NASA Contractor Report 3771

Evaluation of Two 1-D Cloud Models for the Analysis of VAS Soundings

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EVALUATION OF TWO 1-D CLOUD MODELS
FOR THE ANALYSIS OF SATELLITE SOUNDINGS

OBJECTIVE: To demonstrate the sensitivity of two 1-D cloud models to their required inputs with specific focus upon those parameters obtained from atmospheric soundings taken by the VAS or rawinsonde.

METHODOLOGY:

1) Perform standard input sensitivity tests on the 1-D cloud models to provide reference states for sounding sensitivity demonstration;

2) Initiate the 1-D cloud models with control soundings have the general characteristics of VAS profiles - i.e. a rather large uncertainty in the mid and upper tropospheric stability;

3) Compare 1-D model performance with observations and with the results of a 2-D model experiment using AVE/VAS data.

RESULTS: Although very encouraging, the results of this study are not sufficient to make only specific conclusions. In general, the VAS soundings are likely to be inadequate to provide the cloud base (and subcloud layer) information needed for inputs to current cumulus models. Above cloud base, the tendency to exaggerate the stability of the atmosphere requires solution before meaningful model experiment can be run.

Evaluation of two 1-D cloud models for the analysis of satellite soundings

1. Introduction

The evaluation of satellite VAS (VISSR Atmospheric Sounder) soundings of temperature and moisture is still in progress. The fundamental task of comparing remote, radiance derived thermodynamic fields with in situ rawinsonde measurements has begun and is beginning to document rather large discrepancies in the vertical distribution of static energy (Figure 1). However, in the horizontal, there currently appears to be some useful and until now unavailable information on horizontal structures in the moisture fields (Figure 2).

The obvious lack of vertical detail in the temperature soundings raises serious questions regarding attempts to use VAS data to calculate stability indices or to initialize numerical models. The most critical shortcomings as far as models are concerned are 1) the excessive smoothing of any inversions that may exist, 2) imprecise measurement of boundary layer moisture, and 3) the tendency for the currently employed retrieval algorithms to "stabilize" soundings (too warm above ~500 mb, too cold below).

In anticipation that some of these problems will be solved within the ongoing VAS study program, a modest effort to evaluate the performance of 1-D cloud models using VAS soundings was initiated. The cloud models are viewed here as advanced sounding analysis tools for diagnosing and predicting the initiation and vertical development of cumulus convection. The model predictions of cloud liquid water content, including rainfall, and the extended (in time) development of the convection are not considered realistic or verifiable. Cloud presence and cloud top height, on the other hand, are more likely to be verified by satellite imagery.

With the primary goal of examining the performance of 1-D cloud models in predicting the early (<30 minutes) evolution of cumulus convection, a series of sensitivity and parametric studies were performed. Specifically, a time-dependent cumulus cloud model based upon the work of Wisner, Orville and Myers (1972) and a steady state cumulus growth model developed by Simpson and Wiggert (1969) were chosen because of their long histories of applications to a wide variety of convective cloud experiments. Both models have been modified to operate on the NASA HP-1000 computer and to more easily ingest archived aircraft, rawinsonde and satellite soundings.

These models are based upon highly parameterized dynamic and microphysical processes, the understanding of which is still evolving. The microphysics in these models (still being used in more current models) are based upon the work of Berry (1967) on droplet growth by autoconversion and Kessler (1969) on conversion of cloud water to precipitation. The dynamics of the one-dimensional cloud models have relied mainly upon an expression for thermodynamic buoyancy and the entrainment principle where the vertical and horizontal growth of the buoyant cloud mass is a function of the lateral mixing with the environment. Although models using the entrainment hypothesis seem to do a reasonable job of predicting cloud top heights, they systematically over predict the liquid water content (Warner, 1970; Cotton, 1975a).

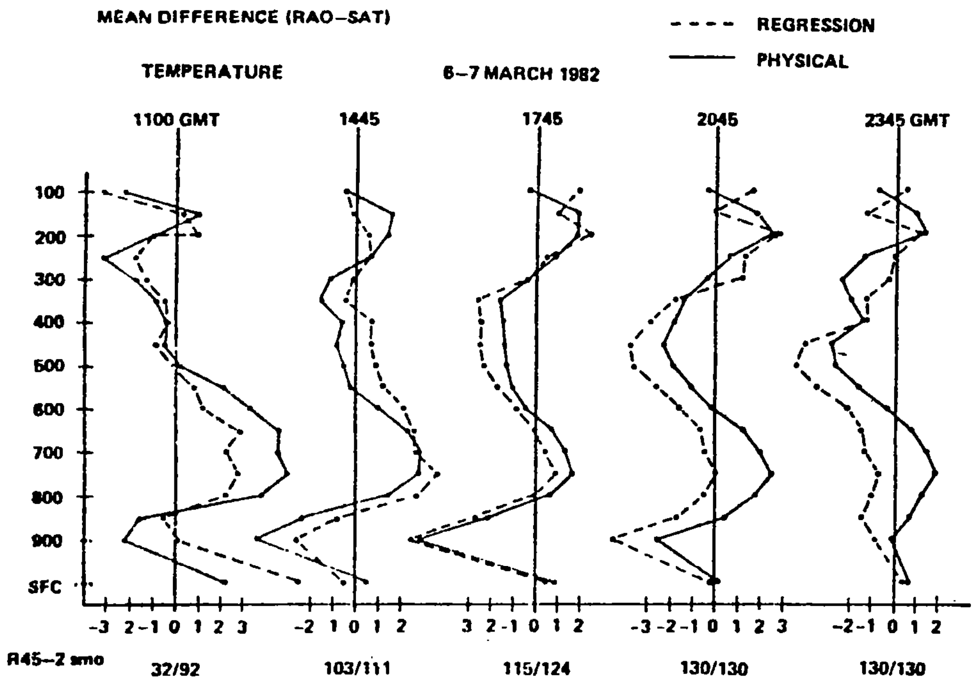

Figure 1. Mean difference (Rao - Sat) between rawinsonde and satellite gridded temperature fields as a function of pressure at 1100, 1445, 1745, 2045, and 2345 GMT. The physical retrieval difference profiles are solid lines (____) and the regression profiles are dashed lines (----). The units are °C. The number of grid points used at each time are displayed for the regression and physical retrievals, respectively. (from Jedlovec, 1983)

Figure 2. 2330 on 6 March 1982. 400 mb dewpoint depression (contours) derived from 6.7 μm water vapor channel on VAS superimposed on the water vapor image. Dark areas are driest.

Review articles such as Cotton (1975b) and Schlesinger (1982) go into detail regarding the assumptions upon which many models are based and the consequent deficiencies in the models' performances. For the 1-D models there are several specific problems that can be summarized. There is a tendency for the 1-D models to

1) over predict LWC by factors of 2 to 3,

2) over predict vertical velocities because of the omission of pressure perturbation effects and the toroidal circulations associated with rising air parcels, and

3) evolve unrealistic drop spectra and precipitation because of insensitivity (through bulk parameterization) to the turbulent non-linear contributions to super saturation and liquid water concentration.

Although 1-D models have several shortcomings and cannot be expected to simulate the full three-dimensional evolution and many of the complex interactions of storm complexes, one-dimensional cloud models can be useful in performing sounding analyses and serving as higher order co-variates or indices in the analyses of rainfall events. It was an original intention to apply one or both of the selected models to a large (~100) number of situations. However, after examining many soundings it was clear that the standard 00Z or 12Z soundings were not likely to represent the environment of convective events in the early afternoon. Also, the sensitivity of the models' performance to the choice of initial cloud radii made a straightforward model experiment difficult. Instead, a series of parametric studies were conducted for a range of values bounded in a manner judged to be appropriate for soundings obtained from the VAS. These computer simulation efforts will be presented in four parts: 1) brief description of the two models, 2) results of model sensitivity to initial inputs, 3) demonstration of the models' dependence upon the vertical distribution of convective available potential energy (CAPE), and 4) presentation of an AVE/VAS case study.

2. Description of Models Used

2.1 A Time Dependent Hail-Bearing Cloud Model

On the basis of its previous extensive use by the South Dakota School of Mines and Technology in a wide variety of studies, the Wisner, Orville and Myers (1972) 1-D cloud model was selected. From hereafter this model will be referred to as WOM. A brief description of the model taken from Wisner et al. (1972) follows.

> The model is one-dimensional and time-dependent, and it employs extensive parameterization of the microphysical processes (Fig. 3). The raindrop and hailstone size distributions are assumed to be exponential at all times. Cloud droplets are converted to raindrops according to Berry's parameterization of the autoconversion process and are accreted by the raindrops according to Kessler's formulation. Raindrops are frozen at a rate consistent with Bigg's freezing equation, and the hailstones so formed then accrete raindrops and cloud droplets. Ice crystals are not allowed by the model, and for consistency, then, it is assumed that the cloud droplets do not freeze except when accreted by hailstones at

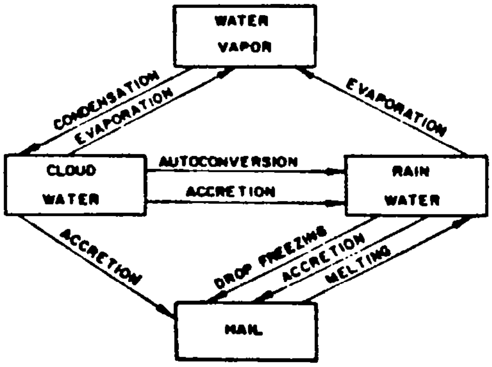

Figure 3. Block diagram of microphysical processes included in the CIC version of the Wisner, Orville and Meyers' (1972) 1-D hail cloud model.

temperatures less than 0C. The melting and evaporation processes are modeled, and their impact on the results is explored.

The atmosphere is assumed to be divided into two regions, the environment and a well-mixed vertical core, which interact only through turbulent mixing and the requirement that pressure in the core and the environment are equal. All variables are assumed to conform to the top-hat profile, i.e., the variables are constant with respect to horizontal displacement in the environment and in the core, possessing a zero-order discontinuity at the boundary separating the two regions. The environment is assumed constant with respect to time and so may be described by variables which are functions only of the altitude. No such requirement is placed on the core, so core variables will be functions of both altitude and time.

Four classifications of water substance are considered (Fig. 3): (i) water vapor; (ii) cloud water, consisting of liquid droplets small enough that their terminal velocities may be neglected compared with the velocity of the air; (iii) rainwater, consisting of liquid drops large enough to possess appreciable terminal velocities; and (iv) hail consisting of ice particles with appreciable terminal velocities. The possibility of cloud ice (ice crystals with negligible terminal velocities) has been neglected for simplification of the problem.

The effects of including cloud ice would be basically two:

1) The deposition of water vapor to cloud ice would release heat to the dynamics.

2) The replacement of cloud water by cloud ice would change the hail growth rate.

The effect on the dynamics would be small in most cases since the cloud water is frozen as it is accreted by the hail. So long as there is sufficient hail to provide a moderately high rate of accretion, most of the heat which would have been released in conversion to cloud ice will be realized in the accretion-freezing process. This may not be true in an attempt to model the introduction of artificial ice nuclei. In such a situation, there might be significant formation of cloud ice in regions where only small amounts of hail are present. Thus, the accretion-freezing process may not provide a satisfactory means of realizing the latent heat in the model which would be realized in the conversion of cloud water to cloud ice.

The conversion of a portion of the cloud water to cloud ice would affect the growth rate of hail in both the dry growth and wet growth situations. Dry hail is a less efficient collector of cloud ice than of cloud water since many of the ice crystals will bounce off rather than adhere to the hail. For a hailstone undergoing wet growth, the collection of ice crystals rather than liquid droplets will reduce the rate of heat dissipation required to balance the rate at which the latent heat of fusion is being released (Musil, 1970). So the exclusion of cloud ice from the model will effect an underestimation of the wet growth rate and an overestimation of the dry growth rate. Dry growth is assumed to take place throughout the model, thus ignoring restrictions placed on the growth rate by the wet-growth phenomena. The total effect is an overestimate of the growth rate of hail.

The model as currently configured requires 50 k bytes of memory for execution. Its CPU time on a .5 MIPS machine is approximately 15 secs for simulating 5 minutes of cloud time. The inputs to the model are as follows:

- a T, T_D sounding from the surface to 17,000 meters AGL
- initial cloud radius (critical)
- initial vertical speed at cloud base (weak sensitivity)
- cloud droplet spectra (cm^{-3}) divided by spectra dispersion (moderate sensitivity)
- estimated cloud base height (strong sensitivity).

2.2 A Steady-State Cumulus Tower Model

Applied extensively to Florida cumulus seeding experiments, the Simpson and Wiggert (1969, 1972) (S/W) steady state 1-D cumulus model was chosen to provide a second evaluation of VAS soundings as 1-D model inputs. The model was designed specifically to parameterize the complex dynamnical-physical cloud processes to obtain realistic values of observable properties such as cloud top rise rates, hydrometer distributions, and radar reflectivity for both seeded and unseeded cumulus towers.

Dynamically, the model is based upon a vertical acceleration which is formulated as the difference between a buoyancy term and a drag term:

$$\frac{dw}{dt} = w\frac{dw}{dz} = \frac{gB}{1+\gamma} - \frac{3}{8}\left(\frac{3}{4}K+C_D\right)\frac{w^2}{R} \qquad (1)$$

where z is height, t is time, gB is the buoyancy force;   is the virtual mass coefficient; K is the entrainment coefficient; C_D is an aerodynamic drag coefficient; and R is the radius of the cumulus tower.

A fundamental relationship between cloud mass (m) and the entrainment of environmental air is employed:

$$\frac{1}{m}\frac{dm}{dz} = \frac{9}{32}\frac{K}{R} \qquad (2)$$

The buoyancy term is calculated by:

$$gB = g\left(\frac{\Delta T_r}{T_r} - \frac{\Delta T_r(LWC)}{T_r}\right) \qquad (3)$$

where ΔT_r is the virtual temperature difference between the cloud virtual temperature and environment; $\Delta T_r(LWC)$ is a reduction in the density difference due to the weight of suspended liquid water.

Equations (1), (2) and (3) are the dynamic basis of the Simpson-Wiggert model. The integration of (1) proceeds in a quasi-Lagrangian manner such that the coordinate system follows the center of the rising tower. It is important to regard the model's output of an apparent profile of cloud properties as really just a time history of the properties of the cloud center as it rose through the noted levels.

A critical omission in this model (as well as in WOM) is the contribution of the in-cloud pressure perturbation to the cloud top rise rates and the vertical distribution of cloud temperature and moisture excesses. Studies by Holton (1973) illustrated the role played by the perturbation pressure in determining preferred radii for mixing plumes. The specification of initial radius is one of the major weaknesses in the 1-D models being considered here. The use of a virtual mass adjustment in the S/W model does retard the cloud growth rate in the same sense as the pressure perturbation would over the entire depth of the cloud. However, near cloud top, the pressure perturbation may actually enhance the thermal buoyancy. Since the errors associated with disregarding the pressure perturbation are likely to be larger for large clouds, Simpson (personal communication) has recommended that the S/W model not be used on very deep convection. Although the following sensitivity tests were performed on both shallow as well as deep convection, caution must be exercised in interpreting the apparently coherent results.

3. Results of 1-D Model Sensitivity Tests

Both the WOM model and the S/W model were run through a series of sensitivity tests. Although such tests are run repeatedly throughout the development of any model, they are redone here using input values that are appropriate for the Texas/Oklahoma region where the 1982 AVE-VAS field experiments were conducted. To begin with, the WOM model results for a sounding (Fig. 4) on a rain day are shown in Figs. 5 and 6. It is clear that the two most important input parameters to the model are the initial radius and cloud base (CCL). It is noteworthy that both these parameters are difficult to specify with any accuracy. The cloud base may vary during the day by many 10's of mb depending upon factors such as the amount of surface heating and/or moisture advection. The proper initial cloud radius for a specific case is usually unknown but thought to range from 500 m to 5 km.

Using a test profile (CLD02) discussed in the next section, the sensitivity of both the WOM model and the S/W model to the initial radius was examined (Figs. 7 and 8). A continental cloud base droplet concentration of $\sim 500\ \text{cm}^{-3}$ and a distribution dispersion of .2 were used in both models. The 1/R dependence of the entrainment (dilution of ΔT_r) and the vertical accelerations is primarily responsible for the behavior of all three response variables plotted. For this particular case, the model outputs are most sensitive to radii less than 3-4 km. Note, however, the weaker dependency on initial radii shown by the WOM model (Fig. 5) for another sounding shown in Figure (4).

The problem of specifying the initial cloud radius for 1-D model simulations is not just a computational pecularity. It is physically possible for clouds to be initiated at various scales by forcing mechanisms such as orographic lifting, thermal plumes or gravity waves. Specification of rational initialization procedures for 1-D model simulation remains an objective of ongoing research.

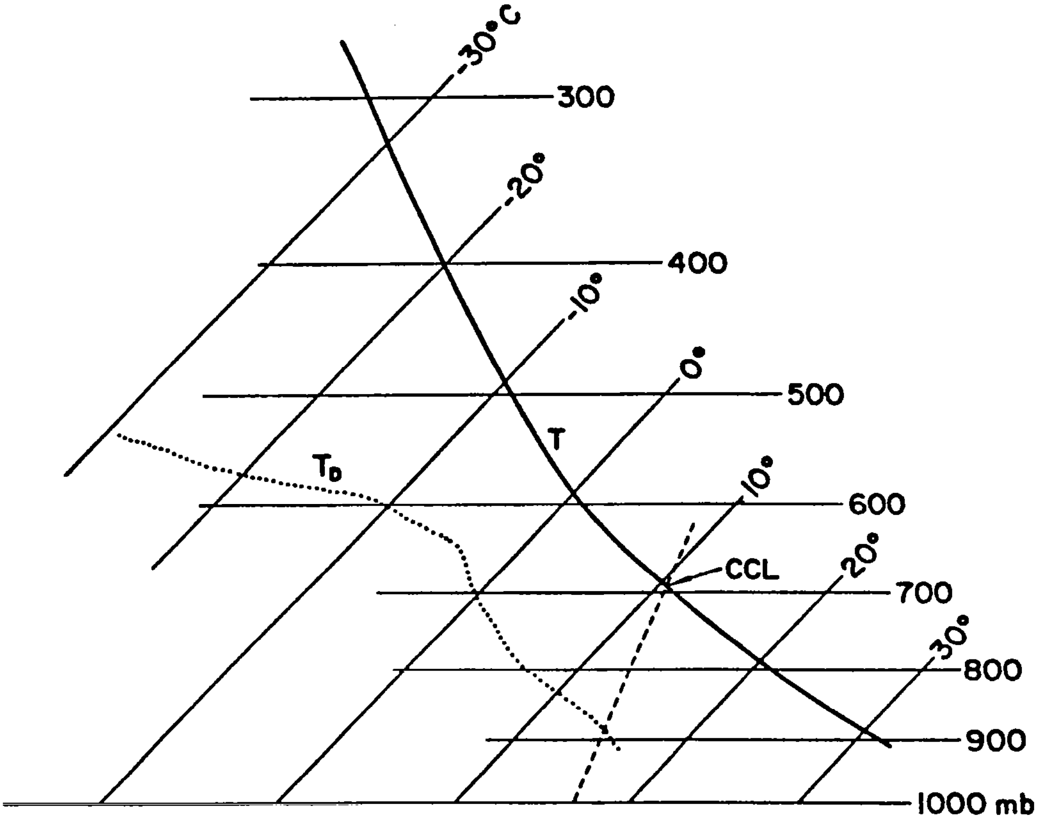

Figure 4. Sounding at 0800 LST January 28, 1980 used in a sensitivity analysis.

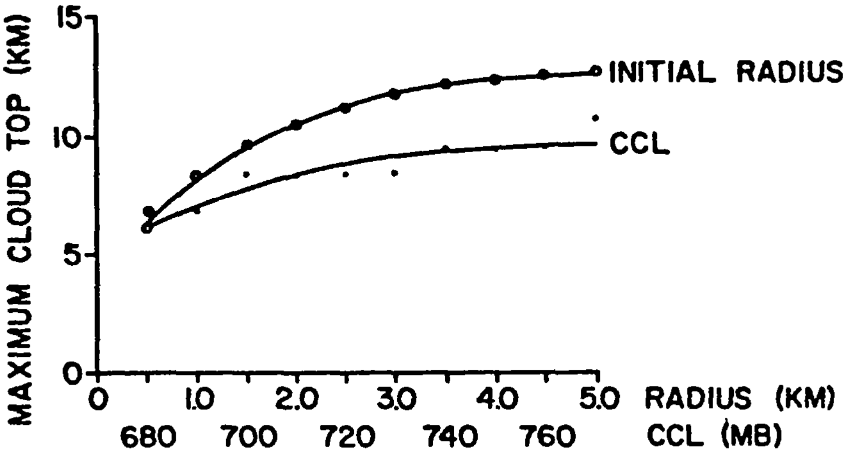

Figure 5. WOM cloud model sensitivity tests for maximum cloud top.

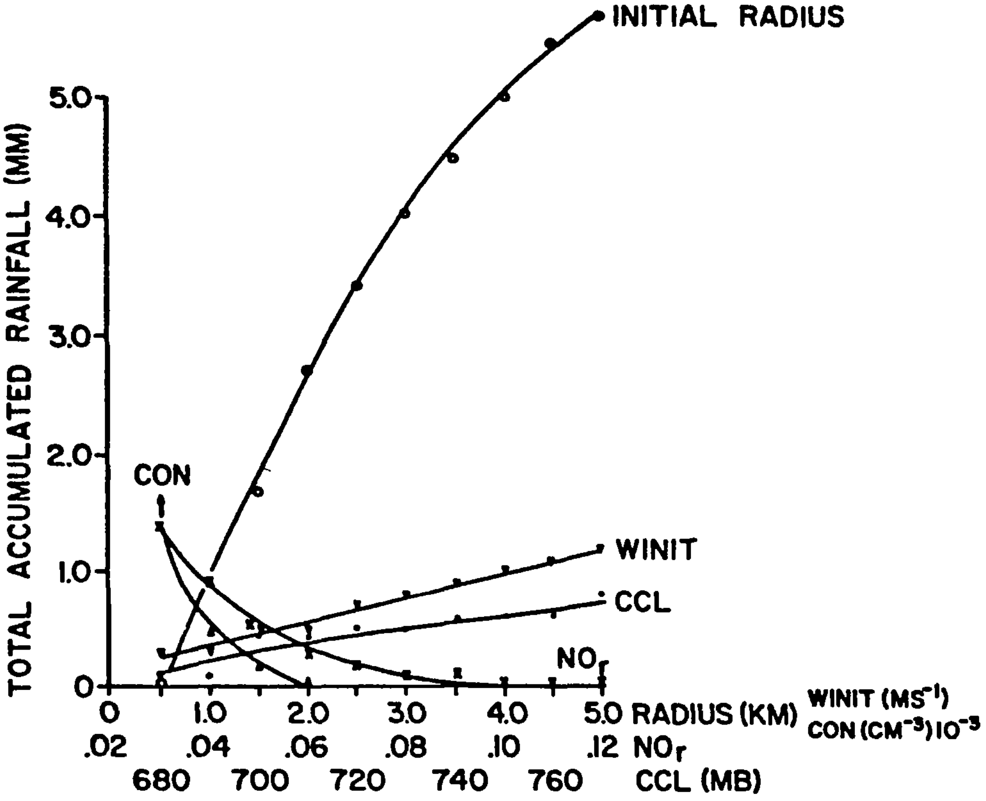

Figure 6. WOM cloud model sensitivity tests for total accumulated rainfall (mm): initial radius, convective condensation level (CCL), initial vertical speed (WINIT), cloud droplet concentration divided by droplet spectra dispersion (CON) and N_o in Marshall Palmer raindrop distribution (NO_r).

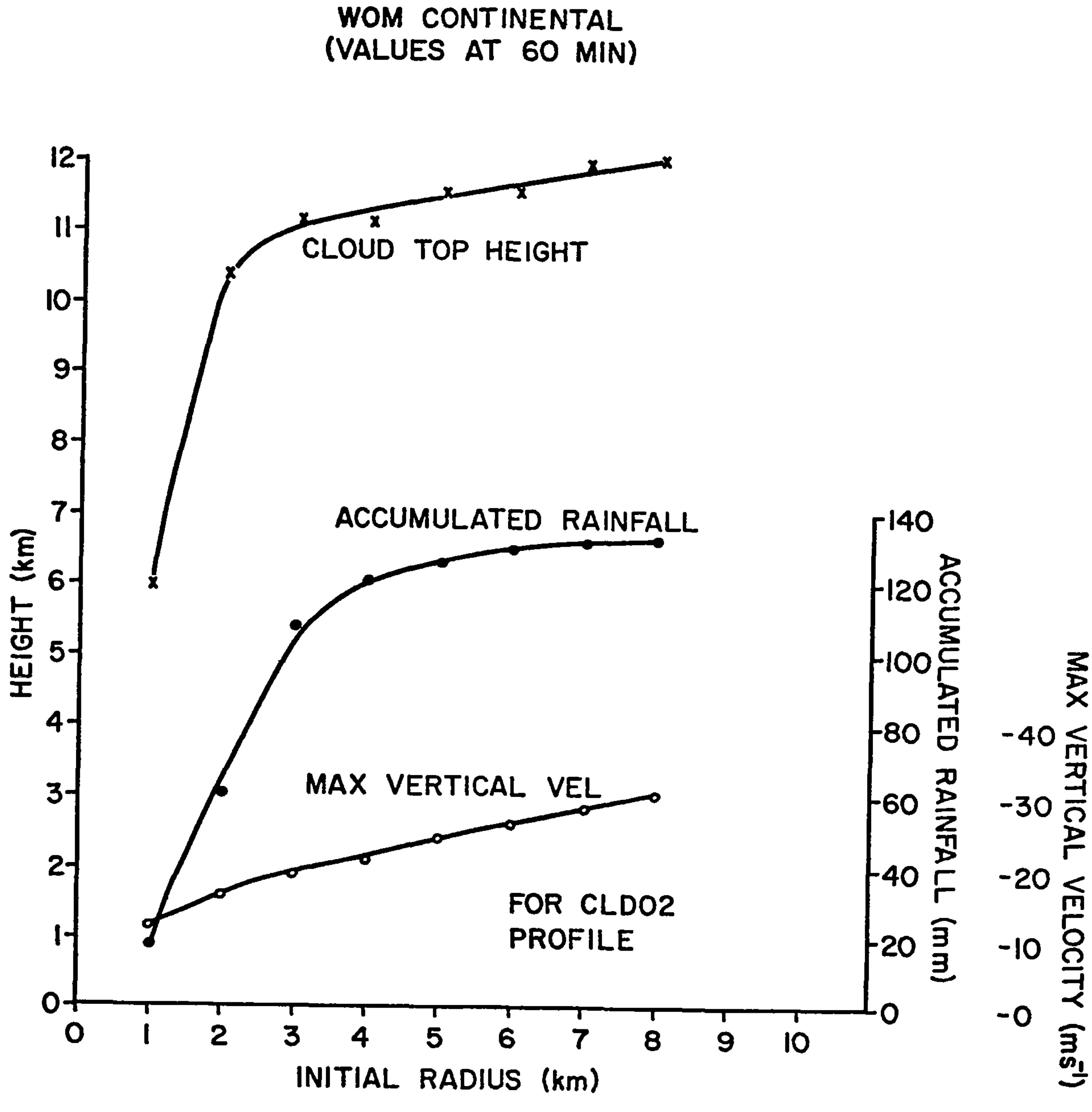

Figure 7. WOM Model predicted cloud top height, accumulated rainfall, and maximum vertical velocity as a function of initial radius. Values plotted are taken at 60 minutes elapsed model time and for a continental cloud base droplet spectrum (1000 cm^{-3}). See Figure 14 for CLD02 profile.

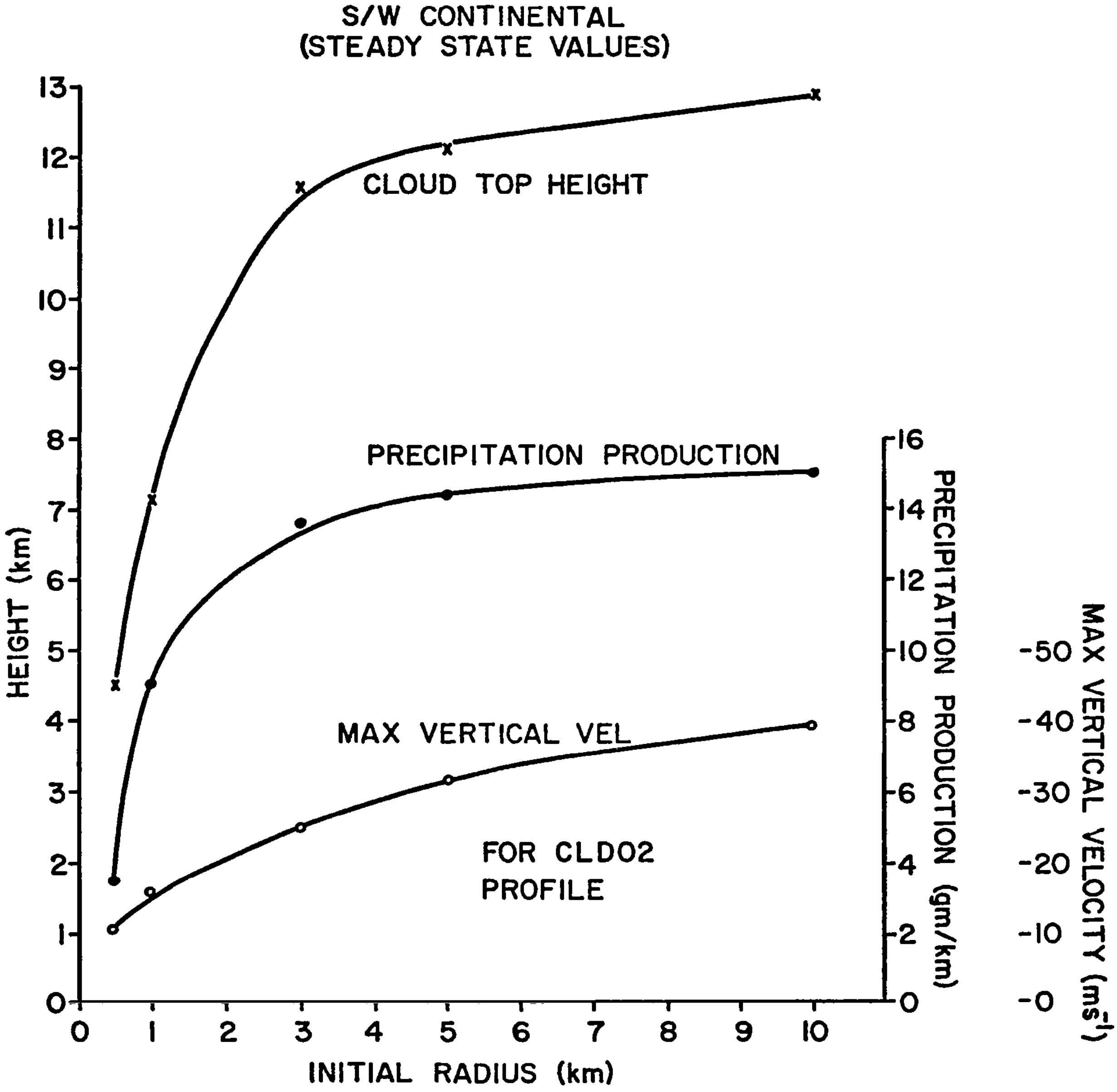

Figure 8. Simpson-Wiggert steady state cloud model results for a continental droplet spectrum and a range of initial cloud radii. See Figure 14 for CLD02 profile.

Further sensitivity tests were run on the S/W model for input variables other than the CCL, initial radius and droplet concentrations. They are summarized in Table 1 where the reference set of inputs is shown on the first row. The input that is then varied is underlined. A change of 25% in the entrainment coefficient effected the most significant changes in the model cloud performance. On the other hand, a 50% change in the initial vertical speed made no discernible difference in the cloud response.

In summary, both the WOM and S/W models showed expected sensitivity to the following inputs:

* initial cloud radius

* CCL

* initial droplet concentration and spectral dispersion

* entrainment coefficient

3.1 Sensitivity of 1-D Models to Vertical Distribution of Convective Available Potential Energy

Once an initial radius (or range of radii) is chosen and a CCL determined, the evolution of a 1-D model cloud further depends upon the vertical distribution of moisture and static stability. From a dynamic point of view, the survival of a cumulus turret will depend in part upon the entrainment, which in turn depends upon the cloud radius and its vertical speed through a relationship such as:

$$\frac{dw}{dt} = a\ B - (b\ K + c\ C_D)\ s^2/R$$

where w = vertical speed of cloud parcel

t = time

$a = 1/(1+\gamma)$ (γ = virtual mass coefficient)

B = buoyancy force

$b = .28$

K = entrainment coefficient

$c = .37$

C_D = aerodynamic drag coefficient

R = radius of cumulus

A measure of the total potential for buoyancy (B) driven vertical motion is the integrated convective available potential energy (CAPE). This quantity was defined by Moncrieff and Miller (1976) as

SIMPSON-WIGGERT MODEL SENSITIVITY

TESTS USING CLD02 PROFILE

CAY2	WINIT	AUTO	NRDR	NMF	DBZ_M	H_M	V_M	P_{SS}	LWC
.65	2	-9	1	8	54	11.6	25.2	13.7	6.6
.65	1	-9	1	8	54	11.6	25.1	13.7	6.6
.65	2	-9	9	8	54.8	11.6	25.15	13.7	6.6
.65	2	.5	1	8	54.0	11.6	25.15	13.7	6.6
.65	2	-9	1	2	-	11.3	24.7	13.9	6.6
.50	2	-9	1	8	54	12.0	28.7	14.1	6.7

CAY2	ENTRAINMENT COEFFICIENT
WINIT	INITIAL CLOUD BASE VERTICAL SPEED (M S^{-1})
AUTO	-9 (N_o = 500 cm^{-3}) FOR BERRY AUTOCONVERSION .5 FOR KESSLER CONVERSION SCHEME
NRDR	1 FOR KESSLER RADAR SCHEME 9 FOR WEXLER RADAR SCHEME
NMF	2 FOR NO FALLOUT OF PRECIPITATION 8 FOR FALLOUT OF PRECIPITATION
DBZ_M	MAXIMUM DBZ IN MODEL CLOUD
H_M	MAXIMUM CLOUD TOP HEIGHT (KM)
V_M	MAXIMUM VERTICAL SPEED (M S^{-1})
P_{SS}	STEADY STATE PRECIPITATION PRODUCTION
LWC	MAXIMUM VERTICALLY INTEGRATED LWC (GM/KG)

$$\mathrm{CAPE} = \int_B^T g\,\delta\phi_p\,dz$$

where g = gravity

$\delta\phi_p = \phi_p - \phi_o$ = deviation of the log-potential temperature

z = height (B = bottom of cloud; T = top of positive energy area on T-ϕ gram)

To examine the sensitivity of model cloud development on the vertical distribution of CAPE, a series of computer simulations were run using both the time dependent model (WOM) and the S/W model. Analysis of several rawinsonde soundings that occur in the south central areas of the USA revealed a range of vertical structures that present to cumulus convection various buoyancy distributions. Six idealized soundings, based upon the real set of profiles, were constructed; 3 for "warm cloud" conditions and 3 for deeper "cold cloud" situations. Each of the two profile sets was constructed with the following constraints:

1) subcloud layer moisture and temperature structure kept the same for each 3 sounding set,
2) moisture distribution throughout the entire convective region kept the same within each 3 sounding set,
3) and the integrated CAPE (convective available potential energy) kept the same within each 3 sounding set.

3.1.1 Warm rain cases/continental droplet spectra

The first set of warm rain cases (no ice phase) were run with three soundings where the top of the positive energy area was near +5°C (Figures 9, 10 and 11) and the cloud base droplet concentrations were 1000 cm^{-3} and the spectral dispersion was .2. In the environment described by the profile in Figure 9 (WRM01) the model cloud experiences a maximum thermal buoyancy force within the lowest few kilometers where the 1/R contribution to the total acceleration is also the greatest but in the opposing sense (Figure 12). The cloud rises at an initial rate of 2.7 m s^{-1} which is the fastest of the three sounding cases. Because of the higher vertical speed in the case of WRM01, the precipitation is delayed in falling out compared to the other two cases, but by 60 minutes the WRM01 cloud was producing the most rain. It must be noted that any discussion of the rainfall predicted by the 1-D model must be done with the knowledge that since the precipitation must fall through the updraft, those clouds with stronger vertical motions, while processing more moisture, will show less rainfall than clouds with weaker updrafts after equivalent elapsed time.

Cases WRM02 and WRM03 with continental droplet spectra started with a slow rise rate (.8 m s^{-1}) as the 1/R entrainment dominated the buoyancy force. However, in both cases the rise rates (WRM02 3.1 m s^{-1}; WRM03 4.0 m s^{-1}) eventually exceeded that of WRM01. In fact, the increasing acceleration with height in case WRM03 caused the model cloud to overshoot the equilibrium level of 4.2 km by nearly 600 meters (Figure 12).

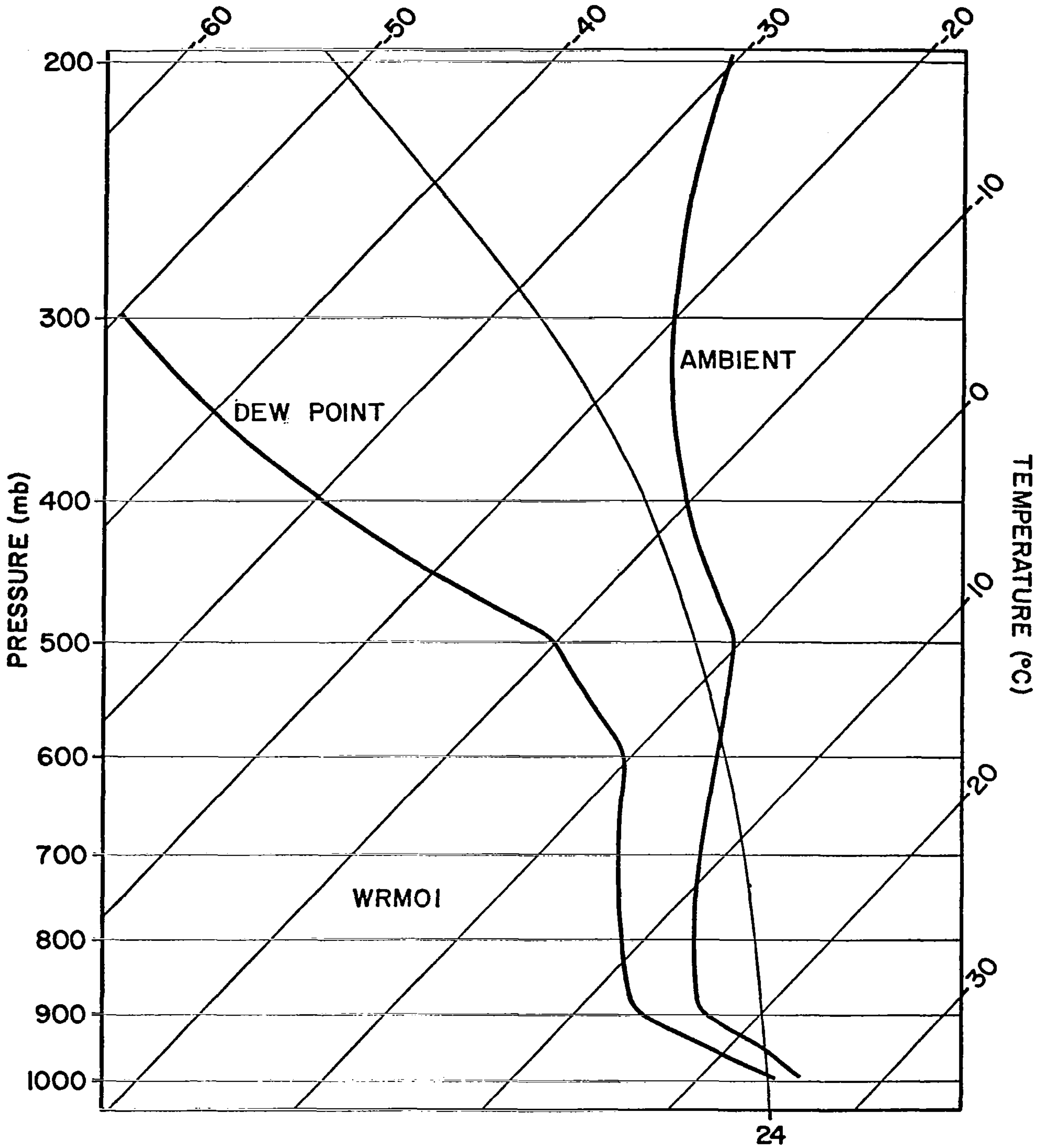

Figure 9. WRM01 test profile with a positive energy area below 600 mb equal to that in the WRM02 and WRM03 profiles shown in Figures 10 and 11.

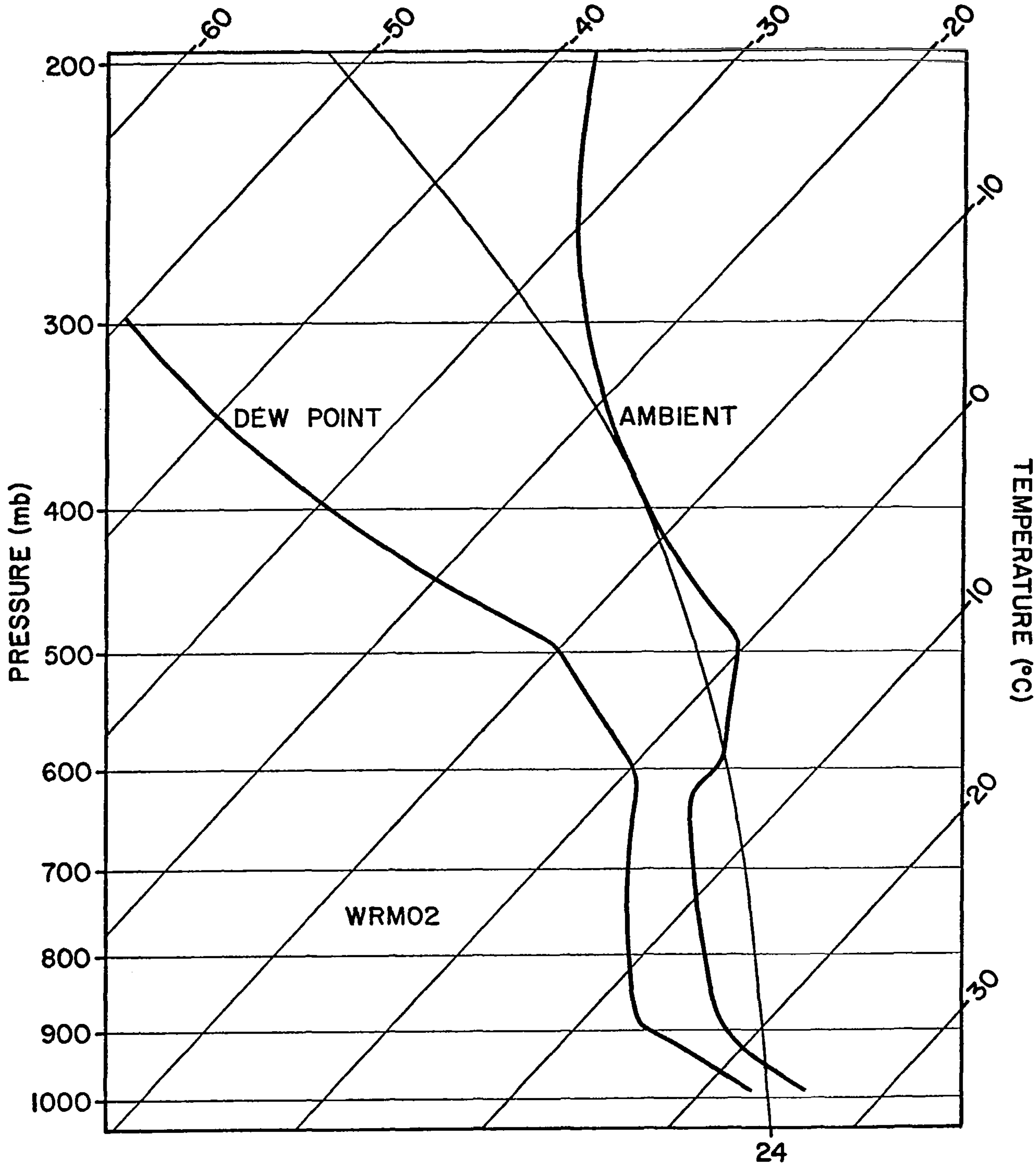

Figure 10. WRM02 test profile with a positive energy area below 600 mb equal to that in the WRM01 and WRM03 profiles in Figures 8 and 11.

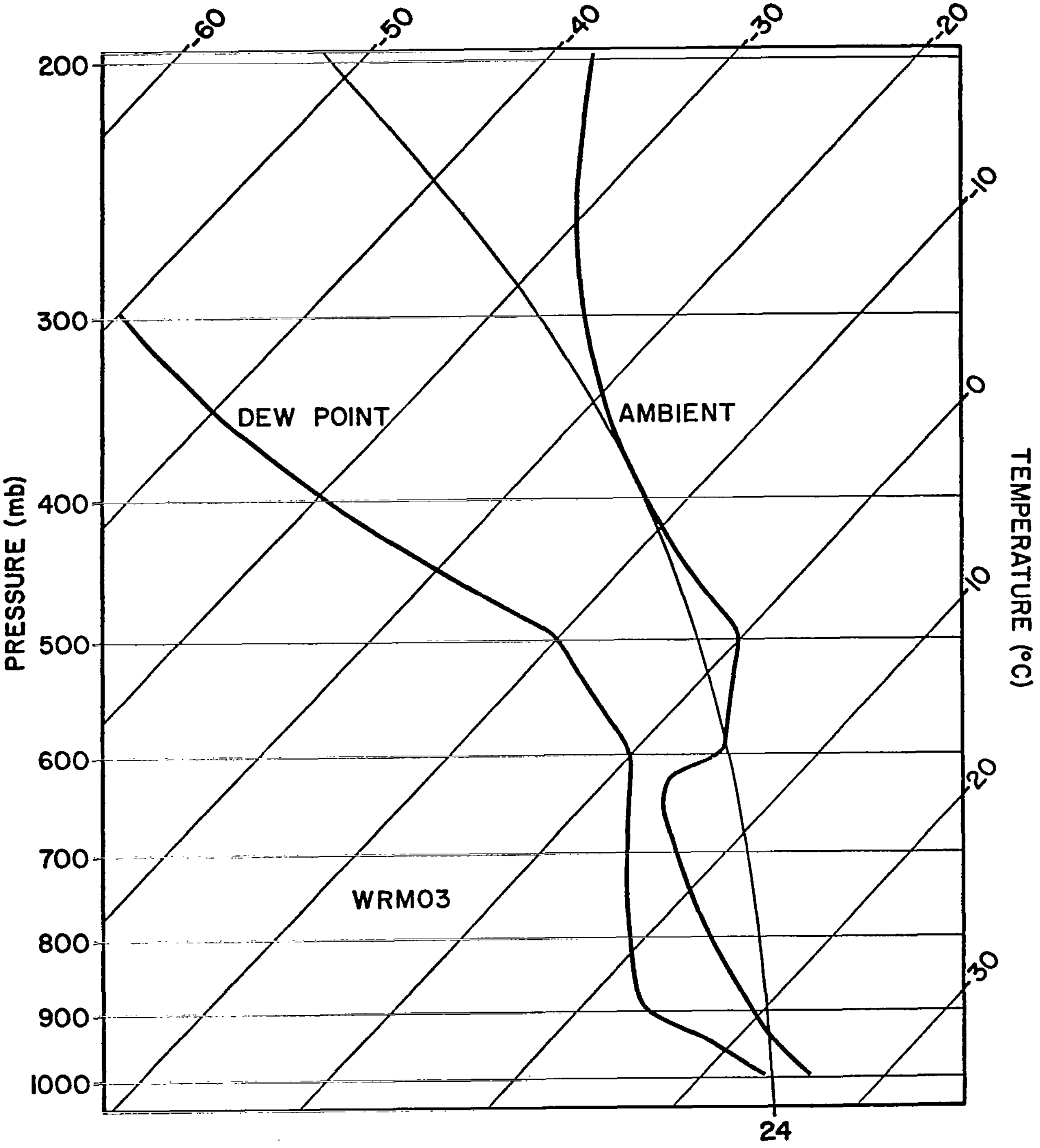

Figure 11. WRM03 test profile with a positive energy area below 600 mb equal to that in the WRM01 and WRM02 profiles in Figures 9 and 10.

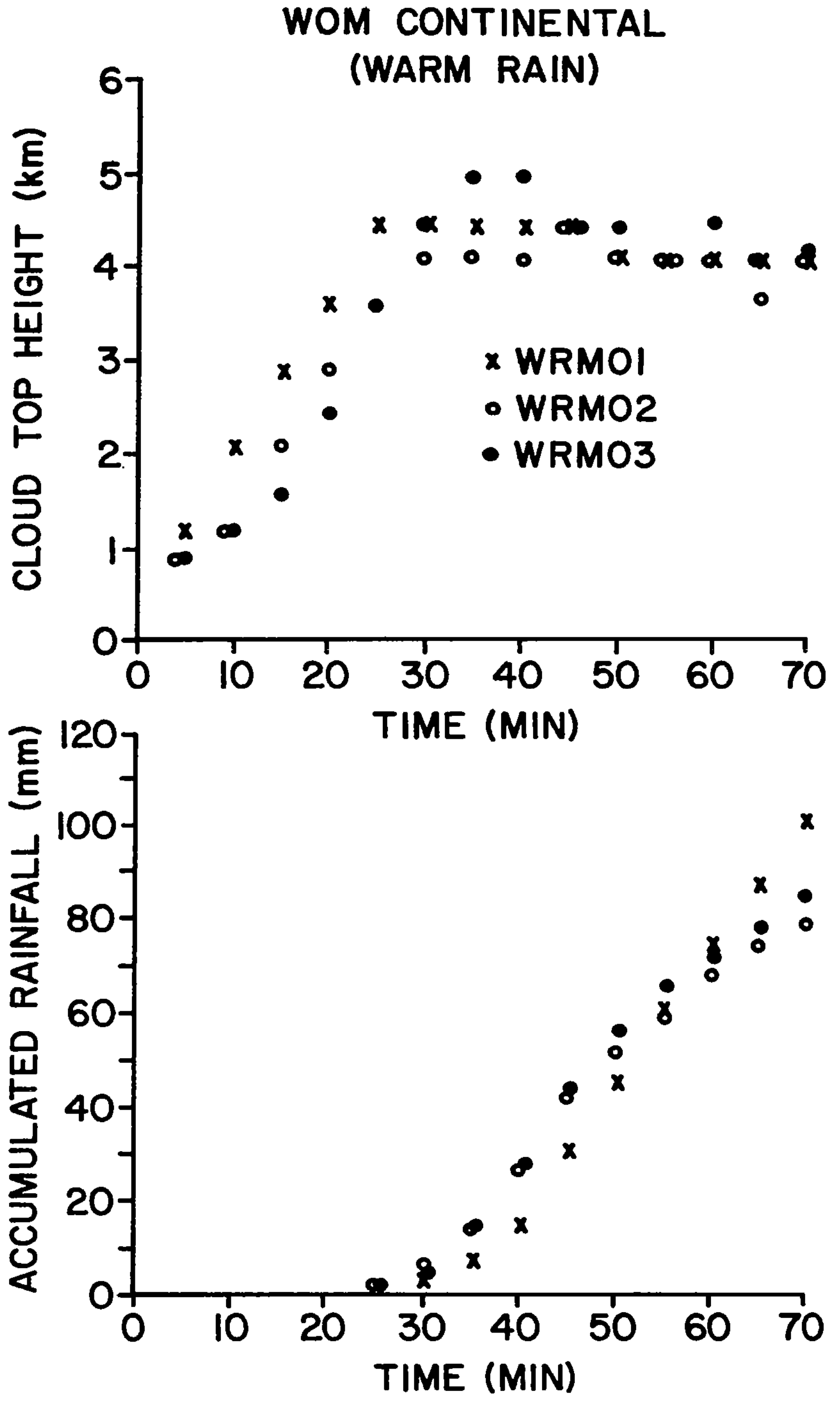

Figure 12. WOM Model results using the profiles shown in Figures 9, 10 and 11. A continental cloud base droplet spectrum (1000 cm^{-3}) was used.

3.1.2 Warm rain cases/maritime droplet spectra

For the modified maritime droplet spectra (200 cm^{-3} and dispersion of .4) the cloud top rise rates for the WRM01, 02 and 03 profiles were about the same as for the continental spectra (Figure 13). The accumulated rainfall, on the other hand, was greater for the three maritime cases. As before, the profile with most of its buoyant force in the lower troposphere, caused the model cloud to produce the most rainfall.

A summary of the cloud model responses to the maritime and continental droplet spectra and the three types of warm rain soundings is presented in Table 2. There are two points to be made based upon that summary. First, the rise rate of the top of the cloud is not necessarily a good indicator of the maximum vertical speed in the cloud. For instance, although WRM02 resulted in a slightly higher cloud top rise rate after 15 minutes of simulation than did WRM01, the maximum vertical speed for WRM02 was about 25% less than for WRM01 (or WRM03). Second, the continental clouds had higher vertical speeds (less precipitation loading) and less rainfall production at the 60 minute mark.

For comparison, some of the responses of the S/W model to the same profiles and maritime droplet spectra used with the WOM model are also shown in Table 2. The major differences are that the S/W model predicted, in all cases, higher cloud tops and greater vertical speeds. In fact, the S/W cloud tops overshot the equilibrium level by 600 to 1800 meters. The reason for this may be that the S/W vertical speeds are 25% to 45% higher than those predicted by the WOM model. This difference could be primarily due to the difference in the computational schemes of the two models; the WOM is a fixed coordinate system while the S/W is quasi-Lagrangian with a coordinate system that moves with the parcel center. The precipitation production of the two models is difficult to compare since the output of the WOM model is an accumulated amount on the ground while the S/W output is a precipitation production rate. However, it is noteworthy that the S/W model shows the WRM03 model cloud producing the most rain while the WOM model predicts the most rain from WRM01.

It should be noted here that some of these differences between models can be "tuned" out by making "adjustments" to certain coefficients such as for the entrainment, virtual mass and drag. What is most important at this stage is the sense of the model outputs in response to changes in the vertical stability structure. In general, both models agree on the sense of the responses except for a sensitivity to the cloud base droplet spectra. For the case shown in Table 2 the S/W model shows very little sensitivity to the droplet spectra while the WOM model shows changes in all three response variables. This point is most troublesome and needs further examination.

3.1.3 Cold cloud cases/continental droplet spectra

Although the warm rain cloud simulations are interesting for examining some of the sensitivities of the two cloud models to the required inputs it is desirable to look at a set of situations where the ice processes would be present. In order to keep comparisons tractable, a set of 3 soundings were prepared that kept the total CAPE invarant but distributed it in the same 3 ways as for the warm cloud cases but over a much deeper layer (11 km vs. 4 km) (Figure 14).

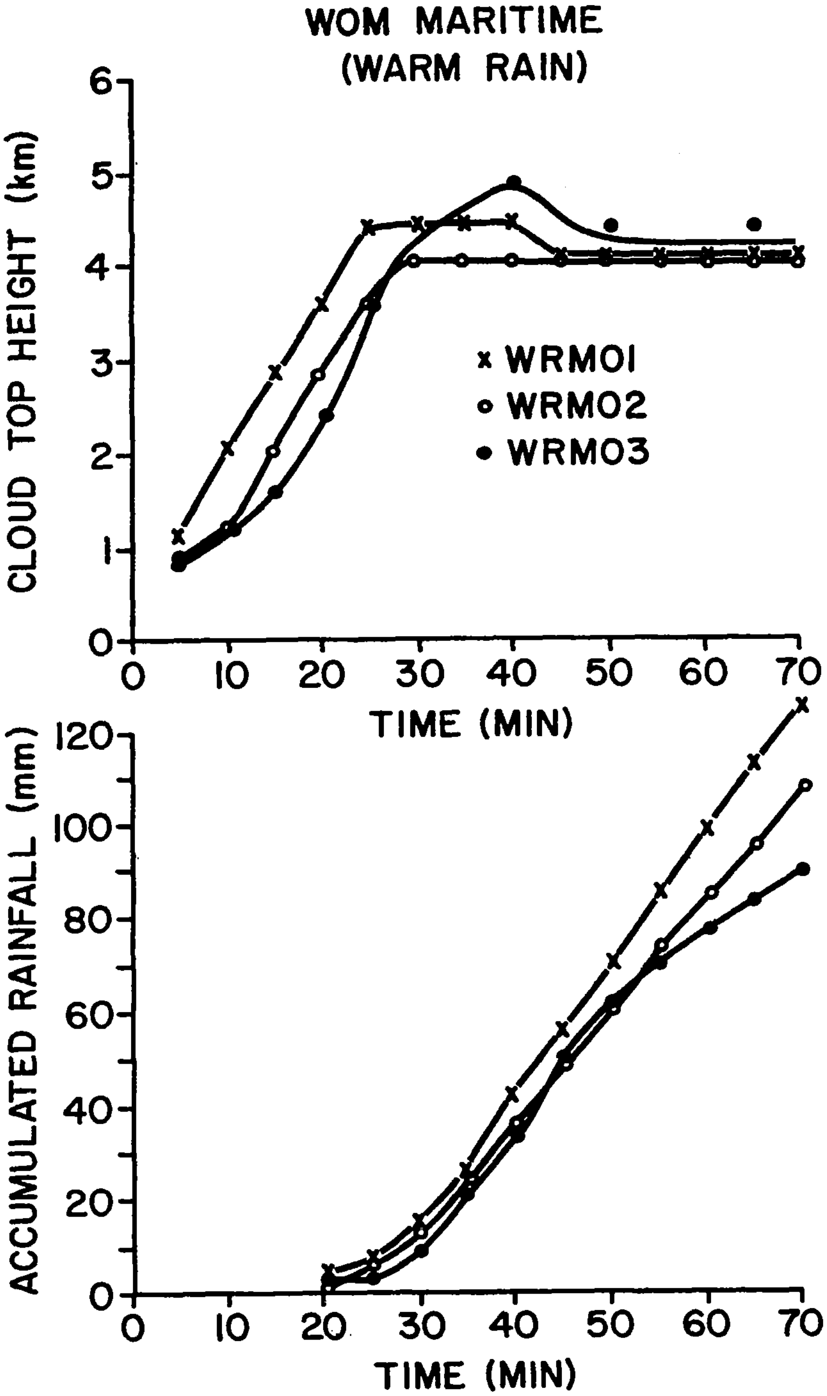

Figure 13. Same as Figure 12 except a maritime cloud base droplet spectrum ($200\ cm^{-3}$) was used.

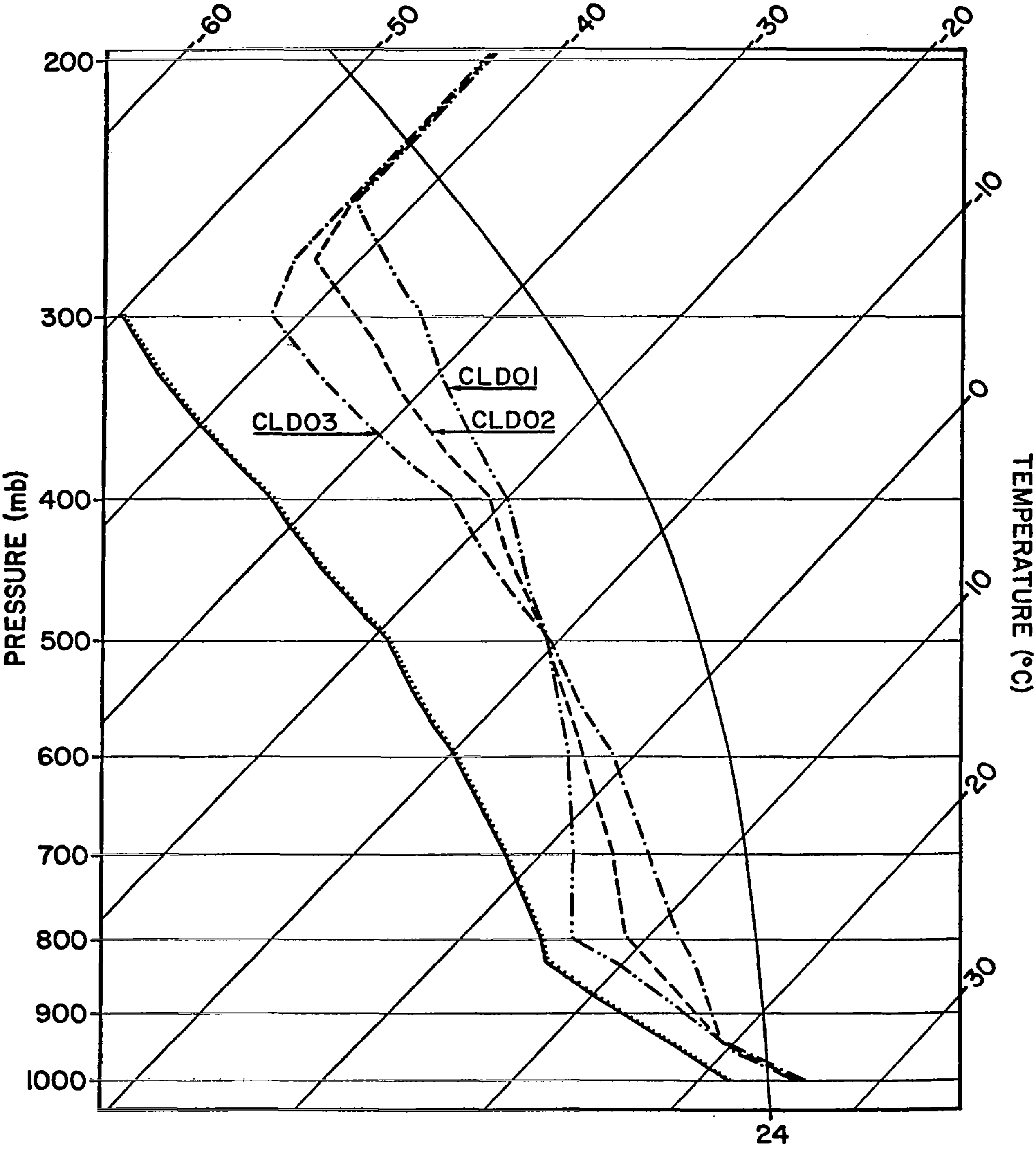

Figure 14. Cold cloud CAPE profiles having equal positive energy areas.

Looking first at the continental droplet spectra (1000 cm^{-3}) with a dispersion of .2 cases, it is clear that the sense of the cloud top dynamics is similar to that for the warm cloud cases except that the maximum rise rates are higher: CLD01 (5.8 m s^{-1}), CLD02 (5.8 m s^{-1}), and CLD03 (5.5 m s^{-1}) (Figure 15). The most significant difference is found in the accumulated rainfall where for deep model clouds a CAPE distributed equally with height is more likely to produce more rainfall than the other two distributions. In fact, the CLD02 profile yielded nearly twice the rain as did the CLD01. The sense of that comparison was exactly the opposite for the warm rain case. However, it must be repeated that the 1-D models tend to show an inverse relationship between updraft speed on rainfall production.

3.1.4 Cold cloud cases/maritime droplet spectra

The dynamics of the deep maritime model clouds do not appear very different from those of the continental model clouds. However, the predicted rainfall is greater and there is not such a difference between the CLD01 case and the other two (Figure 13). The CLD02 type profile, as it did with a continental droplet spectra, yielded the most rainfall.

As were the warm cloud CAPE experiments, some of the responses in the cold cloud experiments are presented in Table 2. Both the WOM and S/W models results are shown. Once again the WOM model showed a sensitivity to the droplet spectra while the S/W model did not. For the deep convection the vertical velocities predicted by the S/W model were nearly 60% higher than by the WOM model but the sense of precipitation production was the same for the two models.

Before summarizing the CAPE distribution experiments, two computer runs are presented to illustrate the caution that must be used in interpreting simple 1-D model results. The usefulness of a 1-D model quickly deteriorates with time beyond the first 30 minutes or so as feedbacks to environment (subsidence, surface outflow, etc.) become more important. Therefore, care must be taken in putting any credence on the long time simulation of clouds with the 1-D model. However, to look further in time at the implied superiority of the CLD02 profile to produce rainfall compared to the CLD01 profile, the WOM model was run to 120 minutes. Figures 16 and 17 show that although the CLD01 model cloud had not produced as much rain as the CLD02 cloud at 60 minutes, it reached steady state and would in time produce more rain than the CLD02 cloud which was modeled to die by 70 to 80 minutes.

4. AVE/VAS Case Study (24 April 1982)

The following results should be regarded as preliminary and are presented as an example of on-going research into the uses of VAS soundings in numerical models. Three separate model experiments will be referred to: 1) South Dakota School of Mines 2-D Cloud Model (IAS Model) using a VAS sounding at 1730Z, 24 April 1982; 2) Wisner, Orville and Meyer's 1-D cumulus model using the 1400Z and 1700Z rawinsonde soundings in the same area as the 1730Z VAS sounding; and 3) IAS model using the 1700Z rawinsonde sounding.

The rawinsonde soundings were taken at Amarillo, Texas as part of NASA's 1982 AVE/VAS field experiment. The VAS sounding was obtained using the University of Wisconsin's physical retrieval technique on radiance data taken within 20 miles of Amarillo. At 1400Z on 24 April 1982 the skies over the

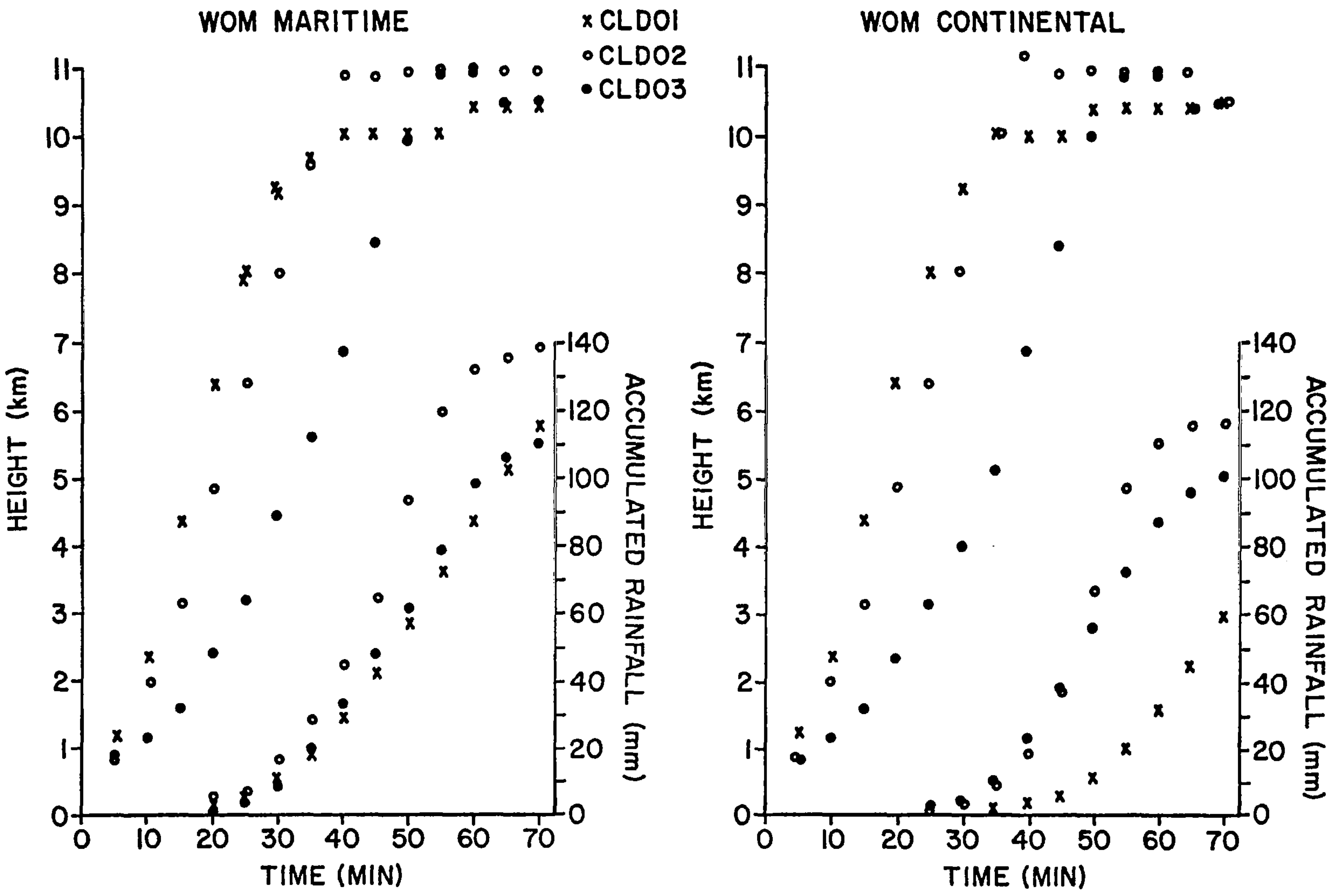

Figure 15. WOM Model results using the three CAPE profiles shown in Figure 14. Both maritime (200 cm^{-3}) and continental (1000 cm^{-3}) cloud base droplet spectra are used. Height is for cloud top height.

MARITIME[1] vs. CONTINENTAL[2]
for
WOM MODEL

TEST CASE	MAX HEIGHT (km)	MAX VELOCITY (m/s)	TOTAL PRECIPITATION (60 min) (mm)
WRM01	4.4 (4.4)	12.5 (13.4)	100 (75)
WRM02	4.0 (4.4)	9.4 (9.9)	86 (68)
WRM03	4.8 (4.8)	12.4 (12.8)	78 (72)
CLD01	10.4 (10.4)	21.6 (22.4)	87 (32)
CLD02	10.8 (11.2)	17.4 (18.0)	132 (110)
CLD03	10.8 (10.8)	17.7 (18.5)	98 (88)

SIMPSON AND WIGGERT

TEST CASE	MAX HEIGHT (km)	MAX VELOCITY (m/s)	TOTAL PRECIPITATION (60 min) (mm)
WRM01	5.4	15.9	9.4
WRM02	4.8 (4.8)	12.0 (12.0)	7.8 (7.7)
WRM03	6.0	18.0	10.2
CLD01	9.8 (9.8)	25.7 (25.6)	12.4 (12.4)
CLD02	11.6 (11.8)	25.1 (25.0)	13.7 (13.7)
CLD03	11.8	28.2	13.1

1. Maritime: 200 cm^{-3} with dispersion of .4

2. Continental: 1000 cm^{-3} with dispersion of .2

CONTINENTAL values in ( ).

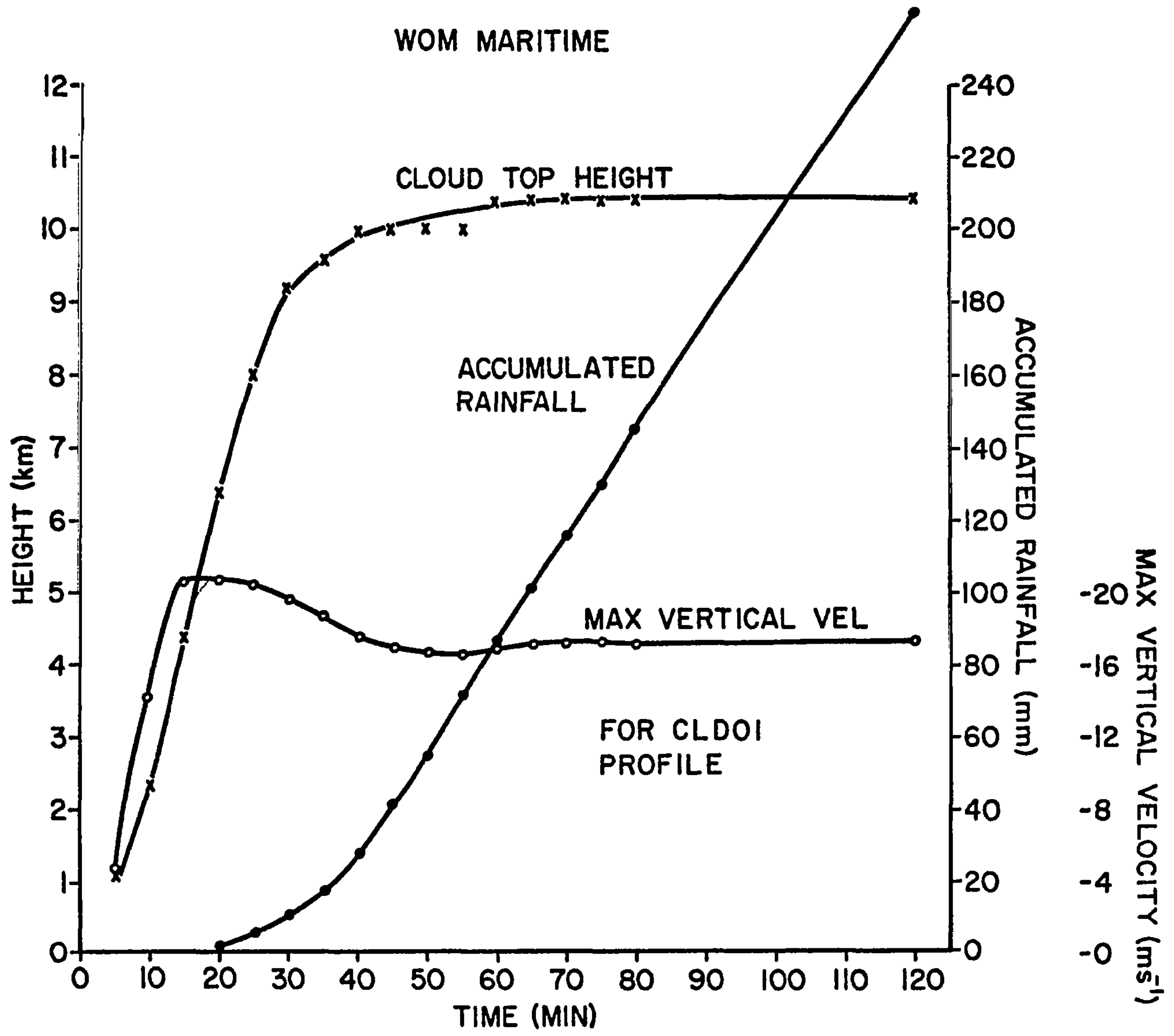

Figure 16. 120 minutes time history of WOM model cloud for a maritime droplet spectrum (200 cm^{-3}). CLD01 sounding is shown in Figure 14.

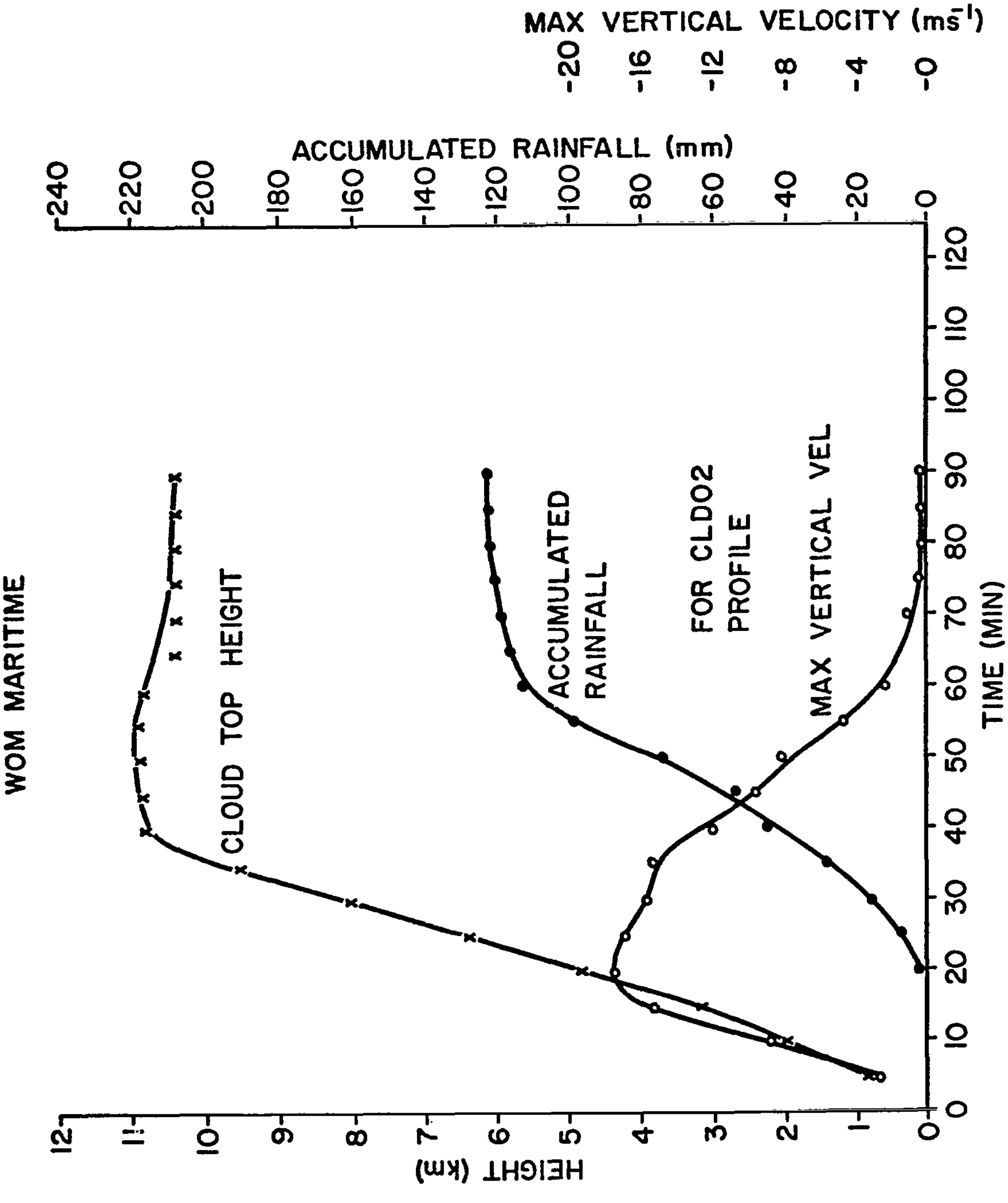

Figure 17. Same as Figure 16 except for the CLD02 sounding shown in Figure 14.

panhandle of Texas were mostly cloud free, although a cold front was moving through south-central Colorado and producing a band of convection ~400 km to the northwest of Amarillo. At 1700Z and still well ahead of the front, a patch of modest cumuli (diameter ~3-5 km) over the Texas panhandle began to appear on GOES E visible imagery. Those clouds continued to grow and organize and eventually produced precipitation over western Oklahoma.

Three questions were posed regarding the evolution of the clouds over Amarillo.

1) Do the VAS soundings describe an environment conducive to modest cumulus development?

2) How does a 2-D cloud model respond to VAS soundings as inputs?

3) How do the corresponding rawinsonde soundings affect the results of a 2-D cloud model? --a 1-D cloud model?

The response of the IAS 2-D cloud model to a VAS sounding at 1730Z is summarized in Figure 18. The primary features of the model cloud that developed are:

cloud base	1.2 km AGL
cloud top (24 min)	6.25 km
cloud width (24 min)	5 km
precipitation (24 min)	none
cloud top rise rate (10-20 min)	4 ms^{-1}

Although the general characteristics of this model cloud are consistent with those of the satellite observed clouds, it is premature to generalize the usefulness of VAS soundings in cloud models. Encouraged by this initial model experiment, other VAS soundings were examined and it was concluded that this initial success was fortuitous. A great many more VAS sounding/cloud model experiments need to be run to make a more quantitative statement.

For comparison with the model results using a VAS sounding, the IAS 2-D model was run on two Amarillo, Texas rawinsonde soundings. First, the model was run using the 1400Z sounding (Figure 19) which was made during a period of cloud-free skies as observed by GOES-E visible imagery. As anticipated, the 2-D model was unable to initiate any clouds, primarily because of a strong low level inversion.

At 1700Z, a rawinsonde sounding (Figure 20) was made through a patch of scattered cumuli over Amarillo. The graphical presentation of the results of the IAS 2-D cloud model run using this sounding is contained in a report by Fred Kopp to NASA/MSFC dated October 1983. A summary (personal communication with Fred Kopp) of the model cloud characteristicis follows:

cloud base	2.1 km AGL
cloud top (40 min)	6.6 km AGL
cloud width (40 min)	6.0 km
accumulated rainfall (90 min)	5 mm
maximum vertical speed (42 min)	12.0 ms^{-1}

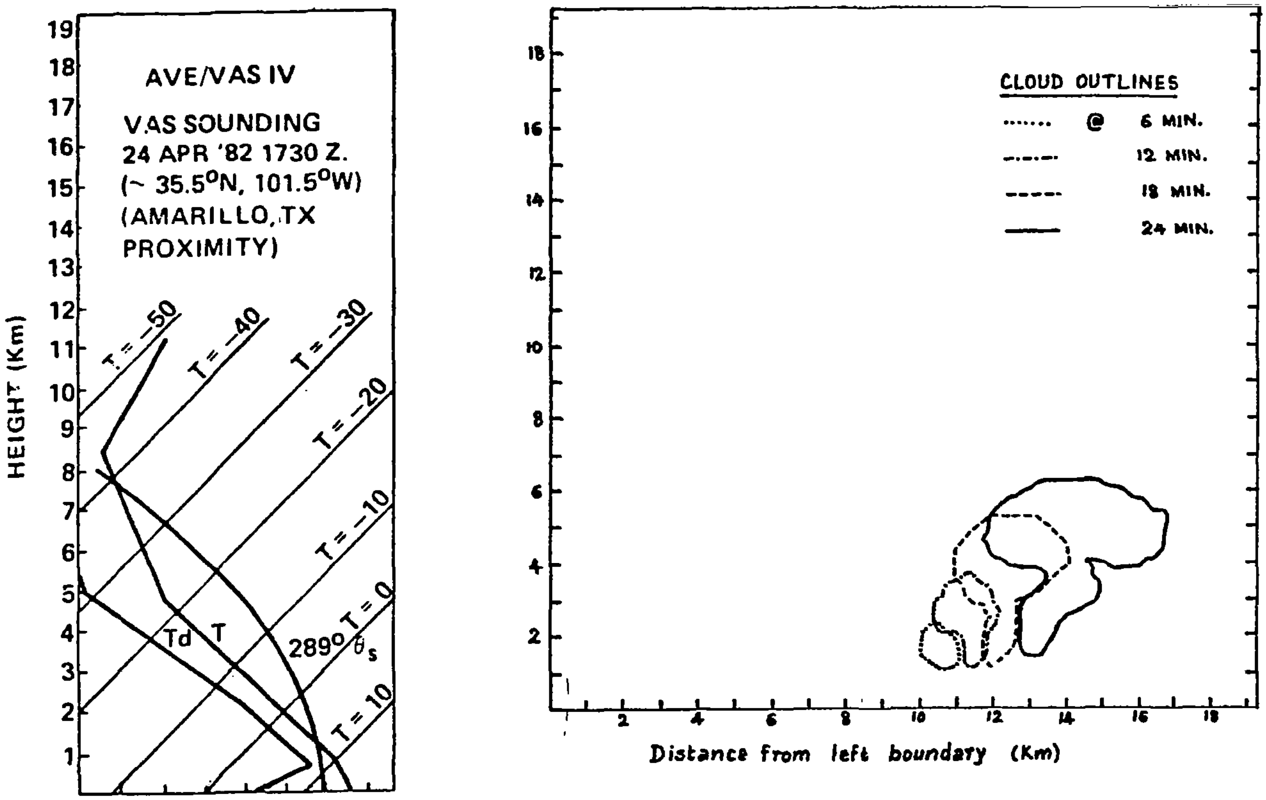

Figure 18. History of a typical convective cloud predicted by the I.A.S. two-dimensional time-dependent cloud model, in an environment specified by a VAS sounding and a convergence field of strength 2 x 10^{-5}/sec.

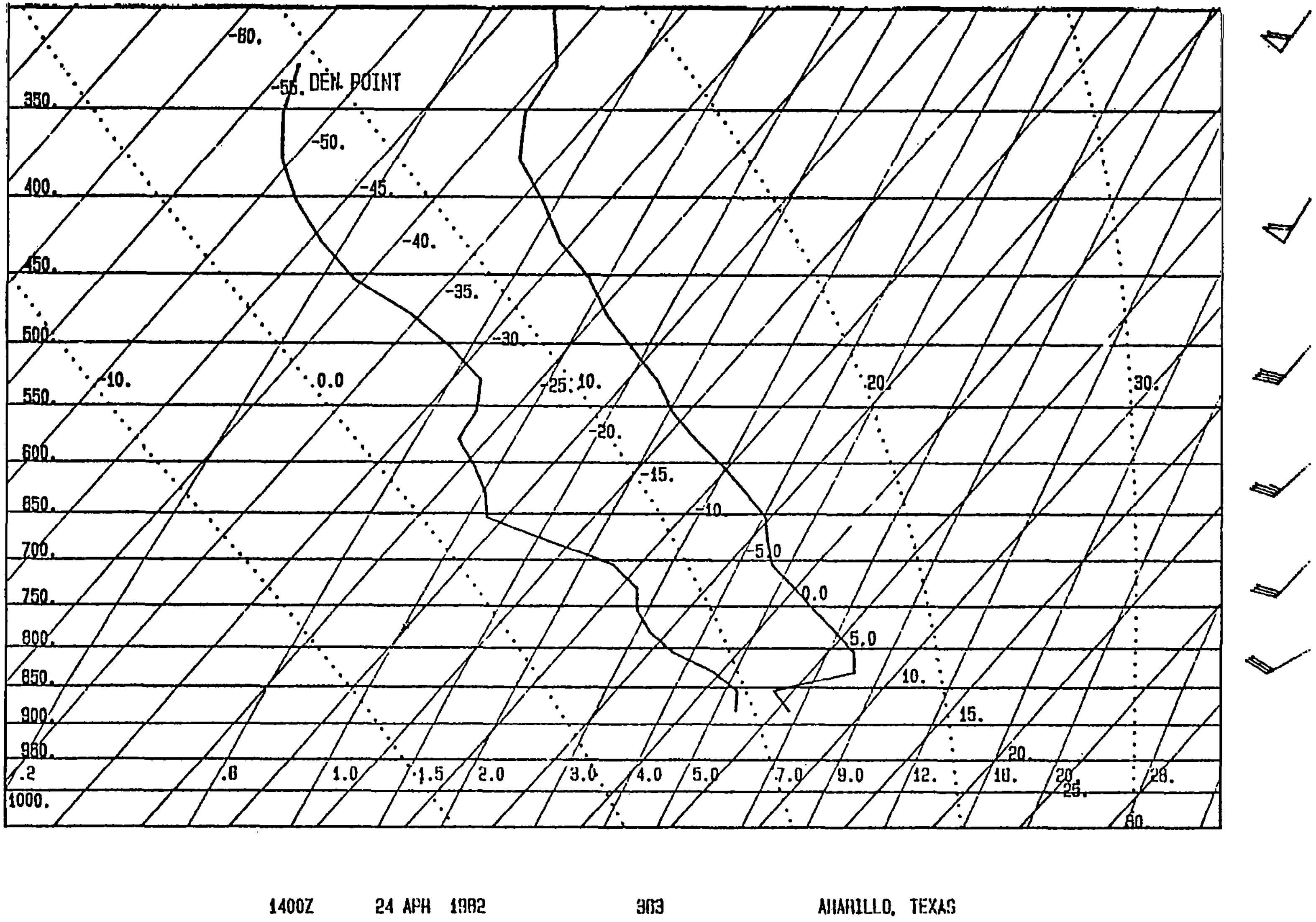

Figure 19. 1400Z 24 April 1982 Amarillo, Texas rawinsonde sounding obtained during the 1982 AVE/VAS experiment. Sounding plotted on standard skew T-log P diagram.

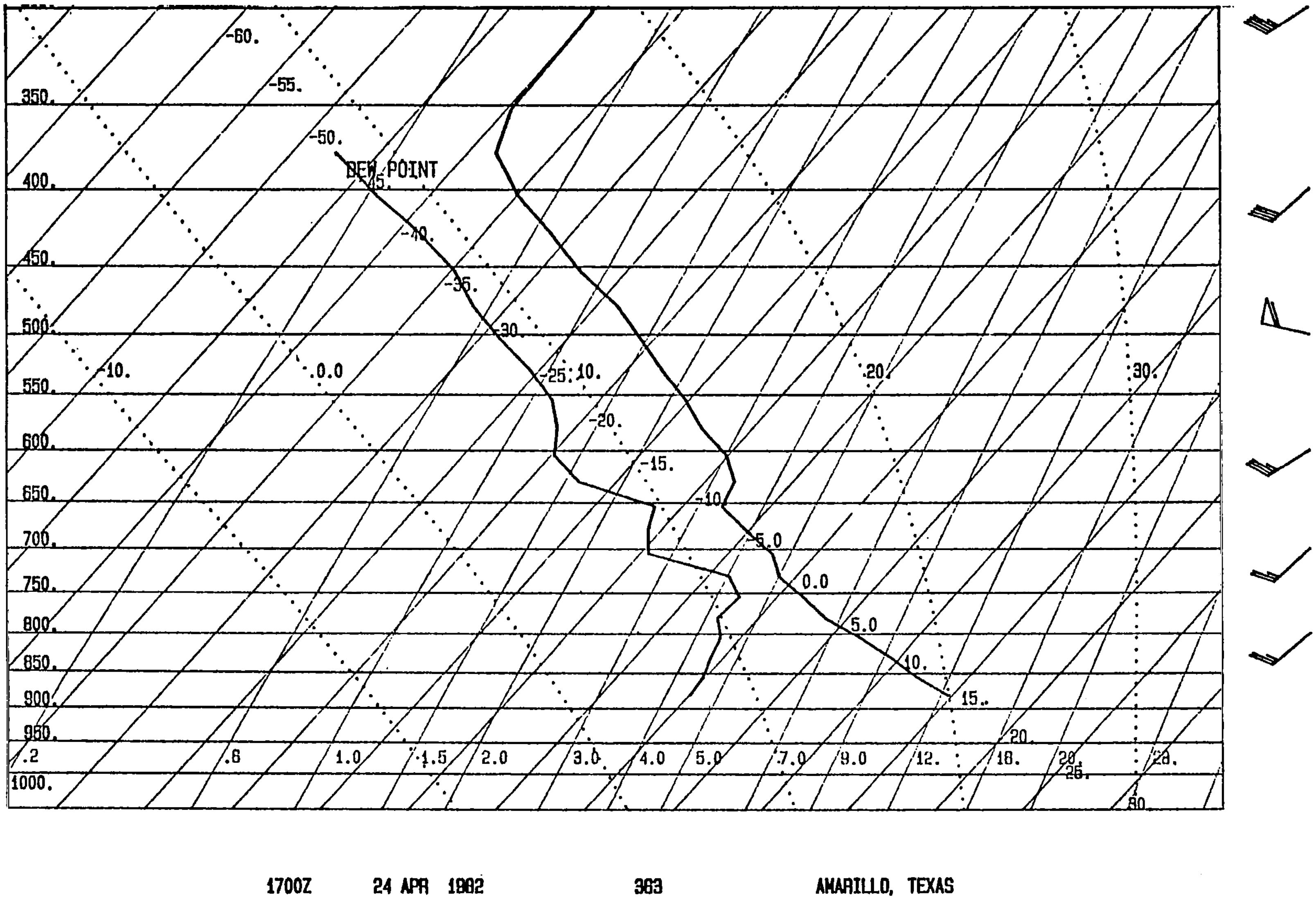

Figure 20. 1700Z 24 April 1982 Amarillo, Texas rawinsonde sounding obtained during the 1982 AVE/VAS experiment. Sounding plotted on standard skew T-log P diagram.

As was the case with the VAS sounding, the rawinsonde initiated IAS 2-D model cloud also had characteristics that were similar to those of the clouds observed. However, the cloud base in the second model experiment is about 35 mb (~.5 km) higher than the CCL (730 mb) obtained by examination of Figure 20. The reason for this difference lies in the way the clouds are initiated in the model. A more complete explanation is available in the Kopp report.

The third set of model runs involved the 1-D cumulus model developed by Wisner, Orville and Myers (1972). For this model the cloud base is a prescribed input and therefore is lower than that of the 2-D model cloud. Figure 21 presents the time evolution of the 1-D model cloud. Note that the height of cloud top is in km MSL. For comparison with the other model runs the following summary figures are given in km-AGL:

cloud base	1.5 km AGL
cloud top (40 min)	7.5 km AGL
accumulated rainfall	5.6 mm
maximum vertical speed (35 min)	12.6 ms^{-1}
cloud top rise rate (10-20 min)	2.5 ms^{-1}

Once again, the general characteristics of the 1-D model cloud are within expectations. The major difference between the 1-D and 2-D model runs on the 1700Z rawinsonde soundings is the cloud thickness, 6.0 km vs. 4.5 km. This 1.5 km difference is probably related solely to the different cloud bases used. The 2-D cloud's base at 2.1 km would also mean an earlier intersection of the moist adiabat with the temperature profile, thus a much shallower cloud.

5.0 Conclusions

Although the CAPE distribution experiments and the one case study presented in this report produced some encouraging results regarding the usefulness of VAS soundings, any general conclusions must be reserved for a much more comprehensive evaluation. The material in this report is intended to demonstrate the progress that has been made in using models available to MSFC to quickly perform preliminary analyses of satellite and rawinsonde data.

Several issues that arose during the reported research are presented here as questions that could serve to guide future investigation:

1) Can VAS soundings be corrected statistically for the exaggerated stability?

2) Can surface measurements of dew point and temperature be used to estimate cloud base with an adjusted VAS sounding providing the cloud layer stability information?

3) Can the VAS soundings be used with rawinsondes to provide additional space and time information on the evolution of the pre-storm environment and therefore permit more appropriate initialization of cloud models?

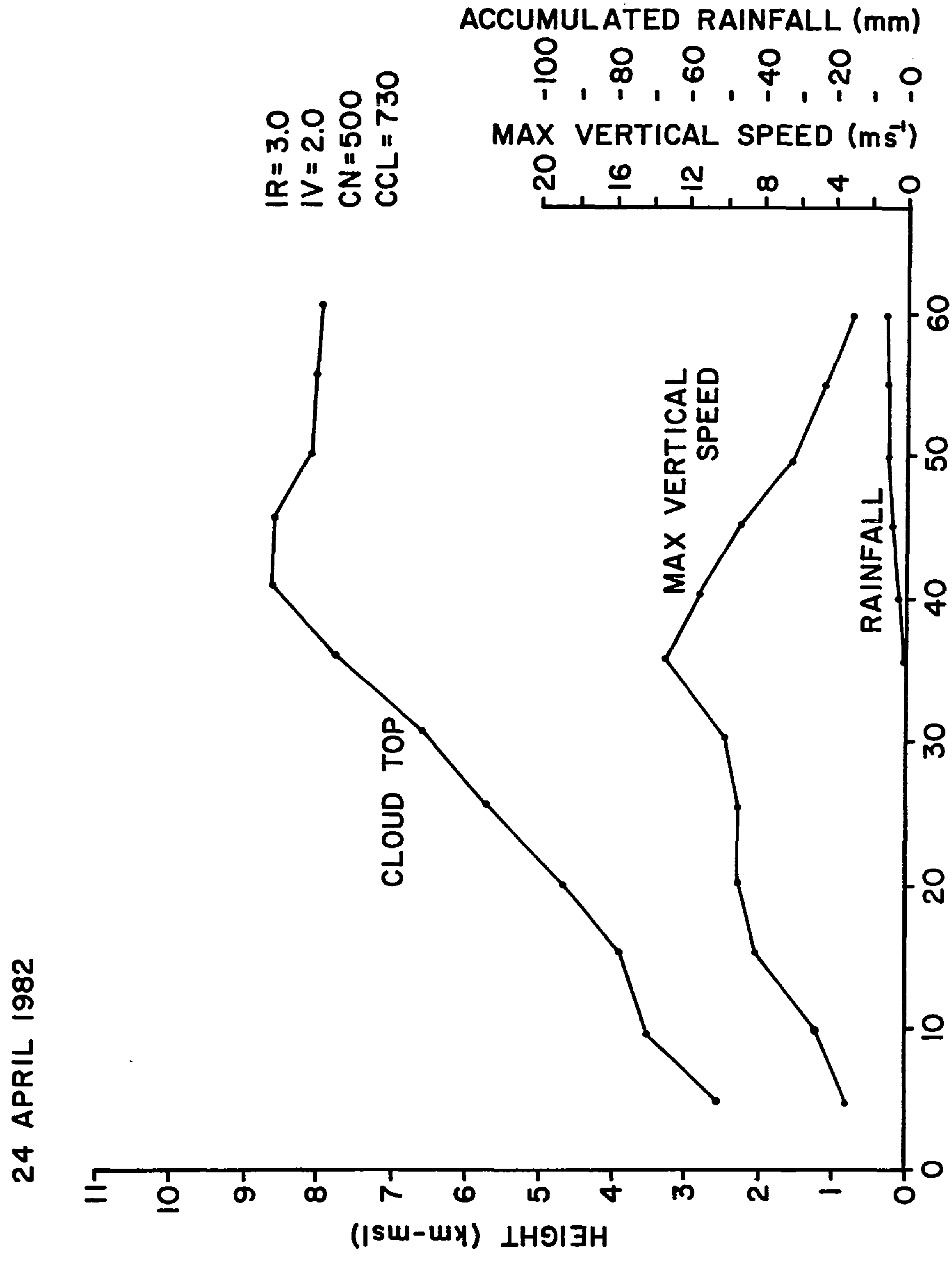

Figure 21. Time series of WOM model cloud using the 1700Z 24 April 1982 sounding shown in Figure 20.

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16. ABSTRACT

Evaluation of the satellite Visual Infrared Spin Scan Radiometer Atmospheric Sounder (VISSR) has begun to document several of its critical shortcomings as far as numerical cloud models are concerned: 1) excessive smoothing of thermal inversions; 2) imprecise measurement of boundary layer moisture; and 3) tendency to exaggerate atmospheric stability.

This report focuses upon the sensitivity of 1-D cloud models to their required inputs with special attention to those parameters obtained from atmospheric soundings taken by the VAS or rawinsonde. In addition to performing model experiments using temperature and moisture profiles having the general characteristics of VAS soundings, standard input sensitivity tests were made and 1-D model performance was compared with observations and the results of a 2-D model experiment using AVE/VAS data (Atmospheric Variability Experiment).

Although very encouraging, the results of this study are not sufficient to make any specific conclusions. In general, the VAS soundings are likely to be inadequate to provide the cloud base (and subcloud layer) information needed for inputs to current cumulus models. Above cloud base, the tendency to exaggerate the stability of the atmosphere requires solution before meaningful model experiments can be run.

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