

INVESTIGATING THE EARTH'S HYDROLOGICAL CYCLE USING H₂O VCDs AND CLOUD RELATED PARAMETERS FROM GOME-II

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ABSTRACT. From the spectra of UV/vis satellite instruments the H₂O VCD can be measured. Compared to other methods, the main advantages of our algorithm are similar sensitivity over land and oceans and for the whole atmospheric column. Also, it does not rely on a-priori assumptions or additional information. From the measured spectra also information on cloud properties can be derived. Besides the absolute radiance, also the absorptions of O₂ and O₄ and the strength of the Ring effect can be measured. Especially from the strong and narrow-band O₂ absorption, cloud information can be analysed with high precision. Here we present global trends of the H₂O VCD and the O₂ cloud cover analysed from GOME observations for 1996-2003. During this period, both quantities show a substantial increase, mostly consistent with the trends of the near-surface temperatures. The time series from GOME-I can be continued with observations of its successors SCIAMACHY and GOME-II; the total time period can thus be extended to up to about 25 years.

1. INSTRUMENTS

The GOME instrument aboard the European research satellite ERS-2 [1] measures sunlight reflected from the Earth's atmosphere and surface covering the wavelength range between 240 and 790 nm with moderate spectral resolution (0.2-0.4nm FWHM). The satellite operates in a nearly polar, sun-synchronous orbit at an altitude of 780 km with an equator crossing time of approximately 10:30 am local time. While the satellite orbits in an almost north-south direction, the GOME instrument scans the surface of earth in the perpendicular east-west direction. During one scan, three individual ground pixels are observed, each covering an area of 320 km east to west by 40 km north to south. The Earth's surface is entirely covered within 3 days, and poleward from about 70° latitude within 1 day. GOME-II is similar to GOME-I, but has a finer spatial resolution (40x80km²) and better global coverage (within one day) [2].

2. DATA ANALYSIS

2.1 H₂O VCD (total column precipitable water)

Several algorithms for the retrieval of the total column precipitable water in the red part of the spectrum from GOME were developed during recent years [3-13]. In contrast to these other methods, our water vapor algorithm is directly based on the results of the spectral

analysis using Differential Optical Absorption Spectroscopy (DOAS [14]) and does not include explicit numerical modeling of the atmospheric radiative transfer. One specific advantage of the DOAS method is that it is sensitive to relative (differential) absorptions; thus our water vapor results are almost independent on instrument degradation (for details see [11-13]).

The total column precipitable water 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:

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

Here SCD_{H₂O} and SCD_{O₂} are the measured slant column densities (the integrated concentration along the light path) of water vapor and O₂, respectively. The VCD_{O₂} is calculated from an average atmospheric pressure profile. The ratio of the SCD_{O₂} and VCD_{O₂} defines the air mass factor (AMF_{O₂}) [15,16], which is used for the conversion of the measured SCD_{H₂O} into the desired total column precipitable water (VCD_{H₂O}). It is important to note that usually, the air mass factor is derived from numerical radiative transfer modeling. In contrast, here we derive a 'measured' air mass factor from the simultaneously measured SCD_{O₂}. The underlying assumption is that AMF_{O₂} is similar to the AMF for water vapor (see below). Our simple approach has the advantage that it corrects for the effects of varying albedo, aerosol load and cloud cover without the use of additional independent information (which is usually not available). Although the effects of clouds on the measured total column precipitable water are basically corrected by the application of the measured air mass factor, due to the different altitude profiles of H₂O and O₂, potential systematic cloud effects might still appear [11-13]. Thus, for the trend analysis, only mainly cloud free observations were used (the O₂ absorption is between 80% and 95% of the maximum O₂ absorption). The application of both, a lower and an upper threshold ensures that systematic changes of the cloud cover during the observed time period have almost no influence of the derived total column precipitable water trends. Our GOME H₂O data set shows a very good agreement with that of SSM/I [13]. It should be noted that while in the meteorological literature the total column precipitable water is usually

expressed in units of g/cm^2 , in DOAS related publications it is often expressed as vertical column density in units of molecules per cm^2 ($1\text{g}/\text{cm}^2$ corresponds to $3.3 \cdot 10^{22} \text{molec}/\text{cm}^2$).

2.2 Cloud cover

From the results of the DOAS fitting process, also information on the cloud cover can be retrieved. While in principle the observation of the O_4 absorption is more sensitive to the shielding of clouds, here we derive information on cloud cover from the strong and narrow-band O_2 absorption. The O_2 absorption can be analysed with higher precision and is thus better suited for trend studies.

If clouds appear, they shield (part of) the atmospheric O_2 profile below the cloud; thus a reduced O_2 absorption is a signal for an increased cloud fraction. However, the O_2 absorption is also influenced by the cloud top height. Thus we refer to the O_2 -cloud product as ‘cloud cover’. It is defined as:

$$\text{Cloud Cover} = 1 - \left(\frac{OD_{\text{measured}}}{OD_{\text{max}}} \cdot 2.5 \right) \quad (2)$$

with OD_{max} the maximum O_2 absorption for clear sky and OD_{measured} the measured O_2 absorption. The factor of 2.5 corrects for the fact that the smallest observed O_2 absorption (for high dense clouds) is about 60% of the maximum O_2 absorption for clear skies. In addition to the O_2 cloud cover we also calculate trends from the cloud fraction derived from broad band intensity measurements (from the so called PMD sensors). This cloud algorithm (Heidelberg Iterative Cloud Retrieval Utilities, HICRU) is described in detail in [17,18].

2.3 Temperature data

We compare our trends for water vapor and clouds with near-surface temperature data from from the Goddard Institute for Space Studies (GISS), see <http://www.giss.nasa.gov/data/update/gistemp/>. Details on this data set can be found in [19,20].

3 RESULTS AND CONCLUSIONS

In Fig. 1 maps of the global trends of the H_2O VCD and the cloud cover are presented. Also shown are the trends of the near-surface temperatures. The best agreement with the temperature trends is found for the H_2O trends over the oceans. There, also the trends for the cloud cover and cloud fraction show good agreement. A strong dependence of the H_2O VCD on the near-surface

temperature is also found for the temporal variation of the monthly averages from 1996-2003 [13].

Over the continents, often better agreement of the trends of the cloud cover with those of the temperatures is found. For H_2O , even opposite trends over the continents appear indicating that the relationship between the surface-near temperatures and the hydrological cycle is much more complex. The differences between the cloud cover (from O_2) and the HICRU cloud fraction are most probably caused by changes in the cloud top height, which mainly influence the cloud cover (but not the HICRU cloud fraction). Our retrievals for the H_2O VCD and cloud cover can be directly adapted to the GOME-II instruments. The combined time series of GOME-I, SCIAMACHY and GOME-II will cover up to about 25 years.

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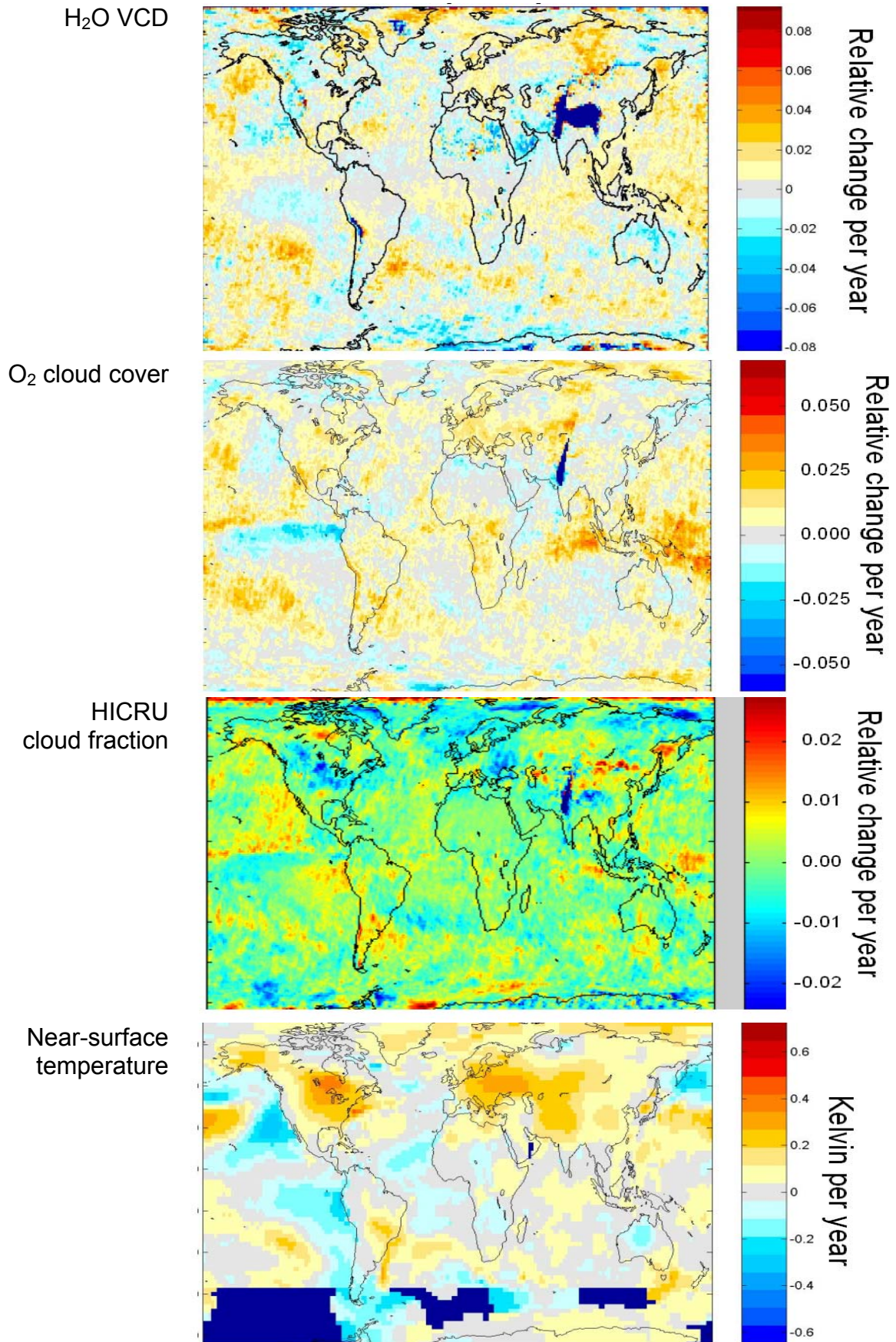


Fig. 1 Global trend maps of the H₂O VCD, cloud cover from O₂ absorption, HICRU cloud fraction and near-surface temperature. The trends are expressed as relative change or Kelvin per year.