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The Structure and Climatology of Boundary Layer Winds in the Southeast United States and its Relationship to Nocturnal Tornado Episodes

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1. Introduction

Previous research has shown that there is a relatively high frequency of tornadoes in the overnight-to-early-morning hours during the cool season in the southeastern United States (US), particularly in areas close to the Gulf of Mexico (Anthony 1988, Fike 1993). For example, most strong and violent tornadoes (F2 or greater) in Florida occur during the cool season, and are associated with extratropical cyclones. Previous research has also documented the importance of the return flow of warm, moist tropical air across the Gulf region (e.g., after the passage of cold fronts through the Gulf) in the development of potential severe weather scenarios along the Gulf coast. The warm Loop Current in the Gulf also can increase fluxes of heat and moisture into this return flow air, which can lead to rapid air mass destabilization. It has also been shown, however, that forecasting the trajectories of return flow air is difficult, and that operational numerical prediction models are not able to accurately forecast the modification of the boundary layer (partially due to lack of data over the Gulf), which can be important in determining the severe weather potential over the Southeast.

The purpose of this study is to examine the climatology of surface and boundary layer winds during the cool season in the southeast United States, and eventually to examine how they might contribute to the development of nocturnal tornado episodes in close proximity to the Gulf of Mexico coast.

2. Data and Methodology

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Pilot balloon (pibal) data were obtained for all available stations in the southeast United States (Fig. 1). Pibal data consists of wind measurements at standard height levels in the atmosphere, and was available for the years 1948 to 1962 for most stations. Pibals were launched four times daily (0300, 0900, 1500 and 2100 UTC from 1948 to 1957, and 0000, 0600, 1200, and 1800 UTC from 1958 to 1962). For this study, only the years 1948 to 1957 were considered, as the data from 1958 to 1962 was much less complete, both spatially and temporally.

Hourly surface data was obtained from the SUNY Albany local tape archive for the years 1995 to 2000 (cool seasons 1995-96 to 1999-2000). While it is recognized that the climatologies of surface and pibal observations were constructed for different time periods, the pibal wind profiles were more useful for examination of the diurnal wind cycle along the Gulf Coast than current radiosonde data, which is only taken twice daily.

Both pibal and surface data will be used to understand the climatology and diurnal structure of the boundary layer winds across the southeast US. Additionally, data will be used to more closely examine tornado days during the cool season in the Southeast to determine what the similarities and differences are from the climatology.

3. Boundary Layer Wind Climatology

At each available pibal station, u and v wind components were averaged for the entire time period (Nov.-Mar., 1948-1957) for 0300, 0900, 1500 and 2100 UTC soundings. The climatology shows that a nocturnal southerly low-level jet develops at many stations between 500 m and 1500 m. Figure 2 shows the daily evolution of the winds at 1000 m for all stations. Stations which are furthest inland are most influenced by the mid-latitude westerlies, while weaker westerly flow is present at stations close to the Gulf

Coast. Stronger southerly winds are present during the overnight/pre-dawn hours (e.g. 0900 UTC) than during the day (e.g. 2100 UTC) at all stations in close proximity to the Gulf of Mexico, including BRO (Brownsville, TX), MSY (New Orleans, LA), TPA (Tampa Bay, FL), and TLH (Tallahassee, FL). The low-level (0-1 km) wind shear is strongest in the average of all stations at 0900 UTC and weakest at 2100 UTC. This diurnal difference in the 0-1 km shear is even greater (appx. 4 m s^{-1}) when a subset of pibals in close proximity to tornado episodes is used for the calculation (not shown).

Figure 3a shows the difference in the v (north-south) component of the wind at 1000 m as a function of latitude for the climatology. Although the 2100 UTC meridional wind exhibits little to no dependence on latitude, the 0900 UTC meridional wind is quite dependent on the latitude of the station. The 0900 to 2100 UTC difference in the meridional wind is strongly dependent on latitude, with approximately 73% of the variance of this difference explained by the latitude of the station. Thus, the development of the southerly nocturnal low-level jet is most pronounced at stations in close proximity to the Gulf of Mexico, while inland stations do not show an increase in southerly flow at night. However the 0-1 km shear calculation does not exhibit a negative correlation with latitude as one might expect. This is due to the fact that the 0-1 km shear actually increases northward due to the stronger influence of the mid-latitude westerlies at stations to the north. When one looks at the meridional shear only (Fig. 3b), there is a strong negative correlation to latitude, which corroborates the hypothesis that the nocturnal southerly low-level jet is most pronounced near the Gulf Coast.

4. Surface Wind Climatology

It has been observed through various case studies of nocturnal tornado events near the Gulf Coast that there appears to be a consistent signature of more strongly backed surface winds at stations in immediate proximity to the Gulf of Mexico. The purpose of the climatology of surface observations was to determine if this more prominent backing signature is real, and if it can be seen on a regular basis (i.e., in the climatology) at stations near the Gulf Coast.

Figure 4 shows a sample of a climatological windrose for an individual surface station, AEX (Alexandria, LA). One can see a gradual backing of the winds from 0000 UTC to 1200 UTC, from southerly to more southeasterly flow. While this backing is not as pronounced at all stations, most stations in close proximity to the Gulf of Mexico did exhibit some degree of backed winds during the overnight/early morning hours compared to the daytime (not shown). For this study, all stations south of AEX were defined as ‘coastal’, while stations north of AEX were defined as ‘inland’.

Figure 5 shows frequency plots for both coastal and inland stations. Illustrated is the percent of observations which occurred during each hour (various colors) for 30 degree direction bins. For example, approximately 17% of observations where the wind direction was 180° to 210° occurred at 2100 UTC for coastal stations (Fig. 5a). If a wind direction were equally likely to be reported at all times, 12.5% (1/8) of the observations would occur for each hour. Coastal stations tend to have a higher percentage of observations report easterly or northeasterly flow during the overnight to early morning hours (0900 to 1500 UTC), while a high percentage of southerly observations occurred during the day (1800 UTC to 0000 UTC). Wind directions greater than 270° (northwesterly flow) show roughly the same percentage of reports at all hours, thus indicating there is no preferred time of day for northwest flow to be reported. This preference for easterly or northeasterly flow to be reported in the pre-dawn hours is not nearly as pronounced for inland stations (Fig. 5b).

The next question to answer is why the surface winds tend to be more backed (i.e., more northeasterly or easterly) at night for coastal stations. While all stations exhibit a pressure rise during the overnight hours, the highest pressure rise by greater than 1 hPa occurs in a region from northern Louisiana eastward through central Mississippi and Alabama (not shown). A hypothesis that remains to be tested is that this stronger pressure rise slightly inland from the coast forces stronger easterly (geostrophic) flow along the immediate Gulf coast.

5. Conclusions

Pibal observations from 1948 to 1957 support the hypothesis that the development of the southerly nocturnal low-level jet is most pronounced during the overnight hours. In the climatological sense, this increases the 0-1 km meridional shear magnitude at stations in close proximity to the Gulf of Mexico.

Examination of hourly surface observations for stations across the southeast United States indicate that there is a preference for more backed (northeast/east flow) to be reported along the immediate Gulf coast during the overnight/pre-dawn hours, at the same time that the low-level jet increases strength in the pibal climatology. It is hypothesized that this more prominent easterly flow is due to stronger pressure rises just inland from the Gulf Coast than along the immediate coastline.

While it is recognized that these climatologies are for two different time periods and may not be related, it is hypothesized that there is still a nocturnal low-level jet that develops along the Gulf Coast today. If this is true, this fact, combined with the preference for more backed surface winds, would climatologically create a more favorable shear profile along the Gulf Coast than further inland for supercell development.

Future work will include examination of a subset of surface and pibal data to see if the boundary later wind signatures, which are present in the climatology, are enhanced in close proximity to tornado episodes. Additionally, future work will include addition of more surface stations to the climatology to further investigate the hypothesis that stronger pressure rises inland contribute to more prevalent easterly/northeasterly flow overnight along the Gulf Coast. Lastly, surface stations along the east and west coasts of the Florida peninsula will be examined as well, as the nocturnal tornado signature is present on the Florida peninsula as well. Comparisons will be made of the diurnal evolution of surface flow along the east and west coasts of the peninsula during the cool season.

6. Acknowledgement

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7. References

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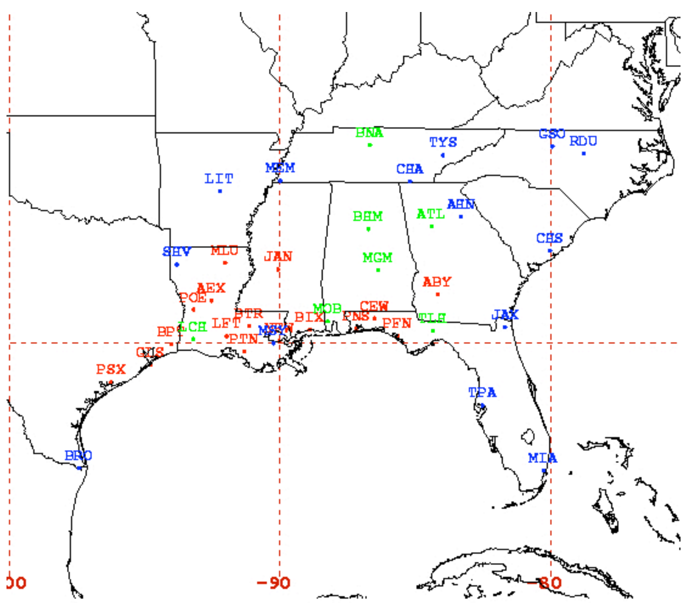


Fig. 1: Surface (red) and pilot balloon (blue) stations used in this study. Green stations are those for which both surface and pilot balloon data were available.

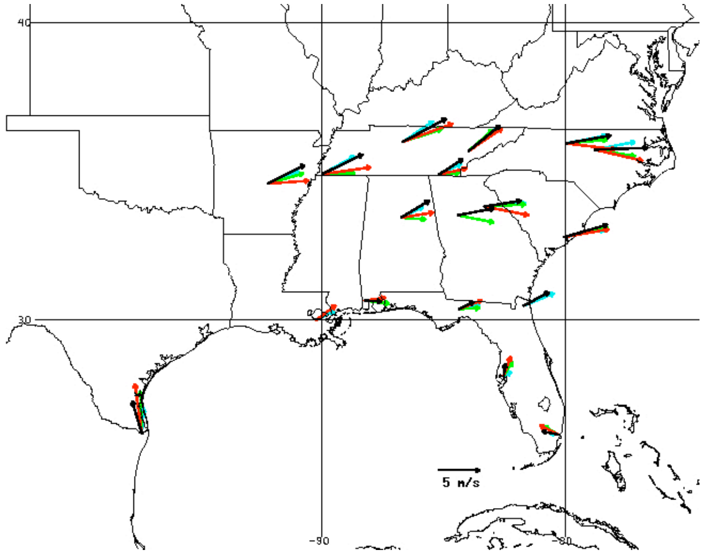
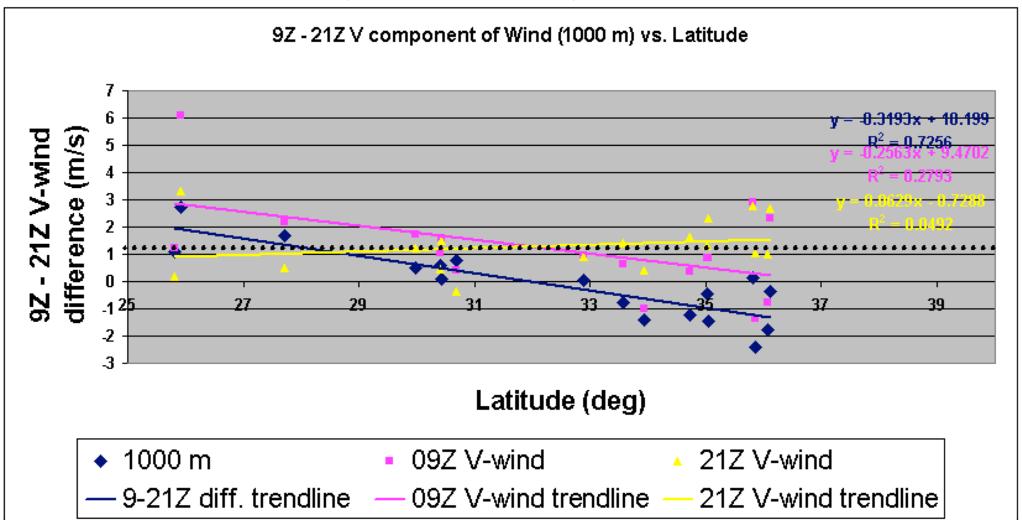


Fig. 2: Climatological wind arrows for southeast United States pibal stations. Black = 0300 UTC, red = 0900 UTC, green = 1500 UTC, light blue = 2100 UTC.

a)



b)

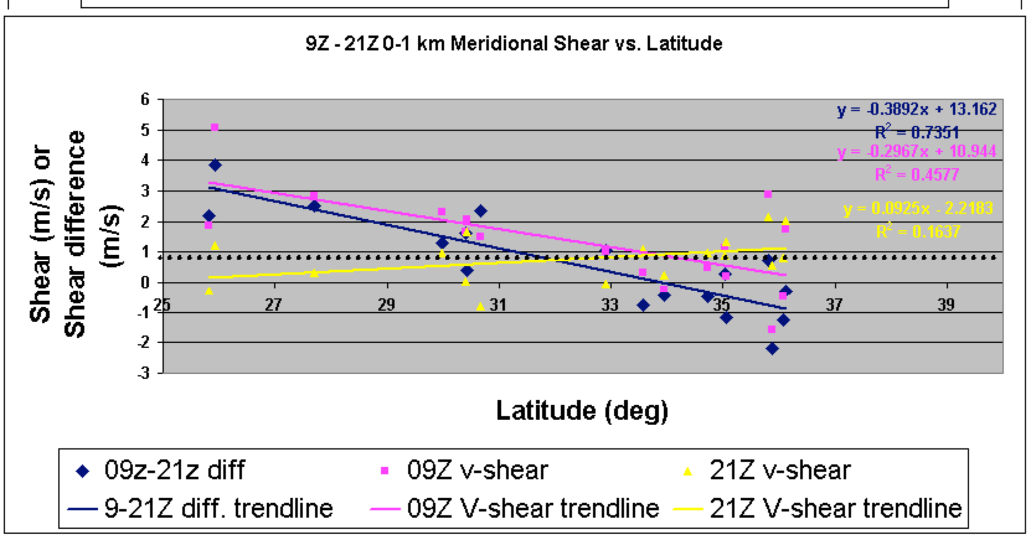


Fig. 3: a) Meridional wind vs. latitude for 0900 and 2100 UTC, and 0900-2100 UTC difference, b) 0-1 km meridional wind shear vs. latitude for 0900 and 2100 UTC, and 0900-2100 UTC difference.

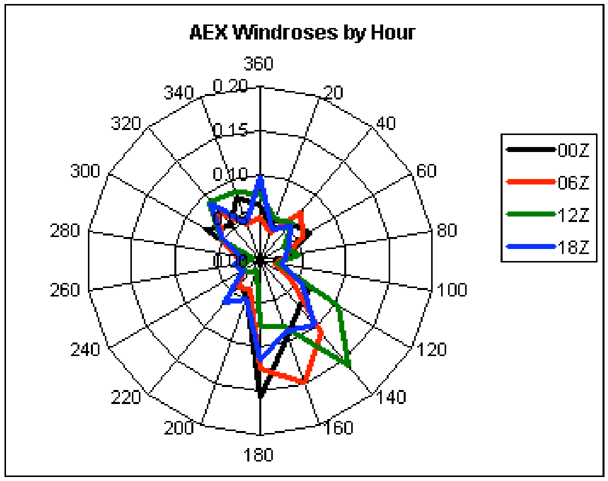
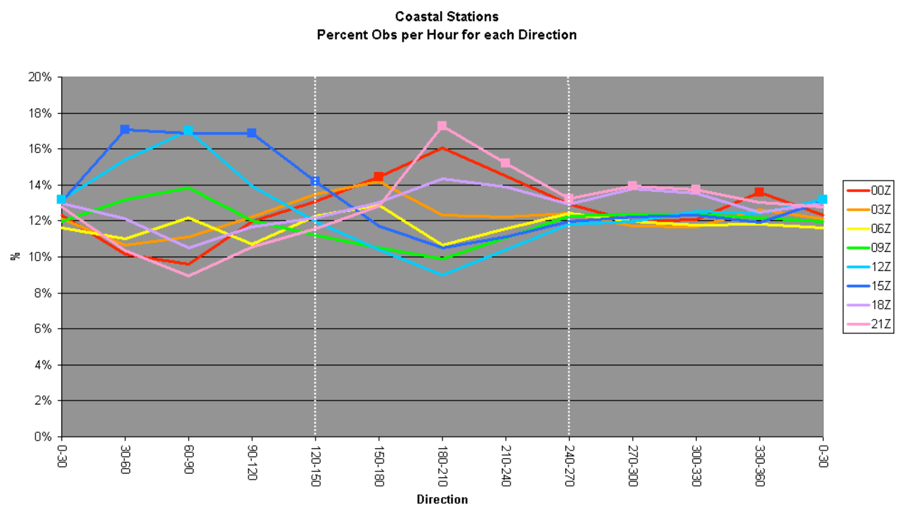


Fig. 4: Climatological windrose for AEX. Radial axis is percent of observations that were from that direction (.20 = 20%).



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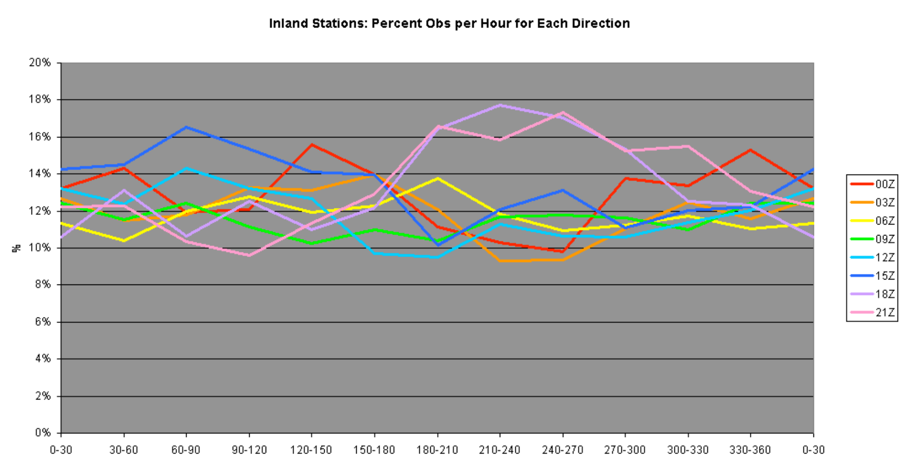

b)

Fig. 5: Percent of surface observations by hour (UTC) for 30 degree wind direction bins for a) coastal and b) inland stations.