Quality Control, Validation and User Feedback of the European Flood Alert System (EFAS)

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Abstract: The quality control, validation and verification of the European Flood Alert System (EFAS) is described. EFAS is designed as a flood early warning system at pan-European scale, to complement national systems and provide flood warnings more than 2 days before a flood. On average 20-30 alerts per year are sent out to the EFAS partner network which consists of 24 National hydrological authorities responsible for transnational river basins. Quality control of the system includes the evaluation of the hits, misses and false alarms, showing that EFAS has more than 50% of the time hits. Furthermore, the skills of both the meteorological as well as the hydrological forecasts are evaluated, and are included here for a 10-year period. Next, end-user needs and feedback are systematically analysed. Suggested improvements, such as realtime river discharge updating, are currently implemented.

Keywords: flood, warning, forecasting, EFAS, probabilistic, skill.

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1. Introduction

Over the last decades severe fluvial floods with a transnational dimension have taken place in Europe, such as the Rhine-Meuse floods in 1993 and 1995, the Oder floods in 1997, and the Po floods in 1994 and 2000. Historic floods affected the Elbe and the Danube river basins in 2002. In 2005, widespread and repeated flooding was again observed in several tributaries to the Danube river basin, particularly in Switzerland and Austria (De Roo et al., 2006) and in the lower Danube countries (Romania and Bulgaria). Only one year later, record floods hit again the Elbe and the Danube river basins in spring 2006 (ICPDR, 2006). The European Environmental Agency estimated that floods in Europe between 1998 and 2002 caused about 700 deaths, the displacement of about half a million people and at least 25 billion Euros in insured economic losses (EEA, 2003). A study by Bakker (2007) suggests that transboundary floods are typically more severe in their magnitude, affect larger areas, result in higher death tolls, and cause more financial damage than non-shared river floods do. The repetitive occurrence of such disastrous floods prompts the investigation of new strategies for flood prevention and protection, with focus on coordinated actions among countries sharing the same river basin.

In addition to flood preventive measures, flood damage can still be reduced through raised preparedness. Unfortunately, precipitation, in most cases the driving factor for floods, cannot be skilfully forecasted with single forecasts more than 2–3 days in advance. In a study based on forecasts from the European Centre for Medium-Range Weather Forecasts, Buizza et al. (1999) showed that, although the skill in weather forecasting has generally increased to 5–6 days, e.g. for temperature, it is only of the order of 2–3 days for precipitation. In particular, in the case of extreme rainfalls, which are of special interest to flood forecasters, the lead-time for skilled forecasts decreases even further.

However, this lead-time for skilled precipitation forecasting can be extended by exploring ensemble prediction systems (EPS) (e.g. Tracton and Kalnay, 1993; Molteni et al., 1996). Although produced by some meteorological services as early as the 1980s (Molteni et al., 1996), it is only recently that EPS have been explored for flood forecasting purposes. The European Flood Alert System (EFAS) has been developed to take advantage of these new developments.

This paper describes EFAS in brief (Chapter 2) followed by several quality control mechanisms (Chapter 3 and 4), end-user feedback and interaction (Chapter 5), and new developments based on end-user feedback (Chapter 6)..

2. The European Flood Alert System

The European Flood Alert System (EFAS) aims at increasing preparedness for floods in trans-national European river basins by providing local water authorities with medium-range and probabilistic flood forecasting information 3 to 10 days in advance (Thielen et al, 2009), complementary to Member State systems. The EFAS research project started in 2003 with the development of a prototype at the European Commission Joint Research Centre (JRC), in close collaboration with the national hydrological and meteorological services. The prototype covers the whole of Europe on a 5 km grid. In parallel, different high-resolution data sets have been collected for the Elbe and Danube river basins, allowing the potential of the system under optimum conditions and on a higher resolution to be assessed. Flood warning lead-times of 3–10 days are achieved through the incorporation of medium-range weather forecasts from the German Weather Service (DWD) and the European Centre for Medium-Range Weather Forecasts (ECMWF), comprising a full set of 51 probabilistic forecasts from the Ensemble Prediction System (EPS) provided by ECMWF. The ensemble of different hydrographs is analysed and combined to produce early flood warning information, which is disseminated to the hydrological services that have agreed to participate in the development of the system.

2.1. End-user needs

A survey of the current practices and future needs of the National water authorities for the Elbe and the Danube river basins in 2003 (Thielen et al., 2003) showed that EFAS could complement national systems with the following information:

i) Extension of lead-times. Typically, the achieved flood forecasting lead-times were 2–3 days, while the desired forecast lead-times exceeded the existing ones by at least 1 day.

ii) Interpretation of probabilistic weather and flood information. In 2003, all authorities with access to EPS information used them qualitatively only because first, the computational burden to run all EPS through their forecasting models was technically not possible, and second, it was felt that there was not sufficient expertise to analyse and interpret the results appropriately. Using all EPS for flood forecasting, interpreting the results and presenting them in a concise and easy to understand way was therefore seen as a definite role for EFAS.

iii) Catchment-based information. Flood forecasters noted that they would appreciate having an overview of the flood situation in upstream and neighbouring areas.

iv) Sharing of information and data. Data infrastructure is particularly fragmented in Europe, leading to diverse data access rights and a variety of formats and reference systems. EFAS was seen as a possibility to bridge gaps between the different communities for improved information exchange on European level.

Following these needs, a prototype for EFAS was designed and tested in pre-operational mode, with regular requests for feedback from end-users. The involvement of the end-users in the design and content of the products ensured that the EFAS products were readily understood and accepted by the different hydrological partner institutions, as well as more easily integrated into their forecasting practices.

Updated end-user needs and feedback is continuously assessed, through annual user-meetings, training sessions, direct feedback after flood alerts and events, and through targeted research by King’s College London (Chapter 5). Although since 2003 there has been an increasing interest in EPS in the National hydrological services, only very few in Europe have implemented EPS based forecasts operationally (Cloke and Pappenberger, 2009) and EFAS continues to respond to a clear need in improving flood forecasting.

2.2. EFAS set-up

A detailed description of EFAS can be found in Thielen et al. (2009), while EFAS is briefly described below.

Meteorological input data for EFAS are the weather forecasts of the German National weather service (DWD) and the deterministic forecasts as well as the probabilistic/EPS forecasts of the European Centre for Medium-Range Weather Forecasts ECMWF. Both the 12:00 and 00:00 forecasts are received on a daily basis. In addition, the higher resolution COSMO-LEPS are incorporated into EFAS once a day at 12:00. For the calculation of the hydrological initial conditions, observed meteorological station data (from about 2000 stations) are used.

These meteorological data are used to drive the hydrological model LISFLOOD (De Roo 1999, Van der Knijff et al 2008) twice daily, producing a total set of 120 hydrological forecasts daily. LISFLOOD is at the core of EFAS and can be categorized as a hybrid modelling system, merging elements of conceptual and physical distributed rainfall-runoff modelling and combining these with a kinematic routing module in the river channel. For EFAS, LISFLOOD was calibrated on a 5-km grid for the whole of Europe with measured discharge data from more than 230 river gauging stations.

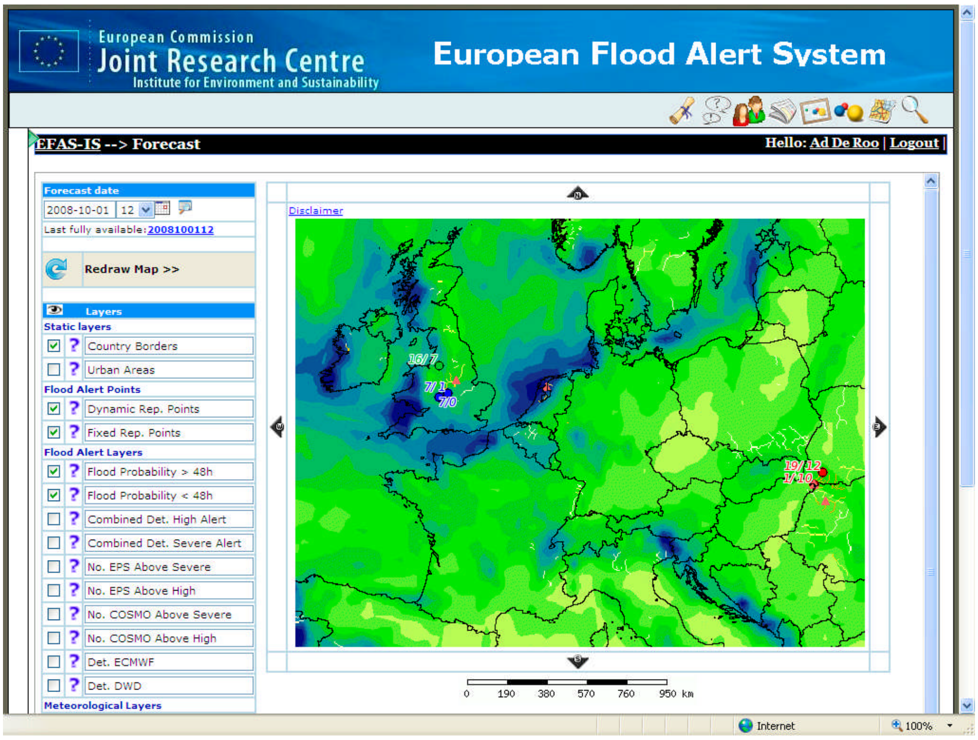

Figure 1. The on-line European Flood Alert System: The system displays locations where flooding is predicted, as well as overlays of accumulated forecasted rainfall over the forecast domain (10-14 days). Users can zoom in and get detailed information on the points where flooding is predicted.

EFAS forecasts discharges for every 5x5km grid cell, treating Europe as a natural catchment: due to lack of available data e.g. hydropower operations, weirs etc and other control mechanisms cannot be taken into account. This set-up necessitates the interpretation of the resulting simulated discharge data in a model-consistent way as direct comparison with measured discharge data is not possible. As EFAS is a pre-warning system, the main aim is to know how a simulated discharge compares to thresholds that indicate the magnitude of the simulated reference discharge in terms of flooding. To obtain these thresholds, a 18-year (i.e. 1990-2007) simulation with LISFLOOD has been carried out with observed meteorological station data. Statistical thresholds have been deduced from the resulting discharges for every grid cell. This approach has the advantage that any systematic over-or under-predictions of the model are leveled out. The two EFAS thresholds that are most important for EFAS forecasts are the “Severe EFAS alert level” (SAL), i.e. a very high possibility of flooding, potentially severe flooding expected; and the “High EFAS alert level” (HAL), i.e. a high possibility of flooding, bankful conditions or higher expected.

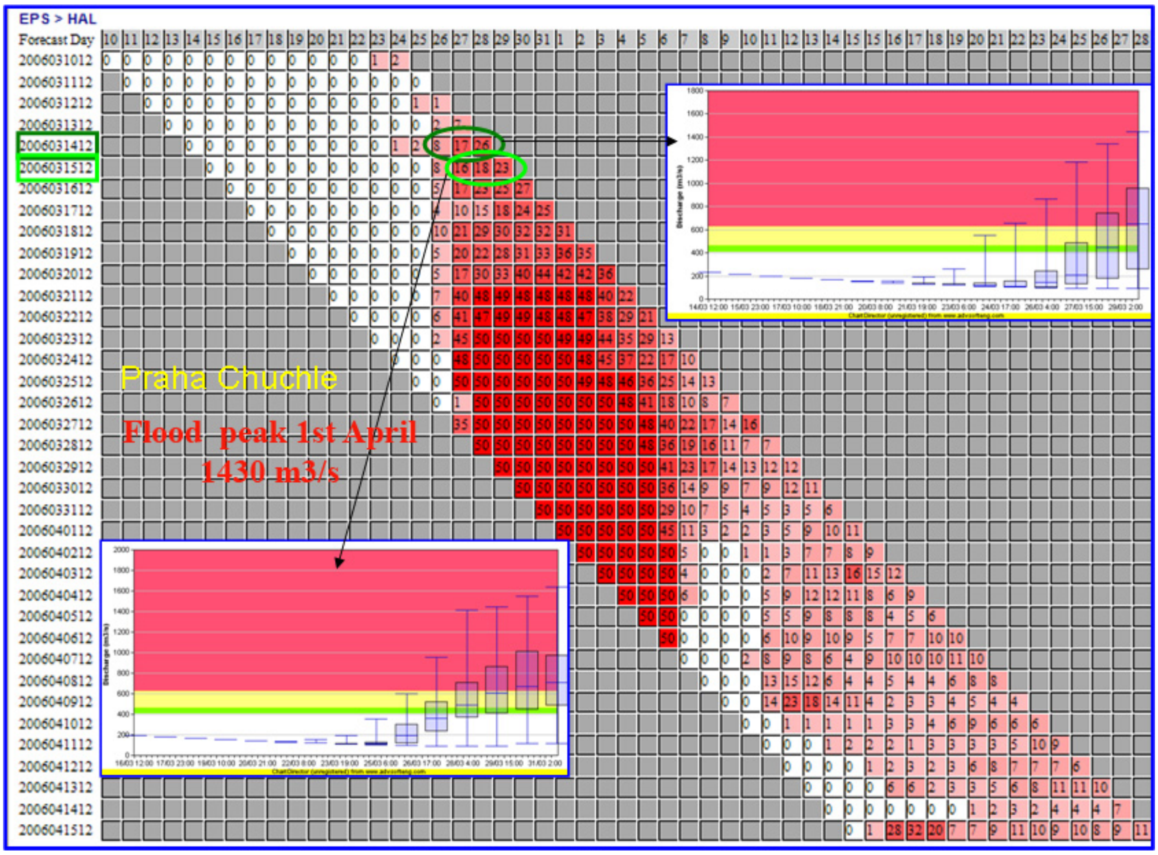

Figure 2. History representation of EFAS forecasts from 10 March 2006 to 14 April 2006 using ECMWF VAREPS weather forecasts for the flood in the Upper Elbe, for the gauge station Prague Chuchie (Czech Republic). The dates of the forecasts are shown on the left hand side. The forecasts are shifted so that the days for which the forecasts are valid (top row) are aligned. The number in the boxes represent the number of EPS exceeding the EFAS high alert threshold.

Figure 2 shows a forecast diagram for Prague during the 2006 flood. Consecutive forecasts are plotted to obtain a forecast ‘history’. The flood was triggered due to a sharp temperature rise while a huge snowpack was available for melting. This temperature rise was forecasted remarkably correct and consistent.Already 12 (!) days before the flood – on the 14th of March, indicated here as 2006031412 - a clear indication was visible of an upcoming flood. EFAS alert the Czech authorities on the 19th March, based on the older EPS system. With VAREPS it is demonstrated that warning could be established even earlier. It should be noted that obtaining leadtimes like the 10-12 days here are likely not possible for summer floods triggered by rain only.

The flood in the Danube and Elbe in 2006 – where EFAS predict the flood with several days leadtime (Figure 2), and during which EFAS sent out daily reports to several countries during several weeks – demonstrated the need of an on-line system, where EFAS users could evaluate the EFAS results themselves as well. The online system is available since 2007. It is password protected, since EFAS information is only disseminated to national and regional flood forecasting centres, who have the national mandate and in many cases obligation to provide flood warning to civil protection and other national services.

3. Hits and False Alerts and the skill of EFAS

EFAS forecasts are continuously monitored, and evaluated if the forecasted flood took place. This is done through direct contacts with its users at the Hydrological Services, through monitoring press-releases and news items on floods throughout Europe using JRC's EMM (European Media Monitoring) system, as well as through exchange of near-realtime river discharge data (via the ETN-R project funded by EC and executed by GRDC, Koblenz).

Figure 3 shows an assessment of the hits and false alarms of EFAS for 2007-2009, showing that the number of hits is larger than the number of false alerts. Correct forecasts are in many cases achieved for 4-5 day leadtime floods. Also it can be seen from the figure, that authorities across Europe receive on average 25 "watches" and "alerts" per year, so maximum 1 or 2 per year per country. False alarms are typically not perceived as negative, since EFAS plays the role to alert the authorities, a sort of wake-up call before the event is captured by the higher resolution national systems. In the case that an alert is withdrawn a few days later, there is little harm done. There is clearly a difference between a false 24-hour forecast – based on which for example an evacuation could be triggered – or a false early warning, which aims to raise awareness and increase preparedness before a flood.

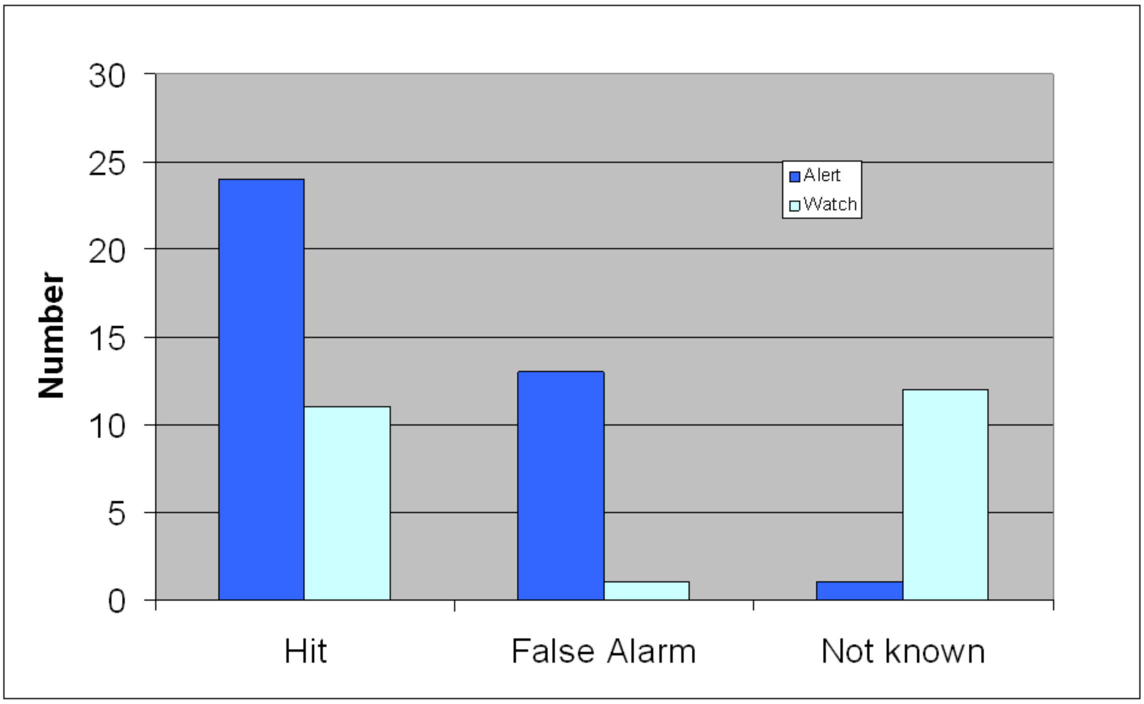

Figure 3. Assessment of hits and false alarms of the European Flood Alert System for 2007-2009. 'Alerts' are as external warnings, where EFAS forecasts show a clear persistent signal already for at least three consecutive forecasts. "Watch" cases are EFAS "informal" alerts where there is a signal, but where the EFAS forecasts is more uncertain.

In addition to the examination of hits and false alerts, more in-depth scientific methods of verification are developed. Bartholmes et al (2009) examined two years of existing operational EFAS forecasts statistically. The skill of EFAS forecasts is analysed with several skill scores. The analysis is based on the comparison of threshold exceedances between proxy-observed and forecasted discharges. Skill is assessed both with and without taking into account the persistence of the forecasted signal during consecutive forecasts. The skill-analysis showed that the use of a persistence criterion, which considers the persistence of the forecasted signal in consecutive forecasts, can reduce the number of false alarms for the deterministic as well as the probabilistic EFAS EPS-based forecasts. The use of EPS in hydrological forecasting proved to be of great added value to a flood early warning system, as the EPS-based forecasts showed, in general, higher skill and longer lead times than the deterministic-based ones.

4. 10-Years analysis of EFAS performance

During the PREVIEW project, the skill of meteorological forecasts for hydrological purposes has been evaluated (PAPPENBERGER & BUIZZA, 2009). The performance of the hydrological forecasts within EFAS is regularly analysed with regard to individual flood events and case studies. Although this analysis provides important insight into the strengths and weaknesses of the forecast system, it lacks statistical and independent measures of its long-term performance.

As a part of the testing of EFAS at ECMWF – which is also carried out in the frame of the SAFER project - an analysis was carried out on the change in quality of EFAS over the last decade (Pappenberger et al, in prep). EFAS river discharge forecasts have been rerun every week for a period of 10 years using the weather forecast available at the time. These are evaluated for a total of 500 river gauging stations distributed across Europe.. The selected stations are sufficiently separated in space to avoid autocorrelation of station time series. Also, analysis is performed with a gap of 3 days between each forecast which reduces the temporal correlation of the time series of the same station. The data are analysed with regard to skill, bias and quality of river discharge forecast.

Closely connected to a potential theoretical limit of predictability is an estimate in the gain of lead time over the last decade. This estimation depends strongly on the chosen score as well as the threshold. It is computed by using recent scores for particular lead times and interpolating which lead time would be achieved 10 years ago. The difference is an estimate of the gain in lead time. Some of the deterministic scores did show no improvement, however, the values of 1 day in 7 years improvement are quoted for the Equitable Thread Score. Note that some of the gain is not related to an improvement in meteorological forecast, but the observational network. In Figure 3 the gain in lead time is shown for each lead time and the three thresholds.

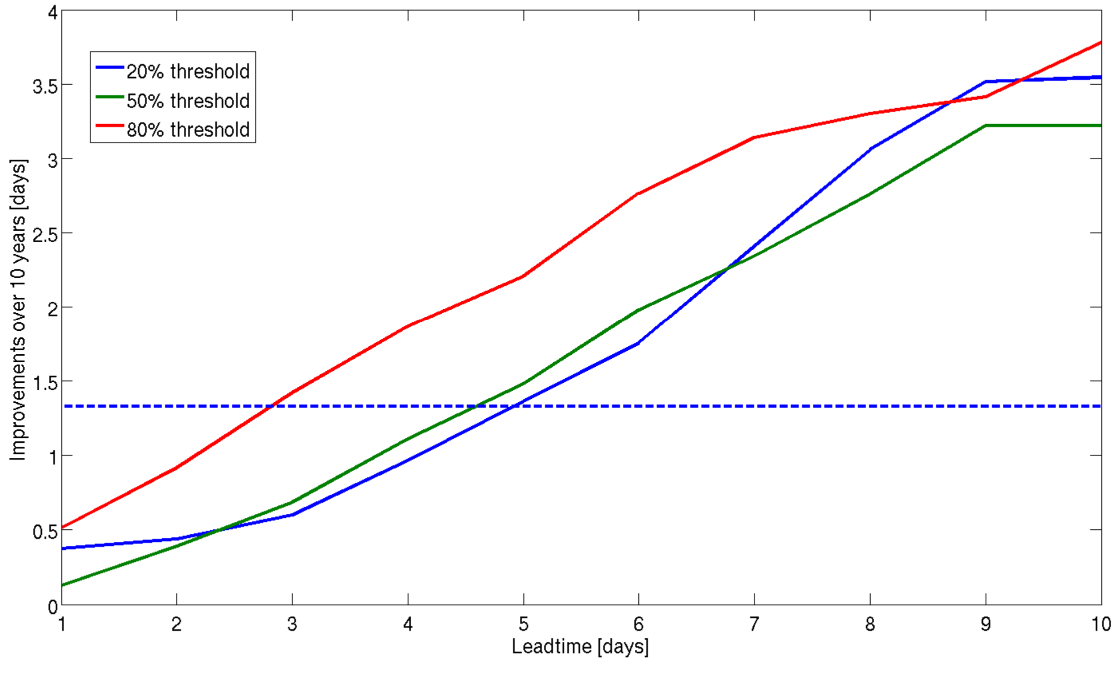

Figure 3. Gain in lead time over a decade for three thresholds (ETS score). The dotted straight line indicates the average gain for precipitation.

The dotted straight line indicates the average gain for precipitation. The plot indicates a considerable gain in lead time over the last 10 years. The gain increases with leadtime, which maybe explained by the cumulative effect a catchment has (earlier gains will more likely influence later gains due to the temporal aggregation). The gain for the 50th and 20th percentile line is on average similar to the gain in lead time of precipitation. The gain for the 80th percentile is higher. It is difficult to explain this discrepancy as no values for gain in temperature or any other surface variable are published.

Similar computations can be made for probabilistic scores such as the Brier Score or the Continuous Rank Probability Score. Gains for these scores are significantly lower (maximum at 1-2days at lead time 10). The overall dampening effect of the catchment, which on average in Europe seems to collapse ensemble spread seems to lower this increase. This is opposite to findings in improvements of meteorological forecasts of upper air fields which increase on average at double the rate to the deterministic scores.

The 10 year simulations clearly show that the skill of the river discharge forecasts have undergone an evolution linked to the quality of the operational meteorological forecast. Overall, over the period of 10 years, the skill of the EFAS forecasts has steadily increased. Important hydrological extreme events cannot be clearly identified with the skill score analysis, highlighting the necessity for event based analysis in addition to statistical long-term assessments for a better understanding of the EFAS system and large scale river discharge predictions in general. The predictability is shown to depend on catchment size and geographical location.

5. End-User Feedback

In close collaboration with the EFAS development team at JRC, scientists of King's College London are examining the end-user understandings of uncertainty, and ensemble flood forecasts (Nobert et al, in prep). Ensemble forecast products, like EFAS are novel and not necessarily well understood by EFAS users (Demeritt et al. 2007). Drawing on a set of 47 semi-structures interviews with EFAS end users in national flood forecasting centres and civil protection authorities (CPA) in 14 European counties (Nobert et al. in review), this Economic and Social Research Council (ESRC) funded project has highlighted that the difficulties often faced by EFAS end users in understanding unfamiliar EPS products and in making use of EFAS forecasts for operational purposes. It is clear from end user feedback that the informational value of EPS forecasts in general, and of EFAS products in particular, is understood in a variety of sometimes contradictory ways. While some users regard the ensemble mean as a useful summary of forecast uncertainty, others dismiss its informational value. Some EFAS users look to EFAS forecasts to help confirm local deterministic models, despite the fact that EFAS is not designed to do this. While there is a general appetite for EPS forecasts among EFAS end users, there is also, clearly, a need for training to improve the understanding of EPS and its potential operational uses. User feedback indicates that the operational utility of EFAS as a pre-alert for forecasting centres is widely accepted, but there is debate about whether probabilistic forecasts would be useful for or can be successfully communicated to CPAs. In this context, one key issue is the translation of EFAS alert thresholds to locally meaningful values. Better communication of the scientific basis for EFAS thresholds and their relationship to river discharge values is required.

4. Responding to End-User Feedback: Discharge-updating

Since the start of EFAS, - where EFAS communicates threshold-exceeding flood alerts only - end-users have requested EFAS to forecast river discharge values. Although discharge values are forecasted from the beginning of EFAS, care must be taken with the interpretation of these values, due to an accumulation of uncertainties: initial conditions uncertainty (limited available realtime observations of weather and river discharge), model uncertainty, weather forecast uncertainty. Therefore, EFAS has not communicated discharge values before.

In order to respond to the end-user requests, and given the recent availability of realtime river discharge in EFAS, EFAS has been further developed to include an error-correction method for points along the river network, where observed discharge data are available. Using the new method, probabilistic flood forecasts are produced by the integration of hydrological and meteorological uncertainties. This new method minimizes the error of the timing, the differences in the volume and the magnitude of the peak itself between observed and simulated flood events. (Bogner and Kalas, 2008 and Bogner et al, in prep)

The error correction is achieved by simple AutoRegressive models with eXogenous input (ARX) models, relating the observed discharge value yt at time t to the previous discharge ỹtl with time lag l and the simulated model output xt at some station. The Bayesian Uncertainty Processor (BUP) method is used to estimate the full predictive uncertainty and is divided into a so called Hydrological Uncertainty Processor (HUP), capturing all model uncertainties, the Input Processor taking into account the meteorological forecast uncertainty forcing the hydrological model and finally the Integrator, which combines the HUP and the Input processor optimally. According to this methodology, the HUP has been applied to the error corrected discharge series at first in order to derive the predictive conditional distribution under the hypothesis that there is no input uncertainty. The uncertainty of the forecasted meteorological input will be derived from the EPS and the Input Processor maps this input uncertainty into the output uncertainty under the hypothesis that there is no hydrologic uncertainty.

Thus the goal is to get an estimate of the conditional probability distribution of the future observed quantity (i.e. the discharge in the next days) given the available sample of model predictions by integrating optimally the hydrological and the input uncertainty.

Figure 4 shows an example of the error-correction method. During the dissemination, only the correct results are shown to avoid confusion and reduce the information. The method corrects the initial model estimate, which is based on a (limited) number of available weather stations, while using real-time river discharge transmitted by the local authorities to EFAS. The method uses the then estimated model uncertainty to combine it with the ensemble spread of the EPS forecasts to obtain the ‘predictive uncertainty’

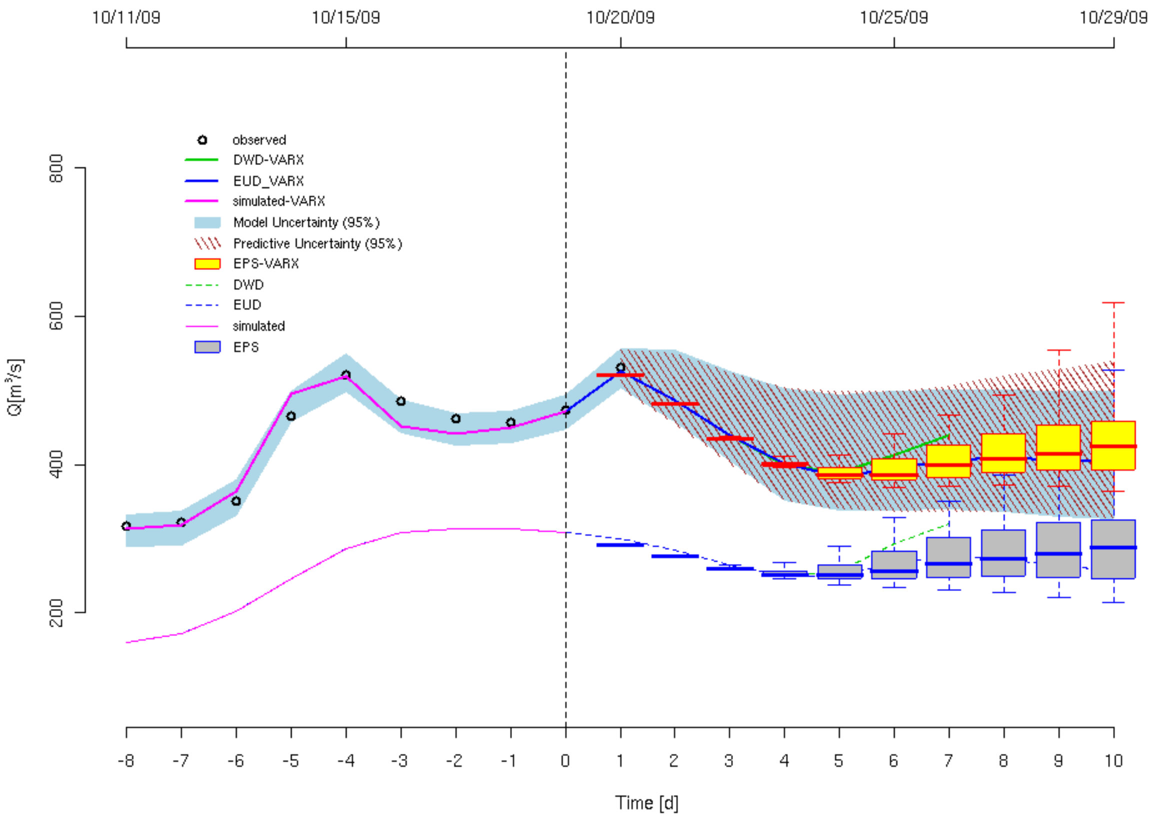

Figure 4. Example of the error-correction application for station Hofkirchen (Germany, Danube). The dashed vertical line is time 0. Measurements available from the previous days (-8) until time 0 are used to correct the original model estimate ('line simulated'). In the forecast window, the model uncertainty derived from this correction, is combined with the spread in the ensemble forecast, resulting in the 'predictive uncertainty' of the forecast.

At the moment this integrated system of error correction and predictive uncertainty has been tested and set up for operational use at some stations in Bavaria, to obtain feedback from the user first. Within the next months, the application of the method and dissemination of the results will be extended to the entire EFAS domain.

Conclusions

The European Flood Alert System applies a continuous quality control mechanism, to monitor hits and false alerts, and the skill of the forecasts. Regular interaction with end-user takes places via annual meetings, dedicated trainings, email contacts, or dedicated visits to receive feedback and updated user-needs. System updates, such as the inclusion of error-correction of the discharge forecasts, are based on some of the feedback received.

It is shown in this paper that the number of hits is large than the number of false alerts, while the annual pan-European number of alerts is around 25 each year. Furthermore, it has been shown that the skill of EFAS has improved over the last 10-years, due to both better antecedent conditions (more available data), as well as improved weather forecast skill.

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