Gulf of Mexico and Caribbean Sea Wave Hindcast: Climatology and Wind Reanalysis Assessment

Christian M. Appendini*, Alec Torres-Freyermuth, Fernando Oropeza, Paulo Salles, José López, E. Tonatiuh Mendoza

*Laboratorio de Ingeniería y Proceso Costeros UNAM-Yucatán, ,MEXICO. * Corresponding author: CAppendiniA@ii.unam.mx*

Summary

A 30 year wave hindcast for the Gulf of Mexico and Caribbean Sea has been developed, motivated by the lack of historical wave observations within Mexican waters (Fig. 1). A third generation spectral wave model (MIKE 21 SW) has been employed, forced with wind reanalysis data. Firstly, an assessment of different wind reanalysis (i.e., NCEP, ERA-interim and NARR) has been done for two simulation periods (2005 and 2006) evaluating their performance for reproducing normal and synoptic/cyclonic extreme wave conditions at different NDBC locations. The NARR was selected as the most appropriate data base for this area and hence 30 years were simulated at 3 hours intervals. From the results it was possible to characterize the wave climate in the different areas within the basins and their trends.

Figure 1. Available wave observation sites in the GoM and CS

Reanalysis assessment

Based on the statistical analysis (Table 1), the assessment of three different wind reanalysis (NCEP, ERA-interim and NARR) for its performance in wave modeling showed that the ERA-interim and NARR reanalysis provided the best accuracy in terms of mean wave climate (correlation coefficient ~0.83 for NCEP, 0.93 for ERA-interim, 0.92 for NARR). However, the detailed analysis of extreme events shows that during cyclonic (hurricane) events the SWH is better reproduced using the NARR wind fields (Fig 4).

Buoy Id	Stat. Param.	2005 - 2006 NCEP	ERA	NARR
42001	No. Obs.		5797*	
	Ẋ Obs.		1.11*	
	Ẋ Sim.	1.37	1.24	1.35
	Bias	0.25	0.12	0.24
	BI	0.23	0.11	0.21
	RMS	0.52	0.35	0.40
	SI	0.47	0.31	0.36
	CC	0.85	0.93	0.93
42003	No. Obs.		5502*	
	Ẋ Obs.		1.12*	
	Ẋ Sim.	1.11	1.03	1.07
	Bias	-0.02	-0.10	-0.05
	BI	-0.01	-0.09	-0.05
	RMS	0.44	0.32	0.34
	SI	0.39	0.29	0.30
	CC	0.85	0.92	0.91
42055	No. Obs.		4581*	
	Ẋ Obs.		1.16*	
	Ẋ Sim.	1.27	1.17	1.21
	Bias	0.10	0.01	0.04
	BI	0.09	0.01	0.04
	RMS	0.44	0.25	0.28
	SI	0.38	0.21	0.24
	CC	0.84	0.94	0.92
42056	No. Obs.		3767*	
	Ẋ Obs.		1.20*	
	Ẋ Sim.	1.40	1.34	1.27
	Bias	0.20	0.14	0.08
	BI	0.17	0.12	0.07
	RMS	0.53	0.30	0.33
	SI	0.44	0.25	0.27
	CC	0.80	0.95	0.92

Table 1. SWH statistical parameters obtained using different wind reanalysis

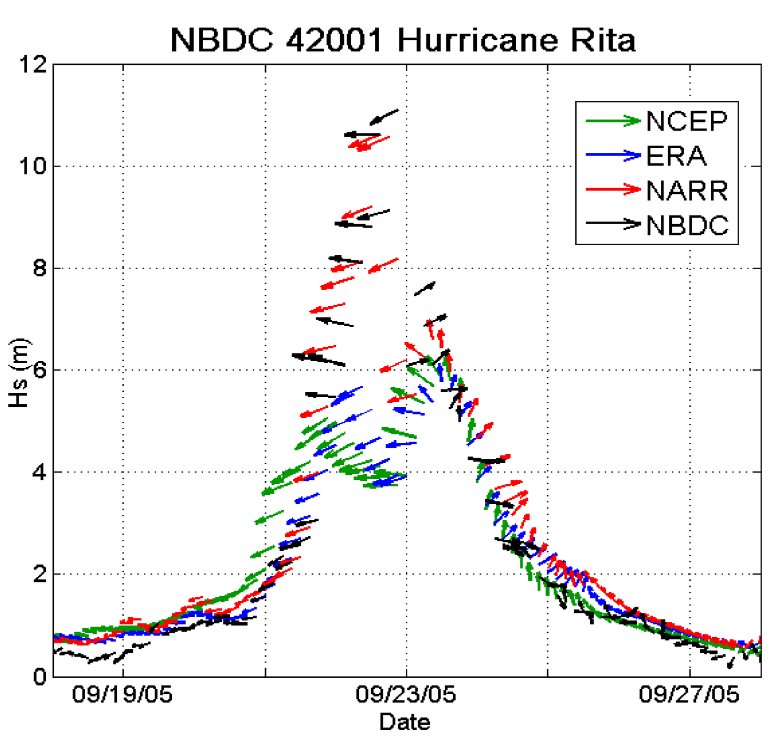

Figure 4. Simulation results for hurricane Rita at buoy 42001 with different wind reanalysis

Calibration and validation

The model was calibrated for mean and extreme wave conditions during the wind reanalysis assessment. While NARR provided the best results, it was then validated against measurements in the GoM and CS (Fig. 3 and Table 2).

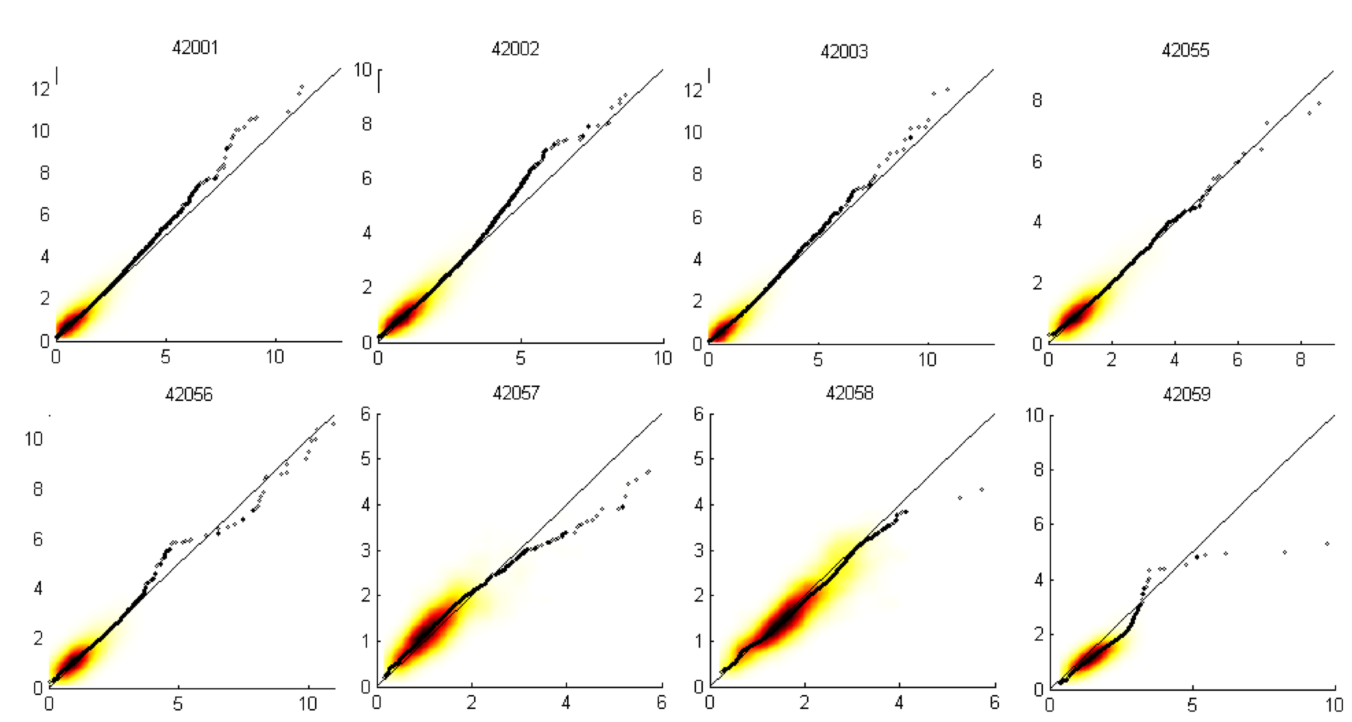

Figure 3. SWH (m) Q-Q and density plots at selected locations for 30 year wave hindcast

Buoy Id	No. Obs	Ẋ Obs	Ẋ Sim	Bias	RMS	SI	CC
42001	79002	1.1	1.25	0.15	0.36	0.33	0.90
42002	70070	1.23	1.3	0.07	0.35	0.28	0.89
42003	72896	1.08	1.05	-0.03	0.32	0.29	0.90
42055	7324	1.16	1.21	0.05	0.28	0.24	0.91
42056	9079	1.22	1.31	0.09	0.33	0.27	0.90
42057	3205	1.24	1.34	0.1	0.33	0.27	0.85
42058	4707	1.76	1.67	-0.09	0.32	0.18	0.90
42059	4721	1.58	1.25	-0.33	0.45	0.29	0.82

Table 2. 30 year hindcast statistical parameters for SWH

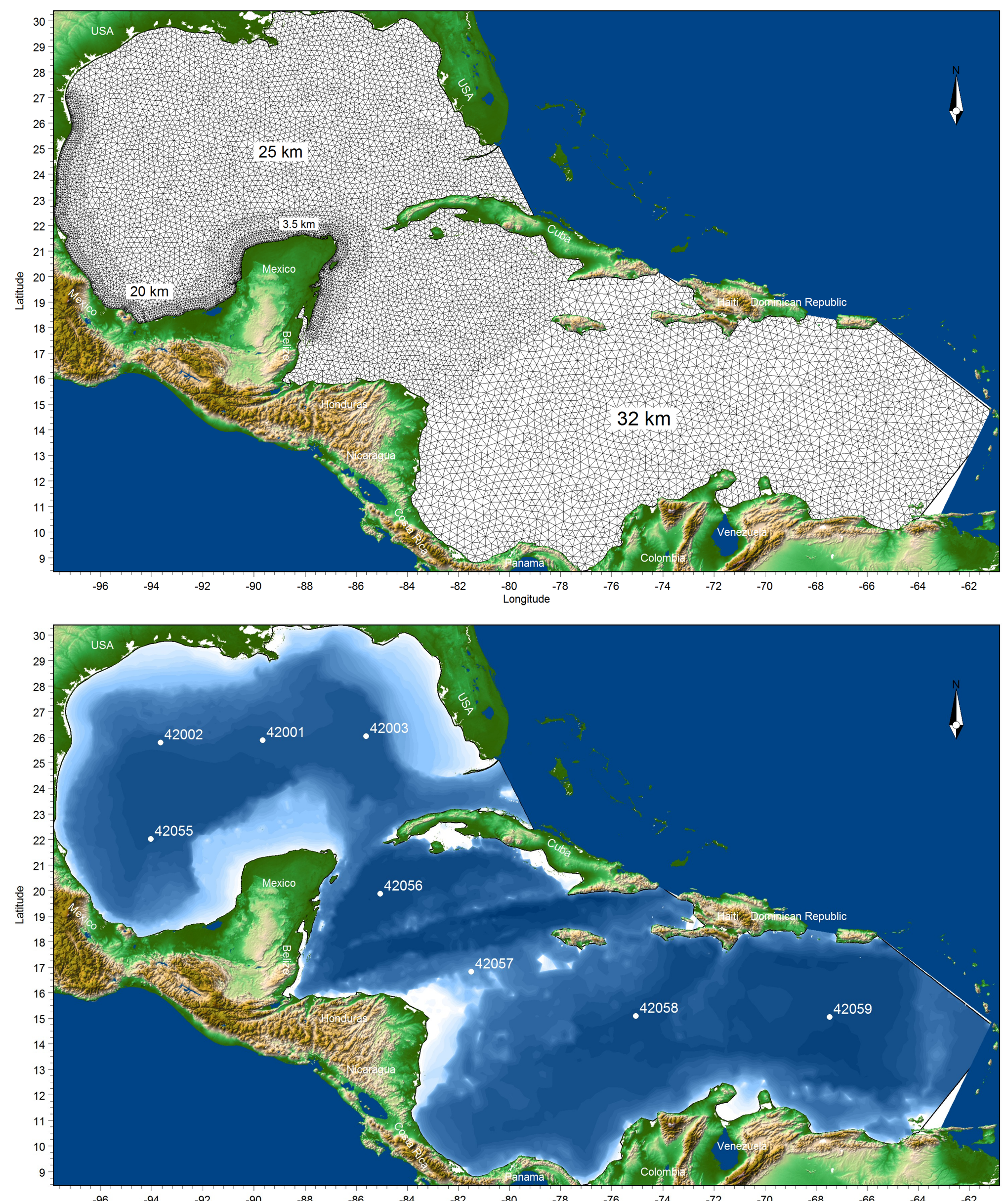

Figure 2. Model mesh and bathymetry from ETOPO1

30 year wave hindcast

Several analysis were performed to characterize the wave climate in the GoM and the CS, based on the 30 year hindcast 3 hourly data. Fig. 5 shows the mean annual SWH where highest waves are under the area influenced by the Caribbean jet. The SWH monthly anomalies are shown in Fig. 6, where positive anomalies are found during the winter months, and negative during summer months (with an exception during June-July due to the Caribbean Jet).

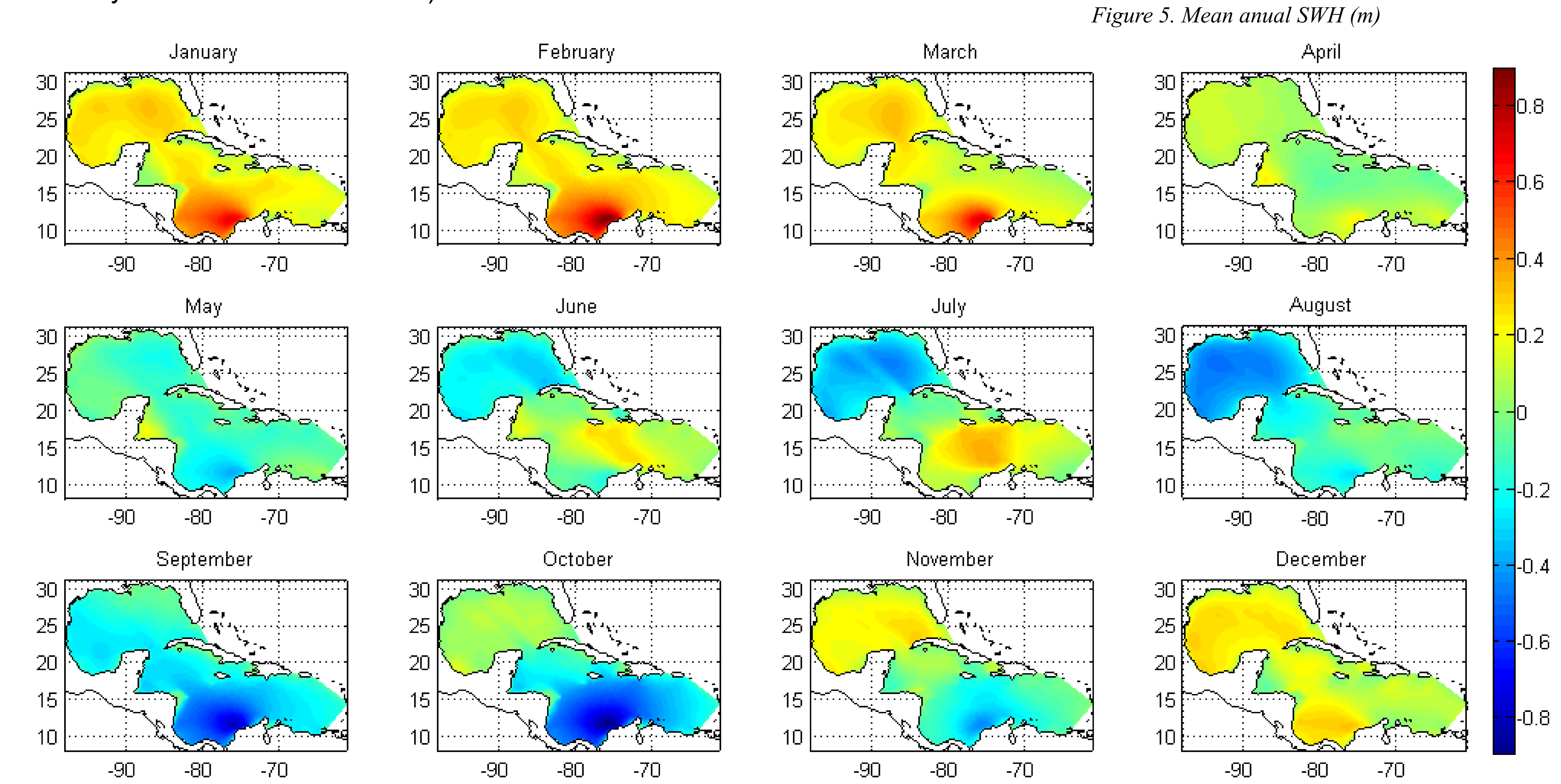

Figure 6. SWH monthly anomalies (m)

Highest storm waves are a result of hurricanes, (Fig. 7a) while most storms are a result of synoptic scale events, such as *Nortes* at the Mexican coast (Fig. 7b,d). The Caribbean jet also produce an important number of storms, which have the longest duration (Fig. 7c,d).

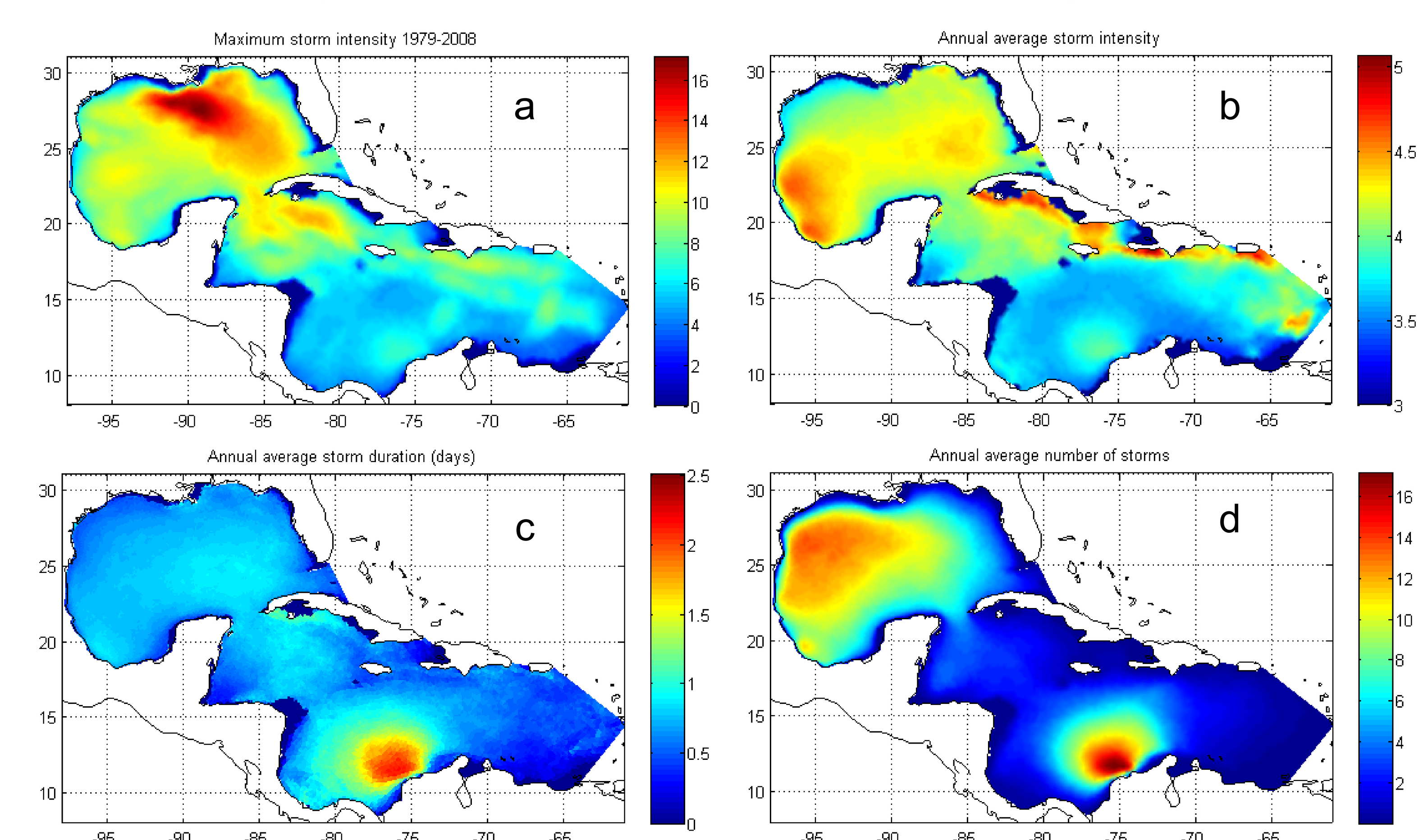

Figure 7. Storm characterization

Acknowledgements

The present study was supported by CONACYT-FOMIX-YUC Project 106400 from the Laboratorio de Ingeniería y Procesos Costeros del Instituto de Ingeniería – UNAM.

Wave model

Third generation spectral wave model MIKE 21 SW model was used using mesh and bathymetry shown in Fig. 2. The model is formulated in terms of mean wave direction, θ, and the relative angular frequency, σ, where the action density, $N(\sigma,\theta)$ is related to the energy density, $E(\sigma,\theta)$ by:

$$N(\sigma,\theta) = E(\sigma,\theta)/\sigma$$

For large applications, the wave action balance equation is formulated in spherical coordinates, where the evolution of the wave spectrum in the position given by latitude ϕ and longitude λ, at a particular time *t*, is given as follows:

$$\frac{\delta N}{\delta t} + \frac{\delta}{\delta \varnothing} c_{\varnothing} N + \frac{\delta}{\delta \lambda} c_{\lambda} N + \frac{\delta}{\delta \sigma} c_{\sigma} N + \frac{\delta}{\delta \theta} c_{\theta} N = \frac{S}{\sigma}$$

The energy source term *S*, represents a superposition of source functions that describe the multiple physical phenomena and is given by:

$$S = S_{in} + S_{nl} + S_{ds} + S_{bot} + S_{surf}$$

where S_{in} represents the wind energy input given by a linear and a non-linear growth rate, S_{nl} represents the non-linear wave-wave interaction, such as quadruplet-wave interactions and triad-wave interactions, S_{ds} is the energy dissipation due to whitecapping, S_{bot} is the energy dissipation due to bottom friction and S_{surf} is the energy dissipation due to depth induced wave breaking. More details are found at Sørensen et al. (2004).

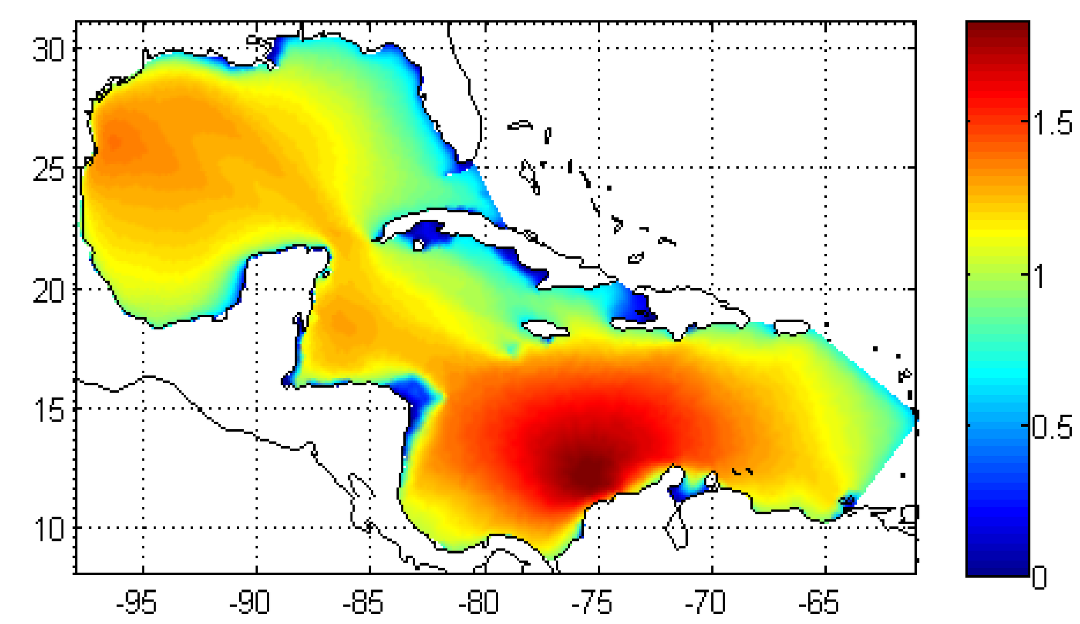

Figure 5. Mean anual SWH (m)

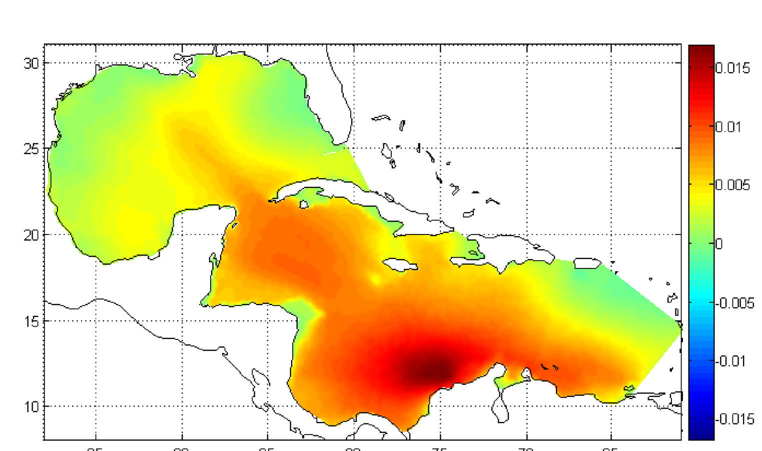

Figure 8. SWH tendencies based on mean SWH

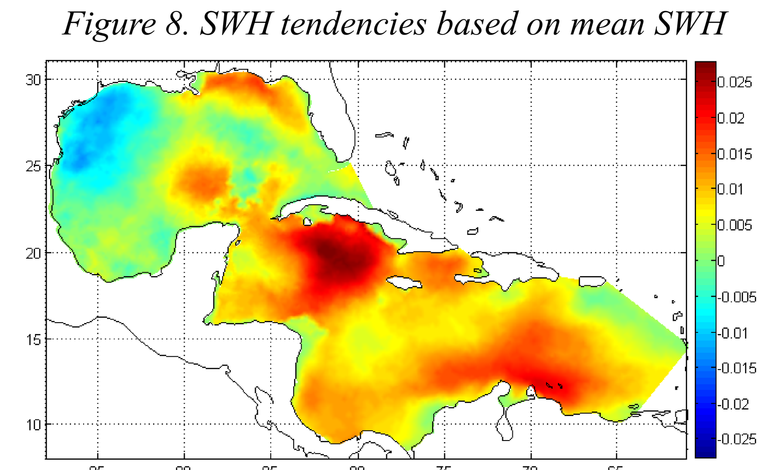

Figure 9. SWH tendencies based on 99th percentile

Analyzing tendencies based on mean SWH, there is an increment in both basins with a higher increment in the Caribbean Sea (Fig 8). While based on 99th percentile, a diminishing tendency is found at the upper western Gulf of Mexico (Fig. 9)