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SIMULATING OF LAND SURFACE SOIL MOISTURE AND ENERGY FLUX IN NORTHERN AFRICA USING A LAND DATA ASSIMILATION SYSTEM AND UKMO OUTPUT

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In this study, we generated hourly surface soil moisture and land surface energy fluxes in the Northern Africa region, by using the land data assimilation system developed at the University of Tokyo (LDAS-UT) which is driven by the UK Met Office (UKMO) weather prediction model output. The soil moisture simulated by LDAS-UT was compared against that simulated by land surface model (LSM), along with the 3-hourly Tropical Rainfall Measuring Mission (TRMM) rainfall in the Medjerda River Basin. The comparison demonstrates the capability of LDAS-UT to partly decrease the error inherited from biased forcing data. For the whole domain comparison, results also show that the soil moisture field simulated by LDAS-UT is more realistic than that by LSM. The comparison between LDAS-UT soil moisture with the Advanced Microwave Scanning Radiometers for EOS (AMSR-E) soil moisture products indicates that LDAS-UT is able to provide more comprehensive information in the region and/or during the period that satellite fails to provide observation. Moreover, by comparing Bowen ratio field generated by LDAS-UT and by LSM with the land cover map, the capability of LDAS-UT to simulate energy flux was verified. This study reveals the potential of LDAS-UT for simulating land surface fluxes in ungauged regions.

***Key Words*:** *Land Data Assimilation System, UKMO, AMSR-E, Soil Moisture, Energy Fluxes, Bowen Ratio*

1. INTRODUCTION

Surface soil moisture is an essential variable which governs the interactions between land surface and the atmosphere[1,2]. In researches related to the global warming and climate change, soil moisture is serving as an excellent environmental indicator. The distribution pattern of soil moisture, both spatial and temporal, is the key to understanding the spatial variability and scale problems. Moreover, soil moisture also is an important factor in animal and plant productivity and it can even be related to the pattern of settlement in arid and semiarid regions.

Soil moisture profile can be observed at point scale by using gravimetric methods or Time Domain Reflector (TDR). These methods are commonly used to provide accurate and temporal-continuous soil moisture information and adopted by the meteorology, hydrology and agriculture stations. But these point information are not enough for the regional research and application, and are also not available in the far regions where difficult to access and to build and maintain such stations. On the other hand, Satellite remote sensing offers a possibility to measure surface soil moisture at regional, continental and even global scales. Passive microwave remote sensing provides a means of direct measurement of surface soil moisture[3,4], with coarse resolution (~ order of 10 km) and frequent temporal coverage (daily or bi-daily), which can partly satisfy the temporal resolution needed in the meteorological modeling. However, in the field of weather forecast and hydrology modeling, finer temporal resolution would obviously improve the accuracy and reliability of the forecast.

On the contrary to the limited observations provided by in situ measurements and satellite remote sensing, Land surface models (LSMs) [5,6] are able to provide continuous estimating of surface soil moisture in any scales. However, due to the model initialization, parameter and forcing errors, and inadequate model physics and/or resolution, quality of the model predictions are usually not so good.

The Land Data Assimilation System (LDAS), developed by merging observation information (in situ measurements, satellites remote sensing and so on) into dynamic models (i.e. LSMs), is expected to provide high quality surface energy and water flux estimates with adequate coverage and resolution[7]. For the ungauged and poor-gauged regions, LDAS is a reliable method to downscale the numerical weather prediction model output and to generate land surface status.

The climate in the Northern Africa varies from humid equatorial regimes, through seasonally-arid tropical regimes, to sub-tropical Mediterranean-type regimes. All these climates exhibit differing degrees of temporal variability, particularly with regard to rainfall. Understanding the land atmosphere interaction in this region, especially in the Sahel region, has become the major challenge facing African and African-specialist climate scientists in recent years[8,9]. Simulating land surface fluxes over this region is also a challenging topic, since in-situ observations are not available for current research.

This study aims to deal with following two issues: one is to generate land surface fluxes over this region by using LDAS-UT which is driven by the weather model output data; the other is to investigate the capability of LDAS-UT by comparing the its results with LSM simulations and satellite products, such as 3-hourly TRMM rainfall data[10] and AMSR-E soil moisture products.

In the following sections, we briefly introduce the components and algorithm of LDAS-UT[11]. The condition of application region and the data used in this study will be introduced in section 3. The simulated fluxes by LDAS-UT and LSM will be shown in section 4 with some discussion and analysis. This paper ends at section 5 with some conclusions.

2. THE LAND DATA ASSIMILATION SYSTEM

LDAS-UT is a variational data assimilation system. The brightness temperature data observed by AMSR-E at C-band and X-band are assimilated into the system to get better soil moisture estimation and then to improve the land surface energy fluxes simulation.

2.1 Three Components of LDAS-UT

From the view of system structure, LDAS-UT is composed by three components: a dynamic model for propagating status variables, an observation operator for introducing new information into the dynamic model, and an optimization model to minimize the cost function of the system.

The dynamic model of LDAS-UT is a Land Surface Model (LSM) named Simple Biosphere model (SiB2)[5], which is used to calculate surface fluxes and soil moisture for each time step.

The model operator of LDAS-UT is a radiative transfer model (RTM), which estimate microwave brightness temperature from corresponding land surface status. The RTM used in LDASUT has two components: a volume scattering part and a surface scattering part[12]. The volume scattering part simulates the radiative transfer process inside soil layer by a 4-stream based RTM in which the multiply scattering effects of dry soil medium is calculated by the dense media radiative transfer model (DMRT)[13]. The surface scattering part simulates the surface scattering effects at the land-atmosphere interface by Advanced Integral Equation Method (AIEM)[14].

The minimization scheme of LDAS-UT is the shuffled complex evolution method[15], which search for optimal values of soil moisture through minimizing the difference between modeled and observed brightness temperature.

2.2 Parameters Optimization by LDAS-UT

LDAS-UT employs a dual-pass assimilation technique. In pass 1, the model parameters are estimated by using long-term (~ months) meteorological forcing data and remote sensed brightness temperature data, while the soil moisture and fluxes are assimilated in pass 2. More details of the algorithm can be found in the figure 1 of Yang et al.[11].

The initial parameters of this system are obtained from global data sets, for example, the LAI from Moderate Resolution Imaging Spectroradiometer (MODIS), and the soil and vegetation parameters and land cover types from International Satellite Land-Surface Climatology Project (ISLSCP) initiative II[16].

As we know, the parameters provided by the global data set sometimes are problematic, due to the different spatial resolutions and the original application purposes of various data sources. The pass 1 of LDAS-UT, parameter optimization pass, is able to generate a good parameter set from the global initial parameters. The physical basis of the parameter optimization is following: (1) the simulated soil moisture is mainly dependent on the forcing data and soil parameters; (2) the parameters are almost stable values during a season (around 3 months); (3) the satellite provides reliable observation. Based on those assumptions, we run the SiB2 continuously for a period around two months, which is so-called optimization window. During this optimization window, a series of brightness temperature was estimated with RTM when the AMSR-E observation are available. The summation of the squared difference between the simulated TB and AMSR-E observed TB is the so-called cost. Through minimizing the cost, the parameter set are optimized. The optimized parameters in pass 1 are soil porosity, soil texture (percentage of sand and clay), surface roughness parameters (r.m.s height and correlation length), vegetation RTM parameters (χ and b'). Besides these parameters, in order to get better performance, the initial soil moisture and temperature at each layer are also optimized in the first run.

3. APPLICATION REGION AND USED DATA

3.1 Description to The Application Region

Northern Africa, experiencing a dramatic climate regimes variation from the semiarid desert in the south to a mild Mediterranean climate in the North, has an environment vulnerable to the climate change. On the other hand, it is very difficult to monitor the environmental changes in this region due to its severe climate conditions.

In this study, the application region is mainly located at Tunis, from 7E to 12 E and from 30N to 37.5 N. The application period is from beginning of January to the end of March, 2003. In this season, some heavy rainfall usually occurred and caused flood disaster.

3.2 Used AMSR-E Data Set

The brightness temperature of AMSR-E observed at 6.925 GHz and 18.7GHz were used as the observation data in this research, by considering the Radio Frequency Interference (RFI) effect is not so strong in this region. Observation times of AMSR-E are local noon and midnight. In this application, only the midnight observation data was used since it was obtained at nighttime overpass and the land surface temperature profile was almost uniform. The assimilation window of LDAS-UT is, therefore, decided as one day. The resolution of LDAS-UT is also decided by the resolution of AMSR-E data, as the 0.5 degree.

3.3 Used Meteorological Forcing Data

In this research, both the LDAS-UT and LSM (SiB2) were driven by UKMO numerical weather prediction model output to generate hourly land surface fluxes. The UKMO data set was archived at the model output data base of the Coordinated Energy and Water Cycle Observation Project (CEOP) [17]. The original data is offered in a 1.25 degree resolution four times per day (at 03:00, 09:00, 15:00 and 21:00 UTC). Interpolation was used to get hourly forcing data.

4. RESULTS AND DISCUSSIONS

With UKMO model output as the meteorological forcing data, we run LDAS-UT and LSM separately to get two sets of land surface fluxes. Since there are not in-situ observed fluxes available, we investigate the simulated results from three aspects: (1) comparing hourly soil moisture time series of LDAS-UT and LSM with the 3-hourly TRMM rainfall in a basin scale; (2) comparing snapshot of simulated soil moisture with AMSR-E products and topographical map over whole domain; (3) comparing monthly averaged Bowen ratio of LDAS-UT and LSM with the satellite land cover map.

4.1 Comparing hourly soil moisture time series in the Medjerda river basin

As the first step, we focused the comparison in the Medjerda river basin (35.9N – 36.6N, 8.3E – 10.0E), the largest water resource in Tunisia, in a time scale of a rainfall event.

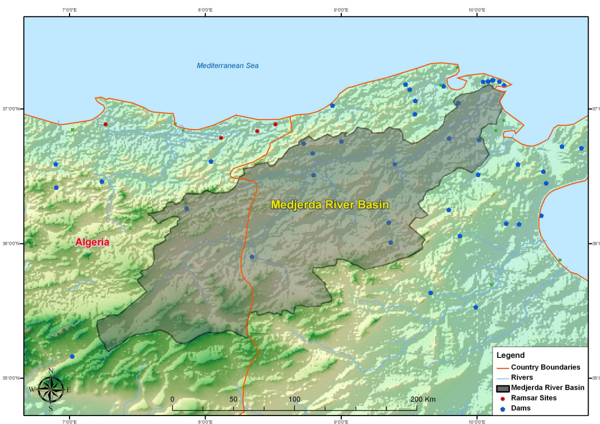


Fig. 1 The location of Medjerda river basin

Figure 1 shows a geography map of the location of Medjerda basin. The Medjerda River flows through the northern part of Tunisia to the Mediterranean Sea and creates a catchment of 23,700km^2. It has a population of 2,100,000 within its basin. A large-scale flood occurred in the Medjerda River Basin in January 2003, which flooded the lower plain area for a month and caused severe socio-economic damage.

The hourly soil moisture estimation field generated by LDAS-UT and LSM were averaged over whole basin and were shown in figure 2 as the

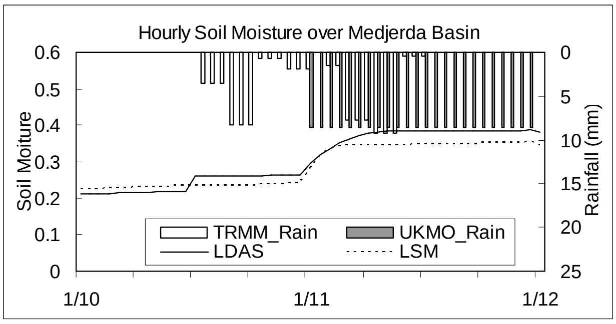


Fig. 2 Averaged hourly soil moisture generated by LDAS-UT and LSM in the Medjerda river basin, from January 10 to 12, 2003. Averaged TRMM rainfall and UKMO rainfall were also plotted as vertical bars.

solid line and dash line, respectively. The 3-hourly rainfall from TRMM and UKMO rainfall were plotted as the vertical blank bars and filled bars.

From figure 2, it is clear that TRMM detected a heavy rainfall event started around 13:00 of January 10, 2003, while UKMO provided a delayed rainfall starting from 0:00 of 11th. Since UKMO rainfall data is biased during January 10th, the soil moisture simulated by LSM only did not show any increase during this day. On the contrary, since the land wet situation was detected by satellite and this information was assimilated into LDAS-UT, the soil moisture simulated by LDAS-UT increased. By assimilating AMSR-E brightness temperature into LSM, LDAS-UT therefore is able to partly decrease the error caused by biased forcing data.

4.2 Comparing soil moisture over whole domain

Figure 3 shows the snapshots of three sets of soil

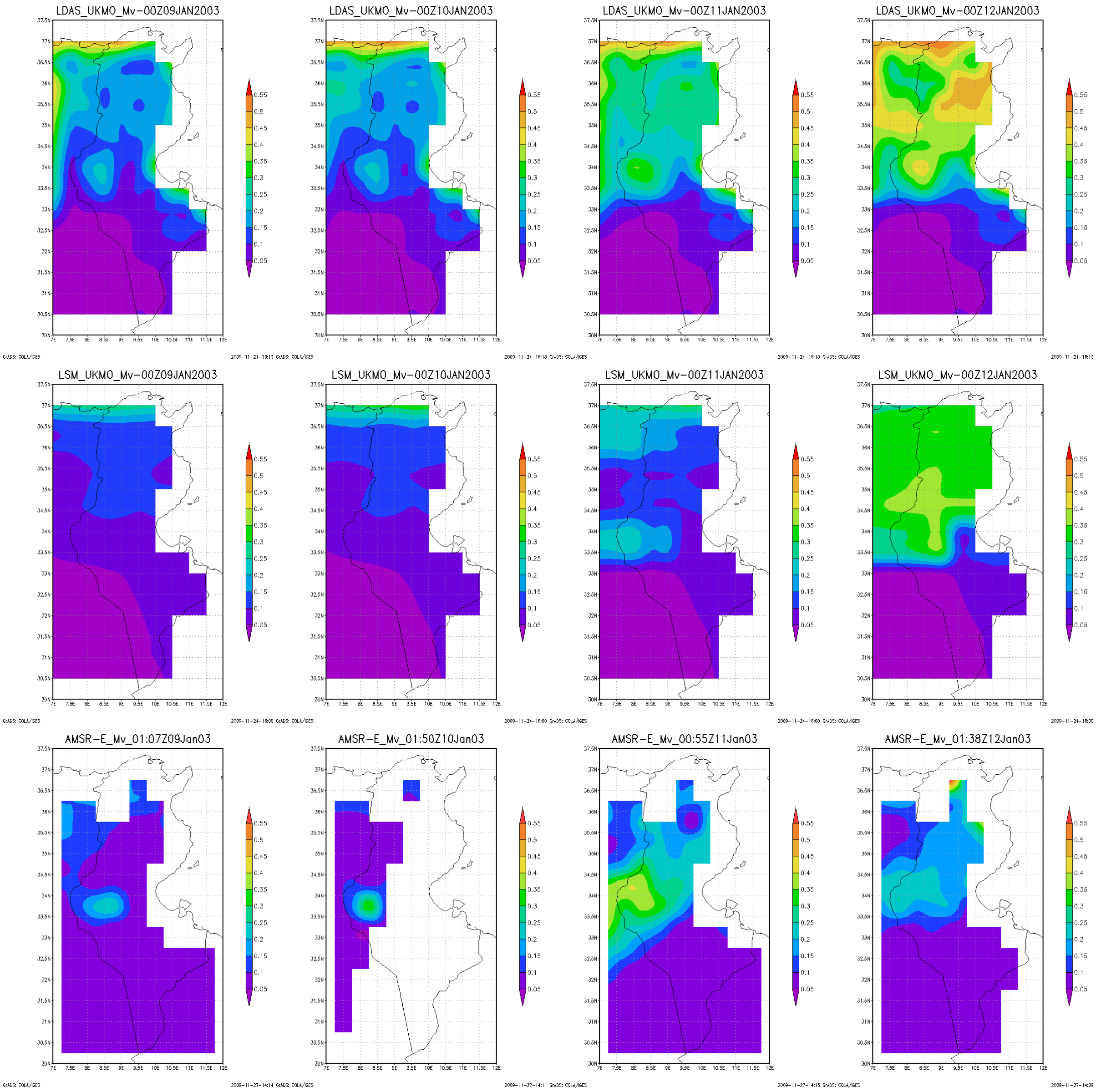
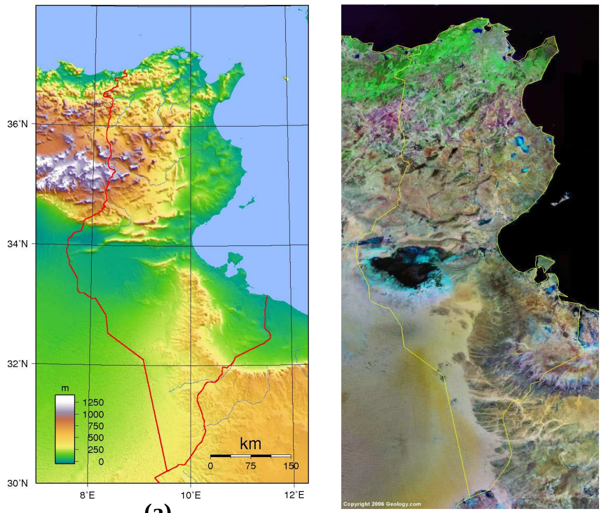


Fig. 3 Comparison of soil moisture field of LDAS-UT (upper row), LSM (middle row) and AMSR-E (bottom row) over whole study domain, from left to right in the order of Jan 9, 10, 11 and 12, 2003.



(a) (b)

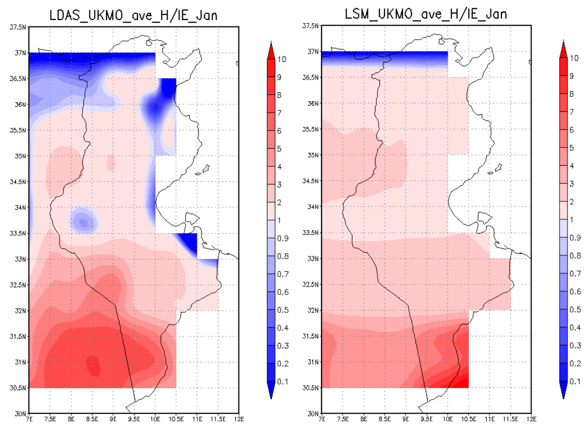
Fig. 4 (a) Topographical map and (b) land cover map of the study region.

moisture over the whole domain: Upper row and middle row are the soil moisture of LDAS-UT and LSM at the 00:00 of January 9, 10, 11 and 12, 2003, respectively. The bottom row is the AMSR-E soil moisture products observed at midnight.

As shown by the LDAS-UT soil moisture map in figure 3, the southwest of study region, where part of Sahara desert located, is the driest part. LDAS-UT also estimated high soil moisture value in the Northwest region, where is the edge of Mediterranean Sea. Comparing the soil moisture patterns with the topographical map (figure 4a), it is clear that the soil moisture simulated by LDAS-UT is more realistic than that of LSM, which shows less variation and poor relationship to the topography. For instance, LDAS-UT simulated a wet region around (34N, 8.5E), where is the salt lake named Chott el Djerid, while LSM failed to generate a wet spot here. This wet region was also detected by AMSR-E. But we also found that AMSR-E failed to provide full coverage over whole domain, partly due to the limitation of algorithm and sensors. One more thing which should be noted is that AMSR-E can only provide twice observation per day while LDAS-UT is able to generate hourly soil moisture. Comparing to the AMSR-E soil moisture products, LDAS-UT therefore is able to provide more information of spatial and temporal variation in surface soil moisture.

4.3 Comparing Bowen Ratio over whole domain

Besides soil moisture, LDAS-UT also generated the land surface energy components: net radiation, sensible heat, latent heat and grand soil heat. As we know, the land surface energy flux is important to understand the land atmosphere interaction and also to weather forecast and climate study. But due to the lack of in situ observation data, we only can validate the LDAS-UT energy flux output indirectly.



(a) (b)

Fig. 5 Comparison the monthly averaged Bowen Ratio simulated by LDAS-UT (a) with that by LSM (b), over whole study region.

Figure 5 shows the monthly averaged Bowen Ration of LDAS-UT (5a) and that of LSM (5b). From figure 5, it is clear that, for both simulations, the sensible heat flux generally dominates the energy budget over whole domain, except the north coast region where the latent heat flux is dominative. The highest Bowen ratio was found in the southwest of study region, Sahara desert, again. By comparing the Bowen ratio show in Figure 5, it is found that LDAS-UT produces more latent heat dominative regions than LSM does. LSM fails to generate the latent heat dominative region around the west coast line and the Chott el Djerid lake. Referring to the land cover map (figure 4b), the distribution patterns of LDAS-UT Bowen ratio are more realistic than that of LSM.

5. CONCLUSIONS

Regional soil moisture distribution is crucial for studies of agricultural, hydrological, ecological and atmospheric processes. In this study, we generated hourly soil moisture and energy fluxes distribution in the Northern Africa region, with using LDAS-UT forced by UKMO numerical weather prediction model output.

The hourly soil moisture time series of LDAS-UT outputs were compared with those of LSM, during a heavy rainfall event in the Medjerda river basin. The results show that LDAS-UT can partly decrease the errors inherited from biased forcing data. Such advantages are based on the assimilating of AMSR-E TB data, which directly related to the land surface status.

For whole study region, LDAS-UT soil moisture shows a good agreement with the topographical map, giving a more realistic pattern than that of LSM. The comparison between LDAS-UT soil moisture and AMSR-E products demonstrates that LDAS-UT is able to provide more comprehensive information in the region and/or during the period that satellite fails to provide observation

Moreover, the Bowen ratio distribution generated by LDAS-UT was also represented in this study. By comparing the results to the geographical and land cover map, we can conclude that the Bowen ratio distribution estimated by LDAS-UT is more realistic than that generated by LSM only.

Due to the lack of in situ observation data, quantitative validation is impossible now. The qualitative results from this study can be served as the primary step for the land atmosphere interaction research in this region. Based on the agreement of GEOSS (the Global Earth Observation System of Systems) African Water Cycle Symposium (AWCS), in situ observation network will be organized in near future. With the in situ observation data provided by AWCS, LDAS-UT can be well calibrated and its performance can be further improved.

In this study, all the data and parameters were obtained from global data set: meteorological forcing data from UKMO output; satellite remote sensing data from AMSR-E; vegetation data from MODIS and parameters from ISLSCP II. All data are public accessible and free. Therefore, The experiences earned from this study are also useful for the region where is ungauged or poor-gauged.

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