Dynamics of Atmospheres and Oceans 71 (2015) 1–20

Contents lists available at ScienceDirect

Dynamics of Atmospheres and Oceans

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

Exceptional Bora outbreak in winter 2012: Validation and analysis of high-resolution atmospheric model simulations in the northern Adriatic area

Silvio Davolio[a,*], Paolo Stocchi[a], Alvise Benetazzo[b], Emanuele Bohm[c], Francesco Riminucci[d,e], Mariangela Ravaioli[d], Xiao-Ming Li[f], Sandro Carniel[b]

[a] Institute of Atmospheric Sciences and Climate, CNR ISAC, Via Gobetti 101, 40129 Bologna, Italy
[b] Institute of Marine Sciences, CNR ISMAR, Arsenale Tesa 104, Castello 2737/F, 30122 Venice, Italy
[c] Institute of Atmospheric Sciences and Climate, CNR ISAC, Via Fosso del Cavaliere 100, 00133 Rome, Italy
[d] Institute of Marine Sciences, CNR ISMAR, Via Gobetti 101, 40129 Bologna, Italy
[e] Proambiente S.c.r.l., c/o CNR ISMAR, Via Gobetti 101, 40129 Bologna, Italy
[f] Institute of Remote Sensing and Digital Earth (RADI), Chinese Academy of Sciences, No.9 DengZhuang Nan Road, Haidian, 100094 Beijing, China

ARTICLE INFO

Article history:
Received 24 November 2014
Received in revised form 8 April 2015
Accepted 5 May 2015
Available online 7 May 2015

Keywords:
Bora
Surface fluxes
NWP model
Validation

ABSTRACT

The Bora wind event occurred in winter 2012 was exceptional in terms of both meteorological effects and impact on the Adriatic Sea circulation. It was associated with intense and persistent winds, very cold temperatures all over the Mediterranean basin and heavy snowfall over the Apennines slopes exposed to north-easterly winds, and it was responsible for triggering dense water formation and driving basin-scale oceanic circulation. The cooling period (29 January–13 February) was characterized by intense air–sea exchanges of momentum and heat, whose accurate simulation is required for a proper description of atmospheric and ocean circulations.

In the present study, results of a number of short-range high-resolution numerical weather prediction (NWP) model simulations for the entire Bora outbreak are discussed. The modeling chain, based on BOLAM and MOLOCH limited area models, has been implemented using initial and boundary conditions provided by different global NWP systems. Model performance has been evaluated in terms of variables of interest for oceanographic applications, such as sea surface temperature (SST), surface heat fluxes, solar radiation and near surface meteorological parameters (air temperature, wind, pressure and humidity). The validation has been undertaken through a comparison against surface data (buoys and oceanographic platforms) available at different locations in the northern Adriatic area, while advanced synthetic aperture radar (ASAR) products have been used to assess modeled wind fields on a larger scale.

Model results indicate a good agreement with the observations concerning meteorological variables, in particular wind, pressure and temperature. However, large differences were found in the SST forecasts, which in turn affect also sea surface flux predictions. The uncertainties in SST forecasts are mainly ascribable to the different initialization fields provided by either the global models or satellite analyses. Thus SST initialization represents a critical issue for an accurate description of surface fluxes at least for this exceptionally severe event.

* Corresponding author. Tel.: +39 0516399620; fax: +39 0516399658.
E-mail address: S.Davolio@isac.cnr.it (S. Davolio).

http://dx.doi.org/10.1016/j.dynatmoce.2015.05.002
0377-0265/

1. Introduction

The northern Adriatic Sea is a shallow and semi enclosed basin, and meteorological conditions may remarkably impact the ocean, being responsible for a large variability in current, temperature and salinity. This is especially true during Bora events, typical in the winter season, when the Adriatic Sea is affected by cold and strong winds blowing from the northeast (Grisogono and Belušić, 2009). Bora events are characterized by intense air–sea heat and momentum exchanges (Stravisi and Crisciani, 1986; Mihanović et al., 2013; Stravisi and Crisciani, 1986; Raicich et al., 2013), thus producing strong effects on the thermohaline properties and circulation of the entire Adriatic Sea. In particular, shelf dense-water formation (DWF) processes (Vilibić and Supić, 2005; Mihanović et al., 2013; Benetazzo et al., 2014) are triggered on the broad, shallow shelf in the northernmost region of the Adriatic basin by the cold and severe Bora winds, which bring cold and dry air from the northeastern Europe, down the Dinaric Alps. The resulting intense evaporation and cooling of the shelf waters produce the North Adriatic Dense Water (NAdDW) (Artegiani et al., 1997; Vilibić and Supić, 2005), which then sinks and flows as a dense bottom current along the western Adriatic continental shelf. NAdDW descends all the way to the southern part of the basin, finally affecting the whole deep eastern Mediterranean circulation (Robinson et al., 2003). In particular, during the exceptional cold air outbreak of winter 2012, characterized by prolonged and severe Bora episodes, shelf and coastal DWF occurred not only at the classical sites, but also at a number of eastern Adriatic coastal channels and bays (Mihanović et al., 2013), and the winter 1929 record of density (about 1030.3 kg/m^3; Vatova, 1934) was broken (Raicich et al., 2013Raicich et al., 2013).

Given the impact in terms of meteorological and ocean dynamics, different modeling and observational studies on the Adriatic area have emerged in the past, focused on the analysis of structure and evolution of specific Bora cases and the induced ocean response. Among the modeling studies, Enger and Grisogono (1998) found high correlation between the sea surface temperature (SST) and the Bora offshore propagation length in a series of numerical experiments using a 2D model. Changing the SST turned out to alter the coastal atmospheric boundary layer buoyancy frequency and, as a consequence, the dynamical development of the wind. Later, Cesini et al. (2004) and Kraljević and Grisogono (2006), performing independent 3D modeling analyses of a Bora event in the northern Adriatic, confirmed the impact of SST on Bora characteristics. In particular, Cesini et al. (2004) used also satellite data for a comparison with model simulations and showed that in turn, the Bora flow was able to produce an SST decrease in the affected areas, reaching 7–8 K, locally, in 48 h.

More recently, coupled air–sea models have been applied to the study of Bora events. Pullen et al. (2006, 2007),) produced a thorough analysis of air–sea interactions and found that heat flux and wind stress were remarkably attenuated in the two-way coupled runs compared with one-way coupled simulations, in better agreement with available observations. In particular, two-way coupling provided a more realistic SST field characterized by small-scale cold pattern in the northern Adriatic and along the Italian coast, thus stressing the importance of a correct and detailed SST definition for representing air–sea exchange processes associated with Bora.

On the other hand, among the monitoring studies, Dorman et al. (2007) exploited the data provided by an oceanographic field experiment in the northern Adriatic to characterize heat fluxes associated with a Bora event in winter 2003. More recently, several studies focused on the exceptional Bora episode of January and February 2012. Mihanović et al. (2013) analyzed the associated exceptional DWF, showing its impact on the whole Adriatic basin and identifying important pre-conditioning factors, such as low precipitation and river discharge. Raicich et al. (2013)Raicich et al. (2013) performed a detailed analysis in terms of overall air–sea interaction and its effect on the seawater in the Gulf of Trieste, showing the exceptional characteristics of the event compared with past episodes.

As pointed out by Dorman et al. (2007) and Pullen et al. (2006, 2007),) turbulent surface (latent and sensible) heat fluxes and SST variations are the two most important parameters that characterize intense air–sea interactions typical of Bora events. Therefore, their accurate simulation is critical in order to properly describe and understand these atmospheric and ocean circulation processes. Numerical weather prediction (NWP) models, applied to short-range forecasts, usually keep SST fixed at its initial value or allow just slow changes according to surface fluxes. This SST representation is generally unrealistic even for short-range forecasts especially in small and shallow basin like the Adriatic Sea during particular meteorological events such as Bora (Cesini et al., 2004).

This framework motivated the present study aimed at investigating the exceptional Bora episode occurred in winter 2012, when winds blew for more than 10 days, the longest duration since 1979 (Benetazzo et al., 2014). High-resolution NWP models (namely BOLAM and MOLOCH, see Section 2) have been used, driven by two different sets of initial and boundary conditions provided by two global NWP systems, namely GFS-NCEP (Global Forecasting System of the US National Center for Environment Prediction) and IFS-ECMWF (Integrated Forecasting System of the European Centre for Medium-range Weather Forecasts). Additional sensitivity experiments have been carried out performing simulations driven by the same global models, but using a different initial SST field provided by near-real time satellite analyses. Thus, in the present study, the sensitivity of Bora simulations to different driving global datasets has been investigated, focusing in particular on the initialization of the SST field that strongly modulates Bora effects at the surface. In order to attain this aim, a number of short-range atmospheric simulations have been performed to cover the entire period (25 January–15 February 2012) and model performances have been evaluated in terms of variables of interest for oceanographic applications. In addition to meteorological variables, surface fluxes, solar radiation and SST fields have been analyzed. The validation has been undertaken trough a comparison with available sea surface and sub-surface data (from buoys and off-shore oceanographic platforms) that allows to suitably monitor the northern Adriatic area and in particular the area characterized by Bora wind jets. Moreover, synthetic aperture radar (SAR) products have been used to assess simulated wind fields on a larger scale.