

Method for Detecting Wind and Cold Water Upwelling Events from Satellite Data

This document describes the method by which we locate regional wind features and associated cold water upwelling events in satellite microwave data. We define a 'gap wind' as the flow of air at high speed through breaks in mountainous terrain. This is a type of wind jet, a regional wind feature that is dependent on terrain. In the cases presented in this document, the gap winds flow through three mountain gaps of the Sierra Madre Mountains. The winds flow in a direction from the Gulf of Mexico and the Caribbean Sea to the Pacific Ocean. The study locations are named for the geographic areas of outflow, where the gap winds meet the ocean. From north to south, these three locations are called the Tehuantepec, Papagayo and Panama.

In this study, we use two satellite data sets, winds over the ocean and sea surface temperatures (SSTs). The winds are from the Cross-Calibrated Multi-Platform ocean surface wind product (CCMP, Atlas et al, 2011). The CCMP data are created using a four-dimensional variational analysis to incorporate satellite microwave wind speeds, *in situ* wind observations and winds from a medium-range weather model. These wind speeds and directions are on a 0.25 degree Earth grid and are available four times daily (0, 6, 12, and 18Z) from 1988 to 2011. The SST data are the OI SST data set from Remote Sensing Systems (Gentemann, et al., 2006). This product is created using SSTs from TMI, AMSR-E and WindSat measurements using an optimal interpolation technique. These daily SSTs are also provided on a 0.25 degree Earth grid and are available from 1997 to present.

The goal of this work is to automatically identify episodes of high winds blowing from the land out over the ocean and evidence of cold water upwelling at the ocean surface often associated with these wind events from the CCMP and OI SST data products. The local gap winds over the Gulfs of Tehuantepec, Papagayo and Panama in Central America occur primarily in the winter months with highly variable frequency. A 'wind event' or 'SST event' is the term we use for a single episode of high winds or SST cooling. The wind and SST events can last anywhere from hours to days, with the temporal length, spatial pattern and intensity varying greatly between these three study locations. The cold water upwelling occurs when the high speed gap winds blow the warm surface waters away from the coast and colder, deep water rises to the surface. This cold water warms slowly over time, often resulting in several upwelling events merging together. The temporal resolution of the data used in this study affects our ability to detect events of short duration. However, the more climatologically interesting events are detectable using the satellite data as they are often quite strong and last for many days to weeks.

In this document we present the methodology used to automatically detect the wind and SST events. The gap winds have significantly higher wind speed than winds at neighboring coastal reference points to the side of the region of wind outflow. The same can be said for the cold SSTs, and we utilize this characteristic in order to better detect the wind and SST events. We also take advantage of the specific geographical patterns of these events. For instance, strong gap winds exist as elongated bands of high

winds that extend quite far into the East Pacific Ocean and have wind directions in an expected narrow range. The shape of the cold water is often similar to the region covered by these high winds.

Method for Gap Wind Detection

The goal of our work is to develop an automated means of identifying the location, shape, size, and intensity of the gap wind events in the CCMP ocean wind data. Since CCMP data are organized into 6-hourly maps, we must first determine whether gap winds are present in each CCMP map and then carefully combine these outcomes to determine the temporal and spatial extent of the gap wind event. A trained scientist can fairly easily identify the presence of a gap wind in one satellite map and can also identify the start and end of the event by examining successive maps. However, transferring what the human can easily do to an automated identification method is not a simple task. The methodology we used to automatically identify gap winds from the satellite-based CCMP data includes several steps as described below. We first identify whether gap winds exist in individual 6-hourly wind maps as described in Steps 1 through 6 and then we combine these individual map results to determine the temporal and spatial extent of a particular gap wind event as described in Step 7.

We chose to use a thresholding method to locate gap winds within wind maps. Thresholding is a simple image processing technique. Two-level or binary thresholding applies a threshold value to partition image pixels into two sets with one set having pixel values larger than the threshold value and the other having pixel values equal to or smaller than the threshold value. In our application, a properly selected intensity threshold should allow us to correctly identify a high wind region in a wind map since we aim to identify regions with the strongest wind speeds. However, we found that since the strength of gap wind events vary, this threshold value is time dependent and differs for all wind maps. Therefore, the threshold value is determined based on the wind conditions of each map.

Many thresholding algorithms exist to automatically determine an optimum threshold based on image contents. One class of algorithms determines the optimum threshold using measures such as class variances (Otsu, 1979) and histogram entropy (Kapur et al., 1985, Abutaleb, 1989). These algorithms are referred to as global thresholding since only one threshold value is calculated as optimum and then applied to the entire image. The Otsu algorithm determines the optimum threshold that minimalizes within-group variance and maximizes between-group variance. We applied the Otsu algorithm for gap wind identification but the results were not satisfactory. The optimum threshold values using the Otsu method were generally lower than what are required to identify the wind jets. As a result, larger wind regions were identified, which contained some less significant winds. We are not surprised by this result as the optimum thresholds are determined solely based on image intensity statistics. For gap wind event identification, it is not only the wind intensity but also the feature shape that matters. The shape of a gap wind is typically elongated and aligned with the wind direction.

Hierarchical thresholding is another class of methods used in the processing and analysis of complex image scenes. Instead of using a single global threshold, as described above, hierarchical thresholding algorithms apply a hierarchy of connected processing steps such as iterating over a range of threshold values, to narrow down solution space for optimal solutions. Yang et al. (1996) proposed a hierarchical entropic thresholding algorithm using a histogram pyramid to significantly speed up the Abutaleb global thresholding method mentioned above. Arifin and Asano (2006) applied hierarchical cluster analysis to image histograms to yield better results as compared to the Otsu algorithm. To identify various cloud

features in satellite imagery, Peak and Tag (1994) used a hierarchical thresholding method to segment images and identify complex cloud features. Satellite images were segmented using a range of threshold values. The segments identified at all threshold levels were connected if they were spatially overlapped to build a hierarchy tree. An artificial neural network was then used to help prune the hierarchical tree to determine proper cloud features.

Based on the success of these other hierarchical studies, we adopted a hierarchical thresholding strategy which allows us to apply a range of threshold values to a wind. Our hierarchical thresholding is an iterative process. It starts with an upper bound value ($highTH$) of the threshold range and decreases the threshold value by a certain decrement at each step (currently set as 0.1 m/s), ending when either the lower bound value ($lowTH$) is reached or one or more terminating conditions are met. The $highTH$ and $lowTH$ values are set for each individual map as described in Step 1.

Several conditions are used to constrain the hierarchical thresholding process. For a region to qualify as a gap wind, a minimum wind region size ($minWsize$) is required in order to exclude any trivial occurrences of high winds that may be due to data uncertainty or other meteorological features. A maximum wind region size ($maxWsize$) is also defined so that only the wind jet is detected. Several other factors are also used as constraints, including the shape of the high wind region identified, the wind speed gradients found in the map, any significant changes in size from one step to another, and the detection of multiple regions that merge. To qualify as a gap wind, the wind direction of the identified region must be within a predefined narrow range that is specific to each mountain gap location.

Further details are provided in the following paragraphs describing the steps used in the gap wind identification algorithm. For each of the steps below, we refer the reader to Figure 1 which shows the location of specific regions mentioned.

Step 1: Determine the upper and lower bounds for the hierarchical thresholding technique for an individual map

The upper bound ($highTH$) of the thresholding range is calculated as the maximum wind speed for the expected gap wind initiation region, shown as the black box close to the coast in Figure 1. The $lowTH$ value is determined using the following four conditions:

The $lowTH$ must be:

- a) No less than the location-dependent minimum speed threshold $minTH$ value, which is empirically-defined for each of the three locations in the study (e.g. set as 7.0 m/s for Tehuantepec). The $minTH$ value is preset to guarantee the minimum strength of a gap wind event.
- b) No less than the calculated Otsu threshold value using the wind data in the $SmallArea$, illustrated as black bounding box in Figure 1. The $SmallArea$ is close to the gulf where gap winds initiate. Using data in the $SmallArea$ ensures us that if a favorable wind pattern is observed in this area, it is most likely a gap wind event.

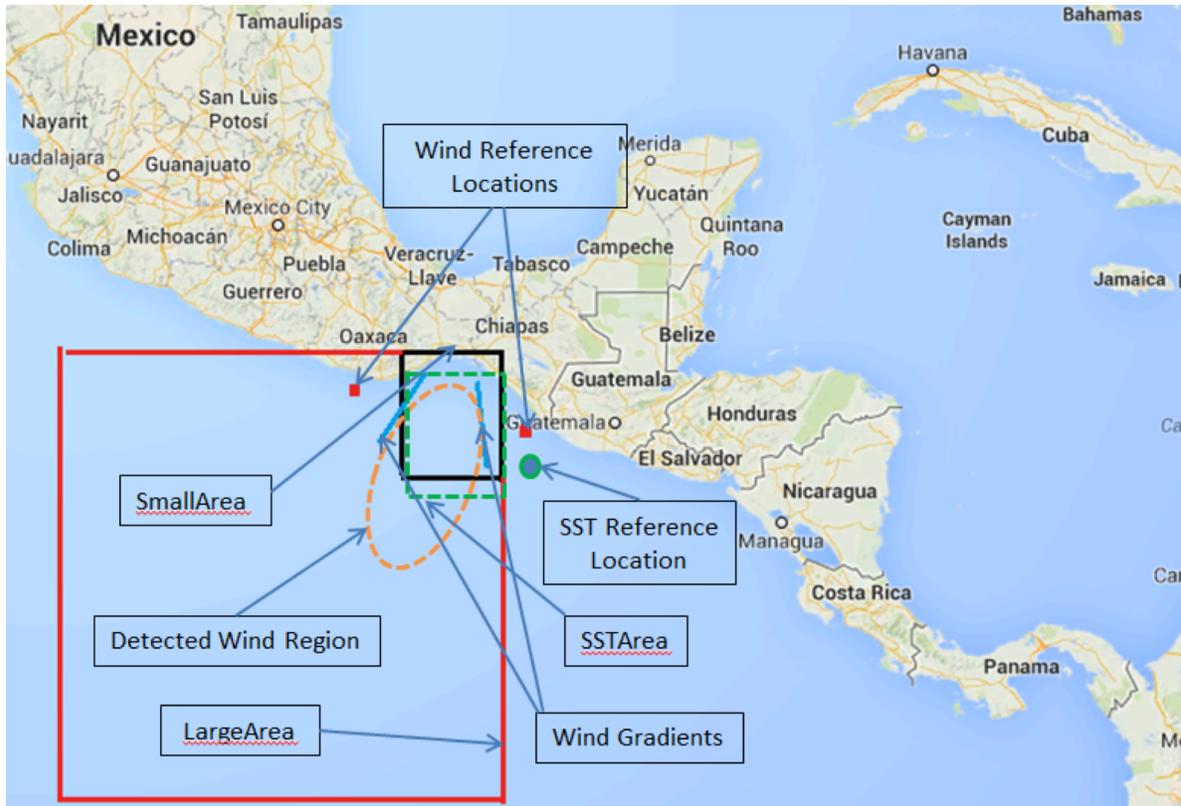


Figure 1: Illustration of sample regions and reference points used in the analysis of gap wind and SST events in Gulf of Tehuantepec.

- c) No less than a value 2.0 m/s higher than the highest wind speed at the two reference locations (red squares in Figure 1). The winds at these reference locations represent neighboring wind conditions outside the expected gap wind region. We expect the detected winds to be stronger than the winds on either side of the wind jet.
- d) No more than 9.0 m/s. Wind field data suggest that for the three gulf study locations, a lowTH of 9.0 m/s is high enough for most gap wind identifications except for a few very strong events such as gale-scale (≥ 34 kt) and storm-scale (≥ 48 kt) gap wind events. As a result, we set the upper limit of the lowTH at 9.0 m/s. In the extreme situations of strong events, the lowTH value is adjusted as explained in Step 3 below.

Step 2: Detect steep wind speed gradients

We expect significant changes in wind speed (high wind gradients) near the boundaries of a gap wind. By using an edge detection algorithm, we identify the wind gradient edges in each map. We use the Canny Edge Detection algorithm [Canny, 1986] which is a well-known image processing algorithm to detect edges in images using a multi-step process. The Canny method produces a number of edge segments. If a gap wind exists in the map, the largest edge segments will exist near the gulf mouth where the high winds blow offshore from the mountain gap. The edge information is then used as a constraint to the thresholding process (Step 3). We find that optimal gap wind identification occurs when the gap wind boundary meets the strongest speed gradients, as illustrated in Figure 1, in which

the two blue lines represent the wind speed gradient locations and the orange oval represents the identified gap wind region.

Step 3: Perform hierarchical thresholding to locate a gap wind region

In this step, we perform the hierarchical thresholding to identify gap winds within individual CCMP maps. Wind gradient information from Step 2 and several other constraints are used as terminating conditions for the hierarchical thresholding process.

The thresholding process starts with the highTH value obtained in the SmallArea where gap winds initiate (black box in Figure 1). In subsequent steps, the threshold is lowered by 0.1 m/s until the one of the constraints are met or the lowTH value is reached.

We begin the detection process in the SmallArea to make sure that if high winds are identified, they are most likely in the expected gap wind region. The detected region size increases with subsequent iterations as the threshold decreases. A minimum of 9 grid cells in the SmallArea is required in order for the process to transition to the large area. This requirement prevents spurious or trivial high winds from being falsely detected. A grid cell in the CCMP map covers an Earth surface area approximately 0.25 degree latitude by 0.25 degree longitude.

Once the detected area for an iteration step exceeds 9 grid cells within the SmallArea, the hierarchical thresholding process then begins for the LargeArea and continues until the entire region is identified as determined by ending conditions. We expect the largeArea, which encompasses the smallArea shown in Figure 1, to contain most of the gap wind. The largeArea for each study location was defined by looking at years of gap wind events in satellite data for each study location. The lower bound of the threshold range for the hierarchical thresholding over the LargeArea remains the lowTH value determined in Step 1, except for cases of strong gap winds. If the current threshold value at the point at which we switch from SmallArea to LargeArea is 5.0 m/s higher than the lowTH value determined in Step 1, we expect we are identifying an extremely strong gap wind and we therefore alter the lowTH value to be 5.0 m/s less than the current threshold.

The hierarchical thresholding process continues until one or more of the following conditions listed below are satisfied. When a condition is exceeded, the gap wind region from the previous iteration is captured. If the size of the resulting region is larger than the minWsize, then wind event is identified. Otherwise, no gap wind is in the map.

- 1) The threshold value reaches the lowTH and the hierarchical threshold process is complete.
- 2) The size of detected gap wind region is larger than the maxWsize allowed (e.g. set at 300 grid cells for the Tehuantepec).
- 3) The detected gap wind region meets the high wind speed gradient lines located in Step 2.
- 4) The detected gap wind region is 'irregularly' shaped. We expect the shape of a gap wind to be elongated, so we use a simple shape factor ($4\pi \cdot \text{area} / \text{perimeter} \cdot \text{perimeter}$) to calculate the shape at each step. If the shape factor is less than 0.7, we expect the region to be of irregular shape, thereby stopping the process.
- 5) The size of the detected region significantly increases (doubles) with respect to the previous iteration. We expect that small threshold changes will slightly increase an area. If the area greatly changes, some other larger-scale feature has been identified.
- 6) The ratio of the eigenvalues of the Principle Component Analysis (PCA) over the detected region decreases by 1.5 times as compared to the ratio at the beginning of the hierarchical thresholding process (i.e., the start at LargeArea). The PCA eigenvalue ratio approximately

- characterizes the elongated shape of a detected region. A significant decrease of the ratio suggests a significant shape change as compared to the region in the first step. This shape measure is applied to further safeguard the shape constraint required for the detected region.
- 7) Either the number of regions identified decreases (indicating region merging) or increases (indicating region splitting).

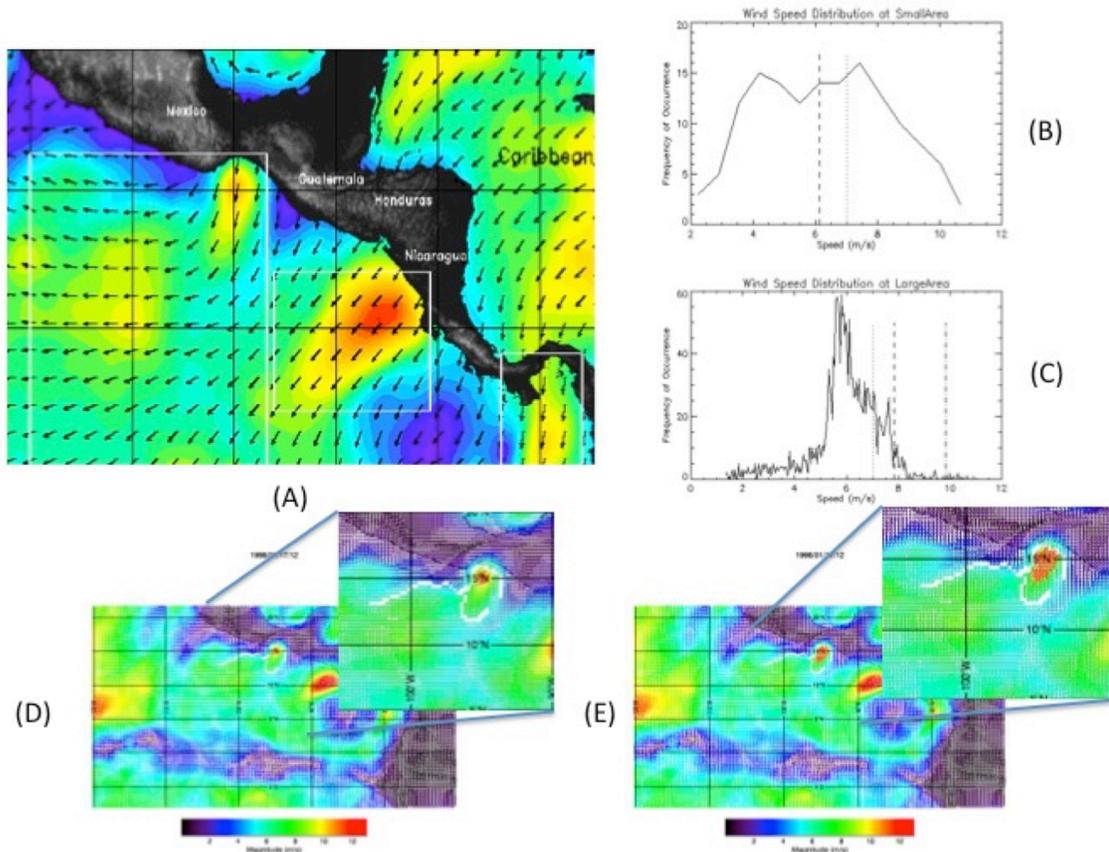


Figure 2: (a) CCMP wind map on January 17, 1998 at 12Z, (b) & (c) wind speed distributions in the SmallArea and LargeArea respectively, (d) wind region detected in the SmallArea with threshold of 9.8 m/s, and (e) the final gap wind region detected in the LargeArea with threshold of 7.8 m/s.

We demonstrate this thresholding process using the plots in Figure 2 for a CCMP map dated January 17, 1998 at 12Z in the Gulf of Tehuantepec. Figure 2-(A) shows the original CCMP wind map. The gap wind is clearly observed in the Gulf of Tehuantepec. Figure 2-(B) shows the wind speed distribution of the grid cells in the SmallArea, a total of 144 grid cells. Two modes (highest frequency occurrences) are shown in the distribution, one at about 7.5 m/s and the other at about 4.2 m/s. The calculated Otsu threshold is 6.13 m/s and is represented as a vertical dash line in the plot. The wind speeds at the two wind reference locations are 2.27 m/s and 1.91 m/s, respectively. As a result, the lowTH determined in Step 1 is 7.0 m/s (shown with a dotted line). The minTH is preset for the Gulf of Tehuantepec and is shown as the vertical dotted line at 7.0 m/s. Figure 2-(C) shows the wind speed distribution of the grid cells in the LargeArea, a total of 2162 grid cells. The majority of wind speeds are around 6.0 m/s. The lowTH is still

represented as a dotted line. The highTH value, the maximum wind speed in the SmallArea, is 10.82 m/s. The white line segments in Figure 2-(D) and 2-(E) are the edges of wind speed gradients calculated using the Canny algorithm in Step 2.

In this example, hierarchical thresholding starts at 10.82 (highTH), the high end of speed distribution in the SmallArea. It decreases the threshold value by 0.1 m/s for each step. After 10 steps at 9.8 m/s, as shown in dot-dash line in Figure 2-(C), a total of 10 grid cells are detected with wind speeds higher than 9.8 m/s which exceeds the required 9 grid cells for area transition. The 10-cell detected region is shown in Figure 2-(D) in dark red. The region is inside the high gradient line segments. At the threshold of 9.8 m/s, the hierarchical thresholding is now applied to the LargeArea. After another 20 steps, the hierarchical thresholding process ends with a final threshold of 7.8 m/s. Figure 2-(E) shows the final detected region in dark red. The hierarchical thresholding process ends as the detected area expands to meet the northern wind speed gradient segment. The final threshold is shown as a dashed line in Figure 2-(C).

Step 4: Post processing of identified gap wind region

To smooth the potential irregularity of the wind jet boundary detected in Step 3, the convex hull of the area is used to replace the detected area. Common image morphological open and close operations (Gonzalez and Woods, 1992) are further applied in sequence to smooth the boundaries and to fill any potential small holes that may exist in the detected wind region.

Step 5: Apply wind direction criterion

For the identified region to qualify as a gap wind event, the mean wind direction has to be within the pre-defined minimum and maximum wind direction angle range. The expected wind direction range for each study location was determined using years of observed gap wind events in satellite data. The wind direction range for the Tehuantepec example is between 200 and 310 degrees.

Step 6: Calculate wind statistics for the gap wind region

Statistical properties of the grid cells in the identified gap wind region are calculated and recorded. These values include: maximum wind speed, mean and standard deviation of the wind speeds, mean and standard deviation of wind directions, region area, and mean latitude and longitude of the detected region. The recorded values are used for web site display.

Step 7: Combine maps to generate gap wind events

In this final step, we combine results from the individual 6-hr CCMP maps to determine the temporal extent of a gap wind event. Gap wind events in these regions typically vary in duration, from as short as a single map (6-hours) to as long as multiple weeks. While our intention is to identify the longer, stronger wind events that generate greater SST upwelling events, some strong short-duration events can also exist that cause cold water upwelling, so it is important to identify these as well.

We record all the identified gap wind events that last for at least three successive wind maps (a total of 18 hours or more - referred to as 3-map events). Shorter gap wind events that have notably high wind speeds are also recorded. Relatively weak and short events referred to as 1-map events (6 hours) or 2-map events (12 hours) are also examined to determine if they need to be merged with previous or subsequent events. The following are the steps we used to determine the temporal extent of the gap wind events.

First we identify 1-map, 2-map and 3-map events in the wind event record as generated in Step 6. We then examine all the data to identify any maps for which a gap wind event was not identified but the map exists temporally next to a 2-map or 3-map event. For all of these maps, if the wind speed at a map is strong (no less than 8.5 m/s at Tehuantepec) and the wind direction is within the preferred wind direction range for the given location, then the map is combined with its adjacent event to form a long-duration event (3-map). We do so assuming that some short-lived influence suppressed detection of the event in the single map, as explained below. Figure 3 shows the diagram for this merging process in Tehuantepec. We also apply a number of rules to connect shorter (1&2-map) duration events into longer ones.

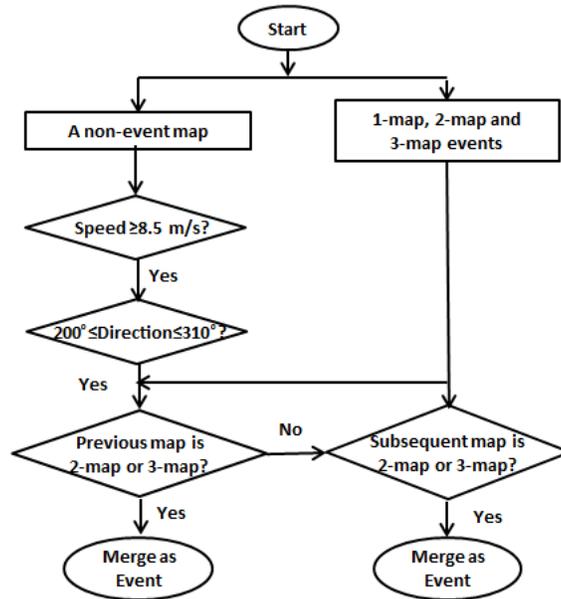


Figure 3: diagram showing the steps for a non-event map to merge with event maps in Tehuantepec.

Wind is a highly variable geophysical parameter and is especially variable in the Central American gulf regions as local-scale coastal winds (i.e. land/sea breezes) increase or decrease the regional winds (gap winds) observed. Night-time land breezes blow offshore in the same direction as the gap wind. However, daytime sea breezes blow onshore, opposite the wind jet momentum and therefore can result in a lower CCMP wind. The local daytime breezes (10 am to 8pm) occur during the 18z and 0z CCMP maps for this geographic longitude. As a result, winds in these maps may appear lower than our threshold even though a wind jet is blowing in the region. In these circumstances, the algorithm fails to identify the wind event due to the local sea breeze effect. We have therefore developed a series of rules to handle 1-map events and recover the long duration events that would have been identified if the local sea breeze patterns had not existed. As a consequence, only the true very short duration weak events are excluded from the gap wind climatology.

- a) If a 1-map event is found to be separated in time from a multi-step event by only 6 hrs, and the wind speed at the interim map is over a pre-defined threshold value (e.g. 5.0 m/s for the Tehuantepec) and it's wind direction is within the location's preferred wind direction range, both the 1-map event and the unidentified interim map are merged with the multi-map event.
- b) If a 1-map event is found to be separated by two maps (12 hrs) from a multi-map event and the wind speed for the two interim maps are over a predefined threshold value (e.g. 7.5 m/s for the

Tehuantepec) and their wind directions are within the location's preferred wind direction range, both the 1-map event and the two interim maps are considered part of the multi-map event.

- c) If a 1-map period was not identified as a gap wind event and it is located in between two longer duration (2 or more -map) wind events, the 1-map's wind speed is over a predefined threshold value (e.g. 6.3 m/s for the Tehuantepec) and it's wind direction is within the preferred range, then it, along with the two longer previously detected events are merged into one event. In particular, if the 1-map record is at 00Z and in-between two longer duration events and the wind speed is over 2.5 m/s and wind direction is within the preferred range, it is connected to the two events to form one event.

After performing the combining steps described above, the gap wind statistics listed below are calculated and preserved in the RASI Climatology dataset at the GHRC, and made available for browsing, analysis and download in the GHRC Regional Air-Sea Interactions (RASI) web environment (web URL).

- 1) Wind events with a duration at least 3 maps
- 2) Wind events with a duration of 2 maps and the wind speed for at least one of the maps is relatively strong (9.5 m/s over Tehuantepec)
- 3) A 1-map wind event that has strong wind speed (10.0 m/s over Tehuantepec)

The impact of the event merging and cleaning process at Step 7 was evaluated for the Gulf of Tehuantepec as an example. A total of 531 3-map events were identified in Steps 1-6 from 1998 to 2009. A total of 248 2-map events and 376 1-map events were also identified for the same time period. Of the 376 1-map events, 48 of them were strong and were subsequently merged with adjacent 2-map and 3-map events. An additional 62 1-map events were merged by the steps required to compensate for the sea-breeze effect. After Step 7, a total of 420 3-map events, 147 2-map events and 109 1-map strong events were identified. The numbers of 3-map, 2-map and 1-map events are all reduced through the event merging process.

Method for cold SST upwelling event detection

Gap winds can induce a decrease in SST due to the removal of surface water away from the coast, resulting in deeper cold water rising to the surface. Stronger gap wind events can cause significant SST cooling that may last for days or even weeks before the SST warms to typical regional temperatures. Weaker gap winds are often of insufficient strength or last for too short a time to cause measureable cold water upwelling. SST events, therefore, vary in both duration and intensity. Our detection algorithm needs to not only identify cold-water upwelling in a single daily map, but also to accurately determine the start and end points of an SST upwelling event.

Some of the same methodology developed for the wind identification is employed in the detection of SST cold-water upwelling; however there are some significant differences. The detection of cold-water upwelling is a simpler process than the detection of gap winds, partly because the individual SST maps represent a daily SST rather than the 6-hour time span of the CCMP wind data, and also due to the fact that SST varies less than the surface wind speeds. Although cold water can surface quickly with strong gap winds, the water typically warms slowly after the cessation of the gap wind event. Since a new SST event can begin before the coastal water has returned to pre-event temperatures, we define the end of an SST upwelling event as the time when the temperature "begins to warm" rather than when the SST returns to its original temperature. This prevents several events from merging together and becoming indistinguishable.

Our SST event detection algorithm locates occurrences of significant temperature decrease over three regions. The three regions we examine are located inside the LargeAreas used in the wind detection methodology. The region at the Gulf of Tehuantepec is shown in Figure 1 as a green dashed box and is referred to as the SSTArea. In general, the SST upwelling events originate near the coast where the gap winds are strongest. We restrict the regions for SST event detection in order to prevent identifying episodes of SST decrease due to other synoptic weather systems or to surface water freshening during excessive rain.

We use an SST reference location outside the SSTArea box to represent the neighboring non-event condition. The SST reference location is shown in Figure 1 as a green dot. To consider a start of the SST event, we not only require an observed decrease in SST but most significantly we require the lowSST to be at least 2 degree Celsius lower than the reference location. We do not perform any temporal merging of individual maps as used in the wind detection methodology since SST is much less variable than wind.

The SST event detection algorithm identifies 16 grid cells, within the SSTArea for each study location, that have the largest (most significant) SST decrease to be used for the calculations and comparisons. The SST event detection algorithm involves the following steps.

Step 1: Calculate relevant SST statistics in the SSTArea

To detect the area of cold water upwelling, we subtract the previous day SST map from the current day SST map and calculate the SST change statistics, focusing on the 16 grid cells with the largest SST decrease. We calculate the mean difference value (meanDifSST) and maximum SST decrease (maxDifSST) of the 16 grid cells. The use of 16 grid cells was selected in order to avoid spurious effects, and to accurately estimate the significance of the temperature decrease. The mean SST decrease of the 16 grid cells with the largest decrease is a strong indicator of an SST event. If the SST decrease is larger than a certain value, which we define as the minSSTth, it is very likely that an SST event has occurred. Besides SST decrease statistics (change in SST from previous day), we also estimate the 'coldness' of the SSTArea by calculating the SST statistics of the 16 grid cells with the lowest SST values in the area, including the mean value (lowSST). This mean value (lowSST) indicates how cold the ocean surface is for the day. Though the 16 grid cells used in the low SST and SST decrease calculations may be quite different on non-event days, they are highly related as the cold SST grid cells are essentially caused by the event. No requirement was made that the 16 cells be next to each other, though for SST events, they are expected to be coherent with each other. For each map, the following parameters are calculated and/or recorded:

- a) The mean and standard deviation as well as the maximum and minimum values of the 16 grid cells with largest SST decrease as compared to the previous SST map. The mean latitude and longitude values of these 16 grid cells are also calculated.
- b) The number of grid cells which have an SST decrease larger than the minSSTth.
- c) The mean and standard deviation as well as the maximum and minimum values of the 16 grid cells with the lowest SST values. The mean latitude and longitude values of these 16 grid cells are also calculated.
- d) The SST at the reference location.

The statistics calculated in Step 1 are the important discriminators utilized in Step 2 to identify the beginning of an SST event.

Step 2: Determine the beginning of an SST event

We define the start of an SST event as the day on which grid cells within the SSTArea are identified as having a mean temperature significantly lower than the previous day. How much lower is determined using a threshold value, minSSTth, which is set at 0.5 degree Celsius for all the three regions. The area of the SST event is identified using grid cells with temperature decreases greater than the minSSTth.

All of the following rules are required to be met by a map to qualify as the beginning of an SST event:

- a) The 16-grid lowSST value (calculated in step 1) is lower than 27.0 degree Celsius. This rule is used to filter out some trivial occurrences of SST event in the summer season, and the threshold is empirically defined.
- b) The maxDifSST value is lower than -1.0 degree Celsius.
- c) The meanDifSST value is lower than -0.5 degree Celsius.
- d) The lowSST value is at least 0.5 degree Celsius lower than that in the previous map.
- e) The lowSST value is at least 2 degree Celsius lower than the SST value at the reference location outside of event region, ensuring that the detected region is significantly cooler than its neighboring area.

Step 3: Determine the end of an SST event

The end of the SST event is selected as the map where the lowSST value of the “next/following” map is higher – indicating the SST is beginning to recover to pre-event levels.

Unlike the wind detection methodology, we do not at this time merge single map events that are separated by a single map. We treat such cases as separate SST events as they may be triggered by separate gap wind events. Our goal is to only identify events when the SST drops, not the extended time over which the SST is recovering and warming. Notice that a 1-map SST event is comparable in time span to short gap wind events of 24 hours or less.

Summary

This document presents the wind and SST algorithms used to automatically identify gap wind and SST upwelling events from years of satellite wind and SST data for three gulf regions located in Central America. Hierarchical thresholding along with a number of rules are used to identify gap wind regions from CCMP wind maps. Successive maps in which gap winds are located are then merged to determine the start and end of the entire gap wind event. Cold water upwelling which may be associated with gap wind events are identified from MW OI SST data by locating regions with significant SST decrease as compared to previous day values. The identified SST events end when SST values in the region no longer decrease.

Wind and SST data statistics over the identified regions are calculated, including mean and standard deviation with results available to the public via a specially tailored web environment. The RASI Climatology is maintained at the GHRC and event information can be viewed, analyzed and downloaded at the RASI web interface (<http://ghrc.nsstc.nasa.gov/rasi>).

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Appendix A

Table 1 provides the pre-defined parameters used in the wind and SST event detection algorithms. The parameters are given for the three regions respectively. Table 1 also gives the sizes of the defined LargeArea, SmallArea and SSTArea in all the three gulf regions for reference. The sizes are given as the number of grid cells. The table also gives the wind reference locations and SST reference locations, respectively. The reference locations are given as longitude and latitude pair in degrees.

Table 1 predefined and actual value for the number of terms used in the wind and SST event extraction algorithm.

	Tehuantepec	Papagayo	Pamana
minTH (m/s)	7.0	6.5	6.5

SmallArea	144	64	204
LargeArea	2162	356	425
minWsize	15	15	15
maxWsize	300	200	200
Wind direction range	(200°, 310°)	(190°, 250°)	(225°, 290°)
Wind Reference Location 1	(-97.625°, 15.375°)	(-91.625°, 13.875°)	(-82.875°, 7.875°)
Wind Reference Location 2	(-92.375°, 14.375°)	(-82.875°, 7.875°)	(-77.375°, 6.875°)
minSSTth (°C)	0.5	0.5	0.5
SSTArea	97	70	120
SST Reference Location	(-92.375°, 13.875°)	(-92.125°, 12.375°)	(-82.125°, 6.875°)