An Examination of the Wet-Bulb Zero as a Hail Forecasting Parameter in the Po Valley, Italy

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The height at which the ambient wet-bulb temperature equals 0C, known as the wet-bulb zero, figures as an important element in the empirical techniques for forecasting severe weather in the United States (Fawbush and Miller, 1953; Miller, 1967a, b). It is found that for severe activity to occur the height of

TABLE 1. Distribution of occurrences of hail as a function of the height of the wet-bulb zero.

	Height of wet bulb zero (km)									
	1.75–<2.0	2.0–<2.25	2.25–<2.5	2.5–<2.75	2.75–<3.0	3.0–<3.25	3.25–<3.5	3.5–<3.75	3.75–<4.0	Total
Frequency of hail of diameter ≥30 mm	0	2	3	2	5	6	4	4	1	27
Frequency of hail of diameter <30 mm	4	5	5	6	6	12	8	7	0	53
Frequency of all hail	4	7	8	8	11	18	12	11	1	80

this surface should lie between 5000 and 11,000 ft (1.5–3.5 km) above the ground, and preferably near 8000 ft (2.5 km). The probability of surface hail and strong winds is found to be low when the wet-bulb zero lies outside these limits.

The physical reasoning behind the importance of the wet-bulb zero seems to rest partly on its identification as the source level for the downdraft and partly on considerations relative to hail melting.

A preliminary investigation of the utility of the wet-bulb zero as a parameter in hail forecasting in the Po Valley, Italy, suggests that what skill it has is due to its correlation with a more basic parameter, the low-level available moisture. Low-level moisture is already taken account of in various other stability calculations used in severe storm forecasting.

First, the maximum frequency of hail occurrences for a number of hail cases in a 10-year period is found with the wet-bulb zero in the height range 3.0–3.25 km (Table 1). The overall range of occurrences lies from 1.8–3.8 km (or from about 825–650 mb). These heights are referred to sea level; there are no large variations of ground elevation in the region of interest. There is only a very weak separation of large and small occurrences of hail according to this parameter. The frequency distribution as a function of the height of the wet-bulb zero is nearly the same for both classes.

The relationship between the wet-bulb zero and low-level moisture is shown in Fig. 1. This shows the result of plotting the height of the wet-bulb zero against the mean mixing ratio in the lowest 100 mb of the atmosphere for the hail cases of Table 1. The relationship displayed is remarkable, but really is not surprising. In fact, it is closely related to the correlation between surface dew point and total precipitable water demonstrated by Reitan (1963), Bolsenga (1965), and Smith (1966). That it is not restricted to hail days alone is indicated by Fig. 2, showing the wet-bulb zero vs mean low-level mixing ratio for all soundings at Udine, in the northeast corner of the Po Valley, between 1 April and 15 September 1967. In Fig. 2 pressure is used as the height coordinate simply because it was more convenient. Fig. 3, from the same location, further reveals this relationship on a day-to-day basis.

Having found that there exists a correlation between wet-bulb zero and low-level moisture, one should expect to find a distribution of hail cases as a function of the low-level moisture analogous to that in Table 1. This is shown in Table 2, and one could con-

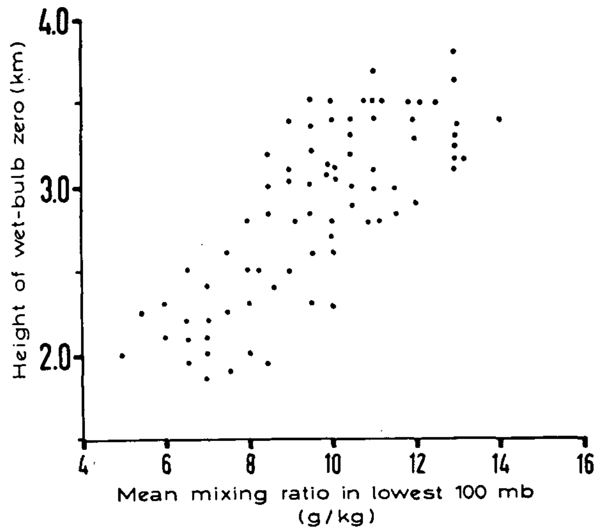

FIG. 1. A plot of height of wet-bulb zero vs mean mixing ratio in the lowest 100 mb for the hail cases of Table 1.

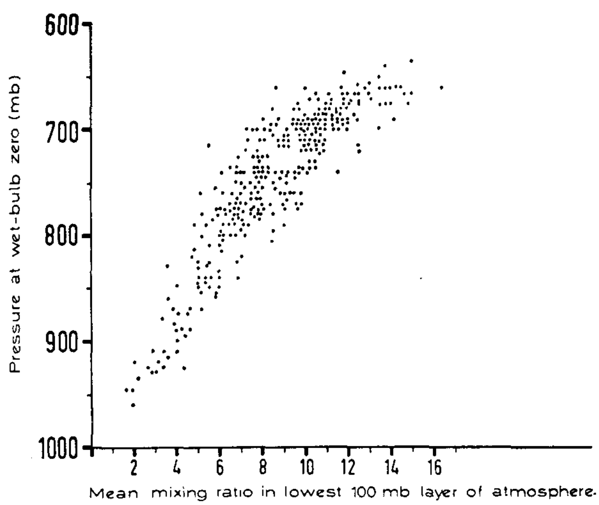

FIG. 2. Pressure at wet-bulb zero vs mean mixing ratio in surface layer at Udine, 1 April through 15 September 1967.

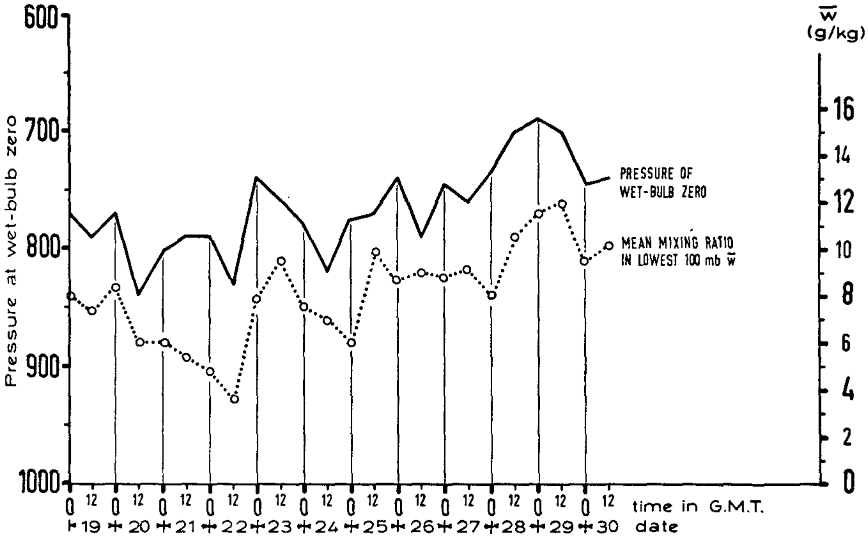

FIG. 3. Example of sequential behavior of pressure at wet-bulb zero and mean mixing ratio in surface layer, 19–30 May 1967, at Udine.

clude that this shows a better separation between large and small hail than does Table 1. This suggests that low-level moisture is the significant predictor and that the wet-bulb zero shows skill only to the extent that it reflects low-level moisture. Once it has been established that there is a correlation between two predictors one of them loses some of its usefulness. In the present case the low-level moisture is the more basic of the two and cannot be discarded or devalued.

As might be expected, in the data samples used for the figures, there is also found a strong correlation between the mixing ratio at 1000 mb and the mean mixing ratio in the lowest 100 mb, as was shown to be the case in the United States by Pearson *et al.* (1967), and a fair correlation between the height of the wet-bulb zero and the mixing ratio at 1000 mb.

It must be born in mind that the Po Valley, being closed in on three sides by mountains, is a region of very sluggish flow in the lowest few kilometers, with changes in moisture stratification being dominated by convective mixing from ground level. This may tend to tie the wet-bulb zero to low-level moisture more than would be the case over open plains, where advection might be more important. Also, the soundings on which this note is based, made at 0100 and 1300 local standard time, are greatly displaced from the expected times of maximum and minimum instability and vertical mixing.

It can be inferred from Figs. 1 and 2 that the higher the wet-bulb zero the more moist (and generally warmer) is the air mass. With a low wet-bulb zero there is, on the average, a lack of available moisture; with a very high wet-bulb zero, conditions favor melting of the hail before it reaches the ground. One could also expect, on the basis of Figs. 1 and 2, to find a correlation between the wet-bulb zero height and cloud base temperature which would suggest that high wet-bulb zero values indicate the failure of hail to form due to the "natural hail suppression mechanism" described by Appleman (1959).

However, the correlation suggested by Figs. 1–3 is not good enough to justify its use in inferring low-level moisture or cloud base temperature from wet-bulb zero height when these can be measured directly on the same sounding more accurately.

TABLE 2. Distribution of occurrences of hail as a function of the mean mixing ratio in the lowest 100-mb layer.

	Mixing ratio W (gm kg^{-1})								
	0–<2	2–<4	4–<6	6–<8	8–<10	10–<12	12–<14	14–<16	Total
Frequency of hail of diameter ≥30 mm	0	0	0	4	6	11	5	1	27
Frequency of hail of diameter <30 mm	0	0	4	10	17	15	9	0	55
Frequency of all hail	0	0	4	14	23	26	14	1	82

Conclusion

These observations tend to raise doubts as to the true efficacy of the wet-bulb zero as a severe weather predictor, at least for hail. Whatever predictive value it possesses is most likely due to its correlation with low-level moisture, which is clearly stronger than its correlation with any form of severe weather. Since low-level moisture can be more accurately estimated by means of the surface dew point or measured directly from the sounding, the wet-bulb zero might be considered a superfluous parameter. If the wet-bulb zero concept is to be of any use in forecasting, one must take account in an explicit way of the simultaneous changes taking place in the low-level moisture. How much skill would remain is a question for investigation. Though it may well be that the present results are only valid for the Po Valley, which in some respects is a rather special region, they suggest the advisability of a similar evaluation of the wet-bulb zero in other areas.

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