Atmosphere-Land Coupled Data Assimilation by Using Satellite Microwave Radiometers

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INTRODUCTION

Soil moisture, snow and precipitation are key parameters in numerous environmental studies, including hydrology, meteorology, and agriculture. They play important roles in the interactions between the land surface and the atmosphere, as well as the partitioning of precipitation into runoff and ground water storage and absorbed solar energy into sensible and latent heat flues at the land surface. Recent studies with the general circulation models (GCMs) using active land surface parameterization have shown that strong feedbacks existed between the soil moisture, snow, and precipitation anomalies and climate. The current techniques or algorithms need to be further improved or developed in order to obtain the required accuracy for atmospheric and hydrologic modeling. The key elements of the radiative transfer models, for example, vertical profiles of soil moisture, snow grain size and water vapor and air temperature, can not be obtained easily only by satellite remote sensing. To solve these issues, it is effective to assimilate remote sensing data with numerical simulation schemes, Land Surface Schemes, Snow Physical Models, and Cloud Microphysics Models, which are embedded in GCMs or regional models.

SYSTEM CONFIGURATION

A Land Data Assimilation System (LDAS) for soil moisture and land surface fluxes and a Cloud Microphysics Data Assimilation System (CMDAS) were developed by coupling Land Surface Schemes (LSSs) and Cloud Microphysics Schemes (CMSs) with Radiative Transfer Models (RTMs) at the lower frequencies and a the higher frequencies, respectively. Based on these two data assimilation systems, an atmosphere and land coupled data assimilation system over land has been developed as shown in Fig.1.

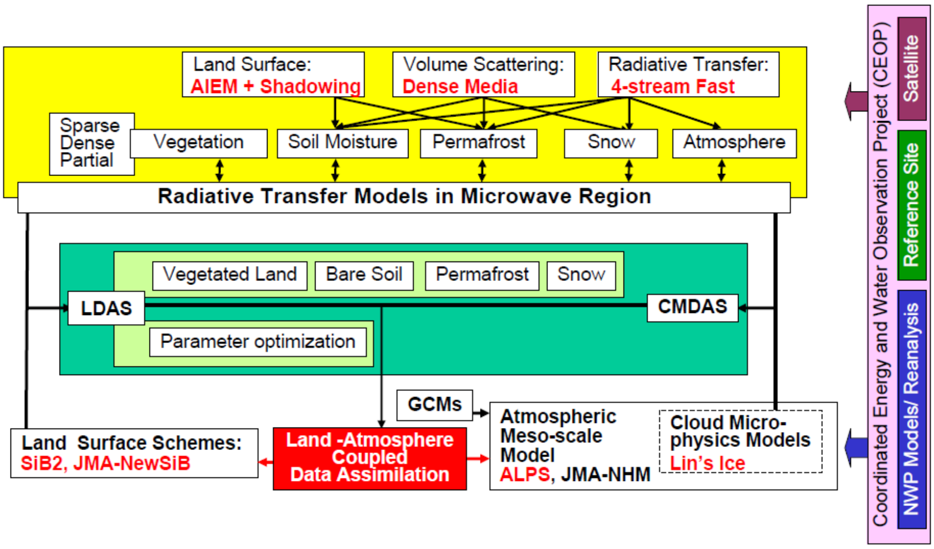

Figure 1 Land-Atmosphere Coupled Data Assimilation System

RADIATIVE TRANSFER MODELS

Passive microwave remote sensing provides the most feasible technique to monitoring spatially distributed soil moisture, snow, permafrost and vegetation over land and water vapor, cloud and precipitation over ocean in a large scale. The high sensitivity to water and small particles in microwave region due to the characteristic dielectric constant and scattering is used for observation of soil moisture, snow, and even vegetation. To observe the water in atmosphere over ocean, the water vapor absorption band at 22GHz and radiation emission and scattering extinction by cloud and precipitation at 37GHz to 89GHz are used basically for monitoring precipitation at high frequencies.

To develop, validate and improve radiative transfer models for vegetation, soil moisture, snow, permafrost and atmosphere in microwave region, ground-based experiments by using microwave sensors have been implemented and the globally distributed match-up data sets have been provided by the Global Energy and Water Cycle Experiment (GEWEX) Coordinated Enhanced Observing Period (CEOP) as shown in Figure 2 and Figure 3, respectively.

Figure 2 Ground Based Microwave Radiometers

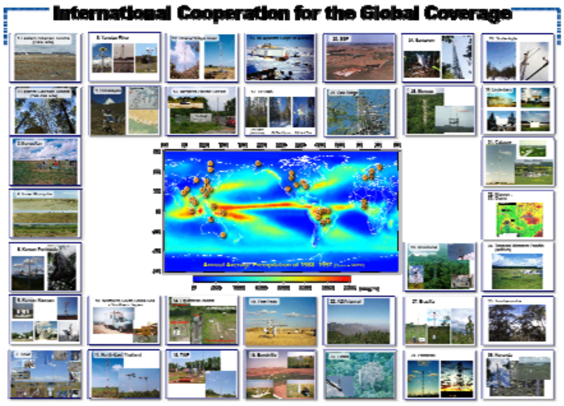

Figure 3 CEOP Reference Site Network

LAND DATA ASSIMILATION SYSTEM (LDAS)

A LDAS has been developed by combining the SiB2 as a model operator and a 0-order Radiative Transfer Model (RTM) as observation operator[1)]. The validations of the LDAS were carried for different land surface classification with several types of vegetations and several land surface roughness conditions by using a ground-based passive microwave radiometer which has same set of frequencies of AMSR and AMDR-E. The results of the experiment shows a high performance of the LDAS and emphasize the relative importance of

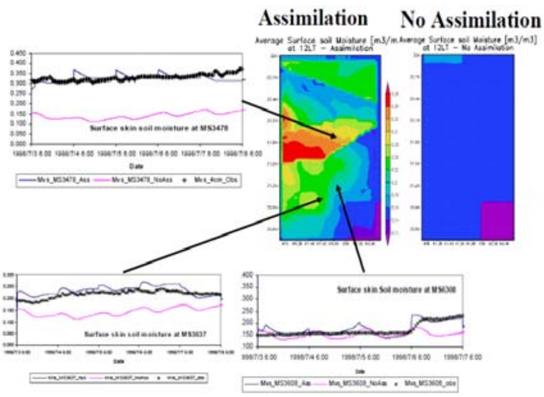

Figure 4 Soil moisture predicted by LDAS

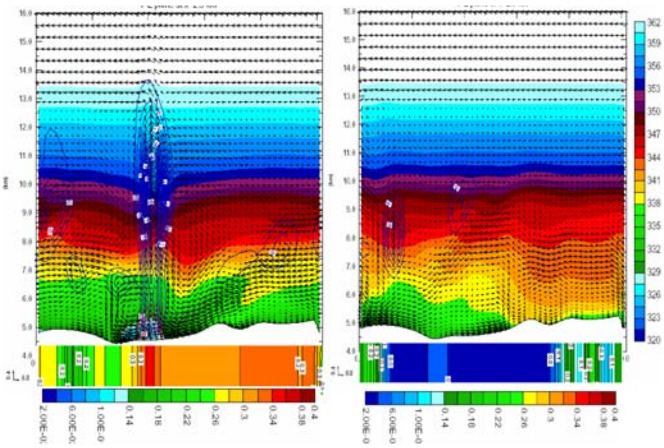

Figure 5 A strong convective system predicted by the atmospheric simulation coupled with LDAS (left)

ground-based experiments and the impact of land surface heterogeneity when using coarse scale satellite database retrieval algorithms. To assess the efficiency of the new system, an idealized 2-dimensional numerical experiment was carried out in the mesoscale area of the Tibetan Plateau. The results showed significant differences compared with standard regional atmospheric model outputs; and were more consistent with the satellite microwave brightness temperature observations that improved the spatial distribution of soil moisture, which strongly affected the convection systems.

CLOUD MICROPHYSICS DATA ASSIMILATION SYSTEM (CMDAS)

An 1-D Cloud Microphysics Data Assimilation Scheme (CMDAS) for mesoscale modeling has been developed[2]. The algorithm includes Lin's ice cloud microphysics scheme, a radiative transfer model (RTM) in microwave region, and an optimization method named Shuffled Complex Evolution (SCE). Initially Lin's scheme without application of CMDAS was analyzed which showed homogeneous structure of brightness temperature (TB) due to homogeneity of external GANAL (Global Analysis) data provided from Japan Metrological Agency (JMA). In order to introduce heterogeneity by improving initial state of the atmosphere, CMDAS was operated by using the output from non-hydrostatic model known as Advanced Regional Prediction System (ARPS) as a first guess by using GANAL data set. RTM is solved using the discrete ordinate method (4 streams) and the Henyey-Greenstein phase function. The SCE method is used to minimize the difference between modeled and observed TB at 89 GHz horizontal polarization by adjusting the atmospheric parameter of cloud liquid water content (CLWC). The algorithm was applied for the period of the Wakasa Bay Experiment 2003 in Japan, which was part of the AMSR/AMSR-E validation project. The performance of algorithm has shown good qualitative and quantitative agreement of TB and integrated cloud liquid water content (ICLWC). By using the assimilated atmospheric hydrologic conditions as an initial condition, the snowfall prediction is improved as shown inn Figure 6,

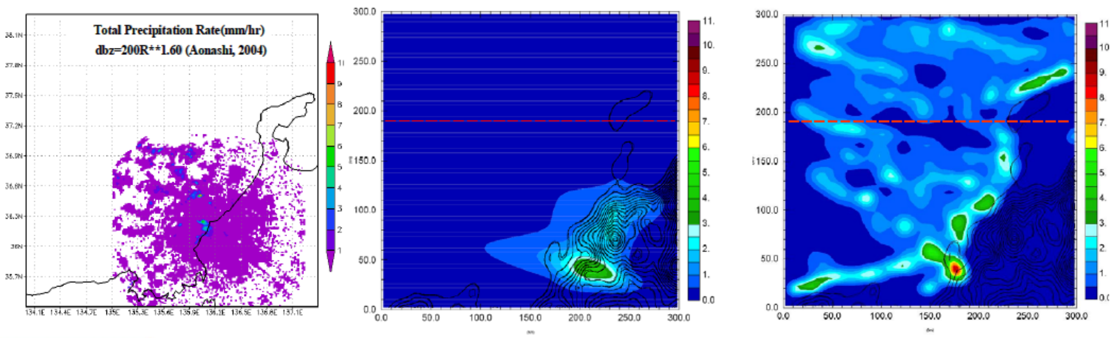

Figure 6 Performance of CMDAS in snowfall prediction. Radar observation (left), three-hour prediction of snowfall without CMDAS (center), and coupled with CMDAS (right).

LAND-ATMOSPHERE COUPLED DATA ASSIMILATION (L-ADAS)

Two data assimilation systems, the LDAS and the CMDAS, are employed for effecting coupled assimilation of both land surface and atmosphere over land. Both systems use the same RTM (LA-RTM) and NHM for simulating evolution of surface and atmospheric conditions with time. This system can be run as follows:

Step 1:

The LDAS with the LA-RTM as the observation operator assimilates lower frequency (6.9, 10.7 and 18.7 GHz) TB satellite observations. Cloud water, ice and light precipitation can be assumed transparent to lower microwave frequencies, and thus the retrieved land surface conditions is representative of prevailing surface conditions.

Step 2:

Output from the LDAS, which now includes some improvements to atmospheric variables, through the refinement of the land surface condition is used to provide initial and boundary condition for the LA-RTM embedded in CMDAS, the observation operator to assimilate high frequency (23.8 and 89.0 GHz) TB observations, with an ice microphysics scheme being used to retrieve water vapor, cloud water, cloud ice, rain and snow columns describing atmospheric state.

Step 3:

This retrieved atmospheric condition is then fed back to the LDAS step to refine surface condition.

The output from this scheme can be validated by the CEOP reference site data sets. The cloud liquid water content derived ARPS coupled with only LDAS and with L-ADAS is compared with the MODIS could IR image in the Tibetan Plateau in Figure 7. L-ADAS can provide better simulation of could liquid path, which is consistent to the cloud derived from the MODIS IR image.

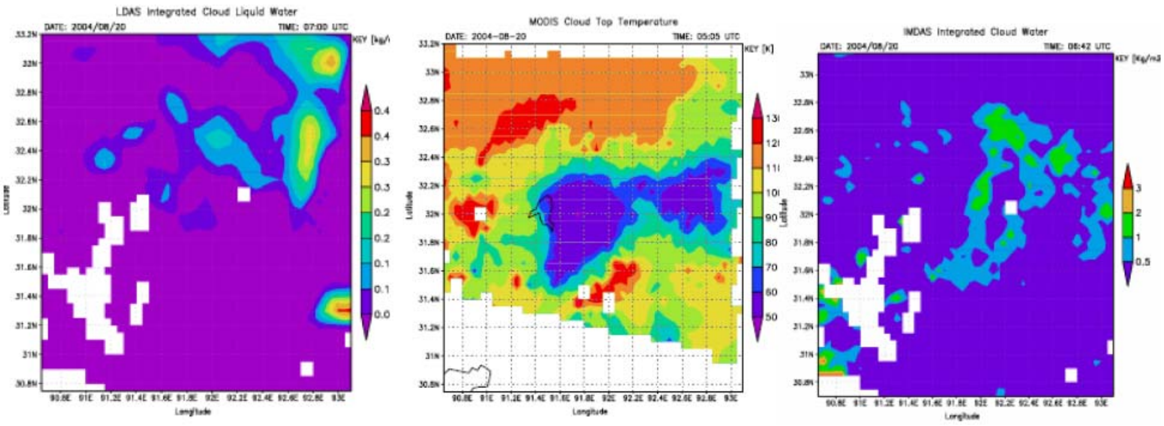

Figure 7 Estimation of cloud liquid water path derived by ARPS coupled with LDAS (left) and L-ADAS (right) compared with MODIS IR image

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