Interprocess Communication Issues with OpenFOAM for Wind Simulation

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***Abstract*—Issues related with the MPI inter-process communications of OpenFOAM in High Processing Computers (HPC) is discussed in this paper. The final goal of this work is realization of wind simulation over rugged terrain, with case study of Albanian territory, using resources offered by the H2020 project VI-SEEM regional platform, The analysis of scalability of the software in three different parallel systems is presented, showing a decrease of performance in low level systems, which is considered as result of inter-process communication between computing nodes. Scalability results indicate limits of model resolution that may be obtained in reasonable time in different parallel systems accessible in VI-SEEM platform.**

Keywords—OpenFOAM; wind simulation; parallel processing

I. Introduction

The H2020 project VI-SEEM (https://vi-seem.eu/) goals are the creation of a Virtual Research Environment (VRE) in Southeast Europe and Eastern Mediterranean (SEEM), using HPC resources of the region, exploitable by different researchers from scientific communities of Life Sciences, Climatology and Digital Cultural Heritage. In the framework of this project we are working to realize the simulation of the wind over rugged terrain of the country, dominated by several mountain ranges of the alpine belt characterized by narrow valleys. The results of the work would help for better planning of economic activities, tourism and wind energy.

For calculations of wind simulation the open source OpenFOAM software was selected. Simulations were done for a quasi-prismatic 3D volume with dimensions 270x480x10km, which bottom was modeled following the terrain with the help of the NASA SRTM Digital Elevation data from USGS archive (https://lta.cr.usgs.gov/), with resolution 3 arcsec per pixel that correspond approximately to a rectangular resolution of 100x100m in equator, in our case an image of 3600x4800 pixels.

The literature review [1-13] showed that for parallel processing with OpenFOAM, the memory, the scalability and inter-process communications are critical for a reasonable runtime especially in small systems: “the size of the problems that can be handled on a HPC cluster lies beyond the limitations imposed by smaller in-house clusters” [6]. This particularity made necessary a careful analysis of performances and resource consumption of OpenFOAM for the concrete problem, and the planning or requirements for HPC resources offered by VI-SEEM.

Following a more detailed description of the VI-SEEM project is presented, and results of OpenFOAM inter-process communication performances in small systems are analyzed. Detailed analysis of runtime in high level HPC systems is presented in [15].

The work was realized in the Faculty of Information Technology (FTI) of Polytechnic University of Tirana, Albania, in collaboration with the Institute for Information and Communication Technologies (IICT) of Bulgarian Academy of Sciences in Sofia.

II. Experimental Setup

The acronym of the project “VI-SEEM” stands for “VRE for regional Interdisciplinary communities in Southeast Europe and the Eastern Mediterranean”. It is funded from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 675121, with duration of 36 months starting at 01/10/2015.

Fig. 1. *map of VI-SEEM partner countries*

The work presented in this paper has been supported by EU under the H2020 programme Grant agreement no. 675121: VRE for regional Interdisciplinary communities in Southeast Europe and the Eastern Mediterranean (VI-SEEM). The collaboration under the COST programme Action IC1305: Network for Sustainable Ultrascale Computing (NESUS) helped for the speedup of the work.

The historical context of this initiative is formed by several previous successful projects in the area of South-Eastern Europe (SEE), focused in networking and high performance computing: SEEREN1-2, Grid SEE-GRID-1/2/SCI, HPC HP-SEE; and Eastern Mediterranean (EM) HPC projects LinkSCEEM1-2.

Based on this historical context the actual project aims at merging of SEE and EM regions in the field of high performance computing, to provide user-friendly integrated e-Infrastructure platform for Scientific Communities in Climatology, Life Sciences, and Digital Cultural Heritage for the SEEM region; by linking compute, data, and visualization resources, as well as services, software and tools (Fig. 1).

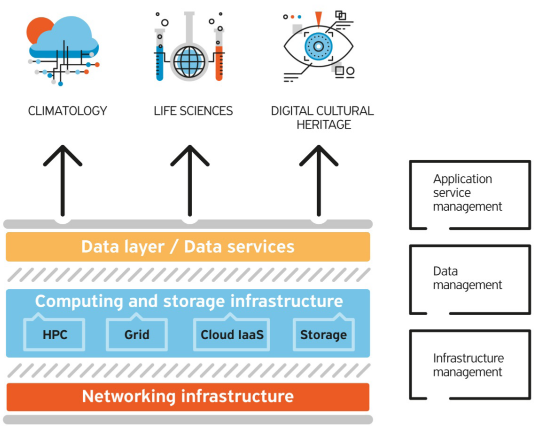

Fig. 2. *VI-SEEM virtual research environment.*

The project is based in a distributed infrastructure composed by HPC systems in partner countries, with a total of 21500 CPU cores, 325000 GP-GPU cores and 18500 Intel Xeon Phi cores of HPC, 2900 grid cores, 10500 cloud VM cores, 11 PBytes of storage (of which dedicated 5-15% , 10-15%, 5% and 10% respectively). This distributed architecture implies diverse computing technologies, advent of big data, and the need for service orientation (Fig. 2).

VI-SEEM unifies SEE and EM high performance computing, grid and cloud infrastructures for the benefit of 3 large regional communities of climatology, life sciences, and cultural heritage through creation of a Virtual Research Environment, unifying networking, computing and data management, with the support for the full lifecycle of scientific research and services provided through a service catalogue.

The 3D atmospheric volume in consideration was digitized obtaining several models with varying size and resolution, reducing the maximal resolution offered by 3” SRTM DEM. The sizes of selected model are presented in Table 1. The factor was used to simplify graphical presentation of results.

We used the software GDAL 1 to transform DEM data from SRTM format into Surfer ASCII and modified the heights (Z coordinates) of mesh points generated by blockMesh module of OpenFOAM. A view of DEM image and related 3D modified volume are presented in Fig. 3.

TABLE I. MODEL SIZES USED FOR EXPERIMENTS.

Factor	X size	Y size	Z size	Elements	RAM KB
10	36	48	10	1.73E+04	1.20E+05
30	108	144	30	4.67E+05	4.98E+05
43	154	206	43	1.36E+06	1.25E+06
60	216	288	60	3.73E+06	3.07E+06
100	360	480	100	1.73E+07	1.31E+07
139	500	667	139	4.64E+07	3.34E+07
1000	3600	4800	1000	1.73E+10	1.43E+09

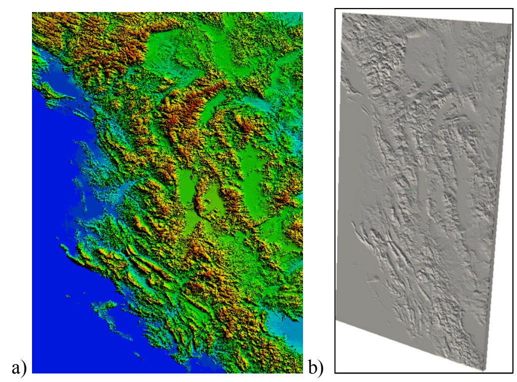

Fig. 3. *a) DEM image for Albania and surrounding area; b) Bottom surface of 3D volume deformed based on DEM.*

Experiments were done in several platforms, running in serial and parallel with MPI in desktop level, in the parallel system SUGON situated in Faculty of Information Technology of Polytechnic University of Tirana, and in HPC systems IPP and AVITOHOL of IICT in Bulgarian Academy of Sciences, all Linux platforms (Scientific Linux and Fedora):

a) Desktop with processor Intel core i7 and 16 GB of RAM,

b) SUGON main node with dual processor Intel Xeon E5506 and 2GB RAM,

c) IPP Infiniband cluster with dual processor Intel Xeon X5560 and 24 GB RAM per node,

d) AVITOHOL system with dual processor Intel Xeon E5-2650v2 and 64GB RAM per node.

Runtime was measured using the /usr/bin/time to execute serial OpenFOAM modules:

- Mesh generation – blockMesh

- Cutting the 3D volume mesh into chunks for parallel processing – decomposePar

- Combining results chunks into a single 3D array – reconstructPar

For the parallel solver icoFoam the ExecutionTime and ClockTime values were used, produced by the module itself for each time step. Memory requirements were evaluated running in parallel the /usr/bin/top command in batch mode. Iterations in time were done for 100 steps of 1 second, 0.1 second and 0.01 second. With the increase of resolution a reduction of the time step was necessary to avoid the divergence of solutions due to the increase greater that 1 of the courant number [14]. The number of time steps was decided considering future needs to analyze oscillations in time of the solution.

For the highest resolution DEM it was not possible to make any test due the huge volume of data, and simple extrapolation was tone for an approximate evaluation.

III. INTER-PROCESS COMMUNICATION ISSUES

First tests were done in the desktop platform, profiting from the central memory of 16 GB. This system was used to evaluate memory and external storage requirements. Evaluation of external storage requirements was a tricky issue because OpenFOAM stores spatial results in time steps. We used the numbers of points and faces of the 3D mesh, which are function of only the spatial mesh of the model, to compare model data sizes in the external storage. In Fig. 4 the number of points and faces of 3D mesh, together with the single process runtime for blockMesh generator and icoFoam solver, are presented.

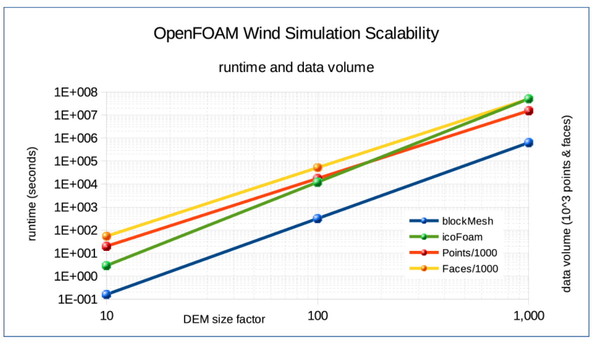

Fig. 4. *runtime and data volume in desktop platform.*

In Fig. 5 the requirements for virtual memory of blockMesh and icoFoam modules is presented.

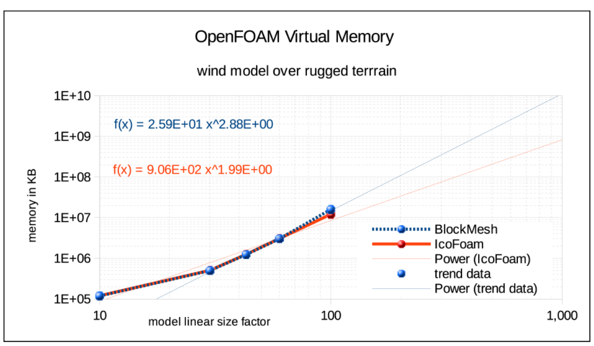

Fig. 5. *virtual memory requirements.*

The results show that for models with resolution higher than 1000m the volume of requested central memory becomes a barrier for most of parallel systems. With the increase of the number of processes the requests for central memory per process decreases (Fig. 6) but only for the solver, other modules are not parallelized (at least with the version 2.3.0 of OpenFOAM). The only way to parallelize the whole calculation in such case remains the manual splitting of the 3D volume in chunks to be digitized and processed by different parallel processes of each of preparatory and solver modules.

The first tentative to run the solver in parallel was done in the SUGON system of FTI.UPT, despite the limited central memory of its nodes. Results (Fig. 7, Fig. 8) showed that with the increase of model size the performance degenerates – the increase of the number of processes did not reduced the runtime, compared with results of tests in higher performance systems.

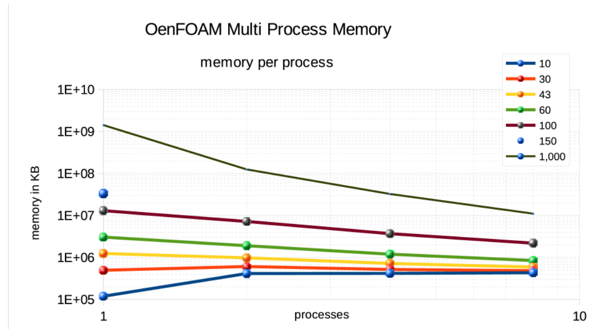

Fig. 6. *virtual memory requirement per process*

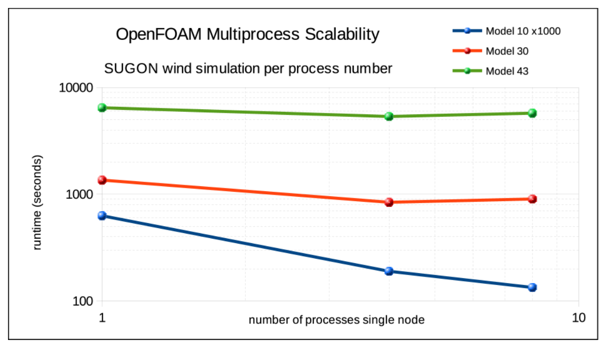

Fig. 7. *runtime of icoFoam per number of processes in SUGON*

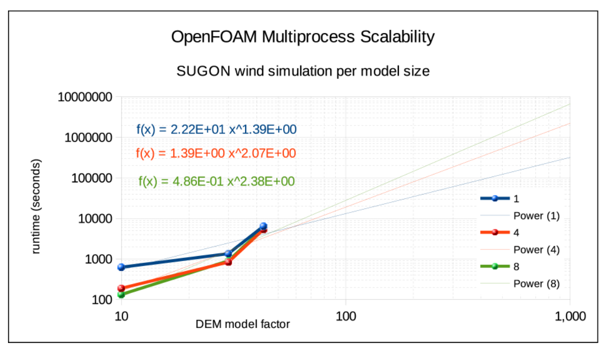

Fig. 8. *runtime of icoFoam per model size (right) in SUGON.*

The next stage of tests was done in the system IPP of IICT in Sofia. The overall runtime for all OpenFOAM modules is presented in Fig. 9. The effect of parallelization resulted not satisfactory, the scalability for the model with factor 100 (medium size) was little improved with the increase of the number of parallel processes as shown in Fig. 10 and Fig. 11.

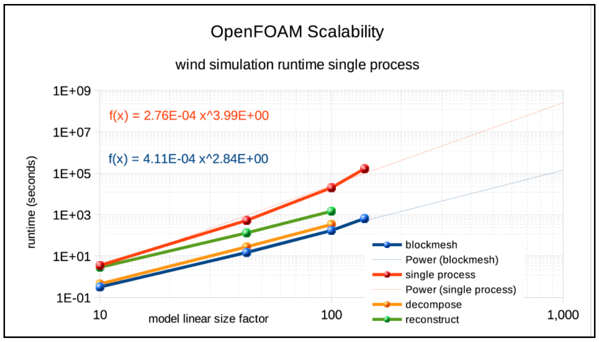

Fig. 9. *runtime for OpenFOAM modules in IPP.IICT.*

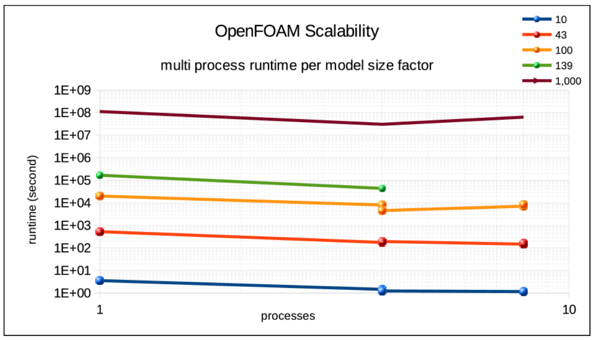

Fig. 10. *runtime of icoFoam per number of processes in IPP.IICT*

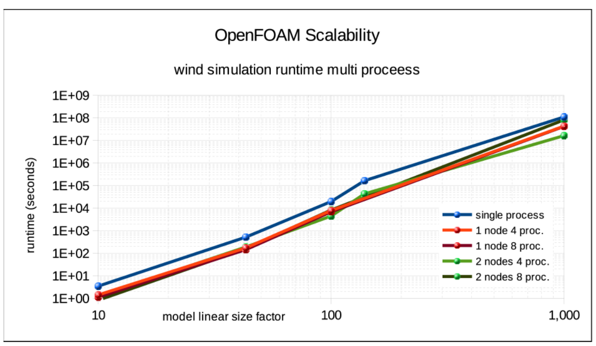

Fig. 11. *runtime of icoFoam per model size (right) in IPP.IICT*

The final tests were done in AVITOHOL system of IICT, where the scalability of the software with the increase of the number of parallel processes (Fig. 12, Fig. 13).

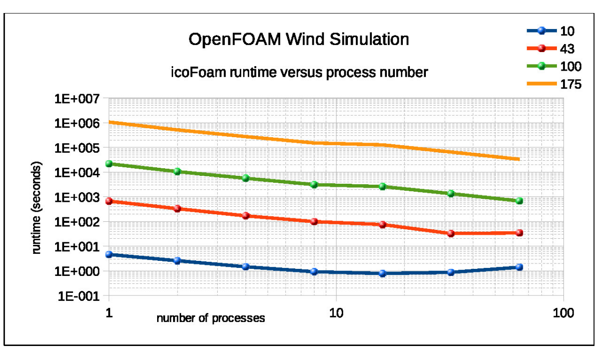

Fig. 12. *runtime per number of processes in AVITOHOL*

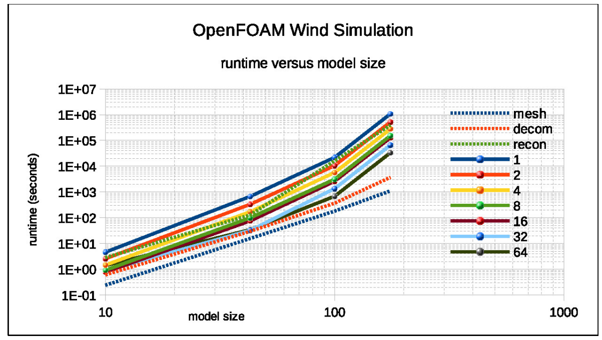

Fig. 13. *runtime per model size in AVITOHOL*

The slight loss in performances when jumping from 8 to 16 processes is supposed by the use of hyperthreading. The loss of performance for small models executed with many parallel processes is also evident. Considering that only in systems as AVITOHOL may be possible to run the OpenFOAM for at least medium resolution models, a test to evaluate the impact of interprocess communication was done with satisfactory results (Fig. 14). For this test a case of 64 processes for the model size factor 100 was done, distributing processes in 1, 2, 4, 8, 16, and 32 nodes.

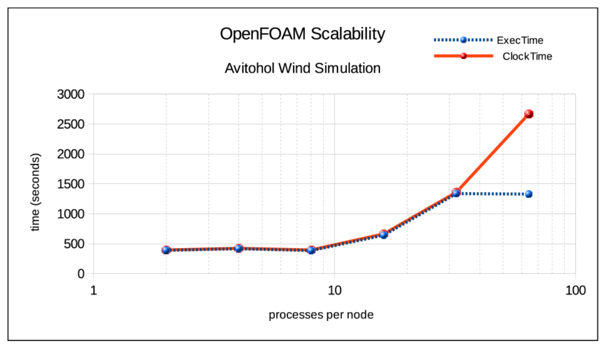

Fig. 14. *runtime for 64 processes in different number of nodes in Avitohol*

There is the same runtime until the number of processes becomes greater than 16, which is the maximum number of hyperthreads accepted by the hardware.

We compared the scalability of the same models in parallel systems that differ from each other from computing node hardware parameters and the interconnecting switch bandwidth. The runtime for the same model in different systems should be different, but the scalability of parallel processing should be similar when only the volume of calculations is considered. The scalability resulted worse in low end systems, which indicated that both the volume of calculations and inter-process communications impacted the runtime.

IV. CONCLUSIONS

Experiments with OpenFOAM for wind simulation in regional scale for the territory of Albania, in small parallel systems, showed that it is not possible to realize simulations with high resolution models because of three factors: requirement for huge virtual memory, very long runtime due volume of calculations, and not effective use parallelization due to inter-process communication.

Simulation of small resolution models may be sufficient to obtain a regional view of wind flows (an example is presented in Fig. 15), while for detailed simulations proper parallel systems are needed.

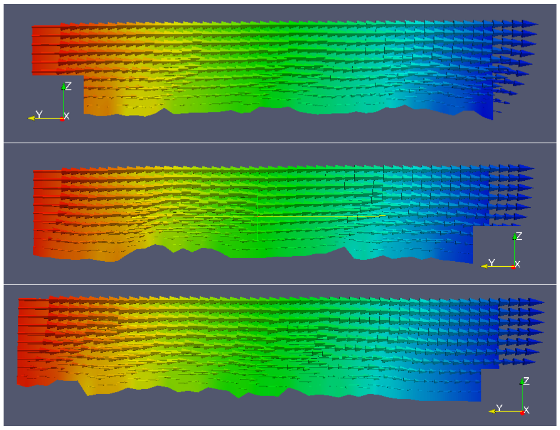

Fig. 15. *Example of three North-South vertical profiles of air flow over rugged terrain (height of the 3D volume is increased 10 times for clarity of presentation)*

Tests are done for simple wind flows north to south. The realization of more realistic cases for Albania, and consideration of other factors as the temperature necessary to take into account local wind factors, remains for the future work.

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