High resolution wind forcing effects on coastal circulation and eddy formation around a cape

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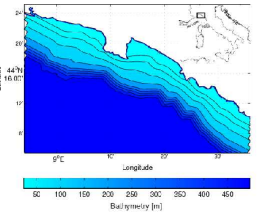
Introduction

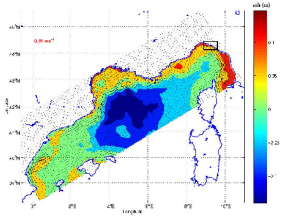
The interaction between winds and a complex topography with a cape has been shown to have a strong effect on shallow water hydrodynamics [e.g. Castelao and Barth 2007, 2006]. Changes in wind speed and wind stress curl are usually associated with flow variability, formation and growth of instabilities around the promontory. This numerical study is aimed at a preliminary assessment of the role of wind stress and of its resolution on coastal circulation and eddy formation in the lee of capes.

Coastal ocean modelling

The coastal-circulation high-resolution numerical model POM [Blumberg and Mellor 1987], in its barotropic version, is used to simulated the circulation around the Promontorio of Portofino, a blunt cape in the Ligurian Sea (Northwestern Mediterranean).

The numerical mesh, rotated 27 degree anti-clockwise with respect to the true north, consists of 200 x 100 grid points. The horizontal resolution varies in the numerical domain: a finer resolution of 500 m is used in the area closer to the headland to better resolve the dynamics around Portofino.

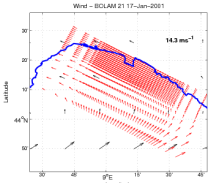


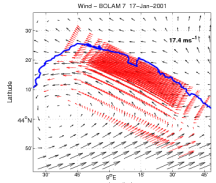


POM is forced at the incoming boundary by data from the regional model Symphonie [HU et al. 2008], which has been used to compute the Western Mediterranean circulation from 2001 to 2003 with a horizontal spatial resolution of 3 km.
By the side, the surface elevation and depth-averaged current field computed by Symphonie on 1 February 2001 are shown.

Atmospheric modelling

BOLAM (BOlogna Limited Area Model) is a hydrostatic primitive equation meteorological model, developed at the ISAC-CNR Institute of Bologna [Buzzi et al. 1994]. At the CFMI-PC, two versions of this model run with different horizontal resolutions:
BOLAM 21, which covers large part of the Mediterranean area with a resolution of 21 km and utilizes as initial and boundary conditions the analysis and forecasts of the ECMWF operational model;
BOLAM 7, which covers the Alpine Region and Northern Italy with a resolution of 7 km and is one way nested into BOLAM 21.
The wind velocity at 10 m above the sea level is computed by BOLAM 21 (left) and BOLAM 7 (right) also over the POM domain (black arrows), and it is horizontally interpolated to match the POM resolution (red arrows).

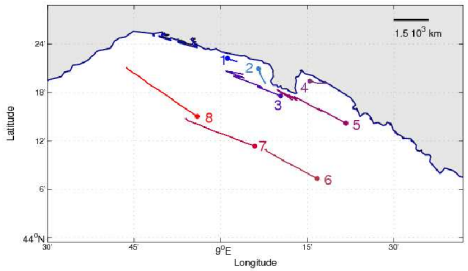




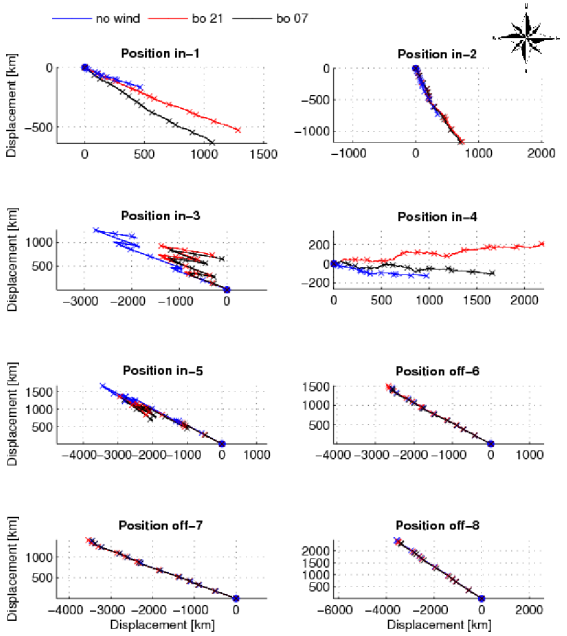
The wind stress $\overline{\tau}_w$ is computed using the classical bulk formula: $\overline{\tau}_w = \frac{\rho_{ar}}{\rho_{wr}} C_D \overline{v}_{10}$, where $\overline{v}_{10}$ is the interpolated wind speed at 10 m above the sea level, ρ_{ar} and ρ_{wr} are the air and water density, respectively, is used to force the coastal circulation. The drag coefficient C_D is fixed to the value $C_D = 10^{-3}$.

Preliminary results

We considered 5 in-shore and 3 off-shore numerical currentmeters. Progressive vectors of velocity of the simulated current without wind forcing in the aforementioned currentmeter positions for the three considered years, are showed below. The full dots represent the initial positions of the current vector and the progressive vector displacements are shown to scale.
All off-shore currentmeters show the north-westward transport observed in the past literature [Astraldi and Manzella 1983], while the numerical currentmeters 1, 2 and 4 reveal current separation and eddy formation around the cape [Doglioli et al. 2004].



Comparing the progressive vector of the simulated current in the in-shore and off-shore currentmeters, it can be noted that the effect of the wind forcing is maximum near to the coast and it actually plays a role in resolving the eddy formation around the Promontorio of Portofino. A cross is drawn every ninety days, starting from January 1st 2001.



In the table below, the maximum and average values of the simulated current in the currentmeter number 5 are reported, for the three considered scenarios (no wind forcing, BOLAM 21 wind forcing, BOLAM 7 wind forcing). In the same position, currentmeter date are available [Astraldi and Manzella 1983].

Model Output		***along-shore*** (cm s^{-1})		***cross-shore*** (cm s^{-1})	
		W - direction	E - direction	N - direction	S - direction
no wind	max	21.7	14.1	2.9	6.5
	average ± std	8.7 ± 5.4	5.7 ± 3.6	0.3 ± 0.3	0.8 ± 0.8
BOLAM 21	max	21.4	15.2	3.2	6.5
	average ± std	8.7 ± 5.4	6.1 ± 3.6	0.3 ± 0.3	0.8 ± 0.8
BOLAM 7	max	21.5	18.4	6.7	6.4
	average ± std	8.7 ± 5.3	6.3 ± 3.8	0.3 ± 0.4	0.9 ± 0.9
Astraldi and Manzella [1983]					
Annual	average ± std	15.7 ± 15.3		-0.3 ± 2.5	

It is worth noting that the coastal model underestimates the annual average current intensity by a factor 2 for the along-shore component (W-direction) with respect to the measured data, while simulated and measured values for the cross-shore component (N-direction) are fair agreement. Moreover, the annual average coastal countercurrent is more intense when a higher-resolution wind forcing is applied. Unfortunately, the data by Astraldi and Manzella [1983] do not distinguish between current and countercurrent contributions to the average values reported in their paper, so that it is not possible to state what forcing is the most realistic one.

Summary

The coastal model reproduces the barotropic, north-westward along-shore transport present in the observations. Periods of flow reversal associated with northerly winds [Astraldi and Manzella 1983] and the presence of anticyclonic eddies associated with eastward countercurrent around the cape [Doglioli et al. 2004] are also simulated. Higher-resolution wind forcing plays an important role in resolving current separation and eddy formation, resulting in an intensification of the recirculations.

Future developments

Next steps of the present study:

- 3D description of coastal current
- test different drag coefficient values in bulk formula for wind stress computation.

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