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SECTION 1: SUMMARY OF PROJECT OBJECTIVES

This project is a continuation of work initiated during COMET Partners project number NA17WD2383. Severe convection which results in strong (F2 or greater) tornadoes has a cool-season maximum during the nocturnal hours along the Gulf Coast of the southeast United States (US). This study focused on understanding the physical mechanisms responsible for this phenomenon in order to increase the lead time and reduce the false alarm rate. Observational and gridded data, including radiosonde, surface, and pilot balloon data, were used to address questions such as: 1) What is the role of the Gulf of Mexico in destabilizing the planetary boundary layer prior to nocturnal convection? 2) What is the role of the nocturnal low-level jet in creating a favorable wind shear profile in the lowest 1 km?, and 3) How does the structure of nocturnal tornado episodes differ from those which occur during the day?

Results indicate that there is a climatological tendency for a 0-1 km shear profile favorable for supercells to occur overnight along the Gulf coast, due to the low-level jet at 1000 m and the tendency for surface winds to back from southerly to southeasterly at night. When a system with strong forcing for ascent (e.g., vigorous 500 hPa trough, upper-level jet streak, and 850 hPa jet > 15 m s^{-1}) and favorable thermodynamics (e.g., CAPE > 1000 J kg^{-1} and 850 hPa equivalent potential temperature > 335 K) moves across the southeast US, a nocturnal tornado episode near the Gulf coast can result.

Results of case studies emphasize the importance of surface boundaries in areas with favorable thermodynamic and shear profiles in serving as a focus for the intensification and organization of convection. The 22-23 February 1998 Florida tornado episode occurred ahead of a strong front where ample moist and unstable air was present and frontogenesis contributed to ascent as convective elements moved onshore. The null case of 29 November 2001 had many features necessary for a tornado episode: an upper-level jet entrance region, upstream trough, and low-level moisture and instability. However, due to factors such as the lack of surface-based CAPE and a unidirectional 0-6 km shear profile, the tornadic threat never materialized.

SECTION 2: PROJECT ACCOMPLISHMENTS/FINDINGS

Composites of all cool season southeast US tornado episodes from 1950 to 2001 created with the NCEP/NCAR reanalysis data were surprisingly robust and indicated a that there is a predominant large-scale pattern which is associated with cool season tornado episodes in this region. A large-amplitude 500 hPa trough is present, as is a very strong upper-level jet entrance region located at approximately 200 hPa (Fig. 1). Additionally, low-level warm air advection (at 850 hPa) and the associated veering wind profile contribute to a favorable wind shear profile for supercell development. The tornado episode tends to begin in the warm sector of the surface cyclone, which is consistent with previous work which shows that this region tends to have a favorable vertical wind shear profile for supercell development, especially in the southeast US (e.g., Bluestein and Banacos 2002). At night, the upper-level jet is > 5 m s^{-1} stronger and the precipitable water in the threat region is > 4 mm higher than during the day in the composites. In short, there tends to be more moisture and stronger forcing present for nighttime tornado episodes than daytime, the reasons for which need to be further investigated. Results of this study are consistent with previous research that indicates that most cool season tornadoes in this region are associated with strong extratropical cyclones (e.g., Hagemeyer 1997).

Surface composites of tornado episodes between 1995 and 2000 confirm the results of the large scale composite that suggested more moisture is present during nighttime tornado episodes than daytime episodes. Dew point anomalies in the threat region were > 2 °C higher at night than during the day. Additionally, results of the surface composites suggest that there are much stronger thermal gradients present at night. In particular, the +4 °C and +8 °C temperature anomaly contours are separated by < 1° (> 2 °) of latitude during nighttime (daytime) tornado episodes at the location where the tornado episode begins (Fig. 2a). By thermal wind balance arguments, a tighter temperature gradient at low-levels at night is consistent with the stronger upper-level jet (by > 4 m s^{-1}) observed in the nighttime large-scale composite. Previous research has documented the importance of mesoscale surface boundaries in the development of tornadic convection (e.g., Maddox et al. 1980; Markowski et al. 1998), and the results of this study affirm the importance of these features in the development of cool season tornadoes in the southeast US (Fig. 3). Results suggest that given a favorable synoptic-scale setup for cool season tornadoes in the Southeast, the tornado episode will tend to begin where the most favorable dynamics and thermodynamics overlap at or just ahead of a mesoscale thermal boundary at the surface.

The climatology of surface and pilot balloon (pibal) wind data provided insight as to why the nocturnal tornado phenomenon is more prevalent in coastal regions along the Gulf of Mexico coast than regions farther inland. The southerly nocturnal low-level jet (at ~ 1000 m) tends to increase the southerly flow along the Gulf coast more at night than at stations further inland. For example, at ~ 26 °N (~ 36 °N), the 1000 m wind difference between 0900 UTC (night) and 2100 UTC (day) is + 2 m s^{-1} (-1.5 m s^{-1}). In other words, the 1000 m wind tends to increase (decrease) at night along the Gulf coast (well inland). This coastal low-level jet signal may be enhanced by the return branch of the land breeze circulation (e.g., Rotunno 1983; Maddox 1993) in the immediate vicinity of the Gulf coast, although this hypothesis needs further investigation. Additionally, the stronger cooling over the continent versus the Gulf of Mexico tends to superimpose a geostrophic easterly wind component on the surface winds along the Gulf coast, which results in a tendency for surface winds to 'back around' to a more easterly direction at night in the climatology (Fig. 4). The combination of stronger (weaker) southerly nocturnal low-level jet at ~ 1000 m and more (less) backed, or easterly, winds at the surface along the coast (inland) at night contribute to a climatologically favorable 0-1 km wind shear profile for supercell development along the coast at night (Fig. 2b). In particular, low-level (0-1 km) veering (due to backed surface winds) and speed shear (due to a strong increase in the 1000 m low-level jet) help to create the favorable clockwise 'quarter-turn' hodograph along the Gulf coast at night (e.g., Weisman and Klemp 1982; Wicker and

Wilhelmson 1995). The net result of the stronger low-level winds and backed surface flow at night would be to increase the curvature of the hodograph in the lowest 1 km. Wicker (1996) showed that increased clockwise curvature in the lowest < 1km can result in stronger, longer-lived low-level mesocyclones than in situations where the hodograph is less curved. The rotation of the horizontal vorticity vector so that it is oriented in the same sense as the baroclinic generation of horizontal vorticity in the forward-flank downdraft results in maximized stretching and tilting of horizontal vorticity about a vertical axis in the updraft (Wicker 1996). Thus, this climatological tendency towards a more clockwise curved hodograph (in the lowest 1 km) at night may help explain the tendency for nocturnal tornadoes to occur preferentially along the Gulf coast, as this signal is not present further inland, away from the Gulf coastline.

Two case studies were completed during the course of this research: the 22-23 February 1998 central Florida tornado outbreak, as well as the 29 November 2001 null event which was forecasted to occur across Mississippi and Alabama. The contrasting case studies of the 22-23 February 1998 central Florida tornado episode and the 29 November 2001 null event highlight the difficulty of applying the results of the composite tornado episodes to real-time forecasts.

Results of case studies emphasize the importance of surface boundaries in areas with favorable thermodynamic and shear profiles in serving as a focus for the intensification and organization of convection. The 22-23 February 1998 Florida tornado episode occurred ahead of a strong front where ample moist and unstable air was present and frontogenesis contributed to ascent as convective elements moved onshore. The 29 November 2001 null event had many ingredients present which were similar to the large-scale composite tornado episode, such as a large 500 hPa trough, a strong surface front, and an 850 hPa low-level jet. However, certain features were absent which prevented the anticipated tornado episode from occurring, such as the lack of surface-based CAPE where ascent was maximized and the unidirectional shear profile due to the southerly (rather than southeasterly) surface winds. Subtle features such as these can often be keys to correctly distinguishing between null events and true threats. While the results of this research will certainly aid forecasters in anticipating potential tornado threats with increased lead time, relaying the threat level properly to the public in the short-term forecast will still be difficult.

A paper entitled "Mesoscale Aspects of the Rapid Intensification of a Tornadic Convective Band across Central Florida: 22-23 February 1998" by Wasula et al. has been submitted to *Weather and Forecasting* and is currently in review.

Co-authors include all participants involved in this project. The paper details a case study of the 22-23 February 1998 central Florida tornado outbreak, one of the deadliest in Florida's history. Special focus is given to the interaction of the convective band with a diabatically-driven front that was present across the Florida peninsula at the time of the event. Observational and numerical model North American Model (NAM, previously Eta) data are used to provide evidence that strong frontogenesis and vorticity generation in the vicinity of this thermal boundary helped to rapidly intensify the convective system as it made landfall after dark on the Florida peninsula. Additionally, discussion of the failure of the Eta model (re-run with both Kain-Fritsch and Betts-

Miller-Janic convective schemes) to accurately maintain the diabatic cooling to the north of the front, and thus ‘wash out’ this key feature, is presented.

Ongoing work involves preparation of another manuscript, to be submitted to *Weather and Forecasting*, detailing the results of the large-scale composite portion of this research. Additionally, Alicia Wasula passed her doctoral thesis defense on 13 July 2005 and was awarded her Ph.D. degree in August 2005.

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SECTION 3: BENEFITS AND LESSONS LEARNED: OPERATIONAL PARTNER PERSPECTIVE

The NWS found that regular communication via conference calls between participating members of this project combined with the web page dedicated to emerging research results (http://www.atmos.albany.edu/student/alicia/phd.htm) were sufficient to allow robust sharing of data and discussion of results. Meetings at national AMS conferences and several visits by the investigators to Norman Oklahoma were also critical to the collaborative research and worked well.

A seminar was held by University at Albany researchers at the NWS Storm Prediction Center that was well attended by forecasters and served to both educate SPC forecasters on the initial research results, and guide University at Albany researchers toward research lines of direct interest to NWS forecast operations. In addition, the University at Albany web site has proved an important vehicle for education of the entire SPC forecast staff on the climatological characteristics of the cool-season tornado threat over the Southeast United States despite the difficulties of communication in a 24x7 shift work environment. The SPC and its NWS partners have encountered no significant problems in our interaction with University at Albany researchers.

SECTION 4: BENEFITS AND LESSONS LEARNED: UNIVERSITY PARTNER PERSPECTIVE

Regular communication via conference calls between participating members of this project and maintenance of a Web page (http://www.atmos.albany.edu/student/alicia/phd.htm) has helped to facilitate sharing of data and discussion of results. An unexpected benefit to this research occurred due to contact with National Weather Service employees at the 84th annual AMS meeting in Seattle, WA, 12-15 January 2004. The Science Operations Officer (SOO) at the National Weather Service Forecast Office in Charleston, SC, attended the presentation given on the results of this research. He was particularly interested in the climatology of tornadoes in the Southeast US, particularly for his forecast area, which includes southern South Carolina and northeast Georgia. As per his request, a climatology of cool-season tornadoes was completed for this particular area in the Southeast and posted on a web page (http://www.atmos.albany.edu/student/alicia/chs.html) for use by the Charleston, SC, NWS office. A number of visits by University at Albany participants to the SPC were very useful. Personal communication at meetings with grant participants was invaluable in discussion of results and sharing of new ideas, and a seminar given by Alicia Wasula as well as meetings with various SPC and National Severe Storms Laboratory (NSSL) forecasters and researchers provided an informal forum at which to discuss preliminary results and ideas for future research.

SECTION 5: PRESENTATIONS AND PUBLICATIONS

Wasula, A. C., L. F. Bosart, R. Schneider, S. J. Weiss, R. H. Johns, G. Manikin, and P. Welsh: The diurnal variation of synoptic scale structure of cool season tornado episodes in the southeast United States. *Weather and Forecasting*, to be submitted in early 2006.

a) Wasula, A. C., 2005: A multiscale analysis of the 24 November 2004 Southeast United States cool season tornado outbreak. *7th Northeast Regional Operational Workshop*, 1-2 November 2005, Albany, NY.

b) Wasula, A. C., L. F. Bosart, R. Schneider, S. J. Weiss, R. H. Johns, G. Manikin, and P. Welsh, 2004: Mesoscale aspects of the rapid intensification of a tornadic convective band across central Florida: 22-23 February 1998. *Weather and Forecasting*, submitted 12/04.

c) Wasula, A. C., L. F. Bosart, R. Schneider, S. J. Weiss, and R. H. Johns, 2004: Cool season tornadoes in the southeast United States: A climatological and case study perspective. *Preprint CD-ROM, 20th Conf. on Wea. and Forecasting*, American Meteorological Society , 11-14 Jan 2004, Seattle, WA.

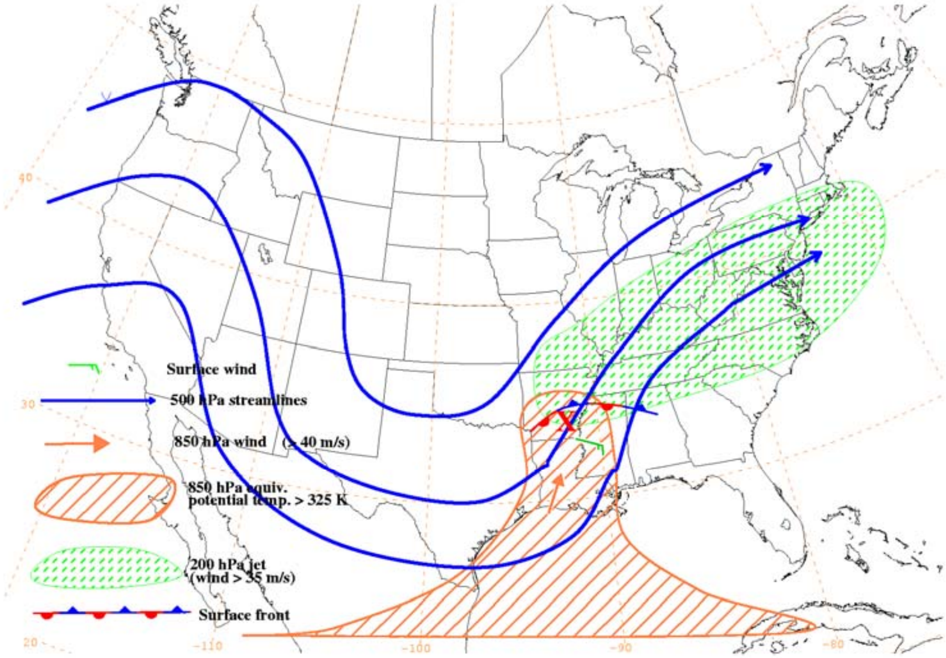
d) Wasula, A. C., L. F. Bosart, R. Schneider, S. J. Weiss, R. H. Johns, G. Manikin, and P. Welsh, 2004: The structure and climatology of boundary layer winds in the southeast United States and its relationship to nocturnal tornado episodes. *Preprint CD-ROM, 22nd conference on Severe Local Storms*, American Meteorological Society, 4-8 October 2004, Hyannis, MA.

e) Wasula, A. C., L. F. Bosart, R. Schneider, S. J. Weiss, and R. H. Johns, 2003: Mesoscale aspects of the rapid intensification of a tornadic squall line across central Florida: 22-23 February 1998. *Preprint* CD-ROM, 10th Conference on Mesoscale Processes, American Meteorological Society, 23-27 June 2003, Portland, OR.

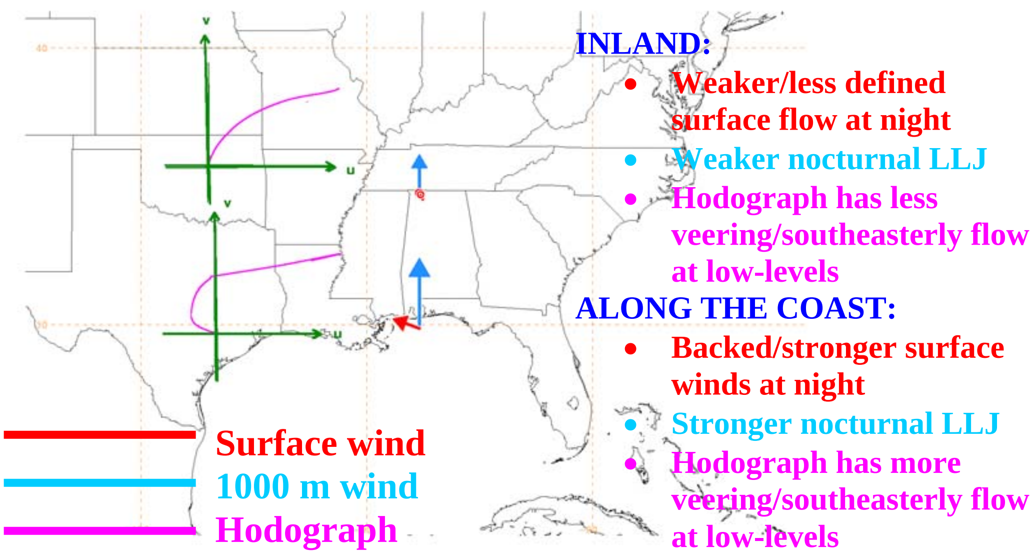
SECTION 6: SUMMARY OF UNIVERSITY/OPERATIONAL PARTNER INTERACTIONS AND ROLES

Personal communication at meetings with grant participants was invaluable in discussion of results and sharing of new ideas, and a seminar given by Alicia Wasula as well as meetings with various SPC and National Severe Storms Laboratory (NSSL) forecasters and researchers provided an informal forum at which to discuss preliminary results and ideas for future research.

The NWS Storm Prediction Center and Environmental Modeling Center were both pleased with the level of collaboration and coordination during the lifetime of this grant. The Albany research team kept in touch through a combination of conference calls, email, a comprehensive web site and select high value interactions in person. Through a combination of an on site seminars and the diverse web site resources, the results of the research have been effectively transferred to NWS forecast operations.

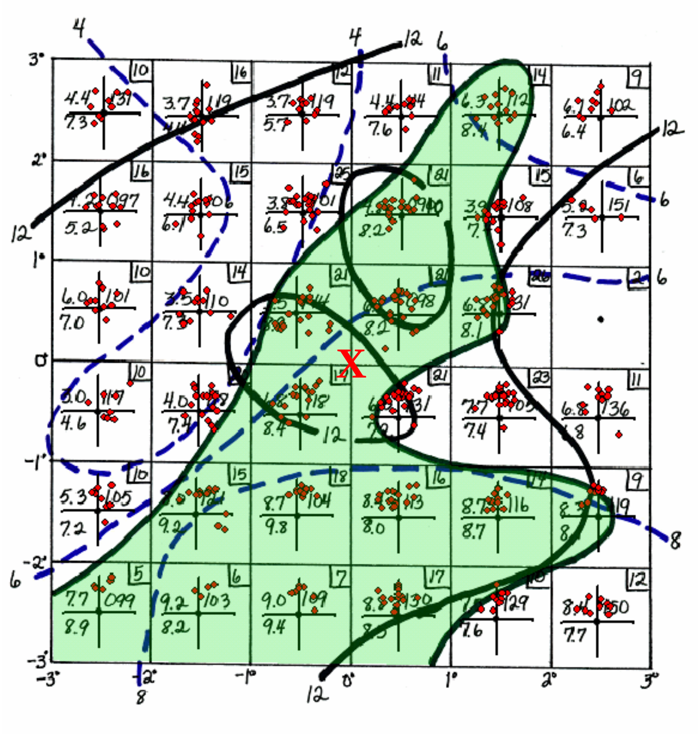


a) **TORNADO THREAT SCHEMATIC**

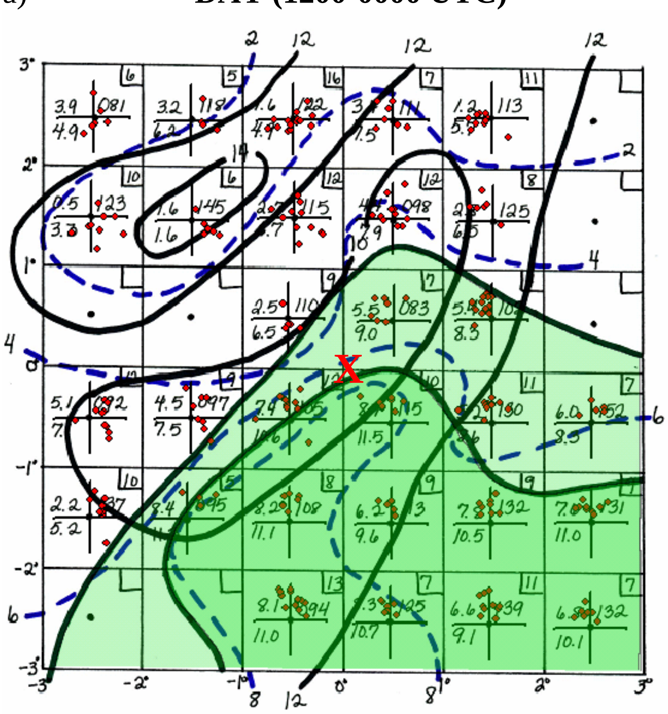


b) **LOW-LEVEL WIND CLIMATOLOGY**

Fig. 2: a) composite tornado threat setup for southeast US. Red 'X' in b) indicates threat region. b) schematic depicting coastal vs. inland low-level nocturnal wind climatology for the surface (red) and 1000 m (blue), as well as representative climatological hodographs for coastal (top) and inland (bottom) stations.



a) **DAY (1200-0000 UTC)**



b) **NIGHT (0000-1200 UTC)**

Fig. 2: Temperature anomaly (every 2 °C, blue dashed), dew point anomaly (shaded, > 8 °C light green, > 10 °C dark green), sea level pressure (every 2 hPa, black solid), and windroses for a) daytime and b) nighttime tornado episodes at t=0 h. Legend is shown to right of plot. Number of cases in each box (n) indicated in small box in top right corner, except where n < 5. Red 'X' denotes first tornado report. u and v axes extend +/- 10 ms^{-1} from center.

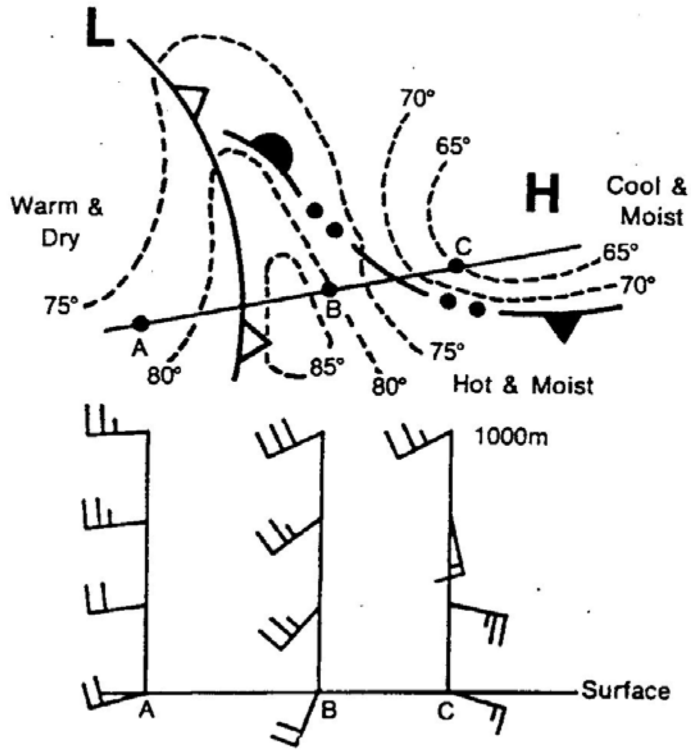
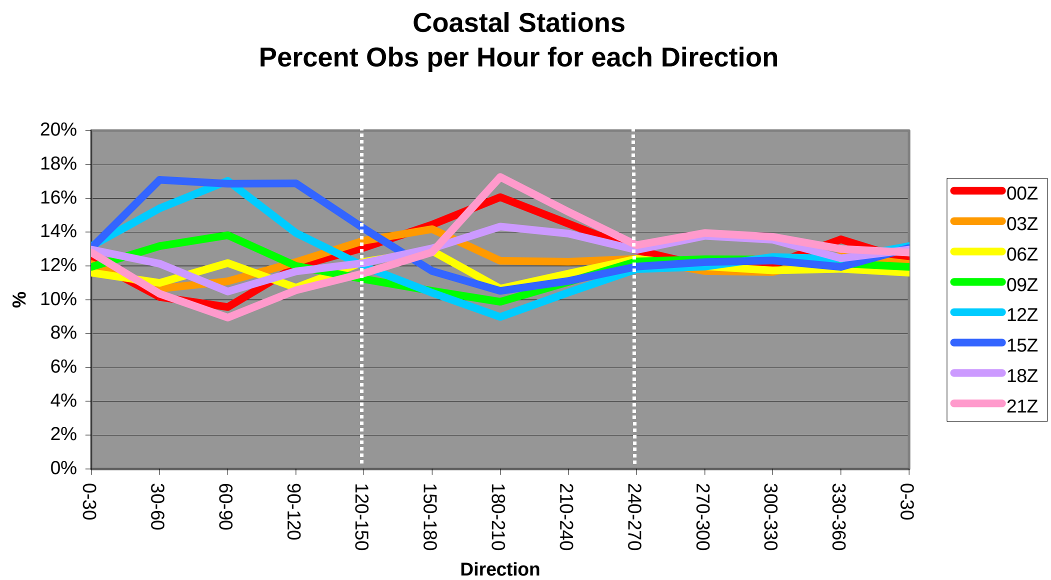
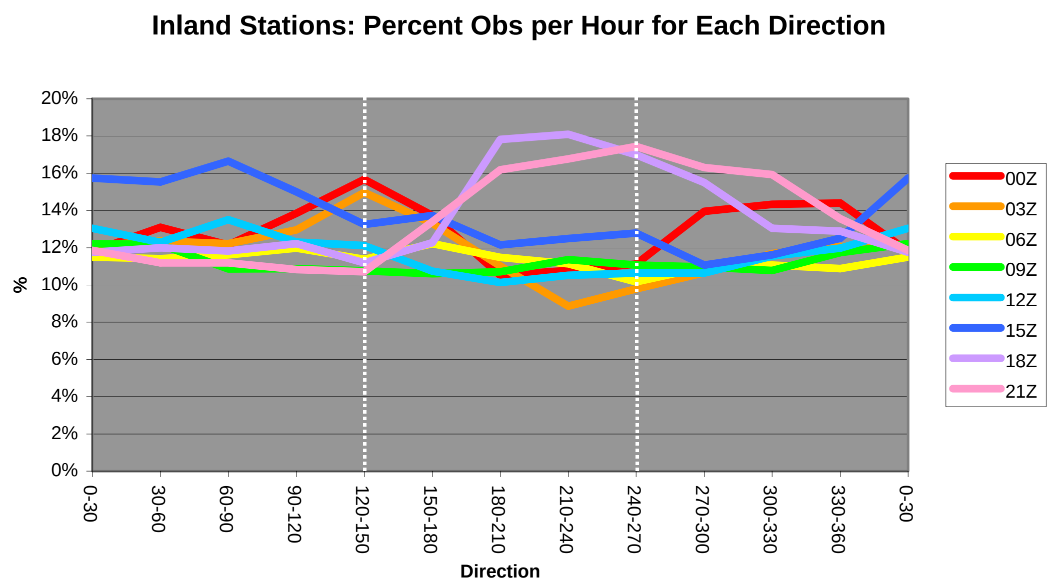


Fig. 3: Conceptual model of flow near a boundary (after Maddox et al.1980).



a) **n=16**



b) **n=17**

Fig. 4: Hourly breakdown (by percent) of surface observations by wind direction. Number of stations used in each plot is indicated at bottom left.