A study on operational atmospheric chemistry monitoring missions ("CAPACITY study")

Jörg Langen, ESA

Scope of the CAPACITY study

- Chemical, dynamic and radiative coupling between air quality, climate change and stratospheric ozone
- Governments have been adviced to optimise emission regulation strategies by combined consideration of air quality and climate
- Overlapping observational requirements
- Common programmatic framework for all three issues

→ **consideration of all "operational" applications of atmospheric composition sounding**

Objectives of the CAPACITY study

- User requirements for operational atmospheric composition sounding
- Quantitative observational requirements
- Possible contributions of current and planned missions
- Mission concepts and instrument requirements for future missions
- Performance assessment with respect to user requirements

Reference time frame: 2010-2020 (Metop/EPS operational)

Study consortium

Prime : KNMI (H. Kelder)

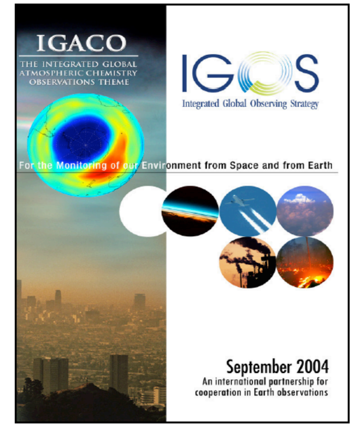
Core team : Rutherford-Appleton Lab (B. Kerridge)
Univ. Leicester (P. Monks, J. Remedios)
Univ. Bremen (H. Bovensmann)
EADS-Astrium (R. Mager)
Alcatel Space (H. Sassier)

Consultants: *Requirements* – WMO, JRC, 5 weather and environmental agencies, Eurocontrol, 11 research institutes and universities

Space instrumentation – 10 research institutes and universities, 1 company

Ground instrumentation – 1 research institute

Sources of user and observational requirements



- IGOS-IGACO Theme report
- EU GMES-GATO report
- EU FP projects, e.g. Create-Daedalus, Evergreen
- Eumetsat user consultation in the frame of MTG
- Environment and climate protection protocols, directives etc. (EU, international)
- GCOS implementation plan, WCRP-SPARC long-term observation requirements
- GMES service element PROMOTE
- ESA studies on CO_2 monitoring
- ESA study on atmospheric chemistry observation requirements (research)
- CAPACITY workshop Jan. '04

… many useful inputs, but …

Capacity Study

… we need a set of requirements …

- for each environmental theme
- for each application type
- self-consistent
- sufficiently complete to perform trade-offs between space mission concepts
- following an integrated observation strategy (IGACO) considering ground, airborne and space observations and assimilation / models

➔ **comprehensive set of observational requirements was established.**

Environmental themes, data usage, applications

Environmental Theme / Data usage	Ozone Layer & Surface UV radiation **A**	Air Quality **B**	Climate **C**
Protocols **1**	UNEP Vienna Convention; Montreal and subs. Protocols CFC emission verification Stratospheric ozone, halogen and surface UV distribution and trend monitoring **A1**	UN/ECE CLRTAP; EMEP / Göteborg Protocol; EC directives EAP / CAFE AQ emission verification AQ distribution and trend monitoring **B1**	UNFCCC Rio Convention; Kyoto Protocol; Climate policy EU GHG and aerosol emission verification GHG/aerosol distribution and trend monitoring **C1**
Services **2**	Stratospheric composition and surface UV forecast NWP assimilation and (re-) analysis **A2**	Local Air Quality (BL); Health warnings (BL)	NWP assimilation and (re-) analysis
Assessment (lower priority for operational mission) **3**	Long-term global data records WMO Ozone assessments Stratospheric chemistry and transport processes; UV radiative transport processes Halogen source attribution UV health & biological effects **A3**	long-range transport processes AQ source attribution AQ Health and safety effects	processes Forcing agents source attribution Socio-economic climate effects

Requirements per application

→

Michiel van Weele, Wed 15.45h

Measurement strategy - example: climate protocol monitoring

Role of Satellite Measurements

- Concentration monitoring for inverse modeling of CH_4, CO_2, CO and NO_2 emissions
- Global concentration distributions of the mentioned gases, O_3 and aerosols

Role of Surface network

- Greenhouse gases trend monitoring (CO_2, CH_4, N_2O, SF_6, CF_4, HFCs)
- Weekly surface concentrations and total columns from a representative network
- Validation of satellite measurements
- Concentration monitoring for inverse modeling of CH_4, CO_2, CO and NO_2 emissions
- Tropospheric O_3: sondes, lidar and surface data
- Tropospheric aerosol optical depth and aerosol absorption optical depth
- Trend monitoring for ozone depleting substances with climate forcing: (H)CFCs

Auxiliary data

- Meteorology from NWP centers including surface data
- Emission inventories and estimates on sinks

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

Observational requirements – example: AQ NRT satellite

B2-S

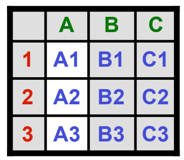
Theme:	**Air Quality**
Category:	**Near-Real Time Data**
Type of Observations:	**Satellite**

Requirement / Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Air Quality Forecast; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	50 / 100	--	12 / 24*3	5%
NO2	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CO	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Ttropospheric Column	5 / 20	--	0.5 / 2	25%
		Total Column	5 / 20	--	0.5 / 2	25%
Aerosol OD	Air Quality Forecast; UV actinic fluxes	PBL	5 / 20	--	0.5 / 2	0.05
		FT	5 / 50	--	0.5 / 2	0.05
		Ttropospheric Column	5 / 20	--	0.5 / 2	0.05
		Total Column	5 / 20	--	0.5 / 2	0.05
Aerosol Type	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	< 10% mis-assignments
		FT	5 / 50	--	0.5 / 2	< 10% mis-assignments
		Ttropospheric Column	5 / 20	--	0.5 / 2	< 10% mis-assignments
		Total Column	5 / 20	--	0.5 / 2	< 10% mis-assignments
H2O	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	10%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	10%
		Total Column	5 / 20	--	0.5 / 2	10%
SO2	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
CH2O	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
HNO3	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	20%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
N2O5 (night)	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	[illegible]
		FT	5 / 50	1 / 3	0.5 / 2	50%
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
PAN	Air Quality Forecast	PBL	5 / 20	--	0.5 / 2	20%
		FT	5 / 50	1 / 3	0.5 / 2	[illegible]
		Tropospheric Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
		Total Column	5 / 20	--	0.5 / 2	1.3e15 molec cm-2
Spectral UV surface albedo	UV actinic fluxes	Surface	5 / 20	--	24 / 24*3	0.1

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

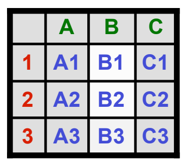
Geographical coverage requirements

Ozone Layer & Surface UV radiation



global

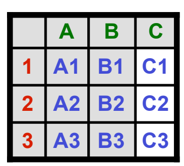
Air Quality



threshold : Europe + surrounding areas (e.g. monitoring of EC directives and national AQ legislation, short-term air quality forecast)

target : global (monitoring, assessment and forecast of global air quality, the oxidising capacity, and the quantification of continental in/outflow)

Climate



global

Capacity Study

Assessment of existing and planned missions - example: Ozone NRT

A2-S (i)		Theme: Category: Type of Observations:			Ozone Layer Near-Real Time Data Satellite	
Requirement Data Product	Driver	Height Range	Horizontal resolution (km)	Vertical resolution (km)	Revisit Time (hours)	Uncertainty
O3	Ozone and UV Forecast	UT	20 / 100	0.5 / 2	6 / 24*3	20%
		LS	50 / 100	0.5 / 2	6 / 24*3	20%
		MS	100 / 200	2 / 3	6 / 24*3	20%
		US+M	100 / 200	3 / 5	12 / 24*7	20%
		Troph. column	10 / 50	--	6 / 24*3	20%
		Total column	50 / 100	--	6 / 24*3	5%
Spectral UV Surf. Alb.	UV Forecast	Surface	10 / 50	--	6 / 24*3	0.1
Spectral UV Sol. Irr.	UV Forecast	Top of Atmosphere	--	--	Daily / Monthly	2%
UV Aerosol OD	UV Forecast	Total column	10 / 50	--	6 / 24*3	0.1
UV Aerosol Abs. OD	UV Forecast	Total column	10 / 50	--	6 / 24*3	0.02
Strat. Aerosol OD	Ozone loss	LS	50 / 100	0.5 / 2	6 / 24*3	0.05
		MS	50 / 200	1 / 3	12 / 24*7	0.05
		Stratosphere	50 / 200	--	6 / 24*7	0.05
ClO	Ozone loss	LS	50 / 200	2 / part. column	24 / 24*7	50%
		MS	100 / 200	2 / part. column	24 / 24*7	50%
		Stratosphere	50 / 200	--	24 / 24*7	50%

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

colours indicate instruments
patterns indicate fulfilment of requirements

No Measurements in Ht Range
NO Requirements met
Requirements met PARTIALLY
Requirements met FULLY

Assessment of existing and planned missions – quick summary

Current status of observational system in 2010-2020 :

MetOp / EPS	GOME-2, IASI
NPOESS	OMPS, CRIS

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

GOME-2 and OMPS

- designed for stratospheric ozone monitoring
- considered appropriate for this purpose
- some contribution to NWP
- **contributions to tropospheric applications very limited**, due to insufficient temporal sampling (~ 1/week/geo-location cloud-free) and too coarse horizontal resolution

IASI and CRIS

- main products: T, greenhouse gases (H_2O, O_3, CH_4, N_2O) and CO
- vertical profiles of H_2O; vertical resolution for tropospheric O_3, CO
- sensitivity decreasing towards planetary boundary layer (main interest)

Main gaps in current / planned operational system

- Climate gases (CO_2, CH_4 and CO) and aerosol monitoring with sensitivity to the PBL

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

- High vertical resolution measurements in the UT/LS region for ozone and climate applications

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

- High temporal/spatial resolution space-based measurements of tropospheric (PBL) composition for application to air quality

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

➔ in line with IGACO findings

Mission concept for climate protocol monitoring applications (lower troposphere)

System: sun-synchronous LEO platform

Instrumentation: UV-vis-SWIR spectrometer for O_3, NO_2, CH_4, CO, aerosol

Mission concept for ozone and climate applications in the UTLS

System: sun-synchronous LEO platform with a limb-sounder, formation flying with Metop or other new mission with nadir-viewing instruments in order to support their tropospheric data products

Instrumentation options:
either mm-wave (MASTER derivative) or mid-IR (AMIPAS derivative)

Mission concept for air quality

Instrumentation options:

1) combined solar backscatter and thermal IR sounding
2) solar backscatter only

Mission concept for air quality - system options

Driving requirements (protocol monitoring, forecast) :

Revisit time	**0.5 – 2 h**	**Spatial resolution**	**5 – 20km**

System options:

A 1 geostationary satellite to satisfy spatio-temporal sampling requirements over Europe, and

1 LEO satellite in sun-synchronous orbit for global pollution transport (Convention on long-range transport of air pollutants, medium-range forecast)

B a constellation of 3 satellites in inclined LEO to satisfy spatio-temporal sampling requirements globally at mid-latitudes, with reduced sampling at low latitudes

C 1 satellite in sun-synchronous LEO, with local time defined to complement Metop and NPOESS diurnal sampling (afternoon orbit)

How to reach 2h revisit time at mid-latitudes with LEO constellation?

1. Increase swath width by elevating orbit altitude

- 2h revisit time with 3 sun-synchronous satellites implies 3000km orbit, at top of proton radiation level
- 3.5h revisit time at latitudes > 30º realistic with 3 sun-synchronous satellites, 900km orbit.

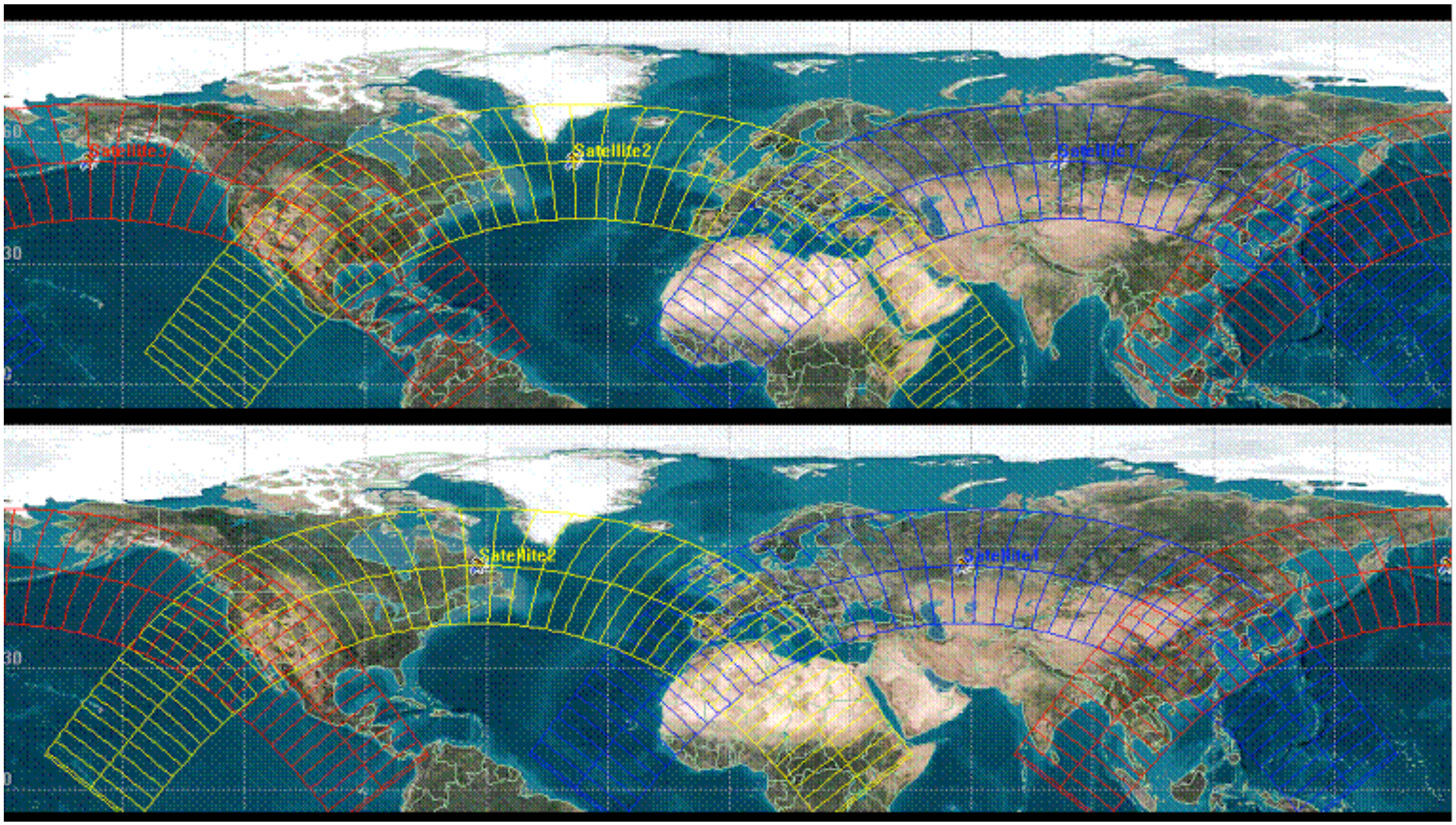
➔ **requirement not fulfilled.**

2. Use inclined orbit (non sun-synchronous)

- orbit more efficient at inhabited latitude ranges
- polar regions not covered
- 3 satellites at 900km provide 1.7 hours revisit time at mid latitudes (~35º… 65º) and reduced sampling at lower latitudes.

➔ **possible solution. High orbit desirable.**

3 satellites at 900km, 125º inclination (two consecutive orbits)



Conclusions from CAPACITY Study for GMES Sentinels 4 and 5

Conclusions for Sentinels 4 and 5

1. **Implement 1 LEO satellite with UV-VIS-SWIR payload for global air quality and climate protocol monitoring as soon as possible**

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

2. Perform trade-off between GEO+LEO and LEO constellation in inclined orbit, and complete implementation of air quality & climate protocol monitoring mission

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

3. Consolidate choice and requirements of instrument for UTLS mission for climate and ozone NRT and assessment applications, and implement the mission

	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

1. Implement 1 LEO satellite with UV-VIS-SWIR payload for global air quality and climate protocol monitoring as soon as possible

- air quality applications are developing quickly, OMI/Aura demonstrating space contribution, continuity issue arising at its end of life
- climate protocol monitoring high on the agenda – continuity of SCIAMACHY CH_4 measurements, aerosol
- technology well demonstrated in space (GOME, SCIAMACHY, OMI; also TOMS, SBUV) – no technology specific failures
- 1 LEO platform is common to all air quality system options; only orbit-specific aspects need separate consideration (e.g. stray light, solar generator, radiation)
- orbit trade-off result needed after phase A

This mission will provide continuity to existing global missions with better spatial resolution.

2. Perform trade-off between GEO+LEO and LEO constellation in inclined orbit, and complete implementation of air quality & climate protocol monitoring mission

Trade-off (during phases 0 and A) involves

- Level 2 error budgets on individual soundings
- spatio-temporal sampling under consideration of cloud
- end-user performance analysis
- maturity, cost and risk

Implementation (assuming one LEO implemented via 1.) **:**
launch of either GEO or remaining two inclined LEO platforms.

This mission will enhance the previous one to provide high temporal resolution, either regional (GEO) or quasi-global (LEO).

3. Consolidate choice and requirements of instrument for UTLS mission for climate and ozone NRT and assessment applications, and implement the mission

- monitoring of ozone, climate and stratosphere-troposphere exchange
- NRT applications now in demonstration phase (MIPAS, Aura-MLS), new hypotheses on stratospheric precursors of weather patterns
- support to tropospheric missions via vertical resolution
- choice of instrument type (mm-wave or mid-IR limb-sounder) depends on priorities of applications
- prototype instrument specifications exist – need to be tailored towards operational applications

The Link to EUMETSAT

The Link to EUMETSAT

- Atmospheric chemistry applications depend on accurate dynamics fields, and some of them are natural extensions of NWP
- Eumetsat has already integrated a basic set of atmospheric chemistry observations on **Metop / EPS (GOME-2, IASI)**
- Eumetsat user consultation for **MTG** and **post-EPS** in cooperation with ESA, ESA performing phase 0 system studies
- UV-VIS sounder and IR sounder with chemistry capabilities being considered for MTG – implementation unclear
- Application experts group for atmospheric chemistry working on post-EPS observational requirements, on basis of ESA Capacity study results
- Eumetsat “natural” agency for operation of GMES sentinels 4 and 5 – precise arrangement between EC, ESA and Eumetsat to be defined

Considerations for post-EPS timeframe

(seen as extension of CAPACITY requirements)

- **air quality / climate protocol monitoring mission needs nadir-viewing** thermal IR sounder (IASI replacement)

- **Global total ozone** data needed, options:
  - **UV-VIS nadir sounder on LEO AQ mission** in sun-synchronous orbit, or on any other platform in polar orbit;

  an alternative might be
  - **mm-wave or thermal IR limb-sounder on UTLS mission**.