Harmonization, Evaluation, and Trend Estimation of Ground-based Tropospheric Ozone Measurements from NDACC and IAGOS instruments.

Roeland Van Malderen[1], Anne M. Thompson[2, 3], Debra E. Kollonige[2,4], Zhou Zang[5], Kai-Lan Chang[6,7], Ryan M. Stauffer[2], Herman G.J. Smit[8], Eliane Maillard Barras[9], Robin Bjorklund[10], Corinne Vigouroux[10], Irina Petropavlovskikh[6,11], Thierry Leblanc[12], Valérie Thouret[13], Owen Cooper[7], Jane Liu[5] and … many other data providers!

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http://hegiftom.meteo.be/

Introduction to TOAR-II Focus Working Group: HEGIFTOM

- TOAR: Tropospheric Ozone Assessment Report, Phase II: 2019-2026
- Harmonization and Evaluation of Ground-based Instruments for Free Tropospheric Ozone Measurements, *chairs: Herman Smit & Roeland Van Malderen*

Key Objective:
Evaluation and harmonization of the different free tropospheric ozone profiling datasets of the established measuring platforms (in-service aircraft, ozonesondes, Brewer/Dobson Umkehr, FTIR, Lidar).

http://hegiftom.meteo.be/datasets

Harmonization and internal consistency

Large role of NDACC!

ozonesondes

- ✓ 43 sites homogenized according to O3S-DQA or **WMO GAW Rep. No 268**
- ✓ data available at HEGIFTOM ftp-server
- ✓ 10 publications

\+ …

Internal consistency paper:

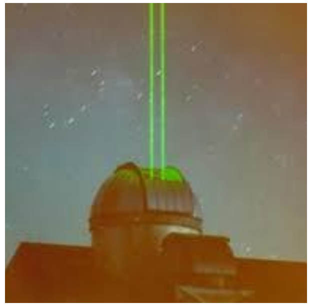
Blot et al., AMT, 2021

IAGOS

FTIR

- ✓ Harmonized NDACC retrieval strategy, using HITRAN 2008
- ✓ 22 "ozone" sites

- ✓ NDACC processing described in **Leblanc et al., AMT, 2016a,b**
- ✓ 2 sites (TMF+OHP) only



Lidar

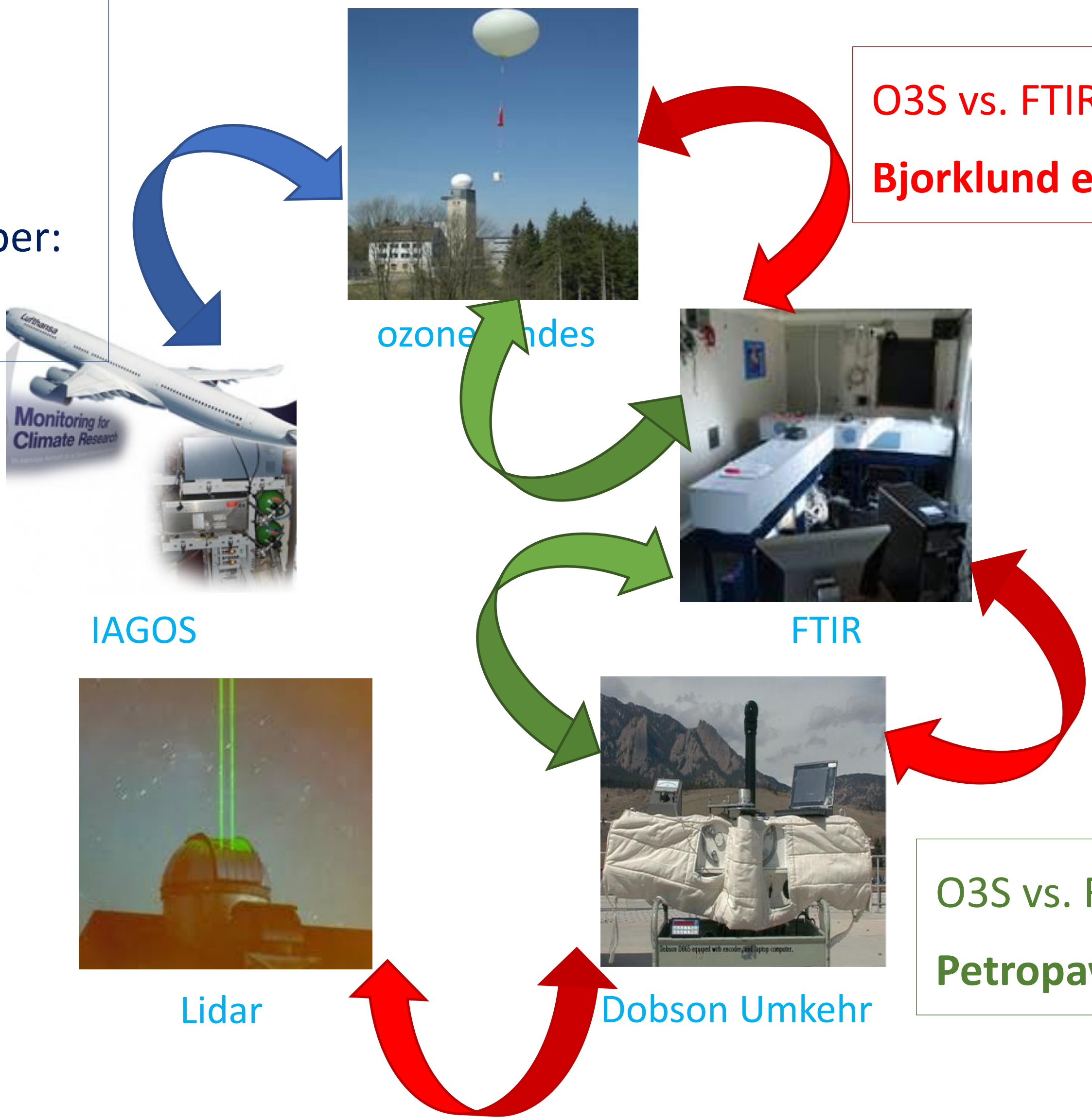
Dobson Umkehr

- ✓ Optimized Umkehr profile algorithm for ozone trend analysis: **Petropavlovskikh et al., AMT, 2022**
- ✓ 6 sites

\+ …

External consistency or intercomparisons

- ✓ IAGOS vs. O3S at 11 airports:
  Wang et al., ACP, 2024
- ✓ IAGOS vs. O3S (Reference) Ozone Photometers in simulation chamber:
  Smit et al., AMT, 2025

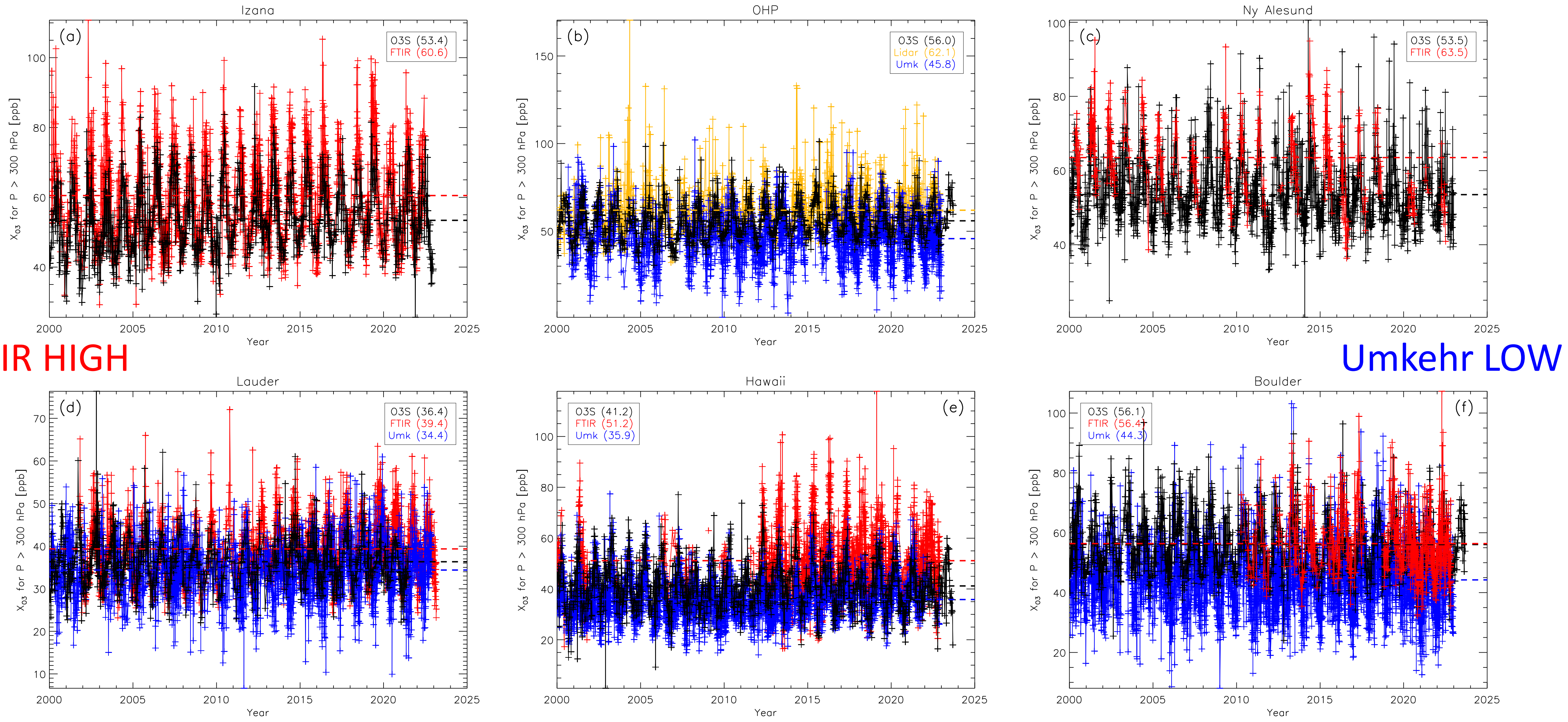


O3S vs. FTIR vs. Umkehr vs. Lidar @Lauder:
Bjorklund et al., AMT, 2024

O3S vs. FTIR vs. Umkehr @Boulder:
Petropavlovskikh et al., poster P_E01

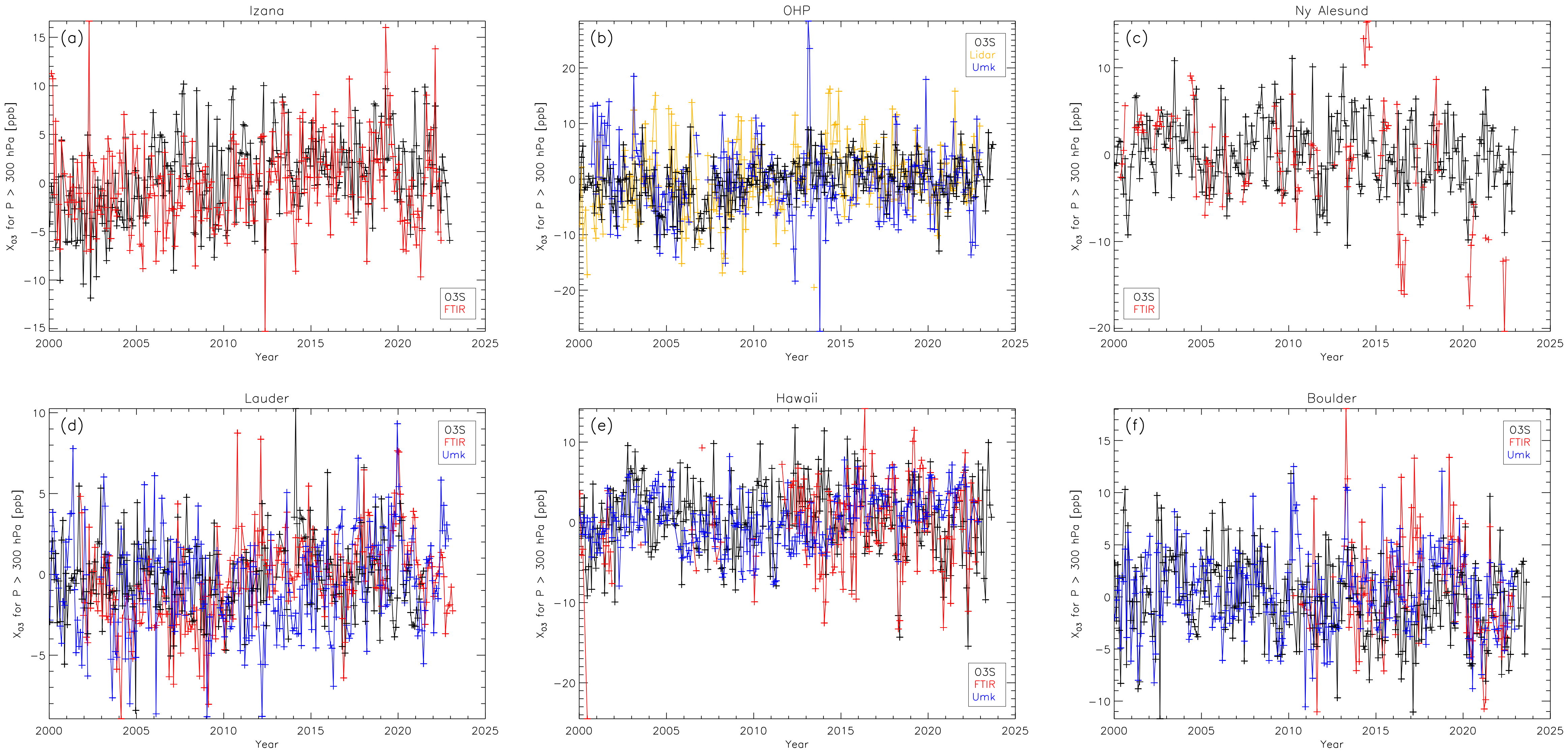
HEGIFTOM: TrOC intercomparisons at collocated sites

Tropospheric Ozone Column (TrOC, here: sfc – 300 hPa) **daily means**



HEGIFTOM: TrOC intercomparisons at collocated sites

Monthly anomalies ➔ TRENDS

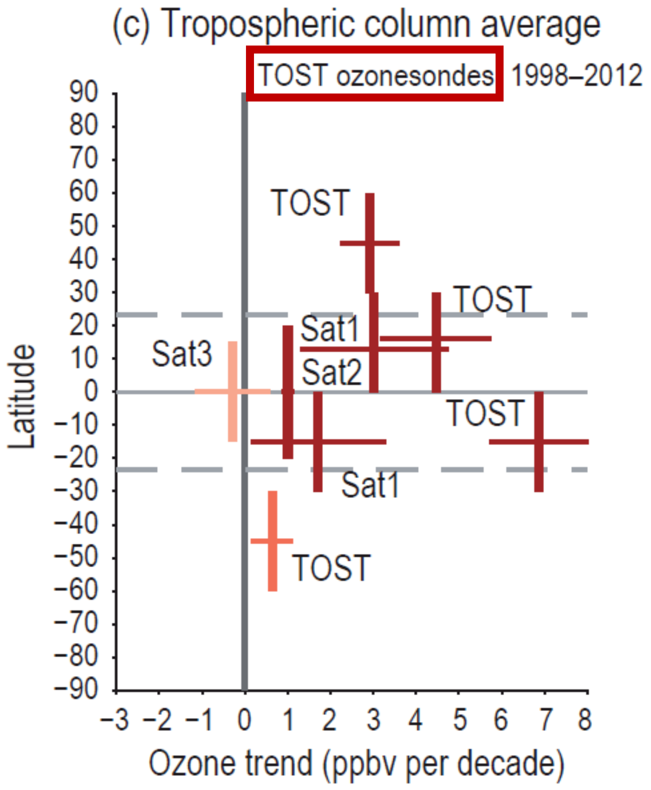


HEGIFTOM: Tropospheric ozone column trends

- TOAR-II: tropospheric ozone **trends** assessment
- In literature:

TOST = Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere

(Wang et al., ACP, TOAR-II SI, 2024)

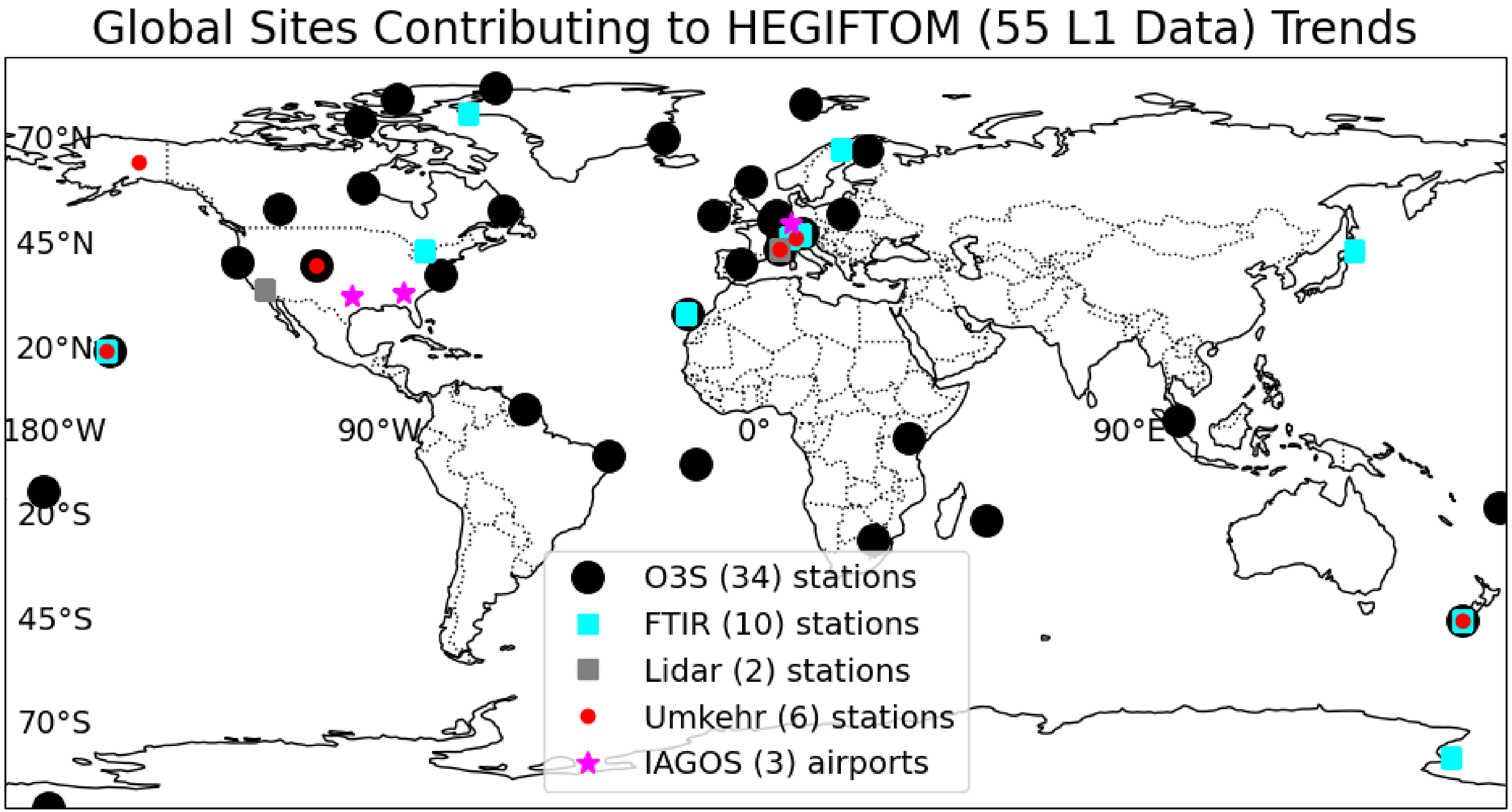


Satellite products:
Sat1 1979–2016 (TOMS, OMI/MLS)
Sat2 1995–2015 (GOME, SCIAMACHY, OMI, GOME-2A, GOME-2B)
Sat3 1995–2015 (GOME, SCIAMACHY, GOME-II)

Fig. 2.8 of IPCC AR6, 2021.

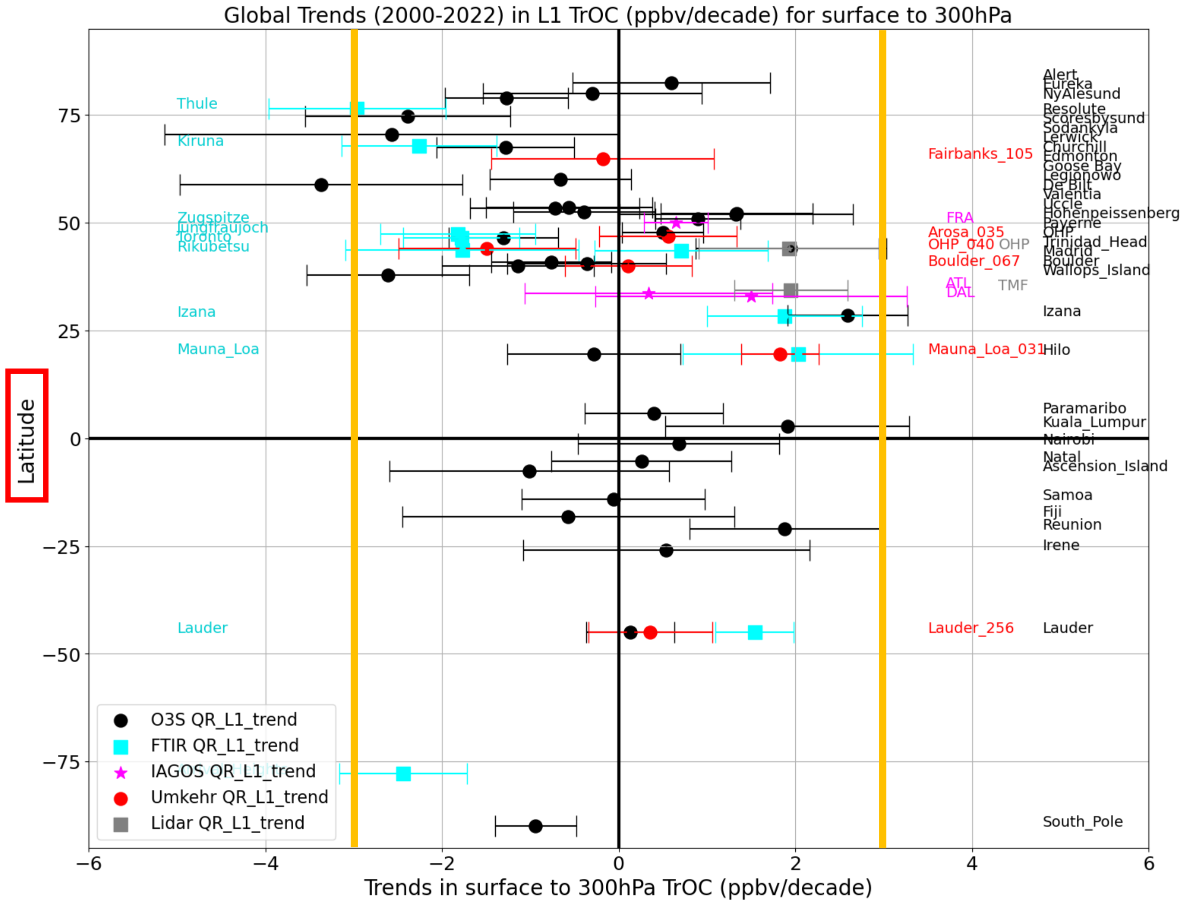
- **HERE**: reproduce this figure, consistently, for high-quality **ground-based** and **in-situ** measurements (individual sites + “merged”)

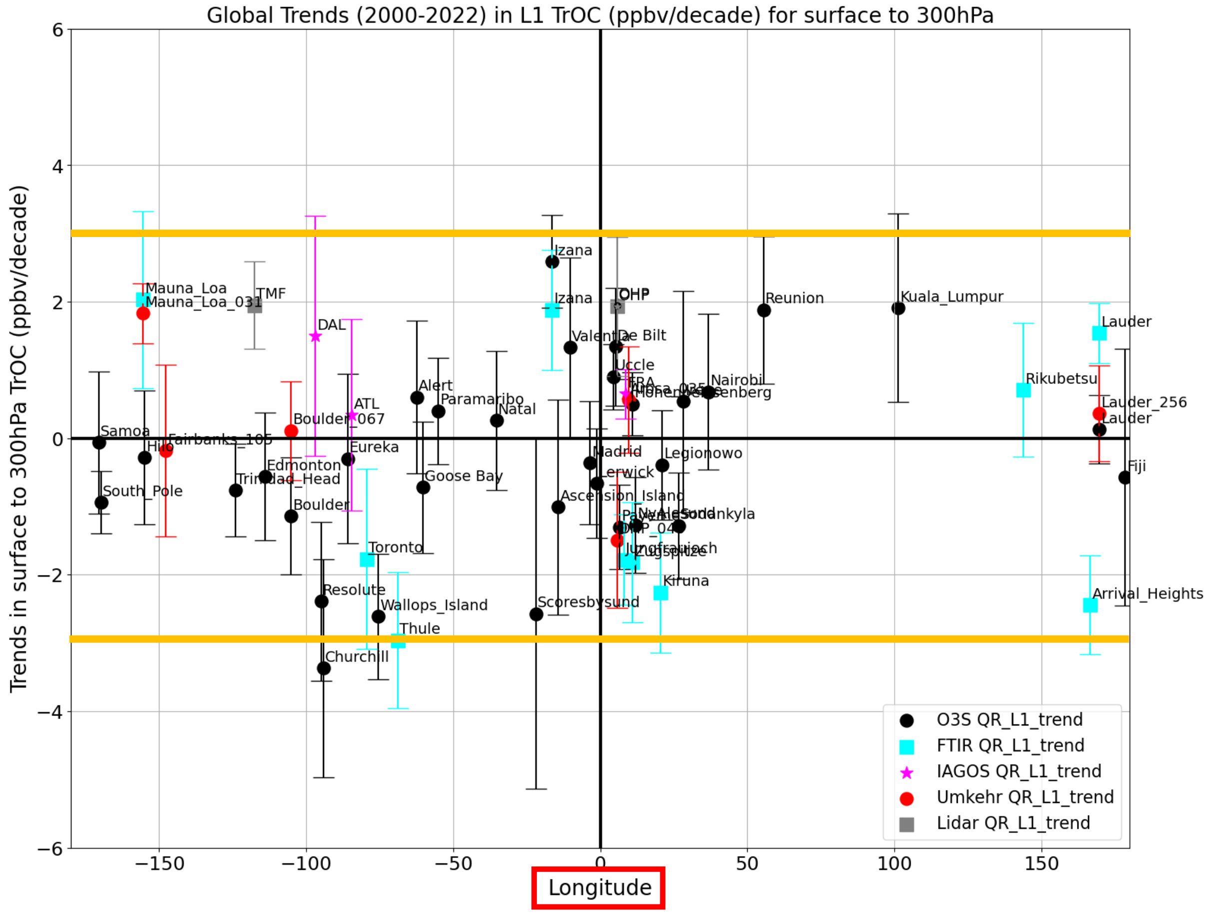
Individual site trends sample



- Sampling (> 120 months of data) and gaps (2000+) put constraints
- 55 sites

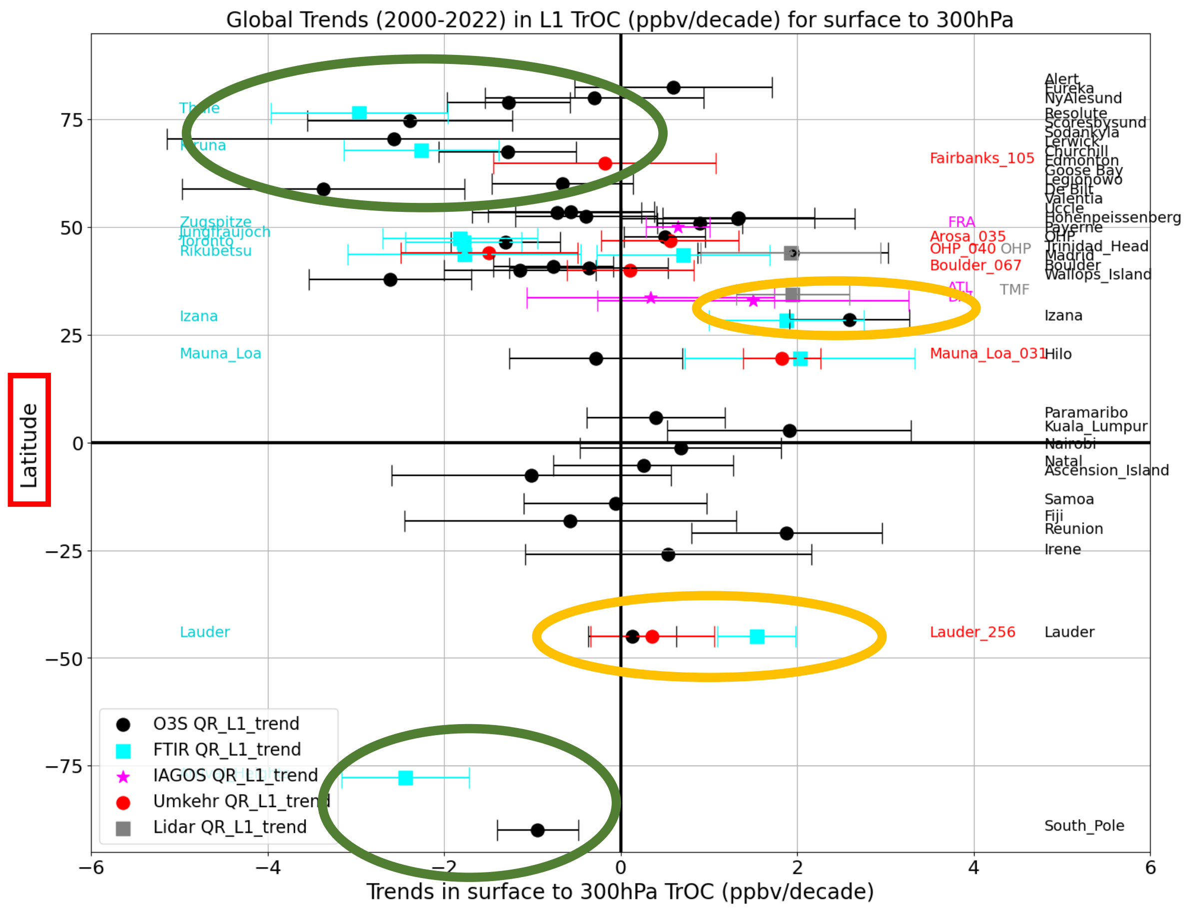
Individual site trends: QR median trends

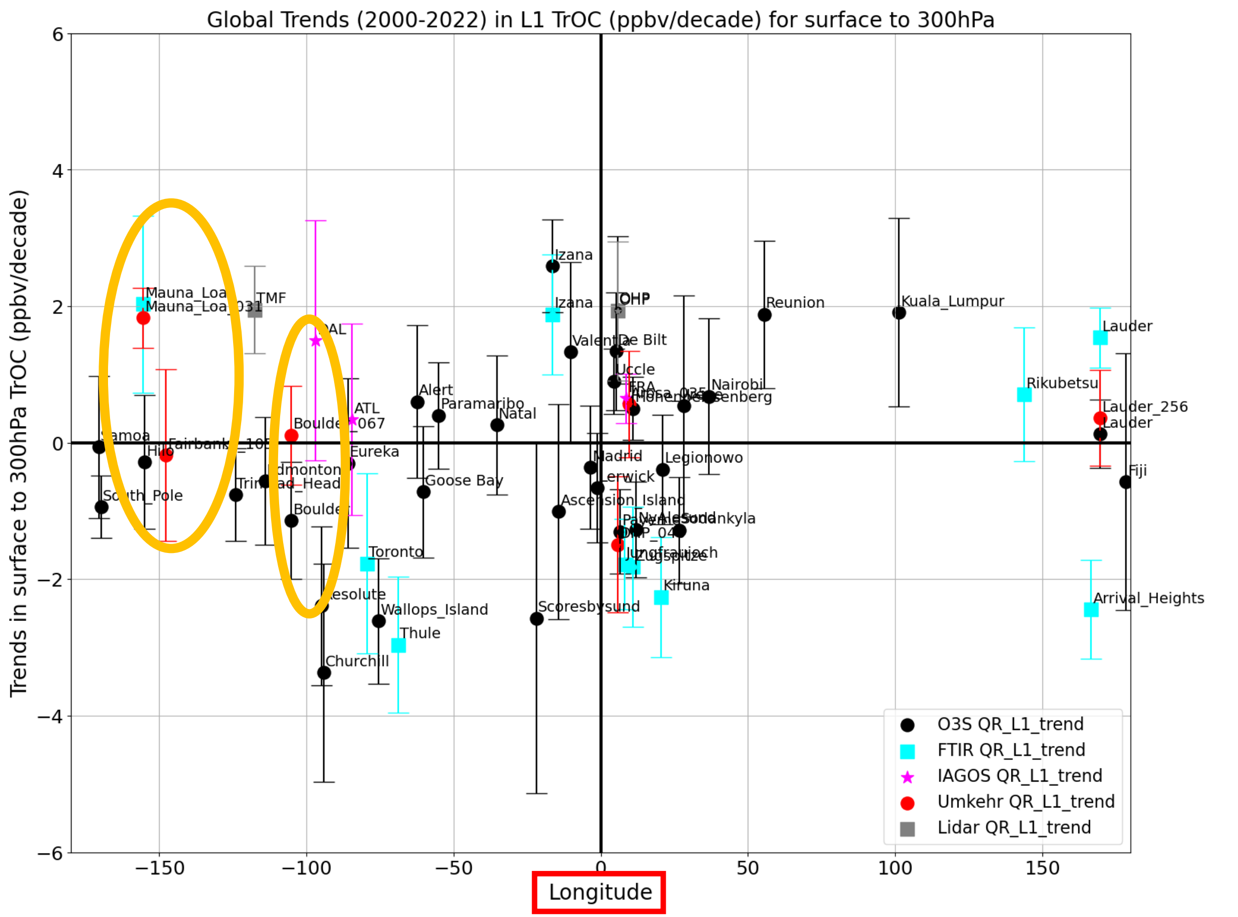




- same number of positive and negative trends, **42%** of the sites with **non-significant trends**
- mostly within **± 3 ppbv/decade** → constraints for satellite and model products

Individual site trends: QR median trends



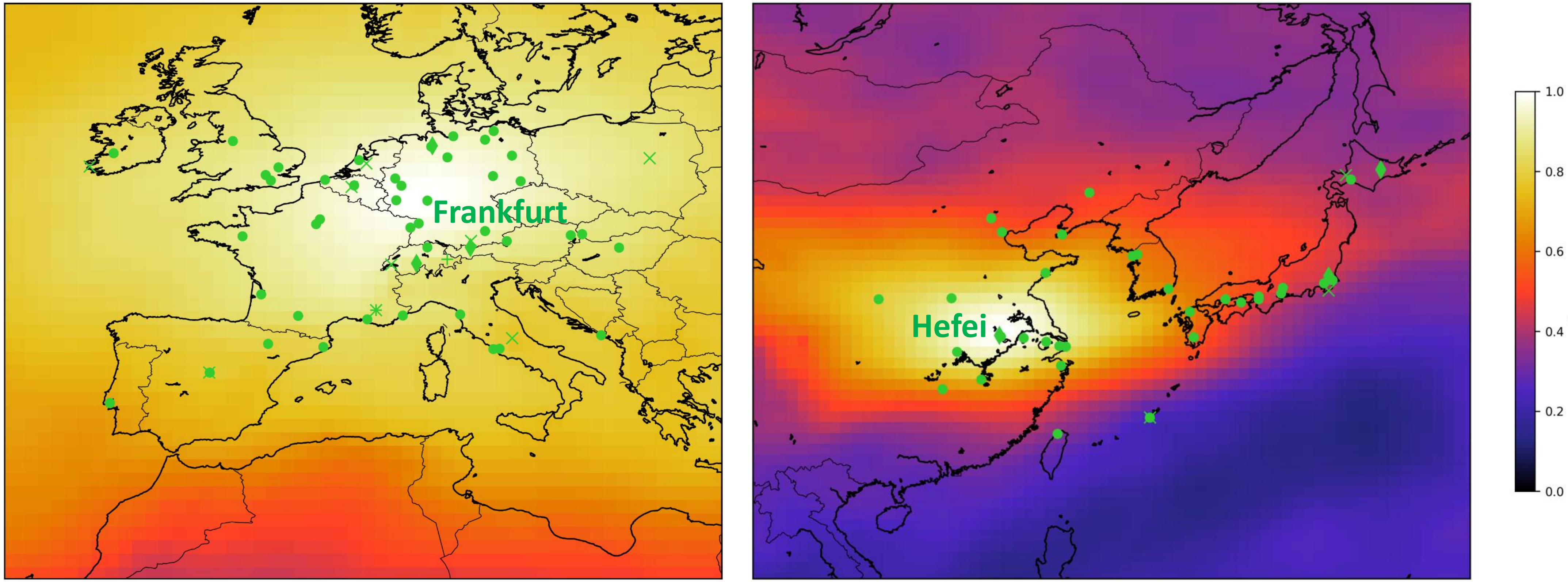


- Negative trends at high (polar) latitudes?
- Trend differences at multi-instrument sites?

→ Regional trend consistency? Merging? Spatial/temporal gap filling?

Strategy for regionalized trends

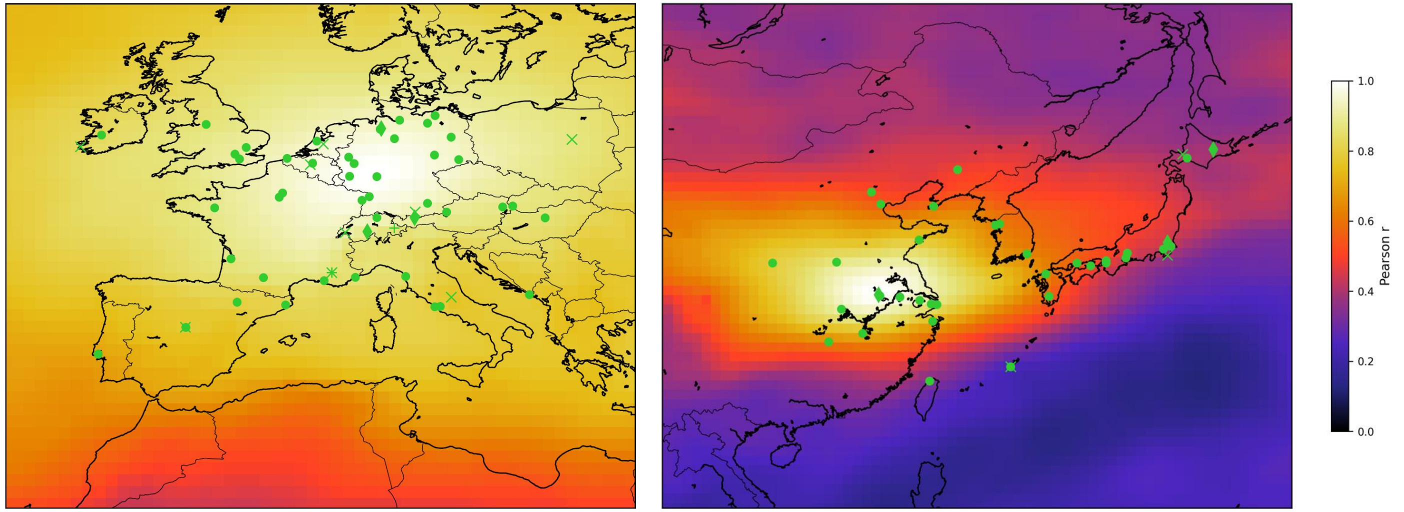
Which regions/sites?



- Correlation maps between CAMS TrOC (sfc – 300 hPa) monthly anomalies at HEGIFTOM sites (here: Frankfurt, IAGOS & Hefei, FTIR)
- r > 0.7!

see also upcoming LOTUS approach
(talk A_09 by Louis Mirallié)

2 strategies for regionalized trends



TOST

1.
regions

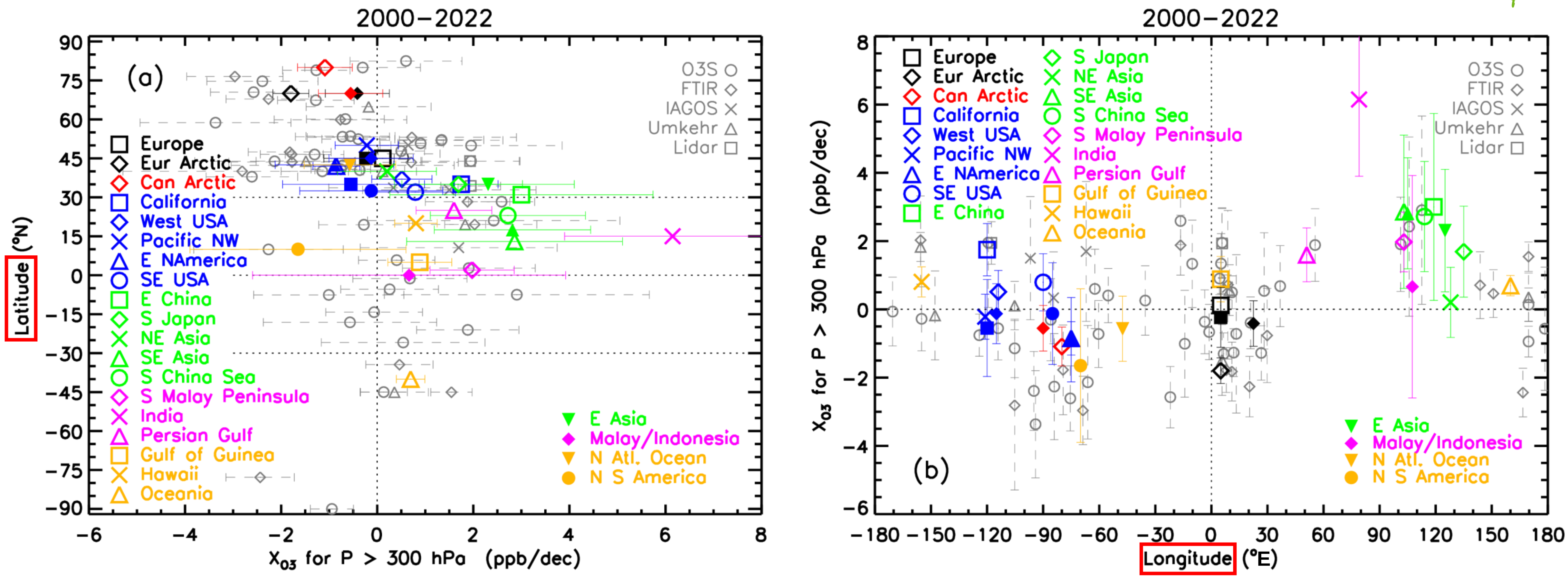
Trends in defined regions with TOST (Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere): **ozonesondes only**!

LMM

2.
sites

Statistical method (linear mixed-effects modelling, LMM) for calculating synthetized trends from **well-correlated individual time series** for **all instruments**, allowing an intercept and a slope to adjust the difference from each individual trend against the overall trends.

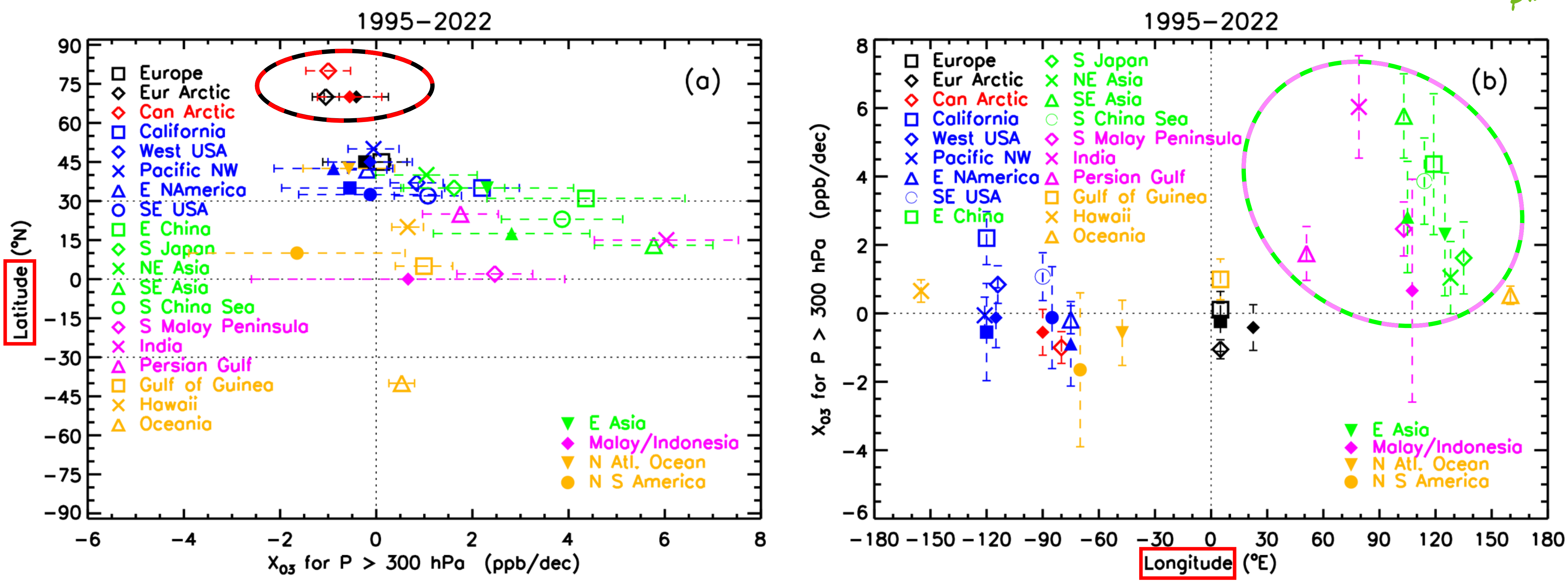
All trends: 2000-2022



background grey = individual site trends
different colors = different regions
open symbols = synthesized LMM trends
filled symbols = TOST regional trends

- Regional trends “summarize” individual trend estimates
- No large trend diff. between similar regions for 2 approaches

All trends: 1995-2022



different colors = different regions
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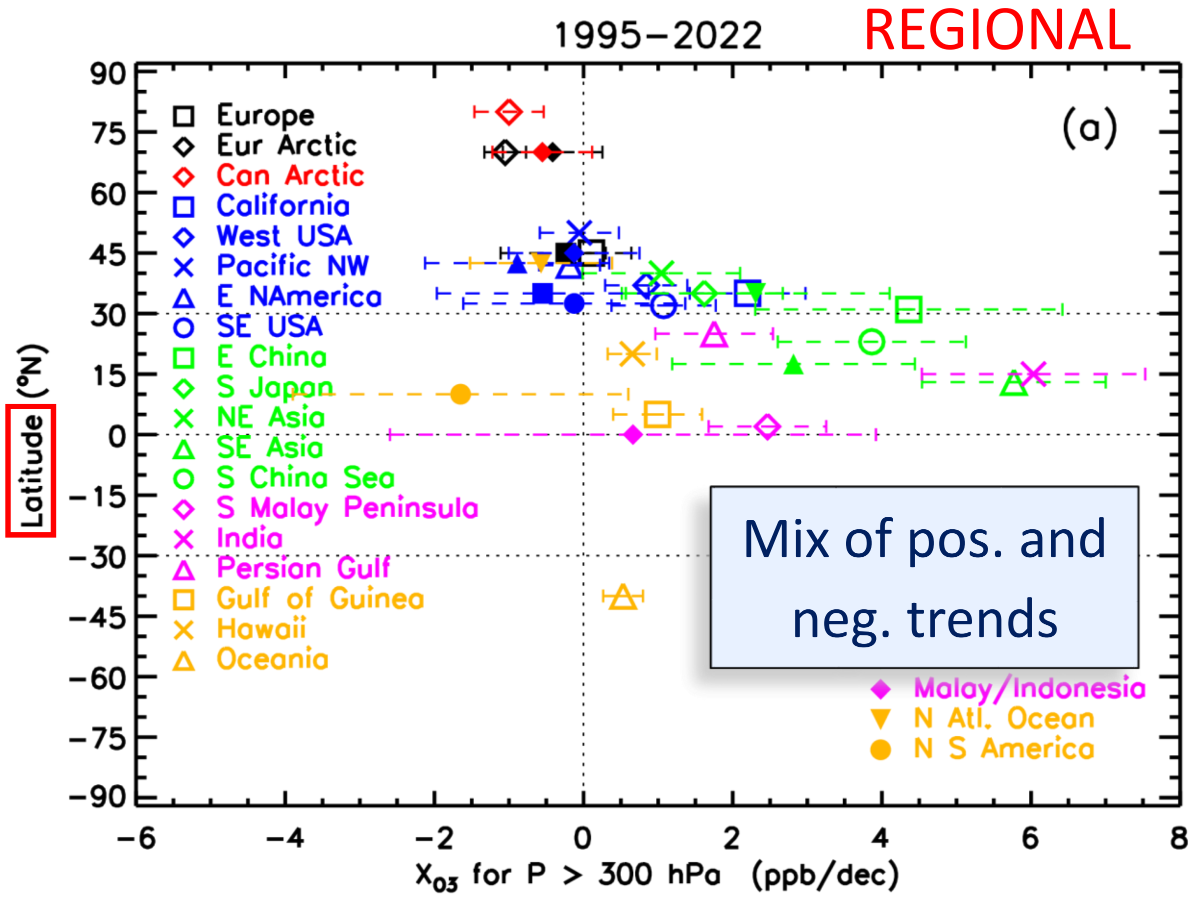
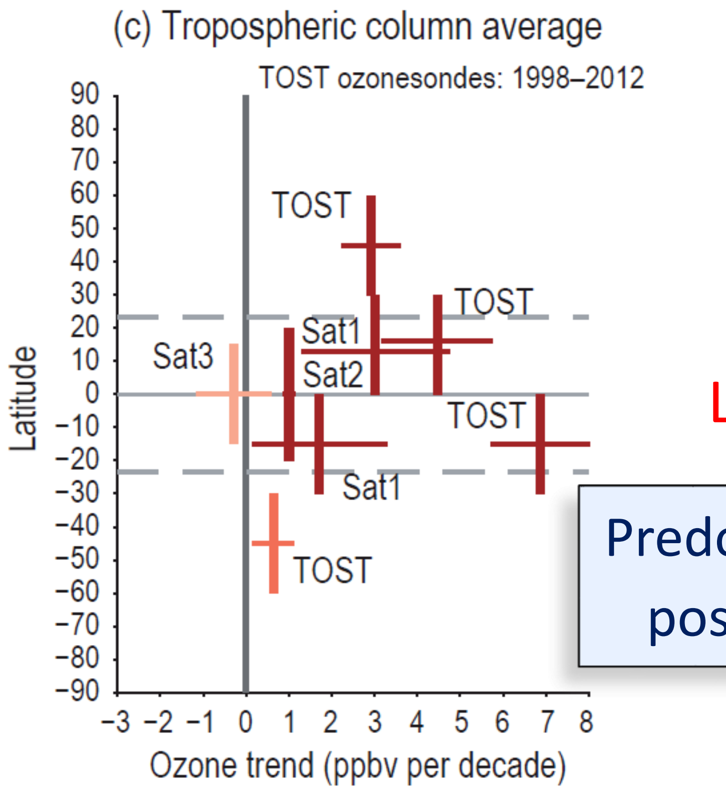
- negative TrOC trends in Arctic regions (very high confidence)
- increasing TrOC over all Asian regions (median confidence)

All trends



Mix of pos. and neg. trends



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Sat3 1995–2015 (GOME, SCIAMACHY, GOME-II)

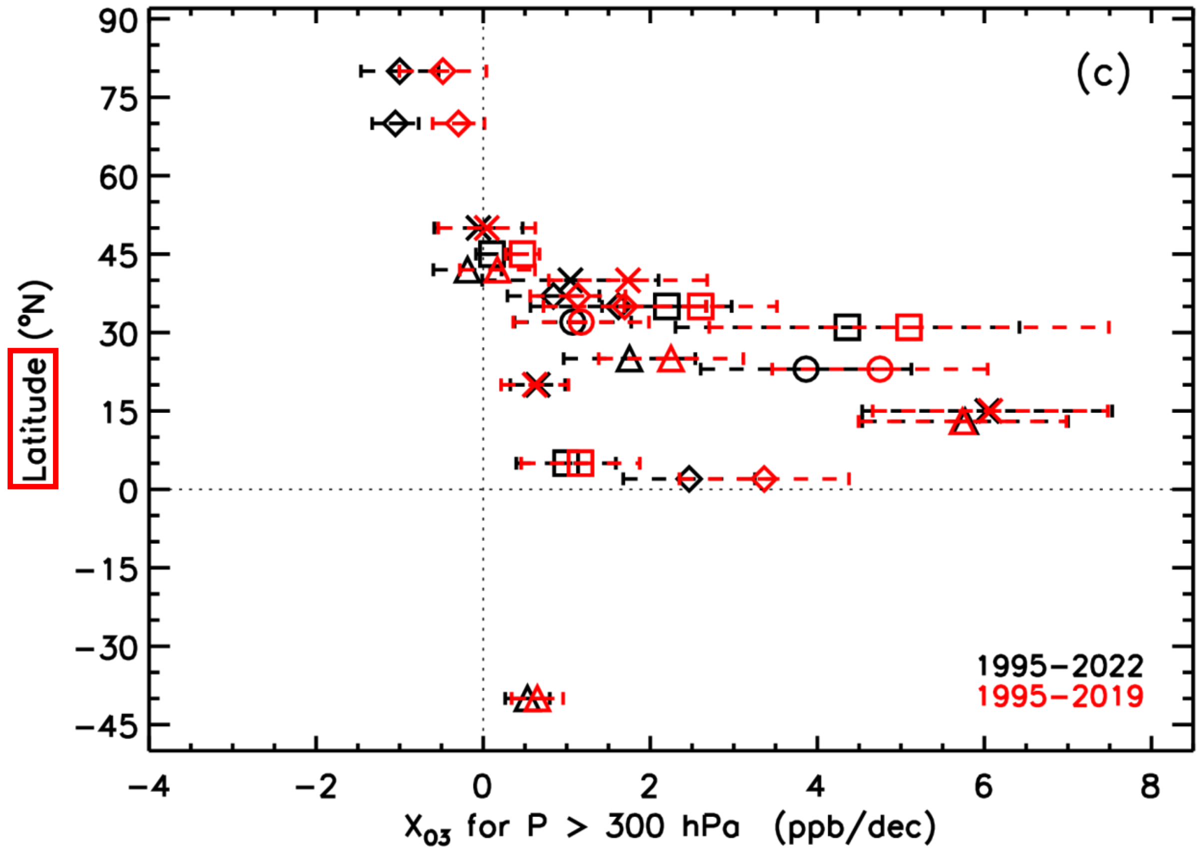
LATITUDINAL

Predominantly pos. trends

different colors = different regions
open symbols = synthesized trends
filled symbols = TOST regional trends

All trends: 1995-2019

1995 – 2019



- for all regions (and bulk of the sites) & periods & methods: pre-COVID trends > post-COVID trends
- COVID-19 restrictions lead to ozone precursor emission decreases!

Conclusions and outlook

- No NDACC, no HEGIFTOM!
- More investigations on ozone differences between different techniques are needed (spatio-temporal representativeness)?
- Mixture of **positive and negative trends** worldwide, but consistently **negative in Arctic** (?) and **positive in East Asia** (continuing increase of NOx emissions)
- **COVID-19 restrictions** led to less ozone precursor emissions and **decreasing TrOC amounts**, impacting present-day (i.e. post-COVID) trends

Further reading and outlook

Atmos. Chem. Phys., 25, 7187–7225, 2025
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Atmospheric Chemistry and Physics
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Global ground-based tropospheric ozone measurements: reference data and individual site trends (2000–2022) from the TOAR-II/HEGIFTOM project

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Ground-based tropospheric ozone measurements: regional tropospheric ozone column trends from the TOAR-II/HEGIFTOM homogenized datasets

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