P1.57 GOES WMSI – PROGRESS AND DEVELOPMENTS

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1. INTRODUCTION

A multi-parameter index has been developed to assess the magnitude of convective downbursts associated with heavy precipitation-producing, deep convective storm systems that occur over the central and eastern continental United States. The Wet Microburst Severity Index (WMSI) is composed of relevant parameters that represent the simultaneous physical processes of convective updraft development and downburst generation, incorporating convective available potential energy (CAPE) and the vertical equivalent potential temperature (θ_e) difference between the surface and the mid-troposphere (Pryor and Ellrod 2004). The WMSI algorithm is given as the following expression: WMSI = (CAPE)($\Delta\ \theta_e$)/1000. $\Delta\ \theta_e = \theta_{emax} - \theta_{emin}$, where θ_{emax} refers to the maximum value of θ_e at the surface and θ_{emin} refers to the minimum value of theta-e in the midlevels of the troposphere (Atkins and Wakimoto 1991) . The Geostationary Operational Environmental Satellite (GOES) WMSI product, as displayed in Figure 1, ingests atmospheric sounding data (i.e., temperature and dew point) provided by satellite retrievals. The WMSI algorithm is designed for use during the warm season, specifically from 1 June to 30 September. Pryor and Ellrod (2004) found that there exists a statistically significant correlation between GOES WMSI and the magnitude of observed surface wind gusts for both daytime (r = 0.66) and nighttime (r = 0.64) events during the warm season.

In addition to large CAPE and a significant θ_e difference, previous research has identified other favorable conditions for severe downbursts during cold-season deep convection events. A primary factor in downburst magnitude associated with cold-season, forced convective systems is the downward transport of higher momentum, possessed by winds in the mid-troposphere, into the planetary boundary layer. Sasaki and Baxter (1986), in their analysis of convective storm morphology and dynamics, identified that downward transfer of entrained momentum from the strong environmental flow aloft was primarily responsible for the generation of strong surface winds. The authors note that descending evaporatively cooled air tends to carry the horizontal momentum that it had at its original level. Duke and Rogash (1992) continued this study by analyzing a severe, downburst-producing squall line that occurred in April 1991. This study also identified that downward transport of higher momentum, possessed by winds in the middle troposphere, by convective downdrafts was a major factor in the strength of surface outflow. Downward momentum transport is important when parcels, in an elevated dry (or low θ_e) layer, conserve horizontal wind velocities as they become negatively buoyant and descend into the boundary layer. A significant additional finding was that wind directions associated with the surface convective wind gusts would suggest a contribution from downward momentum transfer. The authors contrasted this finding with the situation in which weak winds aloft were associated with considerable variability in surface wind gust direction. Wakimoto and Bringi (1988) have noted that surface convective wind gusts, under those circumstances, radiate from the downburst impact area in a starburst pattern. Thus, the convective downburst process results in a positive vertical momentum flux in the boundary (sub-cloud) layer.

Accordingly, this paper will investigate the role of downward momentum transport in the magnitude of convective winds during the cold season. Product validation efforts will be discussed. Case

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studies, contrasting downburst-producing, warm and cold-season convective systems, will be presented. Finally, a modification to the use of the GOES WMSI will be explored to apply to cold-season forecasting situations.

2. METHODOLOGY

Data from the GOES WMSI was collected during the 2003 convective season from 29 July to 11 September and during the 2004 convective season from 2 June to 24 September for a total of 135 downburst events (89 daytime, 36 nighttime) and validated against conventional surface data. Data was also collected for the period from 24 November 2004 to 6 April 2005 to assess the performance of the WMSI product during the cold season. Validation was conducted in the manner described by Pryor and Ellrod (2004). In addition, GOES sounding profile data, most representative of the preconvective environment, was collected for each downburst event between 24 November 2004 and 6 April 2005. For each sounding, the height of the dry (low θ_e) layer was documented as well as wind velocity and direction in the low θ_e layer. Correlation between observed surface and dry layer winds, and between GOES WMSI values and observed surface wind gust velocities was computed for the period. In a similar manner to the warm season events, hypothesis testing was conducted to determine the statistical significance of the relationship between observed surface and dry layer winds and WMSI values.

3. VALIDATION

Validation, as presented in Table 1, determined that there exists a statistically significant correlation, and thus a strong positive linear relationship, between GOES WMSI and observed surface wind gusts for both daytime and nighttime events during the warm season. Also shown in Table 1, a strong relationship between surface and mid-tropospheric dry layer winds, during the cold season, was found to be associated with downburst events. Based on hypothesis testing, this relationship was determined to be statistically significant. However, the correlation between WMSI values and surface wind gust magnitude was much weaker and determined to be statistically insignificant. Based on previous research and the case studies presented later in this paper, the strong correlation between mid-tropospheric and surface winds suggested that downward transport of momentum from the midlevels of a convective storm environment to the surface played a major role in the downburst magnitude during this observation period.

Unlike during warm season events that are typically characterized by strong static instability and weak vertical wind shear, the absolute value of the WMSI is arbitrary during dynamically forced, cold season events. The significance of the WMSI is in its relation to the likelihood that instability is sufficient to result in updrafts that will lift the precipitation core to the mid-levels of the convective storm, whereby lateral entrainment will occur and result in downdraft acceleration.

4. CASE STUDIES

4.1 *Warm Season Event: 7 June 2004 East Texas Downbursts*

A multi-cellular cluster of deep convective storms developed over east-central Texas, near College Station, during the afternoon of 7 June 2004. The air mass in which the convective activity was developing was statically unstable, due to intense solar heating of the surface, as displayed by Figure 2a, the 1800 UTC GOES WMSI image. High WMSI values, as well as the presence of widespread towering cumulus convection, were an indicator of the strong instability in the region into which the convective cluster was propagating. Also apparent was the presence of a mid-tropospheric layer of dry (low θ_e) air that could be entrained into the downdraft of a mature convective storm and result in subsequent downdraft acceleration and downburst development.

By 1913 UTC, NEXRAD (KSHV) reflectivity imagery animation (not shown) displayed the evolution of the convective cluster into a bow echo (Przybylinski 1995) in the region of strong instability that was characterized by towering cumulus and moderate WMSI values between 50 and 80.

Downburst activity commenced upon development of the bow echo. The first observed downburst wind gust of 40 kt (21 m s^{-1}) occurred at Palestine at 1925 UTC, where a well-defined bow echo was indicated in radar reflectivity imagery. The bow echo continued to track to the northeast during the next hour into a progressively more unstable air mass with increasing WMSI values. At 2011, a stronger downburst wind gust of 55 kt (28 m s^{-1}) was observed at Tyler, where a considerably higher WMSI value of 172 was indicated.

In this case, large WMSI values implied the presence of large convective available potential energy (CAPE) as well as relatively dry air at mid levels that would result in evaporative cooling and the generation of large negative buoyancy as dry air was entrained into the convection cells (Pryor and Ellrod 2004). Wind profiler data between 1800 and 2030 UTC from nearby Cleburne, Texas (Figure 2b) displayed conditions typically expected over the southeastern United States during the summer season, most noteworthy, the presence of only weak wind speed shear in the low and middle levels of the troposphere. In fact, wind velocities near the low θ_e layer at the 700-mb level, were only near 20 kt (10 m s^{-1}). Compared to the magnitude of the downburst wind gusts observed at the surface, it is apparent that the role of downward momentum transport in this case was minimal. Therefore, in this typical warm season event, buoyancy and instability effects primarily drove downburst strength with negligible contribution from downward momentum transport.

4.2 *Cold Season Event: 30 March 2005 Severe Squall Line*

During the afternoon of 30 March 2005, a squall line developed over northern Missouri and southern Iowa ahead of negatively tilted upper-level short wave trough. The squall line intensified as it tracked east and northeastward into a moderately unstable air mass, producing several strong downbursts and wind damage over eastern Iowa, northern Illinois and southern Wisconsin. Associated with this dynamically forced system was a pre-convective environment that was characterized by strong wind shear in the low and middle levels of the troposphere, as inferred from the Davenport, Iowa GOES sounding profile displayed in Figure 3a. The downward transport, by the strong convective downdrafts, of higher momentum from the mid-troposphere to the surface most likely resulted in the strong winds produced by the squall line. The GOES WMSI image at 1800 UTC (not shown) displayed an area of elevated WMSI values, in excess of 50, extending from east-central Iowa to the Chicago metropolitan area as well as over central and west-central Illinois. The elevated WMSI values indicated significant potential instability and positive buoyancy to result in strong convective updrafts.

Over the next three hours, the squall line intensified as it moved northeastward. By 2000 UTC (Figure 3b), the atmosphere destabilized over western Illinois, as indicated by WMSI value of 66 near Moline. Positive vorticity advection (PVA) ahead of the short wave trough enhanced lifting and served as an initiating mechanism for deep convection. In addition, the negatively tilted trough, sloping in the direction opposite to the upper-level wind flow with latitude, provided favorable conditions for deep convective-storm activity by enhancing vertical circulation and static instability. In this image, a well-defined comma cloud signified the presence of the short wave trough. Deep convection was developing in the comma cloud “tail” where the environment was most potentially unstable.

Between 1900 and 2100 UTC, as shown in Table 2, significant downburst winds were observed at several reporting stations in the vicinity of the Iowa/Illinois border between Burlington and Dubuque. The strongest downburst wind gust of 51 kt (26 m s^{-1}) associated with the squall line was recorded at Clinton, Iowa at 2035 UTC.

In contrast to the warm season case, this downburst event was the result of strong synoptic-scale forcing in the presence of moderate convective instability. Also, as expected with this cold season case, strong vertical wind shear was in place with high winds and large momentum present in the mid-tropospheric dry air layer.

The entrainment of low θ_e air into the convective system resulted in evaporative cooling and the subsequent generation of negative buoyancy and downdraft acceleration. The intense downdrafts transported the higher momentum air from the midlevels of the troposphere to the surface, as was evidenced by the close correspondence between the velocity and direction of the mid-tropospheric (low θ_e layer) winds and wind gusts observed at the surface. This event demonstrated the importance of downward momentum transfer in the magnitude of downburst wind gusts associated with cold-season convective systems.

5. SUMMARY AND CONCLUSIONS

This study has identified an important relationship between GOES WMSI and downward momentum transport in cold-season deep convective storms. Based on a review of previous literature, and an analysis of real-time surface observations, GOES WMSI product imagery and GOES sounding data for 14 cold-season downburst events, it has been found that downward transport of higher momentum, possessed by winds in the mid-troposphere, into the boundary layer, is a major factor in downburst magnitude. This finding was exemplified by two case studies that contrasted warm and cold-season downburst events and thus, highlighted the role of downward momentum transport in the strength of convective wind gusts observed at the surface. During the cold season, the WMSI has been found to be effective in identifying regions of enhanced static instability and downburst potential. A strong correlation between surface and mid-tropospheric dry layer winds, as indicated by GOES sounding profiles, emphasized further the interconnection between downward momentum transfer and downburst magnitude. This study underscores the relevance of considering winds in the mid-tropospheric dry layer when using the GOES WMSI product to "nowcast" the magnitude of convective downbursts during the cold season.

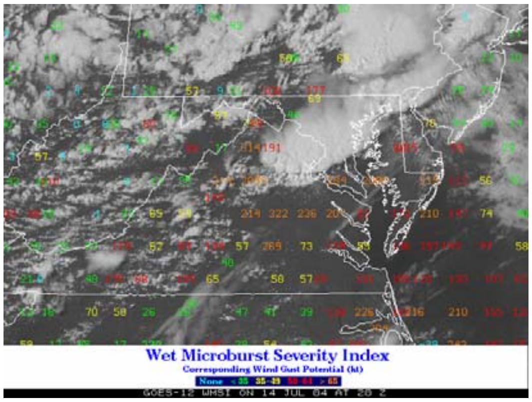

Figure 1. An example of a GOES WMSI image at 2000 UTC 14 Jul 2004.

6. REFERENCES

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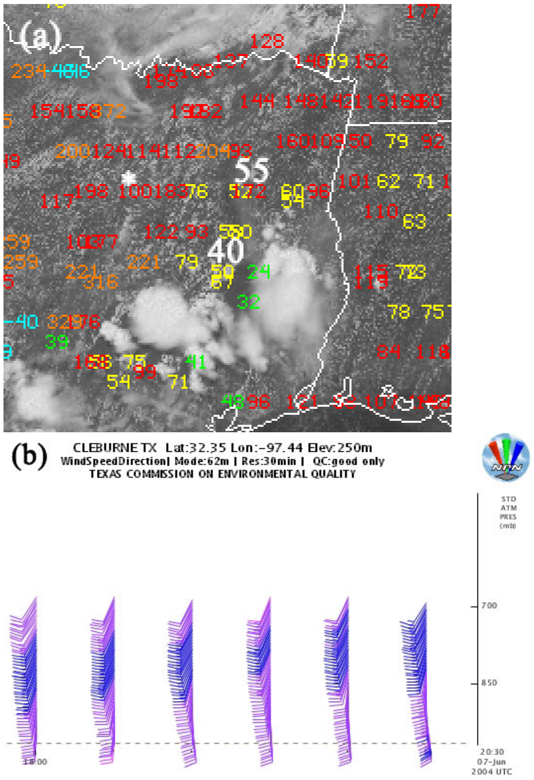

Figure 2. a) 1800 UTC 7 Jun 2004 GOES WMSI image. Location of Cleburne, Texas indicated by asterisk and b) 7 Jun 2004 wind profile (m s^{-1}) at Cleburne (from NOAA/FSL).

2003/04	Daytime (N=89)	Nighttime (N=36)
Correlation	.66	.64
2004/05 (N=14)	**Wind Speed**	**WMSI**
Correlation	.82	-.32

Table 1. Observed surface wind speed vs. WMSI (2003/04 warm seasons, 2004/05 cold season) and dry-layer wind speed (2004/05 cold season).

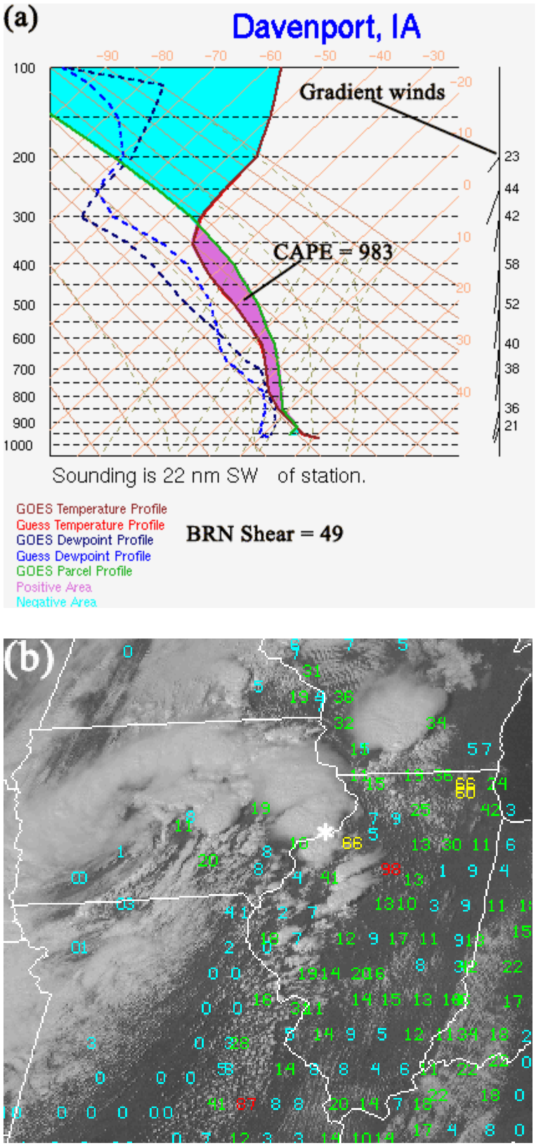

Figure 3. a) GOES sounding at Davenport, Iowa from 2000 UTC 30 Mar 2005 and b) 2000 UTC 30 Mar 2005 GOES WMSI image. Location of Davenport, Iowa indicated by asterisk.

Time (UTC)	Location	Surface Wind Speed	Surface Wind Direction	Dry Layer Wind Speed	Dry Layer Wind Direction
1904	Burlington, IA	41	200	48	220
2005	Moline, IL	45	270	52	200
2024	Dubuque, IA	37	220	50	220
2035	Clinton, IA	51	200	52	200

Table 2. Observed Surface Wind vs. Dry-layer Wind Speed (kt) for 30 March 2005.