5th Atmospheric Composition And The Asian Monsoon (ACAM) Workshop

Long-term trends and seasonal persistence of the total column ozone changes over the Tibetan Plateau

Yajuan Li[1,2], Jianchun Bian[2], Wuhu Feng[3], Sandip Dhomse[3], Martyn Chipperfield[3], Yuan Xia[1] , Faquan Li[4], and Dong Guo[5]

1 School of Electronic Engineering, Nanjing Xiaozhuang University, Nanjing, China
2 Institute of Atmospheric Physics, Chinese Academy of Sciences (CAS), Beijing, China
3 School of Earth and Environment, University of Leeds, Leeds, UK
4 Innovation Academy for Precision Measurement Science and Technology, CAS, Wuhan, China
5 Nanjing University of Information Science & Technology, Nanjing, China

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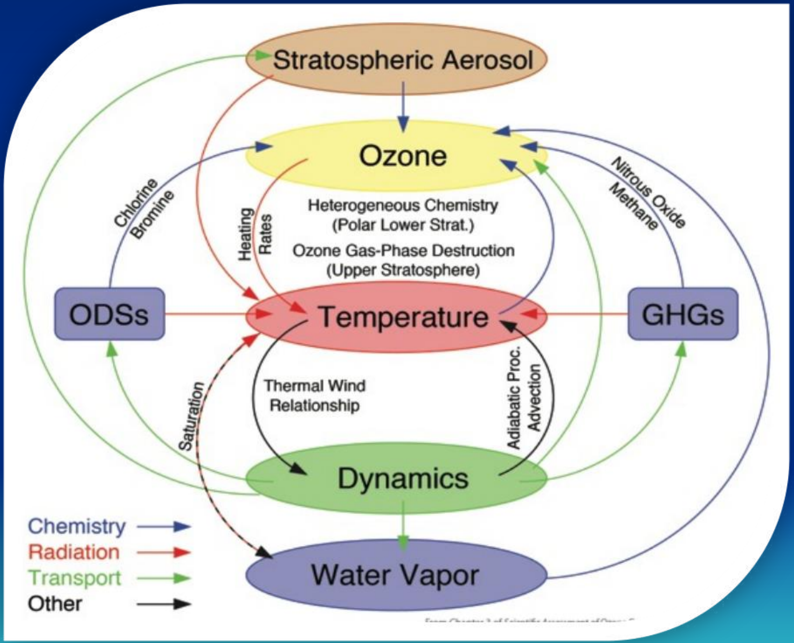
ACAM
ATMOSPHERIC COMPOSITION & THE ASIAN MONSOON

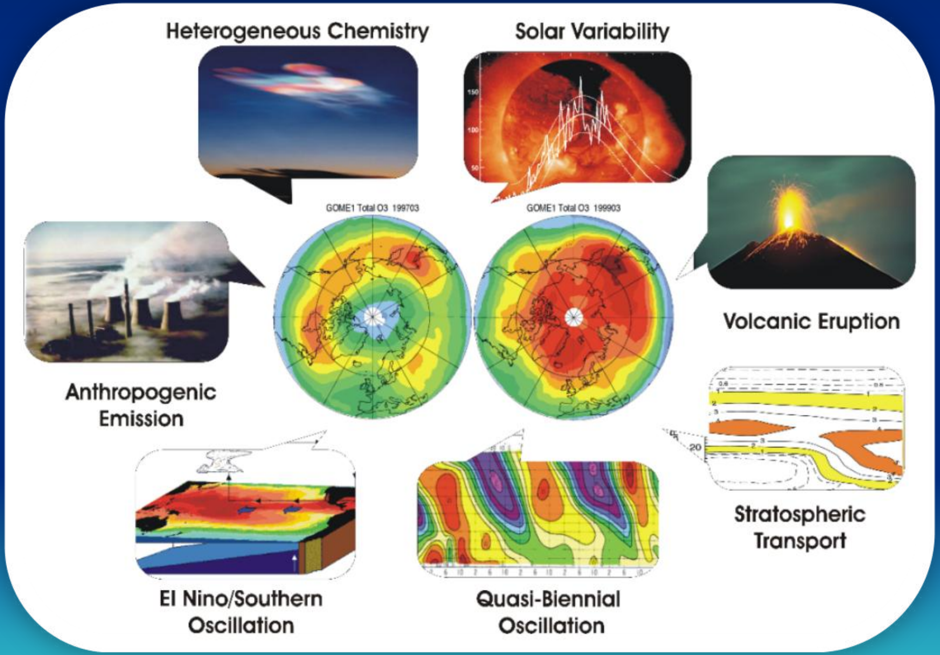
Outline

- **Background**
- **Data & Methods**
- **Results**
- **Summary & Outlook**

Accurate quantification of ozone change is challenging

WMO, 2022: Actions taken under the Montreal Protocol contribute to ozone **recovery**
Outside the Antarctic region, **limited evidence** of total column ozone (TCO) recovery since 1996



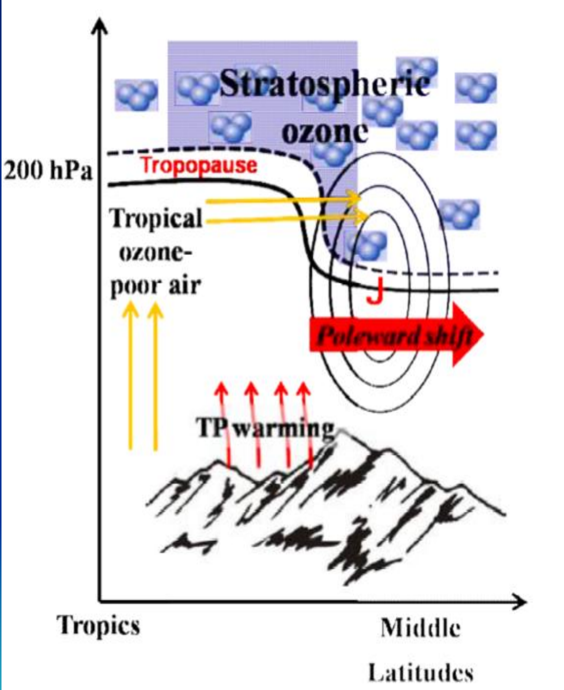


- **Chemistry-Climate feedback circles**
- **Processes controlling stratospheric ozone**

Thermal-dynamical effects of the TP on stratospheric ozone

- **Summertime "ozone valley" over the TP** (Zhou et al., 1994)
- **Ozone "minihole" over the TP in Dec 2003** (Bian et al., 2006)

Tibetan Plateau (TP)



- **High geographic effect**
  - Terrain-induced local circulation; air expansion...
- **The upward motions of tropospheric ozone-poor air**
  - Deep convection; uplift of tropopause…
- **The poleward transport of tropical ozone-poor air**
  - Brewer–Dobson circulation; South Asian High…

Seasonal variability of the total column ozone (TCO) and ozone low (TOL) over the TP

Long-term trends, possible influencing factors, and seasonal persistence?

Satellite Data

Copernicus Climate Change Service (C3S)

- Monthly mean total column ozone (L4) from 1970 to present.
- Multi-sensor Reanalysis (MSR) dataset: Merge of 15 sensors by using gap-filling assimilation methods, e.g. SBUV, TOMS, GOME, SCIAMACHY or OMI ...
- Resolution: 0.5° x 0.5° gridded data.
- Long-term stability below the 1%/decade level.
- Systematic and random errors below 2% and 3-4%, respectively.

https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-ozone-v1?tab=overview

Model & simulation

TOMCAT/SLIMCAT:

- a global 3-D Off-line chemical transport model (CTM)
- Chemistry: ‘Full’ stratospheric chemistry scheme (64 species, 160 reactions)
- Horizontal winds and temperatures from (UKMO, ECMWF etc) analyses
- Vertical motion from diagnosed heating rates (SLIMCAT)
- 2.8°× 2.8° grids (T42), 32 hybrid sigma levels (surface to ~60km)
- **Model simulation (ERA5)** forced with ECMWF ERA5 reanalysis (1979 - 2021)

Chipperfield, 2006; Feng et al., 2011; 2021; Dhomse et al., 2016; 2019; 2021; Li et al., 2020; 2022

Methodology

Multi-variate linear Regression (MLR) models:

TCO(t) = Independent linear trends (ILTs, pre-1998 and post-1998)

+ Solar + QBO terms (30 hPa and 10 hPa) + ENSO + AO + Aerosol

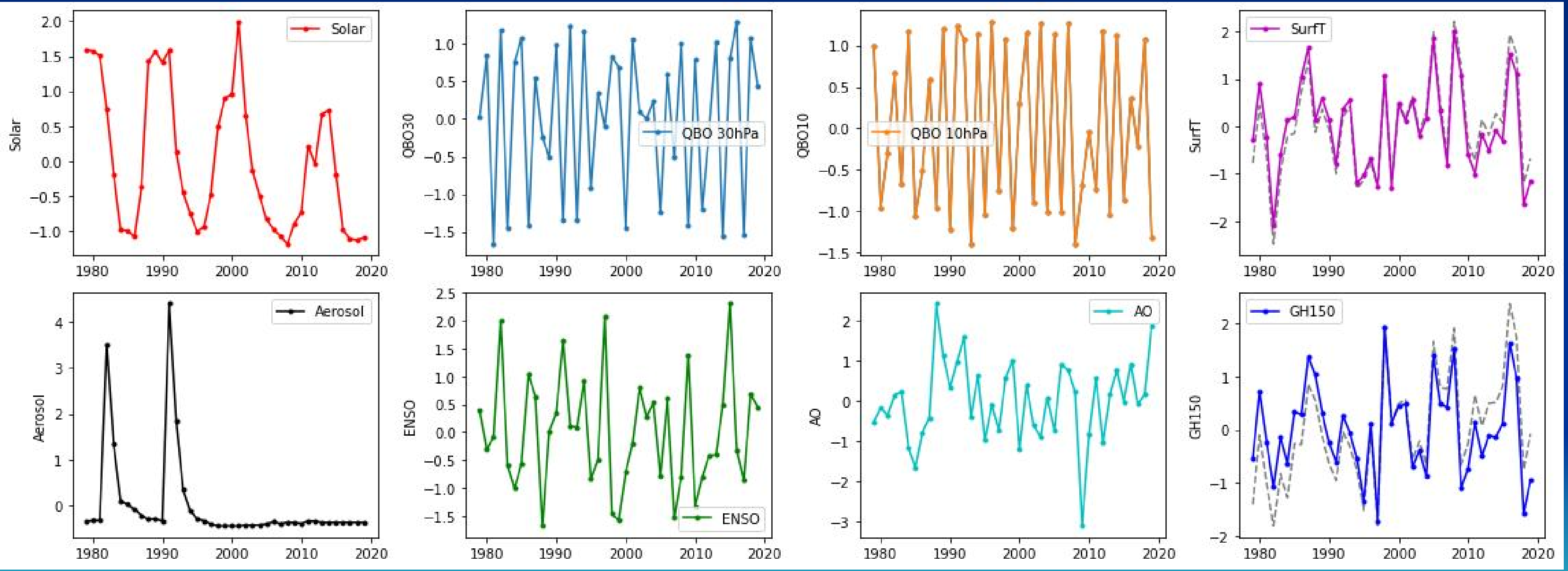
+ SurfT / GH150 + residuals

Zhang et al., 2014; Li et al., 2022

- **Solar** (Mg ii index) from IUP Bremen
- **QBO, ENSO** and **AO** indices from Climate Prediction Center
- Surface Temperature (**SurfT**) or 150 hPa geopotential height (**GH150**) over the TP region from ECMWF reanalysis to represent **the tropospheric dynamical influence**

MLR models with DJF mean explanatory variables

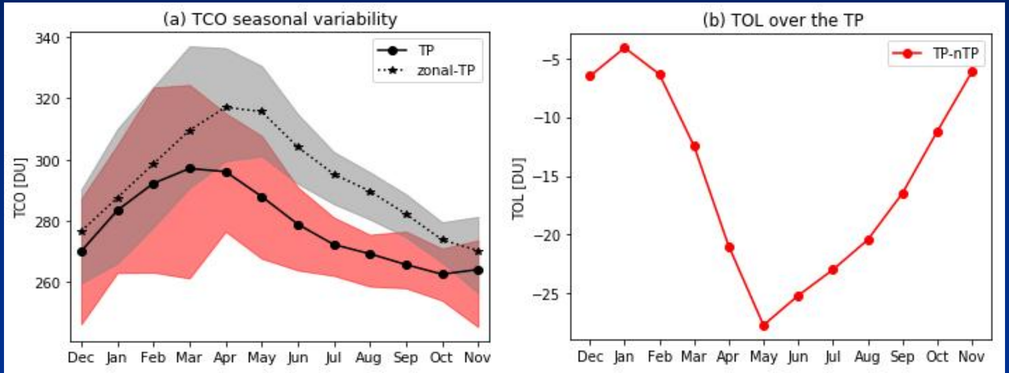
- Pre-processing for explanatory variables:
  a) standardized, b) de-trended and c) Correlation analysis

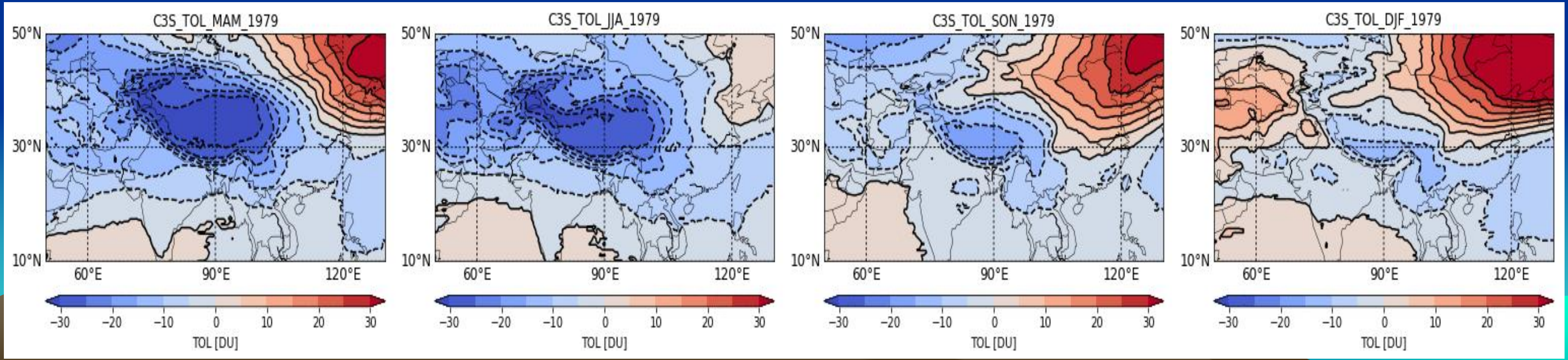


- ➢ **TCO(t) = C_0 + Trend1 + Trend2 + Solar + QBO30 + QBO10 + ENSO + SurfT**
- ➢ **TCO(t) = C_0 + Trend1 + Trend2 + Solar + QBO30 + QBO10 + GH150**

Seasonal variations of TCO and TOL over the TP

- Wintertime ozone **buildup**
- Summertime ozone **decline**
- ~1 month earlier phase and smaller amplitudes in **TCO** over the **TP**
- Different **TOL** magnitudes in different seasons (JJA>MAM>SON>DJF)
- **Wintertime ozone largely controlled by dynamical processes, while in summer, photochemical loss dominates.**



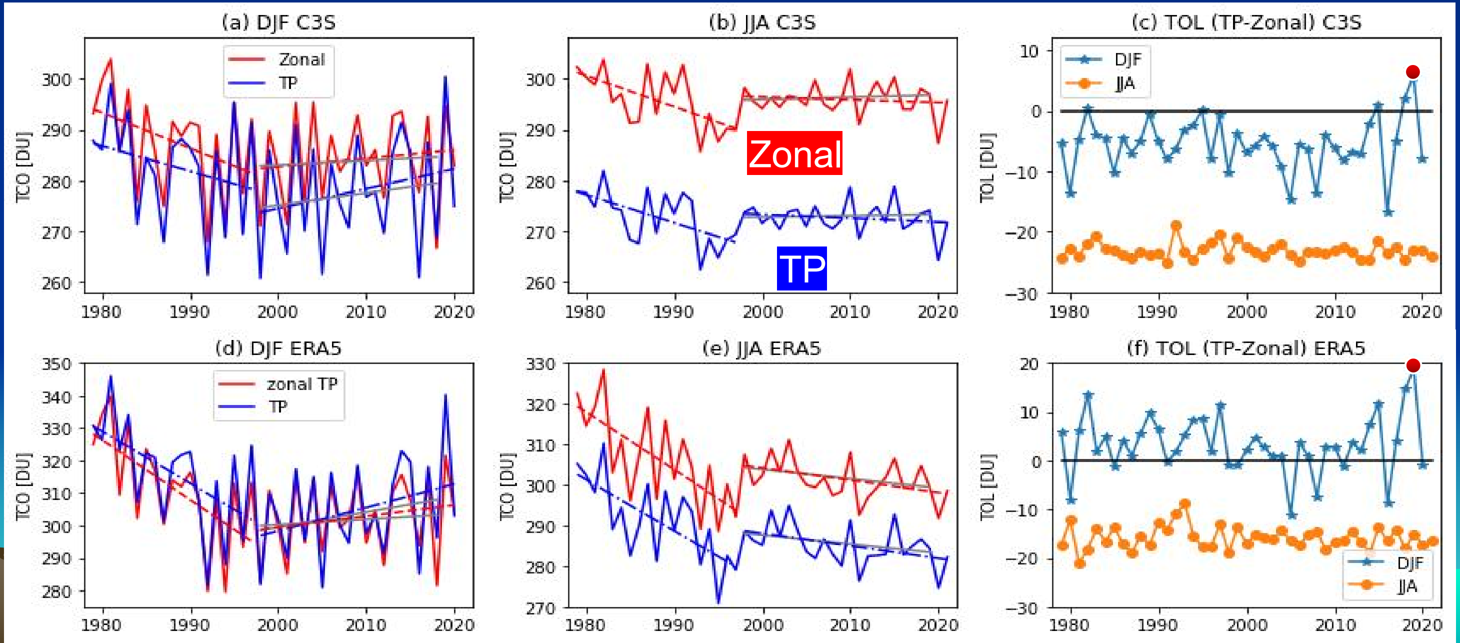


DJF & JJA-mean TCO and TOL time series

- **Corr. (C3S, ERA5)=0.95, 0.79** for DJF, JJA mean TCO over the TP
- ERA5 TCO are **overestimated** compared to C3S TCO
- Linear trends (post-1998)： **DJF increase** (TP>Zonal); JJA decrease (TP~Zonal)
- **Positive (+) TOL** over the TP during **wintertime 2019**

C3S

ERA5

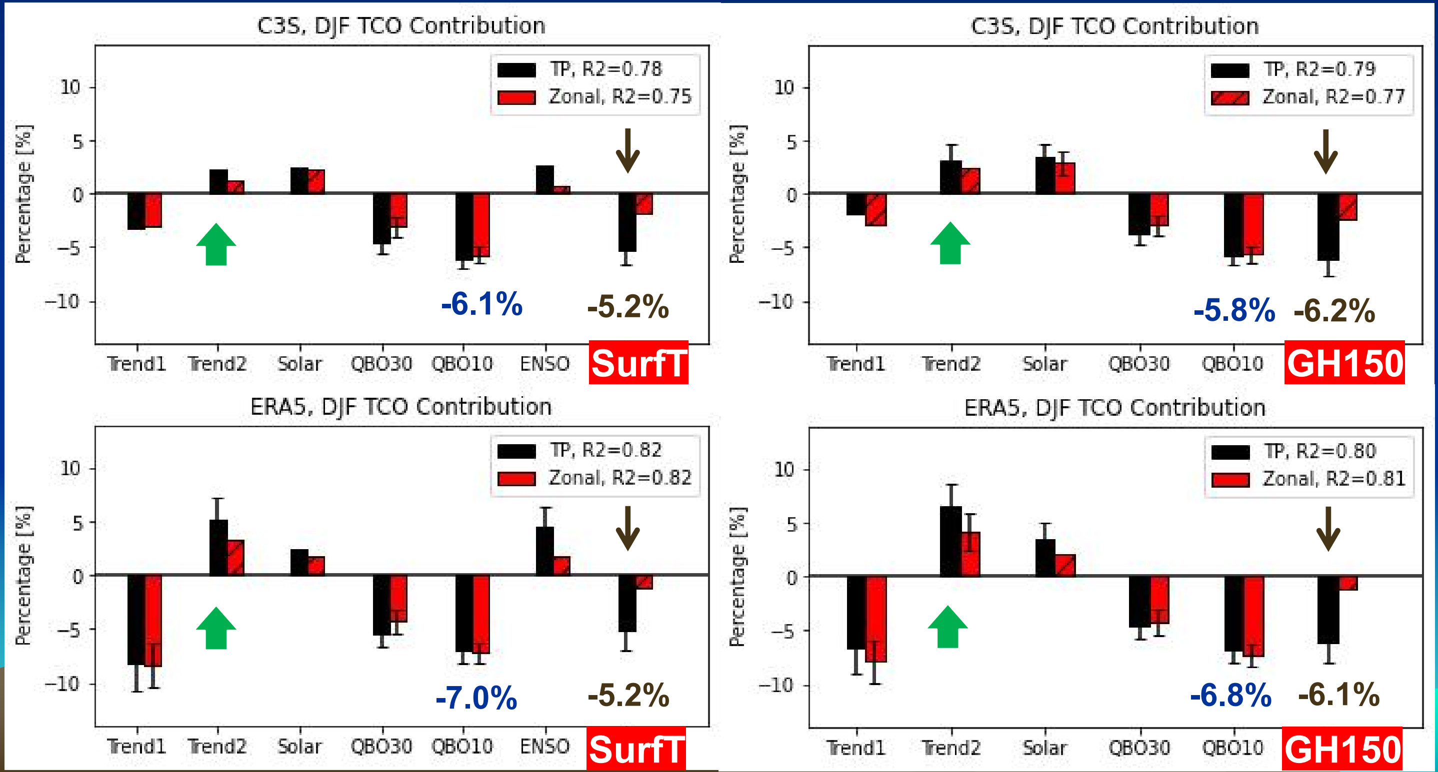


Long-term TCO trends and atrribution in DJF

- DJF TCO over the **TP** since 1998 **recovers** more significantly (compared to zonal region)
- QBO (10hPa) and **SurfT/GH150** dominats the DJF TCO over the **TP** for both C3S and ERA5

C3S

ERA5



TP

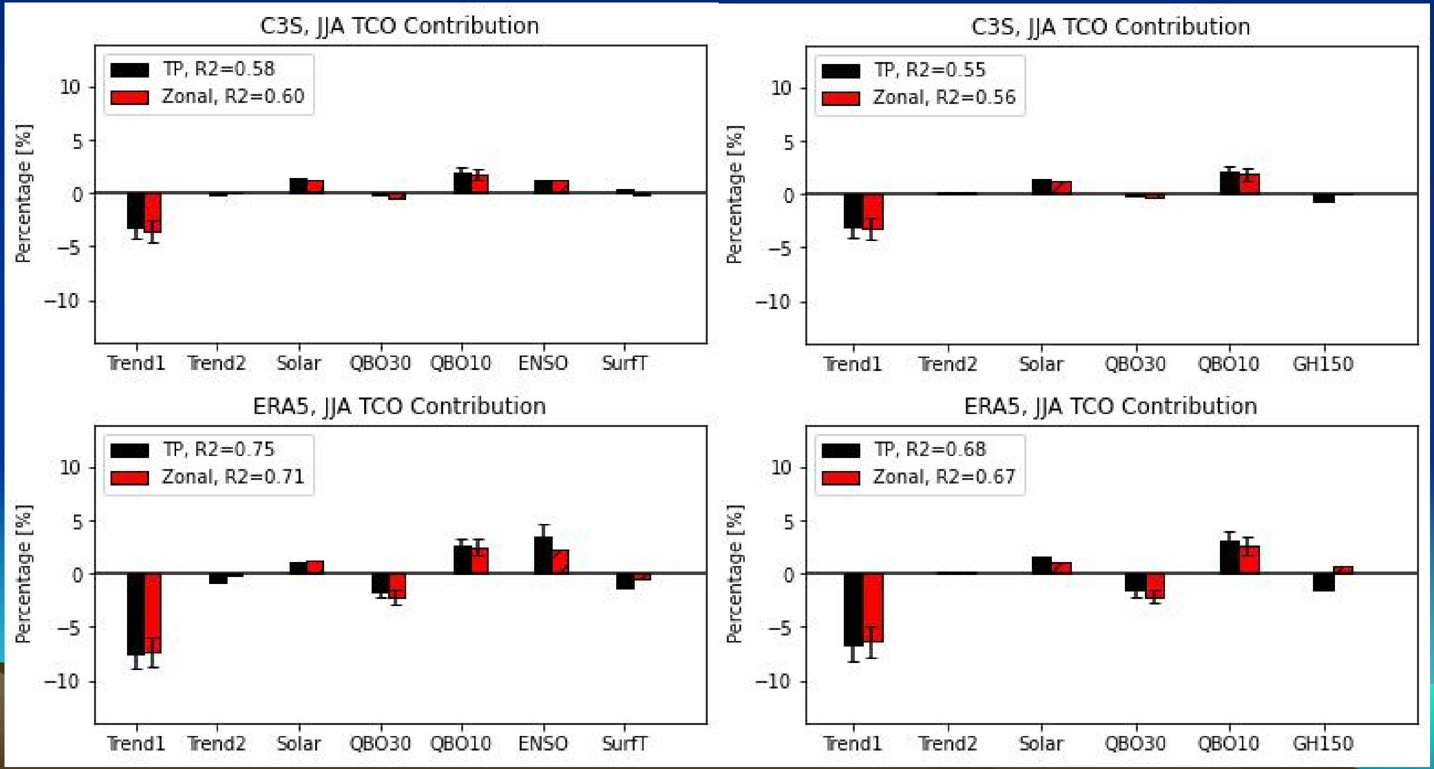
Zonal

Long-term TCO trends and atrribution in JJA

- **No sign of recovery** (post-1998) for JJA TCO over the TP and zonal region.
- Contributions (SurfT/GH150) are **small** for JJA TCO variability (with much smaller R^2).

C3S

ERA5

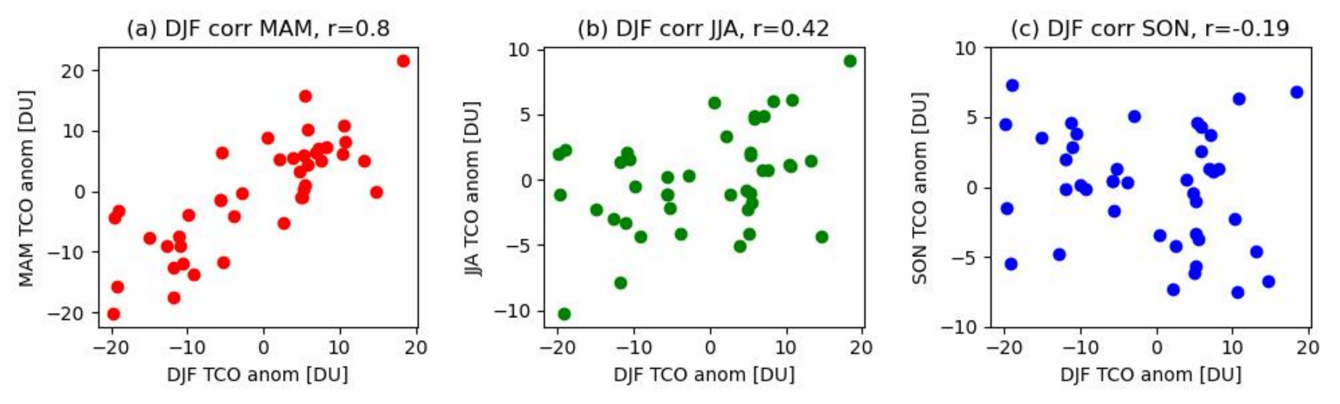


TP

Zonal

Seasonal persistence of TCO over the TP

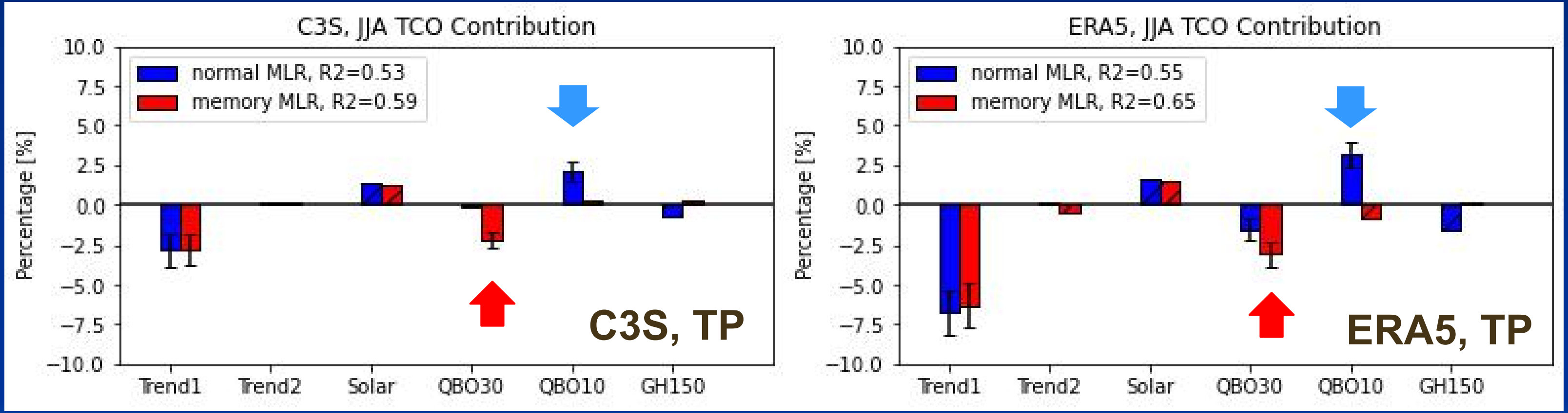
- Seasonal persistence (Fioletov and Shepherd, 2003)
  - ✓ data validation of chemistry climate models (Tegetmeier and Shepherd, 2007)
  - ✓ useful for filling data gaps (Tegetmeier et al., 2008)
  - ✓ improve the explanatory power of MLR (Tegetmeier et al., 2010a ,b)
- Wintertime TCO anomalies over the TP persist through the summer period.



Can **seasonal persistence** help to improve the explanatory power of MLR in **JJA TCO over the TP**?

Initial results with “memory” regression model

- “Normal” MLR: **JJA mean (QBO & GH150)** for JJA mean TCO (**QBO10 +**)
- “Memory” MLR: **DJF mean (QBO & GH150)** for JJA mean TCO (**QBO30 -**)
- **Determination coefficients (R2) are improved with “memory” MLR.**



- ☐ **DJF QBO (30hPa) dominates the JJA TCO in the “memory” MLR while JJA QBO (10hPa) dominates in the “normal” MLR**
- ☐ **DJF/JJA GH150 over the TP makes little contribution in both MLRs**

WHY?

Tegetmeier et al., 2008: QBO has an asynchronous effect on summertime ozone through “seasonal memory”

Summary & Outlook

- Seasonal variations in TCO over the TP with wintertime ozone buildup and steady summertime ozone decline
- TOL in different seasons are associated with different chemical and dynamical processes.
- Significant recovery for DJF TCO over the TP while no sign of recovery for JJA TCO
- Wintertime TCO anomalies over the TP persist through the summer period.
- "Memory" MLR improves the explanatory power for JJA TCO through seasonal persistence.

➢ **To further analyze the structure of ozone trends and seasonal persistence with altitude and how QBO might affect the summertime ozone variability over the TP through seasonal persistence?**