# Integrated Regional Climate Study with a Focus on the Land-Use Land-Cover Change and Associate Changes in Hydrological Cycles in the Southeastern United States

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Colorado State University

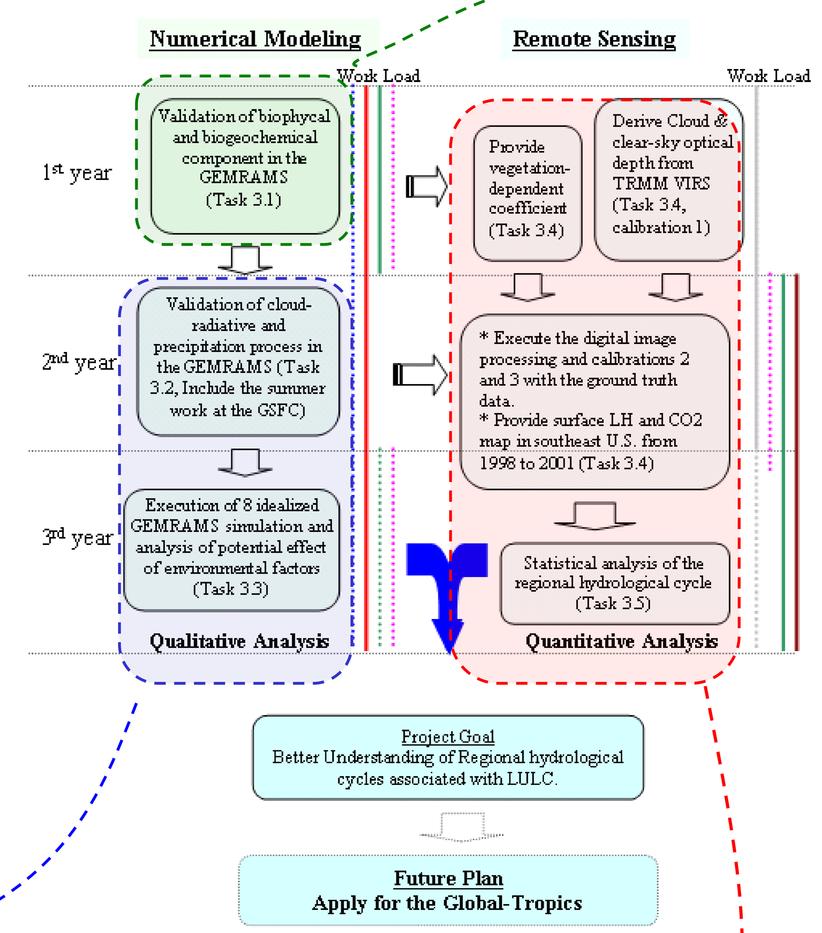
Knowledge to Go Places

## Overall Project Plan

### Objective

The main objective of this research is to examine the individual, as well as the combined effect, of variability in surface latent heat flux (evaporation and transpiration) and the regional hydrological cycle due to changes in LULC, cloud-precipitation process, and terrestrial ecosystem processes, under drought and non-drought conditions, using detailed process models and remote-sensed satellite data and products.

As a collaborative, interdisciplinary project involving universities and NASA researchers, first, we plan to customize and utilize a sophisticated atmosphere-ecological modeling system - GEMRAMS, composed of the Regional Atmospheric Modeling System (RAMS) and the General Energy and Mass Transfer Model (GEMTM) to study the sensitivity of the latent heat flux and regional hydrological cycle to variability in LULC, shortwave cloud radiative forcing, soil moisture, and terrestrial ecosystem processes. Our study area is focused over the southeastern United States. For the regional climate simulations, a number of remotely-sensed data will be utilized, including land-surface boundary conditions from MODIS/AVHRR and validation of simulated surface radiation budget from CERES. Second, since the direct effect of LULC change is on surface latent heat flux, we will develop and implement a TRMM/Aqua-derived surface latent heat flux (and surface CO2 flux) mapping approach. The proposed algorithm, will account for canopy to landscape-level processes including radiation interactions via sunlit/shaded leaf and canopy scaling, more realistic stomatal and ecological responses based on dynamical simulations with GEMRAMS and multi TRMM/Aqua products: soil moisture, cloudiness, and cloud-free atmospheric optical depth. In this study, we will implement and identify the advantage of such a derived surface latent heat (and surface CO2) flux map for an improved characterization of the regional land-atmosphere interactions and water cycles associated with LULC. After implementing the surface latent heat flux algorithm in the southeastern U.S., this approach and product can be readily expanded for a global application.



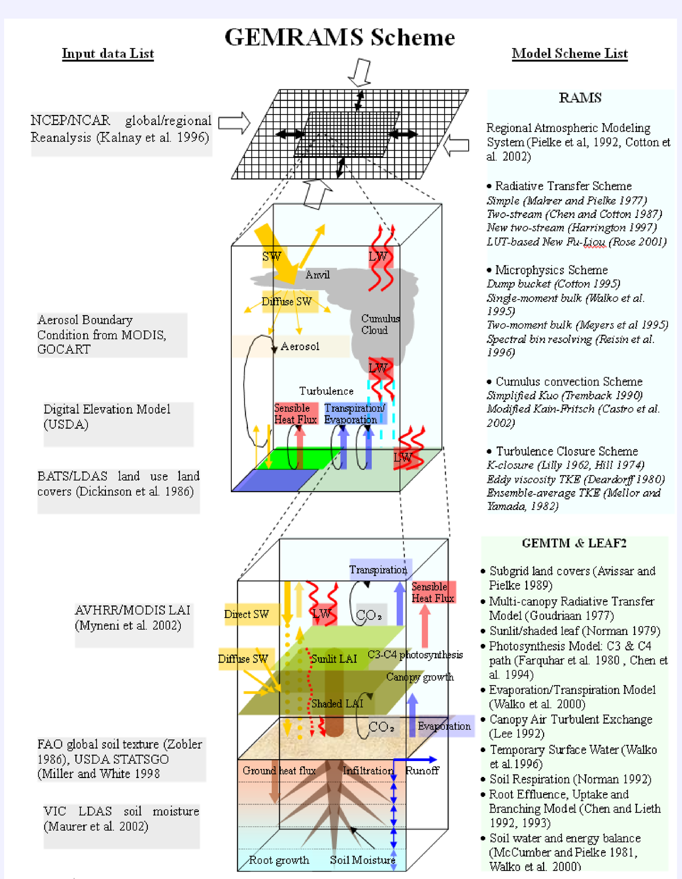

## Numerical Simulation

### Task 2 validation of cloud-precipitation process in GEMRAMS

We will perform several month- to season-long control simulations in both a wet and dry year to validate/calibrate i) precipitation and ensuing diabatic latent heating, and ii) cloud Re and associated shortwave CRF. Giorgi and Mearns (1999) suggest that the domain choice may simply rely on a trial-and-error approach and on an assessment of the sensitivity of the lateral boundary condition to the model solution. This customization process should be carried out by using analyses of observations to drive the model and comparing the results with actual station or satellite observations (Giorgi and Mearns 1999). Therefore, control simulations are conducted with the observed lateral and initial atmospheric and surface boundary conditions. During this process, surface fields (e.g., soil moisture and LAI) will be nudged to avoid a coupled two-way interaction that occurs in GEMRAMS. The simulation results will be compared with the gauged precipitation, satellite-derived cloud properties, and CERES-derived net shortwave radiation in the southeastern United States. Since unidentified inhomogeneous distributions of the cloud condensation nuclei (CCN) affect the microphysical process in different regions, the regionally-based calibration/validation in the cloud-radiative and precipitation process is important to avoid the simulated processes from diverging from the observed values in the seasonal model simulations.

### Task 3 GEMRAMS coupled simulations

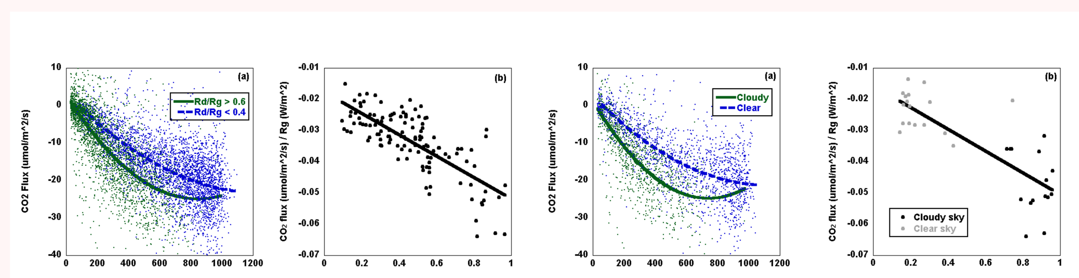
Through modulating or activating/inactivating the environmental factors, we will execute eight experiments to examine the nonlinear feedback that exists in the regional climate system. Environmental factors include LULC changes (current and potential vegetation), soil moisture (drought and non-drought), and DDR (dynamic and fixed) on the canopy. For example, current and potential LULC (from the HYDE database, e.g. Pielke et al. 2002) would simulate the sensitivity of the regional climate due to the historical evolution of land-cover change in the southeastern United States. Dynamic and fixed DDR would examine the influence of variability in surface LH flux and seasonal vegetation growth on the regional climate (as is also seen in observations over the southeastern U.S. in particular). Both the direct forcing effect and feedbacks are explicitly represented through this technique and will assist in diagnosing the LULC- radiation – hydrology – carbon flux coupling (see for e.g. Eastman et al. 2001).




## Remote Sensing and Ground observation

### Task 4. New Satellite algorithm for $CO_2$ and LHF

Unlike other existing methods including the Triangle Method, we will develop an *original remote sensing algorithm for $CO_2$ and LHF*. This TRMM/Aqua-based surface latent heat flux algorithm will consider landscape-level feedback processes, surface radiative feedback including sunlit/shaded leaf and canopy scaling, a more realistic stomatal/transpiration and ecological responses based on dynamical simulations with GEMRAMS, and multi TRMM/Aqua sensors and products. Whereas the existing methods focus on the satellite observations of VI and Ts, our algorithm additionally focuses on the satellite observations of ambient conditions such as cloud cover and soil moisture conditions. Generally, the presence of cloud cover or haze in the remote sensing data are problematic for the Triangle Methods, however, they are one of the parameters to improve the LHS estimate in the proposed new TRMM-based algorithm. Our proposed algorithm is able to derive ET at each TRMM/Aqua-satellite overpass (i.e., instantaneously), in comparison with 8-day composite in the Triangle Methods.



CO2 flux in response to the DDR (Source from Niyogi et al. 2004)

### Task 5. Analysis of Regional Hydrological Cycle

*Evaporation/transpiration* and *Precipitation* will be derived from TRMM/Aqua satellite at each pixel. Selecting specific river basins within our study region, and using the 0.5-degree Total Runoff Integrating Pathways (TRIP) (Oki and Sud 2000), we can estimate the seasonal and annual amount of the water storage within a given basin from (Precipitation) – (Evaporation/transpiration) – (river discharge). Indeed, "precipitation minus evaporation" is able to provide the seasonal and annual moisture convergence, at each pixel. In this study, we will provide a 4-year regional water budget (from 1998 to 2002) to examine hydrological cycles in the southeastern United States principally through satellite products. The derived regional water budget will be examined and compared to that from the off-line VIC LDAS product (Maurer et al. 2002).

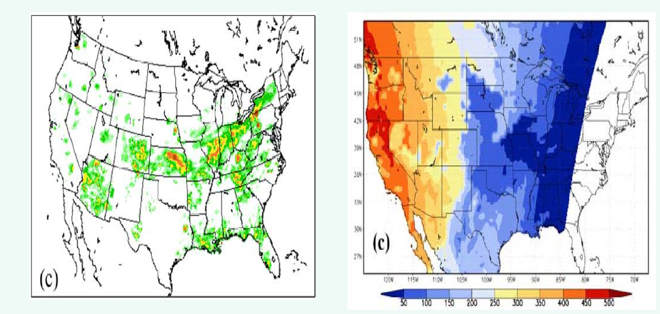
## Task 1. Regional Land Surface Model (LSM) calibration: Application for GEMTM-LEAF2

### Objective

This study first attempts to establish a regional calibration framework using the off-line mode of the GL (GEMTM-LEAF2) [*Chen and Coughenour* 1994, *Walko et al.* 2000, *Beltran et al.* 2003] for the Midwest to Eastern U.S. through an adjustment of tunable parameters in the land surface model to the satellite-derived surface visible/near-infrared reflectances and land-surface radiative temperatures. For this, we utilize i) the MODIS land product (MODLAND), ii) the North American Land Data Assimilation (NLDAS) forcing datasets [Cosgrove et al. 2003], and iii) efficient calibration software, called the Multi-objective Shuffled Complex Evolution Metropolis (MOSCEM) algorithm [*Vrugt et al.* 2003]. Local observations will be used to verify the regional LSM calibration.

### Why Regional Calibration?

Land surface models (**LSMs**) simulate terrestrial water-energy exchange, and biogeophysical, biogeochemical, and biogeographycal process, which are critical for applications in weather forecasting, climate analysis, hazard mitigation, agricultural production, and water resource/quality management [Kabat et al, 2004]. In last two decades, hydrological science communities have developed numerous different types of LSMs for their research applications. A number of these LSM participated in the Project for Intercomparison of Land-Surface Parameterization Schemes (PILPS) [*H.-Sellers et al.*, 2002, EOS]. PILPS found a significant diversity of performances in different LSMs [*H.-Sellers et al.*, 2002, EOS]. This is simply because different LSMs contain a different combination of parameterizations of the soil-plant-turbulent processes, and each parameterization contains many tunable coefficients that usually cannot be measured directly or extensively in time and space. Therefore, we must calibrate LSM not only at the meteorological site, but also for each grid increment against satellite-derived radiance.



### NLDAS forcing

High-quality, fine-resolution atmospheric forcing datasets are critical for a LSM calibration. This study uses the assimilated forcing datasets derived from the multi-institutional NLDAS project [*Mitchell et al.* 2003]. Hourly National Weather Service Doppler radar-based (WSR-88D0 precipitation analyses was used to disaggregate the daily National Center for Environmental Prediction (NCEP) Climate Prediction Center (CPC) gauge-based precipitation [*Cosgrove et al.* 2003]. Surface downwelling solar and thermal radiation are derived from the Geostationary Operational Environmental Satellite (GOES) radiation data processed by *Pinker et al.* [2003]. Surface air temperature, water vapor mixing ratio, u-v-wind, and surface pressure are derived from the NCEP Eta Data Assimilation System (EDAS) output field [*Rogers et al.*, 1996]. Those comprehensive forcing datasets are archived on 0.125-degree grid intervals every one-hour across the conterminous U.S. [source from *Cosgrove et al.* 2003].

### GEMTM-LEAF2

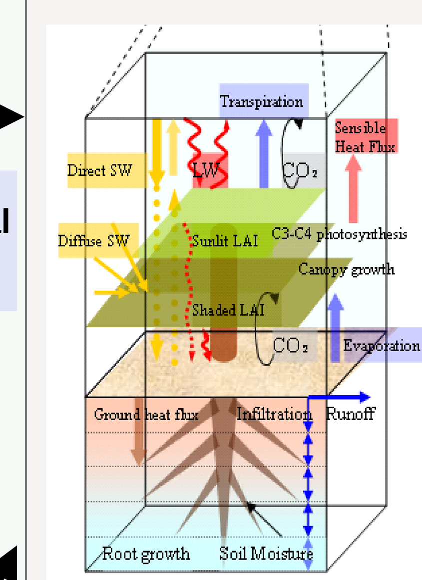
GL (GEMTM-LEAF2) has been coupled in the Regional Atmospheric Modeling System (RAMS) in order to examine complex interactions between plants, surface hydrology, and atmospheric and related regional weather process [*Eastman et al.* 2001, Beltran et al. 2002]. GL has been recently re-coded in a more object-oriented style that is suited for this regional calibration system. LIS is also plugged in NASA Land Information System (LIS).

GL has two components:

*Land Ecosystem-Atmosphere Feedback 2 (LEAF2)* model is a prognostic model of the heat and water fluxes between the soil, snow, plant and canopy air, and includes turbulent and radiative exchange between these components and with the atmosphere on sub-grid surface patches [*Lee* 1992, *Walko et al.* 2000].

*General Energy and Mass Transfer Model (GEMTM)* explicitly accounts for leaf-level processes, canopy microclimate, soil abiotic processes, plant growth (LAI), and biomass production dynamics. The plant canopy is divided into shaded leaf and sunlit leaf sub-layers in a canopy microclimate submodel, and stomatal conductance and photosynthesis of shaded and sunlit leaves are simulated separately. The leaf photosynthesis process distinguishes the C3 and C4 pathway of carbon assimilation. The root model computes effluence, uptake, and branching [*Chen and Coughenour* 1994].

Meteorological Forcing



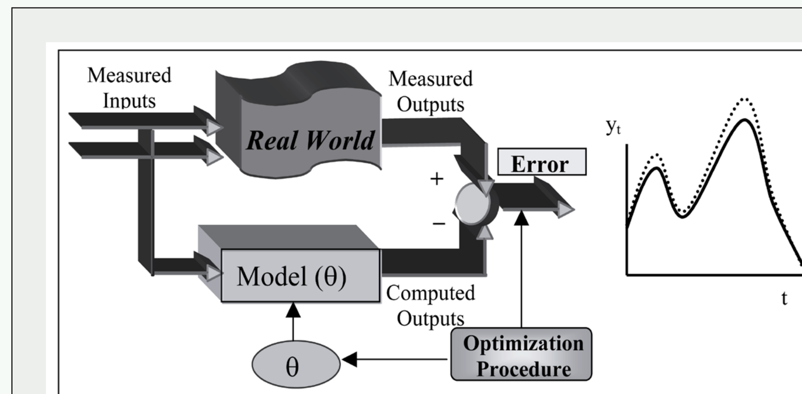

Iteration on parallel process

Apple Xserve

Updating Tunable coefficients

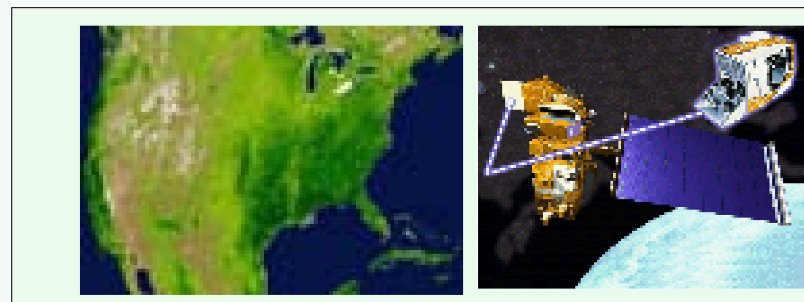
Initialization

Observations for Calibration




### MOSCEM

MOSCEM is an improvement over the Shuffled Complex Evolution Metropolis (SCEM-UA) global optimization algorithm, using the concept of Pareto dominance to develop the initial population of points toward a set of solutions stemming from a stable distribution (Pareto set), rather than direct single-objective function evaluation. Optimization criteria measure multi-aspects of the model behavior and use multi-criteria optimization to identify the set of less dominated, efficient optimal solution [*Vrugt et al.* 2003]. We are developing the MOSCEM code for parallel computing on the Apple Xserve in order to minimize the wall-clock time of iteration process in MOSCEM. (Source from SAHRA, University of Arizona).

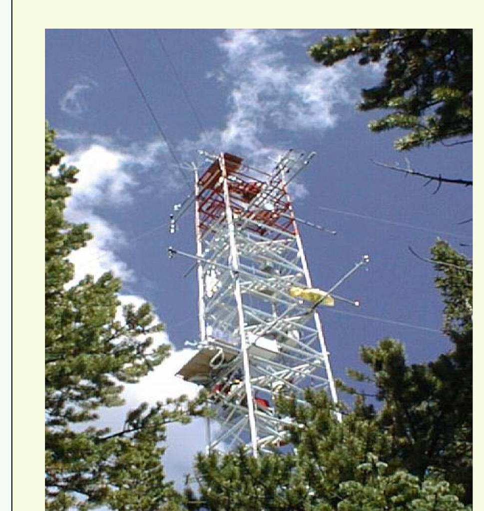


### Satellite data

The Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument aboard the EOS Terra and Aqua satellite has been providing critical monitoring information with local overpass times around 10:30 AM/PM and 1:30 PM/AM, respectively [*Barnes et al.* 2002]. Although there are various MODIS land products, we only use the data which is directly linked to the observed radiances. Therefore, we utilize the

- MODIS LULC map for initialization,
- MODIS spatially complete MODIS BRDF albedo datasets [*Moody et al.* 2004] for initialization and calibration of the LAI dynamics, and
- MODIS land-surface temperature (LST) datasets [Wan et al. 1999] for calibration of the LSM's skin temperature and plant stress.

We extensively utilize the MODIS QA that allow us to select the better-quality observation pixels.



### Ground Observation

Observations from a number of *insitu* sites are being used in the study. AmeriFlux observations are principally used for estimating the ability of the model to simulate realistic latent heat flux, surface soil moisture, and energy balance, and field-scale CO2 flux values (public.ornl.gov/ameriflux/Participants/Sites/Map/index.cfm). There are over fifty sites distributed across the country with each site representing a different landscape. There are sites in FL, NC, and TN, located in the southeastern United States but other sites such as those in KS, MA, WI, and OK have landscapes similar to the prominent land use in the southeastern United States. The seasonal model simulations will be compared with point observations from the various sites. Additionally, we will analyze observations from a selected set of AmeriFlux sites from different geographic and surface conditions to study the processes (diffuse radiation, soil moisture changes, etc.). We are also utilizing data from the NASA AERONET, NOAA SURFRAD sites, USDA UVB Network, and the operational ASOS/AWOS for evaluating the coupled GEMRAMS.