TOAR
tropospheric ozone assessment report

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Long-term trends of tropospheric ozone over South and East Asia

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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.

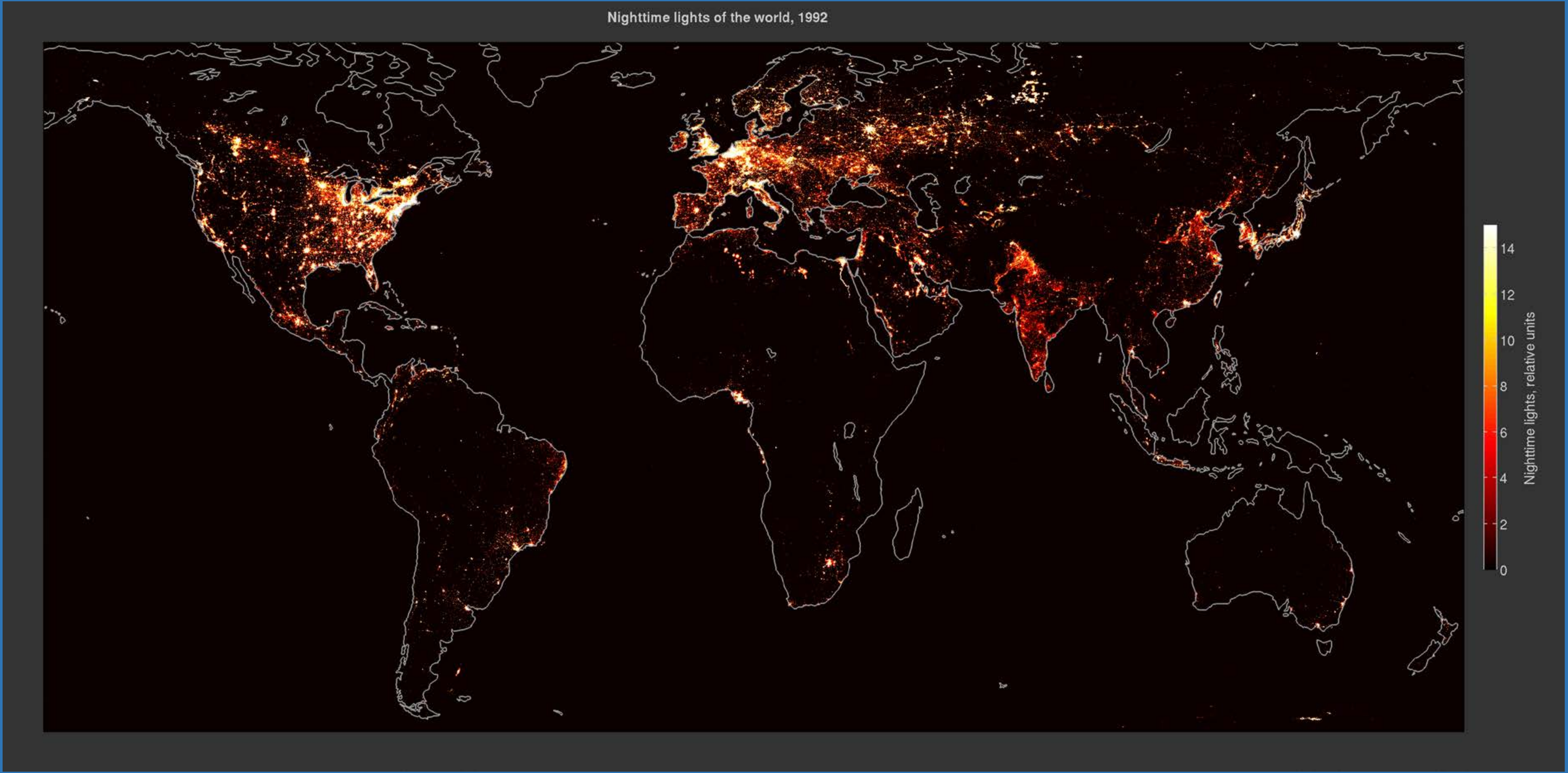
Deliverables:

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

Stakeholders:

Nighttime lights of the world in 1992

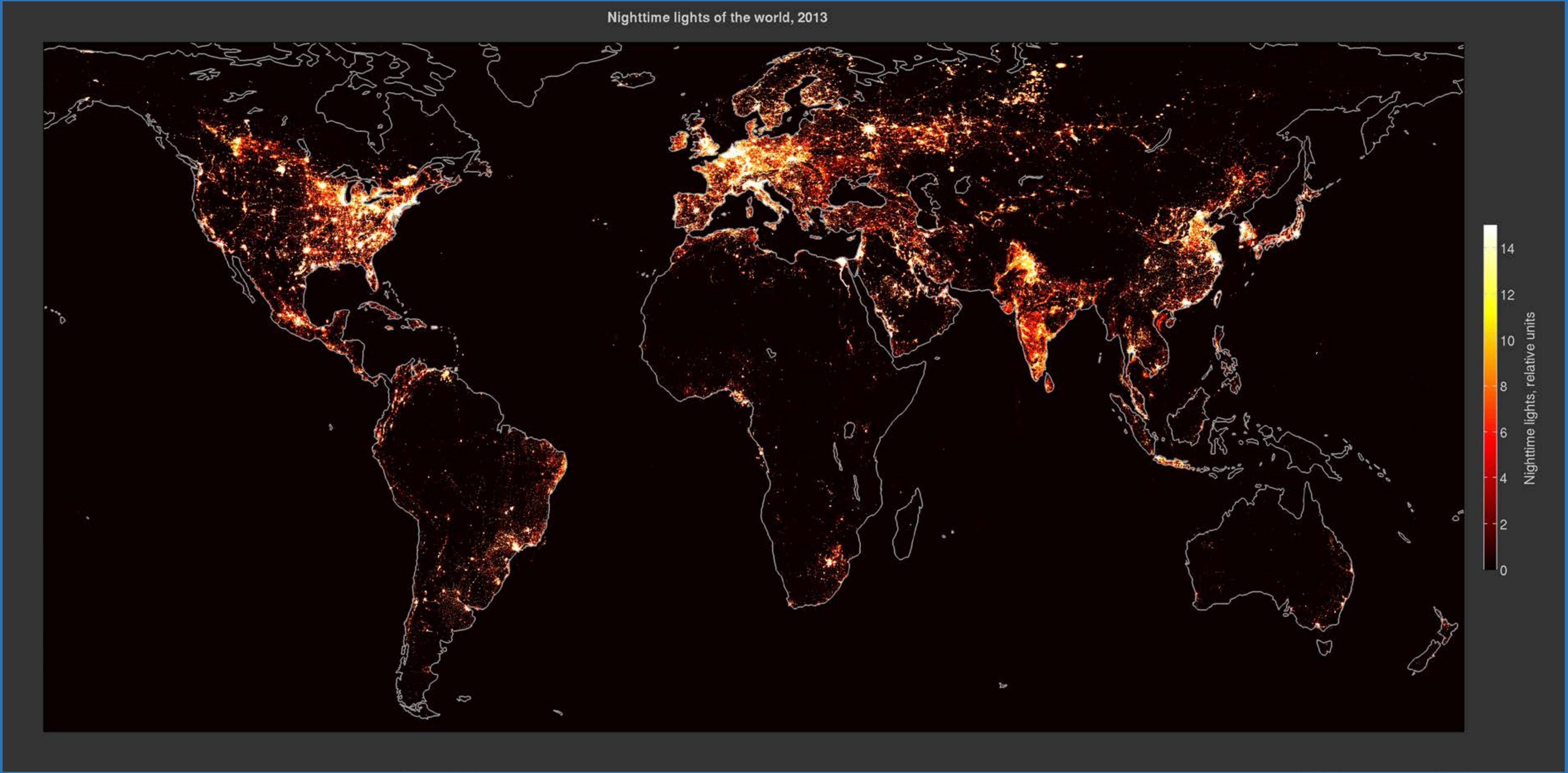
Global population (*United Nations*): 5.5 billion



DMSP-OLS nighttime lights (V4) detected by The Defense Meteorological Satellite Program: http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html
Data collected by US Air Force Weather Agency, processed by NOAA NGDC and plotted by Owen Cooper, CIRES, U. of Colorado/NOAA ESRL

Nighttime lights of the world in 2013

Global population (*United Nations*): 7.2 billion (30% increase)



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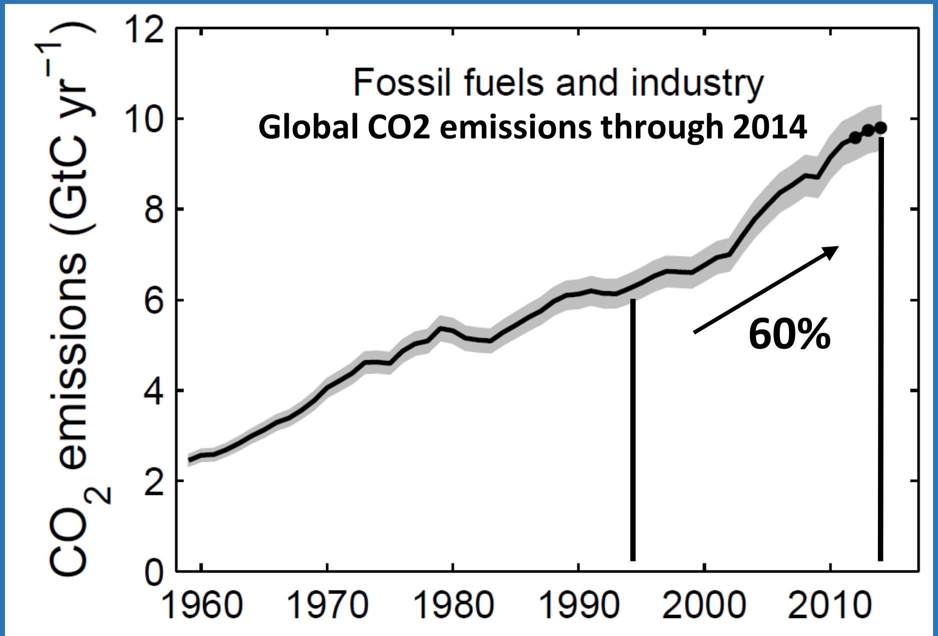
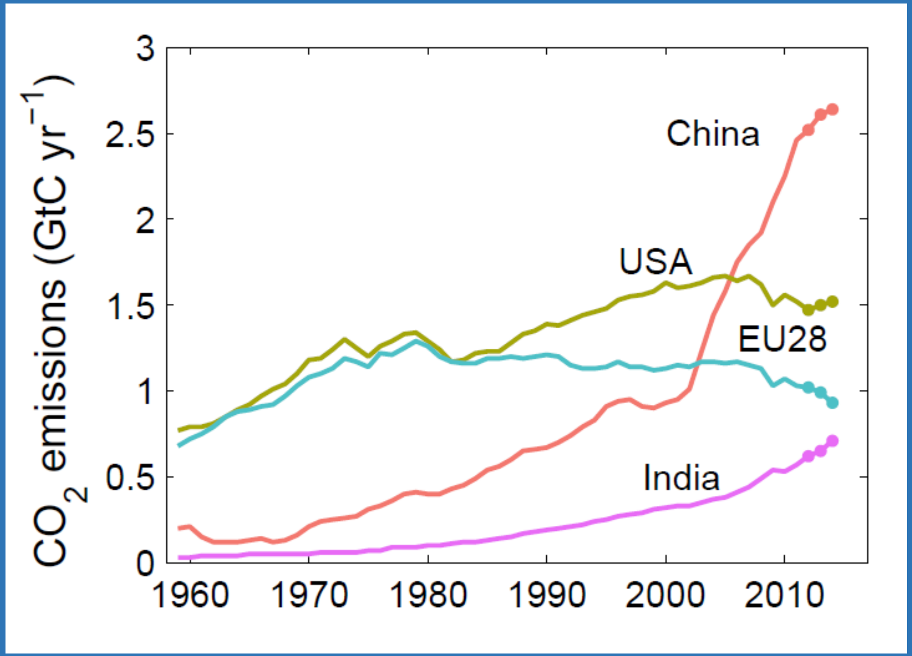
During 1994-2014 the global CO_2 emission rate from fossil fuels and industry increased by 60%.

Le Quéré et al., Global Carbon Budget 2015, Earth Syst. Sci. Data, 7, 349–396, 2015.



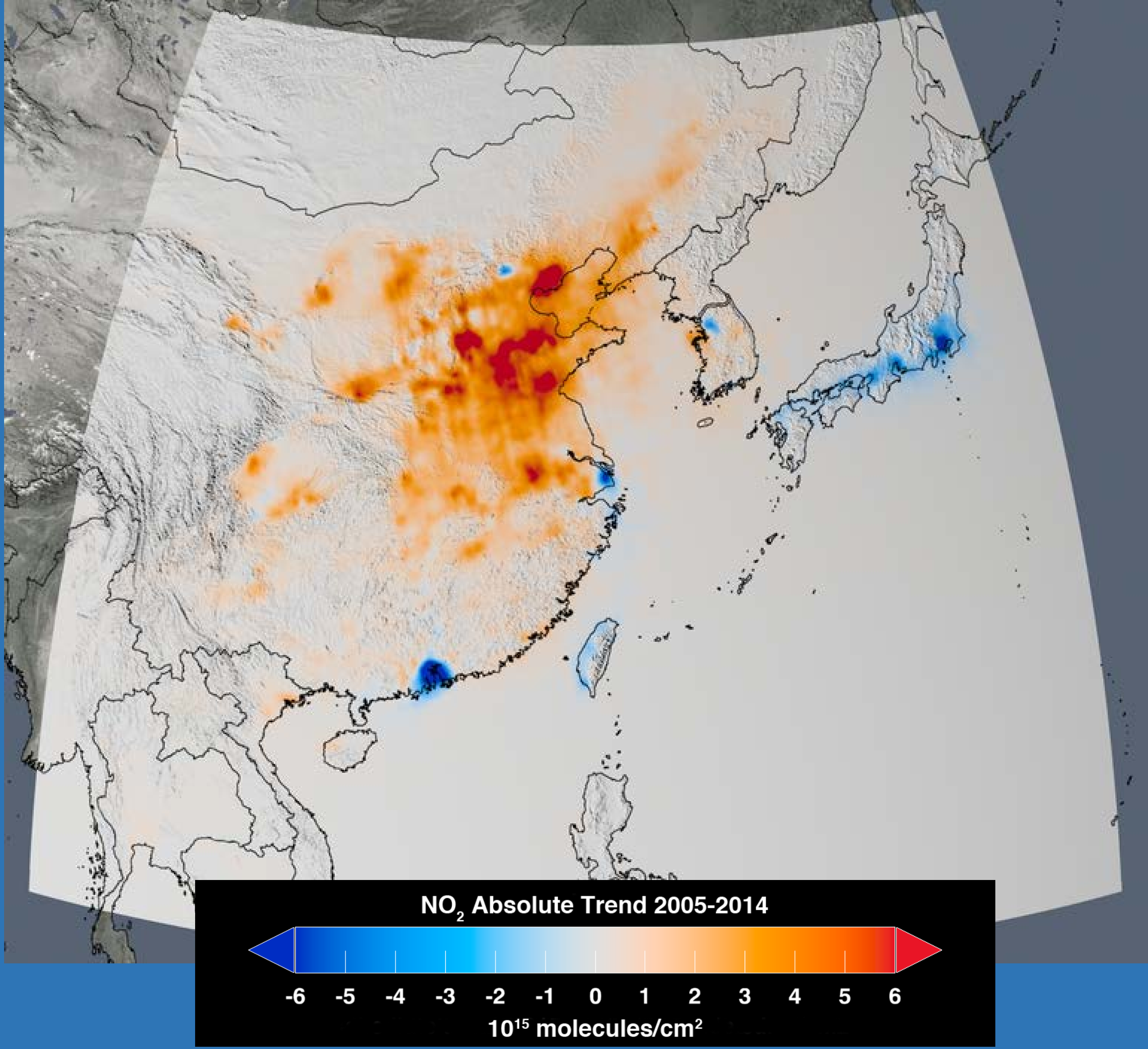
CO_2 emissions over China and India are increasing, whereas CO_2 emissions over USA and Europe are decreasing



Global CO2 emissions through 2014.

Le Quéré et al., Global Carbon Budget 2015, Earth Syst. Sci. Data, 7, 2015.

Changes in OMI tropospheric column NO_2 above China, 2004-2014.



Duncan, B. N., L. N. Lamsal, A. M. Thompson, Y. Yoshida, Z. Lu, D. G. Streets, M. M. Hurwitz, and K. E. Pickering (2016), A space-based, high-resolution view of notable changes in urban NOx pollution around the world (2005–2014), J. Geophys. Res. Atmos., 121, 976–996, doi:10.1002/2015JD024121.

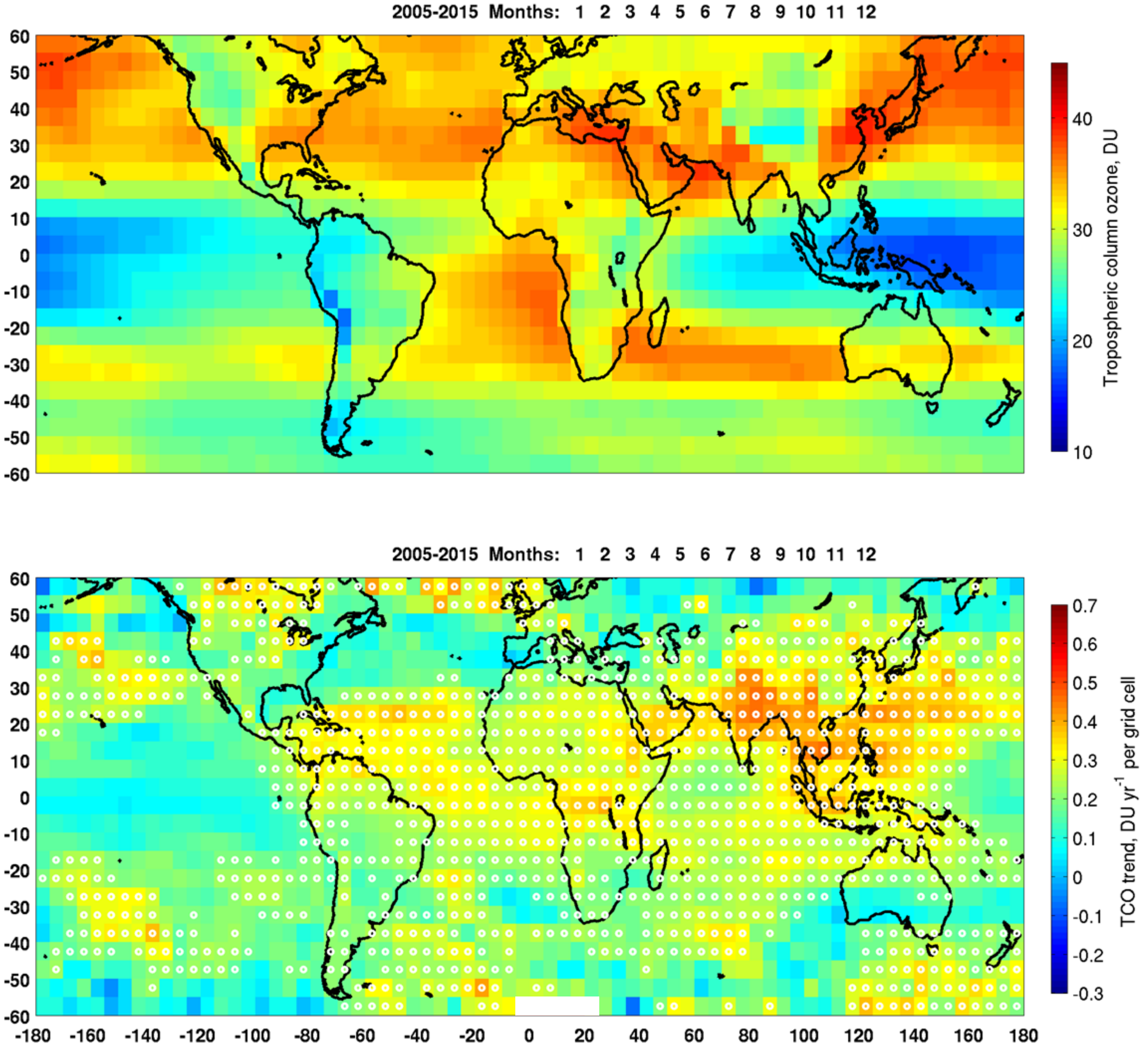
OMI/MLS tropospheric column ozone and trends, 2005-2015: Annual

Lower panel: White dots indicate grid cells with statistically significant trends

The strongest increases in ozone are at low latitudes, especially over the growing emissions regions of India and south east Asia.

Are the satellite-detected increases above Asia confirmed by in situ observations?

OMI/MLS tropospheric column ozone product produced by Jerry Ziemke, Morgan State University/NASA GSFC

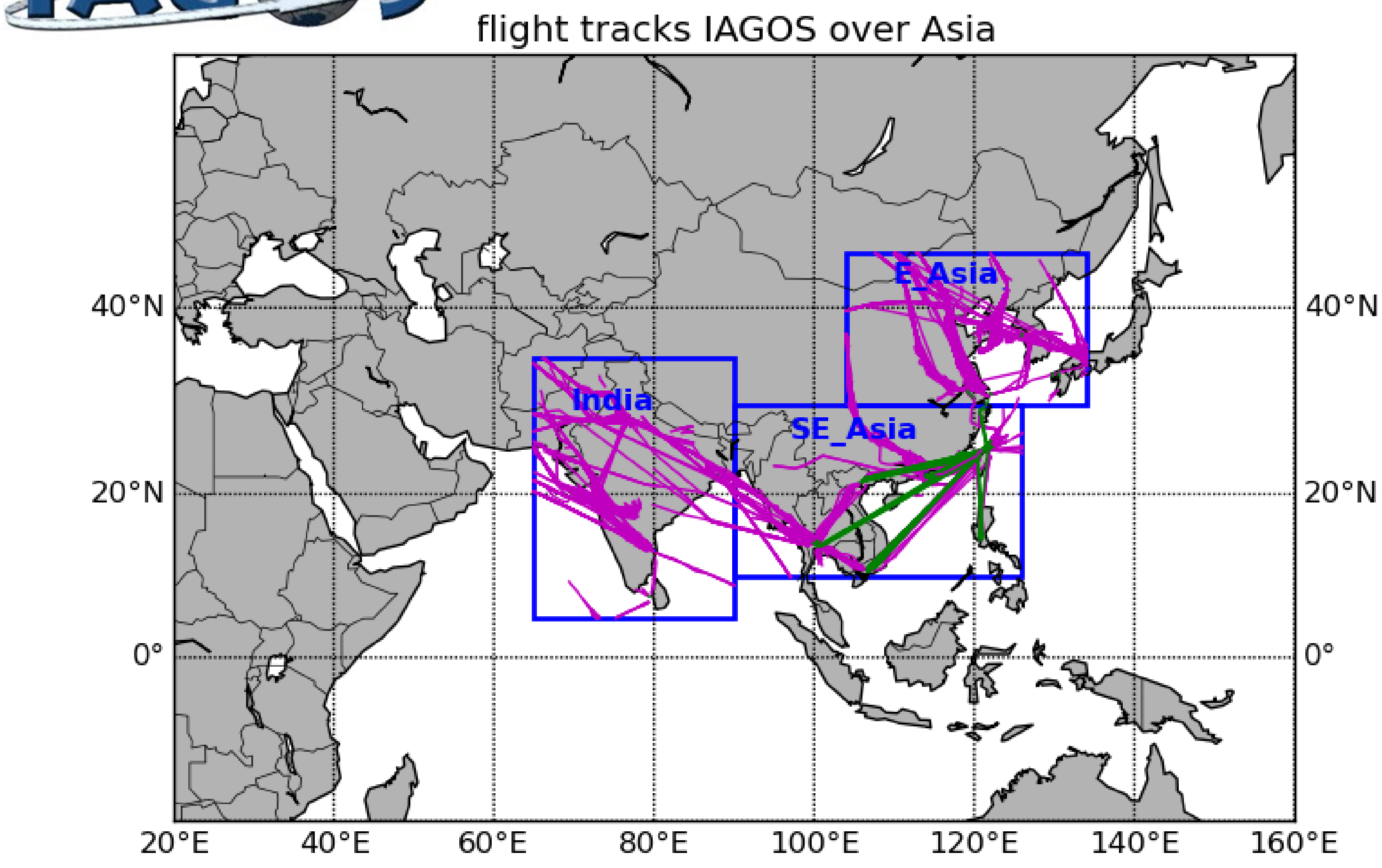


IAGOS observations over Asia 1994-2014

3 regions:

- **India**
- **South-East Asia**
- **East Asia**

About 500 flights per season for the 20-year period



IAGOS data freely provided by the IAGOS Team, http://www.iagos.org/

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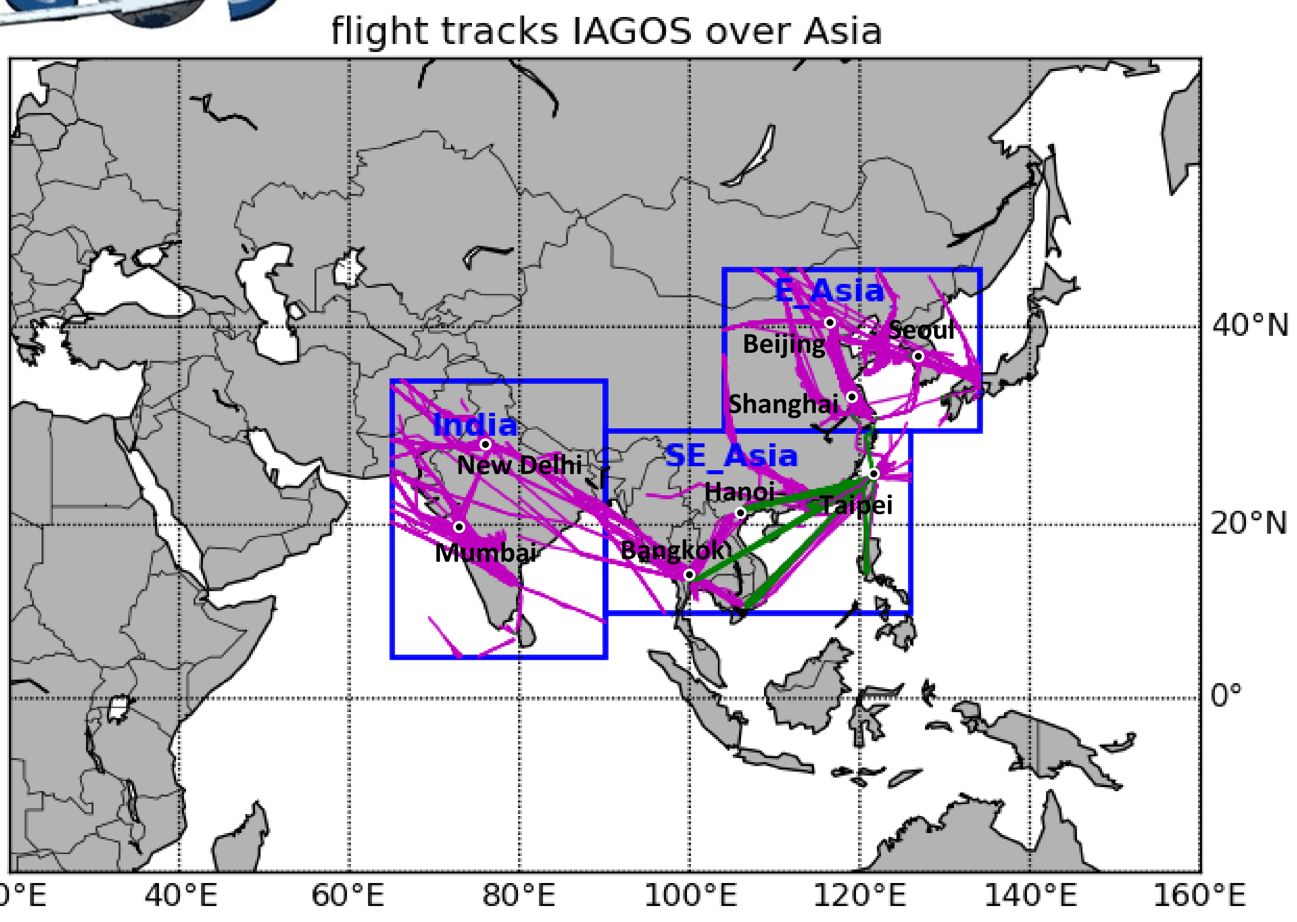


IAGOS data freely provided by the IAGOS Team, http://www.iagos.org/

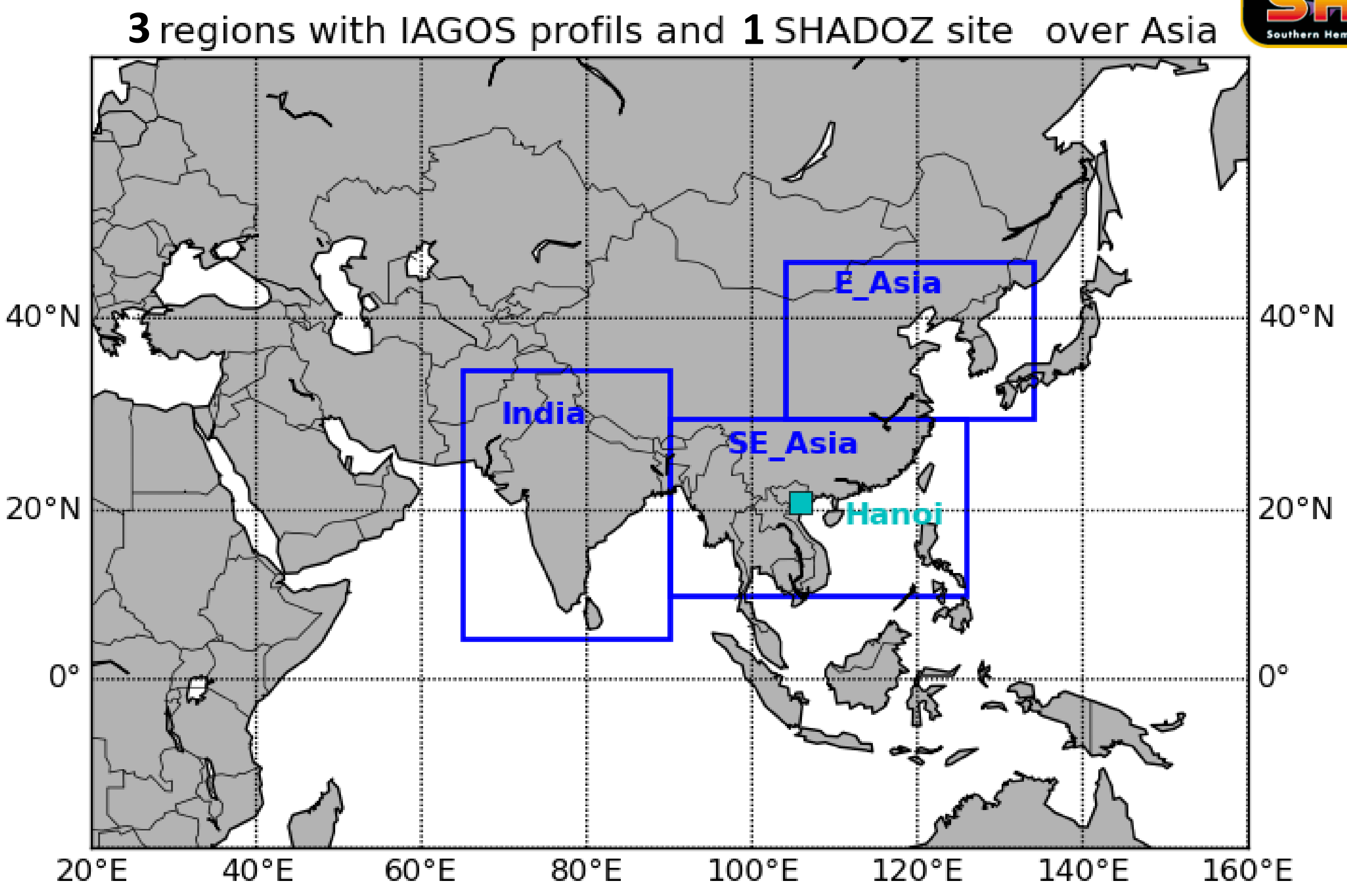
IAGOS observations over Asia 1994-2014

3 regions:
- India
- South-East Asia
- East Asia

About 500 flights

+ Ozonesondes above Hanoi in 2004-2015.
40-50 profiles per season, mostly after 2005

High quality, in situ data sets to evaluate the 2005-2015 satellite data.
In situ observations require a longer time period (1994-2014) to achieve robust sampling statistics.



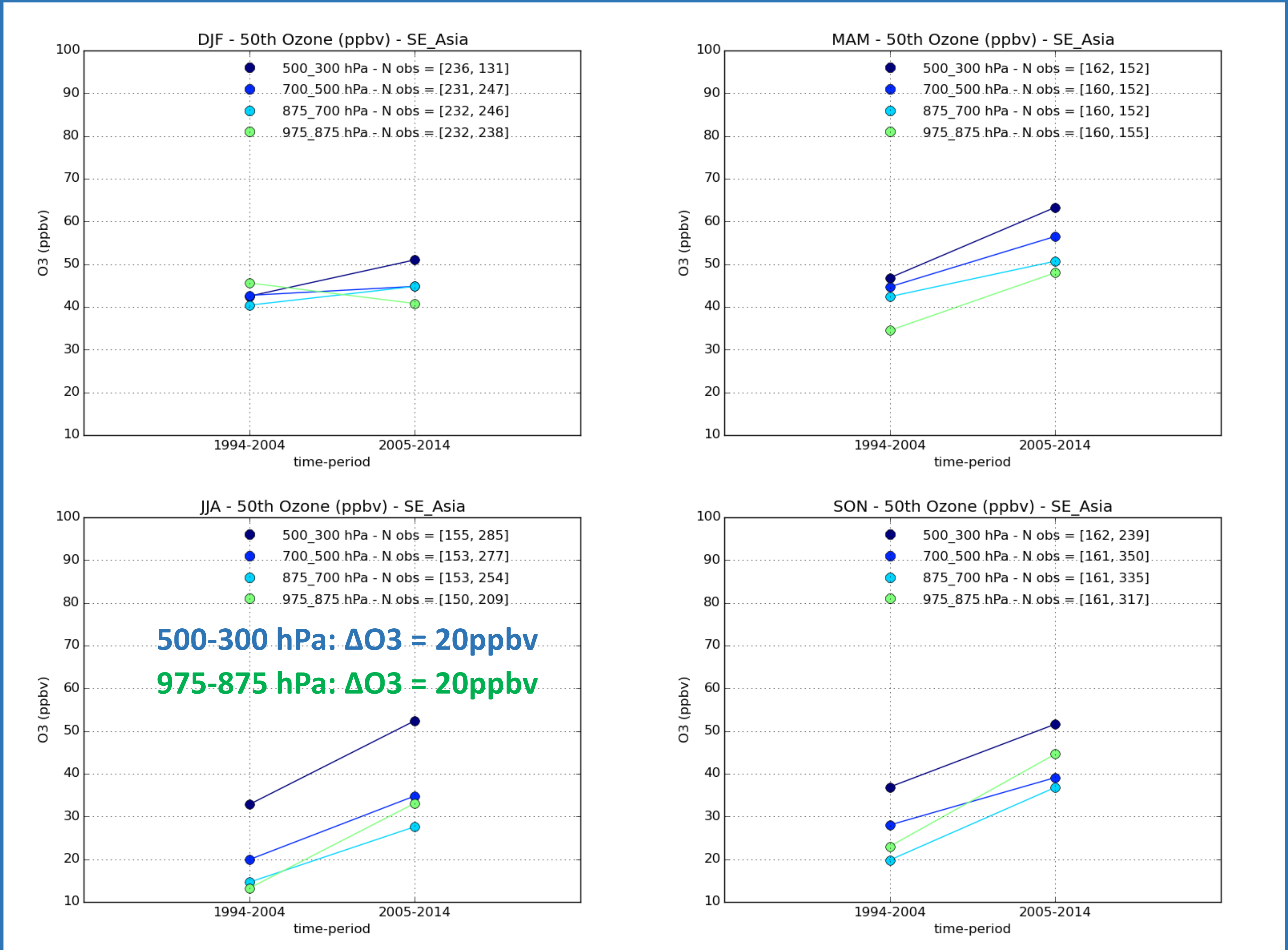
SHADOZ ozonesonde data freely provided by A. Thompson and J. Witte, NASA GSFC, http://croc.gsfc.nasa.gov/shadoz/

South East Asia
50^{th} percentile

Increase between 1994-2004 and 2005-2014

Except in DJF in the lower troposphere

ΔO3 ~ 10 to 20 ppbv
or
~ 15 to 60%

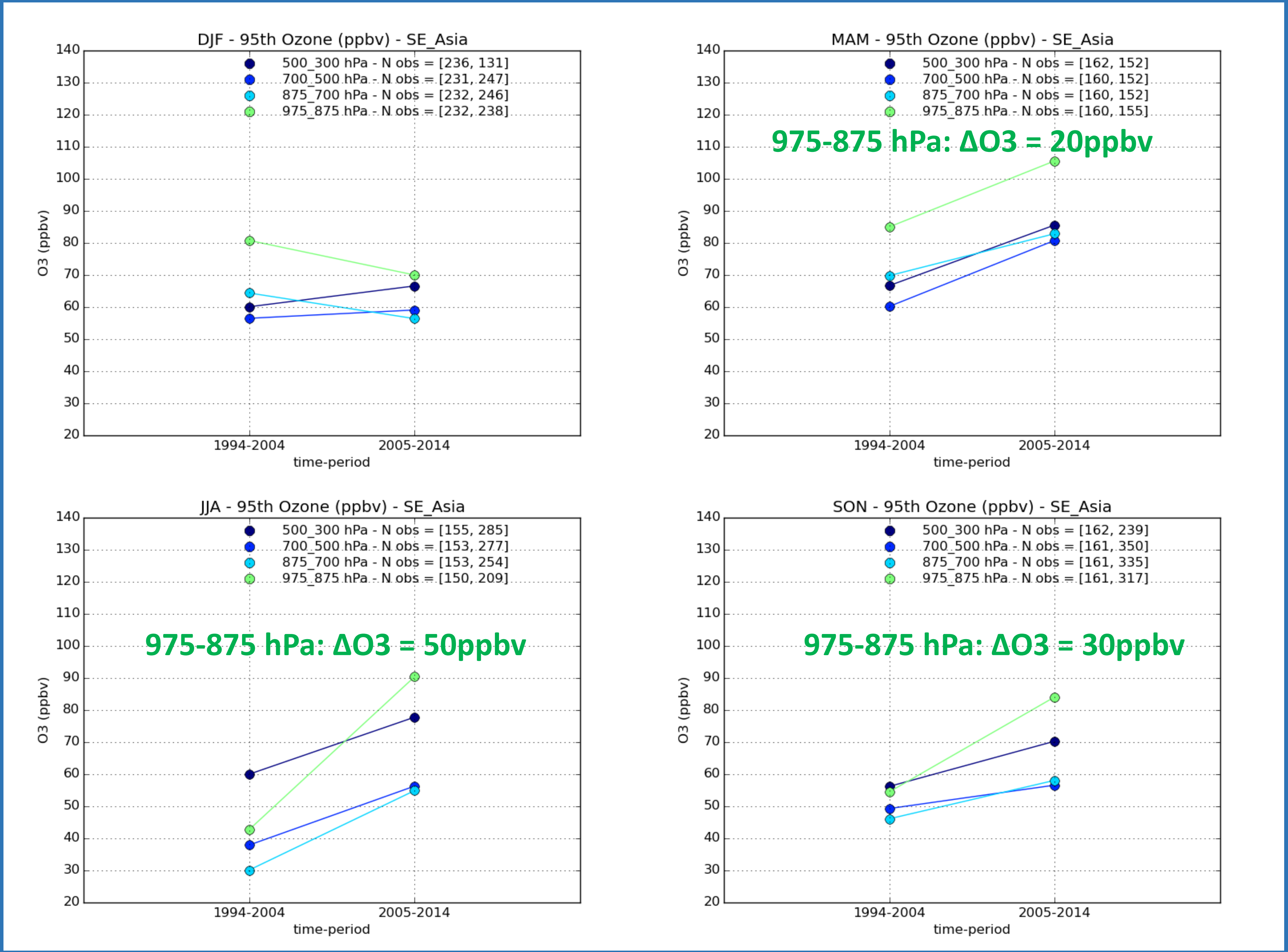


South East Asia
95th percentile

Increase between 1994-2004 and 2005-2014

Except in DJF in the lower troposphere

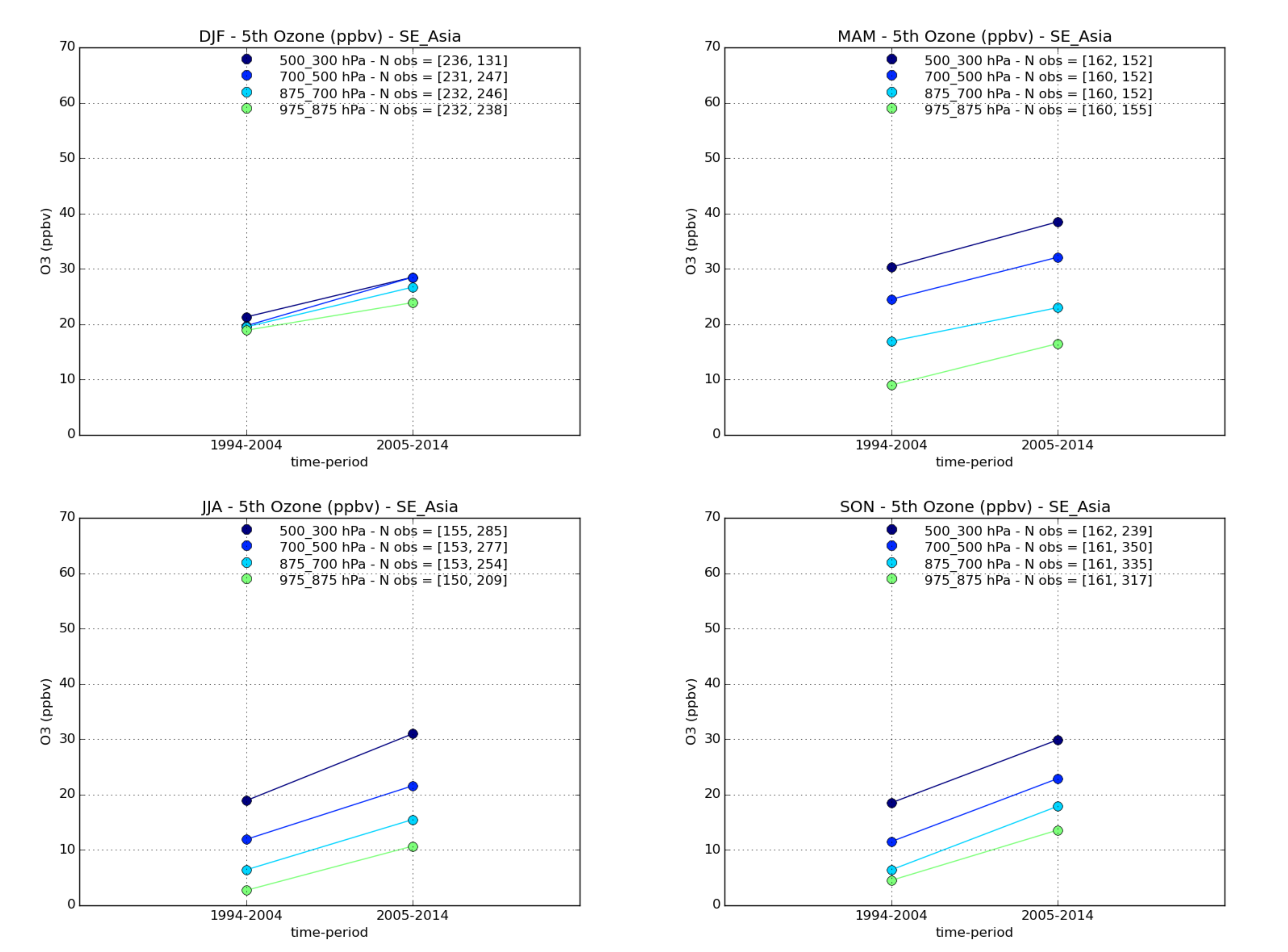
ΔO3 ~ 10 to 50 ppbv
or
~ 10 to 55%



South East Asia
5th percentile

Increase between
1994-2004 and 2005-2014

ΔO3 ~ 10 ppbv
or
~ 20 to 75%



East Asia ΔO3 (ppbv) and % change between both time period 1994-2004 and 2005-2014

*** Indicate statistically significant difference between averages**

ΔO3 (ppbv) % change	DJF	MAM	JJA	SON
Pressure level (hPa)	Avg	Avg	Avg	Avg
500-300	1.1 2%	2.2 3%	7.1* 9%	5.4* 9%
700-500	0.5 1%	2.9* 4%	4.9* 8%	5.1* 9%
875-700	3.4* 7%	6.8* 10%	8.5* 14%	7.6* 14%
975-875	1.6 4%	9.1* 14%	20.4* 30%	9.9* 19%

East Asia ΔO3 (ppbv) and % change between both time period 1994-2004 and 2005-2014

* **Indicate statistically significant difference between averages**

ΔO3 (ppbv) **% change**	**DJF**	**MAM**	**JJA**	**SON**
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875-700	3.4* 7%	6.8* 10%	8.5* 14%	7.6* 14%
975-875	1.6 4%	9.1* 14%	20.4* 30%	9.9* 19%

- High increase of ozone in MAM through SON in the lower troposphere

India ΔO3 (ppbv) and % change between both time period 1994-2004 and 2005-2014

*** Indicate statistically significant difference between averages**

ΔO3 (ppbv) % change	DJF	MAM	JJA	SON
Pressure level (hPa)	Avg	Avg	Avg	Avg
500-300	2.8* 6%	5.6* 8%	-3.4 -6%	0.7 1%
700-500	1.9* 4%	5* 8%	-3.7 -8%	1.4 3%
875-700	3.8* 8%	4.9* 9%	-2 -6%	1.7 4%
975-875	3.9* 8%	3.1 7%	-0.9 -4%	-1.6 -4%

Conclusions

- South East Asia : Increase for 50th, 95th, 5th for all altitudes and seasons except in DJF in the lower troposphere, specifically for 95th percentile
- East Asia: Maximum of increase of the ozone means in MAM through SON in the lower troposphere
- India: Increase of ozone means in DJF/MAM. Also in the mid-troposphere in JJA/SON

  + Decrease of ozone means in JJA, but not statistically significant

Direct comparison between in situ and satellite observations is not possible, however:

- ➢ Ozone changes in South East Asia and East Asia are consistent with OMI/MLS results
- ➢ Ozone changes over India need to be studied further

OMI tropospheric column NO_2 and trends, 2005-2015: May-October

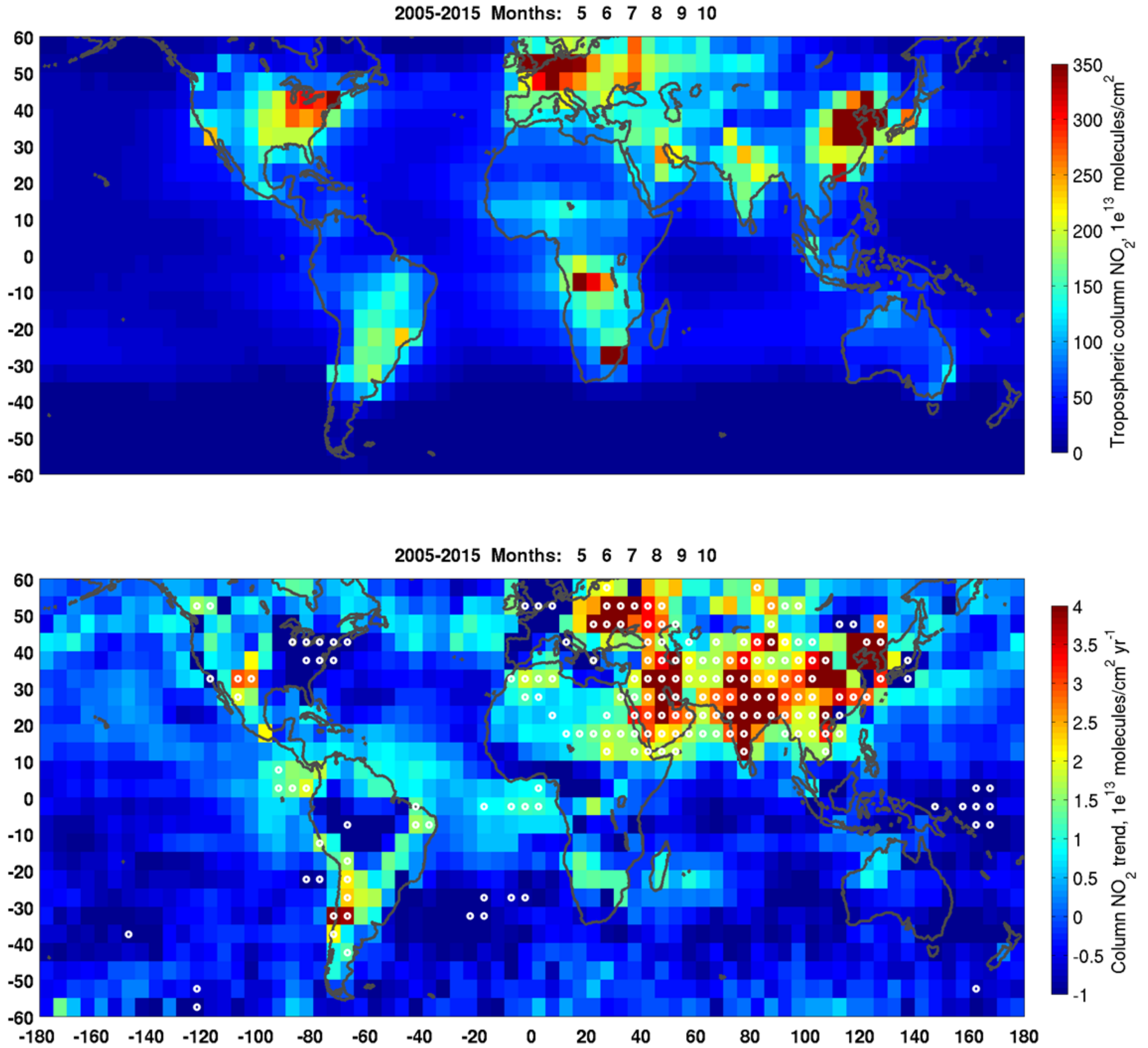
Lower panel: White dots indicate grid cells with statistically significant trends

The total mass of tropospheric NO_2 in the N. Hemisphere increased by 5% from 2005-2007 through 2013-2015.

2/3 of the increase occurred at low latitudes (0-30 N) where ozone production efficiency is greatest.

OMI tropospheric NO2 data freely provided by www.temis.nl

Boersma et al., An improved retrieval of tropospheric NO2 columns from the Ozone Monitoring Instrument, Atmos. Meas. Tech. , 4, 1905-1928, 2011



OMI/MLS tropospheric ozone burden, 2005-2015

Data produced by Jerry Ziemke, Morgan State U./NASA Goddard

The global (60°N – 60°S) tropospheric ozone burden has increased by 9% (25 Tg) over 11 years (2005-2015).

Also shown is the NOAA CPC Niño 3.4 Index which is the monthly sea surface temperature anomaly in the Niño 3.4 region (5°N-5°S, 120°-170°W) of the east-central tropical Pacific Ocean.

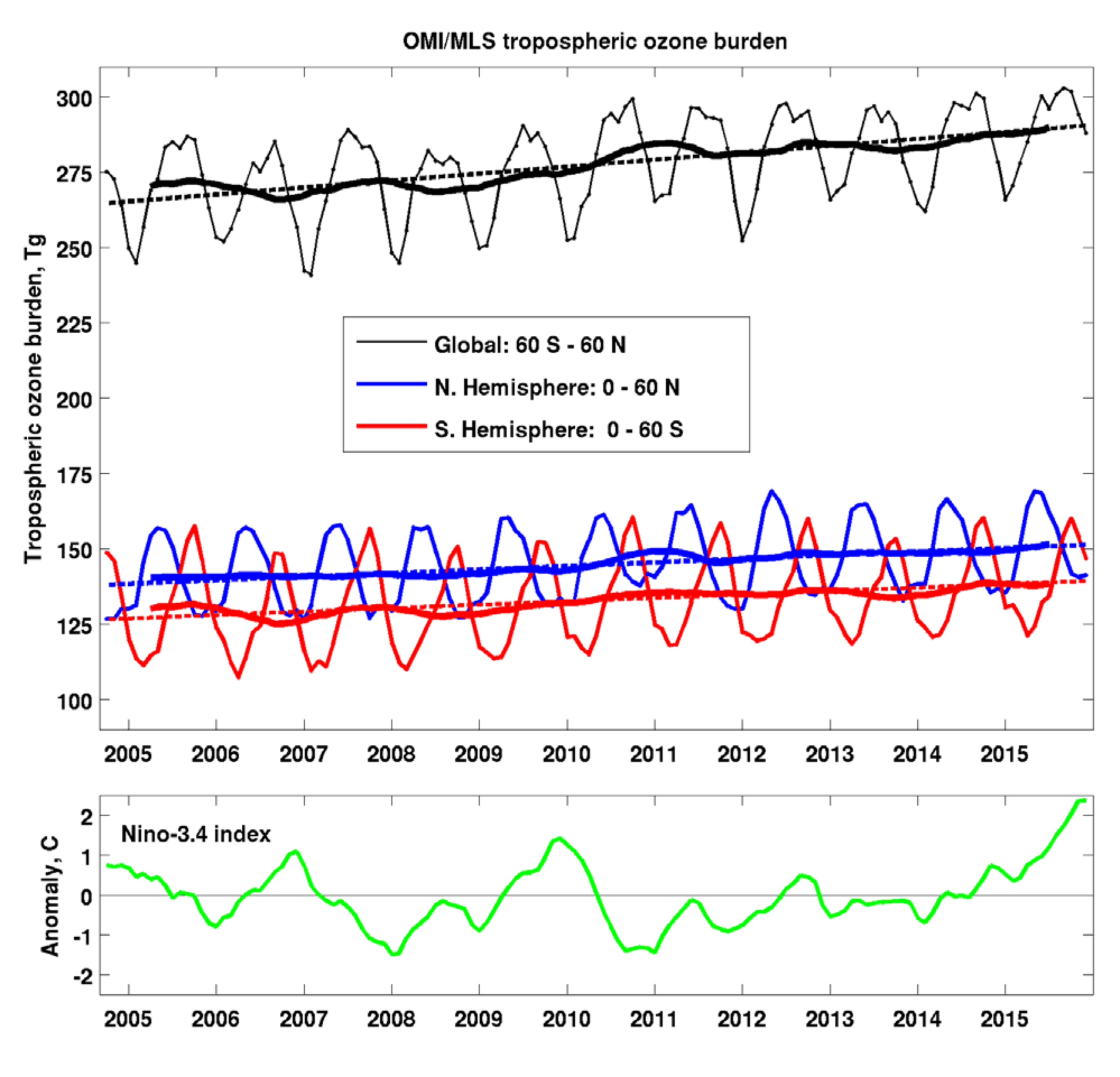
The 2004-2015 OMI/MLS record began and ended under El Niño conditions with 2 other El Niño periods occuring in 2006-2007 and 2009-2010.

NOAA CPC Niño 3.4 Index and Oceanic Niño Index (ONI) can be downloaded from:

http://www.cpc.ncep.noaa.gov/data/indices/

For further information on the variability of ozone with ENSO, see:

Ziemke, et al., Tropospheric ozone variability in the tropics from ENSO to MJO and shorter timescales, Atmos. Chem. Phys., 15, 8037-8049, doi:10.5194/acp-15-8037-2015, 2015.



OMI/MLS tropospheric column ozone and trends, 2005-2015: Seasonal