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Seasonally steady planetary disturbances in the troposphere and stratosphere as seen in 30 years of NCEP reanalysis data

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Abstract

Zonal velocity and temperature daily global reanalysis data of 30 years are used to search seasonally steady planetary disturbances in the middle troposphere (400 hPa) and middle stratosphere (10 hPa). Significant wavenumber 1, 2 and 3 modes are found. Constant phase lines of zonal velocity 1 modes exhibit significant inclination angles with respect to the meridians. The winter hemisphere generally shows a more significant presence of structures. The Northern Hemisphere (NH) exhibits all over the year a larger amount of structures and more intense amplitudes than the Southern Hemisphere (SH). Middle latitudes exhibit the most significant cases and low latitudes the least significant ones. Longitudinally oriented land–sea transitions at ±65° and −35° latitudes appear to play a significant role for the presence of steady planetary modes. The stratosphere exhibits a much simpler picture than the troposphere. Large scale structures with respectively NE–SW (NH) and NW–SE (SH) tilts in the observed temperature and zonal velocity constant phase lines recall the quasi-stationary Rossby wave trains that favor the poleward transport of angular momentum.

Keywords: Reanalysis; Planetary scale disturbances

1. Introduction

A large fraction of the spatial variability of the atmosphere is produced by modes of global scales and temporal intervals on the order of seasons. They are mainly forced by airflow over topography and large-scale thermal factors. Lau (1979) indicated that this quasi-steady component plays a dominant role in the local balances of momentum and energy, whereas the transient contributions have a secondary importance. This showed that a better knowledge of these nearly stationary structures was very relevant to an adequate description of the general circulation.

Planetary scale disturbances like Kelvin and Rossby waves have a significant role in the winter or spring stratosphere, but they are also important in the troposphere in relation to meteorological phenomena (see e.g. Hansen and Sutera (1986)). Stationary planetary waves largely contribute to the middle and upper atmosphere dynamics and are related to the sudden stratospheric warmings. There is a strong seasonal variation of stationary planetary waves in the stratosphere (see e.g. Randel (1988)). Charney and Eliassen (1949) and Smagorinsky (1953) in the troposphere and Charney and Drazin (1961), Matsuno (1970) and Schoeberl and Geller (1977) in the stratosphere were probably among the first ones to develop a framework trying to explain some of the features of planetary waves. Diverse observational works contributed later on to the description of these waves (Hartmann, 1977; Smith, 1983; Barnett and Labitzke, 1990; Li et al., 2006; Shepherd and Tsuda, 2008; Xiao et al., 2009; Mukhtarov et al., 2010). However, many aspects of the planetary disturbances are presently not completely understood, so further studies of them should be performed. As a large fraction of planetary disturbances generated in the troposphere propagate into the

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stratosphere, knowledge of their presence and seasonal evolution throughout both layers may be important. Analyzes in both hemispheres may yield clarifications because forcing mechanisms and climatologies are different in both areas. Notable differences in the features between the two geographical halves have become apparent (see e.g. Hio and Hirota, 2002): in the Northern Hemisphere (NH), the forcing during winter of stratospheric stationary planetary waves is considered to be due mainly to the large-scale topography, whereas in the Southern Hemisphere (SH) stratosphere forcing from the Indian Ocean region as well as orographic and thermal forcing from the Antarctic continent have been suggested. The surface topographies are also quite different in the two hemispheres. All these studies may provide validations for numerical global model solutions. The present study takes advantage of a long dataset, which provides robust estimates of seasonal characteristics of stationary planetary structures in the troposphere and stratosphere all over the globe.

2. Data

Apparent climate changes resulted from modifications introduced in the operational global data assimilation system to improve forecasts about 20 years ago. This motivated the National Centers for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) reanalysis project. The basic idea is to use a frozen state-of-the-art analysis/forecast system and perform data assimilation using information from the past up to the present to produce a retroactive record of more than 50 years of atmospheric fields (Kistler et al., 2001). Data from rawinsondes, balloons, aircraft, ships, surface stations, and satellites are first scrutinized through a quality check, then they are fed into the assimilation model that includes parameterizations for all major physical processes, and finally they become analyzed again for self-consistency. All data are given on a 144 x 73 global grid at constant pressure levels. The NCEP reanalyses now cover the years from 1948 to the present. In 1979 the satellite-observing system was established, which partially affected reanalysis results. For example, some phenomena as depicted in the NCEP reanalysis data exhibit a discontinuous behavior around 1978 in diverse variables (Huesmann and Hitchman, 2001; Huesmann and Hitchman, 2003; Kistler et al., 2001). The emergence of satellite data resulted in a significant change, indicating that the results from 1979 to present day are the most reliable and coherent ones. The global features before that year are rather governed by the model outcome in data-sparse areas, leading to the possible generation of some spurious results in those regions.

Different outputs of the reanalyses are not equally reliable. The NCEP/NCAR fields have been graded according to the relative influence of the observed data and the assimilation model on the output field. Atmospheric temperature (T) and zonal wind (U) are significantly affected by the observations, and the numerical model does not have a strong influence. Therefore they are among the variables with the highest grade, which are considered to provide an estimate of the state of the atmosphere better than would be obtained just with measurements. In this work we analyzed global zonal oscillations of seasonal means of daily air temperature and zonal wind reanalysis data over 30 years (1979–2008). We grouped data into seasons DJF (December, January, February), MAM (March, April, May), JJA (June, July, August), SON (September, October, November). We have chosen levels in the middle troposphere at 400 hPa and in the middle stratosphere at 10 hPa. We performed Fourier analysis on the 144 data at each of the 73 latitudes. Zonal averages were initially removed in each dataset. In order to keep the most relevant fluctuations of the analysis, the following procedure was followed in each dataset. Typical planetary waves exhibit an amplitude of 1 K in temperature and 2 m/s in zonal velocity (Andrews et al., 1987; Mohanakumar, 2008). We used these values as the lower limits in order to keep the modes coming out from the Fourier analysis. We set a priori no upper constraint on the wavenumber w representing planetary scales and the shortest mode that emerged from all our analyzes with a relevant structure (amplitude above the lower limits) was $w = 3$.

3. Results

Significant features that differ from the well-known behavior of a wave have been found below in several cases and therefore these patterns are called here structures. For example significant perturbations in one variable have not been always accompanied by the other variable or clear phase differences between them (polarization relations) did not clearly come out. However, we cannot discard that the wave relations are present, but are small or obscure enough to avoid detection. The amplitude limit selection criterium outlined above was partially arbitrary (but necessary) and therefore the latitude ranges of modes exhibited below should be considered of an indicative rather than of an accurate nature. In particular, temperature and zonal wind oscillations exhibit similar features at some given altitudes and seasons but the latitude bands of occurrence exhibit moderate differences among them in some cases. In order to represent the detected structures we used amplitude and phase from the Fourier analysis to plot the location of maxima and minima of modes $w = 1$, 2 and 3 on topographic maps.

Regarding the use of any possible spectral representation tool of quasiperiodic structures, every particular choice gives more visibility to certain patterns of the data and obscures other characteristics. The way information is processed ultimately affects the results and their corresponding interpretations. Applying a Fourier decomposition to given atmospheric data and interpreting the components as waves implies that we assume that nature has building blocks with a certain shape. In addition, we should check if observations reproduce the physical laws