Implementation of an operational flood warning system for an alpine catchment with a state and event driven system

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Abstract: The article describes the implementation of an early flood warning system for the alpine catchment of the Ammer river (southern Germany). It employs the numerical weather prediction model (NWP) MM5 and the hydrological water balance model WaSiM-ETH. The warning system is run daily in a hindcast mode with station-observed meteorology and hydrology data first. It provides all required input for the forecast mode. The forecast with NWP modeled meteorology data continues providing a forecast for up to 48 hours. The warning system is driven with a set of agents written in object-oriented Perl. They perform observational input data provision, facilitate the link to the NWP model, and run the hydrological model within the Perl Object Environment (POE). The POE-based forecast system is completely non-linear. On well defined conditions POE issues events, such as provision of input data, hydrological model setup and run. Those events are handled by event handlers. Event handlers interact by changing states and issuing events according to the progress and outcome of the tasks they perform.

1. Introduction

In recent years large flood events in many Alpine areas revealed a strong need for reliable early warning systems. Due to the fast response of river runoff to precipitation events in Alpine catchments, such systems can only be driven by coupling precipitation forecasts from numerical weather prediction (NWP) models with hydrological models. At IMK-IFU the hydrological Water balance Simulation Model (WaSiM-ETH) (Schulla and Jasper, 2006) is a cornerstone of an early warning system being developed for the Ammer river. The scientific topics include hydrological model calibration, coupling with different NWP models, such as Meteorology

Model (MM5) (Dudhia, 1993), Meteorology Chemistry Climate Model (MCCM) (Grell, 2000) or Weather Research and Forecast (WRF) Model. Other topics are the estimation of rainfall intensities with radar reflectivities (Marx et al., 2006) and development and test of environmental software approaches to the integration of various components of the forecast system. Coupled modeling systems have been developed for the Mangfall (MM5-WaSiM-ETH, Kunstman and Stadler, 2003) and Ammer (WRF-WaSiM-ETH, Marx, 2007) catchments.

The article describes a system integration approach based on Perl Object Enviroment (POE). It is used to operate the WaSiM-ETH with the MM5 meteorology forecasts. The article describes the setup of the hydrological model and the meteorological model. It presents the structure of the POE-based system and application of the POE components as well as some results obtained in the year 2006.

2. Modeling system

The present system is implemented for the Ammer catchment located in the area of Bavarian Ammergau Alps and alpine forelands, Germany (see Figure 1). The size of the catchment is 609 km^2. It is characterized by big north-southerly differentiation in soils, land use, and climate. The elevations range from 533 m a.s.l in the northern part close to the outflow into the Lake Ammersee up to 2185 m a.s.l. in the mountainous southern part. Long term mean annual precipitation ranges from 1100 mm/a to more than 2000 mm/a with a maximum in summer. The mean annual temperatures are around 8 °C in the alpine forelands and 4.5 in the southern part.

Within the basin, data from five river gauges operated by the Wasserwirtschaftsamt (WWA) Weilheim are available. Geographical input data (elevation from interferometric ERS-data, land use from Landsat-TM fuzzy logic classification, and soil data from Bavarian Bodenguetekarte) were obtained from the RAPHAEL Project (RAPHAEL, 2000).

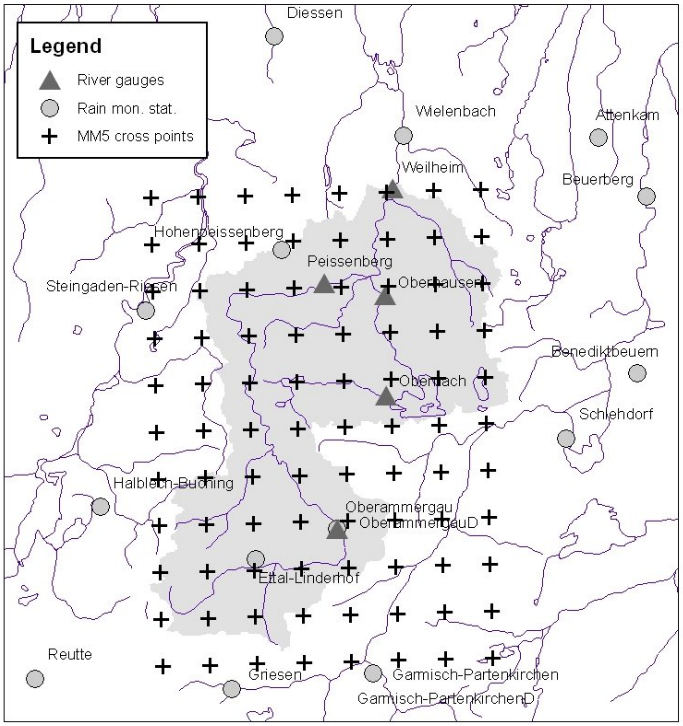


Figure 1 Catchment of the Ammer river

The hydrological model WaSiM-ETH (Schulla and Jasper, 2006) employs a set of conceptual approaches and physically based algorithms in the description of hydrological processes. A two step procedure of Peschke (1987) is used to model the infiltration of water into the soil and the surface runoff generation. Vertical water fluxes in the unsaturated zone are described by the discrete Richards Equation. The surface runoff is routed using a subdivision of the basin into flow time zones. Interception is considered with a leaf area index dependent storage capacity and the Penman-Monteith (Monteith, 1975) approach is used to calculate the evapotranspiration. WaSiM–ETH contains a simple 2-D groundwater model dynamically coupled with the unsaturated zone.

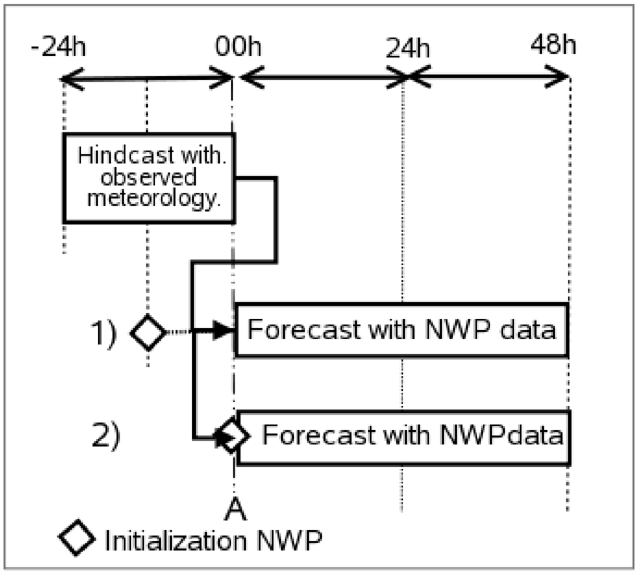


Figure 2 Scheme of the two step modeling approach

In order to provide initial conditions for the hydrological forecasts the flood warning system is operated in a two step hindcast/forecast approach as indicated in Figure 2. In the hindcast part WaSiM-ETH is run continuously in 24 hours time slices with observed meteorological and hydrological input data of the last 24 hours. The storage grids of the 00:00 UTC output are used to initialize the 48 hours forecast part with meteorology data provided by the MM5 model. MM5 is run in the version 3.7 twice a day with initializations at 00:00 UTC and 12:00 UTC with forecasts from the Global Forecasting System (GFS). MM5 is run in 1-way nesting approach on 4 modelling domains with 60km, 15km, 3.75km and 1.25km resolutions and with 25 vertical layers. WASiM-ETH is passively (no feedback interactions) coupled with the 3.75 km domain run. The domain cross points covering the catchment are indicated in Figure1.

WaSiM-ETH has been calibrated using information provided by Krause (2003) and Mayr (2004) as well as with meteorological data from 15 monitoring stations located in the vicinity of the basin (see Figure 1). It is run in 100m x 100m grid resolution with a time step of 60 minutes. In the hindcast run all measurements are interpolated using inverse distance weighting (IDW) method. The NWP output at the specified cross points is interpolated by application of Thiessen polygons. This procedure provides best possible transfer of the precipitation data from the NWP model into WaSiM-ETH.

The entire system is implemented with a suite of object-oriented Perl programs. They provide methods for observation data download from various sources on the Internet, data import from the MM5 model, provision of WaSiM-ETH input data and the model run as well as retrieval and presentation of the results. The system is operated since 2005 with a set of Perl scripts executed by cron-jobs at fixed times. The experience revealed a need for a more flexible solution. It should enable a simple setup of diagnostic runs of the system for any specified periods in the past and with different options. It should be linked directly to the NWP and additionally flexible react to data availability and network failures. The MM5 runs are completed at varying times depending on the availability of data from the GFS and the Internet traffic. Here, Perl object environment (POE) provides appropriate functionalities.

3. System integration with POE

Perl object environment (POE) is a free and open powerful multitasking framework toolkit. It allows applications to be distributed across a network of machines and perform several tasks at once (Caputo, 2003). POE provides three levels of abstraction enabling developers to rapidly create and deploy applications tailored to their needs. The POE environment consists of states, the kernel and sessions. States or events are routines that are executed when some specified events occur. The kernel runs the entire system. POE sessions handle the state, send POE messages, create child session etc.. POE comes with a steadily growing number of drivers, filters, wheels and components (Taylor and Goff, 2001) and is available from CPAN (Comprehensive Perl Archive Network) (www.cpan.org).

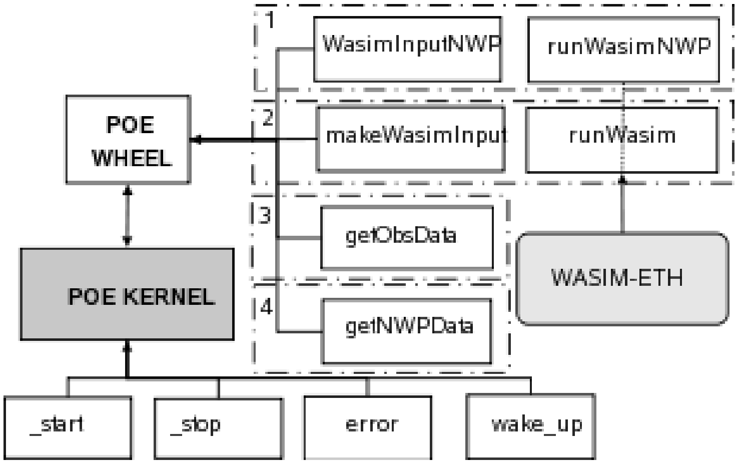


Figure 3 Scheme of a wheel - based solution with 4 tasks run in parallel

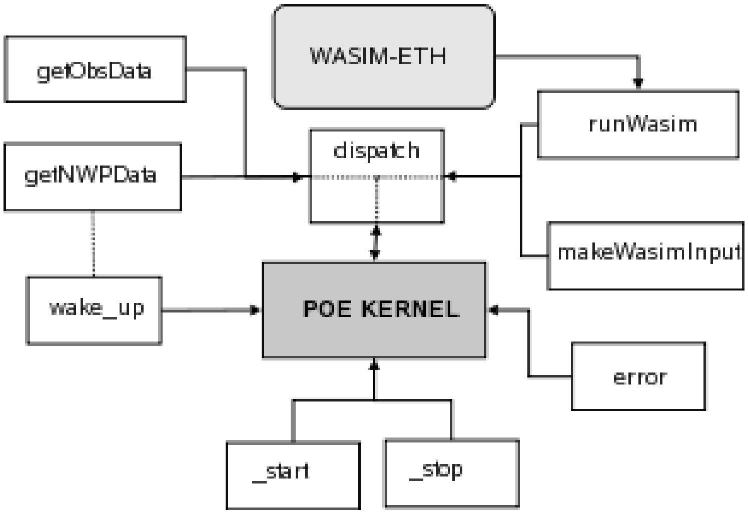


Figure 4 Scheme of a sequential solution

In principle the flood forecast system consists of 4 parts: (1) provision of appropriate measured input data (2) hindcast run of WaSiM-ETH at the time when appropriate input becomes available (3) provision of the meteorology inputs from the NWP and (4) the forecast runs. The WaSiM input consist of hourly air temperature, precipitation, relative air humidity, global radiation and wind speed data. At the current stage, the hindcast is run in 24 hours time slices and is initialized with storage fields from previous model run. Furthermore the system has to ensure a consistent state of storage fields and react to the varying times of the NWP runs and any network failures.

As always with Perl, there are several solutions to the described problem. Figure 3 shows the scheme of a system based on POE Wheel. POE Wheels are event handlers encapsulating some useful code. They are created by a POE session and belong the session. Each wheel defines its own states (i.e. *WasimInputNWP*, *runWasimNWP* in Figure 3).The major advantage of this solution is that the tasks 1- 4 can be run in a non-blocking way on the same host or even distributed over a

```
use POE;

POE::Session->create
  ( inline_states =>
   {_start          => \&start,
    _stop           => \&handleStop,
     error          => \&handleError,,
     dispatch       => \&handleDispatch,
     getObsDat      => \&handleObsData,
     getNWPData     => \&handleNWPData,
     makeWasimInput => \&handleWasimInput,
     runWasim       => \&handleWasimRun,
     wake_up        => \&wake_up_handler,
   }
  );
$poe_kernel->post("wake_up");
$poe_kernel->run();
exit 0;
```

Figure 5 Definition of the main POE session

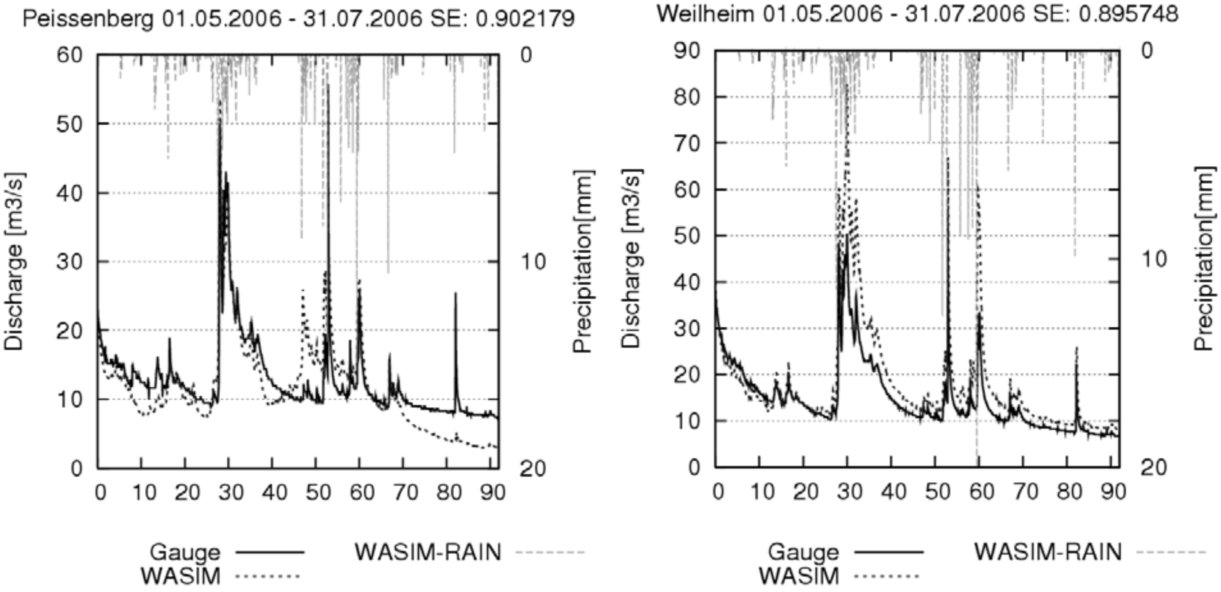
number of network hosts while reacting to states and events occurring in other tasks. Smiatek (2006) shows a multitasking system coupling Geographical Information System (GIS), input data download from the Internet and a biogenic emission model run exposed over a WEB service.

Figure 4 shows a scheme of a system based on sequential run of the particular tasks. A *dispatch* state reacts to events occurring and creates appropriate events needed to perform a specified task.
Figure 5 shows the POE session definition. It needs only a few lines of code and defines the events and starts the event processing. The events *_start* and *_stop* are native POE states. *_start* is always called when a POE Session is created, while *_stop* will terminate the session. The session will run in an infinite loop until the event _stop occurs putting the session into the _stop state. The events themselves are handled by calling the appropriate Perl subroutines, i.e. *&start* at the event *_start*.

When started, in *&start* event handler, the system is put into one of two available modes: diagnostic mode with a defined modeling period in the past and operational mode implementing the hindcast of the last 24 hours and 48 hours forecast. Both can be run with measured input only as well as with both measured and NWP modeled input. In addition various WaSiM-ETH run options, such as different interpolation routines, are defined as global variables enabling a fast setup of various test runs of the entire system. Its ability to run in different configurations is a key element in improvement of the coupled system.

The dispatcher issues the evens *getObsData* or *makeWasimInput.* The event handler *handleWasimInput* will issue the event *runWasim* or *dispatch* if a WaSiM-ETH run is not specified. The dispatch event handler issues *getDataNWP* event or switches to the next date according to the options chosen in the *_start* event. The POE-based system is completely non-linear. On well defined events POE kernel automatically issues events while the event handlers change states or issue events according to the progress and outcome of the tasks they perform. It should be noted that the same event handles are used to provide the WaSiM-ETH input and the model run in the hindcast as well as in the forecast runs. In POE a hash called the *heap*, available in every event of the session, is used to store session specific data. Thus the event handler can get information on the current date, any objects defined by other event handlers and the specific task they should perform, i.e. run the WaSiM-ETH with NWP data resulting from initialization at 00:00 hours UTC by the event handler *runWasim.* Some practical Perl modules, such Date::Calc and Log::Log4perl, available from CPAN, providing a large range of functions for date calculations based on the Gregorian calendar and logging respectively, simplify the programming of the event handlers significantly. In forecast mode the system has to react to the availability of data from the NWP. Here the postback event handler *wake_up*. The kernel will delay and resume the processing for a specified time until the data is available or some other specified events occur. The event handler *handleError* handles any processing errors. Information on errors or successful runs is written to log files or send by email.

Figure 6 and Figure 7 show some results of the system application in 2006. Starting from the 01.01.2006 with storage fields saved at 31.12.2005 the system has been run in the hindcast mode with observation data only. Figure 6 shows the comparison of measured and modeled discharge at the gauge Peissenberg and Weilheim in the period from first of May to July 31. The overall agreement specified as index of agreement (Willmott et al., 1985) is with 0.9 very high (possible range 0 – 1), although on some days the discharges are significantly overestimated by the hydrology model. Figure 7 shows an example for a forecast for the May 28th. The results are rather typical. While the run with NWP data initialized at May 26th provides reasonable estimates, the forecast with NWP data initialized at the same day is rather poor. In addition there is time lag between the predicted and observed peaks. In mountainous areas timing, intensity and spatial distribution of precipitation modeled by a NWP is very sensitive to geometrical resolution, employed parameterizations and the model setup.
From results in their experiments Jasper et al. (2002) point out that future improvements of the flood forecast systems mainly depend on the further development of the NWP models. Here the flexible POE-based system provides means to access results of various model setups or parameterizations used in the NWP model.


Peissenberg 01.05.2006 - 31.07.2006 SE: 0.902179

Weilheim 01.05.2006 - 31.07.2006 SE: 0.895748

Figure 6 Observed vs. predicted discharge at the river gauges Peissenberg and Weilheim. Observed precipitation was interpolated using the IDW method.

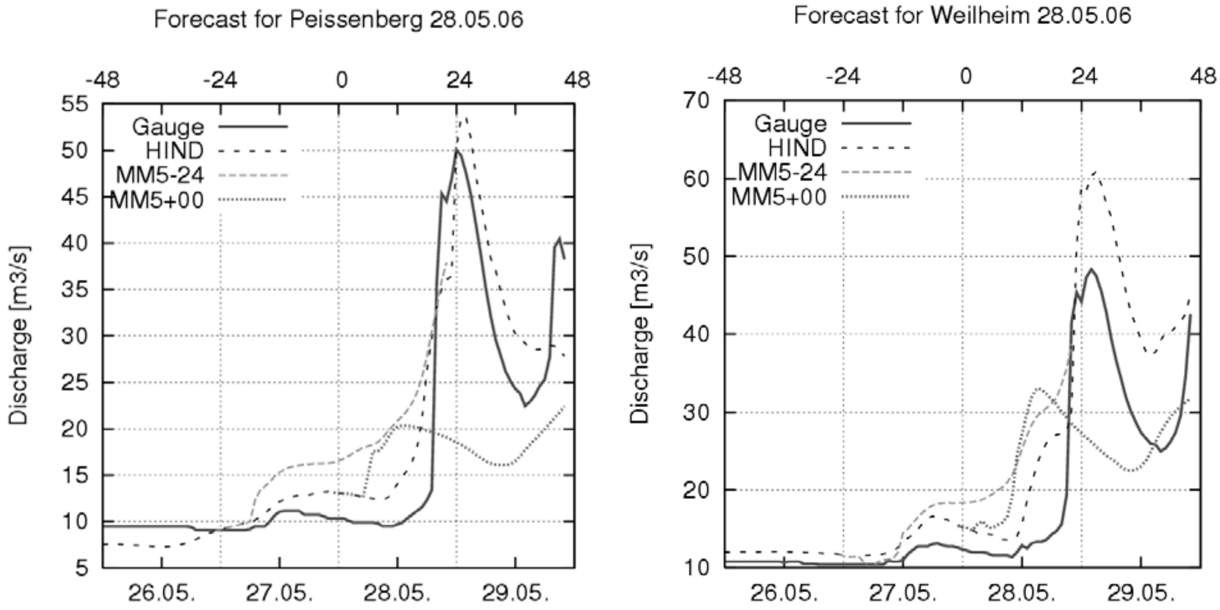


Figure 7 Observed, modeled (HIND) and predicted discharge at the monitoring stations Peissenberg and Weilheim. MM5-24 – MM5 initialization at 27th 00:00 UTC, MM5-00 – MM5 initialization at 28th 00:00 UTC

5. Conclusions

The Perl POE toolkit provides excellent means to create and deploy powerful cooperative applications in Perl. POE comes with a large number of contributed components, tutorials and example applications making it extremely easy to be used in any environment. There is of course programming needed to implement the various event handlers. But those parts are the genuine domain of the environmental modelers. Thanks POE, programming of the system integration can be reduced to a minimum.

Acknowledgments

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