The Tropospheric Ozone Assessment Report:

Quantifying the global distribution and trends of tropospheric ozone using satellite instruments

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Please note:

All figures showing TOAR analyses are preliminary and therefore should not be cited.

Final figures will be available after the report has been accepted for publication by the peer-reviewed journal, *Elementa: Science of the Anthropocene*.

Tropospheric Ozone Assessment Report (TOAR)

Global metrics for climate change, human health and crop/ecosystem research

Mission:
To provide the research community with an up-to-date scientific assessment of tropospheric ozone's global distribution and trends from the surface to the tropopause.

Deliverables:

1) The first tropospheric ozone assessment report based on all available surface observations, the peer-reviewed literature and new analyses.
2) A database containing ozone exposure and dose metrics at thousands of measurement sites around the world, freely accessible for research on the global-scale impact of ozone on climate, human health and crop/ecosystem productivity.

http://www.igacproject.org/activities/TOAR

Stakeholders:

WMO GAW World Health Organization NOAA LRTAP Task Force on Hemispheric Transport of Air Pollution

TOAR Organization

TOAR is a science effort initiated by IGAC, and developed by an international team of experts.

TOAR receives financial and logistical support from:

- IGAC
- Forschungszentrum Jülich
- The World Meteorological Organization
- US National Oceanic and Atmospheric Administration (NOAA)

TOAR Steering Committee Members:

Owen R. Cooper (Chair)
CIRES U. of Colorado/NOAA Earth System Research Laboratory, Boulder, USA

Aijun Ding
Institute for Climate and Global Change Research, Nanjing University, Nanjing, China

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University of York, UK

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David Tarasick
Air Quality Research Division, Environment Canada, Downsview, Canada

Anne Thompson
NASA Goddard Space Flight Center, Greenbelt, USA

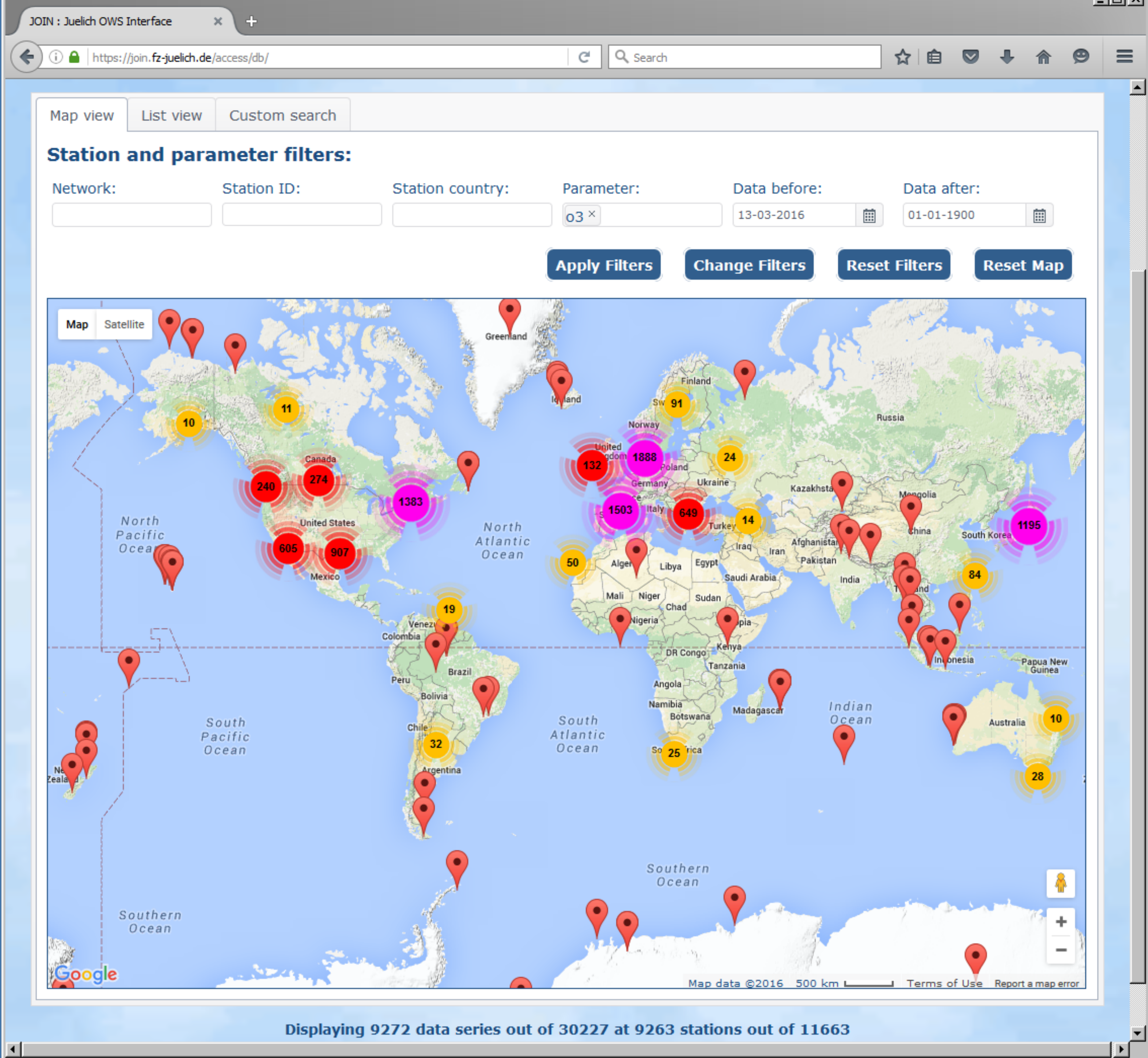
TOAR members: 220+ scientists from 36 nations, representing research on all 7 continents

TOAR Database

TOAR has built the world's largest database of ozone metrics.

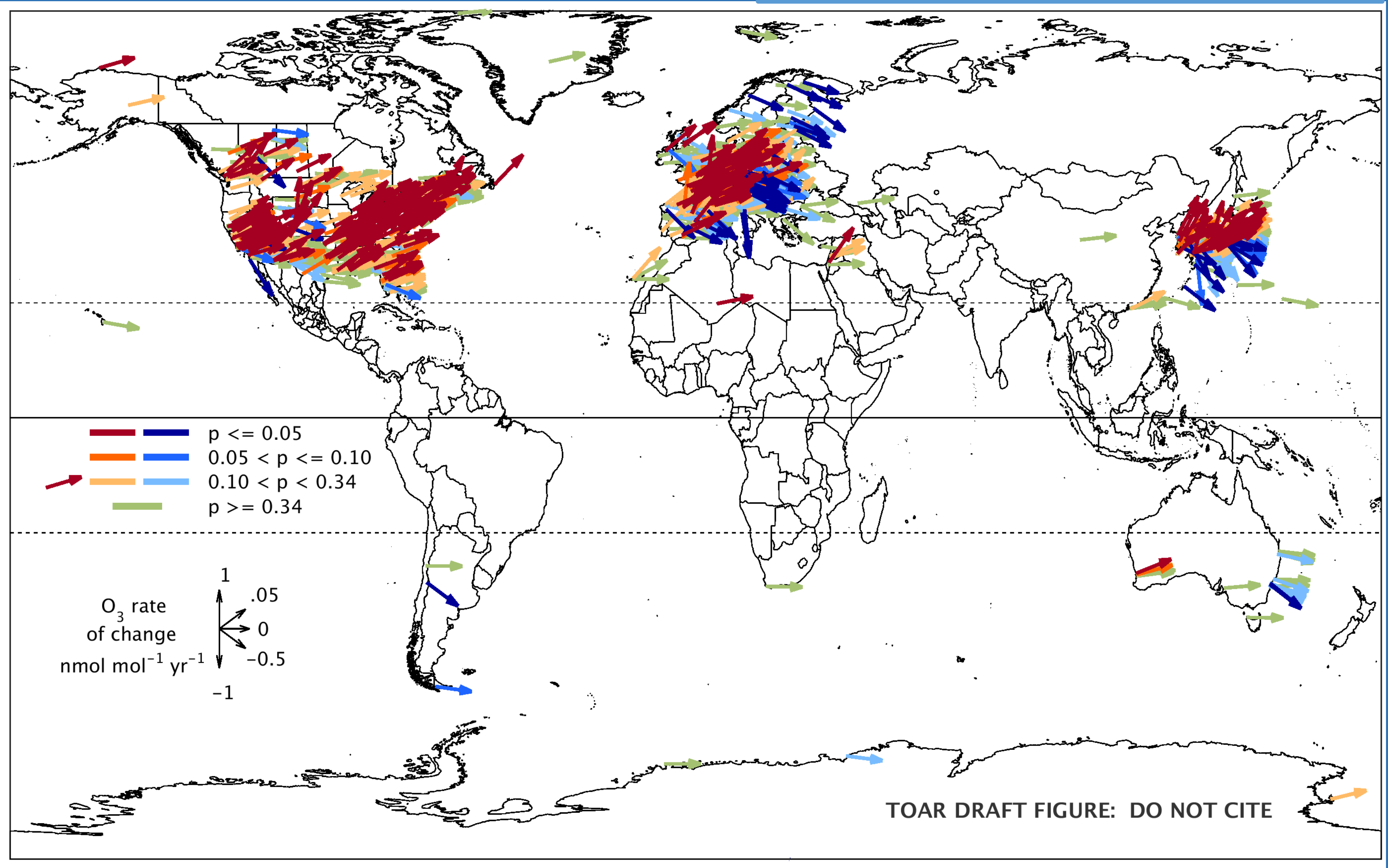
Developed by Forschungszentrum Jülich: ***Martin Schultz***, Snehal Waychal, Sabine Schröder, Olga Lyapina and Michael Decker

Ozone observations from over 9000 monitoring sites in dozens of countries



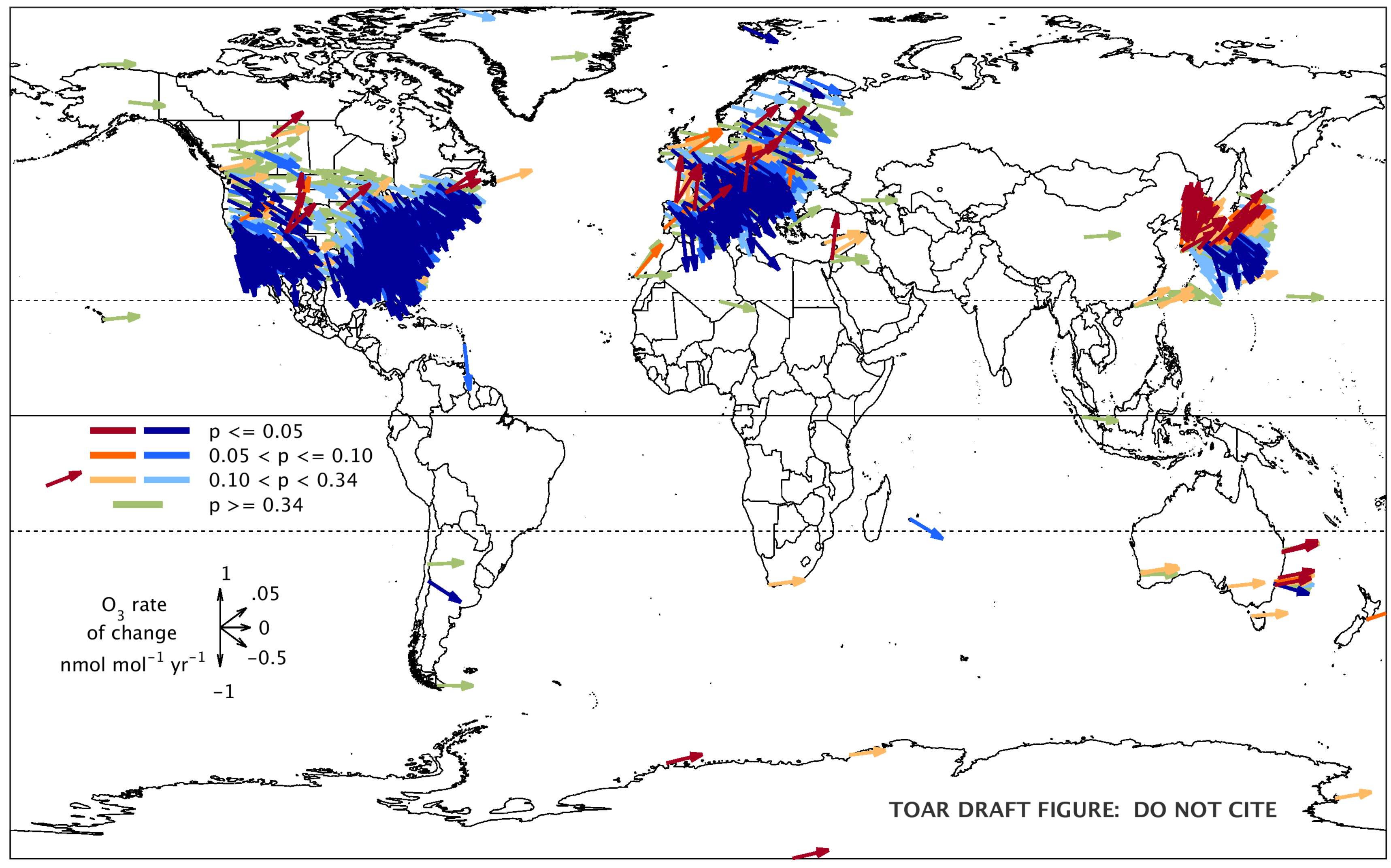
Increase of daytime average ozone between 2000-2014 in NH winter

1374 non-urban sites in DJF

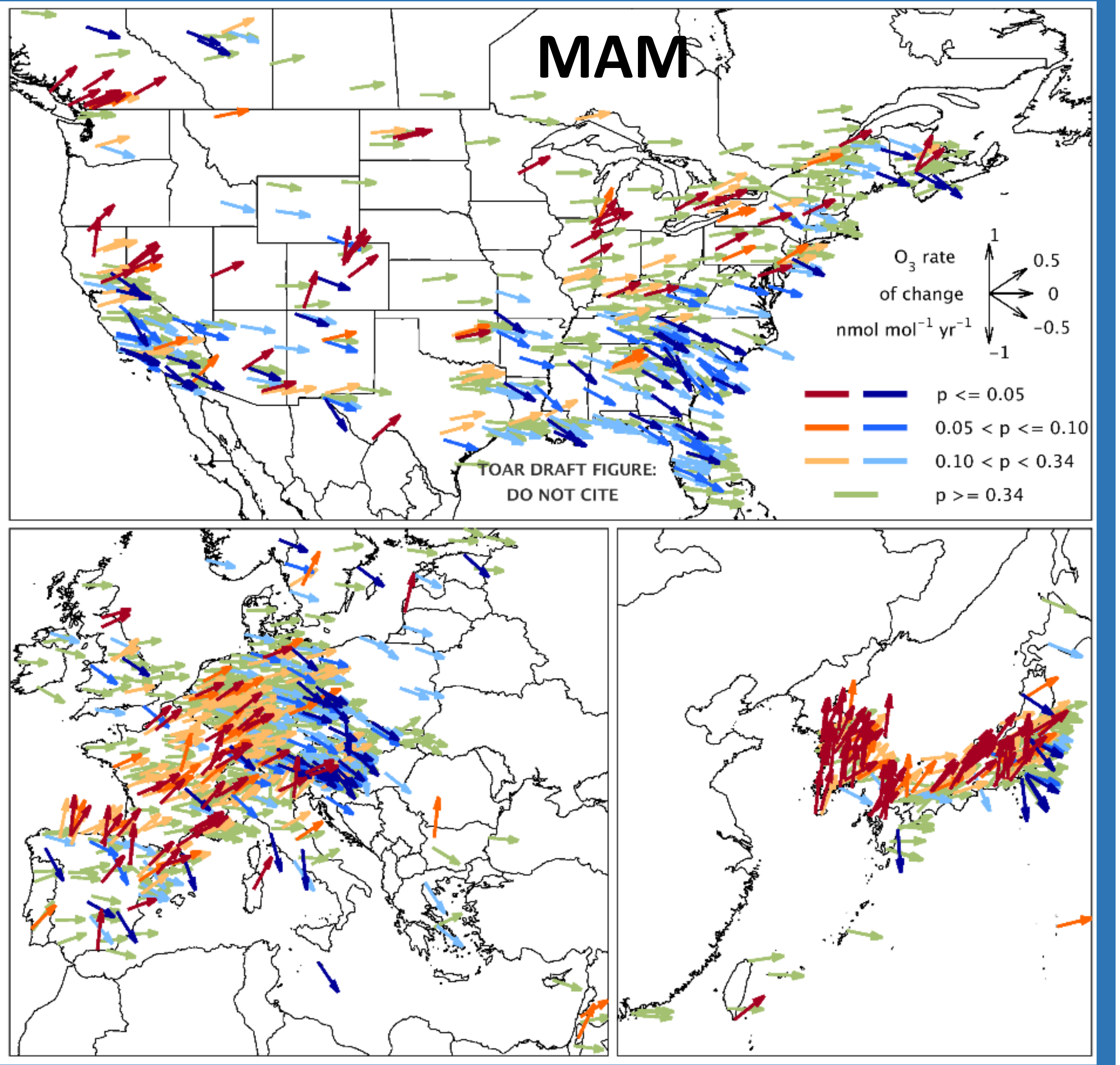


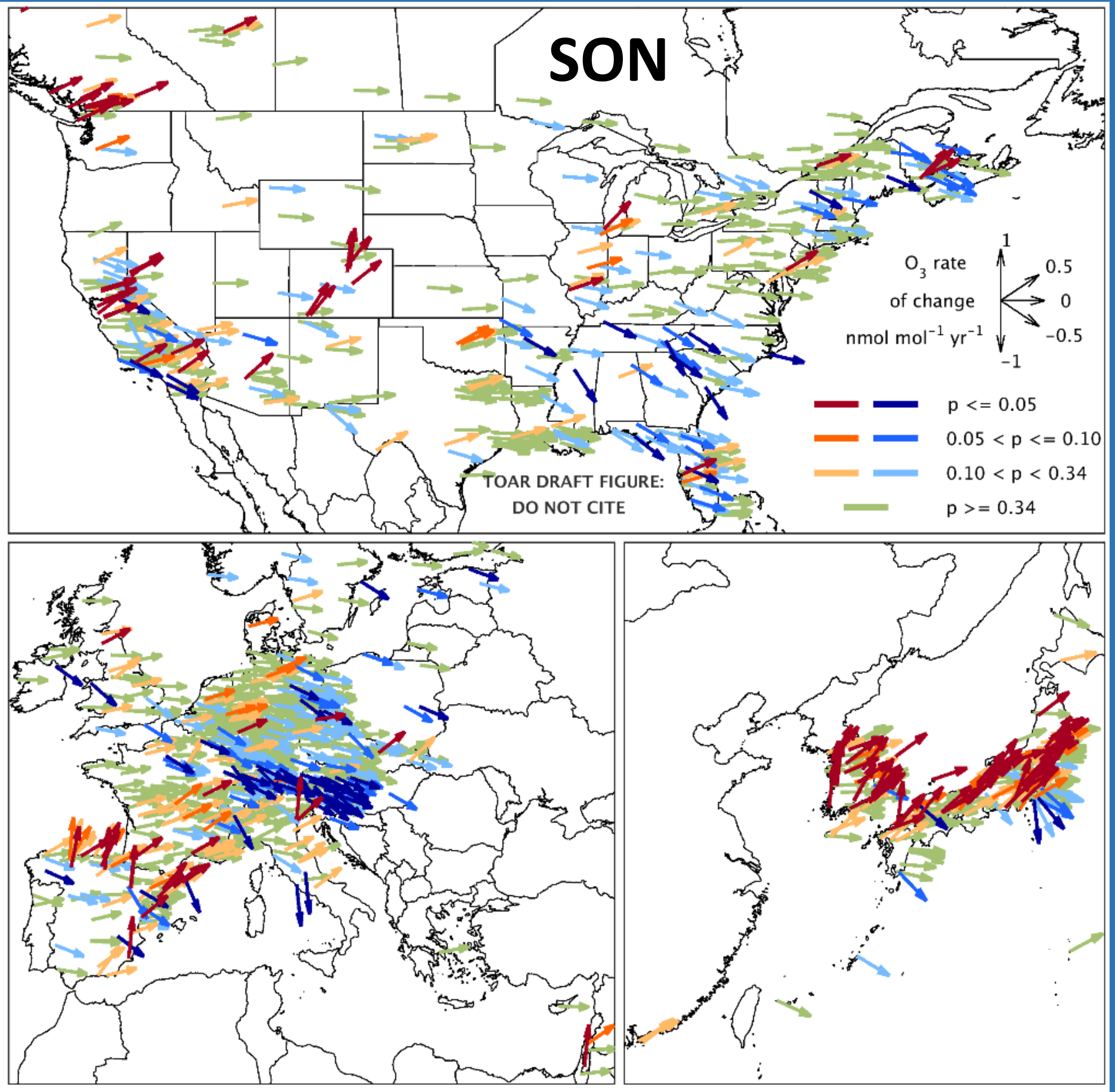
Decrease of daytime average ozone between 2000-2014 in NH summer

1784 non-urban sites in JJA



Increase of daytime average ozone between 2000-2014 all seasons over East Asia





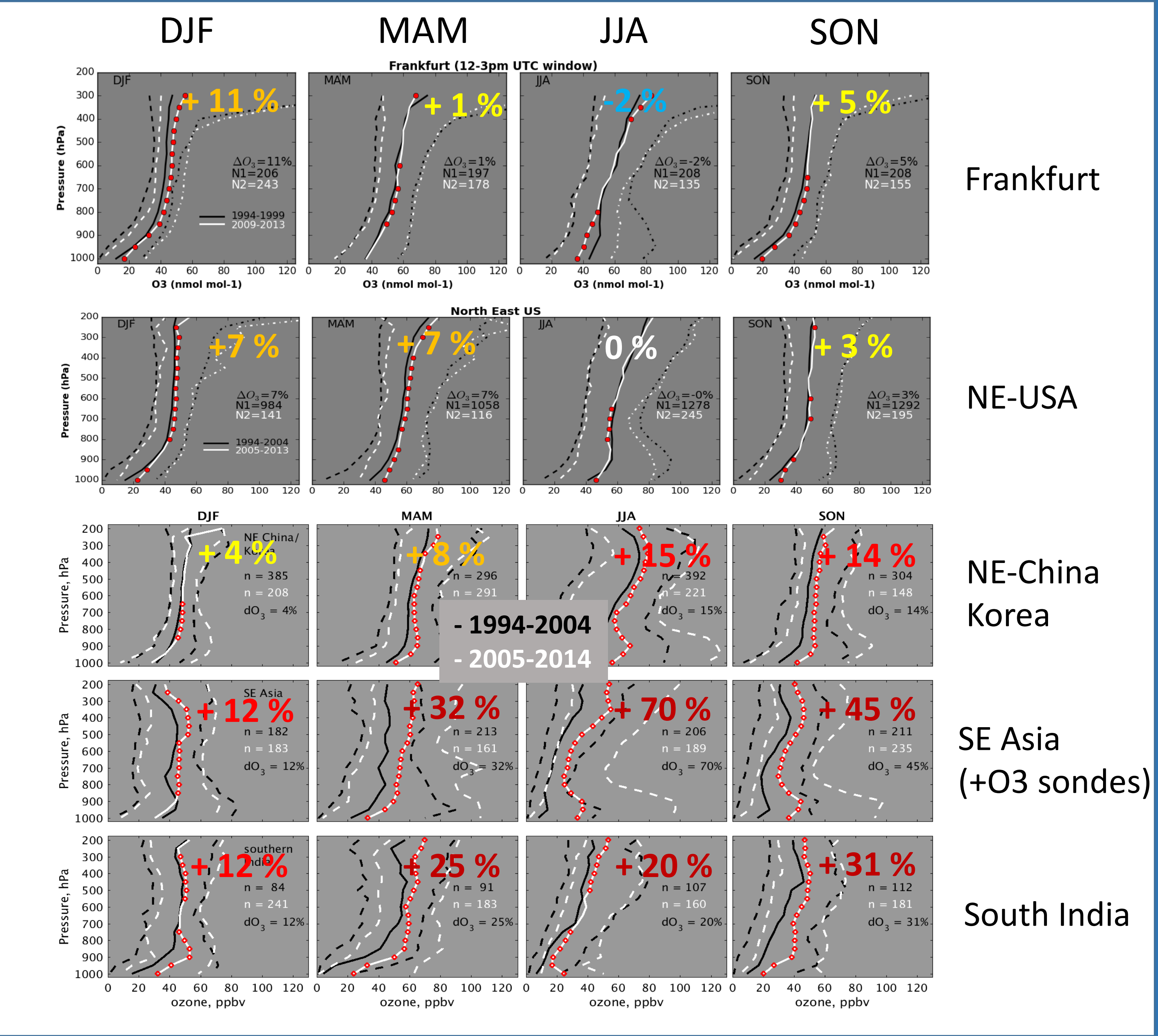
IAGOS Ozone profiles

W Europe and NE USA:

- significative increase in winter
- nul to negative trend in summer

Asia:

- increase for all seasons and regions
- largest increases (up to 70%) from MAM to SON



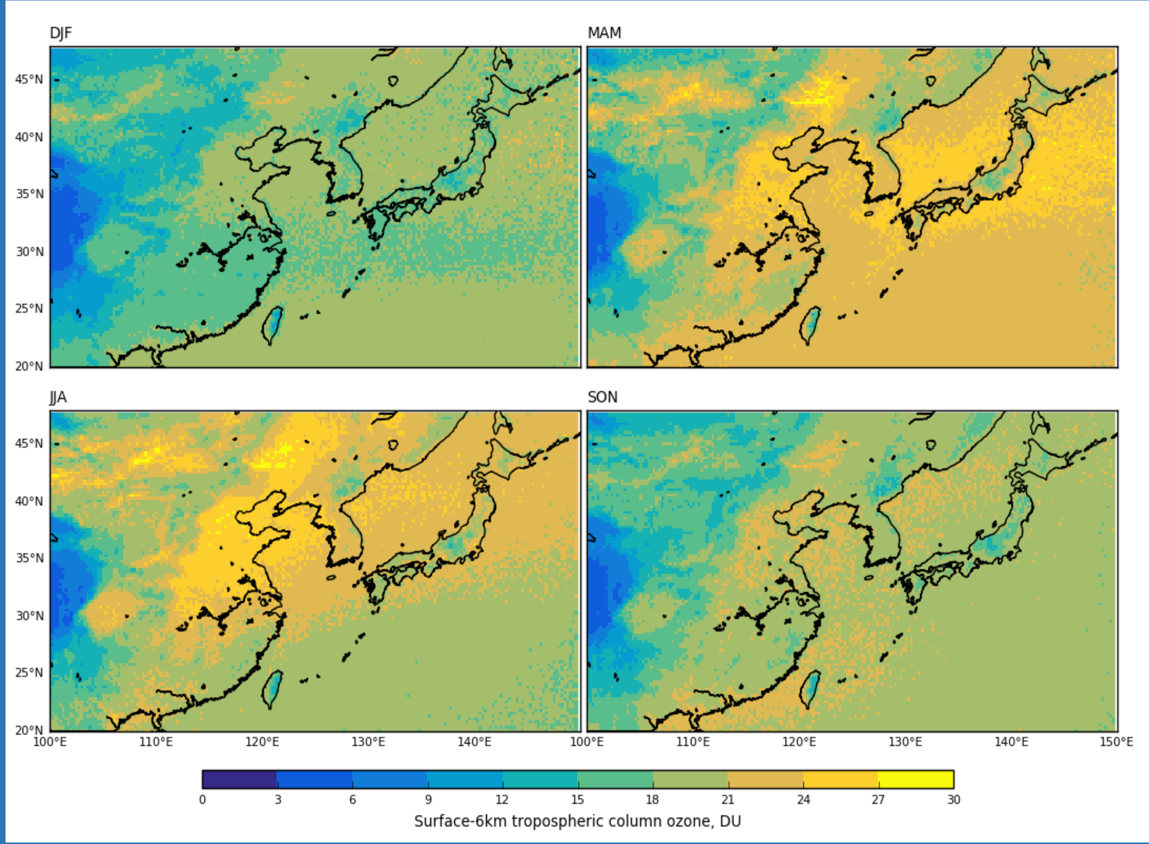
Tropospheric Column Ozone (TCO) TOAR satellite products

Product name and institution	**Horizontal resolution**	**Horizontal coverage**	**Vertical range (tropopause definition)**	**Temporal resolution/time of day**	**Record length**
OMI/MLS *NASA GSFC*	1° × 1.25°	60°S - 60°N	Surface to tropopause (WMO 2 K km^{-1} lapse-rate)	Monthly/ Seasonal 13:45	2004 – 2016, continuing
GOME & OMI *Harvard-Smithsonian Center for Astrophysics (HSCfA)*	1° × 1.25°	60°S - 60°N	Surface to tropopause (WMO 2 K km^{-1} lapse-rate)	Monthly/Seasonal OMI: 13:45 GOME: ??:??	1995 – 2015, continuing
OMI-RAL *Rutherford Appleton Laboratory (RAL)*	5°x5°	60°S - 60°N	Surface to tropopause (WMO 2 K km^{-1} lapse-rate)	Monthly/Seasonal 13h45	1995-2016, continuing
IASI-LISA *LISA*	Averaged over 0.25°x0.25° grids	Regional (Europe, Asia)	Surface-6 and 6-12 km	Seasonal 9:30	2008-2014, continuing
IASI+GOME2 *LISA*	5°x 5°	Regional (Europe, Asia) Global since 2017	Surface to 3 km, and 3-9 km	Monthly/ seasonal 9:30	2009-2010
IASI - FORLI *ULB and LATMOS/IPSL*	12 km footprint Averaged over 5°x 5° grids	90°S-90°N	Surface to tropopause (WMO 2 K km^{-1} lapse-rate)	Seasonal 9:30	2008 – 2016
IASI - SOFRID *LA/OMP - Toulouse*	12 km footprint Averaged over 5°x 5° grids	80°S-80°N	Surface to tropopause (WMO 2 K km^{-1} lapse-rate)	Seasonal 9:30	2008 – 2015, continuing

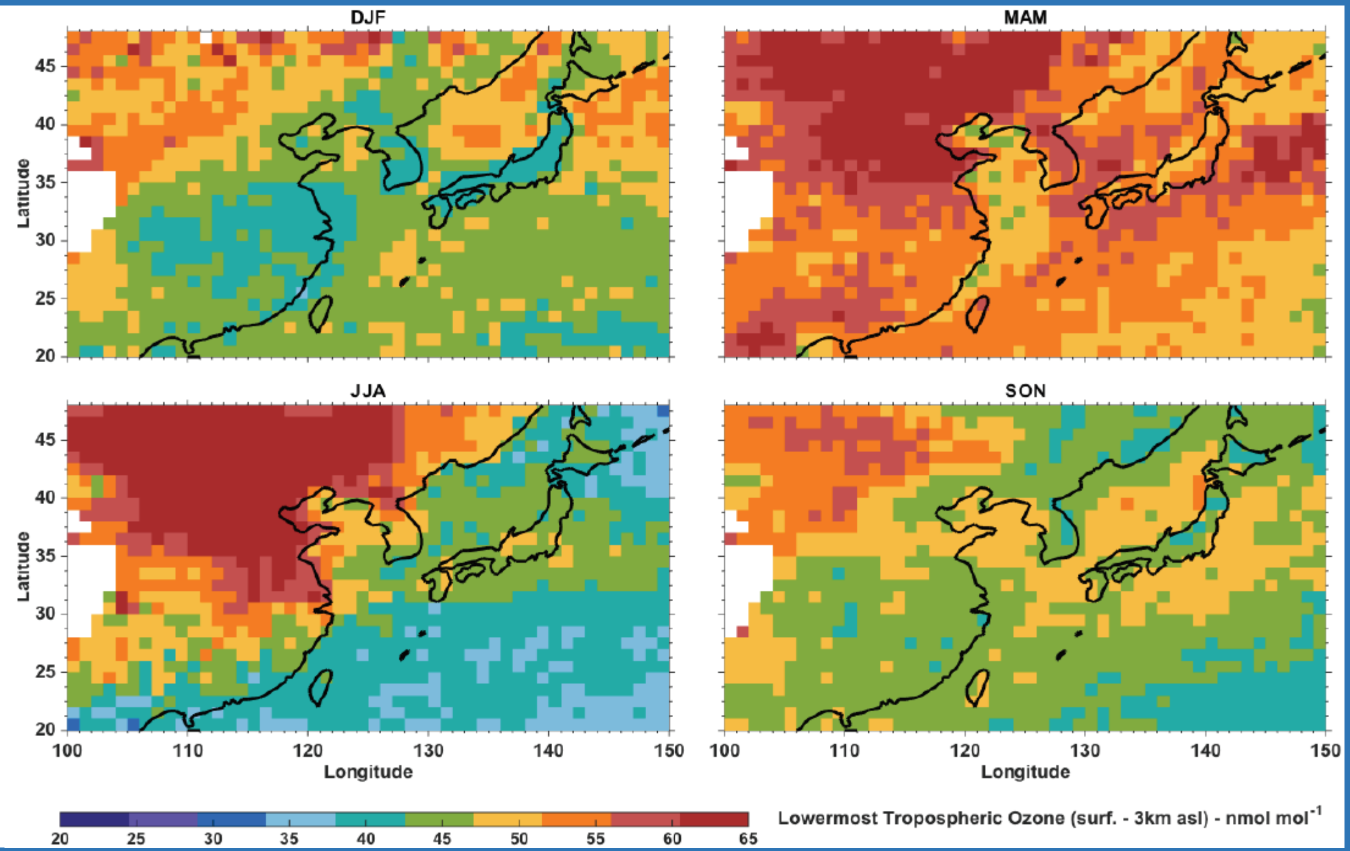
LISA IASI and IASI+GOME 2 tropospheric Ozone

⇒Increased sensitivity to lower troposphere
⇒ no global retrievals on the whole IASI period for trends calculation

Surface-6 km **IASI** partial ozone columns [DU] over East Asia (2010-2014).



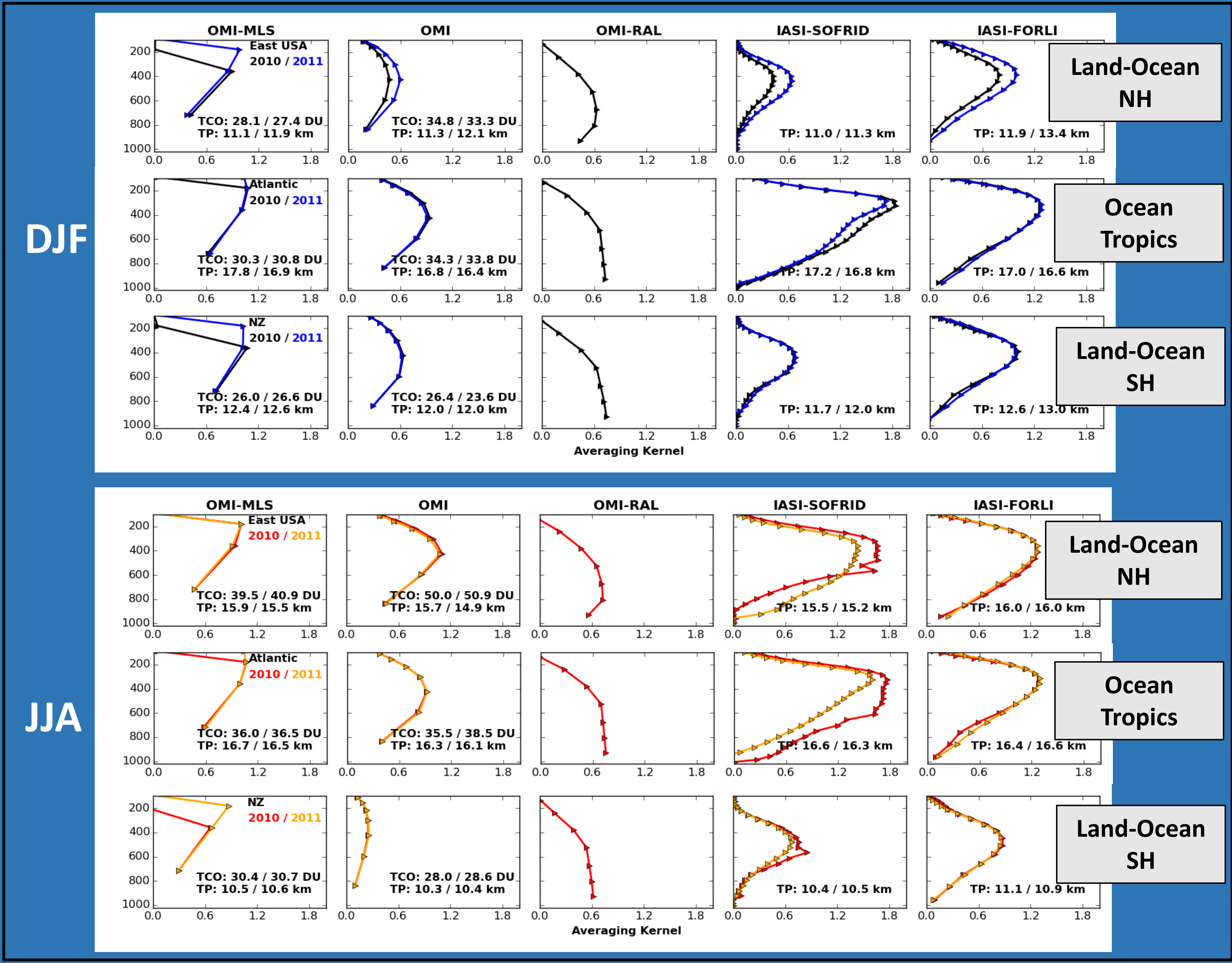
Surface-3 km **IASI+GOME2** partial column ozone over East Asia (2010) (global retrievals since 2017 /AERIS data centre).



TCO Averaging Kernels
for 5 global satellite products

OMI and IASI
- Higher sensitivity in summer than in winter
- sensitivity 200-800 hPa
- little 2010-2011 differences

OMI-RAL
- Sensitivity down to the surface
- no winter-summer difference



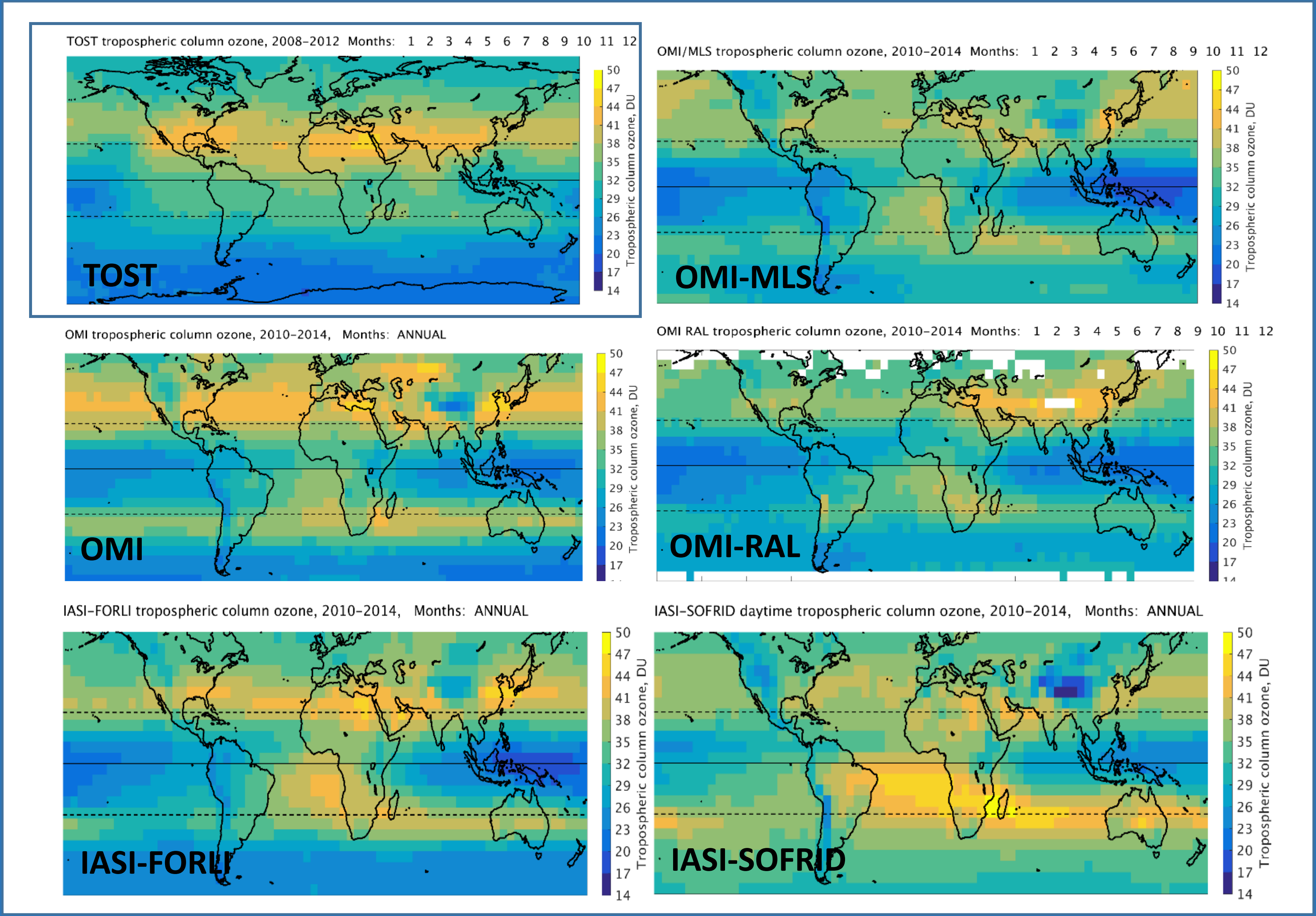
TCO annual means (DU) from TOST (sondes) and Satellites (2010-2014)

Main TCO features captured by 6 products

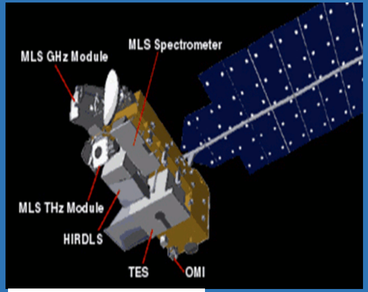
-high TCO northern mid-lat land/oceans

- tropical wave-1 with South-Atlantic max and central Pacific min.

- high TCO from Africa to Australia over Indian Ocean (less pronounced in TOST)



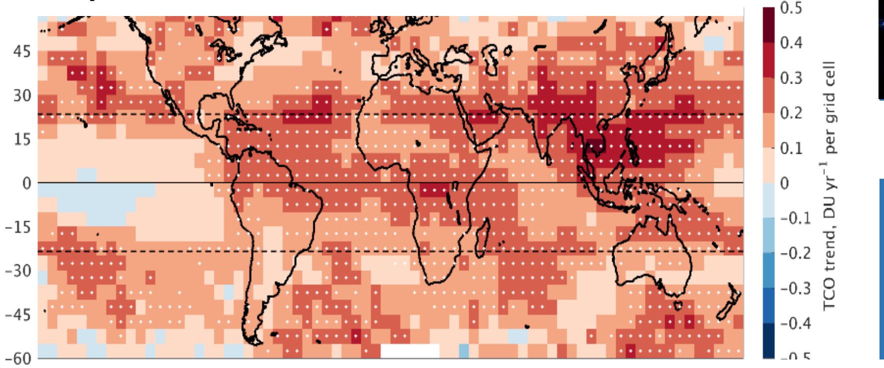
TCO trends from Satellites : discrepancies

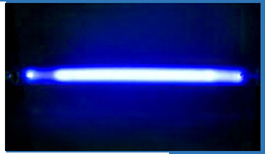


Satellite

3 retrievals from OMI

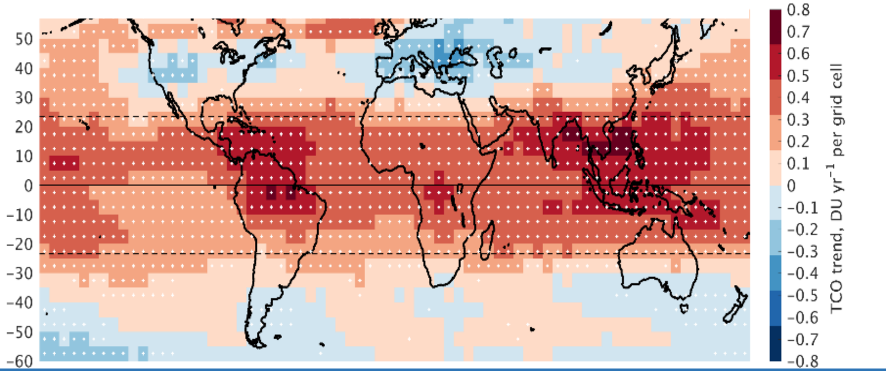
OMI/MLS 2005-2016



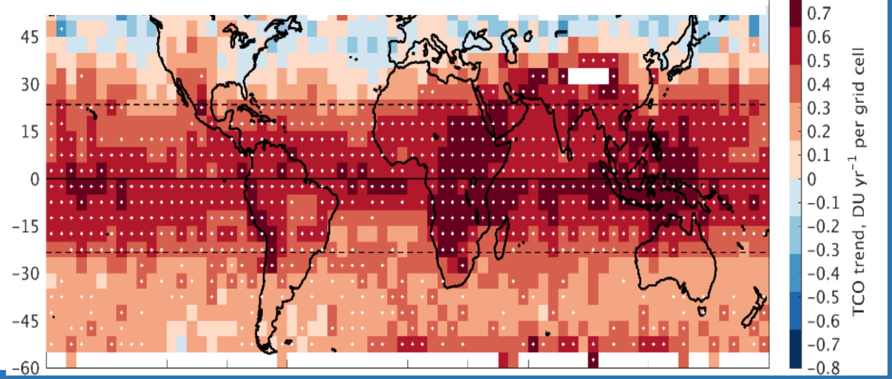


UV-vis

OMI 2005-2015

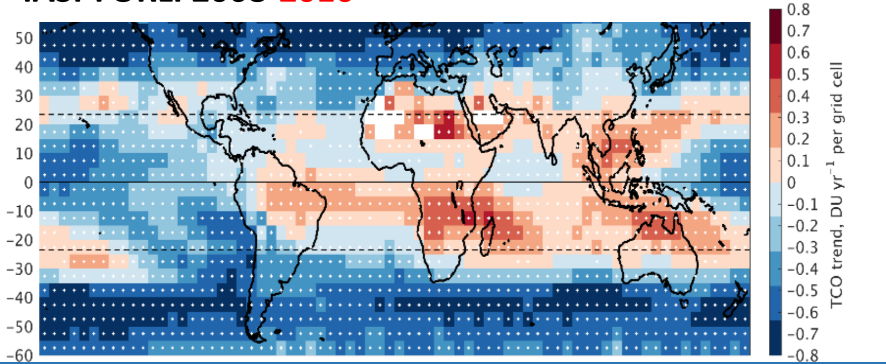


OMI-RAL 2005-2015

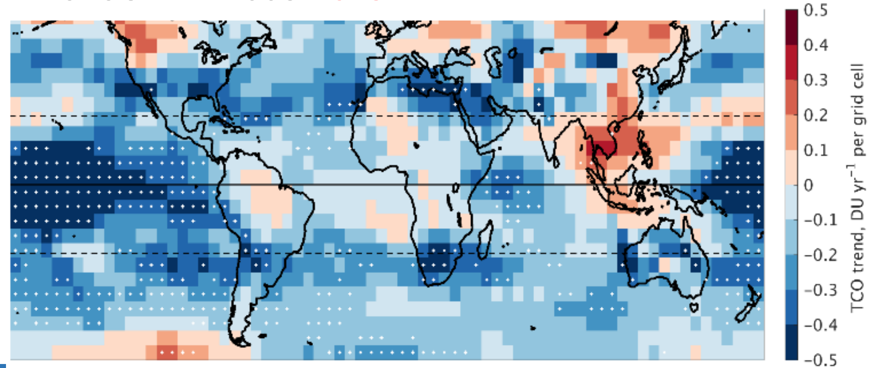


2 retrievals from IASI

IASI-FORLI 2008-2016



IASI-SOFRID 2008-2015



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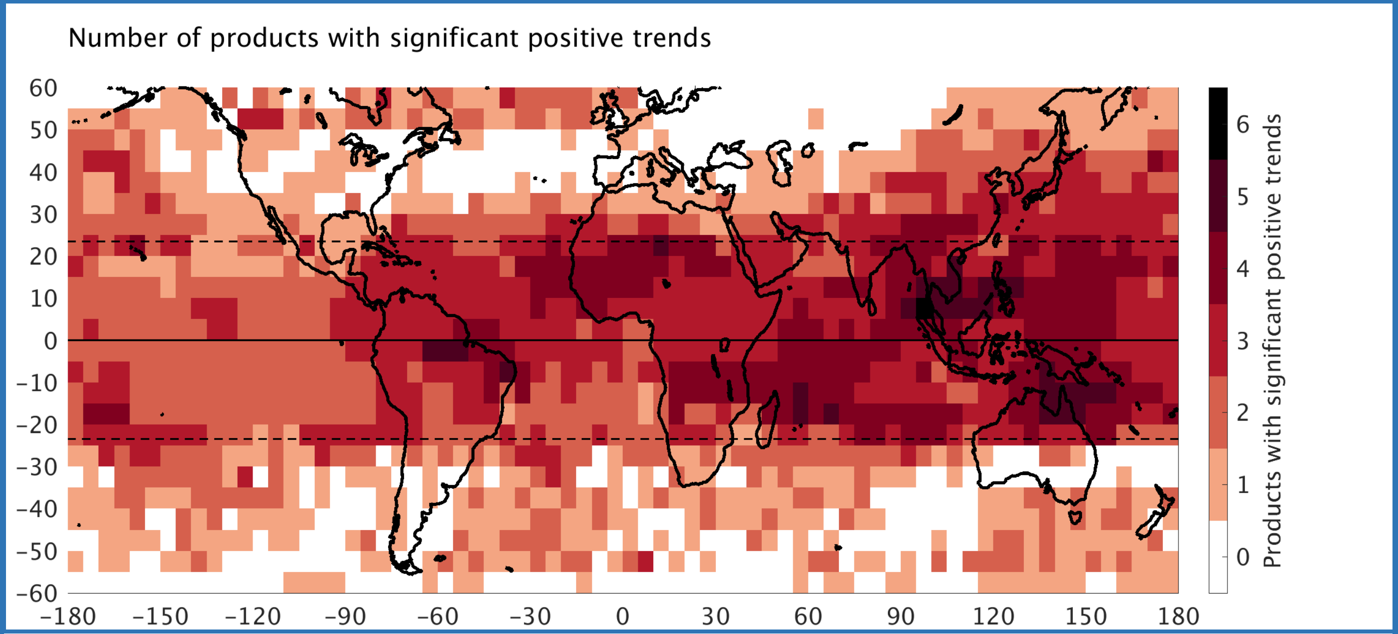
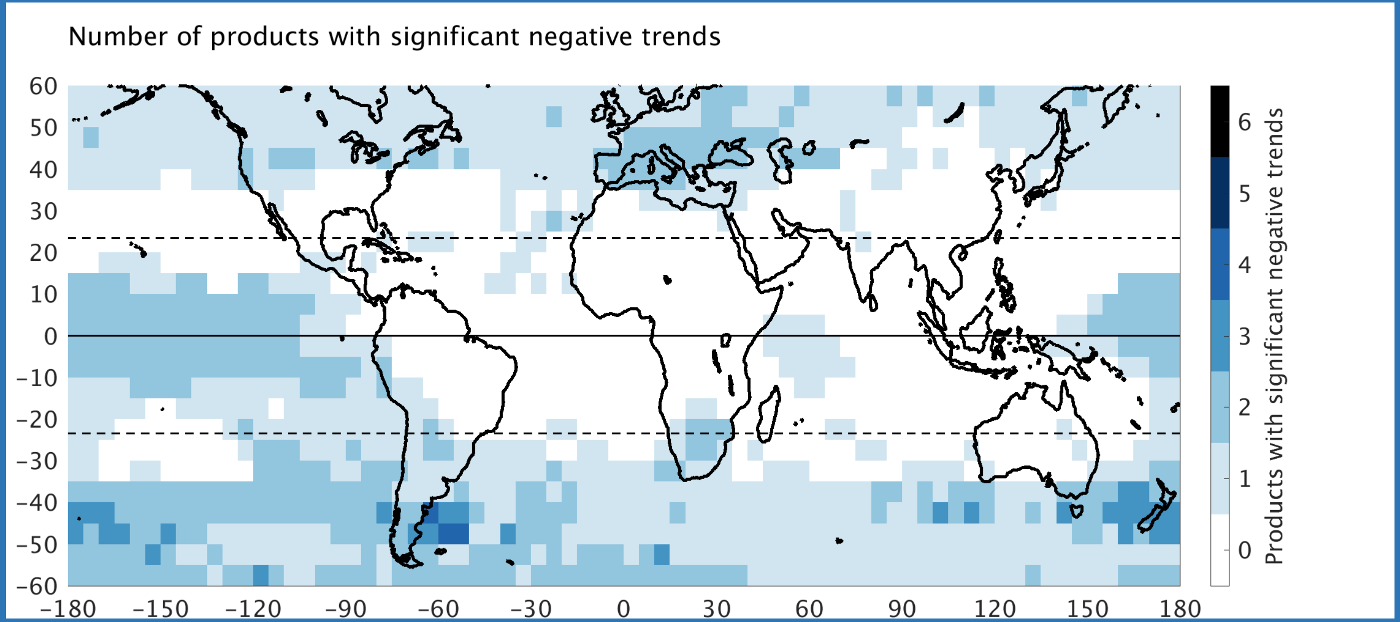
TCO from Satellites: agreement





Number of products with statistically significant

- **positive (red) trend**
- **negative (blue) trend**

Very new exciting result:

Ozone burden (2014-2016) from 5 satellite products:

296 Tg ± 4%

Tropospheric ozone burden trends

Seasonal variations consistently captured by 6 products

OMI

- Global increase = 1.5-2.8 Tg/yr
- NH and SH 0.3-1.8 Tg/yr

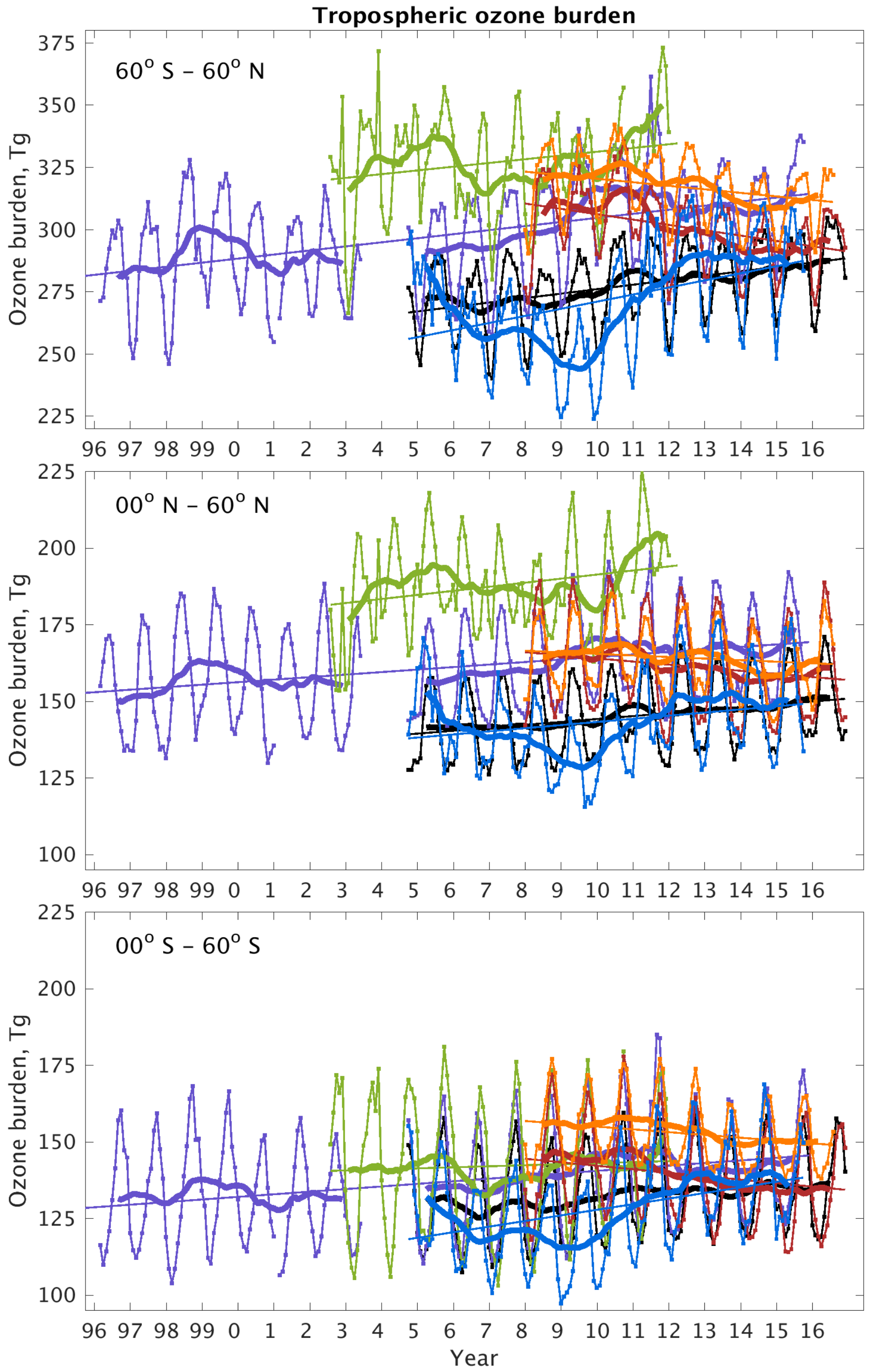
IASI

- Global decrease = 1.4-2.1 Tg/yr
- NH and SH 0.5-1 Tg/yr

Note:

Trends over different periods

Convergence over IASI period



60° S – 60° N

	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	-1.42 +/- 0.99	0.01
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

00° N – 60° N

	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	-0.51 +/- 0.86	0.24
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

00° S – 60° S

	change, Tg yr^{-1}	p-value
Black: OMI/MLS	0.83 +/- 0.64	0.01
Brown: IASI-FORLI	-1.14 +/- 1.14	0.05
Orange: IASI-SOFRID	-0.91 +/- 0.85	0.04
Purple: GOME/OMI	0.85 +/- 0.39	0.00
Blue: OMI-RAL	1.83 +/- 0.84	0.00
Green: SCIAMACHY	0.34 +/- 1.48	0.65

Conclusions:

1) NH surface data => significant seasonal trends with winter increase and summer decrease
2) NH IAGOS profiles => increase of tropospheric O3 with largest trends in Asia
3) Satellite data => 3 OMI and 2 IASI products

   - UV-Vis and TIR sensitive to mid-upper troposphere

   - OMI and OMI/MLS: global increase

   - IASI-SOFRID and FORLI: global decrease

   - OMI and IASI consistent tropical/Asian increase

   => different periods for GOME/OMI, OMI/MLS, IASI-SOFRID and IASI-FORLI but relative convergence for the IASI period (Ozone burden to +/-4% for 2014-2016)

Next steps:

1) Finish the assessment report and submit all 8 papers to *Elementa*
2) Release the database of ozone metrics to the general public in July 2017
3) Encourage human health, ecosystem and climate researchers to utilize the database for their impact studies.
4) Continue collaborative research to reconcile the trend differences between satellite products
5) Begin planning TOAR-II