Global long term data sets of the atmospheric H_2O VCD and of cloud properties derived from GOME and SCIAMACHY

A contribution to subproject ACCENT-TROPOSAT-2 (AT2), Task Group 1

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Summary

From measurements of GOME we analysed global trends of total column precipitable water for the period January 1996 – June 2003. In contrast to other retrieval methods our analysis does not use independent or a-priori information making it in particular well suited for trend studies. It has a similar sensitivity for observations over land and ocean and thus can yield a consistent global picture. To minimise the influence of clouds on the water vapor trends we selected observations for mainly clear sky conditions. The temporal evolution of the monthly or yearly averaged total column precipitable water, especially in the tropics, is highly correlated to that of the surface temperature indicating a strong water vapor feedback. Also the spatial patterns of water vapor are correlated to those of the surface temperatures (except for the continents). During the period 1996 – 2002 the globally and yearly averaged total column precipitable water increased by 2.8±0.8% (excluding the ENSO period).

Introduction

Atmospheric water vapor is the most important greenhouse gas contributing about 2/3 of the natural greenhouse effect. In contrast to other greenhouse gases like CO_2 and CH_4 it has a much higher temporal and spatial variability. The correct understanding and assessment of water vapor with respect to the earths energy budget is further complicated by its role in cloud formation and for the transport of latent heat. Today, many details of the way in which the hydrological cycle reacts to climate change (water vapor feedback) are still not understood. Especially for the tropics, which contribute strongest to the water vapor greenhouse effect, the strength of the water vapor feedback is under intense debate [Held and Soden, 2000 and reference therein; Minschwaner and Dessler, 2004]. Here we present global trend studies over a period from 1996-2003 during which the globally averaged surface temperatures showed a strong increase. Thus it is possible to directly investigate the water vapor feedback as a function of time and location and compare it in particular to the expectations of simple equilibrium physics (based on the Clausius-Clapeyron law).

Scientific activities

Several algorithms for the retrieval of the total column precipitable water in the red part of the spectrum from GOME and SCIAMACHY were developed during recent years [Noël et al., 1999, 2000, 2002; Casadio et al., 2000; Maurellis et al., 2000; Lang et al., 2003; 2004; Lang, 2003; Wagner et al., 2003, 2005a,b]. In contrast to other methods our water vapor algorithm is directly based on the results of the spectral DOAS fitting [Platt, 1994] and does not include atmospheric radiative transport calculations.

For the trend study we used a modified retrieval: While the spectral analysis is almost unchanged (for details see Wagner et al. [2003, 2005a]) we now use the measured O_2 absorption (instead of the absorption of the oxygen dimer O_4) for the correction of the atmospheric radiative transport. The desired total column precipitable water (TCPW) is the vertically integrated water vapor concentration (in DOAS remote sensing literature it is often referred to as vertical column density VCD). It is calculated as follows:

$$TCPW = VCD_{H_2O} = \frac{SCD_{H_2O}}{SCD_{O_2}/VCD_{O_2}} = \frac{SCD_{H_2O}}{AMF_{O_2}} \quad (1)$$

Here SCD_{H2O} and SCD_{O2} are the slant column densities (the integrated concentration along the light path) of water vapor and O_2, respectively. The VCD_{O2} is calculated from an average atmospheric pressure profile. The ratio of the SCD_{O2} and VCD_{O2} defines the (measured) air mass factor (AMF_{O2}) [Solomon et al., 1987; Marquard et al., 2000; Wagner et al., 2003], which is then used for the conversion of the measured SCD_{H2O} into the desired total column precipitable water (VCD_{H2O}).

For the new water vapor data set a detailed error analysis was performed and a new cloud screening procedure was applied. The data set was compared in detail to SSM/I observations. For details see Wagner et al. [2005b].

Scientific results and highlights

Latitudinal averaged time series of water vapor

In Fig. 1 the monthly mean atmospheric total column precipitable water for the period 1996 – 2003 is presented as a function of latitude (10° bins) and time. Several interesting features of the hydrological cycle can be identified. The total column precipitable water distribution follows the surface near temperatures; the highest values are found for the locations with highest surface temperatures. The tropical total column precipitable water has a minimum during northern hemispheric winter. During 1997/98 the strong ENSO phenomenon leads to significantly higher tropical values compared to other years. The total column precipitable water in northern mid and high latitude is systematically larger than in the southern hemisphere mainly reflecting the different distribution of land and ocean in both hemispheres. The amplitude of the seasonal cycle is much larger in the northern hemisphere.

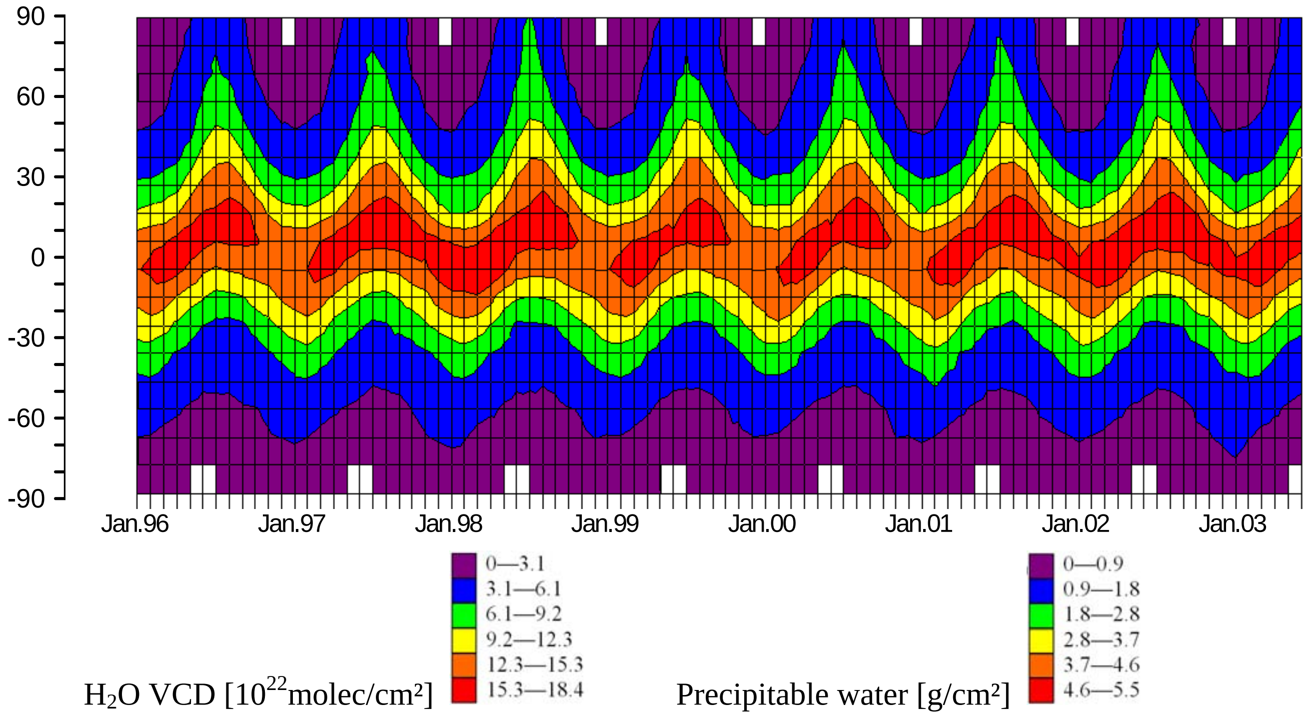

Fig. 1 Monthly mean total column precipitable water (averaged for 10° latitude bins) for the whole time series 1996 – 2003. According to the ERS-2 orbit parameters no data with an SZA < 90° were obtained for latitudes from –90 to –80°S.

Temporal evolution of water vapor and surface temperature

In Fig. 2 the time series of anomalies of the globally and monthly averaged total column precipitable water with respect to the monthly mean values from 1996 – 2002 are presented. Also shown are the globally averaged surface temperature anomalies (with respect to the monthly averages from 1961 – 1990) analysed by the Climate Research Group at the Hadley Centre of the UK Meteorological Office (HadCRUT2(v), see Jones and Moberg [2003] and http://www.cru.uea.ac.uk/cru/data/temperature/). Both time series show a similar temporal evolution with enhanced values of total column precipitable water during periods of enhanced surface temperatures and vice versa. An even more pronounced correlation of the total column precipitable water and surface temperature is found if the mean values for the Tropics are calculated (30°N – 30°S, see Fig. 3). We find that the total column precipitable water increases by about $7.4 \cdot 10^{21}$ molec/cm² and $9.6 \cdot 10^{21}$ molec/cm² per K temperature increase for the whole globe or the Tropics, respectively. The relative changes of the total column precipitable water are 9% and 8% per K temperature increase for the whole globe and the Tropics, respectively.
In contrast to the tropics, the extratropical data sets (latitude bands >30°N and <30°S) of the total column precipitable water and surface temperature show almost no correlation [Wagner et al., 2005b].

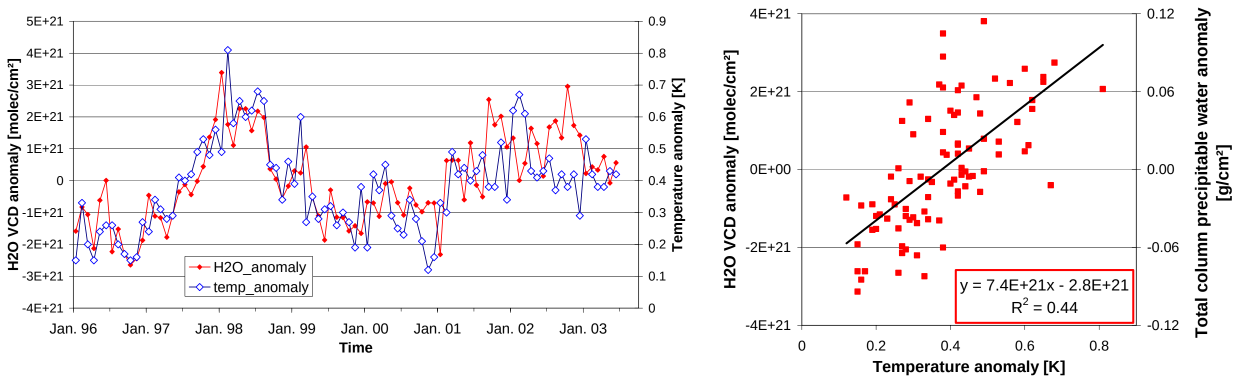

Fig. 2 Left: Time series of monthly anomalies of the globally averaged temperature and total column precipitable water. The temperature anomalies are calculated relative to the monthly average values of the period 1961 – 1990, see http://www.cru.uea.ac.uk/cru/data/temperature/. The total column precipitable water anomalies are calculated relative to the monthly average values of the period 1996 – 2002. Right: Correlation analysis of both data sets.

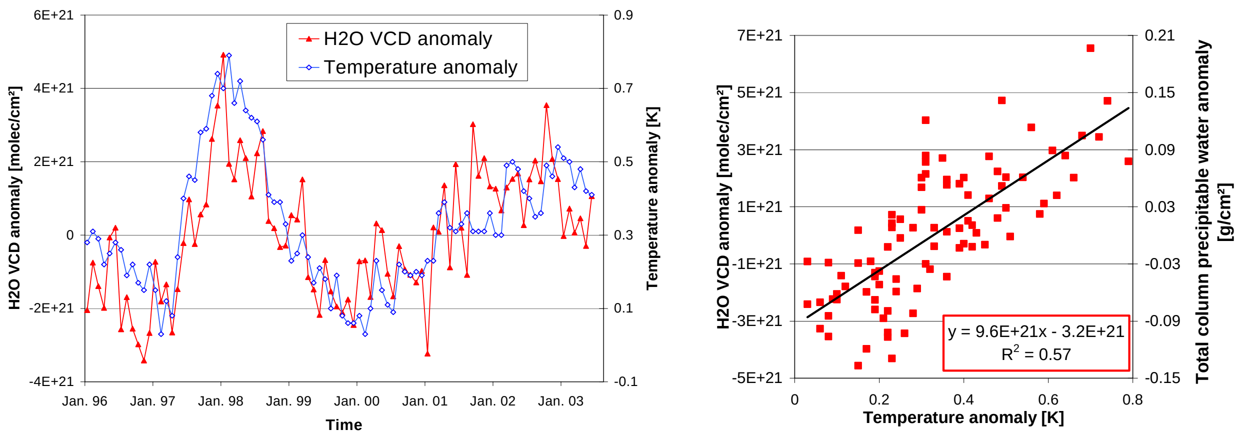

Fig. 3 Same as Fig. 5 but for the Tropics (latitude between 30°N and 30°S).

Spatial trend patterns of water vapor and surface temperature

We compare global maps of trend patterns for the total column precipitable water and surface temperature (from the Goddard Institute for Space Studies (GISS), see Hansen et al. [2001] and Reynolds et al. [2002]) for the period 1996 – 2002 (Fig. 4). Positive trends of the total column precipitable water are found over the western tropical Pacific, over the Pacific south of Alaska, over Siberia; strong increases are also detected for large parts of all southern Oceans. Negative trends of the total column precipitable water are found over parts of North America, the Pacific west of the USA, over northern Australia, the Arabic peninsula and over the southern Atlantic close to Antarctica. Especially over the oceans, the trends of the total column precipitable water and surface temperature are very similar. In contrast, over the continents the correlation is substantially worse and even opposite trends are often found (e.g. over Northern America). These differences might be related to the fact that in contrast to the ocean, over the continents the total column precipitable water is strongly influenced by long range transport and the specific precipitation history of air masses. Also the surface type and water availability has a strong influence on the evaporation rate.

Surface temperature trend 1996 - 2002 Total column precipitable water trend 1996 - 2002

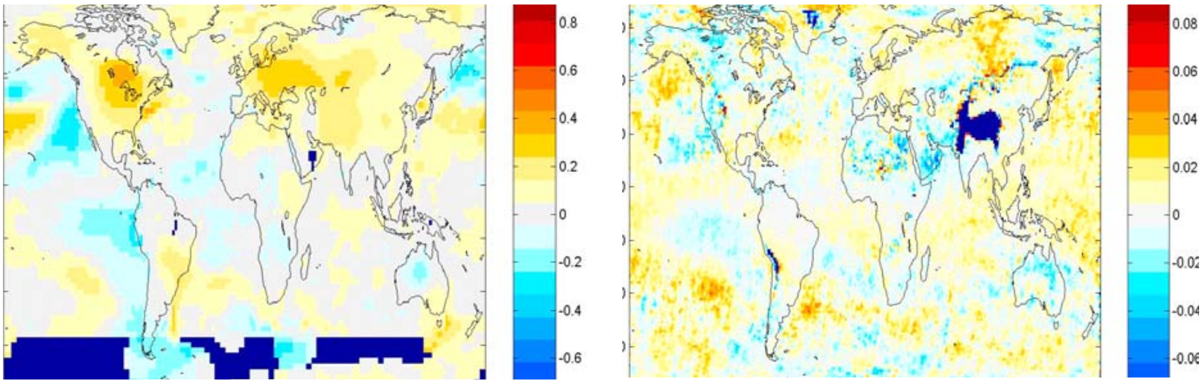

Fig. 4 Global trend patterns of yearly averaged total column precipitable water and surface temperature (from http://www.giss.nasa.gov/data/update/gistemp/, Reynolds et al., 2002). Especially in the tropics and the southern hemisphere many similarities between the trends of the total column precipitable water and the temperature are found. Over the northern hemispheric continents also opposite trends occur. The trends are expressed as relative trends per year. Dark blue color indicates areas without data.

Future outlook

In summer 2003 the global measurements of GOME ended because of the break-down of the on board storage unit (the instrument itself is still in operation and observations close to ground receiving stations can still be obtained). Fortunately, there is a long temporal overlap (from mid 2002 to mid 2003) between GOME and its successor (SCIAMACHY, see Bovensmann et al. [1999]), for which nearly identical analysis procedures can be applied. Thus it will be possible to continue the GOME time series without interruption. A further elongation of the time series until 2020 will probably be possible including the measurements of the three instruments of the GOME-2 series [EUMETSAT, 2005].

In the near future the GOME water vapor data sets will be made available to the scientific community. Also the cloud analysis using PMD observations and DOAS retrievals of the O_2 and O_4 absorption are further improved [Wagner et al., 2005a]. The data analysis will be adapted to SCIAMACHY and GOME-2 instruments and the trend studies will be applied to the then extended time series.

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