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Geoscientific Model Development Discussions

Interactive comment on "Sensitivity of the Mediterranean sea level to atmospheric pressure and free surface elevation numerical formulation in NEMO" *by* P. Oddo et al.

P. Oddo et al.

oddo@bo.ingv.it

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The manuscript aims to investigate whether inclusion of air pressure as a force at the surface boundary may alter sea level solutions by the NEMO model in the Mediterranean at different frequency bands. The paper is nicely written and for sure deserves the publication, but after solving a major methodology problem and some small issues. The major problem with the methodology is that the authors analyse modelled high-frequency sea level oscillations (on hourly timescale), while all model runs are forced by 6-h ECMWF operational fields, including the winds and air pressure which are dominantly driving sea level oscillations on these frequencies.

- We thank the Referee1 for the general positive comment on our manuscript. However we partially agree on the potential methodology problem regarding the forcing data frequency. Detailed comments and answers are provided in the following text.

First, I wonder how the forcing fields are interpolated from 6-h resolution to the model resolution – linear, quadratic or else?

- The 6hr frequency ECMWF data are linearly interpolated onto the model time-step, the text will be modified accordingly.

Whatever method of interpolation is used, it cannot properly describe the processes visible in air pressure and wind series that are occurring on the periods below a day (and there are a lot of them visible in air pressure and wind measurements, like rapidly moving frontal zones and cyclones, convective systems, gravity waves, squall lines, etc.), resulting in aliased forcing and therefore in aliased modeled hourly sea level series. For that reason a number of conclusions (e.g., regarding the Adriatic seiches at 21-h period, see below) in the manuscript are wrong. Therefore, the analysis in frequency domain should be cut down not at 2 h period, but on at least 24-h period.

- The reviewer is right, 6hr frequency atmospheric data under-sample atmospheric phenomena occurring at higher frequency and therefore could produce aliased model results. However, previous works have already proved the possibility to simulate spectra of high frequency oceanic oscillations (the seiches in the Adriatic Sea, or other processes in the Mediterranean basin) forcing ocean models with operational ECMWF products characterized by 6hr temporal resolution. For instance:

- Pascual et al. (2008), suggested by the referee, compare model response to atmospheric pressure and wind forcing using ECMWF fields (6hr the DAC data according the manuscript nomenclature) and higher frequency forcing data (HIPOCAS) concluding that, with the only exception of the Portuguese Atlantic coast, differences between the two simulations are negligible at frequencies higher that 20 days. See Figure 11 of the suggested manuscript.
- Wakelin and Proctor (2002), compare Storm Surge model results forced with different atmospheric data (namely UK-MetO 3hr observations, ECWMF 6hr operational and LAMBO 6hr high horizontal resolution data) and obtain good results when comparing model result with tide-gauges observations power spectra in the Adriatic Sea during occurrence of Seiches (Figure 10 and 13 of their manuscript). They have identified and underlined major limits of model run forced with ECMWF data; however a good reproduction of the energetic content has been achieved.

In the manuscript we focus on the spectra because it is important to understand the frequencies that our NEMO-Mediterranean implementation is able to resolve on the base of the numerical formulation used to solve the SSH equation and connect these frequencies to atmospheric phenomena. We are aware about ECMWF limits but the agreement between obtained results (see the new Venice power spectra) and previous studies suggest that the 6hr data could be enough for the manuscript purposes. For these reasons we think our analysis of the Mediterranean high frequency response in terms of power spectra is appropriate. However following Reviewer's suggestion we suggest to include a new sentence at the beginning of the paragraph 4.2 about the possible limitations due to the ECMWF forcing frequency as following:
"It is worth to mention that the 6 hr frequency ECMWF forcing field does not properly sample the full spectra of the atmospheric phenomena and aliasing problems may occur. Consequently the corresponding oceanic response could be only partially resolved by the NEMO configurations. Thus, some differences between modelled and observed sea level at high frequency could be due to the sampling frequency of

the atmospheric data. However previous studies (Pascual et al. 2008, Wakelin and Proctor, 2002) have already proved the possibility to reproduce the energetic content of high frequency (up to 4hr) Mediterranean processes using similar atmospheric data (Wakelin and Proctor, 2002). Prior to the comparison, the tidal signal was removed from the observed dataset and steric effect superimposed on model results."

Minor to moderate suggestions:

Page 3897/3898. There is newer literature on the inverse barometric effects in the Mediterranean, like Le Traon and Gauzelin (1997), Pasaric et al. (2000), Raicich (2003), Vilibic (2006), Pasqual et al. (2008) – the authors limit their literature mostly to a 30 of more years old papers (which should be mentioned, but not limited to). Generally, the references about IB effect in the World Ocean and the Mediterranean are pretty old and should be accompanied with some of fresh research and findings.

- We thank the Referee1 for this important and very useful comment. More recent and most of the suggested manuscripts have been included in the discussion and therefore in the bibliography.

Page 3989. What is r.h.s?
- r.h.s means right hand side. We think it is not necessary to explicitly write the acronym, however if the reviewer insist we can easily modify the manuscript accordingly.

Page 3990, lines 5-15. They belong to introduction.
- The text will be modified accordingly and the sentence moved to the introduction.

Page 3994, lines 12-13. ": : : and the structures are more realistic in the atmospheric forcing cases". Please proof this statement with the reference!"
- The reference to Pinardi et al 2013 paper will be included. The paper provides a

detailed description of the Mediterranean surface circulation structures based on a reanalysis dataset.

Page 3999, line 15. "sea level" not "seal level".
-Thanks, text will be modified.

Page 4000, lines 16-17. 21 h-1 is not inertial frequency of the Adriatic Sea (it is seiches frequency), but 17 h-1.
- We apologize for the mistake, and thank the Referee1 for pointing out this error in the manuscript. The corresponding sentence will be corrected.

Page 4000, lines 17-22. The existence of seiches on the Venice measured series is reproduced by the model when introducing air pressure forcing, but in my opinion not because of realistic forcing but because of introduction of aliased air pressure high-frequency energy due to 6-h forcing resolution. The Adriatic seiches are normally generated by rapid changes in winds (from sirocco towards lebicchio and tramontana/bora) after pronounced pushing up of waters in the northern Adriatic by strong and long-lasting sirocco wind (e.g., Cerovecki et al. 1997; Raicich et al., 1999), and air pressure is of minor importance for the process – this is also wrongly stated in page 4003, lines15-19. Again, the effects of 6-h forcing to the modeling of 21-h process should be carefully assessed. As suggested above, it would be wise to rise the lower period of analysis to 24 h (and not to only Nyquist's 12 h), to avoid these problems and not to discuss the frequency range which is affected with aliasing problems.

- *Cerovecki, I., Orlic, M., Hendershott, M.C., 1997. Adriatic seiche decay and energy loss to the Mediterranean. Deep-Sea Res. I, 44, 2007-2029.*
- *Raicich, F., Orlic, M., Vilibic, I., Malacic, V., 1999. A case study of the Adriatic seiches (December 1997), Il Nuovo Cimento C, 22, 715-726"*

-The possibility to simulate Adriatic seiches with ECMWF 6hr forcing data has been

evaluated in previous scientific studies (Wakelin and Proctor 2002). Based on this manuscript and on our results we think that the analysis provided in our manuscript is correct. The Referee is right about the sentence at page 4003 lines 15-19 where the effect of the Atmospheric pressure seems to be overestimated. The sentence will be rephrased. We will try also to include the references suggested by the Referee1. Moreover redrawing the Venice power spectra according the Referee2 suggestions the occurrence of Adriatic Seiches and the model skill in reproducing this phenomenon is more evident. A new Figure for the Venice (also Mahon and Valencia) power spectra have been added where it is now more evident that the model configurations with time-splitting both simulate the seiches but the one with atmospheric pressure ameliorate the model results. On the other hand the NEMO configuration using the filtered free surface without the atmospheric pressure forcing does not capture the 21 hr peak. The text describing the figure will be modified accordingly.

References:

- Pascual, A., Marcos, M., Gomis, D., 2008. Comparing the sea level response to pressure and wind forcing of two barotropic models: Validation with tide gauge and altimetry data. J. Geophys. Res., 113, C07011, doi: 10.1029/2007JC004459.
- S.L. Wakelin, R. Proctor. 2002. The impact of meteorology on modelling storm surges in the Adriatic Sea. Global and Planetary Change 34 (2002) 97– 119

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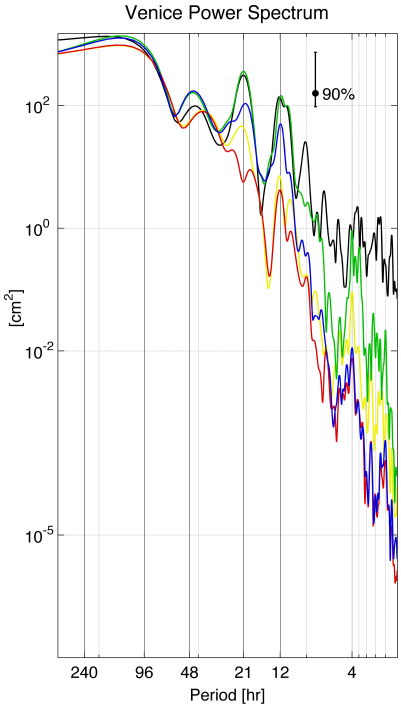
Venice Power Spectrum
90%
10^2
10^0
10^{-2}
10^{-5}
[cm^2]
240
96
48
21
12
4
Period [hr]

Fig. 1.