P218 THE EQUATORIAL QBO INFLUENCE ON THE NORTHERN WINTER EXTRATROPICAL CIRCULATION

Hiroaki Naoe* and Kiyotaka Shibata
Meteorological Research Institute, Tsukuba, Japan

Abstract

The effects of the equatorial quasi-biennial oscillation (QBO) on the extratropical circulation (Holton-Tan relationship) are investigated with statistical methods based on 44 years of the ERA-40 reanalysis dataset (1958-2001) and 125 years of ensemble simulated datasets, focusing on the Northern Hemisphere winter. Our results confirm that planetary waves can propagate more upward as well as more equatorward during the easterly QBO. This result cannot be explained by the conventional hypothesis of the Holton-Tan relationship that planetary waves would penetrate into the tropics during the westerly QBO at 50 hPa, whereas during the easterly QBO these waves would encounter the critical line and be refracted poleward.

1. Introduction

The QBO is indeed a tropical phenomenon, but it also affects the stratospheric circulation from pole to pole, due to modulating extratropical waves. Using observational data, Holton and Tan [1980, 1982] conducted the pioneering work that found a close relationship between the phase of the QBO and the winter stratospheric circulation. When the QBO is in the westerly phase at 50 hPa at the equator, the polar vortex is deeper and the polar jet becomes stronger. In contrast, the stratospheric polar vortex is weaker, warmer, and more disturbed in the easterly phase of the QBO. Such equatorial QBO influences on the extratropical atmosphere are commonly known as the Holton-Tan relationship, and these influences have been investigated in many statistical studies [Labitzke, 1982; Naito and Hirota, 1997; Lu et al., 2008].

Modeling studies have attempted to simulate the QBO using general circulation models (GCMs). Much of the required wave forcing for the QBO oscillation is generated by Kelvin waves, Rossby-gravity waves, and gravity waves. Because gravity waves are difficult to effectively resolve in the GCM, many GCMs have failed to reproduce the QBO. Thus, unresolved small-scale waves is preferably included for the QBO simulation.

Until now, only several groups [Takahashi, 1999; Hamilton et al., 1999; Scaife et al., 2000; Giorgetta et al., 2002; Watanabe et al., 2008; Shibata and Deushi, 2005b] have simulated the QBO with GCMs. Chemistry-Climate-Model (CCM) based on such GCMs can also reproduce the QBO [Butchart et al., 2003; Shibata and Deushi, 2005a, 2005b; Schmidt et al., 2006]. In this study, we use the MRI-CCM, which includes full stratospheric chemistries and employs the Hines non-orographic gravity wave drag scheme [Shibata and Deushi, 2005a, 2005b].

In the present study, we aim to identify the modulation of the extratropical circulation by the equatorial QBO (i.e., to identify the Holton-Tan relationship). Our analysis in this study follows Naito and Yoden [2005], but is based on both the ERA-40 reanalysis dataset [Uppala et al., 2005] (1958-2001, 44 years) and ensemble-simulated datasets under the REF1 common scenario [Eyring et al., 2005] (1981-2004 x 5 members = 125 years). Long-term simulated data are also expected to increase the confidence level. Thus, we seek to investigate the equatorial QBO influence on the extratropical circulation with statistical methods, focusing on the Northern Hemisphere winter.

2. Data and Model

The observational dataset used in this study is based on daily and monthly ERA-40 reanalysis data for 44 years, from 1958 to 2001 [Uppala et al., 2005]. The data of the zonal-mean zonal wind (*U*) and of the zonal-mean temperature (*T*) are analyzed for the northern winter months (December, January, and February). It is noted that the ERA-40 analyzed temperatures in the stratosphere have made an important difference in the use of satellite data, which has been available since 1979 [Pascoe et al., 2005].

The dynamic module with a chemistry climate model (CCM) includes major physical processes (i.e., convection, radiation, planetary boundary layer, and ground hydrology with biosphere). The model has a resolution of T42 and 68 layers with a top of 80 km. In the stratosphere the vertical resolution has 500 m (100-10 hPa). Horizontal diffusion is weakened to become one-tenth of the standard value above 100 hPa. The non-orographic gravity wave drag scheme by Hines [1997] is introduced as gravity, which gives a crucial forcing for the QBO. Note that vertical diffusion is not applied in the stratosphere in order to keep the sharp vertical shear in the QBO. The chemical module contains major stratosphere species (i.e., 34 long-lived and 15 short-lived species) with 79 gas-phase reactions, 34 photochemical reactions, and six heterogeneous reactions on polar stratospheric clouds and three heterogeneous reactions on sulfate aerosols. The transport process uses a semi-Lagrangian scheme, which is of flux form in the vertical direction and is of ordinary form in the horizontal direction.

The model is integrated under the REF1 scenario [Eyring et al., 2005]. REF1 is designed to reproduce at least the core period of the 25 recent past years (1980 through 2004), during which ozone depletion was well recorded. This transient simulation includes all anthropogenic and natural forcings based on changes in trace gases, an 11-year solar cycle, volcanic eruptions, and sea-surface temperatures (SSTs). Five members with slightly different initial conditions are integrated in the ensemble simulations. Thus, 125 years of the simulated dataset (5 members times 25 recent past years) are available and used for investigating the equatorial QBO influence on the extratropical circulation in the Northern Hemisphere winter.

The 50-hPa zonal winds at the equator are chosen to define the QBO phase in order to be consistent with Holton and Tan [1980] and other studies [e.g., Lu et al., 2008]. In this study, the westerly phase is defined as the monthly *U* at 50 hPa at the equator ≥ 1 m s^{-1}, and the easterly phase is defined as the monthly *U* at 50 hPa at the equator ≤ –1 m s^{-1}.

3. Results

Figure 1 indicates the composite difference in zonal-mean zonal wind [*U*] and zonal-mean temperature [*T*], along with statistical significances in the Northern Hemisphere winter for ERA-40 and the simulation.

The composite difference in *U* for ERA-40 (Fig. 1a) is positively large at 50 hPa over the equator, but in this area the simulated *U* (Fig. 1c) is underestimated (70% of the observed *U*). The positive difference in *U* in the high-latitude stratosphere implies a stronger polar night jet in the westerly phase. The largest [*U*] appears at the core of the polar night jet at 60°N, whose amplitudes at 10 hPa are 7 m s^{-1} for ERA-40 and 5 m s^{-1} for the simulation. The pattern in the stratosphere displays a dipole changing sign at 40° to 45°N. The high-latitude positive anomaly and the subtropical negative anomaly with small amplitudes penetrate the troposphere for ERA-40 and the simulation.

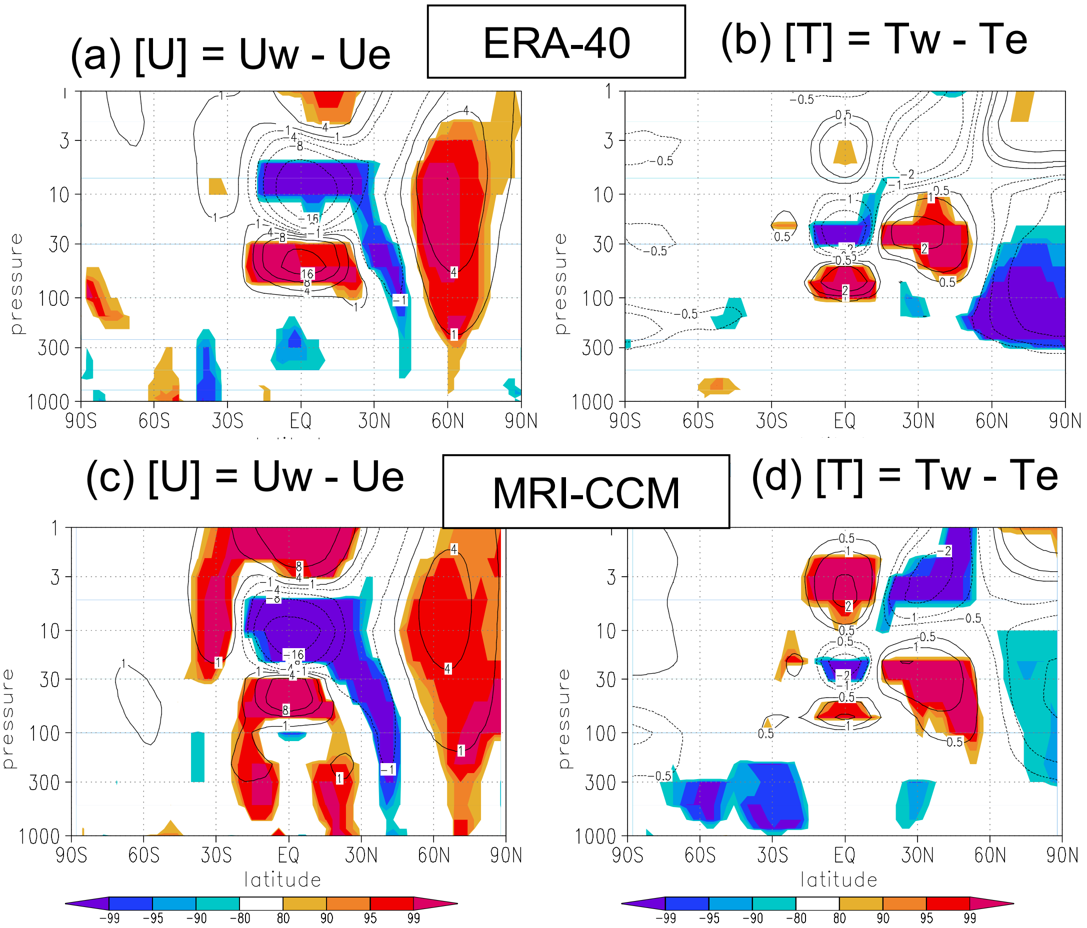

Figure 1. Latitude-height cross sections of the composite difference in zonal wind and temperature between the westerly and easterly phases of the QBO, along with the statistical significance for ERA-40 and the simulation. The zonal wind is in units of m s^{-1}, and the temperature is K.

The QBO exhibits a clear signature in *T* with pronounced signals in both the tropics and the extratropics. The extratropical QBO signals arise from the secondary meridional circulation induced by the main equatorial QBO [e.g., Plumb and Bell, 1982]. The tropical temperature QBO has a thermal wind relationship with the vertical shear of *U*. For both ERA-40 and the simulation, the composite difference in *T* over the equator is positive (warm) in the westerly shear zone at 70 hPa and is negative (cold) in the easterly shear zone at 20 hPa. The mid-latitude QBO signals demonstrate a well-defined pattern of the QBO-induced secondary circulation, which is connected by meridional and vertical positive/negative temperature anomaly cells [Lu et al., 2008]. Warming exists in the lower to mid-stratosphere (2 to 3 K) and weaker cooling does in the lowest stratosphere (0.3 K). The Arctic lower stratosphere is cold by up to 3 K for ERA-40 and 2 K for the simulation.

Figure 2 presents latitude-height cross sections of *U* and the Eliassen-Palm (EP) flux during the easterly phase of the QBO for ERA-40 and the simulation (left panels). The right panels indicate the composite difference in *U* and EP flux between the westerly and easterly QBO phases. Positive wind differences (Figs. 2b and 2d) are observed or simulated in the high-latitude stratosphere, implying a less disturbed polar vortex during the westerly QBO. In Figs. 2b and 2d, we see that a three-cell vertical structure of the QBO is evident in the

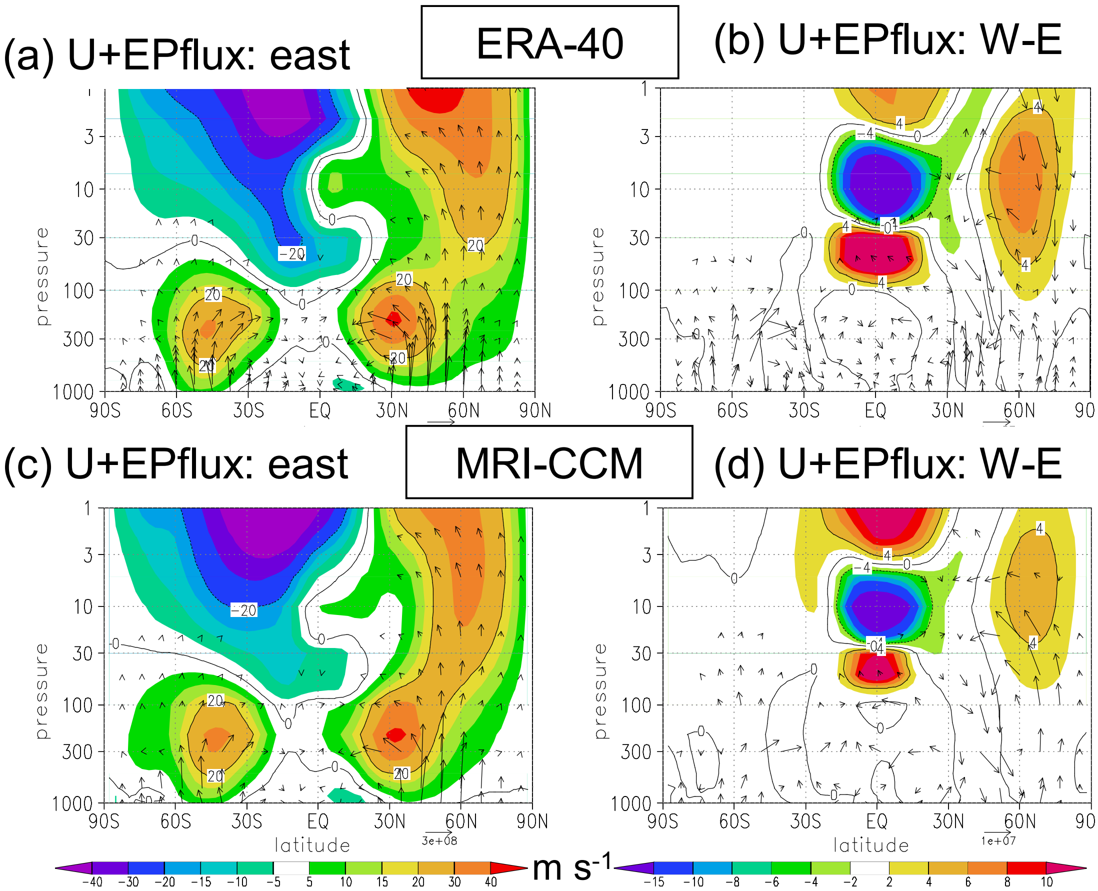

Figure 2. Left panels: Latitude-height sections of zonal wind and EP flux during the easterly phase for ERA-40 and the simulation. Right panels: Composite difference in zonal wind and EP flux (westerly minus easterly). Small arrows are omitted, and EP flux is scaled by $(P/1000)^{-0.5}$, where P is pressure in hPa.

tropics [Pascoe et al., 2005; Shibata and Deushi, 2008a, 2008b; Lu et al., 2008]. The center of a positive anomaly is located at 50 hPa over the equator, and above this anomaly easterly regions exist throughout the middle and upper stratosphere. Below the 50 hPa anomaly a very weak easterly region exists at the lowest stratosphere.

During the easterly phase of the QBO (Figs. 2a and 2c), zero-wind lines (critical lines) are located in westerly regions between the equator and subtropics on the side of the winter hemisphere. A stationary planetary wave can propagate in a region of westerly winds, which are important as a waveguide. According to the traditional Holton-Tan explanation (hypothesis) [Holton and Tan, 1980; Baldwin et al., 2001], these narrowed waveguides refract the planetary waves away from the subtropical region and consequently redirect them poleward. However, in Fig. 2a we can see that the composite difference in EP flux is directed poleward and downward in the subtropical region. Therefore, when the QBO is in the easterly phase, the stationary planetary waves can propagate upward as well as equatorward. Thus, the conventional Holton-Tan hypothesis cannot explain this result in terms of the critical line.