The Earth Explorer EarthCARE is launched

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The Launch

On the 28 May the time has finally come that EarthCARE, the Earth Cloud Aerosol und Radiation Explorer, was launched and sent its first signals back to Earth. The mission comes just right in time to continue NASA's successful tandem missions CALIPSO/CloudSat, which ended in 2023, and to start a new era of atmospheric satellite observations.
The joined mission by the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA) was launched with a Falcon 9 from SpaceX in Vandenberg, California, US (Figure 8). The countdown ran like clockwork and the launch was perfect. About ten minutes after take-off separation took place and the EarthCARE satellite could be seen drifting away (Figure 9). This was a very emotional moment for the whole team. But the relieving moment was yet to come with the first signals acquired at the satellite receiving station in Hartebeesthoek, South Africa. The signal was received and EarthCARE told us it was well with all systems nominal and the solar array already deployed. As soon as the first instruments are running smoothly the work starts for the Calibration and Validation teams.

Figure 8: *ESA's EarthCARE satellite lifted off on a SpaceX Falcon 9 rocket from the Vandenberg Space Force Base in California, US, on 28 May, 15:20 local time. Image credits: ESA - S. Corvaja.*

What to expect from this mission?

EarthCARE is the most complex Earth Explorer mission ESA ever built, with an unprecedented accuracy of measurements in space. This mission will advance our understanding of the role that clouds and aerosols play in Earth's climate system, reflecting incident solar radiation back into space, as well as trapping infrared radiation emitted from Earth's surface. While the understanding of cloud and aerosol feedback mechanisms on climate and weather in numerical weather and climate models has steadily improved since EarthCARE was selected as the sixth of ESA's Earth Explorer Mission in 2000 (Illingworth et al., 2015), there are still few data sets of co-located observations that provide high-resolution vertical profiles of clouds and aerosols in parallel with high resolution radiation budget measurements for verification and further process understanding.
To answer key scientific questions, i.e., to better understand the role of aerosols and clouds and their radiative effect on climate, EarthCARE will provide important observables with its four instruments (Wehr et al., 2023):

- *Atmospheric LIDar* ATLID: This is one of two active remote sensing instruments and consists of a linearly polarized High Spectral Resolution Lidar (HSRL) operating at a wavelength of 355 nm designed to characterize aerosols, clouds and precipitation. It will provide vertical profile information from the ground to 40 km, with 100-500 m vertical resolution on 280 m horizontal sampling. The first Level 1 data product will be attenuated backscatter profiles.
- *Cloud-Profiling Radar* CPR: The second active remote sensing instrument is the first Doppler radar in space, designed and maintained by JAXA,

which allows to detect also moving hydrometeors. It operates at 94 GHz with a 2.5 m deployable antenna and has a viewing range of -1 km to 20 km from nadir. The horizontal resolution is 800 m and a vertical resolution 500 m.

- *Multispectral Imager* MSI: This instrument will measure infrared and reflected radiation in a 150 km swath (-35 km to +115 km from the nadir point), 500 m resolution, in seven visible and thermal infrared spectral bands. It will complement the ATLID and CPR measurements along the flight path with additional information on aerosol and cloud characteristics. The first order data product will be radiances (VNS), brightness temperature (TIR).

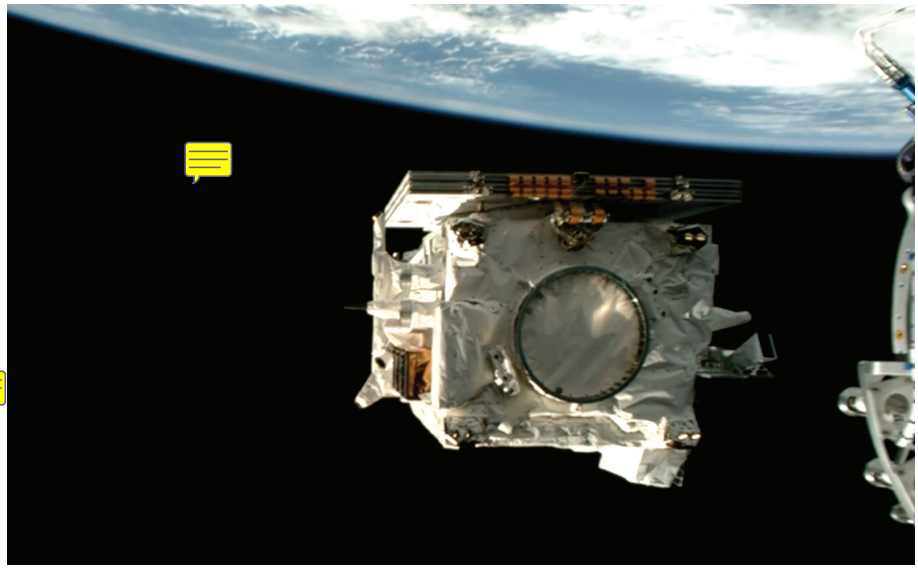

Figure 9: *Deployment of EarthCARE from its launcher, ten minutes after liftoff. Screenshot from ESA WebTV "Taking EarthCARE into orbit". Image Credits: SpaceX*

Table 1: *Satellite specifications of EarthCARE*

Body Measurements	Start-Configuration	4.2 m x 3.5 m x 2.5 m
	Flight-Configuration	17.2 m x 3.5 m x 2.5 m
Mass	Total	2.210 kg
Power	Total	1.560 W (on average)
Duration	planed	3 years
Orbit	Sunsyncronous	
	Local time	14:00 (Descending Note)
	Altitude	389 km
	Inclination	97°
	Re-Visit	25 Days

- *Broad Band Radiometer* BBR: Entire solar backscatter (SW 0.25 µm to 4 µm) as well as terrestrial radiation (LW 4 µm to > 50 µm) is measured by the second passive remote sensing instrument. The instrument is an imaging radiometer with three telescopes with different fixed observation angles (0, ± 55°) with a spatial resolution of 10 x 10 km and a spatial sampling of 1 km. This measurement setup allows the signals to be traced back to different heights between the satellite and the ground, which in turn makes it possible to calculate the radiant flux. The first order data product (L1) will be solar and thermal TOA radiance.

But you can expect more from EarthCARE than only four separate data products from the four instruments. Due to the simultaneous measurements there will be numerous synergistic data products related to clouds, aerosols and radiation. An overview on the different data types and levels that will be available after the commissioning phase is given in Figure 10. All that will be accessible through ESA's eogateway and a detailed description of the data products can be found in the AMT special issue by Wandinger et al. (2024) and in Eisinger et al. (2024), which comprises all the necessary information's for scientists.

For the fundamental questions of radiative closure, EarthCARE provides vertical profiles of clouds, aerosols and precipitation from the nadir angle, spatially resolved cloud-aerosol scenes spanning the satellite track, and fluxes of solar and thermal radiation. Some datasets might not be completely new in atmospheric science, but with its measurements and therefrom derived synergistic data, EarthCARE will set new standards for atmospheric observations. Here we want to name only a view highlights of these synergistic data products:

- AC-TC: This is a synergistic product of the instruments ATLID and CPR and providing a target classification of aerosol and cloud scenes.
- ACM-CAP: Cloud and aerosol properties from ATLID, CPR and MSI, providing liquid cloud-ice cloud-rain water content and effective radius or diameter, aerosol number concentration and extinction.

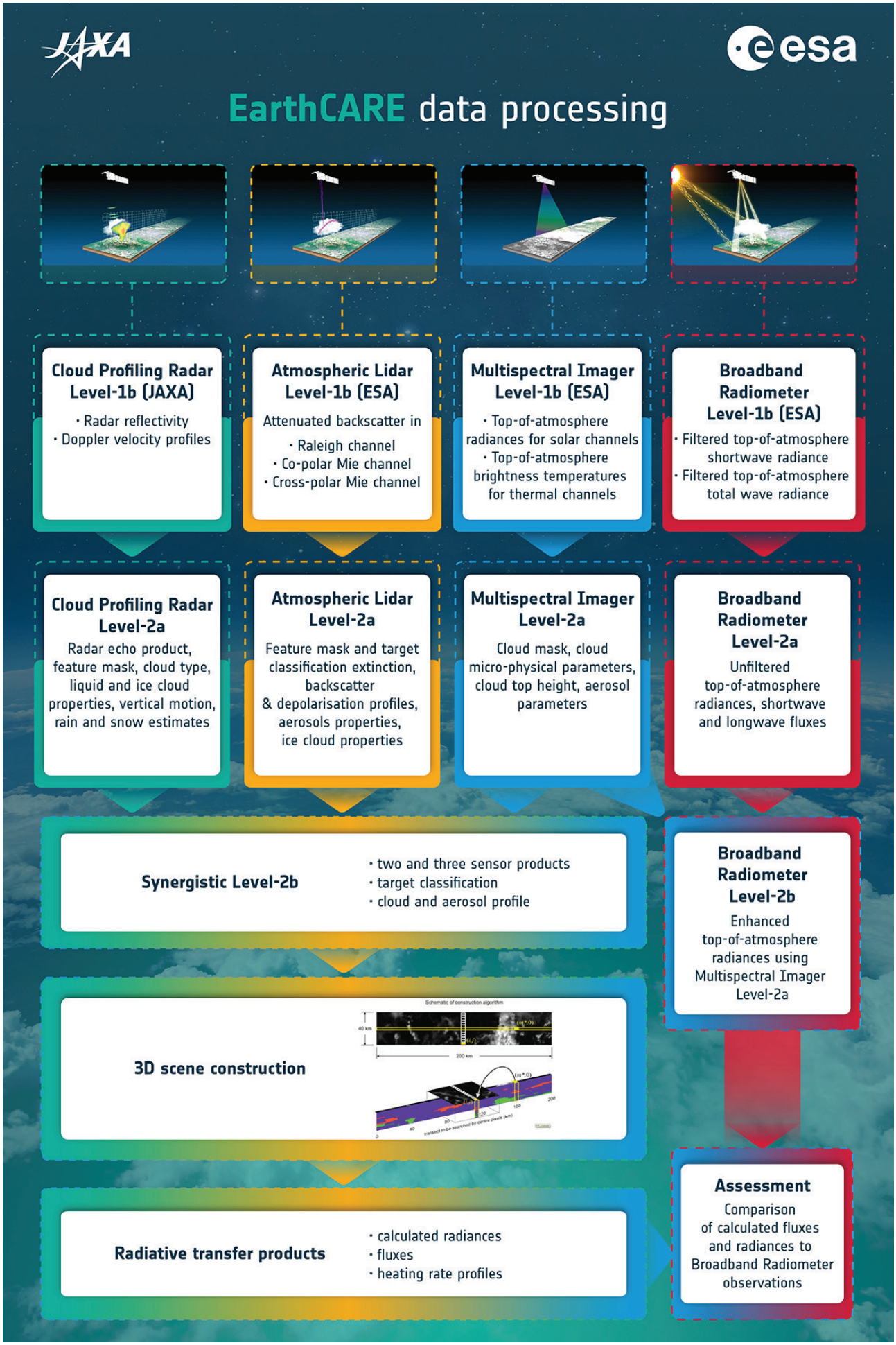

Figure 10: *Overview of the data products available after launch of EarthCARE, shown in a flow chart. Image credits: ESA*

- ACMB-3D: From all four instruments 3D scene of the atmosphere is constructed.
- ACMB-DF: Radiative closure assessment, comparing broadband radiances and fluxes measured by BBR to broadband radiances and fluxes derived from radiative transfer models for the two atmospheres.

In general, the data processing chain is organized into levels from level 0 (L0) up to level 2 (L2). The time-sorted raw data from the sensors and housekeeping data are defined as L0 and will not be available to the public. The L1 data has four subclasses spanning data products from pre-processed data of the individual instruments, and calibrated data respective instrument "native"-grid, up to special data products for higher product levels. The L2 products, which refer to derived geophysical variables with the common or ~~a~~ "native"- grid resolution, are separated into two EarthCARE specific sub-levels, ~~being~~ L2a: L2 data product derived from individual EarthCARE instrument; and L2b: L2 data products derived from synergistic measurements of EarthCARE instruments. Data processing up to Level 1 products is managed by the respective space agency responsible for the instrument. This means that ESA is responsible for the Level 1 products of the instruments ATLID, MSI and BBR, while JAXA is for the Level 1 product of CPR. For the Level 2 products, independent algorithms for processing were developed by both JAXA and ESA. A detailed description of the individual products of the different levels can be found in Eisinger et al. (2024).

In addition to answer the key scientific questions on the Earth's radiation budget, EarthCARE data products will also be operationally used in ECMWF's Integrated Forecasting, which will improve the accuracy of weather forecasts.

What is EarthCARE without scientists?

Now that EarthCARE is launched and has completed its launch and early operations, it entered the commissioning phase. In this phase EarthCARE undergoes functional checks, the payload instruments are calibrated and characterized, and in-orbit performance verifications are made. This phase is meant to last about six months, before first Level 1b data will be released to the public towards early 2025. These activities are accompanied with many field campaigns to provide ground-based and airborne measurement data for calibration and validation of the satellite payload. One of the largest efforts in this regard is the flight campaign PERCUSION (Persistent EarthCARE underflight studies of the ITCZ and organized convection), which is carried out by the German research aircraft HALO (High Altitude and LOng range, Figure 11). This aircraft is very well known by the APARC-Community and does not need any further introduction. However, for this campaign it is deployed with an EarthCARE-like payload, which consist of the following instruments:

- HSRL-Lidar (WALES): The high spectral resolution lidar on HALO measures profiles of aerosol and cloud backscatter, extinction and depolarization at 532 nm and is provided by the German Aerospace Center (DLR). It represents the ATLID instrument on EarthCARE.
- Cloud-Profiling Radar (MIRA35): The Doppler radar, jointly deployed by DLR, MPI Hamburg and University Hamburg, is operating at 35 GHz and represents EarthCARE's CPR.
- Hyper-Spectral Imager (specMACS): The Ludwig-Maximilians-University Munich (LMU) measures provides the hyper-spectral radiometer. It will validate the MSI instrument on EarthCARE.

Figure 11: *HALO in preparation for the next campaign in front of the hangar. Image credits: Andreas Minikin (DLR-FX).*

- Radiometers: EarthCARE's BBR is validated with multiple instrumentation onboard HALO. University of Leipzig provides a long wave radiation imager (VELOX), but also HALO is equipped with a solar and terrestrial radiometer (BARCARDI).
- Additionally, WALES provides additional water vapor profiles using differential absorption lidar (DIAL) technique and dropsondes will be provided by MPI Hamburg.

With this payload, HALO is the most complete airborne payload capable of mimicking EarthCARE. The great benefit of an airborne demonstrator is its targeted applicability. For example, measurements of various meteorological situations could already be carried out in dedicated pre-launch campaigns (Schäfler et al., 2018; Stevens et al., 2019; Stevens et al., 2021) for the characterization and pre-validation of EarthCARE algorithms and retrievals. During the validation of EarthCARE after launch, HALO makes it possible to carry out targeted coordinated underflights, which enables a quasi-direct comparison of the measurements.
The PERCUSION campaign, jointly led by the Max-Planck-Institute of Meteorology Hamburg and the DLR Institute of Atmospheric Physics, is one of seven sub-campaigns in a larger effort called ORCHESTRA (Organized Convection and EarthCARE Studies over the Tropical Atlantic) in which many other European institutes with various measuring platforms (e.g., ground-stations from EARLINET, FS METEOR vessel, drones, other aircrafts such as the Romanian INCAS King Air and French SAFIRE ATR-42) are involved. The overarching goal of the campaign is to better understand the physical mechanisms that organize tropical mesoscale convection and the impact of convective organization on climate and Earth's radiation budget.
The PERCUSION campaign itself is divided into three parts at three locations and follows a strict timetable to not only catch EarthCARE for coordinated underflights, but also to coordinate with other platforms for simultaneous measurements. Starting on 8 August, HALO will first be based at Sal on Cape Verde and after three weeks will move to Barbados for another three weeks of campaign activities. The third and final part of this campaign is fully dedicated to EarthCARE Cal/Val and will be carried out from HALO's homebase at DLR in Oberpfaffenhofen, Germany.
While HALO and other airborne platforms are providing valuable data for validating and calibrating EarthCARE, an additional large number of ground-based stations (LACROS/EARLINET/ACTRIS) equipped with similar instruments as the satellite payload will support the EarthCARE commissioning phase.

What happens next?

As soon as all instruments on EarthCARE are successfully calibrated and running smoothly, the mission will move into its operational phase. For the data user this means EarthCARE is ready to share its data with the public. But for EarthCARE this means a lot more. At this stage the DISC Team (Data, Innovation, and Science Cluster) is now taking over the responsibility to study and improve the data quality of EarthCARE products. The DISC is ESA's data quality framework for the EarthCARE mission and is comprised of an international expert consortium with various key tasks:

- End-to-end system performance monitoring with the systematic routine quality control of the instrument performance as well as the Level 1 and Level 2 products.
- Long-term monitoring of the instrument performance as well as Level 1 and Level 2 products against the mission requirements.
- Assessment and optimisation of calibration and characterization of all instruments and baseline evolution of the operational calibration processing.
- Validation of the products in collaboration with the independent EarthCARE Validation team
- Maintenance and evolution of the ESA ground data processors in order to meet and if possible, exceed the required product quality.
- Coordination and support of outreach activities.

Scientific applications of EarthCARE data

There are various areas of application for the use of EarthCARE data, both in the field of observation and in the development of models. The mission does not only provide an extension of space borne lidar measurements from CALIPSO and radar measurements from CloudSAT. Due to the innovative combination of EarthCARE's remote sensing instruments, the large amount of synergistic level 2 data will open up numerous new possibilities to effectively use the data and enlarge the scientific field on aerosols, clouds, its interactions and the implications for climate science. For example, the synergistic lidar-radar products from ATLID and CPR will play a major role in further development of models and for reanalysis data. But EarthCARE data also has a wide range of applications with regard to validation of retrievals. By determining various physical cloud variables from the ATLID and CPR data, it is possible to determine basic data

for radiative transfer calculations and subsequently calculate radiative closures. The further development of cloud retrievals can also be well advanced with EarthCARE data, as the range of synergistic data between ATLID, CPR and MSI means that the atmosphere structure in a 3-dimensional space is well represented and, for example, aerosol layers as well as mixed-phase clouds can be better characterized.

By combining EarthCARE data with aircraft measurements or other satellite data, such as CALIPSO, various observed phenomena can also be statistically analyzed also on a long-term trend. Special care must be taken when combining lidar data, as data conversion is required for different wavelengths (i.e., EarthCARE: 532 nm, CALIPSO: 355 nm).

These are only a view possible application, to name some. Of course, you can think of many more interesting studies you can do with the range of brand-new space borne data, EarthCARE will provide. In any case, a mission like this only gets successful with the great work of its scientists. So, let's make sure that EarthCARE achieve the success it deserves. GO EarthCARE!

References

Eisinger, M., et al., (2024). The EarthCARE mission: science data processing chain overview, Atmos. Meas. Tech., 17, 839–862, https://doi.org/10.5194/amt-17-839-2024.

Illingworth, A. J., et al., (2015). The EarthCARE Satellite: The Next Step Forward in Global Measurements of Clouds, Aerosols, Precipitation, and Radiation, B. Am. Meteorol. Soc., 96, 1311–1332, https://doi.org/10.1175/BAMS-D-12-00227.1.

Schäfler, A., et al., (2018). The North Atlantic Waveguide and Downstream Impact Experiment. Bull. Amer. Meteor. Soc., 99, 1607–1637, https://doi.org/10.1175/BAMS-D-17-0003.1.

Stevens, B., et al., (2019). A High-Altitude Long-Range Aircraft Configured as a Cloud Observatory: The NARVAL Expeditions. Bull. Amer. Meteor. Soc., 100, 1061–1077, https://doi.org/10.1175/BAMS-D-18-0198.1.

Stevens, B., et al., (2021). EUREC4A, Earth Syst. Sci. Data, 13, 4067–4119, https://doi.org/10.5194/essd-13-4067-2021.

Wandinger, U., P. Kollias, A. Illingworth, H. Okamoto, and R. Hogan (Ed.), 2024: EarthCARE Level 2 algorithms and data products. [Special issue]. AMT, https://amt.copernicus.org/articles/special_issue1156.html.

Wehr, T., et al. (2023). The EarthCARE mission – science and system overview, Atmos. Meas. Tech., 16, 3581–3608, https://doi.org/10.5194/amt-16-3581-2023.