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Approved for public release; distribution unlimited		Diagnostic and modeling studies have been performed to improve our understanding of, and skill at forecasting, mesoscale weather systems and circulations. In particular, we have investigated: The effects of entrainment and detrainment on convective cloud heating and moistening profiles, The effects of mesoscale water bodies and ocean currents on the large scale environment and transient weather systems, The effect of subcloud-layer evaporative cooling and changes in radiatively produced surface fluxes on low-level circulations, How soil moisture can be modeled, The synoptic climatology of the elevated mixed layer and lid in the southwestern U.S., The life cycle of the lid in the southwestern U.S., and the skill associated with cloud forecasts from the Penn State/NCAR mesoscale model.		
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Final Technical Report

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"Modeling and Observational Studies of Mesoscale  
Air-mass Boundaries and Warm-season Convective Precipitation"

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## 1. Introduction

Diagnostic and modeling studies have been performed to improve our understanding of, and skill at forecasting, mesoscale weather systems and circulations. In particular, we have investigated

- the effects of entrainment and detrainment on convective cloud heating and moistening profiles,
- the effects of mesoscale water bodies and ocean currents on the large scale environment and transient weather systems,
- the effect of subcloud-layer evaporative cooling and changes in radiatively produced surface fluxes on low-level circulations,
- how soil moisture can be modeled,
- the synoptic climatology of the elevated mixed layer and lid in the southwestern U.S.,
- the life cycle of the lid in the southwestern U.S., and
- the skill associated with cloud forecasts from the Penn State/NCAR mesoscale model.

## 2. Summary of the Results of the Research

A summary of the results for each of these topics is provided below.

### A.) Entrainment/detrainment

The extreme sensitivity of numerical model predictions to the vertical profiles of convective heating and moistening is well established. Because of this sensitivity, it is imperative to determine the profiles as accurately as possible. For many numerical models, the profiles are obtained from a convective parameterization which utilizes a simple, entraining-plume cloud model. Our results suggest that modification of the entraining-plume cloud model to include a much better representation of mixing with the

environment can considerably enhance the sensitivity of the convective parameterization to variations in the cloud environment. The new formulation for mixing uses a buoyancy sorting mechanism to predict where mixed subparcels will reside, i.e., in the cloud (entrainment) or in the environment (detrainment). Estimation of bulk updraft thermodynamic properties, vertical mass flux, and cloud detrainment is accomplished by integrating over an assumed distribution of mass in mixed subparcels at each vertical level. We have found that this scheme allows the vertical profile of convective mass flux, and hence the profiles of parameterized heating and drying, to respond strongly to environmental variations in buoyancy and relative humidity.

#### B.) Water bodies and ocean currents

For many years, meteorologists have recognized that large water bodies (e.g., the Great Lakes) and ocean currents (e.g., the Gulf Stream) have affected traveling weather systems, especially during the cool season. Nevertheless, operational numerical models have either ignored these effects (e.g., the NMC LFM) or used a bulk planetary boundary layer mixing formulation (e.g., the NMC NGM) that severely limits the vertical extent of the surface-induced heat and moisture fluxes. Since remote-sensing systems are now able to provide detailed surface temperature data for large lakes and oceans, it should be possible for high resolution models to generate the surface-forced mesoscale effects of water bodies and currents. Successful simulations and predictions would, however, require a more sophisticated formulation for handling surface fluxes than the formulations now used in operational models. In preparation for numerical experiments to test the model's ability to forecast surface-flux-forced mesoscale effects, we have completed mesoanalyses of Great-Lake-induced mesoscale disturbances. The results

clearly show that the Lakes profoundly influence large scale traveling weather systems and that the present operational models grossly underestimate these effects. For example, our analyses show that the Lake fluxes sometimes are instrumental in splitting synoptic high pressure systems into two separate circulation centers, altering the path of lows, and grossly distorting the horizontal location and distribution of clouds and precipitation. Moreover, it is clear that the effects of the Lakes extend well beyond the immediate boundaries of the Lake aggregate and therefore may be producing influences that are much more extensive than previously realized. It is reasonable to assume that the same type and extent of effects are occurring as a result of ocean current fluctuations. Numerical experiments are currently being performed.

C.) Evaporative cooling

Empirical studies of the strength of Appalachian cold air damming clearly document that clouds and precipitation strongly influence damming strength. We have completed a case study analysis of a cold air damming event and have constructed a conceptual model of how clouds and precipitation effect the strength of the damming. Briefly, the conceptual model shows how radiative and evaporative cooling lead to differential horizontal temperature advection that acts to stabilize the mountain layer and thereby inhibit flow over the mountain, i.e., damming is strengthened. Through geostrophic adjustment processes, the low-level cooling also results in a deeper upslope layer, more adiabatic cooling, and therefore a stronger mesoscale wedge ridge. Numerical simulation of these processes will require a resolvable-scale liquid water budget and a high resolution boundary layer.

D.) Soil moisture modeling

We have made progress in the development of a method for initializing soil moisture availability in the Penn State/NCAR mesoscale atmospheric model. The purpose is to better predict precipitation and runoff during heavy rain events. The method is based on formulation of a simple hydrological model that uses routine surface meteorological measurements to calculate the soil moisture availability. The model will operate on a seasonal basis, with half-day time steps. It is based on an amalgam of ideas by Camillo et al. (1983), Abramopoulos et al. (1988) and Mahfouf et al. (1989), and includes elements of the British Meteorological Office Rainfall and Evaporation Calculating System (MORECS).

Richard's equation (Shaw, 1983) (essentially the water diffusion equation with a gravity component) is solved in one-dimension ( $z$ ) with internal sources (precipitation) and sinks (evapotranspiration) of water. A simple water budget equation governs a shallow top layer, with precipitation and evaporation as source and sink of water. Internally, infiltration from the top layer and transpiration constitute the source and sink. Runoff occurs through an excess of precipitation over infiltration to lower levels. Water conductivities and diffusivities are a function of soil water content and soil type, according to parameterizations given by Cosby et al. (1984). A simple account is taken of rainfall interception. So constituted, the soil moisture profile will evolve not only in response to atmospheric demand, internal water movement and precipitation, but indirectly because of vegetation type and root depth.

Above ground, the primary input variables in the hydrology model are the average daily temperature, dewpoint, windspeed, cloud cover and precipitation. Soil type and

vegetation height and type are also required. Net radiation is computed from average cloud cover, temperature and dewpoint. Substrate heat storage is neglected.

Evaporation and transpiration are calculated from Penman equations, with the canopy resistance expressed in terms of the soil moisture availability.

The model has been tested against field measurements made in the Mahantango watershed area of the Susquehanna river basin in Pennsylvania.

#### E.) Synoptic climatology of the EML and lid

A synoptic climatology has been defined of the atmospheric conditions associated with the creation of the elevated mixed layer (EML) and the lid, where the lid is formed when the EML overruns moist, unstable air. The geographic area of the study is the Kansas-Oklahoma-Texas region and surrounding states, and the period of study spans four spring seasons (April, May, June) from 1983 through 1986. The climatology consists of two parts: a compilation of statistics and analyses of various parameters associated with the EML and lid, and a definition of a set of synoptic types that prevail in this region during the three-month period. The synoptic types are categorized by simultaneously examining the surface isobaric patterns and the predominant 500-mb flow direction over the study region, and designating the flow as either "favorable" or "unfavorable" for EML and lid formation based on the implied thermal advection in the layer and the number of lid soundings observed over the region.

Our statistical analyses reveal that a typical lid only covers about 20 to 25 percent of the three-state study region, and a lid coverage greater than 50 percent occurred on less than two percent of the study days. High lid-frequency values expand northward during the season, and the maximum-frequency axis shifts westward. We show that this

seasonal change is primarily caused by the northward expansion of the EML source region from Mexico into the central Rockies and Great Basin, and a westward shift in the mean low-level moist axis. The westward shift in the low-level moist axis is related to the westward expansion of the Bermuda anticyclone. We find that the relative airstream configuration associated with the classic models of lid formation and severe weather occurs most frequently in April and May, and corresponds to a flow type associated with southerly low-level flow and southwest flow aloft. As the season progresses, the expansion of both the EML source region and low-level moist areas allows the lid to be created with a variety of additional flow configurations. In addition to the classic southwesterly midtropospheric flow type, these configurations include northwest and anticyclonic 500-mb flows by May and June. The dominance in late spring of flow types associated with large-scale subsidence leads to an airstream configuration in which the inversion base sinks and the lid strengthens downstream from the source region, in stark contrast to the classic lid model where the inversion base rises and the lid weakens in an environment of large-scale vertical ascent.

F.) The life cycle of the lid

This study documents, for the first time, the entire cycle of lid formation and dissipation over the south-central U.S. The period of study spans four spring seasons (April, May, June) from 1983 through 1986. The database includes conventional surface and rawinsonde data, as well as derived parameters that define the lid structure based on an automated sounding-analysis procedure. We examine temporal and spatial analyses of lid occurrence and surface/500-mb synoptic flow patterns to determine the periodicity

of lid occurrence, seasonal tendencies, and relationships between different stages of the lid cycle and specific flow types.

Our results indicate that the lid has a mean life cycle of around 7 days. Our synoptic typing results show that there are basically two types of lid cycles: one that begins with a surface high-pressure incursion into the southern Plains, and one that begins with a weak southerly surface flow. The first type of lid cycle occurs about 70 percent of the time and appears throughout the entire season. The second type first appears around mid-May, and later becomes as frequent as the first type. The first type of cycle is longer than the second, and is associated with strong baroclinic waves in the westerlies over the study area. The second type of lid cycle is typically associated with the weak midtropospheric anticyclonic and cyclonic circulations that drift across the region in late spring and summer after the jet has retreated northward. Based on these analyses, we can define a four-phase composite of the lid cycle:

1. A beginning phase (about 36 h long), associated only with the first type of lid cycle during which a surface anticyclone moves through the Plains and drives the low-level moist layer into the Gulf of Mexico, while a warm, dry mixed layer forms over the western U.S.
2. A weak return-flow phase (lasting about 24 h), in which the surface anticyclone exits the region, and the low-level moist layer returns into southern Texas. The mixed layer from the western states moves into the western Plains and becomes elevated, but is not yet in phase with the returning moist layer.

3. A lid-formation phase (lasting about 80 h), in which the low-level moist layer moves rapidly northward in response to the formation of a lee-side trough over the western Plains and eastern Mexico, and phases together with the elevated mixed layer (EML). Maximum lid coverage occurs in this phase.
4. The ending phase (about 24-36 h long), in which a surface frontal system moves through the region and cuts off the EML source. This is followed by a new high-pressure incursion. In late spring, the front often stalls or dissipates, leaving the moist layer intact over the region, and signals the beginning of the second type of lid cycle.

G). Cloud forecasting skill

In an evaluation of the skill with which the Penn State/NCAR mesoscale model predicts (diagnoses) cloud fraction, the calculation of error statistics have been completed for ten 72-h forecasts. The verification fields of cloud fraction were based on the 3DNEPH analyses obtained from the USAF ETAC. Interpretation of these cloud-prediction skill statistics have provided valuable insight about how well the model can generate mesoscale boundaries resulting from differential solar forcing at cloud edges.

3. Publications

The following publications have resulted from, and formally acknowledge the support of, Grant AFOSR-88-0050.

### Journal papers

- Graziano, T.M. and T. N. Carlson, 1987: A statistical valuation of lid strength on severe thunderstorms. *Wea. and Forecasting*, **2**, 129-139.
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