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Ocean Dynamics Simulation during an Extreme Bora Event using a Two-Way Coupled Atmosphere-Ocean Modeling System

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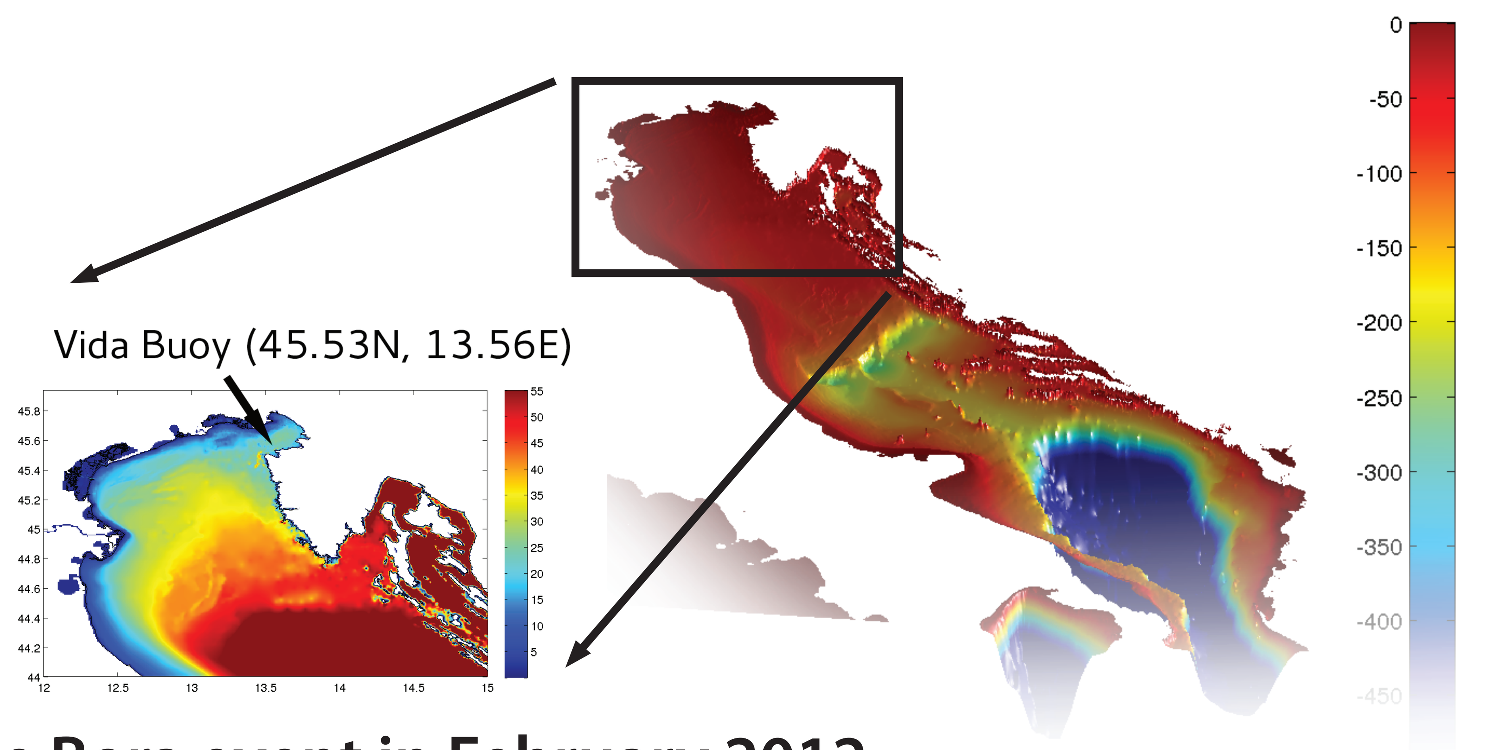

Abstract

The response of the Adriatic Sea to cold north-easterly Bora wind forcing has been modeled numerous times, but usually using one-way coupling techniques. One of the most significant events of the kind took place in February 2012, when hurricane force Bora was blowing over the Northern Adriatic almost continuously for over three weeks, causing extreme air-sea interactions leading to severe water cooling (below 4 degrees Celsius) and extensive dense water formation (with density anomalies above 30.5 kg/m3, Mihanovic et al. 2013).

The intensity of the atmosphere-ocean interactions during such conditions calls for a two-way atmosphere-ocean coupling approach. We compare the performances of a) fully two-way coupled atmosphere-ocean modelling system and b) one way coupled ocean model (forced by the atmospheric model hourly output) to the available in-situ measurements (coastal buoy, CTD). The models used were ALADIN (4.4 km resolution) on the atmospheric side and ADRIPOM (1/30 × 1/30 degree resolution) on the ocean side. The atmosphere-ocean coupling was implemented using the OASIS3-MCT model coupling toolkit.

We show that the atmosphere-ocean two-way coupling significantly improves the simulated temperature and density response of the ocean since it captures the short-termed transient features better than the offline version of the ocean model. On the other hand the coupled system overestimates the upward fluxes, leading to overcooling in the shallow regions.

Models and OASIS-MCT3 coupling setup

The coupling scheme, depicted on Figure 2, connects two models and two pseudo-models with domains shown on Figure 1. ALADIN, ADRIPOM, pseudoMFS and pseudoMERGER are treated by OASIS as independent separate models exchanging data at prescribed timesteps.

- **ALADIN** - Atmospheric model. Receives SST field from the MERGER pseudo-model and sends the computed mean sea-level pressure, air temperature, precipitation, wind speed (u and v directions), humidity, solar and longwave downward radiation fields to the POM model. ECMWF lateral boundary conditions are applied every three hours. Initial conditions for ALADIN are provided by local data assimilation using 3-hourly 3D-Var using surface observations, radiosondes, atmospheric motion vectors, AMDAR aircraft observations and satellite radiances (MSG, NOAA, Metop).
- **ADRIPOM** - Adriatic POM ocean model. receives mean sea-level pressure, air temperature, precipitation, wind speed (u and v components), humidity, solar and longwave downward radiation fields from the ALADIN model and sends the computed SST field to the MERGER pseudo-model. ADRIPOM uses MFS lateral boundary conditions and is hotstarted every 24 hours.
- **pseudoMFS** - a pseudo-model of the Mediterranean, which initializes ADRIPOM and during runtime reads daily SST fields from the MyOcean MFS model NetCDF files (Tonani et al. 2009), and sends them to the MERGER pseudo-model. These SST fields are updated every 24 hours of coupled system runtime.
- **pseudoMERGER** - a pseudo-model, which receives the SST fields from ADRIPOM (in the Adriatic) and pseudoMFS (in the Mediterranean), merges them on a common mask and sends the merged SST field to the ALADIN model. Merger is needed because ALADIN domain extends beyond ADRIPOM domain into the Mediterranean (see Figure 1).
- **HFS** - The hydrological forecasting system on the Soča River Basin which provides ADRIPOM with hourly forecasts of the Soča river runoff in the Gulf of Trieste.

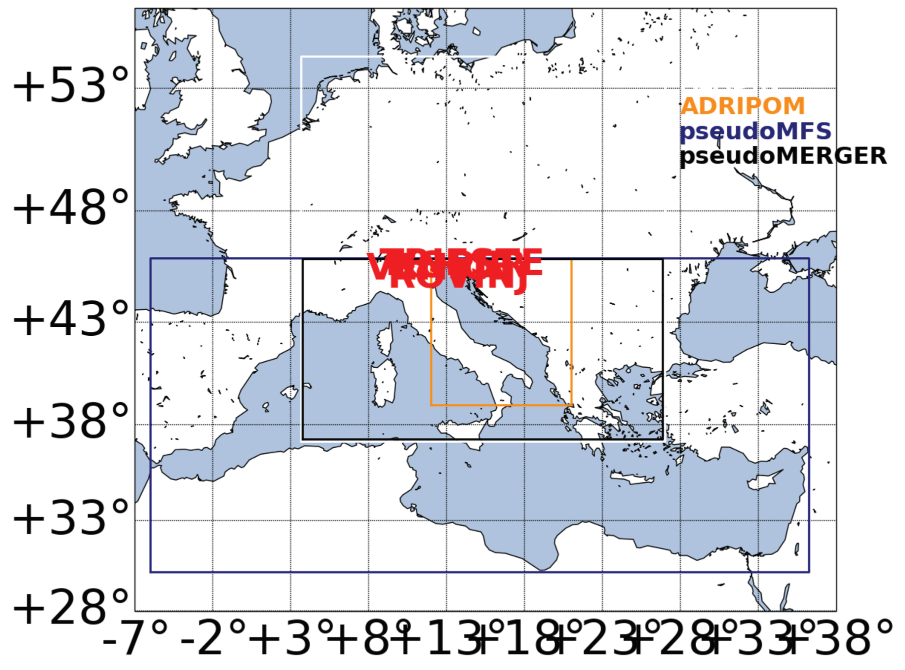

Figure 1. Coupled model domains.

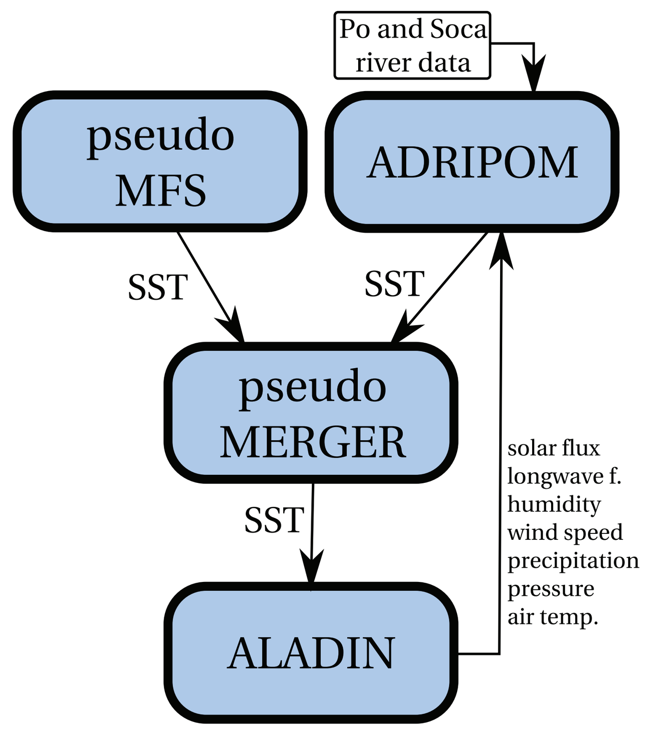

Figure 2. OASIS-MCT3 model coupling scheme.

Coupling physics in ADRIPOM and heat flux corrections

In POM we use standard bulk formulas for heat flux parametrizations (symbol names are as commonly used). Net longwave heat flux through the ocean surface is thus:

$$QB = \texttt{emiss} \cdot \sigma T_{sea}^4 - \texttt{dlong}$$

Where `emiss` stands for sea-surface emissivity and `dlong` is net longwave downward heat flux, obtained via OASIS from ALADIN. Sensible heat fluxes are computed using the Kondo schemes:

$$Q_H = \rho_{ma} c_p C_H |\vec{V}| \Delta T\,, \qquad |\vec{V}| = \sqrt{(u_{sea} - u_{air})^2 + (v_{sea} - v_{air})^2}$$

Latent heat fluxes are computed following Budyko: $QE = E \cdot (\alpha + \beta T)$

Net upwards heat flux through the ocean surface amounts to: $QU = QB + QH + QE$

Coupled system was exhibiting systematic overcooling by an amount which was found to be correlated with the local ocean depth (Figure 3). We thus introduced, during each coupling timestep, a heat flux correction, depending on ocean depth alone:

$$QU \longrightarrow QU + \frac{\partial (QU)}{\partial T_{sea}} \delta T(H(i,j))$$

The depth dependence of the SST error $\delta T(H(i,j))$ was obtained from comparisons between modeled SST (from a *different* numerical experiment) and satellite SST measurements. Initial ocean temperature was also warmed up in accordance with satellite SST measurements during the first step to provide a better estimate of initial conditions. The obtained results are promising, as shown in Figures 4 and 5.

Case Study: extreme Bora event in February 2012

In February 2012 an two-week long episode of hurricane strength Bora wind occured in the north and middle Adriatic, leading to extreme air-sea interactions, severe water cooling and extensive dense water formation. Several measurement campaigns were performed throughout the event, making it a perfect candidate for verification of our coupled system behaviour and skill. We performed a 5 month (January-June 2012) coupled model run, and compared the model to the *in-situ* measurements at a coastal buoy Vida, stationed in the south of the Gulf of Trieste (45.53 N, 13.56 E). The results are shown in Figures 4, 5 below.

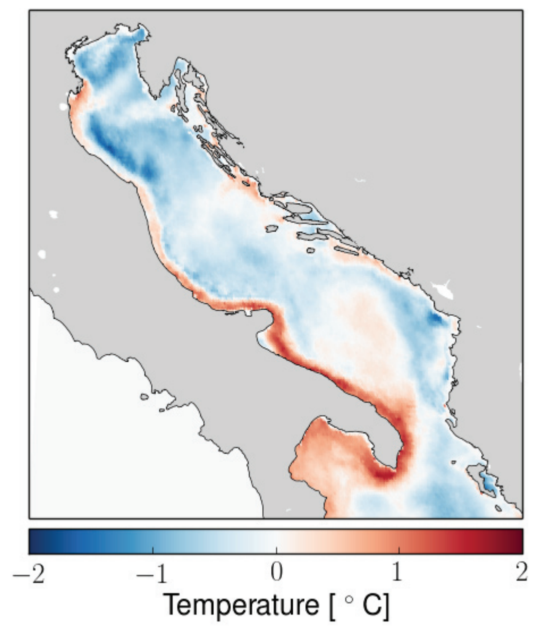

Figure 3. Time-averaged SST difference between ADRIPOM and satelite observations.

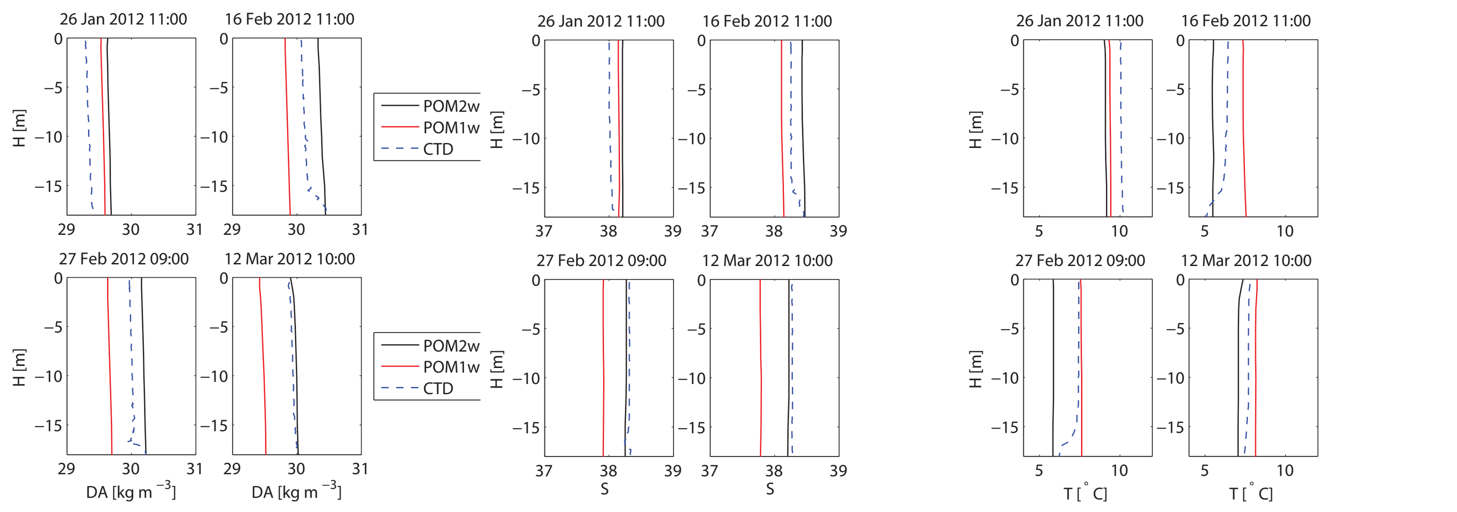

Figure 4. Comparison of CTD measurements versus modeled density anomaly DA (left), salinity S (center) and temperature T (right) profiles at buoy Vida location. Uncoupled ADRIPOM (POMu,red), two-way coupled ADRIPOM with flux and initial condition corrections (POMc, black), CTD (dashed blue).

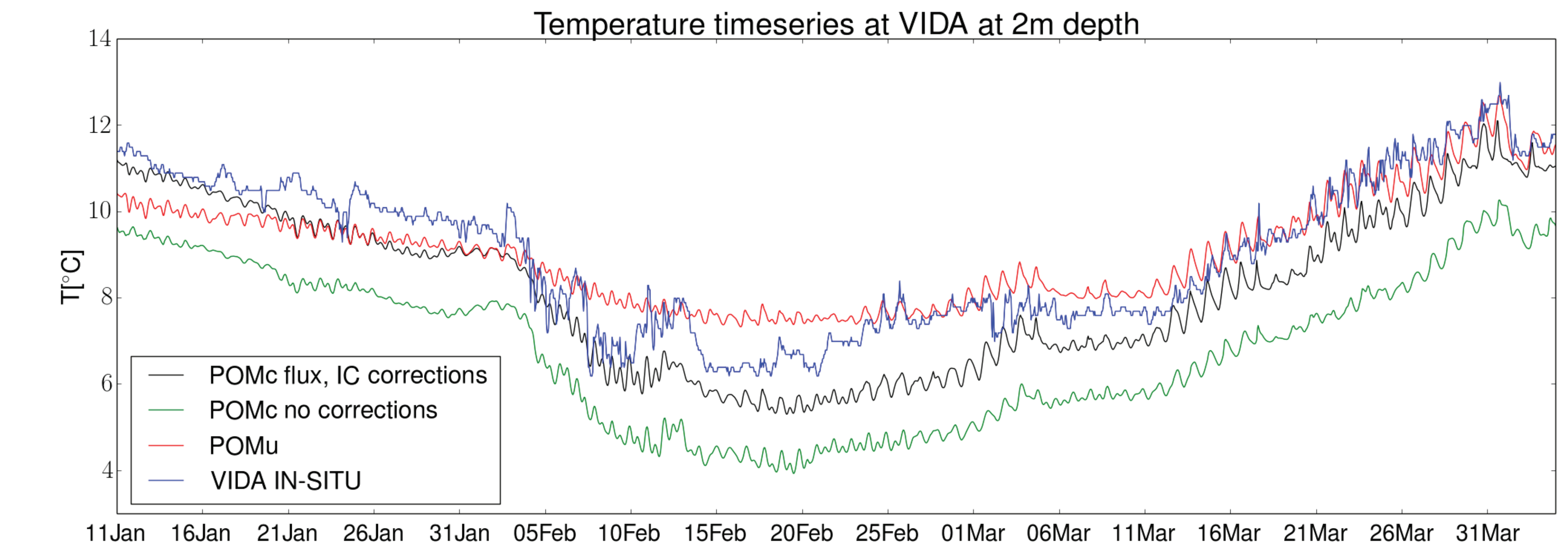

Figure 5. Comparison of observed sea temperature at 2m depth at buoy Vida location (blue curve) with coupled ADRIPOM with flux and initial condition corrections (POMc, black curve), without any corrections (POMC, green curve) and uncoupled POM (POMu, red curve). Coupled system captures the transient features well but overestimates the net upward fluxes, leading to overcooling in ADRIPOM as well as ALADIN.

References
M. Tonani et al., Ocean Science 01/2009; 5:649-660. DOI:10.5194/os-5-649-2009
H. Mihanovic et al., Ocean Science 09/2013; 9: 561–572, DOI:10.5194/os-9-561-2013