Algorithm theoretical basis document (ATBD) of the algorithm to derive total water vapor content from ADEOS-II/AMSR

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1. Introduction

An algorithm for the physical-statistical retrieval of total water vapor content (PWA) from satellite-based microwave radiometers named AMSR has been described. Input data are brightness temperature (T_{BB}) of 6 channels, i.e.19 GHz V/H, 24 GHz V/H, 37 GHz V/H, observation time, latitude and longitude. Ancillary data are land/open sea/sea ice map data, sea surface temperature data, sea surface wind speed data, temperature data at 850 hPa, and a few look-up tables. Sea surface temperature (SST), sea surface wind speed (Vs), and temperature at 850hPa (T85) is given by global analysis, forecast data or another standard product by AMSR etc.. Several flags, which are related to success/failure and accuracy, are added to each result by the algorithm.

The characteristics of this algorithm are the follows:

- One retrieval is carried out by measurement in a field of view.
- The algorithm is applicable over open sea region.
- The algorithm is based on single-layer atmosphere model.
- Complicated radiative transfer calculation and detailed temperature and water vapor profile as a first guess are unnecessary.
- An iteration calculation is included to obtain atmospheric transmittance and vertical mean atmospheric temperature. The iteration is stable.
- Dependencies of surface emissivity to SST and Vs are considered statistically.
- Ancillary data such as land/open sea/sea ice map, surface temperature, and sea surface wind speed and temperature at 850 hPa are needed.
- The dynamic range of the algorithm is 0-70 Kg/m^2 for PWA.
- The algorithm assures that the probability of retrieved PWA is equivalent to that of radio sonde of match-up data set.
- Flag related to success/failure and accuracy is added to each result.

2. Background and forward model

This algorithm is based on a model consists of single-layer atmosphere and sea surface as shown in Fig.2.1. The atmosphere includes water vapor and cloud liquid water as absorber and emitter at microwave region. Sea surface is assumed to be Fresnel reflection surface.

Tr is square of atmospheric transmittance at a frequency and a satellite zenith angle (θs) , namely microwave emitting direction. Ta is vertical mean temperature of atmosphere at the frequency and θs . Tr and Ta depend on vertical profile of temperature, water vapor, and cloud liquid water. We ignore the dependency of Tr and Ta to polarization since the dependency can be detected only in heavy rain region by measurements of higher frequency.

To be exact, Ta also depends slightly the direction of radiation transfer, i.e. upward or downward, due to inhomogeneity of temperature and water vapor. In our algorithm, we define Ta as the average of upward Ta and downward Ta.

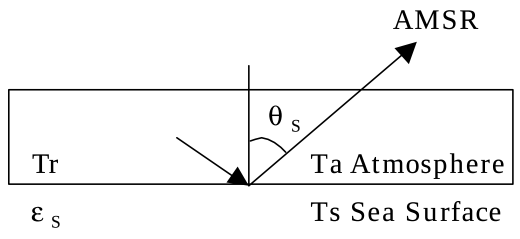

Fig.2.1 RT model for AMSR

ε_{SV} and ε_{SH} are sea surface emissivity for vertical and horizontal polarization, respectively. ε_{SV} and ε_{SH} depend on frequency, SST, Vs and θs.

By using the model, the difference between brightness temperature of vertical polarization T_V and that of horizontal polarization T_H at a frequency is given by

$$T_V - T_H = Tr*(\varepsilon_{SV} - \varepsilon_{SH})*T, \qquad ($$

where

$$T \equiv Ta + (SST-Ta)/Tr^{1/2}.$$

Brightness temperature T_{BB} at a frequency is related to Tr and ε_S as

$$T_{BB} = \alpha*\{1-Tr*(1-\varepsilon_S)\},$$

where vertical mean temperature of atmosphere-sea surface system α is defined by

$$\alpha \equiv Ta+(SST-Ta)*Tr^{1/2}*\varepsilon_S/\{1-(1-\varepsilon_S)*Tr\}. \quad (2.4)$$

From (2.3) and (2.4), Tr and Ta can be calculated by the following manner. For 19 GHz V/H, 24 GHz V and 37 GHz V/H,

1) ε_S is calculated from frequency, SST, Vs, and θ s.

2) Initial value of Tr is set.

$$Tr = \exp(-0.2) \quad (2.5)$$

3) Ta can be approximated as a function of Tr and T85. Ta is determined from a two dimensional look-up table.

$$Ta = Ta(Tr,T85) \quad (2.6)$$

4) α is calculated by (2.4).

5) Tr is calculated using the formula derived from (2.3).

$$Tr = (1-T_{BB}/\alpha)/(1-\varepsilon_S) \quad (2.7)$$

6) From 5), two Tr value can be calculated both for vertical polarization channel and horizontal polarization channel, then calculate new Tr by taking square root of the product of Tr_V and Tr_H.

$$Tr = (Tr_V*Tr_H)^{1/2} \quad (2.8)$$

7) Step 3) to 6) are repeated until Tr value is converged. Usually, this iteration calculation is stable and converges within a few iterations.

When Tr is obtained, optical depth of atmosphere τ is calculated from Tr.

$$\tau = -0.5*\ln(Tr) \quad (2.9)$$

τ is summation of optical depth of water vapor and optical depth of cloud liquid water.

$$\tau = (kv*PWA + kl*LWC)/\cos(\theta s), \quad (2.10)$$

where PWA is total water vapor content, LWC is total cloud liquid water content, kv is vertical mean absorption coefficient of water vapor, kl is vertical mean absorption coefficient of cloud liquid water. kv and kl depend vertical profile of temperature, water vapor and cloud liquid water and frequency. Tr at 19GHz is denoted as Tr19. Tr at 24GHz is denoted as Tr24. From (2.9) and (2.10), PWA can be calculated by the following formula:

$$PWA = 0.5*\cos(\theta s)*\{kl24*\ln(Tr19)-kl19*\ln(Tr24)\}/(kv24*kl19-kv19*kl24). \quad (2.11)$$

However, it is difficult to calculate kv and kl theoretically because kv and kl depend vertical profile of temperature, water vapor and liquid water. Instead of the theoretical calculation, we construct water vapor content index (PWI) as a linear combination of ln(Tr19) and ln(Tr24). In addition, we introduce a cloud liquid water index CWI, which is deduced from (2.1) and (2.2) for 19GHz and 37GHz.

$$CWI = \ln\{(T19V-T19H)/(\varepsilon_S\ 19V-\varepsilon_S\ 19H)/T19\} - \ln\{(T37V-T37H)/(\varepsilon_S\ 37V-\varepsilon_S\ 37H)/T37\} \quad (2.12)$$

where T19 and T37 are given by

$$T19 = Ta19+(SST-Ta19)/Tr19^{1/2}, \quad (2.13)$$
$$T37 = Ta37+(SST-Ta37)/Tr37^{1/2}. \quad (2.14)$$

In conclusion, PWI is calculated by

$$PWI = \beta*\ln(Tr19)-\ln(Tr24)+\gamma*CWI \quad (2.15)$$

where β and a constant γ is determined so that we can get the maximum correlation between PWI and PWA from radio sonde in the match-up data set described later. Since it is found that β strongly depends SST, we give β as a function of SST. β is given at SST of 0°C , 16°C , 24°C , 28°C , 30°C and β at any SST is given by interpolating these values.

3 Detail description of the algorithm

This section describes the detail of the algorithm. Input data of these programs are shown in Table 3.1 and flags added by the algorithm are summarized in Table 3.2.

3.1 Land and sea ice mask

Land and sea ice is masked by using land/ocean flag and sea ice data. Sea ice data will be revised once a day by using the latest data such as AMSR sea ice level-3 products. If a FOV of AMSR is judged as land or sea ice, then the flag 'land/sea ice' is set and the retrieval is quit.

3.2 Quality check of AMSR brightness temperature data

1) Brightness temperatures T19V, T19H, T24V, T24H, T37V and T37H are within the range from 90 K to 300 K,
2) T19V-T19H is positive,
3) T24V-T24H is positive,
4) T37V-T37H is positive, and
5) T24V-T19V is less than TBD K.

If above conditions are false, then the flag 'bad TBB' is added and the retrieval is quit.

3.3 Quality check of ancillary data

If sea surface wind speed (Vs) of ancillary data set is out of the range from 0 to 60 m/s, a default value Vs = 5 m/s is set.

If sea surface temperature (SST) of ancillary data set is out of the range from 0 to 35 °C, the flag 'others' is added and the retrieval is quit.

If temperature at 850 hPa (T85) of ancillary data set is out of the range from 200 K to 300 K, a default value T85 = SST - 10 K is set.

3.4 Calculation of index of cloudiness and its quality check

Sea surface emissivities (ε_S) at 19 GHz V/H, 24 GHz V/H, and 37 GHz V/H are calculated from frequency, SST, and θ_S theoretically, and then corrected with SST and Vs. λ is given by look-up table and δ is a constant.

$$\varepsilon_{SH} = 1-(1-\varepsilon_{SH})\lambda^{\delta}, \quad \varepsilon_{SV} = 1-(1-\varepsilon_{SV})\lambda^{\delta\ -1} \quad (3.1)$$

The index of cloudiness is calculated by the formula:

$$CCI = \ln\{(T19V-T19H)/(\varepsilon_S 19V-\varepsilon_S 19H) /(T37V-T37H)*(\varepsilon_S 37V-\varepsilon_S 37H)\}. \quad (3.2)$$

If the CCI is less than -0.05, the flag 'bad TBB' is added and the retrieval is quit.

3.5 Decision of clear, cloudy, or rain category

If T19V is larger than 240 K, it is assumed to be rainy condition.
If T19V is less than 240 K and CCI is larger than 0.2, it is assumed to be cloudy condition.
If T19V is less than 240 K and CCI is less than 0.2, it is assumed to be clear condition.

3.6 Calculation of vertical mean temperature of atmosphere and square of atmospheric transmittance and their quality check

For each channel, i.e. 19GHz V/H, 24GHz V/H, 37GHz V/H, square of atmospheric transmittance (Tr) and vertical mean temperature of atmosphere (Ta) are calculated from temperature at 850hPa (T85), sea surface emissivity (ε_S), sea surface temperature (SST) and brightness temperature iteratively. The details are described at section 2. In the case that Ta cannot be obtained or α is less than T_{BB}, the flag 'bad TBB' is added and the retrieval is quit.

3.7 Calculations of water vapor content index and cloud liquid water index

Water vapor content index (PWI) is calculated from (2.15) and (2.12).

3.8 Conversion PWI to water vapor content

PWI is converted to total water vapor content (PWA, kg/m^2) using a look-up table. If PWI is out of range of look-up table, the flag 'low accuracy' is added.

flag	description	availability
normal	normal (clear condition)	available
cloudy	normal (cloudy condition)	available
rainy	normal (rainy condition)	available
land/sea ice	land or sea ice region	inavailable
low accuracy	accuracy may be low	available
bad TBB	brightness temperature is illegal	inavailable
others	no sea surface temperature failure of sea surface emissivity estimation	inavailable

Table 3.1 List of input data for PWA retrievals

flag	description	availability
normal	normal (clear condition)	available
cloudy	normal (cloudy condition)	available
rainy	normal (rainy condition)	available
land/sea ice	land or sea ice region	inavailable
low accuracy	accuracy may be low	available
bad TBB	brightness temperature is illegal	inavailable
others	no sea surface temperature failure of sea surface emissivity estimation	inavailable

Table 3.2 Summary of flags added by the algorithm

3.9 Heavy rain correction to water vapor content

In the case of rainy category, PWA is corrected by T19H/T19V.

If T19H/T19V is less than 0.884, PWA = PWA-1.51.
If T19H/T19V is more than 0.884, PWA = PWA+(T19H/T19V-0.884)/(0.960-0.884)*16.5-1.51.

4. How to construct look-up tables and to decide retrieval coefficients

This section describes the procedure for determination of several coefficients used in the algorithm, proposal for a match-up data set, from which the coefficients are determined. The scheme of coefficient decision should be in automated processing appropriate for operational retrievals.

Look-up tables and several coefficients for the retrieval are derived from a match-up data set between AMSR observation and in-situ observation, i.e., radio sonde data of international radio sonde network. The GANAL analysis provided by JMA and AMSR level3 products should be included in the match-up data set.
Table 4.1 shows proposed list of elements to be included in the match-up data set. The data set is also used in validation.

4.1 Look-up table of sea surface emissivity correction on sea surface temperature and sea surface wind

A coefficient λ defined as (4.1) is calculated with the match-up data set between radio sonde, sea surface temperature, sea surface wind and AMSR T_{BB}. Then the results are compiled into two dimensional table with axis of SST and Vs.

$$\lambda = \{(1-T_{BBH}/\alpha_H)/(1-T_{BBV}/\alpha_V)\} / \{(1-\varepsilon_{SH})/(1-\varepsilon_{SV})\} \quad (4.1)$$

4.2 Look-up table to calculate Ta from T85 and Tr

Ta and Tr is calculated theoretically from temperature and water vapor profile observed by radio sonde in the match-up data set. The results are compiled as a look-up table to get Ta from T85 and Tr. Optical parameters used in the radiative transfer calculation are refered to Janssen (1993).

4.3 Coefficients to construct PWI from linear combination of atmospheric optical depth at 24GHz and that at 19GHz.

It is estimated with a match-up data set between radio sonde data and T_{BB} so that the correlation between PWI and PWA accomplish maximum. The β(Ts) and constants γ and δ will be determined after launch of AMSR.

Radio sonde at island or coastal area
Sonde ID
Observation time (min)
Pressure (hPa), Temperature (K), Relative humidity (%) at all level
PWA from sonde profile (kg/m^2)
PWA from GANAL at sonde station (kg/m^2)
AMSR observation within 150km from sonde station
Observation time (min)
Latitude, Longitude (deg)
Time lag between sonde obs. & AMSR obs. (min)
Distance between sonde station & AMSR FOV (km)
Granule number, Line number, Swath number
AMSR Land /Ocean flag
AMSR incidence angle (deg)
AMSR sun azimuth/ elevation (deg)
AMSR brightness temperature (K)
PWA from AMSR observation (kg/m^2)
GANAL interpolated at AMSR FOV
SST (K), Surface wind U,V (m/s)
Temperature (K), Relative humidity (%)
PWA from GANAL at AMSR FOV (kg/m^2)
AMSR level3 interpolated at AMSR FOV
SST (K), Sea Ice
Sea Winds level3 interpolated at AMSR FOV
Surface wind U,V (m/s)

Table 4.1 Proposed list of coefficients for retrieval and validation

4.4 Look-up table from PWI to PWA

The look-up table is designed as the provability of PWA with AMSR retrievals is equivalent to that of PWA with radio sonde.

4.5 Coefficients for heavy precipitation correction for water vapor content

It is estimated with a match-up data set between PWA sonde and PWA AMSRnocor and T19H/T19V.

Finally, It is noted that careful treatment of producing match-up data set is essential to attain the accuracy require-ment of AMSR total water vapor amount. Well checked radio sonde data, brightness temperature data, and good collocation data should be selected. Consistency between the match-up data set and a validation data set is also essential to evaluate the algorithm correctly.

Reference

Janssen, M.A. Ed.(1993) Atmospheric Remote Sensing by Microwave Radiomeroty, Jhon Wiley & Sons, Inc., 572pp.