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Regional Climate Model for the Lower Volga: Parallelization Efficiency Estimation

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We have deployed the regional climate model (RCM) RegCM 4.5 for the Lower Volga and adjacent territories with a horizontal spatial resolution of 20 km. The problems of choosing the computational domain in the RCM RegCM version 4.5 are considered. We demonstrate the influence of this factor on the forecast of rainfall distribution in the numerical simulations. The study of rainfall and snowfall is a more demanding test in comparison with temperature or pressure distributions. We investigate dependencies of calculation time, parallel speedup and parallelization efficiency on the number of processes for different multi-core CPUs. Our analysis of the efficiency of parallel implementation of RegCM for various multi-core and multi-processor systems show a strong dependence of the simulation speed on the CPU type. The best effect is achieved when the number of CPU threads and the number of parallel processes are equal. The parallel code speedup is in the range of 1.8 – 11 for different CPUs.

Keywords: regional climate model, domain size, simulations, parallelization.

Introduction

The solution to the problem of improving the accuracy of the climate changes forecast for a specific region is based on the massive use of regional climate models (RCMs) for calculations [7]. There are a number of reasons for the general interest in climate forecasts. In addition to the increasing global warming, which is investigated on the basis of general circulation models, we observe multidirectional trends of regional changes that are very important for engineering infrastructure, agricultural production, recreational projects, evaluation of the state of natural landscapes and especially river systems [2]. The study of extreme weather phenomena is at the forefront of climate sciences. RCMs allows to take into account the region-specific orographic features [1].

It is important to emphasize that it is not enough to increase only the spatial resolution of RCM in order to improve the quality of simulation results [6, 7]. We must successfully configure a large set of parameters describing heterogeneous subgrid processes for the study area. Parameterization of physical subprocesses, data reanalysis, radiation models, methods of meteorological parameters downscaling, boundary conditions, and choice of the calculation domain are crucial for the results of climate modeling [5]. In this work, our main efforts are aimed at analyzing the efficiency of parallel computing for the regional climate model RegCM 4.5. We examined several various multi-core processors for climate modeling.

1. Regional Climate Model for Low Volga

When performing calculations, we used the standard set of parameters recommended by the Weather and Climate Physics Group of ICTP for the Caspian region (Fig. 1), and only the sizes and positions of the computational domain varied. We based our study on the hydrostatic core with the numerical grid resolution of 20 km and 18 vertical σ-levels and used the topographic data of GTOPO with resolution of 30 seconds, the data from the global climate model of the European Center for Medium-Range Weather Forecast's ERA-Interim (EIN15) for setting the

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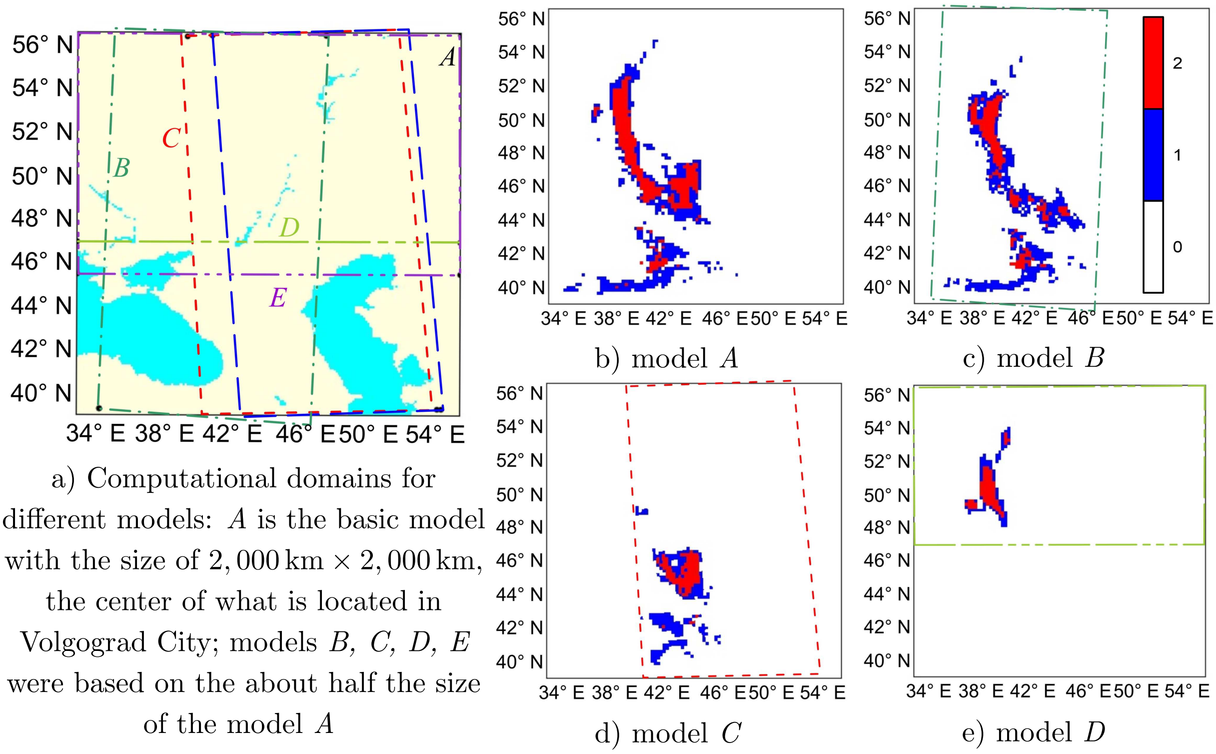


a) Computational domains for different models: A is the basic model with the size of $2,000\,\text{km} \times 2,000\,\text{km}$, the center of what is located in Volgograd City; models B, C, D, E were based on the about half the size of the model A

b) model A

c) model B

d) model C

e) model D

Figure 1. Examples of rainfall distributions are shown on the right for different computational domains

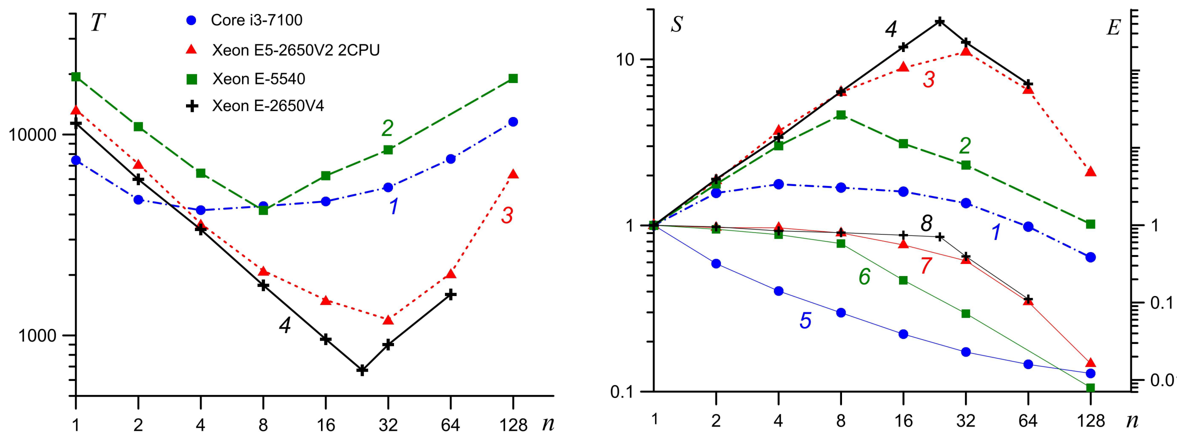
initial and boundary conditions in all our numerical experiments. The determination of the sea surface temperature is based on the reanalysis data of the Indian Ocean Sea Surface Temperature (IOSST). Our basic computational domain is located between 40°N – 56°N and 34°E – 54°E. The size of this domain (Fig. 1a) is typical for regional climate models.

We investigated the occurrence of special meteorological events, in particular, related to the rainfall formation. This approach seems more suitable, rather than considering the distributions of temperature or pressure [5]. In Fig. 1, we distinguish three types of events: very weak rainfall ($I < 0.86\,\text{mm}\,\text{day}^{-1}$, symbol "0"), weak or moderate rainfall (symbol "1", blue color), heavy rainfall ($I > 24\,\text{mm}\,\text{day}^{-1}$, symbol "2", red color). Fig. 1 $b-e$ show the spatial distributions of rainfall for the four computational domains on May 19, 2016 and for the initial state on May 1, 2016. The choice of the computational domain significantly affects the results of rainfall modeling. For the same area of the computational domain, we have quantitative and even qualitative differences in the meteorological situation when the center and the orientation of the domain change. Solving this problem requires expanding the modeling domain, and the computational resources is the limiting factor.

2. Parallelization Result

The climate modeling demands a large amount of calculation due to the need to vary a large number of parameters [4, 8]. The construction of very large data cubes is the basis for climate models. The dependence of the results in RCM on the computational domain requires the maximum possible sizes of the simulated area while maintaining the minimum scale of the numerical cell of about 10 km. And the ideal solution would be to use general circulation models with a resolution of up to 10 km for non-hydrostatic equilibrium. Let us consider the time of calculating T for modeling the climate system for 1 month with integration step of $\Delta t = 150\,\mathrm{sec}$ to evaluate the parallelization efficiency in OpenMP. The time $T = T^{(cal)} + T^{(rw)}$ is determined by the time of pure integration of the hydrothermodynamics equations $T^{(cal)}$ and the time $T^{(rw)}$, which is necessary for reading and writing various data. The standard situation is to record the state of the climate system every 6 hours. We used the MPI2 library to run in parallel mode for multi-core systems.

Figure 2 shows the dependencies of T on the number of parallel processes n on different CPUs. Each processor has n_{cor} cores, for example, $n_{cor} = 2$ for Intel Core i3–7100, $n_{cor} = 16$ for Intel Xeon E5–2650V2 2CPU, $n_{cor} = 4$ for Xeon E–5540, $n_{cor} = 12$ for Xeon E–2650V4. Intel Hyper-threading technology doubles the number of logical processes, and we have $n_{th} = 2n_{cor}$ threads for a particular CPU type. The software using the MPI2 library allows you to specify an arbitrary number of processes n (Fig. 2), including $n \gg n_{th}$. The minimum time T is reached at $n = n_{th}$ for all the CPUs under investigation, and a very wide extremum is a characteristic feature. The transition from $n = 1$ to $n = 2$ gives the largest decrease of T. The fast growth of T with increasing n is observed in region $n > n_{th}$, so that $T((2 \div 4)n_{th}) \sim T(n = 1)$. These peculiar properties are due to the significant contribution of $T^{(rw)}$ to T.



a) Dependencies of calculation time T on the number of processes n for different multi-core CPUs

b) Parallel speedup $S = T(1)/T(n)$ (left axis, curves *1–4*) and parallelization efficiency $E = S/n$ (right axis, curves *5–8*) for the same computing systems

Figure 2. Parallelization result

Conclusions

Modeling of climatic changes for the territory of the Lower Volga region was carried out using the regional climate model RegCM version 4.5. We demonstrated the influence of the computational domain choice on the forecast of rainfall distribution in the numerical model. The study of rainfall and snowfall is a more demanding test in comparison with temperature or pressure distributions and requires a computational domain with a size of at least 3,000 km in the conditions of the Lower Volga.

The maximum speedup of parallel computing for OpenMP strongly depends on the CPU Type and varies from 1.8 to 11 for different CPUs. Mass transfer of regional climate models to GPUs is a priority task in accordance with the general trend of development of computational fluid dynamics [3].

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References

1. Hui, P., Tang, J., Wang, S., Wu, J., Kang, Y.: Future climate projection under IPCC A1B scenario in the source region of Yellow River with complex topography using RegCM3. Journal of Geophysical Research: Atmospheres 119(19), 11,205–11,222 (2014), DOI: 10.1002/2014JD021992

2. Kalugin, A.S., Motovilov, Y.G.: Runoff Formation Model for the Amur River Basin. Water Resources 45(2), 121–132 (2018), DOI: 10.7868/S0321059618020013

3. Khrapov, S., Khoperskov, A.: Smoothed-Particle Hydrodynamics Models: Implementation Features on GPUs. Communications in Computer and Information Science 793, 266–277 (2017), DOI: 10.1007/978-3-319-71255-0_21

4. Kuhn, M., Kunkel, J., Ludwig, T.: Data Compression for Climate Data. Supercomputing Frontiers and Innovations 3(1), 75–94 (2016), DOI: 10.14529/jsfi160105

5. Politi, N., Nastos, P., Sfetsos, A., Vlachogiannis, D., Dalezios, N.: Evaluation of the AWR-WRF model configuration at high resolution over the domain of Greece. Atmospheric Research 208, 229–245 (2018), DOI: 10.1016/j.atmosres.2017.10.019

6. Raghavan, S.V., Liu, J., Nguyen, N.S., Vu, M.T., Liong, S.Y.: Assessment of CMIP5 historical simulations of rainfall over Southeast Asia. Theoretical and Applied Climatology 132(3), 989–1002 (2018), DOI: 10.1007/s00704-017-2111-z

7. Wang, Y., Leung, L.R., McGregor, J.L., Lee, D.K., Wang, W.C., Ding, Y., Kimura, F.: Regional Climate Modeling: Progress, Challenges, and Prospects. Journal of the Meteorological Society of Japan. Ser. II 82(6), 1599–1628 (2004), DOI: 10.2151/jmsj.82.1599

8. Wang, Y., Jiang, J., Zhang, J., He, J., Zhang, H., Chi, X., Yue, T.: An efficient parallel algorithm for the coupling of global climate models and regional climate models on a large-scale multi-core cluster. Journal of Supercomputing 74(8), 3999–4018 (2018), DOI: 10.1007/s11227-018-2406-6