Quantifying the stratospheric contribution to tropospheric ozone radiative forcing

Junhua Liu[1,2], Chenxi Wang[2,3], Joanna Joiner[2], Jose Rodriguez[2], Xiuhong Chen[4], Luke Oman[2], Sarah Strode[1,2]

[1]USRA, Columbia, MD, USA, [2]NASA GSFC, Greenbelt, MD, USA, [3]UMBC, Baltimore, MD, [4]University of Michigan, MI

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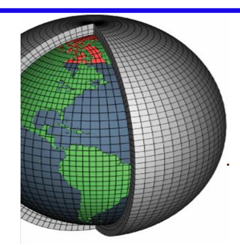
1: Summary

Liu et al. (2017) shows that strong stratospheric influence on the interannual variation of O_3 in the upper troposphere, where its radiative impact is largest. Given the observed and predicted net global decrease in emissions and the predicted increase in O_3 stratosphere-troposphere-exchange, distinguishing the role of stratospheric contribution from that of emissions to tropospheric O_3 variations and resulting changes in radiative forcing is critical to understand how they will change in the future.

In this study, we quantify the stratospheric and emissions contributions on tropospheric O_3 radiative effect (RE) using sensitivity runs of the AER offline radiative transfer model (RRTM) with different O_3 fields, including stratospheric ozone tracer ($StratO_3$) and O_3 simulated from the high-resolution GEOS-5 Replay run (~50 km). The $StratO_3$ is used to quantify O_3 of stratospheric origin in the troposphere at all locations and times. The offline module is set up so that all input fields except O_3 remain fixed. Our study shows that RE from tropospheric O_3 with stratospheric origin accounts for significant contributions to the global tropospheric O_3 RE.

2. Model and Approach



GEOS-CCM (MERR2-GMI replay run) → input fields → **AER Radiative Transfer Model (RRTM_LW and RRTM_SW)**

Lon x Lat: 0.625° x 0.5°
72 vertical level

Input fields are reading from outputs from MERRA2-GMI replay run:

- Concentrations of molecular absorbers include water vapor, carbon dioxide, ozone, nitrous oxide, methane, oxygen, nitrogen
- Surface conditions including surface emissivity, skin temperature etc. (Reflected and emitted radiation from surface)
- View geometry (local zenith angle, polarization)
- Cloud influence: ice or water fraction and size, cloud-water-path (CWP)

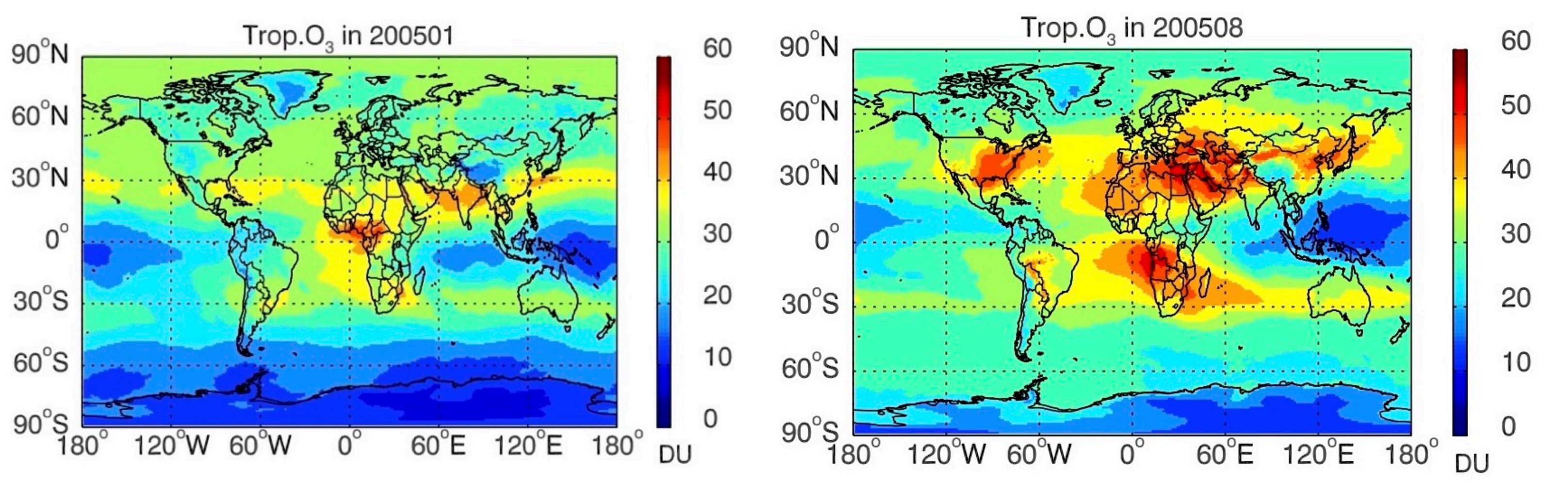
Sensitivity runs with different O_3 input fields (O_{3_in}):

In the stratosphere: $O_{3\_in} = O_3$
In the troposphere:

1. O_{3_in} = 0 ppb
2. $O_{3\_in} = O_3$
3. $O_{3\_in} = StratO_3$ *(an artificial stratospheric O_3 tracer)*
4. $O_{3\_in} = O_3 - StratO_3$ *(O_3 from emissions)*

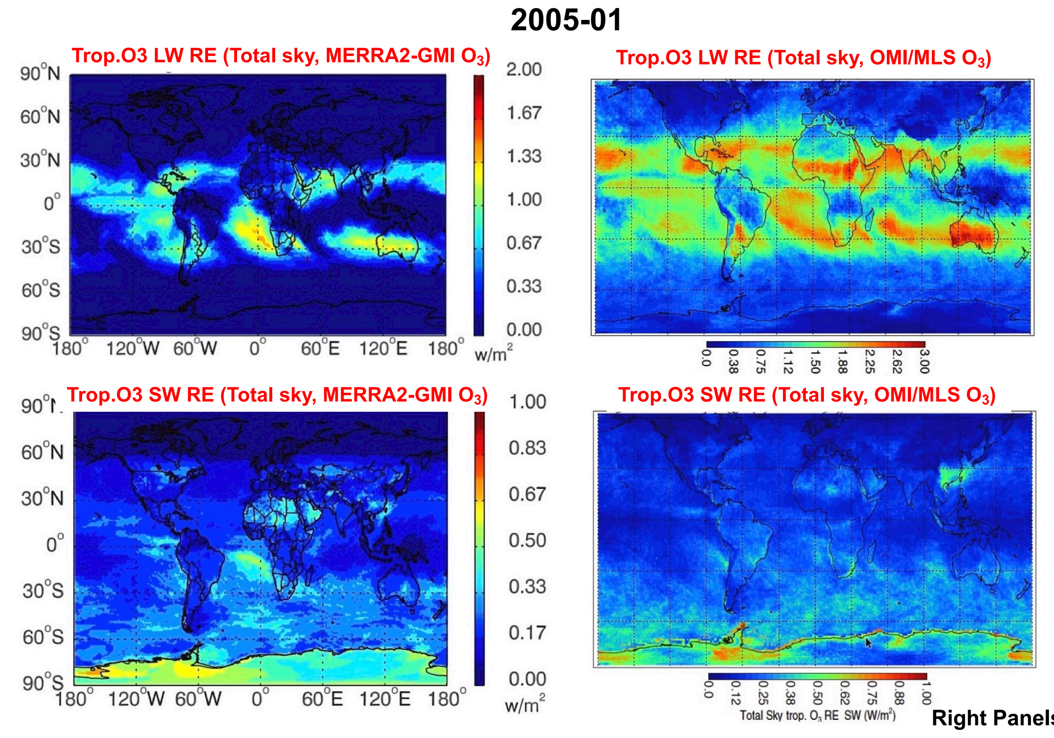
Tropospheric O_3 RE	Irradiance difference (run 2 - run 1)
Tropospheric O_3 RE from stratosphere	Irradiance difference (run 3 - run 1)
Tropospheric O_3 RE from emissions	Irradiance difference (run 4 - run 1)

3.1. Tropospheric O_3 column (TOC)



- Significant spatial variations of TOC, with O_3 minimum in west Pacific warm pool.
- January 2005: Elevated TOC occurs near subtropical jets with increased stratospheric O_3 influence. TOC maximum over western Africa.
- August 2005: TOC shows regional maximum over the downwind of polluted N.H. continents, and tropical south Atlantic (wave-1 pattern).

3.2. Model agrees with tropospheric O_3 RE calculation based on satellite observations



Right Panels from Joiner et al. 2009

O_3 LW RE:
High tropospheric O_3 LW RE occurs between 30°N and 30°S

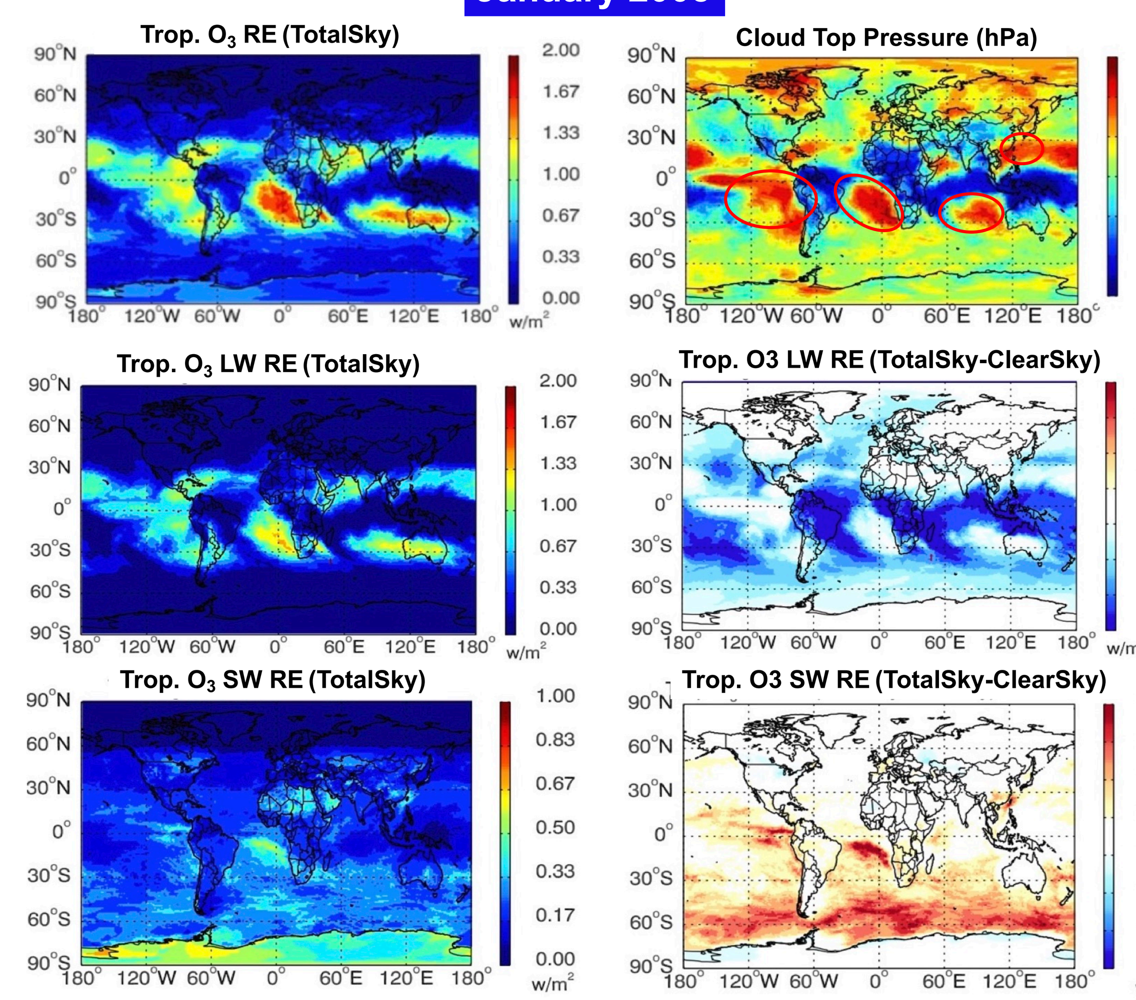
- Warmer temperature.
- Clouds: negative effect.

O_3 SW RE:

- High tropospheric O_3 SW RE occurs over regions with high surface albedo (Antarctica, northern Africa).
- Low bright cloud: positive effect.

4. Tropospheric O_3 radiative effect and clouds effect

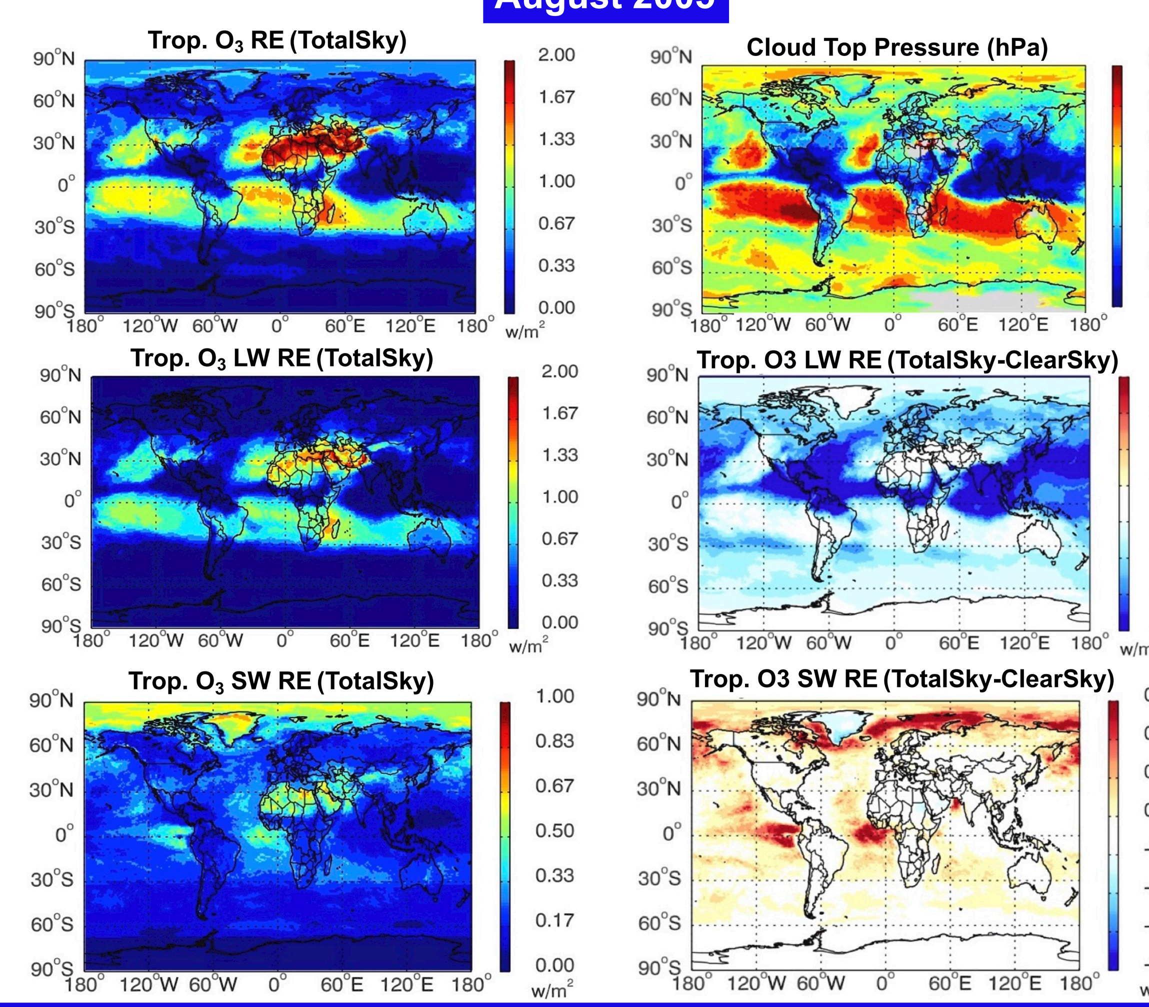
January 2005



High tropospheric O_3 RE occurs over:

- Regions around subtropical Jets: Elevated O_3 + small cloud negative effect.
- Regions with low clouds: much weaker negative effects on LW RE + positive effects on SW RE.

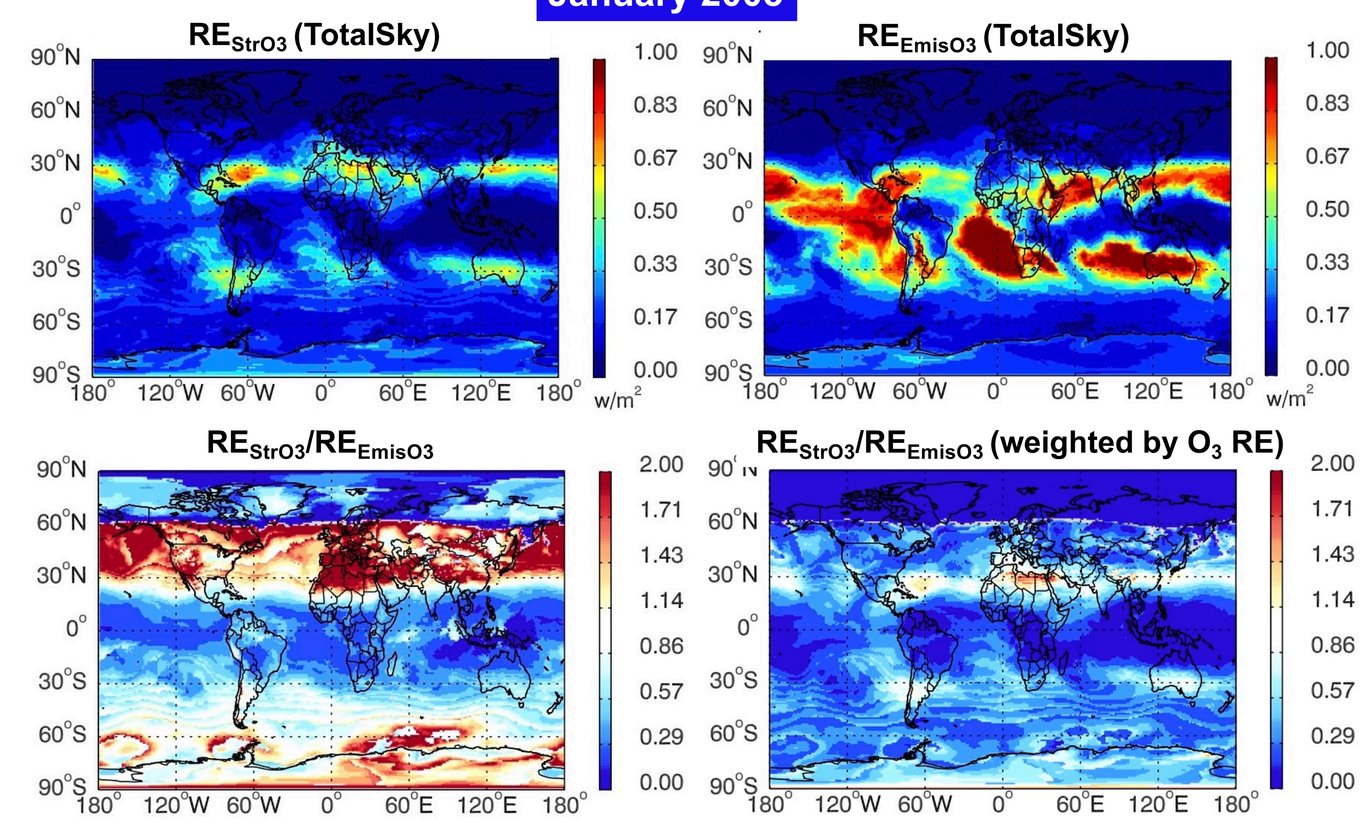
August 2005



- Regions, where elevated O_3 and low clouds are co-located, show regional RE max.
- The cloud effects on tropospheric O_3 RE is dominated by its strong negative effects on LW RE from middle and high clouds.

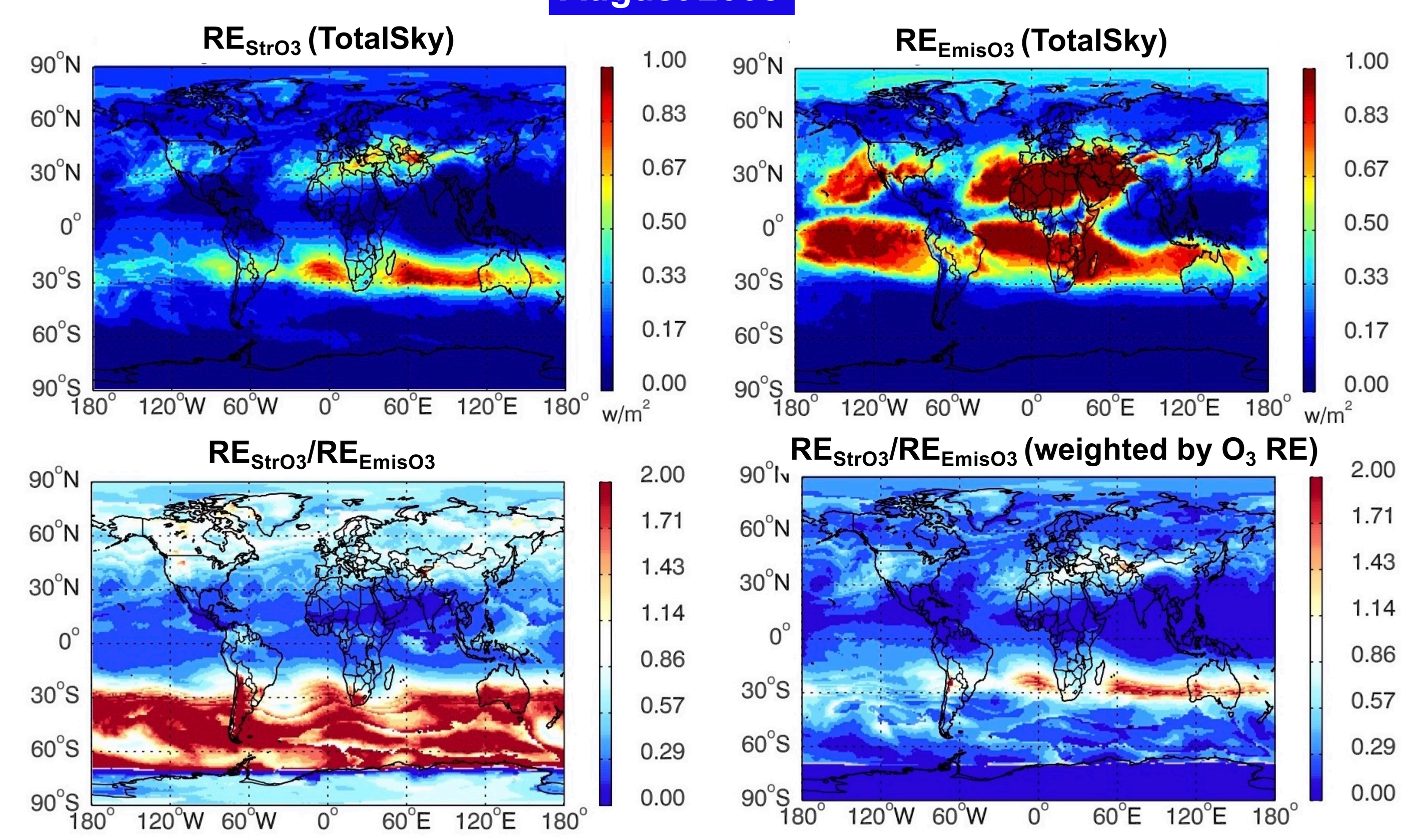
5. Stratospheric and emission components of tropospheric O_3 radiative effect

January 2005



- The $StrO_3/EmisO_3$ RE ratio is weighted by trop.O_3 RE to highlight regions where stratospheric contribution is important to the global radiation budget.
- RE from trop. O_3 with stratospheric origin accounts for ~40% of the global trop. O_3 RE, with regional maximum around subtropical jets, terrain area of Antarctica in January 2005.

August 2005



- Stratospheric O_3 accounts for ~36% of the global trop. O_3 RE, with regional maximum over S.H. subtropical jet regions, northern Africa, eastern Mediterranean and the Middle East in August 2005.

Key Findings:

1. RE from tropospheric O_3 with stratospheric origin accounts for ~40% and 36% of the global tropospheric O_3 RE in January and August 2005.
2. On regional scale, RE from tropospheric O_3 with stratospheric origin exceeds that from emissions and shows dominant contributions to tropospheric O_3 RE over following regions:
   January: *around subtropical jets, terrain area of Antarctica, and southern ocean.*
   August: *SH subtropical jet regions, the eastern Mediterranean and the Middle East.*

REFERENCE:
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Liu, J., Rodriguez, J. M., Steenrod, S. D., Douglass, A. R., Logan, J. A., Olsen, M. A., Wargan, K., and Ziemke, J. R.: Causes of interannual variability over the southern hemisphere tropospheric ozone maximum, Atmos. Chem. Phys., 17, 3279–3299, https://doi.org/10.5194/acp-17-3279-2017, 2017.

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