Figure 12: Participants at the Drag Processes-workshop held in Reading, UK, in September 2016.

at resolutions of a few hundreds meters over large regions, to help understand the underlying processes contributing to orographic drag and to constrain current parameterization schemes. As surface drag cannot be observed on large scales, this type of simulation could provide a reference estimate of surface drag that would be extremely valuable for improving the parameterizations used in global models.

- Explore new methods to identify the parameterizations responsible for model errors and devise ways of optimising poorly constrained parameters that go beyond empirical tuning. These can include initial tendency diagnostics, nudging techniques, data assimilation methods, but also a more process level-based evaluation of the phenomena represented by the parameterizations (*e.g.*, waves *vs.* turbulence) or the evaluation of theoretically understood far-field responses to changes in drag.
- Make more extensive use of existing direct or indirect observations to evaluate the representation of drag processes in models. Here, examples include emerging observations of momentum fluxes, gathered either in observational campaigns or at permanent supersites, and scatterometer wind data or bulk measures of drag impacts on the circulation, such as the change in wind direction throughout the boundary layer.

The presentations from the workshop are available at: **www.ecmwf.int/en/learning/workshops-and-seminars/drag-processes-and-their-links-large-scale-circulation.**

Annotation

Report on the SPARC QBO Workshop: The QBO and its Global Influence - Past, Present and Future
26-30 September 2016, Oxford, UK

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There is no known atmospheric phenomenon with a longer horizon of predictability than the quasi-biennial oscillation (QBO) of tropical stratospheric circulation. With a mean period of about 28 months, the QBO phase can routinely be predicted at least a year in advance. This predictability arises from internal atmospheric dynamics, rather than from external forcings with long timescales, and it offers the tantalizing prospect of improved predictions for any phenomena influenced by the QBO. Observed QBO teleconnections include an apparent QBO influence on the stratospheric winter polar vortices in both hemispheres, the Madden-Julian Oscillation (MJO), and the North-Atlantic Oscillation

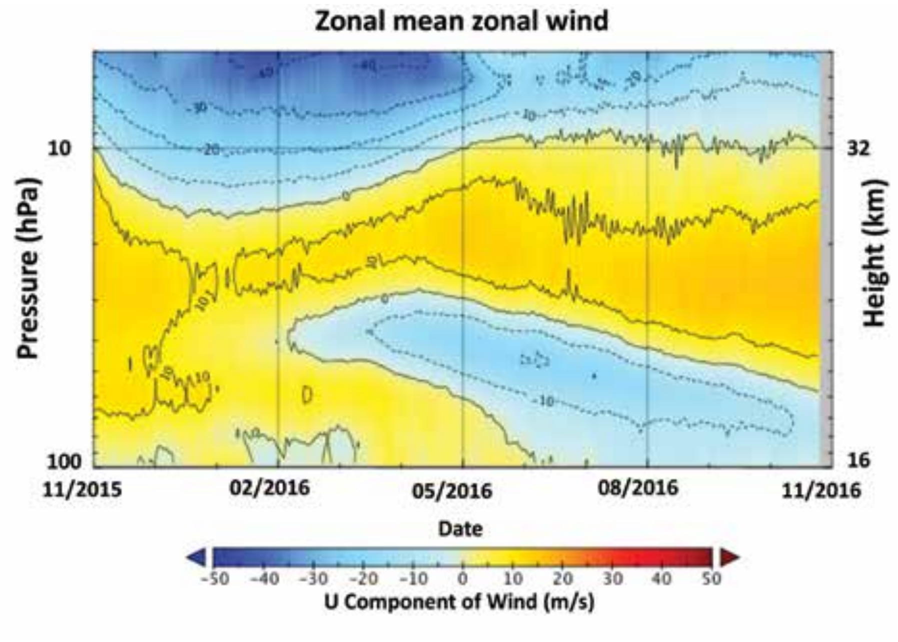

Figure 13: Vertical profile timeseries of 6-hourly zonal-mean zonal wind from the ECMWF Operational Analysis showing the recent disruption of the QBO and its recovery. Units are m/s.

(NAO). Yet the degree to which such teleconnections are real, robust, and sufficiently strong to provide useful predictive skill remains an important topic of research. Utilizing and understanding these linkages will require atmospheric models that adequately represent both the QBO and the mechanisms by which it influences other aspects of the general circulation, such as tropical deep convection.

The 2016 QBO workshop in Oxford aimed to explore these themes, and to build on the outcomes of the first QBO workshop, held in March 2015 in Victoria, BC, Canada (as reported in SPARC Newsletter No. 45). This earlier workshop was the kick-off meeting of the SPARC QBOi (QBO Initiative) activity, and its key outcome was to plan a series of coordinated Atmosphere General Circulation Model (AGCM) experiments (the "phase-one" QBOi experiments). These experiments provide a multi-model dataset that can be used to investigate the aforementioned themes. While the focus of the Victoria meeting was primarily on the QBO itself, the Oxford workshop has broadened the scope of the QBOi activity to encompass QBO impacts. Its primary outcome is a planned set of core papers analysing the phase-one QBOi experiments, which will be described in more detail below.

The phase-one experiments address the ability of AGCMs to capture the QBO in the present climate, to predict its behaviour under climate-change forcings, and to predict its evolution when initialized with observations (*i.e.* hindcasts). A goal of QBOi is to provide guidance to the wider climate community about the importance of representing the QBO and its teleconnections in global model climate projections. The phase-one experiments should also help expose and diagnose differences in the response among models that may have been tuned to produce similar present day QBO simulations. Because the QBO is well known to be sensitive to many aspects of model formulation (as will be described in more detail below), it is expected that trade-offs between compensating errors will differ among models.

The apparent fragility of the QBO in models – *i.e.* its sensitivity to many aspects of model formulation – seems to stand in stark contrast to the robust predictability of the real QBO as observed since the early 1950s. Yet midway between the Victoria and Oxford workshops, the real QBO produced a surprise. A shallow layer of equatorial easterlies appeared near 40hPa in February, in the middle of a prevailing QBO westerly phase, which subsequently deepened and descended (**Figure 13**). A casual perusal of the observed record of QBO winds shows that this event is unprecedented (**http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/qbo/**). In sharp contrast to previous experience, the 2016 disruption was completely missed by current seasonal forecasting systems. This failure indicates that the models have great difficulty capturing the full range of QBO variability, suggesting that they may be over-tuned to represent the typical behaviour of the present-day QBO. The disruption also raises the possibility that the real QBO is less robust than previously thought.

The early 2016 QBO disruption provided a unique impetus to the Oxford workshop. It was the subject of a special session on the Monday afternoon, and discussion returned to it throughout the week. Other sessions focused on teleconnections, observations and reanalyses, constituents and transport, and idealized simulations. Approximately fifty people attended (**Figure 14**), and over the five days ample time was allowed for discussion, including three breakout sessions on outstanding science questions, new experiments, and teleconnections. The teleconnections theme was further bolstered by the Oxford workshop doubling as the inaugural meeting of the new Belmont Forum JPI-Climate GOTHAM project (Globally Observed Teleconnections in Hierarchies of Atmospheric Models), which involves a number of the QBOi modelling groups (Belmont Forum: **http://www.igfagcr.org/**, Joint Programming Initiative "Connecting Climate Knowledge for Europe" (JPI Climate): **http://www.jpi-climate.eu/home**).

Teleconnections

The workshop began with a keynote talk by **Peter Haynes** reviewing current understanding of the QBO and its role in climate variability. The most well known QBO teleconnection is the coupling between the QBO and the Northern Hemisphere (NH) winter stratospheric polar vortex, often referred to as the Holton-Tan effect. This terminology has been the source of some confusion, since Holton and Tan (1980) presented both a statistical correlation and a hypothesized mechanism. While the statistical link has persisted so far, its mechanism is still not clearly established. Less studied is the similar effect on the Southern Hemisphere (SH) winter stratospheric polar vortex, which manifests as a modulation in the timing of the late-winter vortex breakdown. At lower latitudes, the QBO affects tropical deep convection (Nie and Sobel 2015) and may also impact the tropics via changes in the subtropical jet. There is no reason to confine attention only to the "stratospheric path" for QBO influence, as the keynote talk by **Adam Scaife** emphasized. Rossby wave trains extending from the tropics to high latitudes, forced by QBO-modulated deep convective heating anomalies, could provide one "tropospheric path" for high-latitude impacts. Improved understanding of stratosphere-troposphere coupling within the tropics seems necessary to better characterize how the QBO influences the tropical troposphere (**Shigeo Yoden**), such as the apparent QBO modulation of the MJO (Yoo and Son 2016; Eriko Nishimoto).

The robustness of the extra-tropical surface teleconnection, which resembles the NAO in NH winter, remains an important topic. The fact that models tend to underestimate the signal in comparison to observations, which could reflect model error or internal variability – *i.e.*, how well the observed signal can be defined from the short observational record – is a recurring issue (**Adam Scaife**, **Martin Andrews**). There seems a clear need for large sample sizes of model data, which is being addressed by extending the phase-one QBOi experiments, since multiple samples that are of similar size to the observed record can exhibit large variations in the extra-tropical response (**Figure 15**). A step change in sample size may result from the incipient Drivers Of Change In mid-Latitude weather Events (DOCILE) project, which will use distributed computing to generate "super-ensembles" of stratosphere-resolving model simulations to search for statistically robust stratospheric influence on the troposphere (**Dann Mitchell**, **David Wallom**). A novel diagnostic approach to potentially address the robustness of teleconnections is the "complex networks" approach discussed in a keynote talk by **Jürgen Kurths**. Application of these methods to climate problems has shown many promising recent results (Donges *et al.*, 2015); **Verena Schenzenger** showed a first application to the QBO-NAO relationship, and there will be more coming soon from the GOTHAM project.

Teleconnections in general – not only those related to the QBO – suggest the prospect of improved predictability at regional scales (*e.g.* of the NAO) achieved through better understanding of the large-scale, low-frequency variability of the atmosphere. Yet many challenges in characterizing teleconnections remain, as outlined in a keynote talk by **Ted Shepherd**: small signal-to-noise ratios, separation of correlation and causality (*e.g.*, Runge *et al.*, 2014), the fact that responses could manifest non-linearly as changes in residence frequency of regimes (*e.g.*, Palmer 1999), the possible

Figure 14: Participants of the SPARC QBO Workshop: The QBO and its Global Influence - Past, Present and Future, 26-30 September 2016, Oxford, UK.

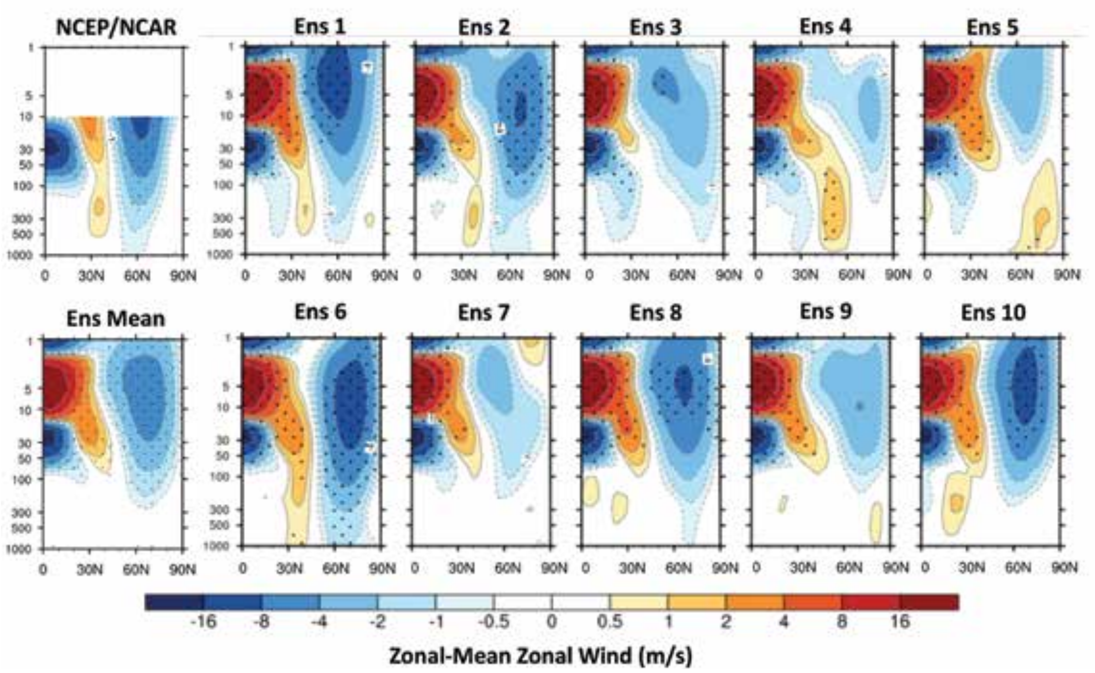

Figure 15: QBO easterly minus westerly composite differences of zonal-mean zonal wind (December-January-February average) for an ensemble of ten 50-year AMIP runs (1952-2001 SSTs) of the NCAR 46LCAM5 model. At left, the corresponding signal in NCEP/NCAR reanalysis is compared with the ensemble-mean model response (figure courtesy Jadwiga Richter).

state dependence of responses, and time lags in responses (such as the seasonal development of a response). The pitfalls and misuse of tools and terminology were also discussed: the use of significance testing is common but can be inappropriate, and there are many examples in meteorology of causal-sounding language being used to describe phenomena that are related but not necessarily in a cause-effect sense.

Dynamics of the QBO

Uncertainties in the spectrum of upward propagating tropical waves that force the QBO remain a key issue. Observational estimates of the zonal forcing by different types of equatorial waves can vary significantly among state-of-the-art reanalyses (**Young-Ha Kim**), and even the basic zonal flow can vary between reanalyses in regions of the tropical belt where there are few radiosonde observations (**Yoshio Kawatani**). High-resolution free-running AGCMs need not agree either: a model with 7 km horizontal resolution still relied on parameterized non-orographic gravity wave drag (GWD) for most of the QBO forcing (**Laura Holt**), but a recent version of the European Centre for Medium-range Weather Forecasts (ECMWF) seasonal forecast model needed to reduce its non-orographic GWD in the tropics to avoid a too-short QBO period (**Tim Stockdale**). Presumably some of these discrepancies arise due to the different deep convective parameterizations used by the models (including the reanalysis models). Several models participating in QBOi use GWD that is coupled to deep convection or is otherwise stochastic (**Andrew Bushell**, **Francois Lott**, **John McCormack**, **Jadwiga Richter**), which should increase the variability of gravity waves driving the QBO, and recent progress in the overall capabilities of gravity wave source parameterizations was reviewed (**Francois Lott**). A lack of variability in resolved or parameterized wave sources, including the seasonal variation (**Young-Ha Kim**), may cause modelled QBOs to be too regular, *i.e.*, to show less inter-cycle variation than is observed. While proper representation of wave sources is desirable, resolving the stratospheric damping of waves can be crucial: high vertical resolution (~ 1km or finer) can strongly affect the damping of resolved waves in the sharp QBO shear zones, and its benefits for the QBO outweigh those of horizontal resolution for equivalent computational cost (**Laura Holt**). It may also affect the QBO modulation of tropical tropopause height and temperature, as can be observed in Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) data (**Vinay Kumar**), that may influence tropical deep convection.

The tropical stratosphere evolves according to a slow interaction between "weak" processes – the large-scale wind is less constrained by thermal damping than in the extra-tropics, and communication by momentum fluxes with the rest of the atmosphere is relatively slow – leading to long timescales, and making the QBO a challenge for modellers (**Peter Haynes**). It is presumably because of this delicate balance that the QBO can be sensitive to many aspects of model formulation, including: vertical resolution, parameterized non-orographic gravity wave drag, dissipative processes (including radiative damping of waves), parameterized deep convection, and the background upwelling of the Brewer-Dobson circulation. The multi-year memory of the tropical lower stratosphere, without which the high predictability of the QBO would not exist, can also give rise to persistently unusual behaviour in models, such as that shown in (Hamilton *et al.*, 2001; Yao and Jablonowski 2015), and at the workshop in slides from **Peter Hitchcock**. Bearing little resemblance to the usual observations, it is tempting to disregard such behaviour as being well outside the regime in which the Earth's stratosphere apparently resides.

Early 2016 disruption

Yet the early 2016 disruption presents a striking challenge: models with seemingly realistic QBOs failed to predict this event, and it bears little resemblance to the QBO's usual regularity. The workshop special session on the disruption was kicked off by **Larry Coy**, who gave an overview of the event; this was then followed by a vigorous group discussion, briefly summarized here. The abrupt occurrence of the 40hPa easterlies (**Figure 13**) was clearly without precedent in the 63-year observational record spanning 1953-2015, and has now been the subject of several published studies (*e.g.*, Newman *et al.*, 2016; Osprey *et al.*, 2016; Coy *et al.*, 2016 under review for J. Climate). Dramatic equatorial wave breaking was presented in a movie showing the November-March evolution of potential vorticity on the 530K (~23km) isentropic surface derived from MERRA-2 reanalyses (**Larry Coy**). This suggests that the usual view of the QBO as a zonally symmetric phenomenon may be questionable in this situation, and the fact that reanalyses are strongly "anchored" by the Singapore radiosonde observations, but can diverge from each other in regions where equatorial radiosonde coverage is poor, could be problematic (**Mark Baldwin**, **Yoshio Kawatani**). Nevertheless, individual radiosonde stations throughout the tropical belt do tend to show a roughly simultaneous onset of the 40hPa February easterlies, indicating a significant zonally symmetric component to the disruption (**Fabian Wunderlich**). Subsequent to the appearance of the easterly layer, downward propagation of wind regimes began to resume, more closely resembling the usual QBO evolution, prompting the disruption to be described as a "reboot" of the QBO (**Larry Coy**).

Although the origins of the disruption are not yet settled, a prevailing view is that strong momentum fluxes from the NH due to equatorward-propagating planetary waves were important. A strong peak appeared at the equator in zonal wavenumber 1-3 Eliassen-Palm flux divergence (**Shingo Watanabe**, **Larry Coy**, **Scott Osprey**) and occurred during a QBO westerly phase when Rossby waves can propagate to the equator. If the proximate cause of the disruption is of extra-tropical origin, this may be consistent with its apparent lack of predictability: the extra-tropics are in general less predictable than the tropics, with sudden stratospheric warmings (SSWs) not being predictable more than ~12 days in advance (**Neal Butchart**). Yet the fact that forecast errors do not correct as the forecast lead-time shrinks suggests that problems with the model, not just random error, are implicated (**Tim Stockdale**). Possible problems could include the fact that non-orographic GWD schemes with fixed wave sources that are tuned to match the observed QBO period give very regular QBOs, or that model resolution limits the fidelity with which tropical wave breaking is represented (**Larry Coy**). The occurrence of a very strong El Niño event during the 2015/16 winter may have led to increased wave activity entering the extra-tropical stratosphere (**Adam Scaife**), and a precursor equatorial wave forcing event involving zonal wavenumbers 4-6 may have been important (**Shingo Watanabe**). Yet if extra-tropical planetary waves are responsible, it is unclear how to reconcile the deep vertical scale of these waves with the shallow vertical scale of the disruption (**Lesley Gray**).

Future projections

Although no seasonal forecasts predicted the disruption, analogous events have appeared – albeit rarely – in free-running models, and they appear more frequently in future projections (**Jadwiga Richter**, **Verena Schenzenger**). This suggest that QBO disruptions may become more common in future, but given model uncertainties such projections should be viewed with caution; preliminary intercomparison of some of the phase-one QBOi future projections shows that the QBO response to climate forcings might vary among models, and this non-robustness could indicate that tuning models to capture the present-day QBO is a case of over-fitting (**John Scinocca**). Using the NCAR model, **Jack Chen** also showed a different QBO response depending on whether future sea surface temperature (SST) or CO_2 changes were specified, leading to the suggestion that idealized experiments separating

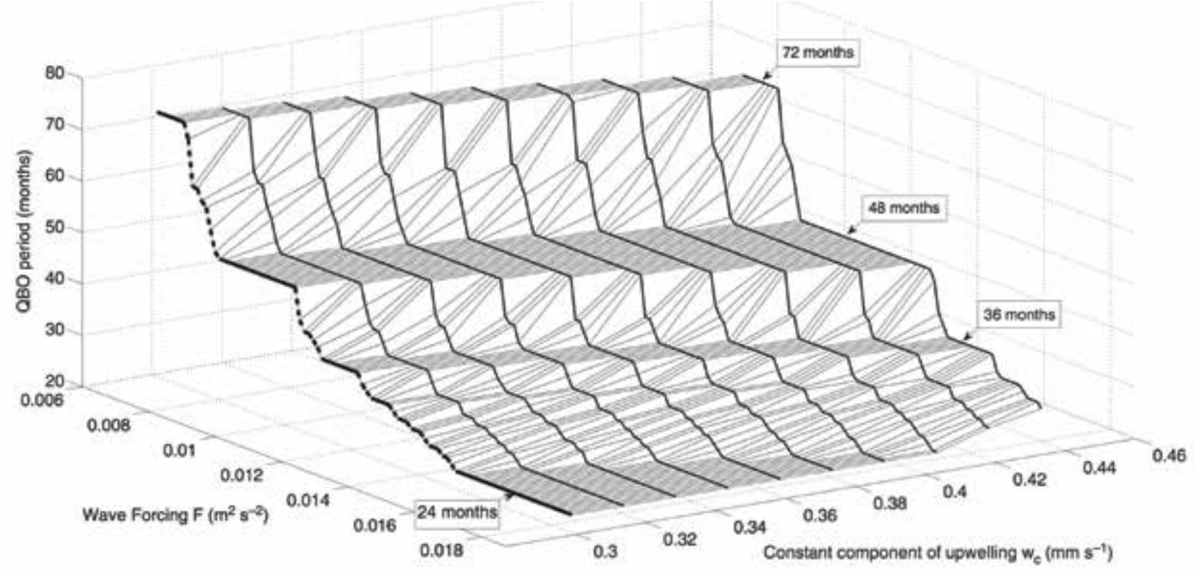

Figure 16: Variation of QBO period as a function of wave forcing strength and background upwelling in an idealized QBO model (figure from Rajendran *et al.*, 2016).

tropospheric and stratospheric climate-change effects could be useful. It is plausible that distinct effects are involved – for example, that changed CO_2 affects the thermal damping rates of waves that force the QBO, while changed SSTs could affect tropical gravity wave sources (which interact with the GWD parameterization in the NCAR model) as well as the tropospheric winds through which the waves propagate before reaching the QBO. Again, the fact that many processes contribute to the QBO creates a potential sensitivity. Apart from changes to the QBO itself, QBO teleconnections may imprint upon changes at higher latitudes: under the RCP4.5 scenario in the MPI-ESM-MR model, significantly stronger middle atmosphere trends occurred for QBO westerly than for easterly years (**Axel Gabriel**).

Idealized simulations

Given this complexity, it is appealing to consider simpler approaches than full AGCMs. In the keynote talk of the idealized simulations session, **Geoff Vallis** introduced one alternative tool, the recently developed Model of an idealized Moist Atmosphere (MiMA). The flexible configuration of this model allows it to explicitly connect from the high end (AGCMs) to the low-end theory, which is a key point: a QBO-resolving configuration of this model could offer a single framework within which to address issues surrounding model uncertainties of the QBO, including its response to climate forcing or the mechanisms underlying its teleconnections. In the same session, **Shigeo Yoden** described recent results from idealized cloud-resolving tropical simulations in which QBO-like oscillations extend from the stratosphere to the surface, modulating the organization of tropical convection; such a model provides a framework for exploring hypotheses regarding the QBO's impact on the tropical troposphere. Using an even more idealized model, a variant of the Plumb (1977) setup, **Kylash Rajendran** showed how the prevalence of QBO phase-locking with the annual cycle could occur over discrete ranges of wave forcing strength, and that this behaviour combined with increased tropical upwelling under climate change could lead to changes in the QBO's seasonal synchronization (**Figure 16**). The daunting complexity of AGCMs, approaching that of the real atmosphere, motivates further consideration of idealized simulations within the QBOi framework.

Constituents and transport

A major reason to represent the QBO in Chemistry-Climate Models (CCMs) is to capture its effects on the transport and mixing of chemical constituents such as ozone, which has historically been a strong focus of QBO research (*e.g.*, Baldwin *et al.*, 2001 and many references therein). An overview talk by **Peter Braesicke** reviewed how trace gases can affect the structure of, and be used to diagnose, aspects of the dynamical QBO. The latitudinal width of the QBO can strongly determine its effects on tracers (Hurwitz *et al.*, 2011), and **Anne Glanville** showed improved isolation of the tropical pipe when a nudged QBO was specified to be narrower. The feedback of ozone on the QBO can be significant: use of the SPARC ozone climatology in the NCAR model, as opposed to the model's usual ozone climatology, was shown to warm the lower tropical stratosphere, weakening the stratification and lengthening the QBO period (**Jack Chen**). Interactive ozone, either from full chemistry or another parameterization scheme, was shown to improve the downward penetration of the QBO easterly phase and break the annual synchronization of the oscillation in the GFDL AM4 model (**Pu Lin**). QBO influence on ozone extends to high latitudes, a behaviour that is well captured in the ESCiMo model (**Tobias Kerzenmacher**). Accurately representing the ozone QBO may be important for assessing the impact, if any, of the QBO on climate projections.

Next experiments

Following the sessions on constituents and transport and idealized simulations, a breakout session on experiments discussed how the set of QBOi experiments might be broadened beyond the current (phase-one) experiments. Because analysis of the phase-one experiments is ongoing, a consensus emerged that there is no need for a new batch of coordinated experiments at this time. However, a reasonably consistent set of suggested experiments emerged from the breakout discussions, which included:

- Extending the phase-one time-slice experiments to examine teleconnection robustness, particularly of the NAO response. (Not a new experiment, but recognition that large sample size is required.)
- Extending phase-one hindcast experiments to examine the 2016 disruption.
- Perpetual El Niño / La Niña perturbations to examine the interaction of ENSO and QBO teleconnections. These would be specified SST anomalies added to the climatological SSTs in the phase-one time-slice experiments.
- Idealized experiments separating tropospheric and stratospheric climate change effects.
- QBO *vs.* no-QBO: for models that can remove their QBOs in a straightforward way (*e.g.* by turning off tropical non-orographic GWD), what is the overall effect of the QBO on present-day climate and on projections?
- Future ozone: specified as a perturbation to prescribed climatological zonal-mean ozone, how does the QBO respond to ozone recovery?
- Interactive ozone: for models that run both with and without ozone chemistry, how does the dynamical QBO respond to ozone changes?

These experiments do not comprise a "QBOi phase two", but are adopted as "coordinated recommendations" for interested groups, so that intercomparison of results can be more easily carried out among groups that do pursue these experiments. Regarding more idealized models, no coordinated efforts are yet proposed, but interest has been building on the edges of the QBOi activity. The Victoria workshop discussed the possibility of comparing QBOs in different dynamical cores (**Christiane Jablonowski**), and the MiMA (**Geoff Vallis**) and tropical convection-resolving regional models (**Shigeo Yoden**) have emerged as useful candidates for testing hypotheses regarding the QBO and its teleconnections.

Core analyses

Rather than concentrate on new experiments, the QBOi activity is now focused on analysis of the phase-one experiments. The current plan, which is an outcome of the workshop breakout sessions and plenary discussions, is to produce the following studies:

Paper 0: Experiment design and overview of participating models, intended for the Geoscientific Model Development (GMD) journal. Provides reference material for subsequent studies.

Paper 1: Present-day (AMIP) experiments. Application of metrics to characterize the QBO and compare models with observations / reanalyses.

Paper 2: Future projections. How does the QBO respond in 2xCO_2 / +2K SST and 4xCO_2 / +4K SST experiments? What do the responses tell us about the robustness of modelled QBOs?

Paper 3: Hindcasts. How predictable is the QBO when models are initialized from reanalyses? How comparable are the different forcing terms in the models when initialization removes their mean-flow biases?

Paper 4: Equatorial waves. How do different types of equatorial waves compare among the models, and to reanalyses?

Paper 5: Extra-tropical teleconnections. Comparing extended time-slice runs across all models, how robust is the extra-tropical teleconnection, in both NH and SH? Does the NAO pattern consistently appear in the NH?

The set of core analyses is of course not intended to restrict the analyses that are possible with the QBOi dataset, but rather to lay groundwork for future progress; further suggestions to complement these analyses are welcome. The goal over the coming year is for the core analysis studies to be submitted by mid-2017, prior to the next QBO workshop which is anticipated for late 2017. Except for the GMD "Paper 0" (which will be submitted earlier), it is anticipated that the core analyses will contribute to a Special Collection on the QBO in the Quarterly Journal of the Royal Meteorological Society.

Links to other activities

As noted above, the scope of QBOi has broadened to include QBO teleconnections, increasing potential synergies with other activities. It should also be noted that the data request for QBOi experiment output is modelled on the Dynamical Variability (DynVar) CMIP6 data request, which may make the dataset of interest to DynVar participants. Updates on the DynVar and Stratospheric Network for the Assessment of Predictability (SNAP) activities were presented by **Andrew Charlton-Perez**. An area of SNAP's common interest with QBOi is to understand why the early 2016 QBO disruption was not predicted by current seasonal forecasting systems. **Steve Woolnough** described the S2S archive of seasonal forecast data, which lags real time by three weeks, that may be valuable for this purpose. Updates were given by **Shigeo Yoden** and **Laura Holt** on the Year of the Maritime Continent 2017-2019 (YMC) and Gravity Waves (GW) activities, respectively, which are highly relevant to QBOi given the importance of tropical observations and the important role of gravity waves in the QBO. An emerging focus of the GW activity on predictability may have strong potential for interaction with QBOi.

Summary

A synthesis presentation by **Mark Baldwin** wrapped up the workshop, encapsulating many of the points already noted above. Quoting from the Baldwin *et al.*, 2001 QBO review paper,

> "Although several GCMs have produced simulations of the QBO, there is no simple set of criteria that guarantees a successful simulation."

it was asked whether this remains equally true today. Part of the answer is that the definition of "successful" has gradually shifted: over the past 15 years the number and quality of QBO-resolving models and reanalyses has increased, placing more stringent demands on what is considered a realistic QBO. Yet key uncertainties highlighted in Baldwin *et al.*, 2001 remain relevant today, such as the partitioning of QBO forcing among different equatorial wave types, the adequacy of AGCMs in representing these waves (whether by resolving or parameterizing them), and the robustness and strength of QBO teleconnections. Current simulations are more realistic, but not necessarily for the right reasons. Improved understanding of these uncertainties is hoped to emerge from analysis of the QBOi coordinated experiments, which in turn should enable increased skill in predicting the QBO, thereby moving toward realizing any additional predictive skill that resides in QBO teleconnections.

Acknowledgements

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Online resources

Workshop agenda (includes abstracts of all oral and poster presentations): **http://users.ox.ac.uk/~astr0092/OC_Agenda.html**

Workshop Twitter hashtag: **#QBOi2016**

QBOi website: **http://users.ox.ac.uk/~astr0092/QBOi.html**

QBOi experiment and data protocol: **http://users.ox.ac.uk/~astr0092/Experiments.html**

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The 12th SPARC Data Assimilation Workshop and 2016 S-RIP Workshop

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The 12th SPARC Data Assimilation (DA) workshop and the 2016 SPARC Reanalysis Intercomparison Project (S-RIP) workshop were held together in Victoria, Canada, from 17-21 October 2016. Similar to the 2014 and 2015 workshops (see Errera *et al.*, 2016), days one and two were dedicated to discussions related to DA activities, days four and five were for S-RIP, and on day three a joint session was held. Eight posters were presented during the week. For more information on each activity see **www.sparc-climate.org/activities/data-assimilation** and Fujiwara *et al.* (2016). The agenda of both meetings, the list of participants and the presentations of the SPARC DA workshop (including the joint session) can be downloaded from **https://events.oma.be/indico/event/12/overview.**

SPARC DA Workshop

The DA workshop focused on three general themes: (1) the representation of the stratosphere and mesosphere in models and analyses; (2) future directions in instruments, modelling, and DA methods; and (3) harmonization and bias correction of long-term reanalyses. The first DA session began with a series of six presentations addressing the representation of the stratosphere and mesosphere in models and analyses. The first three presentations described different aspects of the recently developed