TOAR II Assessment of satellite ozone

CEOS AC-VC #21, 10-13 June 2025

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Lead authors

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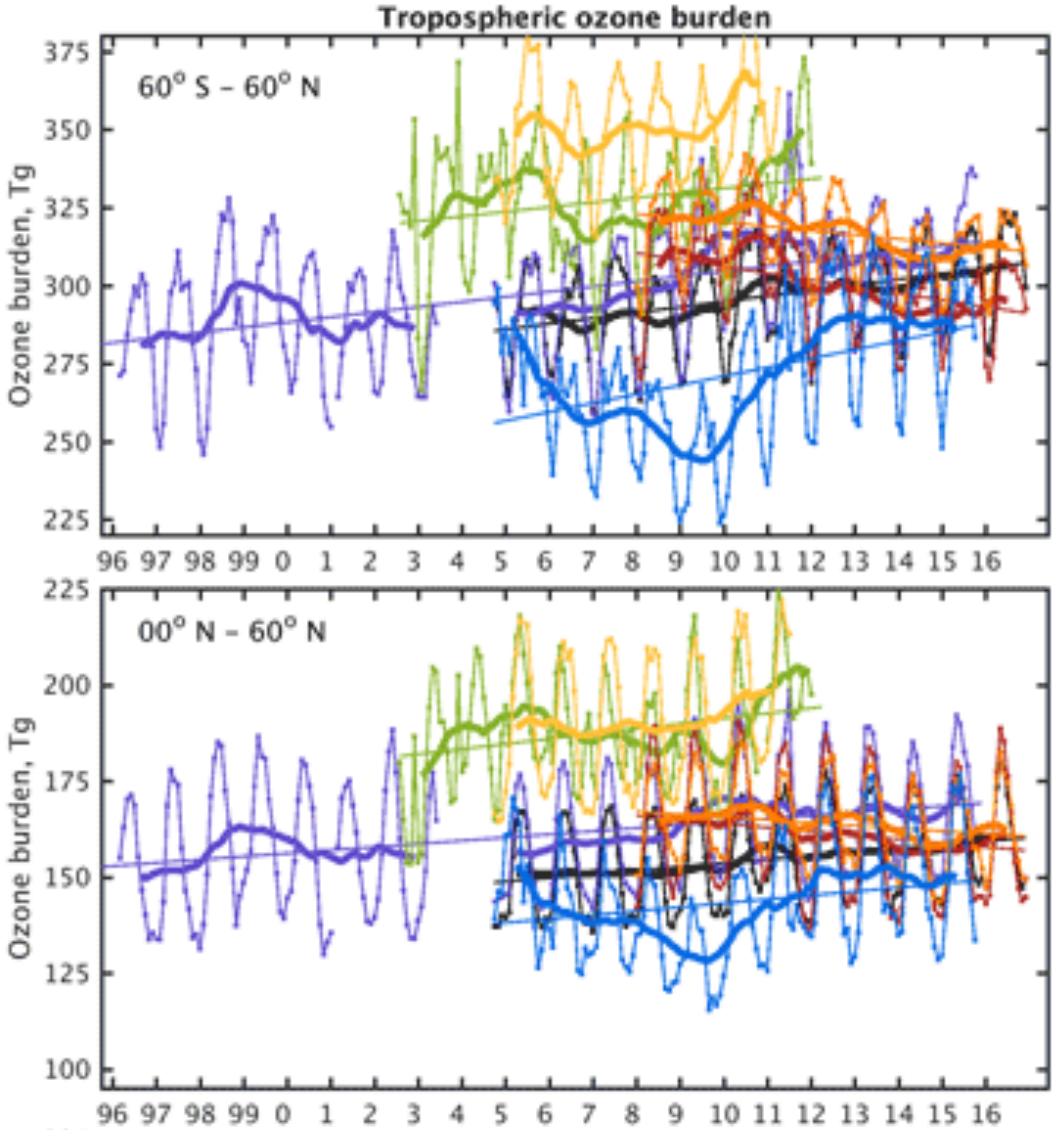
Acknowledgements to CEOS and all satellite data providers

TOAR I Satellite ozone assessment (2018)



	change, Tg yr^{-1}	p-value
Black: OMI/MLS	1.79 +/- 0.66	0.00
Brown: IASI-FORLI	-2.15 +/- 1.03	0.00
Orange: IASI-SOFRID	-1.34 +/- 0.92	0.00
Purple: GOME/OMI	1.63 +/- 0.45	0.00
Blue: OMI-RAL	2.85 +/- 1.16	0.00
Green: SCIAMACHY	1.50 +/- 1.39	0.03
Yellow: TES		

	change, Tg yr^{-1}	p-value
Black: OMI/MLS	0.95 +/- 0.55	0.00
Brown: IASI-FORLI	-1.01 +/- 1.17	0.09
Orange: IASI-SOFRID	-0.73 +/- 0.81	0.08
Purple: GOME/OMI	0.82 +/- 0.35	0.00
Blue: OMI-RAL	1.02 +/- 0.79	0.01
Green: SCIAMACHY	1.33 +/- 1.04	0.01
Yellow: TES		

- 7 data sets, not harmonized
- Not integrated
- Large discrepancies
- 5° & seasonal resolutions
- 60°S-60°N (w/o high latitudes)

TOAR II Satellite data records 21 considered

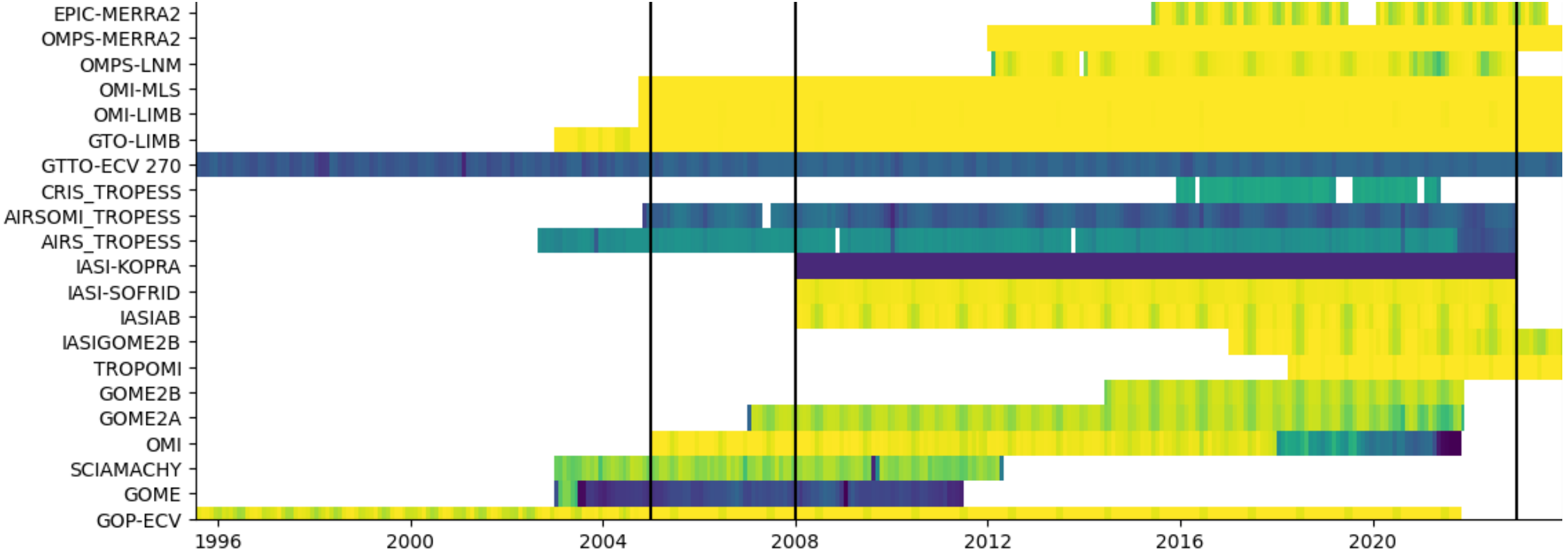
Product	Provider	Coverage	Vert.	Meas.
IASI-FORLI	ULB / LATMOS / AC SAF	2008/01–2022/12	X	NP
		global		IR
IASI-SOFRID	LAERO	2008/01–2022/12	X	NP
		global		IR
IASI-KOPRA	LISA	2008/01–2022/12	X	NP
		*		IR
IASI+GOME2B	LISA/AERIS	2017/01–2023/12	X	NP
		global		IR+UV
CRIS-TROPESS	NASA JPL	2015/12–2021/05	X	NP
		65°S - 85°N		IR
AIRS-TROPESS	NASA JPL	2002/09–2022/12	X	NP
		65°S - 85°N		IR
AIRSOMI-TROPESS	NASA JPL	2004/11–2022/12	X	NP
		65°S - 85°N		IR+UV
TROPOMI	KNMI/ESA	2018/04–2023/12	X	NP
		global		UV
GOP-ECV	DLR/RAL/ESA	1995/07–2021/10	X	NP
		global		UV
GTTO-ECV 270	DLR/BIRA-IASB/ESA	1995/07–2023/12	X	CCD
		20°S - 20°N		UV
GTO-LIMB	FMI/DLR/ESA	2003/01–2023/12	X	LNM
		global		UV
OMI-LIMB	FMI/DLR/ESA	2004/10–2023/12	X	LNM
		global		UV
OMI-MLS	NASA GSFC	2004/10–2023/12	X	LNM
		60°S - 60°N		UV+MW
OMPS-LNM	IUP-UB	2012/02–2022/12	X	LNM
		60°S - 60°N		UV
OMPS-MERRA2	NASA GSFC	2012/01–2023/12	X	LNM
		global		UV+mod
EPIC-MERRA2	NASA GSFC	2015/06–2023/08	X	LNM
		global		UV+mod

- 21 data sets, harmonized (smoothing, a-priori, sampling, tropopause. See Keepers's talk)
- 1° x1° & monthly resolutions
- 90°S-90°N

↓

- more accurate ozone climatology
- strengthen the basis for detecting and attributing long-term changes

TOAR II Satellite data records 21 considered



- UV nadir (OMI, TROPOMI, OMPS)
- Thermal infrared nadir (AIRS, CrIS, IASI)
- Limb-nadir matching (MLS-OMI, GTO-LIMB, OMPS-LNM)
- Multi-sensor (IASI+GOME-2, AIRS-OMI)

19 data records were harmonised, 2 more are in the pipeline

- 1 IASI data sets (SOFRID)
- 1 TROPESS data sets (CrIS)

→ Support robust intercomparison and ensemble-based ozone trend detection.

TOAR II assessment topics

- Present-day state (2018 – 2022)
  - Mean state
  - Seasonal cycle
- Long-term changes (2000s – 2022)
  - Annual means
  - Seasonal changes
- Impact of COVID lockdown and recovery (2020 – 2023)
- Comparison to ground-based data (HEGIFTOM sonde)

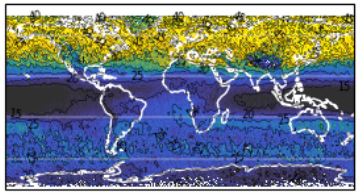
Present day (2018-2022) TOC mean state

!!! Preliminary !!!

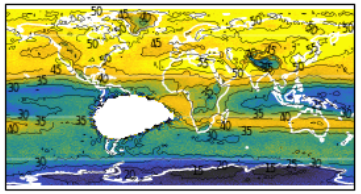
TOAR tropospheric ozone assessment report

original

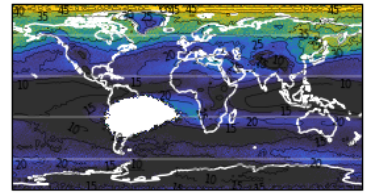
OMI (26.2 ± 10.6 ± 0.0): plrt_merra2/orig



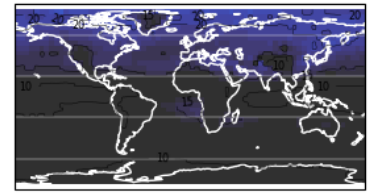
GOME2A (37.9 ± 9.2 ± 0.0): plrt_merra2/orig

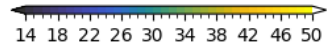


GOME2B (17.8 ± 7.7 ± 0.0): plrt_merra2/orig

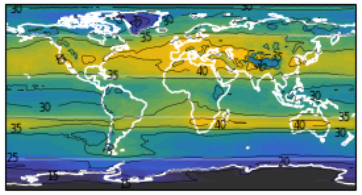


GOP-ECV (13.1 ± 3.4 ± 0.0): p450/orig

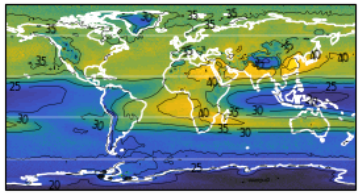


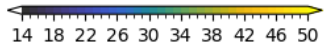


TROPOMI (32.3 ± 5.5 ± 0.0): plrt_merra2/orig

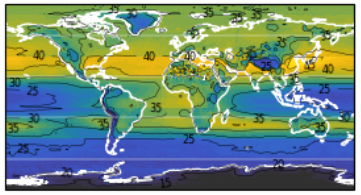


IASI-FORLI (31.8 ± 6.2 ± 0.0): plrt_merra2/orig



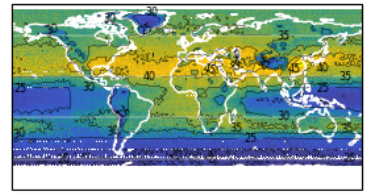


IASI-SOFRID (31.6 ± 6.5 ± 0.0): plrt_merra2/orig

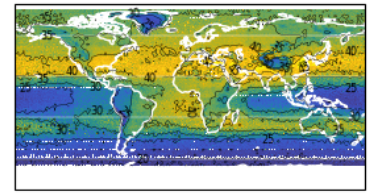


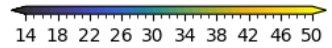
IASI-KOPRA (35.9 ± 3.0 ± 0.0): plrt_merra2/orig

AIRS_TROPESS (31.5 ± 6.7 ± 0.0): plrt_geos5/orig

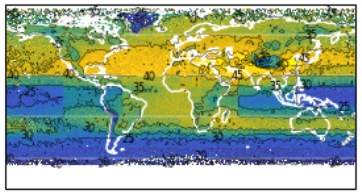


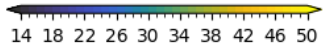
CRIS_TROPESS (32.8 ± 7.0 ± 0.0): plrt_geos5/orig



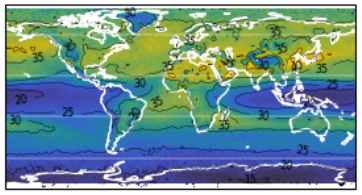


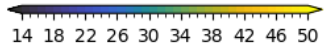
AIRSOMI_TROPESS (33.4 ± 7.1 ± 0.0): plrt_geos5/orig



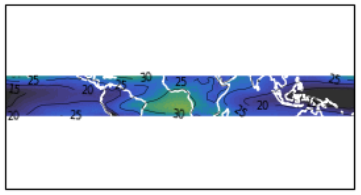


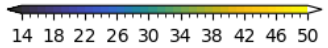
IASIGOME2B (29.8 ± 5.9 ± 0.0): plrt_merra2/orig



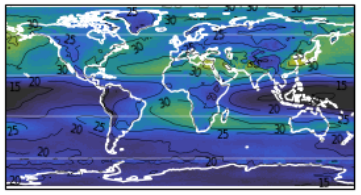


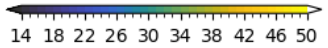
GTTO-ECV 270 (22.5 ± 5.0 ± 0.0): p270/orig



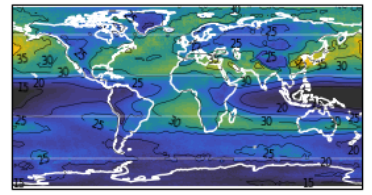


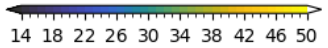
GTO-LIMB (24.0 ± 5.6 ± 0.0): plrt_era5_fmi/orig



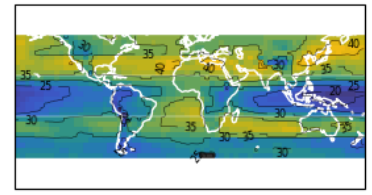


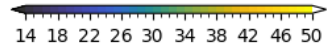
OMI-LIMB (25.2 ± 5.8 ± 0.0): plrt_era5_fmi/orig



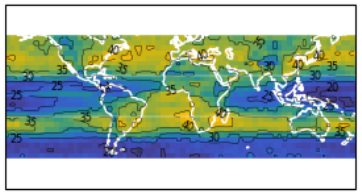


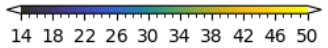
OMI-MLS (31.5 ± 5.2 ± 0.0): plrt_ncep/orig



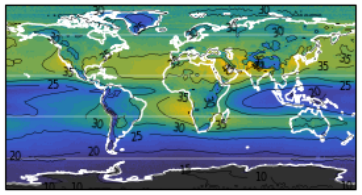


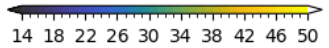
OMPS-LNM (31.3 ± 6.0 ± 0.0): plrt_era5l/orig



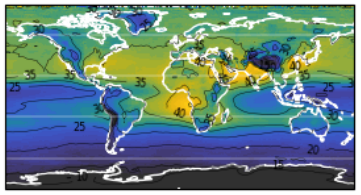


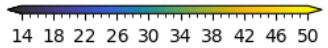
OMPS-MERRA2 (28.6 ± 6.0 ± 0.0): pdyn_merra2/orig



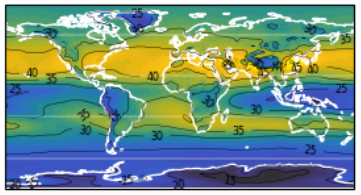


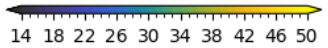
EPIC-MERRA2 (29.0 ± 7.4 ± 0.0): pdyn_merra2/orig





CAMSRA (32.4 ± 6.3 ± 0.0): plrt_merra2/orig



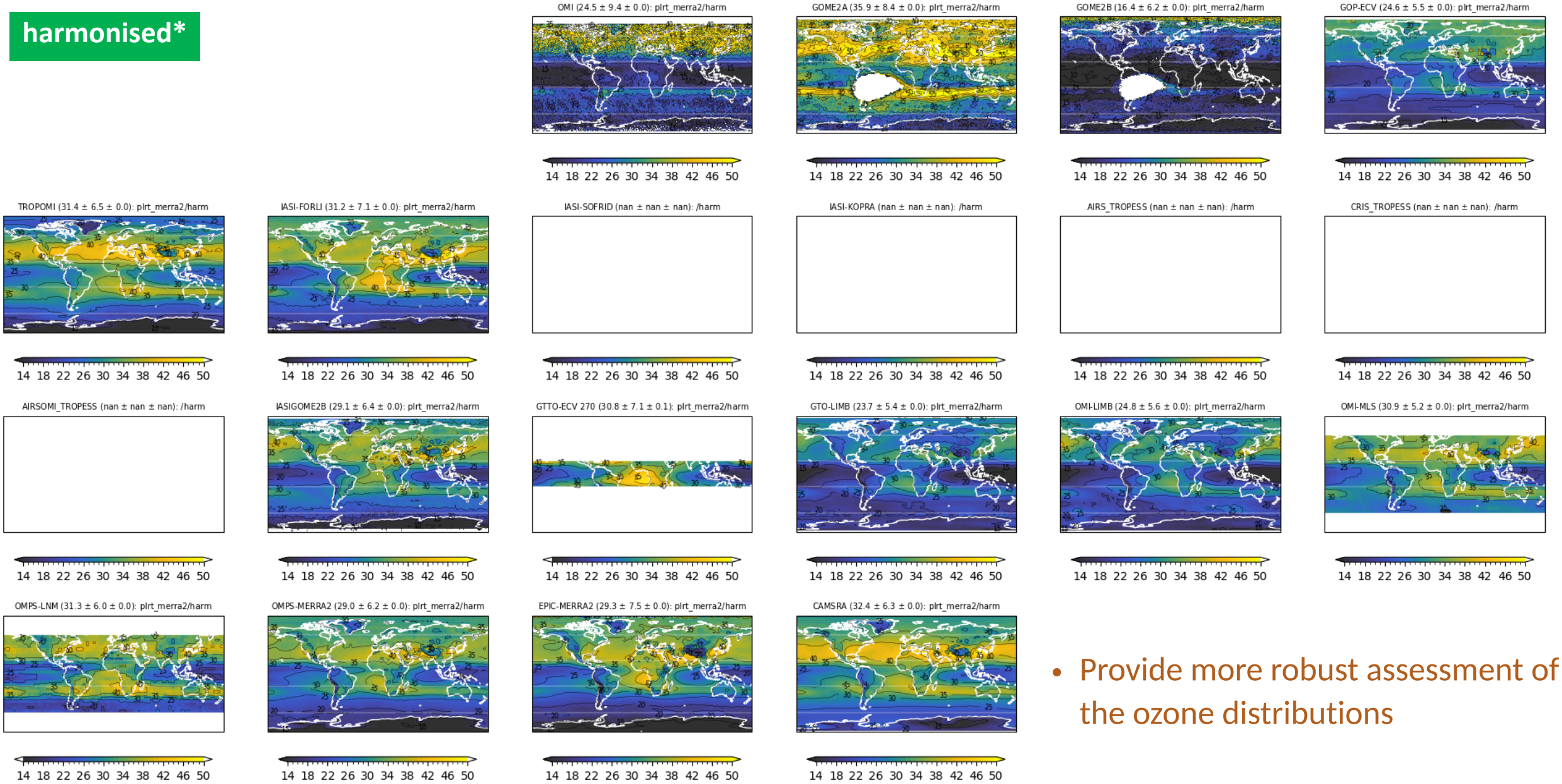


Present day (2018-2022) TOC mean state

!!! Preliminary !!!

TOAR tropospheric ozone assessment report

harmonised*



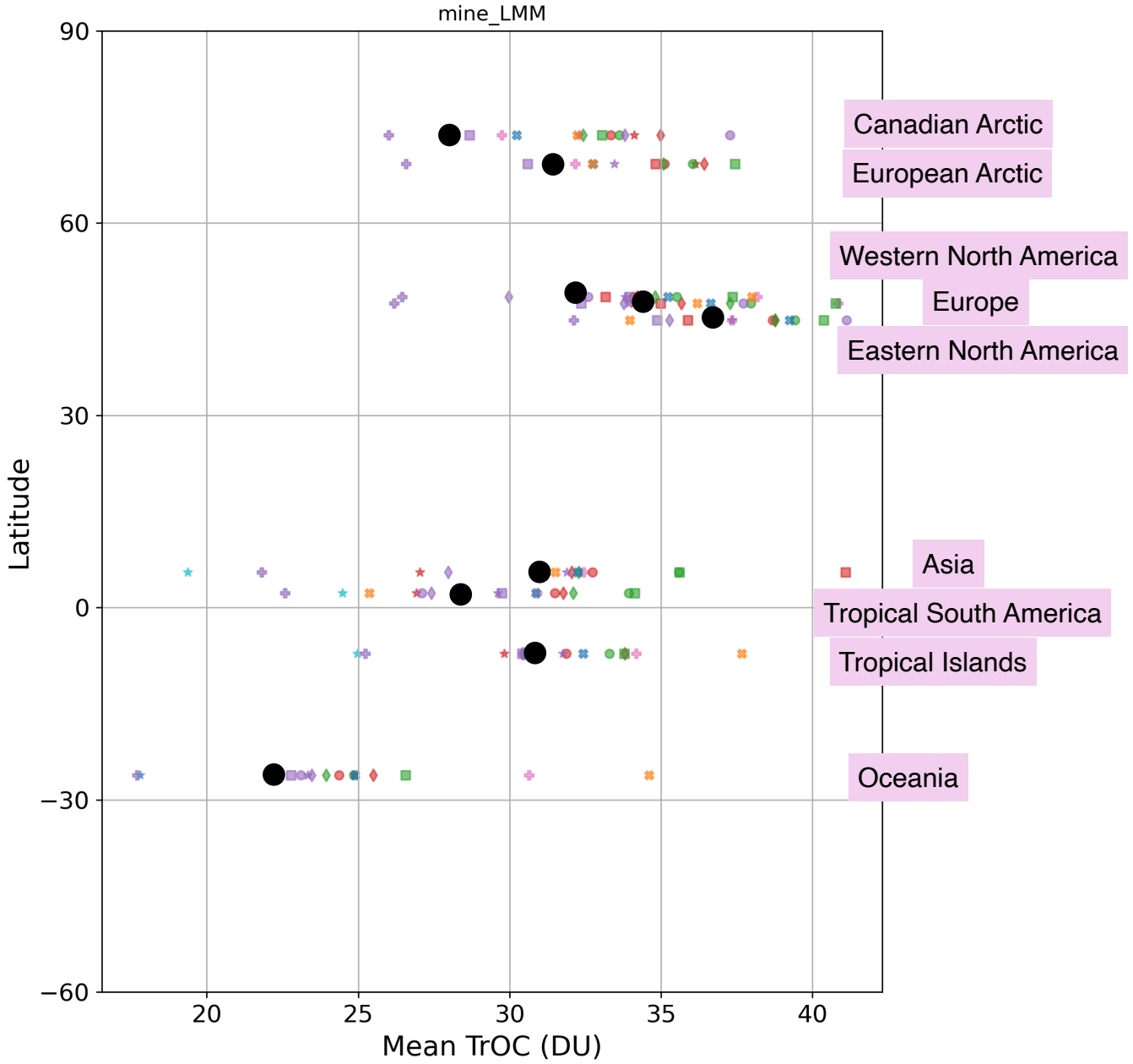
- Provide more robust assessment of the ozone distributions

Present day (2018-2022) TOC mean state

!!! Preliminary !!!

TOAR tropospheric ozone assessment report

Comparison with sonde

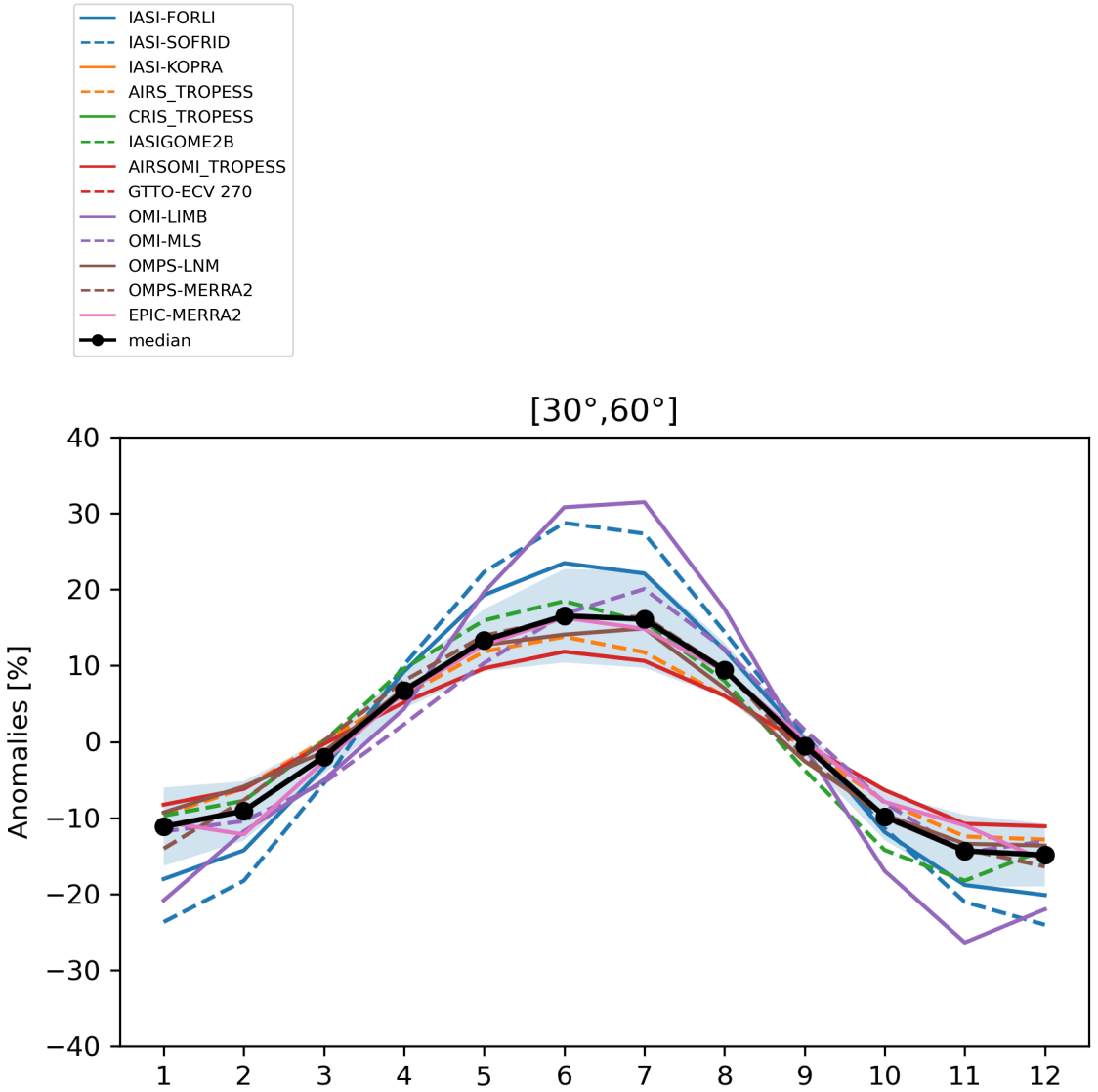


- GTTO-ECV 270
- TROPOMI
- IASI-FORLI
- IASI-SOFRID
- IASI-KOPRA
- IASIGOME2B
- AIRS_TROPESS
- CRIS_TROPESS
- AIRSOMI_TROPESS
- OMI-MLS
- OMPS-LNM
- OMPS-MERRA2
- EPIC-MERRA2
- OMI-LIMB
- Sondes
- CAMS
- TCR2

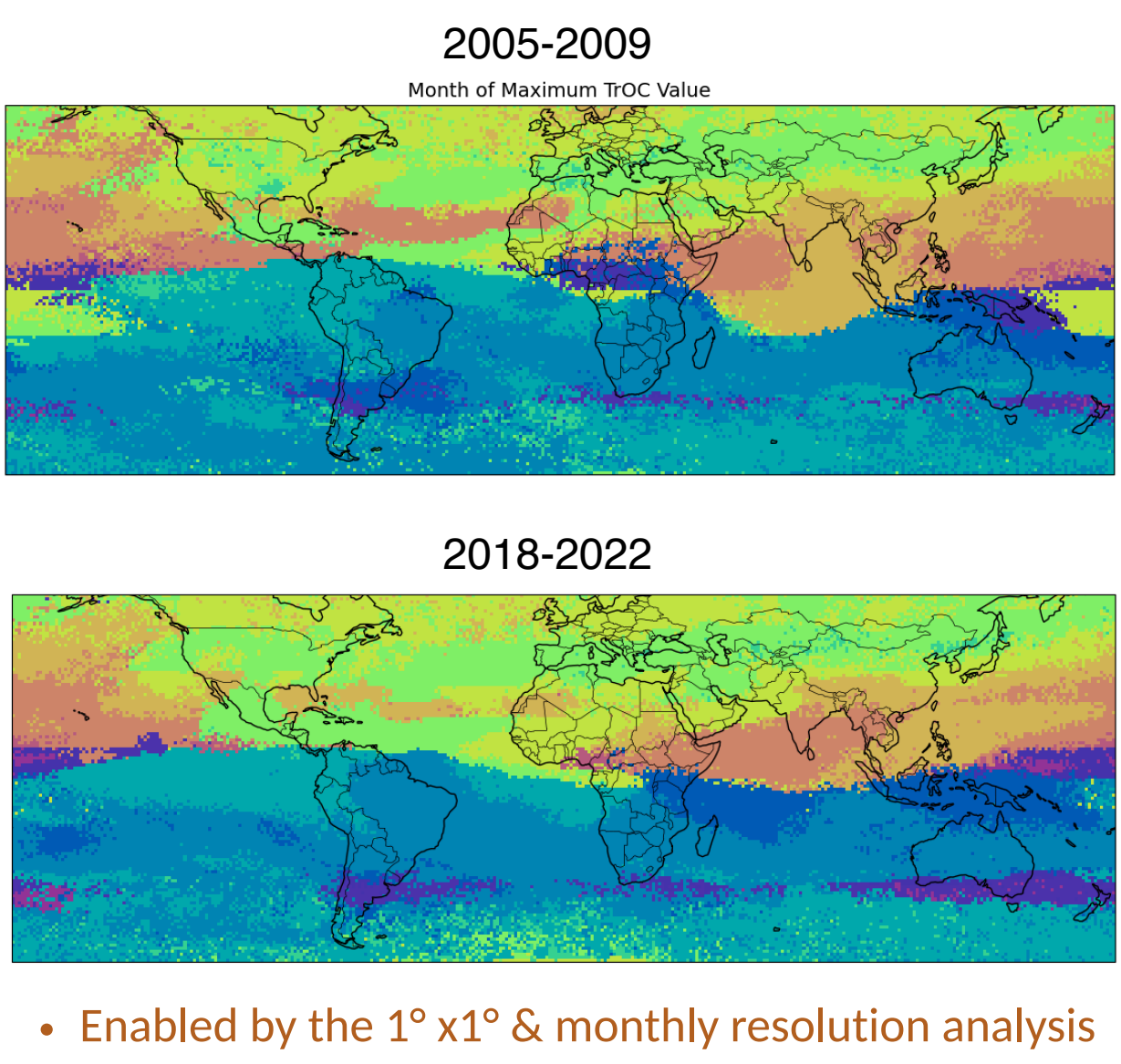
Present day (2018-2022) Seasonal cycle

!!! Preliminary !!!

TOAR tropospheric ozone assessment report



Month of maximum TOC value



- Enabled by the 1° x1° & monthly resolution analysis

Independence of satellite data records

!!! Preliminary !!!

TOAR tropospheric ozone assessment report

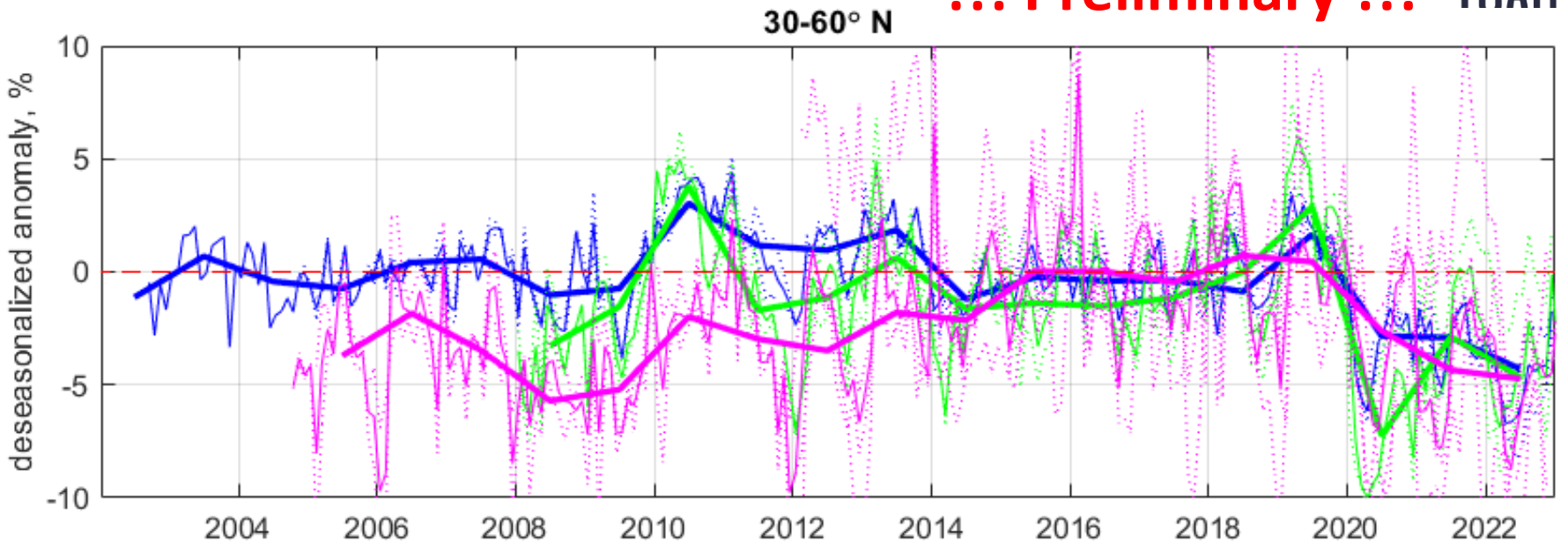
- A careful assessment of each product is essential for long-term trend analysis
- 20+ data records were considered, but not all are truly independent.
- Ensemble approaches to combine (a selection of) satellite tropospheric ozone data records.

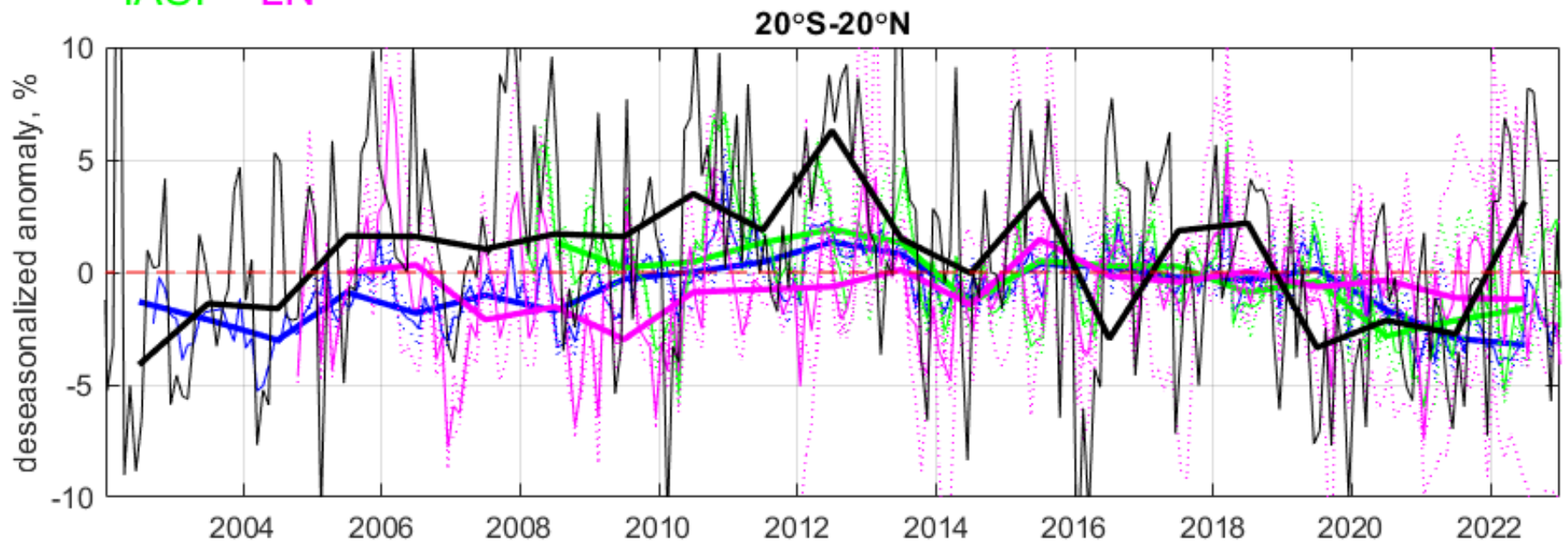
Group	CDRs	similar	different
1	GOP-ECV, TROPOMI	GOME-type sensor	sensor, L2
2	AIRS, AIRS-OMI	L2 TROPESS, AIRS	spectral
3	IASI-FORLI, IASI-SOFRID, IASI-GOME2B	IASI	sensors, L2
4	OMI-MLS, OMI-LIMB	OMI total O3	sensors, total/strato O3
5	OMPS-LNM, OMPS-MERRA2, EPIC-MERRA2	OMPS total O3, MERRA2 strato O3	sensors, total/strato O3

Long-term changes

!!! Preliminary !!!

TROPESS CCD
IASI LN



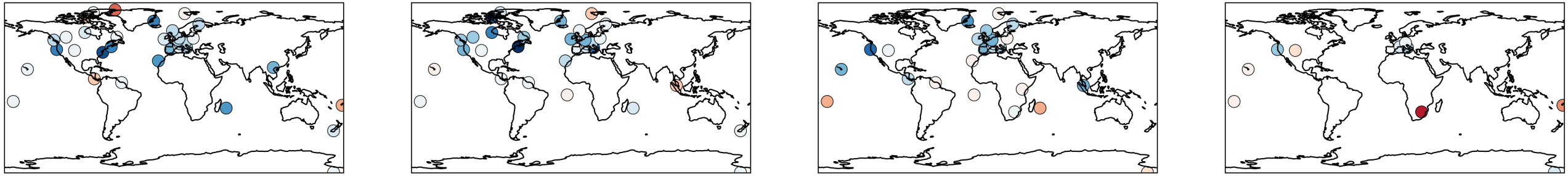


Impact of COVID lockdown and recovery (2020 – 2023): May-Jun

!!! Preliminary !!!

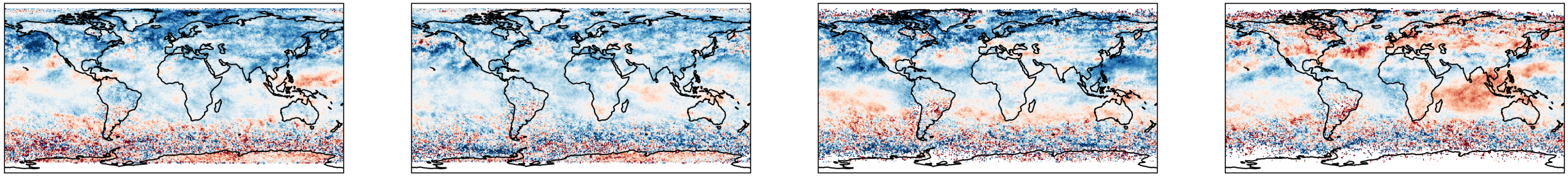
Ozonesonde

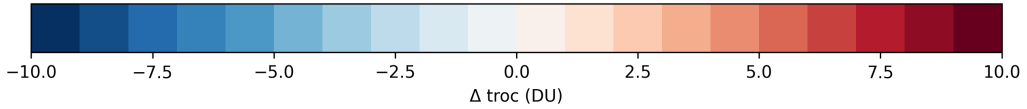
2020 2021 2022 2023



IASI-GOME2

2020 2021 2022 2023





Conclusions

There is very clear progress since TOAR I (2018)

- **Better satellite observations** : more data sets, more complementary, longer data sets, higher-quality data sets, higher resolution data sets, harmonised data sets
- This allows ensemble approach for all parameters and more complete characterisation of uncertainty (TOAR I: all results were for single satellite records)
- There is **much improved agreement** between satellite observations : present-day mean state (2018-2022) and long-term changes are more robust and better constrained
- **Improved resolution** : global maps at 1° (instead of 5°), seasonal cycle at monthly level (instead of seasonal)
- **Improved coverage** : true global average (instead of near-global 60°S-60°N)

These are excellent achievements by CEOS and the wider EO communities.

Recommendations

Finalise TOAR II assessment papers (see talk H. Worden)

- Results reviewed and ready by end 2025.
- Published by end 2026 (Philos. Trans. R. Soc. A).

Recommendations to CEOS / data providers by TOAR II satellite assessment team

- Satellite data continuity is paramount : natural variability and human-induced variability (lockdown) hide the small and non-linear long-term changes, data gaps will complicate robust assessments.
- Preserve independence between satellite records :
  - The upcoming loss of Aura MLS will impact the quality of the products derived limb-nadir matching considerably → the continuity of stable densely sampled limb profile measurements are vital !
  - Don't correct satellite using ground-based data unless really unavoidable
- Coordinate / ensure that sufficient metadata is provided to users such that harmonisation can be done.
- Explore capabilities of GEO sensors to characterise the tropospheric ozone diurnal cycle (if any), a possible source of bias between data records.
- Scientific interpretation in collaboration with other assessments is key to ensuring the robustness of satellite records.