Observations of Gulf of Tehuantepec Gap Wind Events from QuikSCAT: An Updated Event Climatology and Operational Model Evaluation

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ABSTRACT

A climatology of gale- and storm-force gap wind events in the Gulf of Tehuantepec is constructed for the first time using 10 yr of ocean surface vector wind data from the SeaWinds scatterometer on board NASA's Quick Scatterometer (QuikSCAT) satellite. These wind events are among the most severe that occur within the National Hurricane Center's (NHC) area of marine forecasting responsibility outside of tropical cyclones. The 10-yr climatology indicates that on average 11.9 gale-force events and 6.4 storm-force events occur in the Gulf of Tehuantepec each cold season. About 84% of these events occur between November and March, with the largest number of gale-force events occurring in December. Storm-force events are most frequent in January.

Operational numerical weather prediction model forecasts of these events from the NCEP Global Forecast System (GFS) and North American Mesoscale (NAM) models were evaluated during the 2006/07 cold season. Results show that neither model is able to consistently forecast storm-force Tehuantepec wind events; however, the models do have some ability to forecast gale-force events. The NAM model showed a significant increase in probability of detection over the GFS, possibly due to increased horizontal and vertical resolutions as well as differences in boundary layer mixing and surface flux schemes.

Finally, the prospects of observing these gap wind events in the post-QuikSCAT era will be discussed.

1. Introduction

The National Hurricane Center (NHC) has high seas forecast and warning responsibility for portions of the eastern tropical Pacific Ocean, including the Gulf of Tehuantepec (Fig. 1). These responsibilities are carried out by NHC's Tropical Analysis and Forecast Branch (TAFB). Gap wind events that occur in the Gulf of Tehuantepec (Fig. 2) are the most frequently observed storm-force (48 kt or greater) wind events that occur outside of tropical cyclones in this region.

The Gulf of Tehuantepec is situated south of the Isthmus of Tehuantepec, the narrowest area of land separating the Gulf of Mexico from the Pacific Ocean (Fig. 2). When cold-air outbreaks occur over the Gulf of Mexico, the Sierra Madres block the large-scale flow of

cold air southward, resulting in the development of a strong north–south pressure gradient across the isthmus. Northerly flow is then funneled through the 40-km-wide Chivela Pass, a narrow break in the Sierra Madres. This gap flow often results in a narrow jet of winds that can reach gale ($\geq$34 kt), storm ($\geq$48 kt), and occasionally hurricane force ($\geq$64 kt) in the Gulf of Tehuantepec, and the gap flow can extend several hundred kilometers downstream.

Previous case studies (e.g., Schultz et al. 1997; Steenburgh et al. 1998; Chelton et al. 2000a,b) and climatological studies (e.g., Schultz et al. 1998; Chelton et al. 2000a) have elucidated the synoptic-scale features responsible for the cold-air surges that drive gap wind events in the Gulf of Tehuantepec. The strongest cold surges into the region are associated with a confluent upper-level jet entrance region situated over the Gulf of Mexico and an upper-level ridge over the western United States, resulting in the equatorward movement of a surface anticyclone of Arctic origin into the Gulf of Mexico (Schultz et al. 1998, their Fig. 14a).

Prior to the advent of satellite-based wind observations, sporadic ship observations provided the only information

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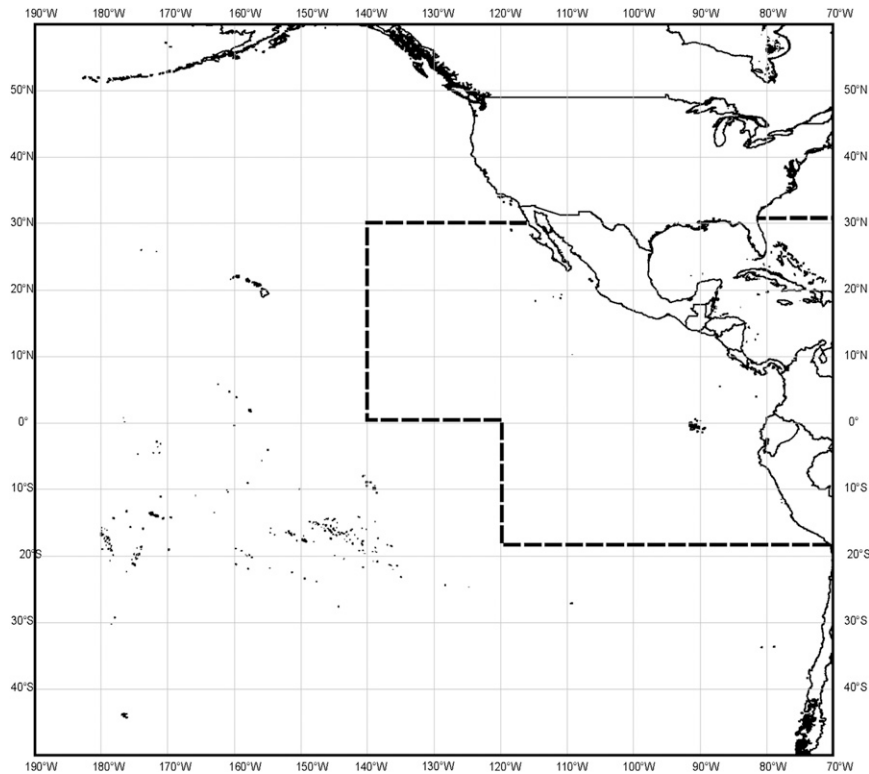E-mail: michael.j.brennan@noaa.gov

FIG. 1. Map showing the east Pacific area of marine forecast responsibility (outlined by the dashed box) of the NHC's Tropical Analysis and Forecast Branch.

on the magnitude of these gap wind events over the open waters of the Gulf of Tehuantepec. With only limited point observations, little was known about the spatial distribution of the strong winds associated with these events. While the appearance of a rope cloud in visible satellite imagery often indicates the leading edge of the cold outflow associated with the gap winds (Schultz et al. 1997, their Figs. 10, 12, and 14; Steenburgh et al. 1998, their Fig. 4), conventional satellite imagery alone cannot provide information on the magnitude of the winds. Chelton et al. (2000a) performed a statistical analysis of gap wind events in the Gulf of Tehuantepec (as well as the Gulfs of Papagayo and Panama) from December 1996 through May 1997, as well as individual case studies, based on ocean surface vector wind (OSVW) retrievals from the National Aeronautics and Space Administration (NASA) Scatterometer (NSCAT). They found more than a dozen "major" Tehuantepec wind events occurred in their study period, while Chelton et al. (2000b) found that midlatitude forcing was more dynamically significant in producing the Tehuantepec gap wind events than those farther south in Papagayo and Panama, which were driven more by tropical forcing.

Since 1999, however, the availability of near-real-time ocean surface vector wind (OSVW) retrievals from the SeaWinds scatterometer on board the NASA Quick Scatterometer (QuikSCAT) satellite has allowed for consistent documentation of the frequency, duration, and intensity (primarily the differentiation between gale- and storm-force events)[1] of Tehuantepec wind events for more than 10 yr.

Near-real-time QuikSCAT wind retrievals have been available at NHC since the fall of 1999, allowing for routine observation of these events and their intensities, the evaluation of operational model forecast performance in these events, and the development of a multiyear event climatology. An initial climatology of Tehuantepec events was constructed by Cobb et al. (2002) based on the first three cold seasons (October–May) of 25-km QuikSCAT retrievals (1999/2000 through 2001/02). Their results showed an average of 15 gale-force events and 2 storm-force events occurred each cold season. The first gale-force event of a season typically occurred in mid-October, with the final gale-force event occurring in late March or early April.

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[1] QuikSCAT data have also been useful in the analysis and warning of gap winds events in the Gulf of Papagayo and Gulf of Panama in NHC's area of responsibility. However, here we will focus on the more frequent and extreme events in the Gulf of Tehuantepec.
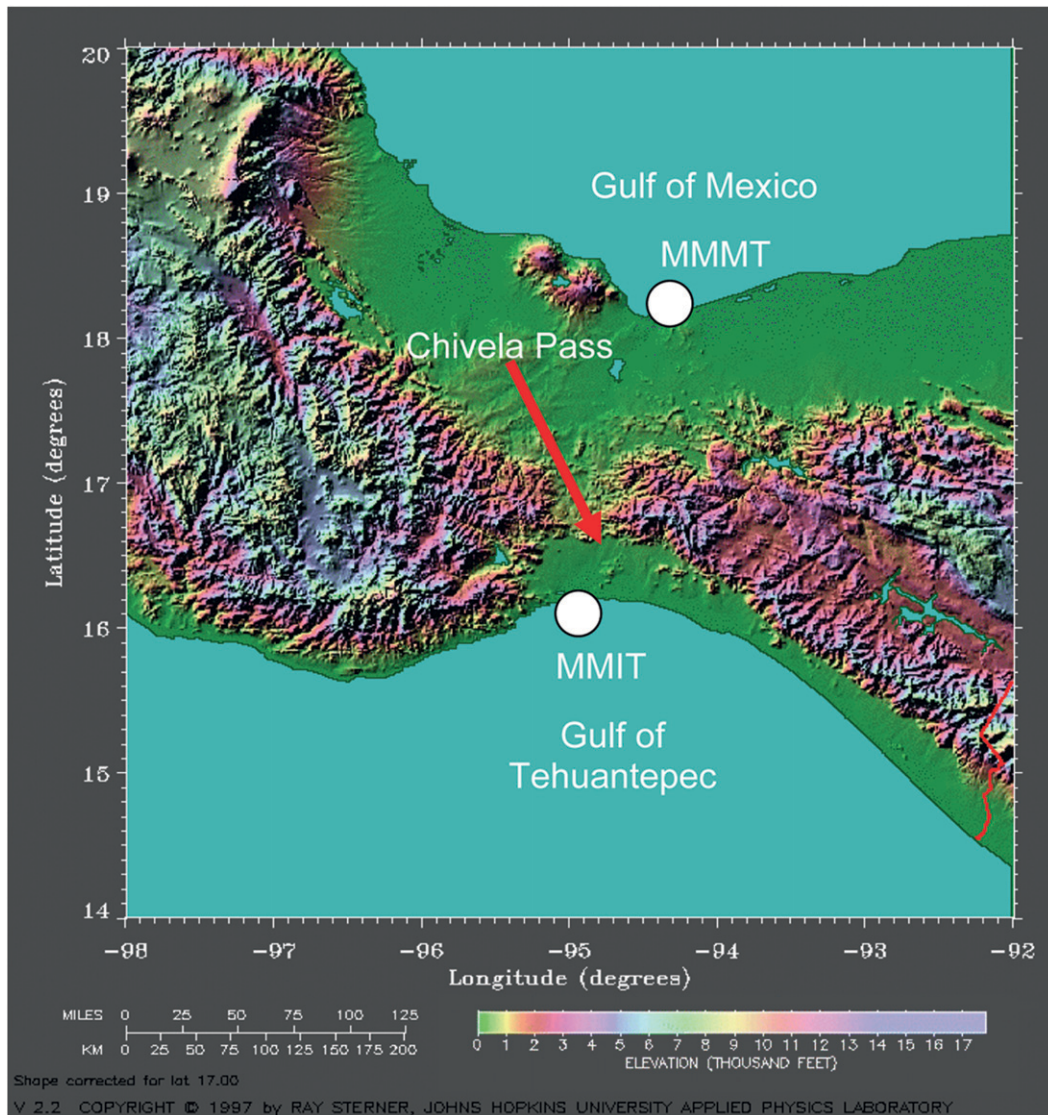
FIG. 2. Topography of the Isthmus of Tehuantepec. MMMT and MMIT mark the approximate locations of Minatitlan and Ixtepec, respectively. (Image courtesy of the Johns Hopkins Applied Physics Laboratory.)

The goals of this study are to utilize the long period of data from QuikSCAT to update the initial climatology of Cobb et al. (2002) and to examine the performance of real-time NWP model guidance available to TAFB forecasters for predicting these wind events during the 2006/07 cold season. A brief description of the scatterometer on board QuikSCAT will be provided in section 2, with the updated event climatology presented in section 3. Section 4 contains an evaluation of the operational NWP model guidance for the 2006/07 cold season. Section 5 will discuss other potential sources of OSVW data for the detection of these events in the post-QuikSCAT era and section 6 will present a summary and conclusions.

2. QuikSCAT description

The SeaWinds scatterometer on board QuikSCAT is a Ku-band scatterometer that estimates OSVW by measuring the backscatter generated by centimeter-scale capillary waves on the ocean surface. QuikSCAT nominally provides wind retrievals with a horizontal resolution of 25 km, and since 2003 near-real-time (NRT) 12.5-km retrievals (Augenbaum et al. 2005) have also been available. The NRT QuikSCAT retrievals available at NHC are processed at the National Oceanic and Atmospheric Administration's National Environmental Satellite, Data, and Information Service (NESDIS) using the NRT retrieval process described by Hoffman

and Leidner (2005). These data are available for display on the National Centers for Environmental Prediction (NCEP) Advanced Weather Interactive Processing System (N-AWIPS) workstations and can be overlaid and compared with myriad other data, including satellite imagery, surface observations, and NWP model output.

QuikSCAT provides wind retrievals in an 1800-km-wide swath, often twice per day, near the Gulf of Tehuantepec. At 16°N (the approximate latitude of the Gulf of Tehuantepec), the gap between adjacent QuikSCAT swaths is approximately 930 km wide, resulting in occasional "misses" when a gap in QuikSCAT retrievals occurs over the region. QuikSCAT passes in the Gulf of Tehuantepec region generally occur within an hour of 0000 and 1200 UTC, which make the data convenient for synoptic analysis and comparison to NWP model output valid at those times.

Confidence in the accuracy of QuikSCAT OSVW retrievals for Tehuantepec gap wind events is high since these events occur in a rain-free environment, eliminating rain contamination as a source of error in the QuikSCAT wind retrievals. Recent measurements of hurricane-force winds in extratropical cyclones in nonraining conditions using the National Oceanic and Atmospheric Administration (NOAA) Stepped-Frequency Microwave Radiometer (SFMR; Uhlhorn and Black 2003) and Global Positioning System (GPS) dropsondes (Hock and Franklin 1999) were in close agreement with collocated QuikSCAT measurements (Chang et al. 2009), confirming that QuikSCAT OSVW retrievals are accurate through the low end of the hurricane-force range in nonraining conditions. Von Ahn et al. (2006) presented composites of hurricane-force extratropical cyclones detected by QuikSCAT in the area of responsibility of the Ocean Prediction Center, and a multiyear climatology of these events is presented by Ahmad et al. (2009). Additional details on scatterometry, including the design and performance of QuikSCAT, are provided by Chelton and Freilich (2005).

3. Tehuantepec event climatology

For each cold season (October–May) from 1999–2000 through 2008/09, all QuikSCAT passes showing winds of gale force or greater in the Gulf of Tehuantepec were cataloged. The classification of an event as "gale force" or "storm force" is based on the peak QuikSCAT wind observed during the event from either the 25- or 12.5-km retrievals. Although the mean duration of a Tehuantepec event is 48 h (Cobb et al. 2002), one or two QuikSCAT passes that "miss" the region could preclude the detection of a short-lived gale-force event, or could result in a storm-force event being erroneously identified as a gale-force event, since the peak winds often only occur during a portion of the overall event.

During the cold seasons (October–May) from 1999–2000 through 2008/09, 119 gale- and 64 storm-force events were observed; an average of 11.9 gale-force and 6.4 storm-force events per cold season. Considering the period since the advent of 12.5-km NRT QuikSCAT retrievals in 2003, the average number of storm-force events detected has increased to 8.1 per season from 2002/03 through 2008/09 because the higher-resolution retrievals are now consistently used to classify events. The yearly count of gale- and storm-force events is shown in Fig. 3. The 2003/04 cold season had the largest number of events reach gale force or greater (24), while the 2006/07 cold season had the most storm-force events (13). The highest number of storm-force events during the 2006/07 cold season occurred during a weak El Niño event. This is consistent with the findings of Romero-Centeno et al. (2003), who showed an increase in the frequency and strength of northerly winds in the southern Isthmus of Tehuantepec during El Niño years, and Schultz et al. (1998), who found that Central American cold surges were more numerous during an El Niño due to a more prominent jet entrance region over the Gulf of Mexico.

The monthly distribution of Tehuantepec events shows that the largest number of gale-force events occur in December (Fig. 4). Storm-force events occur most often in January. Gale-force events have occurred as early as September and as late as May; however, about 84% of all events occur between November and March.

4. Operational model evaluation

TAFB forecasters include forecasts and warnings for Tehuantepec events in a high seas forecast[2] issued 4 times daily (at 0430, 1030, 1630, and 2230 UTC). NWP model guidance available in the region includes various global models, including the NCEP Global Forecast System (GFS). During the 2006/07 season the domain of the NCEP North American Mesoscale (NAM) model was expanded to include the Gulf of Tehuantepec region. This section will show the results of an evaluation of operational model guidance from the GFS and NAM for Tehuantepec events during the 2006/07 cold season.

At the time of this study, the GFS model was run with horizontal spectral truncation at wavenumber 382 (an effective horizontal grid spacing of approximately 40 km) and 64 vertical levels through the first 180 h of the

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[2] These forecasts are available under World Meteorological Organization (WMO) header FZPN03 KNHC.
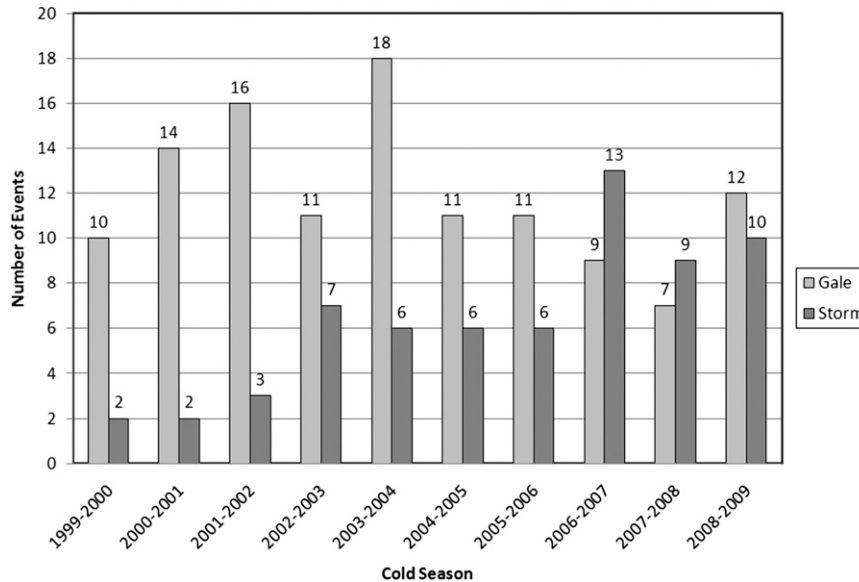
FIG. 3. Annual count by cold season (October–May) of gale- and storm-force Tehuantepec event observed by QuikSCAT from 1999–2000 through 2008/09. Note that 12.5-km QuikSCAT retrievals became available in January 2003.

forecast, while the NAM model was run with 12-km horizontal grid spacing and 60 vertical levels through the entire length of its 84-h forecast. At the time of this study, GFS output was available to NHC forecasters on global 1° grids (approximately 110-km horizontal grid spacing at 15°N), and output from the NAM was available on grids with horizontal grid spacing of approximately 90 km. Also at the time of this study, QuikSCAT data were assimilated into the GFS through the Spectral Statistical Interpolation (SSI) three-dimensional variational data assimilation (3DVAR) scheme. However, the data were assimilated as 1° superobs, and any rain-flagged data were not assimilated, greatly reducing the influence of QuikSCAT data in high-wind areas given the large number of high-wind retrievals that are typically rain flagged. The fact that QuikSCAT data are only available at a single level also reduces their impact on the analysis. While Chelton and Freilich (2005) found that QuikSCAT data improved the 10-m wind analysis of the GFS and the global model of the European Centre for Medium Range Weather Forecasts (ECMWF), the information provided by QuikSCAT is considerably underutilized by both modeling systems as shown in detail by Chelton et al. (2006). QuikSCAT data were not assimilated into the NAM model analysis at the time of this study.

At all times when QuikSCAT data indicated winds of at least gale force in the Gulf of Tehuantepec, the maximum forecast wind speeds from the GFS and NAM (to the nearest 5 kt) were recorded at 12-, 24-, 36-, and

48-h lead times. Table 1 summarizes the number of gale- and storm-force events, as observed by QuikSCAT, when forecasts from each model were evaluated. The maximum QuikSCAT wind speed was taken from gridded analyses of the wind retrievals with $\frac{1}{4}°$ ($\frac{1}{8}°$) grid spacing for the 25-km (12.5 km) retrievals.[3] The probabilities of detection (PODs) of a gale- or a storm-force event (as observed by QuikSCAT) from both the GFS and NAM were computed at 12-, 24-, 36- and 48-h lead times. POD is defined in (1) as the number of hits (H) divided by the number of hits plus the number of misses (M):

$$\text{POD} = \frac{H}{(M + H)}. \qquad (1)$$

A hit is defined as a forecast by the model that correctly identifies the category of wind (gale or storm) observed by QuikSCAT at the verifying time. A miss is defined as an underforecast by the model (i.e., the model forecasts winds below gale force when gale conditions are observed by QuikSCAT).[4]

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[3] At 15°N the spacing between individual points on the $\frac{1}{4}°$ ($\frac{1}{8}°$) grids corresponds to 27 (13.5) km.

[4] A forecast of a gale-force event by a model at a time when QuikSCAT observed storm-force conditions would count as a "hit" in the gale category and a "miss" in the storm category.
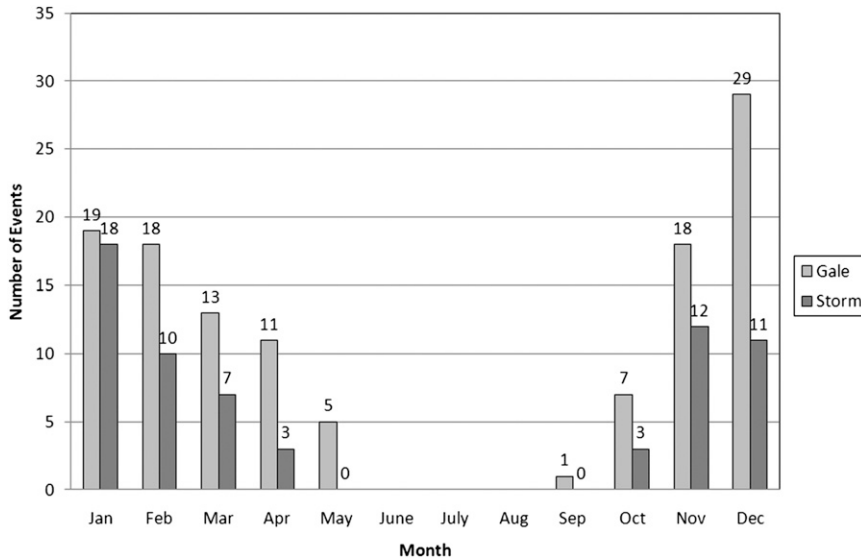
FIG. 4. Monthly count of gale- and storm-force Tehuantepec events observed by QuikSCAT from 1999–2000 through 2008/09.

Model wind forecasts at the 10-m level were evaluated from the GFS and NAM, while winds from the lowest model sigma level in the GFS model ($\sigma = 0.9950$), colloquially referred to as the "30-m wind," were also evaluated (the 30-m winds are frequently examined by TAFB forecasters as they are perceived to perform better in high-wind conditions). POD results presented here have been verified against the 12.5-km QuikSCAT retrievals, the data source used by TAFB forecasters to classify the intensity of Tehuantepec events since 2003.

Results indicate that 10-m wind forecasts from the GFS are unable to predict the occurrence of storm-force Tehuantepec events, with a POD of zero for all lead times (Fig. 5a). The NAM 10-m wind forecasts show some ability to detect storm-force events, with POD values of ~0.16 averaged over all lead times. The 30-m winds from the GFS have the highest POD (~0.19 averaged over all lead times) for storm-force events but still missed more than 80% of these events.

The performance of the NAM and GFS is demonstrated during a long-duration Tehuantepec event from November 2006. This was a strong storm-force event, as indicated by numerous 60-kt vectors in the 12.5-km retrievals from a QuikSCAT pass at 0030 UTC 22 November (Fig. 6). Figure 7 shows 12- and 36-h 10-m wind forecasts from the GFS and NAM valid at 0000 UTC 22 November (30 min prior to the QuikSCAT pass). The GFS (Fig. 7a) shows a maximum wind of 40 kt, at least 20 kt too weak compared to QuikSCAT (Fig. 6). Also, the spatial coverage of gale-force winds in the GFS is too small compared to QuikSCAT. The NAM forecast does indicate a storm-force event, with a single 50-kt wind barb (Fig. 7b).

The NAM also shows a wider swath of gale force winds, in better agreement with the QuikSCAT observations.

Both the NAM and GFS models show more skill in the detection of gale-force events, with POD values of 0.84–0.88 for the NAM 10-m winds at 48-, 36-, and 24-h lead times, decreasing to 0.81 at 12 h (Fig. 5b). POD scores are sharply lower for the 10-m GFS winds, between 0.47 and 0.55, while the 30-m GFS winds have a higher POD, between 0.68 and 0.77.

Interestingly, for both gale- and storm-force events, the POD scores for the NAM model decrease slightly at the 12-h lead time while POD scores for the GFS generally increase at the 12-h lead time relative to longer lead-time forecasts. The reasons for this loss of skill in the NAM as the event approaches are unclear. However, the NAM does not assimilate QuikSCAT retrievals, and this may have a negative impact on the NAM's very short-term forecasts of these gap wind events. Regardless of the reason for this trend, it can result in decreased forecaster confidence as an event approaches and should be the focus of further study.

TABLE 1. Number of GFS and NAM forecasts evaluated for gale- and storm-force Tehuantepec events detected by 12.5-km QuikSCAT during the 2006/07 cold season.

	Forecast hour							
	48		36		24		12	
Model type	Gale	Storm	Gale	Storm	Gale	Storm	Gale	Storm
GFS 10 m	59	27	61	27	60	27	60	27
GFS 30 m	58	27	61	27	61	27	61	27
NAM	53	21	52	21	52	21	52	21

a

POD for 2006-2007 Storm-Force Tehuantepec Events Indicated by 12.5-km QSCAT

b

POD for 2006-2007 Gale-Force Tehuantepec Events Indicated by 12.5-km QSCAT
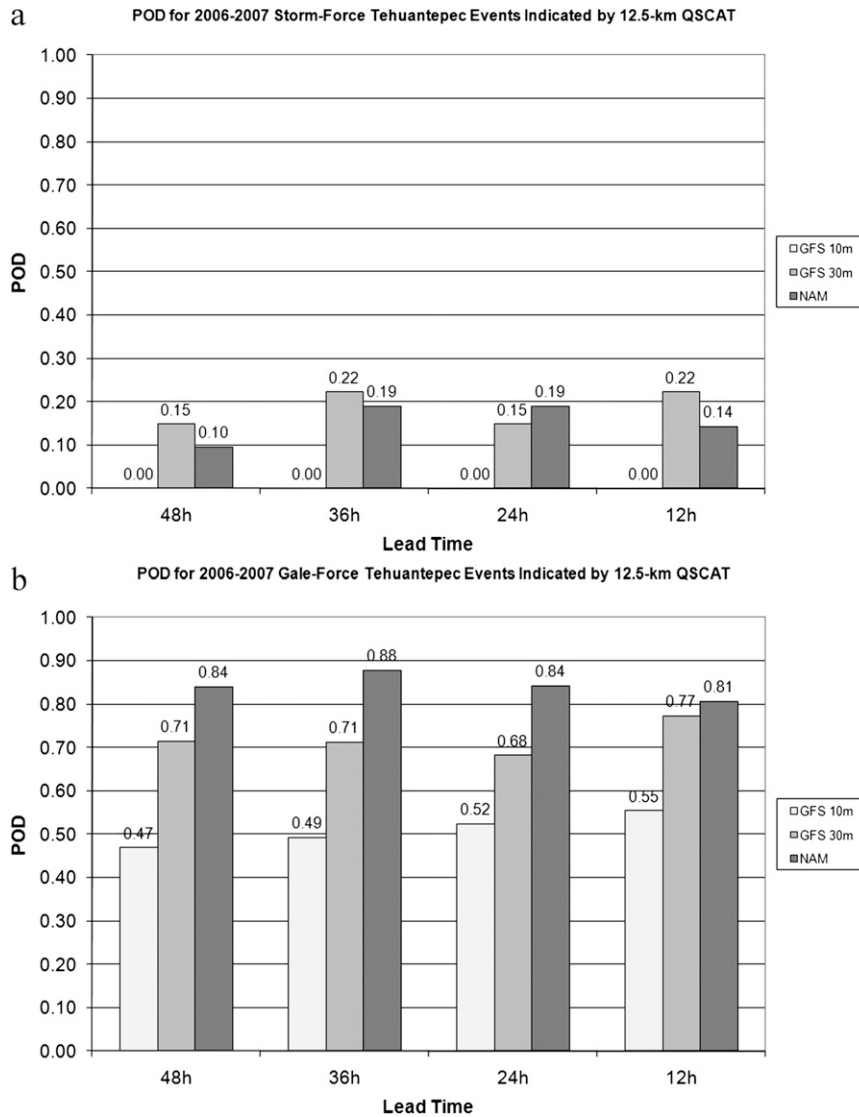

FIG. 5. (a) POD scores for GFS 10- and 30-m winds, and NAM 10-m winds for 2006/07
storm-force Tehuantepec events. (b) As in (a), but for gale-force events.

False alarm ratios were not computed for the entire evaluation period. However, 10-m wind forecasts from the NAM, the model with the highest POD, were examined for the period from 29 October 2006 through 19 February 2007. Instances where the model predicted winds of gale and/or storm force in forecasts with lead times of 12, 24, 36, or 48 h valid at 0000 or 1200 UTC were noted. These dates and times were compared to gale or storm force winds observed by QuikSCAT. There were 79 forecasts from the NAM that showed winds of gale force, and 1 of storm force, when those winds were not observed by QuikSCAT. However, for 77 of these forecasts, there was no QuikSCAT pass observed over the region at the valid time, and the majority of these

instances occurred immediately before, immediately after, or between QuikSCAT observations of gale- or storm-force winds. As a result, there were only three false alarms during the period examined, and two of these occurred when there was only a partial QuikSCAT pass in the region that did not explicitly show gale-force winds.

These verification results demonstrate a lack of reliable NWP near-surface wind speed guidance available to TAFB forecasters, particularly for storm-force Tehuantepec events. As a result, forecasters are forced to utilize pattern recognition and interrogate model wind forecasts at levels above the boundary layer, assuming that vertical mixing will transport these winds down to
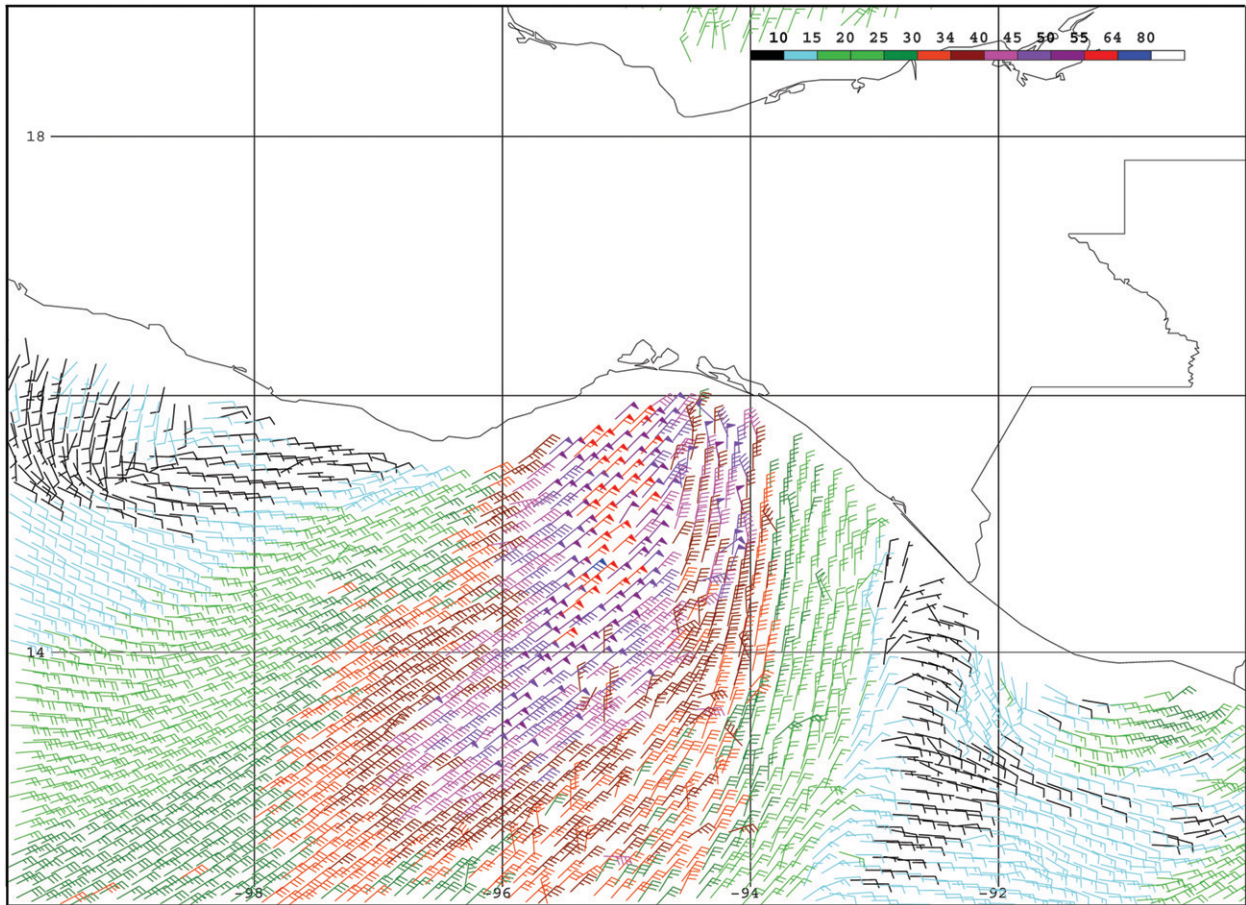
FIG. 6. The 12.5-km QuikSCAT wind retrieval (kt) valid at 0030 UTC 22 Nov 2006. Barb colors indicate wind speeds as shown in the legend.

the surface, to accurately forecast and warn for storm-force Tehuantepec events.

The higher POD scores for the NAM 10-m winds suggest that the increased horizontal resolution of this model, which improves its ability to resolve the terrain features that help drive the gap outflow, may be important to the improved detection of these events. However, differences in the planetary boundary layer schemes in the NAM (Mellor–Yamada) and GFS (Pan and Marht) and their corresponding surface flux schemes could also be important factors in the accuracy of the 10-m wind forecasts through their impact on boundary layer stability and momentum transport. Additionally, the higher POD scores for the GFS 30-m winds relative to the 10-m winds in that model suggest that an inability to properly mix higher winds down to the surface may be partly responsible for the poor performance of the 10-m GFS winds, particularly in storm-force events. Also, the lack of influence of QuikSCAT data in the GFS analysis may also play a role in the poor short-term forecasts of these gap wind events.

To examine the relationship between GFS model forecast errors of 10-m wind speed and the synoptic pattern forecast by the model, GFS model 10-m wind speed errors were compared to GFS model errors in the magnitude of the sea level pressure gradient across the Isthmus of Tehuantepec. The sea level pressure gradient magnitude was computed between Minatitlan (MMMT) and Ixtepec (MMIT; Fig. 2) and compared to observations. At the same approximate time, the GFS 10-m wind speed error was computed by comparing the maximum forecast GFS 10-m wind speed with the maximum wind speed in the 12.5-km QuikSCAT retrieval. This comparison was performed 37 times for 36-, 24-, and 12-h GFS forecasts, and 36 times for the 48-h GFS forecast.

Results indicate that large underforecasts in the GFS 10-m wind speed are associated with large model underestimation of the magnitude of the cross-isthmus SLP gradient in some cases (Fig. 8). This finding suggests that errors in the overall synoptic pattern (e.g., the position and intensity of the surface anticyclone) forecast by the GFS are associated with large model wind speed
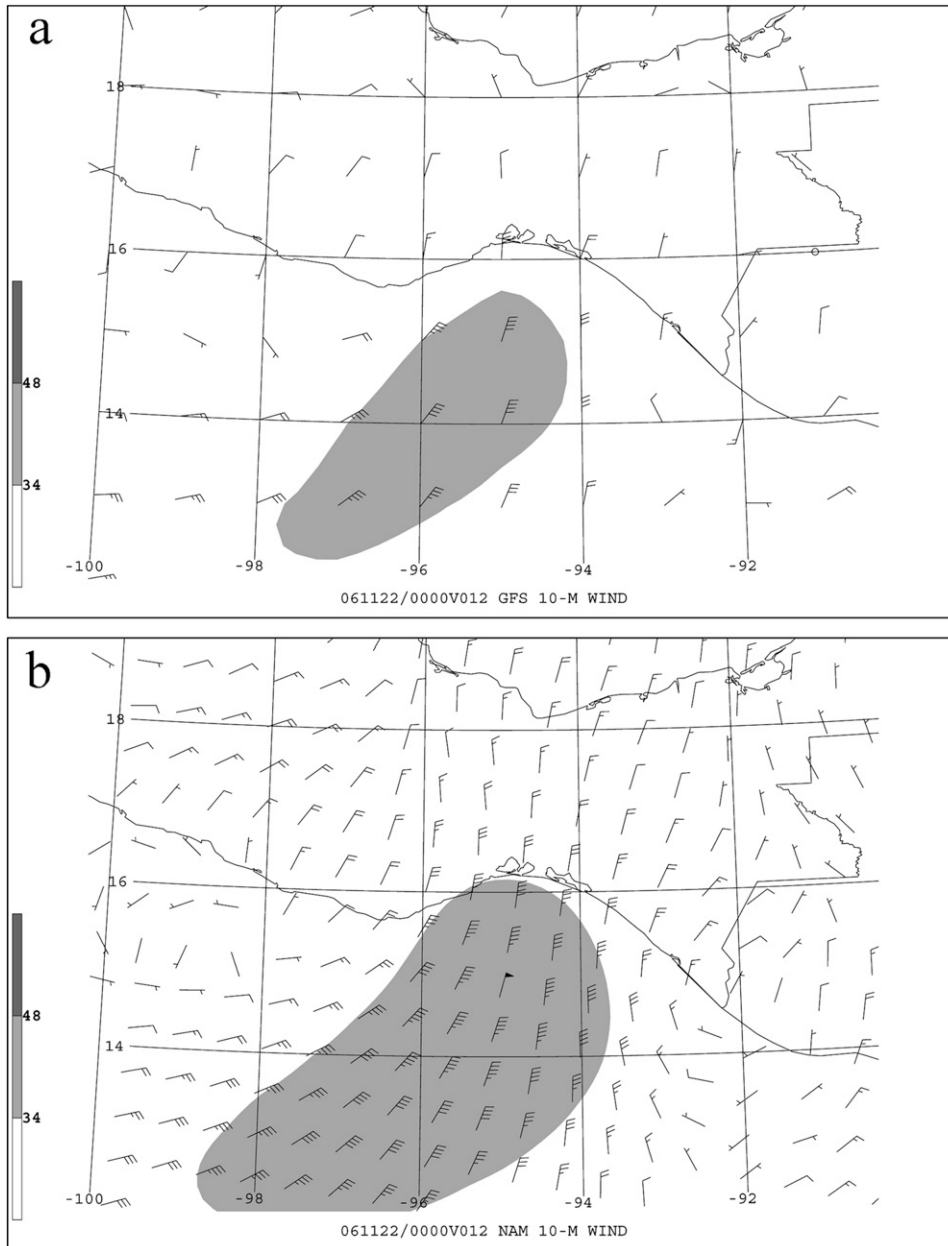
FIG. 7. The 12-h forecast of 10-m winds (kt) from the (a) GFS and (b) NAM models valid at 0000 UTC 22 Nov 2006. Wind speed is shaded according to the legend.

forecast errors. This finding is consistent with that of Chelton et al. (2000b) who showed that the cross-isthmus pressure gradient was dynamically important to gap wind events in the Gulf of Tehuantepec. However, large model forecast errors in wind speed (underforecasts) also occur when the model-forecasted SLP pressure difference across the isthmus is accurate or even overestimated. This result suggests that some large wind speed errors in the GFS are *not* due to errors in the lower-tropospheric mass field forecast, further supporting the hypothesis

that boundary layer processes such as vertical mixing, in addition to horizontal resolution deficiencies, play a role in accurate model forecasts of these events.

5. Beyond QuikSCAT

Without the benefit of QuikSCAT observations in the region, only 21 of 61 storm-force Tehuantepec events (34.4%) detected by QuikSCAT since 1999 would have been identified as being of storm force by synoptic hour
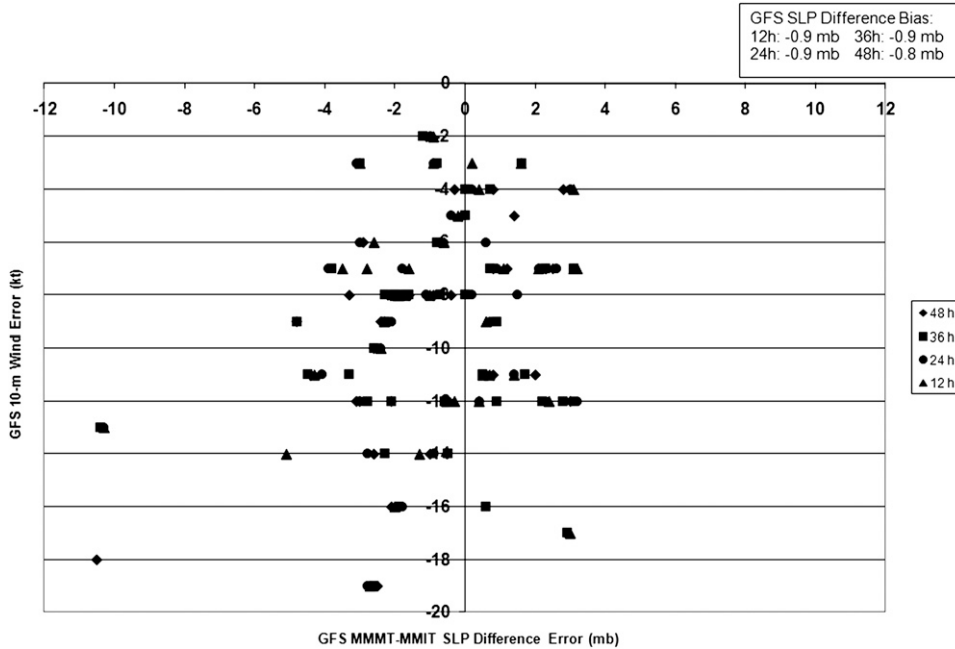
FIG. 8. Scatterplot of GFS sea level pressure difference errors across the Isthmus of Tehuantepec (hPa, *x* axis) and model wind speed errors (kt, *y* axis). Different forecast lead times are represented by the various symbols. Negative values on the *x* axis indicate that the GFS underforecast the magnitude of the sea level pressure gradient. Box in upper right shows average bias of the GFS sea level pressure gradient at various forecast lead times.

ship observations. Given that QuikSCAT has already exceeded its designed 5-yr life expectancy, an overview of other potential sources for OSVW data to observe Tehuantepec events is provided. If left to rely on other currently available and planned satellite OSVW missions, NHC's ability to detect Tehuantepec wind events will likely be severely degraded once QuikSCAT data are no longer available.

Wind retrievals from the multifrequency, polarized, passive microwave WindSat radiometer on board the U.S. Navy–U.S. Air Force *Coriolis* satellite have been available in near real time at NHC for evaluation since June 2006. WindSat wind retrievals received at NHC are processed using NOAA's WindSat Ocean Environmental Data Record retrieval algorithm (Jelenak et al. 2005), with 50-km resolution.

During the 2006/07 season, 22 WindSat passes occurred over Tehuantepec events of at least gale force. Fifteen of the WindSat passes were in sufficient temporal proximity to the 12.5-km QuikSCAT retrievals to allow for a comparison (Fig. 9). WindSat retrievals showed gale-force conditions in six passes, winds of less than gale force in nine passes, and did not retrieve any storm-force conditions. On average, the maximum WindSat-retrieved wind speed was 11.0 kt less than the maximum 12.5-km QuikSCAT-retrieved wind speed. The difference is likely due to

several factors, including WindSat's resolution and land mask and the fundamental differences between retrievals made by passive and active sensors. The 50-km resolution of the WindSat wind retrievals appears to be too coarse to resolve the core of the strongest winds in Tehuantepec events, particularly those of storm force where the strongest winds are typically confined to a relatively narrow swath. Also, WindSat wind retrievals have a 100-km land mask due to contamination by land influences within 100 km of the center of the antenna footprint. This land mask results in a data void in the nearshore region where the maximum wind in QuikSCAT retrievals is often observed. In fact, in 12 of the 15 collocated passes, a WindSat retrieval was not available at the point where the QuikSCAT maximum wind speed was found.

These results clearly show that WindSat will be unable to routinely identify storm-force Tehuantepec events, but could identify some gale-force events, although not the peak wind or the full horizontal extent of the gale-force winds. In addition to spatial resolution issues, another limitation of the operational use of WindSat for Tehuantepec event identification is the reduced coverage compared to QuikSCAT due to the relatively narrow swath (1000 km) of WindSat wind retrievals.

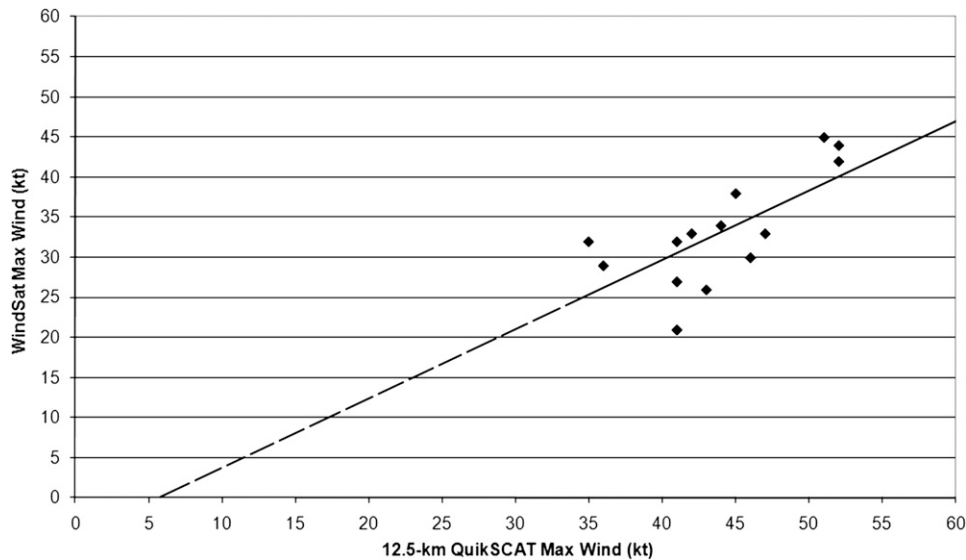The Advanced Scatterometer (ASCAT) was launched on board the European Space Agency's *METOP-A* satellite

FIG. 9. Scatterplot of maximum winds from WindSat and 12.5-km QuikSCAT retrievals in collocated passes during 2006/07 Tehuantepec events.

on 19 October 2006. Near-real-time wind retrievals from ASCAT have been available at NHC since mid-2007, and these retrievals are currently being produced by NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) using the CMOD5.5 model function (S. Soisuvarn 2009, personal communication). The coverage of ASCAT is only about 60% of QuikSCAT, and ASCAT retrievals are available with a nominal resolution of 50 km, with postprocessing techniques resulting in the availability of 25-km retrievals. A preliminary evaluation of ASCAT wind retrievals at NHC (Cobb et al. 2008) showed that ASCAT wind speed retrievals have a low bias of roughly 5–10 kt compared to QuikSCAT at speeds of gale force or higher. Therefore, relying on ASCAT alone will result in a reduction in the number of Tehuantepec events detected due to the decrease in resolution and spatial coverage relative to QuikSCAT.

6. Summary and conclusions

OSVW retrievals from QuikSCAT have become the critical tool used by TAFB forecasters to identify and warn for gale- and storm-force wind events in the Gulf of Tehuantepec. The long data record from QuikSCAT has allowed the development of a 10-yr climatology of Tehuantepec events, indicating that, on average, 11.9 gale- and 6.4 storm-force events occur per cold season. Since the advent of 12.5-km QuikSCAT retrievals in 2003, the average number of storm-force events detected is 8.1 per season. The majority of Tehuantepec events occur between November and March, with some

gale-force events occurring as early as September and as late as May.

An evaluation of operational NWP model guidance during the 2006/07 cold season showed that the GFS and NAM models are unable to accurately forecast storm-force Tehuantepec events. Gale-force events are better identified in 10-m wind forecasts from the NAM relative to the GFS. Additionally, the use of the 30-m wind from the GFS by TAFB forecasters is justified (as a proxy), since winds at this level were shown to have considerably higher POD scores for gale- and storm-force events than the GFS 10-m wind.

Large errors in GFS 10-m wind forecasts occurred even when GFS forecasts of the magnitude of the sea level pressure gradient across the Isthmus of Tehuantepec were accurate, suggesting that while some GFS wind errors were associated with poor model forecasts of synoptic-scale features (e.g., surface anticyclones), large wind speed errors also occurred when the model's synoptic-scale forecast was accurate. The improved performance of the NAM relative to the GFS and the persistence of large GFS wind errors even when the synoptic-scale forecast was accurate suggest that both horizontal resolution and the vertical mixing of momentum may play roles in the accuracy of operational NWP guidance for Tehuantepec events. Suggested future work includes examination of the GFS and NAM output closer to the native resolution of the models to see if the PODs of Tehuantepec events would be increased. Additionally, improvements in the resolution of model data received operationally at TAFB would be beneficial to forecasters trying to predict these small-scale gap wind events.

An additional unexplored error mechanism in real-time NWP model forecasts of Tehuantepec events is the impact of sea surface temperature (SST) reduction due to strong mixing of the upper ocean after the onset of high winds. Previous work has shown that this SST cooling can be both rapid and extreme, exceeding 8°C in several hours (e.g., Schultz et al. 1997). Since current operational NWP models in this region are not coupled with an ocean model, SST values remain fixed for the duration of the model runs, likely resulting in an underestimation of the boundary layer stabilization after the onset of high winds. The neglect of this factor should result in an *overestimation* of the winds in model guidance relative to observations; however, since large *underestimates* of wind speeds in this region are currently seen in operational model forecasts, it seems that this lack of oceanic coupling is not currently the largest source of NWP model error in these events. Coupled model simulations of these events should be undertaken to quantify the impacts of upper-oceanic mixing on the transport of high-momentum air to the surface.

As QuikSCAT moves into its 11th year of operation, well beyond its planned mission life, the prospects for improving or even maintaining the current coverage and quality of the OSVW retrievals that have revolutionized the analysis and forecasting of these gap wind events are uncertain. Resolution and associated land-mask limitations of the WindSat passive radiometer preclude the satellite from providing wind retrievals in the region where the highest winds in Tehuantepec events are often observed with QuikSCAT. Wind retrievals from the ASCAT scatterometer are available at a lower resolution than that currently available from QuikSCAT. Additionally, the coverage of both WindSat and ASCAT wind retrievals is only approximately 60% of that from QuikSCAT, resulting in reduced observations of these events.

Increasing the resolution of ocean vector wind retrievals into the 2.5-km range would provide for much more detailed observations of these events, and likely result in increased detection of storm- and hurricane-force Tehuantepec wind events. A multisatellite constellation, such as the extended ocean vector winds mission (the Extended Ocean Vector Winds Mission; XOVWM) recommended to NOAA by the National Academy of Sciences' *Decadal Survey* (National Research Council 2007) would provide a substantial increase in both the quality and quantity of remotely sensed ocean surface vector wind data for the real-time observation of these and other extreme weather events.

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