Estimating climate feedback through water vapor and cloud cover from GOME satellite observations

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Summary. Cloud climate feedback constitutes the most important uncertainty in climate modelling, and currently even its sign is still unknown. In the recently published report of the intergovernmental panel on climate change (IPCC), from 20 climate models 6 showed a positive and 14 a negative cloud forcing in a doubled CO_2 scenario (Solomon et al., 2007). The radiative budget of clouds has also been investigated by experimental methods, especially by studying the relation of satellite observed broad band shortwave and longwave radiation to sea surface temperature (e.g. Ramanathan et al., 1989). Here we present results from UV/vis satellite observations of the backscattered radiance and the O_2 absorption, from which information on the dependence of cloud cover and cloud top height on surface-near temperatures can be derived. In addition, also the total atmospheric water vapour column is retrieved. We find that over most parts of the globe, an increase in surface-near temperature is connected with an increase of cloud top height and decrease of cloud cover (except the Tropics). These findings indicate a positive cloud climate feedback. Also for atmospheric humidity a positive feedback is found for almost the whole globe. Climate models should aim to reproduce our findings to reduce uncertainties in climate change predictions.

Introduction

Clouds have a strong impact on both, the short-wave solar radiation and on the outgoing thermal radiation. If cloud cover increases, less solar radiation reaches the ground, but also more thermal radiation from the surface will be trapped in the atmosphere. Both effects influence the surface-near temperature with opposite signs, and their net effect depends on various cloud properties, especially on the cloud altitude (Stephens, 2005; Cess et al., 1992; Hartmann et al., 2001). Today, the magnitude, and even the sign of cloud feedback is still not known (see e.g. the IPCC 4th assessment report (Solomom et al., 2007) and references therein). In this study we investigate the climate feedbacks due to clouds and water vapor for fixed locations on a global scale using correlation analyses of monthly anomalies of cloud fraction, cloud top height (derived from the atmospheric O_2 absorption), and atmospheric humidity with those of the surface-near temperature. The cloud and water vapour data is derived from 7.5 years of observations of the Global Ozone Monitoring Experiment (GOME) on board the European research satellite ERS-2. We relate the GOME results to surface-near temperature observations for the same period (surface temperature data are obtained from the Goddard Institute for Space Studies (Hansen et al., 2001; Reynolds et al., 2002) (GISS, see http://www.giss.nasa.gov/data/update/gistemp/).

GOME on ERS-2

The GOME instrument aboard the European research satellite ERS-2 measures sunlight reflected from the Earth’s atmosphere and surface covering the wavelength range between

240 and 790 nm with moderate spectral resolution (Burrows et al., 1999) (0.2-0.4nm FWHM). The satellite operates in a nearly polar, sun-synchronous orbit at 780 km altitude with an equator crossing time of approximately 10:30 a.m. local time. This has to be taken into consideration for the interpretation of our results, which might be only representative for mid-morning because of the diurnal variation of clouds (Bergman and Salby, 1996). The ground pixels cover an area of 320 km east to west by 40 km north to south. Simultaneous to the spectral channels, also broad band intensities are measured by the so called polarization monitoring devices (PMD). Compared to the spectral channels, they have a much finer spatial resolution of 20 x 40km². The Earth's surface is entirely covered within 3 days, and poleward from about 70° latitude within 1 day.

Data analysis

Here we analyse three products retrieved from GOME observations: the total column precipitable water, the effective cloud fraction, and cloud top height. The effective cloud fraction (HICRU, Grzegorski et al., 2006) is based on broad spectral measurements with a high spatial resolution. In addition, the absorptions of water vapour and oxygen are analysed using Differential Optical Absorption Spectroscopy (DOAS, Platt 1994). Details on the spectral analysis can be found in Wagner et al., (2006). From the retrieved absorptions of H_2O and O_2, the total column of atmospheric water vapour is derived. From the effective cloud fraction and the O_2 absorption also information on the cloud top height is derived. For this purpose, we apply radiative transfer modelling using our Monte Carlo model TRACY-2 (Deutschmann and Wagner, 2006; Wagner et al., 2007). From the three quantities (effective cloud fraction, cloud top height and total water vapour column) as well as the surface-near temperature, we calculate monthly averages. Finally, from these monthly averages, anomalies for individual months are derived (deviation from the mean value of the respective month for all years). Using these monthly anomalies we performed correlation analyses of the three quantities versus surface near temperatures.

Results

The results of the correlation analyses are shown in Fig. 1. For the effective cloud fraction (top) we find decreasing values with increasing surface-near temperatures for most parts of the globe, except over the tropical oceans close to the equator. These findings are in good agreement with those of Bony et al. (1997), who found a negative correlation of CF (and cloud optical depth) for surface-near temperature < 26°C and a positive correlation for surface-near temperature > 26°C.

For the cloud top height (middle), we find increasing values with increasing surface-near temperatures. Very strong changes in CTH are found over the tropical oceans close to the equator. Again our findings are in good agreement with those of Bony et al. (1997), who found a weak positive correlation < 26°C and strong positive correlation > 26°C. Also Larson and Hartmann (2003) found an increasing cloud top height of tropical clouds for increasing surface-near temperatures. They found in particular that over tropical oceans, the frequency of situations with large scale uprising air and high clouds increases strongly for surface temperatures > 26°C.

For the total atmospheric water vapor column, we find and increase with increasing surface-near temperatures for almost the whole globe. This dependence is expected from the Clausius-Clapeyron relationship and leads to a positive water vapor feedback (see also Wagner et al. 2006).

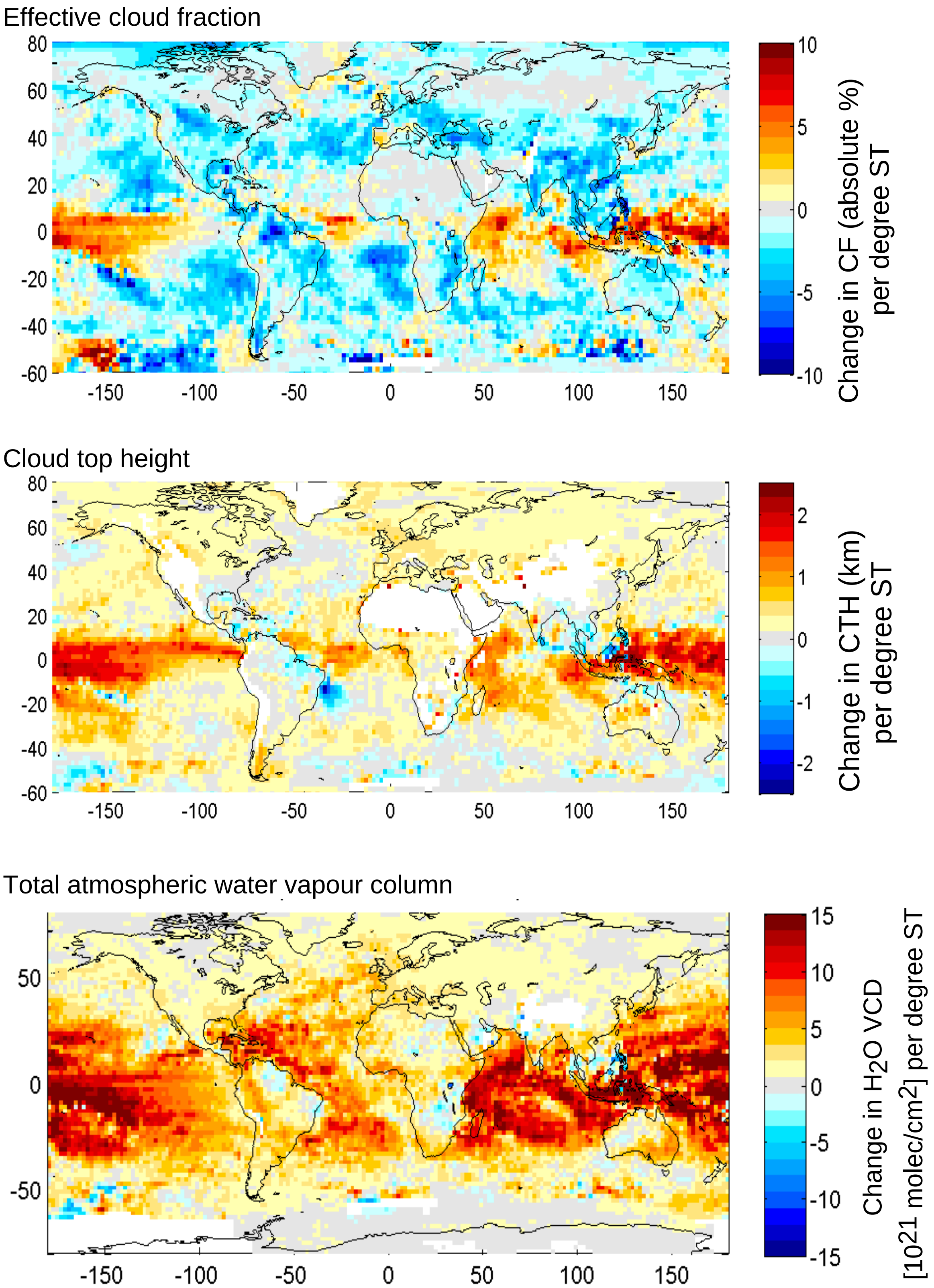

Fig. 1 Dependence of cloud fraction (top), cloud top height (middle) and total atmospheric water column (bottom) on surface temperature (ST) as derived from the correlation analysis.

Conclusions

The observed dependencies of the cloud fraction, cloud top height, and the total atmospheric water vapour column on surface-near temperatures can be used to derive information on the respective climate feedbacks. For water vapour, a clear positive feedback is observed: if temperature rises, also atmospheric humidity increases. Since water vapour is the most important atmospheric greenhouse gas, this leads to an increase of the greenhouse effect. Especially for the tropics, a rather strong water vapour feedback is found (Wagner et al., 2006). For the interpretation with respect to cloud climate feedbacks, the general dependencies of cloud forcing have to be considered. Cloud forcing depends on many factors, in particular on cloud optical depth, cloud top height; it varies also with latitude. In a simplified way, this can be summarized as follows:

a) clouds tend to heat (cool) the atmosphere at low (high) latitudes compared to clear skies (Stephens, 2005; Ramanathan et al., 1989; Harrison et al., 1990).

b) cloud heating increases with increasing cloud top height (Stephens, 2005; Cess et al., 1992; Kubar and Hartmann, 2007).

Based on these dependencies, the observed changes of cloud fraction with increasing surface temperature can in general be interpreted as a positive cloud feedback: at high latitudes the decrease in cloud fraction will lead to a reduced cooling; at low latitudes over the oceans, the increase in cloud fraction will increase the heating. In addition to the effect of changing cloud fraction, also the increase of cloud top height will increase the cloud heating and can be interpreted as an additional positive cloud feedback. It should, however, be taken into account that these simplified conclusions might not be true for individual cases. More detailed information on these complex interactions can (and should) be gained from the comparison of our results to model simulations.

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