The QBO impacts on tides and the SAO

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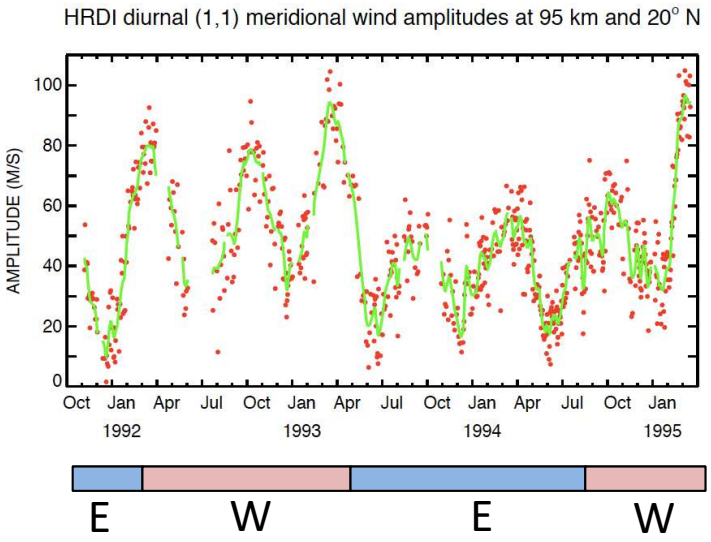
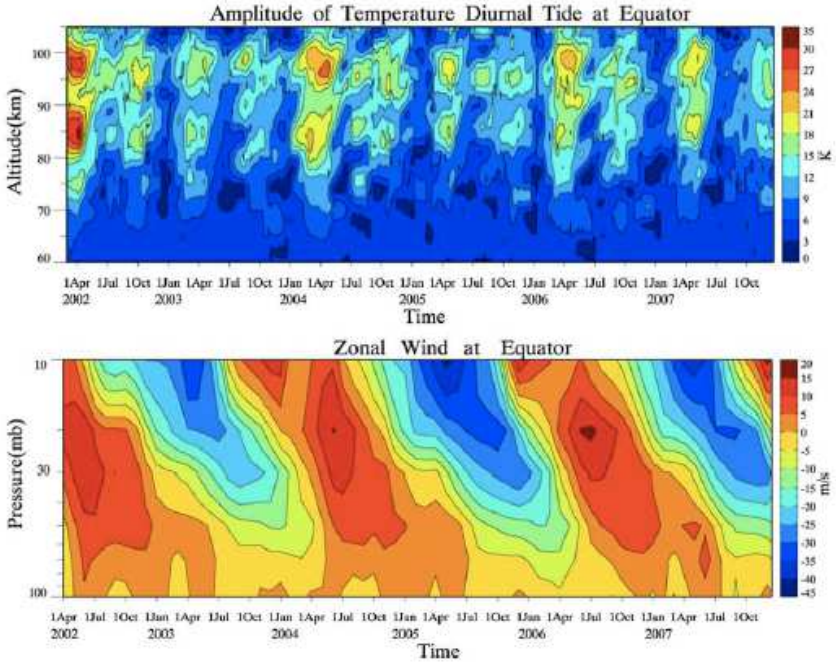
QBO variation in amplitude of DW1 tide

QBO-E =>> easterly (westward)
QBO-W=>> westerly (eastward)

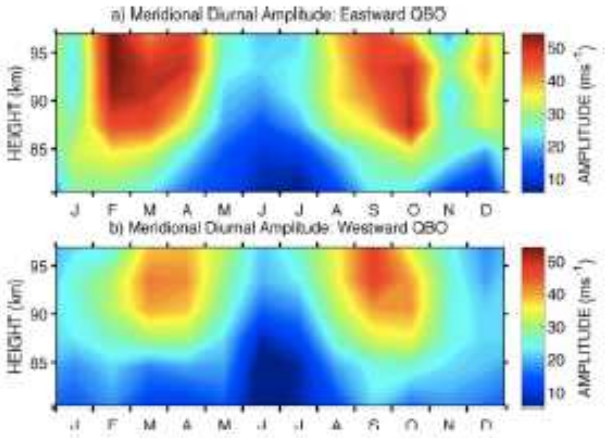
HRDI tidal v'
Burrage et al., GRL, 1995



SABER tidal T'
Xu et al., JGR, 2009



Multiple observations show that the diurnal tide amplitude in the upper mesosphere varies in phase with the QBO winds in the tropical lower stratosphere.



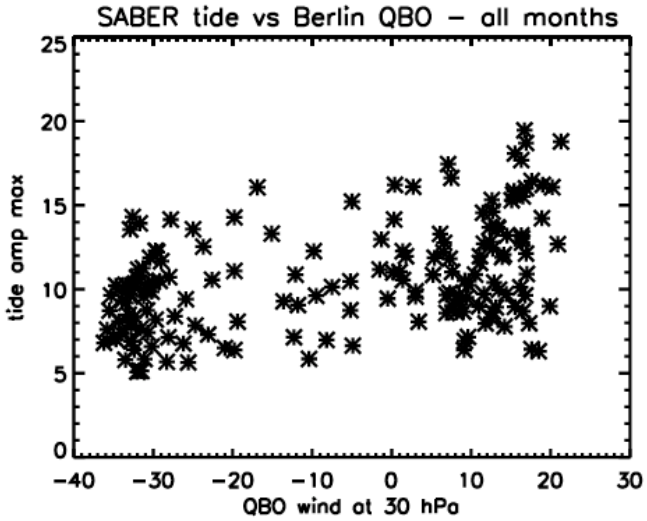
Ascension Is. radar (8°S)
Davis et al. ACP 2013

tool for investigating the mechanism: WACCM4

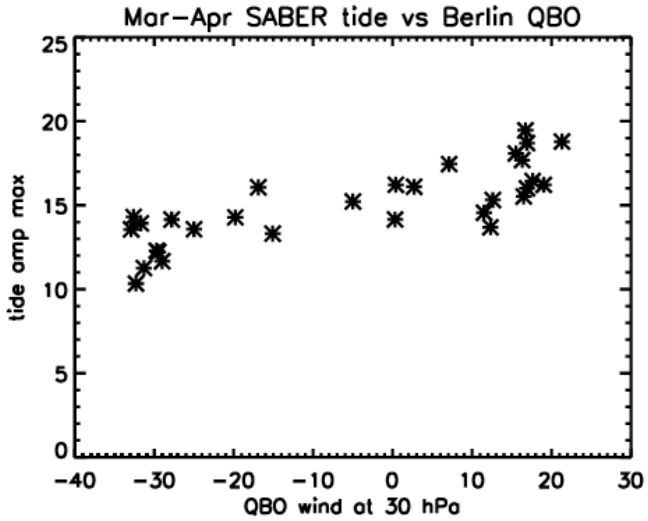
- WACCM4 is the NCAR Whole Atmosphere Community Climate Model.
- NOTE: This version of WACCM *does not* spontaneously generate a QBO.
- QBO is imposed by nudging to QBO winds over the pressure range 100-0.3 hPa.
- Winds for nudging are based on Singapore radiosonde data as compiled by Freie Universität Berlin.
- Current simulations are 12 years (2002-2013) – longer simulations are in progress but not yet complete.

DW1 amplitude in the MLT vs QBO wind

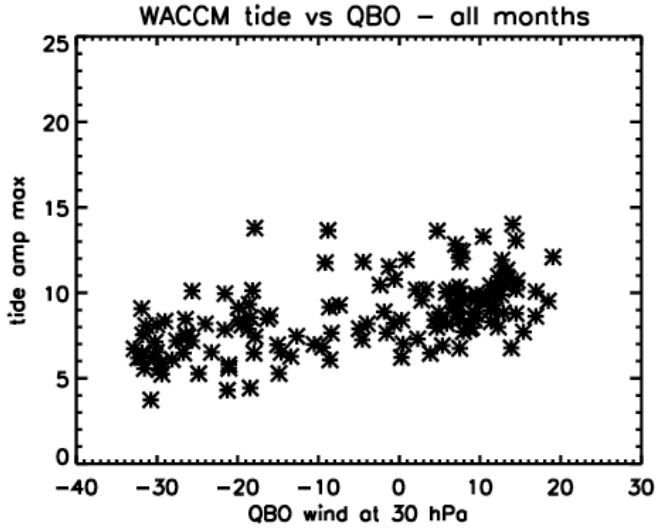
SABER all months



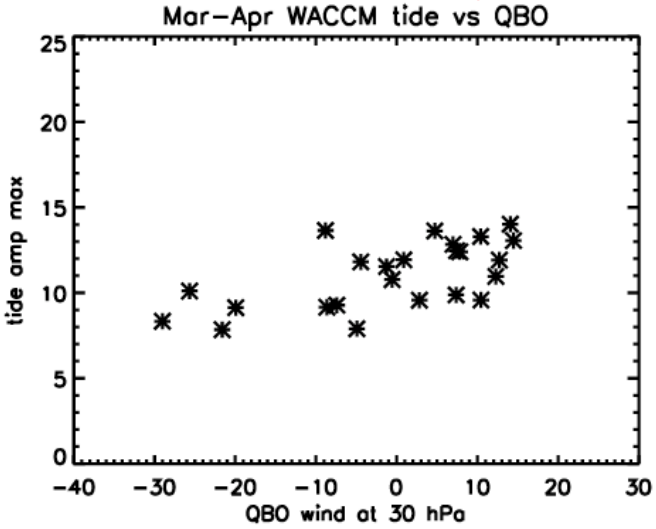
SABER March-April



WACCM all months

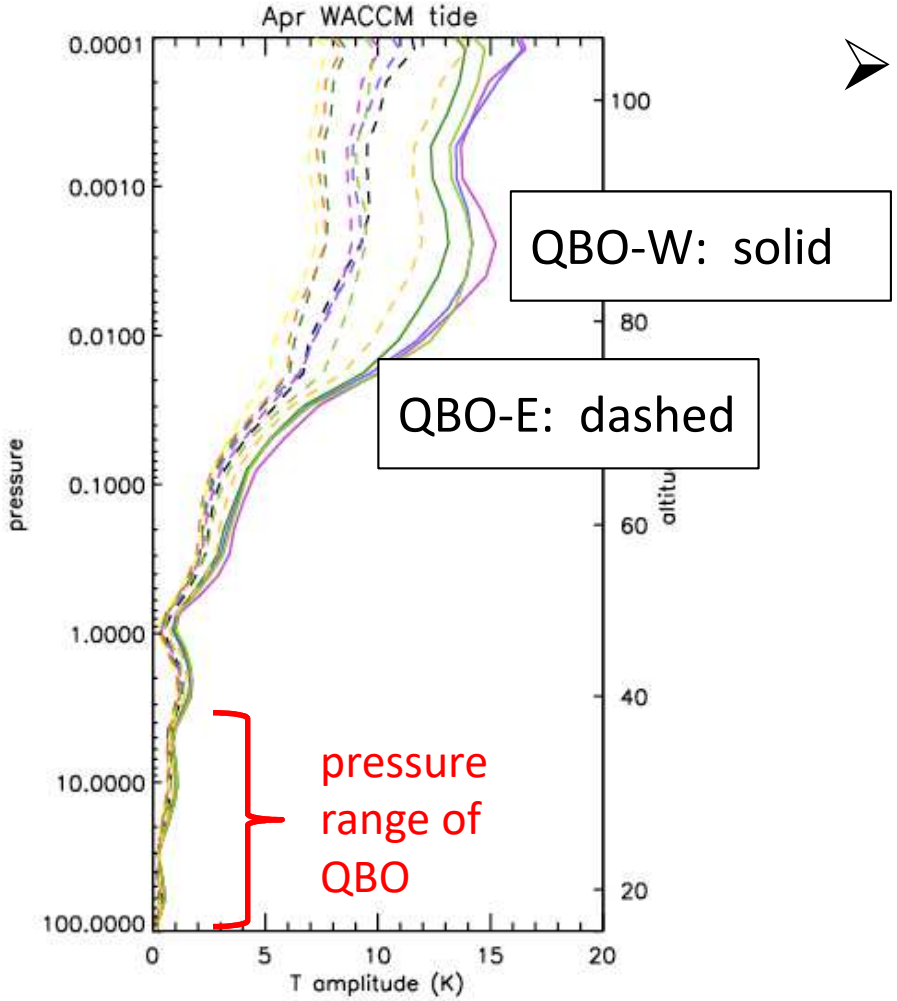


WACCM March-April



DW1 amplitude in WACCM is smaller than that in SABER and other observations – a long-standing problem.

WACCM QBO variation in DW1 tide

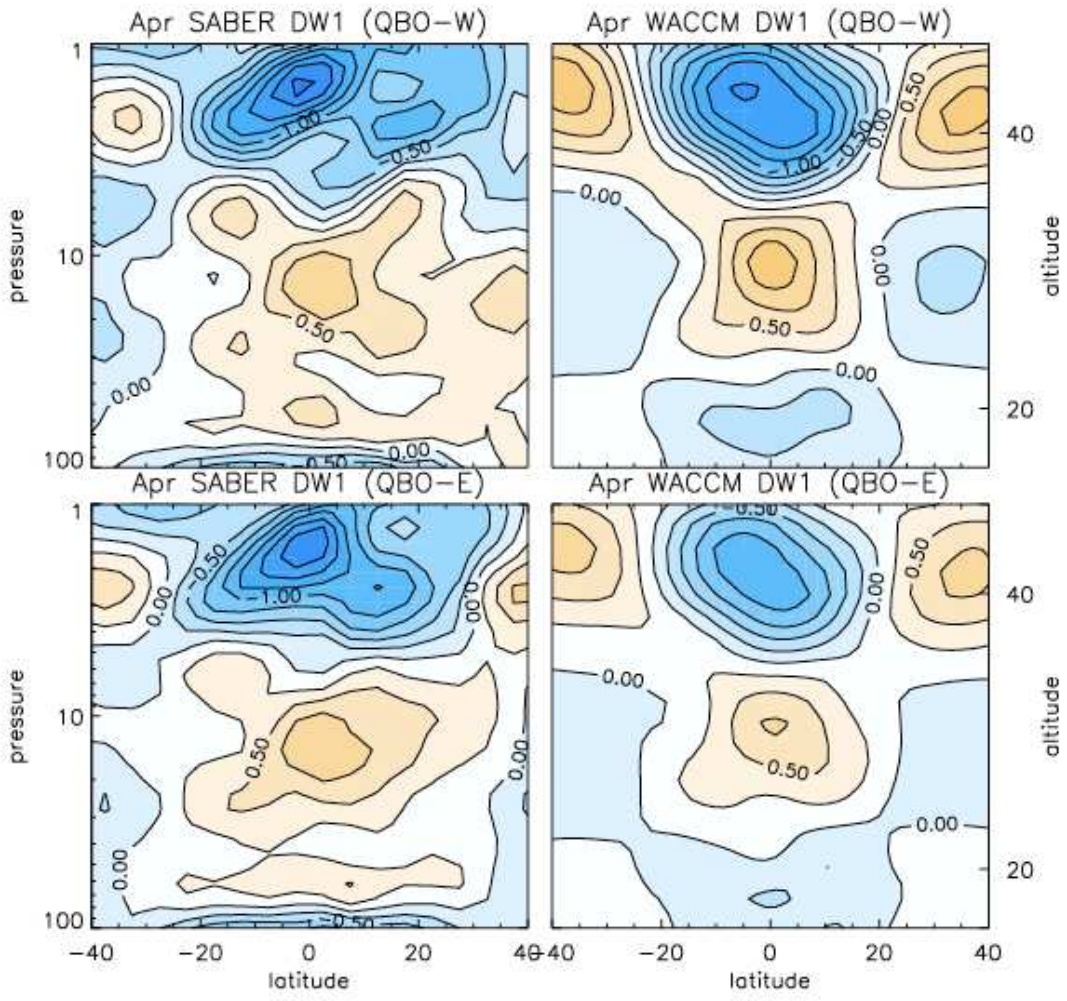


- Use WACCM to explore processes that contribute to the QBO in tidal amplitude:
  - stratospheric ozone (and therefore heating) varies with QBO
  - direct impact of stratospheric zonal wind on tide forcing or propagation
  - mean winds and waves above the QBO region may have a coordinated interannual variation due to variability in wave forcing or background atmosphere

QBO-W = westerly (eastward, positive)
QBO-E = easterly (westward, negative)

At what altitude does the QBO tidal signal originate?

SABER (obs) WACCM

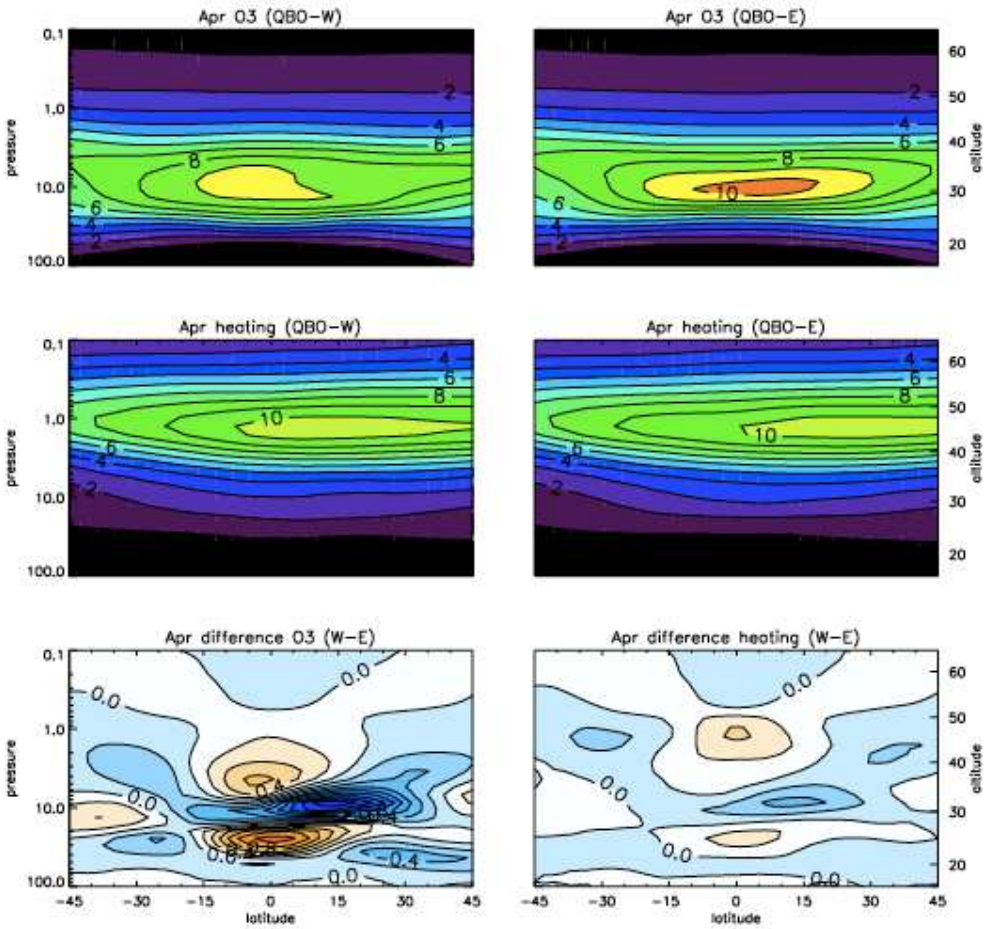


snapshot of tidal temperature perturbations

Both obs and WACCM indicate that difference in QBO-W and QBO-E already exists in the stratosphere.

Ozone variation due to QBO

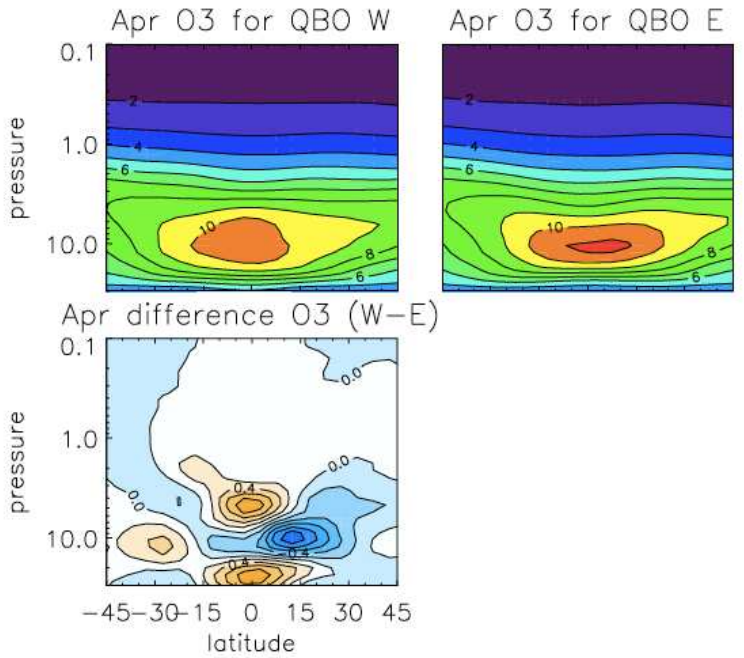
WACCM



QBO variation in ozone is due to:

- transport by perturbation v and w
- temperature dependent reactions
- QBO in NOx

SABER (obs)



similar magnitude and pattern

experiments with SC-WACCM
SC="specified chemistry"

1. Run WACCM with interactive chemistry and nudged QBO. Save all radiatively active chemical fields. There will be variation in ozone and ozone heating due to the QBO.
2. Run WACCM again but with the nudging of the QBO disabled and save chemical fields.
3. Use ozone and other composition from these two runs in the SC experiments.

ozone: no QBO
zonal wind: no QBO

ozone: no QBO
zonal wind: QBO

ozone: QBO
zonal wind: no QBO

ozone: QBO
zonal wind: QBO

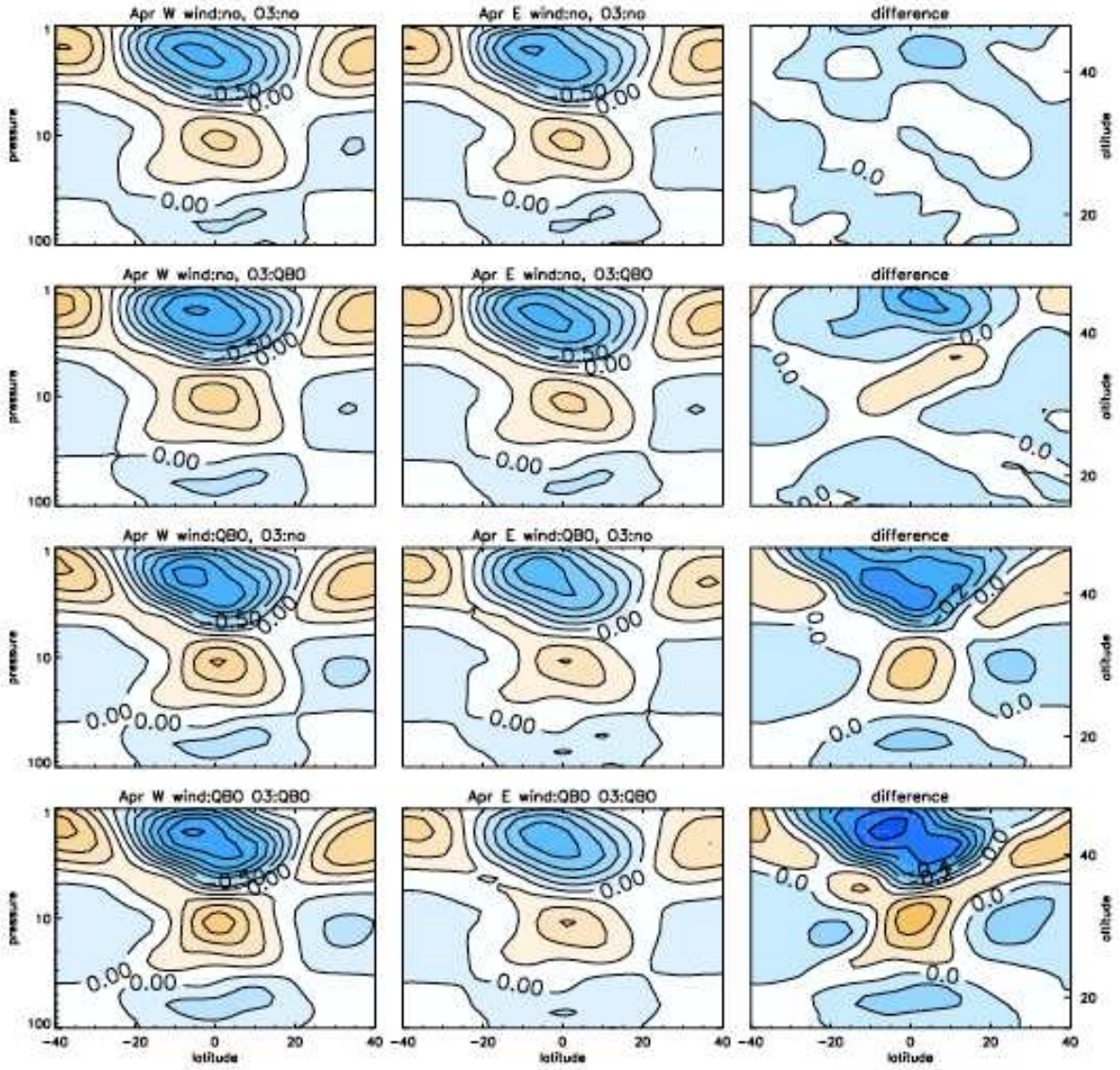
temperature tide in the stratosphere

wind: no QBO
O3: no QBO

wind: no QBO
O3: QBO

wind: QBO
O3: no QBO

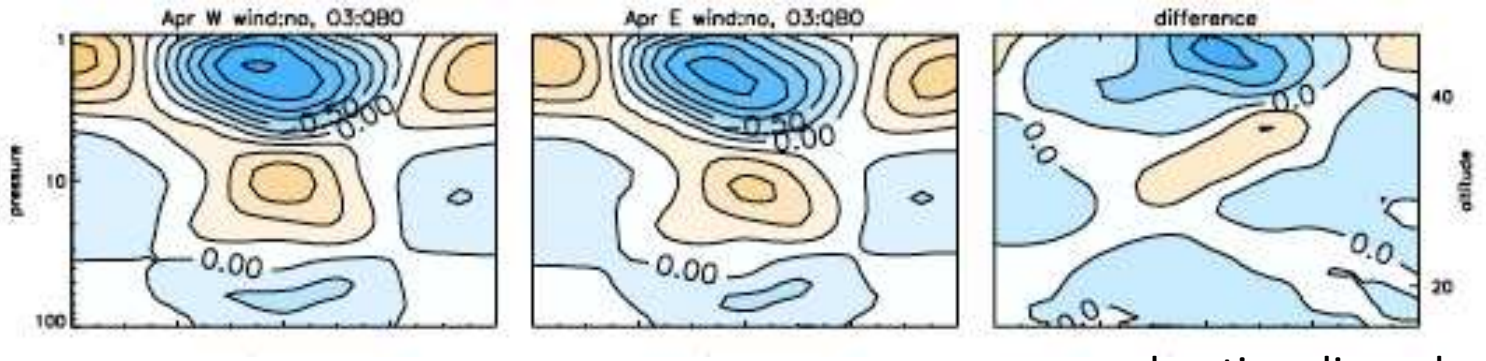
wind: QBO
O3: QBO



Mechanism for QBO in heating to affect the tide

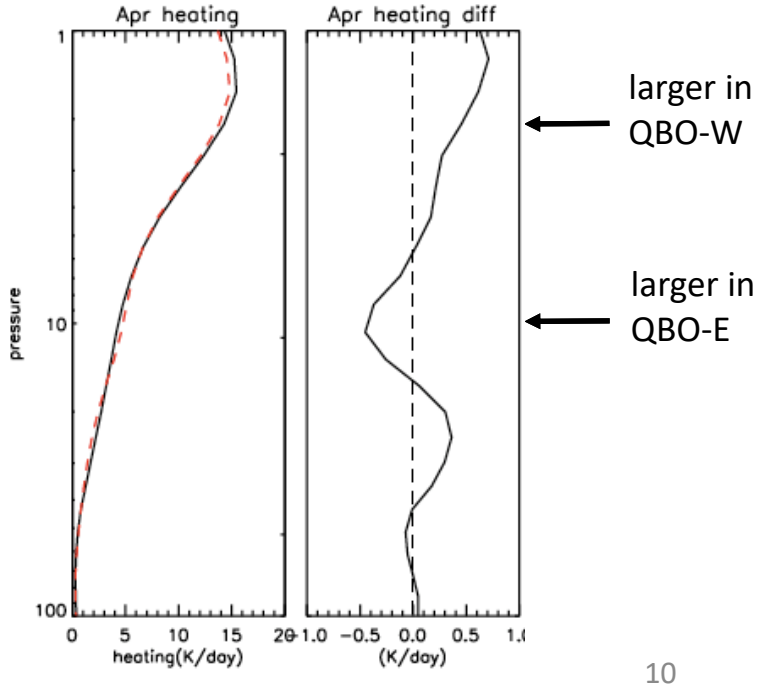
wind: no QBO
O3: QBO

These are snapshots at local midnight.

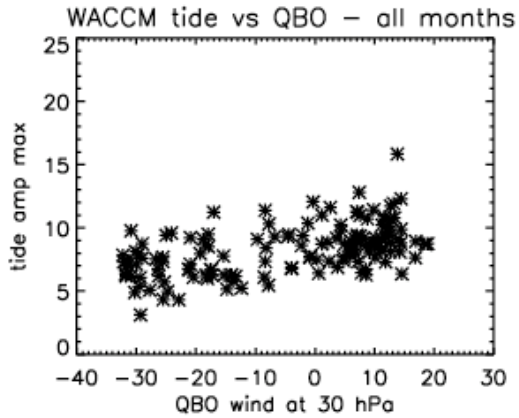


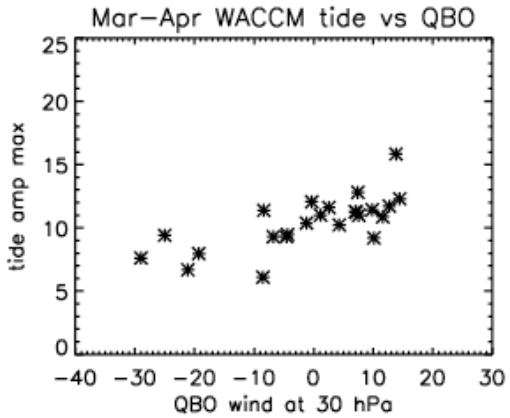
- Ozone heating gives a large forcing (up to 15K/day in the stratosphere) with a phase of 12 hrs, i.e. maximum at local noon.
- The temperature response can interfere constructively or destructively with the tide propagating from below.
- QBO signal is small but it shows:
  - QBO-W heating is larger where the heating & tide are in phase
  - QBO-E heating is larger where the heating & tide are out of phase

heating diurnal amplitude



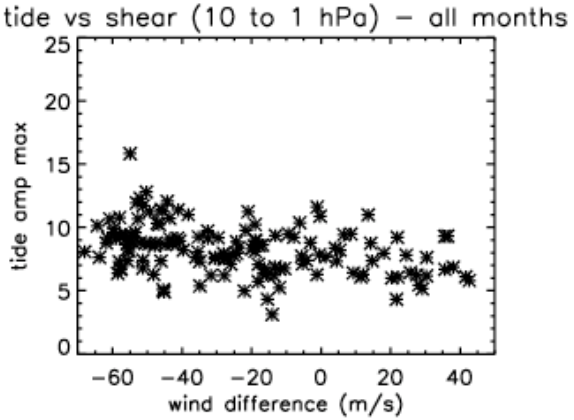
Mechanism for the wind QBO to affect the tide

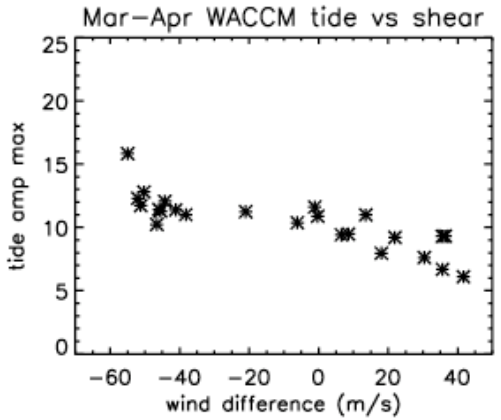




(from simulation with QBO in wind but not in ozone heating)

DW1 tidal amplitude vs QBO wind





DW1 tidal amplitude vs 10 to 1 hPa wind difference
(shear from QBO to stratopause SAO)

DW1 amplitude in MLT is positively correlated with QBO wind speed:

- DW1 phase speed at the equator is ~463 m/s -> the QBO-E to QBO-W difference in (u-c) is ~10%.

DW1 amplitude is negatively correlated with the shear from the QBO to the SAO:

- The shear could affect the structure or propagation of the tide itself or other (gravity, Kelvin) waves that could damp or interact with the tide.

conclusions

- WACCM simulations of the QBO variation in DW1 is similar to that from SABER and other observations.
- Simulations and observations show that the QBO variations in DW1 tide originates in the stratosphere.
- The QBO influences the tide both through ozone heating and through zonal wind differences.
- The ozone influence is consistent with the phase relationship between the propagating tide and the ozone heating.
- The mechanism for the zonal wind impact on tidal amplitude is not clear but is at least in part local to the stratosphere.
- This suggests that the background wind affects the tide directly.
- Additional influence by filtering gravity waves that will dissipate above and damp the tide or alter the mesospheric background wind cannot be ruled out without additional simulations.