Principles of Atmospheric Remote Sensing
PME Air Quality Training Session

Thilo Erbertseder, Julian Meyer-Arnek
DLR

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

GAFAG

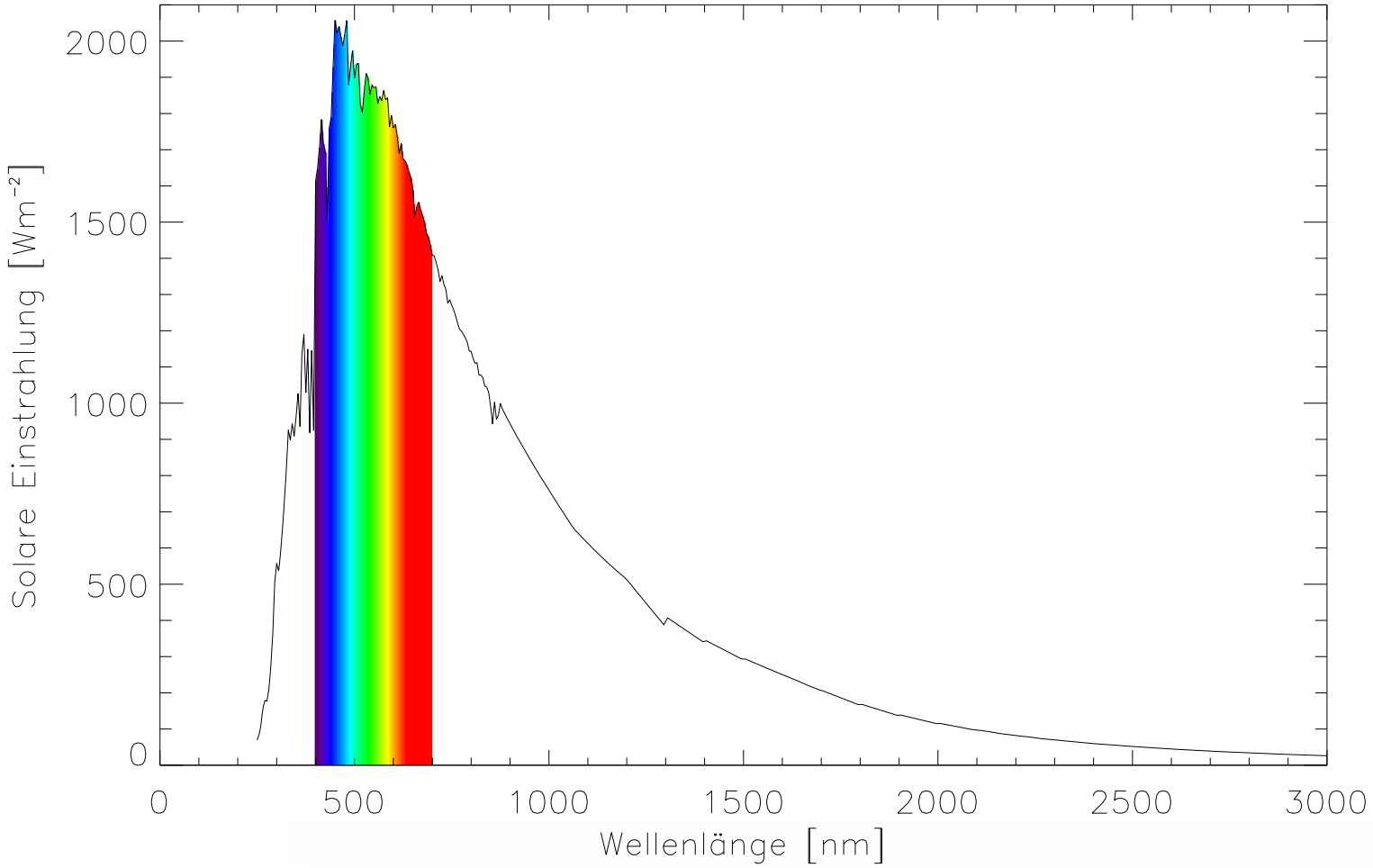
الرئاسة العامة للأرصاد وحماية البيئة
PRESIDENCY OF METEOROLOGY AND ENVIRONMENT (PME)

What is Remote Sensing?

- "*Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation*"
  (Lillesand and Kiefer 1987)

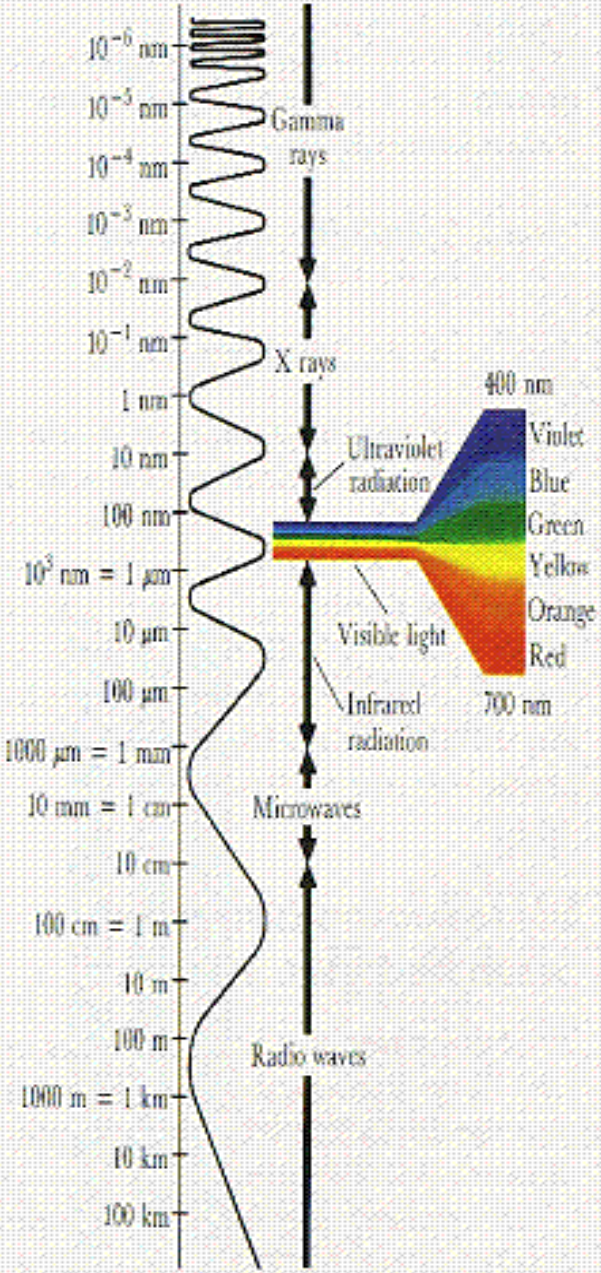
This is remote sensing…

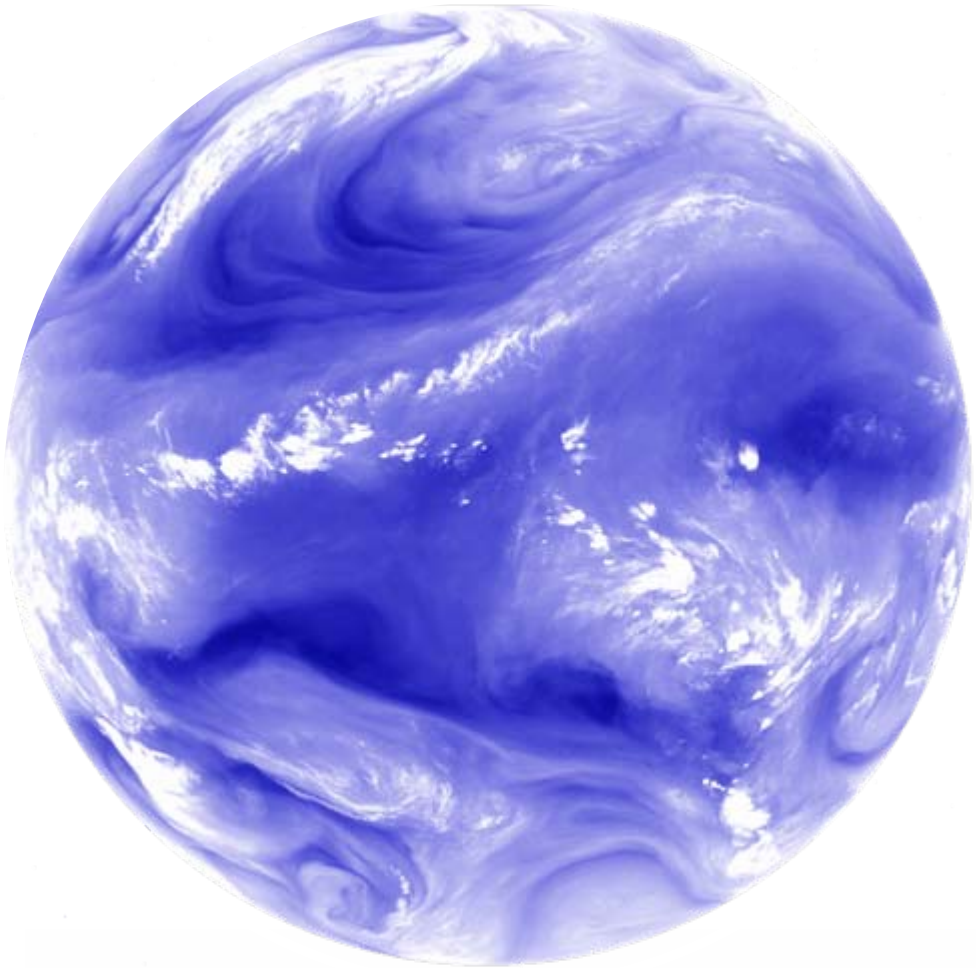
Solar Spectrum



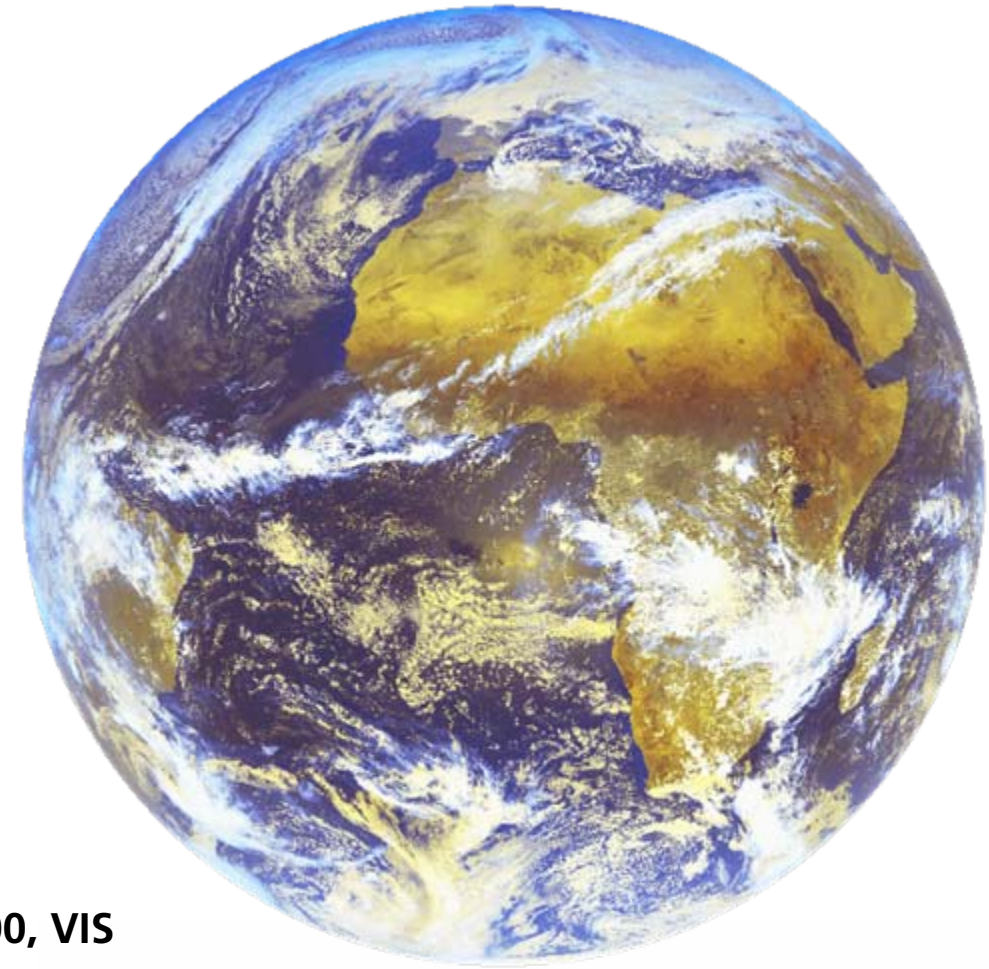
Wavelength Ranges in RS

- **UV:** some absorptions + profile information
  aerosols
- **VIS:** surface information (vegetation)
  some absorptions
  aerosol information
- **IR:** temperature information
  cloud information
  water / ice distinction
  many absorptions / emissions
  + profile information
- **MW:** no problems with clouds
  ice / water contrast
  surfaces
  some emissions + profile information



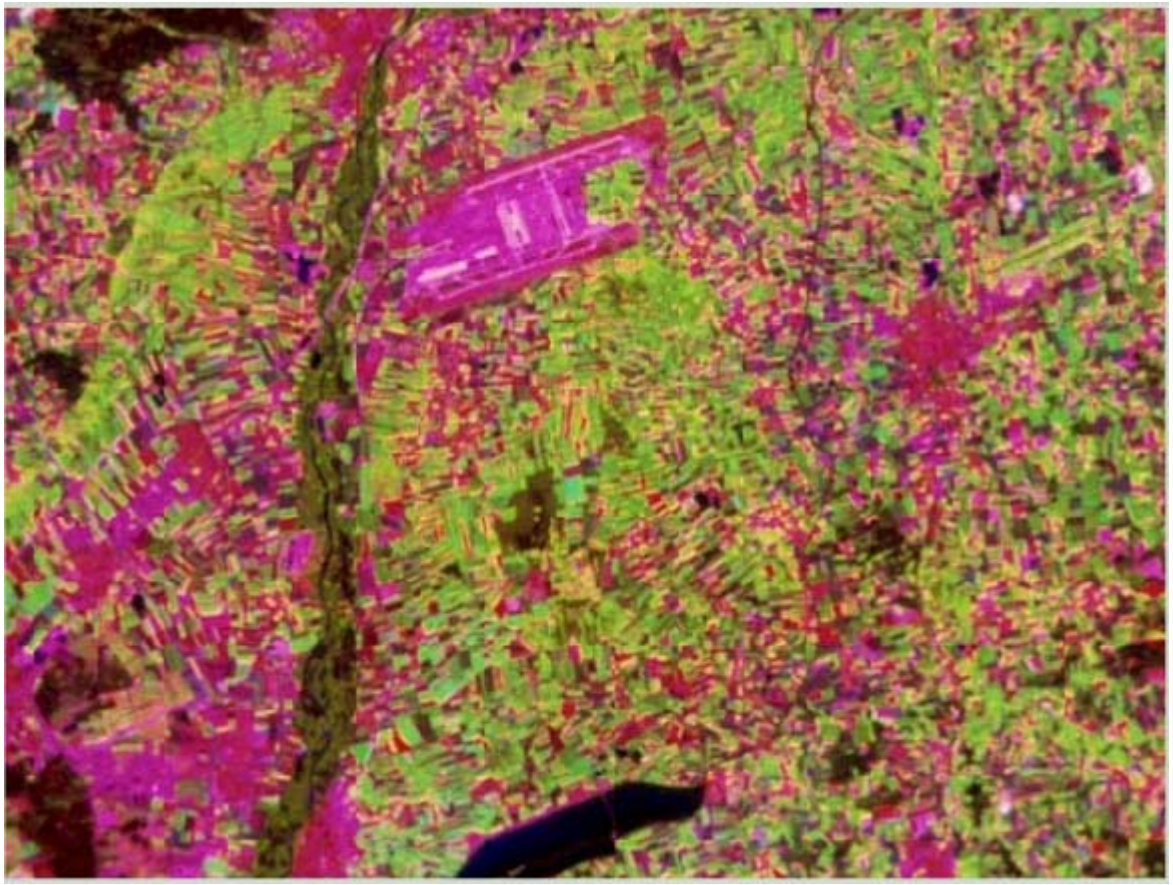


Meteosat

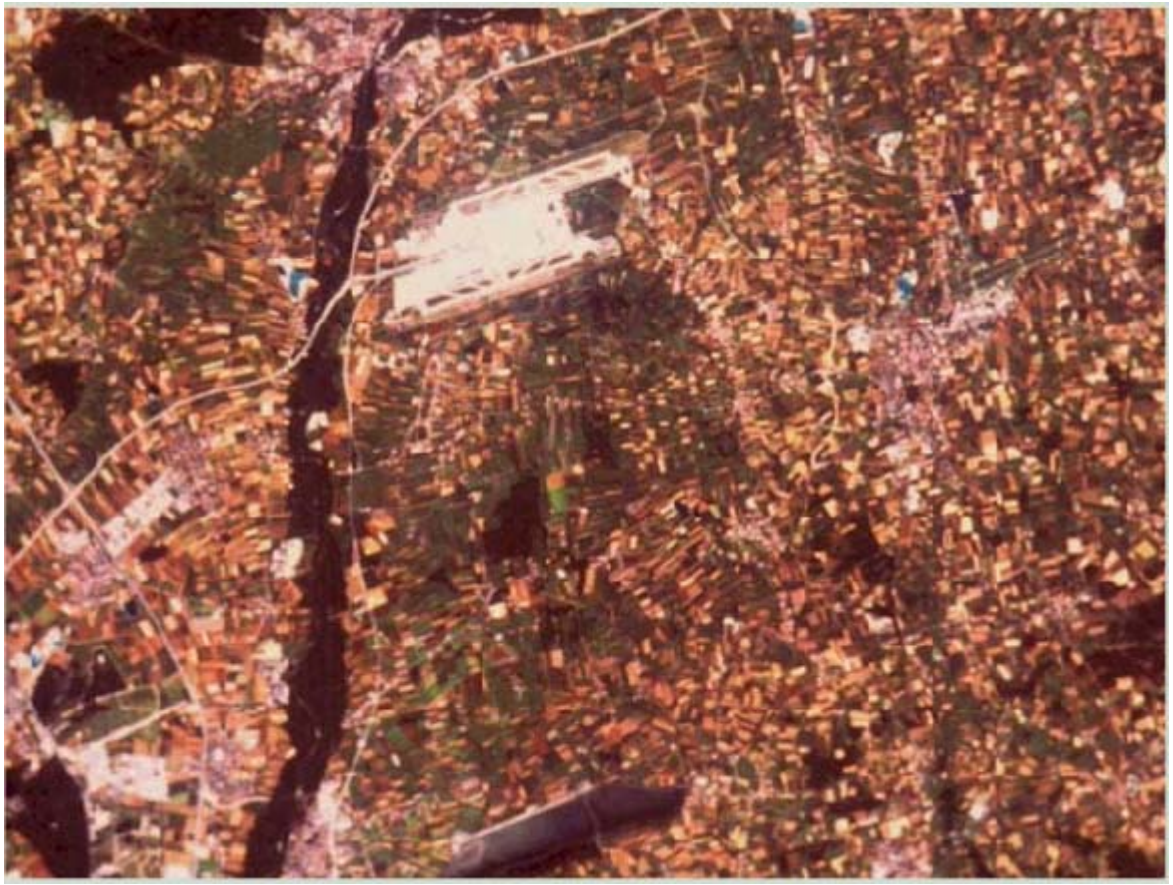


02.FEB 99, 12:00, VIS

Landsat



Landsat



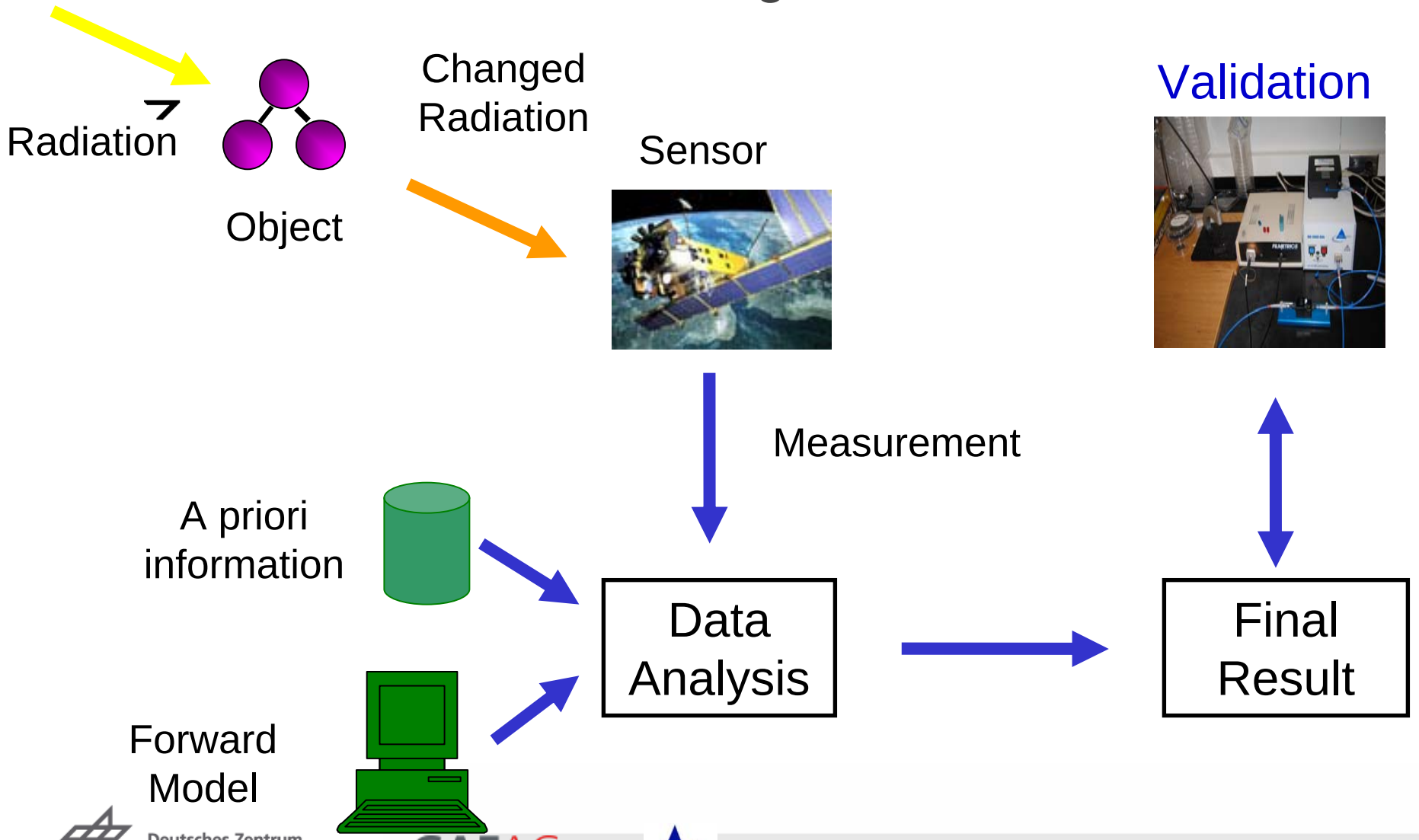
Why apply Remote Sensing?

- it gives us an insight to phenomena invisible to the human eye
- not all measurement locations are accessible (atmosphere, ocean)
- remote sensing facilitates creation of long time series and extended measurement areas
- for many phenomena, global or synoptic measurements are needed
- remote sensing measurements usually can be automated
- often, several parameters can be measured at the same time
- on a per measurement basis, remote sensing measurements usually are less expensive than in-situ measurements

Which Quantities can be Determined?

- **Chemical composition of the atmosphere**
  - trace species / pollutants
  - aerosol burden
  - aerosol type
- **Meteorology**
  - pressure
  - temperature
  - cloud cover
  - cloud top height
  - cloud type
  - lightning frequency
- **Surface**
  - height
  - albedo
  - vegetation type
  - surface (water) temperature
  - fires
  - surface roughness
  - wind speed
  - water turbidity / chlorophyll concentrations
  - ice cover
  - ice type

Scheme of Remote Sensing Observation



Classification of Remote Sensing Techniques

- active / passive
- platform
- wavelength range
- spectral resolution
  - low / medium / high
- spatial resolution
  - low / high
- detection technique
  - absorption, emission or extinction spectroscopy
  - spectral reflectance

Active vs. Passive Remote Sensing

Active Remote Sensing:

Artificial source of radiation, the reflected or scattered signal is analysed:

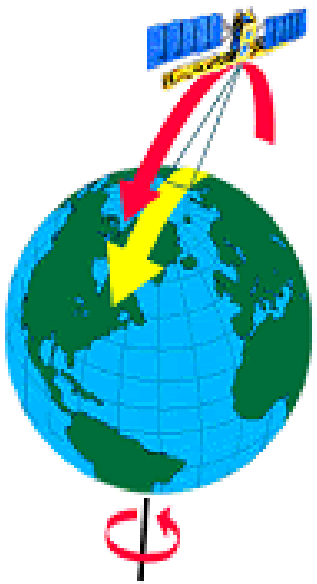
- sound: SONAR
- radio waves: RADAR (**RA**dio **D**etection **A**nd **R**anging)
- laser light: LIDAR (**LI**ght **D**etection **A**nd **R**anging)

Passive Remote Sensing:

Natural sources of radiation, the attenuated, reflected, scattered, or emitted radiation is analysed:

- solar light
- lunar light
- stellar light
- thermal emission

Satellite Orbits I



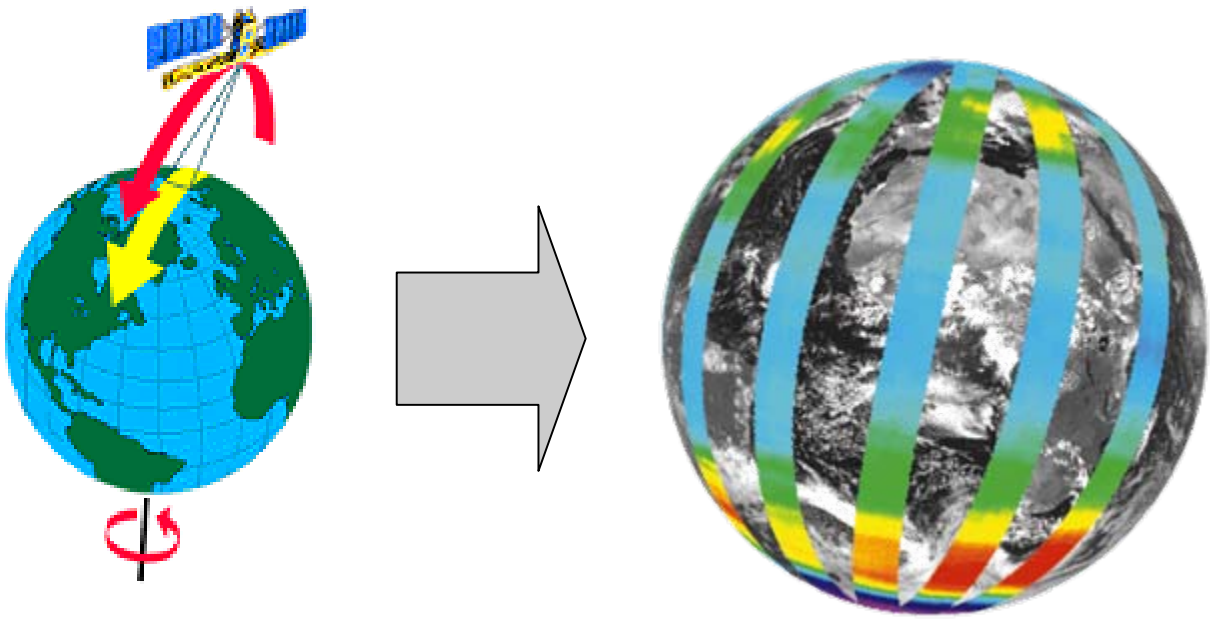
(Near) Polar Orbit:

- orbits cross close to the pole
- global measurements are possible
- low earth orbit LEO (several 100 km)
- ascending and descending branch
- special case: **sun-synchronous orbit:**
  - overpass over given latitude always at the same local time, providing similar illumination
  - for sun-synchronous orbits: day and night branches

http://www2.jpl.nasa.gov/basics/bsf5-1.htm

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter2/chapter2_2_e.html

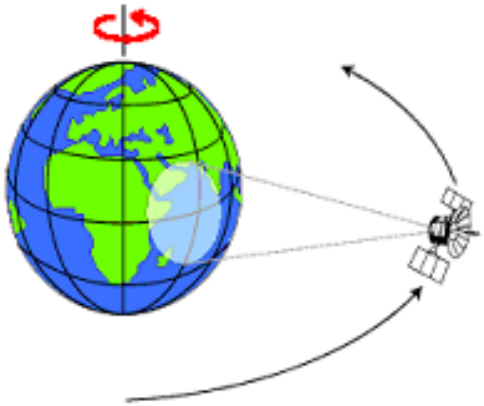
Satellite Orbits I



http://www2.jpl.nasa.gov/basics/bsf5-1.htm

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter2/chapter2_2_e.html

Satellite Orbits II



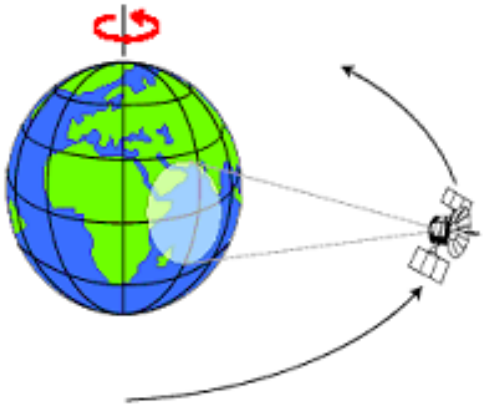
Geostationary Orbit:

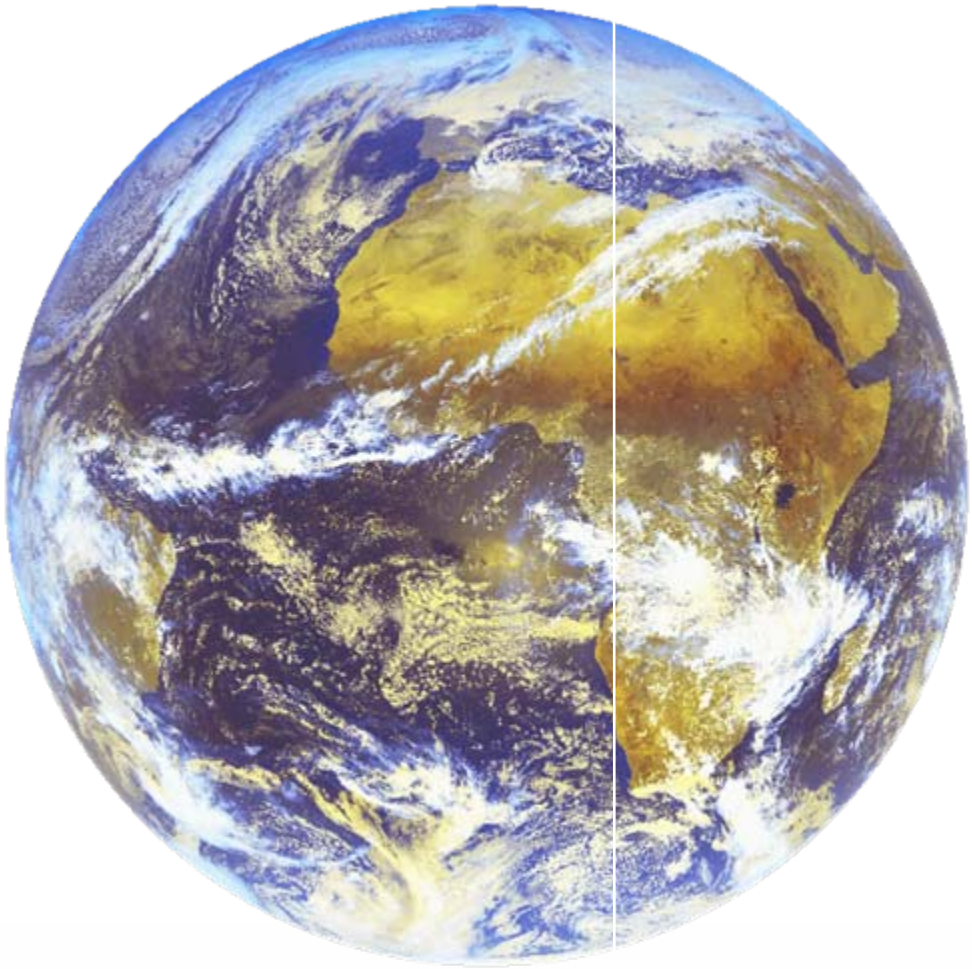
- satellite has fixed position relative to the Earth
- parallel measurements in a limited area from low to middle latitudes
- 36 000 km flight altitude, equatorial orbit

http://www2.jpl.nasa.gov/basics/bsf5-1.htm

http://www.ccrs.nrcan.gc.ca/ccrs/learn/tutorials/fundam/chapter2/chapter2_2_e.html

Meteosat



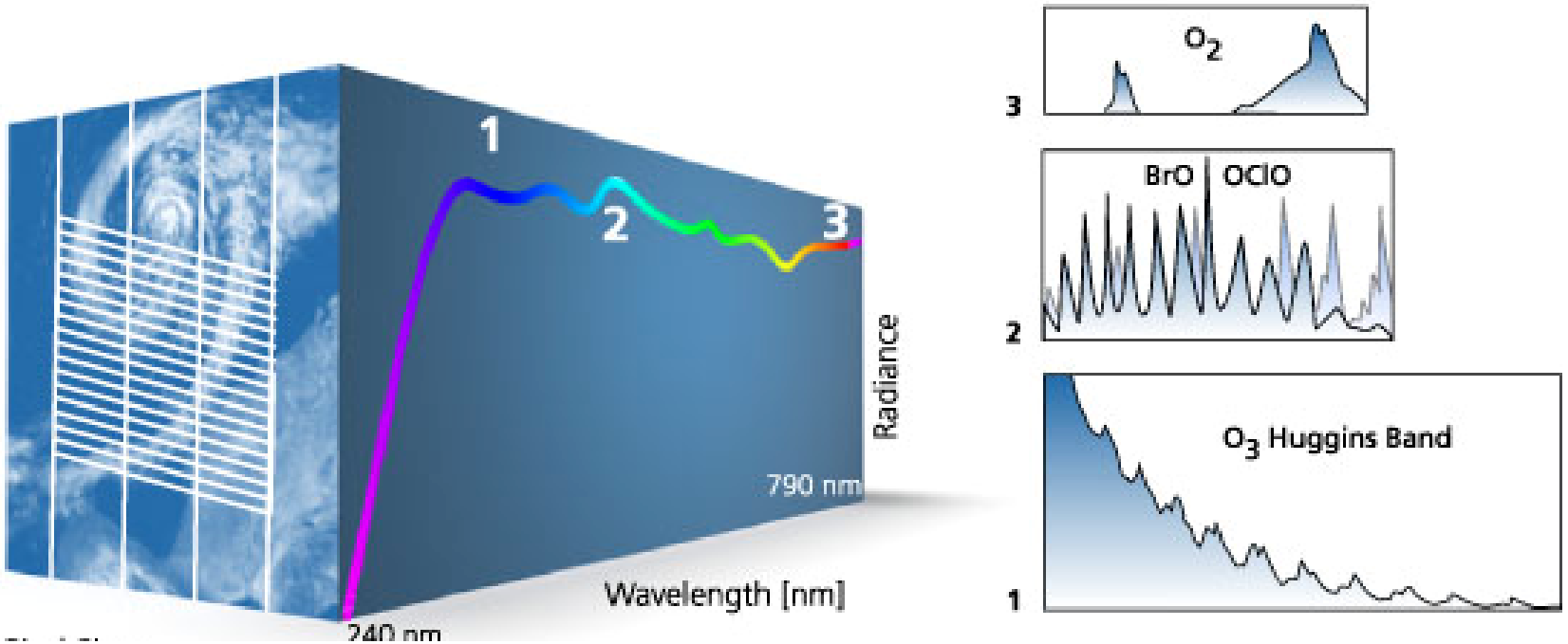


02.FEB 99, 12:00, VIS

Which Quantities are Measured?

- absolute intensities in dedicated wavelength intervals
- intensities relative to the intensity of a reference source
- ratios of intensities at different wavelengths
- variations of intensities
- degree of polarisation

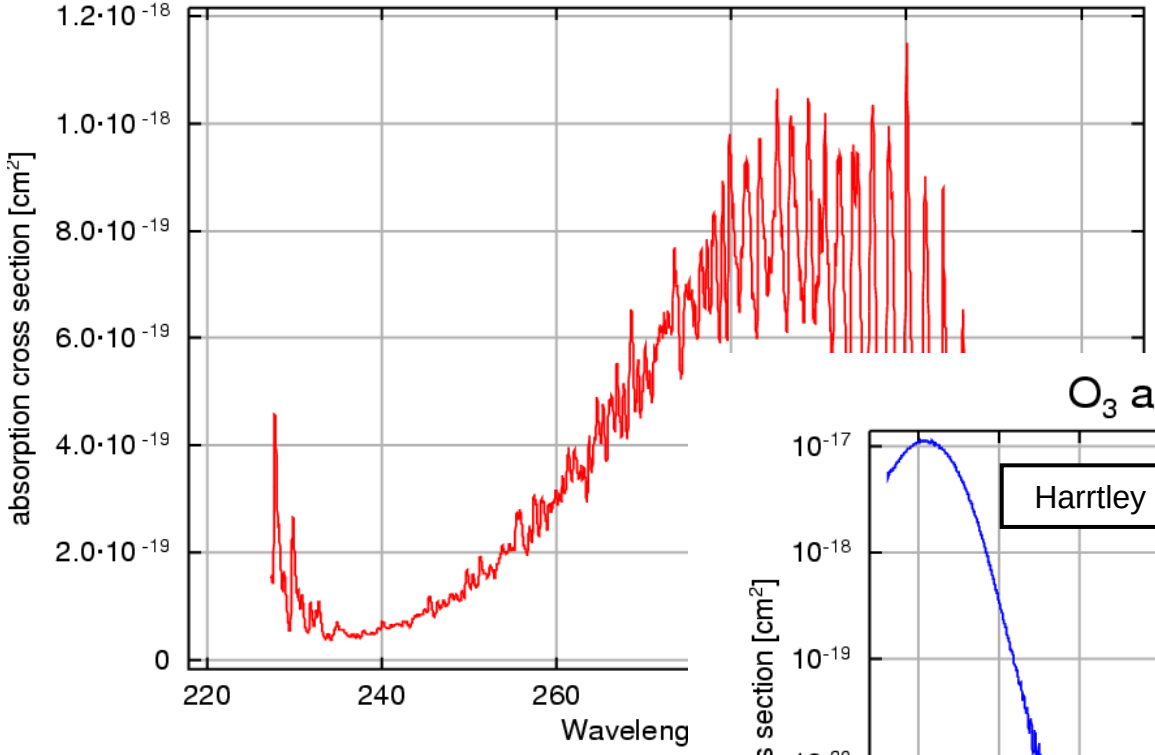
Atmospheric Spectroscopy



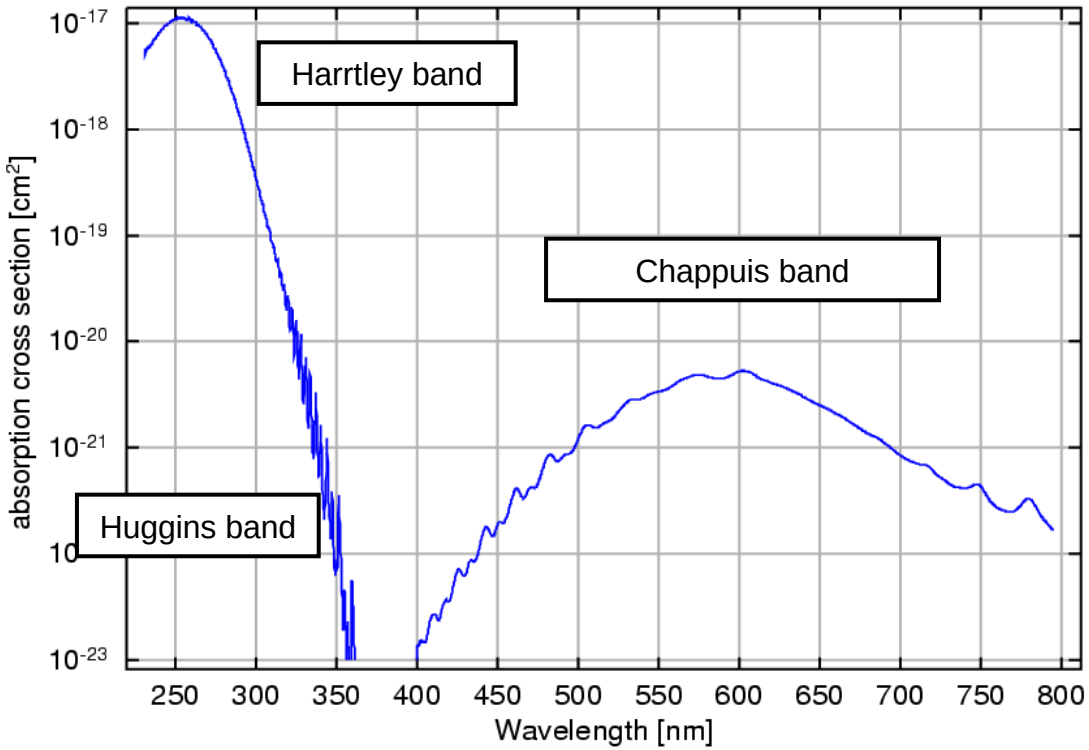
Absorption

$$I(s) = I(0)\exp\left(-\int_0^s k_a(s')ds'\right)$$

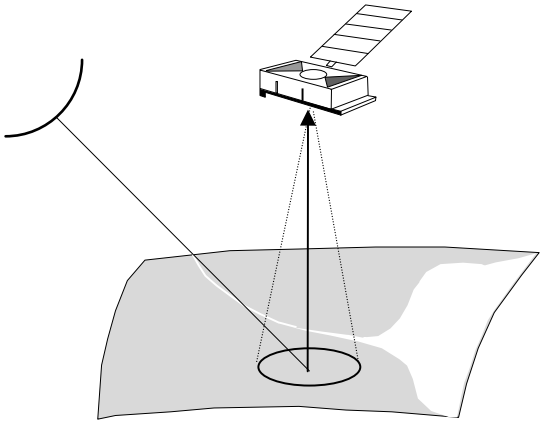
SO_2 absorption cross-sections



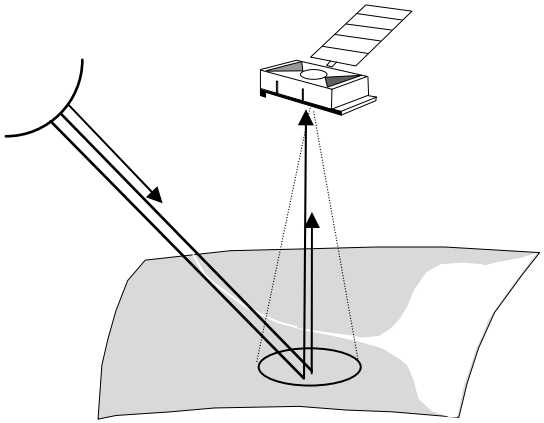
O_3 absorption cross sections



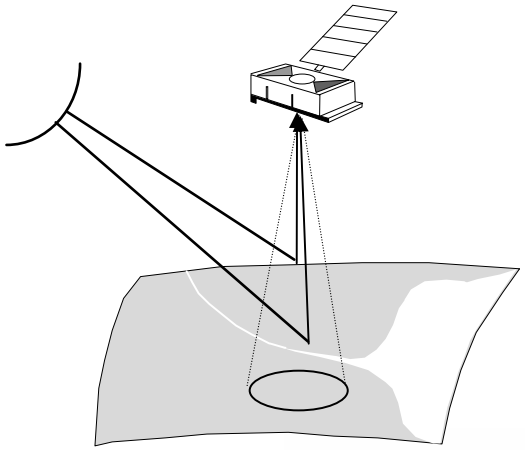
Radiative Transfer in the Atmosphere



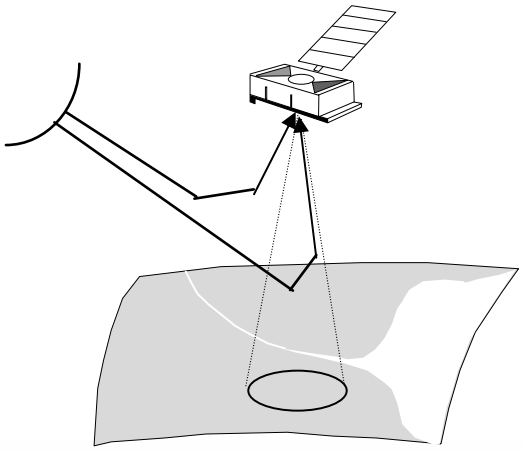
Direct radiation



Absorption

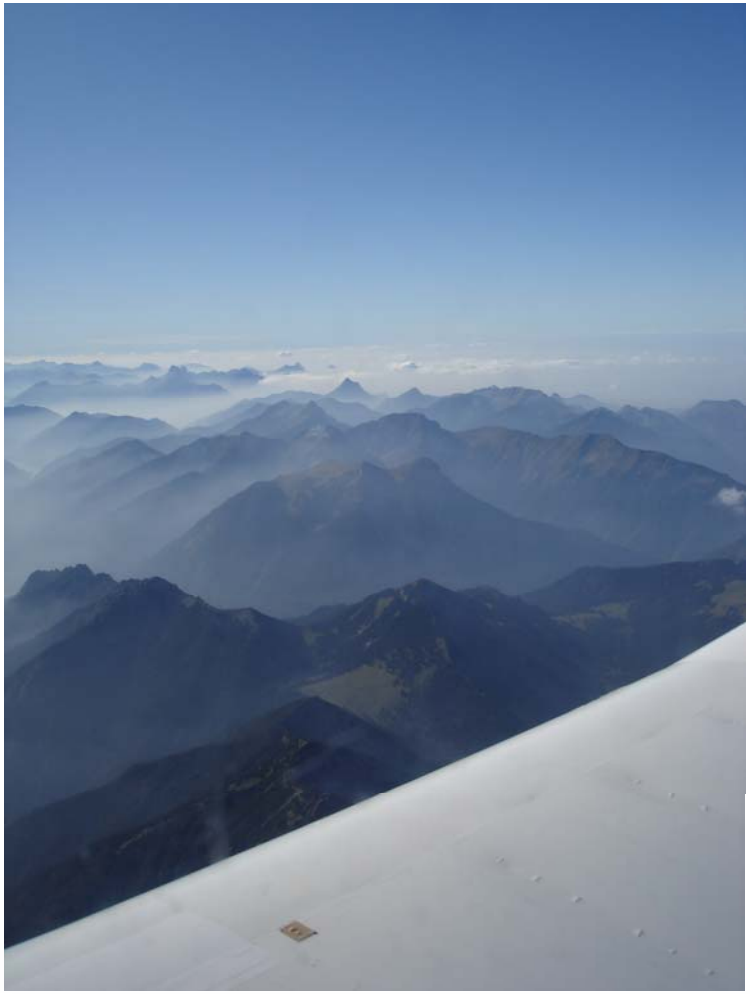


Single Scattering



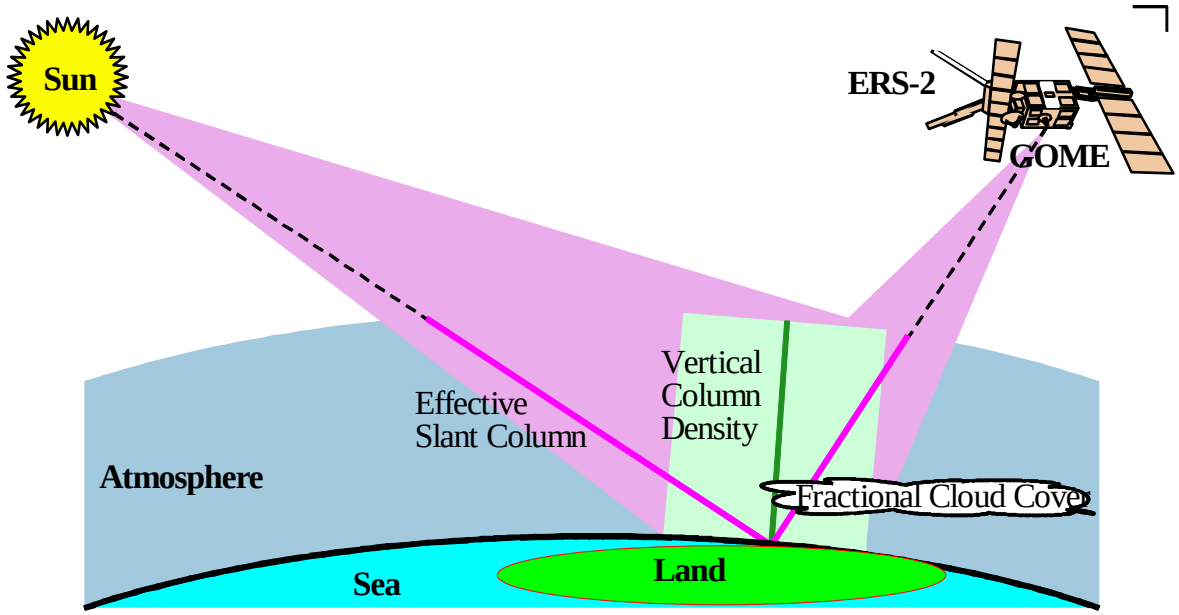
Multiple Scattering

Radiative Transfer in the Atmosphere

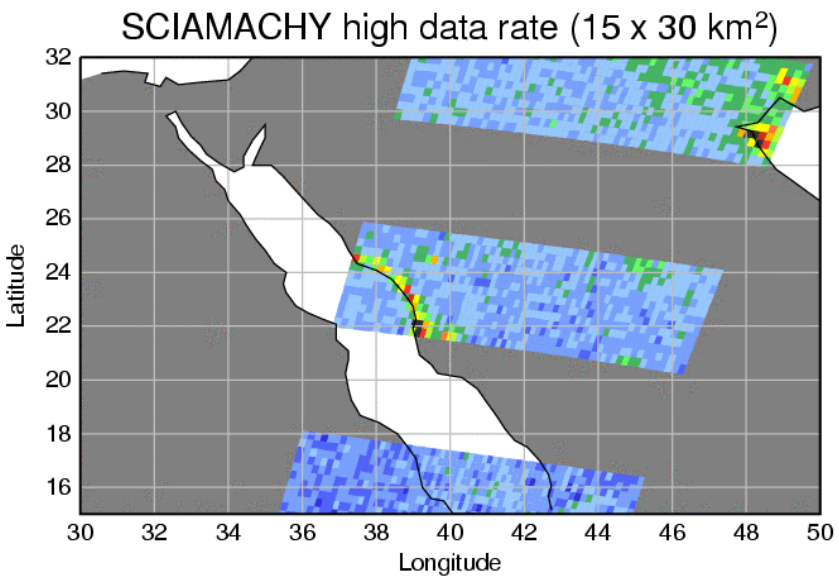


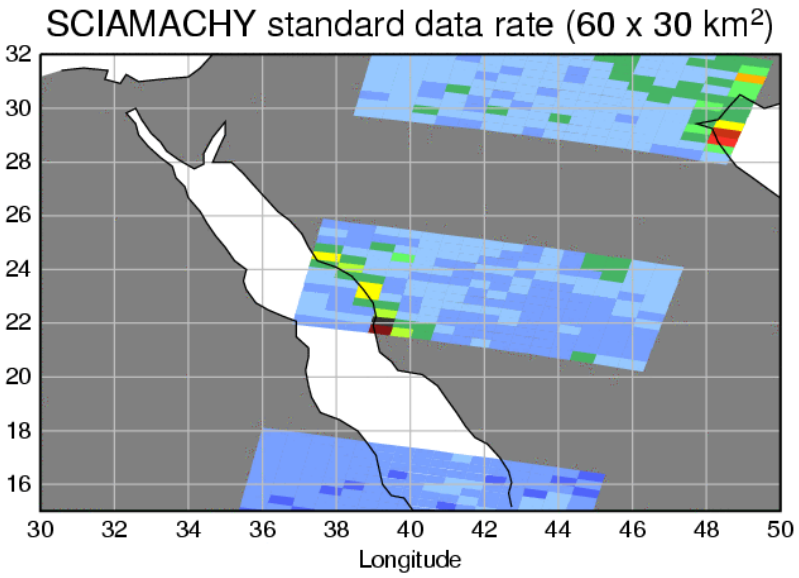
Atmospheric Spectroscopy

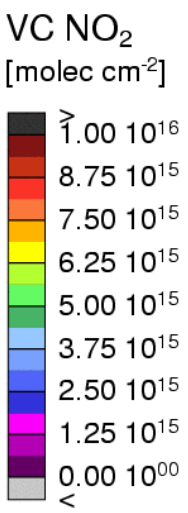
We measure the slant column but we need the vertical column

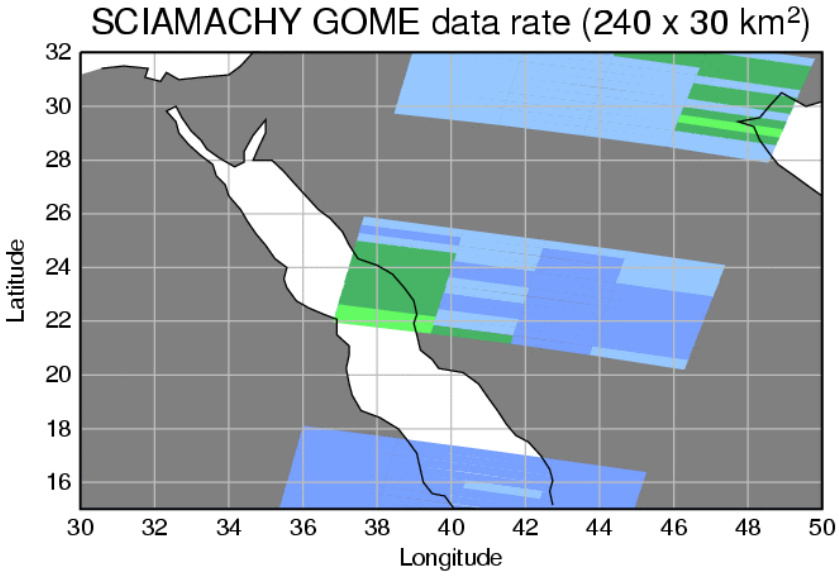


Effect of spatial resolution on air pollutant observations

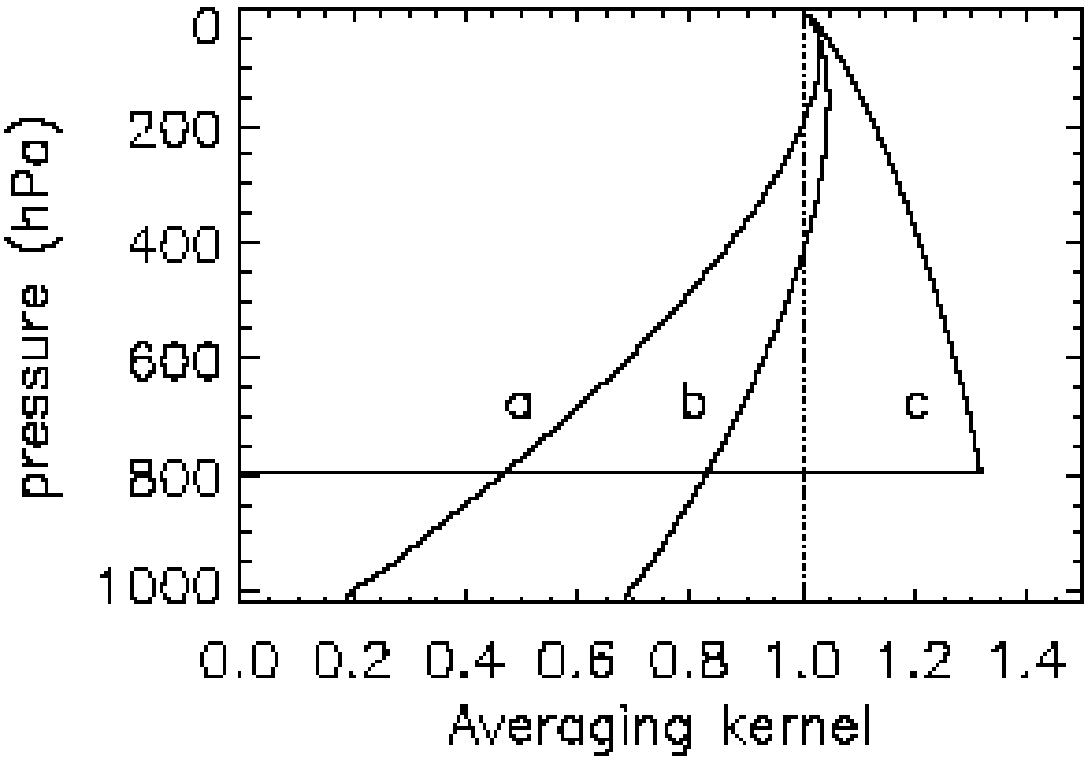






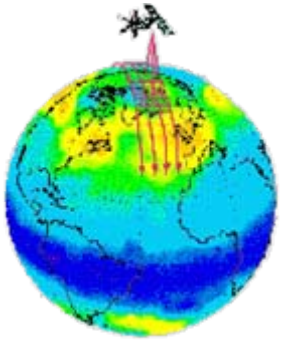


Sensitivity of RS to air pollutants at the surface

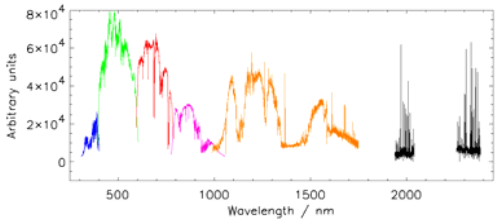


Pollutant	Sensor	Spatial resolution	Temporal resolution*	Representation of surface concentrations
NO2	MetOp/GOME-2	40x80km²	daily	Yes
NO2	ENVISAT/SCIAMACHY	30x60km²	Every 6 days	Yes
NO2	AURA/OMI	13x24 km²	Daily	Yes
PM10	MetOp/GOME-2/AVHRR	40x80km²	Daily	Yes
PM10	ENVISAT/SCIAMACHY/ AATSR	30x60km²	every 6 days	Yes
PM10	MERIS	1x1km²	Daily	Yes
PM10	MODIS	1x1km²	Daily	Yes
PM2.5	ENVISAT/SCIAMACHY/ AATSR	30x60km²	Every 6 Days	Yes
Aerosoltype	ENVISAT/SCIAMACHY/ AATSR	30x60km²	Every 6 Days	Yes
Aerosoltype	MetOp/GOME-2/AVHRR	40x80km²	Daily	Yes
SO2	MetOp/GOME-2	40x80km²	Daily	Yes (not during volcanic eruptions
SO2	AURA/OMI	13x24 km²	Daily	Yes (not during volcanic eruptions
CO	MOPITT	22x22km²	Daily	Unterste 4km
O3	GOME-2	40x80km²	Daily	Nein

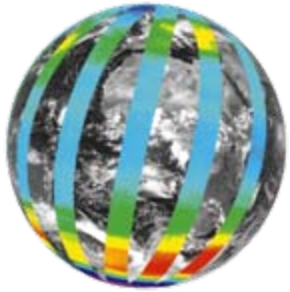
Processing chain in near-real-time



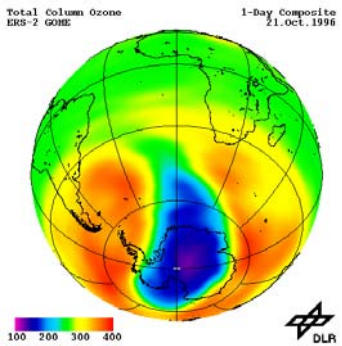
Data Reception
Level - 0



Calibration
Level - 1



Radiative Transfer Modeling
Level - 2



Data Assimilation Analysis and Forecasting
Level - 3 / 4

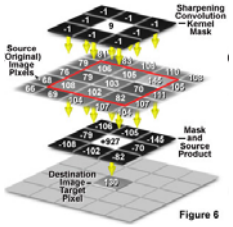
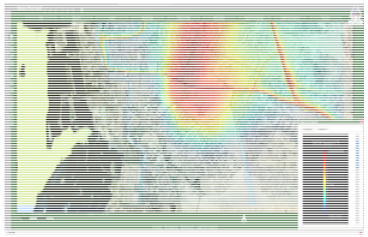


Image Processing and Mapping



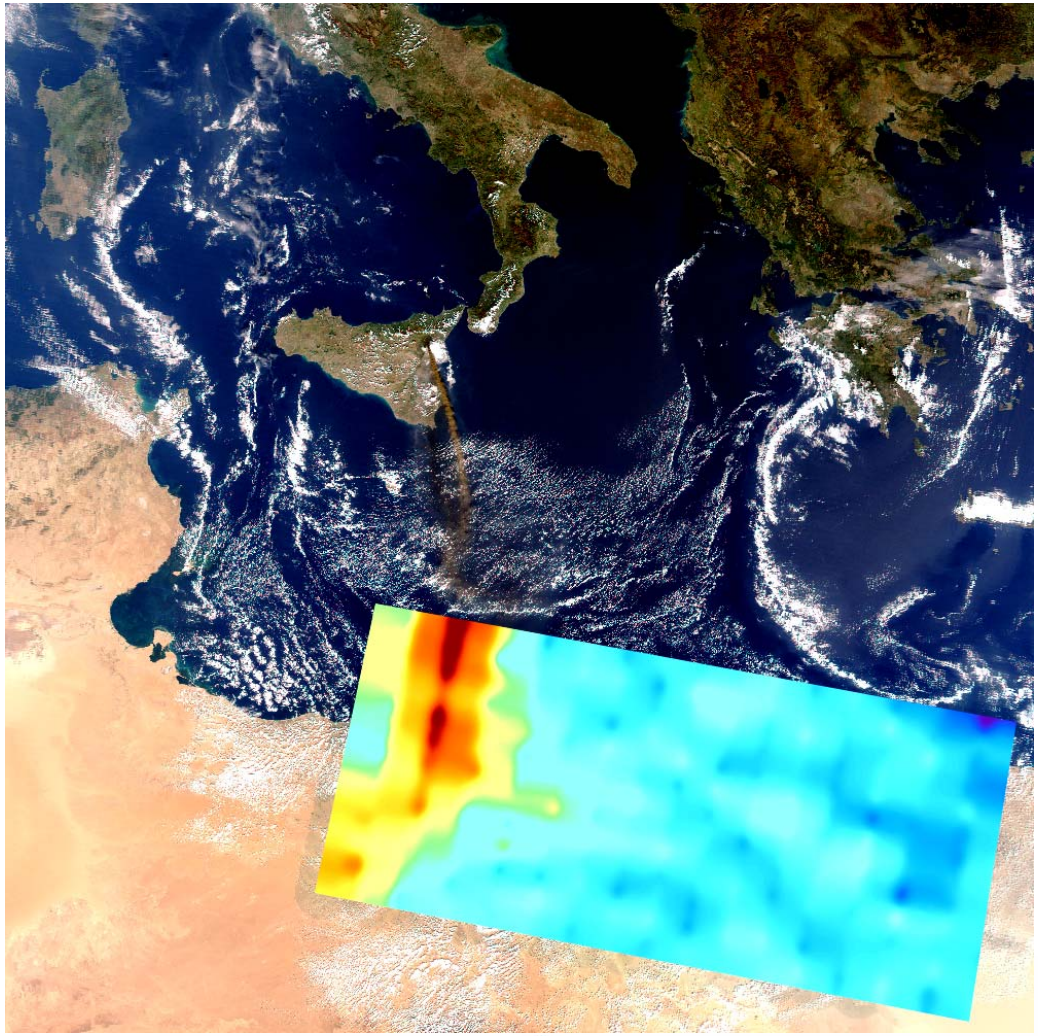
Publishing in Geoportal

Sadychev / Siberia
Photo taken from International Space Station (ISS)

Atmospheric Monitoring of Volcanic Activity from Space

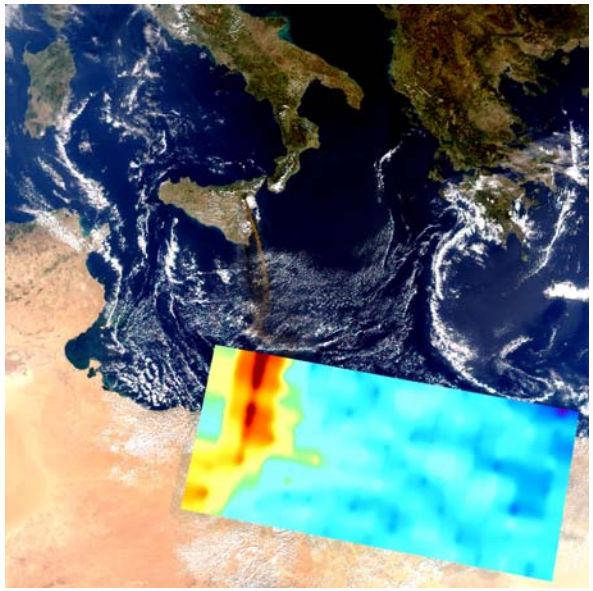
MODIS: July 24th 2001

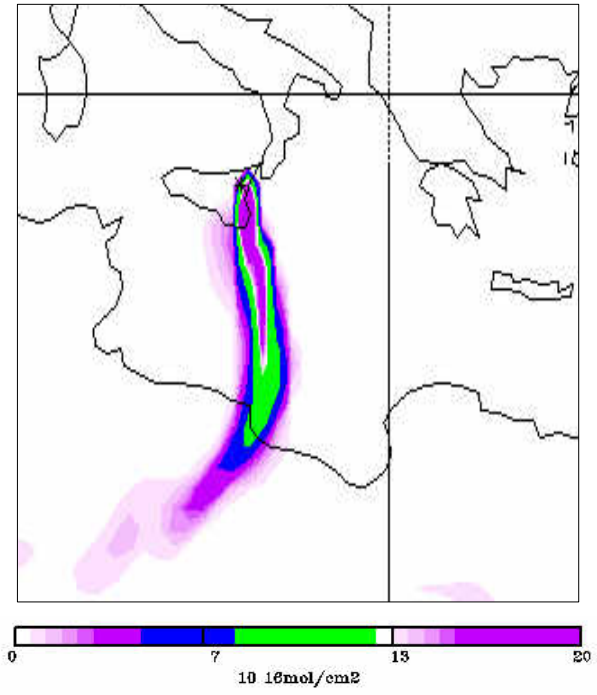
Mt. Etna



SO2 SCIAMACHY
+ MERIS:
29th October 2002

Mt. Etna





SCIA: SO2 / MERIS: VIS

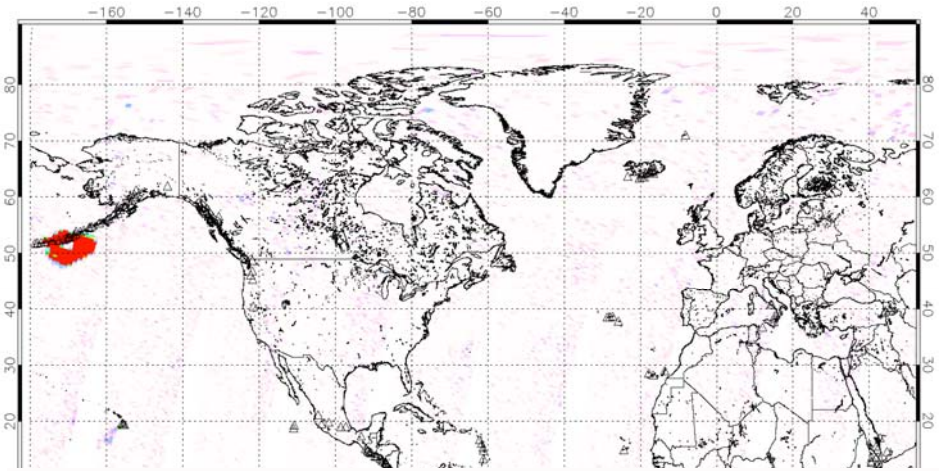
Particle Dispersion

Volcanic SO2: Kasatochi eruption (07-08-2008)

- Kasatochi Island:
- (Aleuten, Alaska)
- Area: 5 qkm
- Crater lake (~ 1km diameter)
- Recent eruption: 07/08/2008

Volcanic SO2: Kasatochi eruption (07-08-2008)

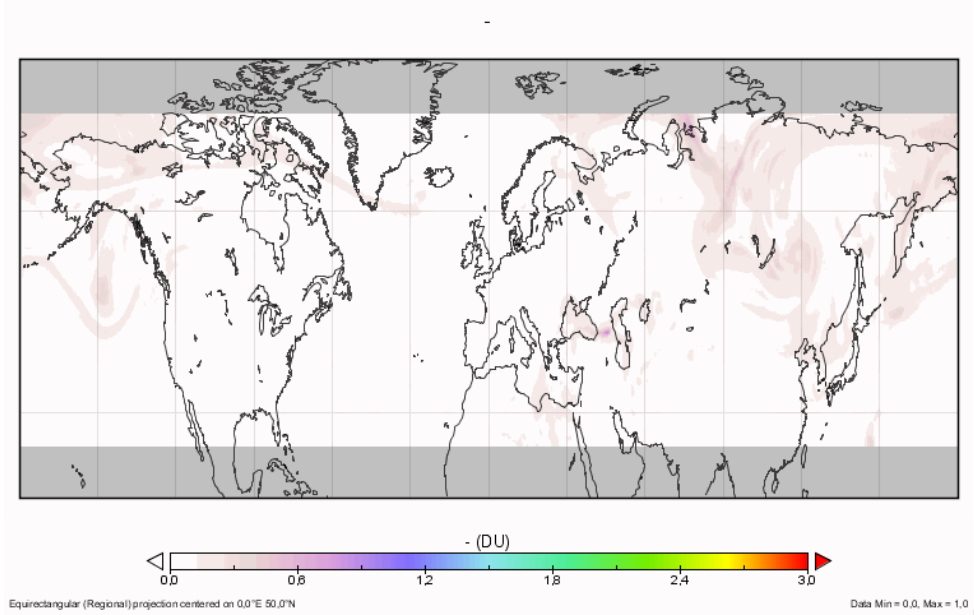
Observation of the long-range transport of SO2 by GOME-2 and OMI
(start: 08-08-2008, end: 24-08-2008)



Modelling of the dispersion

Model: FLEXPART

(Stohl et al., 2005,*Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2*, Atmos.Chem.Phys,5,2461-2474)

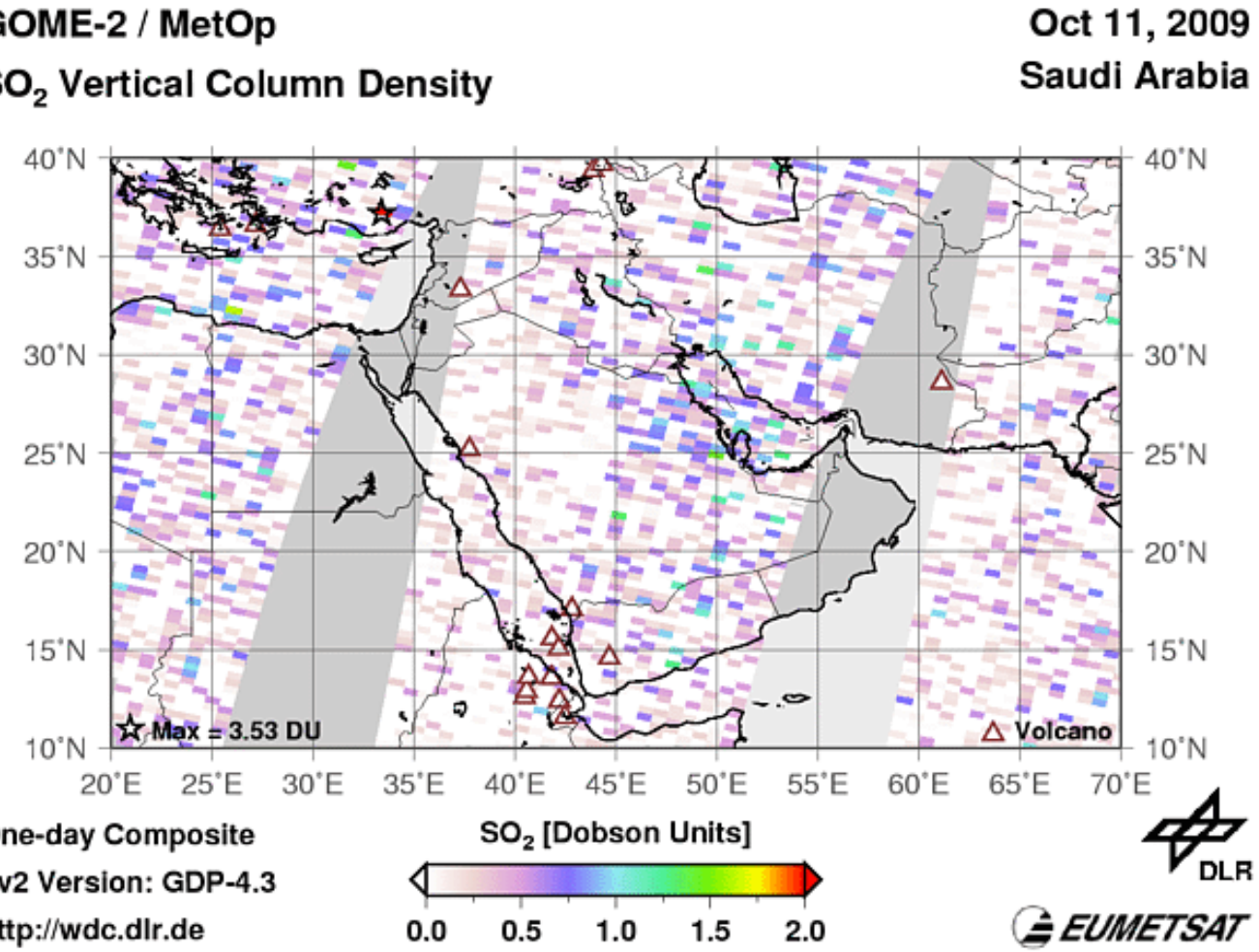


MetOp/GOME-2

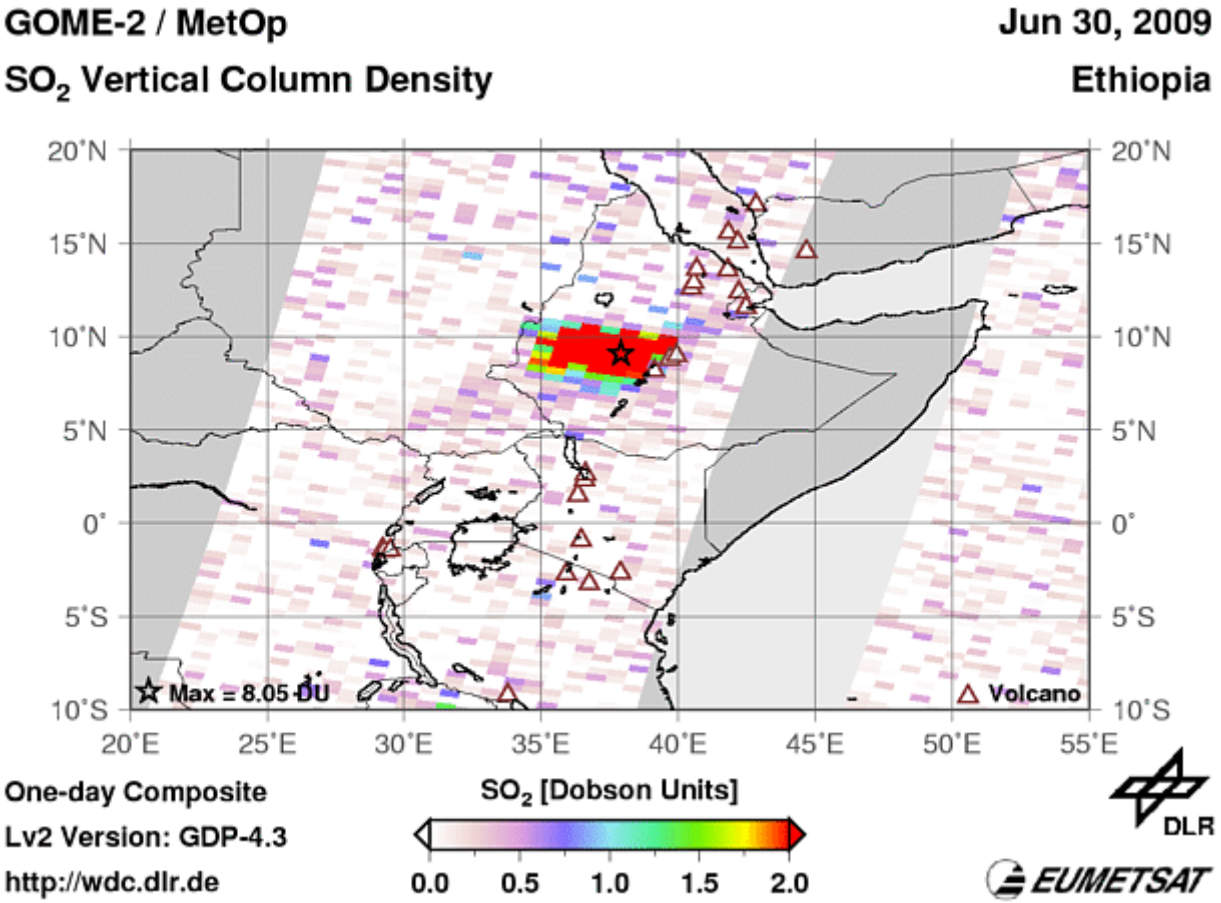
The instrument: MetOp/GOME-2

- Guarantees 25 years of data (~until 2030)
- Robust data processing system operated on behalf of EUMETSAT
- Spectra available in near-real time
- Near-real time trace gas retrieval
- Dedicated and special products for PME are generated
- Spatial resoltion 40x80 km²
- One overpass per day

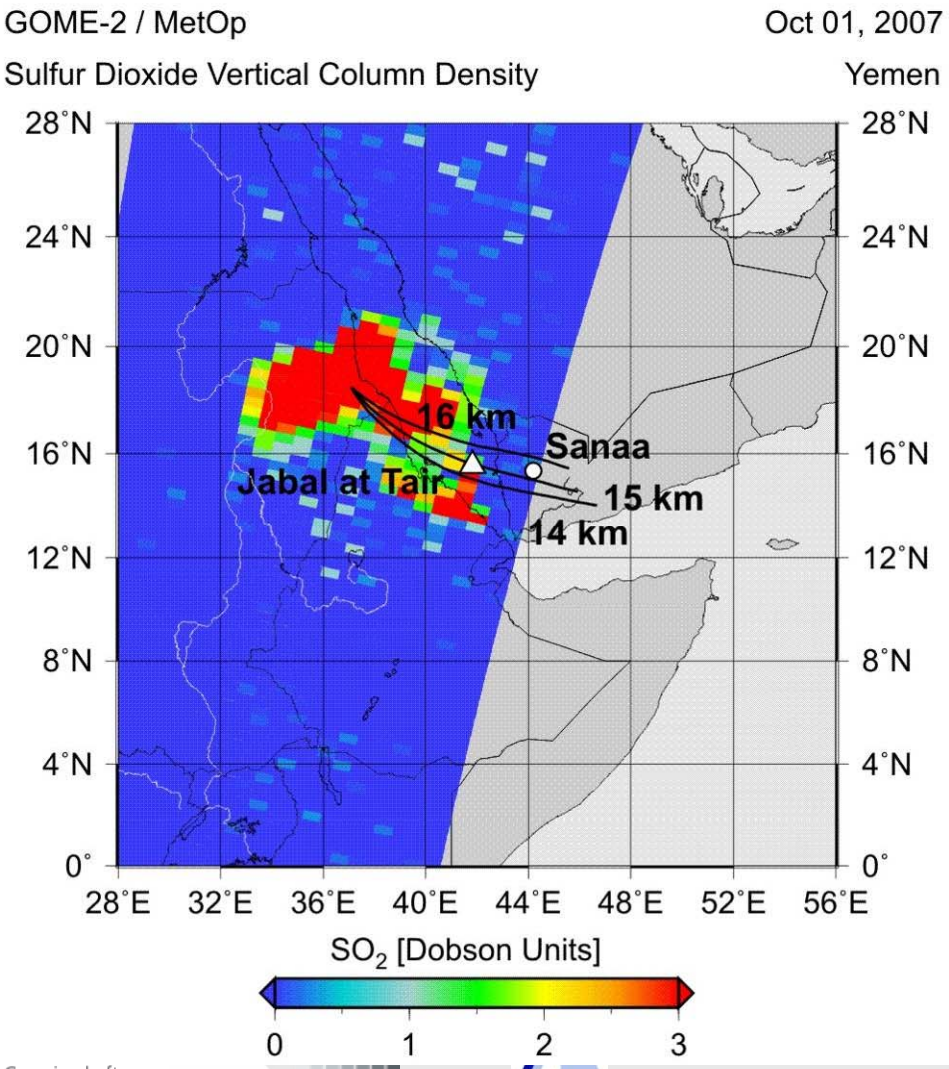
Volcanic Activity Monitoring from Satellite



Tracking SO2 emissions from Ethopian Volcanoes



Eruption of Jabal at Tair – near-real-time data



- Estimation of plume height by inverse modelling (14 km)
- Therefore, people in Jeddah not affected

Conclusion

- **Atmospheric Remote Sensing:**
- provides insight into regional to large scale distribution of air pollutants
- provides complete coverage including remote locations
- deliveres data continuously and automatically
- relevant pollutants are measured at the same time
- satellite and ground-based measurements complement each other perfectly