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INCA-CE: a Central European initiative in nowcasting severe weather and its applications

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Abstract. The INCA-CE (**I**ntegrated **N**owcasting through **C**omprehensive **A**nalysis – **C**entral **E**urope) project aims at implementing a transnational weather information system as well as applications for different socio-economic sectors to reduce risks of major economic damage and loss of life caused by severe weather. Civil protection and also stakeholders from economic sectors are in a growing need of accurate and reliable short-term weather forecasts. Within INCA-CE, a state-of-the art nowcasting system (INCA) is implemented at weather services throughout the European Union's CE (Central Europe) Programme Area, providing analyses and short term forecasts to the aforementioned end-users. In a coherent approach, the INCA (Integrated Nowcasting through Comprehensive Analysis) system will be adapted for implementation and use in a number of partner countries. Within transregional working groups, the gap between short-term weather information and its downstream activities in hydrological disaster management, civil protection and road management will be bridged and best practice management and measure plans will be produced. A web-based platform for outreach to related socio-economic sectors will initiate and foster a dialogue between weather services and further stakeholders like tourism or the insurance sector, flood authorities for disaster management, and the construction industry for cost-efficient scheduling and planning. Furthermore, the project will produce a compact guideline for policy makers on how to combine structural development aspects with these new features. In the present paper, an outline of the project implementation, a short overview about the INCA system and two case studies on precipitation nowcasts will be given. Moreover, directions for further developments both within the INCA system and the INCA-CE project will be pointed out.

1 Introduction

Technological and scientific developments in nowcasting during the last 10 yr have opened up new opportunities in public safety, in risk management and environmental protection, and in cost effectiveness of services provided by the public and private sector. Since weather phenomena do not "stop at borders", the development of a truly integrated nowcasting system (which includes the whole chain from modeling to protective action) is best achieved in a transnational collaboration. Cooperation of several trans- and international institutions is needed to improve the quality of nowcasting for all partners. INCA-CE is a cooperation of 16 partners from 8 Central European countries which bridges the gap between the development of a nowcasting system and the specific demands of the application aspect on a transnational basis. Six meteorological and hydrological institutions work together to enhance the nowcasting system INCA (Integrated Nowcasting Through Comprehensive Analysis; Haiden et al., 2010, 2011) as part of a transnational framework. Together with 10 partners from the scientific and application fields, the INCA-CE community sets up pilot implementations for applications in hydrology, civil protection and road safety. INCA-CE is co-financed by the Central Europe Programme of the European Union (http://www.central2013.eu).

2 Project motivation and implementation

Generally, the INCA-CE project aims at "Reducing Risks and Impacts of Natural and Man-made Hazards" (area of intervention as defined by the CE Programme of the European Union). The INCA-CE project specifically has the goal of setting up a web-based trans-national weather information system that uses state-of-the-art nowcasting methods developed by several countries. It enables users in the public and private sector to take into account weather-related risks and hazards in a more timely fashion, more precisely, and in greater geographical detail. More precise information about heavy rainfall and associated rise of water levels (flooding) will help to set up improved procedures and strategies in the management of mitigating measures for the protection of buildings, roads, and other infrastructure. Civil protection will benefit from a more comprehensive assessment of meteorological threats, and a more detailed and timely forecast, leading to more efficient warning protocols and dissemination strategies. Road safety will be enhanced by a more detailed road weather forecast made available both to the road management authorities as well as to the general public.

2.1 Expected benefits

The importance of real-time, high-resolution weather information has increased during the past decades. A continuously growing number of human activities critically depends on meteorological conditions. The project addresses the problem of regional differences in the quality and availability of this information, especially in areas which are highly topographically structured, in order to develop a high-resolution real-time meteorological information system. Secondly, the implications and benefits for potential stakeholders e.g. for risk warning, road maintenance and civil protection need to be based on evaluated best practice examples.

This project establishes the scientific, technical and administrative cooperation that is needed for significant progress in nowcasting and weather warnings. Economically, there is an increasing market for reliable, quantitative, and problem-oriented meteorological information. One of the outcomes of this project is that each Central European country will have at its disposal a state-of-the-art system from which it can provide meteorological services and products. A web-based information system for the general public will provide weather information in a much higher quality than in the past, which will increase the ability of citizens to plan their commercial as well as other weather-sensitive activities in better accordance with meteorological conditions and avoid unnecessary hazards.

The necessity of this project also results from the fact that we are facing changing weather conditions as a result of climate change, with serious socio-economic repercussions. Paradoxically, technology has made our society and industry at the same time less dependent on, but more sensitive to, weather and its effects. The better prepared a region enters into this new phase of human-induced climate change, the better it will be able to cope with its day-to-day effects. An efficient nowcasting and warning procedure based on meteorological and hydrological modeling and an optimized dissemination strategy can help communities to implement mitigating action and reduce damage.

2.2 Project implementation

The INCA-CE project is divided into 6 work packages (WPs), two of which are committed to project management and communication/knowledge management, respectively. This strategy ensures a strong coordination and control over the project activities as well as dedicated mechanisms for internal and external communication. Both work packages are depicted in light blue boxes of Fig. 1 which indicate the framework of the project. Four work packages (light orange in Fig. 1) are dedicated to the actual development and setup of an integrated warning system for hydrological, civil protection and road safety purposes. The major points to be tackled by these work packages are described in the text boxes. The project's core outputs are the establishment of a permanent cooperation, the implementation and joint use of a common tool, and the increase in public safety and environmental conditions as a result of an improved, transnational strategy. Corresponding to the three transnational Working Groups "Operational Hydrology", "Civil Protection", and "Road Safety" in WP3, there will be three core outputs in the form of transregional strategies, formulated in a strategy paper, for optimal use of nowcasting and weather warnings in the respective application. A coordinated evaluation of the actual benefit for targeted users is carried out during the pilot studies (WP5). This cooperation includes both providers of weather information and warnings as well as user groups, and ensures the implementation of application-oriented strategies and tested recommendations. At least three different types of hazards including flood, storm and snowfall events will be evaluated in the pilot studies.

The common nowcasting tool (INCA) will be developed and refined, respectively, in WP4 (Adaptation and refinement of nowcasting for users) in a joint effort by the provider-level partners. The core output of WP4 is a set of warning system modules incorporating the hydro-meteorological developments specifically carried out towards improved application in Operational Hydrology, Civil Protection, and Road Safety. The user level-partners will implement the methods and feedback the experiences to provider level as a basis for the joint definition, by providers and users, of recommendations and guidelines (WP6). Another core output is a web portal which will be accessible for stakeholders and the general public on the www.

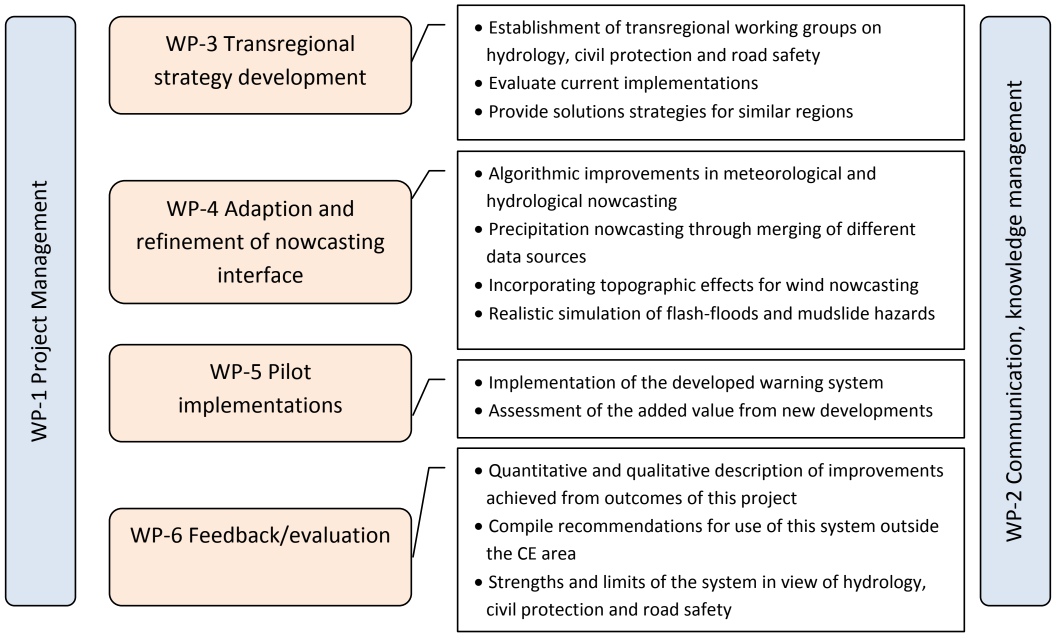

Figure 1. High level description of the INCA-CE work packages (WPs).

3 The nowcasting system INCA

3.1 Generalities

Most existing observation-based forecasting systems focus on the prediction of precipitation and convective activity (Browning and Collier, 1989; Li et al., 1995; Hand, 1996; Golding, 1998; Pierce et al., 2000; Seed, 2003). During the World Weather Research Program (WWRP) Forecast Demonstration Project of the 2000 Sydney Olympics several of these methods were tested and compared (Pierce et al., 2004). In the same project, a wind analysis and nowcasting system was evaluated (Crook and Sun, 2004). However, research has generally focused not so much on forecasting the wind field as such but its effect on the initiation and development of deep convection (Wilson and Schreiber, 1986; Wilson et al., 2004). Real-time flood-warning systems are implemented based on hydrological models that require meteorological input at small scales and short lead times. Weather services face the challenge of issuing weather warnings at a high update frequency and with more precise geographical specification. In order to satisfy these requirements the INCA system is developed.

In the case of the 3-D INCA analyses of temperature, humidity, and wind, NWP forecasts provide the first guess on which corrections based on observations are superimposed. For this purpose the output of the limited area model Aire Limitée Adaptation Dynamique Développement International (ALADIN) running operationally at ZAMG is used. The NWP fields are 1-hourly, at a resolution of 9.6 km, with 60 levels in the vertical (Wang et al., 2006). Recently, the operational ALADIN version has been updated to a resolution of 5 km (ALARO5). The most important data sources for the INCA system are surface stations. In Austria, ZAMG operates a network of about 250 automated stations which provide measurements in one minute intervals. Data are transferred every 5–10 min. Additionally, a large number of third party observations are taken into account, in particular the hydro-meteorological stations network which provides temperature and precipitation data. The Austrian radar network is operated by the civil aviation administration (Austro Control). It consists of five radar stations located at Vienna airport, near the city of Salzburg, near the city of Innsbruck (on Patscherkofel mountain), in southern Austria (on Zirbitzkogel mountain) and in western Austria (on Valluga mountain). ZAMG operationally obtains 2-D radar data synthesized from these 5 locations, containing column maximum values in 14 intensity categories, at a time resolution of 5 min. Ground clutter has already been removed from the data. The Meteosat 2nd Generation (MSG) satellite products used in INCA are “Cloud Type” (Derrien and Le Gléau, 2005), which consists of 17 categories, and the visible brightness image. The cloud types distinguish between different degrees of opaqueness and whether clouds are more likely to be convective or stratiform. The 1-km topography used in INCA is obtained through bilinear interpolation from the global 30″ elevation dataset provided by the US Geological Survey.

A full description of the INCA analysis and nowcasting scheme is given in Haiden et al. (2010) and (2011). In the present paper, a brief overview describing the methods used is presented.

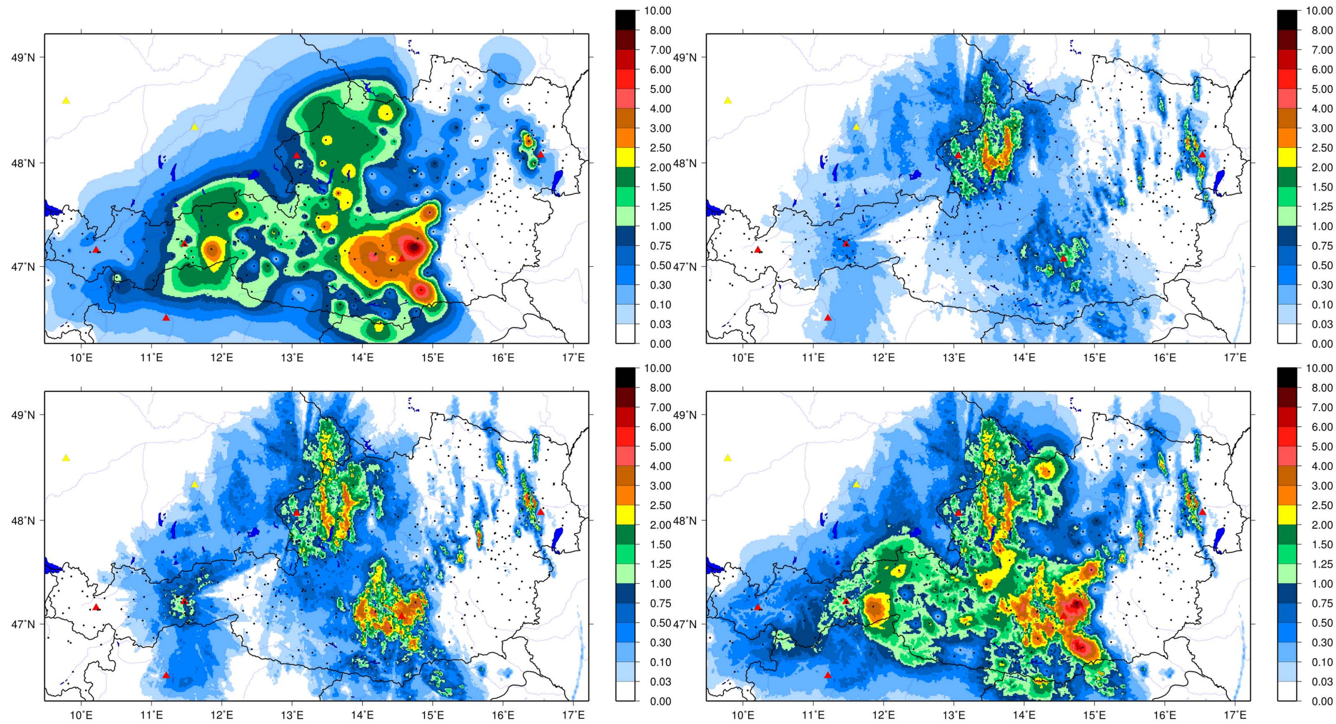

Figure 2. Example of a 15-min INCA precipitation analysis [mm/15 min] (issued for 18 July 2009, 07:30 UTC) based on the combination of station and radar data. Upper left panel: pure station interpolation, upper right panel: uncorrected radar field, bottom left panel: corrected and scaled radar field, bottom right panel: final INCA precipitation analysis.

Those fields which are analyzed three-dimensionally (temperature, humidity, wind), are generated as follows. The NWP (ALADIN) fields are interpolated tri-linearly to the INCA grid (horizontal resolution 1 km, vertical resolution 200 m for temperature and humidity, 125 m for wind). Within valleys that are not represented by the NWP model, a downward shifting of the first guess to a so-called valley-floor surface is performed. Differences between station observations and first guess are interpolated three-dimensionally. The interpolation uses a distance-squared weighting method with geometrical distance weighting in the horizontal and distance weighting in potential temperature space in the vertical. Finally, the resulting difference field is added to the first guess. For the wind analysis, a relaxation algorithm is additionally applied to ensure mass-consistency of the wind field with respect to the INCA topography. In the nowcasting mode, the trend of the NWP forecast is superimposed on the most recent INCA analysis. At lead times beyond +6 h, the INCA nowcast is blended into the bias-corrected NWP forecast. The effect of errors in the NWP cloud forecast is also taken into account in the temperature nowcast.

Turning to the precipitation module, surface station data are algorithmically combined with radar data. In this way the higher quantitative accuracy of the station data, and the better spatial coverage of the radar data, is utilized. The resulting analysis reproduces the observed values at the station locations. In-between it contains the spatial structure given by the remote sensing data. An intensity-dependent parameterization of elevation effects is used (Haiden and Pistotnik, 2009) in addition to the station-radar combination. Figure 2 illustrates the individual steps of the precipitation analysis procedure. In the nowcasting mode, motion vectors are computed using a correlation method from consecutive analyses. The resulting vectors are filtered statistically by setting a threshold for the correlation, and meteorologically by comparing it with the NWP wind at the 500 and 700 hPa levels. Using these vectors, the nowcast of precipitation is computed. Between +2 and +6 h, the nowcast is merged with the NWP forecast with a linearly decreasing weight, so that from +6 h onwards the pure NWP forecast is used. The most important application of the INCA precipitation forecast is operational flood prediction (Komma et al., 2007). For improved nowcasting of convective cells (Steinheimer and Haiden, 2007) a number of additional 2-D fields are computed, such as Convective Available Potential Energy (CAPE), Convective Inhibition (CIN), Moisture Flux Convergence and others.

Cross validation of the temperature analysis typically shows a mean absolute error (MAE) near 1 K, and a root mean square error (RMSE) near 1.5 K (not shown, see Haiden et al., 2011). The main reason for larger analysis errors, especially in winter, is insufficient information about inversion heights and about patterns of Foehn-induced mixing in mountain areas. Averaged over all stations and seasons,

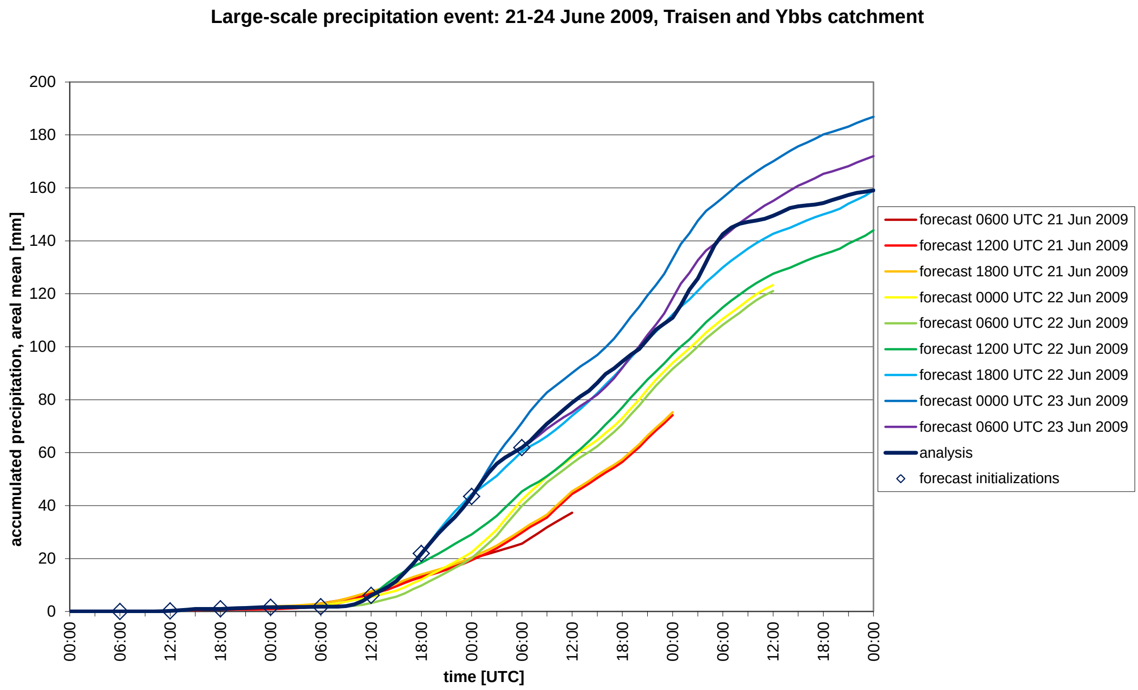

Figure 3. Hydrographs of analyzed precipitation (thick black curve) and forecasted precipitation (colored curves) with various initialization times (open diamonds) during the 21–24 June 2009 precipitation event, depicted as areal mean values over the Traisen and Ybbs catchments in Lower Austria.

the nowcast of temperature is significantly better than that of the NWP model during the first 6 h of the forecast (not shown). Beyond +6 h there is a small but non-negligible benefit from the downscaling procedure. Verification of the precipitation nowcast shows a similar result, with significant improvements relative to the NWP forecast in the nowcasting range. However, as it can be expected, the benefit of the nowcasting vanishes earlier (at forecast ranges of 2–3 h) in the case of precipitation (Haiden et al., 2011).

3.2 Case study: nowcasting of precipitation events

3.2.1 Large-scale precipitation event: 21–24 June 2009

In late June 2009, many parts of Austria were affected by a heavy precipitation event with severe flooding that lasted for several days. Following the passage of a cold front from the Northwest that advected a cool maritime air mass into Central Europe, a secondary low developed over Italy on 20 June 2009 and moved eastward to the Balkan Peninsula. At its Northern periphery, the return of wrapped-around warm and humid air from the Northeast began on 21 June 2009. The strong warm air advection caused extensive rainfalls, which were further enhanced by orographic lifting along the Northern Alpine rim. Most of the precipitation occurred in form of steady and stratiform rainfalls from 22 to 24 June 2009, followed by widespread (though less abundant) convective precipitation only later when the warm air mass finally established itself also at lower levels. This weather pattern is well-known for bearing a potential of excessive rainfalls in the Alpine region; however, this time its degree of strength and its persistence over several days were extraordinary.

One of the areas that were particularly affected was the Northern Alpine region of Lower Austria. The Traisen, the Ybbs and several smaller rivers drain this moderate-sized physical region (5222 square kilometers) towards the North and discharge into the Danube River. The area is very prone to "Stau" (upslope flow) enhancement of precipitation when the steering level air flow is from Northerly directions. Consequently, the areal mean of the 3-day precipitation sum in the Traisen and Ybbs catchment from 22 to 24 June 2009 amounted to approximately 160 mm, with highest peaks reaching up to 230 mm. The resulting floods of these two rivers and their smaller neighbors had statistical return periods of 10 to 50 yr.

Figure 3 shows forecasted and analyzed hydrographs for this precipitation event in the Traisen and Ybbs catchment. The thick black line is the areal mean of the accumulated precipitation according to hourly INCA precipitation analyses. The colored lines show the areal mean of accumulated INCA precipitation forecasts (with the open diamonds denoting the various initialization times), starting at 06:00 UTC 21 June 2009 and following with an update interval of six hours in order to illustrate the temporal development of forecast quality. It should be noted that the actual update interval of INCA precipitation forecasts is 15 min; however, most of the updated information affects only the nowcasting range, i.e. the first 6 forecast hours. New NWP information is available only four times a day, namely new ALADIN runs usually around 06:00 and 18:00 UTC, and new ECMWF runs usually around 08:00 and 20:00 UTC. For the reconstruction of this case study, an availability of both NWP model data at 09:00 and 21:00 UTC has been assumed, which corresponds to the rare "worst case scenario" in case of a delay due to technical problems. A thinning of the update interval to six hours was considered sufficient to address the issue of the forecast quality development for this large-scale precipitation event.

It can be seen in Fig. 3 that the initial forecast, started at 06:00 UTC 21 June 2009 (dark red curve) – approximately 36 h prior to the start of the heavy rain – considerably underestimated the precipitation sums. Stepwise improvement of forecast quality can be seen for the 12:00 UTC initialization of the same day and the 00:00 and 12:00 UTC initializations of 22 June 2009, indicating that each new NWP model runs provided more valuable information. On the other hand, the 18:00 and 06:00 UTC initializations in-between, which could only rely on new nowcasting information, could not further improve the performance, due to the fact that the event was still out of the nowcasting range.

The first INCA forecast that showed a very good quality was the 18:00 UTC 22 June 2009 initialization, shortly after the start of the main precipitation event. Since precipitation was already present in the latest analyses, also the nowcasting part could begin to provide reliable estimations for the following 6 h and contribute to the further rise of forecast quality. The subsequent INCA forecasts kept a fairly good performance, with forecast errors less than 20 % of the actual precipitation sums.

It also corresponds to our experience that the totals of large-scale precipitation events can usually be well predicted at the latest when the event actually starts. This is due to the good predictability of these events by NWP models, as well as to the "reliable" behavior of these precipitation fields in terms of nowcasting.

3.2.2 Convective precipitation event: 23 July 2009

Convective precipitation events form the other wing of the spectrum of precipitation. They are characterized by higher intensities and shorter durations than their stratiform counterparts, plus an often high spatial and temporal variability that reduces their predictability for NWP models as well as for nowcasting methods.

The chosen day for a case of convective precipitation is 23 July 2009, an outstanding thunderstorm day in Austria and other parts of Central Europe. Ahead of a cold front that was approaching from the Northwest, extremely hot and energetic air from Northwestern Africa and the Iberian Peninsula was advected to Central Europe. In the early evening, a pre-frontal convergence line triggered a first round of thunderstorms that travelled eastward along the Northern Alps, followed by a second and more violent surge of storms a few hours later when the cold front arrived. Severe wind gusts and large hail caused enormous and widespread damage; the high precipitation intensities also led to localized flooding, although the fast translation speed of the thunderstorms kept this threat rather low and subordinate.

Figure 4 shows hourly INCA precipitation analyses at 17:00, 18:00, 19:00, and 20:00 UTC on this evening. Again, we focus on the area of the Ybbs and Traisen catchment, which is sketched by a red rectangle in the 17:00 UTC analysis (upper left). The first thunderstorms, which were associated with the passage of the convergence line, can be seen in the 17:00 (upper left) and 18:00 UTC analyses (upper right). They were moving from West to East and affected only the Northern part of the area of interest, before the second and more severe round of thunderstorms arrived shortly before 20:00 UTC (lower right).

Figure 5 illustrates the temporal evolution of the INCA precipitation forecasts for this event. Again, the thick black line is the hydrograph of the areal mean of the hourly precipitation analyses in the Ybbs and Traisen catchment, and the colored lines show the succession of INCA precipitation forecasts with selected initialization times depicted by the open diamonds.

The initial 06:00 UTC forecast (dark red curve) considerably underestimated the forthcoming precipitation event, with an areal mean of only 2.4 mm compared to almost 10 mm according to the verifying analyses. Even the 12:00 UTC initialization (bright red curve), though it had new NWP information to its disposal, could only insignificantly raise the expected areal precipitation mean to 3.1 mm. Since the next NWP update would not arrive before evening, no new information could be expected from the NWP part for this event any more.

The 15:00 UTC (orange curve) and 16:00 UTC (yellow curve) initializations further reduced the expected precipitation amounts, because still no signals were present in the precipitation analyses. Therefore, the nowcasting part could not react adequately and wrongly began to dampen the NWP data, which showed first weak precipitation signals starting from 18:00 UTC. It was not before 17:00 UTC (bright green curve) that the nowcasting picked up the signals of the first thunderstorms and correctly moved them over the Northern part of the catchment. Finally at 18:00 UTC (dark green curve), the first signal for the second surge of thunderstorms appeared in the INCA forecast, though still two hours too late between 21:00 and 22:00 UTC. In reality, the second line of thunderstorms continuously accelerated and arrived much earlier than anticipated. The time lag of the precipitation nowcasts was reduced in the 19:00 UTC initialization (bright blue curve) but did not completely vanish before 20:00 UTC (dark blue curve), when the severe thunderstorm event was already in full swing.

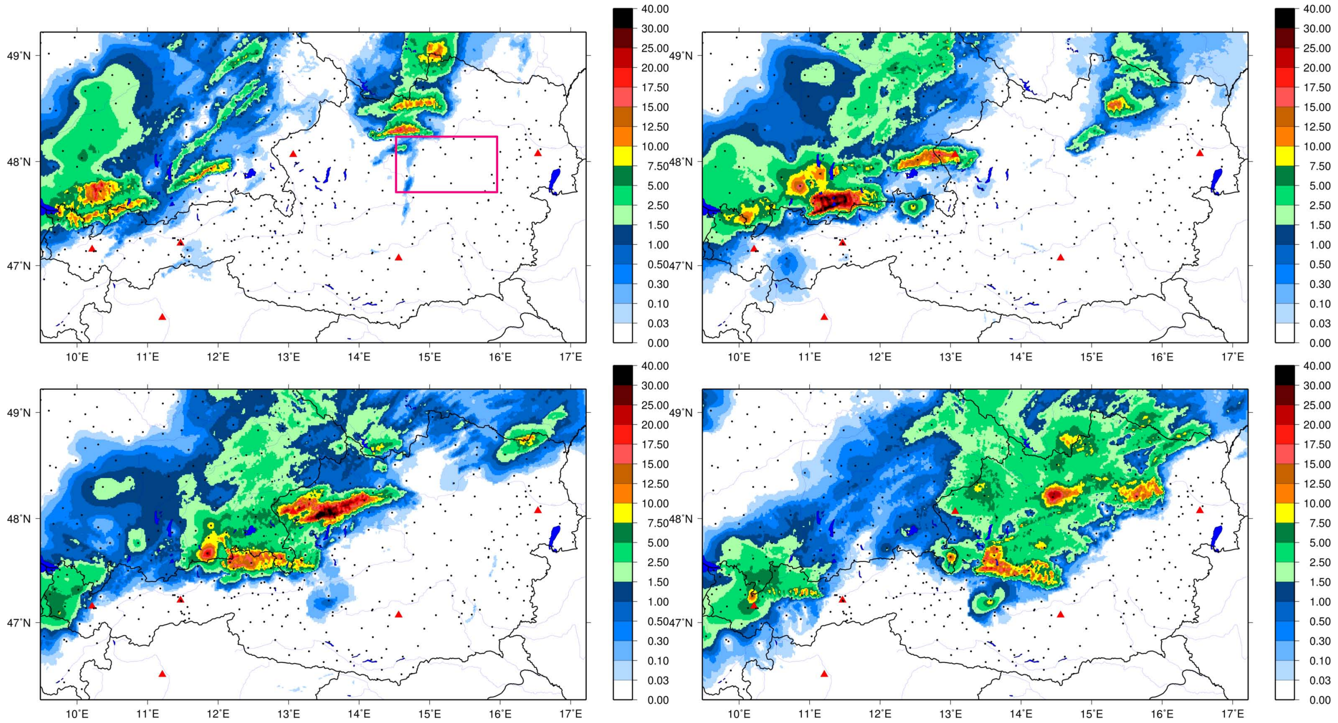

Figure 4. INCA precipitation analyses [mm h^{-1}] at 17:00 UTC (upper left), 18:00 UTC (upper right), 19:00 UTC (lower left) and 20:00 UTC (lower right) on 23 July 2009. The area of interest for Fig. 5 is sketched by the red rectangle.

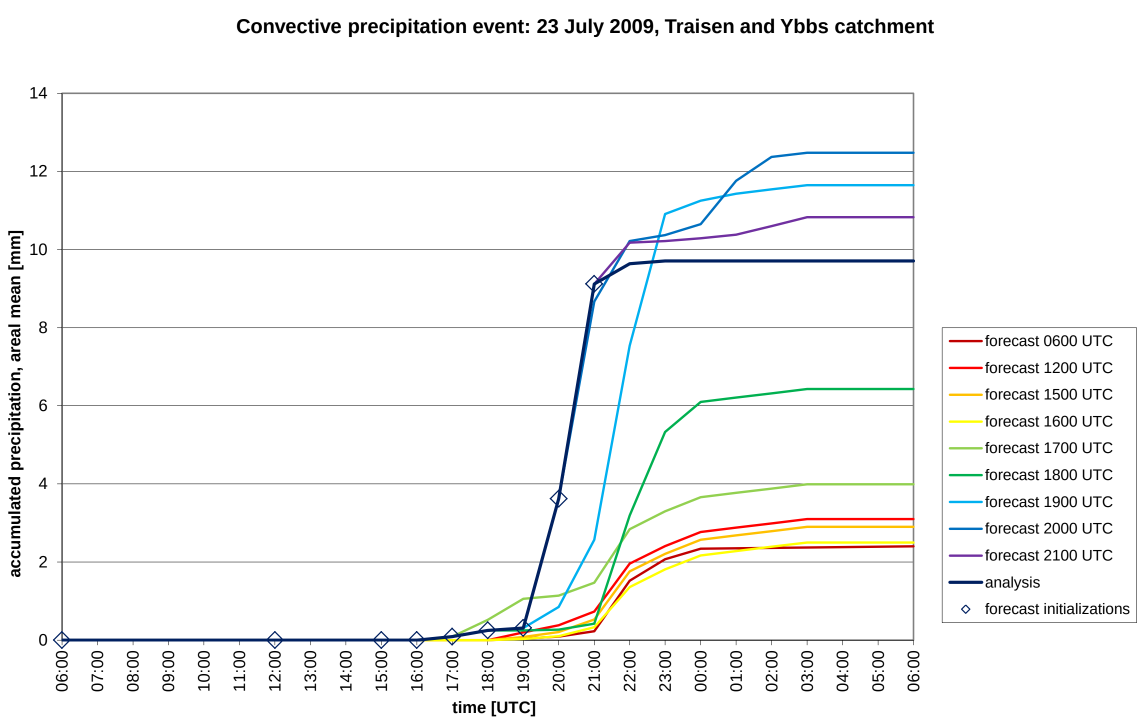

Figure 5. As in Fig. 3, but for the 23 July 2009 precipitation event. Note the different scaling of both axes.

The decline of quality of INCA forecasts, as compared to a large-scale precipitation event, is evident. Indeed, experience shows that many convective precipitation events are still poorly predictable even when they have actually started. It is the high spatial and temporal variability, plus the repeated cycle of formation, growth and decay of individual convective cells, that keeps the predictability low. This applies to NWP model forecasts and to nowcasting procedures likewise.

4 New developments in INCA-CE

The case studies presented above reveal both the requirements and challenges that need to be addressed when introducing new or improving existing modules of the INCA system. Within the project duration, a refinement of algorithms in INCA is currently carried out. Special focus in the developments is given to parameters which are important for applications in flood warning, civil protection (mostly storm forecasts) and road safety.

For hydrological applications, the prediction of convective precipitation needs to be improved. Currently, only a translation of convective cells is used for forecasts whereas an approach including the life cycle of convective cells is needed. Based on diagnostic fields already present in INCA, such as CAPE, CIN, moisture flux convergence and others, the susceptibility of certain areas to initiation, intensification, weakening and dissipation of convective cells could be assessed. The most critical factor for storm evolution is the existence of boundary layer convergence zones. Hence, convective nowcasting algorithms rely heavily on the quality of the near-surface wind field forecasted by the NWP models. Developments in wind nowcasting are focusing on improvements in the way topographic effects (downslope windstorms, channeling) are treated, as well as in a better analysis of the downburst potential of thunderstorm cells. For Road Safety, the nowcasting of surface temperature is refined, especially in the temperature range close to the freezing point. However, all developments with respect to precipitation, wind and temperature are contributing to improved road safety applications.

5 Conclusions

An overview of the INCA-CE project is presented. The core module, i.e. the INCA nowcasting system, which forms the basis for downstream applications in hydrology, civil protection and road safety, is introduced briefly. The INCA-CE project provides the framework to jointly develop a high-level nowcasting system with respect to the specific needs of applications in hydrology, civil protection and road safety. The user-oriented development is guaranteed by the feedback mechanisms implemented in the project structure which allows for a permanent revision and improvement of the nowcasting tools and methods. Trainings including practical examples will be provided to the end-users in order to ensure a proper use and to avoid misinterpretations of nowcasting products, especially for convective events. Thus, the project can be regarded as a proto-type of demand-side scientific research and development, bridging the gap between science and application.

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