Ocean Modelling 120 (2017) 1–17

Contents lists available at ScienceDirect

Ocean Modelling

journal homepage: www.elsevier.com/locate/ocemod

Comparison of in situ microstructure measurements to different turbulence closure schemes in a 3-D numerical ocean circulation model

Andrea Costa[a,b,*], Andrea M. Doglioli[a], Patrick Marsaleix[c], Anne A. Petrenko[a]

[a] Aix-Marseille Université, Université de Toulon, CNRS, IRD, Mediterranean Institute of Oceanography (MIO), Marseille, France Personnels UTLN, France
[b] IBS Center for Climate Physics (ICCP), Pusan National University, Busan, Republic of Korea
[c] Laboratoire d'Aérologie UMR 5560, Université Paul Sabatier, CNRS, 31400 Toulouse, France

ARTICLE INFO

Keywords:
Scalar vertical diffusivity
Kinetic energy dissipation rate
Turbulence closure schemes
Stability functions
Surface boundary conditions
Microstructure
Symphonie numerical model

ABSTRACT

In situ measurements of kinetic energy dissipation rate ε and estimates of eddy viscosity K_Z from the Gulf of Lion (NW Mediterranean Sea) are used to assess the ability of $k-\varepsilon$ and $k-\ell$ closure schemes to predict microscale turbulence in a 3-D numerical ocean circulation model. Two different surface boundary conditions are considered in order to investigate their influence on each closure schemes' performance. The effect of two types of stability functions and optical schemes on the $k-\varepsilon$ scheme is also explored. Overall, the 3-D model predictions are much closer to the in situ data in the surface mixed layer as opposed to below it. Above the mixed layer depth, we identify one model's configuration that outperforms all the other ones. Such a configuration employs a $k-\varepsilon$ scheme with Canuto A stability functions, surface boundary conditions parameterizing wave breaking and an appropriate photosynthetically available radiation attenuation length. Below the mixed layer depth, reliability is limited by the model's resolution and the specification of a hard threshold on the minimum turbulent kinetic energy.

1. Introduction

Turbulence is an essential mechanism for the transport of energy, salinity, and suspended and dissolved matter. Turbulent fluxes of such quantities are the result of correlated, small-scale fluctuations of the velocity field and of the transported quantity itself. The prevalent turbulence production mechanisms in coastal ocean are: mean shear, unstable stratification, Langmuir circulation (Farmer and Li, 1995) and breaking surface waves (Agrawal et al., 1992). For coastal ocean, mean shear is mainly generated by the action of winds and tides, but also by surface waves and baroclinic flows (e.g., Thorpe, 2005), including nonlinear internal waves (Toole and Schmitt, 1987). Unstable stratification results from surface processes such as surface cooling, evaporation or differential advection (e.g., Kantha and Clayson, 2000). Destruction of turbulence occurs by transformation into potential energy during stable stratification or viscous dissipation into heat (e.g., Kantha and Clayson, 2000). The complexity of these processes by themselves and of their interactions requires numerical models to cover a wide range of spatio-temporal scales and Reynolds number (e.g., Burchard et al., 2008). This is especially true in the upper ocean where all the above phenomena concur together to generate turbulence.

Upper ocean connects –through various turbulent mechanisms– the surface forcing from the atmosphere with the quiescent deeper ocean where heat and fresh water are sequestrated and released on longer time and global scales (Ferrari and Wunsh, 2009). Also, upper ocean turbulence plays an important role in biological phenomena by, for example, determining phytoplankton growth rate (Thomas and Gibson, 1990), influencing primary production (Flierl and Davis, 1993) and the onset of blooms (Taylor and Ferrari, 2011).

The complexity of modelling such mechanism within ocean circulation numerical models gave rise to several approaches. In particular, many turbulence closure schemes have been proposed. The ones most frequently found in the ocean modelling community's literature are the $k-k\ell$ by Mellor and Yamada (1982); the $k-\varepsilon$ by Rodi (1987); the $k-k\omega$ by Wilcox (1988); the $k-\ell$ by Gaspar et al. (1990) and the KPP by Large et al. (1994). Following recent numerical modelling literature (Ilicak et al., 2008; Reffray et al., 2015), in the present study, we consider the $k-\varepsilon$ and $k-\ell$ second moments closure (SMC) schemes. Note that other kinds of closure schemes such as the KPP (Large et al., 1994) are not considered here being not as well suited as the other two schemes for a comparison with in situ data of kinetic energy dissipation rate ε.

Additional complexity is added to the modelling by the interplay of the SMC and the choice of boundary conditions. The choice of surface

* Corresponding author at: IBS Center for Climate Physics (ICCP), Pusan National University, Busan, Republic of Korea.
E-mail address: andrea.costa@pusan.ac.kr (A. Costa).

http://dx.doi.org/10.1016/j.ocemod.2017.10.002
Received 22 November 2016; Received in revised form 25 September 2017; Accepted 11 October 2017
Available online 24 October 2017
1463-5003/

and bottom boundary conditions can also profit from a vast literature (e.g., Craig and Banner, 1994; Stacey and Pond, 1997; Estournel et al., 2001; Warner et al., 2005), aiming at modelling different forcing mechanisms. Furthermore, different stability functions can be chosen in order to include the effect of the parameterized non-local moments and pressure strain correlations in the dynamical equations (e.g., Galperin et al., 1988; Kantha and Clayson, 1994; Canuto et al., 2001). The choice of the optical scheme is particularly important considering the high number of studies coupling Symphonie to biochemical models as it can influences turbulent fluxes and nutrient availability.

Thus, the in situ validation of the closure schemes, boundary conditions, stability functions, optical scheme and their interplay is fundamental for assessing the reliability of numerical models (Warner et al., 2005; Peters and Baumert, 2007; Arneborg et al., 2007; Ilicak et al., 2008).

The current study presents the comparison of kinetic energy dissipation rate ε measurements and vertical eddy viscosity K_Z estimates issued from a Self Contained Microstructure Profiler (SCAMP) with the predictions of a 3-D numerical ocean circulation model (Symphonie; Marsaleix et al., 2008) obtained with different model's setup. The aim is to gain some insights on which scheme and/or boundary conditions permit to have the representation of turbulence activity closer to the observations.

Microstructure measurements with the SCAMP profiler have already been used for turbulence estimates in lakes and ocean (e.g., Ruddick et al., 2000; Sharples and Moore, 2001; Burchard et al., 2002; Anis and Singhal, 2002; Sharples et al., 2003; Peters et al., 2009; Steinbuck et al., 2010; 2011; Cuypers et al., 2012; Jurado et al., 2012; Bouffard and Boegman, 2013). The dataset we exploit is described in Section 2. It consists of measurements taken in a coastal environment in the Gulf of Lion (GoL).

The GoL is located in the northwestern Mediterranean Sea and is characterized by a large continental margin (Fig. 1) and complex hydrodynamics (Millot, 1990). Its circulation is strongly influenced by the southwestward along-slope Northern Current. This density current flows in a cyclonic way and constitutes a barrier between the coastal waters of the continental shelf from the open northwestern Mediterranean Sea (Alberola and Millot, 1995; Sammari et al., 1995; Petrenko, 2003). Cross-shore exchanges between the GoL and offshore waters are regulated by wind induced dynamics (Estournel et al., 2003; Hauser et al., 2003; Petrenko et al., 2017) and by processes associated with the Northern Current, such as intrusions into the continental shelf and barotropic and baroclinic instabilities (Conan and Millot, 1992; Flexas et al., 1997; Petrenko et al., 2005; Barrier et al., 2016). The Gulf of Lion is a suitable case study because of the high number of physical (Qiu et al., 2010; Hu et al., 2011), sediment dispersion (Bourrin et al., 2011) and biochemical (Pinazo et al., 2001; Herrmann et al., 2014) numerical studies carried out there.

Symphonie has already been validated on a variety of different aspects like current modelling and eddy generation (Rubio et al., 2009; Hu et al., 2011; Kersalé et al., 2013), river plume dynamics (Reffray et al., 2004; Gatti et al., 2006) and dense water formation (Dufau-Julliand et al., 2004; Estournel et al., 2016). But a study of the different SMC that the user can implement in the Symphonie code has not yet been done. In particular, the modeling of the near-surface physical and biogeochemical processes is sensitive to the choice of SMC and the computed K_Z values (Fraysse et al., 2014).

In general, we can regard all modeled large-scale circulation features in an integrated fashion as they result from successive calculation steps and approximations. Hence, a major difficulty in validating numerical models –beside the high number of variables at play– is the possible compensation of different errors between each other. This fact makes difficult to attribute a specific amount of the total error on a certain quantity to a specific step in its calculation, in the present case the turbulence scheme. Here, our goal is to assess the model predictions focusing on turbulence modelling in the most realistic configuration we

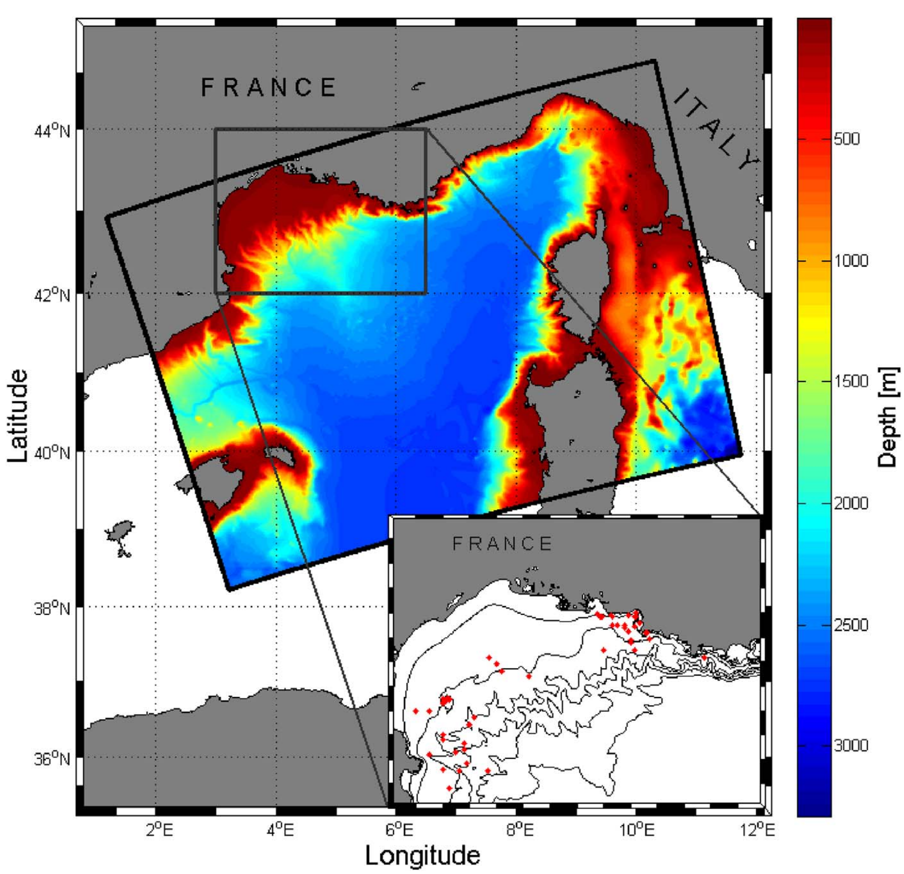

Fig. 1. Numerical model domain. The color code represents the water depth. The Gulf of Lion is magnified in the smaller box where the measurements sites are represented by red dots. Note that many profiles were taken at the same location over time. The black lines in the smaller box represent the 0, 50, 100, 500, 1000 and 1500 m isobaths. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)