Ocean Sci. Discuss., 9, 1577–1598, 2012
www.ocean-sci-discuss.net/9/1577/2012/
doi:10.5194/osd-9-1577-2012

Ocean Science Discussions

Assimilation of SLA along track observations in the Mediterranean with an oceanographic model forced by atmospheric pressure

S. Dobricic[1], C. Dufau[2], P. Oddo[3], N. Pinardi[3], I. Pujol[3], and M.-H. Rio[3]

[1]Centro Euro-Mediterraneo per i cambiamenti Climatici (CMCC), Bologna, Italy
[2]Collecte Localisation Satellites (CLS), Toulouse, France
[3]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Bologna, Italy

Received: 23 February 2012 – Accepted: 14 March 2012 – Published: 10 April 2012

Correspondence to: S. Dobricic (srdjan.dobricic@cmcc.it)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

A large number of SLA observations at a high along track horizontal resolution are an important ingredient of the data assimilation in the Mediterranean Forecasting System (MFS). Recently new higher frequency SLA products have become available, and the atmospheric pressure forcing has been implemented in the numerical model used in the MFS data assimilation system. In a set of numerical experiments we show that in order to obtain the most accurate analyses the ocean model should include the atmospheric pressure forcing and the observations should contain the atmospheric pressure signal. When the model is not forced by the atmospheric pressure the high frequency filtering of SLA observations, however, improves the quality of the analyses. It is further shown that MFS analyses, produced by an assimilation system given by the numerical model and the high frequency SLA observations, have a correct power spectrum at high wave numbers and they filter efficiently the SLA assimilated observations which, on the other hand, are contaminated by high wavenumber noise.

1 Introduction

The Mediterranean Forecasting System (MFS) (Pinardi and Coppini, 2010) each day provides ten days long oceanographic forecasts of the Mediterranean Sea. The forecasts are initiated by the analyses of the state of the ocean at the daily frequency. The analyses combine estimates by the ocean model (Oddo et al., 2009), satellite observations of Sea Surface Temperature (SST) and Sea Level Anomaly (SLA), and in situ observations of temperature and salinity by Argo floats and of temperature by Expandable Bathy Thermograph (XBT) instruments (e.g. Dobricic et al., 2007).

The SLA along track observations have the largest impact on the state estimates by the MFS system. Their important impact arises from the fact that, in addition to barotropic effects, SLA represents a vertically integrated effect of variations in temperature and salinity over the whole water column. While in situ observations provide more accurate direct observations of the temperature and salinity variability along the water column, their spatial scarcity limits their impact only to small areas of the Mediterranean. There are also many SST observations, but their impact is often limited only to the estimate of the temperature distribution close to the surface of the ocean. On the other hand, the SST observations can be combined with in situ observations of vertical profiles to get a three-dimensional estimate of the state of the ocean. Even in this case the ability to construct three-dimensional estimates of is, however, limited due to the small number of in situ observations. Another important property of SLA observations is that they provide information on geostrophic component of surface currents, a product that is used in a number of applications requiring MFS analyses and forecasts. For example, surface currents are implemented to forecast the oil spill movement, assist search and rescue operations and detect sources and the spreading of the pollution. Figure 1 shows the spatial and temporal coverage by SLA and in situ observations in 2009. It can be seen that the SLA observations repeatedly observe the whole Mediterranean Sea, whilst the in situ observations sample only some limited parts of the basin. The relative importance of the large number of SLA observations in the Mediterranean has been investigated in detail in Pujol et al. (2010).

The daily frequency of MFS analyses and the ability of the MFS system to simulate a large number of high frequency oceanographic processes may require SLA products that are specially prepared for the MFS system. In particular recently the atmospheric pressure forcing has been added to MFS model equations (Oddo et al., 2012). In a semi-enclosed basin like the Mediterranean the inverse barometer estimate cannot fully remove the impact of the atmospheric pressure gradient, because the slow water exchange between the Mediterranean and the Atlantic through the narrow Gibraltar Strait often generates large scale oscillations that can last for several days (e.g. Candela and Lozano, 1994). In the past, these oscillations were removed from SLA observations by adjusting several SLA satellite tracks in consecutive days (Le Traon and Gauzelin, 1997). Since 2004, the ocean response to the high frequency atmospheric pressure, winds and tidal potential has been simulated with a barotropic ocean model, and this

OSD
9, 1577–1598, 2012

simulated high frequency signal has been removed from SLA observations (Carrere and Lyard, 2003).

This procedure, however, creates inconsistencies when the MFS assimilation system uses the ocean model forced by the atmospheric pressure. In order to compare observations and background model fields, that contain the atmospheric pressure effects on sea level, it would be necessary to subtract from the model background field the same SLA high frequency correction of the SLA observations. This quantity may be difficult to assess, and therefore, the use of a more sophisticated ocean model forced by the atmospheric pressure gradient could even degrade the quality of the analyses.

In this study we will describe the procedure implemented for the assimilation of SLA observations when the model is forced by the atmospheric pressure. We will assimilate the "Tailored Altimetry Products for Assimilation Systems" (TAPAS) observations with and without the high frequency correction. These experiments will help us to draw the guidelines for the future use of SLA along track observations in the MFS data assimilation system in which the model is forced by atmospheric pressure gradient. In Sect. 2 we describe the TAPAS data product, and the data assimilation system methodology for the use of the model forced by atmospheric pressure. Section 3 describes the set-up of numerical experiments and compares the results of the assimilation with different model implementations, with and without the atmospheric pressure forcing and with TAPAS observations containing and excluding the high frequency correction. Section 4 provides a discussion and offer some guidelines for the future use of the SLA products in the MFS data assimilation system.

2 SLA observations and data assimilation system

2.1 SLA observations

An experimental product called TAPAS was developed that provides SLA observations without the high frequency signal corrections, i.e. the inverse barometer corrections and others. The TAPAS data set further address issues encountered with advanced modeling systems that may contain most of the high frequency signal in the sea level. A first TAPAS along-track product based on Delayed-Time (DT) observations was delivered in 2010 for the global ocean. These SLA observations are without along-track filtering and sub-sampling (raw 1 hz altimeter data at the horizontal resolution of 7.5 km). In addition, a new subset of TAPAS observations is produced over the Mediterranean Sea for this study. For each SLA observation it gives the information on the modifications made in different stages of the processing: the long wave error correction, the low frequency inverse barometer, the correction for ocean tides, and the high frequency correction obtained after the application of a barotropic model forced by high frequency winds and atmospheric pressure. This allows us to put the high frequency signal back into SLA observations, and to estimate the impact of SLA high frequency components on the MFS assimilation system. Therefore, with the TAPAS data set we could test the effect of unfiltered SLA data in the MFS assimilation system that includes the atmospheric pressure forcing.

2.2 Data assimilation system

The MFS data assimilation system consists of the Mediterranean set-up of the NEMO ocean model (Oddo et al., 2009) and the OceanVar data assimilation scheme (Dobricic and Pinardi, 2008). The model has the horizontal resolution of 1/16° and 72 unevenly distributed layers in the vertical direction. In the Atlantic it is nested with the global 1/4° model by Mercator-Ocean (Barnier et al., 2006). The atmospheric turbulence fluxes are calculated in bulk formulae by using the atmospheric fields of wind, temperature, humidity and surface pressure from the ECMWF operational analyses, while short and long wave radiation are parameterized with the use of the cloud cover operational analyses by the ECMWF (Pettenuzzo et al., 2010). Recently the forcing by atmospheric pressure is introduced into the MFS model. It is applied by adding an additional pressure gradient term into horizontal momentum equations (Oddo et al., 2012):

$$\frac{\partial \boldsymbol{v}}{\partial t} = \ldots - \frac{1}{\rho_0}\nabla p_{\mathrm{A}} + \ldots, \tag{1}$$

where $\boldsymbol{v}$ is the horizontal velocity, ρ_0 is the reference density, and p_{A} is the atmospheric pressure. The data assimilation is a variational scheme in which the slowly evolving vertical part of temperature and salinity background error covariances is represented by seasonally and regionally variable Empirical Orthogonal Functions (EOFs), whilst their horizontal part is assumed to be Gaussian isotropic depending only on distance. The rapidly evolving part of the background error covariances, consisting of the sea level and the barotropic velocity components, is modeled in each step of the minimization algorithm by applying a barotropic model forced by the vertically integrated buoyancy force resulting from temperature and salinity variations. The velocity is then estimated by applying the geostrophic relationship, modified along the coast in order to eliminate the horizontal divergence. In this way OceanVar combines long term three dimensional variational scheme for the slow processes with a scheme that fully dynamically evolves the covariances by model equations for the fast processes.

The background SLA estimate is formed by subtracting the Mean Dynamic Topography (MDT) estimate from the background sea level estimate. The MDT is obtained by combining the estimate by Rio et al. (2007) with the information from the in situ observations in a procedure similar the one applied in Dobricic (2005).

When the assimilation uses the high frequency corrected SLA data and the ocean model is forced by the atmospheric pressure gradient, it is necessary to modify the model background SLA field in order to represent the same quantity that has been observed. It is then necessary to subtract an estimate of the sea level response to high frequency atmospheric pressure forcing from the background SLA field. On the contrary, when the model is not forced by atmospheric pressure and the SLA observations contain the high frequency sea level signal, this contribution must be added to the model background SLA field. The relationship between the model background field

OSD
9, 1577–1598, 2012

from a numerical model with and without atmospheric pressure forcing can be written as:

$$\eta_{\mathrm{A}}(x,y,t) = \eta_{\mathrm{NA}}(x,y,t) - \frac{p_{\mathrm{A}}(x,y,t)}{\rho_0 g} + A(t) + \varepsilon(x,y,t), \tag{2}$$

where η_{A} is the model background sea level model estimate produced by the model with the atmospheric pressure forcing, η_{NA} is the same estimate produced by the model without the atmospheric pressure forcing, p_{A} is the atmospheric pressure field, g is the acceleration due to gravity, and $A(t)$ is a horizontally constant field over the whole model domain, which includes the Mediterranean and a part of the Atlantic Ocean. The second term in the right hand side of Eq. (2) is the so-called inverse barometer effect that assumes the full isostatic balance between the atmospheric pressure and the sea level (e.g. Ponte, 1993). In addition term $A(t)$ is estimated by:

$$A(t) = \overline{\eta_{\mathrm{A}} - \left[\eta_{\mathrm{NA}} - \frac{p_{\mathrm{A}}}{\rho_0 g}\right]}^{xy}. \tag{3}$$

Term ε represents differences due to the nonisostatic response of the model forced by the atmospheric pressure in the Mediterranean Sea. Equations (2) and (3) are also applied to model background estimates of SLA fields obtained after subtracting the MDT from the background sea level.

In the assimilation scheme the mean residual is subtracted from the residuals along each SLA satellite track. In this way the unknown steric height signal is removed together with the largest scale oscillations that may originate from the atmospheric pressure forcing, or from other small scale processes, like for example the local variations of wind near the Gibraltar Strait, that may be unresolved by the ECMWF analyses (Fukumori et al., 2006). Residuals are calculated at the observational time, and the atmospheric pressure available from the ECMWF analyses at the interval of 6 h is interpolated in time to the observational time. This procedure can produce aliasing of the atmospheric pressure signal due to the atmospheric tides (e.g. Ponte and Ray, 2002),

OSD
9, 1577–1598, 2012

but since this part of the signal has a very large spatial scale it is most likely also removed by the subtraction of the mean residual along the satellite track. It should be noticed that the model has an implicit numerical scheme for the adjustment of the sea level and the vertically integrated velocity. Therefore, gravity waves in deep ocean are strongly damped instead of being dispersed.

3 Numerical experiments

3.1 Scales of sea level differences in simulation and assimilation experiments

Six experiments are performed to estimate the impact of the atmospheric pressure forcing on the simulated sea level and in the analyses produced by different models and SLA observation processing methods. Two simulation experiments, without data assimilation, are carried out with (SIM1) and without (SIM2) atmospheric pressure forcing only in January 2009. The four assimilation experiments cover the whole 2009 and include models with (ATMPR) and without (CONT) atmospheric pressure forcing and with (ATPR1, CONT1) and without (ATPR2, CONT2) high frequency corrections to SLA observations. Table 1 summarizes the differences between the experiments.

When the sea level estimate from SIM1 is compared with SIM2 by using Eq. (2) the difference between the two solutions gives the term ε. The field of ε is shown in Fig. 2. It can be seen that the differences mostly have large scales. In particular, the basin scale dominates the differences, and there are the gradients between the western and the eastern basins, and further in the semi enclosed Adriatic and Aegean Seas. In addition there are some smaller scale differences, concentrated mainly in the western basin, and especially along the Northern African coast. The smaller scale differences along the Northern African coast can be explained by the propagation of Kelvin waves along the coast generated by the differences in the transport through the Gibraltar Strait. In general these differences are expected because, as mentioned above, the Mediterranean sea level response to atmospheric forcing is not well captured by the

OSD
9, 1577–1598, 2012

inverse barometer effect due to the slow exchange of water with the Atlantic Ocean through the Gibraltar Strait.

The simulation differences are further compared with differences between assimilation experiments ATPR1 and CONT1 in January 2009. Figure 3 shows the Root Mean Square (RMS) differences of sea level estimates between the two simulations (SIM1-SIM2) and between the two analysis estimates in January 2009 (ATPR1-CONT1). It can be seen that, when averaged over the whole month, the differences between simulations have small amplitudes and they are at large scales (top panel in Fig. 3). This happens because the small scale differences in snapshots shown in Fig. 2 are mainly due to the barotropic Kelvin waves that appear less frequently and are rapidly dispersed. Therefore they do not leave a strong signal over a longer period of time. On the other hand the monthly averaged RMS of differences between the analyses in ATPR1 and CONT1 contains both large and small scales (middle panel in Fig. 3). The large scale structure of the analysis differences is very similar to the structure of the simulation differences. Clearly the data assimilation does not change the sea level signal at the large barotropic scales which originates from the atmospheric pressure forcing. On the other hand, the combination of the information coming from the SLA observations and the differences in the background fields due to the atmospheric pressure forcing create different sea level estimates at smaller scales. In the analyses the small scale differences propagate slowly, because they reflect the changes in temperature and salinity in the ocean's interior. Therefore their signal is clearly visible even when the RMS of differences is averaged over the whole month (bottom panel of Fig. 3). The next subsection will evaluate the impact of these differences on the accuracy of the analyses.

3.2 Analysis accuracy

The accuracy of the analyses is estimated by the evaluation of the RMS of residuals with respect to the SLA observations and the in situ observations of temperature and salinity by Argo floats. Assuming that the time between the two subsequent

OSD
9, 1577–1598, 2012

observations by the satellites or the Argo floats is only several days long, we may assume that the background errors are mainly due to the errors in the initial state represented by the analyses, and not due to the errors in the model integration or in the atmospheric forcing. Figure 4 shows the evolution of the RMS of SLA residuals in the 2009 obtained by experiments ATPR1 and CONT1. It can be seen that the RMS of SLA residuals is very similar in both experiments, but throughout the 2009 it is lower when the model is forced by the atmospheric pressure gradient. In the second set of twin experiments the analyses assimilated TAPAS observations of SLA with the high frequency correction. This time the CONT2 experiment gives a slightly lower RMS of SLA residuals on average, although sometimes it is larger than with the ATPR2 experiment (Fig. 5). The RMS of the temperature and salinity residuals (Fig. 6) is the lowest in experiment ATPR1 when the model is forced by the atmospheric pressure gradient and the observations are not corrected for the high frequency dynamical signal. When the model is not forced by atmospheric pressure, experiment CONT2 on average gives a lower RMS of temperature and salinity residuals than CONT1 in which the observations are not corrected for the high frequency signal (Fig. 6).

The data assimilation combines the information from the observations with the information from the background fields and it produces analyses that contain the dynamical constraints given by the model dynamics. This feature of the MFS data assimilation system is demonstrated in Fig. 7. The power spectral density of sea surface height observations follows approximately the $k^{-2.5}$ slope at scales larger than 50 km. This slope is flatter than the slope of k^{-3} that could be predicted theoretically for larger synoptic scales (e.g. Nastrom and Gage, 1985). In the Mediterranean the wind is strongly modified by the surrounding topography, and therefore the topography may significantly impact the slope of the power spectrum at these scales. On the other hand at the shorter scales we could expect that the power spectrum of the sea level depends less on the external forcing, and it should have a slope that is closer to the theoretical estimate for the geostrophic turbulence. At scales shorter than 50 km SLA observations show a power spectrum slope that is quite flatter than the theoretical one of $k^{-5/3}$, indicating

OSD
9, 1577–1598, 2012

the presence of the spatially correlated observational noise at these scales. Contrary to the observations, the power spectrum of the analyses (ATPR1) has a slope that is very close to the theoretical, since the model equations provide a dynamical constraint for the distribution of energy among the scales following the assimilation of observations. It becomes flatter only at the scales comparable to or shorter than the model 3-grid spacing. It may be a consequence of a false energy aliasing due to the inaccurate simulation of the non-linear energy cascade, or simply a consequence of an insufficiently selective horizontal diffusion operator.

4 Discussion

The study describes the impact of the atmospheric pressure forcing in the numerical model associated with the assimilation scheme of MFS. The analyses that use non filtered SLA observations and atmospheric pressure forcing in the numerical model (ATPR1) show differences in SLA at the small spatial scales with respect to the simple assimilation case. These SLA differences are due to the temperature and salinity changes in the water column at the mesoscales, introduced by the data assimilation scheme.

Due to the semi-enclosed nature of the Mediterranean Sea, the assimilation with the model forced by the atmospheric pressure gradient required the evaluation of the level of the SLA data set processing in order to achieve the most accurate ocean state estimates. It was shown that, when the model was forced by the atmospheric pressure, the unfiltered SLA data set led to the most accurate analyses. The improved accuracy was obtained when compared both with satellite SLA and in situ Argo observations. On the other hand, when the model was not forced by the atmospheric pressure gradient, the assimilation of the SLA data set that included the high frequency dynamic correction on average produced more accurate analyses. It was further shown that the analyses successfully filtered the noise present in the power spectrum of the SLA observations.

OSD
9, 1577–1598, 2012

Analyses had the correct slope of the power spectrum at shorter scales, up to the shortest scales hardly resolved by the model dynamics.

One major motivation for this study was to give indications for the future design of the most efficient oceanographic analyses of SLA data in the Mediterranean. The study shows that in order to achieve the most efficient extraction of the information from the SLA observations the model should include as much as possible all processes influencing the sea level variability in the Mediterranean in order to assimilate the observations that contain the most of the original unprocessed signal. In particular, it was found that in the experiment that used a model forced by atmospheric pressure and observations containing the full atmospheric signal at high frequencies, the RMS of SLA, temperature and salinity residuals was consistently lowered by a few percent with respect to other experiments in which either the model was not forced by atmospheric pressure or the high frequency signal was removed from the observations.

Acknowledgements. The study was supported by the European Commission MyOcean Project (SPA.2007.1.1.01, development of upgrade capabilities for existing GMES fast-track services and related operational services, grant agreement 218812-1-FP7-SPACE 2007-1).

References

Barnier, B., Madec, G., Penduff, T., Molines, J.-M., Treguier, A.-M., le Sommer, J., Beckmann, A., Biastoch, A., Böning, C., Dengg, J., Derval, C., Durand, E., Gulev, S., Remy, E., Talandier, C., Theetten, S., Maltrud, M., McClean, J., and de Cuevas, B.: Impact of partial steps and momentum advection schemes in a global circulation model at eddy permitting resolution, Ocean Dynam., 56, 543–567, doi:10.1007/s10236-006-0082-1, 2006.

Candela, J. and Lozano, C. J.: Barotropic response of the western Mediterranean to observed atmospheric pressure forcing, in: The Seasonal and Interannual Variability of the Western Mediterranean Sea, edited by: La Violette, P. E., Coastal and Estuarine Studies, 46, 325–359, American Geophysical Union, 1994.

OSD

9, 1577–1598, 2012

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◀| |▶

◀ ▶

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Carrère, L. and Lyard, F.: Modelling the barotropic response of the global ocean to atmospheric wind and pressure forcing – comparisons with observations, Geophys. Res. Lett., 30, 6, doi:10.1029/2002GL016473, 2003.
Dobricic, S.: New mean dynamic topography of the Mediterranean calculated from assimilation system diagnostics, Geoph. Res. Lett., 32, L11606, doi:10.1029/2005GL022518, 2005.
Dobricic, S. and Pinardi, N.: An oceanographic three-dimensional assimilation scheme, Ocean Modell., 22, 89–105, 2008.
Dobricic, S., Pinardi, N., Adani, M., Tonani, M., Fratianni, C., Bonazzi, A., and Fernandez, V.: Daily oceanographic analyses by Mediterranean Forecasting System at the basin scale, Ocean Sci., 3, 149–157, 2007, http://www.ocean-sci.net/3/149/2007/.
Fukumori, I., Menemenlis, D., and Lee, T.: A near-uniform basin-wide sea level fluctuation of the Mediterranean Sea, J. Phys. Oceanogr., 37, 338–358, 2006.
Le Traon, P.-I. and Gauzelin, P.: Response of the Mediterranean mean sea level to atmospheric pressure forcing, J. Geophys. Res., 102, 973–984, 1997.
Nastrom, G. D. and Gage, K. S.: A climatology of atmospheric wavenumber spectra of wind and temperature observed by commercial aircraft, J. Atmos. Sci., 42, 950–960, 1985.
Oddo, P., Adani, M., Pinardi, N., Fratianni, C., Tonani, M., and Pettenuzzo, D.: A Nested Atlantic-Mediterranean Sea General Circulation Model for Operational Forecasting, Ocean Sci., 5, 461–473, 2009, http://www.ocean-sci.net/5/461/2009/.
Oddo, P., Pinardi, N., and Bonaduce, A.: Introducing Atmospheric pressure forcing in the Mediterranean Forecasting System, Ocean Sci. Discuss., in preperation, 2012.
Pettenuzzo, D., Large, W. G., and Pinardi, N.: On the corrections of ERA-40 surface flux products consistent with the Mediterranean heat and water budgets and the connection between basin surface total heat flux and NAO, J. Geophys. Res., 115, C06022, doi:10.1029/2009JC005631, 2010.
Pinardi, N. and Coppini, G.: Operational oceanography in the Mediterranean Sea: the second stage of development, Ocean Sci., 6, 263–267, 2010, http://www.ocean-sci.net/6/263/2010/.
Ponte, R. M.: Variability in a homogeneous global ocean forced by barometric pressure, Dynam. Atmos. Oceans, 18, 209–234, 1993.

Ponte, R. M. and Ray, R. D.: Atmospheric pressure in geodesy and oceanography: A strategy for handling air tides, Geophys. Res. Lett., 29, 24, doi:10.1029/2002GL016340, 2002.
Pujol, M.-I., Dobricic, S., Pinardi, N., and Adani, M.: Impact of Assimilating Multi-Altimeter Sea Level Satellite Data in a High-Resolution Mediterranean Forecasting Model, J. Ocean. Atmos. Techn., 27, 2065–2082, doi:10.1175/2010JTECHO715.1, 2010.
Rio, M.-H., Poulain, P.-M., Pascual, A., Mauri, E., Larnicol, G., and Santoleri, R.: A Mean Dynamic Topography of the Mediterranean Sea computed from altimetric data, in-situ measurements and a general circulation model, J. Marine Sys., 65, 484–508, doi:10.1016/j.jmarsys.2005.02.006, 2007.

OSD
9, 1577–1598, 2012

Table 1. Summary of experiments.

Experiment	Atmospheric pressure forcing in dynamical model	High frequency signal present in SLA observations	Period covered by the experiment
SIM1	YES	none	January 2009
SIM2	YES	none	January 2009
ATPR1	YES	YES	2009
CONT1	NO	YES	2009
ATPR2	YES	NO	2009
CONT2	NO	NO	2009

OSD
9, 1577–1598, 2012

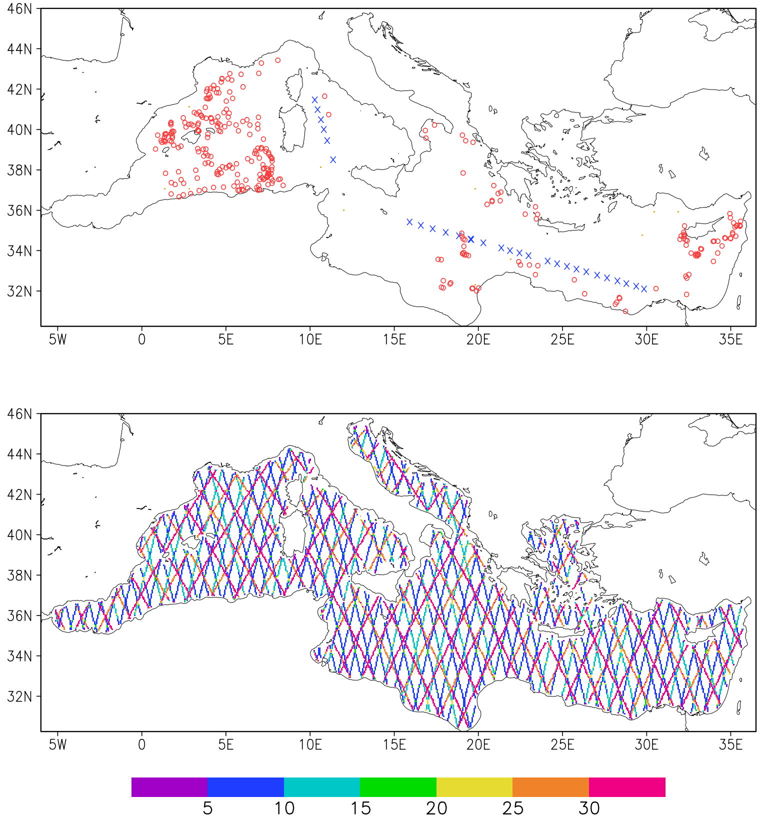

Fig. 1. Number of SLA and in situ observations in the Mediterranean during the 2009. Top panel shows the position of Argo (red open circles) and XBT (blue crosses) profiles in the 2009, while the bottom panel shows the number of SLA observations along tracks from both Jason and Envisat satellites during the 2009. Each Argo and XBT profile was performed only once.

OSD

9, 1577–1598, 2012

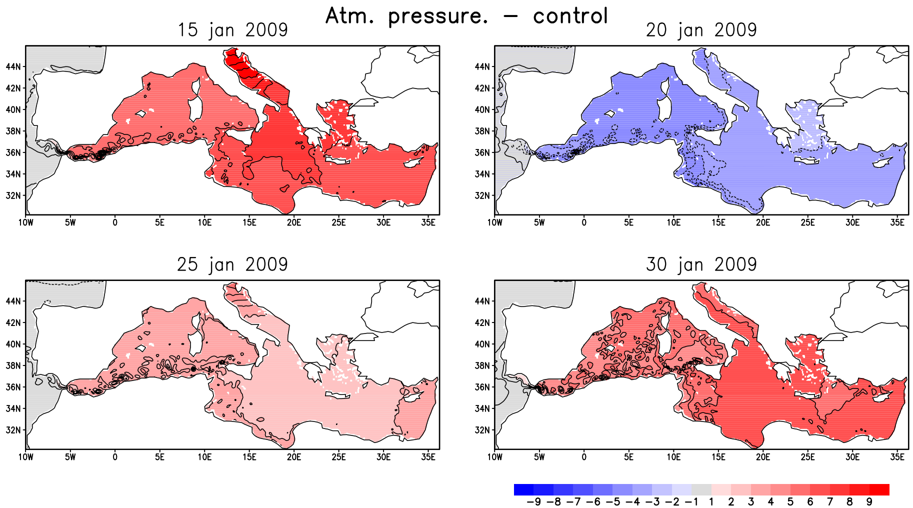

Fig. 2. Snapshots of differences of sea level (cm) in January 2009 between simulations forced with and without the atmospheric pressure gradient. Simulations started on 1 January 2009, and snapshots are on days 15, 20, 25 and 30 after the start of the simulation. Isolines are drawn with the interval of 0.5 cm.

OSD
9, 1577–1598, 2012

Assimilation of SLA along track observations in the Mediterranean

S. Dobricic et al.

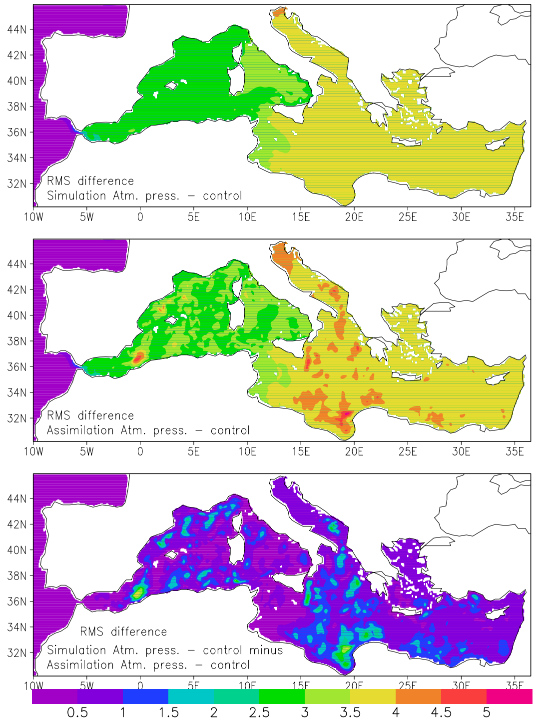

Fig. 3. The RMS of the differences between the sea level (cm) in January 2009 from simulations with and without the atmospheric pressure gradient forcing (top panel). The RMS of the differences between the sea level (cm) in January 2009 from the analyses with and without the atmospheric pressure gradient forcing (ATPR1-CONT1, middle panel). The RMS of the differences between the sea level differences (cm) in January 2009 obtained from the simulations and from the analyses with and without the atmospheric pressure gradient forcing (bottom panel).

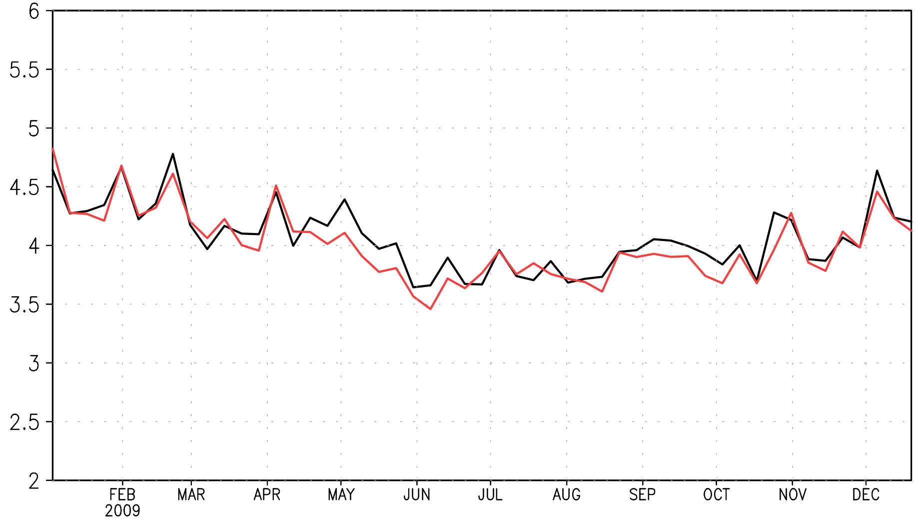

Fig. 4. RMS of SLA residuals (cm) in experiments ATPR1 (continuous red line) and CONT1 (continuous black line) during the 2009. The RMS of SLA residuals is calculated once a week.

OSD
9, 1577–1598, 2012

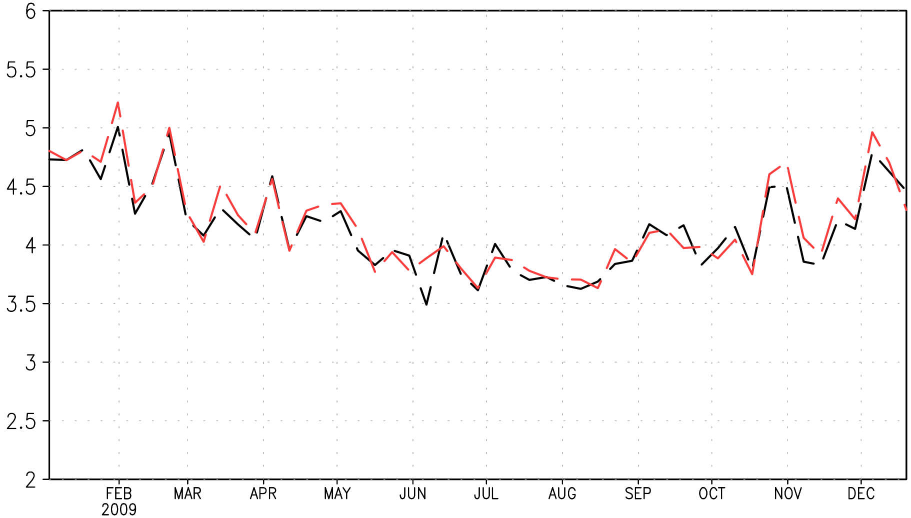

Fig. 5. RMS of SLA residuals (cm) in experiments ATPR2 (dashed red line) and CONT2 (dashed black line) during the 2009. The RMS of SLA residuals is calculated once a week.

OSD
9, 1577–1598, 2012

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

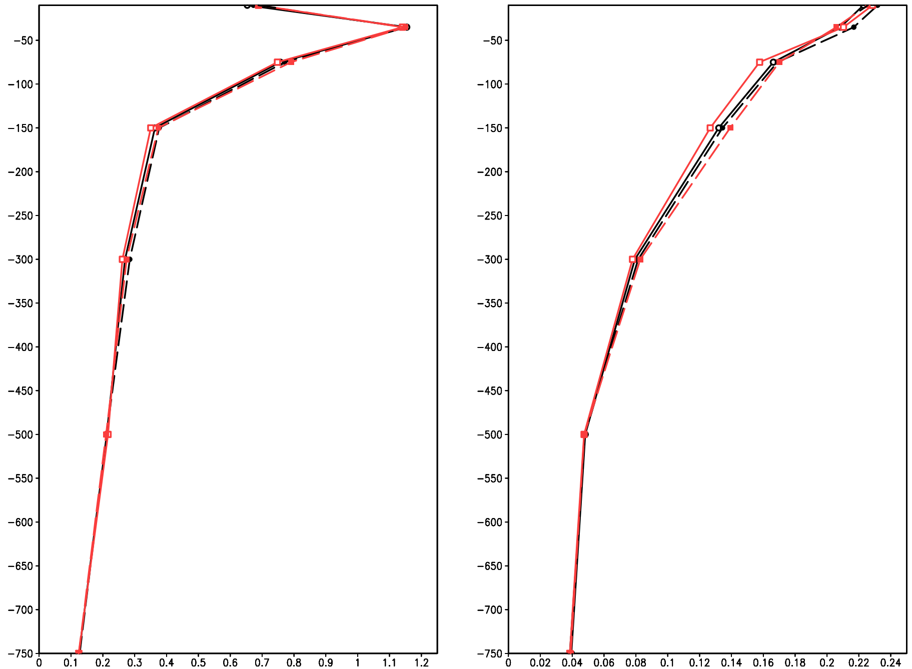

Fig. 6. RMS of temperature (°C) (left) and salinity (right) residuals calculated with respect to observations by Argo floats in experiments ATPR1 (continuous red line), ATPR2 (dashed red line), CONT1 (continuous black line) and CONT2 (dashed black line) during the whole 2009.

OSD
9, 1577–1598, 2012

Assimilation of SLA along track observations in the Mediterranean

S. Dobricic et al.

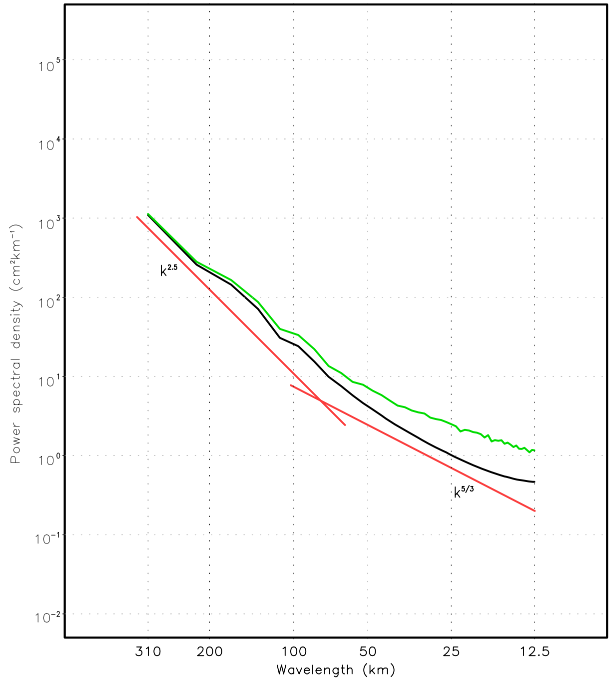

Fig. 7. The power spectrum density ($cm^2\ km^{-1}$) as the function of the wavelength of the background (black line, experiment ATPR1, see Table 1) and the observed sea level estimate (green line). Both spectra are calculated at the same observational points along the SLA tracks in 2009. Only tracks longer than 650 km were taken into account in order to reduce the effects due to the variable geometry of the Mediterranean. The observed sea level estimate is obtained by adding the MDT to the SLA. The logarithmic scale is applied on both axes. Red lines indicate the −2.5 and −5/3 slopes.