ACtIon4Cooling
Aerosol Cloud Interactions for Cooling

Pascal Hedelt (DLR)
Athina Argyrouli (DLR)

24/03/2026

Project Objectives

ESA ITT: AEROSOL AND CLOUD INTERACTIONS IMPACT IN THE CONTEXT OF SOLAR RADIATION MANAGEMENT

Timeframe: 03/2025 – 03/2026

Project Partners:

DLR (Germany, Prime), NOA (Greece),
Leipzig University (Germany)

Project objectives:

- Research on aerosol cloud interaction (ACI) impact in the context of Solar Radiation Modification (SRM) using EO data
- Finding natural analogues, analyzing study-cases for the assessment of potential SRM deployments
- Examining radiative and climate impact
- Examining detection and monitoring capabilities of potential SRM deployments from space

Project website:

https://climate.esa.int/de/solar-radiation-modification/action4cooling/

Project LinkedIn group:

https://www.linkedin.com/groups/10061777/

SRM mechanisms addressed in ACtIon4Cooling

Stratospheric Aerosol Injection (SAI)

- **Characterization of volcanic aerosols as natural analogues**, including microphysical evolution & radiative stratospheric effects
- **Assessment of large-scale climate responses**, focusing on impacts on precipitation patterns and atmospheric circulation.
- **Evaluation of regional climate imbalances,** e.g. tropical overcooling or insufficient high-latitude cooling.

Marine Cloud Brightening (MCB)

- **Identification of susceptible marine stratocumulus regions** and monitoring of aerosol-induced perturbations in cloud microphysics and TOA radiative properties using EO data.
- **Quantification of radiative and precipitation responses** to MCB-like perturbations
- **Improvement of ACI constraints**, including methodologies to distinguish MCB signals from natural variability

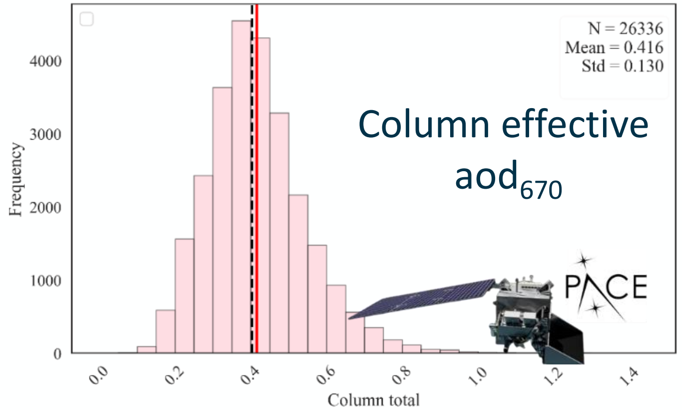
Cirrus Cloud Thinning (CCT)

- **Characterization of aviation-induced cirrus modifications**, including analysis of microphysical & optical properties using airborne observations in high-aviation and pristine regions.
- **Regional and temporal analysis of cirrus properties**, including long-term trends associated with increasing aviation activity.
- **Assessment of climatic impacts**, including potential changes in precipitation, atmospheric circulation, and radiative forcing from CCT-like perturbations.

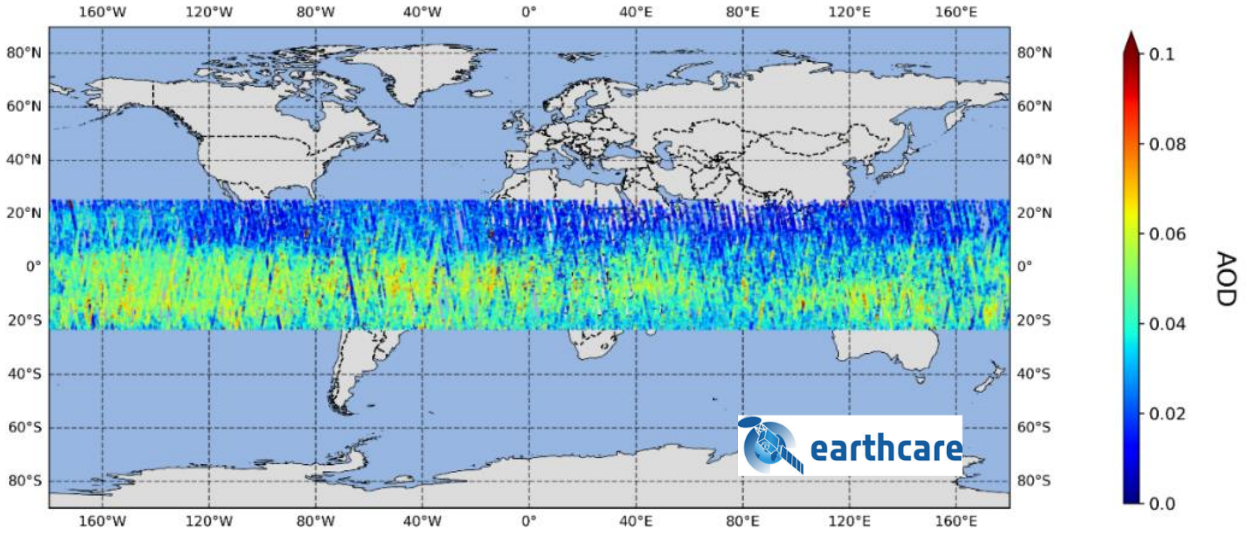
Approach & Results: SAI

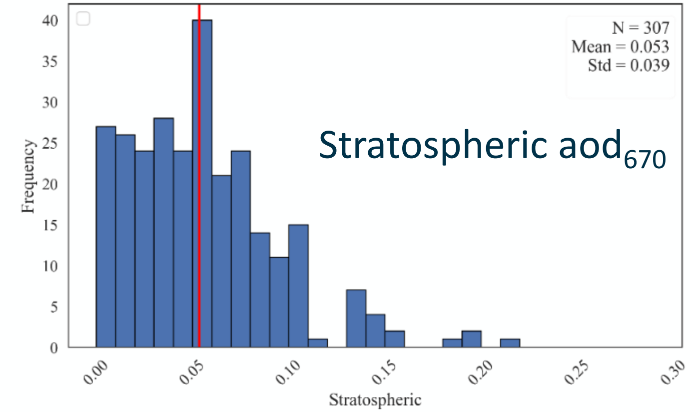
Stratospheric Aerosol Injection (SAI) – Mt. Ruang 2024

- Observations: Synergistic EarthCARE (ATLID) & PACE (HARP2) retrieval
  → retrieval of stratospheric AOD & sulfate aerosol r_{eff} above liquid clouds
- Extensions of tropospheric methods, improving state-of-the-art stratospheric products
- Detection of persistent, spherical stratospheric aerosols; tropical AOD ~0.06 @355 nm
- EarthCARE data enables monitoring of stratospheric aerosol budget changes following injections from volcanic eruptions



Stratospheric AOD from EarthCARE @355nm (left) PACE @670nm (right)

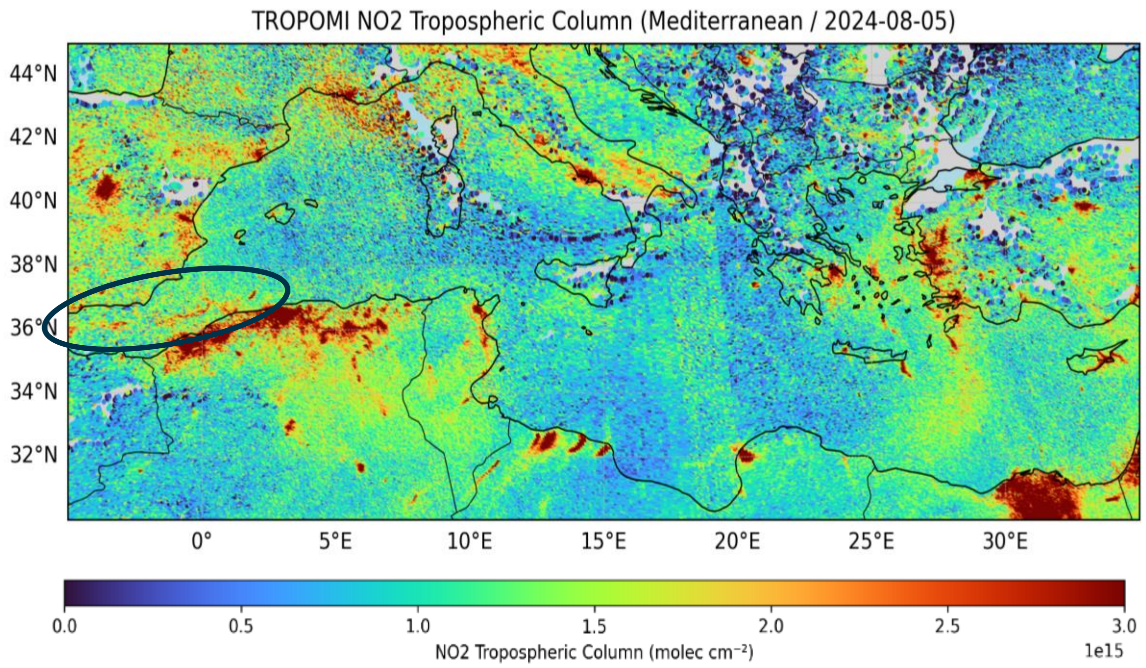


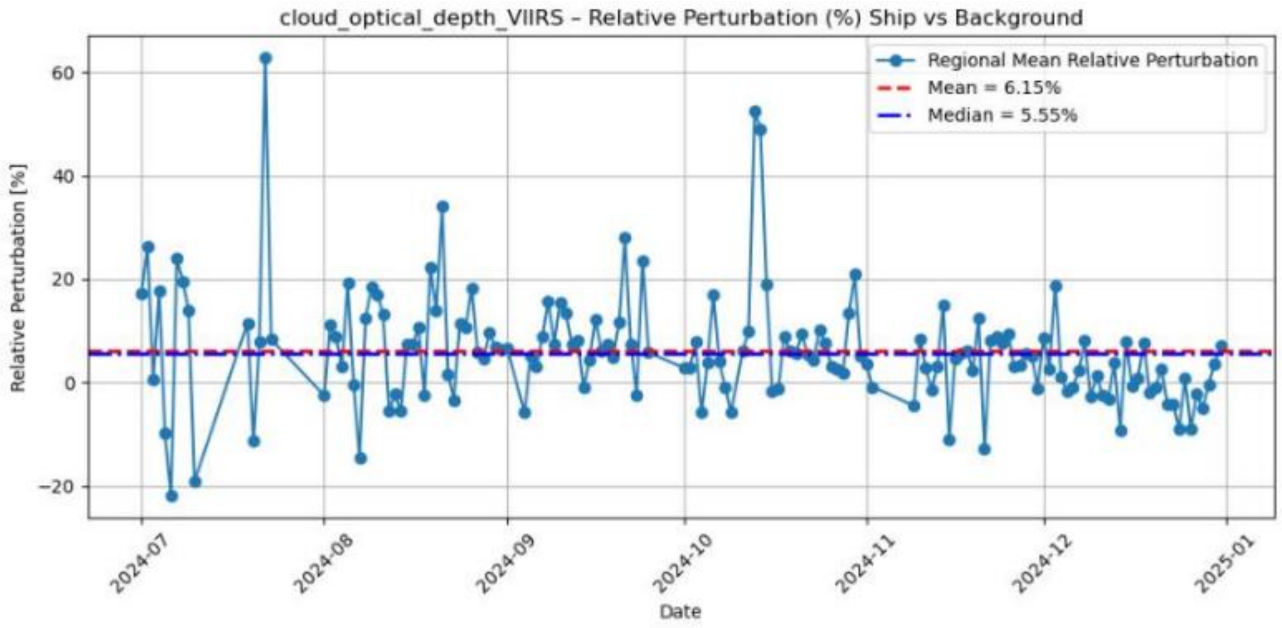


Approach & Results: MCB

Marine Cloud Brightening (MCB) – Shipping Corridors

- Observations: EMODNet vessel density maps + TROPOMI NO_2, Aerosol & Cloud products, VIIRS
- **NO_2 vertical information as a proxy of the ship emisions**
- Cloud Optical Depth relative perturbations **verify the brightening effect on marine clouds** ~5% enhancement
- Implementing a **perturbation of clouds into ICON climate model**, guided by observations-based perturbation of clouds by ships.

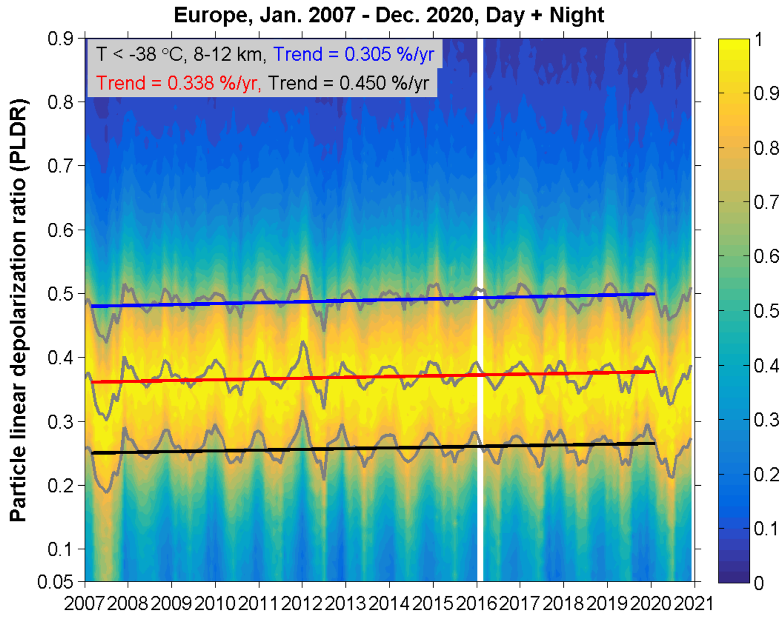


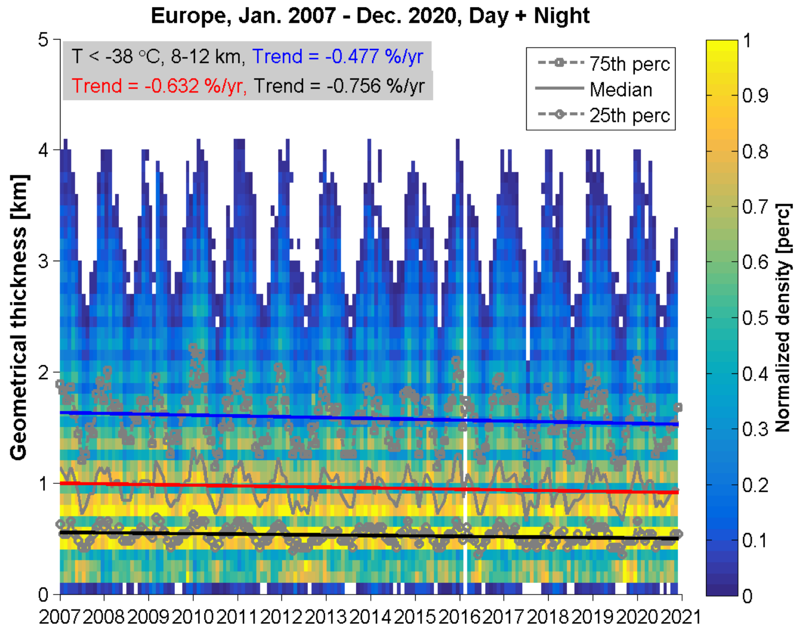


Approach & Results: CCT

Cirrus Cloud Thinning (CCT) – Aviation-relevant Cirrus

- Observations: ML-CIRRUS airborne + CALIPSO data from 2007 to 2020
- Monthly-averaged normalized number densities of cirrus particle linear depolarization ratio (PLDR) by Li and Groß (2022):
  → Aviation-influenced clouds show **larger ice crystals**
- Normalized number densities of cirrus geometrical thickness (CGT):
  → **Cirrus thinning effect** over time
- Radiative effects partly cancel: **shortwave warming, longwave cooling**

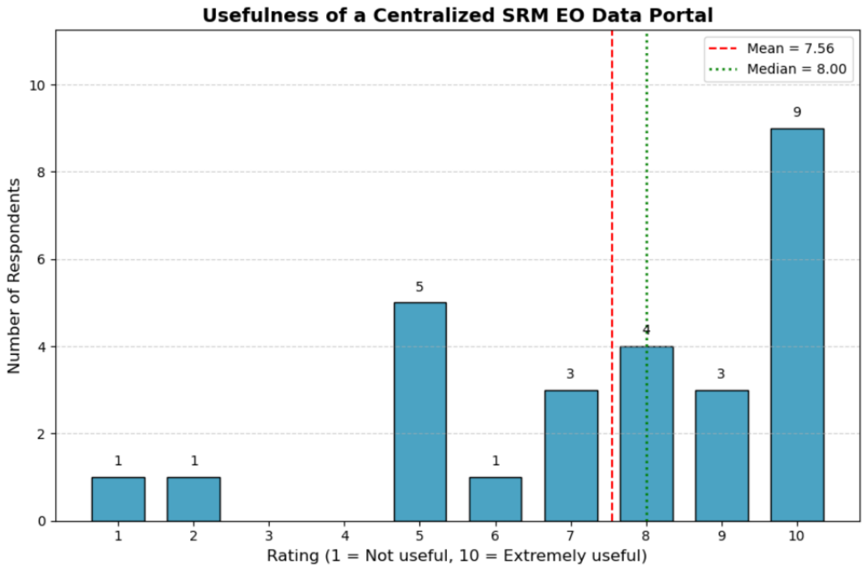




SRM expert survey:
EO Challenges for SRM Monitoring

Key EO limitations and needs

- Spatial and temporal resolution often **insufficient to detect small SRM signals**.
  → **Broad range of EO missions required** due to diverse SRM monitoring needs.
  → **Long-term climate data records are essential**, especially from MODIS, AVHRR, VIIRS, and SLSTR on Sentinel-3.
- **Risk of losing long-term datasets** (e.g., MODIS, CERES, CALIPSO).
- **Measurement gaps of** aerosol composition, particle size, and stratospheric baseline state
- **Limited vertical profiling** of aerosols and clouds, especially in the stratosphere.
- **Need for geostationary sensors** to capture diurnal cycle.
- **Need for broadband radiometers** to measure Earth radiative budget.
- **Need for stronger integration with models and more in situ observations.**
- **Need for a centralized SRM EO data portal,** potential to significantly facilitate SRM and climate research workflows.



From Earth Observations to Detection & Attribution of SRM-like Signals

In the ACtIon4Cooling project we use real-world analogues and EO-constrained modelling to develop detection and attribution capabilities for SRM-like climate signals.

The conceptual workflow that we try to establish is similar to a pipeline from data to science and application

Natural Analogues (EO) → Detection & Attribution → EO-constrained Modelling → Monitoring SRM and potential unintended climate impacts and side effects

- **Natural analogues can be investigated via the available EO datasets (CCI relevance):**

Volcanic eruptions / Ship emissions / Aviation-induced cirrus / Wildfire Smoke and other real-world analogues that allow characterization of trace gases, aerosol and cloud perturbations using satellite, airborne and ground-based observations.

- **Detection & attribution framework:**

Identify observable SRM-like signals / Define attribution thresholds / Towards operational monitoring system

- **EO-constrained modelling (CMUG relevance):**

Weak vs strong perturbation regimes / Masked signals in radiation and temperature / Regional impacts (e.g. precipitation shifts)