nonuniform data distribution of the mass field. That is, anomalous circulations can develop at the edge of a data-dense region.

Finally, Stauffer discussed the use of the adjoint equations of a numerical model for internal parameter estimation. In an example using a 1-D shallow-fluid model, optimal control theory is applied to the determination of an "optimal" set of weighting coefficients used in the nudging approach, which relaxes the model state toward the observed state by adding to one or more of the prognostic equations artificial tendency terms which are proportional to the difference between the two states. The "proportionality constants" are usually based on scaling arguments, and modified by weighting functions which reflect the time and space separation of the model solution from the data, as well as data quality and representativeness. He demonstrated that the magnitude and distribution of these coefficients can be determined using the shallow-fluid model and its adjoint such that the model error during the assimilation period is optimally reduced subject to some constraints.

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## 3.4 Measurement and modeling of moist processes

***William Cotton: Explicit Simulation of Mesoscale Convective Systems***

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| *David Starr:* | *Measurement of water vapor and other constituents of the hydrologic cycle* |
| *Kenneth Mitchell:* | *NMC plans for initializing soil hydrology for mesoscale models* |
| *Rex Fleming:* | *Water vapor measurement concepts for GCIP* |
| *Steve Koch:* | *Mesoscale moisture analysis using satellite data* |
| *Steve Smith:* | *Mesoscale wind analysis using satellite data* |
| *Jocelyn Mailhot:* | *Recent activities in modeling of moist processes in mesoscale systems* |
| *Don Perkey:* | *Effects of temporal resolution on heat and moisture budgets for cumulus parameterization* |
| *Greg Tripoli:* | *Modeling scale interaction processes* |

The keynote talk given by William Cotton summarized five years of his work simulating observed mesoscale convective systems with the RAMS (Regional Atmospheric Modeling System) model. *Excellent results are obtained when simulating squall line or other convective systems that are strongly forced by fronts or other lifting mechanisms.* Although the overall existence of convection was reproduced, the Doppler-observed mesoscale circulations could not be reproduced, even when exploiting alternate analysis software and using grids with sufficient resolution ($\Delta x$ = 2.2 km) to explicitly resolve cloud-scale motions. *Less highly forced systems are difficult to model* (e.g., the 3-4 June and 23-24 June 1985 PRE-STORM MCCs (Fig. 11)). It was surmised that in such weakly sheared, nearly barotropic environments, accurate predictions of MCSs may require: (a) details about the surface forcing (e.g., soil moisture and vegetation, outflow boundaries and gravity waves triggered by earlier convection); (b) either improved cumulus parameterization schemes or explicit simulation of deep convection over domains as large as $(1000\text{km})^2$ for a substantial part of the diurnal cycle; and (c) increased upper air sampling by rawinsondes and wind profilers to capture weak short-waves and jet streaks.

The discussion turned next to the measurement of water vapor. David Starr showed impressive accuracy measuring water vapor with both the airborne DIAL (Differential Aborption Lidar) system and the ground-based Raman lidar. The latter system can attain temporal sampling of 2 min and vertical resolution of 75 m to altitudes as high as 7 km at nightime, though with poorer resolution in the daytime. By contrast, the High resolution Interferometer Sounder (HIS) instrument resolves structure comparatively less well than the Raman lidar when operated from the ground, though its performance improves greatly when operated in a downlooking mode from the NASA ER2 platform, which flies at 20 km altitude. The rawinsonde performs well up to -40C and even reveals useful structure up to the -50C level. It is important to appreciate that *cloudy conditions compromise the measurements of all the remote sensing systems with the exception of satellite microwave data.* Although the rawinsonde used in some countries is seriously affected by moistening of the temperature sensor, the VIZ and Vaisala sondes used here and in Europe possess thermistor wetting problems that tend to be of limited duration and are quite recognizable. Starr also showed intercomparisons of SSMI and TOVS satellite moisture retrievals with ECMWF and NMC analyses.

Kenneth Mitchell presented NMC's plans for initializing land water hydrology in mesoscale models. By the end of the decade, NMC plans to run a national mesoscale model at 4 km, but surface observations of moisture and vegetation on that scale are unlikely. As a consequence, NMC plans to develop the AGROMET model to run daily in order to predict surface moisture and maintain a surface hydrology. The AGROMET model will run separately from the atmospheric prediction models. NMC expects to have an 80 km/38-level model operational by summer 1993 and a 40 km model operational by summer 1994, in time for the planned CME.

Rex Fleming spoke next on plans for enhanced observations for GCIP. He described plans for putting moisture sensors on commercial aircraft in a program called CASH, which would complement the ACARS program. Fleming emphasized the need to define water and energy processes and enhance low-level moisture and wind observations, particularly in a ``picket fence'' along the southwestern coast of the Gulf of Mexico so as to provide adequate sampling of the inflow conditions for GCIP.

Steve Koch and Steve Smith spoke on the subject of using satellite data to provide mesoscale moisture and wind analyses. Koch demonstrated that cloud cover can make an enormous difference in mesoscale flow and temperature structure across fronts, causing temperature variations on the order of 5C. Use of a satellite cloud classification scheme to provide three-dimensional relative humidity fields in cloudy conditions (thus, a useful complement to the ground and satellite-based sensors described by Starr) was shown to significantly improve mesoscale model forecasts of thermal fields and frontal circulations. Smith discussed the current satellite ability to obtain representative winds from cloud motions over land. Stereo methods of calculation yield height accuracies of 0.5 km compared to cloud shadow techniques which have 1 km accuracy. The usefulness of these winds depends on the availability and representativeness of the cloud motions (i.e., not only the existence of clouds, but on their character).

Jocelyn Mailhot reported on modeling activities at the Canadian Atmospheric Environment Service (AES) using a hydrostatic, variable-resolution grid model. He presented the results of two case studies involving a squall line and a cyclone from CASP II. The results showed the model did well distinguishing heavy from stratiform precipitation and finding icing zones. Mailhot concluded that more work was needed to improve model validation.

Don Perkey spoke next on the spatial resolution effects of moisture budgets. He showed that background budgets were essential to getting the local budgets correct, since they act as a check on the integral properties of the local system. The assumption that liquid and solid water storage does not vary over the averaging period as is commonly made in larger-scale moisture budget calculations is highly questionable at the mesoscale. This factor must be considered when attempting to relate the net source of water vapor to the atmosphere to the time/space averaged vapor flux divergence. Furthermore, residuals computed from the gridscale transport processes (derived from rawinsonde data) require knowledge of the radiative heating profile to define the apparent heat and moisture sources from sub-gridscale processes. Since the observed precipitation by rain gauges and WSR-88D radars must be equal to the fallout of water generated in the column and transported into it (or stored from an earlier time), any discrepancies between the observed and diagnosed rainfall is a measure of the importance of water storage and transport processes (assuming that the integrated effects of ice microphysical processes and the net convergence of eddy fluxes is negligible). Storage effects can become substantial when stored water falls out as rain from dissipating convection in an MCS. Significant heat and moisture transports occur at the mesoscale by convection, in particular the transport from the convective to the stratiform region is important during the early and mature phases of such systems.

Greg Tripoli reported on some of his modeling studies showing scale-interactive processes both within a convective weather system and between the system and larger scales. Tripoli then presented what he found to be the processes causing spiral rain bands in a tropical cyclone: these include the complex scale interactions between the cyclone circulation, deep gravity-inertia waves in the cirrus outflow, and density currents driven largely by ice microphysical processes. He then showed the processes modeled to form gravity-inertia waves within a strongly baroclinic weather system. The processes were depicted in part through three-dimensional animation using VIS5D.

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## 3.5 Parameterization of sub-grid scale convection

***William Frank: Overview of the cumulus parameterization problem***

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| *John Molinari:* | *Interactions between explicit and implicit processes in mesoscale models* |
| *Jack Kain:* | *Effects of model grid size on the cumulus parameterization problem* |
| *Mitch Moncrieff:* | *Parameterizing convective effects on momentum fields in mesoscale models* |
| *Mohan Karyampudi:* | *Differences between slantwise and vertical cumulus parameterization* |
| *Georg Grell:* | *Experiments with different closure hypotheses* |
| *William Frank:* | *Coupling cumulus parameterizations to boundary layer, stable cloud, and radiation schemes* |

Rather than give the details of each of the talks presented in this session, a summary of the issues will be given here. The discussion first briefly overviews the cumulus parameterization problem. More complete reviews of this topic already appear in the literature (e.g., Frank and Cohen 1987; Molinari and Dudek 1992). Current approaches are next discussed. Third, the strengths and weaknesses of existing parameterizations are presented. Recommendations appear in the workshop summaries.

***1) Overview of the parameterization problem***

Cumulus convection and mesoscale convective systems (MCSs) have major effects upon the mass, moisture and momentum fields. However, in most numerical models some or all of these phenomena are subgrid-scale. Hence, their effects on the resolvable-scale circulation must be parameterized. It is necessary to parameterize the combined effects of cumulus convection and MCSs in models with grid sizes $\Delta x > 100$ km, whereas in mesoscale models, which typically use grids of 10-50 km, the mesoscale circulations can be