Connecting Extreme Storms and Trace Gases with TEMPO

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Key Points

- Tropospheric O_3 anomalies are known to occur within dry intrusions associated with extreme storm events (e.g. extratropical cyclones and atmospheric rivers)
- STT of O_3 has been quantified in connection with ECs and ARs, and determined to contribute to a non-negligible amount of tropospheric O_3 -- up to 42% (32%) of NH STT O_3 flux for ECs (ARs).
- There is known transport of other trace gases and particles along ARs, e.g. Saharan dust over Europe

Introduction

- **Extratropical Cyclones (ECs) and Atmospheric Rivers (ARs)** are synoptic storm events in the lower troposphere.
- ARs are independent of ECs about 20% of the time.
- ARs intensities are variable, and strong AR events can have catastrophic consequences upon landfall, such as causing flooding and mudslides.

→ A broad community of researchers endeavors to understand all aspects of ARs and ECs from inception to weather upon landfall, and their connection to large-scale dynamics.

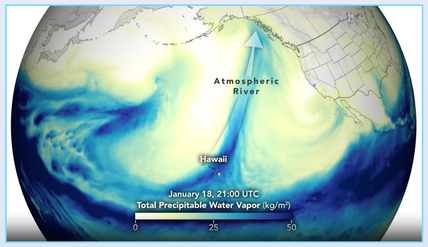

Image: Example AR not associate with EC
Credit: NASA Earth Observatory. Screenshot from an animation generated by the Goddard Earth Observing System Data Assimilation System (GEOS DAS).

What is the connection between Storms and Tropospheric O_3?

- Understanding the total stratospheric contribution to tropospheric O_3 is a significant area of research.
- Disentangling the contributions to tropospheric O_3 by STT from the production of O_3 due to precursor emissions is vital for understanding air pollution and future warming due to greenhouse gases.
- In addition to the planetary-scale continuous downward flow of air masses, in the extratropics, STE also occurs as an episodic phenomenon in association with synoptic-scale processes that perturb the tropopause.

Why do we need TEMPO?

- There are known concerns in tropospheric O_3 reanalysis data products, and now with TEMPO we can have O_3 profiles at high spatial **and temporal** resolution directly from retrieval products
- Consistent tracking of O_3 and other trace gases

Based on work in collaboration with :
Huiqun Wang[1], Amir H. Souri[2,3], Xiong Liu[1], and Kelly Chance[1]
Thank you to Junsung Park[1] for the TEMPO Ozone data products shown here!!
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[2]NASA Goddard Spaceflight Center
[3]Morgan State University

References: Hall+ 2024JGRD..12939949H ; Lyatt+ 2017JGRD..12213436J

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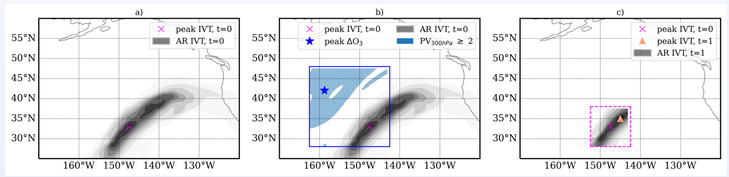
Method – To be adapted from Hall+2024

1. Track ARs using ARTMIP AR catalogs and the integrated vapor transport (IVT) computed from reanalysis data (in this case MERRA-2), as well as their associated O_3 anomalies – **this time use O_3 from TEMPO**



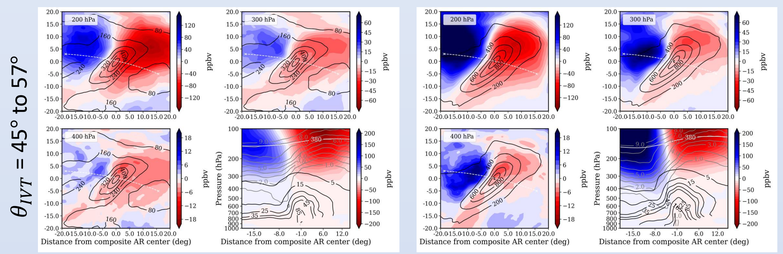
Left, step 1: identify the AR and its peak IVT (magenta x). Middle, step 2: Identify potential tropopause lowering (blue shading), find the peak value of anomalous O_3 (blue star), e.g. at 400 hPa. Right, step 3: within a 10 degree latitude by 10 degree longitude box (magenta) centered on the peak IVT at t=0 (magenta x), identify peak IVT for the AR at the next time step, t=1 (peach triangle). The algorithm repeats steps two and three until the AR dissipates or a new AR enters the smaller search box.

2. Track tropopause lowering/folding using reanalysis potential vorticity via a vertical cross section across storm system tracer (e.g. peak IVT for ARs) and maximum anomalous O_3 at, e.g., 400 hPa – **Now directly from TEMPO** at high spatial **and temporal** resolution!
3. Assess the EC/AR IVT – O_3 relationship for case studies and composites

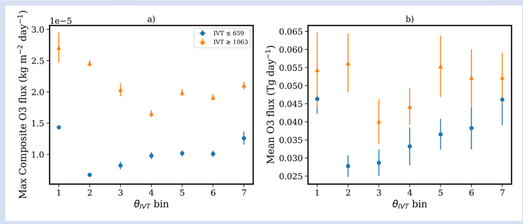
Composite Results from Hall+2024 (ARs) and Lyatt+17 (ECs)

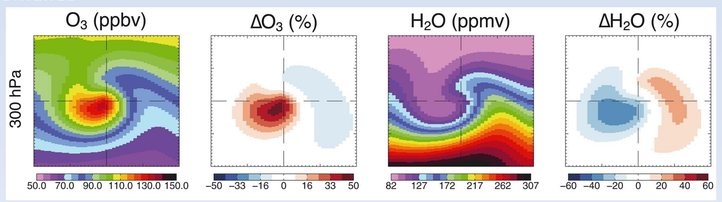
ARs placed in bins of direction of travel θ_{IVT}, and peak IVT; Compare lowest (left) and highest (right) →For each, top left: 200 hPa, top right: 300 hPa, bottom left: 400 hPa, bottom right: vertical cross section over white dashed line in the other panels

Peak IVT ≤ 659 kg/m/s | Peak IVT ≥ 1063 kg/m/s



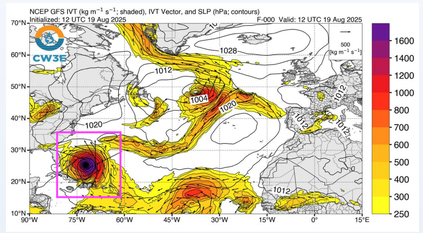
→ Right: Hall+24 AR Composite maxima (left) & mean area averaged O_3 flux (right)
→ Below: Lyatt+17 EC Composite O_3 and H_2O concentrations and anomalies



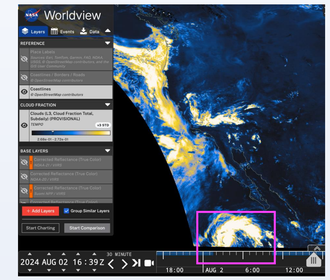


TEMPO TROPOPHERIC O_3 – PROVISIONAL, EXAMPLES ONLY

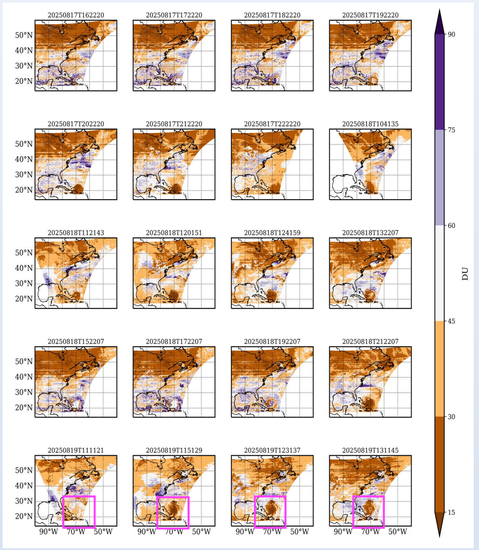
Hurricane Erin, Aug. 19, 2025



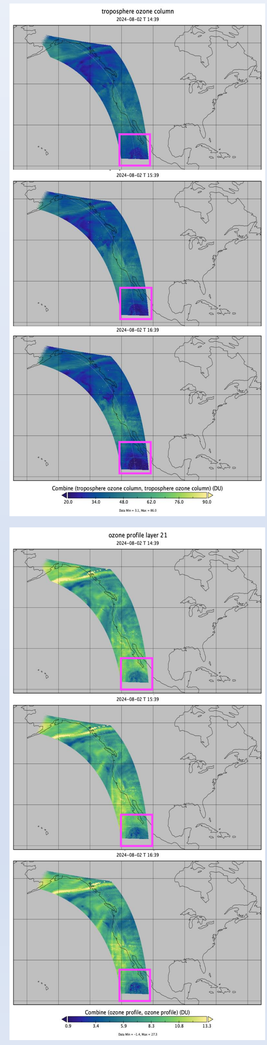
Pacific EC, Aug. 2, 2024



PROVISIONAL V03



PROVISIONAL V04



→ Example hourly data for extreme storm events covered by existing TEMPO Ozone data products
→ Above: V03 troposphere ozone column
→ Right, Top: V04 troposphere ozone column
→ Right, Bottom: V04 single layer ozone

Main takeaway:
With the future of these data, we can carry out high temporal resolution studies of the transport of ozone and other trace gases associated with extreme storms

*This is demonstration and proof of concept for an algorithm (Methods) that already exists