On the Use of a Coastal Mesonet to Reveal Anomalous Mesoscale Flows in Weakly-Forced Synoptic Conditions

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1. INTRODUCTION

The Sea Port of Debarkation (SPOD) Vulnerability and Ship Protection in the Littoral Region Weather Model Experiment was conducted during the summer of 2001 on the lower Chesapeake Bay. The primary goal of the experiment was to measure the improvement in the prediction of weakly forced mesoscale circulations in a littoral region based on an increased spatio-temporal resolution of surface characteristics.

Historically, the primary mesoscale flow feature prevalent during periods of weak synoptics is the sea breeze. The sea breeze circulation typifies the type of mesoscale feature that could be modeled more accurately with improved spatio-temporal input data streams. For example, a higher temporal resolution soil moisture data set would reveal the areas in which incident short-wave radiation can be used more efficiently for direct heating of land surfaces. This direct heating sets up a greater cross-coast temperature gradient yielding a stronger sea breeze.

Another important result from this experiment was that the spatially dense mesonet revealed other anomalous flows in which modeling efforts either completely failed to detect or struggled to model the proper spatial and/or temporal properties. Two of these events will be examined.

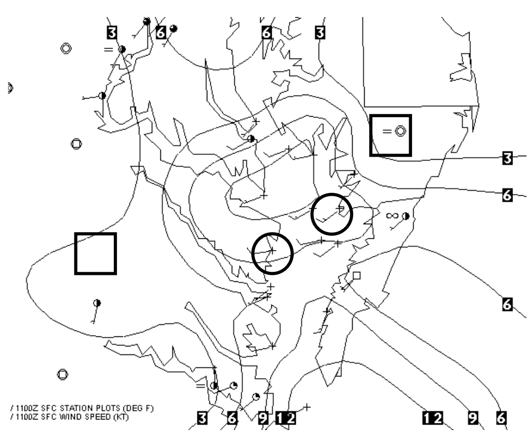

Figure 1 – Chesapeake Bay

2.1 NOCTURNAL ACCELERATED FLOW OVER THE BAY

The first is a nocturnal accelerated south to southwest flow that quickly blossoms over open waters of the bay. Although most of the experiment did not involve any extended periods of weak synoptics, there were a few instances in which some sites exhibited rather sharp increases in wind speeds during the overnight hours. Figure 1 represents a surface depiction indicating local maxima in wind speeds over the bay with broad SW flow impinging on the surface during the early morning hours of July 17th. The feature appears over the open waters of the bay but fails to reach the 10 m surface of surrounding inland reporting sites.

The summer of 2002 was unseasonably warm and dry. That is, unlike the synoptic set-up during the SPOD experiment, the June/July period was dominated by extended periods of weakly forced synoptic conditions. Two WeatherFlow sites, Great Wicomico Light (GWL) and Crisfield (CRIS) marked with circles in Figure 1, are examined for several occurrences of enhanced nocturnal flow during this period. These two weather stations are located over bay waters.

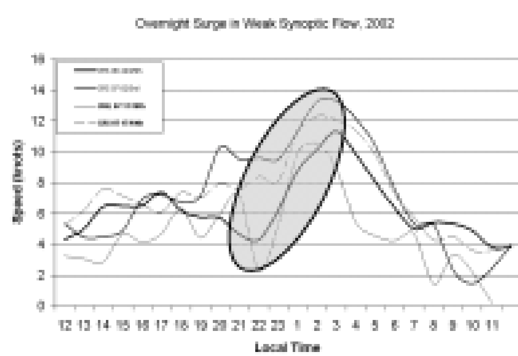

Figure 2

Figure 2 depicts three such enhanced nocturnal flow events occurring June/July of 2002. The abscissa represents local time centered on midnight, while the ordinate represents speeds in knots. The revealing feature from this figure is that on all three occasions, an abrupt rise in speeds occurs between midnight and 1 am.

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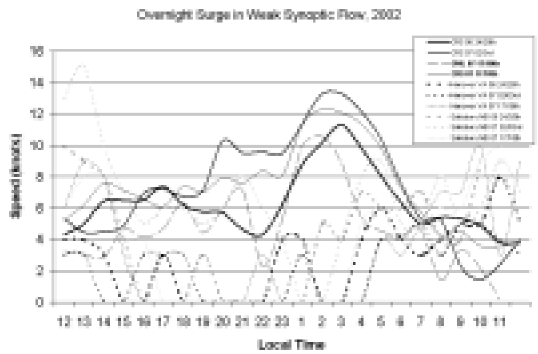

Figure 3

Conversely, Figure 3 depicts the same three events with the addition of time series from two National Weather Service sites located nearby, but inland, at Hanover County Airport VA, and at Salisbury Wicomico County Airport MD. These two sites are labeled with square boxes on Figure 1, and generally lie on a transect that aligns itself with the prevailing southwesterly flow during these events. The revealing feature on Figure 3 is that the inland sites did not experience the same abrupt rise as the two WeatherFlow sites.

In each of the three events, the region experienced hazy and hot conditions with high temperatures at or in excess of 35 degrees C with overnight low temperatures away form the water around 22 degrees C. But over the bay, water temperatures during these events still hovered near 32 degrees C, even during the overnight hours. Quite likely, the very warm water of the open bay creates a meso-region of unstable conditions in the lower boundary layer that allows a low level jet-like feature to penetrate the near surface zone. While inland, a cooler, more stable environment develops and prevents the stronger breezes from descending to the surface.

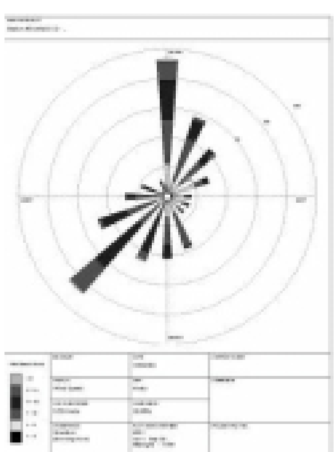

Figure 4 – Grt. Wicomico Light

Finally, Figure 4 and Figure 5 are roses of hourly winds binned for nighttime hours only through the summer for two of the WeatherFlow sites, Great Wicomico Light and Crisfield. The most striking feature on both is the high incidence of SW flow, indicating that accelerated flow from the SW occurs quite frequently.

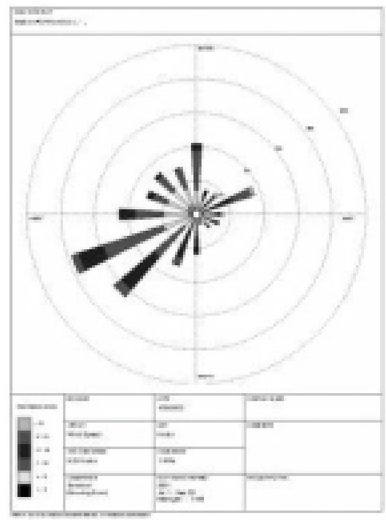

Figure 5 - Crisfield

2.2 TIDALLY AIDED VARIATIONS IN WIND MAGNITUDE

Unlike the previous analysis, variations in wind speed influenced by tide appear to be most prevalent during daylight hours. Preliminary results also seem to indicate that certain locations have stronger effects than others. Tidal influences are often rather difficult to detect, as there generally needs to be an absence to larger-scale synoptic and mesoscale influences in order for these influences to become apparent. Overall, the most significant dependencies appear to be related to phasing of the tidal cycle with the diurnal evolution of the sea breeze. In addition, the degree of tidal variation influence appears to also be a function of the lunar cycle.

Generally speaking, during weakly forced synoptic situations, incoming tides tend to accelerate sea breeze magnitudes, while outgoing tides tend to decrease. This relationship appears most robust when low tide occurs during the mid-day period when sea breezes are in the beginning stages. The effects of tides are most likely accentuated at locations with a tidal flushing that pushes and pulls water in a zone with some temperature gradient. E.g., a location near an inlet or the mouth of a tributary where water within a bay or tributary that is experiencing a different temperature than that of the adjacent open bay or ocean. In addition, tidal effects may be more of spring/fall phenomena when there are larger differences occurring between open water and tributary (shallower) waters.

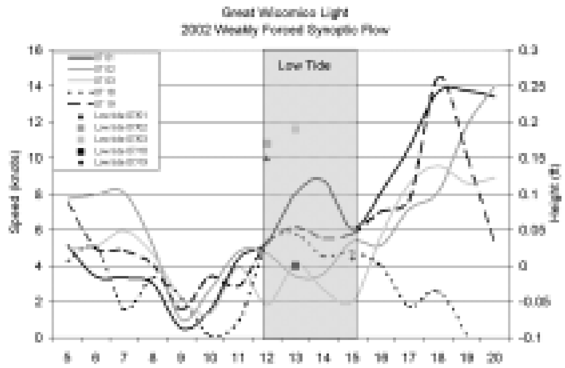

Figure 6

Figure 6 depicts some excellent examples of significant variations in wind speed that seem to be influenced by the tidal cycle. Five July days are analyzed at Great Wicomico Light in which low tide occurs between noon and 2:30 pm local time. All five occasions experience a significant drop in speed during the outgoing tide (~10 am), while four of the five days see impressive gains in speed midway through following incoming tide.

Figure 7

Conversely, as depicted in Figure 7, the remaining three weakly forced synoptic days during July 2002 at Great Wicomico Light have low tide occurring earlier in the day, around 9 am. As a result, the pattern seen in Figure 6 is virtually absent in Figure 7. Only July 27th shows a significant increase on the subsequent incoming tide. Interesting to note that the accelerated trend is unable to maintain itself past about 2 pm when the next outgoing tidal cycle may be exerting an influence.

The second aforementioned preliminary finding is a correlation between the magnitudes of sea breezes as a function of the tidal departures from normal. In particular, it appears as though the greater the low tide departure from normal, the greater overall magnitude of wind speed through the entire sea breeze event. Again, preliminary results seem to indicate that this influence may be greater during the spring.

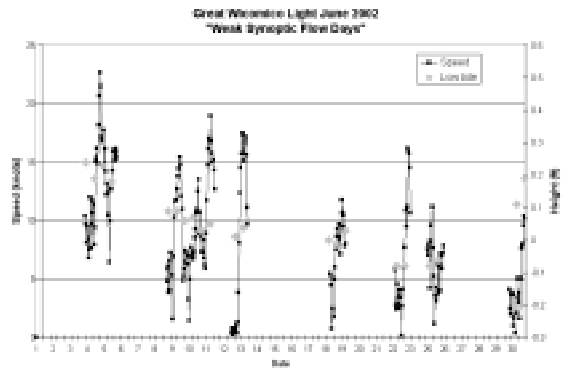

Figure 8

Figure 8 depicts the average wind speeds as well as the time of low tide and departure from zero during weakly forced synoptic days for June 2002 at Great Wicomico Light. Despite some daily scatter, an interesting correlation is seen in that during the weakly forced days, the higher the positive departure from zero, the higher the overall wind speeds.

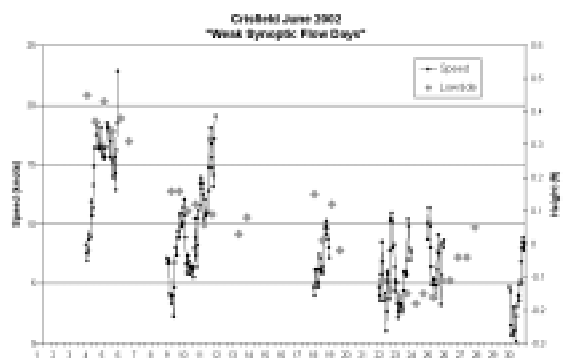

Figure 9

Figure 9 shows the same relationship for June 2002 at Crisfield. The relationship appears even stronger at Crisfield, and may be due to the fact that Crisfield had higher tidal departures (0.6 feet, versus 0.3 feet), thus dramatizing the relationship.

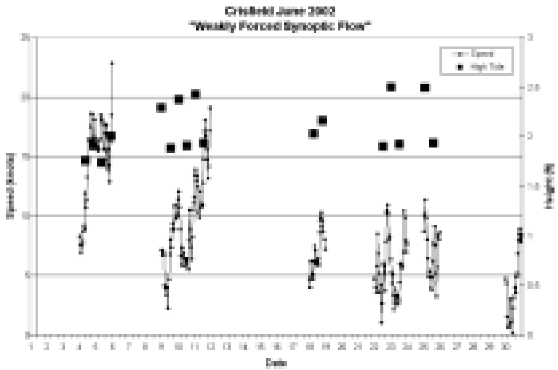

Figure 10

The relationship seems to fall apart when examining high tide departure as seen in figure 10 as the departures do not dip over the course of the month, whereas the weakly forced days exhibit a general declining trend through most of the month. One potential relationship that warrants further investigation is that when there is significant variation between the major and minor high tidal departure each day, there is a tendency for larger variation in magnitude. Two spans, the 9th through 12th, and the 22nd through 26th both have large departure differences coupled with significant daily magnitude variation.

CONCLUSIONS

Weakly forced synoptic conditions in littoral regions often result in wind patterns that are difficult to model. Diverse, dynamic, and highly variable quantities such as soil moisture, water temperature, precipitation, and cloud cover are difficult to quantify, especially in the spatio-temporal resolution required for input into meso-scale models that are being run at ever-higher resolutions. Complicating factors include feedbacks from air-sea interactions. For example, stronger winds associated with sea breezes can couple with surface current to cause upwelling which in turn can strengthen cross-shore thermal gradients, further enhancing flow. Conversely, sea breezes can display negative feedback too.

Sea breezes transport cooler air inland, and thus diminish the cross-shore gradient and associated enhanced flow.

Enhanced data collection in littoral zones is critical to the further understanding of meso and micro-scale processes. Additional data: 1) Reveals anomalous flows not captured by any other method, 2) Refines known, but not well understood, air-sea interactions, 3) Provides an independent data source for model verification, 5) Provides critical additional data such as water temperature for model assimilation, and 6) Provides ground-truth for other emerging hardware such as radar and codar.

The preliminary findings in this analysis are not meant to conclude that hard and fast relationships have been found between boundary layer processes and air-sea interactions, but intended to highlight the fact that processes governing wind behavior are quite complex, and warrant further study. More attention needs to be paid to the keyword “interaction” as land and sea are integrally tied, much more so than conventional forecast techniques currently employ.