GeoFIS (Geostationary Fourier Imaging Spectrometer) as part of the GeoTROPE (Geostationary Tropospheric Pollution Explorer) mission: scientific objectives and capabilities

J.-M. Flaud, J. Orphal, G. Bergametti, C. Deniel, Th. v. Clarmann, F. Friedl-Vallon, T. Steck, H. Fischer, H. Bovensmann, J. P. Burrows, M. Carlotti, M. Ridolfi, L. Palchetti

GeoTROPE: Geostationary Tropospheric Pollution Explorer

Mission proposed to ESA in early 2002

J. P. Burrows(1), G. Bergametti(2), H. Bovensmann(1), J.-M. Flaud(3), J. Orphal(3), S. Noël(1), P. S. Monks(4), G. K. Corlett(4), A. P. Goede(5), T. v. Clarmann(6), T. Steck(6), H. Fischer(6), F. Friedl-Vallon(6)

(1) IUP Bremen, Germany

(2) CNRS LISA, Créteil, France

(3) CNRS LPPM, Orsay, France

(4) University of Leicester, UK

(5) KNMI, Utrecht, The Netherlands

(6) IMK, Karlsruhe, Germany

together with an industrial consortium lead by Astrium

“The scientific objective of the GeoTROPE mission is

to assess accurately
the atmospheric importance of anthropogenic activity
and natural phenomena

originating in Europe and Africa

on the changing tropospheric composition

by performing synoptic measurements
of the relevant trace gases

with high spatial and high temporal resolution.”

Ref. COM2-32, ESA EEOM 2002

GeoTROPE: Monitoring tropospheric air pollution

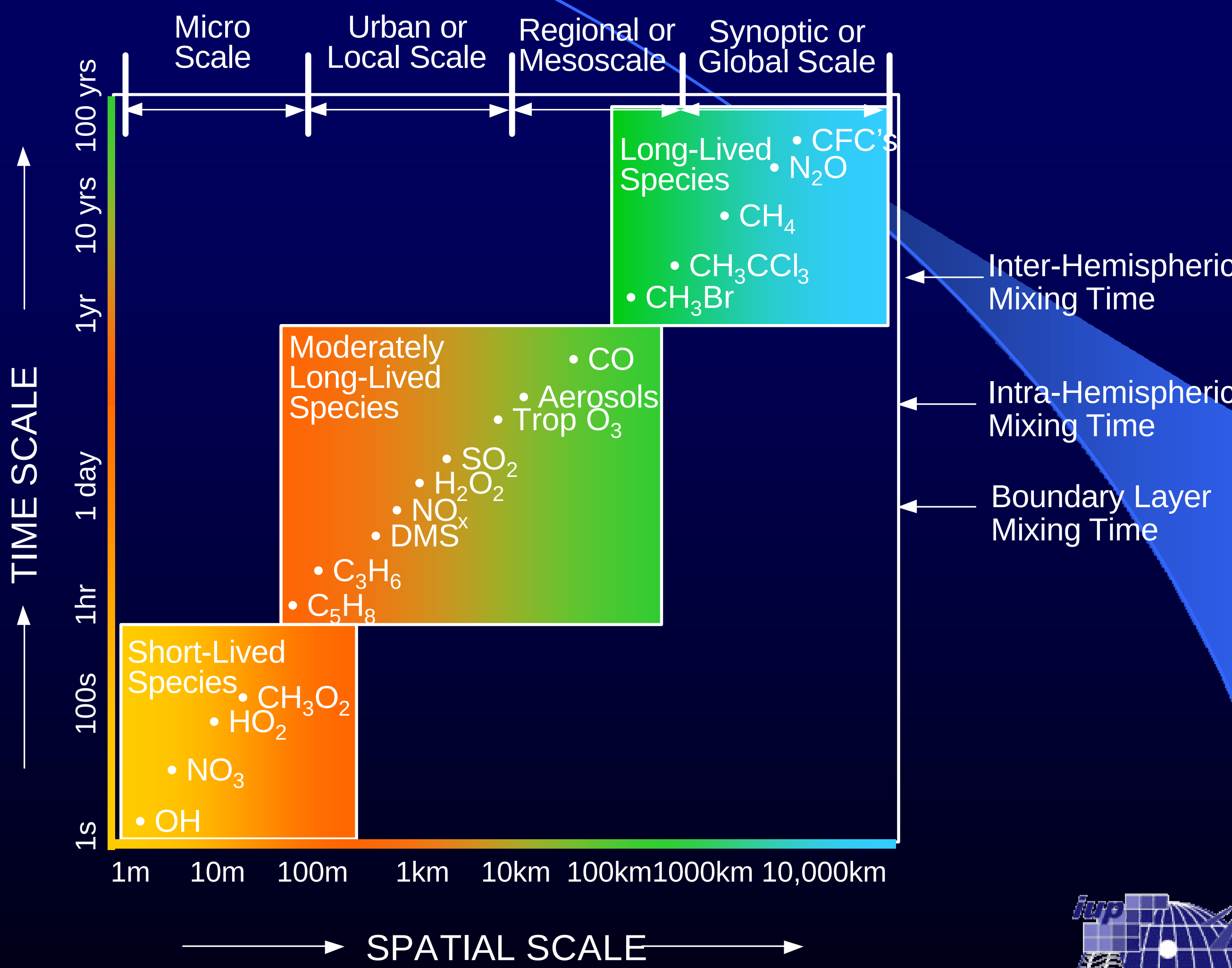
Scientific objectives:

- to study, understand and quantify the impact of anthropogenic emissions on the quality of air
- to identify and observe the sources, the sinks and the chemical processes, at local, regional and continental scales

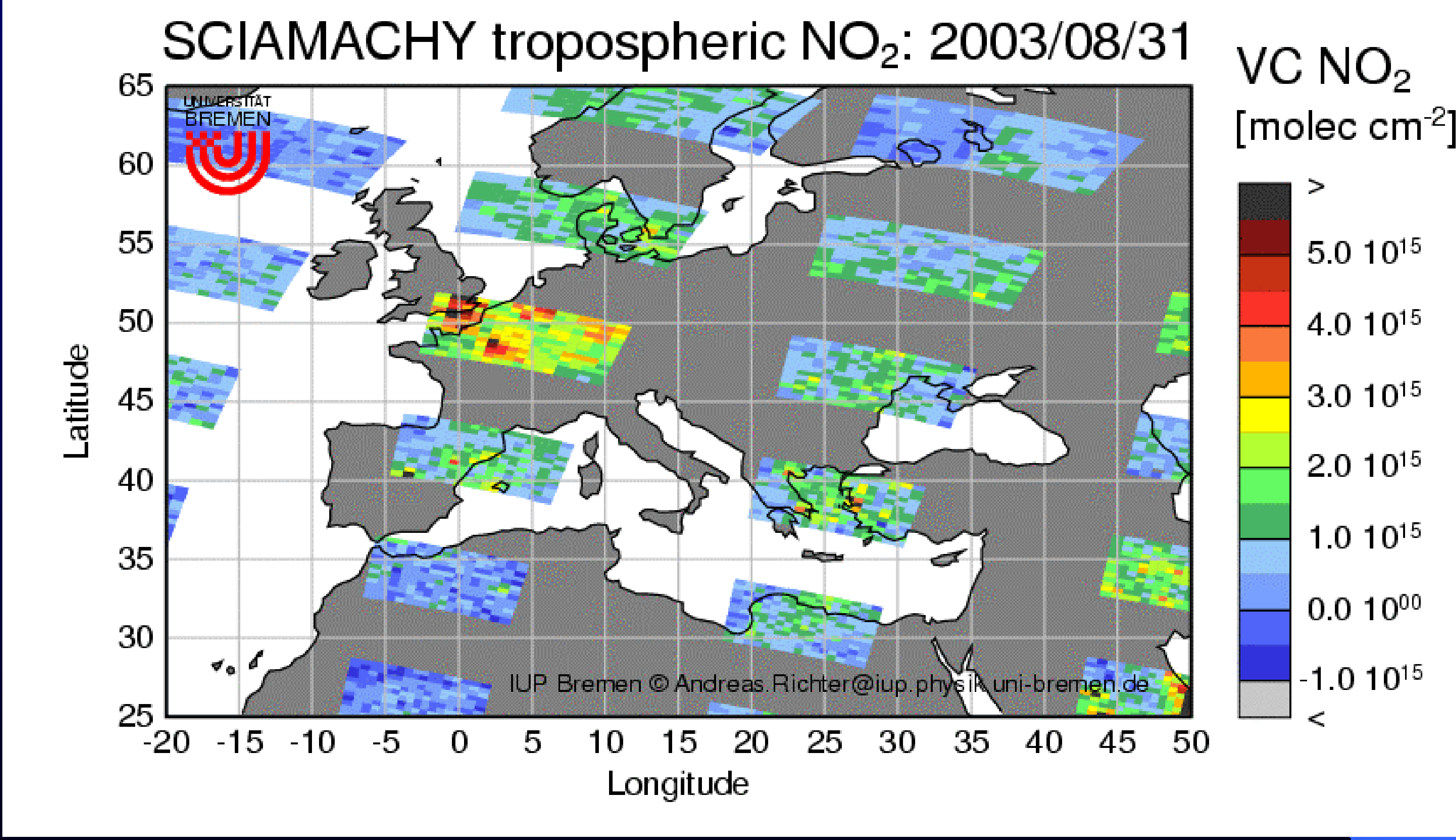
Methodology:

- monitor the relevant trace gases (short to medium lifetimes)
- perform measurements at timescales that are characteristic for the different processes (hours, days, seasons, years)
- sample the troposphere at the relevant horizontal (20´20 km^2) and vertical resolutions (2-3 km), with sub-continental coverage

The troposphere: spatial and temporal scales

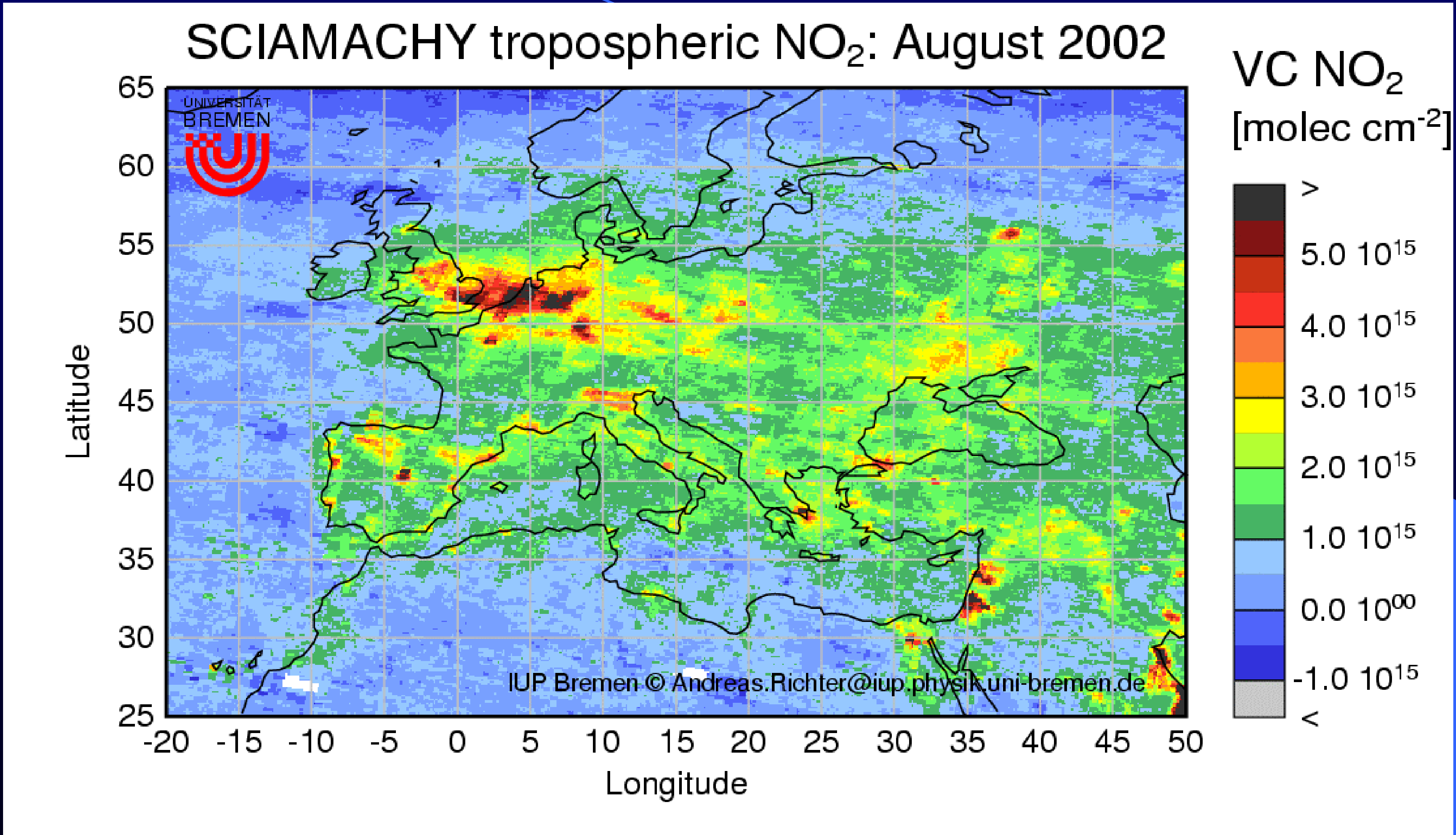


The troposphere: spatial and temporal scales



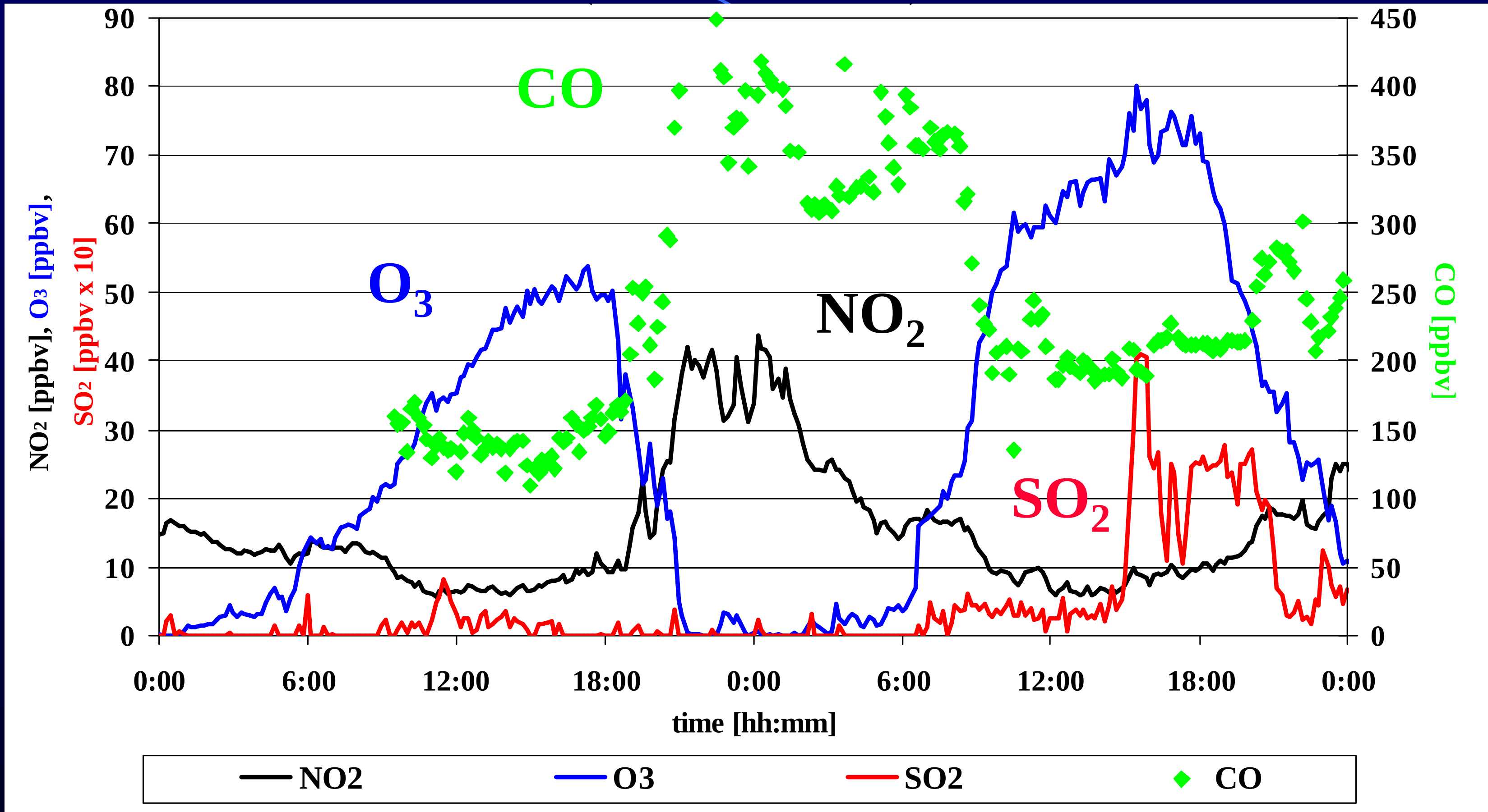
The troposphere is significantly under-sampled with data from satellites in Low-Earth Orbit (LEO)

The troposphere: spatial and temporal scales



Problem: increasing the spatial coverage / resolution leads to much lower temporal resolution when using LEO data

The troposphere: spatial and temporal scales



In-situ measurements in London (1998)

(IUP Bremen, Germany)

Monitoring the troposphere

- temporal resolution: £ 1 hour, observations day and night
- horizontal resolution: at least regional scale (20´20 km^2)
- vertical resolution: at least several points in the troposphere (resolution about 2-3 km)
- spatial coverage: local, regional, continental

⇒ only feasible from a geostationary orbit

⇒ project GeoTROPE

Parameters, science questions, and precisions (goals / thresholds)

GeoSCIA & GeoFIS

GeoSCIA

GeoFIS

Parameter	Primary Science Questions: Pollution	Biomass Burning	Surface Fluxes	Natural Processes	Precision Goals Single Measurement	Horizontal Resolution Sub-Satellite G - T $[km^2]$	Vertical Resolution G – T [km]	Temporal Sampling G - T [min.]
O_3	X	X	X	X	2-10 %	10 x 10 – 25 x 25	2-5 - TRC	30 – 60
CO	X	X			10 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 120
CH_4	X		X	X	1 – 5 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 120
NO_2	X	X	X	X	20 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
SO_2	X		X	X	10 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
HCHO	X	X	X	X	20 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
C_2H_6	X	X		X	20 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
PAN	X		X		20 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
BrO				X	10 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
H_2O		X		X	2 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
OCS				X	20 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 60
CO_2		X	X	X	1 %	10 x 10 – 25 x 25	2-5 - TRC	30 - 120
N_2O			X	X	2 – 7 %	10 x 10 – 25 x 25	2-5 TRC	30 – 60
T profile	X	X	X	X	<= 2K	10 x 10 – 25 x 25	1-2	30 - 60
Aerosol Optical Depth Cloud Optical Depth	X	X	X	X	5% - 20%	10 x 10 – 25 x 25	NA	30 - 60
Aerosol Layer Height	X	X	X	X	500 m	10 x 10 – 25 x 25	NA	30 - 60
Cloud Top Height	X	X	X	X	200 -500 m	10 x 10 – 25 x 25	NA	30 - 60
Fractional Cloud Cover	X	X	X	X	0.02 – 0.05	10 x 10 – 25 x 25	NA	30 - 60
Strat. O_3 profile	X	X		X	10 %	25 x 25 – 100 x 100	2 – 5	60 – 120
UV-A, UV-B	X	X			10 %	10 x 10 – 25 x 25	NA	30 – 60

From Ref. COM2-32, ESA 2002

Parameters, science questions, and precisions (goals / thresholds)

Geostationary Satellite Obs
Atmospheric Composition

Autho
Mainz

Contents

Table 6.1. Data products from geostationary atmospheric chemistry measurements and the resolution (in the region of interest) needed for operational and climate applications. The required threshold and the target resolutions are given, the latter in parentheses.

Data product[1]	Horizontal resolution in km	Vertical resolution[2] in km	Temporal resolution[3] in hr	Accuracy[4] in %	Coverage[6]
O_3	10 (2)	T (2)	$1^{d(n)}$ (0.5)	10 (5)	MFV - hemispheric
CO	10 (2)	T (2)	$2^{d(n)}$ (0.5)	10 (5)	MFV - hemispheric
SO_2	10 (2)	T (2)	$1^{d(n)}$ (0.5)	50 (20)	regional
HCHO	10 (2)	T (2)	$1^{d(n)}$ (0.5)	50 (20)	regional
NO_2	10 (2)	T (2)	$1^{d(n)}$ (0.5)	50 (20)	regional
PAN	10 (2)	T (2)	$1^{d(n)}$ (0.5)	50 (20)	MFV
UV-A	10 (2)	Surface	$1^{d(n)}$ (0.5)	20 (5)	regional
UV-B	10 (2)	Surface	$1^{d(n)}$ (0.5)	20 (5)	regional
AOT_{fine}	5 (0.5)	T (BL+FT)	$1^{d(n)}$ (0.25)	0.05 (0.01)[5]	regional - MFV
AOT_{course}	5 (0.5)	T (BL+FT)	$1^{d(n)}$ (0.25)	0.05 (0.01)[5]	regional - MFV
Aer R_{eff}	5 (0.5)	T	$1^{d(n)}$ (0.25)	30 (10)	regional - MFV
SSA	5 (0.5)	T	$1^{d(n)}$ (0.25)	0.03 (0.01)[5]	regional - MFV
H_2O	5 (0.5)	T (BL+FT)	$1^{d(n)}$ (0.25)	5 (1)	regional
CO_2	50 (10)	T	$6^{d(n)}$ (1)	2 (1)	MFV - global
CH_4	50 (10)	T	$6^{d(n)}$ (1)	5 (1)	MFV - global

[1] AOT is aerosol optical thickness (for the fine and course fraction, D<1 μm and D>1 μm, respectively), Aer R_{eff} is aerosol effective radius, SSA is aerosol single scattering albedo, PAN is peroxyacetyl nitrate
[2] T refers to the troposphere (column), BL to the boundary layer and FT to the free troposphere
[3] superscript d refers to daytime (threshold), n to night (target)
[4] Absolute accuracy

J. Lelieveld, 2003

Jos Lelieveld, 2003 (EUMETSAT study):

Geostationary Satellite Observations for Monitoring Atmospheric Composition and Chemistry Applications

« The important advantage of geostationary satellite measurements is that spatial and temporal variability of reactive gases and aerosols can be captured at a resolution that is compatible with that of regional models. Measurements of short-term, e.g., diurnal concentration changes are particularly important for short-lived reactive trace gases and aerosols. It will be possible to assimilate the satellite data together with ground-based measurements into regional and nested mesoscale models, which will provide the amount of detail needed for specific operational applications.

…

Reactive trace gases with a lifetime of about a day to several months should be measured with a spatial resolution of 10 km and preferably better. The main target gases are carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), formaldehyde (HCHO) and sulphur dioxide (SO_2). Some information about the vertical distribution, e.g., to distinguish the lower from the upper troposphere, will be necessary to assess long-range transport and regional air pollution. »

Jos Lelieveld, 2003 (EUMETSAT study):

Geostationary Satellite Observations for Monitoring Atmospheric Composition and Chemistry Applications

« Finally it should be mentioned that a European consortium presently prepares a proposal for the Geostationary Tropospheric Pollution Explorer (GeoTROPE) as an ESA Earth Explorer Opportunity Mission. Two nadir-viewing instruments are being considered, one that includes solar UV-VIS-NIR channels based upon the GOME-SCIAMACHY heritage, and one thermal IR sounder based upon MIPAS-IASI.

…

The first instrument has the advantage that solar radiation measurements provide accurate information down to the earth's surface or cloud top, while the second instrument can measure during day and night. The targeted horizontal resolution is 10-25 km and the temporal resolution 30-60 minutes. It is planned to distinguish at least 2-3 vertical layers within the troposphere, while the stratosphere may be resolved at 1-3 km. If successful, GeoTROPE could be an important forerunner of an operational geostationary system for atmospheric chemistry applications. »

GeoTROPE: Geostationary Tropospheric Pollution Explorer

GeoSCIA: Geostationary Scanning Imaging Absorption Spectrometer

H. Bovensmann[1], M. Buchwitz[1], K. U. Eichmann[1], S. Noel[1], J.-M. Flaud[2], J. Orphal[2], P. Monks[3], G. Corlett[3], A. P. Goede[4], T. von Clarmann[5], T. Steck[5], V. Rozanov[1], and J. P. Burrows[1]

(1) IUP Bremen, Germany, (2) CNRS LPPM, Orsay, France, (3)University of Leicester, UK,

(4) KNMI, The Netherlands, (5) FZK IMK, Karlsruhe, Germany

GeoFIS: Geostationary Fourier Imaging Spectrometer

J.-M. Flaud[1], J. Orphal[1], G. Bergametti[2], C. Deniel[3], Th. v. Clarmann[4], F. Friedl-Vallon[4], T. Steck[4], H. Fischer[4], H. Bovensmann[5], J. P. Burrows[5], M. Carlotti[6], M. Ridolfi[6], and L. Palchetti[7]

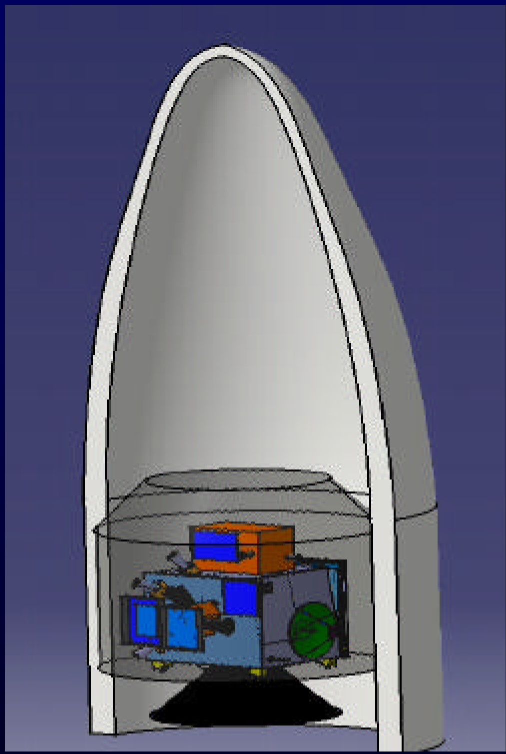
(1) CNRS LPPM, Orsay, France, (2) CNRS LISA, Créteil, France, (3) CNES, Paris, France

(4) FZK IMK, Karlsruhe, Germany, (5) IUP Bremen, Germany

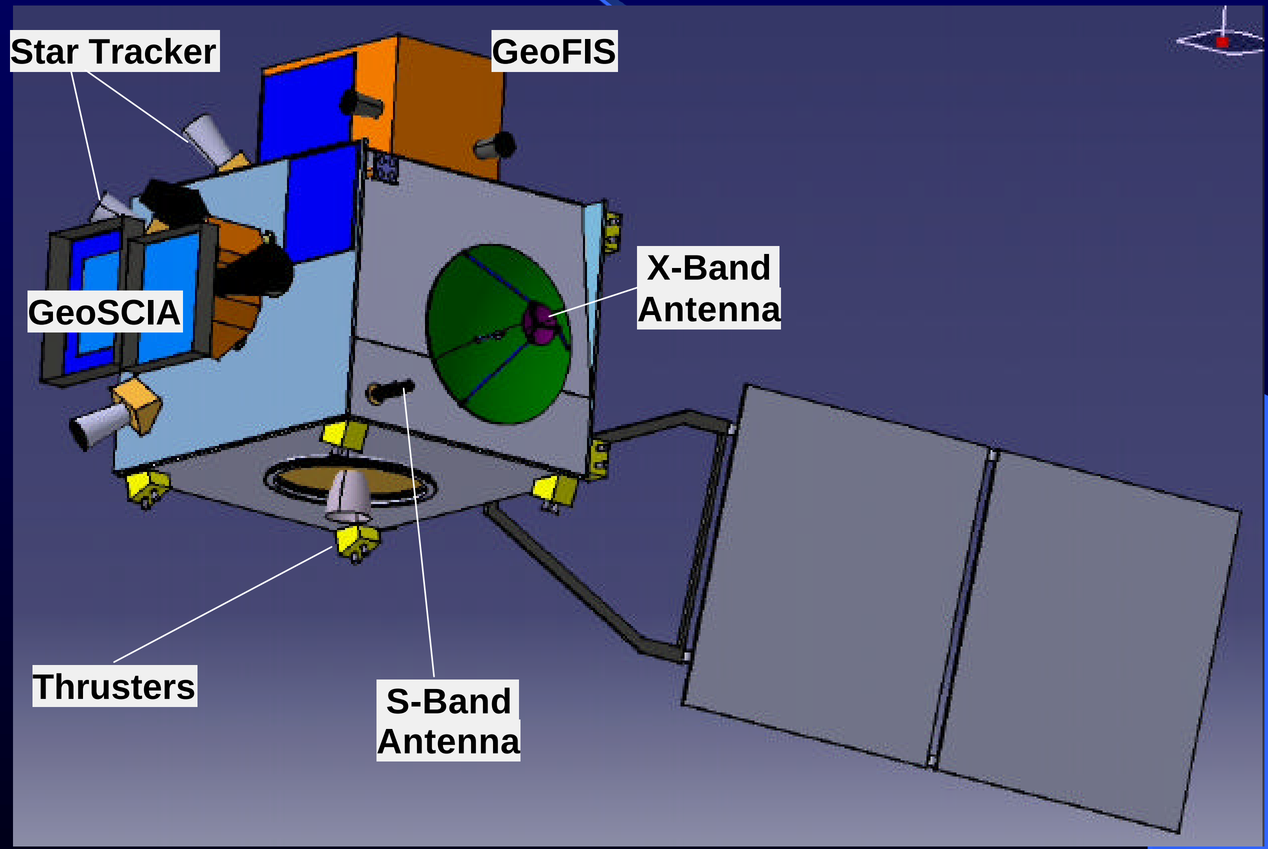
(6) University of Bologna, Italy, (7) CNR IFAC, Florence, Italy

Presented at the COSPAR World Space Congress, Houston, 2002

EUROSTAR 2000 structure and propulsion, improved AOCS with 4 reaction wheels, 3 star trackers, two 2-axis Earth sensors, three 2-axis sun-sensor head assemblies, two GPS receivers



GeoTROPE stored in the Ariane V



Sketch of the GeoTROPE satellite (Astrium Germany)

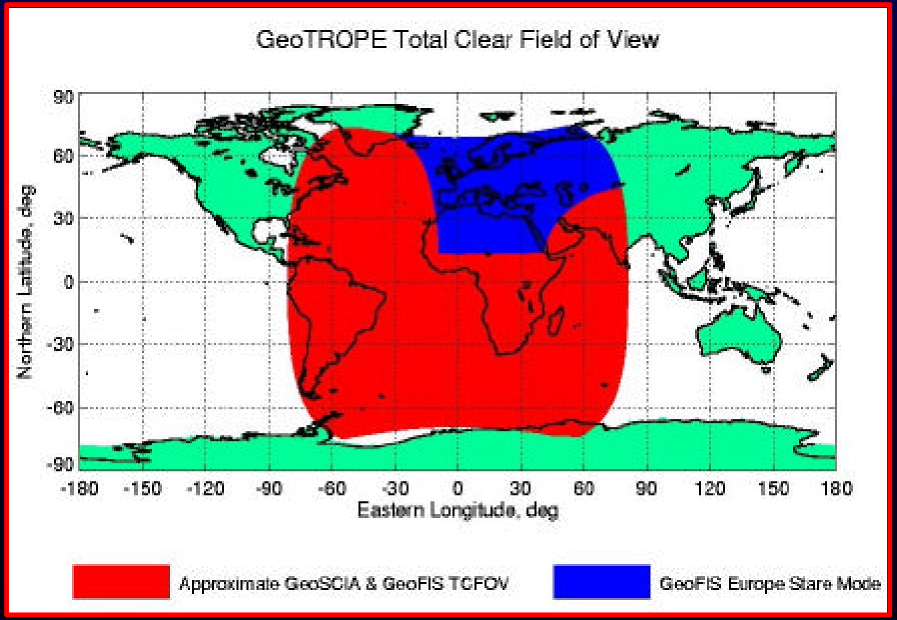
A few words about the thermal infrared

- atmospheric and surface thermal emissions peak in the mid-infrared region (measurements are possible day <u>and</u> night)
- the molecular absorptions (“fingerprints“) are well separated
- infrared photons are mainly emitted in the troposphere
- there are many other LEO instruments in the mid-infrared (ATMOS, IMG, AIRS, MIPAS, SCISAT, IASI, TES, …)

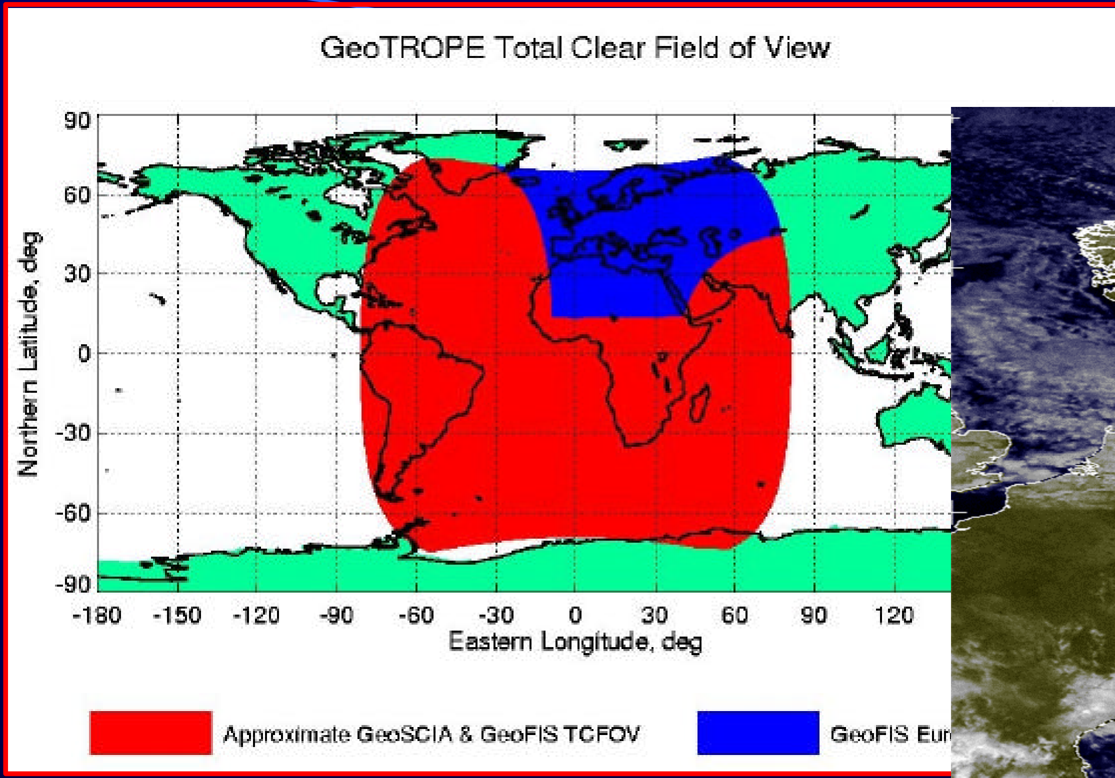
⇒
the GeoFIS instrument as component of the GeoTROPE mission

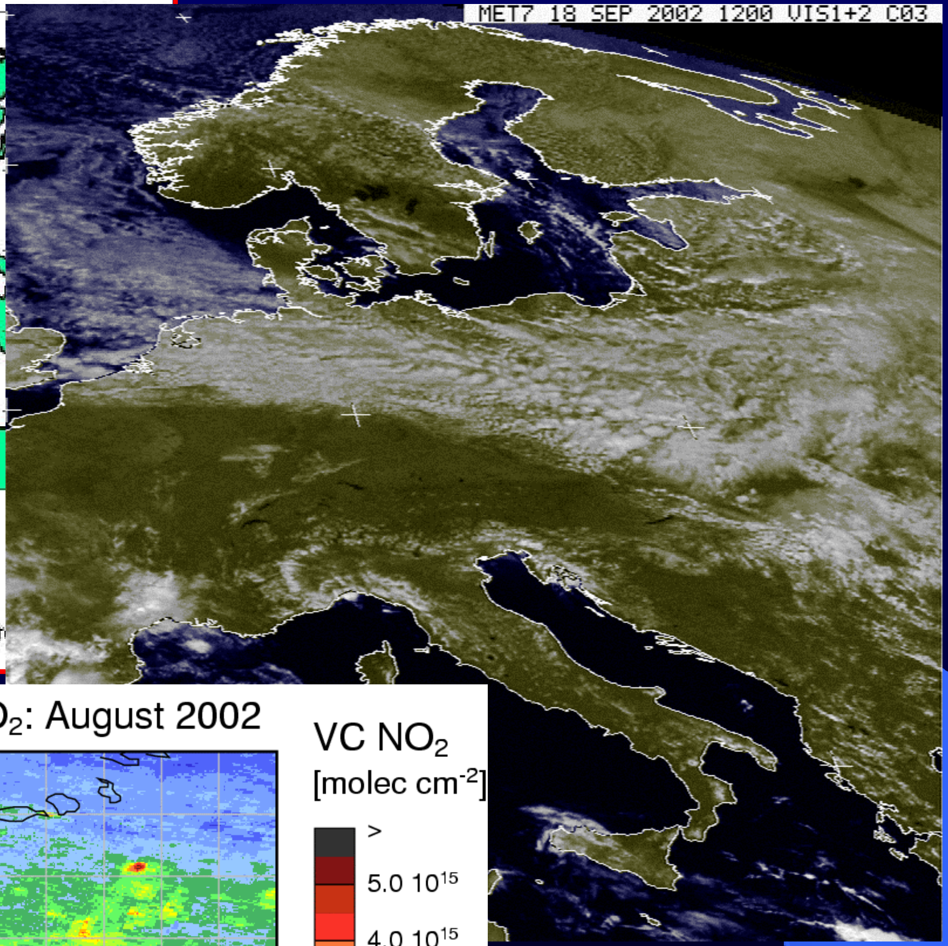
GeoFIS: feasibility, performance

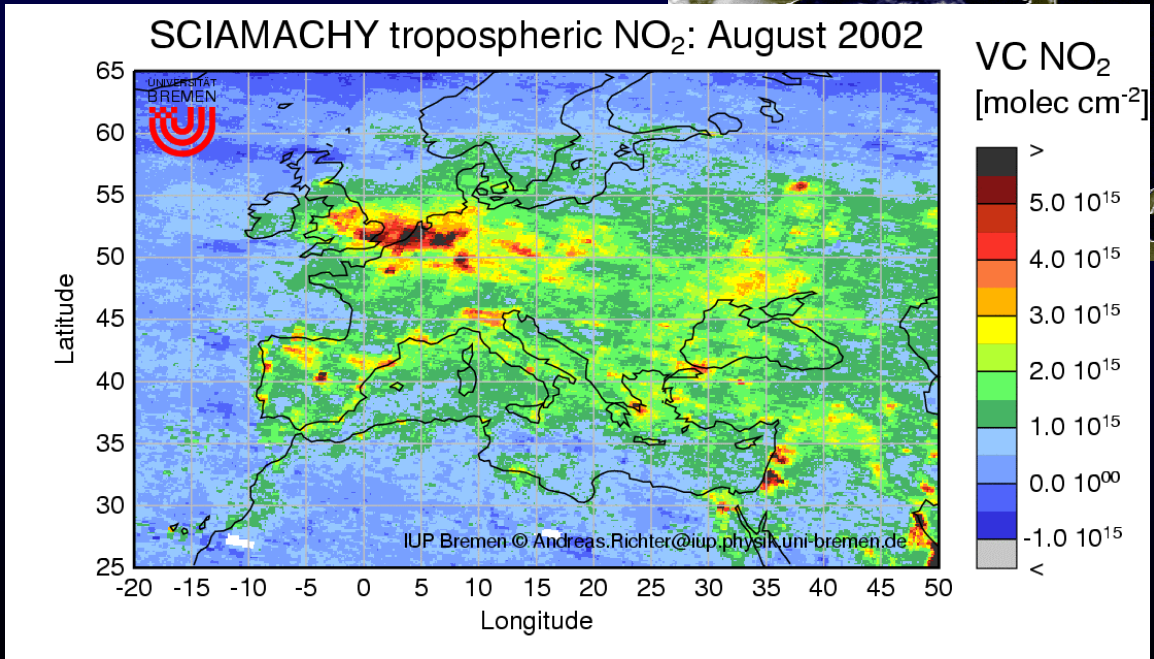
- current baseline: IASI heritage (CNES, Alcatel)
- radiative transfer calculations : KOPRA (Karlsruhe)
- FOV: slightly off-Nadir, centered over Europe, including Northern Africa and the Near East



- horizontal resolution » 20´20 km^2
- temporal resolution » 30 min
- vertical resolution » 2-6 km for the main target species: O_3, H_2O, CO, N_2O, CH_4

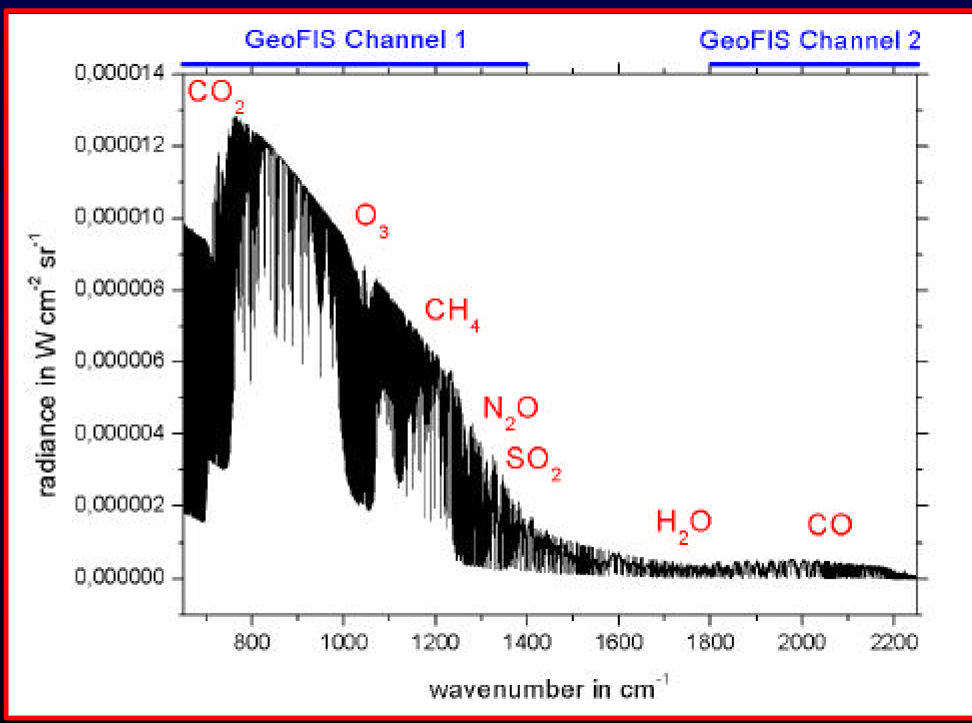

GeoTROPE Total Clear Field of View
Northern Latitude, deg
90
60
30
0
-30
-60
-90
-180
-150
-120
-90
-60
-30
0
30
60
90
120
Eastern Longitude, deg
Approximate GeoSCIA & GeoFIS TCFOV
GeoFIS Eur

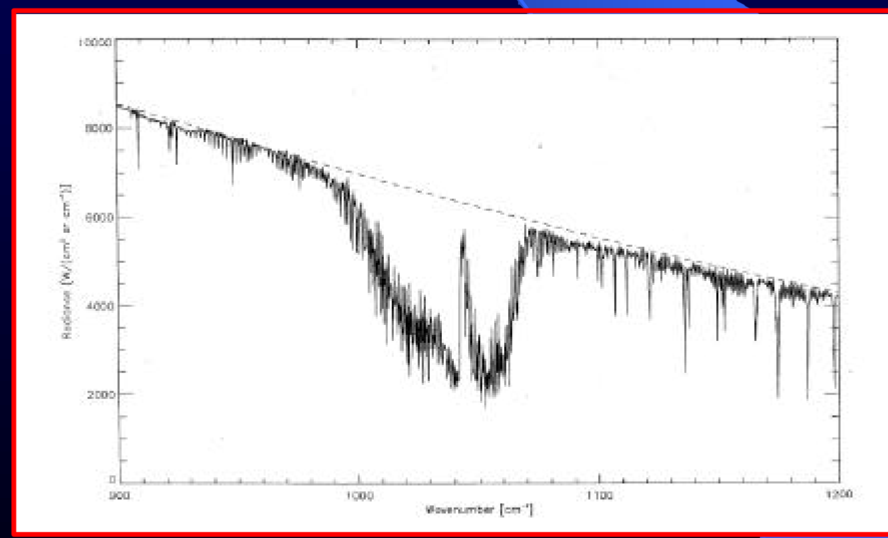

MET7 18 SEP 2002 1200 VIS1+2 C03


SCIAMACHY tropospheric NO_2: August 2002
UNIVERSITÄT BREMEN
Latitude
65
60
55
50
45
40
35
30
25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
Longitude
IUP Bremen © Andreas.Richter@iup.physik.uni-bremen.de
VC NO_2
[molec cm^{-2}]
>
$5.0\ 10^{15}$
$4.0\ 10^{15}$
$3.0\ 10^{15}$
$2.0\ 10^{15}$
$1.0\ 10^{15}$
$0.0\ 10^{00}$
$-1.0\ 10^{15}$
<

GeoFIS: the instrument

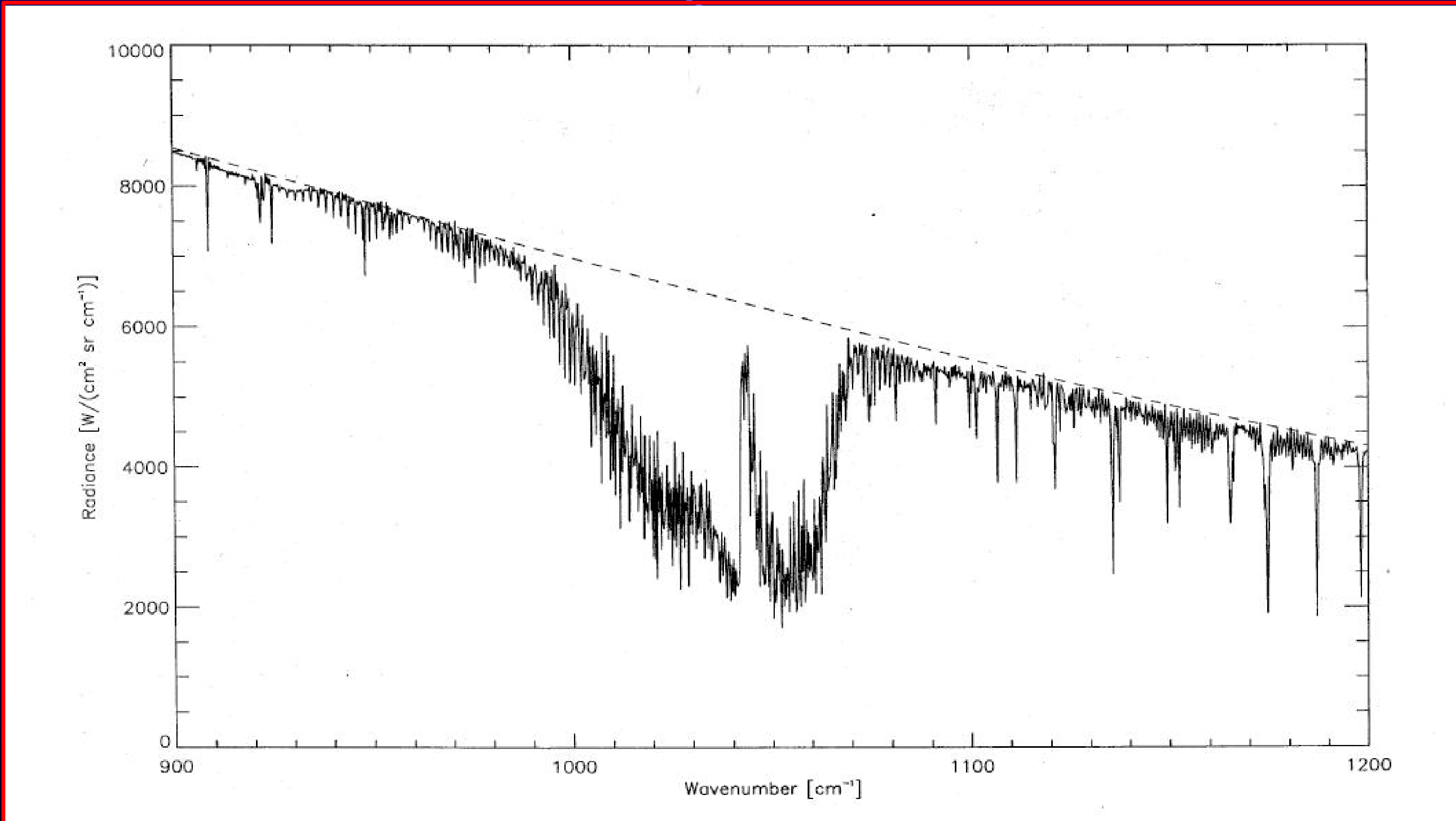
- Michelson interferometer (IASI heritage)
- spectral resolution : 0.25 cm^{-1}
- two channels (centered around 10 mm and 5 mm)
- detectors: 2D matrices made of HgCdTe, 240´320 pixels





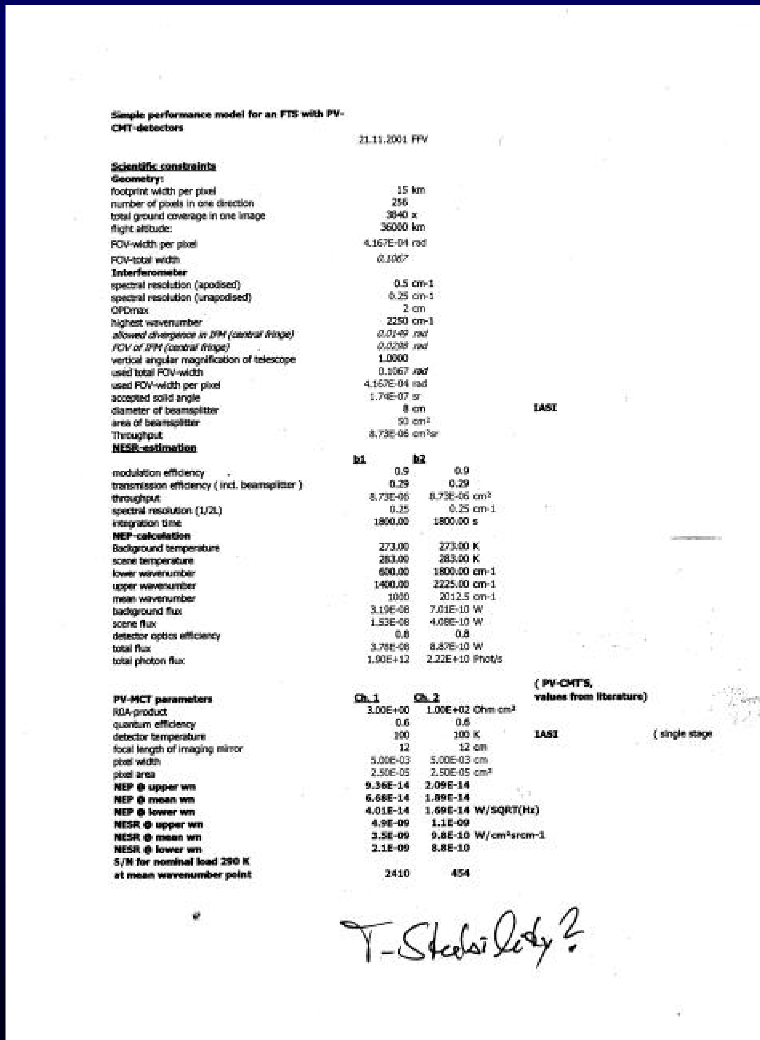
Synthetic spectrum calculated with the instrumental parameters of GeoFIS

GeoFIS: the instrument



The signal/noise ratio is comparable or better than for Nadir-viewing instruments in LEO (integration time in GEO up to 30 min.)
[see also the recent EUMETSAT study lead by C. Clerbaux]

GeoFIS: the instrument



Simple performance model for an FTS with PV-CMT-detectors

21.11.2001 FFV

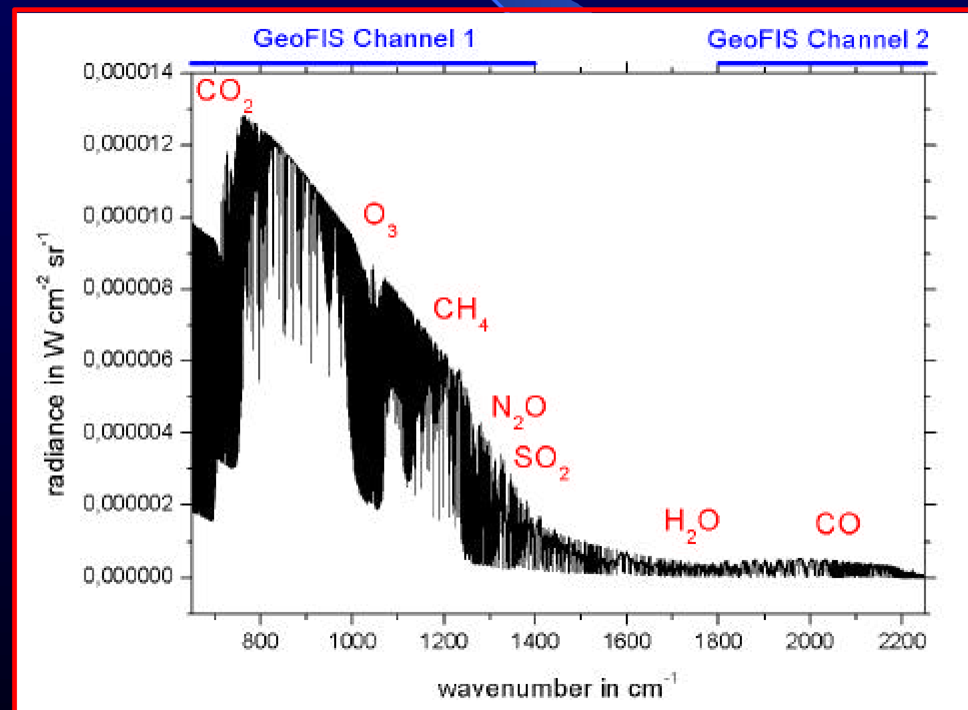
<u>Scientific constraints</u>			
Geometry:			
footprint width per pixel	15 km		
number of pixels in one direction	256		
total ground coverage in one image	3840 x		
flight altitude:	36000 km		
FOV-width per pixel	4.167E-04 rad		
FOV-total width	*0.1067*		
Interferometer			
spectral resolution (apodised)	0.5 cm-1		
spectral resolution (unapodised)	0.25 cm-1		
OPDmax	2 cm		
highest wavenumber	2250 cm-1		
allowed divergence in IFM (central fringe)	*0.0149 rad*		
FOV of IFM (central fringe)	*0.0298 rad*		
vertical angular magnification of telescope	1.0000		
used total FOV-width	0.1067 *rad*		
used FOV-width per pixel	4.167E-04 rad		
accepted solid angle	1.74E-07 sr		
diameter of beamsplitter	8 cm		**IASI**
area of beamsplitter	50 cm²		
Throughput	8.73E-06 cm²sr		
<u>NESR-estimation</u>			
	<u>b1</u>	**<u>b2</u>**	
modulation efficiency	0.9	0.9	
transmission efficiency (incl. beamsplitter)	0.29	0.29	
throughput	8.73E-06	8.73E-06 cm²	
spectral resolution (1/2L)	0.25	0.25 cm-1	
integration time	1800.00	1800.00 s	
NEP-calculation			
Background temperature	273.00	273.00 K	
scene temperature	283.00	283.00 K	
lower wavenumber	600.00	1800.00 cm-1	
upper wavenumber	1400.00	2225.00 cm-1	
mean wavenumber	1000	2012.5 cm-1	
background flux	3.19E-08	7.01E-10 W	
scene flux	1.53E-08	4.08E-10 W	
detector optics efficiency	0.8	0.8	
total flux	3.78E-08	8.87E-10 W	
total photon flux	1.90E+12	2.22E+10 Phot/s	
			(PV-CMT'S, values from literature)
PV-MCT parameters	**<u>Ch. 1</u>**	**<u>Ch. 2</u>**	
R0A-product	3.00E+00	1.00E+02 Ohm cm²	
quantum efficiency	0.6	0.6	
detector temperature	100	100 K	**IASI** (single stage
focal length of imaging mirror	12	12 cm	
pixel width	5.00E-03	5.00E-03 cm	
pixel area	2.50E-05	2.50E-05 cm²	
NEP @ upper wn	**9.36E-14**	**2.09E-14**	
NEP @ mean wn	**6.68E-14**	**1.89E-14**	
NEP @ lower wn	**4.01E-14**	**1.69E-14 W/SQRT(Hz)**	
NESR @ upper wn	**4.9E-09**	**1.1E-09**	
NESR @ mean wn	**3.5E-09**	**9.8E-10 W/cm²srcm-1**	
NESR @ lower wn	**2.1E-09**	**8.8E-10**	
S/N for nominal load 290 K at mean wavenumber point	**2410**	**454**	

T-Stabilität?

Signal/noise:

Ch. 1: > 2400

Ch. 2: > 450



Based on first calculations by F. Friedl-Vallon (IMK FZK)

GeoFIS: the instrument

- two IR LFPA (Sofradir): 320´256 pixels (HgCdTe)
- no need for a telescope (F. Friedl-Vallon)
- near-IR diode-laser for sampling control (to be improved)
- two on-board blackbodies plus « deep space » for calibration
- 2 ´ 81920 interferograms every 35 seconds (14-16 bits)
- on-board quality control, averaging, and data compression
- compensating for platform movements (by 2D interpolation)
- data rate estimate < 19 Mbit/sec
- optional: latitude scan mirror (Europe – Africa)

<u>A detailed instrument study should start very soon</u>

GeoFIS: data products and analysis

- **total data £ 100 TBytes/year**
- **fast analysis (near real-time) with « standard » PC's (cluster)**
- **concentration profiles (at least 3 points in the troposphere) of: O_3, CO, CH_4, N_2O, H_2O, T**
- **tropospheric columns of:**
  SO_2, H_2CO, PAN, C_2H_6, OCS, CFC-11, CFC-12
- **more products possible with reduced temporal resolution**
- **synergy with the GeoSCIA data (UV-visible, SWIR, NO_2)**
- **data assimilation using other techniques (satellites in LEO, *in-situ* measurements, ground-based remote-sensing, air planes, balloons), integration into chemical transport models**
- **development of inverse modeling (CNES study ongoing)**

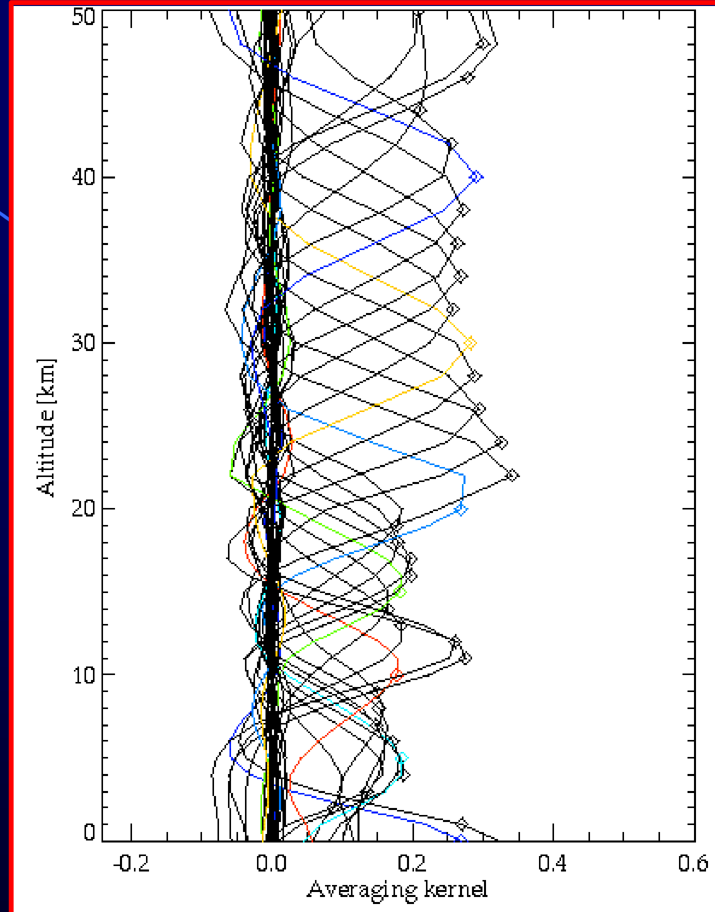
GeoFIS: data products (IMK FZK, examples)

At least 3 points in the troposphere

	points	precis.	2´NESR	res./km
C_2H_6	1	5.8%	11.7%	-
	2	85.6%	171%	5.9
PAN	1	1.5%	3.0%	-
	2	33.2%	66.5%	6.7
SO_2	1	28.7%	57.4%	-

NESR : simulation of GeoFIS

O_3	2	2.5%	4.9%	7.3
	3	13.2%	26.4%	6.2
	4	28.7%	57.4%	4.4



O_3 averaging kernels, 3 degrees of freedom in the troposphere (Th. von Clarmann, T. Steck)

Improved vertical resolution by the synergie GeoFIS - GeoSCIA

Conclusions:

- tropospheric air pollution: strong political interest
- the proposed GeoTROPE mission is driven by the needs of current tropospheric chemistry and transport models concerning the spatial and temporal sampling
- very important support from the « chemistry » community
- amongst the ESA EEOM proposals, GeoTROPE is one of the two missions highlighted « of very high scientific interest » by the ESAC
- GeoFIS/GeoSCIA are potentially interesting for the next Meteosat generation (EUMETSAT studies …)
- possibly an element for the GMES initiative (ESA / CEC)