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LOW-ALTITUDE WIND SHEAR CHARACTERISTICS* IN THE MEMPHIS, TN AREA BASED ON MESONET AND LLWAS DATA

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1. INTRODUCTION

As part of the 1984-85 FLOWS (FAA-Lincoln Laboratory Operational Weather Studies) Project, mesonet and Doppler radar data are being collected on rain and thunderstorms in the Memphis, TN area. One of the key goals of the FLOWS Project is to characterize and evaluate the various forms of potentially aviation-hazardous low-altitude wind shear in parts of the country where this type of high spatial and temporal resolution meteorological data have not previously been collected.

The 1982 JAWS (Joint Airport Weather Studies) Project revealed that the "microburst", a small scale, intense downdraft which hits the surface and causes a strong divergent outflow of wind, has been the source of much of the hazardous wind shear in the Denver area. The 1978 NIMROD (Northern Illinois Meteorological Research on Downbursts) Project revealed that microbursts occur there on convectively unstable days along with gust fronts and "macrobursts" (scale 4-40 km). Other experiments have largely failed to detect microbursts because their observational networks have not been dense enough to resolve this small scale.

A compilation of pioneering studies of microburst-related aircraft accidents around the world by Fujita (1985) illustrates clearly the inherent danger of the microburst wind pattern to jet aircraft, wherever it occurs. In developing ways to best meet the goal of providing warning and protection from low-altitude wind shear in the airport terminal areas, the FAA will need to characterize the problem in different parts of the country. It may be misleading, for example, to use the results on wind shear in the Denver area, or any other single geographical locale, to typify the requirements for microburst warnings at all airports in the country.

An important region in terms of its frequency of commercial air traffic and of thunderstorms, in which high resolution measurements capable of revealing microbursts have never before been collected, is the southeastern part of the United States (excluding Florida). During 1984 Lincoln Laboratory continuously collected surface meteorological data from 25-30 mesonet stations and FAA Low Level Wind Shear Alert System (LLWAS) data from the 6 anemometers at the Memphis International Airport from May through November (212 days total). Presented here are preliminary results on the characteristics of wind shear events in the Memphis area. Microburst statistics for Memphis are contrasted with those computed by Fujita and Wakimoto (1983) for the Denver area during JAWS and the Chicago area during NIMROD. A detailed analysis of a microburst that occurred on August 11, 1984 is also presented.

2. DATA COLLECTION AND PROCESSING

The mesonet stations operated by Lincoln Laboratory for the FAA are modified PROBE stations (Wolfson, et al., 1984) obtained from the Bureau of Reclamation in 1983. New data collection platforms permit the collection of 1-min averaged wind speed and direction, temperature, relative humidity, pressure, and precipitation amounts, as well as the 5-s peak wind speed each minute. Extensive sensor refurbishment and calibration have greatly increased the accuracy of the data. The LLWAS data (wind speed and direction, 6 stations, every 8 s) is recorded continuously on a Lincoln-built system and converted before analysis to 1-min averages and 8-s peak winds for comparison with the mesonet data. The location of the network is shown in Fig. 1.

Before searching the dataset for low-altitude wind shear the winds were corrected for meso- and miso-scale obstructions (Fujita and Wakimoto, 1982). Different correction factors were applied for each month based on the average wind speed as a function of azimuth. For a dataset of 45-60 days different factors would not have been necessary, but it was found for this 7-month dataset that the mean monthly "unobstructed" wind (the greatest value among the stations at each azimuth) varied considerably.

3. LOW-ALTITUDE WIND SHEAR CHARACTERISTICS

The peak wind speed values were used to initially identify any possible microbursts. A version of the objective technique used by Fujita and Wakimoto (1983) which essentially identifies wind spikes in the data was implemented. For each

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positive detection, a synoptic map and a 15-min time series for each of the recorded variables were plotted. These plots were then analyzed individually for evidence of an evolving divergent wind pattern, significant changes in temperature, dew point, and pressure, and/or increasing influence of the microburst winds on the surrounding stations with time. Of a total of 3210 algorithm detections, 94.3% were eliminated as cold front passages, high gusty winds, or insignificant wind peaks. It was found that a total of 84 or 2.6% were actually gust fronts, and that 102 or 3.1% were true microbursts. In many cases, a gust front signature was evident somewhere in the network at the same time a microburst was occurring.

3.1 Daily Count

The count of 102 microbursts represents the total number of stations impacted by microburst winds during the data collection period. This daily count is compared with similar counts compiled for NIMROD and JAWS in Fig. 2(a)-(c). The FLOWS Memphis data shows that, at least in the spring and fall, the microbursts occur in response to the synoptic scale forcing creating the conditions for convective instability on a large scale. During June, July, and early August the percentage of dry microbursts (<0.25 mm rain) did increase and there was a small clustering of microburst events in mid-July, but never did microbursts occur on a near-daily basis as they did during July 1982 in the Denver area. Of the 102 microburst hits in FLOWS 1984, 41 were dry microbursts, 57 were wet, and 4 were unknown (LLWAS data only were available). Although this total fell between that for NIMROD and JAWS (see Table 1), the per day microburst rate was much lower for Memphis. This remains true even when considering only the 42 days common to all 3 experiments.

A preliminary analysis of the data allowed an estimate of the total number of individual microbursts to be made. This number totalled 49 for the Memphis 7-month dataset. For each day the estimate of the number of individual microbursts that occurred is written above the station count bar in Fig. 2c.

3.2 Diurnal Variation

The diurnal variation of the NIMROD, JAWS, and FLOWS microbursts are compared in Fig. 3(a)-(c). The peak in the Memphis data occurs between noon and 5 p.m. local time (CDT) with a significant peak between 7 and 10 p.m. Thus the Memphis dataset shows similarities to both the Denver summertime picture, with the solar heating providing much of the forcing for convective instability in the afternoon, and the northern Illinois picture with no strong diurnal dependence and some evidence of nocturnal thunderstorms. The nocturnal thunderstorm phenomena, sometimes related to the occurrence of the southerly low level jet, is quite pronounced in the Memphis area.

3.3 Rainfall Rate

During FLOWS, roughly one third of the days on which microbursts occurred had dry microbursts only, similar to the ratio during NIMROD. The JAWS results were just the opposite with rain detected at the surface on only one third of the microburst days (Fig. 2). Most of the JAWS microburst rainfall rates were below 1 in/hour and all were below 3 in/hour. During NIMROD most microburst rain rates were below 3 in/hour except on one day when 5 microbursts with rates up to 8 in/hour were detected. In contrast, the rainfall rates in FLOWS "wet" microbursts were almost all above 1 in/hour with 17 of 57 or nearly 30% above 3 in/hour (Fig. 5). Thus the microbursts in the Memphis area (south-central Mississippi valley area) can be typified as very wet with very heavy rain accompanying, and perhaps causing, a significant percentage of them.

In Fig. 4 the FLOWS microburst rainfall rates are plotted against the peak wind speeds. As with the NIMROD and JAWS microbursts, no clear relationship between the two variables emerges. Except for one case which may have actually been a tornado, all of the microbursts with rainfall rates below 1.5 in/hr had peak wind speeds of 25 m/s or less. However since this category includes all but 10 of the wet microbursts, its significance is doubtful.

3.4 Wind Characteristics

In characterizing the microburst winds, the distributions of peak wind speed, wind direction, and duration, defined as the period of one-half of the peak windspeed, are of key interest.

The algorithm used to locate microbursts allowed a minimum of 15 m/s for the central peak wind measurement. Thus there is an abrupt cutoff at the low end in Fig. 5. Except for a probably insignificant maximum of peak winds between 22 and 23 m/s, the number of microbursts decreases exponentially as the peak wind speed increases, illustrating the decreasing probability of occurrence with increasing wind speed. The NIMROD and JAWS distributions reach a maximum between 13 and

Table 1

	NIMROD	JAWS	FLOWS
Dates	19 May - 1 Jul 78	15 May - 9 Aug 82	2 May - 29 Nov 84
Days	42	86	212
Microburst Hits	50	186	102
Dry Microbursts	18	155	41
Microbursts per day	1.19	2.16	0.48
		19 May - 1 July Only	
Microburst Hits	50	71	30
Microbursts per day	1.19	1.69	0.71

15 m/s while the FLOWS peak wind speed distribution has its maximum around 17 m/s, but the FLOWS data has been corrected for site obstruction effects. The FLOWS distribution is less sharply peaked around the low wind speeds than the JAWS results are, but it is also more sharply peaked and not as uniform as the NIMROD distribution.

The distribution of the microburst wind direction shown in Fig. 6 is heavily weighted by winds with a westerly component (190° - 350°). Winds appear at all azimuths because of the strong directional shear in the microbursts. The maximum in microburst wind direction coincides with the climatologically preferred direction of storm approach. This information has great significance for the siting of a Doppler weather radar to be used for airport terminal wind shear detection. The distribution in Fig. 6 suggests that one should locate a Doppler radar east and slightly south of the region to be protected in the Memphis area in order to detect the maximum radial wind speeds.

The duration of the peak winds in FLOWS (shown in Fig. 7) appears to be quite uniformly distributed from 1.5 to 9 minutes with the suggestion of two peaks centered about 2.5 and 5.5 min. This distribution differs quite considerably from those for NIMROD and JAWS which are both peaked around 2.5 minutes and decay exponentially at longer durations. There were only 3 microbursts in JAWS and 1 in NIMROD with durations greater than 7 min. In understanding the significance of this, one can relate the duration of the peak wind to the spatial scale of the microbursts. All microbursts confirmed in FLOWS began as divergent wind events less than 4 km in diameter, but most quickly grew to greater diameters. An expanding travelling microburst will produce a wind speed trace that is sharply peaked but has sustained high winds. This was commonly the case in the data analyzed.

3.5 Thermodynamic Characteristics

Fig. 8 shows the distribution of temperature changes in FLOWS microbursts. Only 11% of the microbursts were characterized by increases in temperature and close to 25% had temperature decreases greater than 3°. This is in striking contrast to both NIMROD and JAWS results which showed temperature increases in 40% of the cases. The FLOWS Memphis results showing temperature decreases are quite consistent with the creation or enhancement of the microburst downflow by evaporative cooling.

The dew point changes (Fig. 9) are also consistent with the mechanism of precipitation cooling of the downflow, with 32% of the cases exhibiting an increase in dew point. However, as in the NIMROD and JAWS datasets, the majority of microbursts were accompanied by decreases in the dew point of the air, suggesting entrainment of drier air from some level into the downdraft and/or origination of the downdraft in dry air aloft.

The distribution of pressure changes in FLOWS microbursts is shown in Fig. 10. Notice that it is basically centered about zero and extends only to ∓2 mb. This is completely consistent with the NIMROD and JAWS results and may be explained by the "pressure ring" theory proposed by Fujita (1985).

4. MICROBURST ON AUGUST 11, 1984

The synoptic charts for August 11, 1984 suggested that scattered convection was probable in the Memphis, TN area. At the surface, a quasi-stationary cold front was positioned just northwest of the FLOWS network. The front was bounded to the north by weak northerly winds and to the south by a weak southwesterly flow. Temperatures at 1800 GMT (noon CDT) were in the high 80s (°F) and dew point temperatures were in the high 70s (°F). There was no contrast in temperature or dew point across the front. The surface air at this time was very unstable with a lifted index of -8°C. Upper level winds showed no vertical shear in the layer between 850 and 500 mb and were very light (~5 m/s) from the north. Vorticity advection at the 500 mb level was neutral. According to the Radar Summary, an isolated thunderstorm with its top near 40 Kft developed over the Memphis mesonet at approximately 1800 GMT. The storm development was probably initiated by surface convergence in this convectively unstable air mass.

Fig. 11 shows the signature of a microburst with its strongly divergent wind pattern detected between stations #11, #17, and #13, about 3 km apart, at 1820 GMT. Evidence of the microburst winds first appeared at the surface 5 min earlier with a divergent 13-15 m/s wind at #11 and #13. The boundary of the microburst at 1820 GMT (barbed front in Fig. 11) was evident not only in the surface wind field but also in the temperature field as the edge of the thermal gradient accompanying this event. The rainfall rate shown with this wet microburst reached 70 mm/hr (~3 in/hr) at station #11, just north of the microburst center (MB).

Fig. 12 shows that this microburst, with its center in about the same location, had by definition become a macroburst only 6 minutes later. Strong wind shear on the order of 45 m/s (80 kts) can be seen between stations #17 and #8, only 5 km apart. Very high rainfall rates of 100-110 mm/hr (4-5 in/hr) were present near the macroburst center.

By 1839 GMT a possible second microburst, shown in Fig. 13, had reached the surface in approximately the same area as the previous microburst, whose outflow boundary is shown directly over the Memphis International Airport in the northwest portion of the network. Strong wind shear, continued decreasing temperatures, and rainfall rates in excess of 100 mm/hr also accompanied this event. The 21° isotherm (dotted contour in Fig. 13) encircles a pool of cold air associated with the 25 m/s winds and heavy rain at #8.

5. SUMMARY

Presented here were preliminary results on the characteristics of low-altitude wind shear in the Memphis, TN area based only on high resolution meteorological surface data. It was shown that the microburst, a recognized potential wind shear hazard to aviation, does occur with some regularity in this area. The Memphis microburst characteristics were contrasted with those for Chicago and Denver and found to be quite different. In general, the Memphis microbursts were very "wet", occurring with rain rates mostly from 1 to 5 in/hr. Most microbursts expanded rapidly to become "macrobursts" with gust fronts at the outflow edges such as the one on 11 August 1984 described in Section 4. There were fewer microbursts in Memphis than in other areas previously studied, but their peak wind speeds were higher, their durations were longer, and they were mostly accompanied by cooler, drier air flows.

6. FUTURE WORK

The preceding summary applies to microbursts detected during one 7-month period in the Memphis area. The validity of generalizing these results to other years and/or surrounding geographical areas is unknown. Lincoln Laboratory continues to collect mesonet, LLWAS, and Doppler radar data in 1985 from the same FLOWS network. Comparison of the 1984 and 1985 mesonet datasets will give the first results ever on the interannual variability of microburst events in a single geographical area. Current plans are to move the FLOWS data collection effort to Huntsville, AL in 1986. Huntsville and Memphis are at about the same latitude and only 300 km apart. The comparison of microburst characteristics from these two locations will help determine the extent to which measurements in one area are applicable to surrounding regions.

The Doppler radar data being collected will be used for single- and dual-Doppler analyses of microburst events. These analyses will help delineate the three-dimensional aspects of the microbursts in the Memphis area and allow a better understanding of the mechanisms involved in their origin and evolution. This information will ultimately be used to characterize the predictability and detectability of microbursts in this area for real-time warnings of low-altitude wind shear for the aviation community.

ACKNOWLEDGEMENTS

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REFERENCES

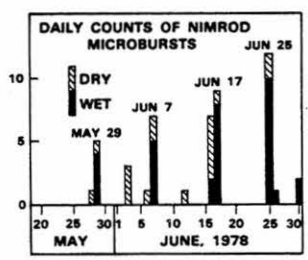
Fujita, T. T., 1985: The Downburst-Microburst and Macroburst, University of Chicago, 122 pp.

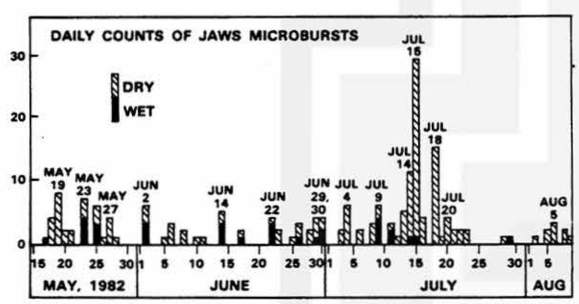
Fujita, T. T., and R. M. Wakimoto, 1983: Microbursts in JAWS depicted by Doppler Radars, PAM, and Aerial Photographs. Preprints, 21st Conference on Radar Meteorology, Edmonton, Alberta. Amer. Met. Soc., 638-645.

Fujita, T. T., and R. M. Wakimoto, 1982: Effects of Miso- and Meso-scale Obstructions on PAM Winds Obtained During Project NIMROD. J. Appl. Meteor, 21, 840-858.

Wolfson, M. M., J. T. DiStefano and D. L. Klingle, 1984: An Automatic Weather Station Network for Low-Altitude Wind Shear Investigations. M.I.T. Lincoln Laboratory Project Report ATC-128, FAA Report No. DOT-FAA-PM-84/13.

Fig. 1. Location of FLOWS 1984 network near Memphis, TN.





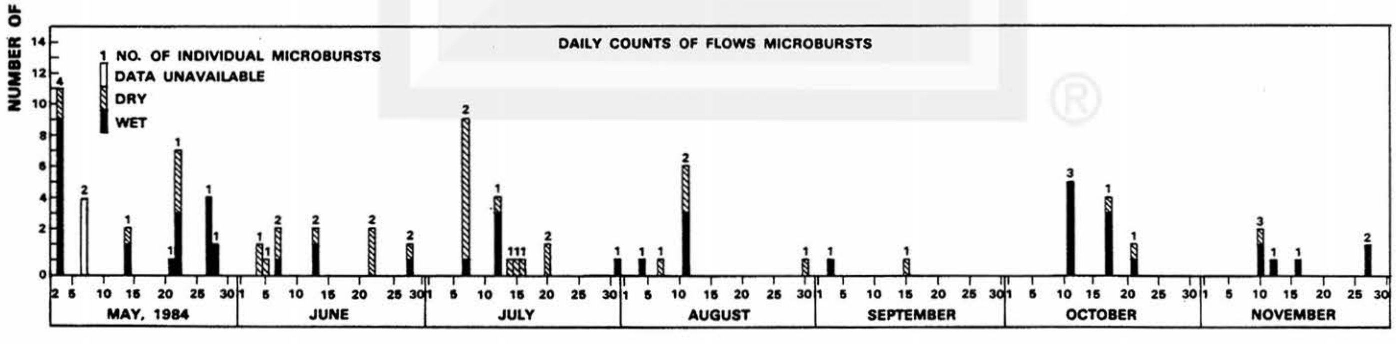


Fig. 2. Daily counts of microbursts, determined by computer and subjective analysis, for a) NIMROD, 1978 (Chicago), b) JAWS, 1982 (Denver), and c) FLOWS (Memphis), 1984.

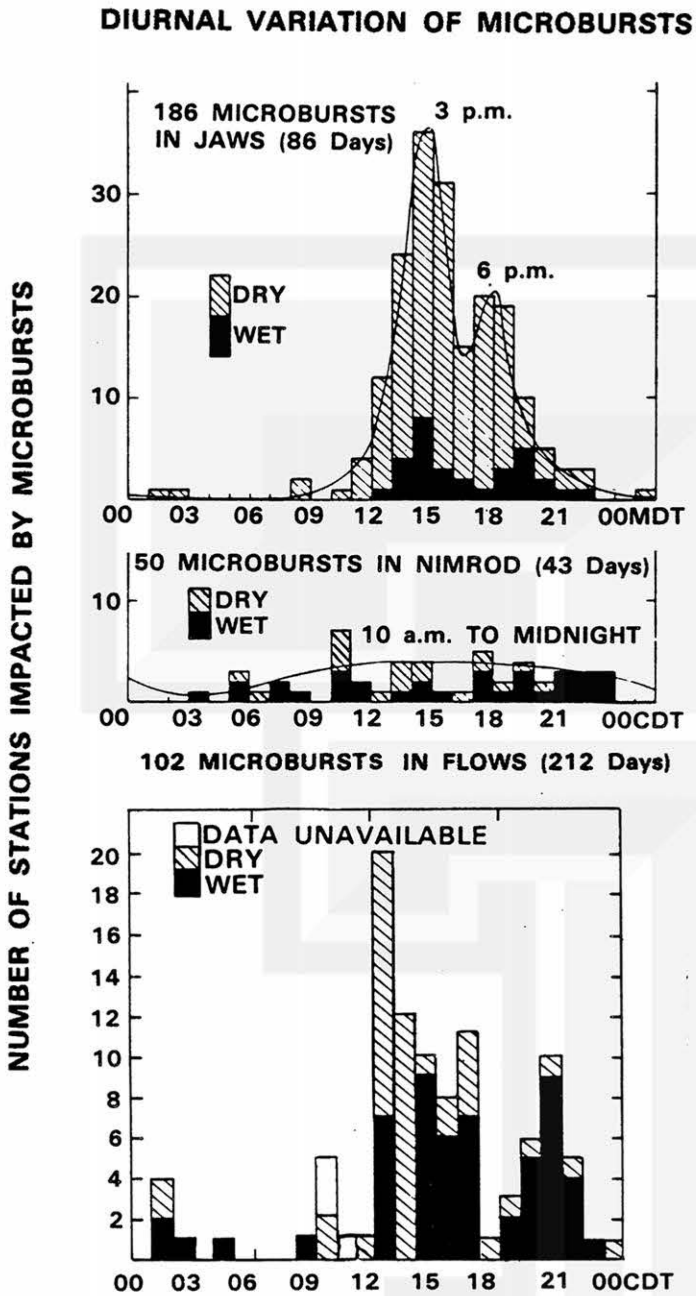


Fig. 3. Diurnal variation of microbursts in a) NIMROD, 1978, b) JAWS 1982, and c) FLOWS, 1984. The FLOWS distribution shares some of the features of both the NIMROD and the JAWS distributions.

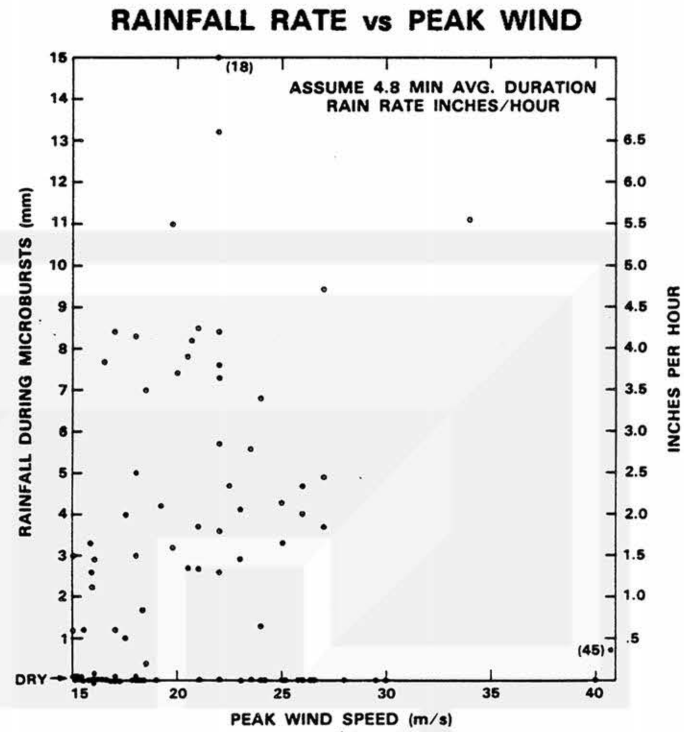


Fig. 4. Total rainfall (rainfall rate assuming 4.8 min duration) versus maximum wind speed in 102 wet and dry (along bottom) microbursts during FLOWS 1984.

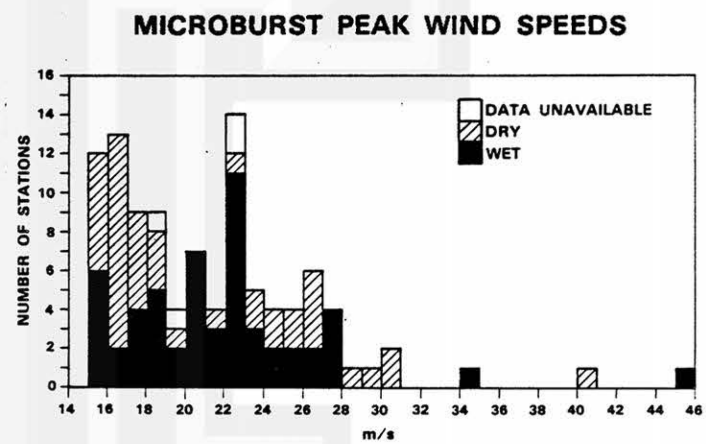


Fig. 5. Distribution of peak wind speeds in FLOWS 1984 microbursts.

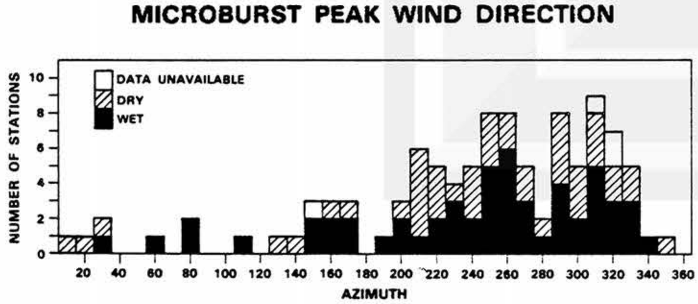


Fig. 6. Direction of peak wind speeds in FLOWS 1984 microbursts.

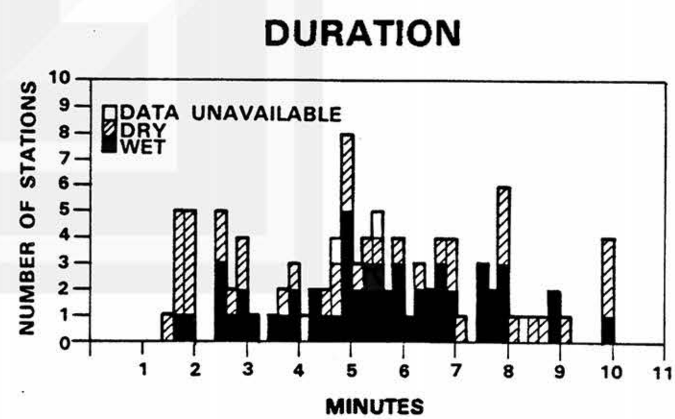


Fig. 7. Duration of FLOWS 1984 microbursts, defined as the period of one half of the peak wind speed.

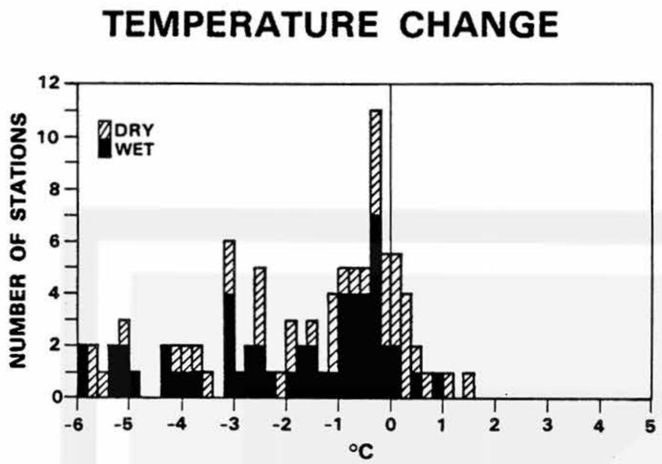


Fig. 8. Temperature change in FLOWS 1984 microbursts.

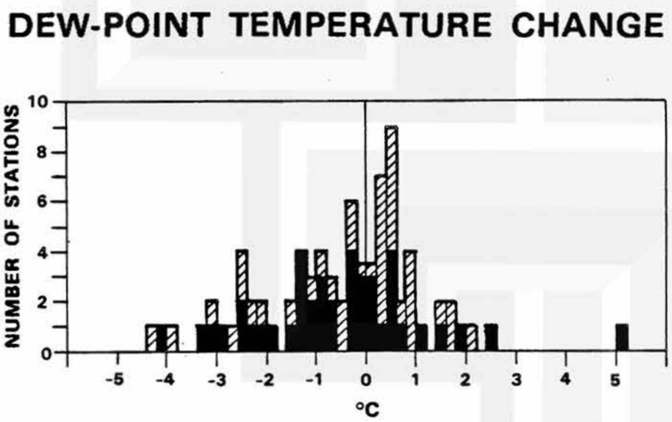


Fig. 9. Dew point temperature change in FLOWS 1984 microbursts.

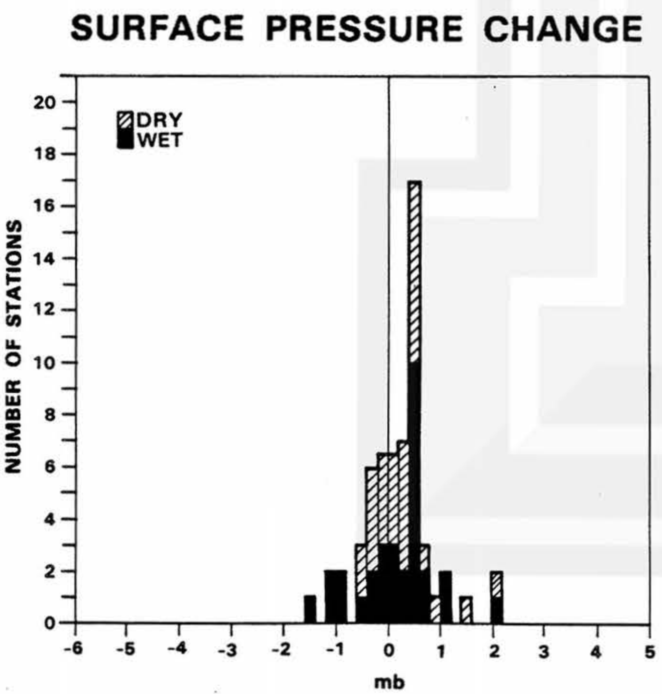


Fig. 10. Pressure change in FLOWS 1984 microbursts.

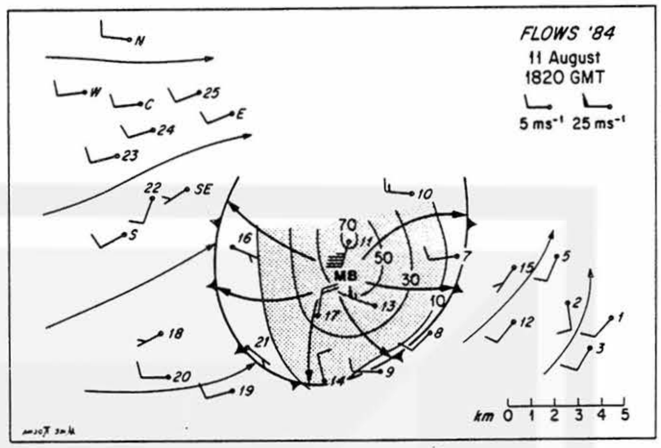


Fig. 11. Microburst at 1820 GMT on 11 August 1984. Stippled area represents rain rates >10 mm/hr. Streamlines are shown as thin lines with arrowheads. Mesonet station numbers appear next to wind plots. FAA LLWAS stations are labelled as: C = center field, E = east, etc.

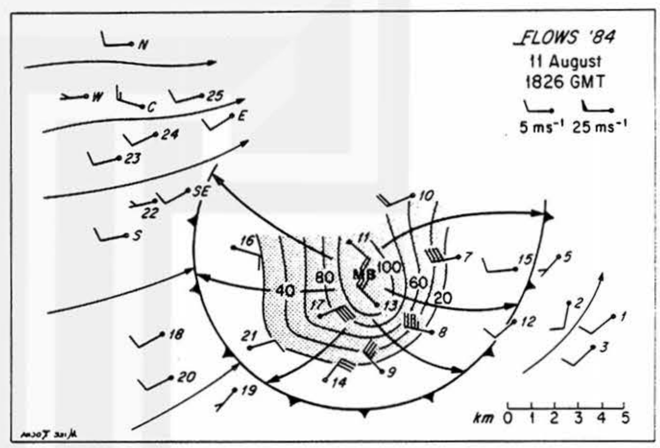


Fig. 12. Same as Fig. 11, but for 1826 GMT. Stippled area represents rain rates >20 mm/hr.

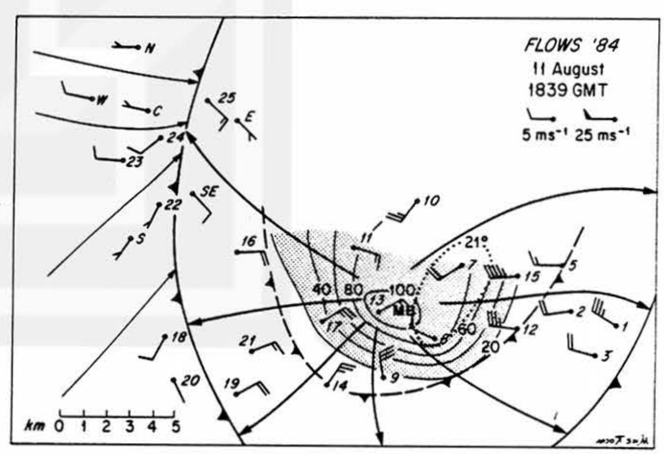


Fig. 13. Same as Fig. 12, but for 1839 GMT.