The contribution of tropical cyclones to seasonal precipitation over Mexico

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Introduction

Tropical Cyclones (TCs) are key atmospheric phenomena in the hydrological cycle of several tropical regions around the world [*Trenberth and Fasullo, 2007*]. For instance, *Shephard et al. [2007]* found that TCs accounted from 8 to 17% of cumulative rainfall during hurricane seasons at different locations along the coastal southeastern United States. *Wu et al. [2007]* pointed out that TCs produce more than one third of the total precipitation between June and November at Hainan Island in China.

A TC that is close to the Pacific coast of Mexico may contribute from 20 to 60% of seasonal rainfall along coastal regions of Mexico, and up to 30% in landmass of western Mexico [*Englehart and Douglas, 2001*]. Hence, **TCs are essential climatic elements of summer rainy seasons in Mexico. An important part of water availability in northern Mexico is related to TC rainfall, which is used to fill reservoirs up**.

For instance, **Hurricane Alex made landfall on July 1st, 2010** and its associated maximum precipitation was 446.5 mm in 24 hours, which is close to the mean summer precipitation in parts of northeastern Mexico. The water level at dams raised enough for providing this resource to several regional socioeconomic activities during the prolonged 2010-2012 drought in northern Mexico [*Magaña and Neri, 2012*]. The impacts of TCs in water balances and management is not a simple task, since seasonal forecasts of TC activity [*Camargo et al., 2010*] do not provide any information of likely future tracks and affected regions. Even when tropical cyclone activity is normal or above-normal, negative anomalies of monthly precipitation may still appear at the regional level if most TC trajectories are not close enough to Mexico.

Clustering and summer rainfall (May-November)

The TC impact was determined according to the different types of tracks grouped into clusters. The percentage of TC contribution to summer rainfall is obtained by aggregating the precipitation that was produced by TCs during their lifetime. The cluster IAS-A and ENP-A significantly contributed to summer precipitation over Mexico (Fig. 1), these types of tracks are likely to make landfall in northeastern and northwestern Mexico. On average, their contribution may be up to 30 percent of mean annual precipitation, particularly in semiarid regions where annual rainfall is around 400 mm. In spite of damages on these regions due to extreme rainfall, the clusters IAS-A and ENP-A supply substantial amounts of water to the north of Mexico.

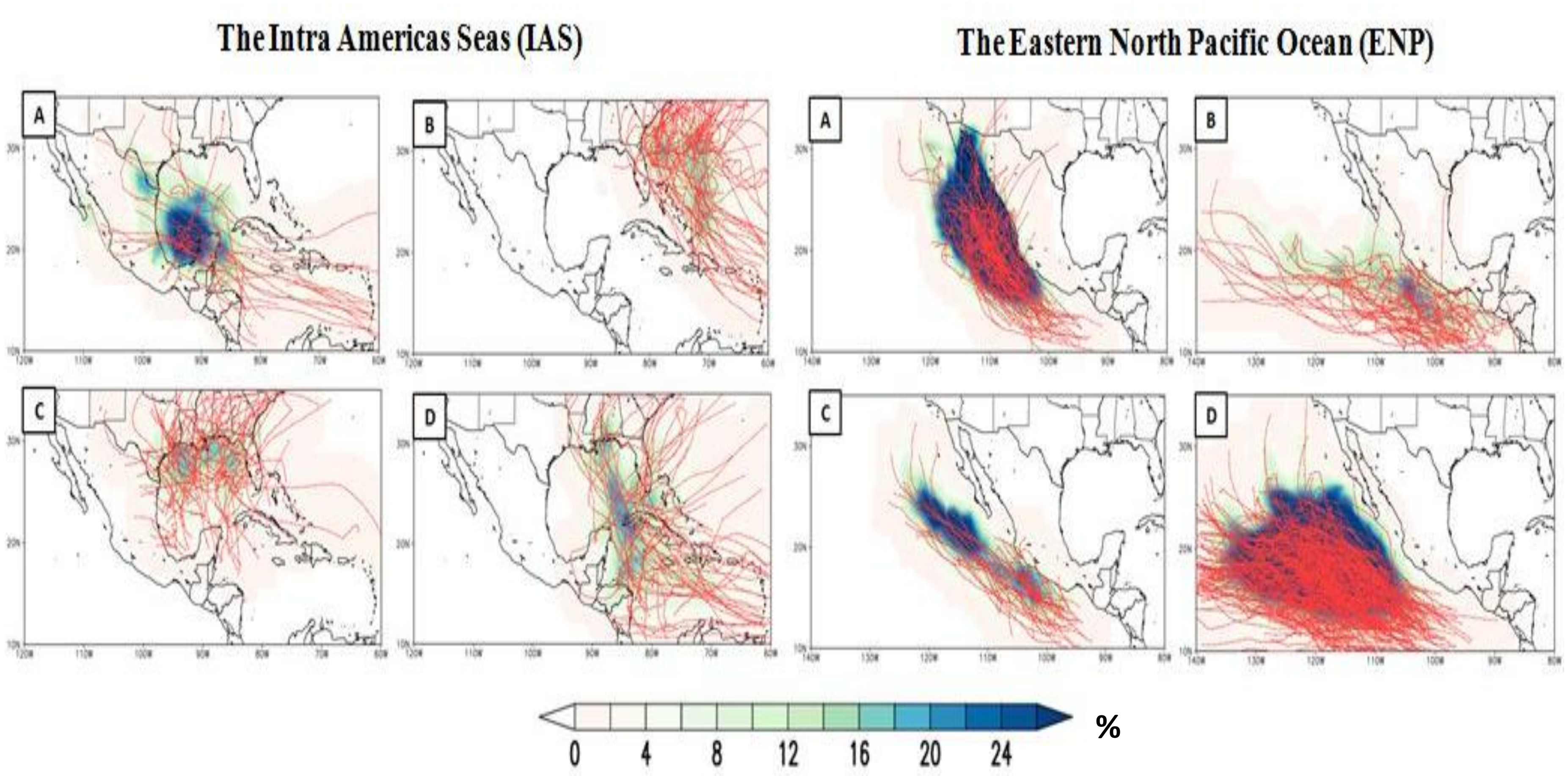


Figure 1. Clusters contribution (%) to summer rainfall over the Intra Americas Seas and the Eastern North Pacific Ocean for the 1979-2009 period. Data: ERAInterim

The contribution of TCs to the summer precipitation strongly depends on whether a TC is close enough to the Mexican continental regions. For instance, years of El Niño conditions are characterized by a weak TC activity over the North Atlantic and this reduces the chances of TCs to make landfall over the eastern Mexican coast. El Niño summers are usually featured by negative precipitation anomalies near the northern Mexico. However, even when TC activity is high, the lack of cluster IAS-A and IAS-C may result in negative precipitation anomalies, as it occurred in the year of 1997, 2001, 2002 or 2009. Positive precipitation anomalies could increase if at least two TCs approached the northeastern Mexico (Fig. 2).

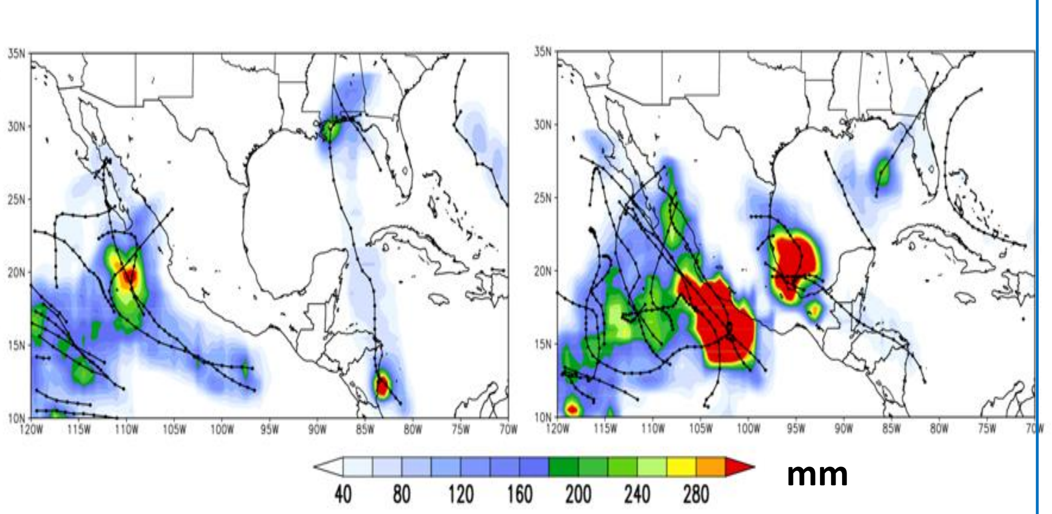


Figure 2. Tropical cyclone tracks and their associated precipitation in 2009 (left) and 2013 (right)

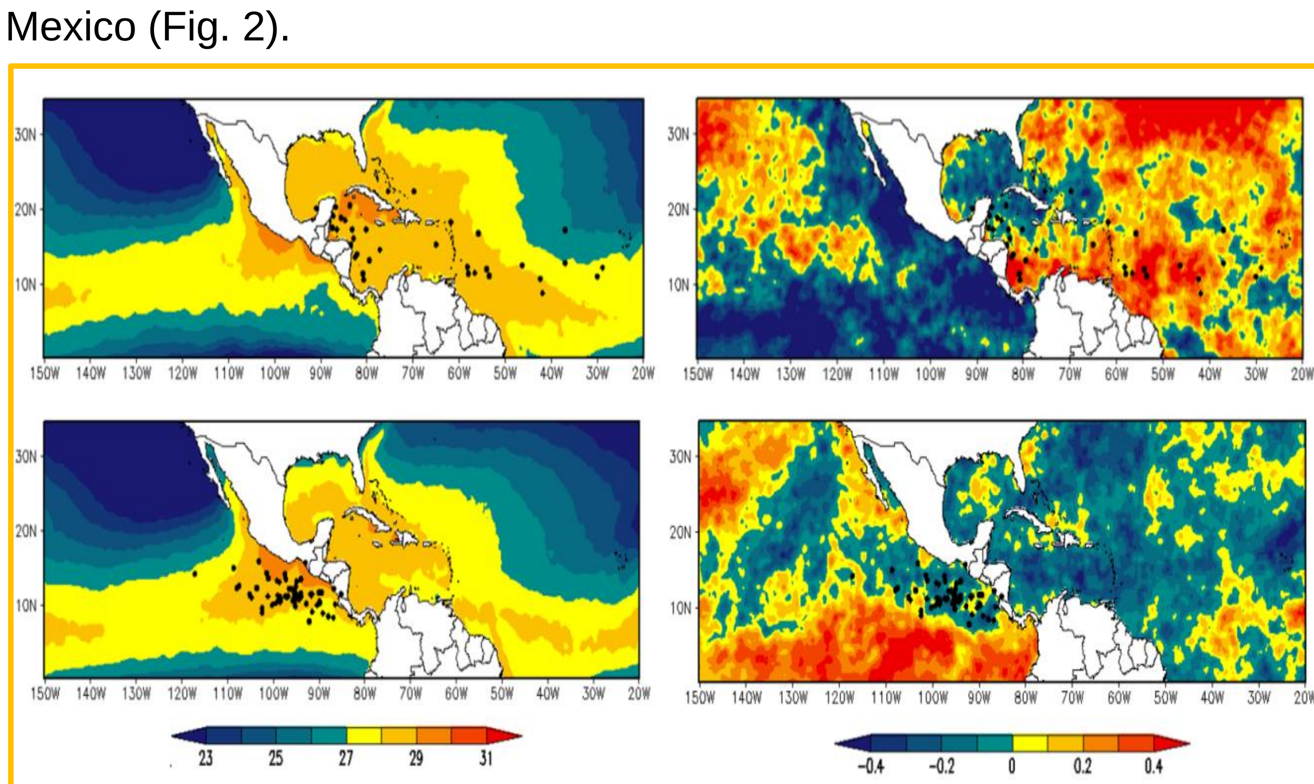


Figure 3. **Composites of daily SST (1981-2009) based on cyclogenesis day for each member of cluster IAS-A (upper left) and ENP-B (bottom left). Standardized SST anomalies for cluster IAS-A (upper right) and ENP-B (bottom right). The anomalies are defined as the difference between the SST in the day that cyclogenesis occurred and its climatologic value.**

Figure 3 depicts that the cyclogenesis of IAS-A occurred over SST> 28 ºC and during negative standardized SST anomalies in the Tropical Pacific Ocean, which represent La Niña Conditions. The t-student test supported that the number of TCs from IAS-A increases during the cold ENSO phase at 99% significance level (not shown) and there was no activity during El Niño years. On the ENP, only one cluster was found to be influenced by ENSO. Figure 3 also shows that the formation of ENP-B occurred in years of the warm ENSO phase because of positive standardized SST anomalies. Furthermore, the increase in frequency of this cluster during El Niño conditions at 97.5% significance level is in agreement with the analysis of SST anomalies (not shown).

Can CFSv2 predict the impact of TCs in regional precipitation?

Predicting ***tropical cyclogenesis, and subsequent TC tracks and precipitation remain a big challenge in climate models***. A typical case of precipitation amounts produced by a climate model is shown. However, the CFSv2 Reforecast of Hurricane Alex (2010) did not capture the precipitation extreme that happened in Northern Mexico due to the coarse resolution of the model –the CFSR did capture the event. Precipitation amounts for Alex are shown for lead times of **2.5,2.0, 1.0 and 0.5 month**.

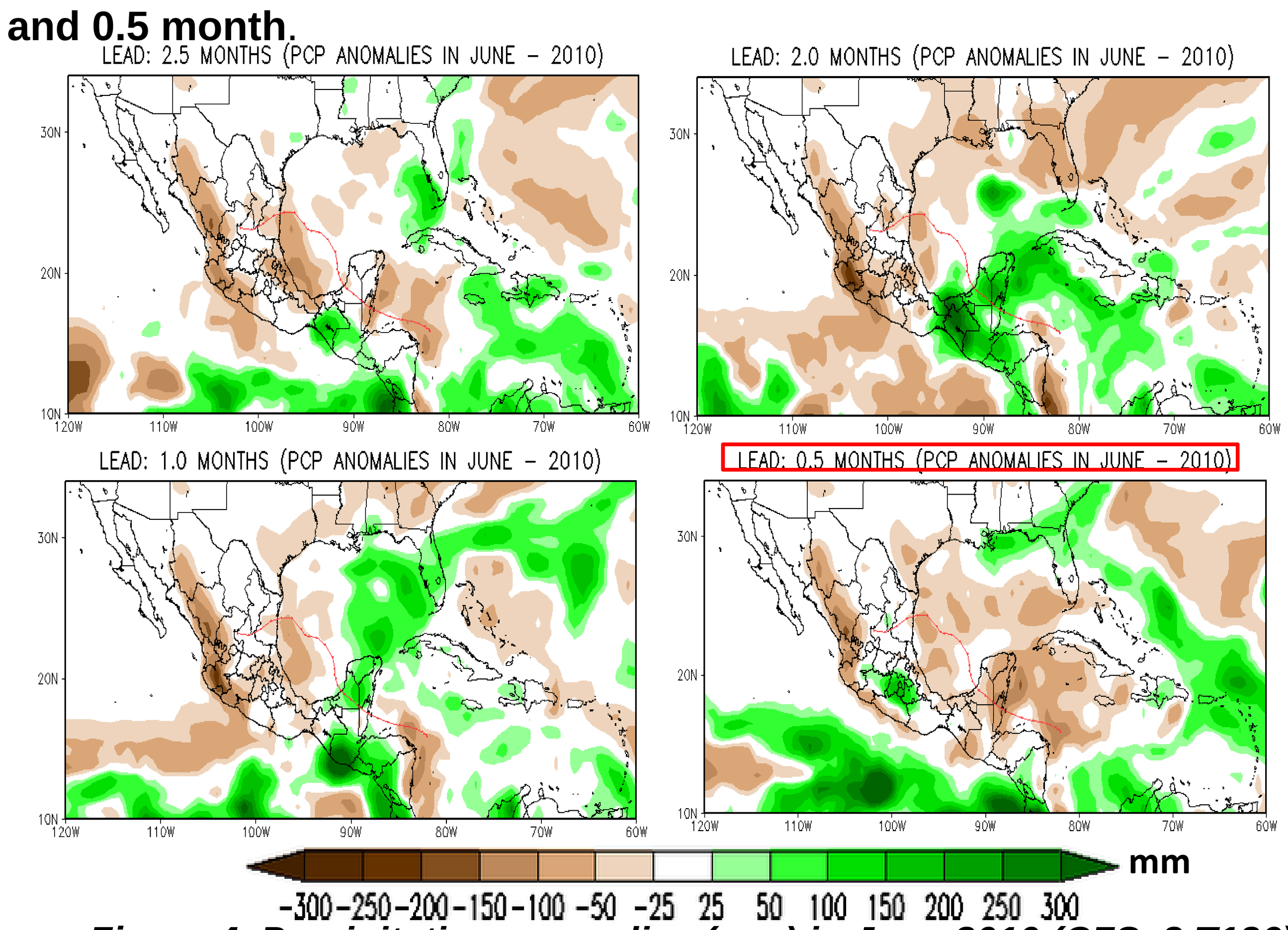


Figure 4. Precipitation anomalies (mm) in June 2010 (CFSv2 T126)

Easterly Waves (EWs) as precursos of TCs

EWs are considered as a main source of predictability on sub-seasonal timescales. Apart from contributing up to 70% in some regions of IAS and ENP (Fig. 5), 60% of TCs over those basins comes from EWs. One of the major constraints of seasonal forecast is to simulate tropical cyclogenesis adequately because climate models are not able to predict cyclogenesis regions 1 month in advance, so missing likely regions of TC formation can conduct to wrong TC tracks.

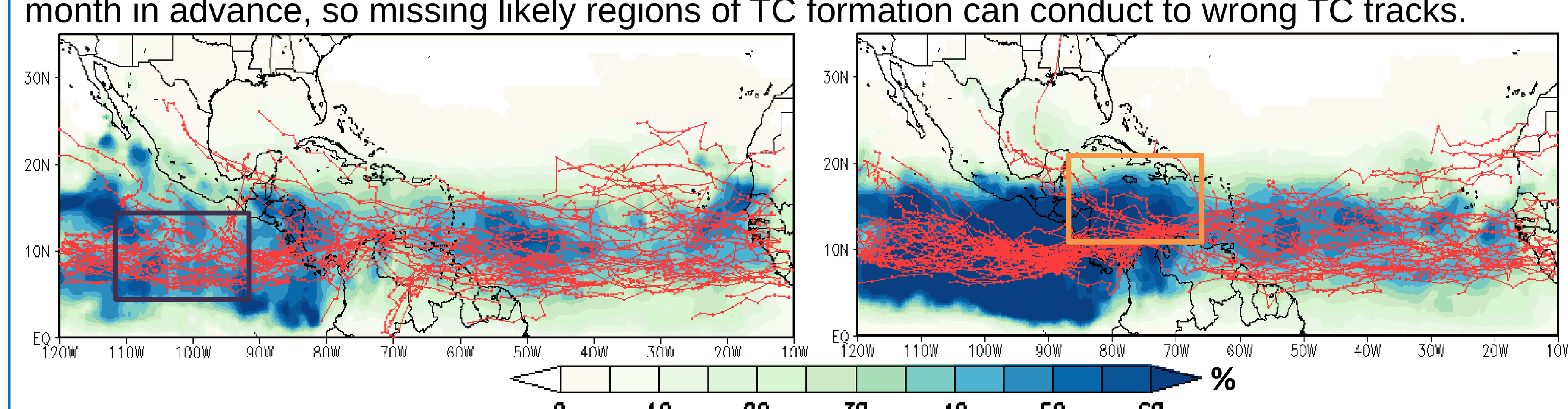
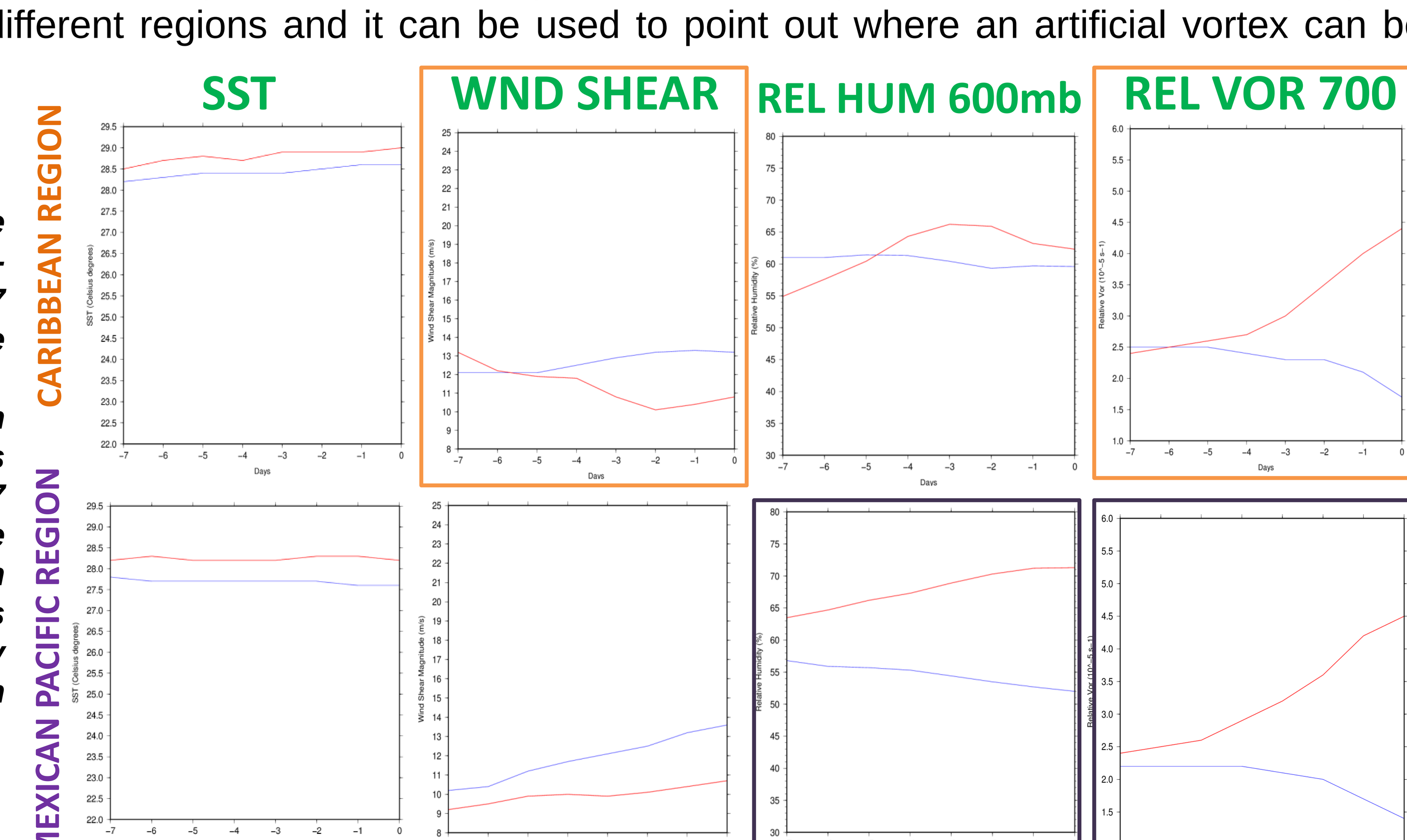


Figure 5. EW tracks and their contribution (%) to summer rainfall over the Intra Americas Seas and the Eastern North Pacific Ocean in 2010 (left) and 2013 (right). Data: ERAInterim.

Based on EW climatology, tropical cyclogenesis was regionalized by using thermodynamical and dynamical variables (Developers vs No-developers). This analysis shows thresholds of tropical cyclogenesis in different regions and it can be used to point out where an artificial vortex can be inserted.

Figure 6. Time series of large-scale variables 7 days before tropical cyclogenesis in developing EWs (red line) and 7 days before dissapearing in no-developer EWs (blue line) by using Lagrangian approach



CONCLUSIONS

The effect of TCs in the hydrological cycle of northern Mexico is missing in most global or regional climate models even when they play a relevant role. Even though TC activity and characteristics should be included in the water management planning process in Mexico, there are no predictive schemes aimed at meeting such goal. Seasonal or even monthly outlooks of TC activity over Intra Americas Seas may not be enough to estimate the TC impact in the hydrological cycle since subtle elements, such as the track and size, are not forecast at least one month in advance. The problem is even more complicated when regional climate change scenarios for the water sector are used to make projections of the potential impacts of such extreme phenomenon. ***Future work should consider the role of large scale forcing in determining preferred TC tracks and ensembles of projections on what their effect could be at regional scale. One possible approach to this problem is to seed TC-like vortices in predicted cyclogenesis regions and explore their development and tracks in high resolution climate models.***

Camargo et al. (2010). The influence of natural climate variability on tropical cyclones, and seasonal forecasts of tropical cyclone activity. (Chapter XI). Global Perspectives on Tropical Cyclones, from Science to Mitigation, 2nd edición. World Scientific Series on Earth System Science in Asia, J.C.L. Chan and J.D. Kepert editors, Volume 4. p. 325-360. ISBN 978-981-4293-47-1. Englehart, P. J. and A. V. Douglas (2001), The role of eastern North Pacific tropical storms in the rainfall climatology of western Mexico, *Int. J. Climatol., 21*, 1357 – 1370. Magaña, V. and Neri, C. (2012), Cambio Climático y Sequías en México. Revista Ciencia de la Academia de Ciencias, vol. 63. Mexico . Shephard, J. M., A. Grundstein, and T.L. Mote (2007), Quantifying the contribution of tropical cyclones to extreme rainfall along the coastal southeastern United States, *Geophys. Res. Lett., 34*, L23810. Trenberth, K. E. and J. Fasullo (2007), Water and energy budgets of hurricanes and implications for climate change, *J. of Geophys. Res., 112: D23107.* Wu, Y., S. Wu, and P. Zhai (2007), The impact of tropical cyclones on Hainan Island's extreme and total precipitation, *Int. J. Climatol., 27*, 1059-1064.