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ANALYSIS AND PREDICTION OF SEVERE STORM ENVIRONMENT(U) 1/1
PENNSYLVANIA STATE UNIV UNIVERSITY PARK DEPT OF
METEOROLOGY T N CARLSON ET AL. FEB 83 AFOSR-TR-83-0440

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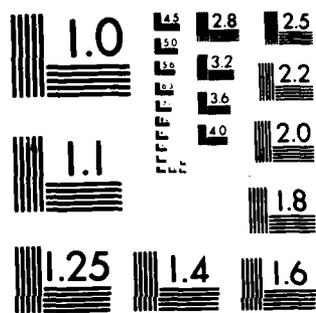
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20..Abstract (cont)

The most significant aspect of this research regards the role of differential surface heating and topography in the development of mesoscale weather. Research has progressed in four areas: conceptual development, model development, model sensitivity tests, and prediction. The effect of surface heating and topography on precipitation and lid generation are forming the basis of current and on-going numerical and conceptual research. The effect of variations in soil moisture on the mesoscale environment has been identified as a most significant factor. The strength of the capping lid has been related to the likelihood and intensity of convective precipitation, especially involving the dynamics of lid edge zone. A great deal of effort was devoted to parameterization of surface heating, cloudiness, and convective precipitation. During this research effort great strides were made in the conceptual awareness of the complexity of the relationships between synoptic forcing and mesoscale development. Enormous improvements were made in parameterizing the surface boundary layer. What began as an examination of the lid mechanism with regard to severe convection broadened to explain the complex interaction of a variety of differing influences on the severe storm environment and on precipitation.

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Analysis and Prediction of Severe Storm Environment

Final Report

to

U.S. Air Force

Grant AF OSR-79-0125

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MATTHEW J. KEEPER
Chief, Technical Information Division

1. Introduction

This final report briefly summarizes the important results obtained during the granting period. A more detailed account of the research is contained in published documents (or those in press). Much of the background on our severe storms work is contained in earlier progress reports, the latest covering the period November, 1980 - November, 1981. To date one journal article has been published in a refereed journal (Anthes et al., 1982), one other article on severe storms has passed the review process (Carlson et al., 1983; Carlson and Farrell, 1983) and one on model initialization and objective analysis is about to be submitted for publication (Benjamin and Seaman, 1983). Two student master's theses (Schwartz, 1980; Goldman, 1981) have been completed and two more (Graziano, 1983; Lanicci, 1983) are nearing conclusion. Two student Ph.D. theses (Benjamin, 1983; Kuo, 1983) are in the final stages of completion. A fourth paper, based on the results of Benjamin's (1983) thesis is planned to be written during the Spring of 1983. In addition, two papers were presented and published in the proceedings of the most recent severe storms conference (Carlson, 1982; Benjamin and Carlson, 1982). Several invited talks pertaining to elevated mixed layers and several local storm prediction were presented by Carlson and by Benjamin.

The forementioned documents contain a detailed description of both conceptual and numerical modeling of the severe storm environment. They deal primarily with the role of the lid and underrunning in severe local storms, stressing the importance of differential surface heating and differential topography in establishing severe storm environment. With the aid of both the Penn State 2-D and 3-D numerical models we have also examined the sensitivity of atmospheric features, such as the lid and the low-level jet, to soil moisture and topography, including an account of the feedback between soil

moisture clouds and the evolution of convective instability in the lower atmosphere. The practical significance of lid analysis and the effects of lids in convective precipitation has also been the subject of much of our research. A paper by Carlson and Farrell, to be published in the National Weather Digest (1983), pertains to the analysis of lids and underrunning using a man-machine method of analysis.

2. Summary of Important Findings.

The lid. The stratification of a capping inversion over a low-level moist flow, an important precursor to severe storm outbreaks, is shown to be generated by differential advection of air from an elevated arid source region, such as Mexico. The maintenance of the stable layer over lower, moister terrain downstream is directly related to the aridity (i.e. low soil moisture) over Mexico and to the establishment a favorable flow aloft which advects the Mexican mixing layer toward the north. Precipitation patterns downstream from Mexico are altered dramatically by the presence of a lid which suppresses convective precipitation even in the presence of low-level moisture convergence. There is apparently some diurnal fluctuation in the strength of the lid due to the variation in the time that air is heated over the arid source region. For example, during the morning hours the lid may be weakest over southern Texas because air arriving aloft may have crossed Mexico primarily during the previous night when surface heating was absent. The lid is apparently strengthened or weakens less rapidly with time when it moves over moist terrain because there the presence of weak surface sensible heating and low-level cloud (such as boundary layer stratus) aids in preventing the erosion of

the lid by inhibiting the growth of the local mixing layer. Therefore, a correct formulation of soil moisture, cloud effects on the surface radiation budget and topography are absolutely essential in numerical models if the lid structure and its consequences are to be predicted. A considerable effort during the past two years has been devoted to properly formulating the lower boundary energy fluxes and cloud cover in the Penn State mesoscale model. We have also found that, while the details of the mesoscale flow pattern can be predicted given the correct model parameterizations, the exact locations of the features such as the lid edge, for example, are sensitive to the initial atmospheric conditions, especially for longer-term (36 h) forecasts.

Underrunning. The process by which moist air in the boundary layer moves out from beneath the lid into an area of low static stability above the boundary layer has constituted an important focus of our research. Underrunning is associated with the focused release of intense convection just outside the lid. Underrunning does not appear to be a continuous process, however, but occurs episodically in response to differential ageostrophic advection in which the component of flow across the lid edge responds to strong ageostrophic motion in the boundary layer. This ageostrophic motion is related to migrating features aloft (i.e jet streak); ageostrophic-vertical circulations are manifested at the surface as an isallobaric wind component associated with migrating pressure change pattern which is enhanced by lowered stability outside the lid edge associated with the presence of intense heating in the boundary layer over arid portions of west Texas. Accordingly, when the upper migrating feature arrives west of

the lid edge a strong ageostrophic component of motion becomes directed westward across the lid edge. The ageostrophic circulation is especially intense during the afternoon. The role of the upper migrating gust streak in inducing strong low-level flow was suggested by Uccellini and Johnson (1979) in regard to the formation of lower-level jets. Thus, in cases examined during SESAME, vigorous under-running occurred in response to a migrating upper tropospheric jet which moved to a location west of the lid edge, near the location of severe storms, just prior to the onset of intense convection. One interesting aspect of the underrunning process, which we have begun to study, is the front-like circulations imposed by the strong confluence in the baroclinic zones along the lid edge, an example of which is the so-called dry line. These circulations appear to be weak but act to destabilize the lid and may therefore be responsible for the rapid rise in lid elevation with distance across the lid edge zone.

The Low-Level Jet. There may be a variety of mechanisms for producing the low-level jet. Although this feature has not been the main subject of our research, sensitivity tests with the 2-D and 3-D numerical models have pointed to additional factors involved in the formation of a strong flow of moist air at low levels from the Gulf of Mexico. Ageostrophic motion which leads to underrunning, as discussed above, may be an important factor in the establishment of the low-level moist flow. However, an unexpected result of Benjamin's (1983) modeling tests is that the presence of Mexico and the variation in differential heating associated with the Mexican plateau establish a lee-side trough of low pressure near the surface and a strong

southerly flow east of the Mexican plateau. The intensity of the lee-side trough is related not simply to the barrier affect of Mexico or to flow over the barrier but to a combination of orography and differential surface heating. Again, this result emphasizes the importance of surface heating and orography in shaping mesoscale flow. As a consequence of the lee-side effect, Mexico not only is responsible for the formation of a lid downstream over the southern Great Plains but the plateau promotes a strong low-level moist southeasterly flow from the Gulf of Mexico when air aloft crosses Mexico from a southwesterly direction.

Dry Line Sensitivity Tests. The dryline sensitivity tests with the Penn State model support Shaefer's (1974) contention that mixing at the surface promotes an eastward movement of the dry line during the day. However, the lee-side troughing north of Mexico, which is also related to the surface heating, tends to counteract the eastward motion of the dryline by promoting a strong flow toward the west; the latter may be responsible for the westward motion of the dry line at night. The westward movement of the dry line may also be due to the gradual intensification of an east-to-west circulation in the lower layers, which occurs in response to differential surface heating across Texas, as suggested by Ogura, et al. (1982) in his discussion of the 'inland sea breeze' effect.

The Role of Surface Friction. Friction, especially that produced by mixing of dry thermals, appears to exert a significant diurnal effect on the strength of highs and lows. Where heating is not prevented by cloud and especially where the soil moisture is low, surface heating results

in a vigorous vertical exchange of momentum which acts as an internal friction throughout a large vertical depth. Consequently, there is a degradation in the surface pressure gradients, manifested by a weakening of surface pressure systems, during the day. This effect apparently exerts influence on the low-level ageostrophic flow and further underscores the importance of a correct surface energy budget in mesoscale numerical models.

Precipitation. We have not examined precipitation mechanisms in detail except to note its response to surface parameterization in the various numerical sensitivity tests. Some work covered by this grant has been in the area of cumulus parameterization in the Penn State numerical model. Ultimately, of course, a correct response of convective precipitation in predictions must depend upon a correct formulation of the cumulus parameterization. The mutual interactions between cumulus convection and its larger scale environment is one of the unsolved fundamental problems in meteorology. In the past two decades, many different cumulus parameterization schemes have been designed for various numerical models. Yet, so far, there is no single scheme shown to be general enough to be applied in all weather situations which improves model forecasts. Kuo (1983) has analyzed data collected in the 1979 SESAME experiment and has calculated heat and moisture budgets to diagnose the feedback of organized midlatitude convective systems to their environment. His major findings are:

1. The heating distribution of midlatitude cumulus convection does not have a significant variation on a scale greater than 350 km, and a time scale greater than 6 h. Though the synoptic situation is

different, the vertical heating distribution of midlatitude organized convection is fairly similar to those obtained by others over the tropics for much longer time scales.

2. The simple, steady-state cloud model used by Anthes (1977) is unable to predict heating distribution accurately. Kuo's scheme gives results similar to Anthes'. This failure is attributed to the lack of moist downdrafts in the steady-state cloud model.

3. The observed precipitation has a time lag with the large-scale moisture convergence. This time lag increases with spatial scale. Similar results have been obtained for the tropics.

4. Further analysis of the budget results indicated that the explicit scheme used by Rosenthal (1978), Jones (1980), and Ross and Orlanski (1982) may be a better alternative to cumulus parameterization for small enough grid size.

5. The error analysis indicates that the signal to noise ratio for heat budget is about 3:1 and 5:1 for moisture budget. The signal-to-noise ratio in general decreases as the space scale increases. Improved temporal and spatial resolution are needed to further improve the budget results. In particular, it is shown that with the same number of stations, a regularly spaced network can significantly reduce the errors introduced by the objective analysis which is necessary for an irregularly spaced network. This has strong implications for the field experiment design.

Mesoscale Convective Complexes. Using a variety of convective parameterization techniques, we have completed a series of sensitivity studies that focus on the variation of convective heating as a function of different large scale environments. The results indicate that the

convective heating profiles change substantially from one type of environment to the next. For example, the severe storm environment typically produces a profile such as shown in Fig. 1, while tropical profiles generally resemble Fig. 2. The two basic profiles also change significantly depending upon such parameters as vertical wind shear, environmental relative humidity, magnitude of potential buoyant energy, etc.. Since previous studies have shown that application of several different types of weather systems is sensitive to the vertical distribution of convective heating (see, for example, Anthes and Keyser, 1979; Koss, 1976; Fritsch and Brown, 1982), we have concluded that numerical simulations of mesoscale weather systems must include fairly sophisticated convective parameterization schemes capable of diagnosing the different heating profiles. Further, we have begun incorporating such a convective parameterization scheme into the 3-D model. We will subsequently conduct numerical studies using the various large scale environments in order to assess the magnitude of the convective effects.

Conclusion and Future Work

The most significant aspect of this research is the findings regarding the role of differential surface heating and topography on the mesoscale environment. Research has progressed in four areas: conceptual development, model development, model sensitivity tests, and prediction. The effect of surface heating and topography on precipitation and lid generation form the basis for our current numerical and conceptual work. In particular, we are concerned with the effects of variations in soil moisture on the mesoscale environment. We are also trying to relate lid strength to the likelihood and

intensity of convective precipitation. Finally, we are investigating the dynamics of lid edge zone. A great deal of effort has been devoted to parameterization of surface heating, cloudiness, and convective precipitation.

In looking back to initiation of this research we are struck by the great expansion in our conceptual awareness of the complexity of the problem and by the enormous improvements we have made in parameterizing the surface boundary layer. What began as an examination of the lid mechanism with regard to severe convection has broadened to explain the complex interaction of a variety of differing influences on the severe storm environment and on precipitation.

Appendix I

List of Publications Associated With Grant

- Anthes, R.A., Y.N. Kuo, S.G. Benjamin and Y.F. Li, 1982: The evolution of the mesoscale environment of severe local storms: Preliminary modeling results, Mon. Wea. Rev., 110, 1187-1213.
- Benjamin, S.G., 1983: Some effects of surface heating and topography on the regional severe storm environment, Ph.D. thesis, Department of Meteorology, The Pennsylvania State University (in press).
- Benjamin, S.G. and T.N. Carlson, 1982: Numerical simulations of the severe storm environment for 10-11 April 1979 (SESAME I) case. Reprint volume, 12th Conference on Severe Local Storms, January 11-15, 1982, San Antonio, TX, AMS, Boston, MA, 201-204.
- Benjamin, S.G. and N.L. Seaman, 1983: A simple scheme for objective analysis in curved flow (to be submitted to Mon. Wea. Rev.)
- Carlson, T.N., 1982: The role of the lid in severe storm formation: Some synoptic examples from SESAME, Reprint Volume, 12th Conference on Severe Local Storms, January 11-15, San Antonio, TX, AMS, Boston, MA, 221-224.
- Carlson, T.N., R.A. Anthes, H. Schwartz, S.G. Benjamin and D.G. Baldwin, 1982: Analyses and prediction of severe storms environment, Bull. Amer. Meteor. Soc., 61, 1018-1032.
- Carlson, T.N., S.G. Benjamin, G.S. Forbes, Y.F. Li, 1983: Elevated mixed layers in the regional severe storm environment: Conceptual model and case studies, Mon. Wea. Rev. (in press).
- Carlson, T.N. and R.J. Farrell, 1983: The lid strength index as an aid in predicting severe local storms, Nat. Wea. Digest, 8 (in press).
- Goldman, J.D., 1981: A conceptual model and its application in the analysis of severe convective storm situations, M.S. thesis, Department of Meteorology, The Pennsylvania State University, 98 pp.
- Kuo, Y.H., 1983: Diagnostic study of severe storm environment, Ph.D. thesis, Department of Meteorology, The Pennsylvania State University (near completion).
- Schwartz, M.N., 1980: Synoptic and mesoscale stability analyses of the Red River Valley severe storm outbreak of 10 April 1979, M.S. thesis, Department of Meteorology, The Pennsylvania State University, 94 pp.

List of Figures

- Figure 1 Vertical distribution of convectively driven temperature change in the mesoscale severe-storm environment.
(Deg. C h⁻¹).
- Figure 2 Vertical distribution of convectively driven temperature change in the mesoscale tropical environment.
(Deg. C h⁻¹).

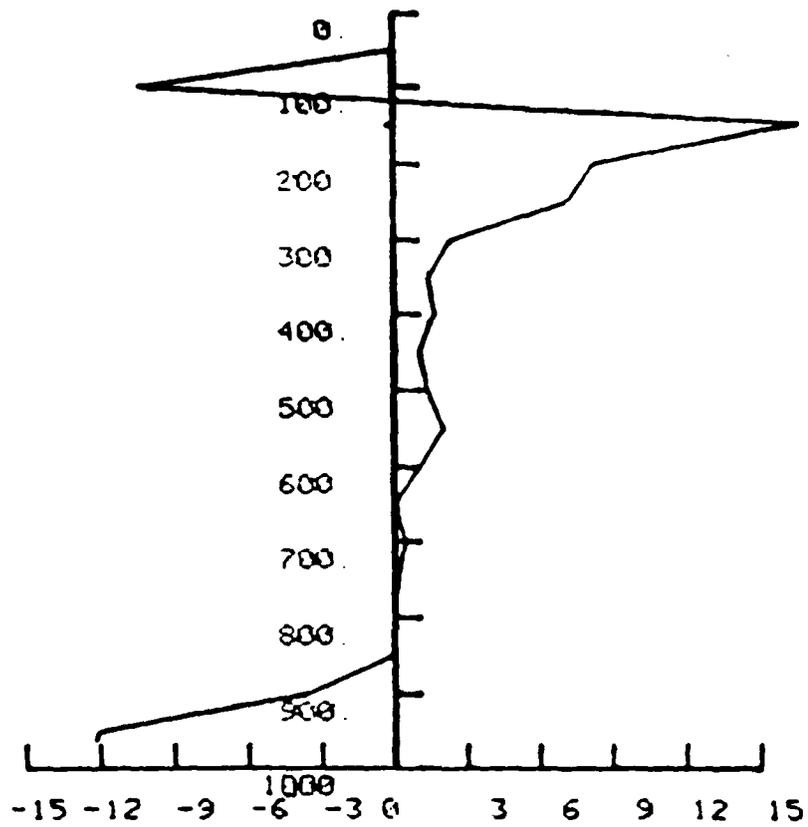


Fig. 1. Vertical distribution of convectively driven temperature change in the mesoscale severe-storm environment. (Deg C h⁻¹)

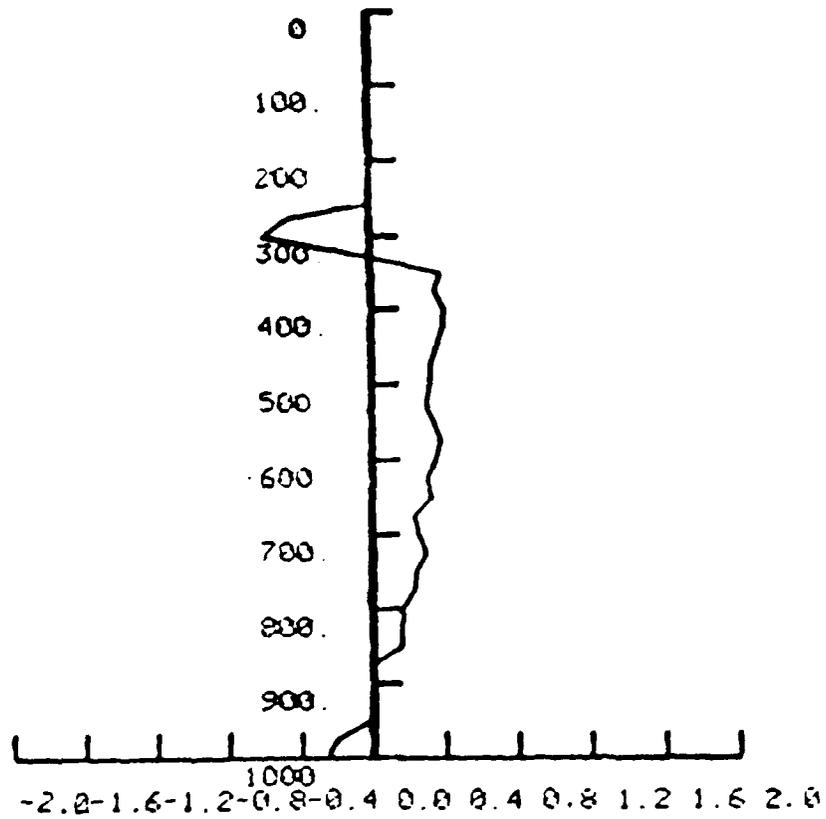


Fig. 2. Vertical distribution of convectively driven temperature change in the mesoscale tropical environment. (Deg C h⁻¹)

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- Anthes, R.A., and D. Keyser, 1979: Tests of a fine mesh model over Europe and the United States. Mon. Wea. Rev., 107, 963-984.
- Benjamin, S.G. and N.L. Seaman, 1983: A simple scheme for objective analysis in curved flow (to be submitted to Mon. Wea. Rev.)
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