ORPHEO: A case study of hurricane signatures in the Amazon-Orinoco plume

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Abstract: Tropical cyclones (TC) represent transient but powerful forcing able to redistribute ocean heat and salt content locally. As largely evidenced over the past, intense hurricane-induced mixing and upwelling act to entrain cool thermocline water into the mixed layer, leaving behind a cool wake of SST. This has been hypothesized to reduce hurricane growth potential, as statistically revealed by analyzing tropical Atlantic TCs. Indeed, discharges from the Amazon and Orinoco rivers create a stable barrier layer (BL) near the surface leading warm sea surface temperature anomalies. The presence of this plume then seems to coincide with an increase of the number of short-living storms that reach hurricane strength (Vizy and Cook, 2010). Passage over freshwater plumes thus generally causes strengthening of hurricanes due to higher SST (Ffield, 2007) and minimization of the cool wake due to this BL effect that inhibits mixing (e.g., Balaguru et al., 2012).

New sea surface salinity (SSS) observations from the SMOS and Aquarius/SACD satellite missions help to confirm the ocean response to TCs which crossed the Amazon-Orinoco plume (e.g. Grodsky et al., 2012, Reul et al. 2012). As revealed, TC passages left a 1 to 2 psu high haline wake, signatures associated with mixing of the shallow BL. If the partial destruction of the plume BL apparently decreased the SST cooling in the different TC's wakes, it first contributes to intensively erode the plume extent. As further revealed, the plume then apparently irreversibly contracts: SST tends to decrease while SSS increases. This SST decrease coincides with a local TC-induced modified ocean circulation. As revealed, large SSH signatures (> 20 cm) within the wake of these intense TCs become distinctively persistent over months. These new local conditions in the plume, combined with the seasonal decrease in surface heating in September, strongly impact the course of the hurricane season.

Hurricane Igor SST and SSS signatures in the Amazon/Orinoco plume region

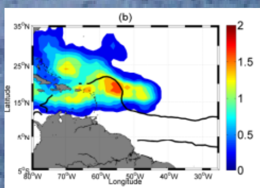

Figure 1: Mean yearly number (1950 through 2010) of hurricanes per one degree square that intensified locally to Cat 4-5. The black curve is showing the historical extent of the Amazon-Orinoco river plume during the hurricane peak season (August to October).

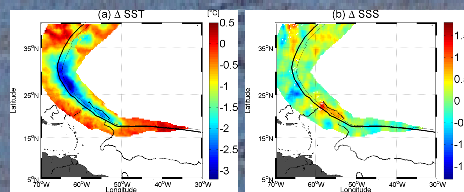

Figure 3: Surface wakes in Hurricane Igor. Post minus pre-hurricane (a) Sea Surface Temperature (ΔSST) (b) Sea surface Salinity (ΔSSS)

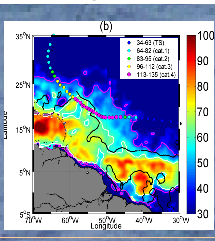

*Figure 2: Ocean Heat Content (OHC) derived by AOML for the 10 September 2010, prior to the Igor hurricane passage. The magenta and cyan contours are indicating the 40 and 60 kJ cm*cm levels. The black curve is the contour of the sea surface salinity at 35.7 deduced from SMOS data prior the hurricane, delineating the horizontal extent of the Amazon-Orinoco Plume. Color-coded circles mark the successive hurricane eye positions and intensity given in the Saffir-Simpson scale.*

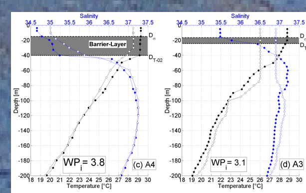

Figure 4: Vertical profiles of temperature (black circles) and salinity (blue circles) measured before the storm (filled circles) and after the storm (open circles) at the two ARGO floats displayed in figure 5 and located on the left (right) side of the Igor track, left (right) panel. The depths D_{σ} and D_{T-02} of the pre-storm mixed layer and top of the thermocline are indicated by horizontal dashed lines. The thickness of the pre-storm barrier layer is defined as $D_{T-02}-D_{\sigma}$ and is indicated by the gray shaded area. The wind power index WPi value interpolated at each ARGO float location is also provided.

Figure 1 shows that historically the most intense hurricanes intensified mainly within the northern part of the Amazon-Orinoco plume, making the monitoring of water characteristics in this region of crucial importance. The figure 2 displays the oceanic heat content(OHC) before the passage of hurricane Igor in September 2010, a time when the SMOS satellite was providing the first satellite-based measurements of ocean salinity. It shows that the plume extent (black line) estimated from SMOS SSS roughly coincides with areas where the ocean heat content is above 60kJ/cm^2 (cyan line). OHC is currently used as an intensification predictor but it lacks information about the vertical stratification that modulates the mixing and thus the air/sea fluxes. Increase in buoyancy from the fresh plume waters explains the maximum found in figure 1.

Figure 3 shows the differences between pre- and post-storm SST and SSS fields, showing a large cooling along the Igor right side track, a classical signature. It also shows for the first time from satellite data a salt wake, in the plume region, also mainly on the right side of Igor track. Such assymetry has long been shown to come from the enhancement of right-sided inertial currents to favor the mixing of colder waters from below the thermocline. The plume fresh waters cause a barrier layer effect, to prevent mixing more on the left side as illustrated with the two Argo floats (located on figure 4), and certainly further favor assymetries in the case of Igor. Both effects result in a complete erosion of the plume on the right side while it is little impacted on the left side. The barrier layer effect should limit the negative feedback that lowers air-sea heat and moisture fluxes available for storm intensification. It explains the distribution of hurricane intensification shown in figure 1.
SST and SSS are passive tracers of the air/sea interactions, altimeter SSH can bring more as discussed below.

Sea level signatures in the wake of hurricane Igor

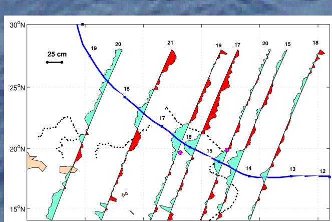

Figure 5: Differences in sea level (elevation in red, depression in cyan) between successive Jason-1/2 altimeter tracks before and after Igor passage. Only tracks roughly perpendicular to the Igor track have been pictured. Numbers above the tracks give the day for one altimeter track after Igor passage, the sea level difference being then computed using the altimeter track for the previous 10-day cycle. Igor eye track is materialized with the blue line, and squares and numbers indicate the Igor location for the day at 12Z.The magenta-colored symbols give the location of the two Argo floats providing vertical profiles in Igor wake (see figures 4). The black dots indicate the pre-storm location of the Amazon/Orinoco plume boundaries.

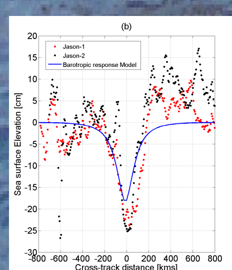

Figure 6: Sea surface elevation change measured by Jason 1 (red dots) and Jason 2 (black dots) altimeters in the plume region and prediction from a barotropic response model based on the GFDL azimuthal component of the wind stress

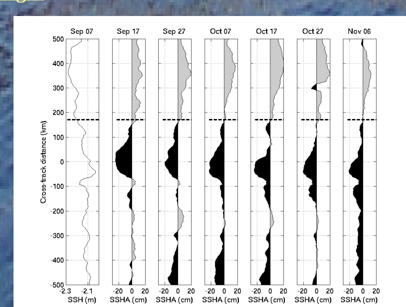

Figure 7: Sea surface height anomalies for the Jason-2 orbit before (left, Sep 07) the Igor passage and differences, for the same orbit number, with values for the subsequent cycles. The Sep 17 orbit (second left panel) thus corresponds to one in figure 5. The black dashed line gives the location where the altimeter track intersects the plume boundary (derived from SMOS before the Igor passage).

The figure 5 displays the Jason-1 and -2 altimeter sea surface height anomalies observed after the Igor passage. The observed throughs (cyan patterns) correspond to the geostrophic adjustment with the depth averaged currents generated by Igor. These currents are mainly the barotropic response to the cyclone forcing, associated to the upwelling resulting from the divergence of the Ekman transport. It is directly related to the curl of the wind stress and to the time of action of the wind forcing, i.e the translation speed of the cyclone. The largest SSH anomalies, ~ up to 35 cm, correspond to the time where Igor was the more intense and the less fast. Using the NAH/GFDL wind stress data we evaluated the across-track distribution of the sea surface elevation balanced with the barotropic response. The figure 6 shows that it compares fairly well with the altimeter signals and is, as expected, a purely symetric pattern. For the case of a slow hurricane as Igor, we expect (Price, 1981) the barotropic response to contribute more to the SST cooling than the entrainment mixing through inertial currents, to produce a more symmetrical SST signal. This is not observed (figure 3) and it thus gives further evidence for the barrier layer effect. It nevertheless demands to be investigated using numerical approaches to better depict how the fresh plume waters contribute to this reduced cooling to favor hurricane intensification.

The figure 7 shows the time evolution of SSH along one orbit crossing the plume (see figure 5) for successive altimeter cycles. It indicates that, for the particular case of Igor, the SSH field never restored to the previous conditions favorable for hurricane intensification (high OHC values), mainly because it is phase-locked with the seasonal cycle, i.e the decrease in solar heating.
Major hurricanes are found to intensify statistically more in the plume region (figure 1), mainly in August/September when the plume is at its peak seasonal extent and the buoyancy frequency N at its maximum. The sea surface salinity is shown to be a good proxy for N (Reul et al.) and satellite measurements from SMOS and Aquarius can certainly be used to improve intensification predictors such as OHC. Nevertheless, beyond the Igor case, further studies will focus on examining the conditions for which these major hurricanes modify the local conditions in such a way to allow, or to prevent, more hurricanes to intensify.

References:

N. Reul et al.: Observations of the upper ocean response to hurricanes in the region of the Amazon Orinoco river plumes. Part I: The salty wake of hurricane Igor. Submitted to J. Geophys. Res.

S.A. Grodsky et al.: Haline hurricane wake in the Amazon/orinoco plume: Aquarius/SACD and SMOS observations. Accepted in Geophys. Res. Let., 2012.