Scientific Reports for ESF-MedCLIVAR Exchange Grant

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Purpose of the 5 weeks visit

The group led by Dr. Vincenzo Artale at ENEA Casaccia has ample experience in working with coupled Atmosphere-Ocean Regional Climate Models (AORCM) in the Mediterranean region. They developed a sophisticated AORCM named "Protheus system" which at the moment represents one of the most advanced modeling systems for Mediterranean climate studies. They used this model to investigate the present-day climate variability in the area (Artale et al., 2009) as well as for climate projections, obtaining satisfactory results.
We are developing an AORCM for the Mediterranean region named MOREA and therefore we are greatly interested in comparing our preliminary results with the ones obtained by Dr. Artale's group. Moreover, we expect this sharing of our respective experience might eventually lead to a deeper collaboration between our institutions, which would undoubtedly prove useful to the advance of research on Mediterranean climate.

Description of the work carried out during the visit

We compared the outcome of a simulation made by MOREA, with analogous results from the ENEA-AORCM named Protheus. Both simulations were forced with ERA40 reanalysis for the atmosphere and Levitus climatology for the ocean components. The period simulated by Protheus goes from 1958 to 2001 while the MOREA run covers the interval from 1989 to 1999.
We found a generally better agreement with observations for the Protheus system. A detailed comparison of the main output fields revealed that the major differences are related to the ocean component. For that reason, we conducted a further intercomparison analysis of standalone ocean simulations driven in both cases by ERA40 reanalysis. The ocean components are ROMS for MOREA and MITgcm for Protheus. From that comparison we concluded that ROMS performs significantly worse in reproducing the Mediterranean thermohaline circulation due to a generally larger bias in both temperature and salinity. In particular, the main problem lies in ROMS yielding too warm summer sea surface temperatures (SST), especially in the eastern basin of the Mediterranean sea, where the summer mean SST exceeds 30ºC (2-3ºC above the observed mean). This bias is illustrated in Figure 1, relative to the Levitus climatology.

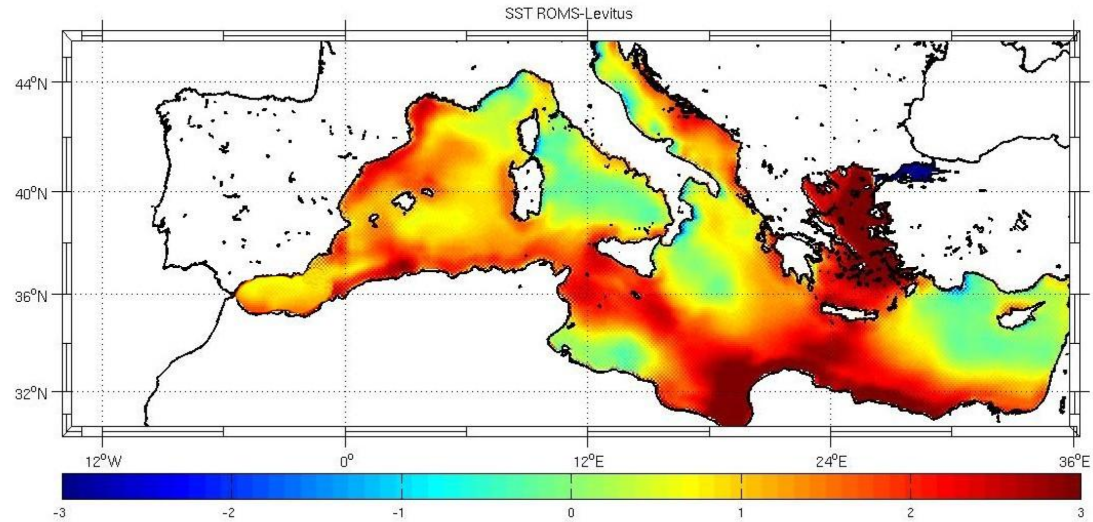

Figure 1 SST difference between ROMS and Levitus climatology. The summer average has been computed over the period 1989–1999.

This SST bias seems to be mostly related to a bad representation of the mixed layer depth, which could be improved changing the parametrization of the vertical mixing scheme. Nevertheless, these results suggest ROMS might not be the best choice for this kind of applications and should be replaced in MOREA by a more suitable model. This is further explained below.

Nowadays, most studies in Mediterranean climate modeling are carried out using horizontal domain resolution of about 1/8-1/12 degree; a higher resolution is computationally too expensive. Despite the wide application of ROMS in regional modeling, its terrain following coordinate (s-coordinate) system does not seem optimal for a region morphologically extreme like the Mediterranean basin when the horizontal resolution is to be kept within the limits specified above. In fact, the use of this s-coordinate demands the maximum slope parameter to be smaller than 0.3 (r-factor) which is archived by iteratively smoothing the raw interpolated grid bathymetry.
The slope parameter is defined as Dh/h (where h is the depth at a grid node and Dh is the depth change to neighboring nodes) and is used to assess the potential impact of pressure gradient errors induced by terrain-following horizontal layers. In regions with a relatively high r-factor, the pressure gradient errors might be significant, resulting in artificial currents developing from a state of rest with no forcing (Mellor et al. 1998, Beckman and Haidvogel, 1993). For our domain we made an estimation of this residual current running a model over 6 month with no forcing and using homogeneous stratification as initial condition. Figure 2 displays the time series of the velocity components induced by the pressure gradient errors for two stations at several depths. The positions of these stations are indicated in Figure 3a. They are located in the Alboran Sea (point A) and in the channel of Sicily (point B).

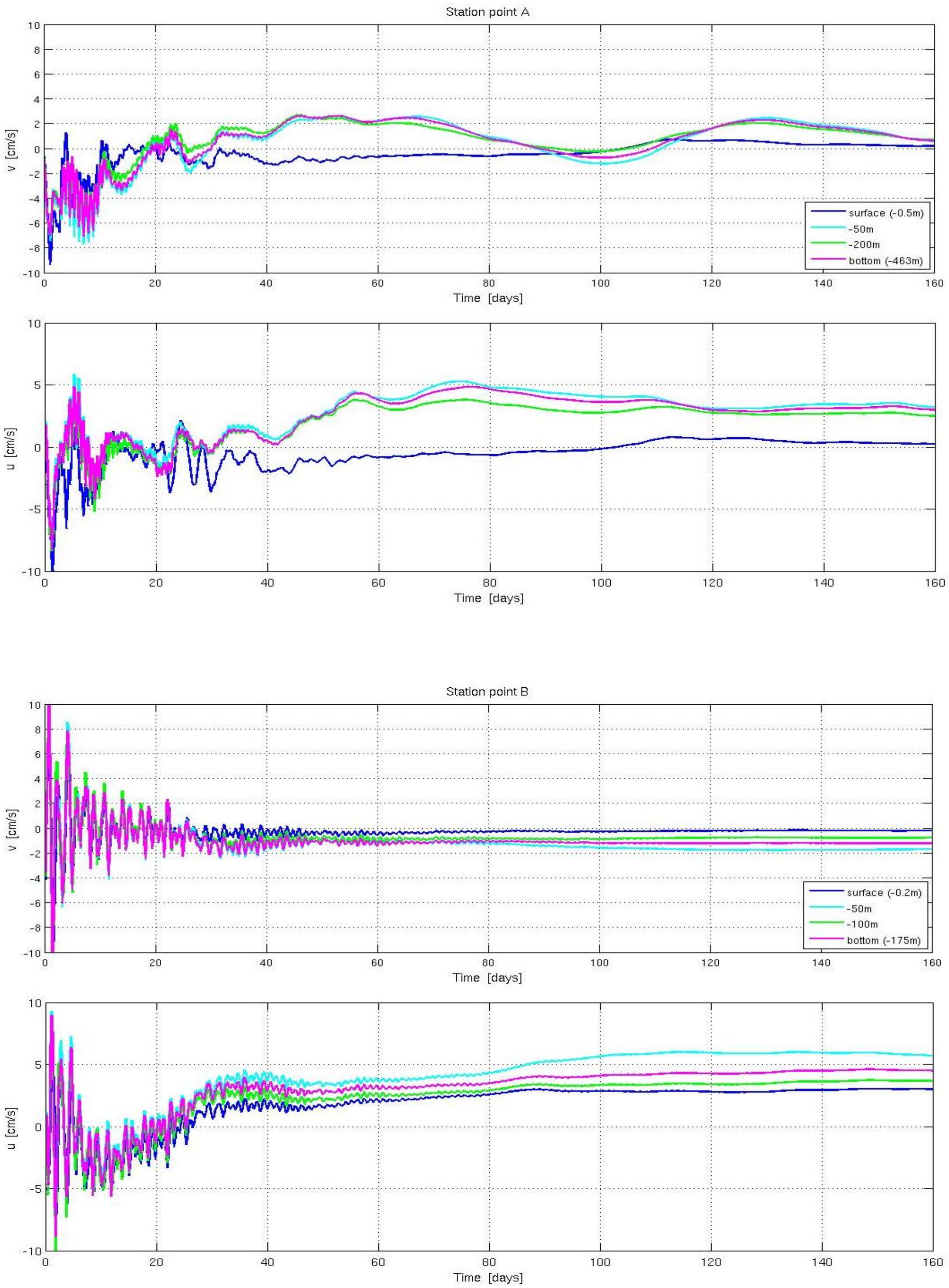

Figure 2 Time series of the u-v current components induced by the pressure gradient errors for two stations and for several depths.

The smoothed bathymetry differs from the raw interpolated grid bathymetry. This difference increases where the bathymetry is steeper, and can in some places significantly alter the local geometry of the Mediterranean basin. The geometrical change of the section area of some channels and straits has, in some cases, a relevant impact on the water mass transport between the interconnected sub-basins.
In Figure 4 we plot the z-x(y) bathymetry section for some critical locations of the Mediterranean basin which are shown in Figure 3. It is particularly evident in the Straits of Otranto (panel 4c) how the smoothed bathymetry strongly modifies the section area of the strait, which becomes around 65% narrower, with the subsequent impact on the mass flux. This strait connects the Adriatic Sea, to the north, with the Ionian Sea, to the south. It plays an important role in the Mediterranean thermohaline circulation as the deep convection, in the southern Adriatic, leads to the formation of the Eastern Mediterranean Deep Water (EMDW). A much shallower Strait as represented in the model grid thus influences the outflow of the Adriatic Deep Water (ADW) and hence the global Mediterranean thermohaline circulation.

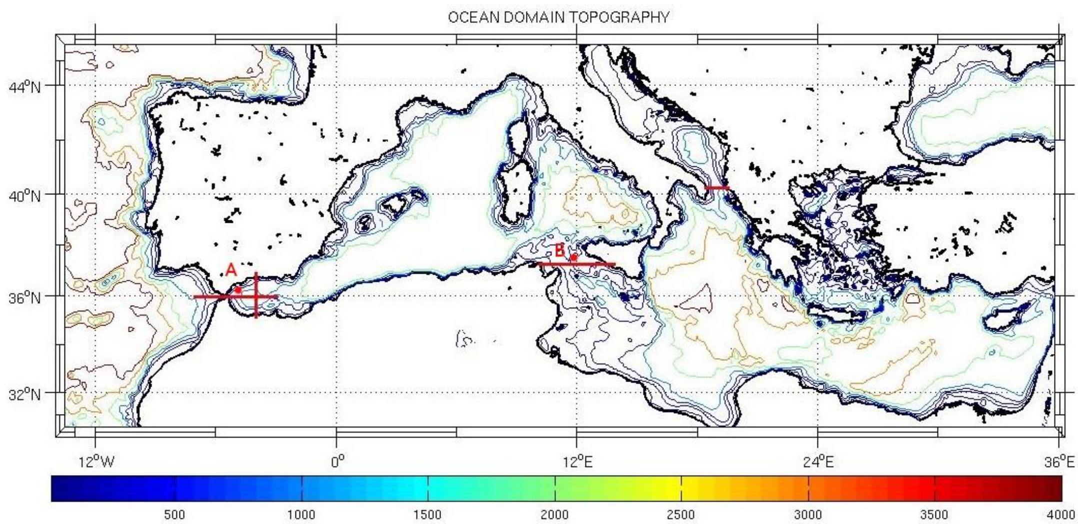

Figure 3 Domain of the ocean component with corresponding bathymetry. The red points are the locations of the time series plotted in the Figure 2 while red lines indicate the locations of the bathymetry sections plotted in the Figure 4. Colorbar units are m.

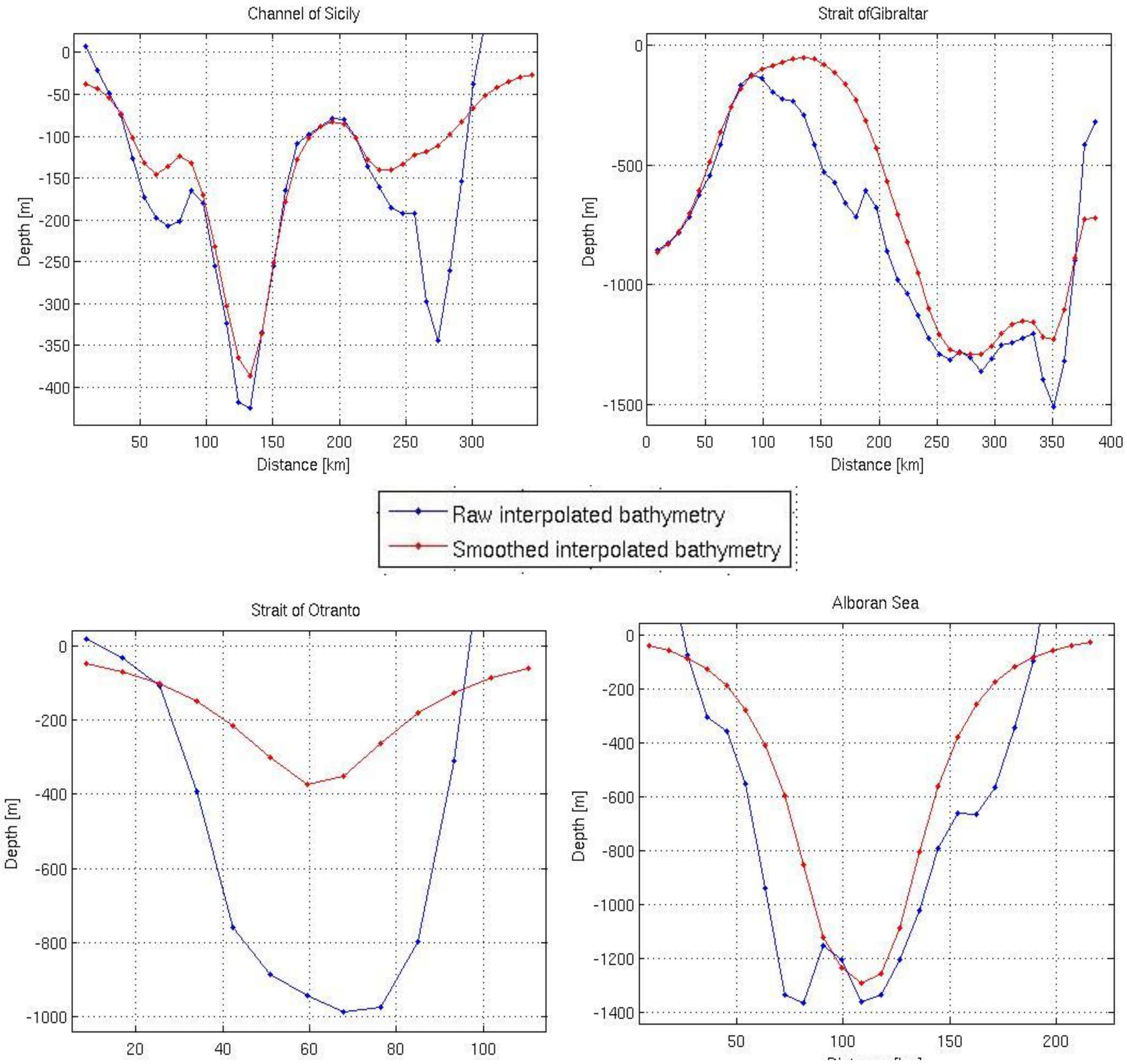

Figure 4 Raw vs smoothed z-x(y) bathymetry sections for some critical locations of the Mediterranean basin.

<u>Description of the main results obtained</u>

The comparison of our coupled model MOREA to the Protheus system points out some considerable deficiencies in our ocean component, mostly stemming from the use of a terrain following system that is not appropriate to the conditions of the Mediterranean basin. This shortcoming leads us to consider the implementation of a different ocean component for our AORCM. The MITgcm ocean model has been shown to perform satisfactorily in the Mediterranean region (Sannino at al., 2009; Artale et al., 2009). Its vertical coordinate can be interpreted as a standard z coordinate when it is used for modelling the ocean. At the moment we are working on the implementation of the MITgcm ocean model on our computational cluster and expect to get the standalone MITgcm model running within one or two weeks.

Future collaboration with host institution

During those 5 weeks stay in Dr. Artale's group, I closely collaborated with Dr. Gianmaria Sannino as he is more directly involved in the Mediterranean modelling activity. We decided to propose a formal collaboration between our institutions, University of Alcalá and ENEA-Casaccia, which would lead to the creation of an independent AORCM for the Mediterranean region. A second and longer visit to the ENEA Casaccia in order to finalize the development of this common AORCM is already being planned.

Projected publications to result from the grant

We think we will be able to have a coupled model running within 4-6 months and get some interesting result in 10-12 months from now. The first goal, which should lead a first publication, will be to evaluate the sensitivity of two different AORCM which share the some ocean component when they are driven by the some boundary forcing. This comparative experiment should isolate the effect on the coupled system of a different atmosphere component leading to a better understanding of the model robustness and coupling mechanisms.

Bibliography

Artale V, Calmanti S, Carillo A, Dell'Aquila A, Herrmann M, Pisacane G, Ruti P, Sannino G, Struglia M, Giorgi F, Bi X, Pal J, Rauscher S (2010) An atmosphere–ocean regional climate model for the Mediterranean area: assessment of a present climate simulation. Climate Dyn 35:721–740

Beckmann, A., Haidvogel, D., (1993). Numerical simulation of flow around a tall isolated seamount. Journal of Physical Oceanography 23, 1736–1753.

Mellor, G.L., Oey, L.-Y., Ezer, T., (1998). Sigma coordinate pressure gradient errors and the seamount problem. Journal of Atmospheric and Ocean Technology 15, 1122–1131.

Sannino, G., M. Herrmann, A. Carillo, V. Rupolo, V. Ruggiero, V. Artale, and P. Heimbach (2009), An eddy-permitting model of the Mediterranean Sea with a two- way grid refinement at the Strait of Gibraltar, Ocean Modell., 30, 56–72, doi:10.1016/j.ocemod.2009.06.002.