Met Office

Evaluation of the Quasi-Biennial Oscillation in global climate models for the SPARC QBO-initiative

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The Stratosphere-troposphere Processes And their Role in Climate (SPARC) **Quasi-Biennial Oscillation initiative (QBOi)** seeks to improve confidence in QBO simulations by general circulation and earth system models (GCM & ESM). Spontaneous QBOs are likely to be more common in CMIP6 models than they were for CMIP5 as more atmospheric GCMs evolve effective combinations of **adequate vertical resolution in the stratosphere** & **parametrized accelerations due to subgrid nonorographic gravity waves (NOGWs)**. The QBOi multimodel ensemble offers a simplified analysis approach to modelling uncertainties related to the QBO and its impacts, which are assessed by running coordinated experiments with atmospheric GCMs that have simplified external forcings and boundary conditions, designed to characterize QBO representation and its response to idealised future climate scenarios.

- Results are analysed for **QBOs in 13 atmospheric GCMs** forced with both observed (Exp1) and annually repeating (Exp2) sea surface temperatures (SSTs). Overall, **modelled QBOs are very similar whether or not the prescribed SSTs vary interannually**
- Mean QBO periods in most of these models are close to, though shorter than, the period of 28 months observed in ERA-Interim (Figures 4, 5)
- Normalised grading of QBO metrics (Figure 7) provides a portrait of overall ensemble performance, highlighting areas of disagreement which signpost further research
- Amplitudes are within +/-20% of the observed QBO amplitude at 10hPa (Figures 3, 5) but **at lower altitudes (50 and 70hPa) typically about half of that observed**
- For almost all models the oscillation's amplitude profile shows **an overall upward shift compared to reanalysis and its meridional extent is too narrow** (Figures 3, 6)
- Westward phases are generally too weak, and most models have an eastward time mean wind bias throughout the depth of the QBO (Figures 1, 2)
- Intercycle period variability is realistic and in some models is enhanced in Exp1 with observed SSTs compared to Exp2 with repeated annual cycle SSTs (Figure 4)
- Mean periods are also sensitive to the SST differences between Exp1 and Exp2 but only (Figure 5) when parametrized NOGW sources are coupled to tropospheric parameters and not prescribed with a fixed value
- To simulate a QBO **all but one model used parametrized NOGWs**, which provided the **majority of the total wave forcing at altitudes above 70hPa** in most models (Figure 9). Thus the representation of NOGWs either explicitly or through parametrization is still a major uncertainty underlying QBO simulation in these present-day experiments.

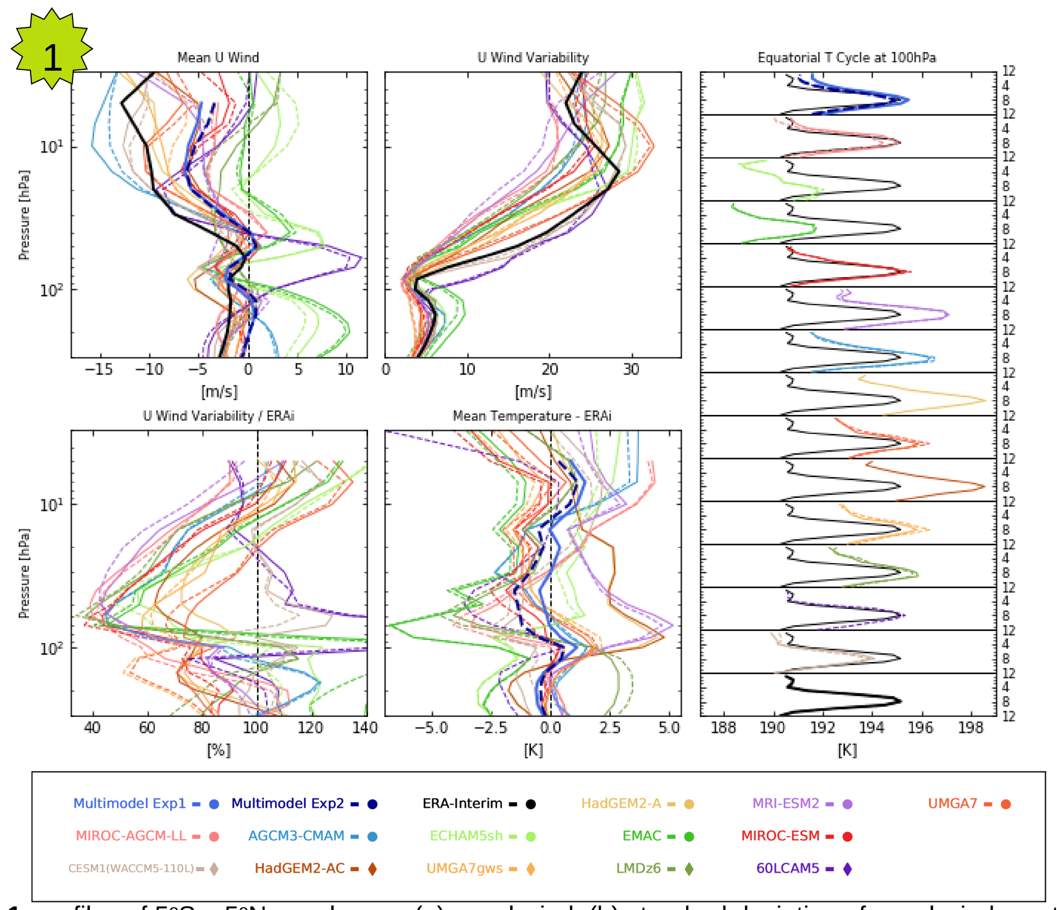


Figure 1: profiles of 5ºS – 5ºN zonal mean (a) zonal wind, (b) standard deviation of zonal wind monthly timeseries x √2, (c) as (b) but percentage relative to ERA-Interim, (d) mean temperature difference from ERA-Interim, (e) mean seasonal cycle in 100hPa equatorial zone mean temperature, over ERA-Interim (thin black) reference. **Models indicated with diamonds parametrize the source of NOGWs.**

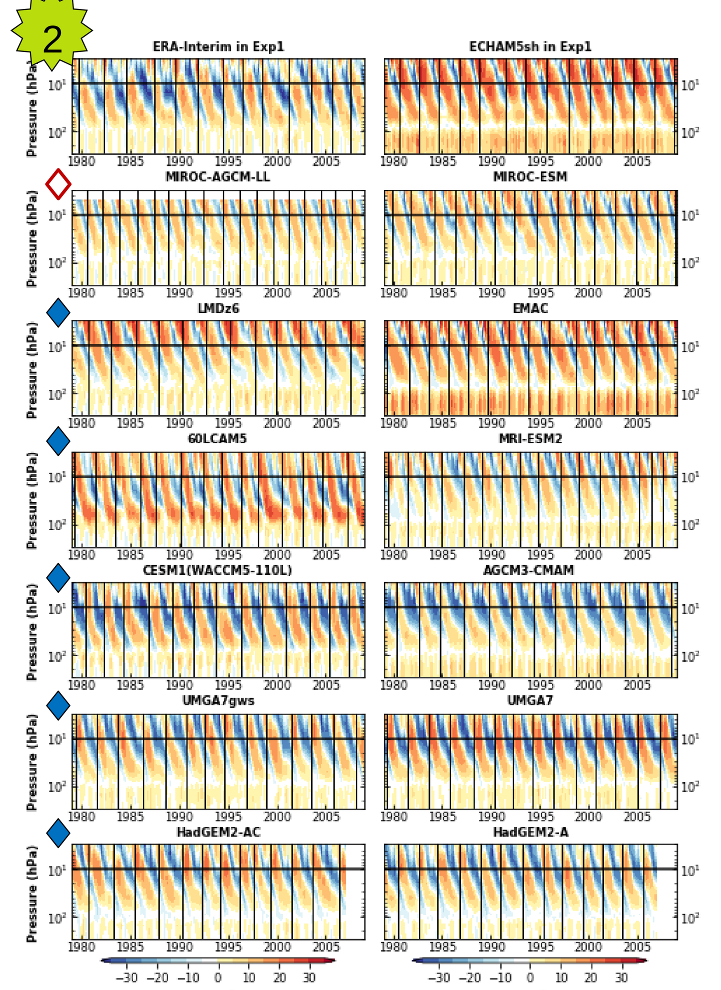
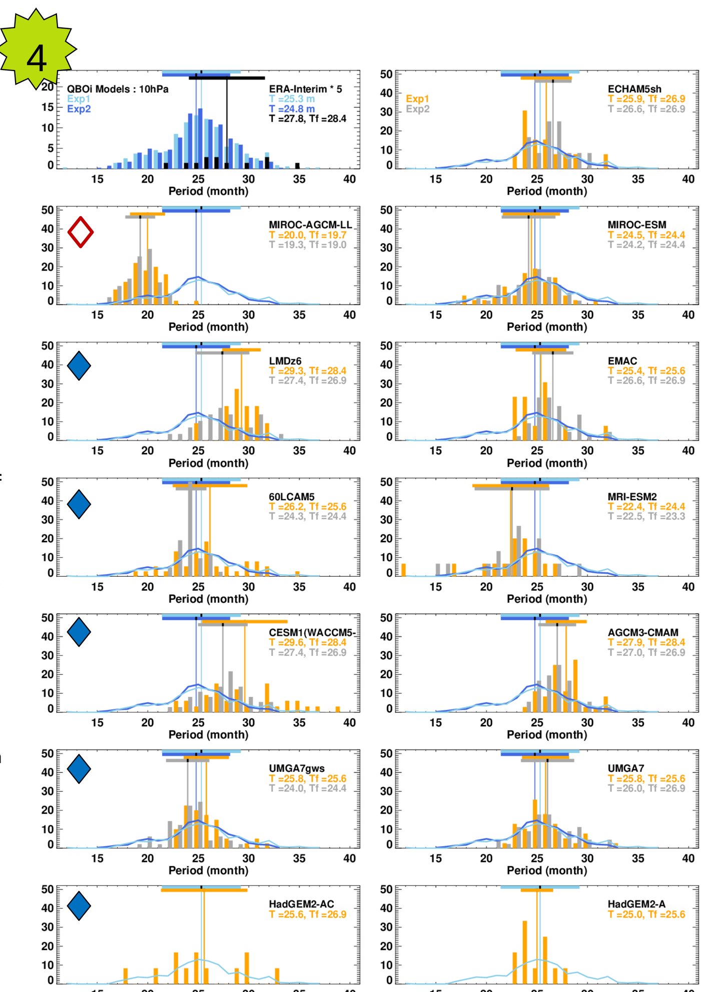
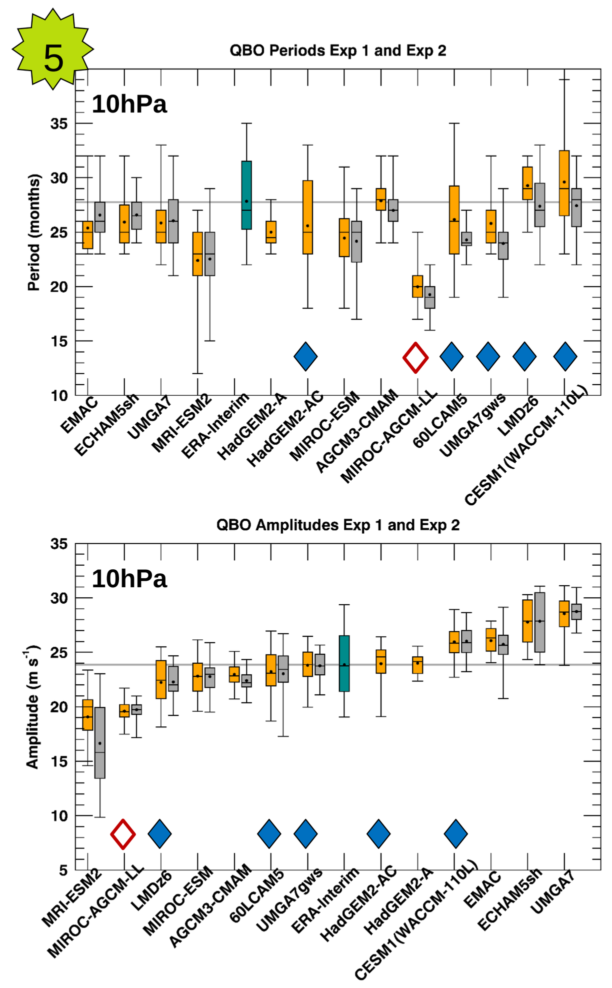


Figure 4: Histograms for distribution of QBO periods as a percentage of total number of cycles in distribution. Top left: all periods simulated for all available model ensembles for Exp1 (light blue), Exp2 (dark blue) and ERA-Interim (black, scaled as Exp1 x5). Remaining panels: histograms for each individual model ensemble in Exp1 (orange) and Exp2 (grey) with combined distributions from Exp1, Exp2 repeated as light, dark blue curves respectively. Coloured vertical lines and horizontal bars indicate mean period (T) and standard deviation for histogram of matching colour. T and mean periods inferred from peak in Fourier transform power spectrum (Tf) are indicated top right on each panel.

Figure 5: Summary of monthly and zonal mean zonal wind QBO period and amplitude distribution statistics, with maximum – minimum range (whisker), 25th to 75th percentile (box) and distribution medians (horizontal lines) for ERA-Interim (blue-green), Exp1 models (orange) and Exp2 models (grey).
* Periods ranked in order of increasing Exp1 – Exp2 mean (dot) values.
* Amplitudes ranked in order of increasing Exp1 mean values.





Parametrized sources for NOGWs

No subgrid NOGW scheme

Model	Period	10hPa amplitude	50hPa amplitude	10hPa width	50hPa width	Depth for 50% amplitude attenuation	**Mean grade**	Eastward phase: period	Eastward phase: 10hPa amplitude	Eastward phase: 50hPa amplitude	Westward phase: period	Westward phase: 10hPa amplitude	Westward phase: 50hPa amplitude
60LCAM5	0.84	0.93	0.46	0.91	0.60	0.99	0.79	0.66	0.57	0.00	0.64	0.55	0.19
ACM3−CMAM	1.00	0.90	0.00	0.49	0.07	0.95	0.57	0.68	0.92	0.84	0.79	0.94	0.00
CESM1−(WACCM5−110L)	0.84	0.77	0.56	0.82	0.20	0.65	0.64	0.89	0.86	0.55	0.92	0.82	0.73
ECHAM5sh	0.82	0.57	0.00	0.44	0.00	0.72	0.42	0.28	0.00	0.03	0.37	0.68	0.00
EMAC	0.77	0.76	0.00	0.63	0.14	0.91	0.54	0.44	0.39	0.98	0.43	0.81	0.00
HadGEM2−A	0.74	0.98	0.49	0.79	0.19	0.71	0.65	0.91	0.81	0.28	0.81	0.86	0.83
HadGEM2−AC	0.79	0.99	0.06	0.78	0.01	0.91	0.59	0.96	0.60	0.26	0.78	0.68	0.25
LMDz6	0.87	0.82	0.00	0.28	0.00	0.96	0.49	0.28	0.61	0.00	0.66	0.44	0.00
MIROC−AGCM−LL	0.27	0.53	0.00	0.21	0.46	0.87	0.39	0.92	0.86	0.22	0.37	0.27	0.00
MIROC−ESM	0.69	0.88	0.00	0.36	0.29	0.96	0.53	0.75	0.88	0.15	0.55	0.75	0.00
MRI−ESM2	0.50	0.47	0.00	0.32	0.18	0.90	0.40	0.91	0.90	0.00	0.58	0.23	0.00
UMGA7	0.82	0.48	0.59	0.78	0.20	0.87	0.62	0.86	0.37	0.86	0.92	0.85	0.53
UMGA7gws	0.81	1.00	0.07	0.65	0.32	0.90	0.62	0.93	0.68	0.38	0.87	0.72	0.17
multi−model mean	0.80	1.00	0.16	0.57	0.18	0.98	0.61	0.85	0.66	0.77	0.71	0.71	0.00

Grade scale: Some work to be done … Well simulated (0.05 – 0.95)

Figure 7: Quantitative performance grades for comparing QBO metrics between Exp1 models and ERA-Interim. Box shadings and numbers denote values of the normalised grade. A value of 1.00 and dark blue shading for a specific metric (column) indicates exact agreement of a given model (row) with ERA-Interim, while numbers in white indicate agreement between the two within the 95% confidence level. Numbers close to zero and red shading indicate poor agreement between a model and ERA-Interim: zero indicates that the magnitude of model bias relative to ERA-Interim is more than three times the standard deviation obtained from ERA-Interim for that metric. On the bottom row, the multimodel mean shows the grades for the mean of mean metrics from individual models: white indicates that the multimodel mean of the mean metrics agrees with the ERA-Interim mean metric with 95% confidence according to a single sample two-sided t-test.

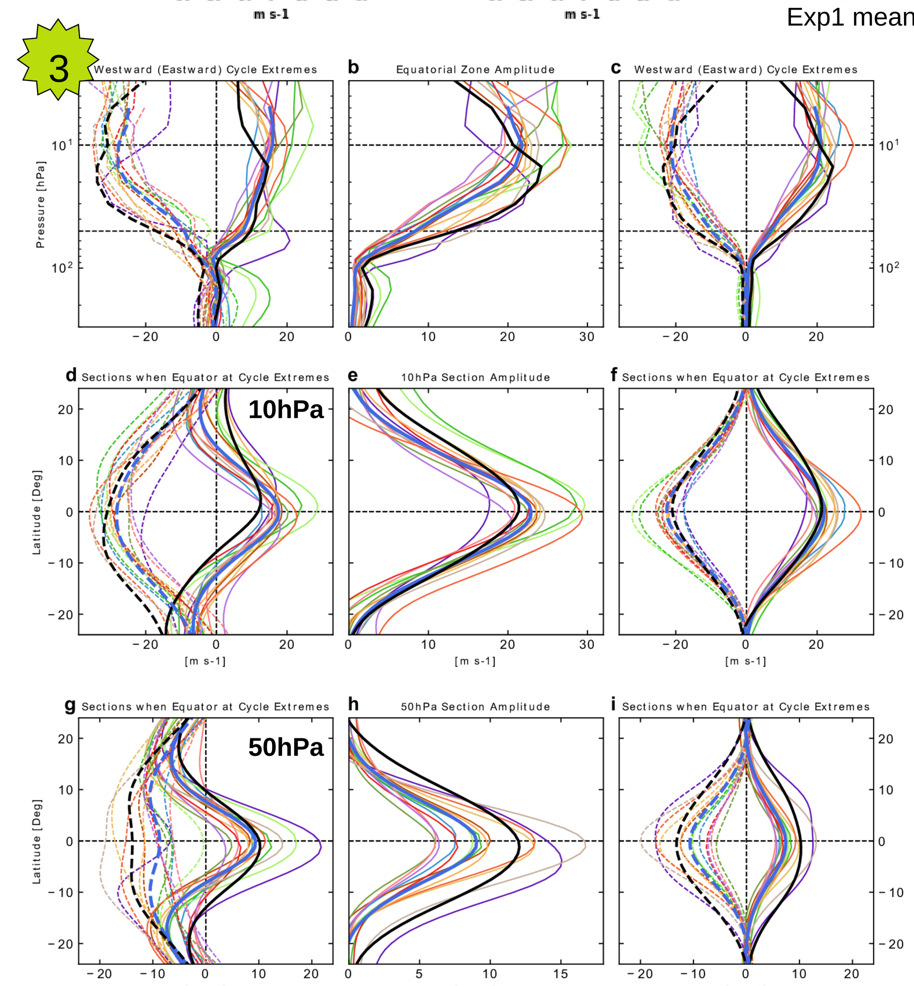
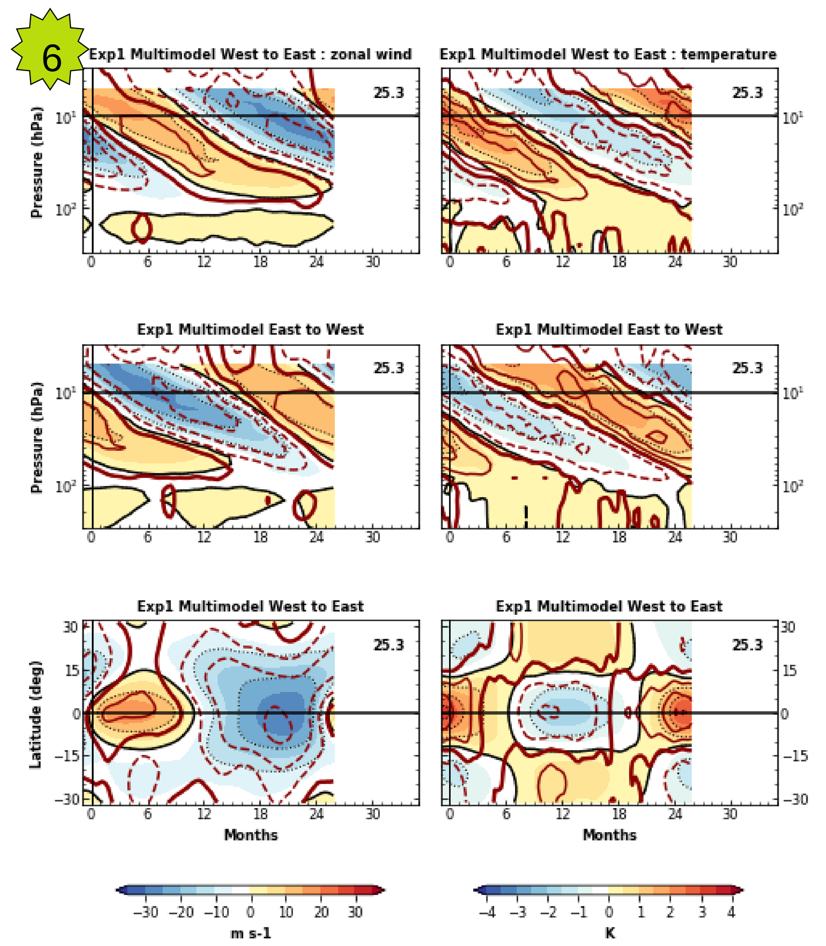


Figure 3: QBO zonal mean zonal wind for Exp1 ensembles and ERA-Interim. (a) vertical profiles of extremes from mean cycles (westward phases – dashed; eastward phases – solid), (b) total amplitudes calculated from extremes, (c) as (a) but from deseasonalised wind, (d) mean meridional cross-sections of 10hPa wind taken at instants when cycle on equator reaches extremes (westward phases – dashed; eastward phases – solid), (e) section QBO amplitudes estimated (where positive) from difference in section extremes, (f) as (d) but from deseasonalised wind, (g, h, i) as (d, e, f) but at 50hPa.

Figure 6: multimodel mean of model QBO cycles in Exp1 (shading) compared to the ERA-Interim mean cycle (thick red contours [left] every 10 m s^{-1} or [right] every 1 K) where (a, b) are cycles of zonal wind, temperature between westward to eastward transitions as per vertical lines in **Figure 2**, (c, d) are as (a, b) but between eastward to westward transitions, (e, f) as (a, b) but depicting latitudinal structure of cycles at 10hPa. The duration of all QBO cycles are scaled to the Exp1 multimodel mean period to facilitate both the averaging and the comparison.



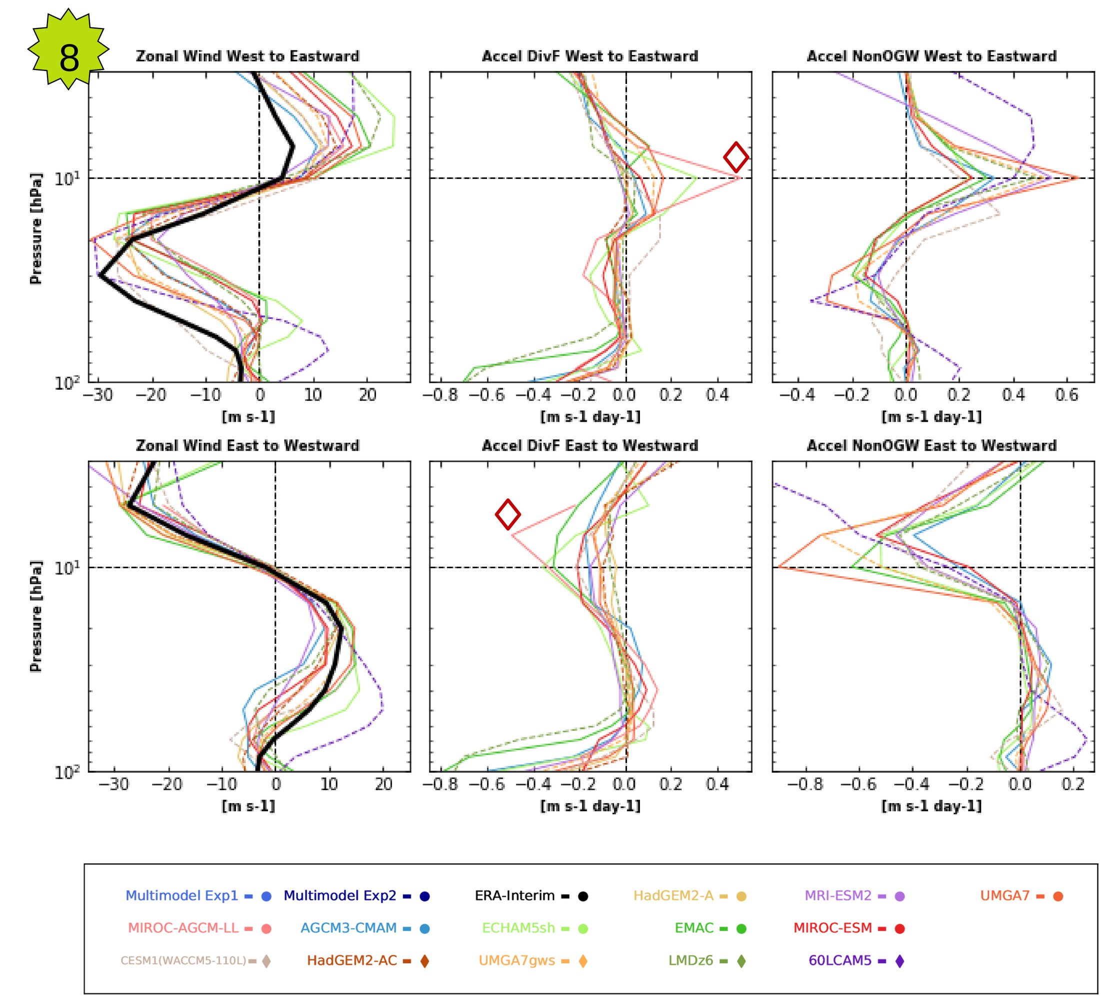


Figure 8: equatorial (5ºS – 5ºN) mean profiles composited at the first month after each (upper) 10hPa westward to eastward QBO wind transition, (lower) eastward to westward transition for Exp1 first ensemble members. Left to right: zonal wind, mean-flow acceleration by resolved waves, mean-flow acceleration by parametrized NOGWs.

Figure 9: (upper) amplitudes, (lower) westward and eastward extremes of vertical profiles of QBO mean cycles (all available Exp1 ensemble members) of zonal mean accelerations. Left to right: resolved wave forcing, NOGW forcing, percentage of combined forcing due to NOGW. Multimodel mean cycle is mean of model cycles and excludes model without NOGW parametrization.

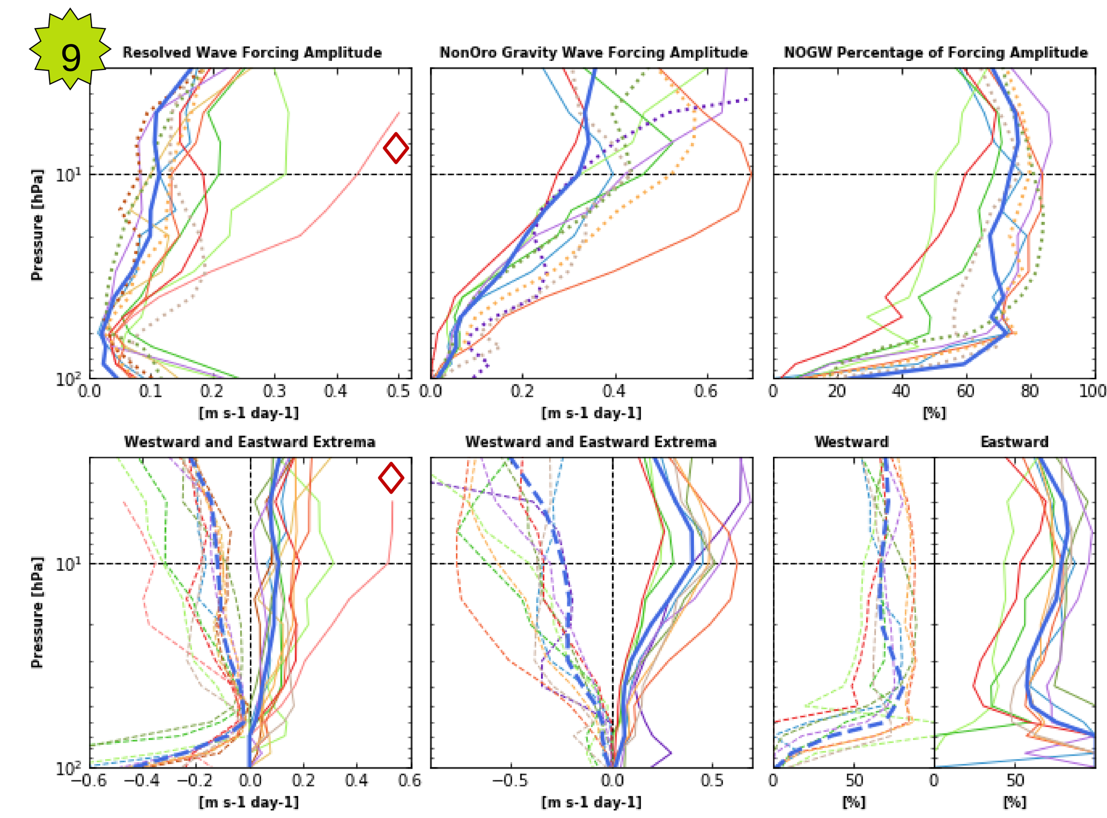
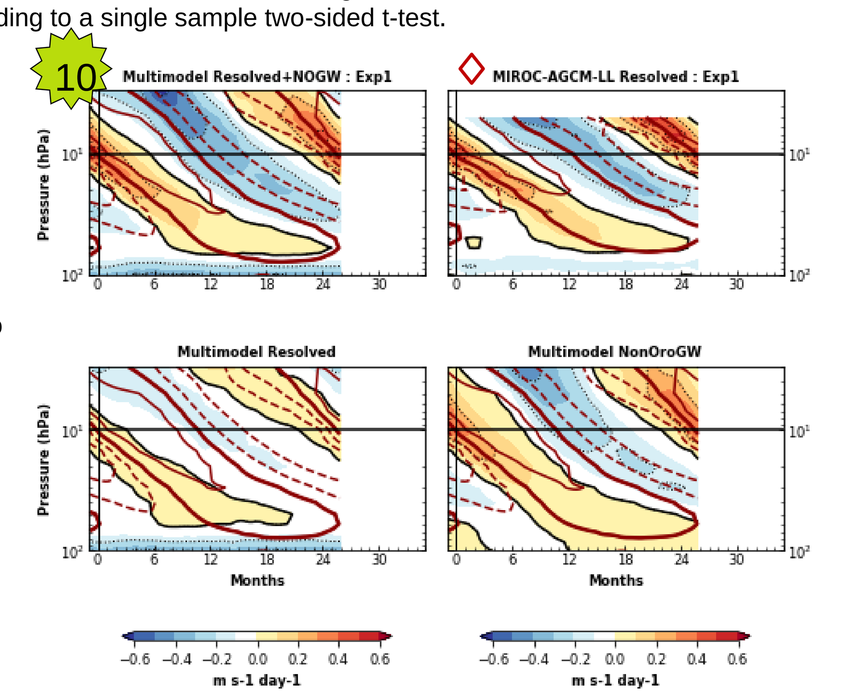
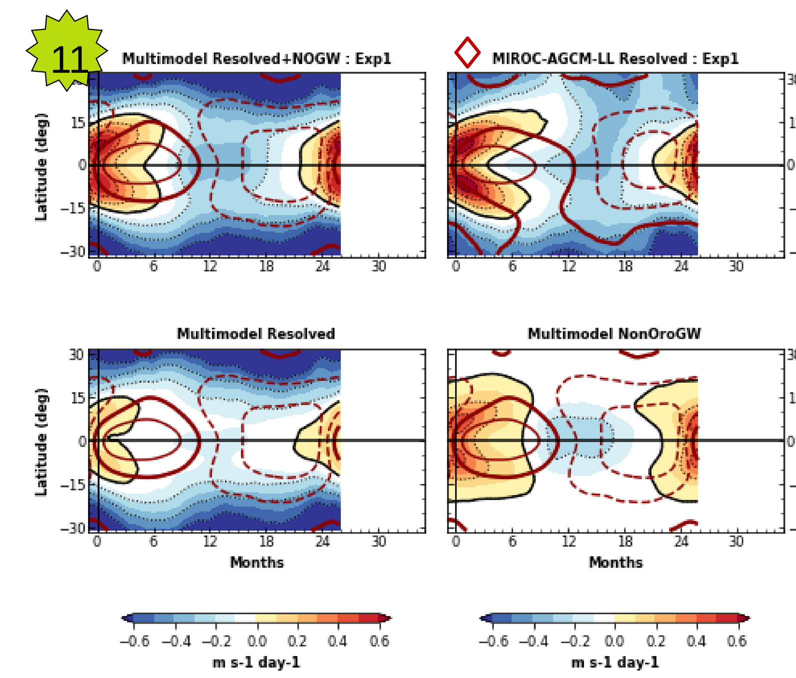


Figure 10: mean QBO cycle, defined by 10hPa westward to eastward zonal wind transitions and normalised to the multimodel mean period, for Exp1 5ºS – 5ºN monthly and zonal mean accelerations of mean flow (shaded) with corresponding zonal wind for reference (thick red contours every 0.2m s^{-1} day^{-1}) due to (upper) sum of resolved and subgrid NOGWs for all model ensembles excluding MIROC-AGCM-LL, versus resolved waves for MIROC-AGCM-LL only, (lower) splitting sum into resolved and NOGW components again excluding MIROC-AGCM-LL.

Figure 11: as for **Figure 10** but depicting QBO cycles at subtropical latitudes on 10hPa pressure level.





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