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Episode of unusual high solar ultraviolet radiation in central Europe due to dynamical reduced stratospheric ozone in May 2005

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Abstract

In late May this year unusual high levels of solar ultraviolet radiation were observed in Europe. In Northern Germany the measured irradiance of erythemally effective radiation exceeded the climatological mean by more than about 20%. An extreme low ozone event for the season coincided with the high solar elevation angles during late spring leading to the highest value of erythemal UV-radiation ever observed at this location in May. This "ozone mini-hole" was caused by an elevation of tropopause height accompanied with a poleward advection of natural low total ozone from the tropics. The resultant increase in UV-radiation is of particular significance for human health. Dynamically induced low ozone episodes that happen around the summer solstice can considerably enhance the solar UV-radiation in the mid latitudes and therefore contribute to the UV-burden of people living in the mid latitudes.

1. Introduction

In the tropics the total ozone column is mainly determined by a balance between photochemical formation and destruction. In higher latitudes, however, total ozone is controlled by both transport and chemistry. Although most of the ozone is formed in the tropical stratosphere, the total ozone concentrations nevertheless increases at higher latitudes due to the mean meridional circulation in the stratosphere with the upward motion of air in the tropics and poleward transport and sinking air masses over the winter poles. Generally, the tropical stratosphere has natural lower total ozone than higher latitudes have (Duetsch, 1980).

If air from the tropical lower stratosphere is directly advected to higher latitudes, it can be mixed and develop so called dynamically induced ozone mini-holes (OMs), as observed and described by Newman et al. (1998) for the southern hemisphere. OMs mainly occur from winter to early spring, especially, when an ozone reduction caused by a displacement of the polar vortex is existent (James et al., 2000). They persist for approximately 3 days, before ozone levels again normalize. James (1998) and Stenke and Grewe (2003) reported increasing occurrence of OM-events for the winter months based on satellite observations and on a coupled chemistry climate model, whereas in late spring or summer such events take place only very rarely. We want to point out the risks for human health by exemplary measurements, when such an event happens at a time people expose themselves unprotected to the sun. In the present paper, we report on an unusual tropospheric/stratospheric situation where a late OM occurs at a time where tropospheric conditions favored large surface irradiation which in turn led to considerably increased risks for human health when people expose themselves unprotected to the sun. Section 2 briefly describes the relevant ground- and satellite based measurements. A more detailled description of the synoptical situation both in the troposphere and in the stratosphere are presented in Sect. 3, followed by a conclusion.

2. Measurements

Measurement were done using a double-monochromator spectroradiometer system (DTM 300, Bentham Instruments Ltd., Reading, England). The input optics was a cosine adapted Teflon diffuser (Ing. Dr. Schreder, Kirchbichl, Austria). The nominal bandwidth (50% points of the slit function) of the system was 1 nm. Spectra were recorded in steps of 0.5 nm in the range from 290 to 320 nm and in steps of 5 nm in the range 320–450 nm respectively. The measured spectra were convoluted by the CIE standard action spectrum for the erythema in human skin (McKinley and Diffey, 1987). The erythemally effective irradiance was calculated by integrating the weighted spectra from 290 to 400 nm wavelength. The instrument was calibrated using a calibration standard (1000 W quartz halogen lamp) derived from national metrology institute standard. The measurement-routine was derived from federal office for radiation protection (BfS, Salzgitter Germany). Spectra were taken every six minutes from sunrise to sunset. The data were measured in Westerland, a seaside resort on the North Sea island of

Sylt, Germany, (geographical position 54.93° N, 8.31° E).

Figure 1 shows the diurnal courses of the erythemal irradiance during 27 May of the years 2002 to 2005, respectively. Since the sky during these days was nearly cloud free, the diurnal cycle can directly be compared to each other. In May the usual level of the erythemal irradiance at noontime is about 150 mW/m^2 in Westerland as shown by the data measured on 27 May in the years 2002 and 2004. In 2005 the erythemal irradiance increased up to maximum 188 W/m^2. During 2003, the "European heatwave summer" (Stott et al., 2004), the irradiance also was unusual high according to a relatively low total ozone column, which was the second lowest value measured on a 27 May between 1979 and 2004, based on the TOMS climatology.

The increases in the biologically effective UV radiation corresponded to decreases of the total ozone concentrations as measurements of the TOMS satellite show: The ozone decrease over the geographical position mentioned above commenced on 25 May. During the three following days the ozone levels were less than 300 Dobson Units. The minimum value of 287 DU was reached on 27 May (Fig. 2). After 30 May the total ozone values again returned to levels that can be considered normal with respect to seasonal and geographical position. The levels of total ozone as measured by TOMS on 27 May during the years 1979 to 2004 ranged from minimum 330 DU to maximum 420 DU, mean 365 DU, median value 360 DU. Thus, the decrease in total ozone during the episode described here was more than 20% below the seasonal level. The deviation from the climatological mean is 3.1 times the standard deviation.

3. Synoptical situation

Since mid April, the Arctic stratosphere was dominated by an anticyclone with easterly winds and relatively high temperatures over the polar cap. The winter polar vortex was broken down with an early transition to summer circulation in the stratosphere. Therefore no conditions for chemical ozone depletion existed. The reported ozone decrease rather has to be explained by dynamical processes.

In the present episode where no polar vortex was existent any more, a tongue of lowermost stratospheric air is advected from the tropics towards higher latitudes into the troposphere due to strong wind shear at the western flank of the stationary high over central Europe (Fig. 3). The stationary tropospheric high-pressure field led to a raising tropopause height with a pressure decrease at the 2 PVU-field over central Europe. OMs often develop during the existence of blocking highs, which was investigated in more detail over a southern European station (Koch et al., 2005).

The tropospheric weather situation confirms a possible development of a very low ozone event. Most of central and south Europe was lying under a nearly stationary high-pressure area. A wide area increase of pressure was observed already on 23 May, which led to an enlargement of this high and to advection of warm air from the Iberian Peninsula to Central Europe, up to high tropospheric regions. A rapid increase of temperature, caused by this advection in front of a low lying to the west of Great Britain and increasing irradiance was expected for 25 May. Finally a nearly cloud-free region and the high-pressure area fit on 27 May over Central Europe (Fig. 4) and led to unusual high temperatures in some cases the highest temperatures measured since 1890 (Berlin Weather map, 29 May) for that tome of the year.

Further Analysis of satellite data (NASA-TOMS) disclosed decreases of stratospheric ozone concentration from 26–28 May over central Europe, showing a minimum concentration of total ozone on 27 May (Fig. 5). From Fig. 3 it can be clearly seen, that this lower ozone event origins from the tropical lowermost stratosphere.

The position of the maximum of the tropopause height and the minimum of total ozone coincide perfectly. The high-pressure field close to the ground explains the ozone minimum (James et al., 2000), since the anomalies in the tropospheric and stratospheric regions match as well, and the ozone minimum has to be right in the middle. Therefore we conclude that the elevation of the tropopause height above central Europe led to a vertical uplift of isentropes and expansion of air parcels which additionally to the horizontal isentropic transport of tropical ozone caused the local ozone minimum, detected in Westerland. According to the study of Wohltmann et al. (2005)

both dynamical processes play a significant role on the total ozone variability observed over Europe from 1970–2002.

4. Conclusions

The meteorological situation observed can be considered of particular medical relevance. The increase in solar UV-radiation coincided with specific weather conditions: the low ozone episode is accompanied by warm fair conditions according to the synoptical situation. In late May many people take the first sunbath of the season. Accordingly their skin is not adapted to the sun. Moreover, the high levels of ultraviolet radiation are not expected during this time of the year.

The occurrence and the impact of OMs during winter and early spring are widely discussed in the literature. Events like the described episode in late May, however, may have a higher impact on the human health, even if they do not have such low ozone levels as OMs in winter. Since they occur during late spring or summer they could contribute much to the UV-burden of people living in the mid latitudes. During such episodes low ozone in combination with high solar elevation can lead to exorbitant high solar ultraviolet radiation.

This concern is supported by a very similar event that happened from 17 June to 24 June this year over Central Europe. Since this second event occurred around summer solstice the combination of low ozone and high solar elevation led to the highest levels (peak value of Eer=214 mW/m^2) of erythemal UV-radiation ever observed since the measurements series started in Westerland in 1994.

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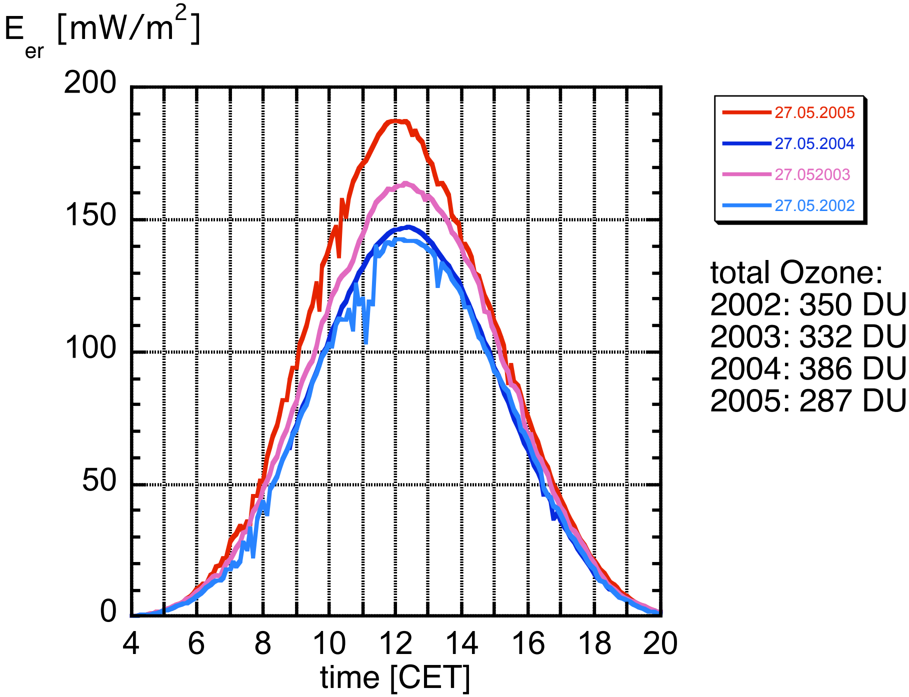

Fig. 1. Measured irradiance of erythemally effective radiation (mW/m^2) in Westerland (54.93° N, 8.31° E) on 27 May 2002–2005. The spectral irradiance was measured every six minutes by a calibrated double monochromator. The measured solar spectra were weighted by the standard CIE action spectrum for the erythema and integrated from 290 nm to 400 nm wavelength.

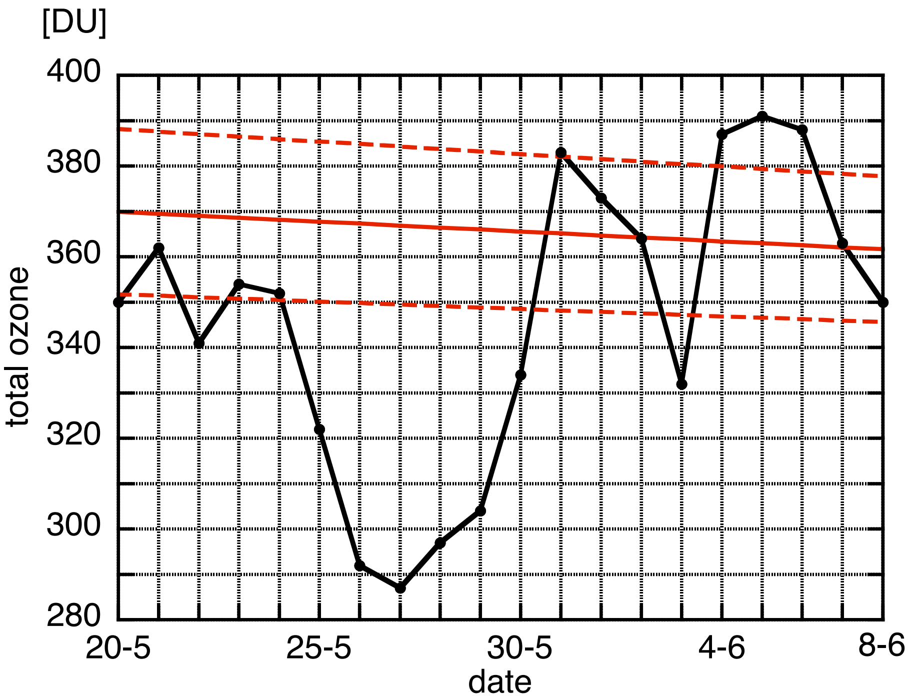

Fig. 2. Time-series of total ozone concentration over 54.93° N, 8.31° E (black line) as measured by TOMS, 20 May–8 June 2005. The red line shows the mean level of total ozone from 1979 to 2004, the dashed lines indicate the range of the standard deviation.

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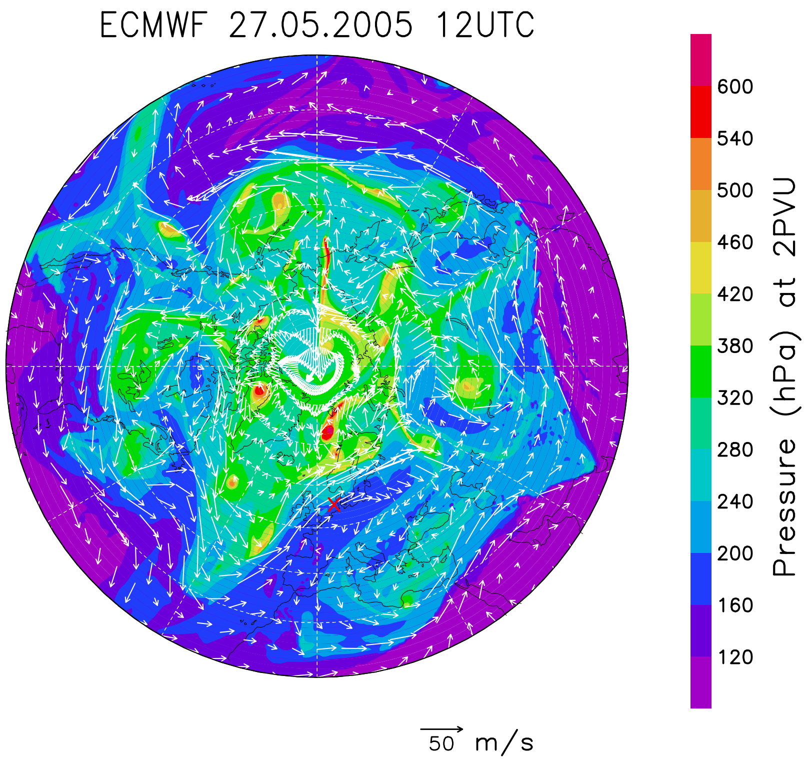

Fig. 3. Pressure (hPa) and horizontal winds (m/s) at the tropopause-height of the northern hemisphere (27 May 2005 12:00 UTC) shown at 2 PVU-niveau ECMWF data (T511/L60). The extra tropical tropopause is dynamically defined as the area with constant potential vorticity of 2 PVU (1 PVU=10^{-6} m^2 K s^{-1} kg^{-1}). In the tropics the low pressure indicates stratospheric air. The blue region over central Europe marks the low ozone event. The red cross marks the UV station in Westerland.

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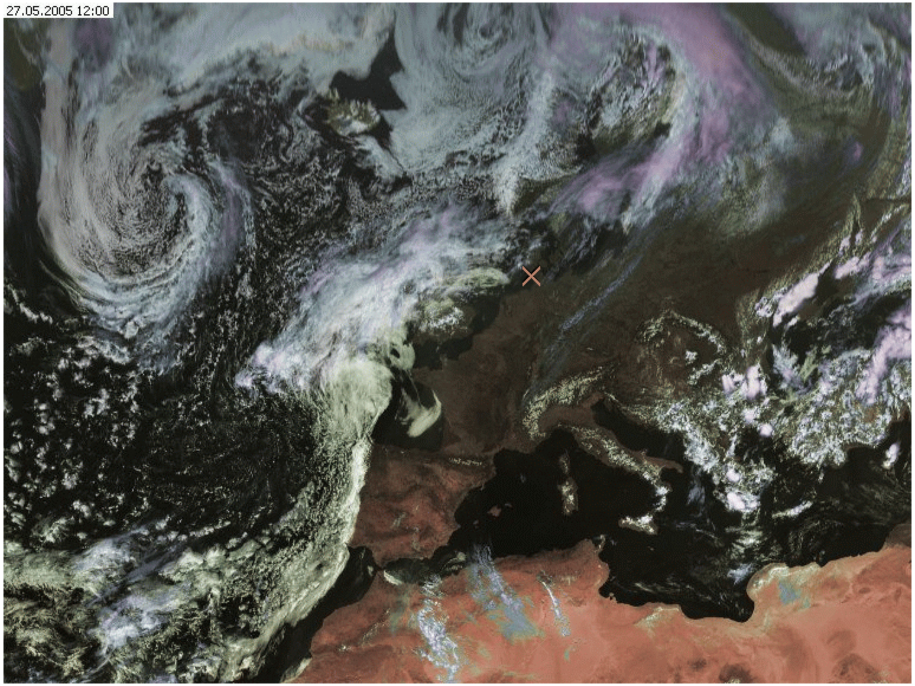

Fig. 4. Satellite picture of Europe on 27 May 2005, 12:00 UTC (copyright EUMETSAT 2003). The cross marks the UV station in Westerland.

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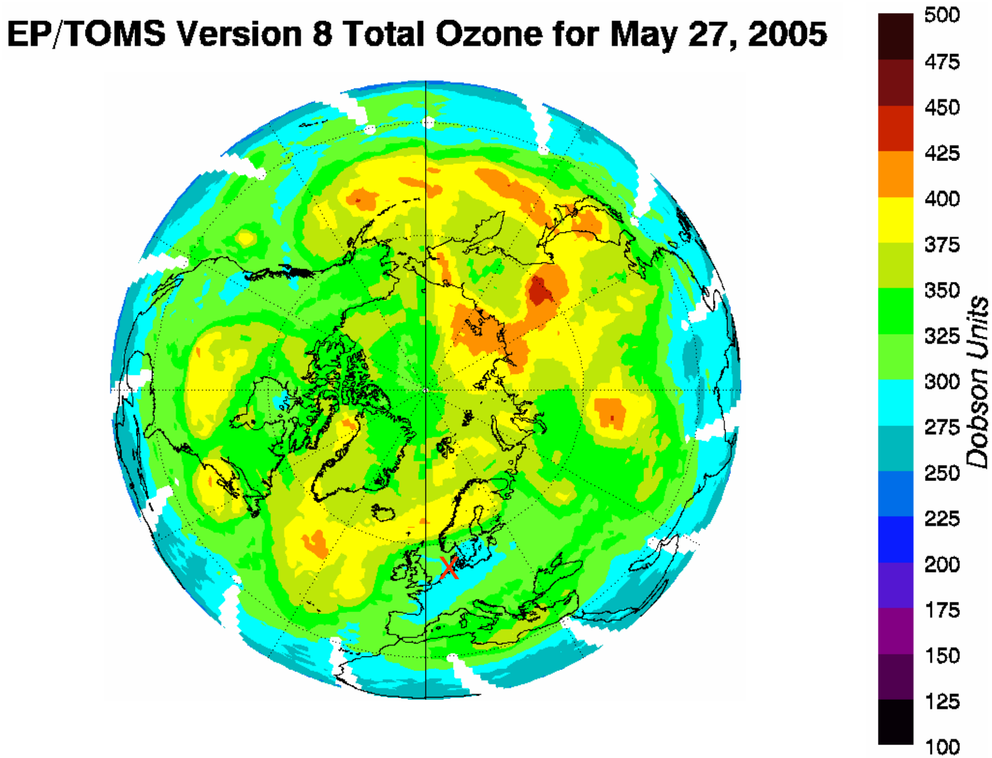

Fig. 5. Total ozone over the northern hemisphere (27 May 2005), EP/TOMS Version 8 in Dobson Units (http://toms.gsfc.nasa.gov/ozone/ozone.html, *North pole image)*. The EP/TOMS measures total ozone over the northern- and southern hemisphere on a single day on board of the NASA-satellite "Earthprobe". The ozone concentration shows for central Europe approx. 290 DU, while north of Scandinavia an increase of approx 150 DU is detected.

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