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THE DAPPLE METHOD FOR COMPUTING TORNADO HAZARD PROBABILITIES: REFINEMENTS AND THEORETICAL CONSIDERATIONS

Robert F. Abbey, Jr.

Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

T. Theodore Fujita

Department of Geophysical Science
The University of Chicago
Chicago, Illinois 60637

1.0 INTRODUCTION

In 1975 Abbey and Fujita proposed the Damage Area Per Path Length (DAPPLE) method for computing tornado hazard probabilities. This paper expands on the empirical approach advanced at that time by adding refinements to the path length statistics that form the base data for DAPPLE and by incorporating theoretical analyses into the computation of path area exposed to windspeeds.

2.0 COMPUTATION OF WEIGHTED PATH LENGTHS

A basic question in assessing the tornado risk is the selection of the statistical area around the specific site. If the selected area were too small, the computed probabilities are influenced by storms which do not represent the climatological average. On the other hand, the selection of an unusually large area around the site will result in the inclusion of storms which may not be related to the climatological conditions at the site.

To overcome such difficulties in site-specific evaluations, the authors devised a weighting function which decreases gradually with the distance from the site. Meanwhile, other geographical and population characteristics around the site were taken into consideration in order to assess properly the risks of tornadoes at the site.

DISTANCE FUNCTION, F(D), is expressed by the equation:

$$F(D) = \cos^{m} (0.9^{o} \times D) \qquad (2.1)$$

$$F(D) = 0.00 \quad \text{when } D \geq 100 \text{ miles} \qquad (2.2)$$

where "M" is a positive constant and D, the distance (in miles) from the site. This function is always 1.0 when D = 0, reaching zero at D = 100 miles. When the distance increases beyond 100 miles, the distance function is assumed "zero" so that tornadoes outside the 100-mile circle from the site do not influence probability computations.

The constant "m" can be chosen to be any positive value in order to shrink or spread the weighting function around the site. Values with m = 0.5 and m = 2.0 are given in Table 2.1. With these constants, the weighting function at the 50 km distance decreases to 0.84 and 0.50, respectively.

HEIGHT FUNCTION, F (ΔH), is also used in the risk computations when areas around the site are characterized by high mountains. These sub-boxes of high mountains are often tornado free; therefore, the inclusion of such sub-boxes will reduce unreasonably the tornado probabilities at the site.

The height function is designed to suppress the effects of mountain sub-boxes as a function of their heights above the site. The height function is computed based on the "height difference,"

$$\Delta H = \hat{H} - H_s , \qquad (2.3)$$

where H_s denotes the height of the site and $\hat{H}$, the elevation of the highest spot inside a 15 X 15 min sub-box. ΔH is determined based on a topographical map with an accuracy of 100 to 500 ft, depending upon the topography around the site. Table 2.2 may be used in determining required height accuracies in relation to this height function.

It is assumed that the height function is 1.00 as long as the height difference ΔH, is less than 1,000 ft. The function decreases to "zero" for mountain sub-boxes with height differences in excess of 11,000 ft. The height function is expressed by

$$F (\Delta H) = 1.1 - \frac{\Delta H}{10{,}000} \qquad (2.4)$$

$$F (\Delta H) = 1.00 \quad \text{when } \Delta H \leq 1{,}000 \text{ ft} \qquad (2.5)$$

$$F (\Delta H) = 0.00 \quad \text{when } \Delta H \leq 11{,}000 \text{ ft} \qquad (2.6)$$

This height function will permit us to suppress the effects of mountain sub-boxes where little or no tornado activities are expected.

TABLE 2.1 CORRECTION FACTORS FOR DISTANCE OF TORNADOES FROM SITE

F(D) with m=0.5

Increment (10 miles)	Distance from the site (1-mile increment) 0	1	2	3	4	5	6	7	8	9 miles
00 mile	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
20	0.98	0.98	0.97	0.97	0.96	0.96	0.95	0.95	0.95	0.94
30	0.94	0.94	0.94	0.93	0.93	0.92	0.92	0.91	0.91	0.90
40	0.90	0.89	0.89	0.88	0.88	0.87	0.87	0.86	0.85	0.85
50	0.84	0.83	0.83	0.82	0.81	0.81	0.80	0.79	0.78	0.77
60	0.77	0.76	0.75	0.74	0.73	0.72	0.71	0.70	0.69	0.68
70	0.67	0.66	0.65	0.64	0.63	0.62	0.61	0.59	0.58	0.57
80	0.56	0.54	0.53	0.51	0.50	0.48	0.47	0.45	0.43	0.41
90	0.40	0.38	0.35	0.33	0.31	0.28	0.23	0.22	0.18	0.13
100	0.00	--	--	--	--	--	--	--	--	--

F(D) with m=2.0

Increment (10 miles)	Distance from the site (1-mile increment) 0	1	2	3	4	5	6	7	8	9 miles
00 mile	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.98	0.98
10	0.98	0.97	0.97	0.96	0.95	0.95	0.94	0.93	0.92	0.91
20	0.91	0.90	0.89	0.88	0.86	0.85	0.84	0.83	0.82	0.81
30	0.79	0.78	0.77	0.75	0.74	0.73	0.71	0.70	0.68	0.67
40	0.66	0.64	0.62	0.61	0.59	0.58	0.56	0.55	0.53	0.52
50	0.50	0.48	0.47	0.45	0.44	0.42	0.41	0.39	0.38	0.36
60	0.35	0.33	0.32	0.30	0.29	0.27	0.26	0.25	0.23	0.22
70	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11
80	0.10	0.09	0.08	0.07	0.06	0.05	0.05	0.04	0.04	0.03
90	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
100	0.00	--	--	--	--	--	--	--	--	--

Table 2.2 Height function, F(ΔH) computed from Eqs.(2.4) through (2.6), the values of which can be obtained by finding the numbers at the intersection of the height difference in 1,000 ft in the left column and that in 100 ft across the top. This function is always 1.00 when height difference is less than 1,000 ft and 0.00 when height difference exeeds 11,000 ft.

Increment (1000 ft)	Height difference (100-ft increments) 0	100	200	300	400	500	600	700	800	900 ft
0 ft	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1,000	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
2,000	0.90	0.89	0.88	0.87	0.86	0.85	0.84	0.83	0.82	0.81
3,000	0.80	0.79	0.78	0.77	0.76	0.75	0.74	0.73	0.72	0.71
4,000	0.70	0.69	0.68	0.67	0.66	0.65	0.64	0.63	0.62	0.61
5,000	0.60	0.59	0.58	0.57	0.56	0.55	0.54	0.53	0.52	0.51
6,000	0.50	0.49	0.48	0.47	0.46	0.45	0.44	0.43	0.42	0.41
7,000	0.40	0.39	0.38	0.37	0.36	0.35	0.34	0.33	0.32	0.31
8,000	0.30	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.21
9,000	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11
10,000	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01
11,000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

LAND FACTOR, C_L , must also be taken into consideration mainly because tornadoes over water are not included in tornado statistics. No waterspouts are assessed by the FPP tornado scale.

Land factor is defined by the ratio of two areas,

$$C_L = \frac{\text{Effective land area}}{\text{Sub-box area}} \qquad (2.7)$$

where the effective land area denotes the area of land on which damage characteristics can be assessed for statistical purposes. When a sub-box is characterized by extensive swamps, marshes, everglades, etc., these areas will reduce the effective land area considerably.

The effective land area in Eq. (2.7) can also be regarded as a climatologically compatible area around the site. For example, extensive areas of inland desert in the State of Washington are entirely different climatologically from the land to the west of the Cascade. For risk computations of a site on one side of the Cascade, tornadoes on the other side must be suppressed or eliminated entirely. Such elimination can be performed by simply reducing the land factor, C_L , of specific sub-boxes to "zero".

The land-factor corrected path length is expressed by

$$L_L = L\, C_L^{-1} \qquad (2.8)$$

where L denotes the reported (or original) path length and L_L , the land-factor corrected path length. The corrected path length is always equal to or larger than the original path length, because the land factor does not exceed 1.00.

LATITUDE FACTOR, C_ϕ , is a correction factor due to the variation of sub-box areas as a function of latitude. This correction factor is expressed by the ratio of sub-box areas,

$$C_\phi = \frac{\text{Sub-box area at } \phi}{\text{Sub-box area at } 37^\circ} = \frac{\cos \phi}{\cos 37} \qquad (2.9)$$

the values of which are shown in Table 2.3.

The latitude-corrected path length is expressed by

$$L_\phi = L\, C_\phi^{-1} \qquad (2.10)$$

where L_ϕ denotes the latitude-corrected path length and L, the reported (or original) path length. By definition, the path lengths in sub-boxes to the north of the 37 N parallel always increases after correction, because the sub-box areas are smaller than those of the standard sub-box at 37°N.

POPULATION FACTOR, C_P, is assumed to vary with the population inside the sub-box. This factor is defined by

$$C_P = \frac{\text{Reported path length}}{\text{True path length}} \qquad (2.11)$$

The basic philosophy behind this population factor is that the path lengths in sparsely populated sub-boxes are reported to be less than the true lengths which could be confirmed if there were a large population and damageable structures. However, we should not assume that Cp is zero when nobody lives within a sub-box area, because tornado damages can be verified by those who move into an uninhabited sub-box after the occurrence of a storm.

The population factor is computed from

$$C_P = 1 - e^{-0.0005(P+500)} \qquad (2.12)$$

where P denotes the population inside a sub-box. Because we cannot always estimate the population inside sub-boxes with an accuracy better than 10 to 15%, it is not necessary to prorate the estimated population according to the sub-box latitude (refer to Table 2.3).

Combining Eqs. (2.11) and (2.12), the population-corrected path lengths are expressed by

$$L_P = L\, C_P^{-1} \qquad (2.13)$$

where C_P^{-1} denotes the population factor; L, the reported (or original) path length; and L_P, the population-corrected path length. Values of C_P are given in Table 2.4

Table 2.3 Latitude factor, C_ϕ of sub-boxes located between 24°N and 49°N. Values for each sub-box can be approximated as those of the closest full degree latitude, because the variation of the latitude factor within one-degree latitude is less than 2%. From Eq.(2.9).

Increment (10°)	Latitudes (increment 1°) 0	1	2	3	4	5	6	7	8	9°
40°	0.96	0.94	0.93	0.92	0.90	0.89	0.87	0.85	0.84	0.82
30	1.08	1.07	1.06	1.05	1.04	1.03	1.01	1.00	0.99	0.97
20	--	--	--	--	1.14	1.13	1.13	1.12	1.11	1.10

Table 2.4 Population factor computed from Eq.(2.12). Values are obtained by finding the numbers at the intersection of the population in 1,000 on the left column and that in 100 across the top.

Increment (1000)	Population in sub-box (100 increment) 00	100	200	300	400	500	600	700	800	900
000	0.22	0.26	0.29	0.33	0.37	0.39	0.42	0.45	0.48	0.50
1,000	0.53	0.55	0.57	0.59	0.61	0.63	0.65	0.67	0.68	0.70
2,000	0.71	0.73	0.74	0.75	0.76	0.78	0.79	0.80	0.81	0.82
3,000	0.83	0.83	0.84	0.85	0.85	0.86	0.87	0.88	0.88	0.89
4,000	0.89	0.90	0.90	0.91	0.92	0.92	0.93	0.93	0.93	0.93
5,000	0.93	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.96	0.96
6,000	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97
7,000	0.98	-----	same	-----						
8,000	0.99	-----	same	-----						
9,000	0.99	-----	same	-----						
10,000	1.00	-----	same	-----						

WEIGHTED MEAN PATH LENGTH, L, used in this site-specific study is defined by

$$\overline{L} = \frac{\Sigma L_C \Psi}{\Sigma \Psi} \qquad (2.14)$$

where L_C, called the "corrected path length", denotes the path length corrected by effective land area, latitude, and population. Ψ is the weighting function designed to compute the average value by weighting the path length in each sub-box.

L_C, in Eq. (2.14), is the path length which would have been reported if the area of a sub-box were identical to that of the standard sub-box at 37°N; if the sub-box were filled entirely with effective land area; and, also, if there were infinite population to observe and confirm all tornadoes all the time. In reality, however, these conditions are not always met, necessitating an estimate of the reasonable path length by applying three correction factors in the equation,

$$L_C = L \times (C_L \, C\phi \, Cp)^{-1} \qquad (2.15)$$

There is no way of knowing if the corrected path length in Eq. (2.15) represents the ideal path length discussed above. Nevertheless, the corrected path length should be closer to the ideal length than the uncorrected, original length.

WEIGHTING FUNCTION, Ψ, which is to be multiplied by the corrected path length in each sub-box is designed to be small when the path length in a sub-box is required to carry less weight. Weights considered in this risk computation are

1. The larger the distance from the site, the lesser the weight. Distance function, F(D), is used to achieve this weighting.

2. Sub-boxes with high mountains must carry less weight. Height function F (ΔH) is used.

3. Weight must be proportional to the area of each sub-box, because the larger the land area the longer the path length inside the box. Latitude factor C_ϕ is used.

4. Weight must be proportional to the effective land area, because the larger the land area, the longer the total path length. Land factor C_L is used.

5. Path lengths in densely populated sub-boxes must carry a larger weight than those in sparsely populated sub-boxes. Population factor C_L is used.

Thus, the weighting function used in this report is a product of the two functions and the three factors mentioned above. This weighting function is expressed by

$$\Psi = F(D)\, F(\Delta H)\, C_L\, C\phi\, C_P \qquad (2.16)$$

For computing the weighted path length, we combine Eq. (2.14) through (2.16) into

$$\overline{L} = \frac{\Sigma L^1}{\Sigma \psi}$$

where

$$L^1 = F(D)\, F(\Delta H) \times L \qquad (2.17)$$

denotes the weighted path length within each sub-box. Since L varies with the tornado's F scale, L^1 also varies as a function of the F scale.

Values of $\overline{L}$, the weighted path length from Eq. (2.17), are used as the input values in computing risk probabilities based on the DAPPLE METHOD.

3.0 COMPUTATION OF DAPPLE PROBABILITIES

Theoretical considerations of the areas swept out by a range of tornado threshold windspeeds gave rise to utilization of the suction vortex model developed by Fujita (1978). Conceptually, the models are identical, but differ in approach.

In assessing tornado risk probabilities, an area of tornado damage is contoured by a number of isolines of maximum wind velocities. The isoline, called ISOVEL (isoline of the velocity of damaging wind), can be determined through an F-scale assessment of the damage.

Figure 3.1 shows the schematic isovels of an F3 tornado characterized by four isovels, I0 through I3. This figure reveals that the path length of a tornado is dependent upon the windspeed.

The path lengths of the tornadoes published in "Storm Data" correspond to those between L_0 and L_1 , where the suffix "0" denotes 40 mph, the F0 windspeed of an F0 tornado, expressed by $\overline{F0}$ tornado, is characterized by a 59 mph windspeed which is likely to cause weak but visible damage to a weak structure. Path length in "Storm Data" is, thus, assumed to be $L_{\bar{0}}$.

Expressing the lengths and the widths of various tornadoes grouped by F scale, the tornado areas as functions of isovels are expressed by

$$\Sigma A_{I(F)} = \overline{W}_{I(F)}\ \Sigma L_{I(F)} \qquad (3.1)$$

where $A_{I(F)}$ denotes the area of isovel (isovel area) of windspeed I inside an F-scale tornado; $\overline{W}_{I(F)}$, the mean isovel width; and $L_{I(F)}$, the isovel length of an individual tornado.

Likewise, we express the sum of the path lengths in this equation by

$$\Sigma L_{I(F)} = \overline{\Psi}_{I(F)} \Sigma L_{\bar{0}(F)} \qquad (3.2)$$

where $L_{\bar{0}\,(F)}$ denotes the path length in "Storm Data" and $\overline{\Psi}_{I(F)}$, the "mean path factor" which varies as a function of both I, the isovel, and F, the F-scale tornado intensity.

DAPPLE, defined as the product of the mean width in Eq. (3.1) and the mean path factor in Eq. (3.2), is expressed by

$$\begin{aligned} \text{DAPPLE} &= \overline{W}_{I(F)}\ \overline{\Psi}_{I(F)} \\ &= \frac{\overline{W}_{I(F)}\ \Sigma L_{I(F)}}{\Sigma L_{\bar{0}(F)}} \\ &= \frac{A_{I(F)}}{\Sigma L_{\bar{0}\,(F)}} \end{aligned} \qquad (3.3)$$

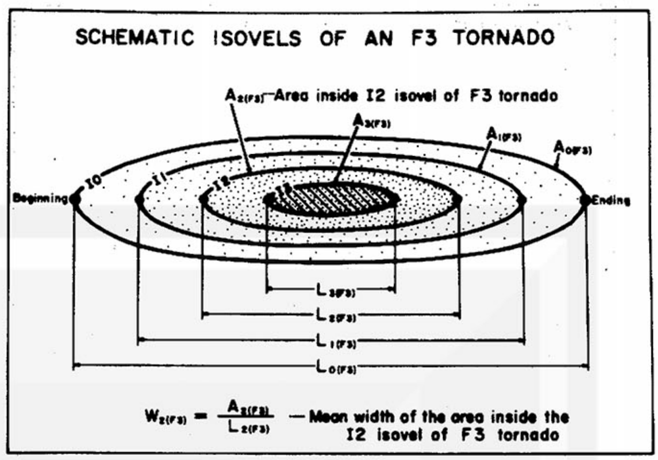


FIGURE 3.1 SCHEMATIC OF ISOVEL DISTRIBUTION IN F3 TORNADO SHOWING AREAS SWEPT OUT BY DIFFERENT TORNADO WINDSPEEDS.

This equation permits us to compute risk probabilities, as a function of windspeed by

$$P_I = \frac{\text{DAPPLE X } \Sigma L_{\bar{0}(F)}}{\text{(Area) X (Year)}} \qquad (3.4)$$

$$= \text{DAPPLE X } \frac{L_{0(F)}}{\text{Area}} \text{ X } \frac{1}{\text{Year}} \qquad (3.5)$$

where "Area" denotes the total area in which the path lengths existed and "Year" the number of years of statistics.

4.0 APPLICATION OF DBT-78 TO DAPPLE METHOD

Figure 4.1 protrays the concept of suction vortices rotating about a common tornado parent.

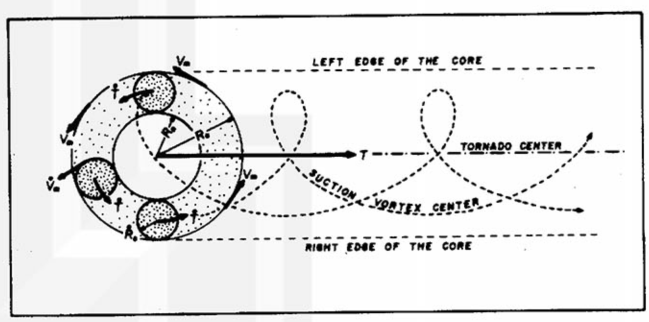


FIGURE 4.1 SUCTION VORTEX MODEL SCHEMATIC

By virtue of its small core radius and fast spinning motion, a suction vortex is accompanied by strong winds at a relatively low level above the surface. Figure 4.2 shows the vertical distribution of the maximum total windspeeds of the weighted mean F4 tornado and embedded suction vortex.

The maximum total windspeed of the suction vortex is 227 mph which is only 17 mph larger than the maximum total windspeed of the parent tornado. At the 15 m level, however, the tornado windspeed is only 167 mph-- 60 mph slower than that of the suction vortex.

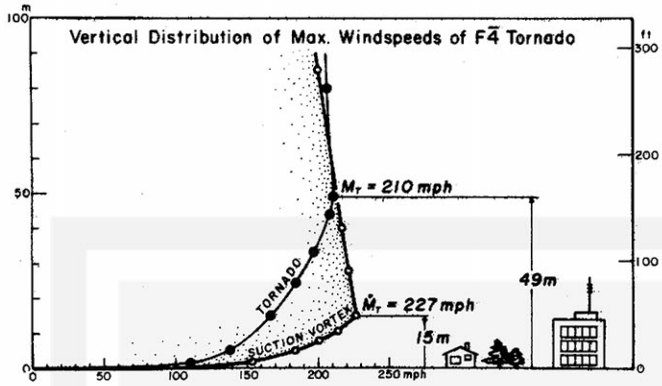


FIGURE 4.2 VERTICAL DISTRIBUTION OF MAXIMUM WINDSPEEDS OF AN F4 TORNADO

Suction vortices are likely to produce small DAPPLEs of high-speed isovels. The patterns of isovels left behind suction vortices are complicated as shown in Figure 4.3

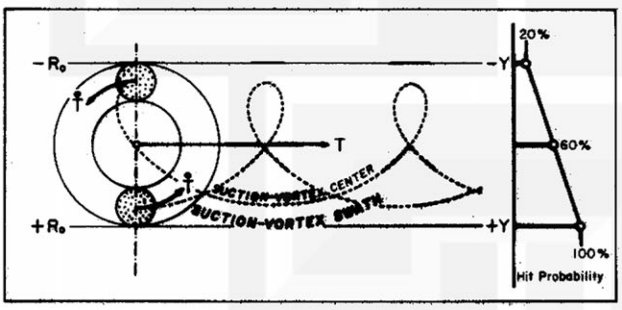


FIGURE 4.3 LOCALIZED SWATHS OF SUCTION VORTICES

A concept of "hit probability" was devised for computing DAPPLE values of suction vortices. If a structure were on the right side of the tornado at the distance Y = + R in Figure 4.3, the hit probability was assumed to be 100% or 1.0. On the left side of the center the probability should be small. Thus, we assumed

$$s = 0.2 \qquad (Y \leq -R_o)$$

$$s = 0.6 + 0.4\,\frac{Y}{R_o} \qquad (-R_o \leq Y \leq +R_o)$$

$$s = 1.0 \qquad (Y \geq +R_o)$$

where s is the hit probability by suction vortices.

An analytical model developed by Fujita (1978), DBT-78, provides the tornado's wind field as a function of the maximum total velocity including embedded suction vortices. It is now feasible to compute the widths of isovel areas, abreviated as "isovel width," based on DBT-78.

The maximum total velocity, M_θ, as defined in Figure 4.4 occuring at the outer-core boundary is computed by

$$M\theta = (T + V_m \cos \theta)^2 + (V_m \sin \theta)^2 + W_m$$

$$= (1.269 + 2/3 \cos \theta)\, V_m^2$$

where θ is the argument of the tornado-centric vector measured from +Y axis which extends toward the right of a traveling tornado. Substituting cos θ by Y/R₀, we have

$$M\theta = (1.269 + \frac{Y}{R_o})^{1/2}\, V_m$$

where Y is positive on the right side and negative on the left side of the tornado center.

The maximum total windspeeds outside the swath of the tornado core can be expressed simply by

$$M = (V_m + T)\,\frac{R_o}{Y} = \frac{4}{3}\,\frac{R_o}{Y}\,V_m$$

and $$M_L = (V_m - T)\,\frac{R_o}{Y} = \frac{2}{3}\,\frac{R_o}{Y}\,V_m$$

where M_R and M_L are the maximum total windspeeds on the right and on the left side, respectively. Note that both T_θ and V decreased outward from tornado core inversely proportional to the distance from the tornado center.

The velocity profile at the top of the inflow level across the swath of the tornado core is shown in Figure 4.4. A jump in the velocity on the core boundary is due to the addition of vertical velocity, W_m.

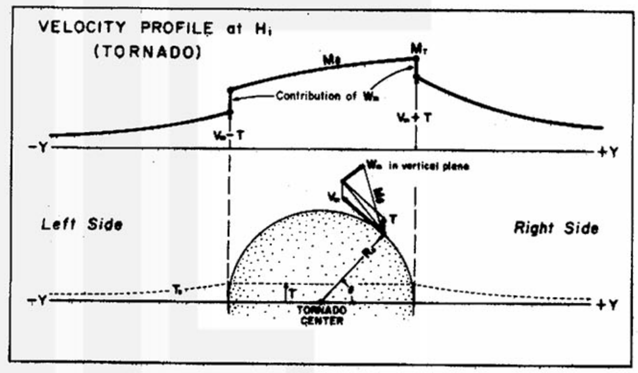


FIGURE 4.4 PROFILE OF THE θ-DEPENDENT MAXIMUM VELOCITY ACROSS THE PATH OF A TORNADO.

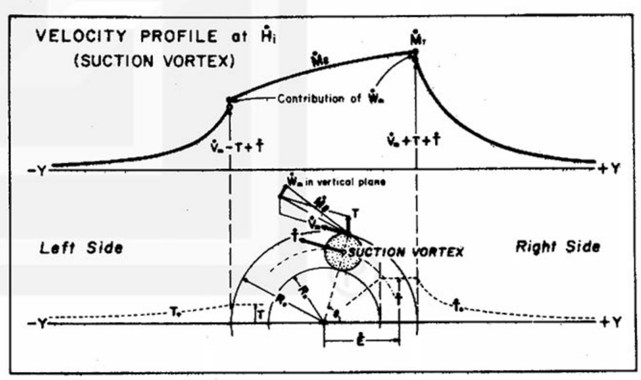


FIGURE 4.5 PROFILE OF THE θ-DEPENDENT MAXIMUM VELOCITY OF A SUCTION VORTEX

A similar velocity profile for a suction vortex is presented in Figure 4.5. The maximum total velocity, in this case, includes four basic parameters.

$$\overset{\circ}{V}_m = \frac{1}{2} V_m$$

$$\overset{\circ}{W}_m = 0.397\ \overset{\circ}{V}_m$$

$$\overset{\circ}{T} = \frac{3}{7}(1 + n)\ V_m$$

$$T = \frac{1}{3} V_m$$

The θ-dependent, maximum total velocity, Mθ can now be given by

$$\overset{\circ}{M}_\theta^2 = \left[(\overset{\circ}{V}_m + \overset{\circ}{T})\cos\theta + T\right]^2 + (\overset{\circ}{V}_m + \overset{\circ}{T})^2 \sin + \overset{\circ}{W}_m^2$$
$$= \left(K^2 + 0.269 + \frac{2}{3} K\cos\theta\right) V_m^2$$

where $K = (\overset{\circ}{V}_m + \overset{\circ}{T}) / V_m = \frac{13}{14} + \frac{3}{7} n$.

Substituting cos θ by Y/R_o, we have

$$\overset{\circ}{M}_\theta = \left(K^2 + 0.269 + \frac{2}{3} K \frac{Y}{R_o}\right)^{1/2} V_m$$

The maximum total windspeeds by suction bortex on both sides of the tornado core are expressed by

$$\overset{\circ}{M}_R = (\overset{\circ}{T} + T)\frac{R_o}{Y} + \frac{\overset{\circ}{R}_o}{Y - \overset{\circ}{\varepsilon}} \overset{\circ}{V}_m$$

and

$$\overset{\circ}{M}_L = (\overset{\circ}{T} - T)\frac{R_o}{Y} - \frac{\overset{\circ}{R}_o}{Y - \overset{\circ}{\varepsilon}} \overset{\circ}{V}_m$$

where $\overset{\circ}{M}_R$ and $\overset{\circ}{M}_L$ are the maximum total windspeeds on the right and left sides, respectively.

Equations through derived from the DBT-78 model will permit us to compute the isovel widths of given windspeeds. These widths, however, represent the values at the levels of the maximum total velocities which vary according to the inflow heights of tornadoes and embedded suction vortices.

Since F-scale assessments of storm damages are based primarily on trees and structures with their usual heights of 5 to 15m AGL (above ground level), isovel widths computed from DBT-78 will have to be at heights of the objects for F-scale assessments.

The height for computing isovel widths was chosen to be 10m. Computation of velocities at 10m AGL can be achieved by substituting V_m, W_m, Tm etc. by height- and radius-dependent quantities.

Figure 4.6 is a schematic profile of the variation of windpseeds in tornadoes and suction vortices computed by the method advocated in Fujita (1978).

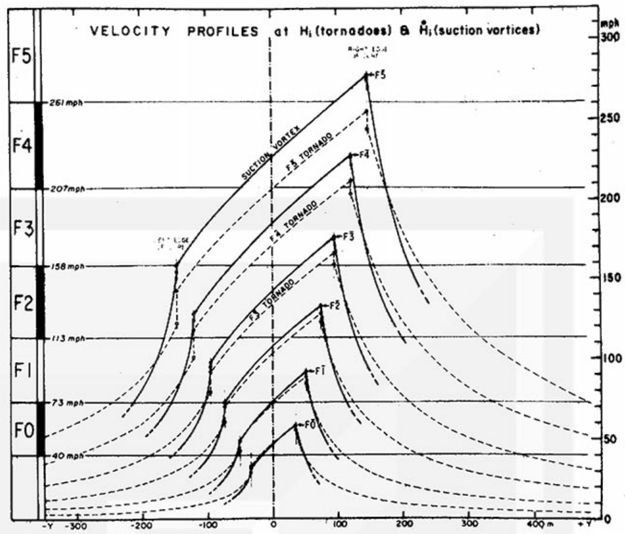


FIGURE 4.6 VELOCITY PROFILES OF FO THROUGH F5 TORNADOES AT 10 m AGL.

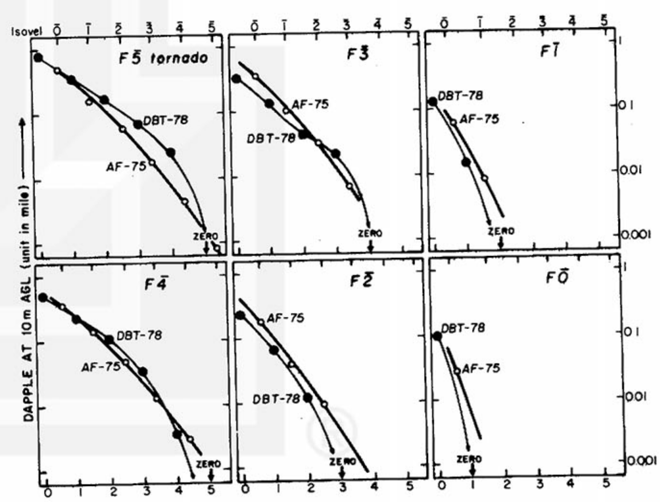
5.0 COMPARISON OF DAPPLE VALUES FROM AF-75 AND DBT-78

In computing isovel widths, Abbey and Fujita (1975) used the empirical formula

$$W_F = W_0\ (2.4)^{-F}$$

while the isovel widths of the DBT-78 were obtained by solving the analytical functions of the model advanced by Fujita (1978). The major difference between these independent computations are the methods of estimating the isovel widths as a function of I and F.

DAPPLE values were computed from these two methods and plotted for comparison purposes in Figure 5.1. The results are encouraging. In spite of a number of assumptions and inevitable uncertainties, these two independent DAPPLEs are in very close agreement.



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