CLIMATOLOGIC DATA DOWNSCALING WITH SIMPLIFIED DYNAMICAL MODELS

M. Gera[1], I. Ď.Bašták[1], I. Damborská[1], R. Drinka[1]

[1] Comenius University, Department of Astronomy, Physics of the Earth and Meteorology, Faculty of Mathematics, Physics and Informatics, Bratislava, Slovakia
E-mail: mgera@fmph.uniba.sk

Abstract: Dynamic adaptation is a process, which allows improving the quality of analysed meteorological data effectively. This method improves the density of grid points with preservation of dynamic consistency among meteorological variables. This effect is mainly important in the territory with varied orography. The resolution of global climatologic circulation models (GCCM) or results from ERA data is about hundred square kilometres. For regional data analysis, where the mountain effects are important, it is necessary to use sophistic methods to interpret model outputs. One way, how to obtain suitable data, is application of simplified numerical model to the sparse data from GCCM or ERA. These data are applied for model initialization and for coupling. For the reason of dynamic adaptation and not classical integration of the model, the model is forced with constant lateral condition in time. Some filtered (Quasi-Geostrophic Equivalent Barotropic Model and Adiabatic-Arakawa -Lamb) models are used and investigated for these purpose. Results are verified on the ERA data and compared with numerical model ALADIN. This cost effective methods, which increase the data resolution, allow us to apply these results, for example, to the investigation of land-energy utilization, create the maps for prevalent wind and choose the suitable territory for wind power-plant building.

Keywords: *ICAM, dynamic adaptation, regional model, data downscaling, mountainous area*

1. INTRODUCTION

Outputs from global circulation models (GCM) show useful information for investigation of global atmospheric variability. This information is not usually sufficient for the regional data analysis. For this reason some sophistic methods are implemented to obtain atmospheric fields with more detailed structure than GCMs are provided.

One suitable method, which retains a physical consistency among the meteorological variables, is dynamical adaptation. The differences between dynamical adaptation and regional model integration are not large. Dynamical adaptation is method that is differed from classical approach applied in regional or limited area climatic models in the using of constant lateral boundary conditions and in the complexity of algorithm. In other way, similar hydrodynamic equations are used in both mentioned approaches. Dynamical adaptation, which we apply for regional analysis, has base in the governed equations of fluid motion.

There are some objects of interest, which require resolution increasing. The background data from ERA 40 are taken for our model initialization. The available data are obtained from regular 2.5° x 2.5° latitude/longitude grid. For our purposes this density is insufficient. With simplest interpolation technique one can obtain on the first view useful results, however deep result analyses show the disadvantages of this method especially in the mountain area. This interpolation can be done with model in the dynamical adaptation regime. It brings some additional problems. In the case that resolution differences between new and primary data are multiple (more than few times resolution increasing) the new transition problems are appeared. The multi-nesting lateral condition approach can solve it. On the next it should be remember that limited area model (LAM) has artificial lateral boundary conditions. It triggers the new kind of solving problems. The relaxation zone or similar technique should be used to prevent noise spreading from these edges. Besides the constant forcing of lateral condition, which is the base of dynamical adaptation, does not allow the long temporary integration due to the advection in the model domain.

After successfully managing of not only difficulties mentioned above this approach can be used for example to the investigation of the territory for some human activities, the revivable sources utilization, etc...

2. DATA AND METHODS

The primary objective of ERA-40 is to produce and promote use of a comprehensive set of global analyses describing the state of the atmosphere, land and ocean-wave conditions from mid-1957 to 2001. ERA-40 is generating supported data sets that comprise for example:

- observations, analysis and forecast fields from the assimilating atmospheric model at full resolution, at standard pressure levels, on isentropic levels (potential vorticity maps);
- analysis and forecast fields from the atmospheric model evaluated on a regular 2.5° x 2.5° latitude/longitude grid;
- analysis and forecast fields from the coupled ocean-wave model on its regular 1.5° x 1.5° latitude/longitude grid;
- monthly and daily-means, variances and covariances.

The coupled atmospheric-ocean model which prepare ERA-40 data has the following spatial resolution:

- 60 levels in the vertical;
- T159 spherical-harmonic representation for basic dynamic fields, a reduced Gaussian grid with approximately uniform 125 km spacing for surface and other grid-point fields;
- an ocean-wave model resolves 25 wave frequencies and 12 wave directions at the nodes of its 1.5° grid.

For our computation the offered data in the regular 2.5° latitude/longitude grid were exploited (original T159 spherical-harmonic fields are truncated to T63 before the 2.5° grid values are computed). For Slovakia territory it means that resolution is about 250 km in both directions. The orography with resolution above hundred square kilometres is absolutely inconvenient for investigation of features, which are observed in regional scale. The varied orography in Slovakia forces us to use dynamical adaptation.

To prevent a big stress from resolution transition, from hundred to tens kilometres resolution, it is convenient apply multi nesting technique. It means, that resolution of the model is changed gradually. For the first transition, where it is supposed that advective and macro-synoptic processes are important, the more simplified governed equations are used. For this reason we try to play with the quasi-geostrophic equivalent barotropic model. This kind of model characterizes balance of the wind and the mass field. The gravity waves are absent in this case, but orography is implemented and acts as forcing force on the right side of equation. These simplifications are valid for large atmospheric processes. This approach is investigated. The advantage is to compute the model on the all sphere. The disadvantage of this approach is slow influence of the orography to the prognostic variables, which handicap this method for their non-effectivity. These results, as one alternative, are used as initialization of limited area model, which works as 3D model. The second alternative is directly using the interpolation technique, which brings less developed fields consistency, however the efficiency and methods disadvantages are less important in this case. Exist some alternatives how to prepare this initial fields. The one possibility is to adapt of all necessary fields to the new grid geometry, where the new orography has an influence to the structure of the all prepared initialization fields. The second choice is differed from previous where only original (sparse) grid points are affected by the new orography in the upper levels. In the surface level in the all points of the new grid changes are done. In this second variant of field modification it is expected that adaptation will be mainly done during the model integration. The input ERA-40 fields in pressure levels were transformed to the new dense "C" grid in horizontal direction and sigma levels in vertical direction.

Here we have to remark, that exist more techniques, how to express orography on more dense grid. We investigate two approaches. A first method has origin in classical spline interpolation. This kind of obtained surface can raise the model instability (the shape of orography can be sharp and it can trigger intense vertical motion). The second method works with spectral filtering. The density of obtained grid is the same that in the first method, but moderate slopes are observed. Third possibility is to provide the weight averaging to the dense grid.

The government equations of used model developing for dynamical adaptation purposes are based on the Arakawa and Lamb energy conservation scheme for non-divergent flow. These features respected some known restrictions to allow us using of this model with higher resolution, which can be above 10 km. This model works with the surface pressure, zonal and meridional wind components and the temperature as the prognostic variables. The geopotential of the general sigma levels and generalized vertical velocity are the diagnostic variables.

In the vertical direction, the staggered grid is used and top of the models is at 500 hPa in this time. The vertical layer is divided on 22 layers and sub-layers. In the horizontal direction staggered "C" grid is used. The government equations have form:

$$\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}t} = -\alpha\sigma\nabla\ \pi - \nabla\ \phi - f\vec{k} \times \mathbf{V} + \mathbf{F}\,, \qquad (1)$$

$$\frac{\partial \pi}{\partial t} = -\nabla \cdot \pi \mathbf{V} - \pi \frac{\partial \dot{\sigma}}{\partial \sigma}, \tag{2}$$

$$\frac{\partial \phi}{\partial \sigma} = -\pi \alpha, \tag{3}$$

$$c_p \frac{\mathrm{d}T}{\mathrm{d}t} = -\alpha\left(\pi \dot{\sigma} + \sigma\left[\frac{\partial \pi}{\partial t} + \mathbf{V} \cdot \nabla \pi\right]\right), \tag{4}$$

where **V** is a horizontal vector, α is a specific volume, σ is a vertical coordinate, $\dot{\sigma}$ is a generalized vertical velocity, ϕ is a geopotential, c_p is a specific heat for constant pressure, T is a temperature and π is a pressure which in the low part model (below p_l =600 hPa) has expression: $\pi = p_s - p_l$ and above this level $\pi = p_l - p_t$ (p_t = 500 hPa).

As it was told above the scheme should have conserved the total energy. In the continuous form of equations the conservative properties are kept (with the use of next conditions: $\dot{\sigma} = 0$, $\partial \pi / \partial t = \partial p_s / \partial t$ at $\sigma = 1$ and $\dot{\sigma} = 0$ at $\sigma = -1$). Discrete forms of these nonlinear equations have to be prescribing to the equivalent conservative scheme. For this reason in the horizontal direction the flux form of equations are taken. In the vertical the special discrete form of the next formula $\frac{c_p T}{(p/p_0)^{R/c_p}} \frac{\partial (p/p_0)^{R/c_p}}{\partial \pi} = \sigma \alpha$ is chosen to keep energy conservation (Arakawa, A. and V.R. Lamb, 1977). It should be noted that in our case the total energy volume divergence is non-zero in consequence of constant forcing in the lateral boundary conditions.

The enstrophy is not conservative characteristic in our case. In the territory of the steep mountain slopes, the terms related to the geopotential and the surface pressure horizontal gradient should be analyse very detailed. Nonlinear effects start to be important in this case. In spite of energy conservative scheme the mentioned terms produced the nonlinear instability. For this reason the spectral filtering is introduced to the finite difference scheme in the selected terms. It invokes additional computational difficulties connected with non-periodic domain features. The biperiodization is necessary to implement, the domain is extended about this zone.

The domain of the model integration is chosen to the territory bounded by intervals (46°, 52.2°) latitude and (13.2°, 24.2°) longitude. The biperiodical zone is not included. The resolution in the horizontal direction is 0.05°×0.05° (for staggered grid 0.1°×0.1°). In the vertical the next sigma levels are introduced: 1.00, 0.98, 0.96, 0.93,0.90, 0.87, 0.83, 0.80, 0.75, 0.70, 0.65, 0.60, 0.50, 0.40, 0.30, 0.20, 0.10, 0.05, 0.00, -0.10, -0.25, -0.75, -1.00. The domain size is not too small for the problems with lateral boundary conditions and not too big for the efficiency (Gera, M. and Martini M., 2004). On the lateral boundaries the relaxation have to be done yet. The eight points on the border is taken for relaxation zone. The general formulation for used Davies relaxation scheme is:

$$Q^+ = (1 - \alpha(r,p))\, Q_c^+ + \alpha(r,p)\, Q_{LS}^+, \tag{5}$$

where Q_{LS} is the model state vector of a large-scale driving model (the upper index indicates the value in new time-level), Q_c is the coupled model vector and $\alpha(r, p)$ is the relaxation function. This function is dependent on the space variable r, which has relation to the relaxation zone width. Variable r varies from zero to one. Parameter p is the tuning parameter. Its magnitude depends on the relaxation zone width and its value is chosen to minimize the reflection from lateral boundaries. All prognostic variables are relaxed (**V**, π, T).

For integration we take every day separately and we perform integration (dynamical adaptation) on the fields for chosen day. The daily data from ERA-40 of thirty years period 1970-1999 were taken for processing.

3. RESULTS AND CONCLUSIONS

The fine resolution of the meteorological variables is asked for industry and society needs. The dynamic adaptation realises the cost effective method with keeping necessary basic physical dependences. The most interested result of this approach is the wind field obtained with non-classical interpolation technique. Other fields especially the temperature fields near the surface should be taken in the mind to know that adiabatic simplification is applied.

The main question is the duration time of the integration finishing. Because of the horizontal diffusion absence the integration time from our experience should not exceed 35 minutes for our purposes. This duration was estimated with two approaches. In the first, the normalized variance of the surface wind field is compared with the orography normalized variance. In the second, the available potential energy is estimated. The contribution to the available potential energy is due to the orography change (the new dense orography versus the smooth old orography). The ten percent of this energy is expected to transform to the kinetic energy. From these approaches 35 or 25 minutes is obtained for (dynamic adaptation) time integration aborting. The linear increasing tendency is removed from the assumption that nonlinear effects are only responsible for needed variance changes. The linear increasing is ineligible effect due to absence of dissipation in the governed equations. In the (Fig. 1a,b), it can be seen the smooth old orography and the new dense orography, which was obtained by the spline interpolation technique. In the (Fig. 2a,b), the result of dynamical adaptation for the wind field in the $\sigma = 0.98$ for the chosen date 26.07.1970 after twenty-five times one minutes integration time step it can be seen.

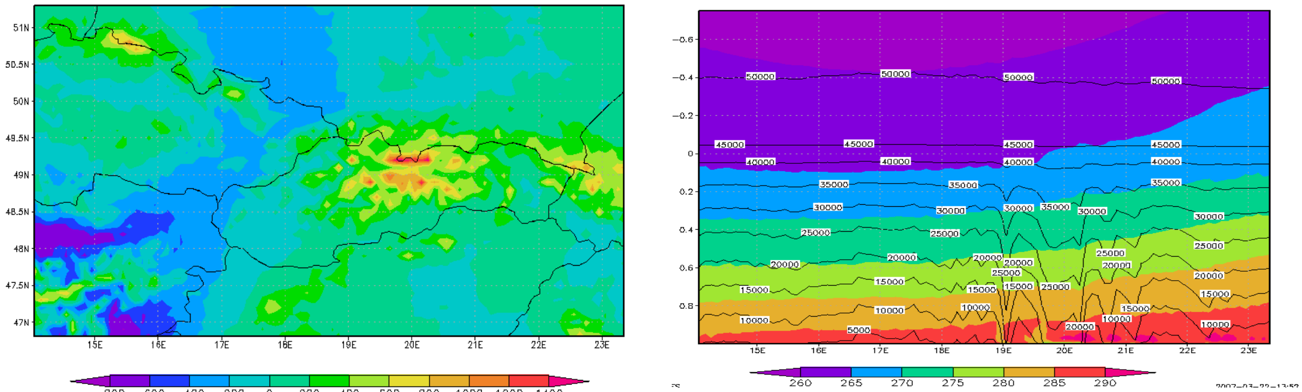

Figure 1a,b: Left: the difference between the new and the old orography. Right: the vertical sigma level cross section for latitude 49.2° for the temperature and the geopotential after 25 minutes of integration

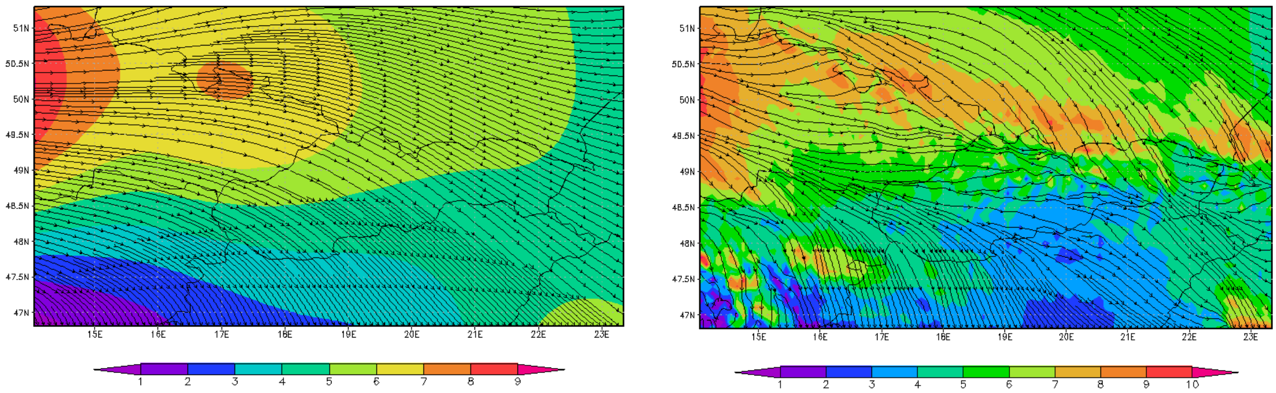

Figure 2a,b: Left: the streamline and magnitude of the wind field in the $\sigma = 0.98$ at initial time. Right: the streamline and magnitude of the wind field in the $\sigma = 0.98$ after 25 minutes of integration

Acknowledgements: *This work was supported by Science and Technology Assistance Agency under the contract No. APVT-20-018804*

REFERENCES

Arakawa, A. and V.R. Lamb, 1977: Computational design of the basic dynamical processes of the UCLA general circulation model, *Methods in Computational Physics*, **17**, Academic press, 174-265

ERA 40, http://www.ecmwf.int/research/era/

Gera, M. and Martini M., 2004: Coupling data influence on the ALADIN model forecast in an extreme synoptic situation, *Acta Meteor. Univ. Comenianae*, **33**, 31-54