GLOBAL DISTRIBUTION OF ATMOSPHERIC PHOTON PATH LENGTHS DERIVED FROM GOME AND SCIAMACHY

Thomas Wagner[1], Steffen Beirle[1], Michael Grzegorski [2], Tim Deutschmann[2], and Ulrich Platt[2]

[1] *MPI for Chemistry, J. J. Becher Weg 27, D-55128 Mainz, Germany, Email: Thomas.wagner@mpch-mainz.mpg.de*
[2] *Institute of Environmental Physics, University of Heidelberg, INF 229, D-69120 Heidelberg, Germany*

ABSTRACT

We present a new concept to determine atmospheric photon path lengths from satellite observations with moderate spectral resolution like GOME and SCIAMACHY. From such instruments it is possible to measure the atmospheric absorptions of the oxygen molecule and its dimer at several wavelengths. Together with the simultaneously measured radiance (top of the atmosphere albedo), the total average atmospheric light path lengths can be derived.

1. INTRODUCTION

The investigation of the average atmospheric photon path lengths is of importance for the short wave budget of the Earth‘s atmosphere. Especially, the contribution of ‚weak‘ absorbers (like e.g. the oxygen dimmer O_4 and the potential water vapor continuum) depends on the length and distribution of the atmospheric photon paths. We propose a method to determine the average atmospheric photon path lengths from satellite observations of the atmospheric oxygen molecule (O_2) and dimer (O_4) at different wavelengths (Fig. 1). These observations allow in particular to investigate the role of clouds: the amount of short wave energy reflected back to space depends on the cloud albedo and cloud amount. The atmospheric photon path lengths for cloudy sky depend in particular on the spatial distribution of the clouds.

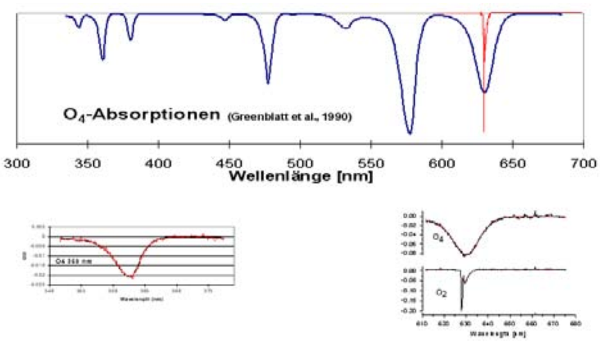

Fig. 1 top: the absorption bands of the oxygen dimer cover the whole UV/vis spectral range. Bottom: in this study, we analyse the bands at 360nm and 630nm. In addition, also the absorption of the oxygen molecule at 630nm is analysed.

Besides atmospheric absorptions by trace gases and aerosols, solar photons can be ‚removed‘ from the atmosphere by two processes:
a) absorption at the ground
b) escape to space at top of the atmosphere TOA

Outside spectral regions with strong trace gas absorptions, and in absence of strong aerosol absorption, the total atmospheric photon path length is the average of the photon path lengths of photons with these two different fates.

In simple cases (without clouds), the average photon path length depends strongly on the surface albedo. For low albedo (Fig. 2 left), almost all photons are absorbed at the ground; these photons have traversed the atmosphere only once (assuming a negligible contribution of atmospheric scattering). For high albedo (Fig. 2 center), almost all photons are reflected and finally escape to space. In this case, the photons have traversed the atmosphere about twice.

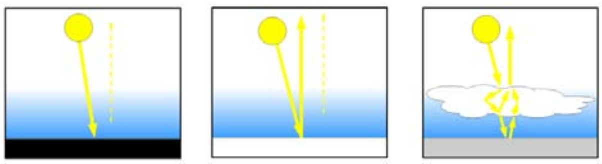

Fig. 2 left: For low surface albedo, the solar photons have traversed the atmosphere only once (the dotted arrow represent the photons scattered by air molecules; this contributions is typically weak). Center: For high surface albedo, the solar photons have traversed the atmosphere twice. Right: In the presence of clouds, the atmospheric radiative transfer becomes more complex. Clouds change the photon path lengths and the partitioning of photons absorbed at the surface or escaping to space.

If clouds are present, the situation becomes more complex. Clouds lead to a redistribution of the photons which are absorbed at the ground or escape to space. Moreover, clouds change the photon paths of both fractions either by shielding lower parts of the atmosphere and/or by multiple scattering inside the clouds (Fig. 2 right).

Combining satellite observations of the absorption of O_2, O_4, and the TOA albedo with atmospheric radiative transfer modelling, it is possible to determine the average photon path length for clear and cloudy conditions.

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It is important to note that the derived average photon path lengths are only representative for trace gases with vertical profiles like those of O_2 (scale height of ~8km) and O_4 (scale height of ~4km). In this study we express the average photon path length as Air mass factor (AMF). An AMF of 1 represents one vertical atmospheric photon path. The AMF can be converted into a geometrical path length if a specific trace gas concentration is assumed. For O_2-and O_4-concentrations near the surface (normal conditions) an AMF of 1 corresponds to a geometrical path length of 8km and 4km for absorbers with a (relative) vertical profile like O_2 and O_4, respectively.

2. GOME on ERS-2

The GOME instrument is one of several instruments aboard the European research satellite ERS-2 [1]. It consists of a set of four spectrometers that simultaneously measure sunlight reflected from the Earth's atmosphere and surface in the wavelength range between 240 and 790 nm with moderate spectral resolution (FWHM: 0.2 – 0.4 nm). 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. Individual ground pixels typically cover an area of 320 km east to west by 40 km north to south. The Earth's surface is entirely covered within 3 days.

3. RESULTS

3.1. Radiative transfer modelling

We performed radiative transfer modelling for a large variety of possible atmospheric scenarios. These scenarios include different surface albedos and varying cloud properties like cloud fraction, vertical extension, cloud top height, and total optical depth. Also the vertical and horizontal structure (homogenous or heterogeneous) was varied.

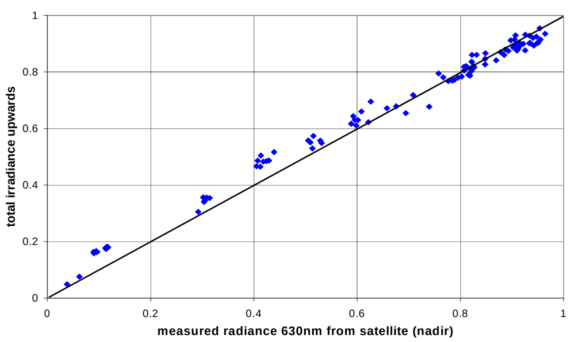

Fig. 3 total upwelling normalised irradiance (630nm) as function of the normalised radiance measured by the satellite

For these scenarios the following quantities were modelled: a) the normalised radiance (top of atmosphere albedo) and absorption of O_2 or O_4 as seen by the satellite, b) the top of atmosphere albedo and absorption of O_2 or O_4 for the total upwelling radiation, and c) the absorption of O_2 or O_4 for all photons (either absorbed at the surface or escaping to space).

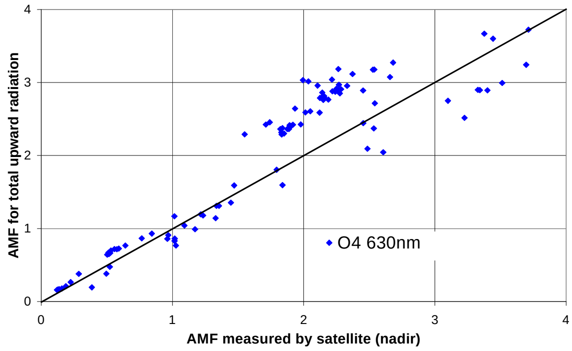

Fig. 4 O_4 AMF (630nm) for the total upwelling irradiance as function of the O_4 AMF measured by the satellite

The radiative transfer modelling was performed with our 3D Monte Carlo model TRACY-2 [2,3]. Several important results were obtained:

- The radiance seen by the satellite is well representative for the total upwelling irradiation (Fig. 3)
- The absorption of O_2 or O_4 as seen by the satellite is fairly representative for absorption of O_2 or O_4 for the total upwelling radiation (Fig. 4)
- The absorption of O_2 or O_4 as seen by the satellite is only roughly representative for the total atmospheric absorption of O_2 or O_4 for all light paths (Fig. 5)
- Fortunately, it turned out that the total atmospheric absorption of O_2 (or O_4) for all light paths can be well described by a low order polynomial of the measured absorption of O_2 (or O_4) and the simultaneously measured radiance (Fig. 6).

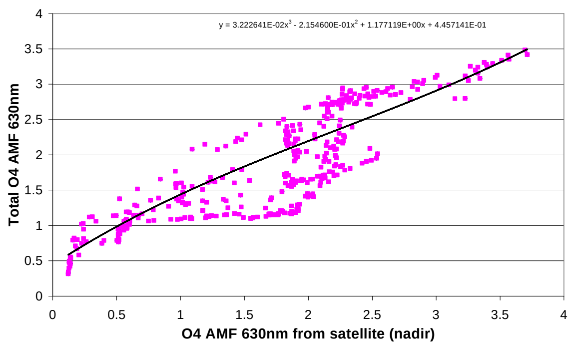

Fig. 5 Total atmospheric O_4 AMF (630nm) as function of the O_4 AMF measured by the satellite.

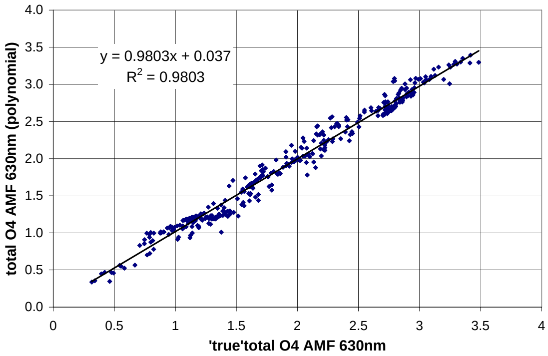

Fig. 6 Total atmospheric O_4 AMF (630nm) (described by a polynomial of the O_4 absorption and radiance measured by the satellite) as function of the true total atmospheric O_4 AMF

The deviations from the true values are in the order of only 10%. Using the determined polynomial function, it becomes possible to determine the average atmospheric photon paths for various atmospheric conditions from satellite observations of O_2 (or O_4) and the absolute radiance (TOA albedo) with a similar accuracy.

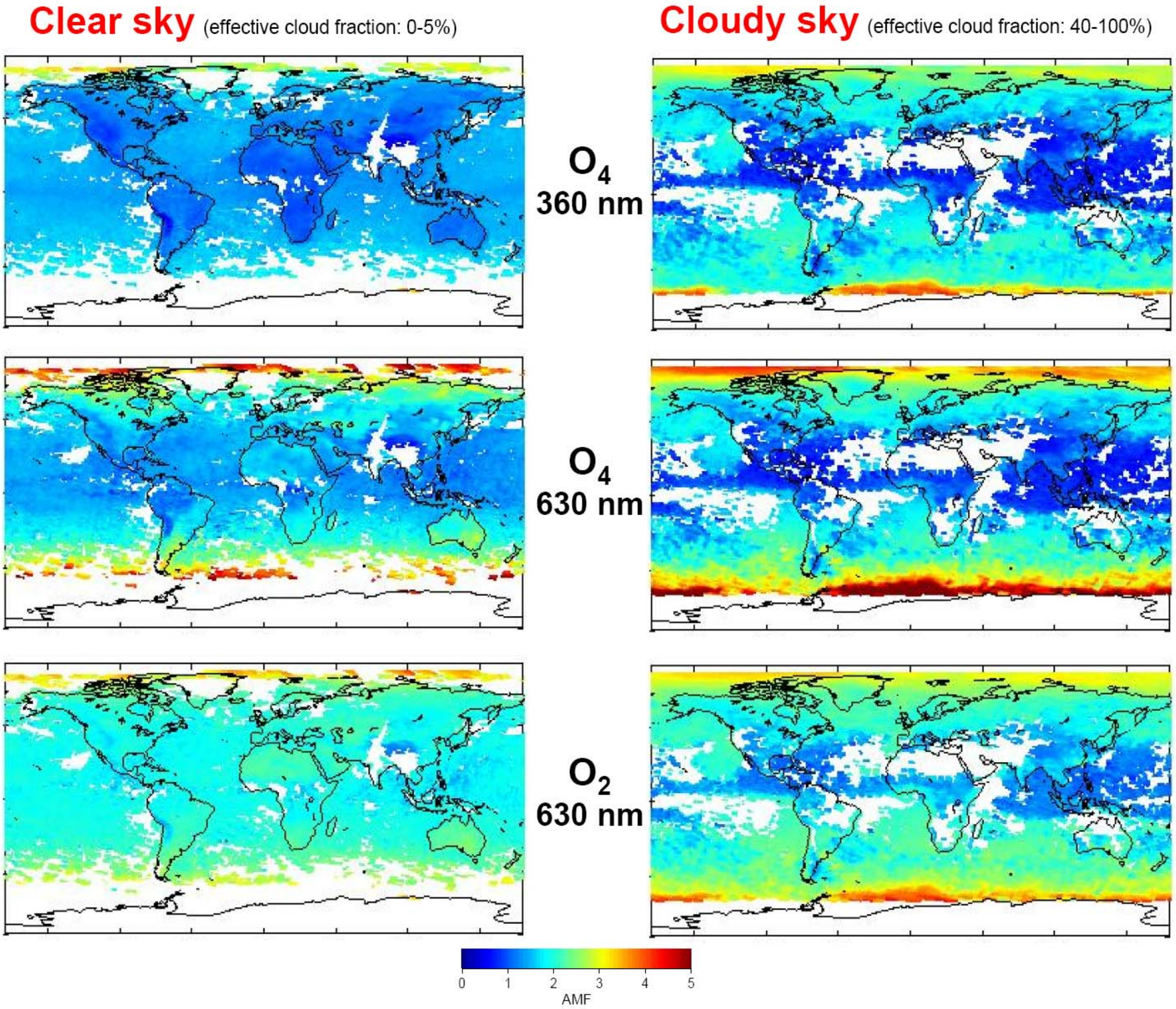

Fig. 7 Measured atmospheric absorptions of O_2 (630nm) as well as of O_4 (360nm and 630nm) for clear (left) and cloudy (right) conditions. The absorptions are expressed as AMF (see ‚introduction'); an AMF = 1 represents one vertical path through the atmosphere (the conversion into AMFs from the retrieved absorptions was performed using the height profiles of the US standard atmosphere).

3.2. Measurements

We analysed GOME observations for August 1998. In Fig. 7 the average absorptions of O_2 (630nm) as well as of O_4 (360nm and 630nm) are presented for almost clear sky (left) and mainly cloudy pixels (right). For details of the analysis see [4]. Compared to clear sky, the AMF for cloudy sky observations is typically higher in the tropics and similar or even larger for other latitudes. The differences between ocean and land are mainly caused by differences in surface albedo and surface elevation; the latitudinal dependence indicates the influence of the changing solar zenith angle.

The atmospheric absorptions observed from satellite are roughly representative for the total atmospheric absorptions (see Fig. 5). Much better estimates of the total atmospheric absorptions will be derived if also the simultaneous measured radiance (TOA albedo) is considered (Fig. 6).

4. CONCLUSIONS

Satellite observations of O_2 and O_4, in combination with radiative transfer modelling, allow to determine the average atmospheric photon path lengths. Applying our method for various atmospheric scenarios (e.g. clear and cloudy sky) it is possible to investigate the influence of these parameters on the atmospheric short wave budget. Our method can be also applied to the successors of GOME: SCIAMACHY and GOME-2. Using these instruments it will be possible to extend the time series into the future and to derive data sets with higher spatial resolution.

5. REFERENCES

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