CEOS-ACC-12, AQ Session, 13 Oct 2016, Seoul, Korea

The Sentinel-4 Mission

& Atmospheric Composition Products

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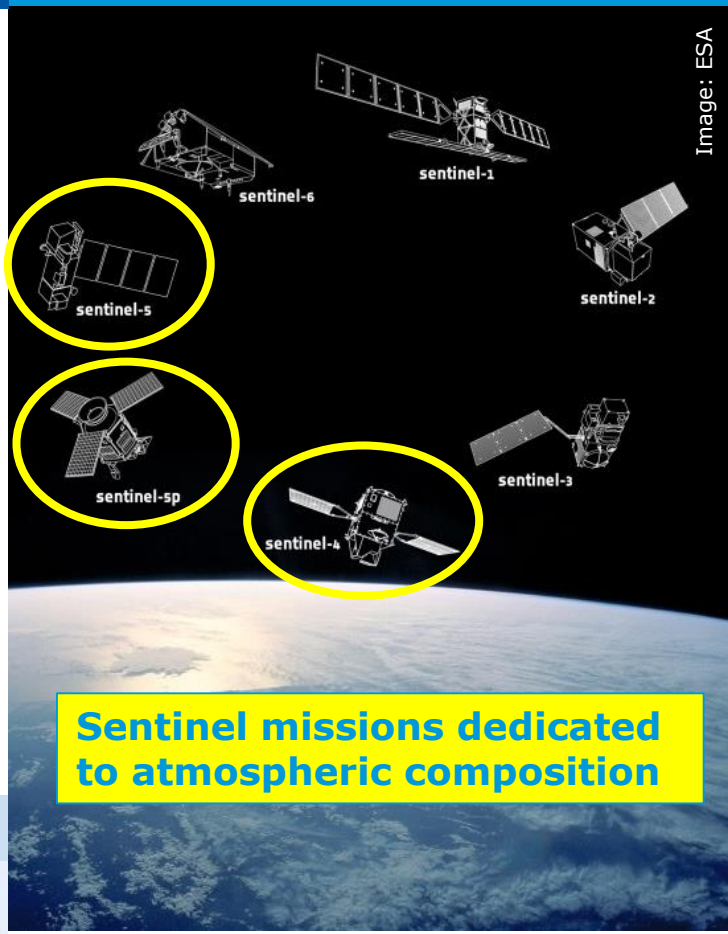
esa sentinel-4 opernicus

Copernicus

sentinel-4
esa

- European system for monitoring
  land, marine, atmosphere, climate change,
  emergency management, security
- Observations from
  satellites, ground-based, air-borne sensors
- Space Component:
  Sentinel missions by European Space Agency
- For policymakers, public authorities, …, citizens

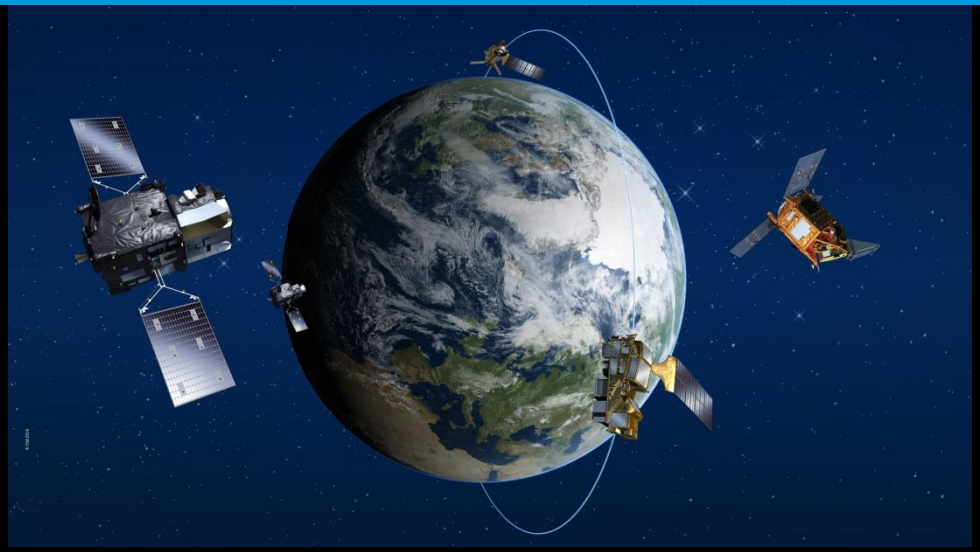


Copernicus Atmosphere Monitoring Services

Air Quality and Atmospheric Composition | Climate Forcing | Ozone Layer & UV | Solar Radiation | Emissions and Surface Fluxes

Copernicus Missions for Atmospheric Composition

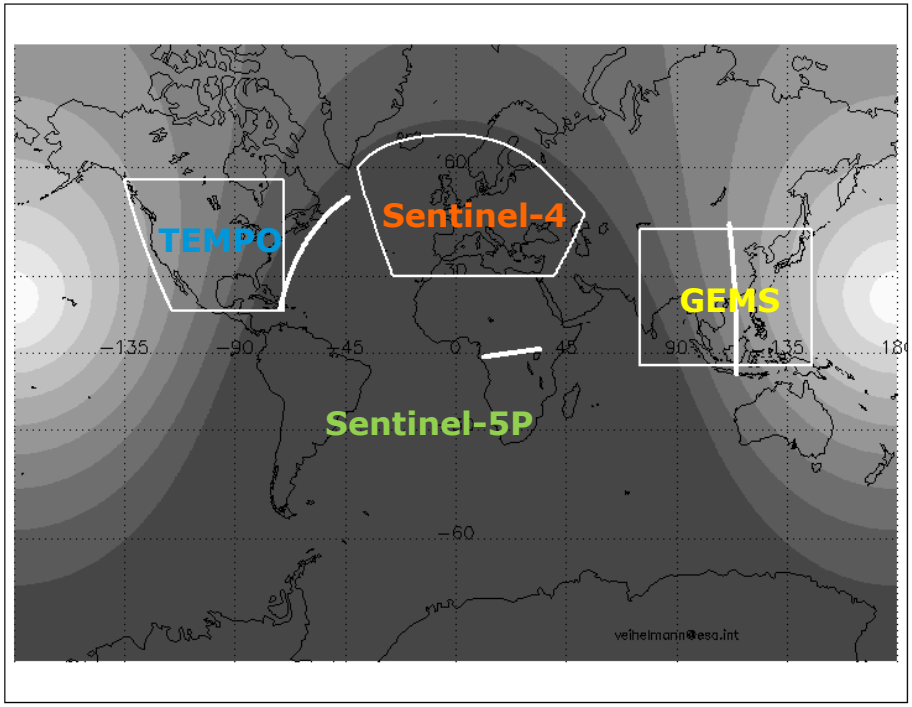
sentinel-4
esa

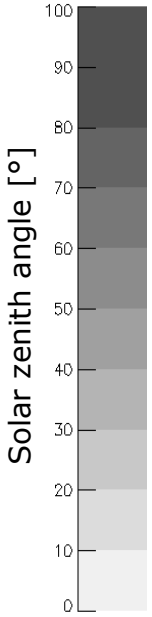


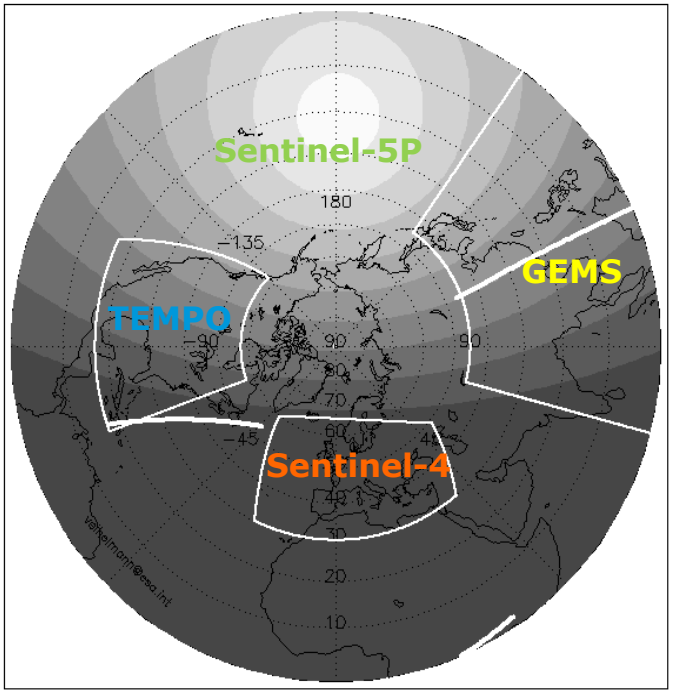
	Sentinel-4	Sentinel-5 & 5 Precursor
Focus	short lived species in troposphere	Short and long lived species in troposphere and stratosphere
Orbit	Geostationary	Low Earth Orbit
Sampling	Hourly over Europe	Daily global
Air Quality	NO_2, O_3, aerosol, SO_2	NO_2, O_3, aerosol, SO_2, CO
Climate	aerosol, O_3	CH_4, CO, aerosol, O_3
Ozone & UV	O_3, cloud, aerosol	O_3, cloud, aerosol
Emissions	NO_2, SO_2, aerosol, HCHO, CHOCHO	NO_2, SO_2, aerosol, HCHO, CO, CH_4

CEOS Atmospheric Composition Virtual Constellation (ACVC)

http://ceos.org/ourwork/virtual-constellations/acc

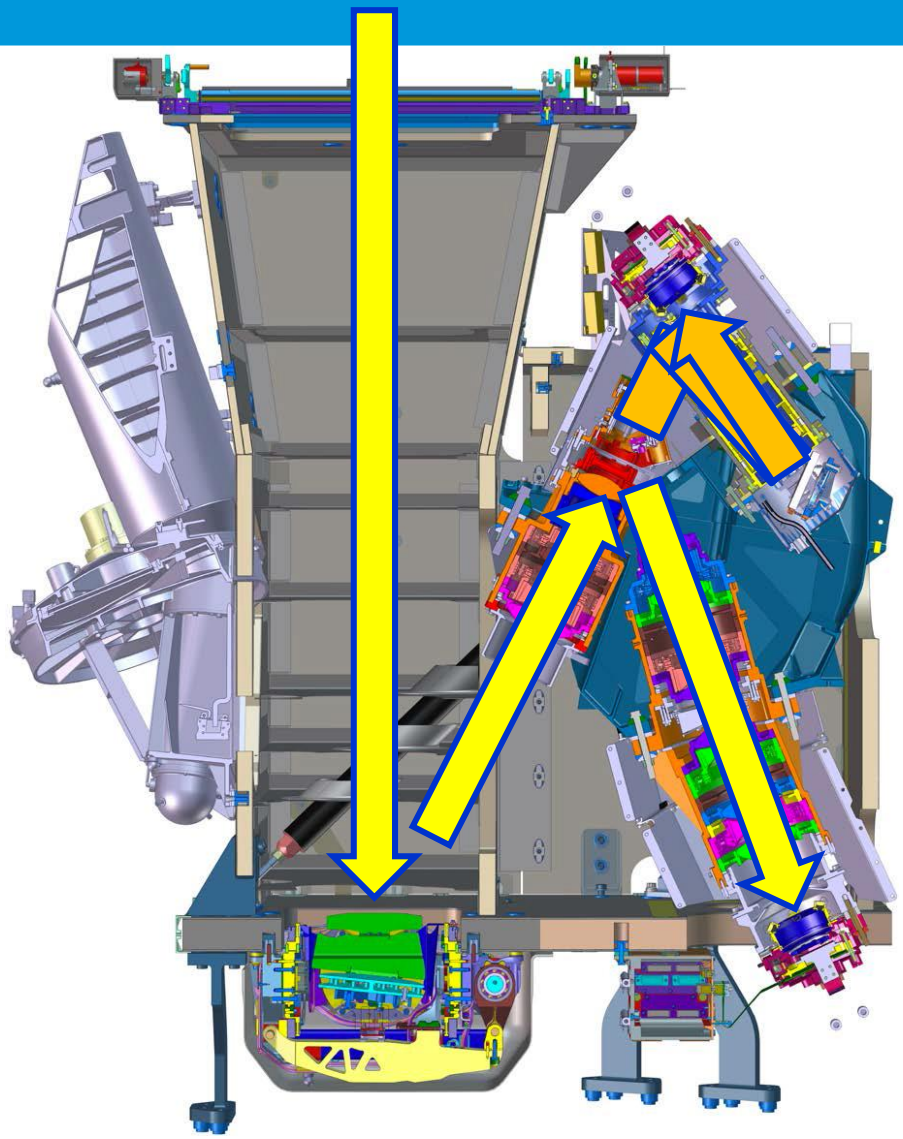




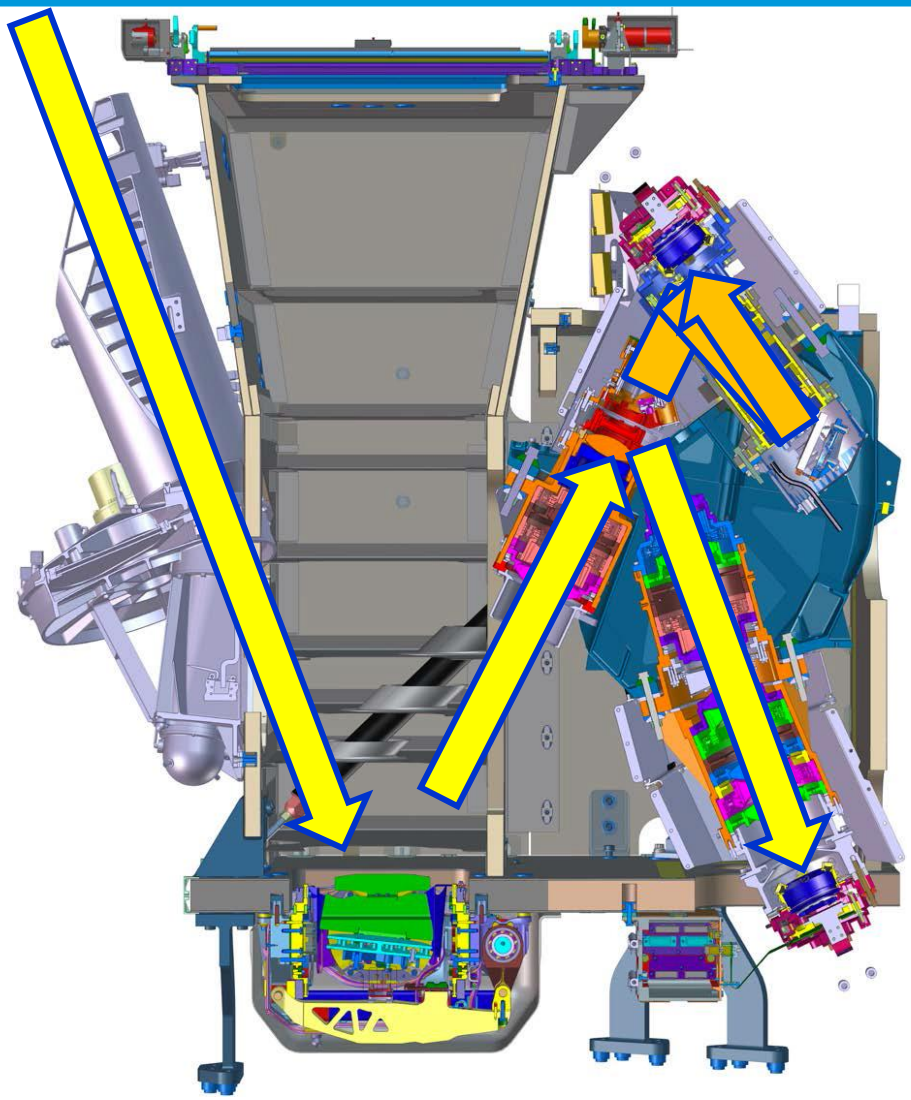


	USA TEMPO	Europe Sentinel-4	Korea GEMS	Sentinel-5/-5P
Orbit	Geostationary	Geostationary	Geostationary	LEO
Domain	North America	Europe and surrounding	Asia-Pacific	global
Revisit [h]	1 hour	1 hour	1 hour	Daily, more @ higher lat
Spectral ranges	UV-Vis	UV-Vis-NIR	UV-Vis	UV-Vis-NIR-SWIR
Key products	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO (TBC), aerosol	O_3, NO_2, SO_2, HCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol, CH_4, CO, …
Spatial res. [km²]	9 x 5 at 35°N	8 x 8 at 40°N	8 x 7, 8 x 3.5 at 38°N	7 x 7 at nadir

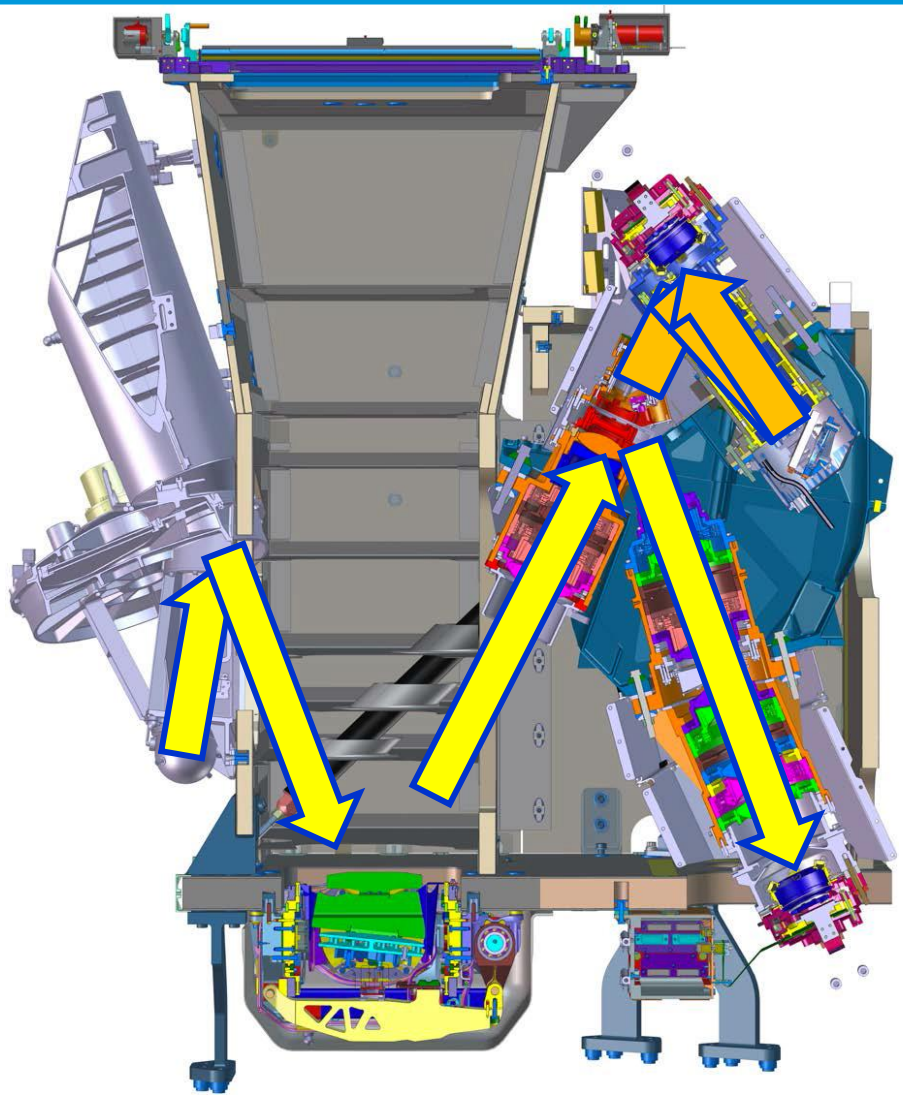
S4/UVN Instrument View



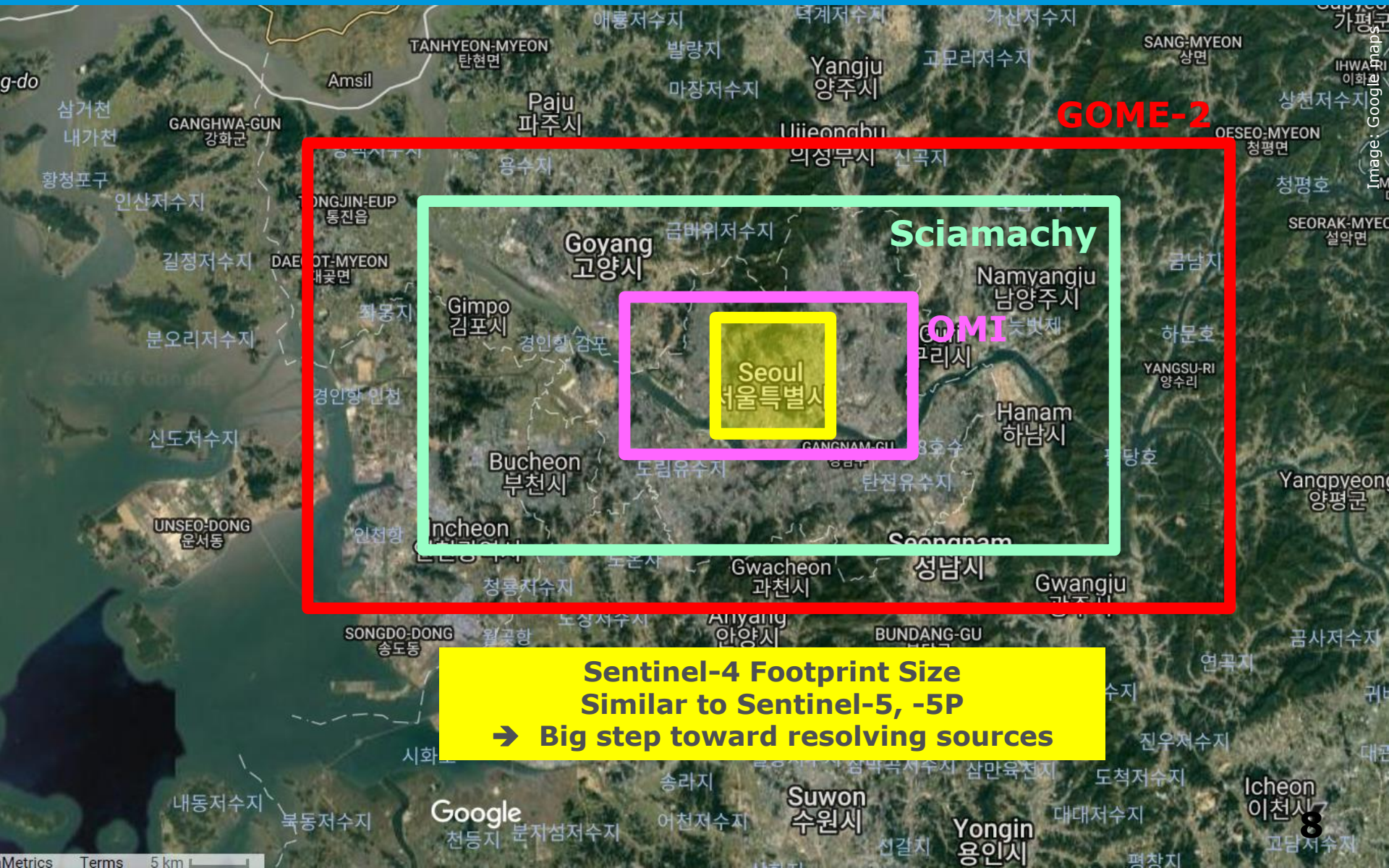
S4/UVN Instrument View



S4/UVN Instrument View



Sentinel-4/UVN Footprint Size



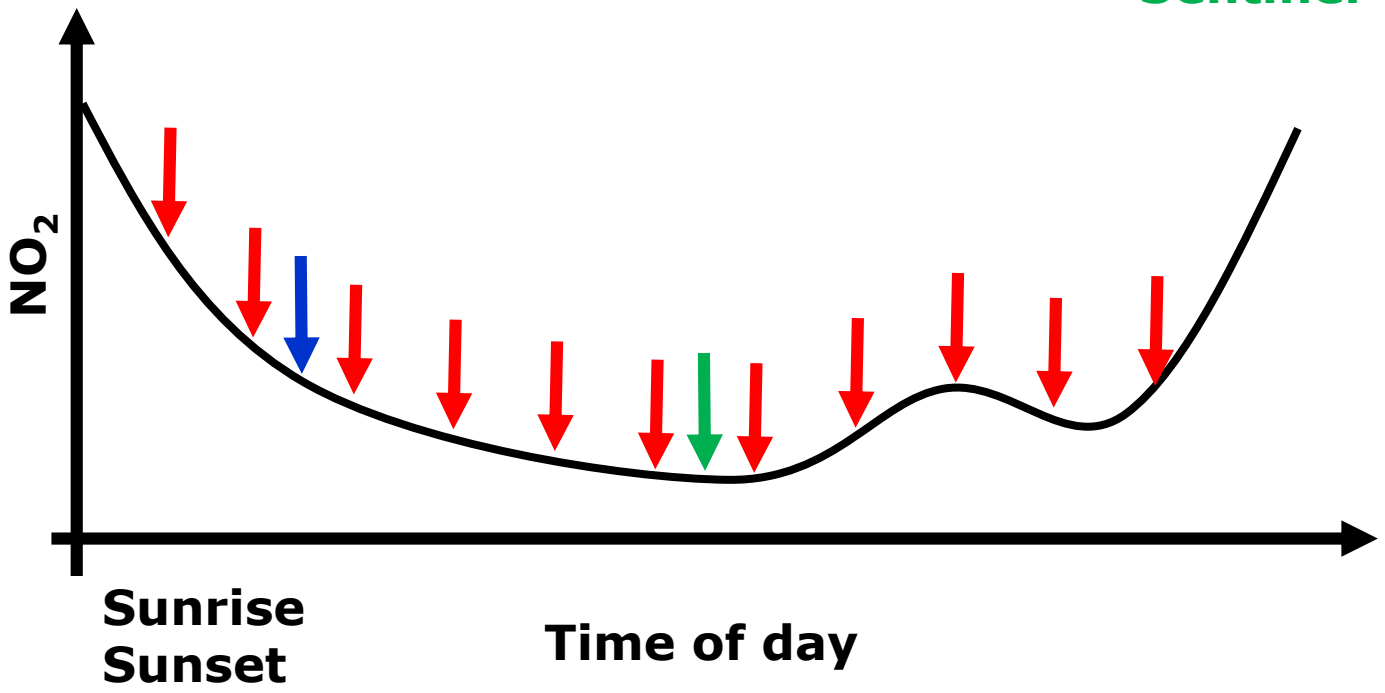
Sentinel-4 Footprint Size
Similar to Sentinel-5, -5P
➔ Big step toward resolving sources

Sentinel-4/UVN Temporal Sampling

Sentinel-4

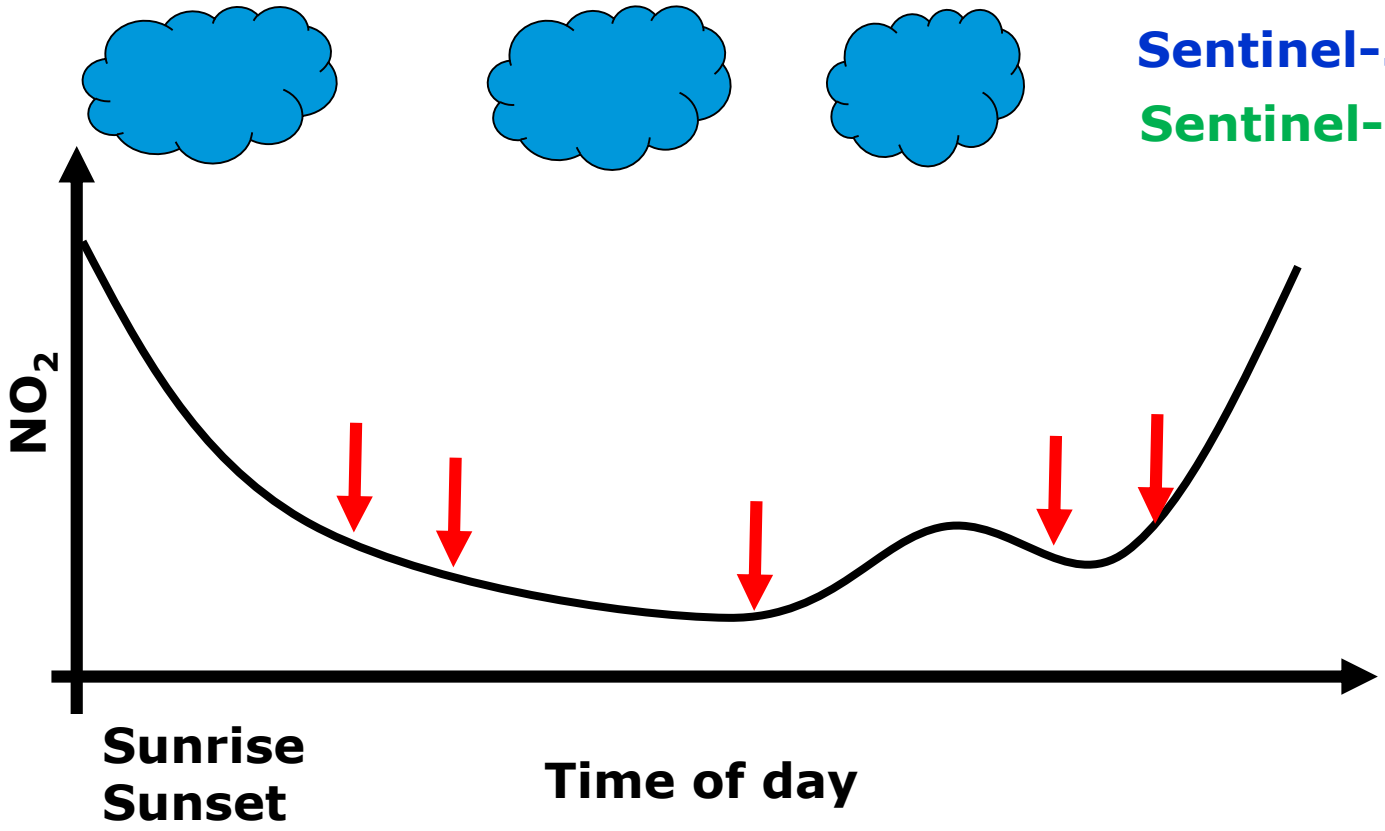
Sentinel-5

Sentinel-5 Precursor



Sentinel-4 will provide diurnal cycle information

Sentinel-4/UVN Temporal Sampling



Sentinel-4 will enhance the likelihood for N≥1 cloud free observations per day

Sentinel-4/UVN
Spectral & Radiometric Performance

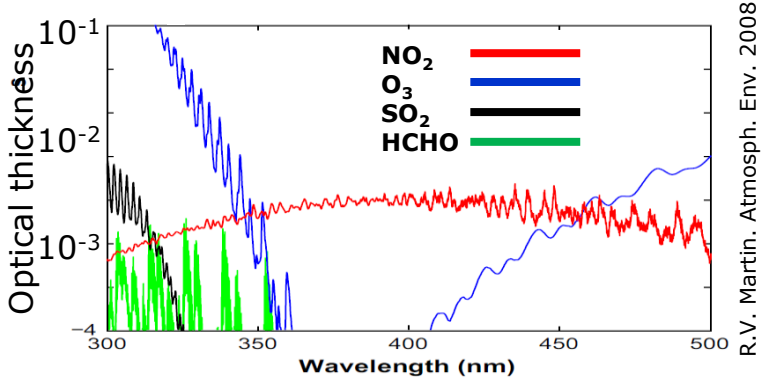
Band ID	Wavelength range [nm]	Spectral resolution [nm]	Spectral sampling ratio
UV	305 - 400	0.5	3
VIS	400 – 500	0.5	3
NIR	750 – 775	0.12	3

Low sensitivity to polarisation (1%)

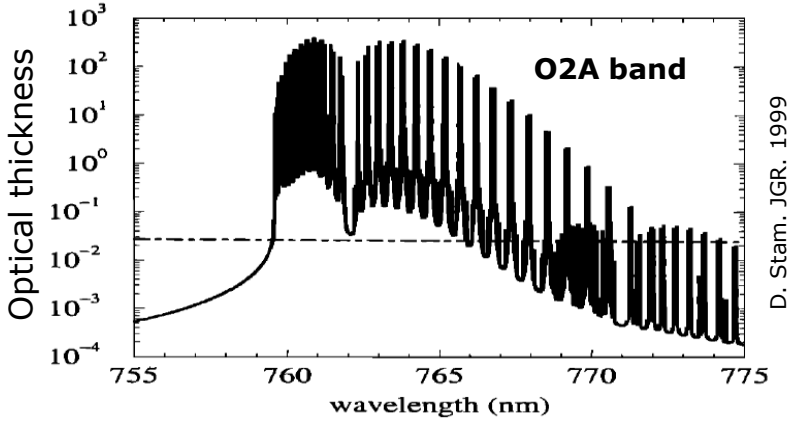
Low level of spectral features (0.05%)

High radiometric accuracy: 3% (thresh.), 2% (goal)

High Signal to Noise Ratio (goal 1800 in vis)



R.V. Martin. Atmosph. Env. 2008



D. Stam. JGR. 1999

Level-2 processors extract information on

- **Trace gas amounts** from absorption signatures
- **Aerosol & clouds & surface** from continuum signal
- **Aerosol & cloud height** from O_2A band

Sentinel-4 Products

Level	Product	Parameter
L1b	Earth radiance UV-vis	Earth radiance, spectr. & radiom. calibrated, geolocated, UV-vis
L1b	Earth radiance NIR	Earth radiance, spectr. & radiom. calibrated, geolocated, NIR
L1b	Solar irradiance	Spectrally and radiometrically calibrated Solar irradiance
L1b	DPPF	L1b data processing parameters
L1b	Star	Star calibration data
L1b	Calibration	Calibration data
L2	Total Ozone	Total O_3 column
L2	Tropospheric Ozone	Tropospheric O_3 sub-column
L2	Trop. Ozone Complement (TBC)	Tropospheric O_3 sub-column retrieval diagnostic information
L2	Tropospheric Nitrogen Dioxide	NO_2 total column, tropospheric sub-column
L2	Sulfur Dioxide	SO_2 total column
L2	Formaldehyde	CH_2O total column
L2	Glyoxal (TBC)	CHOCHO total column
L2	Aerosol Index	Aerosol absorbing index
L2	Aerosol Layer Height	Aerosol layer height
L2	Cloud Properties	Cloud optical thickness, fraction, altitude
L2	Surface Reflectance	Surface reflectance (LER and BRF), aerosol optical thickness
L2	Gapless Surface Reflectance	Surface reflectance (LER and BRF), aerosol optical thickness
L2	Cloud Mask Support	FCI-L2 Cloud Mask data regridded to S4 L1b radiance
L2	Cloud Analysis Support	FCI-L2 Optimal Cloud Analysis data regridded to S4 L1b radiance
L2	Cloud Imager Support	FCI-L1c spectral subset regridded to S4 L1b radiance
eng	Forecast meteorological data	ECMWF forecast met data, extracted, regridded and converted
eng	Forecast composition data	CAMS forecast composition data, extracted, regridded and converted
eng	Stratospheric correction for NO2	Stratospheric NO2 sub-column data
eng	Background correction for NO2	Background NO2 data
eng	Background correction for SO2	Background SO2 data
eng	Background correction for HCHO	Background HCHO data
eng	Background corr. for CHOCHO	Background CHOCHO data
eng	Forecast snow and ice data	NISE forecast snow & ice data extracted, regridded and converted

Level-2 Target Performances

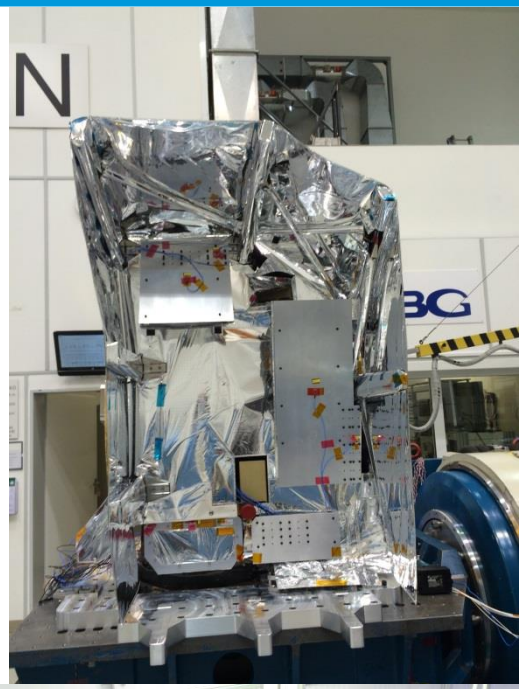
Species	Uncertainty	Conditions (#)
O_3 total col	3% (goal) / 4% (threshold)	all cloud conditions
O_3 tropospheric col	25% (goal) / 40% (threshold)	cloud fraction < 20%
NO_2 tropospheric col	$1.5*10^{15}$ molec/cm² or 30% (goal) / 50% (threshold)	cloud fraction < 20%
HCHO total col	$1.5*10^{16}$ molec/cm² or 50% (goal) / 100% (threshold)	cloud fraction < 20%
SO_2 total col	$1.0*10^{16}$ molec/cm² or 80% (goal) / 100% (threshold)	cloud fraction < 20%, pollution cases
CHOCHO total col	$7.0*10^{14}$ molec/cm² or 50%	total col > $5.0*10^{14}$ molec/cm², cloud fraction < 20%
Aerosol Optical Depth	0.05 (from surface product)	cloud-free
Aerosol Layer Height	1 km	AOD > 0.3 at 760 nm, layer height > 1.5 km
Aerosol Index	0.3 (goal) / 0.5 (threshold)	all cloud conditions
Surface	first BRF parameter 0.01	cloud-free
Clouds	TBD by L2 developers	

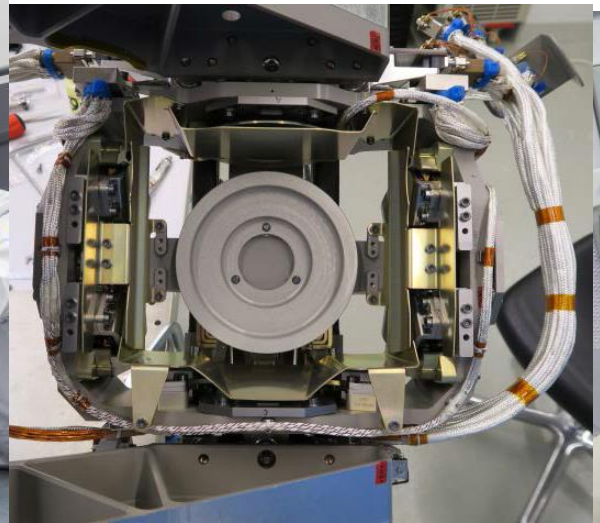
(#) For all species: solar zenith angle and viewing zenith angle < 60°

Implementation Status

Space Component Development lead by ESA

- UVN Instrument & Instrument Quality Tool, incl Instrument Data Simulator and Level-1b Prototype Processor
- Airbus Defence & Space prime contractor
- Unit level detailed design and implementation, H/W and S/W development, manufacturing, and testing
- Critical Design Review Q4 2016
- Proto Flight Model and Flight Model 2 delivery to MTG 2019





Implementation Status

- Level-2 Processor Development lead by ESA
  - Algo breadboarding, independent verification, operational processor
  - DLR prime contractor
  - System Requirements Review June 2016
  - Preliminary Design Review with external ATBD review end 2016
  - Acceptance Reviews: AR1 end 2018, AR2 end 2019, AR3 after launch

Implementation Status

- Ground Segment Development and Operations lead by EUMETSAT
  - Ground Stations and Mission Operations Facilities
  - Data Processing Facility (in which S4 processors will run)
  - Multi-Mission Elements for data archiving, distribution, and product quality monitoring
- EUMETSAT will
  - operate the Sentinel-4/UVN instrument and
  - process the mission data up to Level-2
- Copernicus Atmosphere Monitoring Service (CAMS)
  - exploit S4 data and generate higher level products
  - implemented by ECMWF
  - operational → http://atmosphere.copernicus.eu
  - Workshop Atmospheric Composition OSSEs: 9-11 Nov 2016 @ECMWF

CEOS-ACVC Targets

1. **Best practices for calibration, characterization, and validation**
   - Share / cross review calibration/characterization plans
   - Post-launch validation strategies (e.g. instrumentation round-robins, joint campaigns)
2. **Radiometric consistency**
   - Post-launch approaches (eg LEO vicarious intercalibration or Earth scenes, GSICS UV-vis)
3. **Sharing and consistency of data products (format, content, metadata)**
   - Share specification documents, sample data, instrument characterization
   - Constellation data products (may differ from standard products)
4. **Consistency in retrieval algorithms and spectroscopy**
   - Cross participation in ATBD reviews
   - Jointly improve retrieval algorithms, inter-comparisons on common radiances
5. **Support scientific collaboration**
6. **Open data policy**

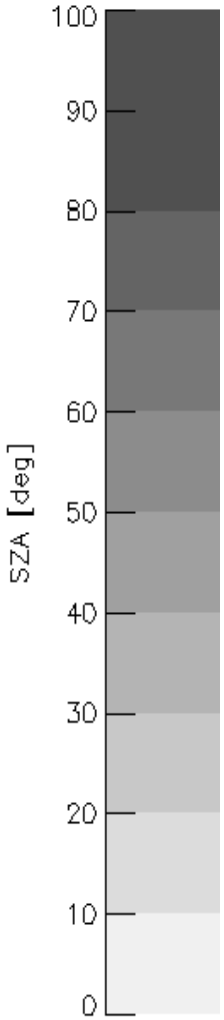
Sentinel-4 is designed to

- **measure atmospheric composition**
- **with hourly revisit time**
- **over Europe**
- **operationally over 15 years**
- **focussing on air quality**
- **for the Copernicus Atmosphere Monitoring Service**

Ben Veihelmann, Sentinel-4 Mission Scientist and the Sentinel-4 Team, ESA/ESTEC
Eumetsat Conference, Darmstadt, Germany, Sept 2016

BACKUP SLIDES

Sentinel-4/UVN Scan Strategy



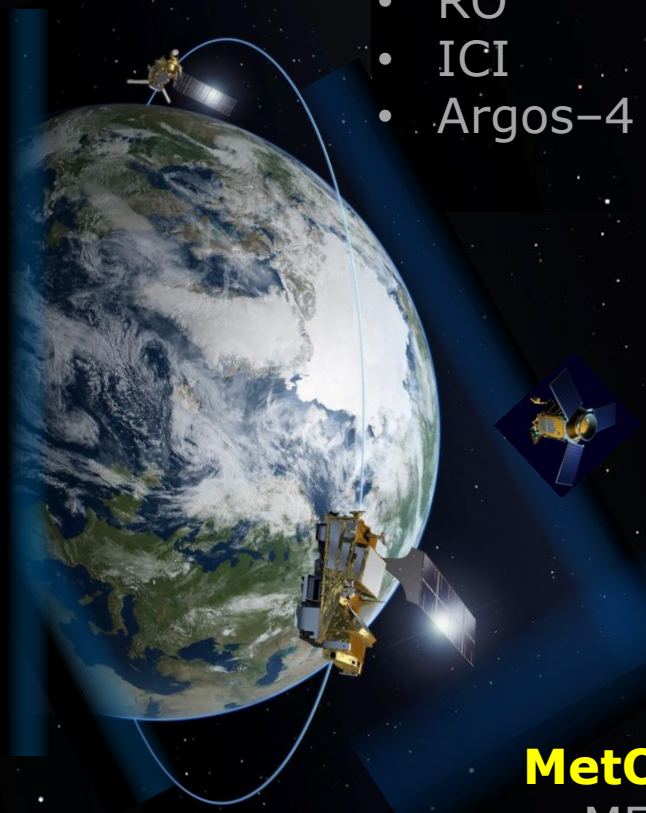
Instantaneous Field of View

SZA = 90 °

SZA = 92°

MetOp-SG B
- SCA
- MWI
- RO
- ICI
- Argos–4

MTG-S
- IRS
- Sentinel-4



Sentinel-5P
- TROPOMI

MTG-I
- FCI
- LI

MetOp-SG A
- METimage
- IASI-NG
- MWS
- RO
- Sentinel-5
- 3MI

Thank you!

Ben Veihelmann, Norrie Wright, Olivier Le Rille, Yasjka Meijer, Grégory Bazalgette Courrèges-Lacoste, Giorgio Bagnasco, ESA/ESTEC

Graphics: ESA

Sentinel-4 Level-2 Product Portfolio

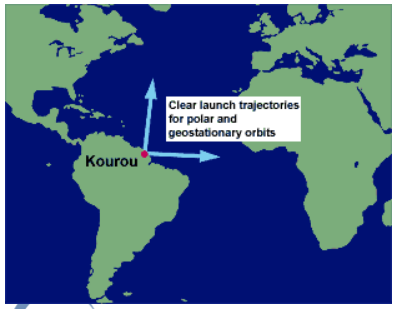
Species	Relevance	
	Air quality	Other
Ozone (O_3)	Toxic, irritates lung and soft tissue, regulated(*)	Reduces plant growth, greenhouse gas, controls oxidising capacity of atmosphere, controls surface UV
Nitrogen Dioxide (NO_2)	Toxic, production of O_3 and nitrate aerosol, regulated(*)	Acid rain
Sulfur Dioxide (SO_2)	Toxic, production of sulphate aerosol, regulated(*)	Acid rain, tracer for volcanic emissions
Formaldehyde (HCHO)	Influences production of O_3 and CO	Volatile Organic Compounds emission estimates
Glyoxal (CHOCHO)	Influences production of O_3 and CO	Volatile Organic Compounds emission estimates
Aerosol or Particulate Matter (PM)	Pulmonary and cardiovascular diseases, regulated(*)	Direct and indirect climate effect, controls cloud formation, aviation control (volcanic ash)
Cloud characteristics		Auxiliary for other products
Surface characteristics		Auxiliary for other products

*) by European Standards: http://ec.europa.eu/environment/air/quality/standards.htm

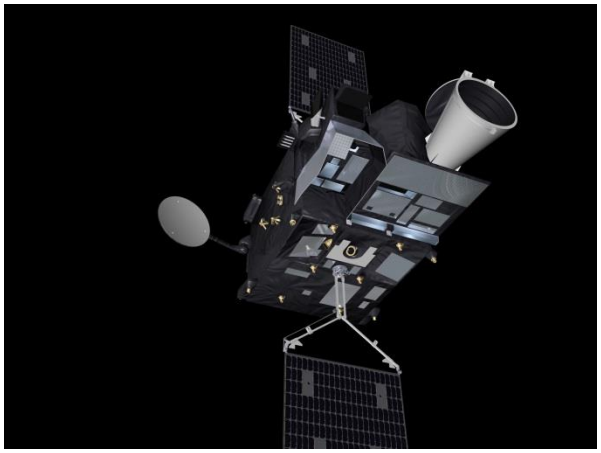
Sentinel-4 Mission Architecture

Launch Segment

Launch Vehicle
Ariane 5



Observatory Segment

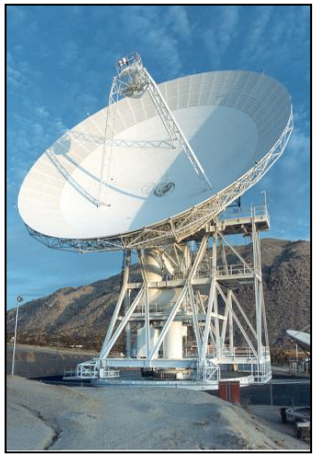


Two MTG-Sounder (MTG-S) S/Cs

Four MTG-Imager (MTG-I) S/Cs

Payload
- Flexible Combined Imager on MTG-I
- Lightning Imager on MTG-I
- Infra-Red Sounder on MTG-S
- Sentinel-4/UVN on MTG-S

Ground Segment

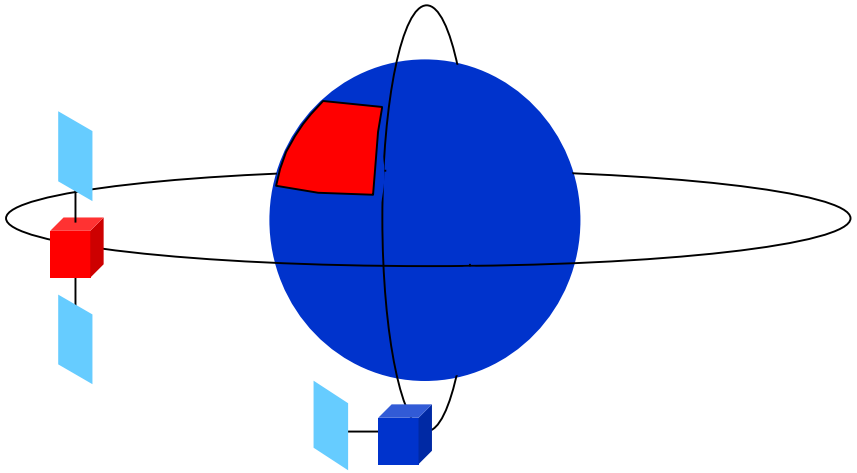


Flight Operations Segment

P/L Data Ground Segment

Ground Station(s)

The Atmospheric Sentinel Missions



GEOstationary (GEO)

- Hourly revisit time over Europe
- Mainly air quality
- Diurnal cycle of tropospheric composition

→ **Sentinel-4**

Low Earth Orbit (LEO)

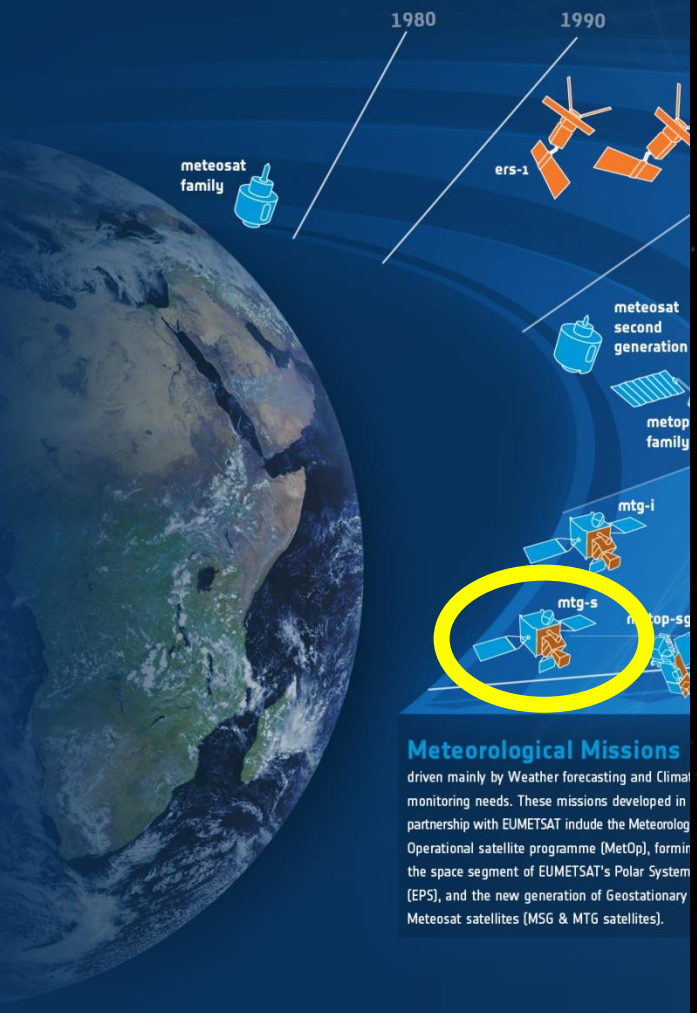
- Daily revisit time global coverage
- Climate, air quality, ozone & UV
- Tropospheric & stratospheric composition

→ **Sentinel-5**

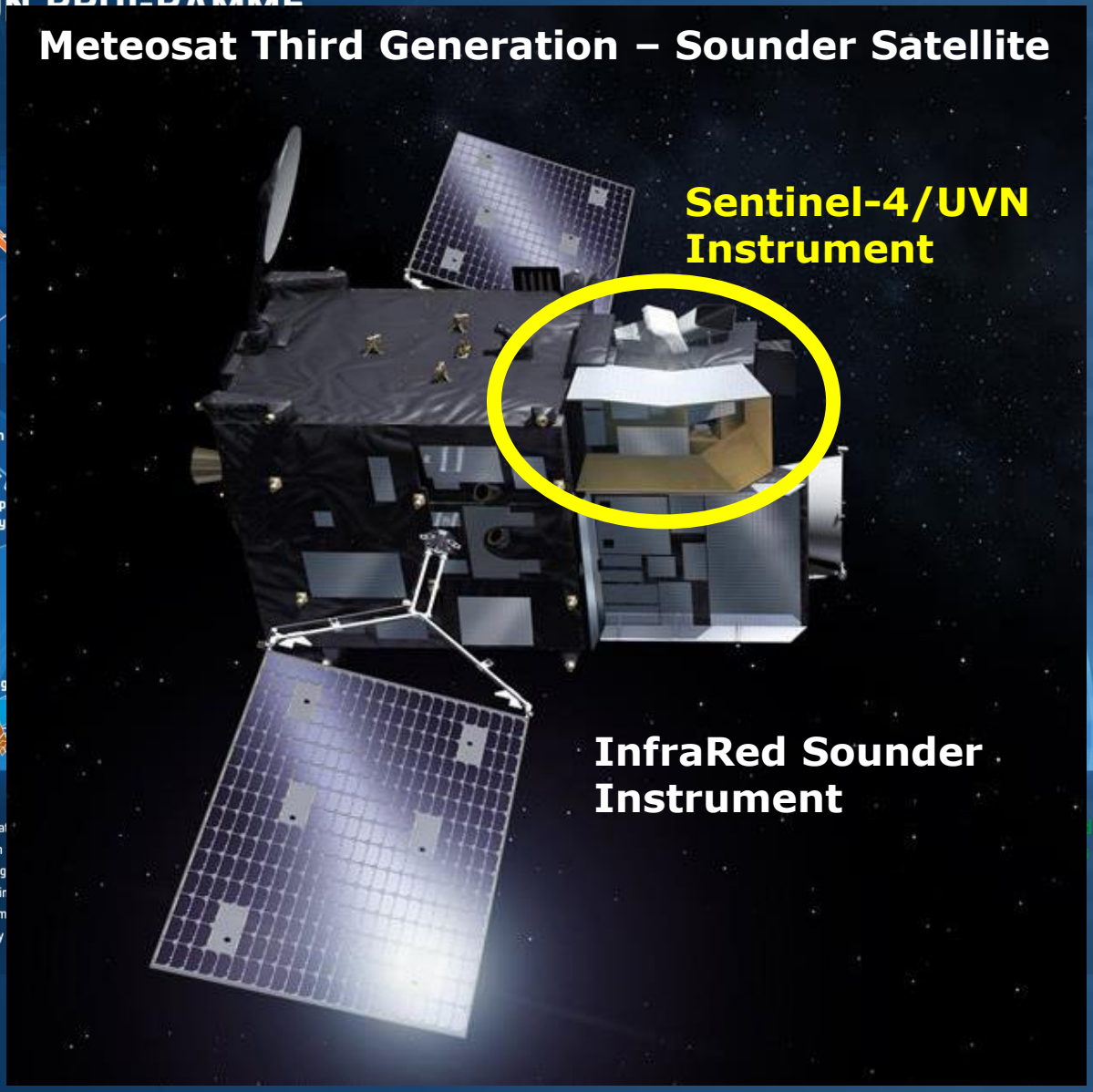
→ **Sentinel-5 Precursor**

	L.T.	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Sentinel-5p	13.30h																									
Sentinel-4 - 1	geo																									
Sentinel-4 - 2	geo																									
Sentinel-5 - 1	09.30h																									
Sentinel-5 - 2	09.30h																									
Sentinel-5 - 3	09.30h																									

→ THE ESA EARTH OBSERVATION PROGRAMME



Meteosat Third Generation – Sounder Satellite



Graphic ESA

Sentinel-4 Mission Objective

Sentinel-4 is designed to provide

- Tropospheric composition measurements
- With fast revisit time
- At high spatial resolution over Europe
- Operationally over 15 years
- For the Copernicus Atmosphere Monitoring Services

http://atmosphere.copernicus.eu