論文の内容の要旨

論文題目 **Development of a Land-Atmosphere Coupled Data Assimilation System for Physical Downscaling**

物理的ダウンスケーリングのための大気ー陸面結合データ同化システムの開発

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Since General Circulation Models (GCMs) are still unable to produce any mesoscale or local atmospheric phenomena, downscaling methods are necessary to bridge the gap between GCMs's scale, and other modeling scales. One standard physical downscaling method is nesting, in which a regional atmospheric model is driven by low-resolution outputs from either GCM predictions or analysis, however, untill now this approach has been unable to accurately reproduce local phenomena and extreme events.

Early investigations of the land-atmosphere interactions and their related mechanisms showed that the specification of an accurate surface soil moisture distribution is a crucial factor in resolving the evolution of the Planetary Boundary Layer (PBL). In fact, the intensity and location of the PBL's related variables are directly linked to the energy partition between latent and sensible heat fluxes and their horizontal gradient, themselves driven by the soil moisture distribution. Furthermore, heterogeneity of atmospheric parameters especially atmospheric moisture is also very important in regional modeling considering its role in atmospheric thermal control through heat release and absorption.

Because such accurate spatially distributed soil moisture data is globally unavailable (limited to the point scale), and distributed atmospheric data is limited to over-oceans areas and few areas in developed countries, to date nested models were unable to reproduce local phenomena or extreme events.

It is therefore essential that nesting procedures include accurate and robust initial surface and atmospheric conditions in order to capture the regional atmospheric structure.

To overcome these limitations, this research addresses the improvement of the initial surface conditions by the assimilation of satellite brightness temperature within a land-surface scheme coupled with a mesoscale atmospheric model in a recursive way.
Furthermore, the improvement of the initial surface condition estimate as a background for the satellite atmospheric observation would also contribute to the development of accurate atmospheric initial condition, which would lead to further improvement in the physical downscaling outputs.

Given the increasing temporal resolution and the larger coverage of satellite observations especially in the microwave region (next missions: ALOS, SMOS, HYDROS), they represent an appropriate tool for quantifiying the temporal and spatial variabilities of the surface state especially those of soil moisture content. However, due to the small penetration depth of these satellite estimates, regional models can't directly use them, as they require the whole soil moisture profiles. In addition, the indirect satellite observations need to be related to the true physical state, radiative transfer models are well-suited bridging tools for this task.

The newly developed land data assimilation systems (LDASs) based on the integration of satellite observations within land surface schemes have the ability to accurately resolve the land surface conditions with a continuous temporal resolution and consistent with atmospheric model use. However, Land Data Assimilation systems still rely on observed atmospheric forcing data, missing the very important reciprocal feedback processes with the atmosphere.

In this study, an integration of satellite observations within a land-atmosphere coupled model through a variational data assimilation process is developed to solve the later problem. Considering the time scale difference between atmospheric processes and land surface processes, this system adopts a recursive cycle coupling a land data assimilation system with a coupled land-atmosphere model for reducing computational demands.

The system consists of a mesoscale atmospheric model as an “atmospheric driver”, a physically based land surface scheme (LSS) as a model operator, a land surface Radiative Transfer Model as an observation operator, a minimization scheme, and the assimilated data is the microwave brightness temperature data observed by satellites.

The Advanced Regional Prediction System (ARPS) is used as an “atmospheric driver”, because of its non-hydrostatic formulation, which allows it to correctly predict local weather features.

The revised Simple Biosphere model (SiB2) is chosen as a model operator because of its physically based formulation that includes a reasonable representation of the vertical water flow, and energy partition.

A simplified zero order non-coherent radiatative transfer model, which has shown good ability to estimate the surface skin moistutre in wet soil conditions is used as an observation operator; while in dry soil conditions, a new radiative transfer model is introduced for taking the effect of soil particle scattering into account.

The heuristic Simulated Annealing scheme is used as an optimization procedure because of its capability to deal with non-linearity and discontinuity in minimizing the variational cost function.

There are three candidates at this moment as space-based observations of brightness temperature: the Defense Metrological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I), the Tropical Rainfall Measuring Mission’s (TRMM) Microwave Imager (TMI), and Aqua Advanced Microwave Scanning Radiometer for EOS (AMSR-E).

These system’s components are combined in the following sequences: first, the land surface scheme is coupled with the mesoscale model to guaranty Land-atmosphere interaction, then the surface heterogeneity is introduced by assimilating the microwave remote sensing data into the land surface scheme and feeding back the new initial surface conditions to the land-atmosphere coupled model.

A mesoscale area of the Tibetan Plateau, is chosen as an application domain for this study, firstly, because it has a heterogeneous soil moisture distribution resulting from its mountain-valley topographical structure, and frequent convective rainfall events; secondly, because it is covered by the TMI satellite products; and thirdly, because of its available comprehensive data sets collected during the GAME IOP 1998 (GEWEX Asian Monsoon Experiment Intensive Observation Period) project including the $0.5^o x 0.5^o$–resolution GAME reanalysis product.

2-dimensional and 3-dimensional simulations were performed respectively to assess the effectiveness of the new system in considering the impact of surface heterogeneity on the land-atmosphere interactions and their related mechanisms, and then to validate the system through a downscaling approach based on observed data.

The 2-dimensional numerical experiments were carried out using: (1) only the coupled land-atmosphere model (ARPS-SiB2), and (2) the full assimilation system. In order to assess the system efficiency on a wide range of climate conditions, both experiments were performed during the Monsoon period (July) as a wet season, then during the pre-Monsoon period (May) as a dry season for which the volume scattering radiative transfer model was introduced in the assimilation. A spatial resolution of 5km was set to be able to capture the land surface heterogeneity and its effects on the atmospheric state and mechanisms.

The 2-D experiment's results show that in general, an increase in soil moisture enhances the atmospheric instability through wet convection process and thus precipitation, particularly in summer season (the wet season in this study). In the opposite direction dry convection generated over dry surface cannot generate precipitation in the absence of "sufficient" available atmospheric moisture. In addition, it is shown that a heterogeneous spatial distribution of soil moisture can produce a variety of convection intensity, which results in different precipitation pattern.

Thus, by implementing the coupled land-atmosphere data assimilation system, the soil moisture amount becomes more consistent with observed satellite brightness temperature. Moreover, through the consideration of the surface heterogeneities given by the satellite observation, the assimilation system provides better spatial distribution of soil moisture, which results in a strong impact on local convection mechanism and precipitation predictability.

It is also possible through the updating process related to the satellite data assimilation system to partially overcome the rough quality of the ancillary surface data.

Considering the effectiveness of this coupled land-atmosphere assimilation system in resolving the surface heterogeneity and its reciprocal effect with the atmosphere, the assimilation system was expanded to a 3-dimensional configuration as a physical downscaling approach.

Initialized and laterally forced by the GAME reanalysis atmospheric data, the coupled assimilation system was applied to a mesoscale area of the Tibetan plateau.

The results illustrate that, in comparison with the standard nesting procedure (ARPS-SiB2), the use of the coupled land-atmosphere assimilation system shows significant improvement in the reproduction of the atmospheric mechanisms. The improvement is possible because of the updating procedure of soil moisture based on the satellite observations. In fact, introducing the correct heterogeneous spatial distribution of soil moisture has a direct impact on the spatial structure of surface heating which produced regions of different convection intensity. This heterogeneous spatial structure results in specific convergence areas, which enhance the vertical moisture transport as confirmed by the GMS satellite-based cloud observation. However, for the case investigated in this study, the system cannot fairly predict precipitation, because precipitation is not only related to surface conditions, but also many other issues such as the initialization of atmospheric moisture and wind fields; and the updraft intensity which is also related to the horizontal spatial resolution.

Based on the results of these experiments, it is possible to qualitatively demonstrate the major roles of soil moisture distribution and magnitude, jointly with topography, in driving the atmospheric mechanisms (mainly cloud and precipitation generation) over the Tibetan plateau. However the quantification of the relative contribution of each of those surface components can be assessed through further investigation by using the coupled assimilation system under different topography configuration.

From the above, it is shown that an accurate surface condition initialization and its reciprocal feedback with the atmospheric state are possible through the development of a satellite data assimilation of land-atmosphere coupled system resulting in a significant improvement in the simulation of atmospheric mechanisms.