Analysis of Daily Monsoonal Wind Circulations in the Lower Troposphere over Estación Obispo, Mexico using Wind Profilers and the Gulf Surge Index

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ABSTRACT

The North American Monsoon dominates over northwest Mexico during the summer and many people both depend on and can be endangered by increasing rains. Atmospheric General Circulation models have not been able to accurately simulate monsoonal rains due to the poor representation of lower-tropospheric wind circulations. This project utilizes wind profiler data from the North American Monsoon Experiment 2004-2006 summers for a better understanding of land/sea breeze characteristics and daily cycles. The 915-MHz wind profiler data is obtained from the 2005 North American Monsoon Experiment ‘supersite’ along the coast of northwest Mexico near the mouth of the Gulf of California. Even though in previous work sea breezes are clearer in the seasonal mean, results show that 36 out of 58 days had sea breezes. Sea breezes in August occurred less often than in July or September. Before this “break” prevailing winds were from the southeast going into the sea breeze while after the “break” northwesterlies transitioned into the sea breeze. Plots of all sea breezes for the summer of 2005 show a common existence from ~12:00PM to ~5:00PM LT. Finally, when hourly wind direction is plotted along with hourly Gulf Surge Index values they show no obvious relationship between surge events and occurrences of sea breezes. This new understanding of the lower-tropospheric wind patterns over northwestern Mexico will help monsoon forecasters evaluate the monsoon prediction models’ likeness to real-time observations.
1. Introduction

The North American Monsoon (NAM) has become known as a widespread phenomenon that affects the entire southwest United States and the northwestern coast of Mexico (Adams and Comrie, 1997). During the monsoon season, interactions mainly between land/sea heating, orographic lifting, and wind circulation patterns are what describe the monsoon. From early July to mid/late September, there is an increase in precipitation over the southwest United States and northwest Mexico. It is during these summer months that the monsoon brings, on average, 70% of annual precipitation (Douglas et al., 1993). Shifts in wind from dry southwesterlies to moist southeasterlies dominate over the NAM region, as well as moisture advection at upper levels from the Gulf of Mexico (GoM) and at lower levels from the Pacific Ocean and Gulf of California (GoC) (Adams and Comrie, 1997; Higgins et al., 2006; Hartten et al., 2005).

What we know today about the NAM comes from a long history of research that first concentrated on the large increases in precipitation in the United States during the transition into summer months. Bryson and Lowry (1955) made the first attempt to understand the mechanics of Arizona’s rainy summers by describing the onset of rains as a link between the changes in flow from westerlies to easterlies in the mid-troposphere. Based on circulation around the Bermuda High, Bryson and Lowry (1955) suggested moisture from the GoM contributed to Arizona rains. Later, “Reitan (1957) concluded that the greatest amount of precipitable water vapor during the Arizona Monsoon is found below 800 mb” (Adams and Comrie, 1997), raising skepticism over the GoM as a moisture source because the topography between Arizona and the GoM rises above 800 mb (Adams and Comrie, 1997; Douglas et al., 1993). In support of the skeptics, Hales (1972) and Brenner (1974) argued that moisture used to support the Arizona Monsoon came from moist tropical air channeled through the GoC in mechanisms called “surges”. They both described an overall land/sea breeze like interaction between the cooler GoC and desert regions in southwest United States that brought a strong shift to south-southeasterlies, lower temperatures, and higher dew points (Adams and Comrie, 1997). Later, Hales (1974) noted larger amounts of rain on the western side of Sierra Madre Occidental while investigating the moisture sources of the Arizona Monsoon, and Douglas et al. (1993) focused on the occurrences of precipitation in southwest United States and northwest Mexico, pointing out
northwest Mexico as the possible center of a bigger monsoon phenomenon, the North American Monsoon.

Understanding of the NAM in previous research was outstanding in that time but due to the lack of observations and the relatively new concept to North America of a monsoon, research is still far from complete. In order to continue investigating the NAM, the significant need for reliable and usable observations had to be addressed. The North American Monsoon Experiment (NAME) is a multi-year and international project centered in the identified core of the NAM, northwest Mexico. The ultimate goal of NAME is to better predict the seasonal precipitation over the monsoon region in order to serve those most affected by it. The most well-known part of NAME is the 2004 Field Campaign, which began an overhaul of the original research strategies by involving the community with science and mingling information between offices which worked to make it a success (Higgins et al., 2006). NAME 2004 deployed numerous instrument platforms including surface meteorological stations, radars, aircraft, research vessels, satellites, wind profilers, rawinsondes, and rain gauge networks (Higgins et al., 2006).

According to Lee et al. (2007), the reason that the Atmospheric General Circulation models (AGCMs) (Figure 1) do not accurately predict precipitation is due to the inaccuracy of the daily wind cycles in the models over the monsoon region. Previously, Hartten et al. (2005) and

Figure 1: The mean diurnal cycle of warm season rain rate (mm day⁻¹) is plotted over the NAME region with the NCEP/NCAR v2 Reanalysis marked as the bold line without dots. The other three simulations compared are the National Aeronautics and Space administration GMAO v2 model marked blue with dots, the National Center for Environmental Prediction GFS v2 model marked in green with dots, and the Geophysical Fluid Dynamics laboratory am2p12 model marked in red with dots. (see Lee et al., 2007)
Jones (2007) looked at the daily cycles of wind but through long-term averages. Instead of smoothing over daily atmospheric variations, this present research focuses on the day-to-day characteristics to get a higher resolution of changes in the sea breezes. A long-term goal of helping people in the NAM region to better prepare for disasters was the hope for AGCM’s capabilities in the future (L.M. Hartten, 2008, personal communication). Specifically, this research analyzes wind direction data from profilers positioned along the GoC in northwest Mexico to investigate daily land/sea breezes, during the summer of 2005. Also, a Gulf Surge Index (Bordoni and Stevens, 2006) is compared to the time series of wind direction to look for correlations between surge events and its effects on sea breezes throughout the day. Discussions of the wind profilers and the GSI used in this analysis, including results, follows.

2. Methods and Data

a. Wind Data

The site for the 915-MHz wind profiler was set along the northwest coast of Mexico, 20 km from the GoC at Estación Obispo (ETO, Figure 2). This site at ETO was located at 24.28° N and 107.16° W and lay 27m above MSL (Hartten et al., 2005). For three years, wind profiler data was collected from different start and end dates (Hartten et al., 2005):

- 2004 – 28 July to 20 September
  (Logistical issues delayed deployment of profiler until July)
- 2005 – 29 June to 19 September
- 2006 – 22 June to 14 September
  (Profiler dismantled by Hurricane Lane and a few days of data was lost)

![Figure 2: Profiler sites near the coast of northwest Mexico along the GoC (Hartten et al., 2005).]
The 915-MHZ profiler used during 2005 emits a radio wave along 3 beams that are angled slightly away from zenith. These radio waves have a dwell time of up to a minute in each direction and measure the radial velocities of wind. The profiler measures changes in the index of refraction, which is related to temperature, humidity, and pressure in the lower troposphere. Due to irregular surface heating and changes in wind direction, eddies are created that can vary throughout the atmosphere on the scale of cm to mm (Vaisala Oyj, 2004). These eddies create differences in the index of refraction that allow the profiler to interpret radio waves scattered back to the antenna from the differences as representations of wind movement (P. Johnston, 2008 personnel communication). The hourly wind data obtained from this profiler are used to gain an idea of how daily wind cycles play a roll in the synoptic-scale circulation pattern’s behavior over northwest Mexico throughout the summer.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Parameter</th>
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<tr>
<td>Wavelength</td>
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<tr>
<td>Antenna Type</td>
<td>3 panel system</td>
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<tr>
<td>Gate Spacing</td>
<td>Low mode 60m</td>
</tr>
<tr>
<td></td>
<td>High mode 100m</td>
</tr>
<tr>
<td>Max height with data</td>
<td>3500m</td>
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<tr>
<td>available 50% of the time</td>
<td></td>
</tr>
<tr>
<td>Dwell Time</td>
<td>37 seconds</td>
</tr>
</tbody>
</table>

*Table 1: 2005 ETO 915-MHz profiler parameters.*

**b. Gulf Surge Index**

Bordoni and Stevens (2006) used wind data from six summers (1999-2004) of QuickSCAT (Scatterometry) to quantify the changes in circulation in the lower troposphere, focusing on the GoC. QuickSCAT creates “nearly daily maps of near-surface winds over the oceans at ~25 km spatial resolution that are accurate to more than 2 m s⁻¹ and 20°” (Bordoni, 2004). Every day, from June to September, there were ascending and descending QuickSCAT measurements that were averaged to get a daily time series. An empirical orthogonal function analysis was then performed on the time series yielding a “gulf surge mode” and a related
principal component time series (Bordoni, 2006). That time series was interpreted as a Gulf Surge Index (GSI) and a threshold of 0.75 was identified for surge events (75% of its standard deviation) (Bordoni and Stevens, 2006). In addition to a GSI of 0.75 or more, a gulf surge is also characterized by a development of strong southerly or southeasterly flow along the GoC and accompanied by a rise in moisture and drop in temperature (Douglas et al., 1993; Hales, 1997; Brenner, 1974; Bordoni and Stevens, 2006; Bordoni et al. 2004). Detailed descriptions of methods and conclusions can be found in Bordoni and Stevens (2006) and Bordoni et al. (2004). Based on previous methods, another GSI time series was created for 2005 and used in this research. (Bordoni, 2008, personal communication).

c. Analysis and Strategy

Profiler data were extracted from four different heights, ~565m, ~765m, ~385m, and ~200m. The work mentioned earlier by Hartten et al. (2005) and Jones (2007) showed in the mean at different heights the sea breeze is characterized differently as seen in Figure 4.

![Figure 4: Mean daily cycle of vector wind and Directional Constancy for summer 2005. A 6.0 m s⁻¹ reference vector coming from the southwest is given at top right corner. Directional Constancy is shaded as in the key below the plot;](image-url)
higher values indicate the wind at that height and time were usually from the plotted direction, lower values indicate the wind was either divided between 2 directions or distributed among all directions. (Jones, 2005).

As the day passes the depth of the sea breeze can vary based on larger scale wind circulations and daytime heating. These changes in the maximum depth are best observed in the ~565m and ~765m heights as shown from Hartten et al. (2005) and Jones (2007) past research in Figure 4. Through the depth of the sea breeze where the persistence through time is the longest, around 385m, would be the best height to investigate just a sea breeze alone. There is also an associated land breeze that occurs in the morning time but is not as strong nor as deep as the sea breeze therefore the sea breeze as well as the land breeze can be seen together mostly in the lower atmosphere at ~200m. Considering the time constraints of this summer’s project, the 385m height was focused on for a detailed investigation of the onset and frequency in the sea breeze characteristics.

For this project’s purpose of investigating sea breezes, a standard for the expected direction of a sea breeze was indentified by graphically determining a line perpendicular to the coast of northwest Mexico at Estación Obispo on a topographical map. The angle of the coast was about 315° making the angle for perfect onshore flow about 225°. (Throughout this paper direction is given using the meteorological convention i.e. 0° is North, 90° is East, etc.) Initial plots of wind roses like Figure 3, showed that for any week during the summer there was onshore flow but not just confined to 225°. This suggested that the initial angle of 225° was not broad enough to encompass what was likely to be the entire scope of the sea breeze, so the expected direction was re-defined to be within a 45° range centered on 225°(i.e. 202.5°-247.5°).

![Wind Rose](image_url)
Hourly wind direction (Figure 4) was plotted to identify larger variances in the wind direction for the entire summer. These plots showed a long-term cycle about a month or more. During that monthly cycle, the wind varied across almost the entire range. Some wind directions graphically seemed to veer from one direction to another at the other end of the scale but in reality were only changing a few degrees (i.e. NW to N or NE). Figure 4 also shows a smaller daily cycle that varies only a few degrees on some days. To see more detail on the daily cycles, weekly plots of the whole summer were made to get a better look at the sea breeze direction.

![2005 Wind Direction at ETO at 358m](image)

*Figure 4: Hourly wind direction for the 2005 summer at 358m from 22 June– 20 September is plotted with expected sea breeze direction (225°) as a horizontal line.*

For the weekly plots of the hourly wind and GSI data, yellow sea breeze boxes (10:00AM - 3:00PM LT) were constructed and plotted along with a noon marker, to help ease visual identification of sea breeze (SB) “events”. Initial SB “events” were determined by any wind direction that happened in the SB range and also occurred during regular SB time, 10:00AM to 3:00PM. Some initial SB “events” were thrown out because they did not meet the final criteria for SBs. The criteria for SBs required winds to be from one direction in the early morning, shifting to be from 202.5° - 247.5° at midday for at least an hour, but not only occurring at 3:00PM LT. Even if large-scale circulations were in place from 10:00 AM - 3:00PM LT, a SB was accepted as long as there was at least an hour (not at 3 LT) where the wind shifted then returned to the larger circulation.
The 2005 GSI (Figure 5) was expanded as a step function to convert a once daily time series to an hourly time series for easier graphical comparison with the 2005 summer wind direction. This comparison was intended to see if the Gulf Surge interfered with the daily sea breeze cycle and perhaps explained why there was not a sea breeze on certain days.

![Gulf Surge Index for summer 2005](image)

*Figure 5: Hourly version of the GSI (Bordoni and Stevens, 2005) for the 2005 summer from 22 June – 20 September. The GSI threshold (0.75) is marked in a black line and surge events for this time period are highlighted by vertical shaded boxes.*

### 3. Results and Discussion

Of 58 possible days with data (3 out of 5 data points in SB box recorded during SB time), 36 SB “events” were initially identified; 8 were thrown out. Even though in Hartten et al. (2005) and Jones (2007) the sea breeze is clear in the seasonal mean, here sea breezes were only found on 36 of those 58 days. All SB “events” from the summer were then plotted on four daily graphs with about 6 to 10 “events”, each progressing through the summer to see the commonality in characteristics of the SB.

The weekly plots of hourly wind direction (ex. Figure 8) showed that at the beginning of the time series (July) and end (September) SB “events” were more frequent than in the month of August. Figure 6 and Table 2 show the “break” in the SBs recorded and all redefined SB “events”, respectively. SB “events” plotted daily (Figure 7) show that before this “break” period winds were generally southeasterlies before shifting into the SB, while after the “break” there were northwesterlies transitioning into the sea breeze. Again due to the constraints of this project, pressure maps were not analyzed to find the larger scale seasonal wind circulations that
Figure 6: Summer 2005 time series of SB “events” plotted from 22 June – 20 September.

Table 2: Summer 2005 list of SB “events” from 22 June – 20 September.
are believed to be in play here, shifting in early August. Another detail from Figure 7 shows that although the criteria used for identifying SBs (yellow boxes) was 10:00AM-3:00PM LT the SB winds for the 2005 summer were usually not in that range until noon and persisted until ~5:00PM LT.

As shown by the examples in Figure 8, hourly wind direction plotted along with daily Gulf Surge Index values showed no obvious relationship between surge events and occurrences of sea breezes. Considering that the Gulf Surge was in close proximity to the ETO profiler site, it was thought that when there was a surge in the Gulf of California that it might override the daily SB cycle and help identify a reason for the absence of a SB on a given day. In Figure 8, on week 3 the GSI reached the threshold (0.75) and there is 4-recorded SBs. Although, on week 5 the GSI reached the threshold again yet there was no SB recorded. This research however holds that there is still a hint of some correlation (Figure 8, week 3) that is not clearly seen and was not further investigated due to time constraints.
Figure 7: Plot of wind direction during all days with a SB “event” (range highlighted in grey horizontal box. Each graph shows 6-10 events. The first graph starts around the beginning of the summer (22 June) progressing close to the end (20 September).

Figure 8: Hourly GSI (solid orange) and wind direction (green with crosses) for 2005 at 358m plotted for 3 weeks in local time. The 0.75 GSI threshold is the orange dashed line.
4. Conclusion

Lee et al. (2006) hypothesizes that the AGCMs do not accurately simulate precipitation in northwest Mexico because the daily wind cycles are not well simulated. This research builds upon previous investigations by looking more at the details of sea breeze characteristics during the summer rather than the averages of the overall circulations throughout. The results show that even though SBs are clear in the seasonal mean, they were only found 36 of the 58 possible days. The hourly wind direction plotted weekly shows that SB were uncommon in August and before this “break” the prevailing winds were mostly from the southeast, while after, winds were from the northwest transitioning into the SB. Weekly plots also suggested that for the summer of 2005 from ~12:00PM to ~5:00PM LT was a common occurrence time for SBs. One final result shows that when comparing GSI (Bordoni and Stevens, 2006) with wind direction at ETO there seems to be no graphical relationship between the Gulf Surge and occurrences of SBs but may still have some type of correlation. This research still leaves unresolved the effects of larger scale circulations on day-to-day cycles of sea breezes. A possible explanation can be found in further research on the Gulf Surges by looking more closely at the colorations between daily wind cycles and the GSI (Bordoni and Stevens, 2006). These results are intended to help better the simulations of monsoonal precipitation to make available critical information to those affected most by the North American Monsoon.

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REFERENCES


