Advancing Earth Observation Science to meet the needs of Anthropocene

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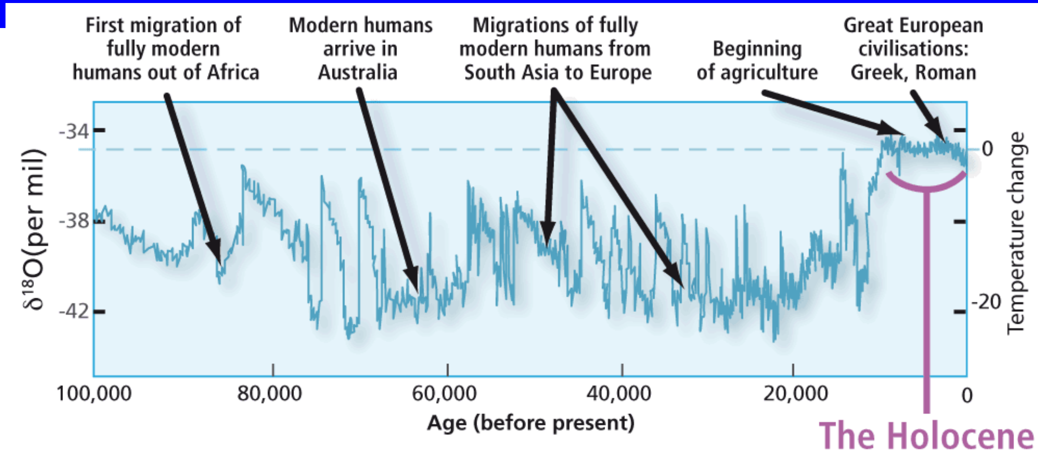
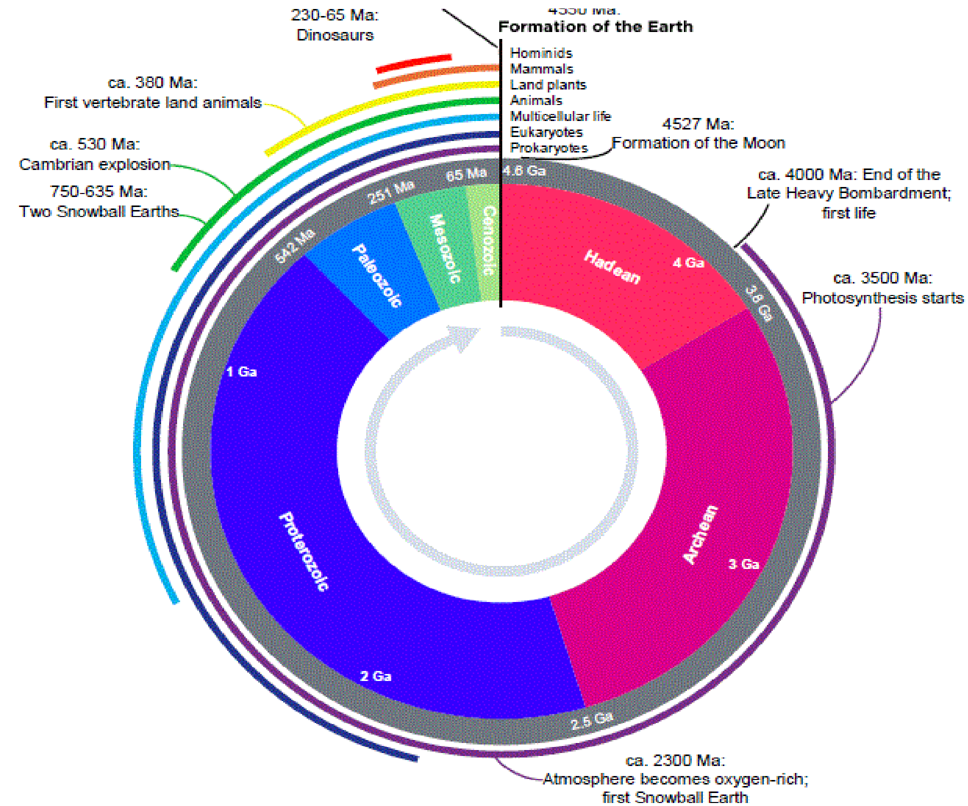
Natural Environment Research Council: Centre for Ecology and

Geological Time Scales

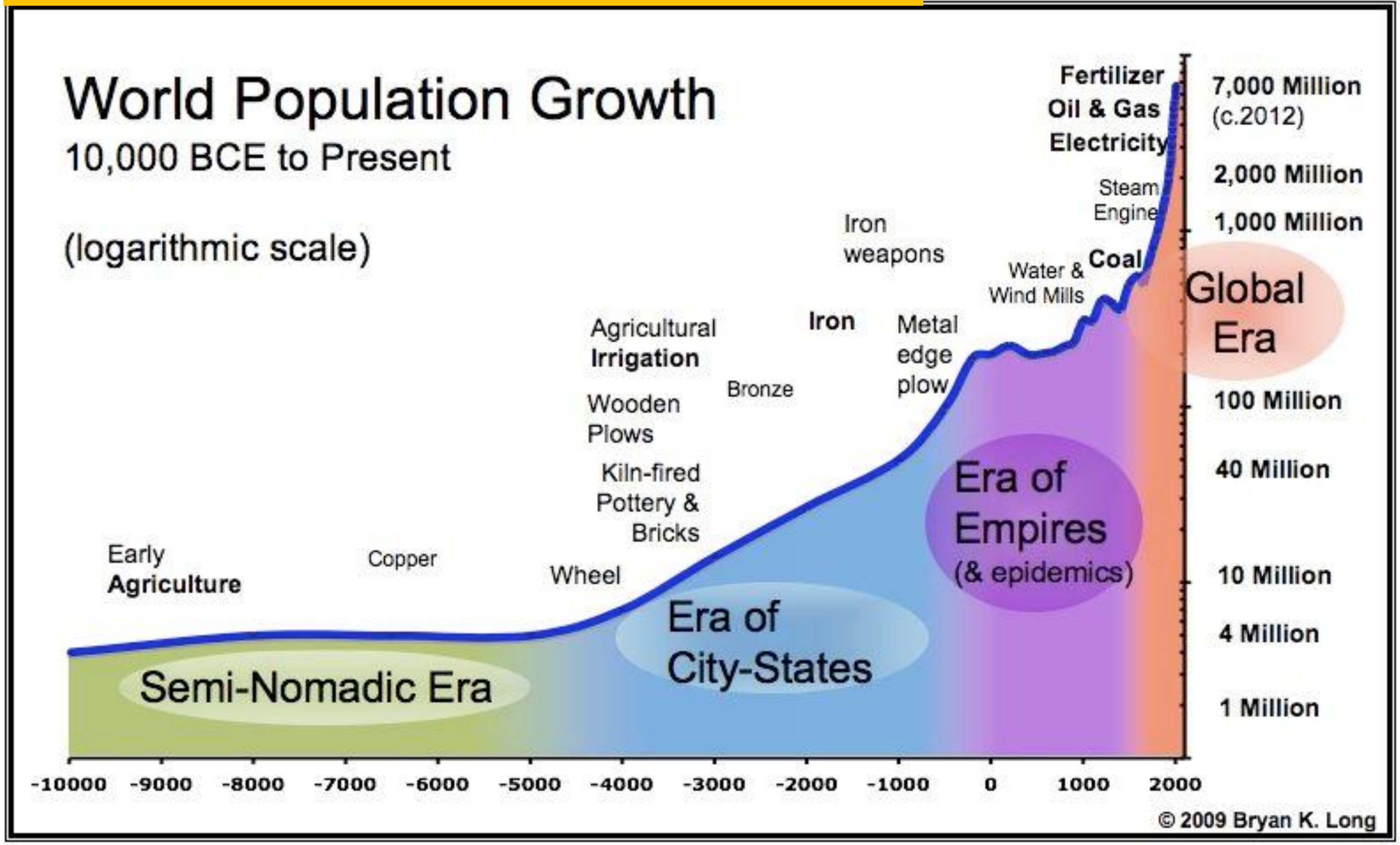
EON	ERA	PERIOD		EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary		Holocene		0.011
				Pleistocene	Late	0.8
					Early	2.4
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	23.0
			Paleogene	Oligocene	Late	28.5
					Early	34.0
				Eocene	Late	41.3
					Middle	49.0
					Early	55.8
				Paleocene	Late	61.0
					Early	65.5
	Mesozoic	Cretaceous		Late		99.6
				Early		145
		Jurassic		Late		161
				Middle		176
				Early		200
		Triassic		Late		228
				Middle		245
				Early		251
	Paleozoic	Permian		Late		260
				Middle		271
				Early		299
		Pennsylvanian		Late		306
				Middle		311
				Early		318
		Mississippian		Late		326
				Middle		345
				Early		359
		Devonian		Late		385
				Middle		397
				Early		416
		Silurian		Late		419
				Early		423
		Ordovician		Late		428
				Middle		444
				Early		488
		Cambrian		Late		501
				Middle		513
				Early		542
Precambrian	Proterozoic	Late		Neoproterozoic (Z)		1000
		Middle		Mesoproterozoic (Y)		1600
		Early		Paleoproterozoic (X)		2500
	Archean	Late				3200
		Early				4000
	Haydean					





The growth of the World Population

Current World Population = 7,413,600,000



The Anthropocene

THE GREAT ACCELERATION

In September 2015 the nations of the world will meet to agree on Sustainable Development Indicators will be essential to asses progress

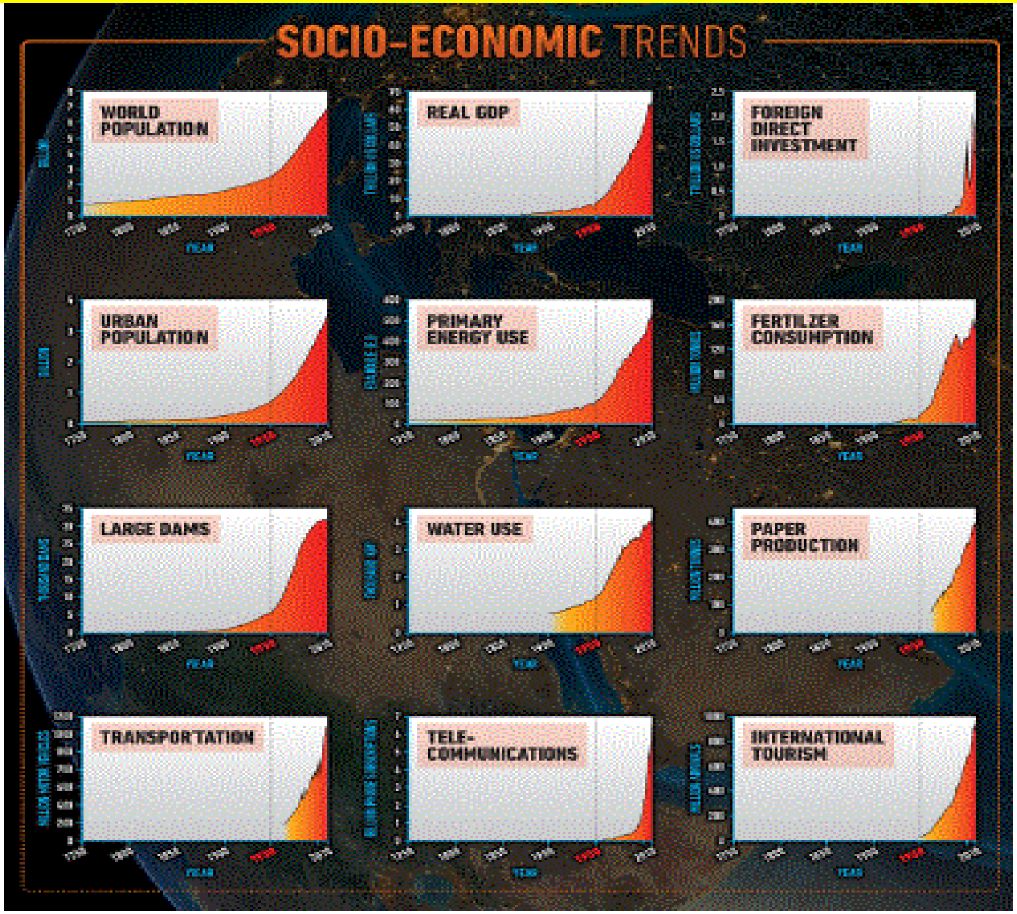


Figure 1: Twelve socio-economic trends from 1750 to present.

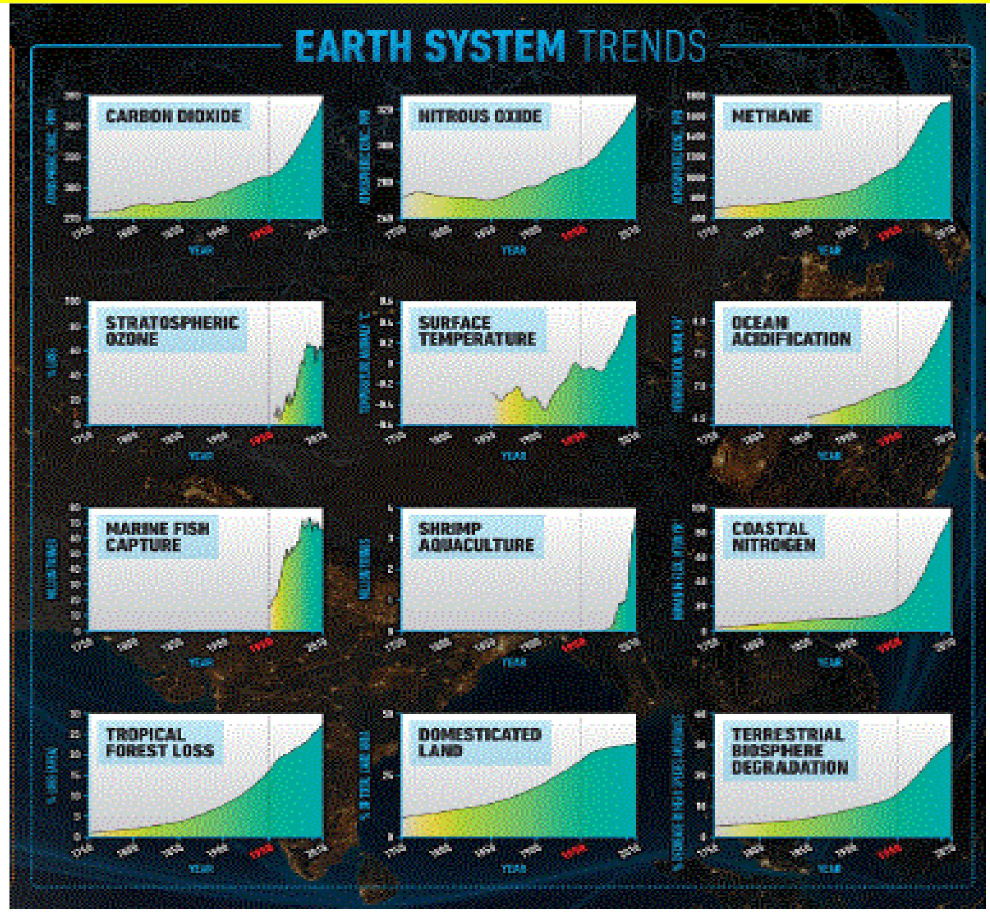


Figure 2: Twelve Earth system trends from 1750 to present.

Why observe the atmosphere from space?

Earth has entered a new epoch, <u>the Anthropocene</u> (E. F. Stoermer and P. J. Crutzen 2001 IGBP) - the Earth System is changing!

image: NASA

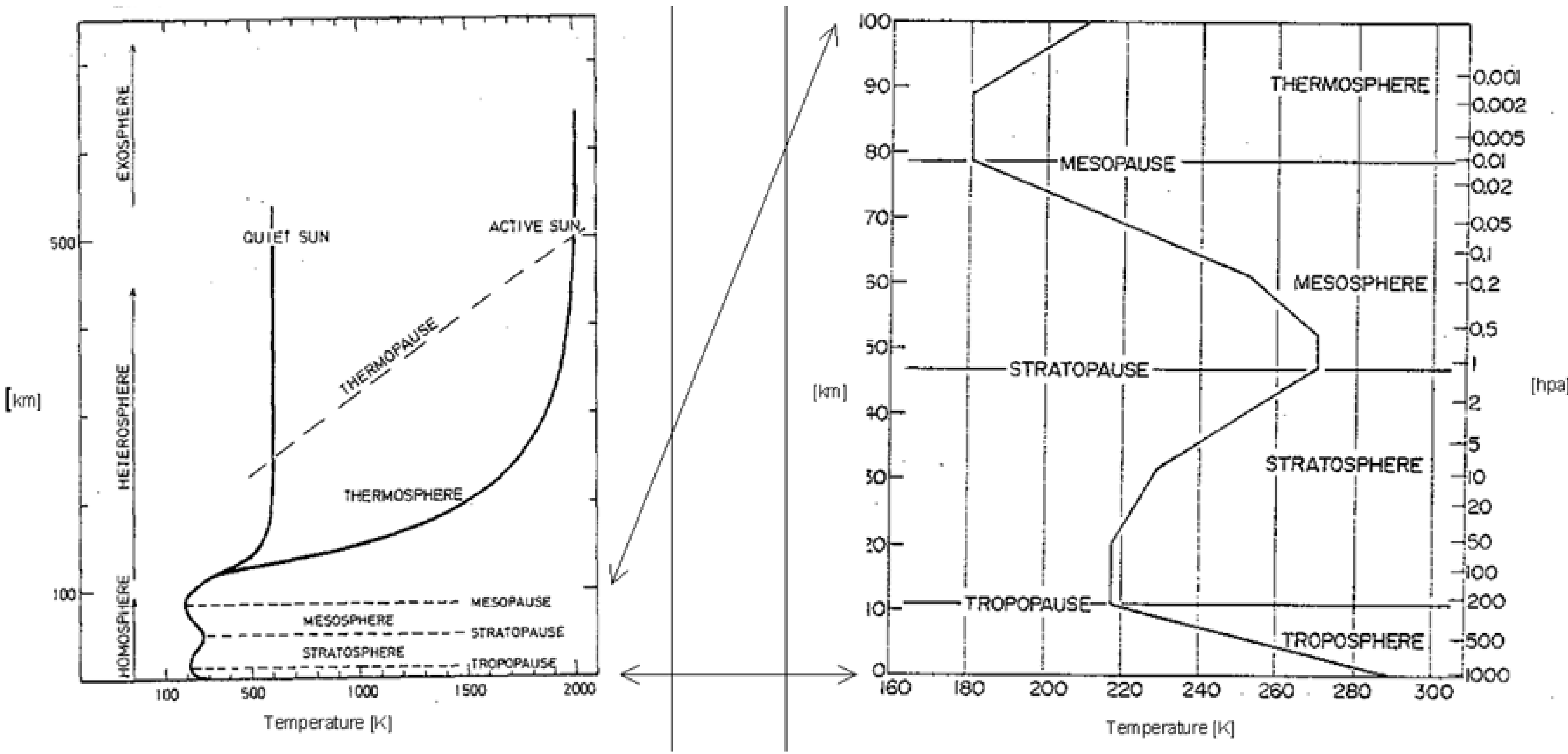
- **From the Neolithic Revolution to 1800 population rose from 4M to 1B**
- **Dramatic changes in population and anthropogenic emissions since 1800! Now + 7B over 50% Urban**
- **Energy supplied primarily by fossil fuel combustion => Release of Long Lived Greenhouse Gases and Short Lived Climate Pollutants**
- ⇨ **Global transport and transformation of pollution and land use change**
- ⇨ **Climate Change - Chemistry climate feedback**
- ⇨ **Global destruction of stratospheric ozone**

⇨ **It is *<u>impossible</u>* to understand/manage *<u>species or conditions not measured!!</u>***

⇨ **Environmental/Climate Change requires Global Observations**

⇨ **Evidence base for <u>science</u> (understanding and prediction) and <u>policymaking</u> (mitigation and adaptation)**

Vertical Structure of the Atmosphere



(Wallace and Hobbs)

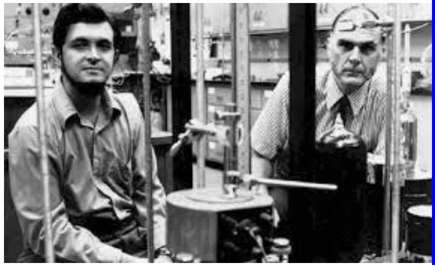
Anthropocene Motivational Issue 1
Stratospheric Ozone

Science: Anthropogenic impact of high flying aircraft and releasing CFCs, possibly on Stratsopheric Ozone depletion and the "Ozone Hole" Phenomenon and now Climate Change

Policy: UN Vienna Convention on Ozone Depleting substance 1985, Montreal Protocol 1987 and amendments,
a success story we hope!

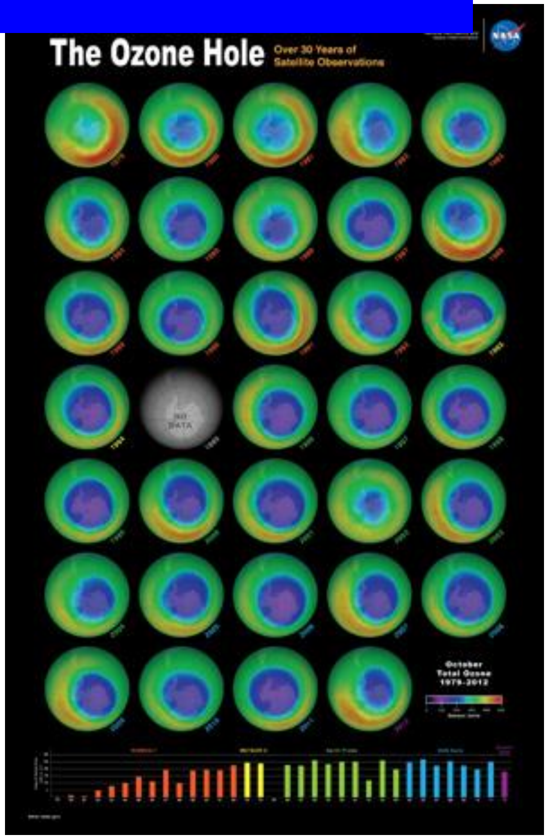
Stratospheric Ozone Depletion and Ozone Hole
Large scale human impact recognised a long way from soruce!!

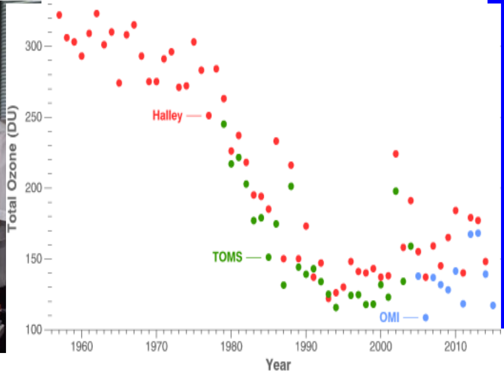
1969/ 1970 H.J. Johnston and P.J. Crutzen raised the issue of pollution of the stratosphere



1970 M. Molina and F.S. Rowland propose that release of CFCs destroy stratospheric ozone.

NASA Ozone Hole over Antartica Using BUV TOMS/SBUV OMS and OMI





BAS team:"Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx interaction" J. C. Farman, B. G. Gardiner and J. D. Shnaklin 1985

The Nobel Prize for Chemistry 1995 M. Molina, F.. Sherwood and P. J. Crutzen

Ozone Production & Catalytic Destruction

Stratospheric Ozone

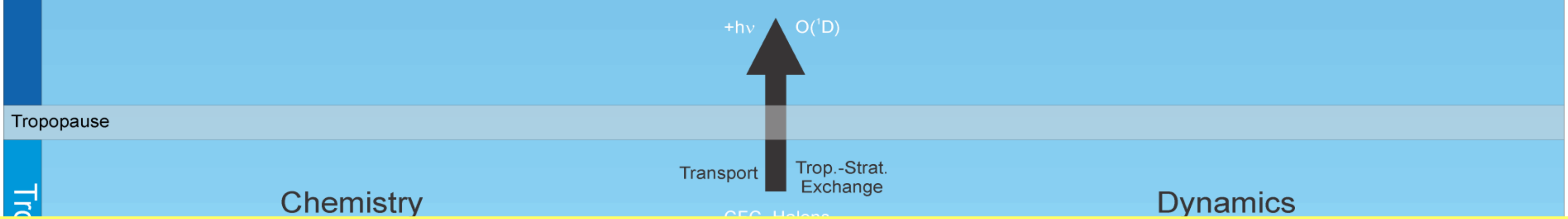
Stratosphere

$$O_2 + h\nu \longrightarrow O + O$$

$$O + O_2 + M \longrightarrow O_3 + M$$

$$O_3 + h\nu \longrightarrow O_2 + O$$

$$O_3 + O \longrightarrow O_2 + O_2$$

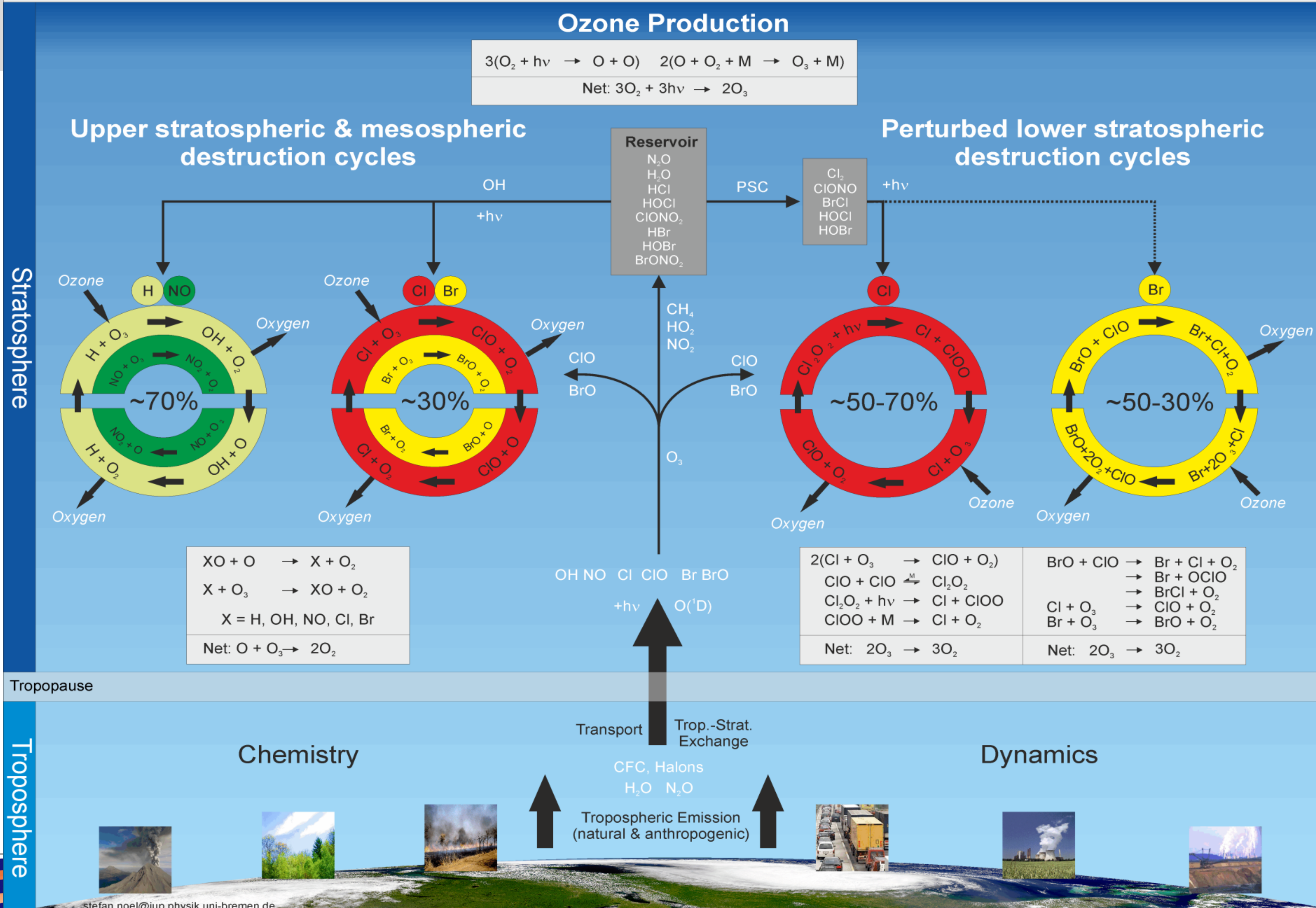


In 1902 the Stratosphere, a temperature inversion above 8-16 km discovered by Leon Philippe Teisserenc de Bort from France and German meteorologist Richard Assmann .
In 1929 Sidney Chapman of Trinity College Cambridge University, explained the observation of Ozone by Dobson Oxford and others. But the reaction $O_3 + O \rightarrow O_2 + O_2$ later discovered to be too slow!

SCIAMACHY

Constellation

Ozone Production & Catalytic Destruction



Anthropocene Motivational Issue 2
Air pollution Air Quality
Short Lived Climate Pollutants

Science: Air Pollution, winter (London) smog, summer (Los angeles) smog, global tropospheric chemistry impact form local to global scales.

Policy: From King Edward 1, via Clean Air act UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and HTAP – some success.

Air Pollution SMOG: local to global scale

London Winter Smog
Claude Monet 1902 und 1952

1948 Los Angeles
Sommer- Smog

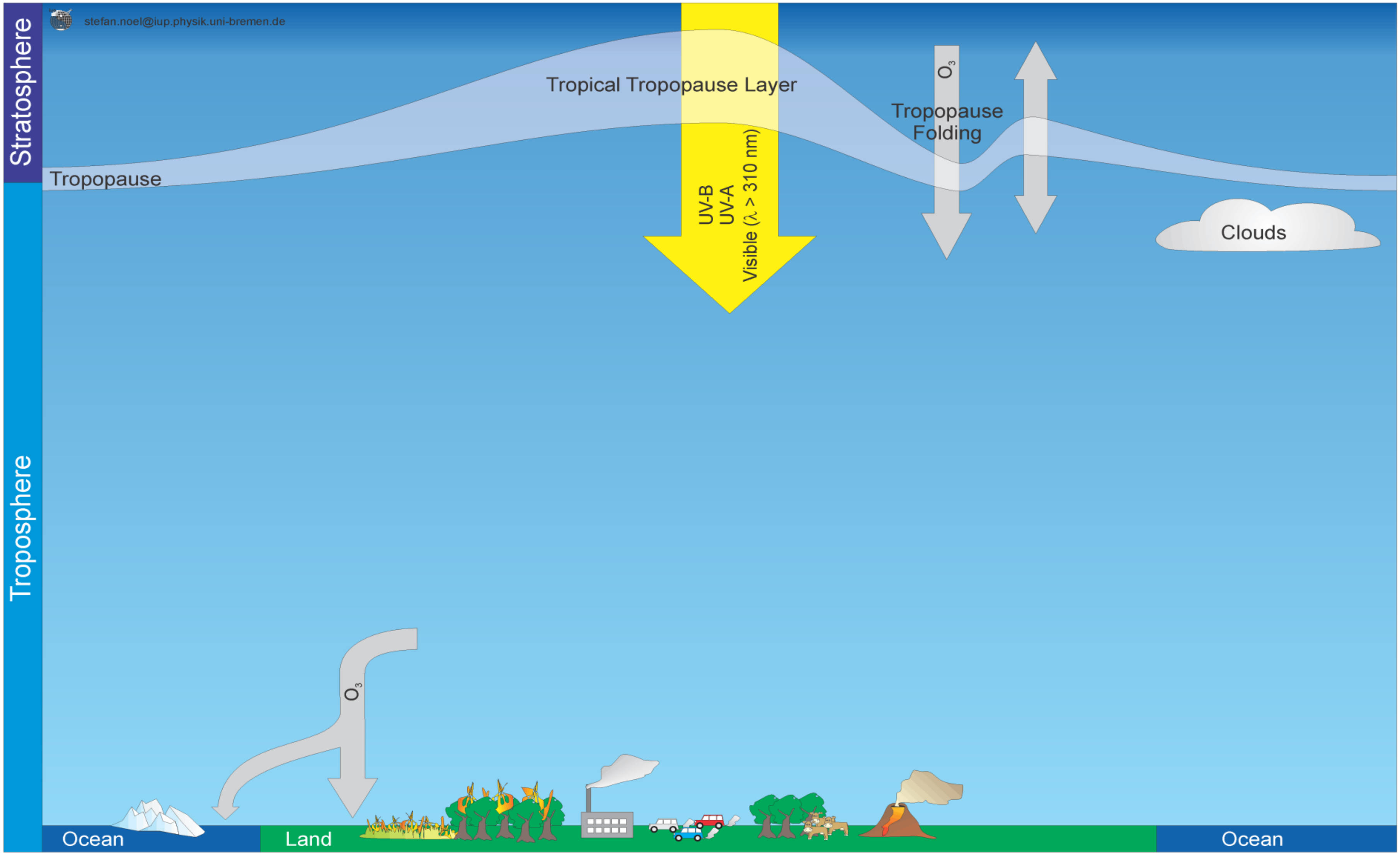
2015 Beijing

2015 Taj Mahal, India

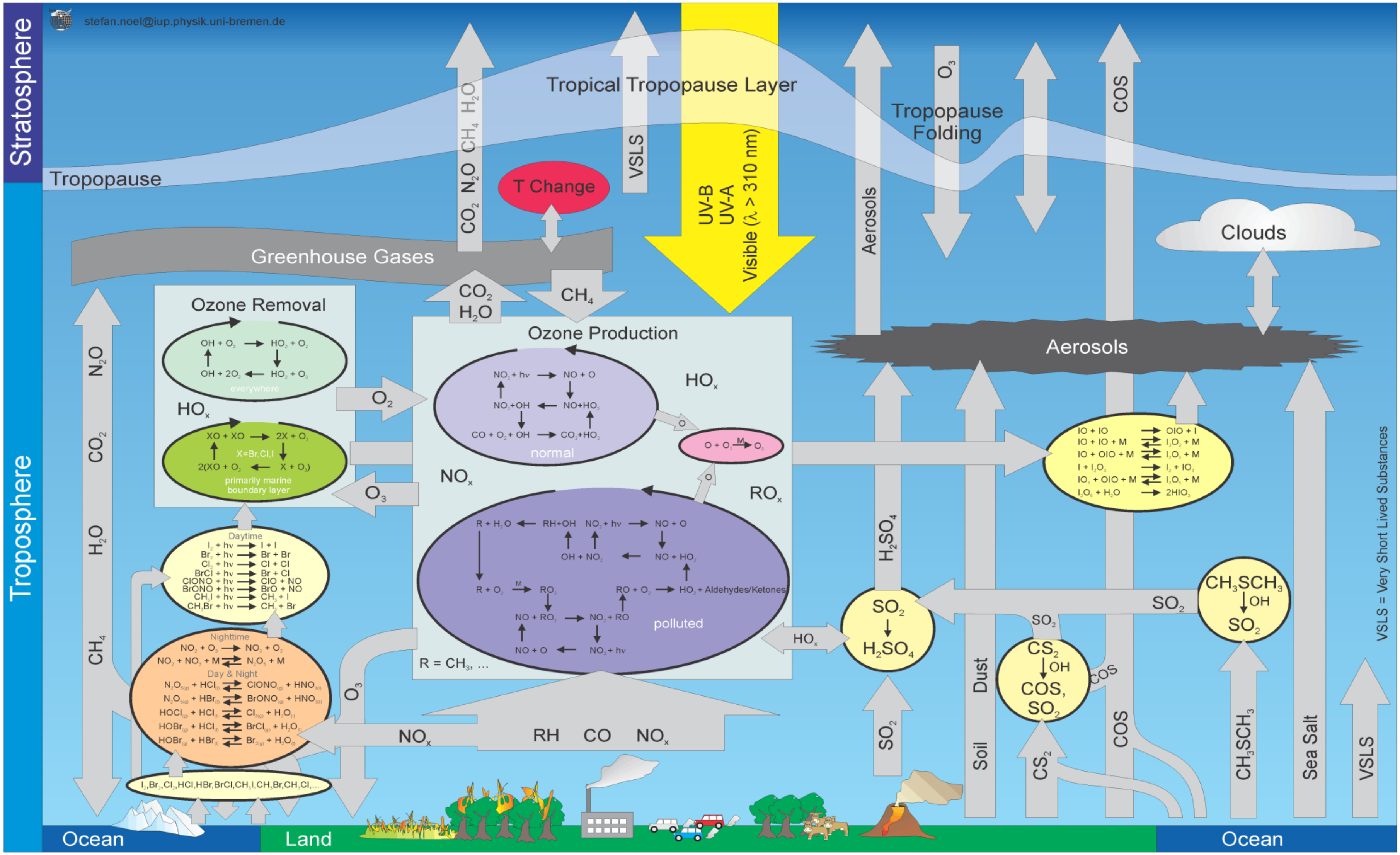
Paris May 2015

Spitzbergen: *26 April 2006* *02 May 2006*

Global Tropospheric Chemistry around 1965



Global Tropospheric Chemistry without OA

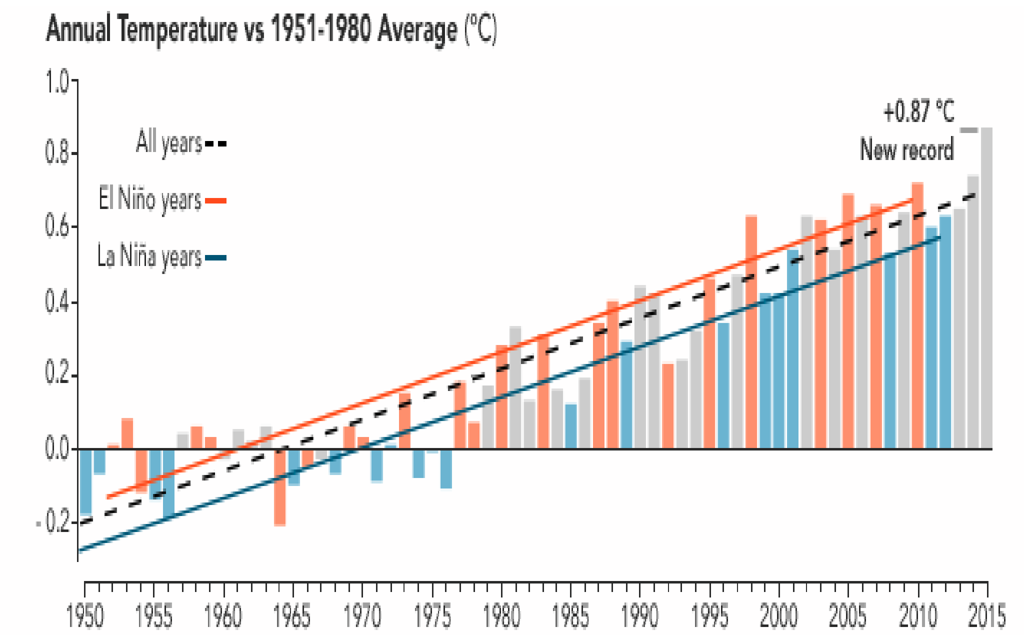


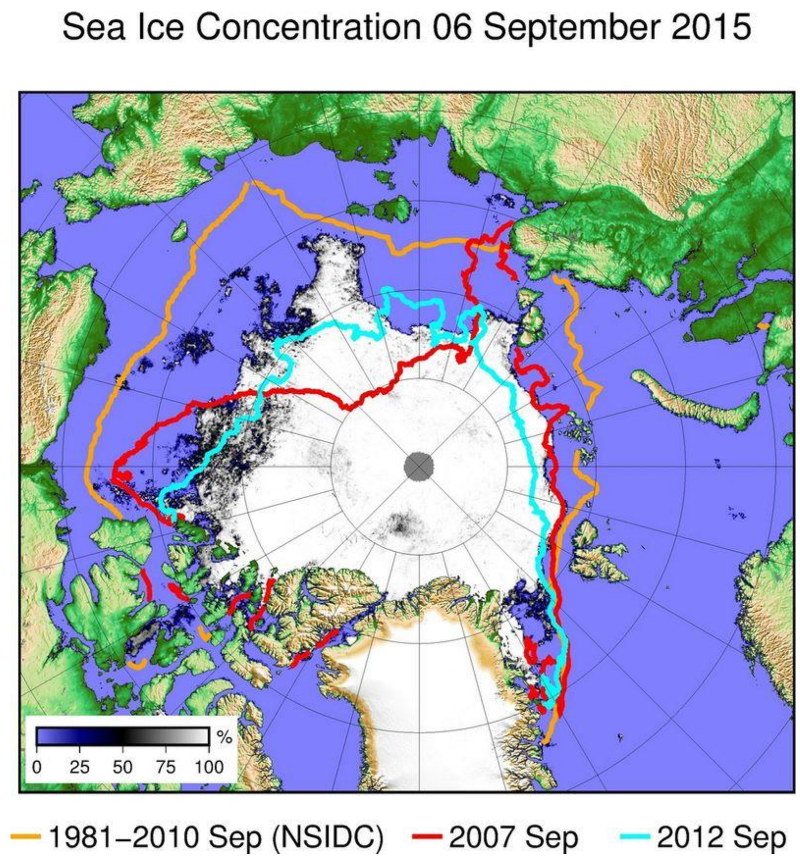
Anthropocene Motivational Issue 3
Climate Change Long lived Greenhouse Gases

Science: Modification of biogeochemical cycles, by i) fossil fuel combustion releasing CO_2, CH_4, ii) use of fertilisers NH_4NO_3 releasing N_2O, iii) biomass burning and land use change etc., leads to changes in T hydrological cycle, cryosphere etc.

Policy: IPCCC 1988- present UNFCCC 1992, Kyoto Protocol various COP agreements including Paris 2015 – now we have plans

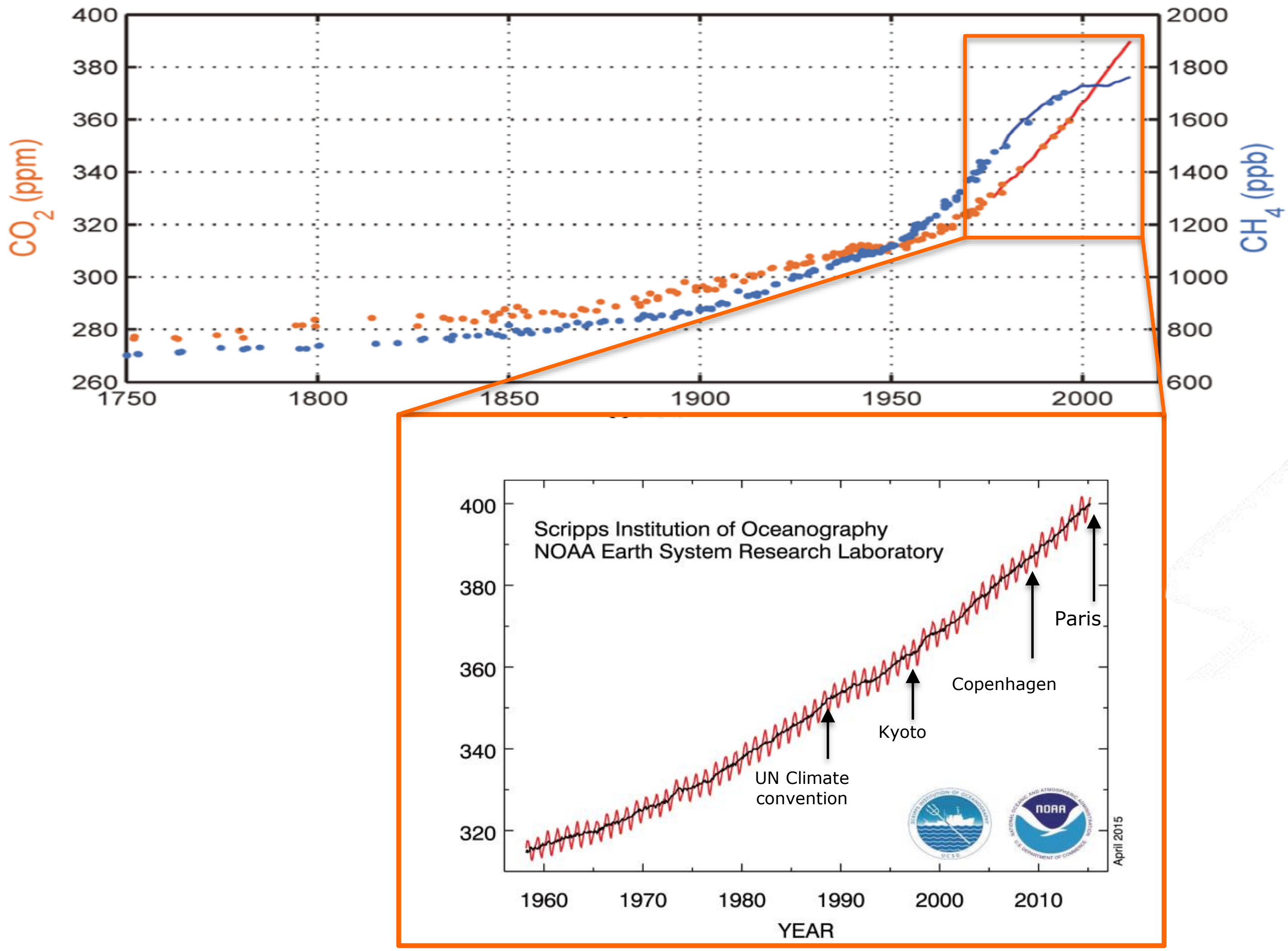
Recent T and Arctic Sea Ice Changes





2012 (cyan) clearly had less ice, but there are a couple of spots where this year had less ice than in 2007 (red). The September graph for ADS-NIPR/JAXA sea ice extent shows how close 2015 came to the lower years, slipping right below 2011 and ending in 3rd position:

CO_2 and CH_4 concentration increases since 1750



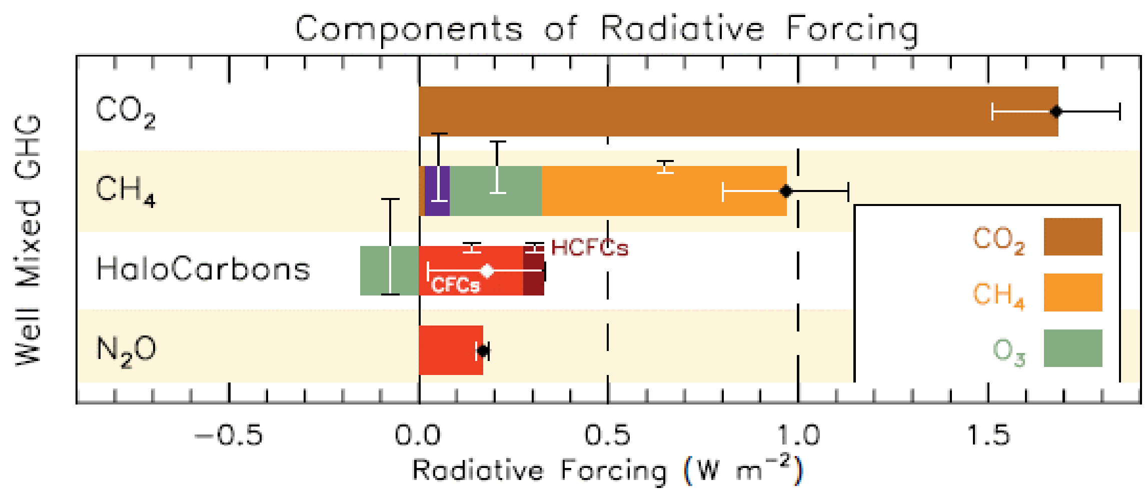
- The increase of these two powerful greenhouse gases accounts for most of the radiative forcing of climate change

Greenhouse gases (GHGs) and Climate Change

GHGs “warm” our planet by absorbing and emitting infrared radiation.

The most **abundant** GHGs in our atmosphere are:

- Water vapor (H_2O)
- **Carbon dioxide (CO_2)**
- **Methane (CH_4)**
- Nitrous oxide (N_2O)
- …



Cooling ← **→ Heating**

CO_2 and CH_4 are the two most important GHG, whose atmospheric burden is anthropogenically modulated!!

The increase in their atmospheric dry mole fractions is a reusl of increasing sources (emissions) and changing sinks
It is in large part responsible for observed global warming (IPCC 2014). => COP21

PARIS2015
UN CLIMATE CHANGE CONFERENCE
COP21·CMP11

Fate of anthropogenic CO_2 emissions (2005-2014 average)

33.0 ± 1.6 $GtCO_2/yr$ 91%

Sources

3.4 ± 1.8 $GtCO_2/yr$ 9%

16.0 ± 0.4 $GtCO_2/yr$
44%

Partitioning

9.5 ± 2.9 $GtCO_2/yr$
30%
Calculated as the residual
of all other flux components

26%
10.9 ± 1.8 $GtCO_2/yr$

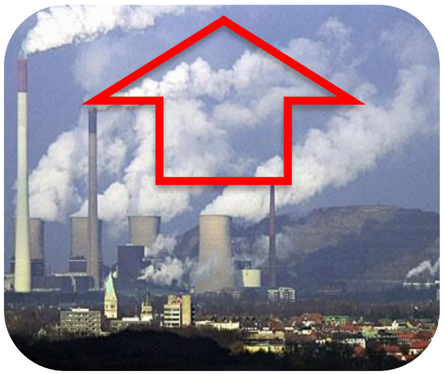
Source: CDIAC; NOAA-ESRL; Houghton et al 2012; Giglio et al 2013; Le Quéré et al 2015; Global Carbon Budget 2015

CO_2 and CH_4 source-sink related science questions

How are the **sources** and **sinks** changing ?

How much is emitted where, when and by what?

Are reported emissions correct?



How much CO_2 is absorbed by land and oceans? Where and when?

How will today's CO_2 sinks behave in a changing climate?

How will today's CH_4 sources (e.g., wetlands) behave in a changing climate?

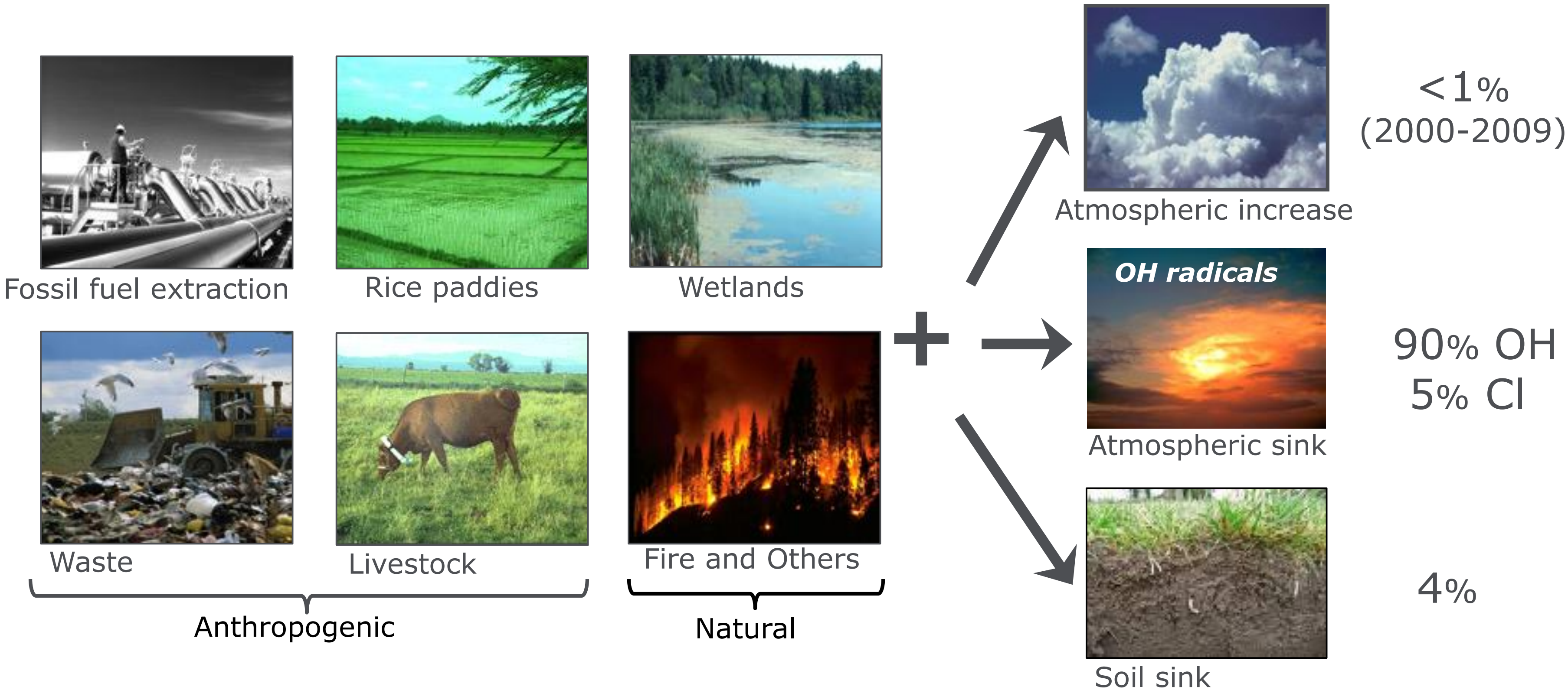
Will natural sinks turn into sources?

Will natural sources be amplified?

How will sources and sinks behave in a changing climate?

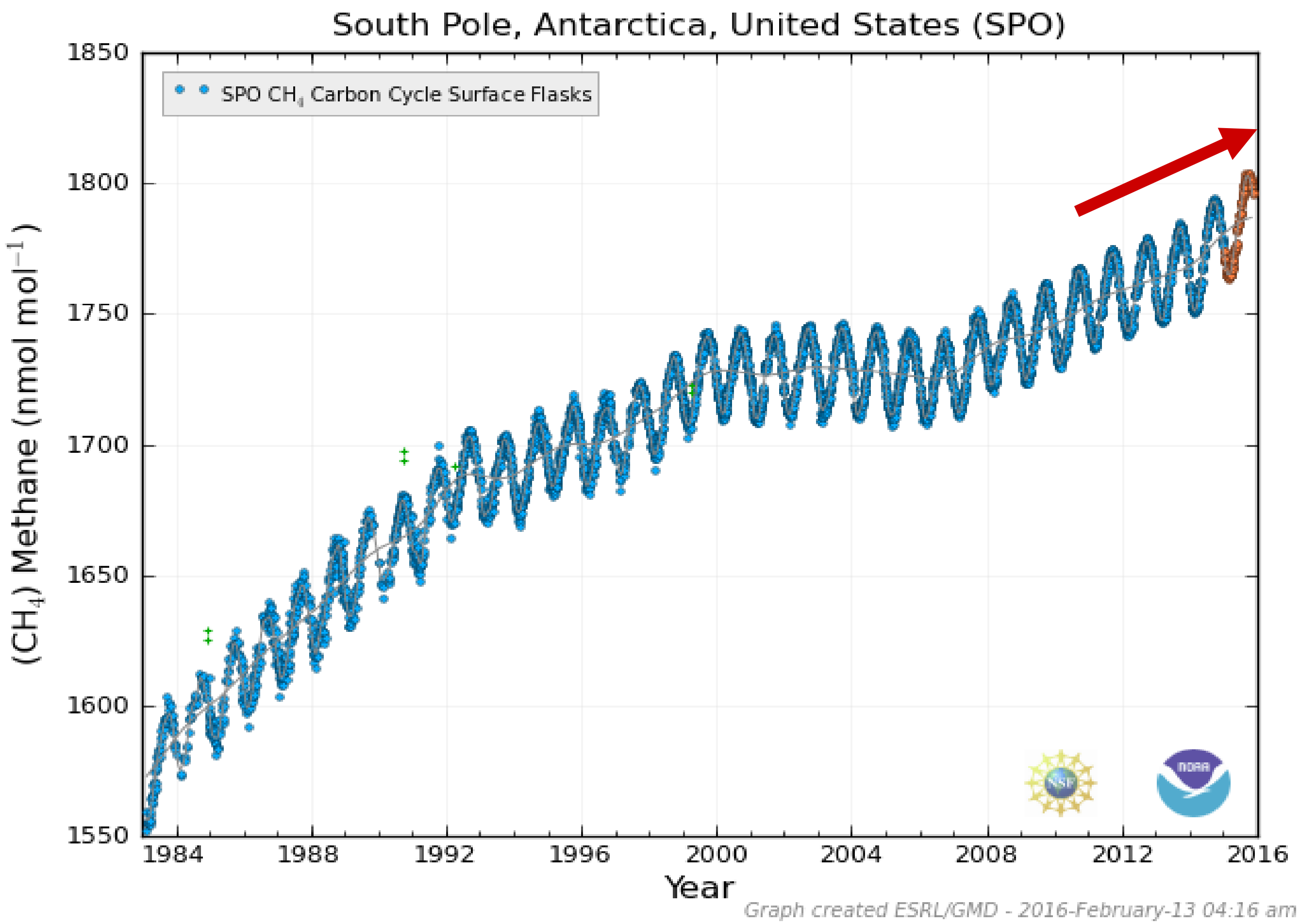
Understanding the CH_4 growth requires accurate knowledge of both sources and sinks

After Kirschke et al. 2013



- CH_4 has both natural and anthropogenic sources
- Wetlands are the largest and most uncertain source
- OH radicals remove each year most of the global emissions
- Uncertainties in sources often in the 30-100% range

In 2006 CH_4 began to increase after a decade of nearly stable concentrations – WHY??



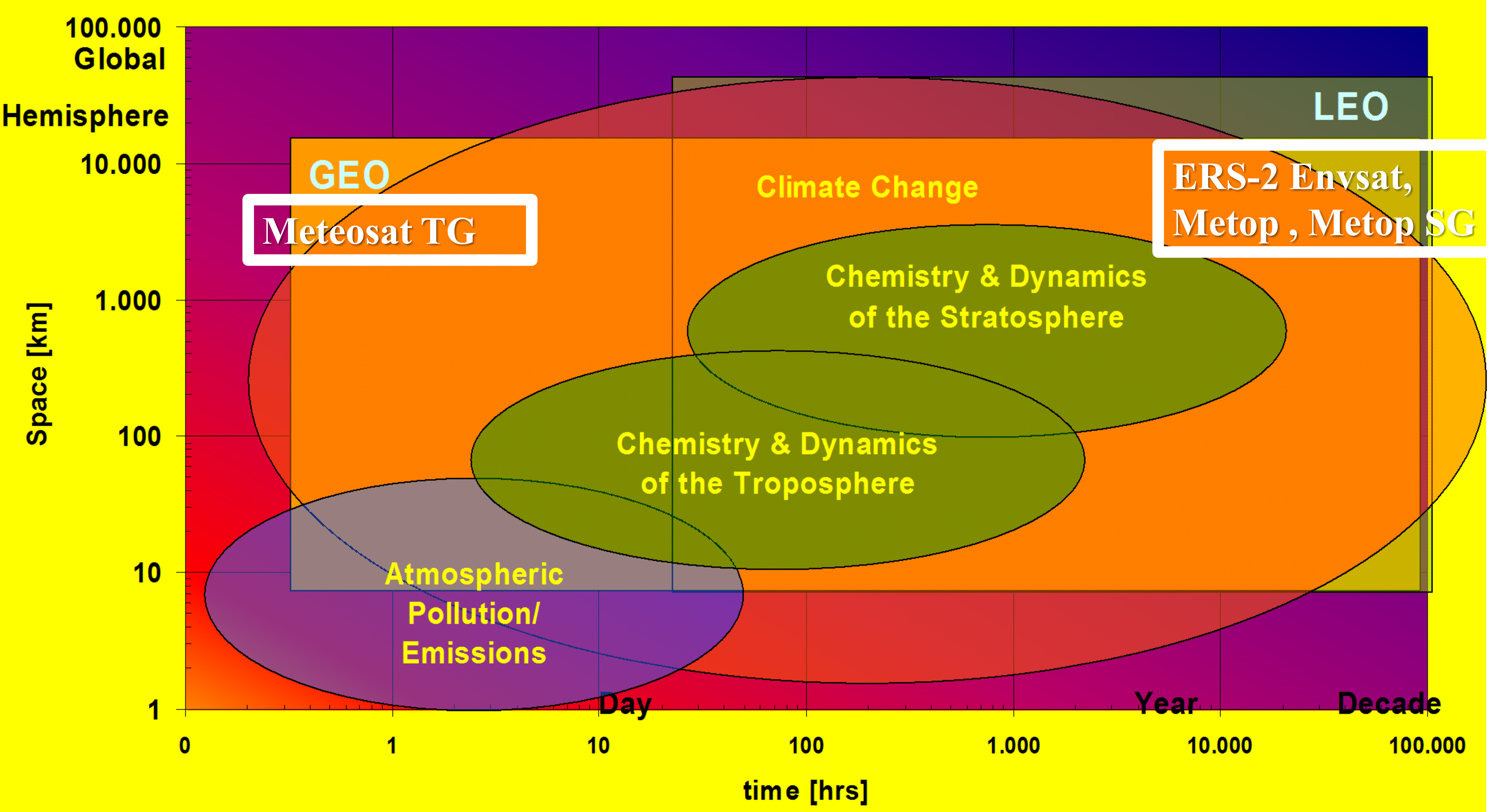
Recent increase since 2006

Wetland emissions ?

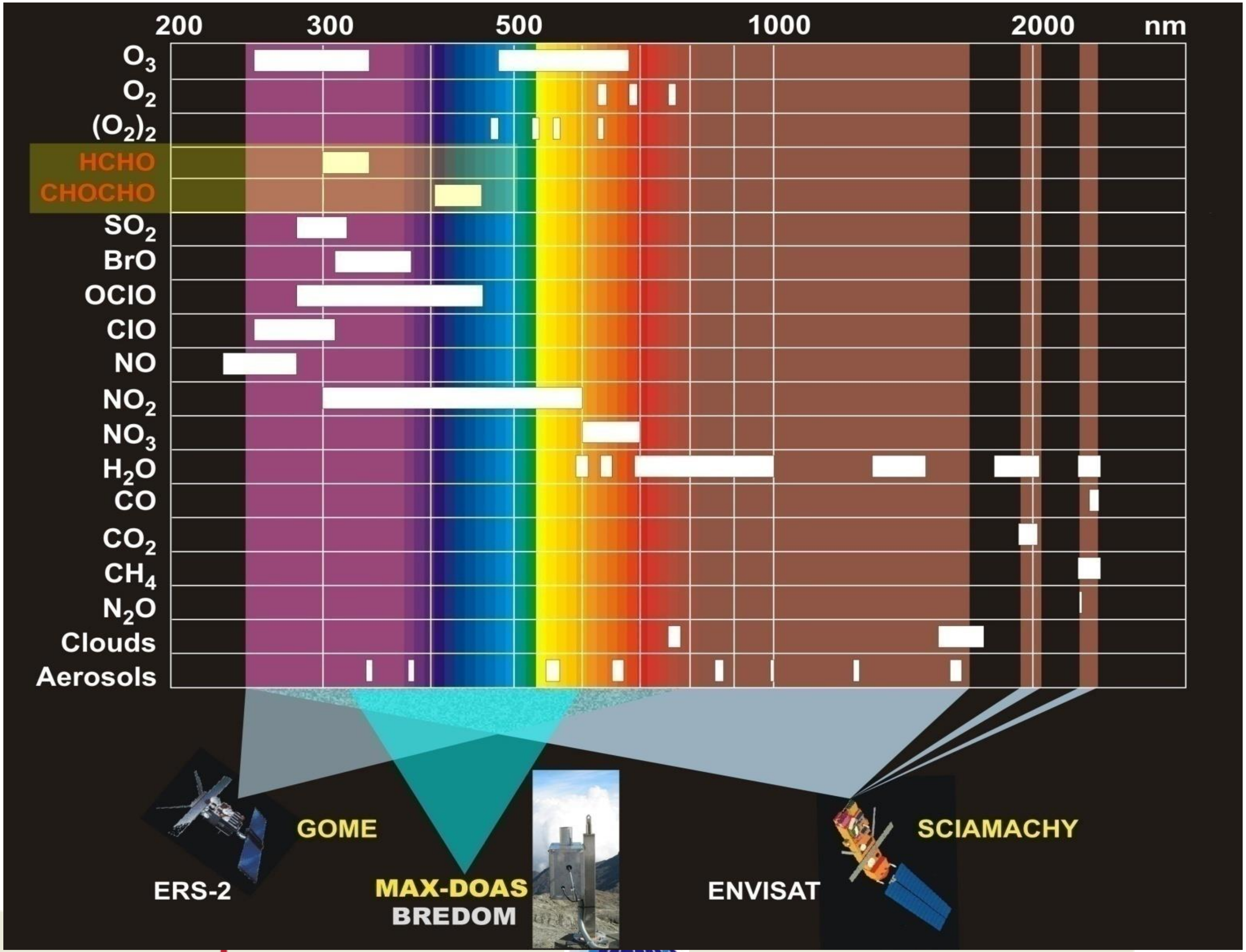
Increased fugitive emissions oil/gas/coal ?

- To understand why CH_4 is increasing, natural and anthropogenic sources must be quantified separately

Spatial and Temporal Scales relevant for measurements from LEO and GEO



SCIAMACHY: Target Molecules



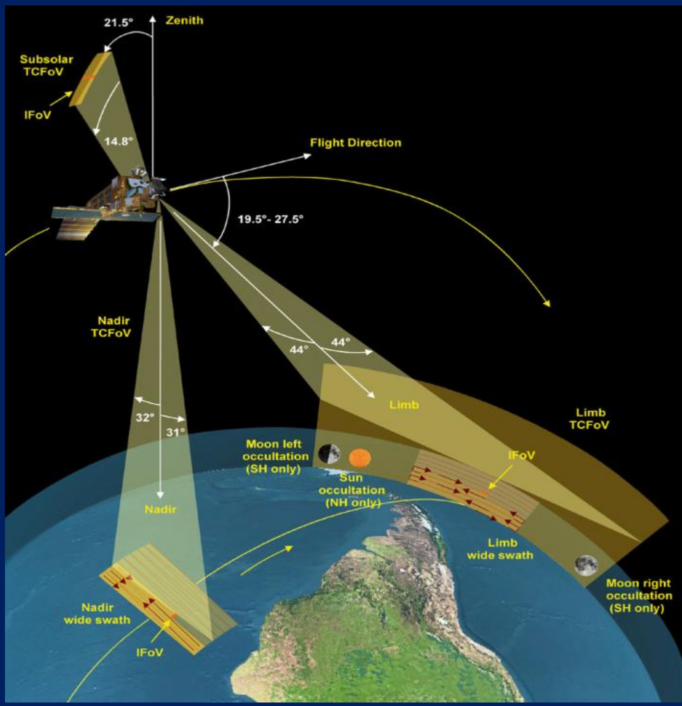
Some Highlights: Remote Sensing in the Anthropocene

1957	USSR launches Sputnik on the 4th October birth of space age and space race.
1958	The first U.S. satellite, Explorer, was launched on January 31, 1958.
1960s	First attempts to measure trace constituents by USSR and NASA.
1960 and 70s	NASA Nimbus Programme.
1980s	NASA Mission to Planet earth.
1970-2010	Pioneering Age perhaps a golden age
2010+	the challenge to create a measuremtn system fit for purpose

European LEO and GEO Passive Remote Sensing of trace consitutents in the Anthropocene - Some Relevant History

1984-1988	Development and Submission to ESA for POEM/ Envisat AO, of SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) concept Burrows et al – hunting light
1988	Proposal of SCIA-mini for ERS-2 later descrped to GOME
1989	Selection of SCIAMACHY for ENVISAT
1990	Selection of GOME for ERS-2
1995	Launch of GOME 20.04.1995
1998	Proposal of GeoSCIA IUP/IFE-UB to ESA EEM-1
2002	Proposal of GeoSCIA++ UV-VIS-NIR-SWIR-TIR/Ligthning/firto ESA EEM-2
2002	Launch of SCIAMACHY on ENVISAT 28.02 2002
2002	Proposal of GeoTROPE UV-VIS-NIR-SWIR-TIR to ESA EEM-3
2004/5	Proposal of GeoSCIA-R and GeoSCIA-Lite
2006	EUMESAT Post Metop Committee recommends GOME-2 follow on UVNS
2006	Methane and carbon dioxide Mapper MaMap 01– Aircraft - UB
2006	EU Copernicus funds UVNS/Sentinel 5 Metop Second Generation
2006	Launch of GOME-2 on MetOp A
2008	CarbonSat and CarbonSat Constellation studies at UB - SCIA Heritage
2010	CarbonSat selected for ESA EE8 Phase AB1 Studies
2011	Start of SCIA-ISS studies UB NICT / Decommssioning of ERS-2
2012	Loss of Envisat 9th April
2012	Launch of GOME-2 on Metop-B 17th September
2013	Sentinel 5 agreed for Metop Second Generation 2020- 2034
2016	Copernicus Carbon initiative

LEO Early Morning, Afternoon and Geostationary DOAS Instrumentation



<u>LEO Early Morning sun synchronous, Eq.crossing time 10:30 10:00 09:30</u>

GOME (SCIA-mini) on ESA ERS-2 1995-2011

SCIAMACHY onboard ENVISAT 2002 -2012
relatively high spectral resolution (0.2 nm to 0.5 nm), 240 – 2380 nm
(8 spectral channels), Pixel size: 30 km × 60 km at best;
Nadir/limb alternating measurements.

GOME-2 onboard MetOp-A, -B, -C 2007-2020
(MetOp-A / –B in operation since 2006 / 2012, MetOp-C planned for 2018)
Sentinel 5 on Metop Second Generation 2020-2035

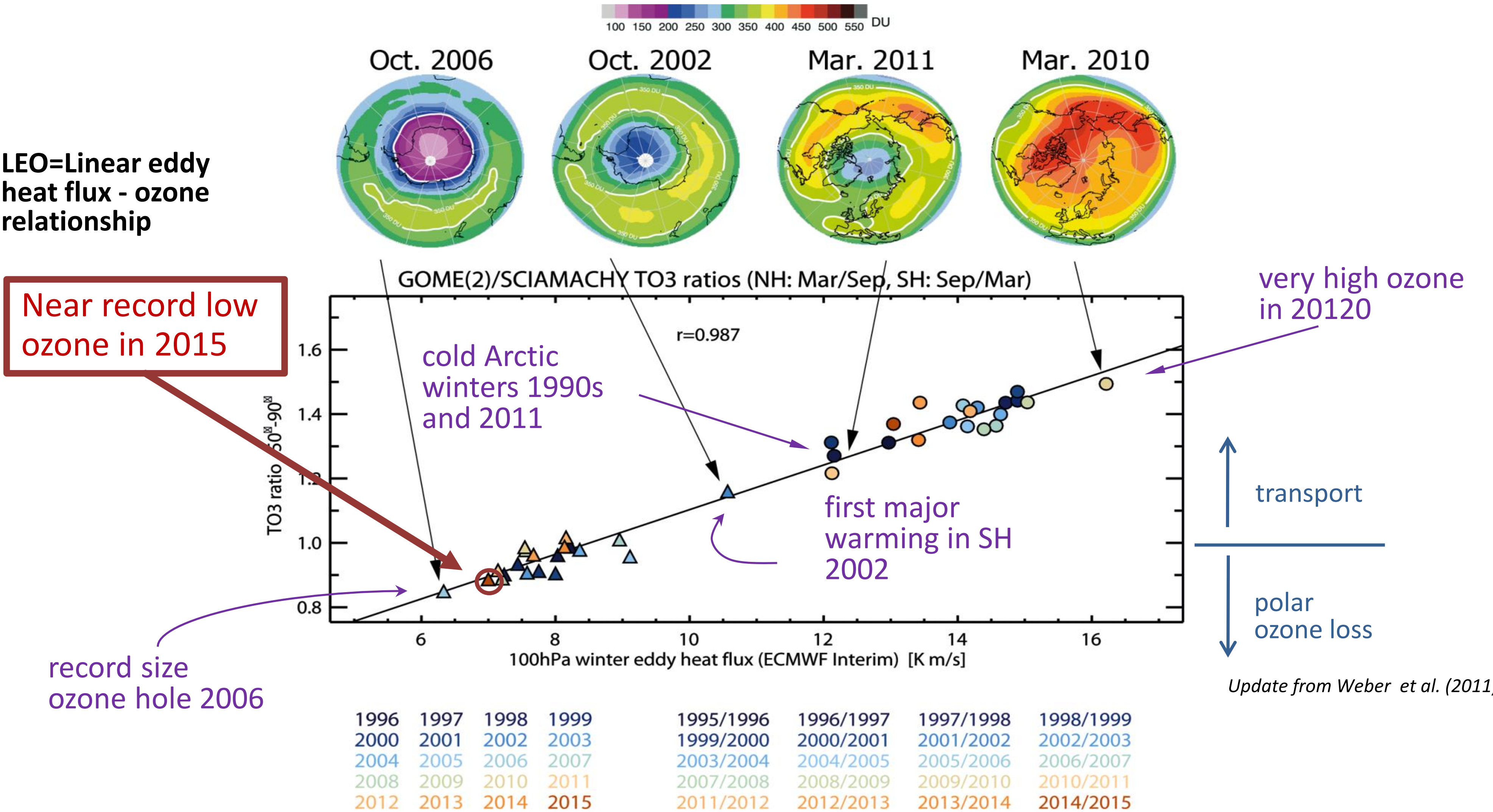
<u>Early Afternoon sun synchronous, Eq.crossing time ~13:30</u>
OMI onboard NASA AURA 2004-present
ESA Sentinel-5P (to be launched 2016)

<u>GEO Geostationary diurnal variation</u> — all independent to be launched 2019
Sentinel 4 (GeoSCIA) on Meteosat Third Generation — Europe North Africa
GEMS KSA — East Asia
TEMPO NASA — N. America, Central America, part of S. America

Some results about stratospheric Ozone from GOME SCIAMACHY GOME-2 data record

Coupling of transport and chemistry

Mark Weber et al - Linear eddy heat flux – ozone relationship„LEO“

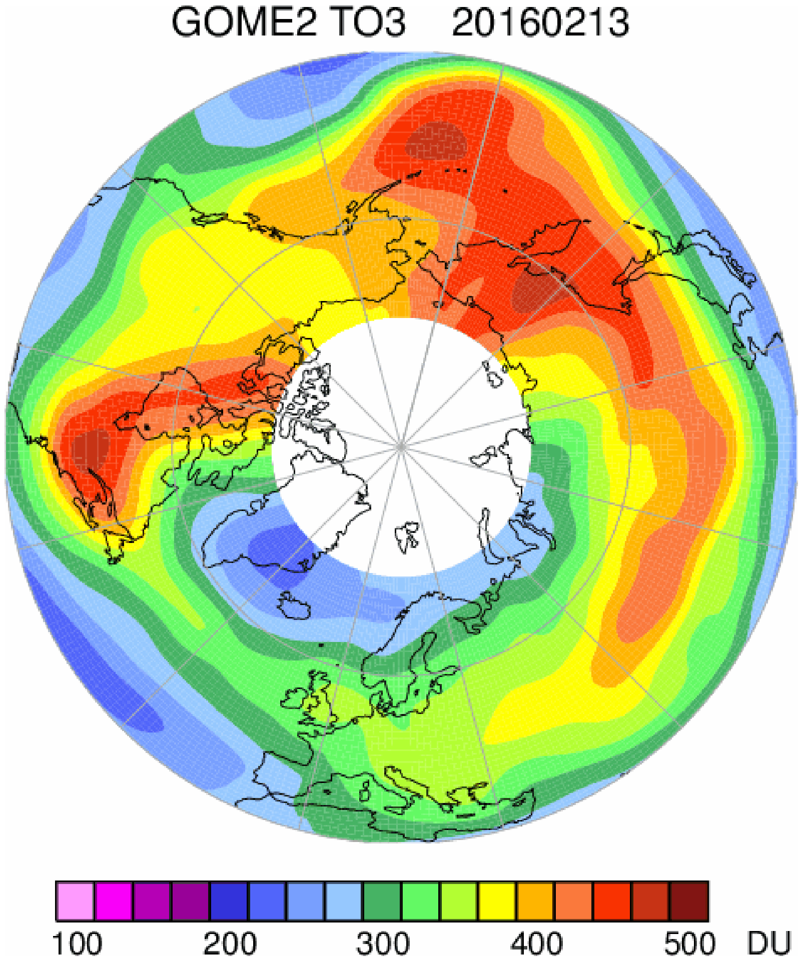


- weak Brewer-Dobson circulation
- low T/strong polar vortex
- high polar ozone loss

↔

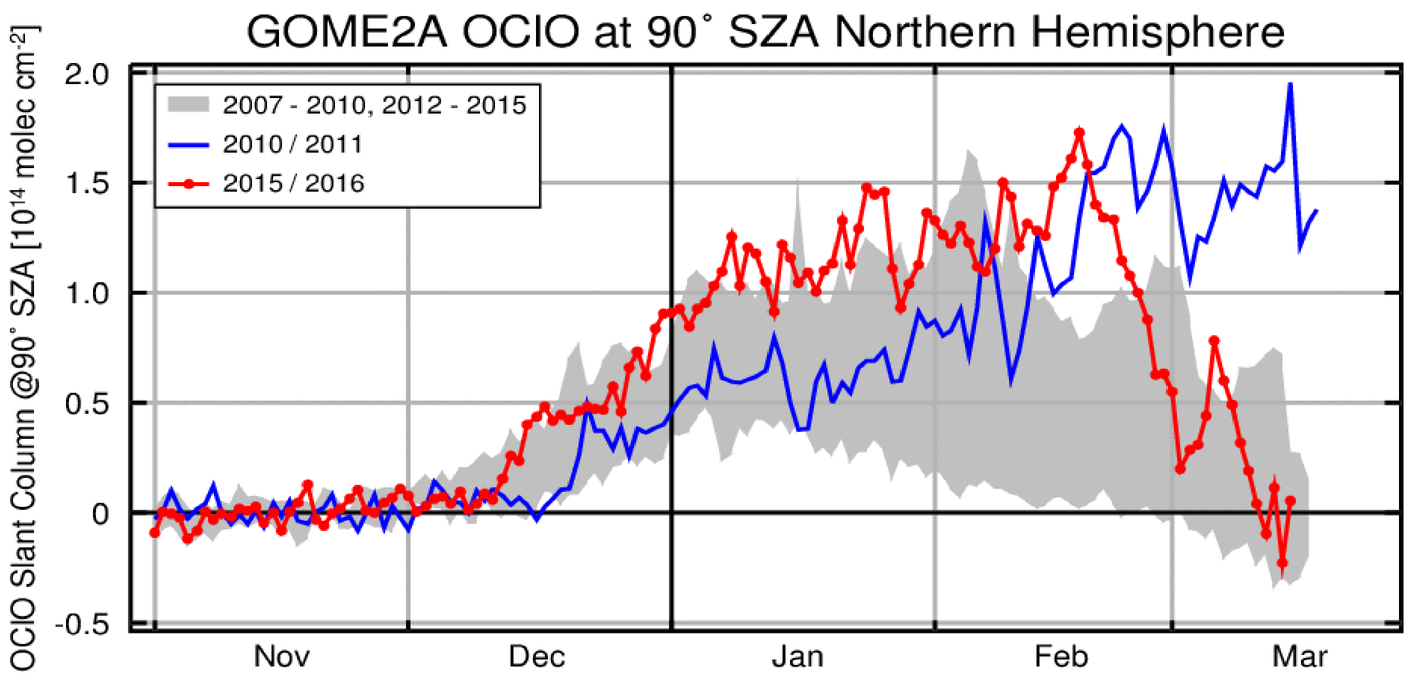
- strong Brewer-Dobson circulation
- high T/weak polar vortex
- enhanced ozone transport

GOME-2 Total Column Ozone 13 02 2016



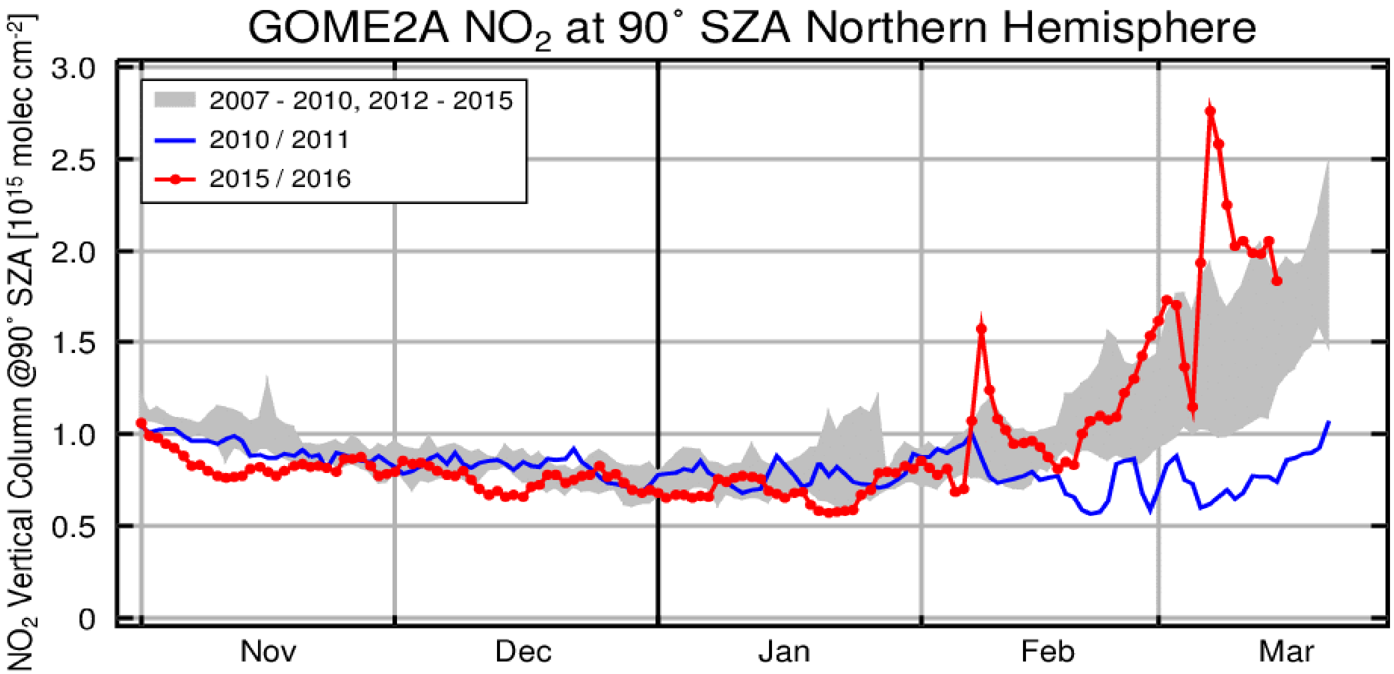
WFDOAS Algrothm Weber IUP Univeristy Bremen

GOME2A OClO Northern Hemisphere



- Large variability in OClO columns in the NH in spring
- 2015 / 2016 characterised by early and strong activation
- On most days from mid December 2015 – mid February 2016, OClO was at its maximum
- Activation stopped earlier than in 2010 / 2011 winter

GOME2A NO_2 Northern Hemisphere



- Small variability in NO_2 columns in the NH before February
- 2015 / 2016 characterised by low values (denoxification / denitrification)
- High NO_2 columns during warmings in February and March 2016
- 2010 / 2011 winter showed much more persistent low NO_2

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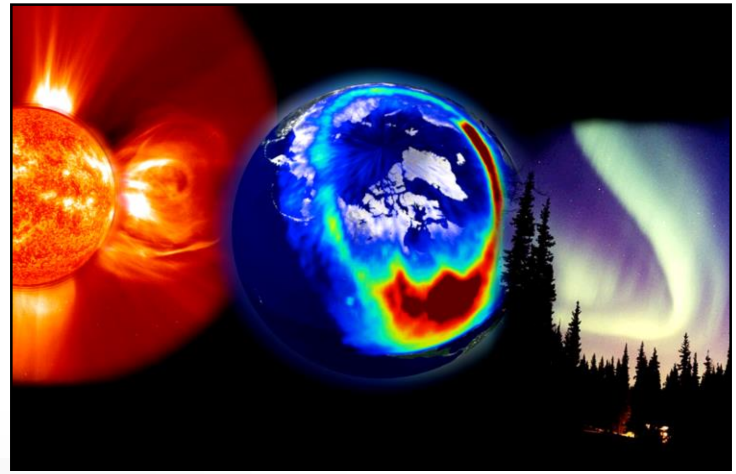
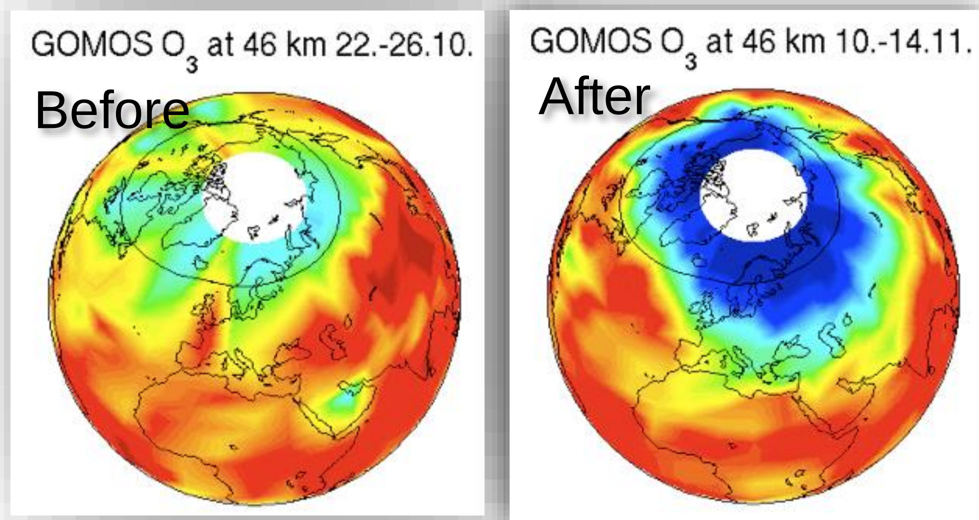
Solar Storm effects on atmospheric composition



GOMOS observations were the first to show ozone loss from solar storms in the polar wintertime atmosphere.



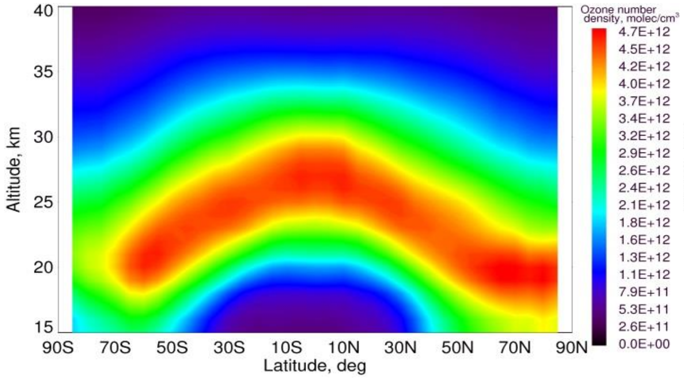
Big solar storms in Oct-Nov 2003 resulted in large amounts of charged particles being blasted out from the Sun. Storms travel through the space and arrive at Earth causing beautiful displays of Aurora in the polar regions. GOMOS observations showed that these particles also lead to large ozone loss in the polar atmosphere.

Seppälä et al. GRL, 2004

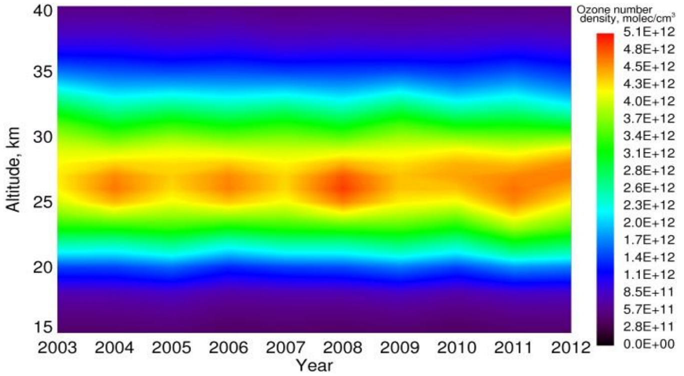
SCIAMACHY limb ozone, V2.9

Number density

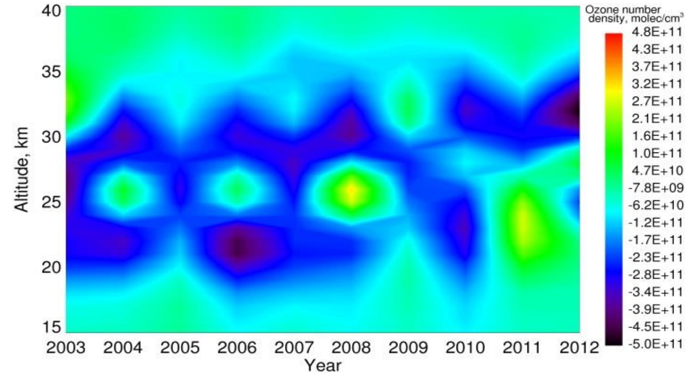
Zonal mean climatology, 2003 - 2011



Time series, 10S – 10S

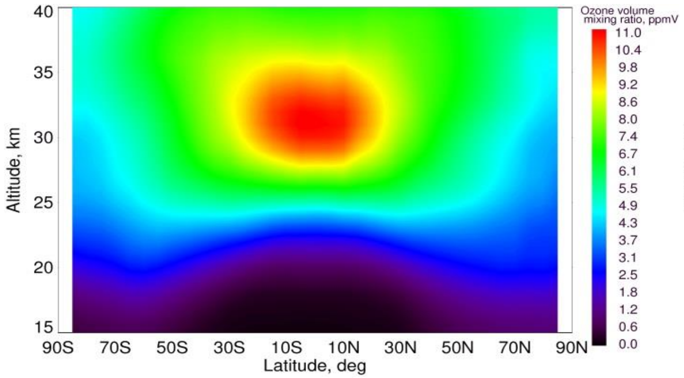


Anomalies, 10N – 10S

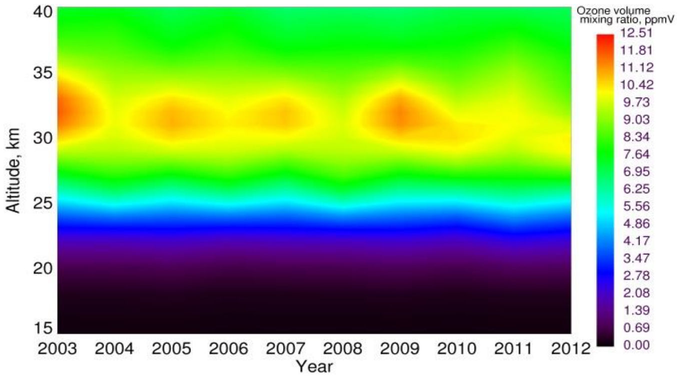


Volume mixing ratio

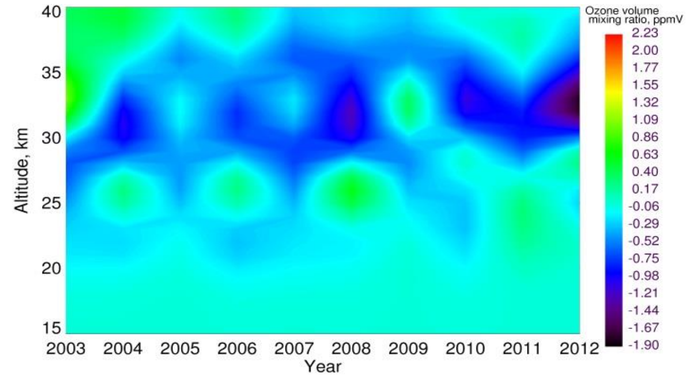
Zonal mean climatology, 2003 - 2011



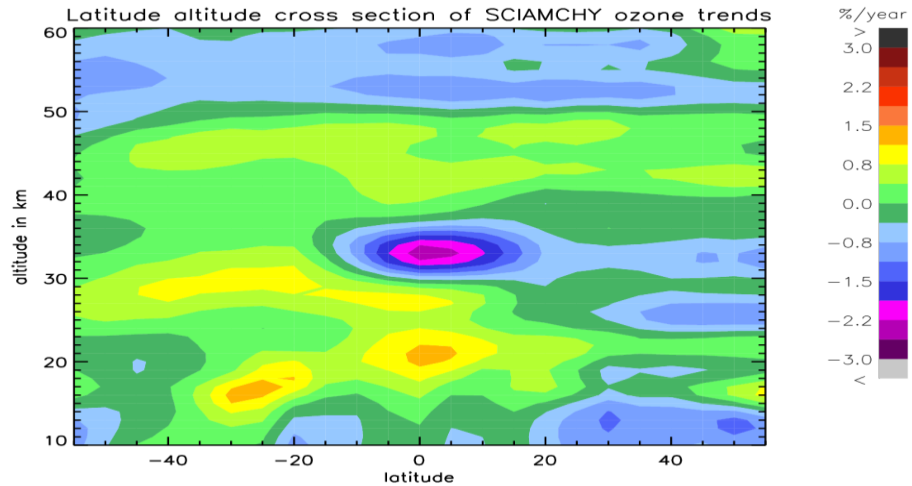
Time series, 10S – 10S



Anomalies, 10N – 10S



Latitude-altitude dependence of ozone trends
Impact of SST / T-hiatus on BDC



- minimum in the tropical 30-35 km range related slowing BDC and changing NO_X
  Gebhardt et al 2012 OQS and ACP 2013 and **Aschmann et al ACP 2014**

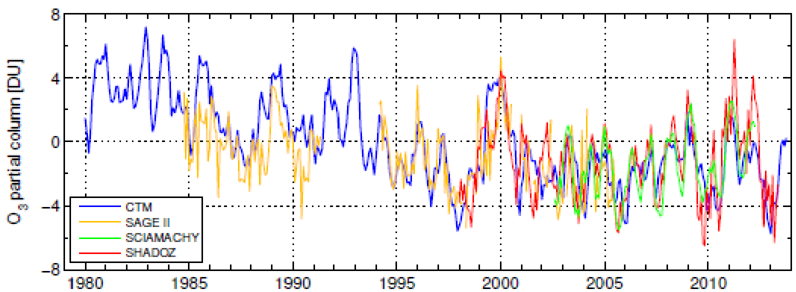


Fig. 2. Observed and simulated tropical (20° N–20° S) LS O_3 partial columns (17–21 km). Anomalies are deviations from the modelled 1980–2013 averages.

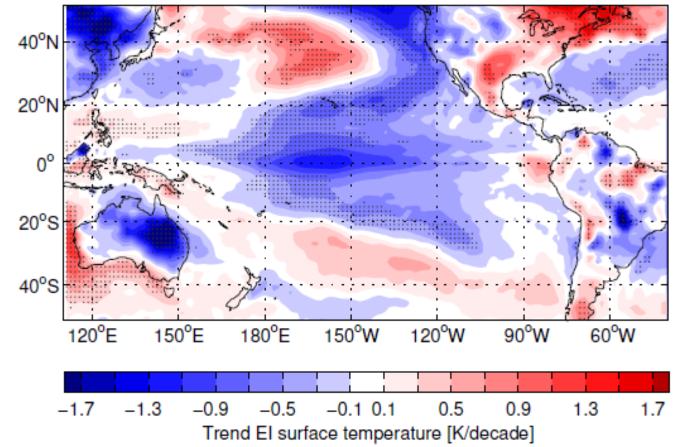
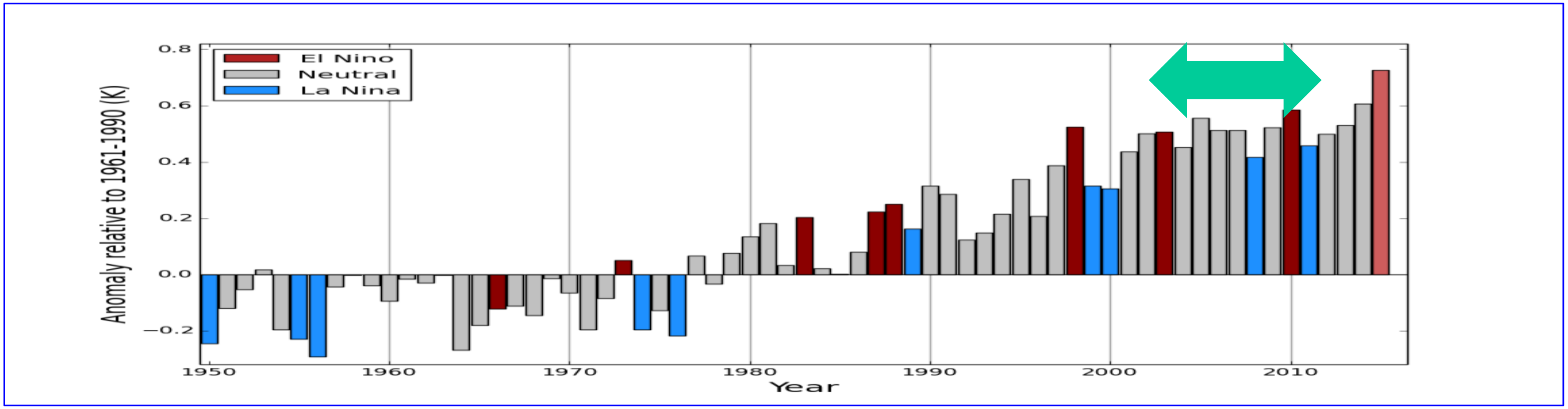


Fig. 5. Linear trends of El surface temperature from 2002–2013. Stippling indicates where the trend exceeds the 95 % confidence threshold. Setup adapted from Kosaka and Xie (2013).

Possible Explanation for the behaviour of O_3, NO_2, and BrO during the period of SCIAMACHY limb measurements



- Relatively cool pacific during the SCIAMACHY years
  perhaps tropical BDC vertical velocity is slower, somewhat longer residence times

- This leads to increase NOx from reaction of $O(^1D) + N_2O$ (or any N_2O + hv)

- This results in
  increase in O_3 when $k(O+O_2+M)[O][O_2][M] > k(O+NO_2)[O][NO_2]$
  decrease in O_3 when $k(O+O_2+M)[O][O_2][M] < k(O+NO_2)[O][NO_2]$

-

- contribution to positive ozone trends in the 15 – 25 km range possible

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Some results about short lived climate pollutants from GOME SCIAMACHY GOME-2 data record: focus on NO_2

Sources of NOx in the Troposphere

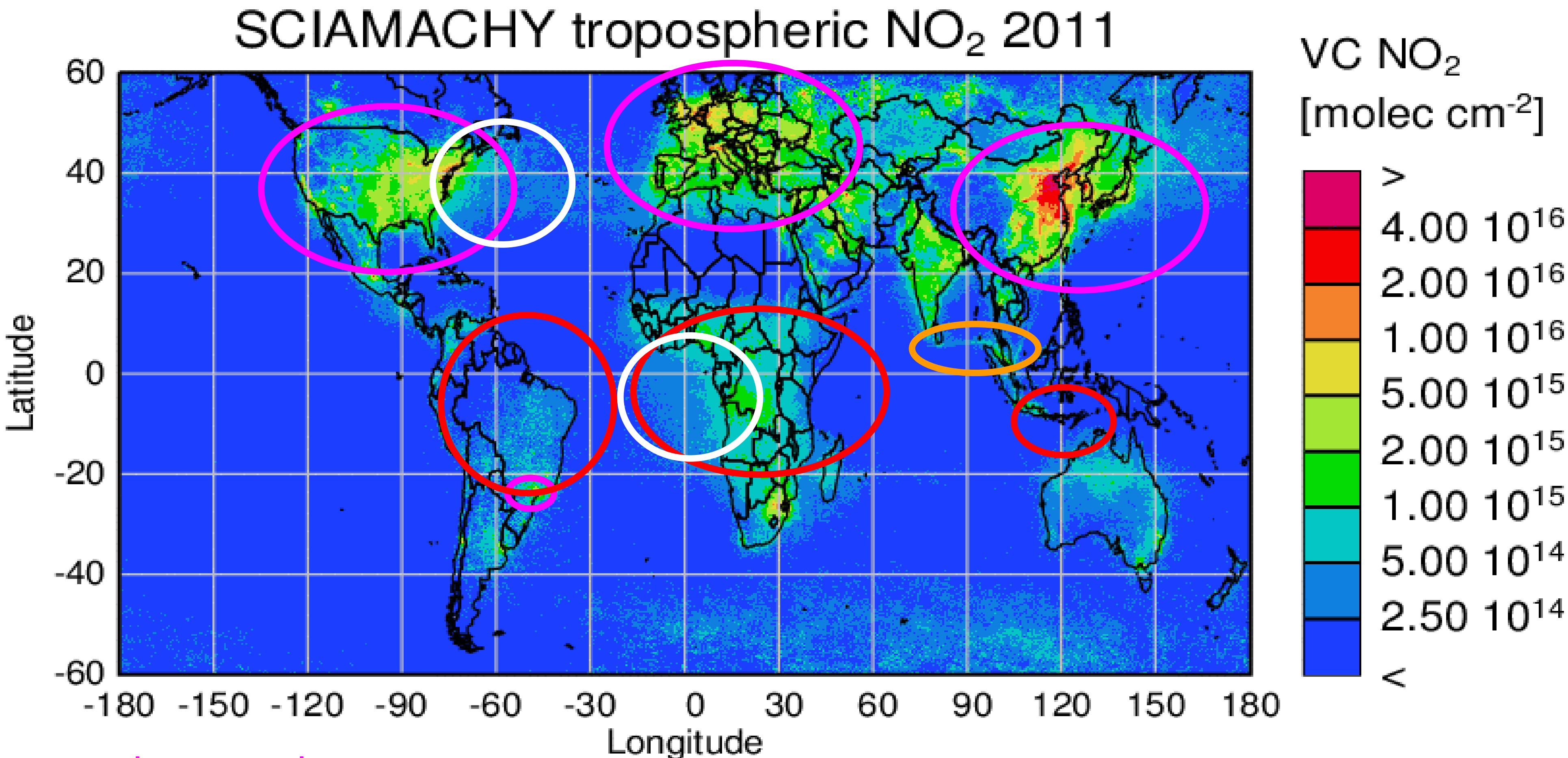
Sources of NO_x (in Tg N / yr) are

• fossil fuel combustion	22.0 (15 – 29)
• fires	6.7 (3 – 10)
• microbial soil emissions	5.5 (3.3 – 7.7)
• lightning	2.0 (1 – 4)
•	5+/-3 (2 – 8)*
• oxidation of biogenic NH_3	1.0 (0.5 – 1.5)
• aircraft	0.5 (0.5 – 0.6)
• stratosphere	0.5 (0.4 – 0.6)

R. Delmas et al., Nutrient Cycling in Agroecosystems, 48, 51 – 60, 1997

*U. Schumann and H. Huntrieser The global lightning-induced nitrogen oxides source Atmos. Chem. Phys., 7, 3823–3907, 2007

Tropospheric NO_2 and Sources?



anthropogenic pollution

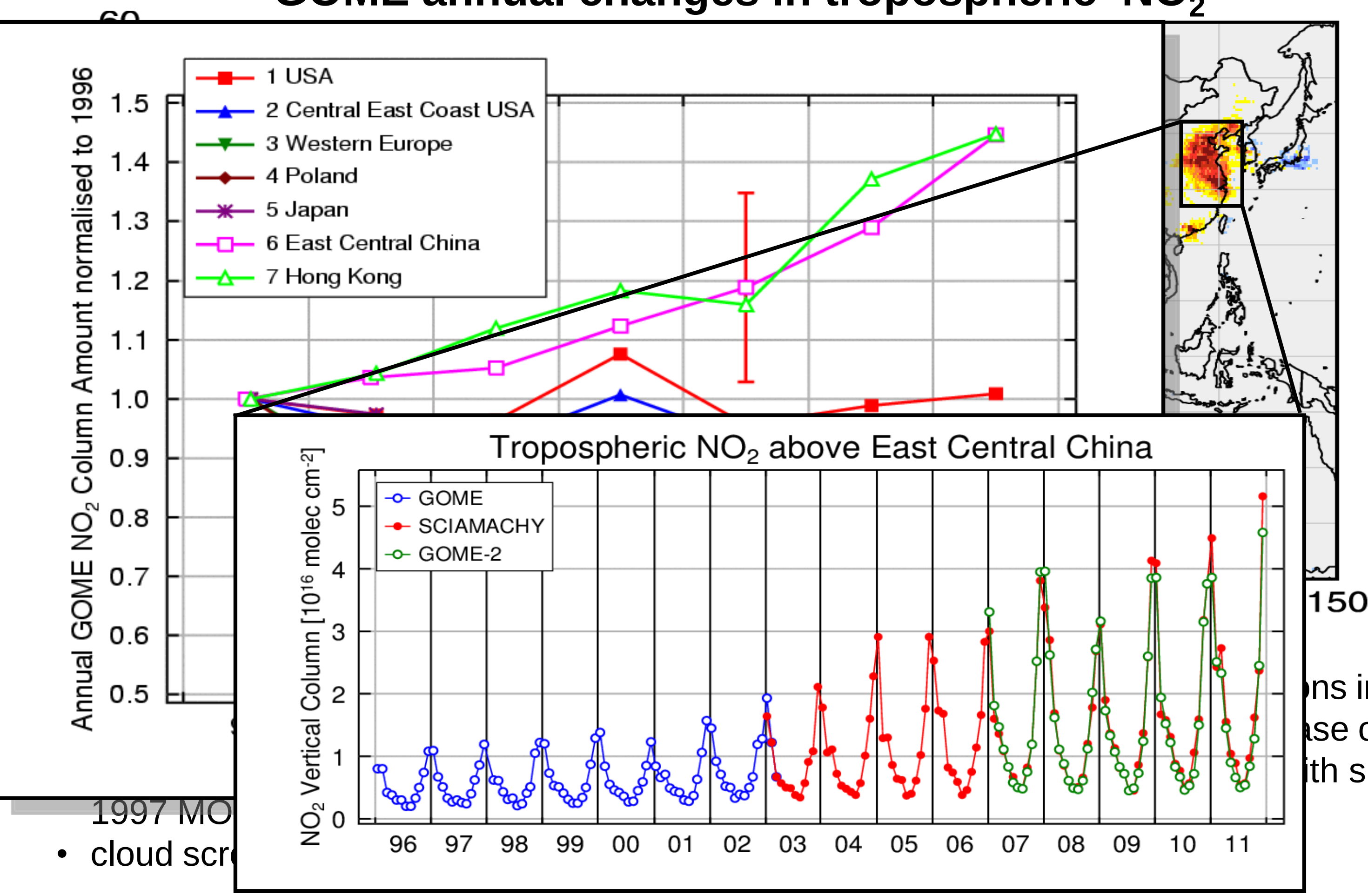
biomass burning

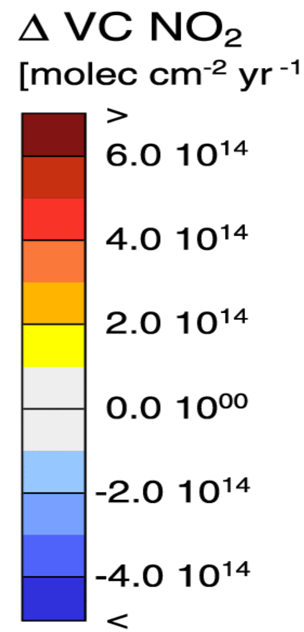
ships

transport

Satellite NO_2 Trends: The Global View

GOME annual changes in tropospheric NO_2





...ns in Europe and parts of the US

...se over China

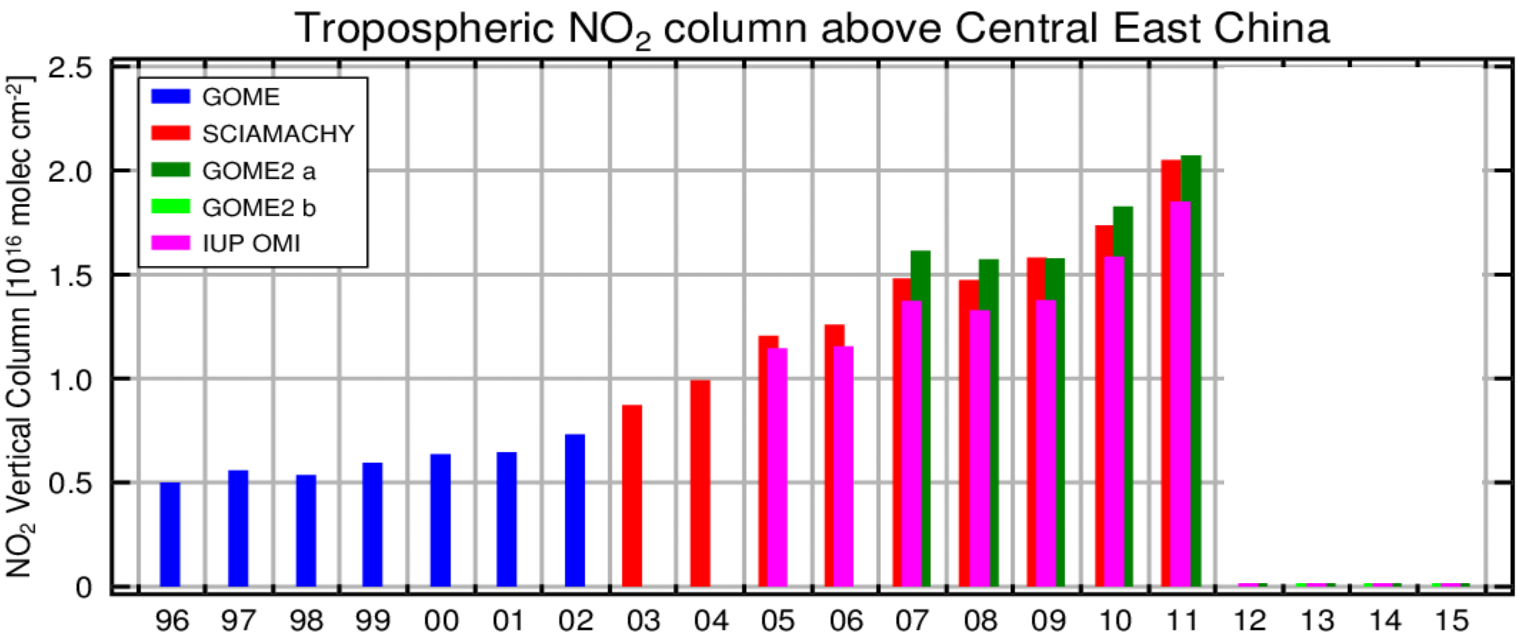
...ith significant NO_x emission changes

1997 MO...

- cloud scr...

A. Richter et al., Increase in tropospheric nitrogen dioxide over China observed from space, *Nature*, 437 2005

NO_2 Trends above Central East China



- Until 2011, there was continuous increase in NO_2
- After two years of stagnation, 2014 and 2015 saw large decreases

⇒ economic slow down?

⇒ Improved technology?

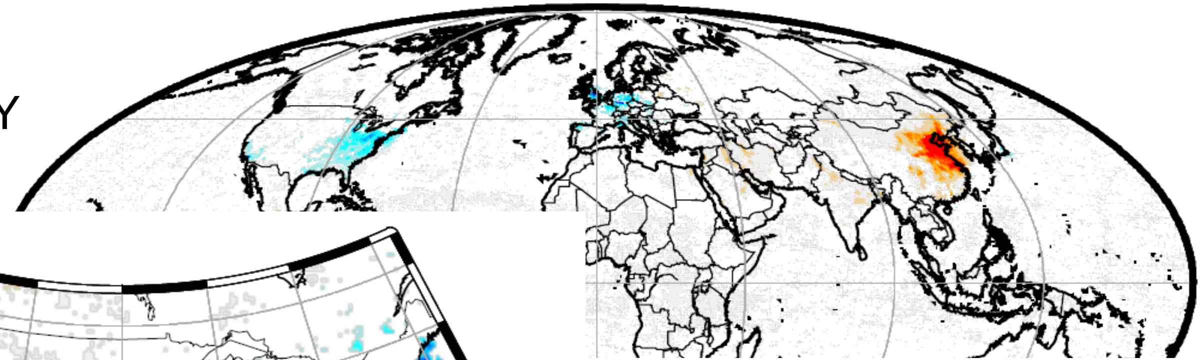
⇒ Switch in fuels used?

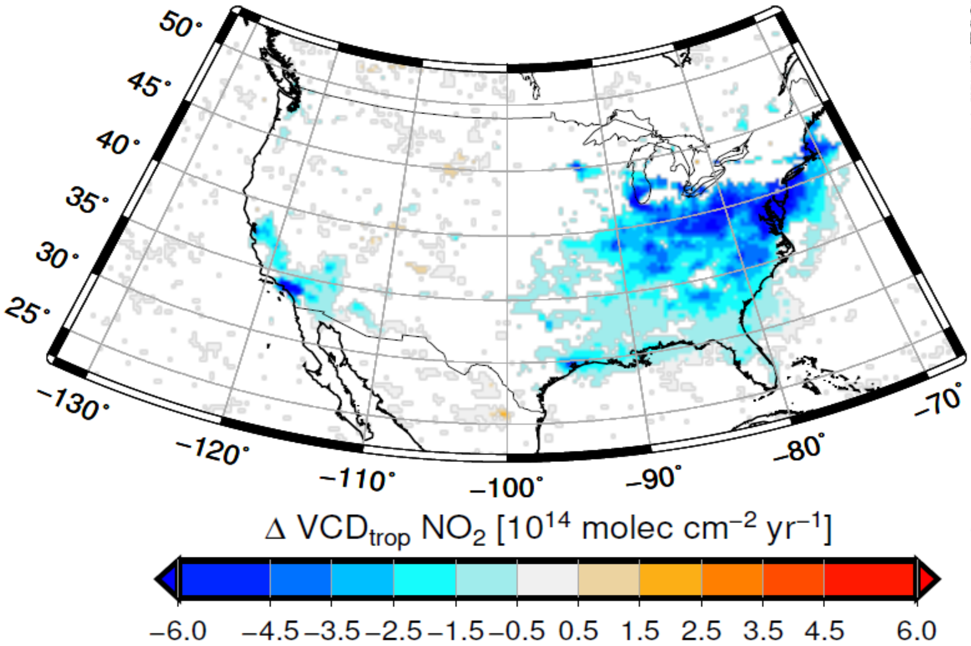
⇒ Other factors?

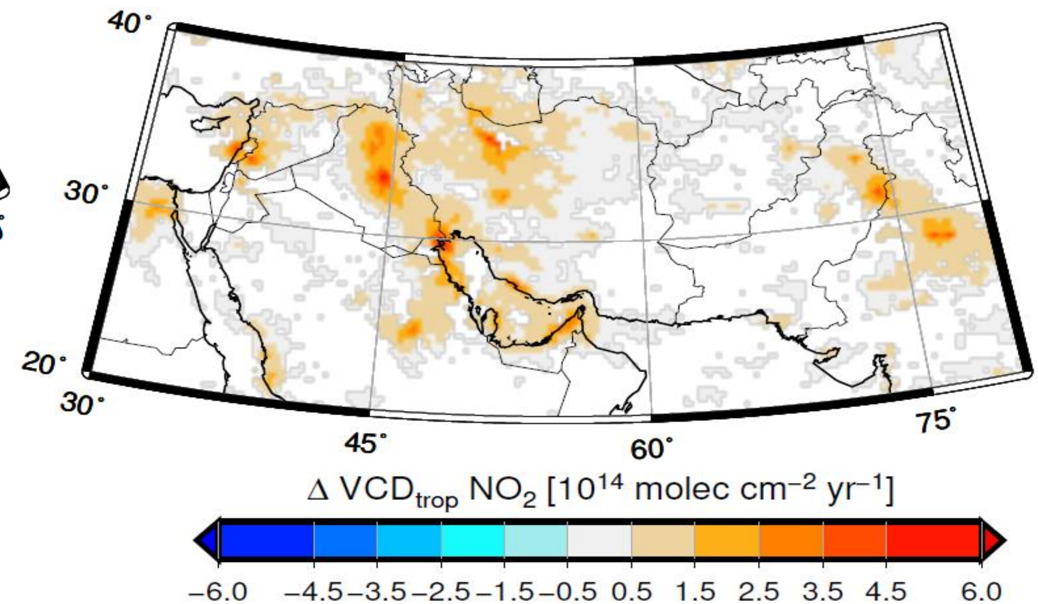
The spatial distribution of satellite NO_2 trends

GOME +
SCIAMACHY

1996 - 2011



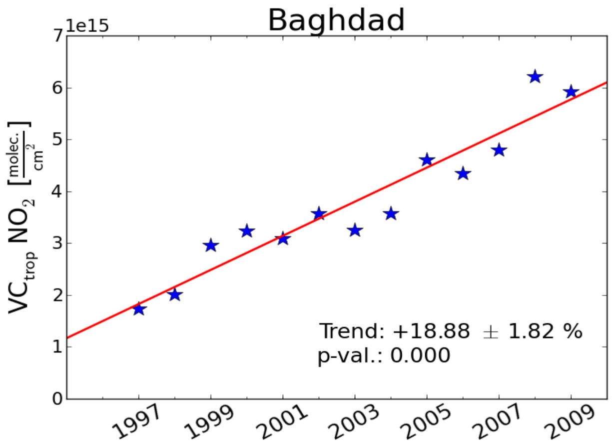


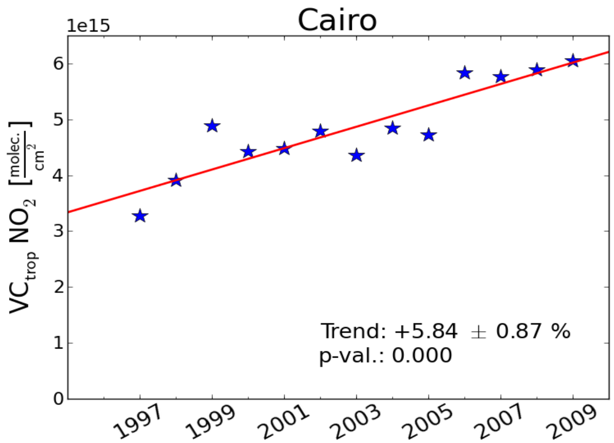


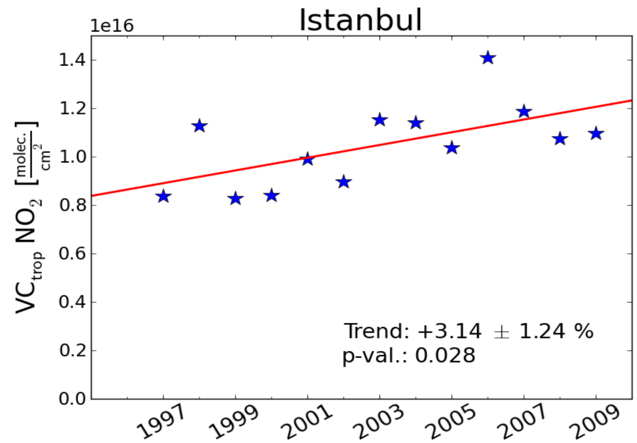
- Very consistent pattern
- Many cities can be identified

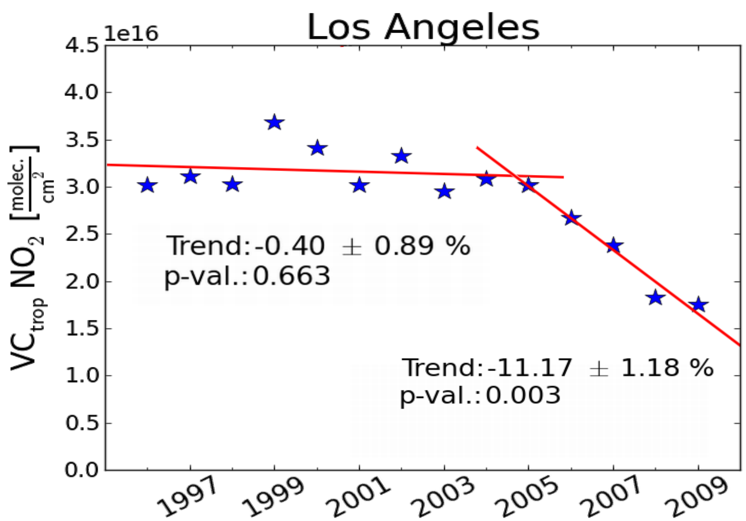
Hilboll et al., : Long-term changes of tropospheric NO2 over megacities derived from multiple satellite instruments, *Atmos. Chem. Phys.*, 13, 2013

NO_2 Trends over some Megacities/Urban Agglomerations





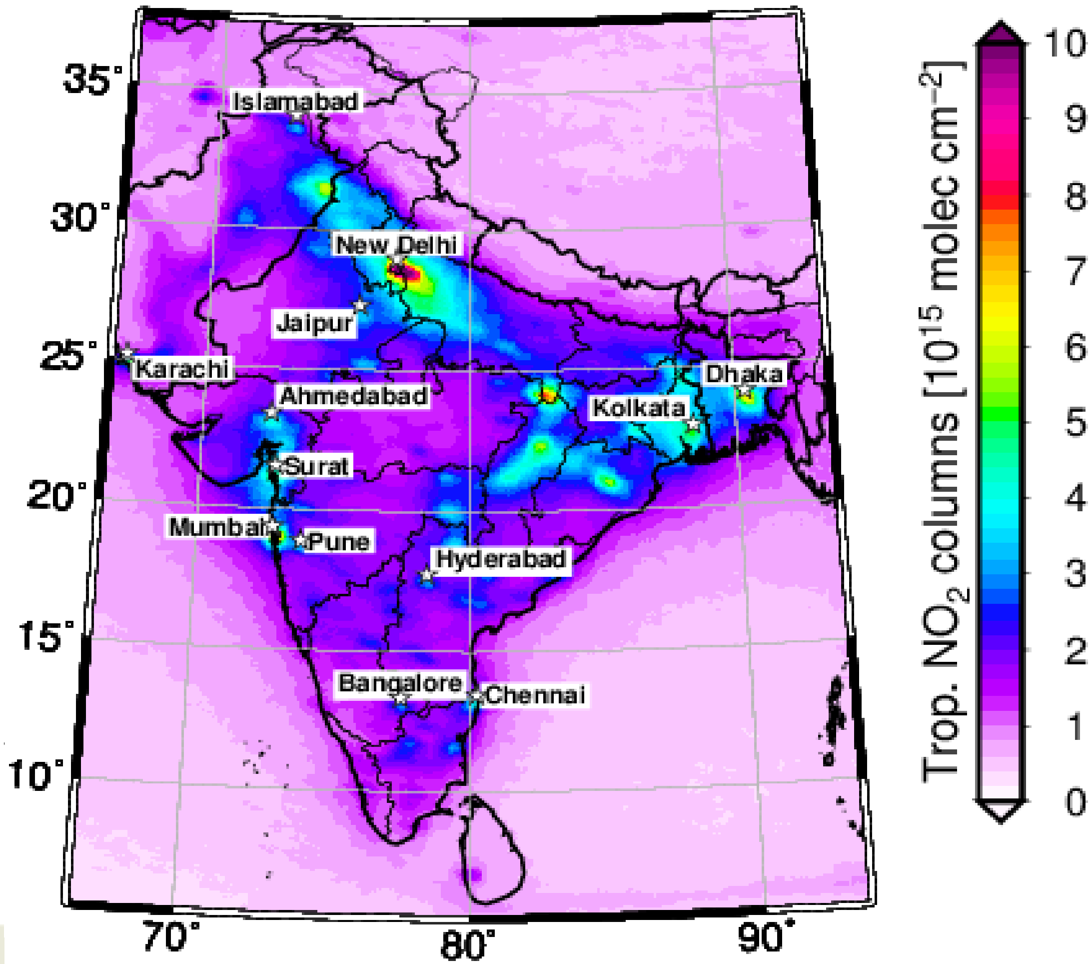




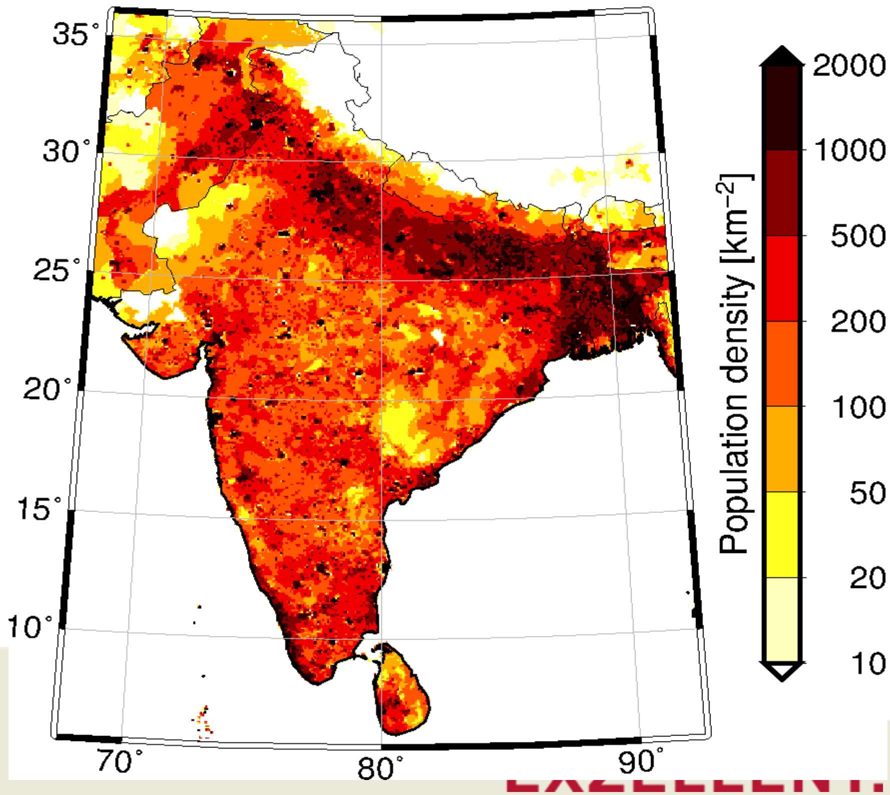
NO_2 levels are changing in cities throughout the world.
Contributing factors are

- Urbanisation
- Population growth
- Increase in standard of living
- changes in fuels used
- Improvements in emission controls

Tropospheric NO_2 column over Indian Subcontinent observed from space: SCIAMACHY (2003-2011)



Centres of Population are clearly visible



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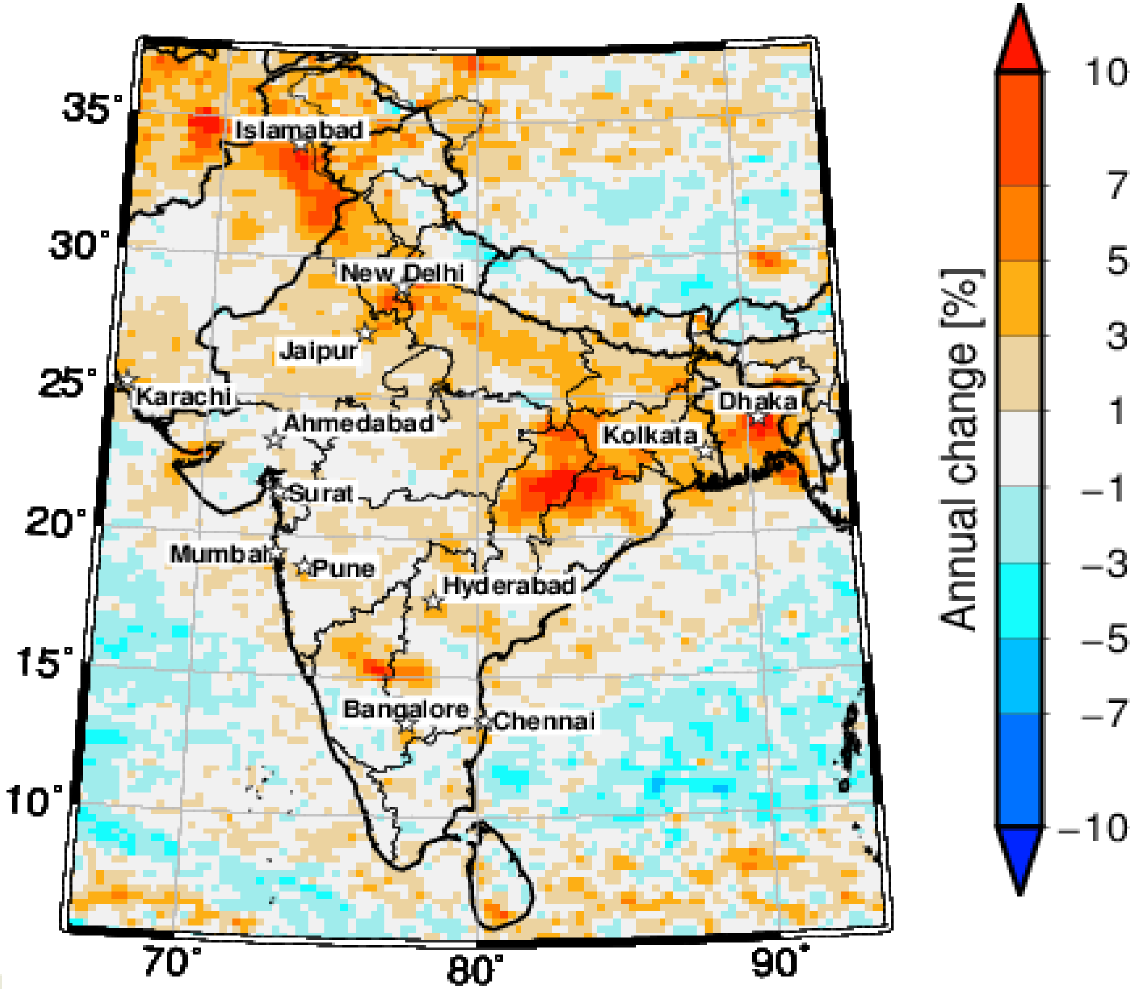
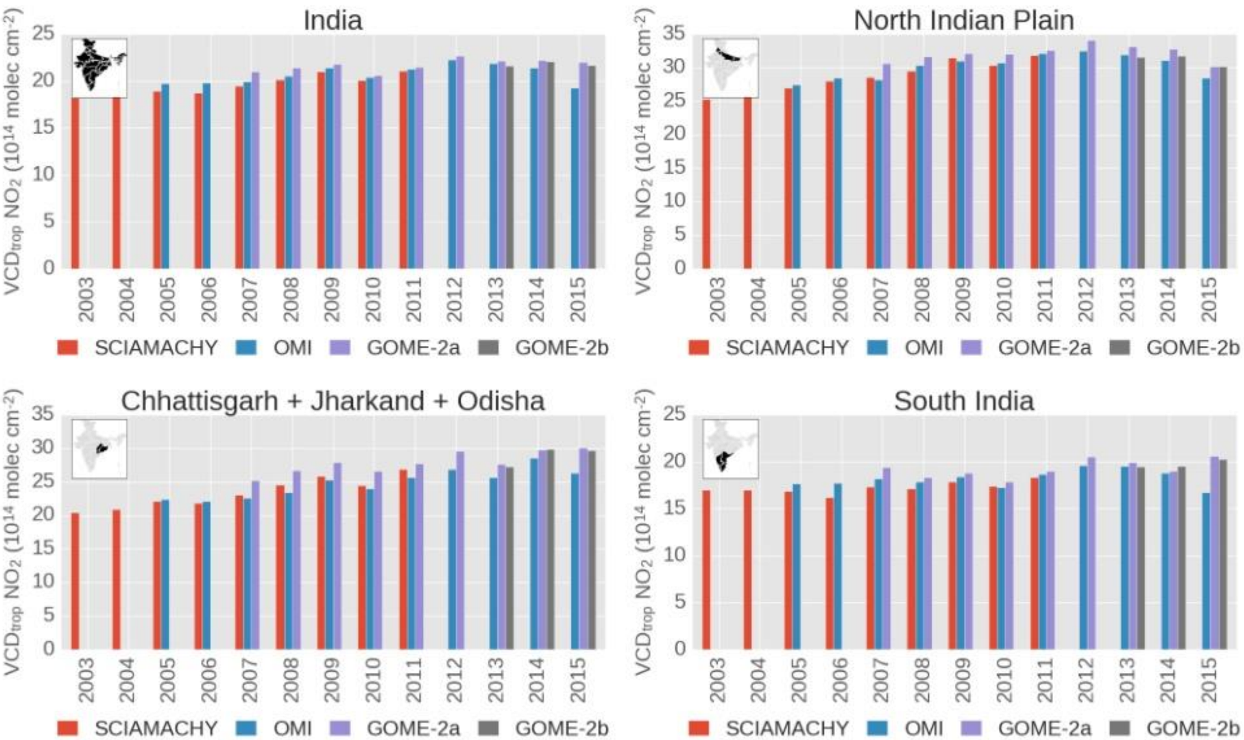
Tropospheric NO_2 over India/ South Asia strongly increasing in populated regions



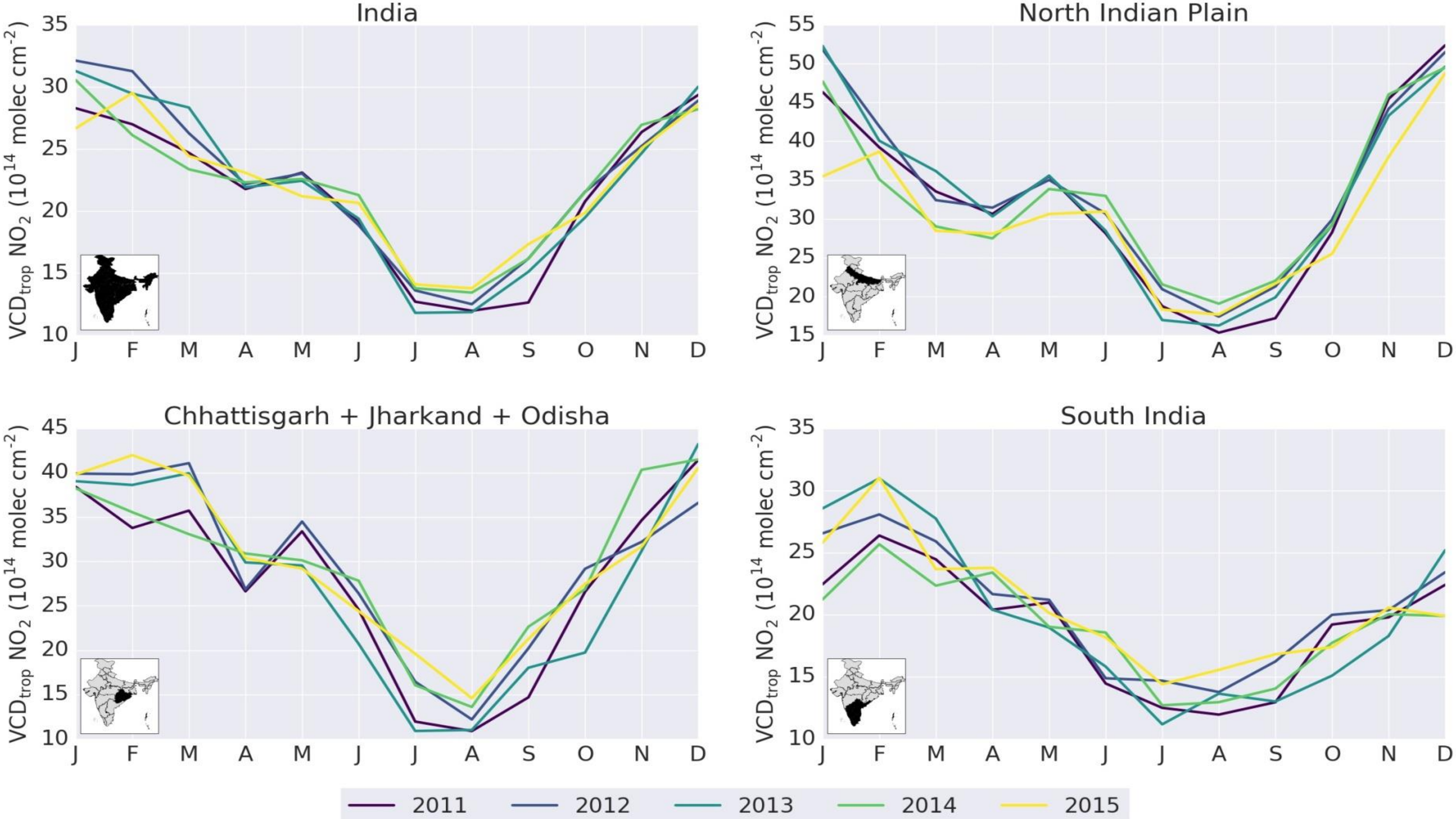
- Tropopsheric NO_2 strongly increases in major centres of population
- Attributed to fossil fuel, domestic heating and cooking and related
- Strongest relative increase is in Odisha and Chhattisgarh
- Attributed to heavy industry + electricity

Tropospheric NO_2 over India/ South Asia strongly increasing in populated regions



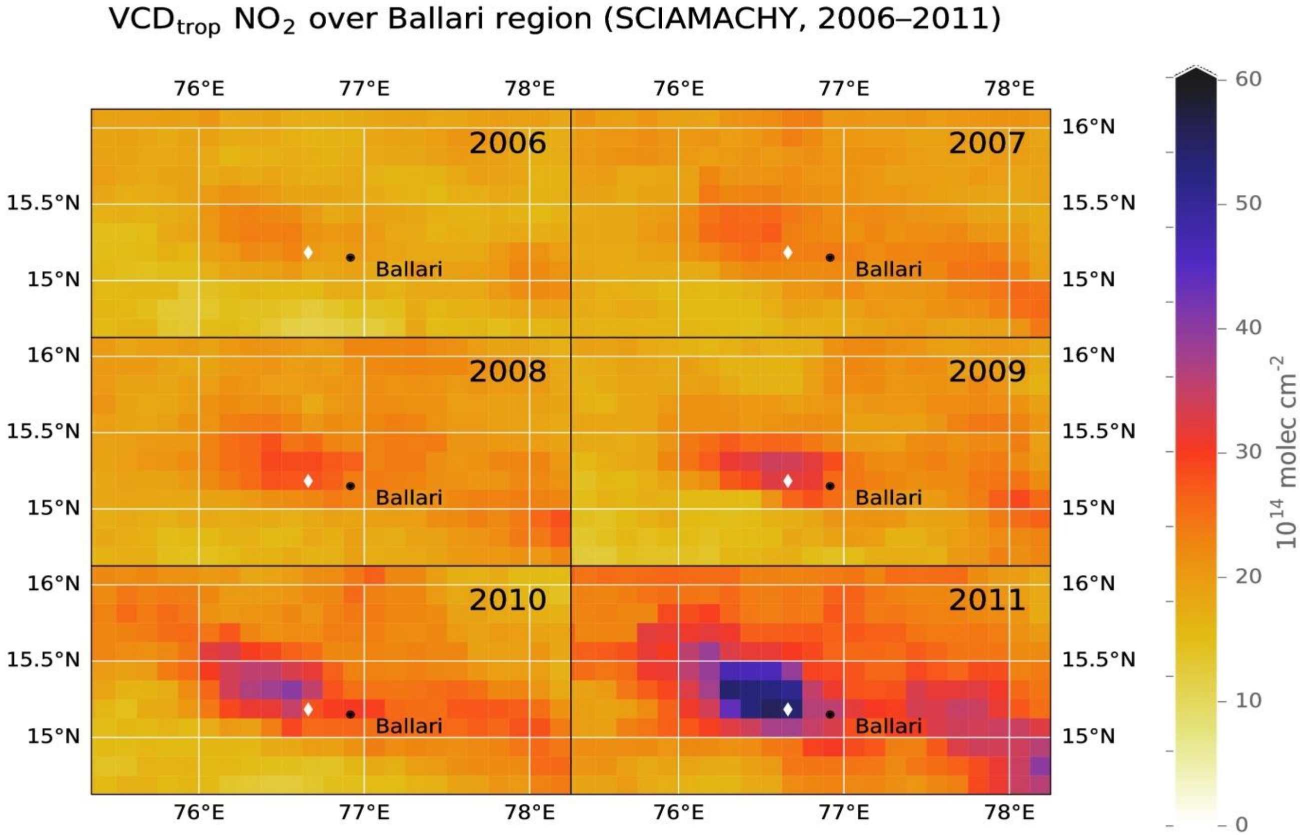
- Tropopsheric NO_2 strongly increases in major centres of population
- Attributed to fossil fuel, domestic heating and cooking and related
- Strongest relative increase is in Odisha and Chhattisgarh
- Attributed to heavy industry + electricity

Annual mean tropospheric NO_2 columns, as observed by the satellite instruments SCIAMACHY/ENVISAT, OMI/Aura, GOME-2/MetOp-A, and GOME-2/MetOp-B: All of continental India (top left), North Indian Plain (Haryana, Punjab, Bihar, Uttar Pradesh, Delhi, top right), Chhattisgarh, Jharkhand, and Odisha (bottom left), and South India (Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh, bottom right). Maps created with Cartopy (http://scitools.org.uk/cartopy) v0.14.2 using Natural Earth data.



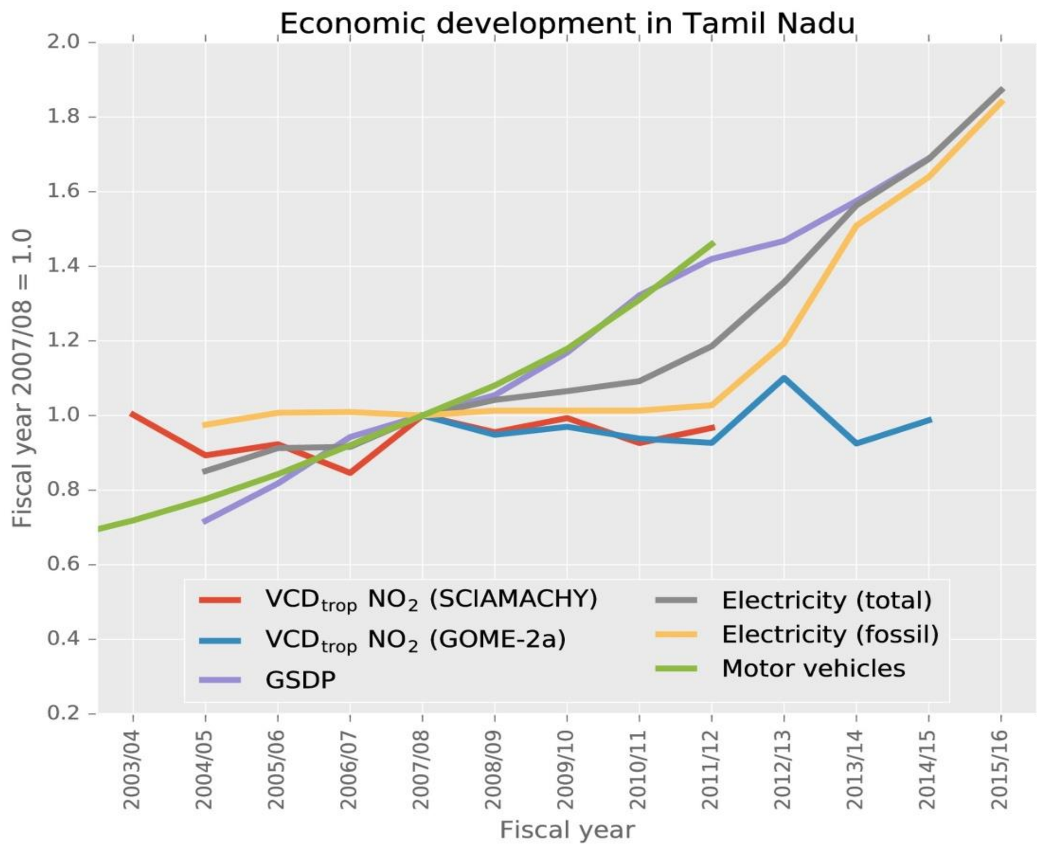
Inter-annual changes of the seasonal cycle of monthly mean tropospheric NO_2 columns, as observed by the satellite instrument GOME-2/MetOp-A: All of continental India (top left), North Indian Plain (Haryana, Punjab, Bihar, Uttar Pradesh, Delhi, top right), Chhattisgarh, Jharkhand, and Odisha (bottom left), and South India (Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh, bottom right). Maps created with Cartopy (http://scitools.org.uk/cartopy) v0.14.2 using Natural Earth data.

Tropospheric NO_2 column over Ballari in Karnataka, for non-monsoon months (SCIAMACHY 2003-2011) Impact of the Vijayanagar steel plant



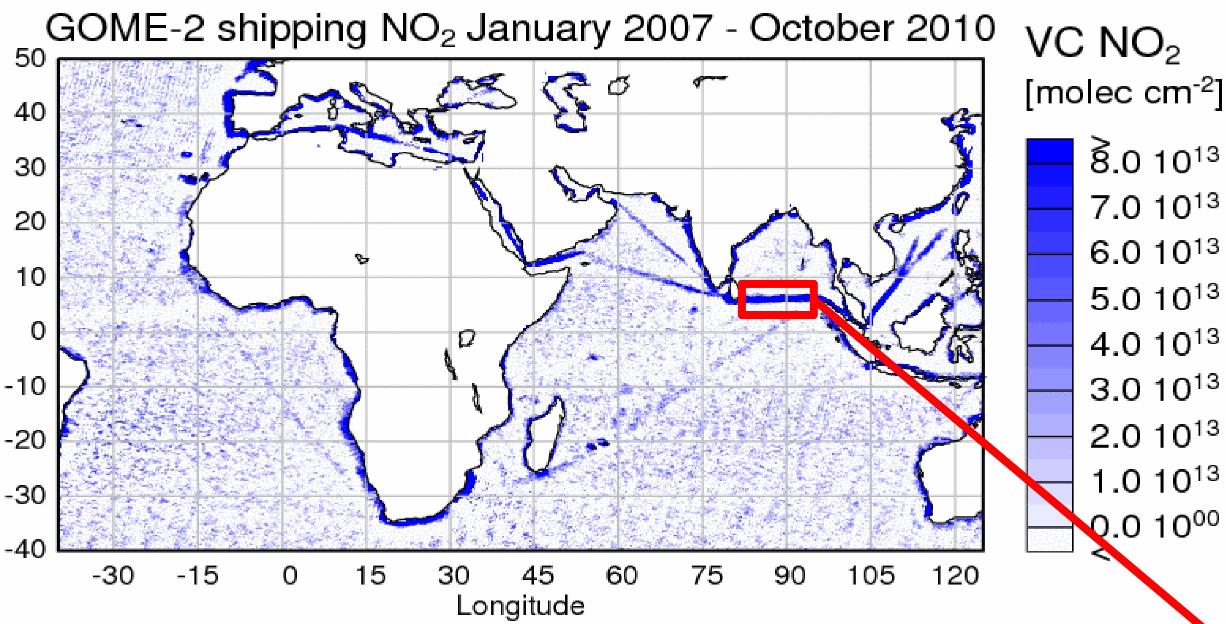
Annual mean VCD_{trop} NO_2 from SCIAMACHY measurements for the region around Ballari in Karnataka, for the years 2006–2011 (non-monsoon months only, i.e., May–Sep are excluded). The location of the Vijayanagar steel plant is marked in white.

Economic development of Tamil Nadu



Time series of VCD_{trop} NO_2 from SCIAMACHY and GOME-2/MetOp-A, as well of gross state domestic product (GSDP), installed electricity generation capacity (total and fossil fuel), and the number of registered motor vehicles. All values are given per fiscal year and have been normalised to 2007/08.

NOx Emissions from Shipping



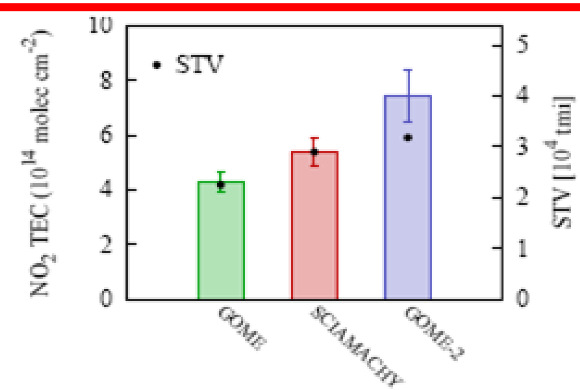
Ship emissions:

- large source of NO_x, SO_x and aerosols
- relevant input into marine boundary layer
- well defined NO_2 patterns in Red Sea and Indian Ocean in GOME-2 data
- consistent with pattern of shipping

With estimate of NO_2 lifetime, NO_x emissions can be estimated => agreement within error bars.

But: error bars mainly from lifetime)

A. Richter et al., Satellite Measurements of NO2 from International Shipping Emissions, *Geophys. Res. Lett.*, 31, L23110, doi:10.1029/2004GL020822, 2004
A. Richter et al..: An improved NO2 retrieval for the GOME-2 satellite instrument, *Atmos. Meas. Tech.*, 4, 1147-1159, doi:10.5194/amt-4-1147-2011, 2011



Franke et al., Atmos. Chem. Phys., 9, 7289-7301, 2009

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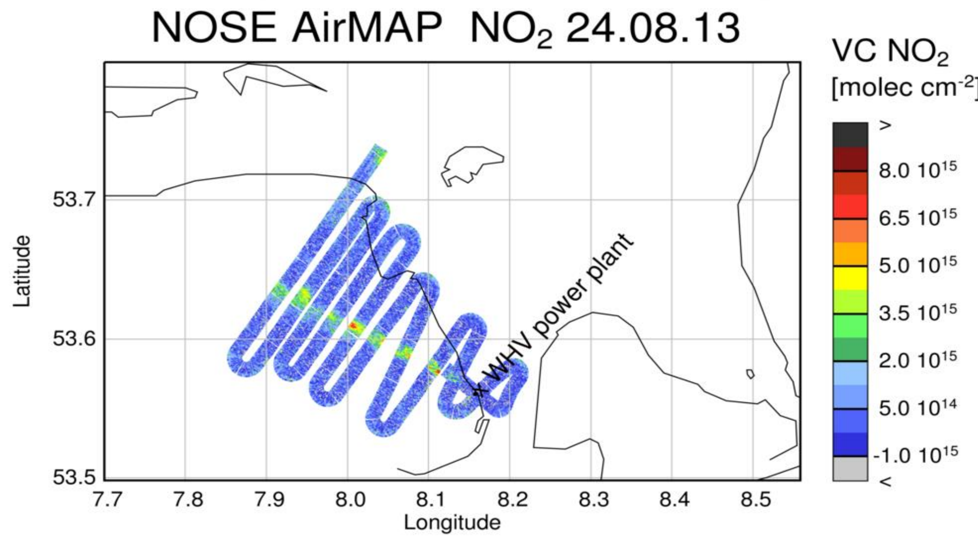
Latest Aircraft Instrument IUP UB - AirMap instrument

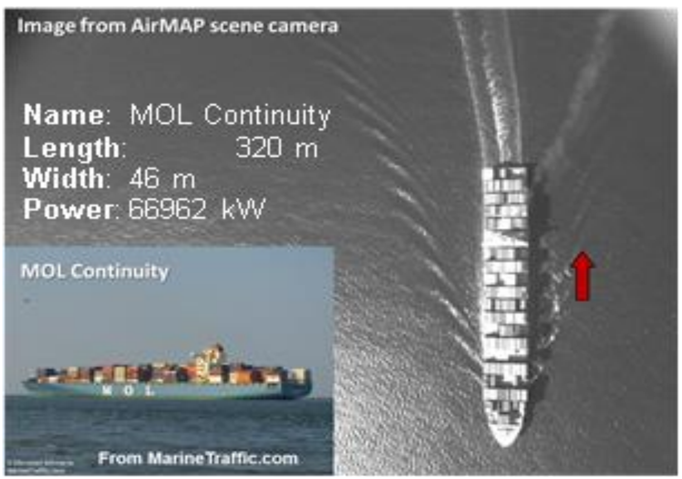
- Push-broom imager
- 48° field of view
- Swath ~ flight altitude
- Acton 300i spectrometer
- Princeton frame transfer CCD
- Fibre optics
- Only narrow spectral range
- Video camera, GPS
- At typical
  - flight altitude (3000m)
  - aircraft speed (60m/s)
  - Integration time (0.5s)

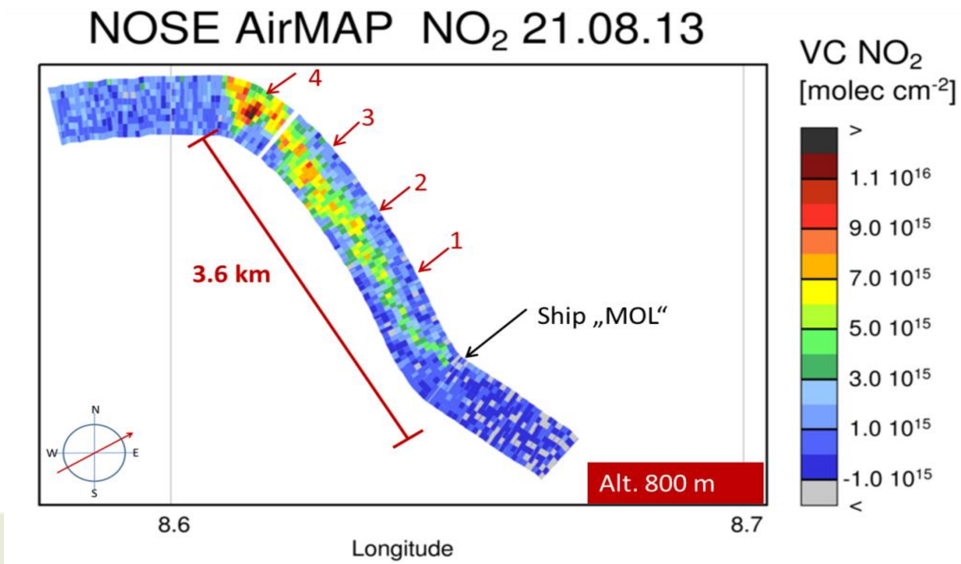
  $\Rightarrow$ 35 pixels @ **80 x 30 m^2**

Schönhardt, A., : A wide field-of-view imaging DOAS instrument for continuous trace gas mapping from aircraft, *Atmos. Meas. Tech. Discuss.*, 7, 3591-3644, doi:10.5194/amtd-7-3591-2014, 2014

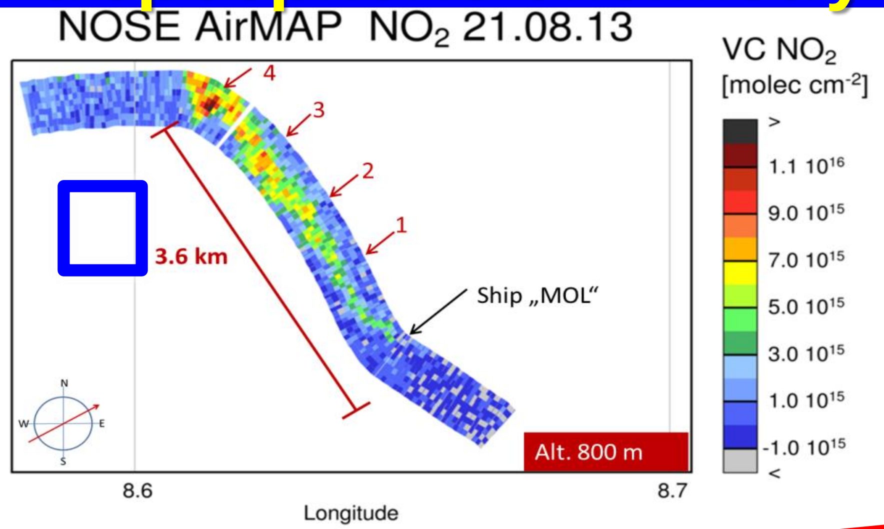
Some Recent AirMap targets – Northern Germany and Shipping

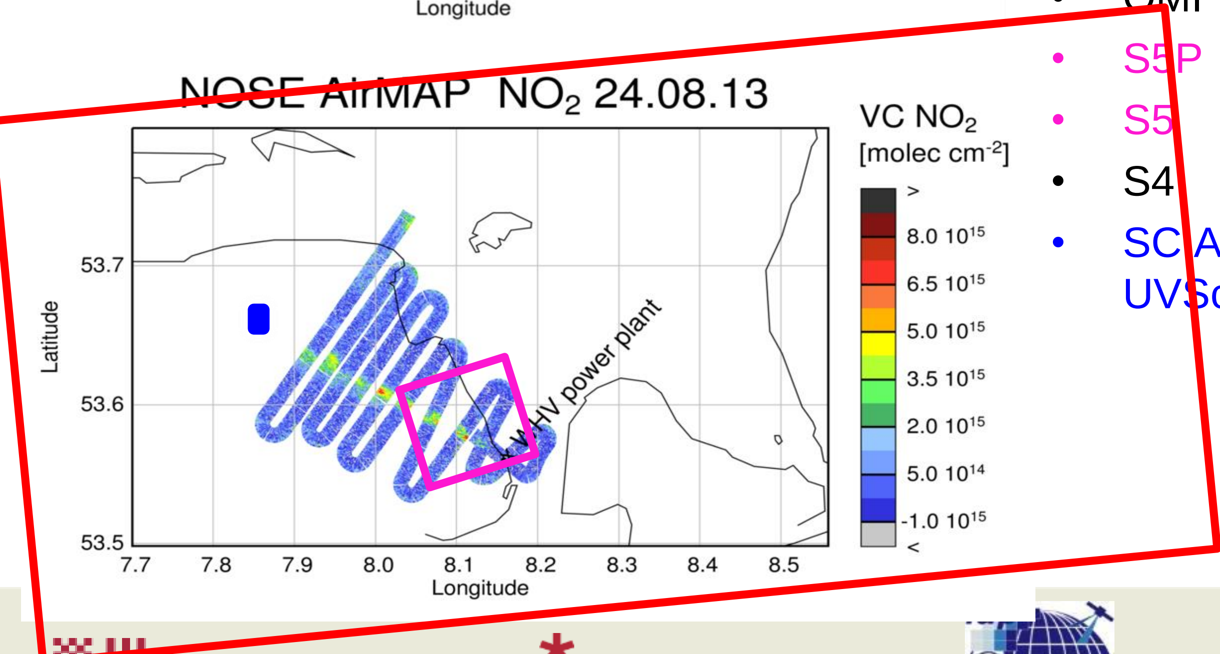






Spatial resolution – the evolution to meet the needs of tropospheric chemistry spatial and temporal scales?





Spatial resolution of satellite instruments is improving:

• GOME G3	40 x 320 km^2	1995-2011
• GOME HR	40 x 80 km^2	1995-2011
• SCIAMACHY	30 x 60 km^2	2002-2012
• GOME-2 G1	40 x 80 km^2	2007-2012
• GOME-2 HR	40 x 20 km^2	2007-2021+
• GOM-2 Tandem 40x40 km2		2012-2021 +
• OMI	13 x 24 km^2	2004-
• S5P	7.5 x 7.5 km^2	2017-2023+
• S5	7 x 7 km2	2017-2034+
• S4	8 x 8 km^2	2019-2034
• SCIA-ISS/ UVScope	1x1 km^2	2020

New challenges:

- Data have more variability
- 3d effects in radiative transfer become relevant

DFG AC3 Project: SMOG in the prisitne Arctic

Spitzbergen: 26 April 2006

Spitzbergen: 02 May 2006

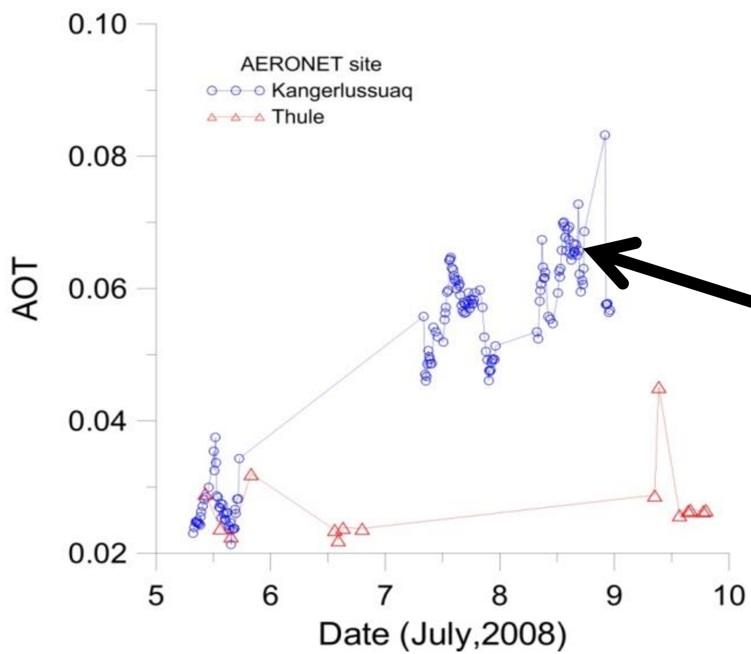
Some case Studies 1) Greenland

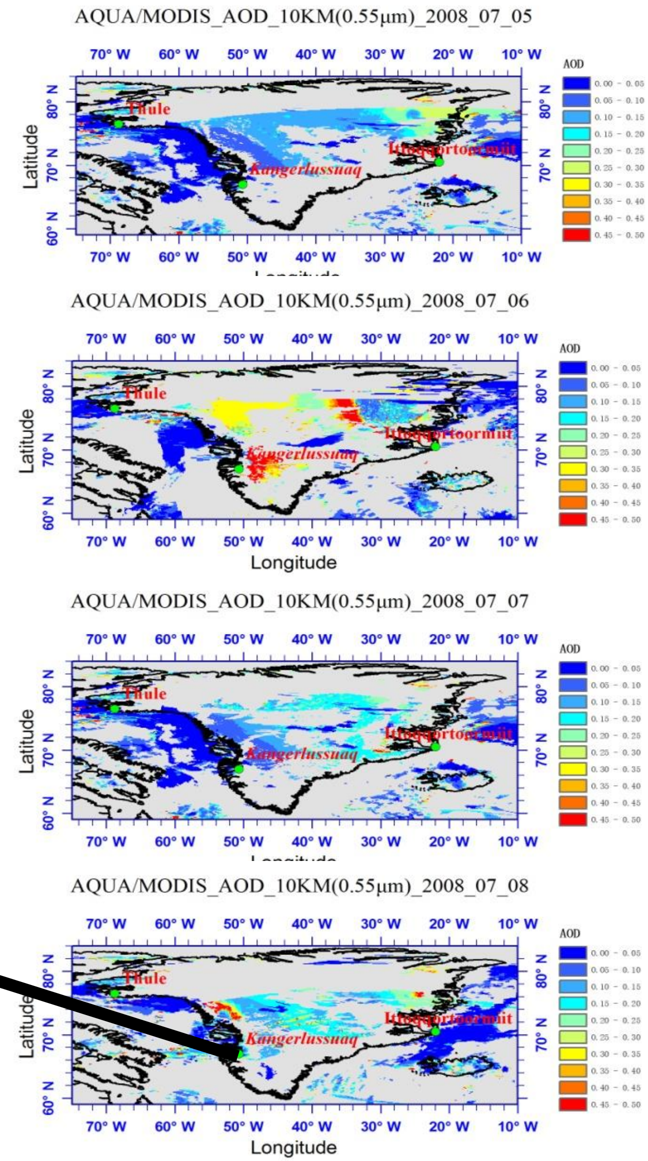
Case studies (transportation)

Pollution transport from North America to Greenland during summer 2008

J. L. Thomas[1], J.-C. Raut[1], K. S. Law[1], L. Marelle[1], G. Ancellet[1], F. Ravetta[1], J. D. Fast[2], G. Pfister[3], L. K. Emmons[3], G. S. Diskin[4], A. Weinheimer[3], A. Roiger[5], and H. Schlager[5]

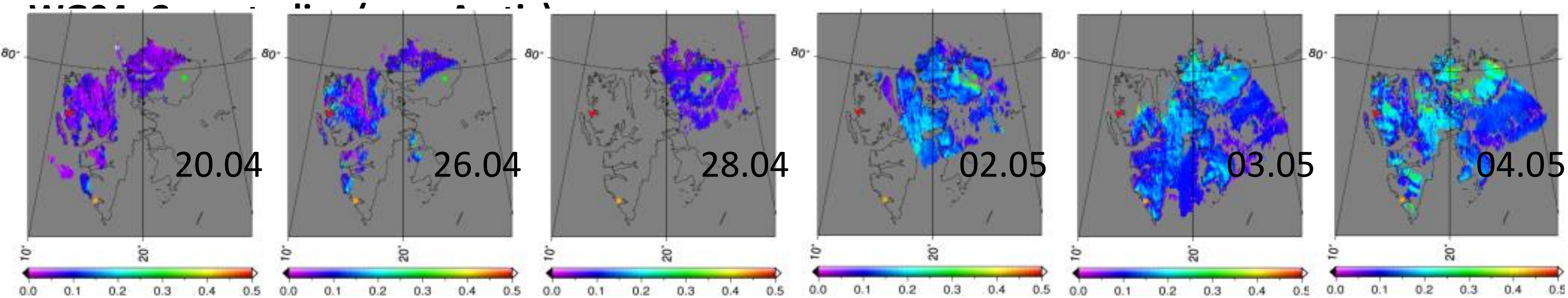
Thomas et al published about this pollution event over Greenland during summer 2008.
We have collated AERONET and retrieved IUP-CAS two view algorithm for AOT from MODIS/Terra, MODIS/Aqua data during 5 – 8 July, 2008.

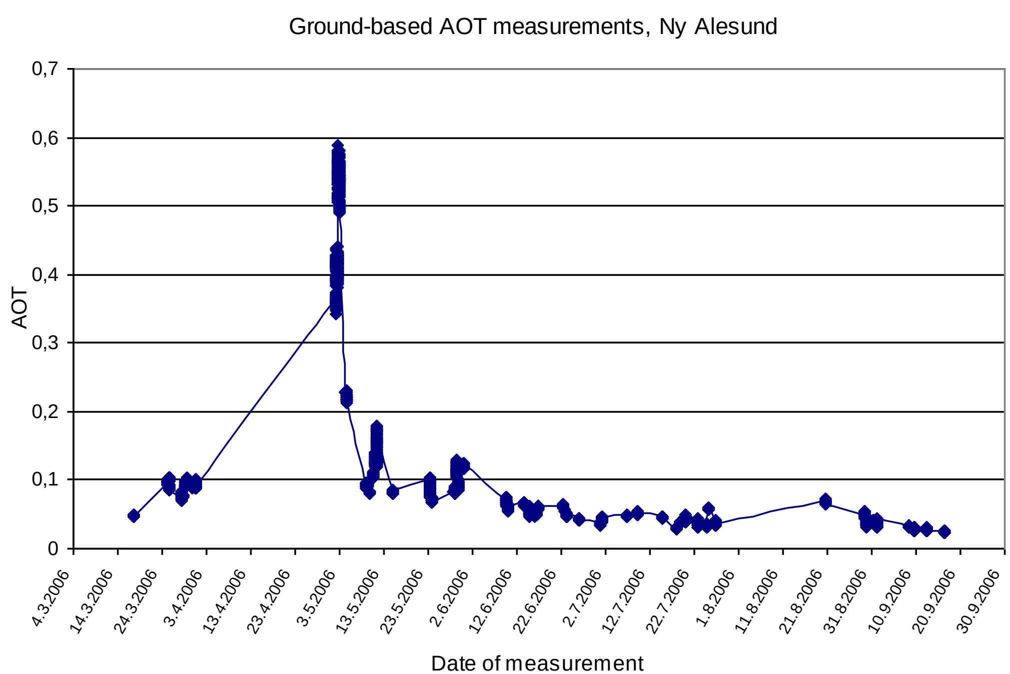


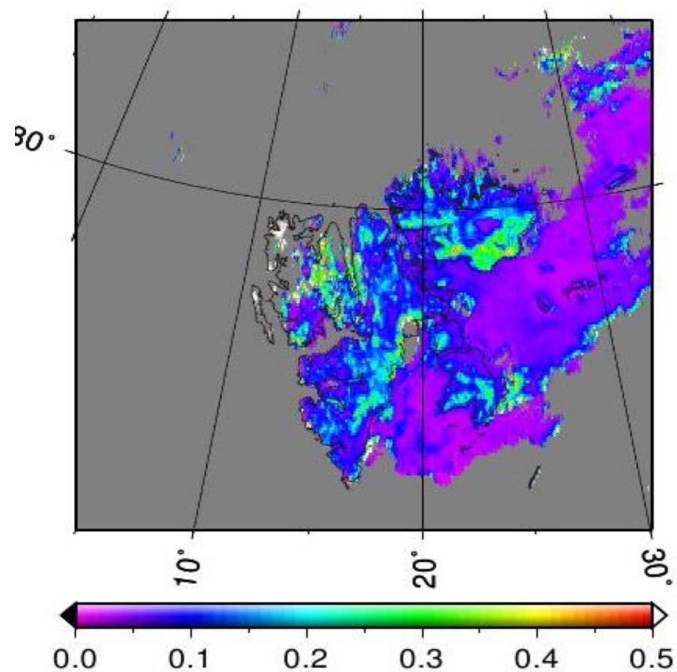


2) Spitzbergen spring 2006

WP04: Case studies (over Arctic) Smoke event from agricultural fires in Eastern Europe over Spitsbergen May, 2006 (Istomina, 2011). This algorithm by L. Istomina uses a snow BRDF model.



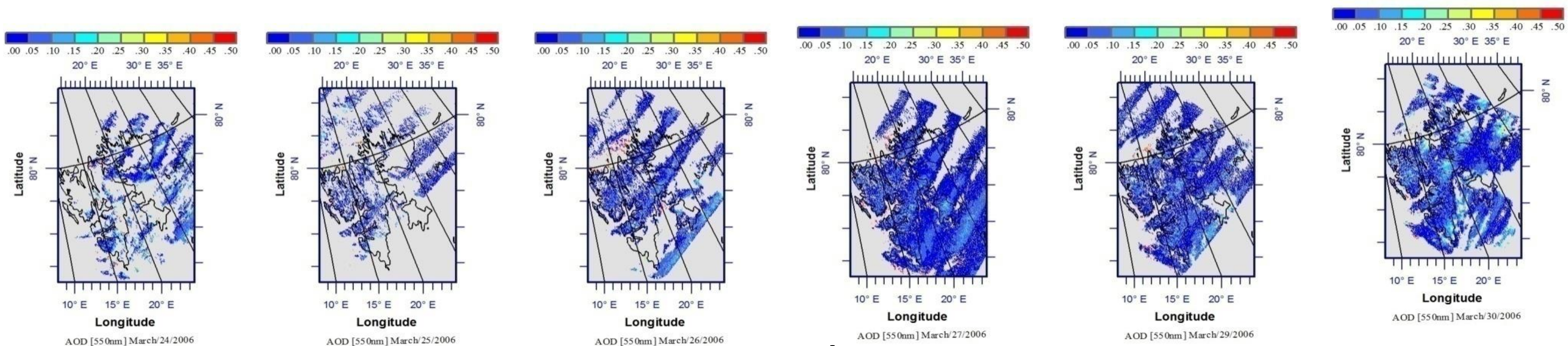




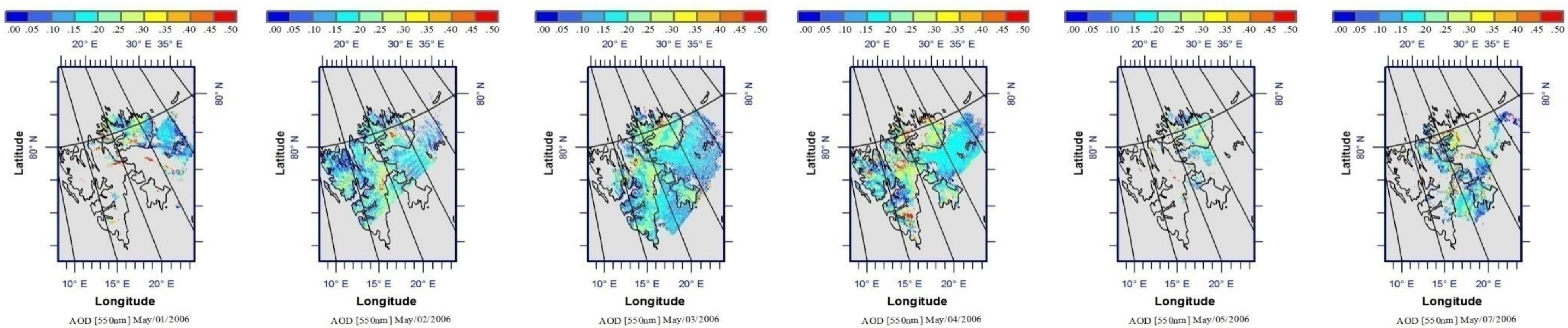
IR retrieval, AOT(550nm)

3) Spitzbergen spring 2006

Case studies (over Arctic) Smoke event over Spitsbergen May, 2006, clean March 2006 (Mei, 2013)
Data from AATSR on Envisat and agorithm by L. Mei uses a mixed snow and ice BRDF model called NDSI (Normalized-Difference Snow Index),



24 – 29 March, 2006

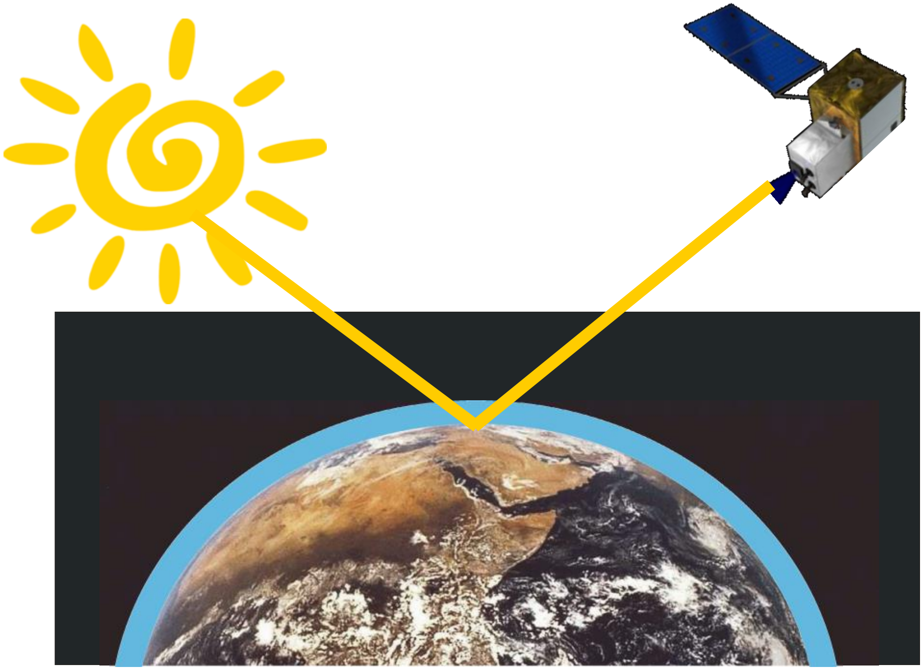


1 – 6 May, 2006

The evolution of the measurment of the dry column of XCO_2 and XCH4

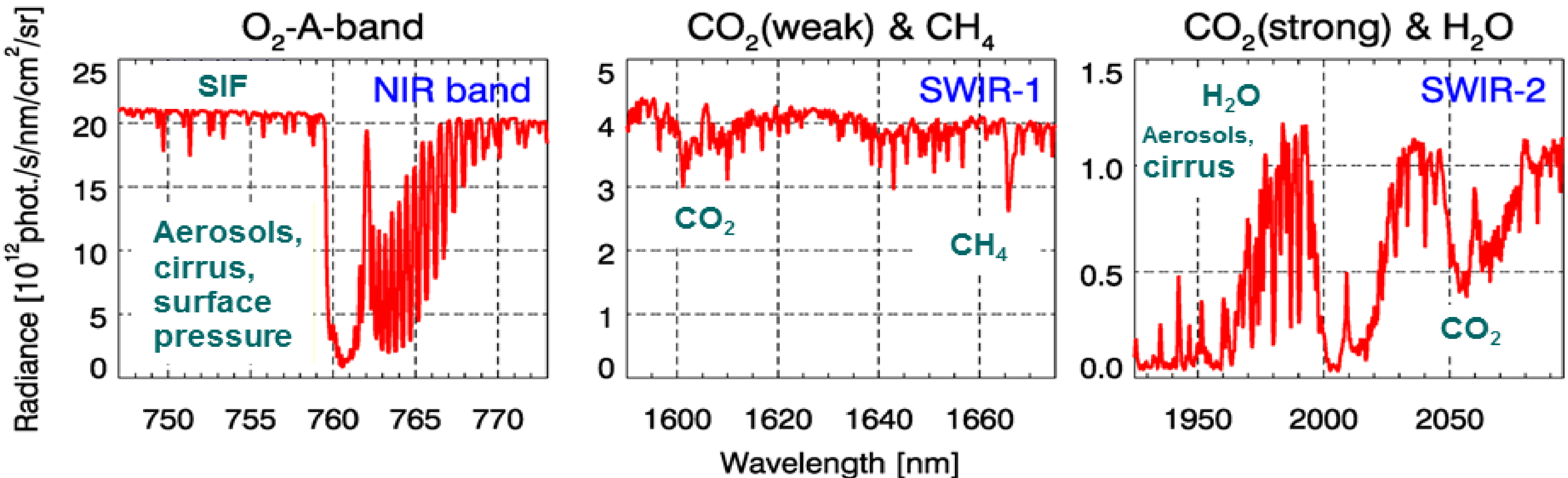
Some Examples using SCIAMACHY GOSAT and OCO-2

Measurement principle



CO_2 and CH_4 dry mole fractions are derived from their absorptions in the ratio of „top of atmosphere" radiance normalised by solar irradiance (absorption spectroscopy)

- Slant column absorptions from CO_2 CH_4 and O_2 spectral features,
- dry mole fraction of CO_2 & CH_4 and light path correction (vertical column) → need for O_2A and strong CO_2 band



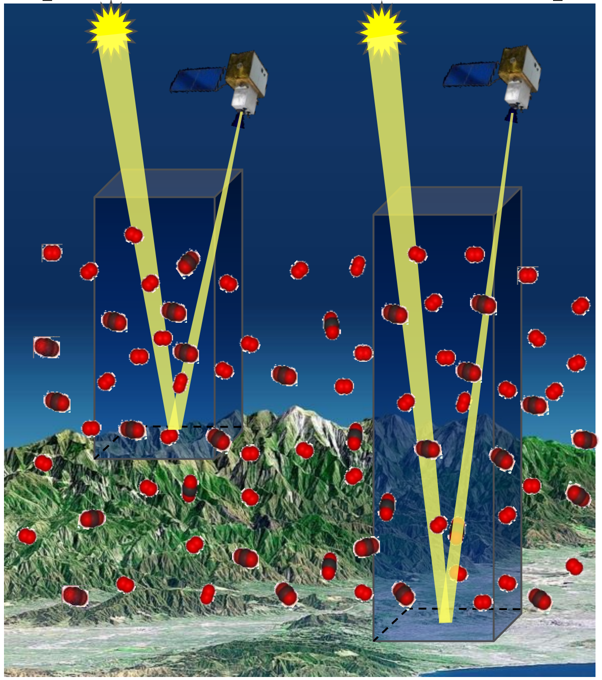
Key quantities delivered by remote sensing: XCO_2 & XCH_4

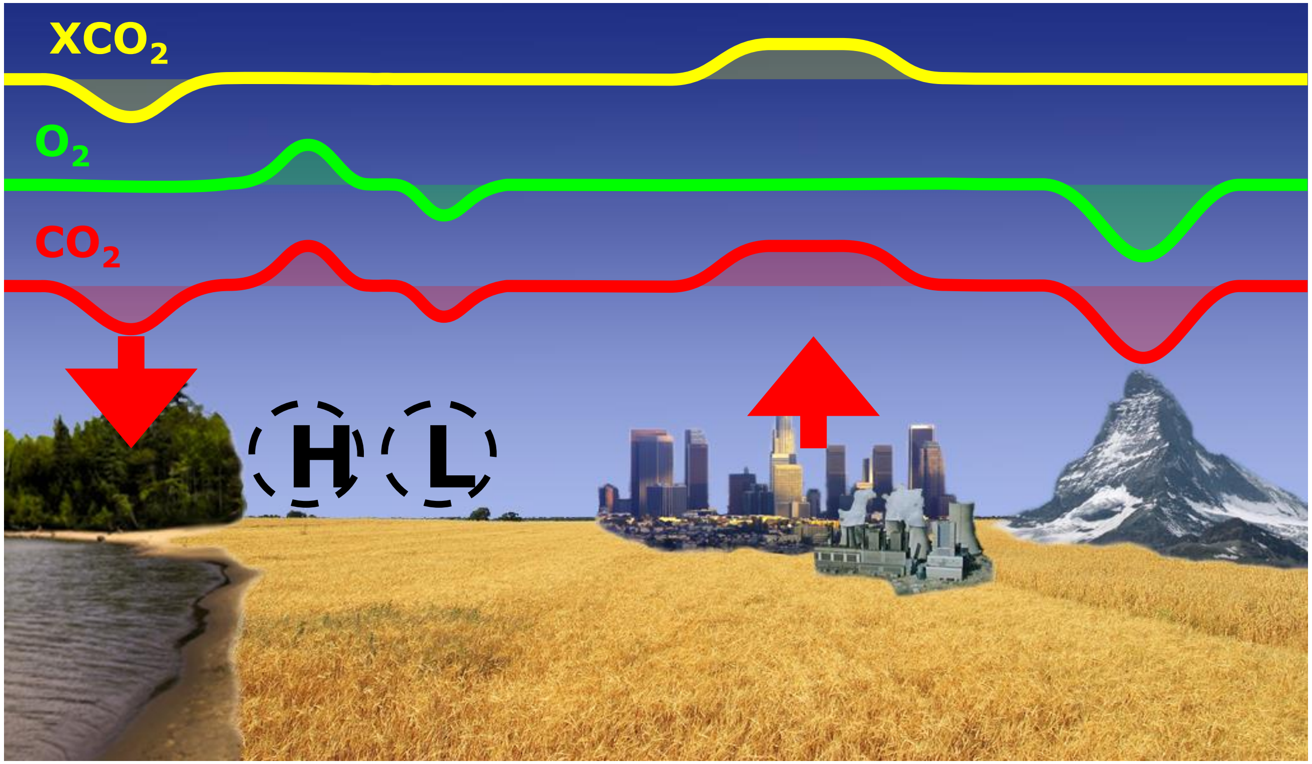
= Column-averaged dry-air mole fraction (mixing ratio) of CO_2

= Vertical CO_2 column / Vertical of dry-air column (via O_2)

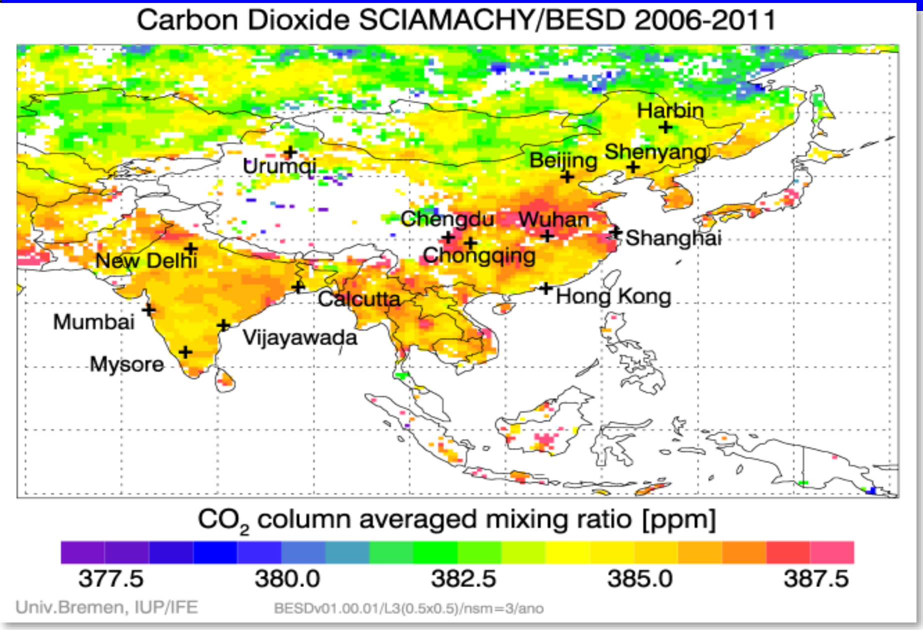
Same for XCH_4

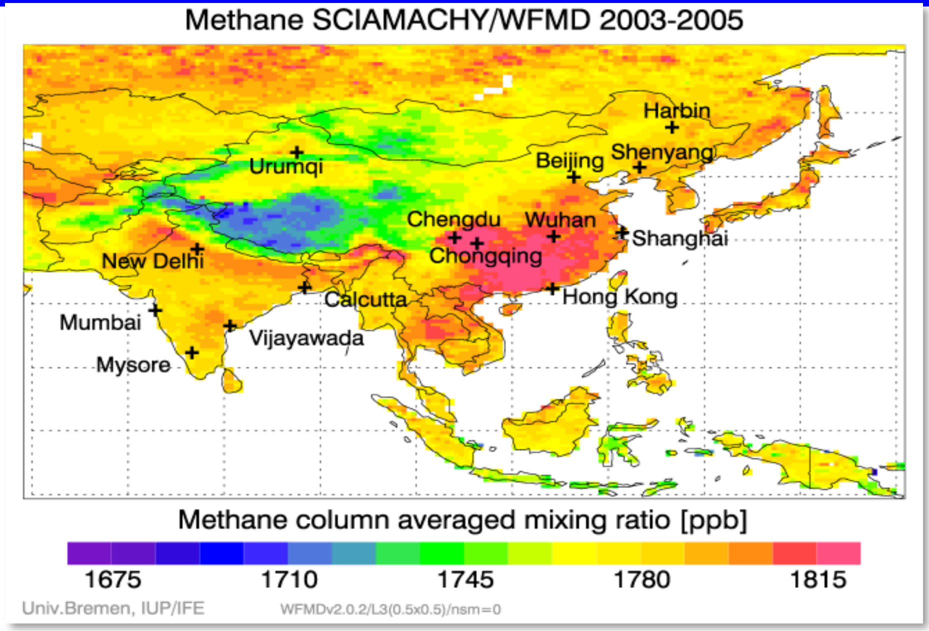
Using absorption spectroscopy to determine vertical columns
[number of molecules/area]

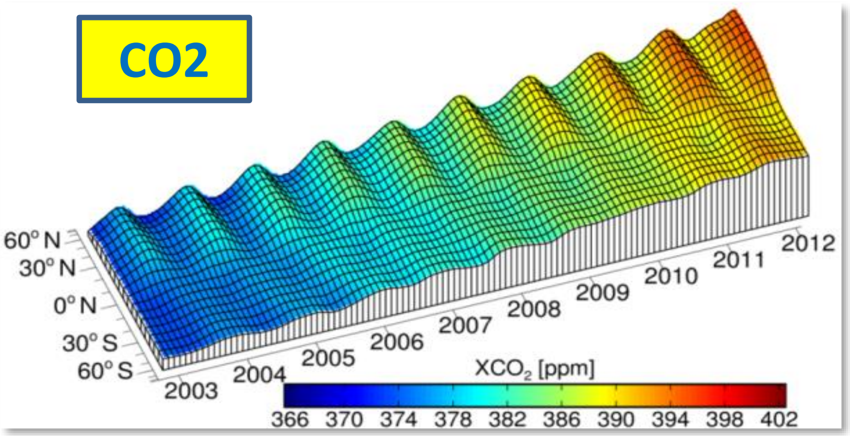


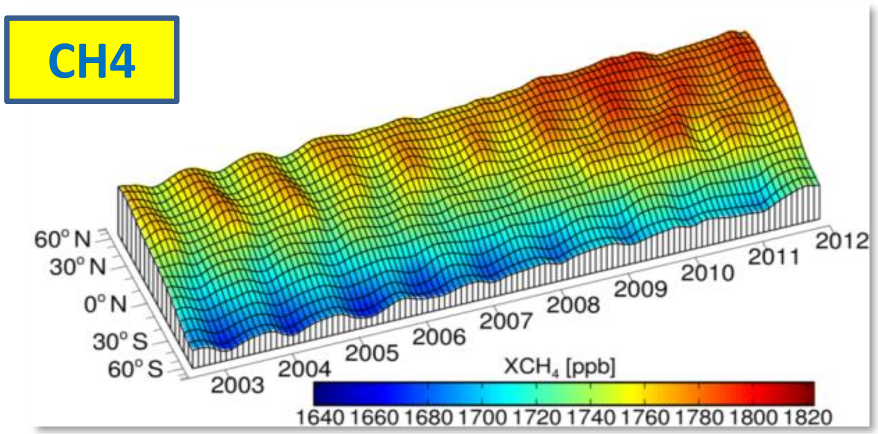


SCIAMACHY on ENVISAT: CO_2 & CH_4 from space









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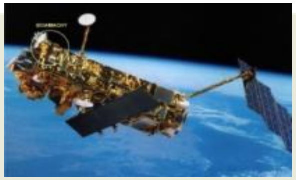
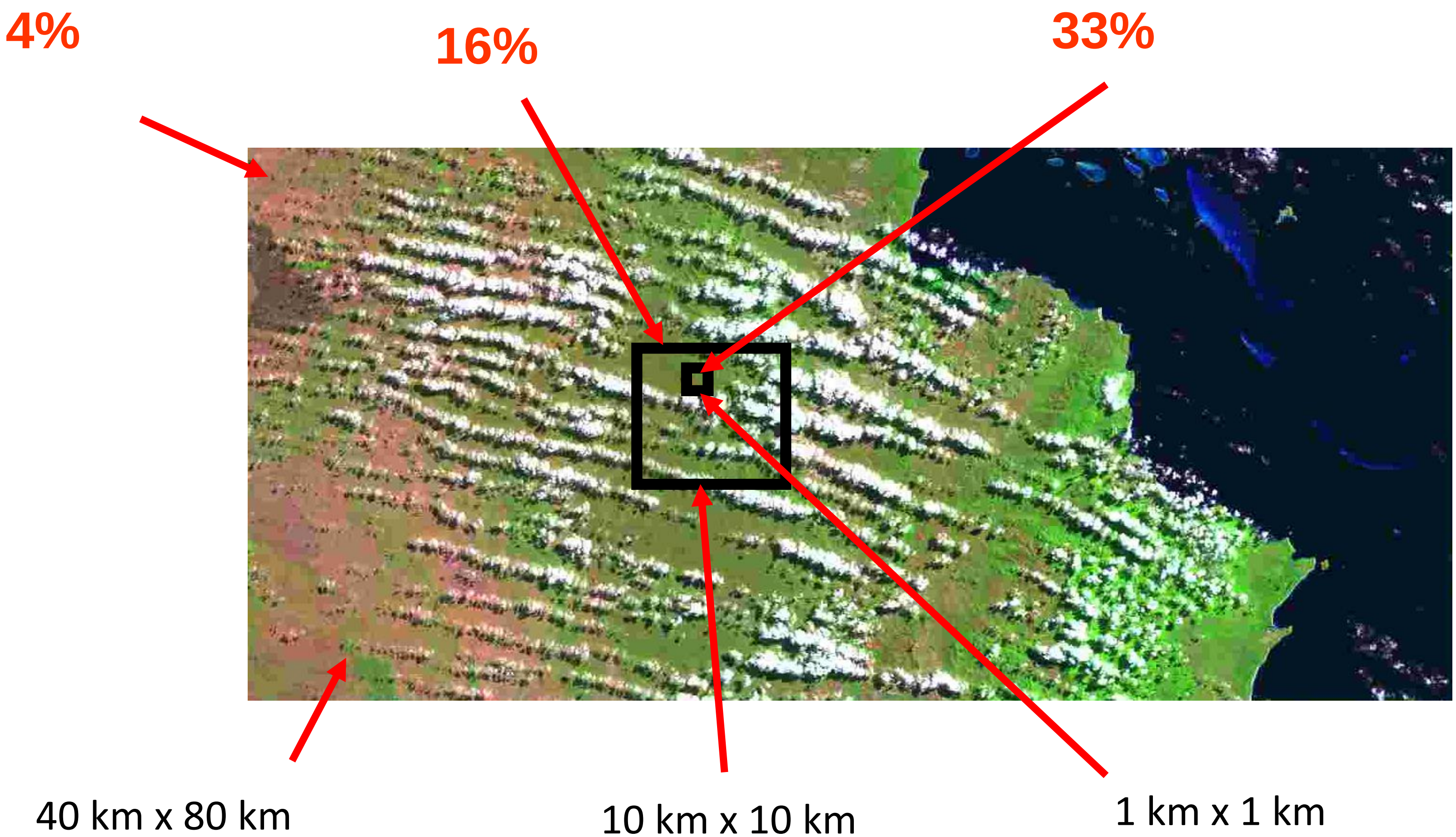


*EXZELLENT.

Cloud Error Reduced with Increasing Resolution

Fraction of global cloud-free observations

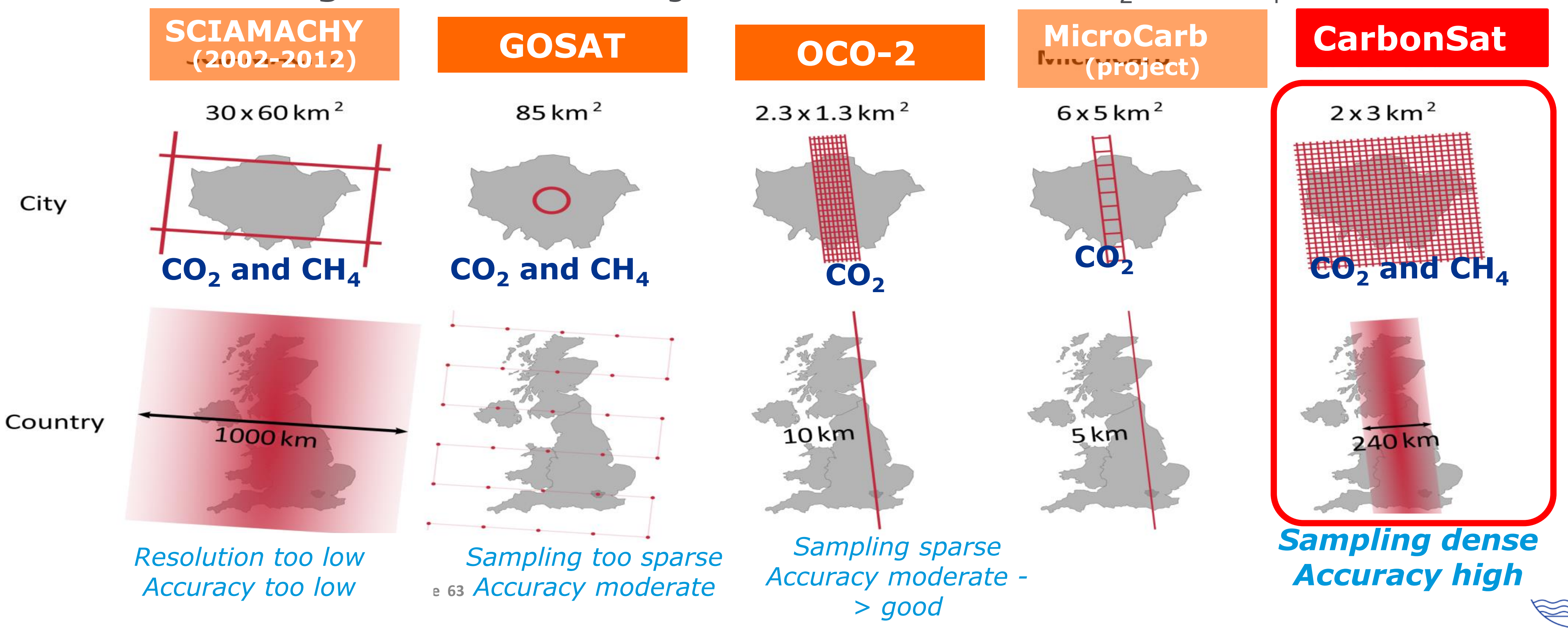


Krijger et al., ACP, 2007

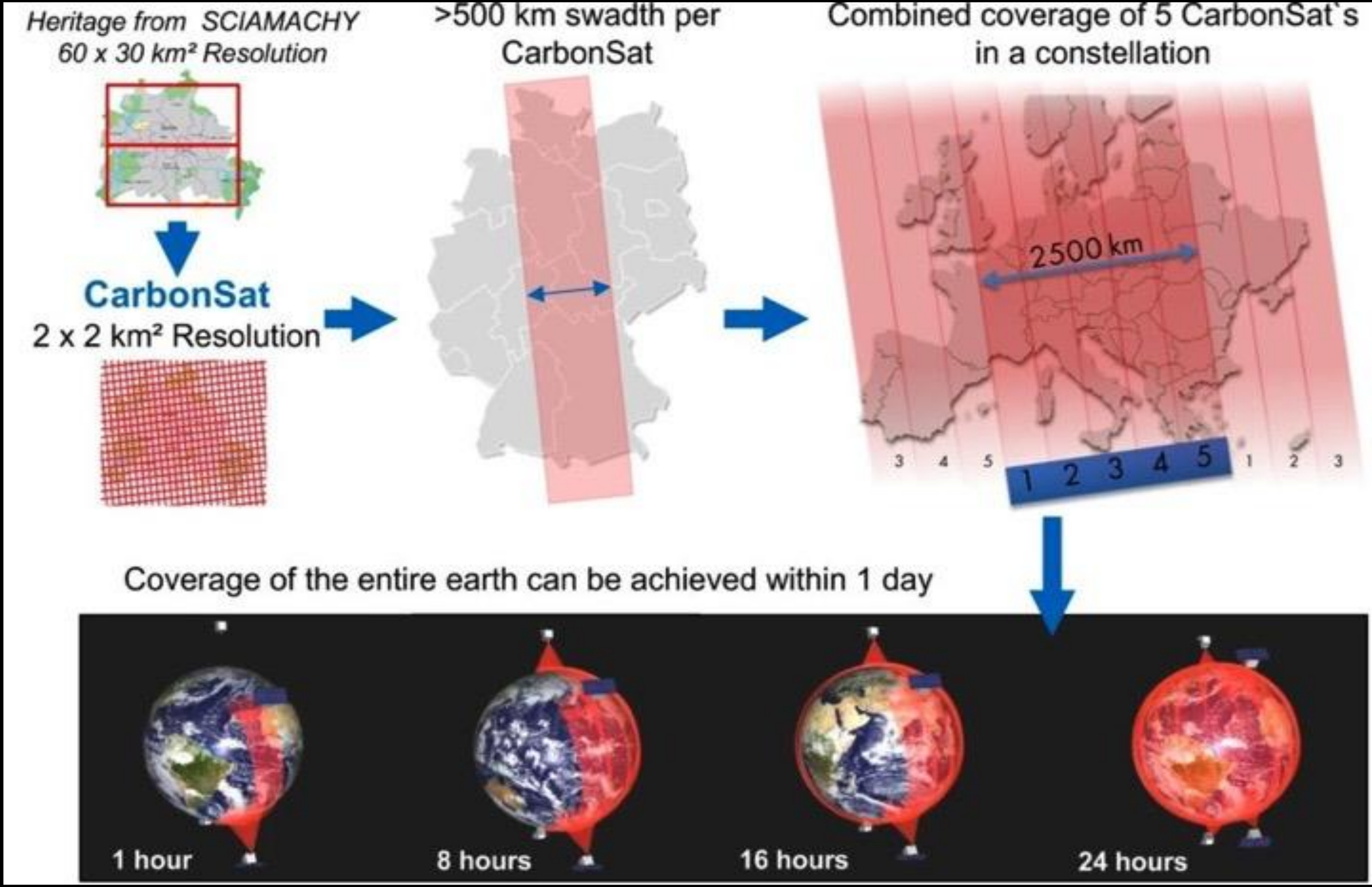
From SCIAMACHY (proposed ~1988) to CarbonSat or Equivalent (212? or 213?)

To meet the scientific and policymaking needs future instrumentation on satellite must have at least the following four attributes:

- **Dense sampling:** imaging of changes in CO_2 and CH_4 "weather" and plumes to determine surface fluxes
- **High spatial resolution:** capture emission hotspots and avoid clouds
- **High accuracy:** because dry column gradients are realtively small fro long lived gases
- **Global coverage:** because most regions of the Earth have CO_2 and CH_4 fluxes



CarbonSat-like Constellation



Highlights GHG

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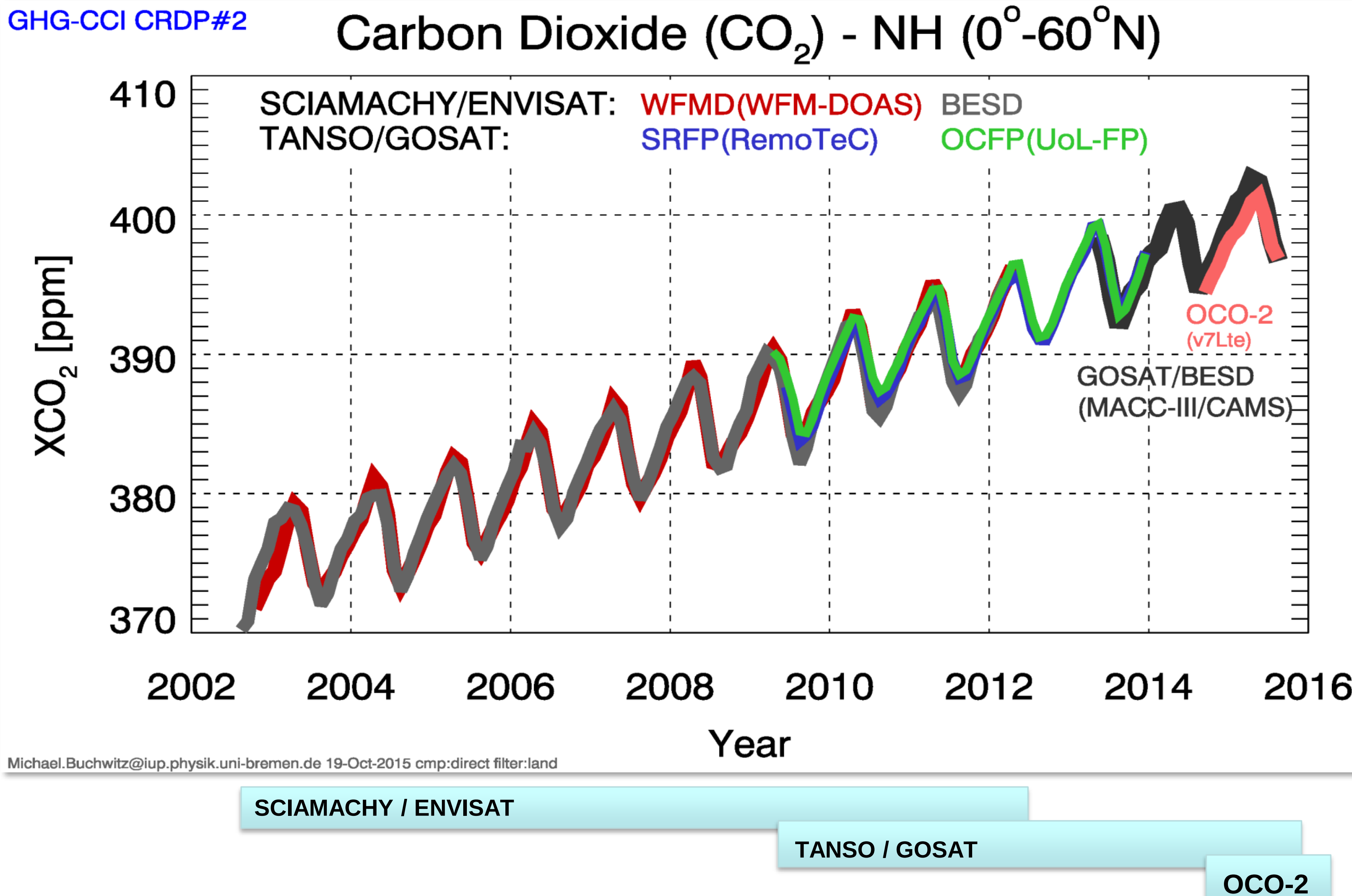
The measurement of the dry column of XCO_2 from space

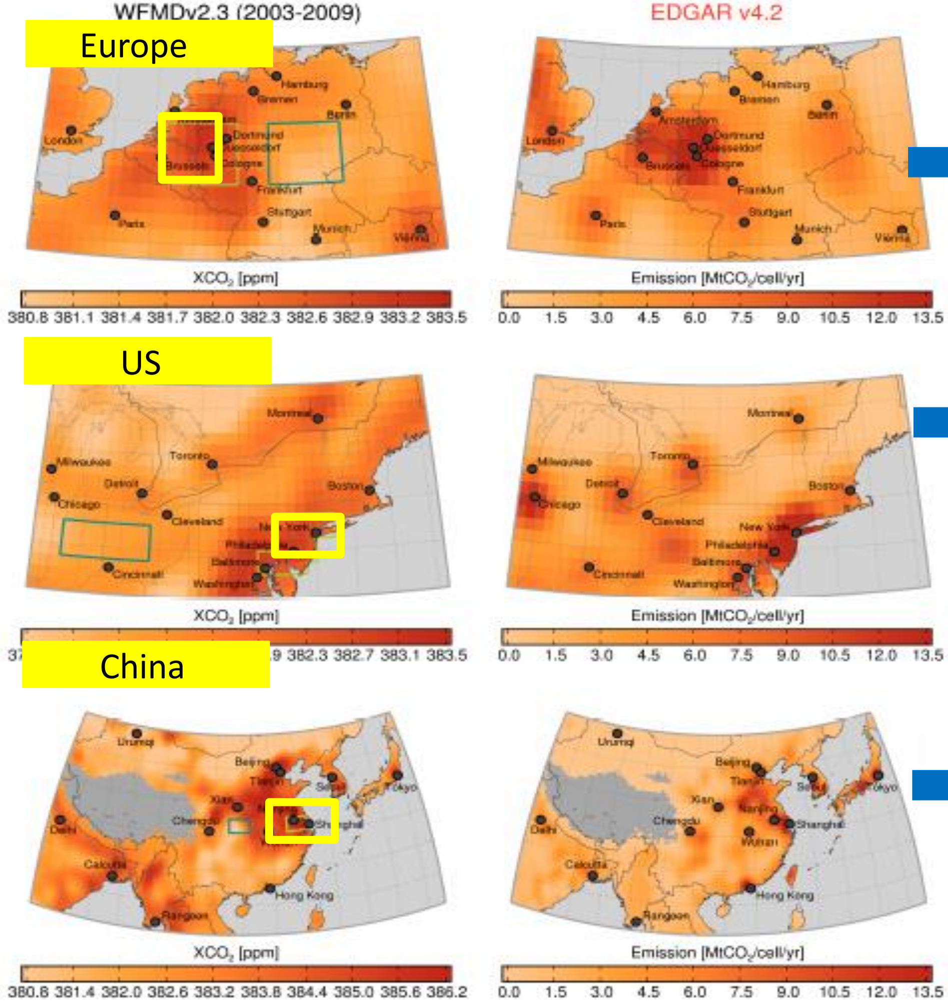
Carbon dioxide from space

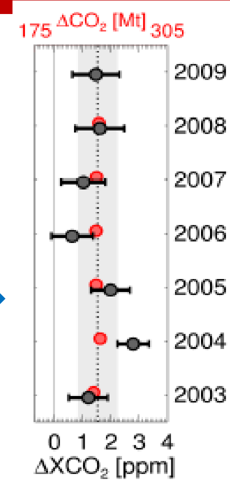


CO_2 over major anthropogenic source regions

SCIAMACHY XCO2

EDGAR CO2 emissions



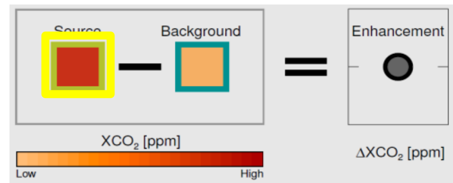


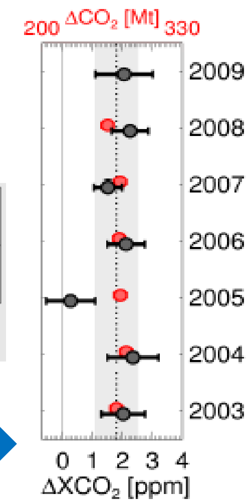
Schneising et al., ACP 2013

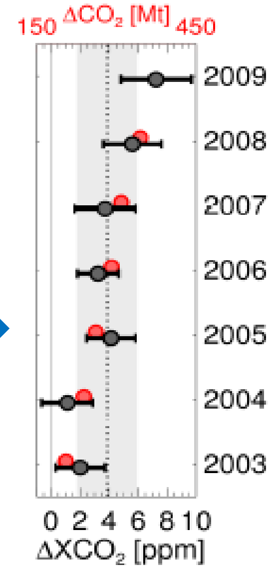
SCIAMACHY

EDGAR

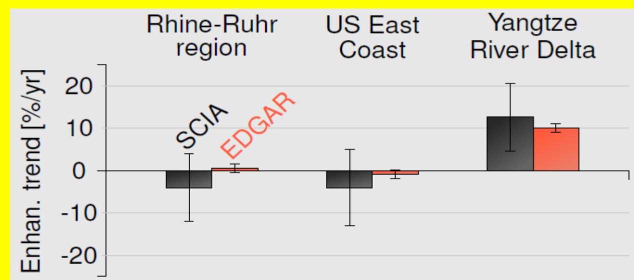
Regional enhancement = Source - Background







Trend [%CO2/yr]

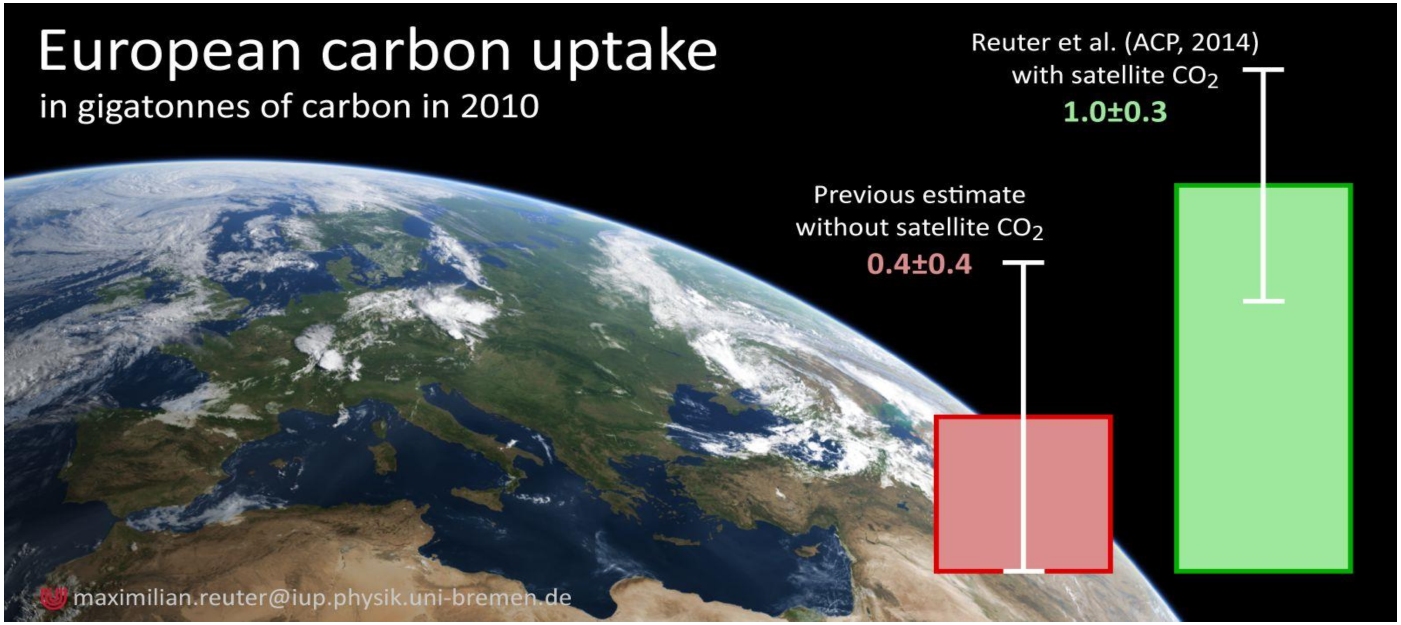


EDGAR emission changes consistent with SCIAMACHY

Satellite CO_2 indicates that European Carbon Sink is larger then expected (Reuter et al., 2014, ACP)

- The **a priori estimate** for the European carbon sink (CT2011_oi) is about **0.4GtC/a**.
- Driven by a stronger uptake during the growing season, the **satellite derived (SCIAMACHY, GOSAT)** European carbon sink is about **1.0GtC/a**.

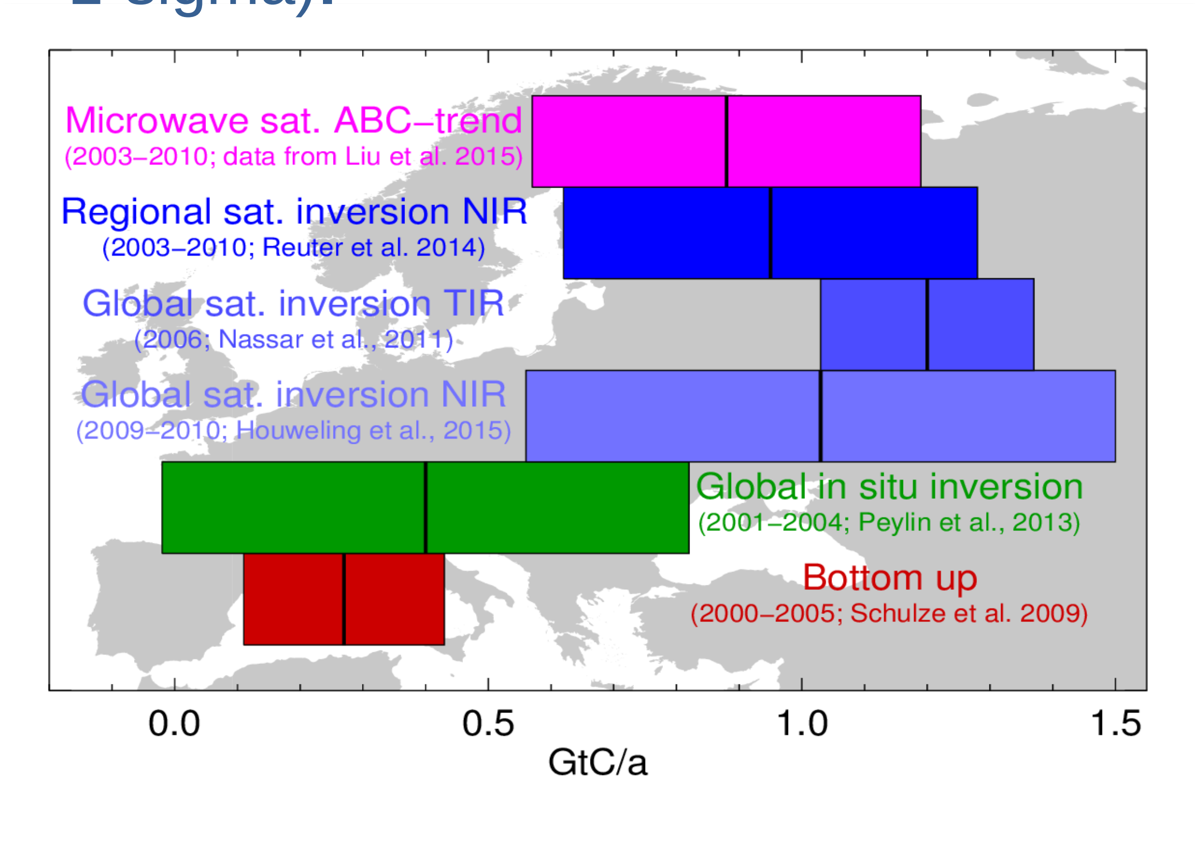
- The **consistency among an ensemble** of five different inversion set-ups and five independent satellite retrievals underlines the **robustness of the findings**.

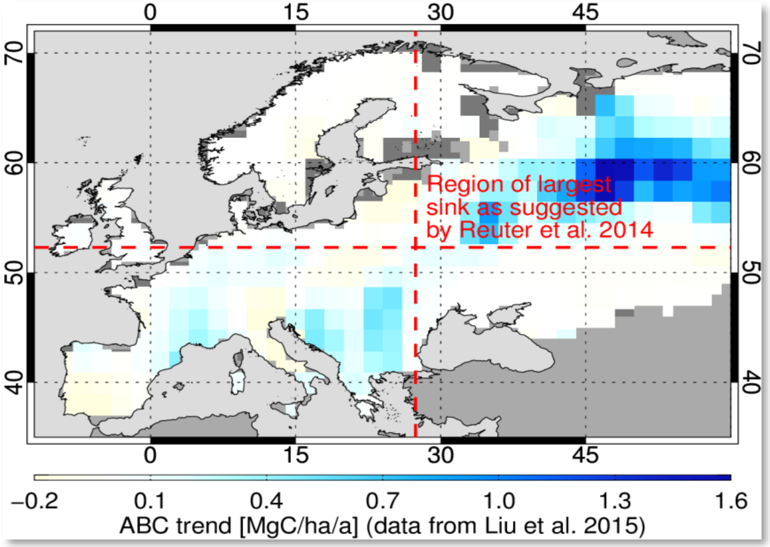


„Europe only“ inversion using STILT-based short range (days) particle dispersion modelling using an ensemble of satellite XCO_2 retrievals

How large is the European terrestrial C sink ?

Overview based on recent peer-reviewed publications (all uncertainties 1-sigma):

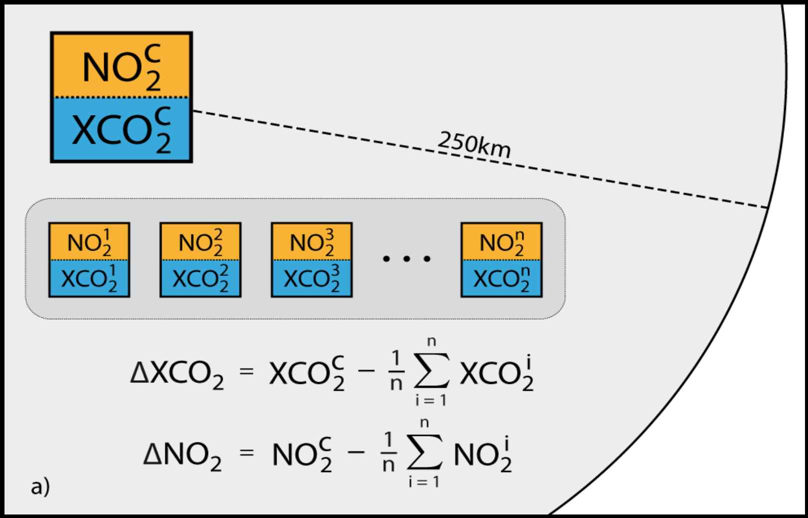


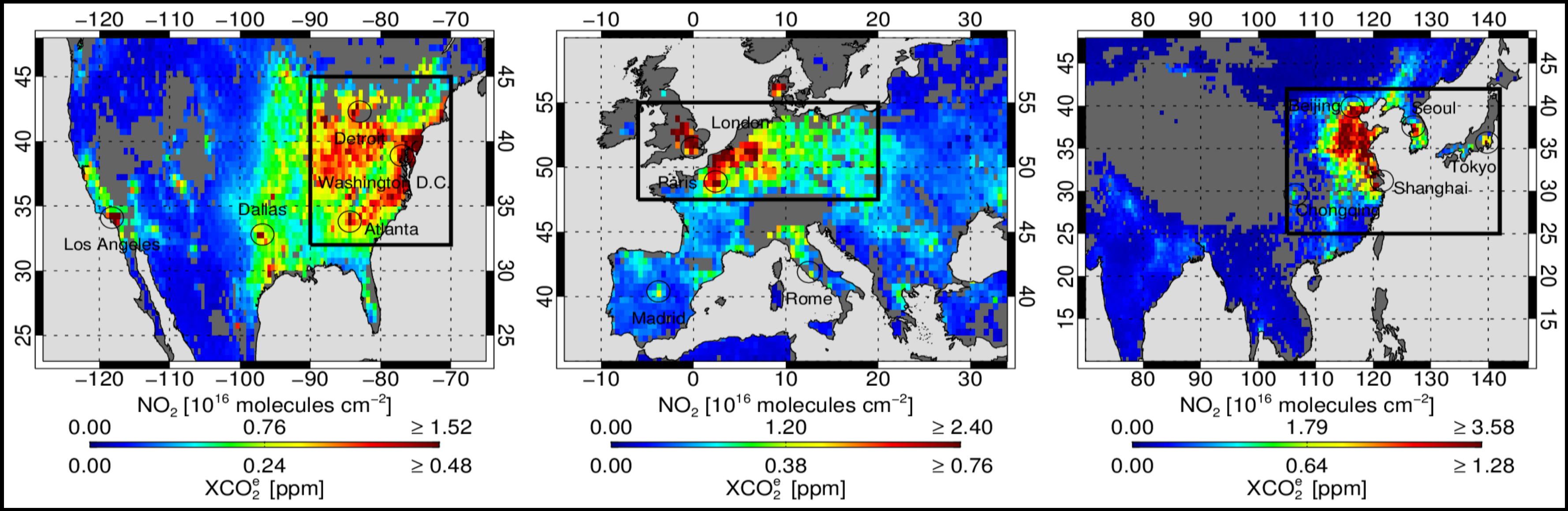


Reuter et al. (manuscript in preparation)

Anthropogenic CO_2 and NO_x emissions (Reuter et al., 2014, nat. geosci.)

- **CO_2** and **NO_x** are **co-emitted** species in anthropogenic fossil fuel combustion processes.
- A **spatial high-pass filtering** method is used to derive co-located regional anomalies ΔXCO_2 and ΔNO_2.
- A **statistical relationship** between ΔXCO_2 and ΔNO_2 allows to conclude on **CO_2 with anthropogenic origin**.





Highlights GHG

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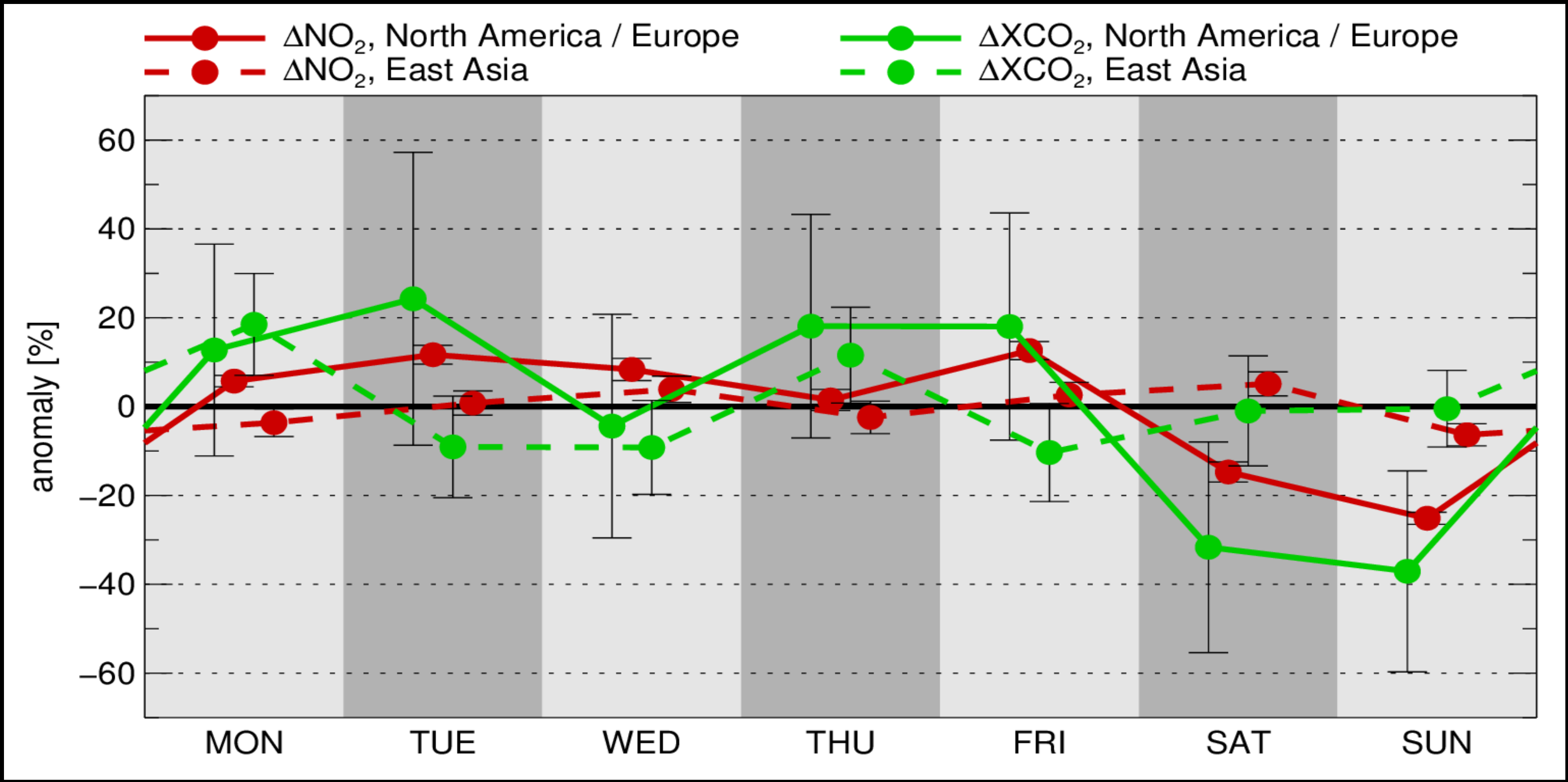
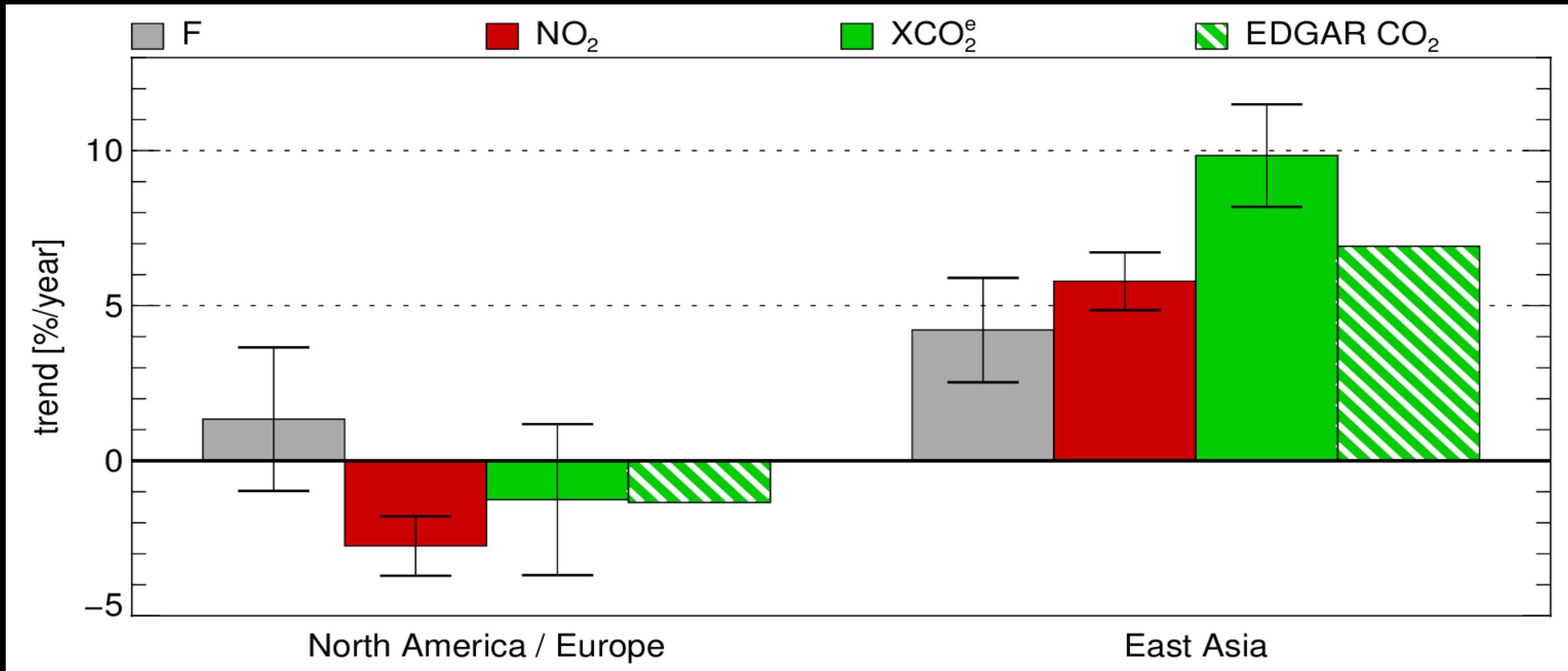
Anthropogenic CO_2 and NO_x emissions (Reuter et al., 2014, nat. geosci.)



- We find significantly **lower ΔXCO_2 levels at weekends** in North America and Europe but not in East Asia.
- The weekend effect of XCO_2 is a tiny signal and this is its **first detection from space**.
- It underlines that the analyzed CO_2 signals originate from **anthropogenic activities**.

Anthropogenic CO_2 and NO_x emissions (Reuter et al., 2014, nat. geosci.)

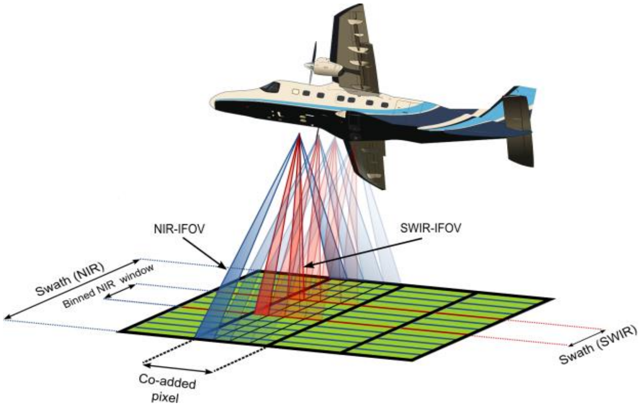


- **North America and Europe:** satellite data show a small **downward trend in emissions** of both, NO_x and CO_2 albeit associated with a large uncertainty.
- **East Asia:** CO_2 emissions increased on average at a rate of 9.8%/a but NO_x increased "only" by 5.8%/a, i.e., significantly less compared to CO_2 (**increasing CO_2-to-NO_x emission ratio F**).
- **Interpretation: technology** used in East Asia is **getting cleaner** thus emitting less toxic nitrogen gases per amount of fossil fuel burned.

Methane Airborne Mapper MAMAP

Sensor:

- 2-channel (NIR, SWIR-1) spectrometer
- Moderate spectral resolution (0.5 - 0.8 nm)
- Spatial resolution 30 m – 50 m depending on airplane used
- Robust sensor and flown on different aircrafts (Cessna 207, Cessna Caravan, AWI P5 DC3T/BT67, Twin Otter)

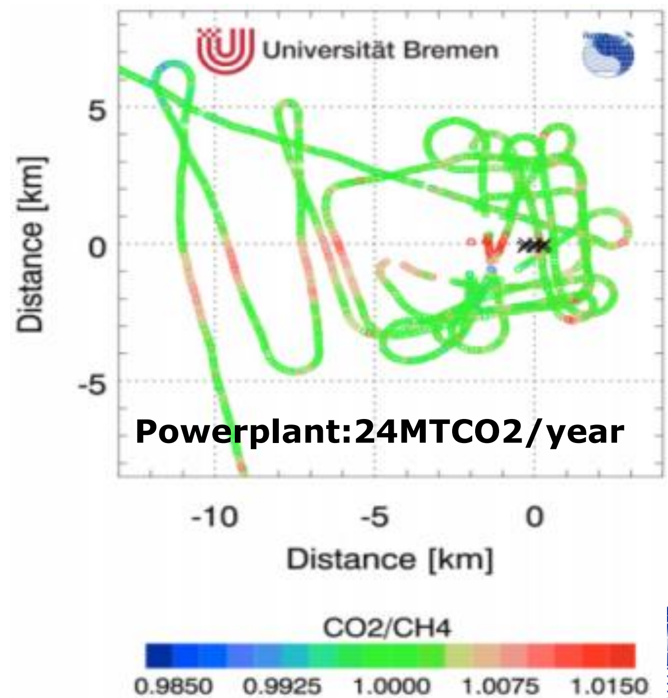


Measurement principle

- Absorption spectroscopy using scattered/ reflected solar radiation (as SCIAMACHY, OCO-2, GOSAT)

Main data product

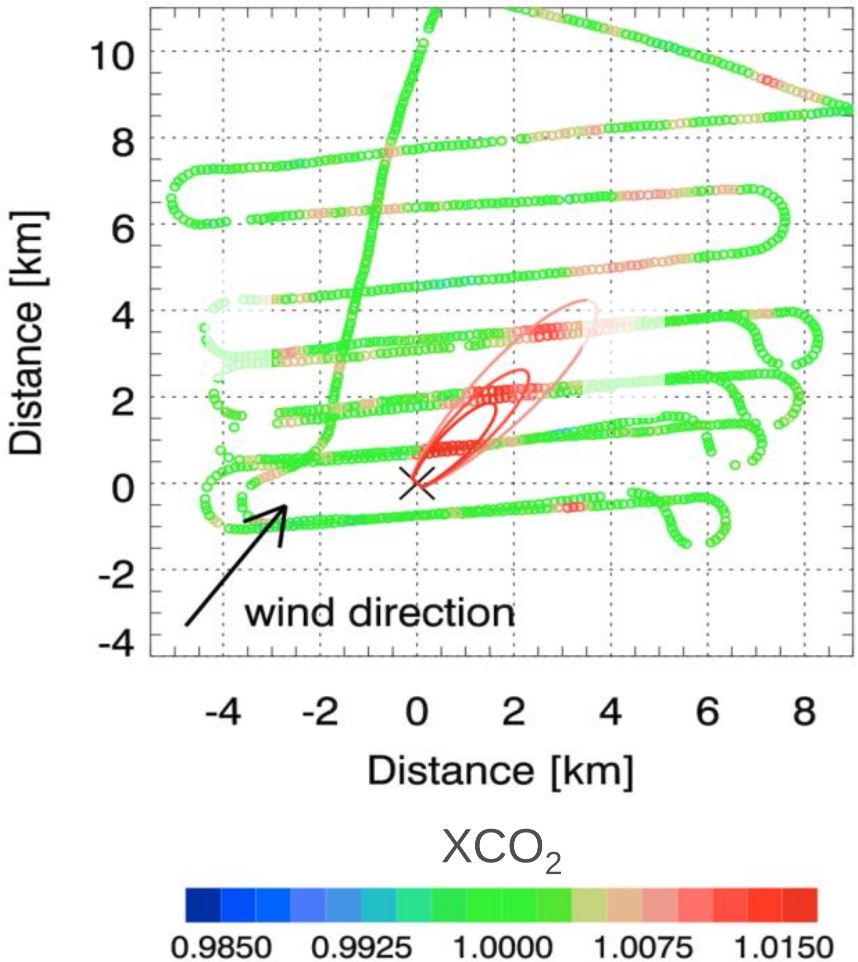
- "Column averaged dry air mole fractions" of CH_4 and CO_2 (XCH_4 and XCO_2) via proxy approach with typical uncertainty of 0.3%



Gerilowski et al 2011 / 2015, Krings et al. 2011 / 2013

Point sources: lignite-fired power plant (CO_2)

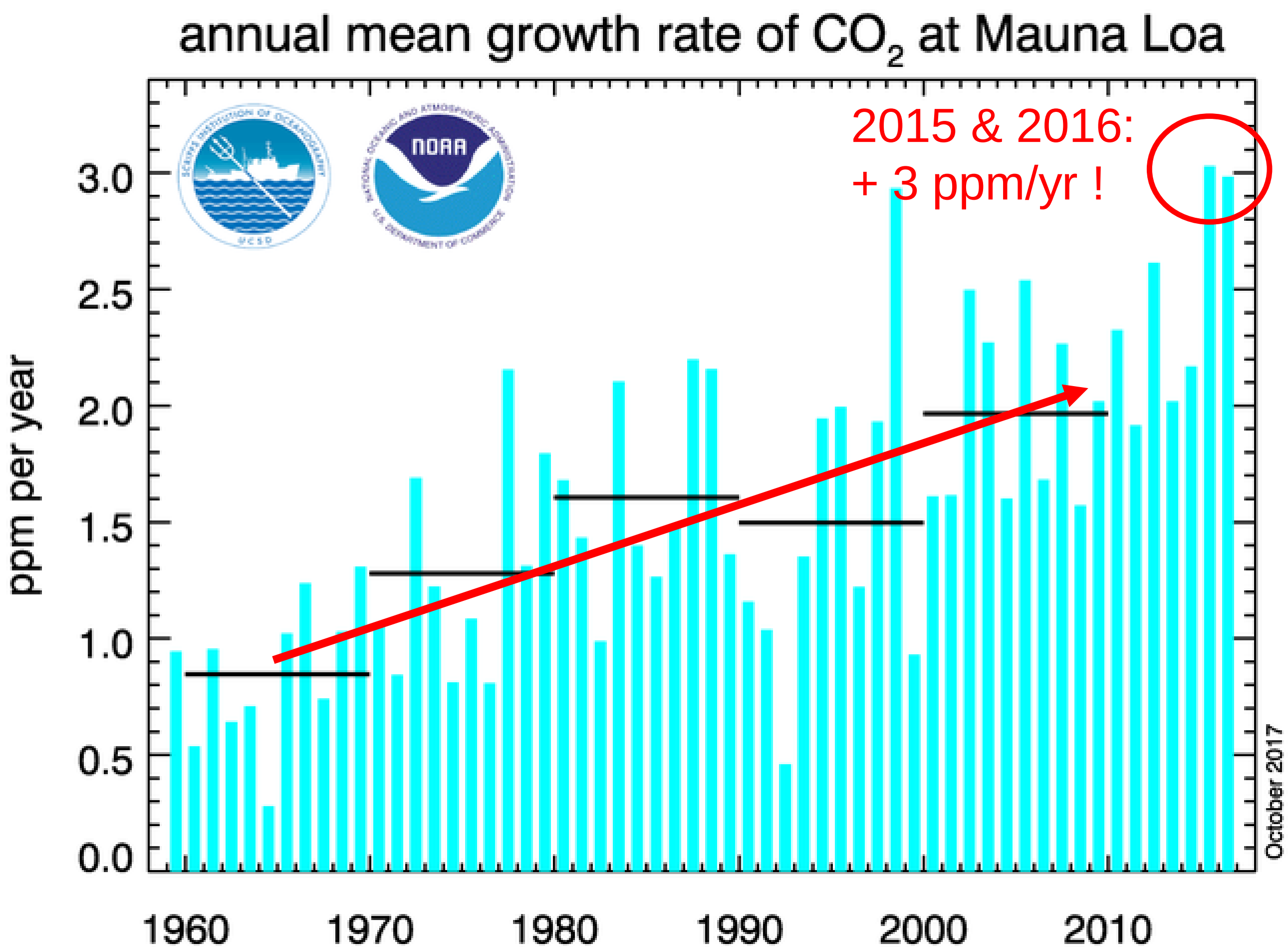
Plume as seen by remote sensing



Weisweiler

Airborne XCO_2 measurements performed over the lignite fired power plant Weisweiler (yearly emission of 19 $MtCO_2$/yr, E-PRTR 2009)

Atmospheric CO_2 growth rate



For each **+1 ppm/yr**:

If in entire atmosphere:
-> + 2.12 GtC/yr
or (x 3.664)
-> **+ 7.8 $GtCO_2$/yr**

-> +3 ppm/yr corresponds to
-> +23.3 $GtCO_2$/yr

2015 emissions are 36.3 $GtCO_2$/yr
-> airborne fraction: 64%

(mean airborne fraction 2006-2015: 44%)

Impact El Nino:
Difference in growth rates 2015 – 2011: 3-2 = 1 ppm/yr which is 7.8/36.3 = 21% of human emissions in 2015

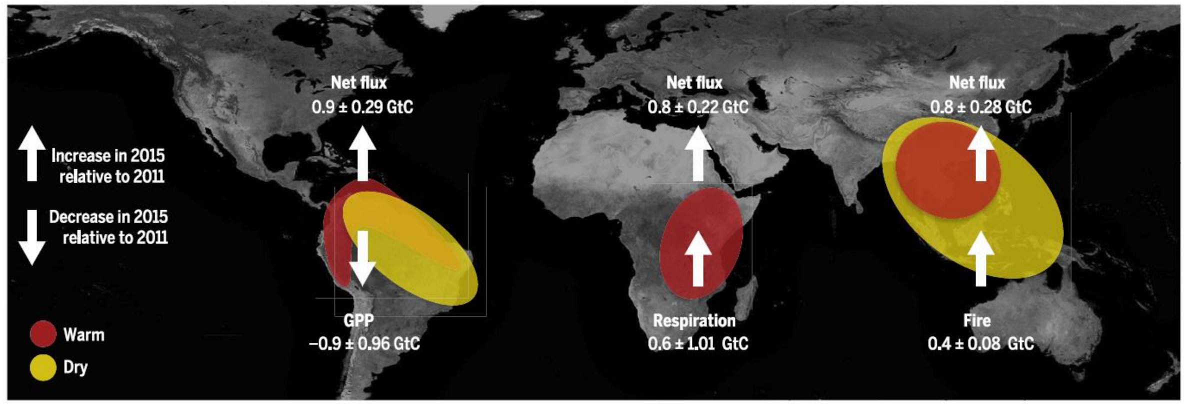
NASA OCO-2 Science Special Issue (13-Oct-2017)

RESEARCH ARTICLE

CARBON CYCLE

Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño

Junjie Liu,[1*] Kevin W. Bowman,[1] David S. Schimel,[1] Nicolas C. Parazoo,[1] Zhe Jiang,[2] Meemong Lee,[1] A. Anthony Bloom,[1] Debra Wunch,[3] Christian Frankenberg,[1,4] Ying Sun,[1†] Christopher W. O'Dell,[5] Kevin R. Gurney,[6] Dimitris Menemenlis,[1] Michelle Gierach,[1] David Crisp,[1] Annmarie Eldering[1]



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GLOBAL CLIMATE CHANGE

Cause of Earth's recent record spike in global CO2 concentration

By Brett Anderson, AccuWeather senior meteorologist
10/18/2017, 5:37:24 PM

Atmospheric carbon dioxide (CO2) increases during 2015 and 2016 were 50 percent larger than the average increases seen in recent years preceding these observations.

A new NASA study based on space-based evidence suggests that El Nino-related heat and drought occurring in tropical regions of South America, Africa and Indonesia were responsible for the record spike in global CO2, according to the NASA report.

THE ECONOMIC TIMES | Global Warming
Oct 19, 2017, 10.08 AM IST
LATEST NEWS Decision day for Catal

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Clean Air Initiative | Global Warming | The Good Earth | Developmental Issues | Flora & Fauna | Pollution | Wild &

ET Home › News › Environment › Global Warming

04:05 PM | 18 OCT EOD MARKET STATS	SENSEX	NIFTY 50	GOLD (MCX) (Rs/10g.)	EUR/INR
	32,584 ▼ -24.81	10,210 ▼ -23.60	29,564.0 ▼ -34.0	76.41 ▼ -0.04

El Nino aided in massive carbon dioxide release

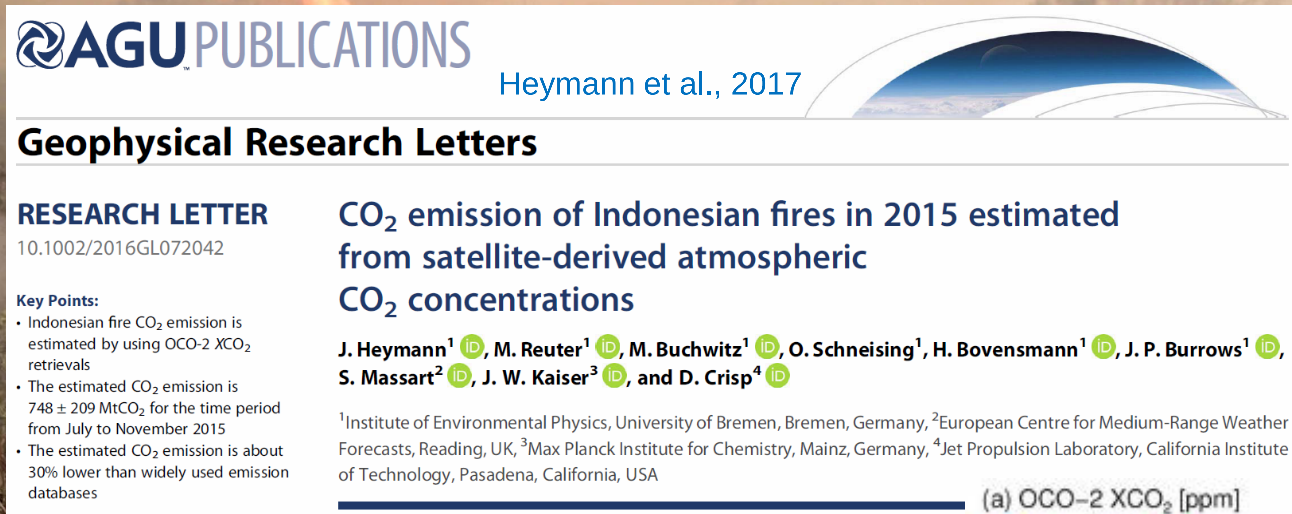
By Subodh Varma, TNN | Updated: Aug 14, 2017, 04.03 AM IST

0 Comments

El Nino is a periodic climate event that causes waters to warm up in east-central Pacific Ocean, and effects weather across the world

Even as carbon emissions from use of fossil fuels flattened out in the past few years, the monster El Nino of 2014-16 caused over 3 billion tonnes of carbon to get released into the atmosphere, pushing carbon dioxide concentration to record levels. This was announced by scientists after they analysed data collected by Nasa's Orbiting Carbon Observatory-2 (OCO-2) satellite, which measures level of carbon dioxide in the atmosphere.

CO_2 emissions of Indonesian fires 2015 ?



AGU PUBLICATIONS

Heymann et al., 2017

Geophysical Research Letters

RESEARCH LETTER

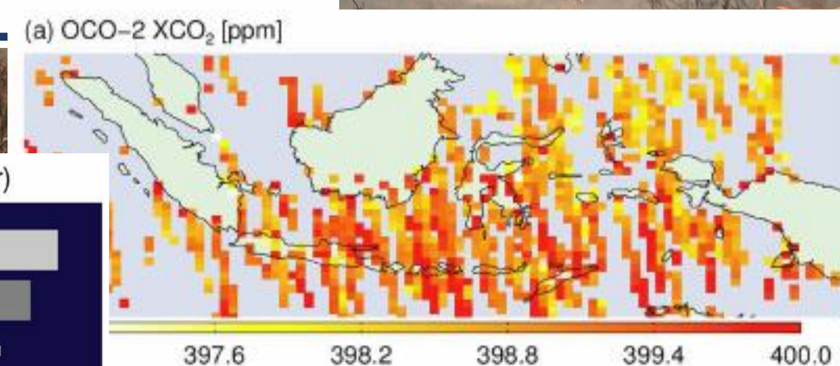
10.1002/2016GL072042

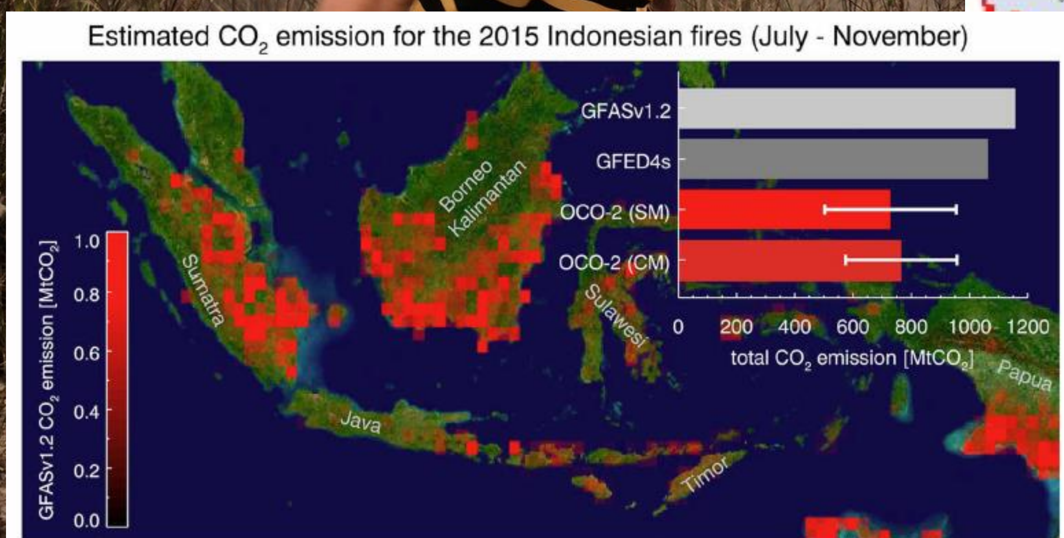
Key Points:
- Indonesian fire CO_2 emission is estimated by using OCO-2 XCO_2 retrievals
- The estimated CO_2 emission is 748 ± 209 $MtCO_2$ for the time period from July to November 2015
- The estimated CO_2 emission is about 30% lower than widely used emission databases

CO_2 emission of Indonesian fires in 2015 estimated from satellite-derived atmospheric CO_2 concentrations

J. Heymann[1], M. Reuter[1], M. Buchwitz[1], O. Schneising[1], H. Bovensmann[1], J. P. Burrows[1], S. Massart[2], J. W. Kaiser[3], and D. Crisp[4]

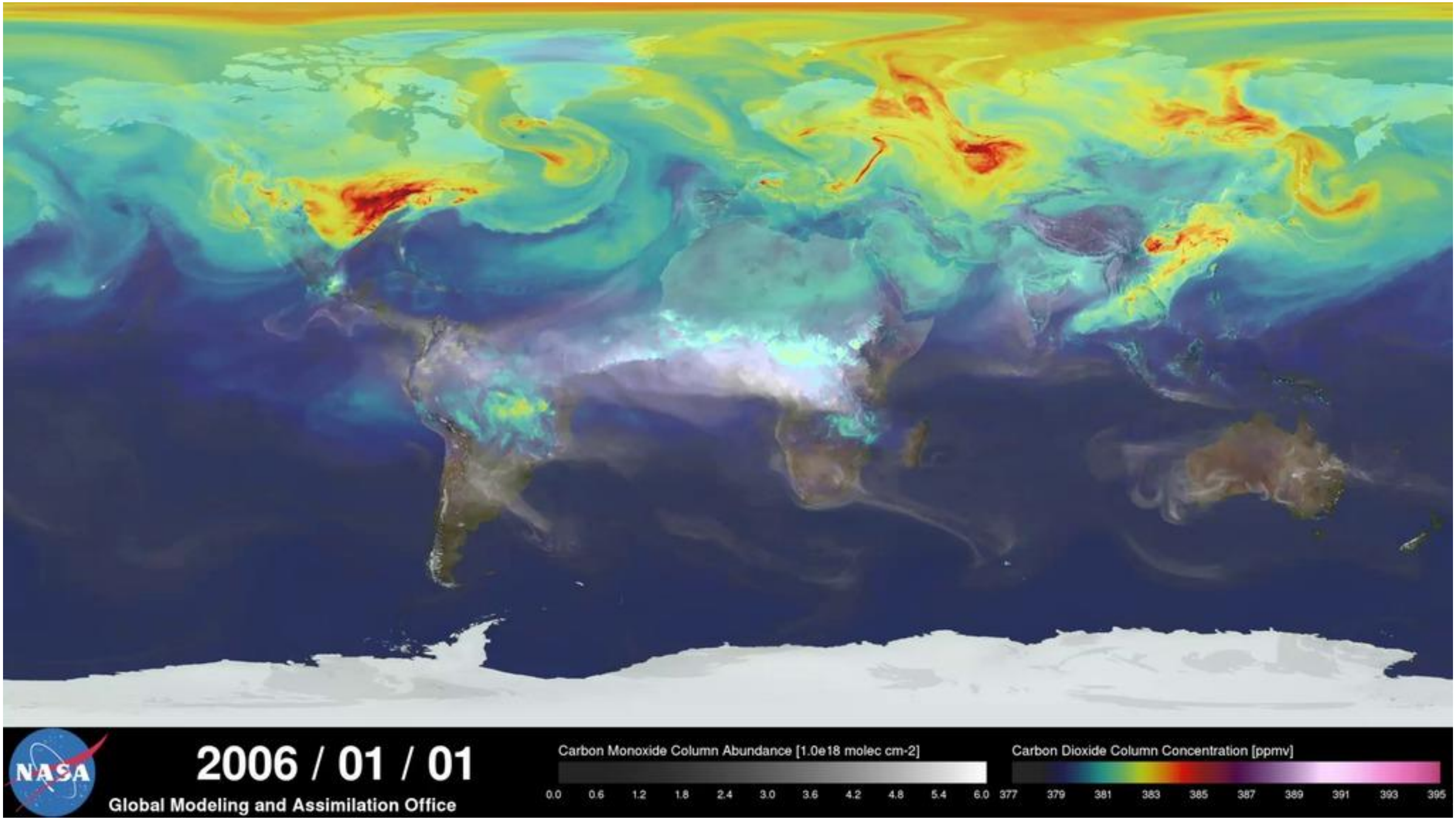
[1]Institute of Environmental Physics, University of Bremen, Bremen, Germany, [2]European Centre for Medium-Range Weather Forecasts, Reading, UK, [3]Max Planck Institute for Chemistry, Mainz, Germany, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA



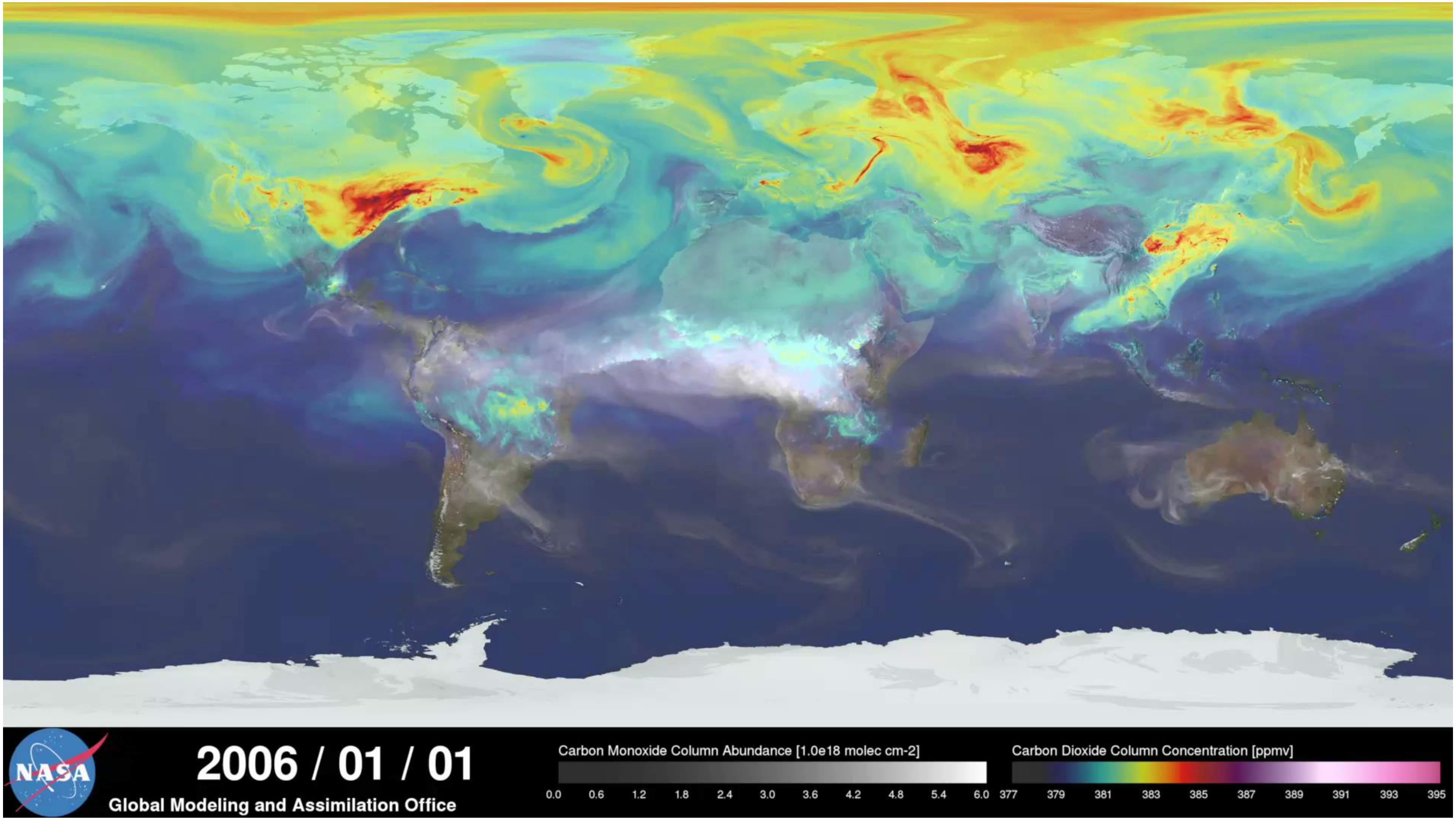


www.theguardian.com

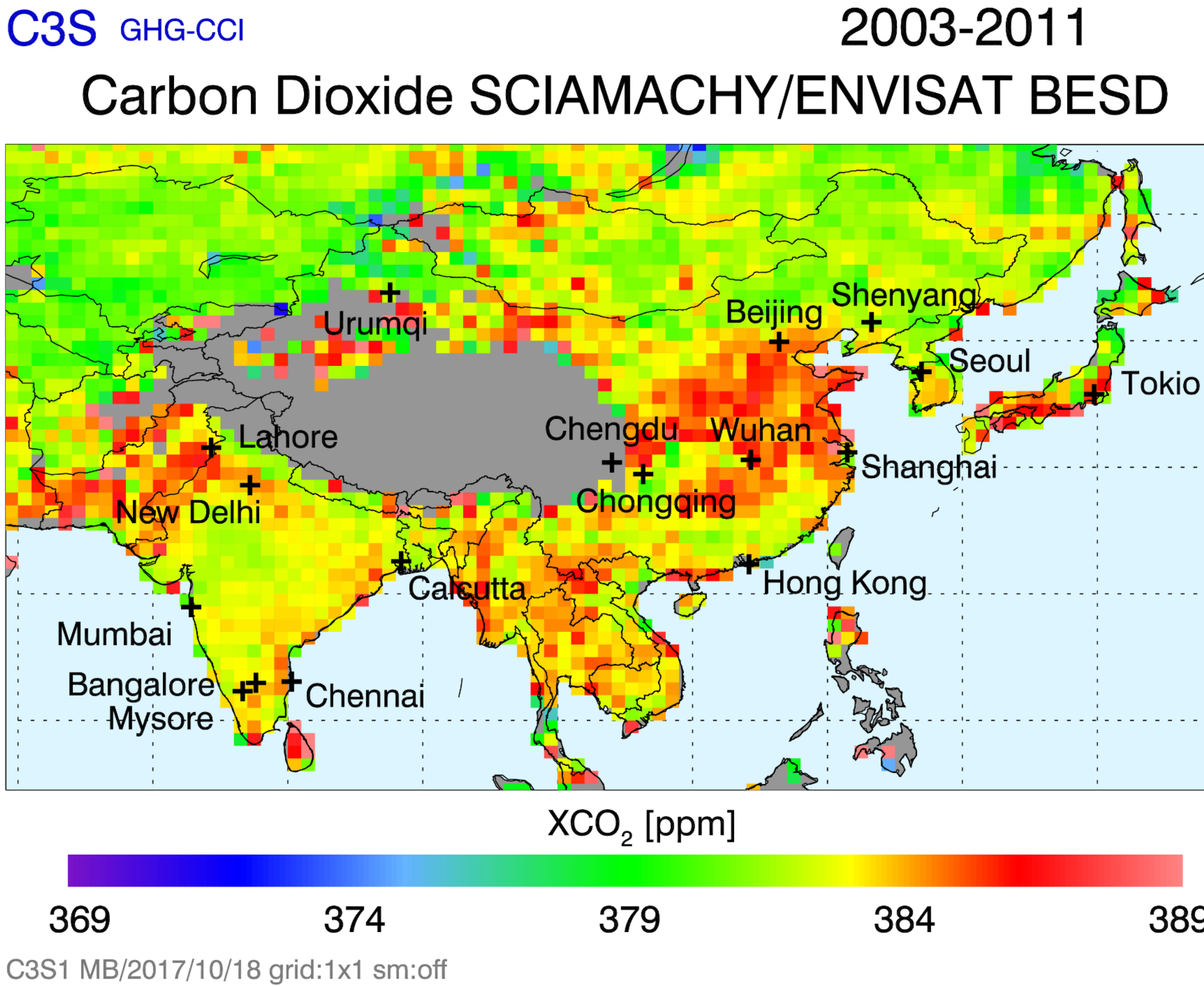
Atmospheric XCO_2 simulation



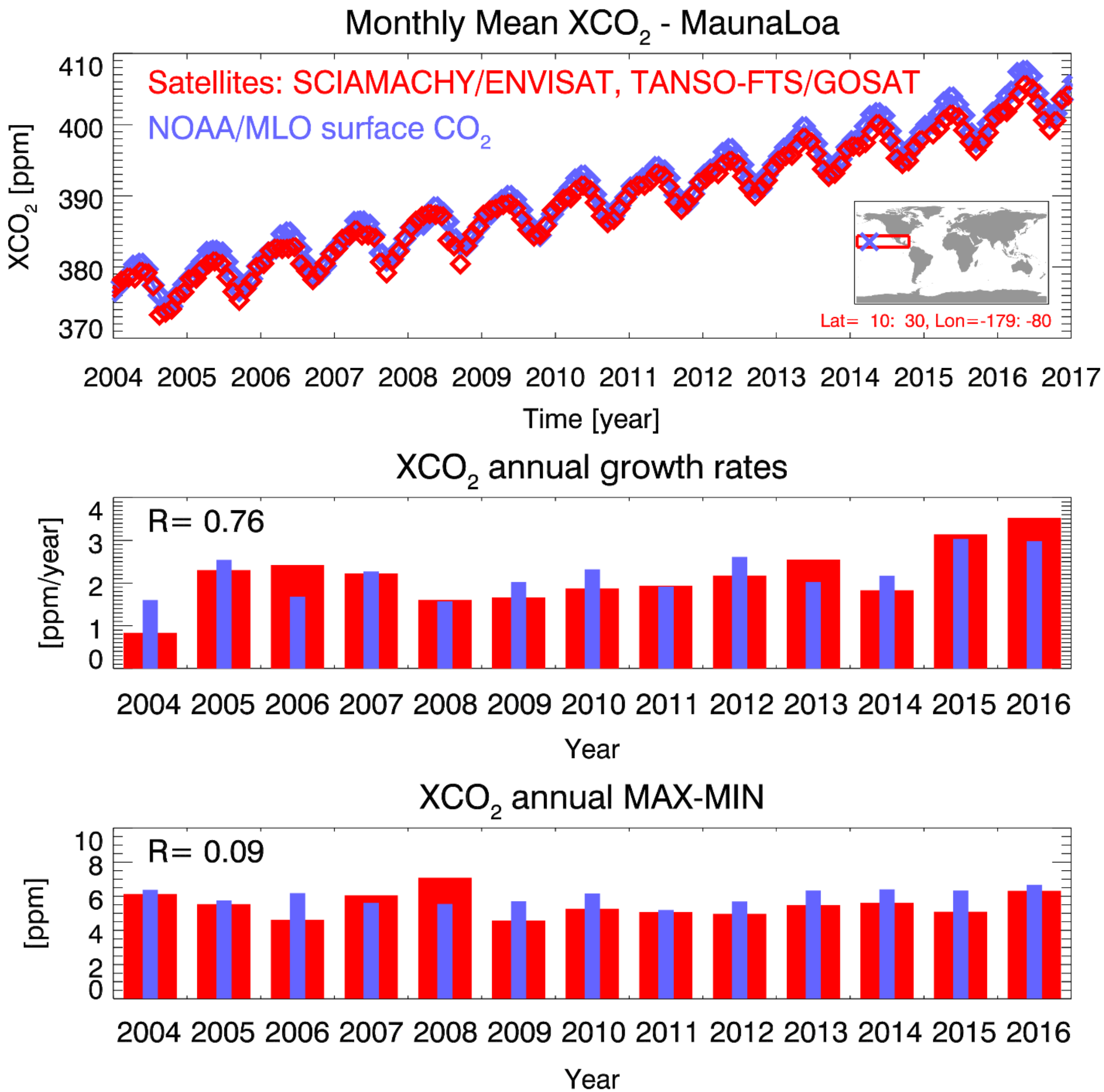
Atmospheric XCO_2 simulation



C3S: XCO_2 China & India (1°x1°)



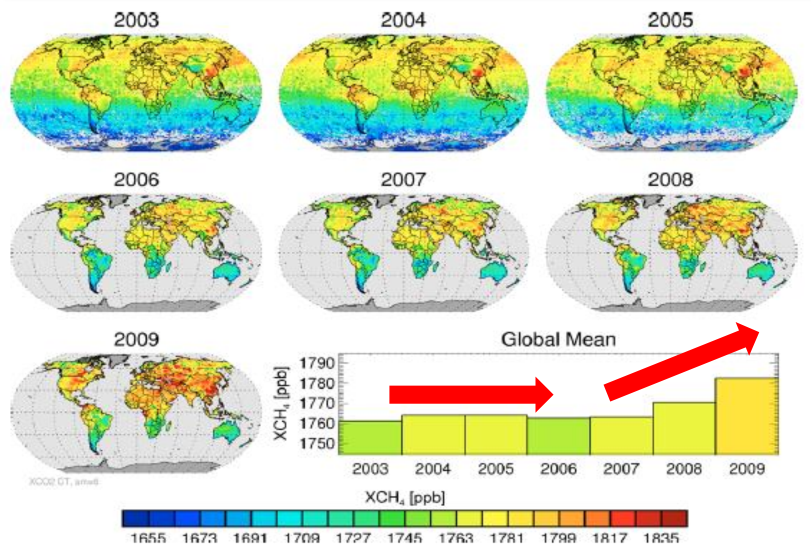
Merged L3 XCO_2: Some details: MaunaLoa



Dry mole fraction of methane, XCH_4 , retrieved from Space?

Since 2007: Renewed methane growth

Schneising et al., 2011



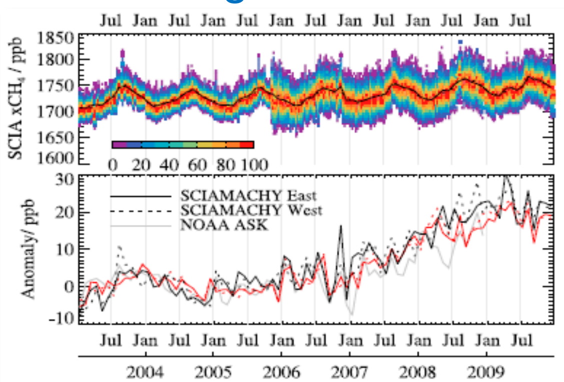
Latitude band	Mean amplitude seasonal cycle [ppb] SCIA	Mean amplitude seasonal cycle [ppb] TM5(2003)	Anomaly since 2007 [ppb yr^{-1}] SCIA	Anomaly since 2007 [ppb yr^{-1}] TM5(2003)
Global	13.4±4.0	9.8±2.9	7.4	−0.4
NH	13.7±2.6	9.3±0.3	8.2	−0.5
SH	8.5±5.3	8.5±1.7	5.4	−0.6
30° N–90° N	12.4±8.0	11.2±0.8	6.6	−0.6
30° S–30° N	7.3±3.7	5.1±0.9	8.2	−0.2
30° S–90° S	10.6±1.2	8.5±3.1	4.4	0.0
0° N–30° N	17.2±1.9	10.8±1.0	9.1	−0.4
0° S–30° S	6.1±2.7	5.2±0.3	5.8	−0.5

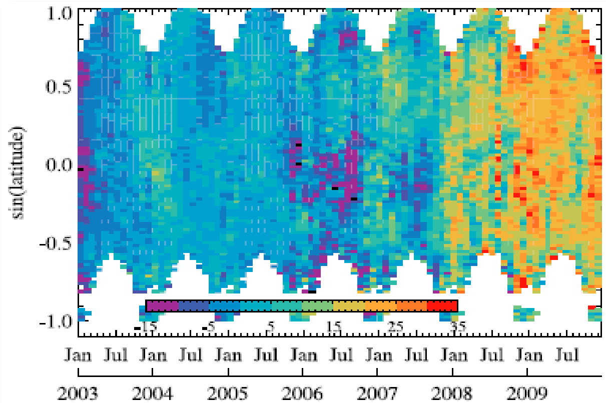
NH (~0- 60°)

Tropics

NH Tropics

Frankenberg et al., 2011

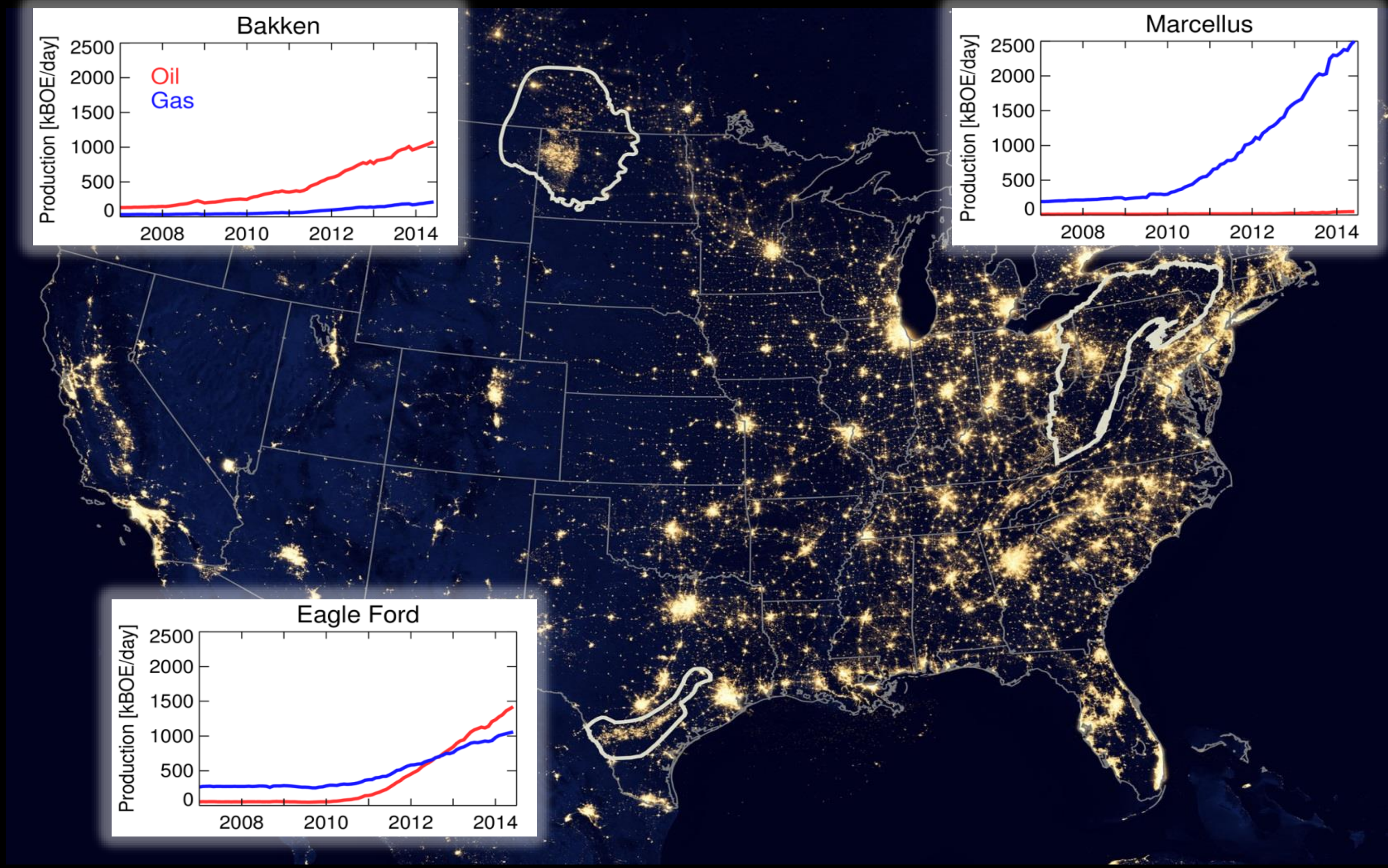




Findings:

- **Increase ~7-9 ppb/yr** (0.4-0.5%/yr) (2007-2009 relative to 2003-2006)
- **Mainly tropics & NH mid latitudes**
- No “local / regional hot spot” found
- Analysis complicated by detector degradation

Fugitive methane emissions from oil and gas production (Schneising et al., 2014, Earth's Future)



- We analyse **methane enhancements** over the fastest growing production regions in the U.S.
- Flaring in **Bakken** and **Eagle Ford** is so extensive that both regions stand out clearly in satellite measurements of nighttime lights from VIIRS onboard Suomi NPP.

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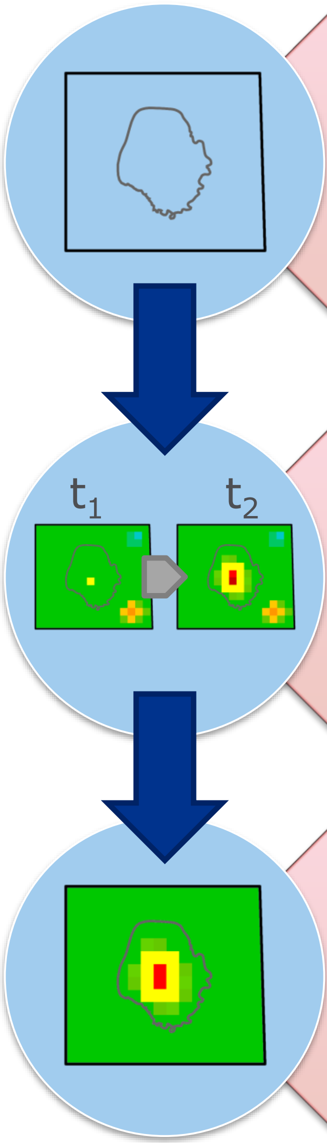
Methodology (Schneising et al., 2014)



XCH_4 anomalies (subtract monthly mean values for the entire region):

Filters out large-scale seasonal variations or increase

Averaging over periods 2006-2008 and 2009-2011:

Achieves the signal-to-noise to identify the fugitive methane emissions (only a few ppb)

Anomaly differences of these periods:

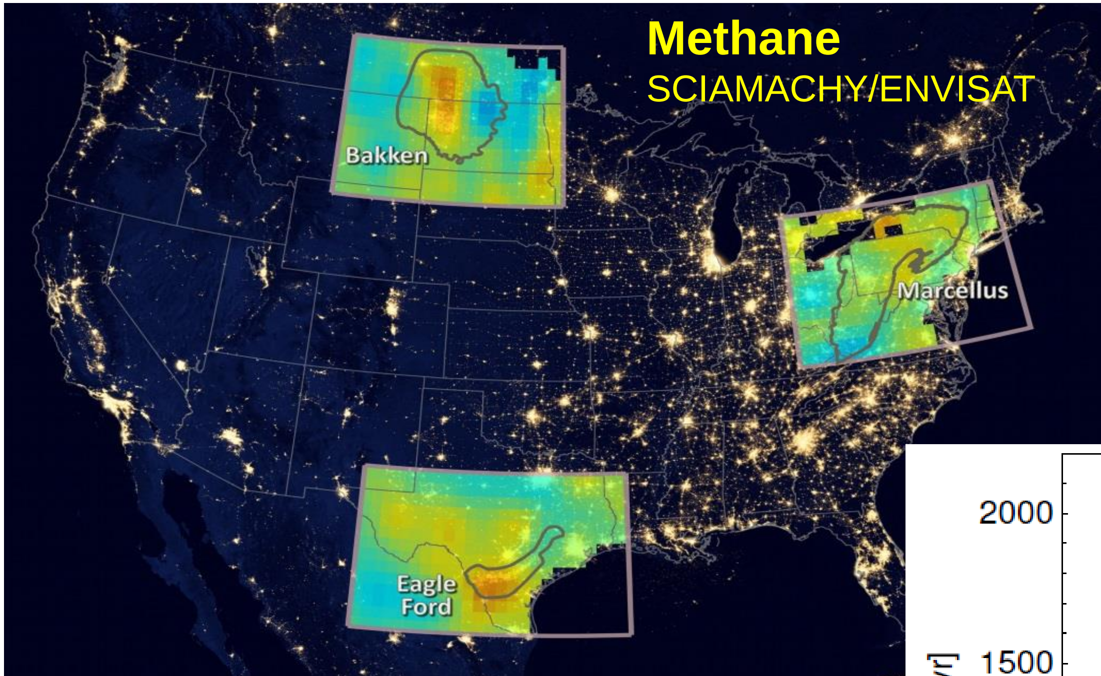
Separates regional emission trends from temporally constant other intraregional emission signals

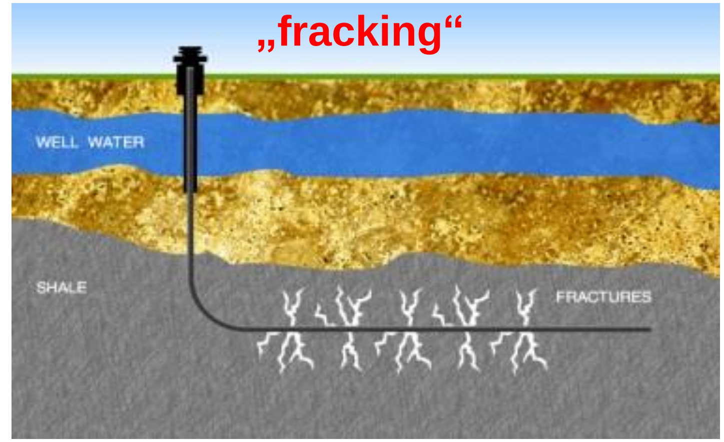
SCIAMACHY methane:

Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations

Oliver Schneising[1], John P. Burrows[1,2,3], Russell R. Dickerson[2], Michael Buchwitz[1], Maximilian Reuter[1], and Heinrich Bovensmann[1]

Schneising et al., Earth's Future, 2014





Estimated emission increase 2009-2011 relative to 2006-2008:

- **Bakken: 990±650 ktCH$_4$/yr**
- **Eagle Ford: 530±330 ktCH$_4$/yr**

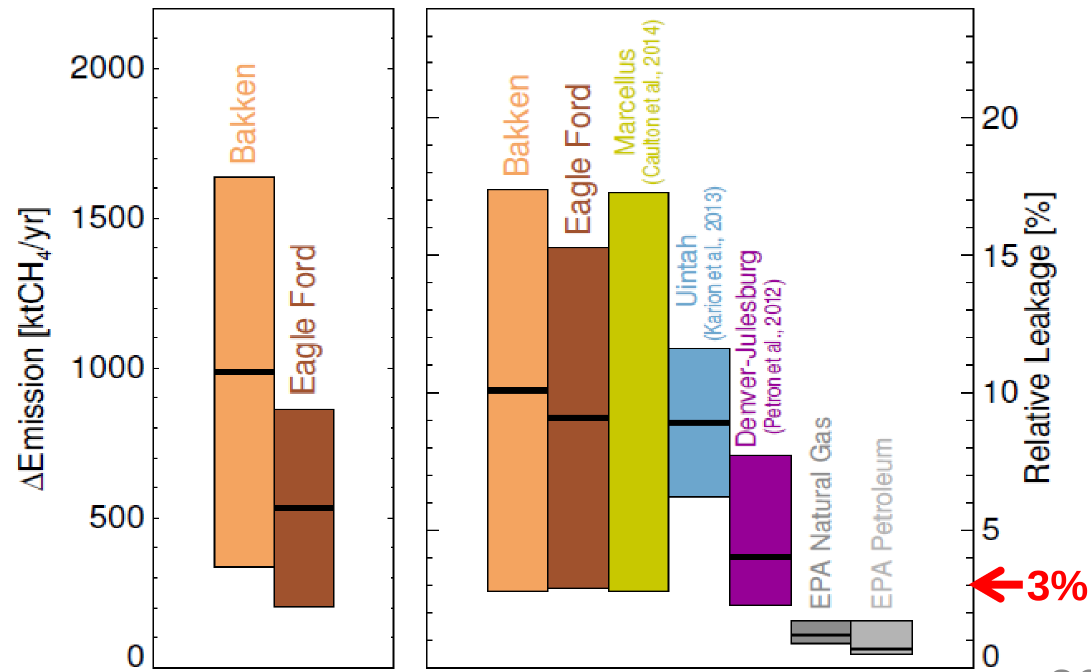
Emission estimates correspond to **leakages** of

- Bakken: 10.1±7.3% and
- Eagle Ford: 9.1±6.2%

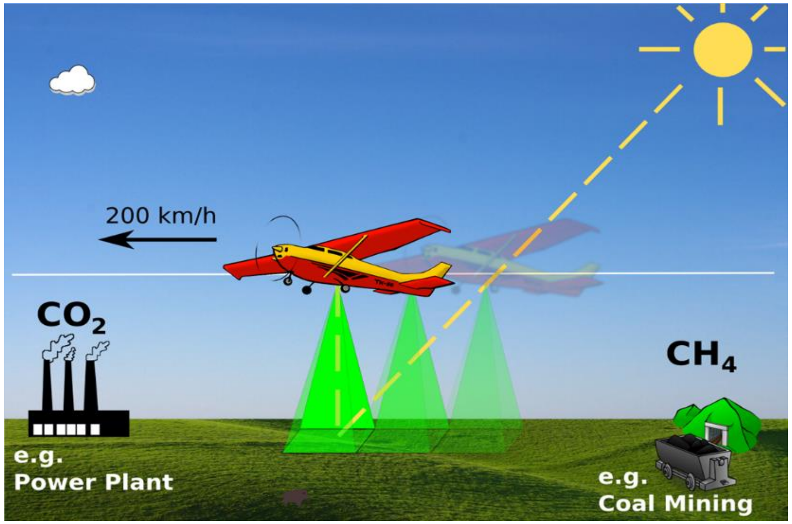
in terms of energy content.

Exceeds 3.2% "climate benefit" threshold (Alvarez et al., 2012) for switching from coal to natural gas

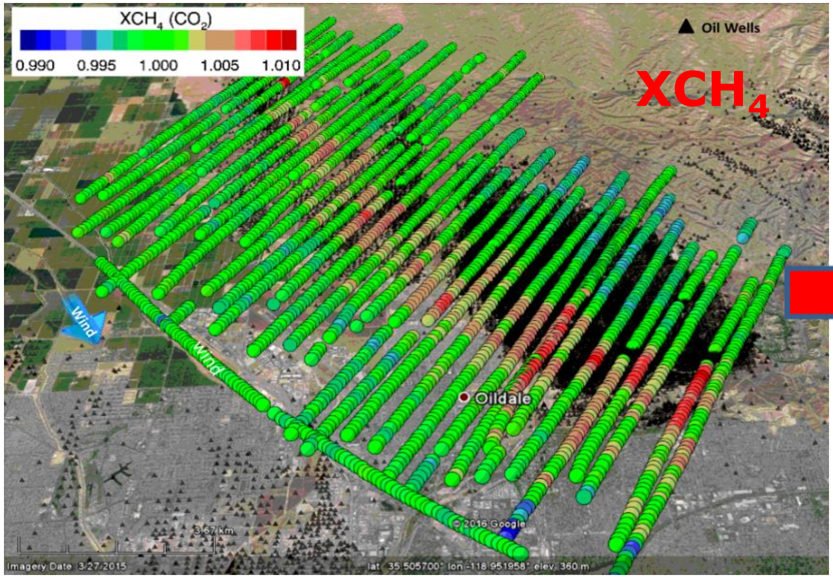
Likely **underestimated in inventories**.

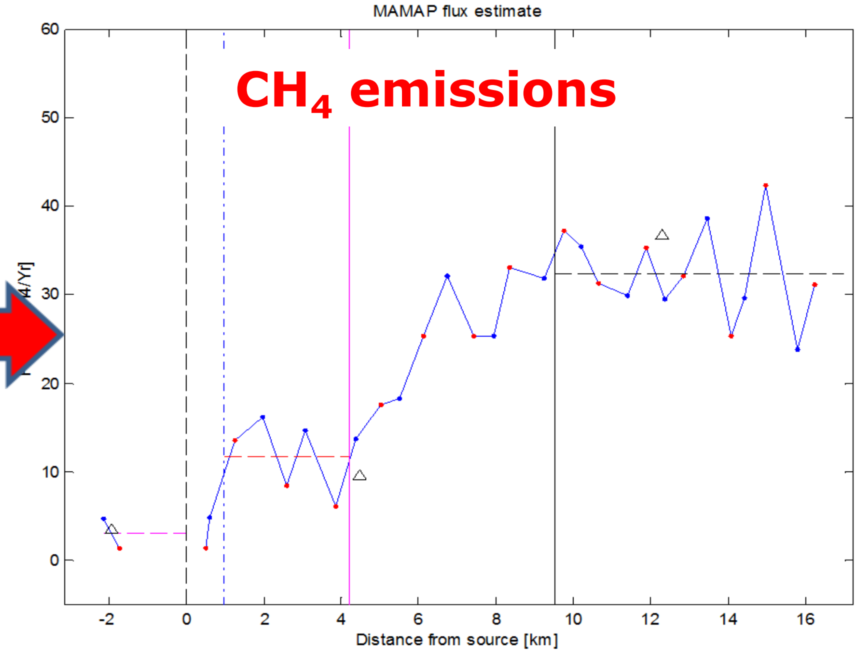


Example: CH_4 from Oil fields as seen by MAMAP

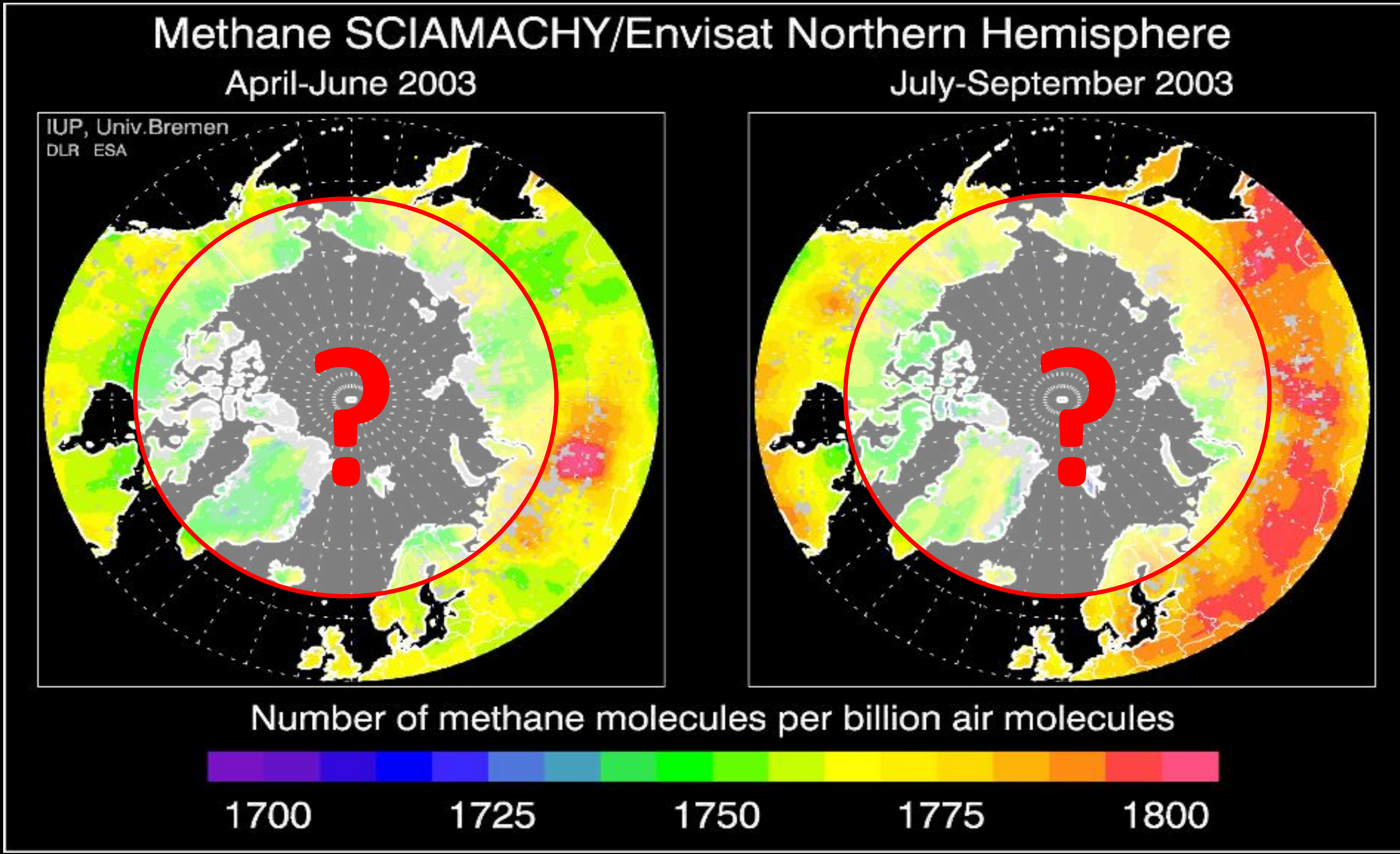


- significantly enhanced CH_4 detected over oil fields in California in summer 2014 (COMEX)
- no emissions reported
- from data emissions were estimated to up to 30kT CH_4/yr at the time of overpass





CarbonSat: Methane @ high latitudes



CarbonSat sun-glint mode allows observation of methane in vulnerable high latitude regions including Arctic sea and shelf areas

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From CarbonSat to CO_2PERNICUS !

CarbonSat

ESA & EU

CO_2pernicus

Conclusion and Perspectives

- The earth has entered a new geological epoch – the anthropocene
- A Golden Pioneering age of remote sensing from space has demonstrated the measurements needed for science and policy-making.
- Limitations are:
    - Sparse sampling in time: analysis better then yearly resolution needs spatial averaging over large regions.
    - Sparse sampling in space: data analysis below the regional scale currently needs multi-year averages to be analysed.
    - Measurement random and systematic errors limit some applications
- Airborne remote sensing has demonstrated the power to quantify local emissions, using „images“ enabling surface anthropogenic fluxes to be separated from natural phenomena.

Conclusion and Perspectives

- The loss of ENVISAT means Europe has now no global measurements of
  - i) CO_2 and CH_4 and

    ii) vertical profiles of O_3, aerosol, NOx, ClOx, reservoir species
- The development of a fit for purpose system is required
- Options:

Use ISS platform for demonstration of 1kmx1km observations

Develop i) **CarbonSat and CarbonSat like constellation** and

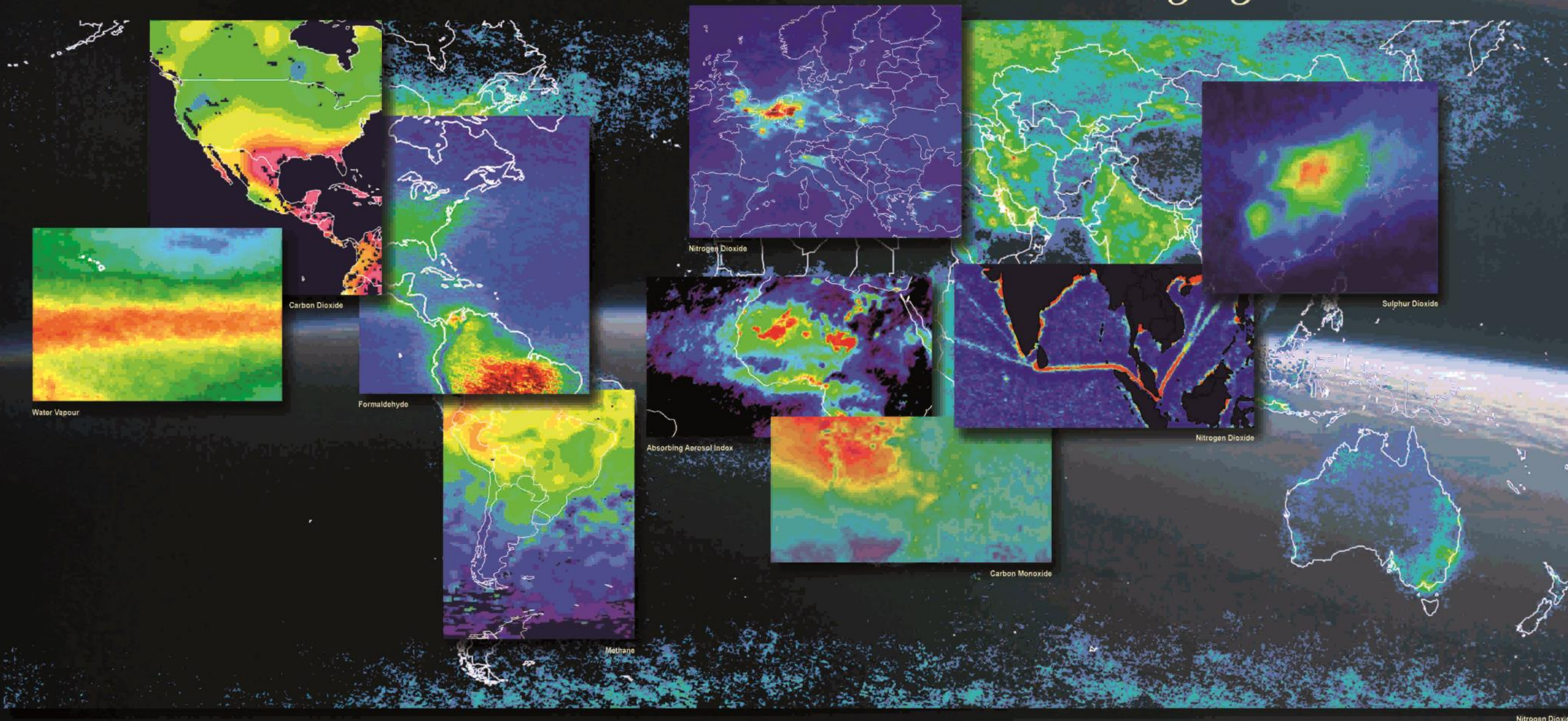
ii) New **limb missions**

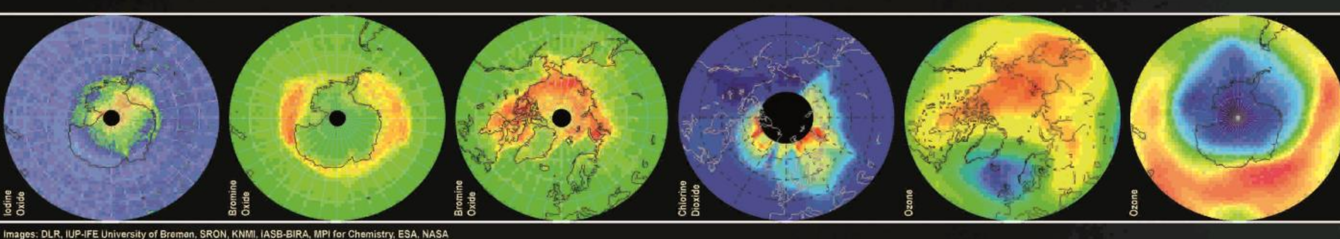
iii) evolve to 1 kmx1 km for Short lived climate Pollutants

to deliver the objective evidence base required for science and the monitoring and evolution of policymaking.

SCIAMACHY 2002-2012

hunting light and shadows





Images: DLR, IUP-IFE University of Bremen, SRON, KNMI, IASB-BIRA, MPI for Chemistry, ESA, NASA

Particular thanks to all my scientific collaborators