

Development of Near Sea Surface Air Specific Humidity Retrieval by Satellite Remote Sensing

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Abstract—Sea surface air specific humidity is important in the remote sensing of the Earth from space. First, the progress of satellite remote sensing near sea surface air specific humidity is studied, then, the principle of near sea surface air specific humidity retrieval is illustrated; further research is suggested at last.

Index Terms—Remote sensing, near sea surface, air humidity.

I. INTRODUCTION

Water vapor in the atmosphere affects atmospheric radiation and thus atmospheric thermal equilibrium. It attenuates electromagnetic propagation through the atmosphere and, therefore, it is important in the remote sensing of the Earth from space. Since surface-level measurements are more available than upper-level ones, atmospheric scientists have long been interested in deriving the total water vapor in an atmospheric column with unit area, often referred to as the precipitable water (W), from such surface-level measurements as dew-point temperature (T_d), vapor pressure (e) or mixing ratio (r) [1]. In the past it has been necessary to rely exclusively on in situ observations to estimate this important parameter. However, with the advent of satellite technology, we now have a unique and complementary way to remotely derive surface humidity. This is made possible because of the uniform spatial and temporal sampling provided by satellites. The principal issue with the satellite method, however, is that accurate estimations of near surface specific humidity (Q_a) is not directly accessible from remote sensing measurements [2].

In this paper, the development of satellite remote sensing near sea surface air specific humidity will be studied. The retrieval of near sea surface air specific humidity based on radiosonde is introduced in section II. The retrieval of near sea surface air specific humidity based on satellite remote sensing is described in section III. The principle of near sea surface air specific humidity retrieval is illustrated in section IV. Conclusions are given in section V.

II. RETRIEVAL OF NEAR SEA SURFACE AIR SPECIFIC HUMIDITY BASED ON RADIOSONDES

Recently Reitan [3] derived a linear relation between the logarithm of W and T_d using monthly-mean data from 15 stations in the continental United States over a period of 3

years, achieved a correlation of 0.98 between mean monthly total precipitable water and mean monthly surface dew point from a total of 540 observations. He found that the line of regression relating these mean values was of the form

$$\ln W = A + B T_d, \quad (1)$$

where W is precipitable water (cm), t_d is the dew point temperature, $A = -0.981$ and $B = 0.0341$. Reitan estimates the standard error from regression at 10 percent. This started a series of evaluations of the coefficients of this relation that lasted for more than a decade, with data coming mostly from weather stations over land. The above result prompted Bolsenga [4] to follow the same procedure to determine the regression relations between mean daily and hourly observations of total water vapor content and surface dew point. Although the correlations he estimates are lower (0.85 to 0.80 for the mean daily and hourly observations, respectively), he found that the same basic relationship given by (1) exists. Bolsenga, however, estimates the coefficients of (1) to be $A = -1.249$ and $B = 0.0427$ for the mean daily observations, and $A = -1.288$ and $B = 0.0384$ for the hourly observations. Estimates of explained variance reveal that about 96 percent of the differences in total water vapor are related to differences in dew point for the mean monthly values, 72 percent for mean daily values and 64 percent for hourly values. Since a unique relationship between total water content and surface dew point depends on the variability of the moisture profile, the tendency towards lower correlations with decreasing time intervals is to be expected. With each investigator working on his own limited set of data in different regions and on time scales from hourly to climatological seasonal mean (Smith, 1966), there is a lack of comprehensive evaluation or universal validation. A number of investigators remain skeptical of the accuracy and general applicability of such a relation suggested a global form of the humidity profile from which a relation between W and T_d can be derived. However, there is disagreement on its physical basis [1, 5, 6]. Ocean surface-level humidity is required in the determination of the ocean surface evaporation and the latent heat it carries. Due to the lack of data over much of the ocean area, only long-term mean distributions are available and not the month-to-month variability. Spaceborne sensors that would provide the much

needed large-scale coverage do not measure Q_a . But spaceborne microwave radiometers can measure W very well[7]; the accuracies were found to be comparable to those of radiosondes. A relation between W and Q_a is needed to apply satellite data in air-sea interaction studies. Over the ocean, the surface is spatially more homogeneous than over land, and the boundary layer, which holds most of the water vapor, is generally subjected to smaller diurnal change and less thermal buoyancy. The Q_a - W relation over ocean may be quite different from that over land. In radiosonde reports from ocean stations, major variances in the atmospheric humidity sounding have time scales of less than a month, and the correlation between W and Q_a is very good when averaged over a month [8]. They suggested that a global statistical relation can be used to derive monthly-mean Q_a from monthly-mean W to an accuracy of 8×10^{-4} , or better than 20 W/m^2 in latent heat flux. They also demonstrated the application of such a relation in deriving Q_a from W measured by a spaceborne microwave radiometer.

III. RETRIEVAL OF NEAR SEA SURFACE AIR SPECIFIC HUMIDITY BASED ON SATELLITE REMOTE SENSING

Progress in this problem appeared in the pioneer study of Liu, who derived an empirical relationship between the total precipitable water (W) from satellite microwave measurements SSM/I and near-surface specific humidity from radiosonde measurements (denoted as Q_a - W relation), he select the radiosonde measurements data from the global monthly summaries of atmospheric soundings archived as Tape Deck (TD) 9648 at the National Climatic Data Center (NCDC) at Asheville, North Carolina. These stations have at least a few years of continuous data of reasonable quality[1]. Because of the inclusion of the 22 GHz water vapor absorption line onboard the SSM/I, W can be retrieved with great accuracy from this platform. Then, by using this empirical Q_a - W relation in conjunction with satellite-derived surface wind speeds and sea surface temperature (SST), determination of latent heat flux over remote areas in the open oceans became feasible[9]. Unfortunately, errors in Q_a originating from the Q_a - W relation can result in large errors in latent heat flux. This was shown by Esbensen et al.[10], who compared one year of latent heat flux derived from satellite data using the Q_a - W relation and in situ estimates from the Comprehensive Ocean-Atmosphere Data Set observations. Their results showed systematic errors of over 2 g/kg in the satellite estimates of monthly averaged Q_a , both in some tropical regions, as well as in middle and high latitudes. Other methods to estimate Q_a from satellite data have been proposed in recent years. Wagner et al.[11] developed a procedure to derive Q_a using W from scanning multichannel microwave radiometer (SSMR), sea surface temperature, and vertical empirical orthogonal functions (EOF). The vertical EOFs were computed from specific humidity profiles from radiosonde data over seven regions in the Atlantic Ocean. Their retrieval algorithm shows root-mean-square (rms) values with collocated in situ data of 1.4 g/kg for individual overpasses to about 0.8 g/kg for monthly averages. Later, Schulz et al.[12] suggested the use of a four-channel regression to retrieve a boundary layer moisture estimate for the lowest 500 m that is

linearly related to the surface humidity. They further developed a linear relationship between W_L and Q_a from radiosonde data and found an rms error of 1.5 g/kg by comparison with collocated ship measurements of Q_a . This led Schuessel et al.[13] to use a direct five-channel regression of Q_a to avoid a "propagation of errors," showing encouraging results. Bentamy et al. [14] also developed a direct four-channel retrieval of Q_a using the same channels as the Schulz study. This was done in hopes of eliminating a possible seasonal bias the authors found in their comparisons. The stated root mean square error (rms) of this algorithm is approximately 1.4 g/kg . This is currently the algorithm of choice in the Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite (HOAPS) product. Chou et al.[15] used SSM/I daily averaged W , W_L retrieved according to Schulz et al.[12], and an EOF procedure to estimate daily averages of Q_a . Their approach included six classes of W -based categories of EOF, which are independent of geographical locations. Comparison with radiosonde data indicated an accuracy of 1.7 g/kg for Q_a daily averages. Miller et al.[16], on the other hand, developed a polynomial fit that estimates the difference between the saturation specific humidity (Q_s) and air specific humidity (Q_a), $Q_s - Q_a$, as a function of W and SST. The rms values for $Q_s - Q_a$ for their linear regressions range from 1.96 to 2.01 g/kg [2].

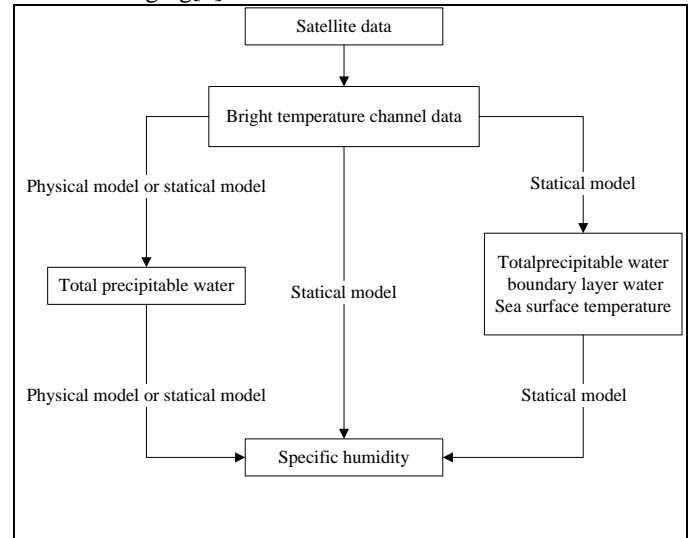


Fig.1. Methods to retrieve specific humidity.

In a study by Jackson et al.[17], a stepwise regression technique using combined instruments was found to improve the accuracy of the retrieval, primarily from the inclusion of the Advanced Microwave Sounding Unit-A (AMSU-A) 52.8 GHz channel that has a peak weighting in the lower troposphere. This study also mentions the impact of high cloud liquid water (CLW) contents on the 37 GHz channels as seen from radiative transfer model simulations. Unfortunately, AMSU-A data only extends from late 1998; for the use of algorithms for longer time scales, SSM/I-only retrievals are necessary. Singh et al.[18] used the Genetic algorithm to find the empirical function relating the input (W , boundary layer water W_b , and SST) and output Q_a . The input data consist of 2 years of daily W , W_b , from SSM/I, and SST data from AVHRR. COADS (Comprehensive Ocean Atmospheric Data Set)

observations of Q_a are used to develop and evaluate the new methodology. The performance of the algorithm is measured with COADS observations, which are not used in the development phase. The global mean rms error for daily averages Q_a is approximately 1.5 ± 0.40 g/kg. Roberts et al.[19] predicted the near surface atmospheric variables from SSM/I using neural networks with a first guess approach, and the rms error of Q_a is approximately 1.3 g/kg.

Based on the relationship between total precipitable water and surface relative humidity[21, 22, 23], Wu et al.[24] developed a statistical relations between the AMSR-E bright temperature data and sea surface meteorological parameters with multi-parameters regression method. The retrieved results in the Pacific Ocean near the equator were compared with the data observed by TAO buoys. Their root mean square errors are 0.53K(SST), 0.74K(T_a), 3.20%(relative humidity) and 1.1m/s(wind speed), respectively. Wang et al.[25] compared AMSR-E and TAO buoy data using genetic algorithm, the rms differences are 1.18K and 1.36 g/kg for air temperature and specific humidity respectively. Methods to retrieve specific humidity are shown in Fig.1, and the development of remote sensing near sea surface air humidity is illustrated in table I.

IV. THE PRINCIPLE OF NEAR SEA SURFACE AIR SPECIFIC HUMIDITY RETRIEVAL

Ordinarily the moisture content is greatest at the earth's surface and decreases to a value of zero at the top of the atmosphere. Regardless of the exact moisture profile, with the proper choice of a power λ for a given atmospheric situation, the average decrease of moisture through the entire atmospheric column may be described by the power law[6, 26]

$$r = r_a (p / p_0)^\lambda, \quad (2)$$

From the definition of the vertical mean mixing ratio \bar{r} ,

$$\bar{r} = \frac{1}{p_0} \int_0^{p_0} r_a \left(\frac{p}{p_0} \right)^\lambda dp = \frac{r_a}{\lambda + 1}, \quad (3)$$

W can be described as

$$W = g^{-1} \int_0^{p_0} Q dp, \quad (4)$$

TABLE I. DEVELOPMENT OF REMOTE SENSING NEAR SEA SURFACE AIR HUMIDITY

Data Source	Authors(Year)	Method	Data Type	Main Conclusion	
Radiosonde	Reitan(1963)	Linear regression	Monthly averaged	A linear relation between the logarithm of W and T_a is derived.	
	Bolsenga(1965)	Linear regression	Daily averaged Hourly averaged	The tendency towards lower correlations between W and t_d with decreasing time intervals.	
	Smith(1966)	Physical mode	Monthly averaged	Reitan's relation in different regions and on time scales is evaluated.	
	Viswanadham(1981)	Linear regression	Monthly averaged	Smith's coefficient in the southern hemisphere is developed.	
	Liu(1986)	Linear regression	Monthly averaged	Mixing ratio error: 8×10^{-4}	
Satellite Remote Sensing	Nimbus-5	Staelin et al.(1976) Chang et al.(1979)	Statistical regression	Individual overpasses	22GHz and 183GHz can be used to retrieve water vapor content.
	AMMS	Wang et al.(1989)	Statistical regression	Individual overpasses	92GHz can be used to retrieve water vapor content.
	SSMR	Wagner et al. (1990)	EOF method	Monthly averaged Individual overpasses	Q_a monthly averaged rms: 0.8g/kg; Q_a individual overpasses rms: 1.4g/kg.
	SSM/I 4 channels	Schulz et al. (1993)	Statistical regression	Individual overpasses	They use of a four-channel regression to retrieve a boundary layer moisture estimate for the lowest 500 m that is linearly related to the surface humidity.
	SSM/I 5 channels	Schuessel et al. (1995)	Statistical regression	Individual overpasses	SSM/I data can retrieve Q_a .
	SSM/I	Chou et al. (1995)	EOF method	Daily averaged	Q_a daily averaged rms:1.7g/kg.
	SSM/I	Miller et al. (1992)	Polynomial regression	Individual overpasses	Q_a - Q_a rms: 2.01 g/kg.
	SSM/I 4 channels	Bentamy et al. (2003)	Statistical regression	Individual overpasses	Q_a individual overpasses rms:1.4 g/kg.
	AMSU-A SSM/I SSM/T-2	Jackson et al. (2006)	Multi-sensor data regression	5 days averaged	Q_a 5 days averaged rms:0.83g/kg.
	SSM/I AVHRR	Singh et al. (2006)	Genetic algorithm	Individual overpasses	The relation between SST and Q_a is evaluated. Q_a relative humidity rms: 1.5 ± 0.40 g/kg.
	AMSR-E	Wu et al. (2007)	Multi-parameter regression	Individual overpasses	Q_a relative humidity rms: 3.2%.
	AMSR-E	Wang et al. (2009)	Genetic algorithm	Individual overpasses	Q_a individual overpasses rms: 1.36 g/kg.
	SSM/I OISST	Roberts et al. (2010)	Neural networks	Individual overpasses	Q_a individual overpasses rms: 1.3 g/kg.

Due to $r \approx Q$, so $W = p_0 \bar{r} / g$, and then

$$W = W(Q_a) = \frac{p_0 Q_a}{g(\lambda + 1)}, \quad (5)$$

(5) is the principle of near sea surface air specific humidity retrieval.

V. CONCLUSIONS

In this paper, the progress of satellite remote sensing near sea surface air specific humidity is studied, and the principle of near sea surface air specific humidity retrieval is illustrated. Further research can be carried out in three aspects: 1. Multi-sensor can be used to improve specific humidity. 2. SST and wind speed should be introduced to retrieve the specific humidity. 3. Latent and sensible heat fluxes calculation may be improved. Specific humidity, wind speed and SST relate to the turbulent latent and sensible heat fluxes over the world oceans, and are important components of the global energy budget, an accurate specific humidity can improve latent and sensible heat fluxes calculation.

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