

SIMULATION OF SEA SURFACE TEMPERATURE TRENDS UNDER SEVERE WIND FORCING WITH A FULL ATMOSPHERE-OCEAN COUPLED MODEL

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Summary The main object of this paper concerns the numerical simulation of air-sea interactions in situations of high frequency variability connected to abrupt severe atmospheric forcing over the sea. A particular attention has been turned to singling out the most relevant mechanical and thermal coupling schemes between the two media and their proper parametrization in terms of mechanical, radiative, and thermal energy fluxes through the air-sea interface. It was demonstrated the importance of a two way forcing mechanism between air and sea in order to explain the experimental observations

Air-sea interaction context

The atmosphere and the ocean represent a stratified two-layer fluid system whose dynamic and thermodynamic state evolution in space and time complies with different forcing conditions. However, they also interact with each other, through exchanges of mechanical and thermal energy. It is a widespread opinion that atmospheric forcing on the ocean (mainly wind stress and partly radiation and sensible and latent heat flux) is far more efficient than the opposite ocean forcing on the atmosphere, when the interaction episodes are characterised by conditions of shallow water and high frequency variability with respect to the situation of deep water and longer interaction periods.

This study aims at going into the above belief, through a comparison of the results of numerical simulations with field observation of mechanical and thermal interaction of strong and intermittent wind with shallow water ocean.

Numerical simulation

The main perturbations induced by wind forcing over the sea concern its circulation, level and pattern of Sea Surface Temperature (SST). In order to better understand the specific role played by each interaction mechanism and its forcing direction (from air to water and vice-versa), we decided to investigate high frequency variability processes connected to abrupt severe atmospheric forcing over the sea. For this reason, cold and intense Bora wind outbreaks over the northern and central Adriatic sea were elected as the investigation subject due not only to their high variability but also to their potential capability to perturb the equilibrium winter regimes of air-sea interaction in the Adriatic Basin (like vertical mixing and dense water production)

Another peculiar aspect of Bora is its short duration and limited spatial extent, which cannot be resolved by the wind fields provided by ECMWF or similar organizations. In order to capture the main features relevant to air-sea interaction in the Adriatic basin through Bora wind episodes, a regional two-way Atmosphere/Ocean Coupled Model (TWAOCM) developed by our group has been used with the purpose to appraise the possible benefit of a two-way coupling with respect to the simpler one-way coupling even in short term variability conditions. The numerical simulations of the above mentioned mechanical and thermal perturbations between air and sea have been performed in the spatial domain corresponding to the northernmost region of the Adriatic Sea basin. Fig. 1 shows the bathymetry of the whole Adriatic basin just in order to show the topographical complexity of the selected domain. The northern Adriatic Sea is shallow and has a fairly even slope gradually deepening to 100 m. The intermediate part has its main feature in a bathymetric depression about 200 m deep. The southernmost part is deeper than the other two parts, and reaches a maximum depth of almost 1200 m (South Adriatic Pit).

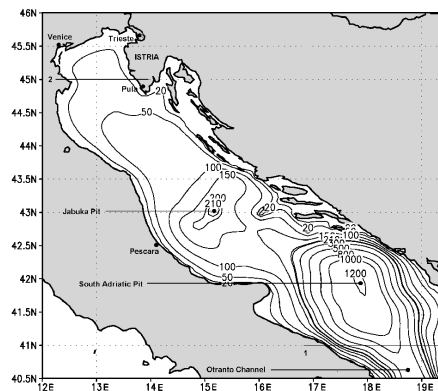


Figure 1

All these features bring about steady and unsteady vortices whose influence is felt as far as the northern regions. Due to the strong cold advection in the planetary boundary layer during Bora episodes, SST becomes an easy-to-monitor “tracer” of the dynamic and thermal response of the water to the wind forcing, which allow a fast quantitative comparison between observed data and model simulations. The SST evolution has been chosen as a validation parameter because it is closely connected to dynamics and thermodynamics of the whole depth of the sea, and also owing to its easy availability.

The peculiar aspect of Bora mentioned before, i.e. its short duration and limited spatial extent, cannot be resolved by the wind fields provided by ECMWF or similar organizations. In order to capture the main features relevant to air-sea interaction in the Adriatic basin through Bora wind episodes, a regional two-way Atmosphere/Ocean Coupled Model (TWAOCM), developed by our group and incorporating two circulation models [RAMS for the atmosphere and DieCAST for the ocean] driven by the global host model of ECMWF, has been used with the purpose to appraise the possible benefit of a two-way coupling (fig.2) with respect to the simpler one-way coupling even in short term variability conditions.

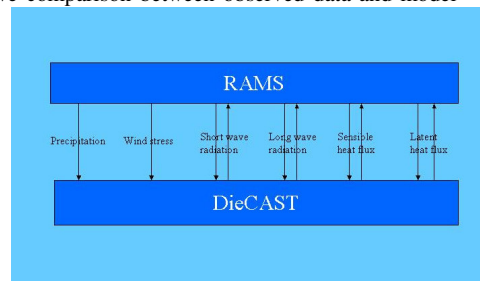


Figure 2

The ECMWF model (T213/L31) is a global semilagrangian model that calculates the meteorological fields on a three-dimensional grid with 31 vertical levels (thereby L31). The input are satellite data, data taken on the ground, on the oceans and in the free atmosphere. The output for the horizontal plane are compressed in a series of spherical harmonics with triangular truncation and a maximum resolution of 213 wavelengths on a great circle (thereby T213).

The RAMS model (Pielke et al., 1992) is a highly versatile numerical code for simulating meteorological phenomena based on the full set of primitive dynamical equations which govern atmospheric motions with The supplements of these equations include optional parameterisations for subgrid phenomena. The RAMS model proved to be particularly able to downscale the meteorological fields from synoptic to regional scale (Qian and Giraud, 2000)

The DieCAST model (Dietrich et al., 1987; R.L. Walko et al., 1995) was derived from the modified Arakawa C grid SOMS (Sandia Ocean Modeling System) model (Dietrich and Ko, 1994). It is a three-dimensional model in a rotating frame, z-level, hydrostatic, Boussinesq, incompressible, rigid-lid model.

Both models (RAMS and DieCAST) use a vertical stretching that allows a better resolution near their separation interface. They have been set up with the same horizontal geometry in a area which includes almost the whole Adriatic Sea as far as the Otranto Strait.

The boundary conditions at the interface of the two-way TWAOCM coupled model used for the simulation of the Bora event are the analyses of the ECMWF model referring to the horizontal rectangular area of the integration domains of the two models, nested inside the larger one of ECMWF. The initial conditions for the SST of the TWAOCM coupled model is the output of a 3 -month "stand-alone" run of the DieCAST initialized and forced by its own MODB-MED4 seasonal climatology. "Stand alone" means that there was no coupling of the DieCAST and the atmosphere model. Initialization obtained in this way is expected to approach the actual initial conditions of the case study rather well, although not always exactly equaling it. In fact, under some circumstances, the use of climatological data might affect the performance of a numerical model due to the actual thermal structures of the upper ocean which do not follow the climatological trend. For this reason, we used also an alternative initialisation of hybrid type, by running DieCAST in "stand alone" mode with the seasonal climatological database but converging toward satellite observation of the SST during the winter season, i.e. the season in which strong Bora winds are more frequent. These satellite observation of SST were retrieved in the file collecting satellite-base AVHRR measurements derived by the Pathfinder Project, after a space-time interpolation using the objective analysis of Mariano and Brown (University of Miami). Once the simulation of the Bora with the coupled model was started, the ocean model DieCAST no longer used the climatological or satellite data anymore, but was forced completely by the real time atmospheric fields provided by the RAMS, hence constituting the boundary conditions during the model run.

In a previous study, we started the coupling of our regional atmosphere-ocean model with a one-way interaction scheme. With this scheme, the model ocean received surface forcing (such as wind stress, radiation, sensible and latent heat fluxes) every ten minutes from the model atmosphere, without giving feedback to the same. Model results of the one-way coupled approach with climatological initialisation gave very low simulated SSTs after the Bora episode, in fact SST on the Gulf of Trieste side of the Adriatic Sea was shown to drop by 4 °C within five days of the Bora, whilst observations showed a drop of only 1 °C. In addition, the overestimate did not keep constant, but was accentuated with the passing of time.

In the present study, the two-way coupling procedure, in which the model ocean gives its calculated SST values back to the model atmosphere, has been adopted in order to allow it to compute heat fluxes in a more realistic way and receive surface forcing at each time step of integration (every 30 seconds). The simulations performed with this full coupling used both the above mentioned climatological initialisation and the hybrid initialisation described above.

Results

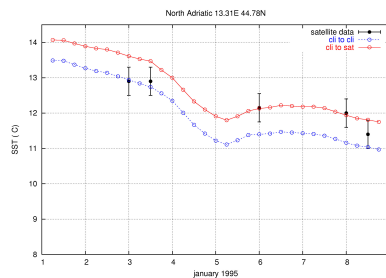


Figure 3

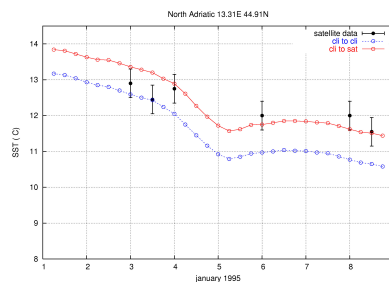


figure 4

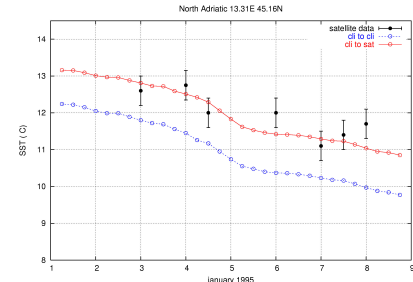


figure 5

This third simulation provided even better agreement with satellite observation made with satellite made in many points of the integration domain, made by satellite (Figs 3,4,5). These figures show the simulated SST trends during the Bora episode respectively at 3 different positions of the Adriatic Sea. Blue dotted lines represent simulation with initial conditions purely climatological; red dotted lines represent simulations with initial conditions of the Hybrid type; black dots, at last, show the satellite observations with their errors. It is evident the improvement of the use of satellite observation in preparing the initial conditions. This new comparison with satellite field observation has confirmed the importance of the two-way coupling for a correct representation of the interaction between the two layers of a sheared and stratified two-layer fluid system

With particular reference to the fluid system represented by wind forcing the sea, this result also shows the importance of satellite observations in preparing the initial conditions.

References

- [1] Dietrich D. et al., *A semi-collocated ocean model based on the SOMS approach*, Int. J. Num. Meth.in Fluids, **19**, 1103-1113, 1994
- [2] Dietrich D., *Application of a modified Arakawa 'a' grid ocean model having reduced dispersion to the Gulf of Mexico circulation*, Dyn. Atmos. And Oceans, **27**, 201-217, 1997
- [3] Pielke R.A. et al.: *A comprehensive meteorological modeling system – RAMS*, Meteor.Atmos.Phys., **49**, 69-91,1992
- [4] Qian M.W. et al., *A Preliminary Numerical Simulation of Bora Wind with a Limited Area Model of Atmospheric Circulation*, Il Nuovo Cimento, **23C**, **5**, 515-523, 2000
- [5] Walko, R.L. et al.:*The Regional Atmospheric Modeling System User's Guide*, Fort Collins Aster Division, pp 121., 1995