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A re-analysis of Black Sea surface temperature

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A B S T R A C T

Two decades of AVHRR Pathfinder data have been used to obtain a daily series of optimally interpolated sea surface temperature (SST) maps over the Black Sea at 1/16° spatial resolution. The interpolated data and associated errors have been first compared with in situ measurements, and successively used to characterize SST variability. The validation evidenced that interpolated data present a mean bias error (MBE) of about −0.05 °C and a root mean square error (RMSE) of about 0.62 °C, while no regional differences or significant temporal drifts were found. The main patterns of variability at different temporal scales have been identified through several Empirical Orthogonal Function (EOF) decompositions. The analysis of the weekly SST data and associated error (assumed as a proxy of cloud cover) evidenced strong interactions with the overlaying atmosphere at short timescales, while examining the EOFs computed from a low-pass filtered SST time series, a significant correlation (up to −0.65) to the North Atlantic Oscillation was found. The SST variations at longer timescales followed the NAO forcing with a relatively large time delay (between 2.4 and 3.5 years), indicating that the processes relating the Black Sea SST to the atmospheric conditions on the longer timescales are more probably linked to the thermal and dynamical balance of the basin as a whole, and not limited to the immediate response of its surface layers.

1. Introduction

Many different factors influence the Black Sea surface temperature variability. First of all, the Black Sea is a semi-enclosed basin with a limited water exchange with the Mediterranean Sea (through the Bosphorus Strait) and even lower exchange with the Azov Sea. Moreover, because of its very high density stratification, it is characterized by a weak vertical mixing (Ozsoy and Unluata, 1997), and the temperature within the relatively shallow upper mixed layer is known to respond very rapidly to the atmospheric forcing (e.g. Schrum et al., 2001). Synoptic, seasonal, and interannual signals related to atmospheric regimes are thus expected to contribute significantly to the surface variability. However, it has been observed that the Black Sea thermal regime is conditioned also by other processes, such as heat advection by currents, river discharge, and also by upwelling and downwelling (e.g. Gavarkiewicz et al., 1999). In addition, increased concentrations of suspended matter near major river estuaries, precipitations, as well as the presence of oil films, may play a role on the sea surface temperature (SST) variations (Fedorov and Ginsburg, 1992; Kara et al., 2005). On the other way round, SST modulates the air–sea heat exchanges that clearly contribute to determine the sea circulation.

As a consequence, it is of crucial importance to obtain reliable information on the SST distribution over the Black Sea, covering a wide range of temporal scales, and keeping also into account that significant and abrupt changes in the Black Sea ecosystem (Oguz and Gilbert, 2007), mainly related to intense surface cooling in the 1980s followed by strong warming in the 1990s, have already been reported by Oguz et al. (2003, 2006), with possible impact on human activities (e.g. fisheries, tourism, etc.). To this aim, satellite data obtained from infrared sensors may be considered the best candidates, provided they are correctly processed and validated against in situ measurements. Satellite data have already been used by Ginzburg et al. (2004), who investigated the seasonal and interannual variability of the Black Sea SST during the period from 1981 to 2000, basing on Advanced Very High Resolution Radiometer (AVHRR) weekly products at 18 km resolution. However, the relative importance of each of the factors affecting SST variations (in terms of explained variance and principal patterns) has never been evaluated up to now. Similarly, it has not been evidenced which of these processes is effectively driving observed climate change.

Therefore, in the framework of the SESAME Integrated Project, supported by the European Commission with the aim of assessing and predicting changes in the Mediterranean and Black Sea ecosystems, a complete re-analysis and interpolation of 1985–2005 AVHRR SST data over the Black Sea has been performed and is presented here. Daily interpolated SST fields have been produced at 1/16° spatial resolution (~7 km) and validated against SST measurements obtained from

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surface drifters. These data were successively used to describe the SST variability in terms of characteristic patterns, through various Empirical Orthogonal Function decompositions. The interpolation algorithm developed has also served as a basis for the development of a near-real time product over the Black Sea, in the framework of MyOcean project.

2. Satellite and in situ dataset

2.1. Satellite SST

A subset of the version 5.0 of AVHRR Pathfinder time series (from 1985 to 2005) has been used for the present study. Pathfinder data consist of two composite images per day, built at 4 km space resolution. Daily and nightly passes are obtained and merged separately from the Global Area Coverage (GAC) data (for more information on Pathfinder version 5 look at http://www.nodc.noaa.gov/sog/pathfinder4km/userguide.html), that use the NLSST (Non Linear Sea Surface Temperature) algorithm proposed by C. Walton (1988), Walton et al. (1990, 1998a,b). The NLSST algorithm reads:

$$SST_{sat} = a + bT_4 + c(T_4 - T_5)SST_{guess} + d(T_4 - T_5)(\sec\rho - 1) \qquad (2.1)$$

where SST_{sat} represents the satellite-derived SST estimate, SST_{guess} is a first-guess SST value, ρ is the satellite zenith angle, and T_4 and T_5 are the brightness temperatures in AVHRR channels 4 and 5, respectively. Coefficients a, b, c, and d are determined empirically from co-located in situ and satellite measurements collected all around the world (hereafter "matchups"). These PFSST coefficients are updated monthly and the matchups are selected within a window of five months around the measurement time, to ensure reasonable accuracy at global scale and absence of sensor drifts (Kilpatrick et al., 2001). This empirical approach makes the Pathfinder algorithm the most suitable for studies on interannual variations of SST and it allows to reasonably evaluate long term trends.

Associated to each SST image, Pathfinder product includes a number of quality flags. These are obtained through a series of tests that are combined to define eight overall quality levels for each pixel (for a detailed description of Pathfinder quality flags see http://podaac.jpl.nasa.gov/pub/sea_surface_temperature/avhrr/pathfinder/doc/usr_gde4_0_toc.html). In this work, only the pixels that have passed all the tests have been selected. Valid data have been successively binned on a 1/16° grid covering the Black Sea. The method chosen to bin the data is a simple median of all valid measurements found within each grid cell. This technique has been preferred to a mean or weighted mean as it reduces the contamination by residual cloudy pixels. Finally, ascending orbits have been excluded to reduce the effect the diurnal cycle, and, consequently, the difference between the pseudo-skin SST measurements provided by Pathfinder algorithm and the SST foundation (see Donlon and GHRSST-PP Science Team, 2004 for SST definitions, and Marullo et al., 2007 for a discussion on Pathfinder measurements).

2.2. In situ datasets

2.2.1. Marine Hydrophysical Institut drifters dataset

Drifters represent the main source of SST-in situ data over the Black Sea. The instruments used in this work are the SVP-Barometer (SVP-B) drifters produced by Marlin-Yug Ltd. The Marlin-Yug MM400 SST module is integrated in SVP-B drifters with a calibrated precision digital thermometer. The thermometer is installed in a capped copper case embedded in the hull, fitted at the base of the surface float, i.e. at an approximate depth of less than 20 cm.

Drifter data were processed by the Marine Hydrophysical Institut, that directly receives them through GTS (Global Telecommunications System), and cover the period between 2001 and 2005. Actually, even if the nominal accuracy of SVP-B drifters is ± 0.2 °C and their resolution attains around 0.08 °C, this kind of instruments may be affected by additional errors that need to be kept into account. Therefore, specific data processing procedures have been developed at MHI, with interactive programs for the identification and flagging of particular error conditions. Data filtering is realized in two steps: 1) checking submergence sensor data; 2) detecting sensor failures. The primary filtering aims to reveal the eventual breaking of the underwater sail (drogue), which may cause the drifter to turn upside down with subsequent sensing of air temperature. That condition is verified examining the average period of submersion, which cannot exceed the one normally related to wave oscillations. Persistence of submerged signals indicates the drogue has broken. The second filtering procedure allows to identify sensor failures and to delete corresponding data in an interactive mode. The screening of the SST measurements is based on threshold criteria taking into account the range of physically reasonable temperature values in each area, at the given time. The data selection is thus performed by an expert human operator, and ensures a significant improvement in terms of data accuracy.

2.2.2. NATO-TU-Black Sea dataset

As a secondary source of in situ measurements for the validation of the OISST product, but dating back to the 80s and 90s, we have used the Black Sea inter-disciplinary multivariable historical database. This dataset, freely available at http://sfp1.ims.metu.edu.tr/, has been created in framework of the NATO-TU-Black Sea (Ecosystem modeling as a management tool for the Black Sea: a regional program of multi institutional cooperation) project in 1994–1997 and is maintained in framework of the NATO SfP ODBMS Black Sea (Ecosystem processes and forecasting/operational database management system) Projects. It includes all main physical, chemical and biological in situ measurements for the entire Black Sea basin, collected by all main regional and international sources. All data were quality checked by qualified groups of regional experts, following quality control protocols defined within MEDAR/MEDATLAS II project (http://www.ifremer.fr/medar/quality.htm).

3. The optimal interpolation scheme

The intense cloud cover over the Black sea generates several data voids in satellite infrared measurements. As a consequence, even though some recently proposed techniques could allow to simultaneously analyse the variability and interpolate a particular dataset (e.g. Beckers et al., 2006), given their relatively experimental nature, and the need to test an interpolation technique to be implemented operationally during MyOcean project, we decided to perform the interpolation and the analysis of the variability in two separated steps. Actually, satellite SST data interpolation cannot be considered a trivial issue, and it has been the object of various studies, that proposed quite different solutions, depending on the areas under study and on the assumptions on the scales to be resolved, as well as on the different sensors considered (e.g. Kaplan et al. 1998; Reynolds et al. 2002; Marullo et al. 2007). Recently, within the Global Ocean Data Assimilation Experiment (GODAE) High-Resolution Sea Surface Temperature Pilot Project, different algorithms have been tested and are now used operationally to provide both near-real time and delayed time SST products (http://www.ghrsst-pp.org/).

The method used during SESAME to fill the data voids is known as optimal (or statistical) interpolation, and its theoretical aspects have been described several times in literature (e.g. Bretherton et al, 1976). In this section, the practical application of the statistical interpolation method to the Black Sea data is described. In fact, any statistical interpolation technique includes a number of 'hidden' assumptions and needs proper tuning, depending on the amount of data available and on computational issues and limitations. The scheme adopted