# Overview on the development of LDAS coupled with atmospheric model for better hydro-meteorological predictions and validation by CEOP

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## Abstract

The research activity within the river and environment engineering laboratory (reel) at the University of Tokyo included studies on the development of a land data assimilation system (LDAS) based on satellite data, coupled to a mesoscale atmospheric model. The LDAS part consists of a land surface scheme (a modified version of the Simple Biosphere model 2: SiB2), a radiative transfer model including dry soil, vegetation, and surface roughness effects, and two minimization approaches to reduce the difference between the observed and simulated microwave brightness temperatures. These assimilation schemes are the simulated annealing method (which is consistent with the 4-DVAR assimilation approach) and the ensemble Kalman filtering method (which corresponds to a sequential assimilation approach). The atmospheric model produces forcing data for the LDAS, and the LDAS produces better initial surface conditions for the atmospheric modelling system. This coupled system has the advantage that it takes into account the land surface heterogeneities through the assimilation of satellite data (in the microwave region). On the other hand, for a better precipitation prediction, the atmospheric model is coupled with a cloud data assimilation system which uses the improved surface condition to predict the brightness temperature over land through a radiative transfer model for the atmosphere. The output of such system is then used in a distributed hydrological model with focus on the support to decision making. To assess the effectiveness of the system and all its components, the CEOP (Coordinated Energy and water cycle Observations Project) data are used. Comparison with in-situ observations shows that the surface soil moisture content and its distribution benefit from the assimilation system and that it leads to an improvement in the atmospheric model outputs. These better surface conditions affect the land-atmosphere interaction through convection systems and lead to better atmospheric predictability as confirmed also by satellite observations. In fact, through the use of satellite brightness temperatures, the coupled land-atmosphere assimilation system has shown the potential to provide better atmospheric predictions that can contribute to the decision making on water resources through the distributed hydrological modelling.

*Key words*: data assimilation, remote sensing, land surface scheme, regional model, downscaling, distributed hydrological modelling, CEOP

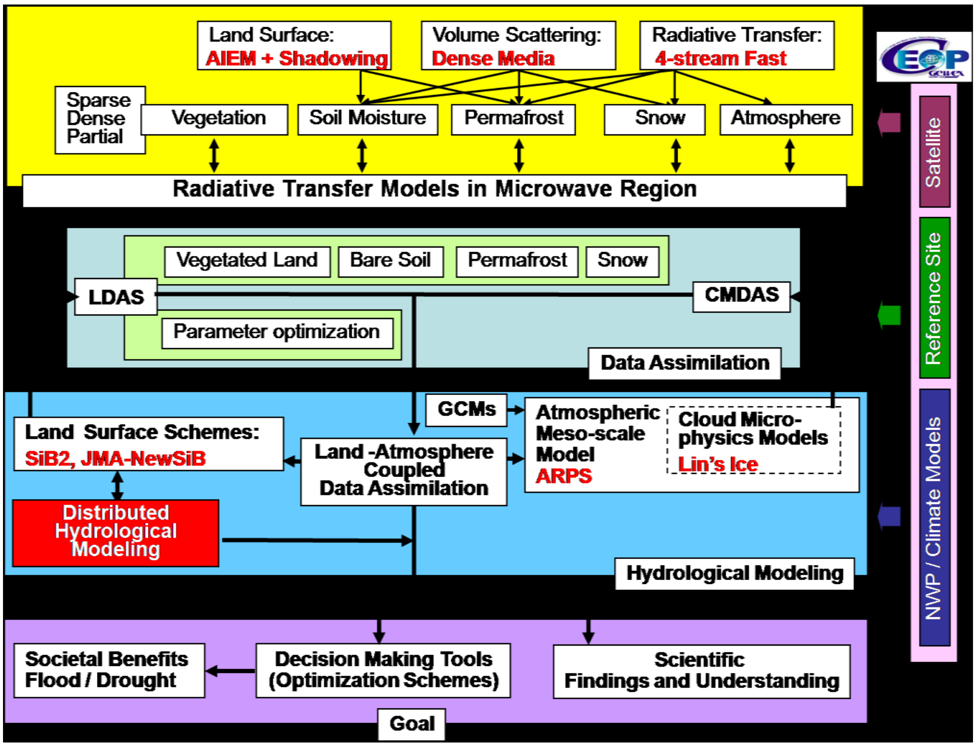

*Figure 1: General framework of the system with the different modelling and verification components*

## 1. System Components and Relevant Modifications

### 1.1. The atmospheric "driver"

The Advanced Regional Prediction System (ARPS) developed at the Centre for Analysis and Prediction of Storms of the University of Oklahoma, which is a three-dimensional, non-hydrostatic, compressible model and has the ability to resolve the atmospheric dynamics at scales ranging from regional to micro-scales, was chosen for this study as a mesoscale prediction model. It consists of four packages: an atmospheric module, a land surface scheme, a radiation code and a package for cloud microphysics parameterization. More details about ARPS can be found in Xue et al. (1995).

### 1.2. The land surface scheme (Model Operator)

The land surface scheme used is the simple biosphere model (SiB2) developed by Sellers et al. (1996). It incorporates simple representations of vertical soil moisture transport, plant-controlled transpiration, interception, evaporation, infiltration, and sensible and ground heat fluxes through physically based mechanisms. SiB2 includes three soil layers: a surface soil layer of a few centimeters, which acts as a significant source of direct evaporation when moist; a root zone, which is the supplier of soil moisture from the roots and accounts for transpiration; and a deep soil layer, which acts as a source for hydrological base flow and upward recharge of the root zone.

Modified versions of SiB2 were developed to take into account some miss-represented processes such as freeze/thaw (Li et al. 2003) and snow processes (Hirai et al. 200).

## 1.3. The Radiative transfer model (Observation Operator)

Based on the emission behaviour of dry soil and liquid water in the microwave region, a radiative transfer algorithm, allowing the estimation of soil moisture from the land surface was developed (Koike et al. 2000). Further improvements include the effects of surface roughness and shadowing (Kuria et al. 2007) as well as the consideration of dry soil conditions (Lu et al. 2005).

## 1.4. The assimilation approaches

This framework focused on two approaches for data assimilation: the first is a heuristic optimization approach called Simulated Annealing (SA), which is capable of minimizing the cost function without using adjoint models (Li et al., 2004). The second is a sequential approach based on the ensemble Kalman filter (Boussetta et al. 2007).

## 1.5. The assimilation cycle

In order to have a continuous scheme, the coupled assimilation cycle is performed as follows. First, the coupled land–atmosphere model (L-AM: ARPS-SiB2) is run for an assimilation window time *T* to provide an initial guess and forcing parameters to the Land data assimilation system (LDAS: SiB2-RTM-SA). Second, the LDAS is run for one assimilation window which then feeds back the new surface initial conditions for the coupled model at time $t-$ ’. Third, the coupled model is run for two assimilation windows *2T*, the first window output is then considered as the optimal one, and the second will serve for the following cycle as forcing for the next LDAS run (Boussetta et al. 2008). Once the new surface conditions are obtained, they are fed as boundary conditions into a radiative transfer model for the atmosphere. The latter is part of a cloud microphysics assimilation scheme (Mirza et al. 2008) to finally produce better atmospheric predictions (Figure 2).

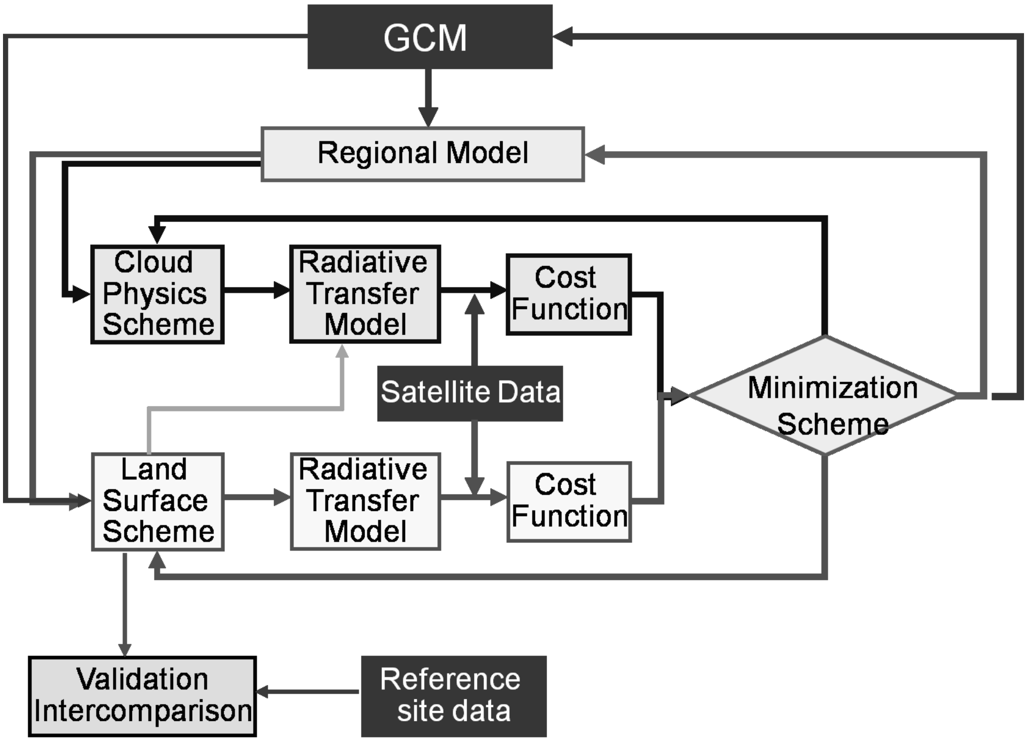

*Figure 2: Coupled land-atmosphere assimilation system*

### 1.6. Distributed hydrological modelling

A water and energy budget-based distributed hydrological model is developed based on the coupling of SiB2 and a geomorphological based hydrological model. It allows a more realistic water and energy flux estimation (Wang et al. 2009). This model can make use of the output of the coupled assimilation system, or the atmospheric reanalysis products combined with their error estimation to predict runoff and release early warning for dam operation based on an optimization scheme (Saavedra et al. 2009).

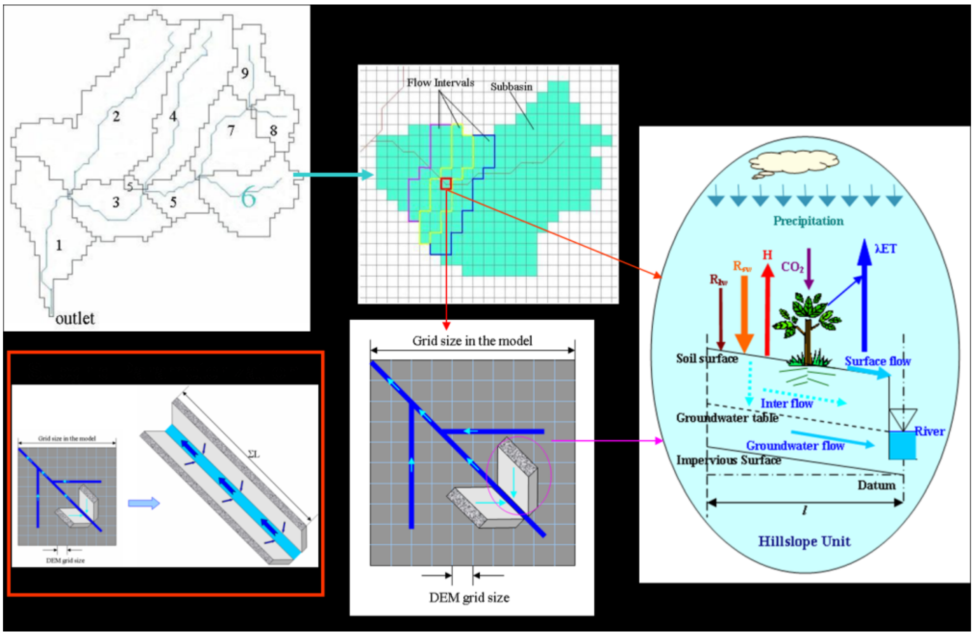

*Figure 3: The water and energy based distributed hydrological model*

## 2. Summary and outlook

In order to improve surface and atmospheric prediction, the (reel) group developed a coupled land-atmosphere satellite data assimilation system as a new approach for physical downscaling. The whole system and its components were tested with the CEOP datasets. It showed that the system can improve the surface initialization and subsequently the representation of its interaction with the atmosphere. Nevertheless, in order to achieve an accurate quantitative precipitation prediction, not only the initial surface condition should be improved, but also a better initialization of the atmospheric condition should be addressed. The coupling of the system with a cloud data assimilation system showed very promising results.

However, it should be kept in mind that when coupling different complex models in one integrated system, challenges arise from the spatial and temporal variability of systematic and random errors. Observations such as those provided through the CEOP experiment are essential to improve the different model parameterization schemes, and to quantify the random errors.

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