ScienceDirect

Science of The Total Environment

Volume 872, 10 May 2023, 162225

Analyzing correlations between GNSS retrieved precipitable water vapor and land surface temperature after earthquakes occurrence

Ao Guo, Yan Xu, Nan Jiang, Yuhao Wu, Zhaorui Gao, Song Li, Tianhe Xu, Luísa Bastos

Show more

https://doi.org/10.1016/j.scitotenv.2023.162225

Get rights and content

Highlights

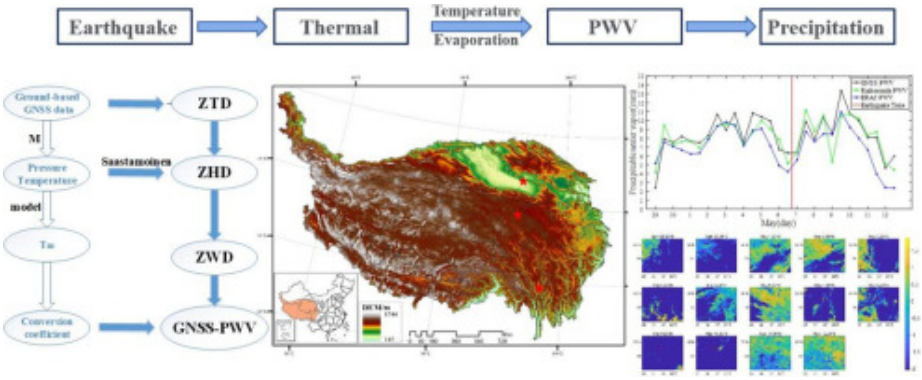
- The RMSE of GNSS-PWV against RS-PWV or ERA5-PWV were less than 1.8 mm during three earthquakes.
- GNSS-PWV increased and subsequently decreased over the epicenter after the major events.
- Thermal anomalies of land surface temperature were detected in two temporal scales after the earthquakes.

Abstract

Earthquake is a common and destructive natural disaster. The enormous amount of energy released from seismic events can result in anomalous land surface temperature (LST) and catalyze the accumulation of water vapor in the atmosphere. The majority of previous works are not consensual concerning precipitable water vapor (PWV) and LST after the earthquake. Here, we utilized multi-

source data to analyze the changes of PWV and LST anomaly after three Ms 4.0–5.3 crustal earthquakes at low depth (8–9 km) that occurred in Qinghai-Tibet Plateau. Firstly, PWV retrieval using Global Navigation Satellite System (GNSS) technology is performed, showing that its root mean square error (RMSE) is less than 1.8 mm against radiosonde (RS) data or European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis 5 (ERA5) PWV data. The PWV change derived from the nearest GNSS stations around the hypocenter during the earthquakes shows anomalies, and the results reveal that PWV anomalies occurred after the earthquakes, mainly obeying a trend of increasing first and then decreasing. In addition, LST increases three days before PWV peak with a thermal anomaly of 12 °C higher than that of previous days. Robust Satellite Technique (RST) algorithm and ALICE index on Moderate Resolution Imaging Spectroradiometer (MODIS) LST products are introduced to analyze the correlation between the abnormality of LST and PWV. Based on ten-year background field data (2012–2021), the results show that LST during the earthquake has more thermal anomaly occurrences than in previous years. The more severe the LST thermal anomaly is, the higher the probability of a PWV peak occurring.

Graphical abstract



Download: Download high-res image (198KB)

Download: Download full-size image

Introduction

Earthquakes are vibrations caused by the sudden rupture and dislocation of the lithosphere under the action of the Earth's tectonic forces, resulting in a dramatic release of energy from the crust. Various physical and chemical changes occur in this process. Singh et al. (2010a) found anomalous changes of multi-parameter in the surface temperature, air temperature, relative humidity, and ionosphere of the Wenchuan earthquake from satellite-based data and ground-based observations. It was found that significant changes in atmospheric parameters during the 2010 Haiti earthquake, with ozone concentrations lowest on the day of the earthquake and then beginning to rise (Singh et al., 2010b). Tropospheric ozone was significantly enhanced in the epicenter five days before the Wenchuan earthquake (Jing and Singh, 2021). Even the increase in radar backscattering coefficient

(BC) in water bodies associated with the Ms 7.3 Madoi earthquake was analyzed, which was actually due to the increase in water turbidity triggered by the event (Jing et al., 2022a, Jing et al., 2022b).

As a neutral gas, water vapor has a small content in the atmosphere but with an extreme variation. PWV has a straightforward relationship with precipitation, specifically in extreme weather and disaster (Suparta et al., 2012; Xie et al., 2010). Furthermore, PWV usually has an evident correlation with temperature changes (Alshawaf et al., 2017; Jin and Luo, 2009). PWV involves the water cycle between the surface system and atmosphere through precipitation, evaporation, surface runoff, and vapor transport in the biosphere, playing an essential role in the interchange of material and energy transmission. The first research on water vapor anomalies associated with the earthquake was reported by Dey et al. (2004). Inversion of the epicenter of the Guangdong earthquake in China using GPS data reveals the presence of water vapor content abnormalities (Chen et al., 2017). During the 2004 Sumatra earthquake, the ZTD presented a significant rising at two of the nearest IGS stations in the east and south of the epicenter, although without high rainfall occurrence and high PWV formed in the Sumatra region moved to the Californian coast by the subtropical jet stream causing the heavy rain and snowfall weather (Akilan et al., 2018). The co-seismic ZTD disturbances emerged in the Wenchuan earthquake (Jin et al., 2011). In fact, many kinds of weather and surface environmental changes take along the variation of water vapor, such as dust storms, monsoons, atmospheric rivers, etc. (Singh et al., 2004; Bhattacharjee et al., 2007; Prasad and Singh, 2007; Wick et al., 2013).

PWV observation techniques commonly include radiosonde, spaceborne radiometers, ground-based microwave radiometers, radio occultation, radar, and ground-based global navigation satellite system (GNSS) observations. In the 1990s, the proposal of Global Positioning System (GPS) meteorology provided a novel high-precision technology for meteorological research (Bevis et al., 1992). Also, GPS is increasingly applied in seismic deformation (Segall and Davis, 1997). PWV retrieved from GNSS has the advantages of high precision, all-weather and low cost. The zenith tropospheric delay (ZTD) can be divided into the zenith hydrostatic delay (ZHD) and the zenith wet delay (ZWD). From the wet term, we can extract the PWV with the characteristics of rapid change due to the active water vapor (Bevis et al., 1992). The ZTD value can be estimated with GNSS processing, and ZHD is calculated using the empirical model. PWV can be derived from ZWD available by subtracting ZHD from ZTD, and the result is named GNSS-PWV. The good agreement and high correlation between GNSS-PWV and radiosonde (RS) PWV have been reported with a correlation coefficient of 0.98 and a standard deviation of 1 mm (Li et al., 2003). Prasad and Singh (2009) showed that the GPS inversion results agree well with ARONET among many water vapor results from multi-source data. The high correlation between GPS water vapor and MODIS and AERONET reflects the high accuracy of GPS measurements (Kumar et al., 2013).

LST integrates the interaction between the land and atmosphere and is an important parameter in the energy balance of the surface. A large amount of geoscientific information is carried out on LST (Betts et al., 1996). A change in LST usually accompanies earthquakes. Many studies showed that

possible LST thermal anomalies occurred before earthquakes (Gornyy et al., 1988; Choudhury et al., 2006; Pergola et al., 2010; Wu et al., 2006; Zoran, 2012). The LST thermal anomaly related to pre-seismic activity has been confirmed with a 4–8 °C increase, relative to the previous day, in LST to the south of the epicenter before the earthquake (Panda et al., 2007). Microwave brightness temperature, skin temperature, and air temperature are all detected as pronounced enhancement in the Ms 7.3 magnitude earthquake in Iran in 2017 (Jing and Singh, 2022). The exchange of energy between the geophysical surface and the atmosphere for evaporation and overflow of water vapor resulted in the anomaly of water vapor content before the Wenchuan earthquake. Thermal anomaly appeared one day before that of water vapor in the Wenchuan earthquake as one of the precursors (Liu et al., 2009). An evident LST variation before the October 8, 2005 Kashmir earthquake was identified (Panda et al., 2007), where the recorded difference on October 2 shows a 5–10 °C rise based on 2000–2004 data. The changes in atmospheric meteorological parameters before and after the earthquake are usually associated with the energy released through the crustal process.

There are previously published studies on the changes in surface temperature and water vapor during earthquake processing, but most of them are only limited to one of the above parameters that overlook the relation between PWV derived from GNSS and LST. Research combining both LST thermal anomaly and PWV is rare. Moreover, many works have examined pre-seismic thermal anomalies, but few focused on post-seismic related fields. Earthquakes and aftershocks are most likely to result in local secondary disasters such as precipitation, landslides, and mudslides. The purpose of this paper is to attempt to review PWV changes after the earthquake and its relation with LST. We take three earthquakes that occurred in China as examples and utilize ground-based GNSS remote sensing technology to retrieve PWV in the nearest GNSS stations to observe changes after the major event. The accuracy of GNSS-PWV results against radiosonde data and reanalysis data from ERA5 is verified. Then the relation between LST thermal anomaly based on MODIS products and PWV retrieved from GNSS in the epicenter and vicinity is analyzed. Thus, the study findings can provide a reliable reference for predicting secondary disasters related to precipitation after the earthquake, which is conducive to the reconstruction work.

Section snippets

Data used

The research data includes five types of information: seismic data, GNSS observation data, Radiosonde PWV data, ERA5 reanalysis data, and land surface temperature products. …

Analysis of PWV change during the earthquake process

PWV exploration was conducted for the time series covering one week before and after each of the three earthquake cases. The PWV is named RS-PWV when using radiosonde data and ERA5-PWV

when using ERA5 reanalysis data. Systematic errors caused by inconsistency of the elevation datum will come up when the PWV derived from different data sources is used. ERA5-PWV data and sounding data are based on the geopotential height system, and GNSS elevation is based on the geodetic height system. Thus, we …

Conclusions

Seismic activity triggers changes in surface, meteorological and atmospheric parameters since a large amount of energy are released with the occurrence of earthquakes. In this study, these changes are revealed as temperature anomalies and anomalous accumulation of water vapor around the seismic event zone. In addition, due to the severe socio-economic impacts that this side event can also cause, especially the occurrence of post-earthquake precipitation-related secondary disasters, thus it is …

CRediT authorship contribution statement

A.G. and N.J. proposed the idea, designed computer programs and wrote the initial draft. A.G., S.L. and Y.W. performed the verification of results retrieved from GNSS and multi-source data. A.G. and Z.G. performed the thermal anomaly data presentation and had a further analysis. Y.X., N.J. and T.X. revised the manuscript and acquired the financial support for this publication. Y.X., N.J. and Luísa Bastos revised equations and format of the manuscript, specifically critical review and revision. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgments

We thank for the data support from China Earthquake Networks Center, National Earthquake Data Center (http://data.earthquake.cn ↗). This study is financially supported by the National Natural Science Foundation of China (42204042), the National Key Research & Development Program of China (2020YFB0505800), the Natural Science Foundation of Shandong Province, China (ZR2020MD045 and ZR2020QD046), the Open Fund of the Key Laboratory of Marine Environmental Exploration Technology and Application, …

Recommended articles

References (49)

J. Chen *et al.*
Diurnal variations of ground-based GPS-PWV under different solar radiation intensity in the Chengdu plain
J. Geodyn. (2013)

S. Dey *et al.*
Anomalous changes in column water vapor after Gujarat earthquake
Adv. Space Res. (2004)

S. Jin *et al.*
Lower atmospheric anomalies following the 2008 Wenchuan earthquake observed by GPS measurements
J. Atmos. Sol. Terr. Phys. (2011)

C.O. Justice *et al.*
An overview of MODIS land data processing and product status
Remote Sens. Environ. (2002)

S. Kumar *et al.*
Variability of GPS derived water vapor and comparison with MODIS data over the indo-gangetic plains
Phys. Chem. Earth A/B/C (2013)

J. Olauson
ERA5: the new champion of wind power modelling?
Renew. Energy (2018)

R. Urraca *et al.*
Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data
Sol. Energy (2018)

W. Wang *et al.*
Validating MODIS land surface temperature products using long-term nighttime ground measurements
Remote Sens. Environ. (2008)

C. Albergel *et al.*
ERA-5 and ERA-interim driven ISBA land surface model simulations: which one performs better?
Hydrol. Earth Syst. Sci. (2018)

C. Aliano *et al.*

Robust TIR satellite techniques for monitoring earthquake active regions: limits, main achievements and perspectives

Ann. Geophys. (2008)

View more references

Cited by (10)

Revealing the water vapor transport during the Henan “7.20” heavy rainstorm based on ERA5 and Real-Time GNSS

2024, Egyptian Journal of Remote Sensing and Space Science

Show abstract

Quasi-coseismic variations and geosphere coupling associated with the strong 2023 Turkey earthquakes

2024, Science of the Total Environment

> *Citation Excerpt :*
>
> …The regional co-seismic temperature response caused by the co-seismic unloading and tension has been observed from the land surface temperature (LST) derived from the satellites (Chen et al., 2013). Guo et al. (2023a) found the increased LST on the earthquake day is incredibly high compared with those pre-event days. The co-seismic ionospheric effects associated with the infrasonic waves triggered by the seismic waves have been observed in the 2011 Great Tohoku earthquake (Hao et al., 2012) and the 2020 Jamaica earthquake (Chai and Jin, 2021).…

Show abstract

Improving the capability of water vapor retrieval from Landsat 8 using ensemble machine learning

2023, International Journal of Applied Earth Observation and Geoinformation

> *Citation Excerpt :*
>
> …Since the 1990 s, GNSS meteorology has been proposed as a new method for PWV retrieval owing to the merits of superior temporal resolution, excellent precision, and cost-effectiveness (Bevis et al., 1994; Ma et al., 2022). The root mean square error (RMSE) of GNSS-derived PWV is usually better than 0.2 g/cm2, and this high accuracy is the prerequisite for creating superior models (Guo et al., 2023; Zhao et al., 2019). Furthermore, GNSS-derived PWV was a ground-based reference in numerous studies but only provides observation over the station (Jiang et al., 2022; Ma et al., 2022).…

Show abstract

An Improved Model for the Retrieval of Precipitable Water Vapor in All-Weather Conditions (RCMNT) Based on NIR and TIR Recordings of MODIS ↗

2024, IEEE Transactions on Geoscience and Remote Sensing

Investigating the ERA5-Based PWV Products and Identifying the Monsoon Active and Break Spells with Dense GNSS Sites in Guangxi, China ↗

2023, Remote Sensing

Co-seismic characterization analysis in PWV and land-atmospheric observations associated with Luding Ms 6.8 earthquake occurrence in China on September 5, 2022 ↗

2023, Geomatics Natural Hazards and Risk

View all citing articles on Scopus ↗

View full text