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## Experimental GOES Sounder Products for the Assessment of Downburst Potential

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### ABSTRACT

Several experimental products derived from Geostationary Operational Environmental Satellite (GOES) Sounder retrievals (vertical profiles of temperature and moisture) have been developed to assist weather forecasters in assessing the potential for convective downbursts. The product suite currently includes the wind index (WINDEX), a dry microburst index, and the maximum difference in equivalent potential temperature ( $\theta_e$ ) from the surface to 300 hPa. The products are displayed as color-coded boxes or numerical values, superimposed on GOES visible, infrared, or water vapor imagery, and are available hourly, day and night, via the Internet. After two full summers of evaluation, the products have been shown to be useful in the assessment of atmospheric conditions that may lead to strong, gusty surface winds from thunderstorms. Two case studies are presented: 1) a severe downburst storm in southern Arizona that produced historic surface wind speeds and damage, and 2) multiple dry and wet downbursts in western Kansas that resulted in minor damage. Verification involved comparing the parameters with radiosonde data, numerical model first guess data, or surface wind reports from airports, mesonetworks, or storm spotters. Mean absolute WINDEX from the GOES retrievals differed from the mean surface wind gust reports by  $<2$  kt ( $1 \text{ m s}^{-1}$ ) for 82 events, but underestimated wind gusts for 7 nighttime events by 22 kt ( $11 \text{ m s}^{-1}$ ). GOES WINDEX was also slightly better than that derived from the concurrent National Centers for Environmental Prediction's Eta Model first guess. There are plans to incorporate these downburst parameters into a future upgrade of the National Weather Service's Advanced Weather Interactive Processing System, with the option to derive them from either GOES Sounder data, radiosondes, or numerical model forecast data.

### 1. Introduction

The downburst is a localized high wind event generated by convective storms that can be extremely hazardous for aircraft during the takeoff and landing phases of flight. Although thunderstorm downdrafts were observed in detail during the Thunderstorm Project immediately after World War II (Byers and Braham 1949), the intensity and effects of large scale (4 to  $>100$  km) downbursts, and smaller scale ( $<4$  km), but powerful,

embedded microbursts were not fully realized until more than two decades later when commercial jet transports became prominent. Several significant aircraft accidents involving commercial jetliners, such as the one that occurred at New York's Kennedy Airport on 24 June 1975, were attributed by Fujita (1976, 1985) to the effects of microbursts on aircraft lift. Twenty-one such fatal accidents have been attributed to microburst "wind shear" from 1975 to 1994 according to the National Transportation Safety Board (Wolfson et al. 1994). The primary hazard to aircraft is a sudden shift from a strong headwind to a tailwind component on landing or takeoff, resulting in loss of lift, and possibly an aerodynamic "stall."

Studies of microbursts in the Front Range region of

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Colorado (e.g., Brown et al. 1982; Caracena et al. 1983; Wakimoto 1985), and in the southeastern United States (e.g., Atkins and Wakimoto 1991), using dense meso-scale surface and upper air networks, aircraft, and Doppler radar have identified two primary types: dry microbursts characterized by high cloud bases and little or no precipitation at the surface, and the wet microburst with its low cloud base, heavy precipitation, and reduced visibility. Atmospheric conditions typically associated with wet and dry microbursts have been identified based on these studies. Dry microburst conditions usually show a deep, nearly dry-adiabatic subcloud layer; a shallow moist layer near 500 mb; weak synoptic-scale forcing with only moderate [ $<50$  kt ( $26 \text{ m s}^{-1}$ )] winds aloft; and weak instability [lifted index (LI) usually  $>-2$  K] (Wakimoto 1985). Wet microburst conditions are highlighted by a shallow dry-adiabatic lapse rate in the subcloud layer, overlain by nearly moist-adiabatic conditions, moderate or strong instability [lifted index  $<-3$  K, convective available potential energy (CAPE) ( $>1500 \text{ J kg}^{-1}$ )], and the presence of relatively dry air at midtropospheric levels (above 500 hPa). The temperature and moisture profiles typical of wet microburst environments result in a strong vertical gradient of equivalent potential temperature ( $\theta_e$ ), which usually exceeds 20 K from near the surface to the middle troposphere (Atkins and Wakimoto 1991). While the physical process driving dry microbursts is generally considered to be subcloud evaporative cooling, that mechanism is quite weak for wet microbursts. A combination of "water loading," a negligible factor in dry microbursts, combined with midlevel evaporation near the melting level have been associated with wet microburst occurrence based on numerical sensitivity studies (Srivastava 1987; Proctor 1989). In some cases, intermediate environmental conditions exist, resulting in a "hybrid" type of microburst (Fujita 1985, Fig 5.1, p. 71; Ellrod 1989). Hybrid microbursts, such as the Dallas, Texas, storm on 2 August 1985, are likely driven by a combination of all of the processes described above, although specific thresholds have not yet been identified to differentiate them from the dry and wet environments.

Short-range warnings of downbursts can now be issued to pilots using data from the Terminal Doppler Weather Radars and Low-Level Wind Shear Alerting Systems that have been installed at numerous major airports across the United States (Wolfson et al. 1994). Despite our increased knowledge of the microburst phenomenon, and improved short-range detection by radar, occasional aircraft accidents still occur as a result of microbursts and downbursts. While some of these accidents may be related to factors such as aircrew decisions, navigational aids, etc, there remains a need for additional short-range (1–3 h) forecast guidance that will bridge the gap between mesoscale numerical model predictions and radar warnings.

The use of data from the Geostationary Operational Environmental Satellite (GOES) Sounders in the as-

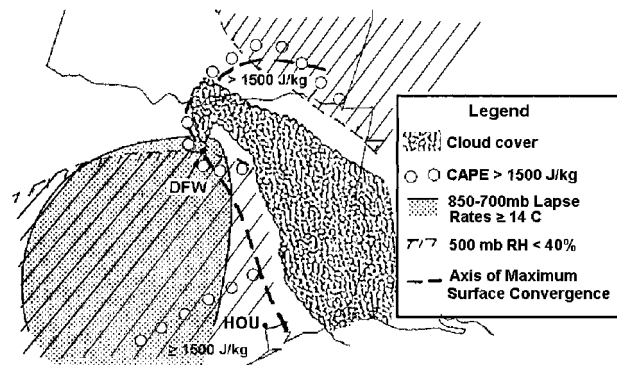


FIG. 1. Composite analysis of atmospheric microburst parameters on 2 Aug 1985. Regions of CAPE  $>1500 \text{ J kg}^{-1}$  (within circled lines), 850–700-mb lapse rates  $>14^\circ\text{C}$  (finely stippled area), and 500-mb RH  $<40\%$  (hatched lines) were determined from GOES-VAS sounder data at 2218 UTC. Surface convergence was obtained from objective analysis of surface station reports at 2200 UTC. Heavily stippled region is where extensive cloud cover prevented GOES soundings from being obtained.

essment of short-term potential for convective storms was first demonstrated in the early 1980s by the Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) Demonstration Project (Montgomery and Uccellini 1985; Mostek et al. 1986). Sounder data were observed to complement conventional surface and upper air data, and to show gradients of convective parameters that could not be determined otherwise. Further work (Zehr et al. 1988) corroborated these findings and showed how VAS data could be used in an operational forecast environment.

The first use of VAS Sounder data to specifically assess downburst potential was described by Ellrod (1989, 1990) using data for the Dallas storm of 2 August 1985, and some cases from the Cooperative Huntsville Meteorological Experiment (Dodge et al. 1986) during the summer of 1986. The meteorological parameters that were found to be most useful in the analysis of wet microburst conditions were nearly dry-adiabatic subcloud lapse rates ( $\text{K km}^{-1}$ ), high CAPE ( $>1500 \text{ J kg}^{-1}$ ), a large vertical difference of equivalent potential temperature ( $\theta_e$ ,  $>20$  K), and low middle-tropospheric (500 hPa) relative humidity ( $<40\%$  RH). An example of how some of these sounder-derived parameters can be synthesized is shown in Fig. 1 using GOES data about 1 h prior to the Dallas microburst storm. The coincidence of suitable values of these parameters in the vicinity of Dallas–Fort Worth showed that it is possible to diagnose the potential for these storms using satellite sounder data to complement information from surface reporting networks, satellite imagery, and numerical prediction models.

Products derived from the current series of GOES Sounders are now being used more extensively in the operational forecasting environment (Menzel et al. 1998). Part of the reason for this is that the GOES I–M Sounder system has been improved considerably over

TABLE 1. GOES Sounder channel characteristics.

Channel	Detector/absorption	Spectral peak ( $\mu\text{m}$ )	Purpose
1	Longwave	14.71	Stratosphere temperature
2	Longwave	14.37	Tropopause temperature
3	Longwave	14.06	Upper-level temperature
4	Longwave	13.96	Midlevel temperature
5	Longwave	13.37	Low-level temperature
6	Window	12.66	Total PW
7	Window	12.06	Surface temperature, PW
8	Window	11.03	Surface temperature
9	Ozone	9.71	Total ozone
10	Water vapor	7.43	Low- to midlevel moisture
11	Water vapor	7.02	Midlevel moisture
12	Water vapor	6.51	Mid- to upper-level moisture
13	Shortwave	4.57	Low-level temperature
14	Shortwave	4.52	Mid-level temperature
15	Shortwave	4.45	Upper-level temperature
16	Nitrogen	4.13	Boundary layer temperature
17	Shortwave window	3.98	Surface temperature
18	Shortwave window	3.74	Surface temperature, moisture
19	Visible	0.67	Clouds

the previous GOES-VAS system (Menzel and Purdom 1994). Major improvements include 1) better signal to noise ratio in radiance measurements, 2) an independent sounder system leading to improved temporal continuity, and 3) the addition of four infrared (IR) channels and a low-resolution visible channel for verifying cloud-free fields of view. Table 1 describes the GOES I-M Sounder channels, their characteristics, and primary applications.

Vertical profiles of temperature and dewpoint retrievals are routinely obtained from the GOES I-M Sounder instruments by means of an improved, nonlinear simultaneous temperature and moisture physical retrieval technique (Ma et al. 1999). In this technique, first guess profiles of temperature and moisture are obtained from a numerical model forecast, with analyses of surface temperature and moisture serving as a lower boundary for the retrievals. Radiative transfer equations are then iteratively solved until the calculated radiances match those observed by the satellite radiometers in each channel, after updated bias adjustments are applied.

Like radiosonde measurements, retrievals can be used to sense the current state of the atmosphere, including evaluations of atmospheric stability and other quantities pertinent to aviation or convective nowcasting. The advantages of GOES retrievals are their relatively high resolution in time (hourly) and space (a  $3 \times 3$  pixel array covers  $30 \text{ km} \times 30 \text{ km}$  in area). The disadvantages are that infrared satellite retrievals can only be obtained under clear or partly cloudy conditions, and the vertical resolution is coarse, so that temperature inversions are sometimes undetected, or poorly defined. However, in the analysis of the many convective environments, a lack of cloudiness is an important precursor to storm development, so loss of retrievals due to clouds is not as detrimental as one might otherwise suppose. Recent experiments have also shown that single field-of-view

retrievals can be obtained that are expected to greatly increase available sounding coverage in cloudy regions.

The National Environmental Satellite, Data, and Information Service (NESDIS) is conducting research on the use of products derived from GOES retrievals to determine whether atmospheric conditions are conducive to convective microbursts or larger-scale downbursts (for the duration of this paper, the latter will be used in most cases as a generic term to cover strong convective downdrafts across all scales). During the convective seasons of 1997–99, three experimental downburst products from *GOES-8/9/10* retrievals were evaluated. This paper will describe the rationale behind the products, display formats, two case study examples, and a preliminary assessment of product quality.

## 2. Description of products

Three experimental GOES microburst products have been generated: one to determine the maximum possible convective wind gusts, and two others to assess conditions relevant to dry (accompanied by little or no precipitation) or wet microbursts. The products rely heavily on prior research on the microburst phenomenon. A complete summary of microburst environmental conditions considered in the development of these products is provided by Nelson and Ellrod (1997).

### a. Wind index

The wind index (WINDEX) is a relatively new parameter that was developed by McCann (1994), based on prior research by Wolfson (1990), Proctor (1989), and Srivastava (1985). The purpose of WINDEX is to provide guidance on the maximum possible wind gusts that can occur with existing atmospheric conditions, if convection were to occur. This type of guidance is im-

portant in producing short-range warnings and forecasts for both the public and aviation community. WINDEX was derived using the vertical equations of momentum and continuity with some simplifying assumptions. The formulation of WINDEX is as follows:

$$WI = 5[H_M R_Q (\Gamma^2 - 30 + Q_L - 2Q_M)]^{0.5}, \quad (1)$$

where WI = maximum wind gusts (kt) at the surface,  $H_M$  = height above ground of melting level (km),  $R_Q = Q_L/12$  but not  $>1$ ,  $\Gamma$  = lapse rate ( $^{\circ}\text{C km}^{-1}$ ) from the surface to the melting level,  $Q_L$  = mean mixing ratio ( $\text{g kg}^{-1}$ ) in lowest 1 km, and  $Q_M$  = mixing ratio ( $\text{g kg}^{-1}$ ) at melting level.

The melting-level height ( $H_M$ ) is an important factor in the generation of strong surface wind gusts because, within convective downdrafts, it is the altitude where cooling due to phase change occurs. While the latent heat lost due to melting is relatively small, the cooling process occurs rapidly, thus providing a strong impetus in downdraft generation. That process continues via evaporative cooling in an unsaturated subcloud layer, resulting in significant negative buoyancy, and strong downdraft winds that may reach the surface.

The WINDEX is a quantitative parameter that employs some simplifying assumptions, such as a linear dependence between outflow speed and vertical lapse rate, and other approximations. The multiplicand 5 in the WINDEX equation converts the wind gust values to knots. The  $R_Q$  factor adjusts the WI for overestimation within dry low-level (i.e., dry microburst) environments (McCann 1994). This correction accounts for situations where all of the precipitation evaporates, and the descending downdraft is very weak, perhaps not reaching the surface at all. The subtractand value 30 is approximately  $5.5^2$ , which is the lowest lapse rate capable of producing microbursts in numerical model simulations, according to Srivastava (1985). When the quantity  $(\Gamma^2 - 30 + Q_L - 2Q_M)$  is less than or equal to 0, WI is set to zero. The maximum wind gust values are conditional upon the occurrence of convection and, thus, will not be observed in many areas. WINDEX may be used in any type of microburst environment (wet, dry, or hybrid).

#### b. Dry microburst index

Dry microbursts occur in situations characterized by high convective cloud bases and strong evaporational cooling in the subcloud layer, resulting in little or no precipitation at the surface. Such conditions are common in the mountainous western United States and the high plains region. For these types of conditions, a dry microburst index (DMI) was developed (Ellrod and Nelson 1998), based on conditions observed primarily in the Denver, Colorado, area (e.g., Wakimoto 1985). The DMI is defined as

$$DMI = \Gamma + (T - T_d)_{700} - (T - T_d)_{500}, \quad (2)$$

where  $\Gamma$  = lapse rate ( $^{\circ}\text{C km}^{-1}$ , 700–500 hPa),  $T$  = temperature ( $^{\circ}\text{C}$ ), and  $T_d$  = dewpoint ( $^{\circ}\text{C}$ ). Based on prior research, the DMI should be  $\geq 6$  for dry microbursts to occur, although firm thresholds have not been established. The DMI is not calculated for any retrieval unless all three of the following criteria are satisfied: 1)  $\Gamma > 6 \text{ K km}^{-1}$ , 2)  $(T - T_d)_{700} \geq 8 \text{ K}$ , and 3)  $(T - T_d)_{500} \leq 8 \text{ K}$ . These constraints assure that appropriate conditions are present, and help prevent the second term of the equation from overwhelming the other two, possibly creating a false positive indicator for dry microbursts. The magnitude of the DMI has not been correlated with the maximum wind speeds associated with dry microbursts, so it is not known if such a relationship exists. DMI is currently produced from *GOES-10* data for the western United States and from *GOES-8* for the high plains region of the central United States.

An important consideration in deciding whether a dry microburst may occur is the strength of the convective updrafts. There is evidence that weak updrafts (characterized by slightly negative LI values and small CAPE) result in small rimed snowflakes that evaporate very quickly [as proposed by Brown et al. (1982) and verified by subcloud measurements by Rodi et al. (1983)]. Although the DMI does not yet consider CAPE as a limiting factor, CAPE is a GOES-derived Souder product that is easily accessible via the Internet from NESDIS<sup>1</sup> and will soon become operationally available to National Weather Service (NWS) forecasters. The NWS Storm Prediction Center currently uses a CAPE value of  $50 \text{ J kg}^{-1}$  as a minimum threshold in assessing the likelihood of “dry” thunderstorms that may trigger wildfires. Use of DMI and CAPE together should be helpful in evaluating the potential risk of dry microbursts on a given day.

#### c. Maximum vertical theta-e ( $\theta_e$ ) differential

The equivalent potential temperature ( $\theta_e$  or theta- $e$ ) is a measure of the total static energy (sensible heat, latent heat, and geopotential) in an atmospheric column. Due to its strong dependence on moisture, theta- $e$  typically decreases rapidly with height above the boundary layer, reaching a minimum in the middle troposphere, then increases again into the upper troposphere and stratosphere due to the increase in potential temperature (with minimal amounts of moisture) at those levels. In situations described earlier where the environment is more favorable for wet microbursts, the maximum vertical theta- $e$  differential (hereafter referred to as TED) from the boundary layer to the middle troposphere can be very large, sometimes exceeding 30 K (Atkins and Wakimoto 1991). Large values of TED have been noted

<sup>1</sup> The URL is <http://orbit35i.nesdis.noaa.gov/goes/soundings/skewt/html/skewtus.html>.

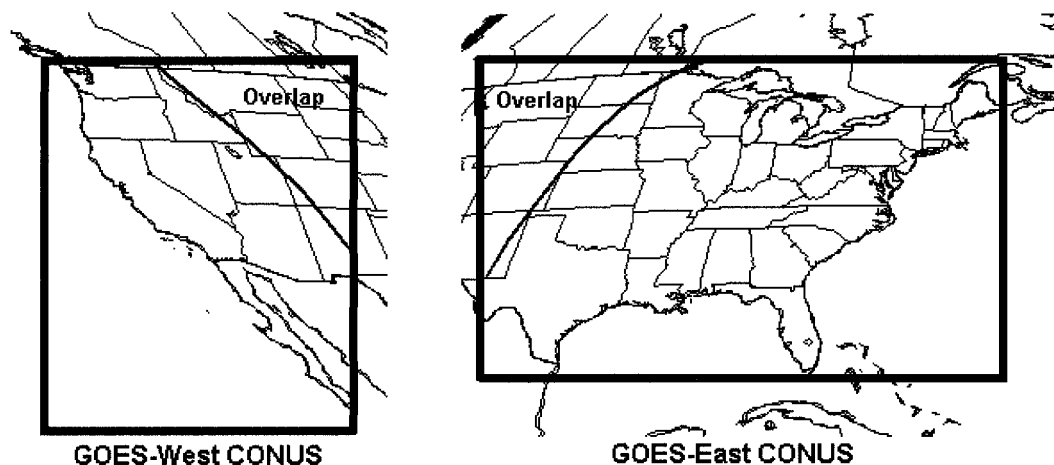


FIG. 2. CONUS sounder coverage from GOES-West (left) and GOES-East (right) in their native projections. Regions of overlapping coverage are shown.

to precede severe convection (Darkow 1968) and were sometimes associated with tornadoes. More recently, large values of TED have been associated with the occurrence of wet microbursts (Ellrod 1989; Atkins and Wakimoto 1991; Wheeler 1996). It should be noted that there are many situations where TED may be large and, yet, convection does not occur due to the presence of a capping inversion above the boundary layer.

At Cape Canaveral Air Station (CCAS), Florida, the maximum TED value from the surface to midtroposphere is used to forecast wet microburst activity (Wheeler and Roeder 1996). CCAS is responsible for launch weather support for all United States space operations at Cape Canaveral and Kennedy Space Center. Division of TED by the value 30 K results in what is referred to as the microburst day potential index (MDPI). The 30-K threshold was based on local empirical tuning. An MDPI of  $\geq 1$  indicates a high probability of microbursts if convection were to occur. MDPI is only used operationally when the probability of thunderstorm activity is forecast to be  $\geq 60\%$ . Other weather forecast offices in the southeast United States are using a form of TED or MDPI, but sometimes with different threshold values.

### 3. Product generation

GOES microburst products are generated hourly at the National Oceanic and Atmospheric Administration's (NOAA) Science Center in Camp Springs, Maryland. There is currently a delay of about 1 h from the start of a GOES Sounder scan to product availability due to 1) the time required to complete the Sounder scan (25–30 min), 2) processing of the sounder data to produce the retrievals ( $\sim 15$  min), 3) built-in time delays to assure completion of the retrievals before microburst product generation, and 4) transfer of data between workstations. Average product delays of 1.5 h during 1997–

98 were reduced by  $\sim 30$  min in 1999 by more efficient processing, and less slack in the scheduling. Further increases in timeliness will not occur until line-by-line processing of the sounding retrievals is achieved, which is a long-term goal of NESDIS. The products are then captured in CompuServe Graphical Interchange Format (GIF), and transferred to a Web server for online access.<sup>2</sup>

Data used in generation of the microburst products are obtained via the GOES-East and GOES-West continental U.S. (CONUS) and “hurricane” (HUR) sounder scans. A CONUS sector is usually available once per hour, chiefly to provide effective cloud amount and cloud-top pressure in support of the National Weather Service to supplement their Automated Surface Observing System (Schreiner et al. 1993). The coverage of the GOES CONUS sounder scans are shown in Fig. 2. The CONUS scans overlap over a large portion of the northern high plains and Rockies. The HUR scans (recently renamed to describe the specific areas of coverage) from GOES-East obtain data from portions of the western Atlantic Ocean, Gulf of Mexico, and Caribbean Sea for the generation of winds and other parameters in support of tropical cyclone analysis. Scheduling of non-CONUS sectors is more variable, but they are usually available at least once every 6 h to provide coverage for the United States territory of Puerto Rico, and the state of Hawaii.

Downburst products consist of Sounder-derived numerical values or color-coded boxes displayed at retrieval locations, superimposed on a visible (VIS), IR, or water vapor (WV) image from the GOES Imager at various resolutions. WINDEX and TED use VIS imagery as a background during daylight, and IR at night. Visible imagery is especially useful to show the pres-

<sup>2</sup> The URL is <http://orbit-net.nesdis.noaa.gov/avad/fpdt/mb.html>.

ence of low-level cloud boundaries related to surface convergence, or moisture boundaries that may serve as focusing mechanisms for future convection. For example, McCann (1994) found that downbursts were most likely when an outflow boundary was moving toward a region of high WINDEX values. The DMI uses WV imagery as a background to show the presence of midtropospheric moisture, an important ingredient for dry microbursts.

GOES downburst products were first made available during the summer of 1997 for the eastern CONUS from *GOES-8*, and the western CONUS from *GOES-9* (and beginning 21 July 1998, *GOES-10*). During 1998, regional product formats (subsectors) became available that displayed the WINDEX images at a higher resolution for greater clarity. Five subsectors were produced from *GOES-8* for the eastern and central United States (including a 1-km-scale product for the Florida peninsula), while two additional sectors from *GOES-9* covered all of the western United States. Generation of regional products was an important step because it allowed the users to more clearly see mesoscale features that could trigger convection (outflow boundaries, surface troughs, etc.). The maximum TED product was first made available in 1997 for the Florida peninsula, and in 1998 coverage was expanded to include the southeastern United States. By late summer 1998, digital values of all three parameters stored in an American National Standard Code for Information Interchange text file format also became available to allow users access to all parameters. In 1999, products were first generated for the United States territories of Puerto Rico and the Virgin Islands, as well as Hawaii, using the HUR sounder scans.

Unavailability of the microburst product can be due to factors such as 1) failure of the GOES Sounder data ingest, 2) numerical model first guess (FG) or ancillary surface data not available in time for use in retrieval generation, 3) processed retrievals not transferred to the microburst product workstation, or 4) workstation failures. The surface data are a critical component of the current retrieval algorithm, as described by Ma et al. (1999). Surface temperature and mixing ratios are used as additional “channels” to describe more accurately the low-level atmospheric structure. In high terrain, temperatures are extrapolated to mean sea level using a fixed lapse rate, interpolated horizontally to the sounder retrieval location, and then extrapolated again to the local elevation height using a high-resolution terrain database. Although some errors in surface temperature are likely by using this process, it provides the best available estimate of surface conditions. Product reliability during the first two summers was poor at times, but improved to >95% by late spring 1999, primarily as a result of reducing workstation failures (factor 4 above).

To test the consistency of data obtained from the east and west satellites, WINDEX values were obtained from *GOES-8* and *GOES-10* on 11–13 August 1998 for 90

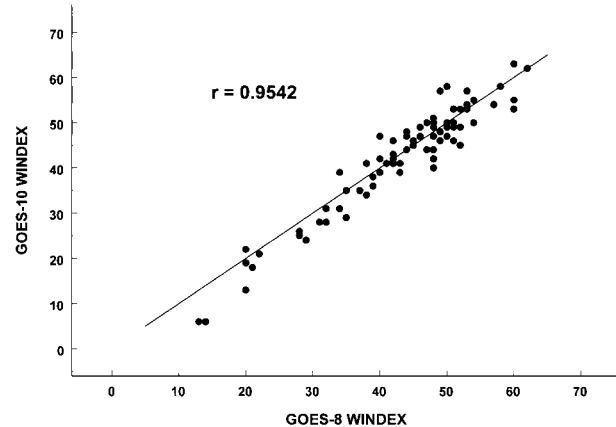


FIG. 3. Comparison of 90 WINDEX pairs derived from *GOES-8* and *-10* at collocated retrieval sites on 11–13 Aug 1998.

nearly collocated [within 50 nmi (93 km)] retrievals in the north-central United States where the CONUS sounder scans overlap (see Fig. 2). A plot of the data (Fig. 3) indicates a high correlation ( $r = 0.95$ ). This comparison tests the consistency of the entire end-to-end process for both satellites, including 1) data ingest and calibration, 2) application of radiance bias adjustments, 3) retrieval processing, and 4) the microburst software used for product generation.

#### 4. Examples

##### a. Southern Arizona windstorms: 14–15 August 1996

On the evening of 14–15 August 1996, severe thunderstorms struck portions of southern Arizona from the northern suburbs of Phoenix (PHX) westward to Yuma. Winds exceeded 100 kt ( $51 \text{ m s}^{-1}$ ) at Deer Valley just north of Phoenix, and there were widespread reports of 50–60 kt ( $26\text{--}31 \text{ m s}^{-1}$ ) winds. Heavy rains ranging up to a maximum of 1.63 in. accompanied the high winds. It was the strongest wind ever recorded in the state of Arizona, and damage exceeded \$100 million (Haro and Green 1996). Conditions in the two days preceding the event were characterized by extreme heat and steadily rising dewpoint temperatures that were  $>5^\circ\text{C}$  above the climatological mean for mid-August. The evolution of storms on the afternoon of 14 August is shown by a four-panel GOES IR image (Fig. 4). By 2130 UTC, convection was developing rapidly over higher terrain to the north and northeast of Phoenix. Around 0030 UTC, an outflow boundary intersection from two separate cells occurred north of Phoenix, resulting in a strong new cell that produced the highest winds and most severe damage (lower-left panel of Fig. 4). The storms swept across southern Arizona from east to west, reaching Yuma by around midnight, Pacific standard time.

Downburst products and soundings were generated retrospectively for this event using data from *GOES-9*

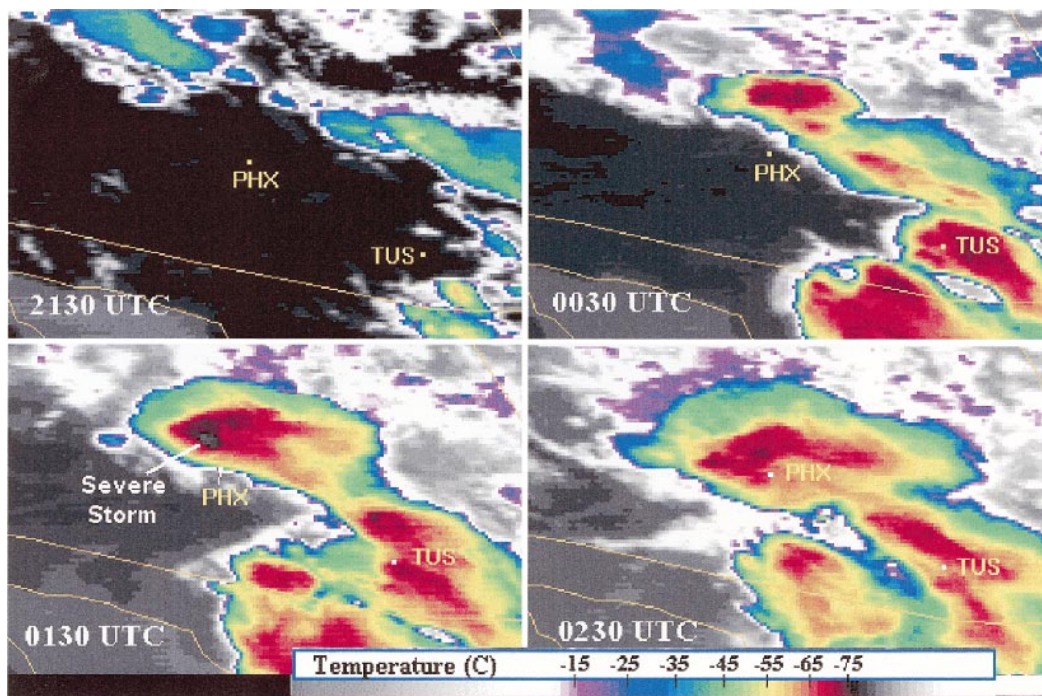


FIG. 4. Sequence of *GOES-9* infrared images showing the evolution of storms in southern Arizona during the afternoon and early evening of 14–15 Aug 1996. An outflow boundary intersection around 0030 UTC is believed to have led to the development of a strong new cell (shown at 0130 UTC) that caused most of the high winds and damage near Phoenix.

beginning at 1803 UTC. A color-coded WINDEX product valid at 2103 UTC is shown in Fig. 5. Maximum potential wind gusts of  $>60$  kt ( $31 \text{ m s}^{-1}$ ) are shown for the Phoenix area, with values  $>70$  kt ( $37 \text{ m s}^{-1}$ ) possible in the desert just to the southwest. It should be noted that after a couple of summers observing WINDEX data for the desert Southwest, it is apparent that values of this magnitude are quite common. However, coupled with the extreme instability and resultant likelihood of storms on this day, WINDEX could have been useful in predicting wind gusts for storms in this area.

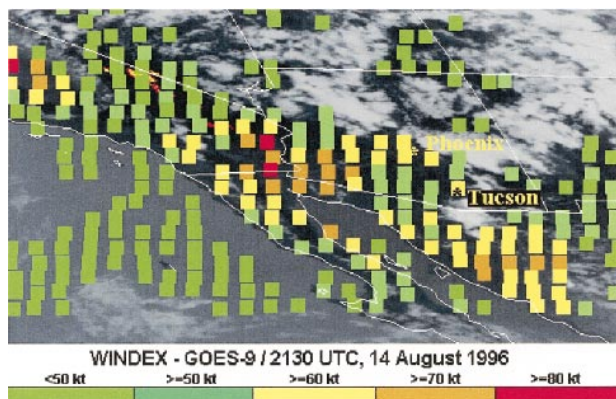


FIG. 5. Color-coded WINDEX (kt) derived from *GOES-9* Sounder retrievals at 2103 UTC 14 Aug 1996, plotted on an infrared image, about 4 h prior to a severe damaging windstorm in southern Arizona.

Although WINDEX values significantly underestimated the 100-kt maximum observed winds, they were representative of most of the other wind reports on this evening. An enlarged plot of *GOES-9* derived WINDEX at 2103 UTC, along with maximum wind gusts from airports and storm spotters that evening (Fig. 6), show generally good agreement, except for the small area just north of Phoenix.

Sounder data from 2103 UTC indicated that there was a strong gradient of DMI across the state of Arizona (Fig. 7). High DMI values in northeast Arizona dimin-

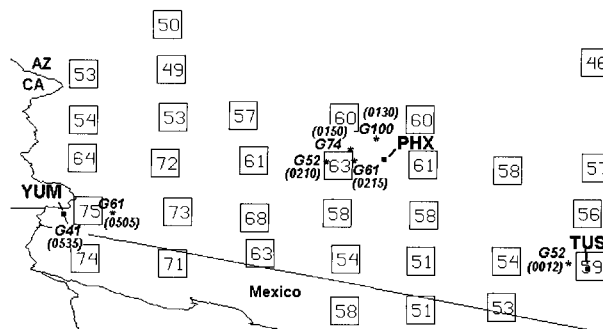


FIG. 6. Wind gusts (kt) from airports or storm spotters during the evening of 14–15 Aug 1996 superimposed on *GOES-9* WINDEX values from 2103 UTC. The first high wind report [100 kt ( $51 \text{ m s}^{-1}$ ) north of Phoenix] was at approximately 0130 UTC 15 Aug 1996. Boxes show the  $5 \times 5$  pixel ( $50 \text{ km} \times 50 \text{ km}$ ) areas used in processing the sounder retrievals.



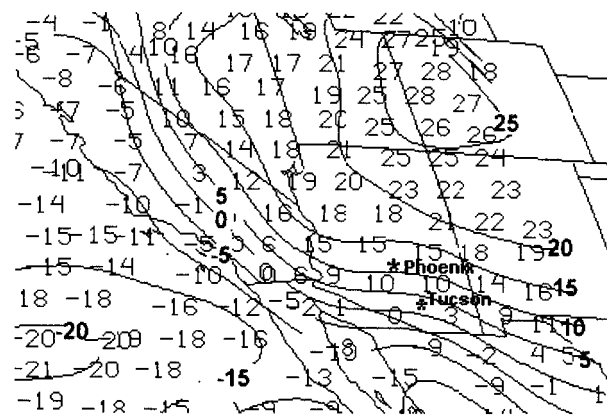


FIG. 7. DMI values from GOES-9 at 2103 UTC 14 Aug 1996.

ished rapidly to near zero in the southern part of the state, indicating a better likelihood of wet (or hybrid) microburst conditions in the Phoenix area.

Figure 8 is a GOES sounding at 0003 UTC 15 August 1996, located near Gila Bend, about 100 km southwest of PHX, the closest available retrieval at this time. Overlain are radiosonde data from Tucson (TUS) at 0000 UTC and a special sounding at Luke Air Force Base (LUF), 30 km northwest of Phoenix, taken as part of the SouthWest America Monsoon Project (Maddox et al. 1996). The LUF sounding was obtained from a highly accurate Cross-Chain Loran Sounding System (CLASS) instrument. There is excellent correspondence between the temperature profiles from the three systems, indicating that the strong lapse rates ( $8\text{--}9\text{ K km}^{-1}$ ) shown by the GOES Sounder data were reliable. The moisture appears to be underestimated by GOES from approximately the surface to 800 hPa, with an overestimate in the middle/upper troposphere from approximately 400 to 200 hPa. These moisture differences resulted in somewhat higher WINDEX values derived from the two radiosonde soundings, compared with GOES. For example, WINDEX calculated from the LUF sounding was 81 kt ( $42\text{ m s}^{-1}$ ), and from the TUS sounding 73 kt ( $38\text{ m s}^{-1}$ ), versus only 66 kt ( $34\text{ m s}^{-1}$ ) from GOES. Since the three soundings were not collocated, some differences are to be expected. A summary of all microburst parameters around 0000 UTC is shown by Table 2. In summary, the downburst parameters derived from GOES on 14–15 August 1996 indicated the potential for very strong winds (60–65 kt), but not of the extreme magnitude observed, and that the storms would most likely result in wet or hybrid-type downbursts.

#### b. Western Kansas downbursts: 24 June 1998

During the evening of 24 June 1998, there were more than 20 reports of downbursts in western and central Kansas that eventually spread into the eastern part of the state. Maximum winds were estimated to be as high as 100 kt ( $51\text{ m s}^{-1}$ ) with a dry microburst at Ulysses

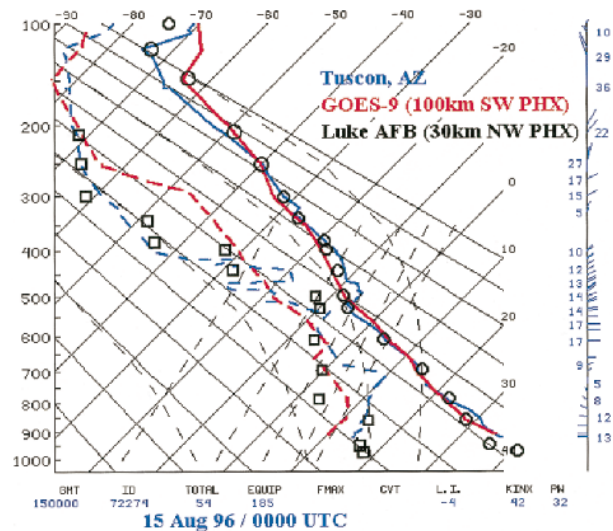


FIG. 8. Radiosonde profile for TUS at 0000 UTC 15 Aug 1996 (blue), compared with a GOES-9 retrieval (0003 UTC) located about 100 km southwest of Phoenix (red), and a concurrent sounding at Luke Air Force Base, 30 km northwest of Phoenix (circles and squares).

in the far southwest corner of the state, but most were in the 50–70-kt ( $26\text{--}36\text{ m s}^{-1}$ ) range in west-central Kansas. There was some minimal damage reported ( $\sim\$30\,000$ ) and no injuries or fatalities (National Climatic Data Center 1998). GOES downburst products on this day demonstrated their ability to detect changes in mesoscale conditions in the lower and middle troposphere that contributed to these high wind events.

A surface trough and dryline were present across western Kansas during the day, as a weak surface low developed in the northwest corner of the state. There was moderate [ $30\text{--}50\text{ kt}$  ( $15\text{--}26\text{ m s}^{-1}$ )] southwest flow aloft. By late afternoon (2046 UTC), GOES DMI showed a narrow band of high values (yellow =  $\geq 16$  units) associated with some midlevel moisture observed in the GOES  $6.7\text{-}\mu\text{m}$  water vapor channel (left panel, Fig. 9), and a deep layer of nearly dry-adiabatic lapse rates. The 2246 UTC GOES DMI still showed this maximum somewhat, although there were fewer retrievals in the moist band due to the formation of high-based, convective clouds (right panel, Fig. 9).

Figure 10 shows the locations of surface wind gust reports relative to GOES WINDEX values at 2200 UTC, about 2 h prior to the onset of most wind gust events. The approximate location of the dryline is shown, based on surface data at 0000 UTC 25 June 1998. A strong

TABLE 2. Microburst parameters at 0000 UTC 25 Aug 1996.

Parameter	GOES	TUS	LUF
WINDEX (kt)	66	73	81
DMI	11.9	8.8	18.9
TED (K)	2.0	2.8	3.5

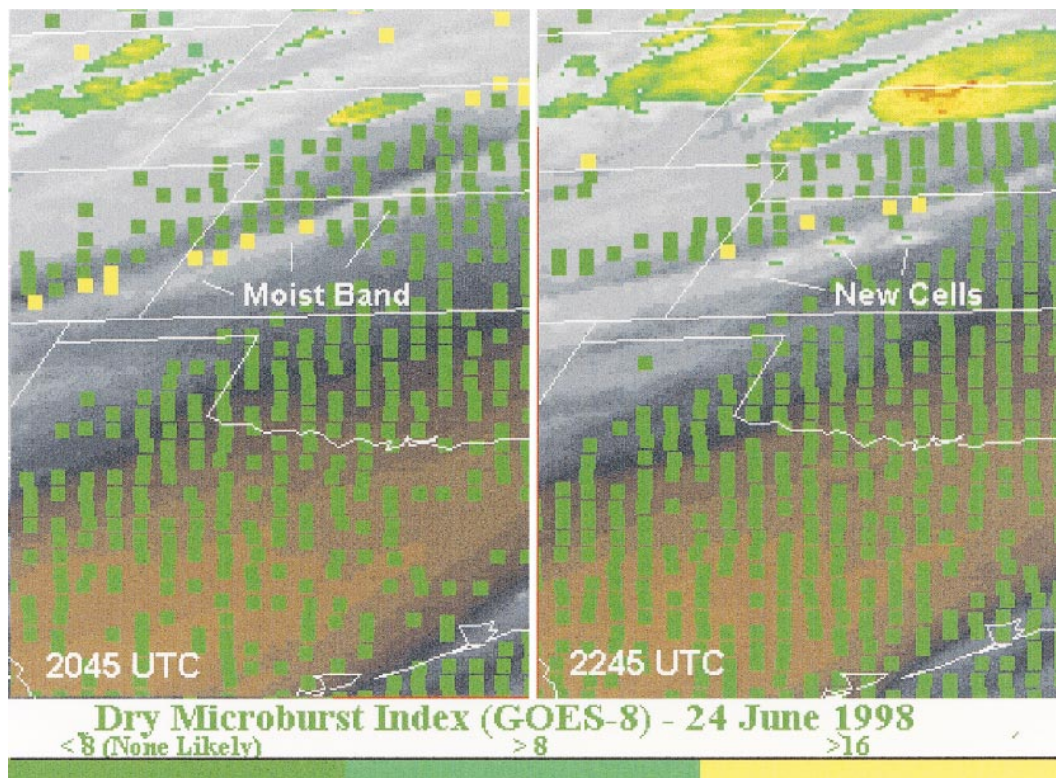


FIG. 9. GOES-8 water vapor images at (left) 2045 and (right) 2245 UTC overlain by color-coded DMI from the sounder valid at 2046 and 2246 UTC 24 Jun 1998.

gradient of WINDEX can be seen, with values in the middle to high 60s (kt) along and southeast of the dryline (Fig. 10) decreasing to the 40s west of the dryline. Surface temperatures on this afternoon were around 100°F (38°C), and dewpoints were in the low to middle

40s (°F; 6°–8°C) west of the dry line. Although no precipitation data were available, the earliest high wind reports (from 2230 to 0100 UTC) located to the west of the dryline were most likely dry microbursts. After 0000 UTC, deep convection with heavy rainfall developed in the moist, high- $\theta_e$  air east of the dryline. Figure 10 shows that the GOES WINDEX values were representative of the observed maximum wind reports in Kansas on this day, except for the isolated dry microburst at Ulysses. Based on operational experience, the limiting value for WINDEX can be expected to be around 80 kt ( $41 \text{ m s}^{-1}$ ) so it is unlikely that an event of this magnitude could have been anticipated from the GOES sounder data.

A possible mechanism for the production of the dry microbursts in western Kansas is one that commonly occurs on the lee side of the Rocky Mountains when convective clouds that develop over elevated terrain drift eastward over the high plains into an environment that is highly unstable, but dry below cloud base. Referred to as “cloud base detrainment instability” (CBDI), this process is described in detail by Emmanuel (1981). CBDI theory accounts for the generation of penetrative, unsaturated downdrafts from small- to medium-sized cumulus clouds that in some cases can reach the ground through evaporative cooling in the subcloud layer.

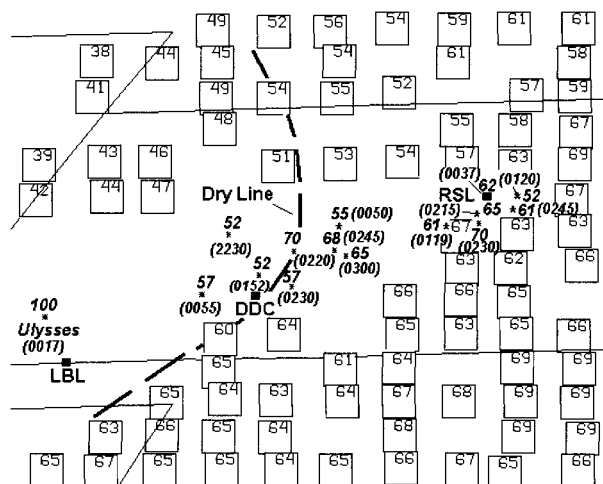


FIG. 10. Same as Fig. 6 except for the afternoon and evening of 24–25 Jun 1998 over western and central Kansas with approximate times (UTC) in brackets. WINDEX values (kt) are from the GOES-8 Sounder at 2146 UTC. Location of the dryline (dashed line) is based on surface observations at 0000 UTC 25 Jun 1998.

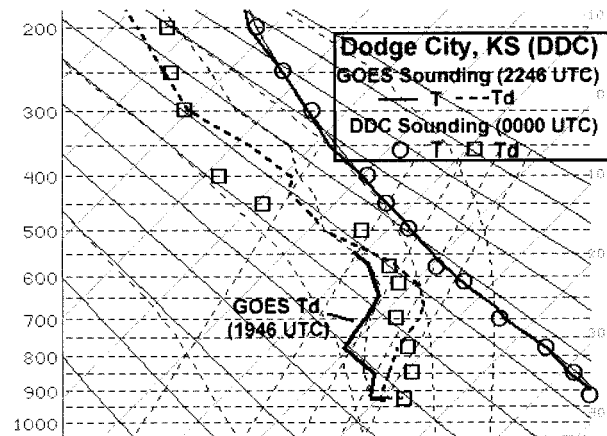


FIG. 11. GOES-8 sounding at 2246 UTC 24 Jun 1998 near DDC, compared with the DDC radiosonde valid at 0000 UTC 25 Jun 1998. The low- to midlevel dewpoint ( $T_d$ ) profile from an earlier GOES sounding at 1946 UTC (heavy line) shows the increase in moisture that occurred in a 3-h period.

A GOES sounding at 2246 UTC, located about 20 km southeast of Dodge City (DDC), is compared with the 0000 UTC DDC radiosonde profile in Fig. 11. Based on comparison with the moisture profile from an earlier (1946 UTC) GOES sounding (solid trace), the most significant increase in moisture occurred from just above the surface (800 hPa) up to about 600 hPa. Thus, there was a deepening in the boundary layer moisture, indicating that conditions near DDC were being modified from a dry downburst environment to one more suitable for wet (or hybrid) downbursts. These soundings appeared to be located just to the east of the midlevel moist band depicted in Fig. 9.

Figure 11 shows excellent agreement between the GOES and DDC temperature profiles. GOES dewpoints were slightly higher than DDC in the 600–750-hPa layer, and slightly lower than DDC below 750 hPa, but were mostly representative of existing conditions. A comparison of all three microburst parameters from GOES versus the DDC radiosonde (Table 3) also compares favorably. Standard convective indices such as LI and CAPE (not shown) were unremarkable (around  $-1^{\circ}\text{C}$  and  $300\text{--}700\text{ J kg}^{-1}$ , respectively), which is typical of dry microburst conditions (Wakimoto 1985), but had destabilized throughout the afternoon. In summary, GOES microburst products, including vertical soundings, would have been valuable in this case to 1) highlight the potential for dry microbursts in western Kansas, 2) estimate the maximum expected wind gusts, and 3) show the steady increase in low- and midlevel moisture, signaling a transition from dry to wet microburst conditions.

## 5. Product validation

Data from GOES downburst products were collected over two summers and validated against conventional

TABLE 3. Microburst parameters at 0000 UTC 25 Jun 1998.

Parameter	GOES	DDC
WINDEX (kt)	67	69
DMI	14.5	15.4
TED (K)	4.9	5.1

surface and upper air data, as well as numerical model data. Since the GOES downburst products are conditional in nature, and not intended as stand-alone predictors, commonly used verification statistics such as probability of detection (POD), false alarm ratio (FAR), and critical success index (CSI) were not considered to be representative and, thus, were not used. One exception was the validation of MDPI (TED) at Cape Canaveral, where such statistics were collected, but only in situations where there was greater than 60% probability of thunderstorm occurrence. The following sections discuss the validation of each of the products from these data.

### a. Wind index

Values of GOES WINDEX were compared with adjacent reports of straight-line wind damage or wind gusts  $>50\text{ kt}$  ( $26\text{ m s}^{-1}$ ) reported in the NWS Storm Prediction Center's (SPC) preliminary storm data. GOES data used in the verification were obtained for retrieval times 1–3 h prior to the observed surface wind gust or damage report so that their predictive value could be assessed. Care was taken to obtain WINDEX away from the influence of any low-level outflow boundaries that would result in values unrepresentative of the inflow air mass feeding the storm. Based on more than 300 reports of wind damage during the summer of 1997, most (92%) of the corresponding WINDEX values were  $>40\text{ kt}$ , while a majority (60%) exceeded  $50\text{ kt}$  ( $26\text{ m s}^{-1}$ ). The distribution of GOES WINDEX for storm damage events is shown in Fig. 12. McCann (1994) obtained a WINDEX distribution derived from surface and radiosonde data for 207 cases that is similar to Fig. 12 with a peak frequency in the  $56\text{--}60\text{-kt}$  ( $29\text{--}31\text{ m s}^{-1}$ ) range and a sample mean of  $58\text{ kt}$  ( $30\text{ m s}^{-1}$ ). It should be noted that there are many microburst events with wind gusts less than  $50\text{ kt}$  ( $26\text{ m s}^{-1}$ ) that are operationally significant for aviation. For example, using a 4-yr data sample from the Cape Canaveral mesonet, it was found that 90% of peak wind speeds for 282 microbursts fell between 25 and  $44\text{ kt}$  ( $13\text{--}23\text{ m s}^{-1}$ ) (Sanger 1999).

As previously mentioned, WINDEX typically has an upper limit of near  $80\text{ kt}$  ( $41\text{ m s}^{-1}$ ), supported by Fig. 12 and results from McCann (1994). Since downburst wind gusts have been measured as high as  $130\text{ kt}$  ( $67\text{ m s}^{-1}$ ) (e.g., Fujita 1983), WINDEX will not be able to account for these extreme events. WINDEX actually estimates the maximum downdraft velocity due to negative buoyancy from a stationary storm. Thus, WIN-

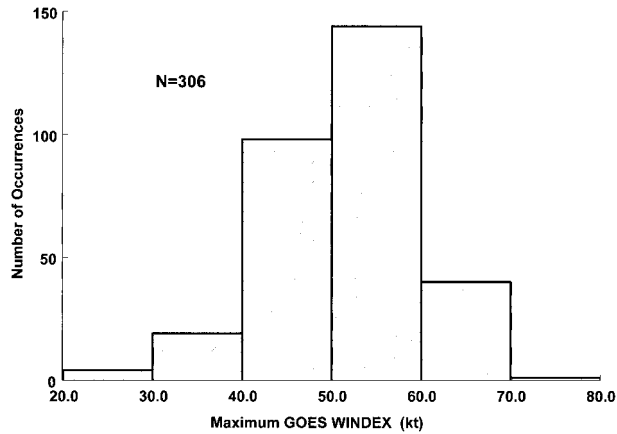


FIG. 12. Frequency of GOES WINDEX values for 306 reports of thunderstorm straight-line wind damage during the summers of 1997–98.

DEX does not include several effects that could help account for these underestimates of extreme events: 1) horizontal acceleration on the ground from hydraulic pressure as cold dense air continues to accumulate behind the downburst leading edge, 2) conversion of rotational energy into straight-line kinetic energy when the rotor vortex collapses, 3) translational speed of the storm, 4) downward advection of momentum, and 5) venturi effects as local land features and structures focus the outflow.

Mean absolute values of GOES WINDEX were also compared with observed surface wind gust reports obtained from SPC storm data, as well as WINDEX calculated from the Eta Model FG. Estimated wind gusts (often reported as 52 or 61 kt, for example) were removed from the database. A tabulation of these data based on 82 comparisons is shown in Table 4. Mean GOES WINDEX differed from mean SPC surface wind gusts by  $<2$  kt ( $1 \text{ m s}^{-1}$ ) with a slight negative bias. Results for the GOES data were slightly better than from the Eta FG (by 0.4 kt), but this difference is not statistically significant. In the 26 cases where GOES differed from the FG by  $\geq 3$  kt, GOES improved upon the FG in 12 of those cases (46%), while the FG was superior in the remaining 14 cases. In their evaluation of temperature and moisture from GOES-8 retrievals, Rao and Fuelberg (1998) also found that while there was improvement over the FG (which in their study was the Nested Grid Model) the majority of the time, there was also occasional degradation. For example, 620-hPa temperatures derived from GOES-VAS were worse than the FG in 11% of the cases, and 620-hPa dewpoints were worse 34% of the time.

The correlation between GOES WINDEX and SPC data for all 82 events was quite poor (0.25), but by eliminating the 7 nighttime [later than 2000 local standard time (LST) and before 1000 LST] events, the correlation improved slightly to 0.37. The correlations for both GOES retrievals and Eta FG are summarized in

TABLE 4. WINDEX (GOES retrievals/Eta first guess) vs storm data ( $N = 82$ ).

	GOES retrievals	SPC storm data	Eta first guess
Min	35	52	36
Max	75	79	74
Mean	59.5	61.0	59.1
Median	60.1	61.0	60.0
Std dev	8.72	5.92	8.14

Table 5. The mean GOES WINDEX error for the nighttime events soared to  $-22$  kt ( $-11 \text{ m s}^{-1}$ ). The diminished boundary layer lapse rate beginning around sunset is undoubtedly an important factor in these poor results, suggesting that a different approach must be used at night.

A recent study (Dickerson 2000) that compared WINDEX derived from the 1500 UTC (1000 EST) Cape Canaveral radiosonde versus maximum wind gusts reported by the CCAS mesonet network between 1500 and 2200 UTC on 114 days showed a correlation of 0.24, a lower value than that obtained from the GOES WINDEX daytime data sample. These results suggest that the accuracy of GOES WINDEX is comparable to, or perhaps better than that which can be obtained using radiosonde data. The poor correlation of these data is likely due to factors such as the high time and space variability of the microburst event, storm motion, and the inability of WINDEX to accurately simulate physical processes in some instances. McCann (1994) found a good qualitative correlation between WINDEX and a small sample of observed microburst events. In a post-analysis of the Dallas microburst storm of 2 August 1985, McCann obtained a WINDEX value of 70 kt ( $36 \text{ m s}^{-1}$ ), which was exactly what was observed. Analysis of GOES-VAS sounder data at 2218 UTC for the Dallas case (the time period used to produce Fig. 1) determined a maximum WINDEX of 68 kt ( $35 \text{ m s}^{-1}$ ).

The sensitivity of the GOES retrievals to their FG temperature and moisture profiles is illustrated by a recent in-house evaluation at NESDIS. In this study, information in the Eta FG below 700 hPa was found to be less accurate than corresponding Aviation Model (AVN) FG data. Corresponding PW and stability indices were found to be significantly improved when the Aviation Model was used as an FG instead of the Eta. The differences were greatest in moist atmospheric conditions when convection is most likely. It is possible that using these superior AVN FG data in the initial retrieval processing could have resulted in improvement upon

TABLE 5. Correlation of WINDEX to storm data.

	GOES	Eta	No. of events
All events	0.2540	0.2177	80
Day only	0.3684	0.3512	73
Night only	0.2684	0.2225	7

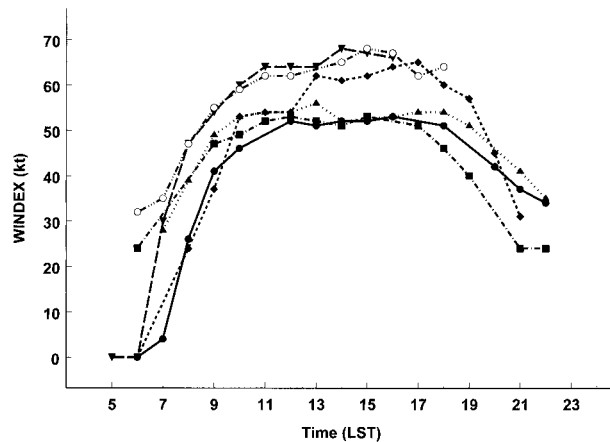


FIG. 13. Diurnal variation of WINDEX (kt) at six continental United States locations during the summer of 1998.

the FG in more than 46% of the cases. As a result, the AVN model was installed as the FG for GOES retrievals at the NESDIS Office of Research and Applications beginning in early October 1999. Evaluation of the effects of this change on WINDEX and other parameters is planned.

WINDEX typically exhibits a highly diurnal variability due to its dependence on the square of the lapse rate. Figure 13 shows how WINDEX changed through the course of a day at six inland locations. WINDEX values increased rapidly through the morning hours, normally reached a maximum by approximately 1100–1300 LST, and remained rather steady until late afternoon, when a more gradual decline began. Since the development of cumulus and cumulonimbus clouds may prevent the determination of WINDEX in some areas during the course of an afternoon, these results suggest that an earlier WINDEX would still be valid. Further analysis of these data may allow prediction of maximum possible winds later in the day by extrapolation of mid-morning values or other statistical techniques. A major assumption would be that no significant changes in air-mass characteristics are expected to occur.

#### b. DMI

DMI from GOES was compared with the same index derived from radiosonde data. A plot of data from the two sources (Fig. 14) shows considerable scatter, with a correspondingly low correlation ( $r = 0.505$ ). Rao and Fuelberg (1998) also found significant differences in satellite-retrieved versus radiosonde-measured moisture at 500 hPa. Most of the scatter can be attributed to 1) poor vertical moisture resolution of the GOES Sounder, 2) errors in radiosonde measurements, 3) differences in the two types of measurements (point vs bulk layer), and most notably 4) the large variability of moisture in time and space. Typical radiosonde errors could be on the order of 0.5 K for temperature, and 10% for relative

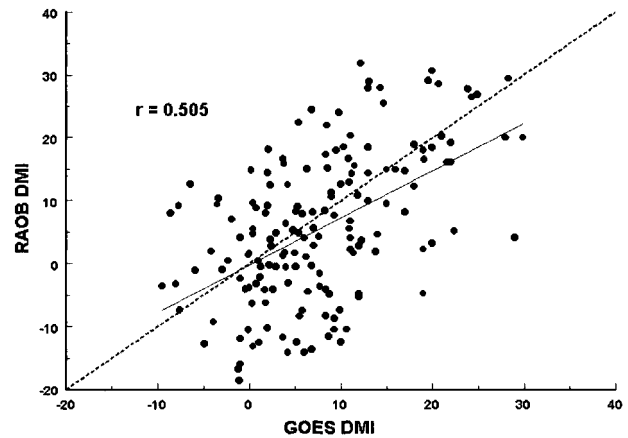


FIG. 14. Scatterplot comparing DMI calculated from GOES vs adjacent radiosonde data within 1 h of retrieval time.

humidity (Schmidlin 1988; Wade 1994). These factors are compounded in the DMI by the use of temperature–dewpoint differences at two levels.

Qualitative evaluation has shown, however, that in areas where DMI is high, atmospheric temperature and humidity profiles obtained from the *GOES-9* Sounder often exhibit the classic hourglass profiles typical for dry microburst conditions. A good example of this is the Dodge City profile shown in Fig. 11. Since the DMI uses data from 500 to 700 hPa, it is best suited as a diagnostic tool for higher terrain west of approximately 100°W.

#### c. Maximum theta-e difference (surface–300 hPa)

The maximum TED from the surface to 300 hPa was validated by calculating similar values using Eta Model FG data. A scatterplot (Fig. 15) for 100 data points indicates good agreement, with a correlation coefficient of 0.77. Additional validation of TED versus radiosonde data is planned. As with WINDEX, the distribution of

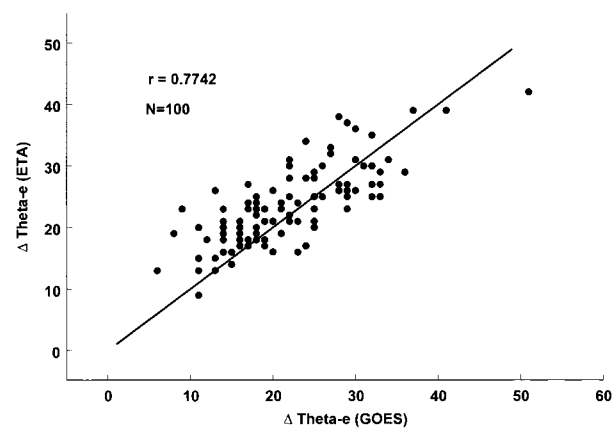


FIG. 15. Scatterplot comparing the maximum TED (K) from the surface to 300 hPa derived from GOES, vs the Eta numerical model first guess.

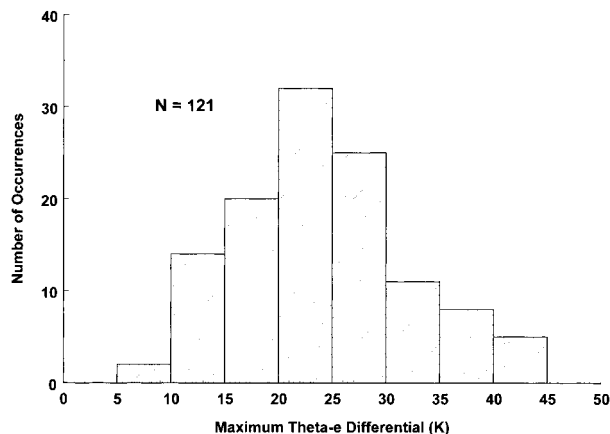


FIG. 16. Distribution of maximum TED (K) for 121 wet microburst events during the summer of 1997 in the central and eastern United States.

TED for a large number of wet microbursts in the central and eastern United States was obtained during the summer of 1997 (Fig. 16). More than two-thirds of the events (67%) occurred with  $TED \geq 20$  K, which has been specified previously as a minimum threshold for wet microburst activity (Atkins and Wakimoto 1991). The large number of cases less than this threshold is an indication that this value must be used with caution, however.

Maximum TED divided by 30 K (MDPI) derived from radiosonde data has been validated at CCAS since 1995 (Wheeler 1996). For this east-central Florida environment, MDPI had a POD of 97%, with a FAR of 28%, a CSI (i.e., a threat score) of 70%, and a Heidke Skill Score of 71% (skill relative to random forecasting) based on 176 events in 1995 and 1997 (Wheeler 1997). These values were sustained even during the summer of 1997, which was considered to be an abnormal year in that many of the significant convective events were synoptically forced (Wheeler 1997), which speaks well for the robustness of the technique. In an independent study conducted by Florida Institute of Technology based on data collected on 26 days during August 1998, the MDPI (once again based on radiosonde data) was evaluated for its utility as a yes–no forecast parameter. Using  $TED \geq 20$  (MDPI = 0.67) as a predictor, the POD was determined to be 100%, but there was a fairly high FAR of 42%. Thus, further tuning of the threshold, or inclusion of other predictors, will be required to reduce the FAR to acceptable levels.

## 6. Use of downburst products in forecast operations

GOES downburst products have seen increasing use in the forecast environment as a short-range tool to supplement other forms of data. In addition to the NWS, typical users have included private weather consultants, military forecasters, government laboratories, commer-

cial airlines and freight carriers, civilian storm spotters, and university researchers. The GOES products can be used to indicate the maximum wind gust potential in aviation terminal, route or area forecasts, and public weather statements, warnings, and short-range predictions (“nowcasts”). Information about the type of downburst (wet/dry) also affects these forecasts in terms of expected precipitation rate and visibilities.

The NWS Weather Forecast Office in Slidell, Louisiana (near New Orleans), has developed a “microburst decision tree” to assist their forecasters in anticipating the occurrence of microbursts. This decision tree (Fig. 17) utilizes numerous environmental parameters obtainable from radiosonde data or GOES retrievals such as lifted index, CAPE, lapse rate, PW, and TED. The GOES products can thus form an integral part of the forecast process.

Based on the results presented in this paper, the best use of GOES downburst products would be to integrate them with other forecast parameters during the early part of the day, such as with a forecast checklist similar to the one in Fig. 17. It is likely that local guidelines and thresholds could be developed for optimum use of the satellite data, such as tuning of the TED MDPI parameter. During the nowcast phase, the occurrence of low-level convergence or outflow boundaries that move toward unstable regions (with associated high WINDEX or TED values) would suggest the likelihood of strong convection with possible downbursts. It should be stressed that the GOES downburst products have not demonstrated any skill in differentiating the severity of individual storm cells within a local warning area, and should never be used for that purpose.

## 7. Future plans

Experimental production of the initial suite of GOES downburst products and their evaluation by research and operations will continue for the foreseeable future. The addition of more products (such as layer mean lapse rates) is also being considered. Improved displays of these parameters such as animations, single-point time sections, or cross sections, would optimize their use by operational forecasters. A future upgrade of the Advanced Weather Interactive Processing System (AWIPS) will allow forecasters to generate WINDEX, DMI, and TED from either satellite sounder, numerical model, or radiosonde data. A site-specific text product for both major and secondary airfields that describes such parameters as relative risk (e.g., low, medium, high), maximum potential wind gusts, microburst type, and trend is attainable with further research and evaluation.

Finally, the development of a composite analysis approach (such as shown in Fig. 1) could further assist the forecaster in identifying potential risk areas by showing where most downburst parameters exceed established thresholds. Composite analysis has been used for many years at the NOAA Storm Prediction Center

### Microburst Decision Tree (Summer, 1998)

Aviation forecaster...please fill out this worksheet **ONLY** on days where the *afternoon max temp is forecast*  $\geq 90F$  **AND** *pulse thunderstorms* are forecast. This should be done **BEFORE** 15Z daily (before the area thunderstorm outlook is issued).

DATE _____	FORECASTER _____			
1. DRY ADIABATIC LAPSE RATE FROM SURFACE. > 6KFT (8)    4-6KFT (4)    < 4KFT (0)	_____			
2. MOIST MID-TROPOSPHERIC LAYER MID T-Td BETWEEN 550-800 MB. < 5C (6)    5-10C (4)    > 10C (0)	_____			
3. DRY LAYER ABV MOIST LAYER T-Td > 15C IN LAYER 50-100MB THICK. YES (6)                      NO (0)	_____			
4. LIFTED INDEX. -7 OR LESS (8)    -4 TO -6 (4)    -4 OR GREATER (0)	_____			
5. CAPE USING SHARP 850MB THETA-E PSEUDOADIABAT. > 3000 (8)    2000-3000 (6)    < 2000 (0)	_____			
6. THETA-E $\geq 30K$ ...DIFF BTWN HIGHEST THETA-E AND MIN VALUE ALOFT. YES (4)                      NO (0)	_____			
7. CAP REMOVAL (USE SHARP PROGRAM)? CAP REMOVED (8)    PSBLY REMOVED (6)    NO (0)	_____			
8. FORECASTED BOUNDARY (CHOOSE MOST LIKELY). OUTFLOW (8)    TROF (7)    SEABREEZE (4)    NONE (0)	_____			
9. PW. > 1.9 (8)    1.7-1.9 (4)    < 1.7 (0)	_____			
10. 500MB WIND DIRECTION AND SPEED. NW-NE = or less than 10kt (4)	_____			
11. 850mb-500mb T (deg C) (JAN study) > 27.5 (8)    26.6-27.5 (4) $\leq 26.5$ (0)	_____			
	TOTAL _____			
<b>VERY HIGH</b> $\geq 66$	<b>HIGH</b> 58-65	<b>MODERATE</b> 46-57	<b>LOW</b> 40-45	<b>NIL</b> < 40

FIG. 17. Experimental decision tree for forecasting microburst potential under evaluation at the Slidell, LA, National Weather Service Forecast Office (courtesy of G. A. Johnson).

to forecast severe weather. The use of advanced multivariate or artificial intelligence techniques (such as “fuzzy logic”), which could objectively analyze many parameters simultaneously (such as those in the decision tree in Fig. 17), appears to be a feasible approach in downburst risk assessment. Such techniques are already being examined for analysis of Doppler radar data to generate downburst warnings with the Damaging Downburst Prediction and Detection Algorithm developed at the National Severe Storms Laboratory (Eilts et al. 1996). In providing up-to-date weather information to pilots in the cockpit, pseudo-color images of these types of parameters could be generated on the ground, then uplinked to aircraft via satellite, as proposed by Lanier et al. (1999).

### 8. Summary and conclusions

Experimental products derived from GOES Sounder retrievals that identify environmental conditions suitable for convective downbursts have been available from NOAA/NESDIS since the summer of 1997. The products currently consist of a wind index for estimating maximum possible surface wind gusts, a dry microburst index, and the maximum equivalent potential temperature ( $\theta - e$ ) difference from the surface to 300 hPa for evaluating wet downburst conditions. The hourly products may be accessed on a Web site within about 1 h after the start of the GOES Sounder scan, and product reliability is high ( $>95\%$ ). Preliminary evaluation of the products indicated that they provide information

useful in the preparation of short-range weather forecasts and advisories. Mean absolute WINDEX error for 82 measured wind gust events was  $<2$  kt ( $1 \text{ m s}^{-1}$ ) based on NWS preliminary storm data, although the statistical correlation was found to be poor. The downburst parameters described in this paper will be integrated into the NWS AWIPS environment, with the capability of deriving them from either GOES Sounder data, radiosonde profiles, or numerical model forecast data.

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