On the Microburst Family

by

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ABSTRACT: A model to predict the maximum microburst gust that may occur in any particular environment is developed and applied to one event.

INTRODUCTION

The microburst phenomenon of damaging winds localised to an area ≤ 4 km across, so classified by FUJITA (1985) as a subset of thunderstorm downdrafts/downbursts is accepted as a discrete process open to physical and numerical modelling. Contenders are the "starting plume" of TURNER (1969) or the alternative "thermal"/vortex-ring model of LUNDGREN *et.al.*(1992) which is SCORER's (1957) "thermal" model with ground effects.

CARACENA *et.al.*(1989) argue that the model of a jet (or plume) impacting at the surface cannot explain observations of a low-pressure ring surrounding a high-pressure impact core. Taken together with photographic suggestions of vortex rings in curling dust and/or precipitation spray at the outer edge of the spreading burst, they strongly support the vortex ring (thermal) model.

However, HJELMFELT (1988), in his study of microburst outflows, using JAWS multiple Doppler-radar data, found outflow structure resembles many features of the laboratory wall jet in both vertical and radial profiles.

Importantly, he also reported that when advected by an external stream (ambient wind) the outflow, to a first order, can be approximated by the vector addition of wind and wall jet outflow expected in a quiescent environment. Horizontal vortices, while common, did not occur with all outflows nor were they well defined in <u>all</u> directions. From his Figs. 10, 11, 12 and 18 we note that near the time of maximum intensity, the maximum speed (V_{MAX}) occurs at a radius ≈ 1.5 times the downdraft radius at a height near 80m. Speed is proportional to distance from impact centre out to V_{MAX}, but beyond is $\propto \frac{1}{r^2}$, not $\frac{1}{r}$ as expected from the jet theory.

Typically any horizontal vortex appears (develops) in the outer region some 5 mins. after the phase of maximum intensity. We also note that during the early phase of outflow the radial profiles are not well represented by those at maximum development.

These features support the view that (most) microbursts are sourced from "starting plumes" with peak intensity determined by the steady plume established behind the cap. The cap may however be the source of/or contribute to the vorticity in the outer rotor.

The plume downdraft speed, W, is not measured in JAWS data but its TOP-HAT value is derived, via assumption of anelastic mass continuity. The systems employed resolve horizontal scales ≥ 1.5 km with some information at 1 km.

Ensemble averaged JAWS data shows

$$< V_{MAX} > = < W > \text{ to } 1.2 < W >,$$

but individual profiles show a V_{MAX} up to 1.5 W, and considering the horizontal scale limitation and sampling at 2 - 2.5 min. intervals we adopt here. G = 1.5 W as the "peak gust" in outflow.

By analogy the "intensity of turbulence" about the $< V_{MAX} >$ value is 0.15 to 0.10. DIDDEN and HO (1985) observed G = 1.6 W, in a wall jet, caused by "vortex" instability at the jet boundary, treated here as turbulence.

MODELLING THE STEADY PLUME PHASE

The steady plume (TOP-HAT) equations for volume (mass), momentum and buoyancy flux are conveniently approximated by;

$$\frac{d}{dZ}(Wa^2) = 2\,a\,E = 2\,a\,\alpha\,W \tag{1}$$

$$\frac{d}{dZ}(W^2a^2) = g.\frac{\Delta\theta_v}{\theta_v}\,a^2 = g'\,a^2 \tag{2}$$

$$\frac{d}{dZ}(Wa^2g') = -\frac{Wa^2}{\theta_v}\,g.\,\frac{\partial\theta_e}{\partial z} + \frac{a^2.g}{\theta_v}\,.\,\gamma\,(T_e - T_s) \tag{3}$$

where; Z is + ve downward; a is plume radius; $E = \alpha W$, the entrainment speed; g gravity; θ_v potential virtual temperature of environment; $\Delta\,\theta_v$ plume deficit in θ_v; γ, a function of T_s, pressure and spectra of raindrops, is derived and discussed by SPILLANE and McCARTHY (1969); T_e is air temperature; T_s surface temperature of raindrops.

All models that attempt to simulate the behaviour of W find entrainment is minimal or zero. A deep dry-adiabatic subcloud layer of low humidity is also a requirement (see WAKIMOTO (1985)), and so $\frac{\partial\theta_e}{\partial Z} = 0$ also. Thus equations (1) - (3) immediately simplify to;

$$W\,a^2 = \text{constant} \tag{4}$$

$$\frac{dW}{dt} = g' \tag{5}$$

$$\frac{dg'}{dt} = \frac{g}{\theta_v} . \gamma . (T_e - T_s) \qquad (6)$$

We will here consider a particular situation where $\frac{g}{\theta_v} . \gamma . (T_e - T_s)$ is also near constant. As this situation is typical of microburst soundings reported by WAKIMOTO (1985), $\frac{g}{\theta_v} . \gamma . (T_e - T_s) = K$, a constant, may have wide application and permits immediate integration of (4) to (6) over depth D to provide;

Time of fall, $t_D = (6D/K)^{1/3}$ (7)

Velocity at D, $W_D = ½ (6D)^{2/3} (K)^{1/3}$ (8)

and $g_D' = (6D)^{1/3} (K)^{2/3}$ (9)

The flux of buoyancy at D is therefore given by $F_D = W_D \, a_D^2 \, g' = 3 a_D^2 DK$ (10)

and may be equated to the cooling rate of the plume volume given by $\bar{a}_D^2 \, D K$, which defines the average plume radius $\bar{a}_D = 3^{1/2} a_D$.

Returning to the requirement of non-entrainment it is well known that in this phase buoyant plumes have an internal FROUDE number (Fr^2) ≤ 5. Indeed the adoption of $Fr^2 = 5$ throughout the entraining phase is an equivalent alternative to entrainment with a constant half angle growth of 0.15.

(Consideration of accoustic soundings of plumes in dry convection below an inversion also suggests that the dominant plumes adopt $Fr^2 \Rightarrow 5$ at their spreading height).

The strongest possible downdraft will thus attain $(Fr^2)D = W_D^2 / a_D \, g_D' = 5$, say. -(11) and substituting from (8) and (9) the relationship (11) is satisfied by $a_D = 0.3$ D and $\bar{a}_D = 0.52D$.

The average $\bar{a}_D = 0.52D$ occurs at a depth of only 0.19D and at that level $W = D/t_D$ the average velocity of the downdraft from cloud base to ground.

The development of an ensemble (family) of downbursts would require a rain area somewhat > 2 $\bar{a}_D$, i.e. » D say, and convective overturning of the sub-cloud layer. Optimum packing of the elements of this convective field occurs with downdraft centres, and thus maximum gusts, spaced approximately 2(0.52 + 0.3)D = 1.64D apart, such spacing permits spreading of ~ 2.73 a_D before impact with adjacent simultaneous outflows.

By analogy with thermal convection confined below an inversion we expect individual plumes to have a lifetime of ~ $2t_D$. That is the plume forms and extends to the ground and subsequently collapses to be replaced by others. This is consistent with the characteristics of 20 microburst lines (families) described by HJELMFELT (1988) with activity and rain continuing for up to an hour, sourcing up to 40 individual microbursts, with individual constituent microbursts having a lifetime around 13 mins.

THE MELBOURNE MICROBURST FAMILY OF 3/1/81.

An approaching "front" prompted radar watch to determine the need for a Terminal Area Severe Turbulence advisory service for Melbourne Airport. The service was not invoked but photographic records of the S band radar displays were obtained. The event was close in time and space to the 2300Z sounding of winds and temperatures from Laverton Air Base, where the radar is located.

A deep well mixed "dry adiabatic" layer extended to cloud base near 700 (mb.). The layer potential temperature, θ was 36°C, and its wet-bulb potential temperature, θ_{sw} was 16.8°C. The radar reflectivity, at minimum beam elevation of 1.5°, attained values > 38 dBZ but < 48 dBZ, corresponding to rainfall > 9mm/hr but < 36 mm/hr.

The parameter K was evaluated at 500m levels below cloud base using γ values from SPILLANE and McCARTHY (1969), appropriate to $\theta = 36^\circ$c and $\theta_{sw} = 16.8$. The mid layer values were;

$K = 15 \times 10^{-5}\ \text{m.s}^{-3}$ for rain rate = 15mm/hr
$= 18 \times 10^{-5}\ \text{m.s}^{-3}$ = 20mm/hr

We note from equation (8) $W_D \propto$ as $(K)^{1/3}$ and as little rain was recorded the value $K = 15 \times 10^{-5}\ \text{m.s}^{-3}$ is adopted here.

The sub-cloud wind was uniform, consistent with a well mixed dry adiabatic layer. The measured speed of 38 knots was in exact agreement with the speed of advection of the radar-rain pattern. For such an advection speed the predicted peak gust = $38 + 1.5\ W_D$ (kts).

For $H = 2500\text{m}$, $K = 15 \times 10^{-5}\ \text{m.s}^{-3}$, $\theta = (273 + 36)^\circ\text{K}$

$\theta_{sw} = 16.8^\circ\text{C}$, $g = 9.8\text{m.s}^{-1}$, equations (7) - (9) yield;

$t_D = 464\text{s} = 7.74$ mins (life of 15.5 mins.)

$W_D = 16.2\ \text{m.s}^{-1} = 31.5$ kts

Peak Gust = $38 + 1.5 \times 31.5 = 85$ kts.

$g'_D = 0.07 \quad \Rightarrow \quad \Delta\theta = 2.2^\circ\text{C}$ and $\theta_D = 34^\circ\text{C}$

For $\Delta\theta = 2.2^\circ$C the corresponding increase in mixing ratio $\delta r = \Delta\theta/2.5 = 0.9$ gm/Kgm, and for an initial mixing ratio of 4.4 gm/Kgm. the evaporative addition of 0.9 yields a plume dew point of 5°C at the ground. The spacing of gust fronts from multiple downbursts is $1.64 \times D = 1.64 \times 2.5 = 4.1$ Km, and being advected at 38 knots a gust front would pass an anemometer every 3.5 mins.

OBSERVATIONS OF GUSTS

ESSENDON AIRPORT anemometer (10m. height)

Max. gust recorded = 78 kts
Temperature of gusts = 34°C
Dew point of gusts = 7°C

Gust spacing; 10 distinct gusts in 33 mins. gives an interval of 3.7 mins and spacing of 4.3 Km.

MELBOURNE AIRPORT anemometer (10m. height)

Max. gust recorded = 74 kts

Gust spacing; 7 distinct gusts in 21 mins. gives an interval of 3.5 mins and spacing of 4.1 Km.

(Readers are invited to consider Fig.3.16 in FUJITA (1985))

CONCLUSION

Regrettably a scientifically acceptable sample of events has not been available to the author. Few events oblige by passing over nearby well sited anemometers within an hour of radio-sonde and upper wind observations, while under radar surveillance.

However, considering the agreement with data obtained during the JAWS and CLAWS programmes the model presented here is recommended as a tool to aid explanation of gust events and in particular to estimate the most intense microburst gust that could occur in any particular situation. Indeed the occurrence of stronger gusts requires other physical explanations.

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