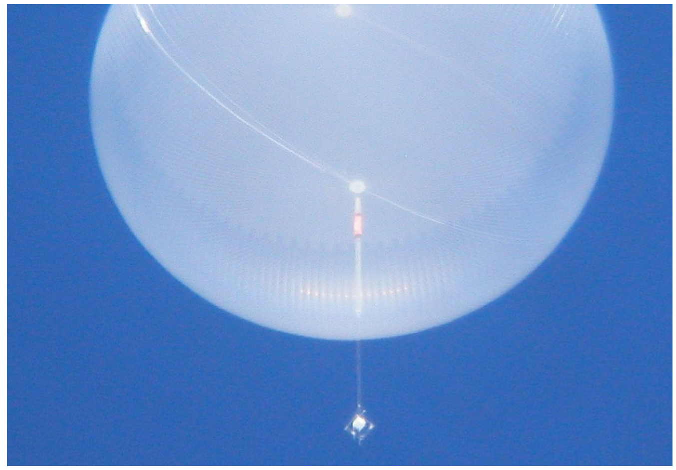
Modeling the Stratosphere's "Heartbeat"



Far above the equator, where the density of air is only about 1-10% of that at the ground, the circulation takes the form of intense zonal jets that display one of the most remarkable cyclical phenomena in the climate system. Figure 1 shows the monthly mean zonal wind determined from daily balloon observations at Singapore (1.3°N) from near the tropopause (100 hPa or ~17 km) up to 10 hPa or ~30 km. At any level, the winds are observed to change from strong easterlies to strong westerlies roughly every other year in a quasi-regular cycle. In the observed record since 1953, the period from cycle-to-cycle has varied between about 22 and 36 months and seems to average about 27 to 28 months. The phenomenon has become known as the Quasibiennial Oscillation (QBO).

Notable features of the QBO include the downward propagation of the wind reversals and the formation of thin layers of strong mean wind shear. The QBO is believed to be forced internally in the tropics by the interaction between the zonal-mean flow with vertically propagating waves. Although primarily a low-latitude phenomenon, this nearly regular "heartbeat" in the tropical stratosphere impacts the circulation and chemistry throughout the global atmosphere, affecting seasonal-mean conditions even at Earth's surface.

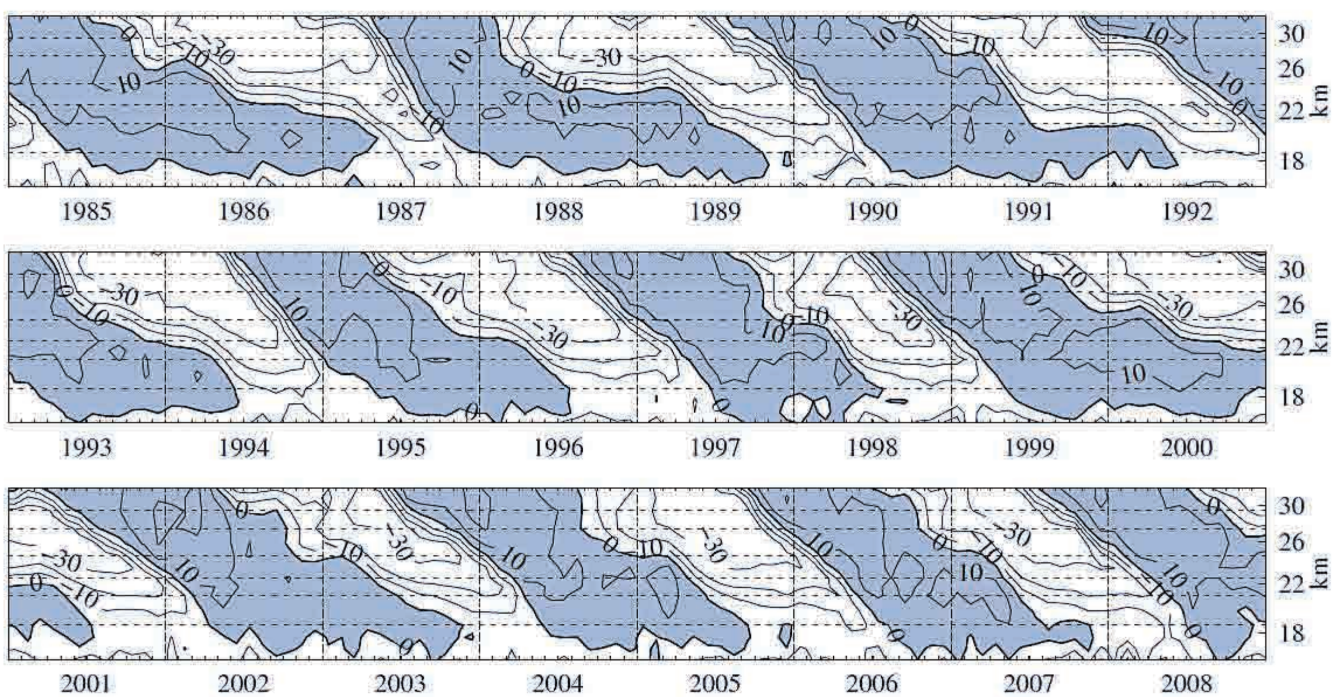


Figure 1. Time-height section of monthly mean zonal wind near the equator based on balloon-borne radiosonde observations. The contour interval is 10 m/s and westerly winds are denoted by shading. Plot courtesy of the Institute for Meteorology of the Free University of Berlin.

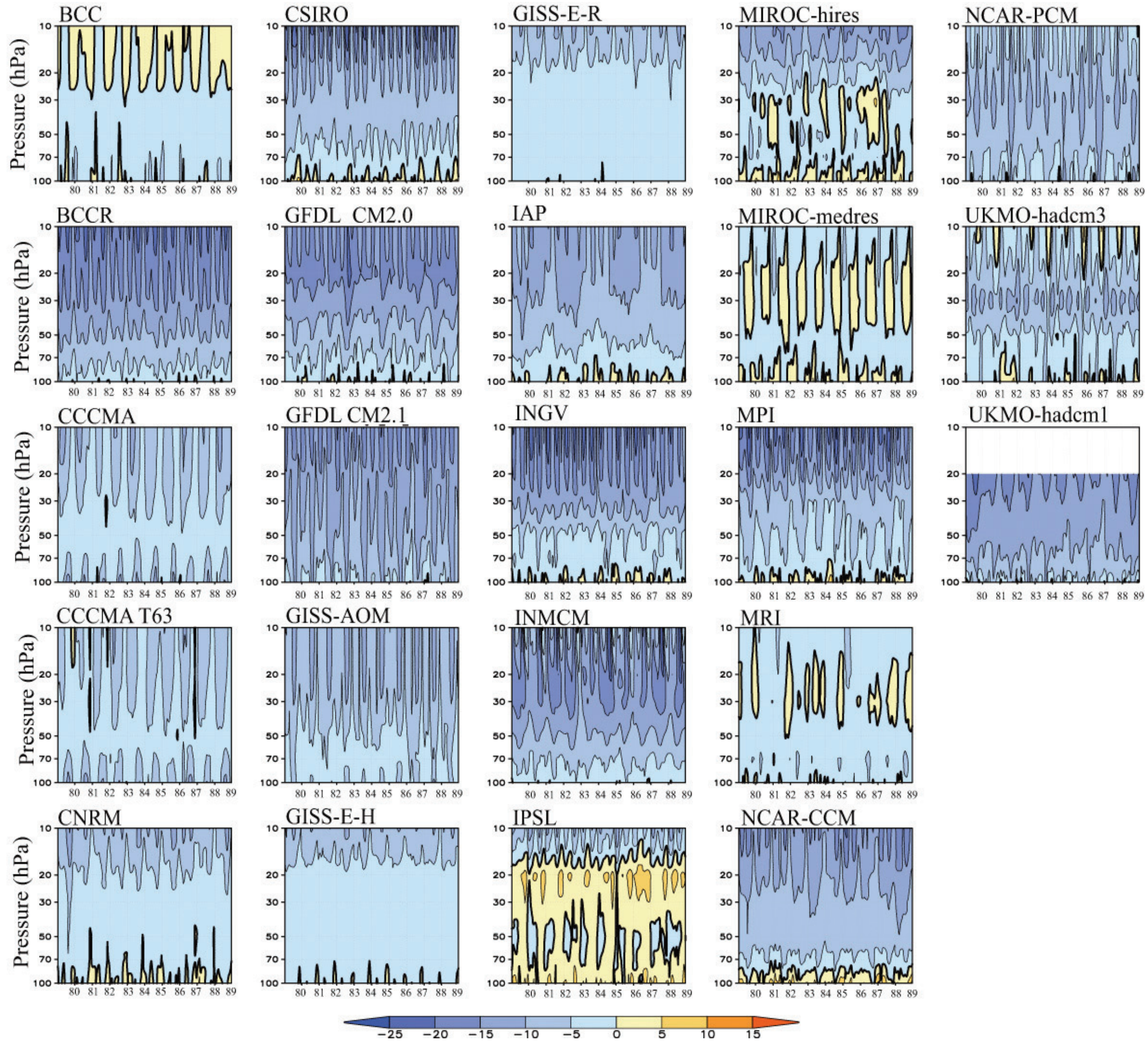


Figure 2. Time-height sections of the monthly mean, zonal-mean, zonal wind at the equator as simulated by 23 individual GCMs. Each panel displays 10 years from "20th century" simulations. The vertical domain shown is from near the tropopause (100 hPa) to about 30 km (10 hPa). Plot courtesy of Yoshio Kawatani, JAMSTEC.

Although the QBO is a very prominent feature of the real atmosphere, it has been a remarkably elusive target for comprehensive global numerical models. JAMSTEC's **Yoshio Kawatani** has analyzed the simulated equatorial zonal wind over 10 years of present-day-simulations by 23 individual Global Climate Models (GCMs) in the model intercomparison conducted for the 2007 Assessment Report of the Intergovernmental Panel on Climate Change (Figure 2). Almost all the models simulate rather steady, weak easterly mean winds in the equatorial lower stratosphere and none displays anything resembling the observed QBO.

A few atmospheric GCMs have spontaneously simulated a mean-flow oscillation in the equatorial stratosphere that resembles to some degree the QBO in the real atmosphere. Such models typically have high vertical and horizontal resolutions and employ convection parameterizations that excite a spectrum of strong vertically propagating waves at low latitudes. Perhaps the most successful GCM in this regard has been the Model for Interdisciplinary Research on Climate (MIROC) developed at the University of Tokyo, JAMSTEC, and the National Institute for Environmental Studies.

A frequent visitor to the IPRC, Kawatani has been partnering with IPRC Director **Kevin Hamilton** in analyzing the detailed mechanisms that maintain the QBO in the MIROC model and in assessing the expected response of the QBO to global warming.

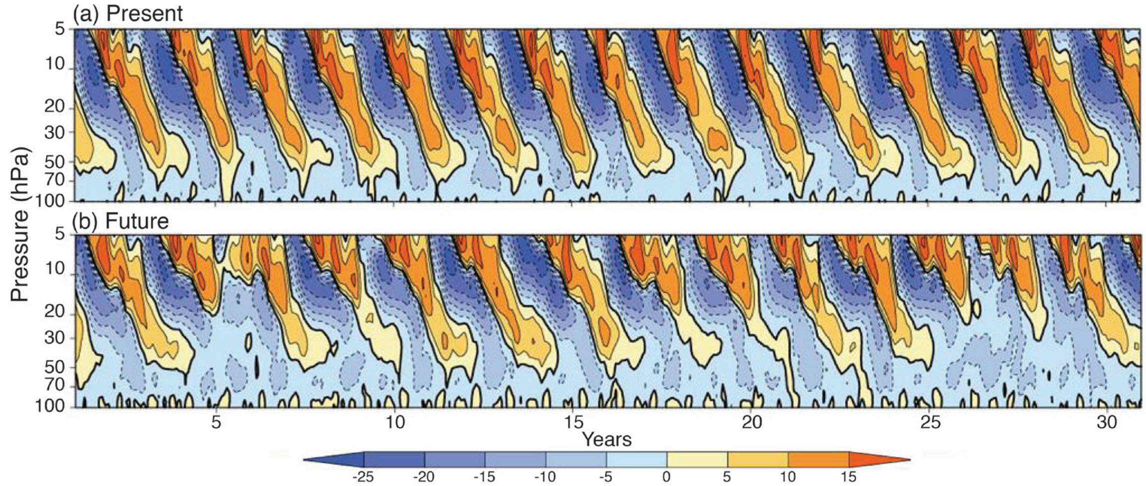


Figure 3. Zonal-mean zonal wind over the equator for (a) present day and (b) double CO_2 conditions. Results shown for pressures between 100 and 5 hPa, corresponding to heights of about 17 to 35 km. The color bar is labeled in m/s and the contour interval is 10 m/s. Adapted from Kawatani et al. (2011).

Figure 3a shows the simulated equatorial wind oscillation in a MIROC run using late 20th century climatological sea surface temperatures (SSTs) and CO_2 concentrations. The simulated wind oscillation has the observed downward propagation, roughly the right amplitude, and a mean period only somewhat shorter than observed (24 months vs the observed 27 – 28 months). The simulated oscillation, however, is more regular than that observed, the period of almost every cycle locking on to exactly two years.

The MIROC was then run with SSTs and CO_2 values expected for the late 21st century (Figure 3b). The rise in SST was taken from a multimodel ensemble of coupled global coupled models that were run under a moderate economic growth scenario for future atmospheric composition. The simulated QBO appears as well in the global warming simulation (Figure 3b), but its properties are significantly changed. The period increases to a mean value of about 26 months and is freed from the apparent locking with the annual cycle that dominates the present-day simulation. Even more striking is the change in the vertical amplitude structure, with the oscillation nearly disappearing around 70 hPa and below.

Further diagnosis and experimentation suggest that the alteration in the QBO in the MIROC global-warming-case is caused mainly by a change in mean upwelling in the tropical stratosphere. In the real world, the QBO zonal wind reversals descend through a region characterized by mean upwelling with magnitude roughly 1 km/month, and the mean upwelling is believed to play a key role in determining the period and vertical structure of the QBO. The situation is depicted schematically in Figure 4. The mean meridional overturning circulation in the stratosphere intensifies, and in the equatorial lower stratosphere, the mean upwelling increases by as much as 40% (largest increase near 70 hPa). Almost all GCM simulations reported in the literature show increased mean upwelling in the lower stratosphere in response to increased greenhouse gas concentrations; so the MIROC results, in this regard, may be quite robust.

Taken at face value, the MIROC results predict that the QBO should eventually disappear at the lower stratospheric levels, while retaining its present amplitude at higher altitudes. Analysis of the monthly mean zonal-wind station-observations (not shown) reveals evidence for a decline in recent decades in the QBO amplitude at 70 hPa, while at 50 hPa and higher altitude, there seems to be no significant trend. This observation may represent an early detection of the expected greenhouse-gas-driven change in the mean meridional stratospheric circulation and a harbinger of quite large circulation changes over the next century, which may have important effects on the chemistry of the middle and upper atmosphere.

This story is based on:

Kawatani, Y., K. Hamilton and S. Watanabe, 2011: The quasi-biennial oscillation in a double CO_2 climate. *J. Atmos. Sci.*, **68**, 265–283.

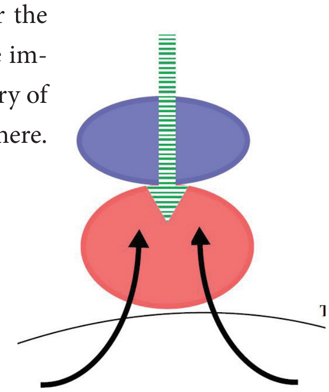


Figure 4. Schematic shows stacked easterly and westerly QBO phases (ovals) descending through the lower stratosphere, which has a mean meridional circulation (black arrows) with significant upwelling.