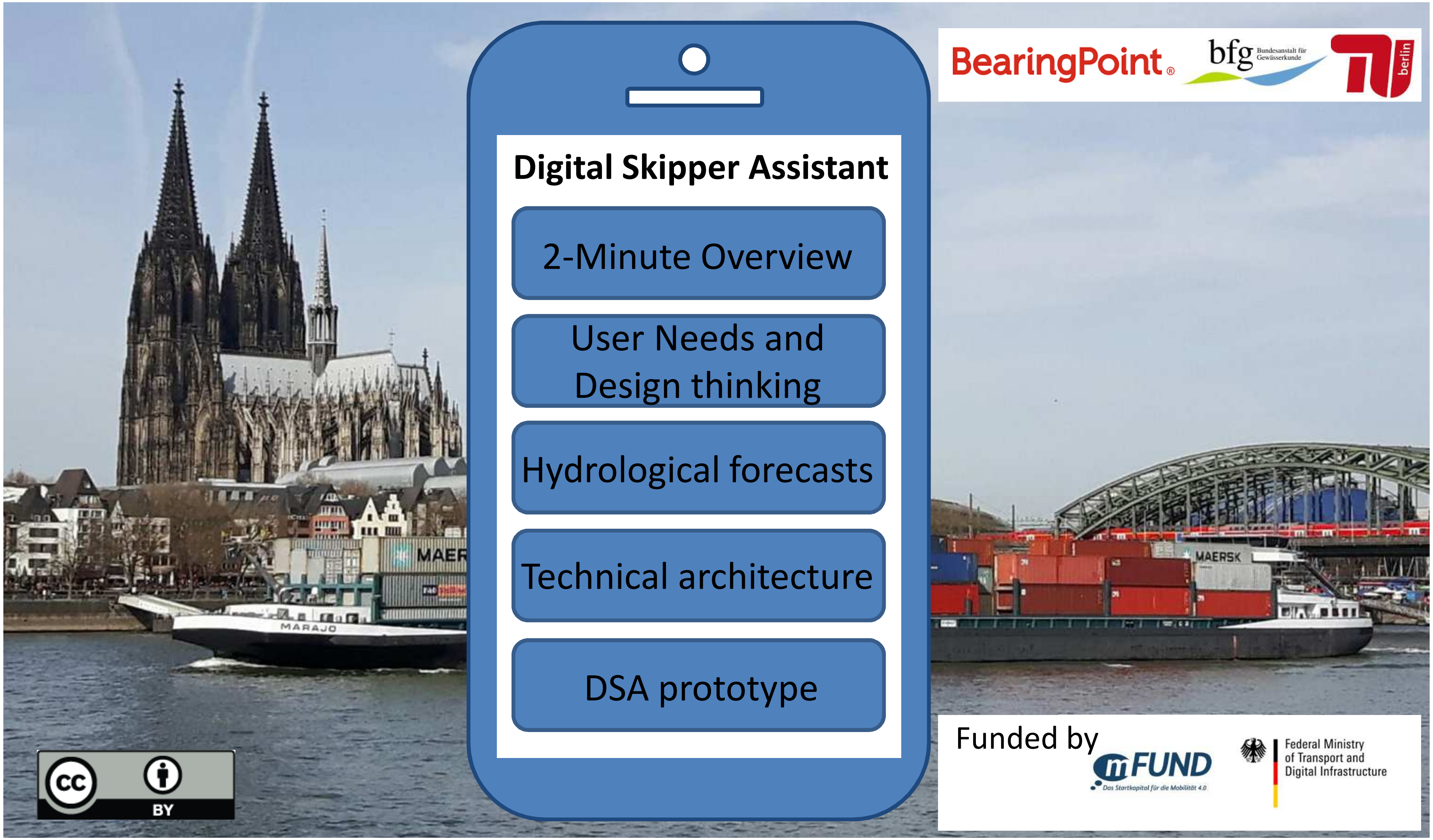
Linking operational hydrological forecasts with a route guidance system to support inland navigation

Dennis Meißner[1], Hanno Schellenberg[2], Gerald Tretter[2], Elena Matta[3]
[1]Federal Institute of Hydrology, [2]BearingPoint GmbH, [3]Technische Universität Berlin



Digital Skipper Assistant

- 2-Minute Overview
- User Needs and Design thinking
- Hydrological forecasts
- Technical architecture
- DSA prototype

Funded by mFUND
Federal Ministry of Transport and Digital Infrastructure

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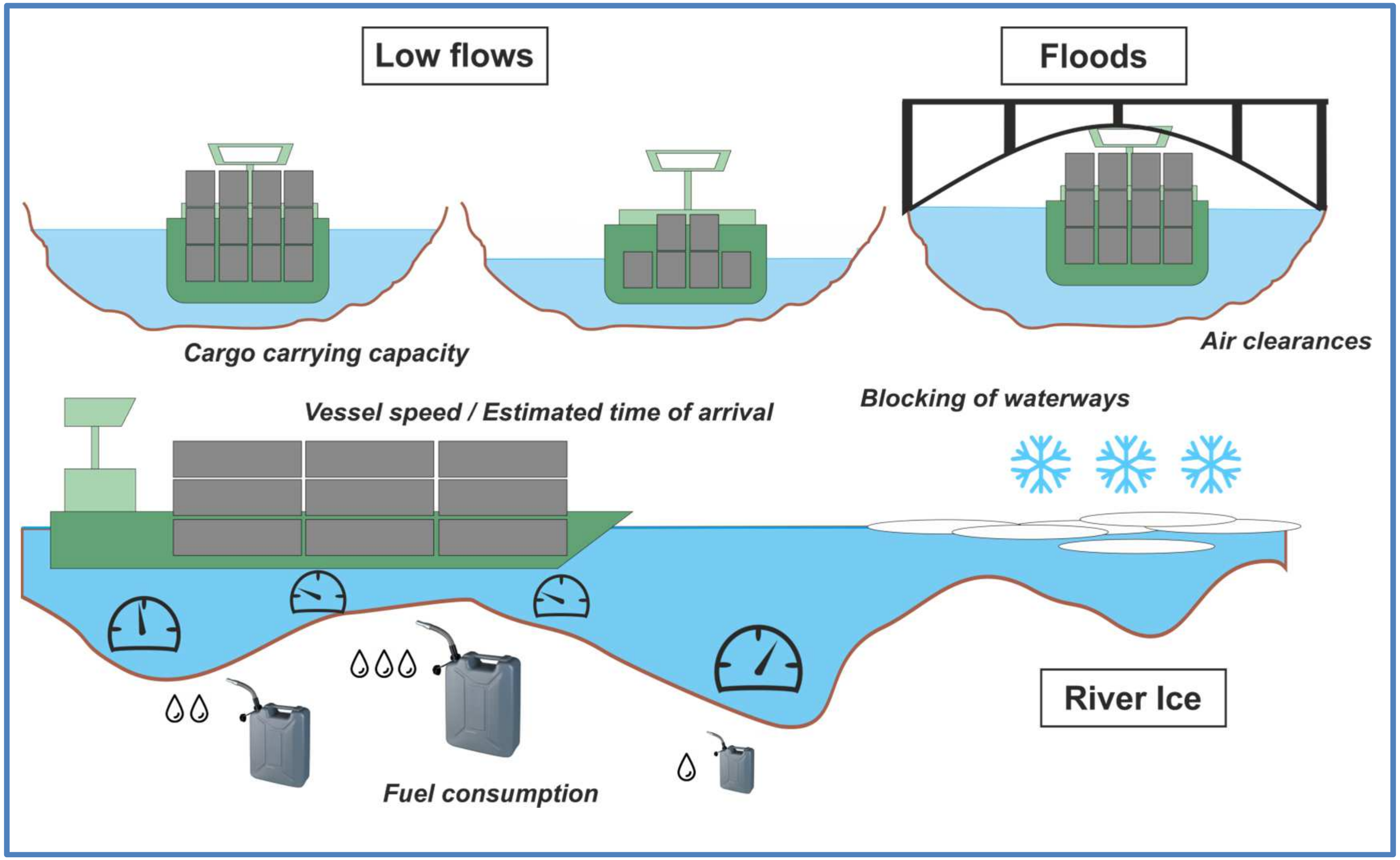
Hydro-meteorological impacts affect Inland Waterway Transport



Hydrological forecasts addressing the relevant impacts are vital for save and efficient waterway transport!

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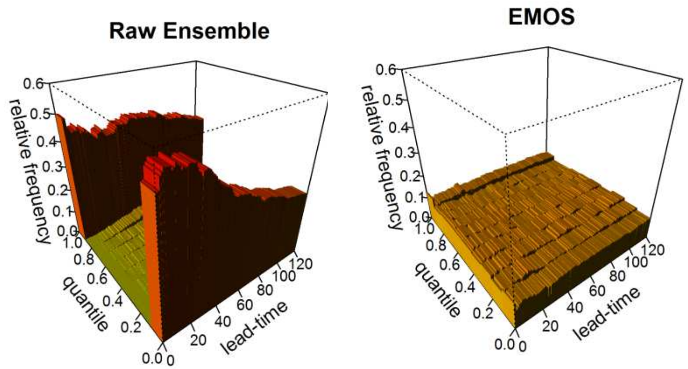
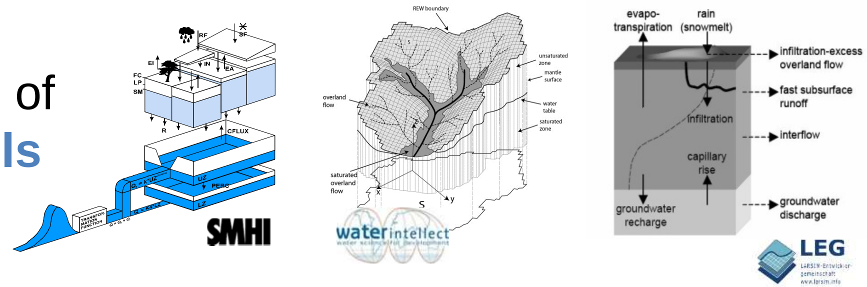
Focus on improving the navigation-related forecasting system for the German waterways (some substantial aspects):

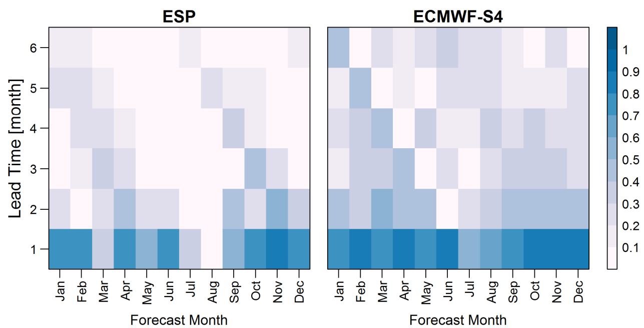
Shift to **probabilistic forecast**, handling of ensemble forecasts



Operation and combination of **multiple hydrological models**



Implementation of **monthly to seasonal forecast** approaches



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➡ Focus on improving the navigation-related forecasting system for the German waterways (some substantial aspects):

➡ BUT: **The real questions of the forecast users** go beyond water-level or flow forecasts …

- ? What is the maximum payload for the trip I‘m planning?
- ? Which is the optimal route to take? Do I have to expect any restrictions on my way?
- ? What is my estimated time of arrival?
- ? Which berthing places are available the afternoon?
- ? …

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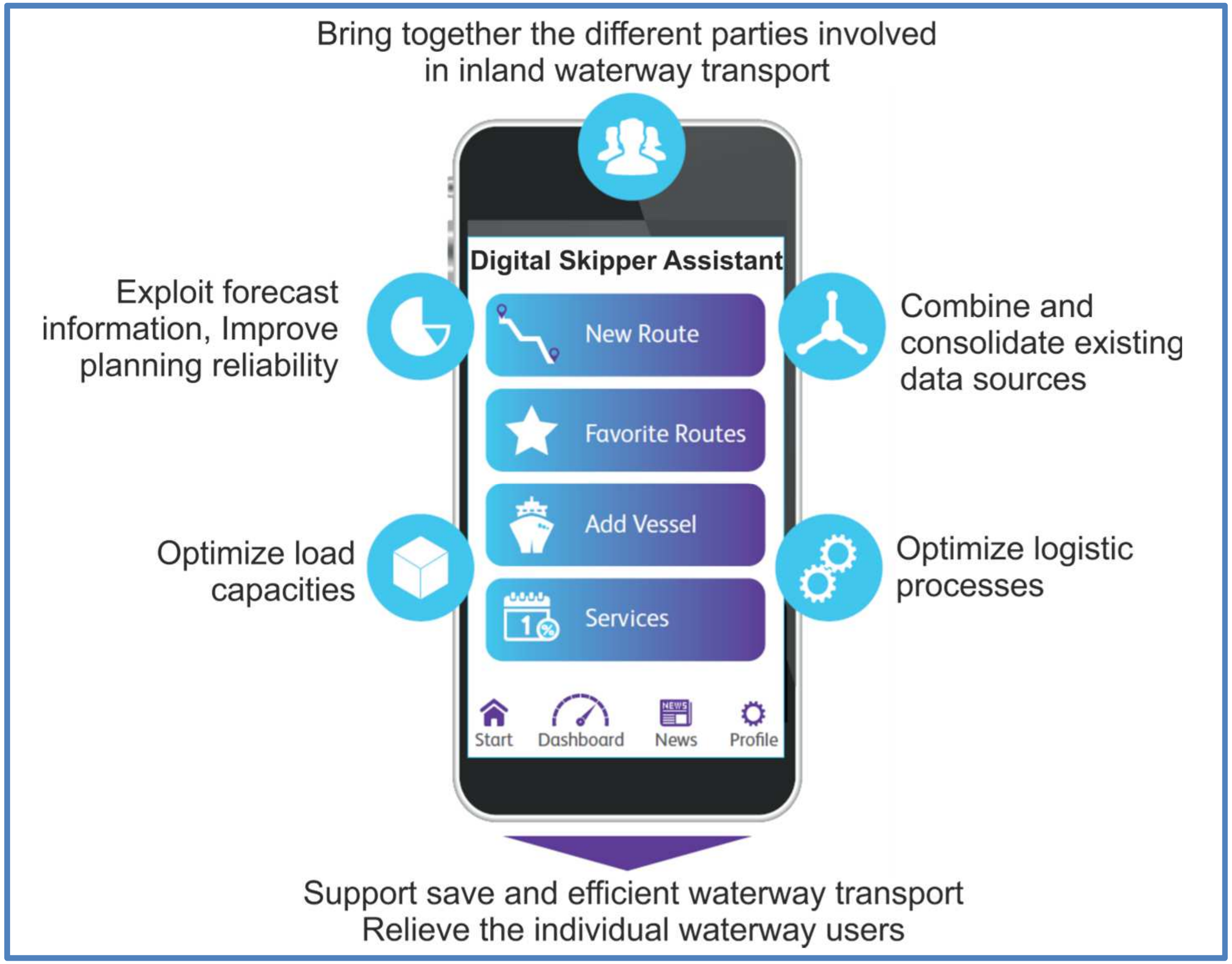
Digital **S**kipper **A**ssistant – cloud-based application to combine customer-specific traffic and forecast information (**forecast value**!)



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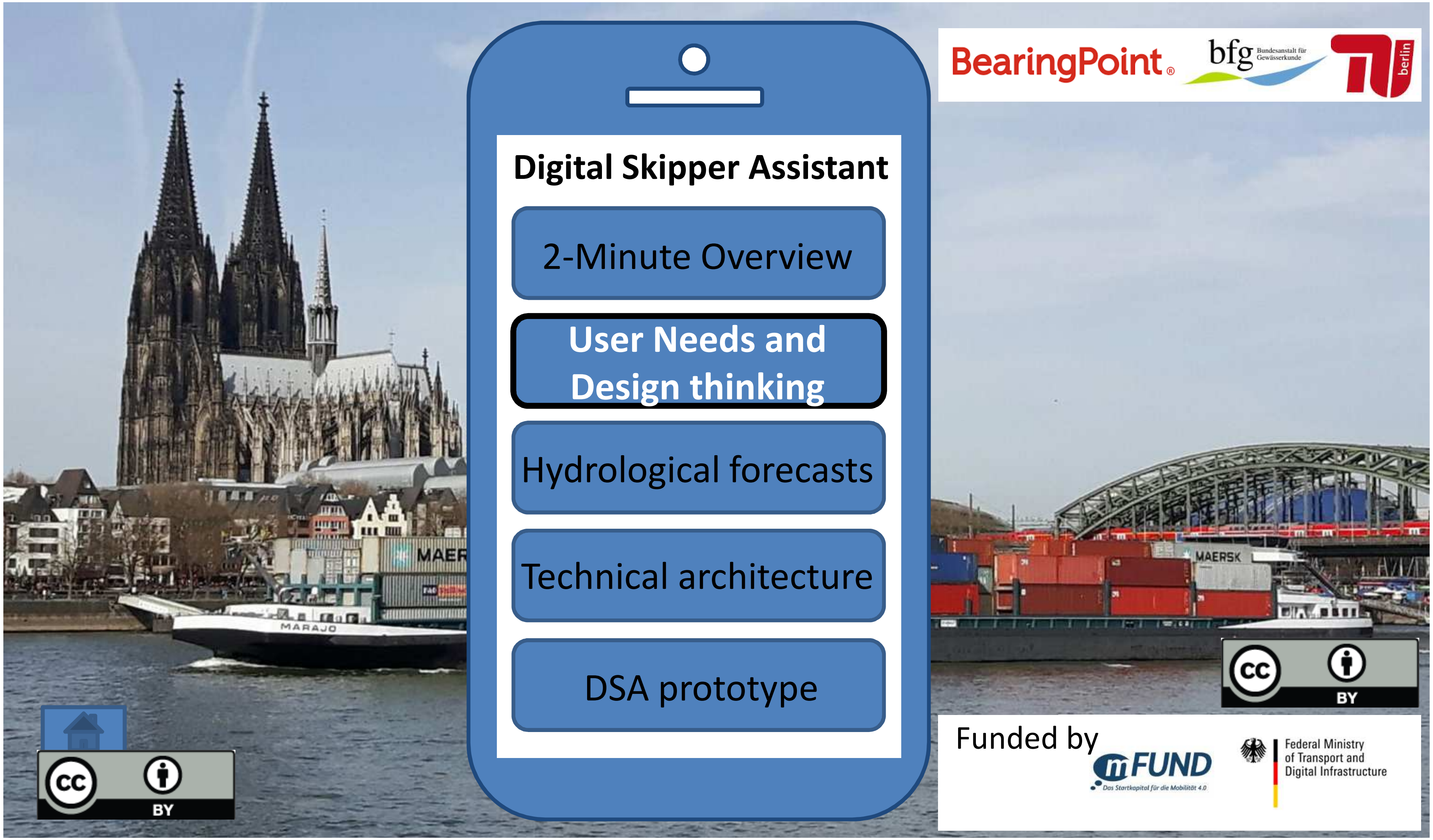

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Rationale of the Digital Skipper Assistant (DSA)

- Economic predictions expect a **growth of about 23% of inland navigation** traffic between 2010 and 2030.
- These expectations put pressure on inland waterway transport capacity.
- With the given waterway infrastructure a **more efficient use of the existing fairway and vessel capacity** is essential.
- The DSA will exploit and tailor information from various sources (River Information Services, hydrological databases etc.) in order to...

… support route and schedule planning

… calculate an estimated time of arrival (ETA) in real-time

… extract and interpret relevant forecast information

… avoid congestion at sluices, harbours, berths etc.

… strengthen the interaction of different parties involved in waterborne logistic chains

Photomontage of BfG's web cam at the confluence of River Rhine and Moselle (http://www.bafg.de/php/deutsches-eck-gross.jpg)

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To better align the DSA-functions with the user needs, the **involvement of users** enjoys high priority during the development of the DSA prototype. An **agile approach** enables the continous integration of user feedback.

Development of the Digital Skipper Assistant (DSA)

Stakeholder Interviews

- Identification of user‘s pain
- Specification of requirements
- Derivation of user stories

Online survey

- Completion of requirements
- Validation of requirements and user stories
- Prioritization of DSA-functionality

DSA field test

- Completion of requirements
- Validation of requirements and user stories
- Prioritization of DSA-functionality

User feedback

- Evaluation and optimization of DSA functionality
- Finalization of DSA prototype
- Identification of future DSA activities

If your are interested, please feel free to take part in the 15 to 20 minutes long DSA questionnaire (online until mid of May).

https://www.soscisurvey.de/DSA/

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The online survey (link see below) is set-up to complete and validate the user requirements. Intermediate results (at the moment ~ 150 participants) proof the relevance of hydrological data and forecasts.
The frequency of data requests by navigational users is much lower than e.g. in case of flood forecasts (mostly once a day)

Which of the following digital products do you use? How often do you use them?

	at most 1x a week	2 to 3x a week	more than4x a week	at most 1x a day	2 to 3x a day	more than 4x a day	No answer
Localisation of ships (AIS-data)	16 %	19 %	10 %	16 %	16 %	13 %	10 %
Notices to Skippers	16 %	23 %	16 %	23 %	10 %	7 %	7 %
Water level measurements (Pegelonline)	20 %	17 %	7 %	23 %	17 %	3 %	13 %
Water-level forecasts (RIS, no floods)	19 %	19 %	9 %	22 %	9 %	9 %	13 %
Water-level forecasts (in case of floods)	17 %	14 %	6 %	20 %	14 %	14 %	14 %
Webcam services at sluices	24 %	8 %	12 %	20 %	8 %	0 %	28 %
Regulations by the Federal Waterways and Shipping Administration	26 %	19 %	11 %	11 %	7 %	7 %	19 %

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

Navigation on inland waterways is affected by…

- River ice
- Floods
- Low flows / droughts

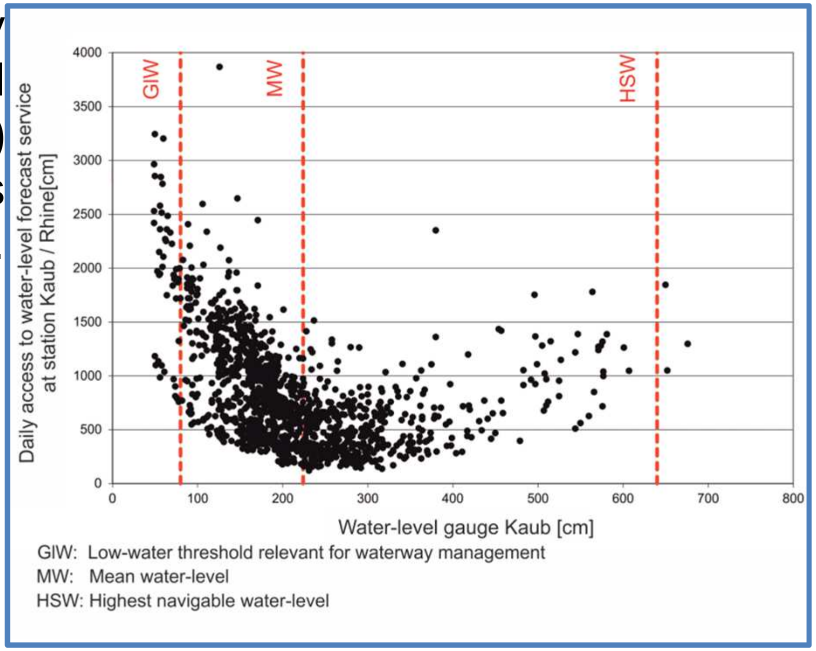
- Floods and river ice restrict the **availability of waterway stretches** (waterways are closed), low flows affect the operation efficiency of waterborne transportation (**transportation costs** increase).

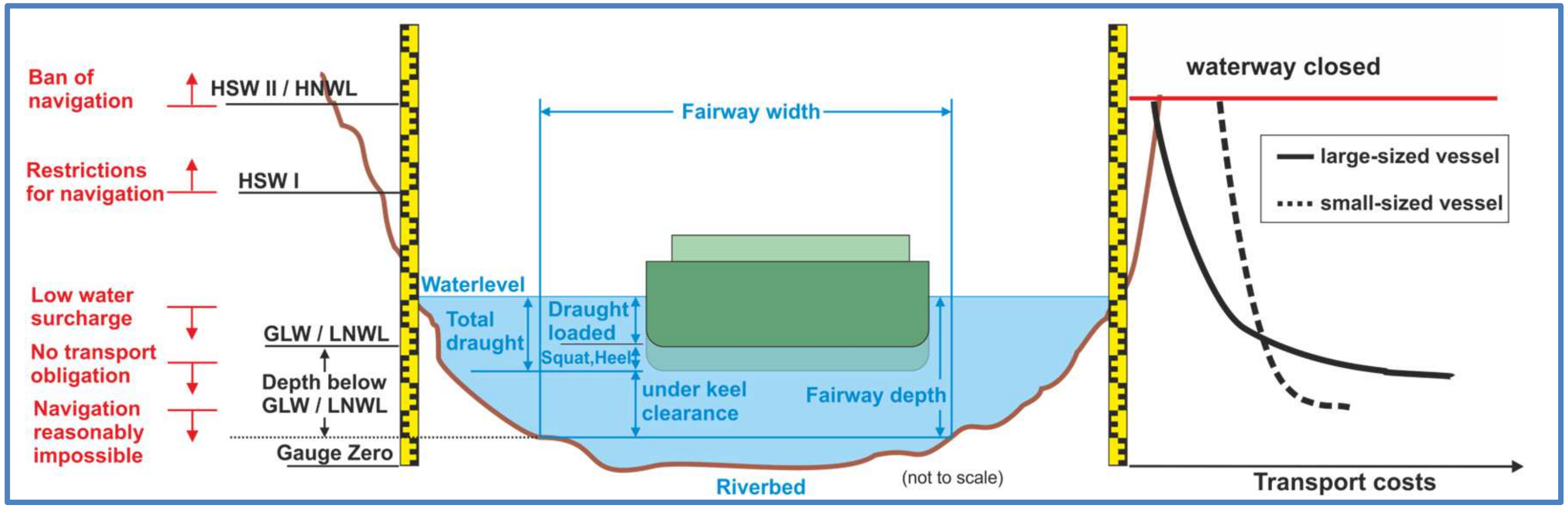
Linking operational hydrological forecasts with a route guidance system to support inland navigation

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

- limit the cargo-carrying capacity
- limit vessel speed, therefore increase time of travel and
- increase fuel consumption.

The **demand for hydrological forecasts** increases during low flows.





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	Required Lead-time of forecast product(s)			
	Short-term (≤ 7 days)	Medium (≤ 14 days)	Monthly (≤ 1 month)	Seasonal (≤ 3 months)
Skipper / Haulier				
Optimization of current vessel load	x			
Scheduling of a complete transport cycles (up- and downstream trip)	(x)	x		
Broker / Logistic company				
Optimized deliverable of goods arriving via maritime vessels	(x)	x	(x)	
Scheduling of special transport (heavy load)		(x)	x	
Shifting cargo from shipping to another mean of transportation		x	x	
Optimized timing of transports to avoid additional costs		(x)	x	x
Adaption of fleet			x	x
Industrial company (consignor)				
Shifting cargo from shipping to another mean of transportation in case of low flows		x	x	
Building up stocks (e.g. coal power plants, refineries etc.)		x	x	
Hire additional storage space for industrial goods (interim storage)		x	x	
Guarantee energy supply (coal)		x	x	
Port operator / Port authority				
Timing of dredge operations		(x)	x	x
reduction of dredge operations		(x)	x	x
Waterway manager / Waterway Administration				
Planning / Timing of measurement projects	x	x	(x)	
Timing / suspending of dredge operations	x	x	x	
Economic outlook			(x)	x

Measurements and forecasts of hydro-meteorological variables are essential to increase the operation efficiency and the strategic management of waterways. Different user groups within the logistic chain require rather **different forecast lead-times** due to the lead time of their decisions (from short-term up to the seasonal scale). Short-term forecasts are still essential in order to practice waterway transport, but there are a lot of users requiring additional lead-time in order to benefit from hydrological forecasts and to **support their decision making**.

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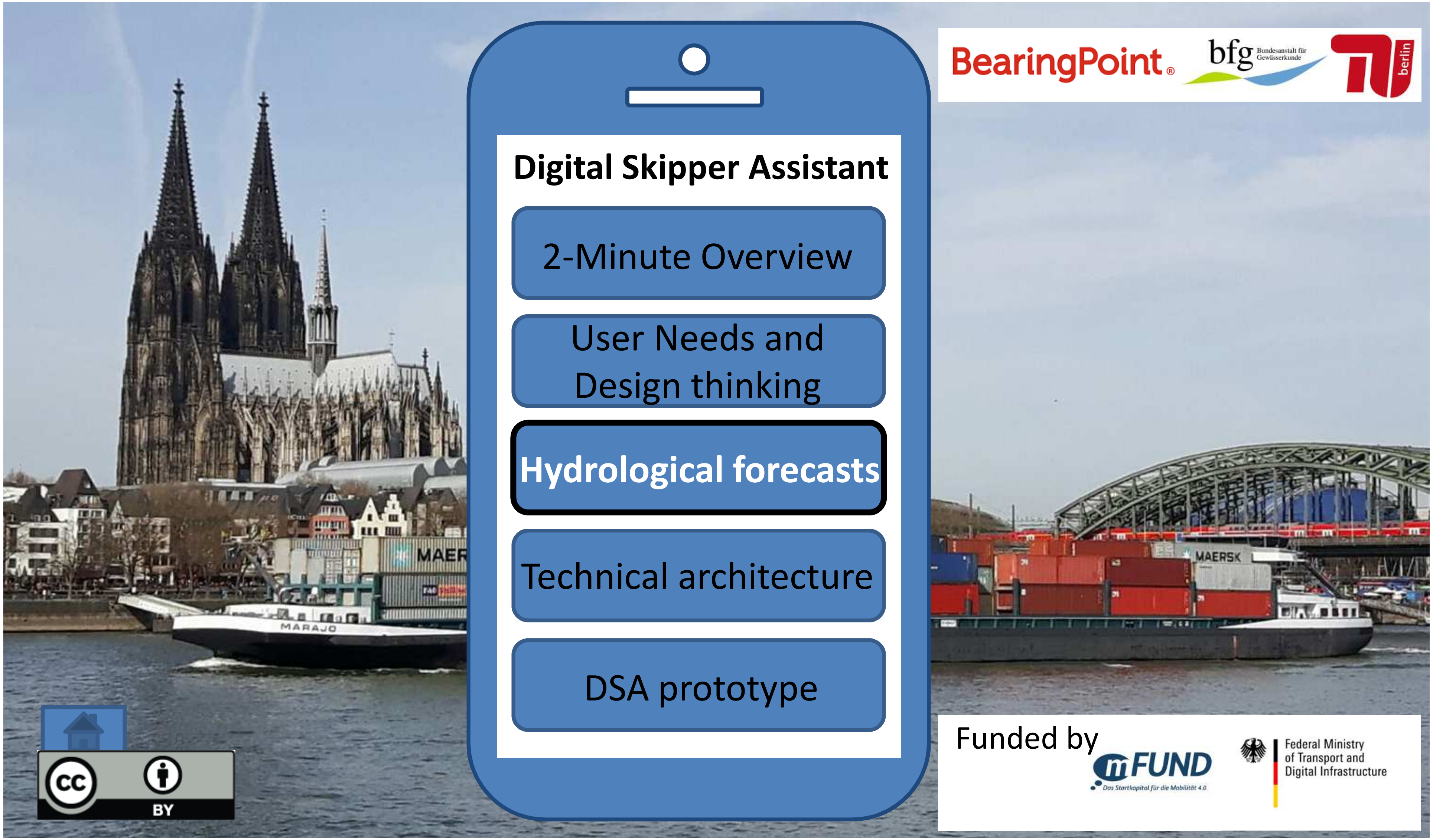

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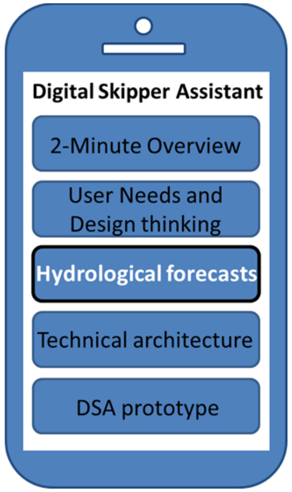
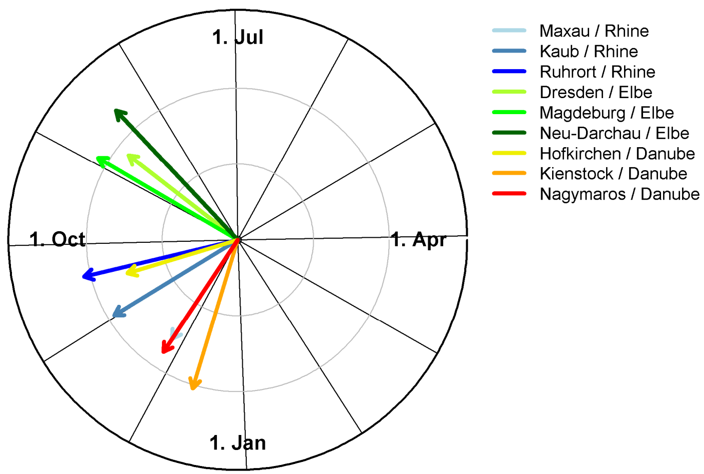
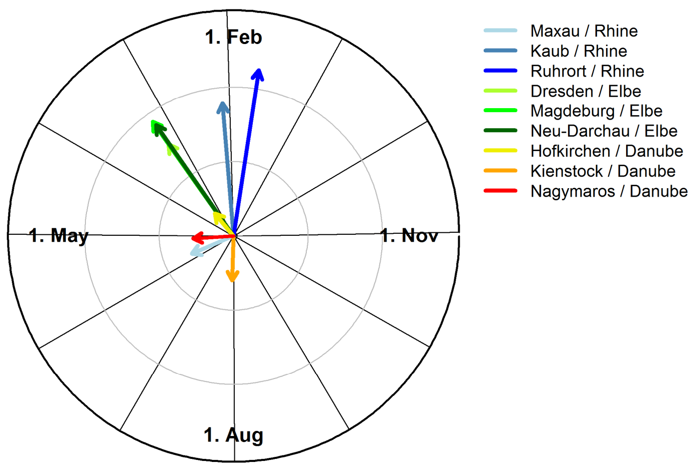


Which are the critical seasons for inland waterway transport?



Low flows (indicator: Annual lowest seven-day mean flow NM7Q)



High flows (indicator: annual maximum flows)

The seasonality vector after Burn (1997) points to the mean date of occurrence of low flow and flood events. The spread of the occurrence dates is represented by the length of the vector (length 1, outer circle: no spread of the occurrence dates indicating **strong seasonality**, length 0: large spread of the occurrence dates indicating **low seasonality** of the events).

Typical low flow season at the Rivers Rhine and Danube is between late summer and end of November / mid of December. The seasonality of floods is limited at the Danube, at the Rhine the first quarter of the year is critical.

Klein, B., and Meißner, D.: Vulnerability of Inland Waterway Transport and Waterway Management on Hydro-meteorological Extremes. IMPREX-Deliverable 9.1, 2016. http://imprex.eu/system/files/generated/files/resource/d9-1-imprex-v2-0.pdf

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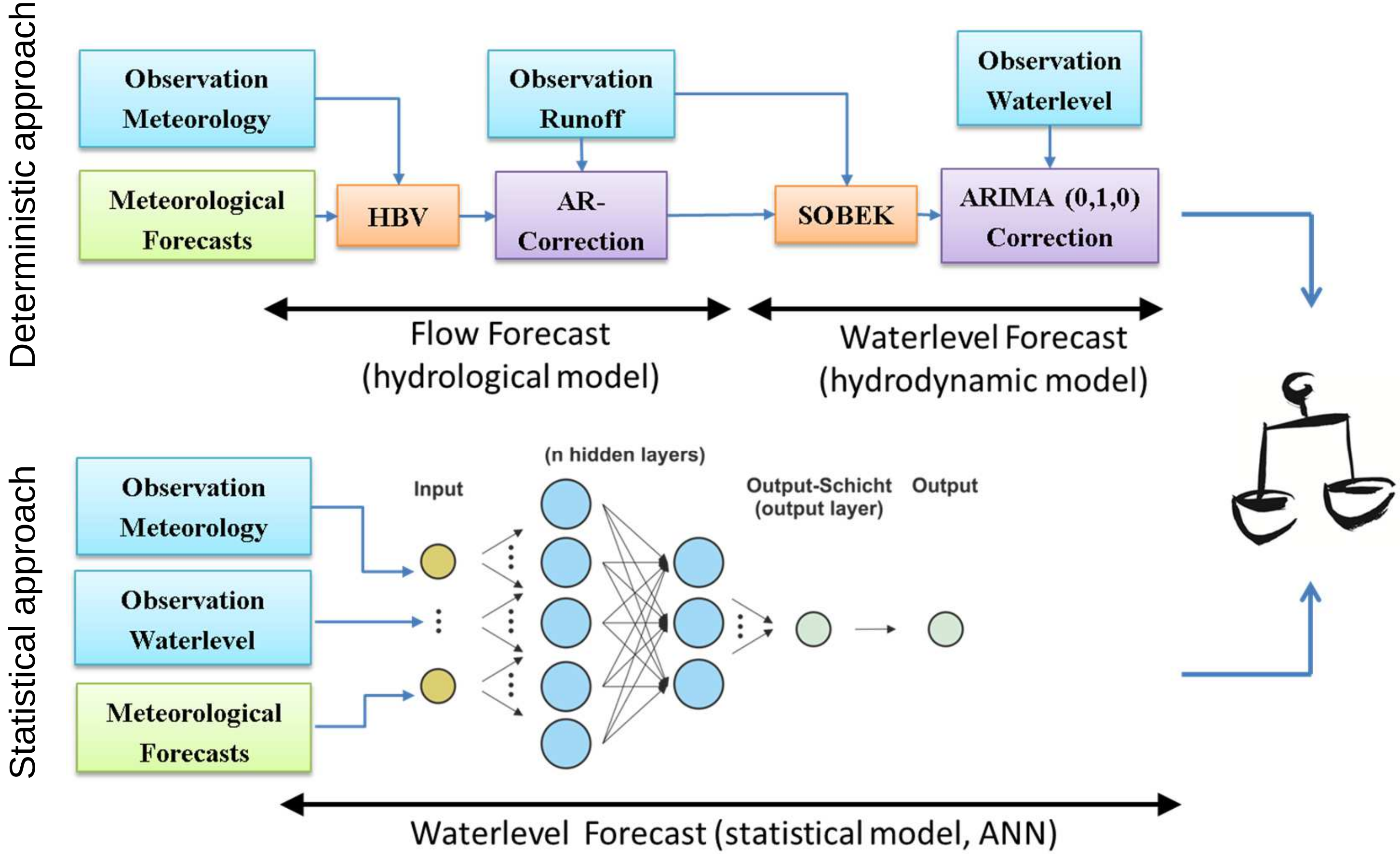
Short-term waterway forecasts

Within the DSA the concept of multiple forecast approaches is implemented, aiming at optimizing forecast skill.



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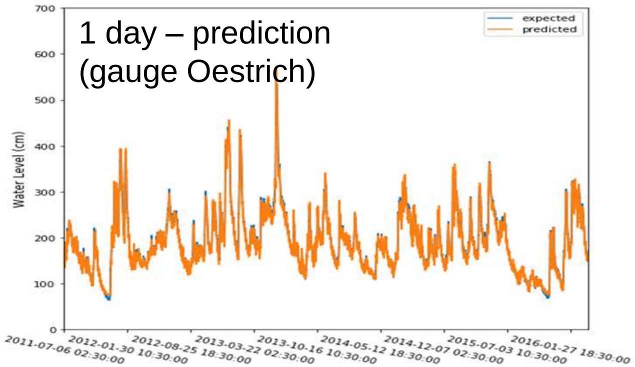
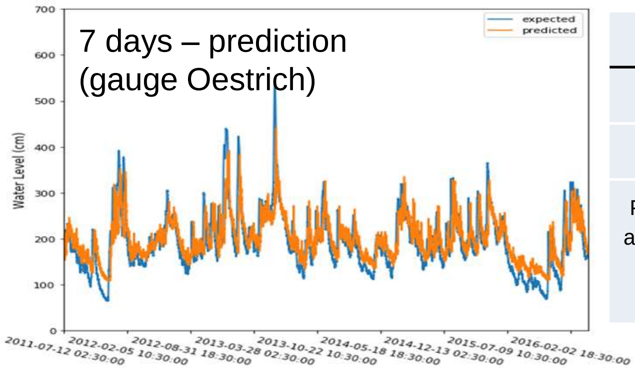
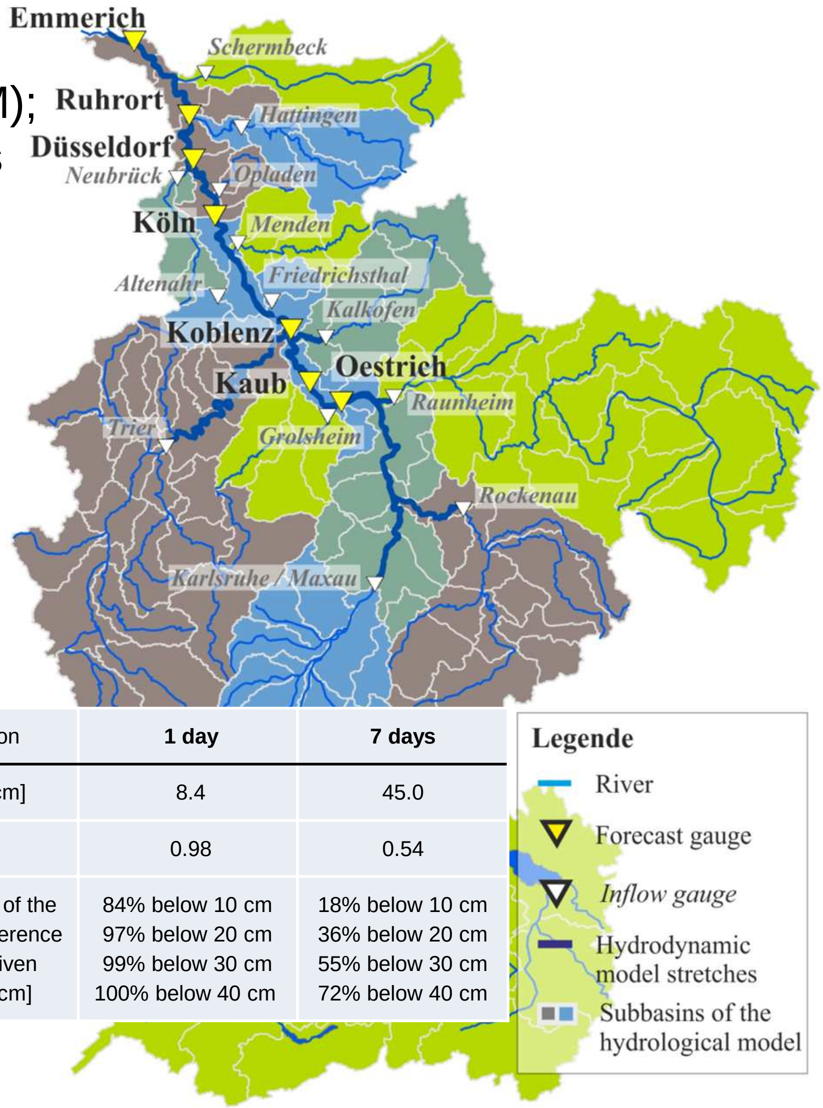
Short-term waterway forecasts

Statistical approach with ANN:
- Long Short Term Memory (LSTM);
- water levels of upstream gauges to predict the downstream ones, assuming a certain flow time.







Prediction	**1 day**	**7 days**
RMSE [cm]	8.4	45.0
R^2 [-]	0.98	0.54
Percentage of the absolute difference below a given value in [cm]	84% below 10 cm 97% below 20 cm 99% below 30 cm 100% below 40 cm	18% below 10 cm 36% below 20 cm 55% below 30 cm 72% below 40 cm

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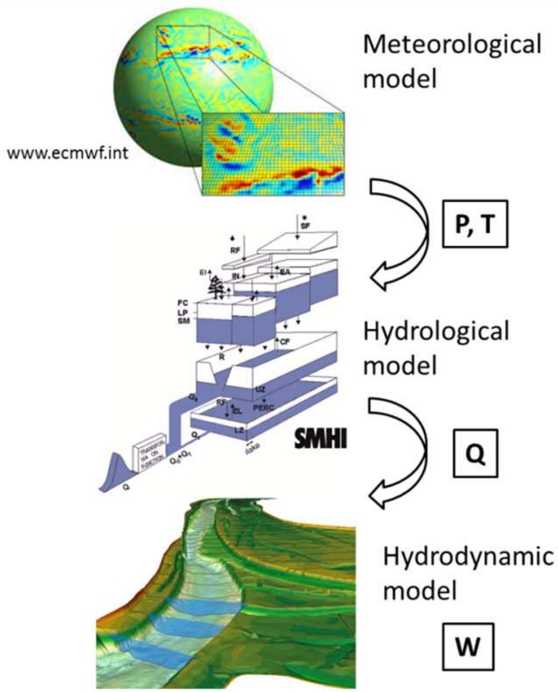
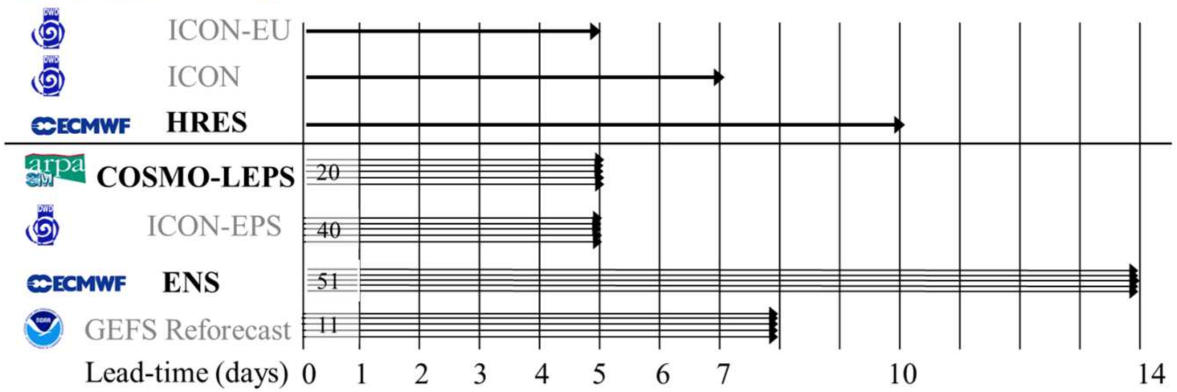
Medium-range waterway forecasts



Medium-range forecasts (up to 10 days) are based on the typical model chain, but the hydrological and hydrodynamic models are forced with a **72-member meteorological ensemble forecast** (composed of ECMWF-HRES, ECMWF-ENS, COSMO-LEPS).

As the raw water-level ensemble forecast is **biased and underdispersed** (uncertainty of the hydrological and hydrodynamic model are neglected, bias / dispersion errors from meteo forecast propagate along the model chain) **statistical post-processing** is required.



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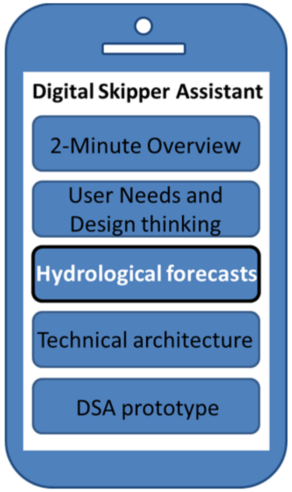
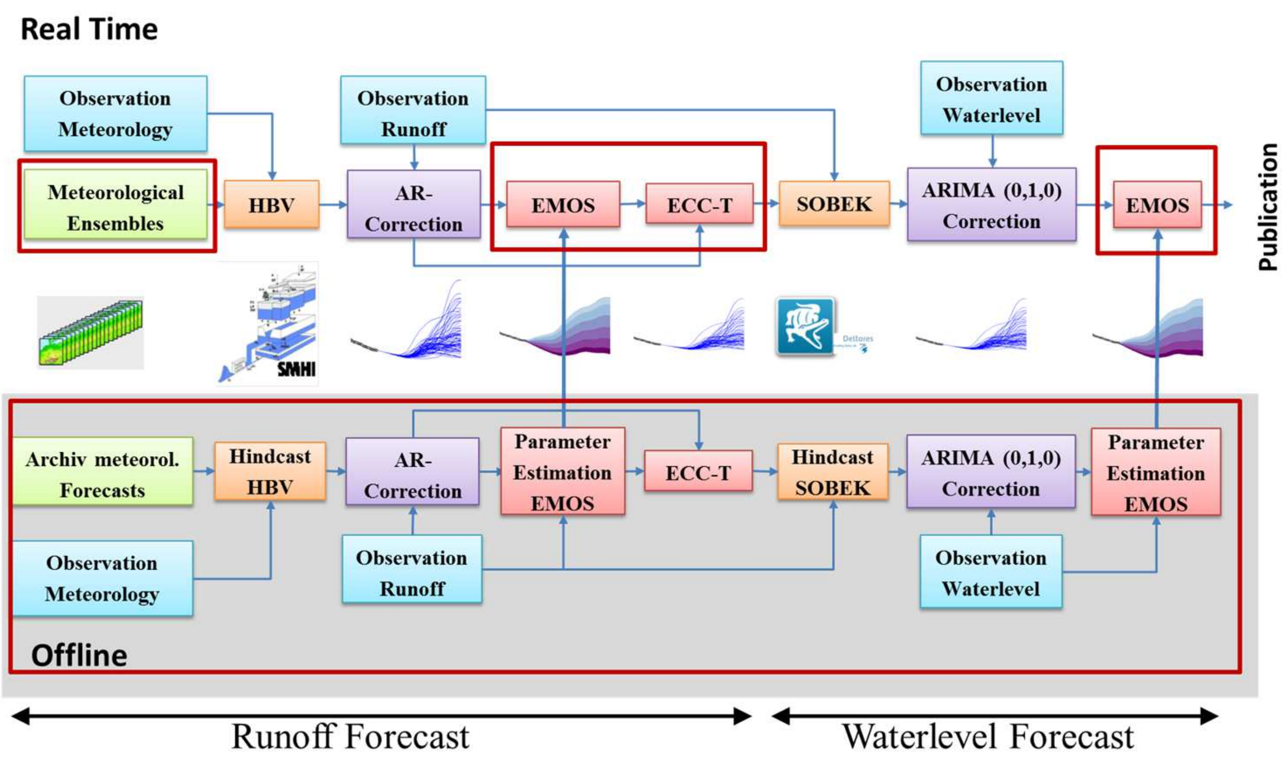


Medium-range waterway forecasts



- **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 again to estimate the predictive uncertainty of water level forecasts, which is published to the users.

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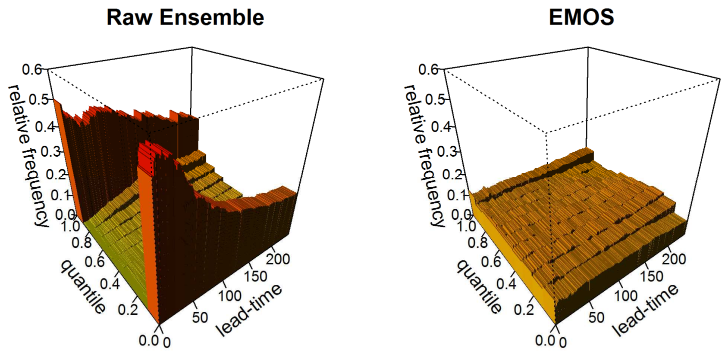
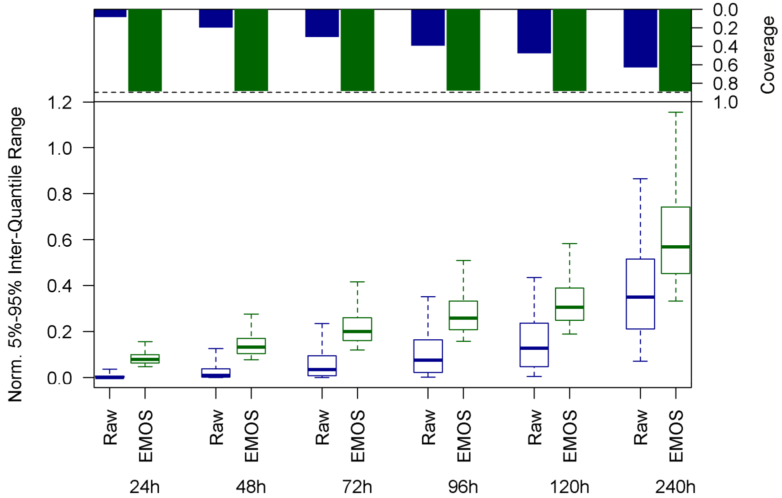
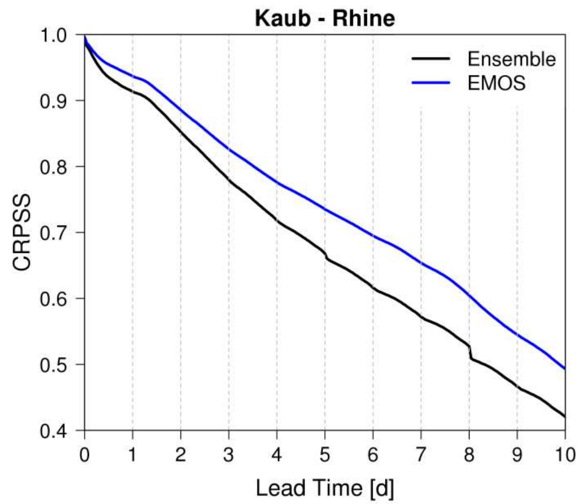


The comparison of the raw water-level ensemble with the post-processed results as well as selected ensemble members proves the **necessity** as well as the **added value** (increase of forecast skill and reliability) **of using statistical post-processing** based on EMOS.





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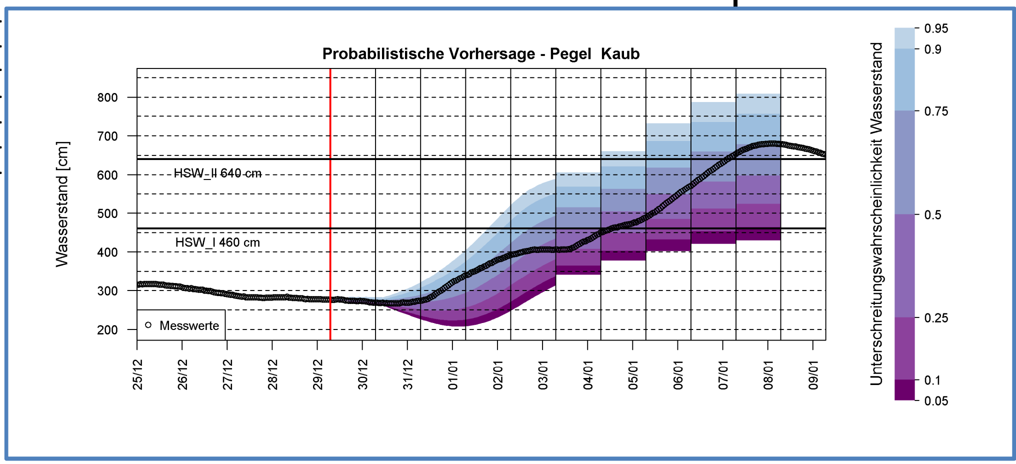
Medium-range waterway forecasts

Example: The small flood beginning of 2018, leading to restrictions for navigation between 04/01 – 12/01, was predicted quite accurately.

	23.12.	24.12.	25.12.	26.12.	27.12.	28.12.	29.12.	30.12.	31.12.	01.01.	02.01.	03.01.	**04.01.**	**05.01.**	**06.01.**	**07.01.**	**08.01.**	**09.01.**	**10.01.**	**11.01.**	**12.01.**	13.01.	14.01.	15.01.
22.12.	0	0	0	0	0	0	10	40	53															
23.12.		0	0	0	0	0	0	0	5	16														
24.12.			0	0	0	0	0	0	0	0	6													
25.12.				0	0	0	0	0	1	30	53	54												
26.12.					0	0	0	0	2	37	60	59	50											
27.12.						0	0	0	0	17	41	48	51	56										
28.12.							0	0	0	0	17	41	48	51	56									
29.12.								0	0	1	15	50	71	83	89	91								
30.12.									0	0	1	17	70	92	98	99	97							
31.12.										0	0	1	28	89	99	99	98	93						
01.01.											0	3	27	57	98	100	100	97	86					
02.01.												0	30	56	85	100	100	100	95	76				
03.01.													8	69	93	99	100	100	93	64	28			
04.01.														96	100	100	100	100	96	67	35	16		
05.01.															100	100	100	100	100	86	48	32	25	
06.01.																100	100	100	100	95	49	21	9	3
07.01.																	100	100	100	100	30	6	2	1
08.01.																		100	100	93	8	0	0	0
09.01.																			100	100	93	8	0	0
10.01.																				100	100	11	0	0
11.01.																					97	1	0	0
12.01.																						0	0	0
13.01.																							0	0
14.01.																								0
15.01.																								

event (04.01. – 12.01.)

Predicted probabilities that a relevant threshold for navigation will be reached between 22/1217 and 15/01/18



Probabilstic forecast initialized on 29/12/2017

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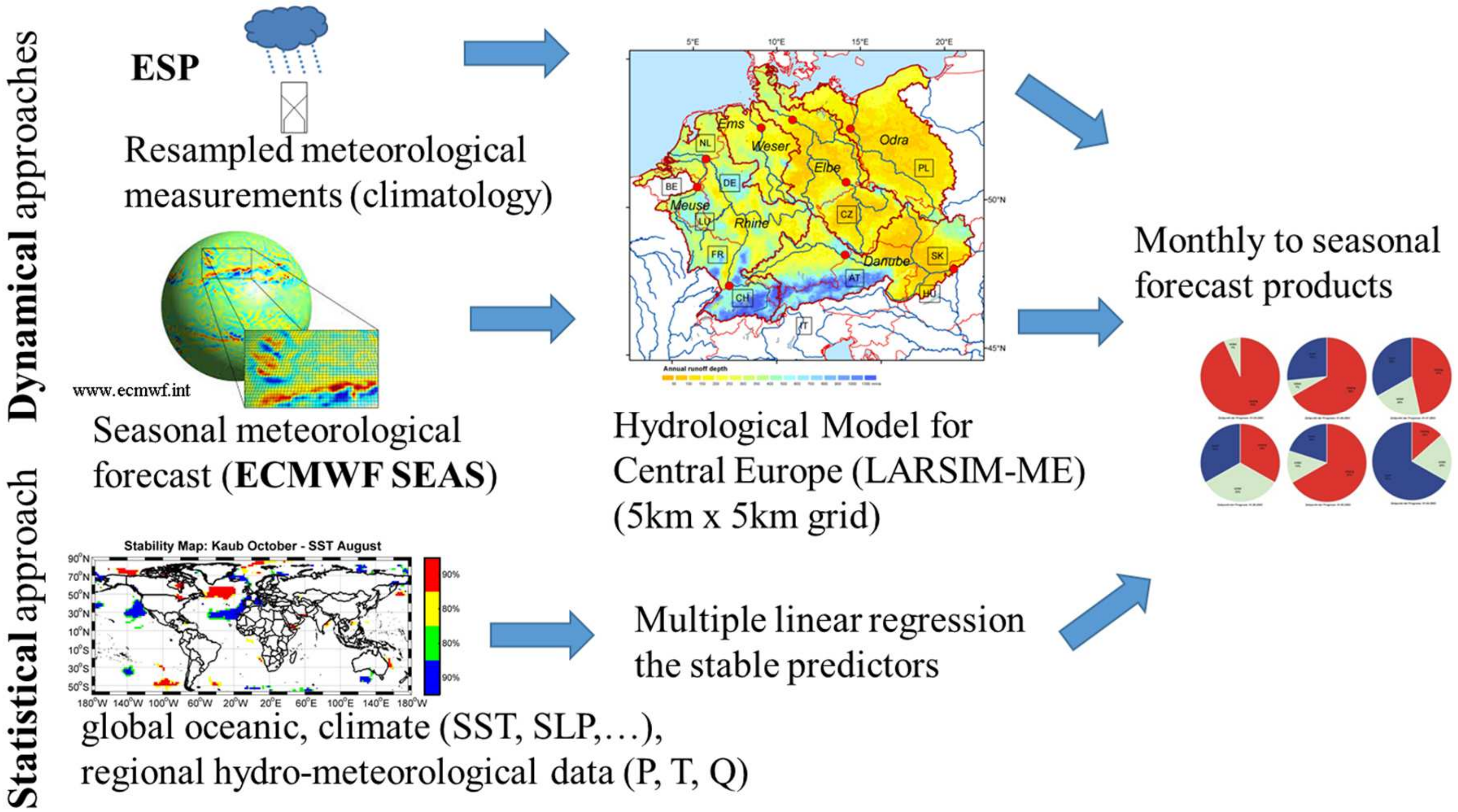
Monthly to seasonal waterway forecasts



Meißner, D., Klein, B., and Ionita, M.: Development of a monthly to seasonal forecast framework tailored to inland waterway transport in central Europe, Hydrol. Earth Syst. Sci., 21, 6401-6423, https://doi.org/10.5194/hess-21-6401-2017, 2017.

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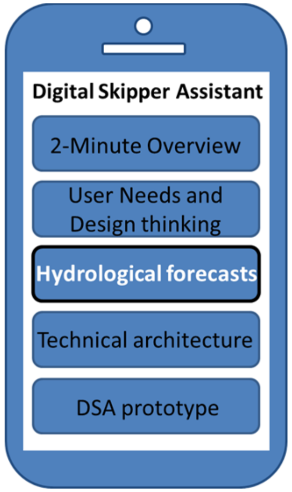

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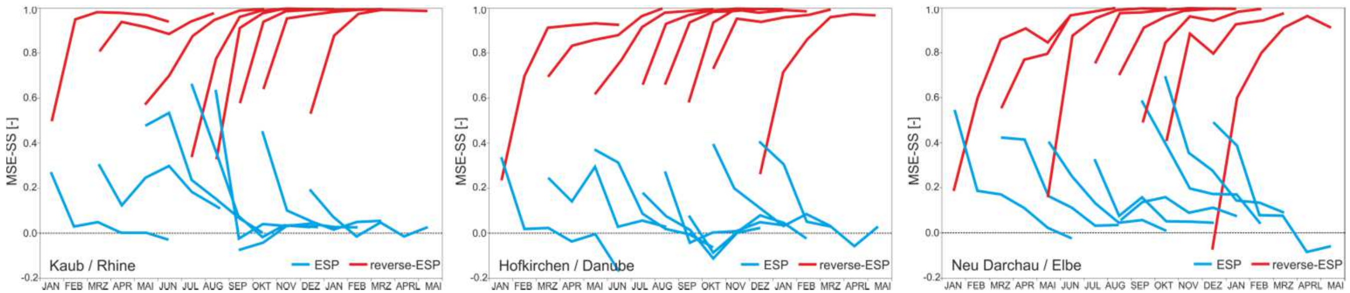
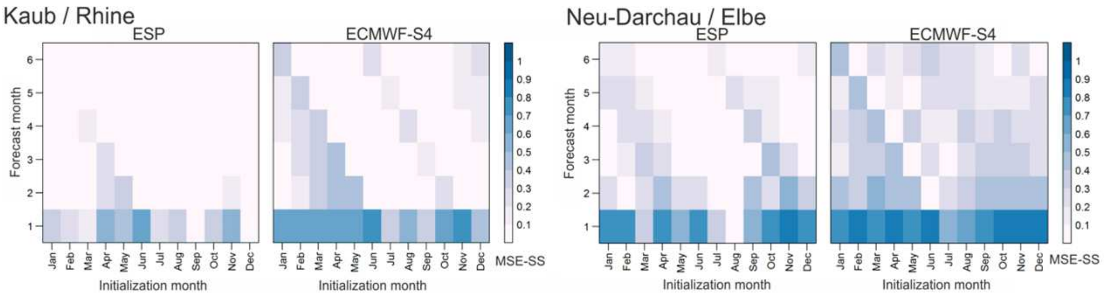
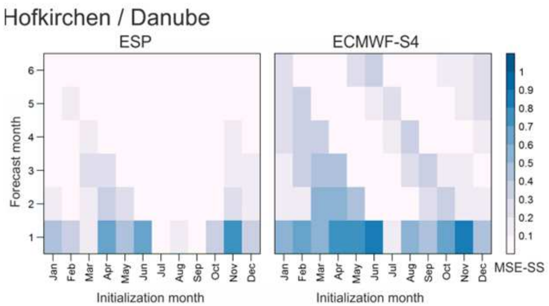






CRPSS (ECMWF-S4 vs. ESP)

	Kaub / Rhine			Neu Darchau / Elbe			Hofkirchen / Danube		
Init.	month 1	month 2	month 3	month 1	month 2	month 3	month 1	month 2	month 3
Jan	-0.09	0.02	-0.05	-0.15	0.04	-0.07	-0.01	0.01	-0.02
Feb	0.16	0.04	0.05	0.07	0.03	0.04	0.13	0.03	0.03
Mar	0.03	0.10	0.08	-0.11	0.08	0.11	0.18	0.09	-0.02
Apr	-0.03	0.00	0.16	-0.03	0.12	-0.02	0.08	0.06	-0.05
May	0.01	0.17	0.17	0.16	0.03	-0.11	0.06	0.03	-0.01
Jun	0.11	0.02	-0.06	0.22	-0.19	-0.10	0.16	-0.05	-0.08
Jul	0.03	-0.03	-0.12	-0.01	-0.22	-0.12	0.03	-0.08	-0.09
Aug	-0.08	-0.09	-0.03	0.08	-0.04	-0.08	0.19	-0.02	-0.04
Sep	0.07	-0.07	-0.14	-0.33	-0.17	-0.28	0.00	-0.07	-0.07
Oct	-0.04	-0.05	-0.08	-0.08	-0.13	-0.29	0.00	-0.03	-0.08
Nov	0.11	-0.04	-0.06	-0.07	-0.08	-0.06	0.08	-0.05	-0.03
Dec	0.04	0.09	0.06	-0.25	0.00	0.02	0.01	0.11	0.04

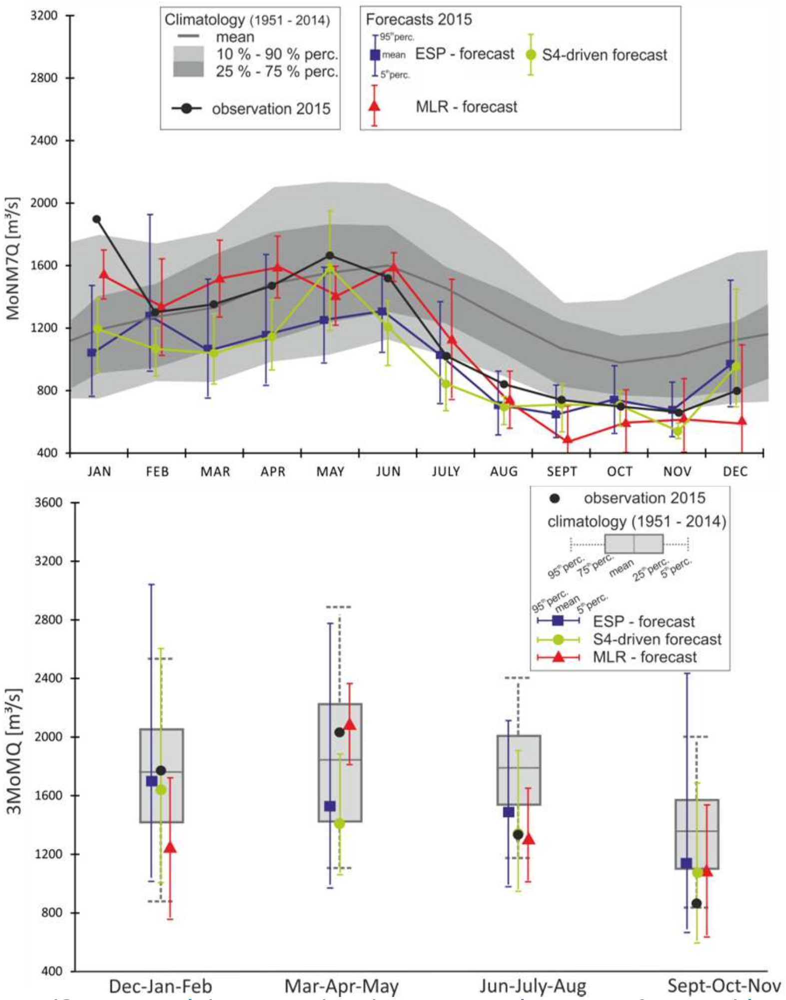
CRPSS (ref. ESP)

Meteorological forcings dominate initial hydrological conditions; nevertheless there is a valuable predictability of streamflow and water-levels on monthly and to some extent even up to seasonal time-scales along the major waterways in Central Europe.

Meißner, D., Klein, B., and Ionita, M.: Development of a monthly to seasonal forecast framework tailored to inland waterway transport in central Europe, Hydrol. Earth Syst. Sci., 21, 6401-6423, https://doi.org/10.5194/hess-21-6401-2017, 2017.

Linking operational hydrological forecasts with a route guidance system to support inland navigation

Monthly to seasonal waterway forecasts



During the **low flow situation 2015** all forecasting methods in place provided meaningful forecasts of the **monthly NM7Q** , while ESP and the dynamical approach (S4-driven forecast) were slightly advantaged compared to the statistical method (MLR) in this particular situation.

Regarding the **tri-monthly forecast** issued at the beginning of the particular meteorological season, the **statistical approach significantly outperformed the other methods** in spring (MAM) and summer(JJA), in autumn (SON) the forecasts of all approaches were relatively similar.

Meißner, D., Klein, B., and Ionita, M.: Development of a monthly to seasonal forecast framework tailored to inland waterway transport in central Europe, Hydrol. Earth Syst. Sci., 21, 6401-6423, https://doi.org/10.5194/hess-21-6401-2017, 2017.

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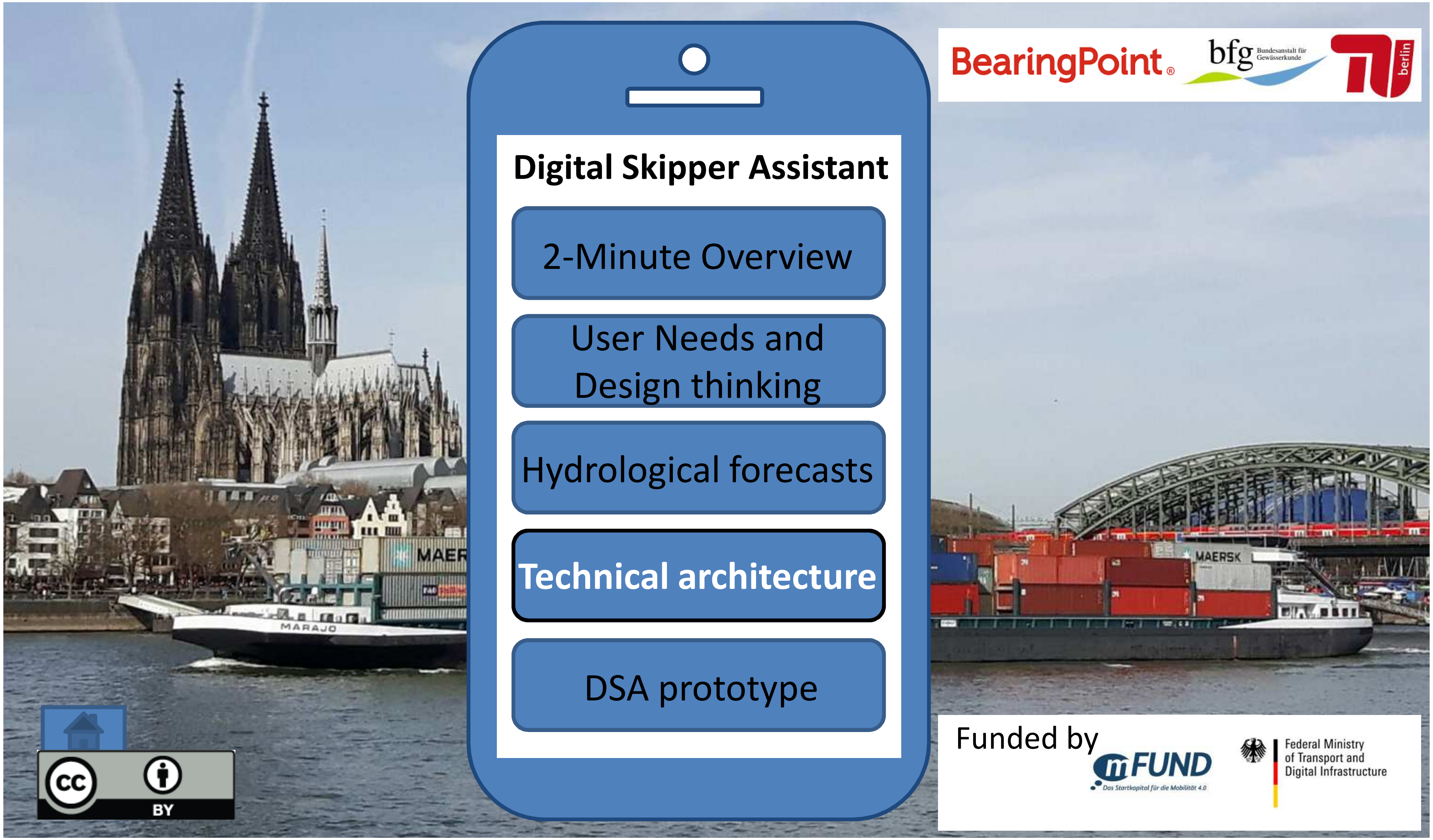

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DSA Technical Architecture

- Cloud based Software-as-a-Service Application running in Microsoft Azure
- Microservice Architecture with strong focus on extensibility
- Ingestion of a multitude of data sources via event streams that are cleansed, aggregated, processed and fed into client facing services
- Client facing functionality is exposed via an application programming interface (API) and can be used by multiple client types
- Incoming event streams, as well as events generated by client facing services are stored for analysis and can be used to improve ETA predictions

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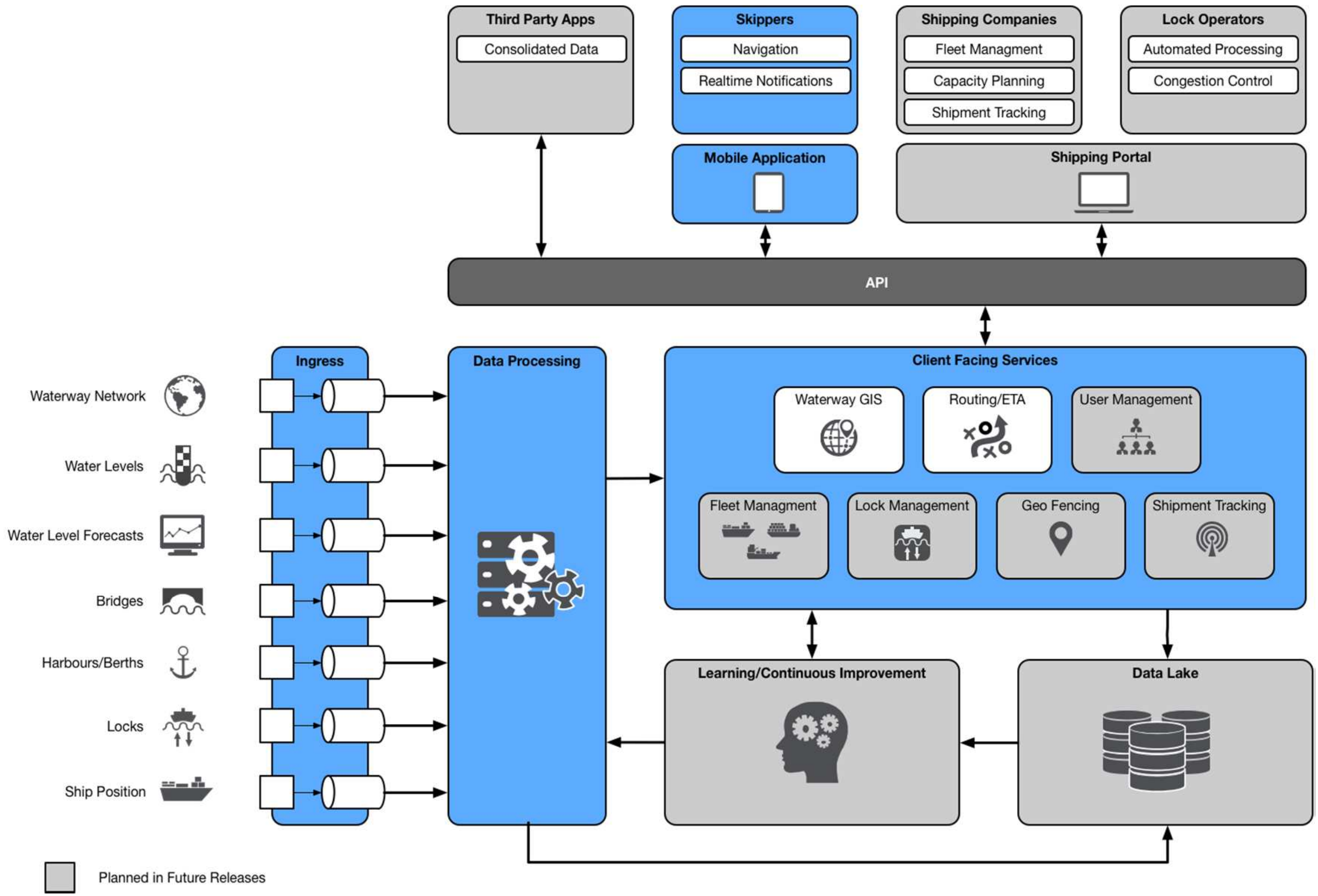
BearingPoint

bfg Bundesanstalt für Gewässerkunde

TU berlin

Digital Skipper Assistant

- 2-Minute Overview
- User Needs and Design thinking
- Hydrological forecasts
- **Technical architecture**
- DSA prototype



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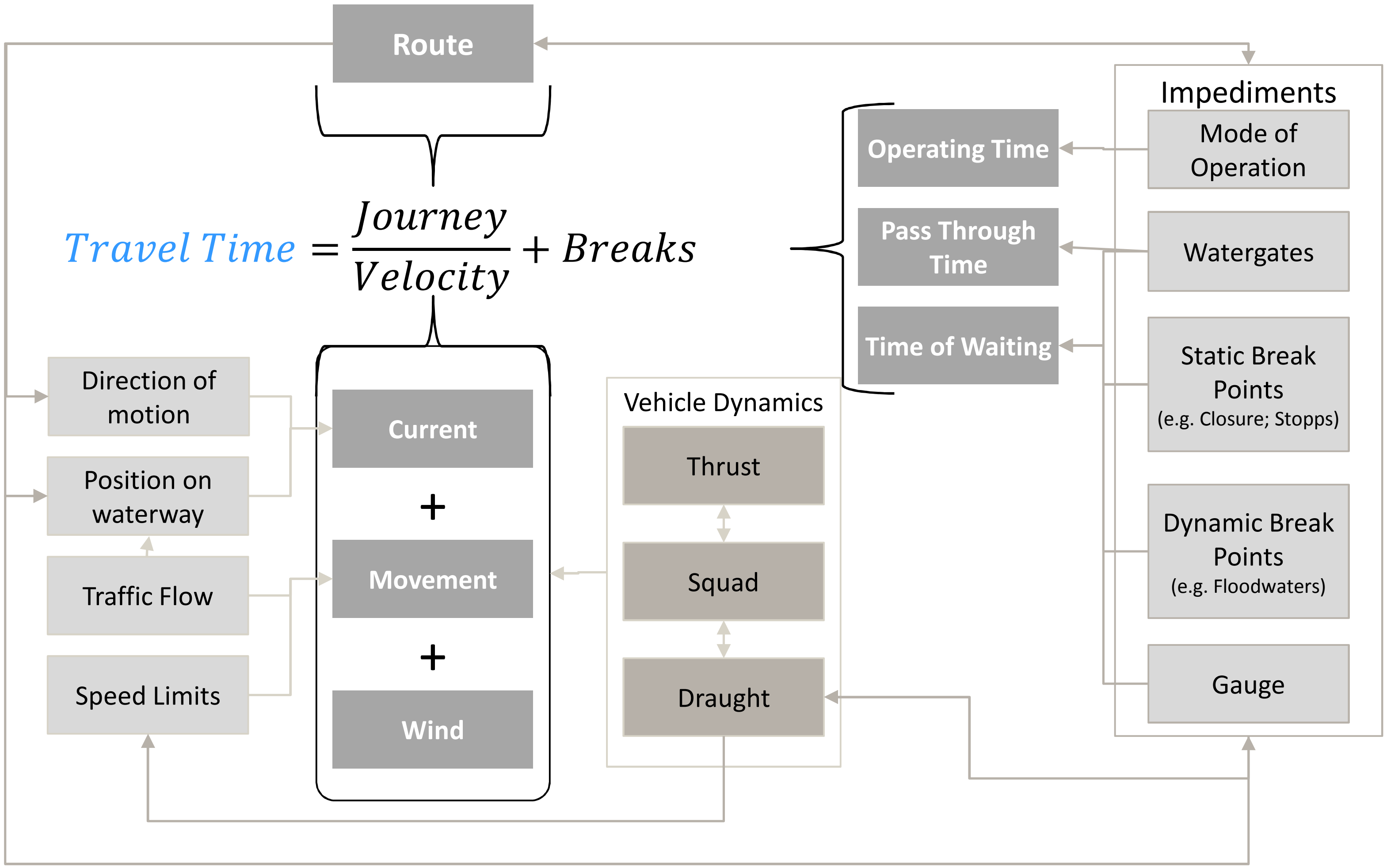
BearingPoint
bfg Bundesanstalt für Gewässerkunde
TU berlin

$$ETA = Starting\ Time + Travel\ Time$$



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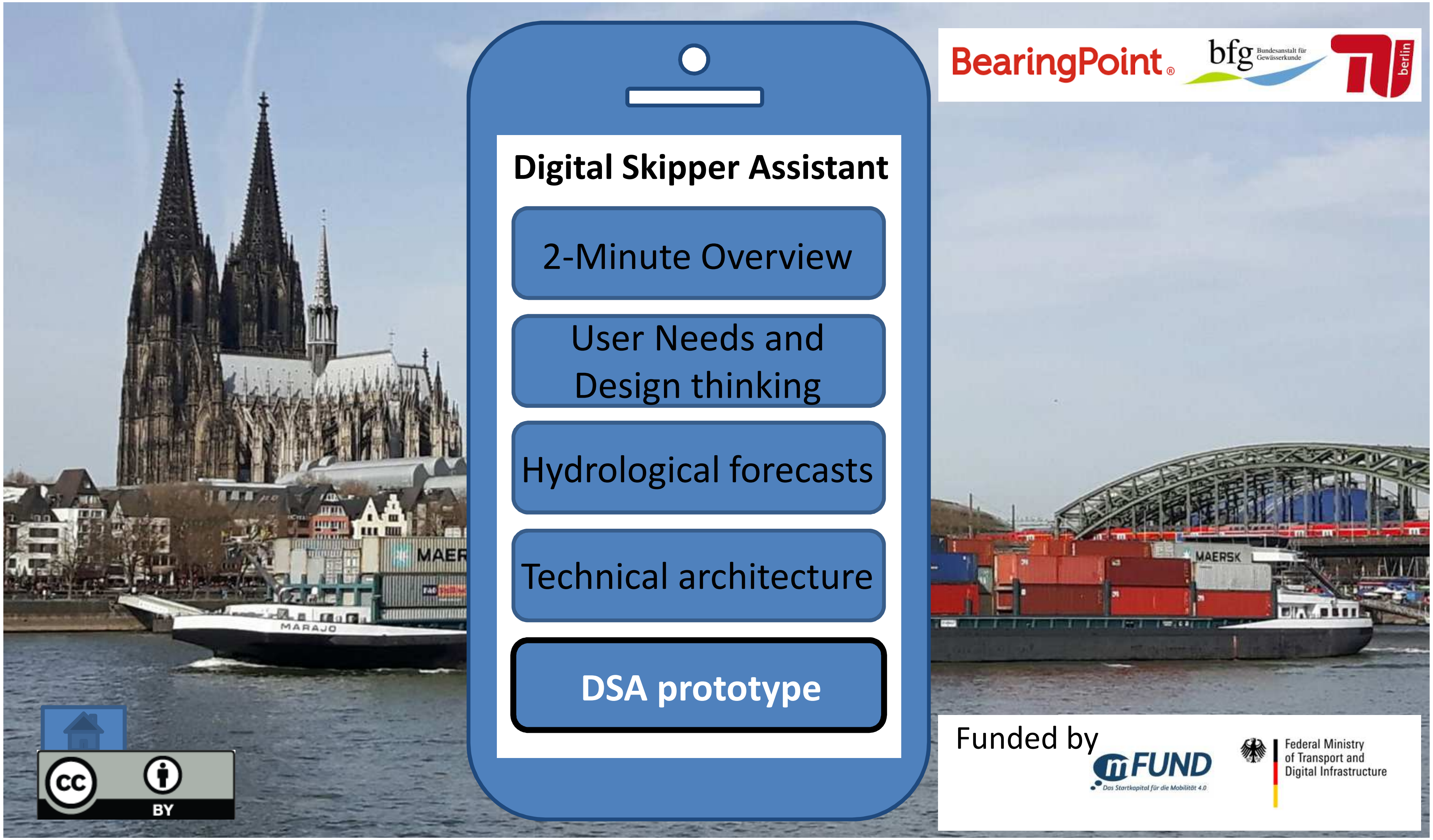

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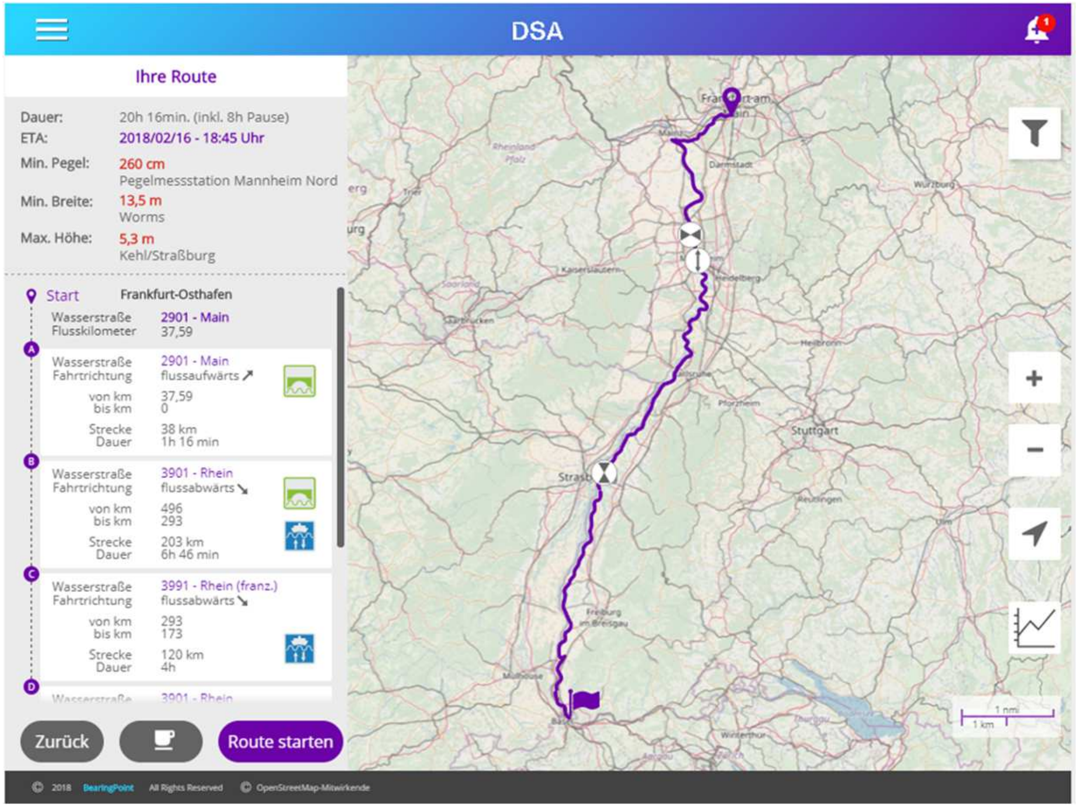
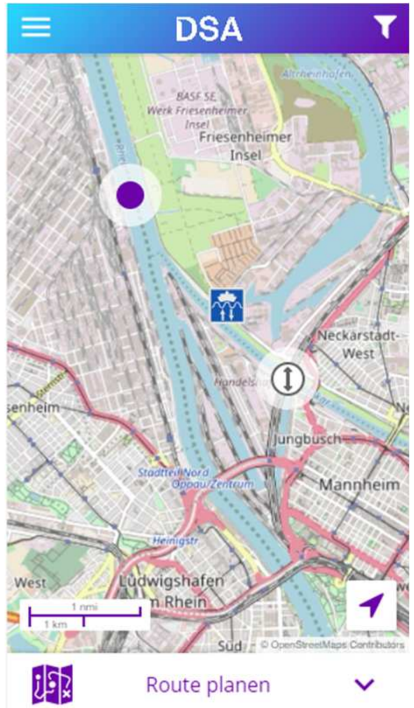
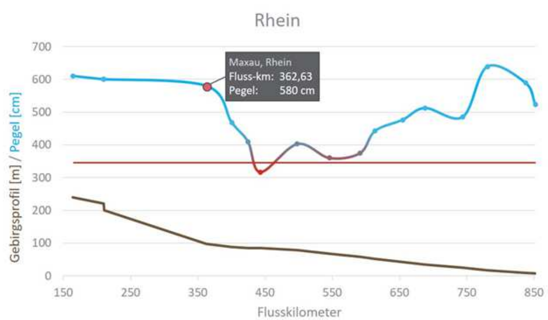


Route Calculation

Mobile View





Gauge Trend