Homogenized Ground-based and Profile Ozone Datasets from TOAR-II/HEGIFTOM: Methods and Station Trends

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Outline

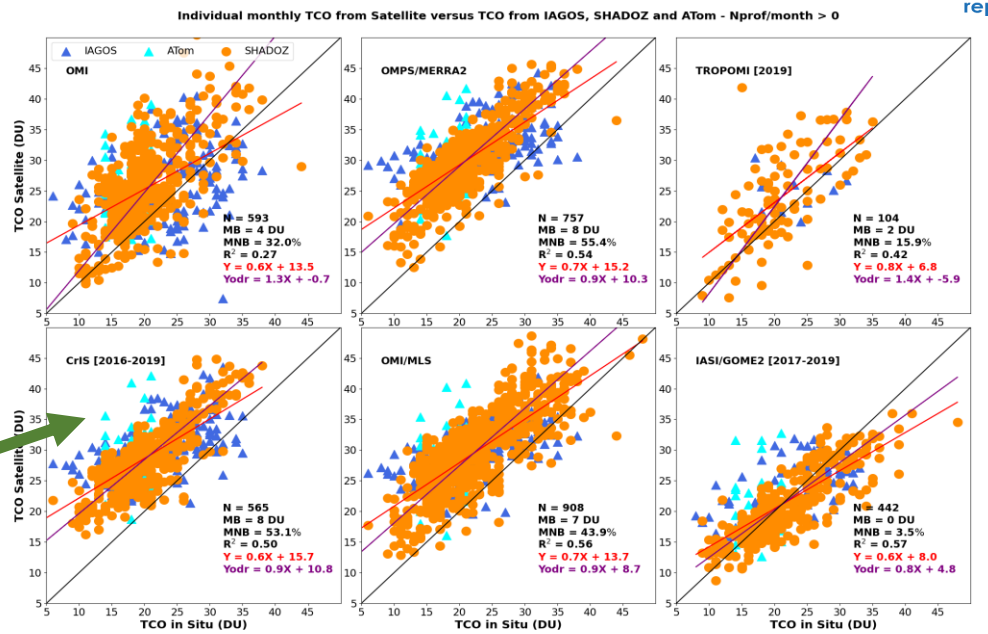
- **WHY Is HEGIFTOM (**Harmonization and Evaluation of Ground-based Instruments for Free Tropospheric Ozone Measurements) **so important in Ozone (TOAR II) & Climate Assessments?**
- **HEGIFTOM: WHAT, HOW, WHERE. Data Status.**
- **Preliminary Global ozonesonde FT column trends (4-8 km) for TOAR II by two statistical methods (QR and MLR)**
- ***Summary: Trends to date (Sonde) for 1998-2021 show:***
  - ***Zero-moderate changes globally, independent of statistical method***
  - ***Mid-latitude trends appear to include FT O_3 losses & increases***
  - ***In cases of FT O_3 increases, rates are typically higher in tropics than mid-latitudes***
- **References**

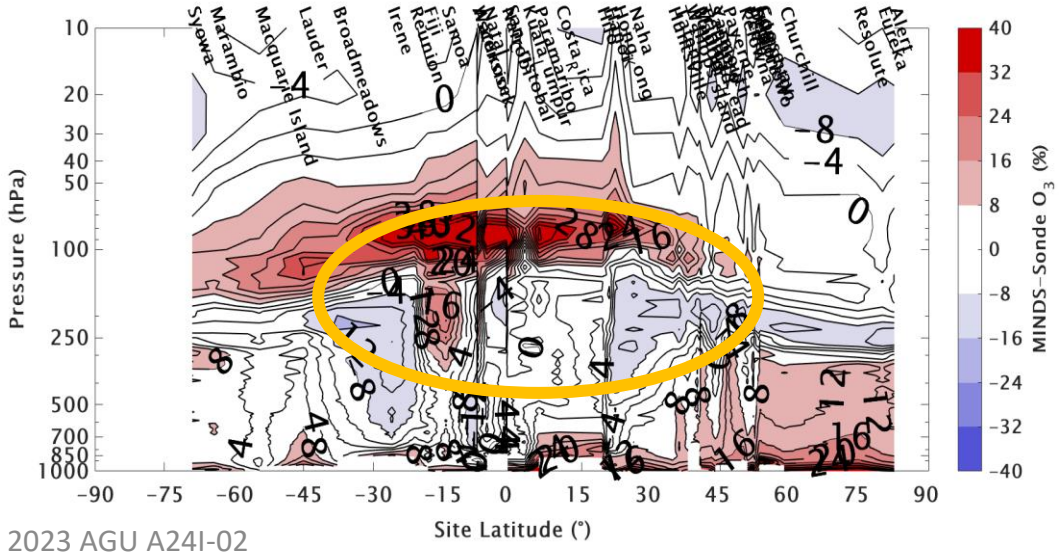
WHY HEGIFTOM?

- **Free Tropospheric (FT) O_3 is Radiative Forcer, amplifying impact of increasing methane emissions**

- **Satellite Tropospheric Column Ozone (TrOC) too limited in duration & quality for trends. Poor correlation, large offsets & uncertainty compared to tropical IAGOS & ATom aircraft profiles and to SHADOZ sondes (Upper from Gaudel et al., 2023)**

- **Typical model O_3 simulations relatively poor in FT: 10-20% discrepancy over range of latitudes, altitudes (gold in Lower, updated from Stauffer et al., 2019)**





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WHAT & HOW: HEGIFTOM Data to the Rescue!

HEGIFTOM: IGAC/TOAR II Activity, Co-Leads: R. van Malderen & H. G. J. Smit

Alternative to still-evolving satellite TrOC (tropospheric ozone column) products:

- **FT ozone from 5 ground-based instruments types, most from NDACC & related networks: in-service aircraft [IAGOS], ozonesondes,FTIR, Brewer/Dobson Umkehr, Lidar (Photos, Right)**
- **Rigorously, regularly calibrated against absolute standards**
- **Common protocols for data re-processing ensure harmonized time-series, with artifacts removed. Selected contributing networks**
- **Each measurement is delivered with *uncertainty* and a *quality flag***
- ***This Study: Preliminary Report on O_3 trends with FT TrOC, 4-8 km, extracted from ozonesondes***

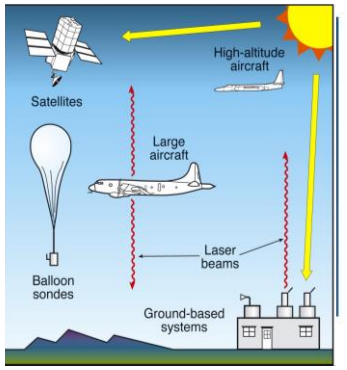
IAGOS


Ozonesondes


Brewer/Dobson Umkehr


FTIR


Lidar



FT, 4-8 km

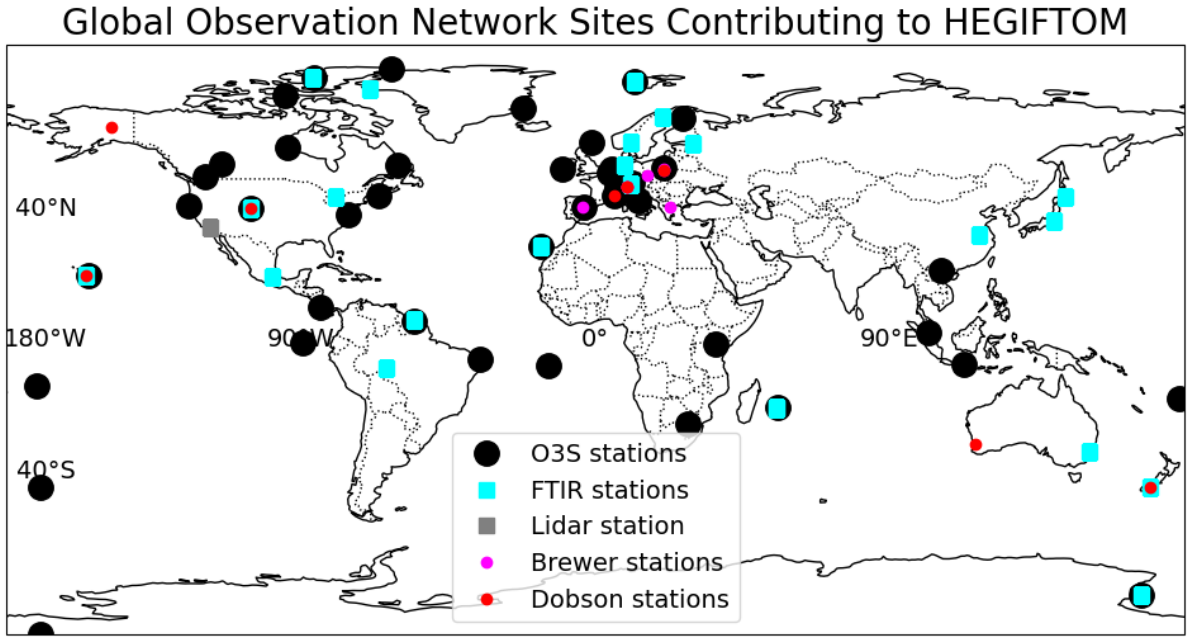
NDACC

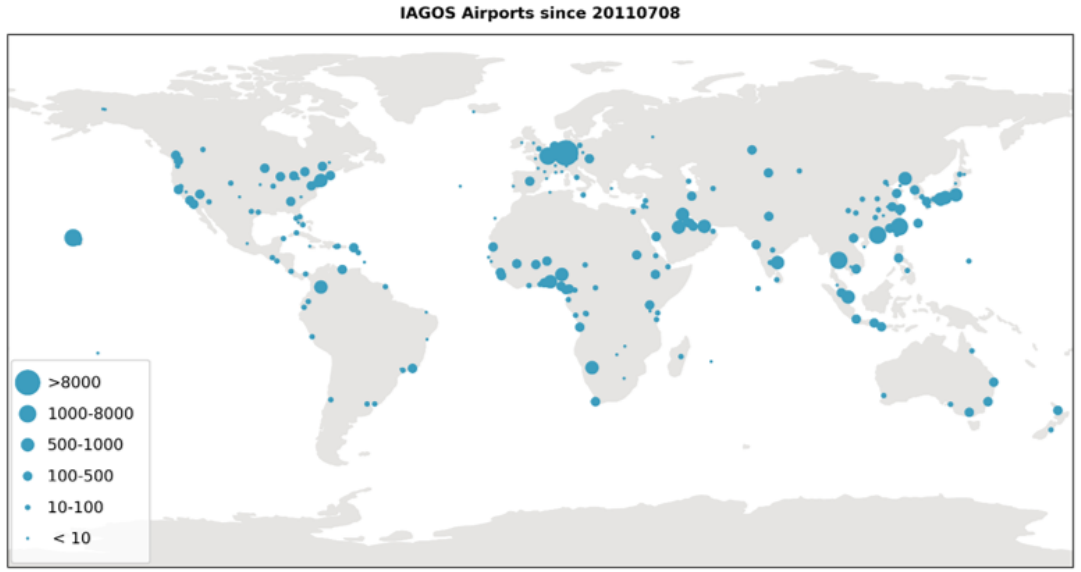
GAW

SHADOZ

http://hegiftom.meteo.be/datasets

WHERE: HEGIFTOM Data from NDACC & Affiliated Networks (SHADOZ, WMO/GAW, IAGOS)

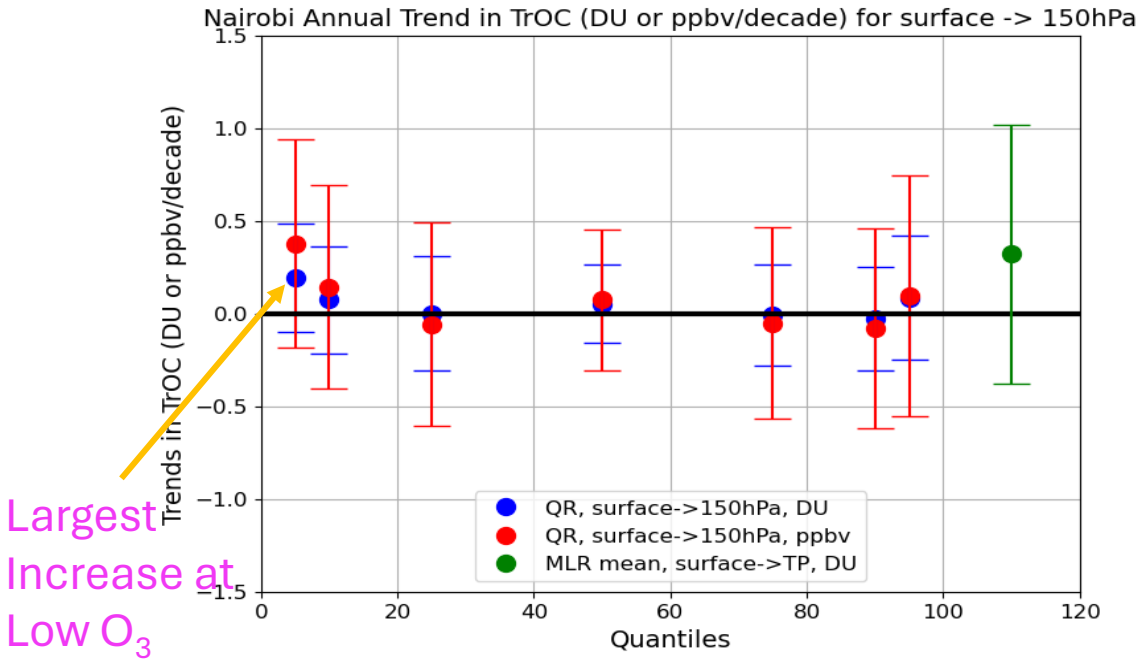


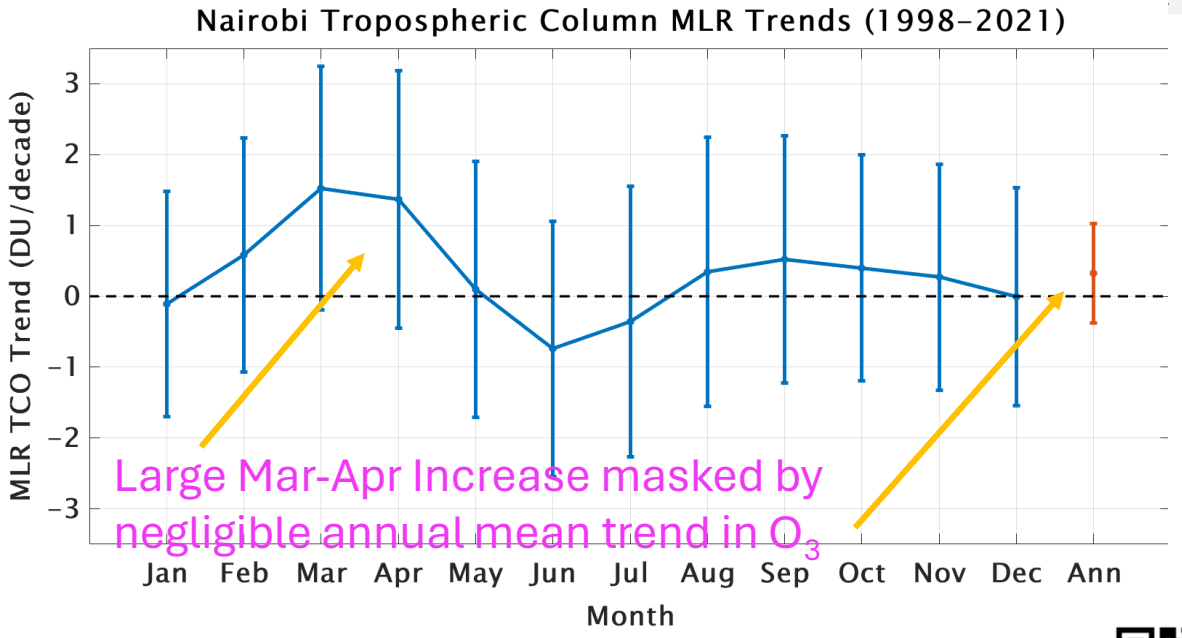


Credit: Left, D. Kollonige; Right, IAGOS

- Many FTIR stations (Left) coincide with ozonesondes, some have Dobson or Brewer: "super sites". Trends consistency among multi-site instruments to be evaluated
- In tropics, sonde, IAGOS (Right) trends & satellite comparisons underway (Gaudel et al., 2023; Kollonige et al., Paper A21H-2369)
- Sonde-IAGOS co-located profiles evaluated (Tarasick et al., 2019; @ IAGOS Users, 11/23)

HEGIFTOM Trends. Input & Guidelines

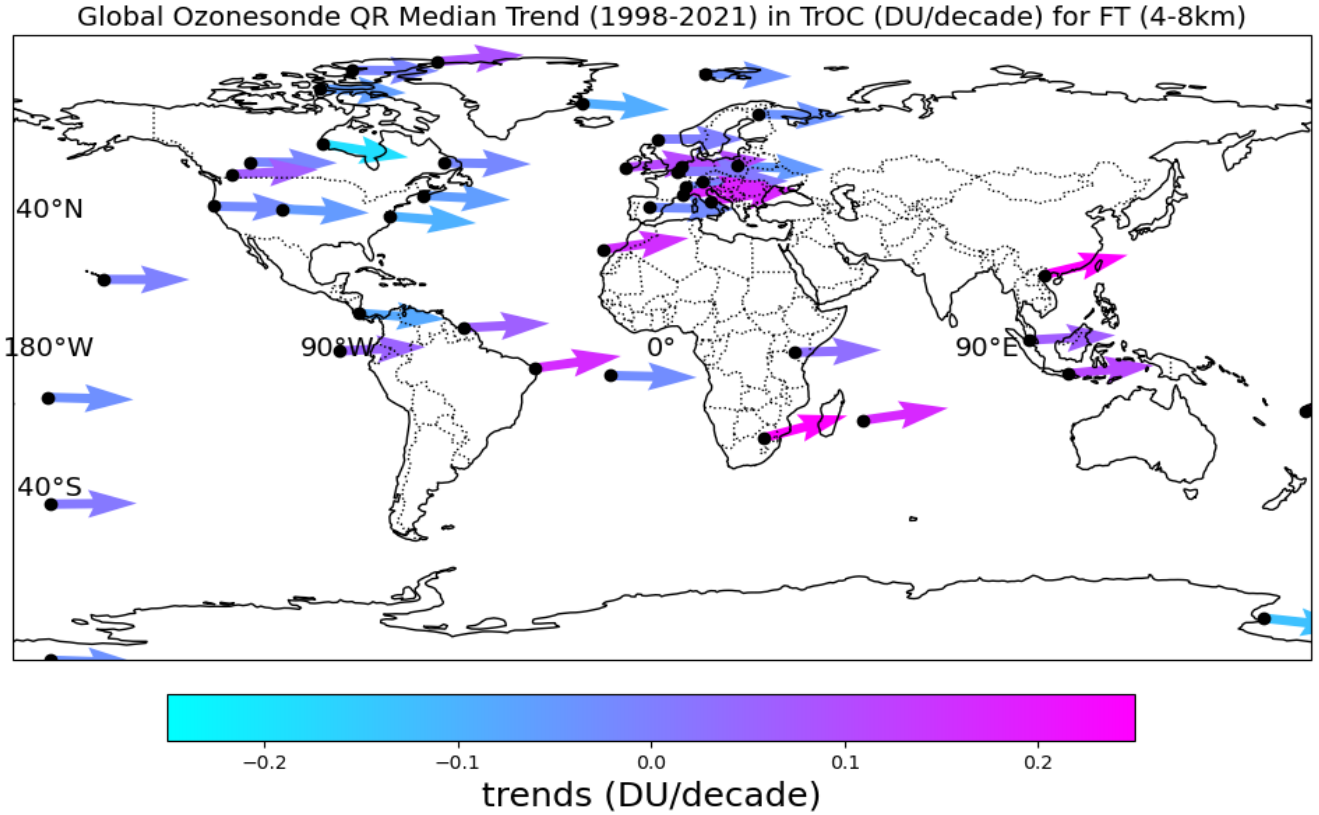


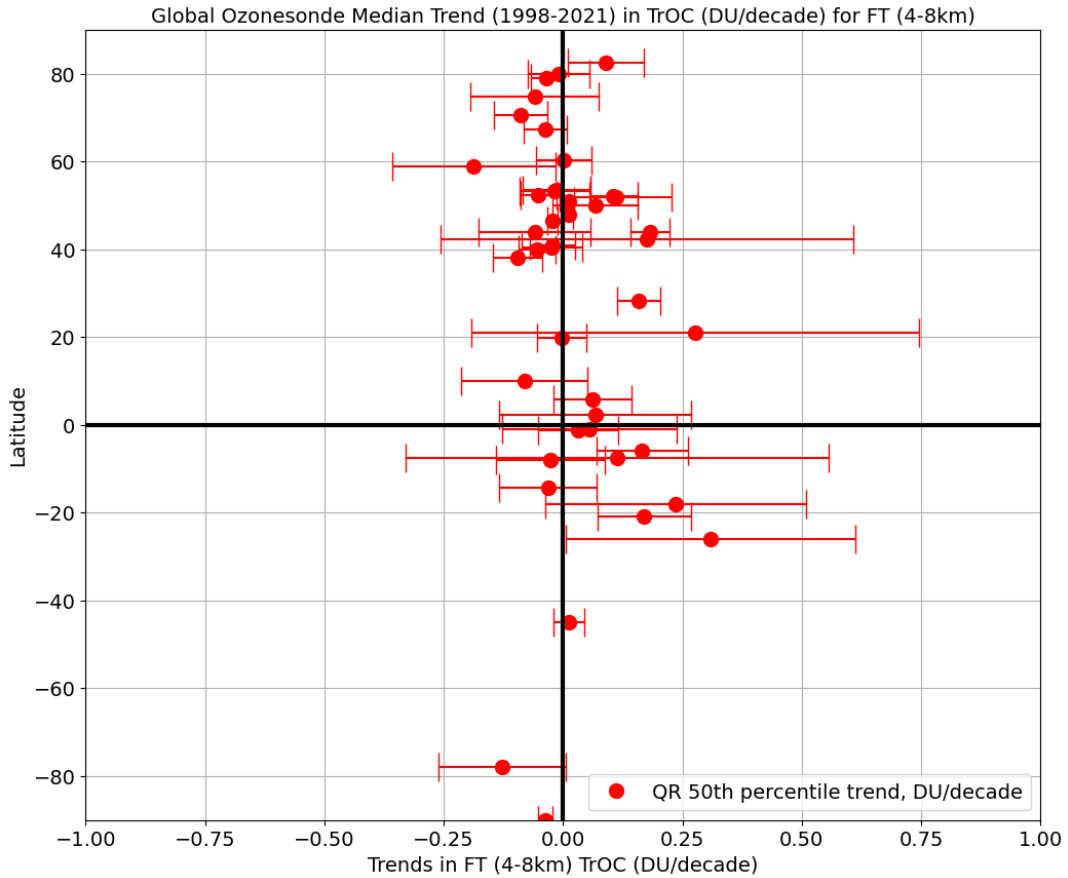


- **Recommended TOAR II statistical approach is Quantile Regression (QR) with NOAA-provided test code, e.g., K-L Chang et al., Paper 51D-0602**
- **Alternative: Multiple-Linear Regression (MLR) as used in Thompson et al., 2021 & Stauffer et al., Paper A21H-2368. MLR is standard of stratospheric ozone Assessment community**
- **Above example for a typical SHADOZ station shows merits of each approach. QR gives insights into low-mid-ozone-O_3 profiles. Monthly means from MLR give insight into meteorological or chemical signatures responsible for O_3 trends**

TREND RESULT 1. MEDIAN TRENDS WITH QR

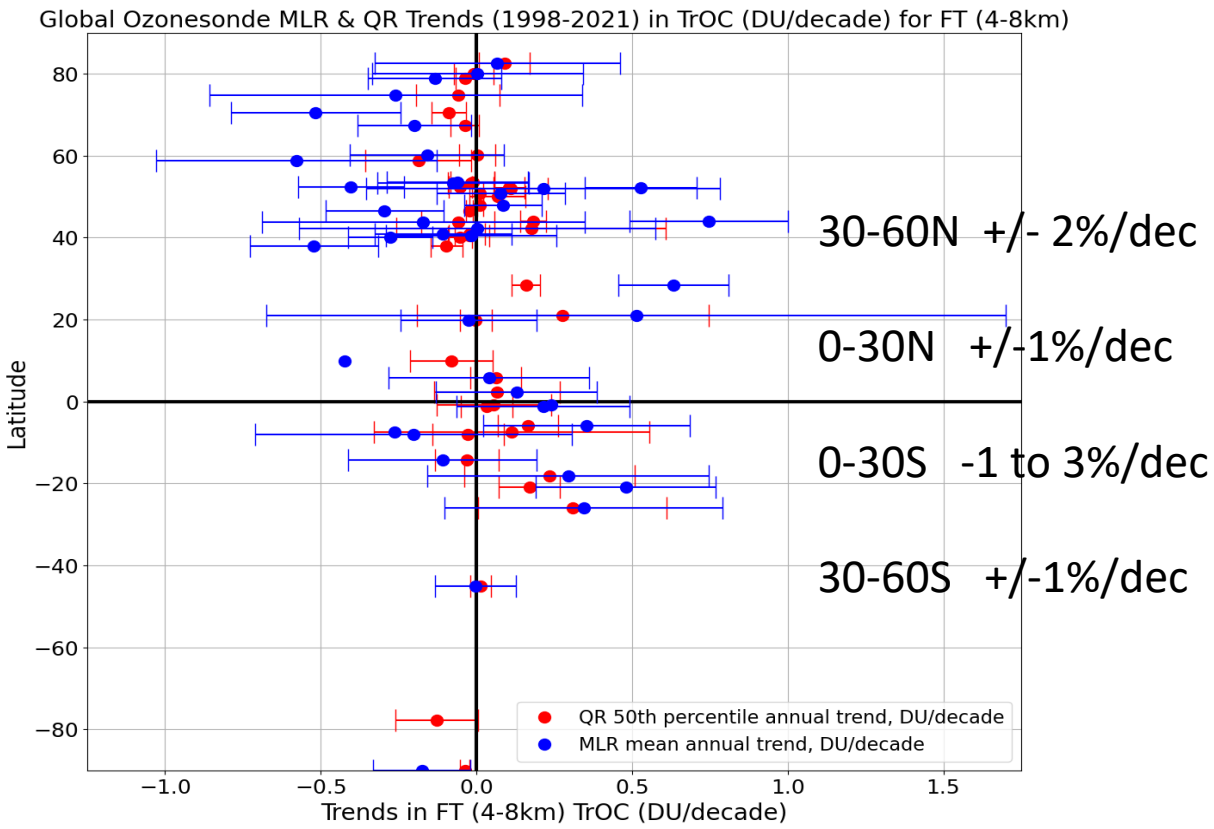
- Sonde (black points), 50-%ile median profiles, analyzed with QR over 24 yrs, 1998-2021
- Mid-upper FT segment, 4-8 km, negative-> no trend in blue colors on map.
- **With few exceptions, changes are < 0.25 DU/dec, positive OR negative, *all latitudes***

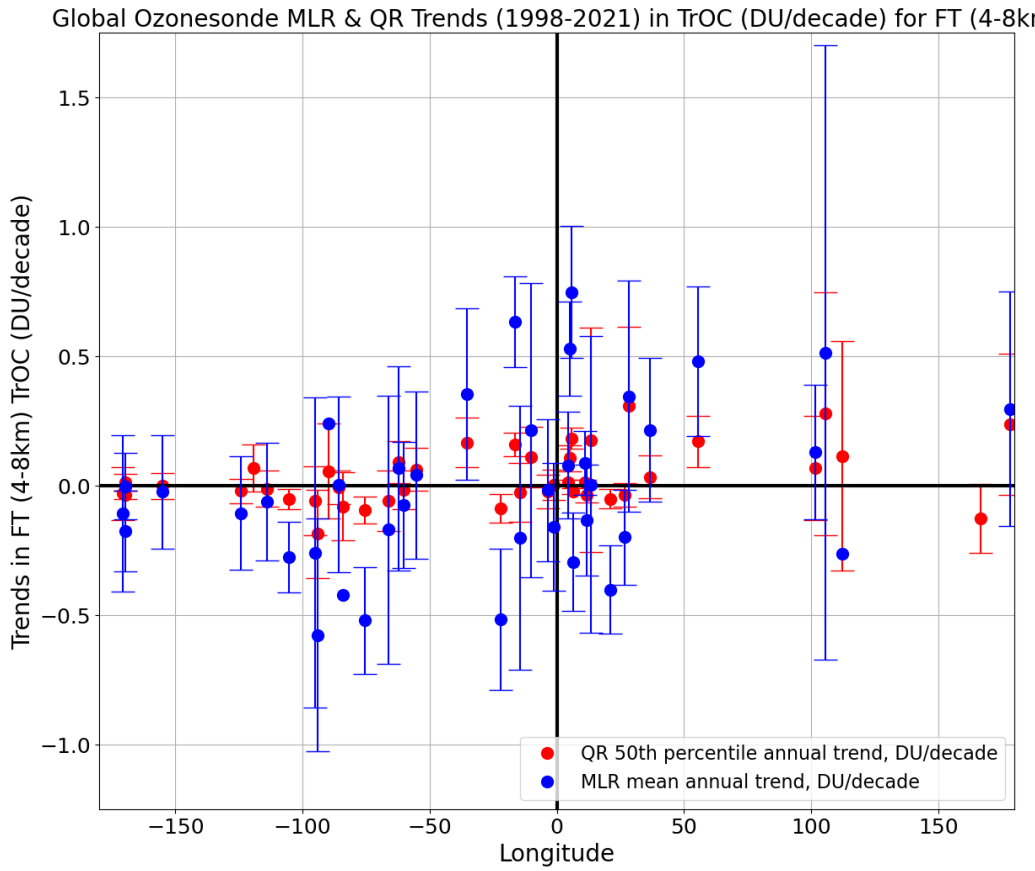




- 43 sonde sites (>70%) in HEGIFTOM database

TREND RESULT 2. MLR & QR TRENDS SIMILAR





- **Preliminary results** show magnitude of trends with MLR is larger than QR for some stations. Work ongoing to be sure comparable trend values are being obtained from each method.
- Equivalent changes for FT amounts (~7-12 DU) range from **-2% to + 2%/dec (Left)**. Exceptions include Izana, Hanoi, and several tropical sites. E. Pacific/Americas display smaller increases than over Europe/Africa or Asia/W. Pacific **(Right).**

SUMMARY. WAY FORWARD

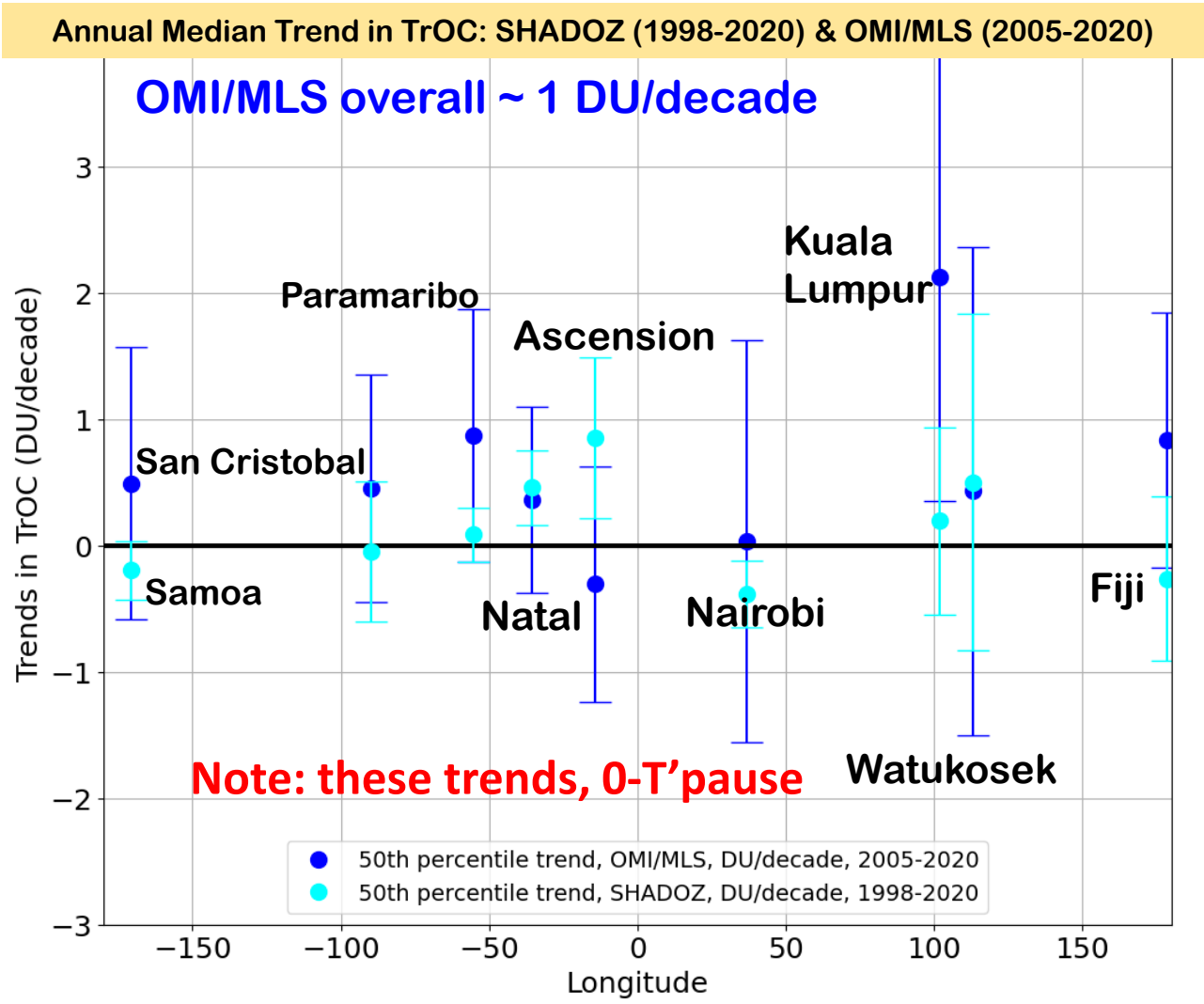
- **HEGIFTOM data provide essential TOAR II reference to evaluate models, satellite products (Right)!** ***Expect High Impact in 2024 Report!***
- Preliminary results with sonde-based 4-8 km FT O_3 columns show:

  -> Mostly small trends, both positive and negative, over all latitudes, regions

  -> Tropical increases tend to be larger than at mid-latitudes
- **Next steps** for TrOC:

  -> Continue using HEGIFTOM to evaluate models, satellite trends, ie beyond tropics.

  -> Compute trends from other HEGIFTOM data (e.g. FTIR), various column segments, 5 and 95 quantiles (50% shown here)



Kollonige et al. A21H-2369

Thank you! Acknowledgments. Related Papers

- **Acknowledgments: Dozens of funding organizations. Hundreds of researchers who have operated and collected ozone ground-based data over the past 30 years!**

Chang, K-L. et al. (2023) Challenges of detecting free tropospheric ozone … Paper SY51D-0602

deMazière, M., et al. (2023) The impact of NDACC on ozone, Air Quality, and Climate Sciences Paper A24I-05

Gaudel, A., et al. (2023) Tropical tropospheric ozone distribution and trends from in situ… in Prep, *ACP*

Kollonige, D. E. (2023) Tropical Tropospheric ozone trends (1998-2020) … Paper A21H-2369

Leblanc, T., et al (2023) Reanalysis and homogenization of the tropospheric ozone lidar… A21H-2364

Stauffer, R, M., et al. (2023) Dynamical drivers of free-tropospheric ozone… Egusphere-2023- 2618

Stauffer, R. M., et al. (2023) Dynamical drivers of free-tropospheric ozone… Paper A21H-2368

Smit, H. G. J., A. M. Thompson et al. (2021) WMO/GAW ASOPOS Report 268

Smit, J. G. J. et al. (2023) New insights from the Juelich Ozone Sonde … Paper A21H-2374

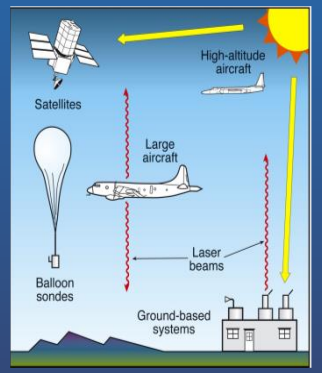
Tarasick, D. et al. (2019) Tropospheric Ozone Assessment Report: Tropospheric ozone from 1877 to 2016, http://doi.org/10.1525/elementa.376

Thompson, A. M., et al. (2021) Regional and seasonal trends in tropical ozone… https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021JD034691,

Van Malderen, R., et al. (2023) Homogenization of the European ozonesonde time series… Paper A21I-2394

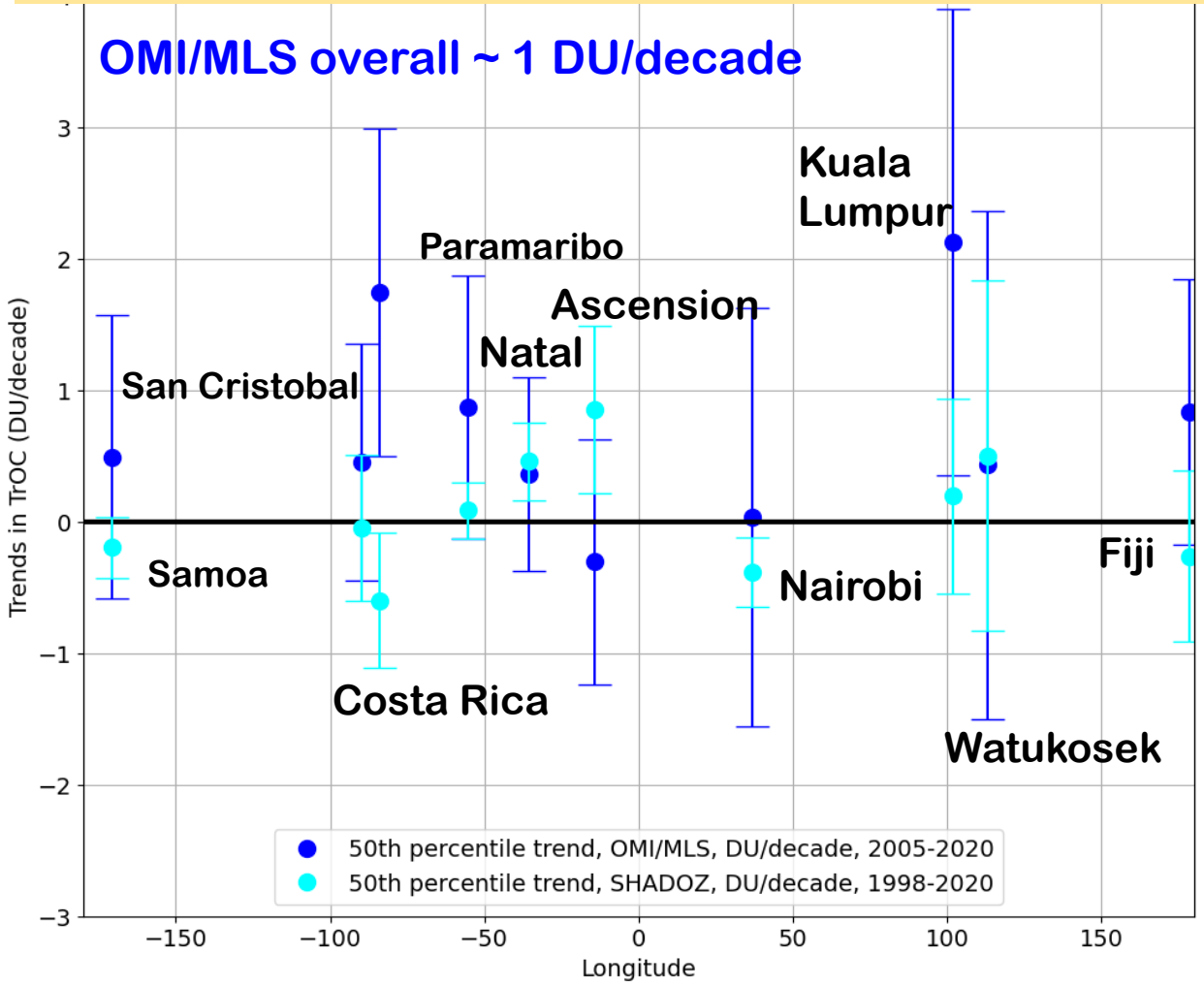
Van Malderen, R. et al. (2023) The cell temperature of ECC sondes in relation to… Paper A21H-2366

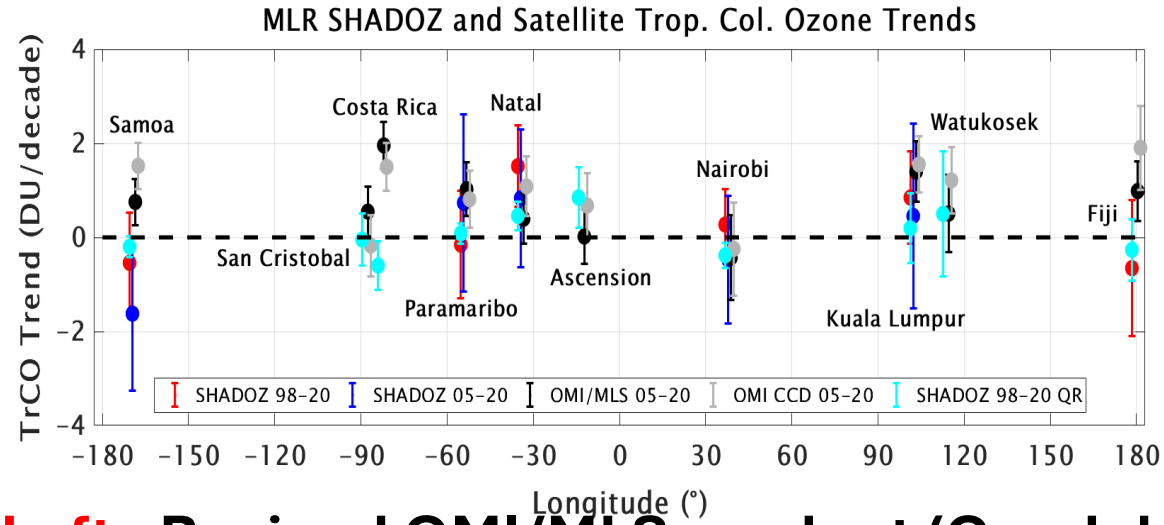
EXTRAS


High-altitude aircraft
Satellites
Large aircraft
Laser beams
Balloon sondes
Ground-based systems

TREND RESULT 3. OMI/MLS Total TrOC & Sonde Trends

Annual Median Trend in TrOC: SHADOZ (1998-2020) & OMI/MLS (2005-2020)





Left: Revised OMI/MLS product (Gaudel et al, 2023) for 2005-2020 has similar trend to SHADOZ stations

Right: SHADOZ MLR, QR comparisons with two OMI-based products over two periods are all in good agreement and mostly < 1 DU/decade, the latter 2-4 x larger than 4-8 km sonde trends

HEGIFTOM Tropospheric Ozone Columns Available

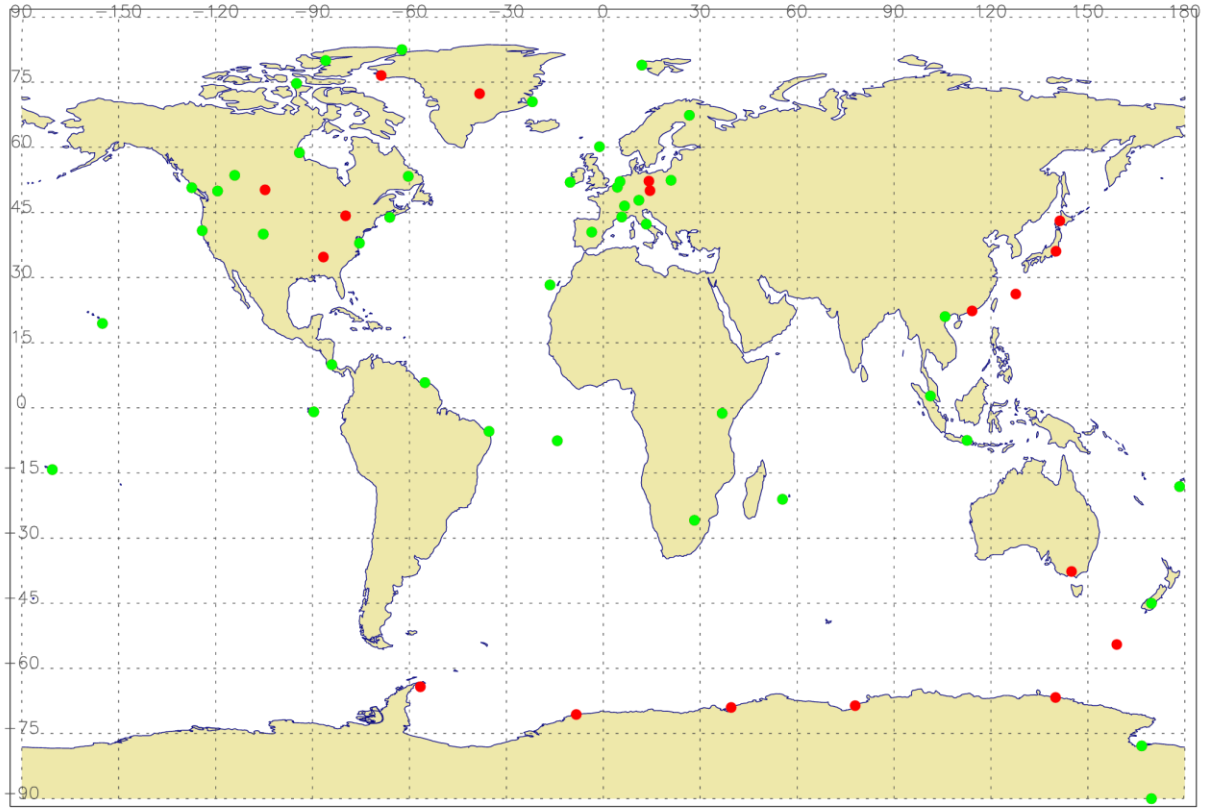
- **Different (partial) tropospheric ozone column metrics**

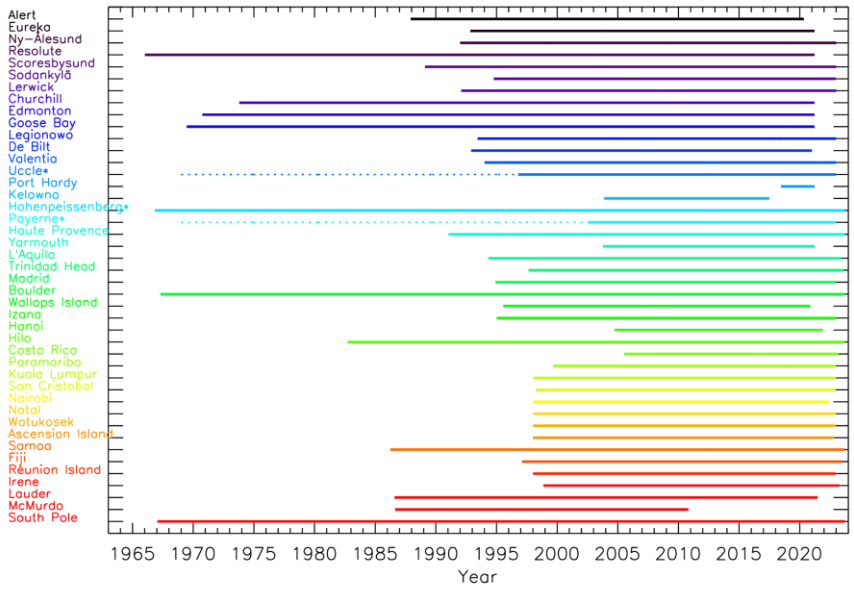
1. P > P_TP (WMO)
2. P > P (lat) (e.g. 150 hPa @ tropics, 400 hPa in polar regions)
3. P > 300 hPa
4. FT: 4 < h < 8 km **AND** 700 hPa > P > 300 hPa
5. LT: h < 4 km **AND** P > 700 hPa
6. BL: h < 2 km
7. Umkehr/FTIR kernel weighted to others
8. 1, 2 & 3 + added with CAMS/MERRA2 for UT (IAGOS) and BL (Lidar)

2 recommended TOAR-II ozone column definitions

- **The (partial) tropospheric ozone columns have been calculated for all sites/techniques, as much as is feasible**

Homogenized Data for Ozonesonde Sites & Record





- 43 sites (green dots) with homogenized ozone profiles.
- TOAR II trends analyses start after 1995, most 1998-2000
- Column amounts available at ftp-server: QR Code →
  https://hegiftom.meteo.be/datasets/ozonesondes

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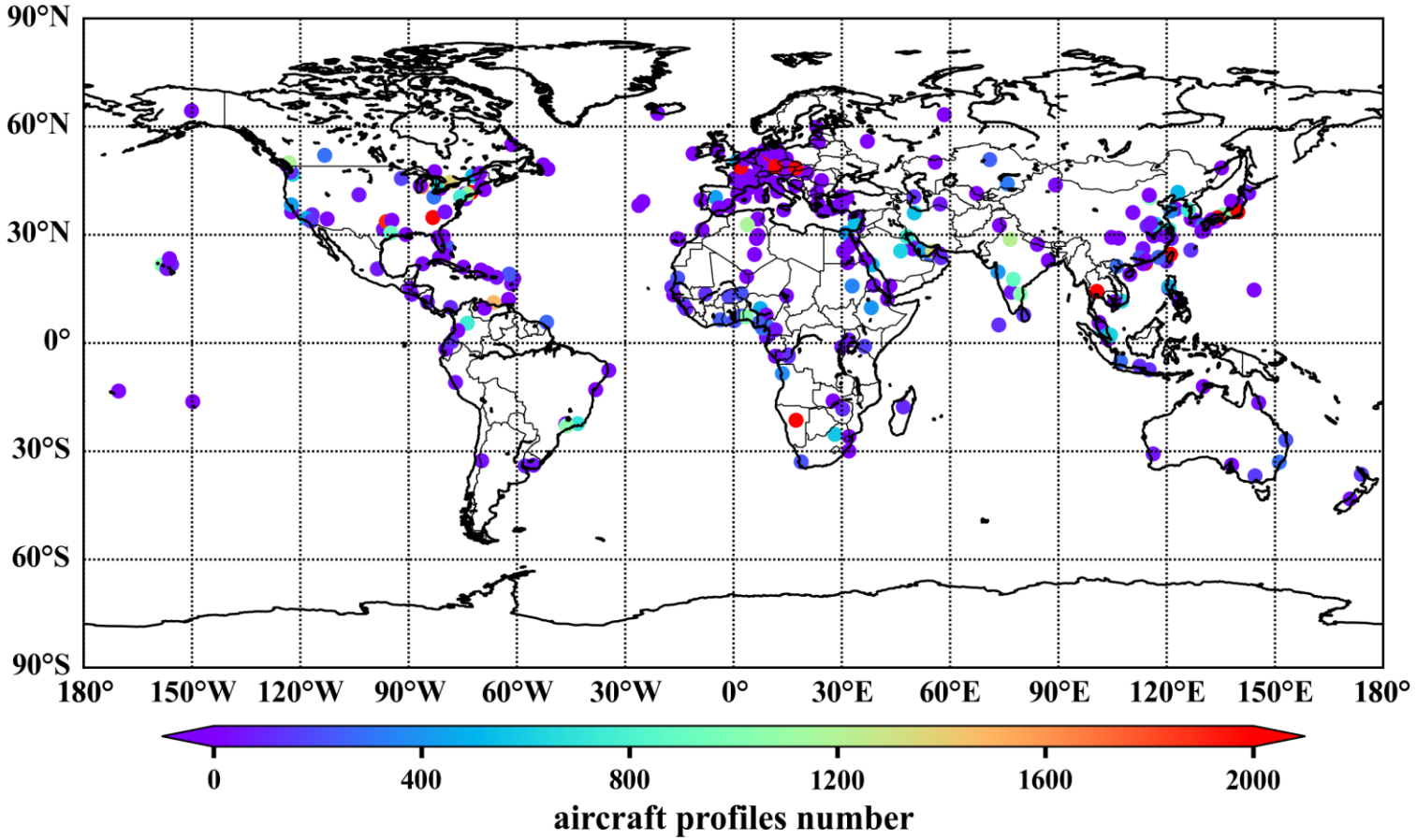
Homogenized Data for IAGOS L/TO Profiles & Record

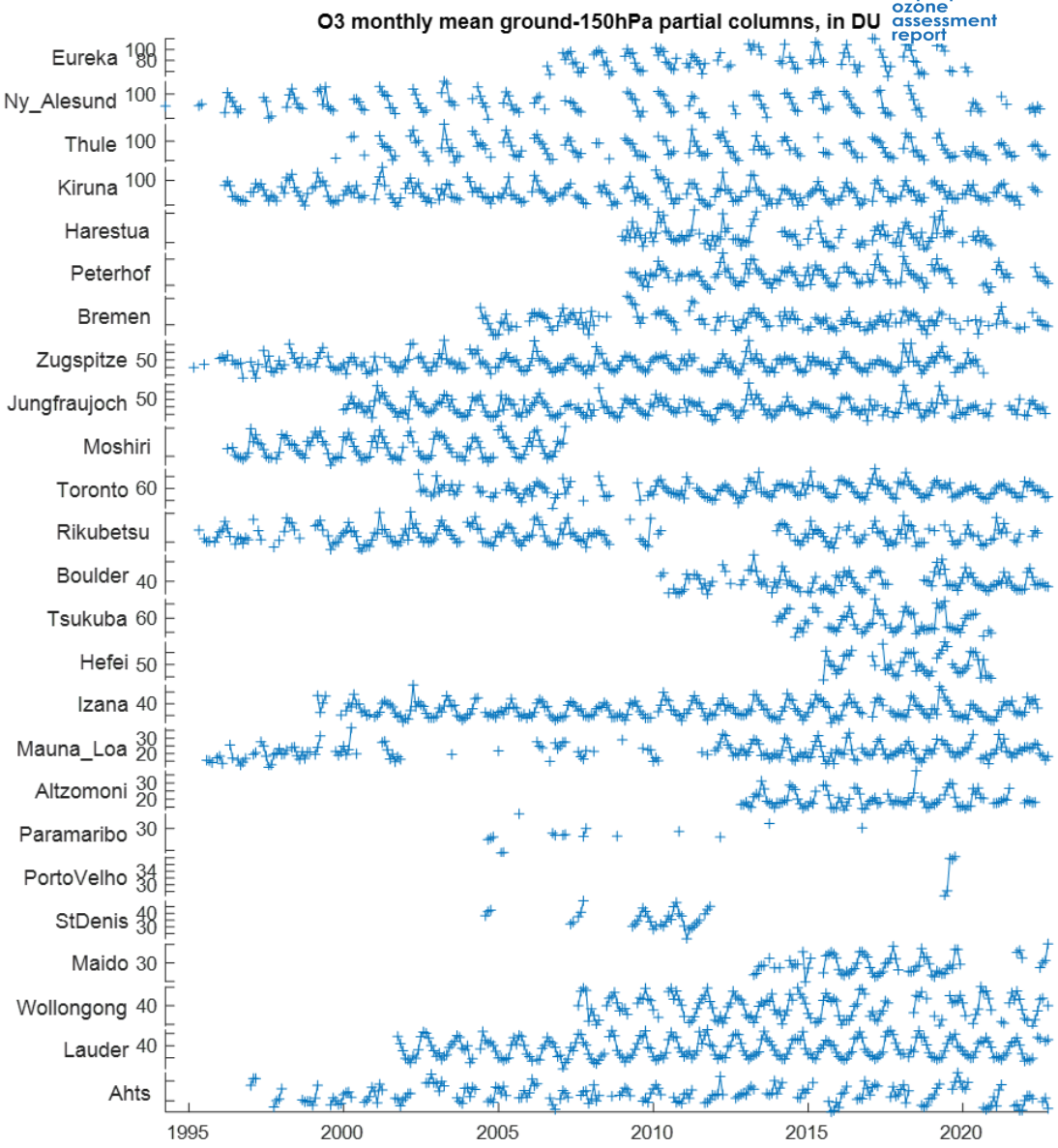
Map of airports



https://hegiftom.meteo.be/datasets/iagos

1994/08 to 2021/03
310 stations
122574 profiles

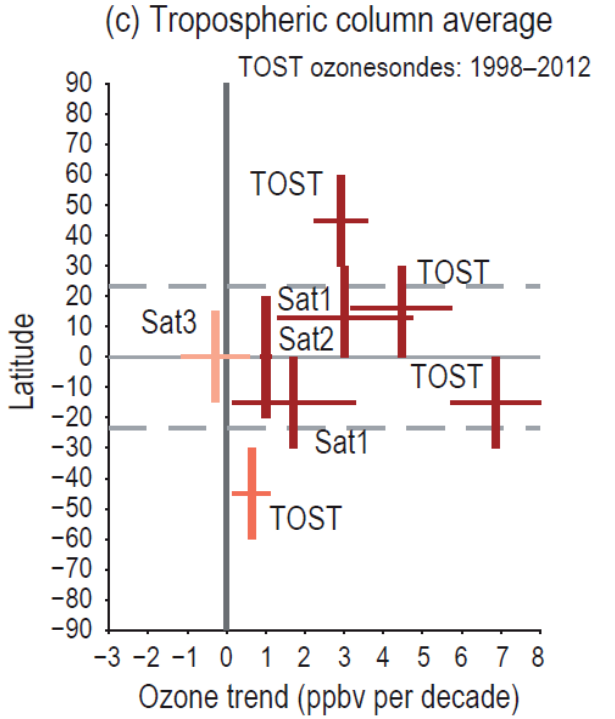
Homogenized Data and Records for FTIR



- 25 sites (22 active in O_3) providing O_3 data. See NDACC Infrared WG: https://www2.acom.ucar.edu/irwg
- Oldest date back to the mid 90s, most since mid 2000s; latter sites also provide CO/HCHO

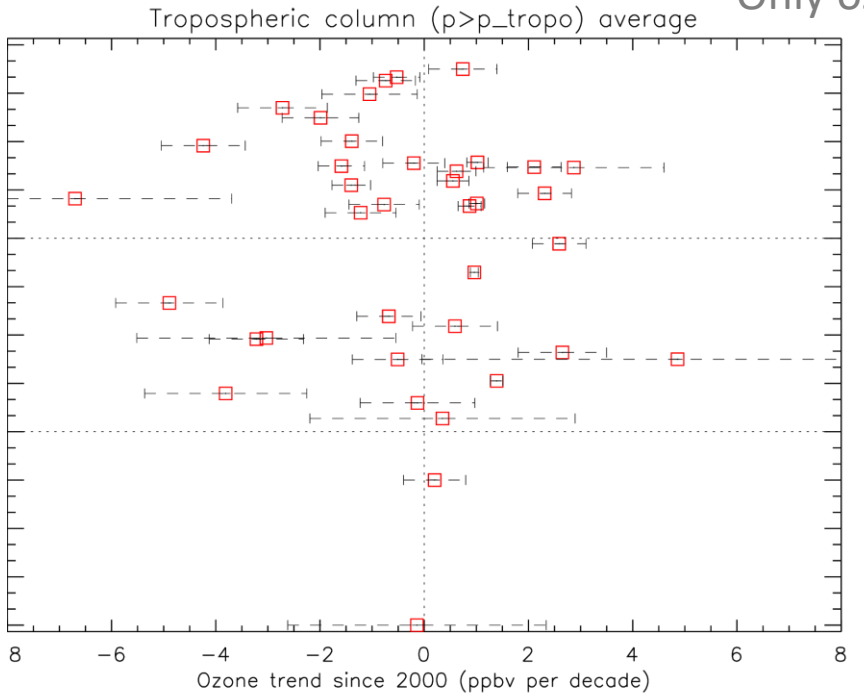
https://hegiftom.meteo.be/datasets/ftir

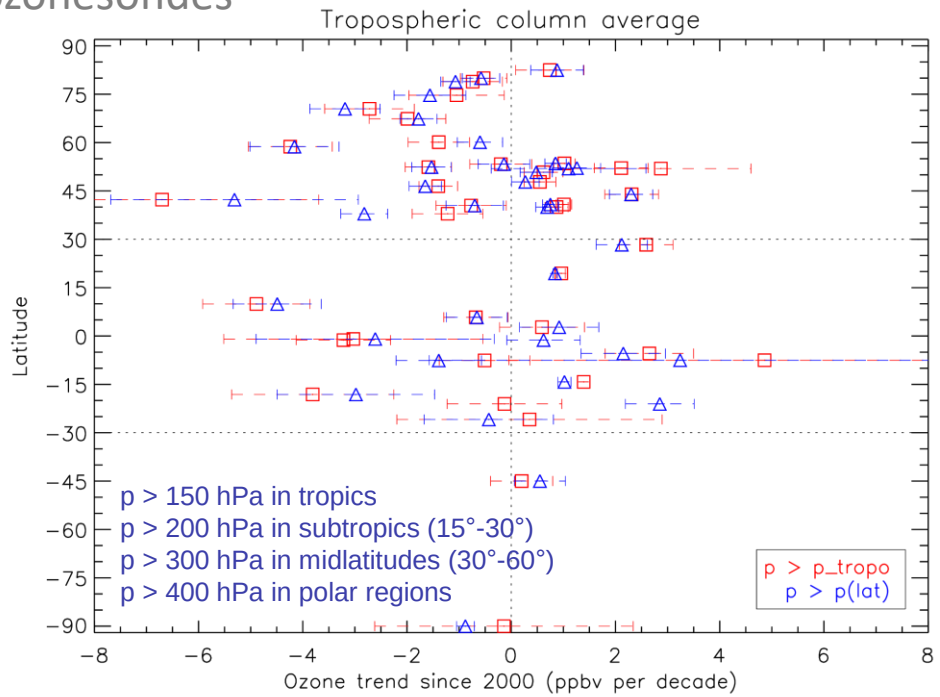
Tropospheric ozone column trend estimates



Satellite products:
Sat1 1979–2016 (TOMS, OMI/MLS)
Sat2 1995–2015 (GOME, SCIAMACHY, OMI, GOME-2A, GOME-2B)
Sat3 1995–2015 (GOME, SCIAMACHY, GOME-II)

Only ozonesondes





- From R. van Malderen -- Simple linear regression trend estimation (just for illustration!)
- different metrics = different trends for bulk of stations!
- Trends are not only function of latitude!