NOTES AND CORRESPONDENCE

Comments on "Observations of an Industrial Cumulus"

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In a note entitled "Observations of an Industrial Cumulus," Auer (1976) stated that his observations may find utility in evaluation of numerical cloud models. The purpose of this brief note is to compare the results of a one-dimensional, steady-state cloud model with Auer's observations. The model is based on Weinstein's (1970) one-dimensional cloud model, but is forced at low heights to agree with the theories of stack plume rise proposed by Briggs (1975). Its purpose is to estimate the environmental effects of cooling tower plumes. A complete description of the model and its application to the cooling tower plumes at the John E. Amos, West Virginia, power plant is given by Hanna (1976). Currently the model is being applied to simulate observations of cooling tower plumes at the Rancho Seco, California, power plant (Wolf, 1976). As input the model requires ambient vertical profiles of temperature, dew point and wind speed. The radius, temperature, vertical speed and mixing ratios of water vapor, cloud water and hydrometeor water of the plume at the source are also required.

Auer's observations were taken with an instrumented light aircraft which was engaged in measuring cumulus clouds in the vicinity of St. Louis under the auspices of Project METROMEX. During one of the METROMEX runs, a cumulus cloud was noticed that was obviously forming in the plume from a refinery complex. Several passes through the cloud were made, and a nearly complete set of cloud data, including temperature excess, turbulence intensity, vertical speed, cloud droplet spectra, CCN, Aitken nucleii and excess water were obtained. Ambient vertical profiles of temperature and dew point were also measured by a slow spiral descent of the aircraft and the vertical wind profiles were measured using pilot balloons.

The surface temperature used in this model application, 300.5 K, is estimated by dry adiabatic extrapolation from the temperature at the lowest aircraft measurement level. The surface dew point, 296.0 K, is estimated by linear extrapolation from the dew points measured by the aircraft in the layer between 250 and 600 m above the ground. Since the source details are sketchy in Auer's paper, it is necessary to arbitrarily choose parameters such as the initial plume radius. In subsequent discussions with Auer, it was decided that the values of 250 m for the initial plume radius and 1 m s^{-1} for the initial plume vertical speed are reasonable. It is assumed that all emissions are at ground level. In Footnote 1 of Auer's (1976) paper, it is stated that the total energy emission is 7×10^{11} cal h^{-1} ($\sim$800 MW), divided about equally between sensible and latent heats. These conditions are satisfied by an initial plume temperature of 302.3 K and a relative humidity of

TABLE 1. Comparisons of observations and predictions for the St. Louis refinery cloud. (All heights are in meters above the surface.)

	Observed	Predicted
Cloud base (m)	700	650
Cloud top (m)	2050	2350
z (m)	Observed liquid water content (g m^{-3})	Predicted liquid water content (g m^{-3})
930	0.046	0.56
1260	0.10	0.74
1860	0.44	1.30
z (m)	Observed vertical speed (m s^{-1})	Predicted vertical speed (m s^{-1})
500	3	2.0
1500	4	2.0
2000	3	2.3
z (m)	Observed temperature excess (K)	Predicted temperature excess (K)
500	0.2	0.1
1500	−0.5	0.3
2000	−0.2	0.5

76.5%. Initial cloud water and hydrometeor mixing ratios are set equal to zero.

The comparisons of Auer's observations and the model output are given in the Table 1. The cloud cross sections presented by Auer were used to estimate averages across the entire width of the cloud at a given height. The observations of temperature excess were obtained by averaging the temperatures in the cloud cross sections sent to the author by Auer in a letter dated 7 July 1976.

It is seen in the table that the heights of the cloud base and top are predicted quite well by the model. There is a slight inversion above about 2100 m which causes the plume to level off. The predicted vertical speed is about 20–50% too low and the predicted liquid water content is a factor of 3–10 too high. The observed and predicted temperature excesses are within 0.8 K of each other.

Auer also calculated the entrainment rate based on his measurements of temperature in the cloud. He finds that the entrainment rate is between 33 and 91% km^{-1} for eight different passes through the cloud. In the numerical model the entrainment rate $(1/V)(dV/dz)$ can be approximated by $0.8/R$, where V is the volume flux UR^2, and U and R are the wind speed and the plume radius, respectively. Thus the model entrainment rate is about 160% km^{-1} at cloud base and about 75% km^{-1} at a height of 2000 m (using $R=R_0+0.4z$).

It can be concluded that this model does a fair job of simulating the observed temperature excess, vertical speed and cloud base and top. The predicted entrainment rate is about a factor of 2 too high and the predicted liquid water content is a factor of 3–10 too high. Auer also measured turbulent energy, cloud droplet spectra, CCN and Aitken nucleii, but none of these variables is used in the present model. It would be interesting to see if a two- or three-dimensional model with more detailed cloud microphysics could improve on these predictions.

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