Coupling of Atmospheric Model MM5 and Land Surface Model SOLVEG by Exchanging Data with MPI on Their Independent Parallel Calculations

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1. Introduction

Simulations of a coupled atmosphere-land surface model were carried out. The coupled model is developed to minutely calculate meteorological field and water circulation around the land surface, which are important for environmental simulations. A non-hydrostatic atmospheric dynamic model of Pennsylvania State University and National Center for Atmospheric Research (PSU/NCAR-MM5; Grell et al. 1994) and a detailed land surface model including the surface layer atmosphere, soil, and vegetation named SOLVEG (Nagai 2002, 2003) developed at Japan Atomic Energy Research Institute (JAERI) are used as the atmospheric and land surface models, respectively.

In this coupling, the models are coupled by exchanging calculation results by using Message Passing Interface (MPI) on their independent parallel calculations. Concerning the MPI, a message passing library named Stampi (Imamura et al. 1998) developed at JAERI that can be used between different parallel computers is used. The modifications of models for this model coupling are easy, simply adding some modules for data exchanges to each model code without changing each model's original structure. This feature is helpful to make a model code coupling with a community model like MM5, which is updated regularly. Moreover, this coupling method is flexible and allows the use of independent time step and grid interval for each model.

In this paper, the coupling method and test calculations to validate the method are described.

2. Overview of models

The non-hydrostatic mesoscale atmospheric model MM5 (Grell et al. 1994) is a community model having many users all over the world, and is used for many purposes, even for the official weather forecast by some countries. It has many useful functions such as nesting calculations, four-dimensional data assimilation, and many options of parameterizations for cloud micro-physics, cumulus cloud, planetary boundary layer (PBL), radiation, and land surface scheme.

The land surface model SOLVEG (Nagai 2002, 2003) consists of one-dimensional multi-layer sub-models for the surface atmosphere, soil, and vegetation, and a radiation scheme for the transmission of solar and long-wave radiation in the canopy. It simulates diurnal variations and seasonal changes of variables in the surface atmosphere, soil, and vegetation canopy, and exchanges of energy and water among these systems, by using meteorological data of the surface layer atmosphere as the top boundary conditions. For coupling with an atmospheric model, one-dimensional model variables are expanded to three-dimensional ones whose horizontal coordinates coincide with those of atmospheric model. However, no interactions in horizontal directions are considered in the model.

3. Coupling method

In this coupling, MM5 and SOLVEG calculations are carried out as independent tasks for different processors and outputs of models are exchanged as MPI communication between processors as schematically shown in Fig. 1. This type of parallel calculation is called Multiple Program Multiple Data (MPMD). MM5 calculation starts at first. Then, it invokes SOLVEG calculation in its initialization processes. After the PBL calculation in the first time step of MM5 time integration, MM5 processor sends the initial values and the first boundary conditions of SOLVEG: air pressure, radiation, precipitation, wind speed, temperature, humidity, etc. With these inputs, SOLVEG calculation proceeds for the same time interval as MM5 and sends its results to MM5: skin temperature, surface heat and vapor fluxes, and albedo. MM5 receives these values before PBL calculation in the next time step and uses them in PBL process. After PBL calculation, MM5 sends the boundary condition of SOLVEG for the next time step, and the same cycle of processes are carried out repeatedly until the end of calculation. The time step of SOLVEG calculation is usually smaller than that of MM5, and several time steps are carried out for SOLVEG calculation during a single time step of MM5 calculation.

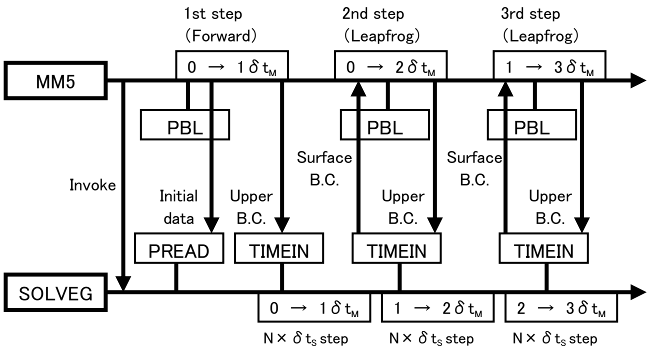

Fig. 1 Data exchanges between coupled models. PREAD and TIMEINT represent SOLVEG routines for the initial and boundary conditions, δt_M and δt_S time increments of MM5 and SOLVEG calculations, respectively.

This coupling method is flexible and allows us to use the nesting functions of MM5. Figure 2 shows the flow of coupling calculation and data exchanges for two-domain, two-way nesting calculation. MM5 nesting calculations for mother and inner domains are carried out successively in one time step of mother domain, and three time steps are done for the inner domain in this procedure. On the other hand, SOLVEG calculations for large and local domains are processed as independent tasks by different processors. Data exchanges between corresponding domains of MM5 and SOLVEG take place independently. This method can be applicable to more complex nesting domains.

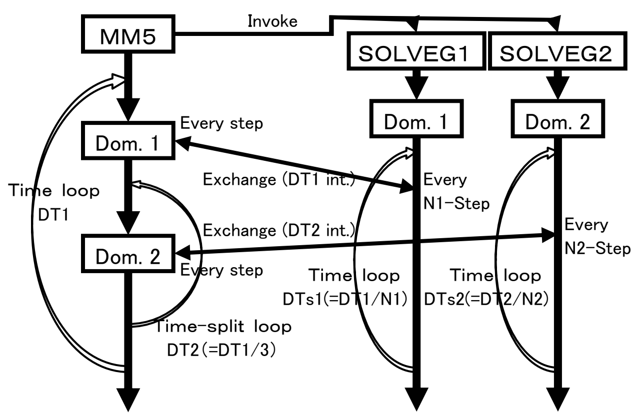

Fig. 2 Data exchanges for nesting calculations. DT1/2 and DTs1/2 represent time increments of MM5 and SOLVEG for Domain1/2, respectively.

The modification of model code for this coupling is simple and easy, just adding some data exchange routines and put some sentences in the original model code which call the routines, and each model code keeps its original structure. This coupling method also has flexibility to use different resolution of grid and time step for each model.

4. Test calculations

Test calculation for two-domain, two-way nesting was carried out to validate this coupling method. Target area is the seacoast desert of south-west Saudi Arabia. Calculation domains are shown in Fig. 3 as the land-use map. This coupling model is planed to be applied to studies related to the greening project of this area, and this test was carried out as a preliminary study. Numerical weather prediction data (GPV) of Japan Meteorological Agency was used for the MM5 input.

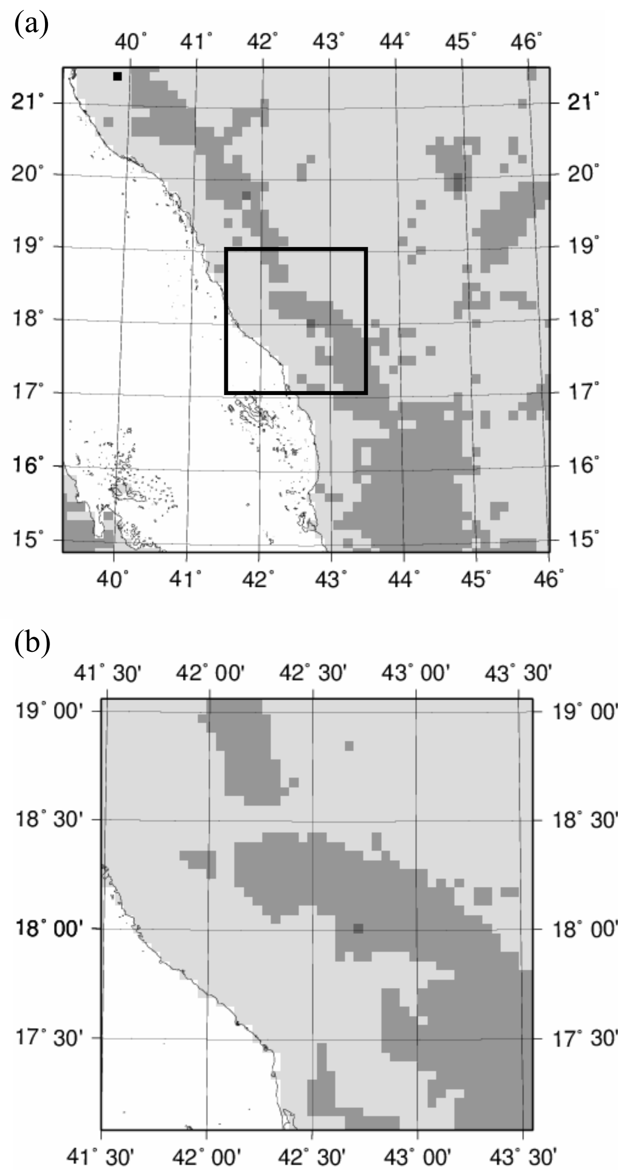

Fig. 3 Land-use maps of calculation domains: (a) mother domain and (b) inner domain. Land-use categories are shown as light gray: desert, medium gray: shrub land, dark gray: crop land, black: urban. The rectangle on the mother domain represents the area of inner nest domain (here and in the following captions).

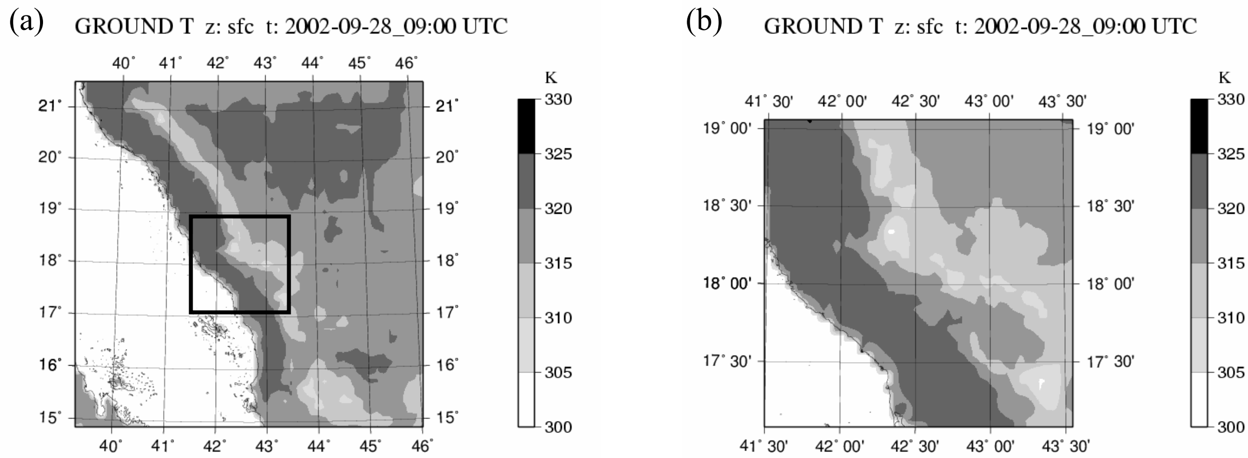

Fig. 4 Skin temperature distribution calculated by the original MM5 for (a) mother domain and (b) inner domain.

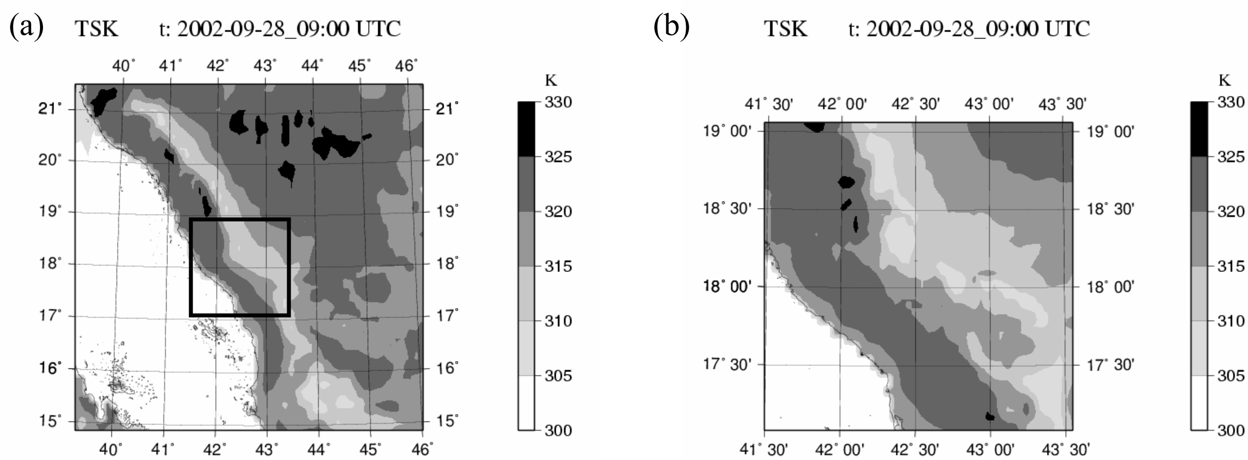

Fig. 5 Skin temperature distribution calculated by SOLVEG in one-way coupling with MM5 for (a) mother domain and (b) inner domain.

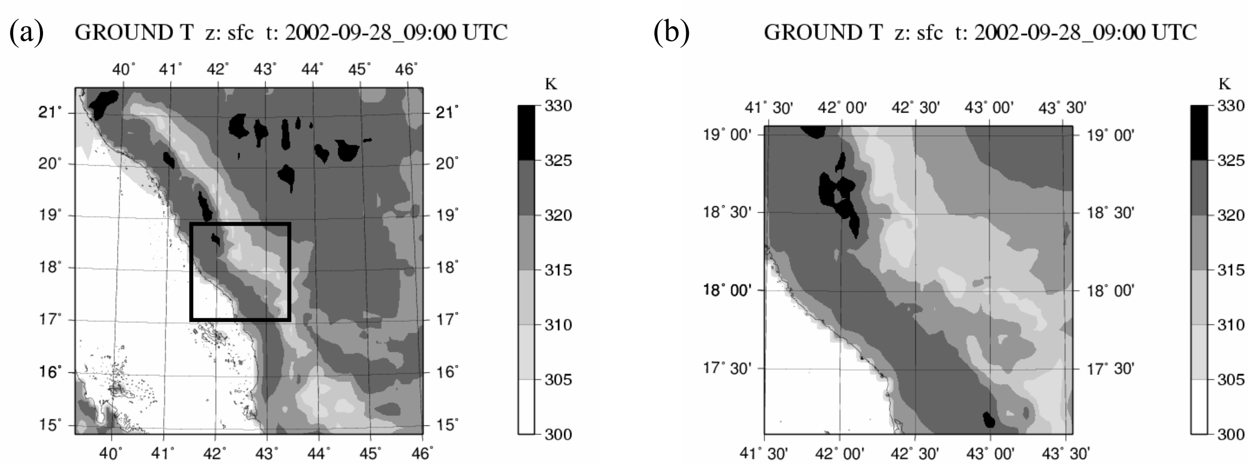

Fig. 6 Skin temperature distribution calculated by MM5 in two-way coupling with SOLVEG for (a) mother domain and (b) inner domain.

a. Calculation conditions

Model settings are as follows.

MM5 options:

- Cumulus	Grell
- Microphysics	Reisner2
- Radiation	Cloud
- PBL	MRF
- LSM	OSU-LSM

MM5 mother domain:

- Area	810 km square
- Grid	55×55×23
- Resolution	15 km
- Time increment	30 s

MM5 inner domain:

- Area	240 km square
- Grid	49×49×23
- Resolution	5 km
- Time increment	10 s

SOLVEG:

- Atmosphere	10 layers, 10 m above the surface
- Soil	7 layers, 2 m below the land surface
- Vegetation	lower 5 layers of atmosphere
- Time increment	5 s (both domains)

Fujitsu scalar-parallel computer Primepower was used to execute 36hour-calculations. As shown in Fig. 2, at least three processors (one for MM5, two for SOLVEG domains) are necessary for this case. The distributed memory parallel execution of MM5 (MPP) can be used in this coupling method, and both single and MPP calculations were tested. Moreover, this coupling method has two coupling modes: one-way and two-way coupling. In one-way coupling, only MM5 sends data to SOLVEG and no feed back from SOLVEG is considered in MM5. In two-way coupling, a dynamical link of MM5 and SOLVEG is realized by mutual data exchanges between them. Both coupling modes were examined, and the validity of this method was confirmed by reasonable model outputs.

b. Results

Calculated skin temperatures at the local noon of the next day of calculation (33 hours from the initial time) by the original MM5, SOLVEG in one-way coupling with MM5, and MM5 in two-way coupling with SOLVEG are shown in Figs. 4, 5, and 6. By comparing Figs. 4 and 5, the skin temperature calculated by SOLVEG was higher than that by the original MM5. It means that SOLVEG has tendency to produce higher skin temperature than OSU-LSM by using the same inputs of the atmospheric variables by MM5. Fig. 6 shows the results of the impact on MM5 calculation caused by the feed back of this higher skin temperature and other ground surface conditions calculated by SOLVEG. In general, the skin temperature by the two-way coupling of SOLVEG and MM5 seems to be higher than that by the one-way coupling. This is because that the higher skin temperature heats up the surface layer air, and the higher air temperature causes the further rise in skin temperature (positive feed back). However, the lower skin temperature was also calculated at some areas as the result with the two-way coupling. It is considered that the wind field was also affected by the feed back so as to lower the skin temperature. It indicates that this coupling method can realize the dynamical coupling of MM5 and SOLVEG as if SOLVEG was incorporated into MM5 like OSU-LSM.

5. Conclusions

The atmospheric model MM5 and land surface model SOLVEG were coupled by exchanging data with MPI in their independent parallel calculations. In test calculations, reasonable model outputs proved the validity of this method and its applicability to develop this kind of complex coupling model including interactions among the atmosphere, soil, and vegetation. In near future, a comprehensive environmental model is planed to be constructed by coupling atmosphere, land, and ocean models with this method.

References

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