# Tropical tropopause layer structure and the roles of waves during QBO disruptions

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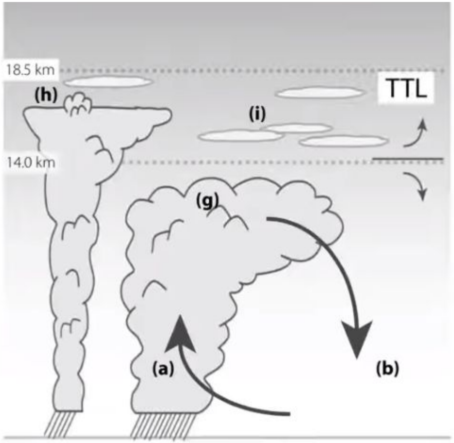
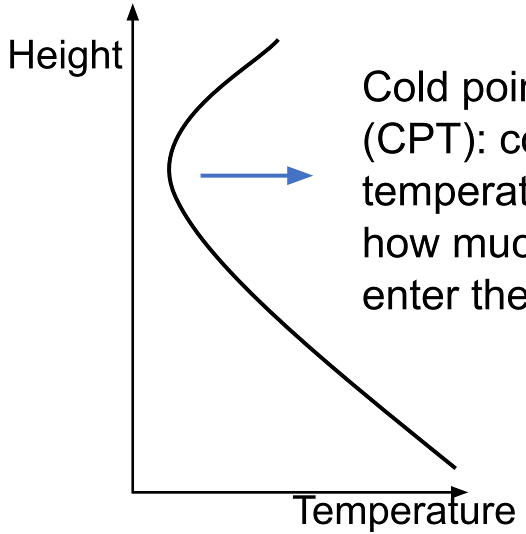


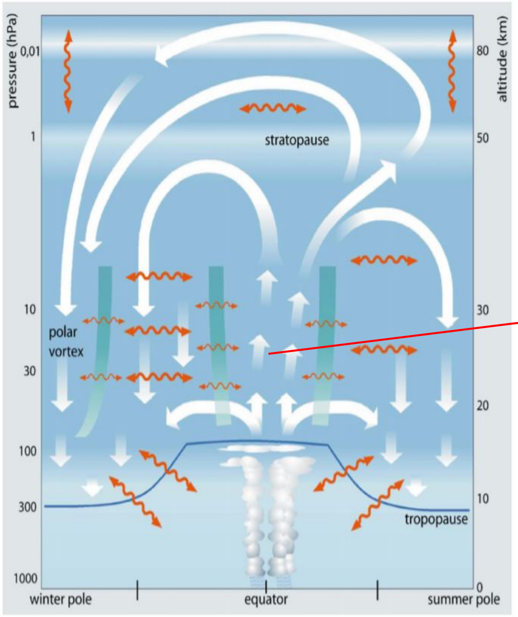

Fueglistaler et al. (2009)

Tropical tropopause layer (14 - 18.5 km)

- A complex upper troposphere (UT) - lower stratosphere (LS) mixing zone
- Feed by deep convection
- Thin cirrus clouds and radiative feedbacks play key roles
- Helps set stratospheric humidity




Cold point tropopause (CPT): coldest level; CPT temperature determines how much water vapor can enter the stratosphere.

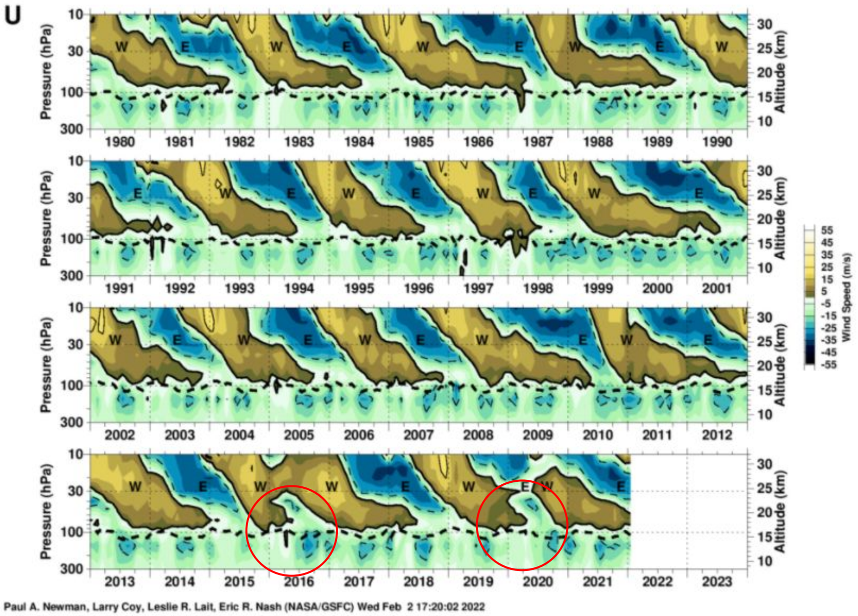


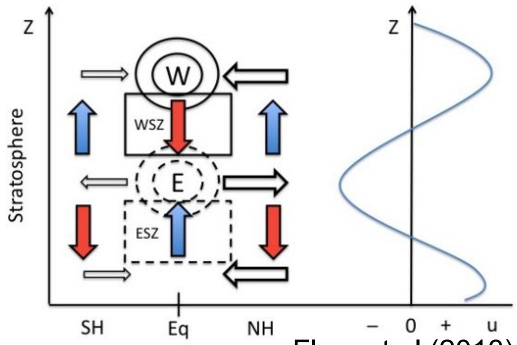

Brewer-Dobson circulation (BDC)

Tropical upwelling

Bonisch et al. (2011)

# Quasi-Biennial Oscillation (QBO)



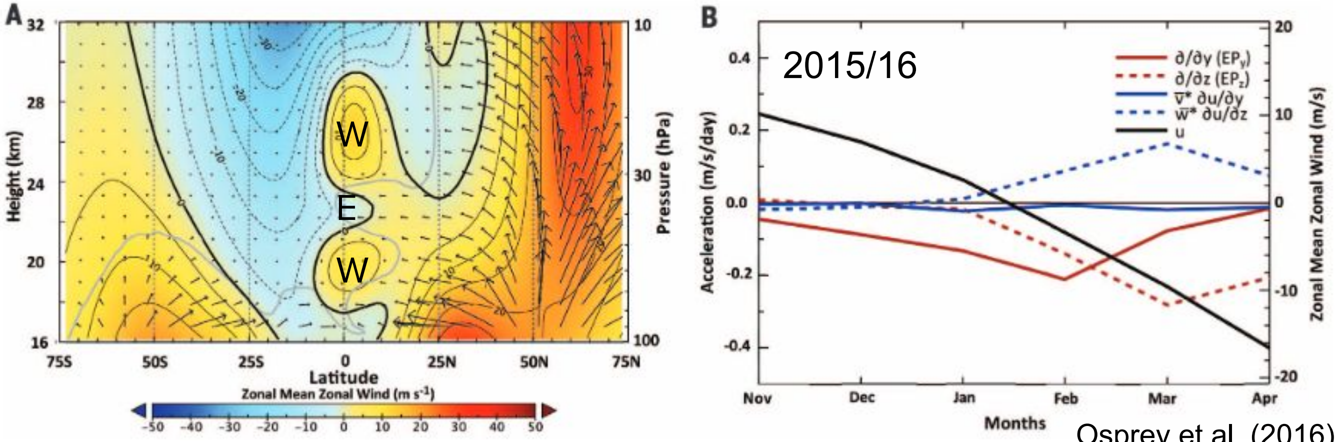




Flury et al (2013)

This secondary circulation can further influence the tropical upwelling and couple with temperature and trace gas anomalies. (Rao et al. 2019)

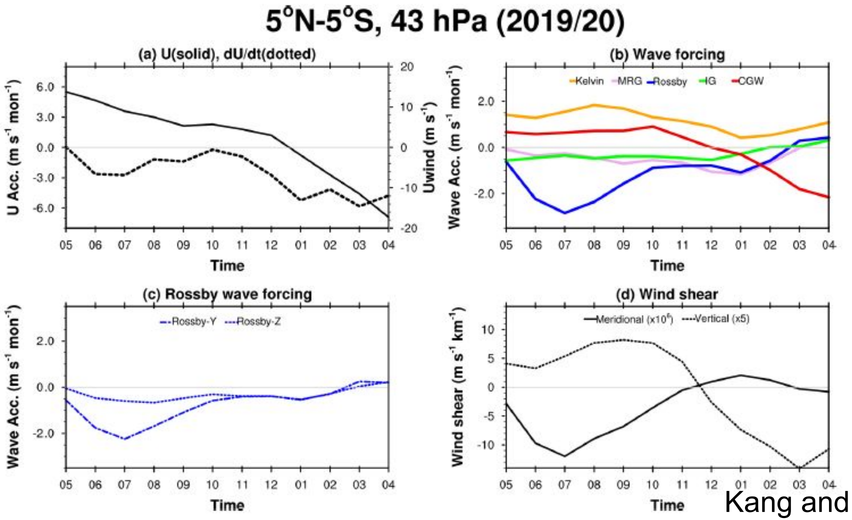
Alternating downward propagating easterly and westerly zonal wind with a period of about 28 months.

Driven by eastward Kelvin, westward Mixed-Rossby gravity waves.

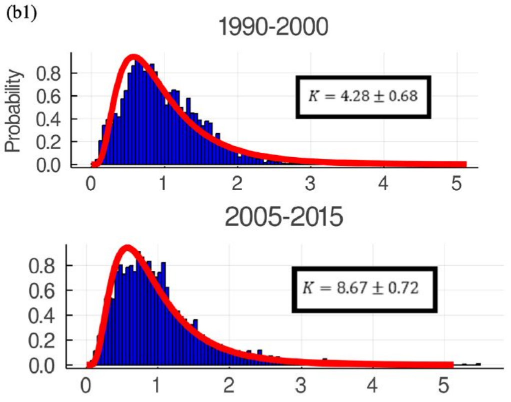



Anomalous momentum from Northern Hemisphere (2015/16 disruption) or Southern Hemisphere (2019/20 disruption)

Osprey et al. (2016)




Kang and Chun (2021)




Background climate drift

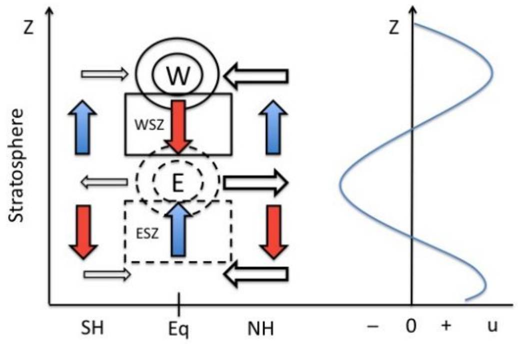
Raphaldini et al. (2020)

Question:

How will QBO disruption influence the tropical tropopause layer structure?

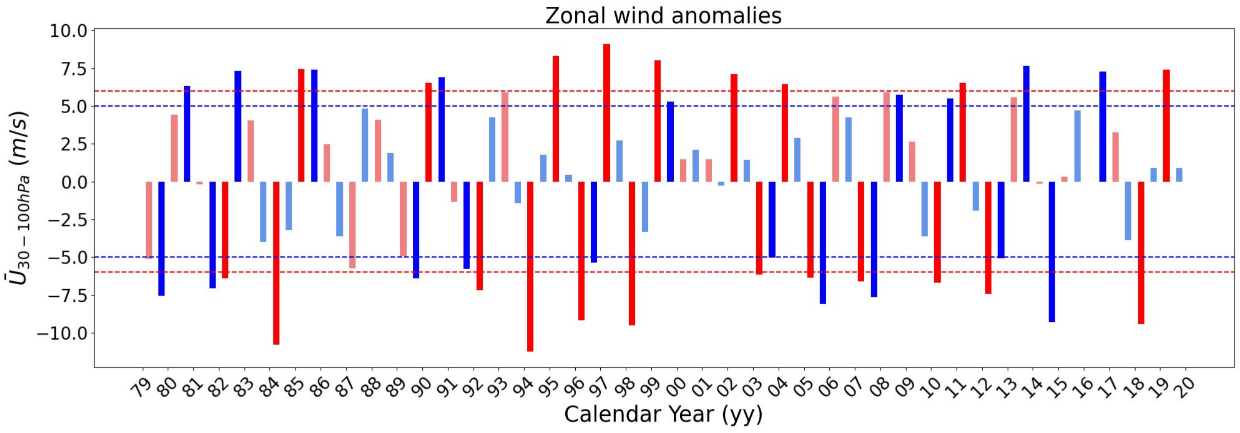
What is the tropical tropopause layer structure at different phases of QBO in different seasons?

QBO disruption happens in boreal winter: 1) strongest tropical upwelling; 2) strongest Rossby wave activities in the Northern Hemisphere




Flury et al (2013)

Easterly shear -> stronger upwelling




Yang et al. (2012)

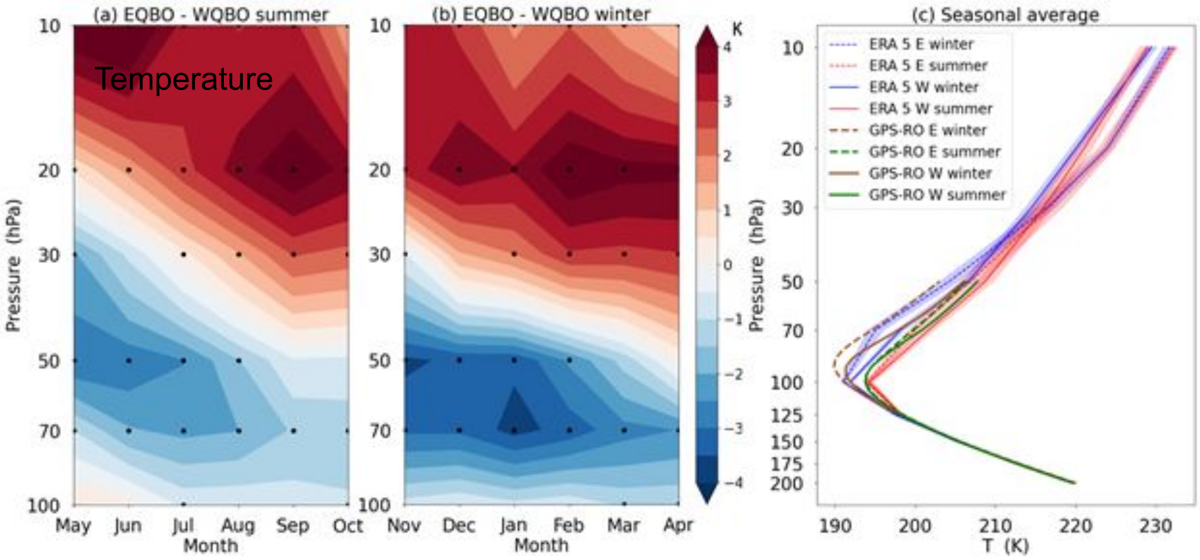
EQBO/WQBO:
5 m/s threshold for winter and 6 m/s for summer

| QBO Phases | Years |
| --- | --- |
| Easterly Summer (12) | 1982, 1984, 1992, 1994, 1996, 1998, 2003, 2005, 2007, 2010, 2012, 2018 |
| Westerly Summer (9) | 1985, 1990, 1995, 1997, 1999, 2002, 2004, 2011, 2019 |
| Easterly Winter (10) | 1979/1980, 1981/1982, 1989/1990, 1991/1992, 1996/1997, 2003/2004, 2005/2006, 2007/2008, 2012/2013, 2014/2015 |
| Westerly Winter (9) | 1980/1981, 1982/1983, 1985/1986, 1990/1991, 1999/2000, 2008/2009, 2010/2011, 2013/2014, 2016/2017 |

ERA 5: wind, temperature (1979-2020)

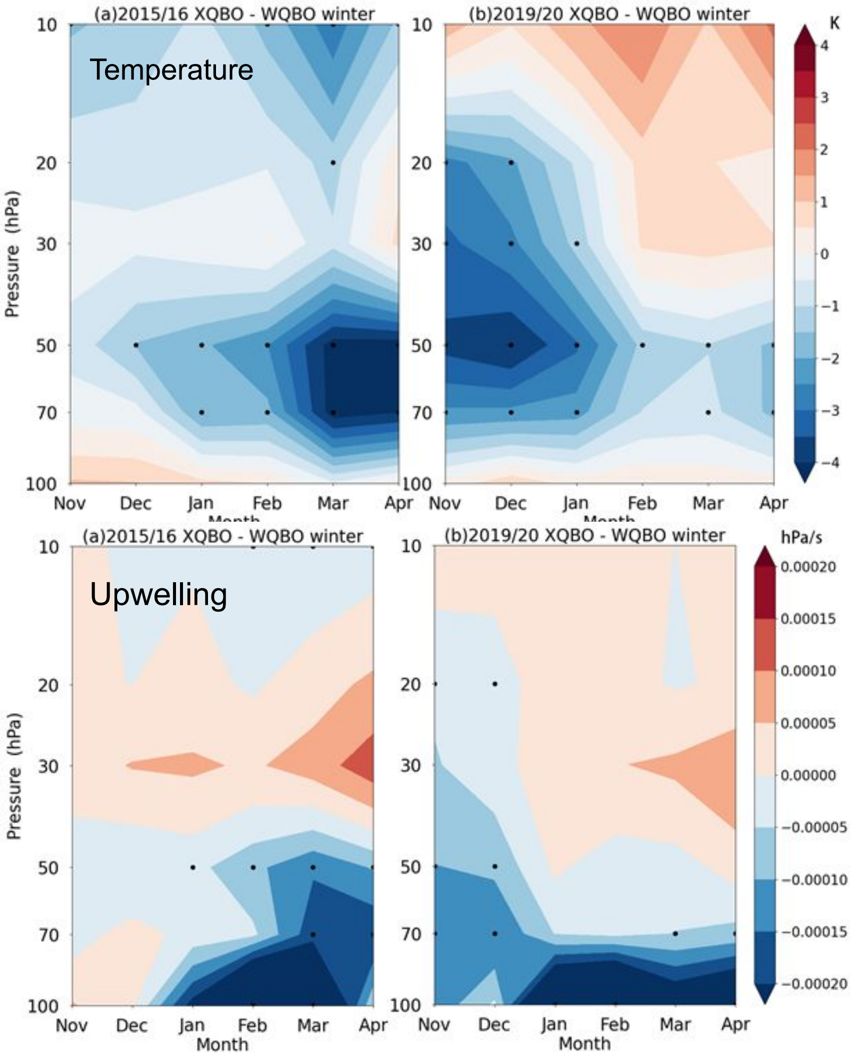
GPS-RO: temperature (2002-2020)

SWOOSH: water vapor and ozone (2005-2020)




Lower stratosphere is colder during EQBO than WQBO, with largest difference during boreal winter ( -3.6 K).

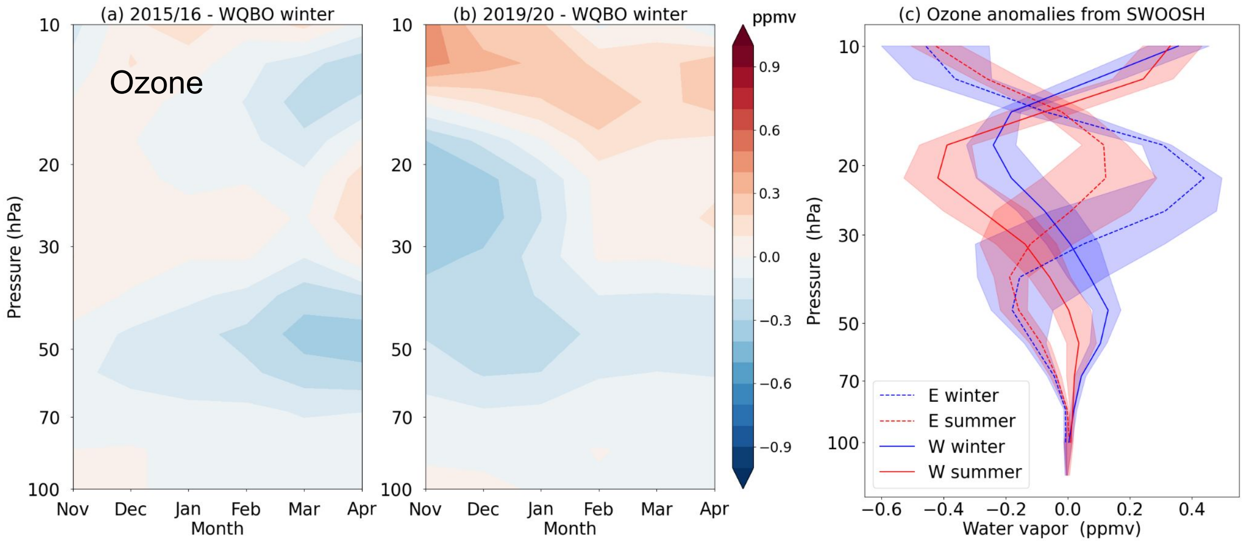
CPT temperature is also coldest during EQBO boreal winter (-1.5 K and ~5 hPa higher).




$$\overline{w^*} = \overline{w} + \frac{1}{\cos\Phi}\left(\cos\Phi \frac{\overline{v'T'}}{S}\right)_\Phi$$

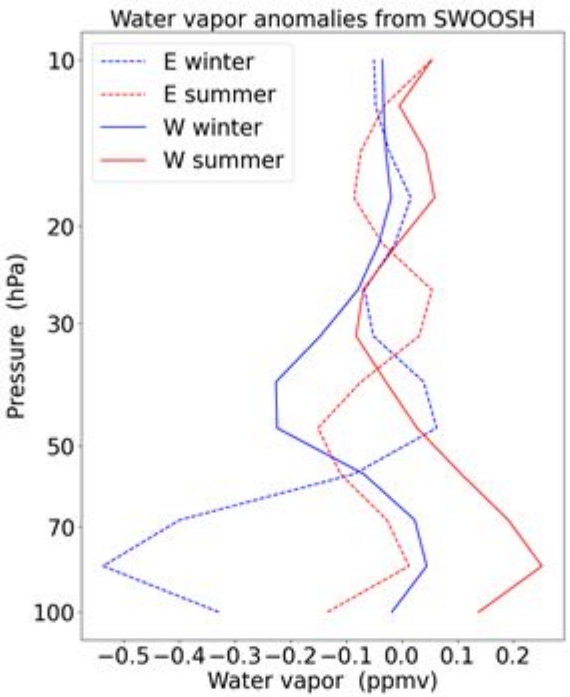
Tropical upwelling is directly calculated from reanalysis shown in Andrews (1987)

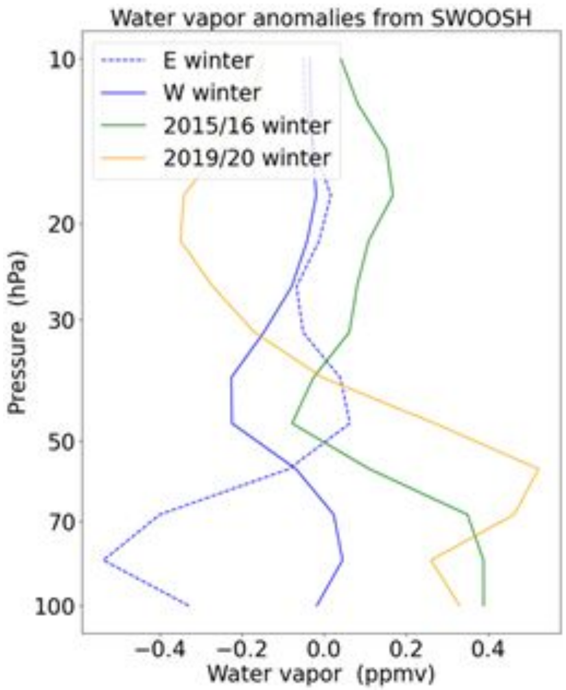
Lower stratosphere is colder and tropical upwelling is stronger during QBO disruptions than WQBO composite.




Consistent with the tropical upwelling, there is less ozone in the lower stratosphere during QBO disruptions.

The ozone anomalies can also lead to temperature anomalies (Ming and Hitchcock, 2022).

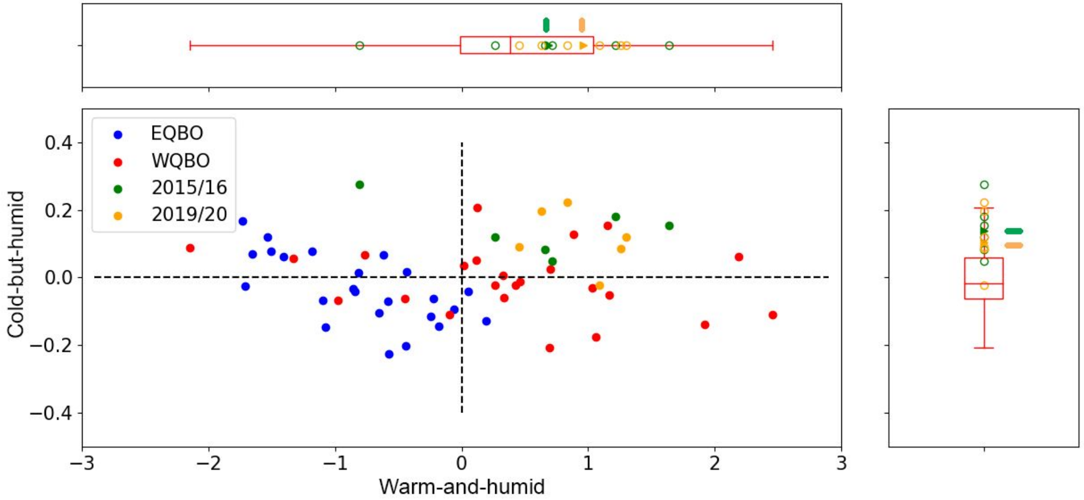



Lower stratosphere has less water vapor during EQBO and boreal winter.

More lower stratospheric water vapor (~0.3-0.4 ppmv) during QBO disruptions.

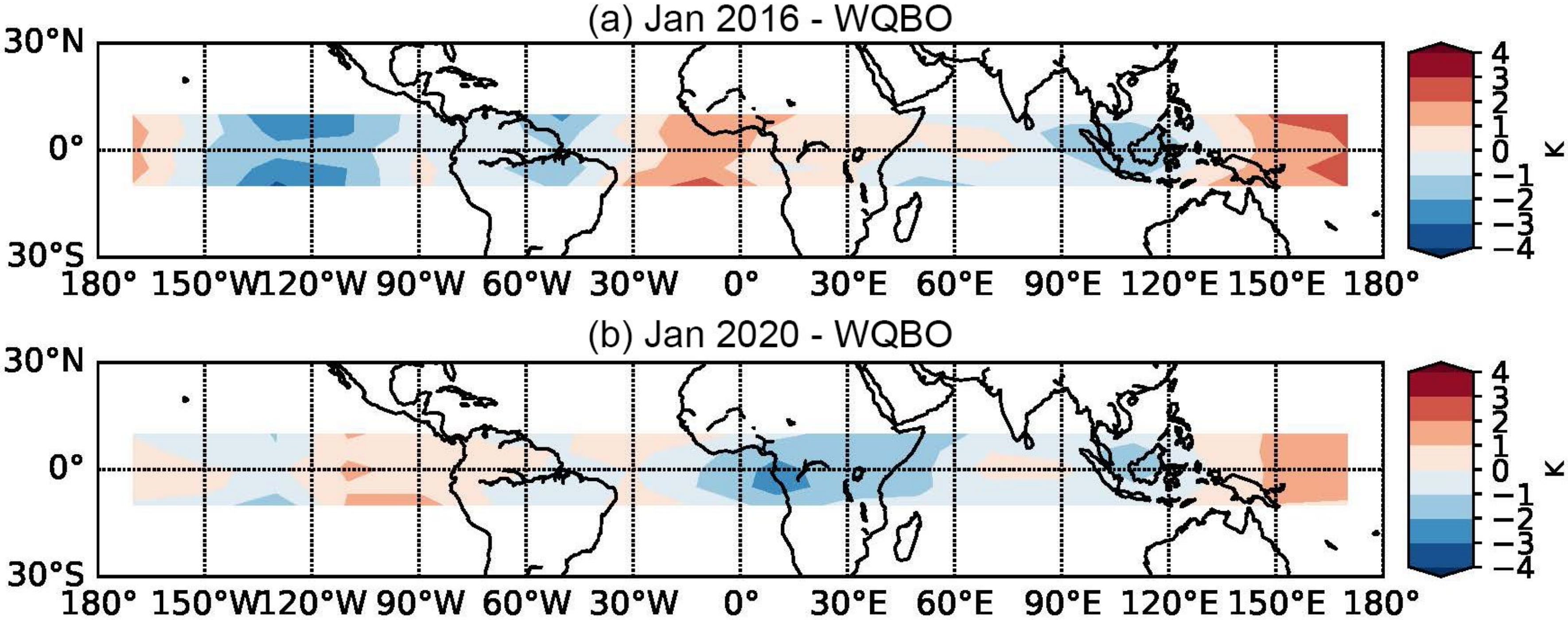
# Principal component analysis (PCA) between GPS CPT temperature and 100 hPa SWOOSH water vapor

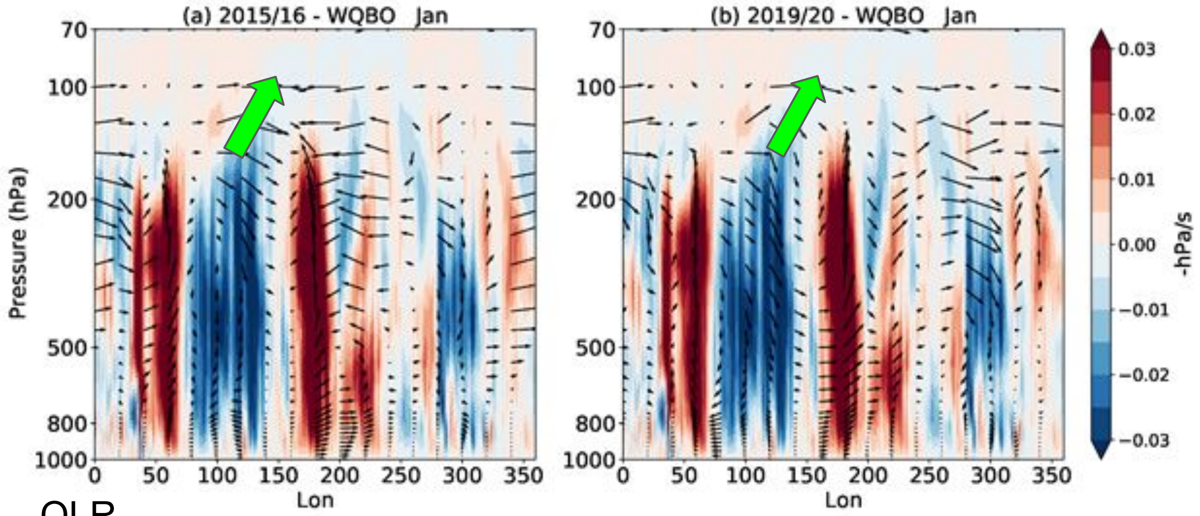



Warm-and-humid (PC 1): cold-dry and warm-moist pattern (linear relationship between CPT and water vapor).

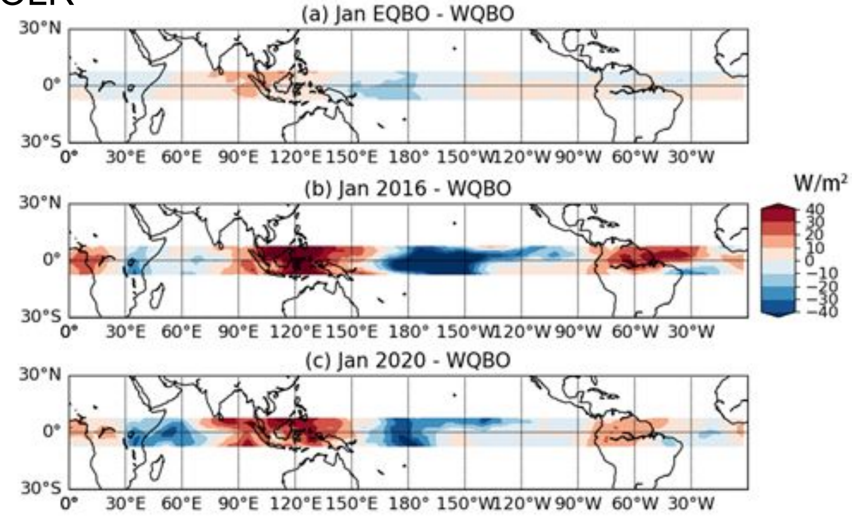
Cold-but-humid (PC 2): unusually moist for a given CPT temperature.

CPT temperature difference between QBO disruptions and the WQBO composite (after removing linear regression of MEI)



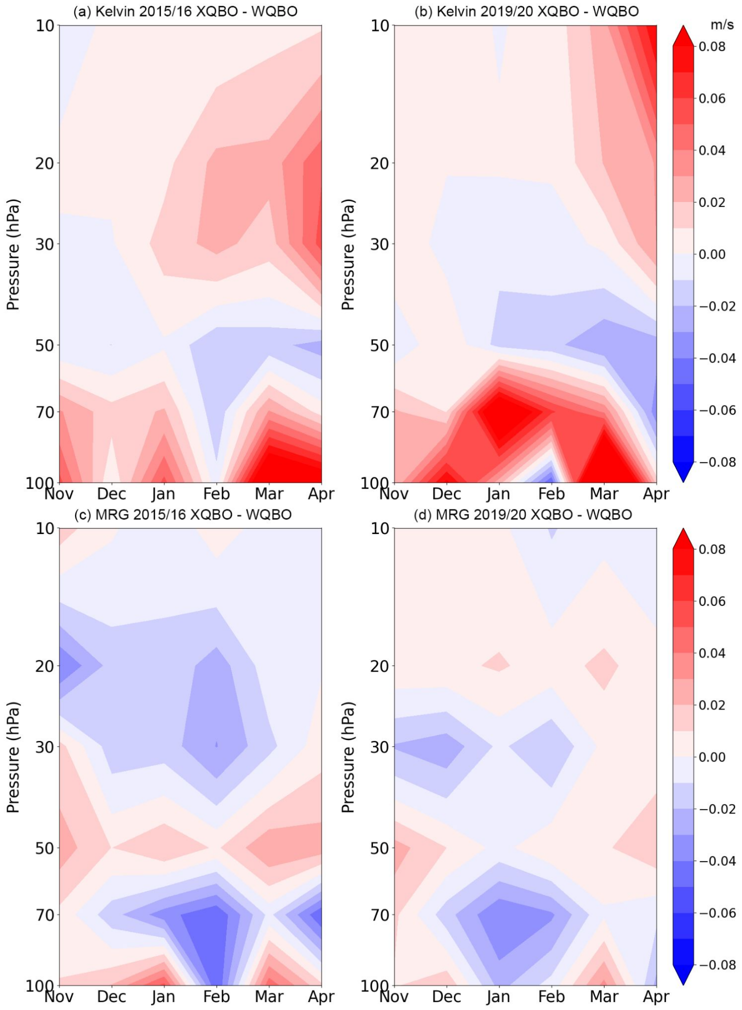



OLR




Anomalous descent and eastward tilt over the cold trap region.

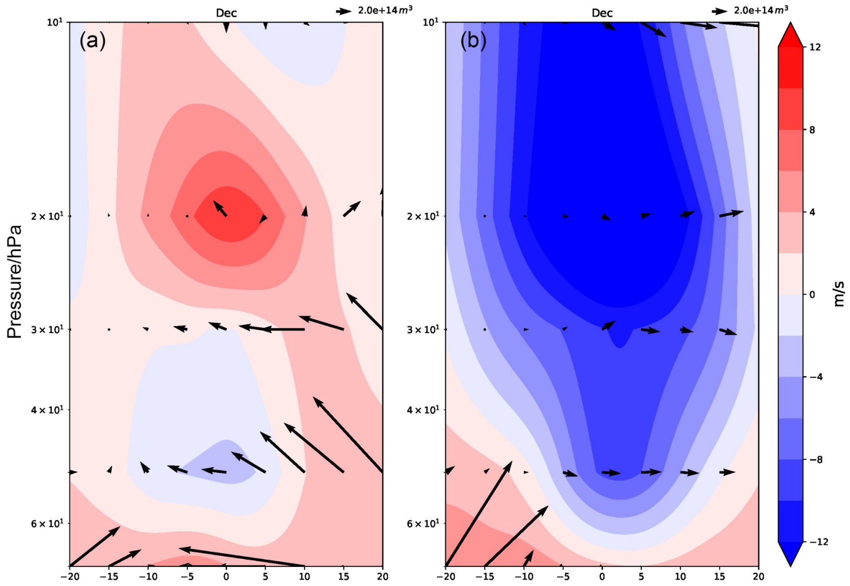
Weaker convections over western Pacific during QBO disruptions.




EP flux divergence difference (unit: m/s per day) between QBO disruptions and WQBO winter composite

Kelvin wave helps to maintain westerly wind and Mixed-Rossby gravity wave helps to bring down the easterly anomaly.

Zonal wind anomalies (shading) during QBO disruptions and EP flux (vectors) in (a) December 2015 and (b) December 2019

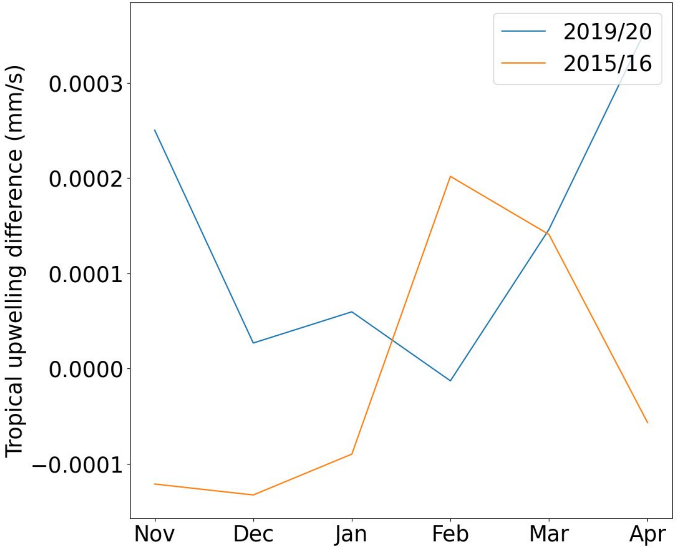



2015/16 QBO disruption: momentum from the Northern Hemisphere

2019/20 QBO disruption: momentum from the Southern Hemisphere

Momentum equation for tropical upwelling calculation (Abalos et al. 2014)

$$< \overline{w^*} > = \frac{-e^{z/H}\cos\Phi}{\int_{-\Phi_0}^{\Phi_0} a\cos\Phi \, d\Phi} \left\{ \int_z^{\infty} \frac{e^{-z'/H}\cos\Phi}{\hat{f}(\Phi,z')} \left[ DF(\Phi,z') - \overline{u}_t(\Phi,z') \right]_{\bar{m}} dz' \right\} \Bigg|_{-\Phi_0}^{\Phi_0}$$




Tropical upwelling is mainly driven by the extratropical waves.

# Summary

- In the lower stratosphere, EQBO has colder temperature, less water vapor and ozone than WQBO, especially during boreal winter.
- Comparing to the WQBO composite, QBO disruptions have stronger tropical upwelling and slightly warmer zonal mean CPT, but more water vapor. The different distribution between CPT and water vapor during QBO disruptions is related to the regional pattern of the CPT.
- Stronger tropical upwelling during QBO disruptions is mainly influenced by the extratropical waves, while tropical waves mainly modify zonal winds.

Thank you!

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