11.1 PREDICTABILITY ISSUES IN HIGH-RESOLUTION NUMERICAL PREDICTION OF STRATIFORM AND CONVECTIVE PRECIPITATION

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1. Introduction

One of the most exciting prospects of using horizontal resolutions at kilometer-scale is the explicit numerical simulation of moist convection. However, convection is an intrinsically chaotic dynamical process with limited predictability. In this study we investigate how predictability of precipitation at meso-β and smaller scales depends upon the type of precipitation, the location with respect to topography, as well as upon temporal and spatial scales.

2. Model description and experimental set-up

The weather simulations presented in this study are performed with the Canadian numerical weather prediction model MC2 (mesoscale compressible community). This model is based on the compressible set of non-hydrostatic equations and thus suited for the simulation of atmospheric flows with explicit convection. It was used during the field phase of the Mesoscale Alpine Program (MAP) quasi-operationally with same physical setup (Benoit et al. 2002). A detailed description of the model can be found in Benoit et al. (1997).

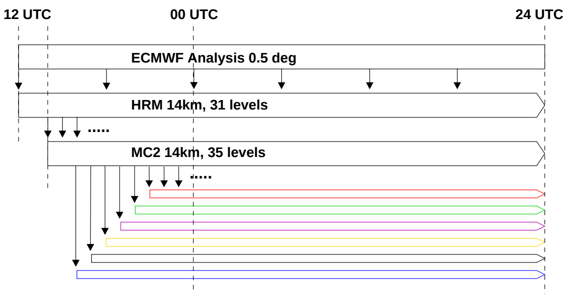

Fig 1. Model chain and setup for the ensemble simlulations. The MC2 3 km ensemble members (thin bars) are generated using a shifted initialization technique.

The model-chain (Fig. 1) is based on a double-cascade with the High Resolution Model (HRM) of the German Weather Service driven by ECMWF analysis, a MC2 simulation with 14 km horizontal resolution and MC2 ensemble simulations with 3 km horizontal resolution and 50 vertical levels over the European Alps (Fig. 2).

The applied ensemble methodology involves conducting six similar weather simulations with slightly modified initial conditions but identical lateral boundary conditions. The different initial conditions are realized by a shifted initialization time. Member one is initialized at 21 UTC, member two at 20 UTC, etc. (see Fig. 1).

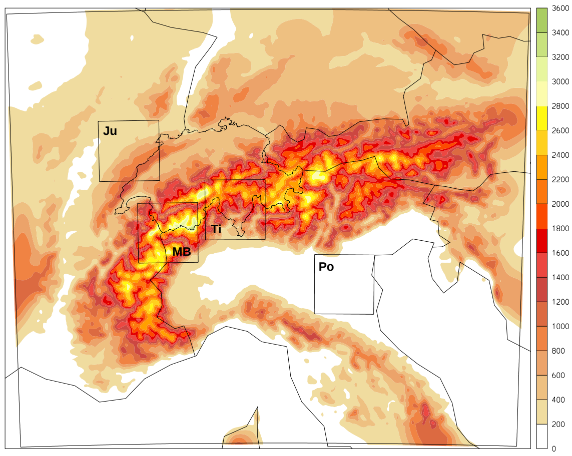

Fig 2. Computational domain and topography [m] used for MC2 ensemble simulations. The four sub-domains used for the analysis (outlined boxes) refer to the regions Jura (Ju), Mont Blanc (MB), Ticino (Ti) and Po-valley (Po), respectively.

Analysis of the ensemble simulations has shown that the RMS difference of prognostic variables to the ensemble mean are well below the typical observational uncertainties. Thus, it is desirable to enhance the differences to the ensemble mean for all members. To this end, the deviations from the ensemble mean are amplified at 00 UTC (i.e. at the beginning of the day of interest) by some factor α. An ad-hoc estimation over all three cases yields a factor $\alpha = 3$ to achieve a realistic representation of the observational uncertainties of the initial conditions.

3. Results

Results are presented from three case-studies so as to represent different synoptic situations. Two of the cases are from the MAP field phase (Bougeault et al. 2001). For the analysis of precipitation, four regions each covering 120 x 120 km are defined. They are called Jura (Ju), Mont Blanc (MB), Ticino (Ti), and Po-valley (Po) and are indicated in Fig. 2.

a. Case 1: 29 July 1999

The summer-day of July 29, 1999 was characterized by a flat high-pressure area over central Europe. Therefore, advection was weak and the very unstable stratified atmosphere led to strong thermal convection in the entire Alpine area.

Mean hourly precipitation is evaluated for the two regions Po and MB. In Po, the ensemble members

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show remarkably little agreement in the evolution of the precipitation (Fig. 3). The poor predictability on this day is related to a chaotic behaviour of convective cells. Consequently, large differences are found in the daily precipitation sum for this 120 x 120 km region. Member 1 forecasts only 3.2 mm mean daily precipitation on average, whereas member 3 suggests 6.3 mm. The consideration of smaller scales does increase these differences even further. As an extreme example, in a 12 x 12 km domain south of Padova, member 3 forecasts 47 mm precipitation within four hours whereas member 6 suggests no precipitation in this domain for the whole day.

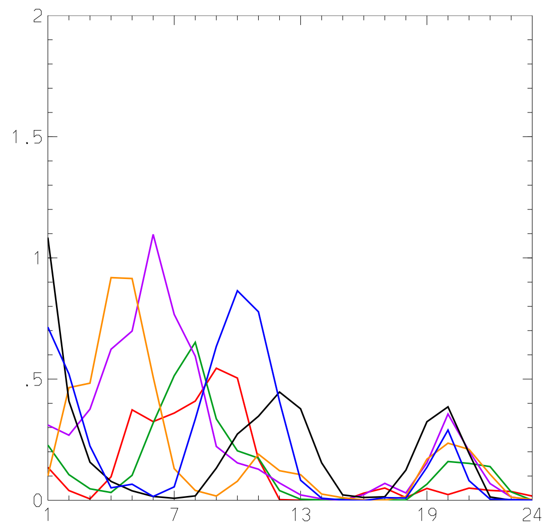

Fig. 3. Domain-averaged precipitation [mm/h] for the region Po-valley on 29 July 1999 for the six ensemble members. Horizontal axis indicates time (UTC).

In the region MB, the spread of the members in the evolution of precipitation is similar as in the region Po. However, probability maps of the simulated daily precipitation sum for both regions point out that the locations of heavy precipitation is more predictable in complex terrain such as the region MB than over flat terrain such as the region Po. In the region MB, the spread is determined by large differences at the locations with the lagest precipitation amounts, while these locations themselves are determined by the topography.

b. Case 2: 25 September 1999 (MAP IOP3)

On 25 September 1999 the synoptic weather situation over Europe was determined by high pressure over the central Mediterranean Sea and a trough extending from the British Islands to Spain. This trough produced a cutoff which moved slowly southwards. Hence, strong southwesterly flow established in western Europe. The related cold front reached the French and Swiss Jura in the afternoon of the day. South of the Alps, in the Ticino region, moist Mediterranean air was advected by the soutwesterly flow towards the Alps, leading to heavy precipitation starting in the afternoon.

This pre-frontal precipitation was enhanced by embedded convective cells triggered by an unstable stratified atmosphere and orographic forcing.

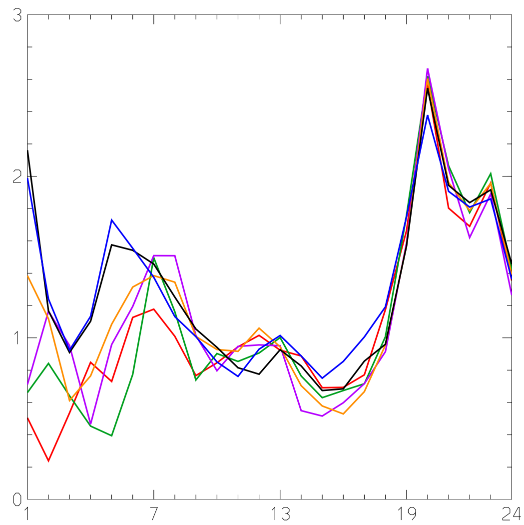

Fig. 4. As Fig. 3, but for region Jura on 25 September 1999.

The ensemble experiment for this case-study point out how predictability of precipitation can differ enormously within the same event. In the region Jura the six members show a remarkable spread in the evolution of the hourly precipitation until about 07 UTC indicating convective activity. Afterwards, especially during the time of maximum precipitation intensity, the members almost coincide (Fig. 4). Radar observations confirm strong convective activity in the morning and rather stratiform conditions during the passage of the cold front in the evening.

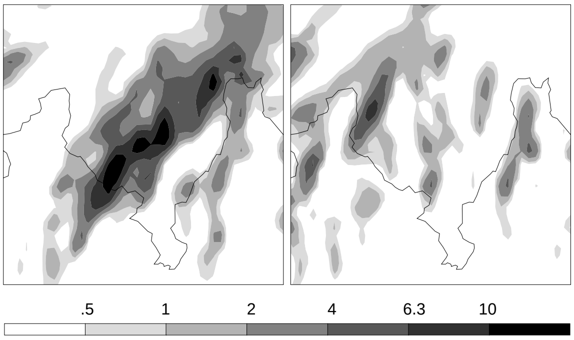

Fig. 5. Hourly precipitation on 25 September 1999 at 19 UTC [mm/h] for ensemble member 2 and 5.

In the region Ticino a large spread of the members occurs towards the end of the day. It is related to convective activity. The maximum spread is reached at about 19 UTC with up to 100% differences and caused by individual convective cells. For example a large cell that occurs in member 1 and 2 over northwestern Ticino is much weaker in member 3. In member 4, 5 and 6, this cell is even of smaller amplitude or does even not exist at all (see Fig. 5).

c. Case 3: 6 November 1999 (MAP IOP15)

On 6 November 1999, a cutoff from a trough north of the British Island moved quickly southeastwards. Strong cold air advection towards the Mediterranean Sea induced by this cutoff was followed by fast lee cyclogenesis centered over the Gulf of Genova. This led to a southwesterly flow with Foehn in the Alps in the morning of the day. At noon, the north-south pressure gradient reversed. Hence, the Foehn ended and Mistral in southeast France as well as North Foehn in the Ticino area came up. The cold front reached the French and Swiss Jura in the early morning, crossed Switzerland and reached the eastern Alps in the early afternoon. North of the Alps the atmosphere is very stably stratified. South of the Alps only isolated convection was observed.

The evolution of the hourly precipitation for the region Jura is depicted in Figure 6. The six members almost coincide, small differences are visible in the precipitation peaks in the early morning and in a second peak after noon. In the Ticino region, the spread, albeit somewhat larger, is also small. The absence of convection north of the Alps and the only weak convective activity in the South lead to a very high agreement between the members.

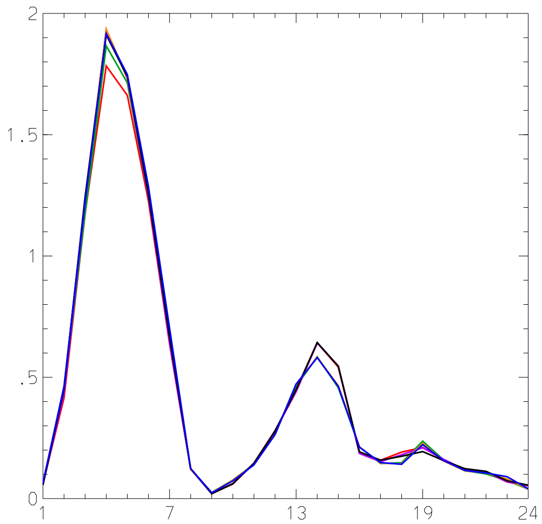

Fig. 6. As Fig. 3, but for region Jura on 6 November 1999.

4. Conclusions

A comparison between the results from the three case-studies demonstrates that predictability depends strongly upon the weather type. The results confirm that predictability at meso-β and smaller scales depends primarily upon the vertical stability of the atmosphere, i.e. upon convective activity. For the spatial and temporal scales considered, the uncertainties in precipitation forecasts increase rapidly with decreasing horizontal scale.

More surprisingly, the results suggest that predictability limitations may be crucial even at scales exceeding ~100 km, in particular during episodes of convective activity when individual convective cells are rendered unpredictable by chaotic aspect of the moist dynamics.

It should be emphasized, that the experiments presented assume perfectly predictable synoptic conditions and only relate to predictability on the meso-β and meso-γ scale. A full limited-area forecast has, in addition, also uncertainties in the large-scale forcing which would superimpose upon the small-scale uncertainties and in general further reduce the predictability.

6. References

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