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Trend and Seasonal Variation of Total Perceptible Water Vapor Content Using Radio-Sounding Observations at Chennai (VOMM) For The Period (1974- 2017).

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Abstract: *The precipitation of atmospheric water vapour to the liquid or solid phase is accountable for clouds, rainfall and snow, which plays important role in climate and climate change. The energy released during vapor condensation affects the dynamics of the atmosphere. Through this interaction, the vertical stability of the atmosphere is modified, influencing the weather systems and their associated precipitation patterns. In this paper, we derived the total water vapour content in atmosphere using radiosonde observation over the Chennai radiosonde station (VOMM) for 44 years (1974-2017). The paper also highlights the statistical analysis of total water vapour content. The trend of total water vapour content in atmosphere is useful to understand the climate and its change in atmospheric conditions at Chennai. The trend of total water vapour content is also studied in this paper using the Mann-Kendall test and Sen's slope estimate. The relationship expression between mean weighted atmospheric temperature and surface temperature depends upon the surface parameters. The values of constants in the expression depends upon the geographical conditions of the station. These constants for VOMM are determined and reported in this paper. The use of local constants in determination of perceptible water vapor will increase the accuracy of the prediction of perceptible water vapor*

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I. Introduction

Troposphere is the lowest segment of earth's atmosphere and the most of the mass (about 75-80%) of the atmosphere is concentrated in the troposphere. The vapour form of water is a vital component of the atmosphere. The precipitation of water vapour to the liquid or solid phase plays important role in climate of atmosphere . During precipitation process the latent heat of vaporization, is released into the atmosphere .The latent heat released during atmospheric convection is responsible for empowering the storms such as tropical cyclones(Lossow 2008). Water vapor is also the prominent greenhouse gas and responsible for absorbing the infra-red waves of the light spectrum. Meteorology is the science of weather. Recent advancements in satellite technology have led to noteworthy progress in meteorology. The radio wave transmission through troposphere affected due to the refractive index of the medium.(Kumar et al. 2015) The refractive index of the atmosphere depends parameters like pressure, temperature and relative humidity (Bevis et al. 1994).This properties of radio wave make it an efficient tool to study the atmosphere. GPS signals and radiosonde observations are used for atmospheric monitoring (Zhang et al. 2018). The stability of an air parcel during the vertical motion depends on the vertical temperature profile of the ambient air and whether the parcel is saturated or unsaturated. In this paper the trend of water vapor content over the radiosonde station over the long period is studied. The various statistical parameters like mean, variance , skewness and kurtosis are used to study the variation in water vapor content at radiosonde station of Chennai. The Chennai radiosonde station (13° 4' 2.7804" N and 80° 14' 15.4212" E). is located in southern part of India .The trend of total water vapour content is studied using the Mann-Kendall test and Sen's slope estimate(Trends et al. 2002). Such study will help to understand the trend in water vapor content. It also useful identifies the crucial condition and parameters which were responsible for change in climate conditions.

II. Material And Methods

Radiosonde technique has been widely used to understand the vertical structure of troposphere. Since it is deployed with various sensors to measure important meteorological variables such as temperature, dew point temperature, pressure, mixing ratio , relative humidity and wind speed along a vertical path. The presence of water vapor will affect the mixing ratio of air of the troposphere(Ross et al. 2002). Radiosonde data are useful to determine water vapor content in vertical column using mixing ratio at various a layers. We retrieved the radiosonde data for 44 years (1974- 2017) for VOMM (Chennai station).The total water vapor content specified at any two vertical levels are represented in terms of height to which that water will stand if it is completely condensed. The total water vapor content (TWVC) between any arbitrary two heights is given by following equation (Nilsson and Elgered 2008).

$$TWVC = \frac{1}{\rho_w g}\int_{P_i}^{P_f} r(p)dp \qquad (1)$$

ρ_w is the density of water which is 1000 [kg/m^3] , r(p) is the mixing ratio at pressure p , p_i and p_f are pressure of initial and final layers. g is the gravitational acceleration 9.8 [m/s^2].The integration over the total path of radiosonde data will provide the total water vapor content. For each sounding the total water vapor content is determined by integration over the whole vertical path of the sounding. The total water vapor content data were filtered and non-available data points were removed from data set. Then the data set was processed by statistical software STATA /SE . The objective the processing to determine mean, variance , skewness and kurtosis for the total water vapor content.

The Mann-Kendall test and Sen's method is used to determine the trend of total water vapor content and its slope. The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model given in the equation 2. (Nury et al. 2017)

$$y_i = f(t_i) + \varepsilon_i \qquad (2)$$

where $f(t_i)$is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. We want to test the null hypothesis of no trend, Ho, i.e. the observations x_i are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. In the computation of this statistical test exploits both the so called S statistics given in Gilbert (1987) and the normal approximation (Z statistics). For time series with less than 10 data points the S test is used, and for time series with 10 or more data points the normal approximation is used.

The Mann-Kendall test statistic *S* is calculated using the formula

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(y_j - y_k) \qquad (3)$$

where y_j *and* $y$are the annual values in years *j* and *k*, *j* >*k*, respectively.

$$\mathrm{sgn}(y_j - y_k) = \begin{cases} 1 & if\ y_j - y_k > 0 \\ 0 & if\ y_j - y_k = 0 \\ -1 & if\ y_j - y_k < 0 \end{cases}$$

The variations of S and Z are computed using equation 4.

$$VAR[S] = \frac{1}{18}[(n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)] \qquad (4)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{VAR}\ [S]}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{\mathrm{VAR}\ [S]}} & if\ S < 0 \end{cases}$$

To estimate the true slope of an existing trend the Sen's nonparametricmethod is used. The Sen's method can be used in cases where the trend can be assumed tobe linear. This means that *f(t)* in equation 2 is equal to

$$f(t) = Qt + B \qquad (5)$$

where Q is the slope and B is a constant.

The integrated perceptible water vapour (IWV) is defined as: (Bevis et al. 1992)

$$IWV = \int \rho_v\ dz = k\ (ZWD) \qquad (6)$$

Where ρ_v is the water vapour density in the atmosphere, $ZWD$is the zenith wet delay, and the "constant" k is given by:

$$\frac{1}{k} = 10^{-6}\left(\frac{k_3}{T_m} + k_2\right)R_v (7)$$

where $R_v$is the specific gas constant for water vapour. Using the mathematical expression for mean weighted temperature of the atmosphere T_m

$$T_m = \frac{\int \frac{P_v}{T} dz}{\int \frac{P_v}{T^2} dz} \qquad (8)$$

Bevis derived the relation between mean weighted temperature of the atmosphere T_m and surface temperature T_s is given by (Bevis et al. 1994)

$$T_m = 70.2 + 072\,T_s \qquad (9)$$

The mean weighted temperature of the atmosphere T_m depends upon surface temperature of station. The relation between mean weighted temperature of the atmosphere T_m and surface temperature T_s are determined for selected radiosonde sites of India using linear regression method for the radio sounding observations for upper air. (Yanxiong et al. 2001)

III. Result

Using the everyday sounding of radiosonde data of VOMM station the total water vapor content is derived. The presence of a statistically significant trend is evaluated. The trend is indicated by Z value . The values of Z are determined month wise as well as season wise. The values of Q and B are determined for Sen's slope estimate. Where Q is the slope and B is the constant. The results are shown in table 1. It can be observed from table 1 that Z has positive value which indicates upward trend. Annual trend and seasonal trends are shown in the plots in figure 1, 2, 3 and 4 respectively. Figure 1 shows the trend of annual variation of total water vapour content at VOMM. Figures 2,3 and 4 show the trends of total water vapour content in summer, monsoon and winter at VOMM. Trends also show the mean value around which the total water vapour content varies during a year or a season. The yearly mean is the average value that of the total water vapour content that VOMM receives over the year .The annual mean value of total water vapour content at VOMM is 43 mm. The mean value total water vapour content at VOMM for summer is 36 mm. The mean value The mean value total water vapour content at VOMM for monsoon is 54 mm. The mean value total water vapour content at VOMM for winter is 39mm

To estimate the true slope of an existing trend the Sen's nonparametric method is used. The value of slope Q and constant B is obtained. The results are shown in the table 1.

Using statistical methods variance, skewness and kurtosis of total water vapor content over the VOMM for each year are determined. We plotted the variation of each parameter for 44 years (1974 - 2017) for VOMM (Chennai station).

The results are shown in the figures (5 to 7).It can be observed from figure 5(a) that skewness has positive values for almost all years except year 2015. If skewness is positive, the data are positively skewed or skewed right, meaning that the right tail of the distribution is longer than the left. It can be observed from figure 6(a) that kurtosis have larger values than 3 which means that the distribution of total water vapor content has heavy tails. The figures 5(b) and 6(b) show the occurrence of skewness, kurtosis of TWVC in terms of frequency at VOMM. Figure 7(a) shows the standard deviation of TWVC at VOMM. Figure 8 shows the trend of annual rainfall at VOMM. It also shows the positive trend.

The expression obtained for by regression analysis of radiosonde observations at VOMM are shown in figs 9. It describes the expression for relationship between mean weighted atmospheric temperature and surface temperature of different radiosonde sites in India.

The obtained expression is as described here.

$$T_m = 99.4 + 0.65\, T_s \tag{10}$$

Table 1 : Value of Z , Q and B in Mann-Kendall trend & Sen's slope estimate

				Mann-Kendall trend		Sen's slope estimate	
Month	First year	Last Year	n	Test Z	Significance	Q	B
January	1974	2017	44	3.04	0.01	0.17	24.84
February	1974	2017	44	0.54	> 0.1	0.04	26.42
March	1974	2017	44	3.42	0.00	0.22	24.72
April	1974	2017	44	3.96	0.00	0.23	33.19
May	1974	2017	44	3.80	0.00	0.32	38.59
June	1974	2017	44	3.04	0.01	0.21	48.63
July	1974	2017	44	3.47	0.00	0.20	49.20
August	1974	2017	44	3.25	0.01	0.22	49.26
September	1974	2017	44	3.01	0.01	0.21	47.08
October	1974	2017	44	2.57	0.05	0.14	46.97
November	1974	2017	44	1.41	>0.1	0.11	41.08
December	1974	2017	44	1.63	>0.1	0.09	31.92
ANNUAL	1974	2017	44	4.82	0.00	0.18	38.97
summer	1974	2017	44	4.54	0.00	0.25	32.69
Monsoon	1974	2017	44	3.69	0.00	0.22	48.40
Winter	1974	2017	44	3.36	0.00	0.13	34.33

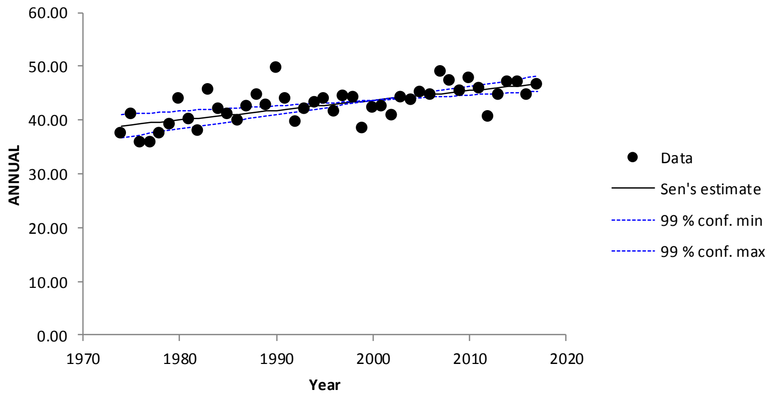


Figure 1 : trend of the annual water vapor content at VOMM

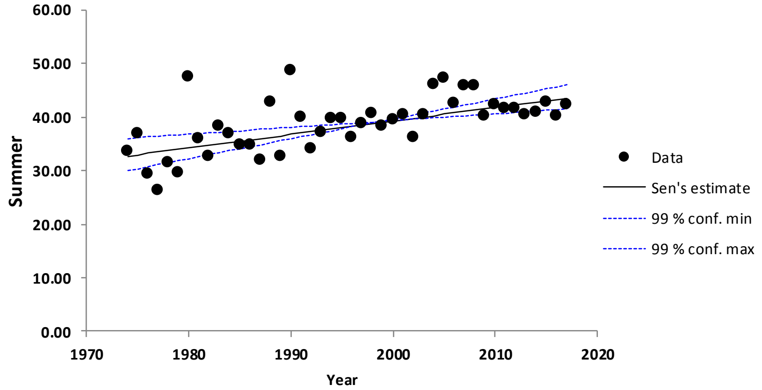


Figure 2: trend of the total water vapor content during summer at VOMM

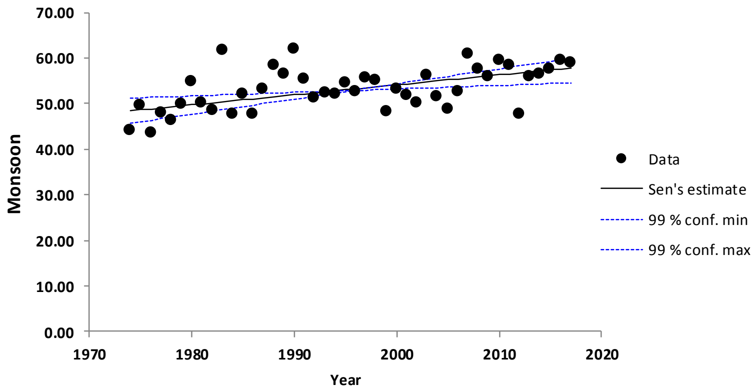


Figure3: trend of the total water vapor content during monsoon at VOMM

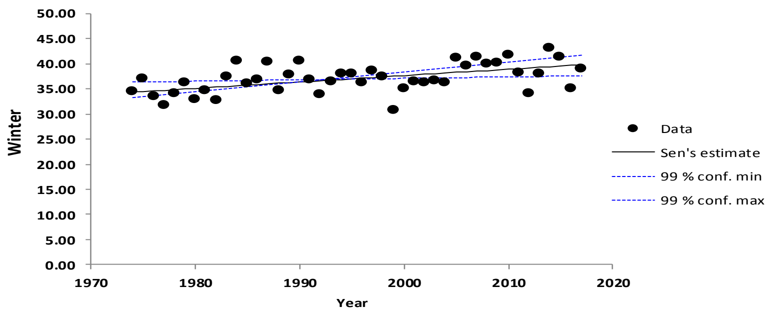
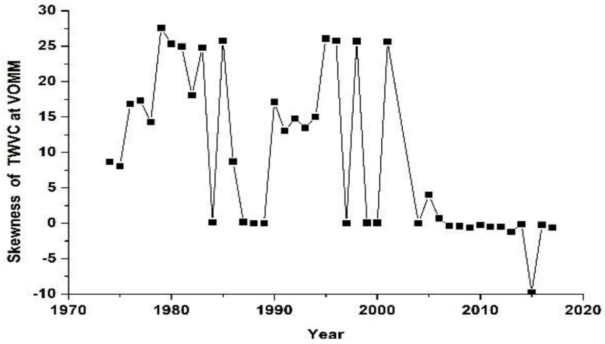
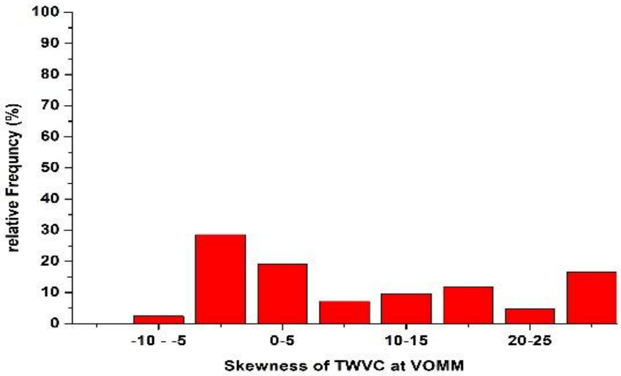


Figure4: trend of the total water vapor content during winter at VOMM

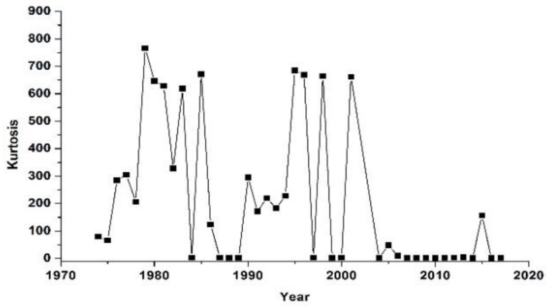


(a) Skewness for TWVC for VOMM

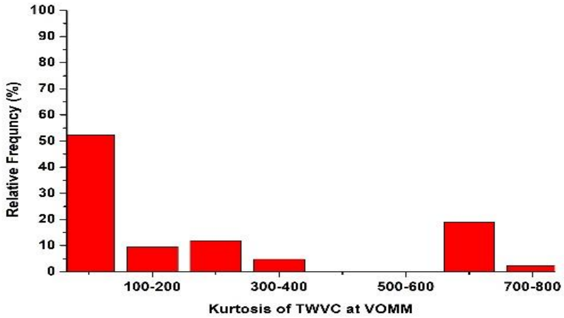


(b) frequency distribution for skewness of TWVC

Figure 5: Skewness and its Frequency distribution at VOMM.

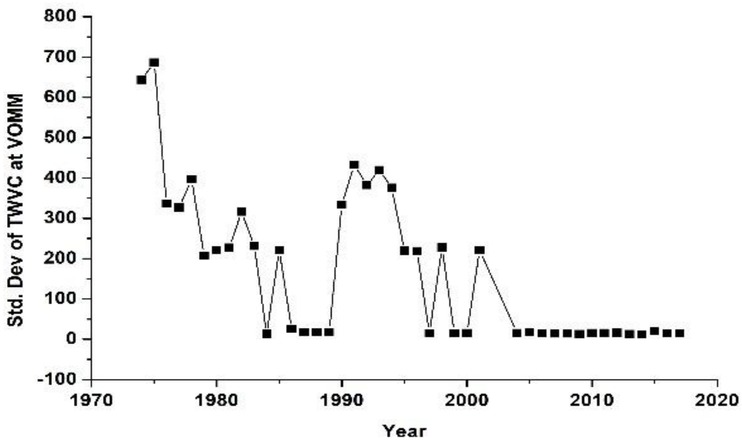


(a) Kurtosis for TWVC for VOMM

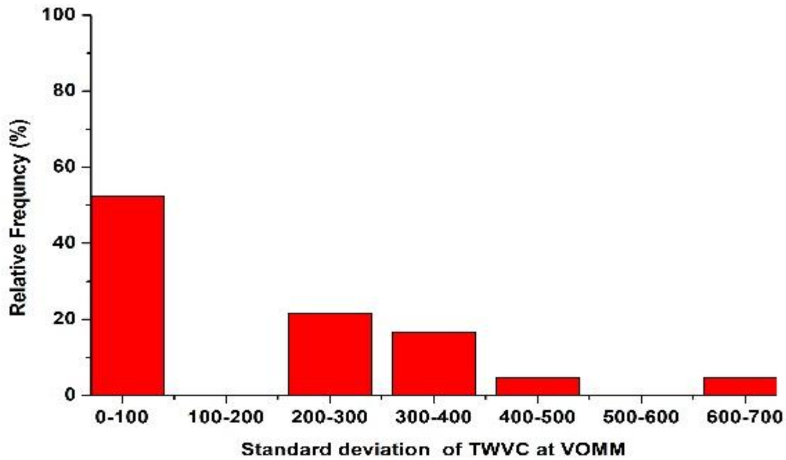


(b) frequency distribution for kurtosis of TWVC

Figure 6: Kurtosis and its Frequency distribution at VOMM



(a) standard deviation for TWVC for VOMM



(b) frequency distribution for Std. Dev of TWVC

Figure 7: Standard deviation and its Frequency distribution at VOMM

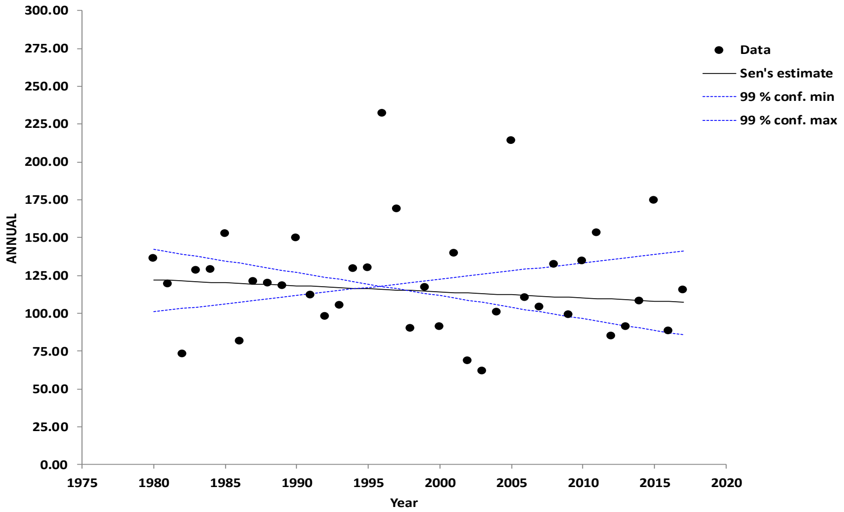


Figure8 : Trend of Annual rainfall at VOMM

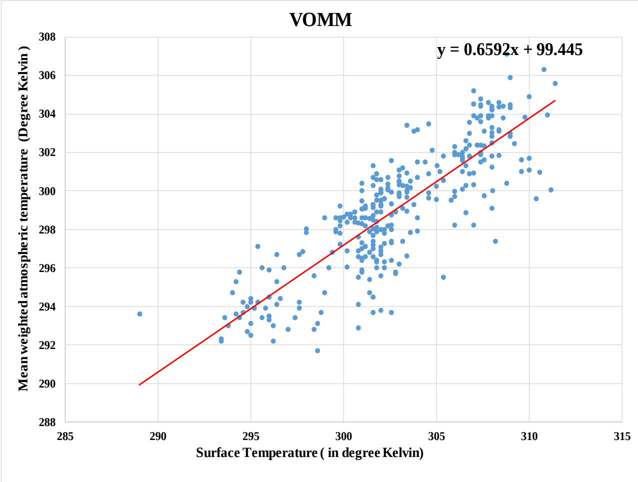


Figure 9: Surface temperature T_s&mean weighted atmospheric temperature T_m at VOMM

IV. Conclusion

We derived the total water vapor content for VOMM using daily sounding of radiosonde observations from year 1974 to 2017. The significant trend is evaluated and value of Z is determined monthly as well as for all seasons. We obtained the positive values for Z for annual as well as seasonal variations. A positive value of *Z* indicates an upward trend. The annual mean value and seasonal mean value of water vapour content at VOMM will increase in near future.

The value of Q and B are determined for Sen's slope estimate. It can be seen that value of slope and constant are having approximately same value for monthly, annual and seasonal variation trends. So trend of water vapor is uniform and linearly increasing in upward direction.

The Skewness and kurtosis values confirms that water vapor content distribution is uniform in nature. We obtained the positive values for skewness and kurtosis values are greater than 3 which indicates that total water vapor continent distribution at VOMM has heavy right tail. The total water vapor content values are more in second half of every year. It indicates rain during the winter season also. Rain during month of November and December at VOMM is due to south –east winds from Bay of Bengal.

The relationship expression between mean weighted atmospheric temperature and surface temperature depends upon the surface parameters. The values of constants in the expression depends upon the geographical conditions of the station. Here the constants are determined for local site VOMM.. The use of local constants in determination of perceptible water vapor will increase the accuracy of the prediction of perceptible water vapor.

Understanding of such trends and water vapor distribution are useful to determine the climate change as well as forecast the weather conditions.

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