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Interannual and intraseasonal variability of stratospheric dynamics and stratosphere–troposphere coupling during northern winter

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ABSTRACT

The UK Met Office reanalysis data have been used to investigate the interannual and intraseasonal variability of the stratospheric dynamics and thermal structure. The results obtained show that the maximum of interannual variability of the mean zonal flow associated with the quasi-biennial oscillation (QBO) is observed at the altitude of about 30 km. It is shown that there is a statistically significant influence of the QBO phase on the extratropical stratosphere, the so-called, Holton–Tan effect. The results of data analysis show that the conditions under the easterly QBO phase are more favorable for the development of the sudden stratospheric warmings (SSW). The statistical analysis of 15 major SSW observed during two last decades has been performed. The obtained results demonstrate that in recent years internal processes associated with nonlinear interactions of stationary planetary waves (SPW) with the mean flow played a dominant role. It is shown that the first enhancement of the SPW1 in the upper stratosphere takes place because of an amplification of nonlinear interactions between this wave and the mean flow. This enhancement is accompanied by a subsequent increase in the wave activity flux from the stratosphere into the troposphere with further redistribution of wave activity in the horizontal plane. Then, an increase of the upward flux from the troposphere into the stratosphere in another region occurs. The secondary enhancement of the planetary wave activity in the stratosphere is accompanied by the heating of the polar region and the weakening, or even reversal of the stratospheric jet. Additionally to the well-known result that meridional refraction of SPW to the polar region in stratosphere is one of the preconditions of development SSW, the nonlinear wave–wave and wave–mean flow interactions can play an important role before and during SSW. It is shown that the upper stratosphere can be considered as the region where SPW2 is generated during SSW.

1. Introduction

Sudden stratospheric warming (SSW) events are prominent processes, during which the troposphere and stratosphere demonstrate the dynamical coupling (Holton, 1980; McIntyre, 1982). According to the existing notions (Stan and Straus, 2009), SSW events may develop due to two reasons: an increase of wave activity flux from the troposphere into the stratosphere (the so-called classic scenario suggested by Matsuno, 1971), and/or caused by the internal dynamical processes, that, as the result of nonlinear interactions of planetary waves with the mean flow at the stratospheric heights (Scott and Polvani, 2006; Pogoreltsev, 2007). Unfortunately, these two mechanisms compliment each other and it is difficult to estimate their relative contribution. The interest in studying SSW events increased substantially in recent years. This increase is primarily due to the obtained results that indicate a significant influence of the SSW on the formation of the weather anomalies in the troposphere (Baldwin and Dunkerton, 2001; Baldwin et al., 2007; Sun and Robinson, 2009; Waugh et al., 2010). It has been found that the SSW events affect the dynamics and energetics of the upper atmosphere (the mesosphere and even the thermosphere) (Siskind et al., 2010; Kurihara et al., 2010; Fuller-Rowell et al., 2010; Funke et al., 2010; Liu et al., 2011; Yuan et al., 2012), that is, they can influence the coupling to space weather, and manifest in the characteristics of ionospheric disturbances (Pedatella and Forbes, 2010; Pancheva and Mukhtarov, 2011). During the last decades, the growth of amplitude of stationary planetary wave with zonal wave number one (SPW1) has been observed in the stratosphere and, as a consequence, the nonlinear interaction of this wave with the mean flow becomes stronger (Pogoreltsev et al., 2009). This leads to rising intensity of irregular fluctuations, the so-called stratospheric vacillations (Holton and

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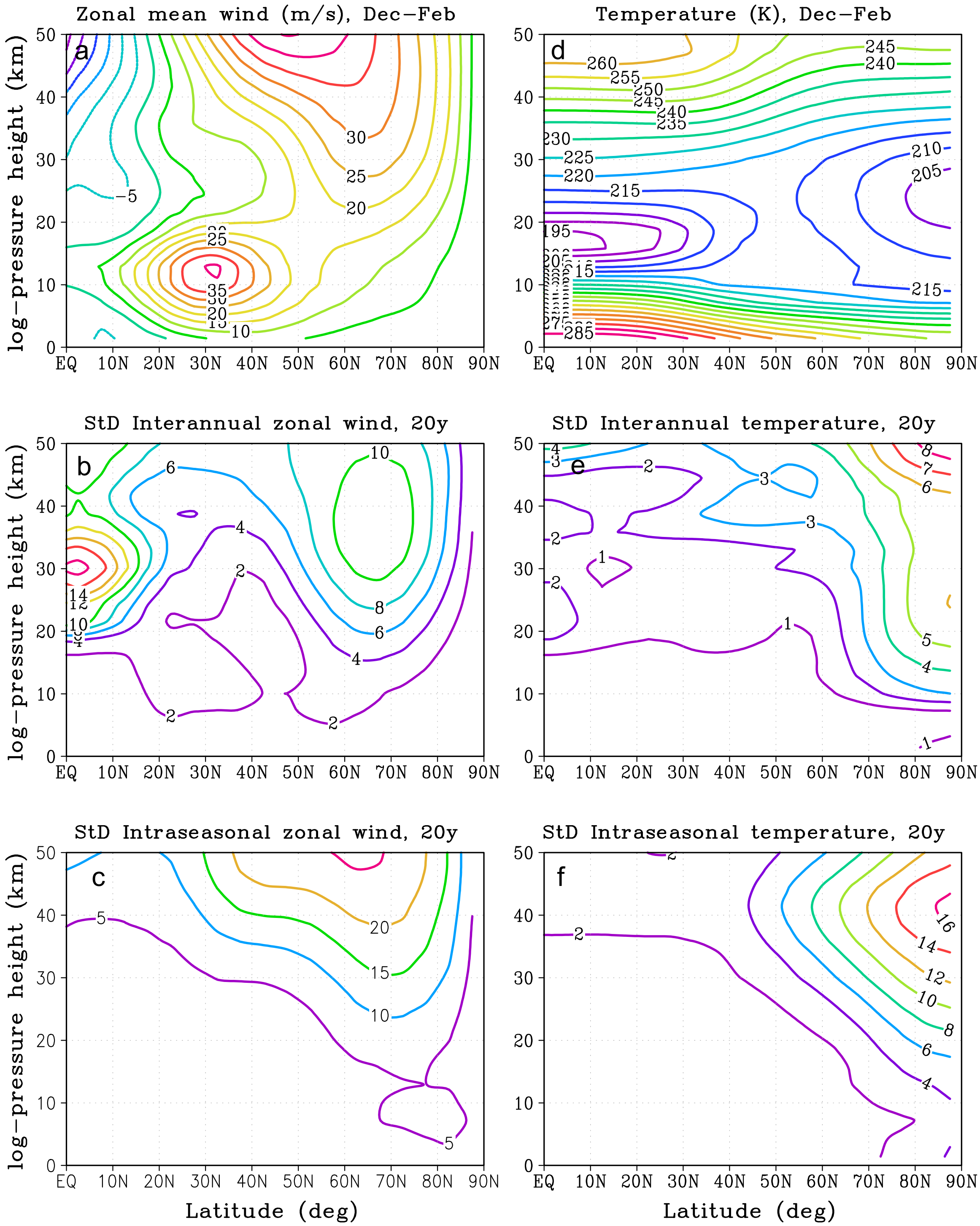

Fig. 1. Left panels show the characteristics of the zonal mean flow: climatic distribution (a), standard deviations of the interannual variability (b), and standard deviations of the intraseasonal variability (c). Right panels show the same for temperature: climatic distribution (d), standard deviations of the interannual variability (e), and standard deviations of the intraseasonal variability (f).

Mass, 1976).

Despite the growing interest in the study of the SSW and its impact on the weather, climate, and upper atmosphere, including the ionosphere, the most of papers only present results of analysis of the SSW distinctive features observed over recent years (Labitzke and Kunze, 2009; Ayarzaguena et al., 2011; Kuttippurath and Nikulin, 2012). The problem of possible mechanisms responsible for SSW forcing is widely discussed in recent publications. For instance, see Esler et al. (2006), Albers and Birner (2014), and reference therein. Nevertheless, the questions concerning the source and/or the cause of the arising SSW are still open (Sun et al., 2011). Analysis of the dynamic processes in the stratosphere based on the UK Met Office data (for the description see Swinbank and O'Neill, 1994) has demonstrated that, during the recent decades (1992–2012), a reassessment of the relative role of different mechanisms responsible for initiating SSW events has occurred. In recent years, internal processes associated with nonlinear interactions of planetary waves with the mean flow played a