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Technical Attachment

POTENTIAL USE OF A ONE-DIMENSIONAL NUMERICAL CLOUD MODEL AT A WEATHER SERVICE OFFICE

Jeffrey T. Davis
National Weather Service Office
Amarillo, Texas

1. INTRODUCTION

The main emphasis of this study is to investigate the feasibility of a cloud scale numerical model in an operational setting. In general, little besides the parcel method or subjective judgement is available operationally for estimating the potential depth and updraft strength of cumulus and cumulonimbus clouds. With the computer power available today, it is possible to supplement current forecast methods by using a simple one-dimensional cloud model that includes a parameterized microphysical scheme.

Various types of one-dimensional cloud models have been developed. Many of these models predict the profile of vertical velocity, cloud temperature, and hydrometeor quantities such as rain, cloud water, cloud ice, and hail as a function of height (Anthes, 1977; Kreitzberg and Perkey, 1976; Dennis and Musil, 1973). The entrainment is usually set inversely proportional to the updraft (or plume) radius. Several models have been used to predict cloud responses to seeding during weather modification projects (Simpson and Wiggert, 1969; Weinstein and McCready, 1969). In an operational mode, Crum and Cahir (1983) experimented with an interactive one-dimensional cloud model in forecasting shower-top heights. The interactive feature of the model allowed them to modify the 1200 UTC sounding at various levels to take in account environmental changes from morning to afternoon. They found that accurate modifications of the morning surface dew points alone produced better results than cases where upper-level changes were made. For interpreting energy availability, Matthews and Silverman (1980) used the Kreitzberg and Perkey MESOCU cloud model to determine a convective potential index (CPI). The CPI was simply the arithmetic sum of all the cloud depths simulated by the model and was taken as a measure of the thermodynamic potential for convective cloud growth. They concluded that the CPI might be a useful forecasting index if mesoscale lifting velocities could be determined and a representative sounding could be obtained.

In principle, it should be possible to use a simple, fast, one-dimensional cloud model in an operational setting either as a stand-alone program or as part of a larger scale numerical model. In practice, such a model has several disadvantages. First, model results are sensitive to the size of the updraft radius specified, and there is little way to predict the particular updraft radii appropriate for a given day. Further, models are very sensitive to initial cloud base conditions and changes in the environmental sounding. Nonetheless, results from Crum and Cahir (1983) suggest that it might be possible to achieve useful model predictions from the 1200 UTC sounding by incorporating forecast surface temperatures and dew points. Likewise, a model could be run on several size clouds to forecast a range of expected updraft strengths and top heights (Weinstein and Davis, 1968).

The numerical model used in this study is a simple one-dimensional steady-state updraft model developed by Weinstein and Davis (1968) and modified by Treddenick (unpublished). The model is suitable for a personal computer and is capable of being run operationally at most weather stations. To make the model usable in an operational environment, an interactive sounding analysis program named 1DCU has been developed at the National Weather Service Office in Amarillo, Texas. For validation purposes, model estimates of maximum hailstone size for several updraft radii were compared with actual hail events. This Technical Attachment briefly describes the 1DCU program, presents preliminary results, and suggests a few operational uses of model output.

2. SOUNDING ANALYSIS PROGRAM

The test version of the 1DCU is a compiled BASIC program designed to run on a personal computer. Atmospheric temperatures and dew points obtained from a standard radiosonde ascent are entered manually or requested from AFOS. The sounding data are plotted on a skew-T diagram and a few standard stability indices are calculated. The program is interactive, allowing the forecaster to move the pressure level and the constant mixing ratio line corresponding to the surface dew point temperature. The pressure level (mbs) and the surface dew point (°F) are automatically updated as the forecaster manipulates the cursor keys. By increasing or decreasing the surface dew point and corresponding mixing ratio, the convective condensation level (CCL) can be determined. The level of free convection (LFC) can be found by lifting a surface parcel. Depending upon the type of lifting mechanism expected, the cloud model can be initialized at either the CCL or the LFC as shown in figures 1 and 2. In this manner the forecaster can run "what if" scenarios based on forecast surface temperatures and dew points.

Inputs to the model consist of significant levels obtained from an atmospheric sounding, interpolated over 200 meter height increments, together with the pressure level of the estimated CCL or LFC and initial values of updraft velocity and updraft core radius. The model outputs (from CCL or LFC to cloud top) heights in geopotential feet above mean sea level, pressures (mbs), cloud temperatures (°C), updraft velocities (m/s), radar reflectivities (dBZ), and hail size concentrations (number of particles per cubic meter). For operational use, values of maximum reflectivity, maximum vertical velocity, maximum hailstone size, height of the cloud top, and height of the 45 dBZ radar reflectivity are extracted from the simulated cloud profile. A sample of the model output is shown in figure 3. Refer to Weinstein and McCready (1969) for a general description of the model and some of its limitations. For additional information on numerical models and conceptual models of cumulus convection refer to Doswell (1985). This source is available at most Weather Service Offices and will provide several references for those interested in pursuing the topic.

3. PRELIMINARY RESULTS

For the purpose of this study it was necessary to check the validity of the model-predicted estimates. Since a data set containing observed heights of the 45 dBZ echo and cloud-top heights was not available to fully test the model, only predictions of maximum hailstone size were compared with actual events. The cloud model was run on four different size updraft radii (1, 2.5, 3.5, and 4.5 km) to determine which radius would provide useful hailstone sizes. Forty-eight hail events selected from the Texas Panhandle were used in validating the cloud model. For each event, estimates of maximum hailstone size were computed using the Amarillo

1200 UTC sounding. The largest hailstones recorded in the Storm Data (1989, 1990) and station records for a given event were assumed to be "ground truth".

From each 1200 UTC sounding, two hail size estimates for the four updraft radii were calculated based on the CCL and the LFC. Observed afternoon surface dew points were used to determine the CCL, and the LFC was found by lifting a surface parcel. All observed surface temperatures and dew points used in the study were considered to be representative values when towering cumulus or cumulonimbus clouds were first recorded in Amarillo's surface observations. Similar criteria to that described by Pino and Moore (1989) were used to select the computed hail size. If the daily maximum temperature was within 1.1 °C (2 °F) of the convective temperature or greater and no capping inversion was present, the hail size computed from the CCL was used. Otherwise, it was assumed that a lifting mechanism other than surface heating was the main trigger producing the storms, and the hail size computed from the LFC was used.

For the four updraft radii tested, the 4.5 km radius proved to be more successful in estimating the actual maximum hailstone size for the 48 events. Compared to the 1 km, 2.5 km, and 3.5 km updraft radii, the 4.5 km radius showed improvement significant at the 10% level using a Student t-test. The 4.5 km radius had a correlation coefficient of .72 and indicated severe storm potential (hail diameter 1.9 cm or greater) for 47 out of the 48 cases studied. Subjectively, however, the 4.5 km radius generally overestimated the actual size of the hail events. Scatter diagrams and correlation coefficients for the 4.5 km and 2.5 km updraft radii are shown in figures 4 and 5, respectively.

Results also showed the importance of choosing the right updraft radius for a forecast. For instance, compared to the 4.5 km, the 2.5 km radius provided better estimates for more than one-half of the 48 hail events studied. Moreover, when using estimates from both the 2.5 km (26 cases) and the 4.5 km (22 cases) radii the correlation coefficient was .83. This suggests, to some degree, that useful predictions of maximum hailstone size might be achieved if the appropriate updraft radius could be selected and an accurate forecast of afternoon surface temperatures and dew points could be made.

4. POTENTIAL APPLICATION OF 1DCU PROGRAM AND MODEL OUTPUT

Operationally, the one-dimensional model is not intended to be used to forecast the occurrence and location of convective storms. That is, other forecasting tools must be used to identify regions of convergence where convection may occur and the cloud model used to predict the depth and intensity of the expected convection. In other words, the updraft model is simply another technique for working up an atmospheric sounding to determine the likely depth and strength of isolated convection under what is believed to be reasonable assumptions. In contrast to the classical parcel method, the model includes the effects of entrainment and hydrometeor drag. Because the model is very sensitive to the height of the CCL or LFC and changes in the environmental sounding, a representative sounding is necessary for useful model results. Unfortunately, representative atmospheric soundings are generally difficult to obtain. However, an interactive computer program that allows a forecaster to modify a sounding at various levels based on numerical guidance and subjective techniques might provide useful input for a cloud model.

The 1DCU sounding analysis program focuses on modifications made to the lower levels of a sounding, notably the surface. Thus, on days when afternoon showers and thunderstorms are expected, forecasts of afternoon surface dew points and temperatures can be used to estimate the CCL and the LFC. If the forecaster expects the convective temperature to be reached, the model would be initialized at the CCL. If a dynamic lifting mechanism is present, then the cloud model could be initialized at the LFC.

The output from the model is straightforward. Predicted values of maximum vertical velocity can be categorized in terms of weak, moderate, strong, and severe. For example, Dennis and Musil (1973) assigned values of 18, 25, and 32 m/s for weak, moderate, and strong updrafts, respectively. Updrafts approaching 50 m/s were considered severe. Predicted heights of the 45 dBZ radar reflectivity above the freezing level combined with predictions of maximum vertical velocity, maximum hailstone size, and maximum cloud-top height may supplement other methods used to forecast convection intensity. The observed height of the 45 dBZ contour above the freezing level, as pointed out by Witt (1990), has proven to be a successful technique for identifying storms that contain hail or no hail. Lastly, the predicted cloud-top elevation above the equilibrium level (EL) might be another indication of the potential updraft strength.

For days when severe thunderstorms are possible, preliminary results suggest that large updraft radii should be used for forecasts of maximum hailstone size. On other days, small and medium size updraft radii might give better estimates. Crum and Cahir (1983) used a similar cloud model for forecasting shower-top heights and found that highest tops were predicted best by the 4 km radius, while prevailing tops were predicted best by the 2 km radius. A combination of vertical wind shear values for a given amount of instability may prove to be helpful in choosing the appropriate updraft radius for at least forecasts of maximum hailstone size. For instance, preliminary results showed that the 1 km and 2.5 km updraft radii produced good estimates of maximum hailstone size on days with weak to moderate vertical wind shears (shear=1/2 U^2) and relatively high values of potential buoyant energy (PBE). For days with lower values of PBE and stronger vertical wind shears, the 3.5 km and 4.5 km radii provided better estimates. The 2.5 km radius also provided useful estimates for cases with both strong wind shear and strong buoyancy. Additional cases need to be studied, but it is likely that the degree of instability, rather than the vertical wind shear, is a more important factor to consider.

5. SUMMARY

An interactive sounding analysis program has been developed which features a skew-T diagram as the user-interface to a one-dimensional cloud model. Forty-eight hail events were used to validate model predictions of maximum hailstone size. For the 48 hail events studied, the 4.5 km updraft radius had a correlation coefficient of .72 which was significant at the 10% level using a Student t-test. The 4.5 km radius also indicated severe storm potential (hail diameter 1.9 cm or greater) for 47 out of the 48 cases studied.

The ability of the model to be run from the CCL or the LFC allows the forecaster to consider a variety of lifting mechanisms contributing to convective development. The model is intended to be used 4 to 6 hours in advance of afternoon convection and should be used along with other forecasting tools. If a good forecast of afternoon surface temperatures and dew points can be made, preliminary results suggest that useful estimates of maximum hailstone size, at least for large updraft radii, might be obtained.

The degree to which the one-dimensional cloud model used in this study might contribute beneficially to operational forecasting is not yet clear. Other one-dimensional models may provide better predictions of various cloud parameters. Unfortunately, most of the one-dimensional cloud models used in research are not used in operational programs, and there has been relatively little documented operational testing of cloud models versus observations. Nevertheless, it appears that one-dimensional cloud models have some potential use in an operational setting and only through daily use will their full potential be determined.

6. ACKNOWLEDGMENTS

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7. REFERENCES

Anthes, R. A., 1977: A cumulus parameterization scheme utilizing a one-dimensional cloud model. Mon.Wea. Rev., 105, 270-286.

Crum, T. D., and J. J. Cahir, 1983: Experiments in shower-top forecasting using an interactive one-dimensional cloud model. Mon. Wea. Rev., 111, 829-835.

Dennis, A. S., and D. J. Musil, 1973: Calculations of hailstone growth and trajectories in a simple cloud model. J. Atmos. Sci., 30, 278-288.

Doswell, C. A., III, 1985: The Operational Meteorology of Convective Weather, Volume II: Storm Scale Analysis. NOAA Tech. Mem. ERL ESG-15. Environmental Sciences Group, Boulder, Colorado.

Kreitzberg, C. W., and D. J. Perkey, 1976: Release of potential instability: Part I. A sequential plume model within a hydrostatic primitive equation model. J. Atmos. Sci., 33, 456-475.

Matthews, D. A., and B. A. Silverman, 1980: Sensitivity of convective cloud growth to mesoscale lifting: A numerical simulation of mesoscale convective triggering. Mon. Wea. Rev., 108, 220-228.

NOAA, 1989: Storm Data. Vol. 31, No. 3-10. NESDIS, National Climatic Data Center, Asheville, NC, 28801-2696.

———, 1990: Storm Data. Vol. 32, No. 3-6. NESDIS, National Climatic Data Center, Asheville, NC, 28801-2696.

Pino, J. P., and J. T. Moore, 1989: An interactive method for estimating hailstone size and convectively-driven wind gusts from forecast soundings. Preprints, 12th Conf. on Weather Analysis and Forecasting, American Meteorological Society, Monterey, CA. pp. 103-106.

Simpson, J., and V. Wiggert, 1969: Models of precipitating cumulus towers. Mon. Wea. Rev., 97, 471-489.

Treddenick, D., unpublished: Final report 1974- Numerical cloud model. Colorado International Corporation, Nelspruit, South Africa. (P.O. Box 3007, Boulder, CO 80303)

Weinstein, A. I., and L. G. Davis, 1968: A parameterized numerical model of cumulus convection. Rep. No. 11, Contract NSF GA-777, The Pennsylvania State University, 44 pp.

———, and P. B. McCready, Jr., 1969: An isolated cumulus cloud modification project. J. Appl. Meteor., 8, 936-947.

Witt, A., 1990: A hail core aloft detection algorithm. Preprints, 16th Conf. on Severe Local Storms, American Meteorological Society, Kananaskis Park, Alta., Canada. 232-235.

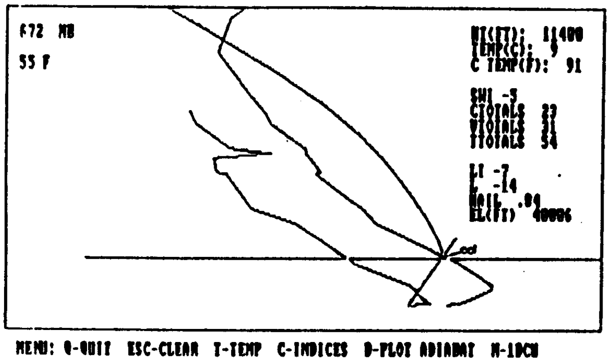

Fig. 1. Model initialized at CCL.

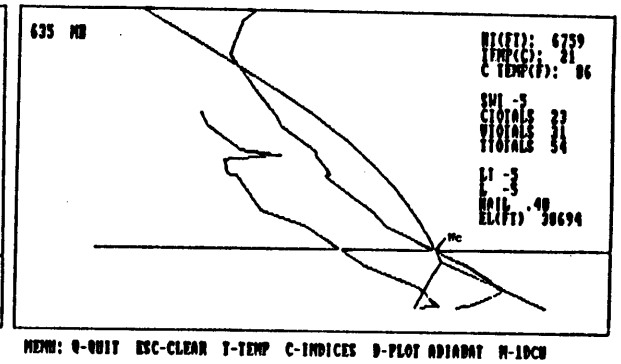

Fig. 2. Model initialized at LFC.

PRES(MB): 635 TEMP(C): 5
CONVECTIVE TEMP(F): 92

RAD(Km)	REFL(dBZ)	W MAX(m/s)	TOP(ft)	45 dBZ(ft)	HAIL(in.)
2	57	29	42481	31982	1.474
3	57	34	44449	30670	1.984
4	57	38	45762	30670	2.201

Fig. 3. Sample of 1-d model output.

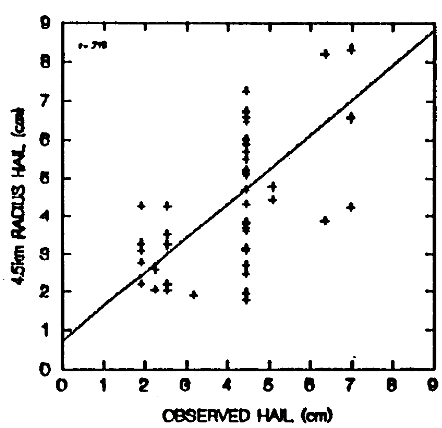

Fig. 4. Scatter diagram for 4.5 km radius.

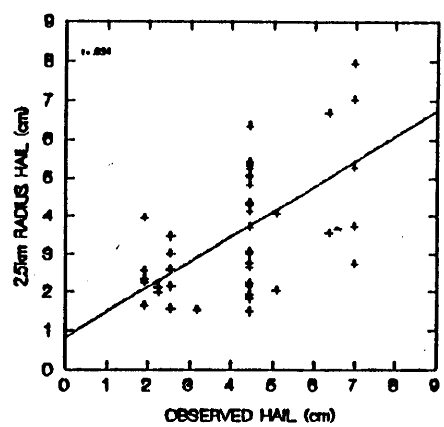

Fig.5. Scatter diagram for 2.5 km radius.