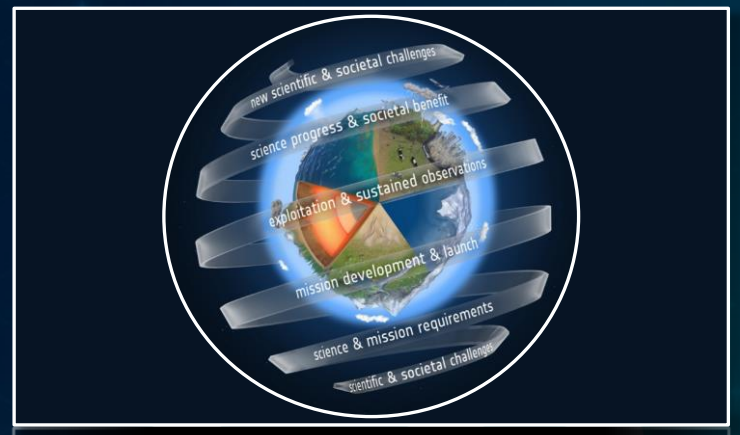
Scientific Exploitation of EarthCARE Phase E2 science activities of ESA

ESA-JAXA Pre-Launch EarthCARE Science and Validation Workshop

2023-11-15

Christian Retscher, ESA/ESRIN

Earth Science, Preparation of EO future and World-class EO Research Missions



Foundations and Concepts

Research Missions

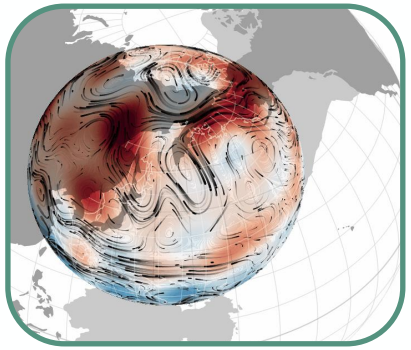
Mission Management

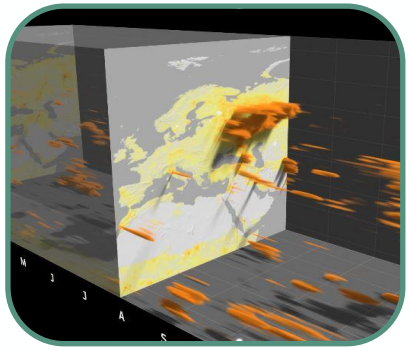
Earth Science for Society

The only ESA (EO) optional programme bringing together all Member States

Science for Society – Principles

- All activities will be driven by **major scientific challenges**, societal needs and global environmental and development agendas to deliver maximum public good;
- All activities shall respond to the **needs** and **recommendations** of authoritative scientific and operational **user communities** and downstream industries, who shall be **consulted systematically** and participate in co-design, implementation and assessment;
- All activities shall be designed to **complement**, **seed**, **cross-fertilize** and enrich **relevant activities** of ESA MS national programmes, Horizon Europe, DestinE and Copernicus;
- **Activities** will be **enhanced** and accelerated using latest **cutting-edge technologies** (ICT) such as AI powered Open EO platforms, Data Cubes, Cloud Computing, Big Data analysis, Open Science and Citizen science.





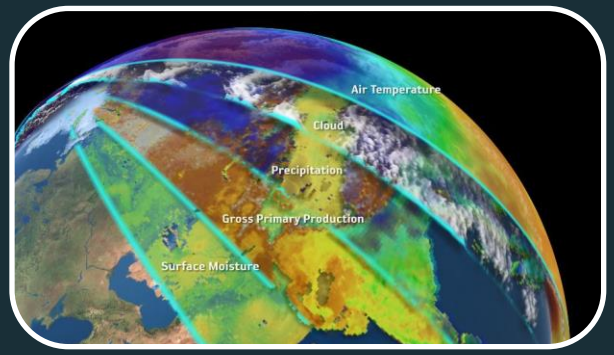

Pushing the frontiers of science

Strategic Activities

Joint ESA-EC Earth System Science initiative strategic partnership with DG-RTD fostering an ambitious European and international scientific collaboration between FutureEO and Horizon Europe

ESA Science Clusters fostering a community open science approach to scientific exploitation bringing together different teams and projects to work together towards common ambitious goals addressing all major scientific domains

ESA Science Hub a new facility in ESA fostering partnerships with academia and collaborative research with centres of excellence in MSs focusing on EO and Earth system science priorities



Developing the "content" of DTE (HPC demonstrators): building a (prototype) advanced digital reconstruction of the Earth system based on the integration of the latest ESA data sets, numerical simulations and science results

A strong partnership in Earth Sciences

ESA

FutureEO

ESA new Science and Innovation Earth Observation Programme

EC-R&I

Horizon Europe

New EU Research and Innovation Framework Programme

The European Commission's Deputy Director General for Research and Innovation, Patrick Child and ESA's Director General, Josef Aschbacher at the signing ceremony, January 2020.

A common goal "…. to jointly advance Earth system science and its contribution to respond to the global challenges that society is facing in the onset of this century"

Common Priorities

EarthCARE – Science Objectives

The EarthCARE mission **basic objective** is to **improve** the **understanding** of the **aerosol-cloud radiation interactions (ACI)** and Earth radiative balance, so that they can be modelled with better reliability in climate and in numerical weather prediction models.

Specifically, the scientific objectives are:

- Observation of the **vertical profiles** of **natural** and **anthropogenic aerosols** on a global scale, their **radiative properties** and interaction with clouds;
- Observation of the **vertical distributions** of **atmospheric liquid water** and **ice** on a global scale, their **transport** by **clouds** and their radiative impact;
- Observation of **cloud distribution** (‘cloud overlap’), cloud **precipitation** interactions and the characteristics of **vertical motions** within clouds;
- Retrieval of **profiles** of **atmospheric radiative heating** and **cooling** through the combination of the retrieved aerosol and cloud properties

Support for EarthCARE – Collection of Ideas, Plans

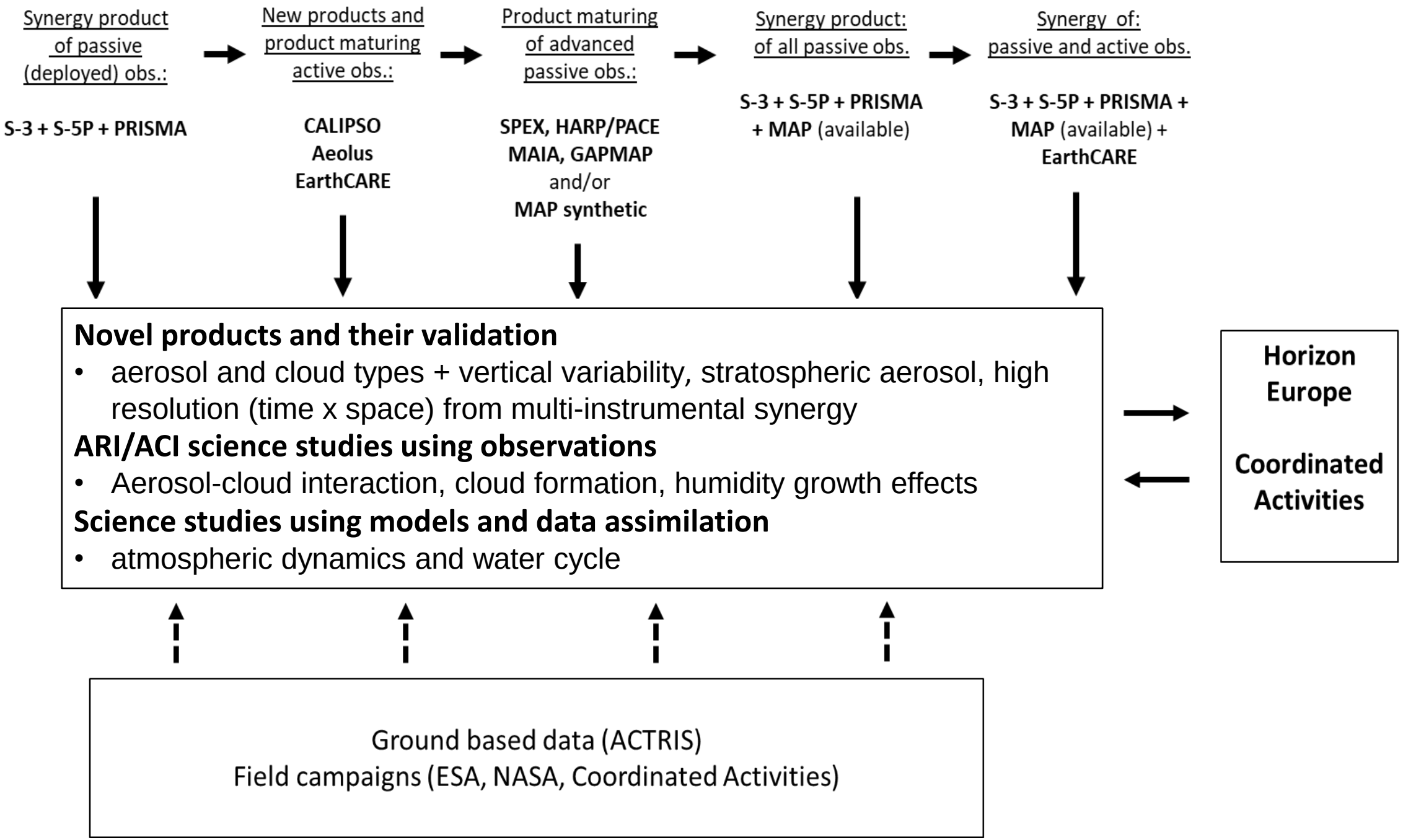
Studies upcoming in the short term

- **Atmosphere Science Cluster** – Research Opportunities 5
- **Coordinated call** with the EC DG-RTD, to be KO Nov 2023
  - Related call HORIZON-CL5-2023-D1-04 winners CleanCloud and CERTAINTY, talks on Mon Nov 13, 2023

=> AIRSENSE

Aerosol and aerosol-cloud Interaction from Remote SENSing Enhancement

O.Dubovik, P. Litvinov, A. Lopatin, U. Wandinger, O. Hasenkamp, V. Amiridis, H. Baars, B. van Diedenhoven, M. Momoi, S. Zhai, B. Torres, F. Waquet, O. Sourdeval, E. Marinou, A.Tsekeri, H. Jia, J. Hofer, A. Tsikerdekis, G.-J. van Zadelhoff, D. P. Donovan, J.-C. Péré, I. S. Stachlewska, L. Janicka


Synergy product of passive (deployed) obs.:
S-3 + S-5P + PRISMA
New products and product maturing active obs.:
CALIPSO
Aeolus
EarthCARE
Product maturing of advanced passive obs.:
SPEX, HARP/PACE
MAIA, GAPMAP
and/or
MAP synthetic
Synergy product: of all passive obs.
S-3 + S-5P + PRISMA + MAP (available)
Synergy of: passive and active obs.
S-3 + S-5P + PRISMA + MAP (available) + EarthCARE
Novel products and their validation
• aerosol and cloud types + vertical variability, stratospheric aerosol, high resolution (time x space) from multi-instrumental synergy
ARI/ACI science studies using observations
• Aerosol-cloud interaction, cloud formation, humidity growth effects
Science studies using models and data assimilation
• atmospheric dynamics and water cycle
Horizon Europe
Coordinated Activities
Ground based data (ACTRIS)
Field campaigns (ESA, NASA, Coordinated Activities)

Support for EarthCARE – Collection of Ideas, Plans

Studies in planning, other funding opportunities

- Several **dedicated science studies** to be started in **2024**, 2 MEUR
- **Support** for EarthCARE product handling functionality in the ESA Atmosphere Virtual Lab (AVL): https://atmospherevirtuallab.org/
- **Permanent Open Call**, 200 kEUR, 1.5 y, https://eo4society.esa.int/2023/09/15/future-eo-1-segment-2-open-call-for-proposal-for-eo-innovation/
  Science, Applications, Industrial Competitiveness, Digital Innovation, Sentinel Users Preparation, Foresight
- **Living Planet Fellowship** (LPF), 200 kEUR, 2 y

Support for EarthCARE – Collection of Ideas, Plans

Input is coming from

- List of proposals for science activities in Phase E2, **collected** from the **JMAG** and **Level 2 teams**;
- ATMOS-2021 **conference recommendations**: https://atmos2021.esa.int/
- **ATMOS-2024**, Bologna, Italy, Jul 1 – 5, 2024
- Further suggestions when closer to launch and in Commissioning;
- …

Aeolus Science Studies

Feasibility Studies concluded: Ensuring a fast exploitation of Aeolus through a set of parallel short feasibility projects advancing beyond the primary products

- LISA - Lidar measurements to **Identify Streamers** and analyze **Atmospheric waves** (Team: DLR)
- NEWTON - ImproviNg **dust monitoring** and forecasting through Aeolus WInd daTa assimilatiON (Team: NOA, Cyl)
- SWAILS+ - Studies on **Wind** and **Aerosol** Information from **Lidar Surface returns** (Team: KNMI)
- SeaFlect - **Ocean Surface Wind** from Aeolus Sea Surface (Team: Verisk Analytics GmbH; Hermess, Informus)
- COLOR - **CDOM-proxy** retrieval from aeOLus ObseRvations (Team: CNR-ISMAR; UNIBAS, AEQUORA; SERCO)
- AOC - **Ocean sub-surface products** and applications (Team: Noveltis; CNRS – LOG)

Science Studies recently launched: Using established Aeolus products

- Aeolus+ Aerosols L2A+ Product (Team: NOA, Cyl, ECMWF)
- Aeolus+ Processes (Team: UHH, ECMWF)

https://eo4society.esa.int

CPR: Ideas centered around main features/advantages

Light precipitation and Low-level oceanic clouds

The EarthCARE CPR will have a smaller footprint (improved LWP estimates), better sensitivity, and better handling of the surface clutter. There is the expectation that will provide improved measurements in LWP, cloud structure, and rain rate in these climatically important cloud systems. Post-launch, the CPR L2 algorithms will be evaluated and refined for extracting the aforementioned information from low-level clouds over the ocean. Then, it will be **important** to **create** a **1- or 2-year climatology**, **compare** this climatology with that available from **CloudSat** and use the data to **evaluate climate models** and conduct studies on the meteorological factors and aerosols that affect the properties of low-level oceanic clouds.

Global estimates of hydrometeors sedimentation rates

The EarthCARE CPR is the first Dopplerized radar in space for atmospheric applications. The CPR L2 algorithms use state-of-the-art corrections and statistical techniques to provide the best estimate of the sedimentation velocity of hydrometeors around the globe. Climate models are very sensitive to the specification of fall speeds. Ice fall speed was the second most important parameter for determining climate sensitivity. A decrease in the fall speed of ice crystals can affect upper tropospheric water vapor amounts while changes to the fall speed of raindrops can induce changes in the evaporation rate and hence affect the temperature structure in the lower part of the atmosphere. **Generating** a **first global climatology** of **hydrometeor fall speeds** using the CPR Doppler observations will be a first and will help us understand the variability of the hydrometeor fall velocities and their dependency on environmental factors.

CPR: Studies on clouds and precipitation

Study of precipitation initiation processes

Precipitation formation is a key process in Earth's hydrological cycle. It keeps ecosystems running and is hence a major concern of current weather and climate research. Recent shifts in global precipitation patterns were pinned down with the help of large-scale measurement data and with numerical modelling. Still, the origins of these changes are obscure, because precipitation formation is complex and involves a large diversity of ice and liquid processes. The melting-layer detection based on vertical-velocity estimation will, for the first time, allow direct distinction between cold and warm precipitation processes and their global distribution. For that, global histograms of precipitation events and their properties (cloud top height, cloud top temperature, melting layer presence) shall be compiled from the global EarthCARE dataset. Data from operational Cloudnet stations shall be used to provide ground-truth datasets for intercomparison.

Characterisation of convection with synergistic GEO and LEO satellite observations

EarthCARE CPR's unique capability of Doppler observations will be used to characterise the upper parts of convective towers. In synergy with GEO and other LEO satellites, an unprecedented climatology will be created. EarthCARE CPR products will require a specialised de-aliasing (re-)processing (beyond the nominal CPR data products).

ATLID: Studies on aerosol and aerosol-cloud interaction

Long-term datasets for aerosol and aerosol-cloud-interaction research

EarthCARE will **continue** the **long-term observations** of **aerosol** and **clouds** that have been **started** with **CALIPSO** in 2006. While CALIPSO uses backscatter measurements at 532 and 1064 nm, the new generation of high-spectral-resolution lidars developed by ESA operate at 355 nm. First aerosol measurements from space at this wavelength are already available from the wind-lidar mission Aeolus as spin-off products. With ATLID, a new observation quality will emerge due to the combined high-spectral-resolution and polarization capabilities and the much better vertical and horizontal resolution of the measurements compared to Aeolus. Therefore, ATLID measurements will also allow the retrieval of CCN (cloud condensation nucleus) and INP (ice-nucleating particle) concentrations following an which has been already applied to CALIPSO measurements. However, the previous work relies on measurements at 532 nm and the retrievals for 355 nm still need to be developed. The developments shall be made in the general context of harmonizing long-term aerosol lidar observations from space at different wavelengths by applying EarthCARE's Hybrid End-to-End Aerosol Classification model and aerosol-type-dependent conversions based on multi wavelength measurements from ground A specific focus of the study shall be on the global dust belt, along which several ground-based observing stations equipped with multi wavelength polarization lidars and photometers exist that can be used to provide the necessary input information to develop the retrievals as well as to validate the new spaceborne products. The global dust belt constitutes the largest aerosol source on Earth, is highly sensitive to global change, and exhibits next to pure dust a variety of complex mixtures of dust with pollution, smoke, and marine aerosol. Dust particles are known as efficient INP, while pollution, smoke, and marine particles mainly act as CCN.

Global influence of smoke in the stratosphere

As a **consequence** of **climate change**, the **frequency** of **extreme wildfires** is **increasing**, which leads to larger emissions of smoke into the UTLS. The influence of this new phenomenon on cirrus formation, radiation budget, and even ozone depletion is not fully understood yet. Smoke injection into the UTLS impacts the entire hemisphere on timescales from several months up to years. The global observations of EarthCARE will enable the research community to study the distribution and temporal evolution of stratospheric smoke plumes. **ATLID L2a products** are **suited** to **detect** the **aerosol layers** in the stratosphere, especially ATLID's polarization and high-spectral-resolution capabilities are essential. However, a specific aerosol classification scheme for the stratosphere is not implemented yet. The distinct optical properties of stratospheric smoke allow the separation of smoke from volcanic aerosol, which has been considered as the dominant aerosol type in the stratosphere for decades. Developing tools to detect and characterize stratospheric smoke layers and creating a first climatology from 1-2 years of EarthCARE observations will serve as the starting point to study the global impact of wildfire smoke.

Change of particle scattering properties by water uptake at high relative humidity

Satellite-based studies of **aerosol-cloud** interactions often **rely** on the observation of aerosol **properties** in the **vicinity** of **clouds**. **EarthCARE** will **allow** global **observations** of **aerosol scattering** properties with **unprecedented accuracy** with its high-spectral-resolution lidar ATLID. However, aerosol scattering properties are affected by water uptake and the respective growth of particles. For the same type of aerosol, a change of scattering properties with height is typically observed in the mixed convective boundary layer. Therefore, the aerosol observations of ATLID should be investigated with respect to humidity-growth effects in different areas of the world and for different aerosol types by comparing them with ground-based measurements during nearby overpasses. **Multiwavelength polarization Raman lidars** that comprise also **water-vapor channels** are best suited for this purpose since they allow the measurement of particle scattering properties, the classification of the aerosol and the determination of relative-humidity profiles simultaneously. By **combining ground-based** and **spaceborne** observations, the particle **water uptake** within the mixed boundary layer shall be **quantified** for **different aerosol types** in different areas and used to estimate the global effect.

ATLID-CPR synergy: Studies on aerosol-cloud interaction

Impact of aerosol conditions and vertical air motion on supercooled liquid clouds

The joint aerosol and cloud observation capabilities of EarthCARE will, for the first time, allow a global view on the relative contribution of vertical air motion and aerosol effects on the phase partitioning in the mixed-phase cloud regime between -40 and 0°C. There is, for instance, still a considerable bias between observations and simulations of the radiative budget over the southern-hemisphere midlatitudes, which is attributed to an underestimation of supercooled liquid water in state-of-the-art atmospheric models over this region. Both, an insufficient representation of cloud-relevant aerosol properties, such as ice-nucleating particles (INP) or cloud condensation nuclei (CCN), or an underestimation of in-cloud vertical dynamics are potential explanations for the excess of supercooled liquid water over this region. However, ground-based observations were so far mostly restricted to locations in the vicinity of the few landmasses of the southern hemisphere midlatitudes, which are subject to the presence of orographically driven atmospheric waves. The impact of these waves or other yet undiscovered vertical air motions on clouds over the southern ocean, where the radiation bias is largest, is to date unclear due to the lack of observations. Using ATLID and the Doppler-capable CPR aboard EarthCARE will allow the adaption of to the whole globe in order to evaluate the relative contribution of vertical air motion and aerosol to the formation of supercooled liquid water in the mixed-phase cloud regime.

Satellite-ground synergy: Aerosol-cloud interaction

Studies on aerosol-cloud interactions from the synergy between space- and ground-based instruments

The **interplay** between **aerosol** and **clouds** is one of the **biggest questions** when **predicting** future **climate**. Regarding the radiative forcing due to aerosol-cloud interactions satellite observations have shown to be the most suitable platform to experimentally estimate the anthropogenic contribution on it, and there is a long history of estimates mostly based on passive remote-sensing instruments. There are important issues when evaluating the effect of aerosol on clouds from space, such as the absence of vertical information about aerosol particles and clouds which the EarthCARE mission will widely be overcome by the unique synergy of lidar, radar, imagery, and radiometry instruments. The spatiotemporal information of aerosol and cloud macro- and microphysics, together with the radiation fluxes, will represent the most complete dataset ever acquired from observations. This data will offer a valuable opportunity to evaluate the Twomey effect and the adjustments of cloud properties and cloud lifetime after perturbation. Another important issue is the fact that in cloudy situations, almost no information beneath thick clouds can be obtained from spaceborne instruments. For this reason, neighboring cloud pixels to estimate the aerosol proxy have been mostly used, but its degree of correlation with cloud properties is at least questionable. Furthermore, the use of near-cloud pixels might induce biases in the aerosol properties because of possible misclassification between aerosol and clouds. The importance of the scale to address aerosol-cloud relations and the difficulty of separating the influence of aerosol and cloud processes on the cloud droplet and ice number gives the information beneath the cloud an essential role. Because of this, and in the context of harmonization, ground-based lidars can help with the construction of 4D scenes in order to extend the observational capabilities to cloudy periods in which information from the ground up to the cloud base will be missing. Ground-based lidars, measuring continuously and at locations close to the overpasses of EarthCARE, can be used in combination with parcel modeling to reconstruct the aerosol situation beneath clouds from elastic lidar products. Microphysical information in the cloud base region of liquid layers will be still missing, as they can be only partially observed by space lidar. **Ground-based lidar/radar** or **lidar** with **dual-FOV capabilities can add** the last **missing part** of information, but this will be limited to only a few stations. Studies on the processes occurring in clouds might be conducted by combining the ground-based and space-based capabilities.

Other ideas

- **Augment the volcanic ash detection and forecasting capability**
  Feeding EarthCARE vertical profiles with images from nadir-viewing optical sensors into an ash forecasting system. The development shall take place in close cooperation with the VAACs as main users.
- **High resolution cloud and aerosol modelling**
  Feasibility Study for the assimilation of EarthCARE cloud and aerosol data in regional models, i.e., mesoscale forecast models used by Met Services.
- **Forward modelling for the utilization of the Doppler effect from convection**
  Feasibility Study for the assimilation EarthCARE Doppler Winds in convective situations in global models (e.g. ECMWF) building on the assimilation of EarthCARE clouds and Aeolus winds.
- **Activities to further exploit MSI, RBR?**
- **…**

Thank you

Backup on Aeolus Innovation

Advancing EO Methods and Techniques

Aeolus+ Innovation

LISA - Lidar measurements to Identify Streamers and analyze Atmospheric waves

Consortium

- DLR (Germany); Czech Institute of Atmospheric Physics (CAS, Czech Republic)

Objectives

- Develop Aeolus products to study atmospheric streamer events

Current status:

- FM: June 28, 2022;
- Visiting scientist – Lisa Kuechelbacher, DLR;
- Outreach – extensive list of conferences;

https://eo4society.esa.int/projects/lidar-measurements-to-identify-streamers-and-analyze-atmospheric-waves-lisa/

Advancing EO Methods and Techniques

Aeolus+ Innovation – LISA – Main results

Scientific Case Studies

Derivation of PW up to wavenumber 6

Aeolus-DAI shows structures more clea

Aeolus data available for the selected ti

Aeolus DAI shows wave breaking with r

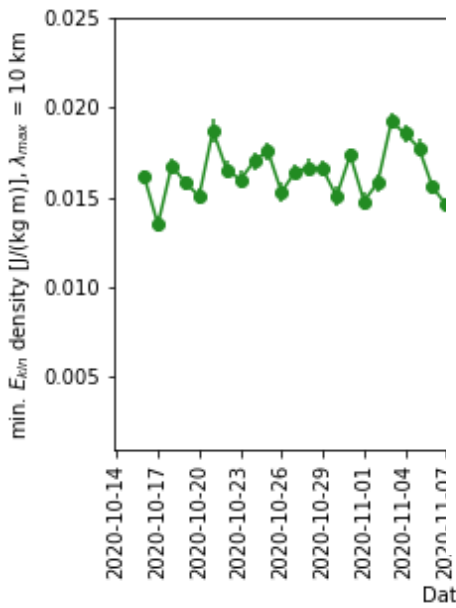
For each event two waves with differen

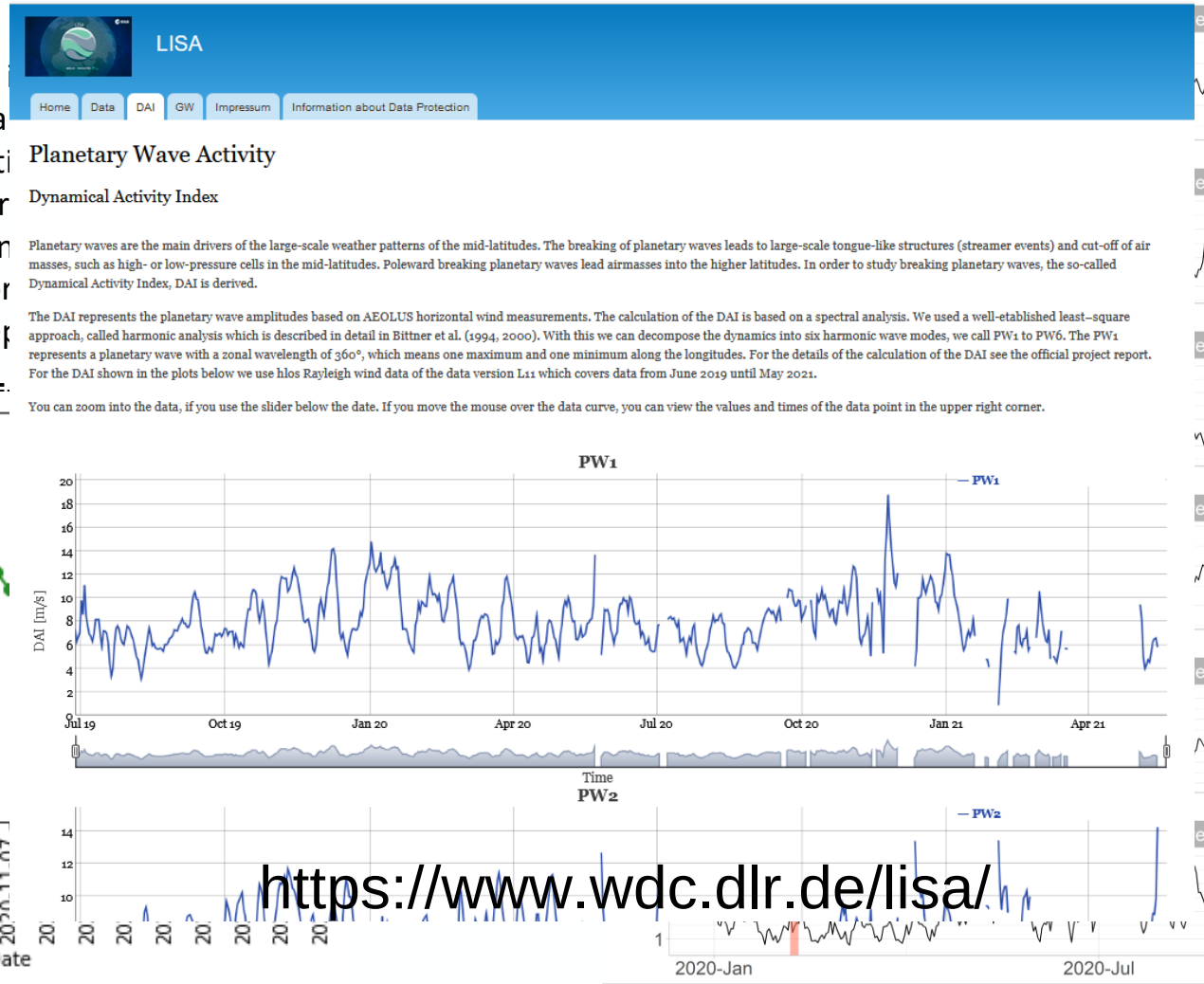
Wave-resonance might explain wave br

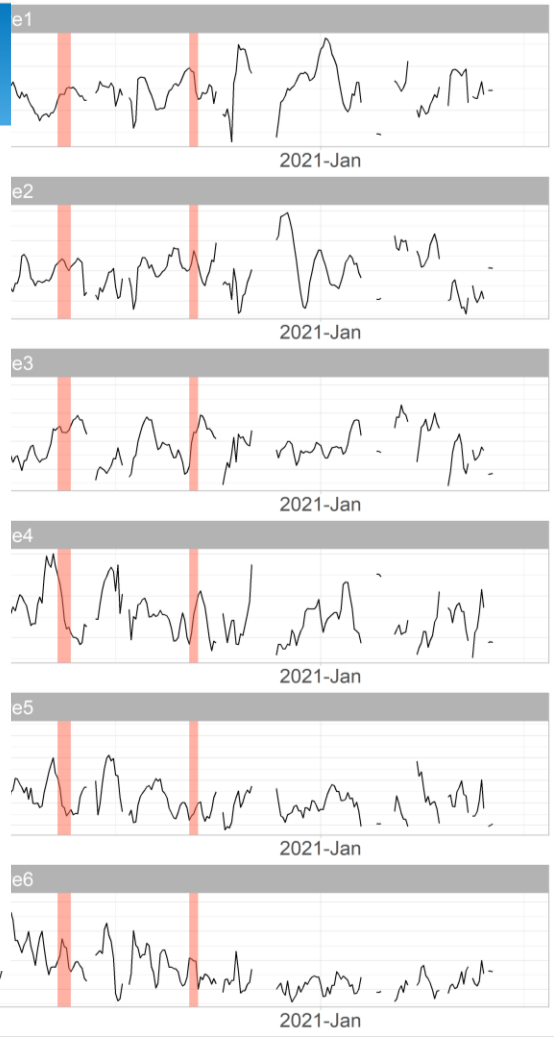
Streamer occur in different heights, dep

Derivati

Normali







https://www.wdc.dlr.de/lisa/

Advancing EO Methods and Techniques

Aeolus+ Innovation

NEWTON - ImproviNg dust monitoring and forEcasting through Aeolus WInd daTa assimilatiON

Consortium

- National Observatory Athens (NOA); The Cyprus Institute (CyI)

Objectives

- Improvement of short-term dust forecasts and DOD through assimilation of Aeolus winds

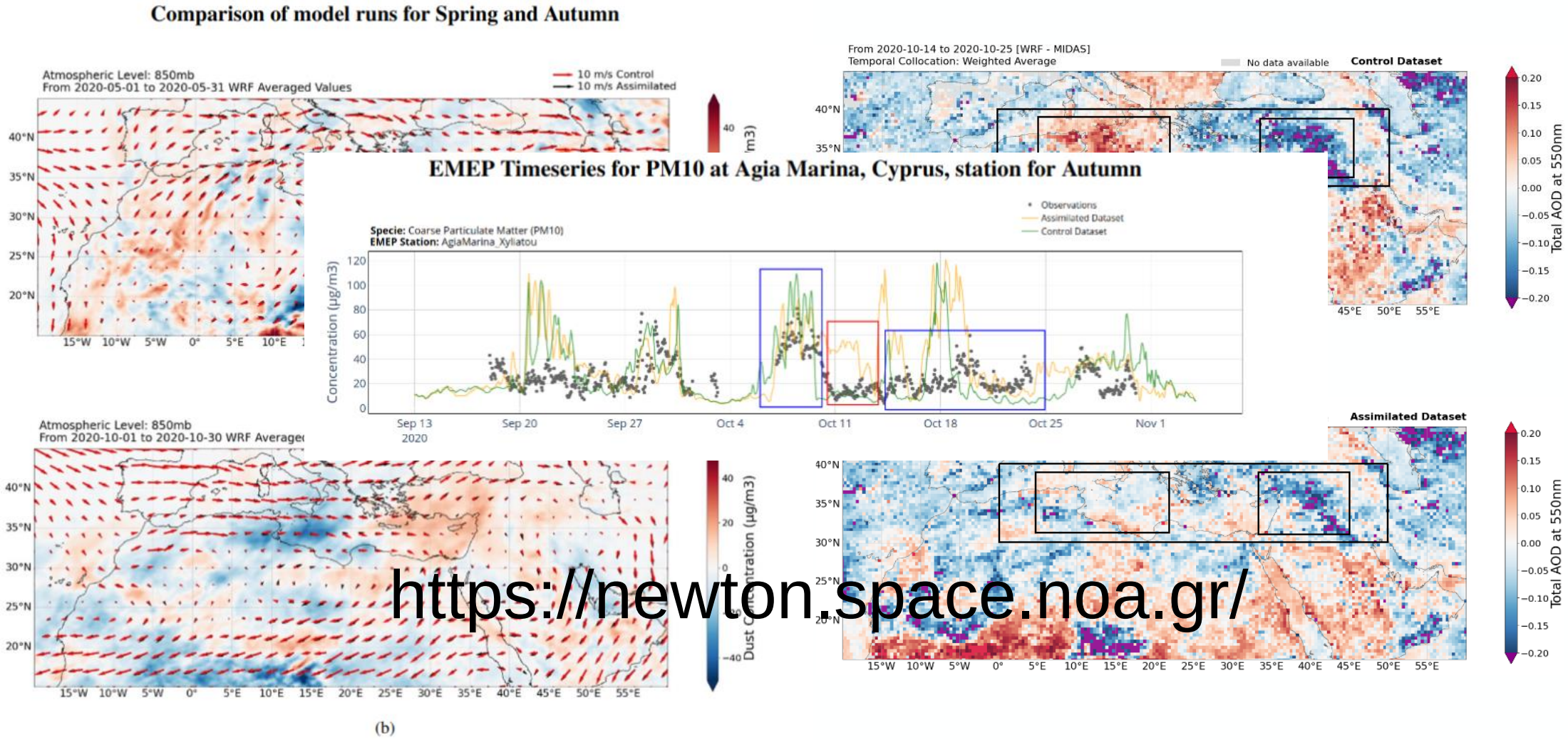
Current status:

- FM: July 14, 2022;
- Further developments based on NEWTON study
- ACP paper submitted

https://eo4society.esa.int/projects/aeolus-innovation-expro-newton/

Advancing EO Methods and Techniques

Aeolus+ Innovation – NEWTON - Main results



https://newton.space.noa.gr/

Advancing EO Methods and Techniques

Aeolus+ Innovation

SWAILS+ - Studies on Wind and Aerosol Information from Lidar Surface returns

Consortium

- KNMI

Objectives

- Derive ocean surface wind product from Aeolus observations

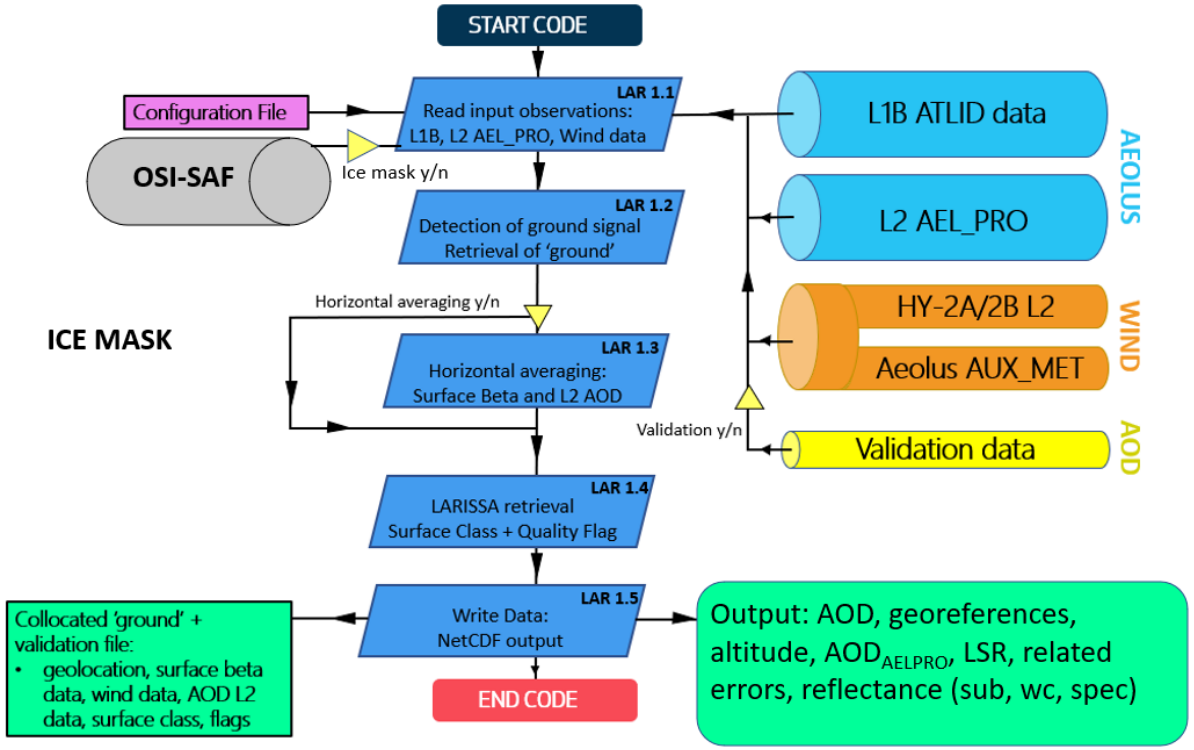
Current status:

- FM: July 4, 2022;
- LARRISA software on GitHub;
  https://gitlab.com/labzovskii/swls/activity

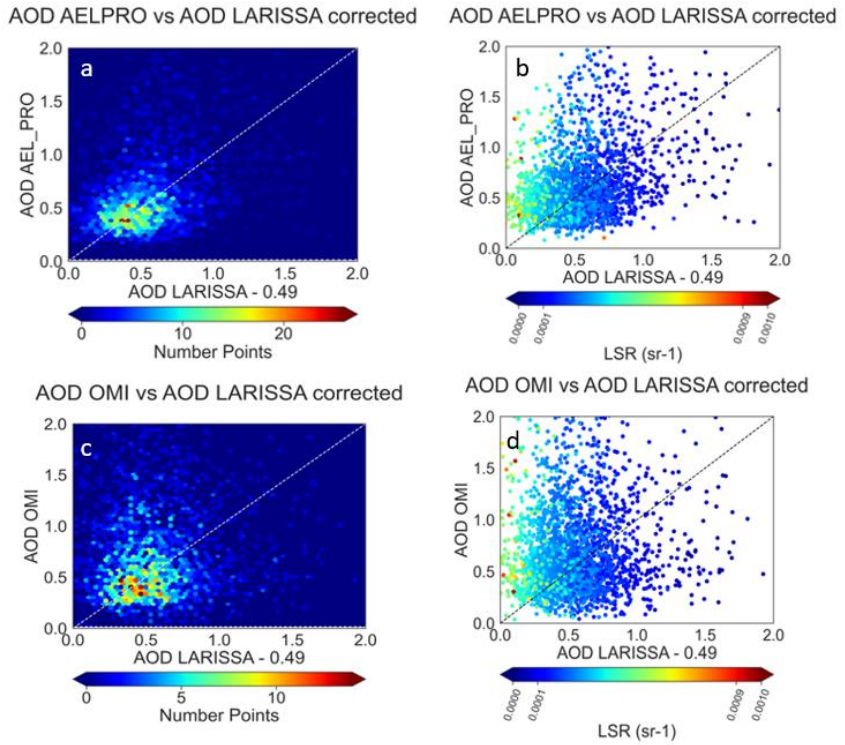
https://eo4society.esa.int/projects/aeolus-innovation-studies-on-wind-and-aerosol-information-from-lidar-surface-returns-swails/

Advancing EO Methods and Techniques

Aeolus+ Innovation – SWAILS+



LARISSA flow diagram



Validation results

LARISSA datasets can be accessed from the KDP:
https://dataplatform.knmi.nl/dataset/aeolus-larissa-2a-1-0

Advancing EO Methods and Techniques

Aeolus+ Innovation

SeaFlect - Ocean Surface Wind from Aeolus Sea Surface

Consortium

- Verisk Analytics GmbH (Europe and US); Hermess (The Netherlands); Informus (Germany)

Objectives

- Define conditions where ocean surface wind products can be retrieved from Aeolus observations, and define, calibrate and validate a novel wind speed retrieval method

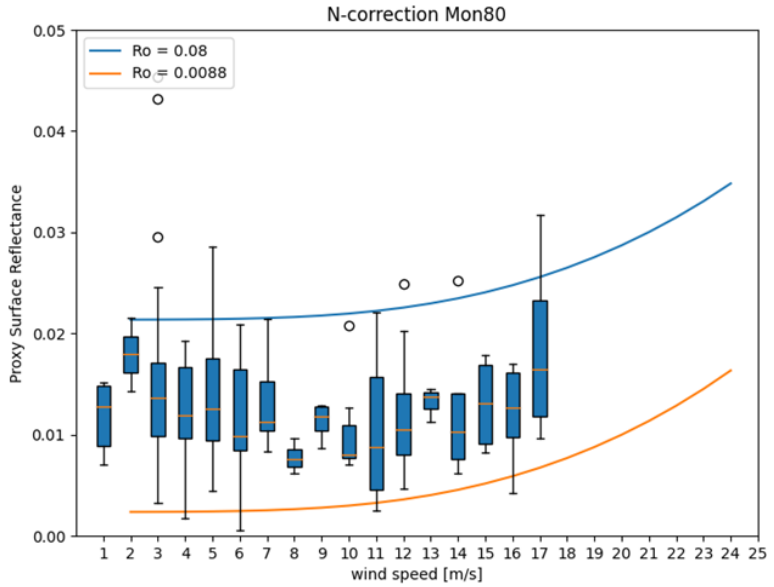
Current status:

- FM: July 1, 2022;
- Definition of quality control and filtering of data in the analysis;
- validation activity started - first draft of the VAL document.

https://eo4society.esa.int/projects/aeolus-innovation-expro-ocean-surface-wind-from-aeolus-sea-surface-returns-sea-flect/

Advancing EO Methods and Techniques

Aeolus+ Innovation – SeaFlect – Main results



Careful consideration on data filtering.
Expected increase in reflectance with increasing wind speed for the high wind regime (wind speed in excess of 10 m/s).

EOL Experiment

- Near-nadir observation geometry;
- Data collection for at least two weeks over the global oceans;
- Aggregation of 20 pulses into a measurement, to arrive at an approximate sampling scale of 3 km.;
- Different observation geometries (e.g., 5°, 20°) for different ROI (Hudson Bay, Bothnian Sea);

The analysis of the data collected during the EoL experience would benefit from the methods developed under the baseline activities and could be performed in a relatively short period (< 6 month).

Advancing EO Methods and Techniques

Aeolus+ Innovation

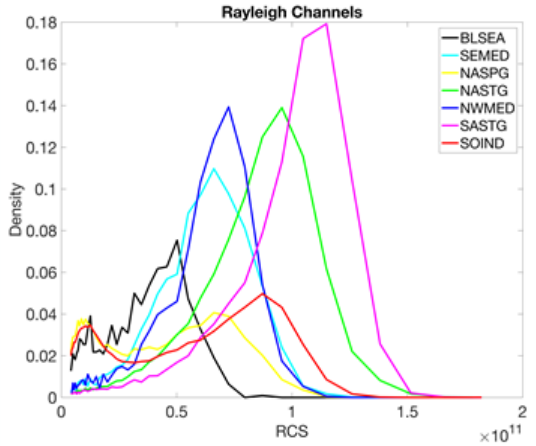
COLOR - CDOM-proxy retrieval from aeOLus ObseRvations

Consortium

- CNR-ISMAR; University of Basilicata (UNIBAS); AEQUORA; SERCO

Objectives

- Study whether in-water products can be retrieved from Aeolus sub-surface returns for indirect chromophoric dissolved organic matter (CDOM) determination



Current status:

- -> MTR - Q1 2022;
- A Monte Carlo based RTM to simulate AEOLUS signal propagation in ocean was developed and validated;
- Algorithm development based on Aeolus signal - in progress.

https://eo4society.esa.int/projects/aeolus-innovation-expro-cdom-proxy-retrieval-from-aeolus-observations-color/

Advancing EO Methods and Techniques

Aeolus+ Innovation

AOC - Ocean sub-surface products and applications

Consortium

- Noveltis (France); CNRS – LOG (France)

Objectives

- Lidar-derived optical parameters
- Ocean optical parameters related to ocean optical properties
- Biogeochemical parameters related to marine biogeochemical cycles

Current status:

- Retrieval algorithm development (based on parametric equations) and AOC products generation; 8 different cases identified;
- Sea campaign in Cabo Verde: CADDIWA campaign, 7 Aeolus overpasses (<100 km) between Sept 15-30th 2021;
- Definition of Aeolus observations / *in situ* measurements match-ups for validation.

https://eo4society.esa.int/projects/aeolus-innovation-ocean-sub-surface-products-and-applications/