Available online at www.sciencedirect.com
ScienceDirect
Journal of Marine Systems 65 (2007) 540–560
JOURNAL OF MARINE SYSTEMS
www.elsevier.com/locate/jmarsys

The Mercator global ocean operational analysis system: Assessment and validation of an 11-year reanalysis

Nicolas Ferry [a,*], Elisabeth Rémy [a], Pierre Brasseur [b], Christophe Maes [c]

[a] Mercator-Océan, 8-10 rue Hermès, Parc technologique du canal, 31526 Ramonville Saint Agne, France
[b] Laboratoire des Ecoulements Géophysiques et Industriels, BP 53, 38041 Grenoble Cedex 9, France
[c] Institut pour la Recherche et le Développement/Laboratoire d'Etudes en Géophysique et Océanographie Spatiales, 14, Av. E. Belin, 31400 Toulouse, France

Received 6 October 2004; accepted 12 August 2005
Available online 28 November 2006

Abstract

This paper presents Prototype Système 2 Global (PSY2G), the first Mercator global Ocean General Circulation Model (OGCM) to assimilate along-track sea level anomaly (SLA) satellite data. Based on a coarse resolution ocean model, this system was developed mainly for climatic purposes and will provide, for example, initial oceanic states for coupled ocean-atmosphere seasonal predictions. It has been operational since 3 September 2003 and produces an analysis and a two-week forecast for the global ocean every week. The PSY2G system uses an incremental assimilation scheme based on the Cooper and Haines [Cooper, M., Haines, K., 1996. Data assimilation with water property conservation. J. Geophys. Res., 101, 1059-1077.] lifting–lowering of isopycnals. The SLA increment is obtained using an optimal interpolation method then the correction is partitioned into baroclinic and barotropic contributions. The baroclinic ocean state correction consists of temperature, salinity and geostrophic velocity increments and the barotropic correction is a barotropic velocity increment. A reanalysis (1993–2003) was carried out that enabled the PSY2G system to perform its first operational cycle. All available SLA data sets (TOPEX/Poséïdon, ERS2, Geosat-Follow-On, Jason1 and Envisat) were assimilated for the 1993–2003 period. The major objective of this study is to assess the reanalysis from both an assimilation and a thermodynamic point of view in order to evaluate its realism, especially in the tropical band which is a key region for climatic studies. Although the system is also able to deliver forecasts, we have mainly focused on analysis. These results are useful because they give an *a priori* estimation of the qualities and capabilities of the operational ocean analysis system that has been implemented. In particular, the reanalysis identifies some regional biases in sea level variability such as near the Antarctic Circumpolar Current, in the eastern Equatorial Pacific and in the Norwegian Sea (generally less than 1 cm) with a small seasonal cycle. This is attributed to changes in mean circulation and vertical stratification caused by the assimilation methodology. But the model's low resolution, inaccurate physical parameterisations (especially for ocean–ice interactions) and surface atmospheric forcing also contribute to the occurrence of the SLA biases. A detailed analysis of the thermohaline structure of the ocean reveals that the isopycnal lifting–lowering tends to diffuse vertically the main thermocline. The impact on temperature is that the surface layer (0–200 m) becomes cooler whereas in deeper waters (from 500 to 1500 m), the ocean becomes slightly warmer. This is particularly true in the tropics, between 30°N and 30°S. However it can be demonstrated that the assimilation improves the variability in both surface currents and sub-surface temperature in the Equatorial Pacific Ocean.

Keywords: Data assimilation; Global ocean prediction; Altimetry; Sea level; GODAE

* Corresponding author. Tel.: +33 5 61 39 38 27; fax: +33 5 61 39 38 99.
E-mail address: nferry@mercator-ocean.fr (N. Ferry).

0924-7963/$ - see front matter
doi:10.1016/j.jmarsys.2005.08.004

1. Introduction

In the last decade, considerable demand for operational monitoring of the oceans has emerged. In this context, the international Global Ocean Data Assimilation Experiment (GODAE, International GODAE Steering Team, 2000) was set up to provide a framework for developing operational oceanic assimilation systems. At the present time, several projects are working to develop global or regional monitoring systems. Among the most important are Mercator-Océan in France, FOAM in the United Kingdom, MFS in Italy, TOPAZ in Norway, HYCOM US, NAVOCEANO and ECCO in the United States and BLUElink in Australia. Mercator-Océan represents the French contribution to the GODAE project for operational oceanography. It has developed a series of operational ocean analysis/forecast systems specially designed to provide useful products for coastal management (such as oil spill monitoring/prediction using surface currents), real-time support for scientists during oceanographic cruises, yacht racing support, oceanic initial conditions for seasonal prediction, etc.

Among these applications, seasonal climate prediction has considerably developed in the past few years and predictions for a couple of months are performed in several meteorological offices (e.g., European Centre For Medium-Range Weather Forecasts, National Center for Environmental Prediction, among others) by running global coupled ocean-atmosphere models. Due to the upper ocean thermal and dynamic inertia, the oceanic initial state has a considerable impact on the reliability of seasonal forecasts. This has led to the development of assimilation techniques which constrain the ocean state in models with available observations (e.g., Ji and Leetma, 1997; Rosati et al., 1997; Segschneider et al., 2002; Weaver et al., 2003 and many others). Such developments were possible due to the availability of both *in situ* and satellite observations, and particularly sea level anomaly (SLA) data provided by altimetric satellites such as TOPEX/Poséïdon (T/P), ERS2, Geosat Follow-On, Jason1 and Envisat. For about a decade these altimetric satellite missions have been providing global coverage at high spatial and temporal resolutions with small measurement errors that allow observation and assimilation of a wide range of oceanic signals, from eddy variability to large-scale climatic signal. In this study, we will concentrate on the first Mercator global ocean operational analysis/forecast system to assimilate SLA data, whose primary objective is to provide initial oceanic fields for seasonal climate predictions.

Hereafter we will describe and evaluate the performance of the system called Prototype Système 2 Global (PSY2G), which was developed by Mercator-Océan. It consists of a coarse resolution (~ 2° horizontal resolution, 31 vertical levels) global ocean circulation model that assimilates sea level anomaly data. Every week, this system produces real-time analyses based on a retrospective analysis for the last 14 days (these can be viewed routinely on the Internet at http://bulletin.mercator-ocean.fr/html/produits/psy2g1/psy2g1_courant_en.jsp). The PSY2G system is the global low-resolution version of the very high-resolution (1/15°) PSY2V1 operational analysis/forecast system that has been operational since 22 January 2003 over the Northern Atlantic and Mediterranean Sea (Lellouche and Tranchant, 2003; Crosnier and Le Provost, 2007). In terms of these main objectives and due to its coarse horizontal resolution, PSY2G is not designed to assimilate mesoscale variability like PSY2V1 but rather to assimilate and reproduce large scale climatic signals. The unique spatial and temporal data coverage given by the altimetric satellites has spurred Mercator to develop a first generation of operational analysis/forecast systems, to which PSY2G belongs, which only assimilates SLA data. The assimilation method was inspired by the Cooper and Haines (1996) lifting–lowering of isopycnals approach and allows the model's state to be corrected at each analysis cycle. This technique is easy to implement and requires only moderate computational resources. Because seasonal forecast tries to predict anomalies (deviations from a mean seasonal cycle) by running coupled general circulation models over several months, it requires a mean reference state which is representative of a very large number of states of the coupled system in order to build robust statistical/empirical schemes for downscaling purposes. That is why such predictions require very long time series for ocean-atmosphere states (approximately 10 years, at least) in order to construct a mean seasonal cycle for the coupled model (e.g., Palmer et al., 2004). The PSY2G system, which is computationally effective, is particularly well suited in that respect and was used to produce an 11-year global ocean reanalysis from 1993 to 2003 by assimilating SLA observations. Thus, the major objective of this study is to perform a retrospective analysis of the global ocean circulation over a long time period and to investigate how the assimilation scheme used impacts the ocean state, what kind of advantages or drawbacks it has and how the ocean's thermodynamic properties are modified. It is also worth mentioning that the PSY2G system represents an important stage before the migration towards Mercator ¼° global ocean model with data assimilation which is required in order to meet GODAE requirements. The PSY2G system is also a first