Early Flood Warning for the City of Zurich: Evaluation of real-time Operations since 2010

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ABSTRACT

The flood forecast system for the river Sihl in Zurich (Switzerland) is operated by the Federal Research Institute WSL on behalf of the Canton of Zurich since 2007. The close collaboration between forecasters and decision makers fosters continuous development of the system.
A management tool was implemented in the system that allows computing scenarios for predicted critical events. The forecast system comprises three forecast chains differing in lead time, spatial resolution and update cycle amongst others. These are the two deterministic chains driven by the numerical weather predictions COSMO-2 and COSMO-7 and the ensemble forecast chain driven by the COSMO-LEPS ensemble. The hydrological forecasts resulting from the three model chains and additional helpful information about the conditions in the catchment are made available on an online platform. The statistical evaluation of the three forecast chains showed that the ensemble forecasts clearly outperform the deterministic forecasts and are more reliable especially for taking decisions that need a lead time of more than just a few hours.

KEYWORDS

flood forecasting; early warning; hydro-meteorological forecast system

INTRODUCTION

This contribution presents the flood forecasting system for the river Sihl for the City of Zurich and its evaluation over more than five years of operational use.
In summer 2005 big parts of Switzerland were flooded after 3 days of heavy rain. The event caused damages of more than three billion Swiss Francs. While many places experienced the worst flood damages recorded, Zurich City stayed relatively dry. However, the city centre of Zurich has a high damage potential, which is estimated to about five billion Swiss Francs.
A lot of infrastructure had been constructed on the alluvial fan of the river Sihl during the last century. A closer look at the event of 2005 showed that if the centre of precipitation would have been over the Sihl catchment, the city centre, including Zurich central railway station would have been flooded. One of the main problems in Zurich is that the river Sihl crosses the central railway station. The riverbed of the Sihl is embraced by the underground tracks and the ground level tracks of the railway station, limiting its capacity to estimated 350m^3/s, corresponding roughly to a hundred year flood (FOEN, 2014). So a forecast system for the river Sihl is needed to be able to take prevention measures in case of expected flood

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events. The most important measure that could be taken to prevent a flood event in Zurich is to drawdown the Sihl lake, which is a reservoir lake for hydropower production and can act as a retention basin for about 46% of the catchment area (Figure 1). This action needs a lead time of about 1 to 3 days.

The forecasting system developed for this purpose is run operationally since 2007 by the Swiss Federal Institute for Forest, Snow and Landscape Research WSL on behalf of the Canton of Zurich (Office for Waste, Water, Energy and Air) (Addor et al. 2011; Zappa et al. 2010). In this contribution the system set up, a statistical evaluation and experiences with the system in operational use are presented.

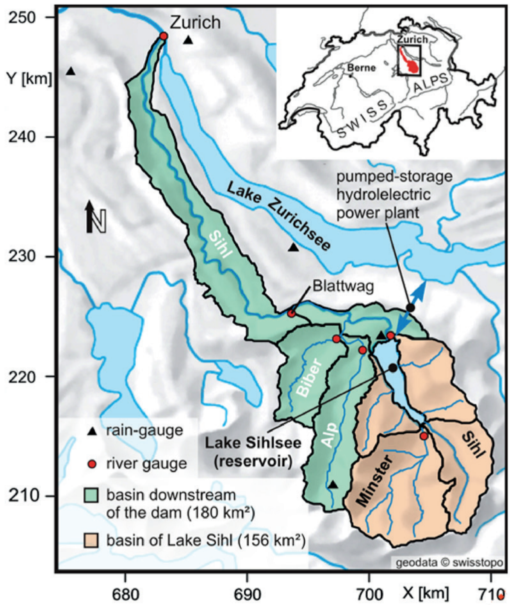

Figure 1: Sihl catchment. The upper part of the catchment coloured in orange (46 %) belong to the accumulation area of the reservoir lake Sihlsee. The remaining catchment area consists of the two tributaries Alp and Biber and the narrow Sihl valley between the lake and Zurich City (source Addor et al. 2011).

METHODS

The presented flood forecasting system consists of a meteorological and a hydrological part (Zappa et al. 2010). Three different meteorological model forecasts are used to drive the discharge forecasts. They differ in their spatial resolution, lead time and update cycle (Table 1). The models COSMO-2 and COSMO-7 are deterministic models, which forecast for each time step one single forecast value. COSMO-LEPS on the other hand is a probabilistic model, which consists of 16 ensemble members. So for each time step COSMO-LEPS forecasts 16 equally likely forecast values (Montani et al. 2011).

Table 1: Numerical weather prediction models used for driving the hydrological model PREVAH. (* After computation and dissemination of COSMO-LEPS 120 h lead time are left in the hydrological forecast).

Model	Horizontal resolution	Initialisation	Lead time	Member
COSMO-2	2.2 km	00, 03, 06, ... UTC	24h	1
COSMO-7	6.6 km	00, 06, 12 UTC	72h	1
COSMO-LEPS	7 km	12 UTC	132h*	16

These meteorological forecasts are fed into the semi-distributed hydrological model PREVAH (Viviroli et al. 2009) and result together with the current state of the catchment in discharge forecasts for the river Sihl. The discharge forecasts have a temporal resolution of one hour and a lead time and update cycle according to the driving meteorological models.
These forecasts are made available on an online platform to the decision makers of the Canton of Zurich (Badoux et al. 2010). The platform includes not only the discharge forecasts for the river Sihl (Figure 2), but also forecasts of the level of the Sihl lake and other meteorological and hydrological parameters that help judging the current and expected situation. Furthermore a management tool allows the realization of discharge scenarios in a pre-event phase. The most valuable element of this flood forecasting system is however the good and close collaboration between researchers and decision makers. Only good communication

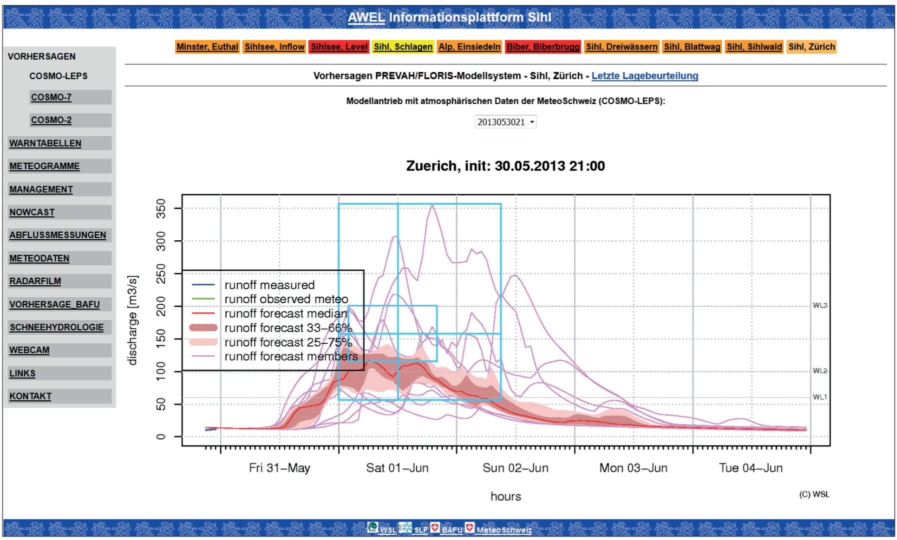

Figure 2: Screenshot of the online platform showing the COSMO-LEPS forecast for the river Sihl in Zurich for the period of May 31st to June 4th 2013. The coloured background of the available forecast locations correspond to the highest warning level reached in the forecast period. The gray panel on the left hand side offers the opportunity to easily switch between the different forecast products and other additional information like measurements, radar data, meteograms amongst others.

makes it possible to operate and further develop a system that meets the user need and can unfold its full potential.

Statistical Evaluation

Since the last model update in late 2009, forced by the increase of horizontal resolution of the meteorological models, more than five years of continuous forecasts from the three different forecast chains are available for the evaluation of the hydrological forecast system.
The evaluations include data from the months March to October of the years 2010 to 2014. The reason for this restriction is, that most flood events in the river Sihl occur during these months due to snowmelt, thunderstorms and long lasting precipitation events. Also during these months forecasters and end users are on standby duty.

The performance of the three model chains were compared to each other by means of several statistical scores. Here the evaluation with the coefficient of determination (R^2) and the Brier Skill Score (BSS) is presented. These scores are a mix of easy understandable measures of agreement (R^2) and well-tailored advanced metrics able to provide hints on the quality of both deterministic and probabilistic forecast systems (Addor et al. 2011; Liechti et al. 2013). The coefficient of determination R^2 is calculated using the observed and forecast daily mean runoff values. It is the squared Pearson correlation coefficient, which for its part is a measure for the linear correlation between forecast and observation. R^2 is a deterministic measure, therefore for the ensemble forecasts the daily mean value of the ensemble mean is used. R^2 indicates the percentage of observed variance that can be explained by the forecast. So the closer R^2 is to one, the better the forecast explains the observation. In the presented case the evaluation is done by lead time, days 1 to 5 for COSMO-LEPS mean, day 1 to 3 for COSMO-7 and day 1 for COSMO-2.

The Brier Skill Score (BSS) is a measure which allows direct comparison of deterministic and probabilistic forecasts without the previous reduction of the ensemble to its median or mean. The BSS is based on the Brier Score (BS) which is the mean squared error of the probability forecast to exceed a predefined threshold given the observed outcome (exceeding/not exceeding the threshold). The BSS then describes, for the predefined threshold, how much better or worse the BS of the forecast is compared to the BS of the climatological forecast. This makes it a good measure to show the added value of the forecast system compared to the climatological 'guess'. For the evaluation with the BSS the hourly time series of forecasts and observations were aggregated with a centred running maxima of 13 hours. This gives the forecast system a tolerance of plus/minus 6 hours. Equations and closer descriptions of the presented scores can be found in Wilks (2006).

Management tool

During the operational use of the presented forecast system it came clear that for the management of individual events a tool was desirable that allows to simulate scenarios. Therefore a management tool was built, which allows computing scenarios by varying the inflow into the Sihl lake, draw down of the Sihl lake, used turbine capacity of the hydro power plant and the contribution from the tributaries not flowing into the reservoir lake first. The time steps over which these parameters should be applied in the calculation of the scenario can be freely chosen by the user of the tool. The tool is accessible online to all eligible users.

RESULTS

Coefficient of determination R^2

As to be expected the coefficient of determination R^2 between forecast and observation decrease with increasing lead time. Table 2 lists the R^2 values for the three forecast chains by lead time for the individual years and the entire period. For the first forecast day both deterministic forecast chains reach mainly higher R^2 than the ensemble forecast. On forecast days two and three the ensemble forecast driven by COSMO-LEPS reach higher R^2 than the deterministic COSMO-7 (except day two 2012). Even the fourth forecast day of the ensemble forecast still reaches higher R^2 than the third forecast day of the deterministic COSMO-7.

Table 2: R^2 of forecast observation pairs of daily mean runoff, listed by lead time for each year from 2010 to 2014 and for all years together. Only data from the months March to October are used.

		2010	2011	2012	2013	2014	2010-2014
COSMO-LEPS	Day 1	0.79	0.87	0.81	0.86	0.84	0.83
	Day 2	0.65	0.49	0.58	0.75	0.52	0.62
	Day 3	0.38	0.43	0.54	0.70	0.52	0.52
	Day 4	0.28	0.41	0.49	0.64	0.40	0.44
	Day 5	0.22	0.15	0.23	0.53	0.30	0.29
COSMO -7	Day 1	0.85	0.87	0.86	0.88	0.83	0.86
	Day 2	0.62	0.39	0.66	0.69	0.45	0.58
	Day 3	0.48	0.25	0.46	0.58	0.25	0.42
COSMO -2	Day 1	0.83	0.83	0.87	0.91	0.81	0.86

Brier Skill Score

The BSS was calculated for several thresholds. Shown here are the results for the thresholds corresponding to the 90-% and 95-% quantile of the discharge climatology (March to October 2007 to 2014, centred running maxima over 13 hours). In addition to the three forecast chains also the ensemble median is evaluated and treated as a deterministic forecast.

Generally it can be seen that the BSS decreases with increasing threshold and with increasing lead time (Figure 3). COSMO-2 is better or equally good as COSMO-7 over its entire runtime. For the lower threshold tested COSMO-LEPS median and COSMO-7 are in the same range. For the higher threshold tested COSMO-LEPS median is performing a bit better than COSMO-7. The COSMO-LEPS ensemble forecast is clearly the best performing forecast chain and reaches positive BSS values over its entire forecast period of five days.

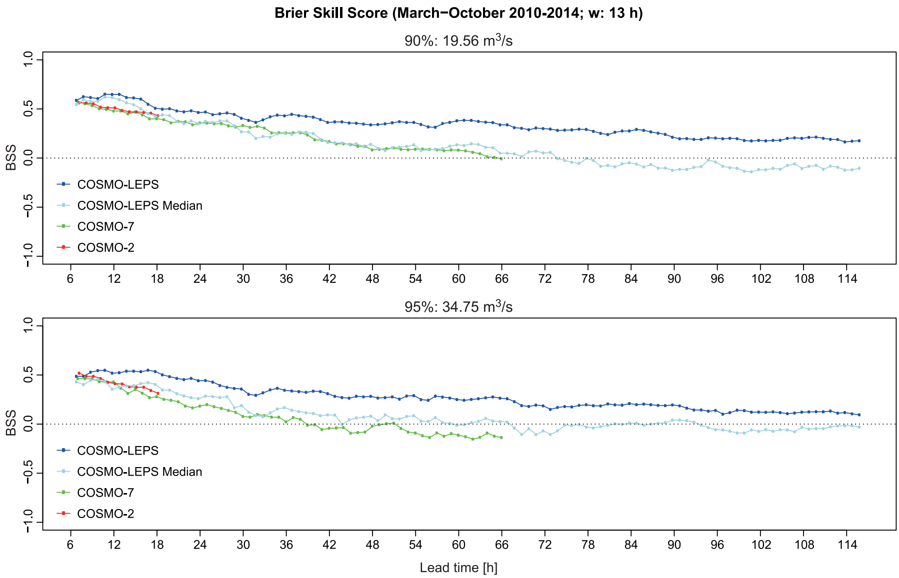

Figure 3: Brier Skill Score. Thresholds 19.5 m³/s and 34.75 m³/s correspond to the 90% and 95% quantiles of the discharge climatology (centerd 13h running maxima, March to October 2007 to 2014).

Management tool

The Management tool is illustrated using an event from 2013. The COSMO-LEPS forecast of May 31st predicted high discharge, i.e. four ensemble members exceeding the third warning level of 200 m³/s, for June 1st and 2nd which would fill the reservoir lake (Figure 4). The end-users then informed the forecasters that they plan to draw down the reservoir lake by 80 m³/s over the next 36 hours.

According to the available forecasts at that time this drawdown would have overlapped with discharge peaks from the tributaries Alp and Biber. The forecasters therefore used the management tool to calculate the expected scenario according to the end-user's plan and according to a counter proposal from the forecasters (Figure 4). The resulting scenarios made clear that with the planned drawdown of 80 m³/s over the next 36 hours the probability to exceed the third warning level of 200 m³/s was quite high (Figure 4, scenario 1). Thus, after a short teleconference with the forecasters to discuss the scenarios and their implications, the end-users decided to shorten the drawdown to a few hours only reducing the probability of exceeding 200 m³/s in Zurich significantly (Figure 4, scenario 2).

The observed event then consisted of four peaks distributed over three days. A first artificial peak from the ordered draw down reached 130 m³/s, the second peak originating from the tributaries reached 190 m³/s, more intensive rain lead to a peak of 140 m³/s, and the last peak originated from the combination of a rule based draw down and more intensive precipitation reached 160 m³/s.

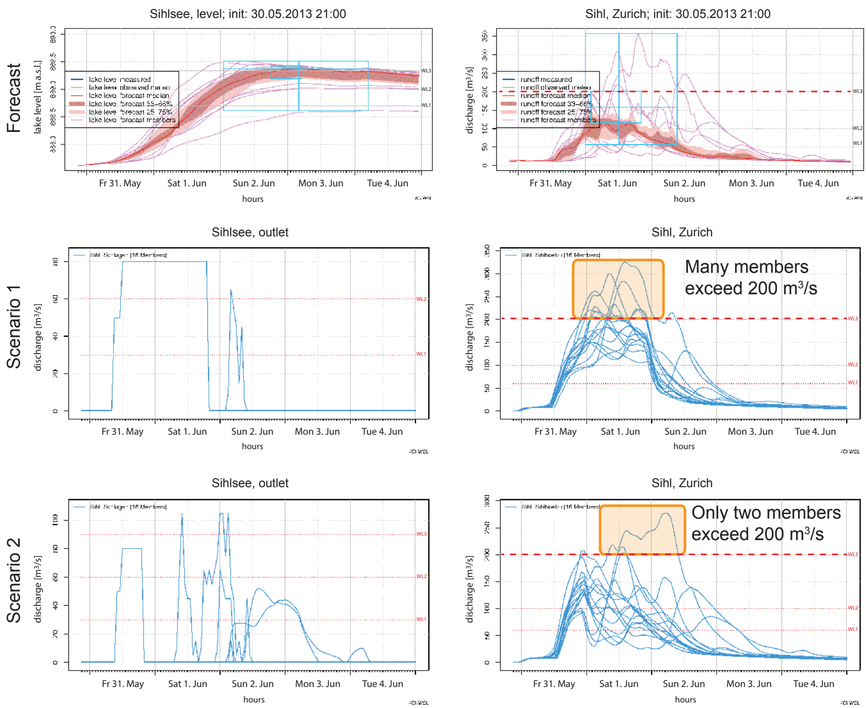

Figure 4: Example of management tool application. Top row: COSMO-LEPS forecasts for the lake level (left) and the Sihl in Zurich (right). Middle row: Scenario 1 releasing 80 m³/s over 36 hours from the lake and corresponding expected peak flow in Zurich. Bottom row: Scenario 2 releasing 80 m³/s over 9 hours and corresponding expected peak flow in Zurich.

CONCLUSIONS

The statistical evaluation shows that for a system like the river Sihl upstream of Zurich, which needs a lead time of one to three days to take preventive measures in case of a coming event, the ensemble forecasts are more reliable than the deterministic forecasts.

The management tool proved to be useful to handle individual critical events. For the event presented here, the tool helped to plan the drawdown of the reservoir lake such that a coincidence of peak flows from tributaries and from the lake outlet were avoided. The tool is not perfect yet and needs further improvement to ease its handling.

The near future will bring significant changes to the system. MeteoSwiss will produce new numerical weather predictions and replace the three forecast products with only one deterministic forecast product called COSMO-1, and the ensemble forecast product COSMO-E. The spatial resolution of these products will be 1.1 km and 2.2 km and the number of ensemble members will increase to 21. Furthermore it is planned to implement post processing into the operational forecast system. Both developments are expected to further improve the discharge forecasts for the river Sihl.

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