Passive Remote Sounding of the Atmosphere in the Ultraviolet, Visible and Near-IR Spectral Regions:

GOME and SCIAMACHY from LEO, and the potential from GEO

Lecture 1

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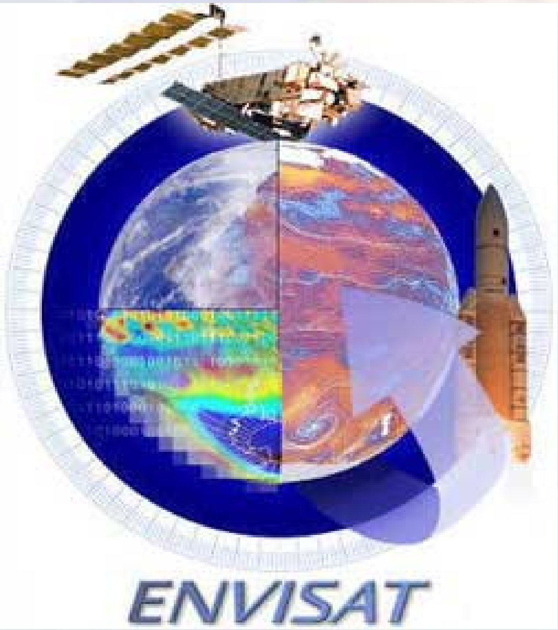
Partners in the SCIAMACHY Project

BIRA-
IASB

Links



- **ESA Envisat Homepage:** http://envisat.esa.int
- **German SCIAMACHY Homepage:** http://www.sciamachy.de
- **IUP/IFE Homepage:** http://www.iup.physik.uni-bremen.de
- **SCIAMACHY Operations Support Team:** http://atmos.af.op.dlr.de/projects/scops/

Contents

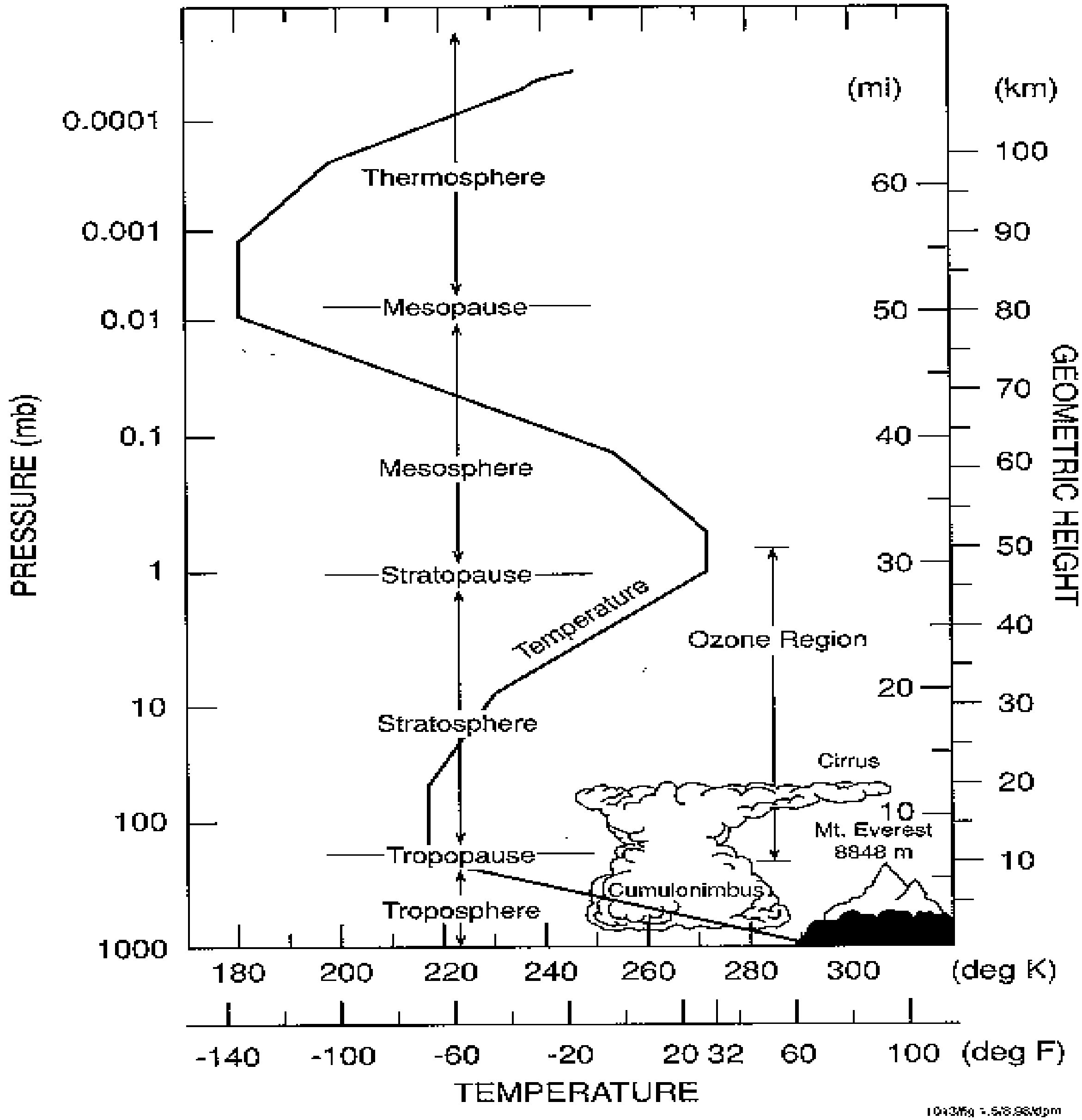
- Introduction
- Motivation for Atmospheric Sounding
- GOME
- SCIAMACHY

Introduction

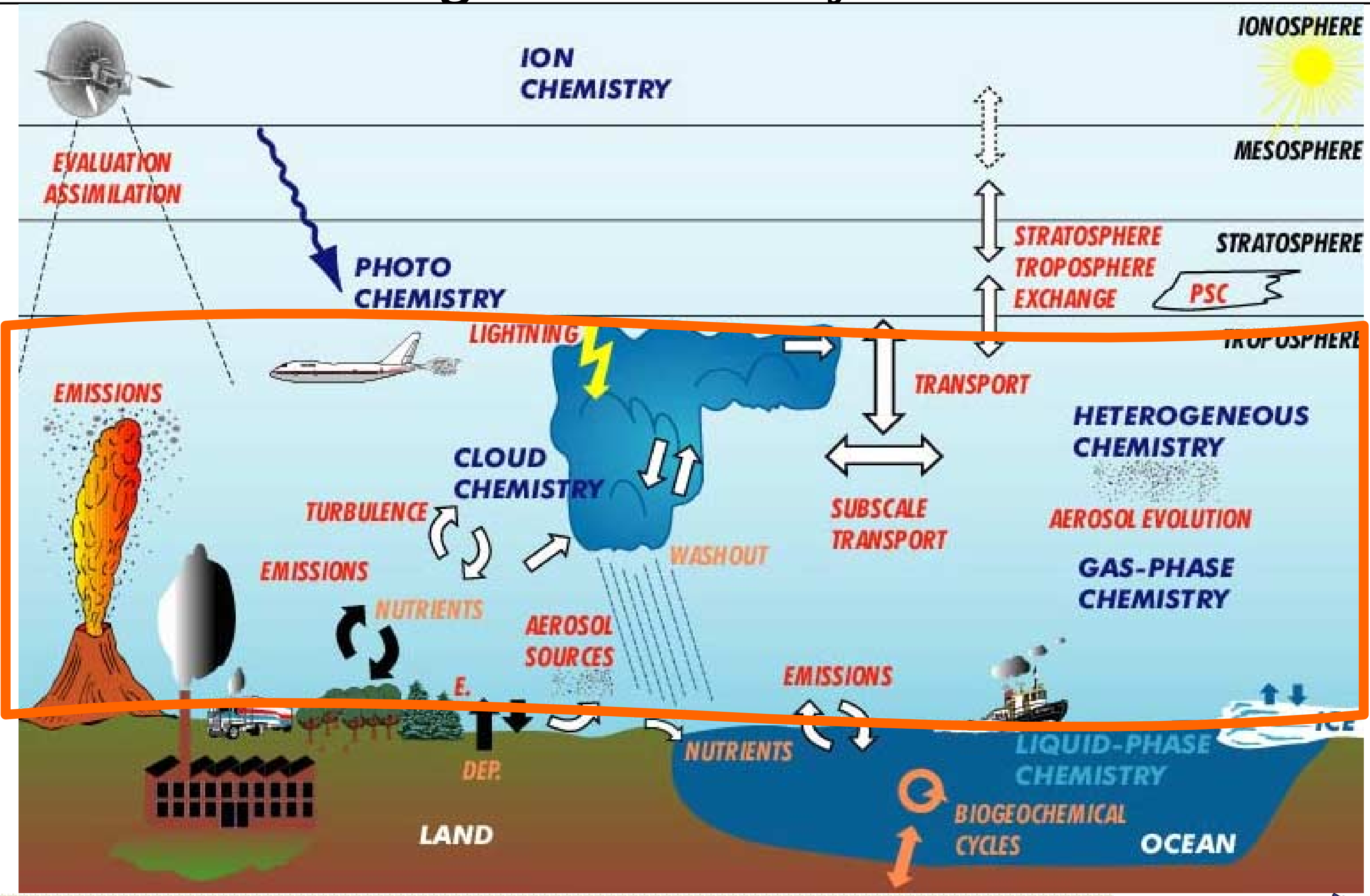
- **Atmospheric Issues**

- **- Troposphere**
- **- Stratosphere**
- **- Mesosphere**

Figure 1.5. *Vertical profile of the temperature between the surface and 100 km altitude as as defined in the U.S. Standard Atmosphere (1976) and related atmosphere layers. Note that the tropopause level is represented for midlatitude conditions. Cumulonimbus clouds in the tropics extend to the tropical tropopause located near 18 km altitude.*



Biogeochemical Cycles



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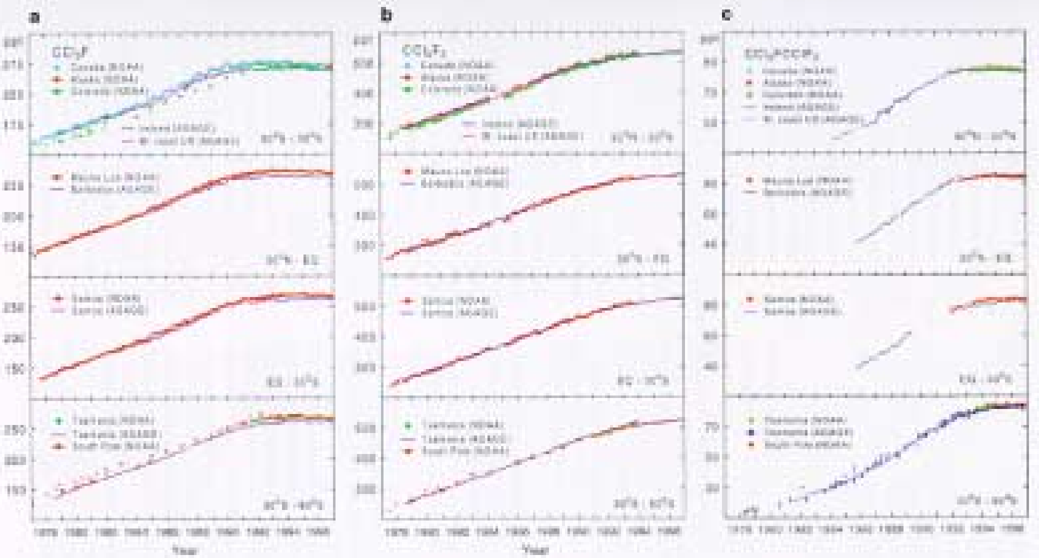
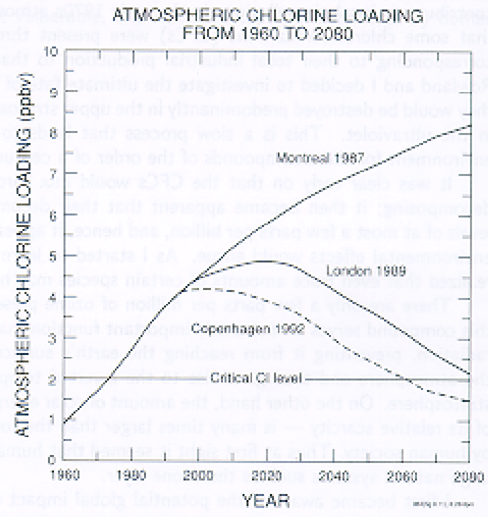


Figure 1-1. Monthly mean background data (in situ and flask) for CCl_3F, CCl_2F_2, and CCl_2FCClF_2 from the ALE/GAGE/AGAGE (Prinn et al., 1998) and NOAA/CMDL (Elkins et al., 1998) global networks.

Figure 8.15. Predicted future atmospheric burdens of chlorine and bromine.



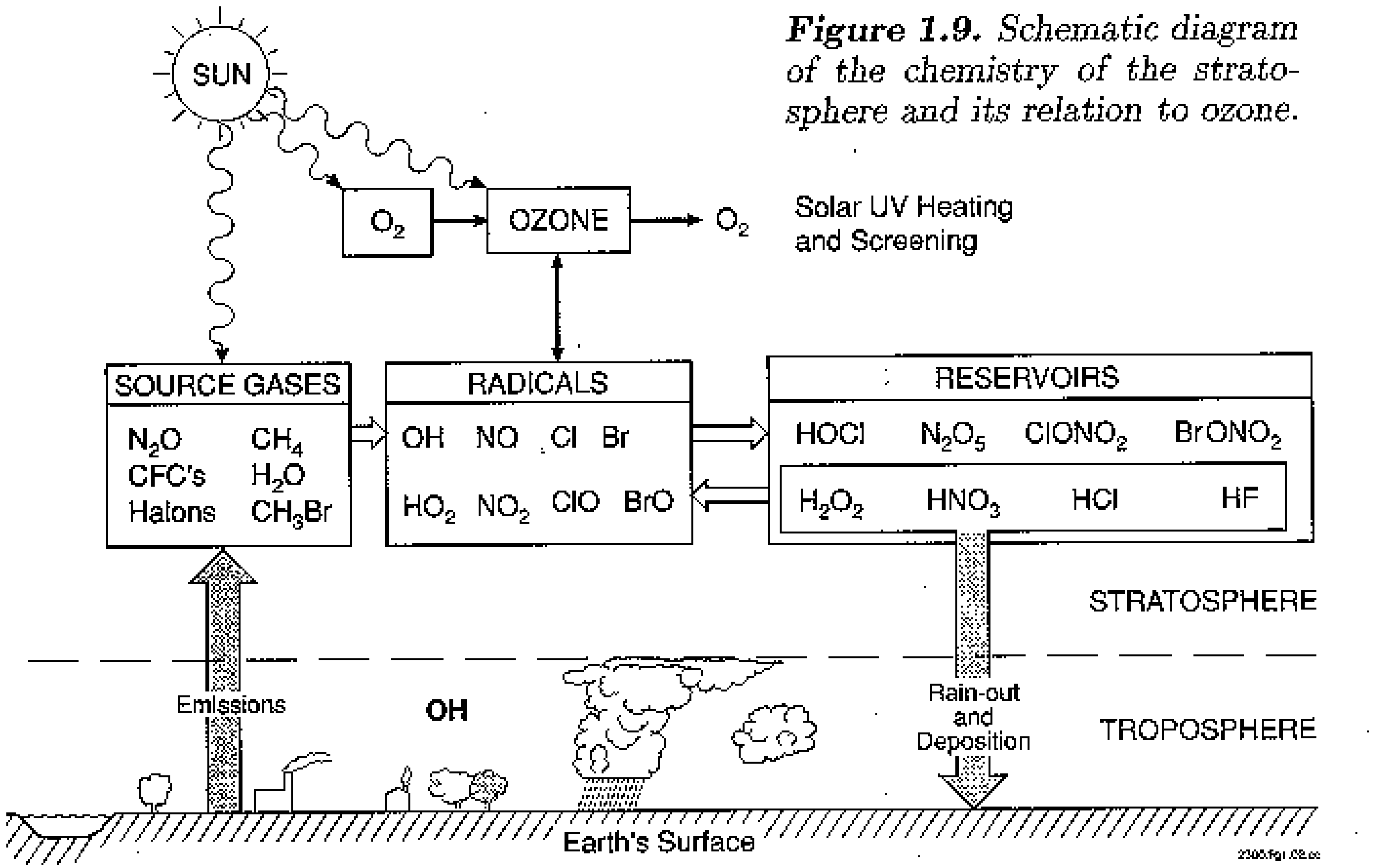
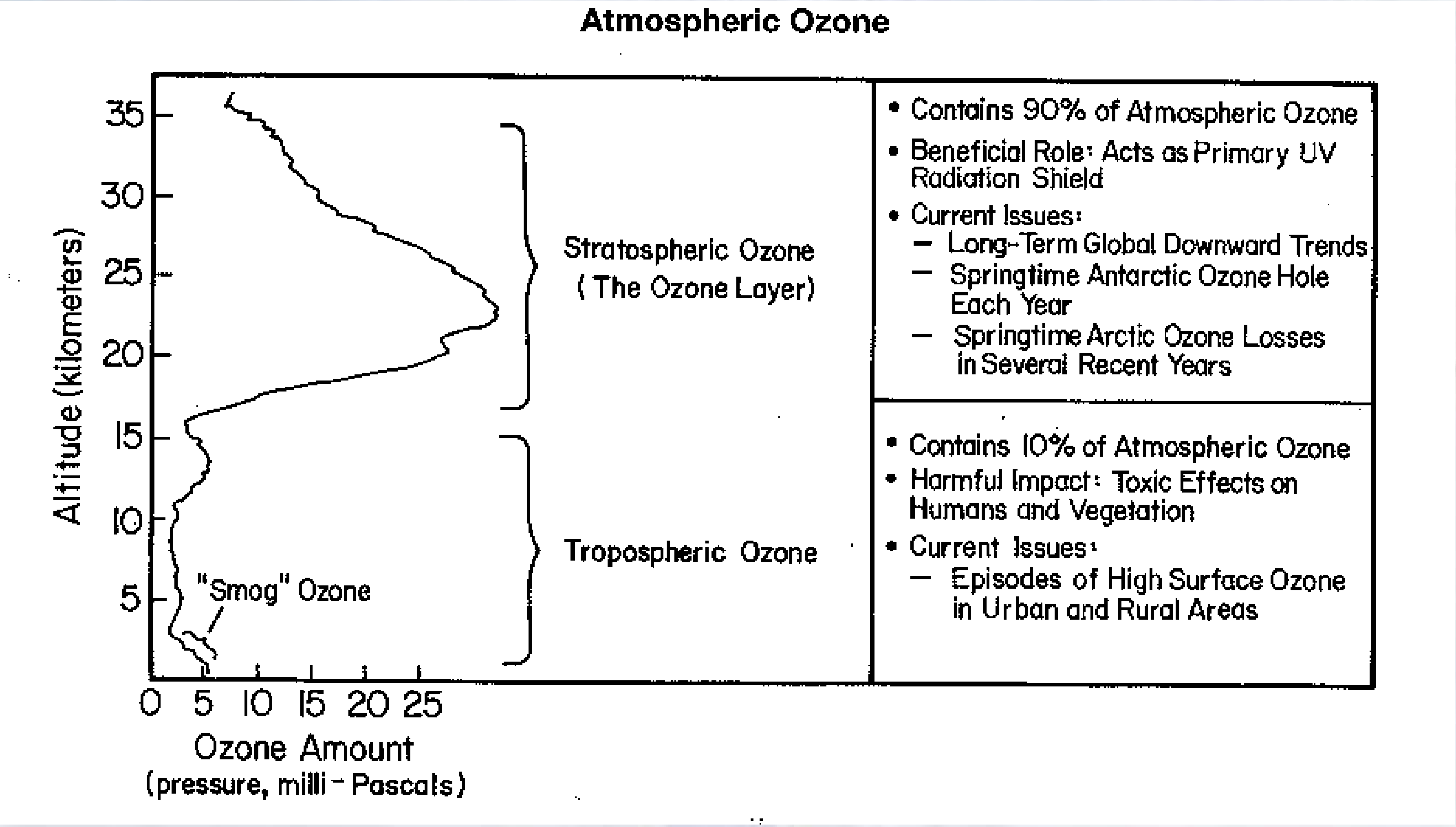
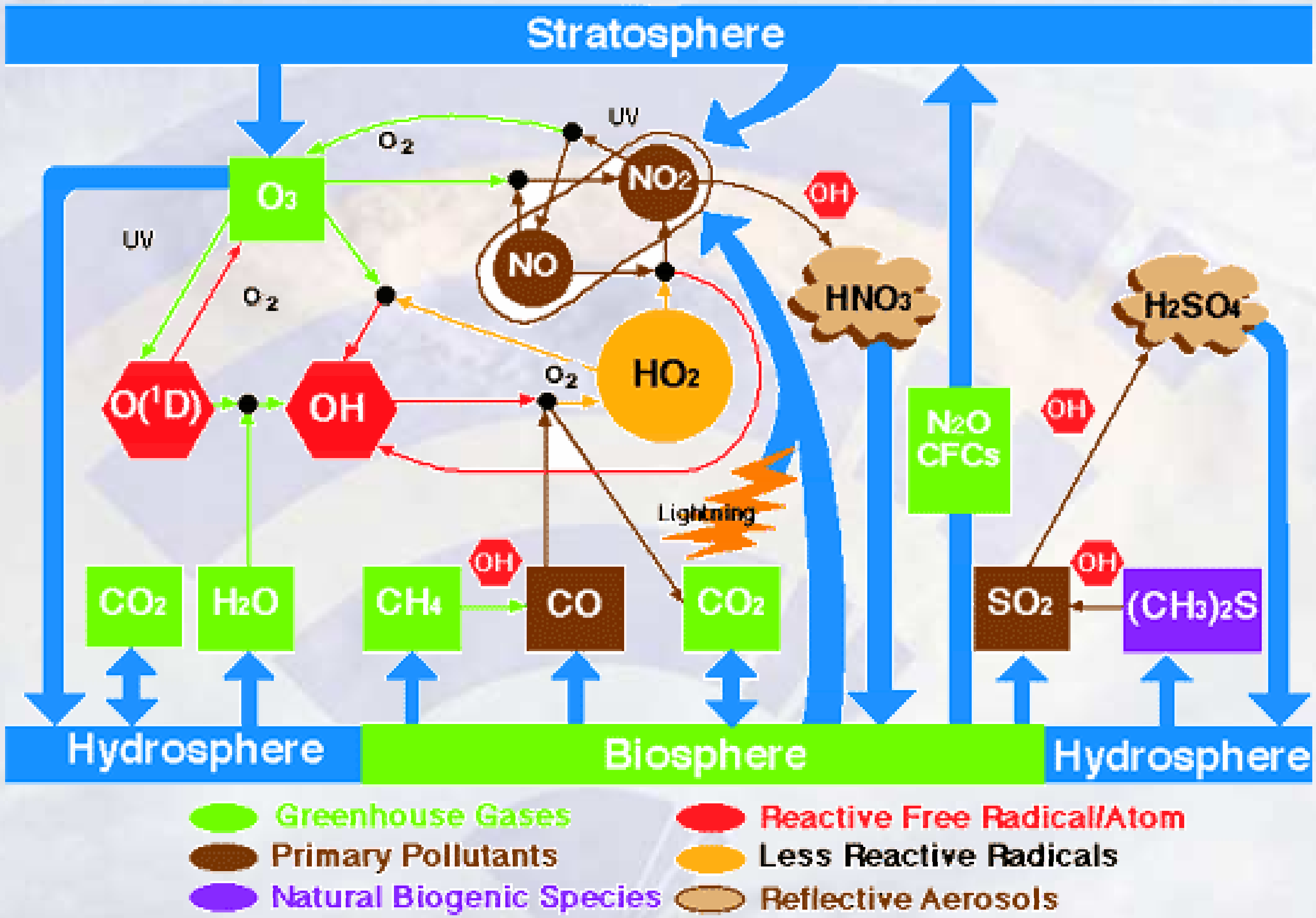


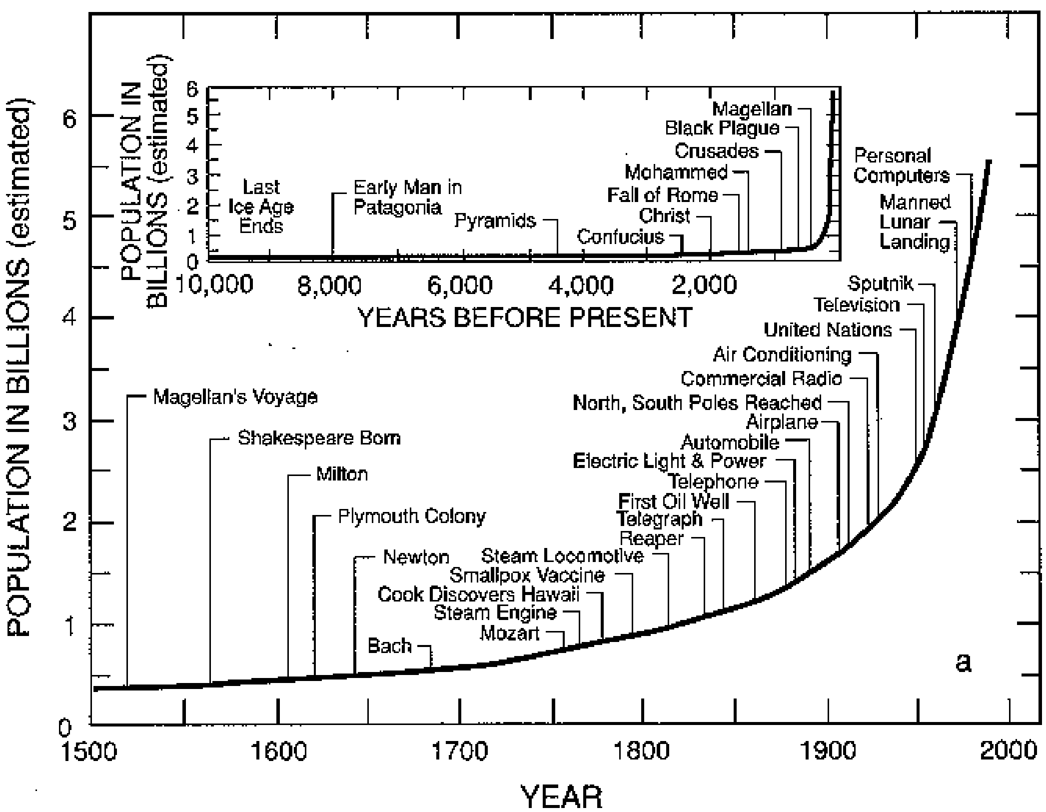
Figure 1.9. *Schematic diagram of the chemistry of the stratosphere and its relation to ozone.*


Atmospheric Ozone
Altitude (kilometers)
35
30
25
20
15
10
5
0 5 10 15 20 25
Ozone Amount
(pressure, milli-Pascals)
"Smog" Ozone
Stratospheric Ozone
(The Ozone Layer)
Tropospheric Ozone
• Contains 90% of Atmospheric Ozone
• Beneficial Role: Acts as Primary UV Radiation Shield
• Current Issues:
– Long-Term Global Downward Trends
– Springtime Antarctic Ozone Hole Each Year
– Springtime Arctic Ozone Losses in Several Recent Years
• Contains 10% of Atmospheric Ozone
• Harmful Impact: Toxic Effects on Humans and Vegetation
• Current Issues:
– Episodes of High Surface Ozone in Urban and Rural Areas

Tropospheric Chemistry



Atmospheric Chemistry and the Earth System



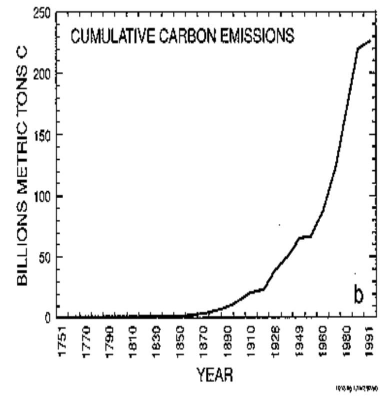
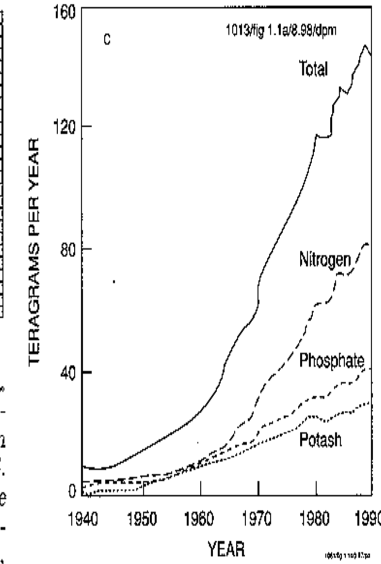


Figure 1.1. *Evolution of (a) the world population, (b) the cumulative emissions of carbon in the atmosphere since 1750 (courtesy of G. Marland, 1994), and (c) world fertilizer use between 1940 and 1990 (from OUR CHANGING PLANET 2/E by Mackenzie/Mackenzie, ©1998, adapted by permission of Prentice-Hall, Inc., Upper Saddle River, NJ).*



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

Tropospheric Issues and Measurement Needs

•Air Pollution: quantification of air pollution and emissions from the PBL, their transport and their distribution in the remote free troposphere
(O_3, CO, NO_2, H_2O, SO_2, HCHO, CH_4, NMHC, UV-A, UV-B, aerosol)

• Biomass Burning: impact on the composition of the tropical troposphere and lower stratosphere
(O_3, CO, H_2O, NO_2, HCHO, SO_2,CH4, NMHC, aerosol, fire occurrence, aerosol)

• Greenhouse Gas Fluxes: quantify the fluxes of GHG into the troposphere
(O_3, CO_2, H_2O, CH_4, N_2O, clouds, aerosol)

=> the relevant tropospheric parameters have a large spatial and temporal variability and/or are covered by the variability of clouds!

Tropospheric Issues (2)

Process	Natural/ Anthrop.	Regions of Importance	Example(s)
Biomass Burning (BB)	N/A	Africa, Southeast Asia, Mediterranean *South America*	Production of CO, H_2CO, NO_2 and Aerosols over Africa resulting in enhanced tropospheric O_3
Air Quality (AQ), Industrial Pollution	A	Central Europe, Middle East, East Asia, *North and Middle America*	Production of SO_2, NO_2, CO and aerosol over industrialised regions (fuel burning)
Lightning (LA)	N	Tropics, Europe	Production of NO_2 by lightning over Africa and ist impact on upper tropospheric O_3
Tropospheric ozone (TO)	A	Europe, Africa, South Atlantic, *Far East, US*	Outflow of enhanced tropospheric ozone from Africa over the Atlantic as a result of pollution, biomass burning or lightning activity
Volcanism (VA)	N	Italy, Africa, *South America*	Observation of SO_2- and aersosol-"clouds" from Nyamayagura/Africa
Global Warming (GW), Kyoto Gas Emissions	N vs. A	Europe, Africa	Aerosol direct/indirect effect CO_2 and CH_4 emission monitoring

Species/parameter	Environmental/Scientific Issue	Approximate lifetimes or cycling time	mixed ?
Stratospheric Ozone (O_3)	***TO, GW, SO, UTLS***	***Highly variable***	***No***
Tropospheric Ozone (O_3)	***TO, GW, BB, AQ, LA, UTLS***	***Highly variable***	***No***
Halogen oxides (ClO, BrO, OClO, etc.)	***SO, TO***	***Highly variable***	***No***
Nitrogen Dioxide (NO_2)	***TO, AD, BB, AQ, LA***	***Highly variable***	***No***
Water vapour (H_2O)	***TO, GW, BB, UTLS***	***Highly variable***	***No***
Carbon monoxide (CO)	***TO, BB***	***2 months, variable sources***	***No***
Methane (CH_4)	***TO, GW, SO, BB***	***10 years, variable sources***	***Yes***
Nonmethane hydrocarbons (NMHC, here H_2CO)	***GW, TO, BB***	***Hours-weeks***	***No***
Chlorofluorcarbons (CFCs)	GW, SO	Many years	Yes
Chlorofluorhydrocarbons (HCFCs)	GW	Many years	Yes
Carbon dioxide (CO_2)	***GW***	***> 100 years, variable sources in the trop.***	***Yes***
Nitrous oxide (N_2O)	***GW, SO***	***> 100 years, tracer***	***Yes***
Sulphur dioxide (SO_2)	***AD, AQ, VA***	***Hours***	***No***
Ammonia (NH_3)	AD	Hours	No
Sulfuric Acid (H_2SO_4)	VA, AD	Hours	No
Nitric Acid (HNO_3)	AD	Hours	No
Aerosol	***GW, BB, AQ, VA***	***Hours-weeks***	***No***
Clouds	***GW, TO, BB, LA***	***Hours to days***	***No***
Polar stratospheric cloud	SO	Days to weeks	No
Surface spectral reflectance	GW, TO	Months	N/A.
Radiation Field (UV/SW/LW)	***TO, SO, GW, BB***	***Highly variable***	***N/A.***
Solar Variability	TO, GW, SO	Days to decades	N/A
Temperature	***GW, SO, TO***	***Highly variable***	***No***
Wind Fields	***AD, TO, AQ, BB***	***Highly Variable***	***N/A***
Fire Activity	***BB, TO, AQ, GW***	***Highly Variable***	***N/A***
Lightning Activity	***TO, LA***	***Highly Variable***	***N/A***

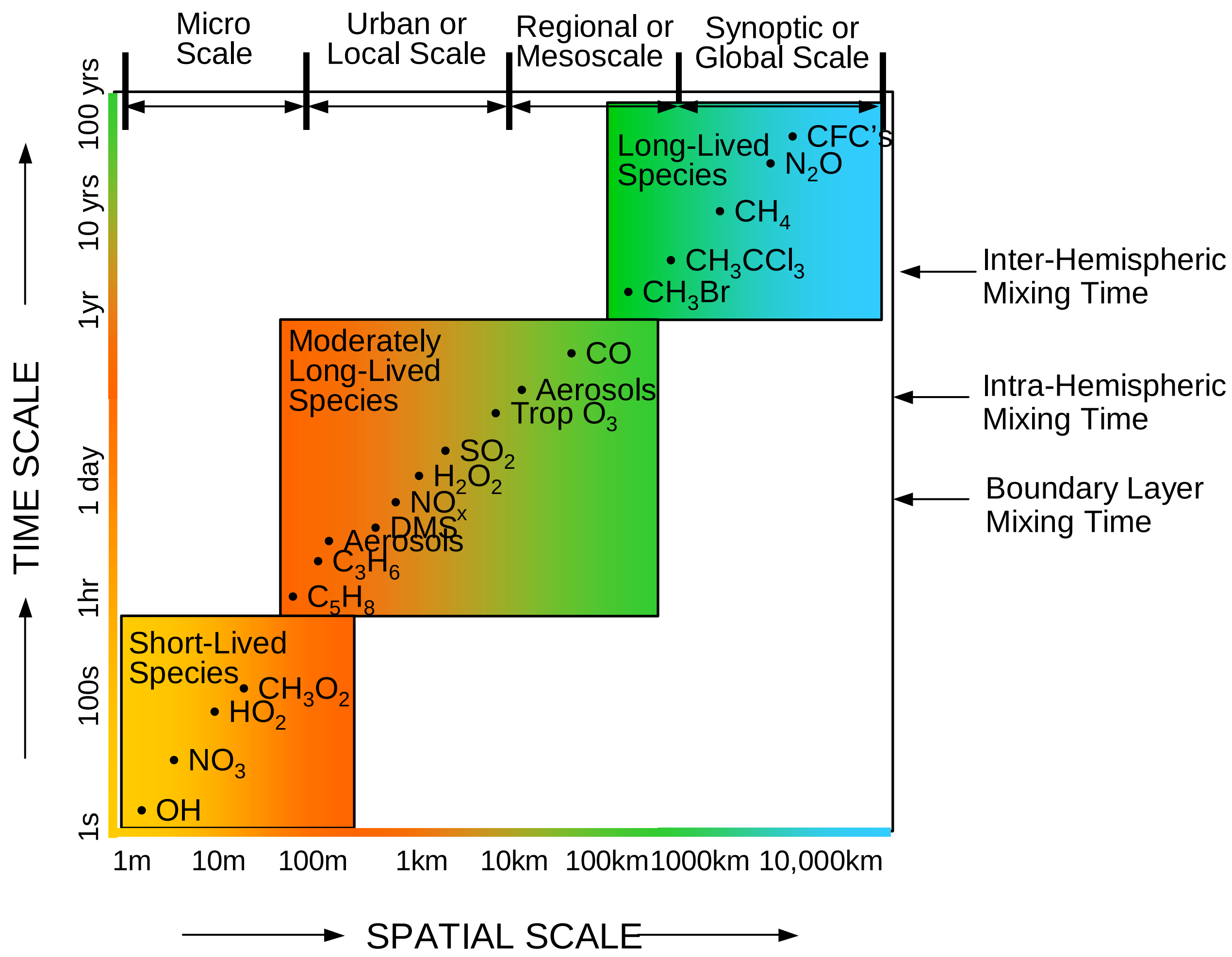
Policy Issues

- **European convention on Long-Range Transboundary Air Pollution (LRTAP). The objective of the LRTAP is to reduce and control transboundary transfer of emission.**
- **Global Monitoring for Environment and Security (GMES) from Space (EU/ESA initiative)**
- **The Kyoto Protocol (UNFCCC). This aims at ”the stabilisation of greenhouse gas concentrations … “ In a first phase, it aims to control emissions of gases having important global warming potentials (GWP): e.g. CO_2, CH_4, N_2O. The latest summary of the IPCC WG1 directly pointed on the necessity of to “*sustain and expand the observational foundation for climate studies by providing accurate, long-term, consistent data including implementation of a strategy for integrated global observations”* (IPCC 2001).**
- **Montreal Protocol: Monitoring of Ozone and impact on human being (UV)**

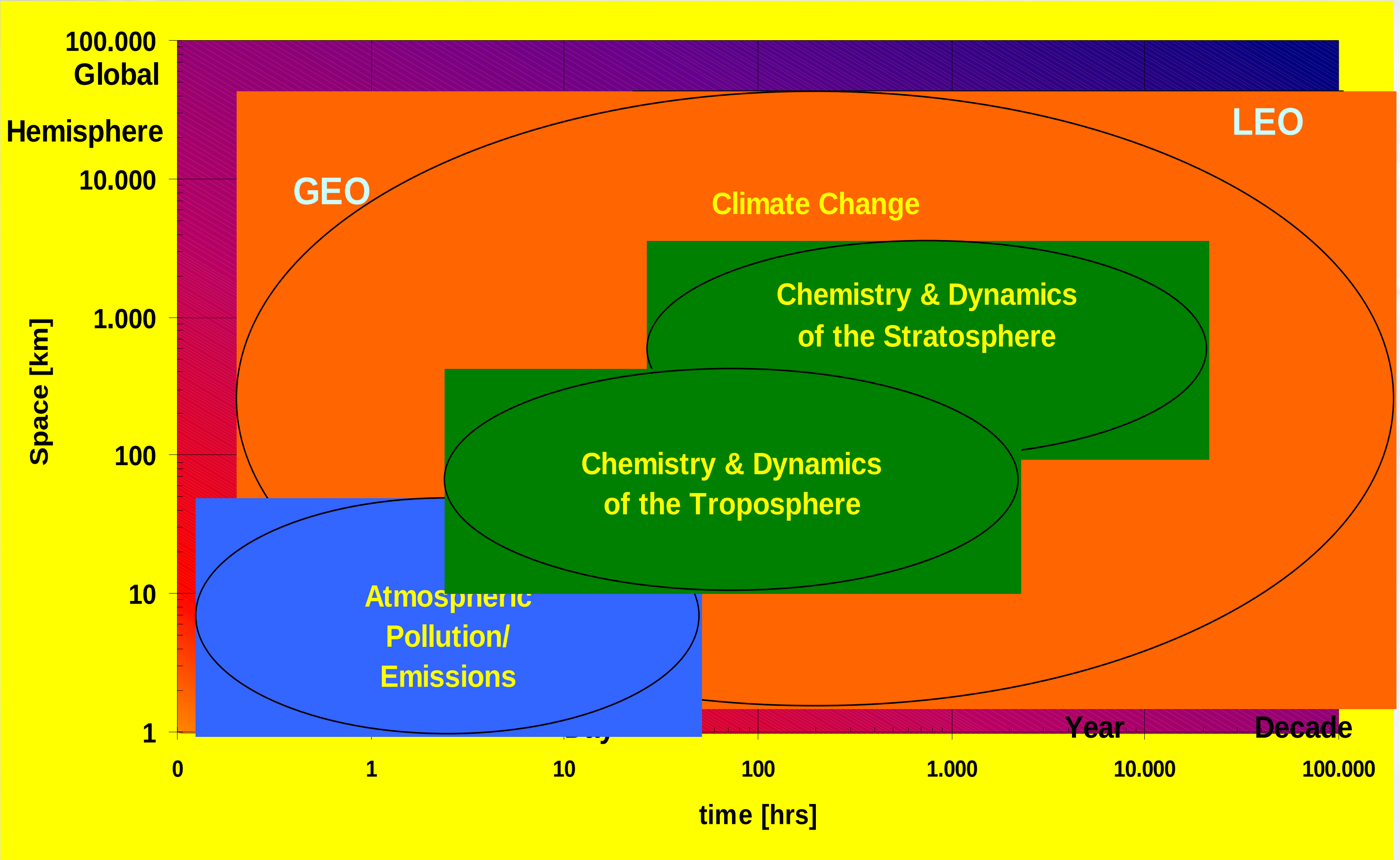
Motivation for Atmospheric Sounding from Space

- **Changing Atmospheric Composition**
  Origin: Natural Processes (Volcanic) and Anthropogenic Activity (Pollution, Combustion of Fossil Fuel, Biomass/Biofuel Burning)
- **Establish the global distribution of key constituents: trace gases, aerosol and clouds**
- **Climate change research**
- **Assessment**
- **Meteorology: Improvement of prediction**

Temporal and Spatial Scales



Spatial and Temporal Scales relevant for LEO and GEO



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LEO and GEO: Targets and Scales

- **LEO: Low Earth Orbit**
  - Sun synchronous – the same local time at the equator each orbit.
  - Sun asynchronous – varying local time every orbit at the equator
  - Global Coverage

- **GEO: Geostationary Earth Orbit**
  - the same disk of the earth in view i.e. 1/3 to 1/5 of the earth in view
  - observations of all local times

SOME HISTORY

- 1920s Dobson and co-workers develop the Dobson instrument and technique to determine Ozone amount.
- 1957 International Geophysical Year – deployment of
- 1957 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
- 1996 -present EPTOMS

SCIAMACHY, GOME and GeoTROPE

(Progress towards the space based Numerical Environmental Prediction/Chemical Weather: space component)

03-1985 **MAP (Measurement of Atmospheric Pollution) proposal idea to ESA for EURECA** ***no significant agency response - ignored,***

05-1985 **Stratospheric Ozone hole observed by Farman et al (Nature).**

1985 – 1988 **Development and submission of the *SCIAMACHY(Scanning Imaging Absorption Spectrometer for atmospheric CHartographY),* 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)***

20-04-1995 **Launch of ERS-2 with GOME**

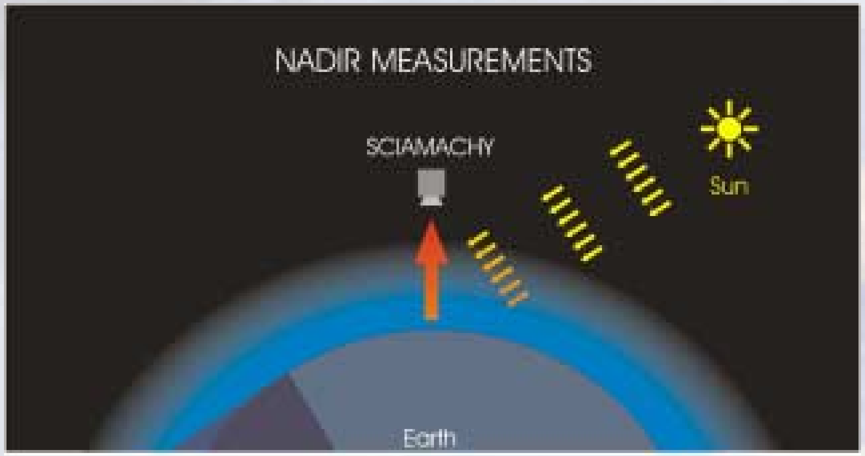
12-1998 **Proposal of GeoSCIA to ESA EEOM-1 – recommended for further study**

1997-2000 **Selection of GOME-2 for the EUMETSAT/ESA operational series Metop**

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.**

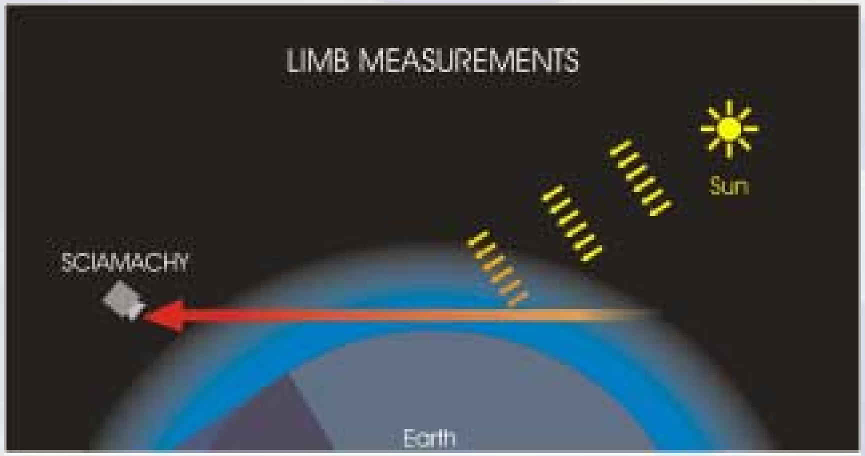
SCIAMACHY and GOME Measurement Geometry

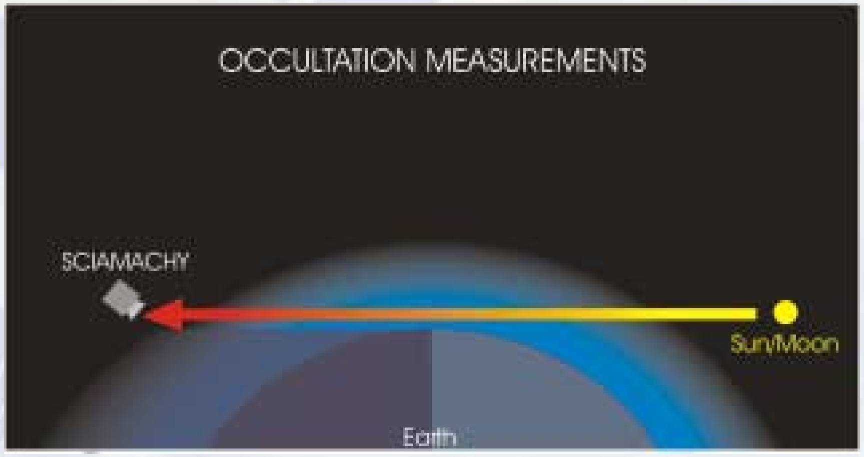


- Typical spatial resolution in nadir:

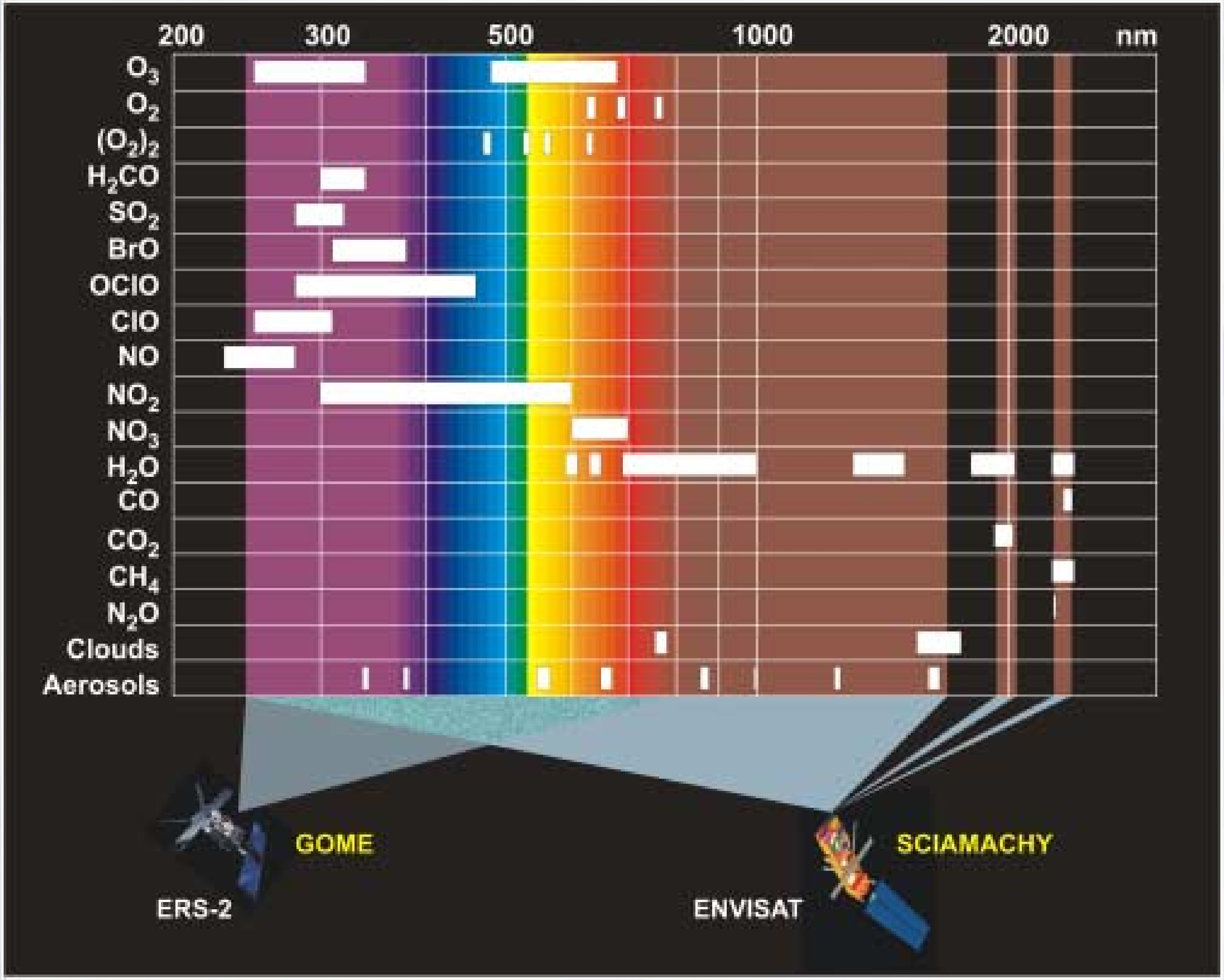
  GOME-1 - 40x320 km^2 1995
  SCIAMACHY - 30x 60 km^2 2002
  GOME-2 - 40x80 km^2 2005/6

- Vertical resolution in limb/occultation: 1.5-3 km
- Global coverage for limb and nadir





GOME SCIAMACHY Targets and Spectral Coverage



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Level 0 and 1 Data Products for GOME and SCIAMACHY

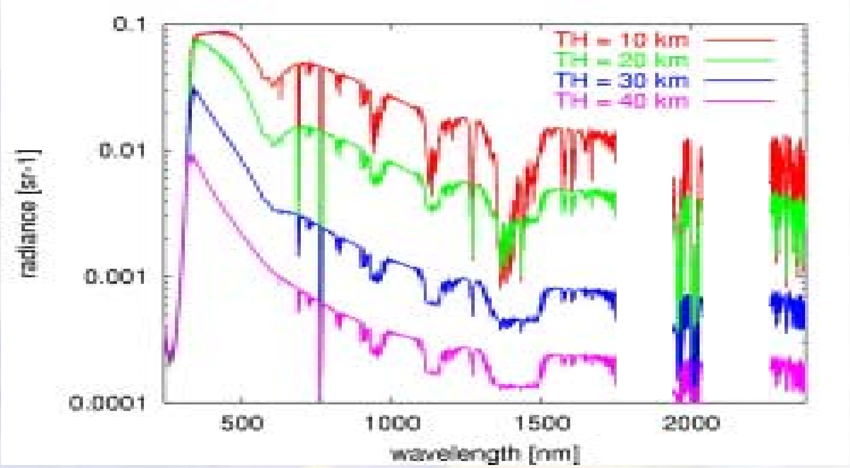
- PLEASE NOTE THIS IS WHAT THE INSTRUMENT MEASURES!!!!!!!
- Level 0 bits,

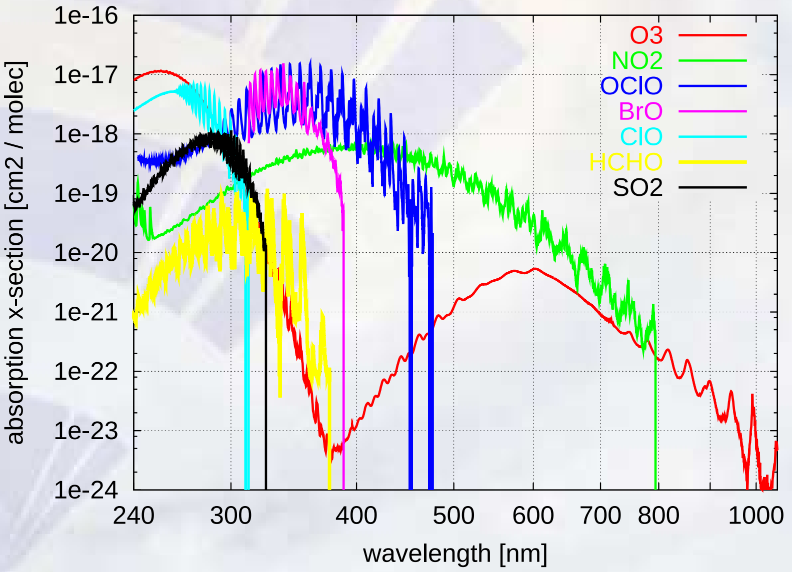
  - electrons produced by photons interacting with a diode - photo-resistive/conductive, photo-voltaic effect.
- Level 1
  - Extra terrestrial Irradiance
  - Earthshine Top of the Atmosphere Radiance
    - GOME – Nadir only
    - SCIAMACHY- alternate Limb and Nadir

      - solar and lunar occultation

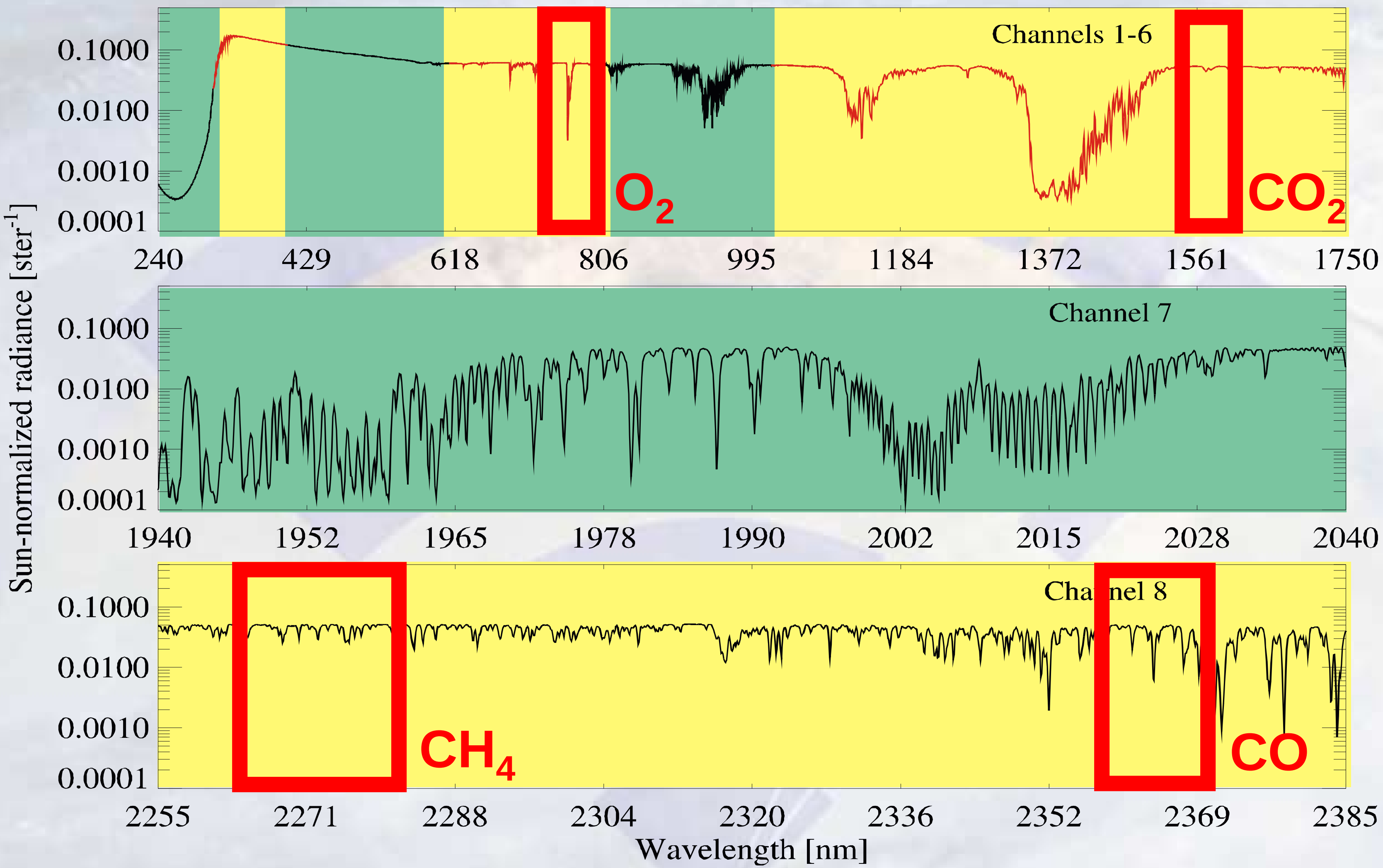
Where the Information comes from?

- ✓ **Trace gas concentrations**
  - **Absorption cross sections**
- ✓ **Pressure**
  - ***Line broadening of O_2, O_4 and CO_2 absorption***
  - ***Rayleigh scattering***
- ✓ **Temperature**
  - ***Line broadening of O_2, O_4 and CO_2 absorption***
  - ***Rayleigh scattering***
  - **Line strengths of CO_2 absorption**
  - **T dependent O_3 absorption in the UV**
- ✓ **Aerosol parameters**
  - **Aerosol scattering/absorption coefficients**
- ✓ **Tangent heights**
  - **Pressure, temperature**





SCIAMACHY nadir spectrum



SCIAMACHY vs. GOME

	GOME	SCIAMACHY
Measurement Modes		
Nadir	X	X
Limb		X
Solar Occultation		X
Lunar Occultation		X
Calibration Modes		
Solar Calibration	X	X
Lunar Calibration		X
WLS Calibration		X
SLS Calibration	X	X
Targeted Parameters		
Total Column	O_3, O_2, O_4, BrO, NO_2, OClO, SO_2, H_2CO, H_2O	O_3, O_2, O_4, BrO, OclO, SO_2, H_2CO, NO_2, NO_3, N_2O, CO, CO_2, CH_4, H_2O
Profiles	O_3	O_3, O_2, O_4, BrO, OClO, SO_2, H_2CO, NO, NO_2, NO_3, N_2O, CO, CO_2, CH_4, H_2O
Radiometric Accuracy Relative Absolut	 < 1% 2 – 4 %	 <1% 2 - 4%
Spectral Range	240 – 780 nm	240 – 2380 nm

Current Scientific Level 2 Product Status (August 03)

	column	profile (1)
O3		
NO2		
BrO		
SO2		X
H2CO		X
OClO		
H2O		
N2O		X
CO		
CH4		
CO2		

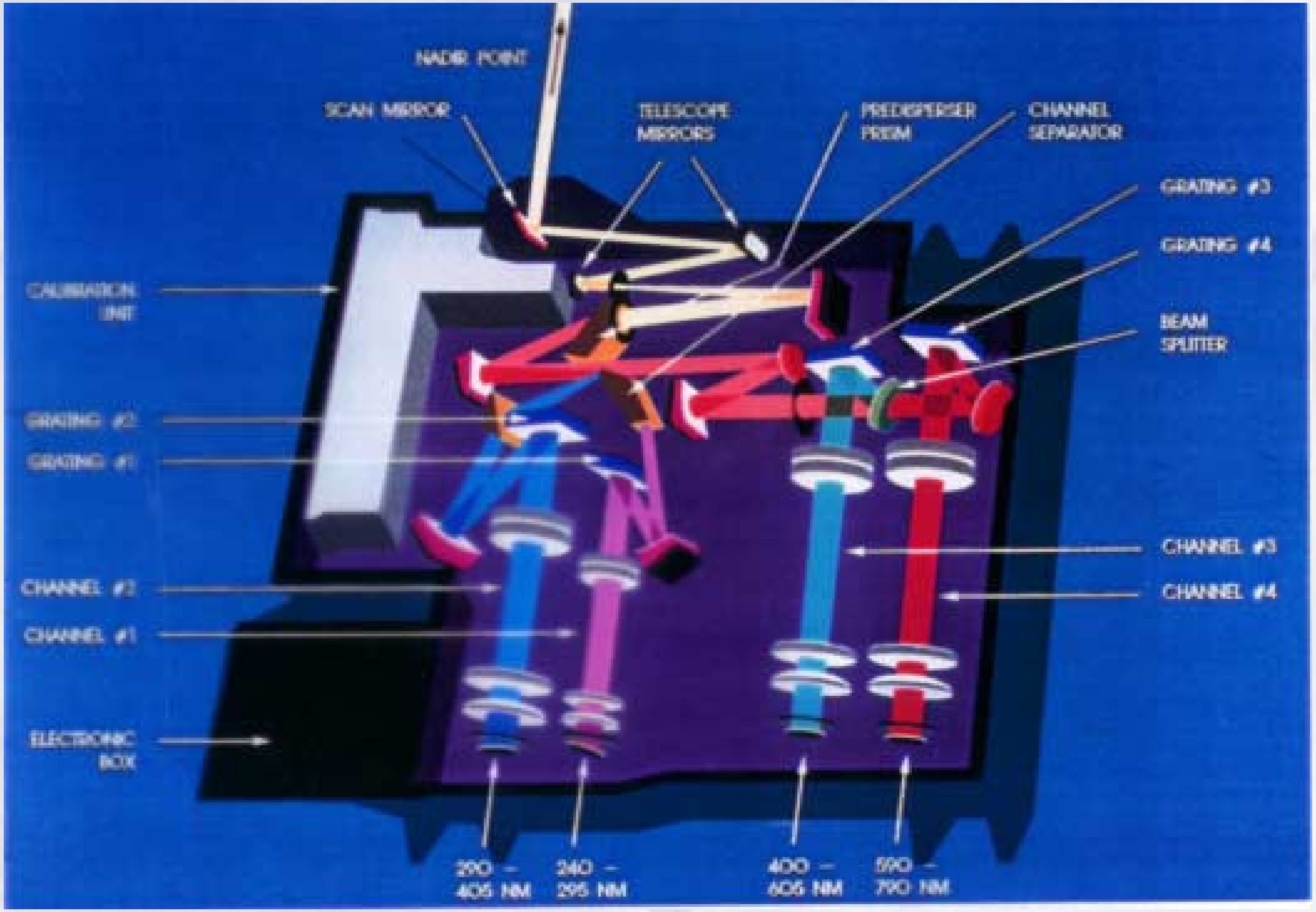
	Misc.
cloud frac	
cloud top	
AAI	
T/p profile	
AOD	
UV-index	
PSC/NLC	

X	= not applicable
	= not yet investigated
	= excellent to good results, partly affected by L1 qual.
	= first results, limited quality due to L1/calibration
(1)	= affected by tangent heigth anomaly
	= affected by ice channels 7 and 8

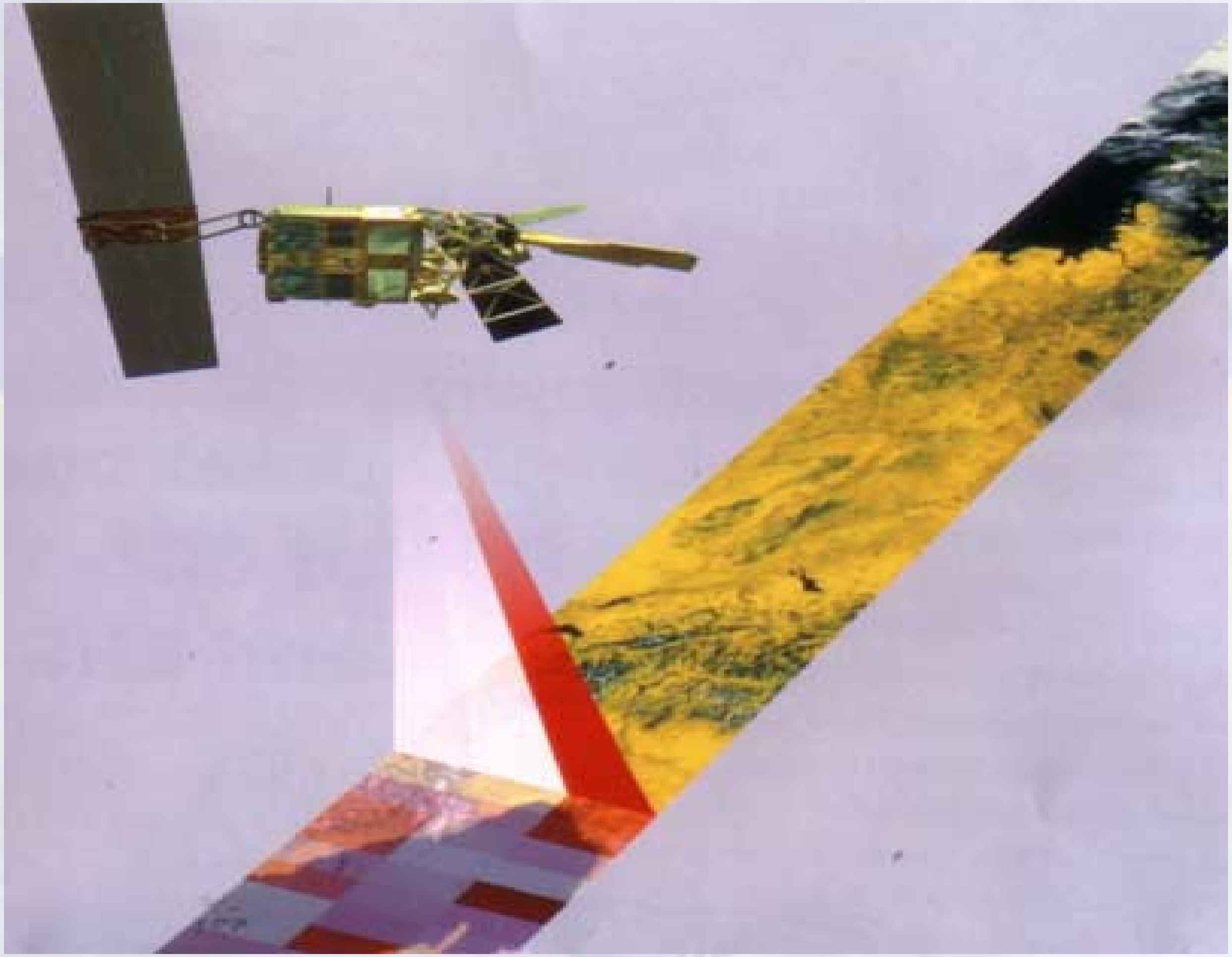
ERS-2 with GOME on board

- **Launched 20th of April 1995**
- **GOME has made 7 years of measurements**

Schematic of GOME Optical Layout



GOME Scan Pattern from ERS-2



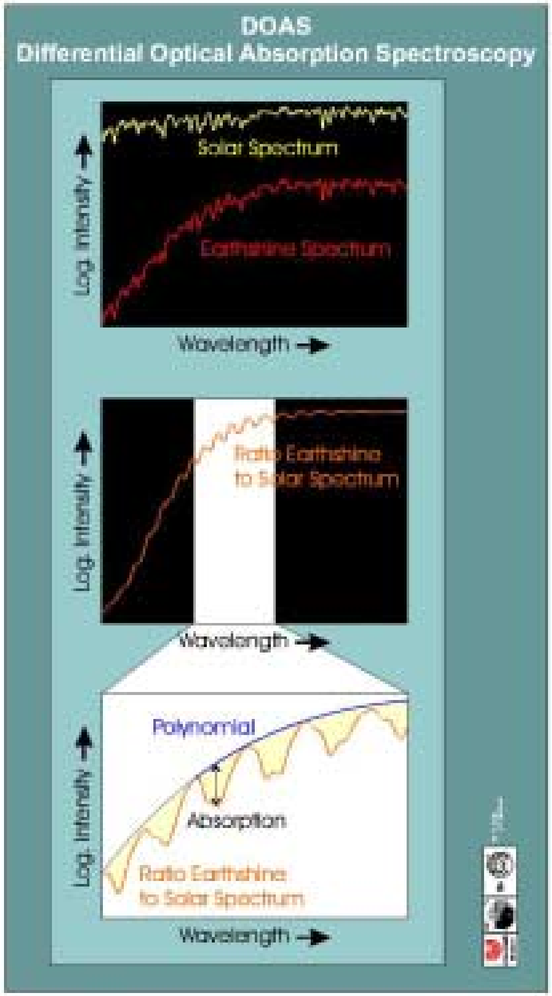
GOME: Solar Irradiance/Lunar Radiance Observations

Retrieval Principles

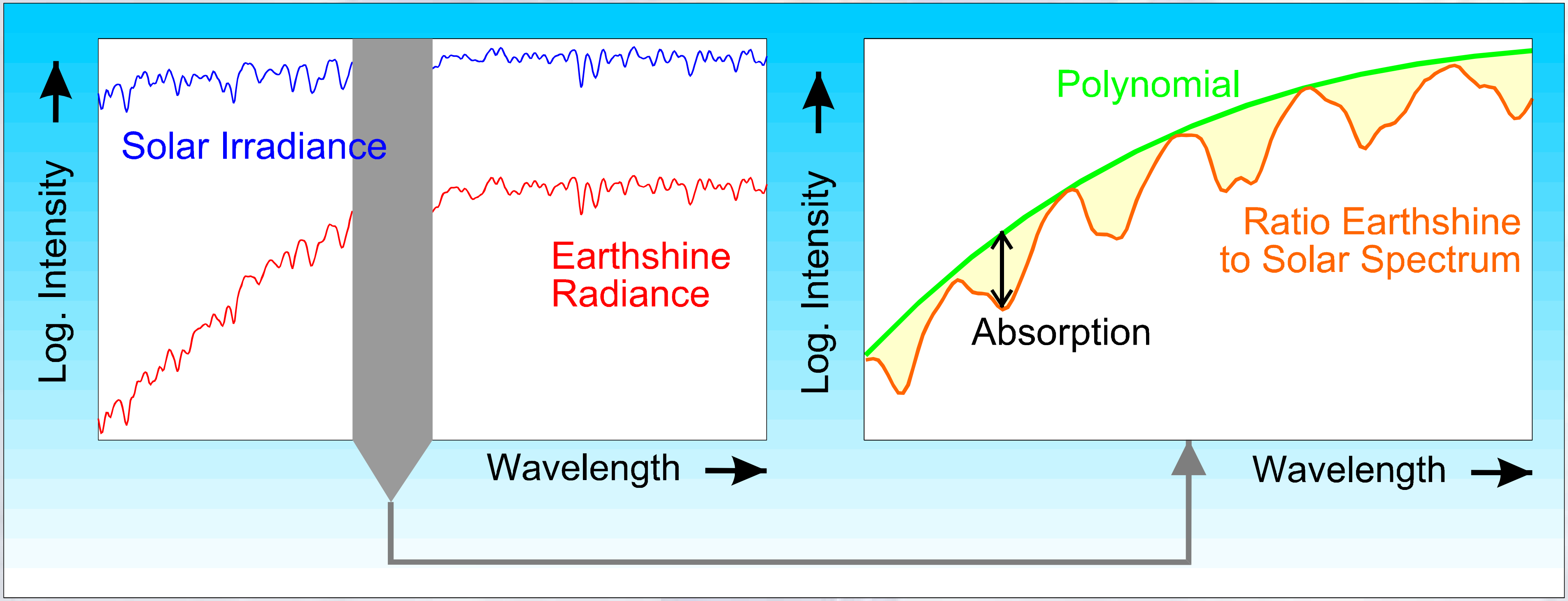
- **DOAS - Differential Optical Absorption Spectroscopy**

- **FURM – FUll Retreival Method**

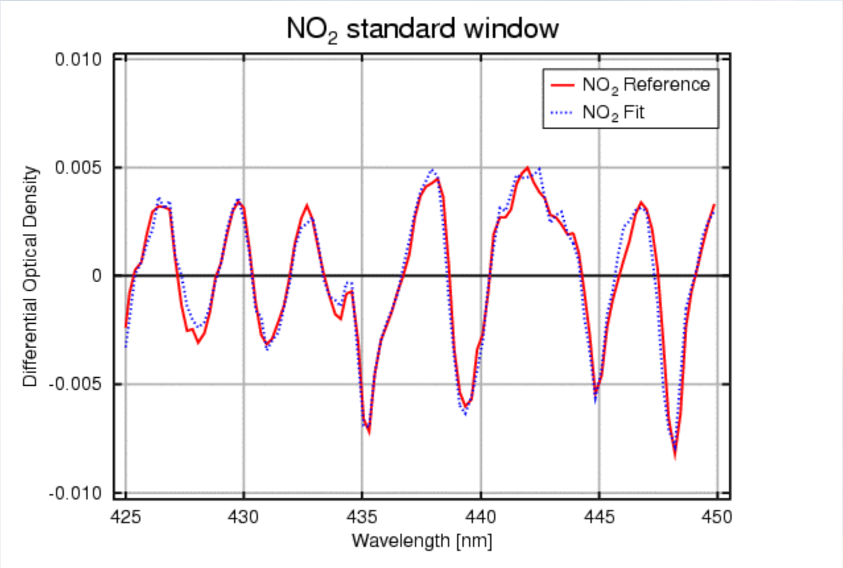
DOAS (1)

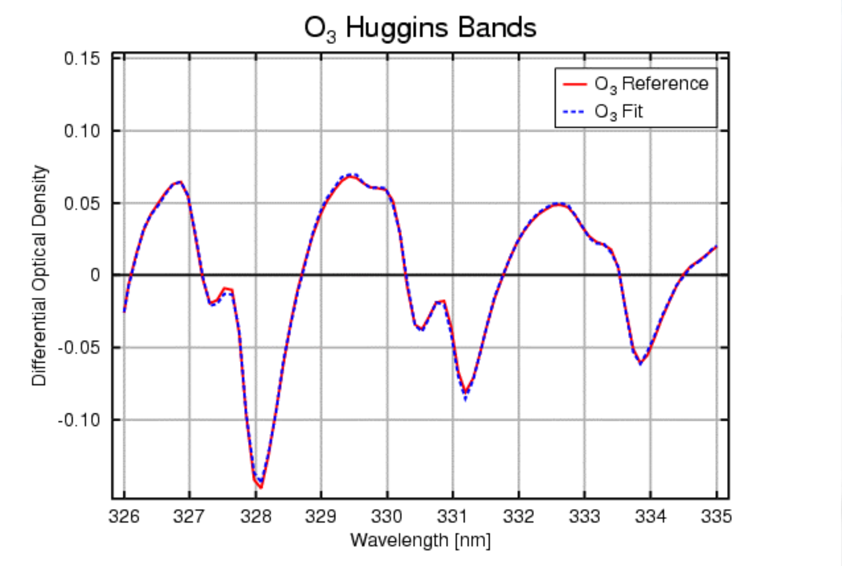

DOAS
Differential Optical Absorption Spectroscopy
Solar Spectrum
Earthshine Spectrum
Log. Intensity
Wavelength
Ratio Earthshine to Solar Spectrum
Log. Intensity
Wavelength
Polynomial
Absorption
Ratio Earthshine to Solar Spectrum
Log. Intensity
Wavelength

DOAS (2)


Log. Intensity
Solar Irradiance
Earthshine
Radiance
Wavelength
Polynomial
Log. Intensity
Ratio Earthshine
to Solar Spectrum
Absorption
Wavelength

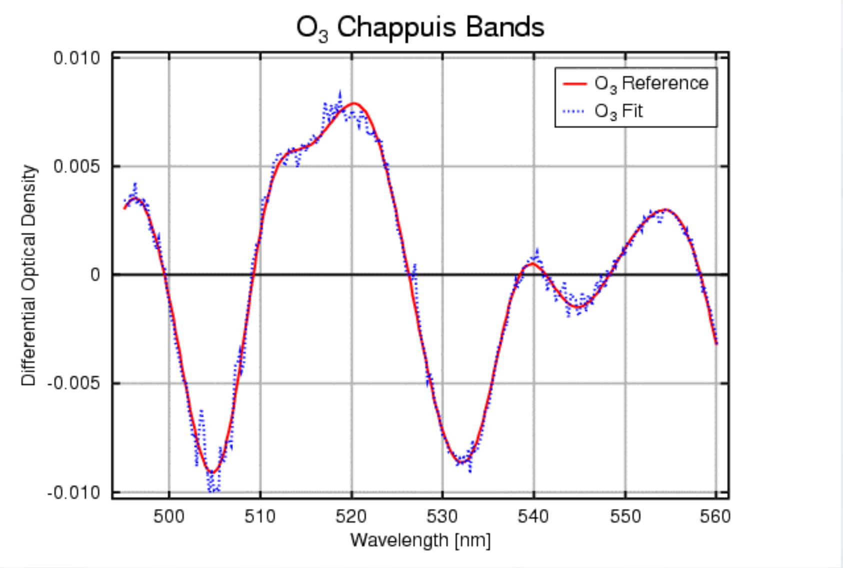
First SCIAMACHY Nadir Spectral Fits



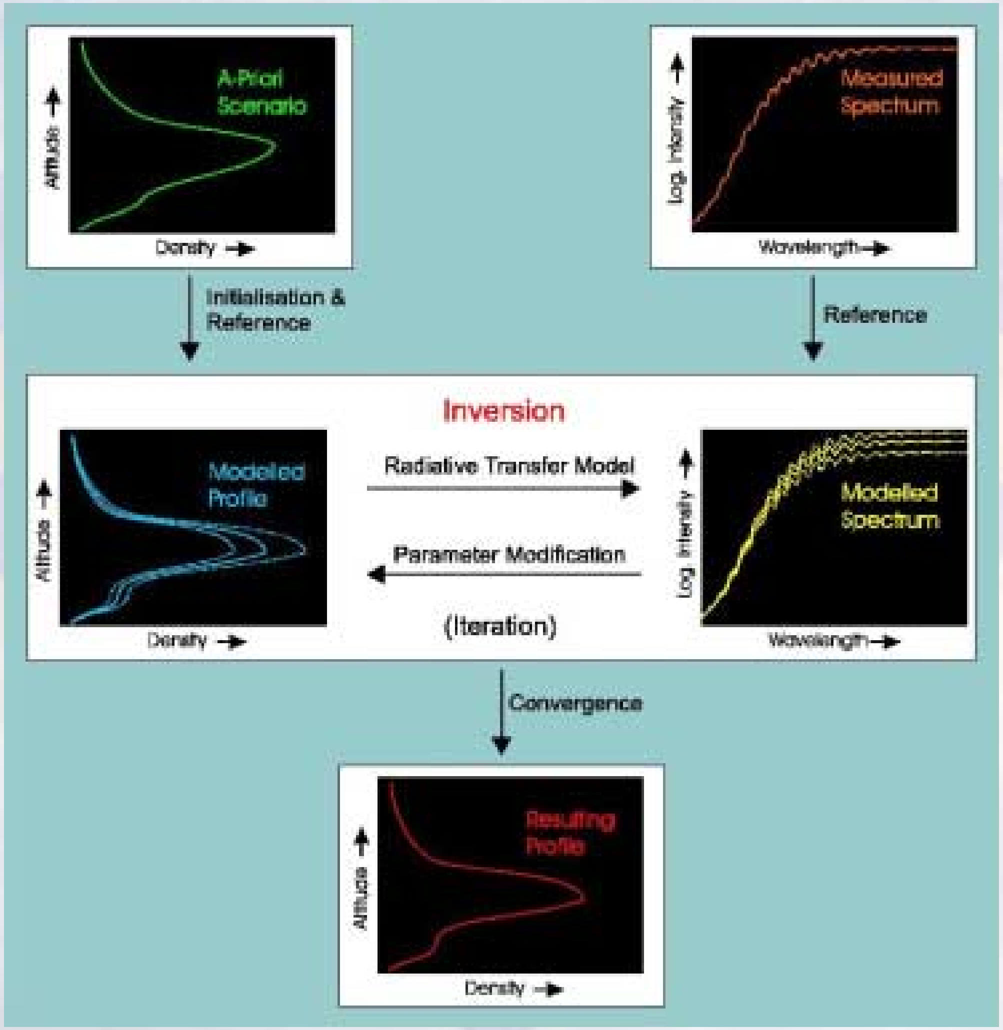


date: 20/06/2002
location: 67.6°N, 20°E
SZA: 80.5°
uncalibrated raw data (lv0)
DOAS analysis using GOME settings

Richter et al., 07 / 2002



FURM


A-Priori Scenario
Altitude
Density
Measured Spectrum
Log. Intensity
Wavelength
Initialisation & Reference
Reference
Inversion
Modelled Profile
Altitude
Density
Radiative Transfer Model
Parameter Modification
(Iteration)
Modelled Spectrum
Log. Intensity
Wavelength
Convergence
Resulting Profile
Altitude
Density

Summary of Lecture 1

- **Atmospheric Issues: the need for global data have been discussed.**
- **Orbit chocies: the advantages and disadvantages of LEO and GEO have been explained.**
- **The history of SCIAMACHY, GOME and GeoSCIA/GeoTROPE is described.**
- **The GOME Instrument has been discussed.**
- **DOAS discussed and the slant column shown.**