



Satellite missions for atmospheric composition examples

Stelios Kazadzis, PMOD World Radiation Center

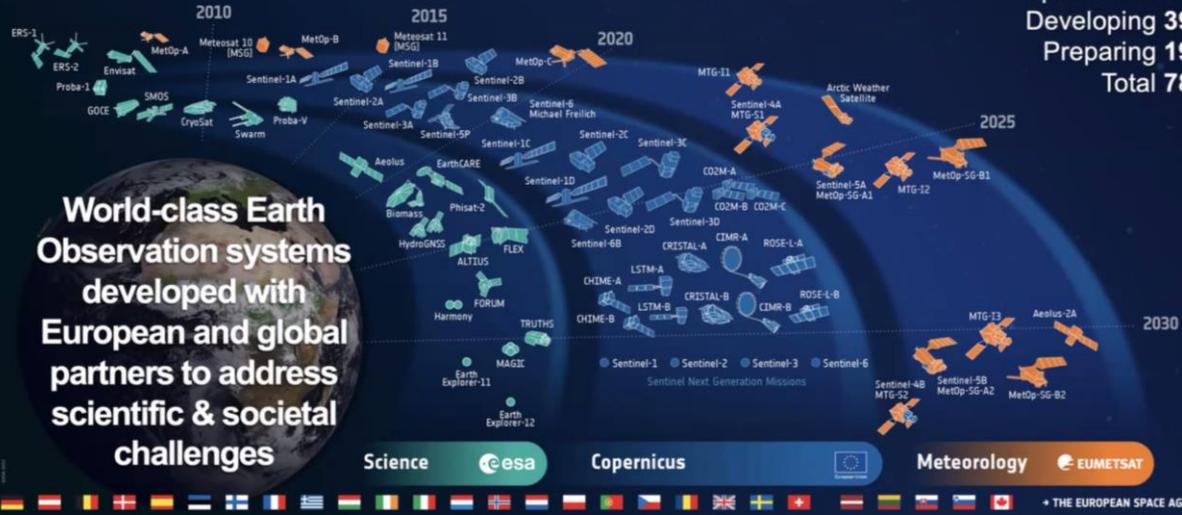
Atarri Workshop: “Aerosol microphysical properties and solar radiation” and Training “GRASP model use”

6–7 March 2025, Limassol, Cyprus

ESA's Earth Observation Activities

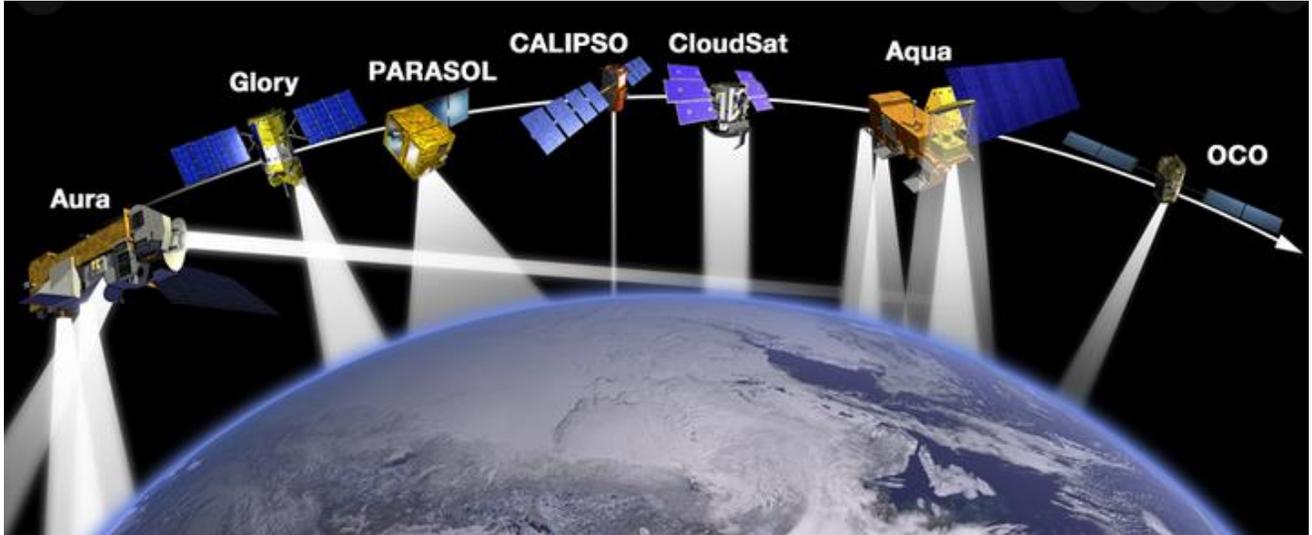


Satellites
 Heritage 06
 Operational 14
 Developing 39
 Preparing 19
Total 78

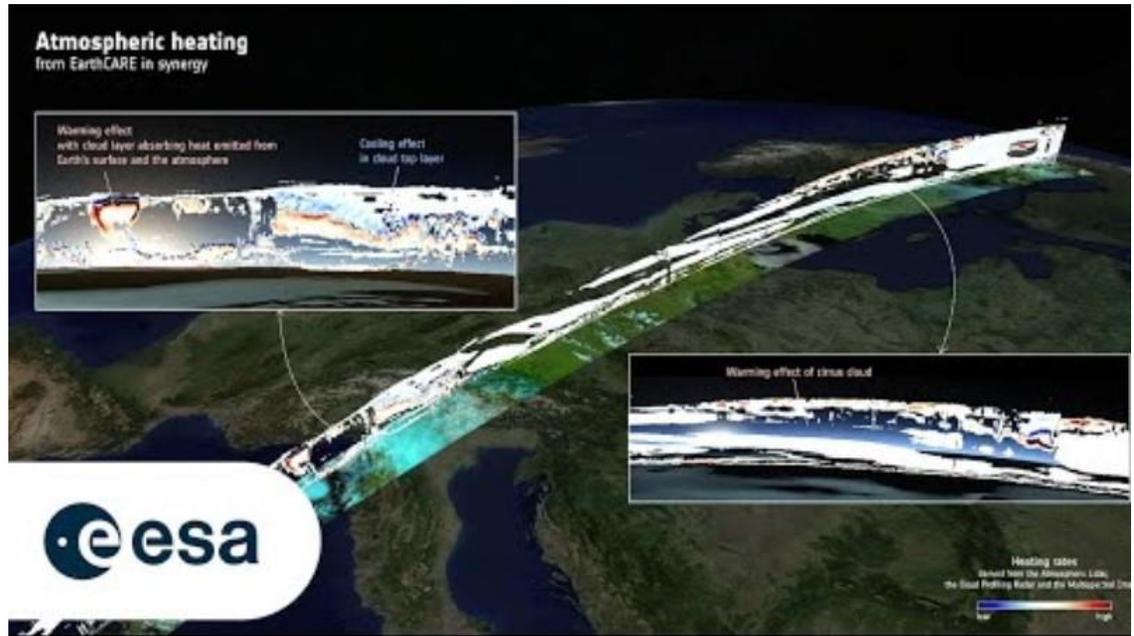


Slide by T. Fehr

A Train



SATELLITE OVERVIEW



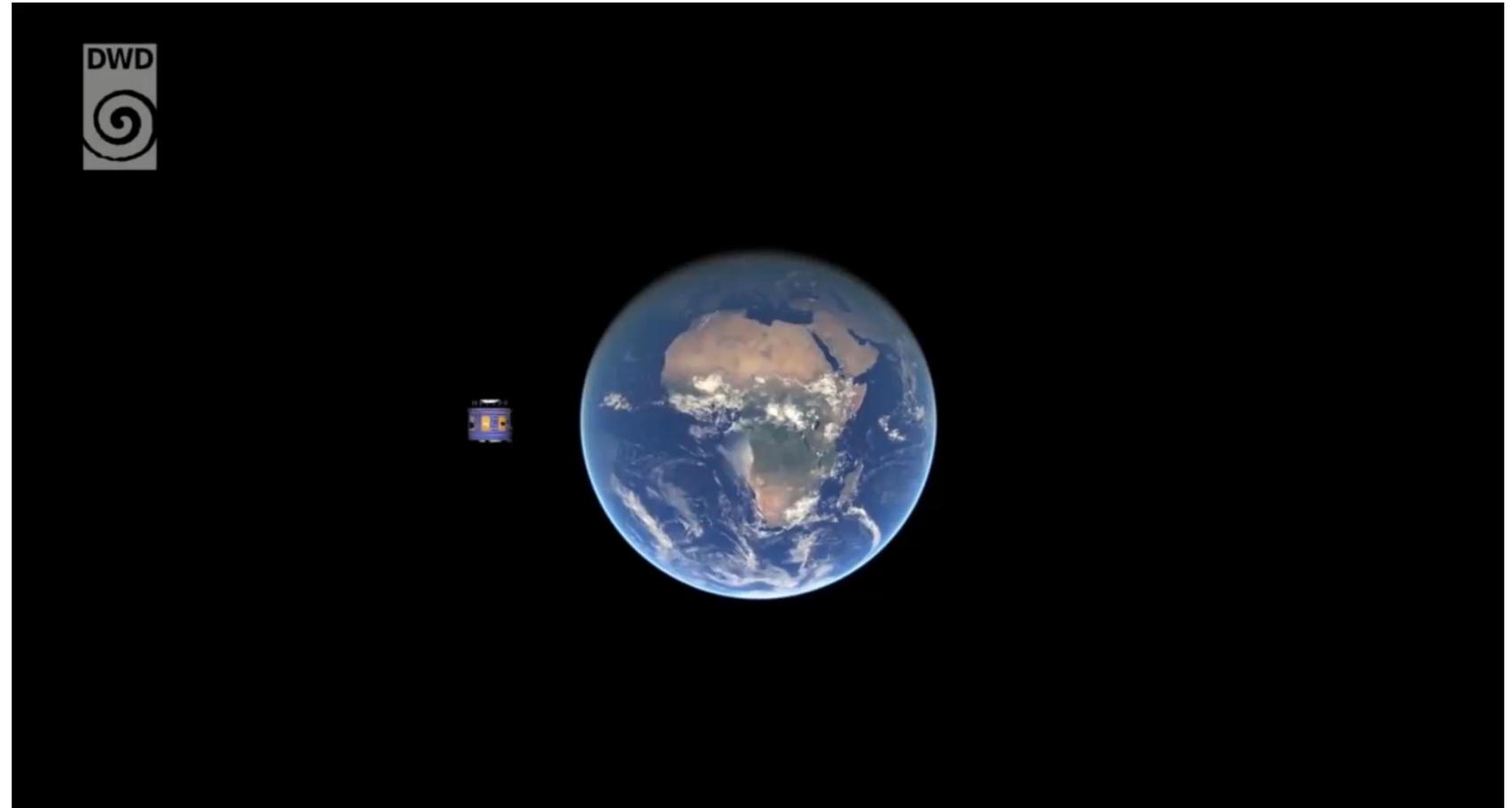
Satellites – Atmospheric remote sensing

Polar Orbiting

Global coverage vs temporal resolution

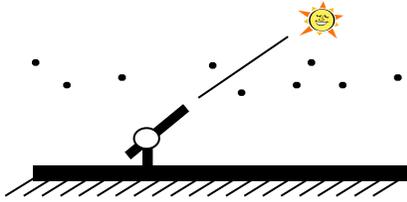
Geostationary

High temporal resolution vs limited coverage

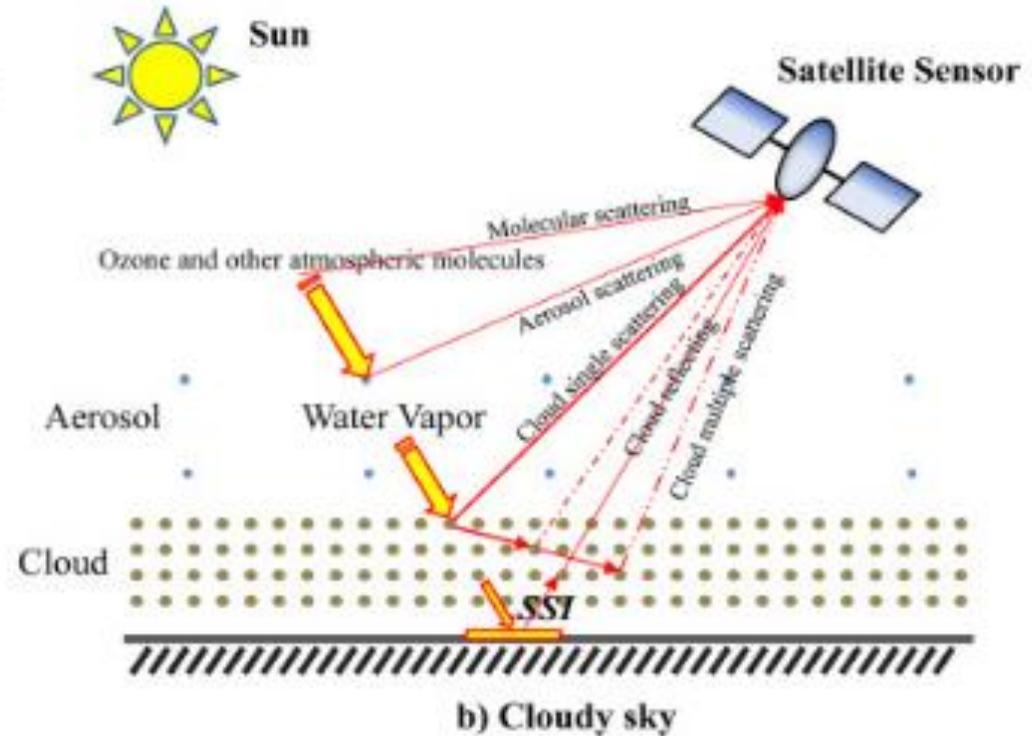
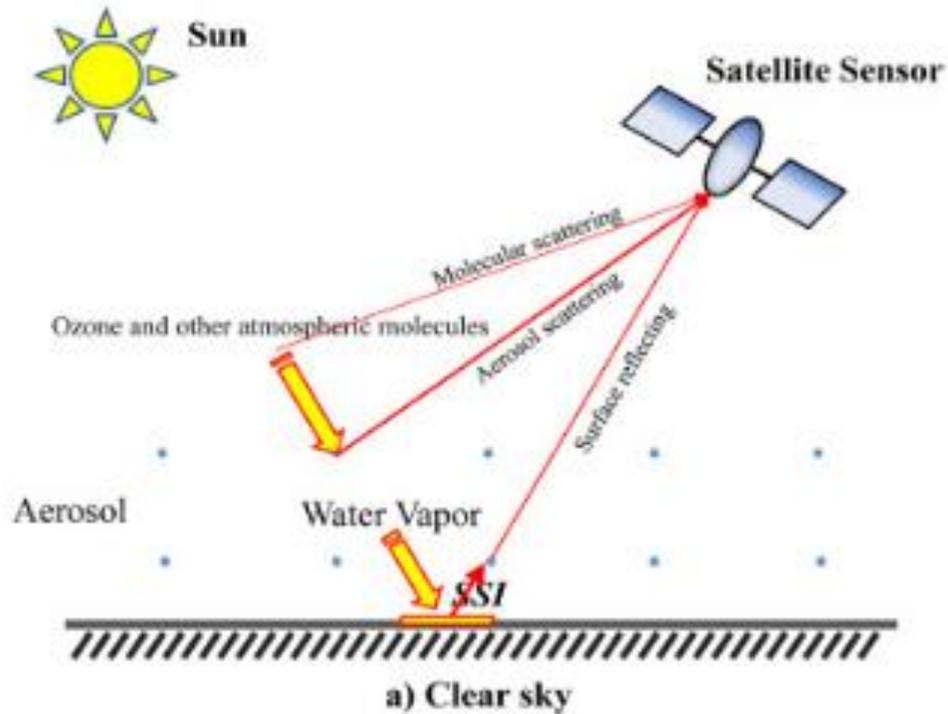


Polar Orbiting

satellite measurements: more difficult !!



Surface measurement - atmosphere – source (sun)



MODIS: Moderate Resolution Imaging Spectroradiometer

- MODIS is a key instrument aboard Terra and Aqua satellites
 - Terra passes from north to south across the equator in the morning
 - Aqua passes south to north over the equator in the afternoon

Specifications

Orbit: 705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular

Scan Rate: 20.3 rpm, cross track

Swath Dimensions: 2330 km (cross track) by 10 km (along track at nadir)

Telescope: 17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop

Size: 1.0 x 1.6 x 1.0 m

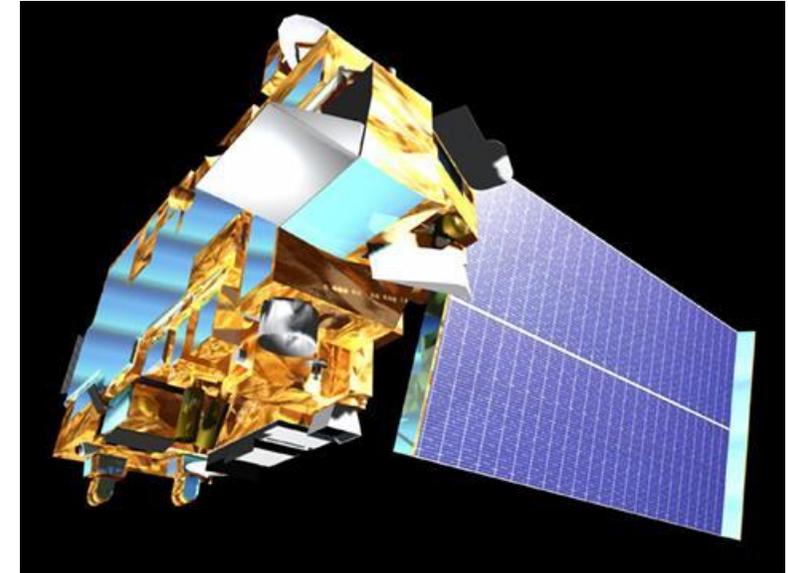
Weight: 228.7 kg

Power: 162.5 W (single orbit average)

Data Rate: 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)

Quantization: 12 bits

Spatial Resolution: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36) Design Life: 6 years



Terra is a multi-national, multi-disciplinary mission



Aqua is NASA's Earth Science satellite mission

MODIS: Specifications

Primary Use	Band	Bandwidth ¹	Spectral Radiance ²	Required SNR ³
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/Phytoplankton/Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

Primary Use	Band	Bandwidth ¹	Spectral Radiance ²	Required NE[Δ]T(K) ⁴
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	0.20
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

MODIS: Algorithm Theoretical Basis Documents (ATBD)

- physical theory and mathematical procedures
- assumptions applied to convert radiances received by instruments to geophysical quantities

Level 1 ATBD's

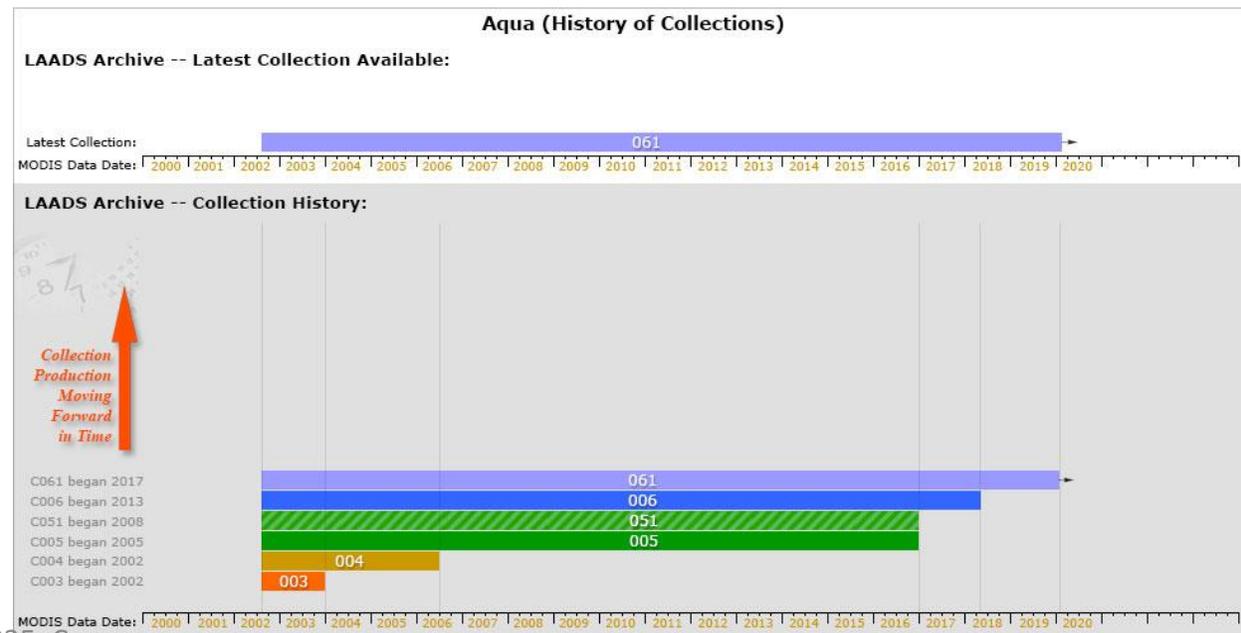
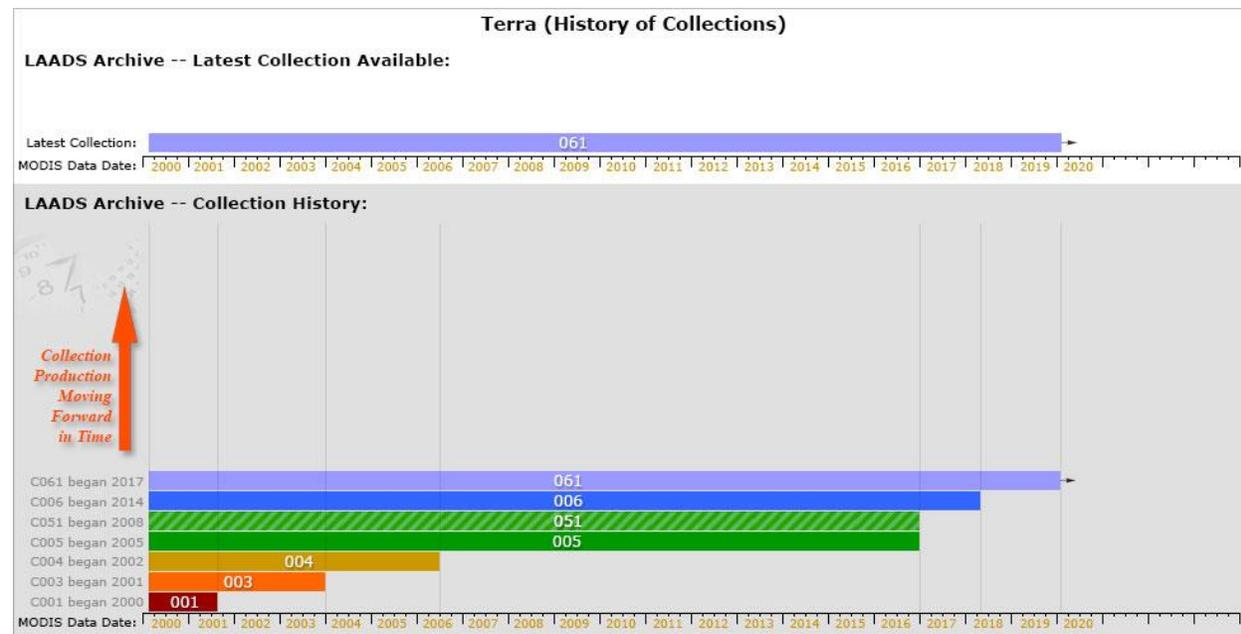
<http://mcst.gsfc.nasa.gov/content/l1b-documents>

Atmosphere ATBD's

<http://modis-atmos.gsfc.nasa.gov/>

http://modis-atmos.gsfc.nasa.gov/reference_atbd.html

Color	Collection	Production_Start	Description
Purple	061	2017	Corrected issues in the input Level-1B (L1B) data -- with a few new L2 and L3 improvements added.
Blue	006	2013	Collection 006 included many new science updates and improvements.
Green stripes	051	2008	Key Update for the L2 Aerosol (04_L2) and L2 Cloud Product (06_L2) -- along with all of L3 to pick up L2 updates.
Green	005	2005	First Major Science Collection, which was widely distributed.
Yellow	004	2002	Second Major Update/Improvement, which went through 3 stages of Validation during it's tenure.
Orange	003	2001	First Major Update/Improvement, however this was still considered "Provisional" Data.
Red	001	2000	Initial Testbed Collection.



* <https://atmosphere-imager.gsfc.nasa.gov/documentation/collection-61>

MODIS: Products

Level 1: Raw Radiances, Calibrated Radiances, Geolocation Fields

MODIS Atmosphere Products: Aerosol Product, Total Precipitable Water, Cloud Product, Atmospheric Profiles, Atmosphere Joint Product, Atmosphere Gridded Product, Cloud Mask

MODIS level 1 data, geolocation, cloud mask, and atmosphere products:

<http://ladsweb.nascom.nasa.gov/>

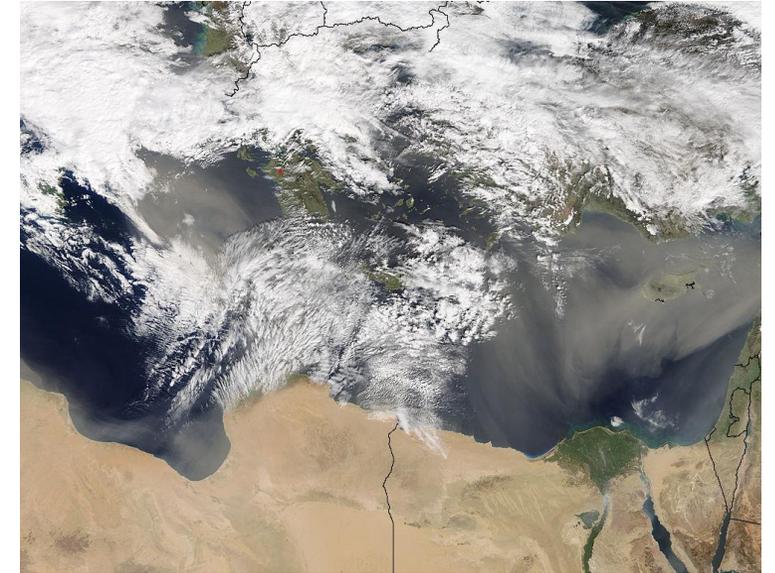
Publications:

Levy, R., Hsu, C., et al., 2015. MODIS Atmosphere L2 Aerosol Product. NASA MODIS Adaptive Processing System, Goddard Space Flight Center, USA

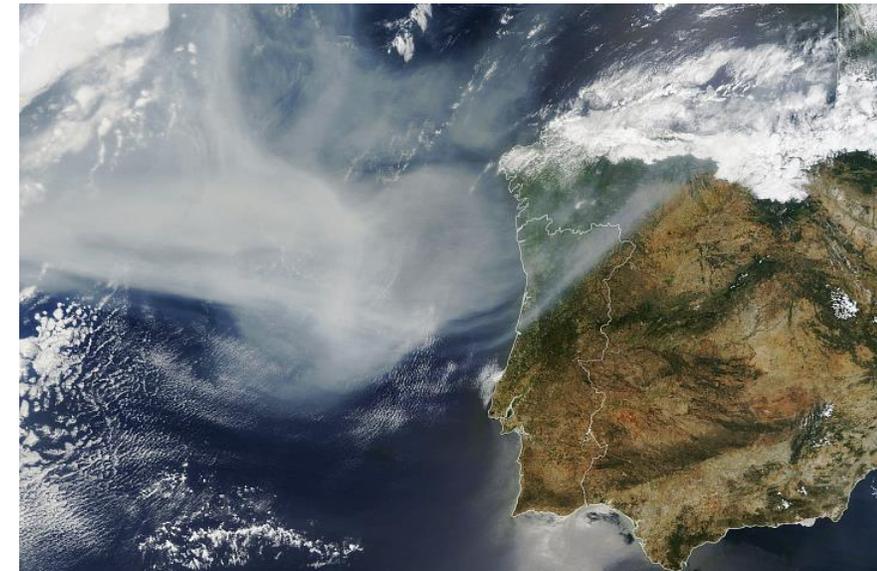
MODIS Aerosol products

- Two different algorithms are provided over land, known as Deep Blue and Dark Target Land
- Dark Target Ocean algorithm is applied over oceanic and inland waters
- Primary data product is aerosol optical depth at 550 nm
- Additionally, selected additional information such as single scattering albedo, spectral AOD, or descriptions of relative aerosol size, as well as quality assurance information are also provided

MODIS true color images



Dust storms across eastern Mediterranean Sea: March 5, 2018



Canadian Smoke Reaches Europe: June 26, 2023

MODIS: Validation and Uncertainty

- MODIS dark target aerosol products are validated by AERONET
 - Ground based instruments for land, and
 - Maritime Aerosol Network (MAN) for Ocean
- MODIS aerosol products are considered "validated" when 67% of the points fall within a bounding envelop of "estimated error" as compared to AERONET
- The uncertainty is different for the land and ocean products as well as wavelength dependent

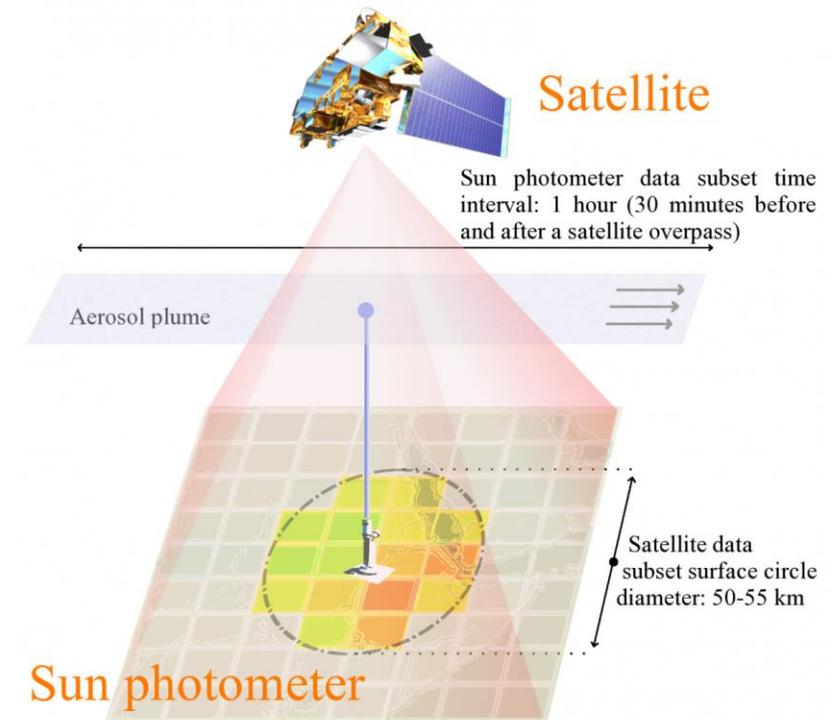
Validation Data Selection:

- AERONET Level 2 AOD data from direct sun radiation measurements is used for MODIS AOD validation
- Spectral AERONET data at 0.44, 0.50, 0.67, and 0.87 μm channels is converted to MODIS equivalent channels using a quadratic interpolation to perform comparisons at MODIS 0.47, 0.55, 0.67, and 0.87 μm wavelengths
- MODIS data quality assurance (QA) designated with values ranging from 0 to 3 where 3 is the highest quality

Details: <https://darktarget.gsfc.nasa.gov/satellite/modis/validation>

Highlight: Long term and global dataset

* <https://darktarget.gsfc.nasa.gov/satellite/modis/validation>

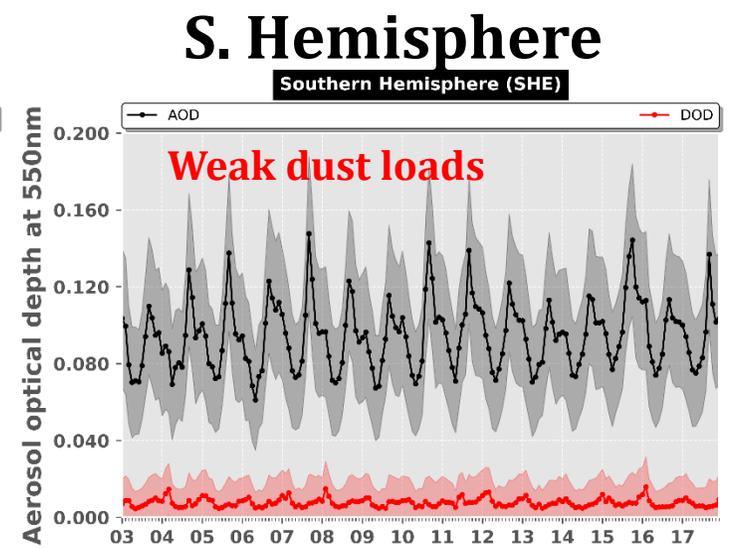
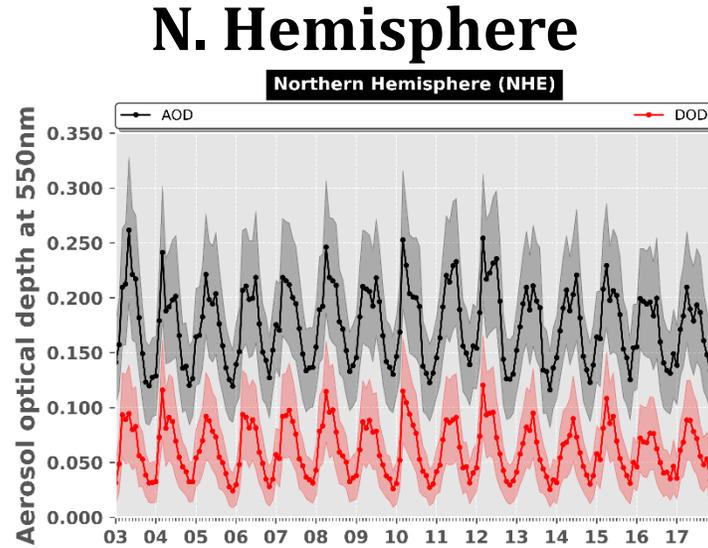
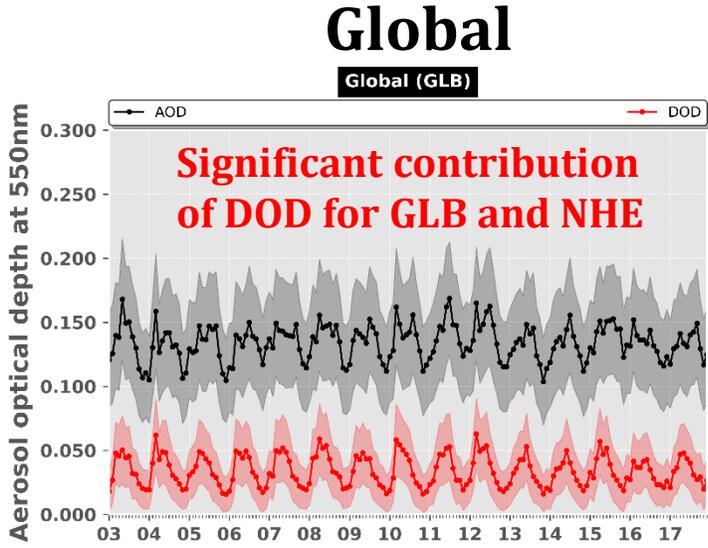


Visualisation tool

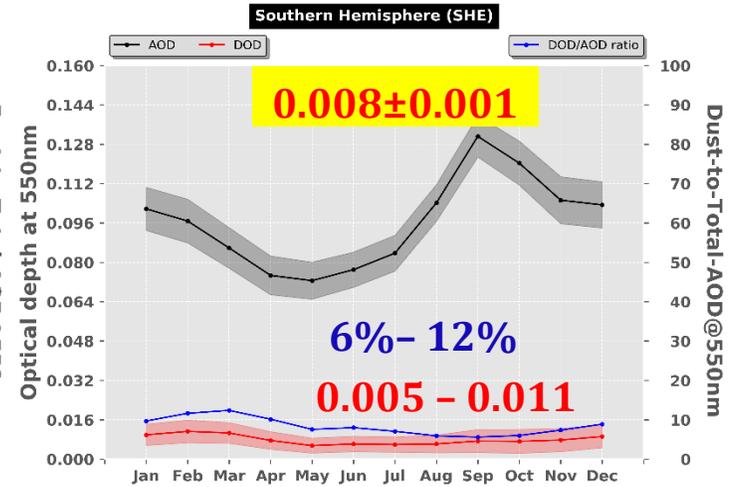
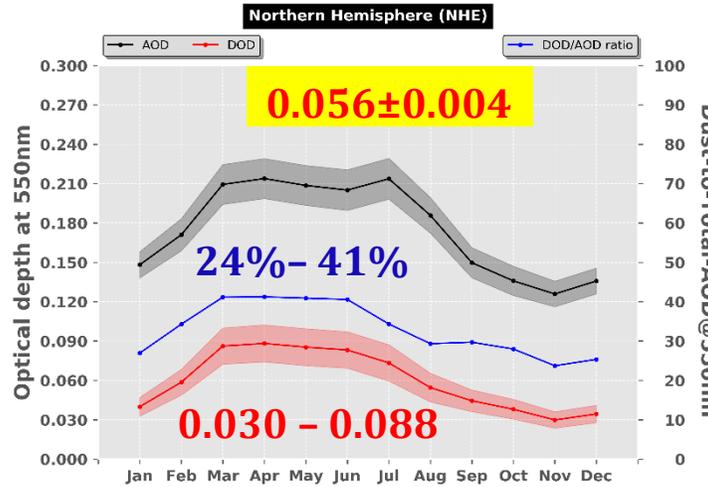
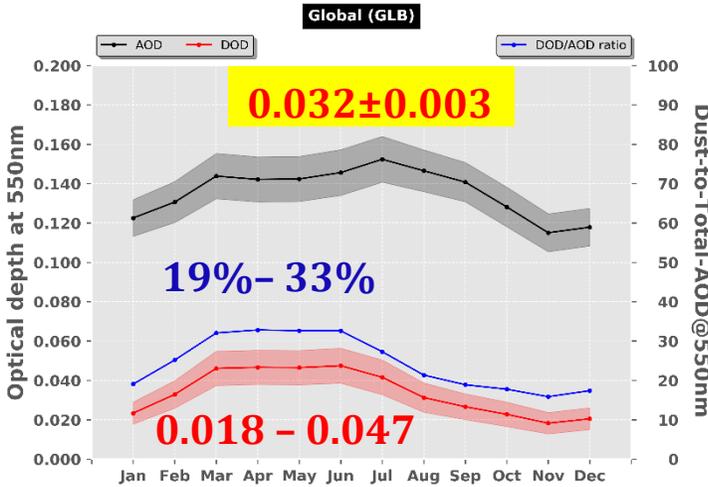
<https://giovanni.gsfc.nasa.gov/giovanni/>

Temporal variation of global and hemispherical averages

Interannual



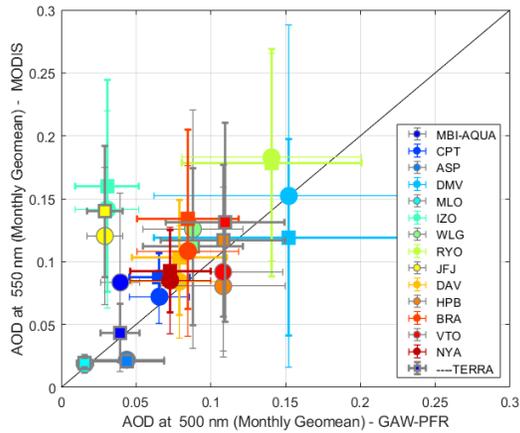
Intra-annual



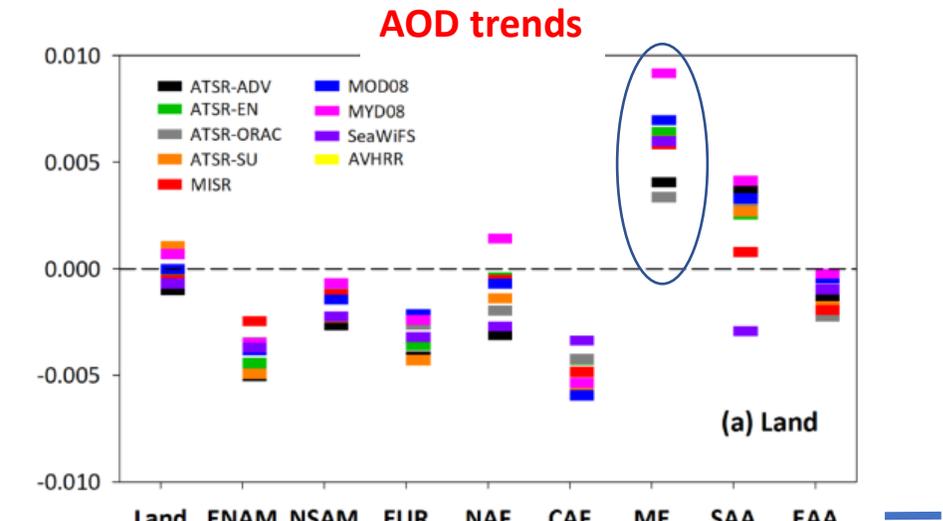
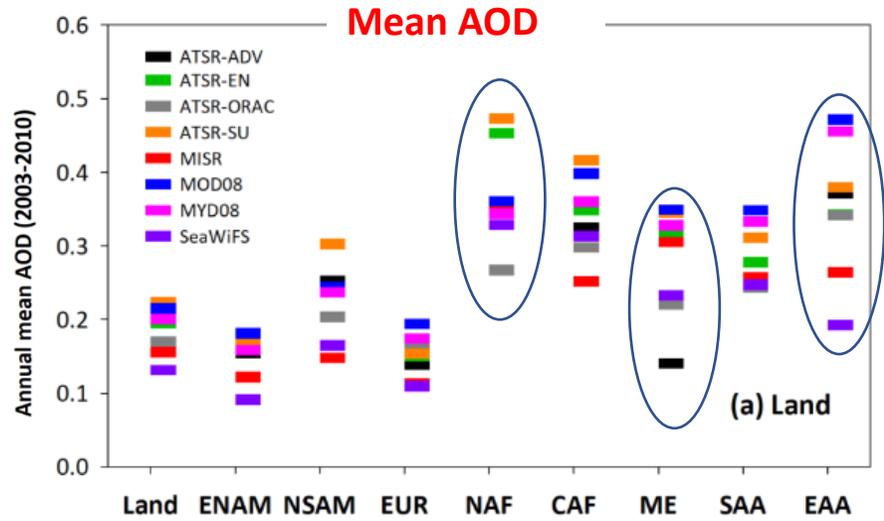
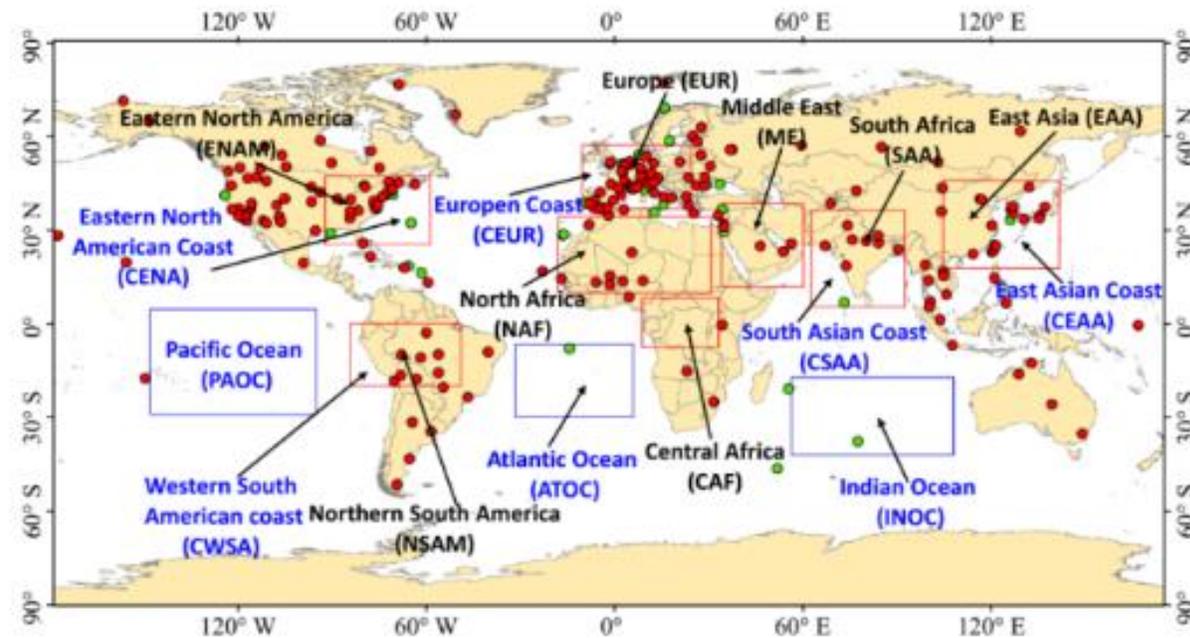
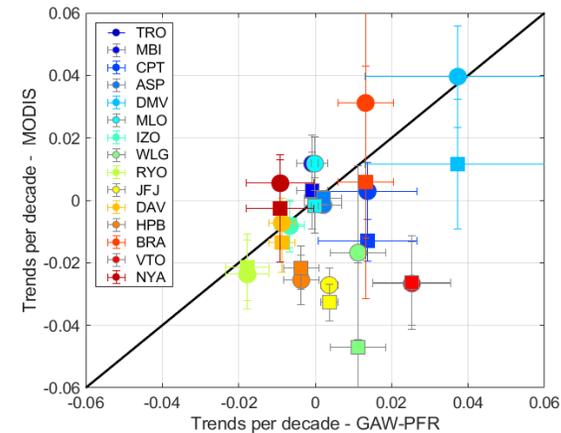
AOD | DOD | DOD-AOD ratio

Why do we need homogenized surface based measurements of AOD ?

comparison



trends



MODIS: Publications

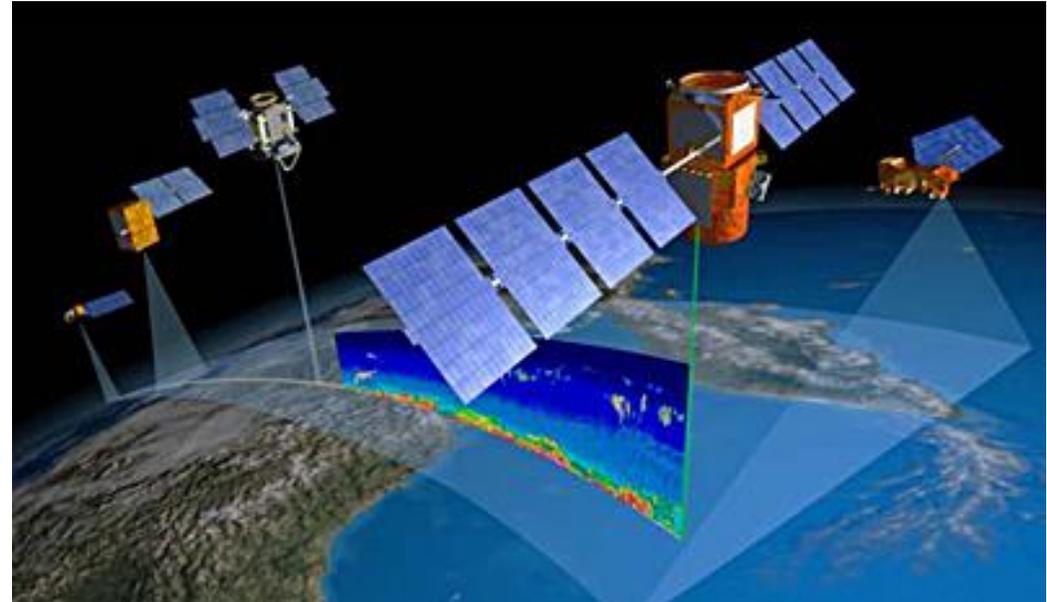
Some publications:

- The MODIS aerosol algorithm, products, and validation: <https://doi.org/10.1175/JAS3385.1>
- Global aerosol climatology from the MODIS satellite sensors: <https://doi.org/10.1029/2007JD009661>
- Satellite-derived aerosol optical depth over dark water from MISR and MODIS: Comparisons with AERONET and implications for climatological studies: <https://doi.org/10.1029/2006JD008175>
- Validation of MODIS 3 km land aerosol optical depth from NASA's EOS Terra and Aqua missions: <https://doi.org/10.5194/amt-11-3145-2018>
- Evaluation of the Moderate-Resolution Imaging Spectroradiometer (MODIS) retrievals of dust aerosol over the ocean during PRIDE: <https://doi.org/10.1029/2002JD002460>
- Testing aerosol properties in MODIS Collection 4 and 5 using airborne sunphotometer observations in INTEX-B/MILAGRO: <https://doi.org/10.5194/acp-9-8159-2009>
- Development of an operational land water mask for MODIS Collection 6, and influence on downstream data products: <https://doi.org/10.1080/17538947.2016.1232756>

Other publications can be found here: https://modis.gsfc.nasa.gov/sci_team/pubs/

CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation

- Insight into role of clouds and atmospheric aerosols in Earth's weather, climate, and air quality
- An active lidar instrument + passive infrared and visible imagers
- To probe global vertical structure and properties of thin clouds & aerosols
- Launched on April 28, 2006 with cloud profiling radar system on CloudSat satellite
- CALIPSO and CloudSat
 - highly complementary and together provide new, never-before-seen 3-D perspectives of how clouds and aerosols form, evolve, and affect weather and climate
 - fly in formation with three other satellites in A-train constellation to enable greater understanding of Earth's climate system from broad array of sensors on these other spacecraft
- Decommissioned on August 01, 2023



CALIPSO launched in 2006 into orbit around the Earth as part of the "A-Train," a constellation of Earth observing satellites

CALIPSO: Products

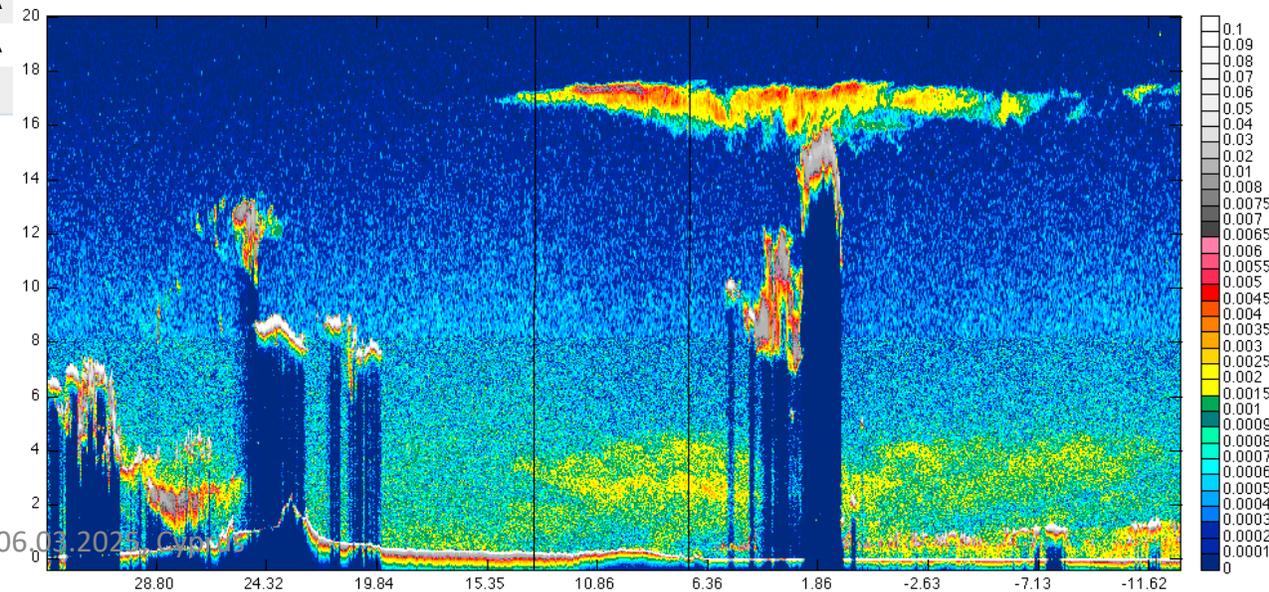
Data Product	Measurement Capabilities and Uncertainties	Data Product Resolution	
		Horizontal	Vertical
Aerosols			
Height, Thickness	For layers with $\beta > 2.5 \times 10^{-4} \text{ km}^{-1} \text{ sr}^{-1}$	5 km	60 m
Optical depth, τ	40% *	5 km	N/A
Backscatter, $\beta_a(z)$	20 - 30%	40 km 40 km	Z < 20 km 120 m Z \geq 20 km: 360 m
Extinction, σ_a	40% *	40 km 40 km	Z < 20 km 120 m Z \geq 20 km: 360 m
Clouds			
Height	For layers with $\beta > 1 \times 10^{-3} \text{ km}^{-1} \text{ sr}^{-1}$	1/3, 1, 5 km	30, 60 m
Thickness	For layers with $\tau < 5$	1/3, 1, 5 km	60 m
Optical depth, τ	within a factor of 2 for $\tau < 5$	5 km	N/A
Backscatter, $\beta_c(z)$	20 - 30%	5 km	60 m
Extinction, σ_c	within a factor of 2 for $\tau < 5$	5 km	60 m
Ice/water phase	Layer by layer	5 km	60 m
Ice cloud emissivity, ϵ	± 0.03	1 km	N/A
Ice particle size	$\pm 50\%$ for $\epsilon > 0.2$	1 km	N/A

Note: * assumes 30% uncertainty in the aerosol extinction-to-backscatter lidar ratio, S_a .

CALIPSO Level 2 Aerosol and Cloud Measurements

An example of total 532 nm attenuated backscatter signal color coded

- molecular scattering and weak aerosol scattering in blue
- aerosols as yellow/red/orange
- stronger cloud signals in gray scales
- weaker cloud returns are similar in strength to strong aerosol returns and coded in yellows and reds



CALIPSO: Validation and Uncertainty

https://ntrs.nasa.gov/api/citations/20210016375/downloads/CALIPSO_Validation_EarthCARE-CalValWkshp.pdf

Some validation publications:

- Assessment of CALIPSO attenuated backscatter and aerosol retrievals with a combined ground-based multi-wavelength lidar and sunphotometer measurement: <https://doi.org/10.1016/j.atmosenv.2013.11.016>
- Assessing lidar-based classification schemes for Polar Stratospheric Clouds based on 16 years of measurements at Esrangle, Sweden: <https://doi.org/10.1002/2013JD020355>
- An Investigation of Optically Very Thin Ice Clouds from Ground-Based ARM Raman Lidars: <https://doi.org/10.3390/atmos9110445>
- Ground-based validation of CALIPSO observations of dust and smoke in the Cape Verde region: <https://doi.org/10.1002/jgrd.50248>
- Vertical distributions and columnar properties of the aerosols during different seasons over Kattankulathur (12.82°N, 80.04°E): A semi-urban tropical coastal station: <https://doi.org/10.1016/j.atmosenv.2021.118457>
- Cloud Ice Water Content Measured by the CALIOP Space-based Lidar: <https://doi.org/10.1029/2011GL050545>

Other publication can be found here: <https://www-calipso.larc.nasa.gov/resources/bibliographies.php#validation>

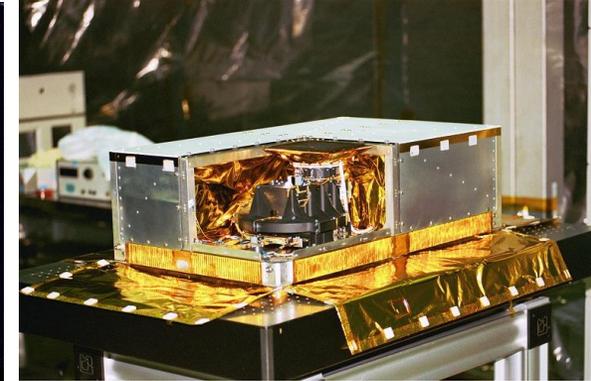
Highlight: Global 3-D profiles

POLDER: POLArization and Directionality of the Earth's Reflectances

- POLDER instrument analyses intensity and direction of light reflected by Earth and its atmosphere, as well as its polarization, that reveal interesting clouds and aerosols properties
- It consists of a digital camera composed of a 284×364 pixels CCD detection matrix, a wide field of view telecentric optics ($\pm 51^\circ$ along the great axis) and of a rotating wheel carrying spectral and polarized filters
- There are 15 filters (plus a dark current measurement) covering a spectral domain from 443 to 1020 nm
- For some wavelength, 3 filters measure the linear polarization of the incoming light in three directions separated by 120° , thus allowing to supply the Stokes parameters and the total radiance
- Moreover, the acquisition of a sequence of images every 20 seconds makes it possible to observe the same target on ground from several directions (12 for POLDER 1 and 2, up to 16 for POLDER 3)



Adeos Satellite



Polder Instrument

Main characteristics of the instrument:

- | | |
|------------------|--|
| • Total mass | about 30 kg |
| • Volume | 0,8 x 0,5 x 0,3 m ³ |
| • Field of view | $\pm 43^\circ \times \pm 51^\circ$ |
| • Swath width | 2200 km (POLDER1 & 2) – 1600 km (POLDER 3) |
| • Resolution | about 6 km |
| • Encoding | 12 bits |
| • Average power | about 30 W |
| • Telemetry rate | 880 bits/s |

POLDER: Algorithm and Products

POLDER-1: onboard [ADEOS I](#) (November 1996 – June 1997)
POLDER-2: onboard [ADEOS-II](#) (April 2003 – October 2003)
PARASOL: onboard a CNES/Myriade microsatellite within the A-train constellation (December 2004 – December 2013)

- POLDER 1 and 2 data are reprocessed with improved algorithms developed for PARASOL

Products:

Aerosol over Land

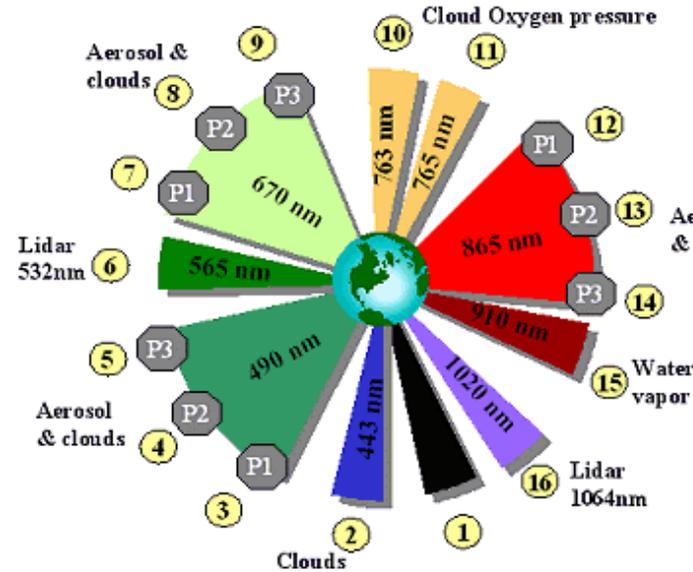
- optical thickness of the small particles, Ångström coefficient of the small mode

Earth Radiation & Cloud

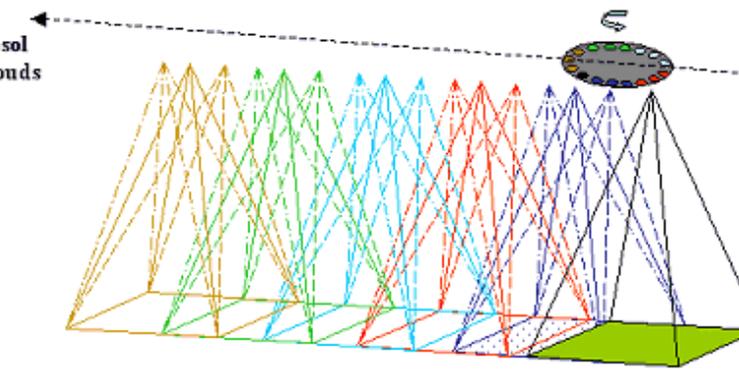
- cloud cover, cloud phase, cloud optical thickness, spectral albedo, shortwave albedo, 2 cloud pressures (from oxygen absorption and from Rayleigh scattering), water vapor integrated content

Aerosol over Ocean

- total and small particles optical thickness (aerosol load), non sphericity index, angström coefficient, effective radius and refractive index of small particle mode, refractive index of large spherical particles



15 filters + dark field :



Acquisition principle with the filter wheel (PARASOL configuration)

POLDER 1&2 channels	PARASOL channels	Bandwidth	Rationale
443P	/	20 nm	Clouds and radiation balance
443	443	20 nm	Cloud detection, ocean color
490	490P	20 nm	Aerosol retrieval, cloud pressure
565	565	20 nm	Aerosols and Calipso lidar at 532 nm
670P	670P	20 nm	Aerosol retrieval, cloud properties
865P	865P	40 nm	Aerosol retrieval, cloud properties
763 765	763 765	10 nm 40 nm	Cloud oxygen pressure by differential absorption technique in oxygen A band
910	910	40 nm	Water vapor retrieval
/	1020	20 nm	Aerosols ans Calipso lidar at 1064nm

Atarri workshop 06.03.2025, Cyprus

POLDER: Validation and Uncertainty

Some publications

- Validation of GRASP algorithm product from POLDER/PARASOL data and assessment of multi-angular polarimetry potential for aerosol monitoring: <https://doi.org/10.5194/essd-12-3573-2020>
- Validation of POLDER-3/GRASP aerosol products using AERONET measurements over China: <https://doi.org/10.1016/j.atmosenv.2019.116893>.
- Validation of POLDER GRASP aerosol optical retrieval over China using SONET observations: <https://doi.org/10.1016/j.jqsrt.2020.106931>

Highlight:

TROPOMI: TROPospheric Monitoring Instrument

- Launched on 13 October 2017 on board of the ESA/Copernicus Sentinel-5 Precursor satellite
- TROPOMI measures daily global distribution of atmospheric trace gases and aerosols
- Key advantages of TROPOMI:
 - Spectral bands: ultraviolet and visible (270–500 nm), near-infrared (675–775 nm) and shortwave infrared (2305–2385 nm) → enabling accurate measurement of wide range of pollutants
 - Spatial resolution: High resolution as 7 km × 3.5 km → potential to detect air pollution over individual cities



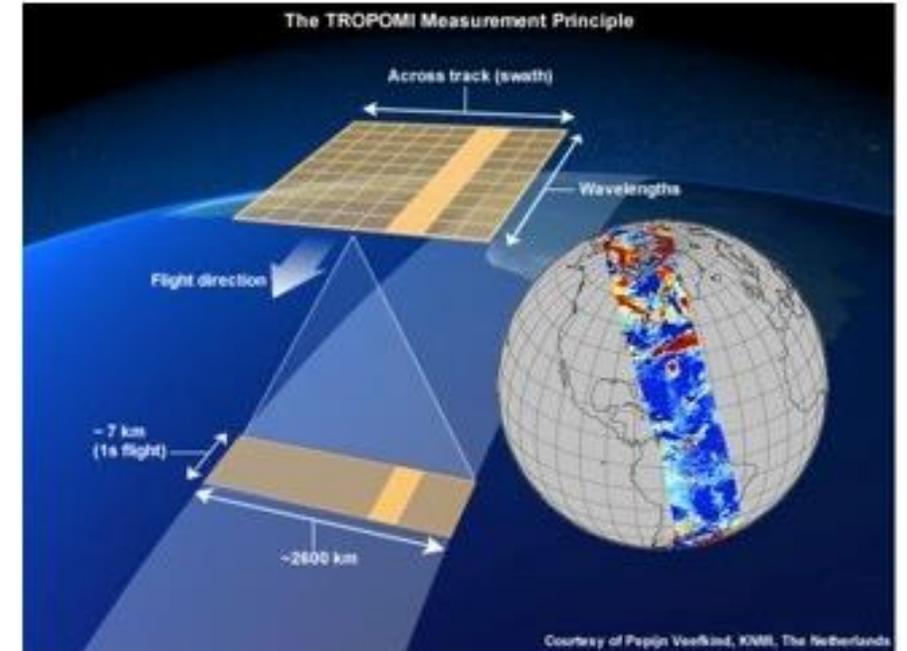
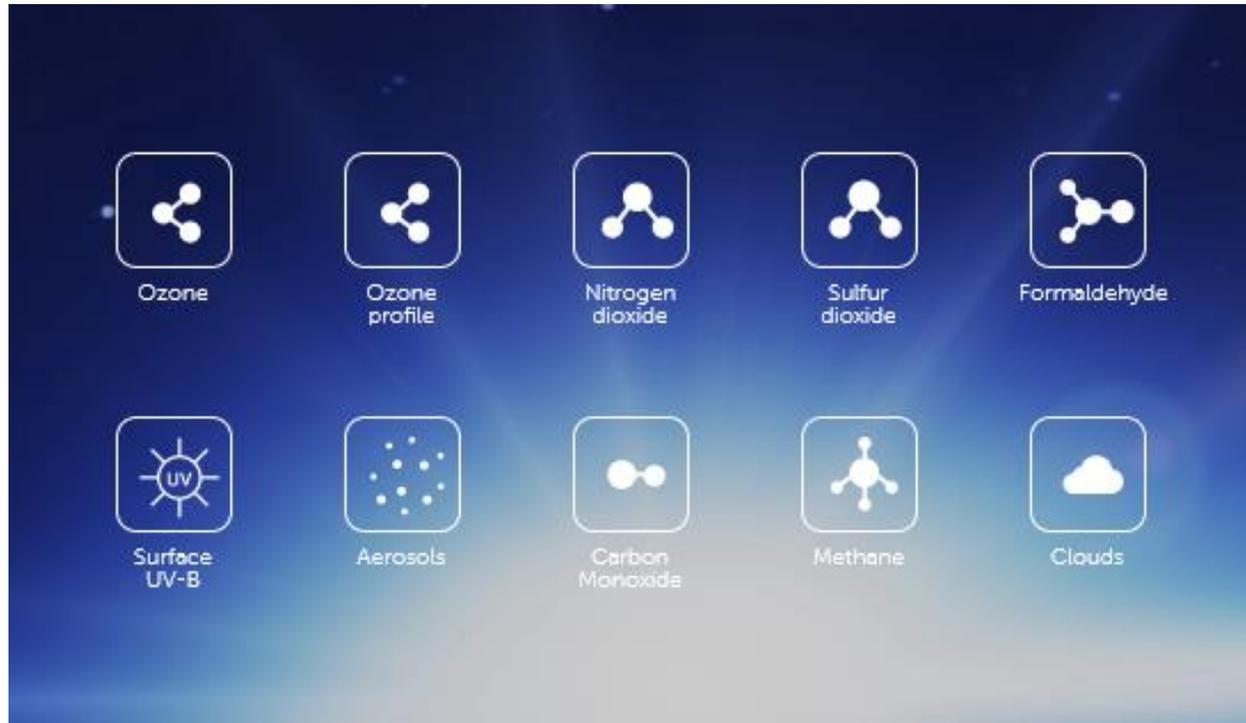
Instrument on board Copernicus Sentinel-5 Precursor satellite

TROPOMI CH₄ total column

Image, 5-day average centered on 4 October 2023

Atarri workshop 06.03.2025, Cyprus

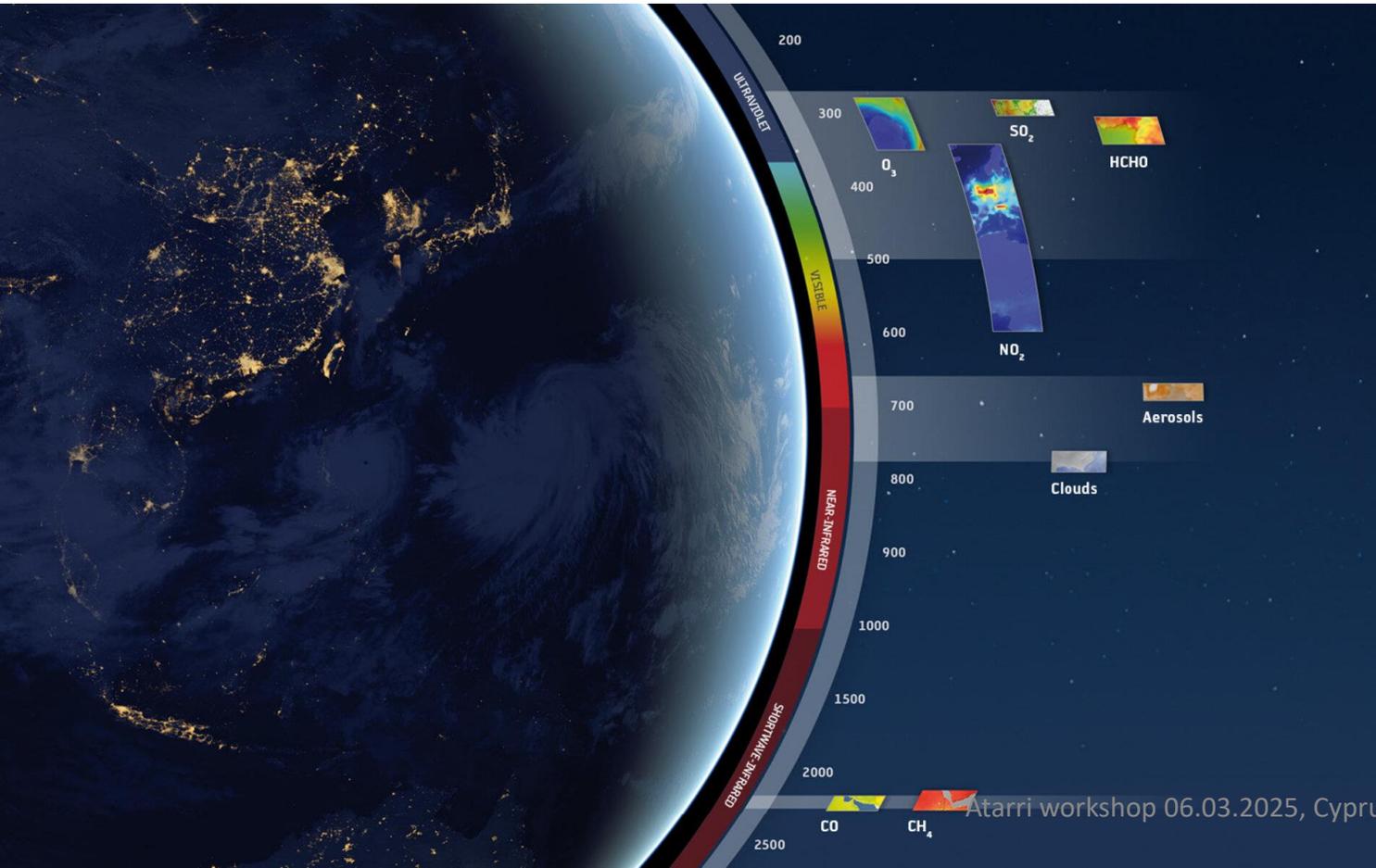
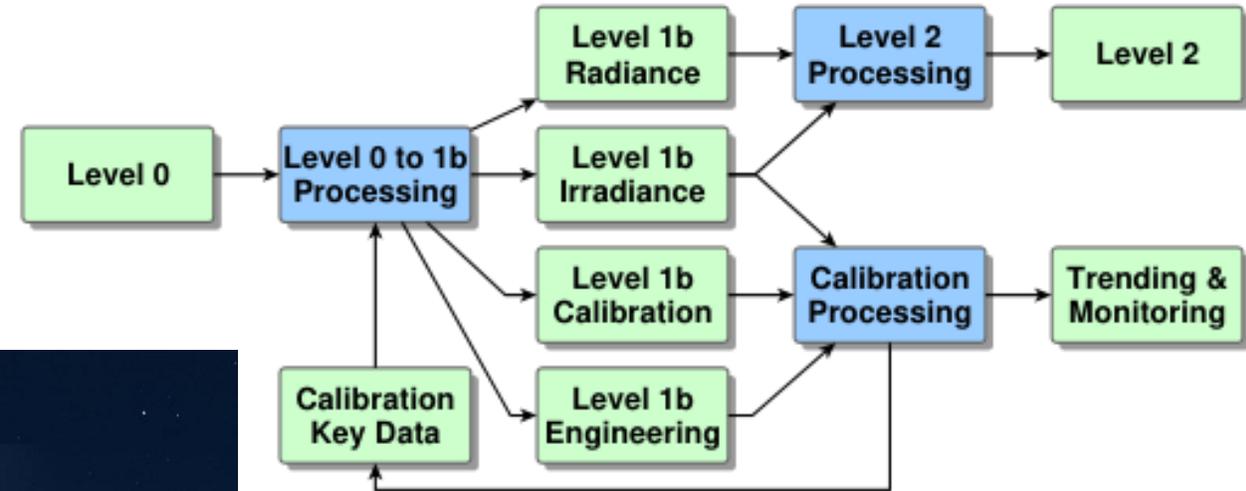
Products



The Sentinel-5P orbit is a **near-polar, sun-synchronous orbit** with an ascending node equatorial crossing at 13:30 h Mean Local Solar time. In a sun-synchronous orbit, the surface is always illuminated at the same sun angle. The orbital cycle is 16 days (14 orbits per day, 227 orbits per cycle).

TROPOMI: Algorithm and Products

Operational perspective of the L01b, showing its data products and position in the processing chain. The blue blocks denote processors; the green blocks are data products



Products:

- Aerosol Index
- Aerosol Layer Height
- Carbon Monoxide (CO)
- Cloud Properties
- Formaldehyde (HCHO)
- Methane (CH₄)
- Nitrogen Dioxide (NO₂)
- Ozone Profile
- Ozone Total Column (O₃)
- Sulfur Dioxide (SO₂)

TROPOMI: Validation and Uncertainty

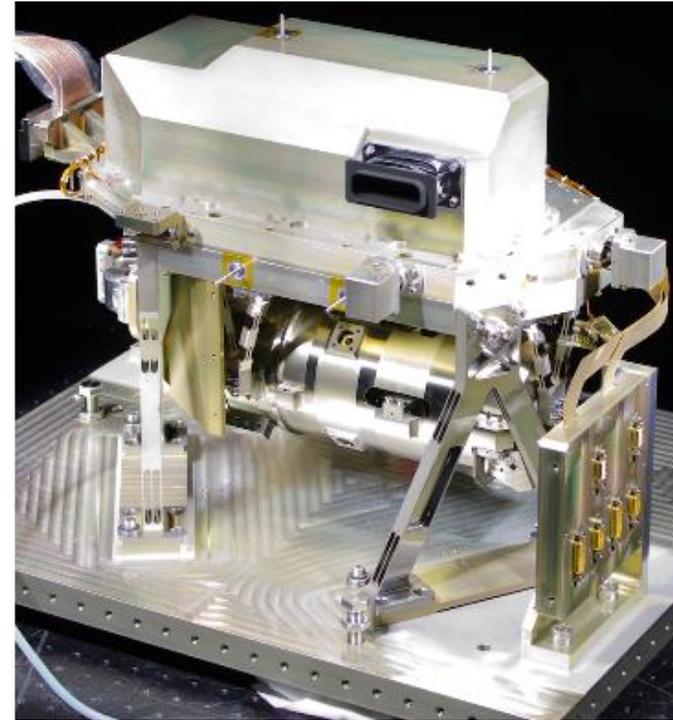
- Sentinel-5P Validation Data Analysis Facility (VDAF) portal provides routine Operations Validation Service for TROPOMI
- Operational validation service for the Level-1 and Level-2 data products generated by the Near Real Time (NRTI) and Offline (OFFL) processors
- Quarterly Routine Operations Consolidated Validation Report (ROCVR) are provided (latest ROCVR issue is shown below)

INTRODUCTION	<i>Quarterly Validation Report of the Sentinel-5 Precursor Operational Data Products #24: April 2018 - August 2024</i> <i>This document reports consolidated results of the routine operations validation service for the Sentinel-5 Precursor Tropospheric Monitoring Instrument.</i>
DOWNLOAD PDFFILE	
CREATED BY	Steven Compernelle
DATE	2024-10-01 19:24:42
INVOLVED TARGETS	AI,ALH,CH4,CLOUD,CO,HCHO,NO2,O3,SO2

https://s5p-mpc-vdaf.aeronomie.be/index.php?option=com_vdaf&view=showReport&format=rawhtml&id=62

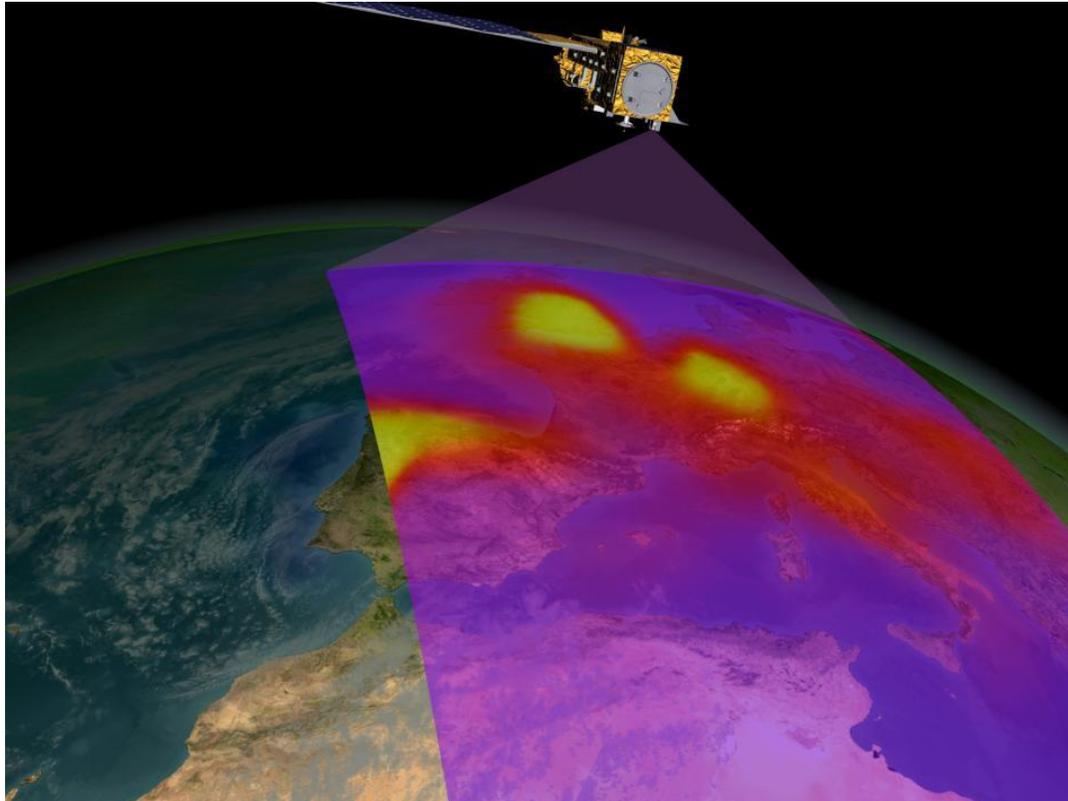
Highlight: High spatial resolution global dataset

Tropomi



OMI: Ozone Monitoring Instrument

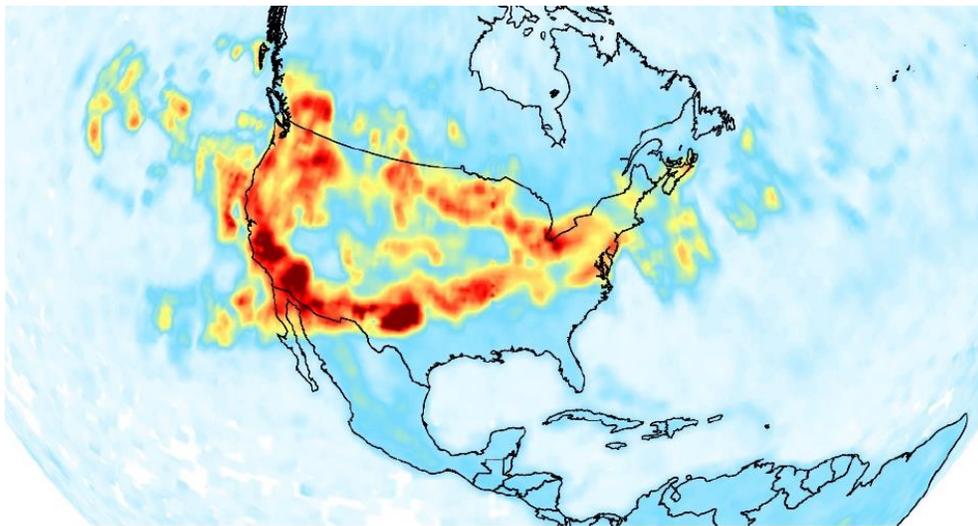
- OMI is a key instrument on Aura satellite for monitoring the recovery of the ozone layer
- OMI is a nadir-viewing wide-field-imaging spectrometer with daily global coverage
- It provides mapping of pollution products from an urban to super-regional scale



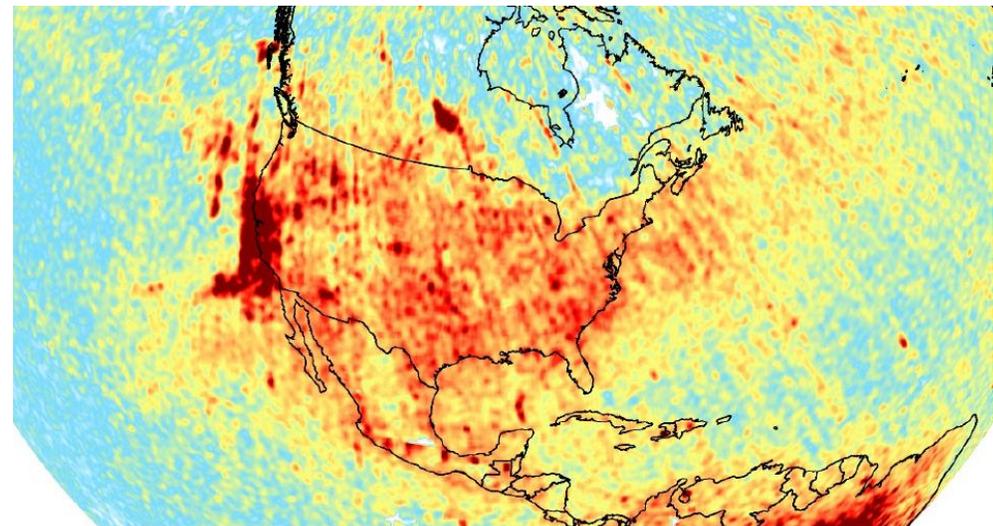
Item	Parameter
Visible:	350 - 500 nm
UV:	UV-1, 270 to 314 nm, UV-2 , 306 to 380 nm
Spectral resolution:	1.0 - 0.45 nm FWHM
Spectral sampling:	2-3 for FWHM
Telescope FOV:	114 (2600 km on ground)
IIFOV:	3 km, binned to 13 x 24 km
Detector:	CCD: 780 x 576 (spectral x spatial) pixels
Mass:	65kg
Duty cycle:	60 minutes on daylight side
Power:	66 watts
Data rate:	0.8 Mbps (average)

OMI: Algorithm and Products

- It measures key air quality components such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), bromine oxide (BrO), OCIO , and aerosol characteristics other than O_3



Aura/OMI Max. Abs. AOD [388 nm, ALH=6 km] Aug 18-Sep 21, 2020



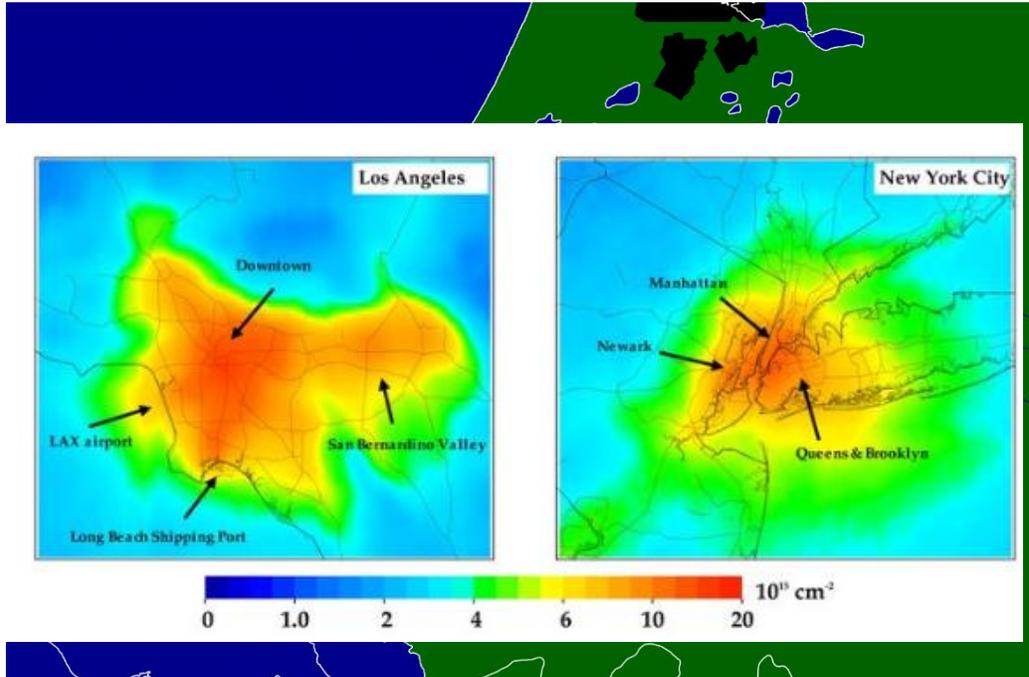
Aura/OMI Max. HCHO SCD ($\times 10^{15}$, mol/cm²) Aug 18-Sep 21, 2020



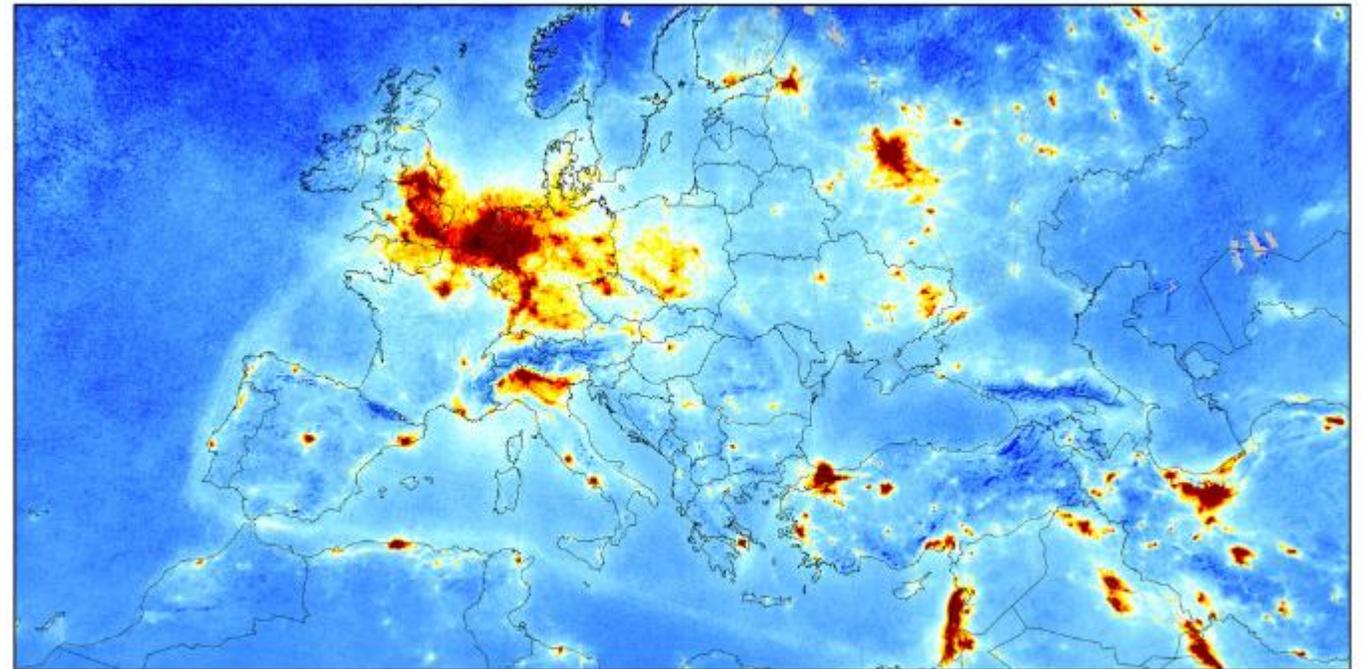
Satellite observations between August 18 and September 21, 2020 by the Aura OMI instrument show the spatial extent of the hemispheric scale smoke plume generated by fires in the US west coast in terms of retrieved 388 nm Aerosol Absorption Optical Depth (AAOD, left) and maximal formaldehyde (HCHO, right) slant column densities (SCDs). There are similarities and differences in the spatial distribution between aerosols and HCHO, as HCHO comes from both fire emissions and also biogenic emissions particularly over the southeastern U.S. Additionally, HCHO is also short-lived and the loading tends to be greater within fresh fire plumes and lower in aged plumes.

Satellite improvement with time : From OMI to Tropomi

Spatial resolution



TROPOMI NO₂ tropospheric column, April 2018



NO₂ tropospheric column gridded mean, TROPOMI sensor ($1e-6 \text{ mol m}^{-2}$)



NO₂ tropomi

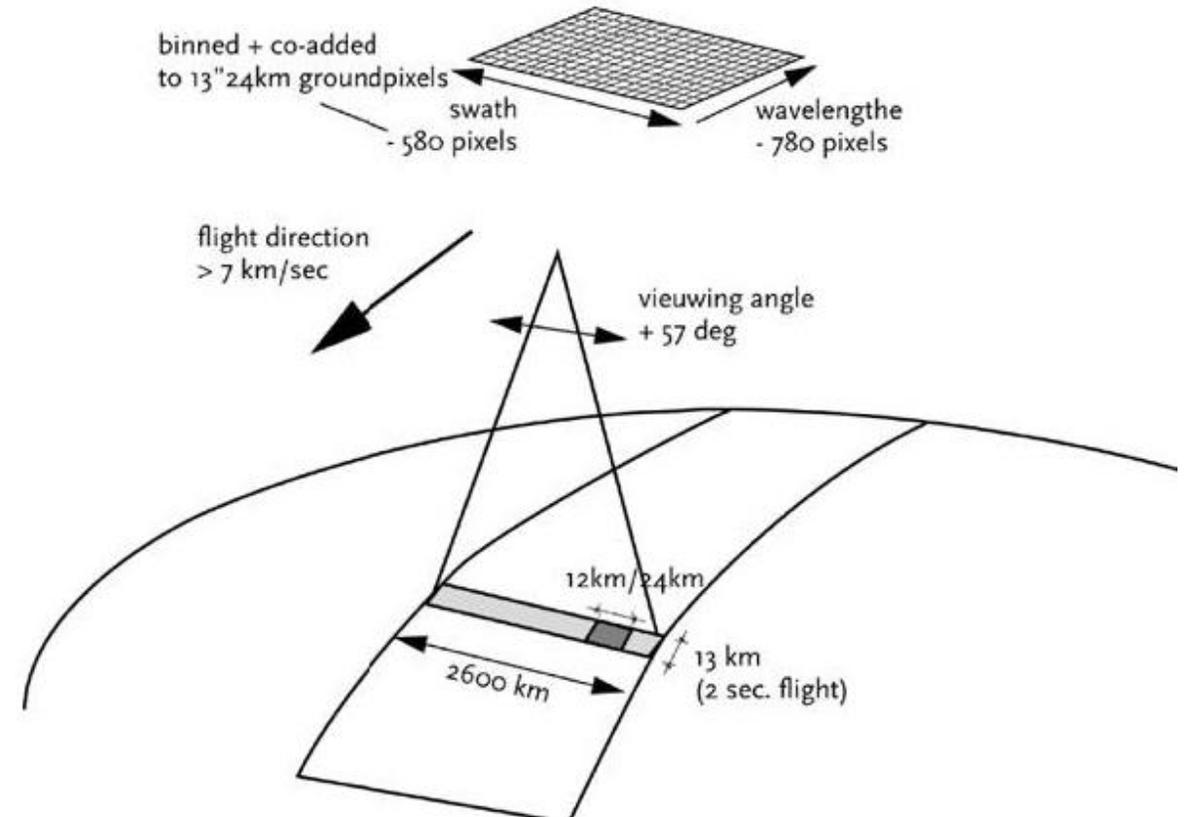
Tropomi/ESA

Satellite Spatial characteristics

OMI

Spectroradiometers in Space

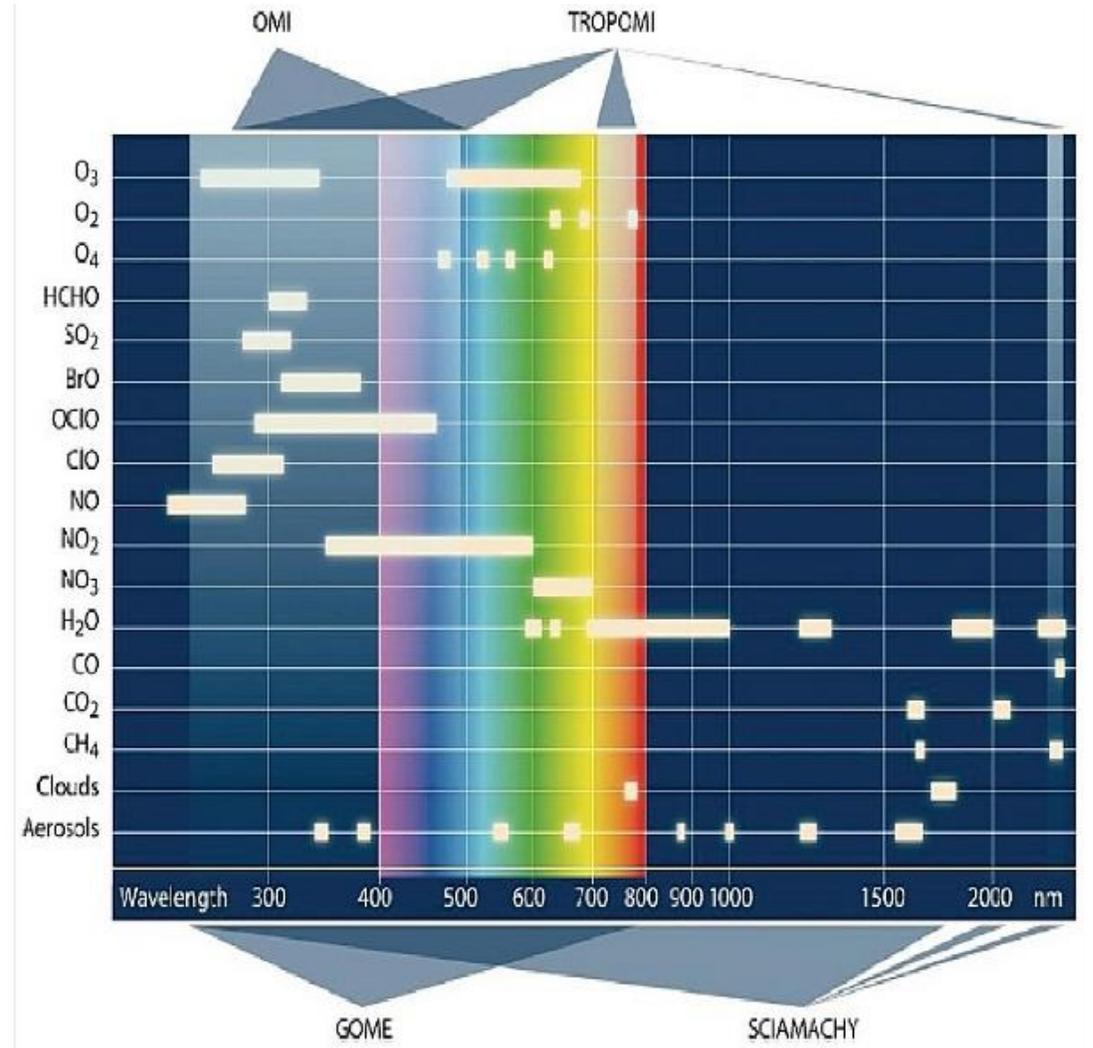
Global coverage in one day



OMI to Tropomi

Spectral resolution

	UV1	UV2	VIS	NIR	SWIR
Range	270-320 nm	300-400 nm	380-490	710-775 nm	2305-2385 nm
Resolution	1.1 nm	0.45 nm	0.52 nm	0.45 nm	0.25 nm
Sampling	~0.4 nm	0.15 nm	~0.18 nm	0.15 nm	0.125 nm
Signal-to-Noise	≥100-1000	≥1000	≥1500	≥100-500	>100
Ground pixel	≥16×40 km ²	≥8×10 km ²			≥10×10 km ²
Swath	2600 km for TROPOMI and 4700 km for TROPIS				2600 km
Dimension	0.56 × 0.45 × 0.38 m ³				0.45 × 0.3 × 0.2 m ³
Mass	35 kg				17 kg
Temp. optics	283 K				220 K
Temp. detector	233 K				165 K



Tropomi Science

TROPOMI: Publications

Some publications on trace gases:

- Potential of TROPOMI for understanding spatio-temporal variations in surface NO₂ and their dependencies upon land use over the Iberian Peninsula: <https://doi.org/10.5194/acp-23-3905-2023>
- Toward global mapping of methane with TROPOMI: First results and intersatellite comparison to GOSAT: <https://doi.org/10.1002/2018GL077259>
- Measuring carbon monoxide with TROPOMI: First results and a comparison with ECMWF-IFS analysis data: <https://doi.org/10.1002/2018GL077045>
- Global observational coverage of onshore oil and gas methane sources with TROPOMI: <https://doi.org/10.1038/s41598-023-41914-8>

OMI: Validation and Uncertainty

Some publications:

- Validation of OMI-TOMS and OMI-DOAS total ozone column using five Brewer spectroradiometers at the Iberian peninsula: <https://doi.org/10.1029/2009JD012003>
- Validation of Aura-OMI QA4ECV NO₂ climate data records with ground-based DOAS networks: the role of measurement and comparison uncertainties: <https://doi.org/10.5194/acp-20-8017-2020>
- Validation of OMI tropospheric NO₂ column densities using direct-Sun mode Brewer measurements at NASA Goddard Space Flight Center: <https://doi.org/10.1029/2007JD008988>
- Validation of OMI HCHO data and its analysis over Asia: <https://doi.org/10.1016/j.scitotenv.2014.04.108>
- Validation of OMI satellite erythemal daily dose retrievals using ground-based measurements from fourteen stations: <https://doi.org/10.1016/j.rse.2012.09.015>

Highlight: Long time series of global observations

Meteosat Second Generation (MSG) satellites

- under cooperation between EUMETSAT and the [ESA](#)
- In geostationary orbit 36,000 km above the equator
- currently operate over Europe, Africa and the Indian Ocean

Satellite	Lifetime	Services
Meteosat-11	15/07/2015 – Availability lifetime is until 2033	0° Service
Meteosat-10	05/07/2012 – Availability lifetime is until 2030	Rapid Scanning Service
Meteosat-9	22/12/2005– Availability lifetime is until 2025	Rapid Scanning Service gap filling and back-up
Meteosat-8	28/08/2002 – Availability lifetime is until 2022	Indian Ocean Data Coverage (IODC) Service,



Full scan service
every **15min**

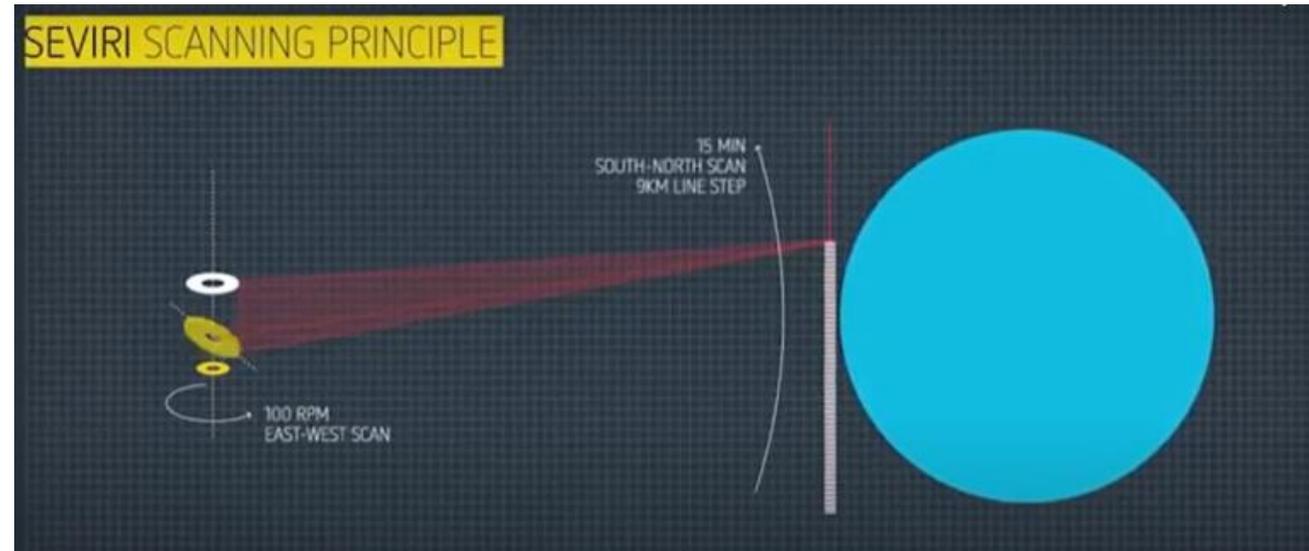
Rapid scan service
every **5min**

Atarri workshop 06.03.2025, Cyprus

<https://www.eumetsat.int/meteosat-second-generation>

Spinning Enhanced Visible and InfraRed Imager (SEVIRI)

- MSG's **primary instrument**
- Observe the Earth in **12 spectral channels**
- 11 channels provide measurements with a resolution of **3 km** at the sub-satellite point with the 12th, the High Resolution Visible (HRV) channel, providing measurements with a resolution of **1 km**.
- Normally the SEVIRI instrument allows for a complete image scan (Full Earth Scan) once every **15-minute period**
Rapid scanning scans a third of the earth disc every **5-minutes**.
- Each pixel containing the received radiation from the earth and its atmosphere in the 12 spectral channels. The appropriate ancillary information provided allows the user to calculate the geographical position and radiance of any pixel.



Spinning Enhanced Visible and InfraRed Imager (SEVIRI)

Channel no.		Characteristics of spectral band (μm)			Main gaseous absorber or window
		λ_{cen}	λ_{min}	λ_{max}	
1	VIS0.6	0.635	0.56	0.71	Window
2	VIS0.8	0.81	0.74	0.88	Window
3	NIR1.6	1.64	1.50	1.78	Window
4	IR3.9	3.90	3.48	4.36	Window
5	WV6.2	6.25	5.35	7.15	Water vapor
6	WV7.3	7.35	6.85	7.85	Water vapor
7	IR8.7	8.70	8.30	9.10	Window
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Window
10	IR12.0	12.00	11.00	13.00	Window
11	IR13.4	13.40	12.40	14.40	Carbon dioxide
12	HRV	Broadband (about 0.4 – 1.1)			Window/water vapor

Main applications

Cloud detection and tracking, aerosol detection
Cloud detection and tracking, aerosol detection
Snow cover and cloudiness discrimination, aerosol inf.
Low clouds and fog detection
Water vapor detection, wind estimation
Water vapor detection, wind estimation
Cirrus cloud information
Ozone estimation
Estimation of cloud top temperature, cirrus detection
Estimation of cloud top temperature, cirrus detection
Cirrus cloud high estimation
High resolution cloud and surface monitoring

Satellite Application Facilities (SAFs)



AC SAF

Atmospheric Composition Monitoring

The AC SAF processes satellite data on ozone, other trace gases, aerosols and ultraviolet data.



CM SAF

Climate Monitoring

The CM SAF generates and archives high-quality climate datasets.



LSA SAF

Land Surface Analysis

The LSA SAF exploits remotely-sensed data on land, land-atmosphere interactions and biosphere applications.



H SAF

Operational Hydrology and Water Management

The H SAF generates and archives datasets and products for operational hydrological applications.



Dedicated centres of excellence for processing satellite data



NWC SAF

Nowcasting and Very Short Range Forecasting

Nowcasting is a weather forecast for the next few hours, based on current information.



ROM SAF

Radio Occultation Meteorology

The ROM SAF generates and archives high-quality GNSS Radio Occultation (RO) data

for NWP



NWP SAF

Numerical Weather Prediction

The NWP SAF supports the interface between satellite data and European activities in NWP.



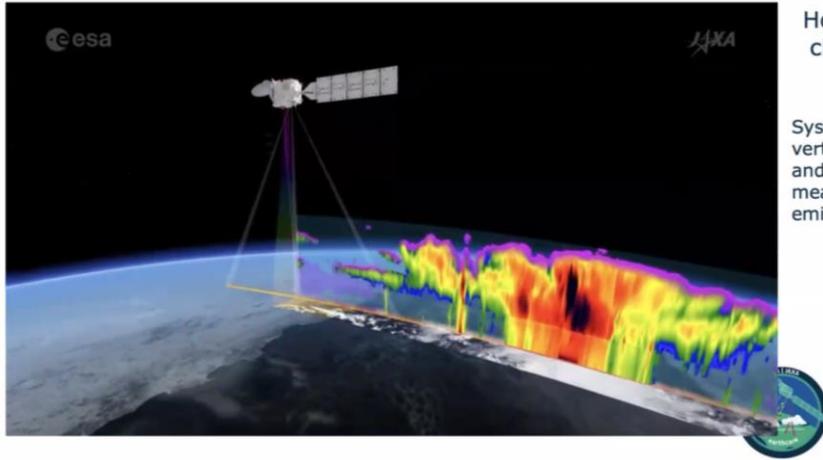
OSI SAF

Ocean and Sea Ice

The OSI SAF provides comprehensive information on the ocean-atmosphere interface.

EARTHCARE: Cloud, Aerosol and Radiation Explorer

EarthCARE – Mission Objective

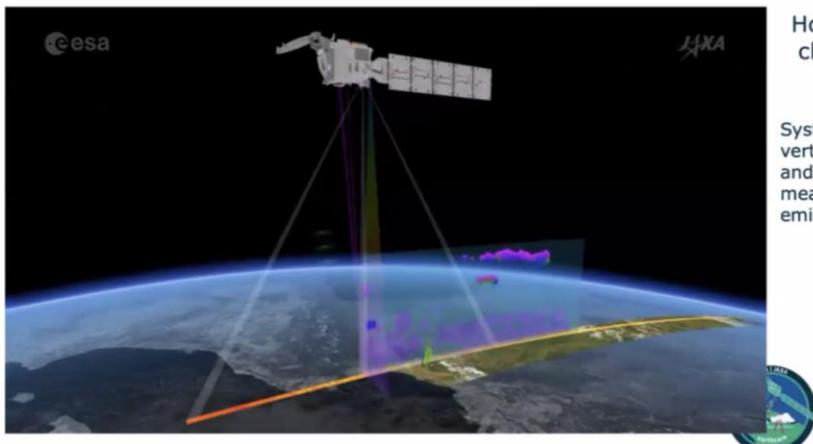


How do aerosols and clouds, heat or cool the Earth?

Systematic provision of vertical profiles of clouds and aerosols, collated with measurements of solar and emitted thermal radiation.

5

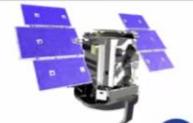
EarthCARE – Mission Objective



How do aerosols and clouds, heat or cool the Earth?

Systematic provision of vertical profiles of clouds and aerosols, collated with measurements of solar and emitted thermal radiation.

EarthCARE: Legacy and Future

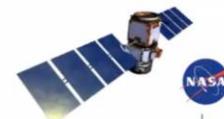
CloudSat
2006-2023
94 GHz Radar



Aeolus
2018-2023
355 nm HSRL Lidar



AOS-Sky
2029-
AOS-Storm
2029-
AOS-Sky/HAWCsat
2031-



CALIPSO
2006-2023
532/1064 nm Lidar



EarthCARE 2024-



ACDL/DQ-1, 2022-
532nm(HSR)/1064nm/
1572nm Lidar
ACDL/DQ-2, 2025-



eps-Aeolus/-2
2034-
355nm HSRL Lidar



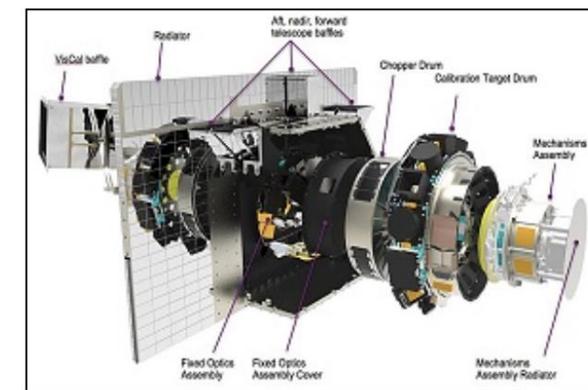
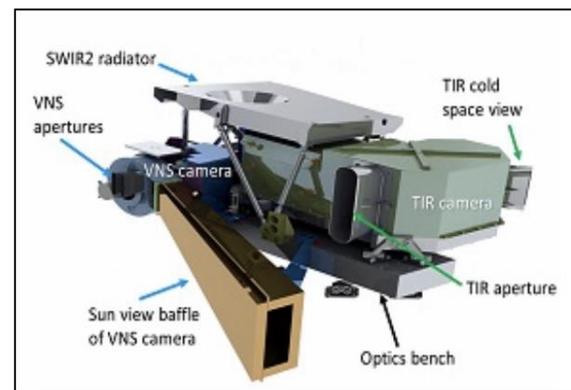
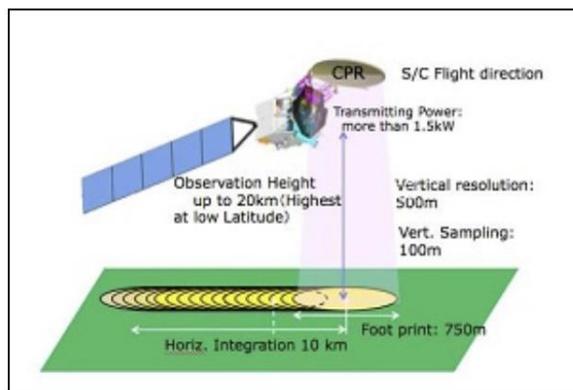
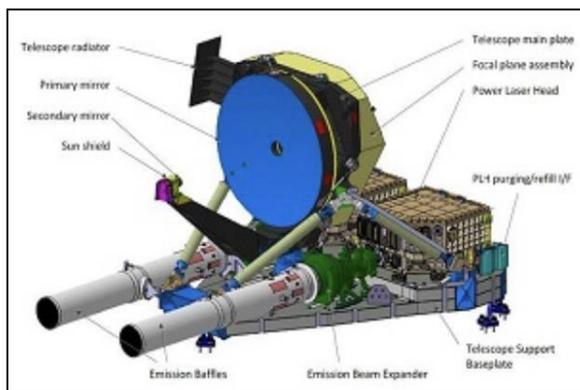
7

EARTHCARE: Cloud, Aerosol and Radiation Explorer



- Employs high-performance lidar and radar technology that has never been flown in space before
- To deliver unprecedented datasets to allow scientists to study relationship of clouds, aerosols and radiation at accuracy levels to improve the understanding of these highly variable parameters

EARTHCARE Instruments



Atmospheric Lidar (ATLID)

- provides vertical profiles of aerosols and thin clouds
- Operates at a wavelength of 355 nm
- high-spectral resolution receiver and depolarisation channel

Cloud Profiling Radar (CPR)

- provides vertical profiles measurements of clouds
- observes vertical velocities of cloud particles through Doppler measurements
- Operates at 94GHz

Multi-Spectral Imager (MSI)

- provides across-track information on clouds and aerosols
- channels in visible, near infrared, shortwave and thermal infrared

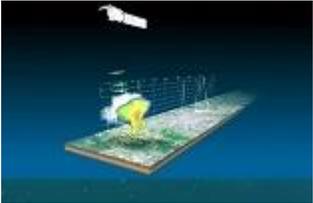
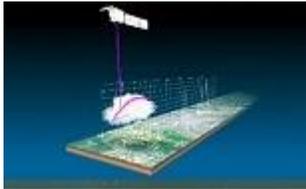
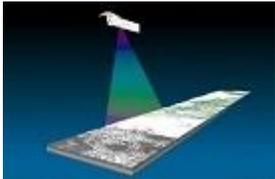
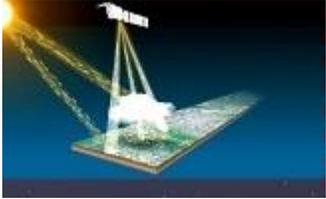
Broad-Band Radiometer (BBR)

- provides top-of-the-atmosphere radiances & fluxes measurements
- a short-wave and a long-wave channel with three fixed viewing directions pointing in nadir and aft-directions

EARTHCARE: Level-2a Products overview

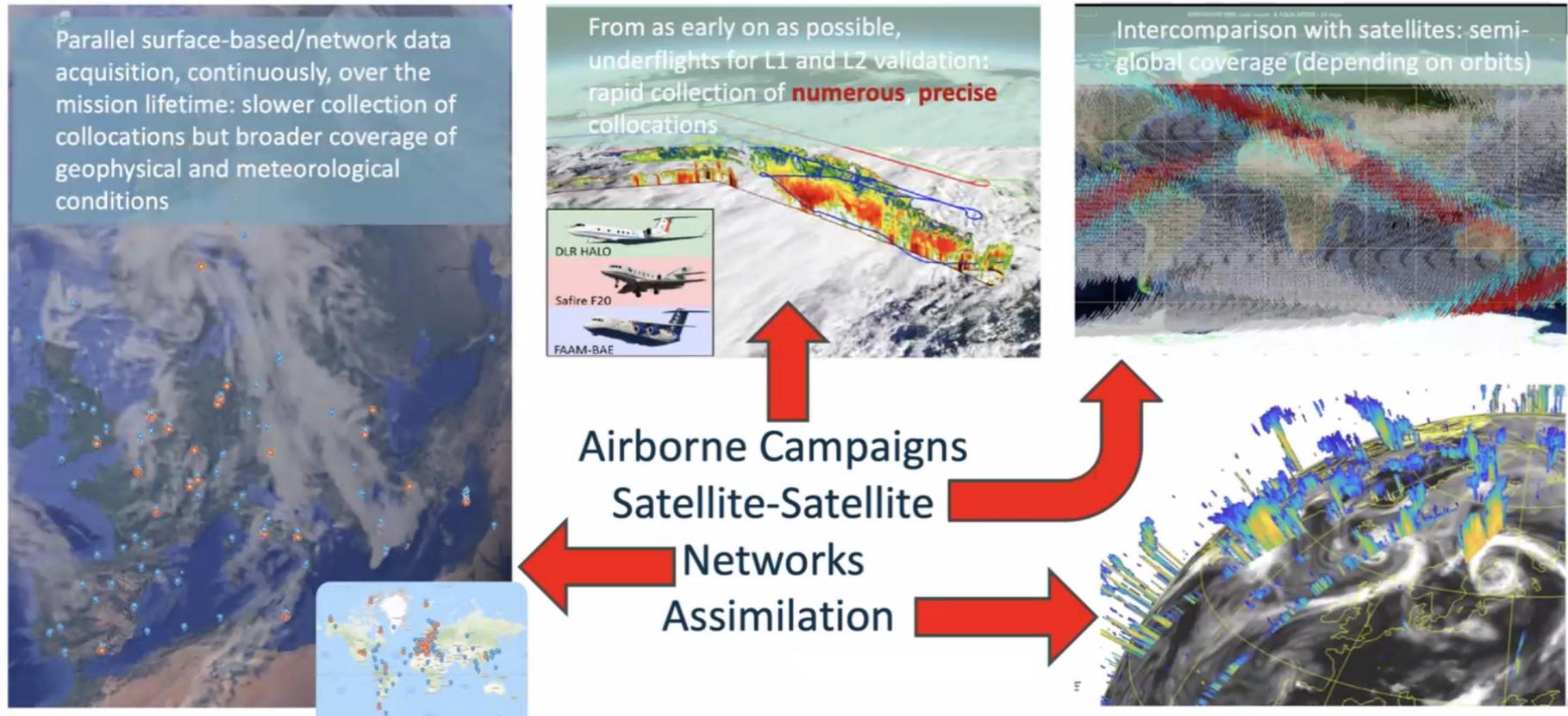
Level 2a (**L2a**) : L2 product derived from **one single EarthCARE instrument**.

geophysical variables, either at the same resolution and location as L1b data (“native grid”) or re-sampled to a common grid (joint standard grid), with error bars, quality flags and geolocations.

CPR 	ATLID 	MSI 	BBR 
Radar echo product	Feature mask and target classification extinction	Cloud mask	Unfiltered TOA shortwave and longwave
Feature mask	Backscatter & depolarisation profiles	Cloud micro-physical parameters	<ul style="list-style-type: none"> • Radiances
Liquid and ice cloud properties	Aerosol properties	Cloud top height	<ul style="list-style-type: none"> • fluxes
Vertical motion	Ice cloud properties	Aerosol parameters	
Rain and snow estimates			

EARTH-CARE: Validation and Uncertainty

- Geophysical validation involves a suite of collocated instruments and meteorological observations
- The validation activities have been presented and discussed at the 1st ESA Earth-CARE Validation Workshop in June 2024 in Berlin, Germany
- Earth-CARE validation activities will continue to collaborate with ESA instrument experts and other Earth observation experts with preliminary Earth-CARE data products as soon as available, as well as before public release of the consolidated data products



Note that several additional meetings may be organised by validation subgroups and are not listed here.

Highlight: High accuracy aerosol, cloud and radiation global observation

EARTH CARE: Level-2a Products overview

Cloud-top, vertically integrated, layerwise

Aerosol

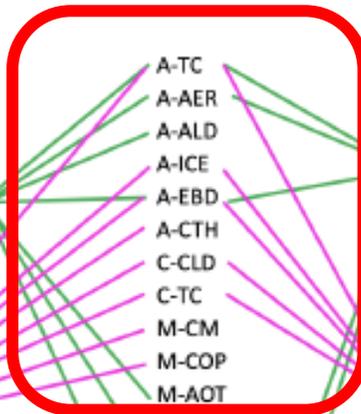
Aerosol layer height/depth and classification
Optical thickness
Layer-mean extinction-to-backscatter ratio
Layer-mean particle linear depolarisation ratio
Ångström exponent

Cloud and precipitation

Cloud-top height, phase and type
Optical thickness
Effective radius
Liquid, ice, rain water path
Surface snow rate
Surface rain rate

Radiation

Radiative fluxes at TOA
Broadband radiances at TOA



Vertical profiles

Aerosol

Aerosol fraction
Aerosol type
Extinction
Extinction-to-backscatter ratio
Particle linear depolarisation ratio

Cloud and precipitation

Extinction
Extinction-to-backscatter ratio
Effective radius
Liquid, ice, rain water content
Snow rate and median diameter
Rain rate and median drop size
Cloud/precipitation fraction
Cloud/precipitation classification

Radiation

Broadband radiances
Radiative fluxes
Heating rates

Level-2a single sensor products

For ESA products:

A for ATLID, C for CPR, M for MSI

Overview of JAXA L2 products

Cloud-top, vertically integrated, layerwise

Aerosol

Boundary layer height
Aerosol optical thickness
Ångström exponent

Cloud and precipitation

Cloud phase
Optical thickness
Effective radius
Cloud-top temperature, pressure, and height
Liquid, ice water path

Radiation

Radiative flux at TOA/BOA
Aerosol direct radiative Forcing at TOA/BOA



Vertical profiles

Aerosol

Aerosol species
Extinction, backscatter, lidar ratio
Depolarisation ratio
Mode radius

Cloud and precipitation

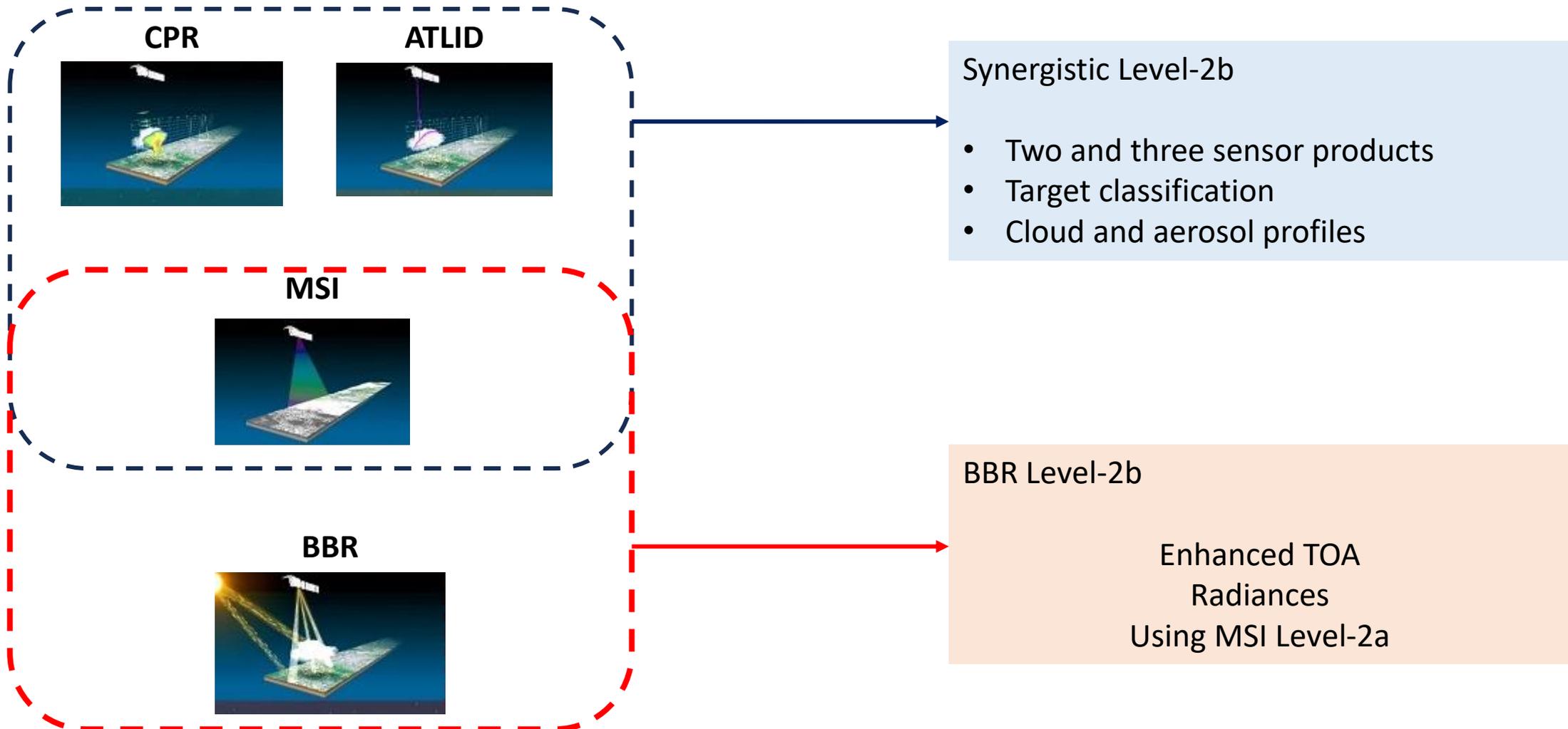
Refractivity
Doppler velocity
Extinction
Cloud mask, cloud particle type
Effective radius, optical thickness
Liquid/ice/rain/snow water content
Rain/snow rate
Vertical air motion
Sedimentation velocity
Mass ratio (2D ice/IWC)

Radiation

Radiative heating rate

EARTHCARE: Level-2b synergistic Products overview

Level 2b (L2b) product: L2 product synergistically derived from two or more EarthCARE instruments.



EARTHCARE: Level-2b synergistic Products overview

Cloud-top, vertically integrated, layerwise

Aerosol

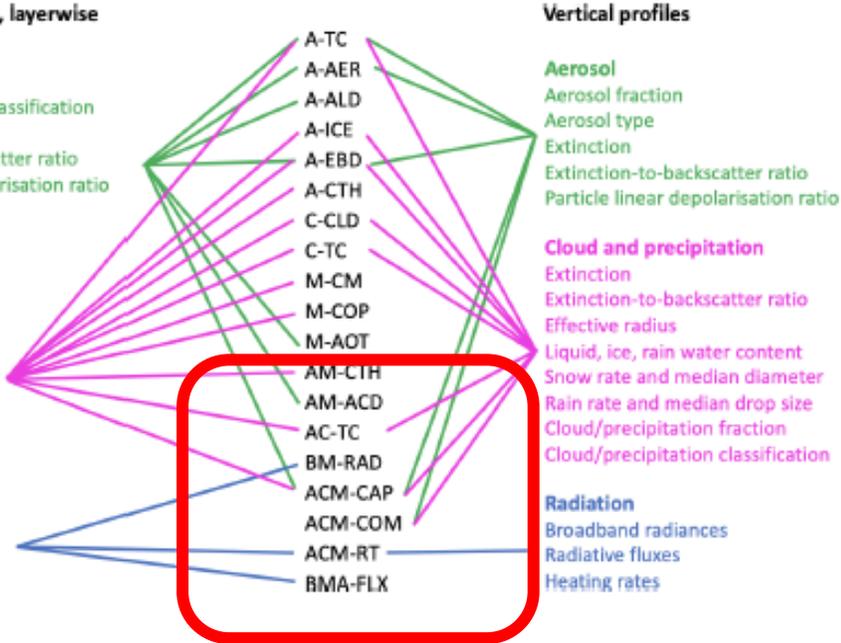
Aerosol layer height/depth and classification
Optical thickness
Layer-mean extinction-to-backscatter ratio
Layer-mean particle linear depolarisation ratio
Ångström exponent

Cloud and precipitation

Cloud-top height, phase and type
Optical thickness
Effective radius
Liquid, ice, rain water path
Surface snow rate
Surface rain rate

Radiation

Radiative fluxes at TOA
Broadband radiances at TOA



Vertical profiles

Aerosol

Aerosol fraction
Aerosol type
Extinction
Extinction-to-backscatter ratio
Particle linear depolarisation ratio

Cloud and precipitation

Extinction
Extinction-to-backscatter ratio
Effective radius
Liquid, ice, rain water content
Snow rate and median diameter
Rain rate and median drop size
Cloud/precipitation fraction
Cloud/precipitation classification

Radiation

Broadband radiances
Radiative fluxes
Heating rates

Level-2b 2 and 3 three sensor products

Overview of JAXA L2 products

Cloud-top, vertically integrated, layerwise

Aerosol

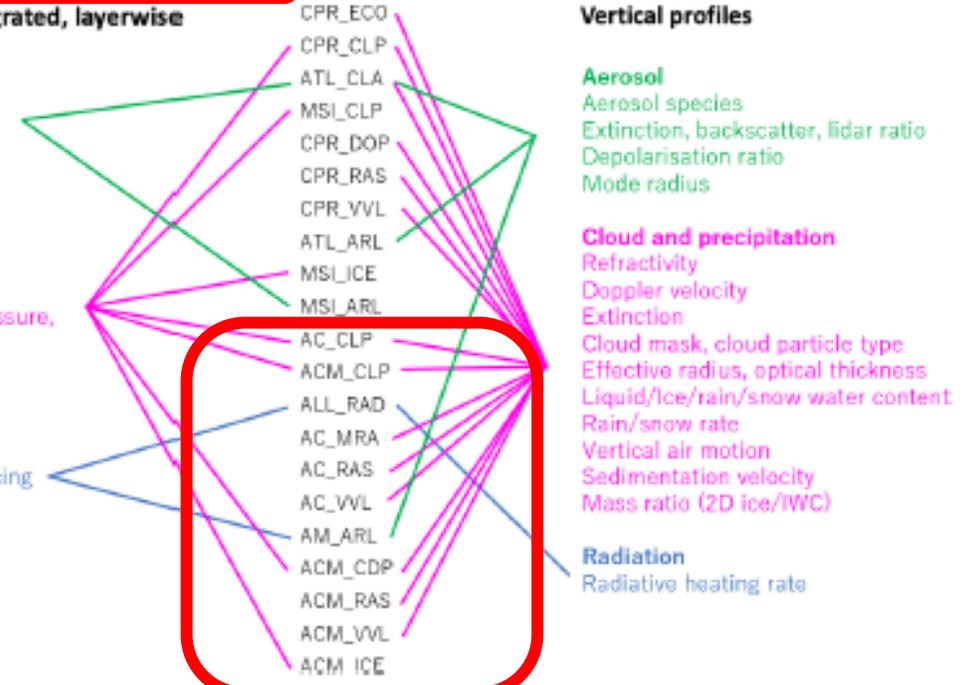
Boundary layer height
Aerosol optical thickness
Ångström exponent

Cloud and precipitation

Cloud phase
Optical thickness
Effective radius
Cloud-top temperature, pressure, and height
Liquid, ice water path

Radiation

Radiative flux at TOA/BOA
Aerosol direct radiative Forcing at TOA/BOA



Vertical profiles

Aerosol

Aerosol species
Extinction, backscatter, lidar ratio
Depolarisation ratio
Mode radius

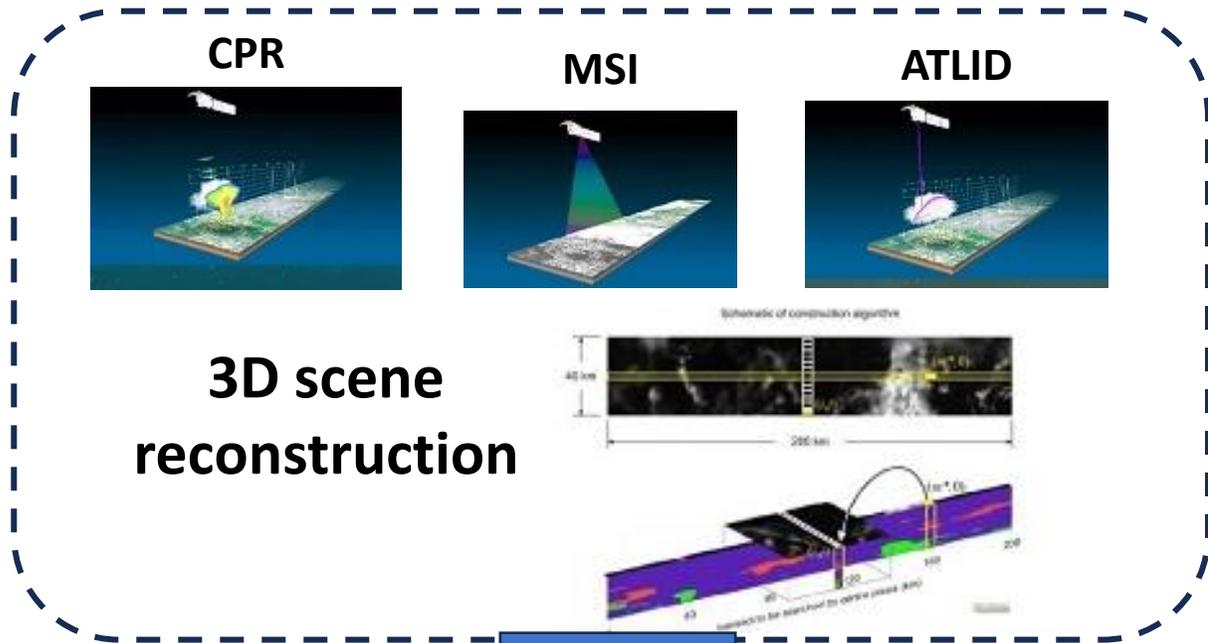
Cloud and precipitation

Refractivity
Doppler velocity
Extinction
Cloud mask, cloud particle type
Effective radius, optical thickness
Liquid/ice/rain/snow water content
Rain/snow rate
Vertical air motion
Sedimentation velocity
Mass ratio (2D ice/IWC)

Radiation

Radiative heating rate

EARTHCARE: Level-2b synergistic Products & Assessment



3D scene reconstruction

Radiative transfer products

Calculated

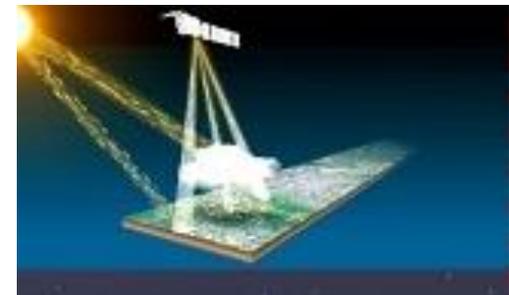
- Radiances
- Fluxes
- Heating rates profiles



Assessment

Comparison of calculated fluxes and radiances to BBR observations

BBR



EARTHCARE: Publications

- Wehr, T., Kubota, T., Tzeremes, G., Wallace, K., Nakatsuka, H., Ohno, Y., Koopman, R., Rusli, S., Kikuchi, M., Eisinger, M., Tanaka, T., Taga, M., Deghaye, P., Tomita, E., and Bernaerts, D.: The EarthCARE mission – science and system overview, *Atmos. Meas. Tech.*, 16, 3581–3608, <https://doi.org/10.5194/amt-16-3581-2023>, 2023.
- And all the publications from the AMT special issue: EarthCARE Level 2 algorithms and data products https://amt.copernicus.org/articles/special_issue1156.html

Thank you

