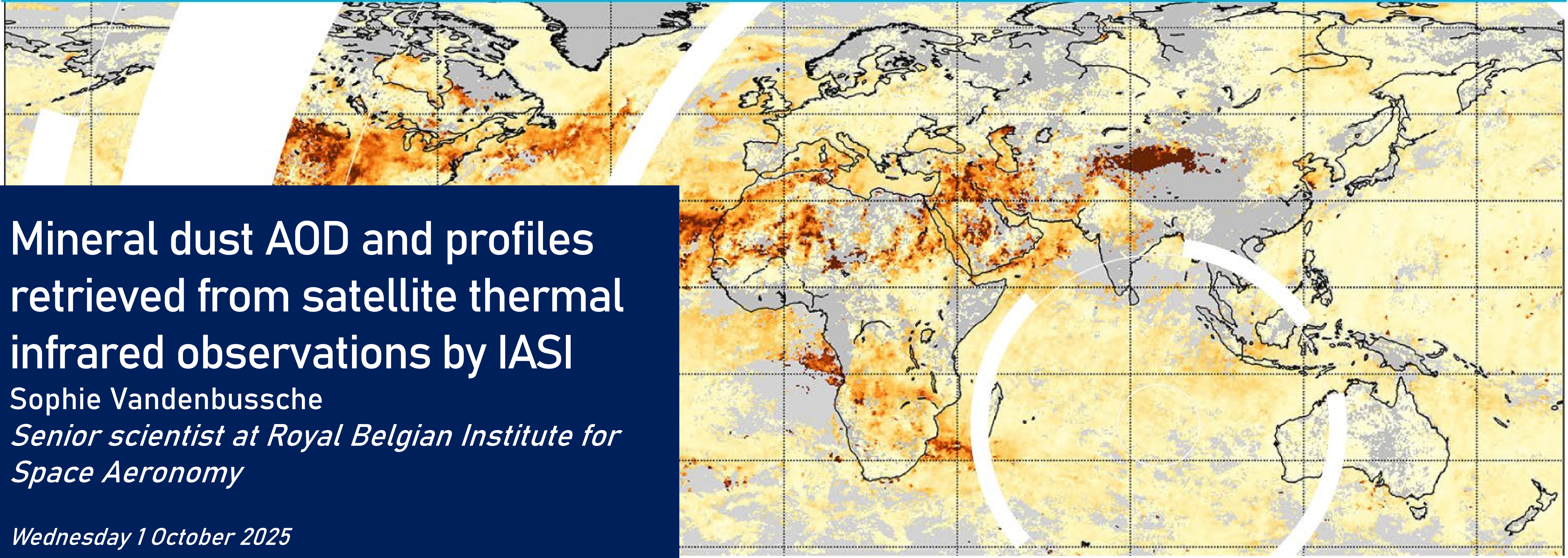
PROGRAMME OF THE EUROPEAN UNION

IMPLEMENTED BY

JOINT TRAINING IN ATMOSPHERIC COMPOSITION

13 -17 OCTOBER 2025, BRUSSELS



Mineral dust AOD and profiles retrieved from satellite thermal infrared observations by IASI

Sophie Vandenbussche

Senior scientist at Royal Belgian Institute for Space Aeronomy

Wednesday 1 October 2025

Agenda

Practicals on Monday 13/10

Introduction

IASI and thermal IR observations

Existing IASI dust products

Dust AOD 10µm, 550nm, mean altitude, vertical profiles – different algorithms

"The technical minute"

A bit on the Optimal Estimation Method

Potential applications

Source analysis, trends, aerosol alerts

Wrap up, future and questions

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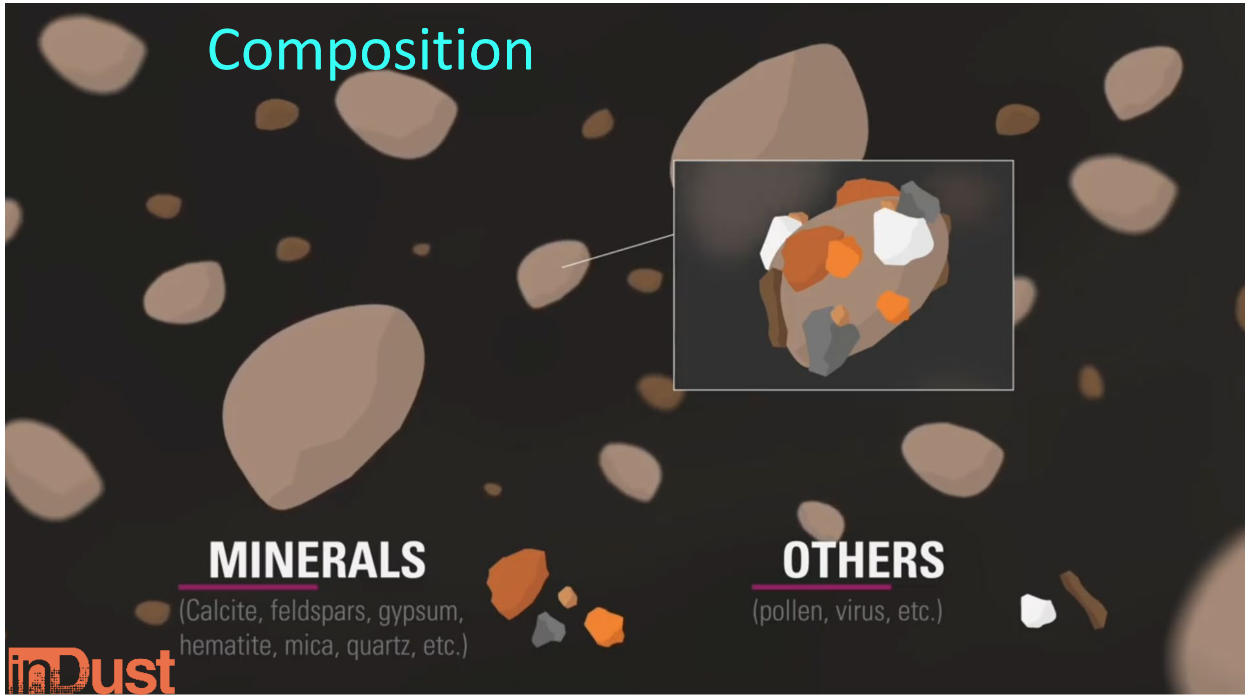
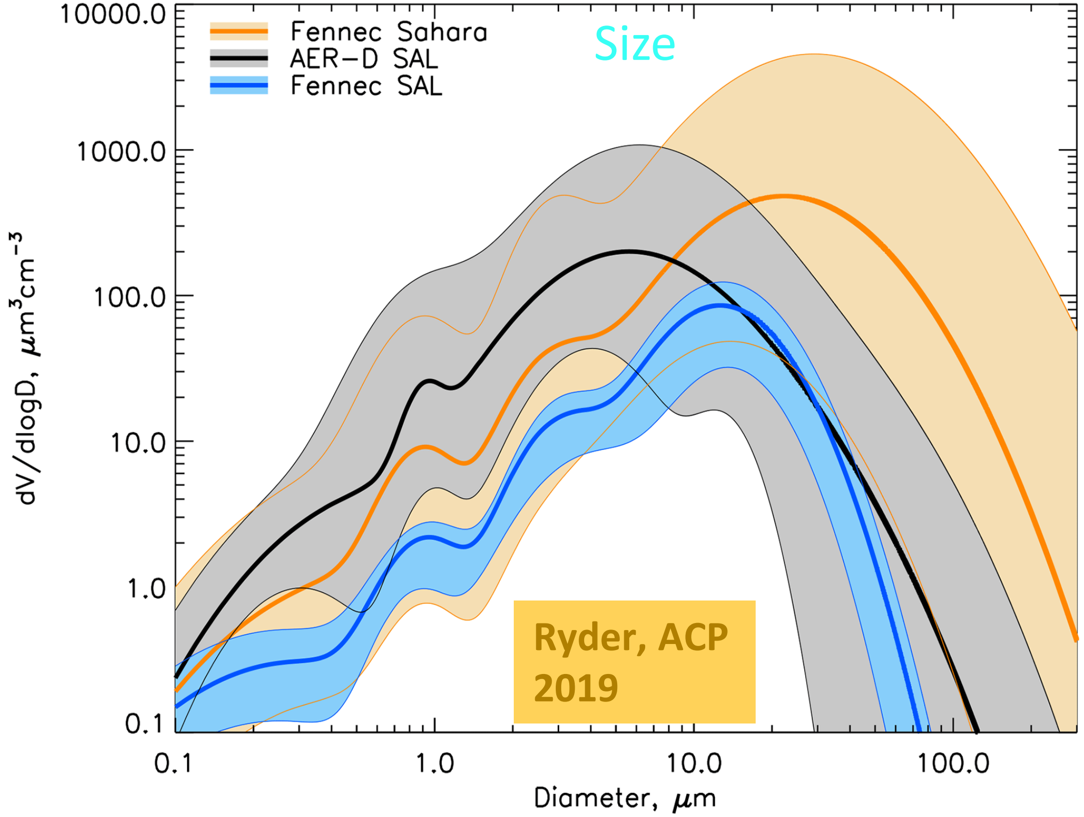
Mineral dust aerosols

Recall talk from Samuel Remy this morning!

Small mineral (sand) particles uplifted by strong winds from dry / bare areas



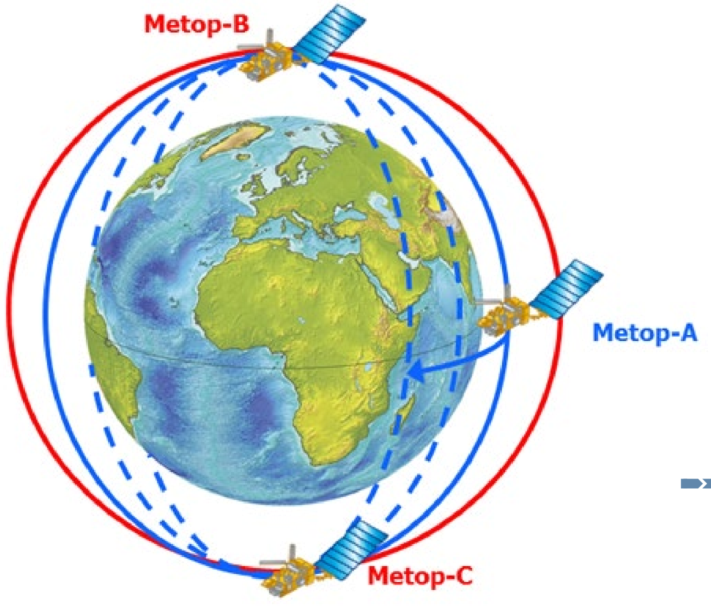


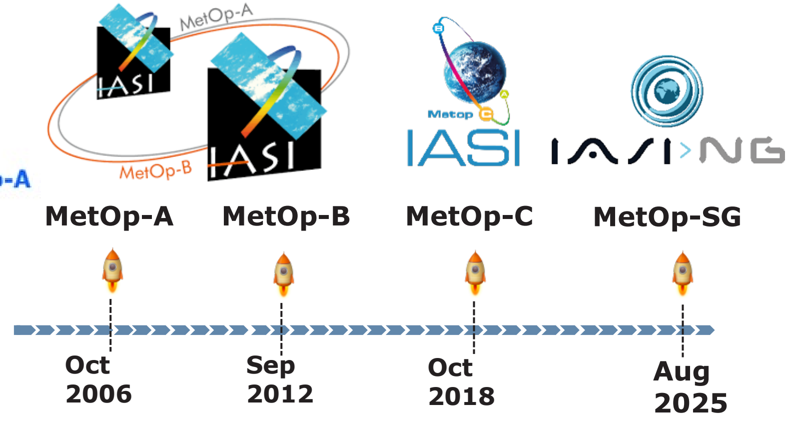
The IASI instrument

Orbital characteristics:

- Sun-synchronous (LEO)
- Overpass at local solar time: ~9h30 and 21h30

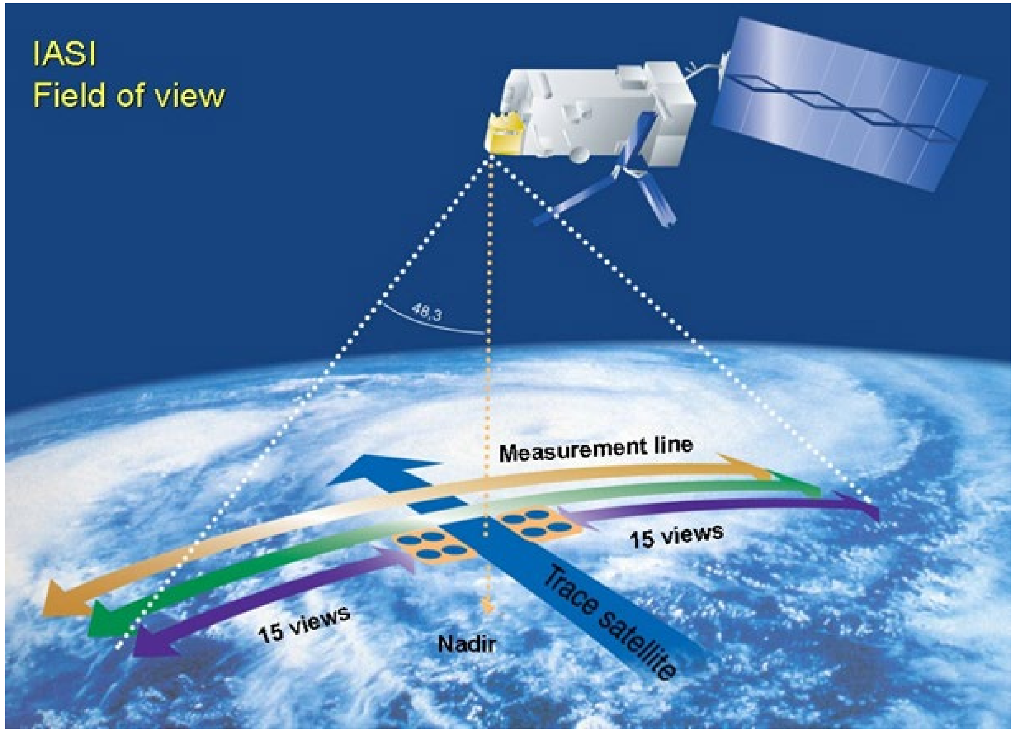
"descending" - "ascending"



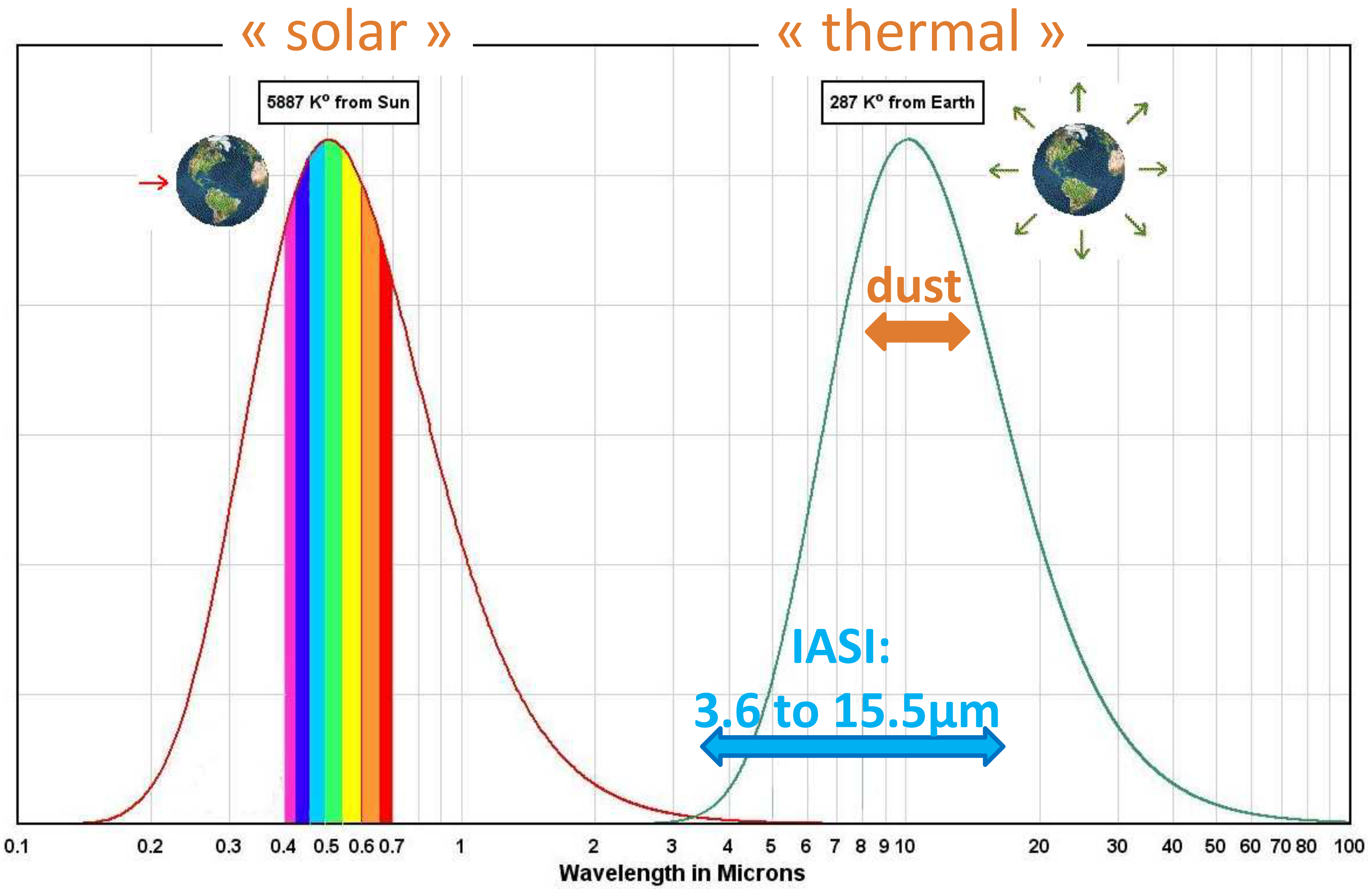


Observation technique:

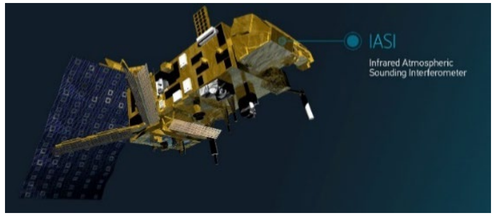
- Nadir, across path scanning, FTIR
- 12km diameter pixels (at nadir)

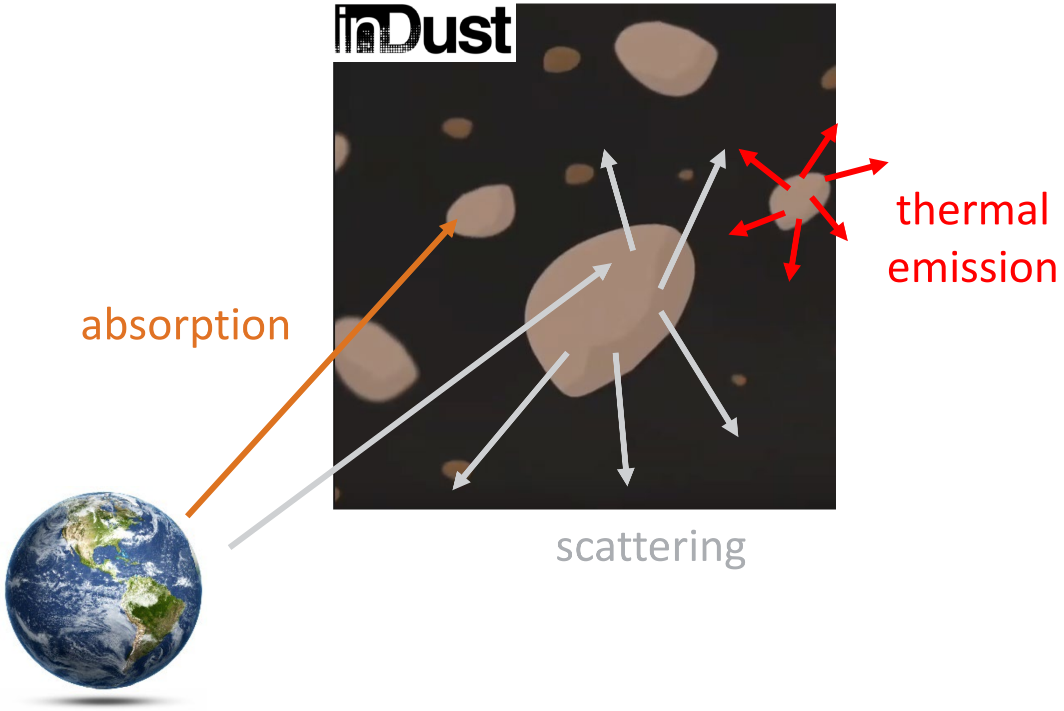


Spectral ranges



Thermal IR specificities





Thermal Infrared radiative considerations

- Surface as **source**: temperature, emissivity
- Atmosphere as **source**: gases, aerosols, clouds (and their temperature)
- Atmosphere as **sink**: absorption and scattering by gases, aerosols, clouds
- No solar light needed -> **day & night**

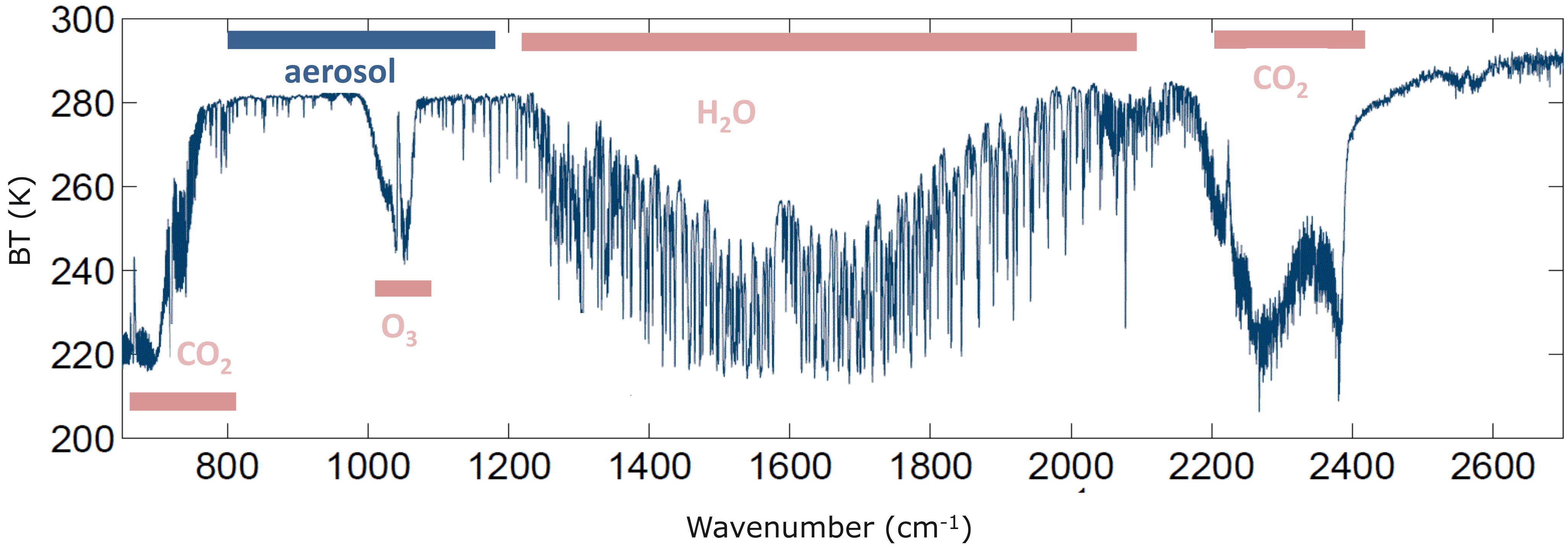
Aerosol signature (in TIR)

- Absorption/emission → minerals
  → **dust and ash**
- Scattering → coarse mode (**large particles**)

Thermal IR specificities: sensitivity

- **Radiance intensity** -> mostly surface temperature + surface emissivity
- **Impact of the dust** on the signal -> total amount of dust
  thermal contrast <-> altitude
- Need for **silicates** in the composition -> not Iceland dust
- Difficulty to **discriminate** dust from **thin clouds** – and dust is a CCN and ICN

Example IASI spectrum



Brightness temperature: a way to measure radiance / energy

$$wavenumber = \frac{1}{wavelength}$$

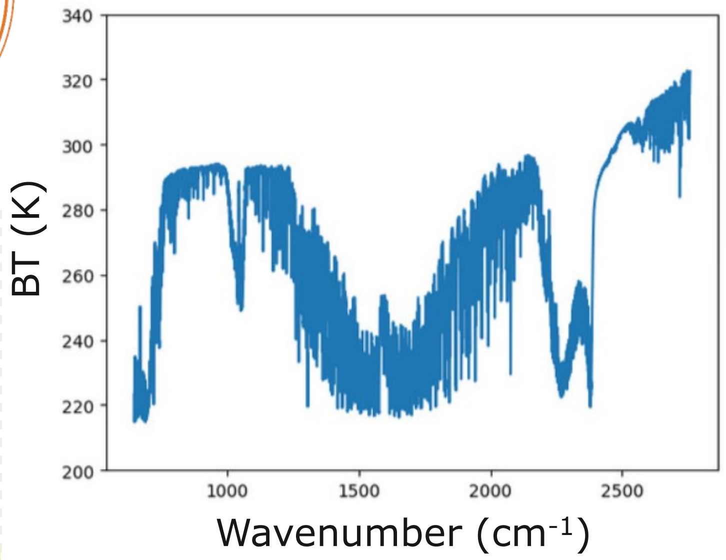
Spectral characteristics:

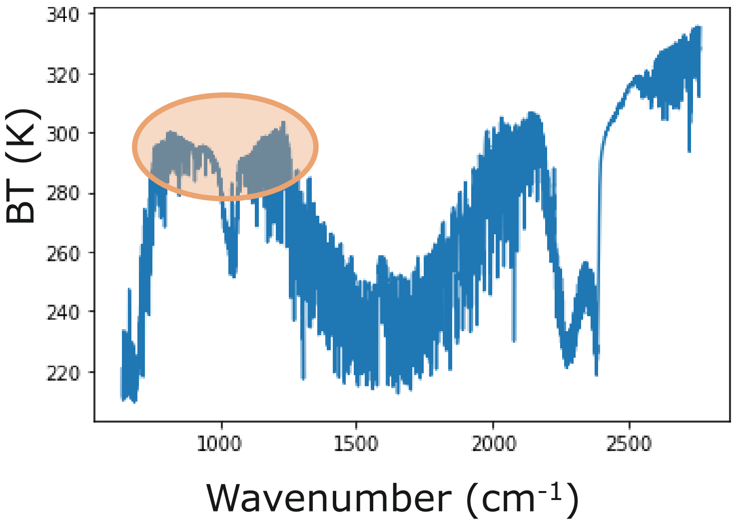
- Resolution 0.25cm^{-1} FWHM 0.5cm^{-1} (gaussian ILS)
- Noise varies with wavenumber, <0.2K in most of the spectrum

Mineral dust observations with IASI

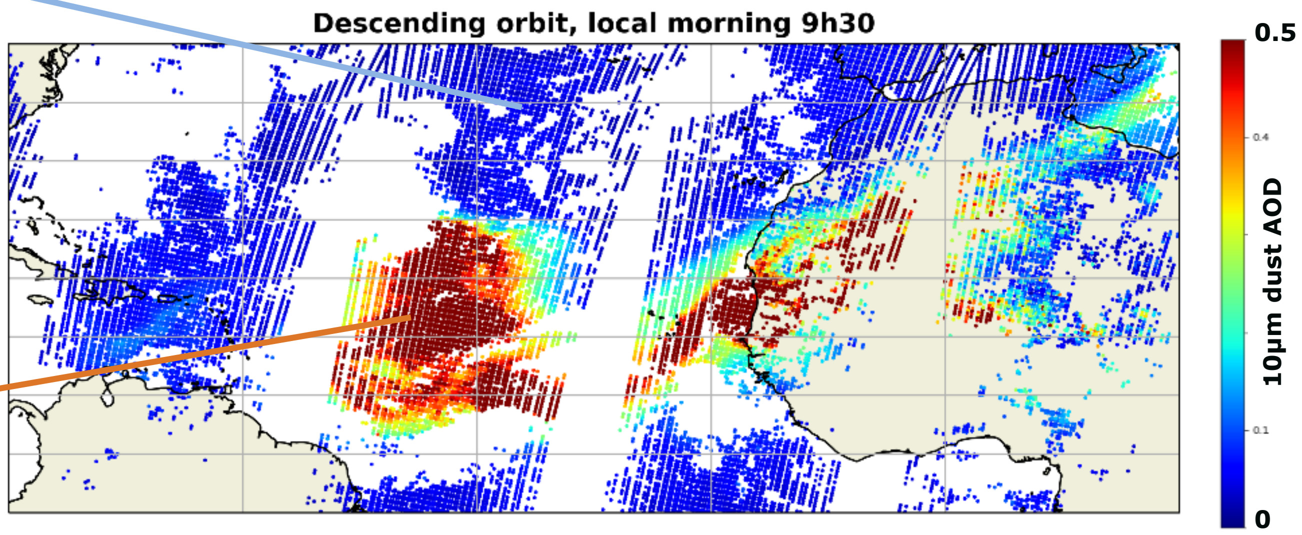
Brightness temperature: a way to measure radiance / energy

$$wavenumber = \frac{1}{wavelength}$$





Godzilla dust storm, (20) June 2020



MAPIR: Mineral Dust Profiling from Infrared Radiances

Mineral dust AOD and profiles retrieved from satellite thermal infrared observations by IASI

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Mineral dust observations with IASI

4 very different algorithms provide full data sets

ULB Dust

Dust index converted to AOD through NN

Parameters: dust AOD - dust index

Availability: CDS (level 3) - EUMETSAT and (level 2) https://www.aeris-data.fr

Infrared Mineral Aerosol Retrieval Scheme (IMARS)

Probabilistic estimations (dust/ice)

Parameters: dust AOD and layer T, dust size and composition

Availability: CDS (level 3)

LMD Dust

Lookup tables (3 steps)

Parameters: dust AOD and mean altitude, dust effective radius (not public)

Availability: CDS (level 3, not the radius) and (level 2) https://www.aeris-data.fr

Mineral Aerosol Profiling from Infrared Radiances (MAPIR)

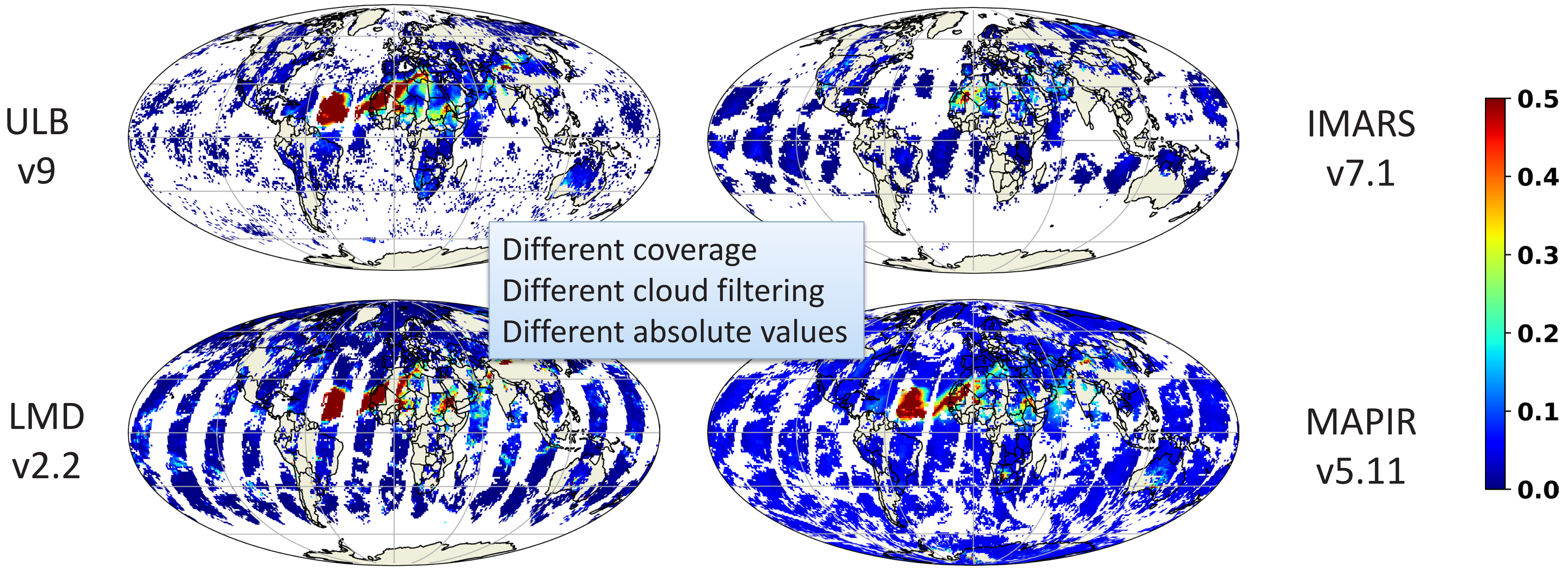
Optimal estimation

Parameters: dust AOD, mean altitude, vertical profile

Availability: CDS (level 3, not the profiles) and (level 2) https://iasi.aeronomie.be

IASI dust AOD 10µm

Example: « Godzilla » storm, 20 June 2020 9h30 LST
(last version available, for each algorithm)



IASI dust AOD 550 nm: « conversion »

IASI data : TIR, dust coarse mode AOD obtained at ~10µm ($1000 cm^{-1}$)

Most other data : IV, VIS, Total AOD usually reported at 500-550nm

Dust AOD conversion 10µm -> 550nm

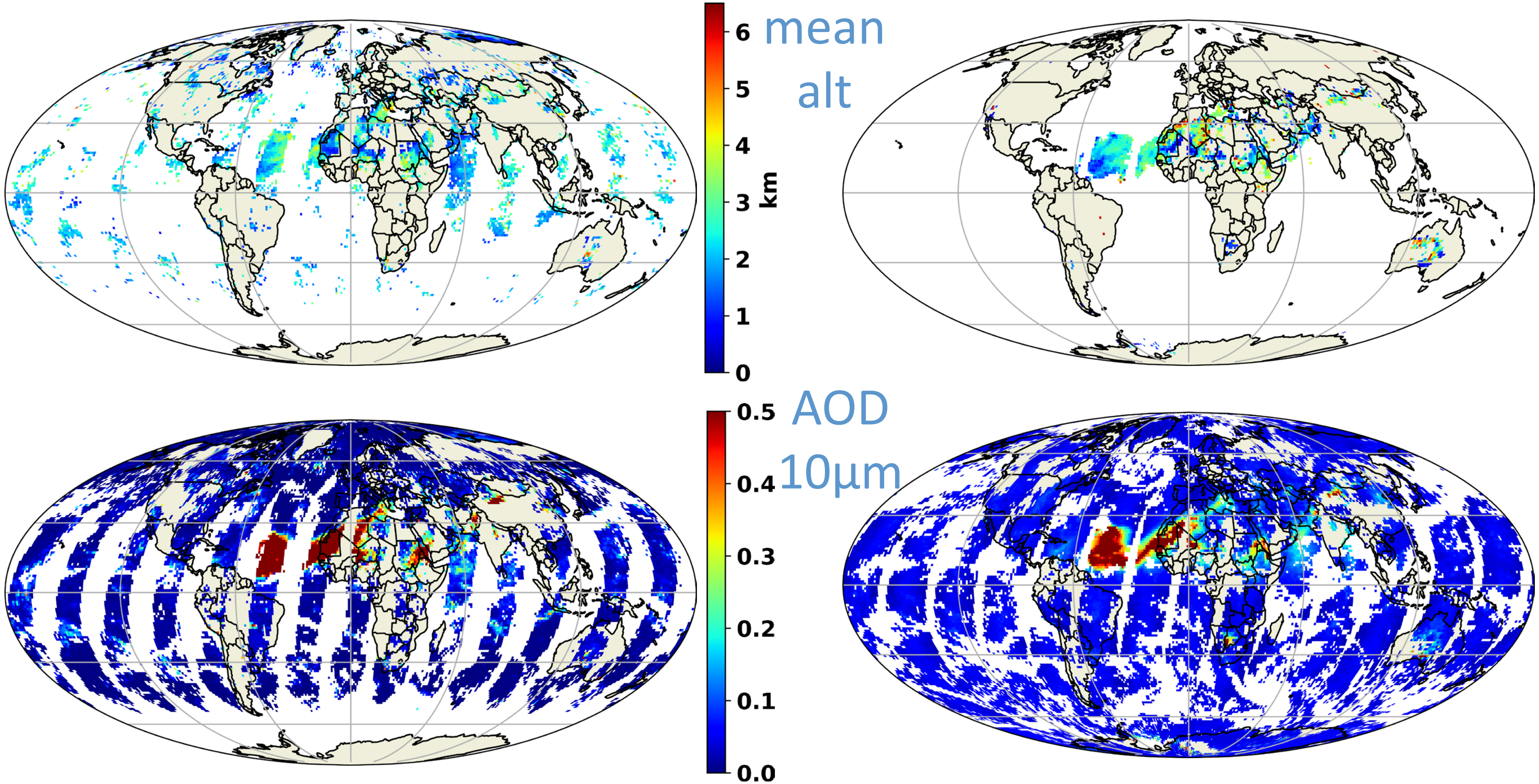
- Requires assumptions on particle optical properties – the conversion is more sensitive to those properties than the retrieval itself!
- Increases the uncertainty
- Converts only what is observable at 10µm (= coarse dust particles)

IASI dust mean altitude

Example: « Godzilla » storm, 20 June 2020 9h30 LST

(last version available, for each algorithm)

LMD
v2.2

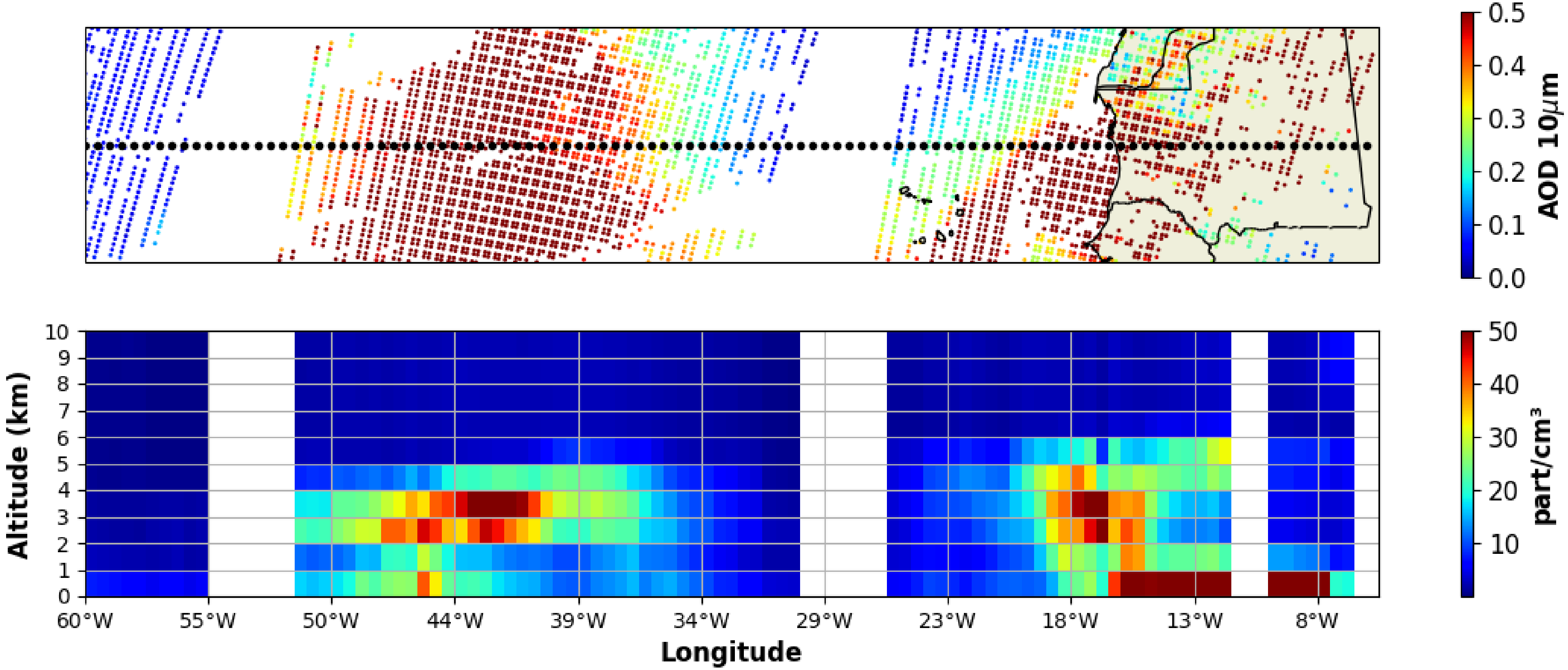


MAPIR
v5.11

IASI dust MAPIR vertical information

MAPIR contains profile information, can separate 2 distinct layers

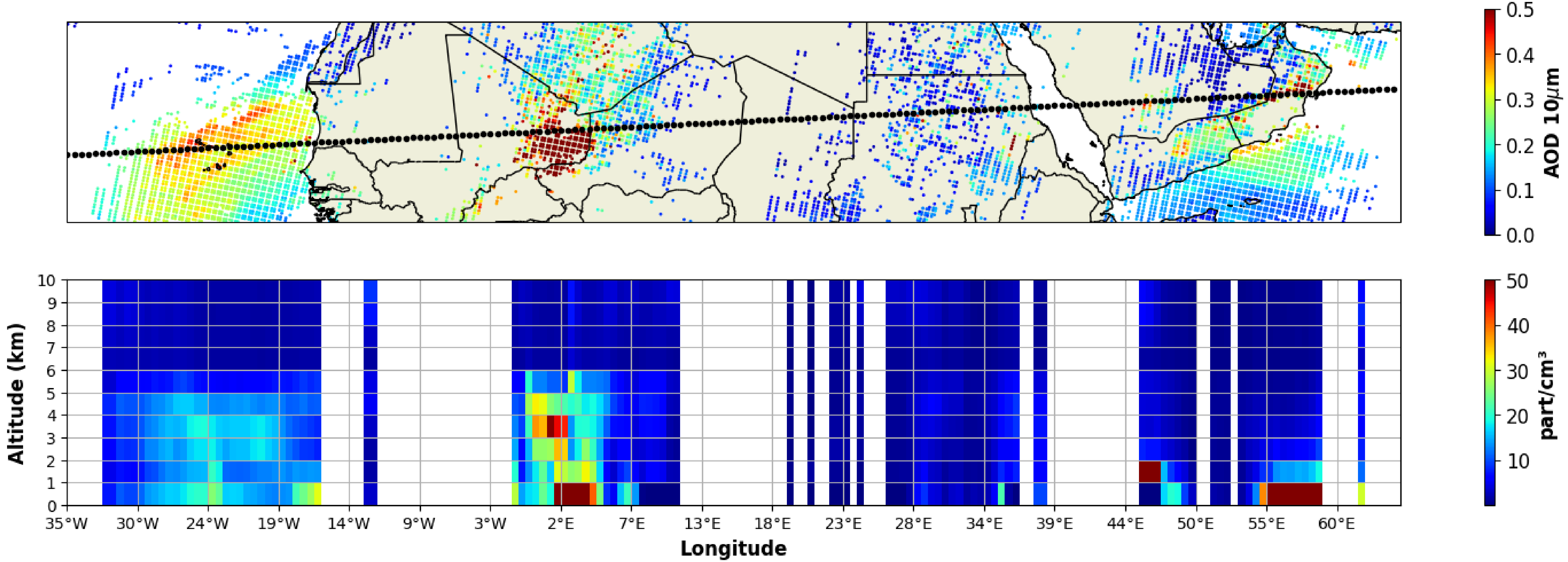
20 June 2020, « Godzilla », morning overpass



IASI dust MAPIR vertical information

MAPIR contains profile information, can separate 2 distinct layers

9 June 2018



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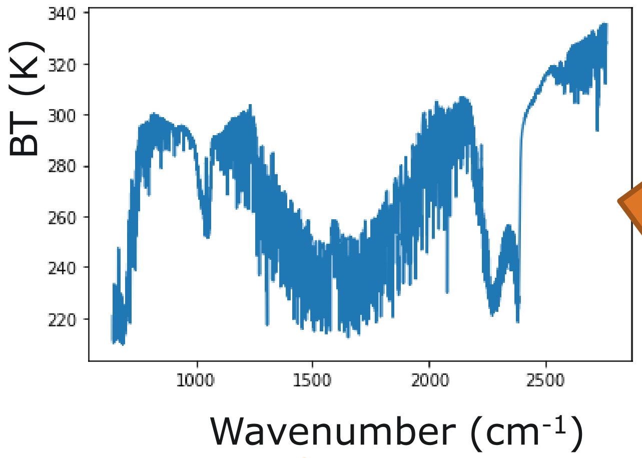
The optimal estimation method

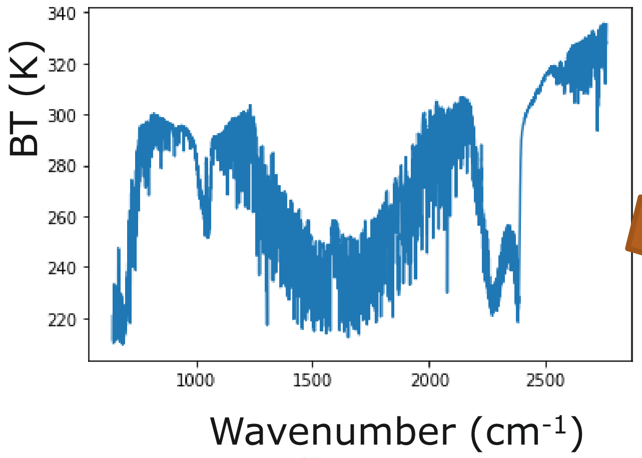


Radiative transfer model, also called « forward » model

It computes the **radiance** that should be observed given:

- An atmospheric state and Earth surface description
- The physics of the light interaction with surface and atmosphere components
- The properties of the instrument one wants to simulate

The optimal estimation method



This is usually called **the « inverse » problem** and it requires **numerical computing**

- More observations than unknowns
- Observations are « **noisy** » and often partially **correlated**
- The « forward » model is most commonly **non linear**
- The **sensitivity** of the observation to the atmospheric and surface state is not perfect, can even be completely masked
- A large number of atmospheric and surface state parameters are fixed, and their **uncertainty** affects the finding of a solution

Different methods exist (based on statistics), and require an **iterative resolution, with constraints, minimizing a defined « cost function »**, and with defined criteria deciding when to stop the process
The solution obtained is not the truth, but a best estimate of it, given some « a priori » knowledge

The optimal estimation method

Radiative transfer (forward) model

Spectrum (or a selected part of it)

$$y = F(x, b) + \epsilon$$

Noise (spectral, model, …)

Parameters that you do not retrieve (fixed)

"State vector" = what you want to retrieve

a priori: «knowledge» of the atmosphere -> Climatology

Noise covariance matrix

"Residual" = observed – modelled spectrum

Function to minimize

$$\chi^2 = [y - F(x,b)]^T S_\epsilon^{-1} [y - F(x,b)] + [x - x_a]^T S_a^{-1} [x - x_a].$$

Departure from the a priori

A priori covariance matrix

"How good we reproduce the observation, knowing its uncertainty"

"How far we are from the a priori, knowing its (co)-variance" -> **constraint**

The optimal estimation method

Iterative resolution

A priori covariance matrix

Noise covariance matrix

$$x_{i+1} = x_i + \left((1+\gamma)\mathbf{S}_a^{-1} + \mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} \mathbf{K}_i\right)^{-1} \left(\mathbf{K}_i^T \mathbf{S}_\epsilon^{-1} (y - F(x_i)) - \mathbf{S}_a^{-1} (x_i - x_a)\right)$$

Initial value x_0: "first guess", often x_a but not mandatory

"Residual" = observed – modelled spectrum

Departure from the a priori

"Jacobians" = derivatives of radiance wrt x

Important note: in MAPIR the state vector is log(concentration), to avoid negative values

The optimal estimation method

"Averaging kernel" or "smoothing functions"

Sensitivity of the retrieval to true state.
Shows how the observation+retrieval system smoothes a vertical profile.

$$A = G K$$

"Jacobians" or "Kernel" or "weighting functions"
= derivatives of radiance wrt x
→ Sensitivity of the forward model to x

Noise covariance matrix

$$G = (K^T S_\varepsilon^{-1} K + S_a^{-1})^{-1} K^T S_\varepsilon^{-1}$$

A priori covariance matrix

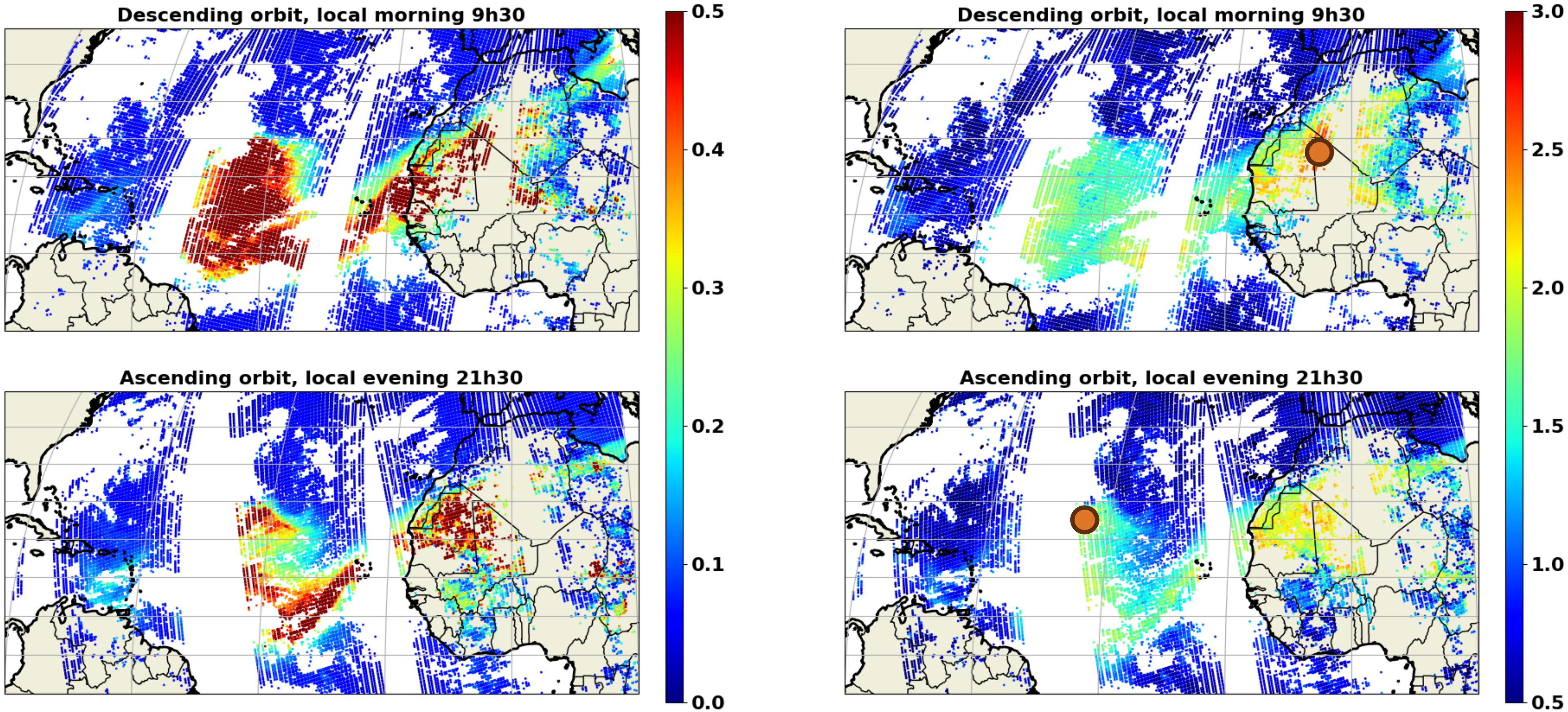
"Gain" or "contribution functions"
→ Sensitivity of the retrieval to observation

Trace(A) -> number of degrees of freedom (**DOFs**) / of independent pieces of information

see Mel Ades tomorrow and practicals on Wed 15/10

IASI dust MAPIR DOFs

Example: « Godzilla » storm, 20 June 2020

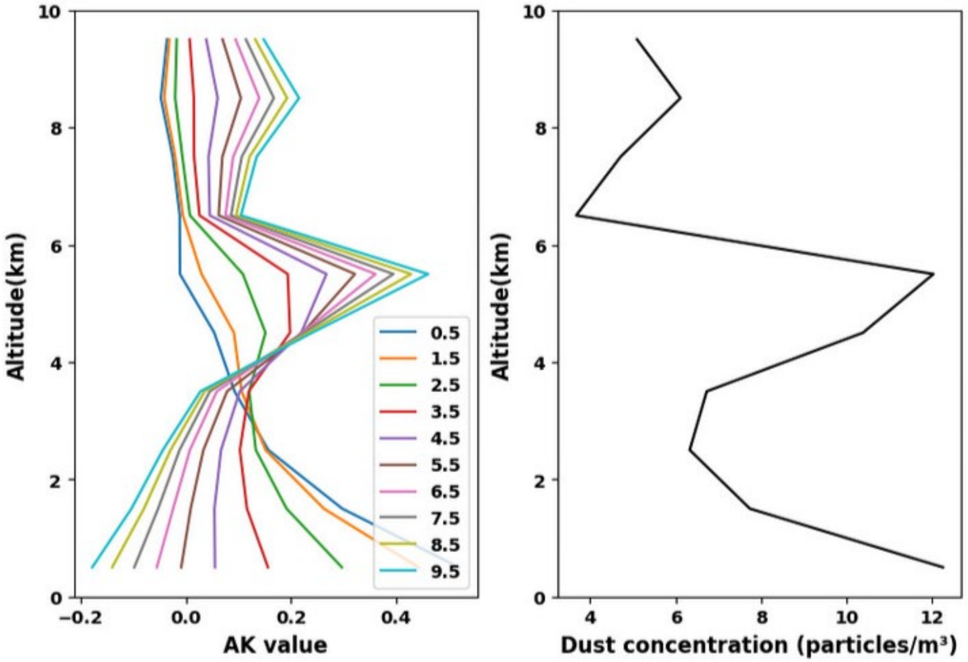


!! Retrieval runs on log(concentration) -> AKs are different, tend to peak where the dust concentration is high

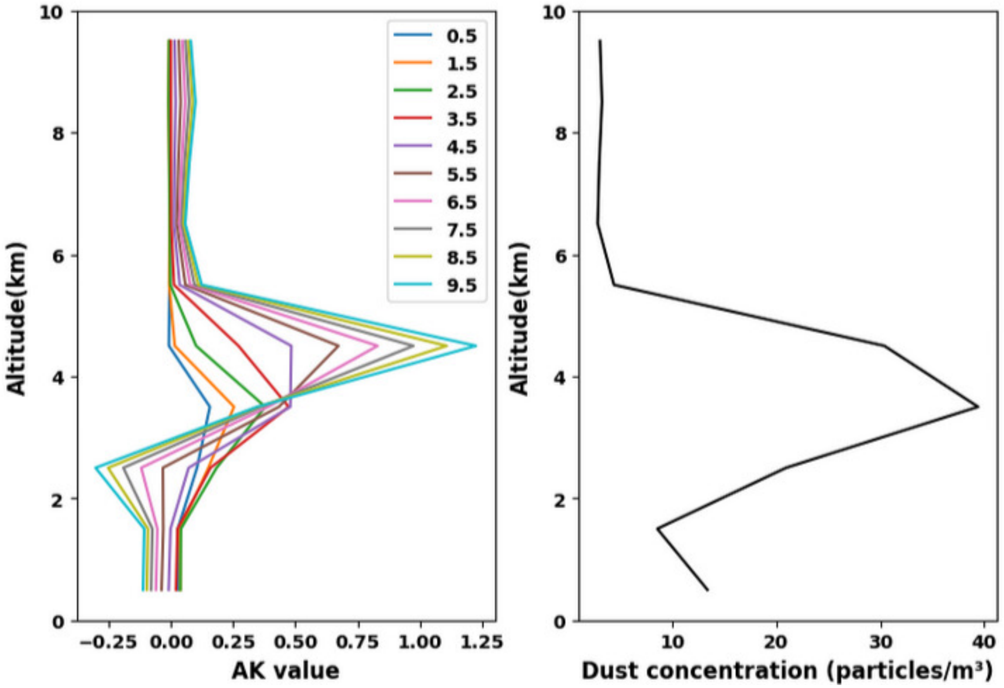
IASI dust MAPIR AKs

Example: « Godzilla » storm, 20 June 2020

Over the desert, DOF > 2



Over the ocean, DOF = 1.5



!! Retrieval runs on log(concentration) -> AKs are different, tend to peak where the dust concentration is high

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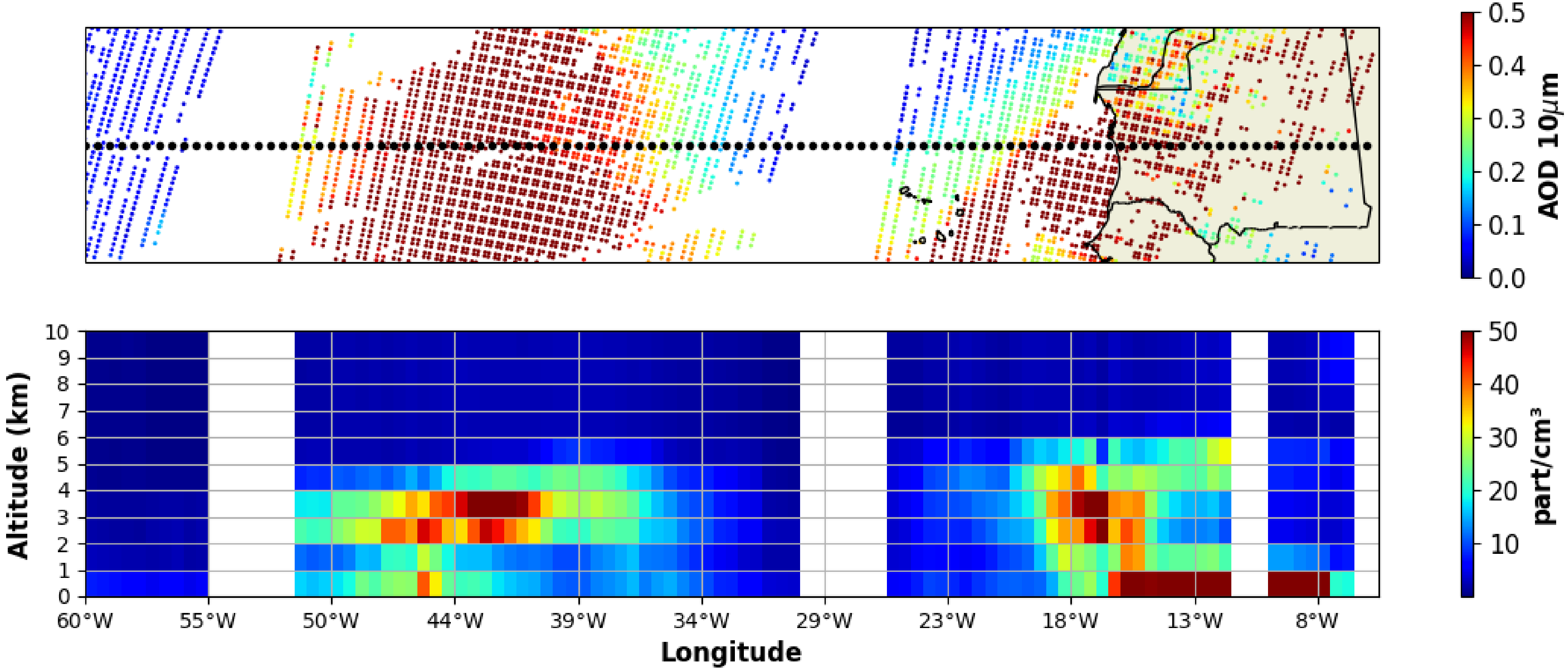
MAPIR contains profile information, can separate 2 distinct layers

20 June 2020, « Godzilla »



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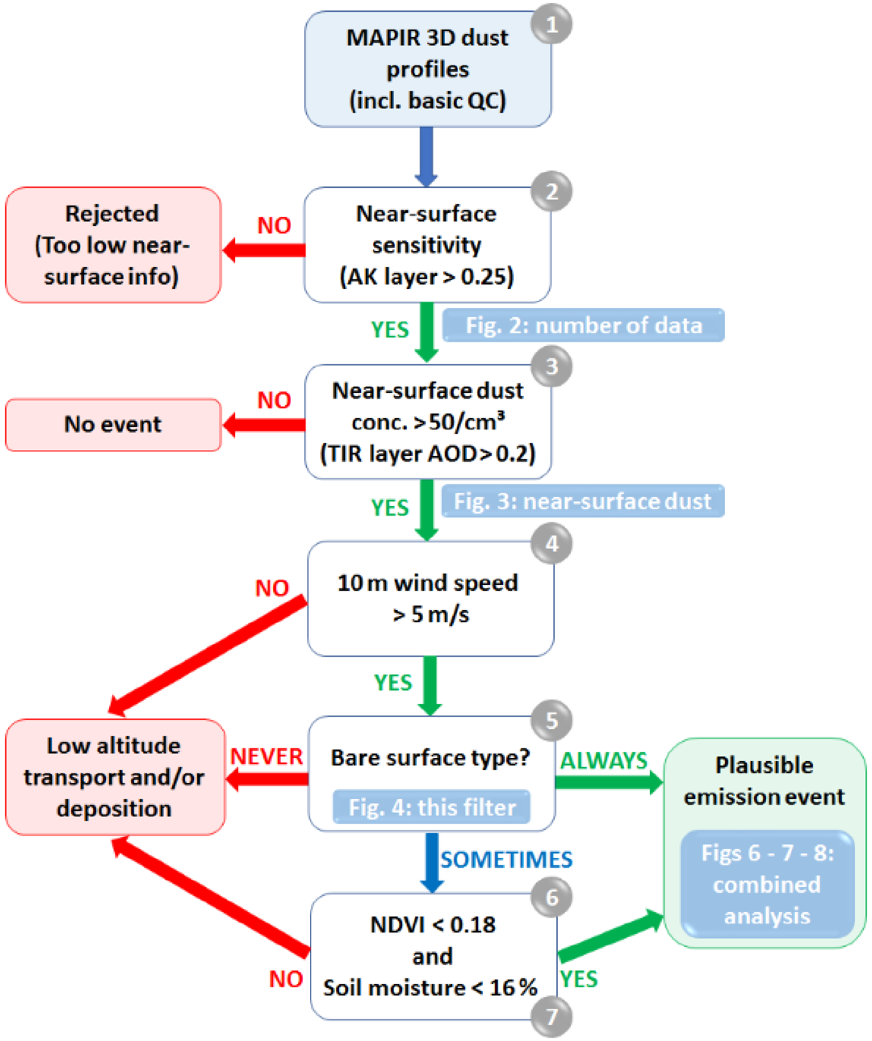
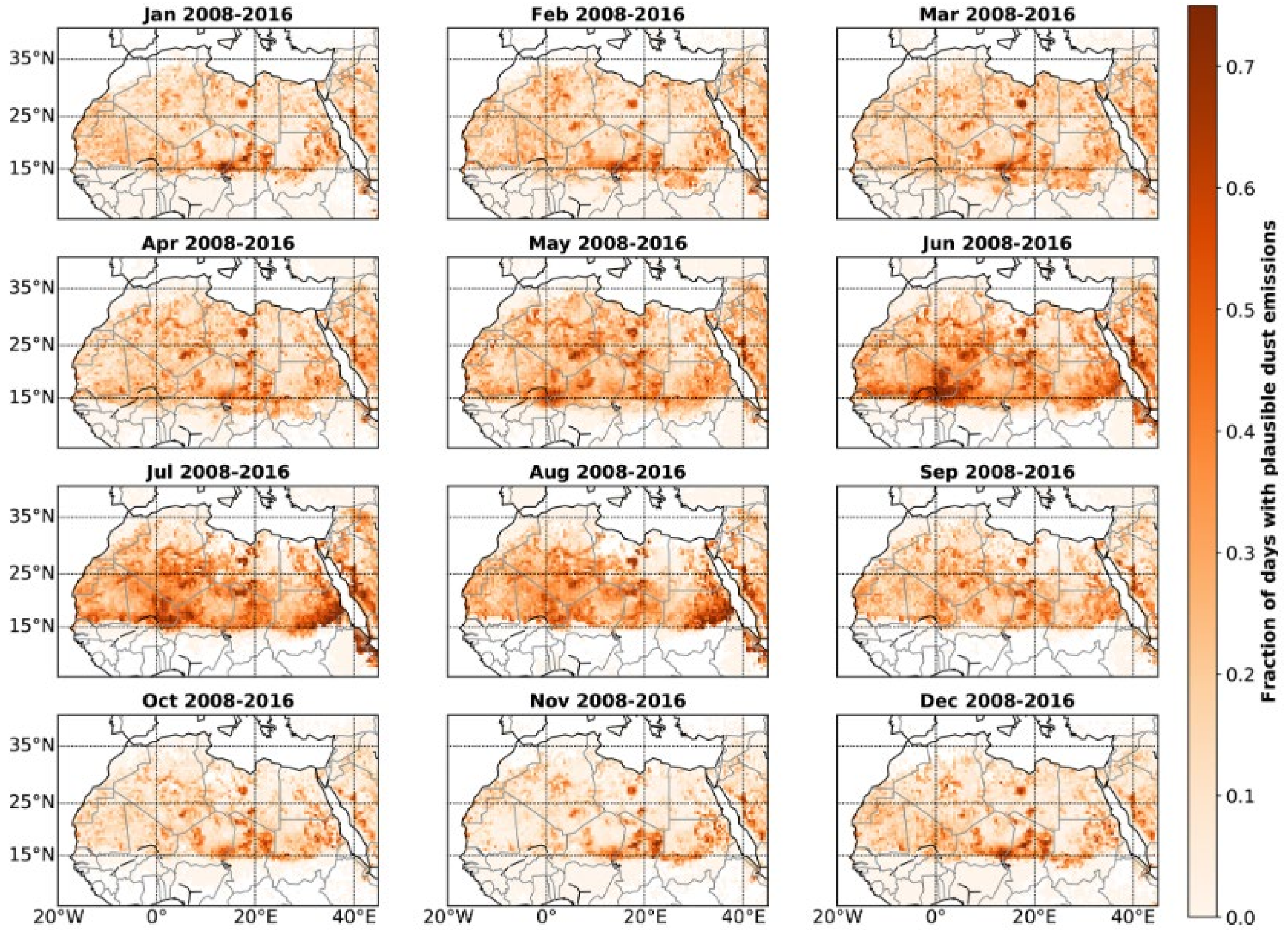
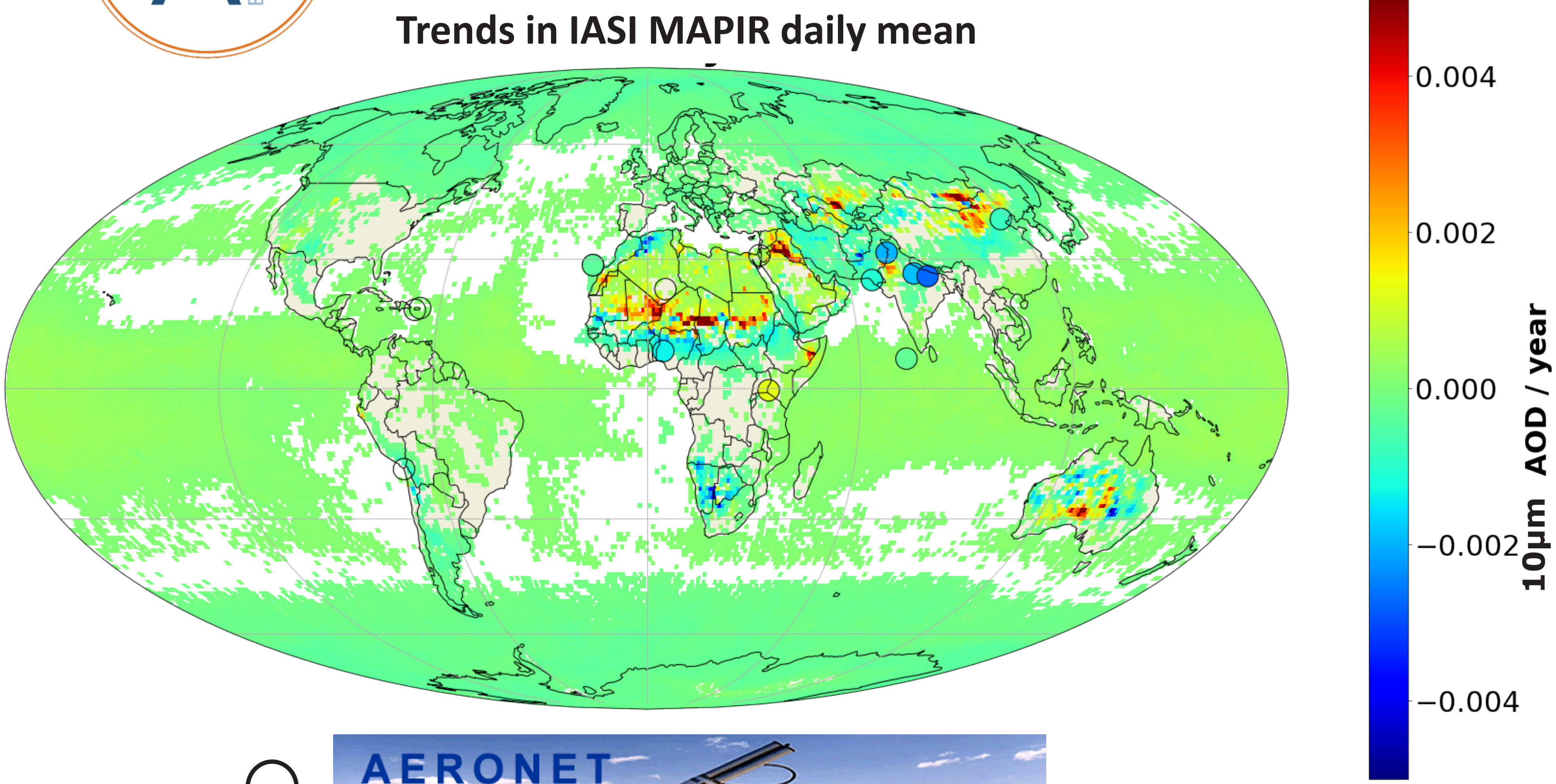
Applications? Sources analyses





Applications? Trends



IASI / Metop-A
07/2007 – 06/2021
(**14 years**)
Daily AOD
5% extreme removal
Theil-Sen estimator
Seasonal sin removal

AERONET stations:

- Coarse mode SDA AOD 500nm (dust, sea salt, volcanic)
- Stations with med CAOD>0.05
- Covering the same time span

!! AERONET trend at 500nm converted to 10 µm AOD trend !!

Applications? Aerosol alerts

- aerosol-alerts.atmosphere.copernicus.eu
  -> see Mel Ades tomorrow

- sacs.aeronomie.be
  -> see practicals on Tuesday 14/10

- dust.aemet.es (SDS WAS)

Some are in development for using IASI dust data …

Applications? Weather forecast

Mineral dust impacts:

- the atmospheric temperature profile (local heating)
- the atmospheric circulation
- the surface temperature (local cooling)
- The cloud properties, lifetime and rain amount / location

-> It needs to be accounted for in weather forecast models

-> Some thinking and discussions have started about using IASI, some centres would prefer to have geostationnary data with higher repetitions

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TIR aerosol observations: wrap up

Four algorithms… results are similar overall but not in details…

A big issue: clouds…

- Wrong classification -> no data…
- Dust is CCN and IN -> quite often mixed…

Difficult over cold surfaces and for low AOD (low sensitivity, higher uncertainty, noise, and lower information content)

« Mineral-specific » but actually requires silicates (local high-latitude dust not observed)

Thermal IR retrievals are « mineral–specific »… while other retrievals have a hard time separating different aerosol types

Night-time observations are available

Vertical sensitivity (limited) with global coverage

Always keep in mind…

IASI « sees » **coarse dust** only

IASI dust product is obtained **at ~10µm**

→ **Converting to 550nm** requires assumptions and increases uncertainty

And towards the future

IASI-NG onboard Metop-SG, launched 13 August 2025
The same AC-SAF products are planned as for IASI (dust index, AOD, profiles)
Expected small improvement in quality due to the lower spectral noise.

InfraRed Sounder (IRS) onboard Meteosat Third Generation, launched 1 July 2025
Geostationnary instrument over Europe and Africa
High repetition time, very interesting to follow emissions and plumes
Very interesting for alerts and weather forecast
Planned within AC SAF: dust flag
Project currently under evaluation: dust profiles

Some links to data

Level 3: Gridded averaged data

Level 2: each satellite obs

"descending"
"ascending"

Level 3 data (DOD, mean altitude, daily, monthly, morning / evening / combined), documentation and quality information: https://cds.climate.copernicus.eu

Level 2 data for LMD (with mean altitude) and ULB: https://www.aeris-data.fr

Level 2 data for MAPIR (with vertical profiles): http://iasi.aeronomie.be

Near-real-time data through EumetCast:
- ULD AOD and dust index (level 2)
- Soon: MAPIR profiles, AOD and mean altitude

Some references

Retrieval algorithms (not always the last version)

- ULB: 10.1029/2018JD029701
- LMD: 10.1016/j.rse.2017.12.008
- IMARS: 10.1016/j.rse.2014.09.036
- MAPIR: 10.5194/amt-12-3673-2019

MAPIR applications:

- Sources:10.5194/acp-20-15127-2020
- Trends: presented at conferences only

Thank you!

Questions are welcome.