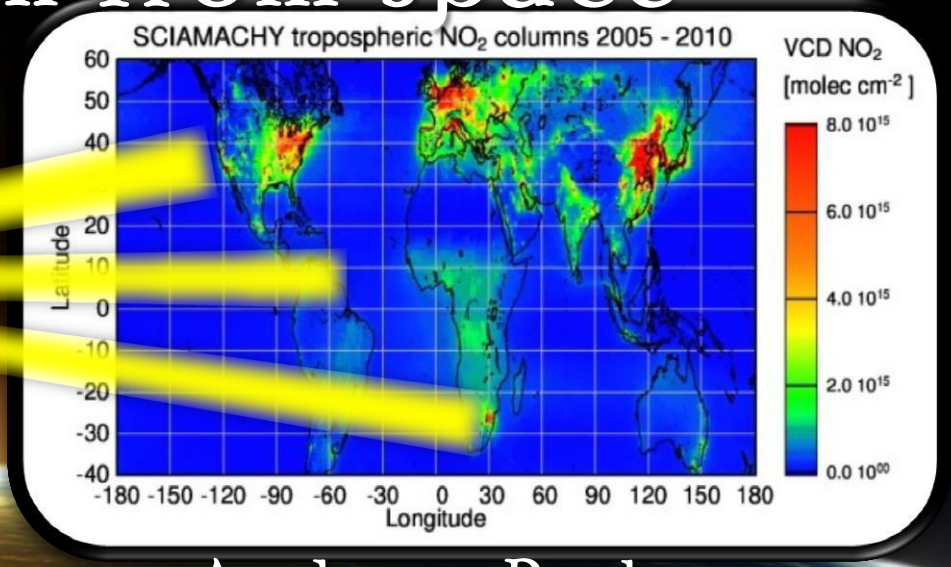
Remote Sensing of tropospheric pollution from space



Mihalis Vrekoussis, Andreas Richter, Andreas Hilboll, Leonardo Alvarado, Folkard Wittrock and John P. Burrows

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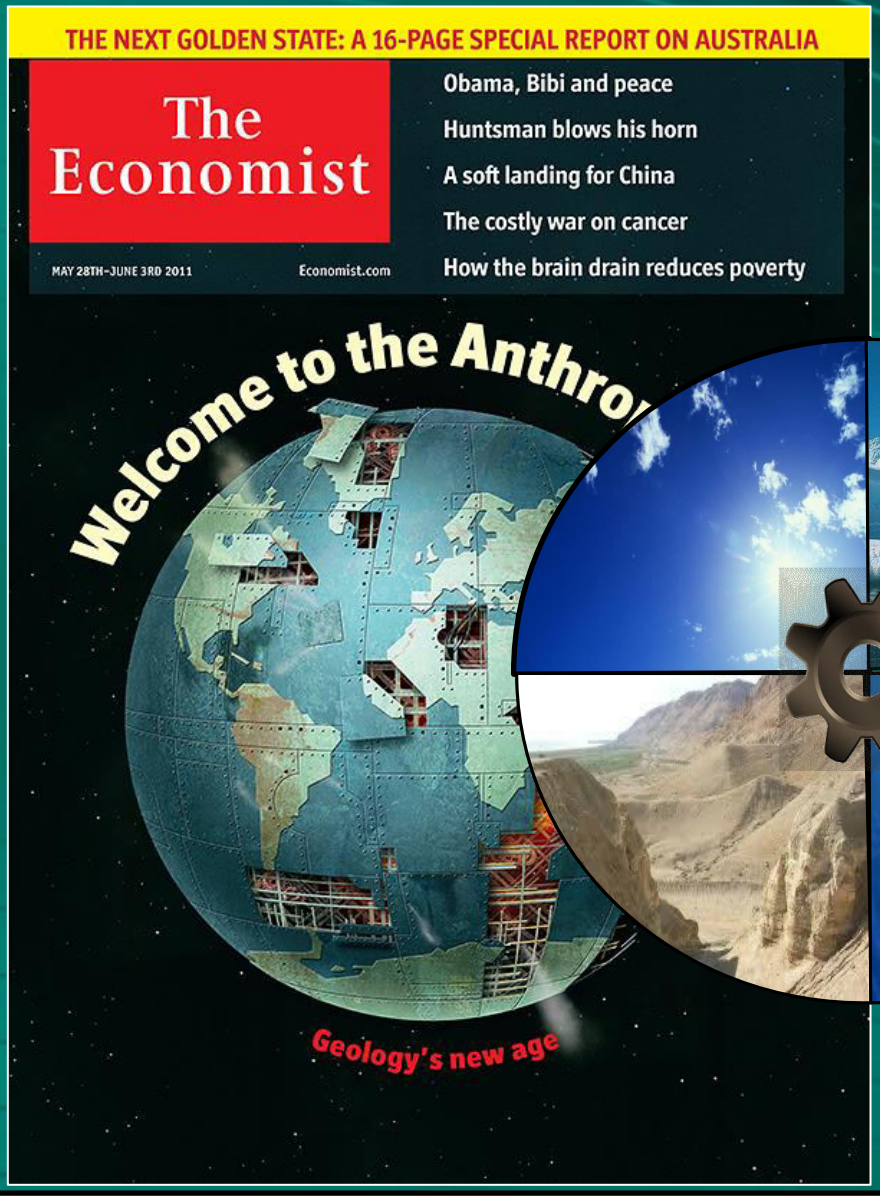
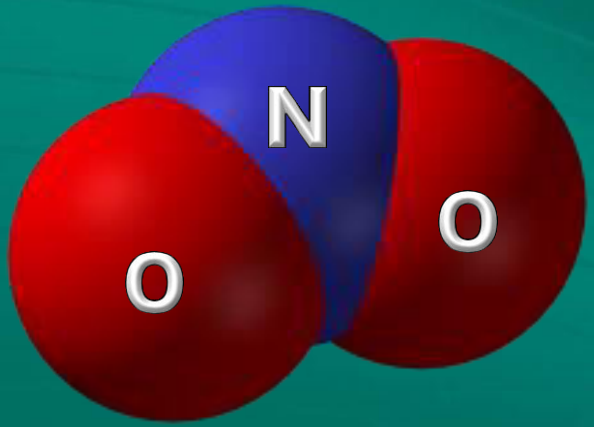
WORKSHOP | 16 - 17 MAY 2018 |
Nicosia, Cyprus
"Mediterranean & Middle East air pollution in a changing climate"

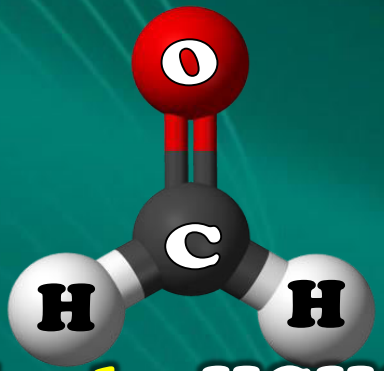


The **Anthropocene** is proposed as the new geological epoch where **human-influence will dominate the fossil records**. *There is overwhelming global evidence that atmospheric, geologic, hydrologic, biospheric and other Earth system processes are now modified by human activity*. (E. F. Stoermer and P. J. Crutzen 2001 IGBP)

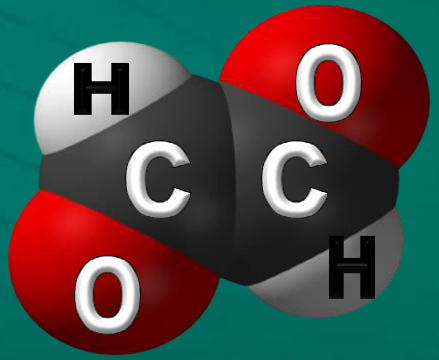


Nitrogen Dioxide: NO_2

STRUCTURE



Formaldehyde: HCHO



Glyoxal: CHOCHO

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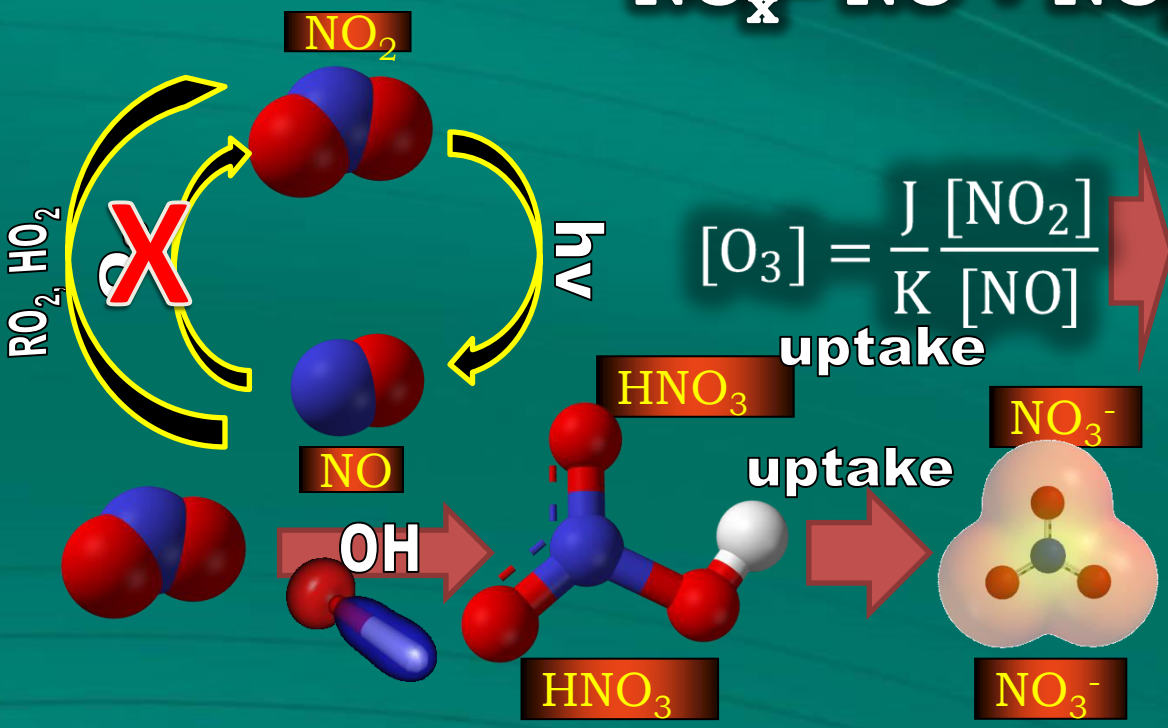
Theoretical aspects

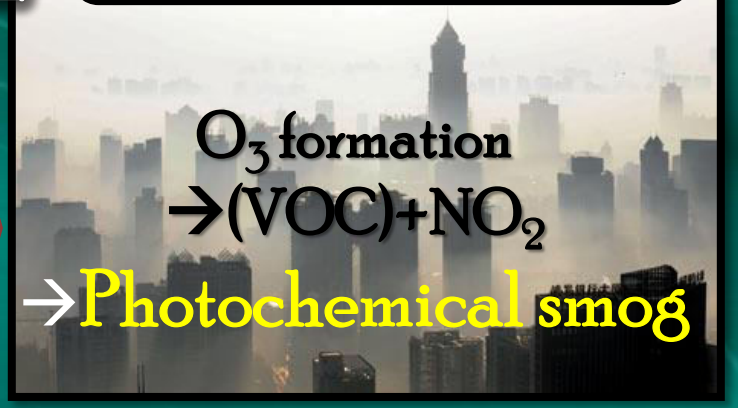
Why should we care about NOx in the Troposphere?

$NO_x = NO + NO_2$



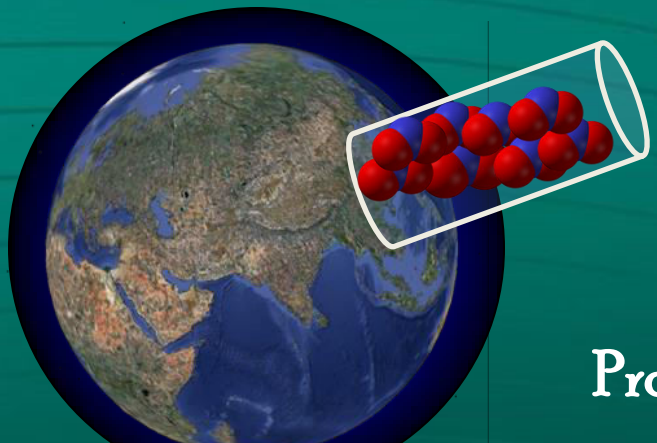
$$[O_3] = \frac{J\,[NO_2]}{K\,[NO]}$$

Impact on climate and human health



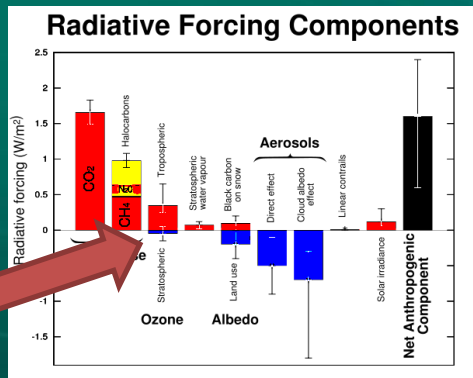
O_3 formation
→(VOC)+NO_2
→Photochemical smog

HNO_3 formation, NO_3^-
(NO_2+OH, NO_3 →N_2O_5)
→Acid rain, changes in eutrophication



Changes in radiative forcing by absorbing sunlight (locally)

Production of O_3: Greenhouse gas

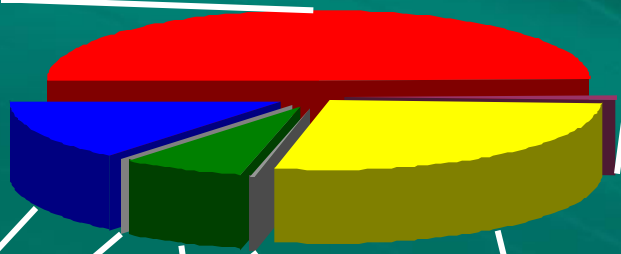


Sources of NOx in Tg $N \cdot y^{-1}$ (Troposphere)

Fossil fuel combustion

22

(51%)



Aircraft

0.5 (1%)

Soil emissions/NH_3 oxidation

6.0

(14%)

Oceans

0.1

Lightning

3.0 (6%)

Stratosphere

0.1

Biomass burning

11.6 (27%)

Wang et al, JGR, 1998

Importance

OVOC → **O**xygenated – **V**olatile **O**rganic **C**ompounds

How much is out there?

500 - 1200 Tg·y^{-1}

150-200 Tg·y^{-1}

20 Tg·y^{-1}

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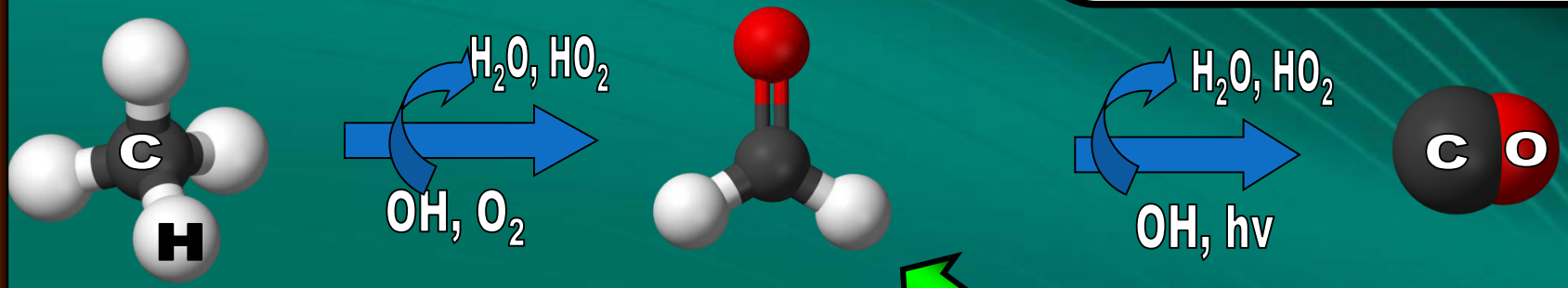
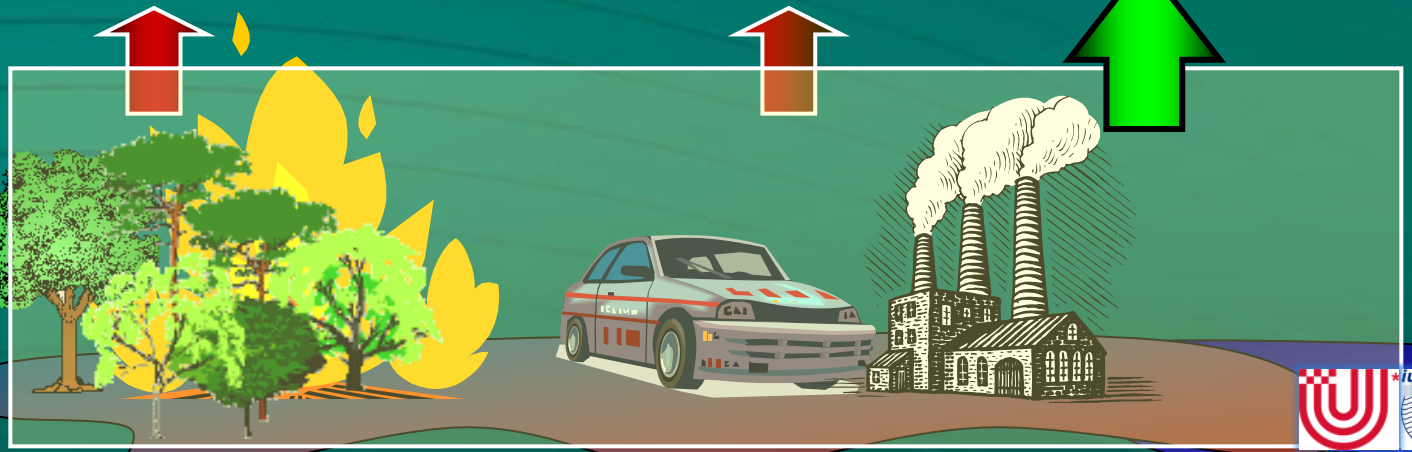
Chemistry (sources and sinks)

Formaldehyde (IUPAC: methanal)

Sources



NMHC



SPECIES ID CARD

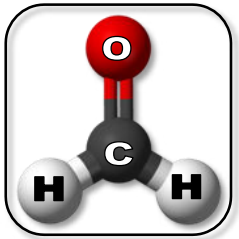
Name: HCHO

Family: oVOC

Known as:

1)The smallest **carbonyl** compound,

2) the most abundant **aldehyde**



027393 000146

Sinks:

OH

hv

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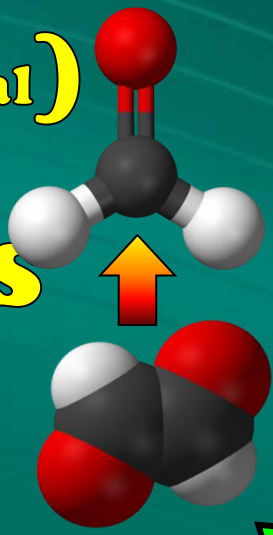
Chemistry (sources and sinks)

Glyoxal

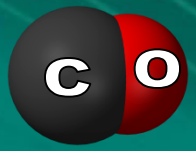
(IUPAC:ethanedial)

Sources



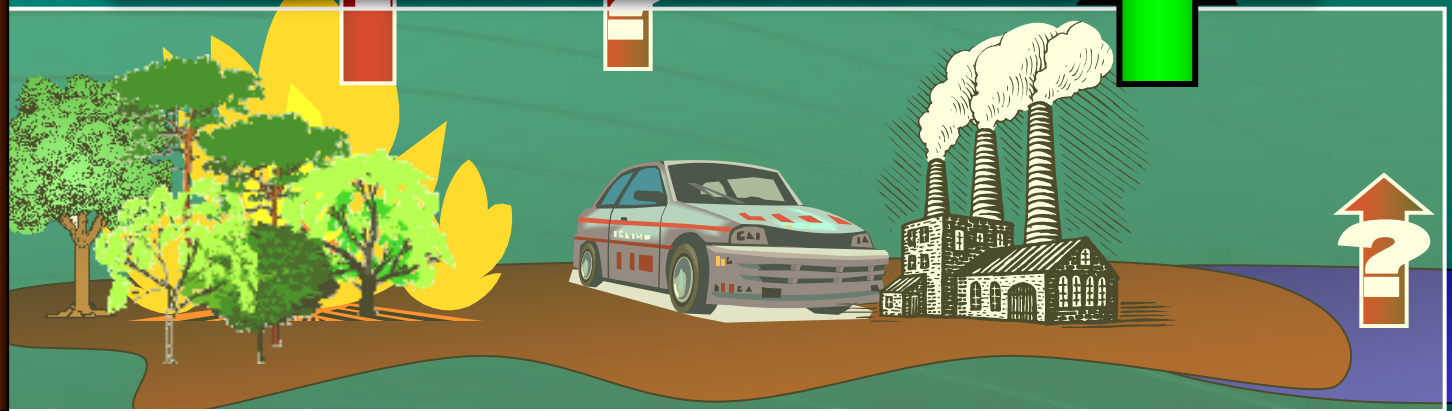
H_2O_2, HO_2

OH, hv



Ethene, Acetylene, Aromatics, Isop e, Terpenes, …

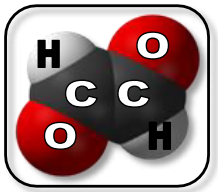
NMHC



SPECIES ID CARD

M.F: CHOCHO

Family: oVOC



CHARACTERISTICS:

THE SMALLEST a-DICARBONYL COMPOUND

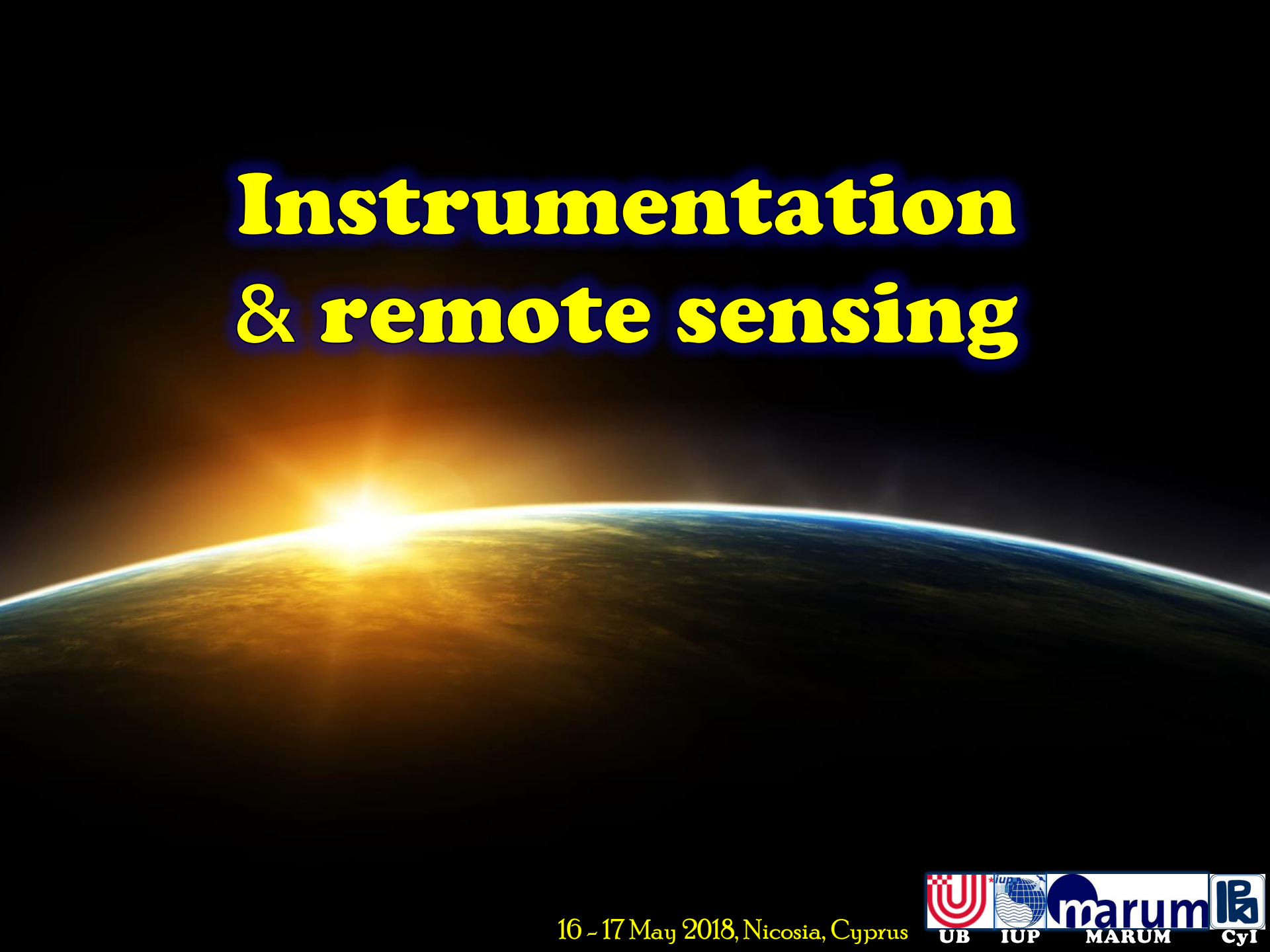
Sinks:

OH

hv

Aerosols

Chemical lifetime~ 2-3h



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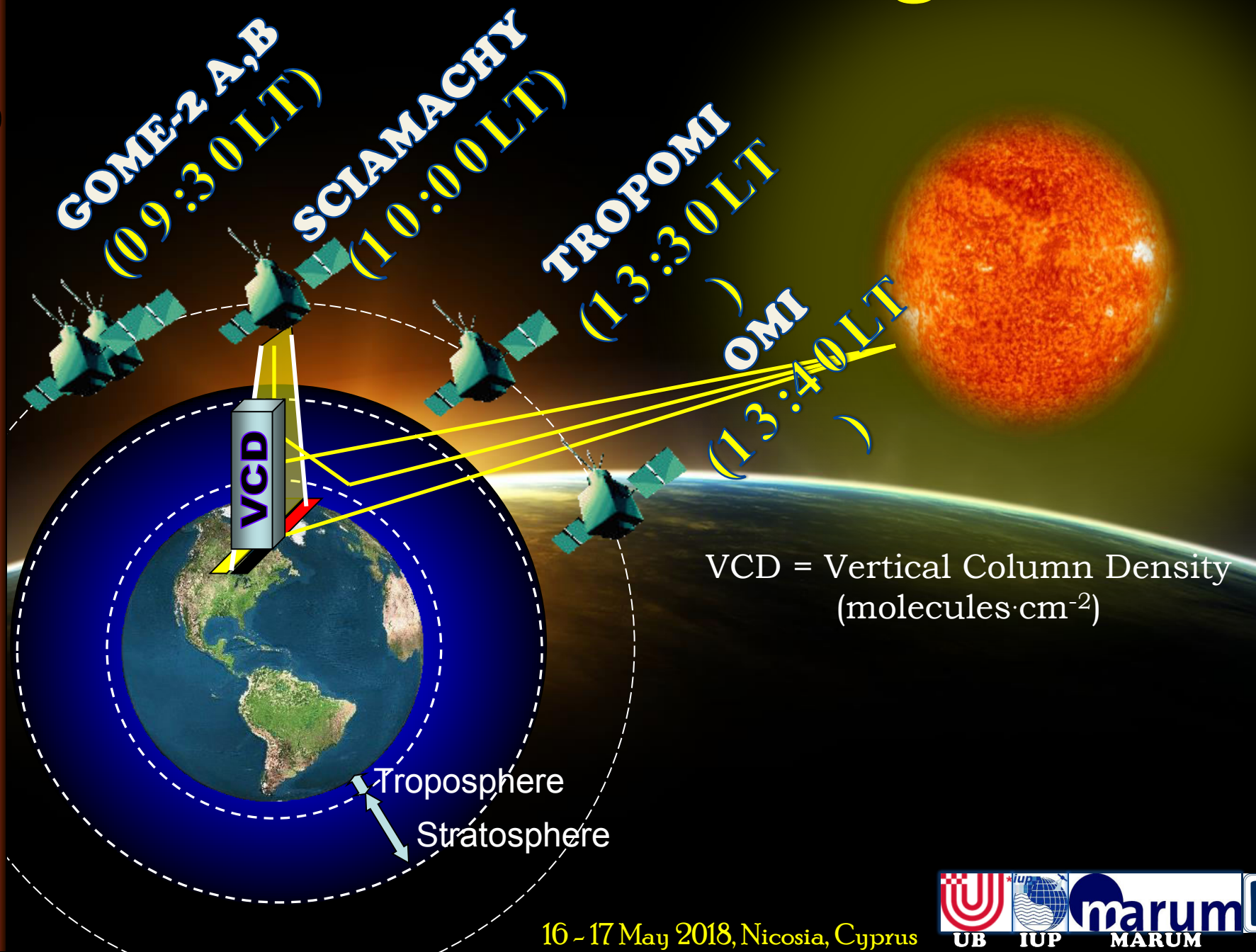
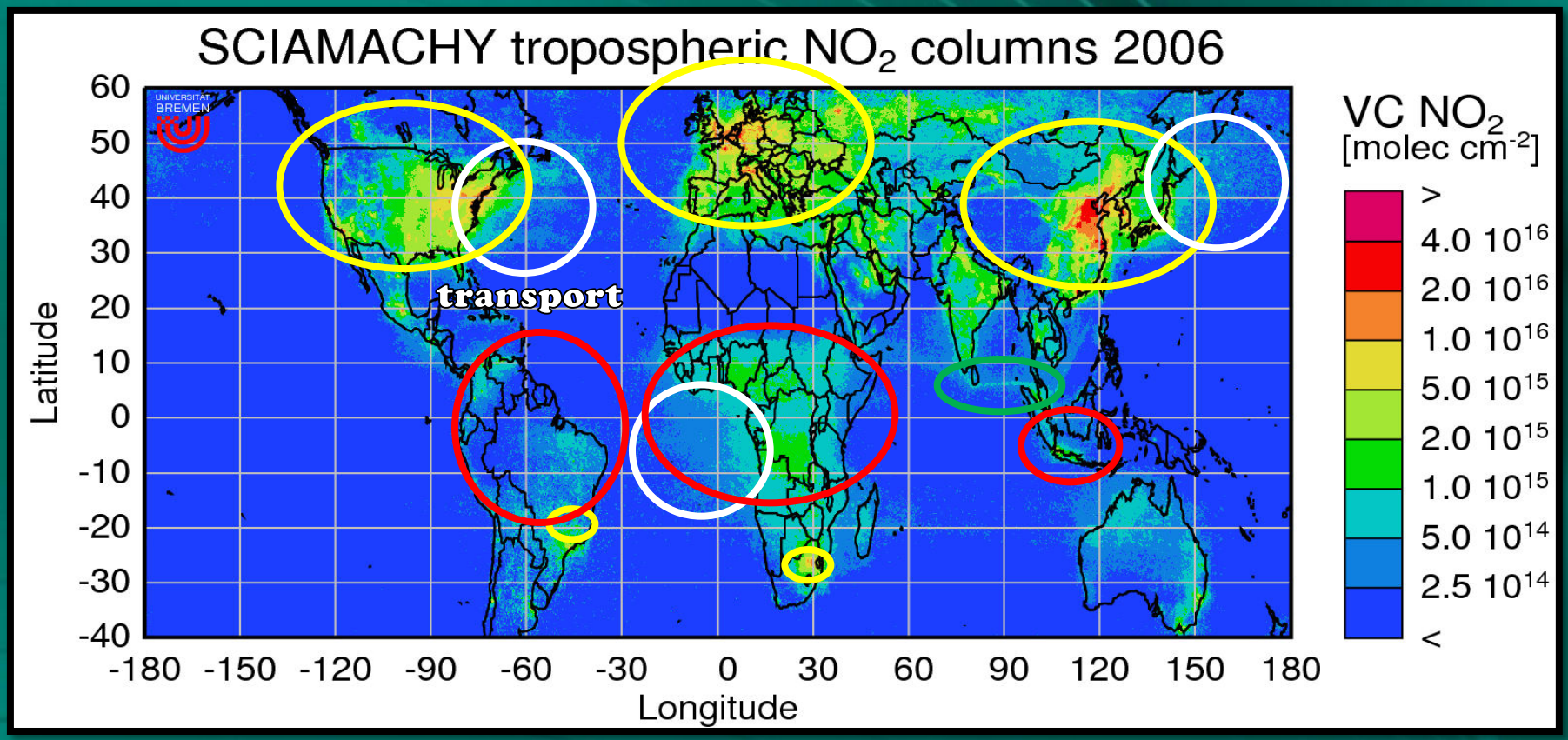
Remote sensing



VCD = Vertical Column Density
(molecules·cm^{-2})

Results
NO2

Satellite NO_2 Measurements: Example



anthropogenic pollution

biomass burning

ships

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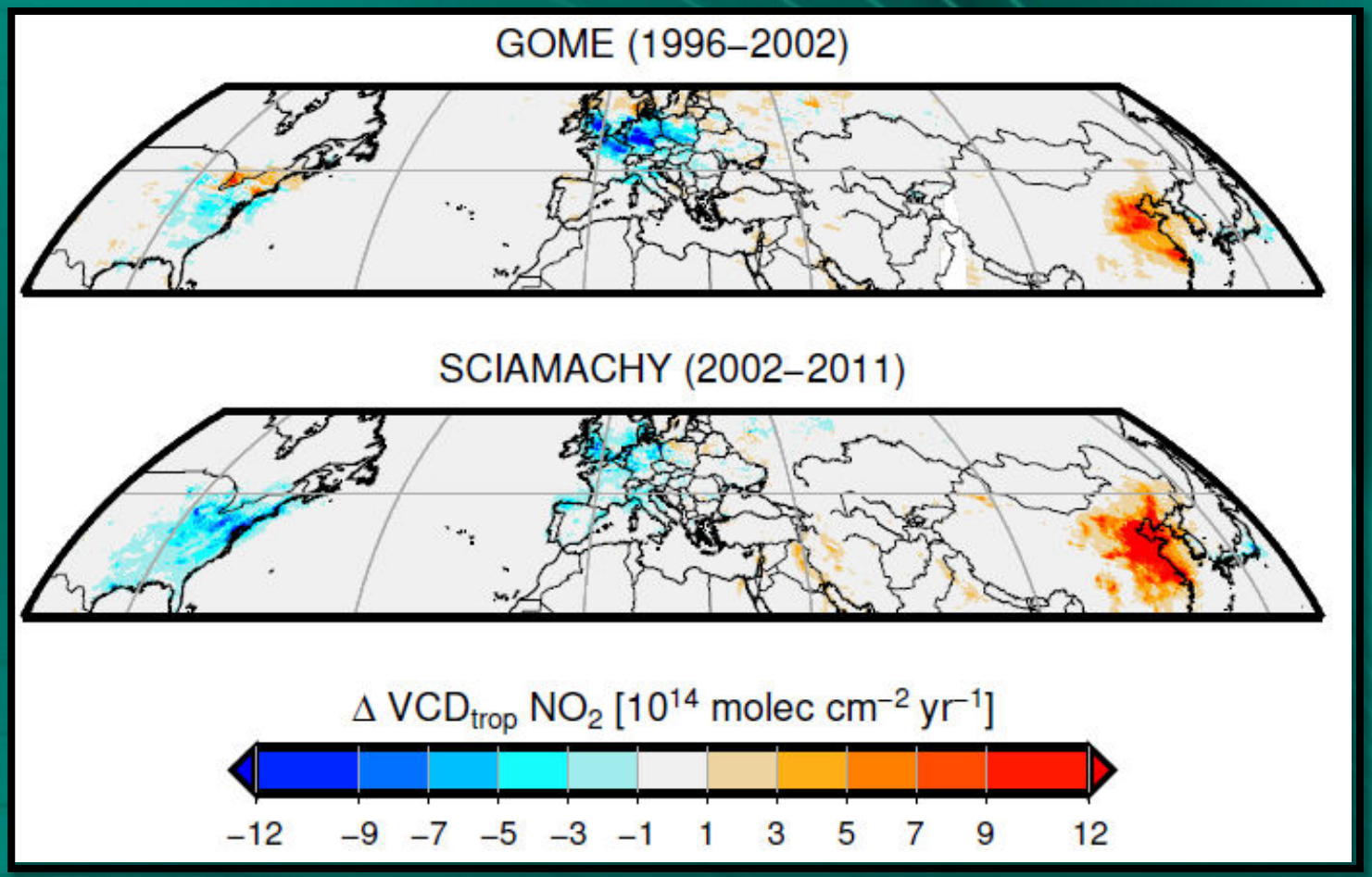
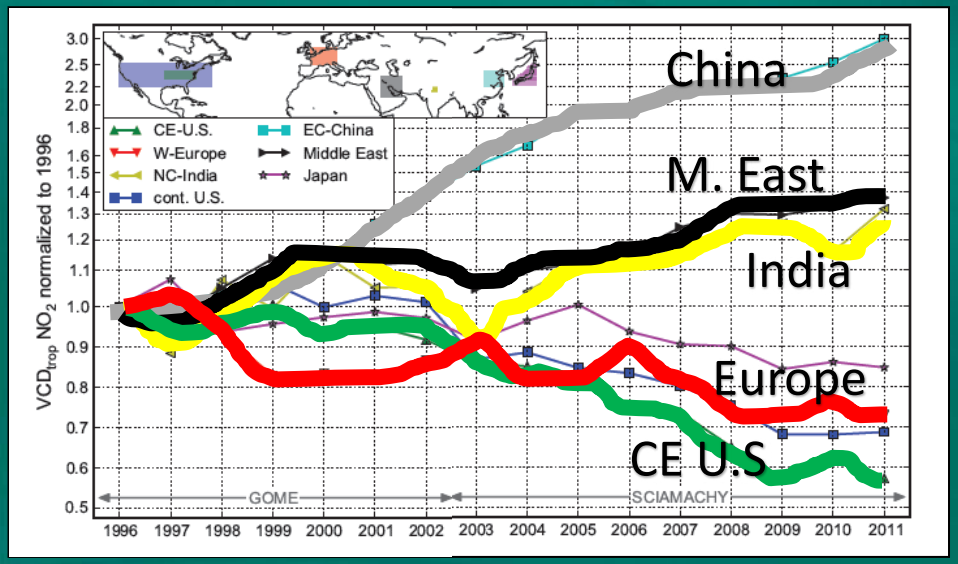
Satellite NO_2 Trends: The Global Picture



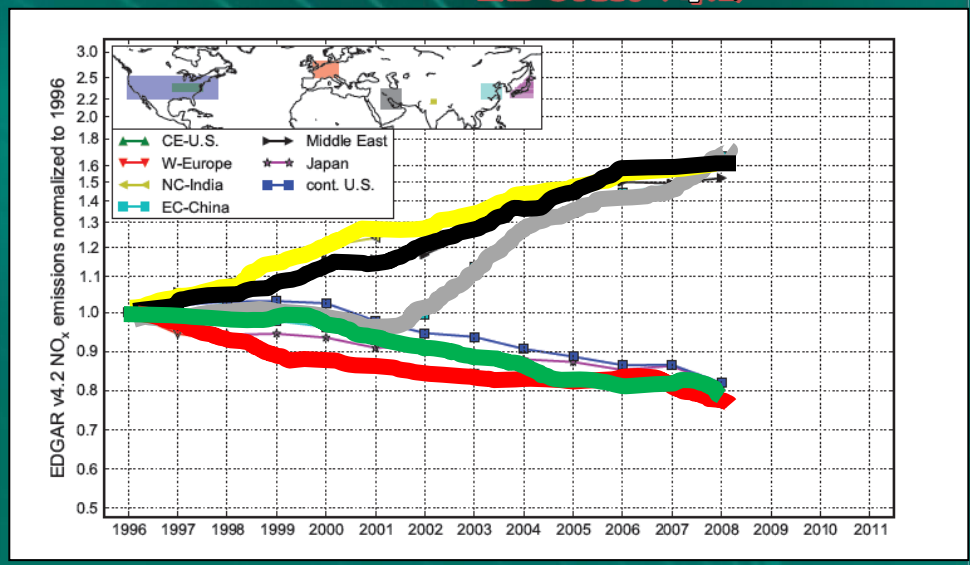
Hilboll, A., Richter, A., and Burrows, J. P.: Long-term changes of tropospheric NO_2 over megacities derived from multiple satellite instruments, *Atmos. Chem. Phys.* 13, 4145-4169, doi:10.5194/acp-13-4145-2013, 2013

NO_2 Trends: Comparison with bottom up estimates

GOME and SCIAMACHY



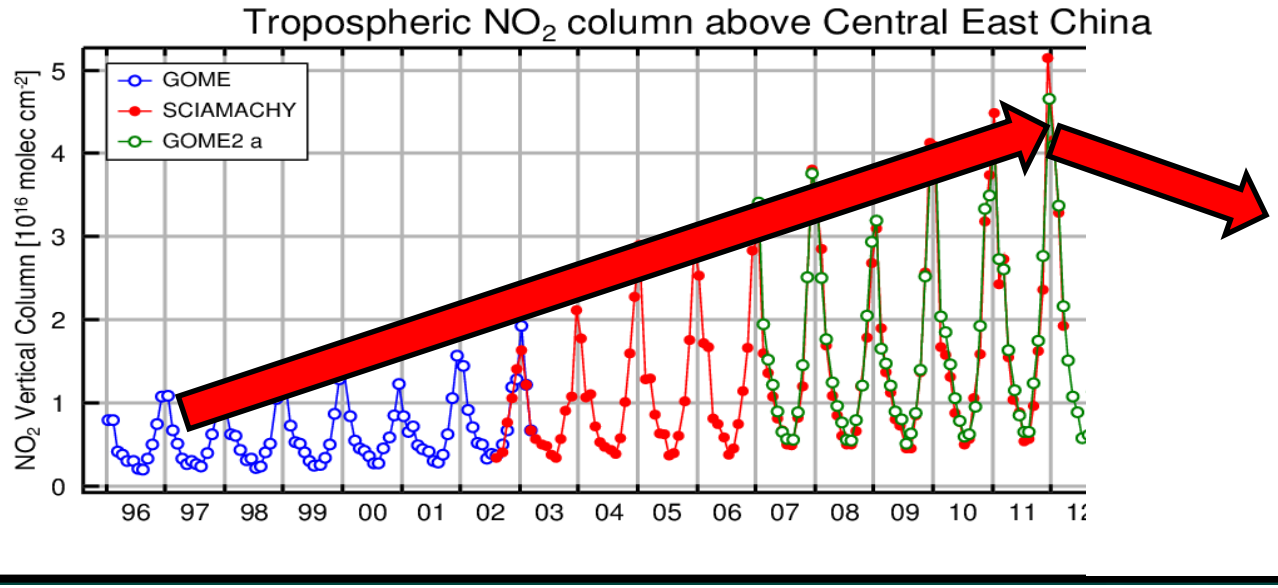
EDGAR v4.2

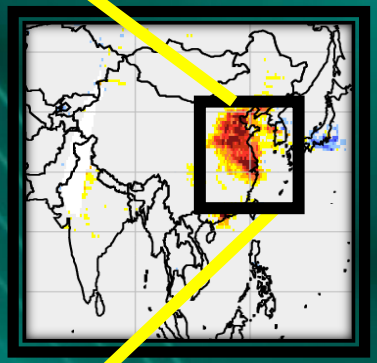


- **Overall pattern in emission data base is correct**
- **Increase in China is underestimated**
- **Increase in India and Middle East is overestimated**
- **Decrease in Europe / US is underestimated**

Hilboll, A., Richter, A., and Burrows, J. P.: Long-term changes of tropospheric NO_2 over megacities derived from multiple satellite instruments, *Atmos. Chem. Phys.* 13, 4145-4169, doi:10.5194/acp-13-4145-2013, 2013

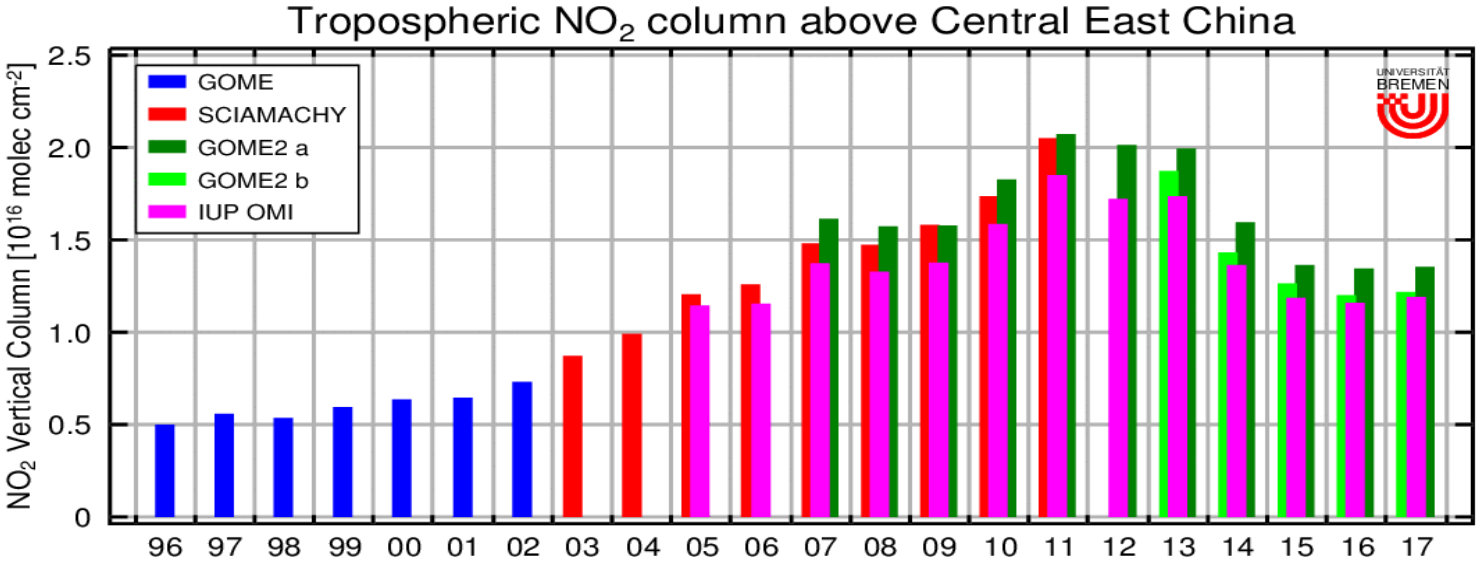
Satellite NO_2 Trends over China





- **Until 2011, there was continuous increase in NO_2**

After two years of stagnation, → large decrease



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NO_2 Trends above Europe: The case study of Athens

$$\frac{d(\text{  })}{dt} = f\left(\text{  }\right)$$

+

+

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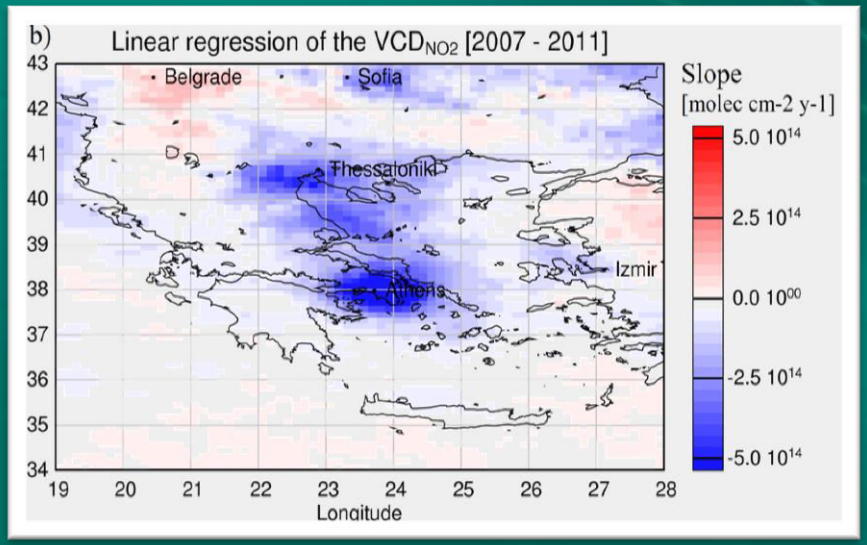
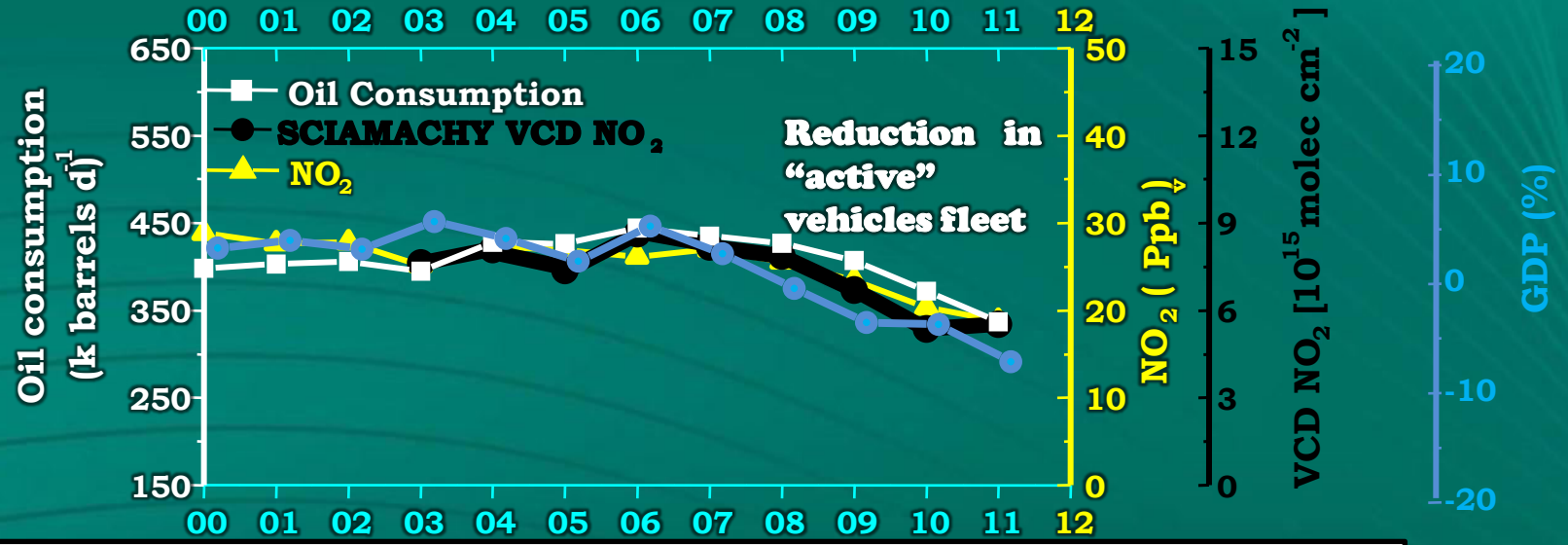
Results (satellite observations)

Linear regressions of the GOME2 VCD_{NO2} 2007 to 2011



~1·10¹⁵ molec cm⁻²y⁻¹

~35% reduction
>3·10¹⁵ molec cm⁻²



Vrekoussis, M. et al., Economic crisis detected from space: Air quality observations over Athens/Greece, Geophys. Res. L ett., 40, doi:10.1002/grl.50118., 2013

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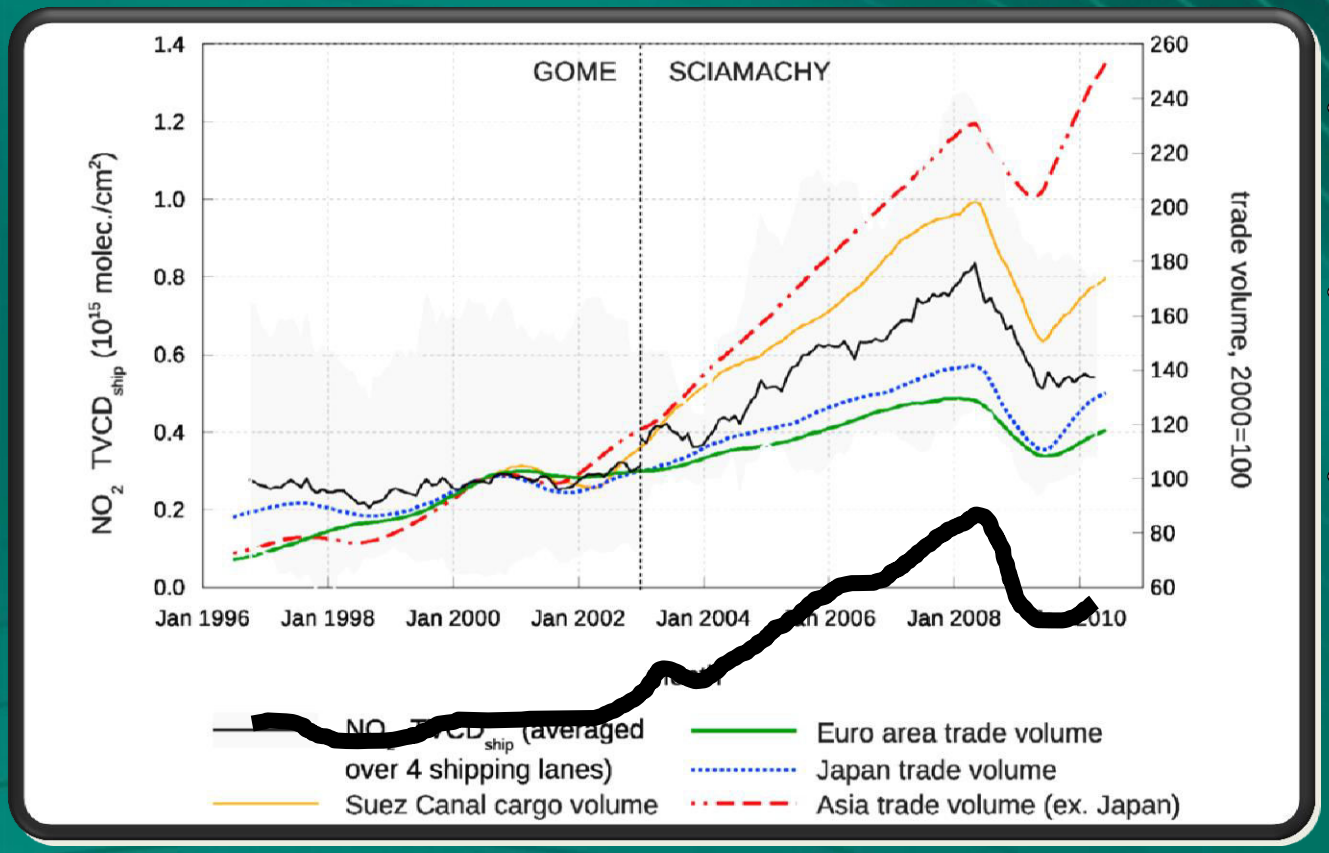
NOx Emissions from Shipping



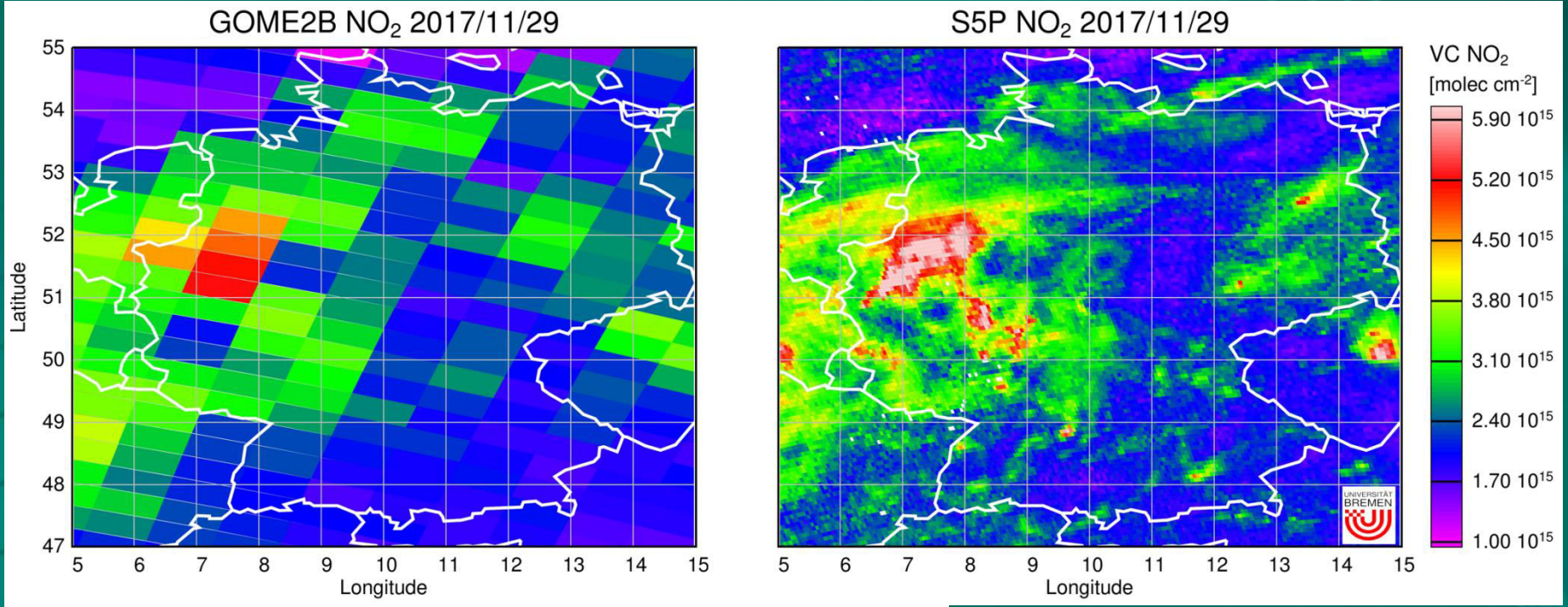
- Trade and cargo volume is increasing
- NO_2 over shipping regions shows similar trend
- Economic crisis in 2008 created clear signature in both, trade volume and shipping NOx

de Ruyter de Wildt, M., H. Eskes, and K. F. Boersma (2012), The global economic cycle and satellite-derived NO2 trends over shipping lanes, *Geophys. Res.Lett.*, 39, L01802, doi:10.1029/2011GL049541.

First IUP S5P Results: NO_2

- **Very good agreement with GOME2B data**
- **Very large increase in spatial detail**

Preliminary – no cloud screening, total column with stratospheric AMF



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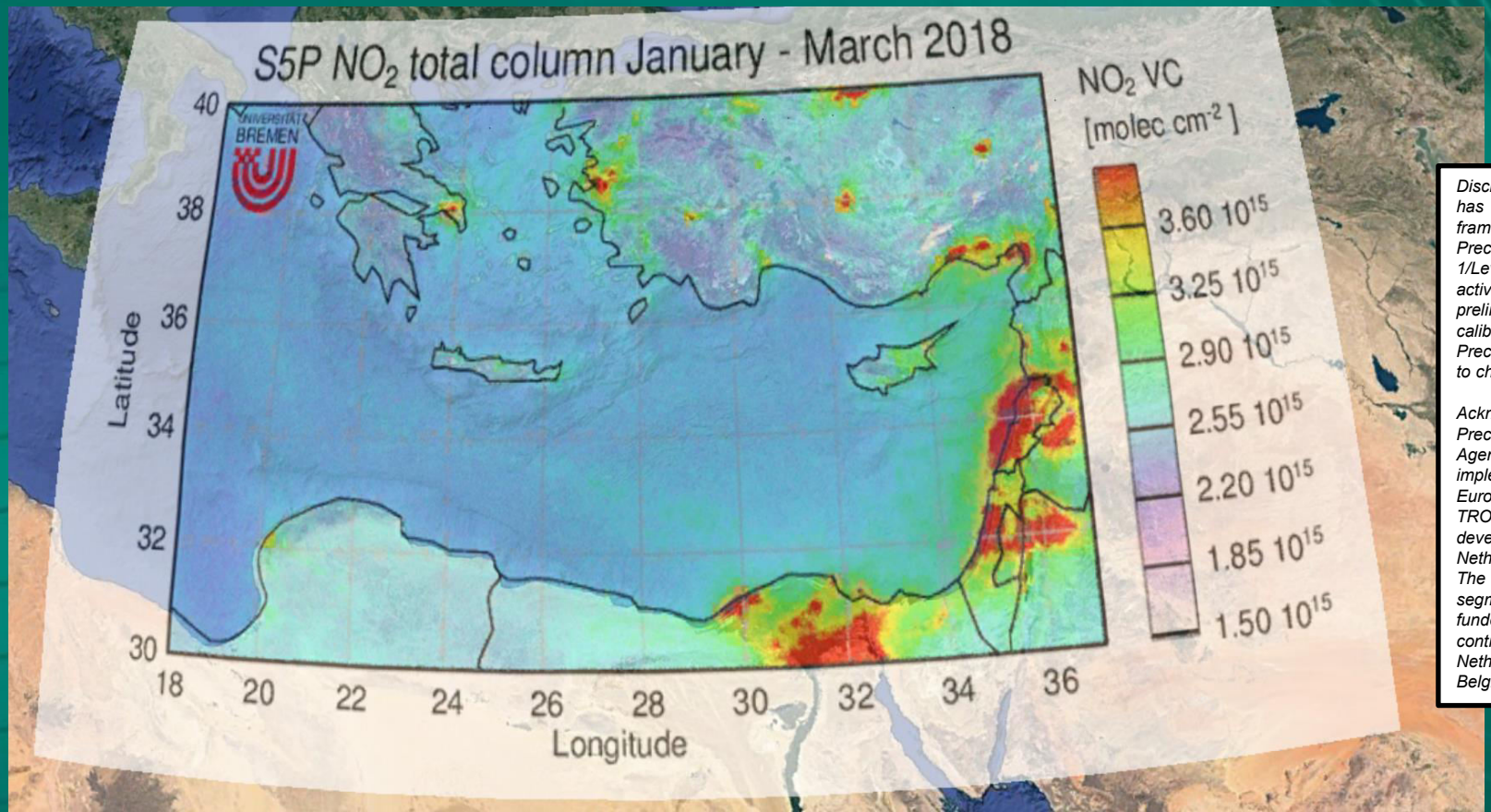
Disclaimer: The presented work has been performed within the framework of the Sentinel-5 Precursor Validation Team or Level 1/Level 2 Product Working Group activities. Results are based on preliminary (not fully calibrated/validated) Sentinel-5 Precursor data that are still subject to change.

Acknowledgement: Sentinel-5 Precursor is a European Space Agency (ESA) mission implemented on behalf of the European Commission (EC). The TROPOMI payload is a joint development by ESA and the Netherlands Space Office (NSO). The Sentinel-5 Precursor ground-segment development has been funded by ESA and with national contributions from The Netherlands, Germany, and Belgium.

First IUP S5P Results: NO_2



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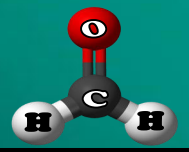
Results VOCs

HCHO – Global picture

SCIAMACHY VC_{HCHO} 2003 - 2008



HCHO

N.America

Europe

Asia

S. America

SAA

Africa

Indonesia/Australia

0 $4 \cdot 10^{15}$ $8 \cdot 10^{15}$ $1.2 \cdot 10^{16}$ $1.6 \cdot 10^{16}$ $2.0 \cdot 10^{16}$

VC HCHO [molec·cm^{-2}]

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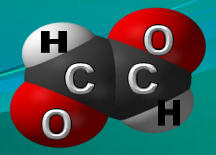
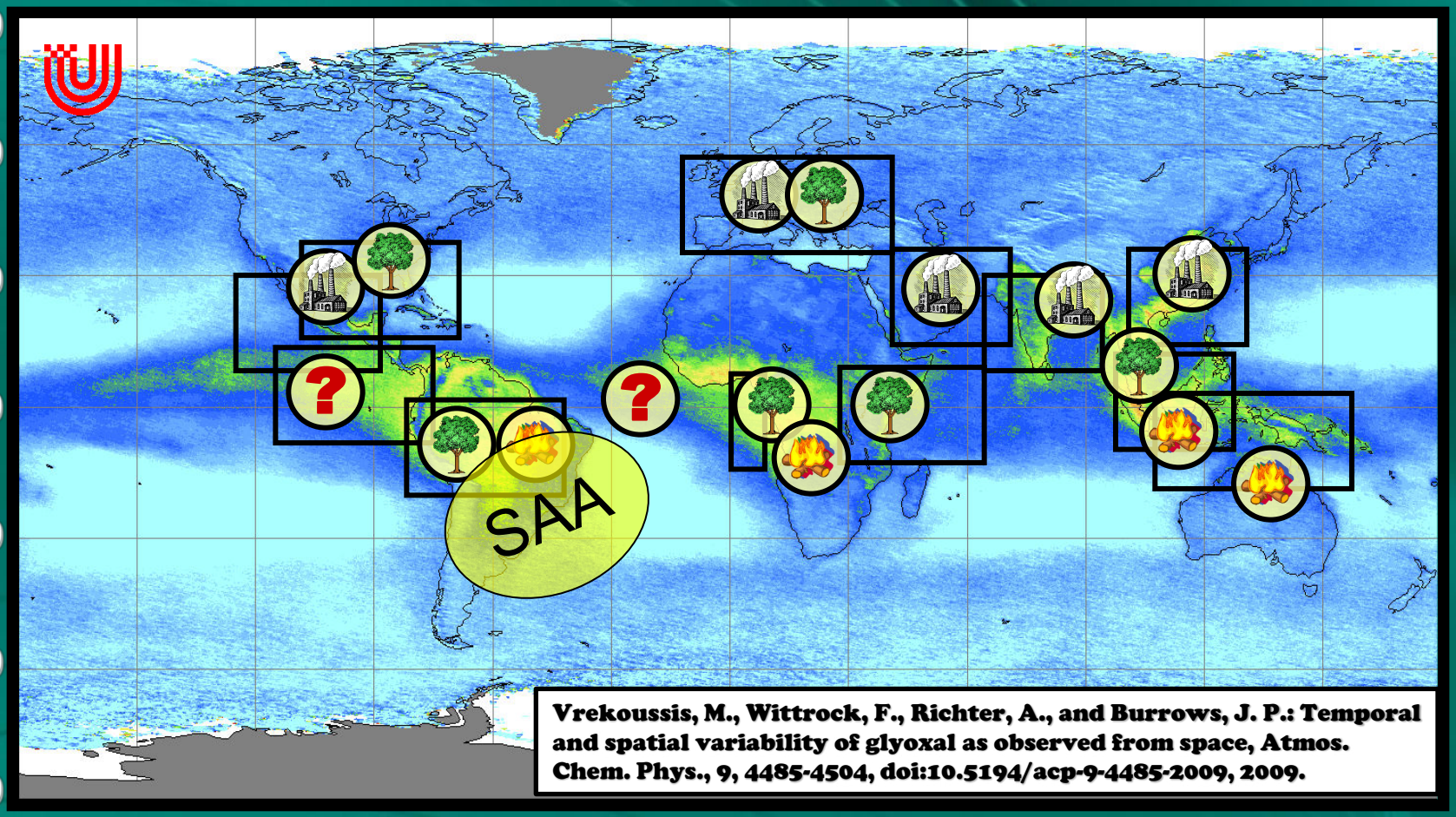
CHOCHO – Global picture

SCIAMACHY VC_{CHOCHO} 2003 – 2008



CHOCHO



-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180

Longitude

0 $2.4 \cdot 10^{14}$ $4.8 \cdot 10^{14}$ $7.2 \cdot 10^{14}$ $9.6 \cdot 10^{14}$ $1.2 \cdot 10^{15}$

VC CHOCHO [molec·cm^{-2}]

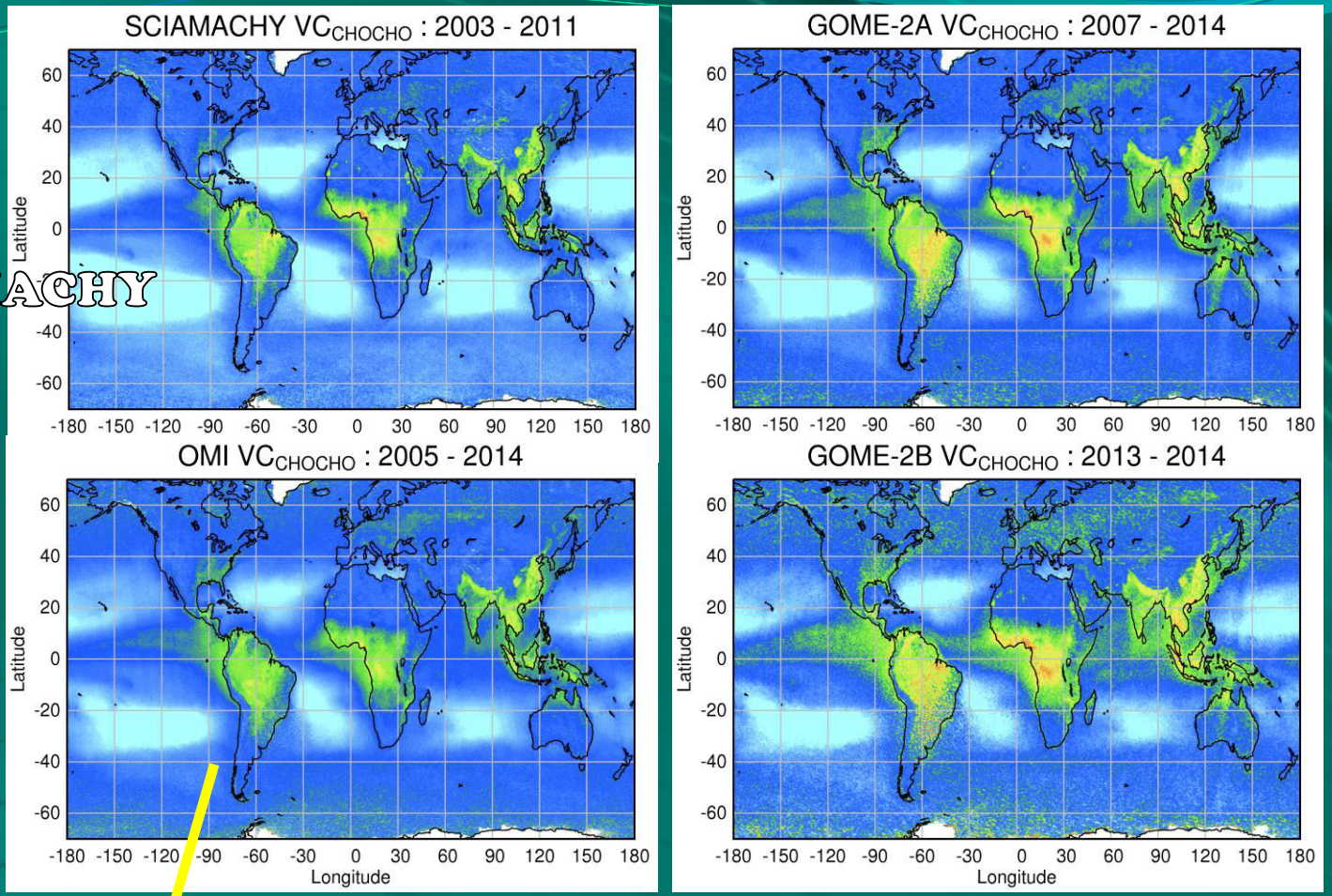
Homogenized glyoxal retrieval

SCIAMACHY

GOME2A

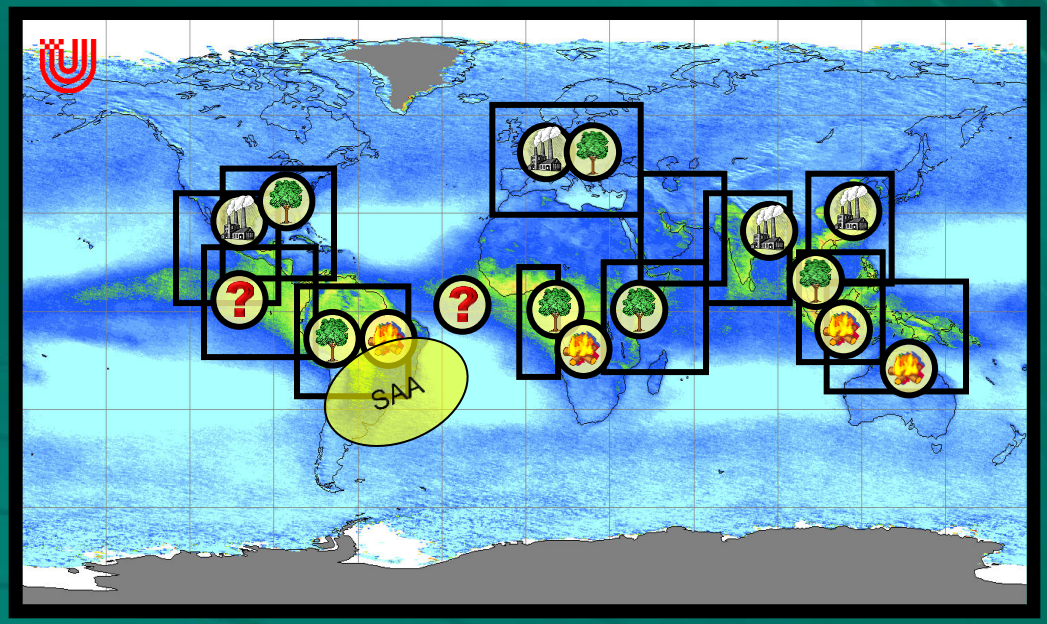
OMI

GOME2B



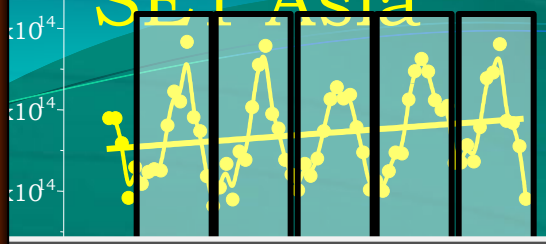
Alvarado, L. M. A., Richter, A., Vrekoussis, M., Wittrock, F., Hilboll, A., Schreier, S. F., and Burrows, J. P.: An improved glyoxal retrieval from OMI measurements, Atmos. Meas. Tech., 7, 4133-4150, doi:10.5194/amt-7-4133-2014, 2014.

Multiannual variations of the VCD_{CHOCHO} above the hot-spots



Multi-annula variations, trends

SE1 Asia

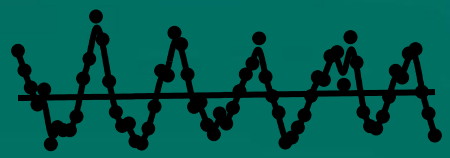


(4.3±1.3) ·10¹⁴ molec·cm⁻²

SE2 Asia

(5.3±0.9) ·10¹⁴ molec·cm⁻²

India



(3.9±1.0) ·10¹⁴ molec·cm⁻²

Indonesia

(4.8±0.8) ·10¹⁴ molec·cm⁻²

Australia

(3.2±1.6) ·10¹⁴ molec·cm⁻²

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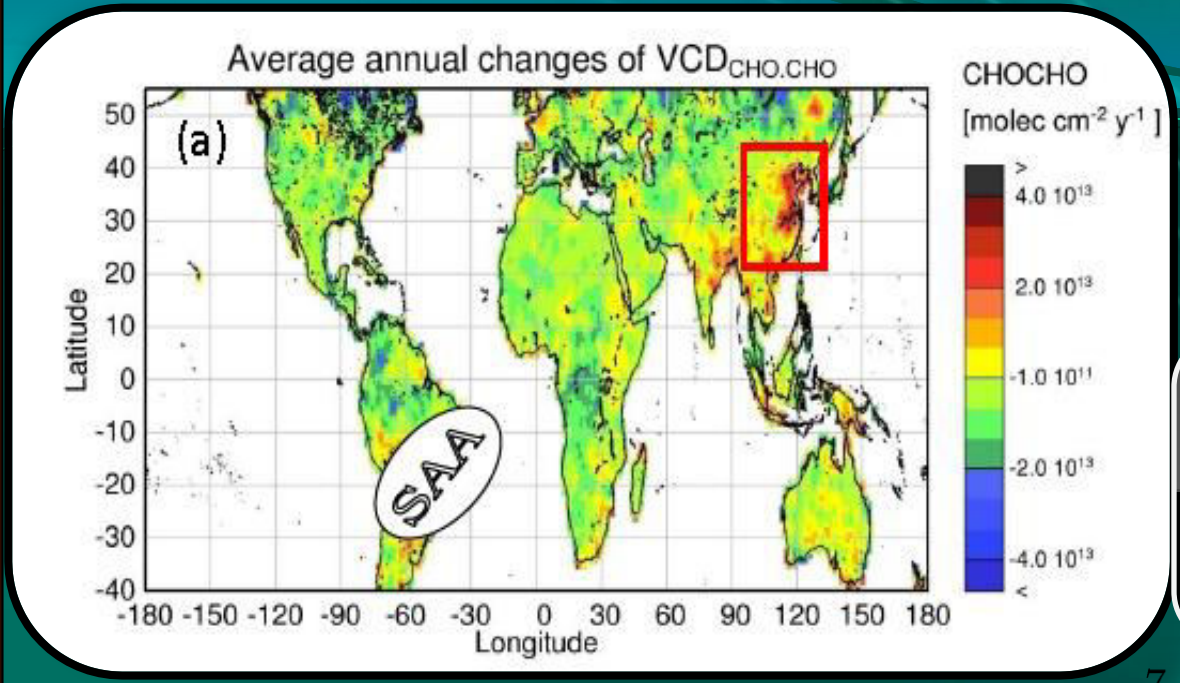
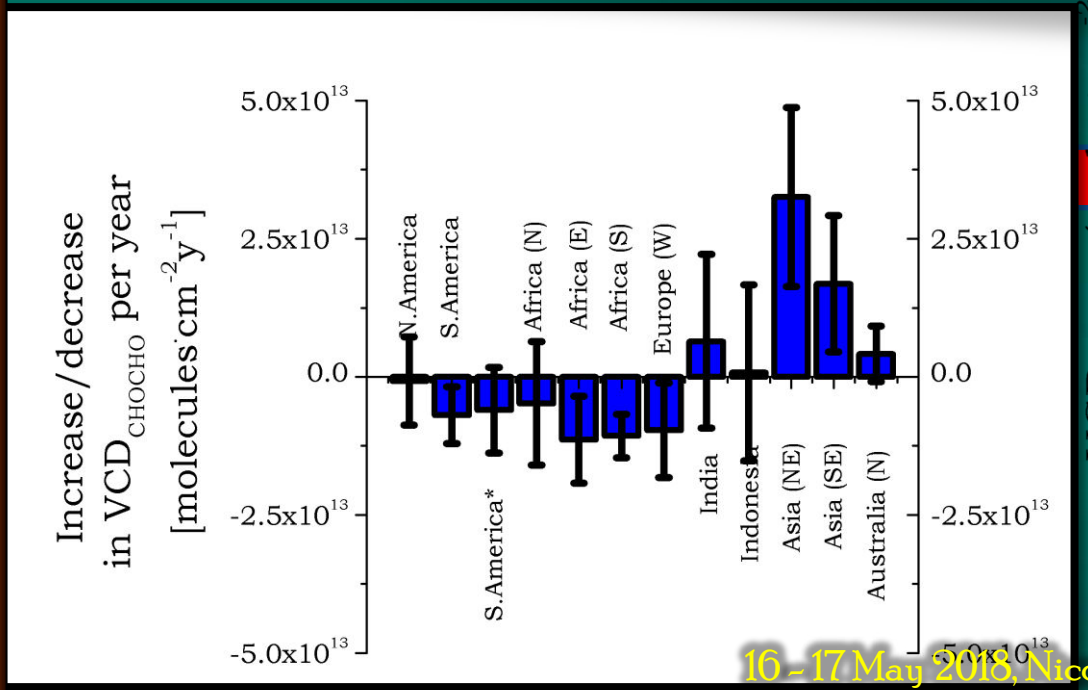
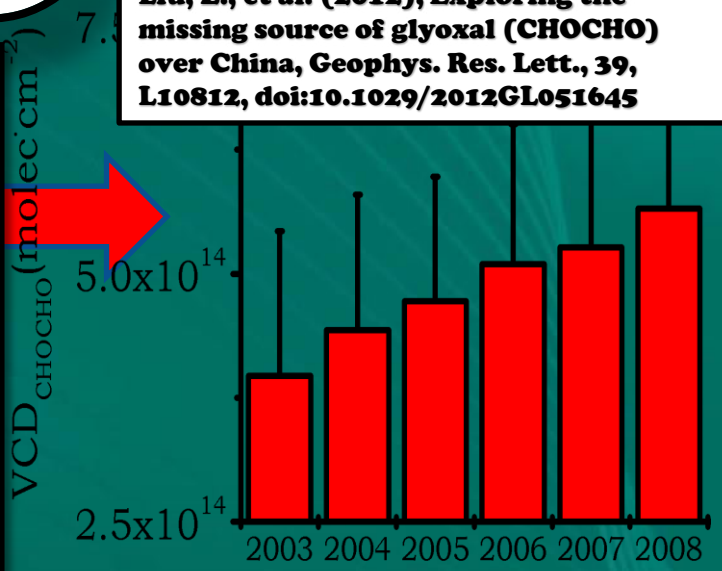
Multi-annula variations, trends



4-10 times underestimation of aromatics emissions over China

Liu, Z., et al. (2012), Exploring the missing source of glyoxal (CHOCHO) over China, Geophys. Res. Lett., 39, L10812, doi:10.1029/2012GL051645





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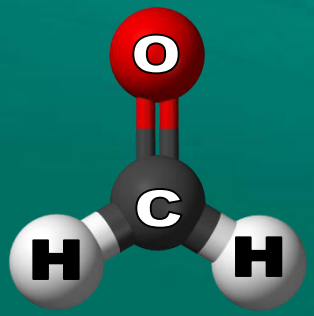
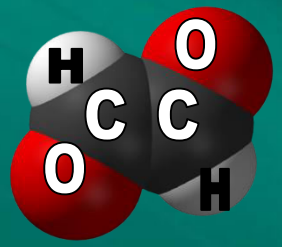
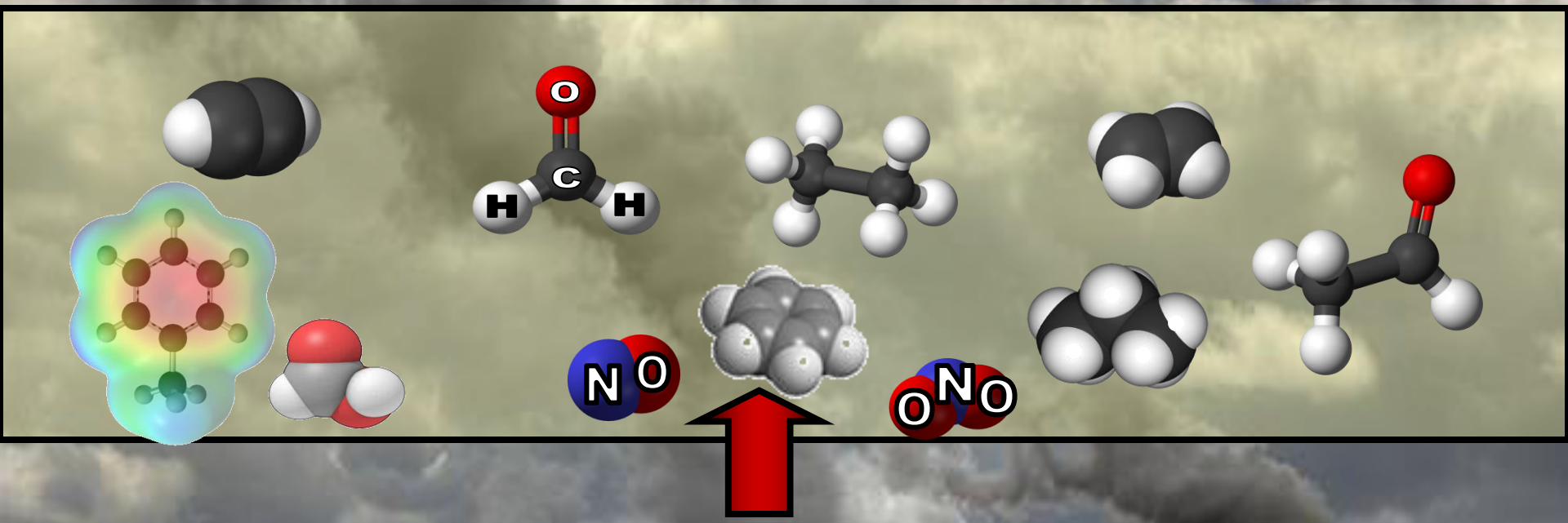
Sources of HCHO and CHOCHO





i) Anthropogenic
ii) Biogenic
iii) Biomass Burning

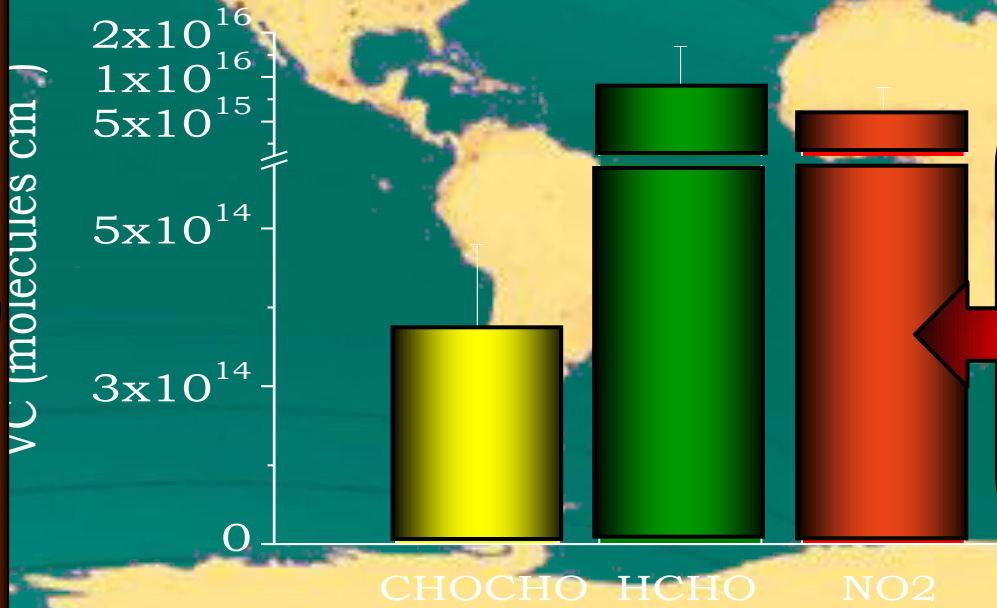
Anthropogenic

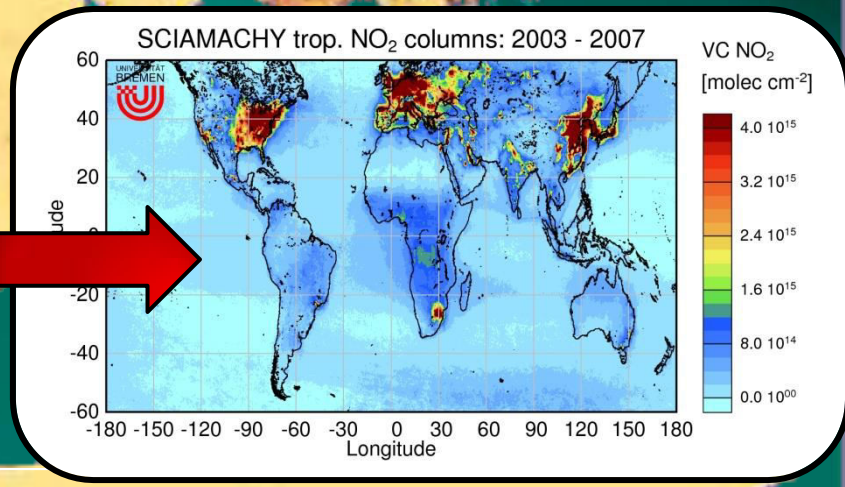


Anthropogenic sources

a) Anthropogenic

36 cities/areas

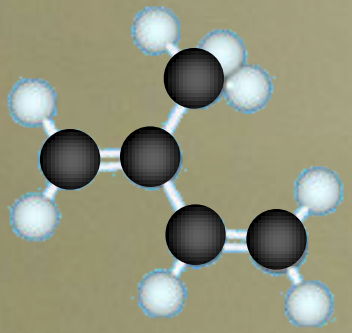


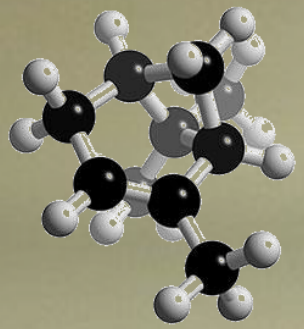


R_{GF} ratio → sources

Vrekoussis, M., Wittrock, F., Richter, A., and Burrows, J. P.: GOME-2 observations of oxygenated VOCs: what can we learn from the ratio glyoxal to formaldehyde on a global scale?, Atmos. Chem. Phys., 10, 10145-10160, doi:10.5194/acp-10-10145-2010, 2010.

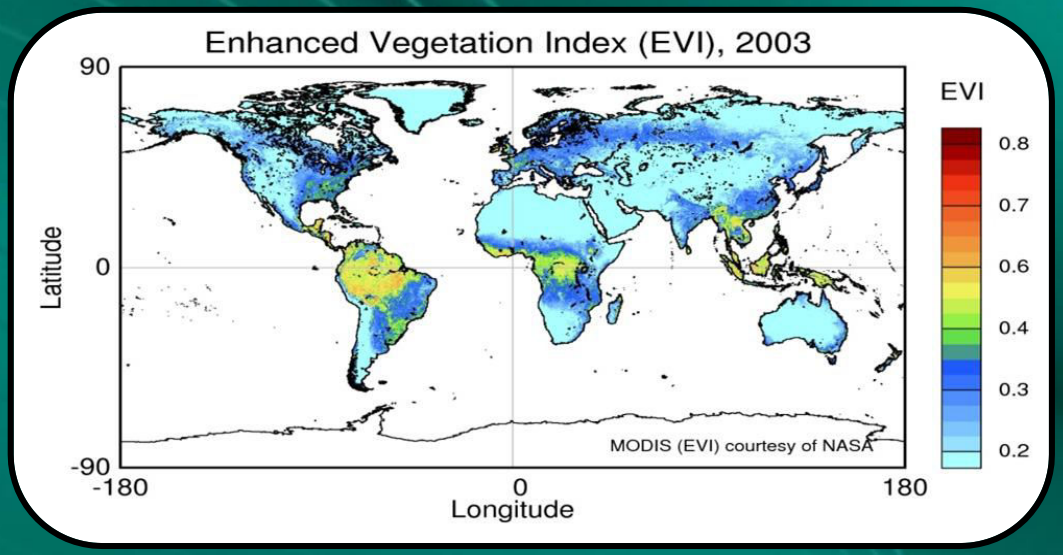
Biogenic sources

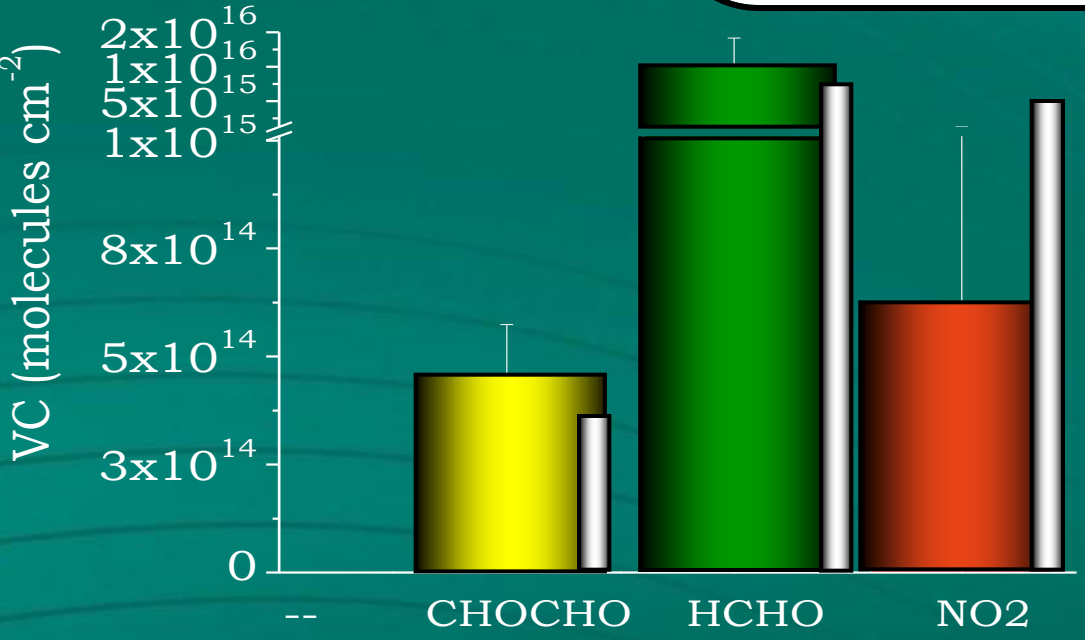




b) Biogenic

EVI





Biogenic sources

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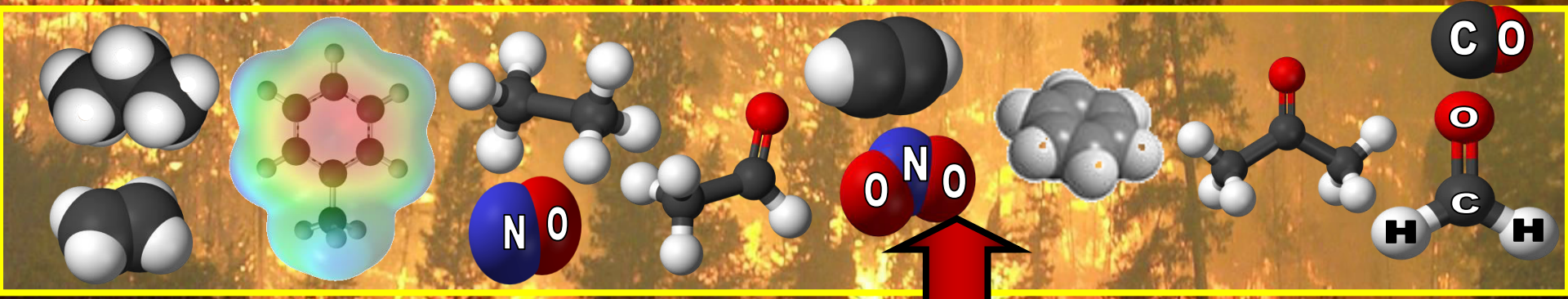
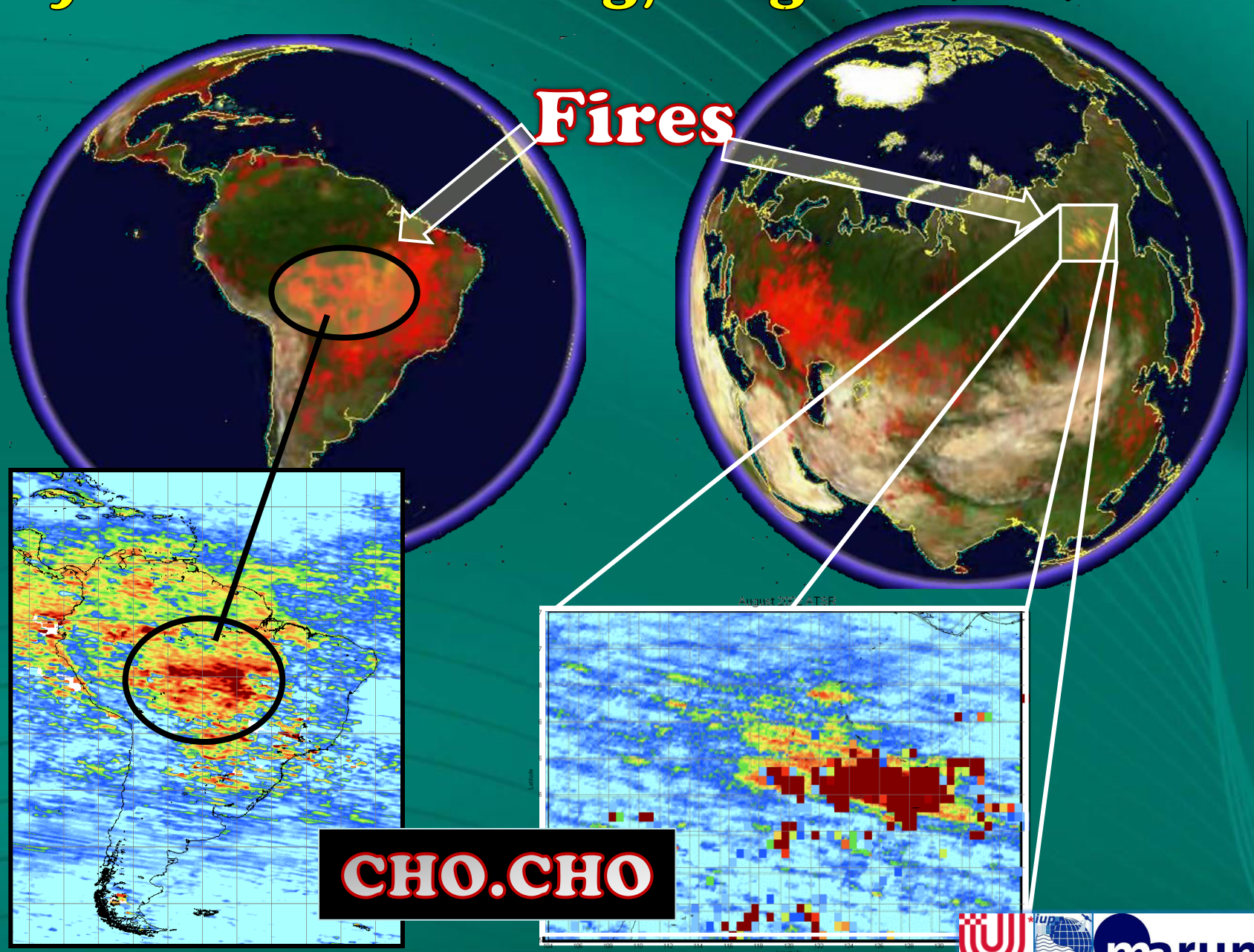
Biomass burning



c) Biomass burning, August 2002

Pyrogenic sources



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Conclusions

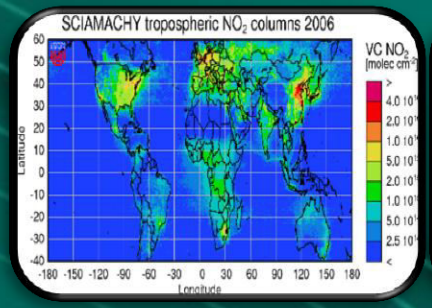
Conclusions

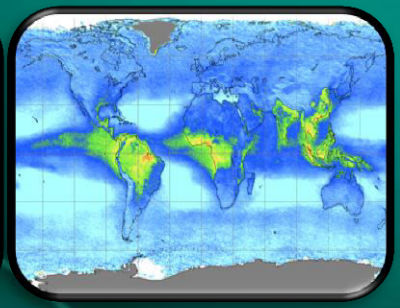
- We can detect NO_2, HCHO and CHOCHO from space.

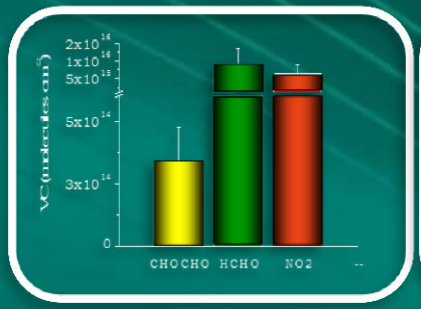
Their global maps reveal sources of anthropogenic, biogenic and biomass burning origin

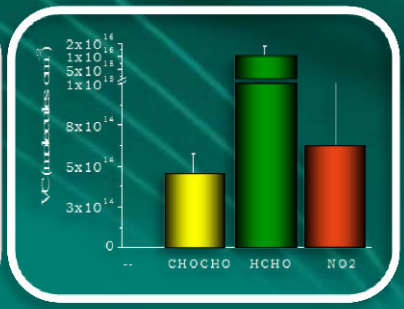
The economic crisis is visible from space over land and sea

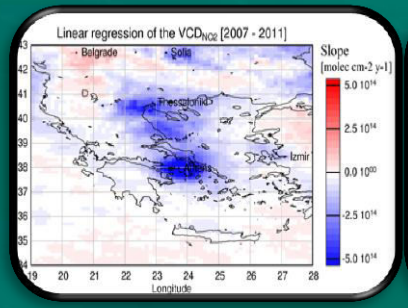
The multiannual analysis of the VCD_s revealed differences at the trends, absolute values and seasonal behaviour.

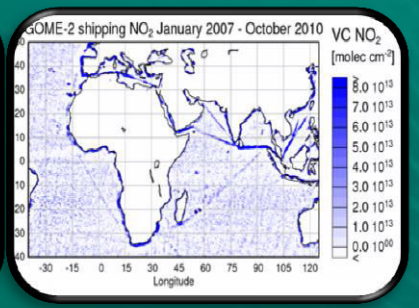


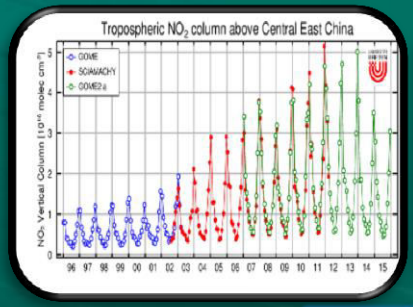


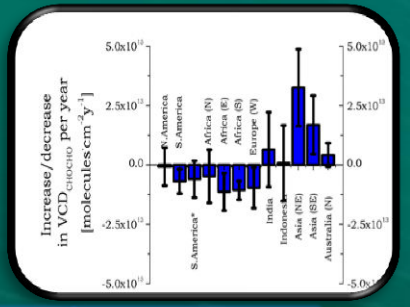












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Thank you for your attention

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