Exploiting TRUTHS state-of-the-art radiation measurements towards constraining aerosol-related uncertainties in radiation transfer modelling

Antonis Gkikas[1], Ilias Fountoulakis[1], Stergios Misios[1],
Stelios Kazadzis[2], Vassilis Amiridis[3], Christos Zerefos[1,4,5,6]

1 Academy of Athens 2 pmod wrc 3 National Observatory of Athens 4 BRFAA Biomedical Research Foundation Academy of Athens 5 Navarino Environmental Observatory 6 Mariolopoulos - Kanaginis Foundation for the Environmental Sciences

Outline

Theoretical background

Sensitivity study of aerosol optical properties on the radiative effects at TOA

The role of aerosol layer position within the atmosphere

Outgoing irradiances at TOA under different aerosol regimes

Advancing our understanding of ARI/ACI impacts on climate

TRUTHS climate mission: Scientific aspects and expectations

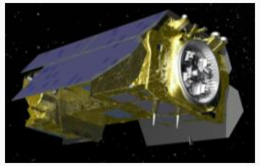
Theoretical background

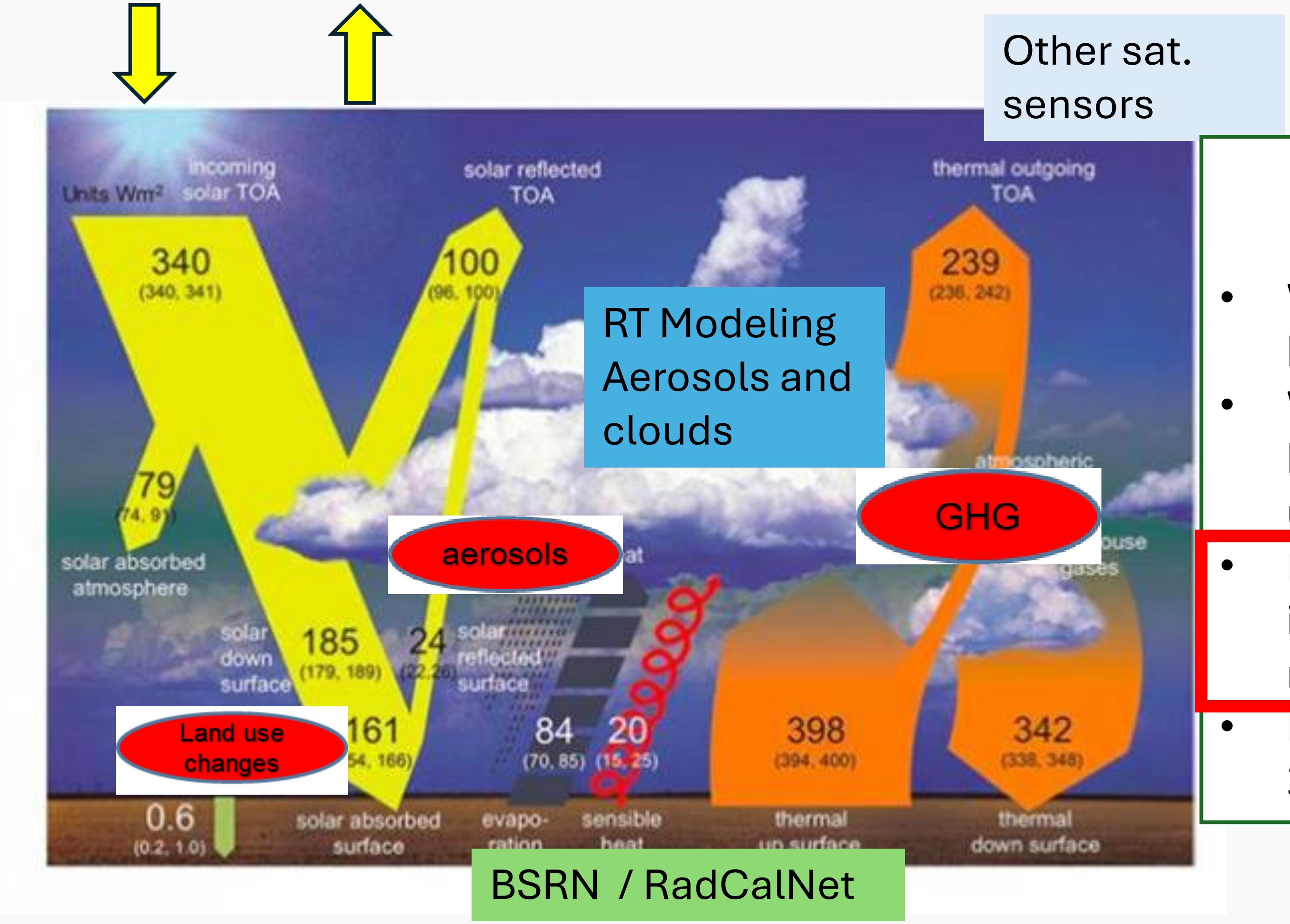
Antonis Gkikas[1], Ilias Fountoulakis[1], Stergios Misios[1],
Stelios Kazadzis[2], Vassilis Amiridis[3], Christos Zerefos[1,4,5,6]

1 Academy of Athens 2 pmod wrc 3 National Observatory of Athens 4 BRFAA Biomedical Research Foundation Academy of Athens 5 Navarino Environmental Observatory 6 Mariolopoulos - Kanaginis Foundation for the Environmental Sciences

truths

TRUTH mission science preparation

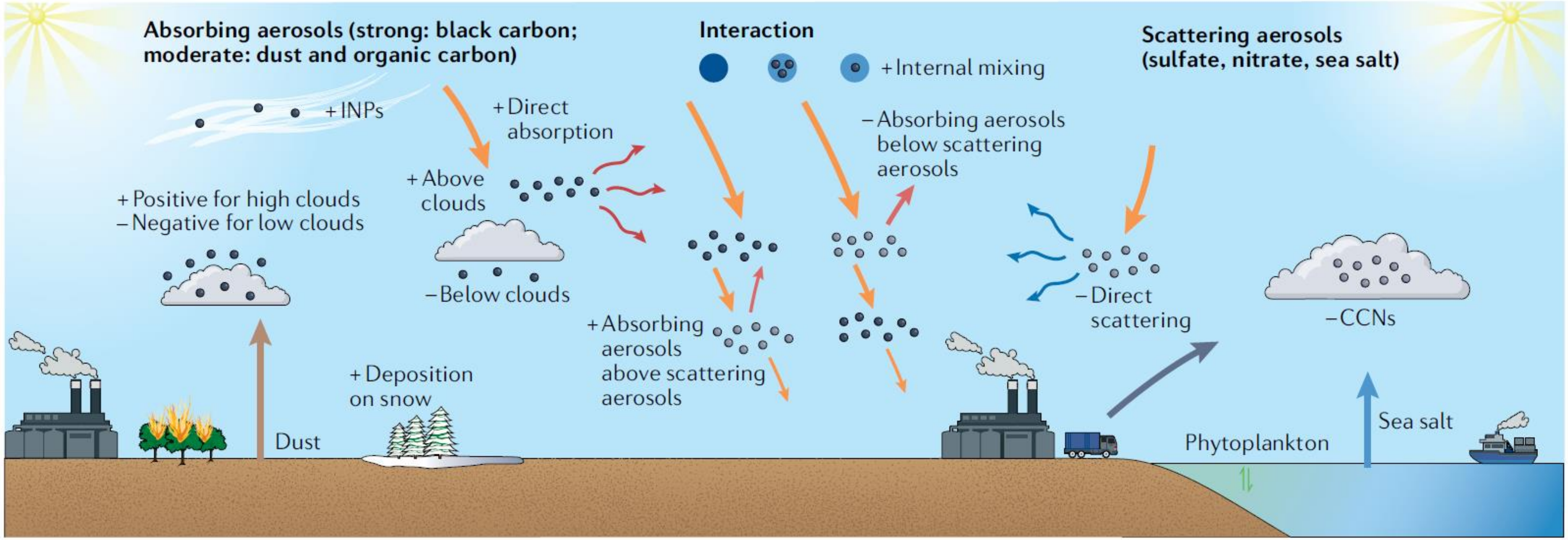




Scientific questions

- What are the factors affecting the Earth-Atmosphere balance as measured by HIS and CSAR?
- What are the other satellite products that can be improved based on TRUTHS (low uncertainty) radiances intercalibration?
- How can atmospheric radiative transfer models can be improved by TRUTHS and ground based solar measurements and related closure studies?
- How can the full TOA in SW spectrum for HIS (300-3000nm) can be simulated?

Aerosol-radiation interactions within the Earth-Atmosphere system



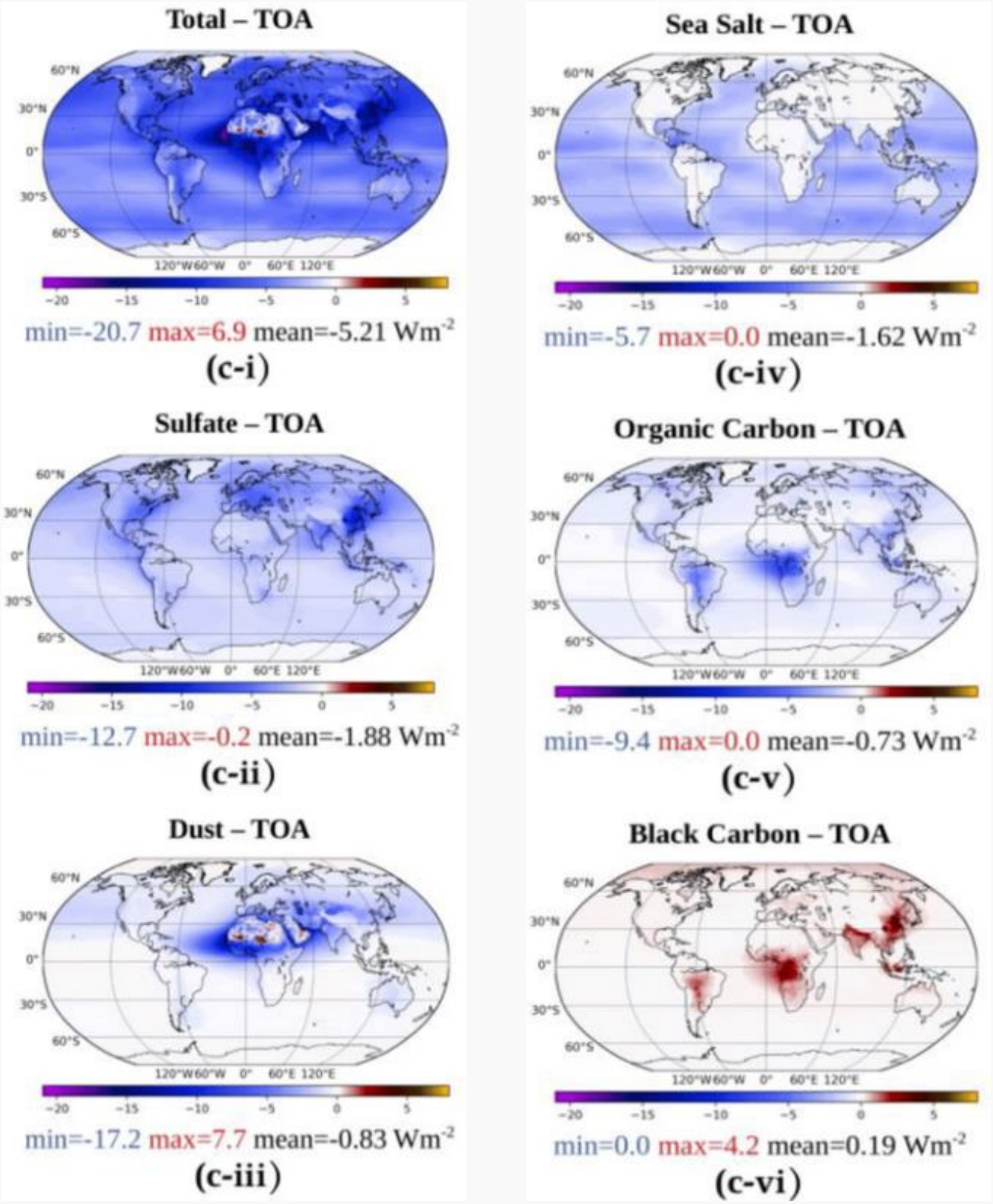
"The latest models still suggest an inter-model forcing spread of about 50% (Thornhill et al., 2021), and the actual model uncertainties are probably larger."

"The fraction of aerosol absorption relative to scattering, expressed as the SSA parameter, is one the of most critical factors in quantifying the role of aerosols in the climate system. Uncertainties in SSA as well as its vertical distribution contribute substantially to uncertainties in ARI."

"In addition, aerosol size distribution, or a proxy of it, is critical in quantifying aerosol–cloud interaction."

Li et al. (2022)

Aerosols’ impact on the Earth-Atmosphere system radiation budget



- Estimation of aerosol-speciated Direct Radiative Effects (DREs), under clear-sky, at the surface, within the atmosphere and at TOA
- Five aerosol types (sea-salt, sulfate, organic carbon, dust, black carbon as simulated by the MERRA-2 reanalysis [1980-2019]
- FORTH spectral radiative transfer model

- **Pronounced heterogeneity of the TOA DREs attributed to the spatiotemporal variation of aerosol loads**
- **Negative DREs dominate at TOA (planetary cooling)**
- **Positive DREs at TOA (planetary warming) under the presence of strongly light-absorbing black carbon particles (fires, anthropogenic acitivities)**
- **The accumulation of mineral particles over/nearby the sources of North Africa results in positive TOA DREs**

Korras-Carraca et al. (2022)

ESR3 - TRUTHS
for Climate Workshop
27-28 June 2024 | ESA-ECSAT

Sensitivity study of aerosol optical properties on the radiative effects at TOA

Antonis Gkikas[1], Ilias Fountoulakis[1], Stergios Misios[1],
Stelios Kazadzis[2], Vassilis Amiridis[3], Christos Zerefos[1,4,5,6]

1 Academy of Athens 2 pmod wrc 3 National Observatory of Athens 4 BRFAA Biomedical Research Foundation Academy of Athens 5 Navarino Environmental Observatory 6 Mariolopoulos - Kanaginis Foundation for the Environmental Sciences

truths

Dependencies of dust properties on DREs

Atmos. Chem. Phys., 24, 4915–4948, 2024
https://doi.org/10.5194/acp-24-4915-2024

Atmospheric Chemistry and Physics
Open Access
EGU
Research article

A sensitivity study on radiative effects due to the parameterization of dust optical properties in models

Ilias Fountoulakis[1,2], Alexandra Tsekeri[1], Stelios Kazadzis[3], Vassilis Amiridis[1], Angelos Nersesian[4], Maria Tsichla[1,5], Emmanouil Proestakis[1], Antonis Gkikas[1,2], Kyriakoula Papachristopoulou[1,6], Vasileios Barlakas[7,8], Claudia Emde[9,10], and Bernhard Mayer[9]

Load | Size | Shape | Solar Zenith Angle [SZA] | Surface type

Impact of dust particles' size on the outgoing radiation at TOA

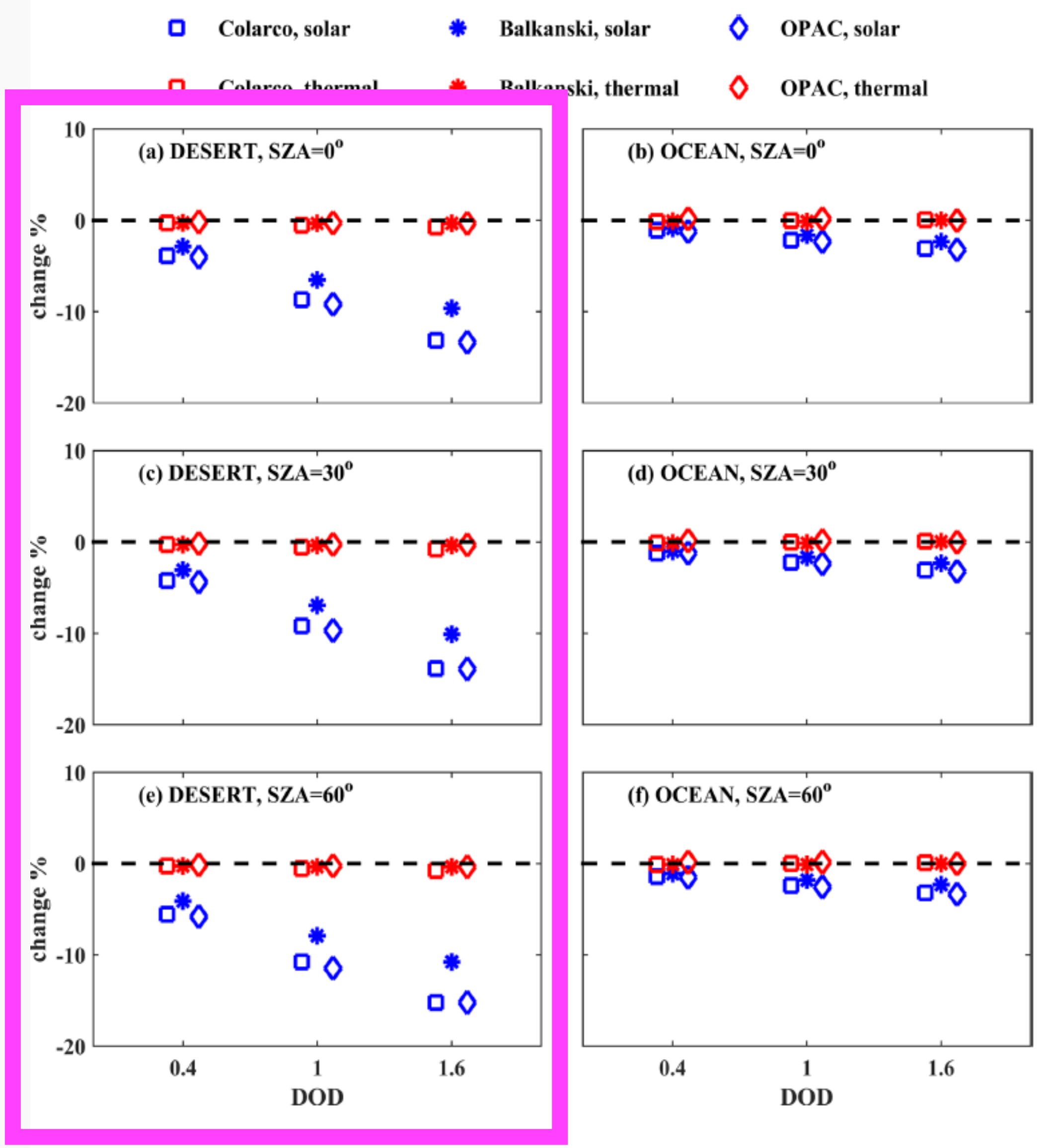


Figure 12. Similar to Fig. 11 for TOA.

$$\Delta F = F_{\mathrm{SD50}} - F_{\mathrm{SD10}}$$

$$\text{change}\,\% = \frac{\Delta F}{F_{\mathrm{SD10}}} \cdot 100\,\%$$

- libRadtran – MYSTIC
- Optical properties – MOPSMAP
- Cloud-free skies
- SW (0.35-2.5μm) | LW (8-13μm)

Solar (SW)

Thermal (LW)

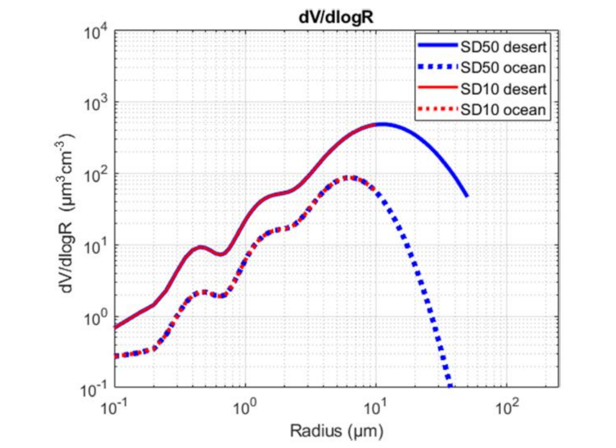
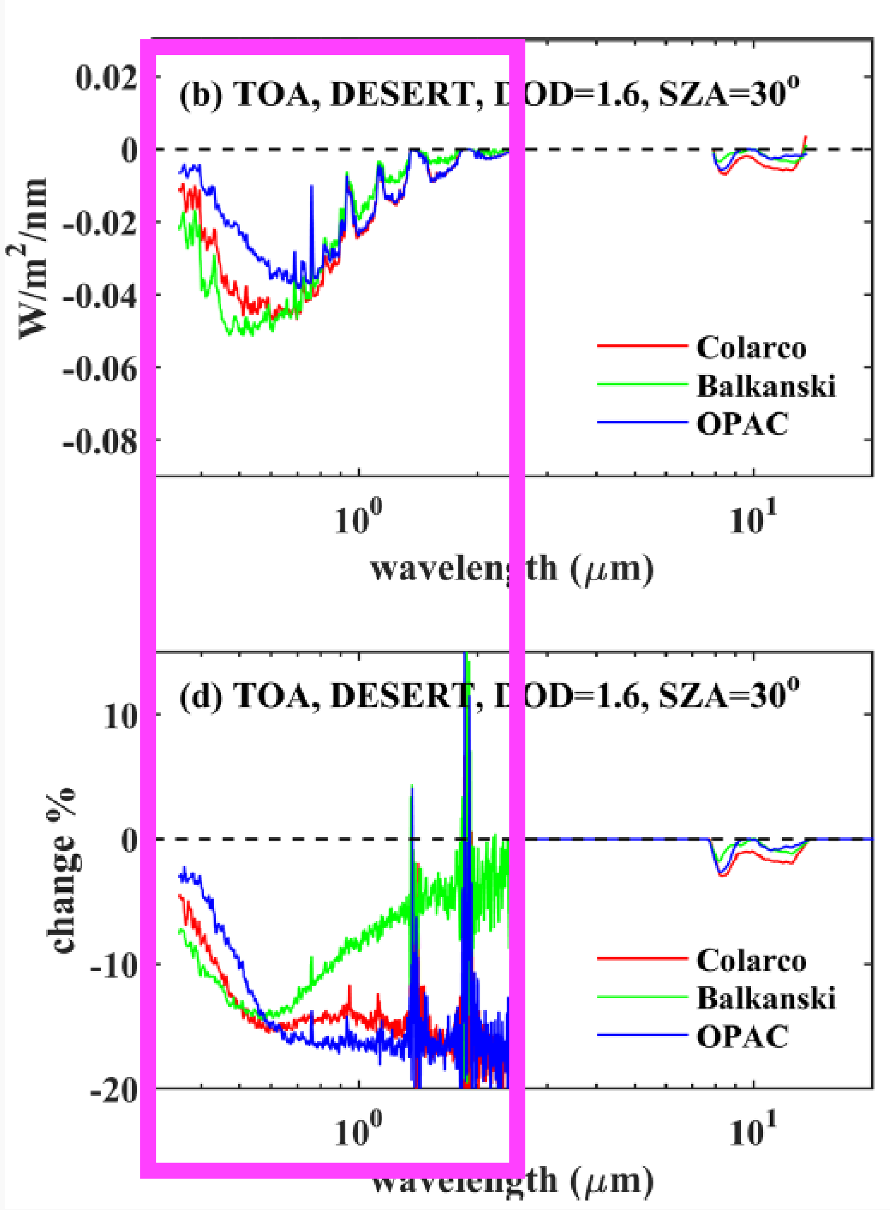


Figure 2. Mean log fit of the volume size distributions measured during the Fennec campaign above the desert (solid lines) and above the ocean in the SAL (dash lines). The volume size distributions of "SD50" with a maximum radius up to 50 μm are in blue. The volume size distributions of "SD10" with a maximum radius up to 10 μm are in red.

- **Larger mineral particles reduce the outgoing SW radiation at TOA**
- **Enhancement of the planetary warming**
- **Strong dependency on aerosol load and the underlying surface type**

Fountoulakis et al. (2024)

Impact of dust particles' size on the outgoing radiation at TOA



- Absolute and relative departures (SD50-SD10) of the spectral TOA-leaving irradiances
- Intense dust load – DOD: 1.6 | SZA=30∘
- Cloud-free skies
- Consideration of three refractive indices → minerals' composition

---

- Negative declinations (i.e., less SW radiation is reflected back to space) reaching up to 18%

- Apparent differences on the magnitude as well as on the spectral signature

- Dust particles' size and composition matters!!

Fountoulakis et al. (2024)

Overestimation of the cooling effect due to the misrepresentation of particles' size

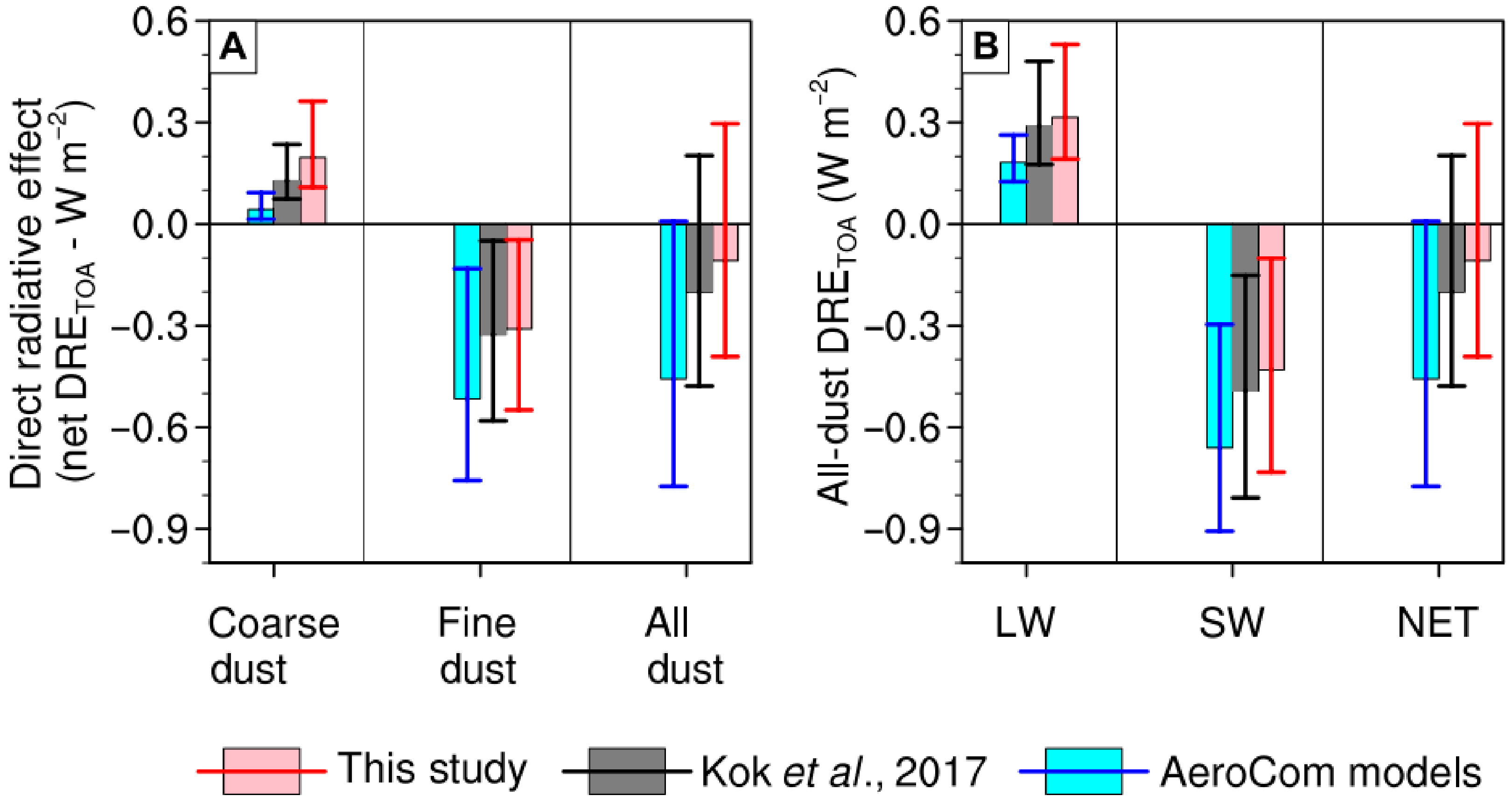


Fig. 4. Constraints on dust direct radiative effects at the top of the atmosphere (DRE_{TOA} W·m^{-2}). Size-aggregated DRE_{TOA} indicates that accounting for the missing coarse dust increases the coarse dust warming, resulting in an overall reduction in the global all-dust radiative cooling. The DRE_{TOA} (W·m^{-2}) values are obtained in this study (red/pink), from Kok *et al.* (*16*) (black/gray), and an ensemble of AeroCom models (blue lines). (**A**) DRE_{TOA} values for the coarse dust (D = 5.0 to 20 μm), fine dust (D = 0.1 to 5.0 μm), and all dust (D = 0.1 to 20 μm). (**B**) All-dust DRE_{TOA} values for longwave (LW) and shortwave (SW) components and the net (LW + SW). The error bars represent the 95% confidence interval.

Kok et al. (2017)   Adebiyi and Kok (2020)

Representation of dust mineral composition towards improving TOA radiation fields

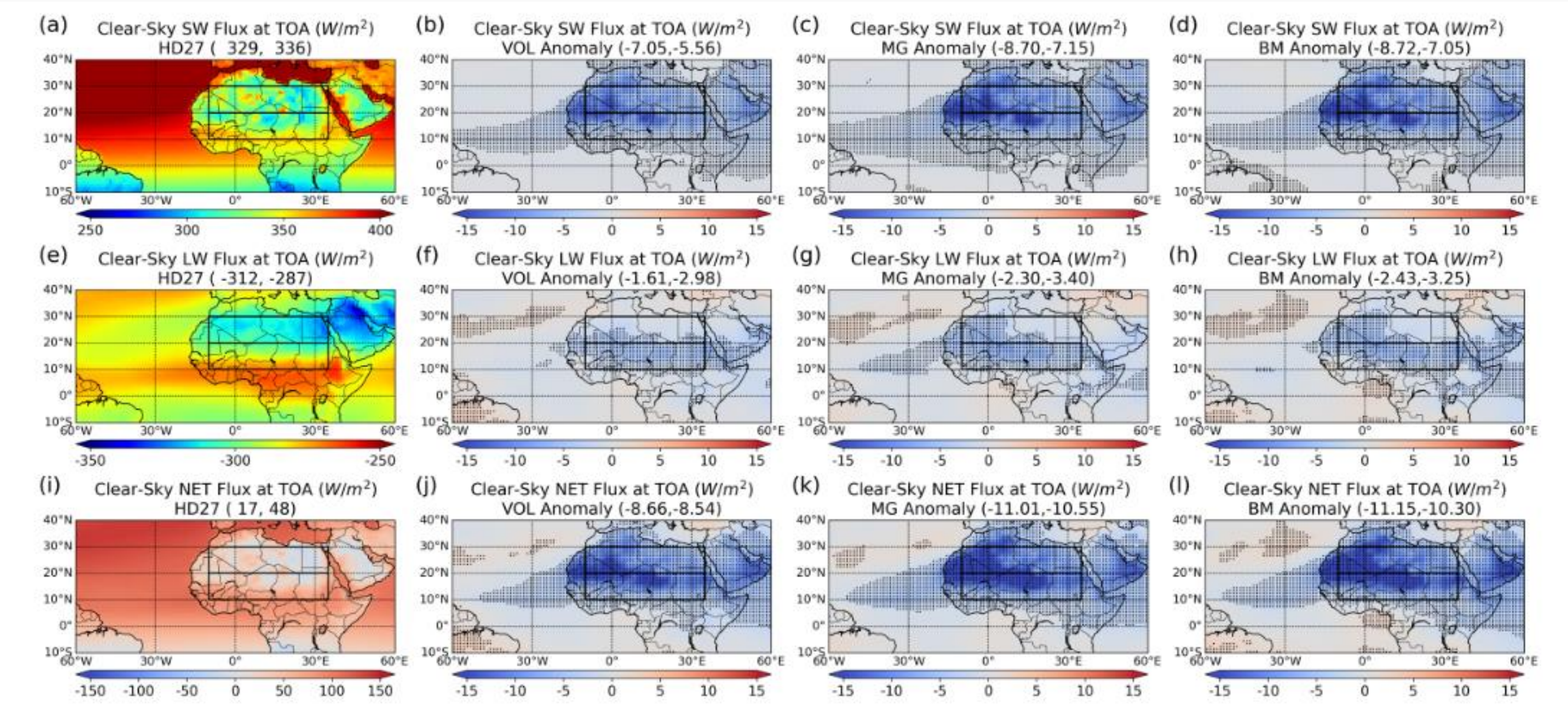


Figure 4. Seasonal mean JJA climatology (2001-2019) clear-sky SW (1st row), LW (2nd row) and Net (3rd row) radiative flux at TOA for the HD27 control run (1st column) and their anomalies resulting from resolving dust mineralogy in vol-mixing experiments (2nd column), Maxwell Garnett mixing experiments (3rd column) and Bruggeman-mixing experiments (4th column).

Song et al. (2023)

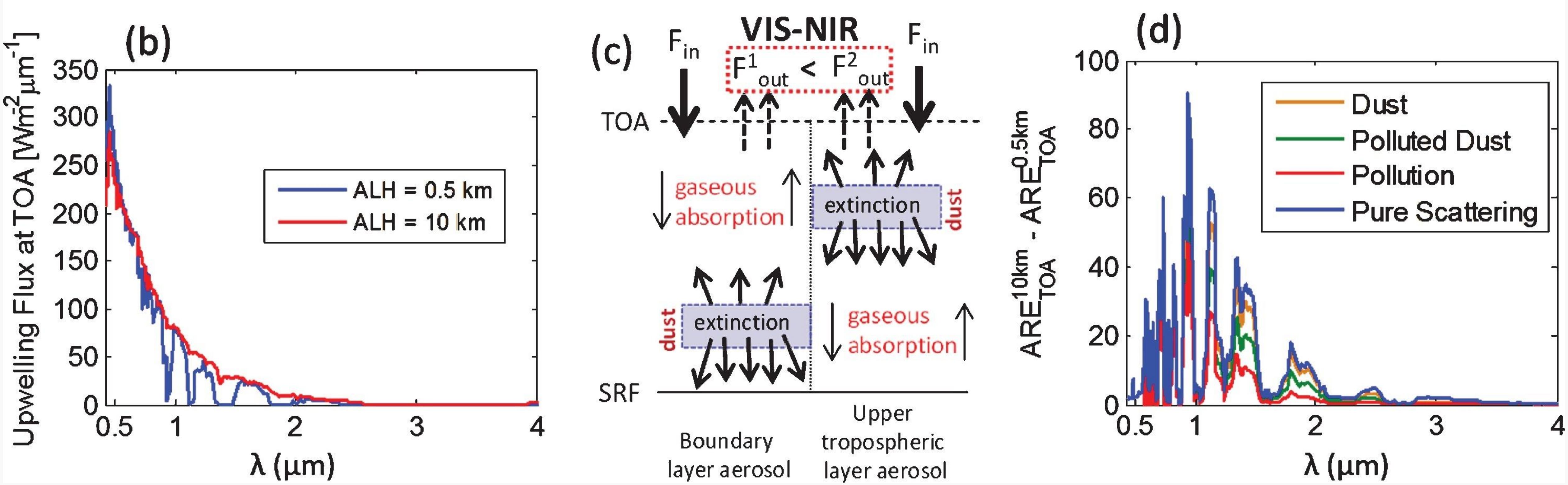
The role of aerosol layer position within the atmosphere

Antonis Gkikas[1], Ilias Fountoulakis[1], Stergios Misios[1],
Stelios Kazadzis[2], Vassilis Amiridis[3], Christos Zerefos[1,4,5,6]

1 ACADEMY OF ATHENS
2 pmod wrc
3 National Observatory Athens
4 BRFAA Biomedical Research Foundation Academy of Athens
5 Navarino Environmental Observatory
6 Mariolopoulos - Kanaginis Foundation for the Environmental Sciences

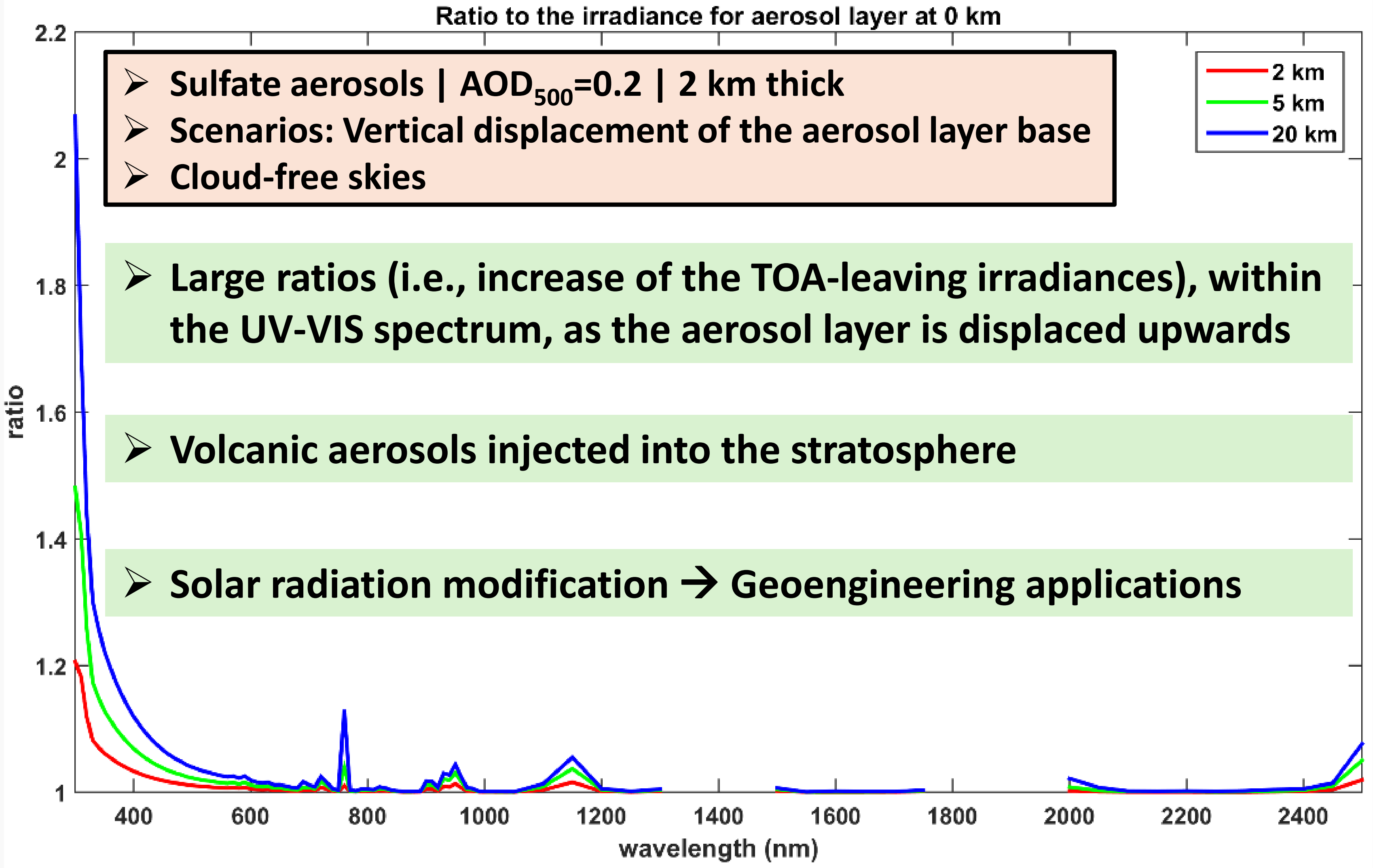
truths

Vertical displacement of a hypothetical dust layer [cloud-free skies]



Mishra et al. (2015)

Position of a hypothetical layer with sulfate particles [cloud-free skies]



- Sulfate aerosols | AOD_{500}=0.2 | 2 km thick
- Scenarios: Vertical displacement of the aerosol layer base
- Cloud-free skies

- Large ratios (i.e., increase of the TOA-leaving irradiances), within the UV-VIS spectrum, as the aerosol layer is displaced upwards

- Volcanic aerosols injected into the stratosphere

- Solar radiation modification → Geoengineering applications

Ratio of the spectral outgoing irradiance at TOA for each assumed aerosol layer wrt the “bottom” aerosol layer (z_{base}=0)

ESR^3 - TRUTHS
for Climate Workshop
27-28 June 2024 | ESA-ECSAT

esa

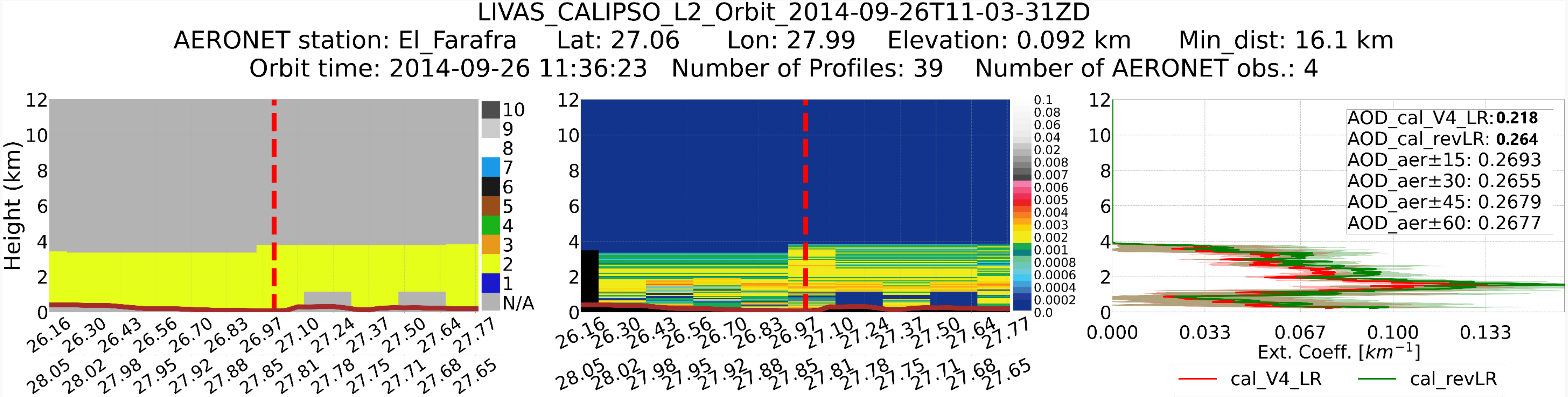
Outgoing irradiances at TOA under different aerosol regimes

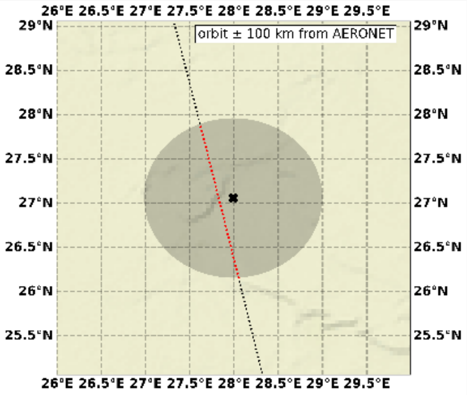
Antonis Gkikas[1], Ilias Fountoulakis[1], Stergios Misios[1],
Stelios Kazadzis[2], Vassilis Amiridis[3], Christos Zerefos[1,4,5,6]

1 ACADEMY OF ATHENS 2 pmod wrc 3 NATIONAL OBSERVATORY ATHENS 4 BRFAA BIOMEDICAL RESEARCH FOUNDATION ACADEMY OF ATHENS 5 NAVARINO ENVIRONMENTAL OBSERVATORY 6 MARIOLOPOULOS - KANAGINIS FOUNDATION FOR THE ENVIRONMENTAL SCIENCES

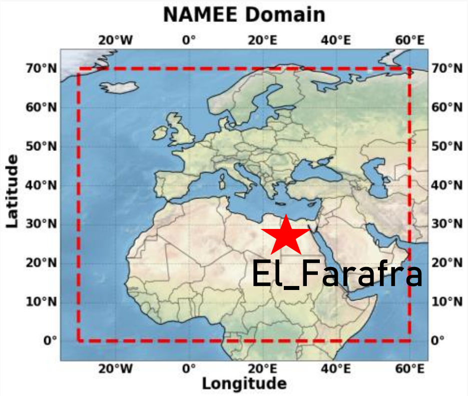
truths

Collocation of CALIPSO and AERONET observations



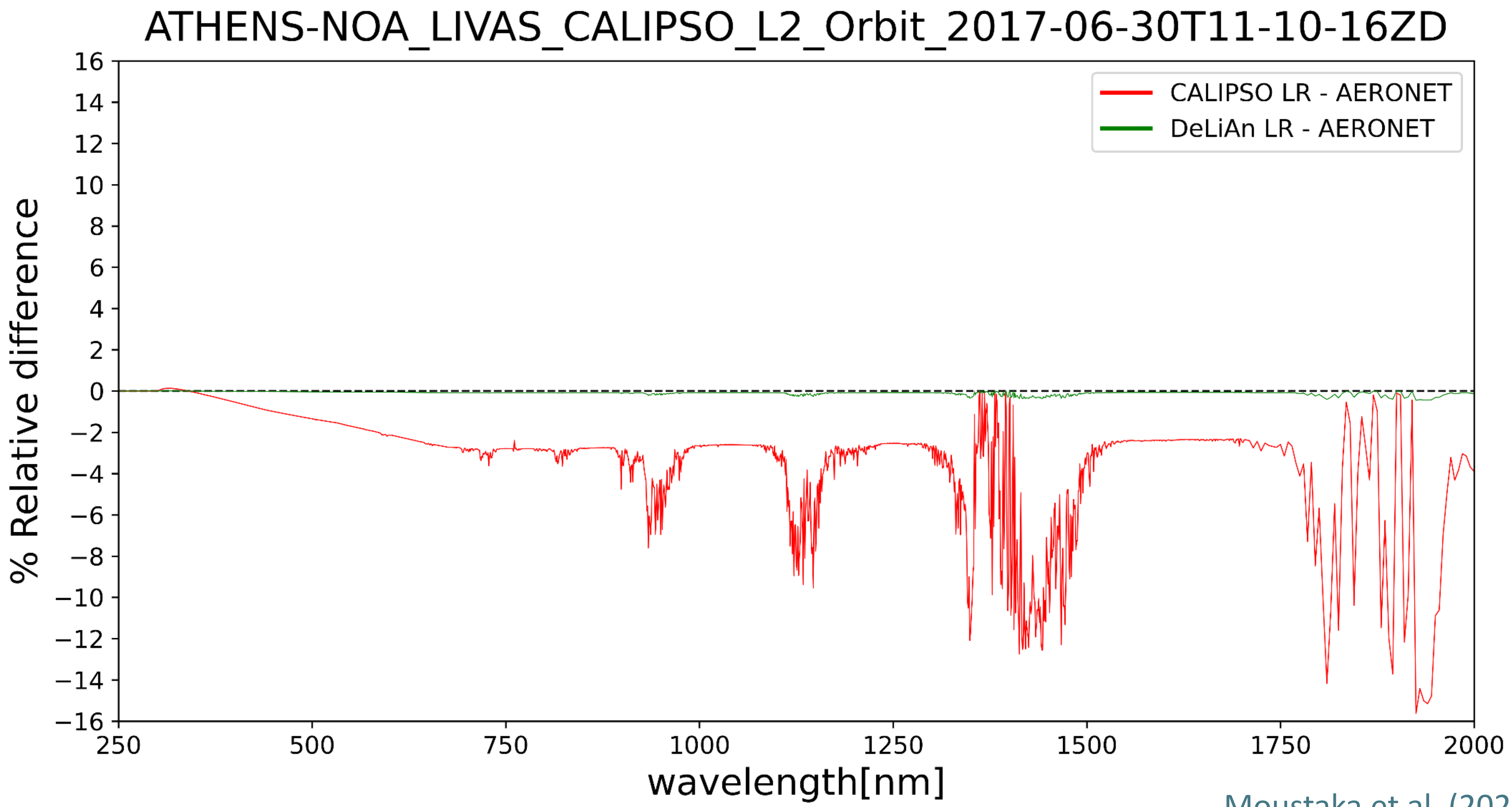


Station	AOD CALIPSO LR=44sr	AOD DeLiAn LR=53sr	AOD AERONET ±30min
El_Farafra	0.22	0.26	0.27



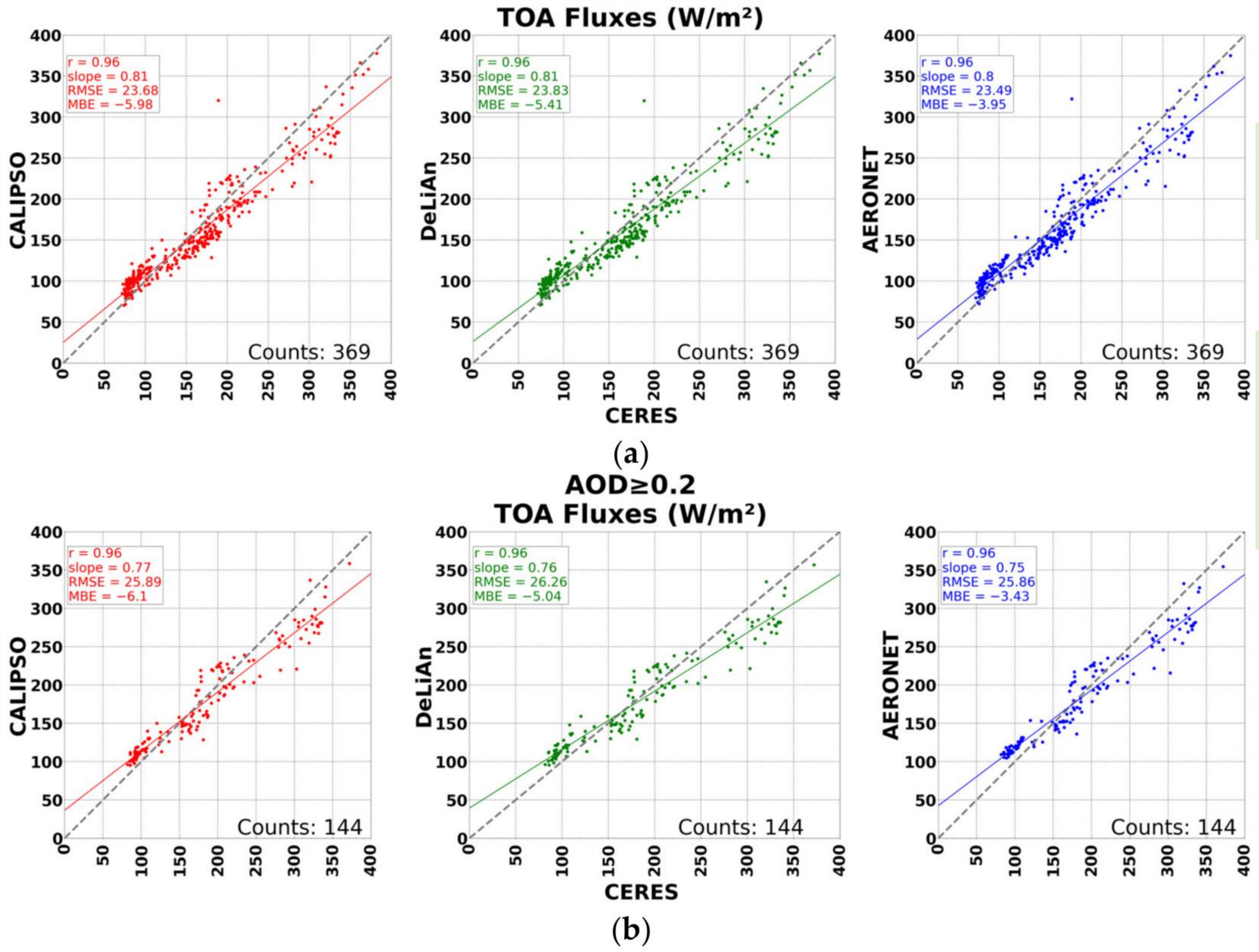
Moustaka et al. (2024)

Dust layer over Athens



Moustaka et al. (2024)

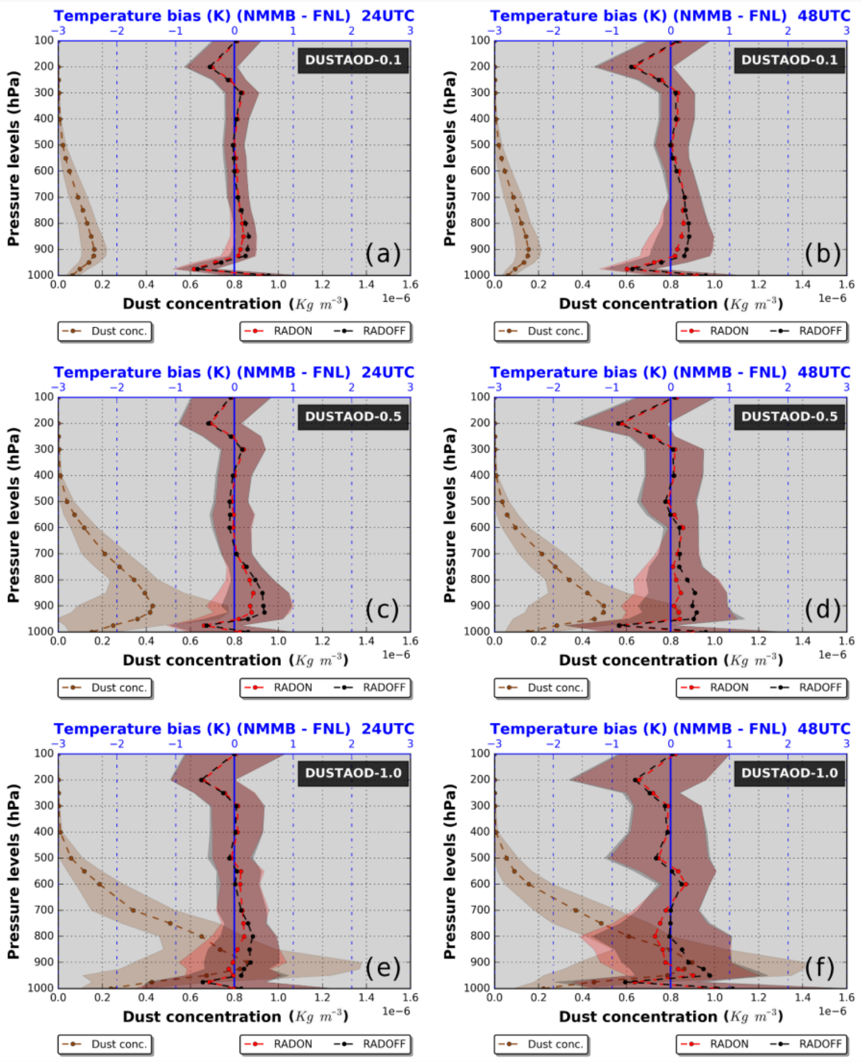
Evaluation of the simulated TOA-leaving radiation versus CERES



- **Broadband SW radiation fluxes at TOA**
- **Better representation of the outgoing SW radiation at TOA when a more realistic LR is adopted (improvement of the columnar AOD)**
- **Observations of the spectral TOA-leaving irradiances will improve the assessment analysis**

Moustaka et al. (2024)

Impacts of aerosol-radiation interactions on NWP



Gkikas et al. (2018)

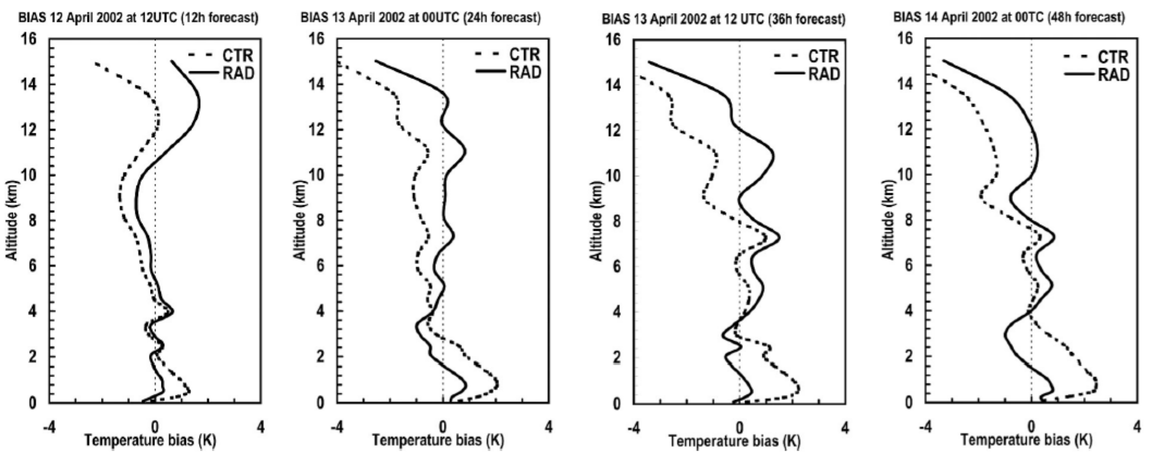
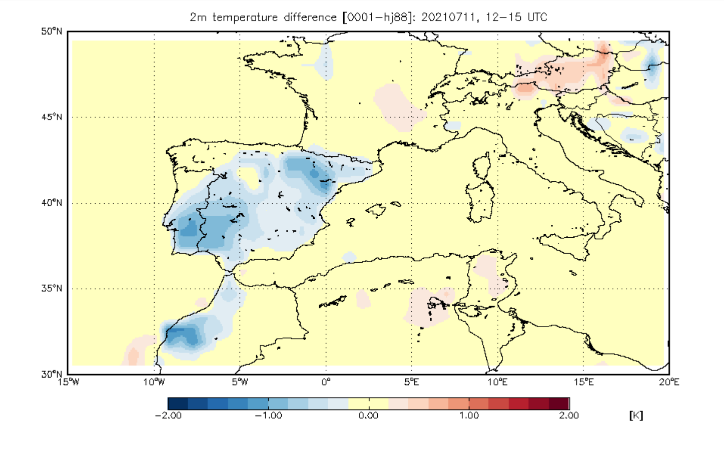
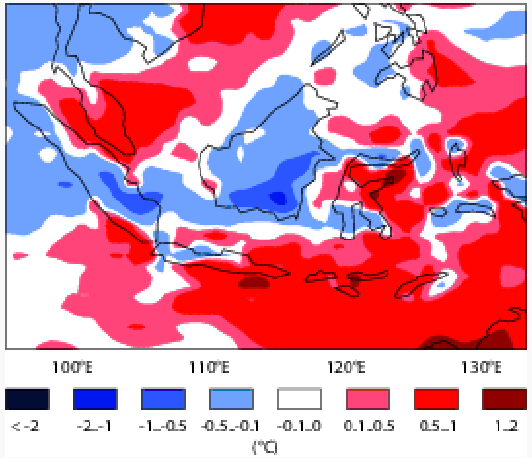


Figure 9. Atmospheric temperature bias of CTR and RAD over the main dust-affected area (comprised between latitude 30°N to 45°N and longitude 0 to 20°E) for the 12, 24, 38, and 48 hour forecasts of the 0000 UTC cycle on 12 April.

Pérez et al. (2006)





A.Benedetti
F. Vitart
F. Di Giuseppe
[ECMWF]

Aerosol-radiation interactions improve NWP at short and seasonal time scales

An accurate representation of the simulated aerosol fields plays a key role!!!

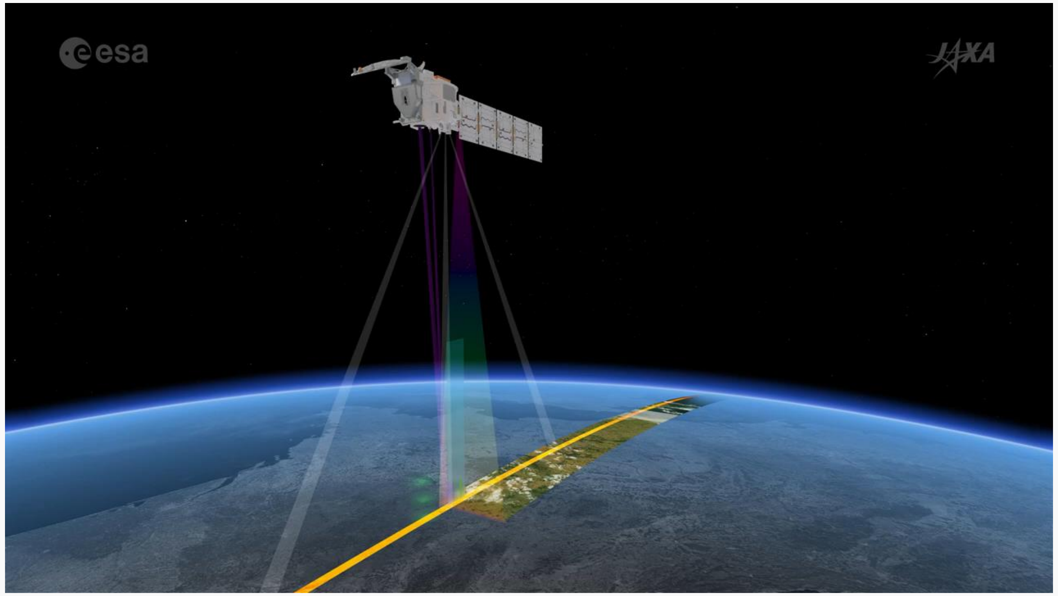
Advancing our knowledge on ARI/ACI impacts on climate

Antonis Gkikas[1], Ilias Fountoulakis[1], Stergios Misios[1],
Stelios Kazadzis[2], Vassilis Amiridis[3], Christos Zerefos[1,4,5,6]

1 ACADEMY OF ATHENS 2 pmod wrc 3 NATIONAL OBSERVATORY ATHENS 4 BRFAA BIOMEDICAL RESEARCH FOUNDATION ACADEMY OF ATHENS 5 NAVARINO ENVIRONMENTAL OBSERVATORY 6 MARIOLOPOULOS - KANAGINIS FOUNDATION FOR THE ENVIRONMENTAL SCIENCES

truths

Earth Cloud Aerosol and Radiation Explorer [EarthCARE]



THE EUROPEAN SPACE AGENCY

esa

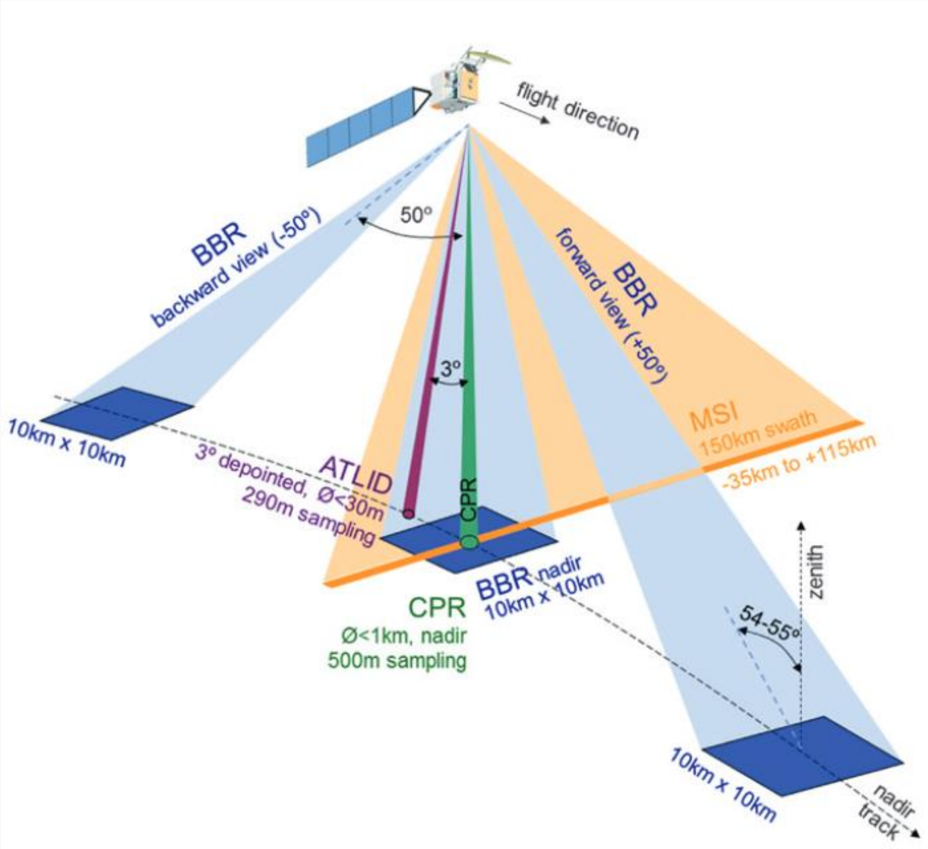
APPLICATIONS

EarthCARE launched to study role of clouds and aerosols in Earth's climate

29/05/2024 7926 VIEWS 66 LIKES

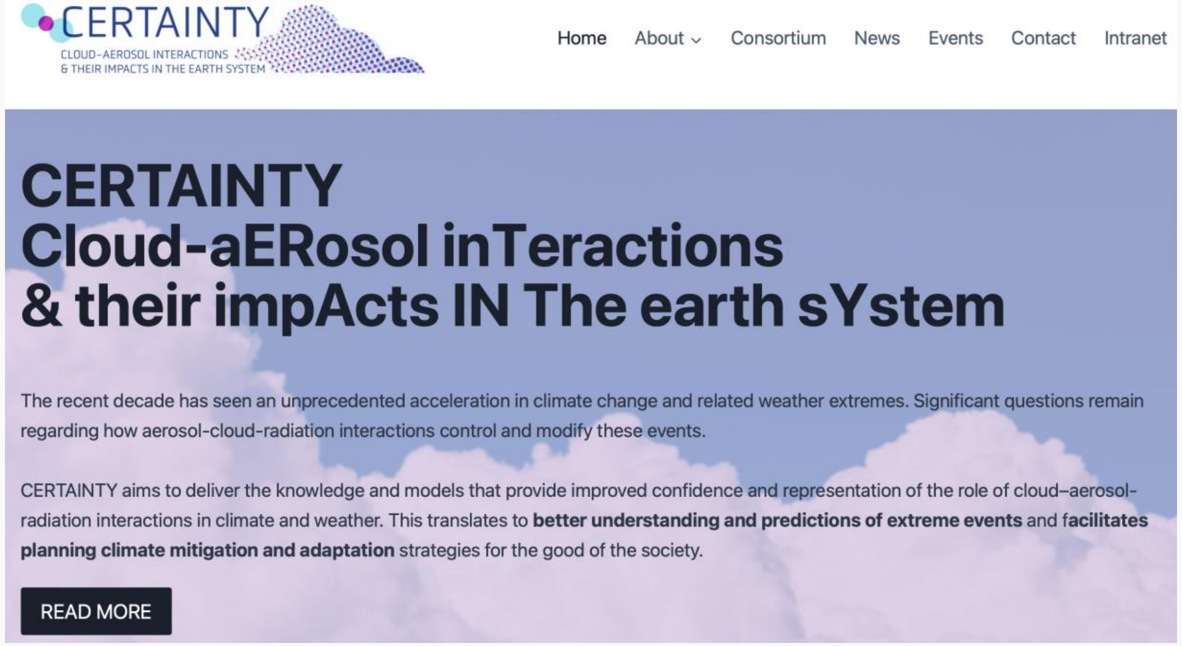
ESA / Applications / Observing the Earth / FutureEO / EarthCARE

ESA's EarthCARE satellite, poised to revolutionise our understanding of how clouds and aerosols affect our climate, has been launched. This extraordinary satellite embarked on its journey into space on 29 May at 00:20 CEST (28 May, 15:20 local time) aboard a Falcon 9 rocket from the Vandenberg Space Force Base in California, US.

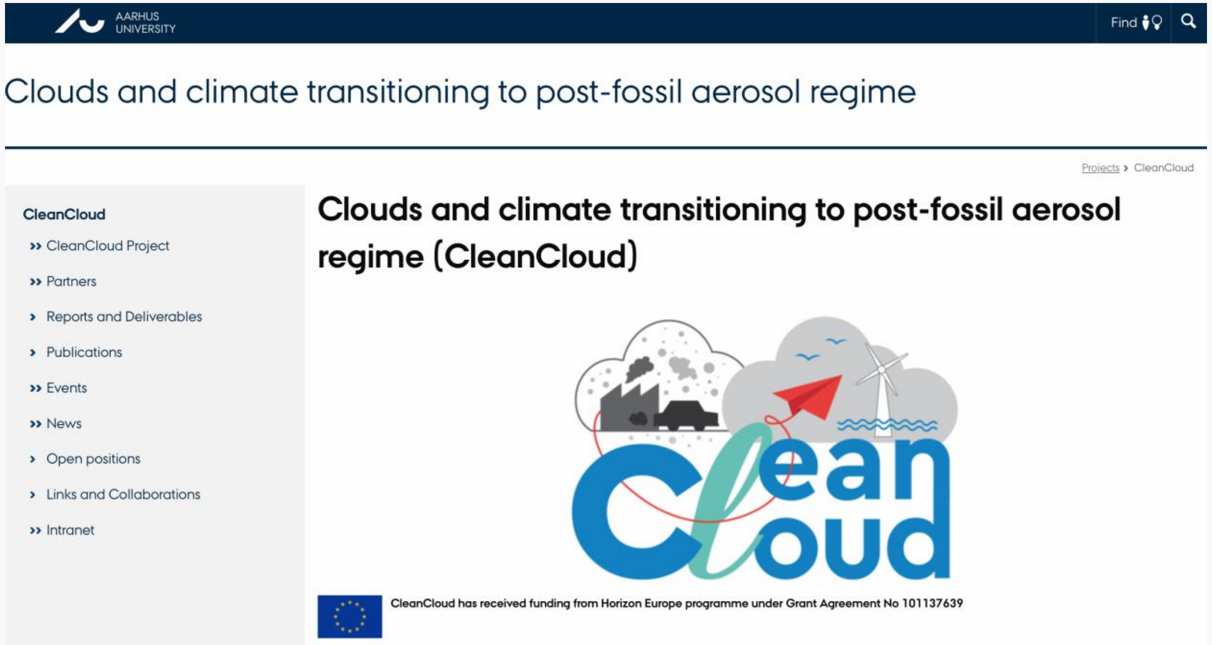


Illingworth et al. (2015)

Advancing our understanding on ARI/ACI impacts on climate



Jennie Thomas, Project Coordinator at the French National Centre for Scientific Research and also coordinator for the EC-funded CERTAINTY project, added, “We combine modelling and observation expertise to understand cloud–aerosol processes and their links to global climate and society. We have a world-leading team of European experts to address this urgent science need.”

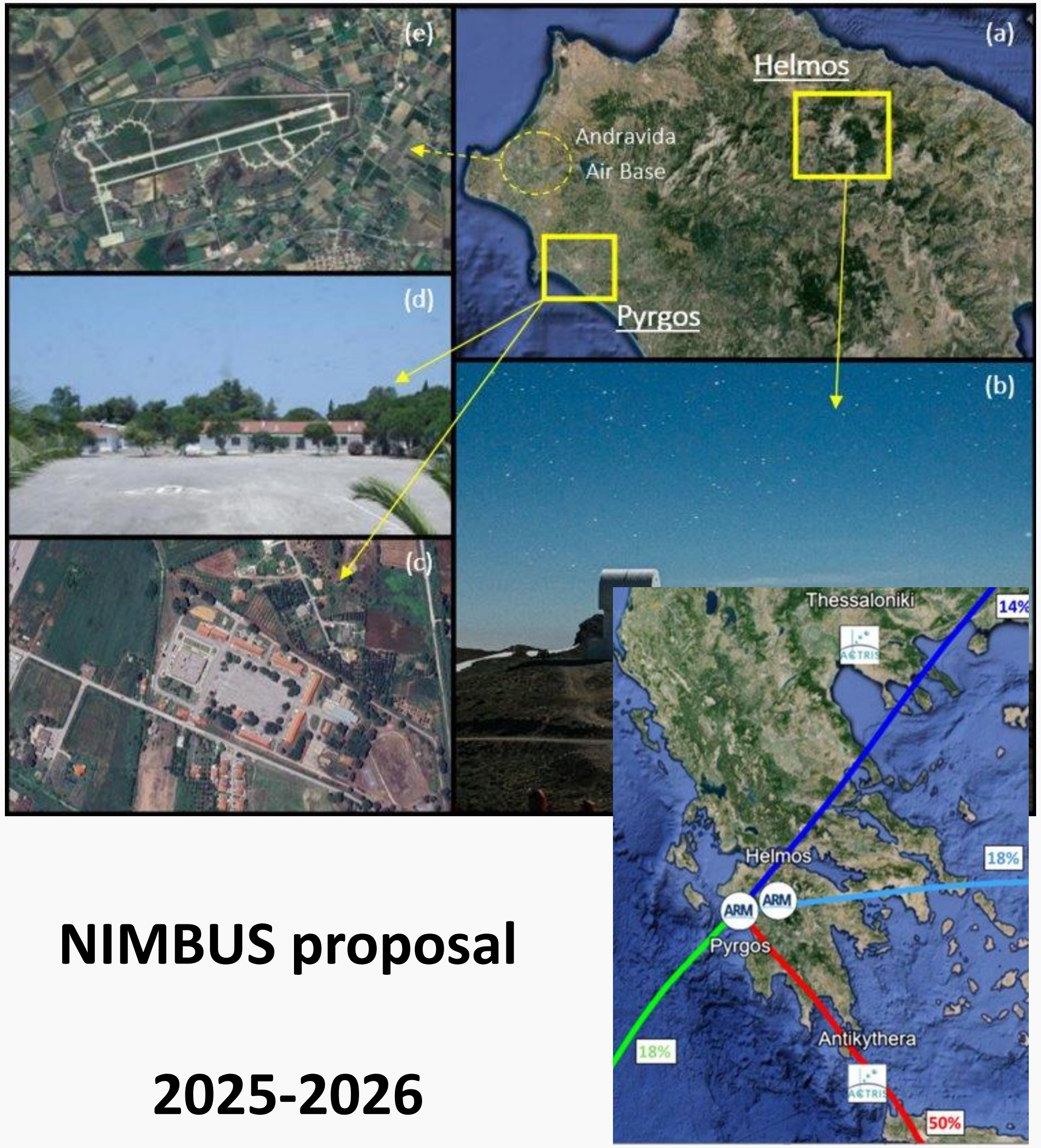


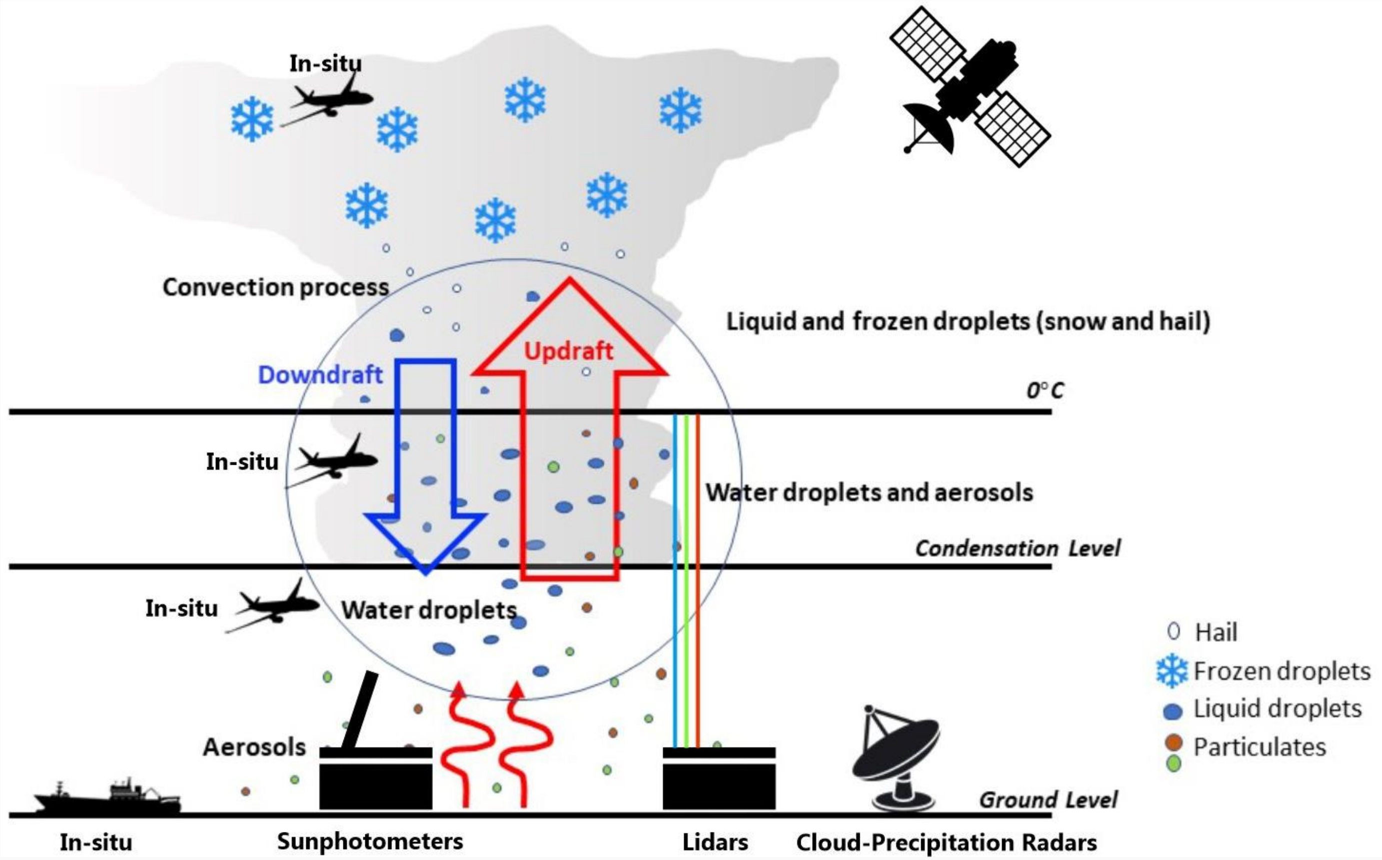
Athanasios Nenes, Professor at the Swiss Federal Institute of Technology Lausanne and and Ulas Im, Senior Scientist at Aarhus University in Denmark, both of whom are coordinators of the EC CleanCloud project, noted, “There are large uncertainties associated with our current understanding of the Earth system and its response to human actions. We need to close these knowledge gaps to be able to predict to what extent the Paris Agreement can be met and what changes lie ahead.”

European Commission

esa

Experimental campaigns - ACROSS





NIMBUS proposal

2025-2026

ARM
CLIMATE RESEARCH FACILITY

PI: Dr. Vassilis Amiridis [NOA]

TRUTHS climate mission: Scientific aspects

Assessment of atmospheric parameters affecting HIS-CSAR, SW measured radiative balance through RTM

Use of HIS to retrieve atmospheric parameters or prepare satellite based collocated atmospheric retrievals for Earth-Atmosphere radiative balance fluctuation assessment

Determination of other satellite retrievals and their improvement, based on absolute radiometry - comparison with (low uncertainty) TRUTHS radiance products. Studies for possible synergistic satellite products.

TRUTHS absolute radiance radiometry could improve other satellite-based radiance products through intercalibration. Which are those and what are the improvement limits?

Atmospheric closure studies vs ground based solar measurements

RT modeling evaluation based on calculated bottom and TOA radiation

Determination of TOA in the full SW spectrum for HIS (300-3000nm)

RT Modeling including WV inputs from HIS own retrievals for 2400 to 3000nm range

pmod wrc

TRUTHS climate mission: Needs and expectations

- Aerosol optical, microphysical and macrophysical properties are determinant factors for the TOA radiation fields
- External factors such as the surface albedo also plays a critical role
- TRUTHS' state-of-the-art measurements will serve as reference towards constraining aerosol-related uncertainties in RTM and numerical simulations
- Synergies with ground-based radiation measurements will further enhance the mitigation of aerosol-related uncertainties in RTM simulations
- Radiative closure studies deploying 1D/3D RTM simulations will shed light on ARI and ACI
- Determination of other satellite retrievals and their improvement, based on absolute radiometry - comparison with (low uncertainty) TRUTHS radiance products → improvement of atmospheric constituents monitoring
- Upgrade the predictability of regional and global models from short- to long-range temporal scales
- 'Gold standard' reference for climate measurements → climate monitoring → climate mitigation/adaptation

Exploiting TRUTHS state-of-the-art radiation measurements towards constraining aerosol-related uncertainties in radiation transfer modelling

This work has been supported by the action titled “Support for upgrading the operation of the National Network for Climate Change (CLIMPACT II)”, funded by the Public Investment Program of Greece, General Secretary of Research and Technology/Ministry of Development and Investments