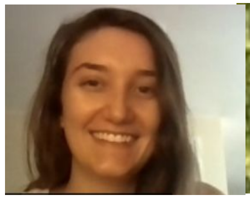
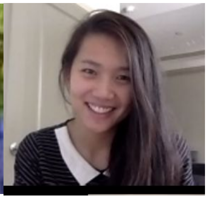
Understanding recent tropospheric ozone trends in the context of internal variability



Sarah Hancock

Gustavo Correa



Muye Ru

Lorenzo Polvani

COLUMBIA UNIVERSITY
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Jean-François Lamarque

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Jerry Ziemke

NASA

Owen Cooper

Audrey Gaudel

Kai-Lan Chang

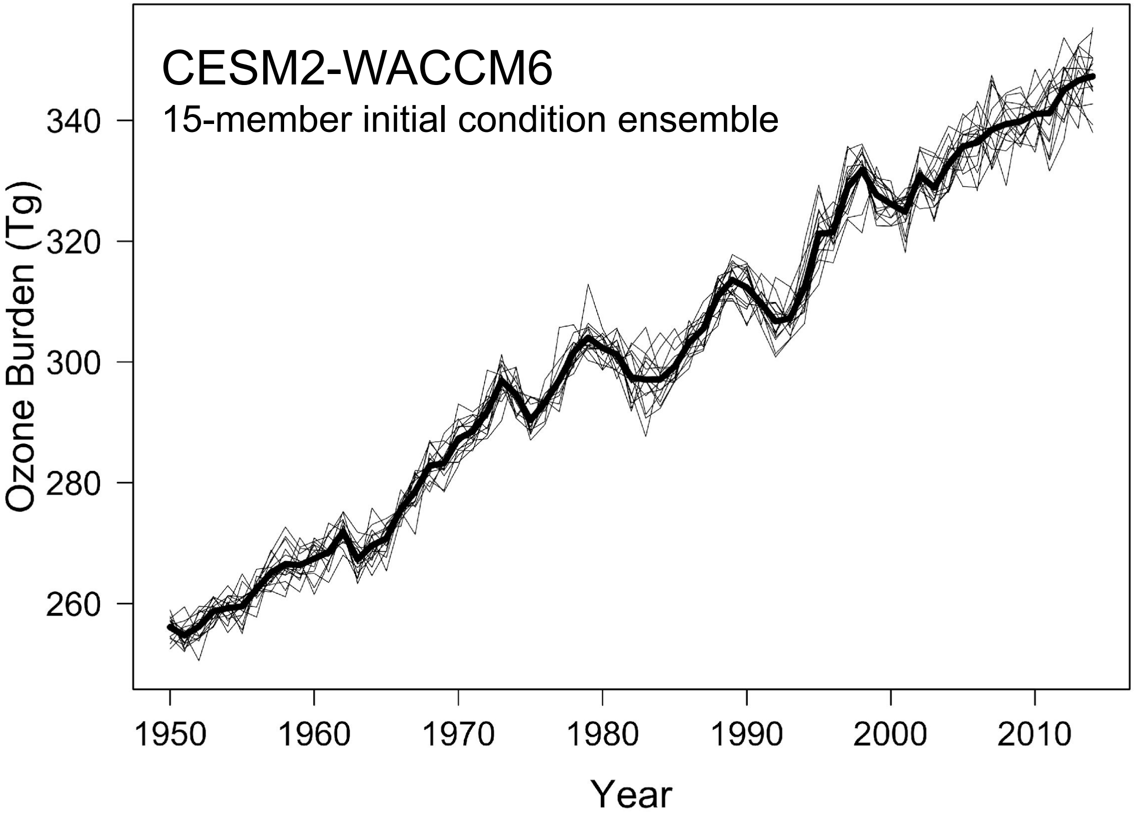
Bastien Sauvage

CIRES

NOAA

Université Paul Sabatier
TOULOUSE III

Annual mean tropospheric ozone burden (Tg)



Fiore, Hancock, Lamarque et al., Environmental Research: Climate, 2022

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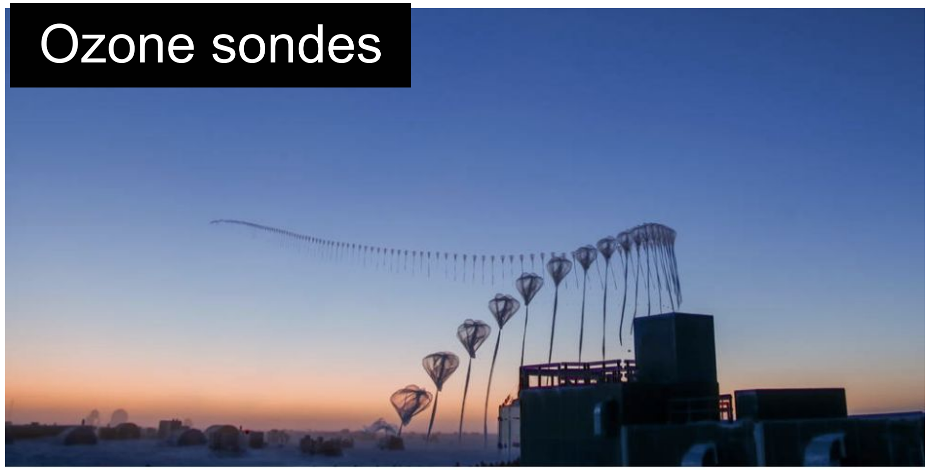
CESM CCWG Meeting
January 31, 2023

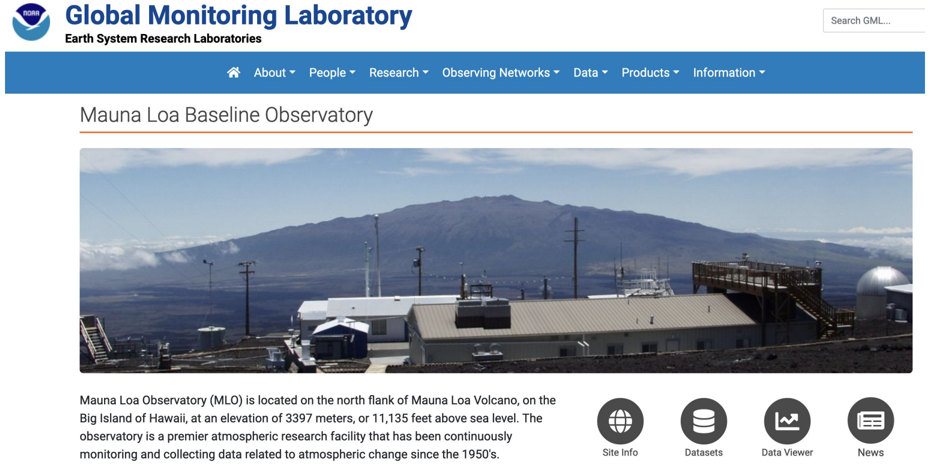
What is the basis for our knowledge tropospheric ozone trends?

Ozone sondes



This time-lapse photo from Sept. 9, 2019, shows the flight path of an ozonesonde as it rises into the atmosphere over the South Pole from the Amundsen-Scott South Pole Station. Scientists release these balloon-borne sensors to measure the thickness of the protective ozone layer high up in the atmosphere.
Credits: Robert Schwarz/University of Minnesota

Ground-based in situ monitoring



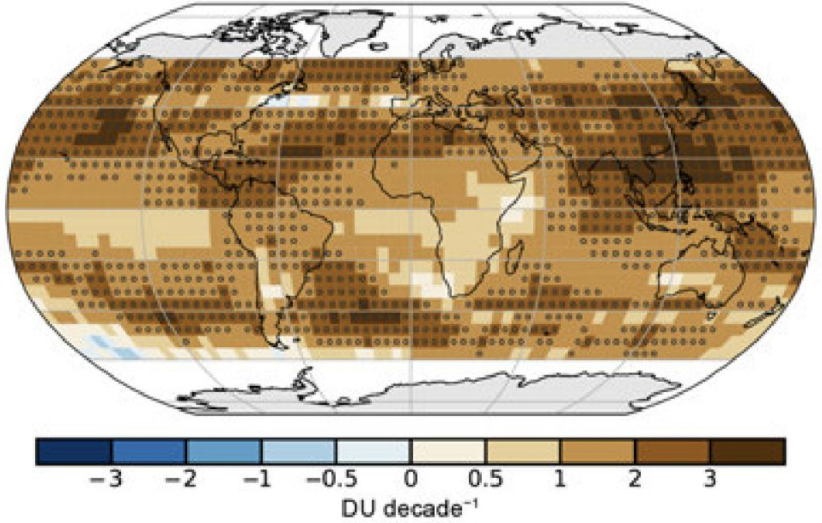
Mauna Loa Baseline Observatory

Mauna Loa Observatory (MLO) is located on the north flank of Mauna Loa Volcano, on the Big Island of Hawaii, at an elevation of 3397 meters, or 11,135 feet above sea level. The observatory is a premier atmospheric research facility that has been continuously monitoring and collecting data related to atmospheric change since the 1950's.

https://gml.noaa.gov/obop/mlo/

Satellite products (OMI/MLS)

2004-2020, Ziemke & Cooper, 2021



Measurements from commercial aircraft

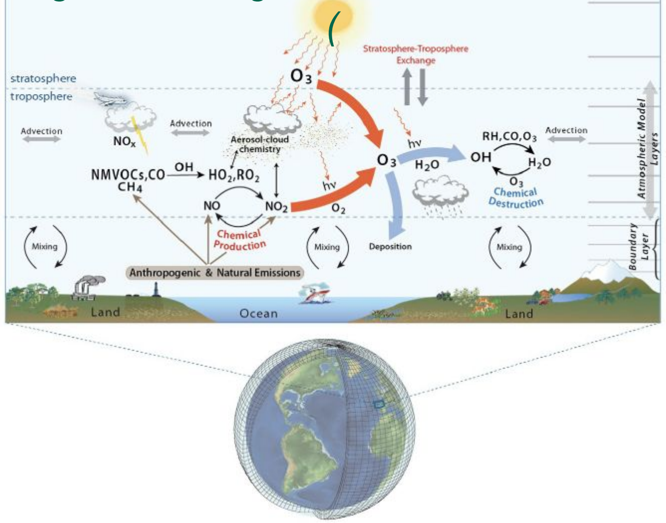
IAGOS

IN-SERVICE AIRCRAFT FOR A GLOBAL OBSERVING SYSTEM

https://www.iagos.org/#

Models

Fig. 1 of Young et al., Elementa, 2018



Recent synthesis by

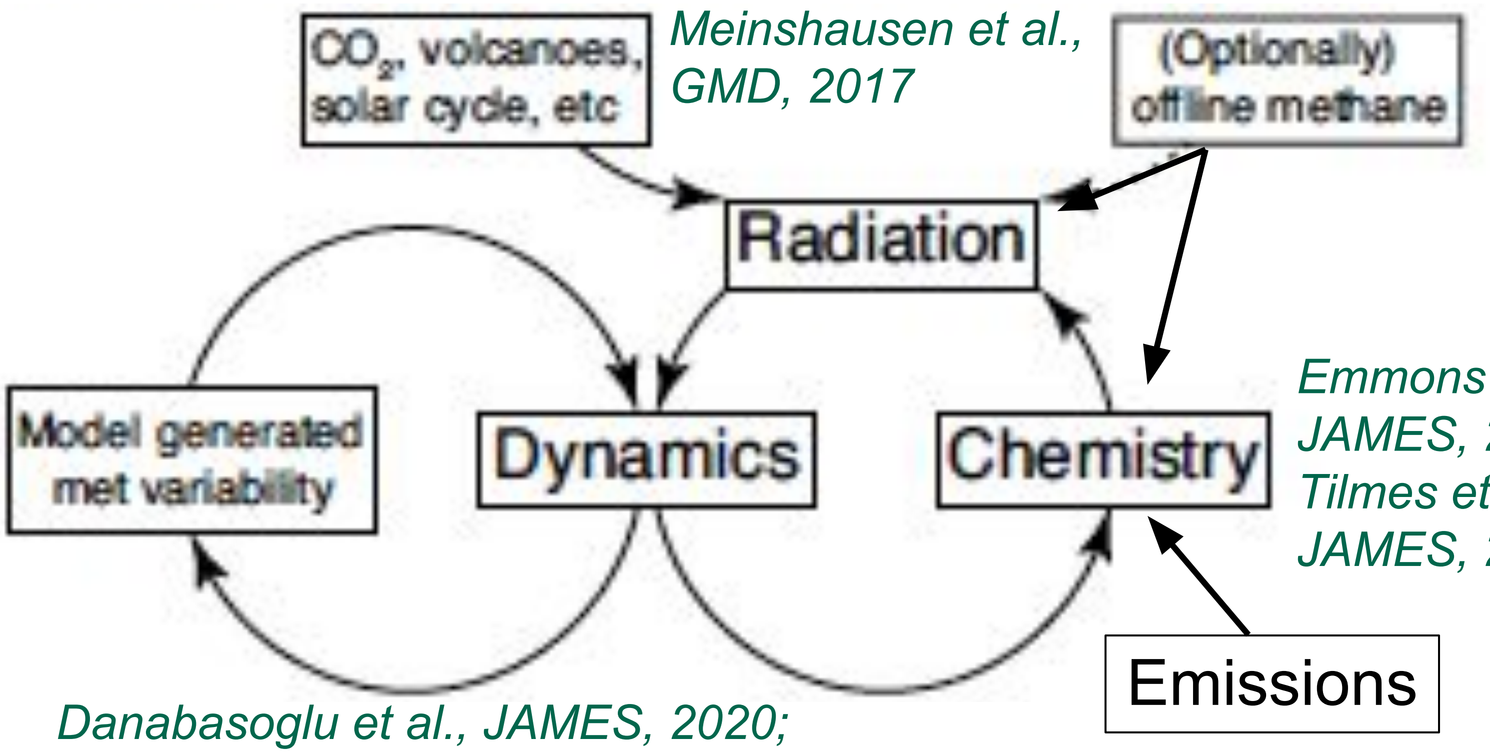
TOAR

tropospheric
ozone
assessment
report

https://igacproject.org/activities/TOAR

Initial condition ensembles with fully coupled chemistry-climate models offer a new lens through which to view tropospheric ozone trends

CESM2-WACCM6: A fully coupled atmosphere-ocean-sea ice-land model with atmos. chem. (gas + aerosol)



Meinshausen et al., GMD, 2017

Emmons et al., JAMES, 2020; Tilmes et al., JAMES, 2019

Danabasoglu et al., JAMES, 2020; Gettelman et al., JGR, 2019

Hoesly et al., GMD, 2018; Van Marle et al., GMD, 2017

Adapted from Young et al., 2018

Stratospheric & tropospheric chemistry, interactive aerosols (MAM4 scheme)

12-member initial condition ensemble
- 1950-2014
- 0.95° × 1.25°
- (+ 3 CMIP6 members)

How do we best evaluate if these models are ‘fit-for-purpose’ ?

Question for chemistry-transport models (driven by observed meteorology)

Do models capture observed long-term trends?

Do observed long-term trends fall in the range of trends simulated by individual ensemble members generated with chemistry-climate models?

Question for chemistry-climate models (generate their own weather)

Trends from routine vertical ozone sampling aboard commercial aircraft (IAGOS)

SCIENCE ADVANCES | RESEARCH ARTICLE

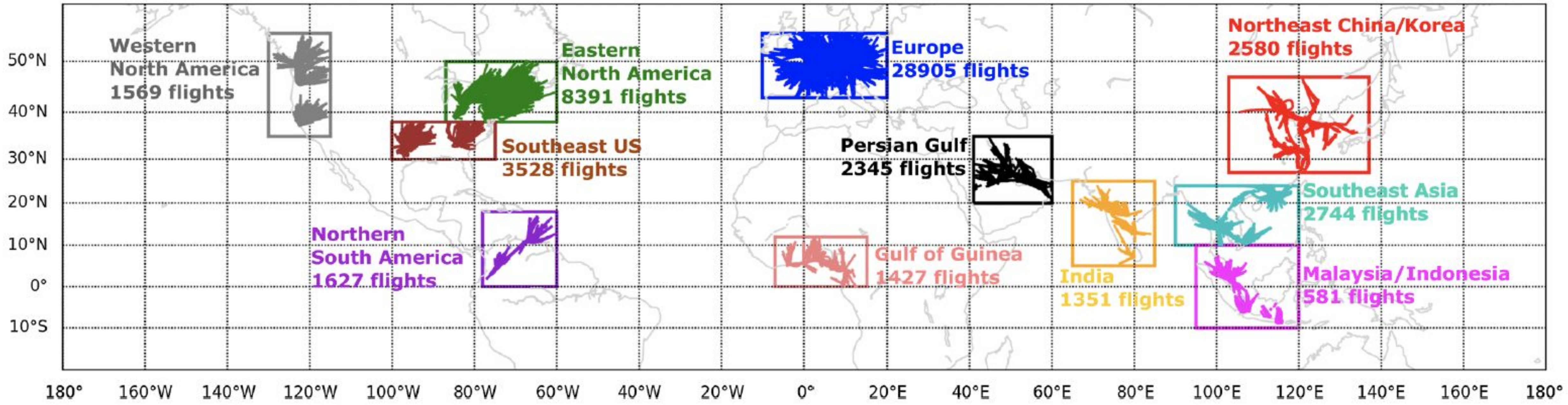
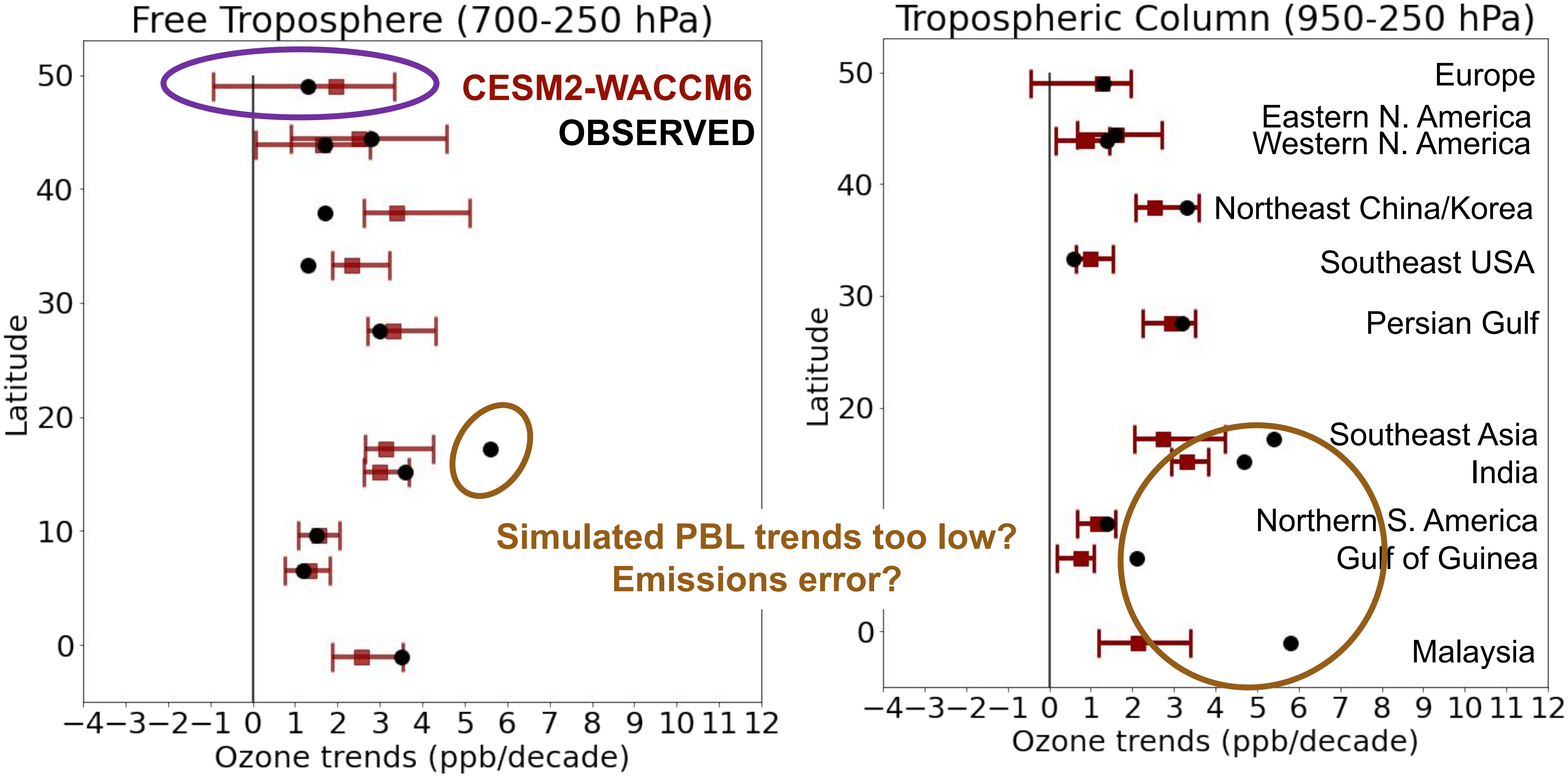


Figure 1 of Gaudel et al., Sci. Adv., 2020, updated from TOAR

The IAGOS observed free tropospheric trends generally fall in the range of the CESM2-WACCM6 ensemble

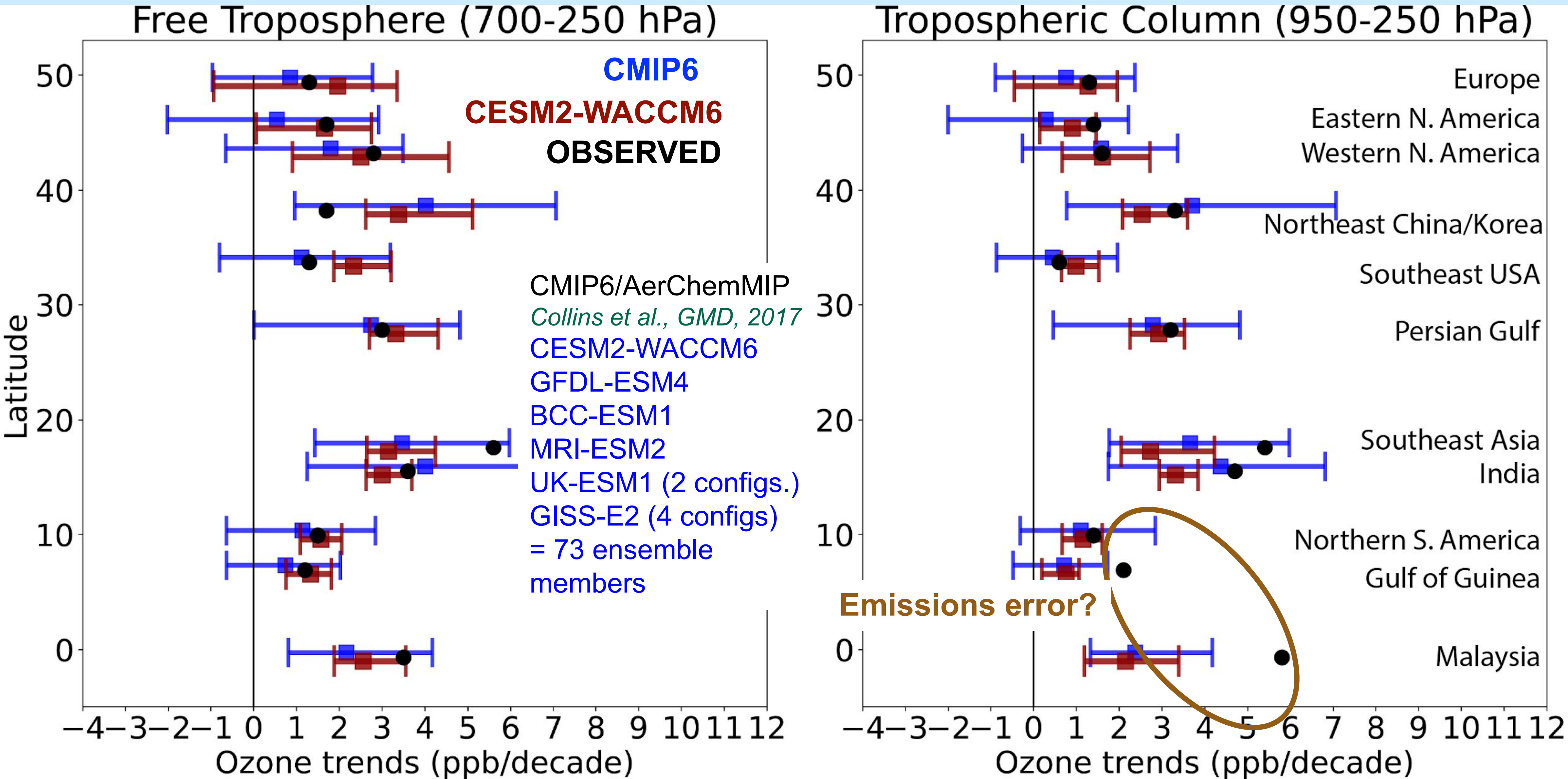
Climate variability □ opposite signed trends



Simulated PBL trends too low?
Emissions error?

[Fiore, Hancock, Lamarque et al., Env. Res.: Climate, 2022]

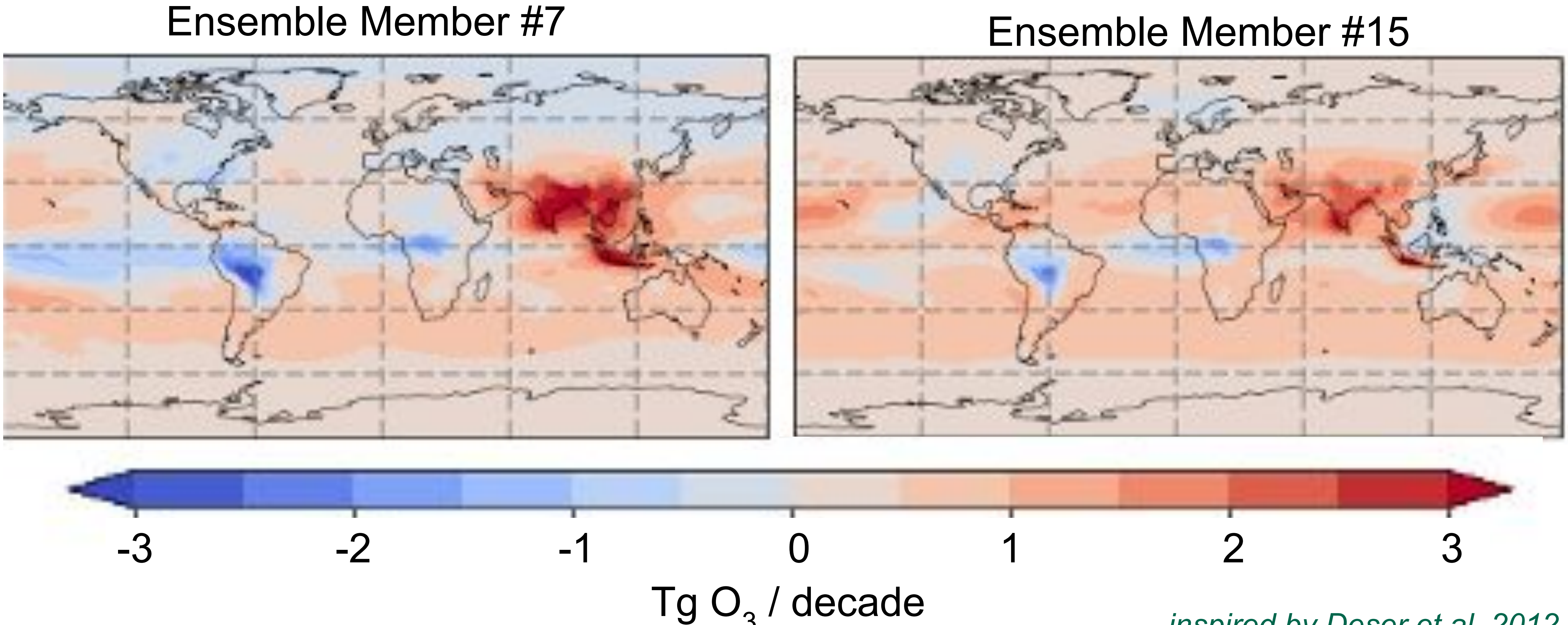
Not one full chemistry CMIP6 model historical model ensemble member captures the tropospheric column trend over Malaysia or Gulf of Guinea



CMIP6/AerChemMIP
Collins et al., GMD, 2017
CESM2-WACCM6
GFDL-ESM4
BCC-ESM1
MRI-ESM2
UK-ESM1 (2 configs.)
GISS-E2 (4 configs)
= 73 ensemble members

The sign and magnitude of 20-year trends can be influenced by internal climate variability

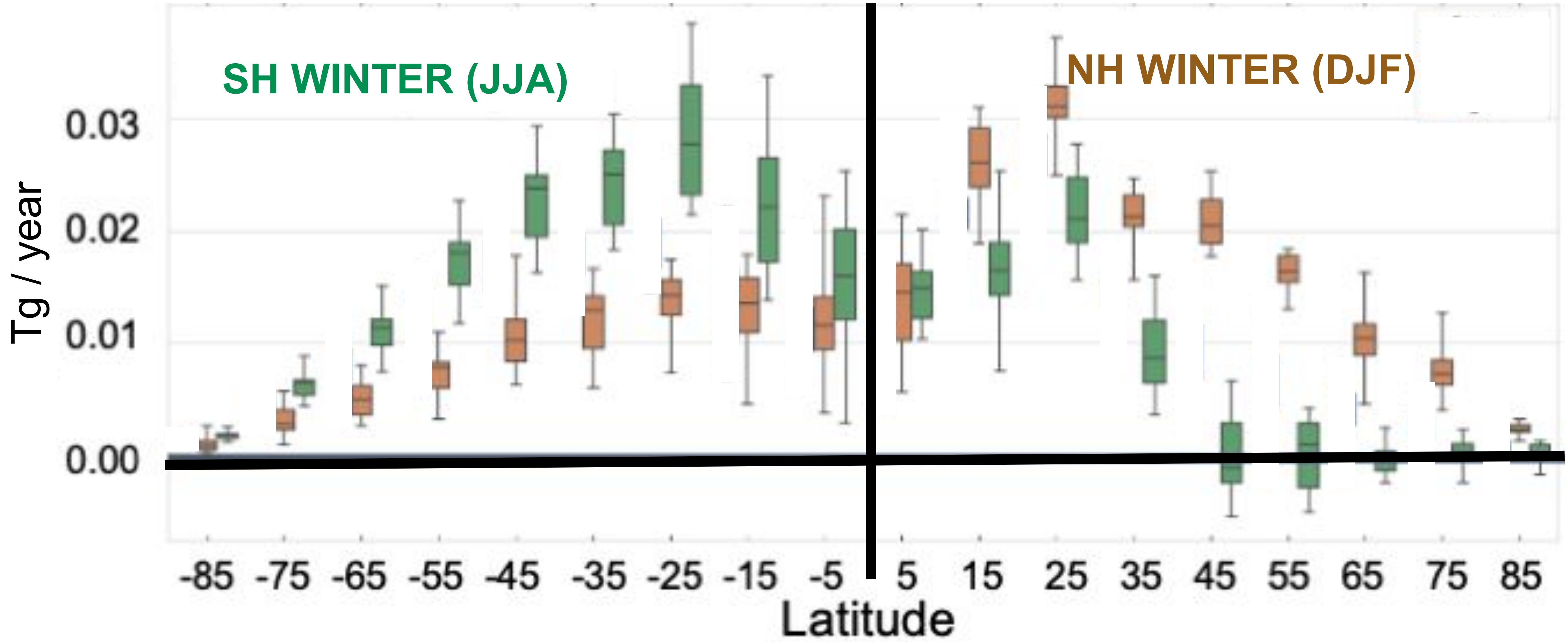
Annual mean lower tropospheric (surface to 690 hPa) ozone burden trends
1995-2014



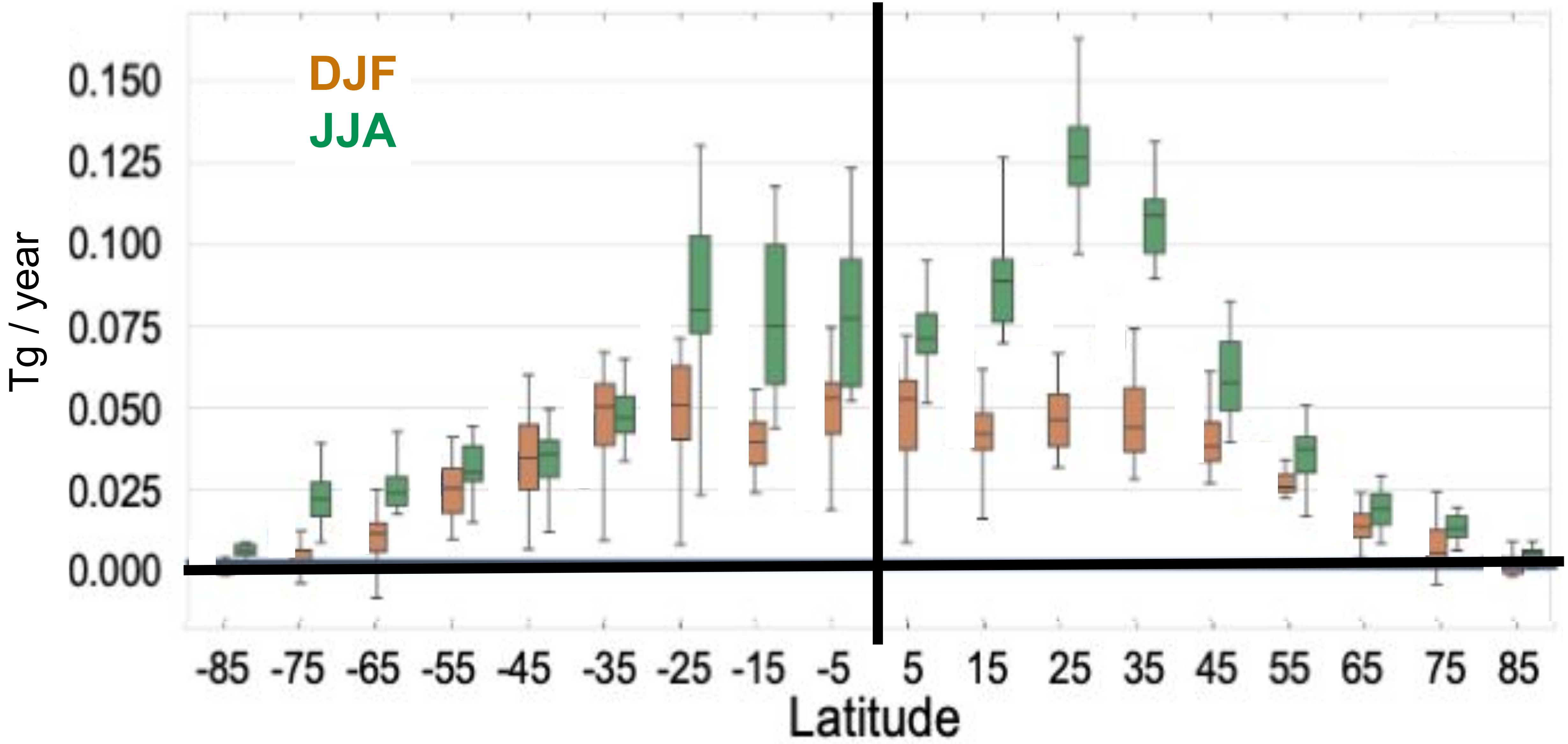
inspired by Deser et al. 2012

Trends over last two decades: Strong seasonal dependence in extratropics Largest increases occur in WINTER (longer lifetime)

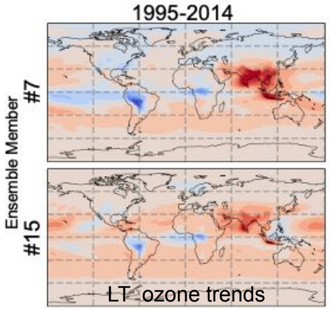
1995-2014 Ozone Trends in Lower Troposphere (surface – 690 hPa)



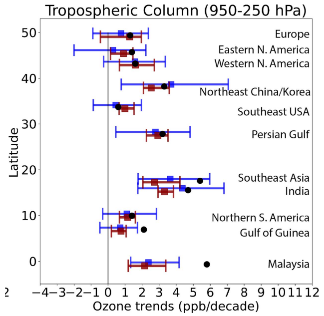
Upper Tropospheric Ozone (380 hPa – tropopause) **continues rising 1995-2014: Largest increases during boreal summer at 30S-40N**



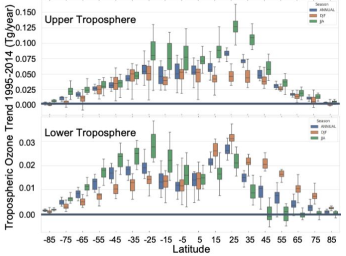
CONCLUSIONS: Understanding recent tropospheric ozone trends in the context of internal variability (with a CESM2-WACCM6 initial-condition ensemble)



- Differences in magnitude, sign of 20-year (1995-2014) lower tropospheric ozone trends
  □ Implications for interpreting observed records
  □ Use ensemble to identify where we can most rapidly detect anthropogenic influence



- Observation-derived trends (from routine ground, airborne, and satellite data) usually fall within the inter-ensemble (& the CMIP6/AerChemMIP) range.
  □ CESM2-WACCM6 overall fit-for-purpose
  □ Climate variability affects trends (opposite signs possible)
  □ All-model discrepancies over Malaysia + Gulf of Guinea □ emissions?



- Trends in tropospheric ozone vary strongly by atmospheric region & season
  □ LT extratropics: increase most in winter; UT 30S-40N: increase most in summer
  □ Decoupled UT (increasing) & LT (little change) trends at N mid-to-high latitudes in summer implies growing radiative forcing despite ground-level reductions