

SPECIAL SECTION QBO MODELLING INTERCOMPARISON

The SPARC Quasi-Biennial Oscillation initiative

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Abstract

Introduction and background to the Stratosphere–troposphere Processes And their Role in Climate (SPARC) project, the QBOi, and the papers contained in this Special Section.

KEYWORDS

WCRP–SPARC, stratosphere, quasi-biennial oscillation, gravity waves, climate modelling

Following its establishment in 1992, the Stratosphere–troposphere Processes And their Role in Climate (SPARC) core project of the World Climate Research Programme (WCRP) has included several initiatives designed to evaluate and potentially improve the representation of the stratosphere in general circulation models (GCMs). With the benefit of contributions from these initiatives, rapid advances have been made over the last 25 years in our capability to model the influences of, and changes

in, stratospheric processes. Notably, developments in chemistry–climate models (CCMs) first supported by the SPARC CCM-evaluation activity (CCMval) and more recently by the SPARC CCM-Initiative (CCMI) have enabled models to play a key role in strengthening the scientific foundations of World Meteorological Organisation (WMO)/United Nations Environment Programme (UNEP) ozone assessments. Nonetheless, shortcomings in the representation of the stratosphere in models

remain and likely affect the representation of interannual variability as well as the two-way coupling between the stratosphere and troposphere. The Quasi-Biennial Oscillation initiative (QBOi) was conceived as a grass-roots initiative in 2012 to focus on the fidelity of tropical variability in model stratospheres and the possible influence of this variability on other parts of the atmosphere. QBOi was formally adopted as a SPARC activity in 2015.

An early SPARC initiative to assess the dynamics underpinning the performance of middle atmosphere climate models was the GCM–Reality Intercomparison Project for SPARC (GRIPS), established in 1996. By the early 2000s GRIPS analysis had shown models were typically deficient in wave drag, leading to climatological biases in mean temperatures and winds throughout the extratropical middle atmosphere. Subsequently, many modelling groups alleviated these circulation deficiencies by implementing non-orographic gravity wave parametrizations to supply the missing wave drag and drive the corresponding adiabatic heating. GRIPS also identified clear issues in the simulation of the tropical middle atmosphere, notably the lack of a QBO in virtually all models at the time. Increasingly, however, QBO-like oscillations of descending eastward and westward winds appeared in model tropical stratospheres as non-orographic gravity wave parametrizations were introduced, provided that suitable parameter settings were used. In fact, due to a lack of strong observational constraints, these wave drag parametrizations can be tuned to simulate oscillations having similar amplitude and period to the observed QBO. Alongside the development of non-orographic gravity wave parametrizations in the 1990s, resolved wave forcing in the tropical lower stratosphere was found to improve with increased vertical resolution and the first realistic simulation of the QBO was actually by a GCM without parametrized non-orographic wave drag. Nowadays it is accepted that the QBO is forced by a spectrum of large- and small-scale tropical waves, and that both high vertical resolution and parametrized non-orographic gravity wave drag are important ingredients for simulating a QBO.

Over the last twenty years, this rather simple recipe of improving vertical resolution and including parametrized non-orographic gravity wave drag has led to a significant increase in the number of stratosphere-resolving GCMs simulating realistic QBOs. In addition, a few models (including one participating in QBOi) have sufficient resolved wave forcing to simulate a QBO without the use of parametrized drag. While this progress has been very encouraging, it also raises important questions about whether these models produce realistic QBOs for realistic reasons, and how sensitive the simulated QBOs are

to changes in model characteristics or external forcings (such as increased greenhouse gas concentrations). Hence there is a need for in-depth analysis and intercomparison of simulated QBOs in contemporary models using a more extensive range of QBO diagnostics, and this provided the initial motivation for QBOi. Longer-term objectives of QBOi are to reduce biases in the simulated circulation of the tropical stratosphere with a focus on those aspects of the QBO identified as being important for teleconnections with extratropical and tropospheric climate variability.

From its inception, QBOi has been community-driven and at the start-up workshop in Victoria, Canada in 2015 the participants, including many of the world's leading QBO experts, prioritised five key areas to focus on during phase one of the initiative:

- Quantitative assessment of simulated QBOs using an extensive suite of metrics;
- Response of simulated QBOs to climate change;
- Predictability of the QBO on seasonal to annual time-scales;
- Simulation of vertically propagating equatorial waves contributing to driving the QBOs;
- QBO teleconnections.

Collaborative research in these priority areas was facilitated by the community agreeing on the design of a suite of coordinated GCM experiments. Details of this suite of experiments are presented in a separate paper (Butchart *et al.*, 2018). Seventeen models completed some or all of these experiments, and output was uploaded to the QBOi data archive hosted by the UK's Centre for Environmental Data Analysis (CEDA). Since many of these models are closely related to the coupled GCMs participating in phase 6 of the Coupled Model Intercomparison Project (CMIP6), analysis of the QBOi database provides an opportunity for interpreting and understanding the behaviour of the CMIP6 models. However, unlike the CMIP6-endorsed MIPs, QBOi is a more focused, flexible and independent community-driven activity, providing an alternative approach for researchers with perhaps limited resources to contribute to coordinated experiments helping to address policy-relevant scientific questions and issues.

The Special Section that follows contains five core papers that provide an overview of the main research findings using the QBOi multi-model ensemble in each of the priority areas identified above, as well as an additional paper analysing the stratospheric semi-annual oscillation (SAO) in the QBOi models. In-depth follow-up analysis, and other studies using the QBOi data archive, will appear in a corresponding Special Collection of the

Quarterly Journal of the Royal Meteorological Society. The first core paper (Bushell *et al.*, 2022) evaluates key metrics of the QBO under present-day forcing conditions, providing an overview of the multi-model ensemble performance. The relative roles of resolved and parametrized waves in driving the QBO are also evaluated, but a detailed breakdown of the momentum budget is reserved for a follow-up study. The second paper (Richter *et al.*, 2022) examines the QBO response to idealised climate change scenarios and the correlation to changes in the QBO drivers. Again a detailed analysis of the momentum budget in a changing climate is postponed to a later publication. The QBO's inherent predictability and the predictability of its stratospheric teleconnections is examined in the third paper of the collection (Stockdale *et al.*, 2022). Analysis of equatorial Kelvin and Rossby-gravity waves in the models and their associated forcing of the mean flow is the main focus of the fourth paper (Holt *et al.*, 2022). Conclusions relating to the QBOs impact on other parts of the atmosphere through teleconnections are elaborated in the fifth core paper (Anstey *et al.*, 2022). Finally, Smith *et al.* (2022) examine how the stratospheric SAO, an equatorial oscillation located above the QBO in the region of the stratopause, is represented by the QBOi models.

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