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2-Minute Overview

Navigation on inland waterways is mainly affected by

- River ice
- Floods
- Low flows / droughts







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2-Minute Overview



- Information about expected fairway conditions and related restrictions are essential to operate / manage waterway transport.
- Tailored hydrological forecast services offering extended lead-time (weeks up to months) is currently one of the main requirements.

Medium-range forecasts

- Shift from deterministic to probabilistic forecasts
- Communicate forecast uncertainty
- Reduce bias and dispersion errors of hydrological raw ensemble

Monthly to seasonal forecasts

- Dominant influence of meteorology compared to initial hydrological conditions
- Limited meteorological forecast skill

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2-Minute Overview









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The ease, safety and efficiency of inland waterway transport is sensitive to hydro-meteorological impacts.

Navigation-related forecasting



- Navigation on inland waterways is mainly affected by
 - River ice
 - Floods
 - Low flows / droughts







- The **availability of waterways** is influenced by hydro-meteorological effects, primarily **river ice and floods** leading to suspension of navigation.
- The main vulnerability of IWT with regard to hydrological impacts result from the close correlation of the operation efficiency and the available water-depths. **Low flows** increase transportation costs significantly.



River Ice forecasting Water-level forecasting

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River Ice forecasting - Overview

- River ice primarily occurs in waterways with low flow velocities (canals, impounded rivers) in areas with low air temperature over longer periods (Scandinavia, Eastern Europe).
- Besides blocking the waterway and interrupting its trafficability, ice run can damage vessels and harm technical structures (weirs, locks etc.)
- River ice forecasts estimating ice thickness, are a valuable information in order to coordinate the operation of icebreakers (e.g. pooling the vessels at hot-spots), as well as to take into account limitations of waterway availability (e.g. shifting transport to another transport mode).
- The figure indicates the impact of river ice on waterway transport to river ice along the Main-Danube canal (connecting River Rhine an River Danube), the Upper Danube and the Odra.

by displaying the number of days with suspension of navigation due

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Navigation-related forecasting

Main-Danube Canal Upper Danube



River Ice forecasting – forecast approach

- Operational service is offered for important canals connecting the natural waterways (e.g. Rhine and Danube).
- Empirical approach: exponential method (to calculate the water temperature); degree-day approach (Stefan-approach, to calculate the change in river ice thickness)
- Operational input data: air temperature (measured + forecasted), ice thickness (measured)

$$T^{*}[i,j] = T_{L}[i,j] * Faktor T^{*}[i] + Offset T^{*}[i]$$

$$A[i,j] = \frac{1}{\frac{0.01 * Ice thickness[i,j-1]}{2.2} + \frac{1}{A_{0}[i]}}$$

$$T_{W}[i,j] = T^{*}[i,j] + (T_{W}[i,j-1] - T^{*}[i,j]) * e^{-t*\frac{A[i,j]}{h[i]*\rho*c}}$$

$$Aequi[i,j] = -100 * c * h[i] * \frac{T_{W}[i,j] - T_{Grenz}}{0.9166 * H_{fus}}$$

$$Ice thickness[i,j] = max \begin{bmatrix} Ice thickness[i,j-1] + Aequi[i,j] \\ 0 \end{bmatrix}$$

- Equilibrium temperature T* (based on air temperature T_L and site-specific constants to be calibrated)
- Coefficient of relaxation A (based on existing ice thickness and site-specific constants)
- Water temperature
- Equivalent ice thickness
- Final ice thickness



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Navigation-related forecasting



River Ice forecasting – forecast product

- Each canal is subdivided into several sections, to account for spatial variability in waterway characteristics and meteorological forcing.
- For each canal a report is generated, which summarizes relevant information / data.
- The reports are sent to the local authority of the Waterway ans Shipping Administration (WSV).

Challenges and ways for improvement

- The number of events is very limited.
- The influences of ice beaker activities and thermal inputs is difficult to consider.
- The locations water temperature and ice thickness are measured have to be optimized to be more representative for the canal sections.
- The way data is measured and stored has to be hamonized amongst the waterways.



Eisvorhersage MLK/EHM

0,50

20.01/20

Zeitpunkt der Berichtserstellung: 20.01.2017 09:06 GM

Navigation-related forecasting

bfg Bandess Geneties

Air temperature (**measured, forecasted**) Input: DWD, ECMWF



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Water-level forecasting - Overview



The main vulnerability of waterway transport with regard to hydrological impacts results from (long-lasting) droughts leading to low stream flow and respectively low water-levels along the free-flowing waterways.

Low water-levels and the corresponding reduced water-depths

- limit the cargo-carrying capacity and
- increase the energy consumption and the time of travel.

These effects are reflected in the transport costs as well as in the demand of the forecast service.

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Forecast-related decisions

	Required Lead-time of forecast product(s)					
	short-range (≤ 7 days)	medium-range (≤ 14 days)	monthly (≤ 1 month)	seasonal (≤ 3 months)		
Transport /	logistic compar	nies (carrier)				
Optimization of current vessel load	x					
Shifting cargo from shipping to another mean of transportation in case of low flows		x	x			
Scheduling of a complete transport cycles (up- and downstream trip)		x				
Optimized deliverable of goods arriving via maritime vessels		x	(x)			
Scheduling of special transport (heavy / large load)		(x)	x			
Optimized timing of transports to avoid additional costs in case of low flows		(x)	x	x		
Adaption of fleet / usable transport capacity			x	x		
Industria	al companies (co	onsignor)				
Shifting cargo from shipping to another mean						

Shifting cargo from shipping to another mea of transportation in case of low flows	an	x	х
Building up stocks (e.g. coal power plants, refineries etc.)		x	x
Hire additional storage space for industrial goods (interim storage facility)		x	х
Guarantee security of energy supply (Redispach)		x	x
	Waterway management		
Planning / Timing of measurement projects	x	x	(x)
Timing / suspending of dredge operations	x	x	
reduction of dredge operations	(x)	x	x
·/¬¬ • • • • • •	<u>^</u>		7

Typical decisions of waterway users and the corresponding lead-times

Navigation-related forecasting



- The variety of decisions taken by the **different types of transport-related waterway users** (skipper, logistic manager, transport operator, waterway manager, transmission grid operator etc.) cover a **range of lead-times**, from days up to several months.
- Short-term forecasts used to optimize the load of an upcoming trip as well as to schedule measurement projects are still vital, but **additional lead-time** supporting strategic decisions is more and more in demand.
- Waterway vessels are operated throughout the whole year, therefore a stable forecast quality over the complete water-level range is required. The main parameter of interest is the waterlevel (leading to some methodical challenges due to hydromorphological changes in the rivers). The required forecast frequency is relatively low, typically forecasts are issued at maximum twice a day.

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Deterministic forecast workflow

Navigation-related forecasting



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- The forecasting system is based on the Delft-FEWS framework.
- The operational environment is set-up as a client-server system, based on several components (see below), which allows automating most of the processes within various workflows (70 workflows at the moment).



The development system(s) are run as local stand alone systems, which mimic the operational configuration using a copy of the operational database or an extended hindcast database.

While minor changes are solely tested on a stand alone system, substantial changes are initially tested on the client-server **shadow system** (hosted by Deltares) before using it on the operational system.

The operation data feed continuously supplies the live system and the shadow system at once. The shadow system serves as **fallback** level in case of live system time-out, too.

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Operational forecast system



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Bundesanstalt fü Gewässerkunde





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Interfaces

The different interfaces of the forecasting system have been configured in order to support the forecast team to easily check the lage amount of input data (~ 1900 meteo stations, 95 hydro stations, 6 meteo forecasts and 5 external hydrological forecasts from other operational agencies) and to evaluate the forecast output and the corresponding forecast products.

Operational forecast system



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 Quantification of the meteorological forecast uncertainty by forcing a hydrological model (HBV) with a 72-member meteorological ensemble forecast (composed of ECMWF-HRES, ECMWF-ENS, COSMO-LEPS)

Medium-range forecasts



• In order to calculate water-levels, the output from the hydrological model is used as boundary condition for a 1D hydrodynamic model.



The raw hydrological ensemble forecast is **biased and underdispersed**, because hydrological model uncertainty is not accounted for and bias / dispersion errors propagate from the meteo ensemble; statistical postprocessing is required.



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Probabilistic forecast workflow

Aim of statistical post-processing (Gneiting et al. 2007): "Maximizing the sharpness of the predictive distributions subject to calibration"



Medium-range forecasts



- Ensemble Model Output Statistics **EMOS** is used to calibrate the flow forecasts
- Ensemble Copula Coupling ECC-T is applied to generate runoff trajectories out of the probability distribution while preserving the space-time dependancy of the raw ensemble
- EMOS is used to estimate the predictive uncertainty of water level forecasts

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EMOS

Nav Nav

24h

Sharpness, Coverage

Raw EMOS

72h

Raw EMOS Raw EMOS

120h

EMOS

240h

Medium-range forecasts

 The comparison of the raw water-level ensemble with the post-processed results as well as selected ensemble members proves the necessity as well as the increase of forecast skill and reliability of the use of EMOS.





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Content / design of forecast products (I)



Unterschreitungswahrscheinlichkeiten derinierter wasserstande [76]

	19.04 07:00	20.04 07:00	21.04 07:00	22.04 07:00	23.04 07:00	Tagesmittel 23.04	Tagesmittel 24.04	Tagesmittel 25.04	Tagesmittel 26.04	Tagesmittel 27.04
GLW: 78 cm	0	0	0	0	0	0	0	0	0	0
98 cm	0	0	0	0	0	0	0	0	0	0
118 cm	0	0	0	0	0	0	0	0	0	0
138 cm	0	0	0	0	0	0	0	0	1	2
158 cm	0	0	0	1	3	4	10	14	19	23

Überschreitungswahrscheinlichkeiten HSW_I und HSW_II [%]

	19.04 07:00	20.04 07:00	21.04 07:00	22.04 07:00	23.04 07:00	Tagesmittel 23.04	Tagesmittel 24.04	Tagesmittel 25.04	Tagesmittel 26.04	Tagesmittel 27.04
HSW I: 460 cm	0	0	0	0	0	0	0	0	0	0
HSW II: 640 cm	0	0	0	0	0	0	0	0	0	0

Medium-range forecasts

- Forecast frequency: daily
- Forecast variable: water-level (absolut values)
- Temporal resolution: 0 – 120 hours: instantaneous values 121 – 240 hours: daily mean values
- Probabilistic hydrograph
 + raw ensemble (as additional information)
- ➡ Non-exceedance probabilities for 5 pre-defined low flow water-levels as table
- ⇒ Exceedance probabilities for relevant flood levels (highest shippable water level HSW I and II) as table



Content / design of forecast products (II)

In the current operational test phase of the probabilistic medium-range product two different diagrams are published:

- Type 1: the color scheme stresses the non-exceedence probability of the water-level
- Type 2: the color scheme follows the most common way (in Germany) of displaying predictive uncertainties; the color scheme is symmetric with respect to the median; bright colors indicate lower exceedance / non-exceedance probabilities



Which design do you prefer? For what reason?

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Medium-range forecasts



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Sources of seasonal predictability

- Typical ESP / reverse ESP experiments have been applied to gain more insight into the relative role of the two main sources of predictability as a function of lead-time and initialization date.
- Although differences in flow regime, climate region and catchment characteristics at the waterways affect the relative importance of the predictability sources within the seasonal cycle, in most cases the meteorological forcing are the dominant source of predictability already in the first forecast



month.



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Monthly to seasonal forecasts



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Gauge Kaub / Middle Rhine

0.7

0.5 0.4 0.3

0.2

MSE-SS

Forecast evaluation

ESP

Long-term (1981 – 2014) evaluationEveof ESP and System-4 based approachevalrelated to climatology ...base

ECMWF-S4

lun bud wig

lan eb Event-based (drought 2015) evaluation of ESP, System-4based and statistical approach...

atology (1951 - 2014

Sept-Oct-No

Rhine: For the three-monthly forecast 2015 issued at the beginning of the particular meteorological season, the statistical approach outperformed the other methods, especially for the MAM and JJA forecast.

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Dec-Jan-Fe

Mar-Apr-May

Jun-July-Aug





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Sontombo

Jul-Aug-Ser

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Forecast products

Monthly to seasonal forecast services and products differ from short- to medium range forecasts in terms of:

- forecast frequency (weekly up to monthly updates instead of daily or sub-daily frequency),
- temporal resolution (weekly to monthly means instead of e.g. hourly or instantaneous values),
- predictand, aggregation of predicted value ranges (box-and-whisker plots up to categorical forecasts instead of continuous variable flow or water level).



1850 m³/s 65 August Climatology July 2015 August 2015 September 2015 July-August-September 2015

12

Example of a **monthly forecast**: uncertainty is illustrated as modified box-and-whisker plots (blue), together with the observed climatology (red).

Example of a seasonal forecast: categorical forecast, the flow regime is separated into 3 categories (low, normal, high) and their probability displayed (†

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Monthly to seasonal forecasts