Atmospheric Physics
University of Toronto

The 2007 Noble Lecture Series

Atmospheric Chemistry and the Remote Sensing of the Global Atmosphere
March 26-30th 2007.

Air Pollution and Climate Change viewed from Space

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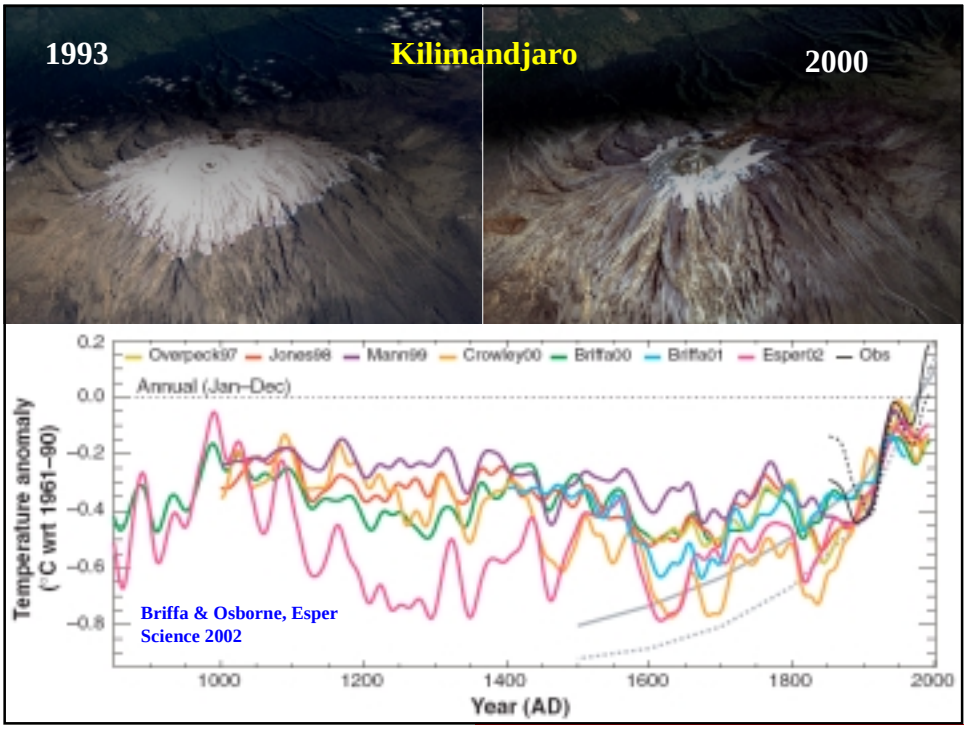
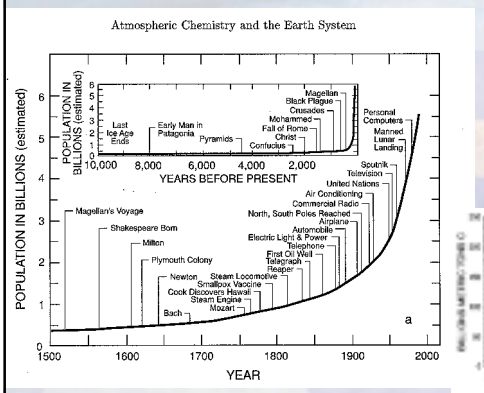
Why do we care?

Dramatic change in population and their emissions

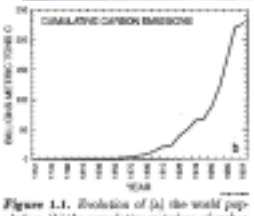
Global Cliante Change



Recent Increase in population



Results in Increasing Emissions to the atmosphere



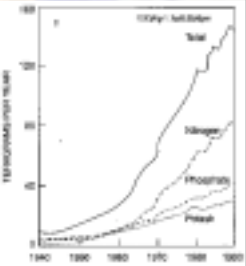


Figure 1.1. *Evolution of (a) the world population, (b) the cumulative emissions of carbon in the atmosphere since 1750 (courtesy of G. Marland, 2000), and (c) world fertilizer use (between 1948 and 2000 from* OUR CHANGING PLANET *3/E by Mackenzie/Mackenzie, ©1998, adapted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ).*

C, N emissions etc. ∨

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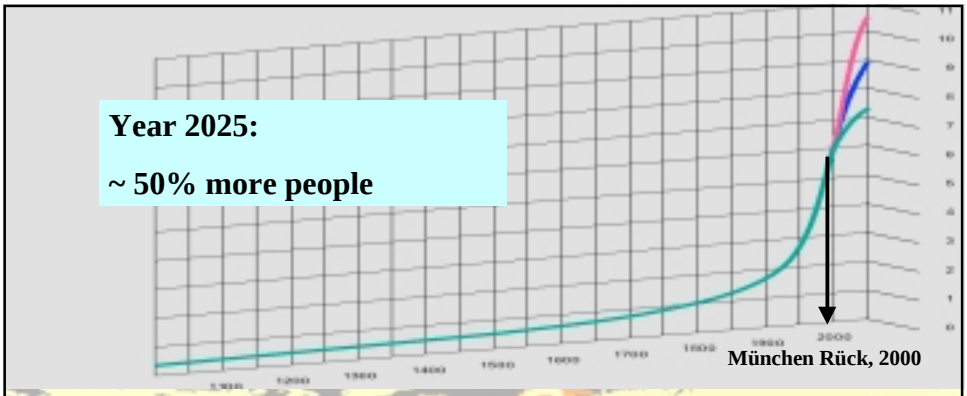
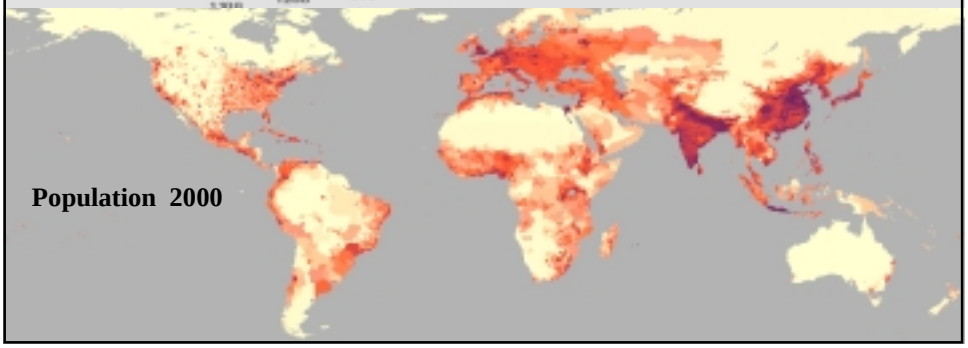
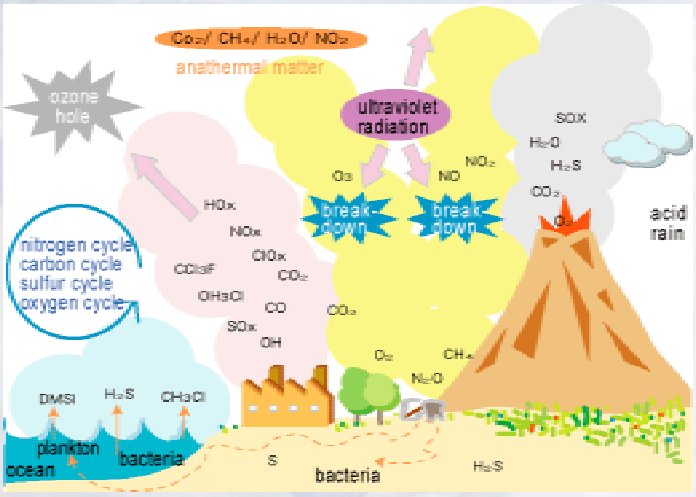




Atmospheric Composition



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Anthropogenic vs. Natural ?

Anthropogenic

- Biomass Burning
- Pollution/Air Quality
- Acid Deposition
- Oxidising Capacity
- Surface Fluxes Greenhouse Gases

Natural

- Biomass Burning
- Lightning
- Volcanoes
- Oxidising Capacity
- Surface Fluxes
  - Emission
  - Deposition

COUPLING

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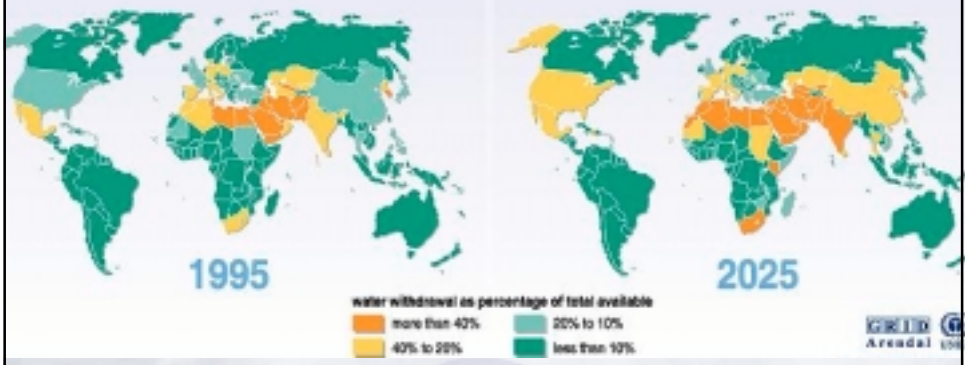
We expect Freshwater stress



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Are there climate changes ?

We observe trends in

Temperature (snow, ice fields)

Sea level (heat content, melting?)

Precipitation

Vegetation (biosphere)

Radiation at ground

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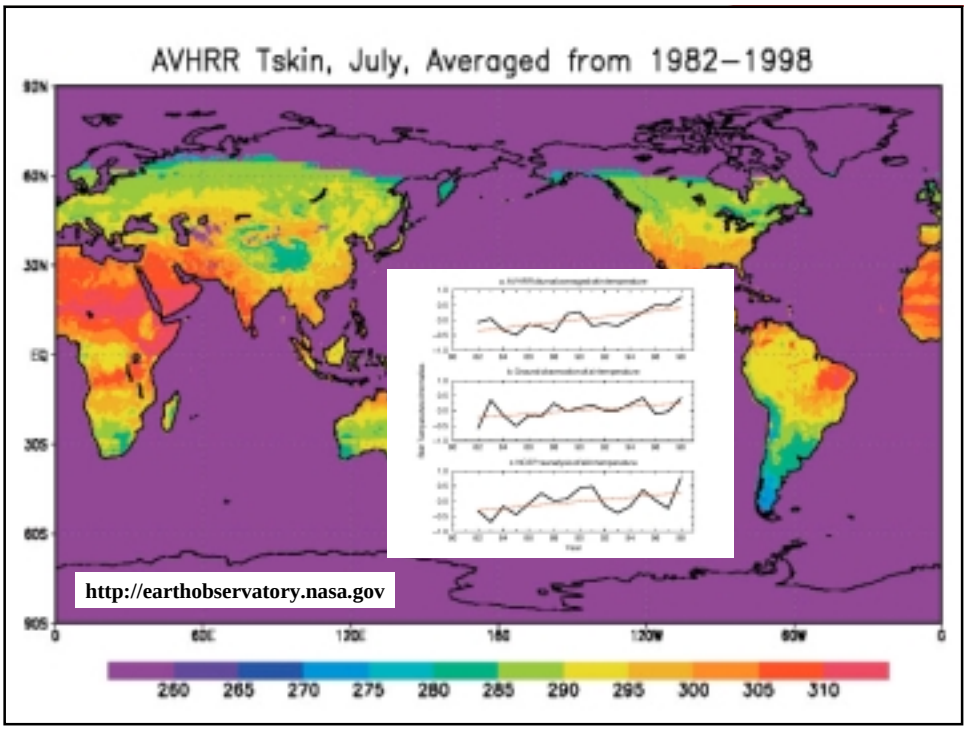
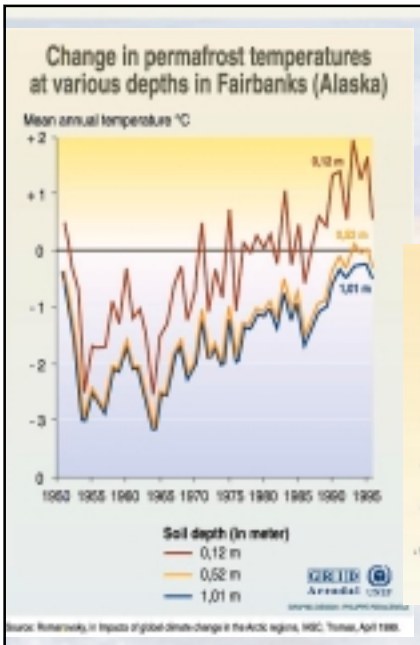
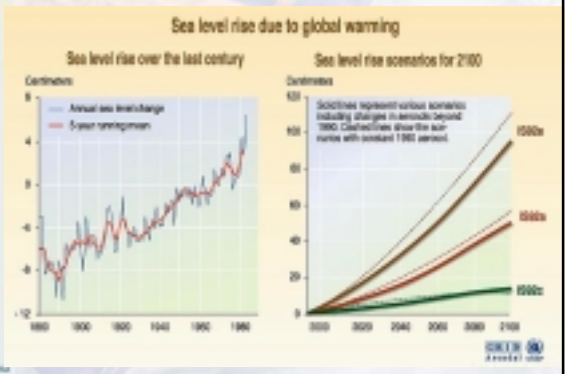
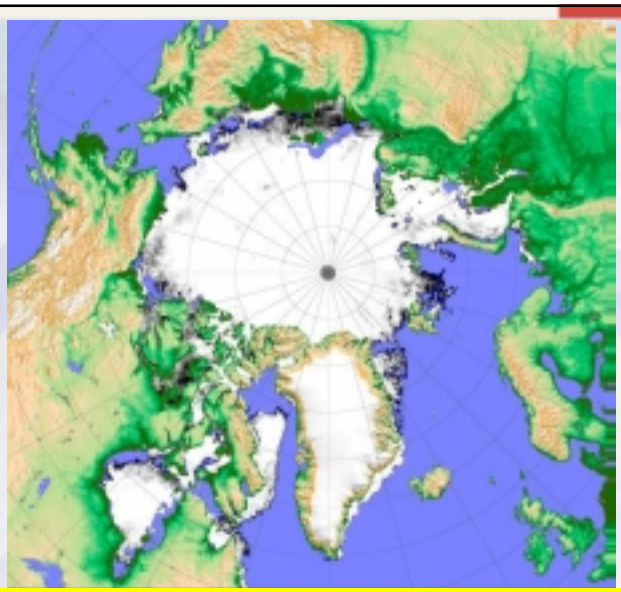


More evidence





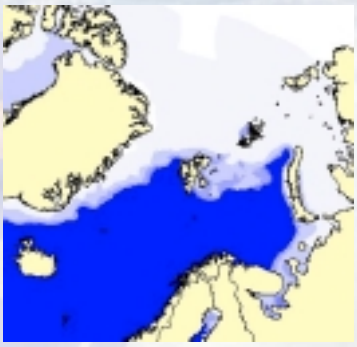


Gunnar Spreen and Prof. Dr. L. Kaleschke Univeristy of Hamburg and IUP University of Bremen Meereseis 2002-2005

ACSYS Historical Ice Chart Archive

22 April 1866

22 April 2002



- Effort started 15 years ago by Torgny Vinje at NP; WWF funded final digitisation, quality control and publication
- Charts cover 70°E to 30°W
- Years 1553 to 2002
- Variety of sources, including ships logbooks, diaries, year-books, hand-drawn charts, electronic charts

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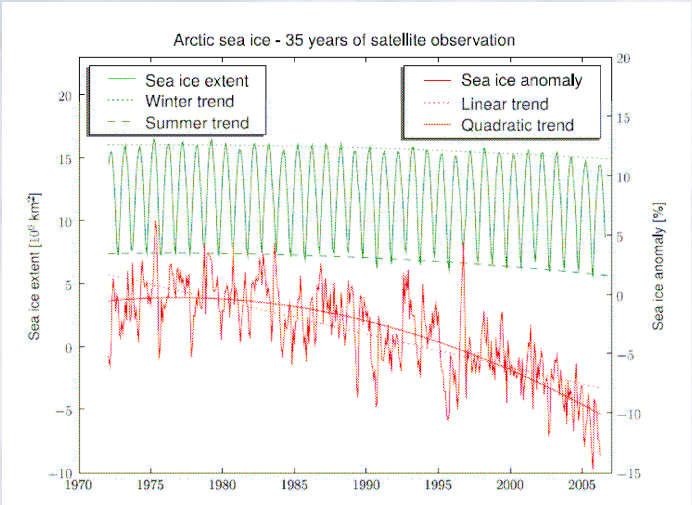
Arctic – Sea Icea as observed from Space: 1970 - 2005



Kaleschke et al 2006

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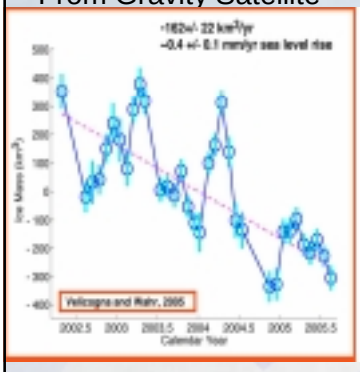
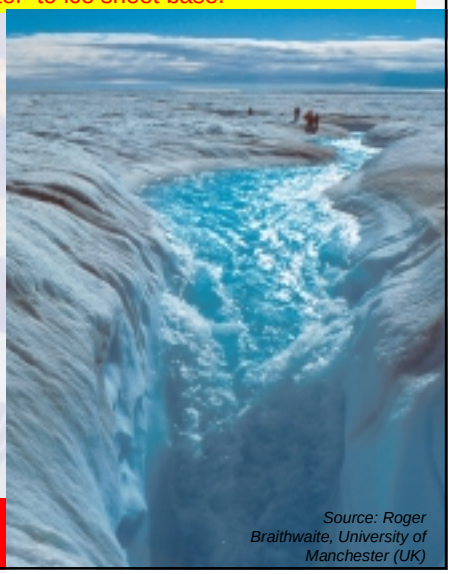
Greenland Mass Loss –
From Gravity Satellite



Surface Melt on Greenland

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.



Source: Roger Braithwaite, University of Manchester (UK)

70 meters of thinning in 5 years

Courtesy of Jim Hansen

Are there climate changes ?

What forces climate (changes) ?

Anthropogenic forcing ?

Impact on human society ?

What can and must we do ?

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On Thursday 31st October Sir Nicholas Stern published his report on The Economics of Climate Change. This review is a bitter pill to swallow but I suspect no surprise to you if you have kept up with this blog. But climate change isn't the only thing effecting the ability of our earth to support life. We're killing forests, poisoning our rivers, fishing out the seas - the entirety of which is raining hell on Earth.

Julian Hector BBC Blog

STERN review ON THE ECONOMICS OF CLIMATE CHANGE

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What do we understand or consider to be Air Pollution??

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Google - Hit Parade – Top 20 Bilder

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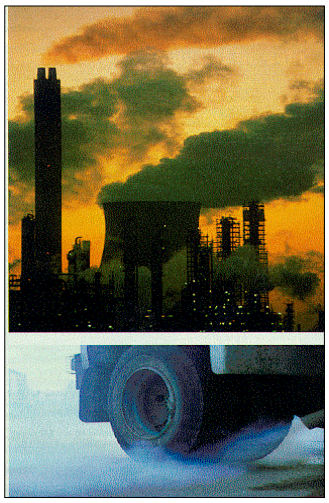
Which is more Polluted?



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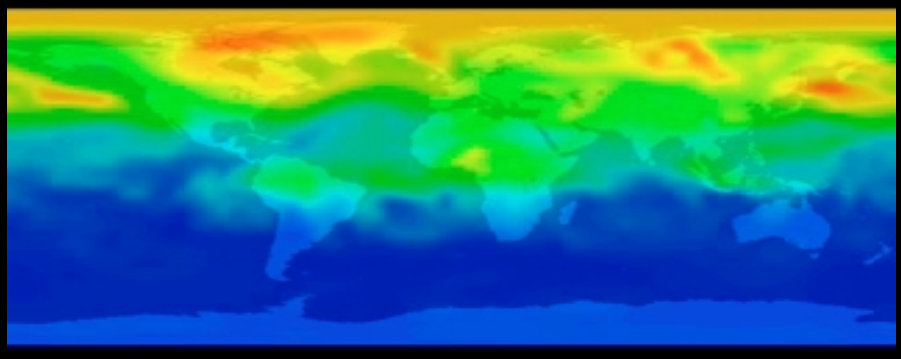
Is it a larger scale problem?
Global Ait´r Pollution?
E.g. Carbon Monoxide,CO, from fossil fuel combustion and biomass burning - Moppit



What are somne of the consequences of Air Pollution?

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Effects of Air Quality

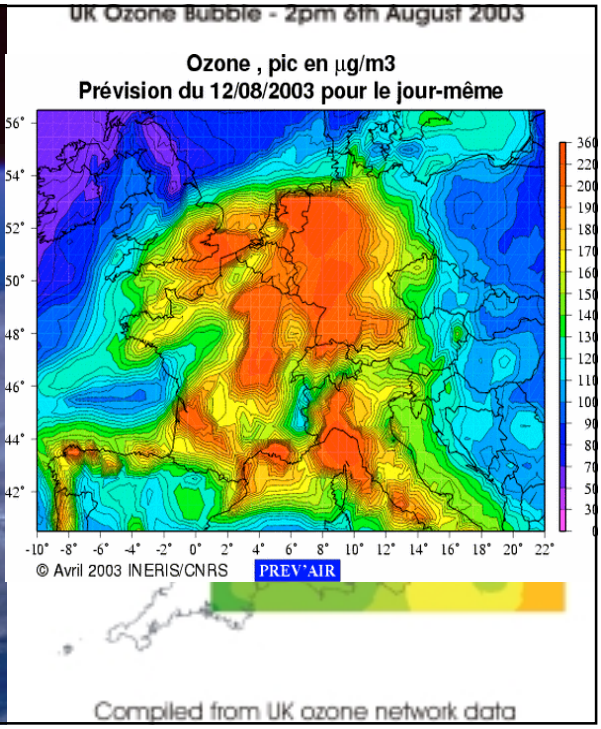
Health

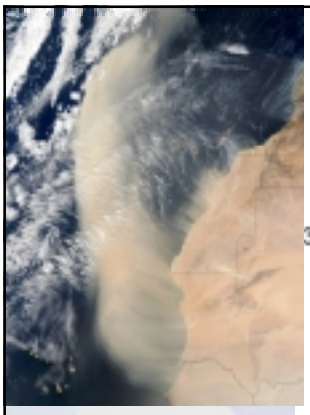
Heritage

Ecosystems

Climate

- **2003 Summer Smog**
- ***22000-44000 addtional deaths***





Zeng, *Science* 2003

Drought in the Sahel

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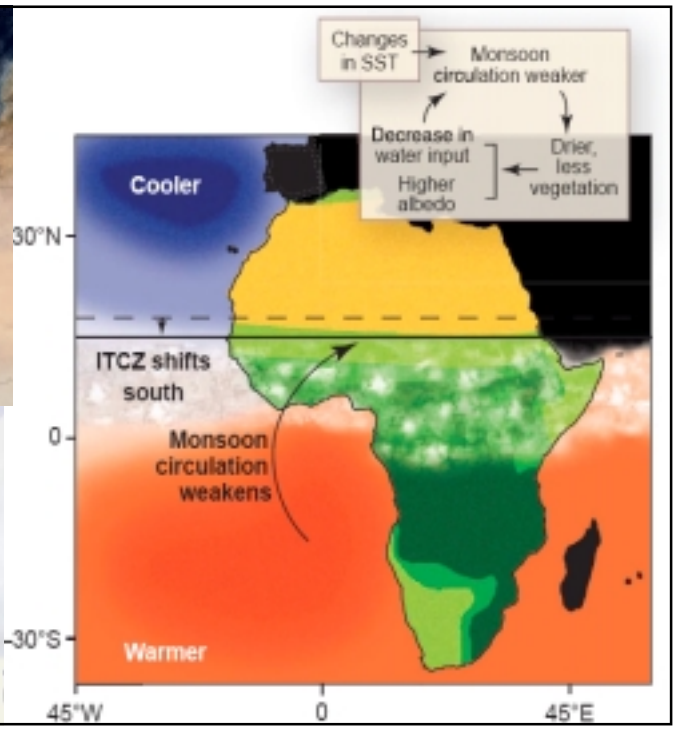
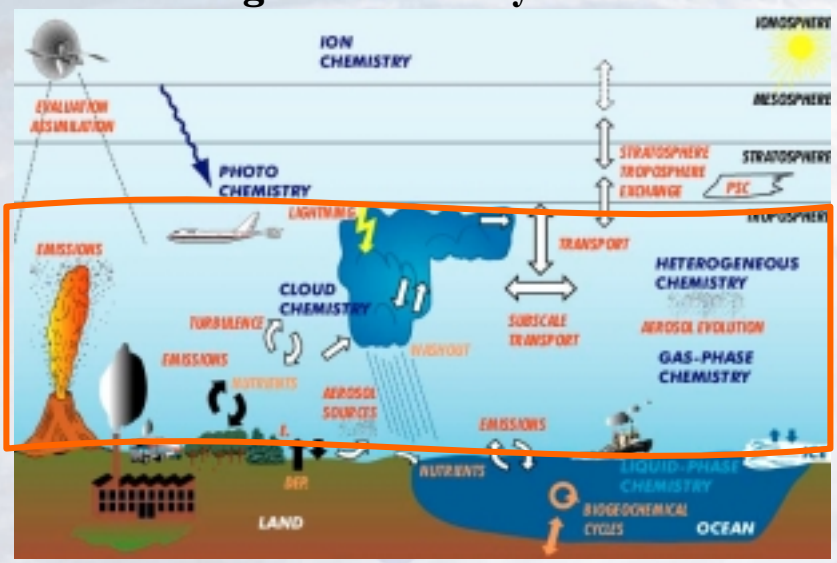


Biogeochemical Cycles



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Motivation for the Atmospheric Sounding from Space

- ***Changing Atmospheric Composition***
  Origin: Natural Processes (e.g. Volcanic SPE) and Anthropogenic Activity (Pollution, Combustion of Fossil Fuel, Biomass/Biofuel Burning)
- ***Climate change research and Assessment***
- ***Improvement of Numerical Weather Prediction***
- ***New Area: Numerical Environmental Prediction or Chemical Weather***
  →→→→→→→→→→→→→→→→→→
- ***Requirement:***
  Determine the global distribution of key constituents: trace gases, aerosol and clouds at adequate temporal and spatial scales

Instruments observing from satellite platforms offer unique spatial and temporal coverage

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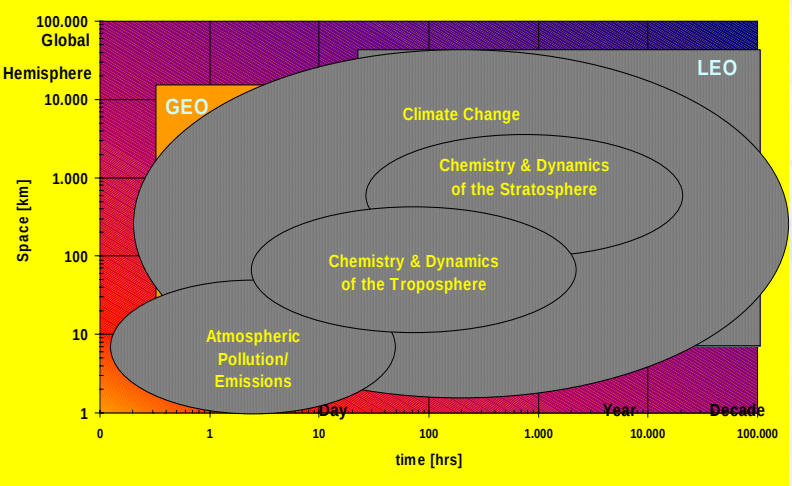
Spatial and Temporal Scales accessible from LEO and GEO!



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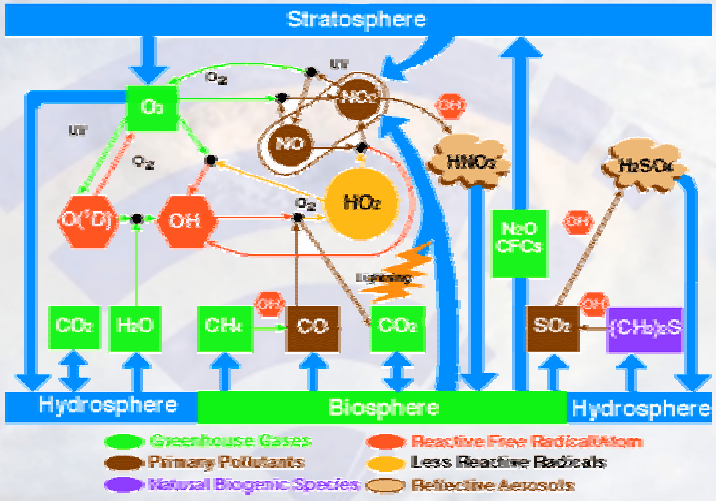
Tropospheric Chemistry



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SOME (PRE-) HISTORY

- *1920s* — *Dobson et al develop a Spectrophotometer and technique for atmospheric O_3 column*
- *1957* — *International Geophysical Year – Dobson network -Singer and Wentworth propose BUV technique*
- *1960s* — *Soviet make first attempts to measure O3 from space*
- *1974 – 1979* — *BUV launched aboard NASA Nimbus 4*
- *1975 –1990* — *Development of DOAS (Differential Optical Absorption Spectroscopy)*
- *1979 – 1991* — *SBUV and TOMS launched on NASA Nimbus 7*
- *1991- 1994* — *TOMS on Russian Meteor*
- *1996 -* — *TOMS on ADEOS and EPTOMS*
- *1979-2006* — *SAM-II, SAGE, I, II and III occultation*

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The unabridged History of SCIAMACHY - GOME – GeoSCIA-GeoTROPE

03-1985	**MAP (Measurement of Atmospheric Pollution) proposal idea to ESA for EURECA** ***not selected***
05-1985	**Stratospheric Ozone hole observed by Farman et al (Nature).**
1985 – 1988	**Submission of the *SCIAMACHY proposal,* supported by Germany to ESA for the Polar Platform, now ENVISAT.**
1988	**Proposal of SCIA-mini for ERS-2**
1989	**Descope of *SCIA-mini to GOME (Global Ozone Monitoring Experiment)***
1989 – 2002	***Selection, Design and Development of SCIAMACHY as German/Dutch/Belgian contribution to ENVISAT***
20.04.1995	**Launch of ERS-2 with GOME**

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The unabridged History of SCIAMACHY - GOME – GeoSCIA-GeoTROPE

1997-1998	Development of GeoSCIA C0ncept
12.1998	Proposal of GeoSCIA to ESA – recommended for further study
1997-2000	Selection of GOME-2 for the EUMETSAT operational series Metop.
2000	GeoSCIA++ - Geostationary Idea for ESA Earth Explorer
2000-2001	Development of GeoFIS
01.2002	Proposal of *GeoTROPE(GeoSCIA+GeoFIS) Geostationary TROPospheric Explorer* to ESA for EEOM-2
	recommended for further study -
28.02.2002	Launch of ENVISAT with SCIAMACHY on board.
12.2003	Proposal GeoSCIA-Lite – small sat for national EO programme Germany – not selected
15.08.2005	Proposal GeoTROPE-R for the ESA Earth Explorer
	- not selected for Phase A
17.10.2006	Launch of Metop-A with GOME-2 and IASI on board.

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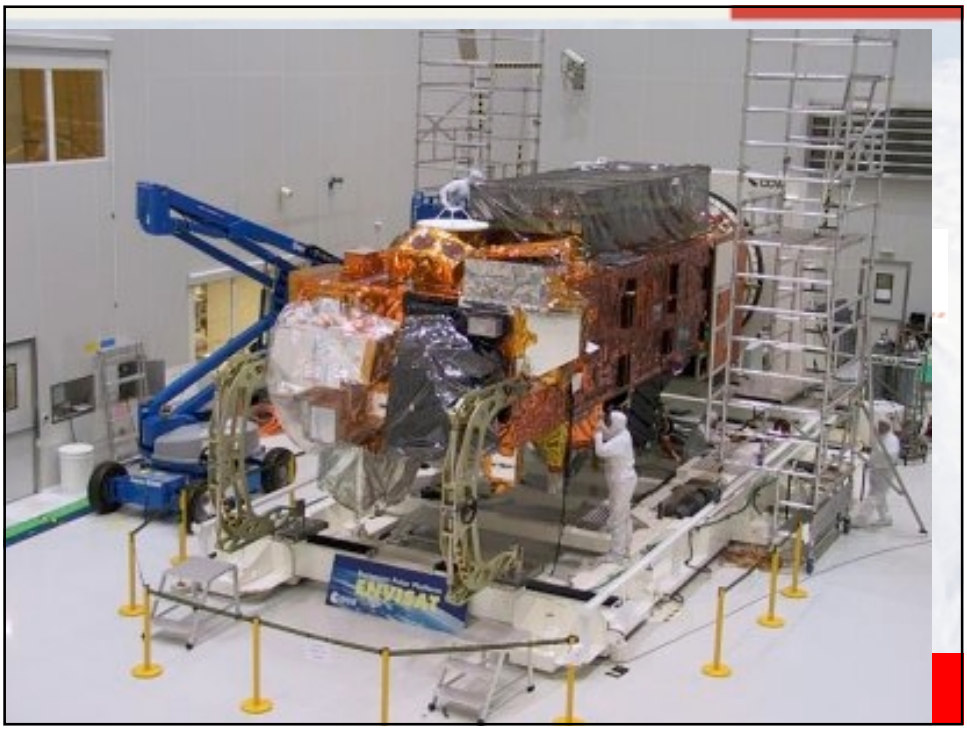
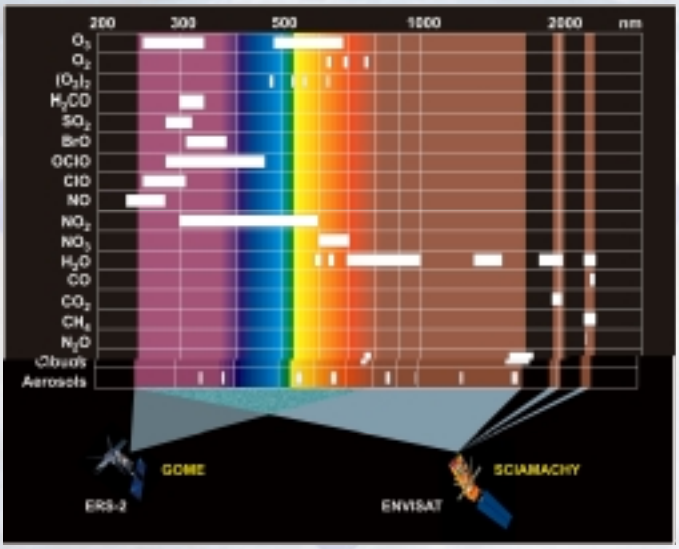


GOME SCIAMACHY Targets and Spectral Coverage



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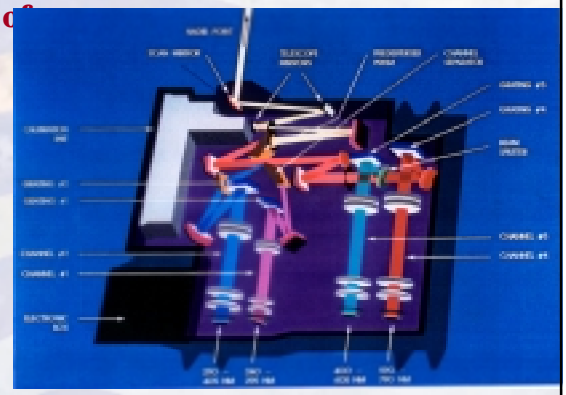
ERS-2 with GOME on board

- **Launched 20th of April 1995**
- **GOME has made 8 years o measurements**



Schematic of GOME Optical Layout

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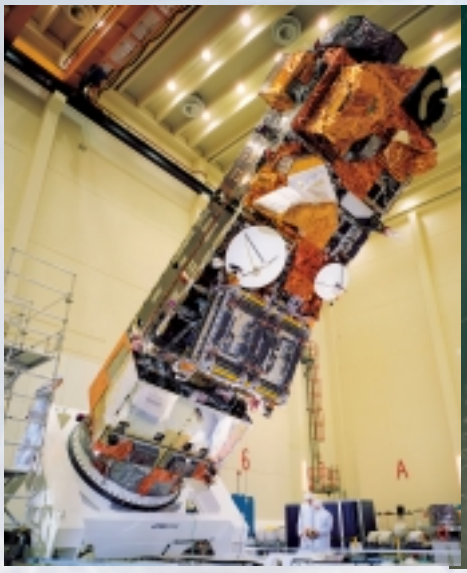
ENVISAT and Launch



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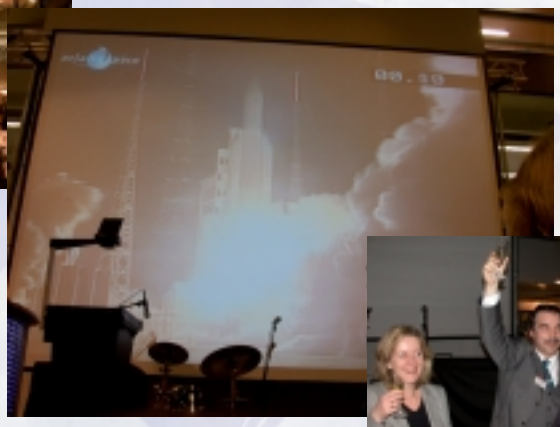
ENVISAT Launch: 1st March 2002, 2:07 CET
Response in Bremen



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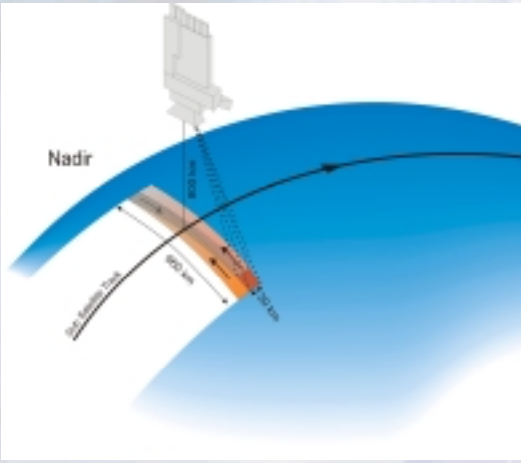
SCIAMACHY: Nadir Viewing Geometry Examples



- horizontal resolution in across track:
  - GOME-1 80 and 320 km global 1995-2003 partial 2003- present
  - SCIAMACHY 30-240 km global 2002- present
  - GOME-2 40-80 km
  - 960 km swath
- horizontal resolution in along track:
  - GOME 40 km
- Global coverage:
  GOME-1 3 days at the equator
  SCIAMACHY 6 days at the equator
  GOME-2 ~1 day at the equator

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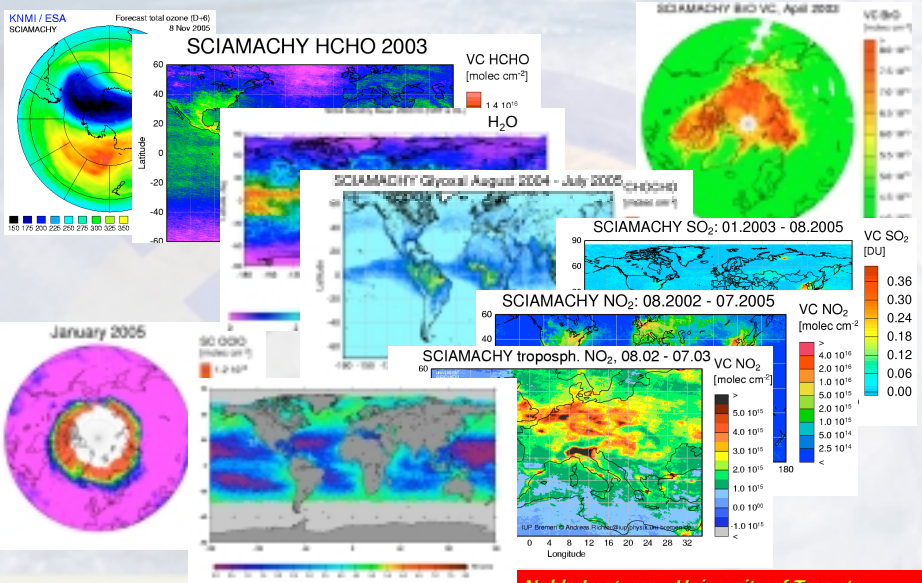
SCIAMACHY - Nadir - UV/Vis/NIR DOAS Data Products



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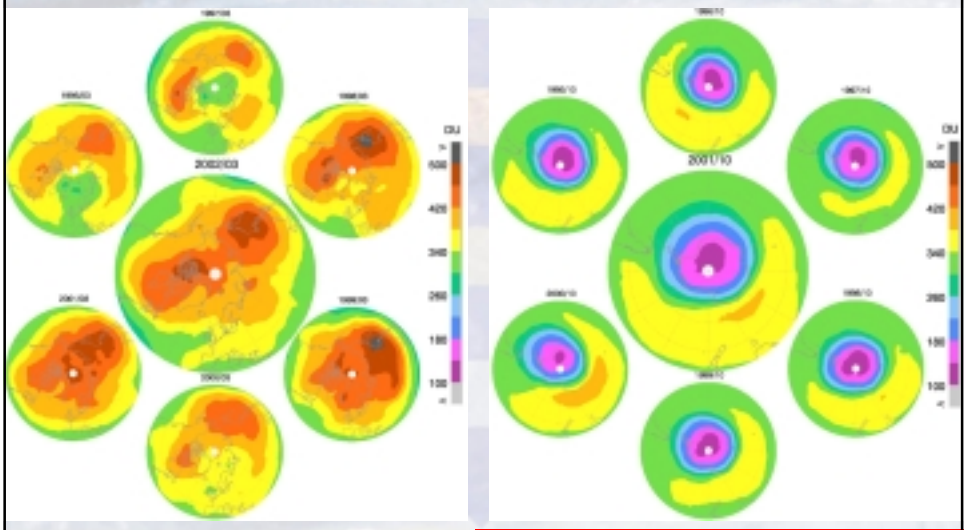
GOME: Polar Ozone [DU]
March in NH und October SH 1995-2002



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NO_2

Nitrogen Dioxide

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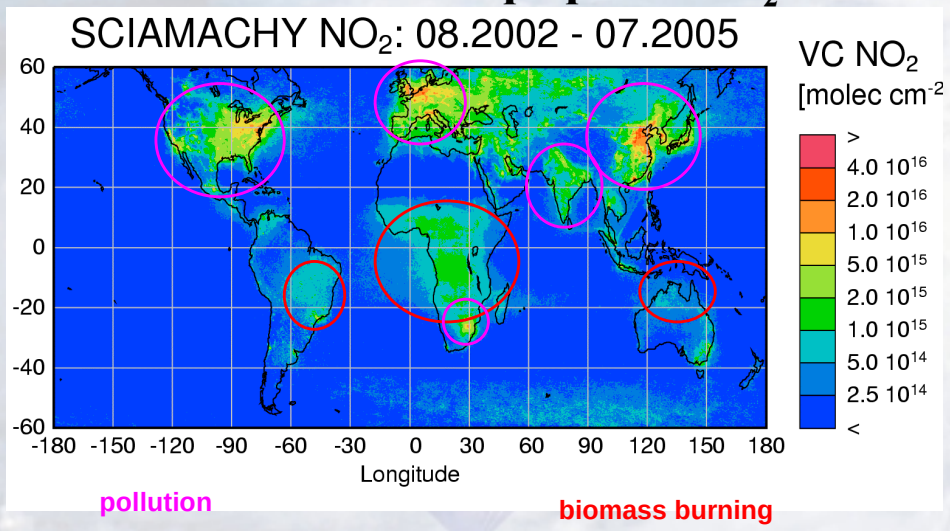
SCIAMACHY Tropospheric NO_2



pollution

biomass burning

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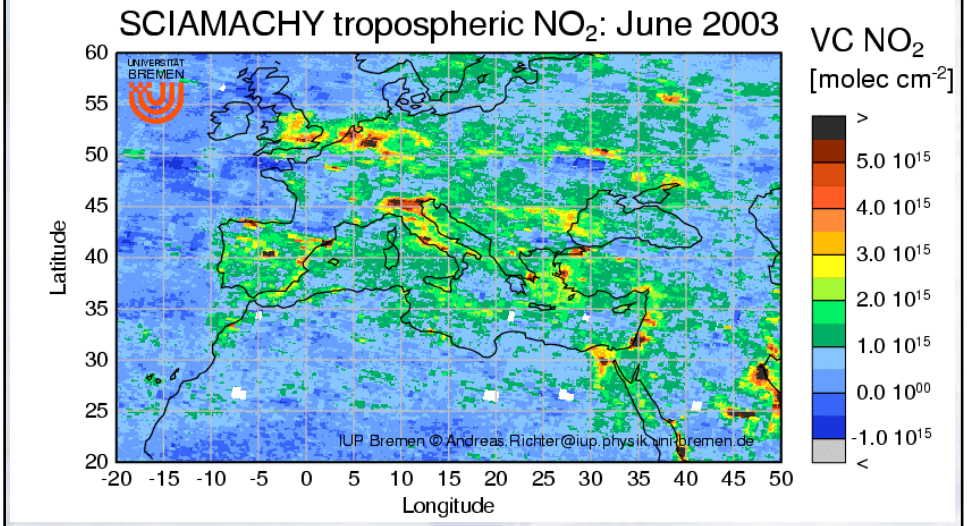

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Figure: A. Richter et al.

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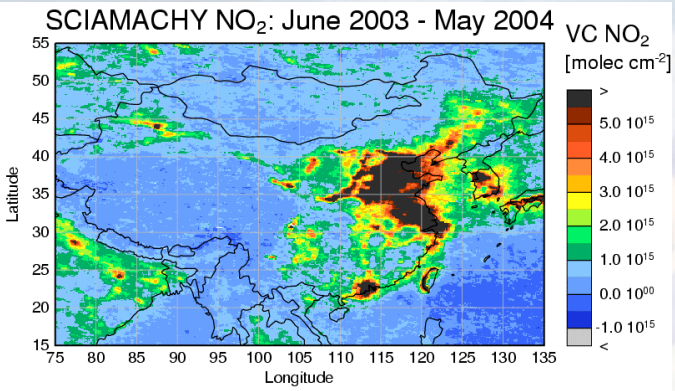
GOME and SCIAMACHY Tropospheric NO_2 - China



GOME:

- **large values**
- **clear signature of swath pattern**

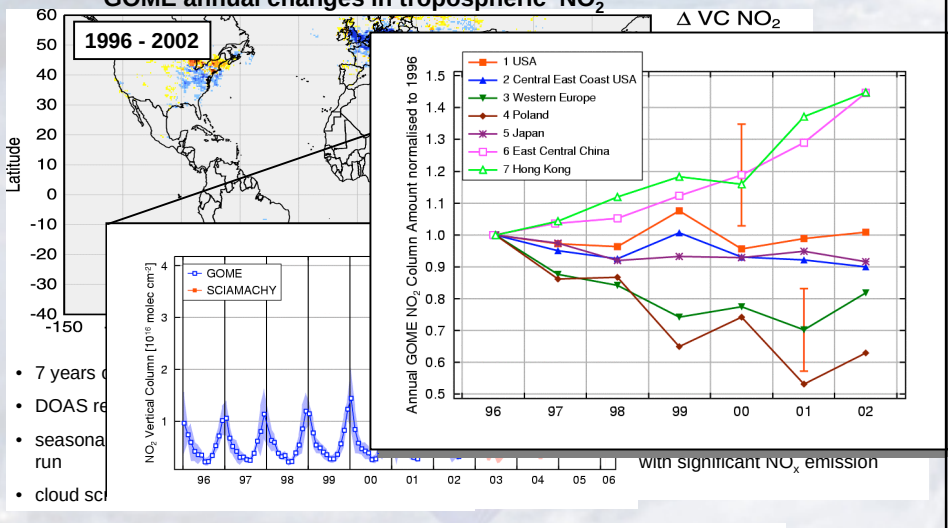
SCIAMACHY:

- **even larger columns**
- **much more detail**

- Not the same time period (NO_2 above China is rapidly increasing)

Trop. NO_2: Trends

GOME annual changes in tropospheric NO_2

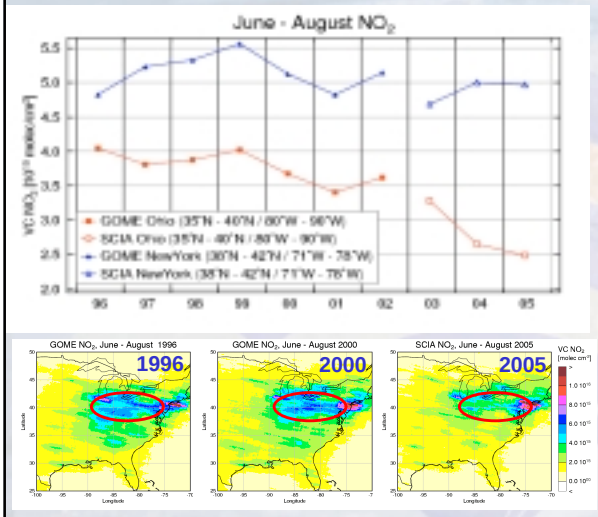


- 7 years (
- DOAS re
- seasona run
- cloud sc

with significant NO_x emission

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

Monitoring Sources/Sinks
NO_2: US Power Plant "Denoxification"



- GOME NO_2 time-series complex in USA
- after 2000, clear decrease (> 30%) in NO_2 in Ohio-valley area
- no change in urban areas
- size and geographical pattern consistent with model simulations

S. Kim, A. Heckel et al 2006 NOAA and University of Bremen

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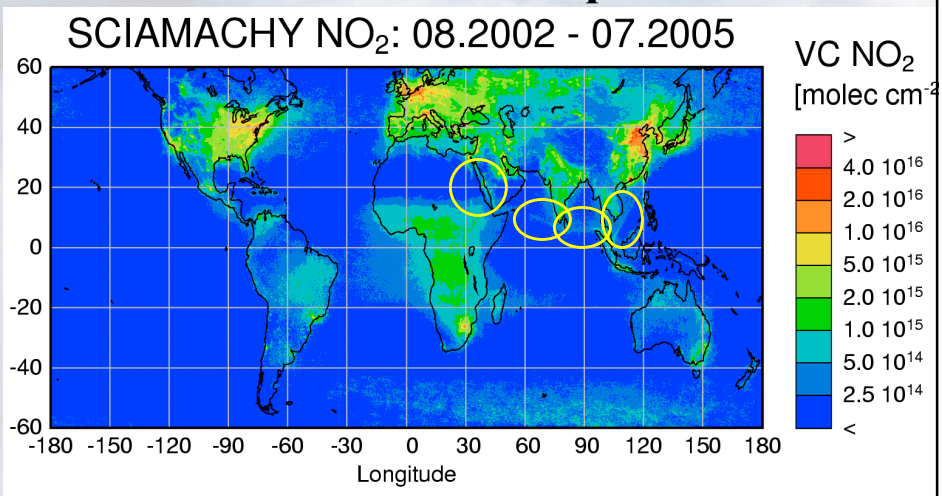
Where are the ships?



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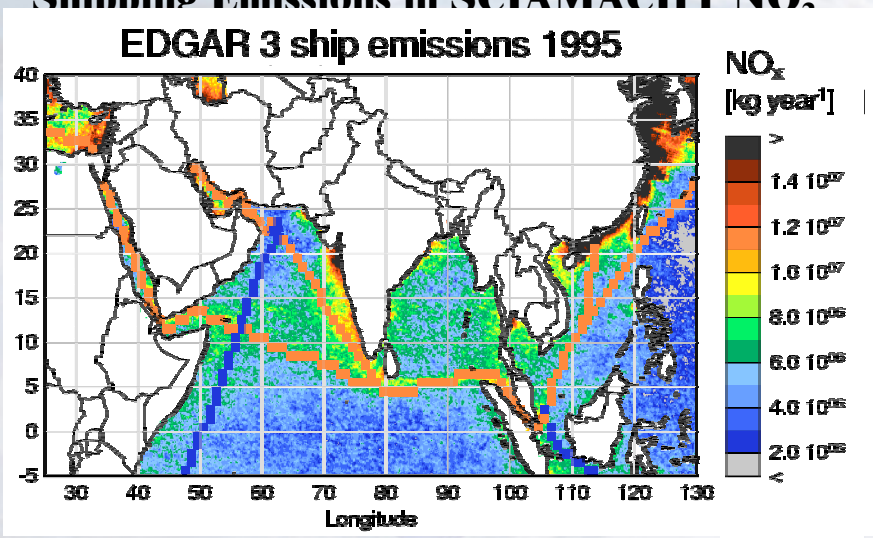
Shipping Emissions in SCIAMACHY NO_2



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Sulphur Dioxide, SO_2 – Precursorr of Acid Precipitation

Sulfur Dioxide

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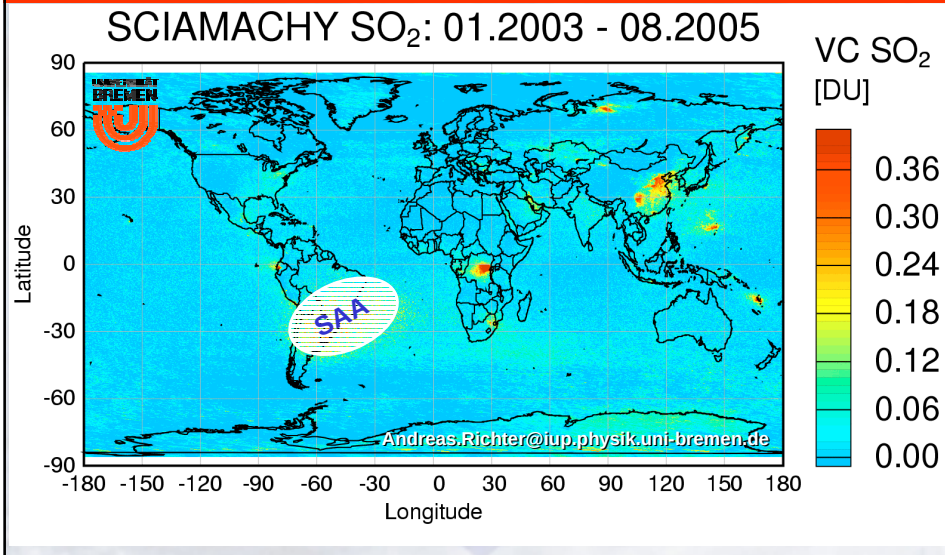
SCIAMACHY SO_2 measurements



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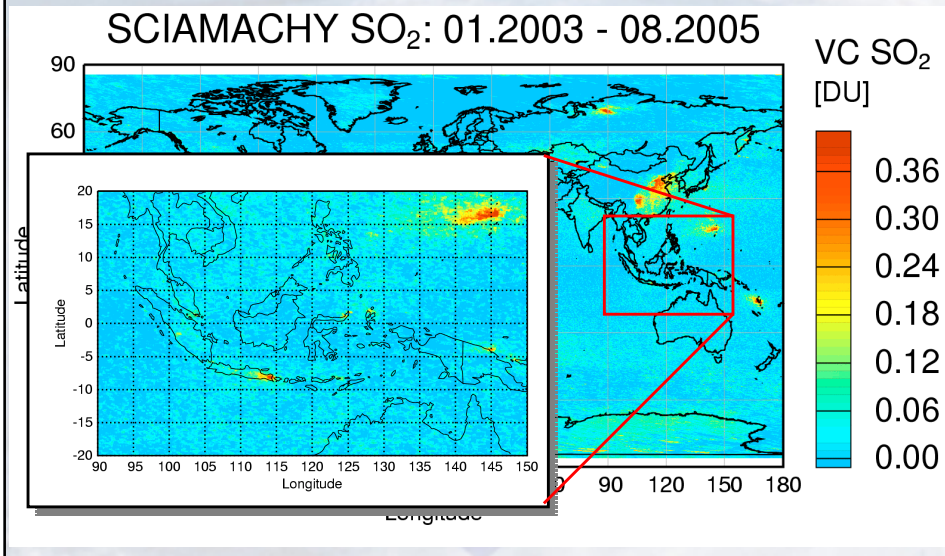
SCIAMACHY SO_2: Volcanic Emissions



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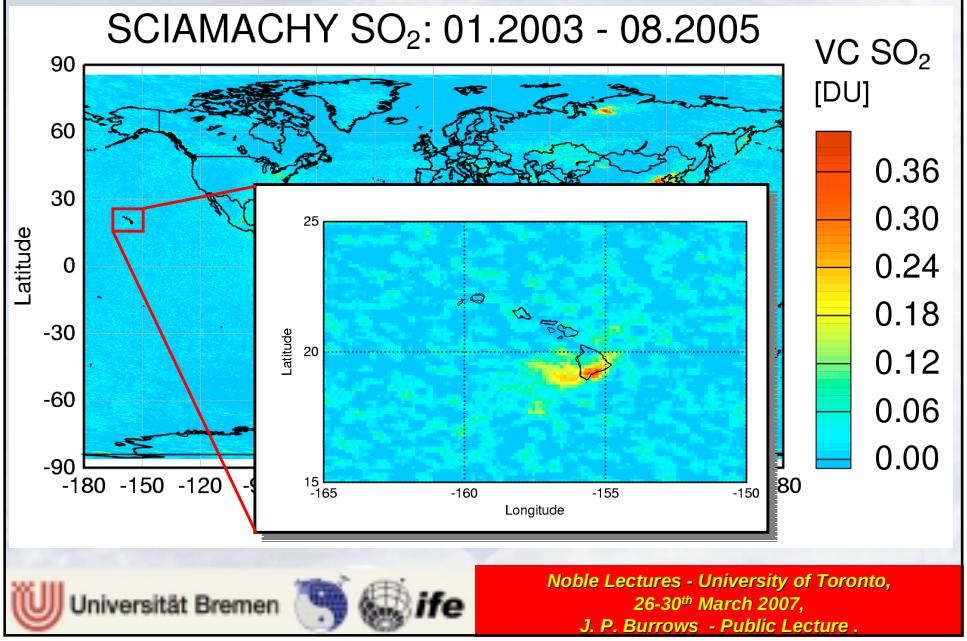
SCIAMACHY SO_2 : Volcanic Emissions



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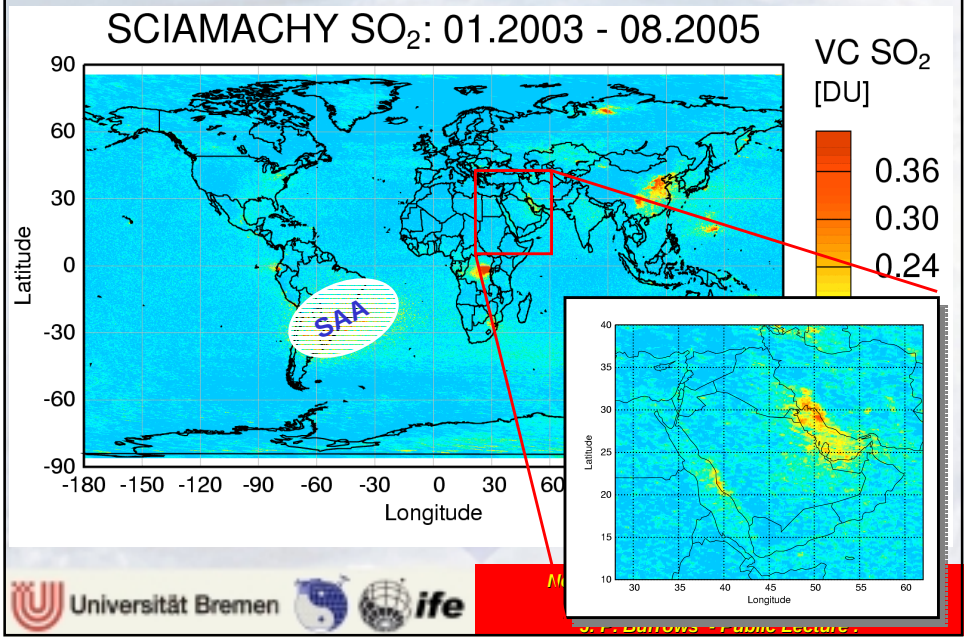
SCIAMACHY SO_2:Pollution



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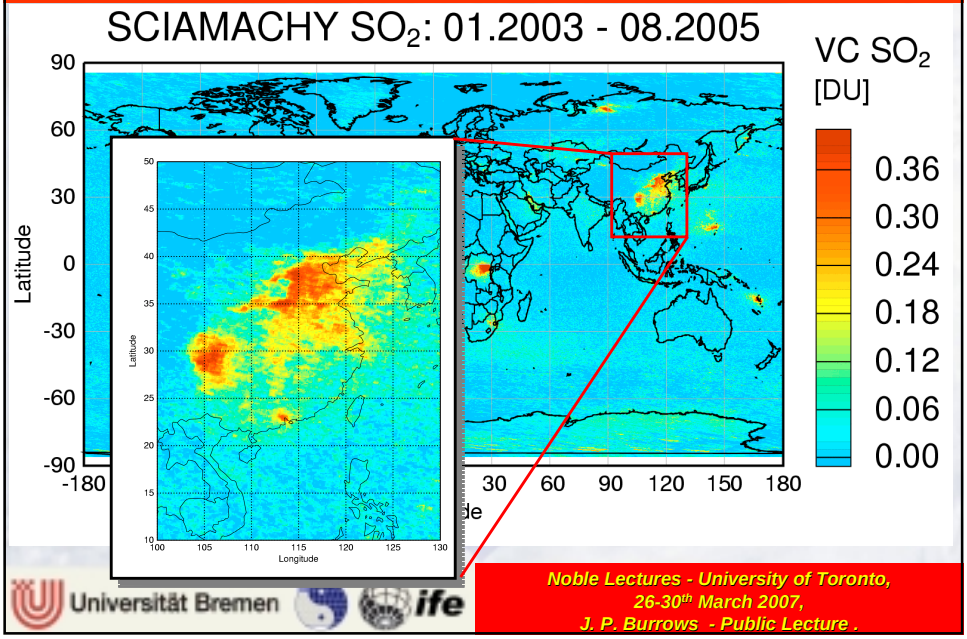
SCIAMACHY SO_2: Pollution



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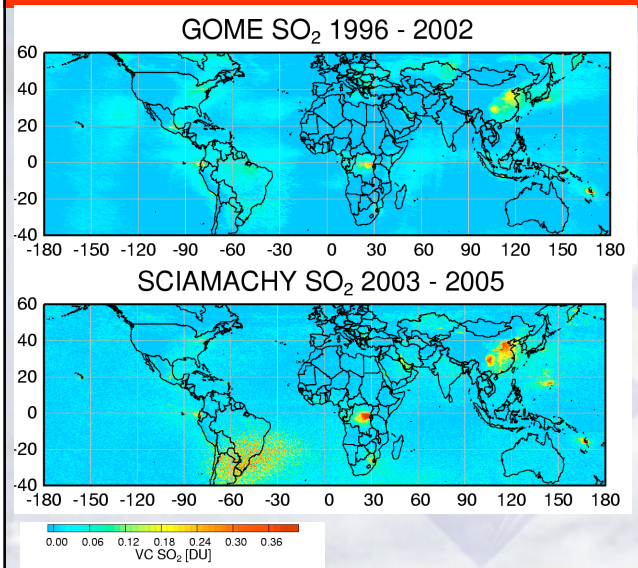
Comparison of GOME and SCIAMACHY SO_2



SCIAMACHY SO_2 has

- **overall similar values**
- **much more detail**
- **higher values over China**
- **slightly reduced columns over Europe and the US?**

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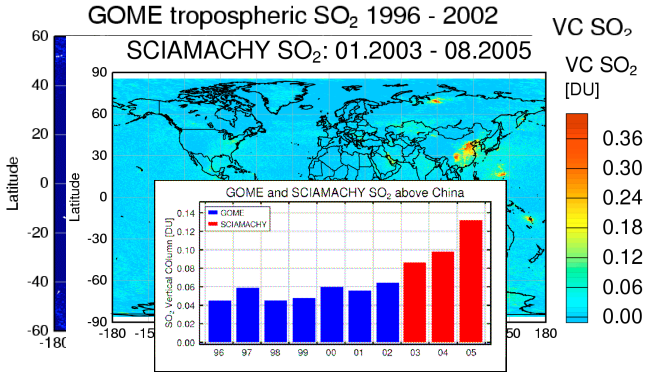
Tropospheric SO_2: The global View



SO_2 sources:

- volcanic eruptions
- coal fired power plants
- coal mine fires
- DMS (small)

Compared to NO_2, SO_2 columns have larger uncertainties:

- low signal (UV)
- small sensitivity to boundary layer
- strong interference by O_3 absorptions

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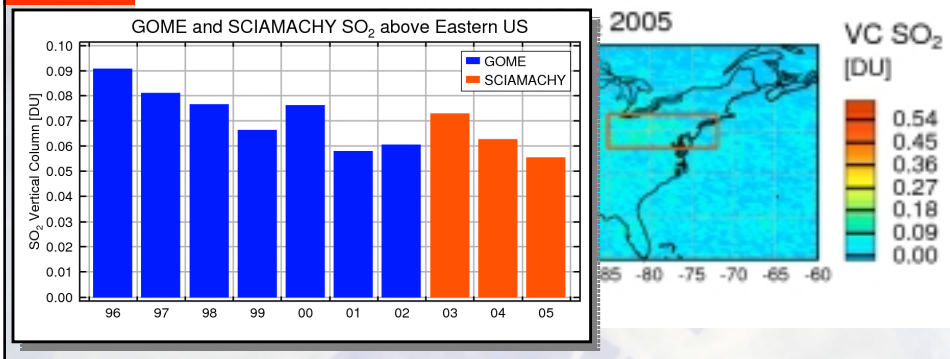
Changes of SO_2 above Eastern US



- **indication for a decrease in SO_2 above Eastern US**
- **high bias in SCIAMACHY measurements?**
- **this is not yet a quantitative result!**

all values still based on "volcanic profile"!

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Aerosol

PM10 and PM2.5 from space

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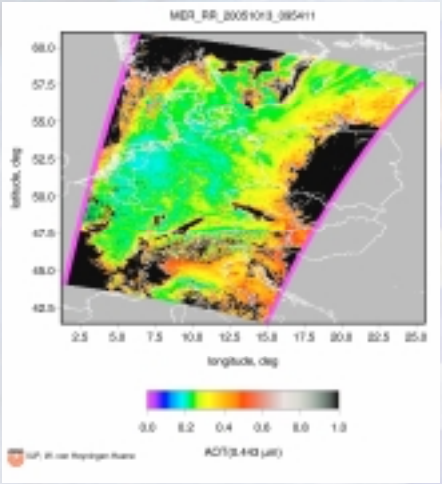
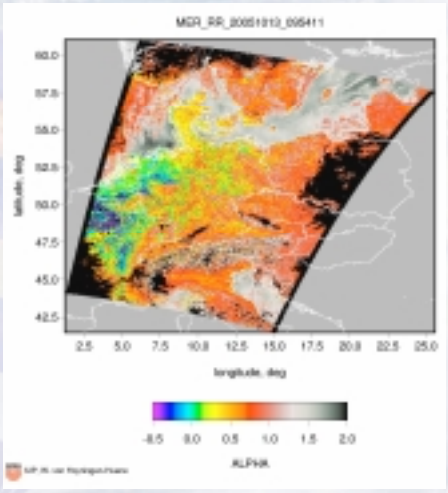
Synergy on ENVISAT MERIS : Simultaneous Data about Aerosols AOT + ALPHA





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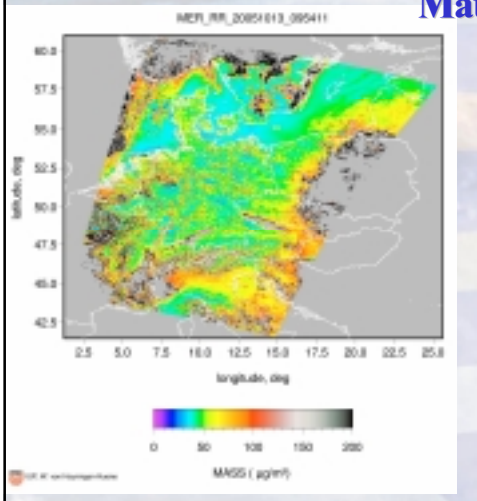
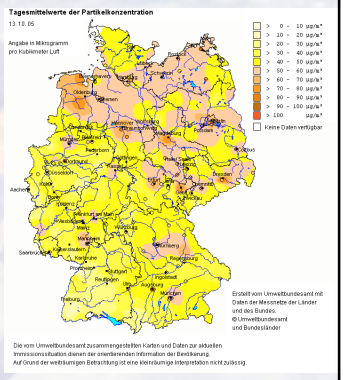
UB - Derived Research Product Particulate Matter





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Space Observations Organic Compounds: Formaldehyde HCHO and GlyoxalCHOCHO

Formaldehyde and Glyoxal

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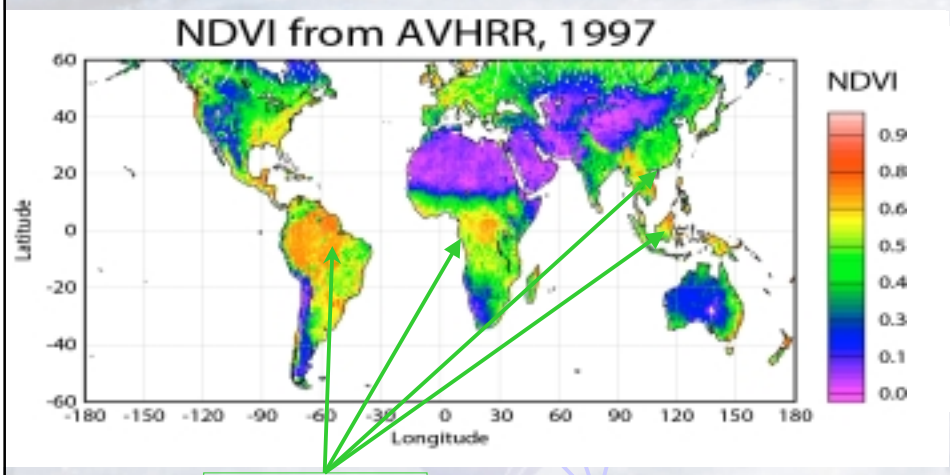
What are the sources of HCHO?



Highest values of HCHO

Main Biomass Burning Regions

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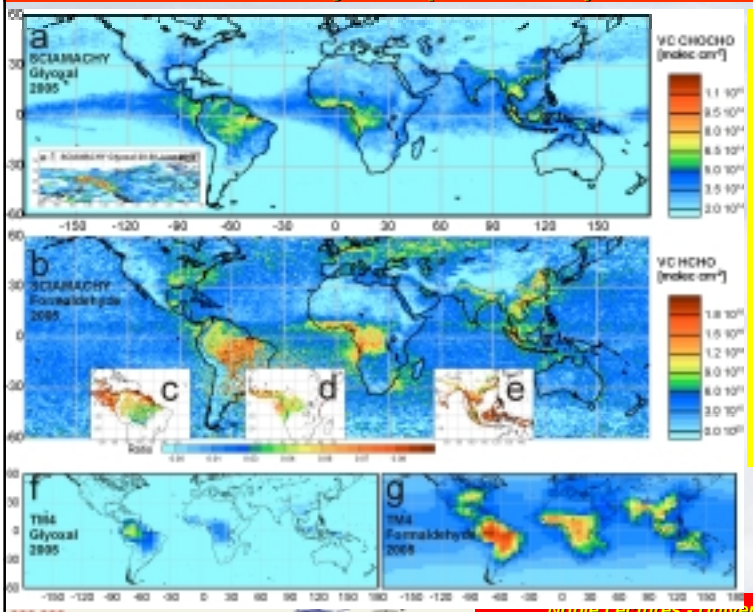
SCIAMACHY: Glyoxal (CHO.CHO) and HCHO in 2005



U. Crete TM4 + Chemistry

Additional sources of HCHO and CHO.CHO required over the ocean: Transport of loner lived VOC, release from SOA,

Local Sounce?

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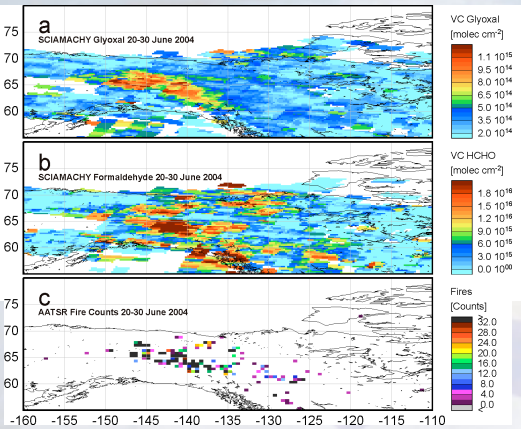
SCIAMACHY: CHOCHO and HCHO Asia and from a Fire



- biogenic emissions result in large CHO.CHO and HCHO
- anthropogenic sources and biomass burning can also be identified
- CHOCHO / HCHO ratioscoupled NO2 and O3 yields valuable information on the oxidation of VOC and O3 production
- overall broad agreement with model predictions

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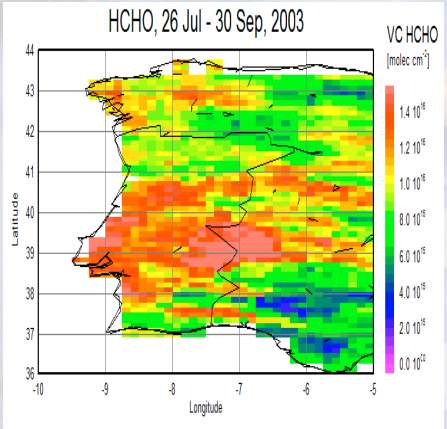
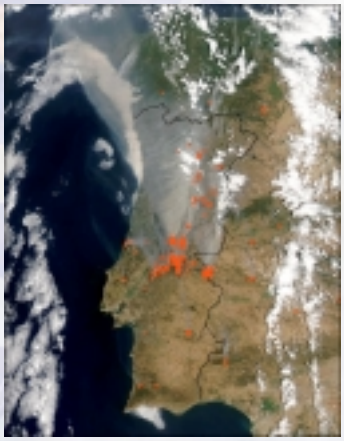
Forest Fires in Portugal 2003

MODIS, 3 Aug 2003





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Observations of the most Important Greenhouse Gases from space: Carbon Dioxide CO_2 and Methane CH_4

Note the concept of dry column

XCO2= CO2/O2

XCH4=CO2/O2

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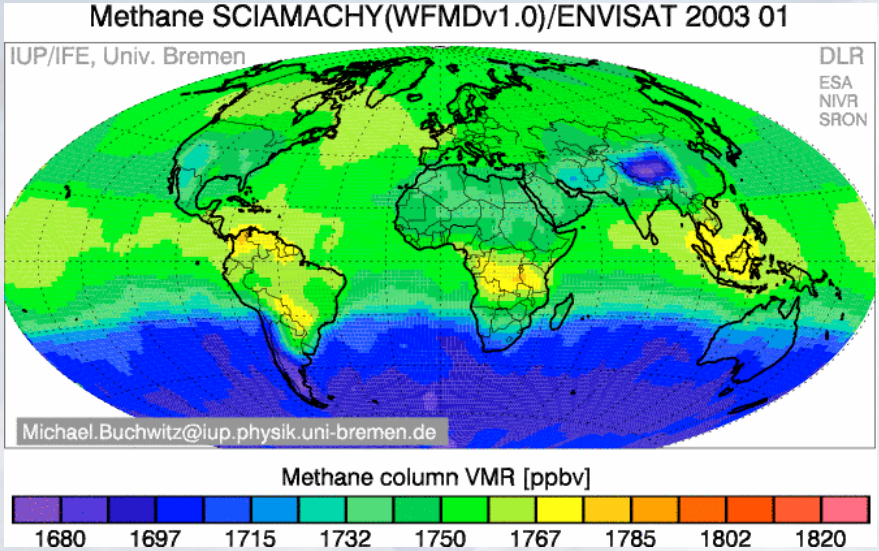
Methane (CH4) from SCIAMACHY 2003-2005 (PROMOTE GHG)



http://www.gse-promote.org/

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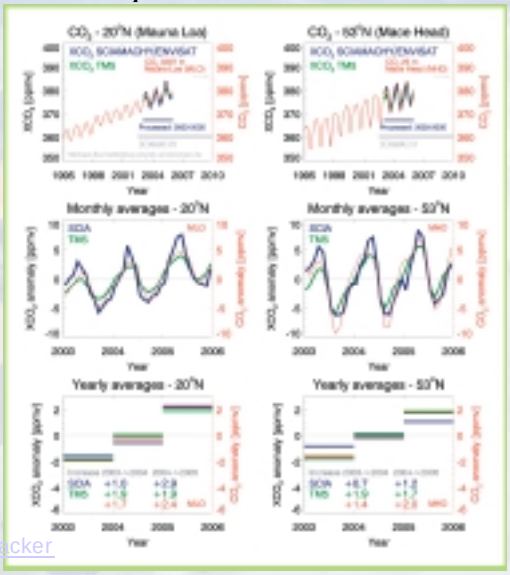
Carbon dioxide from SCIAMACHY: Comparison with TM5/NOAA

SCIAMACHY
IUP-Bremen / PROMOTE
Buchwitz et al.

CO2 NOAA
flask sampling
T. Conway, P. Tans et al.

TM5 model NOAA
W. Peters, P. Tans et al.
http://www.cmdl.noaa.gov/carbontracker



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Preliminary !

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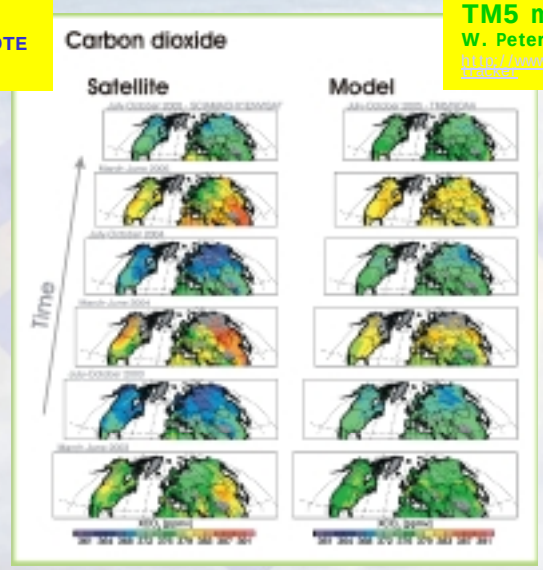

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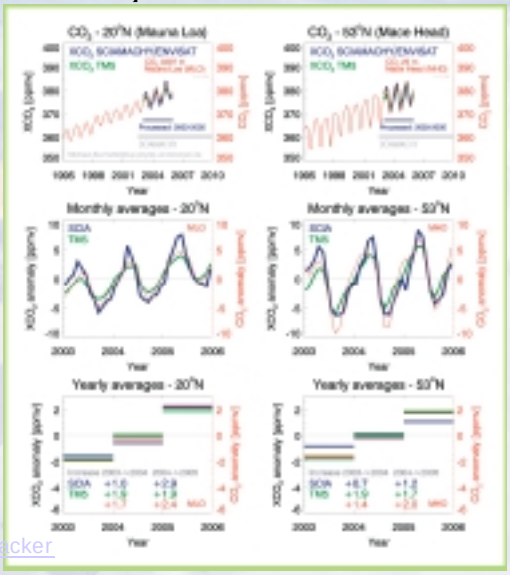

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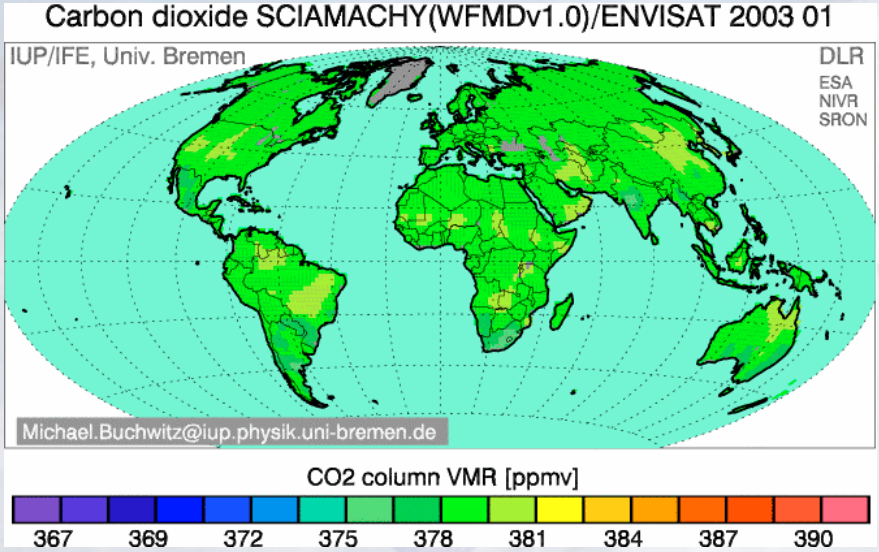
Carbon dioxide (CO2) from SCIAMACHY 2003-2005 (PROMOTE GHG)



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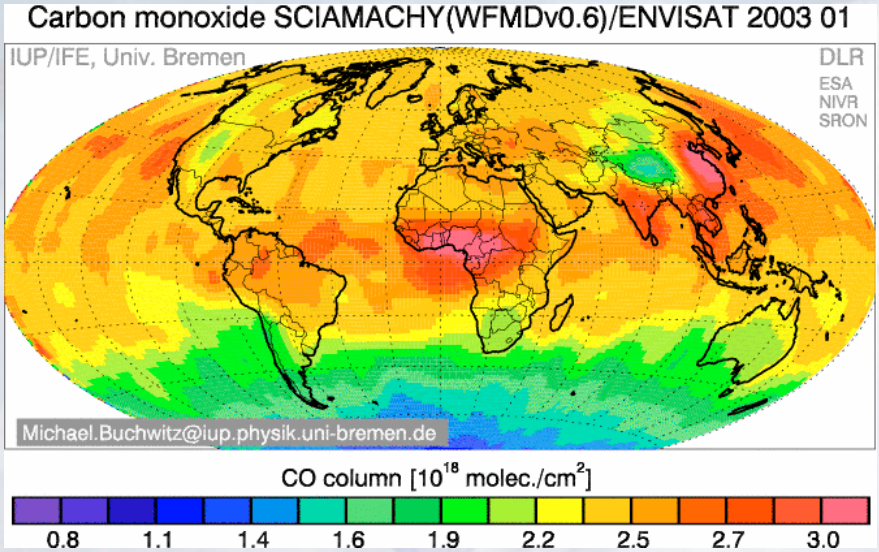
Carbon monoxide (CO) from SCIAMACHY 2003-2005 (PROMOTE AQ)



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Summary and Conclusions

- *Air Pollution and Climate Change are signifcant threats and require study and action.*
- *Remote Sensing from space is cost effective and unique success, now a proven concept!!!*
- *Remote sensing of atmospheric composition from space provides the global information required to study and follow global climate change.*
- *New initiatives urgently needed to follow and build on the success of the first pioneering instruments addressing tropospheric research and applications: Geo etc.*