

SPACE-BORNE MICROWAVE RADIOMETER CALIBRATION/VALIDATION IN CHINA

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ABSTRACT

We summarize the activities concerning to the space-borne microwave radiometer (RAD) calibration and validation (Cal/Val) in China. It is important to know in advance the brightness temperature of a given sea surface before external calibrating RAD due to its special characteristic of system. In the paper, we analyse some modeling results on sea surface emissivity and atmospheric transmissivity at different frequencies, and compare the calculated brightness temperatures with those measurements from some air-borne microwave radiometers. We also introduced the whole contents on RAD Val and developed two methods of retrieving sea surface winds. We compared the retrievals of wind speeds to those from NDBC buoys. At last, we introduce some plans of Cal/Val for testing our RAD.

KEY WORDS: microwave radiometer, calibration, validation

1. INTRODUCTION

Space-borne passive microwave remote sensing is an important means of obtaining global oceanic and atmospheric geophysical parameters. It has been greatly improved in China since the beginning of 1990's. In the near future, the frequencies of space-borne microwave remote sensors scheduled to be launched range from centimeter wave to sub-millimeter wave. It is a precondition of quantitative application of the data measured by such sensors to calibrate the in-orbit sensors and validate the geophysical products retrieved.

The microwave radiometer RAD, a mode of multi-mode microwave remote sensor (M³RS), will be launched in the late of this year. RAD is a multi-channel remote sensor, which includes frequencies at 6.6, 13.9, 19.35, and 37GHz with horizontal and vertical polarization, and 23.8GHz with vertical polarization for atmospheric application. In those frequencies, 13.9GHz is collocated and use the same antenna with the scatterometer with a conical scanning antenna to get the image of the surface of the Earth, while the other channels is only a non-imaging mode with a fixed local incidence angle of 43°.

Since the beginning of the program, we have done many researches on the methods of calibration and validation, developed some models for the RAD Cal/Val, and conducted some experiments to test the performances of the sensor and the models. In the paper, we introduce the main activities concerning to the Cal/Val of RAD, which consist of radiative calibration in chapter 2, data products and validation in chapter 3, and some in-situ experiments plans for Cal/Val in chapter 4. At last, we summarize the paper and draw a simple conclusion.

2. RADIATIVE CALIBRATION

In order to know the performances of a radiometer system and to set up the relationship between the voltage outputs and input brightness temperatures, which is called calibration, it is necessary to find two standard targets with known brightness temperatures as two exact input signals, which is called two points calibration. As a rule, there are two standard calibration

sources, one is liquid nitrogen as a cold load, another is material with known emissivity, highly absorbing, non-reflective. Due to the material's emissivity close to unity, its brightness temperature is approximately equal to its physical temperature. Usually space-borne microwave radiometer has a perfect calibration system, such as Special Sensor Microwave/Imager (SSM/I) aboard the Defense Meteorological Satellite Program's (DMSP) satellite and TRMM Microwave Imager (TMI) aboard the Tropical Rainfall Measuring Mission (TRMM), which all utilized an external calibration program, that is to say, all calibration sources are located outside the sensors.

But RAD, which is applying a technique of computer-controlled gain compensated circuit, has no calibration source outside of the sensor. Although the radiometer has been calibrated in the lab before its launch, its performances may alter because of the shake during launching and bad environment exposed in-orbit, such as temperature oscillation, cosmic radiation. So it is hard for the sensor to hold in the same condition as in the ground. Therefore, we take an alternate external calibration program to test the sensor performance and evaluate the ability of retrieving geophysical parameters. In the Cal process, the brightness temperatures calculated by Cal models are as a truth of cold resource for calibration. The hot resource is the internal thermal resistance. After having obtained the two points brightness temperatures as known inputs, the Cal equations are adjusted and the re-calibrated brightness temperatures are derived using the new equation and they are sent to Val system for retrieving data products.

The program is involved to calculate the brightness temperature received by the antenna main beam by using a complete radiative transfer equation. In no rain, the assumption of horizontal uniformity is made to the atmosphere. The total brightness temperature at the antenna level may be in the following form.

$$T_B(\mu) = T_{BU}(\mu) + \tau(0, \infty)[e_p T_s + (1 - e_p) T_{BD}(\mu)] \quad (1)$$

Where $T_{BD}(\mu)$, $T_{BU}(\mu)$ is down-welling, up-welling atmospheric brightness temperatures respectively. Here $T_{BD}(\mu)$ includes atmospheric contribution to cosmic background brightness temperature T_{BC} , which generally equals to 2.7K in the range of frequencies concerned. $T_{BD}(\mu)$, $T_{BU}(\mu)$ is the functions of temperature $T(h)$, absorption coefficient $\alpha(h)$ at height h respectively. τ represents the atmospheric transmittivity. $\mu = \cos\theta$, and θ is incidence angle. e_p is the emissivity at polarization p (p in H or V polarization), and T_s is the physical temperature of the sea surface. In order to accurately calculate the brightness temperature $T_B(\mu)$, we should have plenty knowledge on atmospheric absorption $\alpha(h)$, temperature profiles $T(h)$, and sea surface emissivity $e_p(\mu, \phi)$. To our knowledge, there are some theoretical models for calculating atmospheric absorption at frequencies from 1~100GHz, such as Ulaby [1981] model and Liebe [1993], which have been widely applied for many fields relating to microwave transfer. In the paper, we used the two models to evaluate the effects of atmosphere. Table 1 gives the results calculated by Ulaby [1981] and Liebe [1992][1989] model (MPM) using radiosonde data of September 21, 1995 from Baoshan weather station, Shanghai, China. We find the results is basically similar, but there are some differences at 37GHz. This maybe account to the cloud effects, because the frequency is more sensitive to the cloud. As many authors indicated from their papers (among which, such as Leihm [1995], Eymard [1996], Wentz [2000]) that the results using Liebe's MPM are higher than the those from in-situ measuring, which is mostly due to the error of water vapor microwave continuum absorption.

Table 1 the comparison of the results calculated by using two atmospheric models

Pressure (mb)	22.235		37.0	
	Ulaby	MPM	Ulaby	MPM
1000	0.2564737	0.2550947	0.1564502	0.1335616
850	0.1688642	0.1689765	0.0925711	0.0786320
700	0.0780726	0.0784025	0.0427091	0.0355751
600	0.0552845	0.0058166	0.0290185	0.0243548
500	0.0241613	0.0244966	0.0169737	0.0145980
400	0.0088427	0.0090653	0.0104384	0.0092368
300	0.0039459	0.0041145	0.0065054	0.0058445
250	0.0025149	0.0026259	0.0048842	0.0044198
200	0.0015439	0.0016156	0.0034256	0.0031230
150	0.0006344	0.0006780	0.0021366	0.0019664
100	0.0003082	0.0003327	0.0013424	0.0009583
50	0.0000759	0.0000809	0.0002351	0.0002161

Sea surface emissivity is a complicate function of many geophysical parameters of ocean and atmosphere, along which the most important parameters are seawater temperatures and salinity, wind speed and direction, and atmospheric transmittivity. In our studies, in considering the accuracy and calculating time, we choose two simple but with enough accuracy models, namely Lojou [1994] and Guissard [1994] models, for the purpose of calculating ocean surface scattering and emission. Lojou summarized a few results related to sea surface emissivity, which included foam coverage and emissivity model, and compared the calculations with those from some other models. The form of emissivity model is:

$$e = (e_s - \Delta e_r)(1 - f_c) + e_f f_c \quad (2)$$

Where e is the surface emissivity. e_s is specular emissivity. Δe_r is a correcting term accounting for effects of roughness. e_f is emissivity of foam, and f_c is the coverage of foam which is a function of wind

speed, the sea water temperature and air temperature at the surface[Monahan, 1986].

In Guissard' model [1994], he treated the scattering of the surface as a specular reflection, meanwhile he introduced a correcting factor δ_p , which is not only the non-linear function of wind friction speed, but also of atmospheric opacity A . His model can be applied for frequencies from 5~40GHz, with providing an accuracy on the calculated brightness temperatures better than 0.5 deg K for all cases in V-pol and for some 85 per sent of the cases in H-pol.

Table 2 and table 3 illustrates the results from two sea emissivity models and two atmospheric absorption models, in which M-1 represents MPM+Guissard models, M-2 represents MPM+Lojou models, M-3 represents Ulaby+Guissard models, and M-4 represents Ulaby+Lojou models.

Table 2 two models calculated results at 22.235GHz

models	M-1	M-2	M-3	M-4
TB_{DN} (K)	105.5533	105.5553	105.3007	105.3007
TB_{UP} at sea surface (K)	204.9986	201.1756	204.8603	201.0474
TB at antenna (K)	127.5208	126.0940	128.1638	126.7370
rms (%)	0.31	0.82	0.81	0.31

Table 3 two models calculated results at 37GHz

model	M-1	M-2	M-3	M-4
TB_{DN} (K)	70.43188	70.43188	78.50898	78.50898
TB_{UP} at sea surface (K)	185.4982	183.9893	190.0627	188.0387
TB at antenna (K)	170.9162	170.0221	162.5797	161.4821
rms (%)	2.77	2.24	2.24	2.90

The averages of calculated brightness temperature at antenna level is 127.13 K in 22.235 GHz and 166.30 K in 37 GHz respectively. The absolute biases for the two frequencies are 0.86 K for 22.235 GHz and 15.63 K for 37 GHz respectively by comparing with the measurements from air-borne microwave radiometers which operated at the same frequencies. The

large bias in 37 GHz may attribute to the atmosphere absorption bias of the two models, as discussed above. In addition, there is a small difference between the two sea models, which may be caused by foam. Because the Lojou's model was based on Stogryn's model for foam emissivity and coverage, while Guissard's model considered no foam additionally. The mechanism of emissivity of white foam is still open for more investigation.

3. DATA PRODUCTS AND VALIDATION

3.1 RAD oceanic data products and retrievals

RAD main oceanic data products include brightness temperature of different channels, sea surface temperature, wind speed, column water vapor contents and liquid water in cloud above the ocean. We developed a program for producing the products of RAD. Because RAD shares some common frequencies as SSM/I and AMSR (Advanced microwave scanning radiometer aboard EOS PM-1), so we use the SSM/I atmospheric and oceanic algorithms at 19.35 and 37 GHz [Wentz, 1997] for RAD's counterparts', and those of AMSR at 23.8GHz [Wentz, 2000] for RAD's 23.8GHz algorithms. Due to incidence angles differences between RAD's and those of SSM/I and AMSR, so we have to treat them carefully.

As for 6.6GHz, although there was a frequency in SMMR aboard Seasat and Nimbus-7, but those two sensors had been no data since 1987, so it is hard to apply their algorithms at 6.6GHz for RAD. Especially, there is an unique frequency 13.9GHz in RAD which have never been used for passive sensing the surface of the earth. So we have to develop our algorithms for the two frequencies. We're applying Liebe'93 model for atmospheric absorption and using global ocean radiosonde data with pressure, relative humidity, and temperature profiles at different levels to calculate the

transmittivity τ , down-welling $T_{BD}(\mu)$ and up-welling brightness temperatures $T_{BU}(\mu)$ of the atmosphere, as well as the vertically integrated water vapor contents V (mm), as Wentz [1997] did. We build the relationships between $T_{BD}(\mu)$, $T_{BU}(\mu)$, τ , and V in the following forms.

$$T_{BD}(\mu) = f(\tau(\mu), T_a, V) \quad (3)$$

$$T_{BU}(\mu) = f(\tau(\mu), T_a, V) \quad (4)$$

$$\tau = f(T_a, V, L) \quad (5)$$

Where T_a is the temperature at the bottom of atmosphere. L is the vertically integrated liquid water contents (mm), which can be related to the atmospheric transmittivity τ by the Rayleigh scattering approximation. The details for it may refer to [Wentz, 2000].

3.2 Wind speed retrieval from SSM/I brightness temperature

We develop an physical retrieval algorithm called W19 using SSM/I measurements at 19.35GHz based on Wentz algorithm [Wentz, 1992] and a semi-statistical algorithm named WSSM for retrieving oceanic surface wind speed. We compared the wind speeds from the two algorithms with in-situ buoy wind speeds. At the same time, we also compare the retrievals from W19 and WSSM with those from Wentz's [1992] and Goodberlet's [1990]. The details of the two algorithms can be found in [Z.Z. Wang, 2002]. The results retrieved from W19 and WSSM are given by figure 1 and figure 2. We find from the figures that the wind speeds from W19 match very well with the buoy wind speeds, while the results from WSSM are slightly higher in the low speed range. In the model of W19, we

have tried to use emissivity model in [Wentz, 1997] for sea surface with and without contribution of foam. By comparing with each other among the retrievals, we found that the results from [Wentz, 1997] some higher evaluated the wind speed at higher wind speed, while W19 retrievals matched the buoy wind speed well, especially at low wind and high wind.

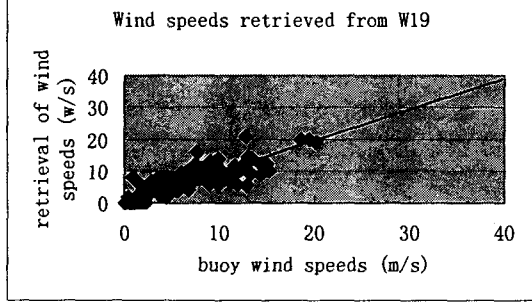


fig. 1 wind speeds retrieved from W19

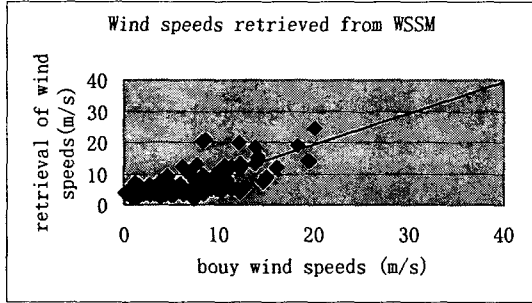


fig. 2 wind speeds retrieved from WSSM

4. PLANS FOR CAL/VAL

In order to calibrate RAD externally and validate the products retrieved from the brightness temperatures received by RAD, we devised a experiment plan which will be scheduled at the beginning next years. The experiment will be proceeding synchronously with the space microwave radiometer in the South China Sea.

We will use two methods for RAD Cal. The first is to perform the direct calculating through microwave radioactive transfer equation given by (1). We will choose some simple sounding condition with calm sea states and clear atmosphere, in order to reduce the uncertainties related the models of sea emissivity and atmospheric absorption. The site for testing brightness

temperatures locates at least beyond 100 km from the nearest coasts. The second method we used is to measure the down-welling and up-welling brightness temperature employing a ground-based microwave radiometer, which can be operated at different looking angle ranging from zenith to nadir on oil platform in South China Sea.

The brightness temperature T_B received by a space-borne microwave radiometer is:

$$T_B = T_{BS} + \Delta T_{BA} + \delta \quad (6)$$

Where T_{BS} is the brightness temperature measured by nadir-look radiometer at satellite incidence angle. δ is error due to ocean emissivity and mismatch of the different resolution of the two sounding systems. ΔT_{BA} is a correction for T_{BS} due to atmospheric absorption, which is educed from the brightness temperature T_{BA} by up-look radiometer at a near zenith angle equal to incidence angle. ΔT_{BA} is a function of transmittivity τ and T_{BA} .

$$\Delta T_{BA} = F(T_{BA}, \tau) \quad (7)$$

As for validating the products of RAD, we plan to use the buoy dataset consisting of a variety of buoy platforms and C-MAN stations located along US coastlines and Hawaii operated by the National Data Buoy Center (NDBC). In comparing the satellite and buoy measurements, especially oceanic surface temperatures and wind speeds, we should carefully consider the spatial-temporal mismatch between the buoy point observation and the satellite large footprint and the difference between the ocean skin temperature at 1 mm depth and the temperature at 1 m depth measured by the buoy. Both of these effects will contribute to the observed difference between these two different types of

observations.

The integrated water vapor contents V is validated by applying radiosonde profiles by nearby weather station locating around the South China Sea and those from NOAA, which can be obtained from <http://raob.fsl.noaa.gov>. We have no plan for validating the global integrated liquid water contents L by now, since we have no enough radar sites for sounding them.

5. SUMMARY

We summarize the activities concerning to the RAD Cal/Val in China. The most important premise for application of the RAD is to calibrate the sensor accurately in advance, which is a complicated system relating to atmospheric effects and ocean surface microwave radiation. We used two atmospheric models, and two accurate sea surface models for emissivity to calculate the total brightness temperatures at plane's levels and compared the calculations with those from air-borne microwave radiometer which operated at 22.235GHz and 37GHz. We find the emissivity models have basically no differences at our frequencies. Whereas the absorption models show some biases in our limited comparison. We also introduced the whole plans for RAD Val and devised some experiments of Cal/Val and develop two methods for testing our RAD.

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REFERENCES

- 1) A. Guissard et.al.,1994, Radioative Transfer Equation With Surface Scattering For Ocean And Atmospheric Parameters Retrieval From Radiometric Measurements, Int. J. Remote Sensing, Vol.15, No.9.
- 2) F. J. Wentz, 2000, AMSR ocean algorithm, Algorithm Theoretical Basis Document (ATBD), Version 2.
- 3) F.J Wentz, 1997, A well Calibrated Ocean Algorithm for SSM/I, Journal of Geophysical Research, Vol. 102, 8703-8718.
- 4) F.T. Ulaby, et al, 1981, Microwave Remote Sensing, active and passive, vol.1, Addison-Wesley publishing company.
- 5) H. J.Liebe, ,1993, "Propagation modeling of moist air and suspended water/ice particles at frequencies below 1000 GHz", Presented at an AGARD Meeting on 'Atmospheric propagation effects through natural and man-made obscurants for visible to mm-wave radiation', May, 1993.
- 6) J. Y. Lojou, et.al., 1994, A Simple Method For Testing Brightness Temperatures From Satellite Microwave Radiometers, J.Atmos. And Ocean, Vol.11.
- 7) Keihm, S.J, 1995, TOPEX/POSEIDON Microwave Radiometer (TMR), III, IEEE Trans. Geos. Remote Sensing, Vol.33, No.1.
- 8) L.Eymard et.al., 1994, The ERS-1 Microwave Radiometer, International J. Remote Sensing, Vol.15, No.4, 845-857.
- 9) Z. Z. Wang, 2002, Oceanic wind speed retrieval from SSM/I, SPIE'2002, Hangzhou, China.