COMMENTS ON "DOWNBURSTS"

by Donald McCann

I would like to comment on the recent *National Weather Digest* article "Downbursts" (Rose 1996). Rose's take on this problem is not new: High surface thunderstorm wind gusts are caused by convective downdrafts transporting higher momentum air to the surface. I myself once evoked this theory to explain certain downburst events (McCann 1978). Now, after considerable study of downbursts, I am much less convinced that downward momentum transfer has anything to do with wet microbursts.

There are numerous flaws in the article. Rose states in his abstract that he will present a "thorough summary of downbursts," but he presents a rather myopic treatment of the problem by only introducing "competing" theories such as buoyancy and precipitation loading that forces downbursts then quickly dismissing them in favor of downward momentum transfer. He also misuses statistical techniques in the section deriving his regression equation for maximum downburst wind gusts. However, more important to me are a number of fundamental defects in his physical model which render it unrealistic.

Rose's equation of downward transport (Eq. 3 in his article) is:

$$V_{max} = (V_d V_{avg} gz)^{1/4} \qquad (1)$$

where V_{max} is the maximum potential downburst speed, V_d is the magnitude of wind shear between the surface and the top of the shear layer (V_z - V_{sfc}), V_{avg} is the average wind speed within the shear layer, g is the acceleration of gravity, and z is the height above ground of the shear layer. This height is the lowest level aloft where $\partial V/\partial z < 3 \times 10^{-3}$ s^{-1}.

This formula is a geometric mean of several environmental wind speeds. Therefore, each component of the mean can be judged with respect to its relevance to the problem. A geometric mean differs from an arithmetic mean in that it is the n-th root of the product of n values. The geometric mean is usually slightly less than the arithmetic mean. To illustrate, the arithmetic mean of 2, 3, and 4 is $(2 + 3 + 4)/3 = 9/3 = 3$. The geometric mean is $(2 \times 3 \times 4)^{1/3} = 24^{1/3} = 2.88$.

Having established that Rose's formula is a mean of several values, we can now look at how each factor acts to capture a portion of the physical problem. The first value, V_d, is the *relative* speed of the wind at the top of the shear layer with respect to the surface wind. If this wind were brought down to the surface, an anemometer would measure a wind shift of V_d magnitude, not a wind of V_d.

Rose does not specify whether the second value, V_{avg}, is a vector average or an average of the speeds. This can be a significant difference in strongly sheared environments when the surface wind has a component opposite in direction from the wind at the top of the shear layer. Assuming that V_{avg} is a vector average, which is the more proper interpretation, then the velocity of parcels descending from the top of the shear layer is diluted by the velocities of parcels in succeedingly lower layers. Most downburst conceptual models, including the ones cited by Rose, keep the downdraft largely undiluted.

Lastly, one may wonder how is the factor, gz, a velocity? This factor (gz) is the potential energy of the air at the top of the shear layer. The total energy per unit mass of air (E) is given by the formula:

$$E = c_p T + gz + \frac{v^2}{2} \qquad (2)$$

which is the sum of the thermal energy (c_pT), potential energy (gz), and kinetic energy ($v^2/2$). Energy may be converted from one form to another as long as the total energy is conserved. In (1), Rose is converting potential energy to kinetic energy and is weighting it twice the other two terms in the geometric mean.

Rose's energy conversion term describes the increase in velocity due to internal energy changes and does not describe any downward momentum transfer process. By including this term, Rose actually weakens his argument that downward momentum transfer is the primary forcing mechanism for downbursts.

In addition, Rose applies this formula incorrectly by violating conservation of energy in two ways. First the conversion of the potential energy to kinetic energy as a parcel descends to the surface is twice what it ought to be ($v^2/2$, not v^2) resulting in double the wind speed.

The second violation is the apparent isothermal descent of the parcel. Air is compressible, so the temperature changes as air ascends or descends. If the process is adiabatic, i.e., no change to the total energy, the temperature change is described by the conversion of potential energy to thermal energy. For a descent to be isothermal, there must be an additional energy source independent of the potential energy to offset the increase in thermal energy.

The process of parcels descending in an evaporatively-cooled downdraft is obviously not adiabatic and this process can be that additional energy source. The temperature warms slower than the adiabatic rate because of evaporation. By incorporating moisture in (2), one can show how the kinetic energy increases in a downdraft at the expense of potential, thermal, and latent energies. Then this describes the buoyant forcing of downbursts that Rose dismisses as being relatively unimportant.

At this point, if the reader remains unconvinced, a little math exercise may help. This (gz) factor alone gives extremely unrealistic answers. Assuming z = 1000 m, this factor gives an estimate of 99 m s^{-1}. A logical conclusion from analyses of the other two factors above is that they usually underestimate V_{max}. In practice, Rose's formula gives reasonable values only because he averages unrealistic extreme values.

Despite the physical and dynamical problems with Rose's model for downbursts, he is correct in one very important observation. Buoyancy does not fully explain the magnitude of surface wind gusts in thunderstorms. Several years ago I developed the Wind Index or WINDEX (McCann 1994) that estimated downburst gust potential due to buoyant processes. After four years of experience, the practical upper limit of WINDEX values appears to be about 75-80 knots. If the WINDEX has been calibrated properly, then buoyancy-driven thunderstorm wind gusts probably do not exceed these values.

The record is full of downburst cases with stronger gusts. From structural damage, Fujita and Wakimoto (1981) estimated downburst gusts in one case as much as 150 knots. On 8 July 1992, the ASOS equipment at Concordia, Kansas, measured thunderstorm sustained winds greater than 50 knots for 20 minutes with a peak gust of 94 knots (Smith 1993). These two cases occurred at night and were north of a surface boundary.

Table 1. Conditions just prior to 26 occurrences of thunderstorm wind gusts > 70 knots or thunderstorm winds causing moderate or major structural damage during summer of 1996. WINDEX units are in knots. Time of day is UTC. Stability is the Brunt-Väisälä frequency squared ($g/\Theta\ \partial\Theta/\partial z$) between the surface and 3 km AGL.

WINDEX (knots	< 30	31-50	51-70	> 70
No. of occurrences	3	12	10	1
Time of Day (UTC)	00-06	06-12	12-18	18-00
No. of occurrences	12	3	1	10
Stability (x 10^{-5} s^{-2})	< 0	0-9	10-19	> 20
No. of occurrences	0	9	14	3

During the 1996 summer season I collected wind gust data for a future Aviation Weather Center thunderstorm gust potential forecast. In lieu of any known climatology of extreme thunderstorm wind events, I present Table 1. It shows some results for those reports of wind gusts greater than 70 knots or thunderstorm winds causing moderate or major structural damage. Most notable is that in a majority of cases the WINDEX was less than 50 knots, with only one case of a WINDEX > 70 knots. In addition, most reports occurred at night.

The most influential atmospheric variable in the WINDEX is the lapse rate between the surface and the melting level. The relatively stable low-level lapse rates in Table 1 explain the low WINDEX values. Low-level stabilities greater than about .0001 s^{-2} are usually found north of summertime surface boundaries. Also, there is generally a temperature gradient north of surface boundaries. If the boundary has been in existence for several hours, the thermal wind equation tells us that there should be some low-level wind shear. Rose suggests that the wind shear enhances downward momentum transfer. I suggest that the wind shear plays a different role.

Even if the sounding winds were combined more realistically than in Rose's conceptual model, adding downward momentum transfer to a wind gust algorithm does not explain many of these extreme cases. Using Smith's (1993) Concordia, Kansas (CNK) case as an example (Fig. 1), the WINDEX was a paltry 27 knots. One simple but realistic approach would be to add the speed of the wind aloft to the buoyancy-generated wind gust to account for both effects. Adding the wind speed at the top of the shear layer (20 knots) to the WINDEX yields 47 knots

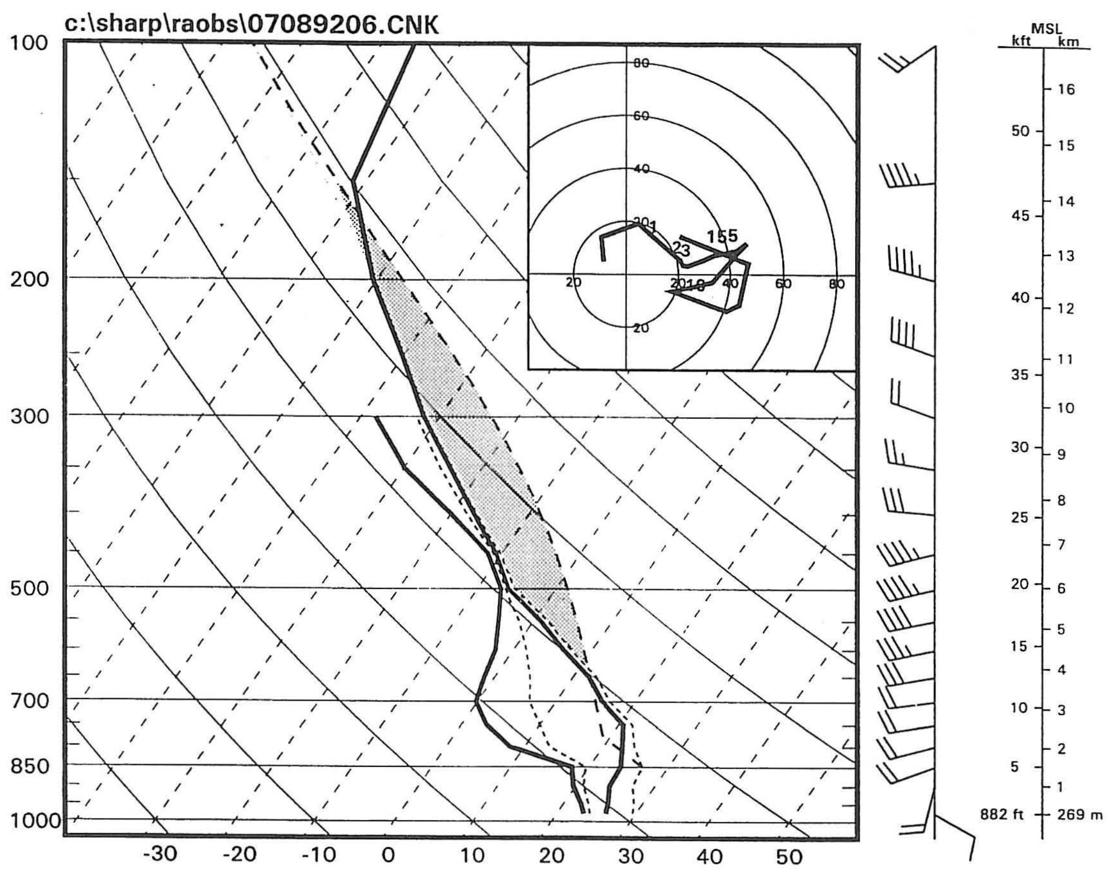

Fig. 1. Constructed proximity sounding for Concordia, Kansas at 0600 UTC 8 July 1992. (From Smith 1993).

Table 2. Computations of the peak gust with the 8 July 1992 Concordia, Kansas downburst using three different methods. Winds are in knots. PGF stands for pressure gradient force.

WINDEX 27	+	Wind speed at top of shear layer 20	= 47 knots
WINDEX 27	+	Wind speed at melting level 40	= 67 knots
WINDEX 27	+	Wind after PGF acceleration 58	= 85 knots

(Table 2). A better combination would be the sum of the wind speed at the melting level and the WINDEX which yields 67 knots. But, in this sounding there is no wind speed that when added to the WINDEX will result in the observed 94 knots.

If downward momentum transfer does not explain the subsequent wind gusts, then what does? Figure 2 shows the station pressure variations with time from the one-minute ASOS observations. For comparison purposes, I have included a similar observation recorded when a tornado passed within 1 km of a NOAA/National Severe Storms Laboratory automated observing site (Barnes 1978). It is readily apparent that mesolows were associated with both events. Although the CNK mesolow was the more intense of the two in this comparison, to make a general conclusion about the intensity of downburst mesolows versus tornadic mesolows would be presumptuous. That a mesolow often accompanies intense downbursts is born out in numerous other studies that include microbarograph information (e.g., McCann 1978; Fujita and Wakimoto 1981; and Alfonso and Naranjo 1996).

A pressure gradient is present between the mesolow and the precipitation-induced mesohigh. If the pressure gradient is large, extreme wind gusts can result. Schmidt and Cotton (1989) use a simple equation

$$V=V_0-\int_0^t \frac{1}{\rho}\nabla p\,dt \tag{3}$$

to estimate a parcel's resulting wind speed after being subjected to a pressure gradient. If $\rho = 1$ kg m^{-3}, $V_0 = 0$, and $\nabla p = 1$ mb km^{-1}, a parcel can accelerate from zero to 60 m s^{-1} (116 knots) in 10 min. A pressure gradient that large may not be likely, but using time-to-space analysis, a $\nabla p > 0.5$ mb km^{-1} probably occurred in the CNK downburst. Assuming t = 10 minutes, $V_0 = 27$ knots, and $\nabla p = 0.5$ mb km^{-1}, V = 85 knots. Given all the uncertainties in the assumptions, this is a very close estimate of the recorded peak wind.

In order for a mesolow to form at the surface, the pres-

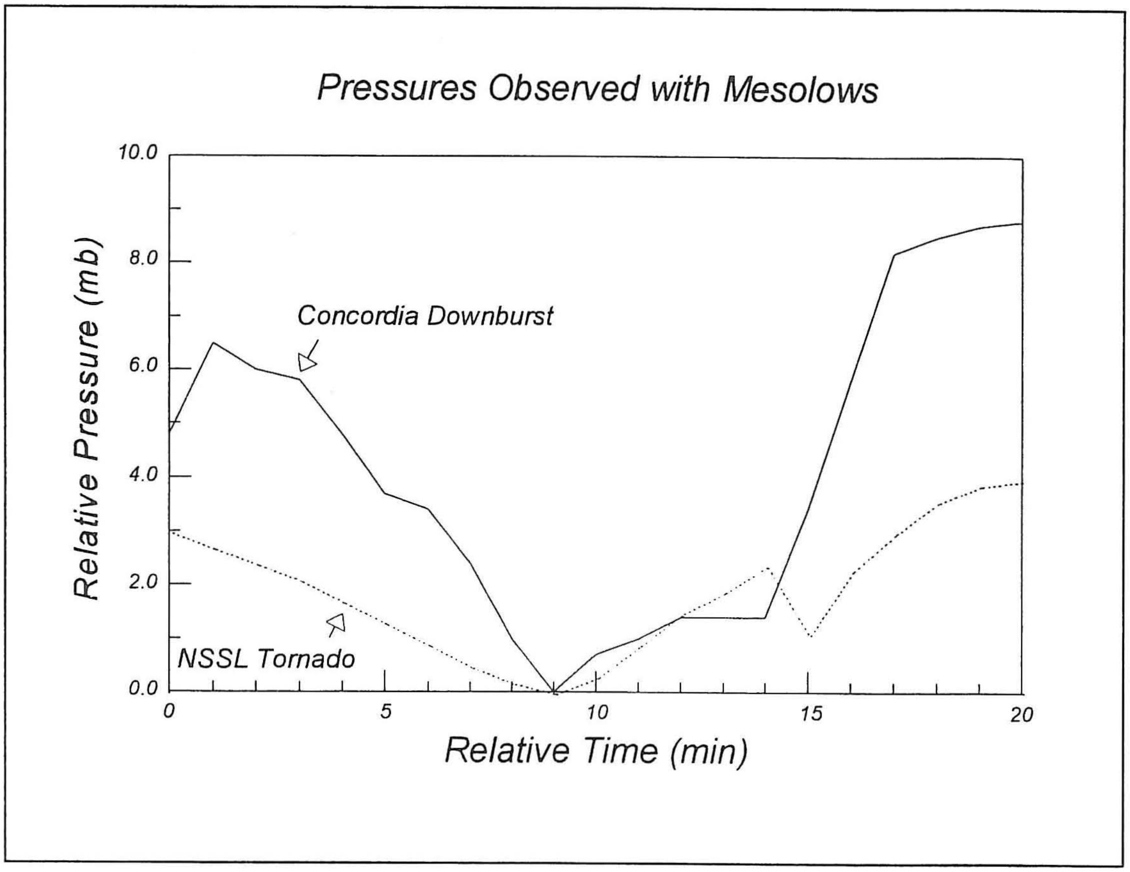

Fig. 2. Relative pressures associated with two mesolows. Solid is from the automated surface observation station (ASOS) at Concordia, Kansas on 8 July 1992 and is associated with a downburst. (Data obtained from Smith 1993). Dashed is from a National Severe Storms Laboratory (NSSL) automated observing site from which a tornado passed within 1 km of the site on 30 April 1970 (Barnes 1978). The pressures are relative to the lowest pressure observed during the event.

sure must drop on the mesoscale. Differentiating the hydrostatic equation with respect to time,

$$\frac{\partial p}{\partial t} = -\int_{0}^{\infty} g \frac{\partial \rho}{\partial t} \delta z \tag{4}$$

shows that pressures lower at a point when the density of the air above that point decreases. Some of the processes that can decrease the density are divergence and advection. But the process that may play the biggest role in thunderstorms is an increase in the column temperature. This increase is a result of the latent heat released in the storm's updraft. Therefore any process that increases the updraft strength also increases the latent heat release and decreases the surface pressure.

So how does low-level wind shear help increase a storm's updraft leading to mesolow development? There are several theories to mention. First, if configured correctly, low-level wind shear can be indicative of an environment with high storm relative helicity (SRH). Storms with high SRH have updrafts that rotate helically which can support stronger updraft velocities than storms that do not rotate (Lilly 1986). Second, the wind shear may set up a favorable vertical pressure gradient as demonstrated in Rotunno and Klemp's (1985) numerical model results. An upward vertical pressure gradient force will increase a storm updraft beyond that expected from buoyancy alone.

Third, as noted above, environments with strong low-level wind shear are also environments with large low-level static stability, sometimes called "capped" environments. Studies such as Raymond (1975) and Crook et al. (1996) imply that the convergence necessary to overcome a thermal cap can enhance upward motion at the Level of Free Convection (LFC). Air parcels reaching the LFC already have substantial upward motion. Then, they are accelerated to higher velocities.

To conclude, while there are many problems with the Rose (1996) paper, I focused only on the physical and dynamical problems associated with the idea that downward momentum transfer is critical to the downburst problem. Not only is Rose's model unscientific and unrealistic, it appears that any other conceptual model incorporating downward momentum transfer may also have problems. Likewise, buoyancy-driven conceptual models are incomplete, especially in extreme events. As an alternative, I offer a little-explored concept, that a pressure gradient acceleration of parcels into a mesolow can account for extreme thunderstorm wind gusts.

Acknowledgments

Thanks go to Brian Smith for providing me with a copy of the CNK sounding on which I relied for this paper. I thank Carolyn Kloth for her excellent review.

Author

Donald McCann is an Experimental Forecast Meteorologist at the NOAA/NWS Aviation Weather Center in Kansas City, Missouri. His duty is to improve forecasting techniques for turbulence, icing, and thunderstorms. Before 1991, he was a Convective SIGMET meteorologist for 14 years. He received a B.S. in Atmospheric Science in 1971 and an M.S. in Atmospheric Science in 1974 both from the University of Missouri.

References

Alfonso, A.P. and L.R. Naranjo, 1996: The 13 March 1993 severe squall line over western Cuba. *Wea. Forecasting,* 11, 89-102.

Barnes, S.L., 1978: Oklahoma thunderstorms on 29-30 April 1970. Part I: Morphology of a tornadic storm. *Mon. Wea. Rev.*, 106, 673-684.

Crook, N.A., J.B. Klemp, and R. Rotunno, 1996: Depth of lifting at a convergence line. Preprints, *15th Conf. Weather Analysis and Forecasting*, Norfolk, Virginia, Amer. Meteor. Soc., 276-279.

Fujita, T.T. and R.M. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts on 16 July 1980. *Mon. Wea. Rev.*, 109, 1438-1456.

Lilly, D.K., 1986: The structure, energetics and propagation of rotating convective storms. Part II: Helicity and storm stabilization. *J. Atmos. Sci.*, 43, 126-140.

McCann, D.W., 1978: Severe convective storms with little or no thunder. *Nat'l. Wea. Dig.*, 3(2), 2-5.

_______, 1994: WINDEX—A new index for forecasting microburst potential. *Wea. Forecasting*, 9, 532-541.

Raymond, D.J., 1975: A model for predicting the movement of continuously propagating convective storms. *J. Atmos. Sci.*, 32, 1308-1317.

Rose, M.A., 1996: Downbursts. *Nat'l. Wea. Dig.*, 21(1), 11-17.

Rotunno, R. and J. Klemp, 1985: On the rotation and propagation of simulated supercell thunderstorms. *J. Atmos. Sci.*, 42, 271-292.

Schmidt, J.M. and W.R. Cotton, 1989: A high plains squall line associated with severe surface winds. *J. Atmos. Sci.*, 46, 281-302.

Smith, B.E., 1993: The Concordia, Kansas downburst of 8 July 1992: A case study of an unusually long-lived windstorm. Preprints, *17th Conf. Severe Local Storms*, St. Louis, Amer. Meteor. Soc., 588-592