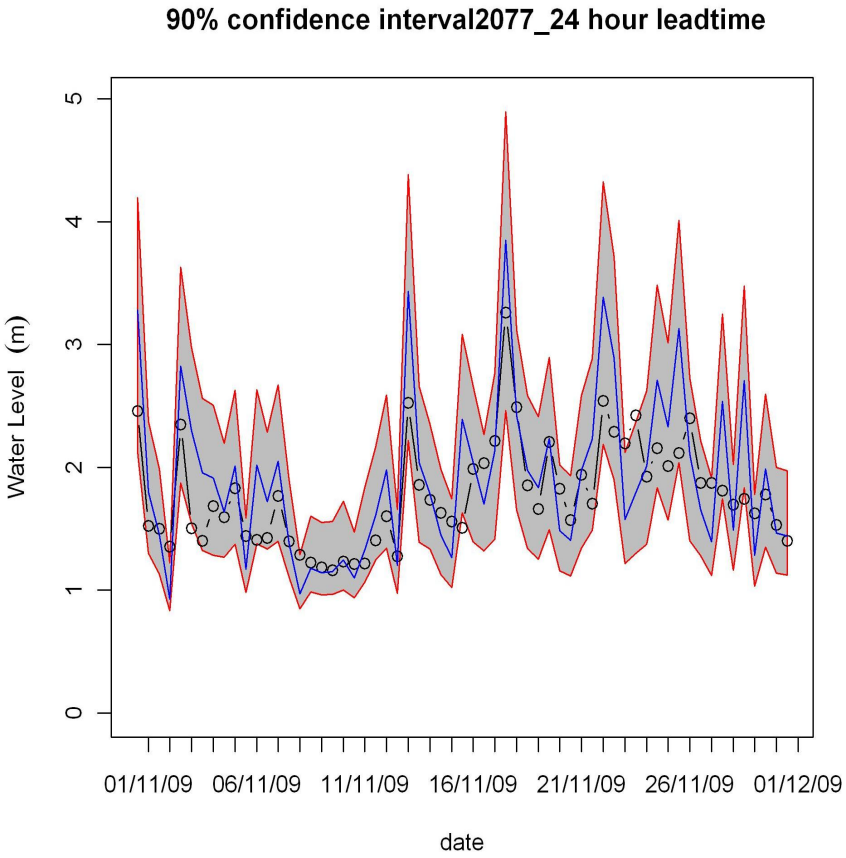
Uncertainty Estimation

Quantile Regression

- Method for estimating of conditional quantiles
- Estimation of the Cumulative distribution function (CDF) of a forecast error conditioned by the value of the present simulated river levels

- promising results
- easy to implement, developed in R
- stage-discharge uncertainties can be taken directly into account
- needs calibration, long time series necessay for reliable results
- only possible at locations, where observations are available



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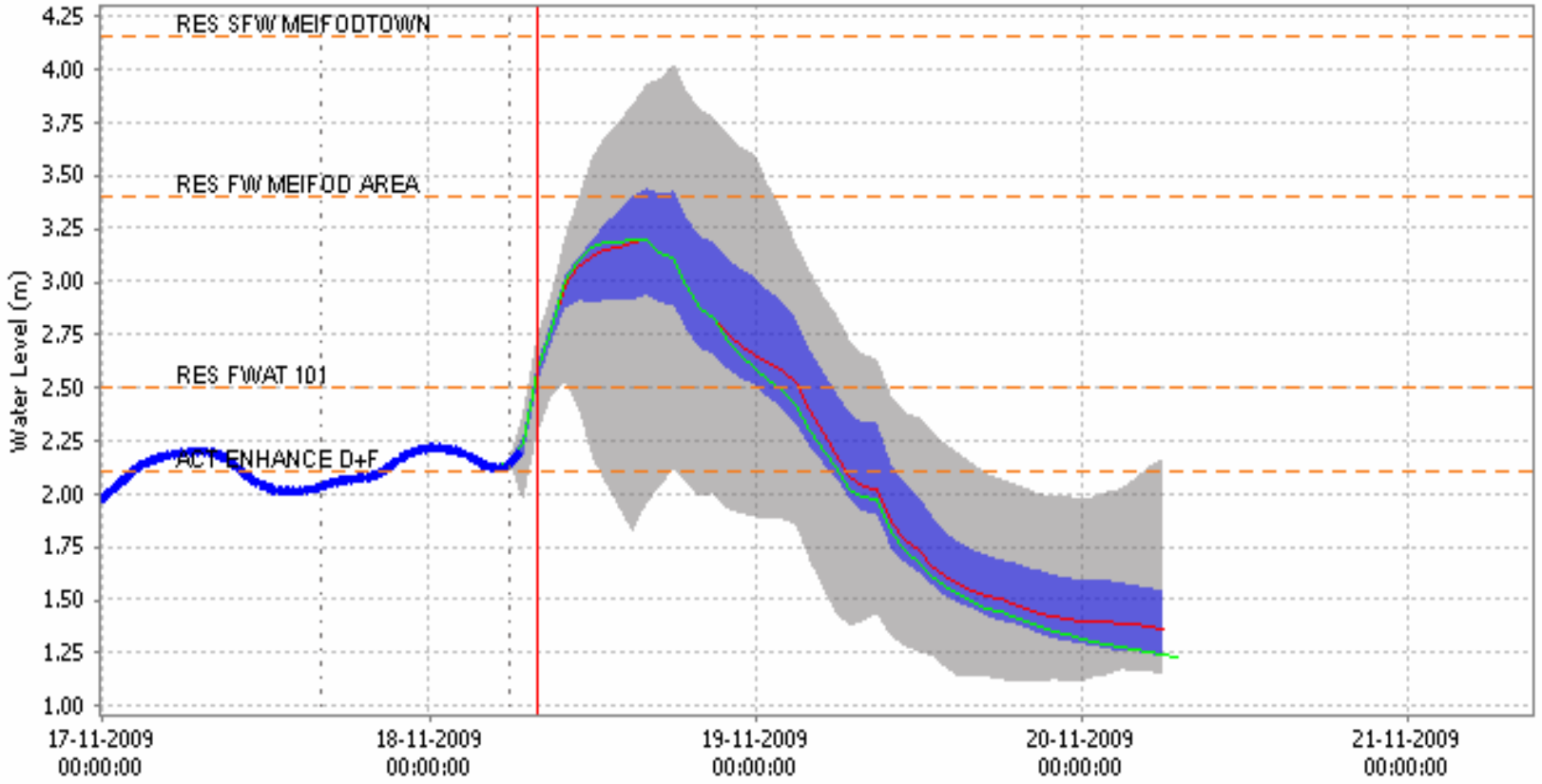
Example Visualisation



[1] 17-11-2009 16:00:00 Current Fluvial_Historical [2] 18-11-2009 06:00:00 Current Severn_Usev_Forecast

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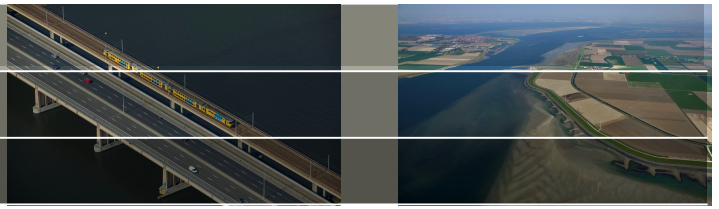
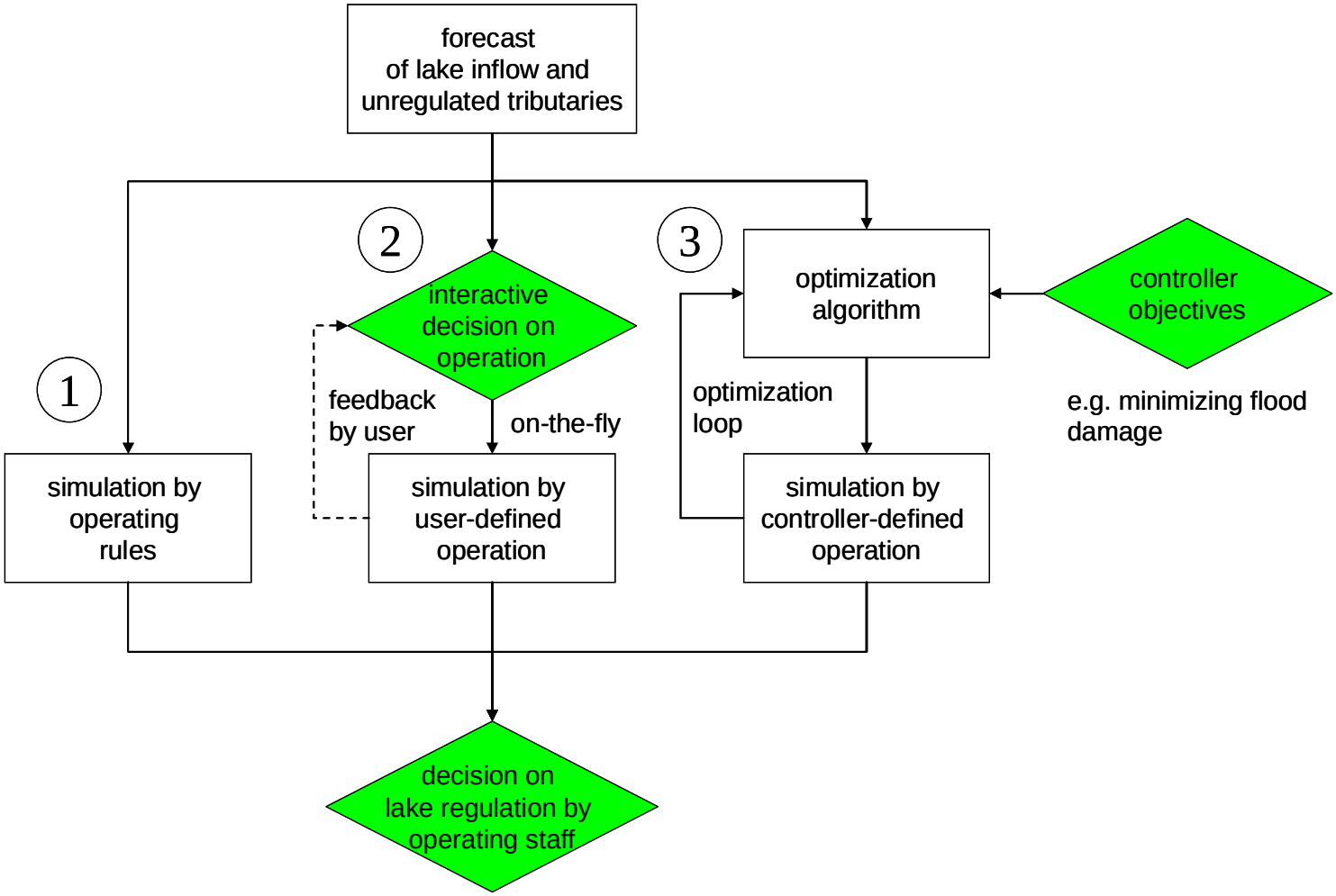
Operational Decision Support





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Real Time Control Tools

RTCTools – a novel framework for supporting real-time control

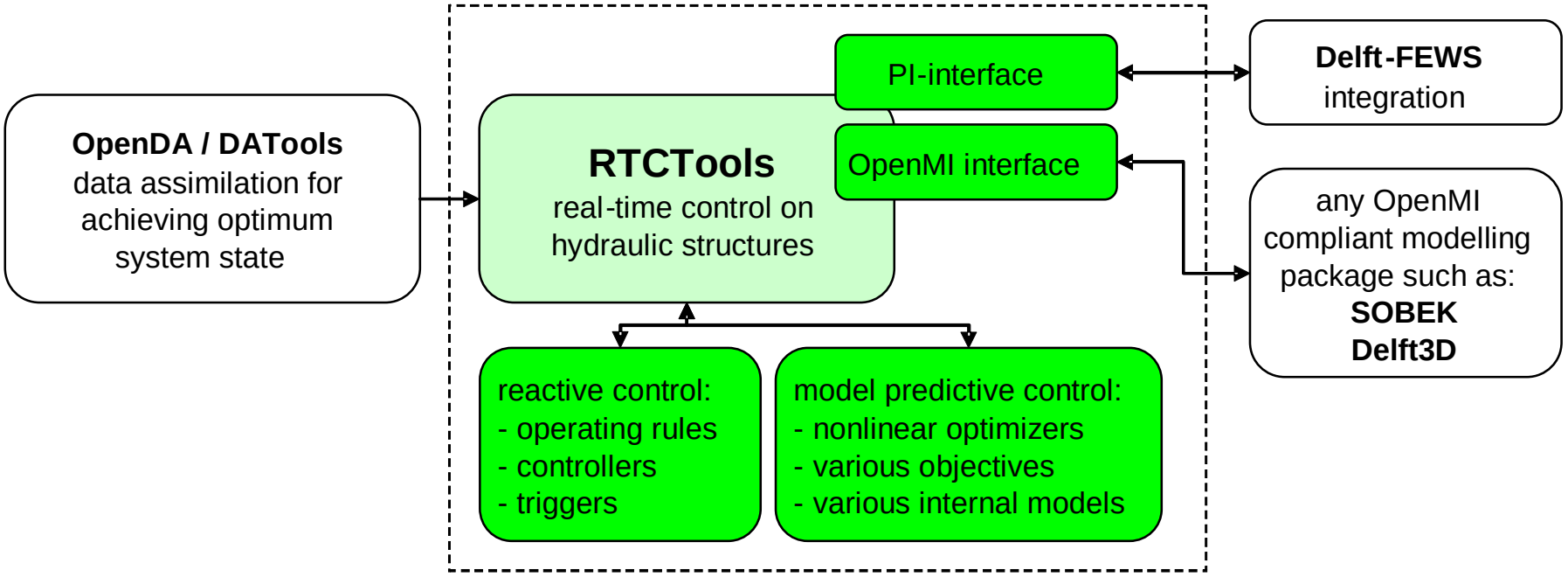
includes:

- collection of operating rules for reservoirs
- simple reactive controllers for hydraulic river structures
  (e.g. PID-controller)
- several sophisticated model predictive controllers, e.g.
  - internal models for pool routing in reservoirs
  - flood routing in rivers and imbedded structures
- logical rules for (de)activating sets of rules / controllers

OpenMI interface

OpenMI: Open Modelling Interface, a standard for the exchange of data between computer software in environmental management
www.openmi.org

Real Time Control Tools - architecture



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Delft-FEWS

Ongoing projects in predictive control

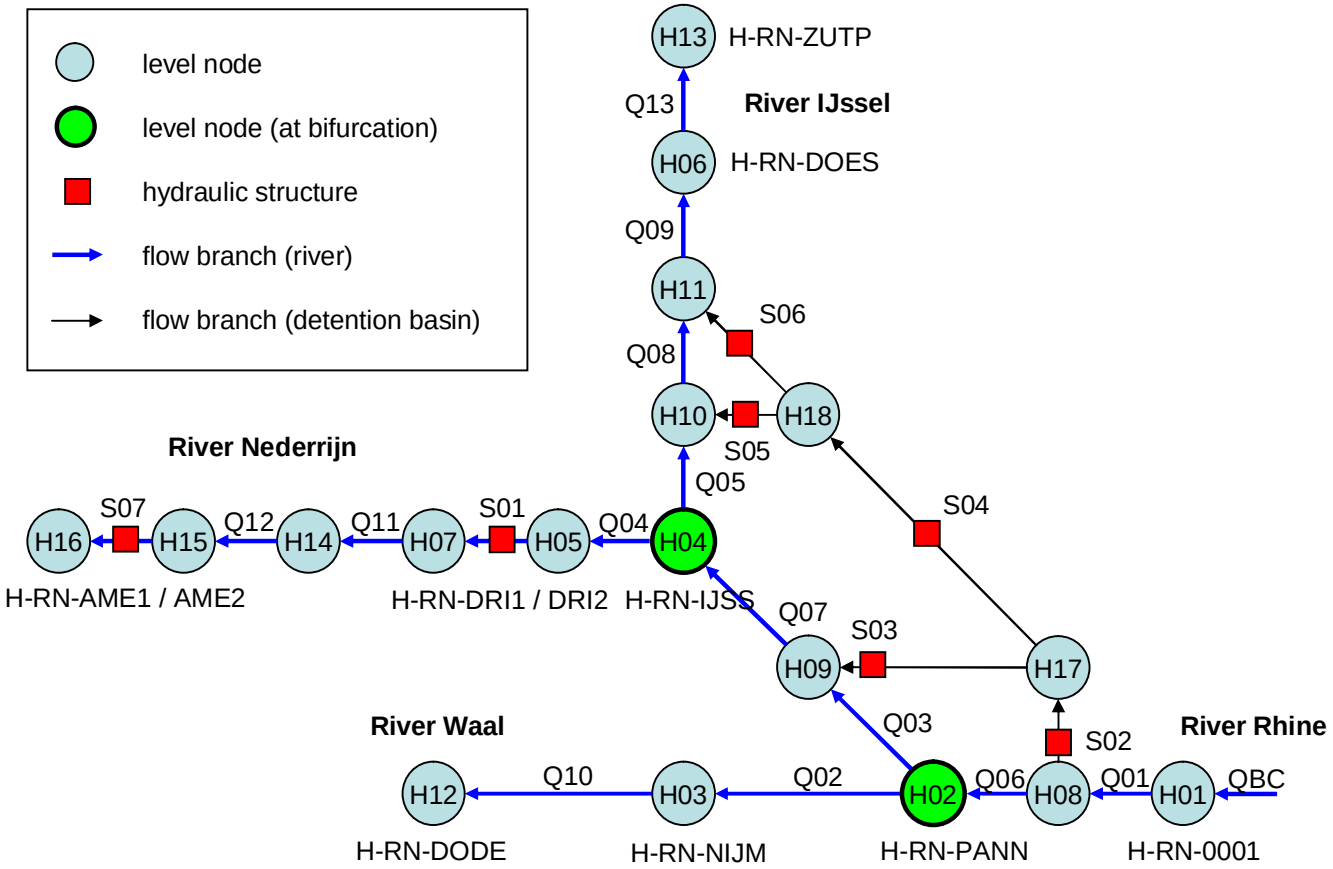
- SDWA MOMRO, Singapore
  Short-term and medium-term control of reservoir systems (Marina Basin / Singapore, Alqueva / Portugal) related to flood control, irrigation, hydropower and water quality
- Flood Control 2015, NL
  Operational decision-making on major hydraulic structures in the Rhine-Meuse-Delta during flood events
- Lake Control, CH
  Operational decision-making on the control of Swiss lakes during flood events

Knowledge of Deltares and strategic partners:

operational optimization of reservoir releases in reservoir systems with up to 50 reservoirs, supervisory control of run-of-river plants, supervisory control of irrigation systems,
all of them in combination with nonlinear objectives, logic constraints, centralized and/or distributed model predictive control

RTC Tools – Example

Layout of internal model of predictive controller (kinematic wave model): schematic overview about nodes and flow branches and hydraulic structure branches



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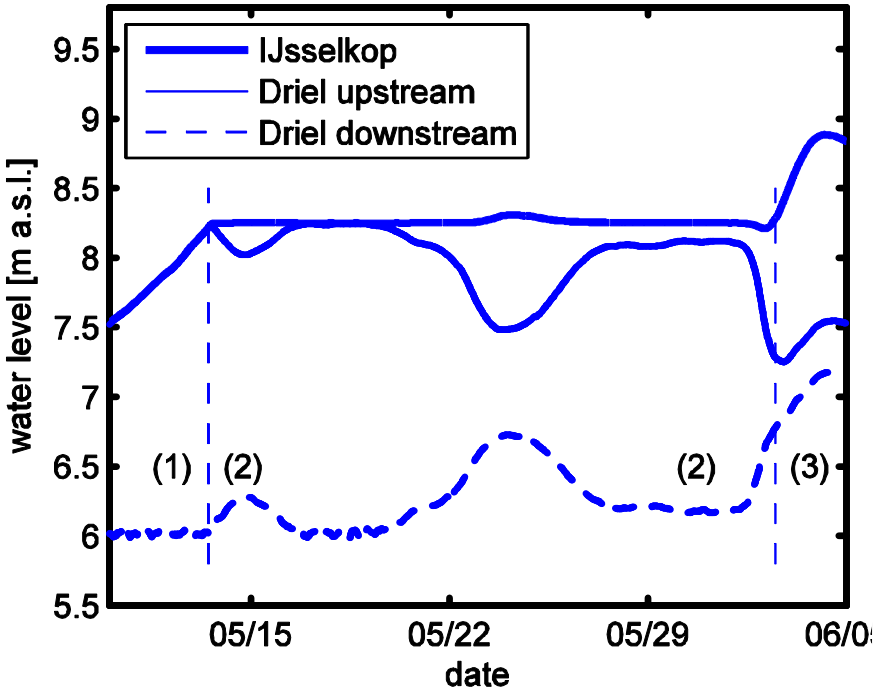
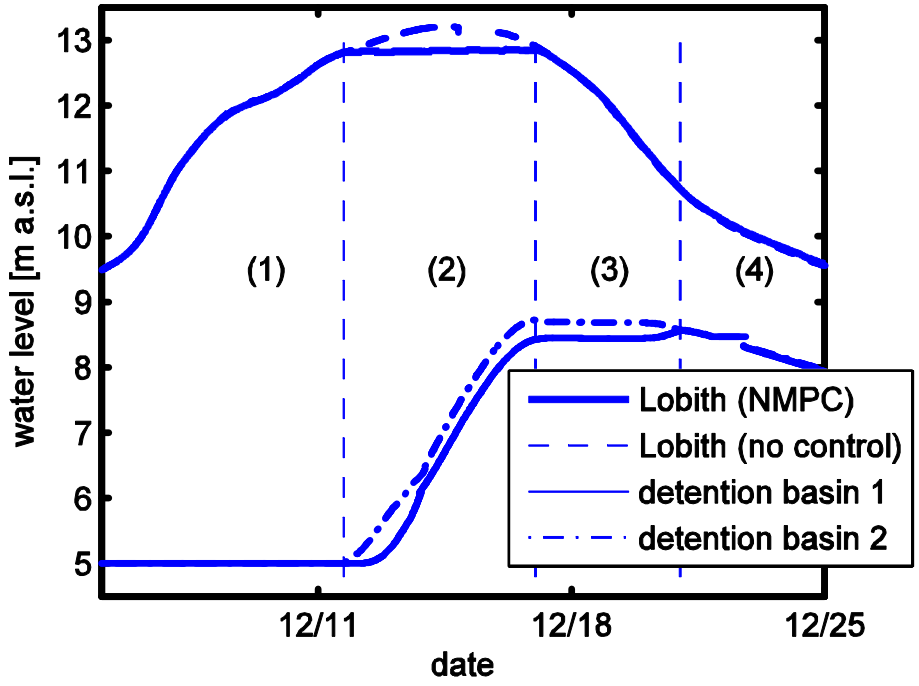
RTC Tools – Example



water level control at Driel during low - medium flow regime in May 2007 with water level set point of 8.25 m a.s.l. at gauge IJsselkop



damping of small flood peak above 12.75 m a.s.l. in December 2007 at gauge Lobith by control of detention basins 1 and 2

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more information?
http://public.deltares.nl/display/FEWSDOC/Home