11D.6 ANALYSIS OF THE STRUCTURE AND GENESIS OF TROPICAL EASTERLY WAVES IN THE CARIBBEAN SEA AND EASTERN NORTH PACIFIC USING THE WRF MODEL

Ewan C. Crosbie & Y.L. Serra*
University of Arizona, Tucson, AZ

1. INTRODUCTION

Tropical easterly waves are the primary mode of variability in winds and organized precipitation across the Intra-Americas Sea (IAS), and are the primary source of tropical storms and hurricanes throughout the region. In addition, easterly waves and their associated tropical disturbances are a significant source of moisture for North American monsoon (NAM) events, further motivating a better understanding of their variability and origin which currently remains somewhat unclear. The main uncertainty with respect to the origin of these waves is whether they are an extension of existing waves propagating from the Atlantic or if there is wave genesis within the Caribbean and East Pacific region. The latter requires a forcing mechanism, of which several have been proposed including wave accumulation, barotropic instability of the low-level flow, and inertial and barotropic instability of the inter-tropical convergence zone (ITCZ).

The present study considers two main aspects: firstly the ability of the Weather Research and Forecasting (WRF) model to adequately simulate the structure and location of easterly waves in the region, and secondly the relative role of background intra-seasonal variability, orography and wave accumulation on the wave forcing, energy conversions and genesis mechanisms specific to the East Pacific. Simulations using the WRF model were run for eight consecutive boreal summer seasons (June –September from 2002 to 2009) with a domain spanning the IAS and a horizontal grid spacing of 22.5km. Our analysis suggests no single origin for East Pacific waves, with some waves passing into the region from the West Atlantic while others originate in the Caribbean and East Pacific, generally off the coast of Panama. Our results also suggest that the Madden-Julian Oscillation (MJO) plays an important role in modifying East Pacific wave amplitude but they do not explain all the intra-seasonal variability observed.

2. MODEL CONFIGURATION AND VALIDATION

The WRF model was configured to dynamically downscale 0.7°x0.7° ECMWF ERA Interim reanalysis data over eight JJAS seasons (2002-2009). The ECMWF forcing data was updated every six hours and spectral nudging was applied to the interior (above the boundary layer) for zonal and meridional wavelengths above 1000km. The model physics options were: WRF Double-Moment 5-class microphysics, RRTMG longwave and shortwave schemes, Eta similarity surface layer with 5-layer thermal diffusion over land, Mellor-Yamada-Janjic PBL scheme and Kain-Fritsch cumulus scheme. The longitudinal extent of the model domain was selected to span the tropical East Pacific, the Caribbean Sea and the tropical West Atlantic. The latitudinal boundaries were chosen to include a significant fraction of the NAM region while centering the domain approximately on the Pacific ITCZ. Previous simulations with a similar setup but with a domain shifted further to the north and west resulted in a poor representation of the cloud and precipitation fields over Venezuela, Colombia and northern Brazil and so this helped to steer the choice of the current domain to include an ocean boundary to the east.

The statistics of the modeled outgoing long-wave radiation (OLR) and rainfall were compared with observations from NOAA's Climate Data Center (CDC)

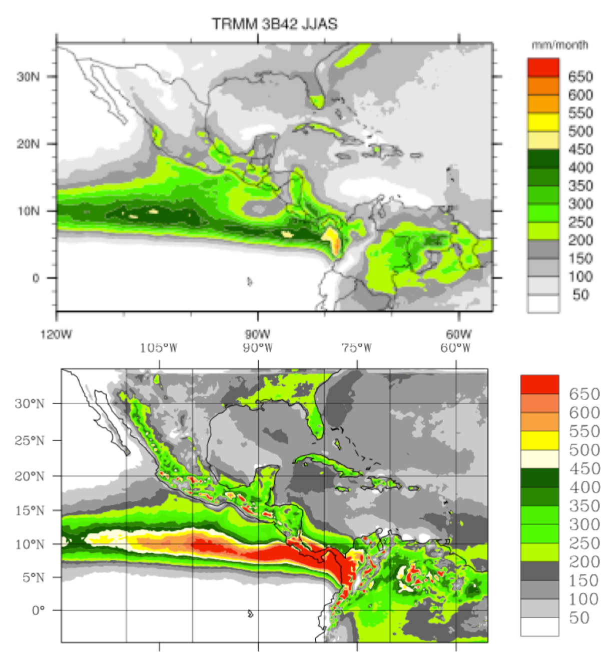

Figure 1: Comparison of TRMM (upper) average monthly rainfall over all seasons with WRF (lower) simulated precipitation

* *Corresponding author address:* Ewan C. Crosbie, Department of Atmospheric Sciences, Univ. of Arizona, Tucson, AZ 85719; email: ewan@email.arizona.edu

and NASA's Tropical Rainfall Measuring Mission (TRMM), respectively. A comparison of the monthly rainfall totals from WRF and TRMM are shown in Figure 1. Qualitatively, the comparison is reasonable and the model correctly predicts the distribution of high and low rainfall. However, the rainfall totals are over-estimated in the WRF simulations compared with TRMM. In the context of this study this is not of significant concern given that it can be largely attributed to a systematic over-prediction within the cumulus and microphysics parameterizations.

3. EASTERLY WAVES IN THE WRF MODEL

The variability in the model OLR field is used to assess enhanced and suppressed convection coupled to equatorial wave activity and a method similar to Wheeler and Kiladis (1999) is used to examine the wave energy distribution in the (zonal) wavenumber-frequency domain. It is worth noting that a Fourier analysis in space on a regional domain is somewhat unfulfilling since global wavenumbers are effectively quantized by the zonal extent of the domain (~90°). In this case, the spectral analysis permits global wavenumbers 4, 8 12, etc. but not intermediate waves. The OLR frequency-wavenumber spectrum was band-pass filtered to permit synoptic westerly propagating waves in the 2-10 day and 1000-10,000 km window corresponding broadly to the “tropical disturbance” (TD) band described in Wheeler and Kiladis (1999). The filtered OLR was also smoothed using a low-pass spectral filter in the meridional direction above 500 km. As will be developed later, the tropical easterly wave is the predominant wave in this window and has approximate scales of 4 days and 4000km. However, the filter was intentionally left as broad as possible to retain the benefit of the regional model in capturing structure and interactions with smaller scale dynamics. Figure 2 shows a comparison of the variability in unfiltered and TD-filtered OLR.

There are two main regions of high TD-filtered OLR variability: the first is situated close to the Lesser Antillies (13N, 65W) and extends into the West Atlantic; and the second is located along the northern edge of the East Pacific ITCZ (between 10N, 95W and 15N, 110W). There is also a third, but lesser, maximum east of the Yucatan Peninsula (17N, 85W). In all these regions, the TD-band contributes a significant fraction of the overall OLR variability. The spectral filter band was modified in both space and time and it was found that the location and relative extent of these maxima was insensitive to the filter specifics. The unfiltered OLR captures the strong diurnal signal of the NAM thunderstorms over the Sierra Madre Occidental in northern Mexico as well as the position of the ITCZ at approximately 10N.

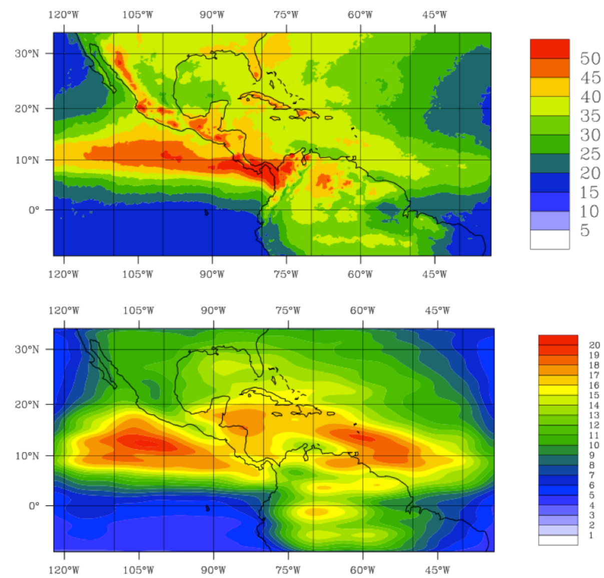

Figure 2: Standard deviation of OLR (W/m^2) variability over all seasons (2002-2009): unfiltered (upper) and TD-filtered (lower)

Time-longitude cross-sections were constructed using the meridional average between 0N and 20N, which captures the features described above. Figure 3 shows the OLR anomaly and the 700 hPa meridional wind anomaly during the 2004 season for both unfiltered and TD-filtered data noting that this pattern was broadly comparable across the other seasons. Easterly wave activity is evident in all four plots, and even in the unfiltered data these waves are seen to be the dominant mode of variability propagating across the region. From the filtered data it can be seen that while there are many waves that traverse from the West Atlantic into the Caribbean, there are also some instances of waves crossing Central America into the East Pacific. Additionally, there are instances of strengthening wave activity in the East Pacific when previously the Caribbean and West Atlantic had been subdued, particularly in the meridional wind field. From this analysis alone, there are no clearly defined regions of wave genesis or lysis nor systematic pattern to the wave passage from one basin to another. Future work will examine the synoptic conditions associated with these various wave tracks to better understand the physical mechanisms involved in IAS easterly wave genesis, maintenance and lysis.

The contours overlaid on Figure 3 represent zonal wind anomalies at 850 hPa, filtered for periods greater than 30 days. This signal is considered to be related to the influence of the MJO in the region. During the westerly phase, which for this example is strongest during early September, the OLR anomaly is broadly negative indicating enhanced convection. In addition, the 700hPa meridional wind is showing higher variability and stronger easterly wave activity in the East Pacific. During the easterly phase (i.e. mid August), the OLR anomaly is predominantly positive indicating suppressed convection and the variability in the meridional wind is far weaker. The TD-filtered meridional wind indicates minimal easterly wave activity at this time. From this alone it could be hypothesized that MJO phase regulates easterly wave activity in the East Pacific, however a counter-example in the same season suggests that the situation is more complex. During early July, wave activity was relatively strong in the East Pacific at a time when Atlantic waves were rather weak, however during this time there was negligible 850hPa zonal wind anomaly. Based on this result we will examine the relationship between the MJO and easterly wave propagation and strength as well as periods of non-MJO enhanced activity.

4. STATISTICAL REPRESENTATION OF WAVE STRUCTURE

The structure of the easterly waves was studied using a linear regression analysis. The raw (unfiltered) OLR, wind, geopotential, temperature and vertical velocity were lag-correlated with the TD-filtered OLR at three distinct points corresponding to the three maxima

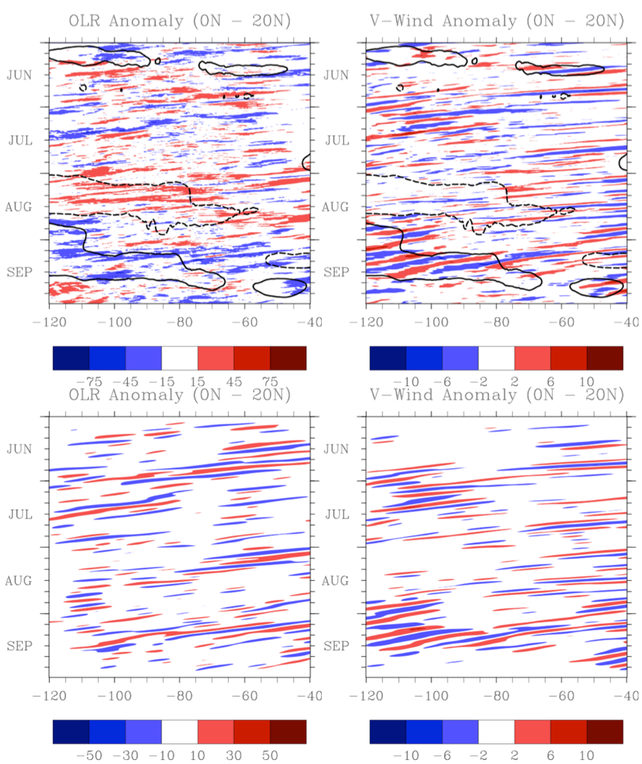

Figure 3: Time-longitude plots averaged over 0N-20N. The upper plots show unfiltered anomalies and the lower plots show anomalies in the TD-band. Left –OLR (W/m^2), right – meridional wind at 700hPa (m/s). Contours show 30+ day 850hPa zonal wind anomalies – dashed lines indicate easterly winds

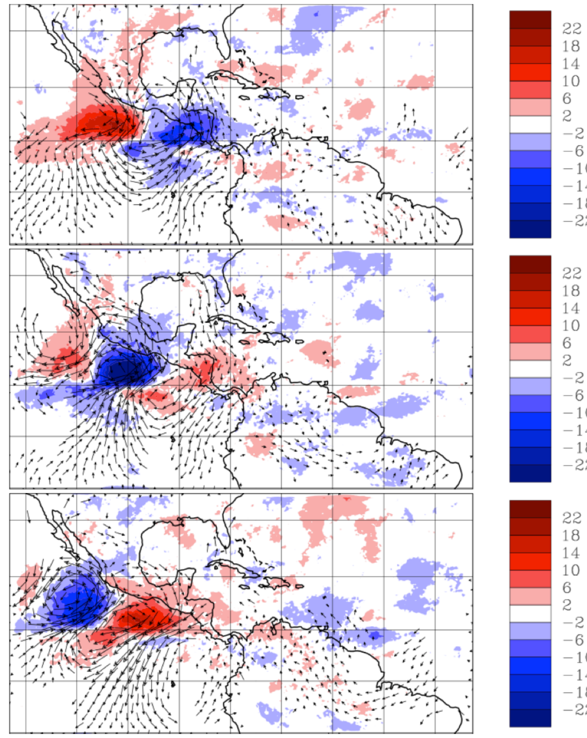

Figure 4: Evolution of the East Pacific wave regression shown at lag-times -2, 0, and 2 days. Contours show OLR anomaly (W/m^2) winds are shown at 700hPa

identified previously. Henceforth these points will be referred to as West Atlantic (14N,60W), Caribbean (17N,85W) and East Pacific (12.5N,100W). The regressed fields were calculated at 6-hourly increments over lag-times -2 to +2 days, which corresponds to a typical wave period. As an example, the evolution of the East Pacific wave at the 700hPa level is shown in Figure 4. The strong convection associated with the wave trough is evident in the negative (blue) OLR contours coupled with the markedly cyclonic wind field in good agreement with observations (Serra et al. 2010). Vectors are shown where the wind field is statistically significant above the 90% level. The regression also captures cross equatorial circulation, characteristic of a mixed-Rossby-Gravity (MRG) type wave, which is interacting with the easterly wave. There is also a statistically significant circulation induced by the passage of the wave which extends into the NAM region. While the influence of easterly waves on the NAM has been discussed extensively in the literature (eg. Stensrud et al. 1997), here we present a unique picture of how circulations associated with easterly waves can move moisture into the core NAM region and into the southwest United States.

A comparison at zero-lag of the West Atlantic, Caribbean and East Pacific regressions is shown in Figure 5. The structure of the wave in each location is notably different. The convection in the West Atlantic

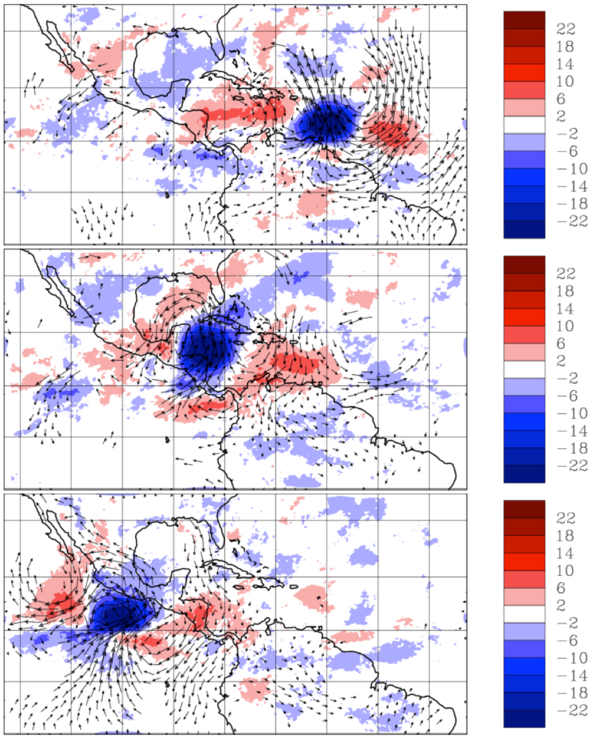

Figure 5: Wave regressions taken in the West Atlantic, Caribbean and East Pacific (shown at zero lag). Contours show OLR anomaly (W/m^2) winds are shown at 700hPa

wave is primarily associated with a confluence region of low-level southerly winds with a weakly defined circulation center some 500-1000 km to the northwest. As the wave evolves, the convection appears to weaken slightly as it moves into the Caribbean. The Caribbean wave also shows convection in the southerlies offset from the trough center, although not as marked as the Atlantic wave. At later lag-times, the convection associated with the wave tracks north-westward along the coast of Central America and decays significantly, however the circulation center traverses the land and reestablishes on the Pacific coast (not shown). Neither Caribbean nor Atlantic wave regressions show any significant cross-equatorial circulation.

5. CONCLUSIONS AND ONGOING WORK

The WRF model has been used to downscale reanalysis data over eight JJAS seasons. The model is able to capture the prevailing climatology and appropriately model the dynamics of easterly waves in the region. Linear regressions of waves in the West Atlantic, Caribbean and East Pacific show noticeably different structure in low-level winds and convective coupling. In addition, the propagation of waves across the region is not associated with constant regions of wave genesis, lysis and/or intensification. These results together suggest the waves are not of a single origin in the region and, more over, they are maintained by differing physical mechanisms across the domain. There is clearly a connection between intra-seasonal variability, such as MJO phase, and the wave activity. In the East Pacific this relationship is complex. Our future work will focus on a better understanding of both the time variability and longitudinal variability of these interactions, as well as conditions which modulate the East Pacific waves which are not attributed to the MJO.

6. REFERENCES

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