Global study of the quasi-biennial oscillation by the pseudo-2D wavelet transform

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Introduction

A waste spectrum of regular oscillations is detected throughout the climate system. The annual cycle, the most pronounced and the most regular of the periodicities, is forced by the variations in incoming solar radiation due to orbiting of the Earth around the Sun. Among the dynamically forced oscillations, the quasi-biennial oscillation (QBO, the quasi-regular change of the zonal winds direction in the lower tropical stratosphere) is the most striking cycle. It is not as regular as the annual cycle and its manifestation is significant primarily across equatorial areas. However, the quasi-biennial oscillation drives most of the tropical dynamics and it remarkably influences global climate system.

An interesting example of QBO's role is provided also by the interaction between the QBO and the solar sunspot cycle (SSC). 11-years solar sunspot cycle is similarly to the annually cycle forced by the variations in incoming solar radiation. In contrast with the annual cycle its signal vary strongly with the phase of the QBO and an analysis of the influence will follow up the presented study in future.

The QBO's signal can be detected over different areas at various atmospheric levels and the use of a spatially oriented method is essential to describe the oscillation's structure in all aspects. To analyze the quasi-biennial oscillation in this study, we have applied the pseudo-2D wavelet transform (p2D-WT) - a technique designed to describe frequency characteristics globally over an analyzed area. We analyzed two types of data at several pressure levels; (1) the HadAT radiosonde dataset and (2) two sets of reanalyzed data (ERA-40 and NCEP/NCAR). The study includes an analysis of time series of air temperature, u and v wind velocities and ozone mass mixing ratios at pressure levels up to 10 hPa, as well as temperature and height of the tropopause. The datasets cover the second half of the 20th century. The results provide a detailed description of the oscillations' spatial distribution, together with mutual comparison of the two reanalyzed datasets.

Study of the quasi-biennial oscillation shows that the cycle is detected over extensive regions. Those are mostly equatorial areas. Nevertheless, the results differ significantly for some regions that are identified in the NCEP/NCAR and ERA-40 reanalysis. That indicates that a study utilizing a reanalyzed dataset should compare the results with an analysis of another type of reanalysis and the result should not be interpreted without careful discussion.

Datasets & Method

In the presented study, we have analyzed both reanalyzed and observed meteorological datasets. The core of the analyses is based on examination of the reanalyzed time series of the ERA-40 (Uppala et al. 2005) and NCEP/NCAR (Kalnay et al. 1996; Kistler et al. 2001) reanalysis datasets. The NCEP/NCAR datasets were studied for the time period of 1949-2007 and they included fields of temperature, u (west-east) and v (south-north) velocities as well as the temperature and height of the tropopause. The ERA-40 reanalysis covers the 1957–2002 time period and they comprised reanalyzed fields of ozone mass mixing ratios, temperature, u and v velocities. Both reanalyzed datasets were provided and examined in the regular geographical grid composed of 73 latitudes and 144 longitudes, with horizontal spacing of 2.5°, at 17 pressure levels (1000 to 10 hPa) and in the form of monthly means.

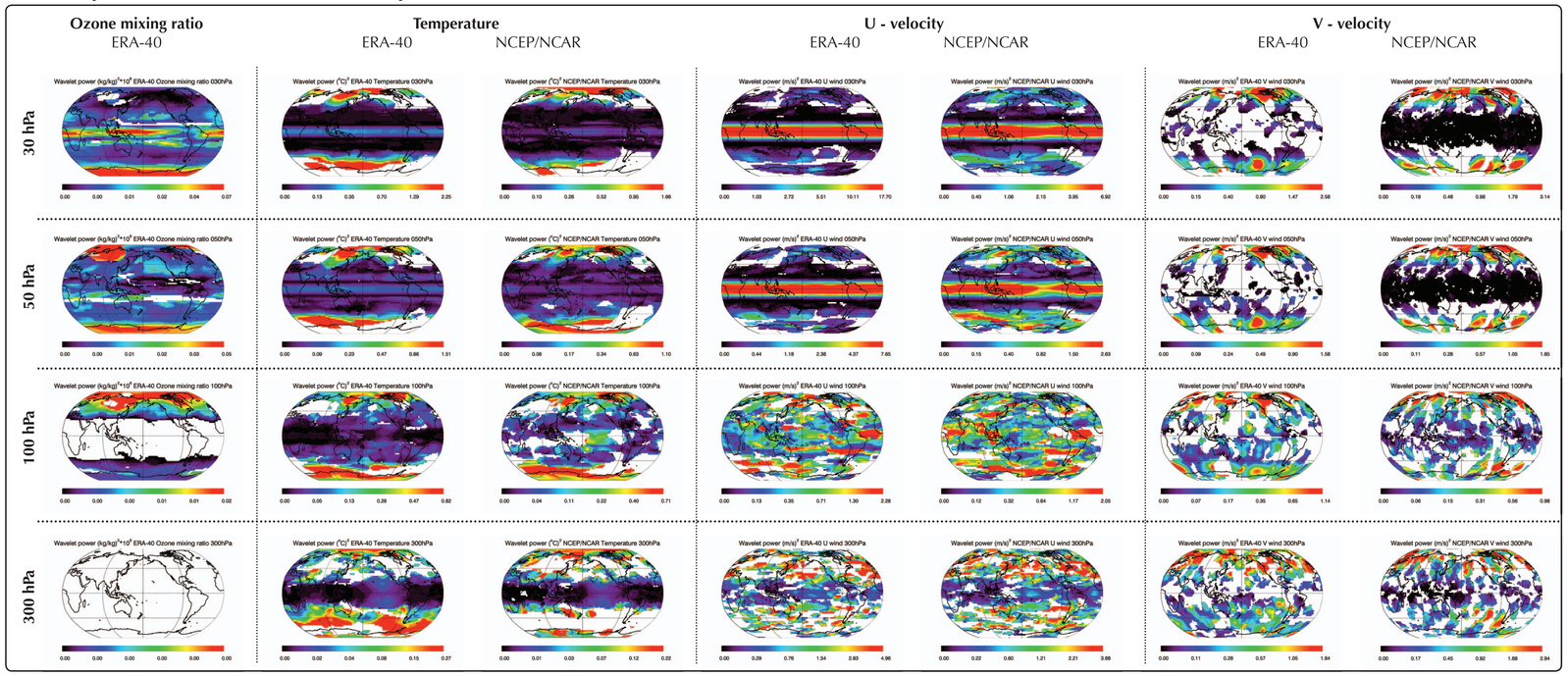
To investigate the reliability of the reanalyzed series, we have also studied HadAT radiosonde temperature dataset (Thorne et al. 2005). HadAT is a radiosonde temperature product of the Hadley Centre that replaced HadRT - formerly used radiosonde dataset. We analyzed the recommended version of the Hadley Centre's radiosonde temperature product (HadAT2), which comes up with monthly time series available at nine pressure levels (850 to 30 hPa) for the 1958-2006 time period. The radiosonde dataset was studied in the form of anomalies relative to monthly 1966-1995 climatology. For application of the wavelet transform, we chose time series that had less than 36 missing values in the 1965-2006 period (the first ten years were not used in the computation because they contained a lot of missing values). The missing values in the chosen time series were substituted by the average of other values for the same month in the same series.

To analyze global frequency pattern of the QBO, we applied the wavelet transform. We used the continuous wavelet transform (CWT, e.g., Mallat 1999 or Percival and Walden 2000) that describes amplitude and also phase in the case of utilization of a complex mother wavelet (e.g., Torrence and Compo, 1998) of regular changes as a function of both frequency and time. To study the QBO areally, to describe both latitudinal and longitudinal variations, we applied an extension of the CWT – the pseudo-2D wavelet transform (p2D-WT, e.g., Pisoft 2008, Pisoft 2011). It is an algorithm that integrates computed wavelet power spectra of every time series within the area of interest into one multidimensional object W(t,s,k,l,m). Particular values of the object W are determined by the time of occurrence (t) and period/frequency band (s) of a detected periodicity and by the position of the original time series in the three-dimensional geographical grid (k,l,m - characterizing position of the source location by latitude and longitude as well as altitude). To interpret the multidimensional result W, it is necessary to employ time and frequency slices - that means that a specific constant values of frequency (s) and time (t) at a specific atmospheric level (m) are selected to reduce the number of dimensions. To analyze the QBO presence in this study, we have chosen oscillations in typical QBO period bands of 24-31 months (Baldwin et al. 2001).

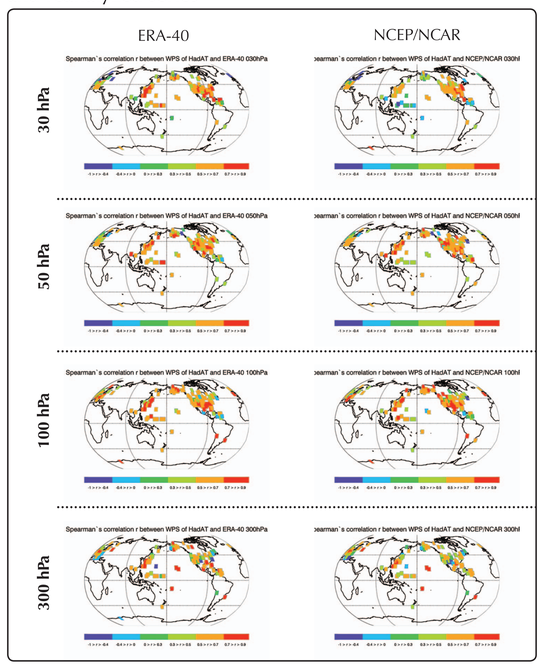
For computation of the CWT, we used the Morlet wavelet (described by, e.g., Percival and Walden 2000) as the mother wavelet, with parameter w_0 equal to 6. The 95% confidence intervals were constructed according to the Torrence and Compo 1998 significance test. Computations of the respective thresholds were carried out for the wavelet power spectra of time series with removed mean annual cycle (averaged cycles for 1949-2007 and 1957-2002 for NCEP/NCAR and ERA-40, respectively). The obtained limits of the confidence intervals were subsequently applied to the CWT of the original temperature series, including the annual cycle. We employed this approach because of the dominance of the annual cycle in the analyzed series at most locations. Because the amplitude of the 1-year cycle is much stronger than for other oscillations, it contributes the most to the variance of the series, and other interesting and prominent periodicities would test as statistically insignificant if the confidence intervals were created for the original series, including the annual cycle. Only statistically significant results outside the cone of influence (COI) were selected for further analysis.

To study correlation between occurrences of the solar cycle in the reanalyzed temperature and radiosonde series, we have computed CWT of the both datasets. Then we have chosen parts of the acquired WPSs in period bands of 10-12 years. Those were averaged through the period interval into time series describing variability of the frequency spectra in the specified period bands. Due to COI limitations, only parts of the series within 1972-1992 (for study of the correlations between NCEP/NCAR and HadAT data) and 1972-1989 (for study of the correlations between ERA-40 and HadAT data) time periods were selected for the correlation analysis. The correlations were computed for the HadAT series and the reanalyzed series in the closest grid points.

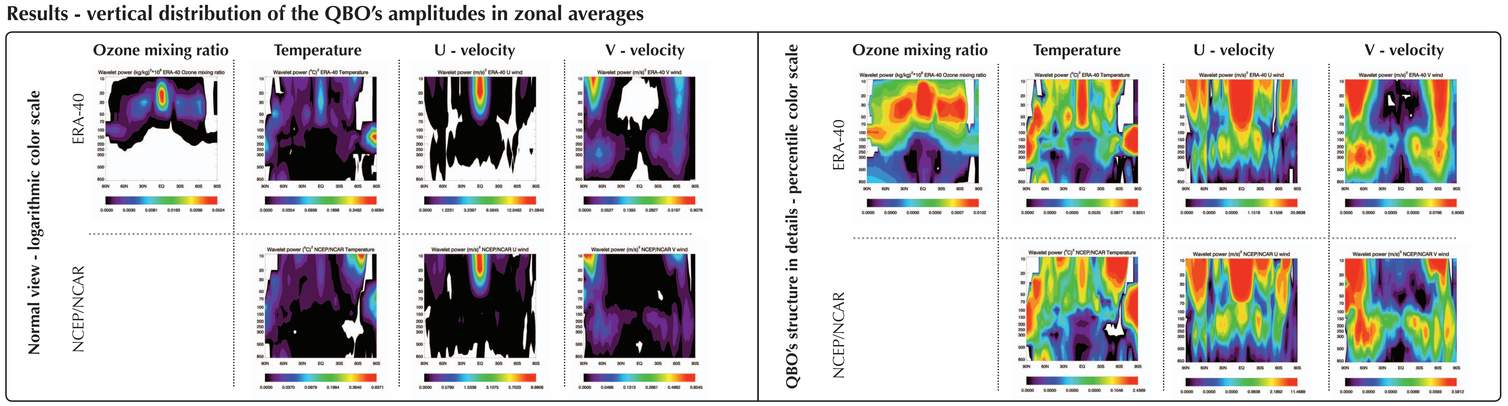
Results - spatial distribution of the QBO's amplitudes



Results - correlation between radiosonde and reanalyzed series



Results - vertical distribution of the QBO's amplitudes in zonal averages



Literature & Acknowledgements

Baldwin, M.P., L.J. Gray, T.J. Dunkerton, K. Hamilton, P.H. Haynes, W.J. Randel, J.R. Holton, M.J. Alexander, I. Hirota, T. Horinouchi, D.B.A. Jones, J.S. Kinnersley, C. Marquardt, K. Sato, and M. Takahashi, The Quasi-Biennial Oscillation, Reviews of Geophysics, 39, 179-229, 2001

Kistler R, Kalnay E, Collins W, Saha S, White G, Woollen J, Chelliah M, Ebisuzaki W, Kanamitsu M, Kousky V, van den Dool H, Jenne R, Fiorino M (2001) The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. Bul. Am. Meteorol. Soc. 82:247-268.

Kodera K, Kuroda Y (2002) Dynamical response to the solar cycle. J. Geophys. Res. Doi:10.1029/2002JD002224

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J, Zhu Y, Leetmaa A, Reynolds B, Chelliah M, Ebisuzaki W, Higgins W, Janowiak J, Mo KC, Ropelewski C, Wang J, Jenne R, Joseph D (1996) The NCEP/NCAR 40-years Reanalysis project. Bul. Am. Meteorol. Soc. 77:437–471

Mallat S (1999) A Wavelet Tour of Signal Processing. Academic Press, San Diego, Calif, USA

Pišoft, P., Holtanová, E., Huszár, P., Mikšovský, J., Žák, M., (2011): Imprint of the 11-year solar cycle in reanalyzed and radiosonde datasets: a spatial frequency analysis approach, Climatic Change (accepted)

Pišoft, P., Mikšovský, J. (2009): An analysis of the spatial distribution of approximate 8 years periodicity in NCEP/NCAR and ERA-40 temperature fields, European Journal of Physics, 174, p. 147-155, DOI: 10.1140/epjst/ e2009-01097-3

Percival DB, Walden AT (2000) Wavelet Methods for Time Series Analysis. Cambridge University Press, Cambridge

Thorne PW, Parker DE, Tett SFB, Jones PD, McCarthy M, Coleman H, Brohan P, Knight JR (2005) Revisiting radiosonde upper-air temperatures from 1958 to 2002. J. Geophys. Res. 110:D18105

Torrence C, Compo GP (1998) A Practical Guide to Wavelet Analysis. Bul. Am. Meteorol. Soc. 79:61-78

Uppala SM, Kallberg PW, Simmons AJ et al. (2005) The ERA-40 re-analysis. Q. J. R. Meteorol. Soc. 131:2691–3012

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