



Long-term Study of Satellite Water Vapor Along with Meteorological Measurements at Synoptic Stations

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Abstract:

One of the key parameters in climate change is Precipitable Water Vapor (PWV) which plays an important role in identifying precipitation distribution, hydrological cycles and important meteorological and climatic phenomena. Therefore, it is important to study the long-term changes in PWV time series in an area. MODIS near-infrared PWV product (MOD-NIR-PWV) provides a suitable spatial coverage of PWV with a resolution of 1 km and temporal resolution of 1 day. This study compares statistically the time series of MODIS PWV from 2000 to 2018 with radiosonde values. MODIS data under cloudless conditions at a maximum distance of 1 km from the position of the radiosonde station were used for statistical analysis. The results show that the consistency between two sets of water vapor data in terms of correlation coefficient was obtained at 0.81, 0.78 and 0.67 in Tehran, Isfahan and Mashhad stations, respectively. Also, the linear trend of PWV time series in the study areas was investigated using Mann-Kendall (MK) statistical test. PWV values in both datasets have undergone similar trends, according to time series analysis of radiosonde and MODIS. Therefore, free remote sensing methods such as MODIS products along with local data can be used for long-term studies of PWV to study the trends of the PWV parameter. Furthermore, a decrease in precipitation and an increase in surface temperature along with an increase in the PWV value of MODIS data was observed in studies with synoptic data in the studied stations, which may in some way reflect the effects of global warming in the studied stations.

1. Introduction

Climate change has significant positive and negative effects on the ecosystem due to the climate-environment interactions. It is necessary to identify the occurrence of climate changes and its impact on the ecosystem to better manage resources, especially water resources. Due to the close relationship and interaction between climate change and the ecosystem, these changes may be due to long-term natural fluctuations or the result of short-term and medium-term changes in human activities such as land use change or greenhouse gas emissions[1].

According to results reported by relevant studies, climate change and global warming have adverse effects on different parts/regions of the earth. In general, greenhouse gases are defined as any gaseous compound that is capable of absorbing infrared radiation thereby trapping and holding heat in the atmosphere, thus contributing to the greenhouse effect. Greenhouse gas emissions have had many adverse effects on the world climate system due to human activities. The results of IPCC studies show that by the end of the 21st century, the average temperature of the Earth will increase between 1.4 and 5.8 °C [2].

Water vapor is considered as the most abundant greenhouse gas in the atmosphere, which plays an important role in distinguishing hydrological cycles, climate changes and global climate. This parameter has also contributed largely to many atmospheric phenomena such as precipitation and floods. As one of the most important greenhouse gases, atmospheric water vapor also greatly affects climate change,

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which involves a positive feedback to global warming and leads to further climate change[3].

In other words, water vapor is the name of water in its gaseous phase in the Earth's hydrosphere. Dry air is a theoretical sample of air that has no water vapor. There is no dry air in the stratosphere. Evaporation, known as the wetting of dry air from the surface of oceans and surface waters and transpiration, is the source of moisture and the formation of clouds and rain. The maximum water vapor in the atmosphere is 3-4%, which plays a major role in keeping the Earth's atmosphere balanced. Because water vapor absorbs longer-wavelength radiation, if the amount of water vapor is low in the atmosphere, the temperature difference becomes very large. Given that the amount of water vapor has 0.0001% of the total natural water resources on the Earth, yet, it plays a very important role in Earth-related surveys. The amount of water vapor is considered as one of the most useful parameters for predicting rigorous weather conditions and precipitation rate[1]. Also, the Earth's atmosphere has been one of the key factors for studying the global water cycle in changing climate conditions and energy exchange. The amount of water vapor in the air can also be used to improve precipitation forecast[2].

Meteorologists have introduced many parameters for the expression of water vapor in the atmosphere, of which Precipitable Water Vapor (PWV) is one of the most common. This parameter is highly variable at different spatial and temporal scales. Therefore, it is necessary to measure PWV as accurately as possible to monitor the spatio-temporal changes of water vapor in order to make more accurate weather forecasts and climate models. In fact, Precipitable water vapor (PWV) is the total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending from the Earth's surface to the top of the atmosphere. This physical parameter is one of the effective parameters on many atmospheric and aquatic processes. As a result, it is important to calculate the PWV with appropriate spatial and temporal resolution in different climatic conditions. Several methods are being developed to measure PWV using terrestrial measurements and satellite remote sensing data. Radiosondes, global positioning systems, microwave radiometers and solar photometers, and remote sensing methods are among ground-based instruments for measuring PWV.

Recently, the use of remote sensing and satellite data retrieval technology has been rapidly expanding. This technology is one of the new tools that have made it possible to access and extract basic information for land resource management[4]. Some of the most important unique features of remote sensing methods are ease of use, high accuracy and cost reduction, and the analysis of processes and patterns and the use of data over time and space that has led to its validation in earth science, specifically the Earth's

climate[5]. Remote sensing, while simultaneously examining large areas using sequential images, makes it possible to provide a temporal and spatial framework for studying the behavior of environmental phenomena, including climate changes. Parameters such as temperature, precipitation and water vapor are measured at the Earth's surface using remote sensing data, and these factors as the most important and influential climatic factors of climate change have been monitored for a long time by examining temporal and spatial changes[6, 7]. It should be noted that the use of remote sensing is not limited to the study of the Earth's surface, and various sensors in the form of various satellite missions measure atmospheric parameters such as the amount of ozone, water vapor, suspended particles and dust and examine the changes in these atmospheric parameters over the time[8-12]. The gap in the database of meteorological data can be well eliminated by continuously studying some parameters by satellite sensors, the parameters that show climate changes, such as temperature, precipitation, water vapor, snow, etc. Also, equal access to water and land is one of the important advantages of remote sensing[13, 14]. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the Aqua and Terra satellites is an efficient sensor in the production of remote sensing products such as water vapor, the data of which have recently been used in several studies. The Terra satellite has five sensors and remote sensing instruments that are used to monitor the environment and the planet's climate.

The Aqua mission is a part of the NASA-centered international Earth Observing System (EOS) that orbits the Earth and studies rainfall, surface evaporation and the water cycle. Aqua is the second major component of the Earth Observing System (EOS) preceded by Terra (launched 1999) and followed by Aura (launched 2004). The MODIS sensor can be considered as one of the best choices for estimating the required parameters due to the large number of spectral bands, daily imaging of the earth and free available images. The MODIS sensor was installed in 1999 by NASA on the Terra satellite and placed into orbit. The device was installed in 2002 on the Aqua satellite and placed into orbit. MODIS has the ability to receive data in 36 bands in the wavelength range of 0.4 microns to 4.14 microns with variable spatial resolution (2 bands in 250 meters, 5 bands in 500 meters and 29 bands in one kilometer). These satellites have the ability to image all of Earth's landmass for up to two days, provide large-scale measurements of terrestrial metamorphism, including cloud cover, radiation, intra-oceanic and terrestrial metamorphism, and the lower atmosphere.

Many researchers have studied the PWV values and its usefulness in monitoring a rainfall event. Barindelli et al. reported a peak in the PWV values in response to a heavy precipitation event, followed by a steep decrease (5–10 mm

in about 1 h) in the observed PWV values as the rain clouds moved past the station using data from a temperate station (of Italy)[15]. Zhou et al have studied the performance of an infrared PWV product near MODIS (MOD-NIR-PWV) in China. At each point in the network, after applying the calibration model to modify MOD-NIR-PWV, the calibrated MOD-NIR-PWV was compared with ERA-PWV and GNSS-PWV, respectively, for accurate analysis. This comparison showed that the model can significantly improve accuracy to 94% and precision to 53%, indicating the effectiveness of the calibration model in improving the performance of MOD-NIR-PWV in China[16]. Previous studies on short-term rainfall forecast using precipitable water vapor (PWV) and meteorological parameters mainly focused on rain occurrence, while the rainfall forecast was rarely investigated. In the study, Zhang et al. proposed an hourly rainfall forecasting (HRF) model based on a supervised learning algorithm to predict rainfall with high accuracy and time resolution[17]. In the mentioned researches, the parameters of precipitation and water vapor were used to predict the weather, and in some cases, 2 categories of water vapor data of radiosonde stations and other methods of estimating precipitable water vapor were examined.

This study investigates the changes in water vapor behavior by measuring the MODIS sensor at Tehran, Mashhad and Isfahan stations over a long period of the years (2000-2018) due to the importance of the water vapor parameter and its close relationship with quantities such as precipitation and global warming. It is also related to other environmental phenomena such as rainfall using time series analysis and trend modeling[18-22].

Long-term study of its time series and rate of changes can be useful in understanding how climate change and global warming affect the desired region. Although remote sensing data has advantages such as convenient spatial and temporal resolution, MODIS data, but in each region it is better to be statistically evaluated before use to determine the accuracy of the data.

For this purpose, the time series of MODIS water vapor products can be compared in the near-infrared band with the corresponding radiosonde time series in a long period, and the accuracy of these products in this period compared to radiosonde observations will be estimated as a reliable method. In general, three goals have been pursued in this study:

1. The degree of agreement on the rate of changes of water vapor obtained from radiosonde and MODIS
2. The accuracy of MODIS's long-term water vapor time series compared to radiosonde
3. Association of long-term changes in water vapor with synoptic changes in the area under study.

2. Study area and methodology

2.1 Study area

Three radiosonde stations were used in Tehran, Isfahan and Mashhad provinces. Table 1 shows the characteristics of these stations along with their location, and the location of synoptic stations is listed in Table 2. Also, the approximate location of stations in the country is shown in Fig.1.

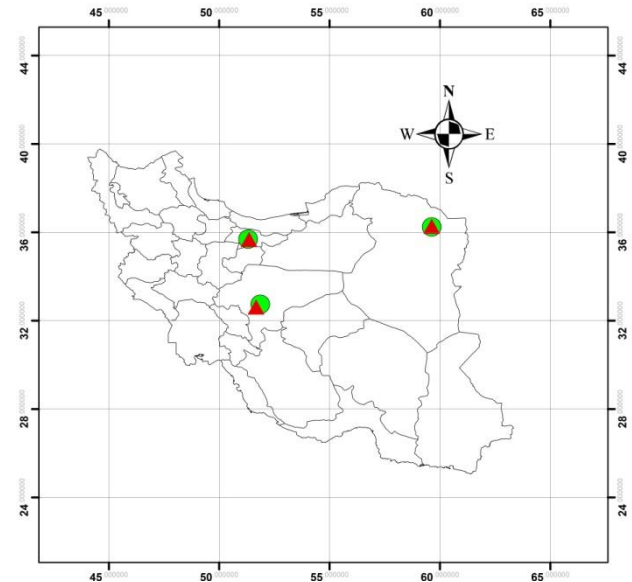


Fig.1: Scattering of radiosonde stations under study
The red triangle indicates the radiosonde stations and the green circles indicate the synoptic stations under study.

Table 1: Locations of the radiosonde stations under study

Radiosonde Station	Province	latitude	longitude
OIII	Tehran/Mehrabad	35.68	51.35
OIFM	Isfahan	32.46	51.71
OIMM	Mashhad	36.26	59.63

Table 2: Locations of the synoptic stations under study

Synoptic station	Province	latitude	longitude
OIII	Tehran-Mehrabad	35.69	51.31
OIFM	Isfahan	32.74	51.86
OIMM	Mashhad	36.24	59.63

2.2 Data

This study introduces three different data sets including ground station measurements, MODIS-derived PWV values, and corresponding values obtained from radiosonde stations, separately.

2.2.1 Radiosonde stations

Radiosonde is considered as an important measuring instrument for measuring temperature, altitude, pressure, relative humidity, wind (both speed and direction) at high altitudes. This measuring instrument is sent to the depths of the atmosphere and is used by meteorological balloons to collect atmospheric information at high altitudes. They are usually equipped with radio receiver equipment of the meteorological stations at high altitudes, in which, according to the standards of the World Meteorological Organization, a radiosonde device is sent to the air every 12 hours by a meteorological balloon. Radiosonde measurements of regions which are downloaded from the University of Wyoming were used in this study to evaluate MODIS satellite data and to examine the trend of PWV changes.

2.2.2 MODIS data

MODIS is the main sensor board on the NASA EOS (Earth Observation System), launched to monitor surface oceans and atmospheric interactions. The sensor was first placed on the Terra satellite in 1999 and then on the Aqua satellite in 2002. The MODIS instrument provides high radiometric sensitivity (12 bit) in 36 spectral bands ranging in wavelength. The MOD05 and MYD05 products consist of two types of PWV data: MOD-NIR-PWV and MOD-IR-PWV. The Level-2 data are generated at the 1-km spatial resolution of the MODIS instrument using the near-infrared algorithm during the day, and at 5 km x 5 km pixel resolution both day and night using the infrared algorithm. In this study, MOD05 with a spatial resolution of 1 km was used because it possesses a higher spatial resolution than the MOD-IR-PWV.

2.2.3 Synoptic data

Synoptic Meteorological Stations simultaneously around the world are responsible for measuring and preparing atmospheric parameters 24 hours a day and sending them in the telecommunication network (according to the rules and the regulations of the World Meteorological Organization), called synoptic, that is archived every three hours and METAR, archived every one hour respectively, that differ depending on the application

The main meteorological stations affiliated with the Meteorological Organization are called synoptic stations. At these stations, the values of temperature, rainfall, relative humidity, wind, evaporation and other meteorological variables are measured regularly hourly and daily. Sea surface air temperature (C), pressure and relative humidity along with 6-hour rainfall observations have been used in this research.

3. Method

The PWV component in MODIS data from 2000 to 2018 related to the studied stations was first extracted to carry out this study. Then, the corresponding data of these stations and the desired time period were downloaded and extracted from the website of the University of Wyoming. The weather information of Synoptic Meteorological Station was prepared by the Meteorological Organization of Iran. The quantities of temperature (in terms of silicon) and precipitation (in terms of millimeters) during the years 2000-2018 were extracted from among the meteorological statistics and the information was recorded at this station. Then, the time series of data were provided in MATLAB to review and compare. The MODIS sensor's PWV data is received by Terra satellite in the morning. But, the radiosonde PWV is achieved two times (every day) often at noon. Therefore, interpolation operations were performed on MODIS data to better compare and synchronize the two data at the same time and Bilinear method was used for interpolation.

The mean difference of these two types of data, namely the mean difference of Radiosonde PWV ($PWVR_i$) and synchronized PWV of MODIS sensor ($PWVM_i$), was used for analysis and comparison in this study. Similarly, the RMSE parameter was calculated according to Equation (2), to estimate the difference between the two sets of water vapor data in terms of accuracy. Then, the correlation coefficient was used to check the correlation (R) and the agreement of these two methods and the average MBE bias (Equation 3) was used to express the systematic error of satellite data. Subsequently, the least squares method was used to examine the time series trend of the data and the Mann-Kendall test was used to determine the significance of the time series trend value. In the following, the quarterly averages of this data are calculated and plotted for more detailed studies.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (PWVR_i - PWVM_i)^2}{N}} \quad (1)$$

$$MBE = \frac{1}{n} \sum_{i=1}^n (PWVR_i - PWVM_i) \quad (2)$$

In these equations, $PWVR_i$ and $PWVM_i$ are radiosonde data and satellite data at the time of radiosonde, respectively, and n indicates the number of time series data.

3.1 Mann-Kendall nonparametric test

This method is widely used in trend analysis of hydrological and meteorological time series and some of its most important advantages are its suitability for time series that do not follow a specific statistical distribution. In order to calculate the Mann-Kendall I coefficient (t), a set with n

members containing X_i is first considered. Then, for each X_i member, the number of members in the series that were before the X_i member and are smaller than X_i (n_i) is calculated, and a new series of n_i is formed for each corresponding X_i member. Next, the cumulative sum of the new series (n_i) is calculated so that $t = \sum n_i$, if before X_i , there were members whose value is equal to the value of X_i , add n_i to their number/2. This quantity under H_0 and with equal mean and variance follows normal distribution.

$$E(t) = \frac{n(n-1)}{4} \quad \text{var}(t) = \frac{n(n-1)(2n+5)}{72} \quad (3)$$

This test is a two-way test, therefore, the null hypothesis is rejected for large values $|u(t)|$ with value $u(t) = [t - E(t)] / \sqrt{\text{var}(t)}$. More precisely, if the probability α_1 using the standard normal distribution table is equal to $\alpha_1 = P(|u| > |u(t)|)$, the null hypothesis (ie., there is no trend) is accepted at the confidence level α_0 , if $\alpha_0 > \alpha_1$ and if $\alpha_0 < \alpha_1$, the null hypothesis is rejected [23, 24].

4. Results and discussion

4.1 Trend analysis

Mann-Kendall test was used to examine the trend of the studied variables and the significance of the trend was calculated at the confidence level (5%) and its summary is given in Table 3. According to the calculations, the radiosonde derived PWV has undergone a significant trend in all stations under study. Also, the satellite derived PWV has a significant positive trend in all stations studied. The synoptic change of rainfall shows only a significant decreasing trend in Mehrabad station (OIII) in the study period, but the other stations show a trend with significant increase for rainfall. The synoptic variable of temperature at Mehrabad station does not show a significant trend due to the rejection of the hypothesis due to the large p-value of the alpha level. Temperature variables undergo a significant increasing trend in Mashhad stations (OIMM) and for Isfahan station (OIFM).

Table 3: Mann-Kendall statistics values for time series of studied variables on a daily scale

	PWV(Radiosonde)			PWV(Satellite)			Rainfall			Temperature		
Station	OIFM	OIMM	OIII	OIFM	OIMM	OIII	OIFM	OIMM	OIII	OIFM	OIMM	OIII
Kendall's tau	0.065	0.063	0.056	0.054	0.033	0.037	0.018	0.017	-0.047	0.030	0.0247	-0.003
p-value (Two-tailed)	<0.0001	<0.0001	<0.0001	<0.0001	0.002	<0.0001	0.006	0.0003	<0.0001	<0.0001	<0.0001	0.3
α_0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

The monthly average was calculated after interpolation by Bilinear method and simultaneity of MODIS and radiosonde data, the RMSE, MBE and data correlation values. As shown in Table (4), there is the highest correlation between PWV satellite and radiosonde data on a monthly basis at Mehrabad (OIII) station with 81% and the lowest value of this correlation is related to Mashhad station (OIMM) with 67%. Also, comparing the average monthly satellite data with the corresponding values obtained from radiosound shows that the average radiosonde data was 68% higher than the corresponding MODIS data in Mashhad station (OIMM) unlike other stations that on average, MODIS data estimated a higher value than radiosonde.

This average error was the lowest compared to other stations. Also in terms of accuracy, Isfahan station (OIFM) with RMSE value of about 3 mm had the highest accuracy in the stations under study. The 19-year time series of PWV values from radiosonde (blue diagram), MODIS (red diagram), and satellite interpolated values at the time of radiosonde observation at 12 noon (orange) have been compared graphically and are shown in Fig2. It should also

be noted that part of the difference between the estimated water vapor from satellite and radiosonde observations is due to differences in the type of measurement, as well as the lack of exact synchronization and collocation of observations, and ultimately the temporal interpolation error.

According to Table 4, in both data sets, the average water vapor in Mashhad station has the highest value compared to other stations, but has the least difference between the two data sets.

Table 4: Statistical comparison between average satellite derived values and radiosonde data on a monthly scale

Satellite Interpolation Vs Radiosonde					
Statistics	MBE(mm)	RMSE(mm)	R	Mean-satellite	Mean-Radiosonde
OIFM	-1.75	3.19	0.78	10.70	8.95
OIMM	0.068	4.33	0.67	13.16	13.23
OIII	-1.60	4.002	0.81	12.68	11.084

4.2 Linear regression

As shown in Table 5, despite the 81% correlation at Mehrabad station (OIII) and the 78% correlation at Isfahan station (OIFM), a linear regression can be used to fit this data between synchronized radiosonde and satellite data, as shown in Fig 3. The information in this regression for the monthly average data from these two datasets is listed in Table 6. The results show that the correlation between water vapor resulting from linear regression in relation (4) and radiosonde water vapor observations in Mehrabad station (OIII) and Isfahan station (OIFM) is up to 67%. But making a fit with this value does not seem logical due to the low correlation value of Mashhad station (OIMM).

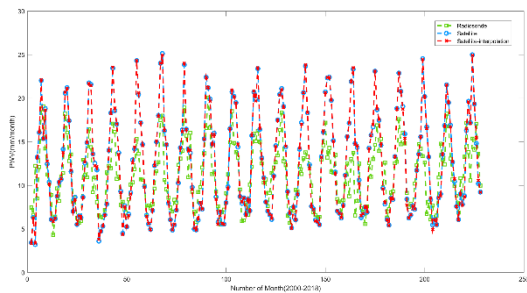


Fig. 2: Comparison of time series of PWV values obtained from radiosonde (blue diagram), MODIS (red diagram) and interpolated satellite values at the time of radiosonde observations, ie 12 noon (orange) at OIII station.

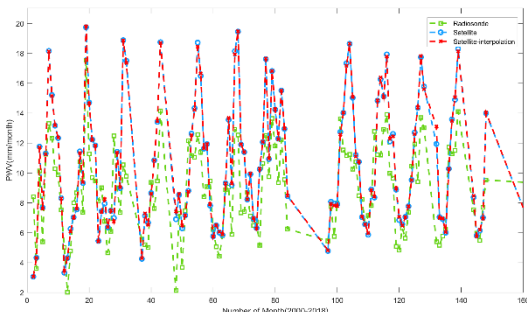


Fig. 3: Comparison of time series of PWV values obtained from radiosonde (blue graph), MODIS (red graph) and interpolated satellite values during radiosonde observations, ie 12 noon (orange) at OIFM station.

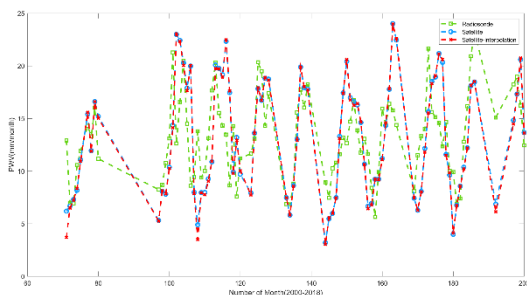


Fig. 4: Comparison of time series of PWV values from radiosonde (blue diagram), MODIS (red diagram) and interpolated satellite values at the time of radiosonde observations, ie 12 noon (orange) at OIMM station.

$$\text{Radiosonde_PWV} = P1 * \text{MODIS_PWV} + P2(\text{mm}) \quad (4)$$

Table 5: Statistical characteristics of linear regression model between PWV obtained from MODIS sensor and Radiosonde

Statistics	RMSE	R	P1	P2
OIFM	1.67	0.6753	0.5737	2.63
OIMM	3.22	0.3471	0.44	7.29
OIII	2.024	0.6747	0.5046	4.528

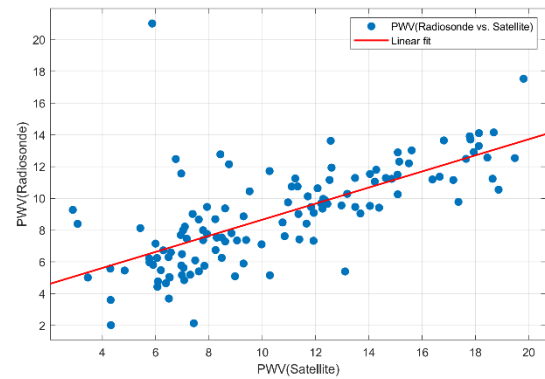


Fig. 5: Monthly linear regression of MODIS PWV and corresponding radiosonde PWV in OIFM Station

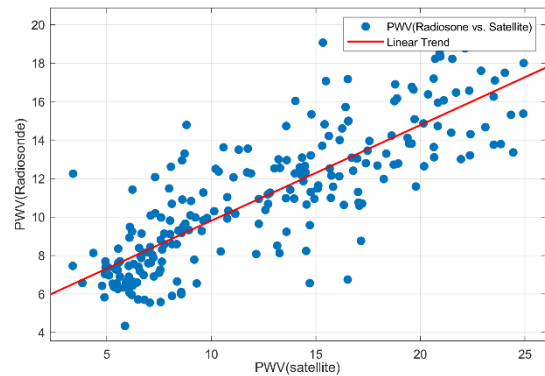


Fig. 6: Monthly linear regression of PWV MODIS sensor and corresponding radiosonde PWV in OIII station

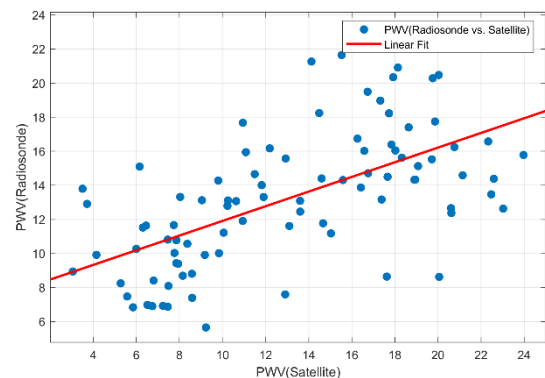


Fig. 7: Monthly linear regression of PWV MODIS sensor and corresponding radiosonde PWV in OIMM station

But according to monthly regressions, establishing a linear relationship can only justify 67% of radiosonde data through satellite data, and errors in satellite data always prevent a high percentage of regression, even when the monthly correlation of stations like Mehrabad (OIII) has a correlation of 81%. For a more detailed study, the linear trend in the PWV data is calculated by the linear fitting coefficients to the data and are listed in Table 6. According to the coefficients of Table 6, these two datasets of the PWV variable show an increasing trend over time at all stations.

Table 6: Linear time series coefficients of precipitable water vapor for satellite and Radiosonde data

Linear Trend	Radiosonde		Satellite-Interpolation	
	P1	P2	P1	P2
OIFM	0.0059	8.9	0.0071	10.23
OIMM	0.0098	11.28	0.0062	12.17
OIII	0.0061	11	0.0074	11.809

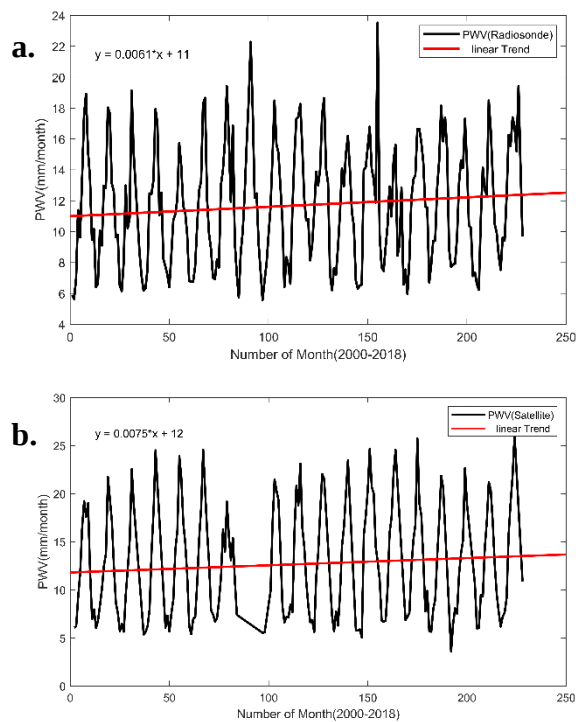


Fig. 8: a. Time series of monthly PWV measured by radiosonde at station OIII b. Time series of monthly PWV measured by MODIS at station OIII

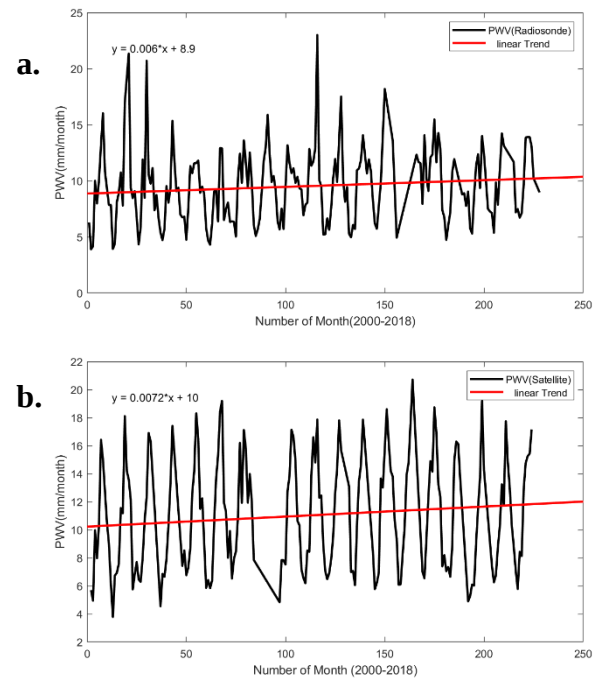


Fig. 9: a. Time series of monthly PWV measured by radiosonde at station OIFM. b. Time series of monthly PWV measured by MODIS at station OIFM

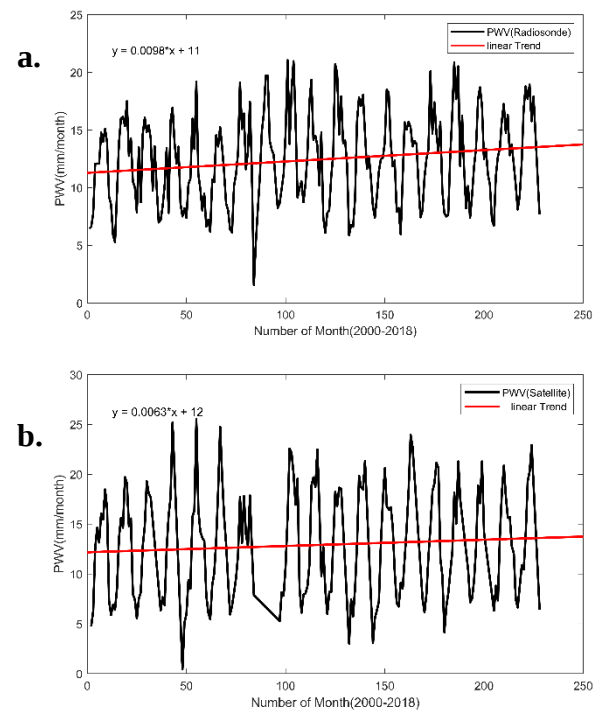


Fig. 10: a. Time series of monthly PWV measured by radiosonde at station OIMM b. Time series of monthly PWV measured by MODIS at station OIMM

According to the results reported by relevant studies and researches, the increase and positive rate of PWV parameter can be one of the positive effects and signals of global warming in a region. The results of studies on the PWV value of radiosonde stations during the past 19 years show an increasing trend. The parameters of surface temperature and precipitation at synoptic stations of the studied provinces are shown for a more accurate analysis of the trend of long-term changes. According to the results, as shown in Fig.11, no significant change was observed in the surface temperature at station OIII during the study period, but an increasing trend was observed in the PWV value at this station (Fig8).

This happened while a significant negative trend was observed (by 0.0132 decrease in precipitation at this station). Some of the effects of global warming in this area are a decrease in rainfall at the station in the long run and also an increase in the rate of Precipitable Water Vapor in these areas. There is no clear effect of global warming at this point. At the OIFM station, due to small changes in the calculated trends and the relative stability of the variables of precipitation and temperature (Fig12), it should be noted that it is actually better for climate studies to provide decades of data, looking at the fact that almost two decades of data have been available to authors here.

An increasing trend was observed in the surface temperature (Fig11.a) along with PWV (Fig10) at the OIMM station during the study period, while the amount of rainfall (Fig11.b) in these 19 years has been almost constant, which can be seen as signals of global warming in these stations. The temperature at Mehrabad station in Tehran changed slightly and underwent an almost constant trend during the study period. This is while the two stations of Isfahan and Mashhad, with a slope of 0.0071, 0.0053 ° C per month, respectively, experienced an increasing trend. For example, Isfahan station has a temperature increase of about 0.085 degrees Celsius every year, so during 20 years, the average temperature in Isfahan province will increase by 1.7 degrees Celsius. The increasing trend of temperature in Isfahan station is highly proportional to the increase in water vapor in this station. So, increase in temperature during these years will increase the amount of water vapor in this station. As shown in figure 12, decreasing trend in rainfall time series along with temperature increase can indicate the effects of global warming in this station.

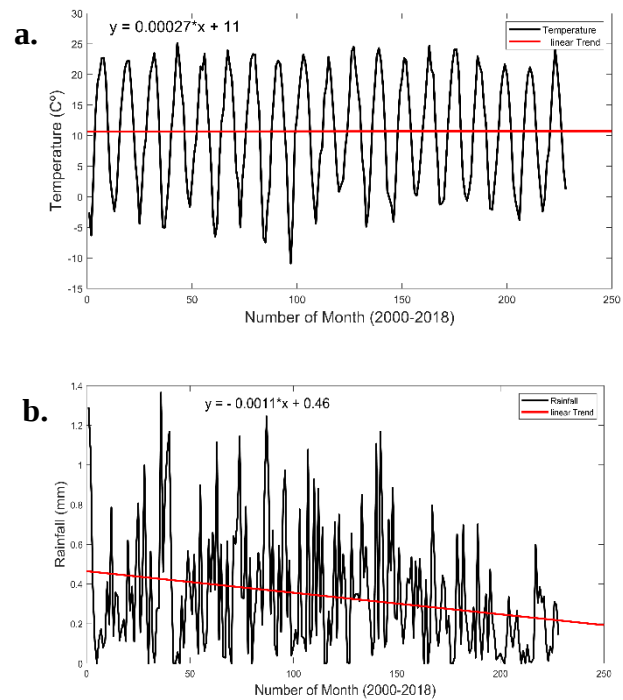


Fig. 11: a. Investigation of the monthly trend of temperature time series in synoptic station OIII **b.** Investigation of the monthly trend of precipitation time series in synoptics in station OIII

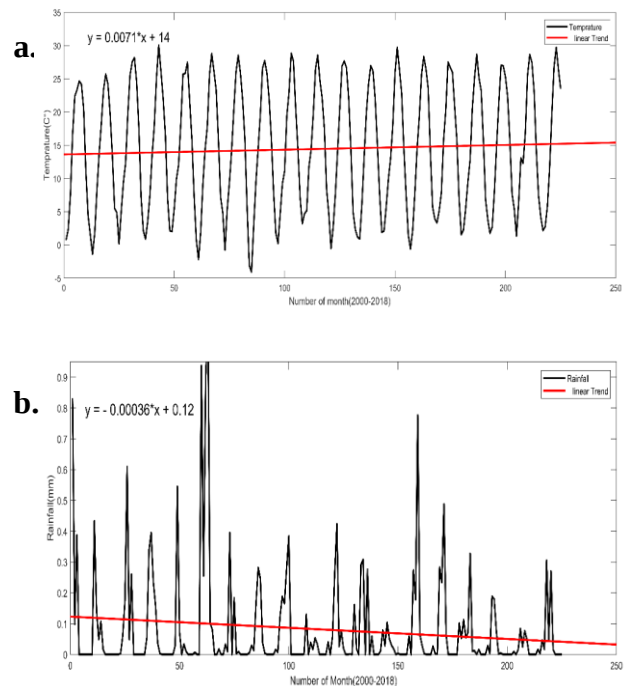


Fig. 12: a. Investigation of the monthly trend of temperature time series in synoptic station OIFM **b.** Investigation of the monthly trend of precipitation time series in synoptic station OIFM

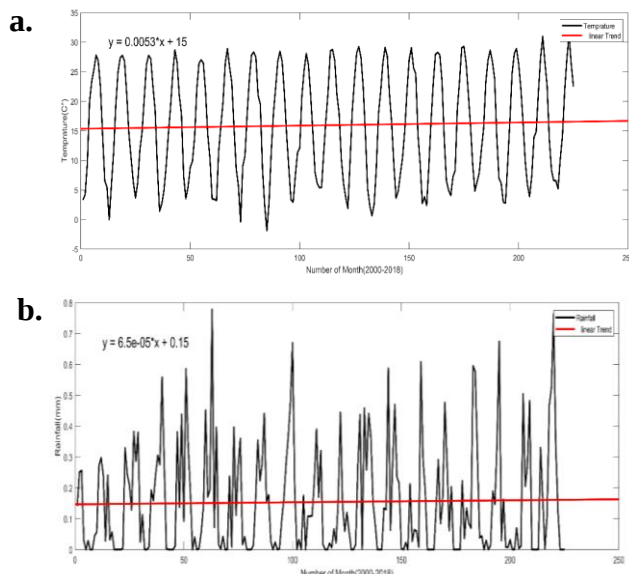


Fig. 13: **a.** Investigation of the monthly trend of temperature time series in synoptic station OIIM **b.** Investigation of the monthly trend of precipitation time series in synoptics in station OIIM

5. Conclusion

In recent years, remote sensing techniques have been used with the help of observations of various sensors mounted on various satellites for long-term as well as instantaneous and short-term monitoring of environmental parameters in the hydrosphere, areas outside of the hydrosphere, the Earth's atmosphere and as well as the earth's crust layers. Global climate and its changes and the effects of these changes on the life of plants and animals is one of the most influential issues in the environment, and humans are at the forefront (of them). Therefore, the study and monitoring of these changes in each region as well as the study of influential factors has always attracted the attention of senior managers and researchers in developed countries and more recently in other countries. Usually, synoptic or atmospheric parameters affecting long-term time periods over several decades are statistically studied to investigate climate changes. Precipitable Water Vapor is one of the important parameters in climate monitoring in an area. This study examines statistically the time series with a length of almost two decades of PWV data from MODIS sensor products along with the corresponding values obtained from radiosonde in selected stations from Iran. The results show that, in general, there is a high concordance between these two datasets for some stations such as Mehrabad (OIIM), but this is not true for all stations studied, as this concordance is reduced to 68% at the Mashhad station (OIIM). Therefore, it is suggested that the long-term water vapor data of the MODIS sensor along with synoptic observations be studied

in other similar areas in the country. Also, a significant upward trend was observed for both satellite and radiosonde-derived PWV time series. On the other hand, a significant decreasing trend was observed for monthly rainfall observations at Tehran station, which can be in agreement with the effects of global warming on the areas under study. Studies related to water resources management have a special place in the environmental sciences [25]. Therefore, it is recommended that effective variables in this field be monitored in different parts of the country using remote sensing methods.

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