3D.8 A CLIMATOLOGY OF CENTRAL AMERICAN GYRES

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1. Introduction

Large low-level cyclonic gyre circulations over Central America (CA) have been observed, but have rarely been studied over the Western Hemisphere. These CA gyres possess similarities to monsoon gyres (MGs) and monsoon depressions (MDs), which are broad low-level closed cyclonic circulations that are commonly found over the western Pacific Ocean (WPAC). These circulations are distinct from tropical cyclones (TCs) due to their exceptionally large radius of maximum winds (> 1000 km in diameter) and relatively diffuse vorticity and convection. Lander (1994) developed the original conceptual model for MGs, indicating that MGs are spatially large (~2500 km in diameter) and associated with asymmetrical convection and vorticity on the south and eastern quadrants of the circulation. From genesis, MGs can last up to two weeks. MDs (Harr et al. 1996, Beattie and Elsberry 2012) are typically smaller in spatial scale (~1000 km in diameter) and have a shorter lifespan (2-5 days). Many MDs beyond this time frame develop into TCs, resulting from more symmetrical, concentrated convection and vorticity near the circulation center.

Previous literature has related heavy rainfall associated with CA gyres as *temporals*, where strong low-level westerly flow associated with a cyclonic circulation over the Caribbean or CA produces upslope precipitation over the higher terrain of CA (Fernandez and Barrantes 1996). No studies, however, have been preformed on the kinematic and thermodynamical characteristics of the CA gyre itself.

More recently, a CA gyre event was observed during the Pre-Depression Investigation of Cloud-systems in the Tropics (PREDICT) field campaign from 23-30 September 2010 (Fig. 1). During this period, several TCs (Matthew, Nicole) interacted with this broad cyclonic circulation. The first TC (Matthew) provided a vorticity source in a large-scale environment favorable for cyclonic vorticity production. The second TC (Nicole) developed from the CA gyre on the eastern quadrant of the circulation over the western Caribbean, where lower vertical wind shear (< 5 m s^{-1}), anomalously high precipitable water (PW; > 55 mm), and warm sea surface temperatures (~30^{o}C) provided a favorable environment for tropical cyclogenesis.

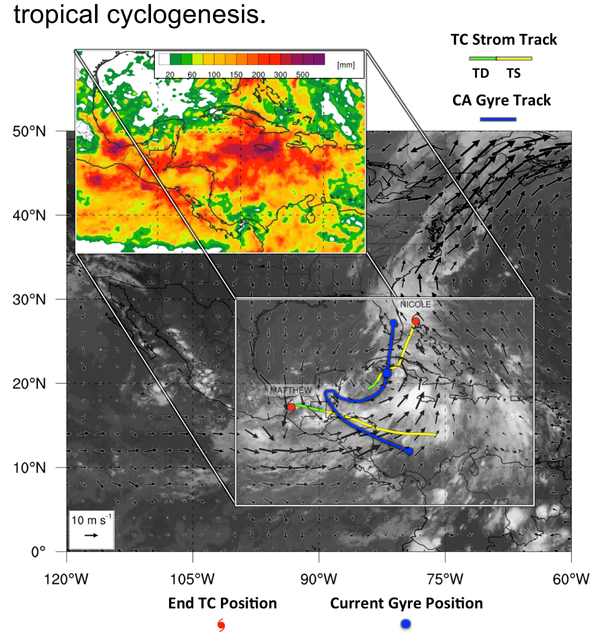

Fig 1. An observed CA gyre from 23-30 September. Plotted is satellite brightness temperature (white shading) and 850 hPa wind vectors (arrows) at 0000 UTC 29 September. TC tracks and CA gyre track from 23-30 September are labeled on top key. Inset is 23-30 September total precipitation (shaded, mm)

The combination of anomalously high PW, a convectively active CA gyre circulation with associated TCs, and strong southwesterly low-level flow equatorward of the CA gyre center produced abundant rainfall in excess of 300 mm over portions of CA, Jamaica, and Cuba (Fig. 1 inset). Given how CA gyres have the potential for significant societal impact, combined with a lack of previous research, there is a need for additional investigations of CA gyres.

To understand the properties and formation characteristics of CA gyres, we will construct a climatology of CA gyres using an objective algorithm. From a set of cases, time-lagged, earth-relative composites will be created to document the atmospheric structure before and during gyre genesis. These gyre composites will be used to determine how TCs are involved with the gyre circulation.

2. Objective Algorithm

An important step necessary for identifying CA gyre events was determining what set of criteria should be used for gyre classification. This research used an objective set of criteria based on prior research in order to construct a climatology of CA gyre events from May-November between 1980-2010 (Fig. 2). The algorithm is broken down into three sequential tests conducted over an area located over CA that are applied at each 6-hour synoptic period using the 0.5 degree Climate Forecast System Reanalysis (CFSR). All tests need to be fulfilled for at least 48 consecutive hours in order for a particular candidate to be classified as a CA gyre.

One variable critical to the development of this algorithm involved using the circulation theorem, which mathematically states:

$$C = \oint \vec{\zeta} \cdot d\vec{l} = \iint_{Area} \zeta \, dxdy \qquad (1)$$

Where C is the circulation and ζ is vorticity, which is integrated counterclockwise around a circular radial to receive positive values of C. The initial circulation magnitude and center test is used to filter out the vast majority of null events, while also providing a gyre center, based on the maximum circulation, that is used to calculate the tangential wind. The azimuthal averaged tangential wind test is most effective at removing large TCs that might fit the size criteria of CA gyres, but possesses an inner core wind maxima that is not characteristic of CA gyre circulations (< 500 km radius). The arc averaged tangential wind test is most effective at removing non-closed cyclonic circulations (such as monsoon troughs), testing to ensure cyclonic flow (> 1 m s^{-1} V_t) is maintained in all quadrants of the gyre candidate.

3. Climatology Statistics

Over a 31-year period (1980-2010), 42 gyre cases were identified. Figure 3 shows the seasonal distribution of CA gyre cases (Fig. 3a) alongside a horizontal map of genesis location (Fig. 3b). A strong bimodal distribution of cases by month exists, with two peaks of CA gyre activity, one peak in May-June, and a second peak in September-November. Little gyre activity is observed during the mid-Summer in July and August. A possible explanation for this limited activity will provide in the next section.

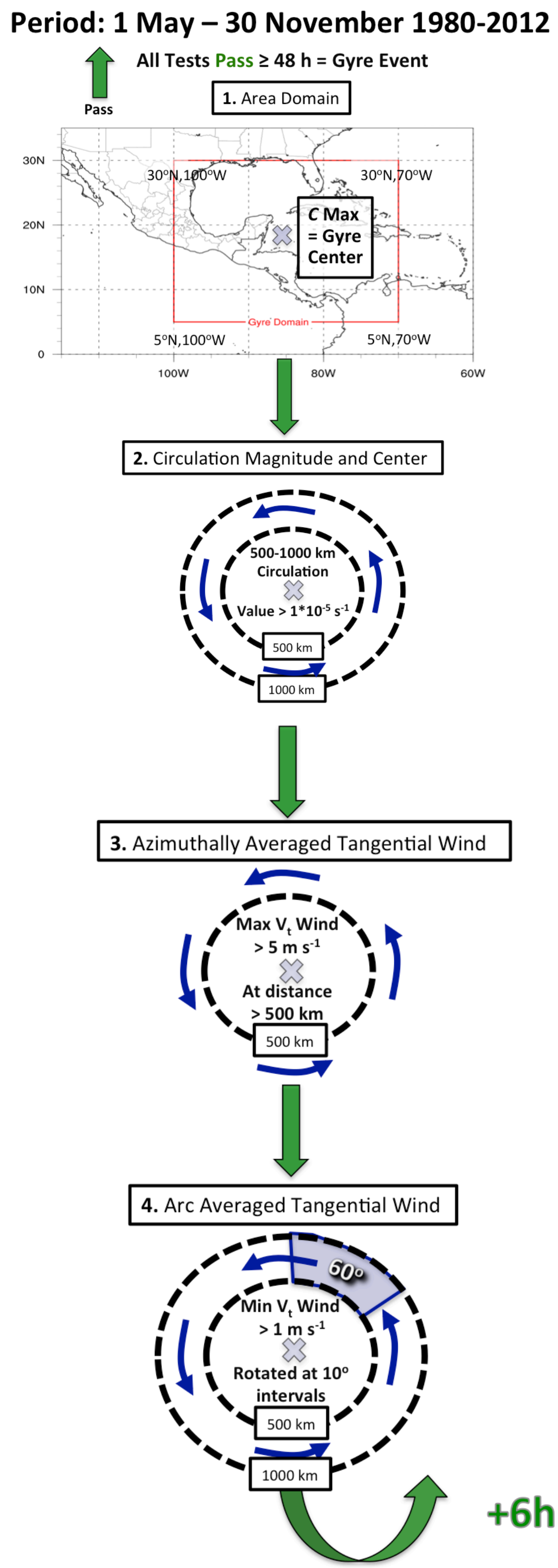

Figure 2. Flowchart illustrating the series of tests used in the CA gyre identification algorithm. V_t represents tangential wind.

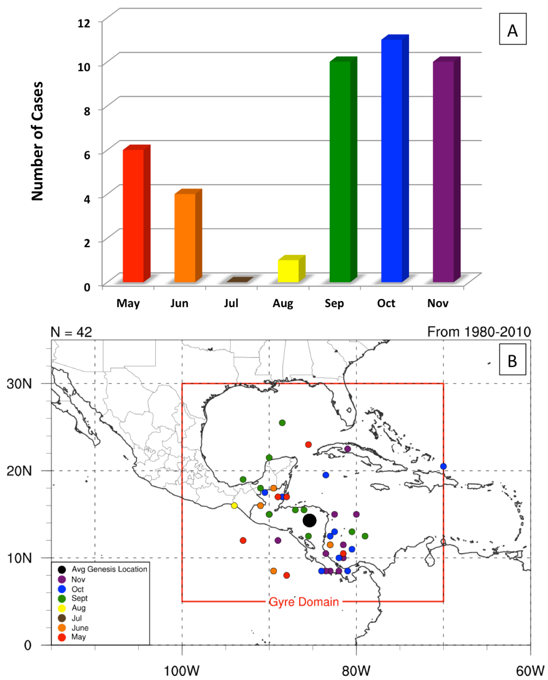

Figure 3. Seasonal distribution of CA gyre genesis events by month for a) histogram showing total number of cases each month and b) horizontal plot depicting genesis locations colorized for each month. The large black dot represents mean position of all CA gyre genesis events.

4. Antecedent Conditions

Composite analysis using earth relative coordinates was used to identify common characteristics associated with gyre occurrences. We used a time-lagged approach in order to identify the antecedent synoptic environment prior to gyre formation, starting five days prior to gyre genesis (t = -120 h) and then progressing forward in time up to five days (t = +120 h) after gyre genesis. Standardized anomalies were calculated for low-level (850 hPa), upper-level (200 hPa), and precipitable water (PW) composites. For brevity we will focus on the low-level and precipitable water composites.

i) Low-level (850 hPa) composite

Three days before gyre genesis (Fig. 4a) there are already statistically significant standardized positive height anomalies over portions of the Central Pacific. 24 hours before gyre genesis (Fig. 4b) this signal has continued to progress eastward, while statistically significant standardized negative height anomalies begin to appear over the western Caribbean and CA. This pattern is also associated with enhanced westerly flow across a large portion of the East Pacific around 10^{o}N.

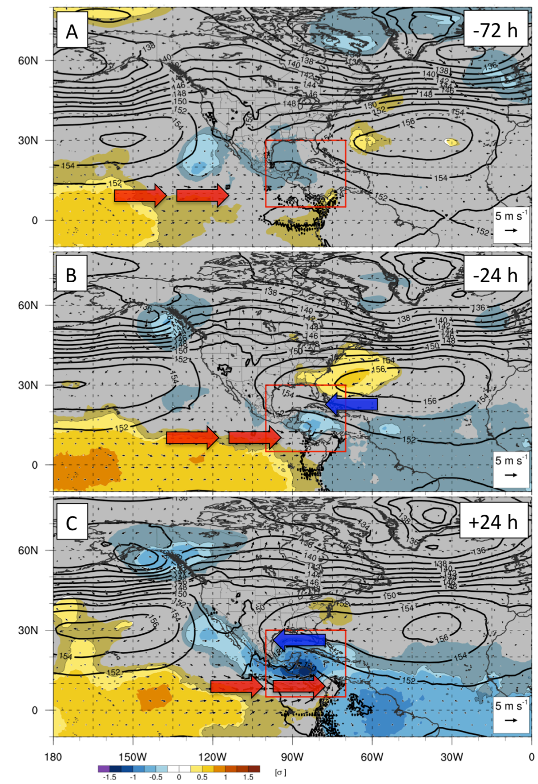

Figure 4. CA gyre time-lagged composites for low-level (850 hPa) standardized anomalous geopotential height (shaded, sigma), gyre mean geopotential height (black contours, dam), and anomalous winds (vectors, m s^{-1}). Highlighted areas are statistically significant to the 95% level.

To the northeast, there is also a statistically significant standardized positive height anomaly just off the southeastern United States in association with an enhanced Bermuda high. The development of this feature aids in the generation of enhanced easterly flow across the Caribbean and western Atlantic. 24 hours after gyre genesis (Fig. 4c), the enhanced westerly flow in the East Pacific and enhanced easterly flow in the Atlantic basin are now juxtaposed at the longitude where CA gyre genesis occurs. This suggests the role that these larger scale wind anomalies play in aiding genesis, where horizontal wind shear gradients poleward and equatorward of CA could provide background cyclonic shear vorticity from which the CA gyre converts to curvature vorticity prior to genesis if the environment is barotropically unstable.

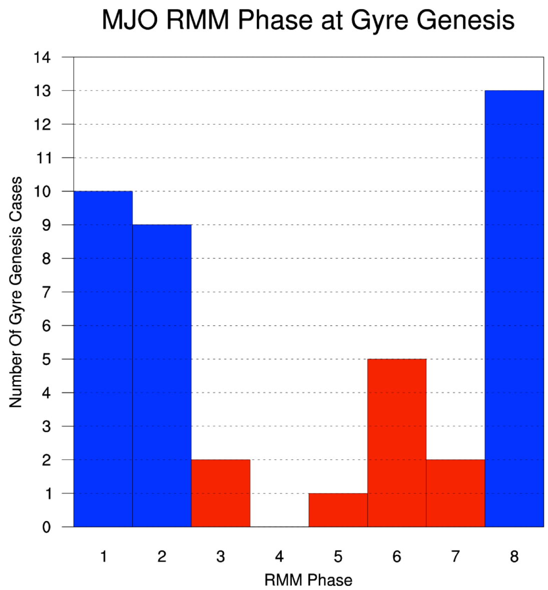

Figure 5. Histogram of CA gyre genesis events binned by the phase of the MJO. Blue bars represent CA gyre events in phases 8,1 and 2 while red bars represent CA gyres that occur in other phases.

Moreover, these low-level geopotential height and wind anomalies in the East Pacific are correlated with specific phases (8,1,2) of the Madden Julian Oscillation (MJO). A simple comparison of the phase of the MJO with the time of CA gyre genesis shows that over 75% of CA gyre events occur in these three phases (Fig. 5). This suggests that the MJO could be modulating the large-scale flow to allow for a more favorable regime for CA gyre formation.

One possible explanation for the lack of CA gyre activity in the mid-Summer months is related to the climatological low-level zonal flow (Fig. 6). On average the magnitude of easterly flow across both the Caribbean and East Pacific increases during July and August (Fig. 6a), limiting the amount of cyclonic shear vorticity generated poleward of this wind maximum. During climatological favored periods for gyre activity (Fig. 6b), these zonal winds relax across the East Pacific and even shift westerly in some locations. Weaker climatological zonal easterlies makes it easier for positive zonal wind anomalies observed in the low-level composite (Fig. 4) to reverse the direction of the climatological flow, enhancing cyclonic shear vorticity on the poleward side of the positive zonal wind maximum.

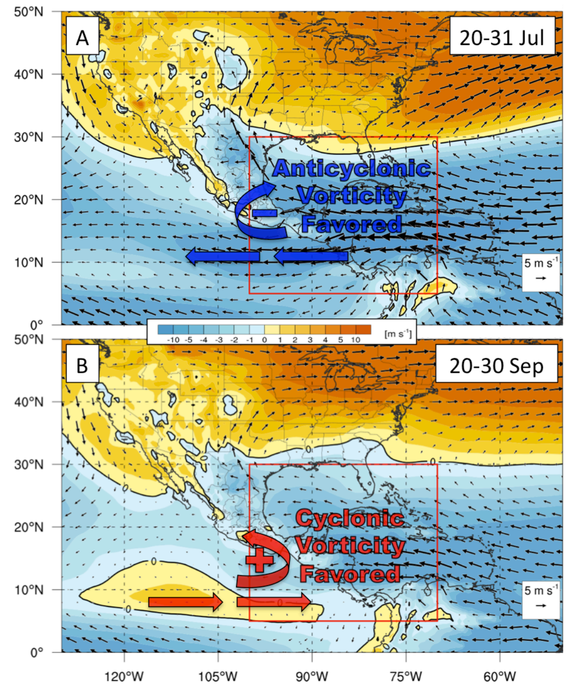

Figure 6. Mean zonal wind values (shaded, m s^{-1}) and total wind vectors (arrows) for a) 20-31 Jul and b) 20-30 Sep. Thick arrows in red (blue) represent positive (negative) zonal flow favoring cyclonic (anticyclonic) vorticity production poleward of max zonal wind magnitude

ii) Precipitable water composite

As mentioned in the introduction, a motivating factor for studying CA gyres is their association with heavy rainfall events over the higher terrain of CA and adjacent landmasses. In the days leading up to gyre formation (Fig. 7 a,b,c) we also see a build up of statistically significant positive standardized PW anomalies in the Western Caribbean. This is likely aided by the confluence of flow observed in the low-level composites (Fig. 5). These PW anomalies continue to grow and expand over CA during and after gyre formation (not shown). As long as there is sufficient forcing, it is likely that these high PW values are contributing to heavy rainfall amounts in gyre events.

5. TCs in proximity to gyre occurrences

TCs are often prevalent in the vicinity of CA gyres. In total 46 TCs were identified within 10 degrees of any given gyre event in the climatology. A preliminary investigation of TC tracks within a gyre-relative coordinates suggests that TCs favor the eastern flank of the

CA gyre and generally rotate cyclonically around the larger flow of the CA gyre (Fig. 8). TC position and motion in CA gyres is roughly consistent with the ideas of Lander (1994) who hypothesized TC formation and propagation occurred in embedded mesovorticies rotating along the south and eastern flanks of gyre circulations.

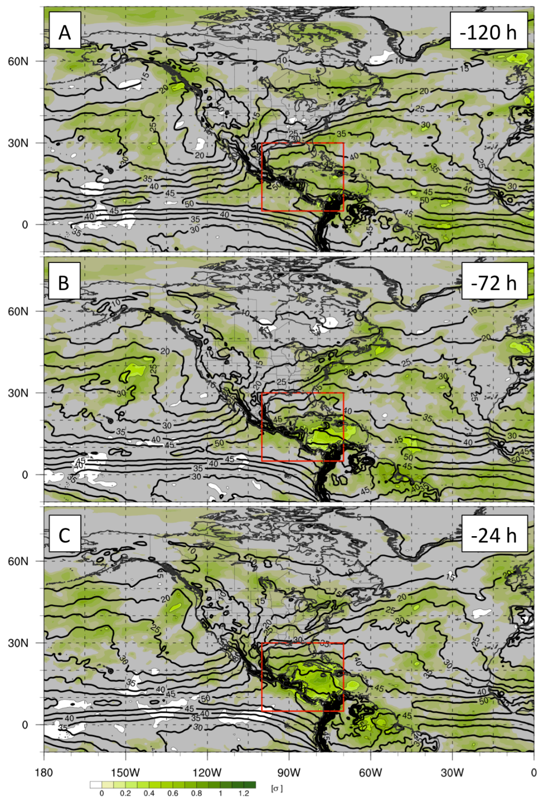

Figure 7. CA gyre time-lagged composites for standardized anomalous precipitable water (shaded, sigma) and gyre mean precipitable water (black contours, mm). Highlighted areas are statistically significant to the 95% level.

Ongoing work is focusing on the dichotomy of CA gyre events, distinguishing events that are more MG-like (possess an upper level trough precursor) versus a MD-like evolution (horizontal shear breakdown into curvature vorticity, transition to TC like structure after a few days). Preliminary results suggest that MD-like CA gyres dominate the climatology, with only a handful of trough-influenced cases (7) appearing. This explains why the composites above bare strong resemblance to a MD-like evolution prior to genesis.

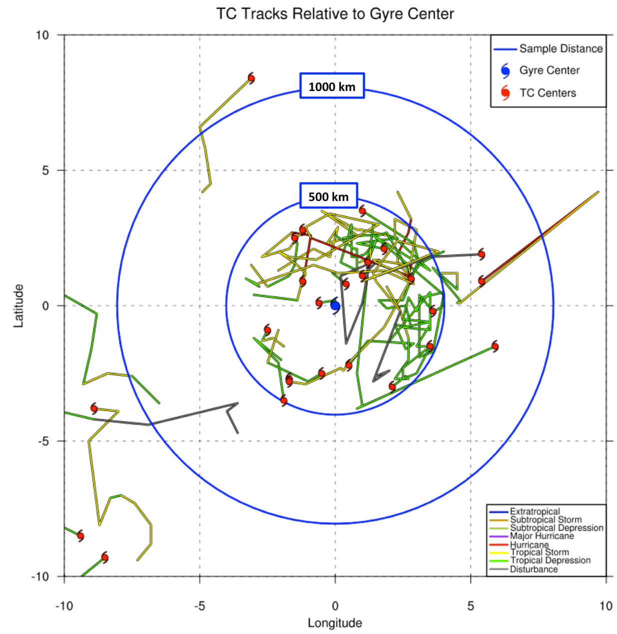

Figure 8. Tropical Cyclone tracks relative to the gyre circulation center.

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