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Establishment and analysis of a High-Resolution Assimilation Dataset of the water-energy cycle in China

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A R T I C L E I N F O

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A B S T R A C T

For better prediction and understanding of land-atmospheric interaction, *in-situ* observed meteorological data acquired from the China Meteorological Administration (CMA) were assimilated in the Weather Research and Forecasting (WRF) model and the monthly Green Vegetation Coverage (GVF) data, which was calculated using the Normalized Difference Vegetation Index (NDVI) of the Earth Observing System Moderate-Resolution Imaging Spectroradiometer (EOS-MODIS) and Digital Elevation Model (DEM) data of the Shuttle Radar Topography Mission (SRTM) system. Furthermore, the WRF model produced a High-Resolution Assimilation Dataset of the water-energy cycle in China (HRADC). This dataset has a horizontal resolution of 25 km for near surface meteorological data, such as air temperature, humidity, wind vectors and pressure (19 levels); soil temperature and moisture (four levels); surface temperature; downward/upward short/long radiation; 3-h latent heat flux; sensible heat flux; and ground heat flux. In this study, we 1) briefly introduce the cycling 3D-Var assimilation method and 2) compare results of meteorological elements, such as 2 m temperature and precipitation generated by the HRADC with the gridded observation data from CMA, and surface temperature and specific humidity with Global Land Data Assimilation System (GLDAS) output data from the National Aeronautics and Space Administration (NASA). We find that the simulated results of monthly 2 m temperature from HRADC is improved compared with the control simulation and has effectively reproduced the observed patterns. The simulated special distribution of ground surface temperature and specific humidity from HRADC are much closer to GLDAS outputs. The spatial distribution of root mean square errors (RMSE) and bias of 2 m temperature between observations and HRADC is reduced compared with the bias between observations and the control run. The monthly spatial distribution of surface temperature and specific humidity from HRADC is consistent with the GLDAS outputs over China. This study could improve the land surface parameters by utilizing remote sensing data and could further improve atmospheric elements with a data assimilation system. This work provides an effective attempt at combining multi-source data with different spatial and temporal scales into numerical simulations, and the simulated results could be used in further research on the long-term climatic effects and characteristics of the water-energy cycle over China.

1. Introduction

Land surface temperature and moisture conditions affect and are affected by numerous climatological, meteorological, ecological and geophysical phenomena. Therefore, accurate, high-resolution estimates of terrestrial water and energy storages are valuable for predicting climate change, weather, biological and agricultural productivity and flooding and for performing a wide array of studies in the broader biogeosciences (Rodell et al., 2004). As it has

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been widely accepted that land-surface processes play an important role in weather and climate, governing exchanges of heat, moisture and momentum between the surface and atmosphere, it is necessary to represent them more realistically in predicting weather phenomenon (Case et al., 2008; Meng et al., 2011; Wen et al., 2012).

Mesoscale modeling is an effective tool in analyzing and understanding the exchange of water and energy over regional areas, but the lack of observational data for accurate specification of these components in the initial conditions of the model is one of the difficult aspects in the evaluation of such modeling (Meng et al., 2009; Wen et al., 2012). It is clear that land surface is crucial to weather and climate prediction, however, uncertainties may exist in land data, and land surface variables are depicted coarsely in mesoscale atmospheric numerical models (Crétat et al., 2012; Yang et al., 2012a). Because of the lack of high quality observation data and unsatisfactory model results, we consider how to reduce land data uncertainties and how to use considerably more data as input into the models (Case et al., 2008; Wen et al., 2014). China has built abundant meteorological stations that collect high quality land surface data for many years, but the application of these data in numerical weather and climate prediction models is inefficient (Lawrimore et al., 2011). It is urgent to develop a good atmospheric data assimilation scheme for modeling applications (Navon et al., 1990; Zou et al., 2006) Data assimilation effectively combines different types of data with different spatial and temporal scales, and atmospheric data assimilation methods can effectively reduce atmospheric model background errors (Andrews et al., 2009; Gupta et al., 2012; Haarpaintner and Spreen, 2007; Ohba and Ueda, 2010; Rampal et al., 2011).

The Land Data Assimilation System (LDAS), consisting of uncoupled Land Surface Models (LSMs) forced by observations, can be a valuable source of accurate initial land surface conditions for numerical weather prediction (NWP) models. Although some LDAS projects, such as the North American Land Data Assimilation System (NLDAS; (Mitchell et al., 2004)), Global Land Data Assimilation System (GLDAS; (Rodell et al., 2004)), High-Resolution Land Data Assimilation System (HRLDAS; (Chen et al., 2007)) and Korea Land Data Assimilation System (Lim et al., 2012) have been developed, various attempts, such as the 3D/4D-Var (Barker et al., 2004) and the Ensemble Kalman Filter (ENKF) (Evensen, 2004) method, have been made to comprehensively account for observation and model background errors to improve the representation of land–atmosphere interaction in NWP models (Chen et al., 1996; Dai et al., 2003; Sellers et al., 1996). The rapid updating cycling (RUC) system (Benjamin et al., 2004) could improve the quality of the model initial field and is suitable for short time-scale simulations.

In dynamic downscaling, the objective is to obtain high-resolution atmospheric and surface states (weather) and their statistics (climate) as close to reality as possible over the region of interest. Therefore, the accuracy of the downscaling tool in reproducing regional structures and their temporal variability becomes critical (Qian et al., 2003). Unlike fully autonomous global models, regional models are constrained by prescribed lateral boundary conditions. Because of this lateral control, the internal error growth is limited (Laprise et al., 2000). The model atmosphere in regional climate models (RCMs) may drift or decouple from their lateral boundary forcing fields provided by general circulation models (GCMs) or observations (Pan et al., 1999). Thus, we can break a long simulation into shorter ones, and thus both cost and wall-clock time could be reduced by performing regional climate simulations. Model reinitialization and continuous observational data assimilation can minimize possible drift caused by accumulated model errors (Druyan et al., 2001; Horel et al., 1994). To take the advantages of land surface data in numerical weather and climate models and the representation of land–atmosphere interaction over long time scales in China, we have established a three dimension variational (3D-Var) cycling Data Assimilation method based on the Weather Research and Forecasting (WRF) model. Using this method, a large number of high spatial and temporal resolution observations are assimilated into the WRF model, and the model is reinitialized for one day in a long simulation. This work not only could prevent false disturbances from the background field in GCMs but could also reduce the "spin-up" time for every reinitialization and finally improve the simulation (Benjamin et al., 2004).

In addition, the performance of LSMs depends mainly on surface characteristics such as land cover, Green Vegetation Fraction (GVF), Leaf Area Index (LAI) (Lim et al., 2012) and terrain height (Pan et al., 2012). Improvements of such land surface characteristics in LSMs have been important research topics of land surface modeling studies (Gao et al., 2004; Miller et al., 2006; Rha et al., 2008). Trier et al. (2004) found that simulated thermo dynamic stability and convection initiation were affected by the initial soil moisture distribution. Case et al. (2008) showed that using high-resolution representations of surface properties, such as vegetation, soil temperature and moisture and sea surface temperature in the WRF model led to a better understanding of land surface–atmosphere interactions and an improvement of numerical weather and climate predictions. In addition, some studies indicated that initializations of weather and climate models with high-resolution land data could also result in a similar improvement (Chen et al., 2007; Holt et al., 2006).

China, with one fifth of the global population, has been undergoing significant environmental changes due to rapid changes in land use and economic growth, which is of great importance for agriculture and water resources (Piao et al., 2010). Therefore, better representation of land surface processes in models can provide pivotal information for sustainability in China. In addition, the lack of improved high-resolution land surface information hinders accurate prediction of weather and climate as well as its impact on sustainable development.

As this point is concerned, a 3D-Var cycling Data Assimilation method and surface characteristics, such as GVF, Digital Elevation Model (DEM) data and land use types will be used for the WRF model to improve simulation and represent a realistic land–atmosphere interaction in China. Its design framework will be introduced in this paper. A High-Resolution Assimilation Dataset of the water-energy cycle in China (HRADC) is finally generated by WRF model, which integrates high-resolution in-situ observation data and up-to-date land surface information from the Moderate Resolution Imaging Spectroradiometer (MODIS). The HRADC has a horizontal resolution of 25 km for near surface meteorological data such as air temperature, humidity, wind vectors and pressure (19 levels from 50 to 1000 hPa), soil temperature and soil moisture (4 levels from 0.1 to 2 m), surface temperature, 3-h downward/upward short/long radiation, latent heat flux, sensible heat flux and ground heat flux. Finally, a comparison of HRADC with the automatic weather station gridded dataset from the China Meteorological Administration (CMA) and GLDAS outputs is used to demonstrate its validity and usability in this paper.

2. Data and model description

2.1. HRADC configuration

HRADC is different from uncoupled Land Surface Models, such as NLDAS or GLDAS, because it is generated by the two-way coupling WRF model, which combines the atmospheric and land surface models. Although the LSM is driven by model-based near-