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Global wave activity from upper stratosphere to lower thermosphere: A new turbopause concept

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Abstract

Global temperature measurements are available from CRISTA (CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere) and from SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) up to 110 km. Standard deviation from zonal mean temperature is used as a wave activity indicator (proxy). Altitude/latitude plots of these standard deviations σ or variances σ^2 show a structure that is dependent on the season. There is also substantial zonal asymmetry.

Vertical cuts through the σ-field show a remarkable transition between 90 and 100 km: linear fit curves above 100 km have a gradient similar to the amplitude increase of freely (upward) propagating waves. The corresponding gradients below 90 km are much flatter and thus indicate considerable wave damping. The intersection of the two fit curves is dubbed the "wave-turbopause" here, and is believed to be near the turbulent or transport turbopause. This wave-turbopause is found in the vicinity of 90−95 km for CRISTA-1, CRISTA-2, and SABER. It is compared to the corresponding cold point mesopause and to the isolines of estimated potential vorticities to show similarities with the tropopause. The height of the wave-turbopause depends on latitude. It also has considerable seasonal variation, which is very different at high and low latitudes.

Keywords: Middle atmosphere; Lower thermosphere; Turbopause

1. Introduction

If a fluid fluctuates about its mean state the coarsest assumption for the distribution of the fluctuation intensity is that it is homogeneous, isotropic, and stationary. If this intensity is expressed in terms of the standard deviation σ from the mean (or the variance σ^2) it should thus be the same everywhere in space and time. It was shown long ago that this is not normally the case for the dynamical parameters (temperature, wind, density) of the middle atmosphere (10−100 km). Hence these variations contain more information than simple random noise. Early radiosonde and rocket

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measurements showed that fluctuation intensity of dynamical parameters is dependent for instance on altitude, latitude, and season (e.g., Cole and Kantor, 1978). Temperature fluctuations were found as high as ± 9 K (upper/lower quintiles, i.e., 20% high/low values) by these authors in the January, 45°N, middle atmosphere (35−80 km). Values in July were considerably smaller (± 6 K). At higher latitudes generally higher values were found. These hemispheric data of Cole and Kantor are from a time interval centered about the period 1965–1970. Data taken somewhat later (1981–1987) at a local lidar station (OHP, 44°N, 6°E) show corresponding values of temperature standard deviations of about $\sigma = \pm 13$ K (January) and $\sigma = \pm 6$ K (July) (Chanin et al., 1990). This is the same order of magnitude as the data of Cole and Kantor. (Note that the quintile is somewhat different from the standard deviation.) Standard deviations of this magnitude are much larger than the noise of (present day) measuring instruments. It therefore appears rewarding to study the various properties of the dynamical fluctuations, for instance by means of their standard deviations σ. The standard deviation is a simple and fairly safe parameter, which is less affected by measurement errors than the basic dynamical parameters. Of course one has to be careful when comparing different measuring techniques as the resolution in space and time may be different.

Dynamical fluctuations can have a variety of origins. Many of these have been studied in the literature. We shall restrict ourselves here to the temperature fluctuations T' which are the deviations of the measurements T from their spatial/temporal mean $\overline{T}$:

$$T' = T - \overline{T}. \tag{1}$$

Emphasis of the present paper will be on the higher altitudes only (upper stratosphere, mesosphere, and lower thermosphere). We shall use T' as an indicator especially of dynamical activity, though additional thermal effects are also possible and need to be analyzed on a case by case basis. The major source of temperature variance is middle atmosphere waves. Gravity waves (GW) have been discussed by means of these variances (wave proxies) by Fetzer and Gille (1994), Wu and Waters (1996) and in many publications since (e.g., Eckermann, 1995; Preusse et al., 2000; Tsuda et al., 2000; Eidmann et al., 2002; Rapp et al., 2004). For recent surveys on GW see Fritts and Alexander (2003) and Wu et al. (2005). Parameter variances have also been used to study long period/large scale structures as planetary waves (PW) or Kelvin waves (Bittner et al., 2002; Eckermann, 1995; see also Newman et al., 2001). Most of these analyses have been performed in the stratosphere and lower mesosphere. Only few temperature data appear to be available at higher altitudes on a large scale basis. Here in the upper mesosphere and lower thermosphere (UMLT) tidal variations become important and can be very large if various modes (migrating/nonmigrating) are superimposed (e.g., Oberheide and Gusev, 2002).

Most of the variance studies have considered zonal means and their altitude/latitude dependencies. Very few analyses of zonal asymmetries have been performed and have mostly been restricted to the stratosphere (e.g., Eidmann et al., 2002, and references therein). Almost no such temperature data are available in the UMLT (Offermann et al., 2003).

Transfer of momentum and energy to the atmosphere requires wave breaking. Very much effort has been spent on its study, especially since the work of Lindzen (1981), Garcia and Solomon (1985), Garcia (1991), and Garcia et al. (1992). The most important part of the question is the altitude and latitude distribution of the breaking process. A specific question is what altitudes these processes and the resulting turbulence may reach. This altitude is traditionally called the turbopause and is expected around or somewhat above the 100 km level. This level may change somewhat depending on what process is used to define the turbopause. A frequent definition is the altitude level where molecular dissipation becomes stronger than turbulent dissipation (e.g., Hines, 1991; Hall et al., 1998; Chabrillat et al., 2002). Another level chosen is the altitude where diffusive separation sets in, i.e., where the constituent mixing ratios start to change with increasing altitude. This mixing turbopause is also called the homopause. It can in principle be determined by means of mass spectrometer measurements (e.g., Danilov et al., 1979; Offermann et al., 1981). These two turbopauses are not necessarily the same. Chabrillat et al. (2002) argue that the homopause occurs at a lower level than that where the molecular and eddy diffusion coefficients are equal.

Many measurements have been performed by various techniques that yield vertical turbulence profiles up to the UMLT and other information to