Technical Progress Report

Use of Cloud Observations and Mesoscale Meteorology Models to
Evaluate and Improve Cloud Parameterizations

1 October 1993 - 30 December 1994

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1. Summary of Project Objectives

The main goal of this research effort is to improve methods for calculating cloud cover within climate models. Until now, cloud cover and heights have been diagnosed from the U. S. Air Force RTNEPH and 3DNEPH archive, and recently, CART measurements are available for analysis. Improved cloud cover formulations have been compared with existing climate model algorithms. Our earlier conclusions were that relative humidity and convective potential were the strongest factors influencing cloud cover on regional scales. Therefore, we are refining and validating an innovative Single Column Model (SCM) cumulus parameterization for calculating heating and moistening tendencies, and precipitation rates attributable to subgrid-scale convection not resolved by climate models. This SCM will be tested and evaluated using tropical convective measurements (GATE) and we will also be applied to the incoming measurements from the Oklahoma ARM site. Further development and testing of this SCM will improve our ability to predict convective effects and cloud cover in climate models. We will quantify the influence of convection on cloud cover using convective measures derived from this SCM.

The output of this research will be a family of validated algorithms for assessing cloud cover under a variety of stable, unstable, continental or oceanic conditions, and an improved cumulus parameterization scheme.

2. Project Progress: 1 Oct. 1993 - 30 Dec. 1994

During the third year of this research program, we have extrapolated the findings from our investigation of the Air Force 3DNEPH and RTNEPH (summarized in Walcek, 1994) to the incoming CART measurements from the Oklahoma site. Among our continuing investigations:

- Implementing an improved cloud cover algorithm in a mesoscale meteorology model and performing various sensitivity studies;
- Additional investigations of the influence of resolvable-scale upward motions on cloud cover;
- Evaluation of cloud cover algorithms using the Oklahoma CART measurements;
- Preliminary testing of a convective parameterization at the CART site;
- Testing the horizontal resolution dependence of our convective parameterization.

Each of these areas will be discussed in more detail here.

Mesoscale meteorology model studies - We have performed a series of multi-day simulations of atmospheric processes using an updated version of the NCAR MM4 mesoscale meteorology model. We have incorporated the improved cloud cover algorithms derived from earlier years of this study, now published in Walcek (1994). These cloud cover algorithms were found to significantly *increase* the cloud cover used for calculating terms of the surface energy and water budgets. This increased cloud cover had the effect of significantly decreasing calculated afternoon temperatures and evaporation rates, while increasing night-time temperatures. A more interesting factor was our finding that the method for vertically aggregating cloud cover was a critical factor for the numerical treatment for clouds in climate models. The base version of the MM4 uses cloud cover from three generic layers (low, middle, and high clouds), and the optical depth and transmittance properties are assigned from a look-up table for each of these broad cloud categories. When aggregating, it is assumed that these cloud layers randomly overlap.

Using the Air Force cloud data, we were able to accurately vertically aggregate cloud observations, and thus provide reliable estimates of cloud cover at *any* model or atmospheric layer. For our mesoscale simulations, we used a 15-level version of the MM4, and could thus explicitly estimate cloud cover at all 15 model levels. However, this additional vertically-resolved cloud cover information could not necessarily be used with the existing radiative algorithms since the existing algorithms were "tuned" to the original crude 3-cloud-layer treatment. We therefore investigated several alternate overlap algorithms for aggregating cloud cover within this meteorology model. In one study, we simply used the maximum relative humidity and cloud cover in the original crude three layers to calculate cloud cover using our improved algorithms, then provided this result to the subsequent radiation algorithm. In another study, we explicitly calculated cloud cover at each MM4 layer, and used cloud properties interpolated from the original look-up table to specify their radiative effects. Two sub-studies of this method were then performed: assuming maximum, random, or minimum overlapping between the 15 cloud levels. All results showed different effects, and we are investigating the validity of any of these approaches based on

comparisons with observations. Larger-scale dynamical features were not significantly affected during these short-term forecasts, but surface-level afternoon temperatures and moisture contents were strongly affected by the method by which clouds were assumed to overlap. These minor surface-layer uncertainties could become significantly more important within longer-term climate simulation, since the seasonal and longer-term climate is strongly influenced by surface energy budgets.

Cloud cover and vertical velocity - We have continued our analysis of cloud cover and its relationship with related meteorological parameters using the U. S. Air Force cloud cover archive. Our first pass through our aggregated cloud cover and related meteorological measurements identified *relative humidity*, *vertical velocity*, and the potential for *convective activity* as three important factors influencing fractional cloud coverage. Our published results (Walcek 1994) fully studied the relationship between cloud cover and relative humidity alone, and we discovered an exponentially-decreasing relationship between cloud coverage and depression of relative humidity below 100%. After further refining our previous analysis into increments of vertical velocity, we find an approximately linear relationship between resolvable-scale vertical velocity and cloud coverage. Thus, the functional relationship between cloud cover and both relative humidity and vertical velocity probably looks something like: $f = A \exp[-(1-Rh)/B] + Cw$, where A, B, and C are empirical constants, and Rh and w are the relative humidity and vertical velocity for a particular atmospheric layer. We are now in the process of estimating from observations the appropriate height and resolution-dependent values for the empirical coefficients for this fitting algorithm.

Use of CART observations to evaluation of cloud cover algorithms - We have used temperature and humidity soundings and radiation measurements from the ARM CART site in northern Oklahoma to evaluate our improved cloud cover algorithms that were derived from Air Force cloud observations. Our earlier analysis of cloud cover showed that relatively dry atmospheres contain small cloud amounts. We have found numerous periods during 1993 at the CART site in northern Oklahoma where maximum relative humidities within any layer of the atmosphere are well below 60-80%, which is the range of threshold relative humidities below which no clouds exist according

to most climate models. During these dry periods, shortwave radiation measurements show that clouds are clearly reducing shortwave irradiance measured by a rotating shadowband radiometer. These ARM measurements support our earlier findings that most current climate models probably underestimate cloud coverage when relative humidities fall below the "threshold humidities" employed by most climate models.

Convective parameterization testing at the CART site - CART observations gathered during the June 1993 Intensive Observation Period (IOP) have been aggregated into the format necessary for testing of our convective parameterization. The parameterization has been operating in a "stand-alone" mode using the GATE convective measurements, and numerous adjustable model parameters have been "tuned" to those measurements. Now that data from a continental location are available, we can assess the generality of the model optimizations that we have performed at the tropical location. Our first run of the convective parameterization simulated considerably greater evaporation of cloudwater and precipitation than at the GATE location, primarily due to considerably drier column-averaged relative humidities at the continental CART site. Because of the greater evaporation, penetration of the boundary-layer convective cells into the upper troposphere was calculated to be more limited than at the tropical locations. In addition, the model calculated considerably greater evaporation of precipitation, particularly in the lower troposphere. Unlike tropical locations, where convective tendencies largely warm the entire troposphere column, at the CART site, our convective model calculates considerable cooling in the lower troposphere, primarily due to the evaporation of precipitation as it falls through the lower troposphere. While we are still processing the CART measurements to assess the accuracy of our model calculations, the results seem physically reasonable, and show stark contrasts between the behavior of convection in the tropics and midlatitude continental locations.

Horizontal resolution dependence of convective parameterizations - Any parameterization of subgrid-scale convective effects will contain an implicit horizontal resolution dependence, since the level of conditional instability in the atmosphere is inherently resolution dependent. If a particular convective parameterization is used in the identical atmospheric model using two different

horizontal (or vertical) resolutions, then the calculated heating rates or convective precipitation rates will be different. We are developing and testing an algorithm to empirically adjust the appropriate triggering functions employed by our convective parameterization so that they are resolution dependent. When implemented in models with differing horizontal resolutions, the parameterization will automatically produce approximately the same convective precipitation rate and convective heating and moistening tendencies. The appropriate model parameters to adjust, and the optimal empirical fitting methods are still under investigation, but our preliminary results suggest that the perturbation temperatures used to define the presence of convection should increase with increasing model grid size.

3. Journal Articles, Conference Presentations, Abstracts, and Seminars Resulting from this Research Effort:

Walcek, C. J., 1994: Cloud cover and its relationship with relative humidity during a springtime midlatitude cyclone. *Monthly Weather Review*, **122**, 1021-1035.

Walcek, C. J., Q. Hu and B. Iacovazzi, 1994: Cumulus clouds parameterized as detraining plumes. Presentation and Extended Abstracts of the *10th Conference on Numerical Weather Prediction*, Portland, OR, 18-22 July 1994, p77-78. American Meteorological Society, Boston, MA.

Walcek, C. J., 1994: Cloud cover and its relationship to other meteorological factors during a springtime midlatitude cyclone. *Cloud Impacts on DoD Operations and Systems (CIDOS) 1993 Conference*, Fort Belvoir, VA 16-19 November 1993. Presentation and conference proceedings. PL-TR-94-2188, Environmental Research Papers, No. 1152. Phillips Laboratory, Hanscomb Air Force Base, MA 01731-3010

Walcek, C. J. and Q. Hu 1994: Use of CART Measurements to evaluate cloud cover and convective parameterizations. *Annual ARM Science Team Meeting*, Charleston, SC, 28 Feb.-3 Mar. 1994. Poster presentation.

Invited Seminar, Department of Atmospheric Sciences, Colorado State University, Fort Collins, CO., 28 April 1994:

- "Convection and atmospheric chemistry"

Invited Seminar, Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT., 3 May 1994:

- "Convection and free will: What really controls cumulus activity?"

Two invited presentations at the *Aspen Global Change Institute*, Aspen, CO. 10 - 23 July 1994:

- "Clouds and relative humidity in climate models: What really regulates cloud cover"
- "A new conceptual model of convection"