1C.6 THE EFFECTS OF GAP WIND INDUCED VORTICITY ON TROPICAL CYCLOGENESIS

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1. INTRODUCTION

The circumstance under which a Tropical Cyclone (TC) forms is still a highly debated and not well-understood topic within the field of meteorology. One particular feature of tropical cyclogenesis to note is the high density of formation that occurs in the Eastern North Pacific (EPAC) basin. It has been suggested that most of the TCs that form in the EPAC originate from Tropical Disturbances formed in the Atlantic basin or easterly waves that traverse the Atlantic Ocean. In this model, some of the disturbances or easterly waves that did not generate a TC in the Atlantic propagate into the Pacific. This study aims to determine how surface vorticity generated by winds passing through the gaps in the Central American mountains (Figure 1) influences the development of TCs in the EPAC basin and how this mechanism contributes to the previously discussed model.

Many of the previous studies related to this topic have used computer models to investigate how the mountains of Mexico and Central America interact with African easterly waves and the Intertropical Convergence Zone (ITCZ) (Zehnder, 1991; Mozer and Zehnder, 1996). These studies have found that flow incident on the mountains is deflected southward until it reaches the gap in the mountains and is channeled through the Isthmus of Tehuantepec creating a wind jet. Cyclonic surface vorticity is then observed to the north of the wind jet.

Studies conducted by Farfàn and Zehnder (1997) and Zehnder and Powell (1999) used computer models and reanalysis data to look at specific TCs and determine how this jet influenced their development. It was found that if this cyclonic surface vorticity occurs in the presence of an easterly wave or the ITCZ it could lead to the development of a TC. Reanalysis data was also used to complete another case study. Molinari et al. (2000) found that the reanalysis data showed there was enhanced low-level flow through the Isthmus of Tehuantepec that occurred ahead of a 700 mb African easterly wave. However, without any available observational data they could only hypothesize that when the 700 mb wave moved westward into the EPAC, it coupled with the surface cyclonic vorticity generated by the wind jet through the Isthmus of Tehuantepec to initiate cyclogenesis.

These previous studies focus on the gap winds generated through the Isthmus of Tehuantepec and do not consider how gap winds generated over the Gulf of Papagayo may impact tropical cyclogenesis in the EPAC. Also, prior to the launch of QuikSCAT (QSCAT) in 1999 there was not an extensive data set of surface winds over the oceans available to complete an observational study. This study aims to do just that in order to determine if the theories suggested by previous studies can be confirmed from observations of TCs and disturbances over several hurricane seasons.

2. METHODOLOGY

The period of interest for this study is May through November of 2002 to 2008. This period of time was chosen in order to encompass the entire EPAC hurricane season for all, but one, of the years included in the Dvorak Fix Archive (Cossuth, 2010). The Dvorak Fix Archive includes data for all named TCs along with disturbances and invests for each hurricane season in the EPAC basin from 2001 to 2008. Unique system Id code, TC name, fix latitude, fix longitude, fix time, hours prior to cyclogenesis, and Dvorak current intensity number are among the variables included in this data. This information allows for improved tracking of the disturbances prior to classification by the National Hurricane Center (NHC).

Jet Propulsion Laboratory's 12.5 km QSCAT wind product is used to analyze wind and vorticity fields over the eastern North Pacific. SeaWinds on QSCAT is a Ku-band scatterometer that was launched on June 19, 1999 and failed on November 23, 2009. It has an 1800 km wide, single swath and a repeat period of approximately 4 days, providing about twice-daily coverage at a given location (Figure 2). For the area of interest to this study, the Gulf of Tehuantepec has significantly better coverage than the Gulf of Papagayo. Some of the data included in the wind product are time, latitude, longitude, surface wind speed (10 m equivalent neutral), wind direction, and a rain flag.

To begin investigating the impact of the gap winds on tropical cyclogenesis, it is necessary to identify when the gap wind events occur. There are four strengths of gap wind events used in this study. A weak gap wind event is one in which the peak winds in the jet are greater than or equal to 6 m/s and less than 8 m/s. A moderate gap wind event has peak winds greater than or equal to 8 m/s and less than 10 m/s, while a strong gap wind event has peak winds greater than or equal to 10 m/s and less than 12 m/s. Finally, a very strong gap wind event is defined as having peak winds greater than or equal to 12 m/s. A fanlike pattern to the winds must also be present to be classified as a gap wind event.

Determining when these gap wind events occurred also created a climatology of gap wind events for the months of May through November for 2002 to 2008.

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Table 1 gives the climatology of gap wind events for the Gulf of Papagayo and Gulf of Tehuantepec. This table shows that the total number of days with coverage is significantly higher for the Gulf of Tehuantepec than for the Gulf of Papagayo. Also, the majority of the gap wind events fall within the strong or very strong categories for the Gulf of Tehuantepec where as the majority for the Gulf of Papagayo fall within the moderate or strong categories. There are also slightly more days with gap winds than without for both gaps. Previous climatology studies have focused on winter gap wind events. Therefore, the climatology developed by this study will provide a new insight into the summer gap winds in this region.

Once the gap wind events are identified, plots of area-averaged surface relative vorticity are created from the QSCAT winds. The vorticity calculation is adapted from Bourassa and McBeth Ford (2010). This calculation uses the circulation theorem to compute the circulation around a 'shape', which is then divided by the area of the 'shape' to give the area-averaged surface relative vorticity at the center of the 'shape'. The 'shape' used for the area averaging is dependent upon the diameter chosen, which is a multiple of the distance between adjacent wind vectors (12.5 km). A 'shape' with a diameter of 12.5 km would be a square. A diameter of 25 km would give a diamond and the 'shape' would continue to become more circular as the diameter increases (Figure 3). As the 'shape' becomes more circular the random error and noise are reduced in the vorticity calculation. A diameter of 125 km is used in this study. When calculating the circulation about the 'shape', a spline fit is used to interpolate between adjacent good wind vectors. This is a slight improvement to the calculation from Bourassa and McBeth Ford (2010) where a linear interpolation was used. Also, there cannot be too many points missing around the circumference of the shape or else the vorticity is set to missing.

In order to track the disturbances between QSCAT overpasses, Gridded Satellite (GridSAT) Infrared (IR) data is used to track the cloud clusters. The GridSAT IR data is provided via the National Climatic Data Center (NCDC) and has 8 km spatial resolution with 3-hour temporal resolution. It is a composite product of IR data from global geostationary satellites. Tracking the cloud clusters allows for the timing and location of the disturbance to be confirmed in the QSCAT surface vorticity plots.

Tracks from the Dvorak Fix Archive and TC reports from the National Hurricane Center (NHC) also aid in the tracking of these disturbances. The TC reports contain information on the development of the storms along with the times at which any sort of disturbance, such as an easterly wave, may have crossed the Central American Mountains and led to the development of the storm. Using the tracks of the disturbances, the TC reports, and the GridSAT IR data makes it possible to pinpoint the location of the precursor disturbances. Once the locations are known for each time, it is possible to observe whether there were gap winds and cyclonic surface vorticity present. The gap winds are said to have a high impact on the development of the disturbance if they produced cyclonic vorticity that provided the main source of vorticity for the initial disturbance or if the gap winds were present with westerly winds to their south creating the main source of vorticity. A medium impact occurs if the gap winds produced vorticity that contributed to the initial disturbance along with another source not associated with the gap winds. Finally, the gap winds had a low impact on the development if they contributed a small amount of vorticity to the initial source or if they produced vorticity that contributed to an existing region of positive vorticity after development begins.

3. RESULTS

This section will present an example case of the methodology for 2005 Tropical Storm Norma. A summary of the results for all of the cases investigated within the period of interest to this study will then be given.

3.1 *2005 Tropical Storm Norma*

Tropical Storm (TS) Norma was classified as a tropical depression at 00Z on September 23, 2005. Using GridSAT IR imagery, and Dvorak fix locations, the disturbance that developed into TS Norma can be tracked back to Central America where it emerged into the EPAC on September 17, 2005 (Figure 4). At 00Z on September 17, 2005 there was an overpass by QSCAT (Figure 5), revealing that strong gap winds over the Gulf of Papagayo were present at the same time that the disturbance was entering the EPAC. Surface vorticity calculated from this swath shows that the gap winds created a region of positive vorticity that can subsequently be tracked in the QSCAT overpasses (Figure 6). At 12Z on September 18, 2005 there was an overpass of the disturbance by QSCAT that also reveals the presence of very strong gap winds over the Gulf of Tehuantepec (Figure 5) that appear to have contributed additional positive vorticity to the disturbance (Figure 6). Due to the fact that there was no other initial source of positive vorticity, besides that produced by the gap winds, when the disturbance first entered the EPAC it is determined that the gap winds over the Gulf of Papagayo had a high impact on the development of the surface vorticity of TS Norma. The gap winds over the Gulf of Tehuantepec created vorticity that contributed to the development of TS Norma after the initial surface vorticity was created and thus had a low impact.

3.2 *Summary of Results.*

Table 2 gives the number of storms (TCs and invests) that had low, medium, high, or no impact from the gap winds over the Gulf of Papagayo for each year in this study. The total number of storms that occurred each year is also given along with the total number of storms that had low, medium, high, or no impact on their development by the gap winds. Overall, 75 of the storms had some level of contribution to the surface vorticity by the gap winds over the Gulf of Papagayo. The majority of these storms that were impacted by the gap winds over the Gulf of Papagayo fell within the medium and high impact categories. There were 116 storms, including storms that had insufficient coverage to determine whether gap winds impacted the development, over the seven years included in this study that were determined to have not been impacted by the Papagayo gap winds.

Table 3 gives the same information for the gap winds over the Gulf of Tehuantepec as Table 2 gives for gap winds over the Gulf of Papagayo. The Tehuantepec gap winds impacted the development of 41 storms during the period of this study. The majority of these 41 storms had a low impact by the gap winds over the Gulf of Tehuantepec. It was determined that 150 storms were not influenced by the Tehuantepec gap winds, including the storms that did not have adequate coverage by QSCAT to determine the impact by the gap winds.

4. CONCLUSION

It is found that positive surface relative vorticity generated in association with gap wind events through the Central American Mountains contributes to the formation of TCs in the EPAC. Based on tables 2 and 3, gap winds over the Gulf of Papagayo contribute more to the development of EPAC storms than gap winds over the Gulf of Tehuantepec. These tables also show that the majority of the storms impacted by Papagayo gap winds fall within the medium or high impact categories whereas those impacted by Tehuantepec gap winds fall in the low impact category. The larger influence by the gap winds over the Gulf of Papagayo is a new result that has not been observed in the EPAC prior to this study. Previous studies have focused on the influence that Tehuantepec gap winds have on cyclogenesis in this region and not how Papagayo gap winds influence it. It is hypothesized that the proximity of the Papagayo gap winds to the ITCZ may be the reason that they appear to have a larger influence on cyclogenesis in the EPAC. However, further research, such as a model study, is needed in order to confirm this hypothesis.

While the gap winds appear to have an impact on cyclogenesis in the EPAC it is difficult to say how large this impact is. Due to the number of storms that fall within the low and medium impact categories, for both gap wind regions, it appears that cyclogenesis is due to the gap wind induced low-level vorticity combining with a large-scale feature such as an easterly wave or the ITCZ. Further research into the influence of the ITCZ and two possible null cases is currently being conducted to solidify the results of this study.

5. REFERENCES

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6. ILLUSTRATIONS AND TABLES

	Gulf of Papagayo	Gulf of Tehuantepec
No Gap Wind Days	474	689
Weak Gap Wind Days	72	33
Moderate Gap Wind Days	211	93
Strong Gap Wind Days	266	329
Very Strong Gap Wind Days	29	303
Total Gap Wind Days	578	758
Total Days	1052	1447

Table 1: Climatology of gap wind events for the time period of May through November of 2002-2008 for the Gulf of Papagayo and Gulf of Tehuantepec. Shown is

the number of days that the different strengths of gap wind events were observed over this time period for each of the gaps along with the total number of days with coverage by QSCAT for each gap.

Year	Low	Medium	High	None	Total Storms
2002	2	8	4	12	26
2003	3	3	8	20	34
2004	2	7	4	16	29
2005	1	6	3	15	25
2006	0	7	4	20	31
2007	1	1	3	15	20
2008	0	7	1	18	26
Total	9	39	27	116	191

Table 2: Summary of the number of storms (TCs and invests) that gap winds over the Gulf of Papagayo had low, medium, high, or no impact on their development, for each year in this study. The total number of storms for each year along with the total number of storms that had low, medium, high, or no impact by the gap winds is also shown.

Year	Low	Medium	High	None	Total Storms
2002	8	2	0	16	26
2003	4	1	2	27	34
2004	5	1	1	22	29
2005	6	0	0	19	25
2006	2	2	0	27	31
2007	1	0	0	19	20
2008	3	3	0	20	26
Total	29	9	3	150	191

Table 3: Same information as Table 2 except for gap winds over the Gulf of Tehuantepec.

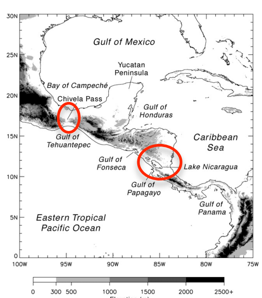

Figure 1: Topographical map depicting the mountain gaps in the Central American Mountains (Chelton et al. 2000). Red circles indicate the mountain gaps of interest to this study.

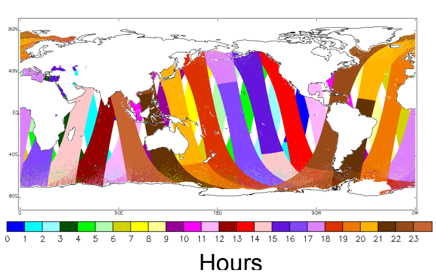

Figure 2: Example of the daily coverage by QSCAT. (MA Bourassa, personal communication, 2010)

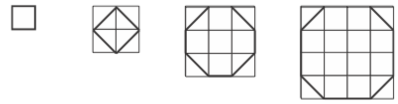

Figure 3: ‘Shapes’ for diameters of 12.5 km (left), 25 km (middle left), 37.5 km (middle right), and 50 km (right). The bold lines show the perimeter of the ‘shape’. (Bourassa and McBeth Ford, 2010)

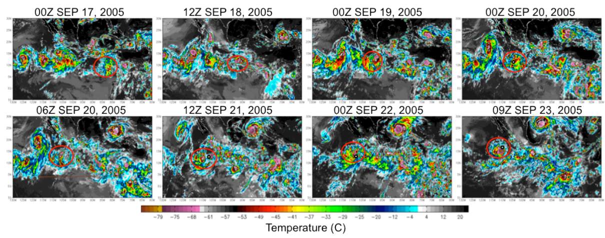

Figure 4: GridSAT IR imagery showing the progression of the disturbance that developed into 2005 Tropical Storm Norma. Red circles indicate the location of the disturbance at each time shown. White circles outlined in black indicate the Dvorak fix location of the disturbance for times that fix locations exist.

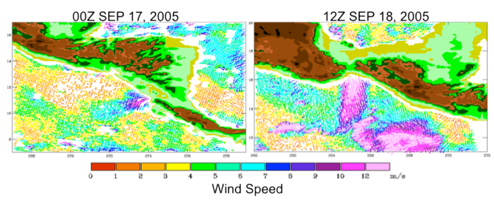

Figure 5: Plots of wind vectors displaying the gap wind events that influenced the development of 2005 Tropical Storm Norma. Strong gap winds over the Gulf of Papagayo occurred on September 17 (left) and very strong gap winds over the Gulf of Tehuantepec occurred on September 18 (right).

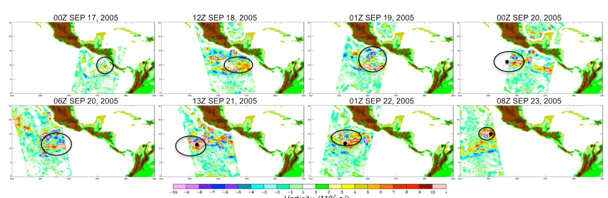

Figure 6: Swaths of surface vorticity from QSCAT showing the progression of the vorticity that can be tracked as the disturbance develops into 2005 Tropical Storm Norma. Black circles indicate the location of the disturbance based on the GridSAT IR imagery while black dots indicate the Dvorak fix location of the disturbance for times that fix locations are available.