Retrieval of atmospheric moisture parameters from Multi-channel Microwave Extinction along Satellite-Earth Path

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Abstract

Atmospheric moisture parameters, such as total water vapor (WV), liquid water path (LWP), and ice water path (IWP), are important to the cloud physics and meteorology. However, because of the observational difficulties in high variability of atmospheric moisture, all measurement techniques cannot yield global datasets of these moisture parameters to meet the needs in numerical weather model and weather modification studies. In this paper we present a concept to determine these moisture parameters from directly measuring microwave attenuation along the satellite-earth surface path. An investigation has been conducted on the optimal choice of channels and errors estimate of the retrieval method. The results show that the proposed method in principle can more accurately retrieve LWP than the available passive satellite remote sensing. The method with dual- or triple-channel combination can simultaneously retrieve atmospheric WV, LWP, and IWP.

1. Introduction

The atmospheric moisture significantly influences many processes of the Earth's weather and climate. Accurate knowledge of the moisture distribution in the atmosphere and its change with time is indispensable for the description and understanding of global climate processes. The moisture parameters, such as total water vapor (WV), liquid water path (LWP), and ice water path (IWP), are important to the cloud physics and meteorology[1-2], and various techniques have been developed to measure these parameters, for instance, the ground and space-born millimeter-wave cloud radar and radiometer, and the ground and air-born cloud particle measuring system [3-4]. However, it is still hard to get global dataset for these moisture parameters since high variability of atmospheric moisture in space and time resulting in more difficulties in retrieval algorithms for passive microwave remote sensing [5-6]. Therefore, we explore a new method to retrieval these moisture parameters, and investigate the optimal channels selection for retrieval and mode of observations.

2. Method

Similar to the retrieval of atmospheric compositions at ultraviolet, visible and infrared wave band from the directly measuring solar radiation extinction, we present a concept to determine these moisture parameters from directly measuring microwave extinction along the satellite-earth surface path in this paper. Fig.1 shows the sketch map for the concept, R is the distance between the satellite and ground receiver. Then the ground receiver can get the power P_r from the microwave emitted power P_t on satellite assumedly isotropic and without the loss in other aspects alone the transporting path as shown in Eq.1.

$$P_r = \frac{P_t A_e}{4\pi R^2} e^{-\tau} \tag{1}$$

Here A_e is the effective antenna area, τ is the total optic depth, coming from the integrated microwave extinction efficient along the satellite-earth path.

For non-precipitation cloud, the τ is the sum of gas and cloud extinction. It is well know that τ_{cloud} is linear with the total cloud water content at microwave band (millimeter and centimeter-wave). Hence we can retrieve the LWP using the directly measuring microwave extinction as Fig.1 shown. Similarly, the ground measuring extinction is also used to retrieve atmospheric water vapor and IWP in cloud.

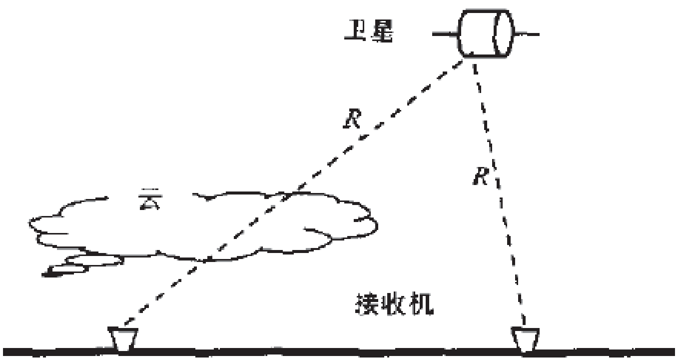

Fig.1 The sketch map of LWP retrieval from microwave extinction along the Satellite-Earth path

3. Channel selections

For better LWP retrieval, the criterion for channel selection is the role of LWP on extinction is as large as possible while the effect of atmospheric gas is as small as possible. Fig.2 shows the total optic depth variation for the standard atmosphere and 1-layer cloud with 150 gm^{-2} column content of liquid water within 1-300 GHz. Here the gas absorb efficient is calculated by Liebe model [7], and the absorb efficient of cloud water is calculated by the Rayleigh formula, and the average cloud temperature is setting as 0°C.

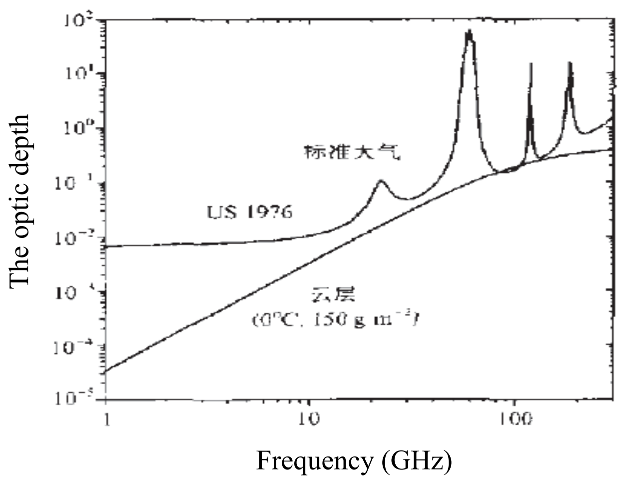

Fig.2 The optic depth of the standard atmosphere and 1-layer water cloud within 1-300 GHz

Based on the criterion for LWP retrieval, within 1-300 GHz, the stronger two water vapor absorb lines (22.35 GHz and 183.75 GHz) and two oxygen absorb band (50-60 GHz and 118.3 GHz) are excluded, also channels below 20 GHz is ignored due to weak cloud absorb. Then it seems four window channels (around the 30, 90, 133 and 220 GHz) available for LWP retrieval. Considering the high cost of sub-millimeter microwave (>100 GHz) techniques, we prefer to chose channels below 100 GHz, such as nearby 30 and 90 GHz. Channel at 90 GHz is more sensitive to ice particle in cloud, which is good to retrieve IWP, although it has certain issues as high-frequency channels. Channel nearby 30 GHz is less influence by ice particles but more influence by water vapor which makes trouble for LWP retrieval. To efficiently correct the water vapor effect on LWP or IWP and also good to retrieve the WV itself, it is better to combine the LWP/IWP channels with water vapor channels. Then we propose the possible combinations of multi-channel to retrieve LWP or IWP or WV simultaneously as listed in Table 1.

Table 1 Channel combinations for atmospheric moisture parameters retrieval

Channel combination	Retrieval parameters	Possibility
Dual-channel 23.8/37 GHz 23.8/89 GHz	LWP WV	Relative matured technology to achieve LWP and WV simultaneously
Triple-channel 23.8/37/89 GHz 23.8/89/220 GHz	LWP IWP WV	Certain challenge for high-freq technology

4. Retrieval precision Estimation

To realize the feasibility of the new method, it is necessary to discuss the retrieval precision.

First, for the directly measuring microwave total extinction τ, its absolute error can be derived from Eq.1 , then shown as the Eq.2

$$\Delta\tau = \left|\frac{2\Delta R}{R}\right| + \left|\frac{\Delta A_e}{A_e}\right| + \left|\frac{\Delta P_t}{P_t}\right| + \left|\frac{\Delta P_r}{P_r}\right| \qquad (2)$$

It is seen that the absolute error of τ is coming from the relative error of measuring distance R, the effective antenna area A_e, received and emitted power. Among them, the R error is too small to neglect, and the A_e error is stable to be corrected, so the error of τ is mainly affected by the uncertainties y of emitted and received power. For the current development of the radar and radiometer, the error of emitted and received power are more stable and can be within 0.2% (at 90 GHz) or 0.05% (at 37GHz) . Therefore, the measuring precision of the microwave total extinction τ along the path can be 1%.

Secondly, we further investigate the retrieval precision of these moisture parameters. Here we focus on LWP retrieval error estimate since it is close relation with WV and IWP retrieval.

For LWP retrieval, the possible errors are cause by the influence of water vapor absorb, the uncertainty of cloud water absorb efficient k_c and the measuring precision of total extinction τ . Based on the model calculation, the estimation of relative error of LWP is listed in Table 2. Clearly, the influence of water vapor is dominated and larger at 89 GHz than 37 GHz, especially the uncertainty on WV, implying that the water vapor correction is significant aspect for reducing LWP retrieval error. As to the absorb efficient of cloud water, k_c, it is the function of temperature and wavelength, and its dependence is weak at 89 GHz so that using 89 GHz seems better for LWP retrieval if only considering reduce the uncertainty of k_c. It is noted that the error estimate in Table 2 is for single channel, if using multi-channel combination, such as 23.8 and 37 GHz or 23.8 37, and 89 GHz, the uncertainty of water vapor would reduce to half of those values in Table 2, so the retrieval precision of LWP would better than 20%, which is acceptable in our knowledge.

Table 2 The statistic of error estimation for LWP retrieval (%) (L=150 gm^{-2})

Factor	Uncertainty of water vapor		Measuring precision of τ		Uncertainty of k_c	
	5% absorb efficient	10% total water vapor	1%	5%	2 ℃	5 ℃
37 GHz	8	16	2.3	11.7	< 5	~11
89 GHz	9.7	19.3	1.8	8.8	< 5	< 5

5. Summary

In this paper we present a concept to determine atmospheric moisture parameters, including LWP, IWP and WV, from directly measuring microwave attenuation along the satellite-earth surface path. An investigation has been conducted on the optimal choice of channels and the errors estimate of the retrieval parameters. The results show that the proposed method in principle can retrieve LWP accurately than the available satellite remote sensing. The method with dual- or triple-channel combination can simultaneously retrieve atmospheric WV, LWP, and IWP, and it will more efficiently yield global datasets of these moisture parameters once using advanced satellite remote sensing techniques. Also, we will carry out more works on demonstrating the potential of this method and providing sufficiently quantitative analysis on WV, LWP, and IWP retrieval.

6. References

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