measurements that would be adequate to verify at least some of the major assumptions of cumulus parameterizations directly from observations.

On the subject of verification, one problem with direct comparisons between the performances of different schemes in models is that each parameterization tends to be a complex package with a large number of components and assumptions. Further, the method of interaction between the scheme and the host model may cause different schemes to work better in different models strictly for numerical or procedural reasons. When testing cumulus parameterization assumptions using numerical simulations, it is highly desirable to use a simple, common parameterization system that allows isolation and testing of one assumption at a time, as demonstrated in Grell et. al. (1991).

### 3.6 Coupled land surface/hydrologic/atmospheric models

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***Roger Pielke***

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| *Lou Steyaert:* | *Prototype land cover characteristics data base for the conterminous United States* |
| *Ray Arritt:* | *Surface evapotranspiration effects on cumulus convection and implications for mesoscale models* |
| *Mercedes Lahtakia:* | *The use of a complex treatment of surface hydrology and thermodynamics within a mesoscale model and some related issues* |
| *Chris Smith:* | *Initialization of soil-water content for regional-scale atmospheric prediction models* |
| *Conrad Ziegler* | *Impact of surface properties on dryline and MCS evolution* |
| *Su Tzai Soong* | *A numerical simulation of heavy precipitation over the complex topography of California by* |
| *Roni Avissar:* | *Representing mesoscale fluxes induced by landscape discontinuities in global climate models* |
| *Peter Wetzel:* | *Emphasizing the role of subgrid-scale heterogeneity in surface-air interaction* |
| *Piers Sellers:* | *Problems with modeling and measuring biosphere-atmosphere exchanges of energy, water, and carbon on large scales* |

Each presenter was asked to submit an abstract summarizing their talks. These are reproduced in the following material with minor editing. Lou Steyaert discussed a prototype land cover characteristics data base developed by the US Geological Survey. The US Geological Survey EROS Data Center, with support from the University of Nebraska-Lincoln, has developed a prototype land cover characteristics data base for the conterminous United States. Biweekly composites of 1 km AVHRR data for 1990 have been analyzed to define seasonally distinct land cover regions. The essential input to the classification process was vegetation greenness profiles as depicted by seasonal variations in the Normalized Difference Vegetation Index (NDVI) derived from daily AVHRR data. The land cover characteristics data base is intended to meet the land data requirements of multiple-user communities such as those involved with land-atmosphere interactions modeling, land and water resource management, and environmental assessment. The data base includes the classification of 157 seasonally distinct land cover regions, biweekly AVHRR time-series data, various ancillary images (e.g., elevation, ecoregions, major land resource areas, and political boundaries), attribute data files providing summary statistics for each land cover class, and derivative data files (e.g., land cover classification systems, based on reclassification of the 157 classes, such as required by the Biosphere-Atmosphere-Transfer Scheme (BATS) and Simple Biosphere (SiB) models; greenness statistics on vegetation seasonality, etc.). Research is underway within the USGS to validate and test the land cover characteristics data base, including its use within global climate and mesoscale models, ecosystem dynamics models, soil biogeochemical cycles models, and ecotone models. These efforts complement ongoing research to improve AVHRR processing with enhanced geometric, radiometric, and atmospheric corrections. The integration of remote sensing and geographic information systems technologies with environmental simulation models is also under investigation. *After final review in early 1993, the prototype land cover characteristics data base will be placed on CD-ROM for distribution* and will complement biweekly AVHRR-image composite data for 1990, 1991, and 1992 now on CD-ROM.

Ray Arritt discussed the importance of inhomogeneous surface evapotranspiration on cumulus convection and its implications for mesoscale models. Land surface moisture is highly variable across a broad range of spatial scales from the continental scale to scales of centimeters or less. These surface moisture irregularities have several implications for the development of mesoscale convection and its representation in numerical models, including (1) local enhancement or suppression of surface sensible and latent heat fluxes; (2) generation of coherent mesoscale circulations that can trigger or suppress convection; and (3) alteration of the nature and statistics of turbulence in the convective boundary layer. Local modification of the surface sensible and latent heat fluxes can affect the magnitude of the conditional instability and can also determine whether the instability is released. The present consensus is that if the individual surface irregularities are of sufficiently small extent, their effects can be included by deriving a weighted average of the fluxes for the different surfaces. Finding average fluxes when the irregularities are larger is much more difficult. *The CME needs to investigate more general approaches for parameterizing surface sensible and latent heat fluxes that are appropriate for surfaces with both large and small moisture irregularities.* Horizontal variability of the surface sensible heat flux produces differential heating of the overlying atmosphere, which in some cases can drive coherent mesoscale circulations (Segal and Arritt 1992). The vertical velocities associated with these circulations can trigger or suppress the release of conditional instability. *The CME presents an opportunity to expand upon our present inadequate knowledge of these circulations and to develop approaches for parameterizing their effects in mesoscale and larger-scale models.* To the extent that convective clouds are "rooted" in the boundary layer, the clouds will be influenced by the boundary-layer turbulence statistics and the characteristics of mixed-layer thermals. It seems reasonable to hypothesize that turbulence statistics may be affected by heterogeneity of the underlying surface, but observational data are inadequate to quantify this effect and numerical models usually disregard any such influence. Some cumulus parameterizations are sensitive to the initial updraft radius at cloud base (e.g., Kain and Fritsch 1990). Therefore, *the CME needs to investigate the linkage between boundary-layer thermals and the characteristics of the underlying surface.* For example, the possibility that the characteristic dimensions of the thermals reflect the dimensions of the surface moisture irregularities needs study. Large-eddy simulations can provide some insight into this relationship, but the LES results need to be corroborated by observations.

Mercedes Lakhtakia described the inclusion and applications of a surface-physics/soil-hydrology parameterization scheme into a modified version of a 1-D, high-resolution, moist PBL model (Zhang and Anthes 1982) within the Penn State/NCAR mesoscale model. The surface processes are simulated by a modified version of BATS, which provides a biophysically based representation of the surface forcing. The complexity of schemes like BATS not only increases the computational cost/time, but it also adds new dimensions to the initialization procedure. For instance, BATS requires the specification of the type of vegetation/surface cover and of soil texture, as well as the initialization of the soil-water-content profile for each grid point within the domain.

Chris Smith reported on the initialization of soil-water content in the Penn State/NCAR mesoscale model. *Soil-water content is the single most important land-surface variable in atmospheric prediction models.* Sophisticated surface physics-soil hydrology parameterization schemes are beginning to be used in mesoscale weather prediction models; however, soil-water content is not measured over large areas on a regular basis so as to provide suitable initial conditions for those models. Therefore, the initialization of the soil-water-content profile has to depend on a knowledge of the hydrological balance of the soil in the area represented by each mesoscale model grid point. In turn, this information must be obtained from a knowledge of the precipitation, evaporation, and substrate recharge from the water table. A systematic means for providing initial values of the soil-water-content profile for the PSU model is composed of three phases: (1) develop an "off line", 1D hydrological model that is driven by conventional meteorological, soil, and vegetation data; (2) develop the data base to drive the hydrological model in a form that is compatible with the BATS surface physics-soil hydrology parameterization scheme utilized in the mesoscale model; and (3) generate an automated update of the soil-water-content profile at each of the mesoscale model grid points.

Conrad Ziegler discussed the impact of surface properties on dryline and MCS evolution. The dryline has long been acknowledged as a favored zone for thunderstorms and MCSs to form. The dryline-prone region (US High Plains) comprises roughly the western quarter of the Mississippi River Basin, which is a focus of the proposed GCIP experiment. A principle result of Ziegler's mesoscale modeling study is that the horizontal variability of soil moisture controls sensible and latent heat fluxes through the atmospheric surface layer, which in turn governs whether a dryline forms and how it evolves. Over periods of many weeks, successive dryline passages and convective rainfalls might selectively enhance soil moisture and surface heat flux gradients, which in turn would enhance the dryline. *There is a critical need for time-series measurements of soil moisture profiles to complement other mesoscale data in the dryline-prone region.*

Zu-Tzai Soong simulated a flood in the Sacramento Valley using a mesoscale model with a 20 km resolution and containing ice microphysics, radiation, and soil / surface / boundary layer processes (the Oregon State University module). This module was tested against HAPEX (Hydrological/Atmospheric Pilot Experiment) observations and, though comparatively simple, it is believed adequate, and is both easy to implement and run. Of course, a more complete model like SiB or BATS is more desirable for future model implementations. The simulated total precipitation of the mesoscale model over the northern Sierra was close to the observed maximum. One direction of future coupled atmospheric-hydrologic models is to study the moisture budget over a large river basin, such as the Mississippi and the Colorado River basin. The model should also be coupled with a river flow model to study the river flow hydrology.

Roni Avissar reported on the parameterization of land-atmosphere interactions in large-scale atmospheric models. Land heterogeneities affect considerably the redistribution of energy absorbed at the surface of the earth and atmospheric dynamical processes at various scales. Among the various land-surface parameters that characterize a landscape, Collins and Avissar (1992) found that stomatal conductance, leaf area index, and surface roughness have a predominant impact on the turbulent heat fluxes between vegetated surfaces and the atmospheric surface layer. For bare land, they found that the most important parameters are soil-surface wetness and surface roughness. The microscale spatial variability of these parameters (as observed in the field) affect significantly the integrated surface energy fluxes at the patch scale, emphasizing the need to develop statistical-dynamical parameterizations for atmospheric models. Heat and mass fluxes associated with mesoscale circulations generated by landscape discontinuities are typically stronger than turbulent fluxes. As a result, they contribute significantly to subgrid-scale fluxes in large-scale atmospheric models (e.g., GCMs), yet are omitted in these models. Avissar and Chen (1992) suggested a set of prognostic equations for large-scale atmospheric models, which accounts for both turbulent and mesoscale subgrid-scale fluxes. They also developed prognostic equations for the mesoscale fluxes, which present a closure problem. Thus, they emphasized the need to develop a parameterization for these fluxes and identified the mesoscale kinetic energy (MKE) as a possible key variable for such a parameterization. Chen and Avissar (1992) used a state-of-the-art mesoscale model to investigate the relationships between mesoscale fluxes, turbulent fluxes, and the spatial distribution of land-surface wetness. These relationships are characterized by analytical functions, which provide a crude primary parameterization of mesoscale fluxes for large-scale models.

Pete Wetzel made three major points with regard to the role of sub-grid heterogeneity in the modeling of land-atmosphere interactions.

- Evapotranspiration modeling presents the most serious challenge because of its complexity.

Observations have shown significant heterogeneity of soil moisture even down to scales of the individual field. Modeling results have shown that failure to account for this heterogeneity leads to erroneous model estimates of regional evapotranspiration. The heterogeneity of vegetation, topography, and, on larger scales, precipitation only add to the degree of heterogeneity which affect regional evapotranspiration. Further, within any mesoscale or GCM model grid cell it is likely that both water-stressed and unstressed (potential) evapotranspiration will be occuring simultaneously in different portions of the cell, both over bare soil and vegetation covered areas. Thus there are four fundamentally different and unrelated processes which affect evapotranspiration. Again, modeling results show that lumping these processes together can lead to unrealistic regional evapotranspiration estimates.

- Results from Wetzel's 1-D PLACE model (Parameterization for Land-Atmosphere-Cloud Exchange), demonstrate that explicit modeling of the fully interactive relationship between the heterogeneous surface, boundary layer and cloud can lead to more accurate predictions of cloud onset and amount over land surfaces.

Surface variability plays a fundamental role in defining the statistical thermodynamic properties of cloud updrafts. Accounting for this heterogeneity markedly improves the predictability of cloud onset time and amount. Within a 48 hour period, the relationship between soil moisture and resultant cloud amount can be completely reversed--that is, where wet soil produces much more afternoon cloud on the first day, the dry soil case is found to produce much more cloudiness 48 hours later.

- Additional PLACE model results indicate that, depending on its distribution and concentration, a given amount of sub-grid precipitation falling on a model grid cell can be primarily re-evaporated (if distributed evenly) will primarily soak into the soil (if distributed with a moderate degree of sub-grid variability), or will primarily run off (when the rain falls as concentrated, heavy downpours).

This fairly intuitive result has especially serious ramifications for modeling of river discharge and of the climatological water balance of a region. It provides a strong motivation for the development of more sophisticated deep cumulus parameterizations which, in turn (see point 2) should account for the surface heterogeneity.

Piers Sellers reported on results from FIFE and the use of models and satellite data to calculate heat, moisture, and carbon fluxes on large scales. Specification of the land surface-atmosphere fluxes of energy, water, and carbon is important for a wide range of atmospheric and Earth System modeling activities. It has been shown that the canopy conductance (inverse of resistance) is a critical term in determining the partitioning of available energy into sensible and latent heat (evapotranspiration) and also in regulating the flux of carbon dioxide into the vegetation for photosynthesis. The Penman-Monteith equation defines the latent heat flux as controlled by the available energy, the vapor pressure deficit, and the surface conductance. When the upper few millimeters of the soil profile is dry, the vegetation contribution to the latent heat flux dominates. Sellers and colleagues have developed a theoretical framework that relates the derivative of the unstressed canopy conductance with respect to the incident photosynthetically active radiation (PAR) to the fraction of PAR absorbed by the green vegetation canopy, FPAR. FPAR has been shown to be a near-linear function of the simple ratio vegetation index (SR), which is the ratio of the near- infrared to red reflectances (or radiances) as observed by a suitably configured remote sensing device, e.g., Landsat or Advanced Very High Resolution Radiometer (AVHRR).