ESA aerosol sensors and activities

This is a selection (leaving out the Sentinel missions)

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European Space Agency
ESA Earth Observation missions

ESA Living Planet Symposium
Prague 9-13 May 2016
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.
EarthCARE spectral measurements

[Diagram showing spectral measurements with UV, VIS, infrared, microwave, and radio bands, and atmospheric transmittance with wavelength on the x-axis.]
Mission Data Sheet

Orbit type: Low earth orbit, polar, sun-synchronous, frozen
Altitude: 393 km (389 orbits/25 days)
Mean Local Solar Time: 14:00h (descending node crossing)
Mass: 2250 kg (including 313 kg of propellant)
Power: 1700 W

System CDR: 2016
System AR and launch: 2018
Launcher: Soyuz (from Kourou, French Guiana)
Mission lifetime: 3+1 years
EarthCARE
Electrical Functional Model
EarthCARE Solar Panel
- Atmospheric Lidar, $\lambda = 355\text{nm}$, linearly polarized

- High Spectral Resolution Lidar (HSRL) using Fabry-Perot etalon centred on the laser centre wavelength $\rightarrow$ separates molecular from particle backscatter signals (lidar ratio can be measured)

- 3 channels receiver:
  - Rayleigh scatter
  - co-polar Mie
  - cross-polar Mie

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

ATLID Stable Structure Assembly (SSA) and equipments

- Mass: 558 kg
- Power: 585 W
- Data rate $< 660 \text{ kb/s}$
- **Airbus (F)** + Selex ES (I)
- **CDR close-out ongoing**
High spectral resolution lidar

- **Molecules**
- **Aerosols**

- **Backscattered light**
- **Wide broadening of the incident light due to Brownian motion**
  - Rayleigh
  - Origin Spectrum shape not affected

- **Mie signal co and cross-polar**

- **Towards detector assemblies**
  - FCA Rayleigh
  - Rayleigh path
  - HSRE
  - Mie Co-polar path

- **FCA co_polar**
  - Towards detector assemblies

- **Folding mirror FOM3**
- **Φ = 31mm**
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
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**

<table>
<thead>
<tr>
<th>Channel</th>
<th>Centre Wavelength [μm]</th>
<th>Bandwidth (50%) [μm]</th>
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<tr>
<td>VIS</td>
<td>0.67</td>
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<td>NIR</td>
<td>0.865</td>
<td>0.02</td>
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<td>SWIR 1</td>
<td>1.65</td>
<td>0.05</td>
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<td>SWIR 2</td>
<td>2.21</td>
<td>0.1</td>
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<tr>
<td>TIR 1</td>
<td>8.8</td>
<td>0.9</td>
</tr>
<tr>
<td>TIR 2</td>
<td>10.8</td>
<td>0.9</td>
</tr>
<tr>
<td>TIR 3</td>
<td>12.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Instrument</td>
<td>Satellite</td>
<td># views</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>MERIS</td>
<td>Envisat</td>
<td>1</td>
</tr>
<tr>
<td>OLCI</td>
<td>Sentinel 3</td>
<td>1</td>
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<tr>
<td>MSI</td>
<td>EarthCARE</td>
<td>1</td>
</tr>
<tr>
<td>AATSR</td>
<td>Envisat</td>
<td>2</td>
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<tr>
<td>SLSTR</td>
<td>Sentinel 3</td>
<td>2</td>
</tr>
</tbody>
</table>
EarthCARE

2. Science products
Heritage: A-Train Observations

granule 2006286023036 02443 II between:13800.1055 and 14599.9453 s

CloudSat Radar

CALIPSO Lidar

target classification

MODIS

MODIS Radiance [Wm^{-2} \mu m^{-1} sr^{-1}]

Latitude [°]

Longitude [°]
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.

**CPR+ATLID+MSI**
- Cloud and aerosol fields
- Modelled radiation fields

**BBR**
- Measured radiation fields
- Assessment
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

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

Radiative Transfer Products
1D & 3D rad. transfer: radiances, fluxes, heating rates

Assessment
Comparison of modelled fluxes and radiances to BBR observations

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

instrument grid for L1 and L2a
“joint standard grid” (≈1km x 1km) for L2b
larger grid cells as needed (aerosols, radiances and fluxes)
ATLID (2D along track/vertical)

Aerosol extinction (\(\alpha\)), backscatter (\(\beta\)), depolarisation (\(\delta\)) 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)
typing based on intensive properties
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)
Tab. B.1: Look-up table for the columnar aerosol type

<table>
<thead>
<tr>
<th>AOT</th>
<th>AE ≤ 0.6</th>
<th>0.6 &lt; AE &lt; 1.0</th>
<th>≥1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>Clean marine (t = 1)</td>
<td>No specific type (t = 0)</td>
<td>Clean continental (t = 2)</td>
</tr>
<tr>
<td>0.15 &lt; AOT &lt; 0.3</td>
<td>No specific type (t = 0)</td>
<td>No specific type (t = 0)</td>
<td>No specific type (t = 0)</td>
</tr>
<tr>
<td>AOT ≥ 0.3</td>
<td>Desert dust (t = 3)</td>
<td>No specific type (t = 0)</td>
<td>Biomass burning, pollution (t = 4)</td>
</tr>
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</table>

Tab. B.2: Aerosol type coding

<table>
<thead>
<tr>
<th>Name of aerosol type</th>
<th>t</th>
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</thead>
<tbody>
<tr>
<td>Unknown</td>
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<tr>
<td>Clean Marine</td>
<td>1</td>
</tr>
<tr>
<td>Clean Continental</td>
<td>2</td>
</tr>
<tr>
<td>Mineral Dust</td>
<td>3</td>
</tr>
<tr>
<td>Pollution/Biomass-burning smoke</td>
<td>4</td>
</tr>
</tbody>
</table>
Preparatory Science Activities

**Level 2 Developments**
- clouds profiles from radar, lidar, imager
- aerosol profiles from lidar, imager
- cloud and radiation from profiles and measured LW \(\rightarrow\) closure

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

**Science Preparation**
Building on CloudSat, Calipso, CERES/GERB, MODIS, ground-/air-based radar/lidar, modelling, ...

**Mission Advisory**

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

**Preparation GCM evaluation**
Dedicated data processor (CFMIP-type)

**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
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.
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

Archive file (zip)
- Header file (xml)
  - Header data
- Datablock file (NetCDF4/HDF5)
  - Header data
  - Science data

common to all EarthCARE products

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

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

**TOTAL DATA VOLUME / ORBIT**

| 71,000 |

**TOTAL DATA VOLUME / ORBIT (ESA → JAXA)**

| 60,000 |

**TOTAL DATA VOLUME / ORBIT (JAXA → ESA)**

| 11,000 |
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
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
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
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
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 $\beta$, $\sigma$, 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
"Trends"

AOD decadal trends


AOD
DJF 0.001

AOD
JJA 0.004

AOD
MAM -0.000

AOD
SON -0.001
Validation vs AERONET

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


AATSR (2002-2012)
Consistency: Overlap ATSR

AATSR minus ATSR2

AOD,550nm

AOD

DJF -0.007

JJA -0.005

MAM -0.005

SON -0.006

ICAP 7, Barcelona, 19 June 2015
Stability vs. AERONET

L3 (1x1 deg) – selected sites
EMAC model radiative forcing of stratospheric aerosol (Brühl et al., 2012/3)

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

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

Changes in liquid water path due to anthropogenic aerosol (ECHAM6-HAM2; Lohmann, et al. 2010)
ESA / Frascati
8+9 October 2015
in association with
AEROCOM and CCMI

-> time for interaction with modelers