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ORIGINAL RESEARCH ARTICLE

Toward downscaling oceanic hydrodynamics — suitability of a high-resolution OGCM for describing regional ocean variability in the South China Sea

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Summary We suggest to transfer the empirical downscaling methodology, which was developed mostly for atmospheric dynamics and impacts, to regional ocean problems. The major problem for doing so is the availability of decades-long and homogeneous and spatially detailed data sets. We have examined the performance of the STORM multidecadal simulation, which was run on a 0.1° grid and forced with 1950—2010 NCEP re-analyses, in the South China Sea and found the data suitable. For demonstration we build with this STORM-data downscaling model for the regional throughflow.

The STORM data is compared with AVISO satellite observations and the ocean re-analysis dataset C-GLORS. We find the seasonal patterns and the inter-annual variability of sea surface height anomaly in both the C-GLORS data and the STORM simulation consistent with the AVISO-satellite data. Also the strong westward intensification and the seasonal patterns of South China Sea circulation steered by the monsoon have been presented well. As an important indicator of vertical movement, the sea surface temperature distribution maps are also very close, especially for the narrow upwelling region in summer. We conclude that the output of the STORM simulation is realistically capturing both the large-scale as well as the small-scale dynamical features in the South China Sea.

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1. Introduction

As the largest semi-enclosed marginal sea located in the southeast Asian waters, the South China Sea (SCS) covers an area of about 3.5 million km^2 in total, with an average depth more than 2000 m and a maximum depth of about 5000 m. It is surrounded by China, Vietnam, Philippine Islands, Malaysia and other countries. Via the Luzon Strait, Taiwan Strait and the Strait of Malacca, it connects the Pacific Ocean, East China Sea and Indian Ocean (Fang et al., 2006a, b, 2012; Ho et al., 2000; Hu et al., 2000; Li et al., 2003).

Due to the influence of the East Asian monsoon system, the SCS circulation represents significant seasonal characteristics. Previous studies have been carried out to analyze the features of the SCS circulation. Dale (1956) determined the SCS surface circulation in winter and summer for the first time from the ship drift data, which clearly revealed the seasonal differences. Wyrtki (1961) pointed out that the monsoon is the main driver of the SCS circulation.

The advent of satellite remote sensing technology allowed the analysis of the details of the SCS circulation. Ho et al. (2000) has described the seasonal variability of sea surface height (SSH) based on the TOPEX/Poseidon altimeter data during 1992—1997. Fang et al. (2006b) used the gridded 11-year AVISO SSH data, which merged data from TOPEX/Poseidon, ERS and Jason, for characterizing the low frequency variability of the SCS surface circulation and to discuss its relationship with El Niño-Southern Oscillation. The conclusion of the annual variability responding to the change of monsoon was confirmed by their study.

Recently, several numerical simulations of the SCS circulation were done. Such simulations help extend our knowledge about past variations beyond the short time period of satellite observations and beyond the sparse sampling of in situ observation and ship observation. Wei et al. (2003) embedded a fine-grid ocean model of the China Sea into a global model so that open boundary conditions were no longer needed. Their modeled monthly SSH anomalies (SSHA) were similar to the TOPEX/Poseidon data, and the model could seasonably reproduce the SCS Southern Anticyclonic Gyre in summer and the SCS Southern Cyclonic Gyre in winter. Using this model, the seasonal features of the water intruding into the SCS through the Luzon Strait in different ocean layers were investigated. Wang et al. (2006) modeled the interannual variability of the SCS circulation and its relation to wind stress and El Niño through on an irregular grid. Such numerical simulations allowed the detailed study of processes and physical mechanisms of some mesoscale phenomena, for example, the topographical effect on the coastal upwelling in the north SCS (Wang et al., 2012, 2014).

In spite of those signs of progress, a systematic, detailed, homogeneous and comprehensive description of the SCS circulation on regional and local scales across several decades is hardly available. The "empirical downscaling" methodology may help to generate such descriptions, which will also allow for detection externally driven change as well as projecting possible future change on such regional scales. Most downscaling efforts were directed at atmospheric phenomena (Benestad et al., 2008; von Storch et al., 1993), but a few oceanic applications dealing with local sea level were presented in the 1990s (Cui et al., 1995; von Storch and Reichardt, 1997).

An alternative to empirical downscaling is dynamical downscaling using regional dynamical models (oceanographic examples are provided by Kauker and von Storch, 2000; Schrum et al., 2003); however, this approach is more challenging and cost-intensive than the empirical approach; also the empirical approach may deal with local phenomena, which are possibly less well resolved by dynamical models. Therefore, we explore the potential of the empirical downscaling of oceanic dynamics.

For doing so for the South China Sea (SCS), we need a consistent and homogeneous description of the regional space-time variability in that region. As a first preparational step, we examine the suitability of a multidecadal global simulation "STORM" with the MPI-OM, the high-resolution global ocean model of the Max Planck Institute of Meteorology (MPI; Li and von Storch, 2013; von Storch et al., 2012), which was forced by NCEP atmospheric re-analyses.

The high resolution of about 1/10° makes STORM capable to describe the small-scale features, while the temporal coverage over 60 years enables STORM to analyze the long-term variability of the SCS circulation. In addition, STORM provides the large-scale states. Therefore, STORM is a good choice for constructing the statistical relationship between large and small scales. Also all relevant second-moment statistics have been archived by accumulating two-variable-products at every time step (von Storch et al., 2012).

In this paper, we first assess the performance of STORM in describing the SCS circulation, by comparing with AVISO altimeter measurements and ocean re-analysis dataset C-GLORS. In Section 2, these three data sets are described in detail. Section 3 presents the comparisons, in terms of sea surface height anomalies (SSHA), surface current and sea surface temperature (SST). Eventually, for demonstration, an empirical downscaling model has been constructed (Section 4), which allows deriving the monthly seasonal near-surface regional throughflow in the South China Sea from the regional wind fields.

2. Dataset description

2.1. Satellite observations

The monthly SSALTO (SSALTO multimission ground segment)/Duacs (Data Unification and Altimeter Combination System) gridded SSHA (sea surface height anomaly) data set from Archiving, Validation and Interpretation of Satellite Data in Oceanography (AVISO) covers almost the entire global ocean with a resolution of 0.25° from 1993 to 2014. It has been built from several satellite products, including TOPEX-POSEIDON, ERS, JASON and ENVISAT (AVISO, 1996, 2009).

As a consequence of its high quality, the AVISO SSHA data has often been used as reference to validate global model output and characterize regional currents (Fang et al., 2006a,b). In this paper, we compare the AVISO SSHA data with SSHA from the STORM simulation and the ocean re-analysis C-GLORS.

2.2. The ocean re-analysis dataset C-GLORS

The ocean reanalysis dataset C-GLORS (version 4) has the same horizontal 0.25° grid resolution as AVISO. It has been