A Survey on Microwave Surface Emissivity Retrieval Methods

De Xing[1,2],Qunbo Huang[1,2,3] ,Bainian Liu[3],Weimin Zhang[2]

[1]*Academy of Ocean Science and Engineering, National University of Defense Technology, Changsha 410073, China;*

[2]*College of Computer, National University of Defense Technology, Changsha 410073, China*

[3]*Weather Center of PLA Air Force, Beijing 100843, China*

xd_wony@icloud.com

Abstract. Owing to its wide coverage and high observation density, remote sensing satellite microwave observation data has become the most data used in numerical weather prediction system. However, due to the influence of the uncertainty of the surface emissivity, most of the data collected from remote sensing satellites are the observations at higher-peaking channels over land. A large number of these observations at lower-peaking channels are discarded, so the accurate surface emissivity is the key of assimilation of remote-sensing satellite microwave observation data over land. This paper introduces several commonly retrieval methods used for passive microwave surface emissivity and discusses their advantages and shortcomings. At last, an evaluation of each retrieval method and a conclusion is made.

Keywords: microwave surface emissivity, retrieval method, remote sensing

Introduction

The surface emissivity is defined as the ratio of the thermal radiation emitted by the surface and the thermal radiation emitted by a black body at the same temperature[1]. It reflects the thermal radiation capability of the surface. It is an important parameter for understanding the geophysical processes that control the surface energy balance and surface radiation[2]. In recent years, the surface emissivity has drawn continuous concern. Microwave surface emissivity not only depends on the soil chemical composition, structure and texture, but also affected by the vegetation type and season. It can be used to detect the change of surface type, and can also be used as land surface information into assimilation system[3].

With the development of atmospheric microwave remote sensing technology, satellite microwave observation has become an important means to obtain atmospheric information. But for those data observed over land, in most cases only the observations of upper-level channels or channels not sensitive to land surface are assimilated, which led to the utilization of observation over land is less than that over sea. The reason for this phenomenon is that the land surface emissivity has a greater uncertainty than the sea surface emissivity[4]. Therefore, if the surface emissivity cannot be accurately described, the surface emissivity component and the atmospheric radiation component cannot be distinguished from the observations. The accurate calculation of the surface emissivity is necessary for accurately determining the long-wave energy radiation from the surface and is a prerequisite for assimilating remote sensing satellite observations over land. Therefore, the surface emissivity retrieval method is of utmost importance in the land surface data assimilation.

Surface emissivity retrieval methods

Empirical statistical methods

Empirical statistical method is based on the strong correlation between the surface emissivity and the satellite observed brightness temperature. Through the statistical methods to establish the empirical equation between the satellite observed brightness temperature and the corresponding pixel surface emissivity, and apply the equation to the whole study area to calculate the surface emissivity. The simple empirical method is to use the satellite observed brightness temperature as the only factor that affects the surface emissivity, and establish the regression equation between the surface emissivity and the satellite observed brightness temperature directly[5].

According to the detection data on the related channels of MSU oxygen absorption band, Grody put forward a statistical retrieval algorithm which is applicable for the microwave surface emissivity of 50.30, 53.74, 54.96 and 57.97 GHz channels[6]. That is,

$$\varepsilon = a_0(\theta) + a_1(\theta)T_{B50} - a_2(\theta)T_{B53}, \tag{2.1}$$

where ε is the surface microwave emissivity of the window channel; a_i (i = 0, 1, 2) is the zenith angle coefficient of different places; θ is the satellite zenith angle of the observation point; T_{B50} and T_{B53} are the bright temperature of 50.30GHz and 53.74GHz channels, respectively. This algorithm uses the combination of bright temperature of low frequency channel to reflect the microwave surface emissivity of the window channel, and the coefficients in the equation are related to the observation angle. The retrieval results of the microwave surface emissivity of the window channels are basically between 0.8~0.95, and the microwave emissivity values of lower channels are often affected by precipitation and clouds. The results show that the lower the frequency, the better the retrieval results.

The NOAA National Environmental Satellite, Data, and Information Service (NESDIS) released the AMSU-A surface microwave emissivity product. Through polynomial combination statistics on microwave brightness temperature of AMSU-A channel 1, 2 and 3 to obtain the surface microwave emissivity of channel 3[7]. The statistical retrieval equation is:

$$\varepsilon = b_0 + b_1T_{B1} + b_2{T_{B1}}^2 + b_3T_{B2} + b_4{T_{B2}}^2 + b_5T_{B3} + b_6{T_{B3}}^2, \tag{2.2}$$

where ε is the surface microwave emissivity of AMSU-A channel 3; b_i is the regression coefficient, i = 0, 1, …, 6; T_{BM} is the brightness temperature of the M channel. M represents the channel number, M = 1, 2, 3.

retrieving surface emissivity using satellite observations

In order to calculate the surface emissivity using satellite observations, it is usually necessary to suppose that the surface is under the plane parallel condition. This assumption is only valid when the transcendental information of the surface is absent. Mazler pointed out that itis not applicable to low-altitude observations, the Lambert component is more significant in this case, thus resulting in greater error. Karbou and Prigent[8] demonstrated that the surface emissivity error obtained by this assumption is less than 1% on non-snow-covered surfaces. Mazler suggests that this error can be controlled less by adjusting specific parameters.

Under the assumption of plane parallel atmosphere and given the satellite zenith angle θ, spectral frequency v, the bright temperature observed by satellite sensors can be denoted as[9]:

$$T_b(v,\theta) = T_s\varepsilon(v,\theta)\Gamma + [1-\varepsilon(v,\theta)]\Gamma T_a^{\downarrow}(v,\theta) + T_a^{\uparrow}(v,\theta), \tag{2.3}$$

$$\Gamma = exp\left[\frac{-\tau(0,H)}{cos\theta}\right], \tag{2.4}$$

where $\varepsilon(v,\theta)$ is the surface emissivity under frequency v and satellite zenith angle θ. T_s is the skin temperature. $T_a^{\downarrow}(v,\theta)$ and $T_a^{\uparrow}(v,\theta)$ are the downward and upward radiation of the atmosphere, respectively. Γ is the transmittance from surface to the top of the atmosphere, which can be expressed as a function of satellite zenith angle θ and atmospheric opacity $\tau(0,H)$. H is the atmosphere top height.

From equation 2.4 we can get the expression of surface emissivity as:

$$\varepsilon(v,\theta) = \frac{T_b(v,\theta) - T_a^{\uparrow}(v,\theta) - T_a^{\downarrow}(v,\theta)\Gamma}{[T_s - T_a^{\downarrow}(v,\theta)]\Gamma} \tag{2.5}$$

For some sensors like AMSU, the bright temperature is observed through a rotating antennae system, which makes the calculated emissivity a mixture of horizontally and vertically polarized emissivities. The relationship could be denoted as:

$$\varepsilon(v,\theta) = \varepsilon_p(v,\theta)cos^2\varphi + \varepsilon_q(v,\theta)sin^2\varphi, \tag{2.6}$$

$$\varphi = arcsin\left(\frac{R}{R+H_{sat}}sin\theta\right), \tag{2.7}$$

where θ is the satellite zenith angle, φ is the satellite scan angle, which can be expressed as a function of θ, earth radius R and satellite height H_{sat}.

One dimensional variational method

One dimensional variational data assimilation(1D-Var) method is actually a physical retrieval method[10]. It can retrieve multiple physical parameters simultaneously using the observations of passive sensors as well as other ancillary data. This method has the advantage of emphasizing the physical constraints of the parameters, and the physical quantities of the parameters can maintain a consistent physical relationship. The theoretical basis of the 1D-Var method is the Bayesian principle, assuming that both the observation error and the background error obey the Gaussian error distribution, then by minimizing the cost function we can get the analysis value with a minimum error[11]. The goal of 1D-Var method is to obtain the best estimation of the retrieved parameters by combing observations and background values from a variety of data sources. Its cost function can be denoted as:

$$J(X)=\frac{1}{2}(X-X_0)^T B^{-1}(X-X_0)+\frac{1}{2}\left(Y^0-H(X)\right)^T E^{-1}\left(Y^0-H(X)\right), \qquad (2.8)$$

where X is the analysis value we want to get, X_0 is the background value, Y^0 is the observation value, H is the observation operator, E is the observation error covariance and B is the background error covariance. The premise of solving this equation is to have a radiative transfer model with relatively smaller error, and the simulated radiation value has a good statistical result in the observation error covariance matrix E[12].

The key to retrieve microwave surface emissivity using 1D-Var method is to establish the global microwave surface emissivity first-guess in accordance with the channel characteristics of the satellite sensors. The European Centre for Medium-range Weather Forecasts (ECMWF) developed A Tool to Estimate Land Surface Emissivities at Microwave Frequencies (TELSEM) based on a monthly averaged surface emissivity calculated from Special Sensor Microwave/Imager (SSM/I) satellite observations. TELSEM can provide the estimation of microwave surface emissivity at the frequency of 19-100GHz and its error covariance matrix[13]. By using TELSEM we can establish the global first-guess of microwave surface emissivity.

Neural network method

Neural network method uses a large number of interconnected neurons to approximate complex nonlinear relationship. This method does not need to know the interaction mechanism between surface emissivity and surface temperature, bright temperature or surface characteristics. It uses the train data set to directly establish the relationship between surface emissivity and input variables. However, this method requires a high degree of accuracy for the first guess, otherwise the result would be not satisfactory.

Aires et al.[14] used first-guess to develop neural network method. They retrieved land surface emissivity between the frequency of 19-85GHz as well as skin temperature using SSM/I observations. The results show that the retrieval accuracy of surface emissivity for each channel under clear sky (or cloudy) condition is less than 0.008 (or 0.010), which indicates this method can retrieve surface emissivity accurately. Aires et, al.[14] also retrieved land surface emissivity of daytime, and the result had a rather small root mean square error.

Index analysis method

If the atmospheric temperature, humidity and surface temperature are known, the microwave surface emissivity can be estimated using the radiative transfer equation. However, in most cases, the atmospheric and surface condition parameters are unknown, so it is necessary to construct a parameter that is sensitive to surface microwave emissivity while insensitive or relatively less insensitive to surface temperature and atmospheric parameters, and then establish a statistical relations between such parameters and microwave surface emissivity. This method is called as index analysis.

A variety forms of feature index can be defined such as soil wetness index (SWI), polarization ratio (PR) and microwave vegetation index (MVI) for different purposes. Morland et al. [15] used the normalized difference vegetation index (NDVI) calculated from satellite observations of visible wavelengths and surface humidity index to estimate the microwave surface emissivity of the African Sahel semi-arid region, which can be denoted as:

$$\varepsilon = a + b \log_c cN, \tag{2.9}$$

where ε is the surface emissivity; a, b and c are the empirical parameters, N stands for NDVI. The result shows that, there is a good agreement between the retrieved results and the ground observations under the clean dry atmosphere condition. But when the atmosphere is humid or precipitation occurred previously, the retrieved results are somewhat less consistent with the ground observations.

Conclusion and evaluation

Due to the microwave can penetrate through clouds, the spaceborne microwave radiometer can provide information on clouds and precipitations in the atmosphere. Therefore, the microwave surface emissivity is important for microwave precipitation algorithm, atmospheric parameter retrieval and satellite data assimilation. The combination of land surface model and surface emissivity retrieval method can be used to study the changes of surface emissivity on a short time scale.

In the retrieval of microwave surface emissivity, the existing empirical method, neural network method and one-dimensional variational method have been universally recognized and applied, but each of them has its strengths and limitations. The empirical statistical method is one of the simplest methods to estimate the microwave surface emissivity, but which cannot solve non-linear problem[6]. The radiative transfer equation method is based on the radiation transmission theory, whose physical meaning is clear, but the physical procedure is very complex[16]. The index analysis method does not need the atmospheric and land surface conditions, but the application scopes of different indexes are limited[17]. The neural network method's biggest advantage is that theoretically it can be used to approximate any complex non-linear relationships while does not need a complex retrieval algorithm, but the its accuracy depends heavily on the estimation of first-guess. The one-dimensional variation method can effectively reduce the root mean square error of the model analysis field. However, only when the forward model's linearity is strong enough and the background information is good enough, this method can get good results. Further research can be done in the study of dynamic retrieval method and the advanced Kalman filter method of the land surface emissivity.

Acknowledgements

The work was supported by the Natural Science Foundation of China (Grant No. 41375113).

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