TOWARDS A FLOOD ALERT SYSTEM FOR EUROPEAN TRANS-NATIONAL RIVER BASINS

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Abstract: The European Flood Alert System (EFAS) for medium-range flood forecasting in trans-national European catchment areas is presented in its concept and its current state of development. The flood simulation model is based on the LISFLOOD hydrological model already in use for the rivers Odra, Meuse and Elbe. Furthermore, an integrated modelling system for the entire Danube catchment will allow for the evaluation of flood protection measures and land use changes at the scale of the entire river basin. The contribution will present the necessary steps in data collection, processing and the preparation for model validation as well as first preliminary modelling results.

Keywords: Floods, Trans-national River Modelling, Flood Alert System, LISFLOOD, Modelling

EIN EUROPÄISCHES HOCHWASSER-FRÜHWARNSYSTEM FÜR GRENZÜBERSCHREITENDE FLUSSGEBIETE

Zusammenfassung: Dieser Beitrag stellt das Konzept und den aktuellen Stand des Europäischen Hochwasser-Frühwarnsystems (EFAS) vor. Das Modell zur europaweiten Hochwasservorhersage basiert auf dem hydrologischen Modell LISFLOOD, das schon für die Einzugsgebiete der Oder, Meuse und Elbe erfolgreich verwendet wurde. Zusätzlich zur Hochwasser-Frühwarnung wird das resultierende integrierte Modellsystem zukünftig auch zur Szenariomodellierung verwendet werden, um die Auswirkungen von Hochwasserschutzmaßnahmen oder Landnutzungsänderungen abschätzen zu können. Neben den notwendigen Schritten der Datenaufbereitung werden erste Ergebnisse der Modellierungen in ausgewählten Einzugsgebieten vorgestellt.

Schlüsselworte: Hochwasser, grenzüberschreitende Flussgebiete, Frühwarnsystem, LISFLOOD, Modellierung

1. Introduction

In the last decade, several large floods have occurred in European trans-national catchment areas, such as, among many others, the Rhine flooding in the winters of 1995, 2001, 2003, or the Odra flooding in 1997 and 2001, the Tisza flood of 2000, or the Danube and Elbe flooding in August 2002. The simulation and forecasting of such events, as well as scenario modelling for future water management and mitigation measures, requires a catchment-wide, trans-national approach. Following the disastrous floods in August 2002 in the Elbe and Danube river basins, the European Commission decided to support the development of a European Flood Alert System (COM(2002)481-final)). Following this decision the Joint Research Centre is developing and pre-operationally testing a European Flood Alert System (EFAS), with the aim to provide National Flood Forecasting Agencies with additional medium-range information besides their own – typically short-range -

forecasting systems. As main pilot basins the Danube and the Elbe have been selected, for which also flood prevention scenario studies are foreseen. This is achieved in close collaboration with national and regional water authorities of the respective member states and with support of International River Commissions like for the Danube (ICPDR), the Odra (IKSO) and the Elbe River (IKSE). Following the Danube and Elbe pilot studies, other trans-national river basins will be tested in more detail.

EFAS will act complementary to local and national forecasting systems and focus on medium-range flood forecasts of three to ten days, thus extending the lead time compared to pure hydrological forecasting and allowing regional and local authorities to take the appropriate measures in case of a flood event. Besides the flood alerting capability of the integrated modelling system, it will allow for scenario simulations to evaluate flood protection measures and land use changes at the scale of the entire river basin.

Including the Danube River catchment area with more than 800’000 km^2 as the largest European catchment area with eighteen countries involved into EFAS poses an extraordinary effort on data requirements, management, and processing. Regarding the Elbe River with a catchment area of about 148’000 km^2 three countries and several national and regional authorities are involved.

The contribution presents the current state of development of EFAS with emphasis on the Danube and Elbe catchment area, explains necessary steps in data processing and preparation for the modelling, and shows first preliminary modelling results. Finally it gives an outlook to the next steps to be taken and still pending problems to be overcome in order to create an operational European Flood Alert System.

2. The European Flood Alert System

Floods in large river basins are predominantly the consequence of extreme meso-scale precipitation events in Europe that usually show a persistence of several days to weeks. The European Flood Alert System makes use of these characteristics and combines medium-range weather forecasts, e.g. from the European Centre for Medium-Range Weather Forecasts (ECMWF) or the German Weather Service (DWD) with forecast times of up to ten days, with a hydrological model that comprises the trans-national catchment areas throughout Europe. The spatial resolution of the hydrological model initially has been set to 5 km and is currently increased to 1 km for all major river basins, including the entire Danube catchment area. EFAS is run twice a day corresponding to the availability of meteorological forecasts. The underlying hydrological model is the LISFLOOD model (De Roo et al., 2000) and will be presented in the following section. Figure 1 shows the principle elements of EFAS in its current phase, including ongoing developments.

After reception of the current weather forecast, the meteorological parameters are downscaled to the hydrological model’s spatial resolution. The LISFLOOD model is run, making use of previously derived calibration parameters and a set of static data that characterize the physical properties of the catchment area. The model run produces forecasted discharges on the basis of the forecasted precipitation and the initial conditions of the previous model run. In the next step, the produced discharge values are compared to long-term statistical threshold values derived from water balance runs over several decades. Currently, forecasts are compared to water balance runs since 1990. As a next step, the ECMWF ERA40 data will be used to obtain a 44-year discharge climatology. These water balance runs have been performed beforehand, making use of the same model code to be applied in the flood forecasting mode, as well as of calibration data derived from model runs with long-term local precipitation and measured discharge data. If the simulated discharge exceeds chosen threshold values of the water balance runs consistently for consecutive forecasts, it will be taken as a strong indication of a flood event to be forecasted in the respective region, and a flood alert will eventually be issued to the respective national or regional river water authority.

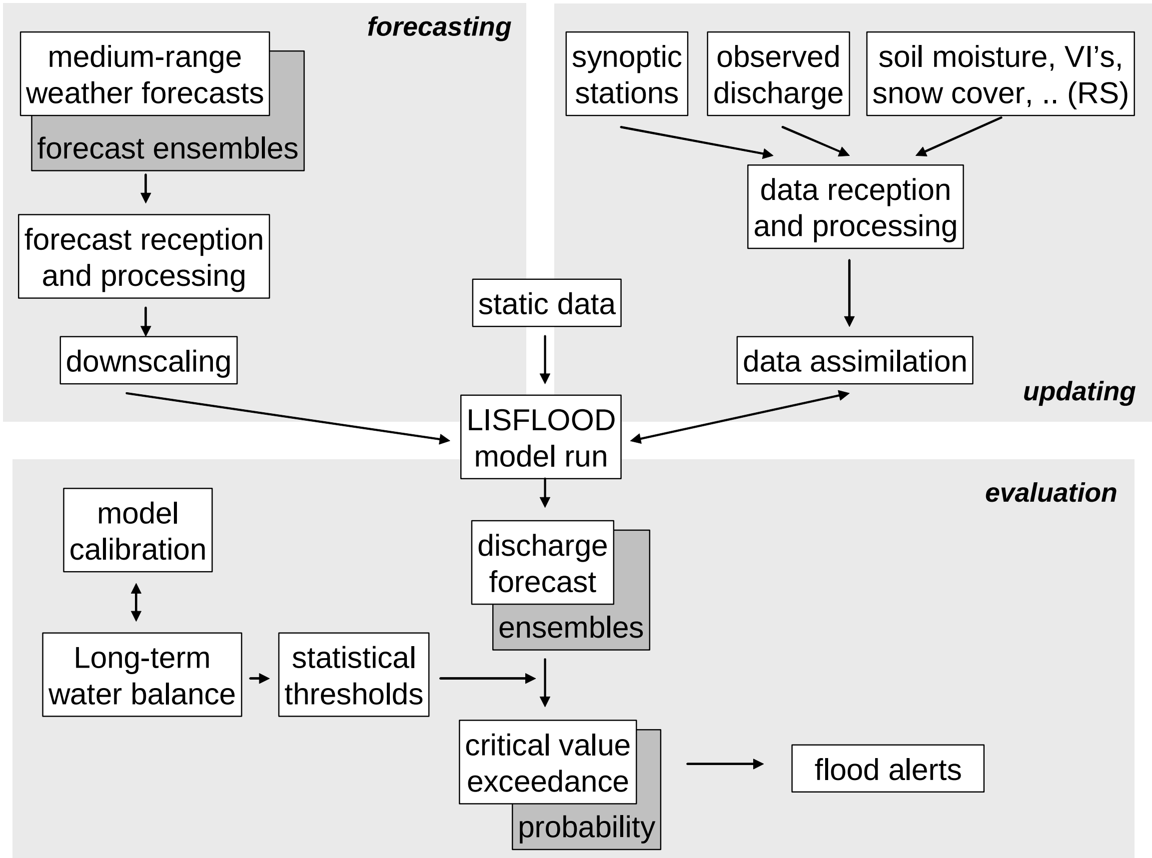

Figure 1: Overview sketch of the current EFAS system, including ongoing developments (shaded boxes).

At the same time, after reception of measured data like precipitation or temperature from synoptic stations, river discharges from gauging stations, or products derived from remote sensing, these data are assimilated into the modelling system in order to update the forecasts by the most accurate, measured values available.

As a novelty in hydrological flood simulation, EFAS explicitly will take into account the uncertainty of medium-range weather forecasts, since the accuracy of the forecasted parameters, especially the absolute quantity of precipitation, is decreasing considerably with increasing lead time. EFAS will incorporate so-called ensemble predictions consisting of a set of several tens of meteorological forecasts computed from slightly different initial conditions and different model parameterisations. Using an ensemble of different realisations of meteorological forecasts as the input rather than relying on a single meteorological forecast, several runs of the hydrological model will produce an ensemble of discharge forecasts as well, thus allowing for the quantification of the uncertainty of the forecasted discharge.

Besides producing medium-range flood forecasts by EFAS, the modelling system is used in parallel for scenario modelling in different catchment areas throughout Europe. In this approach, the consequences of various potential flood protection measures can be simulated for the large catchment areas, benefiting from the trans-national model set-up for EFAS. At the moment, a study is ongoing in the framework of the Elbe Flood Action Plan from the IKSE on the effect of reservoirs and polders on the Elbe discharge.

2.1. The LISFLOOD model

The physically based LISFLOOD (De Roo, 1999, De Roo et al., 2000) model has been developed explicitly for the simulation of floods in large European drainage basins. It is capable of simulating large areas, while still maintaining a high resolution, proper flood routing methods and overall physical process descriptions. LISFLOOD is embedded in the PCRaster GIS (Wesseling et al., 1995) and is using readily available European datasets, such as Corine Land Cover (EC, 1993) and the European Soils Database (King et al., 1995 and Heineke et al. 1998). LISFLOOD simulates the hydrological processes at the surface, in the soil, and in the river channel network on a regular horizontal grid (figure 2).

In the ground a total of four different layers are considered. For each grid point a value is calculated at every time step. Processes simulated are interception, soil freezing, snowmelt, evapotranspiration, infiltration, percolation and capillary rise, groundwater flow and surface runoff.

Overland flow is simulated using a kinematic wave approximation. Channel flow is simulated using either a kinematic wave or dynamic wave approximation, depending on river channel bed gradient and the occurrence of backwater effects. The cross section of the river and associated floodplain is taken into account by using series of water-level, wetted perimeter, and hydraulic radius values for locations for which river geometry is available. The user can define which sections of the river to simulate with a kinematic wave, and which sections with a dynamic wave. The user also can choose both the spatial and temporal resolution of the model. For European trans-boundary flood simulations, typically a grid-size of 1 km and a time-step of 1 h are used. A detailed model description can be found in De Roo et al. (2000).

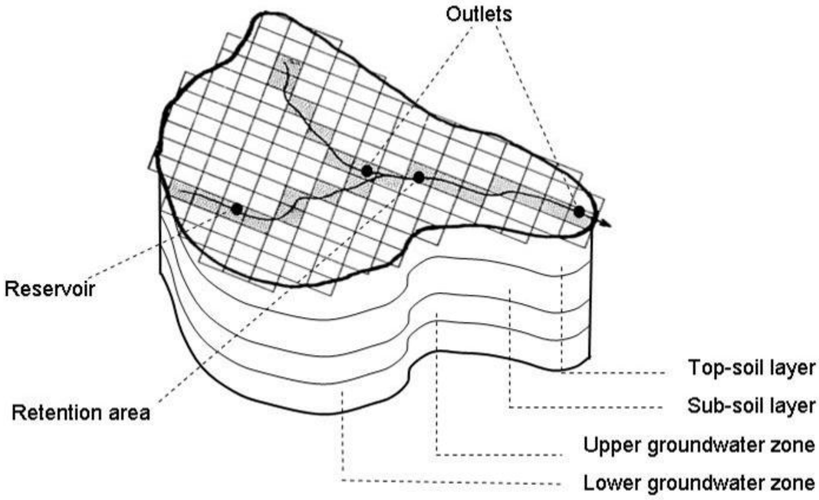

Figure 2: Schematic view of a catchment in LISFLOOD including soil and groundwater layers.

The input parameters for the LISFLOOD catchment model are maps of topography, land use, soil depth, and soil texture (see figure 3). Time series of precipitation amounts and other meteorological parameters (minimum and maximum daily air temperature, actual vapour pressure, sunshine duration, cloud cover, horizontal wind velocity) are needed for as many meteorological stations within the catchment as possible. All meteorological parameters are spatially interpolated, if necessary, and where appropriate the variables are corrected for altitude, like e.g. air temperature.

The output of LISFLOOD consists of hydrographs at user-defined locations within the catchment area, usually at the locations of gauging stations where the measured discharge is known, too. Furthermore, time series of model parameters like, e.g. evapotranspiration, soil moisture content or snow depth, can be created at selected locations. The model can produce maps of any simulated variable, such as water source areas, discharge coefficient, total precipitation, total evapotranspiration, total groundwater recharge or soil moisture.

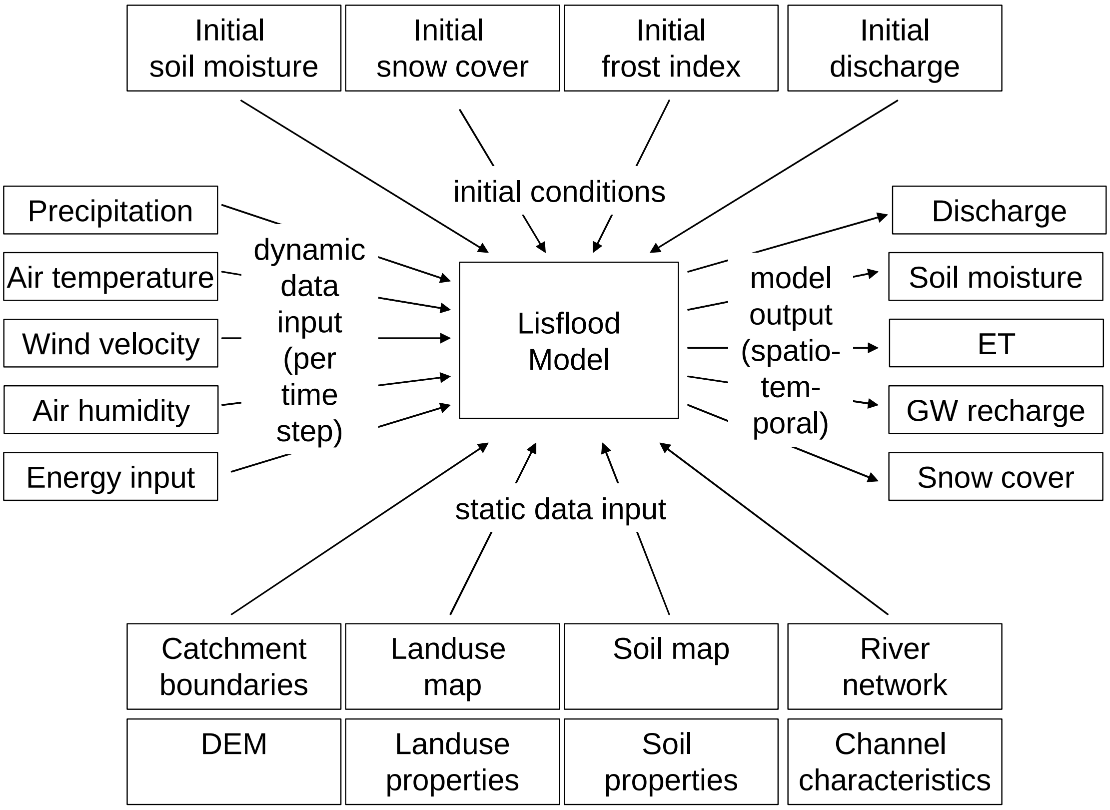

Figure 3: Data requirements of the LISFLOOD model.

3. Data preparation and model set-up

Data collection and preparation for the model runs requires substantial efforts and a chain of tasks that consist of the following steps:

- data collection
- integrity checking of incoming data
- data conversion: re-formatting of received heterogeneously organised data
- transformation of co-ordinates and altitude to common reference system
- detection and correction of outliers in meteorological data
- spatial interpolation of meteorological data
- conversion of cross section geometry into channel properties for model input
- implementation of reservoirs and polders into the model
- model validation: comparison and evaluation of simulated and observed discharges

Of this list, data collection, co-ordinates' transformation and spatial interpolation will be discussed in more detail in this chapter.

Furthermore, the large trans-national European catchment areas have been divided into sub-catchments during data preparation, in order to work in parallel on different sub-catchments, in correspondence to the continuously incoming data, as well as to be able to calibrate sub-catchments by using local data in high spatial resolution. As an example, data processing has already been started or even completed on parts of Morava River, most Slovakian rivers, the Tisza and Sava catchment areas. While the Elbe River catchment area has been divided into nine sub-catchments, the Danube River catchment area has been divided into the eight sub-catchments Upper Danube until Achleiten, the Danube stretch down to Bratislava, the Morava catchments including Vah and Hron, Drava, Tisza, Sava, the Danube down to the Iron Gate, and the Lower Danube (see figure 4).

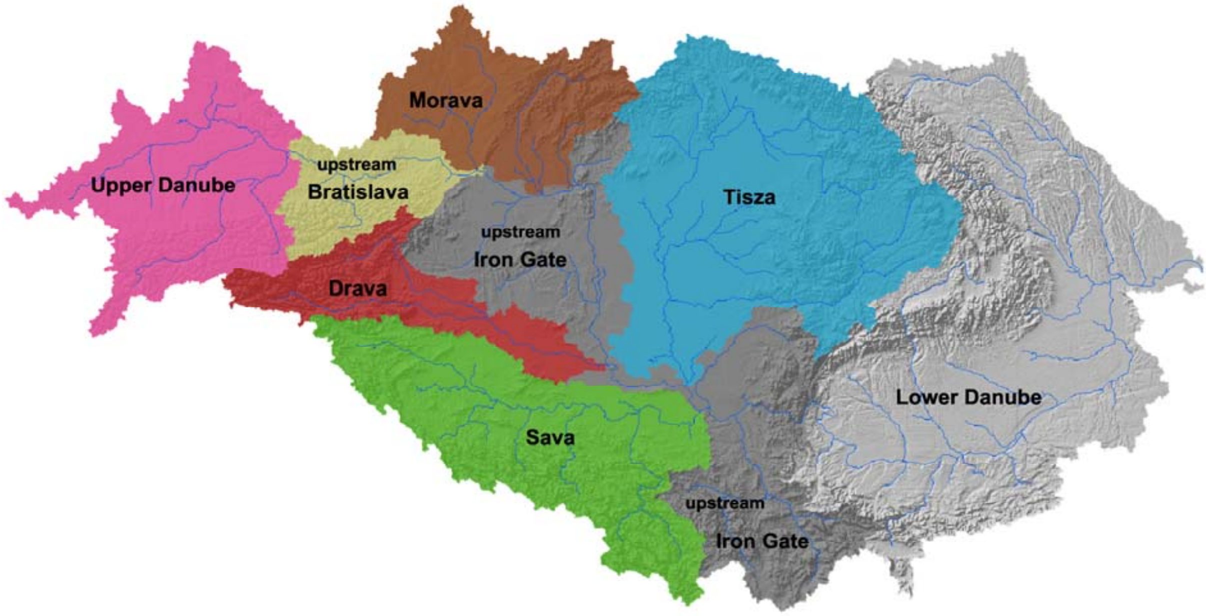

Figure 4: The Danube catchment area divided into eight sub-catchments.

3.1. Data collection

The Danube catchment area comprises eighteen countries, of which fourteen covering the major part of the basin have been contacted for data collection. Relevant authorities that hold necessary data are usually the national meteorological and hydrological services, administrations responsible for landuse, soil and geological data as well as authorities of national and regional water resources management. Some of these branches are divided again into federal and regional or even local administrations with different tasks so that sometimes it has been difficult to get in contact with the actually responsible person. These problems have been encountered especially in countries with a distinct federal administrative structure. Consequently it has been necessary to get in touch with more than 40 administrations altogether. Looking at data collection for the German part of the Elbe catchment area, for example, at least six German state authorities and two federal institutes have had to be contacted. For one of the biggest tributary only, the Saale, four German states and one federal institute are responsible. On the contrary, the Czech part of the Elbe catchment area is represented by three institutes only.

In addition, experience has shown that data delivered are usually very different in format and content of the respective files; some data are not available in digital format at all.

3.2. Data transformation

Information on discharge gauging stations, rainfall stations, cross sections and reservoirs as well as polders usually arrives with co-ordinates according to each country's standards. The definition of the corresponding projection systems and the precision of co-ordinates vary considerably among the countries, and often even within one country or within one authority (e.g. different dates of measurement, methodologies, geodetic surveys). Hence it is necessary to convert these data to a common altitude and co-ordinate reference system before feeding them into the LISFLOOD model. Regarding altitude, the European Altitude reference system has been chosen (Altitudes of Amsterdam), while for the horizontal projection the Lambert Azimuthal Equal Area reference system has been adopted (ETRS89-LAEA, Annoni et al., 2003).

In order to perform the projection transformations, all necessary projective parameters of the source projection system have to be known. Unfortunately, this piece of information is often not provided together with the data delivery, sometimes it is not known to the data providers, either. In these cases the projection parameters have to be examined and retrieved on a case by case basis.

3.3. Processing of precipitation data

As precipitation is the most important input to a hydrological model, the precipitation data received are processed carefully before being submitted to the modelling system. Basically there are two sources of precipitation data. On the one hand, at JRC a meteorological data base called MARS data base is existing (EC, 1998) that holds daily point data from synoptic stations and spatial fields of meteorological parameters. On the other hand, high-resolution historical measured rainfall data have been received from the respective national, regional and local authorities. Besides precipitation, both sources of data usually provide air temperature and sometimes the parameters horizontal wind speed, air humidity and/or solar radiation input as well.

Before a spatial interpolation of the station data can be performed, a filtering of the time series have had to be performed in order to identify outliers and anomalies in the received precipitation data. A study on spatial interpolation method showed that Kriging using an adaptive recognition algorithm of local anisotropy is the most suitable method for interpolating point data of precipitation (Szabó, 2004). Figure 5 shows an example of the chosen interpolation method in comparison to the MARS data.

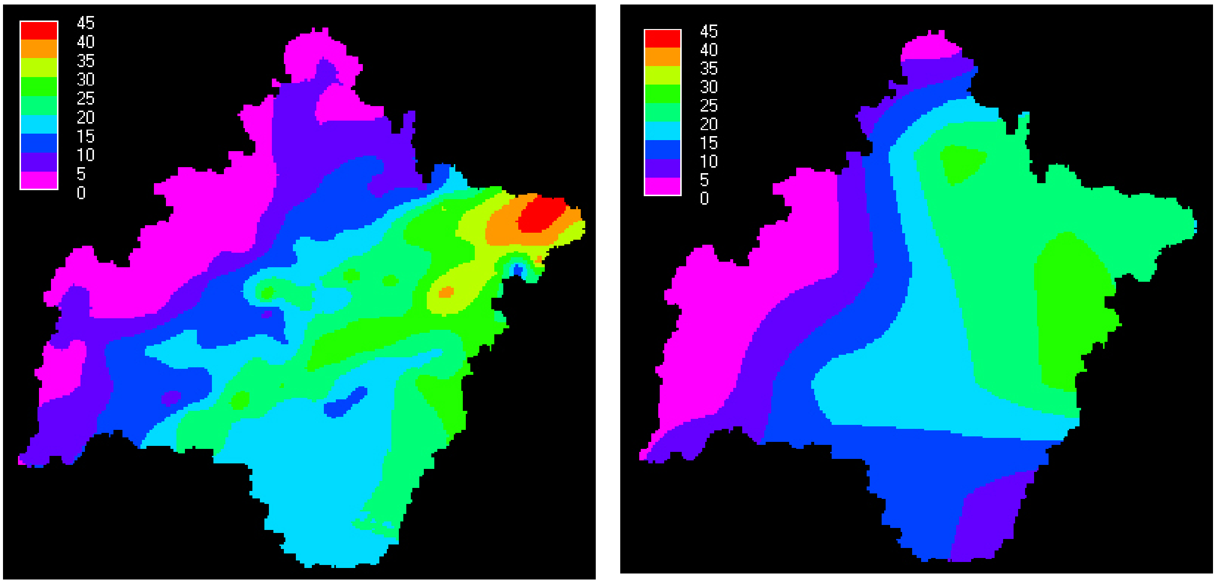

Figure 5: Example of interpolated precipitation data; left: MARS data, right: local network data interpolated with Kriging using adaptive recognition of local anisotropy (17.06.1997, Morava catchment area).

The influence of the meteorological input data on the resulting hydrograph is illustrated in figure 6. Because the MARS data are based on the synoptic network whose density is lower than national networks, the volume of interpolated precipitation is generally underestimated, producing a generally lower discharge values compared to the hydrograph from high-resolution station data.

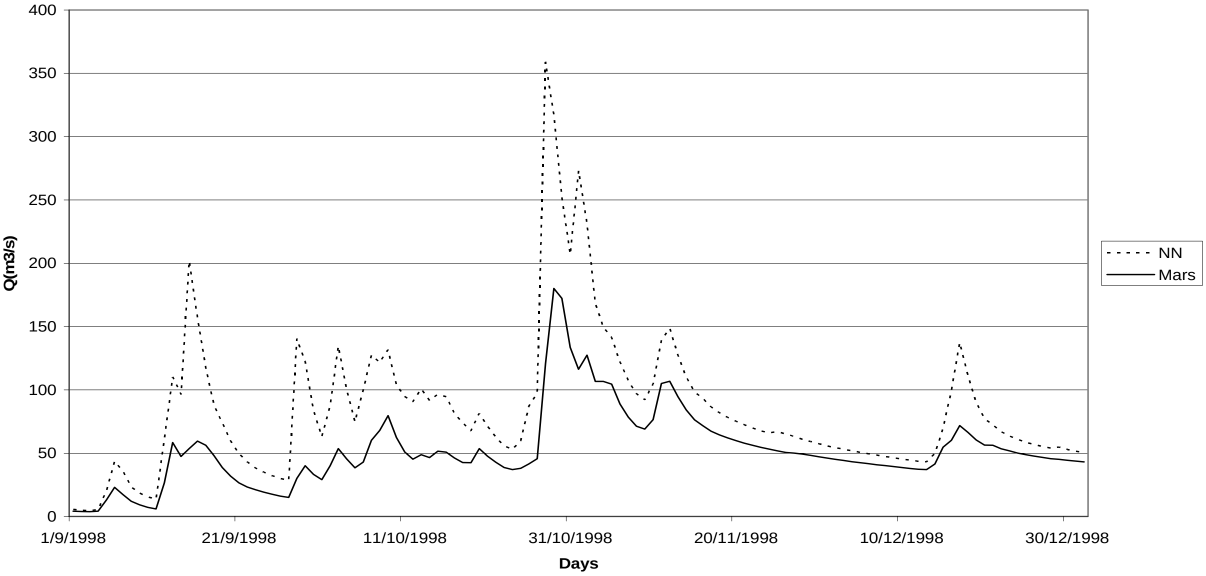

Figure 6: Comparison between the resultant simulated hydrographs of Morava River at gauging station Kromerir, 1998, using MARS (Mars) and local network data (NN).

4. First results of simulation

The first simulations with LISFLOOD were run using both MARS and high resolution historical meteorological data received from the national authorities. Figure 7 shows first results for the Elbe River catchment area with MARS data; it produces big differences between simulated and observed discharge data. Figure 8 shows the same simulation with high resolution meteorological data; the resulting discharge values are in better correspondence with the measured discharges.

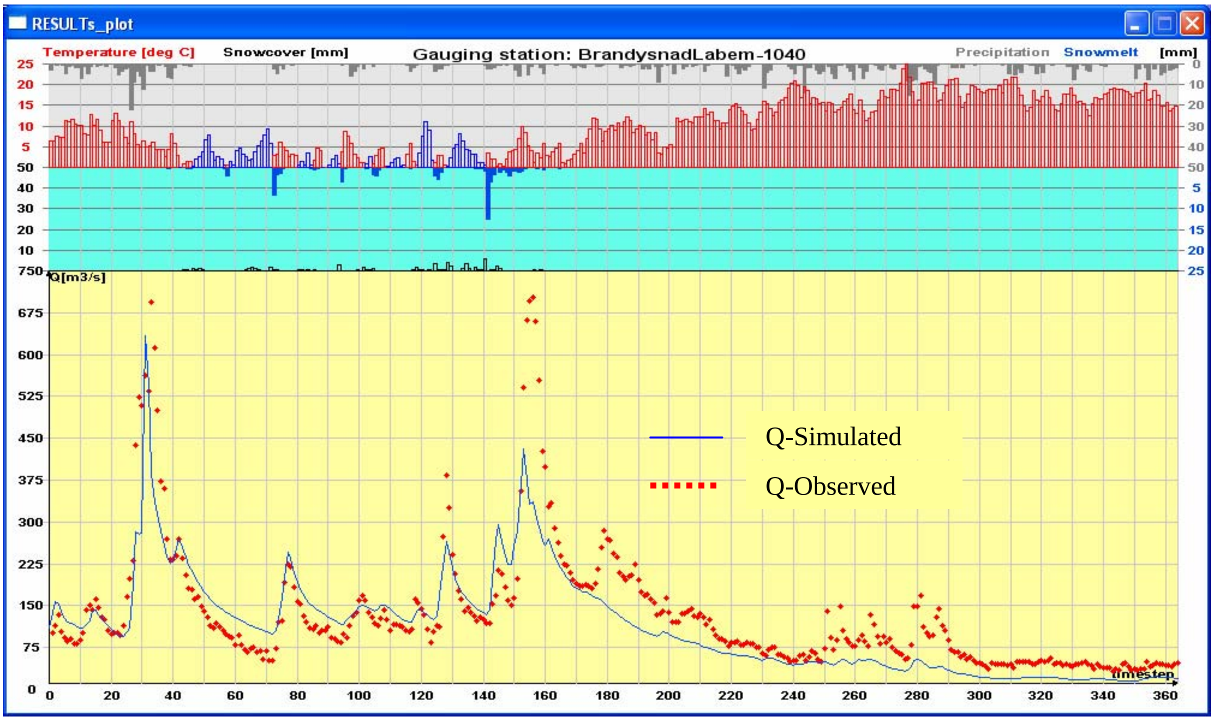

Figure 7: Simulated and measured discharge of Elbe River at Brandys nad Labem gauging station, Poland, 1.10.1998 – 30.09.1999, using MARS rainfall data.

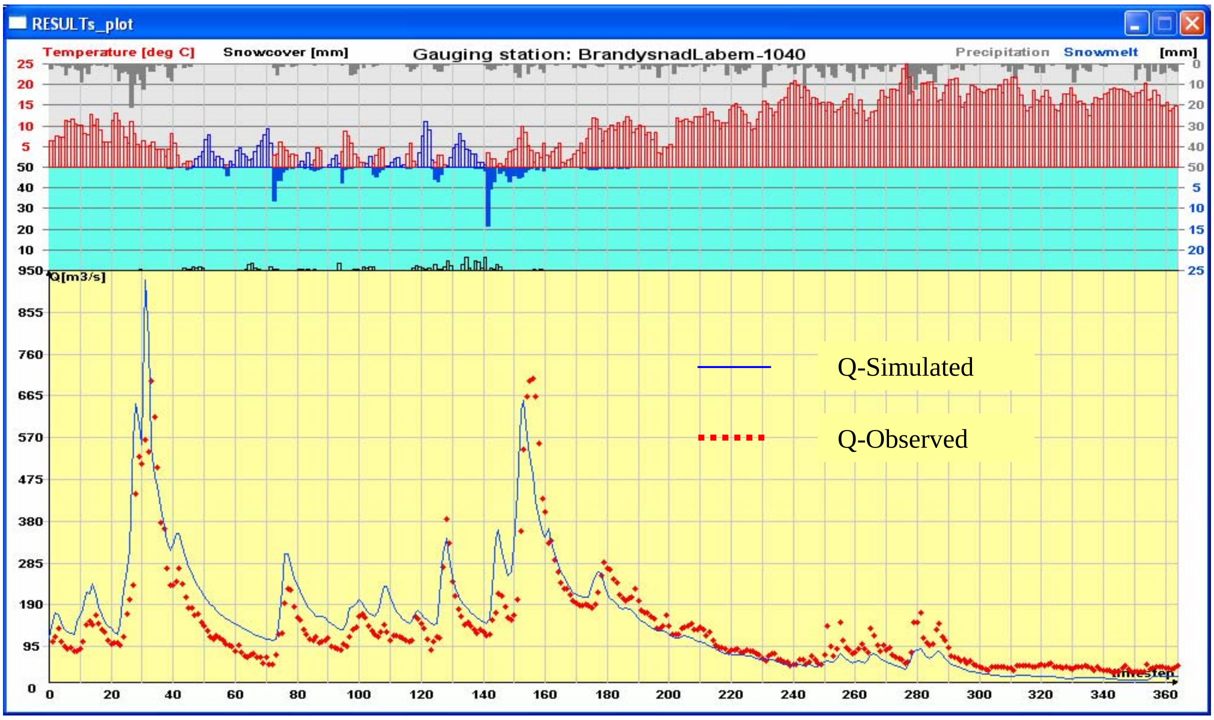

Figure 8: Simulated and measured discharge of Elbe River at Brandys nad Labem gauging station, Poland, 1.10.1998 – 30.09.1999, using high resolution historical meteorological data.

Figures 9 and 10 show simulation results for the Morava River at Kromerir gauging station and for Hron River at Banska Bystica gauging station, both within the Danube River catchment area. For both simulations, high resolution meteorological data have been used. Measured discharge values are reasonably well reproduced by the model.

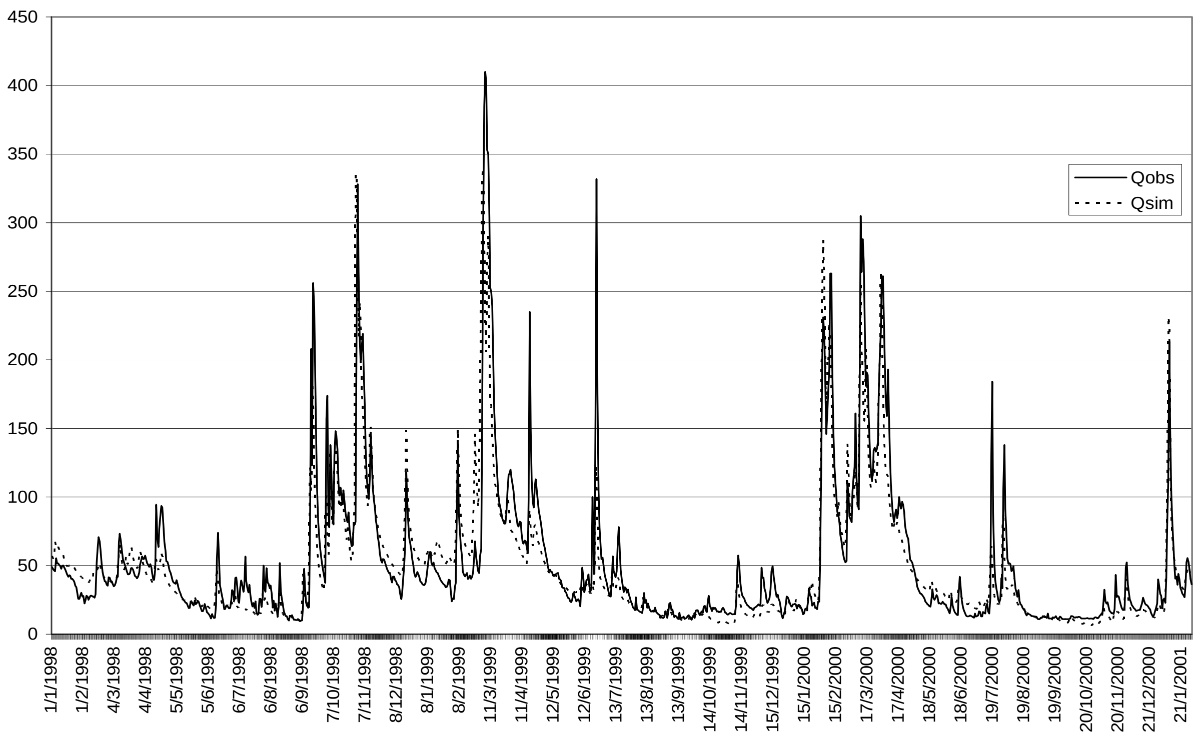

Figure 9: Simulated and measured discharge of Morava River at Kromerir, Slovakia, using high resolution meteorological data.

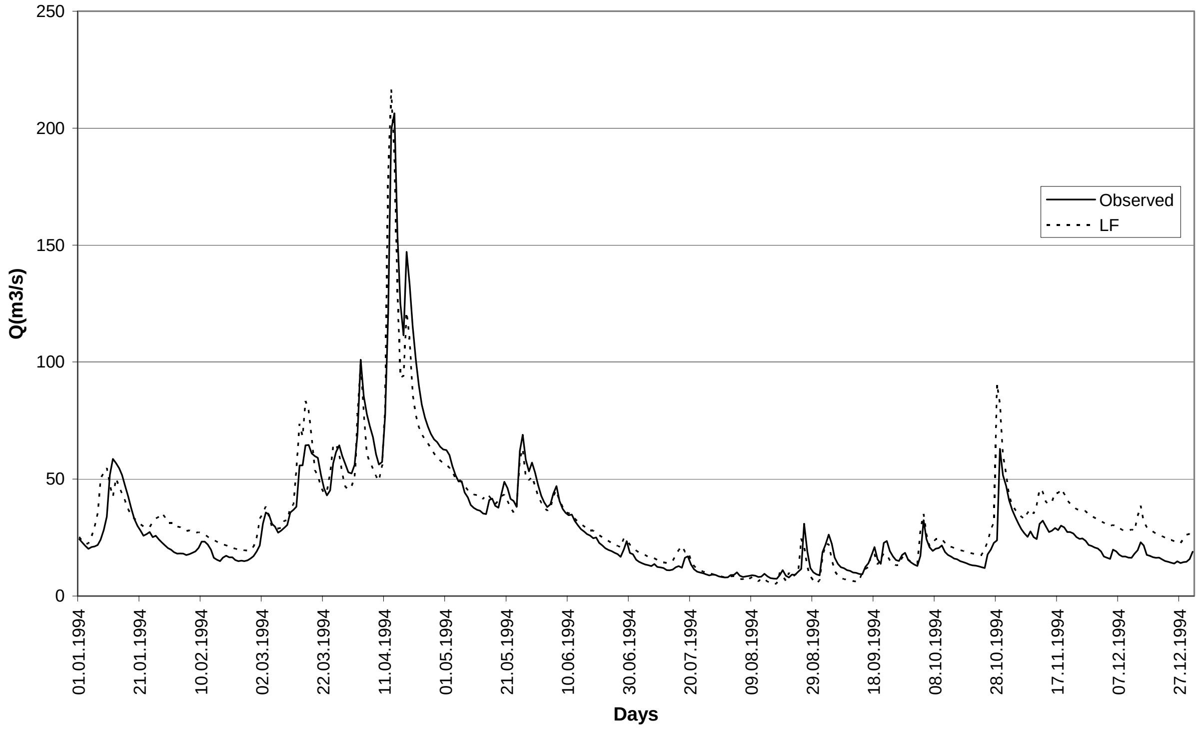

Figure 10: Simulated and measured discharge of Hron River at Banska Bystica, Slovakia, using high resolution meteorological data.

First interim modelling results have been obtained from for the Upper Danube catchment area as well (see figure 11).

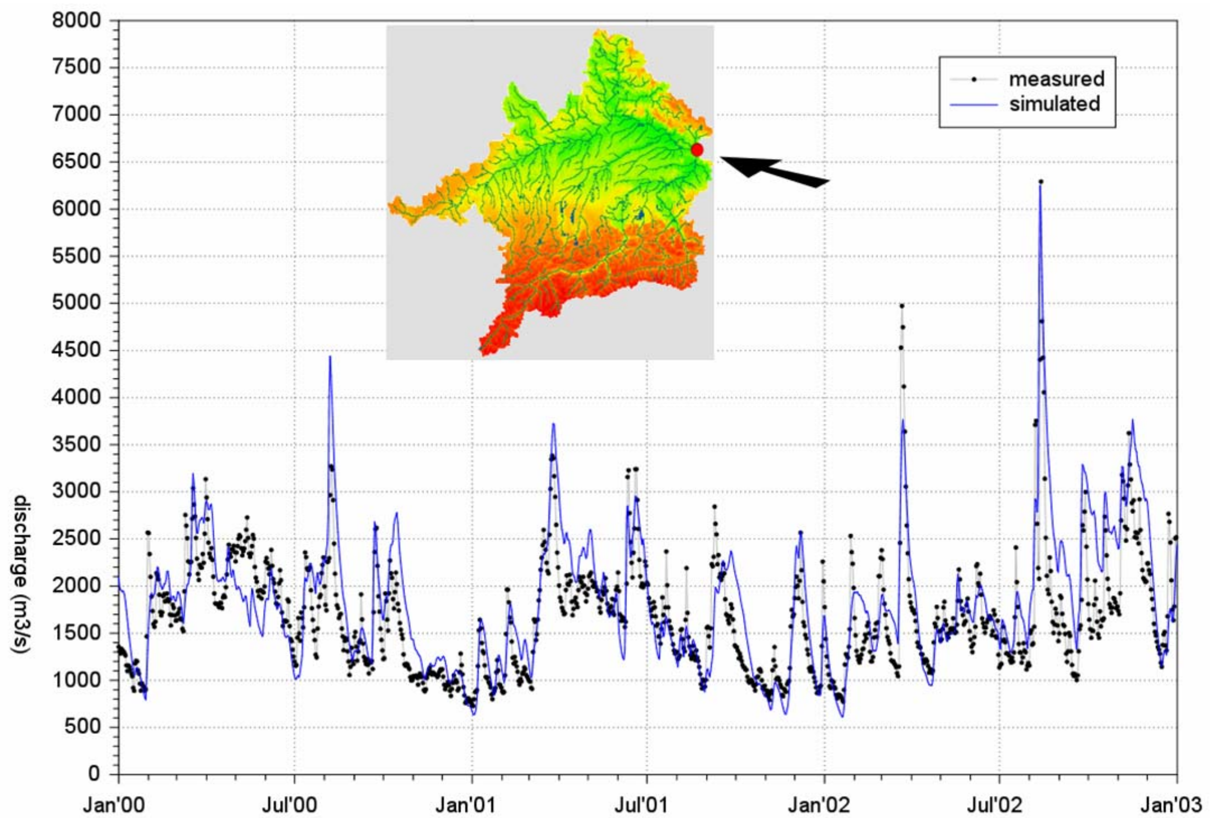

Figure 11: Preliminary LISFLOOD simulation result of the discharge of the Upper Danube at Achleiten, Austria (see arrow) for 2000 to 2002. MARS data has been used for meteorological input data and no calibration has been performed so far.

As local precipitation data have not been available yet, the simulations have been run with MARS data. No calibration of the hydrological model has been performed so far. While the general annual variation and especially the flood in August 2002 has been well reproduced, minor peaks especially between summer 2001 and 2002 have been underestimated by the simulation, which might be caused by the already mentioned underestimation of the precipitation data. Further improvement and calibration is ongoing.

5. Conclusions

Setting-up the LISFLOOD model for the European Flood Alert System and scenario modelling in trans-national catchment areas comprises many steps from data collection to model calibration. The choice of the precipitation data input has proved to be most critical to the resulting hydrographs. The results presented in this work show the usefulness of having high-resolution rainfall and temperature data as input to the model. This is especially true for regional scenario modelling, while for European-wide flood forecasts the model will have to be run with the existing spatial forecast data. For the updating procedure of the modelling system, the inclusion of additional precipitation data from automated national or regional networks would be of great advantage.

6. References

Annoni, A., Luzet, C., Gubler, E., and Ihde, J. (eds.) (2003): Map projections for Europe. *Institute for Environment and Sustainability, Joint Research Centre, Commission of the European Communities*, Ispra, Italy.

De Roo, A.P.J. (1999): LISFLOOD: a rainfall-runoff model for large river basins to assess the influence of land use changes on flood risk. In: Balabanis, P. et al. (eds.): Ribamod: river basin modelling, management and flood mitigation. *Concerted action, European Commission, EUR 18287 EN*, 349-357.

De Roo, A.P.J., Wesseling, C.G., Van Deursen, W.P.A. (2000): Physically-based river basin modelling within a GIS: The LISFLOOD model. *Hydrological Processes,* **14**, 1981-1992.

EC (1993): CORINE Land Cover – Guide technique. *Commission of the European Communities, Office for Official Publications of the European Communities, EUR 12585 FR,* Luxembourg, 144 pp.

EC (1998): Agrometeorological applications for regional crop monitoring and production assessment. *D. Rijks, J.M. Terres, P. Vossen (eds.), Joint Research Centre of the European Commission, Ispra, Italy*, EUR 17735 EN, 31-55.

Heineke, H.J., Eeckelmann, W., Thomasson, A.J., Jones, R.J.A., Montanarella, L. and Buckley, B. (eds.) (1998): Land Information Systems: Developments for planning the sustainable use of land resources. *European Soil Bureau Research Report No. 4, Office for Official Publications of the European Communities, EUR 17729 EN*, Luxembourg, 546 pp.

King, D., Jones, R.J.A. and Thomasson, A.J. (1995). European Land Information Systems for Agro-environmental Monitoring. *Office for Official Publications of the European Communities*, *EUR 16232 EN,* Luxembourg, 285pp.

Szabó, J. A. (2004): Application of Adaptive Recognition Algorithm of Local Anisotropy in Case of Spatial Interpolation of Precipitation Fields with Kriging. *In: Proc. XXIInd Conference of the Danubian Countries on the Hydrological Forecasting and Hydrological Bases of Water Management. 30 Aug. – 02 Sept. 2004, Brno, Czech Republic* (to appear).

Wesseling, C.G., D. Karssenberg, W.P.A. Van Deursen & P.A. Burrough (1995): Integrating dynamic environmental models in GIS: The development of a dynamic modelling language. *Transactions in GIS,* **1**, 40-48.