Chin. Geogra. Sci. 2017 Vol. 27 No. 1 pp. 1–7
doi: 10.1007/s11769-017-0841-6
Springer Science Press
www.springerlink.com/content/1002-0063

Global Water Vapor Content Decreases from 2003 to 2012: An Analysis Based on MODIS Data

MAO Kebiao[1], CHEN Jingming[2], LI Zhaoliang[1], MA Ying[1], SONG Yang[3], TAN Xuelan[4], Yang Kaixian[5]

(1. *National Hulunber Grassland Ecosystem Observation and Research Station*, *Institute of Agricultural Resources and Regional Planning*, *Chinese Academy of Agricultural Sciences*, *Beijing* 100081, *China*; 2. *Department of Geography*, *University of Toronto*, *Toronto M5S 3G3*, *Canada*; 3. *School of Geographical Sciences*, *Northeast Normal University*, *Changchun* 130024, *China*; 4. *College of Resources and Environments*, *Hunan Agricultural University*, *Changsha* 410128, *China*; 5. *Department of Geography*, *University of Cincinnati*, *Cincinnati* 45221, *USA*)

Abstract: Water vapor in the earth′s upper atmosphere plays a crucial role in the radiative balance, hydrological process, and climate change. Based on the latest moderate-resolution imaging spectroradiometer (MODIS) data, this study probes the spatio-temporal variations of global water vapor content in the past decade. It is found that overall the global water vapor content declined from 2003 to 2012 (slope b = –0.0149, R = 0.893, P = 0.0005). The decreasing trend over the ocean surface (b = –0.0170, R = 0.908, P = 0.0003) is more explicit than that over terrestrial surface (b = –0.0100, R = 0.782, P = 0.0070), more significant over the Northern Hemisphere (b = –0.0175, R = 0.923, P = 0.0001) than that over the Southern Hemisphere (b = –0.0123, R = 0.826, P = 0.0030). In addition, the analytical results indicate that water vapor content are decreasing obviously between latitude of 36°N and 36°S (b = 0.0224, R = 0.892, P = 0.0005), especially between latitude of 0°N and 36°N (b = 0.0263, R = 0.931, P = 0.0001), while the water vapor concentrations are increasing slightly in the Arctic regions (b = 0.0028, R = 0.612, P = 0.0590). The decreasing and spatial variation of water vapor content regulates the effects of carbon dioxide which is the main reason of the trend in global surface temperatures becoming nearly flat since the late 1990s. The spatio-temporal variations of water vapor content also affect the growth and spatial distribution of global vegetation which also regulates the global surface temperature change, and the climate change is mainly caused by the earth's orbit position in the solar and galaxy system. A big data model based on gravitational-magmatic change with the solar or the galactic system is proposed to be built for analyzing how the earth's orbit position in the solar and galaxy system affects spatio-temporal variations of global water vapor content, vegetation and temperature at large spatio-temporal scale. This comprehensive examination of water vapor changes promises a holistic understanding of the global climate change and potential underlying mechanisms.
Keywords: water vapor content; climate change; moderate-resolution imaging spectroradiometer (MODIS)

Citation: Mao Kebiao, Chen Jingming, Li Zhaoliang, Ma Ying, Song Yang, Tan Xuelan, Yang Kaixian, 2017. Global water vapor content decreases from 2003 to 2012: an analysis based on MODIS data. *Chinese Geographical Science*, 27(1): 1–7. doi: 10.1007/s 11769-017-0841-6

1 Introduction

Global mean surface temperatures have increased about 0.75℃ over the past century, and a mean decadal rate at about 0.13℃ (IPCC, 2007; Rahmstorf and Coumou, 2011). However, the trend in global surface temperatures has been nearly flat since the late 1990s despite the continuous increases in the forcing due to the sum of well-mixed greenhouse gases (IPCC, 2007; Solomon *et al*., 2010; Rahmstorf and Coumou, 2011). Water vapor

Received date: 2016-08-12; accepted date: 2016-11-01
Foundation item: Under the auspices of National Key Research and Development Program (No. 2016YFC0500203), National Natural Science Foundation of China (No. 41571427)
Corresponding author: MAO Kebiao. E-mail: maokebiao@caas.cn

in the earth′s upper atmosphere plays a crucial role in the radiative balance, hydrological process, and climate change (Solomon *et al*., 2010; Dessler *et al*., 2012; Ravishankara, 2012). Water vapor is a greenhouse gas, whose increase will lead to a positive feedback when the climate warms due to increased emission of CO_2, thereby further accelerates the warming trend due to the initial forcing that arises from the burning of fossil fuels (Cess, 1989; Raval and Ramanathan, 1989). Based on mainly Halogen Occultation Experiment (HALOE) data sets and Bern 2.5CC intermediate complexity model, Solomon *et al*. (2010) found that the stratospheric water vapor very likely provided substantial contributions to the flattening of the global warming trend after 2000, and the concentration of stratospheric water vapor decreased by about 10%, which acted to slow the rate of increase in global surface temperature over 2000–2009 in comparison with which would have occurred due only to CO_2 and other greenhouse gases.

In addition to examining climate change processes associated with changes of a full spectrum of greenhouse gases, remote sensing of the total precipitable water vapor is also important for a better understanding of the global hydrologic cycle, biosphere-atmosphere interactions, and the earth′s radiant energy budget. It is particularly important to monitor seasonal and annual changes in the precipitable water on regional scales in order to predict drought conditions and desertification processes (King *et al*., 1992).

National Aeronautics and Space Administration (NASA) has two polar-orbiting Earth Observing System (EOS) satellites (Terra and Aqua) in orbit at all times. Terra crosses the equator in the early morning (local time 10:30) and early evening (local time 22:30), and Aqua crosses the equator in the afternoon (local time 13:30) and late evening (local time 1:30). The MODIS instruments on the EOS provide an improved source of information for the study of global water vapor with a high spatio-temporal resolution, from which water vapor concentrations can be retrieved four times a day, which is more approximate to real global mean water vapor content. It depends on the algorithm used for retrieving the water vapor information, and the spatial resolution also depends on the used algorithm/product.

2 Data and Methods

The Goddard Distributed Active Archive Center (GDAAC) provides precipitable water products including level-2 and level-3 products (MOD05, MOD07 and MOD08 products). The MOD05 product (Total Precipitable Water, W) is generated at 1-km spatial resolution using near infrared (NIR) algorithm and, therefore, it exists only as a diurnal product (two times a day). The MOD07 product (Atmosphere Profiles) also contains information about W, but W is derived using the thermal infrared (TIR) algorithm and, therefore, there are diurnal and nocturnal W data from this product (four times a day), but at 5-km of spatial resolution. The accuracy of MOD05 is higher than MOD07, and the level-3 product water vapor content in MOD08 is derived from MOD05 (NIR algorithm) and MOD07. There are two MODIS Monthly Global data product files: MOD08_M3, containing data collected from the Terra platform; and MYD08_M3, containing data collected from the Aqua platform. The MOD08 is used as the main data source to make analyze the variation of water vapor content in this study. The mean difference of standard deviation error in different years is under 0.001 g/m^2, and some invalid values in the products have been interpolated and validated (Hubanks *et al*., 2008). In order to facilitate the calculation, all the data are computed at 1° × 1° spatial resolution. The following equation depicts the statistical analysis for the global mean water vapor content.

$$W_{\mathrm{m}} = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{l} S(j)(W_{ij}^{1:30} + W_{ij}^{10:30} + W_{ij}^{13:30} + W_{ij}^{22:30})/4 \quad (1)$$

where W_{m} is mean water vapor content, n is the number of day every year, l is the number of pixel, $S(j)$is the area weighting function of the pixel j, and $W_{ij}$is the water vapor content of ith day and jth pixel in time (1:30, 10:30, 13:30, 22:30). On the other hand, there is no data for Aqua satellite in 2001 and in January–July 2002, so we calculate the mean water vapor content from 2003. Equation (2) is used to estimate the change rate of water vapor content from 2003 to 2012.

$$b = \frac{n\sum_{k=1}^{n}(k \times W_{\mathrm{m}k}) - \sum_{k=1}^{n}k\sum_{k=1}^{n}W_{\mathrm{m}k}}{n \times \sum_{k=1}^{n}k^2 - (\sum_{k=1}^{n}k)^2} \quad (2)$$

where b is change rate, k is the number of year, $W_{\mathrm{m}k}$ is the mean water vapor content of kth year, and n is 10. $W_{\mathrm{m}k}$ is computed from MOD08_M3 and MYD08_M3. Equation (3) is used to compute correlation coefficient (R).

$$R=\frac{n\sum_{k=1}^{n}(k\times W_{mk})-\sum_{k=1}^{n}k\sum_{k=1}^{n}W_{mk}}{\sqrt{n\sum_{k=1}^{n}k^2-(\sum_{k=1}^{n}k)^2}\times\sqrt{n\sum_{k=1}^{n}W_{mk}^2-(\sum_{k=1}^{n}W_{mk})^2}} \quad (3)$$

3 Results and Analyses

The annual mean of water vapor concentrations over ocean, land, and the globe from 2003 to 2012 is shown in Fig. 1, which indicates clearly that global mean water vapor content is decreasing. The global mean of water vapor content is 2.48 g/cm^2. The highest is 2.54 g/cm^2 in 2003 and lowest is 2.40 g/cm^2 in 2012. There is an obvious decreasing trend (b = –0.0149, R = 0.893, P = 0.0005). The global mean water vapor content is 1.85 g/cm^2 over terrestrial surface, 2.74 g/cm^2 over ocean surface. The decreasing rate over ocean region (b = –0.0170, R = 0.908, P = 0.0003) is more significant than that over terrestrial region (b = –0.0100, R = 0.782, P = 0.0070).

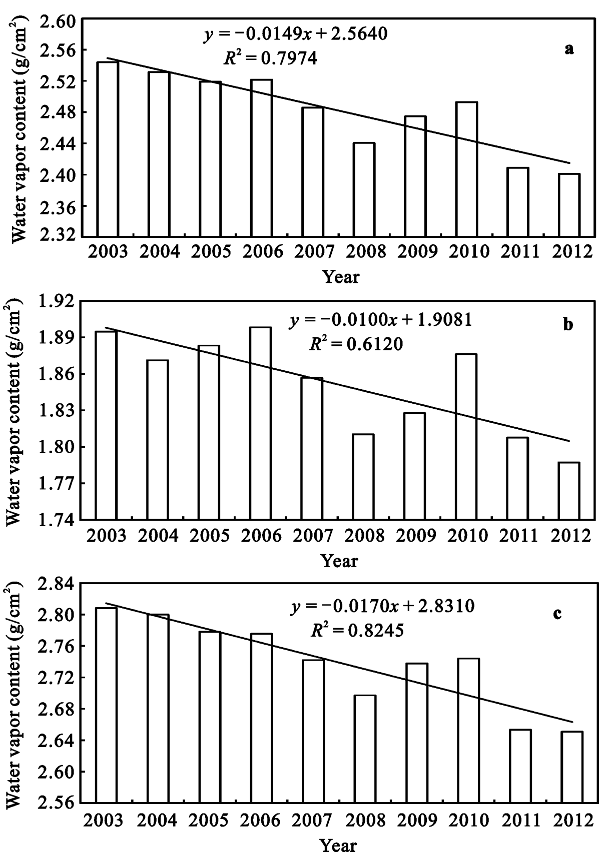

Fig. 1 Globe (a), land (b), and Ocean (c) mean water vapor content from 2003 to 2012

We also examined the variations of water vapor content between northern and southern hemispheres. The results are given in Fig. 2. The mean water vapor content of the Northern Hemisphere is 2.59 g/cm^2, and the highest and lowest years are 2003 and 2012, respectively. The mean water vapor content of the Southern Hemisphere is 2.38 g/cm^2, and the highest and lowest years are 2003 and 2011, respectively. The statistical analysis indicates that a similar decreasing trend of water vapor content can be observed in both hemispheres, and the decreasing rate over the Northern Hemisphere (b = –0.0175, R = 0.923, P = 0.0001) is higher than that over the Southern Hemisphere (b = –0.0123, R = 0.826, P = 0.0030).

The variations of the mean water vapor content over seven continents are shown in Fig. 3. The mean water vapor content over South America in recent ten years is 3.52 g/cm^2, which is the highest amongst all continents. The mean water vapor content over Africa is ranked the second, at 2.58 g/cm^2, followed by Oceania and Asia at 2.36 g/cm^2 and 1.65 g/cm^2. That over Europe and North America is consistently low, at 1.2 g/cm^2 and 1.18 g/cm^2, respectively. Except for the Antarctic where the mean water vapor content over is very low and it is very difficult to estimate due to the existence of many invalid values, the lowest mean water vapor content is at only 0.03. The occurrence of highest and lowest water vapor content values varies across different continents. Nevertheless, a general decreasing trend of the water

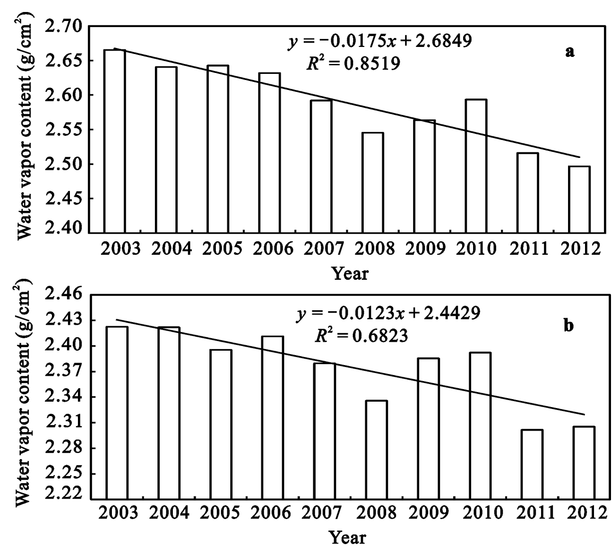

Fig. 2 Northern hemisphere (a) and Southern hemisphere (b) mean water vapor content from 2003 to 2012

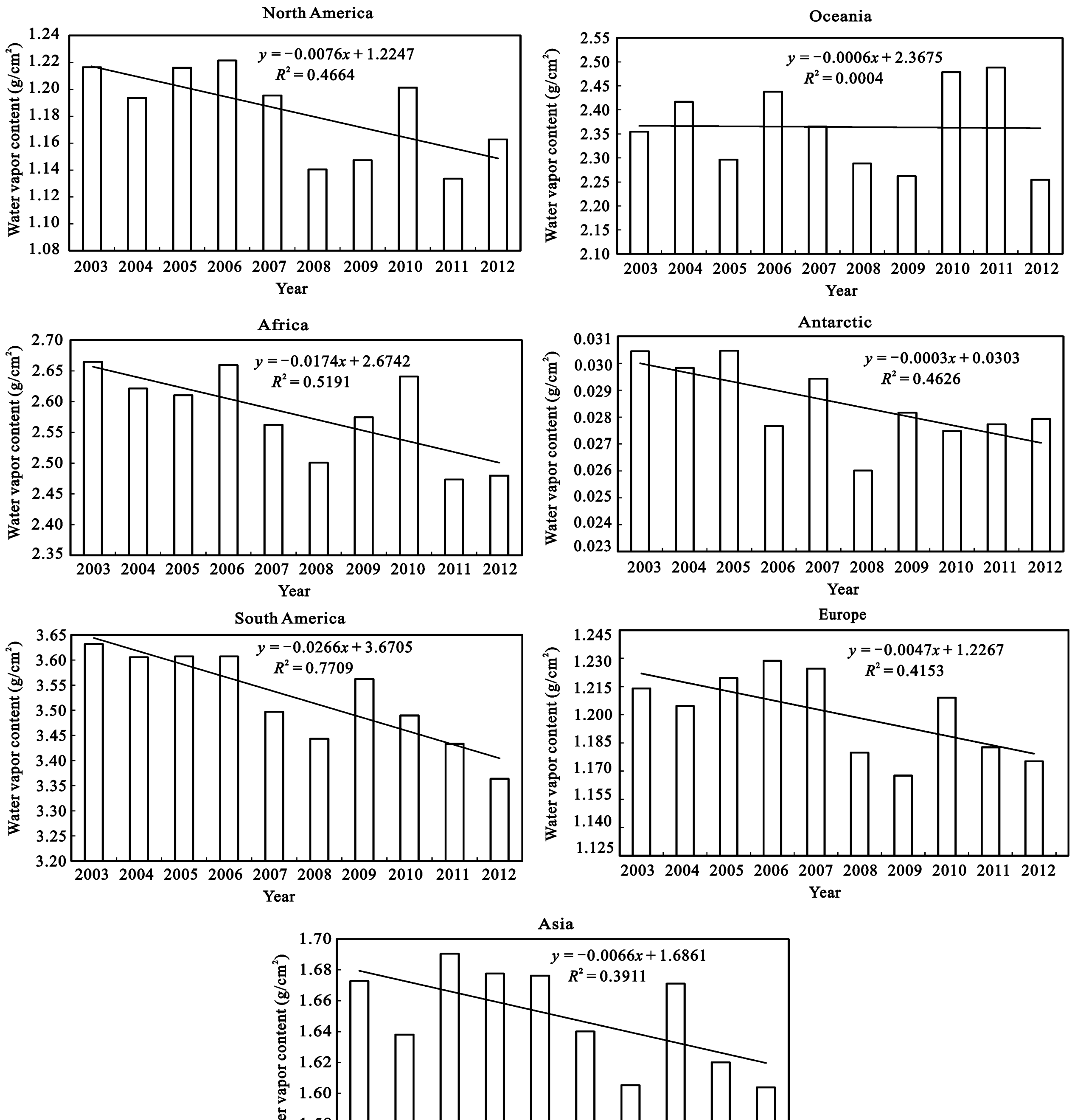

Fig. 3 Annual mean water vapor content over seven continents from 2003 to 2012

vapor content can be found over all continental regions, except that the decline is not significant over Oceania. These findings suggest that the water vapor content values are decreasing over continents.

The water vapor content over oceans shows similar pattern in comparison with that over continents (Fig. 4). The mean water vapor content over the Pacific Ocean is the highest at 3.03 g/cm^2, followed by Indian Ocean (2.71 g/cm^2), Atlantic Ocean (2.57 g/cm^2), and Arctic Ocean (0.57 g/cm^2). Analysis indicates that the water vapor content over the Pacific, Indian and Atlantic Oceans is decreasing in the last ten years, while it is increasing slightly over Arctic Ocean.

The spatial variations of global mean water vapor

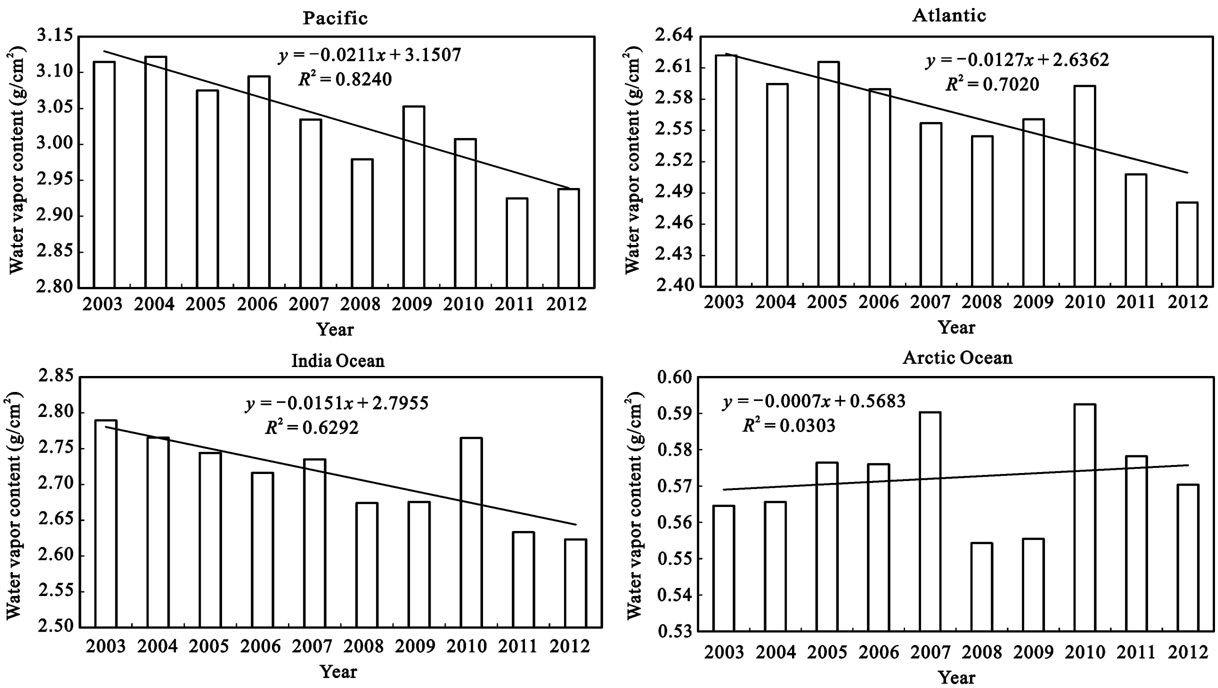

Fig. 4 Mean water vapor content over four oceans from 2003 to 2012

content from 2003 to 2012 are shown in Fig. 5a. The high concentration of water vapor content is mainly in the vicinity of the equator, especially in the center regions of Southeast Asian. The lowest concentration of water vapor content is in Antarctica. The slope and correlation coefficient have been obtained for every pixel from 2003 to 2012 (Figs. 5b and 5c). It can be found that the concentrations of water vapor content are decreasing obviously between latitude of 36°N and 36°S (b = –0.0224, R = 0.892, P = 0.0005), especially between latitude of 0°N and 36°N (b = –0.0263, R = 0.931, P = 0.0001), and the decreasing and spatial variation of water vapor content is the main reason of the trend in global surface temperatures becoming nearly flat since the late 1990s. The water vapor concentrations are increasing slightly in the Arctic regions. The largest increasing rate is observed in the Pacific Ocean regions near the northern regions of South America, and the decreasing rate is largest in the main center of the Pacific Ocean near the south-east regions of Asia. Mao *et al.* (2009; 2015) proposed that climate change research needs to consider the impact of celestial motion, and they made an analysis for global surface temperature and global vegetation, and found that the surface temperature and vegetation in north high latitudes are increasing (Mao *et al.*, 2016c; 2016d), which is the main reason for the increasing of water vapor content in North Asia. The analysis for global vegetation in different seasons which indicates that spatial distribution of global temperature and water vapor will affect the spatial distribution of vegetation, and the spatial distribution of vegetation will also regulate the global temperature and water vapor spatial distribution at large spatio-temporal scale. The effects of carbon dioxide were offset by the spatial variation of water vapor content and vegetation, and the analysis of global surface temperature and vegetation indicates that climate change is determined by earth′s orbit position Mao *et al.* 2016a; 2016b). Mao *et al.* (2016a; 2016b) proposed to build a spatial weather-climate model based on gravitational-magmatic change with the solar and the galactic system. The thought of this model is that the climate change such as temperature and water cycle is mainly caused by the earth′s orbit position in the solar and galaxy system which affects the distribution and grows of vegetation at large spatio-temporal scale (Mao *et al.*, 2015; 2016a; 2016b).

4 Discussion and Conclusions

Although it is very difficult to analyze the global water vapor content change using data obtained from mete-

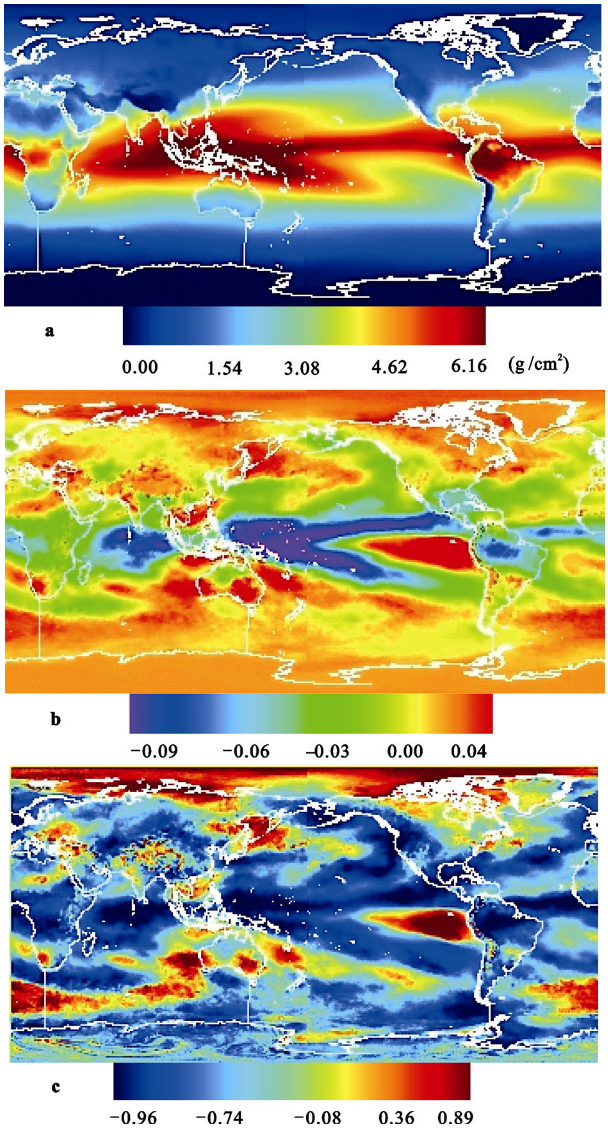

Fig. 5 Annual mean water vapor content from 2003 to 2012 (a), rate of water vapor content change from 2003 to 2012, shown as the slope of a linear regression (b), correlation coefficient computed by Equation (3) (c)

orological stations because the local does not have representation, the MODIS data provides a chance for us to do this work. As common sense, water vapor is a greenhouse gas, whose increase will lead to a positive feedback when the climate warms due to increased emission of CO_2, thereby further accelerates the warming trend due to the initial forcing that arises from the burning of fossil fuels. On the contrary, this study found that there is an obvious decreasing (b = –0.0149, R = 0.893) for overall the global water vapor content from 2003 to 2012 based on MODIS data. The statistical analysis indicates that the rate of variation for water vapor content is different for different regions. The decreasing rate over the Northern Hemisphere (b = –0.0175, R = 0.923) is higher than that over the Southern Hemisphere (b = –0.0123, R = 0.826). The water vapor content over oceans shows similar pattern in comparison with that over continents except for increasing slightly over Arctic regions. The decreasing water vapor content maybe is the main reason of the trend in global surface temperatures becoming nearly flat since the late 1990s, and the effects of carbon dioxide were offset by spatial variation of global water vapor content and vegetation which is mainly determined by the earth′s orbit position in the solar and galaxy system.

The spatio-temporal variations of water vapor content also affect the distribution of precipitation (cloud), solar radiation, and growth and spatial distribution of global vegetation at the solar and the galactic system is proposed to be built for analyzing how the earth′s orbit position in the solar and large spatio-temporal scale, which regulates the global surface temperature change. Therefore, we think that carbon dioxide has little effect on the earth′s temperature change, and earth can regulate temperature by regulating the spatio-temporal variations of water vapor, precipitation (cloud), solar radiation, the release of seabed geothermal, ocean currents, and so on. The climate change is mainly determined by the earth's orbit position in the solar and galaxy system, and the earth′s orbit position determines the spatio-temporal variations of temperature, water vapor content, vegetation including other species at large scale. A big data model based on gravitational- magmatic change with galaxy system affects spatio-temporal variations of global water vapor content, vegetation and temperature at large spatio-temporal scale. This comprehensive examination of water vapor content changes promises a holistic understanding of the global climate change and potential underlying mechanisms.

References

Cess R D, 1989. Gauging water vapour feedback. *Nature*, 342: 736–737. doi: 10.1038/342736a0

Dessler A E, Schoeberl M R, Wang T *et al*., 2012. Stratospheric water vapor feedback. *Proceedings of the National Academy of Sciences of the United States of America*, 110: 18087–18091. doi: 10.1073/pnas.1310344110

Easterling D R, Wehner M F., 2009. Is the climate warming or cooling? *Geophysical Research Letters*, 36: L08706. doi:

10.1029/2009GL037810

Hubanks P A, King M D, Plantnick S *et al*., 2008. *MODIS Algorithm Theoretical Basis Document No. ATBD-MOD-30 for Level-3 Global Gridded Atmosphere Products* (08_D3, 08_E3, 08_M3). Collection 005 Version 1.1, 4 December 2008, 1–96.

King M D, Kaufman Y J, Menzel W P *et al*., 1992. Remote sensing of cloud, aerosol, and water vapor properties from the moderate resolution imaging spectrometer (MODIS). *IEEE Transactions on Geosciences and Remote Sensing*, 30(1): 2–27. doi: 0196-2892/92

Mao K B, Li Z, Chen J M *et al*., 2016a. Global vegetation change analysis based on MODIS data in recent twelve years. *High Technology Letters*, 22(4). (in press)

Mao K B, Ma Y, Tan X L *et al*., 2016b. Global surface temperature change analysis based on MODIS data in recent twelve years. *Advances in Space Research*. doi: 10.1016/j.asr. 2016. 11.007. (in press)

Mao K B, Ma Y, Xu T R *et al*., 2015. A new perspective about climate change. *Scientific Journal of Earth Science*, 5(1): 12–17.

Mao K B, Ma Y, Zuo Z Y *et al*., 2016c. Global water vapor content and vegetation change analysis based on remote sensing data. *International Geoscience and Remote Sensing Symposium*, 16: 5205–5208.

Mao K B, Ma Y, Zuo Z Y *et al*., 2016d. Which year is the hottest or coldest from 2001–2012 based on remote sensing data. *International Geoscience and Remote Sensing Symposium*, 16: 5213–5216.

Mao Kebiao, Wang Daolong, Li Zirui *et al*., 2009. A neural network method for retrieving land surface temperature from AMSR-E data. *High Technology Letters*, 19(11): 1195–1200. (in Chinese)

Rahmstorf S, Coumou D, 2011. Increase of extreme events in a warming world. *Proceedings of the National Academy of Sciences of the United States of America*, 108: 17905–17909. doi: 10.1073/pnas.1101766

Raval A, Ramanathan V, 1989. Observational determination of the greenhouse effect. *Nature*, 342: 758–761. doi: 10.1038/342758a0

Ravishankara A R, 2012. Water vapor in the lower stratosphere. *Science*, 337: 809–810. doi: 10.1126/science.1227004

Solomon S, Qin D, Manning M *et al*, 2007. *Climate Change 2007*: *The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge*: *Cambridge University Press*, 1–50.

Solomon S, Rosenlof K H, Robert W P *et al*., 2010. Contributions of stratospheric water vapor to decadal changes in the rate of global warming. *Science*, 327: 1219–1223. doi: 10.1126/ science.1182488