# Identification of Non-precipitating Clouds using PWV Analysis

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## Abstract

**Background:** The objective of this paper is to identify non-precipitating cirrus, cirrostratus, and cirrocumulus clouds by measuring the Precipitable Water Vapor (PWV). **Method:** PWV is a measure of the liquid water that obtained if all the water vapor in the atmospheric column is condensed and precipitated which calculated from the water vapor channel data obtained from geostationary satellites. In this paper, places with particular non-precipitating clouds are selected and PWV value is calculated. The study is conducted over a period from 1st January to 31st December of 2014. Results: The range of PWV values measured is used to identify the high level, non-precipitating clouds. **Application:** PWV values obtained can be used along with more climatic data for cloud classification.

Keywords: Non-Precipitating Clouds, PWV, Water Vapor Channel

# 1. Introduction

The clouds are the visible form of water vapor or ice crystals in the atmosphere. It is a key component in Earth's hydrological cycle<sup>1</sup>. Weather phenomena such as cyclones, storms and hurricanes are the outcome of latent heat from clouds. Clouds have inevitable role in maintaining Earth's radiation budget<sup>2,3</sup>. By reflecting the solar radiation, low level thick clouds make the Earth surface cool. While the high level thin clouds allow the incoming radiation and trap the outgoing radiation hence, maintaining warming action.

The latest technology uses satellite and radar data for weather forecasting. Long term weather forecasting is possible with geostationary satellite data characterizing high temporal resolution. Clouds are classified as low, middle and high level clouds based on cloud base height. The visible, IR and water vapor channel data from geostationary satellites are utilized by the meteorologists for long term weather forecasting. Non-precipitating clouds usually composed of super cooled water droplets and ice crystals. These clouds do not produce precipitation, but indicates the changes in weather condition. High level clouds cirrus, cirrostratus and cirrocumulus are belongs to non-precipitating clouds and normally formed at a height between 16500 ft and 45000 ft.

Cirrus clouds are indicators of fair weather condition. Cirrocumulus ( $C_c$ ) clouds mostly found during winter season and indicate cold weather condition.  $C_c$  is short living clouds found as patches. Formation of cirrocumulus patches along with other forms of cirrus clouds utilized for weather forecasting. Small  $C_c$  cloud patches alone indicates the good weather, patches along with cirrus or cirrostratus indicates rain within 8-10 hours while the cirrocumulus clouds after rain denotes improving weather condition.  $C_c$  clouds occasionally produce virga, type of precipitation that evaporates before reaching ground. Cirrus and cirrostratus primarily composed of ice crystals while small amount of liquid water droplet

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present in cirrocumulus cloud. Cirrostratus is relatively transparent cloud, forms as sheets and composed of ice crystals.

PWV is the amount of liquid water that is obtained if water vapor in the atmosphere column is condensed and precipitated. PWV is measured either using direct method or indirect method. Data measured by Radiosondes is used in direct methods while infrared or radio waves from atmospheric transmittance and emission is utilized to obtain PWV in indirect method. Since PWV analyze the atmospheric humidity, a number of studies have been conducted for site selection of astronomical observatories based on PWV measurement.

The data from geostationary satellite is used, to calculate the PWV at a high altitude location for the site selection. This method is applied to Atacama Pathfinder Experiment (APEX) and Cerro Toco sites which are located at an altitude above 5000 m4. A study was conducted in northwest Africa and southern Spain as the part of site selection for European Extremely Large Telescope (E-ELT). The work included calibration of Upper Tropospheric Humidity (UTH) of Meteosat-5, Precipitable Water Vapor (PWV) and cloud cover utilizing the aerial analysis. The result of aerial analysis is compared with ground based observation to verify the accuracy5. Geostationary satellite provides data, which have high temporal resolution. The water vapor and IR channel data from geostationary satellite is used in an assessment of cloud cover and water vapor in a region of north Chile. To calculate the UTH and PWV of the selected location, radiance data acquired from the satellite is converted into brightness temperature<sup>6</sup>.

This paper presents a study of non-precipitating cloud based on PWV measurement. The remaining of the paper is organised as follows. Section 2 gives the details of the data used for the study. Section 3 includes the methodology and section 4 gives the results. Section 5 concludes the study.

# 2. Data

### 2.1 GridSat

Geostationary satellites are mainly intended for weather and communication applications. Even though geostationary satellites provide Earth observations with high temporal resolution, the data access is limited due to the lack of central archive for the data from all satellite, different calibration and navigation format impeding the uniform processing of multi satellite data. To overcome these problems International Satellite Cloud Climatology Project (ISCCP) created an archive called ISCCP B1 data which consists of data from international meteorological satellites. ISCCP B1 data is processed into GridSat data format, to reduce the complexity in accessibility and further processing. The mapping of data is done equirectangular projection. GridSat data includes data from Geostationary Operational Environmental Satellite (GOES), Meteorological Satellite (MeteoSat), Geostationary Meteorological Satellite (GMS), Multifunctional Transport Satellite (MTSAT), Feng Yun (FY).

The GridSat data includes observations from IR window, visible channel and water vapor channel in Network Common Data Format (netCDF). The standards used to store the data leads to easy and fast data processing using various tools and libraries<sup>7</sup>. For the calculation in our study, water vapor channel ( $6.7\mu$ m) brightness temperature data is used. According to the measured brightness temperature (T<sub>B</sub>), each pixel in the water vapor channel image is assigned with a gray shade.

#### 2.2 Global Forecast System

Global Forecast System (GFS) is a numerical weather prediction model generated by National Centers for Environmental Prediction (NCEP)<sup>8</sup>. The model runs by the center four times per day to produce forecasts up to 16 days in advance. The temperature and pressure data are obtained from the GFS data for the calculation. The GFS model is a combination of four separate models including an atmosphere, an ocean, a land or soil, and a sea ice model combined together to generate an accurate depiction of weather conditions. The model is being updated on a regular basis to improve the performance and accuracy of forecast.

#### 2.3 Students' Cloud Observation On-Line

Students' Cloud Observation On-Lin (S'COOL) is a project by National Aeronautics and Space Administration (NASA). In this project, students are reporting the ground observation regarding clouds which have been used to validate NASA's Clouds and the Earth's Radiant Energy System (CERES) instruments in various satellites. The satellite overpass schedule is provided. The clouds are observed within a particular time of the satellite passage and these observations are used for comparison with the corresponding satellite data<sup>9</sup>.

## 3. Methodology

The observed cloud types at various levels are noticed in S'COOL data. Along with the cloud type observed in that particular place, data such as latitude, longitude, time of observation, parameters such as temperature, pressure, humidity are also noticed. PWV values are calculated for the sites where only non-precipitating clouds were present and result is analyzed. The  $6.7\mu$ m channel measures the radiations from water vapor at a layer having pressure levels from 300 hPa to 600 hPa. The calculation of PWV includes Upper Tropospheric Humidity (UTH) and saturation mixing ratio calculation.

## 3.1 Upper Tropospheric Humidity Calculation

The humidity in the upper troposphere is a major component in the climate system. UTH is the relative humidity averaged vertically over a region having pressure range between 200 mb and 500 mb. 6.7µm Water vapor channel and 183.31 GHz microwave channel data are mainly used to calculate the UTH utilizing the satellite data<sup>10</sup>. Data obtained by Atmospheric Infrared Sounder (AIRS) is also used to calculate the relative humidity in upper troposphere<sup>11</sup>. Based on radiative theory an analytical expression has been derived to relate the satellite water vapor radiance data and layer average relative humidity. This radiance to humidity transformation is utilized to interpret the satellite water vapor observations from TIROS vertical sounder in terms of averaged relative humidity over the lower, middle and upper regions of troposphere<sup>12</sup>. In the algorithm developed by Soden and Bretherton<sup>13</sup>, the relation between  $T_{\rm B}$  and UTH is explained. This algorithm is applied for the assessment of water vapor in upper troposphere<sup>14</sup> and for the analysis of deep convection, UTH and green house effect<sup>15</sup>. The relation is given as

$$UTH = \frac{\exp(a + b^*T_B)\cos\theta}{P_0}$$
(1)

In the above empirical relationship the variable a is the least squares fit intercept and b is the least squares fit slope of the regression line. And the values are a=31.5 and b=-0.115K<sup>-1</sup>.  $\theta$  is the satellite viewing zenith angle. The normalized pressure  $P_0$  (hPa) is

$$P_0 = \frac{p(T_{240k})}{p_1}$$
(2)

 $p(T_{240k})$  Represents the pressure at a level where the temperature is 240 K and P<sub>1</sub> is 300 hPa. Normally the value of P<sub>0</sub> is chosen as unity.

#### **3.2 Saturation Mixing Ratio Calculation**

Saturation mixing ratio is defined as the maximum amount of water vapor the air can carry at a particular temperature and pressure. The temperature and pressure data for the calculation is obtained from GFS data. The following formulas used to calculate saturation mixing ratio.

$$w = \frac{.622 \times e}{p - e}$$
(3)

$$e=6.11 \times \exp(\frac{17.27t}{273.3+t})$$
(4)

Where w is the saturation mixing ratio at pressure p in hPa, e is the vapor pressure, and t is the temperature in degree Celsius. Saturation mixing ratio is expressed in gm/kg.

#### 3.3 Precipitable Water Vapor Calculation

On multiplying the saturation mixing ratio with UTH water vapor mixing ratio is obtained. Then the PWV is calculated as follows

$$PWV = \frac{1}{g} \int q_v \cdot dp = \frac{1}{g} \int UTH \cdot w.dp$$
(5)

where g=9.8m/s<sup>2</sup> and  $q_v$  is the water vapor mixing ratio in kg/kg and it represents the mass of water vapor per mass of dry air. The incremental pressure change is given by dp. PWV is expressed in kg/m<sup>2</sup> or mm of water.

## 4. Result and Discussion

PWV is calculated for location with particular clouds. A sample image of brightness temperature data and corresponding indicator is given in Figure 1(a) and 1(b) respectively. The brightness temperature for the observing location is obtained from an array corresponding to this image.



**Figure 1.** (a) Brightness Temperature sample data; (b) Brightness Temperature Indicator.

Table 1. PWV values for cirrocumulus clouds

Sl.	Lat (°)	Long (°)	Date	Tem-	T <sub>B</sub>	PWV
No				perature	(K)	(kg/
				(K)		<b>m</b> <sup>2</sup> )
1	51.52	-0.13	21-01-2014	269.5	231	5.216
2	38.99	-1.87	23-01-2014	272.2	242.2	2.928
3	51.52	-0.13	27-01-2014	267.9	230.5	8.616
4	38.99	-1.87	10-03-2014	275.1	242.7	4.242
5	25.09	121.41	17-04-2014	288.3	246.1	4.121
7	44.81	-72.19	01-05-2014	275.2	243.1	3.248
8	-34.69	-58.5	19-05-2014	277.7	242.6	5.437
9	-29.42	-66.85	20-05-2014	284.3	245.5	6.450
10	-26.83	-65.2	03-06-2014	282.5	248.7	3.800
11	-34.69	-58.5	14-06-2014	276.0	239.2	5.486
12	40.23	-80.21	12-07-2014	286.7	244.6	8.243
13	29.42	-66.85	22-10-2014	289.3	243.1	8.676
14	45.29	4.24	13-11-2014	278.9	234.8	8.204
15	38.04	-78.0	14-11-2014	262.2	237.6	2.262

Table 1 shows the calculated PWV values for cirrocumulus clouds. From the table it is found that the minimum PWV value is 2.262 kg/m<sup>2</sup> in November. Atmospheric temperature for this PWV value is 262.2 K which is the smallest temperature among the observations. Corresponding T<sub>B</sub> value is 237.6 K, a medium value. The maximum value of PWV found is 8.676 kg/m<sup>2</sup> in October. The brightness temperature for maximum PWV value is 243.8 K which is a medium value and atmospheric temperature measured is 289.3 K. The range of PWV is obtained between 2 to 8 kg/ $m^2$ . Atmospheric temperature varies between 260 K and 290 K. The brightness temperature value changes from 230 K to 250 K. The saturation mixing ratio of the minimum PWV is 1.62gm/kg and in case of maximum PWV is 11.49 gm/kg. The UTH values for the above cases are 45.62% and 24.66% respectively. Saturation mixing ratio increases with temperature. Here for maximum PWV case the case saturation mixing ratio is 11.49 gm/ kg, hence more water vapor content is present. For the minimum PWV, saturation mixing ratio is 1.62 gm/ kg with atmospheric temperature of 262.2 K. Even though the difference between maximum and minimum atmospheric temperature is around 30 K, large variation is observed in case of saturation mixing ratio. The UTH value for minimum PWV is higher than UTH of maximum PWV value.

Table 2. PWV values for cirrostratus clouds

<b>S1</b> .	Lat (°)	Long (°)	Date	Tem-	T <sub>B</sub>	PWV
No				perature	(K)	(kg/
				(K)		<b>m</b> <sup>2</sup> )
1	46.42	-84.35	07-01-2014	246.8	232.3	1.24
2	40.23	-80.21	24-01-2014	250.4	234.3	1.71
3	46.42	-84.35	06-02-2014	253.1	230.6	2.14
4	42.58	-71.08	06-02-2014	261.7	230	7.44
5	45.29	4.24	22-02-2014	270.4	235.1	9.34
6	46.42	-84.35	19-04-2014	271.4	232.2	11.66
7	40.23	-80.21	19-04-2014	276.1	235.2	10.75
8	40.23	-80.21	20-04-2014	279.6	244.2	3.147
9	40.23	-80.21	20-04-2014	279.9	238.8	4.39
10	-29.42	-66.85	27-04-2014	286.3	244.1	8.26
11	-29.42	-66.85	24-05-2014	278.6	243.1	3.66
12	25.09	121.41	26-05-2014	291.5	238.4	14.26
13	-26.83	-65.2	27-05-2014	283.4	246.8	5.28
14	-29.42	-66.85	10-06-2014	284.4	238.9	13.05
15	-36.83	-73.1	26-06-2014	274.4	240	6.06
16	40.23	-80.21	27-08-2014	288.4	243	11.47
17	35.62	-78.15	08-10-2014	286.9	232.1	15.37
18	41.02	-84.47	27-10-2014	286.6	232.7	15.50
19	-34.69	-58.5	13-11-2014	278.7	244.4	3.86
20	45.29	4.24	19-11-2014	277.0	234.8	12.72
21	45.29	4.24	20-11-2014	282.3	234.8	11.42

Table 2 shows the PWV values calculated for the cirrostratus clouds. From the table it is found that the maximum PWV value is 15.50 kg/m<sup>2</sup> and the minimum value is 1.24 kg/m<sup>2</sup>. For Highest PWV value, atmospheric temperature 286.6 K and  $T_{\rm B}$  is 232.7 K. In case of lowest PWV value, atmospheric temperature is found as 246.8 K and corresponding  $T_{\rm B}$  is 232.2 K. The atmospheric temperature range for the cirrostratus cloud is between 246 K and 292 K.  $T_{\rm B}$  values lies between 230 K and 247 K. Most cases the atmospheric temperature is observed above 260 K. In first three observations the temperature is below 254 K. For this case PWV values are lower compared with other values. It also shows lower values for brightness temperature. Cirrocumulus and cirrostratus clouds have almost similar range in brightness temperature. However, most of the  $T_{B}$  values are below 240 K and above 230 K.

The saturation mixing ratio for highest PWV value is 9.64 gm/kg and UTH value is 52.55%. In case of lowest PWV value the saturation mixing ratio obtained is 0.44 gm/kg and UTH is 92.09%. Atmospheric temperature for this case is 246.8 K, which is the lowest temperature among the observations. Due to the lower temperature, saturation mixing ratio is also very low.

Table 3. The PWV calculated for the Cirrus clouds

Sl.	Lat (°)	Long (°)	Date	Tem-	T <sub>B</sub>	PWV
No				perature	(K)	(kg/
				(K)		<b>m</b> <sup>2</sup> )
1	46.42	-84.35	28/01/2014	247.4	226.8	1.62
2	42.58	-71.8	10/02/2014	270	236	5.87
3	40.23	-80.21	23/02/2014	272.6	234	10.13
4	36.2	-115.12	25/02/2014	282.2	246.3	2.95
5	40.23	-80.21	4/05/2014	275.6	236.8	7.39
6	40.23	-80.21	6/05/2014	278.4	238.3	6.69
7	-26.83	-65.2	29/05/2014	289	257.1	2.26
8	-26.83	-65.2	4/06/2014	293	253	2.07
9	40.23	-80.21	10/06/2014	282.9	240.6	10.25
10	40.23	-80.21	25/07/2014	282.2	241.2	5.56
11	40.23	-80.21	7/08/2014	284	243.1	6.03
12	40.23	-80.21	19/08/2014	286.8	246.8	3.61
13	-34.69	-58.5	12/09/2014	281.2	244.6	3.53
14	45.29	4.24	19/09/2014	282	229.3	21.86
15	-34.69	-58.5	27/09/2014	278.3	237.7	8.73
16	40.23	-80.21	4/10/2014	281.4	245.5	2.33
17	40.23	-80.21	27/10/2014	284.4	236.3	13.99
18	40.23	-80.21	10/11/2014	279.3	235.3	13.13
19	40.23	-80.21	14/11/2014	259.2	241.3	0.998
20	40.23	-80.21	26/12/2014	275	238.5	7.65
21	40.23	-80.21	27/12/2014	276.6	241.8	2.54

Table 3 shows the calculated PWV values for cirrus clouds. The highest value of PWV obtained is 21.86 kg/m<sup>2</sup> in October the corresponding temperature is 282 K. The brightness temperature is lowest value and is 229.3 K. The lowest PWV value measured is 0.998 kg/m<sup>2</sup> in November. The atmospheric temperature is 259.2 K and  $T_B$  is 241.3 K. From the observations it is found that most of the cases the PWV values are below 10 kg/m<sup>2</sup>. The atmospheric temperature variation is between 247 K and 293 K. Lowest brightness temperature among the observation is 226.8 K with a PWV value of 1.62 kg/m<sup>2</sup>. For this case the atmospheric temperature measured is also a low value. For the highest atmospheric temperature value, the  $T_B$  value measured is also high and obtained as 253 K. The maximum  $T_B$  obtained from the data is 257 K.

Even though cirrus clouds are non-precipitating in nature, anomalies are found in observation. On 28/01/2014 and 19/09/2014 precipitation is observed and maximum value of PWV observed in later case. Lowest value of brightness temperature observed in above two days.

# 5. Conclusion

This paper presents a detailed study of high level nonprecipitating cloud using PWV measurement. The observation shows that, the minimum PWV value for the non-precipitating cirrus cloud is 0.998 kg/m<sup>2</sup> and maximum PWV value for cirrostratus clouds is 15.50 kg/m<sup>2</sup>. The PWV value ranges for different clouds are obtained from this study. Lower range of PWV value is obtained for cirrocumulus clouds, which is in the range of 2-8 kg/m<sup>2</sup>. The range of PWV values for the cirrostratus cloud obtained is 1-15 kg/m<sup>2</sup> whereas, in case of cirrus clouds the PWV values varies from 1 to 14 kg/m<sup>2</sup>.

Water content in the clouds is one parameter which can used to identify the clouds. In this work PWV values for high level non-precipitating clouds are calculated and range for different clouds are obtained. Up to a certain limit these parameter can use to identify the clouds. Since there is an overlapping in PWV values, additional infrared channel information can be included to get more accurate result.

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