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Artículo Original

Analysis of ocean dynamics during the impact of Hurricane Matthew using ocean-atmosphere coupling

Análisis de la dinámica oceánica durante el impacto del huracán Matthew utilizando el acoplamiento océano-atmósfera

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ABSTRACT: The main goal of this investigation is to improve the understanding of ocean-atmosphere coupling during hurricanes. The present work involves the integration of the ocean-atmosphere coupled components of the Coupled Ocean-Atmosphere-Wave-Sediment Transport Modeling System in the Very Short Term Prediction System (SisPI). Three experiments are performed: First, using a dynamic sea surface temperature, consistent with the daily updated atmospheric model Weather Research and Forecast (SisPI); second, using the Regional Oceanic Modeling System and third, using a dynamic coupling between the atmospheric and the oceanic models. The coupled system improves the tracks of the hurricane simulations respect to the SisPI. The use of the oceanic model allows a more detailed representation of the sea surface temperature. Using the coupled model, a more precise diurnal cycle of the surface net heat fluxes is obtained.

Keywords: ocean-atmosphere coupling, Hurricane Matthew, oceanic dynamic.

RESUMEN: El objetivo principal de esta investigación es mejorar la comprensión del acoplamiento océano-atmósfera durante la ocurrencia de huracanes. El presente trabajo implica la incorporación de la componente de acoplamiento océano-atmósfera del Coupled Ocean-Atmosphere-Wave-Sediment Transport Modeling System en el Sistema de Pronóstico Inmediato (SisPI). Se realizaron tres experimentos: Primero, usando una temperatura superficial del mar dinámica, que consiste en una actualización diaria en el modelo atmosférico Weather Research and Forecast (SisPI); segundo, usando el modelo oceánico Regional Oceanic Modeling System y tercero, usando un acoplamiento dinámico entre los modelos oceánico y atmosférico. El sistema acoplado introdujo mejoras en el pronóstico de trayectoria con respecto al SisPI. El empleo del modelo oceánico permite una representación más detallada de la temperatura superficial del mar. Mediante el acoplamiento, en la capa de mezcla oceánica, se obtiene con mayor precisón el ciclo diurno del flujo superficial de calor.

Palabras claves: acoplamiento océano-atmósfera, huracán Matthew, dinámica oceánica.

1. INTRODUCTION

Ocean-atmosphere interaction plays a fundamental role in the weather forecast in Cuba. In order to obtain a better representation of the meteorological and physical conditions from numerical prediction in Cuba, it is necessary to consider the dynamics in the sea-air interface. Besides, the improvement of the forecast of extreme phenomena such as hurricanes and their interactions with the atmosphere and ocean environments allows to improve the prediction of disasters associated with this tropical systems (Warner *et al.*, 2010; Zambon *et al.*, 2014; Pant & Prakash, 2020).

The first attempt to design a coupled sea-air model was in the late 1960's and during the past two decades several coupled models have been developed for a variety of applications. A full review of recent advances, core technical and scientific issues in the development of coupled modeling systems is presented in (Peng *et al.*, 2012). At present, advancements in regional coupled ocean-atmosphere models have allowed more detailed studies of exchanges in the sea-air interface and feedbacks during extreme phenomena (Nelson *et al.*, 2014; Warner *et al.*, 2017; Aristizabal-Vargas *et al.*,2020).

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(Chen *et al.,* 2007) and (Lee & Chen, 2012) shows that two-way interaction must be included, in order to improve atmosphere and ocean forecast skill in storm prediction, using three-dimensional coupled ocean-atmosphere models to predict the interactions between a tropical cyclone and the ocean. Recent efforts to accomplish a coupled ocean-atmosphere numerical forecast is shown by (Kim *et al.*, 2014) and (Alaka *et al.*, 2020) with the development of a coupled model to improve enthalpy fluxes in the sea-air interface and for multiple storm.

(Warner *et al.*, 2010) developed the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Numerical System to increase their capability to investigate impacts of storms on coastal systems and different ocean-atmosphere physical process interactions. The COAWST System has been shown to increase predictability of sea surface temperatures for simulating Hurricane Isabel (Warner *et al.*, 2010); the effects of waves to increase the sea surface roughness producing more accurate atmosphere-ocean dynamic during Nor'Ida (Olabarrieta *et al.*, 2012); to provide more accurate intensity predictions for Hurricane Ivan due to sea surface temperature feedbacks (Zambon *et al.*, 2014a); that there was a lack of considerable ocean feedback on the hurricane intensity dynamics for Hurricane Sandy (Zambon *et al.*, 2014b); and the importance of sea-air interactions during extratropical cyclones (Nelson *et al.*, 2014) and coastal storm events (Renault *et al.*, 2012).

In Cuba, the Very Short Term Prediction System (SisPI, Sistema de Pronóstico Inmediato) (Sierra Lorenzo *et al.*, 2014, 2017) is used for weather prediction; which uses a dynamic sea surface temperature (SST) in the atmospheric model Weather Research and Forecast (WRF) (Vázquez Proveyer *et al.*, 2017). Several studies about ocean-atmosphere interactions have focused on updating the atmospheric fields obtained from the atmospheric model, in an oceanic model without feedback; using a flux of data in one direction only (Pérez Bello *et al.*, 2014; Mitrani Arenal *et al.*, 2019; Pérez Bello *et al.*, 2019).

This investigation is part of a study to propose a numerical coupled method, which allows a two-way exchange of information between the atmospheric and oceanic models and a more complete representation of the air-sea interaction during hurricanes in the Very Short Term Prediction System (SisPI). The coupled method proposes the integration of the ocean-atmosphere coupled component of the Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Numerical System into the Very Short Term Prediction System (SisPI).

Inside the process of evaluation of the proposed coupling method, the aim of this investigation is to perform an analysis of the impact of the numerical coupling in the simulations of the ocean dynamics during hurricanes. The incorporation and analysis of the coupled system are a first attempt to necessary sensibility studies to improve the numerical weather prediction in Cuba. Until now, the studies about coupled models have not focused on the geographical area analyzed in this work.

This paper is organized as follows: section 2 reviews the methodology, including the oceanic and atmospheric modeling components and the experiments design. Section 3 analyzes the impact of the ocean-atmosphere coupling in the ocean dynamics simulations. Conclusions are found in section 4.

2. MATERIALS AND METHODS

In this section, a description of the COAWST Modeling System and the experiment design are given.

2.1 COAWST

The Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modeling System (Warner *et al.*, 2010) was used to study ocean-atmosphere interactions during Hurricane Matthew. In this application, the Regional Oceanic Modeling System (ROMS) (Shchepetkin & McWilliams, 2005; Haidvogel *et al.*, 2008) and the atmospheric model Weather Research and Forecast (Michalakes *et al.*, 2005) (WRF, as integrated to SisPI) components were two-way coupled using the Model Coupling Toolkit (MCT) (Larson *et al.*, 2005). Also, a method for regridding was used (Warner *et al.*, 2010).

2.2 Hurricane Matthew

Hurricane Matthew was a major hurricane that impacted the eastern Cuban coast in October 2016. It is considered the most intense and deadliest system in that hurricane season. Coastal impacts were severe in the regions which the hurricane pass. In Haiti, it provoked significant loss of life and an economic crisis. In the Southwestern United States, the extreme waves and water level caused coastal erosion, in addition to flooding due to storm surge and rainfall (Hegermiller *et al.*, 2019). In Cuba, material damages were due to strong winds, intense precipitations, storm surge and coastal flooding. (Ballester & Rubiera, 2016)

2.3 Experiments Design

In order to evaluate the coupled system a 72-hour forecast was performed, initialized on October 4th (0000 UTC). During this period, the hurricane Matthew directly affected Cuba.

Three numerical experiments were performed. First, using a dynamic SST in the WRF model (WRF(SST)), consistent in a daily upgrade in the atmospheric model; this is the actual configuration used in the SisPI. Second, the oceanic model Regional Ocean Modeling System (ROMS) was used, initializing and upgrading the forcing data with output fields of the Global Forecast System (ROMS(GFS)). Finally, a coupled WRF and ROMS models was performed (WRF-ROMS) using the COAWST Modeling System.

The configurations used in the atmospheric and oceanic models were selected according to the available computational resources.

2.3.1 Atmospheric Model Configuration

For the experiments which the WRF model is used, the atmospheric model configuration was the same that is used in the SisPI (Sierra Lorenzo *et al.*, 2014, 2017), as shown in Table 1.

The SST data used in the WRF model was obtained from a daily, high-resolution, real-time, global, sea surface temperature (RTG_SST_HR) analysis; which combines the last 24-hours data derived from buoys, ships and satellite (Gemmill *et al.*, 2007).

2.3.2 Oceanic model configuration

In the ROMS(GFS) and WRF-ROMS numerical experiments, the simulations were performed over a grid with a resolution of 9 km in the oceanic model (Figure 1 (b)). The vertical resolution and stretching parameters are shown in Table 2. The model was forced by TPXO7 tides (Egbert & Erofeeva, 2002) and atmospheric forcing obtained from the GFS model. The bathymetry data was obtained from the General Bathymetric Chart of the Ocean (GEBCO) updated in 2014 (Weatherall *et al.*, 2015). The hurricane enters the domain on October 4th, at 1200 UTC.

The ocean model configuration used (the same in all experiments where the ROMS model is used) has not been validated for the physical-meteorologist conditions in the studied region. For this reason, the goal of this investigation is the assimilation of the coupled system and the analysis of the simulations obtained using coupling; to serve as a starting point for future and necessary sensitivity studies in the ROMS model as well as in the coupled system, and allow more precision on the oceanic prediction.

2.3.3. Regridding and coupling dynamics

WRF and ROMS models were coupled at a coupling time step of 1800 seconds. The heat and momentum fluxes as computed by the atmosphere model were used in the ocean model. This allowed both models to use same fluxes at the interface. Also, in the data exchange during coupling, the SST was updated

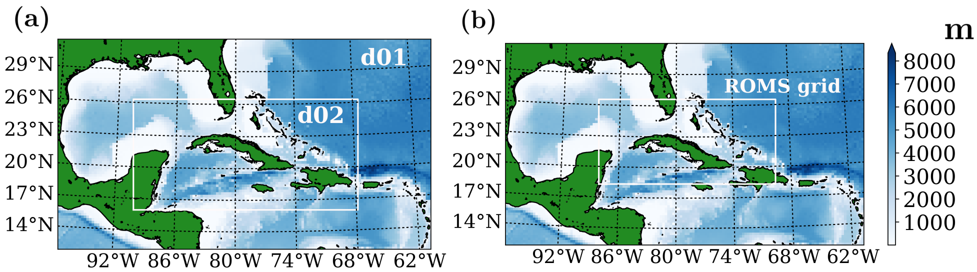

Figure 1. (a) Nested domains of 27 km (d01) and 9 km (d02) in the WRF model. (b) Domain used in the ROMS model

Table 1. Atmospheric model configuration

Initialization	Global Forecast System and RTG_SST_HR product
Domains	Nested domains of 27 *and* 9 km of resolution (Figure 1 (a))
Projection	Lambert Conformal Conic
Vertical levels	26
Time step	150 seconds
Parameterization of Microphysics	WSM5 (Lim *et al.*, 2004)
Parameterization of cumulus	Grell-Freitas (Grell & Freitas, 2014)

Table 2. Oceanic model configuration

Initialization	Hybrid Coordinate Ocean Model (HYCOM) (Wallcraft *et al.*, 2003)
Domain	9 km of resolution (Figure 1 (b))
Projection	Lambert Conformal Conic
Vertical levels	12
Time step	15 seconds
Vertical layer transformation equation	Vtransform=2
Vertical stretching function	Vstretching=4

from ROMS to the WRF model. The RTG_SST_HR product was used in the areas of the WRF mesh that is not included in the ocean grid. To allow the data exchange during coupling, in meshes with different resolutions and spatial coverage, the Spherical Coordinate Remapping Interpolation Package (SCRIP) (Jones, 1999) was used.

2.4 Verification data

To evaluate the behavior of the coupled system during hurricane Matthew simulations, data for the minimum center pressure, maximum sustained wind and best track were obtained from Atlantic HURricane DATabase (HURDAT2) (Landsea & Franklin, 2013). For track simulations, the submodule Cysearch, from the Detection, Report and Evaluation Module (MDRE) (Sierra Lorenzo *et al.*, 2016) was used.

In the SST analysis, data derived from the geostationary satellite (GOES) were used as verification (Maturi *et al.*, 2008). To analyze the SST simulations in each experiment, respect to the GOES data, the Mean Error (ME), Mean-Squared Error (MSE) and Root-Mean-Squared Error (RMSE) were calculated. Those parameters are defined as:

$$ME = \frac{1}{n}\sum_{i=1}^{n}(f-o) \quad (1)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(f-o)^2 \quad (2)$$

$$RMSE = \sqrt{MSE} \quad (3)$$

Here n is the total grid points where SST data is obtained, □ is the SST field in each numerical experiment and □ is the GOES SST field. The termn $ME = \frac{1}{n}\sum_{i-1}^{n}(f-0)$ is defined as the absolute error in each grid point.

During the evaluation process, the python language was used (Oliphant, 2007; Millman & Aivazis, 2011), mainly the packages Numpy (Van der Walt et al., 2011), Scipy (Virtanen et al., 2020) and Matplotlib (Hunter, 2007).

3. RESULTS AND DISCUSSION

In this section, first an analysis of the track simulations is realized and a study of the SST simulations is shown. Finally, the impact of the air-sea interaction in the oceanic dynamics in the oceanic mixed layer during hurricanes is studied.

3.1 Hurricane track simulations

Analyzing the behavior of the hurricane Matthew according to the verification data (best track), it was located at 16.6° N and 74.6° W on October 4th, 0000 UTC (when the experiments were initialized). In the first 24 hours it kept a movement to the north and then acquired a W-N component until October 7th. During the simulation period the hurricane Matthew was considered a major hurricane (Category 3-4, in the Saffir-Simpson scale).

In the track analysis (Figure 2), during the first 12 hours of simulations, the three experiments are in good agreement; until the hurricane center is located inside the geographical area covered by the oceanic mesh. According to the best track, Matthew made landfall on October 5th, 0000 UTC, in Guantanamo. In the numerical experiments, it made landfall at 20.69 km offset from the real position (best track) in the WRF(SST) and WRF-ROMS experiments and at 38.83 km in the ROMS(GFS) experiment.

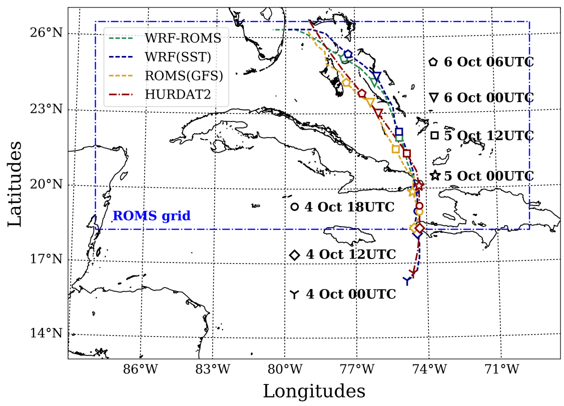

Figure 2. Comparison of hurricane track simulations in each experiments respect to the best track

Position error, shown in Figure 3, is defined as the difference between the best track and the hurricane center position in each experiment (computed using the Cysearch submodule) at 6 hour's intervals. Figure 3 shows that the WRF(SST) and WRF-ROMS experiments are in good agreement during the first 24 hours of simulation. The differences between this experiments and the ROMS(GFS) ranges from 1.33 to 18.13 km, being maximum on October 5th, 0000 UTC.

After 24 hours of forecast the ROMS(GFS) experiment has the lower position errors in track simulations. Also, during the coupling (WRF-ROMS experiment) the errors in track simulations are less than the position errors obtained using the SisPI configuration (WRF(SST) experiment). In general, the coupled system improves predictions with respect to SisPI from 8.51 to 25.92 km; being maximum at 48 hours of forecast (October 6th at 0000 UTC).

The WRF configuration used in the WRF(SST) and WRF-ROMS numerical experiments is the same used in SisPI, which was evaluated for short term prediction in Cuba (Sierra Lorenzo et al., 2014, 2017). By increasing the simulations period in these experiments, bigger position errors are obtained as is shown in Figure 3.

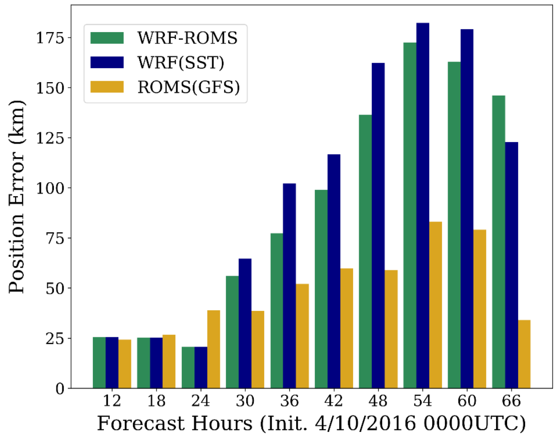

Figure 3. Position Error of the hurricane center (in km) respect to the best track

3.2 SST analysis

The cloudiness associated with the passing of the hurricane does not allow for estimation of SST in the GOES data. Two states are defined in the analysis of the SST field: the initial state of the sea surface thermal field, before the hurricane pass, using the SST data on October 1st at 0400 UTC; and a final state, after the hurricane pass, with the data corresponding to 8th at 0500 UTC. Figure 4 shows the SST simulations in the initial and final states (before and after the hurricane passes) in each numerical experiment and the verification (GOES) data.

The SST field behavior is analyzed in each experiment and it is compared with the SST simulation obtained from the GOES data (Figure 4 d)). Using the ROMS model, without and with coupling (Figure 4 b) and c) respectively), the SST simulations are more detailed, while in the WRF(SST) experiment (Figure 4 a)) is more smoothed. However, in both experiments where the ROMS model is used, in some areas the SST values are overestimated, fundamentally at south of Cuba (Figure 4 b) and c), second column); and in other areas (fundamentally in the region of the Bahamas) the SST values are below verification data (Figure 4 b) and c), first column). The differences between the ROMS(GFS) and WRF-ROMS experiments increases with the forecast time.

Figure 5 shows the absolute error field for each experiment, respect to the SST data obtained from the GOES satellite. In Figure 5 b) and c), is shown how the ROMS model configuration used induces that SST values are underestimated in the region of the Bahamas, before and after the hurricane passes. This values of absolute error are the basis in the calculation of the statistical parameters presented in Table 1.

The cooling of the sea surface in the area where the hurricane passes, phenomenon known as coldprint, is shown in Figure 4 for each numerical experiment and the GOES data. The study of this phenomenon depends on the best track (Figure 2). According to the track simulation in each numerical experiment, in the area where the hurricane passes, in the WRF(SST)

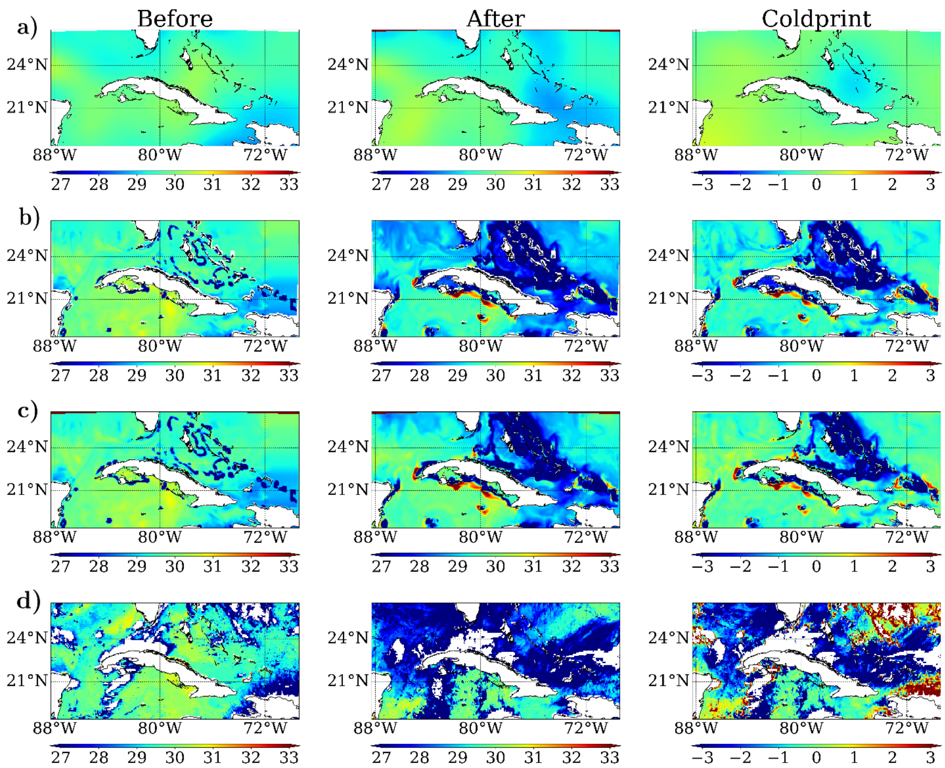

Figure 4. Sea surface temperature field (°C) before and after the hurricane Matthew passes and the coldprint phenomenon obtained in a) WRF (SST), b) ROMS(GFS), c) WRF-ROMS and d) GOES

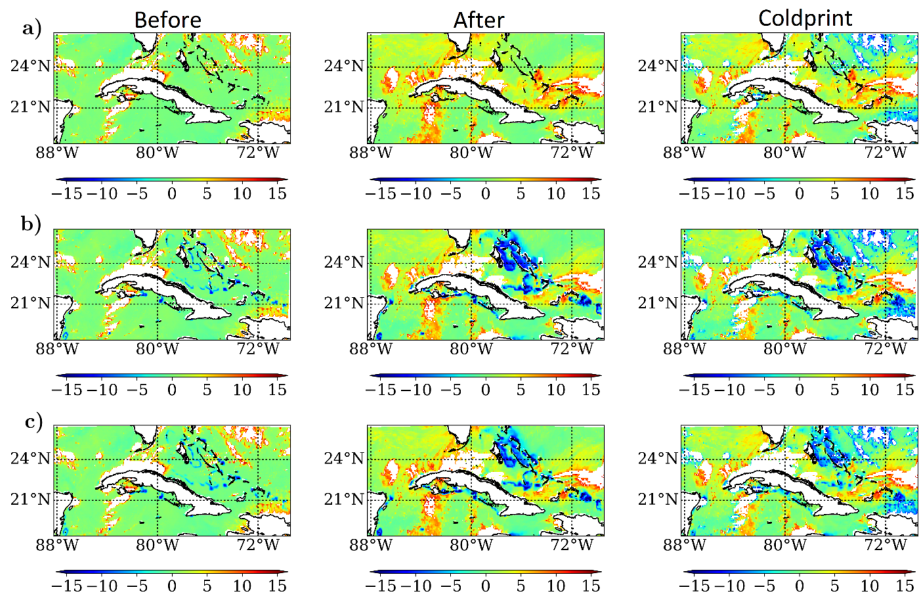

Figure 5. Absolute Error of the sea surface temperature field in each numerical experiment respect to the GOES data. a) WRF (SST), b) ROMS (GFS), c) WRF-ROMS

Table 3. Mean Error, Mean-Squared Error (MSE) and Root-Mean-Squared Error (RMSE) of the sea surface temperature field for each numerical experiment respect to the GOES data

	Before			After			Coldprint		
	WRF (SST)	**ROMS (GFS)**	**WRF-ROMS**	**WRF (SST)**	**ROMS (GFS)**	**WRF-ROMS**	**WRF (SST)**	**ROMS (GFS)**	**WRF-ROMS**
Mean Error	0.748	0.552	0.551	2.145	0.705	1.092	1.349	0.102	0.478
MSE	4.890	5.903	5.884	11.388	13.898	13.955	12.259	14.371	13.933
RMSE	2.211	2.430	2.426	3.375	3.728	3.736	3.501	3.791	3.733

experiment the SST variation is approximately 1°C while in the experiments which the ROMS model is used (ROMS(GFS) and WRF-ROMS) the SST values decrease approximately 3°C. According to the best track and the SST data obtained from the GOES satellite, the coldprint ranges from 2°C to 3°C.

In the final state, after the hurricane passes (Figure 4, second column), it is necessary to consider the position error in the track simulations (Figure 2 and 3). After going out to sea, at north of Cuba, the hurricane moved faster and its center was located further north in the numerical experiments with respect to the best track. Due to the position error in the last hours of simulation, the cooling of the sea surface in the numerical experiments is observed more to the north than that shown in the SST data obtained from the GOES satellite. Although quantitatively the coldprint phenomenon is better represented in the ROMS model simulations (region of the Bahamas), the position error causes the absolute error in this area to be greater (Figure 5 b) and c)) and therefore the statistics parameters showed in Table 3.

Table 3 shows the Mean Error, the Mean-Squared Error (MSE) and the Root-Mean-Squared Error (RMSE) calculated for each numerical experiment respect to the SST data obtained from the GOES satellite. In the analysis of the sea thermic field, the Mean Error is smaller in the simulations where the ROMS model is used. In the experiment ROMS(GFS) the slightest mean error is obtained after the hurricane passes and in the coldprint simulation. Before the hurricane passes, the mean error is similar in the ROMS(GFS) and WRF-ROMS experiments.

The lowest values of MSE and RMSE are obtained in the WRF(SST) experiment. In the ROMS(GFS) and WRF-ROMS the big values of the absolute error, especially in the Bahamas region, are maximized in the MSE when squared so the highest values of the MSE and RMSE are obtained. However, the values of RMSE differ only in the decimal part.

In general, there are no big differences between the statistics calculated for each numerical experiment (Table 3). This differences are mainly due to the use of a first approximation (not validated) in the ROMS model configuration. For this reason, the statistics shown in Table 3 are a starting point to future sensibility studies.

3.3 Oceanic Mixed Layer

To analyze the behavior of forecast variables in oceanic mixed layer (until 100 meters deep) and the impact of the SST variations in the oceanic dynamic in water of different bathymetry, two points of interest are defined: S1, approximately 2778 meters deep and S2, in shallower waters, approximately 1245 meters deep (Figure 6). This analysis is performed using the numerical experiments which involve the ROMS model (ROMS(GFS) and WRF-ROMS numerical experiments).

In Figures 7 and 8, positive values of U means movement east, V movement north and W vertically upward.

In S1, the behavior of the oceanic variables simulated in both numerical experiments are similar. The net latent heat flux (positive toward ocean), in the first 12 hours of simulation, corresponds to the longwave radiation from the surface to atmosphere and the influences of the hurricane circulation. The next time steps, this output flux intensifies due to the hurricane wind effect. Approximately at 18 hours of simulation, a peak of maximum ascendant flux is reached, associated with the maximum wind velocities located in this point. The amount of heat transferred to the atmosphere begins to decrease after this time, because of the calm in the hurricane eye, and then starts to increase again due to the effect of the winds circulation of the hurricane. After the 30 hours of forecast, in the coupled system, the variations of the net heat flux are dominated by short wave solar radiation demonstrating a clear diurnal cycle throughout the model run.

SST values greater than 27ºC predominated at point S1 during initial forecast interval (0-12 hours) until a depth of 60 meters, which are favorable conditions for a hurricane intensification. After 12 hours of forecast, due to the strong winds and vorticity, the colder water mixes upward, the sea surface gets cold and salinity decreases. Also, there is a stronger upward W-velocity after 24 hours associated with the upwelling due to the hurricane influence, and the magnitude of velocity of the currents is maximum. The U and V currents clearly demonstrate an inertial oscillation after the hurricane's passage.

At point S2 (Figure 8), where the water is shallower, the dynamics in the mixed layer is different. The thermal inertia is smaller. Due to the shallower depth, the SST varies more abruptly, under the effect of radiation diurnal cycle and the oceanic movements. It is important to take the position error into account in this analysis.

In S2 (Figure 8), after the 36 hours of simulation, the location begins to have influence from the hurricane winds, which causes a SST decrease, a maximum of the ascendant heat flux to the atmosphere, upwelling and a salinity decrease. The change in the surface

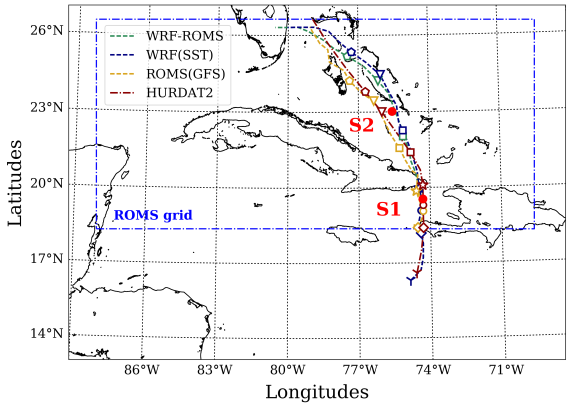

Figure 6. S1 and S2 points selected for the ocean mixed layer analysis

net heat fluxes is more perceptible in the WRF-ROMS experiment (Figure 8 b)). The SST decreases below 26ºC in both experiments, which is disadvantageous for hurricane development and explains the hurricane weakening in this area observed during coupling simulations.

In general, the bigger differences between the two experiments are obtained in their prediction of the net heat fluxes, mainly in the representation of the diurnal cycle. In the coupled system, the variations of the heat fluxes are more perceptible. During coupling the heat fluxes as computed by the WRF model are used in the ocean model. In the ROMS(GFS) numerical experiment, the implemented surface scheme (COARE) computes turbulent heat fluxes (latent and sensible heat); but radiative fluxes (i.e., shortwave and longwave radiation flux) are not calculated and are provided in the forcing file from the GFS data. These differences in the estimation of the heat fluxes could account the differences observed in the SST simulations.

4. CONCLUSIONS

In this investigation, the assimilation of the coupled ocean-atmosphere component of the COAWST Modeling System was achieved for a hurricane forecast; which means the starting point for sensitivity studies of the ROMS model and to incorporate the coupled system in the numerical forecast in Cuba.

Three numerical experiments were performed: 1) Using a dynamic SST in the WRF model, 2) using the ROMS model initialized with GFS output and 3) using a dynamic coupling between the ROMS and WRF models.

In the hurricane track simulations, in short term simulations (6-12 hours of simulations) the numerical experiments are in good agreement. After 24 hours of forecast, the lower position errors are obtained in the ROMS(GFS) experiment. The coupled system improves the track prediction obtained from the SisPI.

The SST simulations were more detailed in the experiments where the ROMS model was used, while in

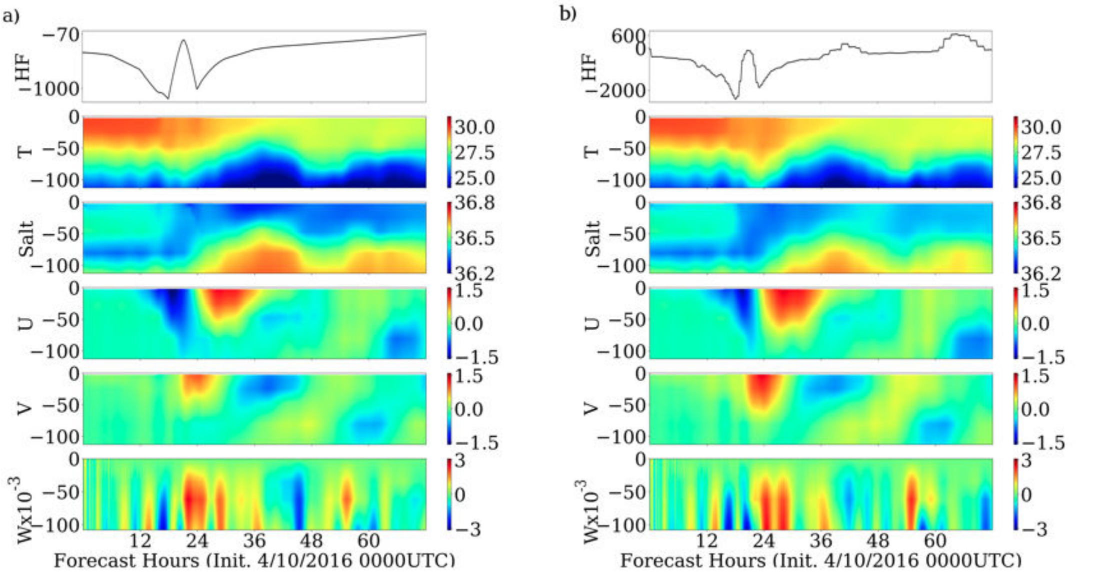

Figure 7. The oceanic dynamics in S1 simulated in (a) ROMS(GFS) and (b) WRF-ROMS experiments; showing Surface net heat flux (HF) in W m^{-2}, Temperature (T) in °C, Salinity (Salt) in psu, U and V velocity components in m s^{-1} and W x 10^{-3} velocity component in m s^{-1}

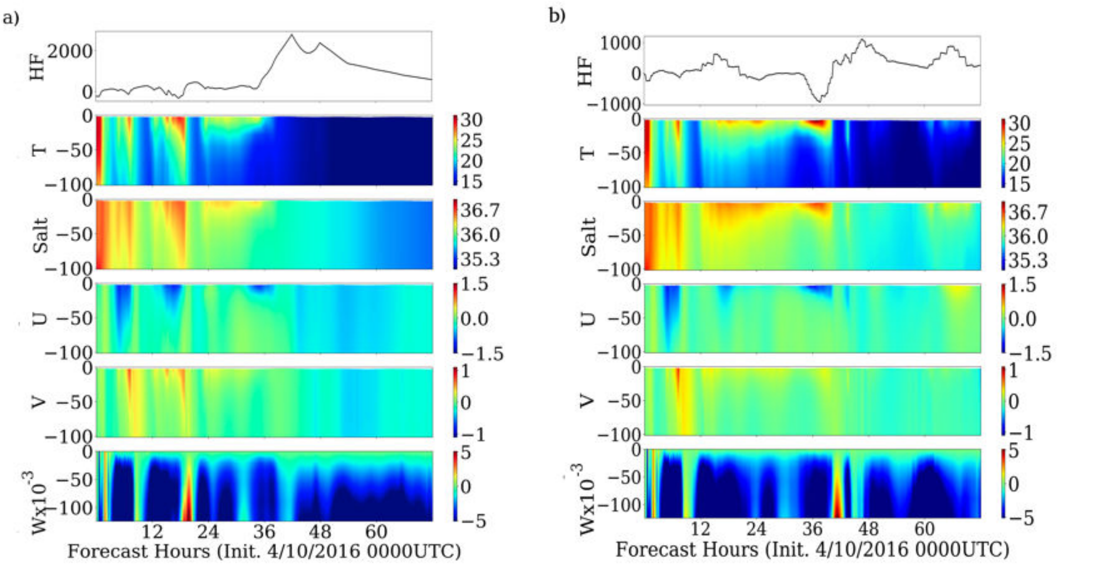

Figure 8. The oceanic dynamics in S2 simulated in (a) ROMS(GFS) and (b) WRF-ROMS experiments; showing Surface net heat flux (HF) in W m^{-2}, Temperature (T) in °C, (c) Salinity (Salt) in psu, U,V velocity components in m s^{-1} and W x 10^{-3} velocity component in m s^{-1}

the WRF(SST) experiment (SisPI) the SST field was more smoothed. Quantitatively, the coldprint phenomenon was better represented using the ROMS model.

In the SST analysis, there is no big differences in magnitude between the errors computed for each numerical experiment respect to the verification data. Starting from the premise that the configuration used in the oceanic model is not yet validated for the physical-meteorological conditions of the studied region, that the obtained results in the coupled system was similar to the obtained with the forecast system used in Cuba is a encouraging starting point.

In the analysis of the behavior of the oceanic variables in the oceanic mixed layer, the simulations in both experiments, using ROMS mode, are similar except for the surface net heat fluxes. Using the coupling, the variations of the fluxes demonstrating a more perceptible diurnal cycle. These differences in the heat fluxes could account the differences observed in the SST simulations in the numerical experiments.

Sensitivity studies in the ROMS model are necessary, to identify the optimal configuration according to the conditions in Cuba for numerical prediction. The results obtained show that an ocean model configuration adapted to the study region must improve the simulations with the coupled system by better representation of the air-sea interaction in the numerical weather prediction in Cuba.

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