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AUTOMATED DETECTION OF GAP WIND AND OCEAN UPWELLING EVENTS IN CENTRAL AMERICAN GULF REGIONS

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1. INTRODUCTION

Low level atmospheric wind jets are events that result from the interaction between large scale atmospheric systems and local orographic effects. Wind jets can have significant regional climate impacts and occur in various locations globally, over both land and ocean. One example of a wind jet that flows out over the ocean is the Tehuano. This is a gap wind that is triggered by cold air outbreaks that originate over the Great Plains of North America. The pressure differences across the Chivela Pass, a narrow gap in the Sierra Madre mountain range, cause high wind speeds in excess of 20 m/s. This gap wind jet extends out into the Gulf of Tehuantepec and beyond into the Pacific. (Steenburgh et al. 1998, and references within).

Strong wind jets can also produce associated cold water ocean regions by triggering intense vertical mixing of the ocean, a phenomenon referred to as ocean upwelling. With cold water upwelling, warm surface water is pushed by the wind jet away from the coast and deep cold water and nutrients rise to the surface. This process significantly changes the regional nutrient distribution and the local ecological environment.

Low level wind jets and their impacts have captured the attention of scientists as well as commercial fishing and military interests since more has been recently learned through the use of satellite data to study these often unique, remote, regional winds. Early satellite images identified ocean upwelling in this region (Stumf, 1975; Clarke 1988; Legeckis, 1988), but more was learned about the Tehauno gap wind using the NSCAT scatterometer launched in 1996 (Bourassa et al., 1999, Chelton et al., 2000).

Recently, Brennan et al. (2010) produced a 10-year climatology of gale- and storm-force Tehuano wind events using QuikSCAT ocean surface wind speeds and directions. They used a thresholding technique to detect gap wind events with thresholds set at 34 and 48 knots for gale-level and storm-level events accordingly. They compared their results with those derived using operational models. The resulting climatology contained 119 gale- and 64 storm-force events observed for the cold seasons (Oct to May) from 1999 to 2009, resulting in an average of 11.9 gale-force and 6.4 storm-force events per cold season. These wind events were determined using the 25 km QuikSCAT winds. When 12.5 km winds became available after 2003, they found the average number of storms increased from 6.4 to 8.1. per cold season.

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funded project. One of our goals is to demonstrate how remotely sensed satellite data derived products can be used in an automated fashion to locate regional events. In particular, we are developing an automated intelligent algorithm to detect gap wind and associated ocean upwelling events globally. In this paper, we present our work in the gulf regions of Central America. In addition to the Tehauno, our analysis includes the winds flowing through the Nicaraguan Lakes region into the Gulf of Papagayo and the gap wind flowing through the Panama Canal area into the Gulf of Panama. We are using the Cross-Calibrated, Multi-Platform (CCMP) ocean surface wind product and the Optimally Interpolated Sea Surface Temperature (OISST) product in our analysis. The method of automated detection presented here differs from the Brennan et al. study in that the 25 km CCMP wind product is produced using a 4D variational analysis of both radiometer and scatterometer winds, and therefore the data set extends from 1987 to the present and likely captures the gap wind climatology with better accuracy. Also, we are looking at associated cold water upwelling with these events. Although our focus area for this paper is over Central America, the algorithm has been developed to be generalized, and is easily configurable for use in studying other wind jets, including the Somali Jet and the Greenland Tip Jet.

In Section 2, the CCMP and OISST data products are briefly introduced. The automated event detection algorithm is described in Section 3. The developed algorithms are applied to 12 years of CCMP and OISST data from 1998 to 2009 and Section 4 shows the results. Section 5 summarizes this research work.

2. DATA

The CCMP ocean surface wind data product was created using a 4D variational analysis method (VAM) to combine wind measurements derived from SeaWinds on QuikSCAT, SeaWinds on ADEOS-II (Advanced Earth Observation Satellite), AMSR-E (Advanced Microwave Scanning Radiometer for EOS on Aqua), TRMM TMI (Tropical Rainfall Measuring Mission's Microwave Imager), and both SSM/I (Special Sensor Microwave/Imager) and SSMIS (Special Sensor Microwave/Imager Sounder) on DMSP satellites. See Atlas et al (2011) for further details on the CCMP product. The data set is distributed at http://podaac.jpl.nasa.gov/ by the NASA Physical Oceanography Distributed Active Archive Center and contains a consistent data record of global high resolution (25 km) ocean surface winds for the period July 1987 through 2010. This study uses the Level 3.0 First-Look (FLK) data set that contains 6-hourly gridded VAM analyses for 0, 6, 12 and 18 Z. For this analysis, twelve years of CCMP data, 1998 to 2009, were analyzed over Central America. We use the reduced period because SST data are also analyzed and satellite SST measurements did not start until 1998 with the launch of TRMM.

The microwave (MW) OISST product is produced by Remote Sensing Systems (http://www.remss.com/sst/) using TMI and AMSR-E SST measurements. TMI spatial coverage is 40N to 40S latitude and AMSR-E has near-global coverage. The spatial resolution of the OISST product is 25 km. These optimally interpolated satellite SST measurements are diurnally corrected and represent a daily 12 noon SST. We use data from 1998 to 2009 in this study.

3. EVENT DETECTION ALGORITHM

A low-level wind jet is a current of air that moves significantly faster than its surroundings. If we consider a CCMP wind field as a two-dimensional image with each image pixel containing wind speed and direction at a given Earth location, a wind jet is normally identified as an elongated region with cross-stream width significantly narrower than the along-stream distance. Wind jets are regional features that often occur within relatively data sparse regions, near coasts, and are sporadic in nature and intensity. Also, the wind direction of a wind jet is limited to a small range of directions dictated by the local topography. These characteristics are useful for distinguishing wind jet events from larger synoptic-scale wind patterns. We use a thresholding method to detect the wind jets. For global thresholding, all pixels with intensity greater than a predefined threshold are marked and a region growing method is used to group these marked pixels into regions. The mean wind direction for a region is then calculated. If the mean is within the predefined direction range expected for the wind jet, the detected region is considered a candidate wind jet event. Although the method is simple, the selection of the threshold wind speed for wind jet definition is a big challenge due to the varying wind speeds possible. If the wind speed threshold is set too high, the wind jet may not be detected. On the other hand, too low a wind speed threshold may identify a region significantly larger than the actual wind jet. To overcome this problem, hierarchical thresholding is used instead of single-value global thresholding. Minimum and maximum thresholds are pre-determined for wind jets over a particular region of interest, based on typical wind jet intensity in the area. Also, minimum and maximum sizes of wind jet regions are specified so that events of neither undersized nor oversized regions are identified.

Hierarchical thresholding is an iterative process. It starts with a minimum speed threshold and iteratively increases the threshold. At any threshold value, if an event is detected but the region size is larger than the maximum region size allowed, and the current threshold is less than the maximum speed threshold, the thresholding process proceeds with an increment in the threshold. Through this iterative process, only regions with strongest wind speed (core wind jets) are detected. A detected region is further validated as a wind jet. A wind jet region is characterized by a high wind speed compared to its surroundings. Therefore, two reference points are pre-defined which are on opposite sides, but out of the known wind jet region. We only detect and label winds as a wind jet event if the mean speed value of the candidate wind jet is larger than that at two reference locations by some pre-determined amount, currently set at 2.0 m/s.

An ocean upwelling event, if triggered by a wind jet, is identified as a significant SST decrease over the wind jet region and often occurs within 24 hours of the onset of a wind jet event. To identify ocean upwelling, the SST difference image is calculated by subtracting the current day's SST image from the previous day's SST image. Only detected wind jet regions are examined for ocean upwelling events. A hierarchical thresholding method is applied to the SST difference image with a minimum threshold set as 0.5°C. The final SST upwelling region is that whose size is smaller than a predefined maximum size. A reference SST value from a point outside the region is selected to validate that the cooling SST within the region is due to an ocean upwelling event. An SST region is considered the onset of ocean upwelling event when the following criteria are met: 1) the mean SST decrease over the region is more than 0.6°C, 2) the maximum SST decrease is more than 1.0°C, 3) the difference between the reference SST value and the mean SST value over the region is greater than 1.0°C, and 4) the difference of the reference SST value and the minimum SST value over the region is larger than 2.0°C. Once the onset of ocean upwelling is identified, it may terminate when either the wind jet event ends, or the mean SST value is higher than the one before the ocean upwelling event occurred.

Although the intensity of a wind jet event is consistently strong over the period of its lifetime, there may be some time steps when jets are not detected due to a short-term weaker intensity which interrupts the continuity of the detected event series. Therefore a post-processing step follows the wind jet detection process. The post-processing step takes the same hierarchical thresholding method with lower minimum speed threshold and applies it to adjacent time steps in which wind jet events were detected. This way we can reduce the potential of gaps in a wind jet event time series.

Scientists visually identified wind jet events over the Gulf of Tehuantepec for 2008, which were used to help develop this automated algorithm as well as the algorithm parameter selections. The developed algorithm was validated by visually inspecting the algorithm-detected events using the QuikSCAT satellite wind product over all three Central American regions of interest: the Gulf of Tehuantepec, Gulf of Papagayo and Gulf of Panama. The results show that the algorithm properly detects the wind events in these regions.

4. RESULTS

The mountain gaps in the Sierra Madre Mountains result in three wind jet and ocean upwelling areas in Central America. They are located at the Gulfs of Tehuantepec (A), Papagayo (B), and Panama (C). Figure 1 shows the CCMP surface wind field over Central America on March 27, 2008. The three bounding boxes A, B and C define the regions where gap wind and ocean upwelling events occur. Gap wind events clearly appear in all the three regions on this example day. The developed event detection algorithm was applied to these three restricted areas. Figure 2 shows a close-up view of region A. Points P and R in Figure 2 are the two reference points used in the algorithm to validate wind jet events. R also happens to be the SST reference point for validating ocean upwelling. The minimum wind threshold in regions A and B is set at 6.0 m/s. The threshold for region C is set at 5.5 m/s, to account for the general lower intensity of wind jets in the Panama gap. The maximum wind threshold for all three regions is set at 10.0 m/s. In the post-processing step, the minimum wind threshold is lowered to 5.0 m/s. The minimum region size of detected events is 8 pixels which approximately represents an area of 0.75° x 0.75°. Figure 3 shows the detected wind jets over the three regions for March 27th, 2008. The strongest wind jet was at the Gulf of Papagayo which had an intensity of greater than 11 m/s. The resulting ocean upwelling events, which lasted for several days in Gulfs of Tehuantepec, Papagayo and Panama started on March 20, March 21 and March 27 respectively.

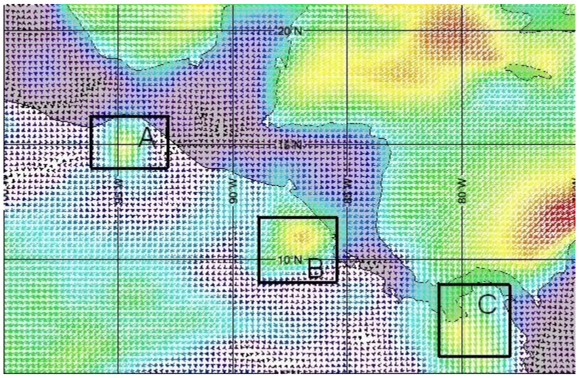

Figure 1: CCMP surface wind field on March 27, 2008

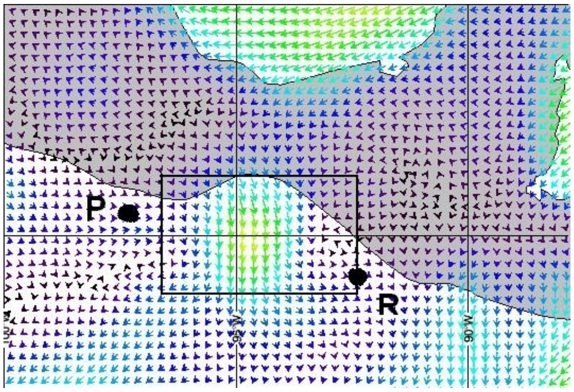

Figure 2: Close-up view of region A from Figure 1. P and R are the reference points used to validate the gap wind. R is also SST reference point to validate the ocean upwelling.

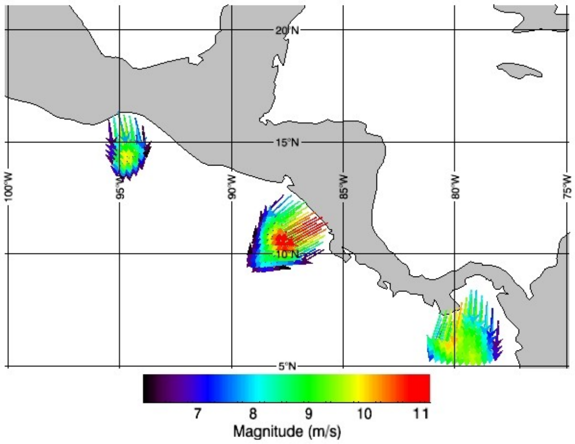

Figure 3: Detected wind jets on March 27, 2008

Figure 4a shows a difference image of the OISST products for March 19 (before all the upwelling events) and March 27 (during the upwelling events). The white pixels indicate land area. The bright pixels over oceans indicate a significant decrease of SST on March 27 as compared to the SST on March 19. On the contrary, dark pixels indicate an SST increase. The strong ocean upwelling events are clearly shown in all three regions as bright areas (SST decrease). Figure 4b shows the detected regions of ocean upwelling using the algorithm.

A number of parameters are calculated for each wind jet event detected. The parameters include date and time of the event, maximum and mean wind speed as well as wind direction, central latitude, longitude and area of the detected region. If an accompanying ocean upwelling event is detected, SST parameters are also calculated, including the maximum, minimum and mean SST decrease over the SST event region, the mean and minimum SST values, the central latitude, longitude as well as the area of the region. The SST value for the reference point is also recorded.


(a) (b)

Figure 4: a) SST difference image between 03/19/2008 and 03/27/2008, b) detected ocean upwelling regions

A wind jet/ocean upwelling event can last from hours to days in duration, and as a result, is represented as a time series at all time steps. Statistics on the event time series improves our understanding on the wind jet/ocean upwelling phenomena and their impacts. Yearly statistics are calculated, including the number of wind events detected, the mean and maximum intensity of wind jets, the number of days that a wind jet persists, the number of gale-scale and storm-scale wind events, the monthly distribution of wind jets, the monthly distribution of gale- and storm-scale wind jets, the number of SST events, the maximum and mean decrease in SST due to upwelling, the minimum wind intensity that triggers SST events, the mean wind intensity for SST events, and the monthly distribution of SST events.

Figures 5 and 6 show the yearly statistics of the mean speed of the wind jets detected and the number of wind event days by year for 1998 to 2009. As expected, the Gulf of Tehuantepec has the strongest gap wind events of the Central American sites, with mean wind intensity over 12 m/s while wind events over the Gulf of Panama are the least significant among the three regions with a mean intensity of little more than 9 m/s.

Figure 6 shows that there are more wind jet events over the Gulf of Papagayo than over the Gulf of Tehuantepec and the number of wind jet event days are significantly less over the Gulf of Panama. Figure 7 shows the maximum decrease of SST due to ocean upwelling events over the three regions. The maximum decrease of SST is largest over the Gulf of Tehuantepec, corresponding to the stronger wind jet events as compared to the other two regions. The largest decrease in SST is near 12°C.

5. Summary

An automated wind jet and ocean upwelling detection algorithm which detects wind jet and ocean upwelling events using CCMP wind and OISST products has been developed and tested as part of the DISCOVER project. The algorithm successfully detects both wind and SST events over the Gulf regions in Central America. The algorithm is designed to be generic and can be easily extended to detect events in other regions through proper parameter selection. Twelve years of CCMP and OISST products from 1998 to 2009 are processed to obtain climatology of gap wind and ocean upwelling events in Central America. The results show that the strongest gap wind and upwelling events occur over the Gulf of Tehuantepec while the Gulf of Papagayo possesses the highest number of gap wind event days per year.

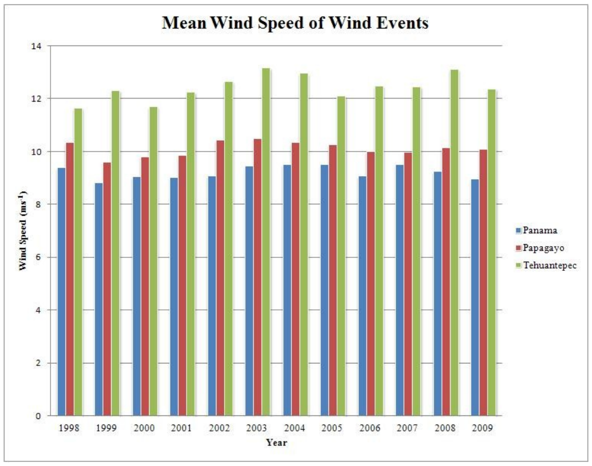

Figure 5: Yearly statistics of the mean speed of wind jets from 1998 to 2009 over the Gulfs of Tehuantepec, Papagayo and Panama.

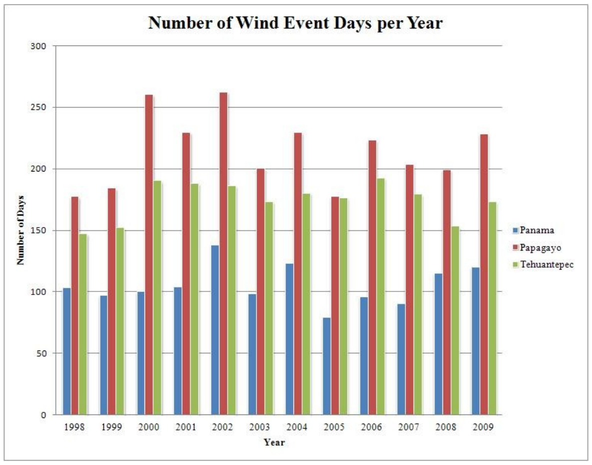

Figure 6: Yearly statistics of the number of wind jet event days from 1998 to 2009 over the Gulfs of Tehuantepec, Papagayo and Panama

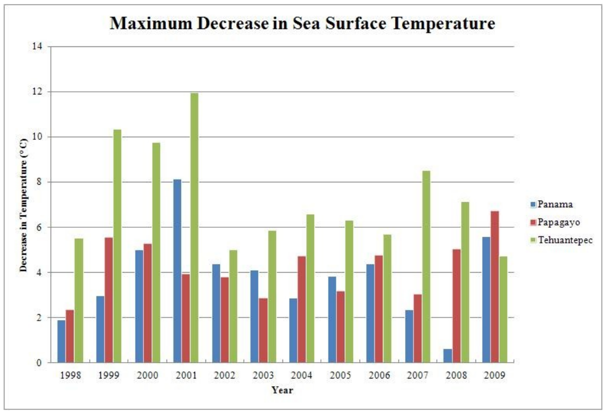

Figure 7: Maximum decrease of SST from 1998 to 2009 over the Gulfs of Tehuantepec, Papagayo and Panama.

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