Optimal exploitation of AMSR-E signals for improving soil moisture estimation through land data assimilation

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1. Introduction

- Regional soil moisture can be estimated by assimilating satellite microwave brightness temperature into a land surface model (LSM). However, currently existing microwave signals are of different properties such as polarization, observing time, and microwave frequency, which have different sensitivities to soil moisture. It is necessary to find out the optimal ways of choosing these signals for assimilation. By using a dual-pass land data assimilation system (LDAS) [1], this study explores how to improve soil moisture estimation based on sensitivity analyses when assimilating AMSR-E (Advanced Microwave Scanning Radiometer for Earth Observing System) brightness temperatures.
- Analyzed are the effects of different polarizations (horizontal and vertical), satellite overpass times (nighttime and daytime), and different frequency (from 6.9 GHz to 36.5 GHz) combinations on the accuracy of soil moisture estimation by the LDAS. Results indicate that the vertical polarized nighttime signals are best for soil moisture estimation in current LDAS. And the land surface model (LSM) need to be further improved to make utilization of horizontal polarized and daytime signals. Finally a frequency combination-based ensemble method is proposed and proved to be robust in soil moisture estimate.

The dual-pass LDAS.

- The LDAS contains a land surface model (SiB2 [2]) to simulate near surface soil moisture, and a radiative transfer model (Q-h [3]) to calculate brightness temperature.
- A time split algorithm is adopted to calibrate time-invariant model parameters in a relative long time window (~months) in pass 1, and optimize near-surface soil moisture in a short time window (~1 day) in pass 2.
- A soil wetness index is defined ($SWI = \frac{T_b(F1)}{T_b(F2)}$ [4]) to extra soil moisture information from microwave brightness temperature measurements.

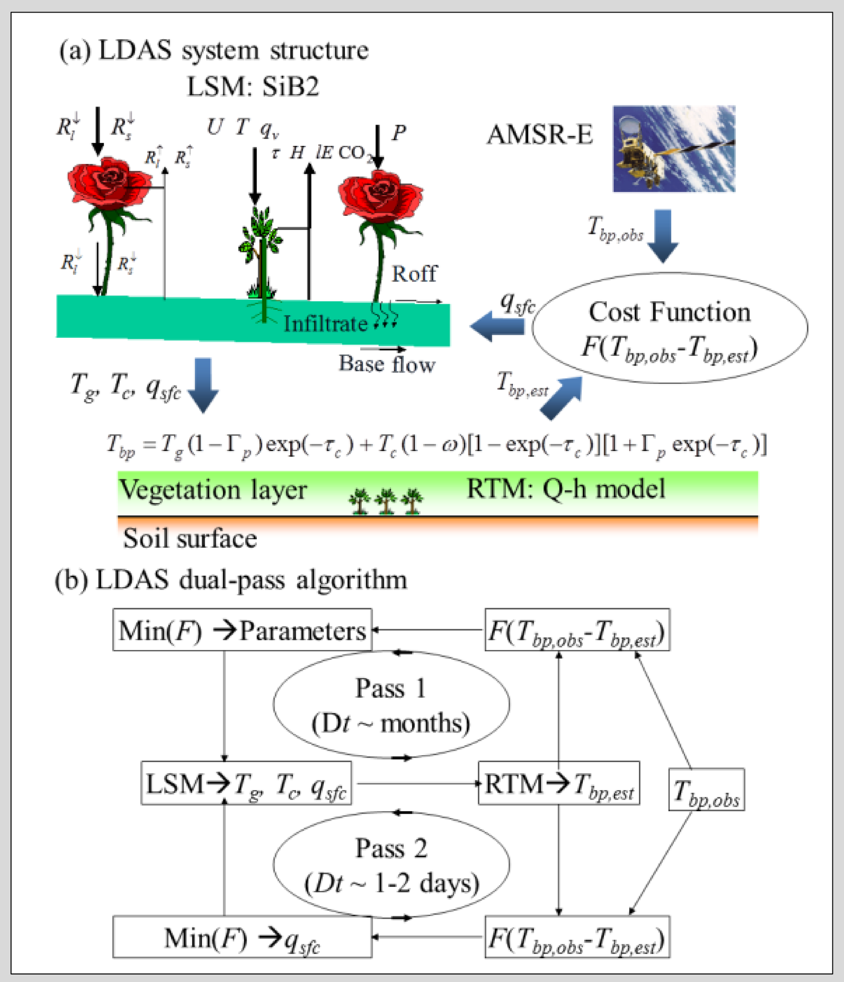


Fig. 1. (a) LDAS system structure and (b) schematic of dual-pass assimilation algorithm. Here, T_g , T_c and θ_{sfc} are land surface temperature, canopy temperature and surface soil moisture, respectively; T_b is the brightness temperature, *F* is the cost function, and Δt is the data assimilation window; R_s is soil reflectivity; and τ_c is the vegetation optical thickness. The polarization, observed value, and estimated value are denoted by the subscript *p*, *obs* , and *est*, respectively.

Study area

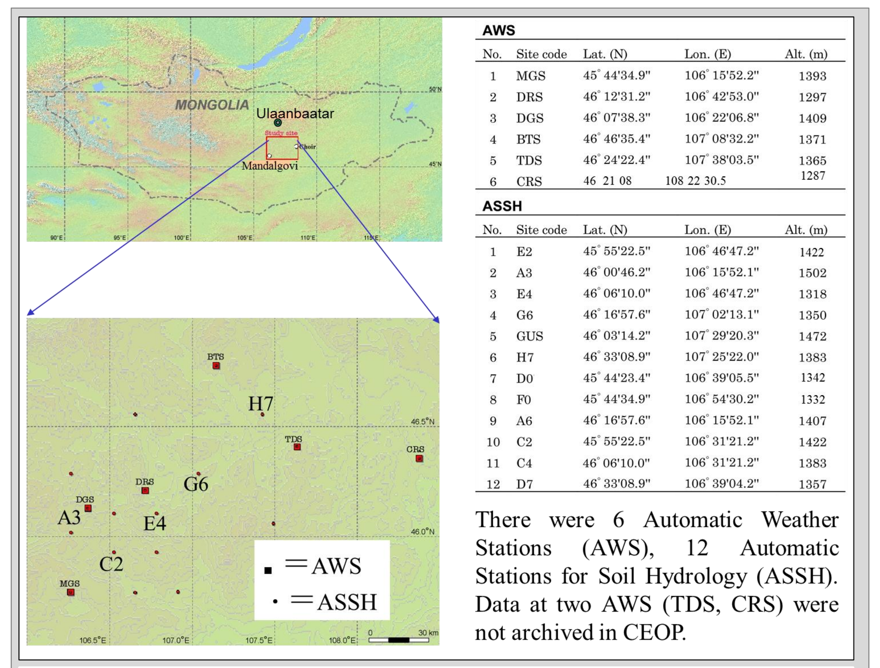


Fig. 2. Sketch of ADEOS II Mongolian Plateau Experiment for ground truth (AMPEX). CEOP archived AWS data at BTS, DGS, DRS, MGS, and soil moisture data at all 12 ASSH and the four AWS.

- The ground truth as well as the forcing data are collected through CAMP-Mongolia reference site (Fig. 2; data available through: http://www.ceop.net/).
- This region is relative homogeneous and provide ideal test base for LDAS validation.

2. Design of experiment cases

Table 1. experiment cases design with respect to different polarizations, observing time, and frequency combinations of AMSR-E signals.

case	Polarization	Overpass time	Frequency combination (GHz)	
			Lower	Higher
Case-ctrl	V-pol	Nighttime	6.9	18.7
case-P	**H-pol**	Nighttime	6.9	18.7
case-T	V-pol	**Daytime**	6.9	18.7
case-Fij	V-pol	Nighttime	***Fi***	***Fj***

- Several cases are designed by choosing different signals (Table 1).
- In addition, supplement cases are designed to study the role of model parameters in soil moisture estimation in LDAS. In these cases the model parameters are set equal to the reference case calibrated ones ("control parameters").

3. Result and discussion

(a) v-pol vs. h-pol

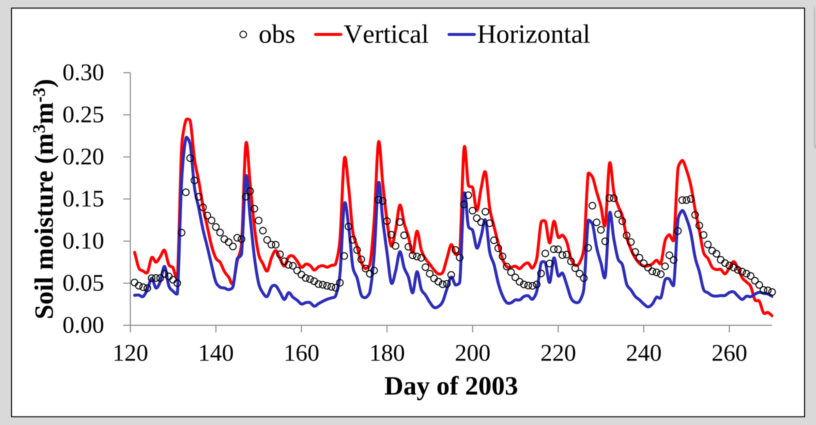


Fig. 3. comparisons of areal-averaged near-surface daily mean soil moisture between in situ observations and LDAS estimate by assimilating different polarization of microwave signals.

Table 2. statistics of LDAS performance and main model parameters in polarization study cases (*h* and *q*: surface roughness parameters).

case	v-pol	h-pol	h-pol+ctrl para
Performance indices			
R	0.81	0.81	0.83
MBE	0.012	-0.026	-0.009
RMSE	0.03	0.036	0.031
Main model parameters			
sand(%)	52.0	32.8	52.0
clay(%)	30.1	13.1	30.1
porosity	0.36	0.36	0.36
h (10^{-4})	2.21	2.52	2.21
q	1.00	0.97	1.00

- The assimilation of two polarized signals follows the observed trend well (Fig 3). Indicating both polarizations are sensitive to soil moisture changing.
- The horizontal one yields underestimate, while is improved when using the "control parameters", indicating that h-pol is more sensitivity to land surface heterogeneity than v-pol.

(b) Daytime vs. nighttime

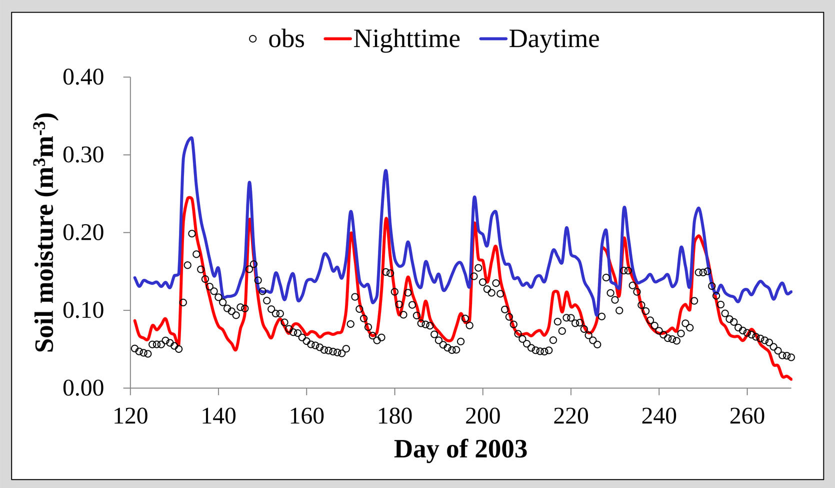
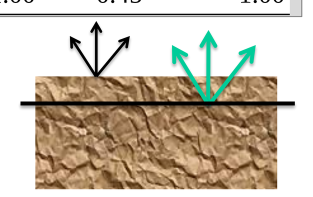


Fig. 4. comparisons of areal-averaged near-surface daily mean soil moisture between in situ observations and LDAS estimate by assimilating different observing time of microwave signals.

Table 3. statistics of LDAS performance and main model parameters in satellite overpass time study cases.

case	nightgime	daytime	daytime+ ctrl para
Performance indices			
R	0.81	0.62	0.59
MBE	0.012	0.067	0.033
RMSE	0.03	0.075	0.045
Main model parameters			
sand(%)	52.0	41.3	52.0
clay(%)	30.1	32.4	30.1
porosity	0.36	0.46	0.36
h (10^{-4})	2.21	11.72	2.21
q	1.00	0.45	1.00

- Assimilating the daytime signal will obviously overestimate surface soil moisture, even when driving by the nighttime case calibrated model parameters ("control parameters").



- The overestimate might be attribute to the effective soil temperature is lower than the surface skin temperature which is simulated by LSM during the daytime. A larger T_g input may require higher soil reflectivity to satisfy the observed T_b, and thus generate higher soil moisture estimate.
- Comparison between calculated effective surface temperature and 3cm depth temperature observations (Fig. 5) supported above explanations.

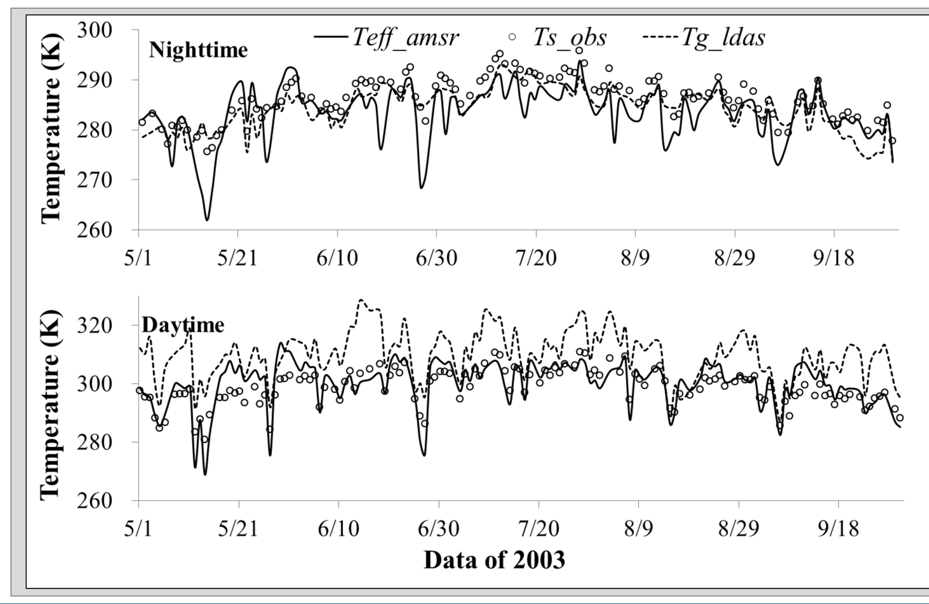


Fig. 5. The upper panel shows the comparison between T_{eff_amsr}, T_{s_obs} and T_{g_ldas} for nighttime, and the lower panel for daytime. Where T_{eff_amsr} is the effective surface temperature calculated from observed soil moisture and AMSR-E brightness temperature; T_{s_obs} is the observed ground soil moisture; T_{g_ldas} is LDAS estimated ground surface temperature.

(c) Frequency based ensemble

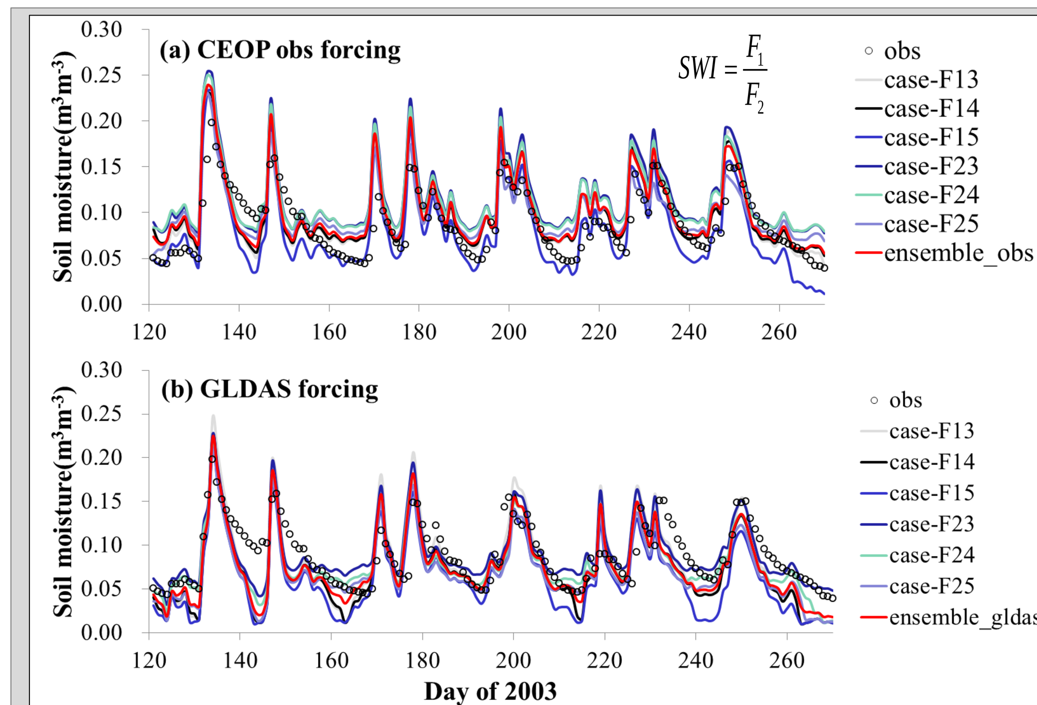


Fig. 6. LDAS estimated soil moisture of all frequency combination cases compared with observed areal mean daily near surface soil moisture: (a) Driven by CEOP observed forcing data; (b) Driven by GLDAS data.

Table 4. Performance indices of soil moisture estimates and their ensemble estimate when assimilating different frequency combinations of microwave data and driven by either CEOP observed forcing data or GLDAS data compared with station-averaged daily mean near-surface soil moisture observations (Unit for MBE and RMSE: m³ m⁻³).

	case-ctrl	case-F14	case-F15	case-F23	case-F24	case-F25	Ensemble
CEOP forcing							
R	0.81	0.79	0.84	0.79	0.77	0.73	**0.80**
MBE	0.012	0.011	-0.009	0.028	0.025	0.010	**0.013**
RMSE	0.028	0.026	0.026	0.037	0.035	0.026	**0.027**
GLDAS forcing							
R	0.80	0.79	0.80	0.74	0.74	0.74	**0.78**
MBE	-0.009	-0.016	-0.027	0.003	-0.008	-0.018	**-0.013**
RMSE	0.031	0.031	0.037	0.025	0.027	0.031	**0.028**

- Assimilating different frequency-combinations produces different soil moisture estimates and none is always superior to the others.
- A single frequency combination performs poor mainly due to three reason:
  1. Imperfect radiative transfer model;
  2. Bias in forcing data;
  3. Uncertainties of frequency-dependent atmosphere influence.

- **Frequency combination based ensemble estimation**

$$\theta_{ensemble} = Average\{\theta_{ij}\}\ (i = 1,2;\ j = 3,4,5)$$

- The ensemble method is expected to filter out the uncertainties, and performs more robust when driven by different forcing data (Fig. 6).

4. Summary

- It is recommended to assimilate vertical polarized, nighttime signal in current LDAS.
- The proposed frequency combination-based ensemble method can give robust estimate of surface soil moisture.
- The horizontal polarized signal is expected to improve soil moisture estimate if the LSM take land surface spatial heterogeneity into account.
- The daytime signal can also improve the estimate by revising LSM to simulate effective surface layer temperature.

References

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