Workshop HPC-TRES

Book of abstracts

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High
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1st Workshop HPC-TRES

High Performance Computing – Training and Research for Earth Sciences

March 13th 2018, Area della Ricerca del CNR – Pisa, Italy

The HPC-TRES program

HPC-TRES is a national initiative promoted by OGS and CINECA aimed to implement a training program focussed on High Performance Computing (HPC) applications for Earth Sciences. HPC-TRES is co-sponsored by the Minister of Education, University and Research (MIUR) under its extraordinary contribute for the Italian participation to activities related to the international infrastructure PRACE – The Partnership for Advanced Computing in Europe.

The major objectives of the program are: capacity building, enhancement of human resources, and advanced training in the fields of Earth System modelling (atmosphere, hydrosphere, lithosphere and biosphere) and numerical models, the latter considered as a strategic cross-cutting element for modelling activities. These objectives will be pursued through the use of national and European HPC infrastructures and services in the framework of PRACE, the optimization of algorithms and numerical codes, the optimal management of "Earth Sciences Big Data", and the graphical visualization techniques for multidisciplinary applications in the Earth Sciences, also in the frame of the "Blue Growth" strategy.

Therefore, the HPC-TRES program establishes, sponsors and oversees training and research awards (in the form of scholarships grants) that support the research lines described in the scientific plan of the HPC-TRES program. A number of Italian research groups and institutions involved in HPC applications for Earth Sciences (INGV-Pisa, CNR/ISAC, CNR/IGG, CMCC, ICTP-ESP, MOX-Politecnico di Milano, ENEA-SSPT, INGV-SST, INGV-CNT, Univ. Bicocca, CRS4, EURAC, ARPA-FVG) have already endorsed the HPC-TRES initiative, contributing to the HPC-TRES scientific plan.

The 1st HPC-TRES workshop

The 1st workshop of HPC-TRES was organized by OGS with the fundamental logistic support of CNR-IGG; the event was hosted at the "Area della Ricerca del CNR", Pisa. The main objectives were: to gather all the research groups that contributed to the HPC-TRES scientific plan, to present the status and the current outcomes of the research activities, and to offer an opportunity of discussion and cross-discipline contamination, supported by the common HPC background which characterizes the different scientific approaches adopted by the research groups involved in the program.
A total of 33 participants registered to the workshop, and 15 past and present HPC-TRES grantees (65% of the total grants acknowledged by the program in the period 2014-2017) presented the main results of their research work, highlighting the scientific and technological challenges they have coped with. Modelling studies at different spatial and temporal scales, implementation of innovative algorithms, model optimization, HPC model data management, covered different Earth Sciences topics: from global to regional climate, atmosphere, ocean, hydrology, volcanic and earthquakes studies.
Tab. 1 shows the list of participants, some information related to the reference HPC-TRES research line where they are involved, and the title of the presentations. The abstracts of the presentations are included in the present report.

	Name, institution	Notes (role, research line, title of presentation)
1	Cosimo Solidoro, OGS	Steering Committee, President (A1, A2, A3, A4, C3, D1, D3)
2	Filippo Giorgi, ICTP	Steering Committee (C2, C6, D3)
3	Antonello Provenzale, IGG-CNR	Steering Committee (C1, D2, D6)
4	Giovanni Aloisio, CMCC	Steering Committee (A5, E1)
5	Jost von Hardenberg, ISC-CNR	Steering Committee (D2)
6	Tomaso Esposti Ongaro, INGV	Steering Committee (B5, B6, B7, C4)
7	Stefano Salon, OGS	Steering Committee, Secretary (A1, A2, D1)
8	Alessia Balanzino, ISAC-CNR	Development and tuning of the high resolution global climate model EC-Earth (D2)
9	Ivano Barletta, CMCC	Advanced Solution of Linear System in Parallel Ocean Models (A5)
10	Julie Baron, OGS	3D numerical simulations of earthquake ground motion (B1)
11	Giacomo Bertoldi, EURAC	(C7)
12	Marco Bettiol, OGS	HPC data management approach for the Copernicus biogeochemical model of the Mediterranean Sea (A1)
13	Luca Bonaventura, POLIMI	(C4)
14	Elisa Bortoli, EURAC	Re-engineering and optimization of GEOtop software package (C7)
15	Federico Brogi, INGV	Towards MagmaFOAM, a computational tool to simulate magmatic systems (B6)
16	Florence Colleoni, CMCC	(C5)
17	Erika Coppola, ICTP	(C6)
18	Peter Danecek, INGV	(E5)
19	Valeria Di Biagio, OGS	The MITgcm-BFM model of the Mediterranean ecosystem: from the basin-scale to coastal areas (C3)
20	Fabio Di Sante, ICTP	The Regional Earth System Model RegCM-ES: recent studies and latest developments (C6)
21	Sandro Fiore, CMCC	(E1)
22	Giovanni Galli, OGS	A Small-scale model of coral ecophysiology used to isolate biologically mediated and abiotic contributions to the process of calcification (A3)
23	Peter Klin, OGS	(B1, B2)
24	Stefania Lombardi, CNR-IGG	Logistic Support
25	Silvia Mocavero, CMCC	(A5)
26	Chiara Montagna, INGV	(B6)
27	Lyuba Novi, IGG-CNR	A numerical study of rapidly rotating Rayleigh-Bénard tilted convection (C1)
28	Stella V. Paronuzzi Ticco, POLIMI	Development of a HPC library for the parallel implementation of p-adaptive discontinuous finite element methods applied to geophysical flows (B5, C4)
29	Eric Pascolo, CINECA	High Performance oCeanography (A1, A4)
30	Michele Petrini (Skype), TU-DELFT	Interplay between grounding-line migration and sub-shelf melting during the last retreat of Bjørnøyrenna (central Barents Sea) ice stream (C5)
31	Marco Reale (Skype), ICTP	Preliminary results of the new Regional Earth System Model RegCM-ES coupled with a Biogeochemical model over the Mediterranean Region (D3)
32	Umberta Tinivella, OGS	(E6)
33	Giovanni Tumolo, ICTP	Development of a HPC library for the parallel implementation of p-adaptive discontinuous finite element methods applied to geophysical flows (C2, C4)

Tab. 1 – List of participants (with affiliations), and notes including role, HPC-TRES research lines, and title of presentation.

Acknowledgement

The 1st HPC-TRES workshop was supported by OGS thanks to the MIUR grant "PRACE-Italy", under the extraordinary contribute for the Italian participation to activities related to the international infrastructure PRACE – The Partnership for Advanced Computing in Europe.
We acknowledge Stefania Lombardi (IGG-CNR) for the logistic support for the workshop organization at the Area di Ricerca premises in Pisa. We also thank Tomaso Esposti Ongaro (INGV) for the organization of the Social Dinner.

The HPC-TRES Steering Committee:
Cosimo Solidoro (OGS, Trieste)
Filippo Giorgi (ICTP, Trieste)
Tomaso Esposti Ongaro (INGV, Pisa)
Antonello Provenzale (CNR-IGG, Pisa)
Giovanni Aloisio (Univ. Salento and CMCC, Lecce)
Jost von Hardenberg (ISAC-CNR, Torino)
Carlo Cavazzoni (CINECA, Bologna)
Stefano Salon (OGS, Trieste)

References

HPC-TRES program, web page:
http://www.ogs.trieste.it/en/content/hpc-training-and-research-earth-sciences-hpc-tres

Index

Development and tuning of the high resolution global climate model EC-Earth

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Keywords: global climate models, net surface flux, radiative energy balance, equilibrium temperatures, satellite observations, model evaluation.

EC-Earth is a state of the art global coupled climate model, which integrates a number of component models in order to simulate the earth system. It is developed by a consortium of European research institutions, which collaborate in the development of a new Earth System Model, with a strong participation and commitment by ISAC-CNR.
The goal of EC-Earth is to build a fully coupled Atmosphere-Ocean-Land-Biosphere model, to be used from seasonal climate prediction to long-term future climate projections.
A number of specific tools, compiler/languages and libraries are needed to configure and build EC-Earth 3 and the necessary support software has been developed by the consortium and is being further developed. The simulations have been performed on HPC machines (i.e. the ECMWF cca machine and MARCONI at CINECA). The parallelization paradigm is MPMD, joining separate executables for the ocean, the atmospheric component and for possible earth system modules, based on MPI communication.

The physical processes associated with radiative transfer, convection, clouds, surface exchange, turbulent mixing, subgrid-scale orographic drag and non-orographic gravity wave drag all have a strong impact on the large-scale flow of the atmosphere. However, these mechanisms are often active at scales smaller than the resolved scales of the model grid. Parameterization schemes are then necessary in order to properly describe the impact of these subgrid-scale mechanisms on the large-scale flow of the atmosphere. In other words the ensemble effect of the subgrid-scale processes has to be formulated in terms of the resolved gridscale variables. These parameterizations are characterized by control parameters, which are only weakly constrained by observations, leaving an opportunity to use them to fine-tune the overall energy budget of the model.
The tuning strategy is mainly based on improving the representation of the main radiative fluxes. A special focus is reserved for the net surface flux. Theoretically the net surface flux should be computed as the sum of the net shortwave, net longwave, sensible heat and latent heat flux (including in the latter the latent heat carried by snowfall). The situation is slightly more complex when trying to detect which are the "correct" values for net surface flux. For this purpose, from different atmospheric runs, we investigated the sensitivity of the EC-Earth radiative fields to some parameters that affect convection, entrainment rates, precipitation, and other various water-cycle-related features. We observed the dependence of different energy fluxes to changes in these parameters. In particular, most efficient knobs are *ENTRORG* (it controls the organized entrainment in deep convection) and *RPRCON* (it controls the rate of conversion of cloud water to rain).

	RPRCON	**RVICE**	**RLCRITSNOW**	**RSNOWLIN2**	**ENTRORG**	**DETRPEN**	**ENTRDD**	**RMFDEPS**
Ref.val.	1.20E-03	0.13	3.0E-05	0.035	1.50E-04	7.50E-05	3.0E-04	0.3
Tuning val.	1.51E-03	0.125	4.20E-05	0.035	1.66E-04	6.90E-05	3.60E-04	0.27

Table1. Convection and microphysical parameters

In table 1, we refer to the optimal choice of tuning parameters that provide reasonable simulated (post-tuning) values (table 2) fluxes at the TOA around 240Wm^{-2} and a positive flux at the surface of about 0.6 W m^{-2}, in accordance with the best estimates from observations (Wild et al., 2013). Indeed, the simulated pre-tuning values (table 2) show unrealistic low values net TOA and a too low net surface flux.

	TOAnet SW	TOAnet LW	Net TOA	SWCF	LWCF	NetSfc
CERES-EBAF_v4.0	240.9	-240.1	0.71	-45.8	28	0.6
sim. val. (pre-tuning)	238.4474	-239.3415	-0.8941	-48.3024	26.8453	-0.5922
sim. val. (post-tuning)	240.3979	-240.0744	0.3235	-46.3214	26.6054	0.6051

Table2. Radiative fluxes W/m^2 (simulated period 1995-2009)

We evaluated the tuning experiments using different post-processing and analysis tools, which have been developed and improved by our research group, including a tool which computes a global energy flux budget and Reichler and Kim (2008) performance indices

The future aims are to investigate the impact on global energy balance of issues such as inclusion of a dynamic vegetation model, atmospheric chemistry and transport model, and a more realistic representation of snowalbedo on ice. In particular, a better understanding of the model at present day allows performing a long-term historical simulation from initial states in 1850. It is worth to highlight that different tuning sets may lead to different model climate sensitivities. A further difficulty is that most of these results were obtained in standard resolution, atmosphere only, simulations. Atmosphere-ocean coupled runs, higher resolution simulations and the inclusion of earth-system components such as active vegetation or dynamic aerosols all require a different tuning, which is currently under development, with the aim of obtaining, in addition to realistic present day fluxes, also realistic equilibrium temperatures in long-term present-day and preindustrial simulations.

Acknowledgement

The research reported in this work was supported by OGS and CINECA under HPC-TRES program award number 2015-10. We acknowledge the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support (Pra13_3311, IscraC “IsC59_ECE3SPH”, IscraB “IsB15_DIXIT”) and ECMWF special projects (spitvonh and spnltune) for resources on their machines.

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Advanced Solution of Linear System in Parallel Ocean Models

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Keywords: linear systems, parallel ocean models, communication overhead, preconditioning

Numerical Ocean Models rely on the solution of linear systems. This happens when the models use implicit schemes to solve the equations (e.g. the free surface equation). Krylov Subspace Methods are most commonly used to solve the linear systems, and in the distributed memory case this introduces a communication overhead that becomes the more onerous the more parallel processes are used. The aim of this work is to search and test new solutions, also in terms of new algorithmic approaches to reduce this overhead in order to improve ocean models scalability in the context of Exascale computing.

Krylov Subspace methods (KSP) is the most common technique deployed by numerical ocean models to solve linear systems of equations, that can be briefly called $Ax = b$ (A,x,b Matrix, solution, right-hand side respectively). They have become a common and powerful tool to solve linear/non-linear system, eigenvalue problems even for large problems and do not require relaxations parameters.

The main idea behind KSP is to generate a basis of vectors of the Krylov Subspace Span$\{v, Av, A^2v, ..., A^{m-1}v\}$ and search for an approximate solution out of this space. The nature of KSP algorithms (e.g. Conjugate Gradient, GMRES, Bi-Conjugate Gradient) is iterative and involves a number of matrix-vector products proportional to the iterations they go through, each one with a new residual ($r_m = Aa_m - b$), where a_m represents the m−th current approximation of the solution. KSP iterative algorithms stop when a certain tolerance (ε) is reached, generally $\|r_m\|/\|b\| < \varepsilon$.

In case of distributed memory, a communication cost is introduced by the update of lateral boundary conditions for matrix-vector products, and one to calculate the norm of residual. Current research mostly works to damp the number of iterations, since each one is affected by these communication costs.

This work has been focused on NEMO (Madec, 2008) model and SHYFEM (Umgiesser, 2004) model. In the first case the aim was to improve the scalability of native solver in case of filtered free surface case, while in the second, the solution of free surface equation in case of semi-implicit scheme has been parallelized. In both case the method consisted of nesting an external package in the model code for the solution of the linear systems on distributed memory architectures. The external package selected for this purpose is PETSc (Satish, 2016), easy to implement and providing interface to a broad choice of algorithms and preconditioners.

Results of performances are shown in fig. 1

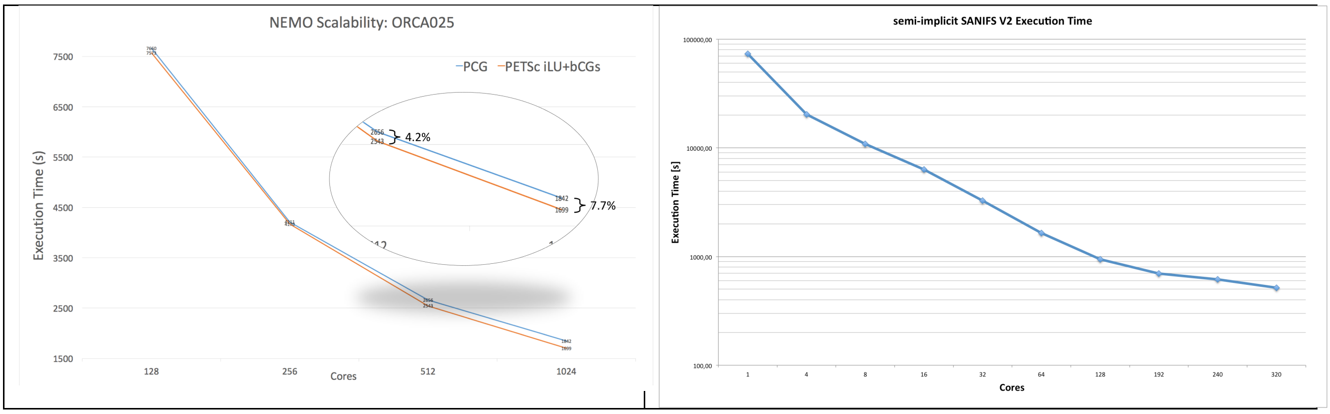

Fig.1 – [left panel] Comparison of NEMO performance on ORCA025 configuration, with PCG native solver and biConjugateGradientStabilized algorithm with incompleteLU precoditioner. [right panel] Scalability of SHYFEM on SANIFS (South Adriatic Northern Ionian Forecast System) configuration (1.2 m elements approximately) with semi-implicit time stepping scheme and free surface equation solved with PETSc.

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The research reported in this work was supported by OGS and CINECA under HPC-TRES program award number 2015-09. We acknowledge the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support (IscraC "HYPER").

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3D numerical simulations of earthquake ground motion

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Keywords: seismic ground motion, numerical simulations, Fourier pseudo-spectral method, spectral element method, topography

The rapid improvement of numerical techniques and computer technologies allows us to adopt the numerical modelling of the seismic waveforms both in ground motion simulation for seismic hazard studies and in seismic tomographic studies aimed at unveiling the geophysical properties of the Earth's interior.

Seismic wave propagation in the Earth is governed by the wave equation that relates the displacement field to the distribution of density and elastic parameters. Several methods have been developed for the numerical solution of the wave equation in 3D heterogeneous media. They mostly differ from each other in their spatial discretization schemes, which can be based either on a structured or an unstructured grid and which affect the choice of the parallelization approaches.

In this project that started in early February, we will use and compare two methods: 1) the Fourier pseudo-spectral method (FPSM3D) based on structured grid and implemented at OGS (Klin et al. 2010) with a hybrid MPI and OpenMP parallelization and 2) the spectral element method (Komatitsch and Tromp, 2002a) based on unstructured grid, as implemented in the open-source SPECFEM3D Cartesian 2.0.2 software (Komatitsch et al., 2012) with pure MPI parallelization. We plan to apply numerical simulations to a number of test cases concerning the evaluation of the expected ground motion during an earthquake with a particular interest on the amplification effects due to surface topography. In a second step, we plan to model and characterise possible seismic ground motion amplifications due to the presence of buildings. Comparisons with observations coming from real case studies will be performed for model validation.

We start with the presentation of two numerical seismic modelling case studies. The first example presents an application of FPSM3D to the forward modelling, of seismic wave propagation in the Po Plain. The study evidenced the role of the heterogeneous geological structure of the Po alluvial basin in the long duration of the ground motion that was observed during the 2012 seismic sequence. The second example presents the workflow and the results of an inverse modelling with a seismic tomography study applied to the Vrancea region (Romania) using SPECFEM3D (Baron and Morelli, 2017). This study provided additional details about the geophysical and geodynamical structure of that peculiar seismic region. For each example, we indicate the computational grid characteristics and the computational costs of the simulations that were performed using the CINECA HPC resources through different ISCRA projects.

Finally we present the preliminary results for our current research project. We simulated the seismic wave propagation through the Mount Etna crust (Sicily), using an unstructured grid that includes the topography and a geophysical 1D model of the region. We used the SPECFEM3D Cartesian 2.0.2 software and CINECA-MARCONI HPC resources. The results, in terms of seismic waveforms, peak ground displacement/velocity/acceleration, and amplitude spectra, can be analysed and compared with respect to a flat model, without topography. This will allow us to identify and quantify which parameters of the seismic response can be correlated to given topographic characteristics.

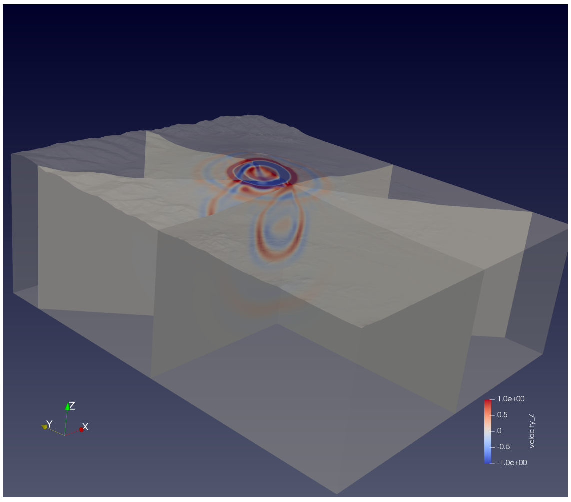

Fig.1 – Numerical seismic ground motion propagation (velocity) on the vertical component for a dipole source placed under Mount Etna (Sicily). The unstructured grid, built with the internal mesher of SPECFEM3D, is made of 173 568 spectral elements and includes topography and the 1D velocity model of Chiarabba et al. (2000). Simulation has been run on the A1 partition of Marconi CINECA HPC resources on 96 cores.

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HPC data management approach for the Copernicus biogeochemical model of the Mediterranean Sea

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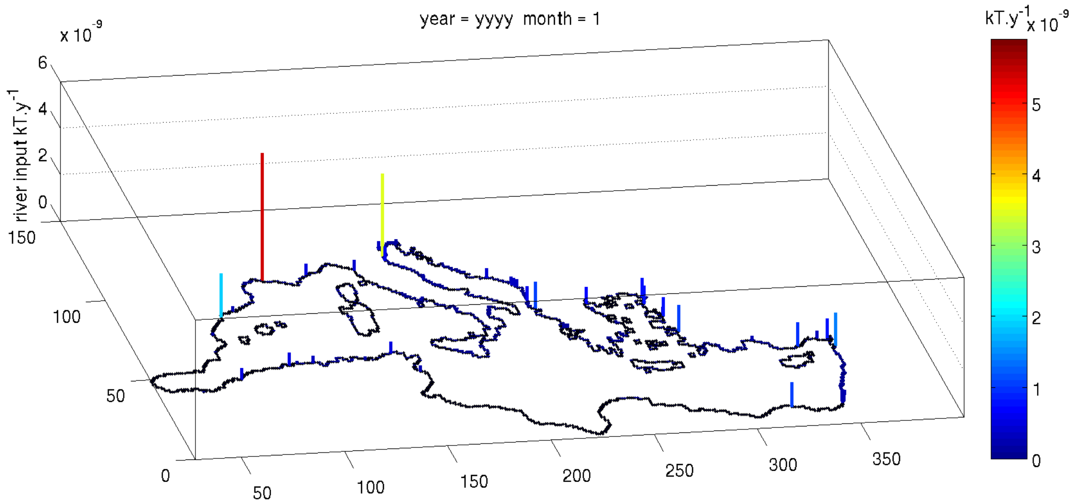
Keywords: MHPC, Biogeochemical model, Mediterranean Sea, Boundary Conditions

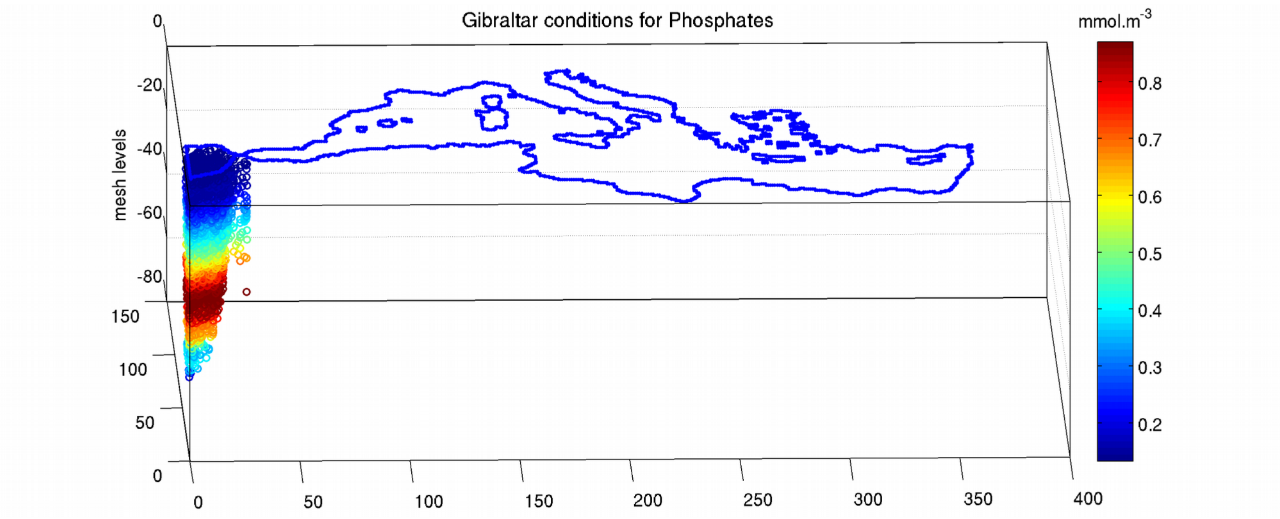
I started the HPC-TRES program after a Master Degree in Environmental Physics and two years as a Big Data Engineer in a consulting company. The first six months of the program were devoted to the theoretical part of a 2nd level Master Degree in High Performance Computing co-organized by SISSA (International School for Advanced Studies, Trieste, Italy) and ICTP (International Centre for Theoretical Physics, Trieste, Italy). Topics included profiling and benchmarking of scientific codes and applications, optimization of serial codes, data structures and design patterns and parallel programming both in shared and distributed memory, also with GPUs. The second part of the Master is a thesis project and this is where my actual collaboration with OGS starts.

The model which I will be working on is the OGSTM-BFM model, i.e. a coupled transport - biogeochemical model describing the Mediterranean Sea. The physical information is obtained from the NEMO3.6 model, offline coupled and acting as a physical forcing. Together with a 3D-VAR data assimilation unit for satellite data, the system is at the basis of two products developed for the EU community under the CMEMS (Copernicus Marine Environment Monitoring Service) framework, and it is under continuous development.

The long term goal of my project will be to create a versatile interface and infrastructure to assign the boundary conditions of the model. Both an addition of physical complexity and a re-factoring of the code are needed for several reasons, such as to couple the Mediterranean forecast system with the global or adjacent CMEMS forecast systems, or to implement a flexible sensitivity/calibration framework for tuning the boundaries in order to get a more accurate model output. Boundaries are of different kinds and include atmosphere, rivers and the Gibraltar and Dardanelles straits. The latter will be actually the object of the first step of the project. The goal will be to move from the current scalar approach (initialization of a few cells on the surface layer) to a full open boundary condition reproducing the mass flow at the vertical section of the Dardanelles strait.



(Fig.1a)



(Fig.1b)

Fig.1a / 1b – Planned evolution of the input pattern for the boundary conditions at the Dardanelles Strait: from the initialization of a few surface cells (a), in a similar way to what is done for the rivers, to the initialization of a 2D wall and of a volume, like what is currently developed for the Gibraltar Strait.

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Re-engineering and optimization of GEOtop software package

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Keywords: hydrological modelling, soil water content, code optimization, parallelization

A hydrological model is a simplification of a real-world system that aims in understanding, predicting, and managing water resources. The so called "integrated" hydrological models are used to solve simultaneously states (i.e., soil water content, snow cover) and fluxes (i.e., evapotranspiration, runoff) in and between multiple terrestrial compartments, such as surface water, groundwater, snow cover. Given that they are quite important in Earth Sciences. However, they are CPU-intensive, need large amount of model parameters and are characterized by uncertainty in boundary and initial conditions (Kollet at al, 2017).

The GEOtop model is an integrated hydrological model that simulates the heat and water budgets at and below the soil surface. It describes the three-dimensional water flow in the soil, using Richards equation, and the energy exchange with the atmosphere, reproducing the interactions between the water and energy balance (Rigon et al, 2006 and Endrizzi et al, 2014). Two configurations are available for the setup: the 1D configuration, in which only vertical fluxes are considered, so the mass and energy balance are performed at local scale, and the 3D configuration, in which both vertical and lateral fluxes are involved, thus the balances are performed at basin scale. Among the inputs parameters there are meteorological data, elevations (DEM), soil parameters and among the outputs there are soil temperature, soil moisture and snow cover.

The core components of the GEOtop package were presented in the 2.0 version, written in C, which was released as free software open-source project and scientifically tested and published. However, despite the scientific quality of the project, a modern software engineering approach was still missing. From 2014 on, researchers and scientists started to develop the 2.1 version, written in C++, open source and documented with track changes on a GitHub repository on which a continuous integration mechanism by means of *Travis-CI* is enabled (http://geotopmodel.github.io/geotop/).

The goal of the study is to optimize and parallelize the code, starting with a code profiling using *gprof* (https://sourceware.org/binutils/docs/gprof/), *perf* or *callgrind* (http://valgrind.org/docs/manual/cl-manual.html) to see where the code code spends most of the time. Then a HP library could be used: actually running *Darshan*, an open source runtime library reporting statistics and timing information for each file accessed by the application (http://www.mcs.anl.gov/research/projects/darshan/), it was noticed that GEOtop was reading and writing a lot of small files (average size of the totally opened files: 49K), resulting in poor performance. The *MeteoIO* library could be a good choice: it is a C++ library that makes data access easy and safe for numerical simulations in environmental sciences. It provides a uniform interface to meteorological data in the models, implements a safe and robust I/O, unobtrusive and simple as possible for the user, and it offers high modularity so that individual elements of the library can easily be replaced/expanded/added (https://models.slf.ch/p/meteoio/).

Using data from two hydro-meteorological stations (named B2 and P2) located in Val Mazia, in South Tyrol, the GEOtop versions 2.0 and 2.1 were compiled and run using the 1D setup.

From Fig.1 it is visible that the temperature values of one of the two stations during October 2009 computed by the two versions are basically the same; instead, analyzing longer time periods (2010-2015) differences appears in some output parameters, such as the soil water content at 45 cm depth. This means that a deep analysis of the code behaviour has to be performed, in order to understand when and why these differences arise.

Summarising, the aim of this work is to optimize the GEOtop 2.1 version: starting from a profiling, the hot-spots of the code will be rewritten to allow faster runs, HP libraries (i.e. *MeteoIO*) could be used to better organize data and finally the ultimate goal would be an MPI parallelization, with a check on the scaling.

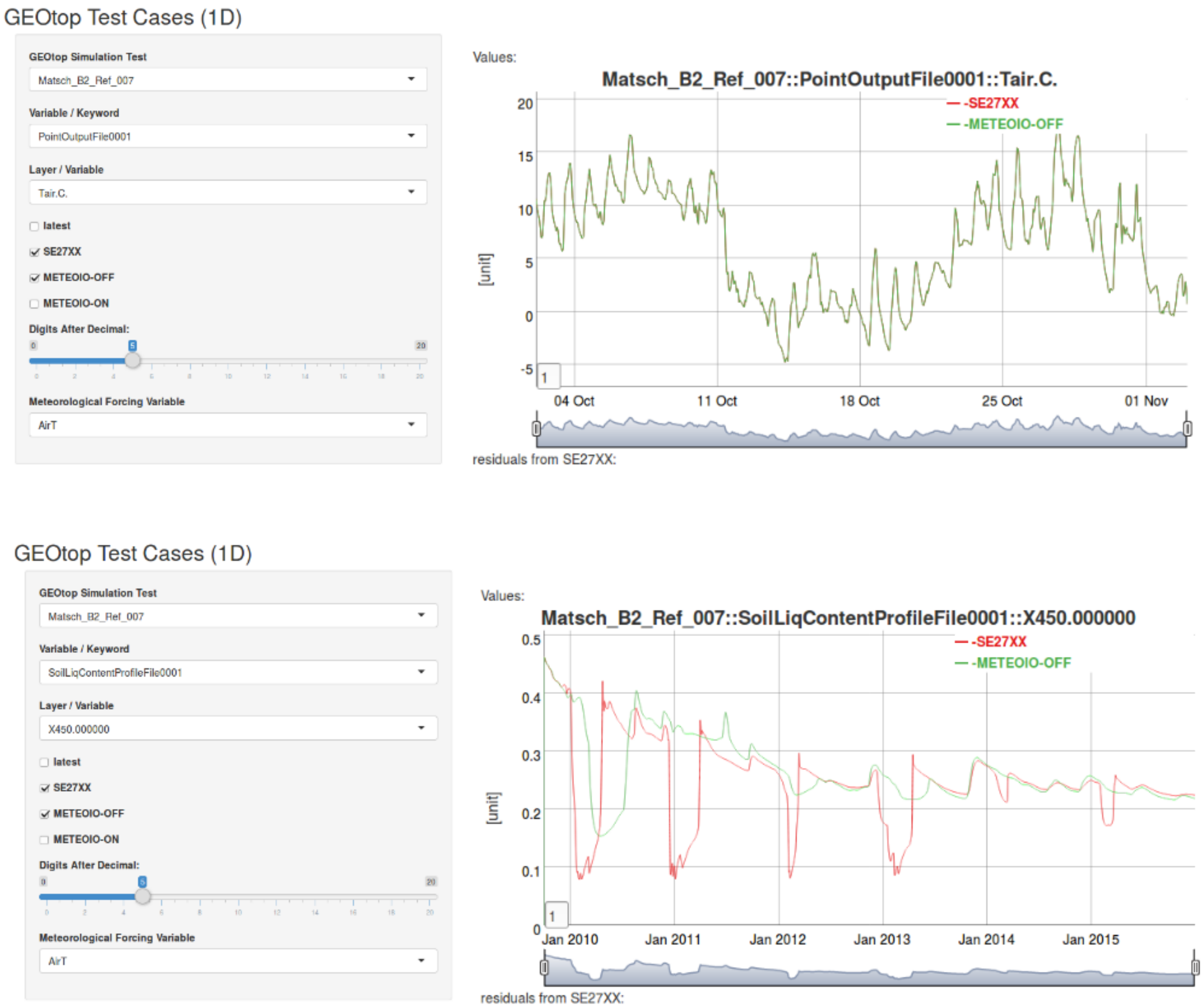

Fig.1 – Comparison between the outputs of the two GEOtop version (2.0 depicted by the red curves and 2.1 by the green ones) in the station B2 of the temperature during October 2009 (upper part) and of the soil water content at 45 cm depth during 2010-2015 (lower part).

Acknowledgement

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Towards MagmaFOAM, a computational tool to simulate magmatic systems

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Keywords: magma, modelling, mixing, multiphase

The unpredictable evolution of volcanic unrest crises is strongly dependent on the complex, non-linear dynamics of magma storage and plumbing systems. A better understanding of magma transport phenomena is of crucial importance not only to determine the eruptive potential but also to correctly interpret geophysical signals recorded by volcano monitoring systems that serve for forecasting the volcanic activity and volcanic hazard assessment. Our aim is therefore to develop and validate a generic computational tool that can be used to study the dynamics of magmatic systems.

Non-equilibrium multiphase flow models are typically required to describe the interactions among liquid magma, solid crystal phases and exsolved volatiles which may be active with disparate time-space scales in different regions of the magmatic system from deep in the magma chamber up to surface. The open source library OpenFOAM (OF), capable of handling the specific thermodynamical and rheological equations that characterize magmatic mixtures, is the ideal platform on which we can develop our dedicated computational toolbox. In addition, the OF modular object-oriented implementation (C++) allows the developers to easily expand and adapt the code and the users to combine different implemented models at run-time with almost no need to code. The newly developed library MagmaFOAM (MF), built on top of OF, is a powerful dedicated toolbox to solve multiphase flows characterizing magmatic systems in general. In particular, the current implementation of MF includes: a multicomponent (melt and volatiles) two-phase fluid solver (melt and gas); thermo-mechanical non equilibrium phase coupling and phase change; state of the art multiple volatile solubility models thanks to the coupling with SOLWCAD (Solubility Water Carbon Dioxide) [Papale, 1999]; realistic models for the equation of state [Lange and Carmichael, 1987] and the viscosity [Giordano et al., 2008] of magmatic mixtures with variable amount of dissolved volatiles.

Magma mixing phenomena are of paramount importance not only to explain the composition of igneous rock and erupted products but also volcanic explosive eruptions. Magma mixing experiments in high temperature labs have been reported by different authors in the literature and provide the unique opportunity to test the capability of MF in resolving such an important process. In particular, for validation we considered the chaotic mixing experiment [Morgavi et al., 2013] which consist in triggering the mixing between two melts (basalt and rhyolite) with a large viscosity contrast using a rotating cylindrical apparatus. Preliminary simulation results (fig. 1) obtained with MF are very promising and reproduce well the stretching and folding mechanism driving the mixing in the experiments. Bigger simulations and quantitative analysis of the results are currently under consideration in order to quantify the effect of the numerical error (numerical diffusion) and hence the resolution needed to correctly reproduce the chaotic mixing dynamics at the natural scale.

Finally, our future work will also focus on testing MF for problems that involves the presence of multiple phases (melt, gas bubbles, crystals), phase change, and evaluate their impact on the mixing and the overall system evolution. From this perspective, the method of moments will be implemented and used to describe the space-time evolution of crystals and bubbles populations in terms of the moments of their respective distribution functions, without the need to retain the microscale details. This will provide a very efficient way to deal with the very different length and time scales that characterize the dynamics of magmatic systems.

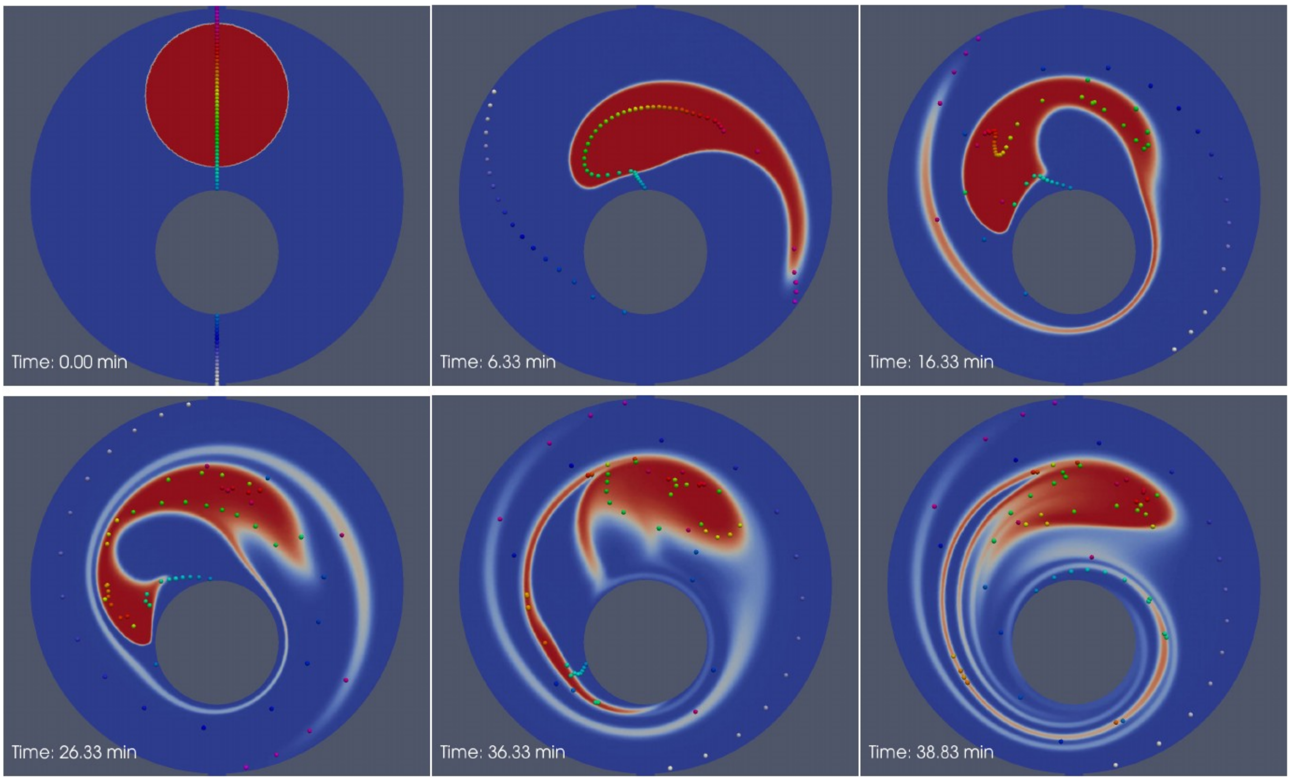

Fig.1 – Snapshots at different times for the simulation of the magma mixing experiment [Morgavi et al., 2013] considered for the validation of MF. As observed in the experiments, the basaltic (low viscosity, red) and rhyolitic melts (high viscosity, blue) mix through a stretch and fold mechanism due to the independent rotations of the outer and inner cylinder walls of the mixing device. Fluid tracers (colored particles) are also added here to better visualize the evolution of the mixing process.

Acknowledgement

The research reported in this work was supported by OGS and CINECA under HPC-TRES program award number 2016-05.

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The MITgcm-BFM model of the Mediterranean ecosystem: from the basin-scale to coastal areas

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Keywords: modeling, ecosystem, Mediterranean Sea, coupling, physics

Oceans are the largest, most complex and in great measure unexplored habitats for life on the Earth. Marine ecosystems have strong impacts on the environment and on human activities (e.g. the fishing), up to the global scale, since the biogeochemical cycles occurring within them, (e.g. the carbon cycle), influence and control the climate of the whole planet. In the present study the marine ecosystem is described using a biogeochemical approach, i.e. focusing on the transformation cycles of matter and energy among its components. Numerical models are fundamental to described such complex systems, providing complementary information to datasets of in-situ and remote measurements, that often lack adequate temporal and spatial coverages. In particular, the MITgcm-BFM coupled model was implemented to describe the main biogeochemical features of the Mediterranean Sea.

This basin is a hot spot for the marine biodiversity, because it hosts about 17000 species (i.e. the 7% of the worldwide catalogued amount), despite its volume is only 0.4% of the total volume of oceans. Moreover, the Mediterranean Sea is strongly affected by a lot of socio-economical activities (e.g. dumping, fishing, tourism, aquaculture) and it is sensitive to climate change (e.g. relevant impacts of the increase of ocean temperatures were recognised on marine organisms).

The hydrodynamics of the Mediterranean Sea is modeled using the MITgcm (i.e. the General Circulation Model developed by the Massachusetts Institute of Technology), that solves the Navier-Stokes equations of the geophysical fluids by the finite volume method. The BFM (i.e. the Biogeochemical Flux Model), developed by a consortium of scientific institutes, describes the Mediterranean marine biogeochemistry solving a system of ordinary differential equations for the mass fluxes of 51 constituents and nutrients, in the water dissolved phase, in the plankton and in the detritus compartment. In a theoretical scheme of coupling, the MITgcm is the master model, that manages hydrodynamics, transport and diagnostics, whereas the BFM is called by the MITgcm as an external library of biogeochemical reactions. The online coupling is implemented upgrading the native package of the MITgcm for the geochemistry and inserting the additional package BFMCOUPLER, that handles the information and communications between the two models. This 3D state-of-the-art coupled model can be used under different configurations to describe marine biogeochemistry from the basin scale down to the coastal areas.

The parallelization strategy of the MITgcm is based on the domain decomposition and the MPI library usage. Further improvements of the execution times of the coupled model was obtained enabling the LONGSTEP package of the MITgcm, that allowed to compute the biogeochemical reactions each LSn iteration of the physics, involving in the computation the physical fields averaged on the LSn timesteps. The value of LSn was chosen equal to 5 on the basis of previous studies on the accuracy of the solution.
About 150000 core-hours were used to run the 1979-2012 coupled simulation of the Mediterranean ecosystem at 1/12° of horizontal resolution, on 75 vertical levels, with 150 s of integration time and 8 terabyte of output data were produced and stored on PICO and GALILEO machines at Cineca.

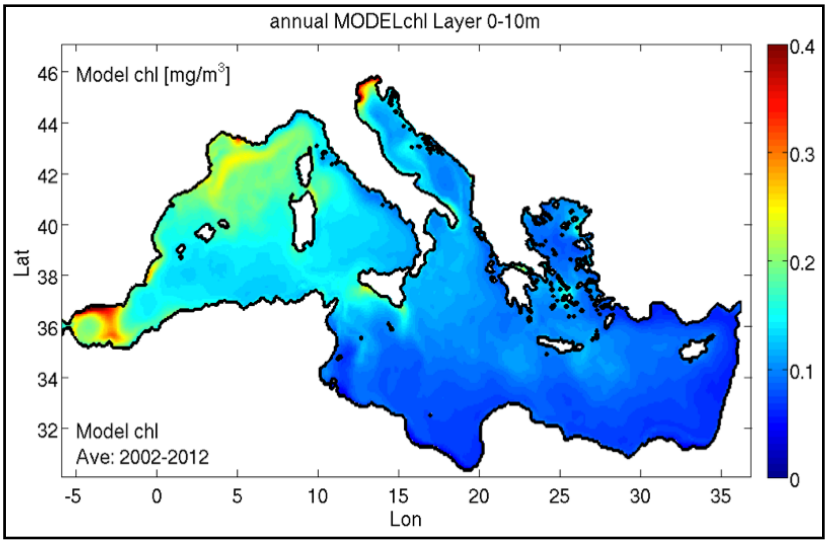

Fig.1 - Annual surface chlorophyll concentration provided by the MITgcm-BFM 1979-2012 simulation.

The MITgcm-BFM model is currently used within the CADEAU project, that is a downstream CMEMS (i.e. Copernicus Marine Environment Monitoring Service) product focused on the monitoring of the water quality and the ecosystem status of the Northern Adriatic Sea for the 2006-2016 period. The high resolution (1/128°) model is driven by the downscaling of the Mediterranean CMEMS hydrodynamics and biogeochemistry and is integrated with a regional dataset of the main environmental variables provided by Friuli-Venezia Giulia, Veneto, Emilia-Romagna and Marche coastal stations.

Acknowledgement

The research reported in this work was supported by OGS and CINECA under HPC-TRES program award number 2016-04. We acknowledge the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support (IscraC “IsC34_BIOMEDCO”, “IsC41_BIOMEDXT”, “IsC45_BLOMEDXT”, “IsC55_CADRI”).

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The Regional Earth System Model RegCM-ES: recent studies and latest developments

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Keywords: Regional Earth System Model, Monsoon, RegCM-ES, Climate

During the last year, a great effort has been put to obtain an instrument that was able to simulate the interaction of the different components of the atmosphere, the ocean, the rivers, the land and the biosphere. To this aim, the new Regional Earth System Model (RESM) RegCM-ES has been developed thanks to the contribute of different institutions and scientists [Sitz et al, 2017].

In RegCM-ES the interactions between the components are in two directions (online coupling) allowing to simulate the two way feedback mechanisms. The online regridding and data exchange among the components is taken into account by a driver developed using the Earth System Modeling Framework (ESMF) and The National Unified Operational Prediction Capability (NUOPC) layer. The atmospheric component is the version 4 of RegCM [RegCM4; Giorgi et al. 2012], a regional climate model used by a very large community and for a wide range of regional climate studies. The ocean component is the Massachusetts Institute of Technology General Circulation Model version c63s (MITgcm) [Marshall et al., 1997; http://mitgcm.org/]. For the hydrological processes the task is carried out by the Community Land Model in the version 4.5 (CLM4.5) and one of the two hydrological models implemented in the coupled system: the HD and the Cetemps HYdrological Model (CHyM). The implementation of the new physically based hydrological model CHyM is the most recent development of RegCM-ES. It allows the use of finer resolution and the possibility of simulate also the small river catchments.

We tested the RegCM-ES with the new hydrological component over two different domain: the Mediterranean and South Asia, both of them being part of the COordinated Regional climate Downscaling Experiment (CORDEX). An evident improvement compared to the previous implementation is related to the hydrological part of the system. In the South Asia experiment, the simulated river discharge by the RegCM-ES using CHyM model is closer to the observation compared to the implementation that make use of HD. The comparison analysis of the simulated monsoon variability between the coupled and the standalone version of RegCM over the Indian Ocean shows interesting results. At first, both the intraseasonal and interannual variability are simulated more realistically by the coupled model confirming what found in previous studies. Moreover, analyzing the lead-lag relationship between El Niño Southern Oscillation (ENSO) and the Indian Summer Monsoon Rainfall (ISMR) an interesting finding arises. The well known decrease of instantaneous negative correlation between the ISMR and ENSO after the 60's is concurrently associated to an increase of positive correlation between the one year leading ENSO and ISMR providing potential predictability of ISMR with several months lead time.
As a future work we have planned to run a new experiment under the Mediterranean Coordinate Regional Downscaling Experiment (MED-CORDEX) using CINECA supercomputer Marconi.

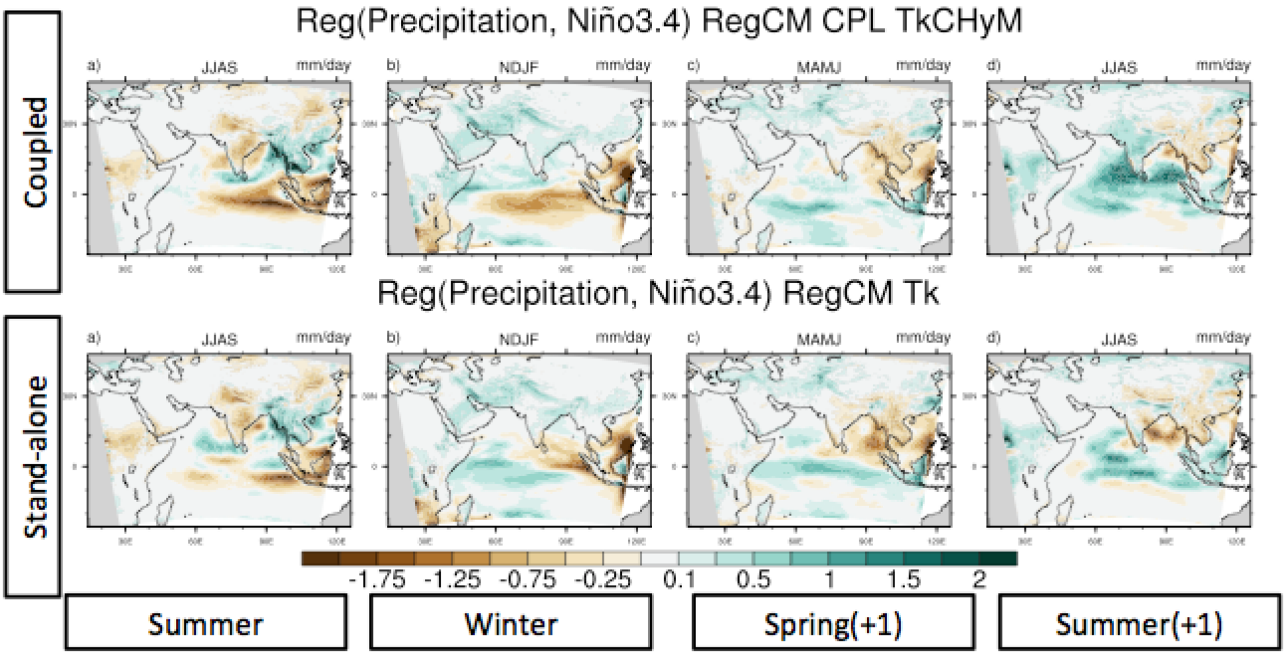

Fig.1 - Regressed precipitation anomalies onto the Niño-3.4 index (calculated for the Summer monsoon season) for the Coupled (first line) and Stand-alone (second line) version of RegCM4

Acknowledgement

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A Small-scale model of coral ecophysiology used to isolate biologically mediated and abiotic contributions to the process of calcification.

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Keywords: corals, calcification, light-enhanced calcification, biological control, calcification cost, calcification model, temperature, acidification

Coral calcification is the process by which corals lay down their calcium carbonate skeleton. Calcification is a key process because this is how coral reefs are formed and grow. The process of calcification is known to be influenced by environmental variables, like seawater temperature and chemistry (i.e. the carbonate system) and by metabolic rates like photosynthesis and respiration. Research into coral calcification ecophysiology has unveiled how each of these variable and processes has a two-fold effect on calcification, with contributions that can be coarsely ascribed to biologically mediated and abiotic mechanisms (Allemand et al., 2011). An obvious example is temperature which is clearly a major determinant of metabolic rates, but also fosters the deposition of calcium carbonate in an abiotic framework. Similarly, low seawater pH may bring to dissolution of carbonates, but also high pCO2 is tied to metabolic depression and imbalance of cellular homeostasis (Pörtner, 2008). Finally, corals that bear photosynthetic algal symbionts (zooxanthellae) are known to increase calcification rates when exposed to light, a phenomenon called light-enhanced calcification that is believed to be mediated by symbionts' photosynthetic activity. There is controversy over the mechanism behind this phenomenon, with hypotheses coarsely divided between abiotic and biologically-mediated mechanisms (Allemand et al., 2011). At the same time, accumulating evidence shows that calcification in corals relies on active ion transport to deliver the skeleton building blocks into the calcifying medium, making it is an energetically costly activity (Zoccola et al., 2015). Here we build on generally accepted conceptual models of the coral calcification machinery (Hohn and Merico, 2012) and conceptual models of the energetics of coral-zooxanthellae symbiosis to develop a model that can be used to isolate the biologically-mediated and abiotic effects of photosynthesis, respiration, temperature, and seawater chemistry on coral calcification rates and related metabolic costs. We tested this model on data from the Mediterranean scleractinian Cladocora caespitosa (Rodolfo-Metalpa et al., 2010), an acidification resistant species. We concluded that most of the variation in calcification rates due to photosynthesis, respiration and temperature can be attributed to biologically-mediated mechanisms, in particular to the ATP supplied to the active ion transports. Abiotic effects are also present but are of smaller magnitude. Instead, the decrease in calcification rates caused by acidification, albeit small, is sustained by both abiotic and biologically-mediated mechanisms. However, there is a substantial extra cost of calcification under acidified conditions. Based on these findings and on a literature review we suggest that the energy aspect of coral calcification might have been so far underappreciated.

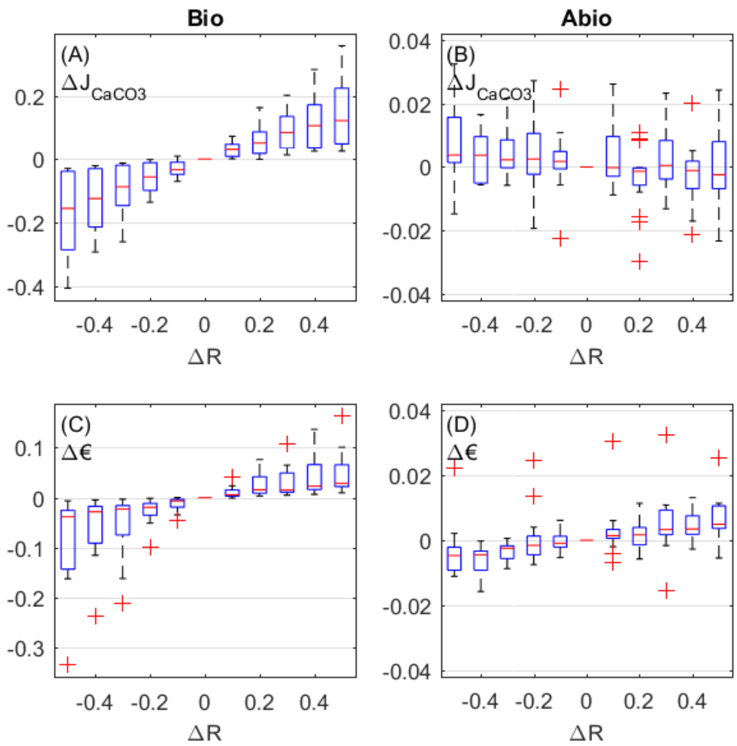

Fig.1 - Biologically-mediated (A,C) and abiotic (B,D) effects of photosynthesis: fractional change in calcification rates (top panels) and calcification costs (bottom panels). x and y-axis values are indicative of fractional change. Each boxplot represents all light setups. This picture clearly highlights how calcification rates increase for increasing photosynthesis, compatibly with the LEC phenomenon, and how this positive change is sustained prevalently by biologically mediated mechanisms, i.e. by the metabolic energy, provided by photosynthesis, that is used to run active membrane transport proteins (Ca-ATPase) that deliver calcium ions to the calcification site while removing protons at the same time.

Acknowledgement

The research reported in this work was supported by OGS and CINECA under HPC-TRES program award number 2015-05. We acknowledge the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support (IscraC "HYPER").

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A numerical study of rapidly rotating Rayleigh-Bénard tilted convection

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Keywords: rotating convection, convective plumes, large-scale pattern, heat transport, tilted rotation

Buoyancy-driven convection plays a key role in a number of physical processes involving heat transport in the oceans and atmosphere of planets and cool stars. Thermal convection in fluids has been explored throughout the past decades with the classical approach of a layer of fluid undergoing a vertical temperature gradient, i.e. Rayleigh-Bénard convection (RBC) (W. S. Rayleigh, 1916). In more realistic situations highly unstable conditions can occur (A.Parodi et al. . 2004), resulting in a turbulent convective dynamics characterized by thermal plumes and pattern formation.

In natural geophysical and astrophysical systems, such as rapidly rotating spherical shells, turbulent RBC is coupled with the system rotation which can dramatically alter the heat transport processes and the fluid dynamics. Previous studies (J.von Hardenberg et al. 2008; C.Guervilly et al., 2014) demonstrate the inherent influence of both rotation rate and rotation axis orientation on convective systems, providing an insight into how RBC is influenced by a rotation-axis orientation either parallel or perpendicular to the gravity vector. The resulting dynamics is enormously different in the two cases. While these two conditions are representative of convection occurring at polar and equatorial regions of rotating spherical shells, this work explores the intermediate-latitude range aiming at filling the existing gap.

Three dimensional high-resolution numerical simulations of rapidly rotating Rayleigh-Bénard convection are performed, being the rotation axis slanted with respect to the gravity direction. By varying the orientation angle withing a rose of values we mimic the longitudinal movement on a rotating spherical shell along its meridian. The Navier-Stokes equations under Boussinesq approximation are numerically integrated in a horizontally-periodic domain. The code is pseudo spectral in the horizontal and uses finite differences in the vertical, and an MPI parallelization is adopted via a vertical partitioning in slices. We run the simulations on the Marconi cluster – CINECA.

The resulting dynamics and the convective heat transport in the mid-latitude range are analysed and explained within a range of physical parameters fixed to be relevant for geophysical and astrophysical fluid dynamics. We reproduced the polar and equatorial convective pattern found by previous authors, and we filled the intermediate-latitudes gap. A sensitive response of the temperature (Fig.1) , velocity and vorticity fields is found, as long as a strong influence of the rotation axis orientation on the integral quantities of the flow. A weaker heat transport is found at low latitudes along with the formation of organized wavenumber-one structures. A possible explanation of the effects of a rapid slanted rotation is finally proposed, as to our knowledge this problem has never been addressed before. This work opens new routes toward further investigations, involving a wider exploration of the parameters space in order to extend the range of relevance of these results and the dedicated numerical code.

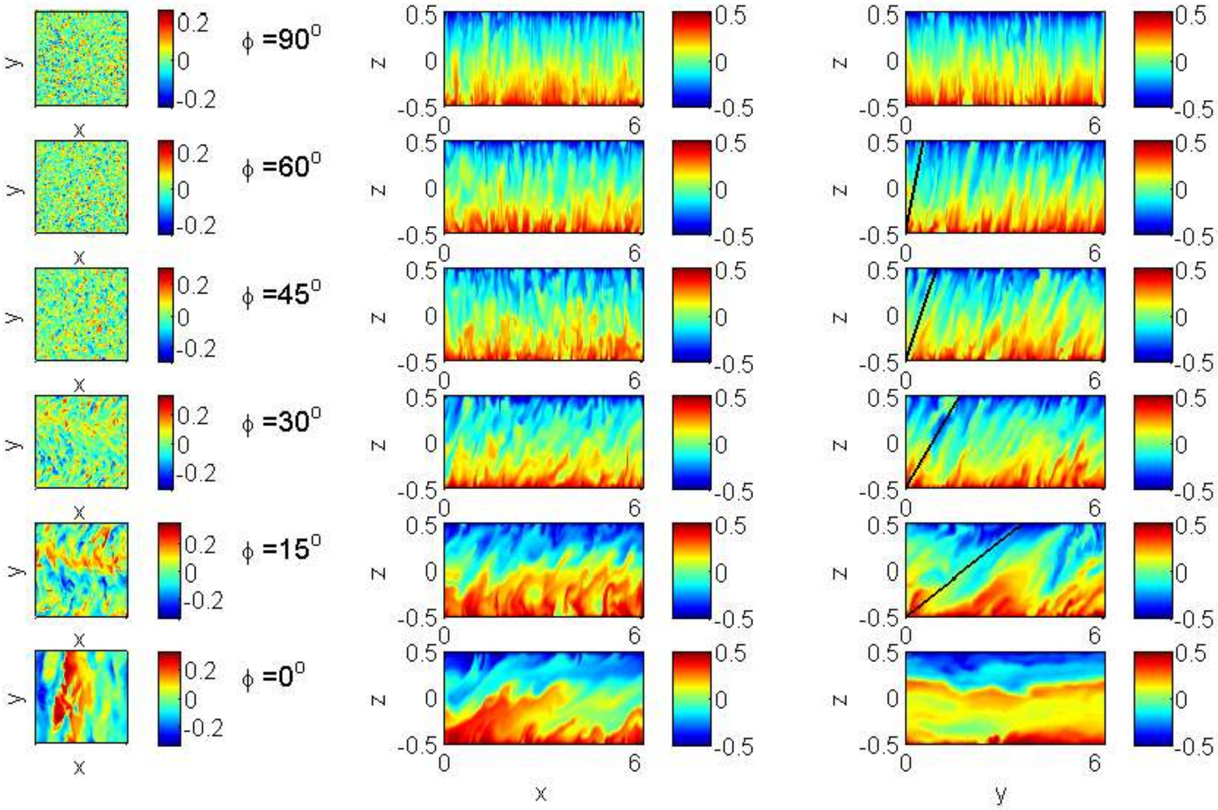

Fig.1 – Horizontal (left column) and vertical (central and right columns) sections of the temperature field computed at statistically stable state, at mid depth and mid width. The rotation axis resides on the y-z plane and its orientation is represented by the black line in the third column panels. The convective plumes align with the rotation axis on the y-z plane at each latitudes.

Acknowledgement

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Development of a HPC library for the parallel implementation of p-adaptive discontinuous finite element methods applied to geophysical flows.

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Keywords: discontinuous Galerkin methods, unstructured meshes, scaling properties

Abstract

Discontinuous finite element methods have been gaining in popularity for large scale geophysical applications. They are also a natural environment to take advantage of adaptive approaches in which the degree of the approximating polynomials is chosen locally and dynamically, in order to minimize memory occupation and computational cost. However, this poses major challenges to the parallel efficiency of the resulting methods, since a greater effort to achieve optimal load balancing is required. At present, no general HPC infrastructure for efficient and natively adaptive implementation of DG methods on massively parallel is available. The purpose of this research is to move towards the development of such a tool especially tailored for the simulation of fluid dynamics problems in climate dynamics, oceanography and volcanology.

The first theme that was issued during this work was the bettering of the I/O layer for the aformentioned tool: a completely parallel Input/Output mechanism has been developed, with respect to the previous (totally serial) output process, that was preventing to restart a given simulation.

In a second moment the problem of meshes generation starting from an orography file (Fig.1) was addressed: a fully unstructured 3D hexahedral mesh is created through a chain of scripts, refined where the orography slope is higher.

In the latter part a study on the performance of Fortran CoArrays (CAF) with respect to a standard MPI implementation is carried out. The two different parallelization paradigms confronted are clearly still not comparable, MPI still being faster and more flexible. A discussion on our decision to implement both the parallelization paradigm is presented.

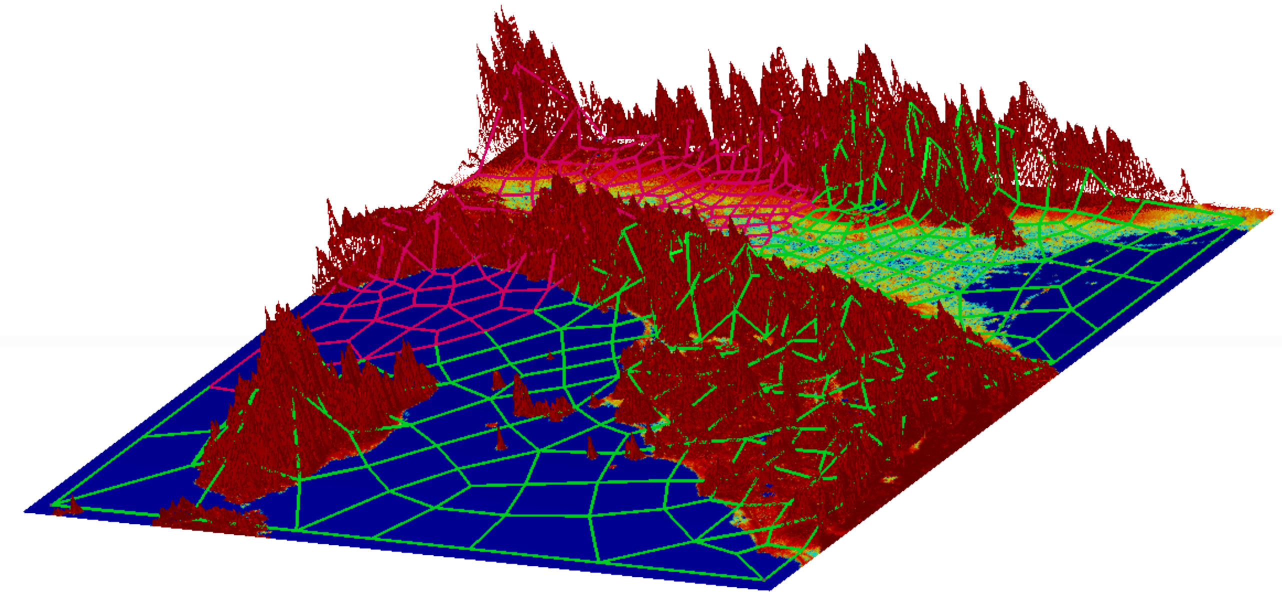

Fig. 1 : Starting from a plane NetCDF binary file a 3D hexahedral mesh is generated, through a chain scripts written in Bash, Python and Gmsh native language.

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High Performance oCeanography

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Keywords: HPC, Education, technological transfers

My presentation is focused on technological transfers and education and how a research experience is reusable in industry to improve services and make innovations in products.
I spend, at the ECHO group of Oceanography OGS Department, two years and I worked mainly on two projects:

- SHYFEM: is a shallow water FEM software used in lagoons and coastal areas for marine forecasting; I worked on shared memory parallelization with OpenMP Task paradigm and for the best of our knowledge this is the first software fully parallelized with this innovative technology (see Pascolo et al., 2016).

- COPERNICUS Forecasting workflow: this workflow is focused on biogeochemical forecasting of Mediterranean Sea. The challenge in this software was to increase the model resolution from 1/16° to 1/24°: to reach the goal we did a number of software optimizations and changed the domain decomposition.

In both projects I spend many hours in parallelization, optimization, software restoration and in collateral activities with OGS users like: support, ad-hoc training and software design consulting. The collateral activities wer not less important than the main one, because an improvement of user knowledge may increase productivity and decrease hours spent in debug, support and code refactoring.
I co-advised also two theses in OGS: a bachelor thesis focused on BFM v.5.0 optimization and a master thesis concerning the parallelization of "Data Assimilation scheme" adopted in the Copernicus forecasting workflow (now this parallel scheme is available for production).
After my experience at a Research institute I moved to the Industry world: my first experience was as HPC consultant, I worked for a machinery manufacturing company that had a realtime speedup problem on its products because they need to elaborate a large number of data in less than 1 second; this activity was very similar to SHYFEM optimization so I resolved the problem thanks to my research experience.
At the moment I work in CINECA Supercomputing center, initially with the User Support team and then as HPC Industrial consultant. Similarly to my past consultant job, I can exploit my research experience to build an easier workflow based on container technology and support a customization of a HPC Cluster in an easy way without reinstall all the software stack.

Acknowledgement

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Interplay between grounding-line migration and sub-shelf melting during the last retreat of Bjørnøyrenna (central Barents Sea) ice stream

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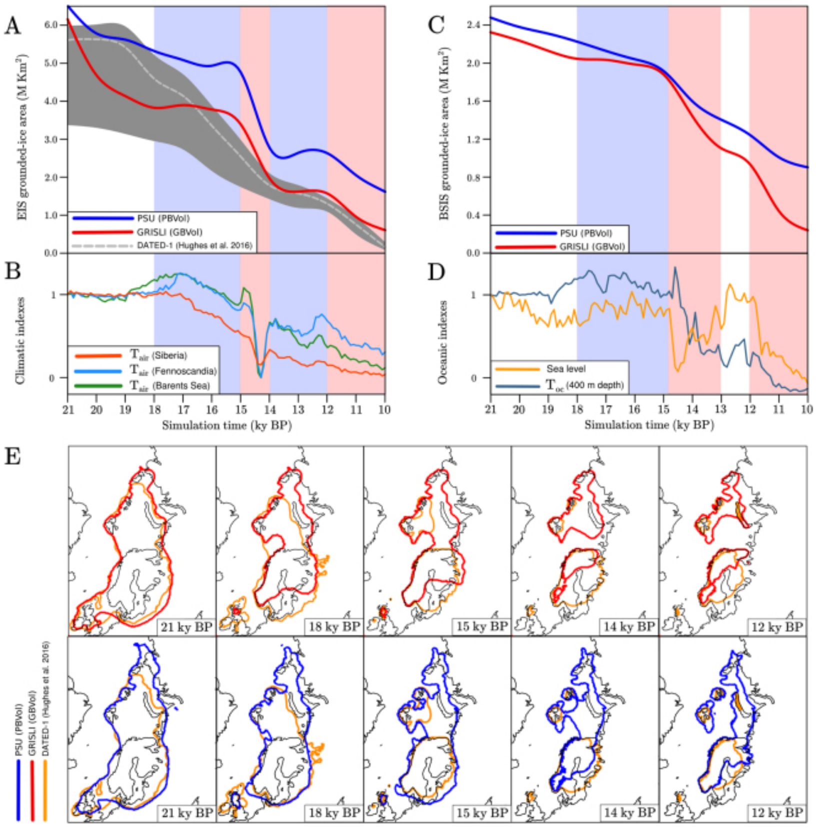
The challenge of reconstructing palaeo-ice sheets past growth and decay represent a critical task to better understand mechanisms of present and future global climate change. Last Glacial Maximum (LGM), and the subsequent deglaciation until Pre-Industrial time (PI) represent an excellent testing ground for numerical Ice Sheet Models (ISMs), due to the abundant data available that can be used in an ISM as boundary conditions, forcings or constraints to test the ISMs results. In our study, we simulate with ISMs the post-LGM decay of the Eurasian Ice Sheets, with a focus on the marine-based Svalbard-Barents SeaKara Sea Ice Sheet. In particular, we aim to reconstruct the Storfjorden ice stream dynamics history by comparing the model results with the marine geological data (MSGLs, GZWs, sediment cores analysis) available from the area, e.g., Pedrosa et al. 2011, Rebesco et al. 2011, 2013, Lucchi et al. 2013. Two hybrid SIA/SSA ISMs are employed, GRISLI, Ritz et al. 2001, and PSU, Pollard & DeConto 2012. These models differ mainly in the complexity with which grounding line migration is treated. Climate forcing is interpolated by means of climate indexes between LGM and PI climate. Regional climate indexes are constructed based on the non-accelerated deglaciation transient experiment carried out with CCSM3, Liu et al. 2009.
Indexes representative of the climate evolution over Siberia, Svalbard and Scandinavia are employed. The impact of such refined representation as opposed to the common use of the NGRIP δ18O index for transient experiments is analysed. In this study, the ice-ocean interaction is crucial to reconstruct the Bjørnøyrenna ice stream dynamics history. To investigate the sensitivity of the ice shelf/stream retreat to ocean temperature, we allow for a space-time variation of basal melting under the ice shelves by testing two-equations implementations based on Martin et al. 2011 forced with simulated ocean temperature and salinity from the TraCE-21ka coupled climate simulation.
Our results suggest that the role played by sub-shelf melting depends on how the grounding-line physics is represented in the models. When an analytic constraint on the ice flux across the grounding line is applied, the retreat of Bjørnøyrenna Ice Stream is primarily driven by internal ice dynamics rather than by oceanic forcing. This suggests that implementations of grounding-line physics need to be carefully assessed when evaluating and predicting the response of contemporary marine-based ice sheets and individual ice streams to ongoing and future ocean warming.



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The research reported in this work was supported by OGS and CINECA under HPC-TRES program award number YYYY-NN. We acknowledge the CINECA award under the ISCRA initiative, for the availability of high performance computing resources and support (IscraC "HYPER").

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Preliminary results of the new Regional Earth System Model RegCM-ES coupled with a Biogeochemical model over the Mediterranean Region

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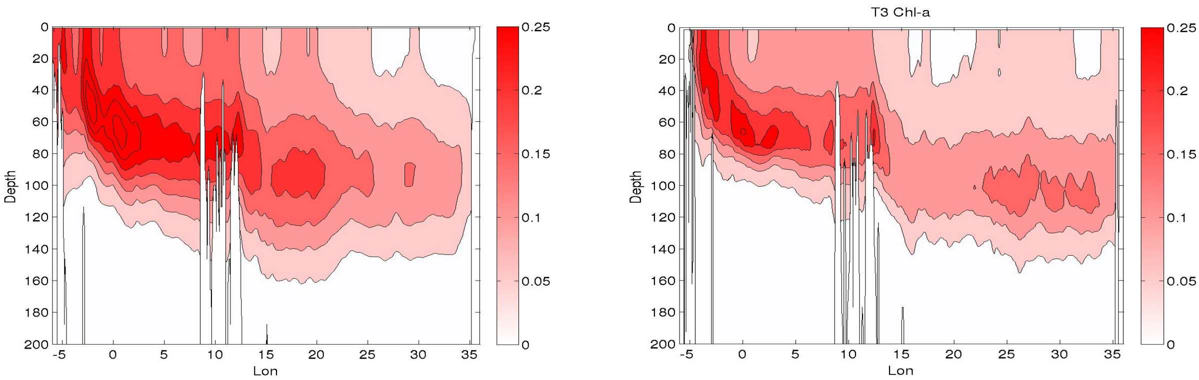
Keywords: Mediterranean Sea, RegCM-ES, Coupling, Chlorophyll-a

The Mediterranean Sea region is located in a transition zone between two different climate regimes (subtropical and mid-latitude). It is characterized by a complex land-sea distribution which affects deeply the atmospheric and oceanic flows and by a high density of population, industrial and touristic settlements which make the region particularly sensitive to extreme events, which are projected to increase in frequency in the area as a consequence of climate change.

The need for reliable climate projections for the area requires the adoption of high-resolution climate modelling tools that take into account the high complexity of the area. RegCM-ES is a newly coupled model developed at the ICTP (Sitz et al., 2017 and reference therein). It is composed by an atmospheric model (RegCM.4.6.1), coupled to a land model (CLM4.5) and river discharge model (HD), and driven by an ocean model (MITgcm) (Sitz et al., 2017 and reference therein). Recently this newly coupled model, which has been implemented and tested over different domains, has been coupled with a biogeochemical model (BFM;Vichi et al.,2015). A biogeochemical model essentially simulates the dynamics of elements such as C,N,P,O,Si but also the dynamics of phytoplankton and zooplankton community in the marine ecosystem. Phytoplankton uses the sunlight to fix the CO_2 in organic carbon (photosynthesis) influencing the level of dissolved oxygen in the water column and exchanges of $CO_2/0_2$ between atmosphere and ocean. The availability of the sunlight and nutrients (as NO_3/PO_4) can influence the efficiency of this process. The projected increasing of Sea Surface Temperature could lead to a reduction of nutrients in the euphotic area, reducing the capability of phytoplankton to do photosynthesis and the size of relative population. This could affect the zooplankton population (which feeds on phytoplankton) and but also the fish population. Consequently in an already heavily affected by human activities Mediterranean marine ecosystems, the effects of climate changes could be further amplified.

The biogeochemical model has been coupled with RegCM-ES following the approach of Cossarini et al., 2017. The newly version of RegCM-ES has been implemented and preliminary tested over the Mediterranean region. The atmospheric model (RegCM.4.6.1) has a resolution of 30 km and 23 vertical sigma levels while the ocean model has a resolution of 1/12 degree (approximately 6-8 km) and 75 not equally spaced vertical levels. The river discharge model has a fixed resolution of 0.5 degree. The model has been run for a period of five years from January, 1th 1998 to December, 31th 2002 over the cluster Argo (hosted by the ICTP). The simulation lasted for 240 hours and used 180 cores.

Preliminary comparison with observational datasets and available reanalysis has shown the capability of RegCM-ES to reproduce correctly interannual/intermonthly variability and spatial patterns of Atmospheric Fluxes, Sea Surface Salinity and Temperature, Chlorophyll-a, Nitrate and Phosphate in the Mediterranean region. Fig.1a,b shows the West-East vertical transect of Chlorophyll-a in the Mediterranean Sea as reproduced by RegCM-ES (a) and Copernicus Reanalysis (Teruzzi et al., 2016; b). Despite a tendency by the coupled model to overestimate the Chlorophyll-a with respect Copernicus both spatial pattern and the Maximum Chlorophyll Depth (MCD) are well captured by RegCM-ES.



(a) (b)

Fig.1 – Vertical West-East transect of Chlorophyll-a in the Mediterranean Region in the period 1998-2002 as simulated by RegCM-ES (a) and Copernicus Reanalysis (b).

Future work includes a longer run in order to provide a complete hindcast of biogeochemistry properties in the Mediterranean Sea since 1980 and the assessment of the impacts of the ocean circulation variability in the Mediterranean Sea on phytoplankton communities and nutrients dynamics.

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Development of a HPC library for the parallel implementation of p-adaptive discontinuous finite element methods applied to geophysical flows

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Keywords: discontinuous Galerkin methods, adaptive finite elements, unstructured meshes

High order DG methods pose stringent stability restrictions on explicit time discretization methods. In recent work by the author with the collaboration of L. Bonaventura, a strategy for the reduction of the computational cost of DG methods has been proposed, based on a novel semi-implicit, semi-Lagrangian time discretization and on a dynamically adaptive choice of the polynomial degree employed in each element which allows to reduce the number of degrees of freedom by a factor of up to 50%. In this work, we will outline the ongoing development of a parallel library that will allow to implement these adaptive techniques by taking full advantage of degree adaptivity in each coordinate direction of generic hexaedral elements.The preliminary results achieved are promising and hint that the proposed approach is useful to achieve the maximum possible flexibility in the application of high order discontinuous finite element methods to environmental flows. In particular the aim of this library is to provide an efficient parallel framework for dynamically adaptive discontinuous finite elements where the scalability is preserved even in presence of dynamic p-adaptation (see Fig.1 as an example) through the use of suitable dynamic load balancing techniques: all data structures behind this library has been indeed designed to efficiently allow elements migration as required in order to dynamically balance the computational load.

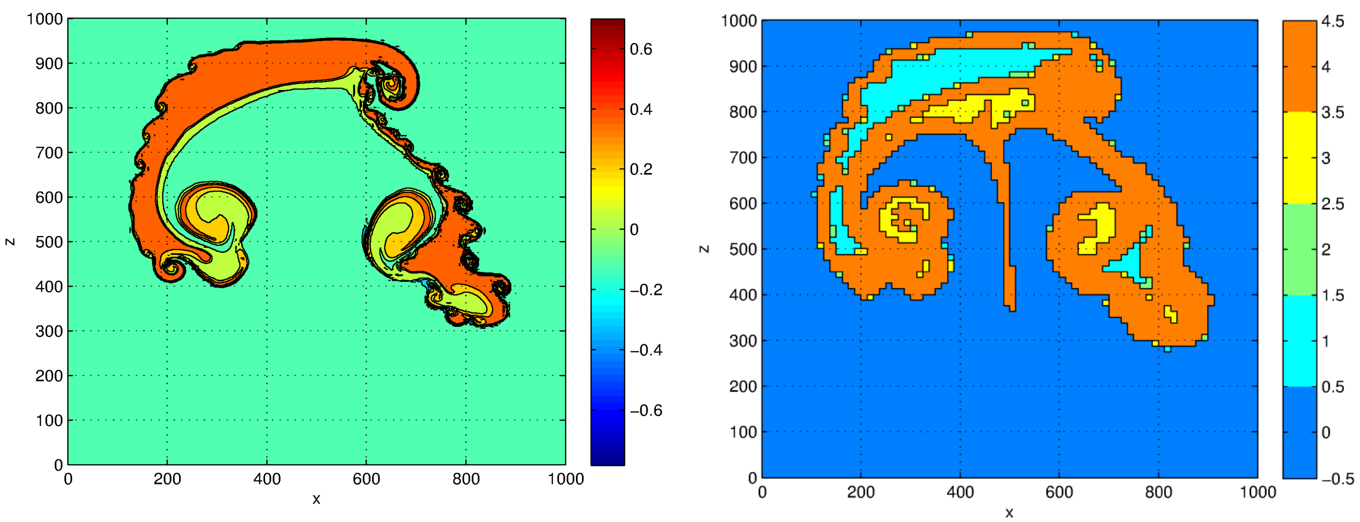

Fig.1 – Double bubble test case (Robert 1993): potential temperature (left) and local polynomial degrees for potential temperature (right).

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