Non-linearity in the extratropical teleconnection to ENSO and the QBO

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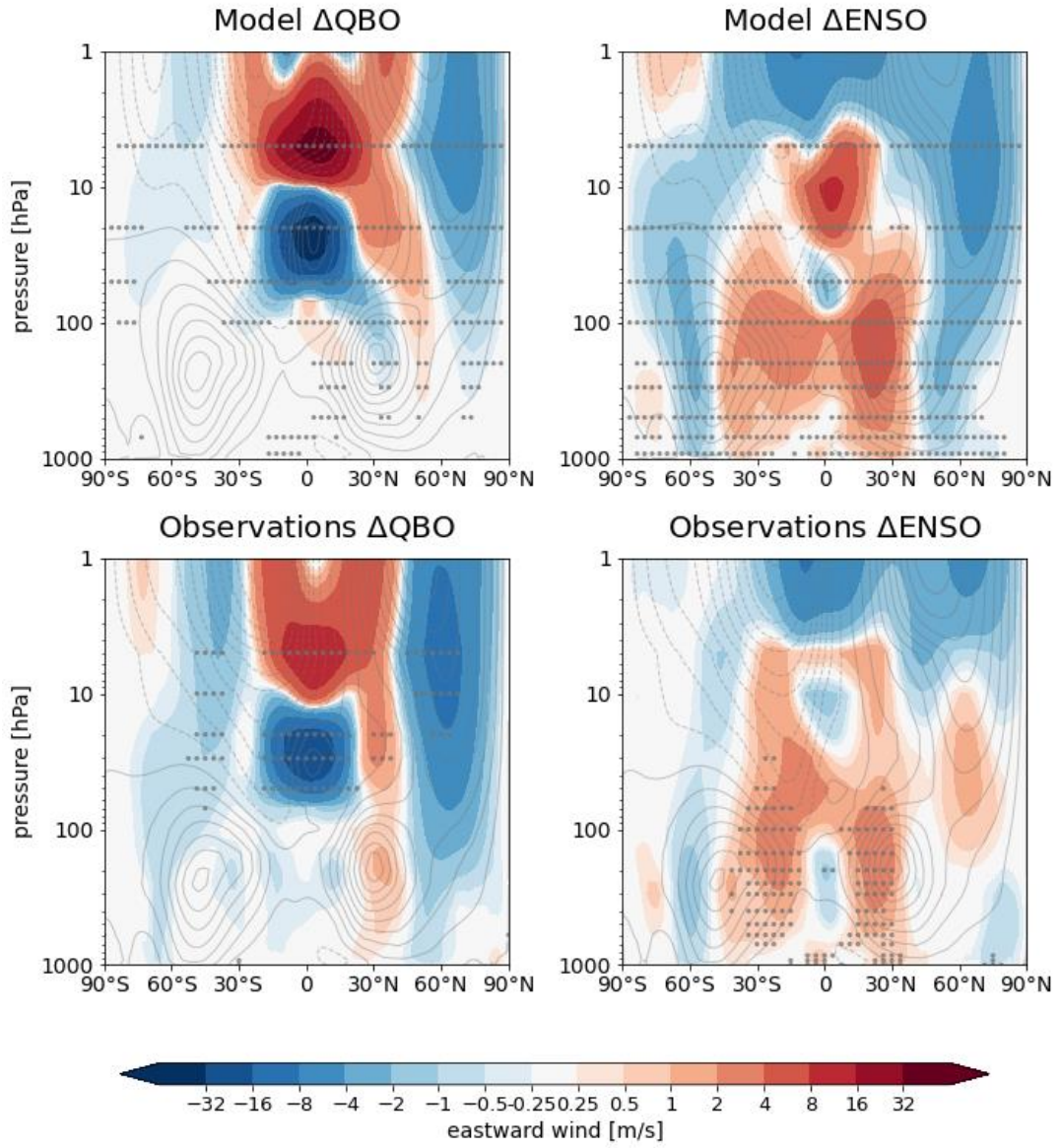
Consistent ENSO and QBO responses in model and observations

DJF zonal wind response for ΔENSO and ΔQBO

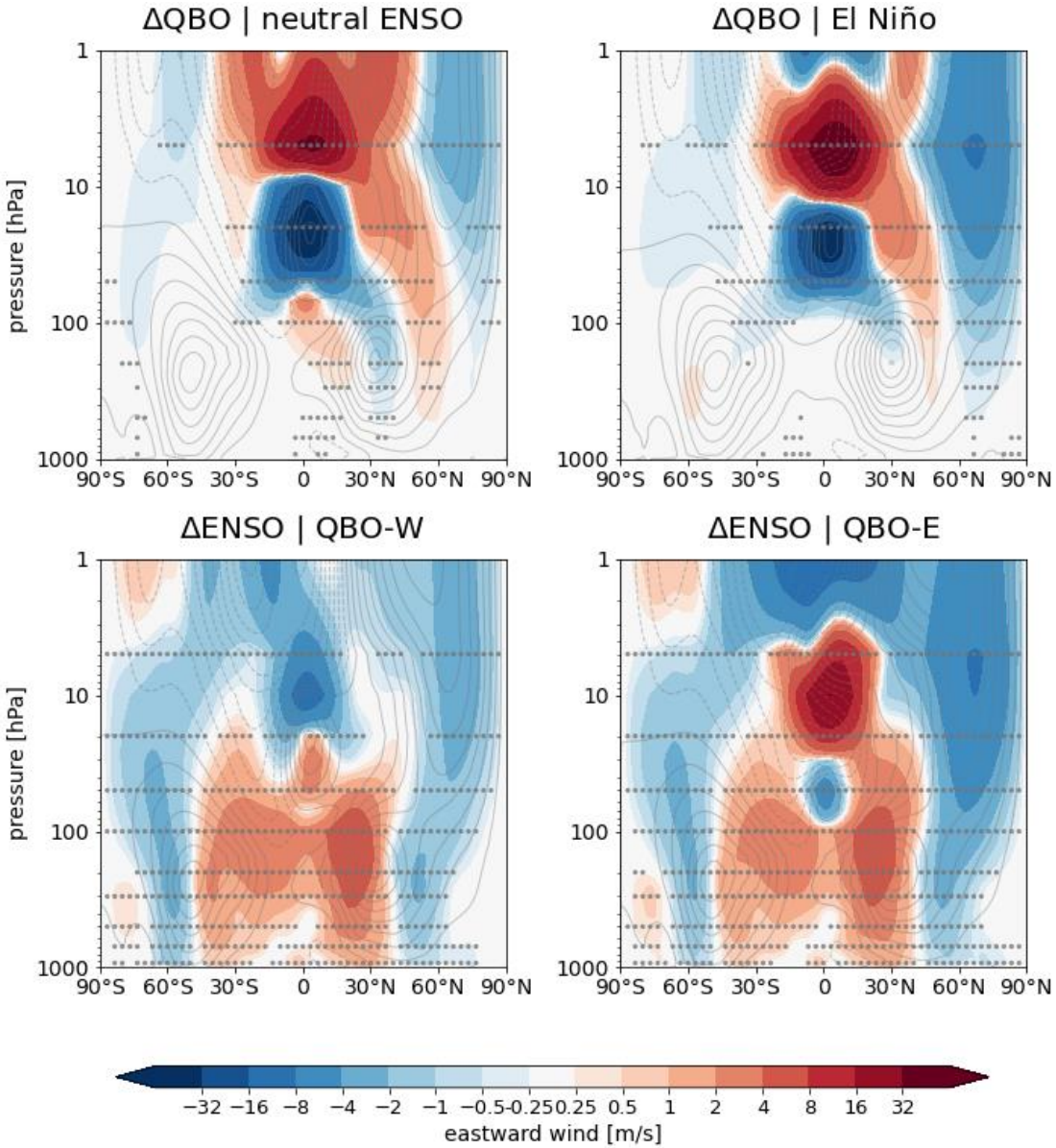
ΔENSO = El Niño – neutral ENSO
ΔQBO = QBO-E – QBO-W

Model: **HadGEM3 N216** (~60km resolution)
Observations: **ERA5 reanalysis** 1950-2020 (split into composites)

- Model and observations qualitatively agree on QBO response.
- ENSO responses are similar in the troposphere, but polar vortex has opposite sign in lower stratosphere.
  - Likely due to small observations sample size.



Evidence of non-linearity in zonal wind response



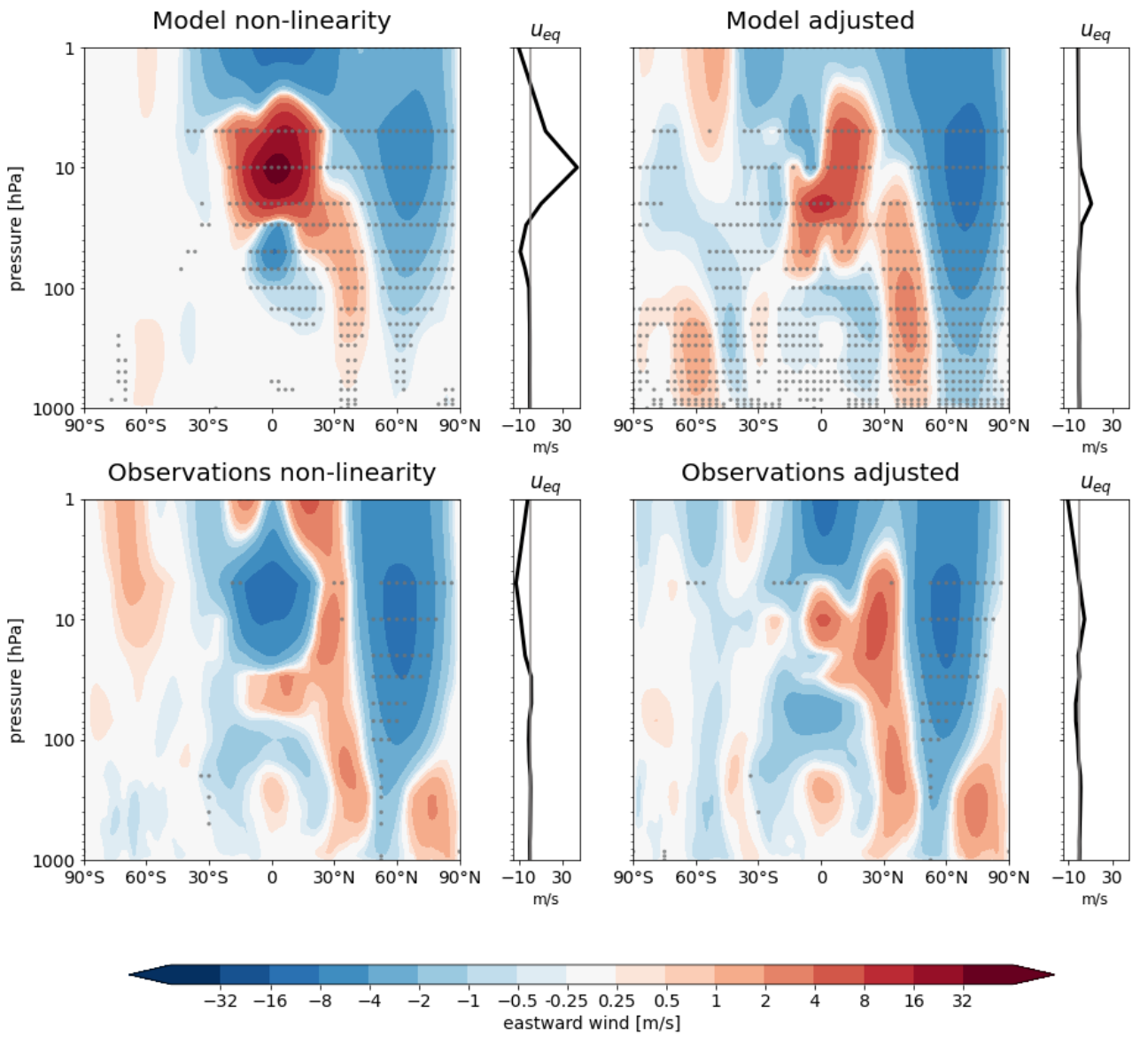
ΔQBO response depends on ENSO phase /
ΔENSO response depends on QBO phase

- **Polar vortex weakening is stronger** in ΔQBO | El Niño case and ΔENSO | QBO-E case compared to in ΔQBO | neutral ENSO case and ΔENSO | QBO-W respectively.
- This indicates that **ENSO and QBO combine non-linearly.**
- Opposite sign tropical signal in the ΔENSO cases – consistent with increase in QBO descent rate.
- Hence ENSO is directly altering QBO in the tropics. We want to remove this effect.

Adjusting the non-linearity to remove tropical effect

Non-linearity defined as ΔENSO | QBO-E – ΔENSO | QBO-W

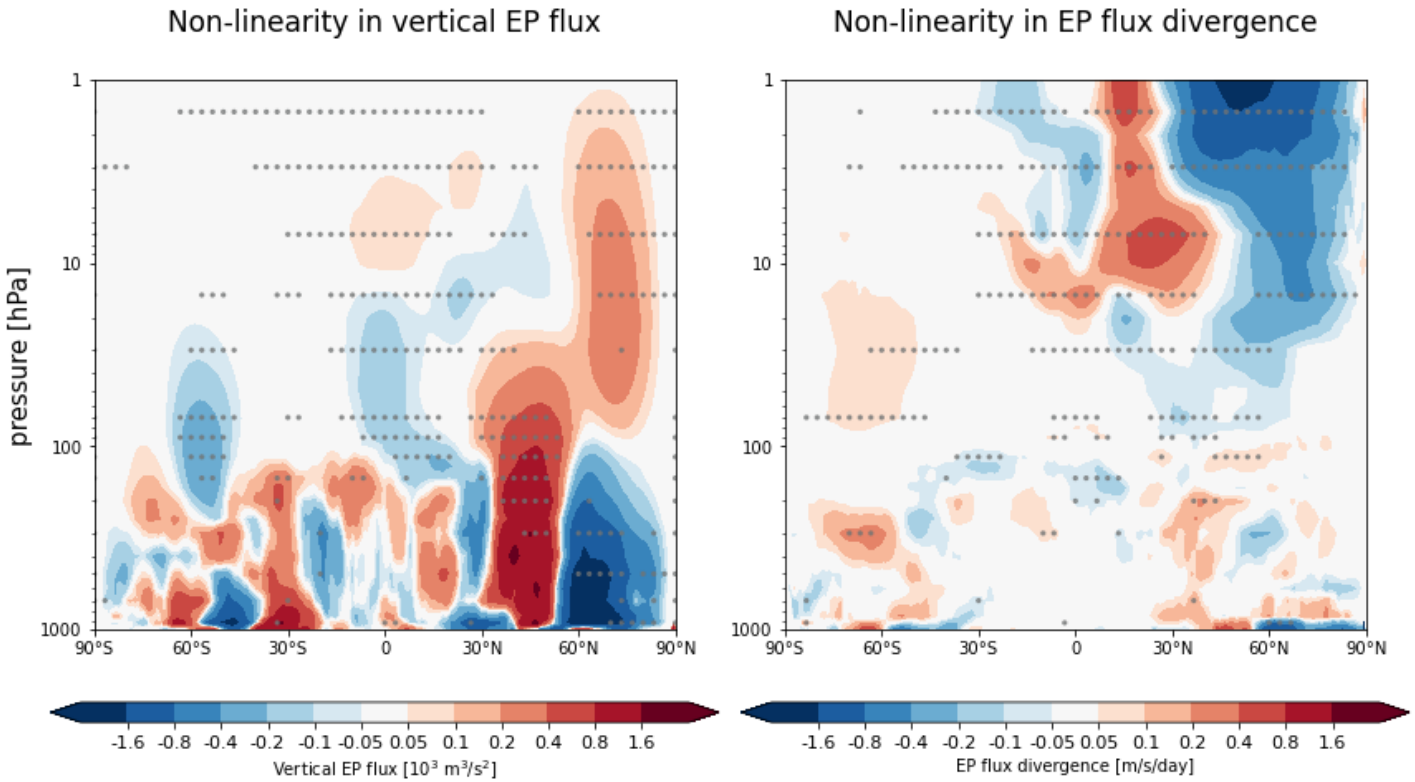
- Model and observations show statistically significant non-linearity in polar vortex.
- Large tropical anomaly in both cases.
  - Multiple linear regression is used to estimate contribution of this anomaly and remove it.
  - Adjusted non-linearities seen in right column.
- Model adjusted non-linearity shows stronger surface response than before.
  - Potentially important to forecasting.



Possible mechanism: changes to wave activity

Increase in vertical EP flux and EP flux divergence in polar stratosphere

- Troposphere dipole pattern in vertical EP flux consistent with equatorward shift in storm track.
- Confinement of waves in upper stratosphere, leading to increased EP flux convergence into pole.



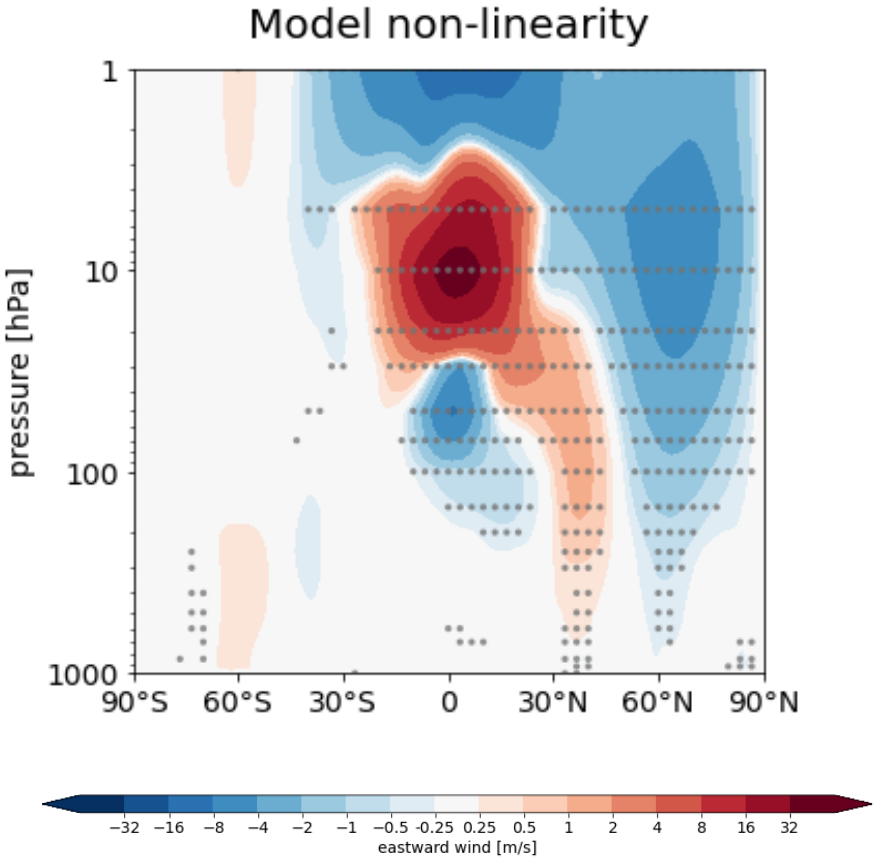
Proposed mechanism:

When El Niño and QBO-E conditions occur together, the confining effect of QBO-E acts on the enhanced waves from El Niño to create a non-linear cross term.

Hence, El Niño | QBO-E is not just the sum of both separately.

Summary

- We have found evidence of non-linearity in the ENSO-QBO extratropical teleconnection.
- This non-linearity is found in both the model and observations.
- ENSO directly interacts with QBO in the tropics. Removing this effect actually enhances the non-linearity.
- Changes in EP flux are consistent with a weaker polar vortex.
- We believe non-linearity arises because QBO-E confines the extra waves generated by El Niño into the extratropics, hence weakening the vortex further.



Key result: non-linearity in ENSO-QBO extratropical teleconnection