ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Environmental Sciences 10 (2011) 2731 – 2739

Procedia
Environmental Sciences

2011 3rd International Conference on Environmental Science and Information Application Technology (ESIAT 2011)

A Microwave Wetland Surface Emissivity Calibration Scheme Using SCE-UA Algorithm and AMSR-E Brightness Temperature Data

Shenglei Zhang[a] and Jiancheng Shi

State Key Laboratory of Remote Sensing Science, Jointly Sponsored by the Institute of Remote Sensing Applications of Chinese Academy of Sciences and Beijing Normal University, Beijing 100101, China

[a] *zhaoshengyong374@126.com*

Abstract

Determination of land surface emissivity is important for land surface characterization, satellite data assimilation and retrievals of geophysical parameters from satellite observations. However, it is a very complex problem to calculate the microwave wetland surface emissivity, and there has not been a land radiative transfer model (RTM) for calculating it. This study presents a microwave wetland surface emissivity calibration scheme based on the National Center for Atmosphere Research (NCAR) Community Land Model version 2.0 (CLM2.0), microwave land emissivity model (LandEM), Shuffled Complex Evolution algorithm (SCE-UA) and gridded Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) satellite brightness temperature (BT) data, which considers the influences of the land surface sub-grid scale heterogeneity. It used the outputs of the CLM2.0 as the inputs of the LandEM to simulate the AMSR-E BT, SCE-UA algorithm to calibrate the microwave wetland surface emissivity with the AMSR-E BT observation data. The experimental results indicate that the SCE-UA algorithm can effectively calibrate the microwave wetland surface emissivity and the calibrated microwave wetland surface emissivity possesses excellent transportability. Although the calibration scheme presented in this study lacks the physical mechanism, this study provides a promising solution to obtain the microwave wetland surface emissivity through parameter calibration method, which will greatly improve land data assimilation study.

Keywords: Wetland, Community Land Model, Microwave surface emissivity, SCE-UA, AMSR-E, Land data assimilation.

1. Introduction

Land data assimilation provides a framework for taking full advantage of land surface model estimation and various observations to obtain the optimal estimation of land surface variables. The applications of microwave remote sensing data in land data assimilation have been a topic of current interest in many

doi:10.1016/j.proenv.2011.09.424

studies due to their high temporal and spatial resolutions and availability. However, the commonly used land surface models, such as the NCAR CLM2.0 [1], are usually designed to consider the land surface sub-grid heterogeneity. To confuse the mean state of the whole grid with that of any fraction in the grid directly would destroy the fundamental framework of the land surface sub-grid heterogeneity. In the CLM2.0, wetland patches are modeled as columns of water (no soil). This is a simple parameterization method in land surface process study, which is not necessarily reasonable. If we take the wetland patch in a model grid cell as a water surface in the process of the BT simulation, the difference between the simulated and observed BT is very obvious, which will have some uncertain effects on the assimilation results. Wetlands and inundated areas (including rice paddies) are estimated to occupy around 8.6×10^6 [km^2] of the Earth's surface. Although they only cover about 6% of the Earth's ice-free land surface, they play a major role in hydrological and biochemical cycles [2]. Therefore, how to calculate the microwave wetland surface emissivity is worthy of careful study.

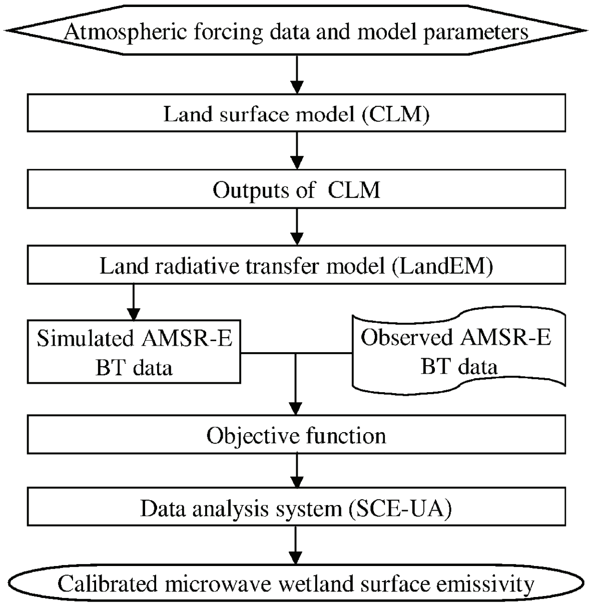

Fig. 1 Flowchart of the microwave wetland surface emissivity calibration scheme.

The gridded AMSR-E BT data is usually the mean state of the whole grid cell and can be regarded as a so-called mixed pixel problem, which is equal to the area weighted sum of all sub-pixels BT. If there is a wetland sub-grid patch in a model grid cell,

$$T_b = \sum_{i=1}^{m-1} \alpha_i T_b^{\,i} + \alpha_m \varepsilon T \,, \tag{1}$$

where m is the number of sub-pixels within the whole grid cell (a sub-pixel corresponding a sub-grid land cover type, such as bare soil, vegetation, snow, glacier, lake and wetland), α_i is the area-weighted fraction of the *i-th* sub-pixel, $T_b^{\,i}$ is the *i-th* sub-pixel BT, ε is the microwave wetland surface emissivity, T is the effective temperature of the wetland patch (provided by the CLM2.0), α_m is the area fraction of the wetland patch in the model grid cell and T_b is the BT based on the grid cell.

It is a very complex problem to calculate the microwave wetland surface emissivity, and there has not been a land RTM for calculating it. To our knowledge, there have been few studies on land surface sub-grid scale heterogeneity and calculating the microwave wetland surface emissivity when directly assimilating the gridded AMSR-E BT data. In this study, we present a microwave wetland surface emissivity calibration scheme, which takes the microwave wetland surface emissivity as a parameter needed to be calibrated in the process of the BT simulation.

2. Methodology

The study presents a microwave wetland surface emissivity calibration scheme based on the NCAR CLM2.0, LandEM, SCE-UA and gridded AMSR-E BT observation data, which considers the influences of the land surface sub-grid scale heterogeneity. Fig. 1 shows the flowchart of the microwave wetland surface emissivity calibration scheme. It used the outputs of the CLM2.0 as the inputs of the LandEM to simulate the BT, SCE-UA algorithm to search for the optimal values of the LandEM parameters and calibrate the microwave wetland surface emissivity in their feasible space by minimizing the objective function.

Land surface model. The CLM2.0 has been developed by combining the best features of three commonly used land surface models: the NCAR Land surface Model (LSM), the Biosphere-Atmos-

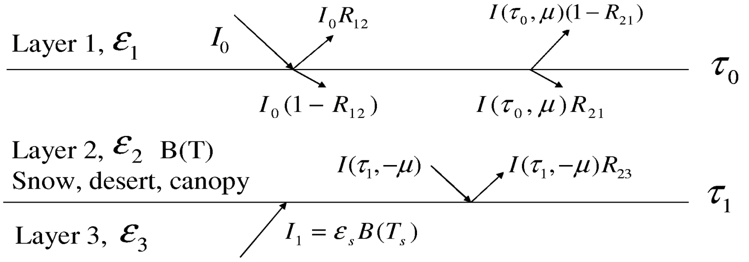

Fig. 2 A schematic diagram of radiative transfer process for scattering and emission material on land surface.

phere Transfer Scheme (BATS), and the model developed at the Institute of Atmospheric Physics (IAP94) in Beijing. Although the CLM2.0 is a single-column model, it considers the sub-grid scale heterogeneity by subdividing each grid cell into a number of sub-grid fractions. Each sub-grid fraction contains a single land cover type. The vegetated fraction of a model grid cell is further divided into patches of up to four plant functional types, each with its own leaf and stem area index and canopy height. Energy and water balance calculations are performed over each patch at every time step and each patch maintains its own prognostic variables. The patches within a model grid cell respond to the mean conditions from the overlying atmospheric grid box, and this grid box, in turn, responds to the area-weighted mean fluxes of heat and moisture from the patches. The patches within a model grid cell do not interact with each other directly. The CLM2.0 has one vegetation layer, ten unevenly spaced vertical soil layers, and up to five snow layers. More details about the specific process and application of the CLM2.0 see [1, 3].

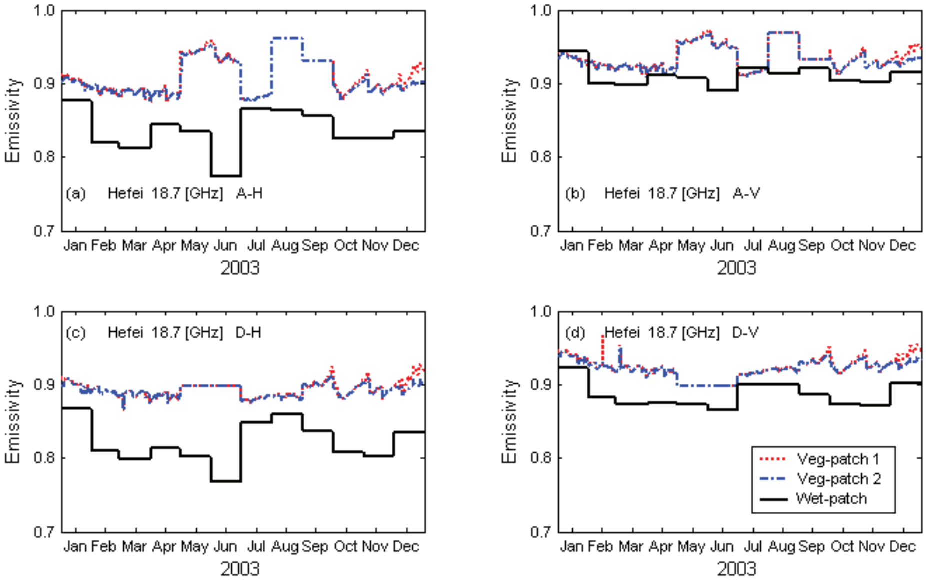

Fig. 3 Time series of the emissivities simulated by the landEM in two sub-grid vegetation patch and calibrated by the SCE-UA algorithm in the sub-grid wetland patch (monthly mean) at 18.7 [GHz] in 2003 at HeFei station: (a) A-H; (b) A-V; (c) D-H; (d) D-V. A-H is ascending orbit and horizontal polarization, A-V is ascending orbit and vertical polarization, D-H is descending orbit and horizontal polarization, and D-V is descending orbit and vertical polarization.

Land radiative transfer model. We used the LandEM [4] to quantify the land emissivity over bare soil, snow and vegetation surface in this study. In general, land surface is represented as a multilayer medium above an irregular subsurface. The LandEM only considers a three-layer medium, as shown schematically in Fig. 2, where τ is the optical thickness; μ is the cosine of the incident zenith angle; I is the radiance; I_1 is the upwelling radiance at $\tau = \tau_1$ from the bottom layer; I_0 is the downwelling radiance at $\tau = \tau_0$ from the top layer; $B(T)$ is the Planck function; T is the thermal temperature; R_{ij} is the reflectivity at the interface between the two layers. The top and bottom layers are considered spatially homogeneous and are represented by uniform dielectric constants. For example, the top layer is the air having a dielectric constant ε_1, whereas the bottom layer is characterized by a dielectric constant ε_3. Conversely, the middle layer is spatially inhomogeneous and contains scatterers such as snow grains, sand particles, and vegetation canopy. Radiative transfer calculations are used to determine the volumetric scattering within the middle layer, while the modified Fresnel equations are used to determine the reflectance at the two interfaces. For bare soil surface, the three-layer model may be regarded as a two-layer model, that is, the top air layer and bottom soil layer. More details about the LandEM see [4].

Brightness temperature of water body. We consider a simple case represented by a smooth, calm, water surface. For a specular surface, the reflectivity is the square of the Fresnel reflection coefficient. The complex dielectric constant is calculated following Klein and Swift model [5, 6].

Optimization algorithm. We used the SCE-UA algorithm [7-8] to search for the optimal values of the LandEM parameters and calibrate the microwave wetland surface emissivity. The SCE-UA algorithm is a global optimization method to automatically calibrate the model parameters of the conceptual rainfall-runoff model for its special difficulties, such as nonlinear, multi-extreme, no specific expression and interval bound constraints. It is an effective and efficient optimization technique for nonlinear constrained problems and does not require an explicit expression for the objective function or the partial derivative of an objective function. In this study, we use it to calibrate the microwave wetland surface emissivity. More details about the SCE-UA algorithm see [7-8].

In order to calibrate the microwave wetland surface emissivity, we defined the following objective function:

$$F_{obj} = \sqrt{\frac{\sum_{i=1}^{m}\left(T_{b,est}^{fh} - T_{b,obs}^{fh}\right)^2 + \sum_{i=1}^{m}\left(T_{b,est}^{fv} - T_{b,obs}^{fv}\right)^2}{2m}}, \quad (2)$$

where $T_{b,obs}^{fh}$ and $T_{b,obs}^{fv}$ are the horizontal and vertical polarization BT observed by AMSR-E sensor at f frequency [GHz]; $T_{b,est}^{fh}$ and $T_{b,est}^{fv}$ are the horizontal and vertical polarization BT simulated by the LandEM at f [GHz], and m is the number of satellite observations in the calibration interval using SCE-UA algorithm.

Table 1. Reference stations information.

Station	Location	Sub-grid Patch Type	Area Fraction
HeFei	(31.87ºN, 117.23ºE)	corn	13.7%
		broadleaf deciduous temperate shrub	0.3%
		wetland	86%
TongYu	(44.42ºN, 122.87ºE)	corn	86.3%
		needleleaf evergreen temperate tree	0.9%
		needleleaf deciduous boreal tree	0.9%
		C_3 non-arctic grass	0.9%
		wetland	11%

AMSR-E BT observation data. The AMSR-E/Aqua daily quarter-degree gridded BT data from 1st January 2003 to 31st December 2003 used in this study was downloaded from the National Snow and Ice Data Center (NSIDC) [9].

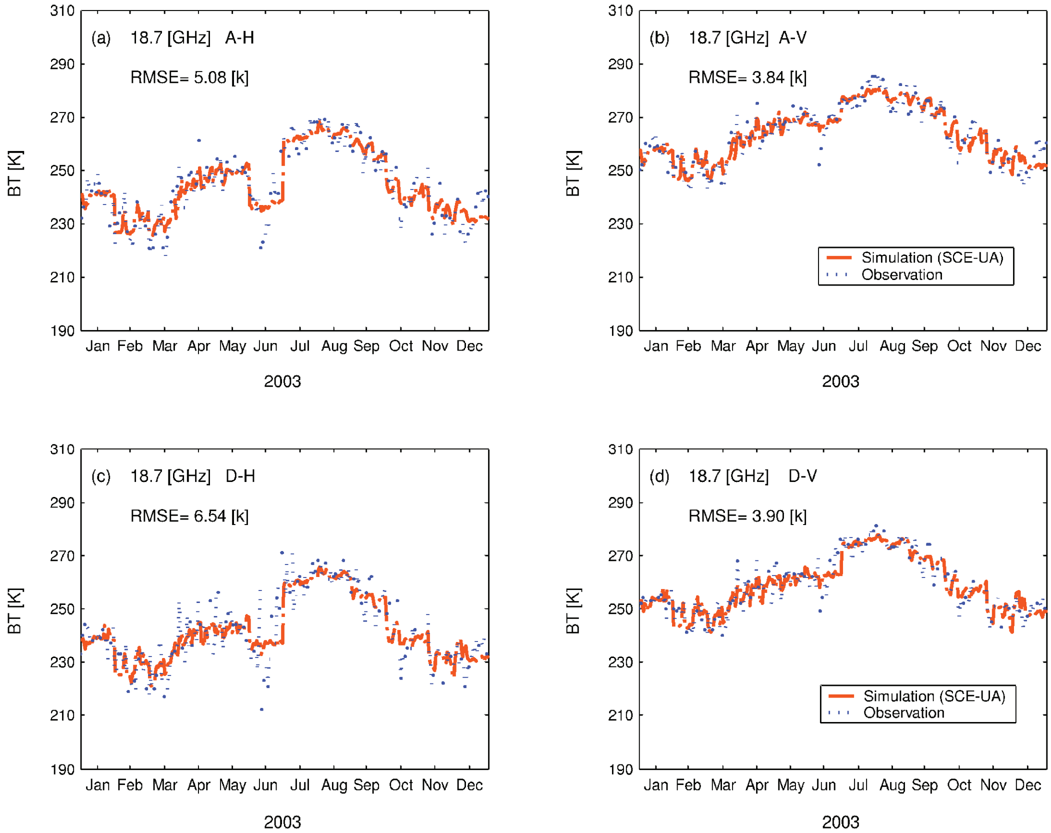

Fig. 4 Time series of the BT simulated by the SCE-UA algorithm and observed by the AMSR-E sensor at 18.7 [GHz] in 2003 at HeFei: (a) A-H; (b) A-V; (c) D-H; (d) D-V. A-H, A-V, D-H and D-V are the same as Fig. 3.

3. Experimental results

In this section, the microwave wetland surface emissivity calibration scheme is implemented and evaluated through case study at two reference stations (HeFei and TongYu).

We constructed two 0.25°× 0.25° model grid cells with the reference stations as the grid cell center, respectively. More details about HeFei and TongYu station information are given by Table 1. The area fraction of the wetland patch in the whole model grid cell is 86% at Hefei station, that is, the wetland patch dominates in whole model grid cell; therefore, we chose HeFei station to calibrate microwave wetland surface emissivities, and then transferred the calibrated microwave wetland surface emissivities to TongYu station.

We ran the CLM2.0 with observation-based atmospheric forcing data [10] from 1st January 2001 to 31st December 2002 to acquire the equilibrium of the CLM2.0, and then ran the CLM2.0 from 1st January 2003 to 31st December 2003 again to implement the microwave wetland surface emissivity calibration scheme.

To evaluate the performance of the microwave wetland surface emissivity calibration scheme, the root mean square error (RMSE) is used as a criterion to indicate the accuracy of the results, which is defined as

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(T_{b,est}^{if} - T_{b,obs}^{if}\right)^2}, \tag{3}$$

where $T_{b,est}^{if}$ and $T_{b,obs}^{if}$ are the simulated and observed BT at f frequency [GHz], m is the number of satellite observations in the calibration interval using the SCE-UA algorithm.

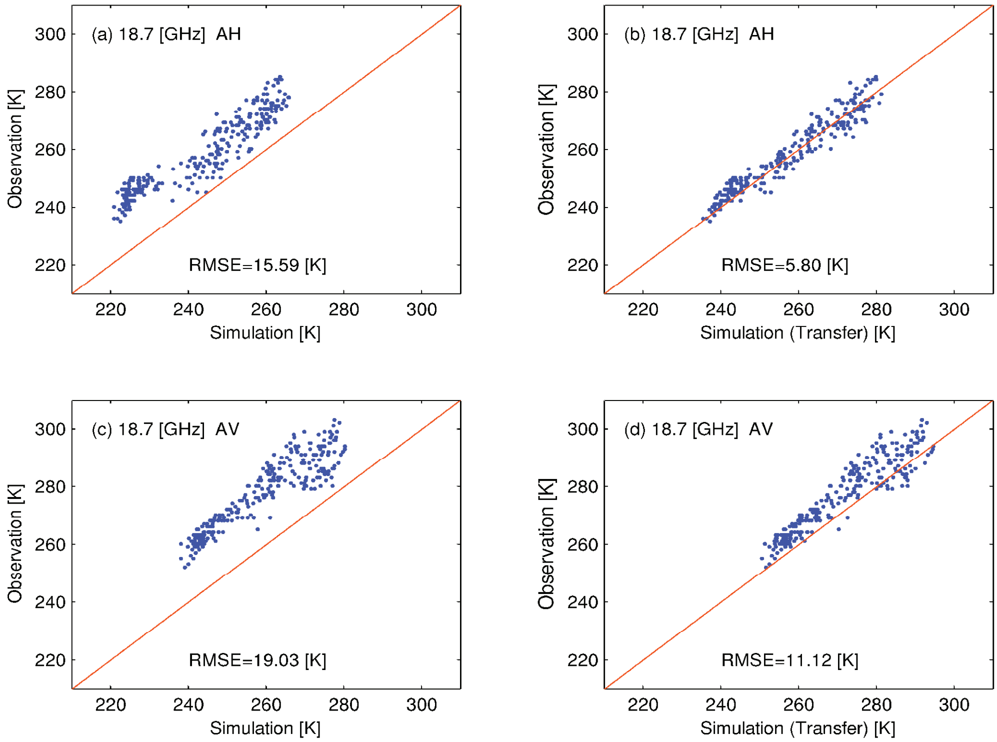

Fig. 5 Scatterplots of the AMSR-E BT simulated by the LandEM (left) and simulated by the parameters transfer scheme (right) versus that observed by AMSR-E sensor at 18.7 [GHz] in 2003 at TongYu: (a)-(b) AH; (c)-(d) AV. AH and AV are the same as Fig. 3.

Fig. 3 shows the time series of the emissivities simulated by the landEM in two sub-grid vegetation patch and calibrated by the SCE-UA algorithm in the sub-grid wetland patch (monthly mean) at 18.7 [GHz] in 2003 at HeFei. The difference between the emissivity in two sub-grid vegetation patch and that in the sub-grid wetland patch is extremely evident, the main cause is that there is more water surface in the wetland patch.

As shown in Fig. 4, the time series of the BT simulated by the SCE-UA algorithm were basically matched with that observed by AMSR-E sensor, the RMSEs between the simulated and observed BT are 5.08 [K] (A-H), 3.84 [K] (A-V), 6.54 [K] (D-H), and 3.90 [K] (D-V) at 10.65 [GHz], respectively.

The monthly mean microwave wetland emissivity values calibrated at Hefei in 2003 were applied for the BT simulation at 18.7 [GHz] in 2003 at TongYu, we can obtain good results similarly. The RMSEs between the BT simulated by the parameters transfer scheme and observed by AMSR-E sensor at 18.7 [GHz] are

5.80[K] (AH) and 11.12 [K] (AV), which are reduced by 62.8% and 41.6% compared to that between the simulated and observed BT (15.59 [K] and 19.03 [K]), respectively.

4. Conclusion and discussion

The study presents a microwave wetland surface emissivity calibration scheme based on the NCAR CLM2.0, LandEM, SCE-UA and gridded AMSR-E BT observation data, which considers the influences of the land surface sub-grid scale heterogeneity. It used the outputs of the CLM2.0 as the inputs of the LandEM to simulate the BT, SCE-UA algorithm to calibrate microwave wetland surface emissivity using the gridded AMSR-E BT observation data. The microwave wetland surface emissivity calibration scheme is implemented and evaluated through case study at two reference stations. The major conclusions obtained from the experiments are as follows:

(1) The AMSR-E BT simulated by using the calibrated microwave wetland surface emissivity is basically matched with that observed by AMSR-E sensor for the grid cell including wetland cover type, which indicates that the SCE-UA algorithm can effectively calibrate the microwave wetland surface emissivities;

(2) The calibrated microwave wetland surface emissivities possess fairly good reliability and transportability.

Although the calibration scheme presented in this study lacks the physical mechanism, this study provides a promising solution to obtain the microwave wetland surface emissivity through parameter calibration method, which will greatly improve land data assimilation study. Our further aim is to develop a microwave wetland surface emissivity model with physical mechanism.

5. Acknowledgement

This work was supported by the National Natural Science Foundation of China (Grant No. 40971229), the Quantitative Remote Sensing of Key Land Surface Parameters and Data Assimilation project (KZCX2-YW-Q10-2), the Special Foundation for Young Scientists of State Laboratory of Remote Sensing Science (Grant No. 08ZY-12) and the Chinese Postdoctoral Foundation of sciences (Grant No. 20080440554). The authors are grateful to NSIDC for providing the AMSR-E BT data.

References

[1] G.B. Bonan, K.W. Oleson, M. Vertenstein, S. Levis, X. Zeng, Y. Dai, R.E. Dickinson and Z.L. Yang: The land surface climatology of the Community Land Model coupled to the NCAR Community Climate Model, Journal of Climate, Vol. 15 (2002), p. 3123

[2] R. Clarke: The pollution of lakes and reservoirs, UNEP environment library, 12, U. N. Environment Program, Nairobi, Kenya (1994).

[3] Y.J. Dai, X.B. Zeng, R.E. Dickinson, I. Baker, G.B. Bonan, M.G. Bosilovich, A.S. Denning, P.A. Dirmeyer, P.R. Houser, G.Y. Niu, K.W. Oleson, C.A. Schlosser and Z.L. Yang: The common land model, Bulletin of the American Meteorological Society, Vol. 84 (2003), p. 1013

[4] F. Weng, B. Yan and N.C. Grody: A microwave land emissivity model, Journal of Geophysical Research,Vol. 106 (2001), p. 20115

[5] L.A. Klein and C.T. Swift: An improved model for the dielectric constant of sea water at microwave frequencies, IEEE Journal of Oceanic Engineering, OE-Vol 2 (1977) No. 1, p. 104

[6] F.T. Ulaby, R.K. Moore and A.K. Fung: Microwave Remote Sensing: Active and Passive. Vol. Ⅲ: From Theory to Applications (Artech House, Norwood, MA, 1986).

[7] Q.Y. Duan, V.K. Gupta and S. Sorooshian: A shuffled complex evolution approach for effective and efficient global minimization, Journal of Optimization Theory and Applications, Vol. 76 (1993), p. 501

[8] Q.Y. Duan, S. Sorooshian and V.K. Gupta: Optimal use of the SCE-UA global optimization method for calibrating watershed models, Journal of Hydrology, Vol. 158 (1994), p. 265

[9] K.W. Knowles, M.H. Savoie, R.L. Armstrong and M.J. Brodzik, updated 2010, AMSR-E/Aqua Daily Global Quarter-Degree Gridded Brightness Temperatures, 1st January 2003 to 31st December 2003. Boulder, Colorado USA: National Snow and Ice Data Center, Digital media (2006).

[10] T. Qian, A. Dai, K.E. Trenberth and K.W. Oleson: Simulation of global land surface conditions from 1948 to 2004. Part I: Forcing data and evaluations, Journal of Hydrometeorology, Vol. 7 (2006), p. 953