APPLICATIONS, EVALUATION, AND IMPROVEMENT OF MULTI-SCALE MODELING SYSTEMS

SCIENCE MISSION DIRECTORATE

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***Figure 1:** Three-dimensional visualization of a simulated convective cloud system that occurred on February 23,1999 over Amazonia in western Brazil. The simulation was made using the Goddard Cumulus Ensemble model with improved cloud microphysics. The visualization shows a rendering of the modeled cloud field, which consists of the sum of the simulated cloud water and cloud ice.*

Project Goals and Objectives: The foremost challenge in parameterizing cloud systems in climate models is the proper representation of the many coupled processes that interact over a wide range of scales, from microphysical to planetary. This makes the comprehension and representation of clouds and convective cloud systems one of the most complex scientific problems in Earth science. The goals of this project are (1) to develop and improve better numerical models to advance our understanding of the global energy and water cycle, (2) to produce multi-dimensional cloud datasets to improve NASA satellite rain retrievals and the representation of cloud processes in climate models, and (3) to use high-resolution NASA satellite cloud data to validate and improve models.

Project Description: The hydrological cycle distinguishes Earth from the other planets. A key component of this cycle is rainfall, which is also the primary heat source for the atmosphere. Present large-scale weather and climate models simulate cloud processes only crudely, reducing confidence in their predictions on both global and regional scales. Multi-scale modeling systems (coupled global model-cloud resolving model and land surface model) were developed and used in a wide range of studies, including investigations of the dynamic and thermodynamic processes associated with hurricanes, surface effects on atmospheric convection, and cloud-chemistry-aerosol interactions from local to regional to global scales.

Relevance of Work to NASA: These efforts (primarily supported by the NASA Headquarters Atmospheric Dynamics and Thermodynamics Program and the NASA Precipitation Measuring Mission, in addition to the NASA Cloud Modeling and Analysis Initiative Program) are an important part of NASA's continuing quest to improve long-range forecasts and climate prediction capability. By combining the NASA satellite programs (for example, TRMM, Terra, Aura, Aqua, and CloudSat) and numerical models, we can provide cloud, precipitation, aerosol, land characteristics, and other data at very fine spatial and temporal scales to improve our understanding of the roles of cloud and precipitation processes on global energy and the water cycle.

Computational Approach: A hybrid parallelism, which uses both distributed-memory Message Passing Interface (MPI) and shared-memory multithreading (OpenMP) is implemented to efficiently solve fluid dynamics, cloud processes, surface (land and ocean) processes, and solar and infrared irradiance radiation in atmospheric models. The simulation code employs both finite-volume dynamic and finite-difference numerical schemes. To improve the performance and scalability, two-dimensional horizontal domain decomposition is necessary to yield the high degree of parallelization required.

Results: We were able to use the new multi-scale modeling systems to produce better and more realistic three-dimensional clouds and cloud systems over different geographic locations (Figures 1,2). These clouds and cloud systems were used to improve the performance of diabatic and rainfall retrieval algorithms for the NASA Tropical Rainfall Measuring Mission (TRMM) Program. We were also able to use the new modeling system for simulating the vertical structure of an intensive hurricane. A realistic simulation of a hurricane allows us to understand the impact of microphysical processes upon the hurricane track forecast and its intensity prediction. In addition, we were able to apply the new modeling system to simulate many weather features/climate phenomena that cannot be simulated with traditional global circulation models and/or climate models. These features include the timing of diurnal variation over land and ocean, a single Intertropical Convergence Zone over the Pacific, and the direction of the propagation of convective systems in the tropics.

Role of High-End Computing: The new multi-scale modeling systems require a substantial amount of computing resources, two to three orders of magnitude more expensive than current climate models. Only supercomputers with thousands of processors such as the Columbia supercomputer are able to achieve results in a timely fashion. In addition, a vast amount of data will be generated by the modeling systems. Storing and retrieving this immense dataset poses a real challenge. However, the aggregate memory available on Columbia, in combination with new tools and methodologies, enable us to manage and display the model-generated cloud datasets. The Columbia modeling projects consumed approximately 95,000 processor-hours on 32–256 processors.

Future: We will continually use multi-scale modeling systems to improve our understanding of the cloud and precipitation processes and their interactions with radiation and land surface. The fine spatial and temporal cloud and precipitation data from the NASA TRMM and A-Train satellites, and NASA field campaigns will be used to validate and improve model performance. We plan to use multi-scale modeling systems in real-time forecasts for NASA's Modeling, Analysis, and Prediction Program (MAP '06) and NASA field campaigns. Approximately 25–30 cases will be performed using the multi-scale modeling systems each year. Each simulation will utilize 32–2,048 processors, and will require approximately 50 gigabytes of temporary disk space. Overall, the total annual resource requirements will be approximately 1,000,000 processor-hours and 10 terabytes of long-term disk storage.

Co-Investigators

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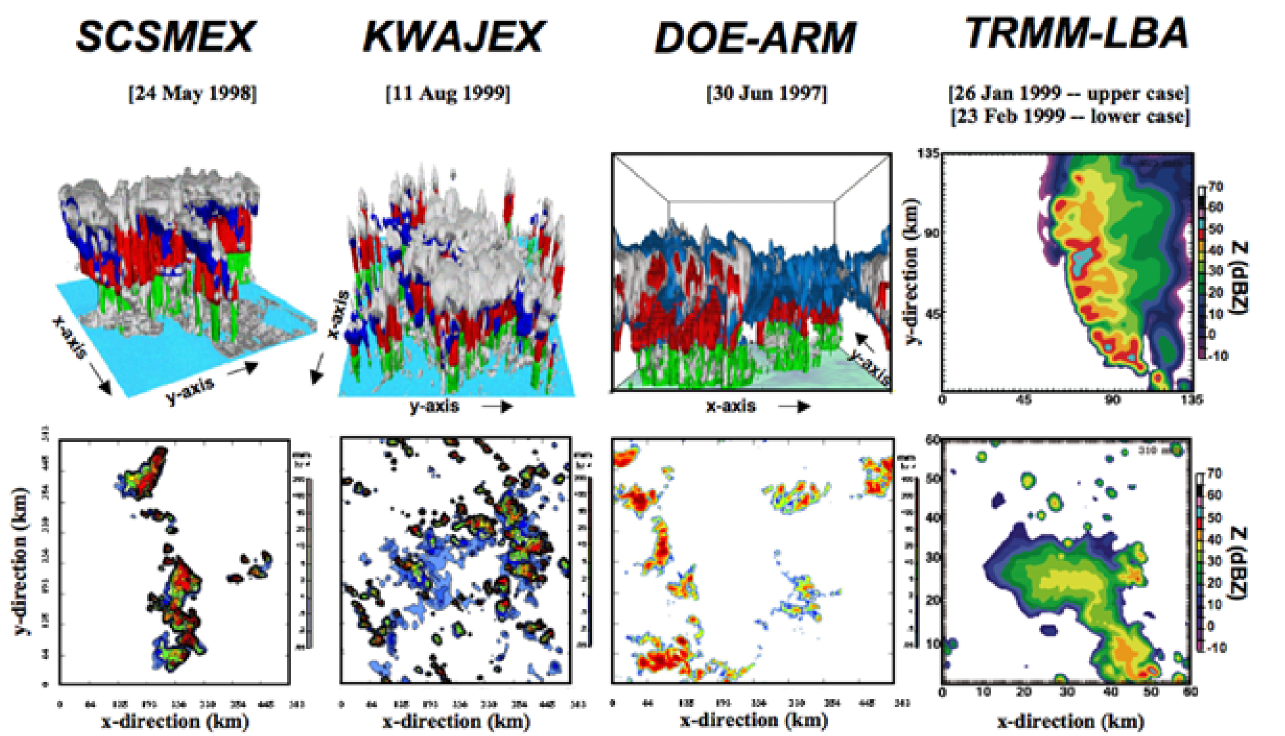

Figure 2: Isometric projections of volume hydrometeor distributions (three left-most upper panels) and plan-view near-surface rain rates (corresponding three left-most lower panels) for instantaneous realizations of three-dimensional Goddard Cumulus Ensemble simulations of NASA South China Sea Monsoon Experiment (SCSMEX), NASA Kwajalein Experiment (KWAJEX), and Department of Energy-Atmospheric Radiation Measurement (DOE-ARM) Mesoscale Convective Systems (MCS) cases. Upper panel isosurface color scheme assigns: (i) white for cloud droplets and ice crystals, (ii) blue for snow, (iii) red for graupel and hail, and (iv) green for rain. Right-most diagram pair shows mid-level simulated radar reflectivity for the Tropical Rainfall Measuring Mission-Large-Scale Biosphere-Atmosphere Experiment (TRMM-LBA) easterly (upper panel) and westerly (lower panel) regime MCS cases.