5.3 ON THE DEVELOPMENT OF A REGIONAL CLIMATE MODEL FOR THE CENTRAL EUROPE

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1. INTRODUCTION

Limited-area numerical weather prediction (NWP) models in operational use are usually run for forecast lead times of up to two to* three days. Integrations beyond this limit are of little value for weather prediction, but may be beneficial for various research purposes. One of such applications is the use of limited-area models (LAMs) as tools for regional climatological modelling. The main idea consists, by analogy to the use of LAMs in weather prediction, in nesting in the driving global climate model (GCM), which provides lateral boundary conditions for a LAM. In order to evaluate the potential of the LAM to be integrated over extended time periods and its ability to reproduce the observed climate characteristics, the LAM should first of all be nested within the atmospheric analyses, representing the observations. In climatological use, the LAM is not required to predict individual episodes or events with great accuracy; rather it must provide a correct climatology, that is, proper spatial and temporal statistics of weather elements. The idea of using LAMs for regional climate modelling emerged in the late 1980's; for a broad discussion of the basic issues related to it, we refer the reader to the pioneering papers by Anthes et al. (1989), Dickinson et al. (1989), Giorgi and Bates (1989), and Giorgi (1990). A comprehensive review of work done in regional climate modelling since then is provided e.g. by McGregor (1997), Giorgi and Mearns (1999), and Giorgi et al. (2002).

The ALADIN limited-area NWP model, discussed in this paper, has been developed under a broad international cooperation headed by Météo-France and is operationally run, among others, at the Czech Hydrometeorological Institute (CHMI) in Prague, Czech Republic, in framework of LACE. The first atempt to integrate it beyond the operational limit was performed by Janisková (1995). The aim of her study was mainly to examine systematic errors in the NWP model and their response to changes in physical parameterizations.

Our aim is to transform NWP model ALADIN into a regional climate model (RCM). In this note we report the results of our first integration performed with the ALADIN model for a one-month-long period. Specifically, we address two of three questions posed by Giorgi (1990) as relevant for the feasibility of the nested modelling approach: (i) can the ALADIN model be run for long simulation times without excessive generation of error?, and (ii) does the ALADIN model reproduce the high resolution spatial detail of climate statistics?

2. DESCRIPTION OF THE ALADIN MODEL

The limited-area prediction model ALADIN has been developed by the international team headed by Météo-France. Its version ALADIN/LACE is operated on the NEC SX-4 supercomputer at CHMI in Prague. ALADIN is a fully three-dimensional baroclinic system of primitive equations using a two-time-level semi-Lagrangian semi-implicit numerical integration scheme and digital filter initialisation. The main purpose of ALADIN is to perform a dynamical adaptation of forecasts of the global NWP model ARPEGE to a high resolution. ALADIN/LACE is run on the domain of 2800x2200 km covering Europe from France to the Black Sea and from Northern Africa to Southern Scandinavia. Every 48 hour forecast uses 9 coupling files from the global model ARPEGE providing lateral boundary conditions upgraded every 6 hours. The version of the model used in this study has the horizontal resolution of 12 km and 27 hybrid vertical η levels.

For the description of the model and its parameterizations, refer e.g. to Bubnová et al. (1994) and Váňa (1998). The physical parameterizations package comprises:

- gravity wave drag parameterization,
- implicit horizontal diffusion computed in spectral space (fourth order and increasing with height),
- vertical diffusion and planetary boundary layer parameterization,
- constant analysed sea surface temperature and amount of sea-ice,
- an improved version of the ISBA (Interaction Soil Biosphere Atmosphere) scheme, including an explicit parameterization of soil freezing (prognostic variables in ISBA: surface temperature, mean soil temperature, interception water content, superficial soil water content, total liquid soil water content, total frozen soil water content),
- simple parameterization of snow cover,

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■ soil characteristics (texture, depth) that are point-dependent, vegetation characteristics that are point- and month-dependent,

■ simplified radiation scheme called at every time step,

■ mass flux convection scheme including the entrainment profile,

■ specific humidity as a solely prognostic variable: no storage of condensate; evaporation of falling rain; treatment of the ice-phase,

■ a sophisticated diagnostic cloud (and cloud content) method used for radiative purposes.

3. CHANGES TO THE OPERATIONAL MODEL

VERSION AND DESCRIPTION OF EXPERIMENT

Before running the ALADIN model in a climate mode, a few modifications had to be made to allow it to be integrated beyond its operational limit of two days. The modifications include mainly changes in lower boundary condition refresh and in the model and availability of the restarts. For the first attempt the model was integrated for a 31-day period of July 1998. It was nested into lateral boundary conditions provided by assimilations (analyses) by the ARPEGE global NWP model. (The assimilations serve as initial conditions for operational runs of ALADIN in a forecast mode.) As initial conditions for the month-long integration, the assimilations at 00 UTC on 1 June 1998 were used.

The comparison between the model outputs and observations are performed in terms of two statistical measures, bias and root-mean-square error (rmse). Denoting $m_{i,j}$ and $r_{i,j}$ model output and observation (reality) at the point at space and time characterized by two indices, *i* and *j*, and defining the model error as their difference, $d_{i,j} = m_{i,j} - r_{i,j}$, we can define the bias as

$$bias_j = \overline{d_j} = n^{-1}\sum_i d_{i,j}$$

and root-mean-square error as

$$rmse_j = \sqrt{n^{-1}\sum_i d_{i,j}^2 - \overline{d_j}^2} \ .$$

If *i* indexes time and *j* indexes space, we obtain a spatial distribution of errors, which can be mapped; if the indexes are interchanged, i.e., *i* indexes space and *j* indexes time, a temporal evolution of errors is described.

4. RESULTS

The dynamical variables [in the following we show 850 hPa heights and sea level pressure (SLP)] are validated against the analyses (assimilations) by the ARPEGE global NWP model, which are available in the same grid as ALADIN's outputs. The question whether the ALADIN LAM can be run for long simulation times without an excessive generation of error, is answered by plots of time evolution of errors for the 850 hPa heights in the top panel of Fig.1. The results for heights of other standard tropospheric levels, as well as for SLP, are qualitatively similar. The bias oscillates around zero without any signature of systematic trend towards positive or negative values. Its magnitude does not exceed 0.6 dam. The spin-up period, during which the rmse grows until a dynamical equilibrium is reached between the information advected from boundaries and the internal model physics (Giorgi 1990) takes about 24 hours. After the spin-up, the rmse is fairly stationary and oscillates around 0.5 dam. Larger magnitudes of both bias and rmse, occurring around July 5 and 10, are associated with a large variability (see the bottom panel of Fig.1), which is related to passages of strong synoptic systems. The stationarity of both kinds of errors indicates that no systematic error is accumulated in the model and no excessive generation of errors is observed.

The map of bias of 850 hPa heights (Fig.2 top) shows that over the majority of domain, the systematic error is within just a few meters. The rmse of 850 hPa heights (Fig.2 bottom) only exceeds 10 m in the north-eastern corner of the integration domain, whereas it is smallest along its western and southern edges. This is a reflection of the prevalent west to south-west direction of flow, which effectively spreads the influence of the lateral boundary conditions towards the interior of the domain, and moves the location of largest errors to the outflow region. For SLP, a similar pattern with low rmse values in the west and south and larger rmse values in the north-east appears (Fig.3), the values being again very small, not exceeding 1.5 hPa over the majority of integration domain. In addition to this general tendency, areas with a relatively larger error are connected with major mountain ranges, specifically the Alps and the Balkans, where SLP becomes rather a measure of the orography heights und thus the agreement in SLP between the model and reality is of little importance. The negligibility of errors of circulation variables (heights of other geopotential levels in the troposhere perform similarly to the 850 hPa level) indicates that the ALADIN model is capable of keeping its large-scale upper-air circulation features close to driving analyses and that it generates no undesirable deflections from the driving fields.

The ability of the ALADIN model to develop its own small-scale climatological features is illustrated by monthly mean temperature and monthly precipitation totals. We compare ALADIN's outputs with Willmott and Matsuura's (2001) monthly climatology, which is available in a 0.5° by 0.5° grid over land. The maps of climatological values for July 1998 are shown in the top panels of Figs. 4 and 5 for temperature and precipitation, respectively. The model outputs were interpolated onto the 0.5° by 0.5° grid and are displayed in the middle panels of Figs. 4 and 5. The interpolation allows a direct comparison with the reality, represented by the climatology. The results of validation are insensitive to the selection of the interpolation method. It can be seen that the model simulates fine small-scale spatial details of both temperature and precipitation fields, mainly (but not limited to) those related to orography. For example, the major mountain ranges (the Alps, Pyrenees, Carpathians) are accompanied with colder and wetter conditions than the surrounding lowlands. The model correctly simulates the cool and wet area in northern England, the wet area on the German-Danish border, drought in western France, as well as some small-scale temperature and precipitation features in central Germany.

The differences between the model and climatology are shown in the bottom panels of Figs. 4 and 5. Temperature is generally underestimated. The underestimation is only slight in the northern part of the domain, but attains more than 5° C over considerable areas in its southern part. The largest errors, up to –10° C, are associated with high mountains, mainly the Alps and Pyrenees. Precipitation tends to be overestimated over most of the integration domain. The overestimation is largest in the Alpine region and in the north-eastern corner; generally it is the areas where the observed precipitation is largest. The large biases in the north-eastern area are likely a result of a misplacement of synoptic-scale strong precipitation events. The patches of underestimation cover western and northern England, southern Italy, and south of the Moldovian-Ukrainian border. Notable is a narrow belt of relatively low precipitation along the boundaries in the north-east. This is probably an unrealistic feature, arising from numerical effects in the vicinity of the boundary.

5. COMPARISON WITH OTHER STUDIES

The spinup period of ALADIN, lasting approximately 24 hours, is relatively short in comparison with other studies (Anthes et al. 1989; Lüthi et al. 1996; Giorgi and Mearns 1999). The reason is in a small size of ALADIN's integration domain, which allows the lateral boundary conditions to affect the whole interior of the domain and to become balanced with internal model physics quite rapidly.

There are relatively few studies reporting validations of circulation variables, surface temperature and precipitation for RCM runs for Europe in summer months, nested in analyses: Lüthi et al. (1996) analyze three monthly runs with the Europa-Modell of the German Weather Service; Christensen et al. (1997) examine seven European RCMs for runs of different duration from one month to three years; and Christensen et al. (2001) compare the one-year-long runs of two RCMs (Danish HIRHAM4 and Spanish PROMES). Any comparison among the models can be only qualitative because integrations are conducted for different years with different synoptic conditions. Nevertheless, some general conclusions can be drawn.

The SLP bias is discussed in Christensen et al. (1997): all of the RCMs involved manifest SLP systematic errors larger than ALADIN. This is not only because of ALADIN's relatively small integration domain, since two of the models in comparison, PROMES and CLAMBO, have their domains even smaller, but their SLP biases exceed 2 hPa.

Surface temperature biases exceeding in absolute value 6°C are quite commonplace in most RCMs in Christensen et al.'s (1997, 2001) studies. In some of the models, the errors of such a magnitude cover substantial parts of the integration domain. In this respect, ALADIN performs moderately well. Its difference from all other models, including Lüthi et al.'s (1996) study, consists in the opposite sign of the error: Whereas in ALADIN, an overestimation of temperature prevails, all the other models are generally too warm. The feature of ALADIN common with other RCMs is a tendency for lower / higher error magnitudes to occur approximately north / south of the Alps.

Only the Europa-Modell (Lüthi et al. 1996) overestimates precipitation similarly to ALADIN; all other models exhibit a tendency towards being too dry (Christensen et al. 1997, 2001). In most models, the extreme errors exceed 150 mm/month in both directions. ALADIN falls well within these ranges. In most models, the patterns of systematic errors have a band-like structure similar to ALADIN, indicating that the errors come from incorrect simulation and / or placement of individual synoptic disturbances yielding precipitation. The inability of RCMs to localize heavy precipitation events and to determine which synoptic disturbances, even if correctly placed, will yield heavy precipitation, is a recognized deficiency of all RCMs (Kunkel et al. 2002).

6. ONE YEAR SIMULATION

Further, longer period experiment were run to asses the model performance in annual cycle. Some modification in the model were adopted, the main one being the change of resolution. For practical reasons we moved to coarser resolution of about 20 km. We used the ARPEGE reanalysis data from year 2000 for driving boundary condition and some examples of results are presented in Fig. 6, where the comparison with the results from supporting run of the regional climate model RegCM3 is available as well. Actually, we used for the purposes of our project regional climate model RegCM3, originally developed in NCAR and (Dickinson et al., 1989; Giorgi, 1990) based on NCAR-PSU (National Center for Atmospheric Research – Pennsylvania State University) MM4 compressible hydrostatic grid point model but with modified physics for use in climate studies, further upgraded by Giorgi et al. (1993a,b) and later on modified in ICTP with some new parametrization schemes. Dynamical core of the RegCM3 is now similar to that of the hydrostatic version of MM5, physical packages are more or less based on CCM3 with some additional changes, mainly in description of cloud and precipitation processes, and optional settings, like inclusion of lakes, choice of horizontal and vertical resolution, map projection and settings of dozens of parameters. With a coarser resolution (45 km in this case) this makes it to be very flexible tool which we used for many tests of methodology and in preparation of extensive experiments with ALADIN-Climate. The presented results are based on driving reanalyses from NCEP/NCAR with GISST. It can be clearly seen the main advantage of ALADIN in the model resolution, but it is rather cold, which is probably due to the physical parameterization not yet fully modified for climatological tasks.

7. EXAMPLE OF USE

To evaluate the ability of the regional climate model to produce the extremes we are running the extensive long run of RegCM3 driven by NCEP/NCAR reanalyses for the period 1961-2000 with GISST in the abive mentioned resolution of 45 km. In Fig. 7 there are presented preliminary results of the first ten years of simulation for precipitation. From the comparison of some stations with the nearest model grids you can see general property of the model to overestimate low precipitation, but it can be pointed underestimation of high precipitation, which can differ in individual seasons. Clearly, the worst performance of the model will be probably in convective precipitation mainly during summer.

8. CONCLUSIONS

This contribution describes the first steps in developing the regional climate model ALADIN-Climate with the resolution being at the high end of RCM integrations available until now. We now have the model, which is integrable over extended time period without the excessive error is generated and accumulated during the integeration. The accuracy of simulation of mean surface temperature and precipitation amounts is within the range of analogous integrations reported in recent studies. The ALADIN model is able to keep its large-scale upper-air circulation very close to the driving analyses, however, it develops its own small-scale features, related mainly to orography, which are observable in the mean surface temperature and precipitation fields. Much work will need for further modification, development and testing of the physical parameterization to move from originally NWP model to real climate model. The example of RegCM3 use and the comparison of both of the models show us the future potential of ALADIN-Climate.

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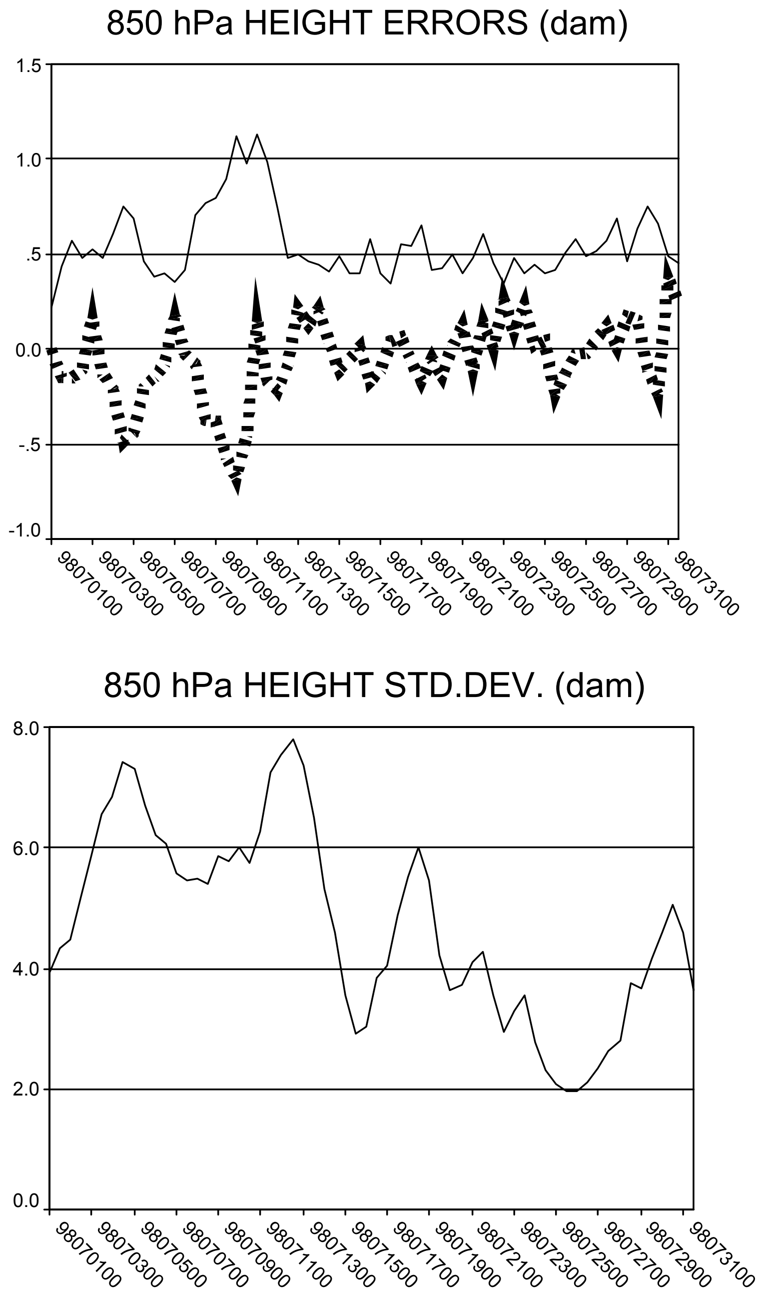

Fig. 1. Top panel: time development of bias (dashed line) and rmse (solid line) of simulated 850 hPa heights (in dam). Bottom panel: standard deviation of the observed 850 hPa heights (in dam).

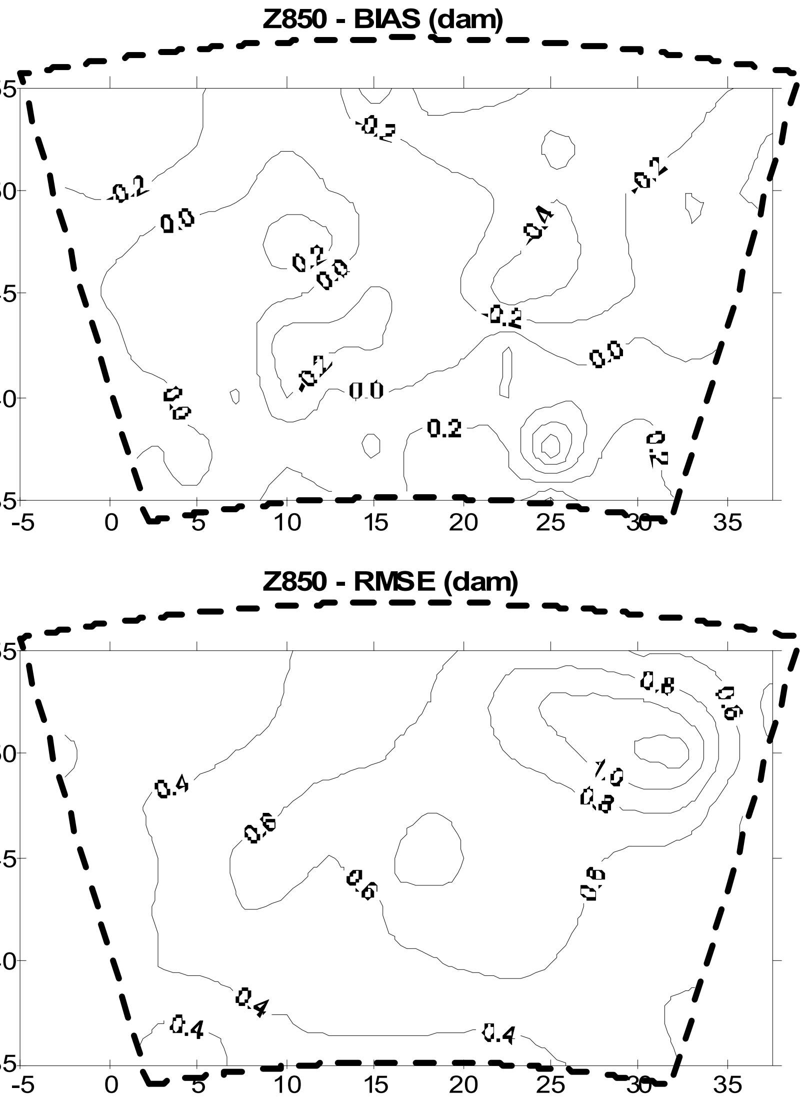

Fig. 2. Spatial distribution of 850 hPa height bias (top) and rmse (bottom), both in dam. The boundaries of the integration domain are shown by bold dashed line.

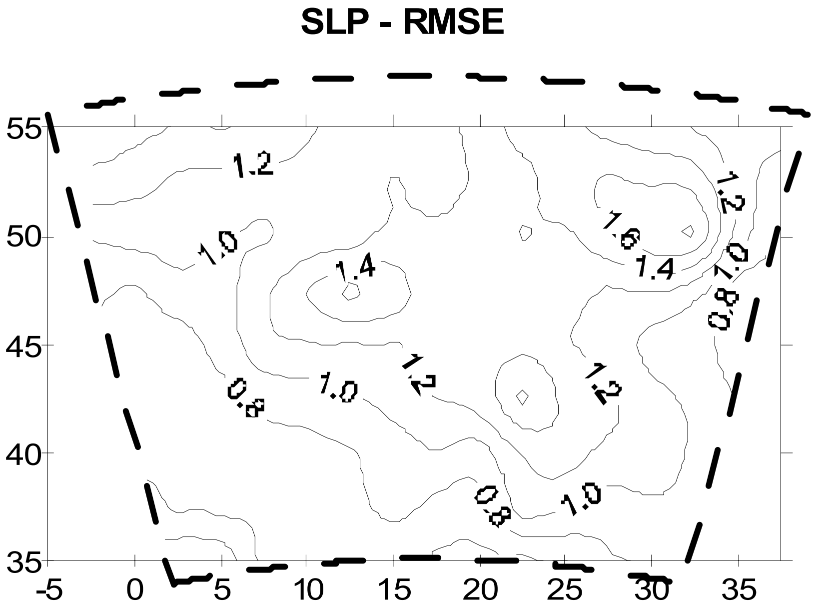

Fig. 3. Spatial distribution of sea level pressure rmse (in hPa). Bold dashed line indicates the integration domain.

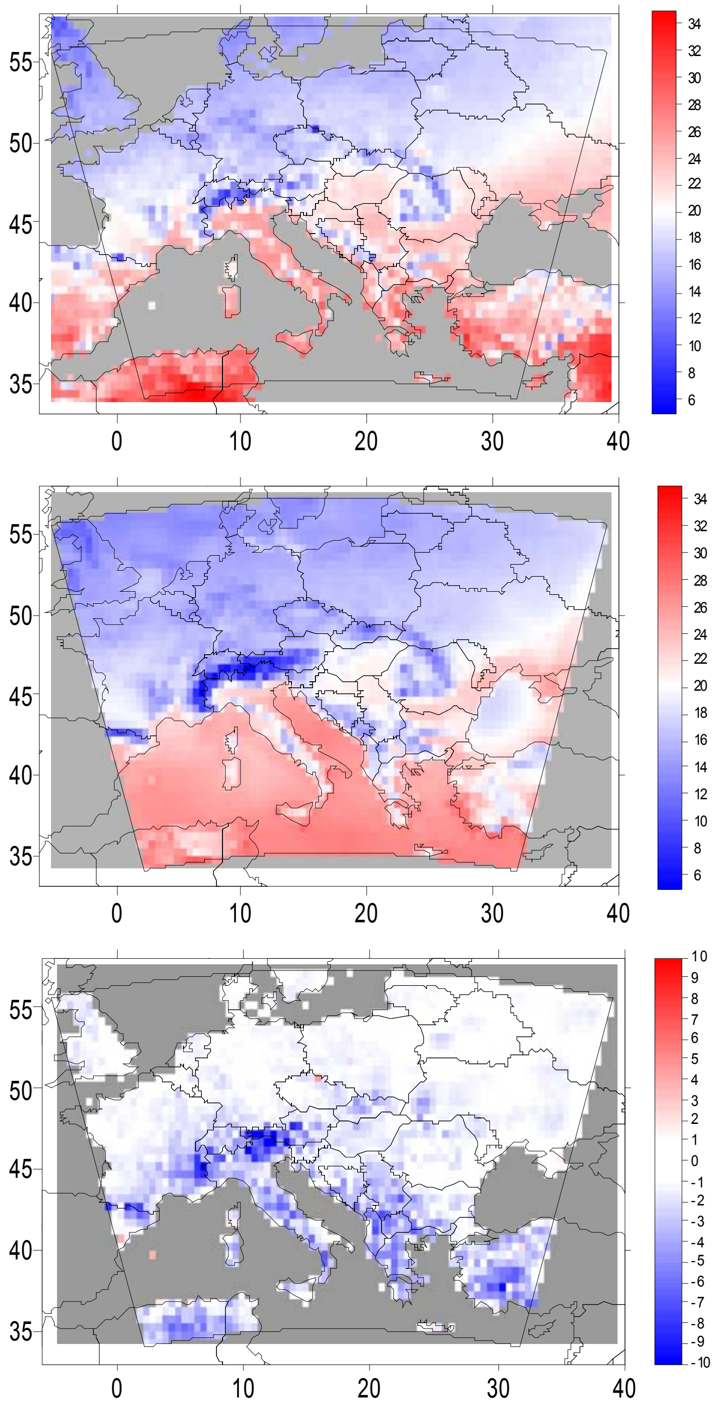

Fig. 4. Mean monthly temperature: observed – from Willmott and Matsuura's (2001) 0.5°x0.5° climatology (top); simulated – interpolated onto the climatological 0.5°x0.5° grid (middle); difference simulated minus observed (bottom). Solid line indicates the boundary of the integration domain; areas where no data are available are in grey.

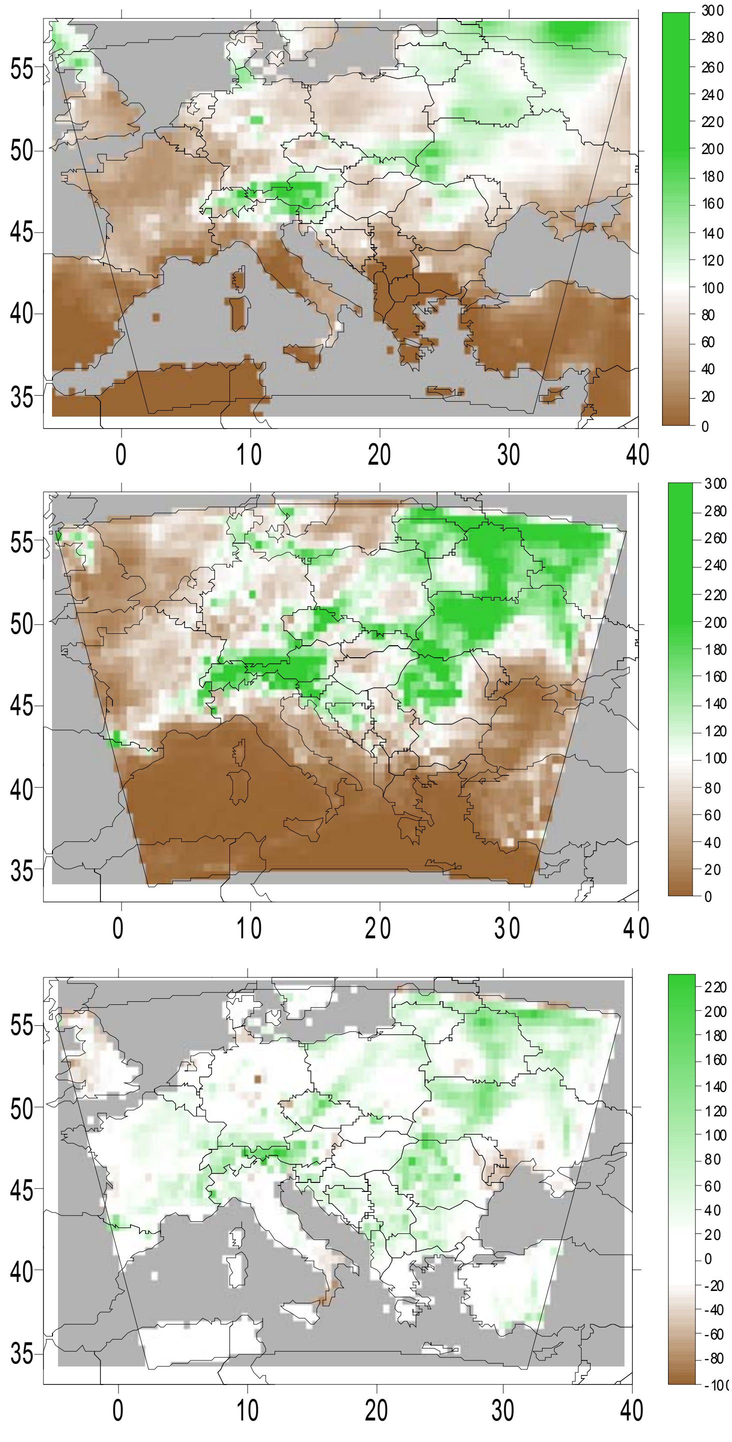

Fig. 5. As in Fig.4, except for monthly precipitation totals.

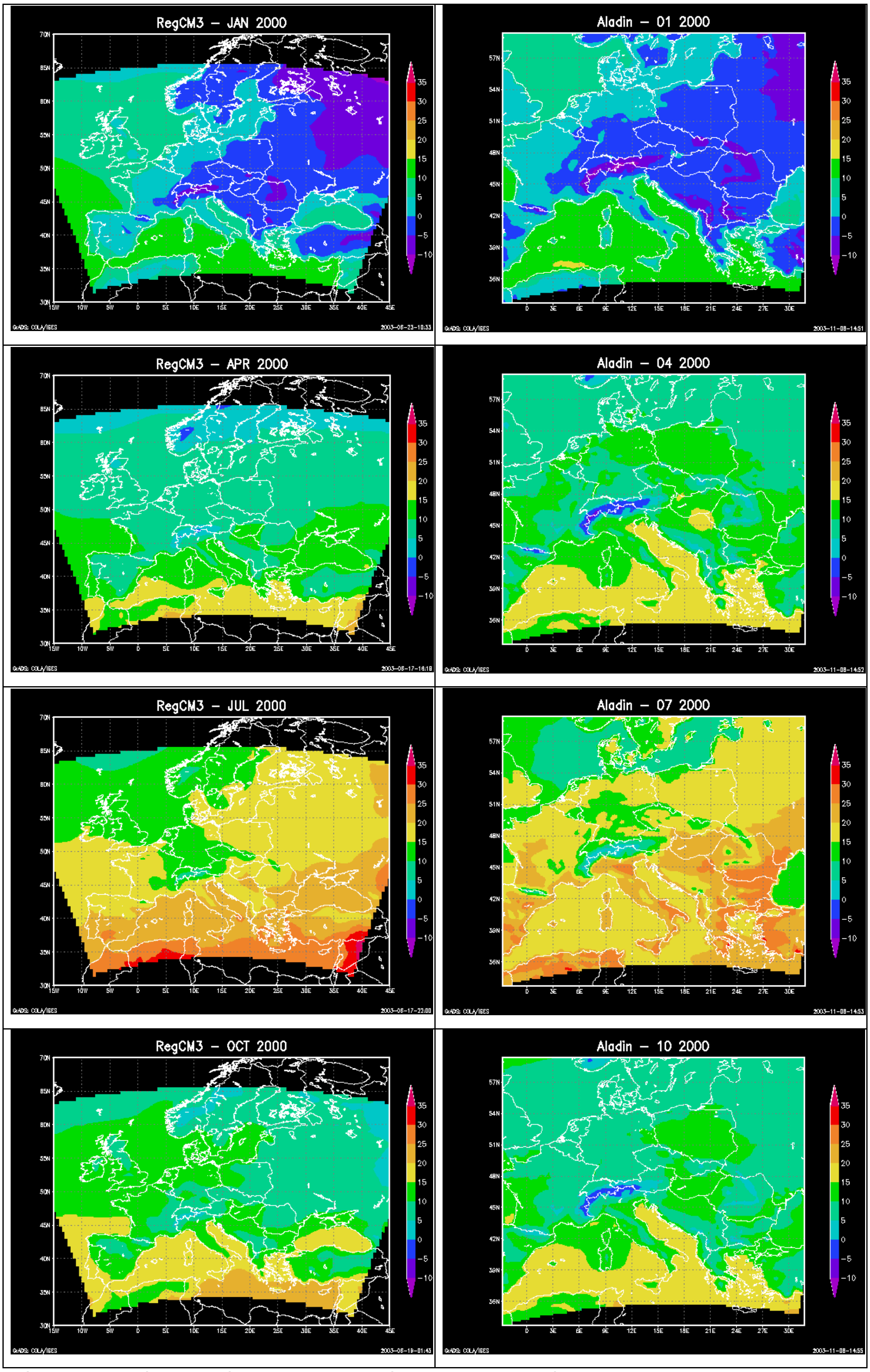

Fig. 6a) Comparison of the RegCM3 and ALADIN-Climate simulation for temperature.

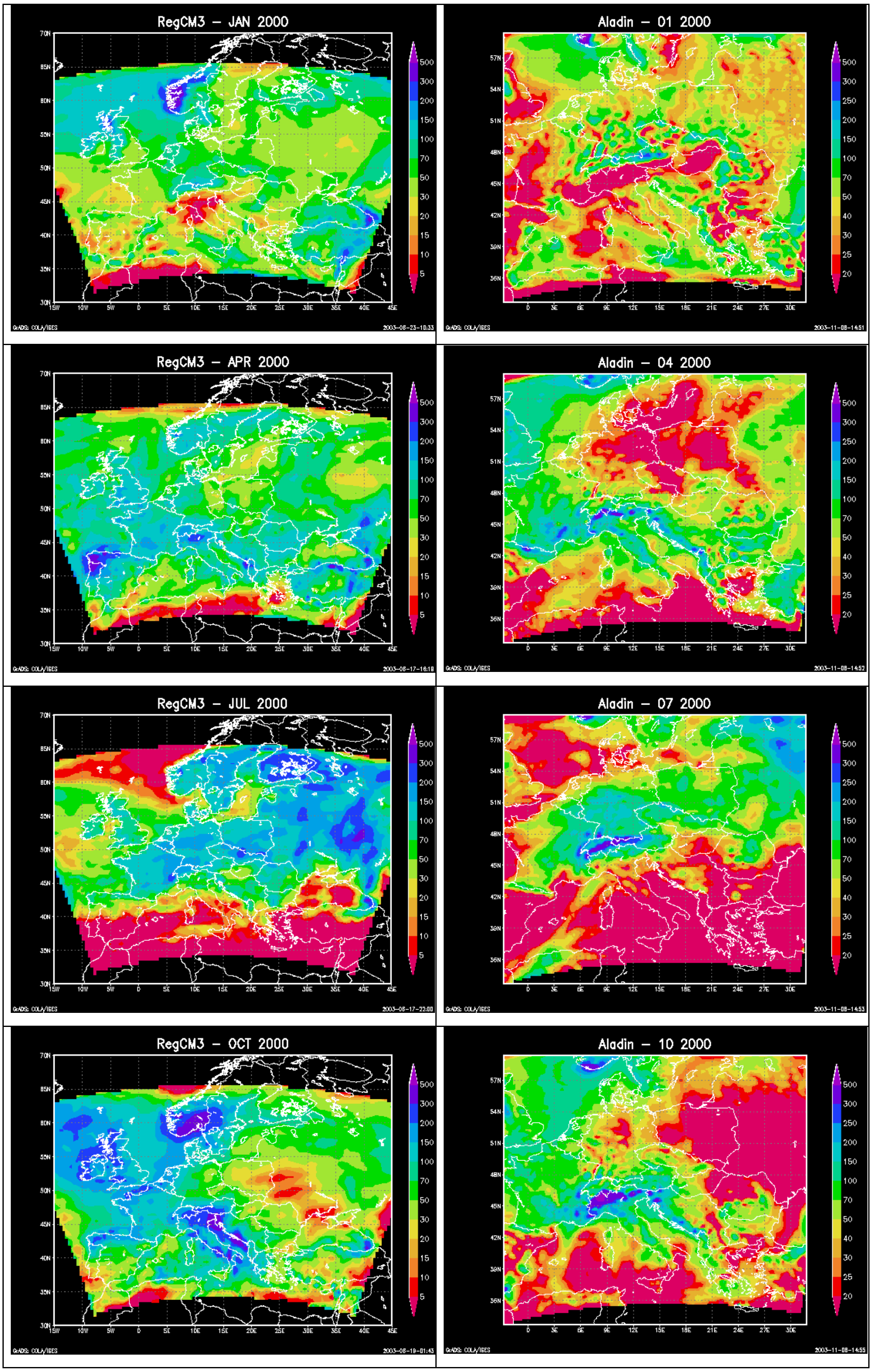

Fig. 6b) Comparison of the RegCM3 and ALADIN-Climate simulation for precipitation.

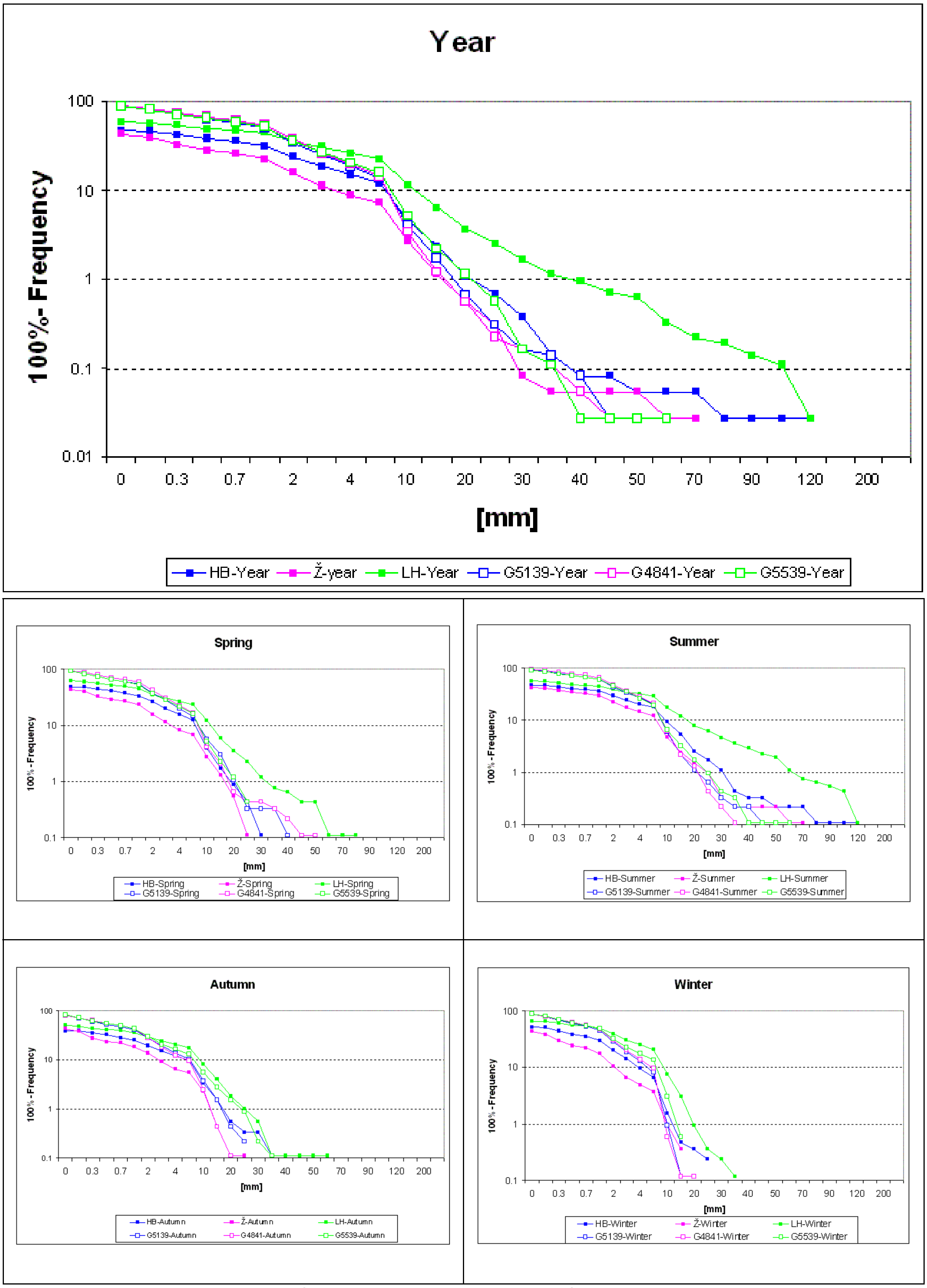

Fig. 7 Preliminary 10-years results of precipitation distribution in RegCM3 simulation.