Climate applications of a global, 2-hourly atmospheric precipitable water dataset derived from IGS tropospheric products

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Abstract A global, 2-hourly atmospheric precipitable water (PW) dataset is produced from ground-based GPS measurements of zenith tropospheric delay (ZTD) using the International Global Navigation Satellite Systems (GNSS) Service (IGS) tropospheric products (~80–370 stations, 1997–2006) and US SuomiNet product (169 stations, 2003–2006). The climate applications of the GPS PW dataset are highlighted in this study. Firstly, the GPS PW dataset is used as a reference to validate radiosonde and atmospheric reanalysis data. Three types of systematic errors in global radiosonde PW data are quantified based on comparisons with the GPS PW data, including measurement biases for each of the fourteen radiosonde types along with their characteristics, long-term temporal inhomogeneity and diurnal sampling errors of once and twice daily radiosonde data. The comparisons between the GPS PW data and three reanalysis products, namely the NCEP-NCAR (NNR), ECMWF 40-year (ERA-40) and Japanese reanalyses (JRA), show that the elevation difference between the reanalysis grid box and the GPS station is the primary cause of the PW difference. Secondly, the PW diurnal variations are documented using the 2-hourly GPS PW dataset. The PW diurnal cycle has an annual-mean, peak-to-peak amplitude of 0.66, 0.53 and 1.11 mm for the globe, Northern Hemisphere, and Southern Hemisphere, respectively, with the time of the peak ranging from noon to late evening depending on the season and region. Preliminary analyses suggest that the PW diurnal cycle in Europe is poorly represented in the NNR and JRA products. Several recommendations are made for future improvements of IGS products for climate applications.

Keywords GPS · Water vapor · Climate · IGS · Zenith troposphere delay

1 Introduction

Water vapor plays a key role in atmospheric radiation, the hydrological cycle and in understanding and predicting global climate change. Therefore it is vital to advance our understanding of water vapor variability, but such advancement is hampered by inadequate observations. Observations of atmospheric water vapor have traditionally been made using balloon-borne radiosondes. Unfortunately, the usefulness of radiosonde data in climate studies is limited, in part by sensor characteristics that vary substantially in time and space. Several studies and reports have called for the creation of global water vapor datasets with sufficient accuracy and temporal resolution, and, more importantly, long-term stability (e.g., GCOS 2004; CCSP 2005; Trenberth et al. 2005). None of the existing radiosonde, satellite or blended datasets can meet these requirements.

There have been considerable efforts in deriving atmospheric precipitable water (PW) using ground-based Global Positioning System (GPS) measurements at high temporal resolution. The advantages of the GPS-derived PW data include continuous measurements, availability under all weather conditions, high accuracy (<3 mm in PW), long-term stability and low cost, all of which make the GPS PW data very compelling for climate studies (Ware et al. 2000). However, the climate applications of the GPS-derived PW data have not been fully explored because of the lack of a global, long-term and continually updated GPS PW dataset.
Although there have been many regional analyses of ground-based GPS PW data (e.g., Dai et al. 2002), there have been only a few studies (e.g., Hagemann et al. 2003; Deblonde et al. 2005) that take advantage of the growing network of the International Global Navigation Satellite Systems (GNSS) Service (IGS) stations around the globe, and the readily available zenith tropospheric delay (ZTD) data computed by the IGS (Beutler et al. 1999).

Since 2004 there has been a project to create a global, 2-hourly PW dataset from ground-based GPS measurements and to use this dataset for a variety of scientific studies, with a focus on its climate applications. A comprehensive analysis technique has been developed to convert the ZTD to PW on a global scale (Wang et al. 2005, 2007). The technique was applied to the global IGS ZTD data to produce a global, 2-hourly PW data set (Wang et al. 2007). Some of the applications of this dataset were highlighted in Wang et al. (2007). In addition, Wang and Zhang (2008) describe an application of this dataset to characterize systematic errors of global radiosonde PW data. The analysis technique and the updated global, 10-year (1997–2006), 2-hourly GPS PW dataset are first briefly described in Sect. 2. Then two climate applications of the dataset are presented, namely evaluating radiosonde and reanalysis PW data (Sect. 3), and studying PW diurnal variations and comparing them with the reanalysis data (Sect. 4). In Sect. 5, several recommendations are made on improving future IGS tropospheric products for climate applications.

2 Data and analysis method

The IGS ZTD data are available from 1997 (at ∼100 stations) to 2006 (at 451 stations), at 2-hourly resolution before November 2006 and 5-min resolution afterwards. The ZTD data can be downloaded from three IGS data archive centers with about 2 ~ 4-week delay from real-time. The 5-min ZTD data are linearly interpolated to the 2-hourly resolution. An analysis technique was developed to convert the ZTD to the PW on a global scale, and is summarized in Wang et al. (2005, 2007). Surface pressure (Ps) and water-vapor-weighted atmospheric mean temperature (Tm) are two key parameters for this conversion. The ZTD is a sum of the zenith hydrostatic delay (ZHD) and wet delay (ZWD). The ZHD can be estimated from Ps; the ZWD is a function of PW and Tm. Ps was derived from global, 3-hourly surface synoptic observations with temporal and vertical adjustments. Tm was calculated from the NCEP/NCAR reanalysis with temporal, vertical and horizontal interpolations.

The analysis technique was applied to the 2-hourly ZTD data to create a global, 2-hourly PW dataset for the period from 1997 to 2004 (Wang et al. 2007). After Wang et al. (2007), the PW dataset has been updated to December 2006 and will continue to be updated as other auxiliary data become available. The PW data are available every two hours (0100, 0300, 0500, ..., 2300 UTC) from 80 to 370 IGS ground stations. In addition, the GPS ZTD product from the U.S. SuomiNet regional network has been processed using the same technique. As a result, the GPS PW data at an additional 169 stations in the contiguous US for 2003–2006 are added to the global PW dataset. Figure 1 shows that the number of stations in 2006 in the PW dataset is 539, with 370 IGS and 169 SuomiNet stations. The PW dataset was compared with radiosonde, microwave radiometer, and satellite data in Wang et al. (2007). The comparisons did not reveal any systematic bias in the GPS PW data and show a root-mean-squared (rms) error of less than 3 mm. The PW dataset also consists of 2-hourly surface pressure derived from the synoptic observations, Tm from the NCEP/NCAR reanalysis, original ZTD, and calculated ZHD and ZWD.

The Integrated Global Radiosonde Archive (IGRA) produced by the National Climatic Data Center (NCDC) (Durre et al. 2006) are matched and compared with the GPS PW dataset in Wang and Zhang (2008) and in this study. Three atmospheric reanalysis products, the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) (NRR), the European Centre for Medium-Range Weather Forecasts (ECMWF) 40-year (ERA-40), and the Japanese Reanalysis (JRA), are matched in time and space and compared with the GPS PW data. The reanalysis data are available at 6-hourly resolution (0000, 0600, 1200, 1800 UTC) for the period of this study (1997–2006), except ERA40, which is unavailable after August 2002.

3 Evaluation of radiosonde and reanalysis PW data

Global radiosonde data have been and will continue to be a valuable resource for weather prediction and studying