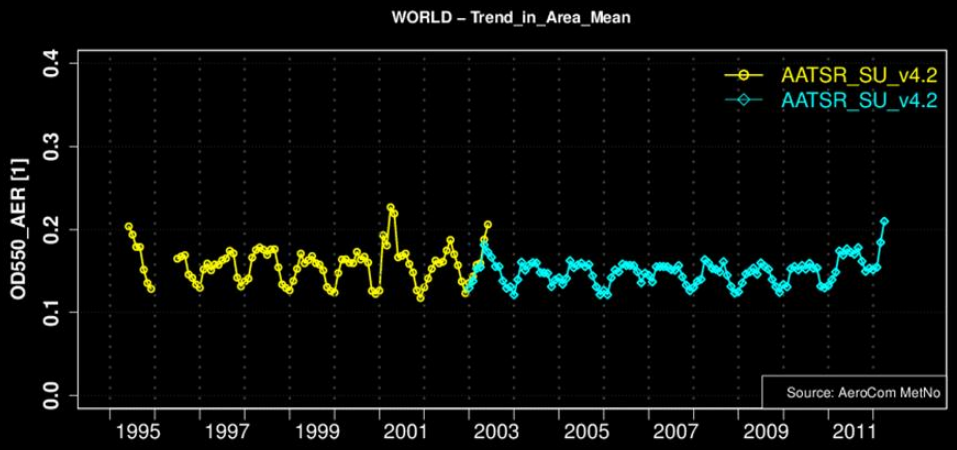


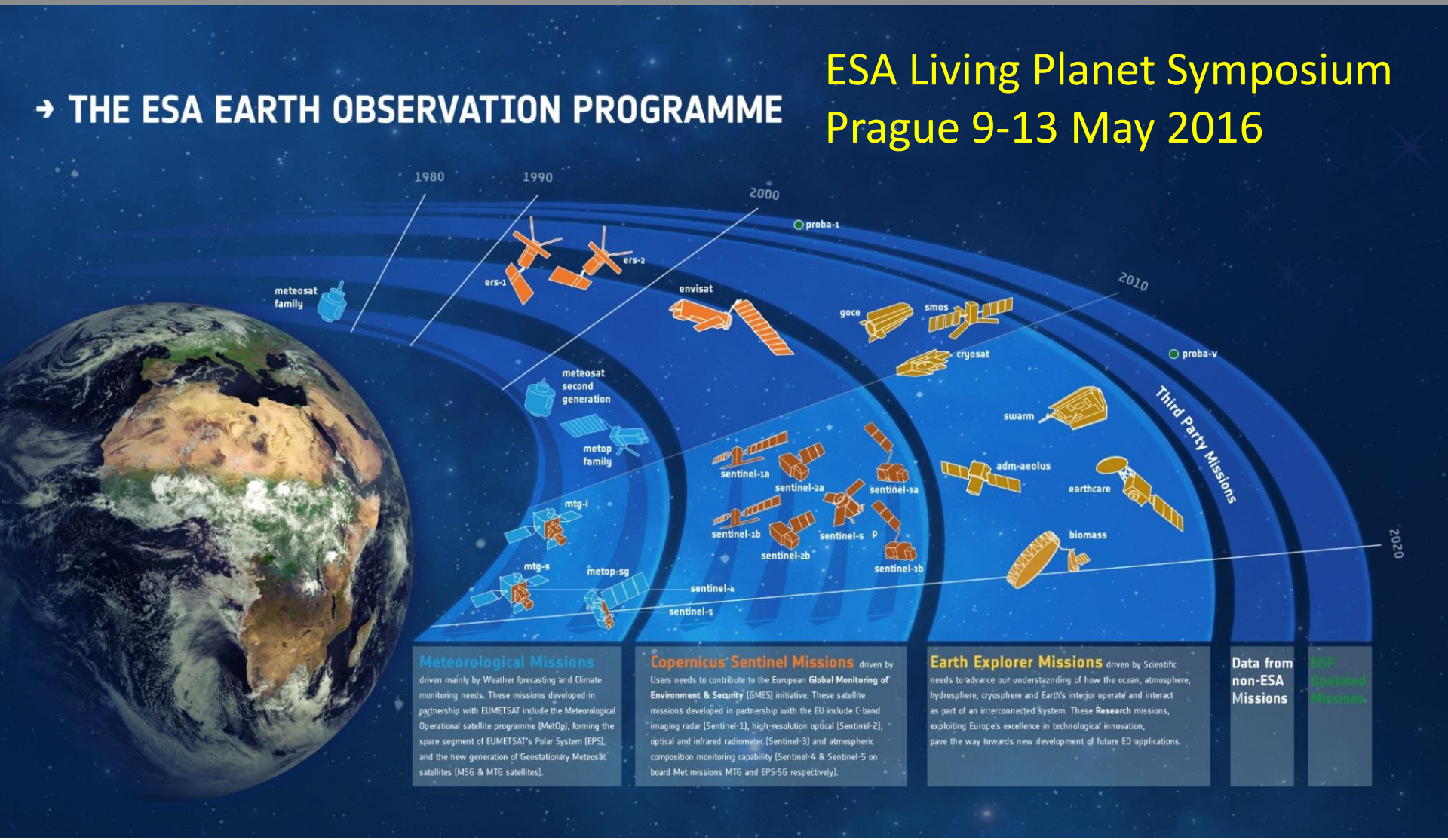
ESA aerosol sensors and activities

This is a selection (leaving out the Sentinel missions)

M. Eisinger, A. Straume, S. Pinnock
European Space Agency

esa

ESA Earth Observation missions



EarthCARE

The ESA-JAXA Cloud-Aerosol-Radiation Explorer Mission

1. The mission

EarthCARE Mission Summary

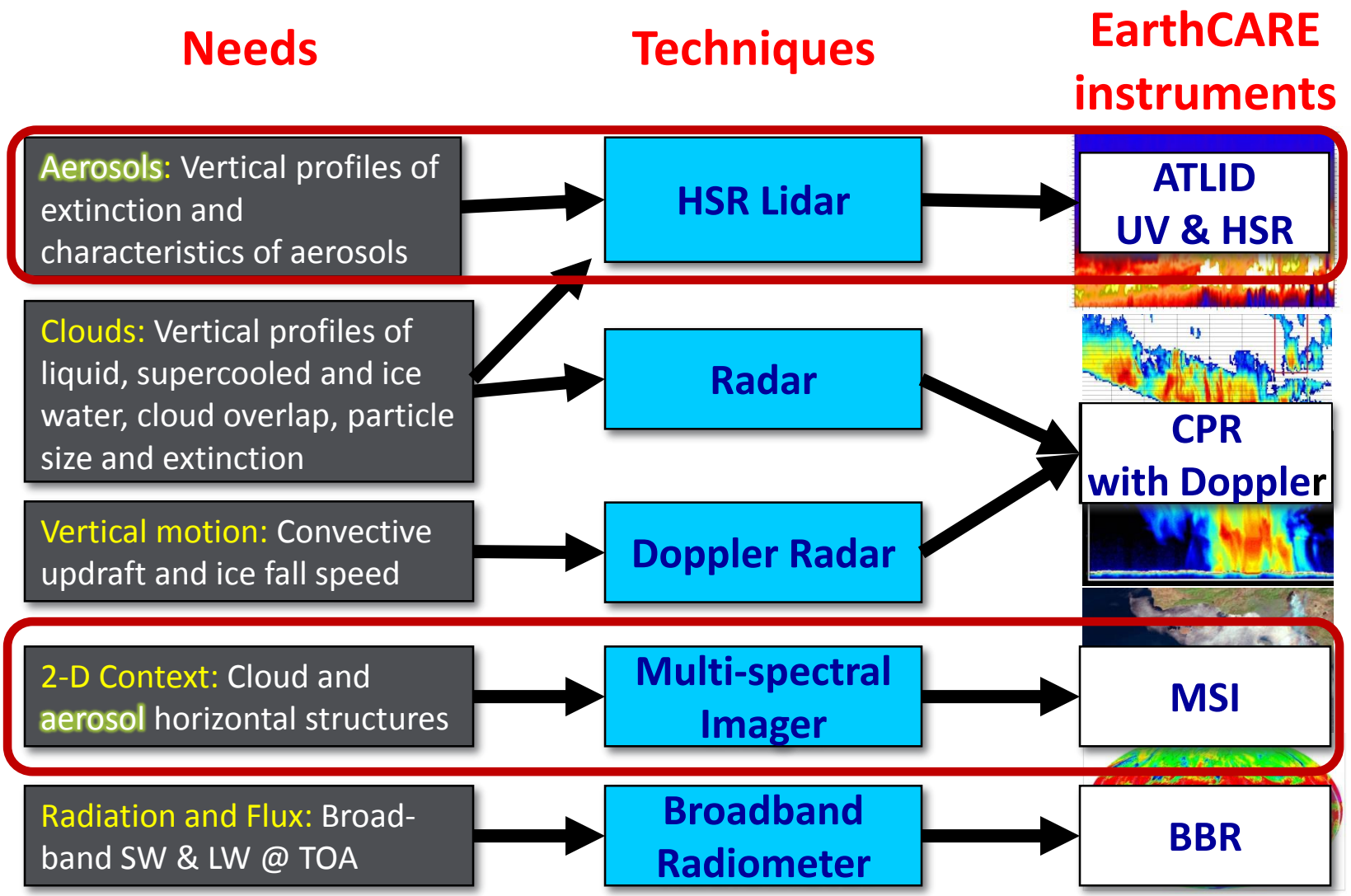
Mission Objective:

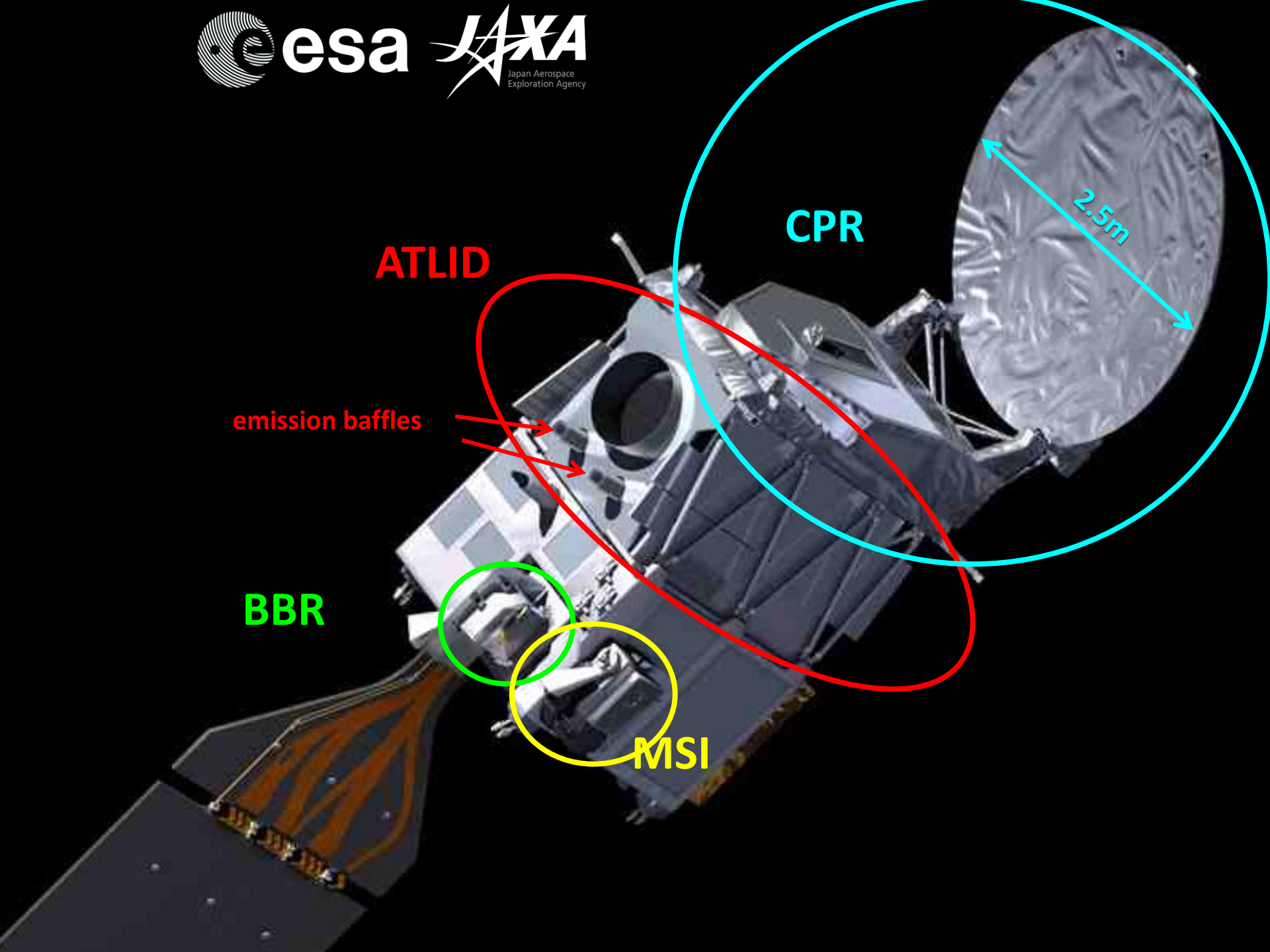
Improve understanding of **cloud-aerosol-radiation interactions** so as to include them (more) correctly and (more) reliably in climate and numerical weather prediction (NWP) models

Required Global Observations:

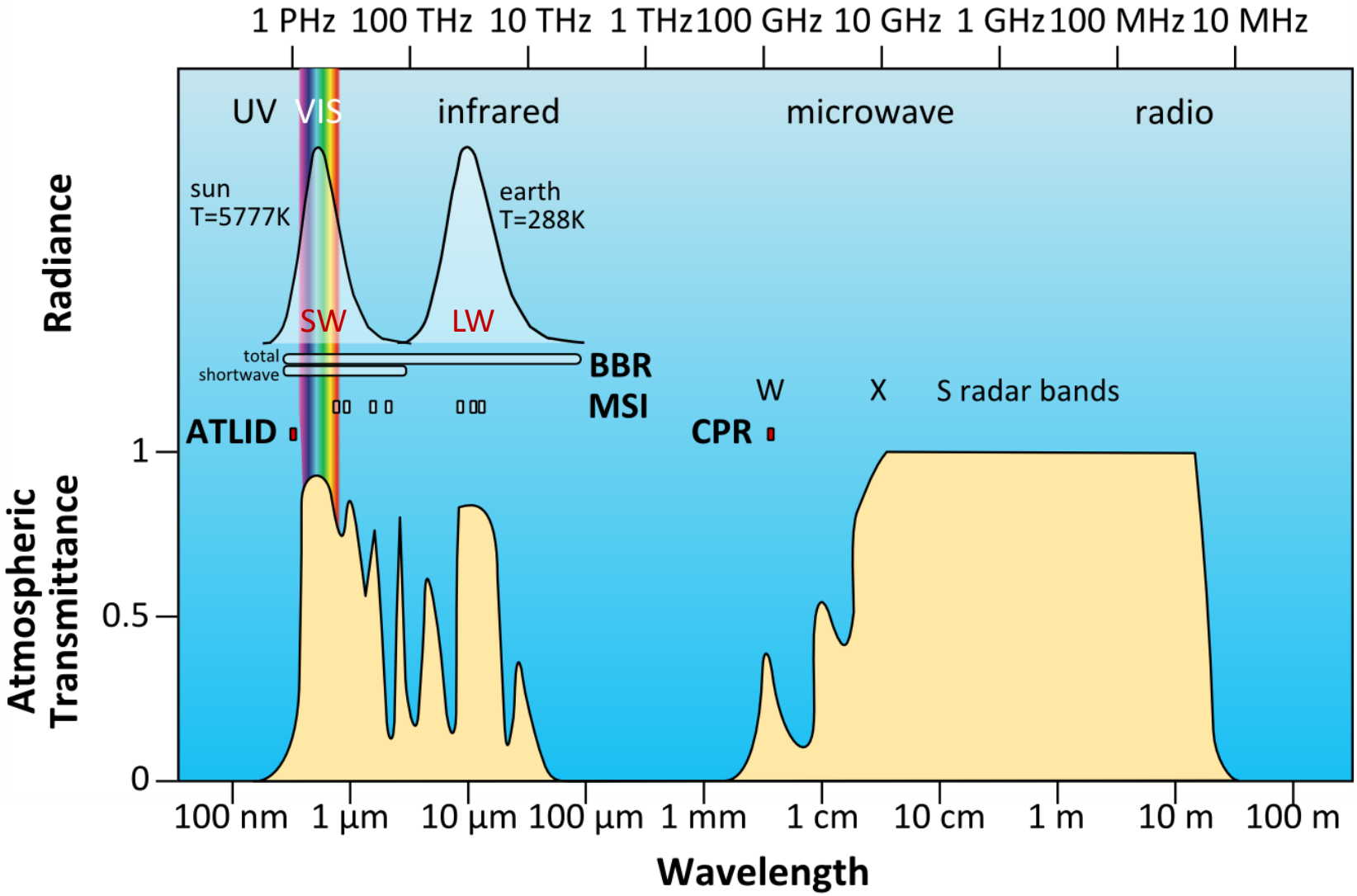
- Vertical distributions of atmospheric liquid water and ice, their transport by clouds and their radiative impact.
- Cloud distribution (cloud overlap), cloud-precipitation interactions and characteristics of vertical motions within clouds.
- Vertical profiles of natural and anthropogenic aerosols, their radiative properties and interaction with clouds.
- Retrieval of profiles of atmospheric radiative heating and cooling through the combination of the retrieved aerosol and cloud properties.

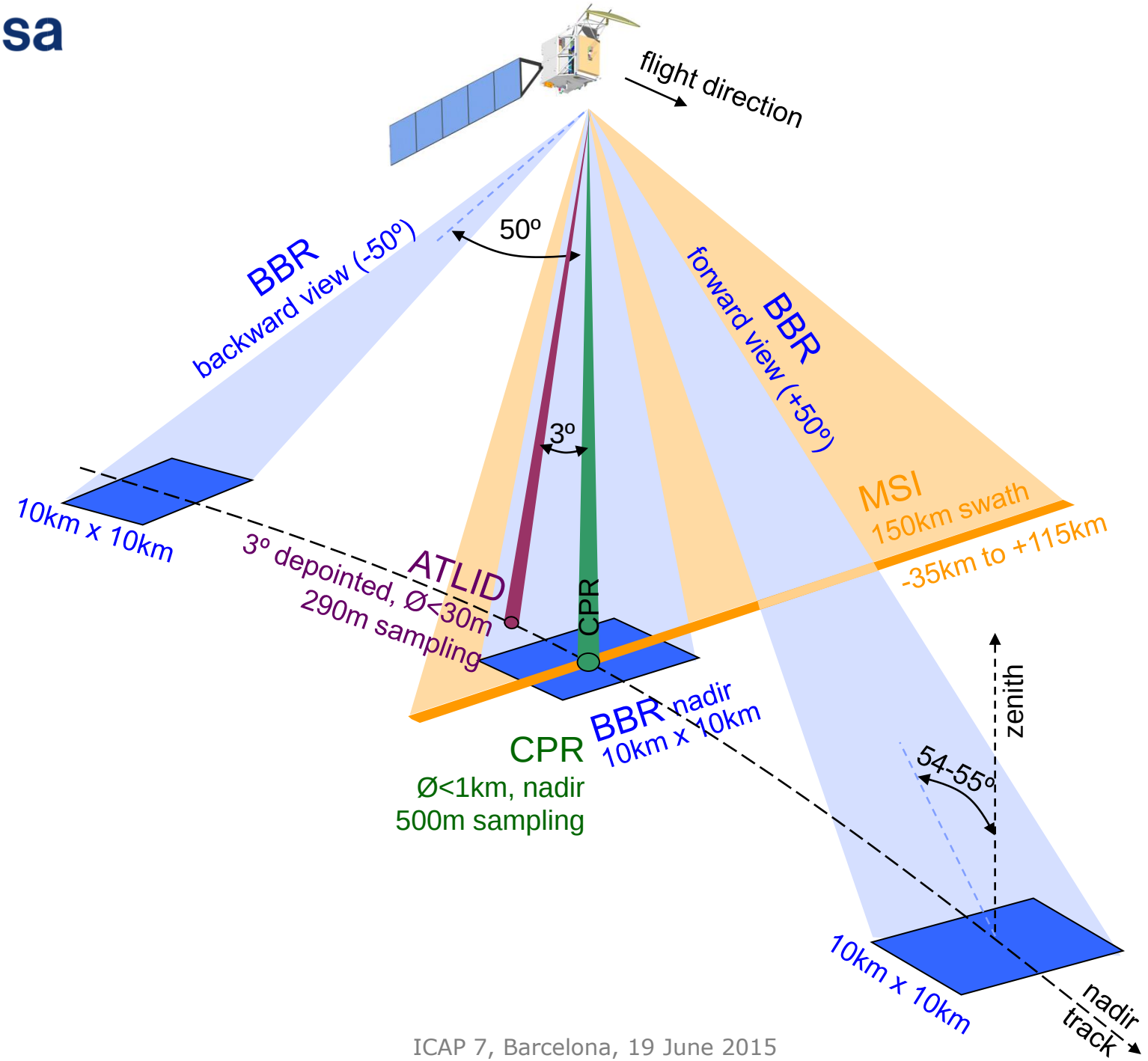
Mission Concept




esa
JAXA
Japan Aerospace Exploration Agency
CPR
2.5m
ATLID
emission baffles
BBR
MSI

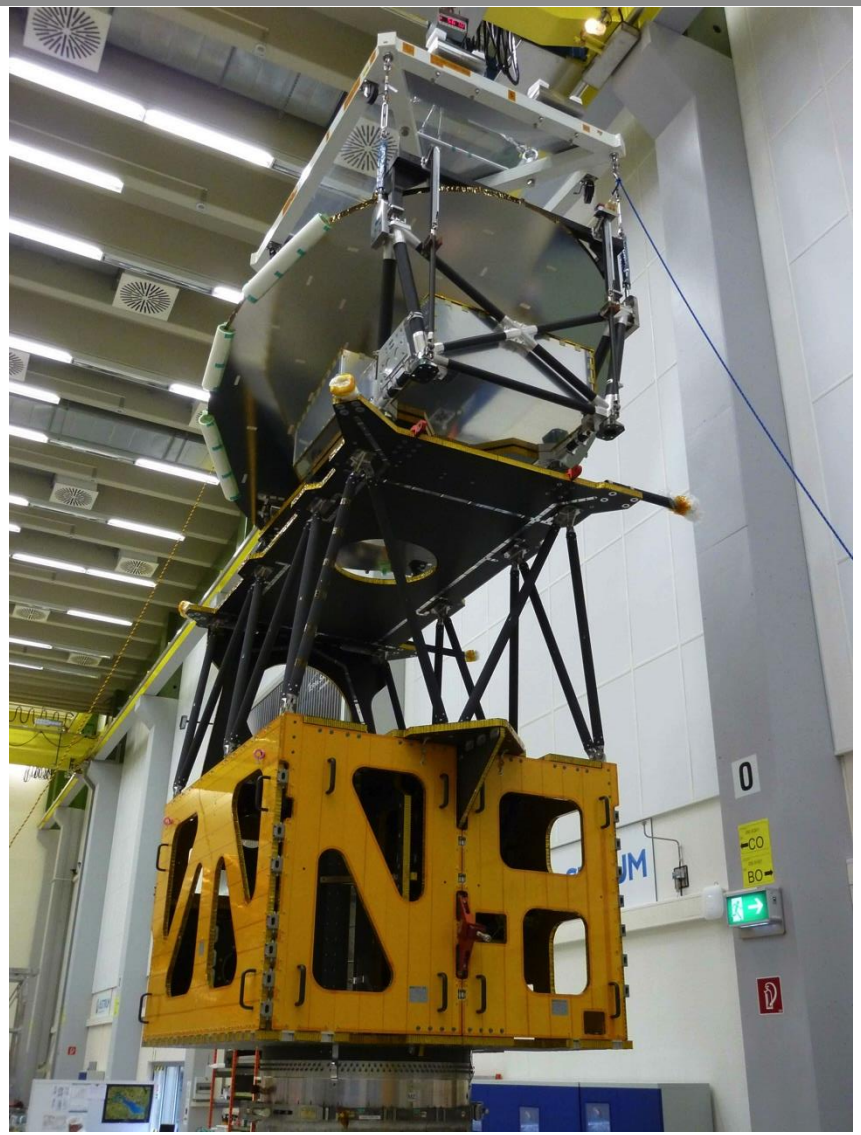
EarthCARE spectral measurements




flight direction
BBR
backward view (-50°)
50°
BBR
forward view (+50°)
3°
MSI
150km swath
-35km to +115km
10km x 10km
3° depointed, Ø<30m
290m sampling
ATLID
CPR
BBR nadir
10km x 10km
CPR
Ø<1km, nadir
500m sampling
zenith
54-55°
10km x 10km
nadir
track

Mission Data Sheet

EarthCARE Flight Model Structure

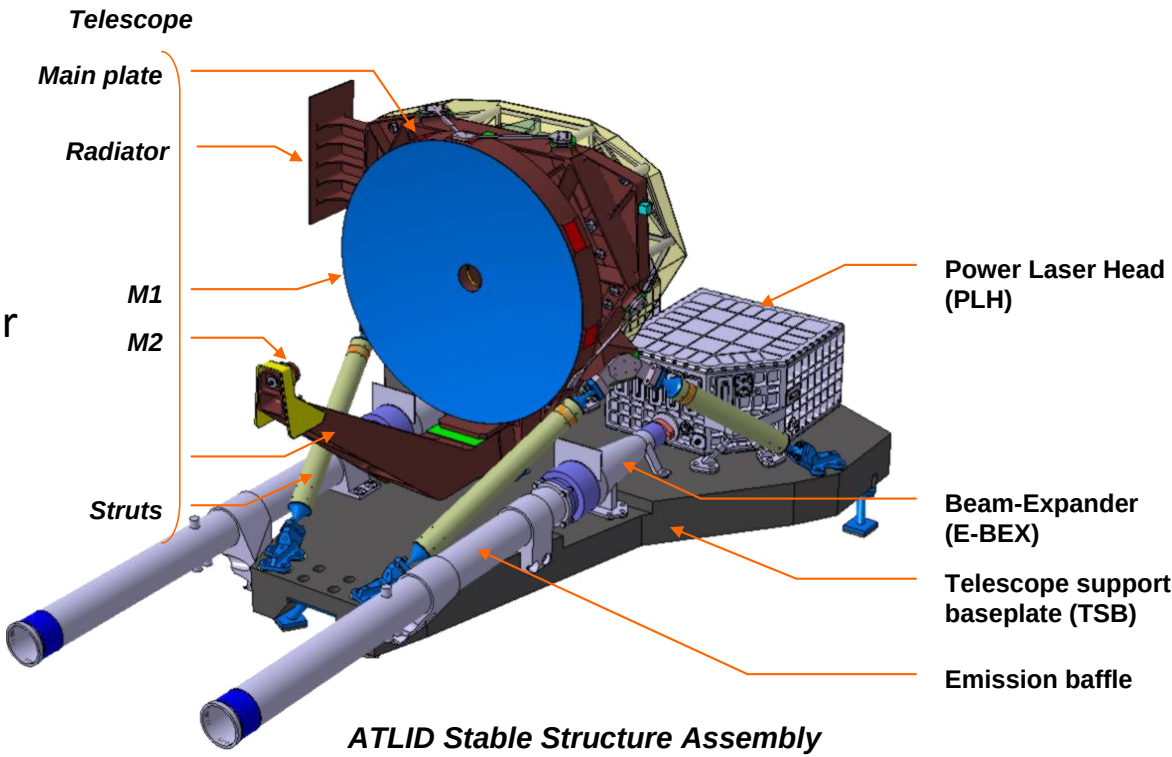


EarthCARE
Electrical Functional Model

EarthCARE Solar Panel

ATLID

- Atmospheric Lidar, λ = 355nm, linearly polarized
- High Spectral Resolution Lidar (HSRL) using Fabry-Perot etalon centred on the laser centre wavelength → separates molecular from particle backscatter signals (lidar ratio can be measured)
- 3 channels receiver :
  - Rayleigh scatter
  - co-polar Mie
  - cross-polar Mie



ATLID Stable Structure Assembly (SSA) and equipments

- Main products are profiles of
  - molecular backscatter signal
  - cloud and aerosol backscatter signal, co-polar
  - cloud and aerosol backscatter signal, cross-polar
  - extinction

Mass: 558 kg
Power: 585 W
Data rate <660 kb/s
Airbus (F) + Selex ES (I)
CDR close-out ongoing

High spectral resolution lidar

molecules

Backscattered light

Wide broadening of the incident light due to Brownian motion

wavelength

Rayleigh

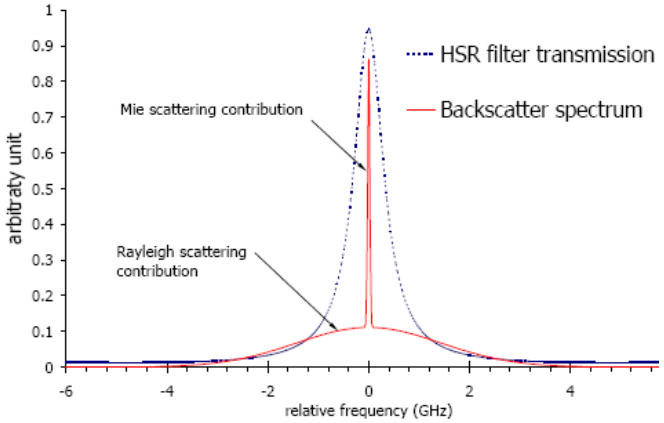
aerosols

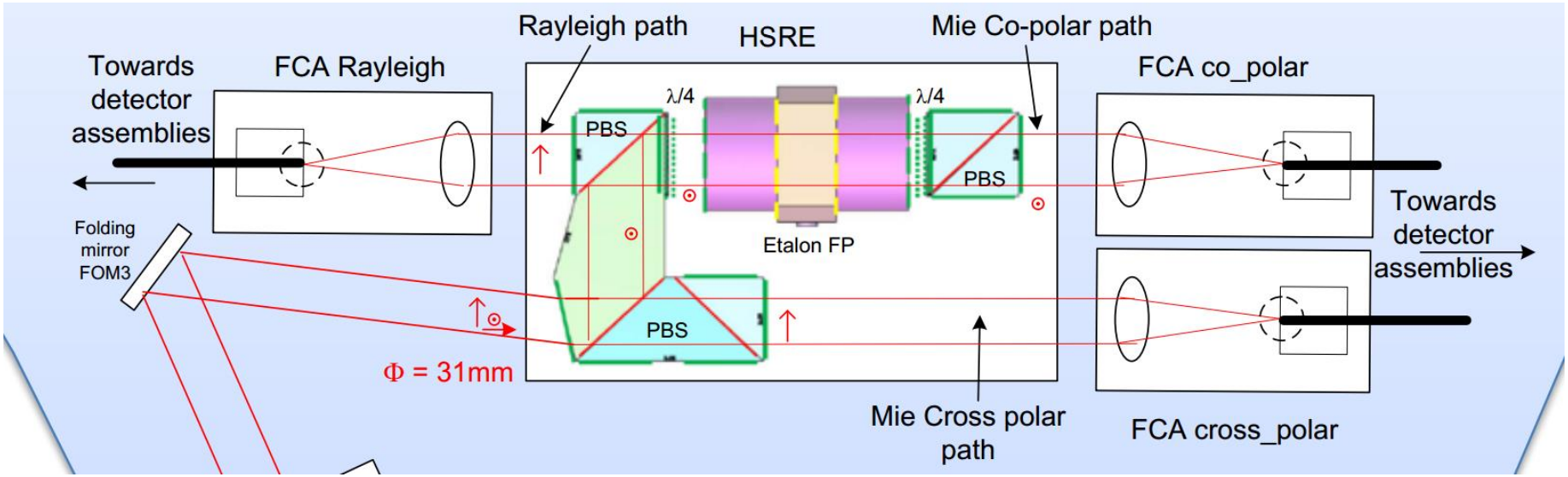
Backscattered light

Origin Spectrum shape not affected

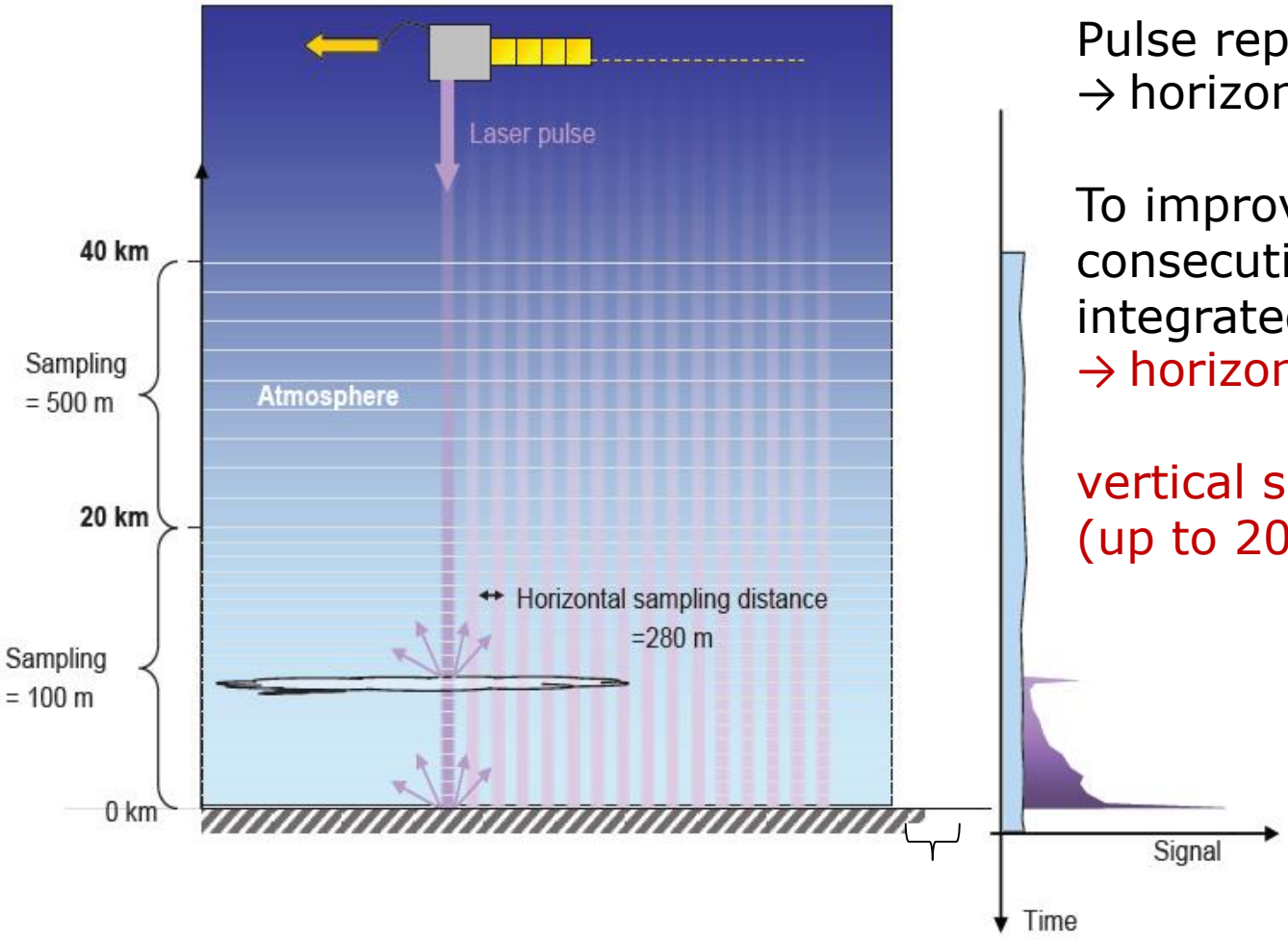
wavelength

Mie signal co and cross-polar





ATLID spatial sampling

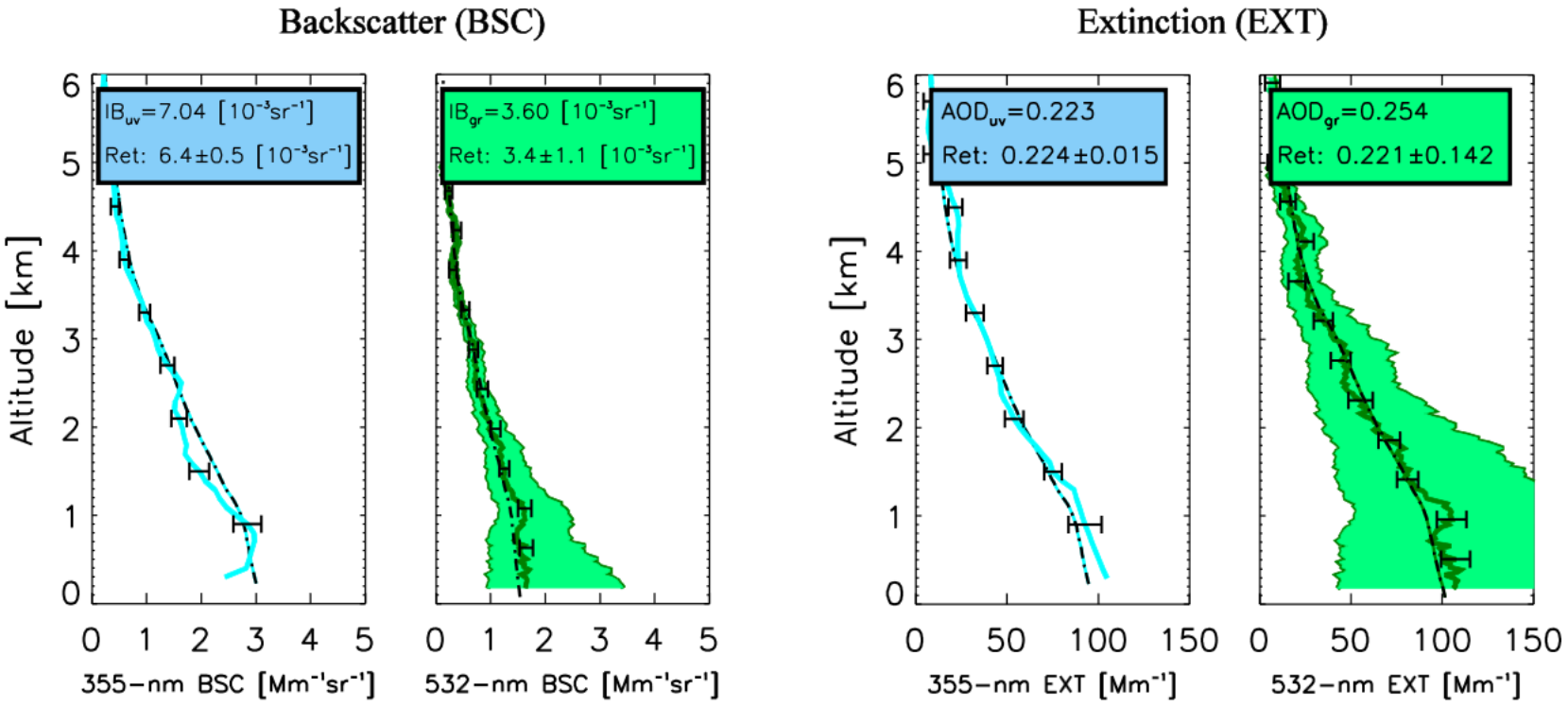


Pulse repetition rate 51 Hz
→ horizontal sampling 145 m

To improve SNR, two consecutive profiles are integrated on-board
→ horizontal sampling 290 m

vertical sampling ≈100m
(up to 20 km altitude)

ATLID retrieval simulation



Sulphate aerosol, AOD=0.223 at 355 nm, 50 km horizontal integration
dash-dotted line = truth, solid line = retrieval

Illingworth et al., BAMS 2015

Multi-Spectral Imager (MSI)

Objective:

To provide contextual imagery information to support the retrievals of geophysical parameters by the active instruments on-board EarthCARE

Characteristics:

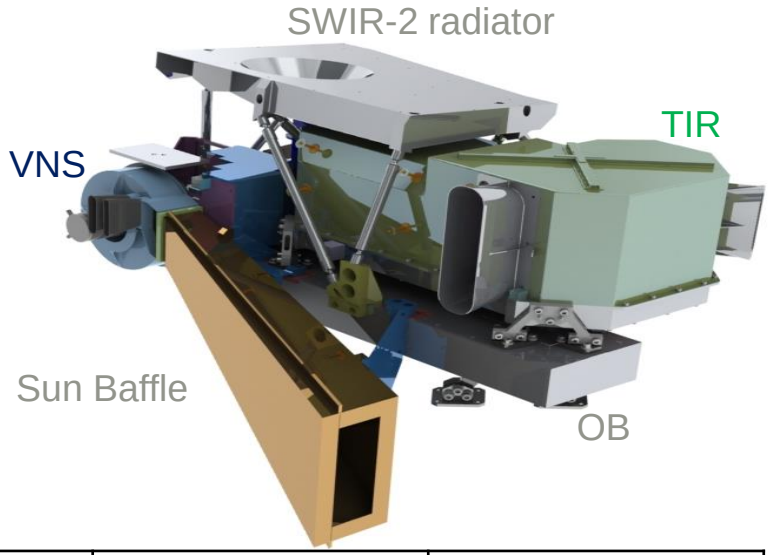
> 150 km swath (–35km to +115 km)
≈ 500 m ground sampling distance
57 W, 60 kg, 652 kbps

Level 1 product: radiances (VNS) & brightness temperatures (TIR)

SSTL (UK) + TNO (NL)

CDR closed, flight model under production

Signal to noise
VIS/NIR 70-500
SWIR 20-250
Noise (NEDT)
TIR 0.25-0.80 K



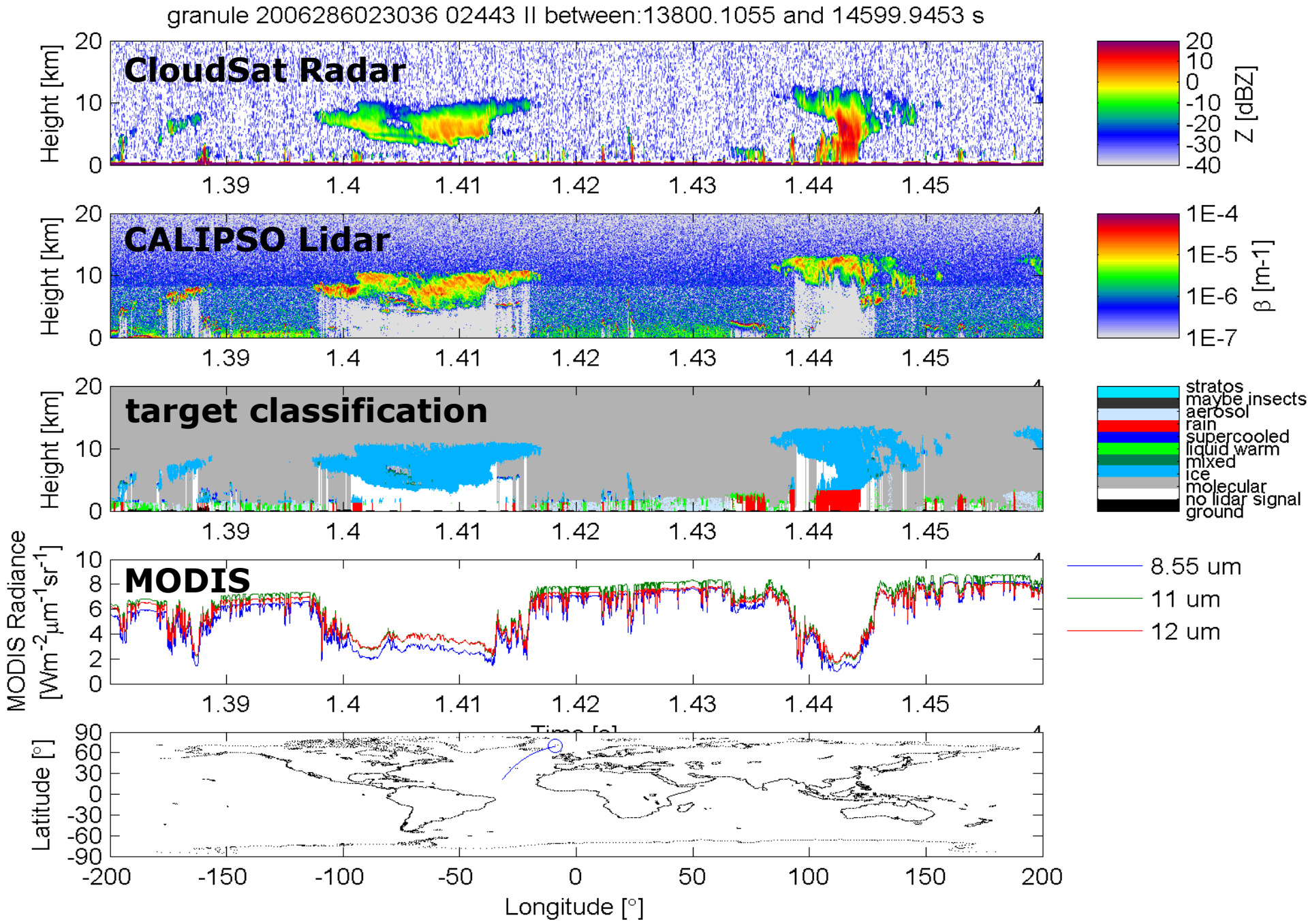
Channel	Centre Wavelength [µm]	Bandwidth (50%) [µm]
VIS	0.67	0.02
NIR	0.865	0.02
SWIR 1	1.65	0.05
SWIR 2	2.21	0.1
TIR 1	8.8	0.9
TIR 2	10.8	0.9
TIR 3	12.0	0.9

ESA imager characteristics

Instrument Satellite	# views	# bands	Spectral range [µm]	Swath [km]	Spatial resolution [m]
MERIS Envisat	1	15	0.4 – 0.9	1150	1200 (RR)
OLCI Sentinel 3	1	21	0.4 – 1.0	1270 tilted	300
MSI EarthCARE	1	4 VNS 3 TIR	0.67 – 2.2 8.8 – 12.0	150 tilted	500
AATSR Envisat	2	5 VNS 2 TIR	0.55 - 3.74 10.85 – 12.0	500	1000/1300
SLSTR Sentinel 3	2	7 VNS 2 TIR	0.55 – 3.74 10.85 – 12.0	1675/750	500

EarthCARE
2. Science products

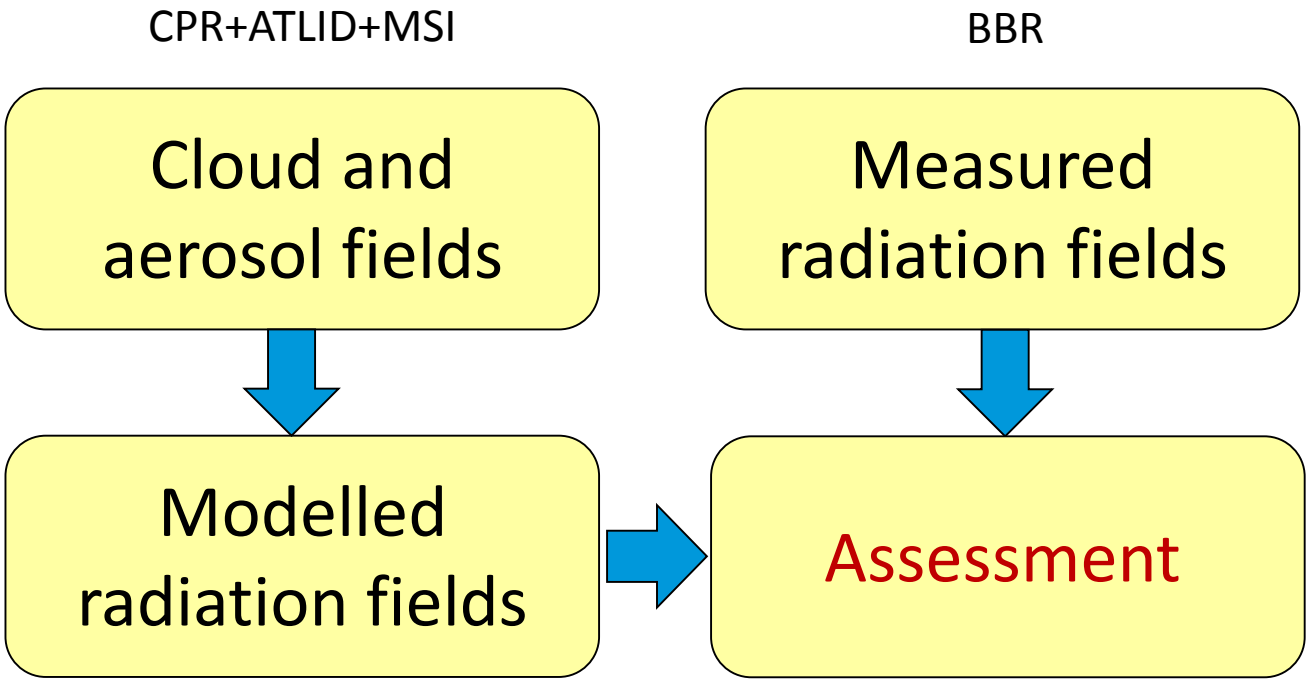
Heritage: A-Train Observations



Instrument synergy

Instruments are used in Synergy:

Measurements from two or more instruments are combined in order to obtain best possible measurement of cloud and aerosol properties and understanding of their interaction with radiation



Science Data Products

CPR Level 1b (JAXA)
Radar reflectivity and Doppler velocity profiles

ATLID Level 1b (ESA)
Attenuated backscatter in
- Rayleigh channel
- Co-polar Mie channel
- Cross-polar Mie channel

MSI Level 1b/c (ESA)
TOA radiances for four solar channels, TOA brightness temperatures for three thermal channels

BBR Level 1b (ESA)
Filtered TOA long-wave and total-wave radiances

CPR Level 2a
Radar echo product, feature mask, cloud type, liquid and ice cloud properties, vertical motion, rain and snow estimates, ...

ATLID Level 2a
Feature mask and target classification, extinction, backscatter & depolarisation profiles, aerosol properties, ice cloud properties, ...

MSI Level 2a
Cloud mask, cloud micro-physical parameters, cloud top height, aerosol parameters, ...

BBR Level 2a
Unfiltered top-of-atmosphere radiances, short-wave and long-wave fluxes

Synergistic Level 2b
Target classification, cloud & aerosol profiles along track

instrument grid for L1 and L2a
"joint standard grid" (≈1km x 1km) for L2b
larger grid cells as needed (aerosols, radiances and fluxes)

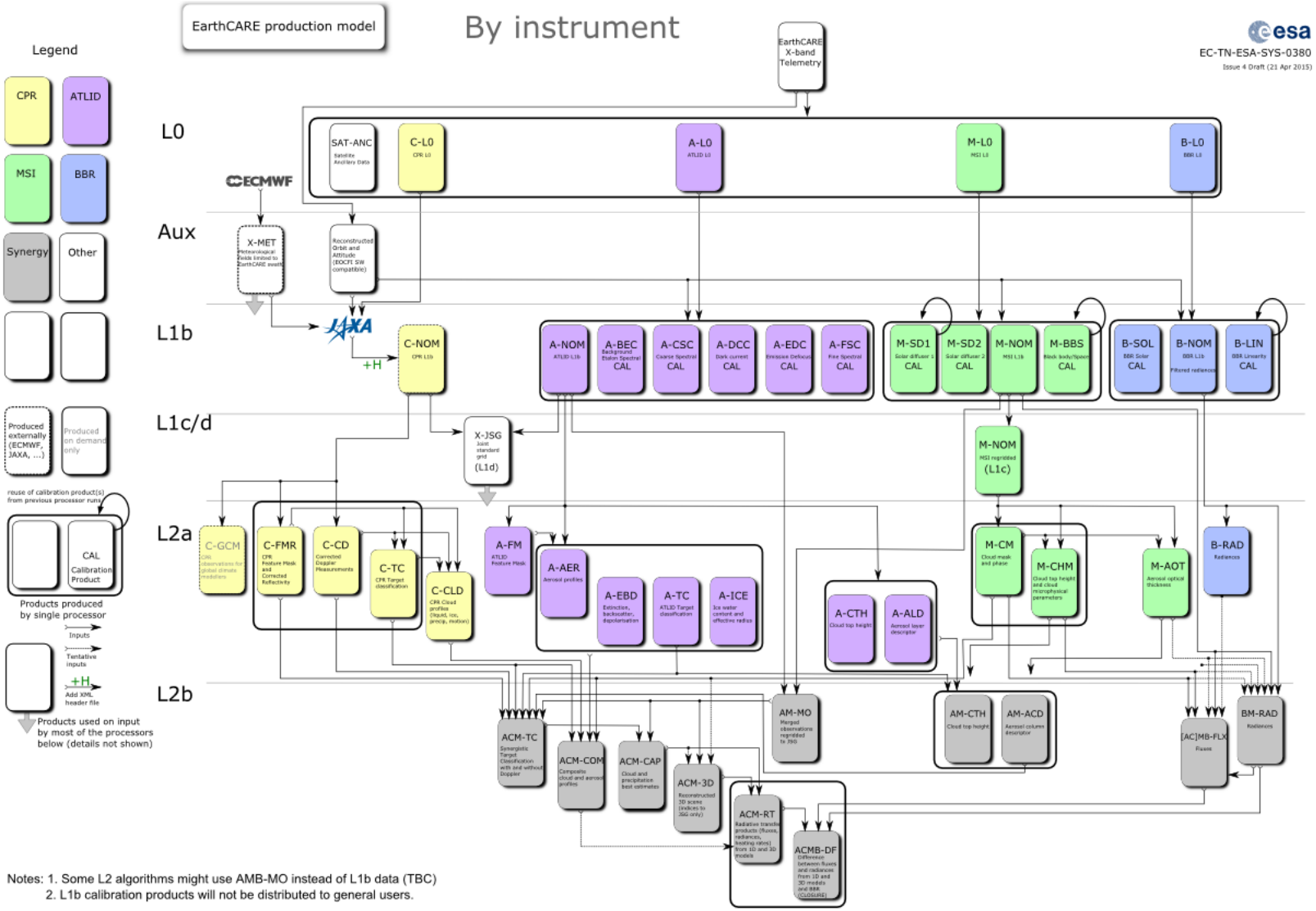
Products will contain:
- Primary parameters
- Error descriptors
- Quality flags
- Algorithm configuration info

3D Scenes Construction
Expand syn. retrievals across-track using MSI information

Radiative Transfer Products
1D & 3D rad. transfer: radi-ances, fluxes, heating rates

Assessment
Comparison of modelled fluxes and radiances to BBR observations

EarthCARE production model



EarthCARE aerosol products (Level 2a)

ATLID (2D along track/vertical)

Aerosol extinction (α), backscatter (β), depolarisation (δ) at 355 nm

Target classification

Aerosol type (see next slide)

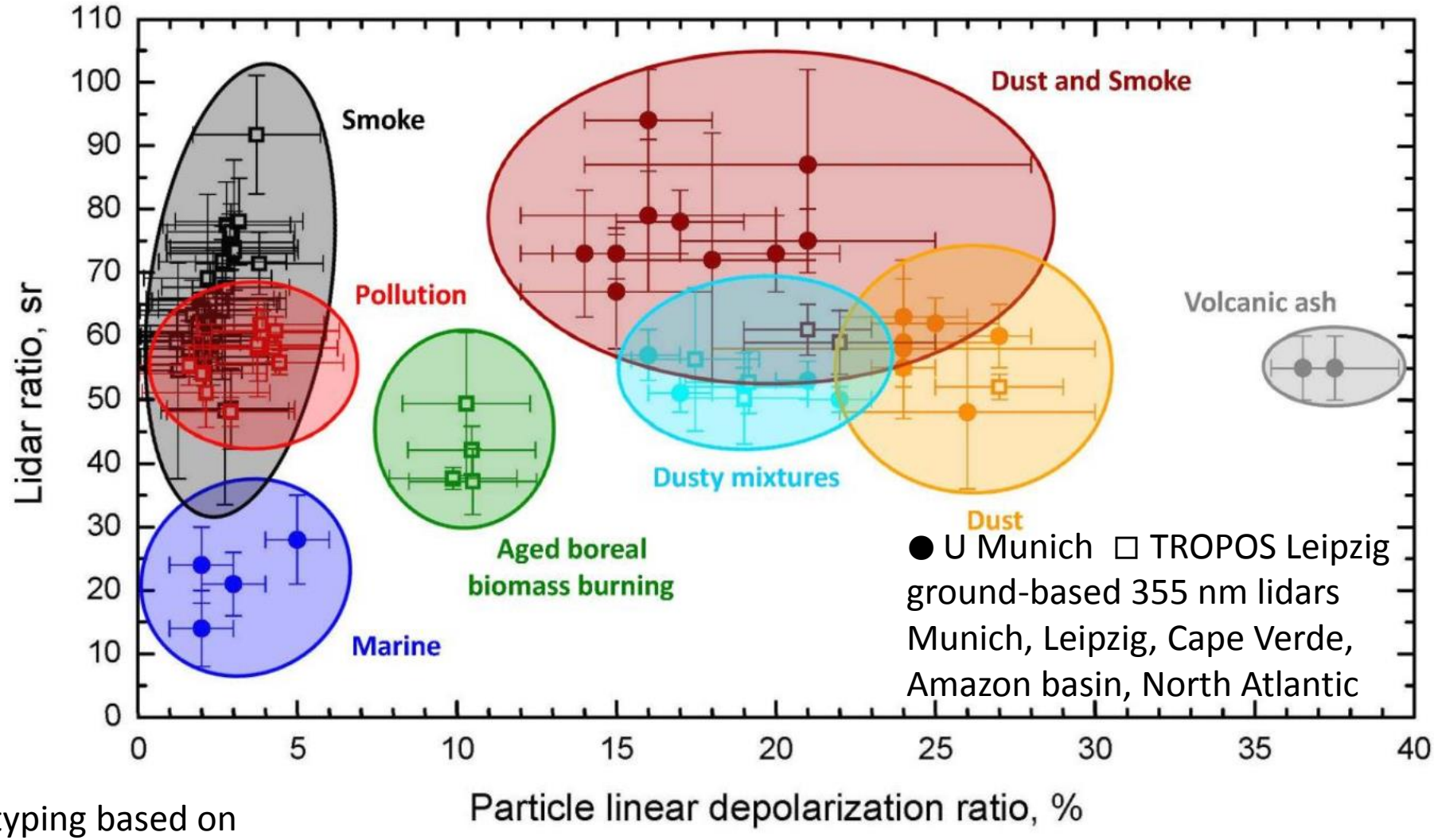
Aerosol layer properties at 355 nm

MSI (2D along/across track)

Aerosol optical depth (AOD)
for ocean: at 659 and 865 nm
for land:at 659 nm

Ångstrøm exponent (ocean only)

Aerosol typing



typing based on intensive properties

EarthCARE aerosol products (Level 2b)

MSI + ATLID in synergy (at least 2D along track/vertical)

Target classification

Aerosol optical depth (AOD) at 355 and **550** nm

Ångstrøm exponent

Aerosol type (combining information from ATLID lidar ratio and depolarisation with MSI optical depth and Ångstrøm exponent)

EarthCARE aerosol products (Level 2b)

Tab. B.1: Look-up table for the columnar aerosol type

	AE ≤ 0.6	**0.6 < AE < 1.0**	**≥1.0**
AOT ≤ 0.15	Clean marine (t = 1)	No specific type (t = 0)	Clean continental (t = 2)
0.15 < AOT < 0.3	No specific type (t = 0)	No specific type (t = 0)	No specific type (t = 0)
AOT ≥ 0.3	Desert dust (t = 3)	No specific type (t = 0)	Biomass burning, pollution (t = 4)

Tab. B.2: Aerosol type coding

Name of aerosol type	***t***
Unknown	0
Clean Marine	1
Clean Continental	2
Mineral Dust	3
Pollution/Biomass-burning smoke	4

Preparatory Science Activities

Level 2 Developments
- clouds profiles from radar, lidar, imager
- aerosol profiles from lidar, imager
- ...d radiation from ...files and measured ...W → closure
- ...

...cience Preparation
...ilding on CloudSat, ...lipso, CERES/GERB, ...DIS, ground-/air- ...ed radar/lidar, ...elling, …

Preparation of NWP Assimilation
ECMWF: preparation of radar and lidar assimilation

Preparation GCM evaluation
Dedicated data pro...ssor (CFMIP-type) ...

... Mission Advisory

Preparation Validation
- JAXA: preparatory contracts in...
- ESA: **announcement of opportunity call planned 2 years before launch**
- Joint validation workshop before launch

Scientific Workshops
- workshops in about 2-year intervals
- most recent: Paris 2012, jointly with CloudSat and Calipso
- Tokyo 2014
- **next: 2017 in Europe**

EarthCARE
3. Operational aspects

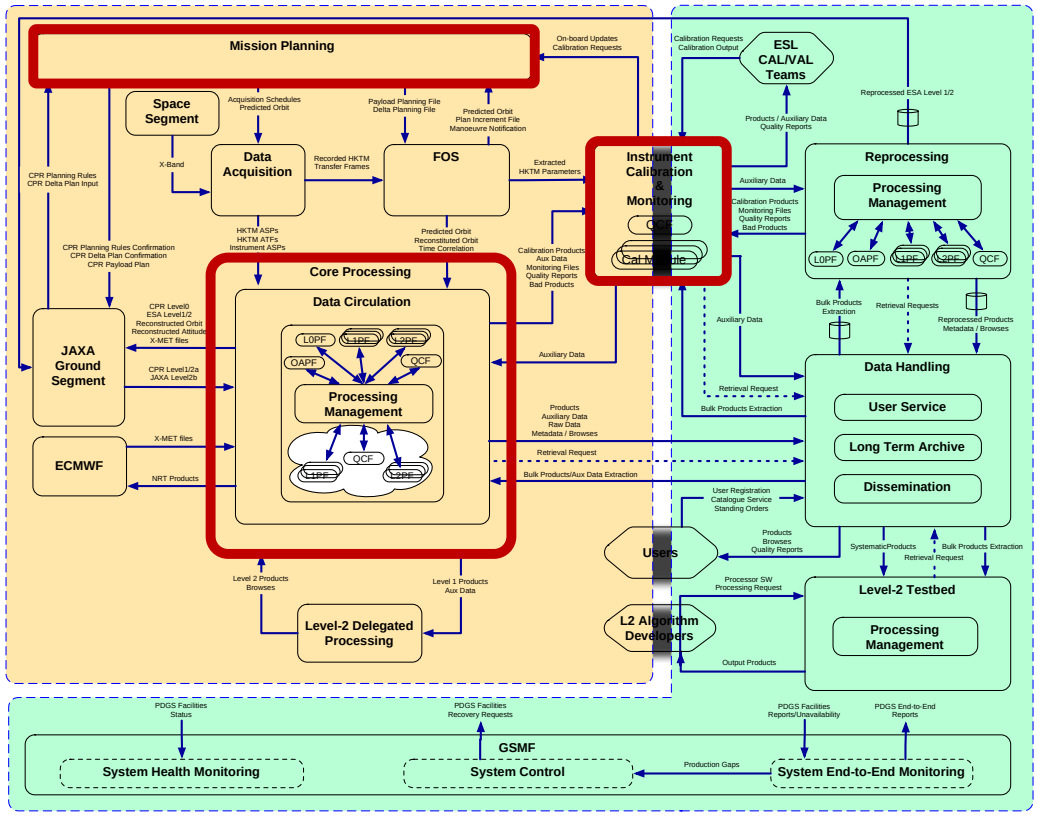
Payload data ground segment (PDGS)

Procurement of the first facilities will start soon. Invitations to Tender (ITTs) for three facilities are being released:

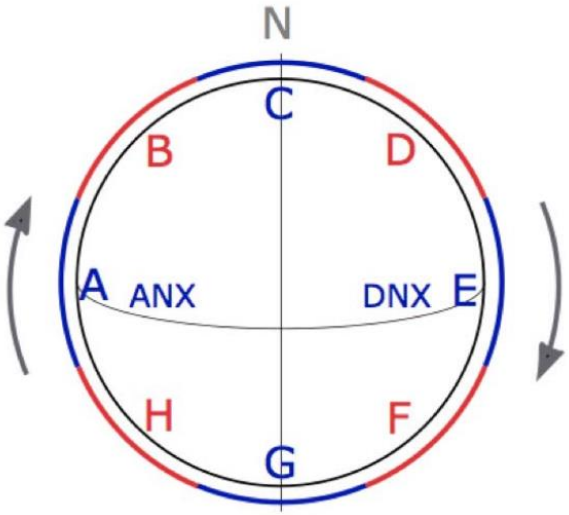
- Core Processing facility (CPF)
- Mission Planning facility (MPF)
- Instrument calibration and Monitoring Facility (ICMF)

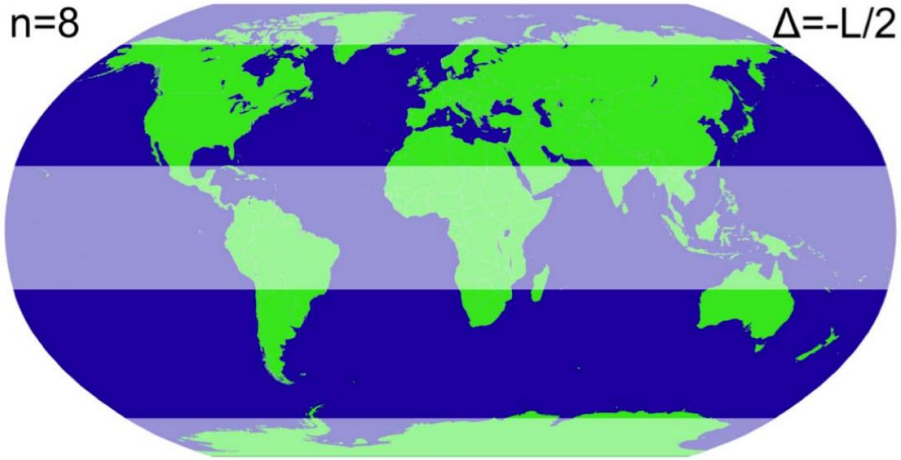
Physical location of EarthCARE PDGS is TBD.

JAXA data products will be archived and disseminated both by JAXA and ESA.



Product granularity

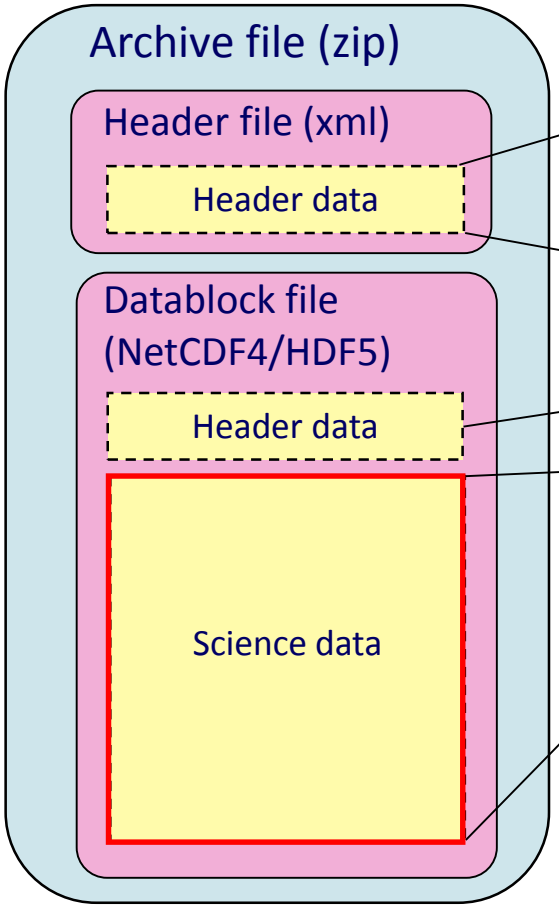




8 fixed frames per orbit → frame length 5000 km along track (694 s)

latitude boundaries at +/-22.5 and +/-67.5 degrees

EarthCARE Data Product Format



common to all EarthCARE products

Fixed header
Main header
Specific Header

Copy of header data from header file (for convenience)

Parameter 1
Parameter 2
…
Parameter N

Most parameters are arrays (1D, 2D, 3D, …) of floating-point values

ESA: No use of “unlimited” dimensions (performance!)
Internal compression of parameters (transparent to users)
Metadata convention TBD. Climate and Forecast (CF)?

Data volume and latency

Data volume estimate

(Total L0 up to L2b)

ESA: 60 GB / orbit

JAXA: 11 GB / orbit

Data latency

Nominal (60% of data*):

Within 5.1 h from sensing (ESA)

(cf ICAP 1 recommendation!)

Worst case (blind orbits):

24h (up to L2a)/48h (L2b)

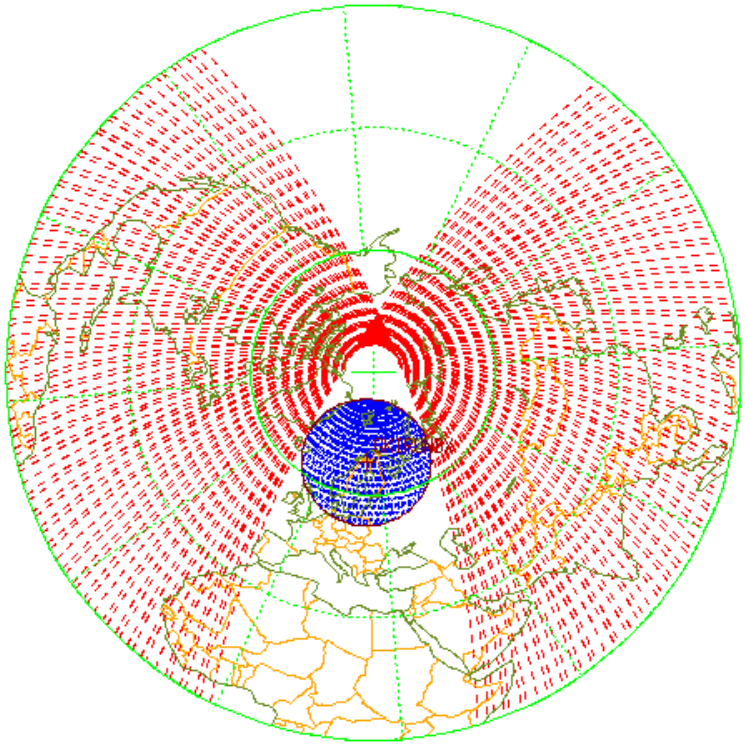
* driven by ground station visibility

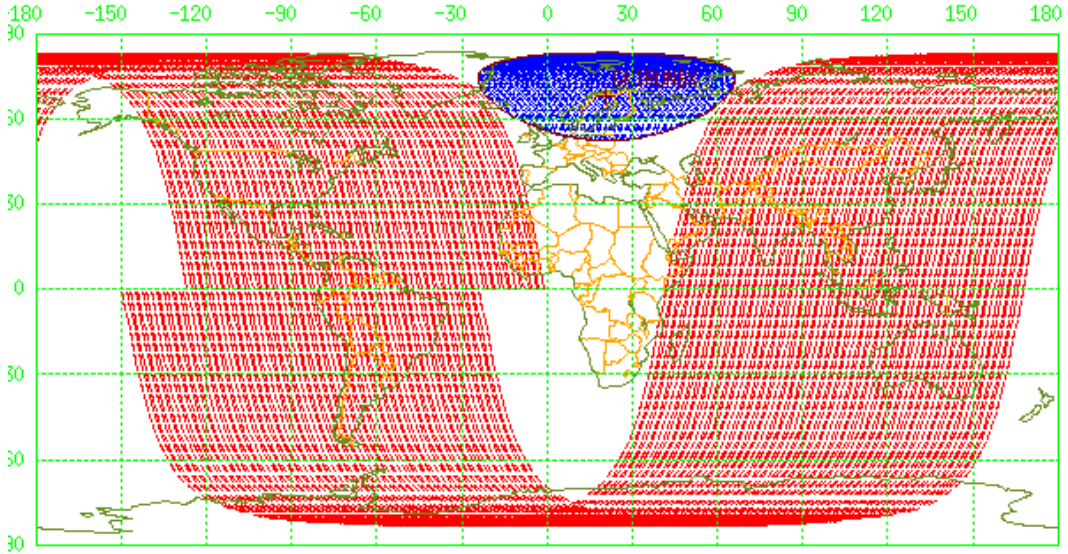
(MB per orbit)		ATLID	CPR	MSI	BBR	TOTAL
Level 0		621	221	485	103	1,430
Level 1b		6,000	640	5,500	150	12,290
Level 1c				1,200		1,200
Level 1d (X-JSG and X-MET)						4,900
Level 2a	ESA	7,400	3,000	10,800	20	21,220
	JAXA	870	3,045	2,010		5,925
Level 2b (Radiation)		6,000				6,000
Level 2b (Cloud/Aerosol)		11,000				11,000
JAXA Level 2b		3,369				3,369
Volume Margins	ESA	2,600				2,600
	JAXA	1,066				1,066
TOTAL DATA VOLUME / ORBIT						***71,000***
TOTAL DATA VOLUME / ORBIT (ESA → JAXA)						*60,000*
TOTAL DATA VOLUME / ORBIT (JAXA → ESA)						*11,000*

Blind orbits

X-band ground station not selected yet, Kiruna (68° N) shown as example

5.6 out of 15.6 blind orbits/day (36%). Max acquisition latency = 12 hours





Blind orbits for Kiruna only scenario,
full 25-day repeat cycle

Further reading

BAMS paper on EarthCARE (early-release version):

A. J. Illingworth et al.

The EarthCARE satellite: The next step forward in global measurements of clouds, aerosols, precipitation and radiation

http://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-12-00227.1

ADM-Aeolus aerosol products

Aeolus: Mission Objectives

Scientific objectives

- To improve the quality of weather forecasts;
- To advance our understanding of atmospheric dynamics and climate processes;

Explorer objectives

- Demonstrate space-based Doppler Wind LIDARs potential for operational use.

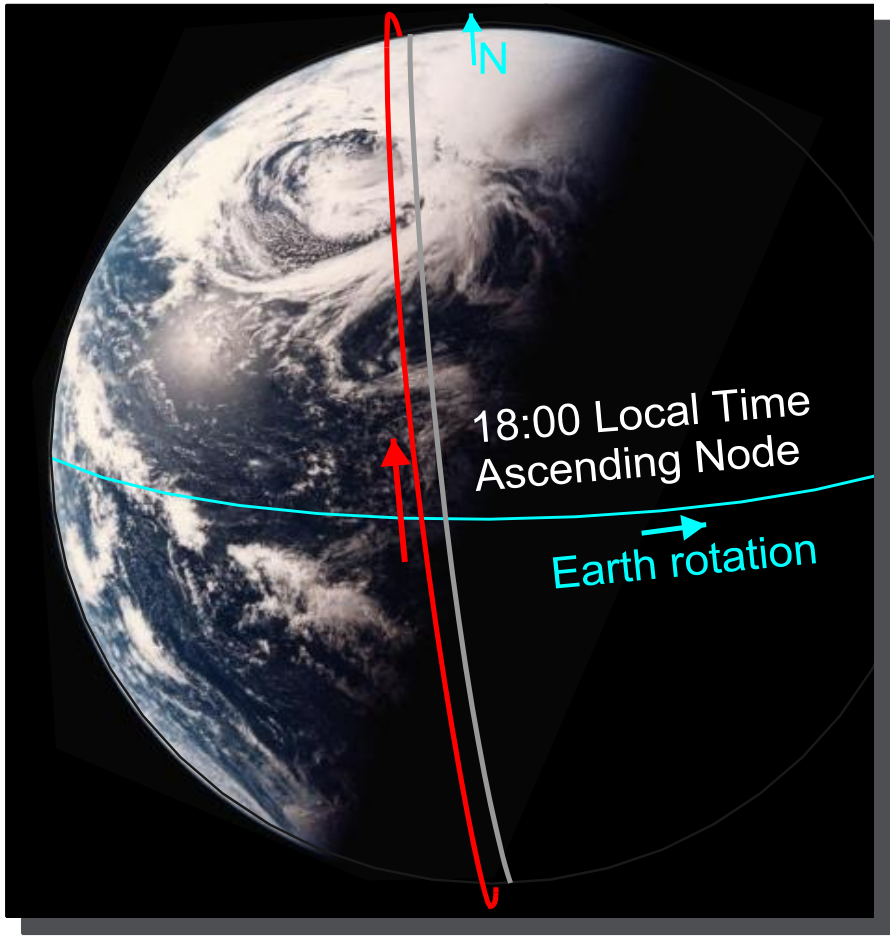
Observation means:

- Provide global measurements of horizontal wind profiles in the troposphere and lower stratosphere
- Spin-off products are atmospheric extinction and backscatter profiles

Payload

- ALADIN: Atmospheric LAser Doppler INstrument

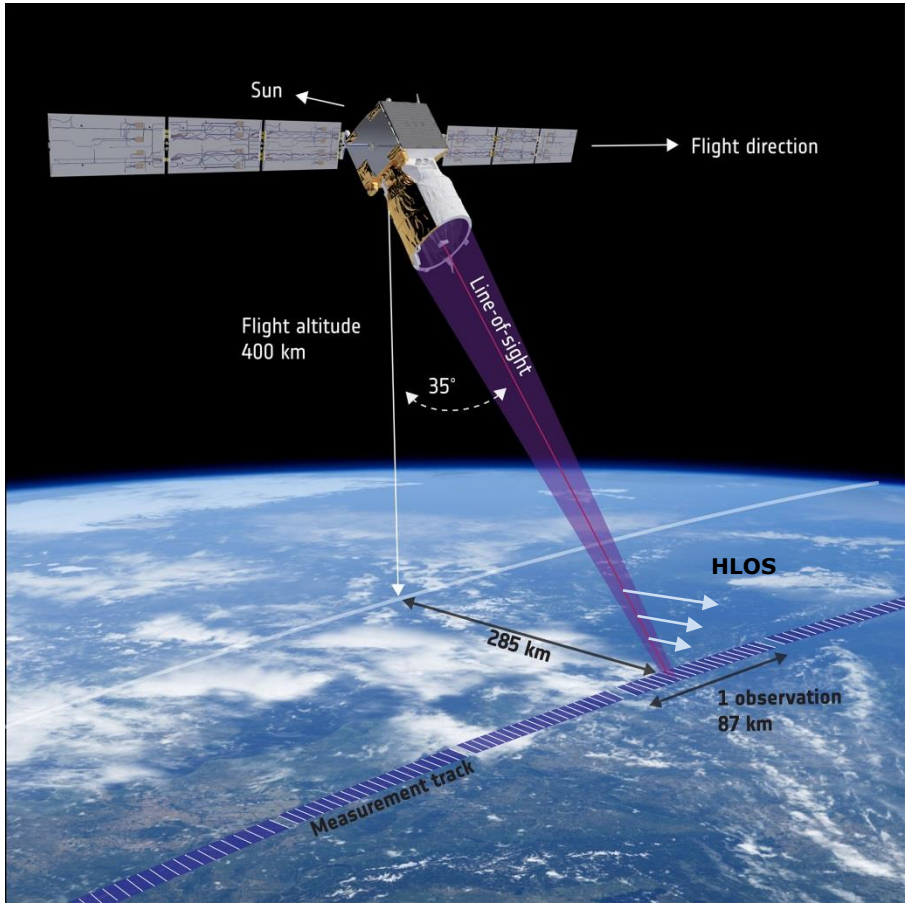
Mission Design



Mission Parameters

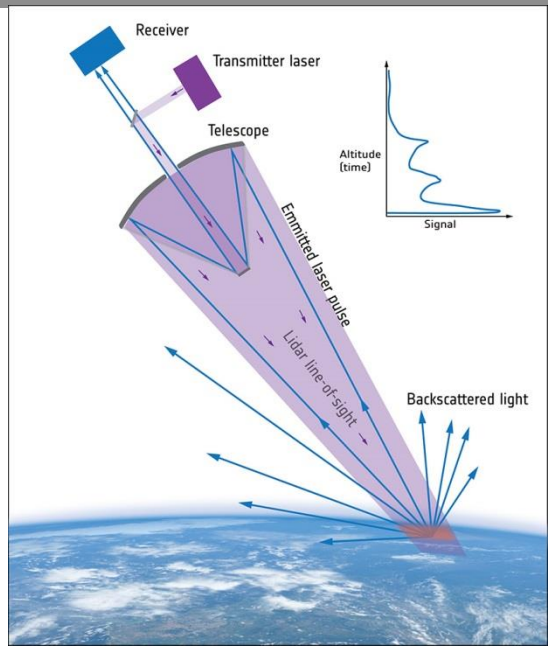
- Orbit: sun-synchronous
- Mean altitude: ~400 km
- Local time: 18:00 ascending node
- Inclination: 96.97°
- Repeat cycle: 7 days / 109 orbits
- Orbits per day: ~16
- Mission lifetime: 3 years

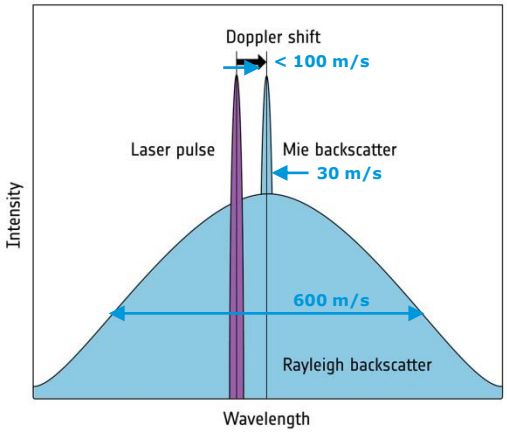
Aeolus: Measurement Principle (1/2)

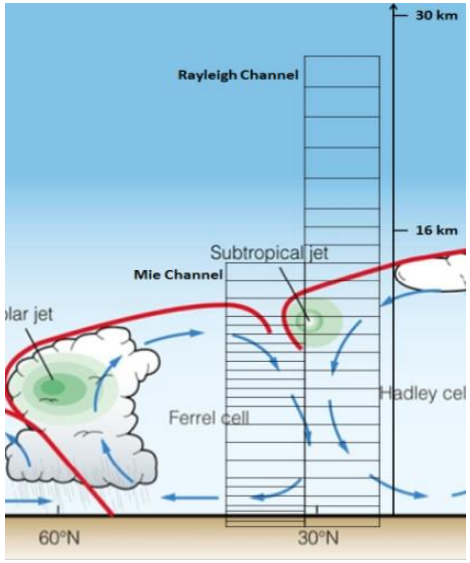


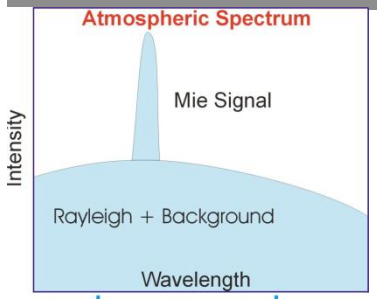
- Direct detection UV Doppler wind Lidar operating at 355 nm and 50 Hz PRF in with 2 receiver channels
- Mie receiver to determine winds from aerosol & cloud backscatter
- Rayleigh receiver to determine winds from molecular backscatter
- The line-of-sight (LOS) is pointing 35° from Nadir to capture single component horizontal wind (LOS wind is projected to HLOS)
- The line-of-sight is pointing orthogonal to the ground track velocity vector to remove contribution from the satellite velocity

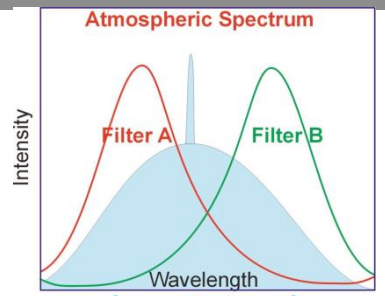
Aeolus: Measurement Principle (2/2)

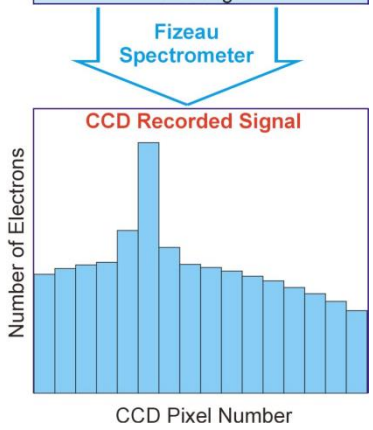


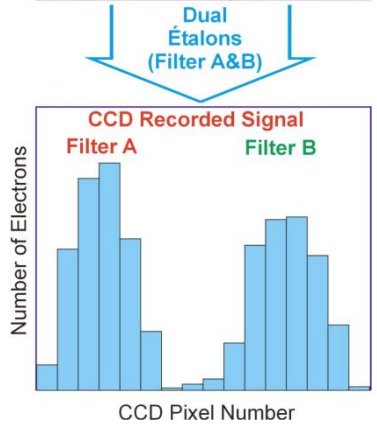












Mie channel:
- Aerosol/cloud backscatter
- Imaging technique

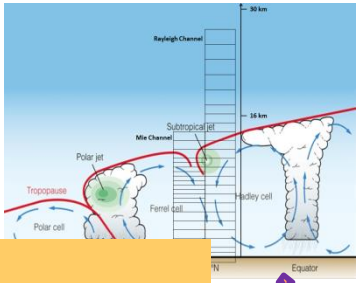
Rayleigh channel:
- Molecular backscatter
- Double-edge technique

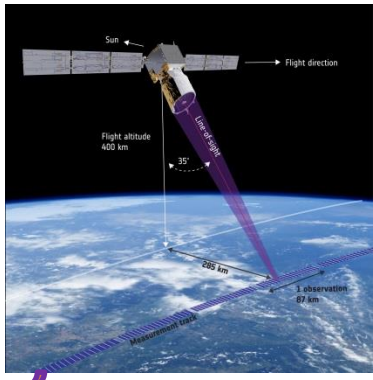
Aeolus atmospheric products

Primary (L2b) product:

Horizontally projected LOS (HLOS) wind profiles

- Approximately zonal at dawn/dusk (6 am/pm)
- ~85 km observation from 3 km subsamples – scene classified
- From surface to ~30 km in 24 vertical layers
- Random errors: 1-2(PBL), 2(Trop), 3-5 (Strat) m/s
- Bias requirements: 0.5 m/s





Spin-off (L2a) products:

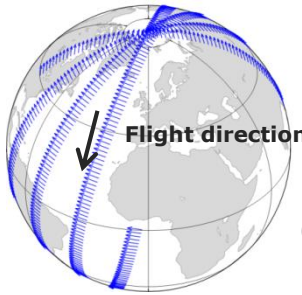
Optical properties profiles

Powerful space-borne lidar with separate molecular and particle backscatter detection

Near Real Time delivery of L1b data + L2b processor serves

*** numerical weather prediction (NWP)**

*** potential for aerosol assimilation in forecast and climate models**



Courtesy N. Žagar

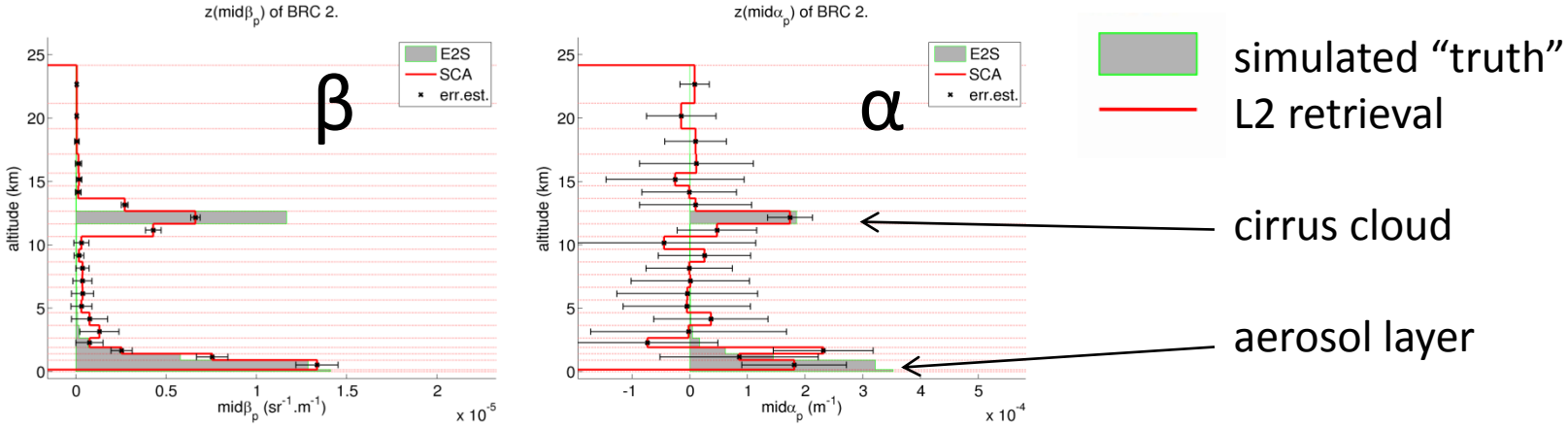
Dusk/dawn orbit

Contribution to aerosol assimilation

Assimilation studies have shown the great potential of lidars to improve on current observation of total OD

Aeolus L2a algorithm developed and being tested

Co-polar β, σ, lidar ratio, potentially also NRT

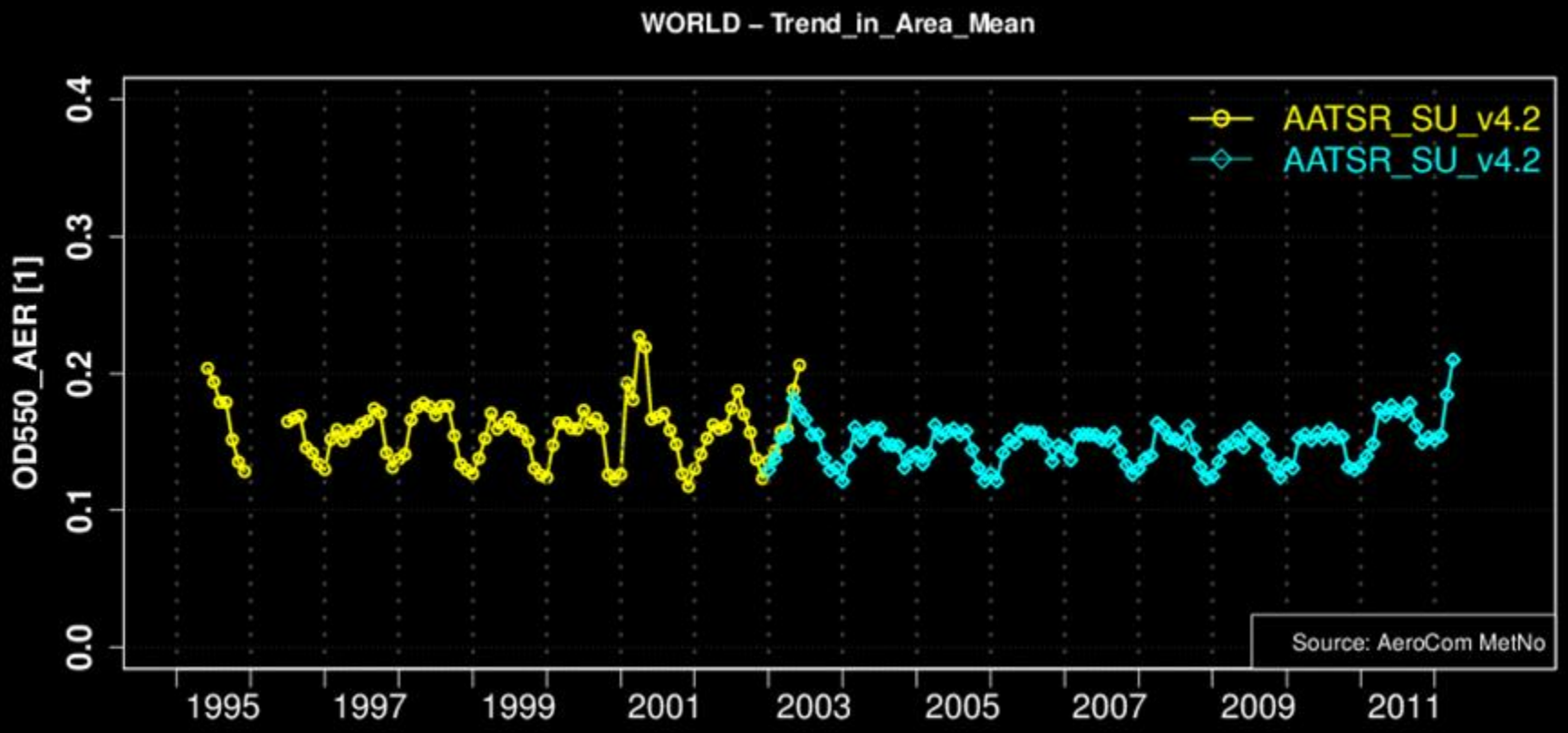


Lack of polarization information in the Aeolus measurements introduce uncertainties in polarizing scenes (only co-polar is measured)

Methods to handle and/or correct for this are being developed (Athens/Leipzig)

Study on the potential of Aeolus for aerosol assimilation being initiated

Aerosol Climate Change Initiative (CCI) update



Overview

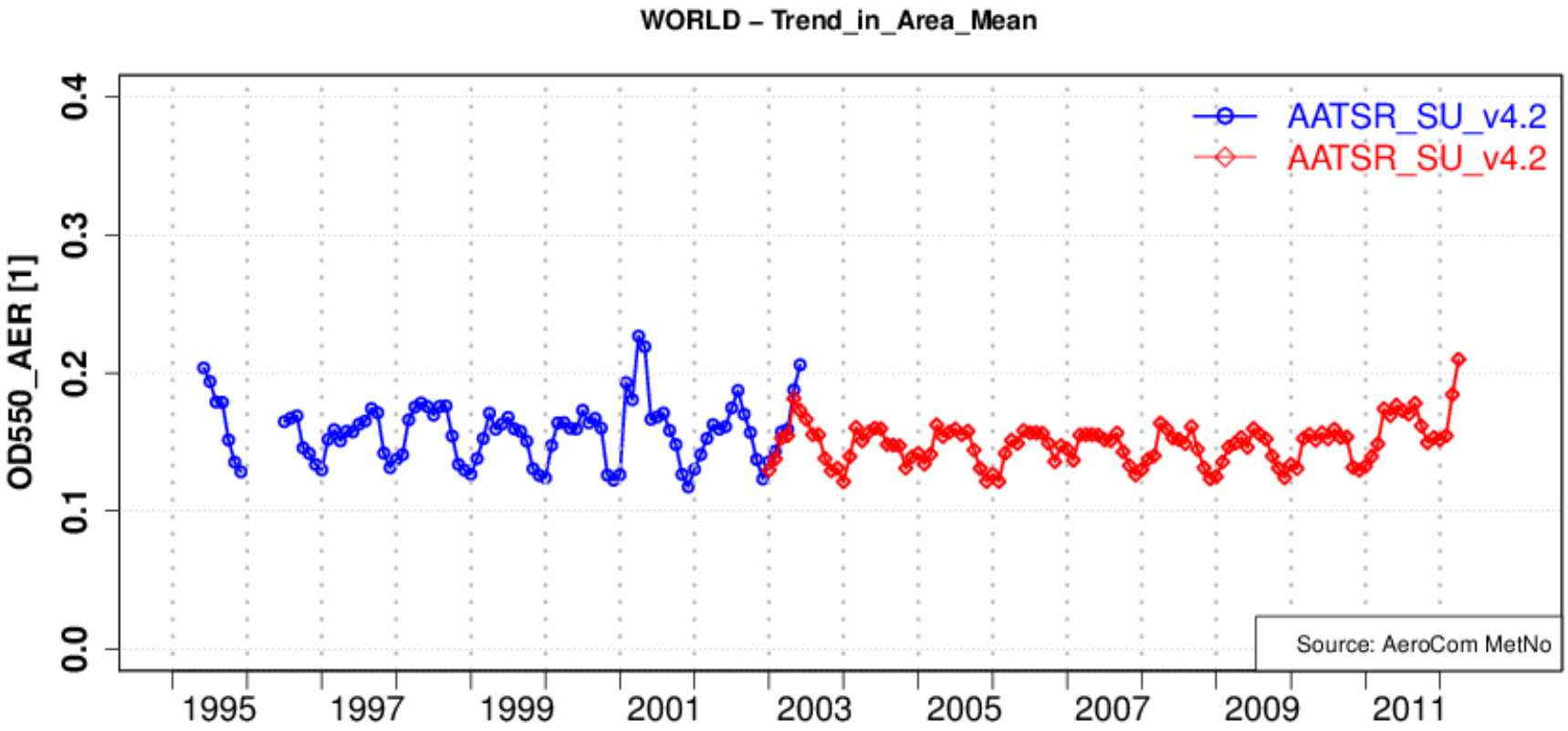
Available datasets

- ATSR-2 / AATSR 17 years / 3 algorithms
  - Validation ongoing
  - Full validation of one algorithm already done (U. Swansea)
- GOMOS 10 years stratospheric extinction profiles
  - Validation ongoing
  - Different resolution on user request
- IASI round robin datasets, 4 algorithms (2013, Arabia/Sahara dust region)
  - Evaluation started
- POLDER GRASP multi-pixel algorithm (test sites) 2008

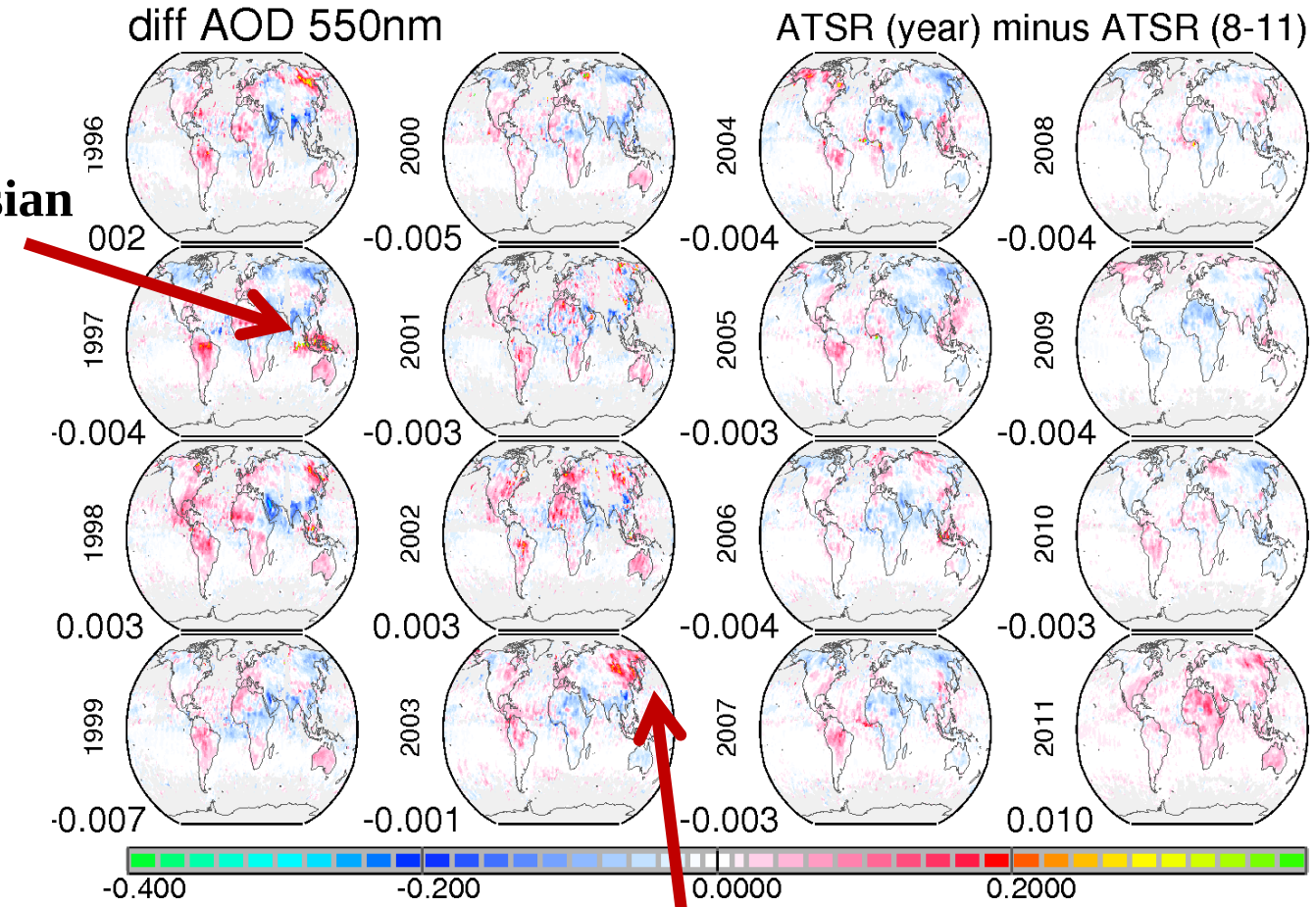
Plans in year 2

- Full cycle: validation, improvement, second full re-processing
- 4 internal user case studies
- ~~MACC~~ CAMS assimilation
- AEROSAT inter-comparison (-> GEWEX aerosol assessment phase 2)
- Consistency analysis with other CCI ECVs

ATSR time series Evaluation report



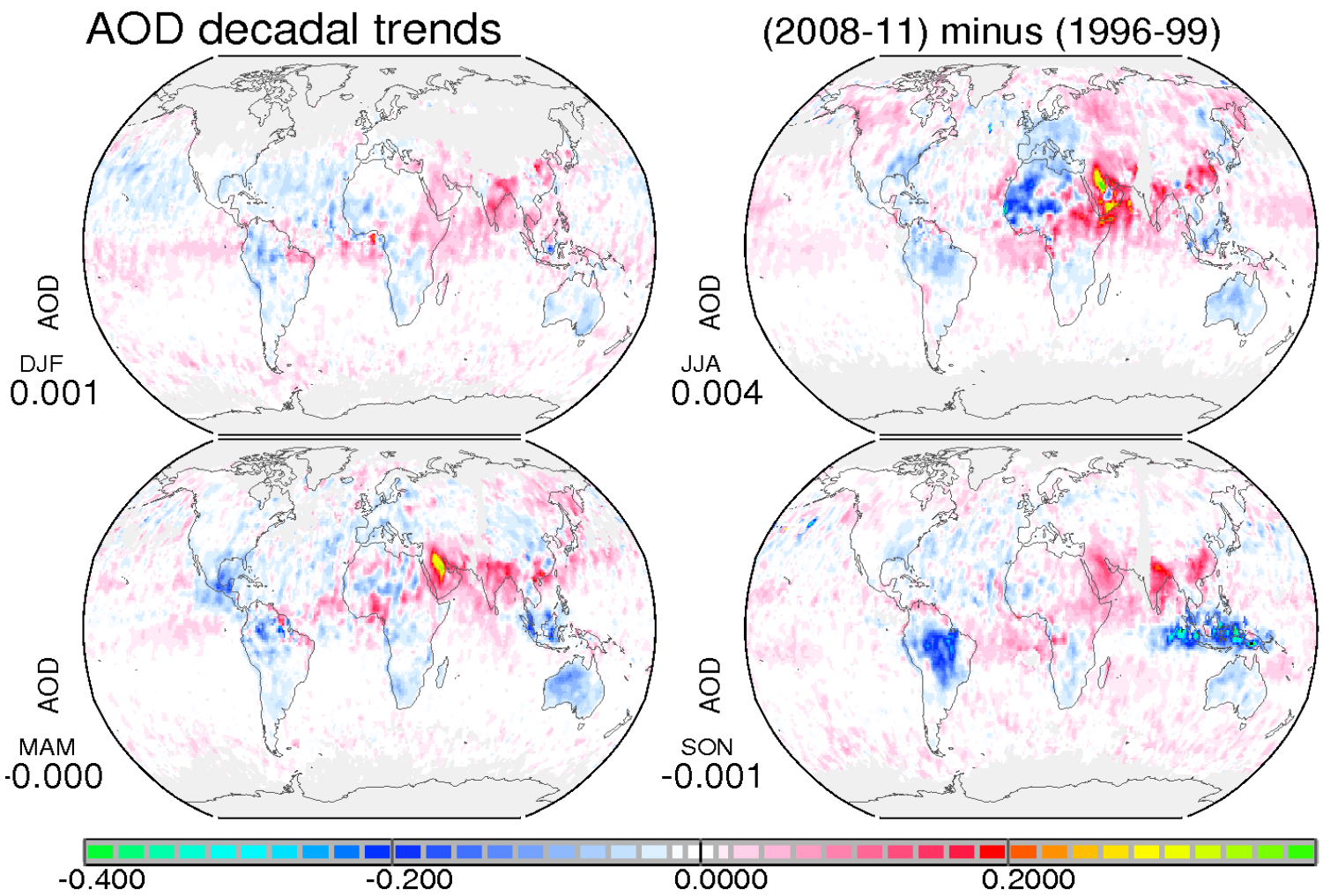
Anomalies



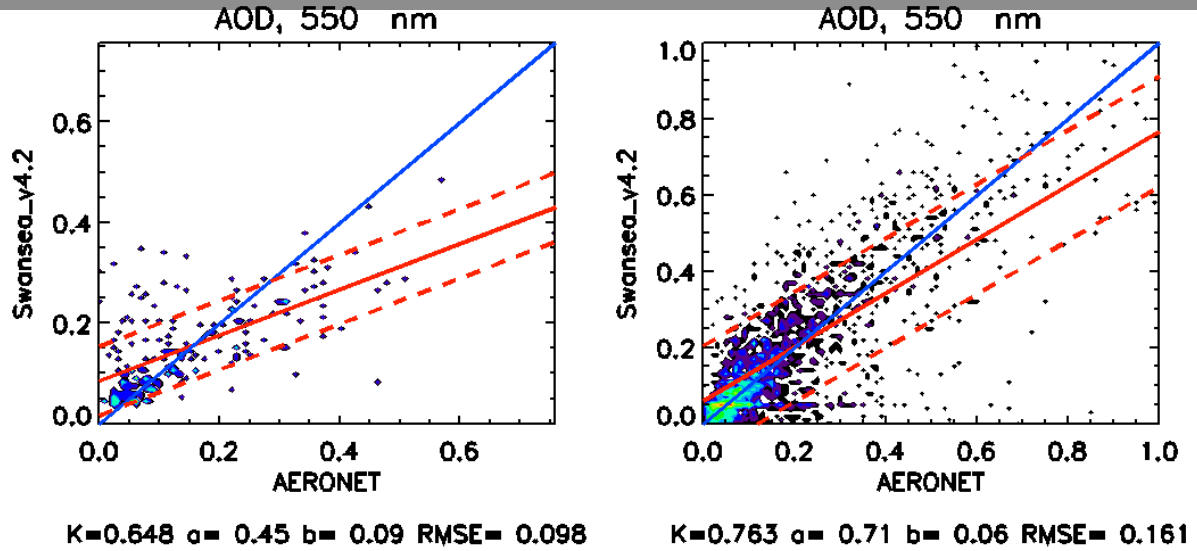
Indonesian fires

Siberian fires

”Trends”


AOD decadal trends
(2008-11) minus (1996-99)
AOD
DJF
0.001
AOD
JJA
0.004
AOD
MAM
-0.000
AOD
SON
-0.001
-0.400
-0.200
0.0000
0.2000

Validation vs AERONET

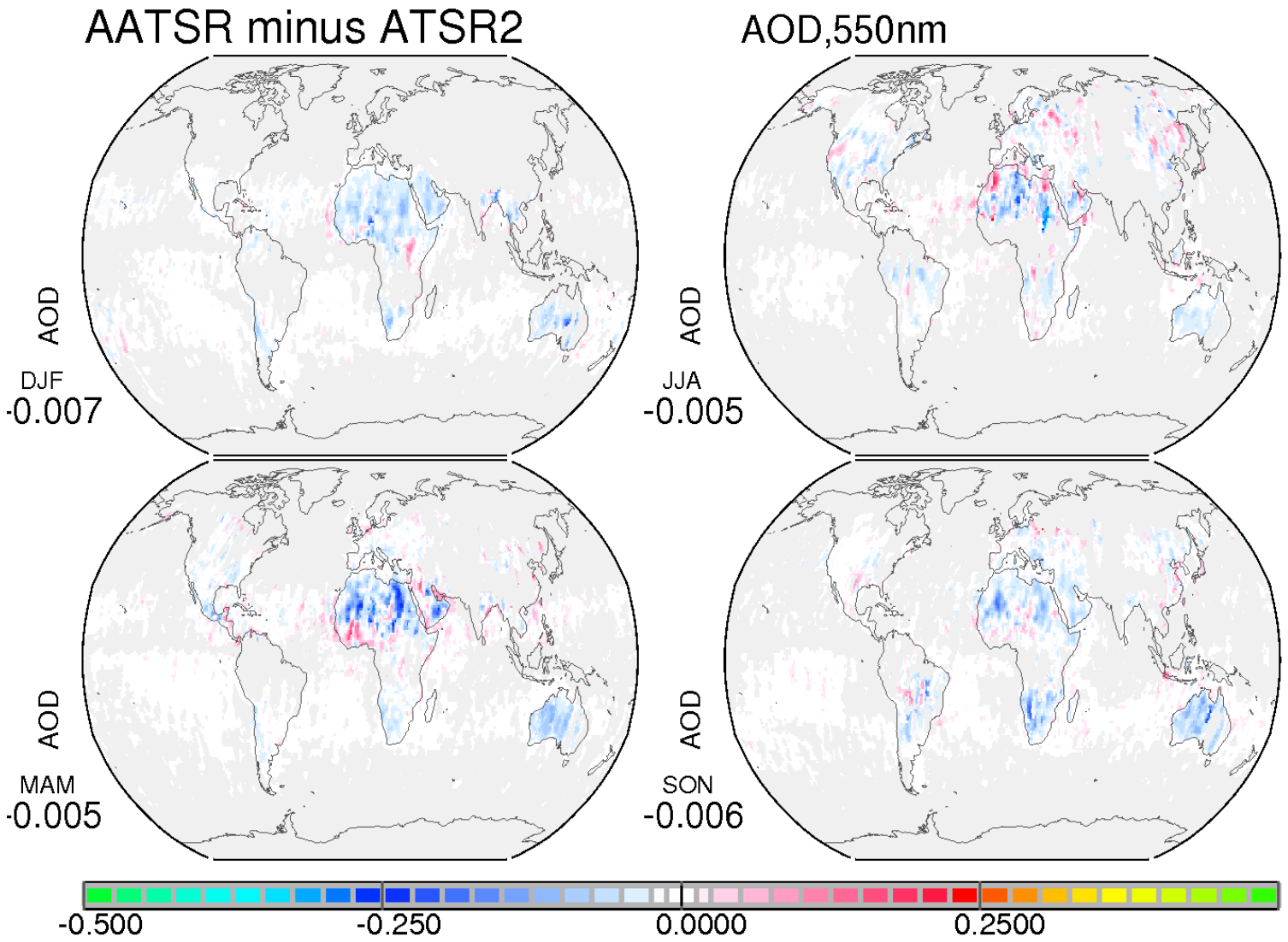


L2 data:
±30 min, 35 km from AERONET stations

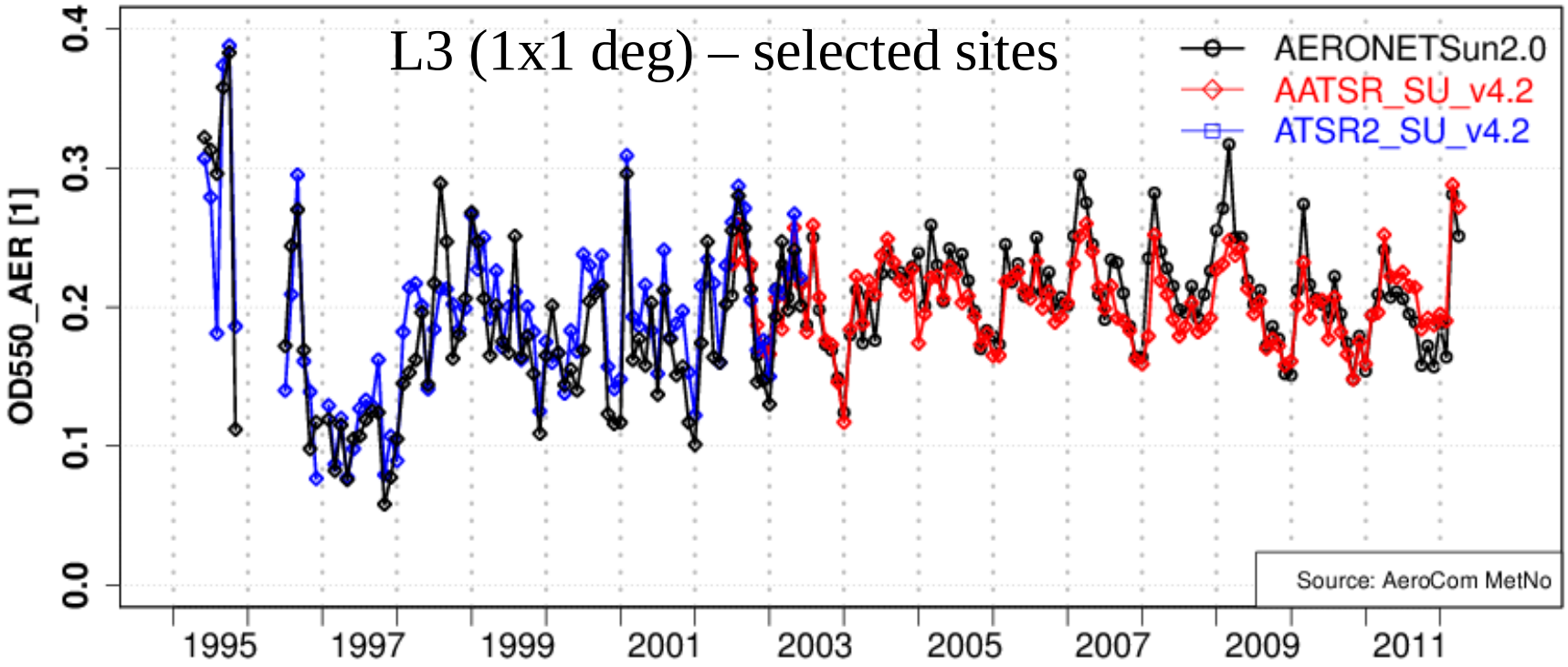
ATSR-2 (1995-2003)

AATSR (2002-2012)

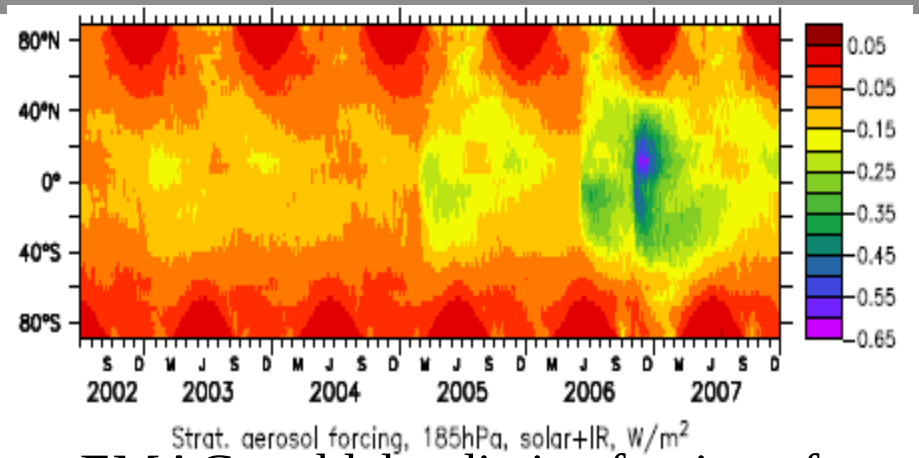
Consistency: Overlap ATSR



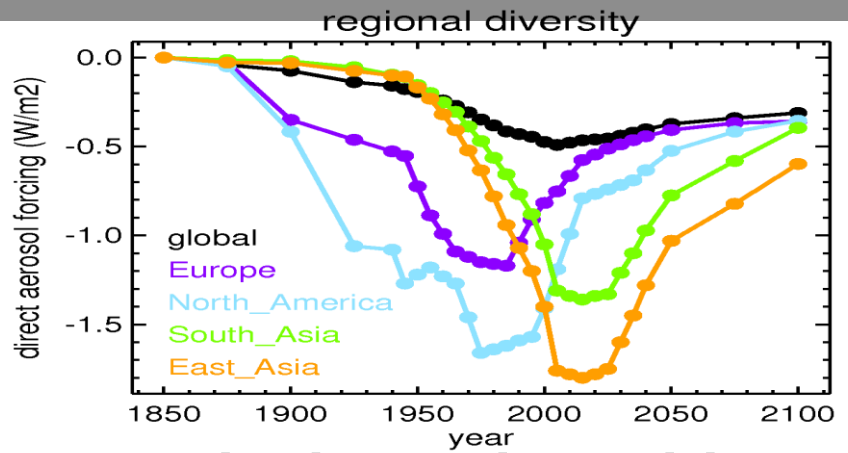
Stability vs. AERONET



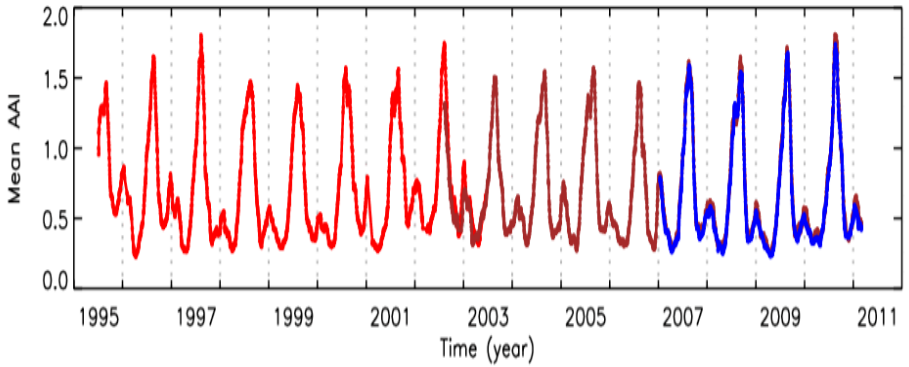
New in Phase 2: Case studies



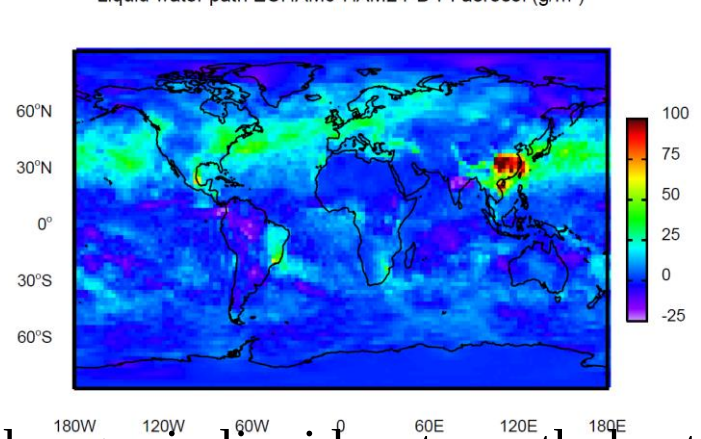
EMAC moldel radiative forcing of stratospheric aerosol (Brühl et al., 2012/3



simulated regional aerosol direct radiative forcing (Kinne et al., 2013)



AAI record for West-Africa (Tilstra et al., 2011). Red GOME-1, Brown SCIAMACHY blue GOME-2A



Changes in liquid water path due to anthropogenic aerosol (ECHAM6-HAM2; Lohmann, et al. 2010)

3rd AEROSAT meeting

ESA / Frascati

8+9 October 2015

in association with

AEROCOM and CCMI

-> time for interaction with modelers