Characterizing impacts of external forcings and internal climate variability on interannual upper tropospheric ozone (UT O_3) variations

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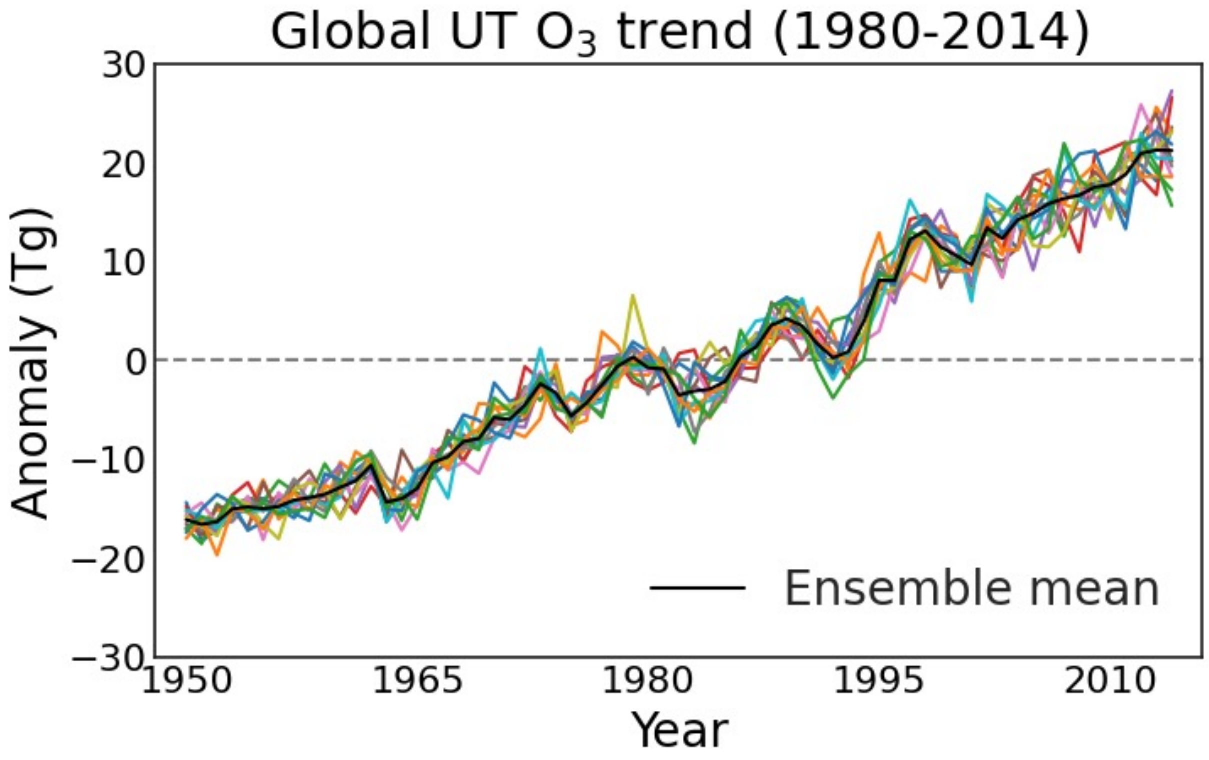
Background

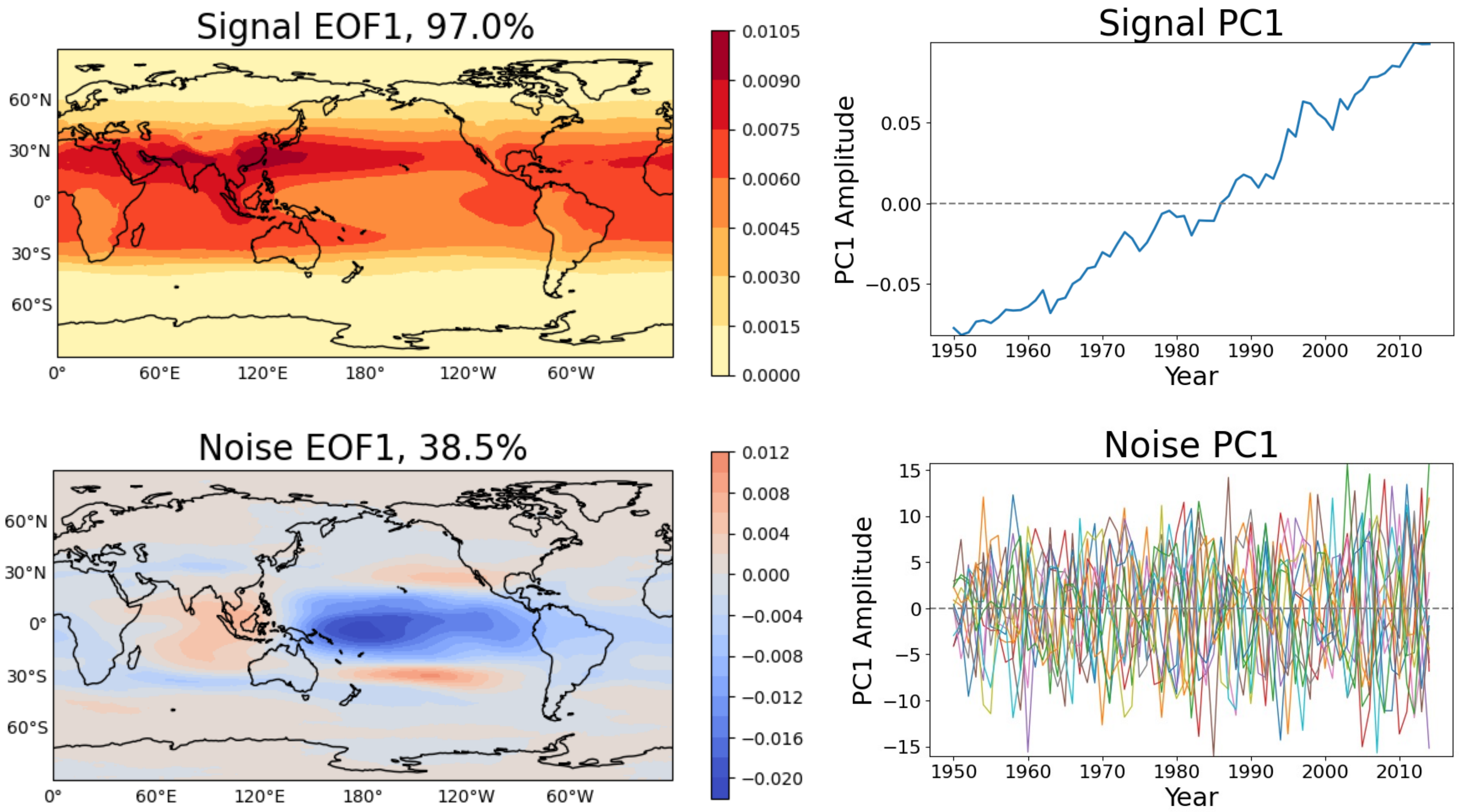
- Internal climate variability may amplify, or mask externally forced tropospheric ozone trends
- 13-member initial-condition ensemble simulations of CESM2-WACCM6 (1950-2014)



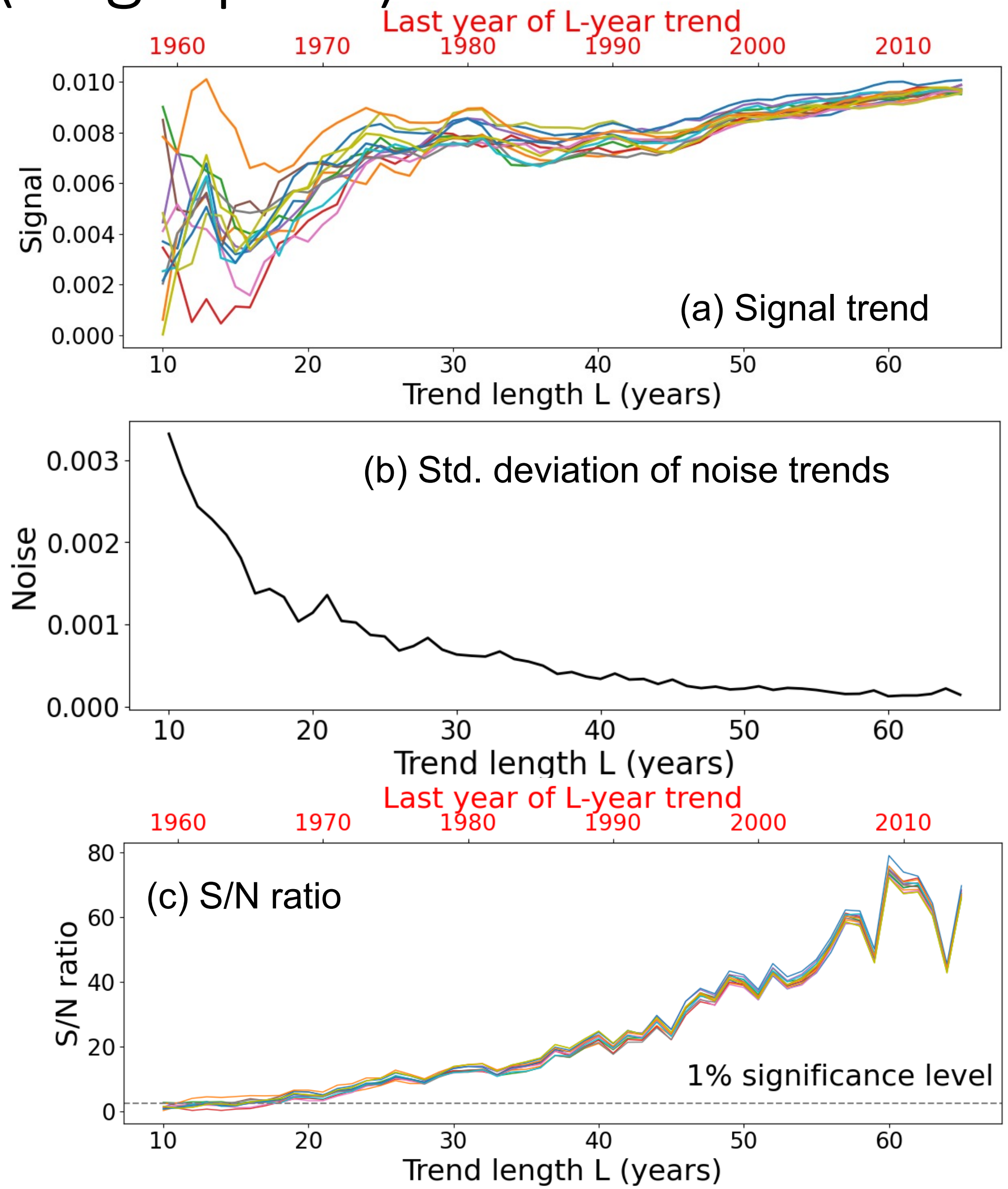
External forcings → UT O_3 "**signal**":
Ensemble mean

Internal climate variability → UT O_3 "**noise**" :
Differences between each individual ensemble member and ensemble mean

Dominant signal and noise patterns of UT O_3: EOF analysis



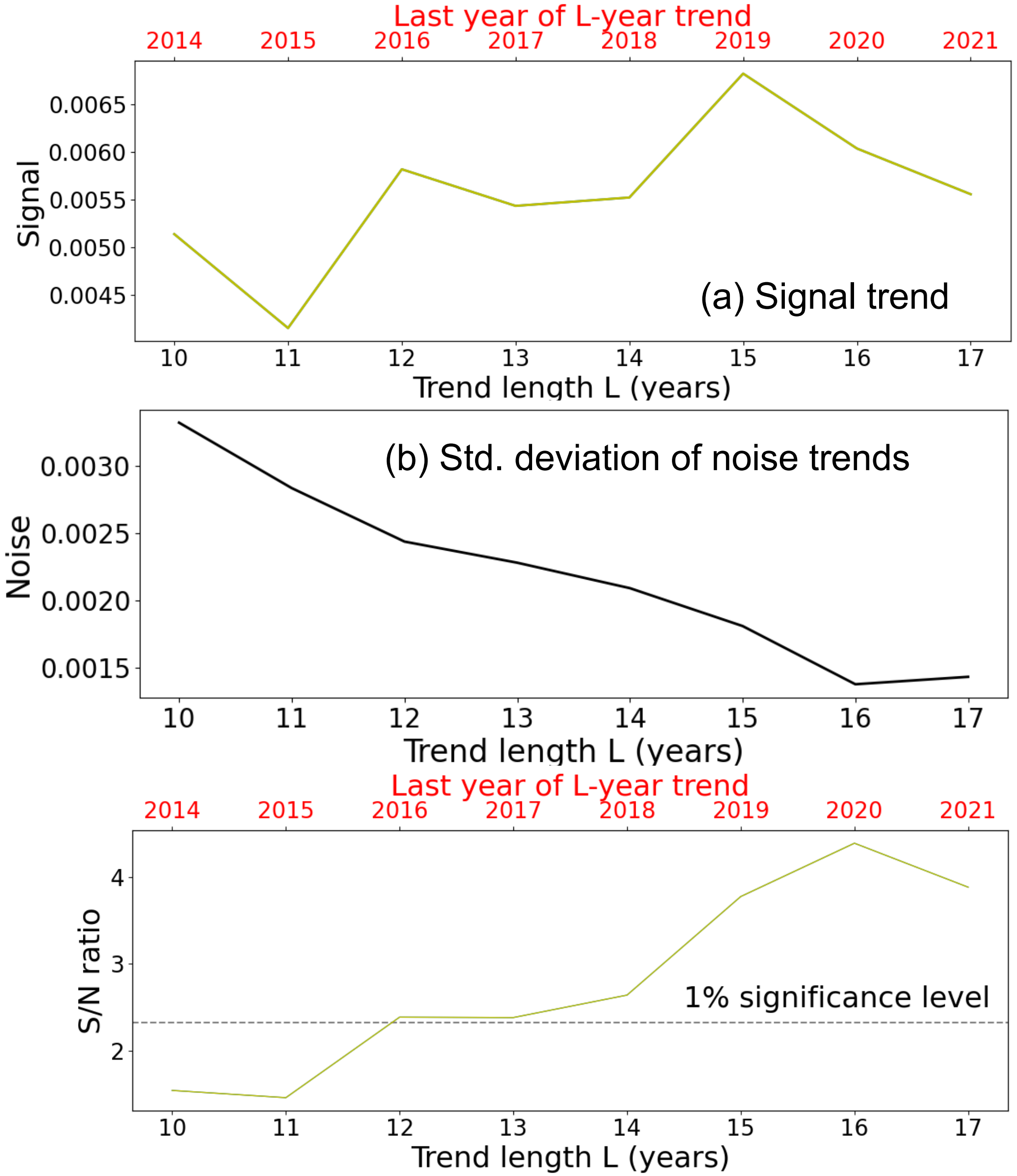
Detectability of the signal patterns driven by external forcing (fingerprint) in modelled UT O_3 trend



- Fingerprint method (Santer *et al* 2022)
- Fingerprint: signal EOF1
- "Model only" signal-to-noise (S/N) ratios

- The model fingerprint is significantly identifiable in each 65-year ensemble simulation with a 1% significance threshold
- The detection time varies from 10 to 18 years

Detectability of the signal patterns driven by external forcing (fingerprint) in modelled UT O_3 trend

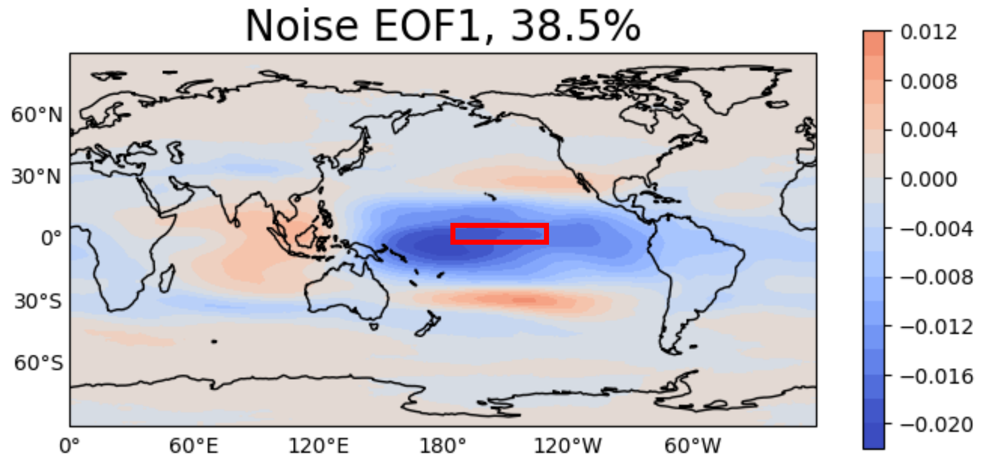


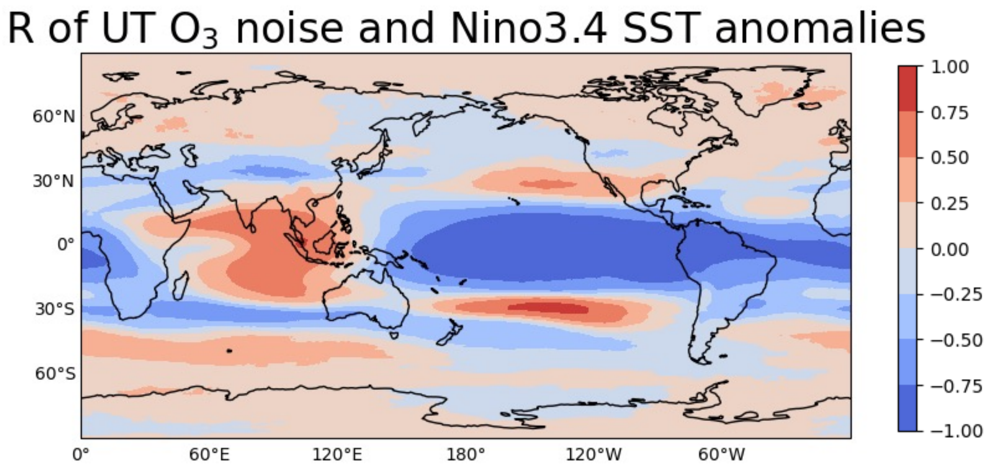
- "Model-observed" S/N ratios
- OMI/MLS satellite-based measurement (2005-2021) (Ziemke *et al* 2019)

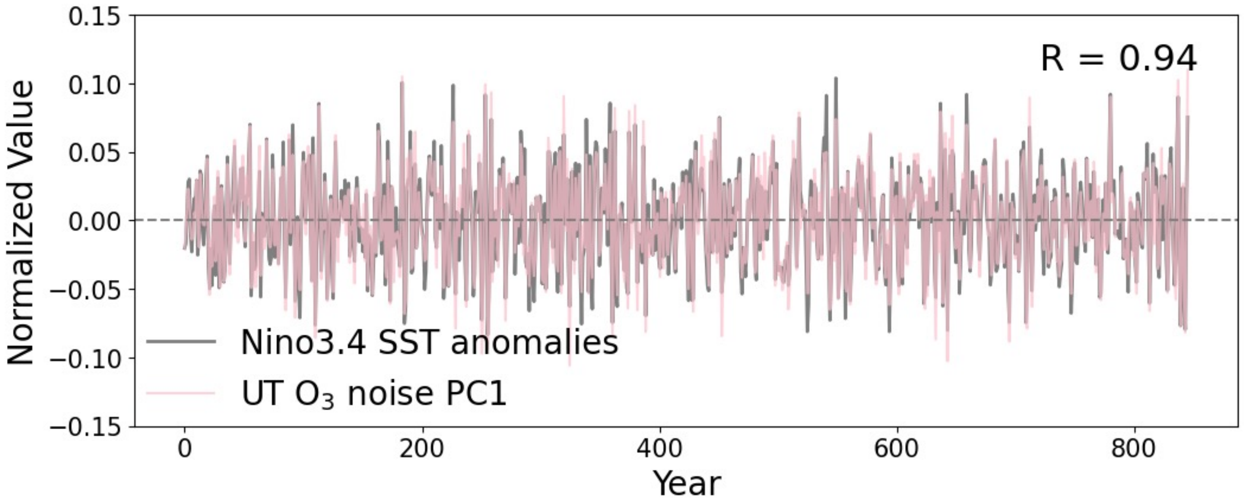
- The model fingerprint is significantly identifiable in the 17-year satellite record with a 1% significance threshold
- The detection time is 12 years

UT O_3 noise driven by internal climate variability: relationship with ENSO

- A strong ENSO signal is found in tropospheric column ozone (Ziemke *et al* 2010; Oman *et al* 2011)



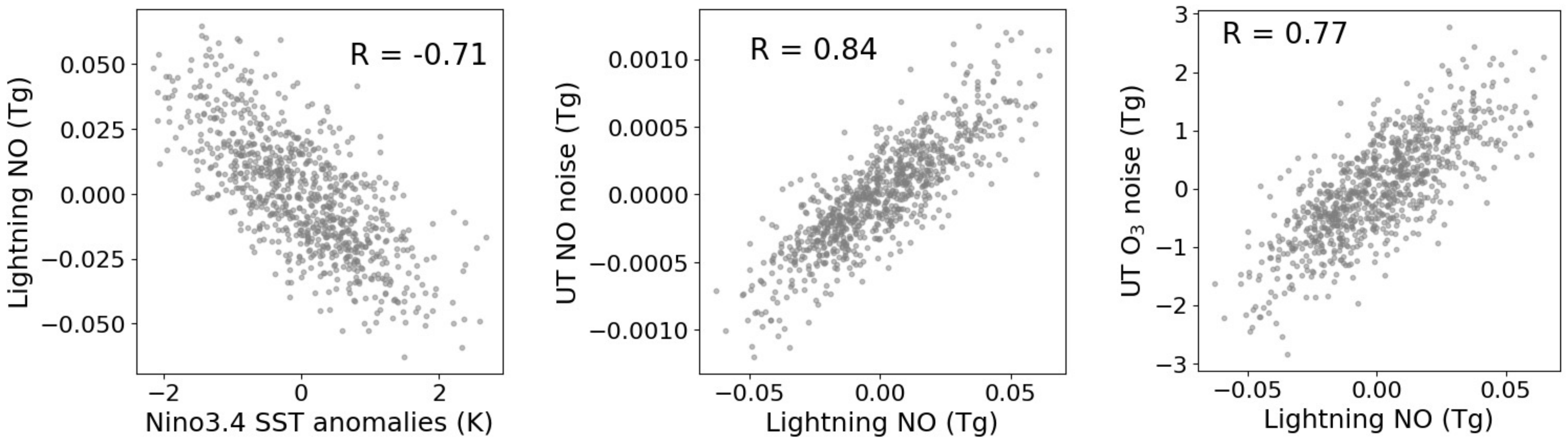




- ENSO-like features is found in UT O_3 noise EOF1

UT O_3 noise and changes of lightning produced NO associated with ENSO

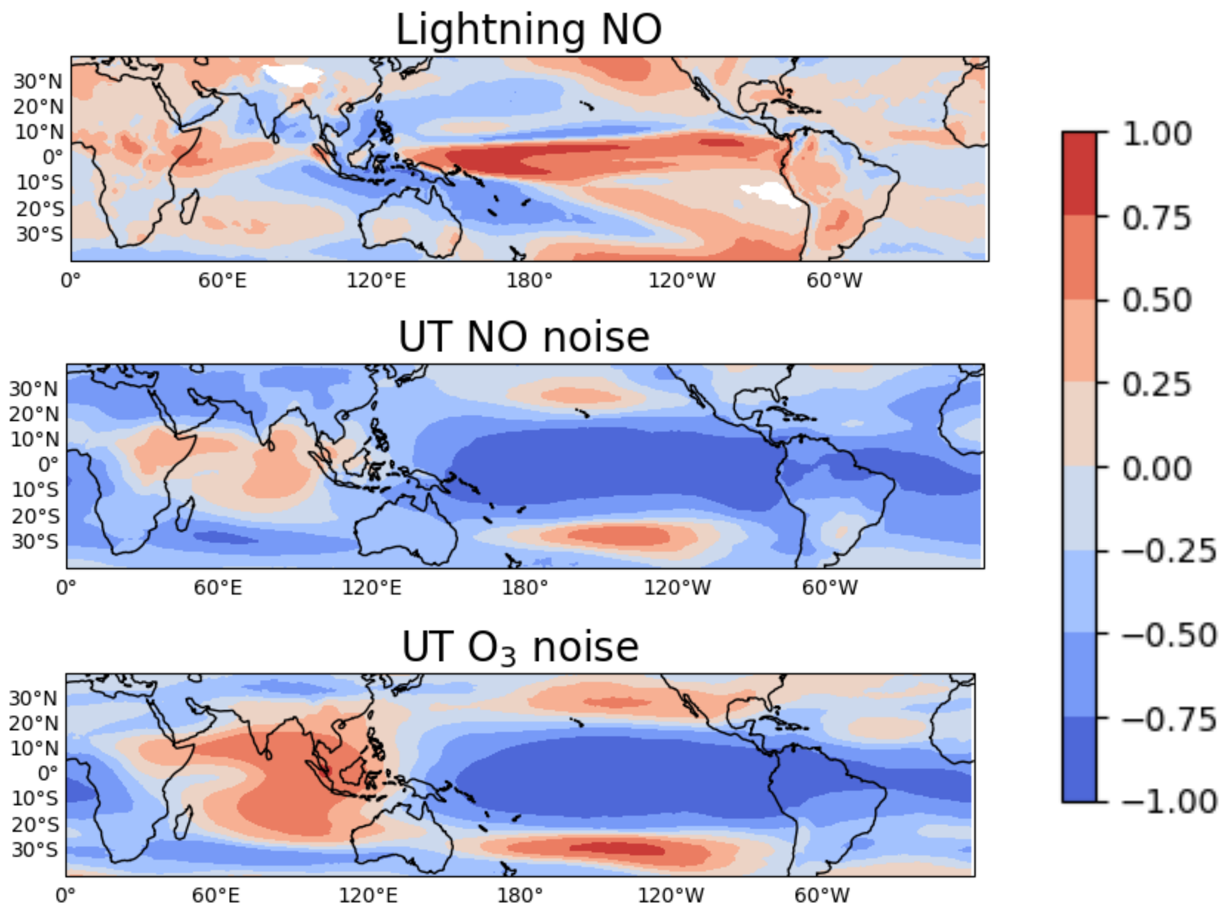
In Tropical Pacific (23N–23S; 125E–85W):



- "La Niña leads to increased deep convection in the Tropical Pacific which increases lightning produced NOx" (Turner *et al* 2018)
- UT O_3 noise as having a strong lightning NO signal: El Niño ~ less lightning NO ~ less UT NO and UT O_3

UT O_3 noise and changes of lightning produced NO associated with ENSO

Correlation coefficient between SST anomalies and:

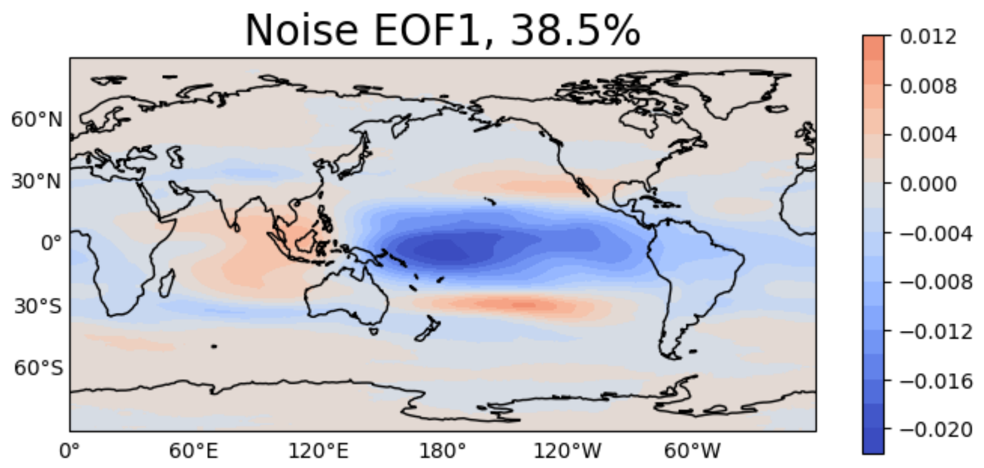


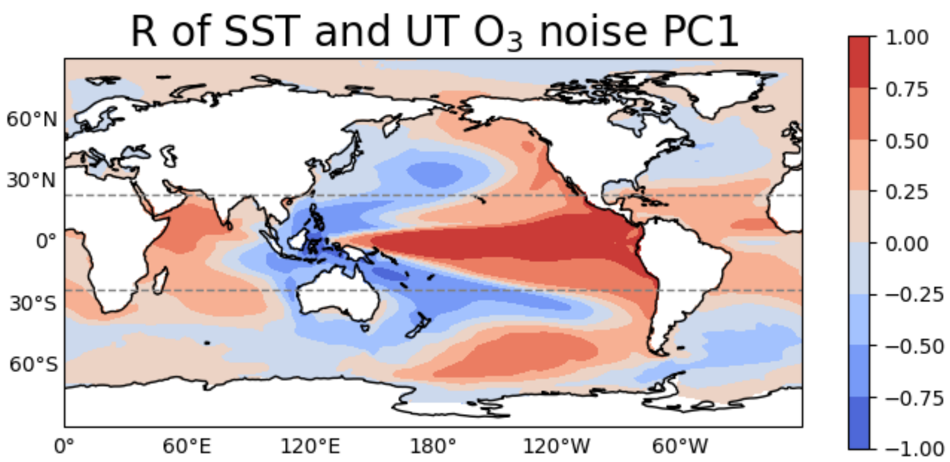
- In the equatorial Pacific:

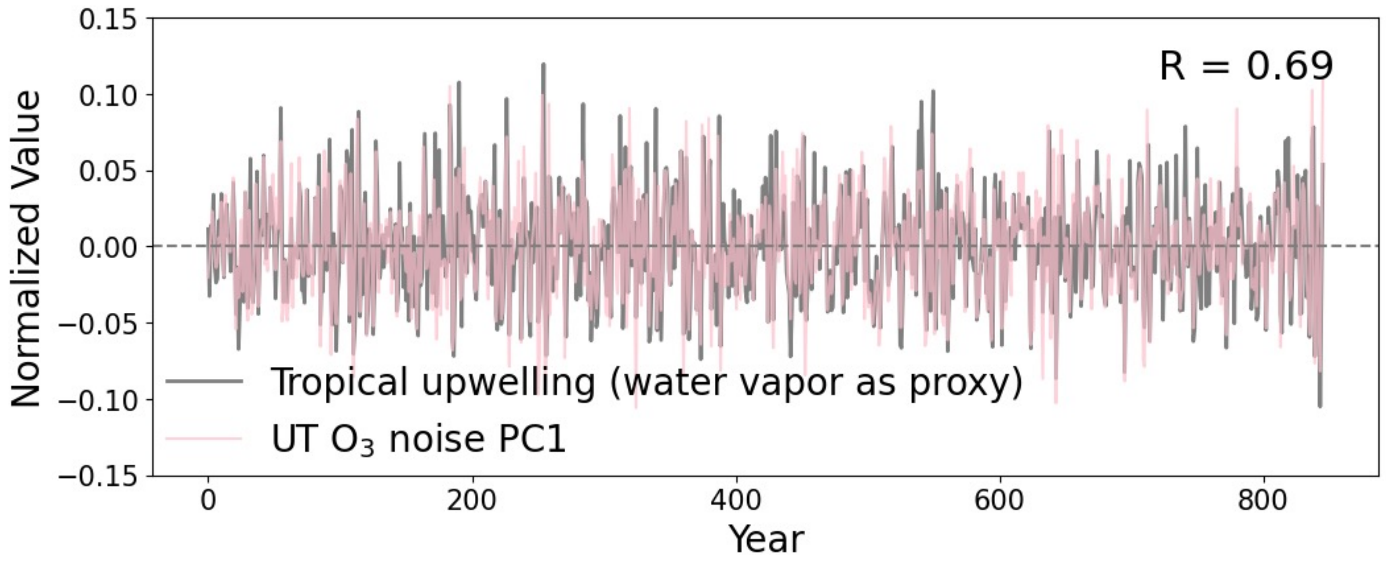
  El Niño ~ higher lightning NO ~ less UT NO and UT O_3

- Offset by other processes: transport?

UT O_3 noise and changes of tropical convection associated with ENSO

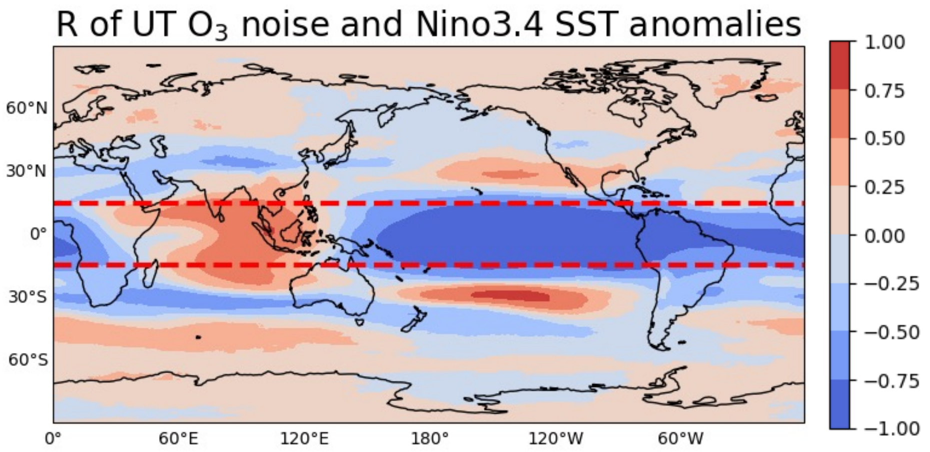


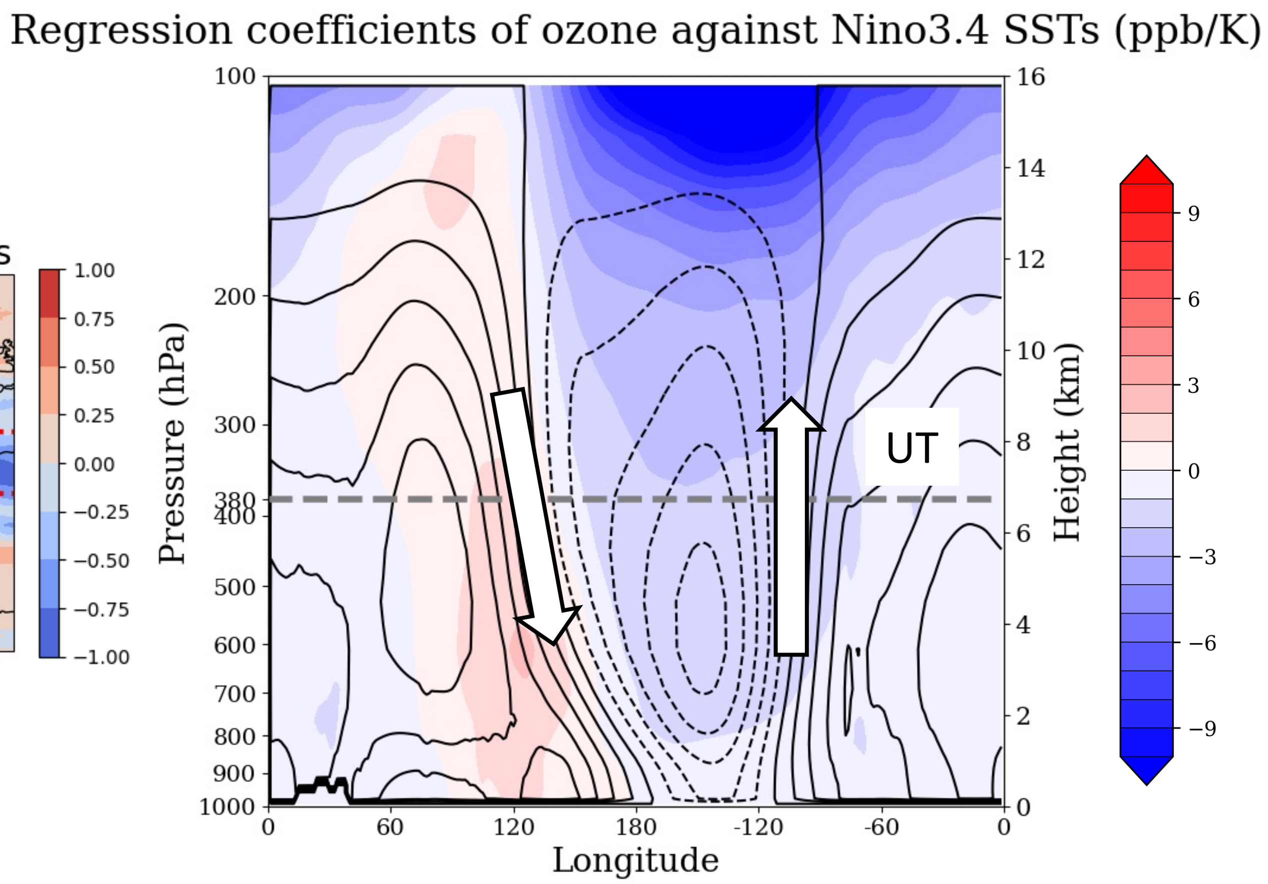




- Higher tropical SSTs ~ lower UT O_3
- The increase of the deep convection in the tropics ~ lower UT O_3

UT O_3 noise and anomalous Walker circulation associated with ENSO

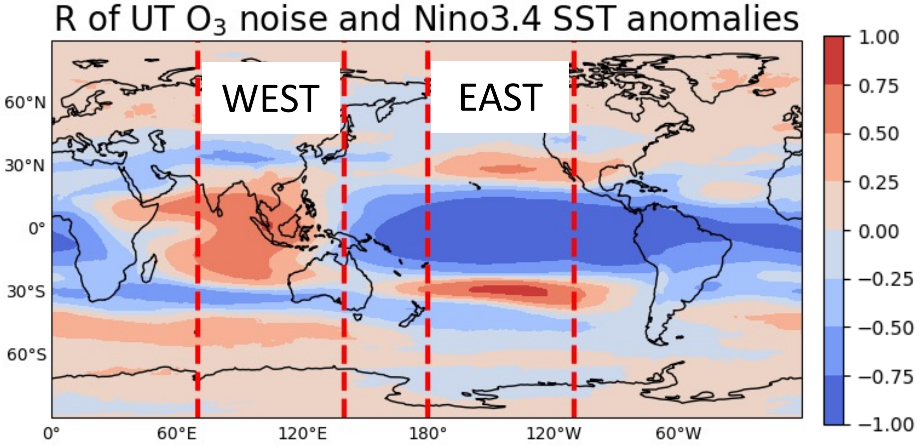


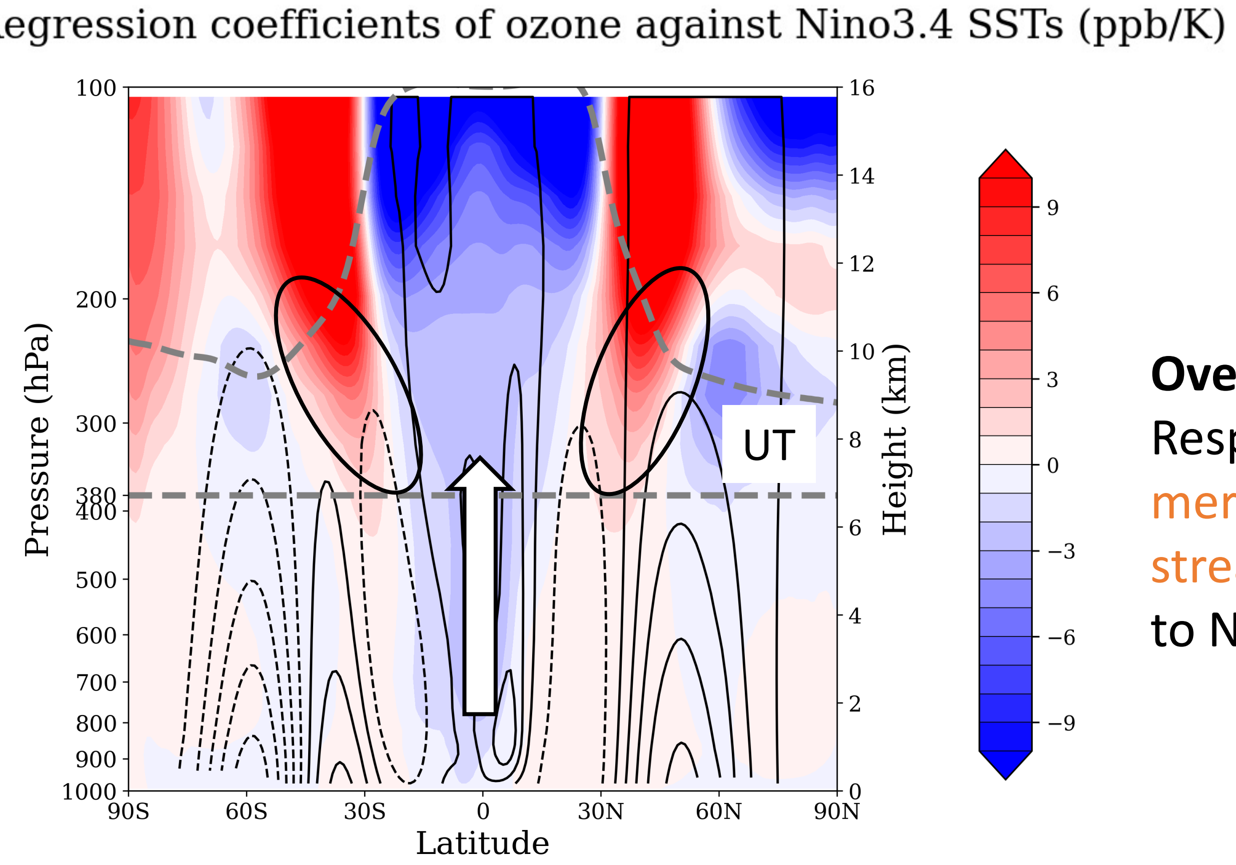


Overlaid: Response of zonal mass stream function to Nino3.4 SSTs

- Walker Circulation is weakened by El Niño and lead to anomalous upwelling to the east and lower ozone values, increased downward flow and higher ozone values to the west

UT O_3 noise and anomalous Hadley Cell associated with ENSO

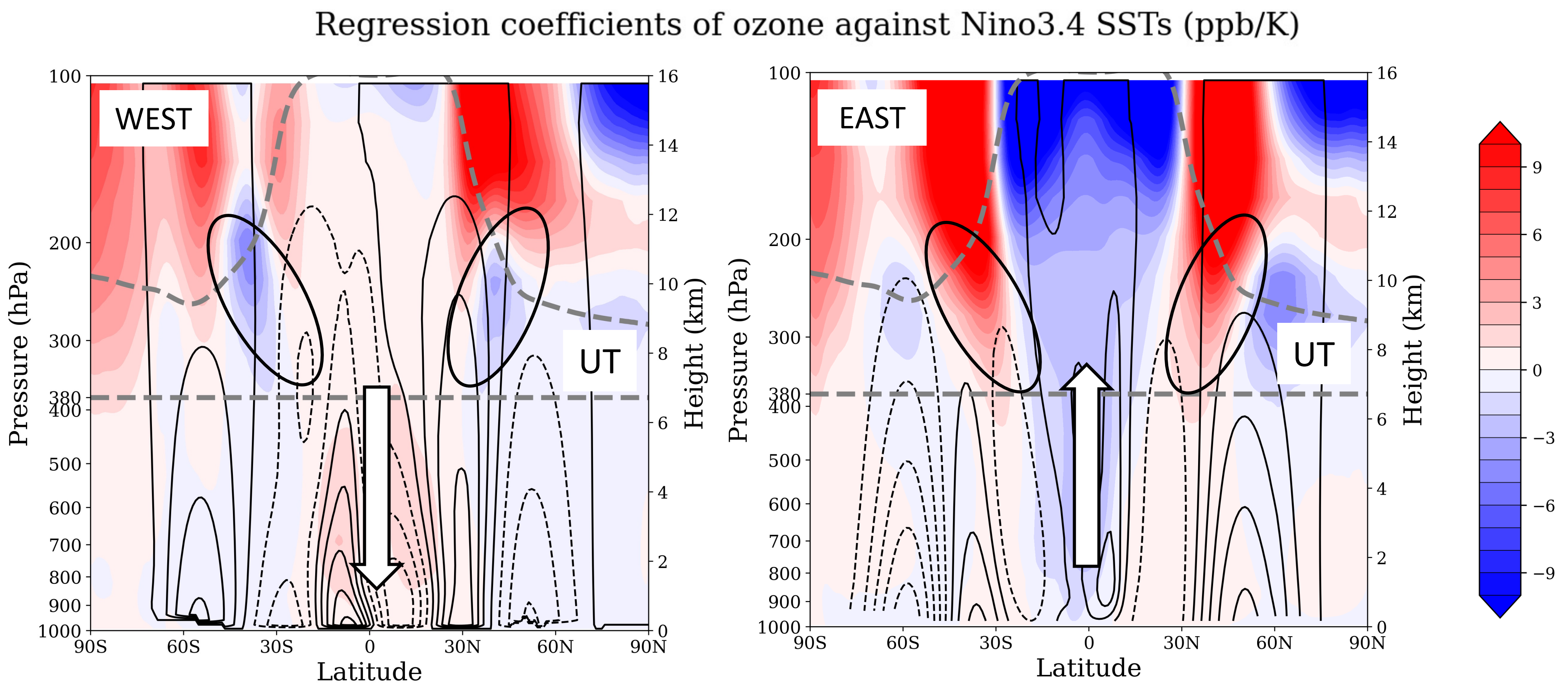




Overlaid: Response of meridional mass stream function to Nino3.4 SSTs

- For eastern region, stronger ascending transport near the equator due to El Niño lead to lower ozone
- The positive ozone anomalies in the midlatitudes may be caused by increased STE of ozone

UT O_3 noise and anomalous Hadley Cell associated with ENSO



Overlaid: Response of zonal mass stream function to Nino3.4 SSTs

- For western region, weaker ascent near the equator due to El Niño leads to higher ozone
- The negative ozone anomalies in the midlatitudes may be caused by decreased STE of ozone

Summary

- The patterns of externally forced changes in global UT O_3 can be significantly identified in both 17-year satellite record and in each 65-year ensemble member simulation
- The externally forced signal shows a significant increasing trend especially in northern mid-latitudes
- ENSO-like features are found in the EOF1 of UT O_3 noise driven by climate internal variability
- Compared with tropospheric ozone in lower altitudes, UT O_3 is generally more sensitive to SST anomalies associated with ENSO
- The modulation of UT O_3 in the absence of external forcing occurs through both changes of chemical production (lightning NO) and transport (convection and large-scale circulation), which are all related with ENSO

Thank you