TROPOSPHERIC OZONE TRENDS IN THE TROPICS (1998-2023): AN OVERVIEW OF OBSERVATIONAL AND STATISTICAL PERSPECTIVES

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Kollonige SHADOZ Poster
Wolff NDACC Wallops Poster

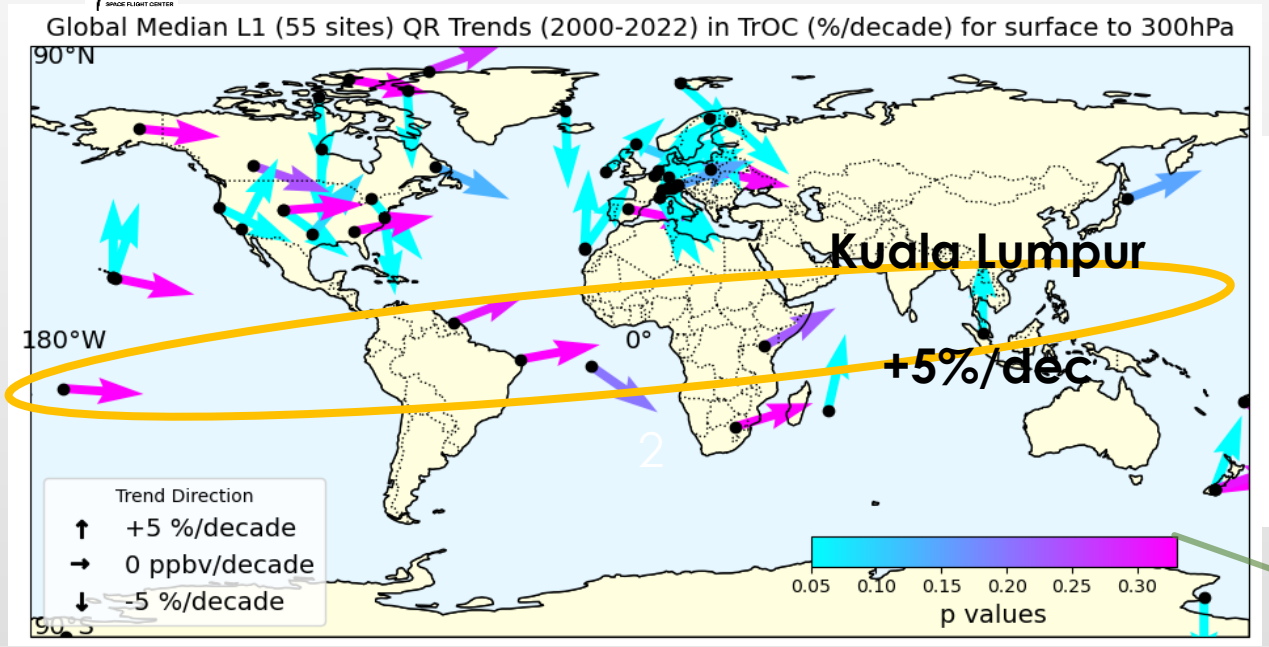
ROADMAP

- **Global tropospheric ozone trends**: Free Tropospheric (FT) ozone role in climate (O_3=GHG, sets global OH, ie, CH_4 lifetime); ambient O_3 levels define "Air Quality"
- **Satellite view required:** D. Hubert (Mon.) talked about role of sondes in satellite validation. As a TOAR II* Lead author, Hubert describes challenges of obtaining distribution and trends with 13 satellite ozone products, starting 2005
- **Progress in global trends from ground-based (GB) data:** Total (TrOC) & FT columns from 5 instruments & IAGOS from TOAR*/HEGIFTOM by R. Van Malderen
- **THIS TALK,** based on newest of 5 related TOAR FT ozone papers (References at end), focuses on the tropics, using mostly SHADOZ profiles to address the following:

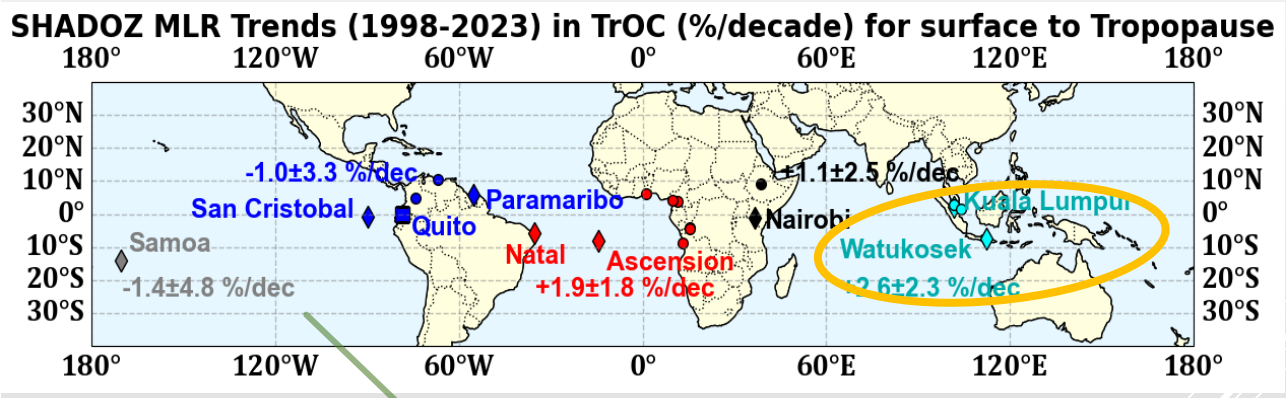
1. How do equatorial SHADOZ trends compare to HEGIFTOM TrOC and FT trends?
2. Have SHADOZ trends from Thompson et al (JGR, 2021) changed with 4 more years of data? Use GSFC MLR model to study start & end point sensitivity
3. Can SHADOZ trends give insight into statistical issues raised in TOAR II? (a) Merits of MLR and QR trend models**; (b) FT ozone sample number sensitivity
4. How do SHADOZ TrOC trends (surface to ~100 hPa) compare to OMI/MLS trends?

* TOAR= Tropos. Ozone Assessment Report; **Quantile Regression (QR) vs Multiple Linear Regression (MLR).

Ques. 1. Tropical (in ± 15°) TrOC Trends HEGIFTOM & SHADOZ



Ques. 2: SHADOZ Trend Start Point Sensitivity

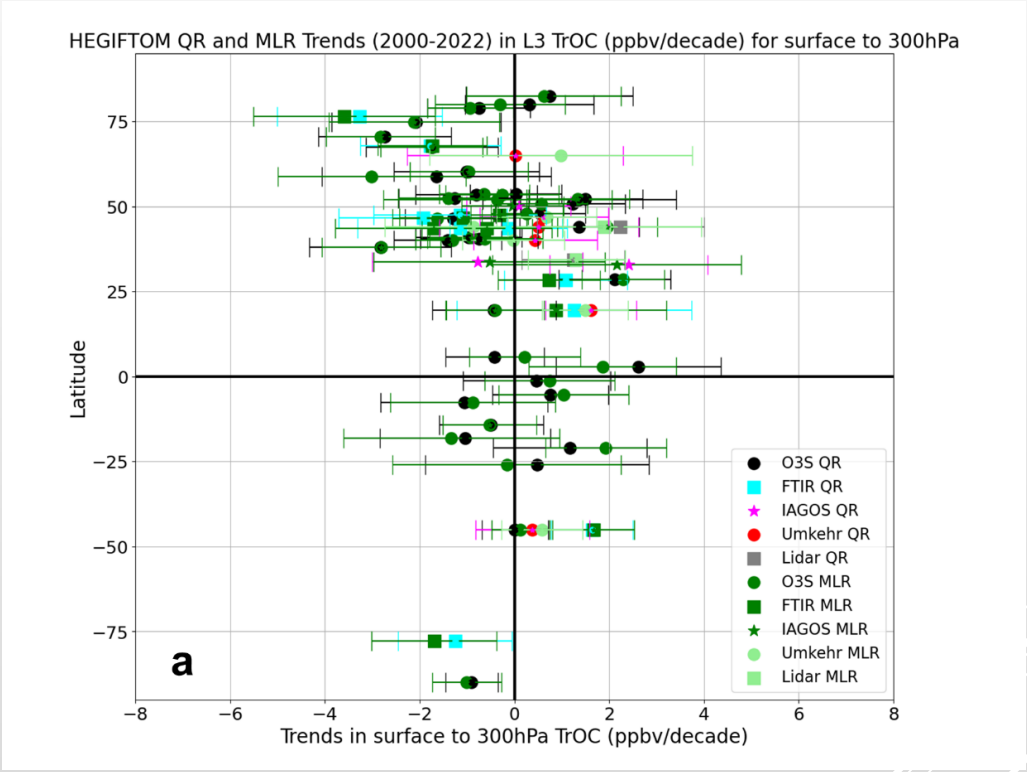


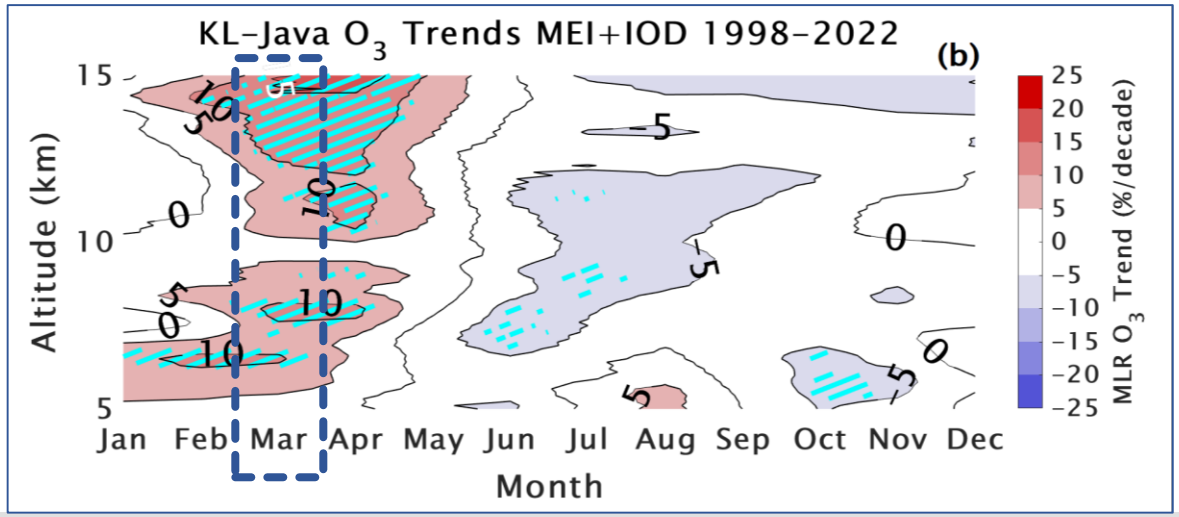
p=0.05 = 95% confidence level
Trends in (ppbv or DU) presented as %/decade

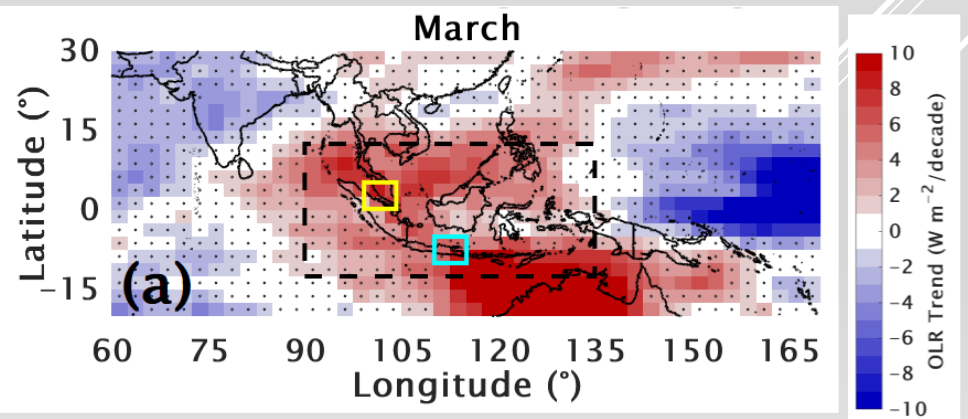
- **Left, HEGITOM-1:** Annual trends from 55 datasets (34 sonde sites, **all data**) with QR medians (TOAR II guideline). TrOC tropical ozone trend (surface-300 hPa) for 2000-2022 is ~0-3%/decade except Kuala Lumpur, %/decade, displayed with p-value*. HEGIFTOM stations in ellipse are 6 of 8 used in **SHADOZ** trends **(Right)** computed with MLR (monthly profiles, 1998-2023).
- 'Five" SHADOZ stations include 3 pair-sites (diamonds) with mix of positive & negative trends (only 2 with p<0.05). Both studies show small trends but years differ. ***When SHADOZ trends are recomputed for 2000 to 2023, KL-Java trend increases to +5%/decade, same as HEGIFTOM***
- End point sensitivity. Adding 4 years (2020-2023) to 1998-2019 record (Thompson et al., 2021) makes positive trends smaller. For San Cris-Para positive FT ozone trends become negative (Thompson et al., 2025 = "T25")

Ques. 3a: How do QR vs MLR Trends Compare?

- HEGIFTOM-1 (Van Malderen et al., 2025a) shows median trends are the same computed with QR and MLR within uncertainties. Circles denote sondes, black=QR; green = MLR **Upper ➔**
- MLR advantage is seasonal information. **Annual** KL-Java FT ozone trend ~3%/dec but +10%/dec in March! Stauffer et al. (2024) demonstrated that declining convection in Feb-April was major cause of early year increase over KL-Java. **Confirmed** with 4 convective proxies that declined only in March, e.g., OLR trend **(Right, below)**!

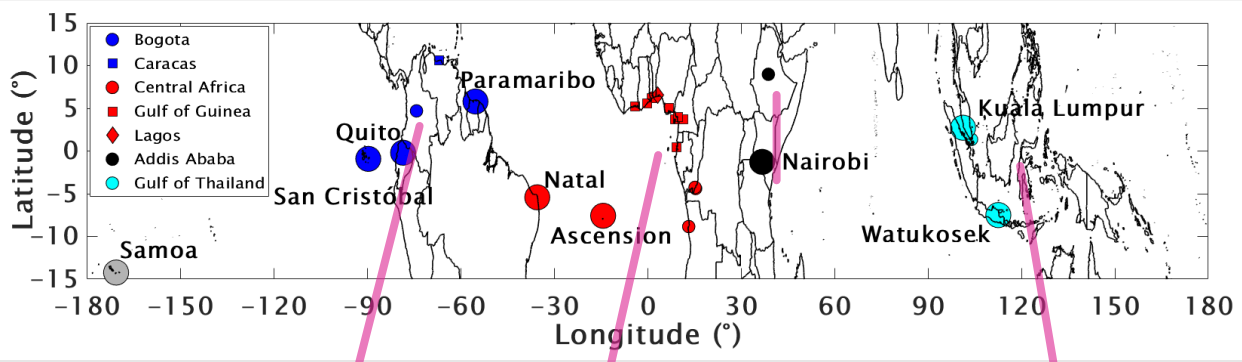


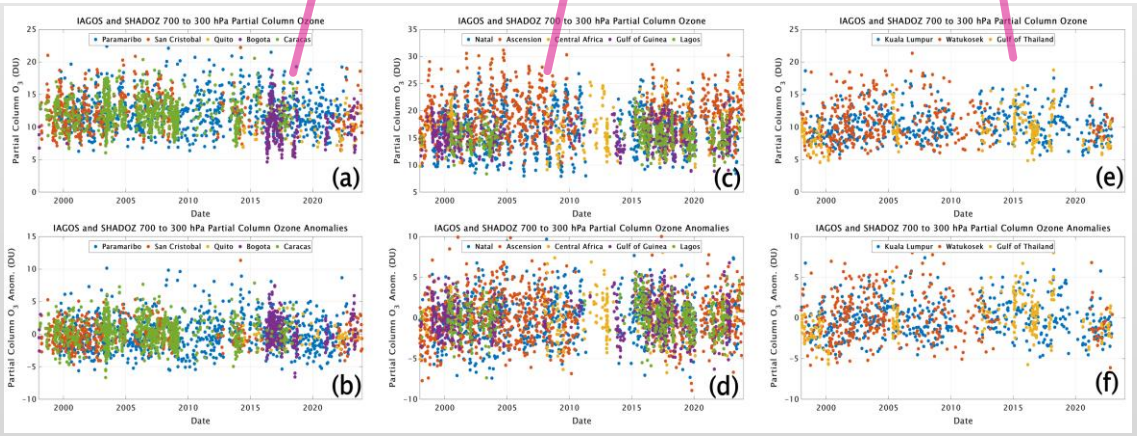


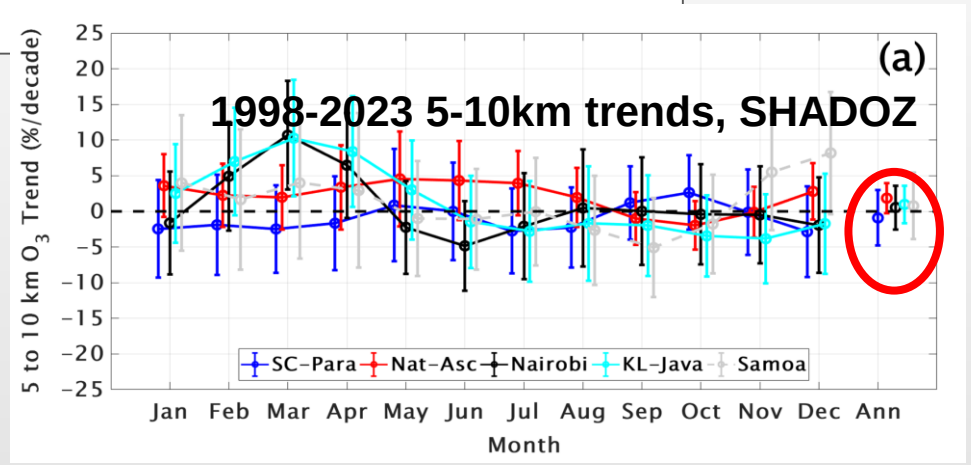


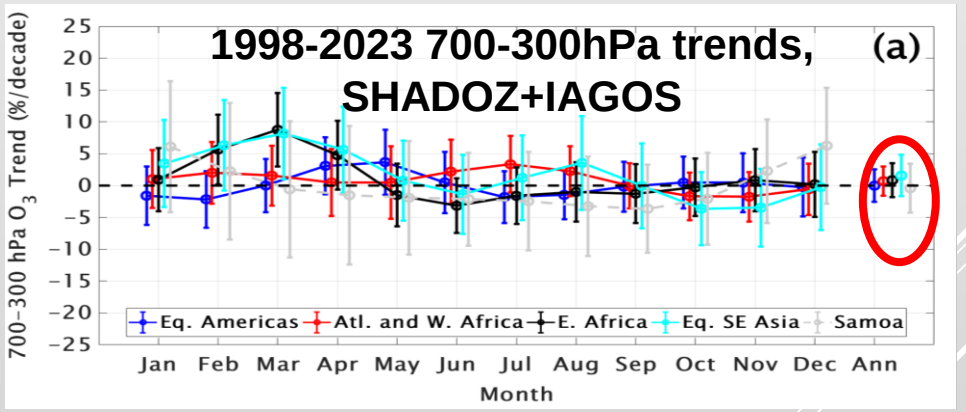
Stauffer et al., 2024

Ques. 3b: How Sensitive are Ozone Trends to Sample Number (SN)?





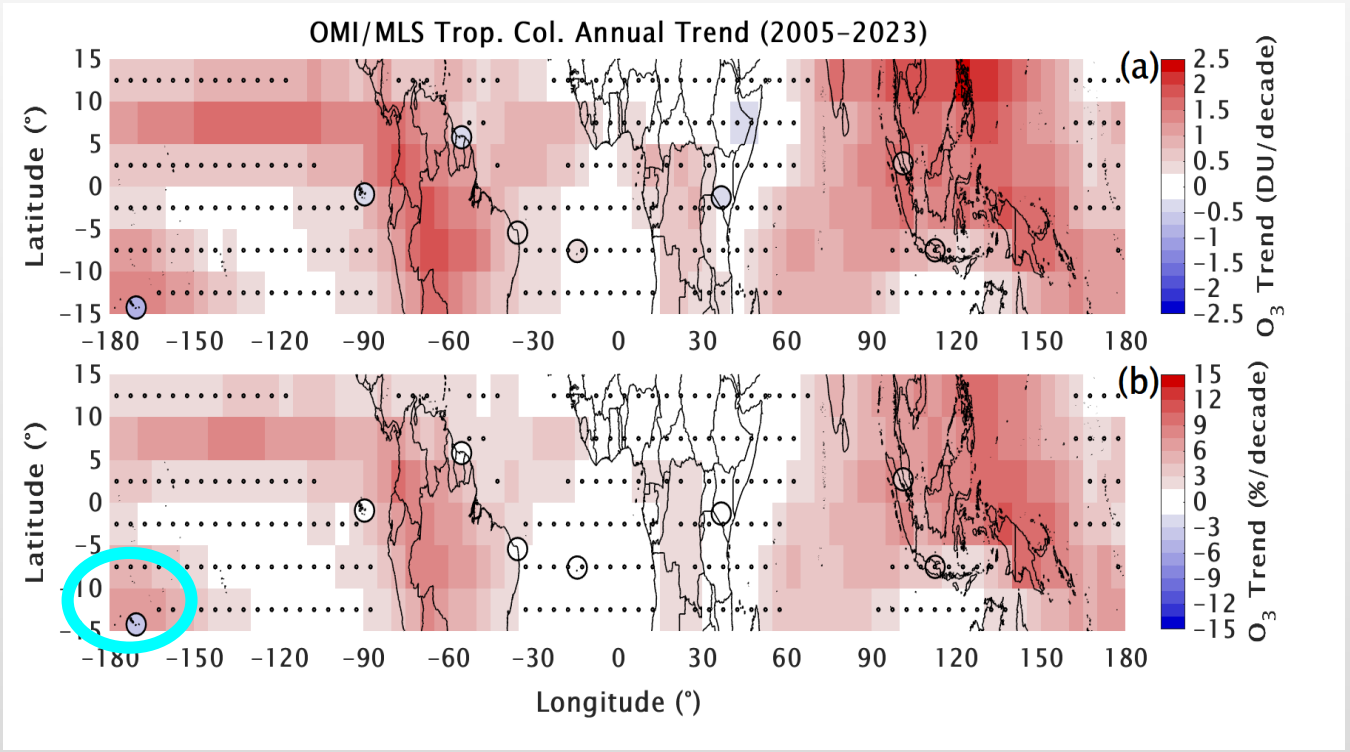


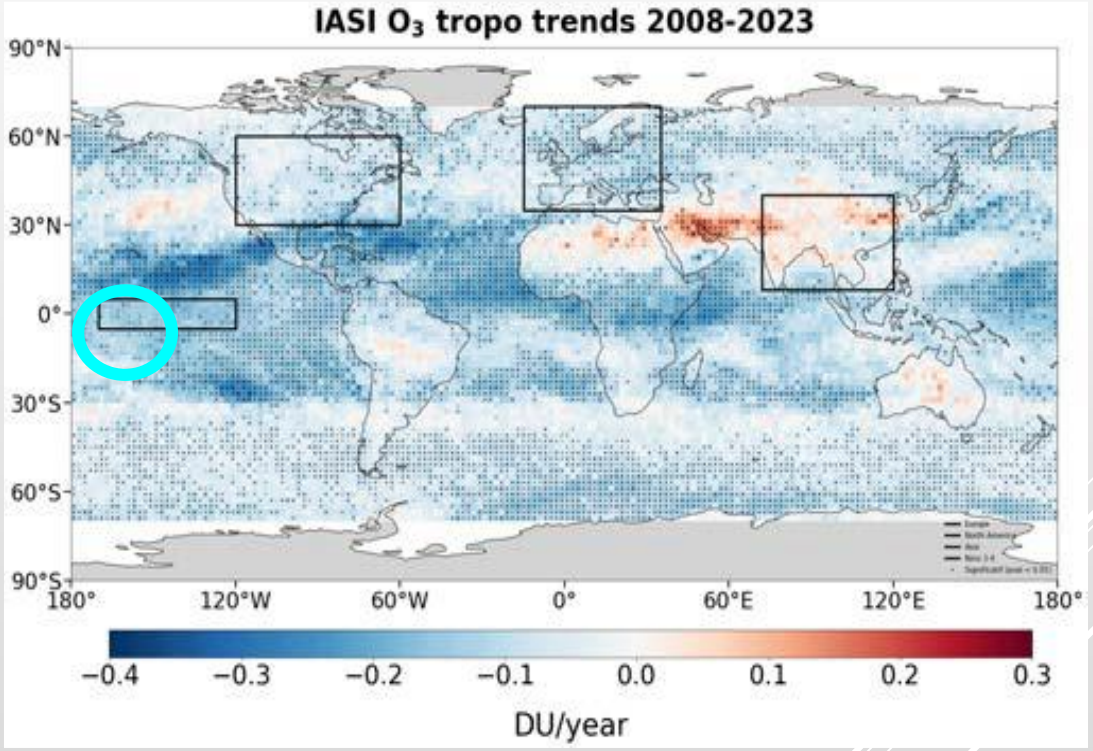


Thompson et al., 2025

- **Upper Left:** Augment FT SHADOZ profiles with IAGOS profiles over 4 regions, doubling SN for trends calculation**.** **Lower left:** Combined SHADOZ-IAGOS FT ozone columns (in DU) for 3 regions, 1998 to 2023. **Right:** SHADOZ-only FT ozone trends and (SHADOZ+IAGOS) monthly & annual (**red circles**) for 1998-2023 nearly identical. ***Doubling SN changes neither seasonal nor annual trends: SHADOZ sampling suffices for FT ozone trends!*** In HEGIFTOM-1 trends from 2 profiles/month – same result

Ques 4: Compare SHADOZ & Satellite Trends





Left: OMI/MLS (2005-2023) compared to SHADOZ station trends within 15 degrees, for 8 individual stations comprising 5 "equatorial" sites. Four of 5 agree with OMI/MLS given uncertainty. Exception is Samoa.

Sondes are -1%/decade; OMI/MLS is +9%/decade

Right: IASI-based trends (2008-2023) nearly all negative near equator, ***-9%/decade at Samoa!***

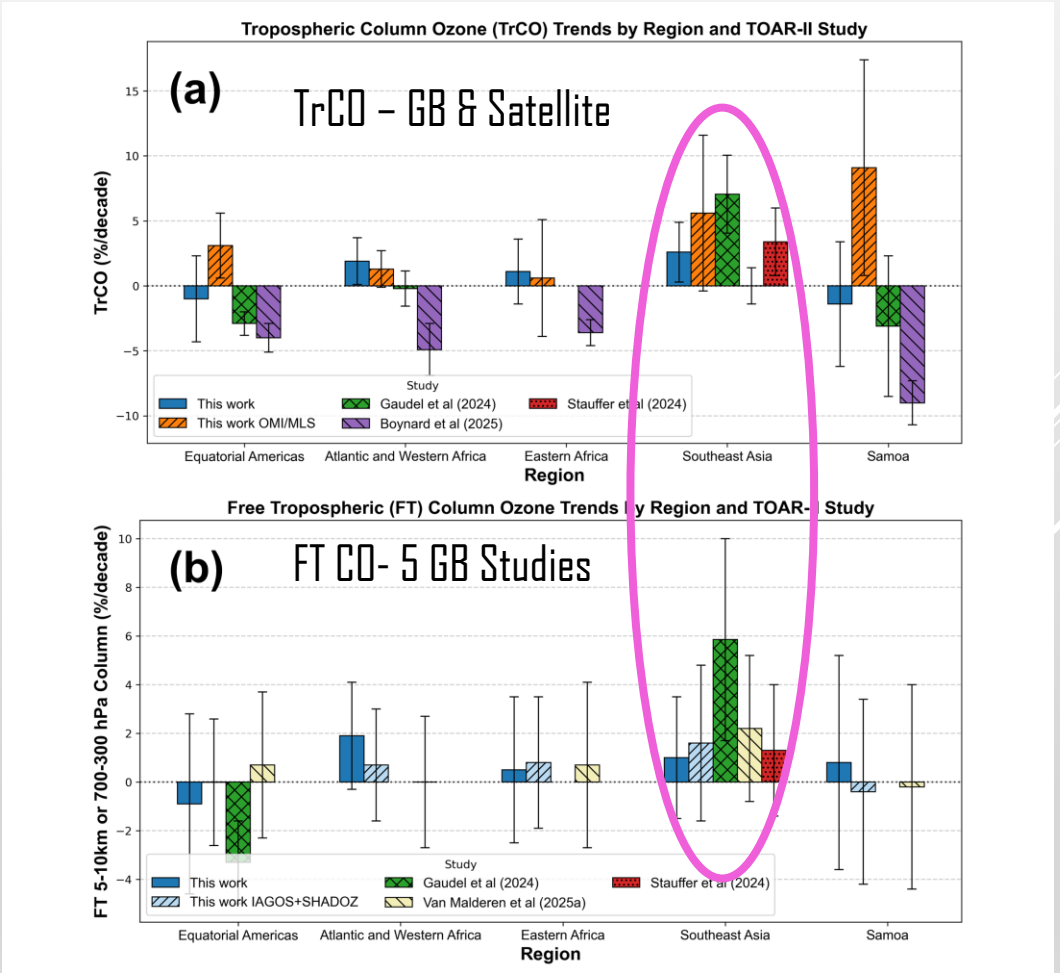
=> ***Sonde data are the only reliable way to evaluate tropospheric satellite products***

SUMMARY: TROPOSPHERIC OZONE TRENDS FROM GB AND SATELLITE STUDIES

- **UPPER FIGURE** compares "mean" total tropospheric column ozone (TrCO) from SHADOZ & IAGOS to OMI/MLS (2005-2023) & IASI (2008-2023) across 5 sites
  - General consensus except for Samoa!
  - Regional trends fairly small except SE Asia (highlight)
  - IASI record disagrees most (record too short)
- **LOWER FIGURE** (*Note Scale difference from (a)*) for FT ozone from 5 studies
  - General consensus among 5 studies!
  - Regional trends fairly small except SE Asia (highlight)

- **Messages for TOAR II and related assessments**
  - Current sampling is good enough but need 20+ yrs
  - Report Regional Trends – no zonal means!
  - Report Seasonal Trends, not only annual trends
  - Dynamical changes in Stauffer et al. (2024), also Millet et al. (2025) at Réunion, are reminders that dynamics may dominate ozone changes, not only emissions increases!
  - ➔ Strode Talk Wed: ENSO impacts on SHADOZ

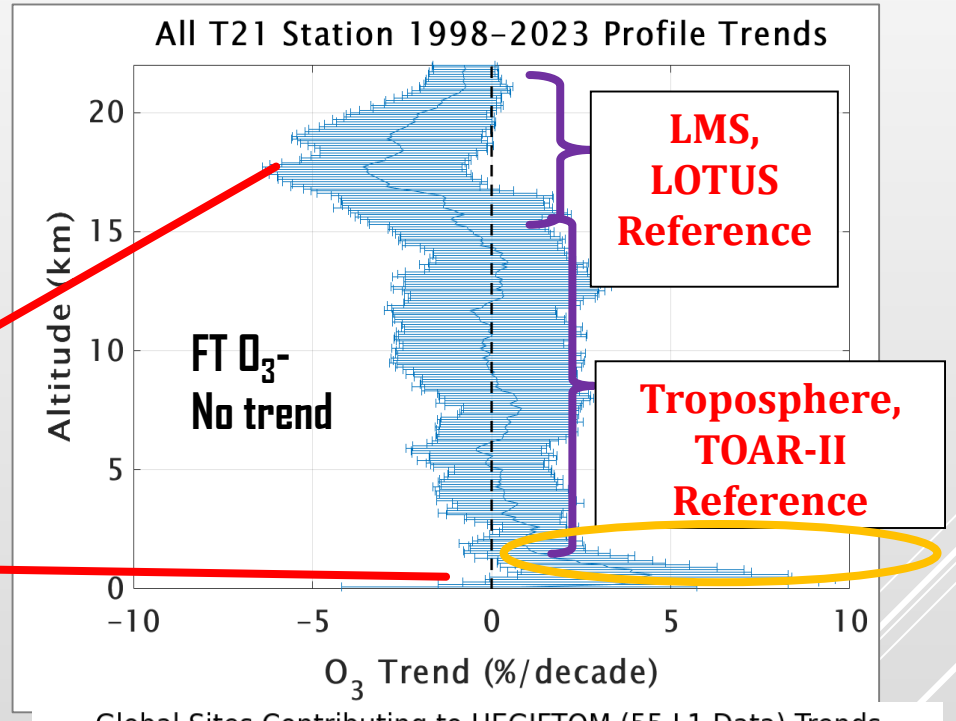
Eq Am. Atl-W. Afr E Afr. SE Asia Samoa



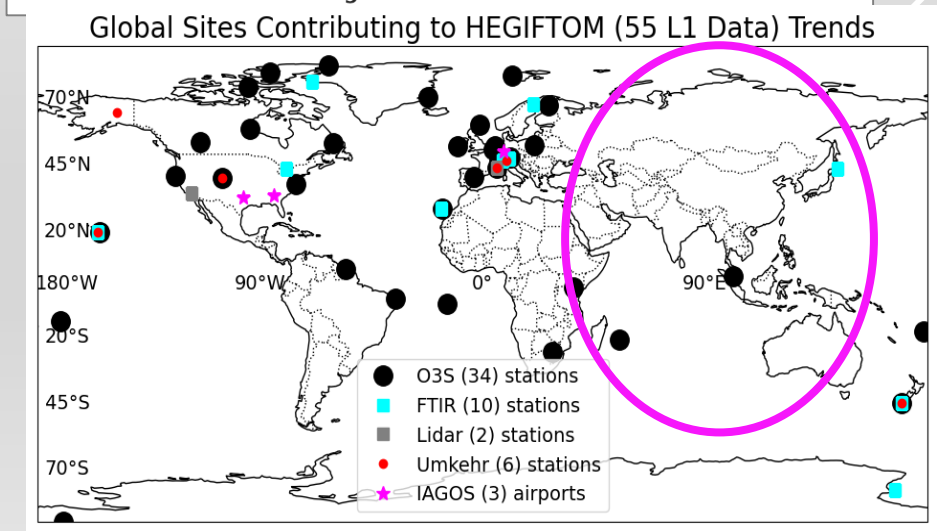
From Thompson et al. (in press). Regions as in Gaudel et al. (2024, Supp. Fig S25)

PERSPECTIVES FOR NDACC

- Given uncertainty in tropospheric ozone satellite data for ~25-30-yr HEGIFTOM & SHADOZ period, ground-based trends are the *most reliable information* for the TOAR II "Climate Assessment"
- SHADOZ trends in Lowermost Stratosphere & FT ozone "Set the Bar" for satellite data to reproduce!
  - LMS O_3 *negative* trends at 17-18 km agree with satellite estimates
  - Ozone increases below 3 km only, mostly SE Asia
- Trends breakthrough due to high-quality, homogenized GB data from NDACC, HEGIFTOM group & ongoing Quality Assurance work of NDACC & WMO ASOPOS!
- Full data range - zonal, surface to 10 hPa; pole-to-pole, are vital for tropospheric, stratosphere ozone trends!
- NDACC Challenges: Sustaining current instruments and sites. Strategize: FT O_3 approaches; So. & E. Asia gaps



Thompson et al., 2025



Van Malderen et al., 2025a

THANK YOU FOR ATTENTION!

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References – 2024 & 2025 articles in TOAR-II Collection ("5 Related")

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Froidevaux, L., et al: *Atmos. Chem., Phys.*, https://doi.org/10.5194/acp-25-597-2025, 2025

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