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A Case Study on Variation of Precipitable Water Vapour for Nimbostratus Clouds

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Abstract

The aim of this paper is to study about detection of Nimbostratus clouds. In recent days the detection of clouds producing precipitation is very necessary for climate research and weather forecasting. Nimbostratus clouds are thick, dark clouds which produces heavy intensity rain. Precipitable Water Vapour (PWV) is a key element which influences atmospheric conditions but is difficult to measure. This study involves the estimation of PWV using temperature and vapour pressure. The brightness temperature observations from 6.7μm water vapour channel are used to calculate the PWV. GRIDSAT data from NOAA's National Climatic Data Centre is also used in this analysis. The variation of PWV for Nimbostratus clouds for a period May-December 2014 is studied in this paper. The analysis of the results obtained from the proposed method shows that, the Nimbostratus clouds have high PWV values.

Keywords: Brightness Temperature, Nimbostratus, Precipitable Water Vapour, Upper Tropospheric Humidity

1. Introduction

Clouds play an important role in weather forecasting and climatic studies, as it causes an important phenomenon called precipitation. Clouds can be classified as precipitating and non-precipitating. The study about precipitation helps to forecast natural hazards such as flood, drought etc. and to take measures to overcome the situation[1].

The clouds can be studied based on ground observations and satellite observations[2]. In this study, satellite observations are used for the analysis. The brightness temperature data is obtained from satellite observations. The satellite observations provide valuable information about the water vapour distribution, atmospheric air mass, temperature of clouds, land etc[3]. In this study Nimbostratus clouds are studied. Nimbostratus is low-level clouds associated with moderate to heavy precipitation. The name Nimbostratus is derived from Latin word nimbus which means rain and stratus which means spread-out. The altostratus clouds get thickened and lowers its base to form thick clouds called Nimbostratus.

Nowadays, the importance of the study of water vapour is increasing as it is a major element causing greenhouse effect. The study of Precipitable Water Vapour is important as it gives an idea about the precipitation produced by the clouds. Precipitable Water Vapour (PWV) is the measure of depth of water present in the atmospheric column, when all the water vapour in it is condensed and precipitated[4]. Precipitable Water Vapour shows annual and seasonal variations due to changes in air mass frequency[5]. The factors such as wind direction, time of day, temperature etc. also affects the Precipitable Water Vapour and this variability makes it difficult to measure[6].

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Another important parameter which has to be taken into account is Upper Tropospheric Humidity. The study about the variation of Upper Tropospheric Humidity (UTH) is necessary to understand the recent climate and the upcoming climatic changes[7]. The studies show that there is a high correlation between Upper Tropospheric Humidity and greenhouse effect[8].

The remaining of the paper is organized as follows. Section II gives details about the different datasets used for the study. Section III describes the methodology used and Section IV explains the results and analysis. Finally, Section V concludes the paper.

2. Datasets

Different datasets are involved in the study and the detailed descriptions of datasets are discussed below.

2.1 GRIDSAT Data

The GRIDSAT Data which is developed by NOAA's National Climatic Data Centre, to access the geostationary data, is used in the study. The Brightness temperature is obtained from 6.7µm water vapour channel and this channel is sensitive to humidity in upper troposphere. The Girded satellite data provides observations from visible, infrared water vapour and infrared window channels[9]. The International Satellite Cloud Climatology Project (ISCCP) B1data is processed into GRIDSAT data format for easy access by the climate researchers. The data are stored in netCDF format. The GRIDSAT data are calibrated data, in equal angle map projection and hence there is no need for the users to apply calibration on raw satellite data[10]. GRIDSAT data provides a spatial resolution of 8km and temporal resolution of 180min. The GRIDSAT data includes observations from FY-2E, GOES-13, GOES-15, METEOSAT-7, METEOSAT-10 etc. The longitude ranges from 70^0S to 70^0N and the data spans the globe in longitude.

2.2 GFS Model

Global Forecast System (GFS) model is a weather prediction model created by National Centers for Environmental Prediction (NCEP) and the model runs 4 times a day to predict weather for 16 days in advance. The data for a period of January-December 2014 is used in the study. The GFS model provides data about temperature, wind, precipitation, soil moisture, atmospheric ozone content etc. The GFS model provides a horizontal resolution of 28km between grid points[11]. The GFS model is modifying regularly to improve its performance. It provides data in Grib format.

2.3 Student's Cloud Observations On-line

Student's Cloud Observations On-line (S'COOL) is a project by National Aeronautics and Space Administration Langley Research Center for students interested in research on clouds[12]. In S'COOL project, the students prepare ground observations and are then compared with satellite observations. S'COOL project is beneficial to both students and scientists. The students observe satellite overpass time using the overpass calculator available in the S'COOL website. Then the different clouds are identified using its shape, altitude, precipitation etc. The recorded observations are then sent to NASA. The data observed by the students are then compared with the satellite observations of the same area[13]. The properties such as cloud cover, temperature, altitude etc. are obtained from satellite data using certain algorithms. These data are then compared with ground observations made by students to provide a reliable cloud data which can be used for cloud research.

The data are stored in NASA Langley Atmospheric Science Data Center. The CERES instrument in Terra satellite is used for accessing satellite observations on clouds. NASA launched Earth observing satellite Terra in 18^{th} December, 1999. Clouds and the Earth's Radiant Energy System (CERES) instrument consists of two scanning radiometers- FM1 and FM2. It consists of three channels- Long wave channel (8-12 µm), Short wave channel (0.3-5 µm) and total channel (0.35-125 µm)[14]. CERES provides a spatial resolution of 20 km at nadir.

3. Methodology

The brightness temperature is obtained from 6.7 µm water vapour channel. The brightness temperature is defined as the measurement of the radiance of the microwave radiation travelling from the top of the atmosphere to the satellite[15]. The brightness temperature is used to calculate another important parameter called Upper Tropospheric Humidity (UTH). UTH is defined as the measure of relative humidity of a layer ranging from 600mb to

300mb[16,17]. Soden and Bretherton derived an analytical expression relating brightness temperature obtained from water vapour channel and UTH[18].

$$UTH = \frac{\exp(a + b * T_b)\cos(\theta)}{Po} \quad (1)$$

where UTH is the Upper Tropospheric Humidity, a and b are least square fit slope and intercept of the regression line as defined by the empirical relationship, θ is the satellite viewing zenith angle and T_b is the brightness temperature value. P_0 is the normalized pressure.

The slope and intercept coefficients a = 31.5 and b = -0.115K^{-1} determined by Soden and Bretherton in their study are used here and these values are consistent with theoretically expected values[18]. The coefficients 'a' and 'b' are obtained by comparing the Brightness temperature with the corresponding Upper Tropospheric Humidity of same temperature and humidity profiles[19].

The expression for Normalized pressure is given as:

$$P_0 = \frac{p(T = 240K)}{p_1} \quad (2)$$

where p_1 = 300hPa and p (T = 240K) is the pressure at the level where the temperature is 240K.

The water vapour mixing ratio can be defined as the ratio of mass of water vapour to mass of dry air (in g/kg) and is denoted as q_v.

$$q_v = q_s * UTH \quad (3)$$

where q_s is the saturation mixing ratio.

Saturation mixing ratio is defined as the maximum amount of water vapour that the air can carry for a specific temperature and pressure and can be calculated as follows[20],

$$q_s = \frac{0.622 * e}{P - e} \quad (4)$$

where q_s is the saturation mixing ratio at pressure P and e is the vapour pressure. The expression for saturation vapour pressure can be given as [21],

$$e = 6.11 * \exp\left(\frac{17.27 * t}{273.3 + t}\right) \quad (5)$$

where e is the vapour pressure in hPa and t is temperature in ^{0}C.

Using the above parameters, PWV can be calculated as,

$$PWV = \frac{1}{g}\int q_v dp \quad (6)$$

where the incremental change in pressure is denoted as dp and PWV is the Precipitable water vapour in kg/m^2 or mm of water.

4. Results and Analysis

The variation of PWV for the Nimbostratus clouds for a period of January-December 2014 is studied. Figure 1 shows the plot of PWV in kg/m^2 for each month.

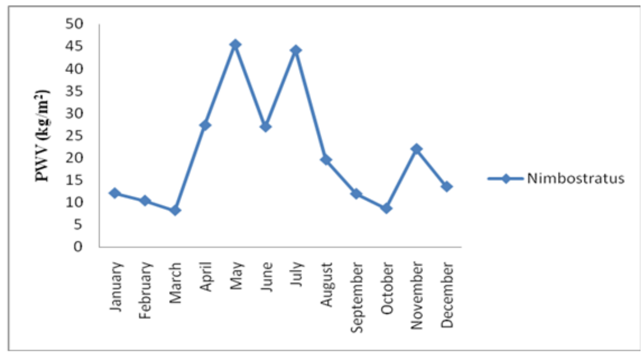

Figure 1. Variation of PWV for Nimbostratus clouds.

The Nimbostratus clouds are showing linear variations for PWV in the graph. Nimbostratus clouds shows high peak for PWV values in May and July. It is observed that Nimbostratus possesses low PWV in March and October. The highest PWV values shown by Nimbostratus clouds are 45.345 kg/m^2 in May and 44.0676 kg/m^2 in July. Nimbostratus clouds give low PWV values 8.2064 kg/m^2 and 8.6429 kg/m^2 in March and October respectively. The Nimbostratus clouds show a significant increase in PWV from March to May as the values varies from 8.2065 kg/m^2 to 45.3451 kg/m^2. After July, the PWV values decreases till October and then show an increase in November. In October the PWV value observed is 8.6429 kg/m^2 and in July it gives a PWV value 44.0676 kg/m^2. The Brightness temperature observed on May and July are 231.118 K and 234.5 K respectively. In March, the brightness temperature obtained is 237.221 K.

Nimbostratus clouds are high intensity precipitation giving clouds. But, it is observed that due to some reasons the precipitation may not occur. Such a scenario is also studied here. Table 1 shows the brightness temperature and PWV for two cases- during precipitation and no precipitation.

Here it is observed that PWV values during precipitation and no precipitation show higher variation. During precipitation the PWV values ranges between 19-

Table 1. Brightness Temperature and PWV during Precipitation and No Precipitation

Month	Precipitation		No Precipitation	
	Brightness Temperature (Kelvin)	PWV (kg/m^2)	Brightness Temperature (Kelvin)	PWV (kg/m^2)
January	224	51.0604	241	1.4952
February	220.5	27.8096	238.1	1.1143
March	227.5	19.3432	257.8	1.3667
April	217.7	37.9674	249.3	2.6522
May	230.8	19.2519	247.1	2.4218
June	236.2	25.3076	246.7	1.3224
July	231.8	32.9290	254.2	2.2084
August	228.1	53.6438	243.4	2.4622
September	232.9	19.7749	-	-
October	231.8	28.5124	242.6	2.0217
November	228.3	22.1209	-	-
December	231.1	26.9670	252.8	2.6346

54 kg/m^2. But the range of PWV during no precipitation varies from 1-2 kg/m^2. In August, the PWV value during precipitation is 53.6438 kg/m^2 and is the highest value observed during the year 2014. It is observed that in August, some days experience no precipitation. In such case, it is observed that the PWV observed during August is 2.4622 kg/m^2. This drastic change in PWV value is the reason for no precipitation during August. In January the PWV value observed during precipitation and no precipitation is 51.0604 kg/m^2 and 1.4952 kg/m^2 resp. The difference between these values is evident for no precipitation even in the presence of Nimbostratus clouds. Nimbostratus shows lowest PWV value 19.2519 kg/m^2 in May during precipitation. In February, the Nimbostratus clouds give lowest PWV value 1.1143 kg/m^2, during no precipitation. It is evident that the PWV values vary annually and seasonally.

It is also observed that the brightness temperature obtained from water vapour channel also varies for the cases of precipitation and no precipitation. From Table 1 it is observed that the brightness temperature during precipitation is smaller than the brightness temperature during no precipitation. In January the brightness temperature during precipitation and no precipitation is 224 K and 241K respectively. Generally as temperature increases water vapour content also increases. Here, it shows some exceptions. For the study of precipitation and no precipitation, both the parameters brightness temperature and PWV are taken into account. The more parameters we consider, efficiency of weather prediction also increases. For the calculation of PWV the temperature and height profiles are also considered.

In April, the brightness temperature obtained during precipitation is 217.7 K and during no precipitation is 249.3 K. In June, the highest brightness temperature value 236.2 K is obtained for the scenario of precipitation. It is noticed that in March, the brightness temperature value 257.8K is the highest, in the case of no precipitation.

Figure 2 shows the Brightness Temperature indicated by different colours. The range of brightness temperature is indicated by different colours. Each pixel of the satellite image will have a corresponding Brightness temperature value. In Figure 2, the Brightness temperature ranges from 166.7 K to 260.7 K

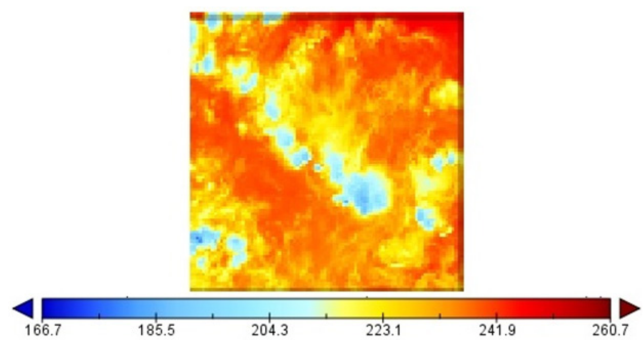

Figure 2. Representation of Brightness Temperature obtained from 6.7 μm channel.

5. Conclusion

The water vapour has a crucial role in greenhouse effect and global warming, which makes its study more necessary in the present scenario. Nowadays it is necessary to examine the amount of water vapour present in the clouds for various applications. The precipitation produced by clouds directly or indirectly affects the climate. The Nimbostratus clouds are continuous precipitation giving clouds when compared to other precipitating clouds. The knowledge about precipitation also supports air navigation and marine navigation. The Precipitable Water Vapour gives the knowledge about the water vapour content that the Nimbostratus clouds can hold. The high precipitable water vapour for the Nimbostratus clouds is one of the reasons for the high intensity of precipitation produced by it. The significance of PWV and Brightness temperature in the case of no precipitation is also studied. The knowledge about the PWV helps to predict the intensity of precipitation the clouds can produce. The climatic changes can be estimated using the PWV of the Nimbostratus clouds. The work can be improved by considering all the precipitating clouds and observing the variation of PWV, in future.

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