

Table S1. Metrics of the vertical and latitudinal extent of the QBO. Bold indicates that the value is within 1 standard deviation (SD) of ERA5.

Model	Vertical extent (km)		Latitudinal extent (°)			
	NoNudge	ObsQBO	10 hPa		50 hPa	
			NoNudge	ObsQBO	NoNudge	ObsQBO
BCC-CSM2-MR	7.8	8.6	23.0	24.1	20.2	21.5
CAS-ESM	6.3	7.9	25.4	28.7	20.8	24.4
E3SMv2	7.1	7.3	23.2	27.6	22.6	27.0
EC-Earth3	7.0	8.2	21.0	27.6	18.5	25.0
GFDL-ESM4	5.1	8.6	17.1	25.8	18.1	23.6
GRIMs4.0	No	8.0	No	28.0	No	22.2
HadGEM3GA7-1	8.6	8.6	22.6	27.8	20.1	25.6
LMDz6	7.5	8.6	20.7	28.7	17.4	22.7
MIROC6.1, p1	5.7	7.8	23.9	29.6	20.6	25.3
MIROC6.1, p2	7.6	7.8	22.5	28.1	18.7	24.6
MRI-ESM2.0	9.1	7.8	24.5	32.8	18.5	28.7
Multi-model mean	7.2	8.1	22.4	28.1	19.6	24.6
ERA5	8.7±1.6		27.9±4.7		25.2±4.4	

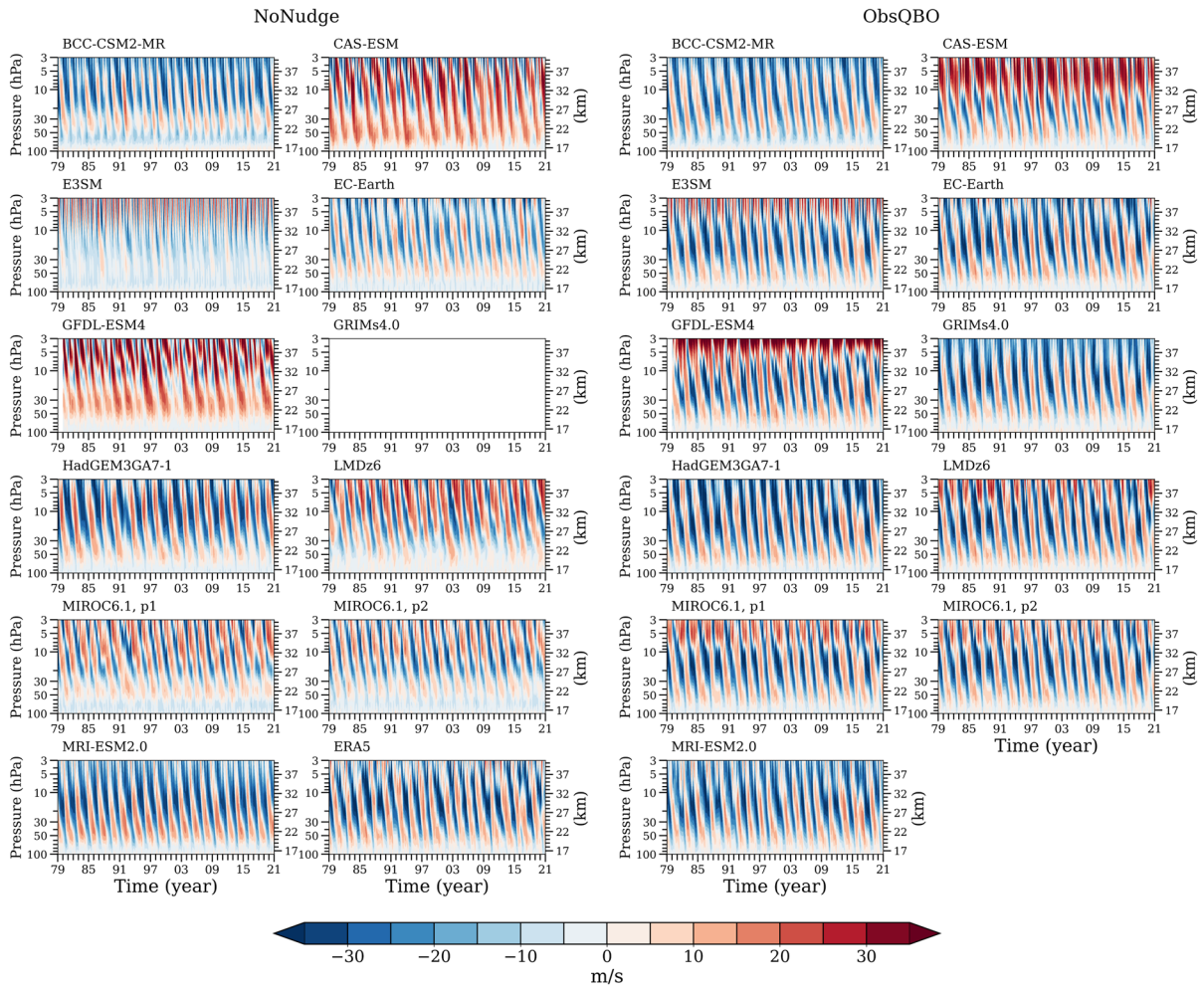


Figure S1: Zonal-mean zonal winds averaged between 5°N and 5°S from the first ensemble member of each QBOi model. GRIMs4.0 does not submit the Exp1 experiments, as it does not internally generate the QBO. The zonal winds of ERA5 are plotted as a reference.

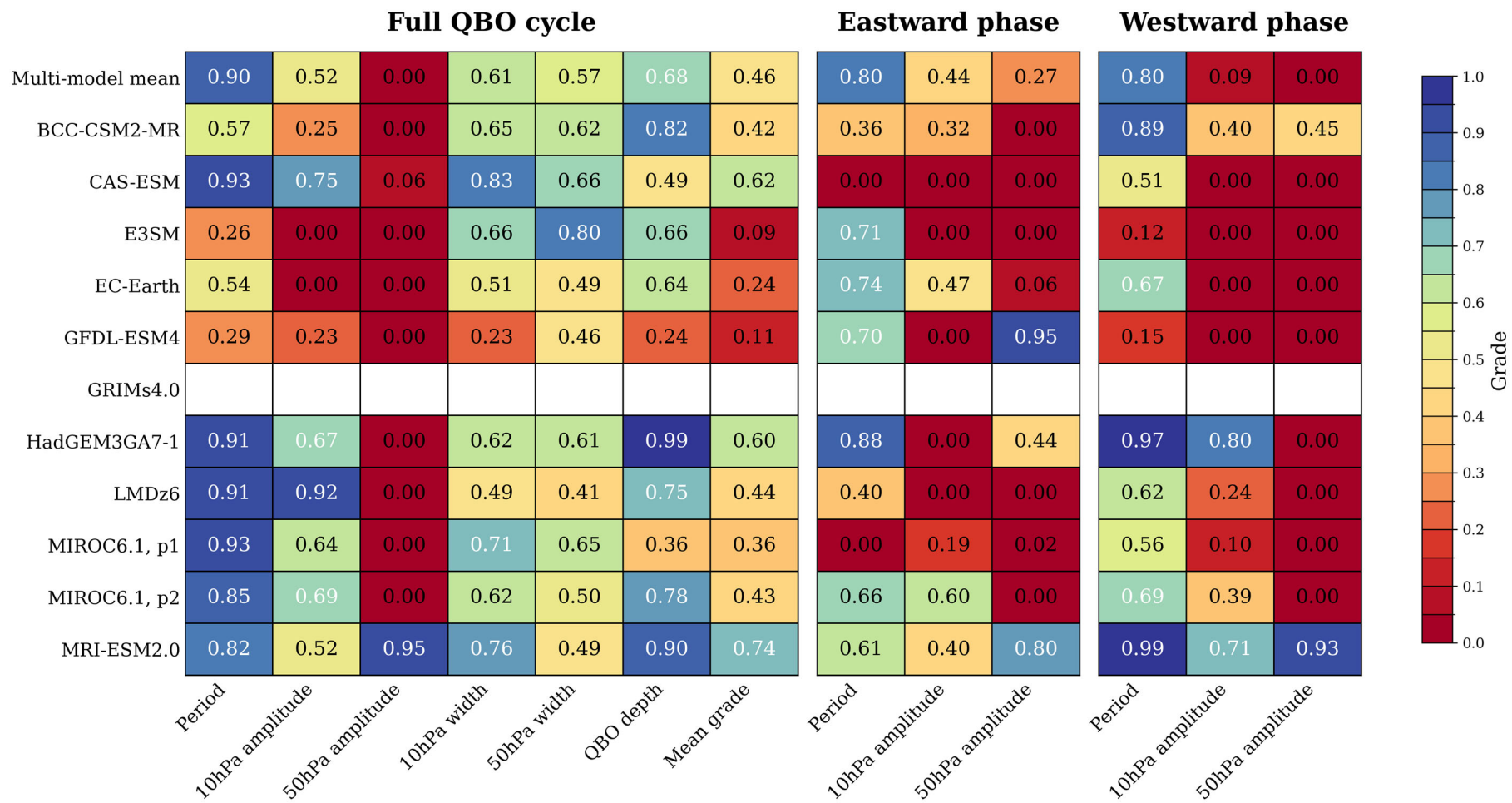


Figure S2: Same as Fig. 2 but for the NoNudge experiments.

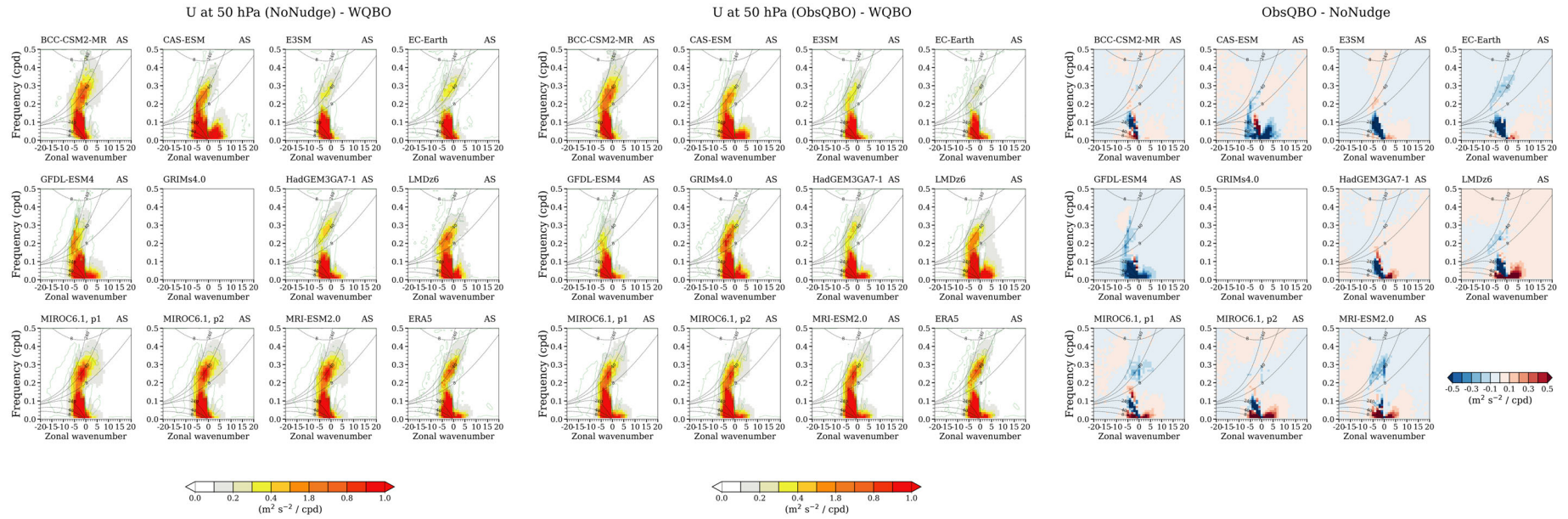


Figure S3: Same as Fig.4 but for the WQBO phases.

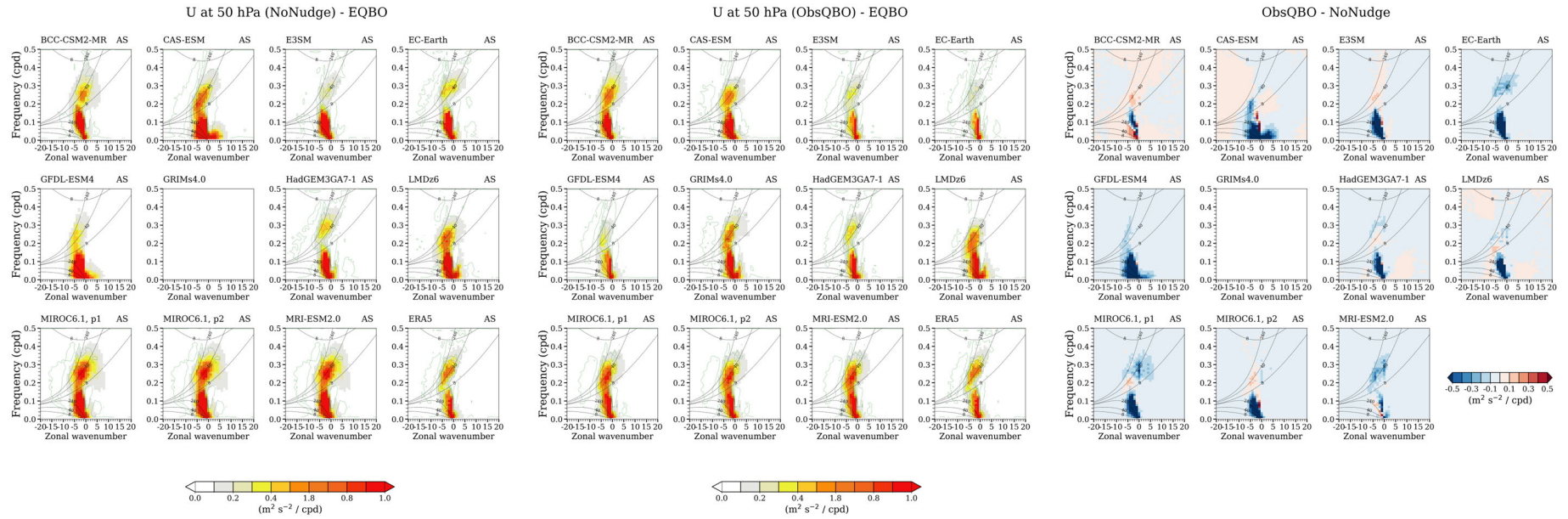


Figure S4: Same as Fig.4 but for the EQBO phases.

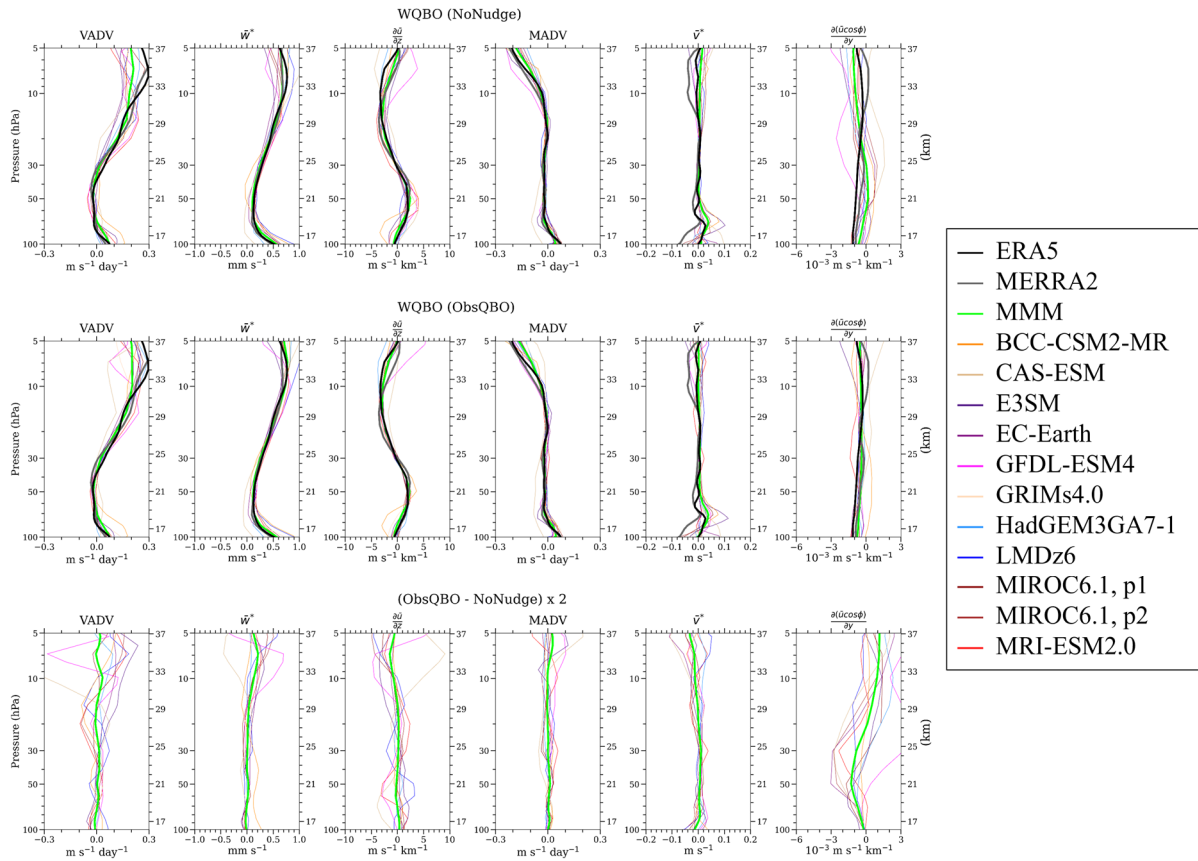


Figure S5: Composites of the vertical advection (VADV), residual vertical velocity, vertical wind shear, meridional advection (MADV), residual meridional velocity, and meridional wind shear averaged between 5°S and 5°N during the WQBO phases for (top) NoNudge, (middle) ObsQBO, and (bottom) their differences. For clarity, the components in ObsQBO minus NoNudge are multiplied by two.

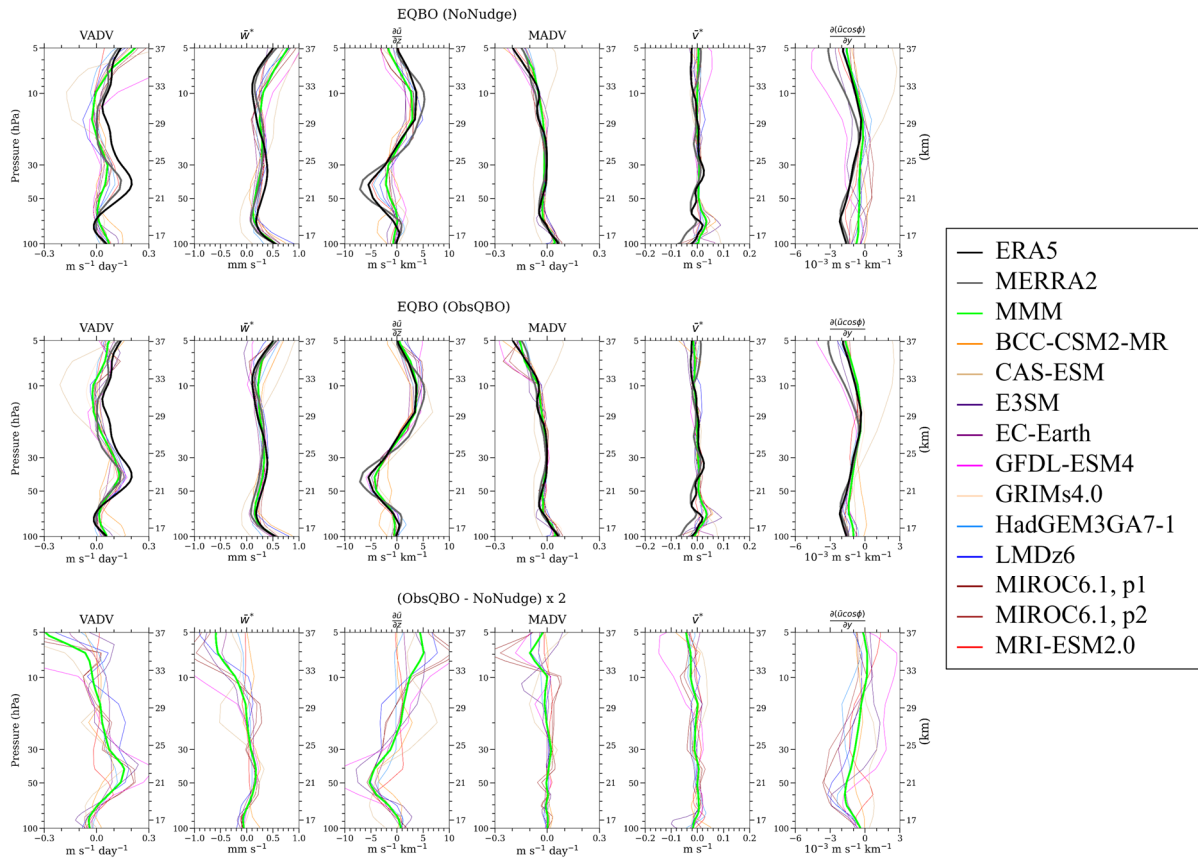


Figure S6: Same as Fig. S5 but for the EQBO phases.

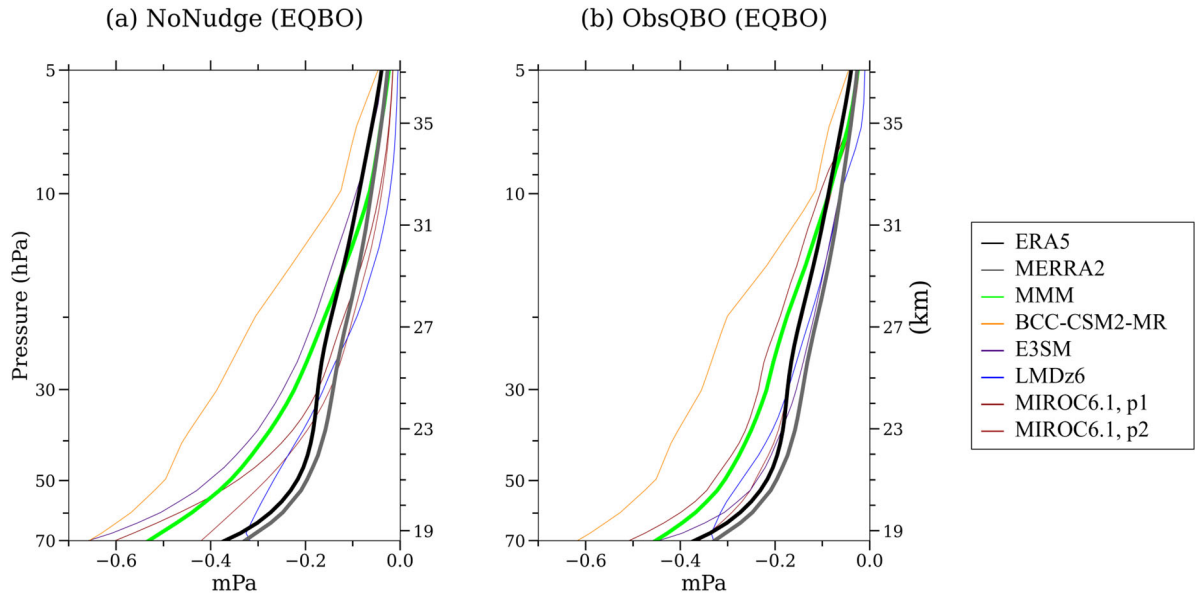


Figure S7: Composite of the vertical component of Eliassen–Palm flux (EPF) of Kelvin waves averaged between 5°S and 5°N during EQBO phases for (a) NoNudge and (b) ObsQBO experiments.

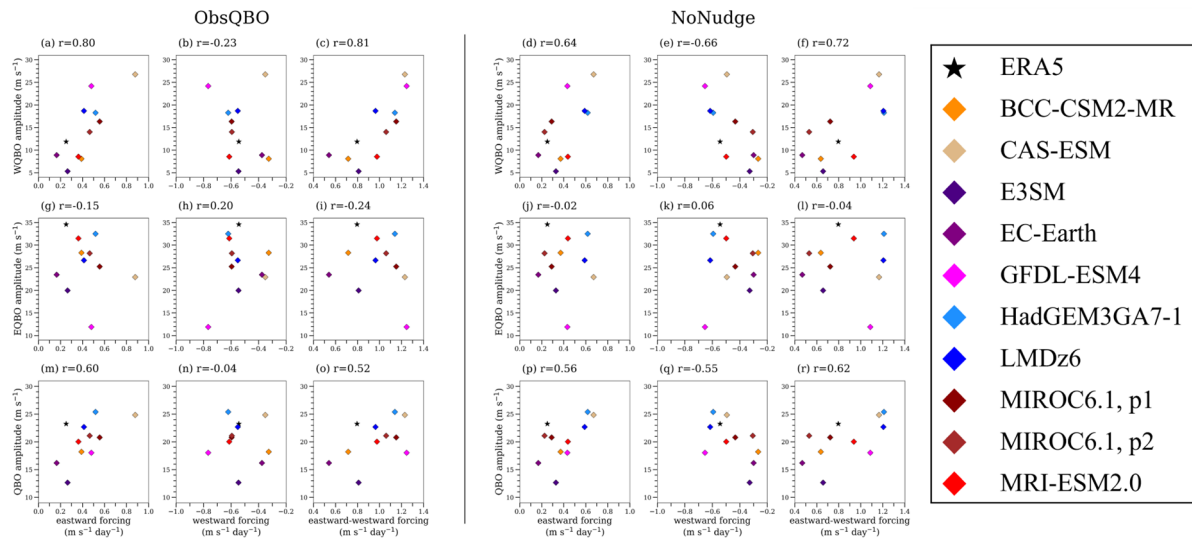


Figure S8: Scatter plots depicting the relationship between the wave forcing at 10 hPa shown in Fig. 16 and the (top) WQBO, (middle) EQBO, and (bottom) total QBO amplitudes. The nine leftmost panels correspond to wave forcing in ObsQBO experiments, whereas the nine rightmost panels correspond to that in NoNudge experiments. For each experiment set, the columns represent: (left) eastward wave forcing, (center) westward wave forcing, and (right) eastward minus westward wave forcing.

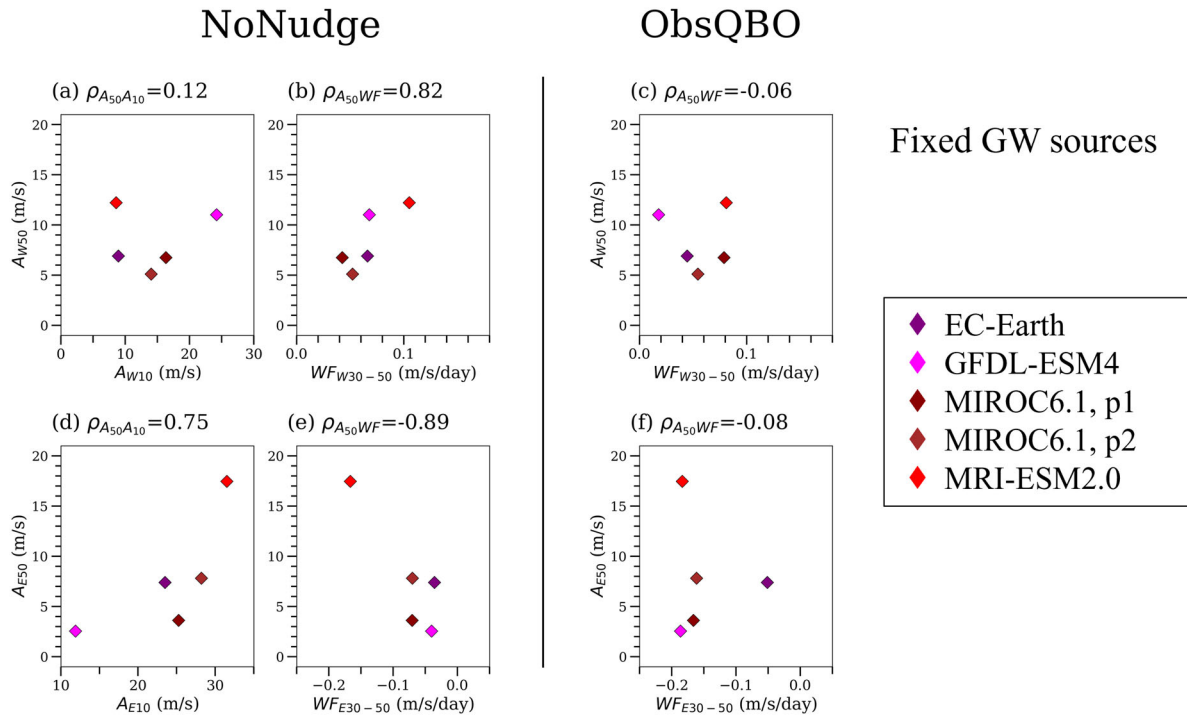


Figure S9: Same as Fig.17 but the models employing with the fixed-source gravity wave parameterization.

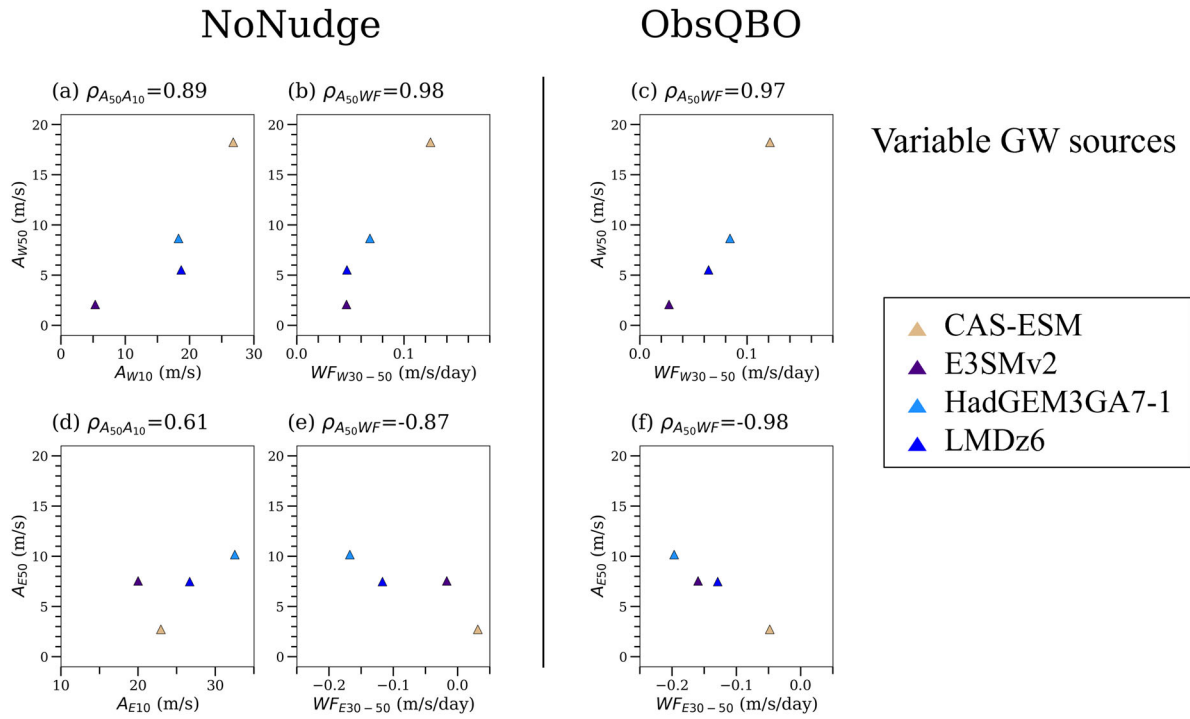


Figure S10: Same as Fig.17 but the models employing with the source-dependent gravity wave parameterization.