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OZONE AND TURBULENCE IN THE TROPO-STRATOSPHERE FROM SIMULTANEOUS RADAR AND OZONESONDE MEASUREMENTS IN JAPAN AND INDONESIA

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Abstract. Results of the analysis of simultaneous observations of atmospheric mesoscale dynamics with the Middle and Upper (MU) Atmosphere radar and of ozone in the tropo-stratosphere with ozonesondes in Japan during years 1990 – 2004 are presented. A broad region around the tropopause was dynamically active. Maxima of turbulent diffusivity were observed at 8 - 22 km altitude. They may produce vertical turbulent ozone fluxes across the tropopause with magnitudes comparable to those required for the global ozone budget. Similar study of turbulence and turbulent ozone fluxes near the tropopause from the data of two campaigns of simultaneous ST radar and ozonesonde measurements in West Sumatra, Indonesia during campaigns in January 2006 and 2007.

Introduction

The Brewer-Dobson circulation is supposed now to be the major global-scale mechanism of ozone transport between the troposphere and stratosphere [Holton et al., 1995]. Mesoscale motions and small-scale turbulence may also produce downward turbulent fluxes and mixing of atmospheric ozone through the tropopause [Lamarque and Hess, 2002]. Turbulent ozone fluxes in the tropo-stratosphere from the data of simultaneous radar and ozonesonde measurements were estimated in [Gavrilov et al., 2006]. In this paper we extend this analysis and study climatology of turbulence and turbulent ozone fluxes near the tropopause from the data of simultaneous MU radar measurements in Shigaraki, Japan (35° N,136°E) and ozonesonde measurements in Tsukuba (36°N, 140°E) during years 1986 - 2007.

The Equatorial Atmospheric Radar (EAR) makes observations of the mean wind and turbulence parameters in West Sumatra, Indonesia (0.2° S, 100.3° E). The EAR transmits an intense radio wave of 47 MHz to the sky in five directions of the antenna beam (one vertical and four inclined 10° from zenith). The radar receives extremely weak echoes scattered back by atmospheric turbulence. It can observe winds and turbulence in the altitude range from 1.5 km to 20 km (troposphere and lower-stratosphere). During two campaigns in January 2006 and in January 2007 series of ozonesondes were launched at the radar site. The ozonosondes give information about vertical profiles of ozone and temperature at altitudes up to 30 km.

Measurements and data analysis

The MU radar in Shigaraki is used for standard observations of the mean wind and turbulence parameters in Shigaraki generally for 5 days every month. The MU radar has antenna beam width of 1.3° and measures in 5 directions: one vertically and four inclined 10° from vertical. Spatial and time resolutions are 150 m and 2 min, respectively. From the World Ozone Data Centre we selected 236 ozonesonde profiles measured in Tsukuba at the same latitude as that of the MU radar during years 1986 - 2007. They measured temperature and ozone concentration with height resolution of 50 m.

Doppler velocity variance, σ^2, registered by the MU radar contains contribution from turbulent eddies. Observed values σ_{obs} were corrected for a spectrum broadening due to the mean wind and shear. Turbulent energy dissipation rates, ε, and diffusivities, K, were calculated from corrected values of σ^2. Vertical gradients of temperature and ozone concentration were estimated from ozonesonde data using least-square fit approximations within 250 m vertical intervals. Turbulent diffusivities combined with ozone gradients give vertical turbulent ozone fluxes (see details in [Gavrilov et al., 2006]).

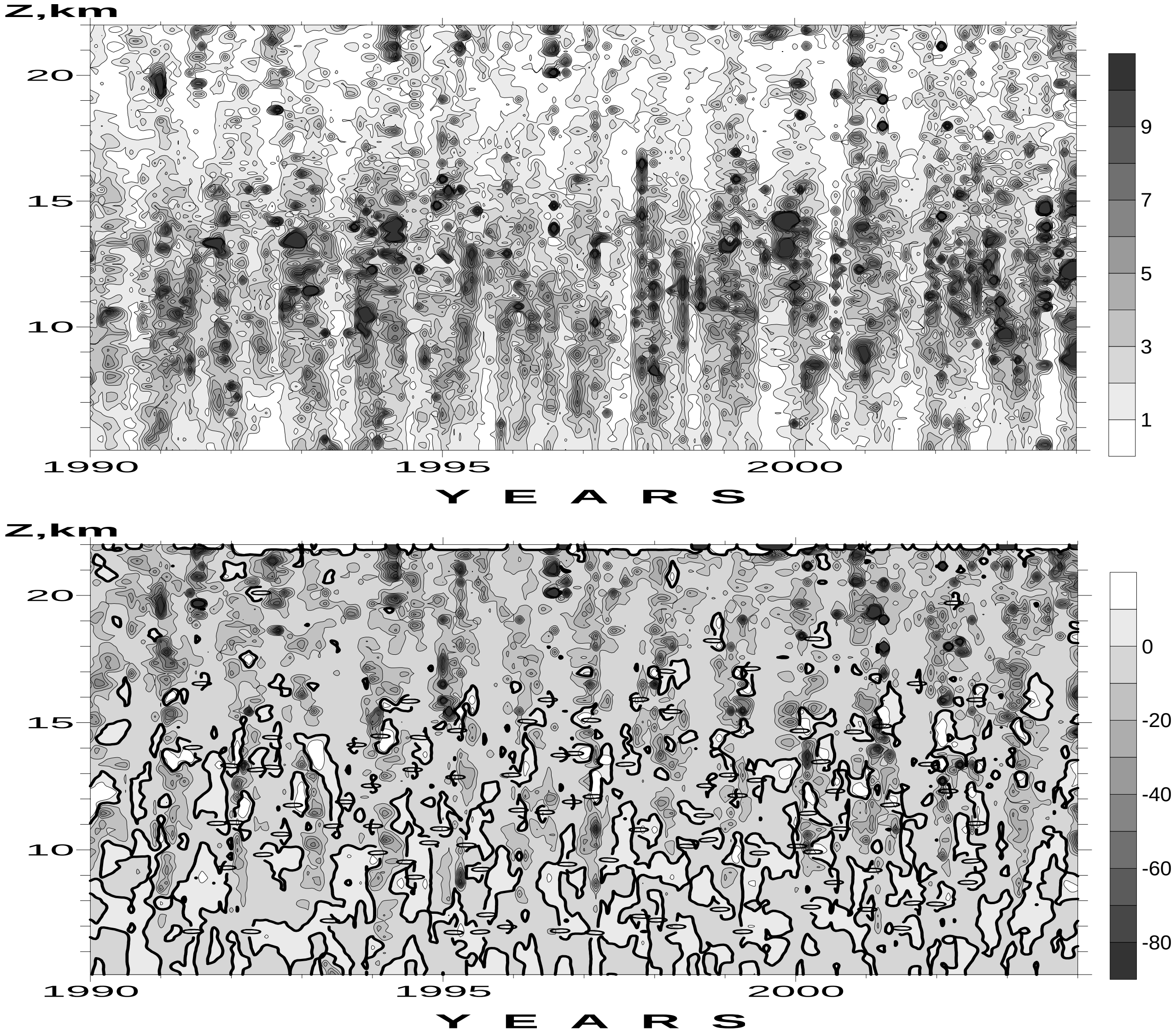

Fig. 1. Turbulent diffusivity in m^2s^{-1} (top) and vertical turbulent ozone flux in 10^{14} $m^{-2}s^{-1}$.Solid contours in bottom plot show zero values.

Results for Shigaraki

Time-altitude variations of turbulent diffusivity and ozone flux are shown in Fig. 1. Turbulent diffusivities in Fig 1 have maxima at altitudes 8 – 16 km in the regions of the jet stream and largest negative temperature gradients below the tropopause. Turbulence is more intensive in winter, when the speed of the jet stream has maximum. Top plot of Fig. 1 shows also frequent local maxima of turbulent diffusivity in the stratosphere above altitude 15 km. They might be produced by strong wind shears and by local negative temperature gradients. Such turbulence below the maximum of stratospheric ozone layer produces turbulent ozone fluxes shown in bottom plot of Fig. 1. The fluxes are mainly negative (downwards) above altitudes 6 – 8 km having maxima in winter.

A global average downward ozone flux from the stratosphere needed for tropospheric ozone budget is estimated to be of (4-8)$\times10^{14}$ m^{-2} s^{-1} [Crutzen, 1988]. Downward turbulent ozone fluxes in Fig. 1 may frequently become the same as or even much larger than these values. Therefore, jet and wave instabilities near the tropopause may locally produce turbulent downward ozone fluxes of the same order of magnitude as ozone transport by Brewer-Dobson circulation.

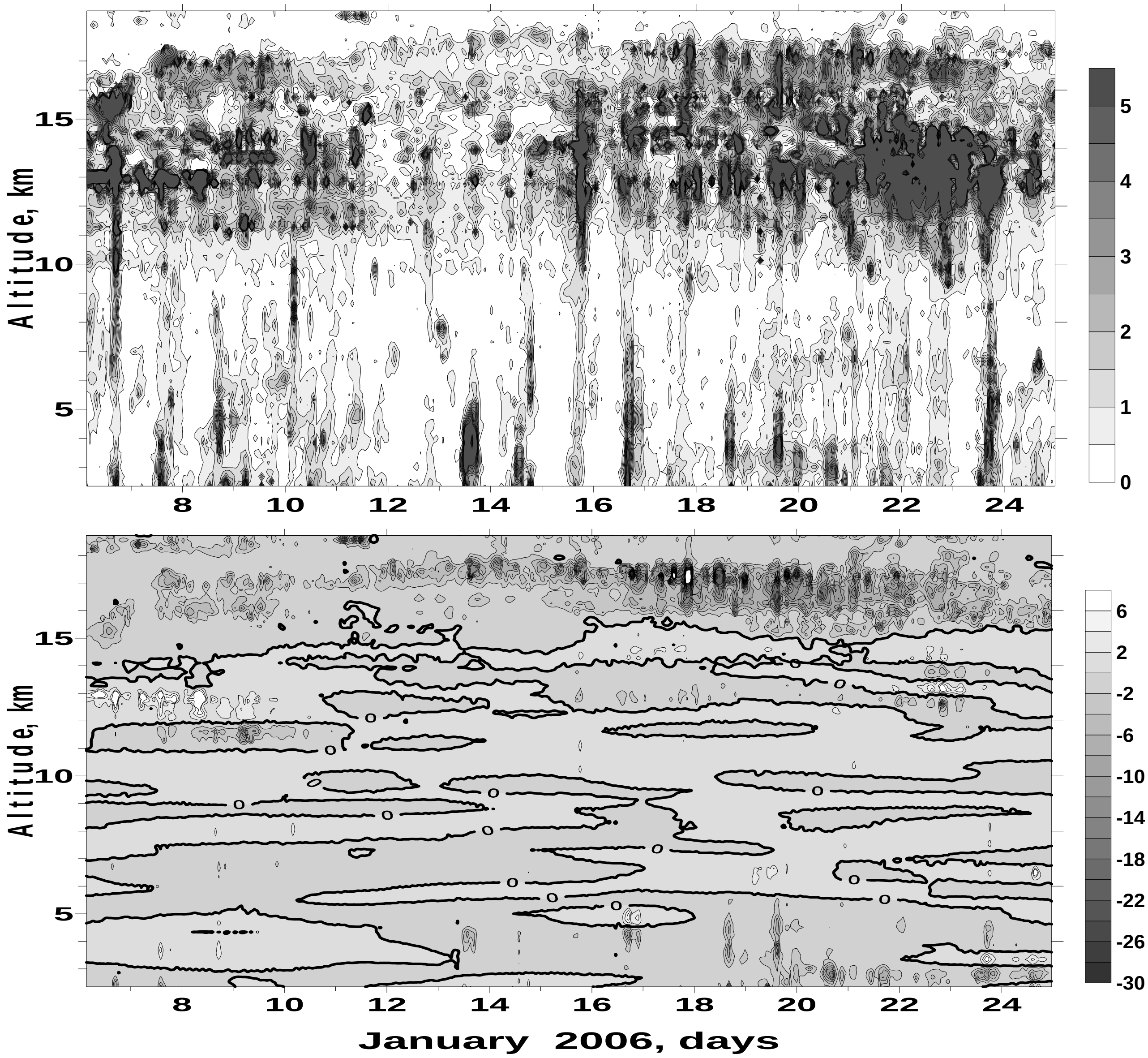

Fig 2. Turbulent diffusivity in m^2s^{-1} (top) and vertical turbulent ozone flux in 10^{14} $m^{-2}s^{-1}$ (bottom). Solid contours in bottom plot show zero values.

Results for Indonesia

Time-altitude variations of turbulent diffusivity and ozone flux for the campaign in January 2006 are shown in Fig. 2. Turbulent diffusivities in Fig. 2 have main maxima at altitudes 10 – 18 km in the convective regions having largest negative temperature gradients below the tropopause. Turbulence is frequently more intensive during daytime, when convective activity is higher. Top plot of Fig. 2 shows sharp decrease in turbulent diffusivity at the top boundary of the convective layer near the equatorial tropopause (z ~ 17 – 19 km in Fig. 2).

Turbulence below the maximum of stratospheric ozone layer produces turbulent ozone fluxes shown in bottom plot of Fig. 2. Vertical ozone gradients and turbulent ozone fluxes are relatively small in most part of tropo-stratosphere due to strong mixing in the convective zone. Near the top edge of the convective region at altitudes 17 – 18 km in Fig. 2 one can see substantial negative (downwards) turbulent ozone fluxes. They may help in transport of stratospheric ozone to the well mixed equatorial troposphere.

Downward local turbulent ozone fluxes near the tropopause in Fig. 2 may become same as or even larger than global average downward ozone flux from the stratosphere needed for tropospheric ozone budget of $(4\text{-}8)\times10^{14}$ m^{-2} s^{-1} (see above). Therefore, convective and shear instabilities at the top of convective layer near the tropopause may locally produce turbulent downward ozone fluxes helping exchange between equatorial stratosphere and troposphere. Further studies of turbulence and turbulent ozone fluxes in the equatorial region are required.

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