Atmospheric-induced effects on oceanic wakes: Madeira Island case study

Xavier Couvelard[1], Isabel B. Araujo[2], Rui Caldeira[2,1], Ricardo Tome[3] and Alexis Mouche[4]
(1) University of Madeira, Centro de Ciências Matematicas, Funchal, Portugal (xavierc@uma.pt), (2) CIIMAR, Porto,Portugal, (3) CCMMG, University of Azores, Portugal, (4) CLS Radar Application divisions, Plouzané, France.

1. Summary

The Madeira Island (FIG. 1) atmospheric-induced ocean wake was investigated by combining remote sensing and in situ data analysis with numerical studies. The ENVISAT and ERS Synthetic Aperture Radar (SAR) imagery archive, for the Madeira region is dominated by wind-induced features, particularly during 2008, an exceptionally year in wake episode detection. The sheltered, leeward island regions are often associated with weaker winds and currents.

Numerical experiments using a primitive equation numerical model (Regional Ocean Modeling System – ROMS) forced by high-resolution winds from WRF-ARW (Weather Research and Forecast model), routinely show oceanic eddies detaching from the island.

This study considers the effect of the wind spatial and temporal variability in the generation of oceanic wakes. The comparison of SAR derived winds with other available datasets is also considered as a cross-validation exercise

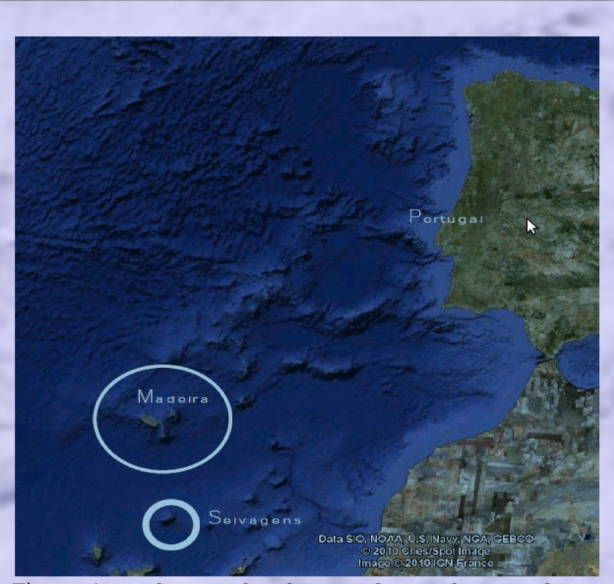

Figure 1 :Madeira Archipelago, in the North East Atlantic

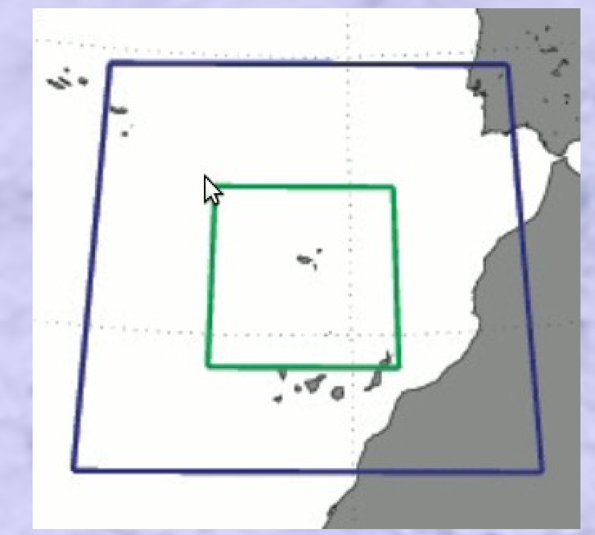

Figure 2: WRF domains; blue is the 18km domain and green is 6km

2. Atmospheric wakes (SAR/WRF)

In the present study the Advanced Research Weather and Forecasting Model, WRF-ARW (version 3.2), was setup with 3 one-way nested domains at 54, 18, 6 km horizontal grid resolutions to replicate the 2008 atmospheric wake episodes, leeward of Madeira. The top of the model is located at 50 hPa and a total of 31 vertical levels were used. It was run for the year 2008 with ECMWF forcing at the boundary. The 18 and 6 km domains are represented in FIG 2. Wind extracted from the 6km WRF-ARW domain was used to force the oceanic model (ROMS).

The WRF-ARW representation of the Madeira atmospheric wake was validated using 4 south wake episodes for which SAR winds (resolution <1km,) were available. QuikSCAT 0.5° gridded wind (www.ifremer.fr/cersat) and a blended product of QuikSCAT, ASCAT, SSM/I and ECMWF reanalysis (www.myocean.eu) on a 0.25° grid where also used in addition to the SAR Level2 wind processed product (Dagestad et al. 2010, www.soprano.cls.fr). Daily mean comparison of the different gridded wind products and SAR image, shows that SAR wind reproduces well wind speed and direction for those different cases (FIG 3). SAR derived wind data, also offers a unique high-resolution view of the leeward wind wake, invisible to QuikSCAT. Furthermore, it also shows that wind speed and direction are reproduced well in WRF, depicting the atmospheric island-induced wake signatures. Leeward wind profiles, extracted at 32.5° N (FIG 3, right), confirm that WRF and SAR have similar wind shear signatures, although WRF seems to slightly underestimate the width of the wake.

Although the WRF-ARW validation remains incomplete and focuses only on south wakes it gave enough confidence on the ability to reproduce the atmospheric wake episodes for 2008, used to force the oceanic model and study its oceanic implication. It also shows that QuikSCAT derived (0,5 degree) wind does not represent the wind shear induce by the island and is therefore a good candidate to be used in a control numerical simulation.

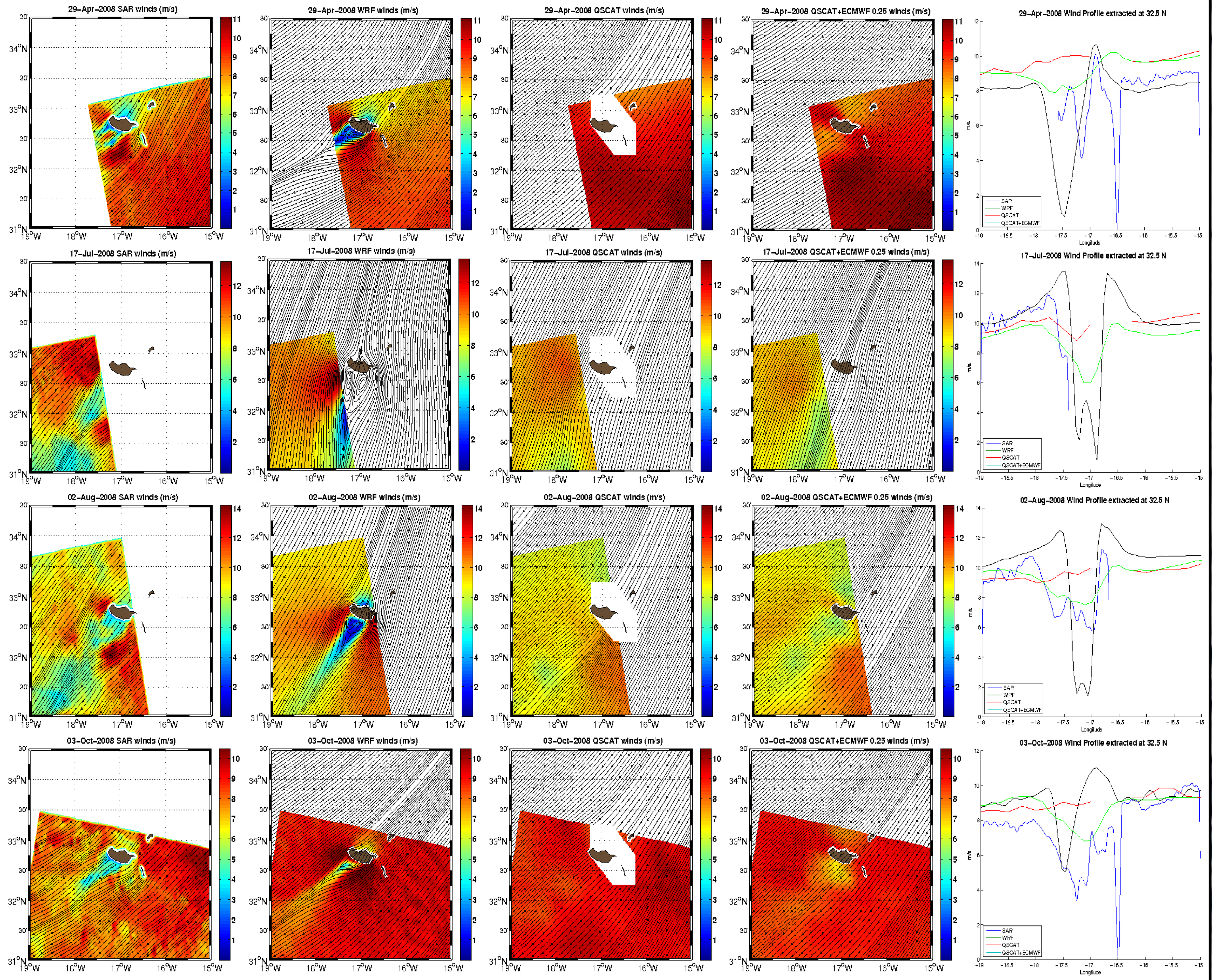

Figure 3 : Wind speed (color) in m/s and wind streamlines considering, by column for from left to right : SAR, WRF, QuikSCAT and QuikSCAT+ASCAT+SSM/I+ECMWF blended product and; from top to botom : 29/04/2008, 17/07/2008, 02/08/2008 and 03/10/2008. Last plots on the right represent the wind section at 32.5°N (leeward of Madeira) associated to each date. Except for SAR, other datasets are shown as daily means.

3. Oceanic wakes

3.1 Model Setting

The Regional Oceanic Modeling System, ROMS (Shchepetkin and McWilliams, 2005). has been used to study wind-induced circulation, leeward of Madeira Island. ROMS was initialised and forced at the oceanic boundaries, by temperature and salinity profiles extracted from the World Ocean Atlas climatology (Locarnini et al., 2006 and Antonov et al, 2006). Atmospheric fluxes (heat and water) were extracted from COADS and introduced through the bulk formulae (Fairall et al., 2003). Forcing also considered wind from different sources. The model domain extends from -22,5º to -12ºE and from 30º to 35,5ºN, on a 1/18º (~5km) regular grid with 35 sigma levels. The results discussed herein were extracted after achieving steady-state model solutions (2 year spin-up period).

Three numerical experiments were carried out: i) a control experiment using wind extracted from QuickSCAT (FIG 3); ii) an experiment using daily mean wind, extracted from WRF-ARW model run; and iii) a last using 2-hourly WRF-ARW wind. The WRF-ARW model set-up is discussed in Section 2.

a

b

c

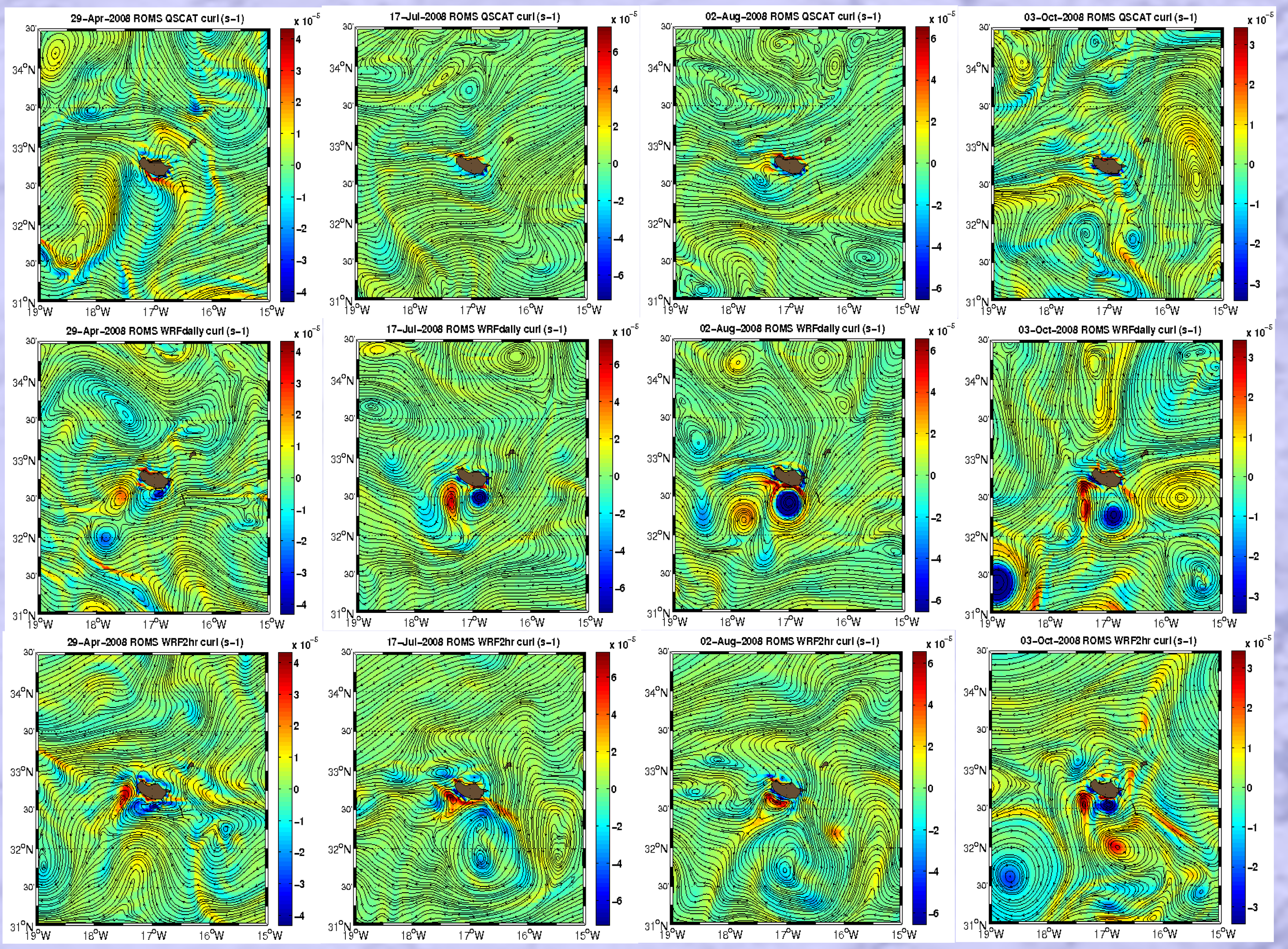

Figure 4 : ROMS oceanic surface vorticity (s^{-1}) considering: (a) QuikSCAT wind forcing; (b) WRF daily wind forcing and; (c) WRF 2-hourly forcing. Several 2008 south-wake episodes were considered. By column, from left to right: 29/04/2008, 17/07/2008, 02/08/2008 and 03/10/2008 (daily average).

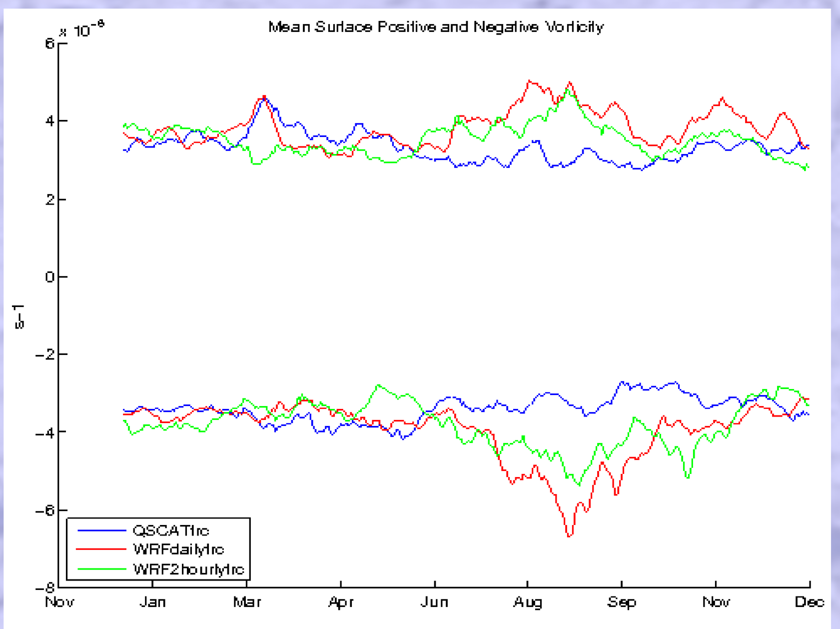

Figure 5 :2008 time-series of spatially-averaged positive (cyclonic) and negative (anti-cyclonic) surface oceanic vorticity, for the domain presented in FIG. 4. Most sea surface vorticity, in our numerical study was generated during summer months. WRF-ARW daily forcing generated more surface vorticity in ROMS than 2-hourly winds and QSCAT winds.

3.2 Results

3.2.1 Spatial variability of the wind

Spatially averaged oceanic surface vorticity was computed for each numerical experiment. A control experiment using QuikSCAT derived wind (FIG. 4a) showed very little influence on the oceanic vorticity field. In contrast, daily WRF-ARW wind, showed the presence of cyclonic and anticyclonic oceanic eddies, in the lee of Madeira (FIG. 4b).
A succession of cyclonic and anticyclonic eddies found on the 29th of April, showed the presence of a well developed Von Karman Vortex Street in the ocean circulation model. This suggests that for the wind curl to have an effect in the generation of (modelled) oceanic vorticity, it needs to be fairly constant during a day. 2-hourly variable winds were not so effective in the generation of oceanic vorticity. Analysis of the WRF-ARW forced ROMS solutions also show a 100% increase in negative and positive oceanic vorticity. This suggests a significant contribution of the wind in the shedding of oceanic eddies in the lee of Madeira. The increase in the oceanic vorticity occurred during the summer months, when trade winds are known to be stronger (Caldeira et al., 2002). This numerical result is also coherent with the eddies frequently detected in SST and Chlorophyll satellite data (Caldeira et al., 2002).

3.2.2 Temporal variability of the wind

The numerical studies suggest that increasing the temporal variability of the wind, tends to reduce the generation of oceanic eddies, leeward of Madeira. FIG-4C shows that 2-hourly winds generate few and smaller oceanic eddies, when compared to the cases forced by daily winds. The time-series plot (FIG5,green line) also show that even if the vorticity remains higher than in the control-run, it is slightly reduced compared to the daily-mean wind experiment. Suggesting a threshold in temporal wind variability beyond which the formation of eddies in the lee of Madeira are inhibited. . Corroborating recent results obtained in a 2D numerical study (Caldeira et all, EGU2011-7492-1).

4. Conclusions

=>2008 time-series (FIG. 5) of spatially-averaged positive (cyclonic) and negative (anti-cyclonic) surface oceanic vorticity, were presented in FIG. 4. Most sea surface vorticity, in our numerical study was generated during summer months. WRF-ARW daily forcing generated more surface vorticity in ROMS than 2-hourly and QSCAT winds.

=>In comparison with a reference run, forced by QuikSCAT, the WRF-ARW daily-wind increased the generation of oceanic vorticity by 100%, in the lee of Madeira. This suggests that one of the main contributors to oceanic eddy-shedding, often observed in the lee of Madeira, is the local wind stress.

=>Effect of the wind temporal variability using 2-hourly wind extracted from WRF-ARW, was shown to reduce oceanic eddies shedding in the lee of Madeira, suggesting that formation and shedding of oceanic eddies need fairly constant wind, at least over a 24hr period.

References

-Antonov, J. I., R. A. Locarnini, T. P. Boyer, A. V. Mishonov, and H. E. Garcia, 2006. World Ocean Atlas 2005, Volume 2: Salinity. S. Levitus, Ed. NOAA Atlas NESDIS 62, U.S. Government Printing Office, Washington, D.C., 182 pp.

-Caldeira R. M. A., S. Groom, P. Miller, D. Pilgrim, N.P. Nezlin, 2002 Sea-surface signatures of the island mass effect phenomena around Madeira Island, Northeast Atlantic, Remote Sensing of Environment 80 (2002) 336– 360.

-Dagestad K-F, A. Mouche, F. Collard, M. W. Hansen1 and J. Johannessen1, 2010 : ON THE USE OF DOPPLER SHIFT FOR SAR WIND RETRIEVAL. http://incusar.nersc.no/files/BayesianSARwind_SeaSAR2010_Dagestad_Mouche.pdf

-Fairall, C.W., Bradley, E.F., Hare, J.E., Grachev, A.A., Edson, J. B., 2003. Bulk parameterization of air- sea fluxes: Updates and verification for the COARE algorithm. Journal of Climate, 16(4), 571-591.

-Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, and H. E. Garcia, 2006. World Ocean Atlas 2005, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 61, U.S. Government Printing Office, Washington, D.C., 182 pp.

-Shchepetkin, A.F., McWilliams, J.C., 2005. The regional oceanic modeling system (ROMS): a split- explicit, free-surface, topography-following-coordinate oceanic model. Ocean Modelling 9 (4), 347– 404.00