Danish Meteorological Institute

Final report for the special project SPDKEFFS: Heavy rain in Europe

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1 Introduction

This report describes the work performed under the special project "Heavy rain in Europe", which is strongly linked to the EU-project "An European flood forecasting system" EFFS (De Roo et al., 2003).

The EFFS project aims at developing a prototype of an European Flood Forecasting system for 4-10 days in advance. This system shall provide daily information on potential floods for large rivers such as the rivers Rhine and Odra as well as flash floods in small basins. It can be used as a pre-warning system to water-authorities that already have a 0-3 day forecasting system. The system can also provide flood warnings for areas that at present do not have a forecasting system (Eastern European Countries). The project consortium consists of several European hydrological institutes and three meteorological institutes (ECMWF, DWD and DMI).

One aspect of the work is concerned with meteorological data collection and supply. DMI provides deterministic LAM hindcasts for selected historical river-flooding events, where the ECMWF deterministic GCM is used as host model. In addition, probabilistic hindcasts have been performed with mini ensembles using DMI-HIRLAM on basis of the 51-member ECMWF-EPS in order to perform uncertainty studies on the precipitation forecasts and to provide the hydrological models with high-resolution probabilistic precipitation data.

The following sections outline the set-up of the model (Section 2) and show some of the results from three historical hindcasts (Section 3). The mini ensemble investigations and some results from these are given in Section 4.

2 Model set-up

The model configuration for DMI-HIRLAM was derived from the operational forecast system at DMI (Sass et al. (2002) gives the latest description). A double nested model system of DMI-HIRLAM was used to scale precipitation fields dynamically down via a 0.3°-model onto a grid of size 0.1°. The 0.3°-model domain covers the entire North Atlantic as well as Europe, and the innermost high-resolution model domain covers all important river-catchments in Europe (Fig. 1). The ECMWF models serve as host model to this nested system, where model level data from the deterministic global model of ECMWF were used in the deterministic hindcasts, and respective data from the 51-member ECMWF-EPS were used in the probabilistic simulations.

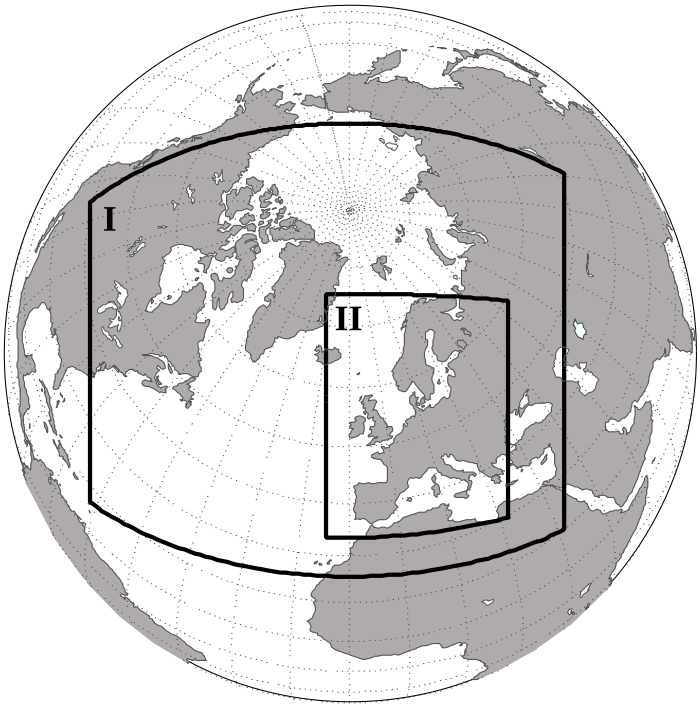

FIG. 1: The DMI-HIRLAM model domains for the hindcasts and mini ensemble experiments. The large outline depicts the domain of the 0.3°-model (I), and the innermost outline depicts the domain of the high-resolution 0.1°-model (II). The host models to drive model (I) are the ECMWF global model and the ECMWF-EPS model, depending on whether a deterministic or probabilistic simulations are performed.

The 0.3°-model is initialized by ECMWF analysis, and its lateral boundaries are updated by the ECMWF forecasts with 6 hour frequency. The high-resolution 0.1°-model is initialized by the 0.3°-model and updated hourly at its lateral boundaries by this model. Both models are configured in the same vertical level structure with 31 vertical levels, and they use a split time stepping in the dynamics and in the physical parameterizations of the model (Sass et al., 2002).

3 Historical deterministic hindcasts

In the first part of the project, deterministic hindcasts of three historical heavy rain events were performed. These events are:

- The severe flooding in the Piemonte region in North Italy in November 1994, affecting the rivers Po and Reno

- The Rhine/Meuse flooding in December 1994 and January 1995
- The severe Odra flooding in Poland in July 1997

In the beginning of November 1994 heavy rainfall occurred in the western part of Northern Italy. The major precipitation amounts were observed during 5th and 6th November 1994. They caused a severe flooding in this region (Buzzi et al., 1995). The second flood occurred at the end of January 1995 and affected the rivers Rhine and Meuse (Meijgaard (1995) and Fink et al. (1995)). Contrary to the case in the Piemonte area, the river floods were, besides hydrological causes, linked to a series of precipitation events with a larger spatio-temporal extent than in the first case. The third flood event occurred in July 1997 and affected the rivers Odra and Vistula (Dziadziusko and Krzymiski, 1998).

The deterministic hindcast simulations include a period of several weeks, which include the respective heavy rain events. A hindcast was launched for every day of a period at 12UTC and run over 72 hours. This results in a 24h, a 48h and a 72h hindcast for each moment.

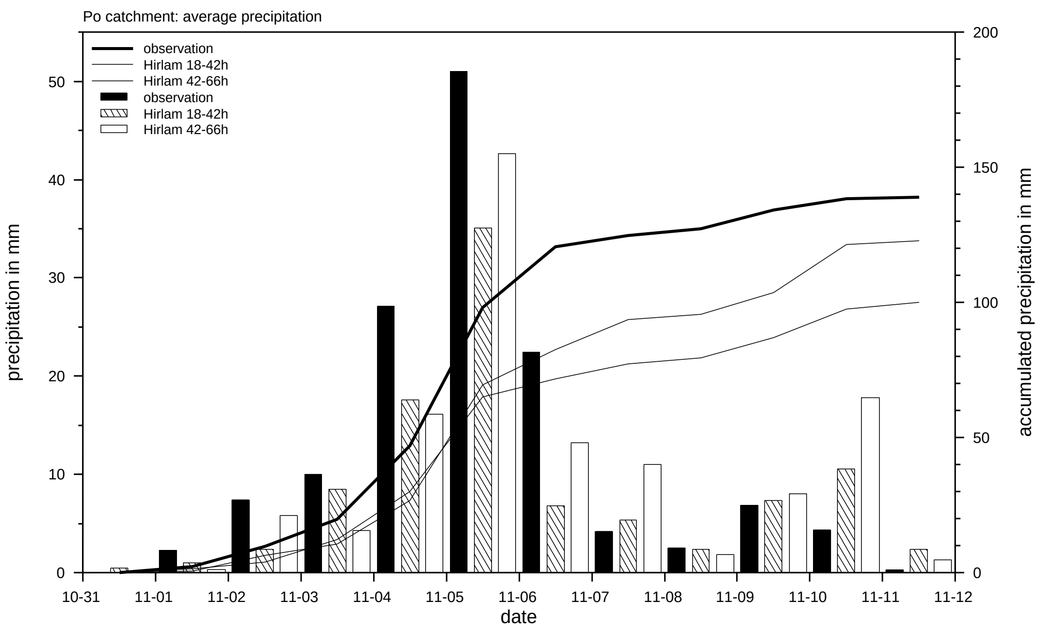

FIG. 2: Accumulated precipitation over 24 hours (columns and left axis) averaged over the Po river-catchment, from the DMI-HIRLAM hindcasts in the forecasting range 18–42h and 42–66h, and from DWD precipitation analysis of synoptic and high resolution precipitation observations (observation). The curves denote the respective accumulations (axis to the right).

Fig. 2 shows results for the precipitation over the Po river basin for the period of the major rainfall event in the Piemonte case. The accumulation periods of 18–42h and 42–66h have been chosen in order to be consistent with the precipitation analysis, which was performed at the Deutsche Wetterdienst (DWD). The major rainfall event of this case is captured well by the hindcasts, the rainfall amounts are, however, underestimated.

For the second heavy rain event Fig. 3 shows the comparison between analysed and hindcasted rainfall over the Meuse river basin during the period at the end of January 1995. There is a good

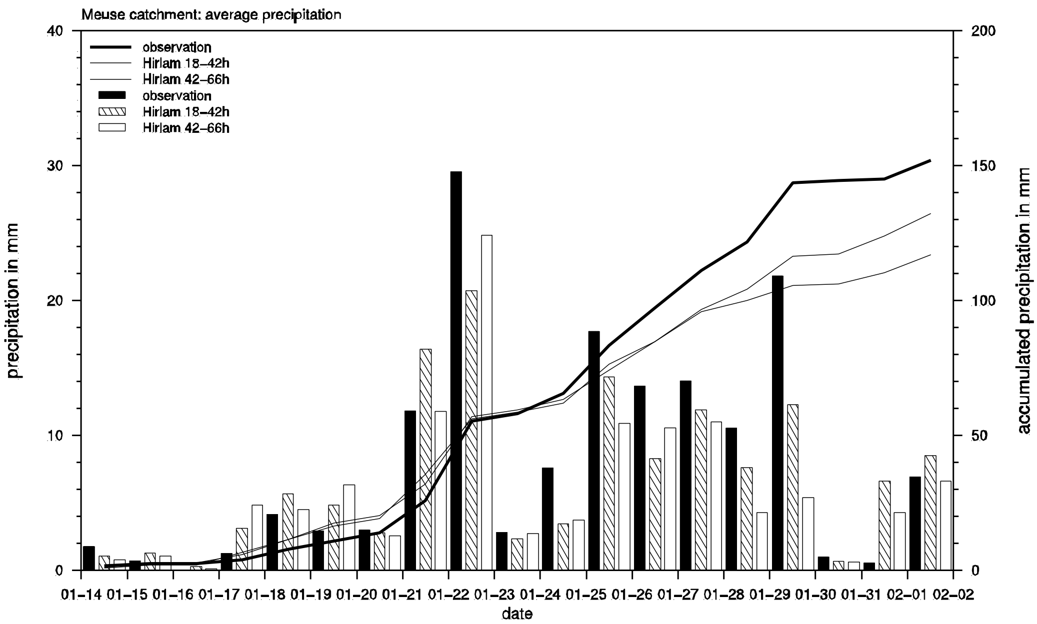

FIG. 3: Accumulated precipitation over 24 hours (columns and left axis) averaged over the Meuse river-catchment, from the DMI-HIRLAM hindcasts in the forecasting range 18–42h and 42–66h, and from DWD precipitation analysis of synoptic and high resolution precipitation observations (observation). The curves denote the respective accumulations (axis to the right).

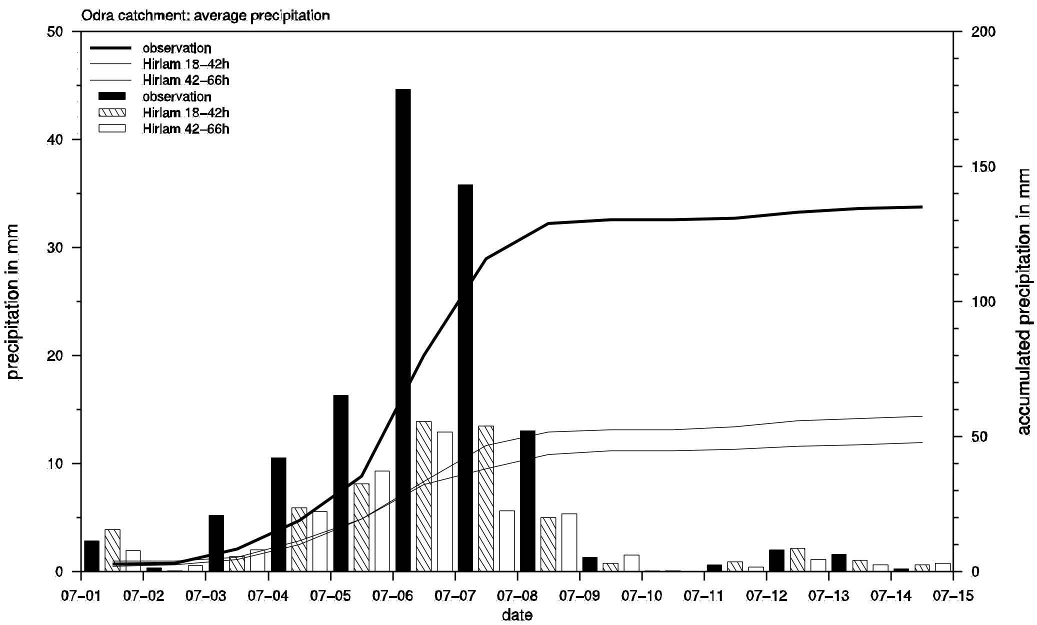

FIG. 4: Accumulated precipitation of the last 24 hours (columns and left axis) averaged over the Odra river-catchment, from the DMI-HIRLAM hindcasts in the forecasting range 18–42h and 42–66h, and from DWD precipitation analysis of synoptic and high resolution precipitation observations (observation). The curves denote the respective accumulations (axis to the right).

temporal correlation between observation and hindcasts, differences in the estimation of the rainfall amounts are, however, present.

In the third event, the hindcasts underestimated the rainfall amounts over the Odra river basin significantly (Fig. 4). Therefore, this case was especially interesting to be investigated more closely with the mini ensemble approaches described in Sec. 4. A more detailed description of the deterministic hindcasts is given by Sattler (2002).

4 Mini ensemble experiments

A widely applied approach to treat uncertainties in NWP is to make use of an ensemble prediction system (EPS), and this has been followed in this work, too. Two different methods have been experimented with. The first is based on a *perturbed host model* and consists of running a limited-area high resolution ensemble of hindcasts based on selected members from the 51-member ECMWF-EPS. This selection ensemble (SE) is to address uncertainties due to initial errors as well as uncertainties at the lateral boundaries in a consistent way. The selection of the ECMWF-EPS members to be used as host models for the SEs was based on the 5-day precipitation, that fell over a target area, which includes the river basin under consideration (Fig. 5). The SE consists of at least 3 members: the control, the member closest to the global ensemble mean, and the member farthest away from the global ensemble mean. Further members are selected such that the dispersion of the SE is maximized. The size of the SE was chosen to a number of 5 members plus the control.

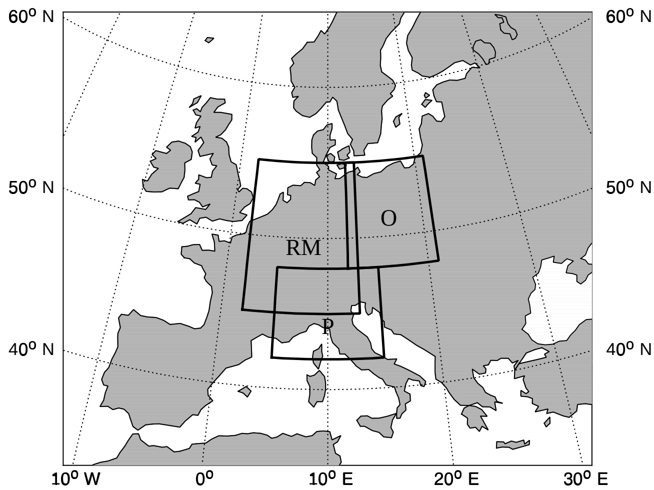

FIG. 5: Target areas of the ensemble member selections for the river basins of Odra (O), Rhine and Meuse (RM) and for the Po (P). Area **P** was regarded in the first historical event, area **RM** in the second case, and area **O** in the third event.

The second ensemble approach is to vary the parameterization of convection and condensation processes by using different parameterization schemes available in DMI-HIRLAM in order to address to some extent the model intrinsic error in parameterization (parameterization ensemble PE). A number of 5 parameterization schemes were available, one of which (the STRACO scheme by Sass et al. (1997)) represents the scheme that was used in the SE. The resulting five members of the PE used the control forecasts from the host model as initial and boundary condition. A more detailed description about the two methodologies can be found in Sattler and Feddersen (2003).

The combination of both ensembles was investigated, too. As the control of the SE is identical to the PE member that utilizes the STRACO parameterization scheme, this combined ensemble (CE) resulted in a size of 10 members.

ECMWF reran the ECMWF-EPS on the historical cases using the latest version of the 51-member EPS, which didn't exist at the time of the historical events. The reruns made it possible to save the model level data from the ECMWF model, which is important when utilizing the data in DMI-HIRLAM.

The ensemble integrations were performed with a similar model configuration as the deterministic simulations, i. e. a 72 hour forecast was started at 12 UTC each day within the respective period of each event. The integration periods were, however, shorter, depending on the available model level data from the ECMWF-EPS reruns. Each period included between 10 and 13 days.

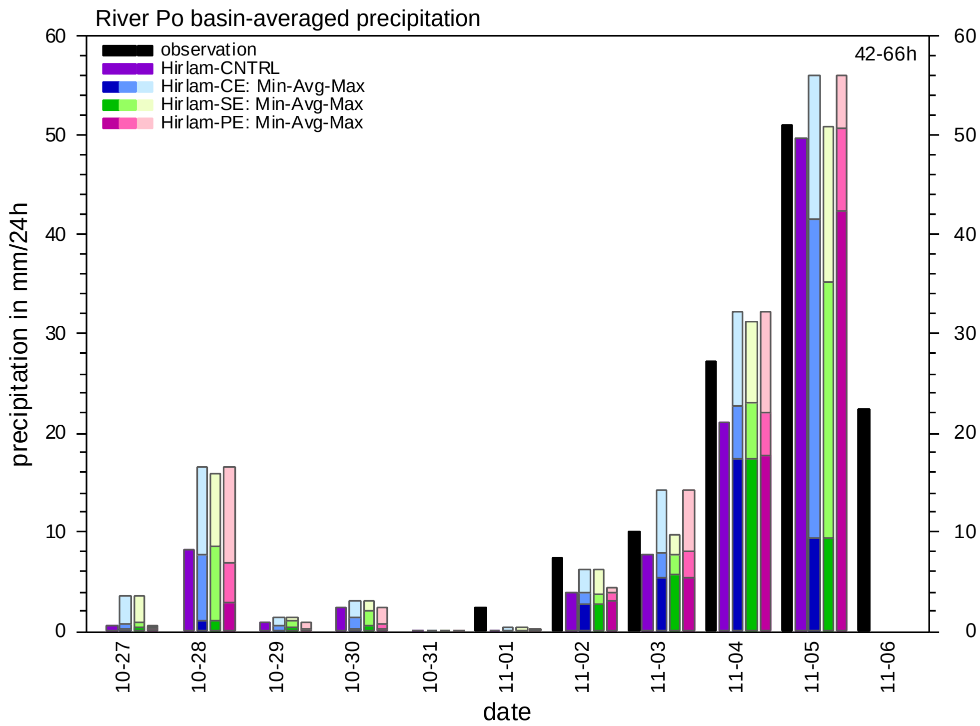

FIG. 6: 24-hourly accumulated daily precipitation between 42 and 66 hours, averaged over the Po river basin during the period before the major rainfall event at the 5th November 1994. The columns show the DWD rainfall analysis of observations (black), the ensemble control (violet), and the ensembles CE, SE and PE (see legend). The dark colours in the ensemble columns depict the minimum rainfall given by any of the ensemble members. The light colours analogously depict the maximum rainfall, and the medium colours indicate the ensemble mean.

Fig. 6 shows a similar graphic as in Fig. 2, now including the data from the ensemble integrations, but only for the 42–66h forecast range. The major rainfall event at the 5th November 1994 was significantly enhanced by the presence of the orography of the Alps, which resulted in a strong forcing for condensation processes. This made all PE members react quite similarly, leading to a relatively small spread between the extreme members of this ensemble in comparison with the spread in the SE. The latter included, through the initial and boundary perturbation, the posibillity for different synoptic developments. This allowed for different placements of the baroclinically unstable depression, that crossed the Alps from South in this case. For the 6th November no model level data from the ECMWF-EPS were available in order to cover this day.

It should be noted in the Piemonte case that the period, where the model level data from the ECMWF-EPS were available, is different from the period, for which the rainfall analysis was available. The former ends at 4th November and the latter starts at 1st November. Therefore, the rainfall forecasted by the ensembles around the 28th October are not a false alarm, they actually occurred (see e. g. Fig. 9 in Sattler and Feddersen(2003)).

For the second heavy rain case that occurred in January 1995, the impact of the ensemble approaches on improving the rainfall predictions seems small (Fig. 7). In this case, the PE often seems to play an important role, because large scale forcings were small, leaving the possibility for more small-scale variablity of the condensation and convection processes.

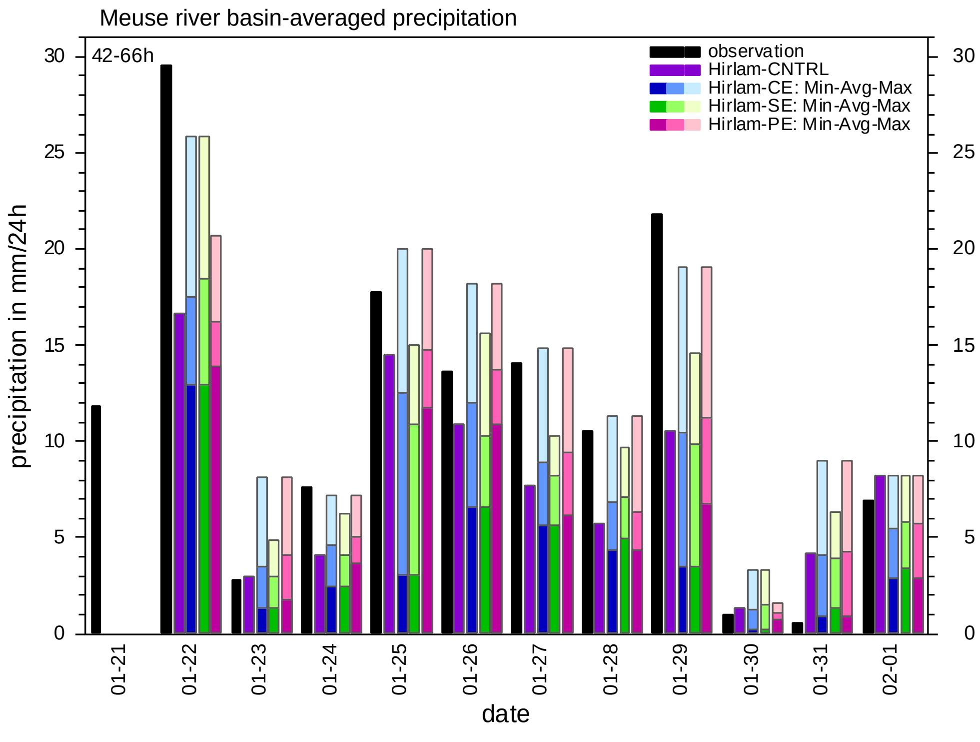

FIG. 7: 24-hourly accumulated daily precipitation between 42 and 66 hours averaged over the river Meuse basin during the end of January 1995. The columns show the DWD rainfall analysis of observations (black), the ensemble control (violet), and the ensembles CE, SE and PE (see legend). Color shadings as in Fig. 6.

The third heavy rain case is osf special interest, because the control forecasts performed rather poorly during the whole integration period. The respective HIRLAM ensemble predictions ar shown in Fig. 8. Both the SE and the PE show a large spread between the extreme members during the days with the largest observed rainfall ammounts. It is interesting to note that a PE member represents the observed precipitation best at the 6th of July, and that a SE member is closest to the observed values one day later. This is a result of the influence of both initial state plus boundary uncertainties and model uncertainties in the condenstion and convection, which can vary from day to day. As a consequence, a combination of the ensembles is an advantage. Sattler and Feddersen (2003) discussed the results in more detail.

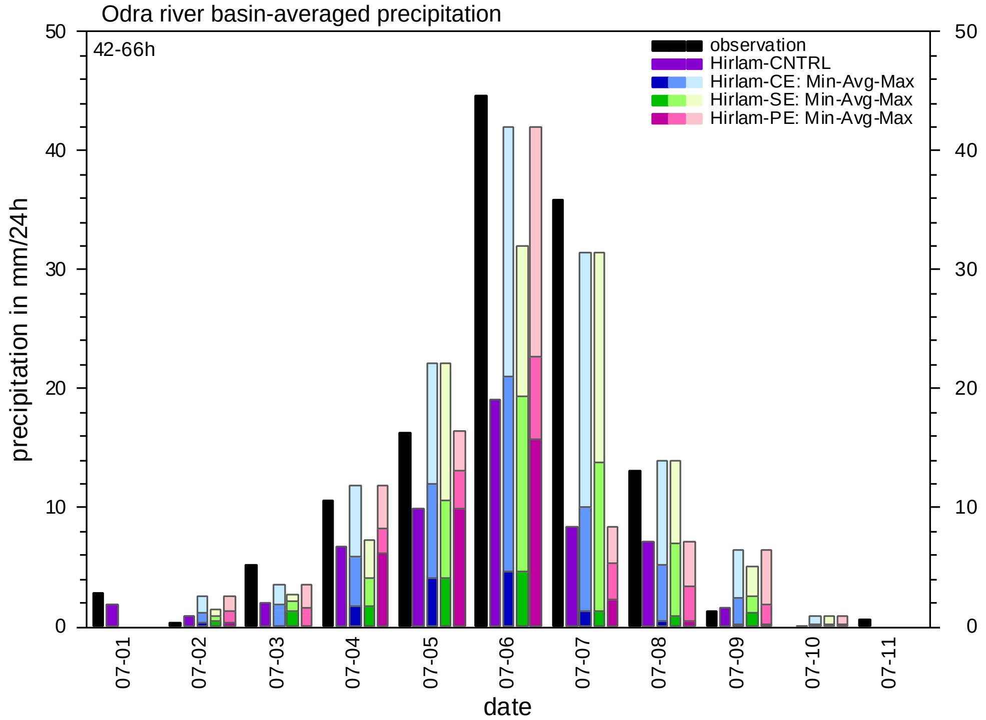

FIG. 8: 24-hourly accumulated daily precipitation between 42 and 66 hours over the river Odra basin during the beginning of July 1997. The columns show the DWD rainfall analysis of observations (black), the ensemble control (violet), and the ensembles CE, SE and PE (see legend). Color shadings as in Fig. 6.

5 Final remarks

The investigations described above of using a high-resolution limited-area ensemble based on the ECMWF-EPS (model levels) have been beyond the first that were performed at DMI. They show that DMI-HIRLAM can be nested into perturbed GCM forecasts. The consumption of computer resources is, however, quite large. The integration over 72 hours of one ensemble member running on one processor of the FUJITSU VPP5000 took about 5 hours.

There is an indication for a potential of the ensemble approaches to improve forecast quality for precipitation in the short range with respect to a single deterministic forecast. The ensemble designs have weaknesses, however, and besides trying to improve them, other aspects should also be investigated, like for example initial mesocale state uncertainties. Also the small ensemble size implies a limited "resolution" in probability space, and a more sophisticated post-processing of the ensemble output should be considered. The selection ensemble design is targeted for precipitation over a certain area. Therefore, it is mainly applicable within the target area.

Acknowledgments

We thank Dr. Roberto Buizza (ECMWF), who performed the 51-member EPS reruns for the three historical events. The hydrological institutions involved in the EFFS project provided the data for the river-catchments, and the Deutsche Wetterdienst provided the precipitation analysis data.

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