Introduction to EarthCARE

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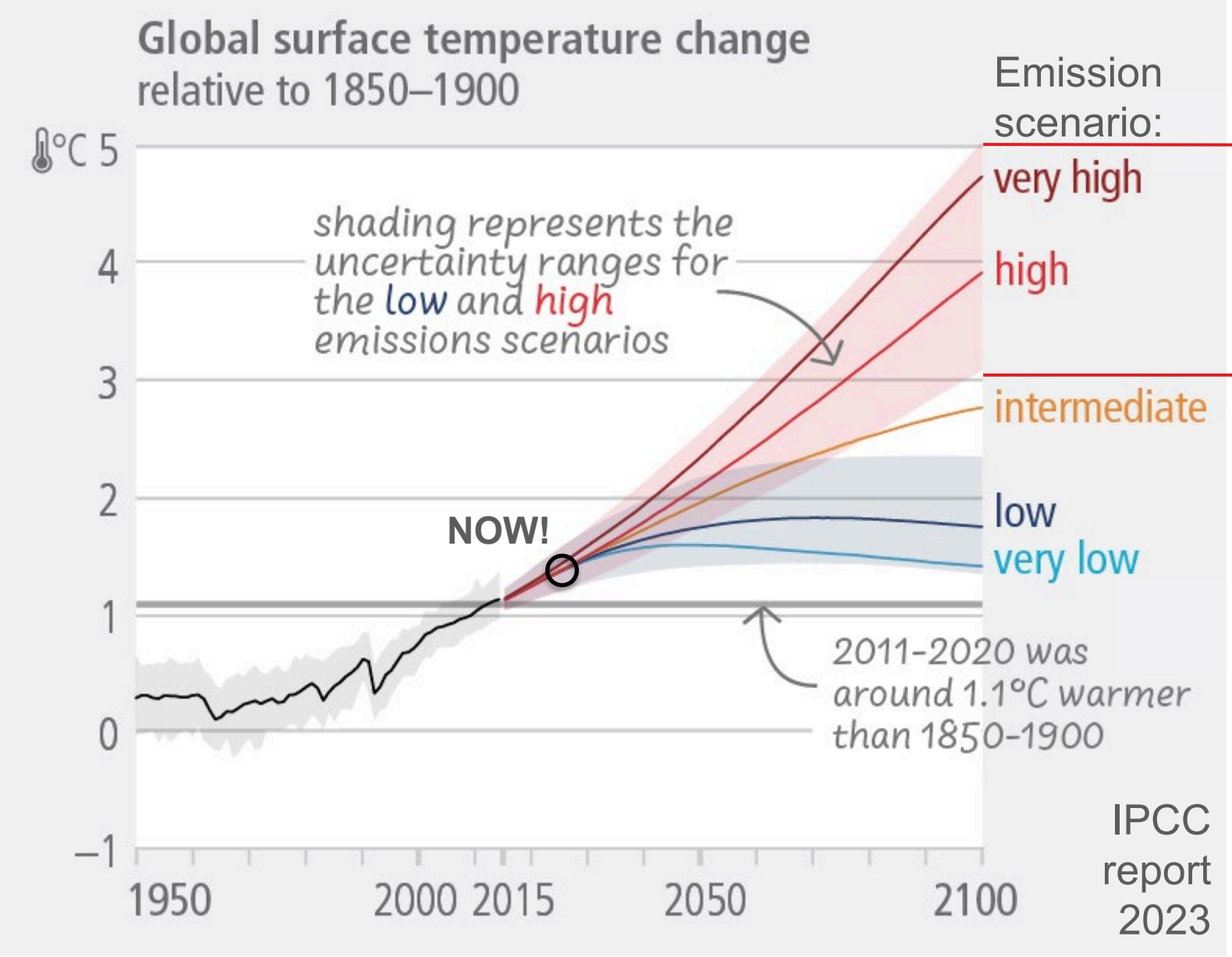
Thanks to
Shannon Mason, Mark Fielding, Peter Hill (ECMWF)
Jason Cole, Zhipeng Qu, Howard Barker (ECCC), Pavlos Kollias,
Bernat Puigdomenech-Tresseras (McGill), David Donovan,
Gerd-Jan van Zadelhoff (KNMI), Almudena Velazquez,
Nicolas Clerbaux (RMIB), Anthony Illingworth (UoR)

How much will the climate change this century?



+5ºC if clouds amplify the warming, a *positive cloud feedback*

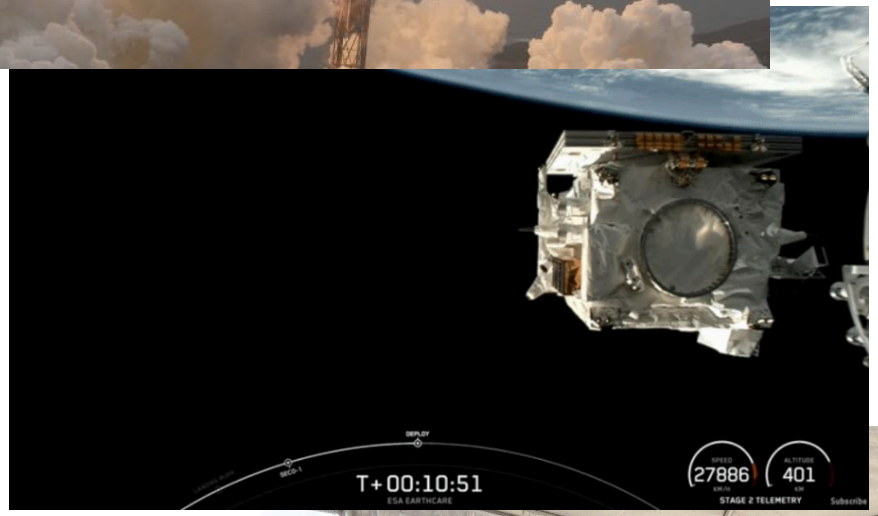
+3ºC if clouds stay about the same

Enter EarthCARE

- The “Earth Cloud, Aerosol & Radiation Explorer”
- EarthCARE’s mission is to improve understanding of clouds, aerosols, precipitation & radiation, and their representation in climate and weather models

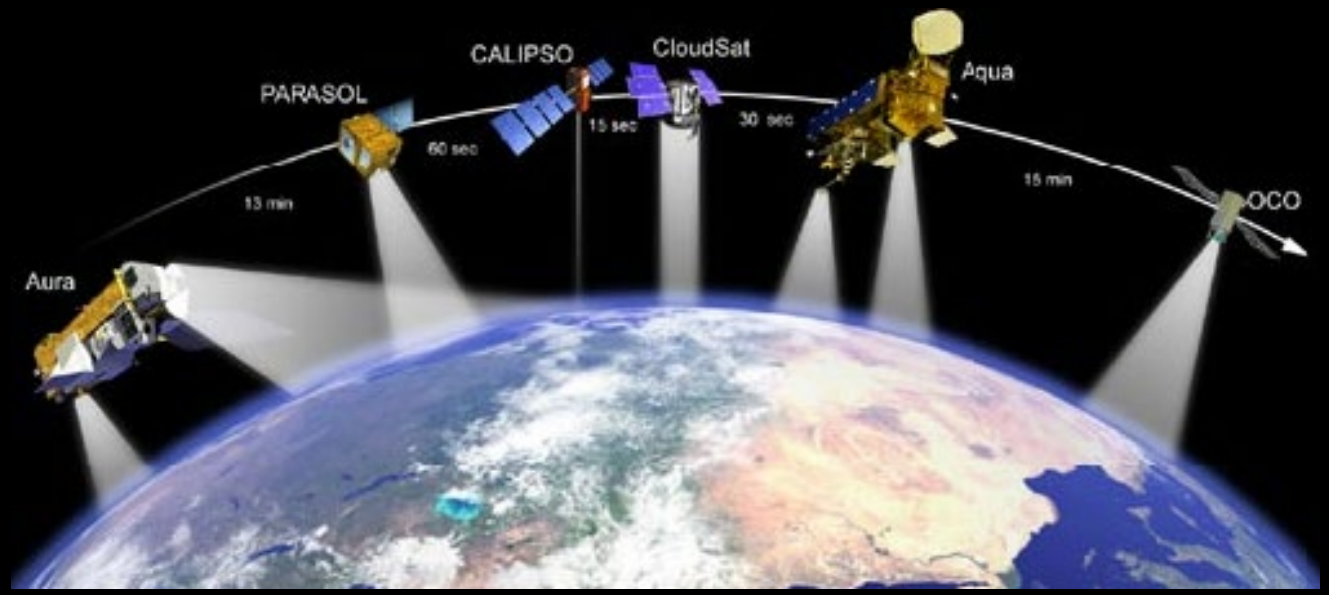
A brief history of EarthCARE

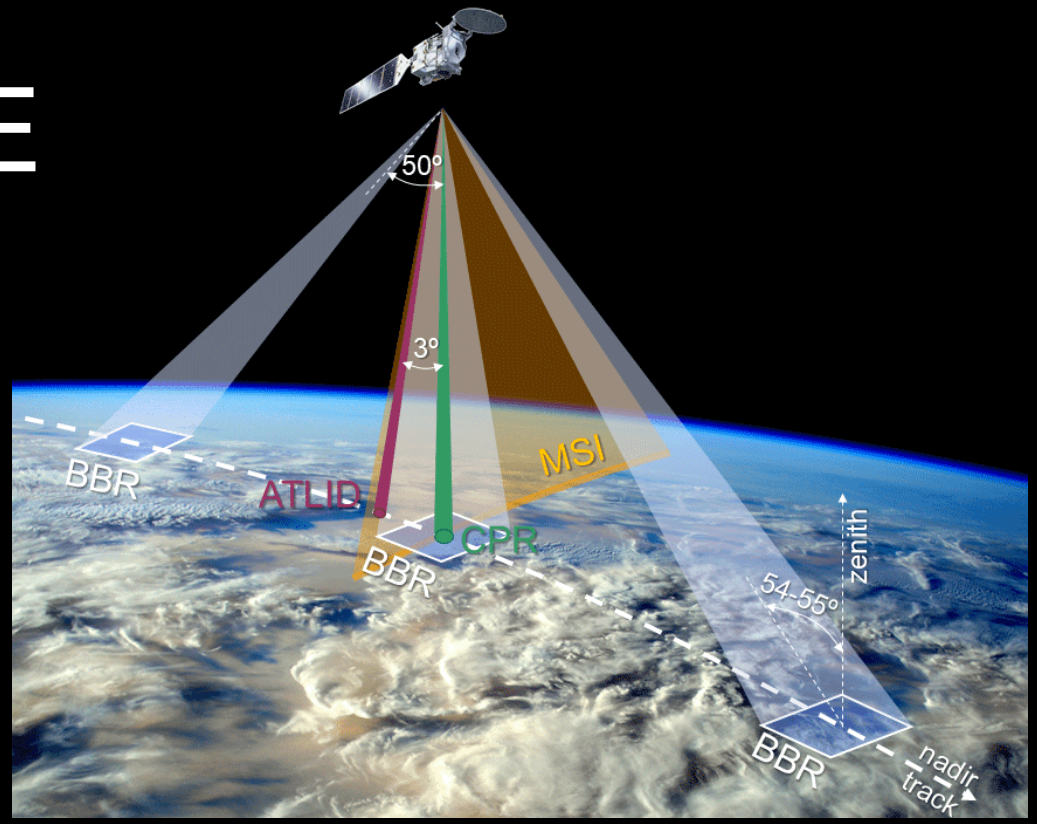
- 1987: Cloud radar in space made possible by Lhermitte building the first 94-GHz cloud radar
- 1994: “LITE”, first cloud/aerosol lidar in space
- 1996, 1999, 2001: “Earth Radiation Mission” (later EarthCARE) concept proposed to ESA by Anthony Illingworth and team
- 2002: Anthony co-chairs the EarthCARE Joint Mission Advisory Group… for the next 21 years
- 2004: EarthCARE selected!
- 2006: launch of CloudSat & CALIPSO
- *Problem solving: laser-induced contamination, radar shorting, Russian launcher unavailability, earthquake…*
- **28 May 2024: Launch from Vandenberg, California!**
- January 2025: First public data release



ECMWF

A-Train versus EarthCARE



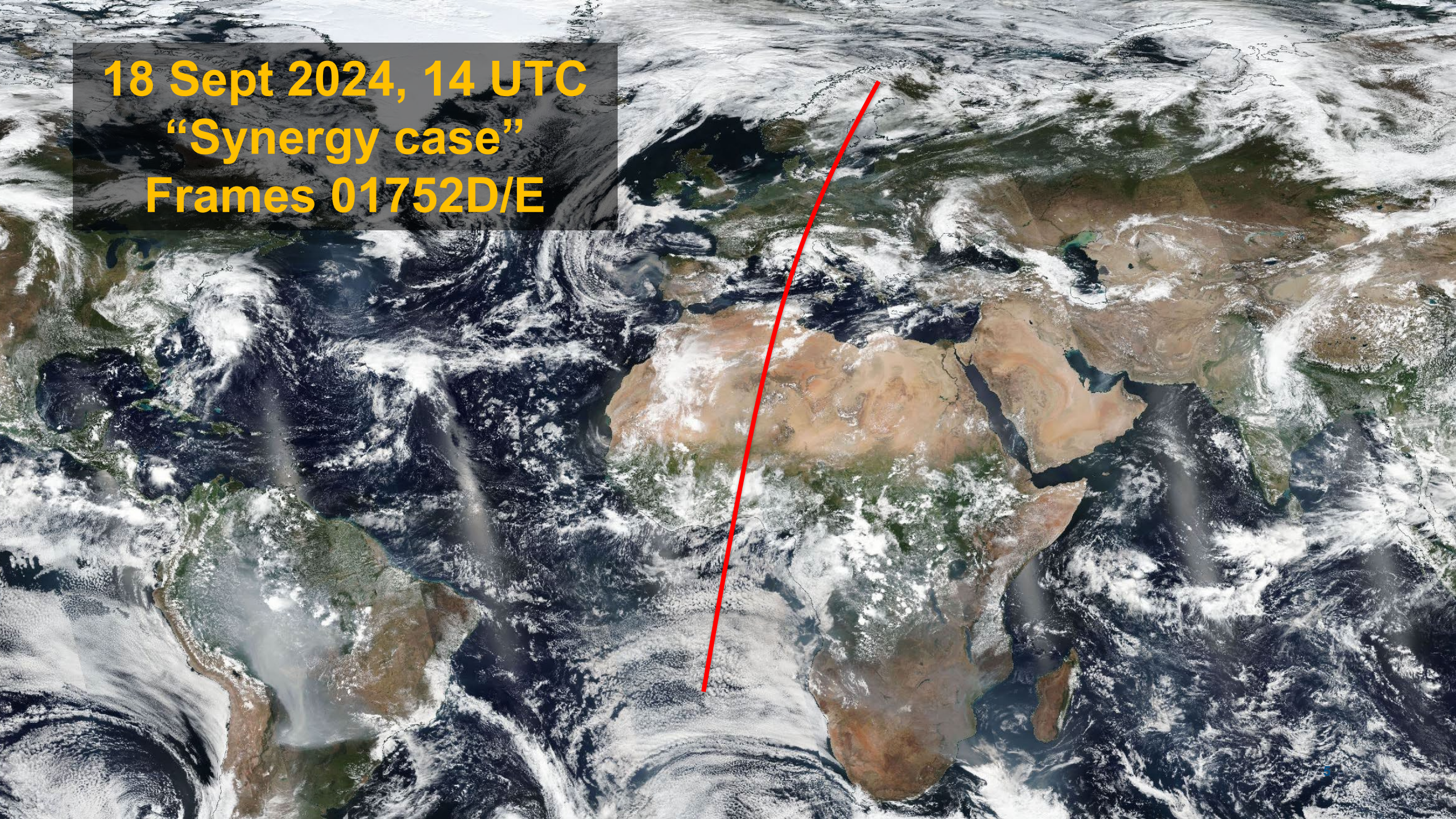


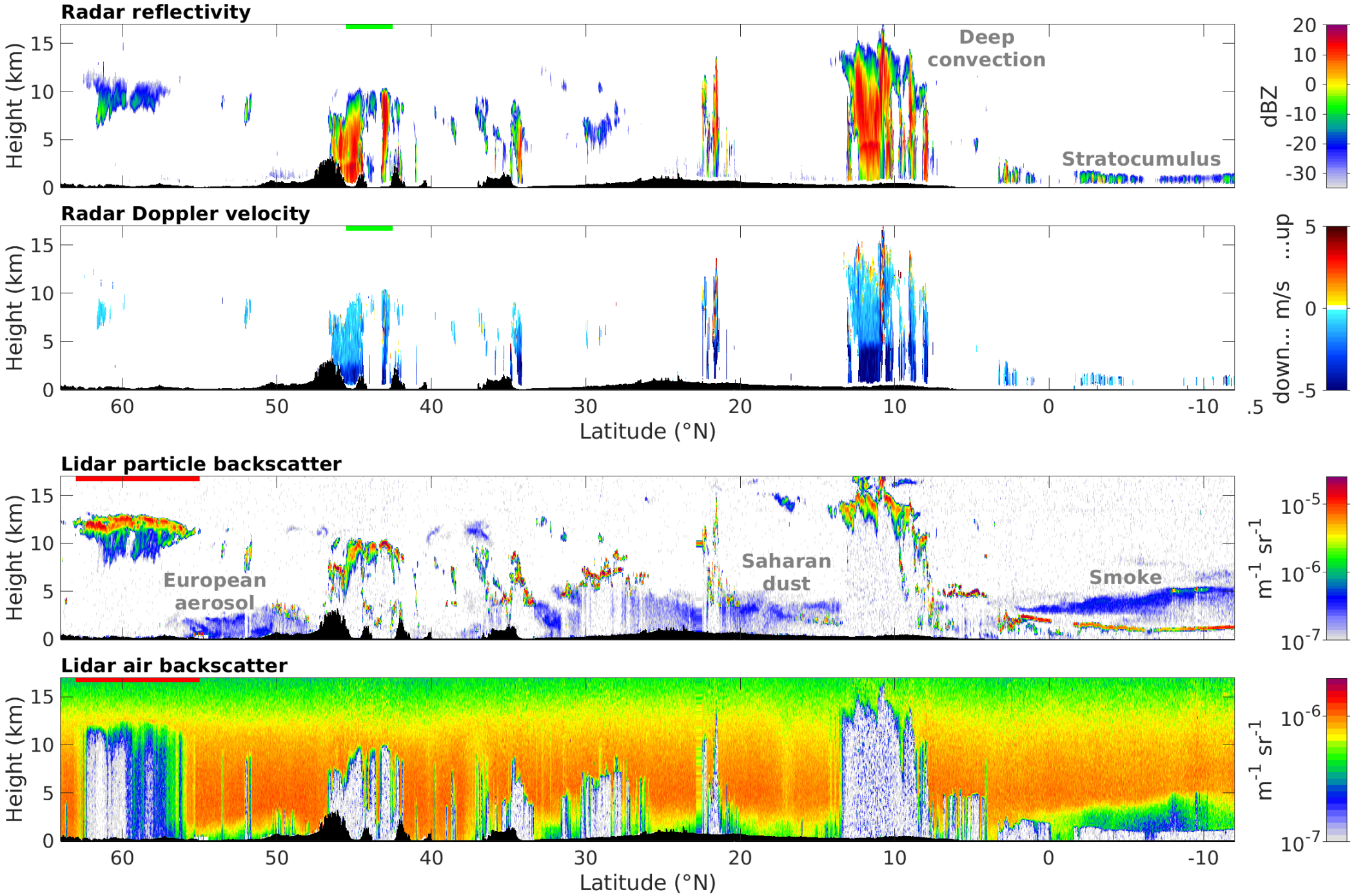
The A-Train (fully launched 2006)

- NASA
- Multiple platforms
- 700-km orbit
- CloudSat 94-GHz radar
- CALIPSO 532/1064-nm lidar
- MODIS multi-wavelength radiometer
- CERES broad-band radiometer

EarthCARE (launched May 2024)

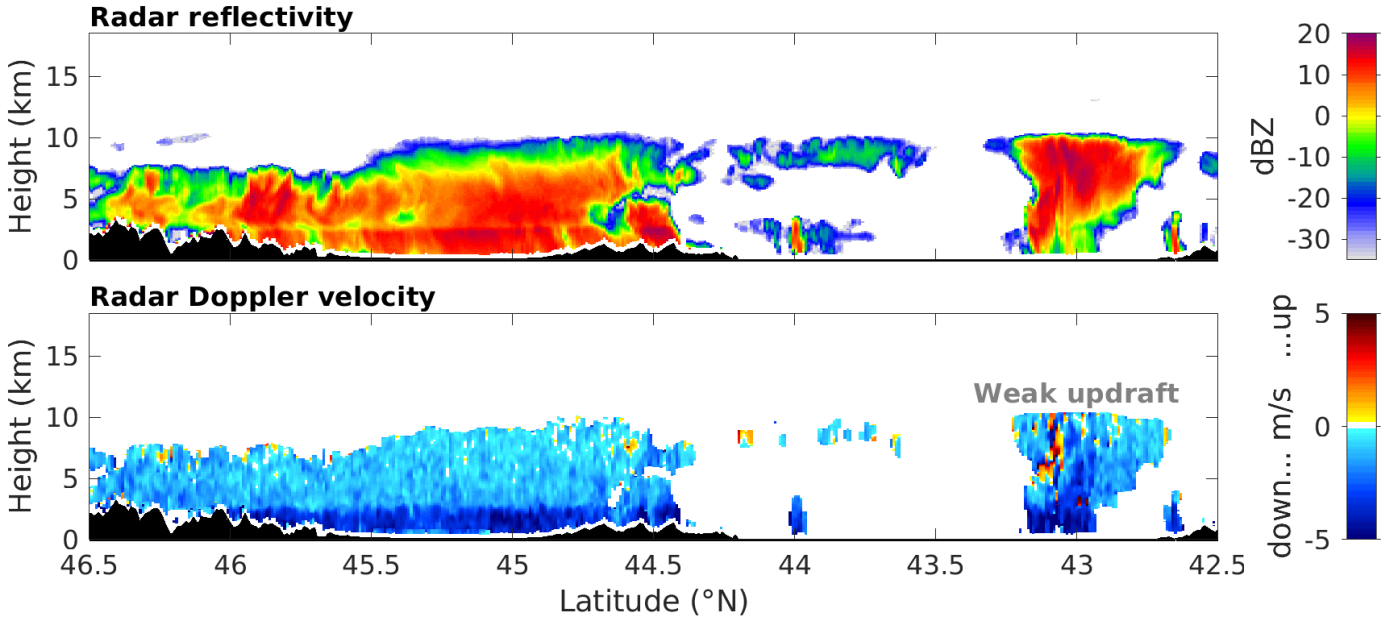
- ESA and JAXA
- **Single platform**
- 393-km: **higher radar sensitivity**
- 94-GHz **Doppler** cloud profiling radar (CPR)
- 355-nm **high spectral resolution lidar** (ATLID)
- Multi-spectral imager (MSI)
- **3-view** broad-band radiometer (BBR)


18 Sept 2024, 14 UTC
“Synergy case”
Frames 01752D/E

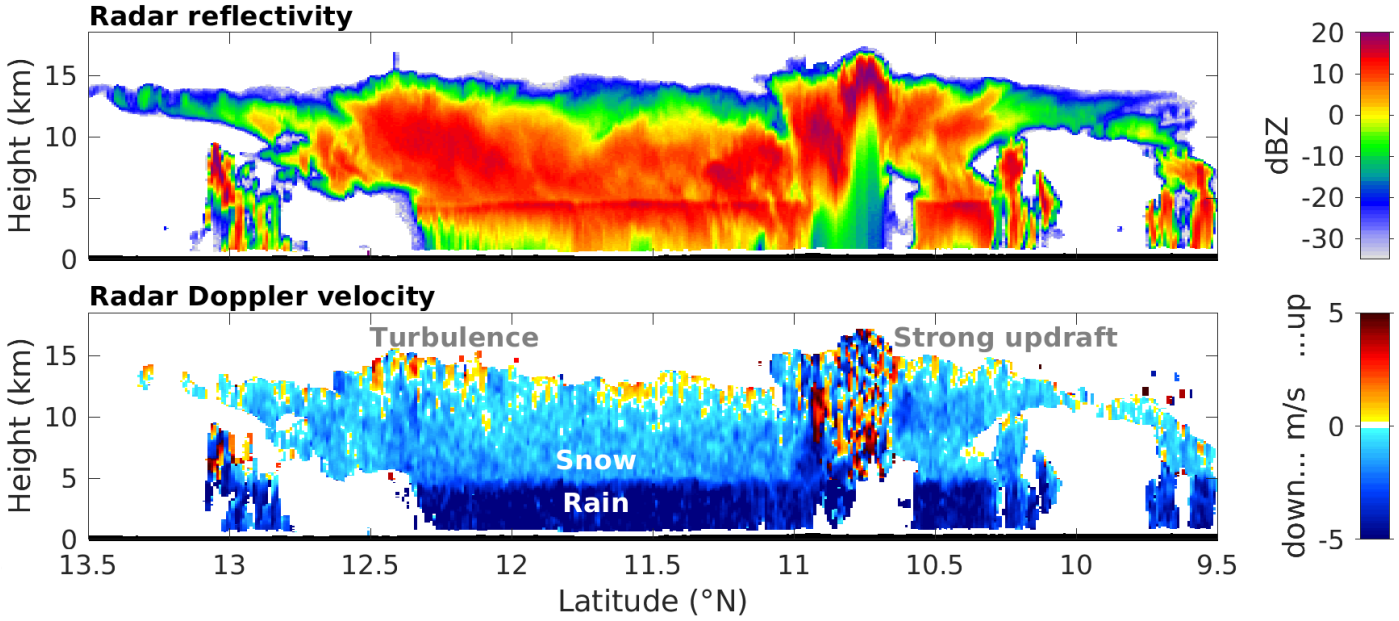

Radar reflectivity
Height (km)
Deep convection
Stratocumulus
dBZ
Radar Doppler velocity
down... m/s ...up
Lidar particle backscatter
European aerosol
Saharan dust
Smoke
m-1 sr-1
Lidar air backscatter
Latitude (°N)

New: Doppler velocity

- Nimbostratus between the Alps (left) and Corsica (right)
  - In stratiform clouds we measure rain and snow fall speeds
  - Infer raindrop mean diameter and snow rimed fraction, as well as rain/snow rates
  - Strength and width of modest updrafts can be characterized (folding velocity 5-6 m/s)



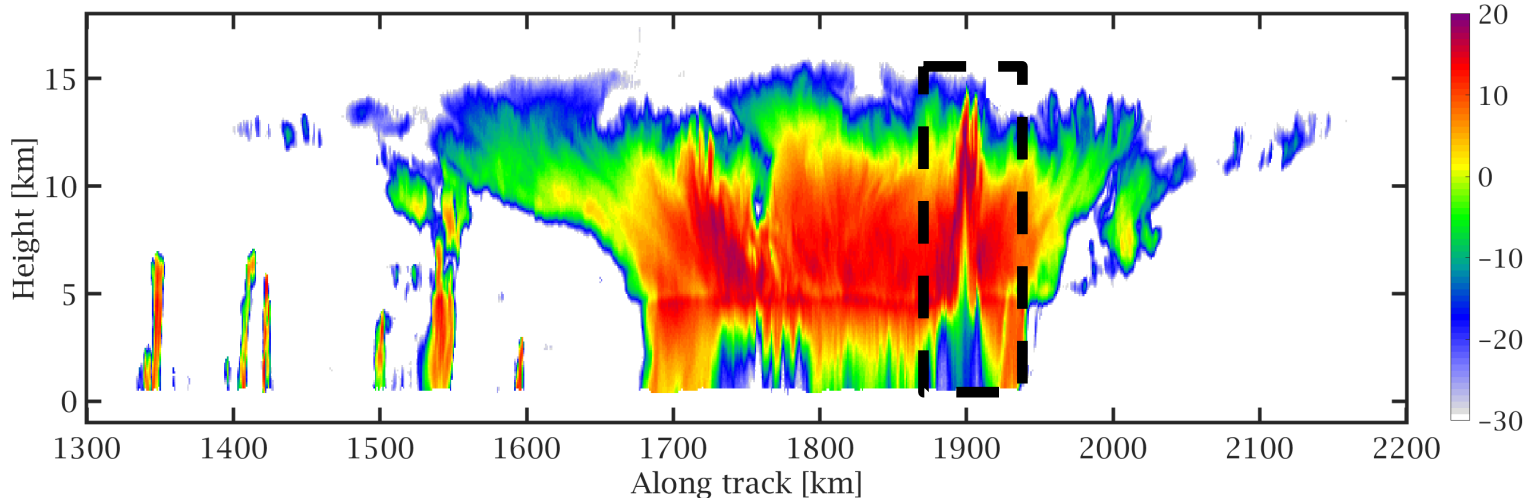
- Deep convection over Benin
  - Multiple foldings of velocity
  - Strong multiple scattering near cloud top
  - Cloud-top turbulence/convection

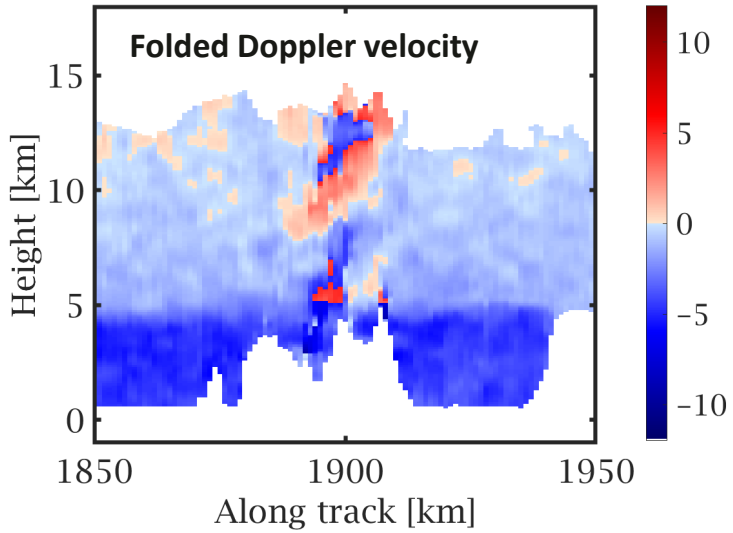


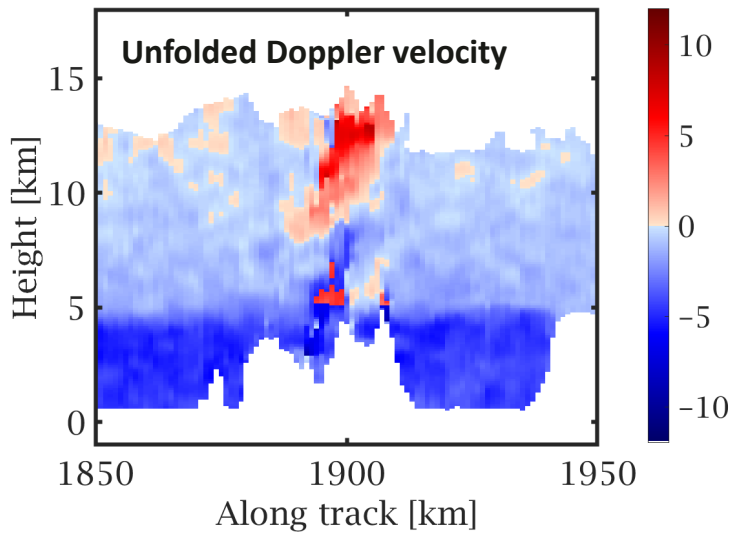
ECMWF

Convective updraft strength & width: unfolding

Pavlos Kollias, Bernat Puigdomenech-Treseras (McGill)





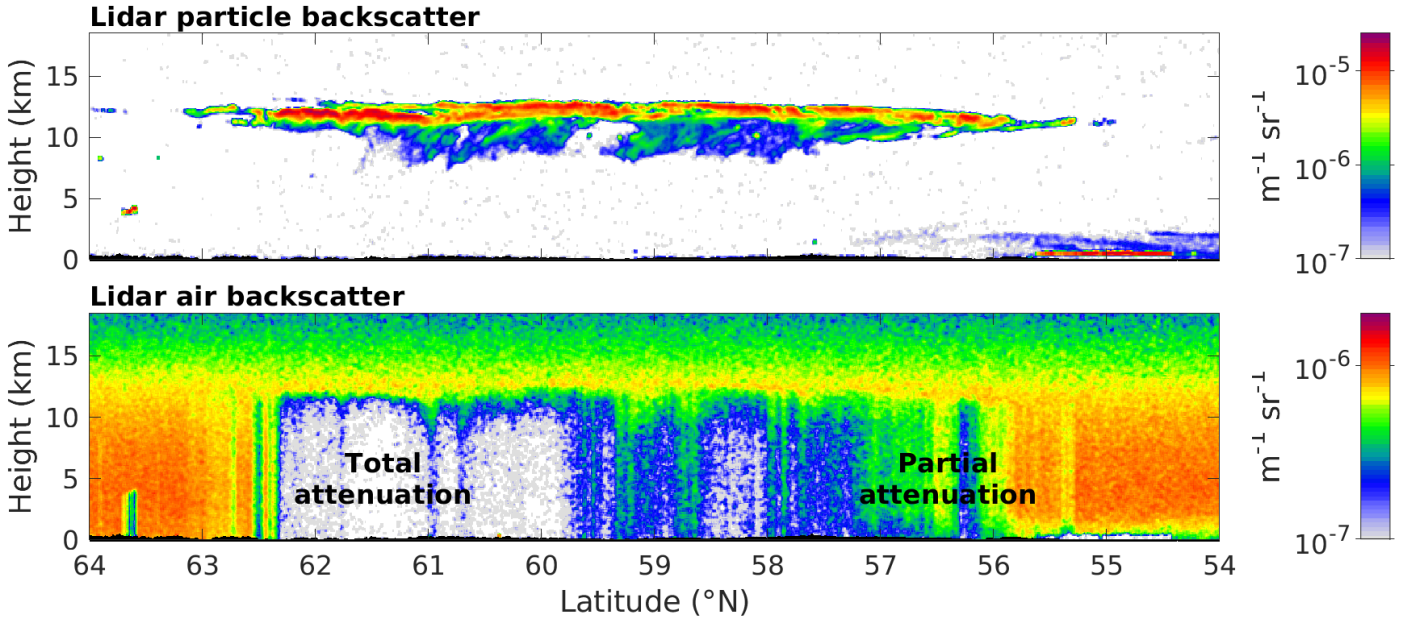


- Unambiguous Doppler range is only +/- 5 m/s, but convective updrafts can be up to 50 m/s!
- Very tricky to “unfold” due to noise and strong updrafts tend to be associated with strong multiple-scattering
- *Need a strategy to evaluate the strength and width of updrafts in models that can deal with these difficulties*
- Masaki Satoh & Robin Hogan are organising “ECOMIP”, the EarthCARE-ORCESTRA Model Intercomparison Project

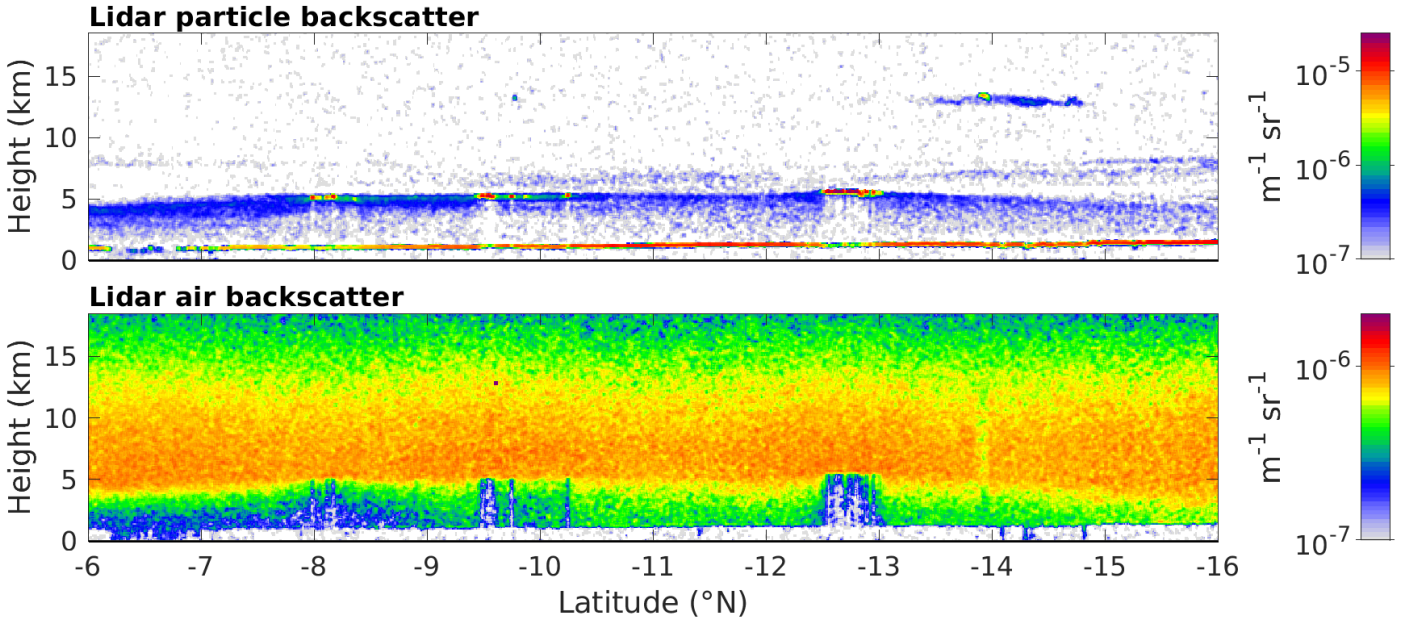
ECMWF

New: high spectral resolution lidar

- Cirrus over Sweden
  - HSRL separates backscatter due to particles (“Mie”) and air (“Rayleigh”)
  - Attenuation of air gives unambiguous estimate of profile of particle extinction coefficient, most important radiative property of clouds or aerosols



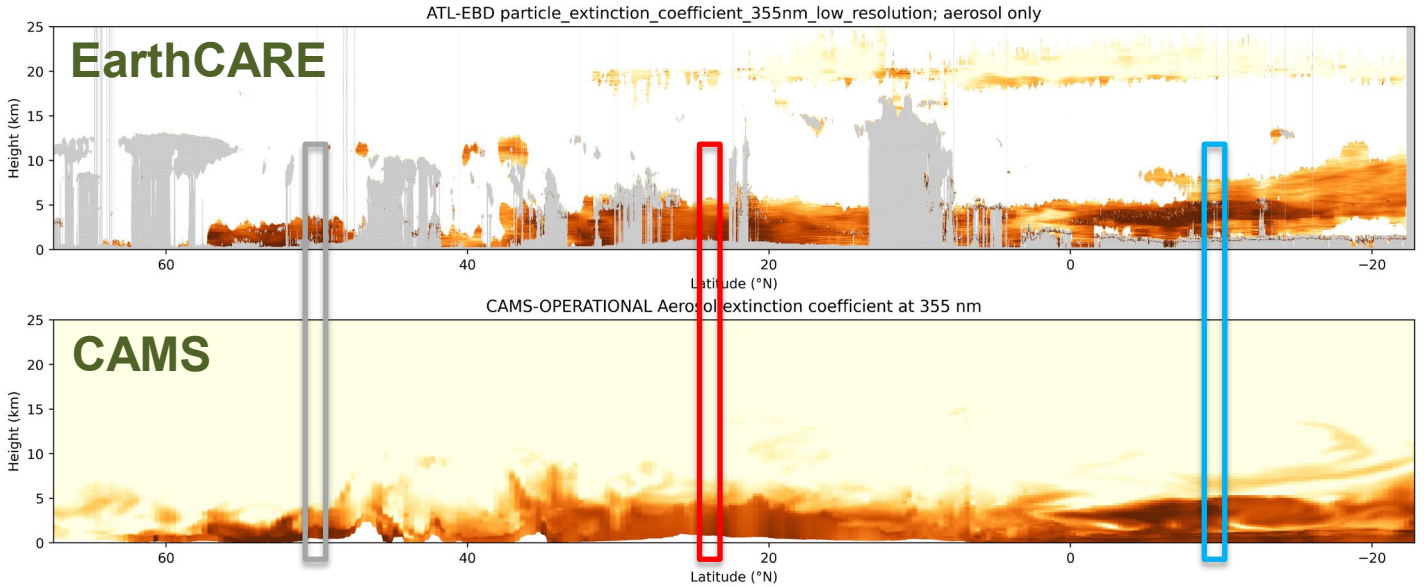
- Smoke over stratocumulus, Gulf of Guinea
  - In this case we can estimate the optical depth of the smoke above the cloud, not possible with passive measurements such as MODIS or AERONET

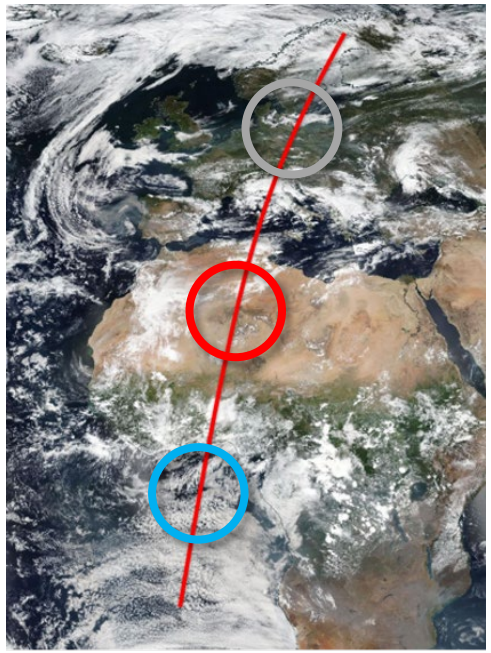


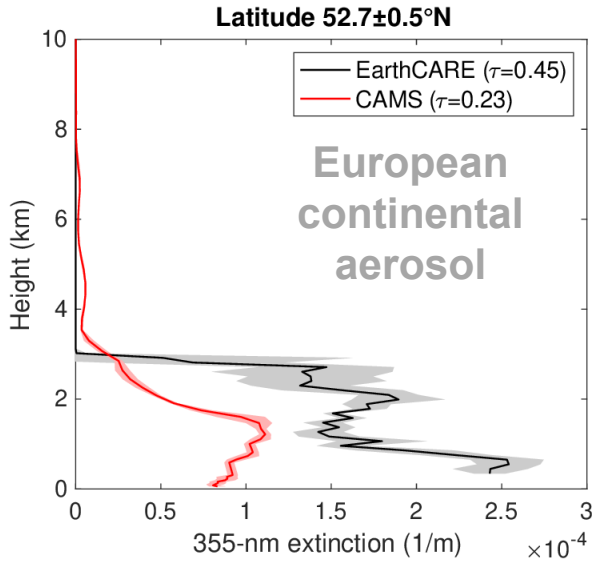
Evaluation of CAMS aerosol extinction coefficient

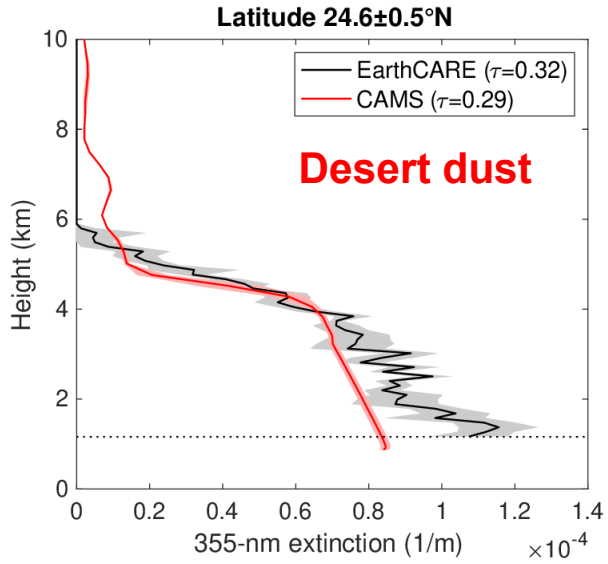
Robin Hogan, Peter Hill (ECMWF),
David Donovan (KNMI)

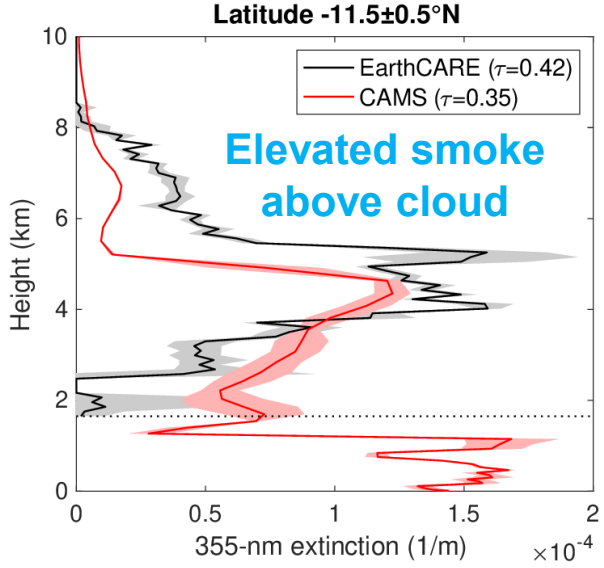
- CAMS: ECMWF's air quality forecast including 15 prognostic aerosol variables
- Evaluate 355-nm extinction coefficient vs. EarthCARE high spectral resolution lidar
- *We have never before been able to evaluate aerosol profiles globally with such resolution & accuracy, nor above clouds!*





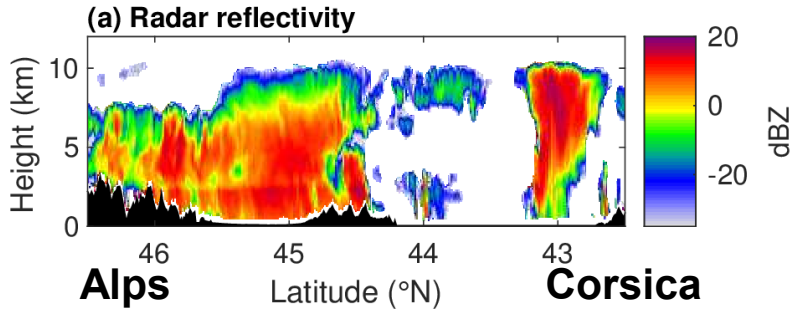


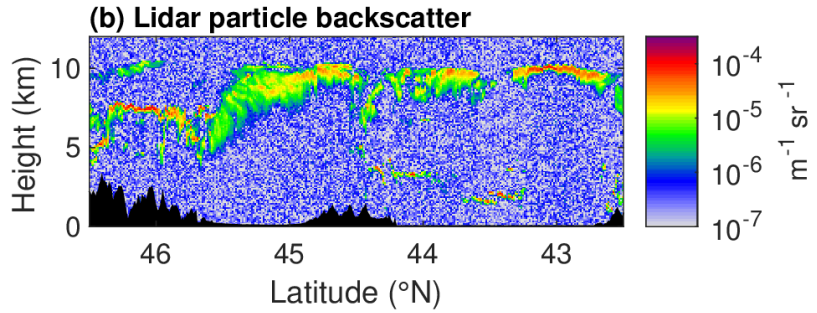


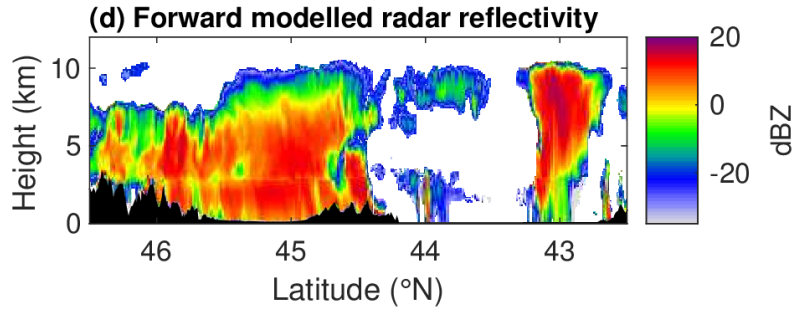


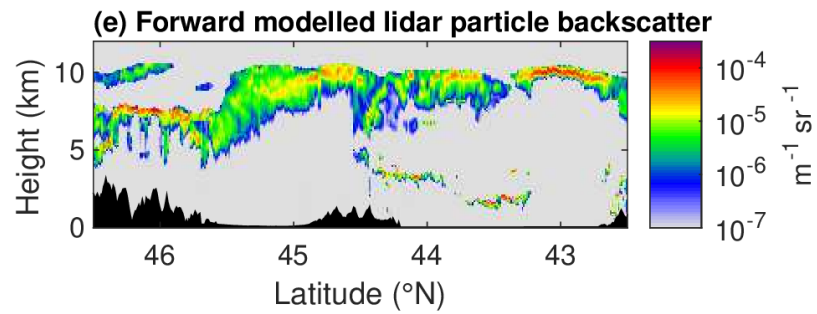
Synergy retrievals

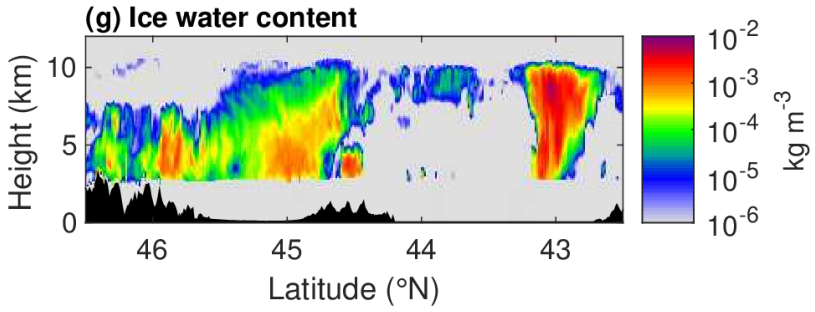
- EarthCARE's "ACM-CAP" synergy product was developed at ECMWF and University of Reading
- It takes the radar, lidar and imager observations…
- …iterates the retrieval until the forward modelled observations match the actual observations…
- …retrieving the microphysical properties of ice clouds and rain...
- …as well as liquid clouds and aerosols (not shown)

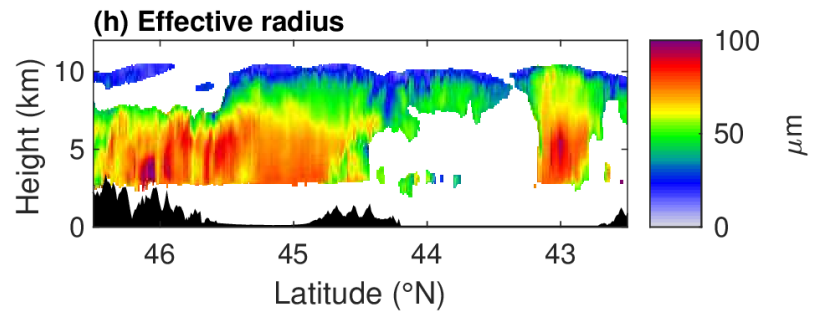


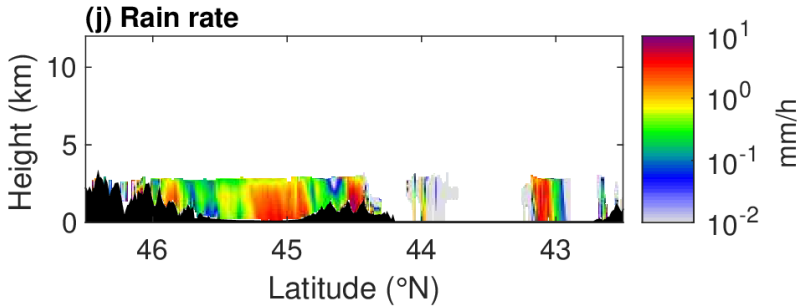


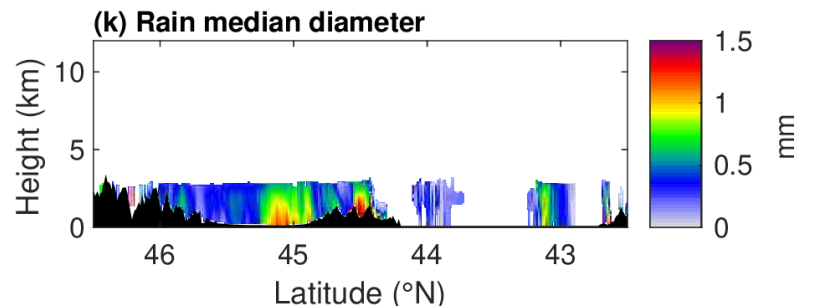












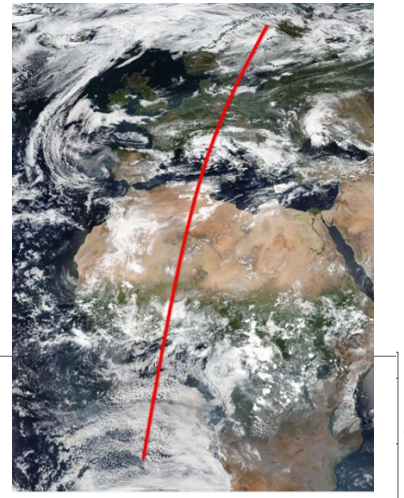
ECMWF

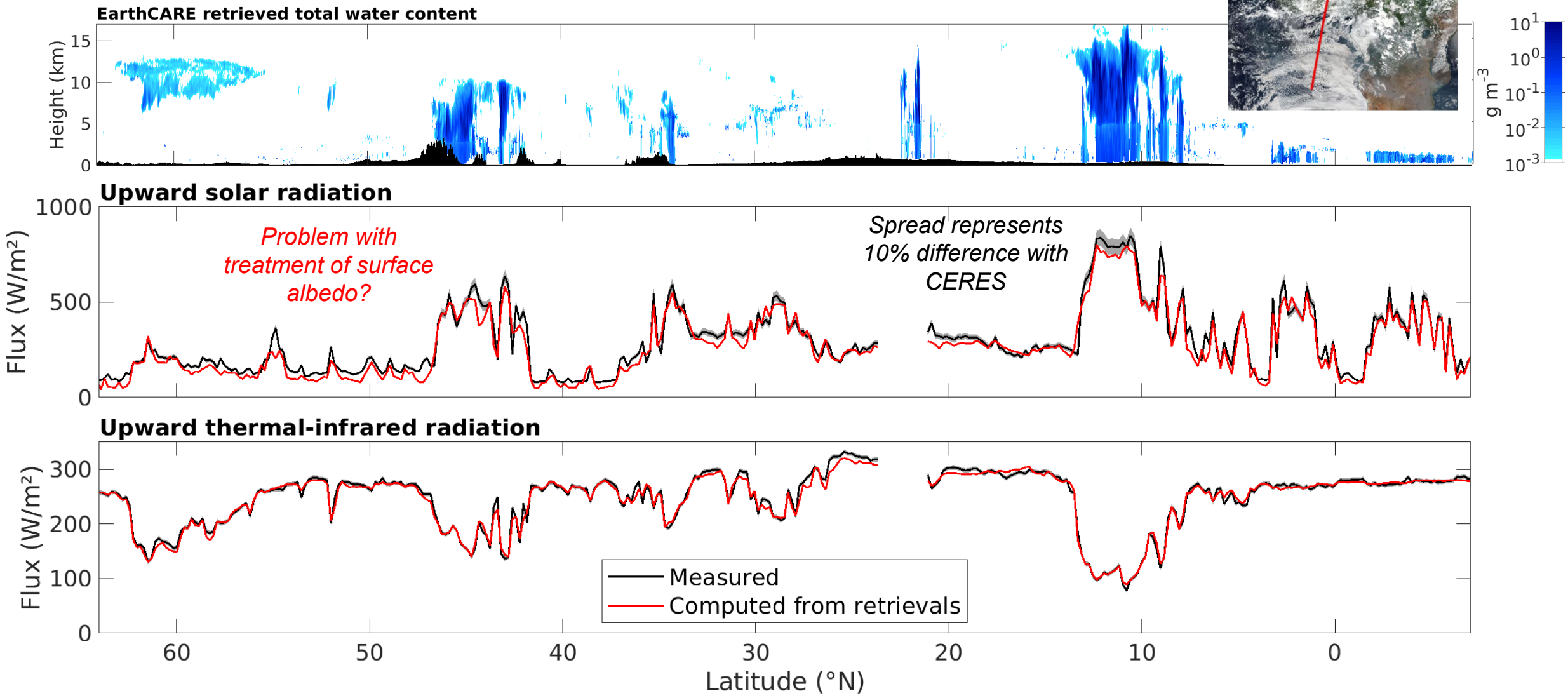
Shannon Mason
18 Sept 2024

Towards radiative closure

Jason Cole, Zhipeng Qu, Howard Barker, Almudena Velazquez

- Test ECMWF retrievals by comparing radiation calculations on them with fluxes measured by the Broadband Radiometer

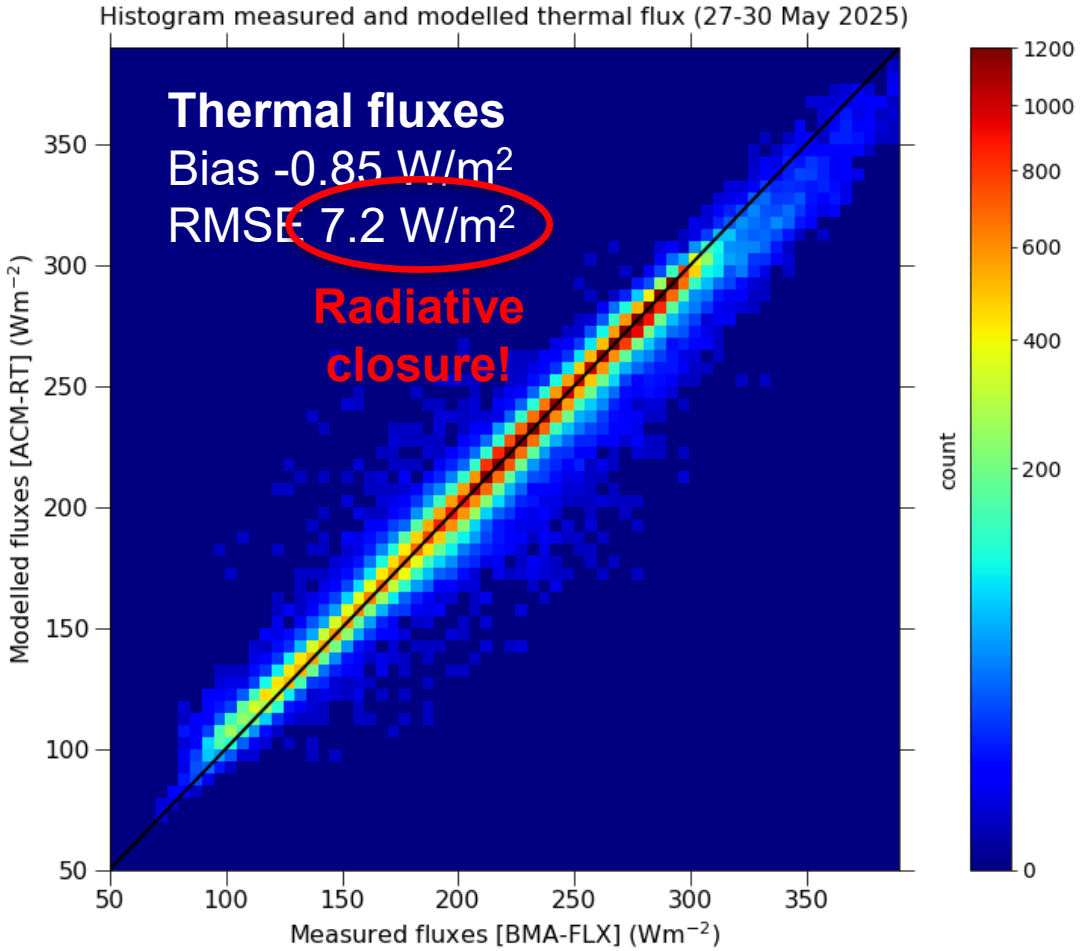


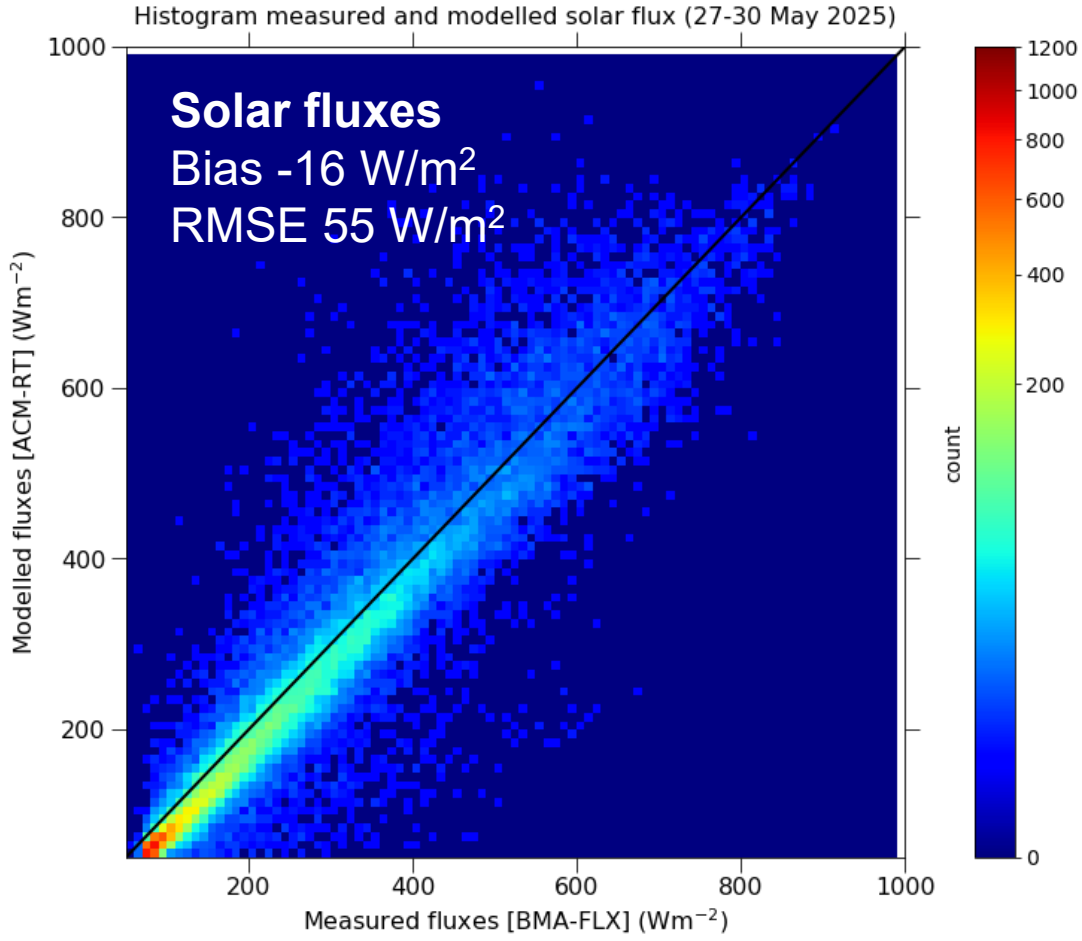


Radiative closure statistics

Jason Cole, Zhipeng Qu, Howard Barker, Almudena Velazquez

- Statistical comparison from 27-30 May 2025, using 3D radiative transfer and latest BBR calibration
- Better treatment of surface should improve solar radiative closure (ongoing work)



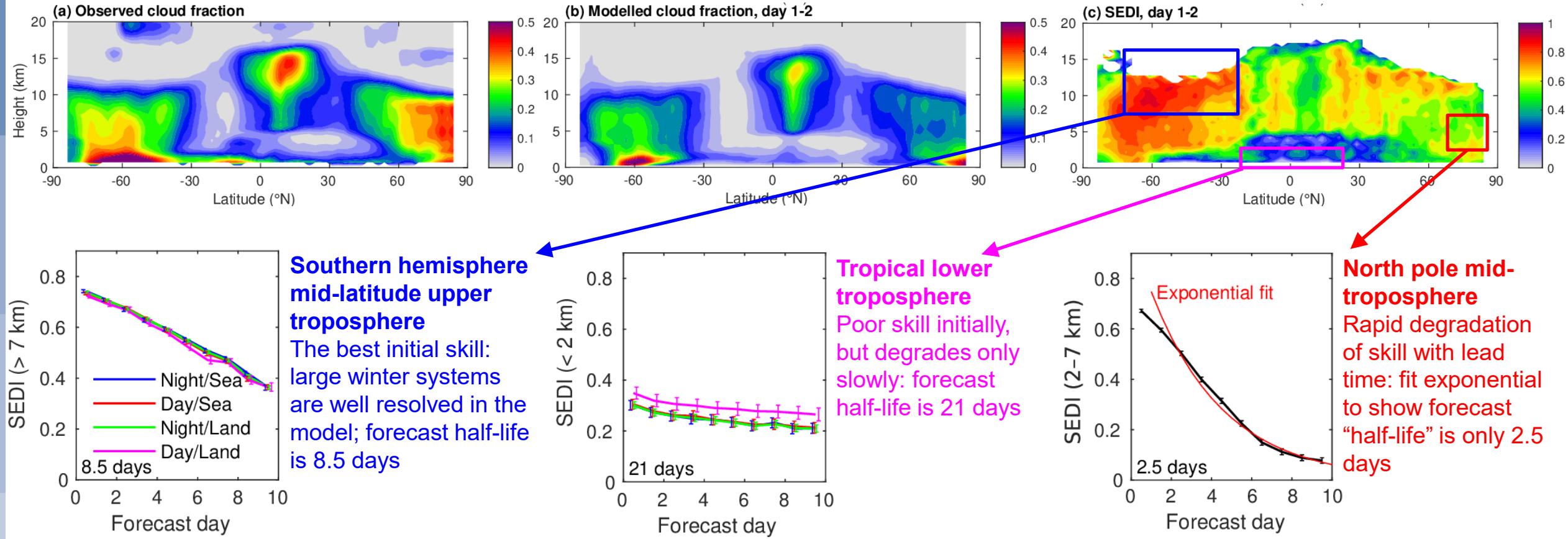


ECMWF

What is the skill of a cloud forecast?

Robin Hogan, Shannon Mason,
Richard Forbes

- Model cloud fraction in Aug-Sept 2024 biased a little low everywhere, *but what is the skill of the forecasts?*
- The **"SEDI" Skill Score**: assesses if the clouds are predicted at the right time/place: 1=perfect, 0=no skill



Southern hemisphere mid-latitude upper troposphere
The best initial skill: large winter systems are well resolved in the model; forecast half-life is 8.5 days

Tropical lower troposphere
Poor skill initially, but degrades only slowly: forecast half-life is 21 days

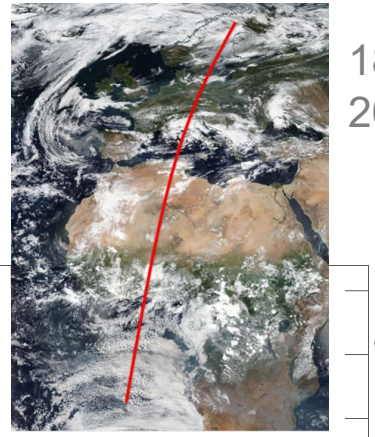
North pole mid-troposphere
Rapid degradation of skill with lead time: fit exponential to show forecast "half-life" is only 2.5 days

This is an extremely useful capability for evaluating how future model changes improve forecast skill!

Outlook

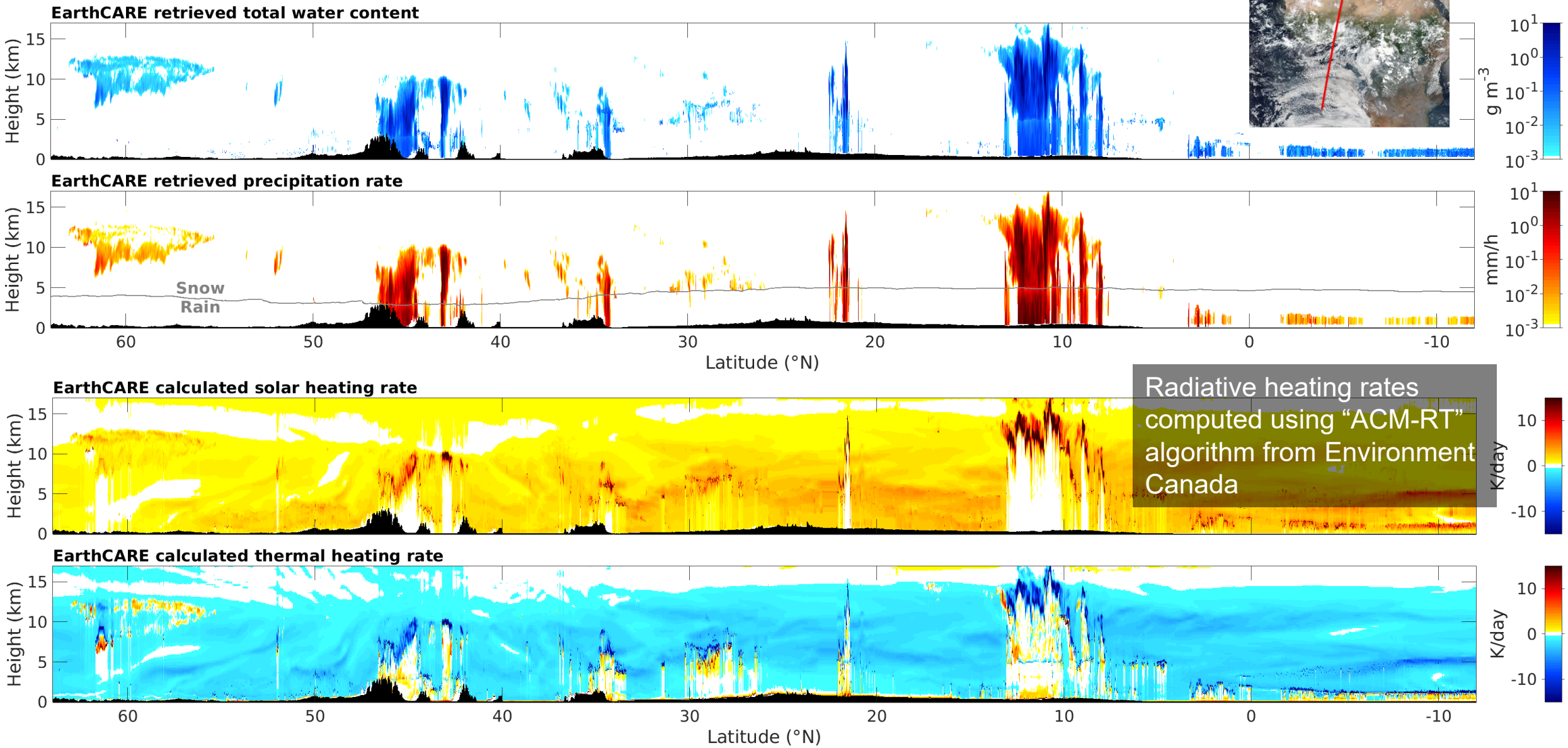
- (Almost) everything works!
- This is thanks to a huge amount of work before launch (Anthony!) and also after launch in ongoing algorithm improvements and extensive calibration & validation campaigns (e.g. Kamil's talk)
- Lots of exciting science to come, some results to be presented today (and I haven't had time to show you observations of polar stratospheric clouds, tropical cyclones, aerosol-cloud interactions, insects and even oceanic phytoplankton!)
- Please start playing with the data yourself, and consider collaborating e.g. in model evaluation via ECOMIP
- A special issue of AMT/ACP/GMD "Early results from EarthCARE" is open for submissions
- Further information and links at www.earthcarescience.net

Cloud/precipitation retrievals and heating rates from EarthCARE



18 Sept 2024

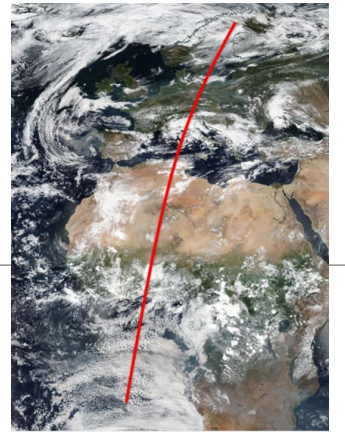
- Official EarthCARE synergistic cloud/precip retrieval developed at ECMWF

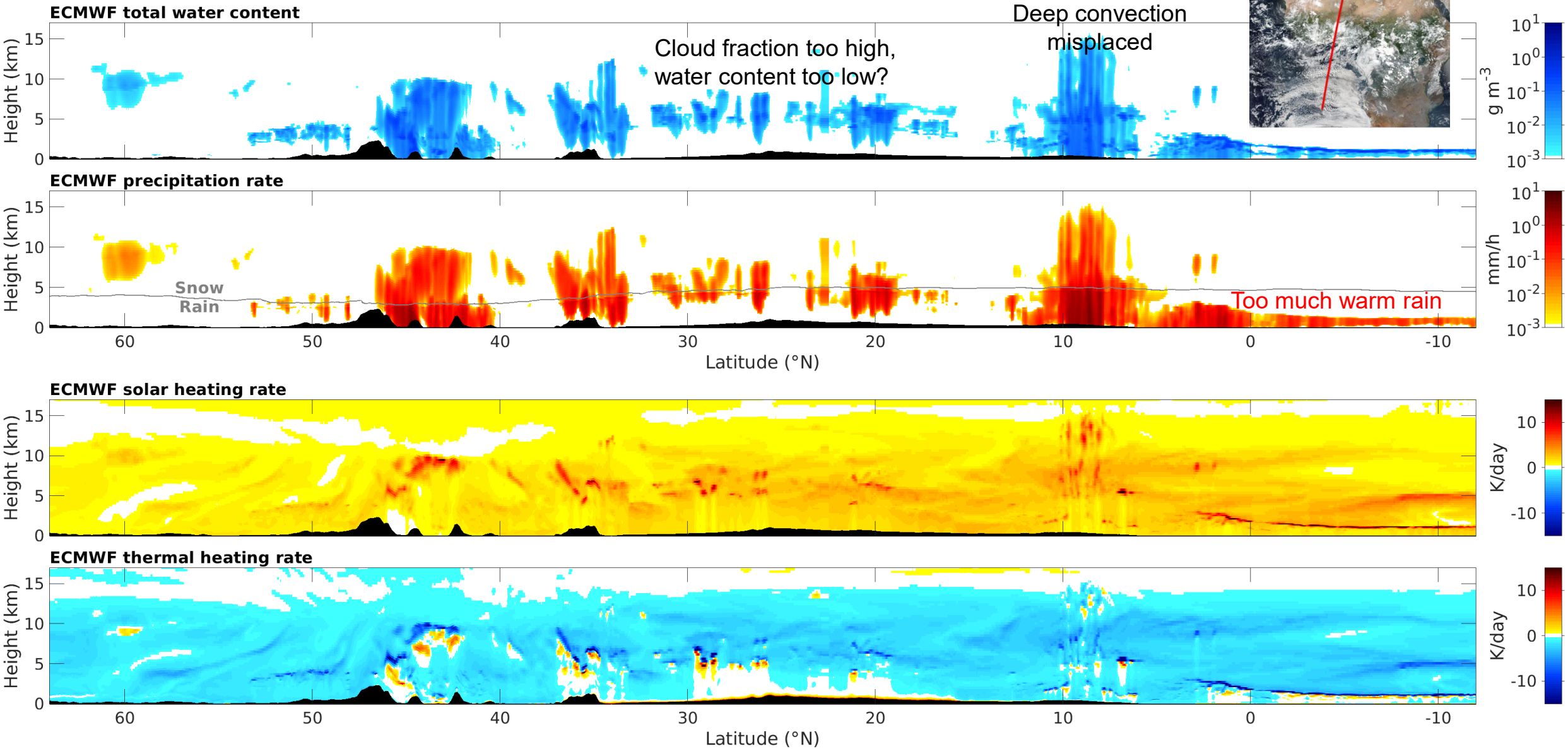


Radiative heating rates computed using “ACM-RT” algorithm from Environment Canada

… use retrievals to evaluate the ECMWF 9-km forecast model

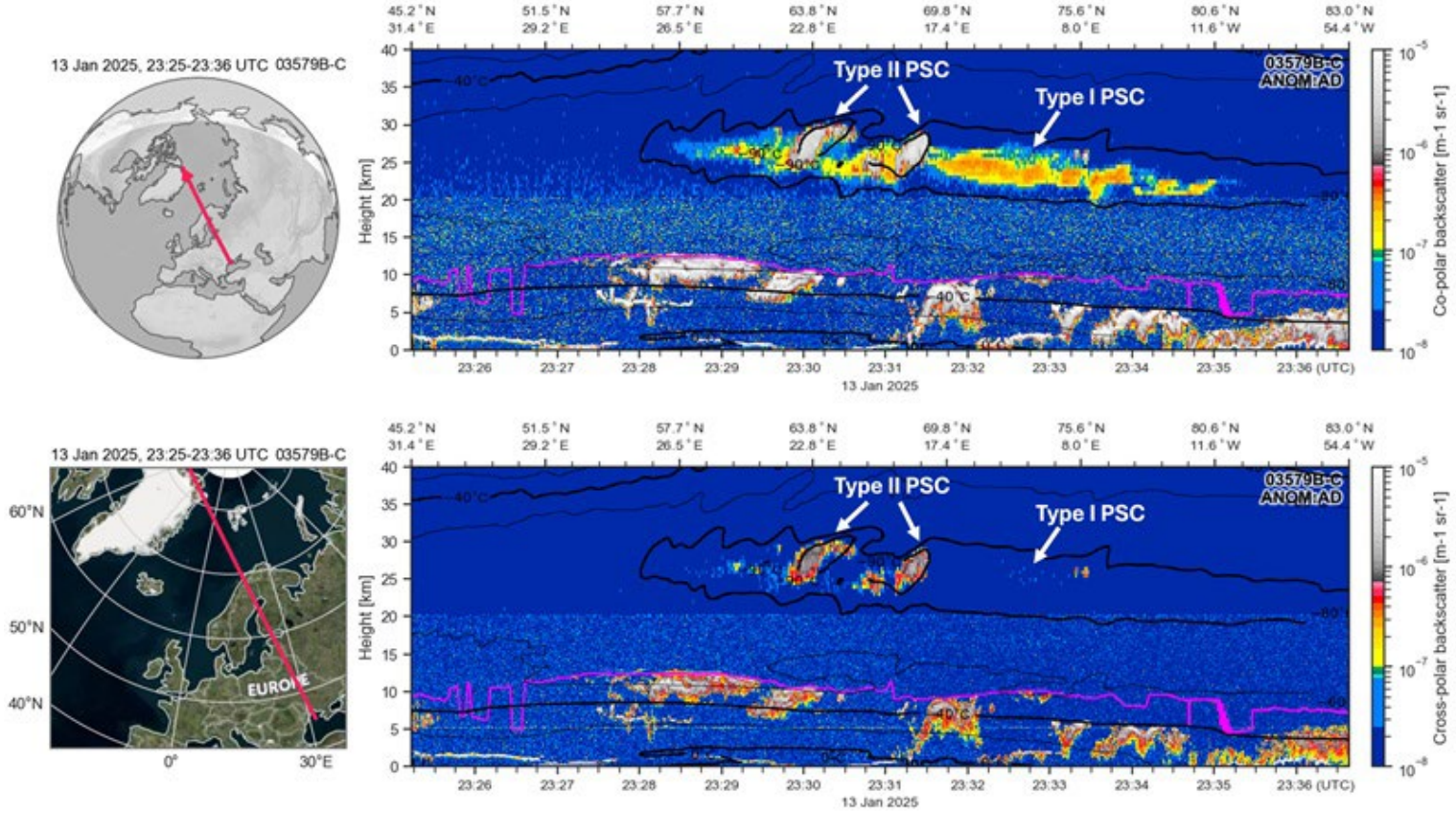
- Good forecast of European rainfall, but tropical clouds less well predicted

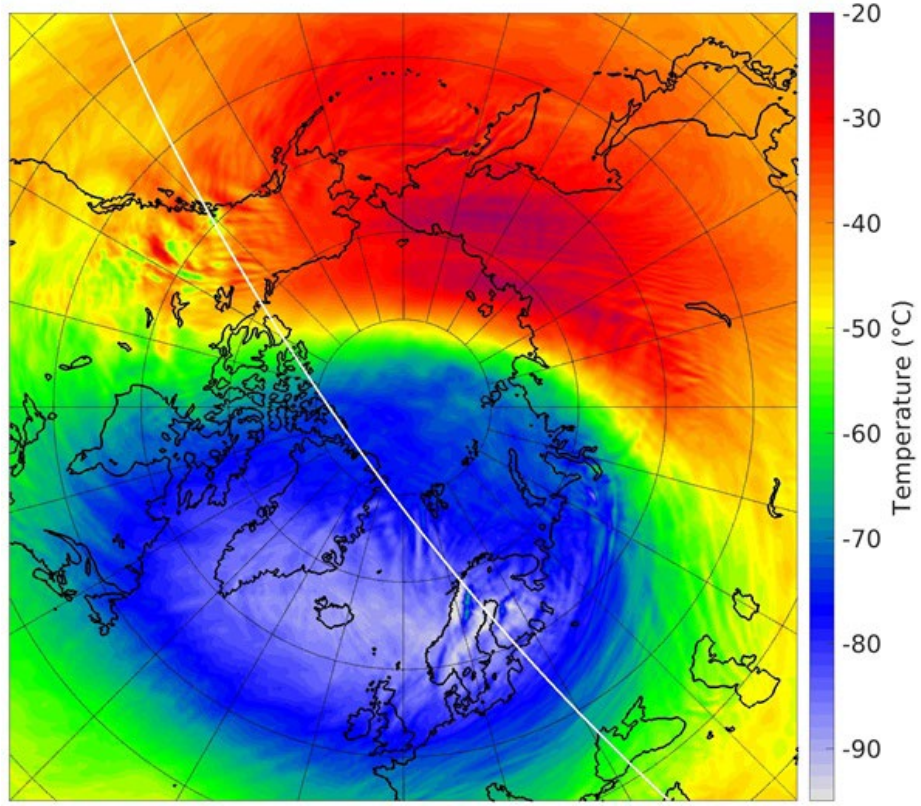




Arctic polar stratospheric clouds

Gerd-Jan van Zadelhoff,
Ulla Wandinger, Amanda Hall





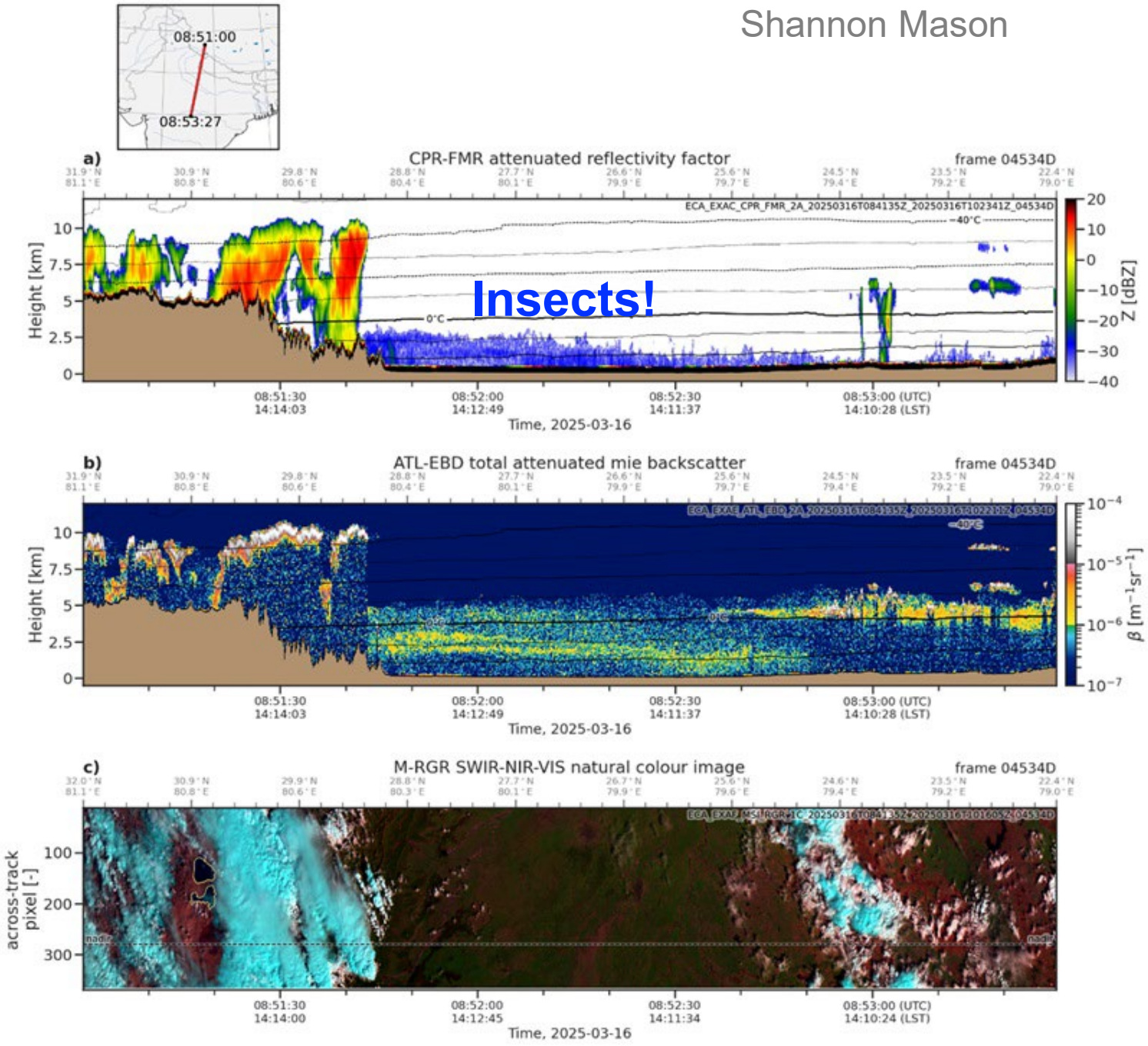
- ATLID depolarization distinguishes Type I PSCs (spheres, <-78ºC) from Type II (ice crystals , <-88ºC)
- ECMWF 10 hPa (25 km) temperature forecast show intense polar vortex down to -97.3ºC
- Adiabatic lifting in gravity waves (seen both in model and ATLID) likely cooled the air sufficiently for Type II

ECMWF

Insects over India

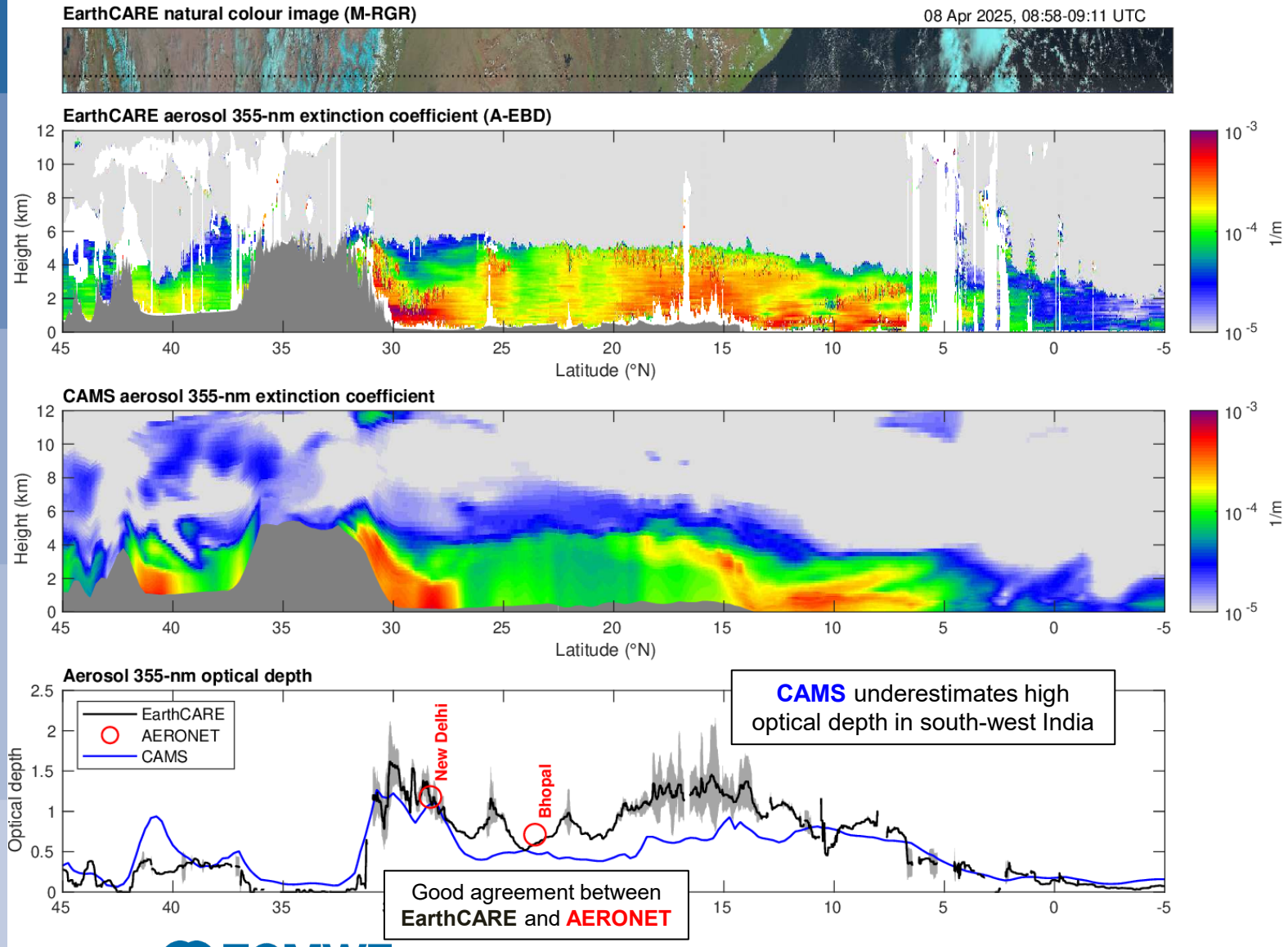
Shannon Mason

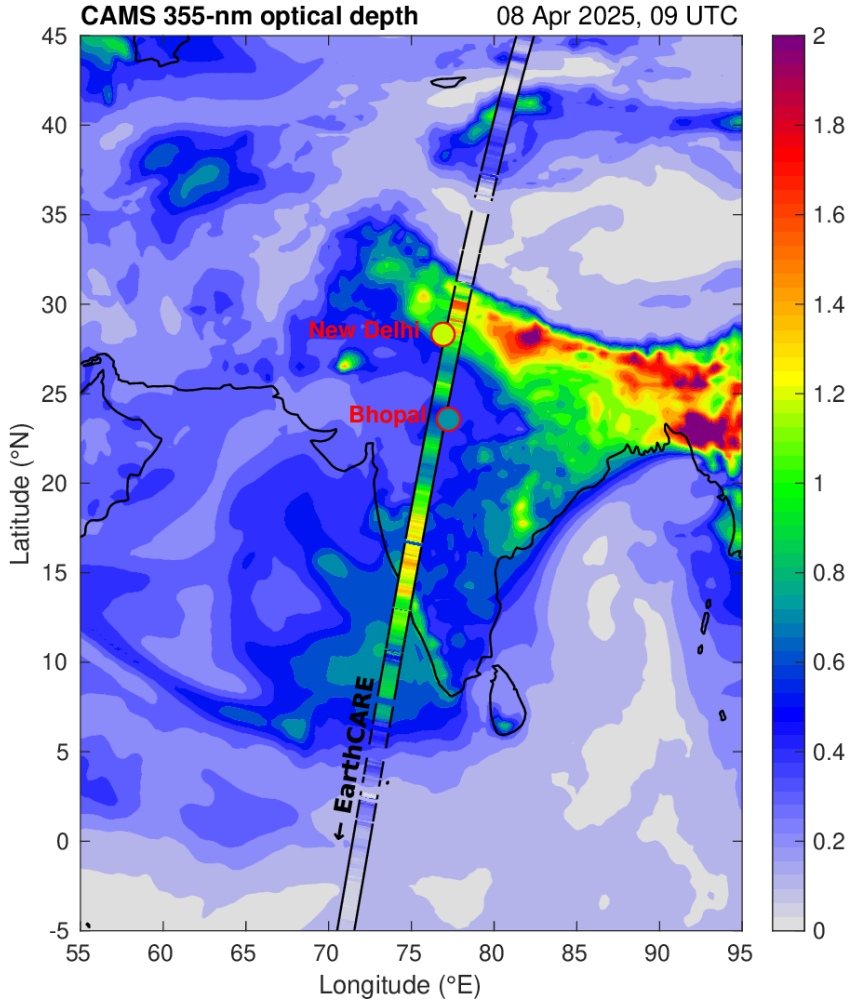
- EarthCARE radar more sensitive than CloudSat and readily detects insects around the world
- Lidar sees aerosols while imager detects no cloud, confirming the signal
- Potential to study global insect distributions for the first time, including seasonality, migration etc.



ECMWF

Evaluating CAMS aerosols in India, 8 April 2025

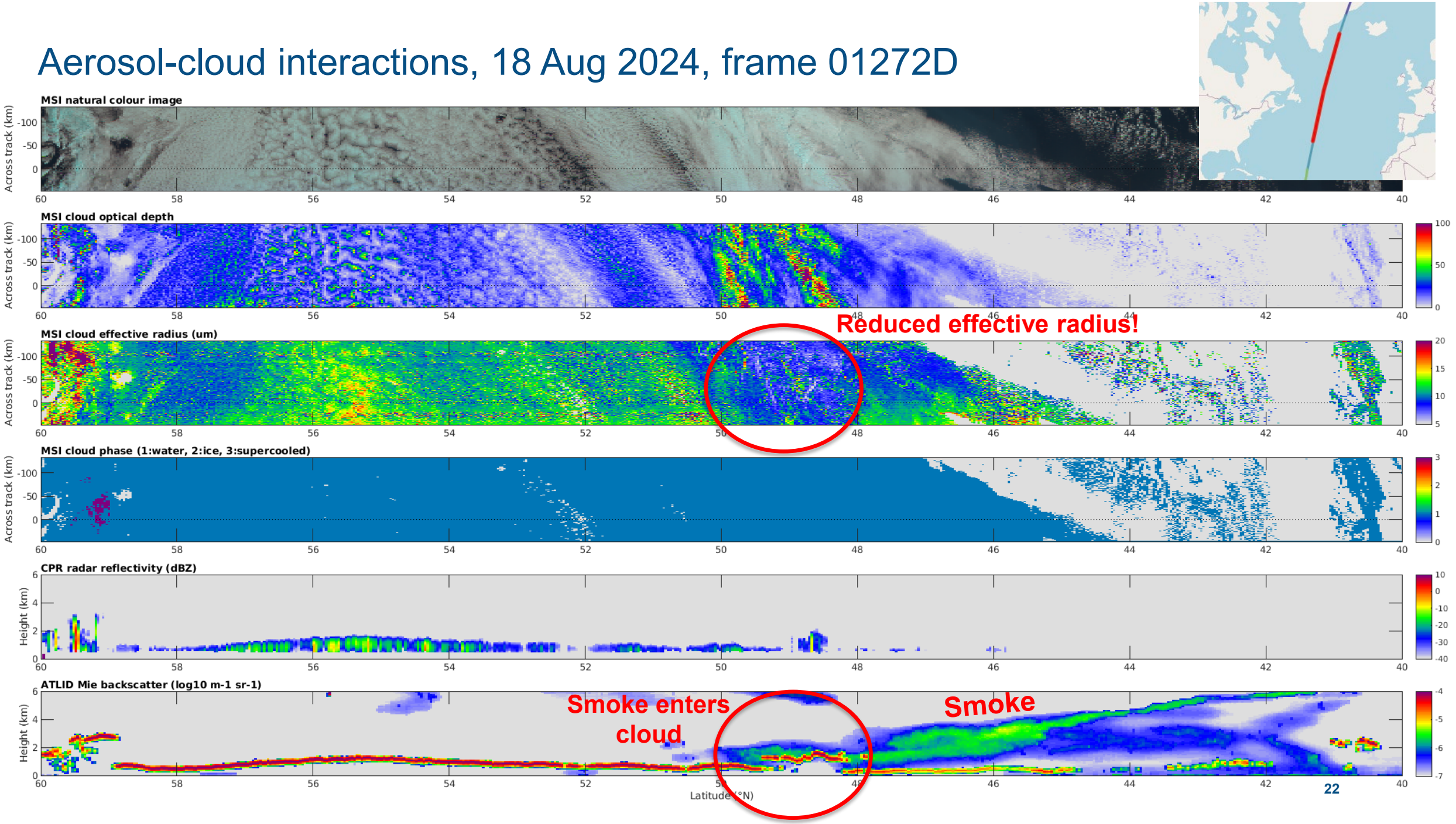




- We hope to use EarthCARE routinely to evaluate CAMS

ECMWF

Aerosol-cloud interactions, 18 Aug 2024, frame 01272D



Tropical Cyclone Vince

- Indian Ocean 7 February 2025

NASA VIIRS