Detection of Convective Initiation by Objective Analysis Methods and its Use for Precipitation Nowcasting

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I. INTRODUCTION

Convective situations pose the biggest challenges to automatic nowcasting of precipitation. Conventional nowcasting techniques, which use a translation of the latest precipitation analysis into the near future, cannot anticipate any temporal development of the precipitation field and are therefore unable to account for a convective life cycle.

Recent work at the Central Institute for Meteorology and Geodynamics (ZAMG) has focused on the predictability of the initiation and life cycle of convective cells, and its use for automatic nowcasting. A new and experimental nowcasting algorithm has been developed with an ability to simulate initiation, intensification and weakening of precipitation according to the latest analysis fields of convective indices, like Convective Available Potential Energy (CAPE), Convective Inhibition (CIN) and near-surface Moisture Flux Convergence (MOCON). These "convective nowcasts" of precipitation were compared to purely translational nowcasts for a set of selected convection days in summer 2009 and 2010. The study has shown that the simulation of a convective life cycle could significantly improve the quality of the precipitation nowcasts over Alpine terrain, whereas the results were only neutral or even slightly worse over the Alpine forelands. This presentation aims to elaborate on these differences and tries to trace them back to the distinction of primary and secondary convection, respectively its initiation.

II. DATA MATERIAL

Precipitation analyses and nowcasts, as well as analyses of convective indices, were provided by the INCA system ("Integrated Nowcasting through Comprehensive Analysis"; Haiden et al., 2011). Its spatial resolution is 1 km, its temporal resolution and its update frequency are 15 min for precipitation analyses and nowcasts, and 60 min for the other parameters like temperature, (specific) humidity, wind and the convective indices.

INCA analyses of the basic parameters (precipitation, temperature, humidity, wind) have in common that they rely on a background (or "first guess") field, which is then corrected according to latest station observations. In the case of the precipitation analyses, the background is provided by radar data, which are readily available on the 1x1-kilometer INCA grid. In the case of the 3-dimensional analyses of temperature, humidity and wind, the background information comes from ALADIN, the operational limited area model at ZAMG (horizontal resolution of 9.6 km). The analyses of convective indices are then derived from the 3-dimensional analyses of temperature, humidity and wind.

For the precipitation nowcasting, which covers the majority of the first 6 hours of the operational INCA precipitation forecasts, a field of motion vectors is computed from two consecutive precipitation analyses, and the latest analysis is extrapolated into the near future. The newly developed "convective nowcasting" algorithm additionally uses information from the latest convective analysis fields in order to decide whether initiation, intensification or weakening of precipitation can be expected. There is a set of (static) thresholds for each option, mainly based on CAPE, CIN and MOCON. For example, for initiation, which is the main issue of this presentation, the necessary conditions are CAPE > 200 J/kg, |CIN| < 200 J/kg, and MOCON > $2*10^{-6}$/s.

The study comprises a set of 32 selected convection days over the Eastern Alpine region in the summers of 2009 and 2010. The majority of days exhibited convection that was only weakly forced and locally triggered (mainly over orographic features), but there are also a couple of days included with stronger synoptic and dynamic forcing and/or more widespread initiation. All in all, it was tried to gain a climatologically representative profile with this selection.

III. PRIMARY VERSUS SECONDARY CONVECTION

Fig. 1 shows the relative RMSE of the convective nowcasts in comparison to the translational nowcasts of precipitation for a forecast time of 3 hours. The verification was done for areal mean values of precipitation over catchments of moderate rivers or physical regions of a similar size, which was typically in the order of a few thousand square kilometres, in Austria and Bavaria (Southern Germany). There is a general improvement of the nowcasting quality in the range of 10 to 20% over most Alpine catchments when using the convective nowcasts, opposed by a minor deterioration over some of the foreland areas.

Fig. 2 presents an example of precipitation nowcasts on 1 July 2010, a day with localized convection confined to the mountains. The shown domain covers the (bigger) Eastern half of Austria and its near surroundings. At 10 UTC, the time of initialization, first isolated showers have already formed in two areas, in the hilly Waldviertel region in Northern Austria (close to the Czech border) and next to the Southeastern Alpine fringe. The translational nowcast slowly relocates them to the Southeast over the following hour (top image), according to the weak Northwesterly steering level flow. The convective nowcast (center image) uses the same motion vectors and therefore does the same, but additionally it initiates and further intensifies another convective cell next to the existing one in Northern Austria, and two more along the Southeastern Alpine fringe. For a better emphasis, the areas with simulated initiation have been encircled in red, those with simulated intensification in orange and those with simulated weakening in dark green.

The verifying 11 UTC analysis (bottom image) shows that actually several additional convective cells have formed in the two mentioned areas. At least some of them have been correctly predicted by the convective nowcasting algorithm, which clearly outperforms the translational nowcast.

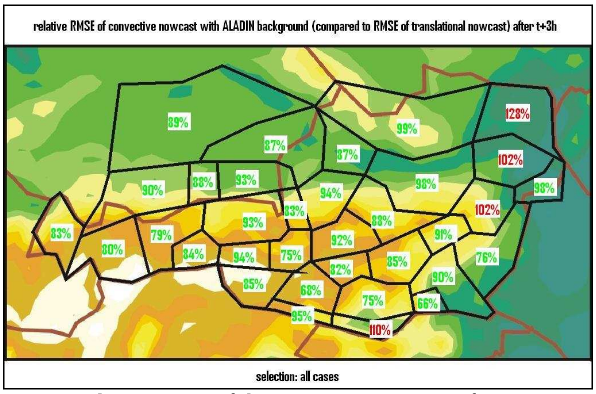

FIG. 1: Relative RMSE of the convective nowcasts of precipitation compared to the translational nowcasts, for 3-hour forecasts over all dates of the 32 selected days. The verification was done for areal mean values over catchments with a typical size of a few thousand square kilometres. Green numbers below 100% indicate that the convective nowcasts performed better, red numbers above 100% show the opposite.

Days like 1 July 2010 fulfilled the expectations that the convective nowcasting algorithm would probably perform best in situations with localized convection strongly tied to orographic features, as these create a semi-deterministic, daily recurring trigger mechanism for convection. It was indeed the majority of such days within the selected data set (which was also justified by their frequent occurrence in a "climatological summer") that helped the convective nowcasting algorithm to achieve its positive results presented in Fig. 1. On the other hand, whenever convection formed over the flatlands, it did so in a seemingly more random appearance (with regard to the time as well as to the place of initiation), which aggravate correct nowcasts.

While the results illustrated in Fig. 1 were the main findings of the conducted study, and were positive enough to justify an operational implementation of the convective nowcasting algorithm (which is planned for 2012), they only act as a base for this presentation, which focuses on an explanation of the different behaviour between mountainous and flat areas, and its implications on possible future work.

The difference between convection over the mountains and convection over flat terrain has long invited to establish the distinction between "primary convection" and "secondary convection" (e.g. Banta and Schaaf, 1986). The quick diurnal heating of the air over mountainous regions and its upvalley and upslope circulations usually lead to an early triggering of primary convection on days when the atmospheric conditions are suitable. On the other hand, secondary convection over the flatlands usually starts later and in a seemingly stochastic way, depending on the availability of transient trigger mechanisms. These may be provided by the gust fronts and outflow boundaries of previous or still existing thunderstorms, hence establishing the link between primary and secondary convection.

However, during this study it was found out that there is hardly any dependency of the results presented in Fig. 1 on the time of day, which would be implied if it was indeed the "primarity" or "secondarity" of convection *in a literal sense* that governs the degree of the predictability of its initiation. It rather seemed like a characteristic that was inherent in the *region*, not in the time of day. In order to find out more about the reasons why convection should be less predictable in some regions than in others, four particularly distinctive days were isolated from the initial 32-day sample, which were supposed to span the whole spectrum from local to widespread initiation and from weak to strong synoptic-scale forcing for thunderstorm formation in the best way (Table 1).

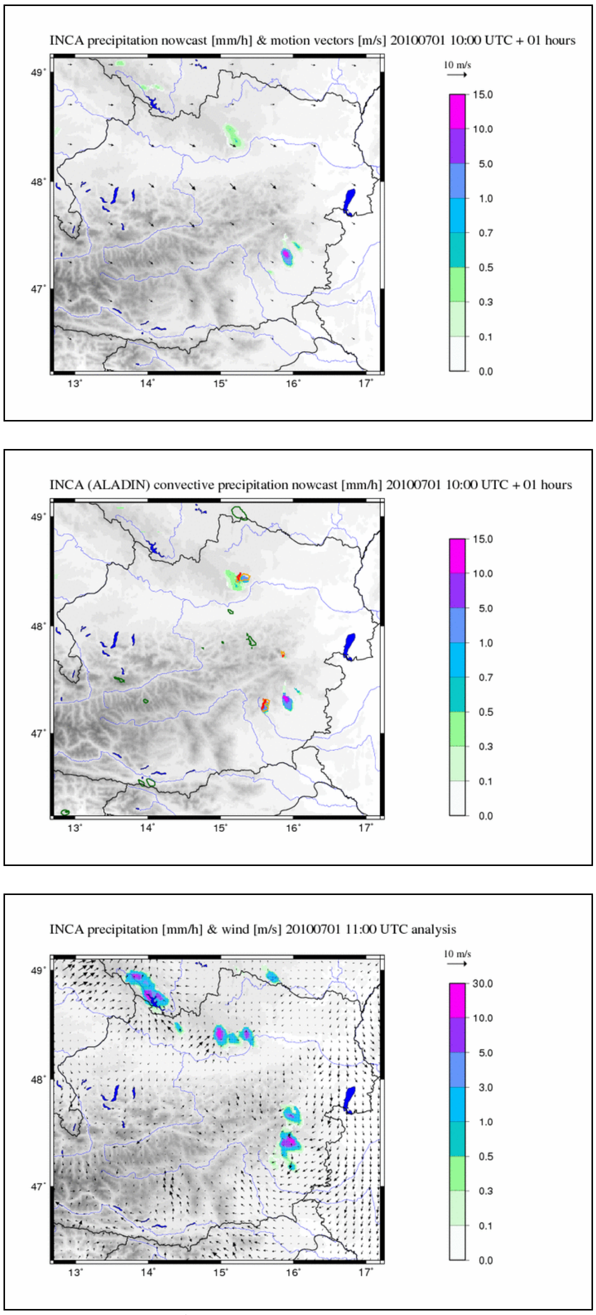

FIG. 2: Example of precipitation nowcasts and a corresponding verifying analysis (each in [mm/h]). Top: 1-hour translational nowcast initialized at 10 UTC on 1 July 2010 plus motion vectors (thinned). Center: 1-hour convective nowcast for the same date; areas of initiation are encircled in red, areas of intensification in orange, and areas of weakening in dark green. Bottom: Verifying precipitation (and 10-m wind) analysis at 11 UTC. Note the good performance of the convective nowcast in predicting the initiation and intensification of at least some of the convective cells.

day	initiation	forcing
01 July 2010	local	weak
15 July 2009	widespread	weak
23 July 2010	local	strong
23 July 2009	widespread	strong

TABLE I: Sub-selection of four days for the deepened investigation of the predictability of convective initiation.

For each of these days, the places of convective initiation as predicted by the convective nowcasting algorithm were compared to those places where initiation actually occurred. The results suggest that it is neither of the two indicators which are commonly used to distinguish between primary and secondary convection, namely the time of day and the region (respectively its topographic characteristics), but first and foremost the weather pattern which governs the predictability of convective initiation. In particular, the strong capping which was associated with the two selected "strong forcing" cases seemed to have the most unfavourable effect.

This leads to the questions: What is it that makes primary convection "primary", and secondary convection "secondary"? Is there a familiar definition at all? Is it purely phenomenological aspects, like that primary convection appears earlier in the day and is tied to the mountains? Or is it the underlying physics, namely that there is significant CIN for secondary convection, but none for primary convection? At least for the current investigation, the latter has proven to be most helpful. The fact that secondary convection tends to form later in the day and over flat terrain, is an implied consequence of the governing physics, but not a *sine qua non* condition. On any given day, there may well be convection *with* significant CIN even over the mountains and/or early in the day, and vice versa.

IV. CONCLUSIONS AND POSSIBLE FUTURE WORK

Our current convective nowcasting algorithm mainly uses information about analyzed CAPE, CIN and MOCON, and is therefore closely related to convective "parcel theory", apart from the consideration that the "thresholds" of CAPE, CIN and MOCON which allow convection in reality are highly dependent on each other, whereas in our case a simplification of static and linearly independent thresholds was used. Parcel theory is the best instrument available to describe convection, but it has an important weakness: it does not tell anything about what happens to the environmental air outside the rising parcel. However, in reality there is strong observational evidence that convective initiation in high-CIN-environments is frequently associated with forced vertical motions that affect the ambient air as well, as sketched in the conceptual model of convective initation in the presence of a strong cap in Fig. 3.

The right part of the diagram shows an arbitrary vertical temperature profile (solid line) which results in some CIN (blue area) and abundant CAPE higher up (red area). The temperature curve of a rising parcel is illustrated by the dashed line. Characteristic niveaus like the top of the well-mixed convective boundary layer, the lifted condensation level (LCL) and the level of free convection (LFC) are drawn in green. The left part of the diagram sketches a field of vertical motions that may evolve under the given temperature profile, if a convergence of the near-surface wind field starts to act. Due to the stable stratification in the layers which cause CIN, there is a laminar ascent of the whole column of air instead of the rise of a single parcel from near the surface. This may well be made visible by laminar cloud formations at the base of a forming cumulus (as depicted in the left part of Fig. 3), or by flanking or topping pileus clouds.

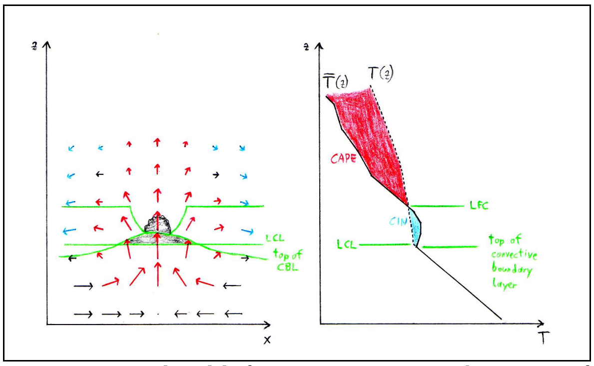

FIG. 3: Conceptual model of convective initiation in the presence of significant CIN. Left: sketched motions in an (x,z)-plane; right: sketched vertical temperature profile.

However, the forced ascent of environmental air enhances the depth of the convective boundary layer, and therefore lifts the cap and decreases CIN. Thus, the LFC may at some point quite suddenly drop down to the LCL, as it is shown in the center of the rising motions, and transform the laminar cloud into a buoyant cumulus.

The quintessence is that there are strong interdependencies between the wind field and the temperature and humidity field in the boundary layer, which are at present not considered at all in the analysis scheme of the INCA system. Apart from further refinements of the convective nowcasting algorithm, it is therefore encouraged to continue the investigations in this direction, in order to bring the algorithm even closer to the actual physical processes and exploit any potential of improvement that may be hidden there, even though it may require a lot of further research.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

Banta R.M., Schaaf C.B., 1986: Thunderstorm Genesis Zones in the Colorado Rocky Mountains as determined by Traceback of geosynchronous Satellite Images. *Mon. Wea. Rev.*, 115, 463-476.

Haiden T., Kann. A., Wittmann C., Pistotnik G., Bica B., Gruber C., 2011: The Integrated Nowcasting through Comprehensive Analysis (INCA) System and its Validation over the Eastern Alpine region. *Wea. Forecasting*, 26, 166-183.