

# **The Availability of Precipitable Water Retrieval Using Split-window Data**

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# The availability of precipitable water retrieval using split-window data

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## ABSTRACT

Water vapor is one of the most significant green house effect gases. A monitoring of water vapor behavior with operational satellite is important to investigate the global changes. Water vapor usually exists at lower troposphere. However, precipitable water is a key property to comprehend the variation since sometimes humid air mass moves to the upper troposphere. Using split window channel data with optical sensors such as AVHRR and VISSR, several retrieval algorithm has been proposed and among them, transmittance ratio method has been often utilized. However, the approach is still controversial because some studies concluded it was available and others not.

We investigated the availability of the method with split window channels' data of GMS-5 / VISSR on a semi-continental scale. A calibration curve of the precipitable water with radiosonde observation had been made in course of the retrieval procedure. However, the calibration curve are hardly sensitive to the precipitable water. Numerical simulations were carried out for the possible condition, and it turned out that calibration was insensitive to precipitable water under some condition at all: larger water variation for a given surface temperature range within a given region. The results of a feasibility study will be discussed.

**Keywords:** precipitable water, split window channels, transmittance ratio, feasibility study

## 1. INTRODUCTION

Water vapor is one of the most dominant greenhouse effect gases as well as the most influential atmospheric components in remote sensing studies targeting at land and ocean. It is important to understand water vapor behavior in a global scale consequently. Water vapor also has great variability in spatial and temporal domain, and then it is optimal to retrieve globally the water vapor amount using satellite data, such as polar orbiters and geostationary satellites at frequent observational intervals. Several sensors, such as optical and microwave radiometers, have been used to retrieve the precipitable water (i.e., vertically integrated water vapor amount). It is said that microwave radiometer data are useful to retrieve precipitable water only over ocean because they are not well available over land due to the complexity of land surface emissivity.

Jedlovac illustrated the Split Window Variance Ratio (SWVR) method is applicable to the airborne Multispectral Atmospheric Mapping Sensor (MAMS) data. He suggested that the Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) suffers in its larger spatial resolution and limited dynamic range.<sup>1</sup>

Kleespies and McMillin analyzed Advanced Very High Resolution Radiometer (AVHRR) and VAS to retrieve the precipitable water.<sup>2</sup> They addressed that the optimal instrumentation was the geostationary satellite with the quality of error reduced as much as AVHRR instrument aboard National Oceanic and Atmospheric Administration (NOAA) satellite. They also suggested that the subpixel cloudiness was critical factor for the VAS application.

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Iwasaki has developed the retrieval algorithm for mesoscale water vapor variation using AVHRR / NOAA data. In the method, air temperature effect was corrected with atmospheric model calculations.<sup>3</sup>

In this study, an algorithm has been under development to retrieve precipitable water in a continental scale using split window data (11 and 12  $\mu\text{m}$  spectral bands) based upon Iwasaki<sup>3</sup>. The algorithm was applied to the VISSR aboard Geostationary Meteorological Satellite - 5 (GMS-5). The retrieved results were compared to the in situ radiosonde observation.

## 2. DATA ANALYSIS

The three types of data were used in this study: one is VISSR / GMS-5 data and others are radiosonde and Automated Meteorological Data Acquisition System (AMeDAS) data as references for precipitable water and surface air temperature around Japan, respectively.

As to the VISSR data, the analyzed region ranges from 70 °N to 20 °S in latitude and from 70 °E to 160 °E in longitude. The spatial resolution is around 5 ° by 5 °, and then there exist 1800 by 1800 pixels in total. The analyzed scene number is 228 for 00 and 12 UTC, which extends from January, April, July, and October in 1997 in particular.

As for the reference data, on the other hand, both radiosonde and AMeDAS data from 1988 to 1997 around a calibration site of Japan in this study, were collected to estimate precipitable water and surface air temperature, respectively.

The algorithm under development utilizes the split window channels (11 and 12  $\mu\text{m}$  spectral bands). In general, these spectral channels contains information in lower troposphere (i.e., boundary layer) where almost all water vapor exists. A 6.7  $\mu\text{m}$  spectral band (so to speak, a water vapor channel), is also available in VISSR / GMS-5 data, which is sensitive to the relative humidity around 200 to 500 hPa (middle troposphere to tropopause).<sup>4</sup> The water vapor channel is expected to add some information on a water vapor profile which is not inferred only from split window channels. It is also interested to compare the water vapor distribution pattern of the upper troposphere in a global scale to that of the lower troposphere using aboard the same sensor / satellite.

The algorithm utilizes a transmittance ratio of two split window bands, rather than difference of those brightness temperatures, based upon AVHRR analysis over land by Iwasaki<sup>3</sup>. In the first step of the algorithm, a calibration curve with statistical regression is made between precipitable water and the transmittance ratio parameter, so as to simply retrieve initial precipitable water with split window data. In the second step, air temperature effect is corrected and then apparent surface temperature (i.e., surface air temperature in the model atmosphere in this study) is derived as a by-product.

The algorithm has several new features such as 1) both 11 and 12  $\mu\text{m}$  channels response function are taken into account, 2) not only water vapor continuum absorption but also line absorption with water vapor and other absorbing gases, are taken into consideration and 3) apparent surface temperature is also retrieved and compared to in situ observation such as surface air temperature.

The retrieval algorithm was preliminarily applied to VISSR / GMS-5 data on 00 UTC, October 19, 1997 in particular of all data described in previous section.

### 2.1. Retrieval with regressive curve (first step)

In the first step of the algorithm, SWVR method is utilized.<sup>1</sup> At first, an unit, which contains 32 x 32 pixels around Cape Shionomisaki (33.45 °N, 135.77 °E), was set to make segment analysis. And then, available pixels, judged as least cloud-contaminated, were picked up among the 228 scenes, and then, the statistical value (SWVR) was calculated to retrieve precipitable water for the unit. Fig. 1 illustrates the relationship between the SWVR and precipitable water estimated from the radiosonde data (00 and 12 UTC) at the Cape Shionomisaki.

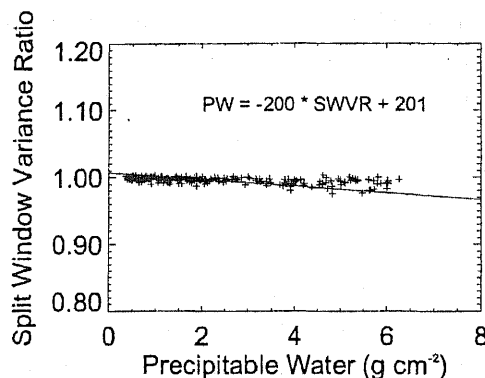


Fig. 1: The relationship between SWVR calculated from VISSR and precipitable water estimated from radiosonde data at Cape Shionomisaki. Dots are the actual data and regressive line is overlaid.

Fig. 1 indicates that linear relationship exists between SWVR and precipitable water. A regressive line was then determined with a least square fitting method:

$$PW = -200 * SWVR + 201. \quad (1)$$

And then, precipitable water is expected to be retrieved from SWVR for all units of the all scenes. For example, precipitable water, retrieved using Eq. (1), is shown in Fig. 2 for the case of 00 UTC October 19, 1997 around Japan.

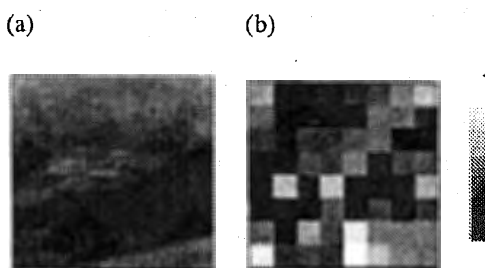


Fig. 2: (a) Water vapor channel ( $6.7 \mu\text{m}$ ) imagery VISSR / GMS-5 and (b) retrieved precipitable water on 00 UTC (09 JST) October 19, 1997. Displayed region of these panels covers from the left top corner ( $42.8^\circ\text{N}$ ,  $129.2^\circ\text{E}$ ) to the right bottom one ( $30.0^\circ\text{N}$ ,  $142.0^\circ\text{E}$ ) in a uniform interval coordinate in latitudinal and longitudinal directions, and then there exist  $256 \times 256$  pixels in total. A level slice is normalized from white to black with which corresponds from maximum to minimum value for panel (b) and vice versa for panel (a).

Precipitable water is retrieved for one unit which consists of  $32 \times 32$  pixels, then it is found that in Fig. 2 the retrieved precipitable water distribution (panel b) is coarser than the spatial variation of water vapor channel image (panel a). Comparing them, tendency of overall distribution is not very different. But the precipitable water retrieved at the units, which contain mountain region, is smaller than that of their surroundings. The precipitable water retrieved at the units, which seems to contain cirrus, has also the same tendency.

Precipitable water estimated from radiosonde data around Japan and that retrieved from the units corresponding to the radiosonde observation sites, are compared to validate the retrieved results on the same scene in Fig. 2. The comparison is

illustrated in Fig. 3.

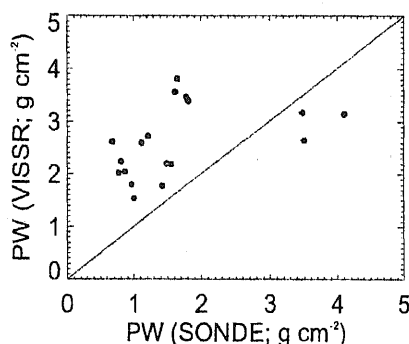


Fig. 3: The comparison of precipitable water (PW) on 00 UTC (09 JST) October 19, 1997 for the same scene in Fig. 2. The abscissa shows the precipitable water estimated from radiosonde data and the ordinate does the one retrieved using split window channels on VISSR. The one-to-one line is drawn as reference.

From Fig. 3, it is found that the retrieved precipitable water using VISSR data overestimates (underestimates) for small (large) precipitable water by about 2 (1)  $\text{g cm}^{-2}$ , respectively, around 18 radiosonde observational sites in Japan.

## 2.1. Correction of air temperature (second step)

In the second step of the algorithm, sensitivity of SWVR to precipitable water was examined with model atmosphere. In the model atmosphere, water vapor and other gaseous absorption were taken into consideration as well as water vapor continuum absorption. Response functions of VISSR split window was weighted in the radiance simulation. Simulation was carried out for some condition. Figure 4 illustrates the condition.

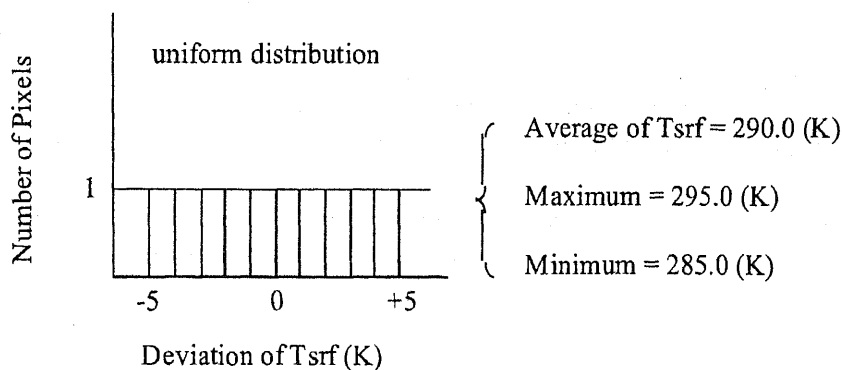


Fig. 4: Schematic for condition used in a simulation of split window variance ratio.

Fig. 5 illustrates a result of SWVR estimated under this condition.

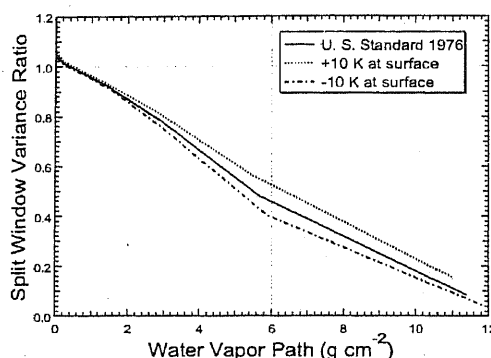


Fig. 5: The relationship between SWVR (ordinate) and Water Vapor Path (abscissa). The U. S. Standard atmosphere 1976 (hereafter USS76), incorporated into the LOWTRAN-7, was assumed as a atmospheric model. It was also assumed that surface radiative temperature in the model ranges from 285 to 295 K uniformly. Solid line is the case for USS76. Dashed line (dotted-dashed) line is the case for which air temperature profile is scaled as the surface air temperature is higher (lower) than USS76 by 10 K.

From Fig. 5, it is found that SWVR estimated using VISSR data is sensitive to precipitable water in a simply decreasing manner. It is also found that the relationship between SWVR and precipitable water is remarkably affected by air temperature when precipitable water is greater than  $2 \text{ g cm}^{-2}$ .

As a result, it is desirable to correct air temperature effect and then improve accuracy of the retrieval of precipitable water. The correction method is also based upon Iwasaki (1994) in principle, but a few devices are added: precipitable water is modified in iterative procedure as air temperature changes under the condition that water vapor volume mixing ratio is constant. A profile of air temperature is also multiplied for all level by the factor of the variation of surface air temperature in the iterative procedure.

Even after the second step of retrieval algorithm, i.e., correction of air temperature influence, however, retrieval accuracy was not improved at all and then the root mean square error was about  $2 \text{ g cm}^{-2}$ . This indicates that the exactness of regressive curve in the first step is more critical than the correction of air temperature when the retrieval method is applied to the VISSR / GMS-5 split window channel data.

It is now turned out that the regressive curves are different very much between from the actual VISSR data (Fig. 1) and from the simulation with a model atmosphere (Fig. 5). Validity of the calibration curve (Fig. 1) is investigated in the next section.

It is also found that in the second step of the retrieval algorithm, apparent surface temperature is retrieved as well as the improved precipitable water. Compared with an in situ observation, the retrieved apparent surface temperature as a by-product at the unit around the Cape Shionomisaki, was lower by about 2 K than the air temperature of AMeDAS data on that scene.

### 3. FEASIBILITY STUDY

As seen in previous section, the retrieved precipitable water using GMS-5/VISSR data showed great discrepancy compared to the radiosonde observation. The reason for this discrepancy should be attributed to the degradation of the calibration curve between SWVR and precipitable water at this stage.

Recently, Barton and Prata have showed that transmittance ratio method, which was equivalent to the SWVR method,

did not work well and then they recommended to use the approach of split window brightness temperature difference.<sup>5</sup> The results in this study actually support their results.

We examined the availability of the split window variance ratio (SWVR) method. Numerical simulations were carried out for several typical cases, changing with surface temperature distribution and water vapor amount. In terms of surface temperature, uniform distribution, and for water vapor amount, on the other hand, U. S. Standard 1976 profile model incorporated in the LOWTRAN 7<sup>o</sup> model, were assumed for simplicity, respectively. One of the result is illustrated in Fig. 6.

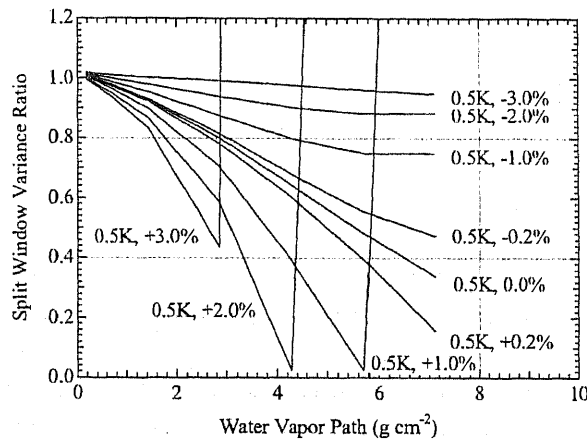


Fig. 6: The simulated relationship between SWVR calculated for VISSR and water vapor path (identical to precipitable water in this case). In this simulation, the surface temperature range (difference between maximum and minimum) is 0.5K. The variation of the water vapor amount is illustrated in percent. The signs plus (+) and minus (-) show the correlation to the temperature variation: e.g., -3.0% means water vapor deviation -1.5% from the standard profile with surface temperature deviation +0.25K, and +1.5% with -0.25K. On the other hand, +3.0% does +1.5% with +0.25K, and -1.5% with -0.25K. Water vapor path is equivalent to precipitable water since scan geometry is a nadir-looking in this simulation.

It is seen from Fig. 6, when water vapor (and atmosphere in this case) is homogeneous, SWVR is sensitive to water vapor amount. But, when water vapor amount varies within some target unit, the calibration curve also varies so greatly that SWVR is not sensitive to the water vapor amount. For example, even if range of surface temperature is 0.5K, when variation of water vapor reaches up to 3.0%, the calibration curve becomes insensitive or disturbed at some case. It could be said that the calibration curves make sense within 2.0% water vapor variation and up to 6 g cm<sup>-2</sup> water vapor path (i.e., precipitable water in this study).

Figure 7 illustrates the case of the surface temperature range 5.0K. It is seen from Fig. 7. that the same aspect as Fig. 6 is shown with the factor ten for both temperature and water vapor variations. It is also found that for the case -30.0%, the simulated line in Fig. 7 resembles the distribution of scatter plot in Fig. 1 which has been made with GMS-5/VISSR and radiosonde data in this study.

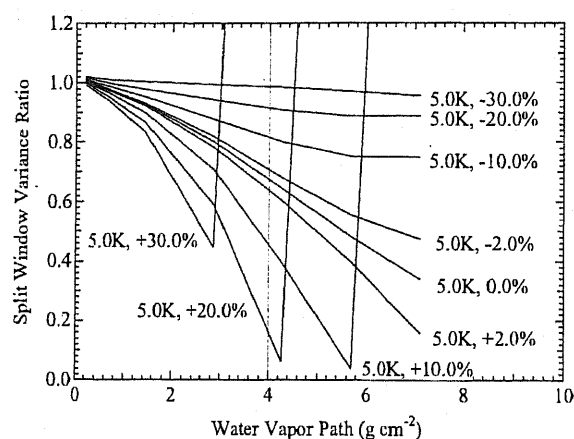


Fig. 7: As in Fig. 6, except for the surface temperature range 5.0K.

Comparing Figs. 6 and 7, under the condition in this simulation, it is found that: (1) when water vapor (and atmospheric temperature in this case) is homogeneous, i.e., with water vapor variation 0%, calibration curve is almost identical to each other, irrespective of surface temperature variation; (2) Almost identical calibration curves are obtained when surface temperature range and water vapor variation are proportional, e.g. (0.5K, -0.2%) and (5.0K, -2.0%).

Such relation is summarized in Table 1. In Table 1, criteria of tolerable water vapor variation corresponding to given surface temperature ranges are shown.

Table 1: Criterion of tolerable water vapor variation corresponding to a given surface temperature range.

Surface Temperature Range (K)	Water Vapor Variation (%)
0.5	< 0.2
1.0	< 0.4
5.0	< 2.0

In actual conditions, these criteria seem to depend upon the unit size. And it is necessary to take care of water vapor variation within the unit to be analyzed. However, water vapor is a property to be retrieved, this statistical method seems applicable under specific conditions, not under global condition.

## 5. SUMMARY AND CONCLUDING REMARKS

To retrieve the precipitable water in a continental scale, a retrieval algorithm has been investigated based upon a transmittance ratio method using split window channel data. The algorithm has been considered as applicable in principle to

the sensor which has the split window channel information such as VISSR / GMS-5 and AVHRR / NOAA. The retrieval algorithm utilizes the statistics estimated from split-window data for a given region, and was preliminary applied to the VISSR / GMS-5 data. The retrieved results were not well consistent with the precipitable water estimated from radiosonde observation around Japan. Barton and Prata also suggested the same results with ASTR and AVHRR data over East Australian Current region.<sup>5</sup> The inconsistency in our study, at this stage, is attributed to the degradation of calibration curve.

In order to investigate the cause of degradation of the calibration curve, numerical simulations were carried out for some specific conditions. As a result, it turns out that even if there is enough surface temperature range (i.e., more than 0.5K) within a given region, when water vapor variation is larger than some criterion (e.g., 0.2%) which depends upon the surface temperature range, the statistics (i.e., calibration curve) is hardly sensitive to water vapor amount.

Air temperature influence is possibly another cause for the degradation of calibration curve. But, it seems that its effect is not larger than water vapor variation very much. Further simulations in terms of air temperature will be carried out as a further work.

The statistics method based upon the transmittance ratio for a given region assumes the atmospheric condition (air temperature and water vapor profile) as uniform. In actual situations on the earth, there possibly be the condition where uniform atmosphere is not obtained to the degree that water vapor variation exceeds the above criteria. When the method is applied to the remote sensing data, it should be taken care that a target region satisfy the assumption. But, since water vapor is the property to be retrieved and its variation affect the results, the availability of the method is considered as restricted very much.

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