Aerosol typing from remote sensing observations

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CNR-IMAA

inDust

EARLINET

ACTRiS

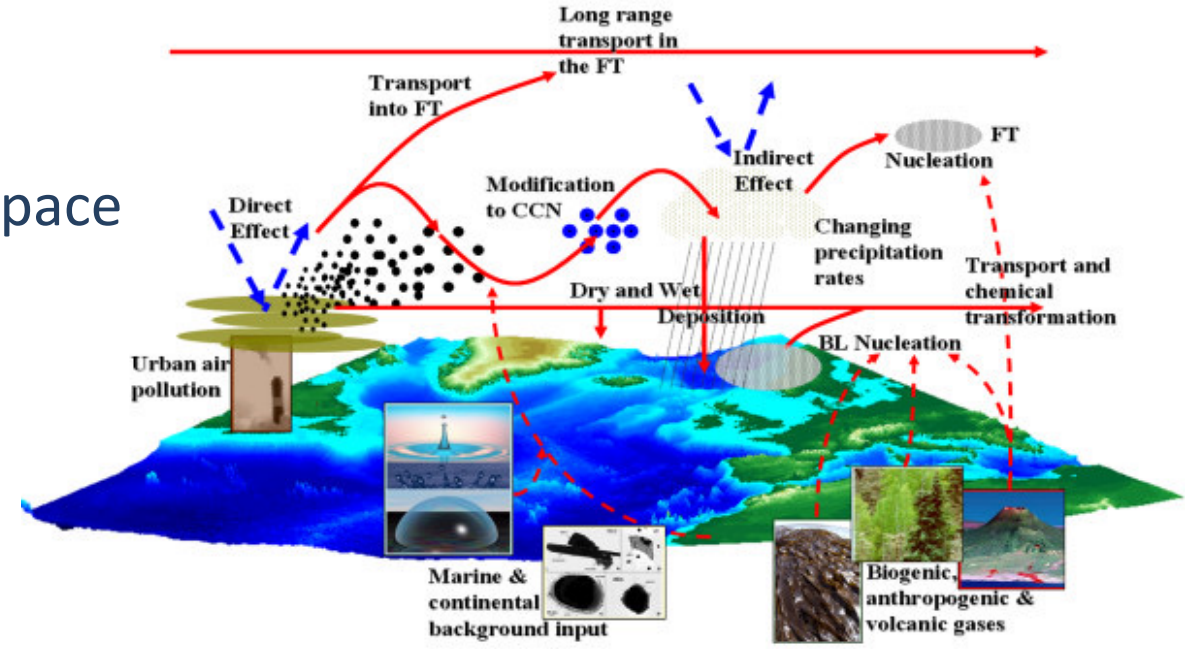
What we will talk about

1. Aerosol typing topic – why relevant
2. How to “know” type of aerosols
3. AEROSATinitiative -WG
4. Aerosol typing review
5. Main actions identified in AEROSAT
6. Comparison of typing scheme – not trivial
7. Applying obs typing scheme in models
8. One type –comparison- dust
9. Conclusions

Impact of different aerosol types

Aerosol: is a suspension of fine solid particles or liquid droplets in air (*Wikipedia*)

Highly variable in space time and composition



Health

Some types related to small particles and certain compositions have larger impacts

Air quality

Natural transported contribution to PM10-2.5 can be subtracted

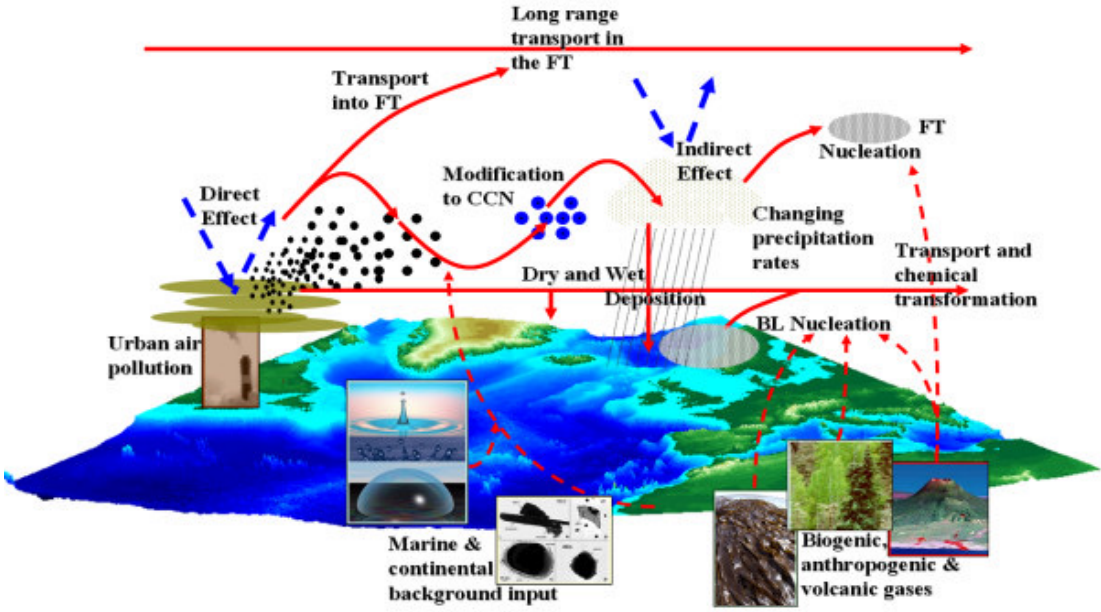
Impact of different aerosol types

Climate change

Absorbing aerosols have a positive impact, while reflecting ones reduce the effects of greenhouse gases

Precipitations

Dependign on size and shape, aerosol can be more effective for occurences of strong events



Aerosol typing – why relevant

Knowing the type of the aerosol can help to:

- **understand** sources, transformations, effects, and feedback mechanisms.
- **improve** accuracy of satellite retrievals; test aerosol models; and
- **quantify** assessments of aerosol radiative impacts on climate.

Aerosol typing – why relevant

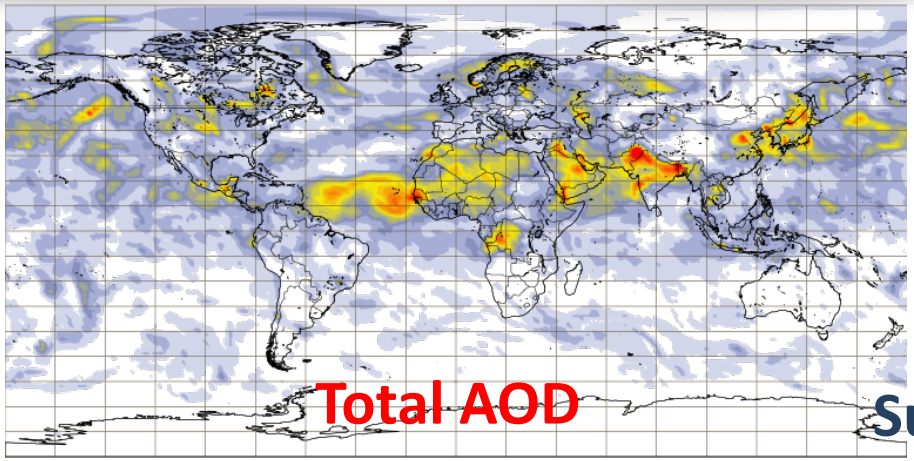
IMPORTANCE

- **impact of the different aerosol sources on climate, precipitation and air quality**.
- **aerosol emissions policies**
- **local authorities and hazards**

The **inhomogeneity** among satellite (and not only) aerosol **typing schemes decreases** fundamental long-term datasets (multi sensors) **consistency**

CAMS example

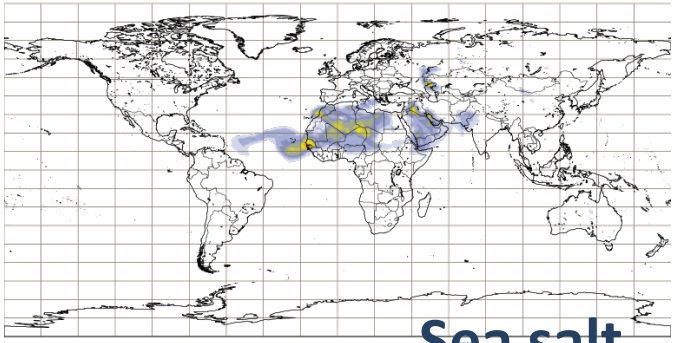
Forecast 15 May 2021
03 UTC



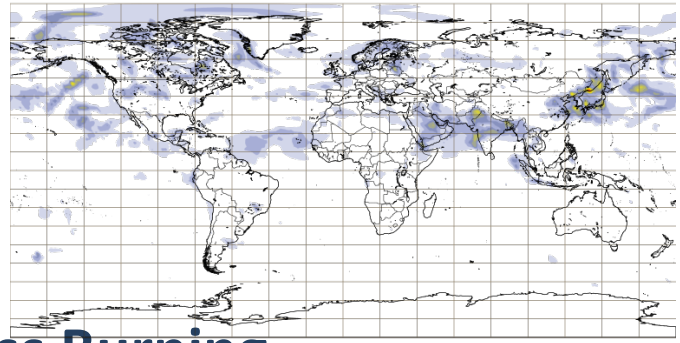
Total AOD

http://atmopsphere.copernicus.eu

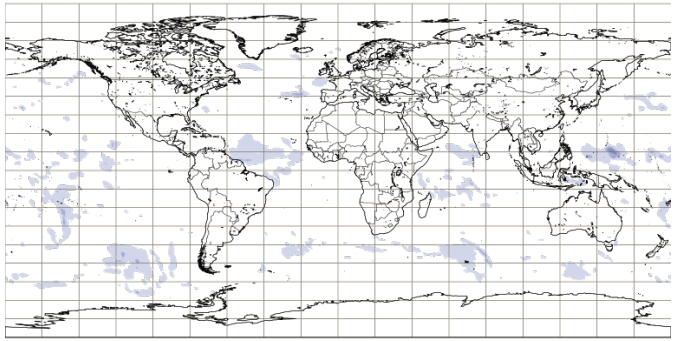
Dust



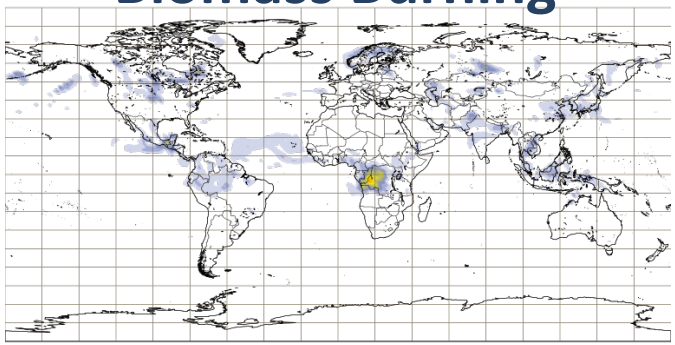
Sulphate



Sea salt



Biomass Burning



How to know about aerosol types

MODELS

- Emission inventory
- Emission model
- Meteorological field for transportation

MEASUREMENTS

Sampling

Chemical composition

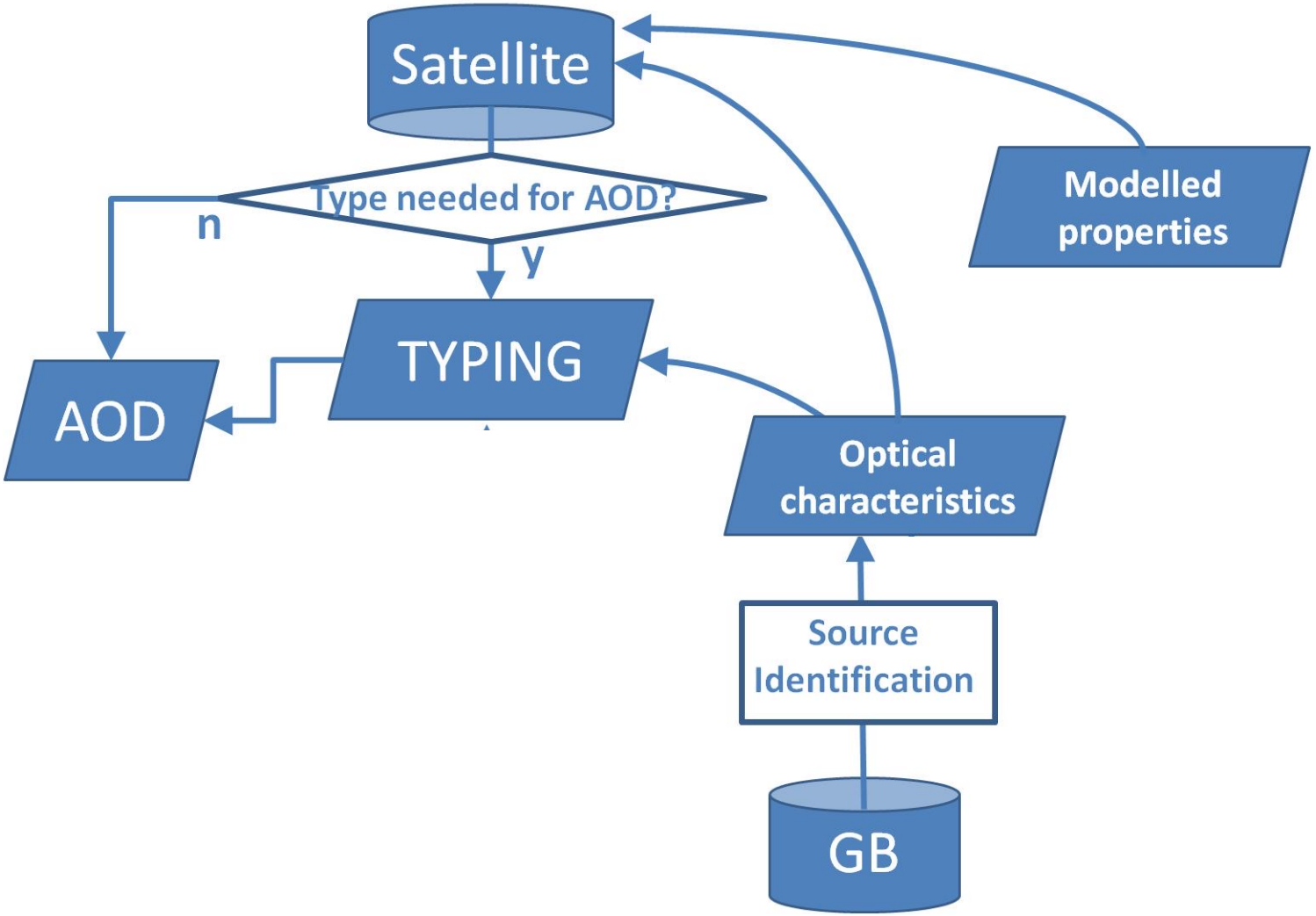
Size characterization

Shape observation

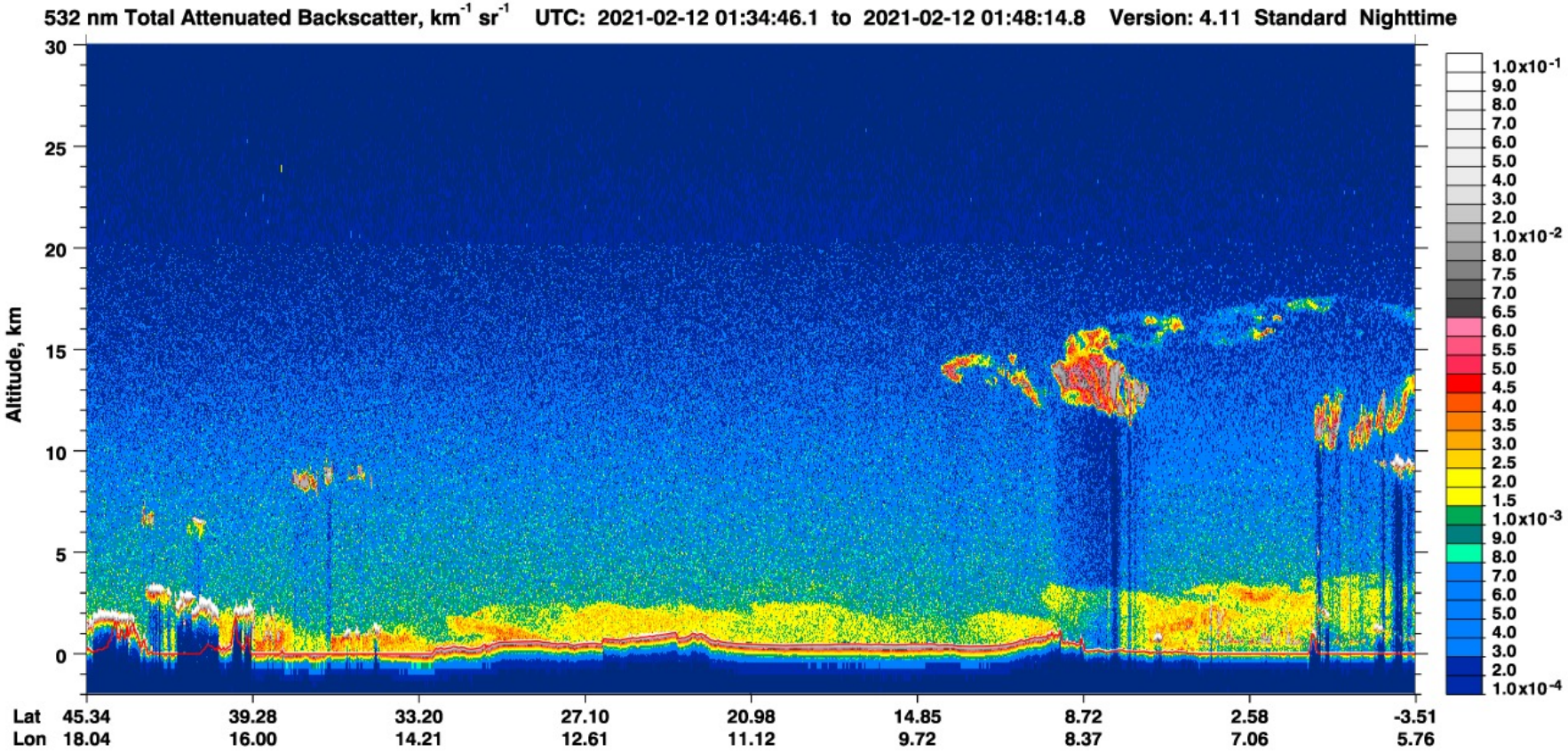
Remote sensing

Optical properties characterization

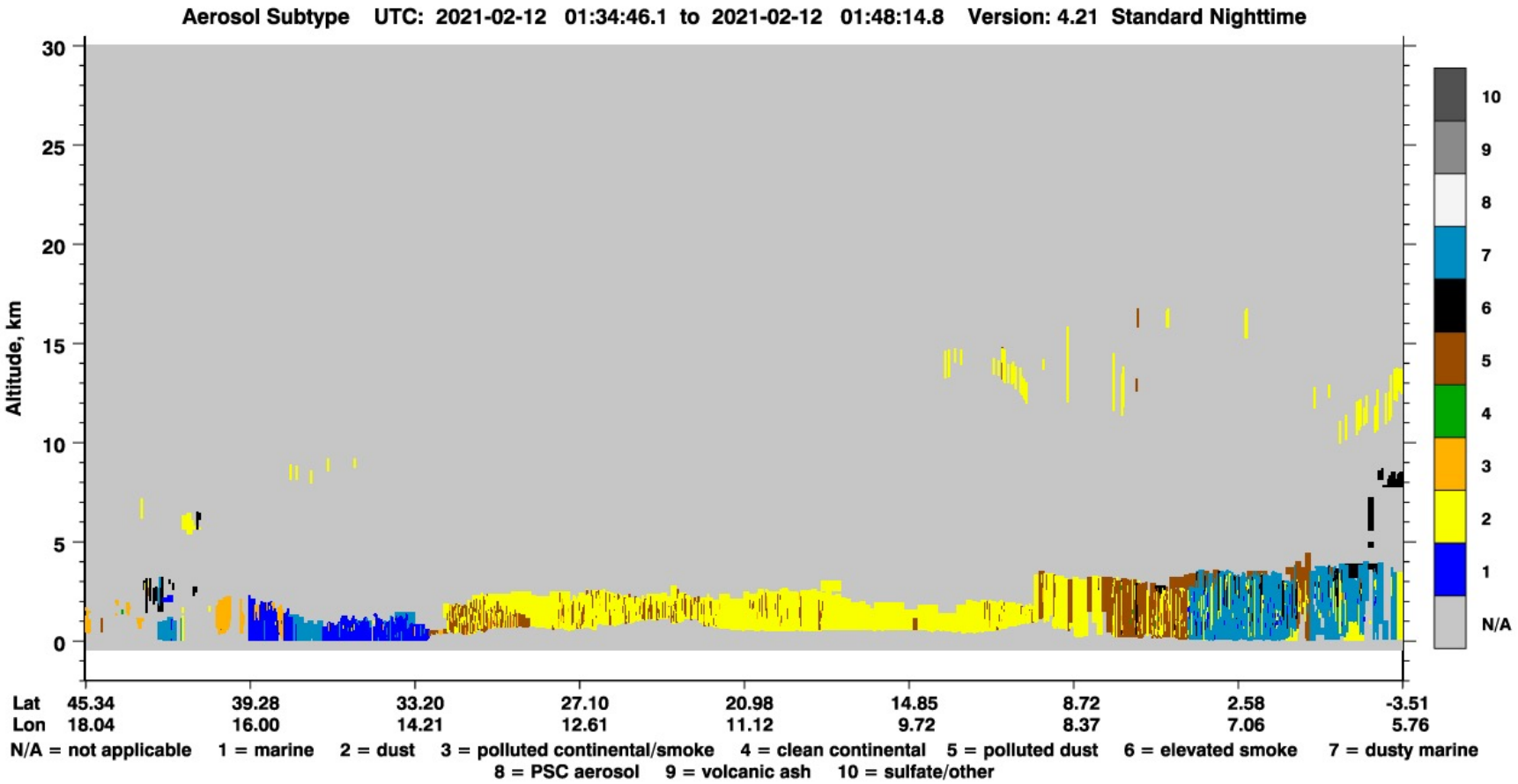
How to know about aerosol types
The general approach



An example: CALIPSO



An example: CALIPSO



Different types provided… but how it works?

An example: CALIPSO

CALIPSO is a backscatter lidar

Basic equation has 2 unknowns: aerosol extinction and aerosol backscatter

CALIPSO to solve it assumes the ext/back ratio time by time altitude by altitude

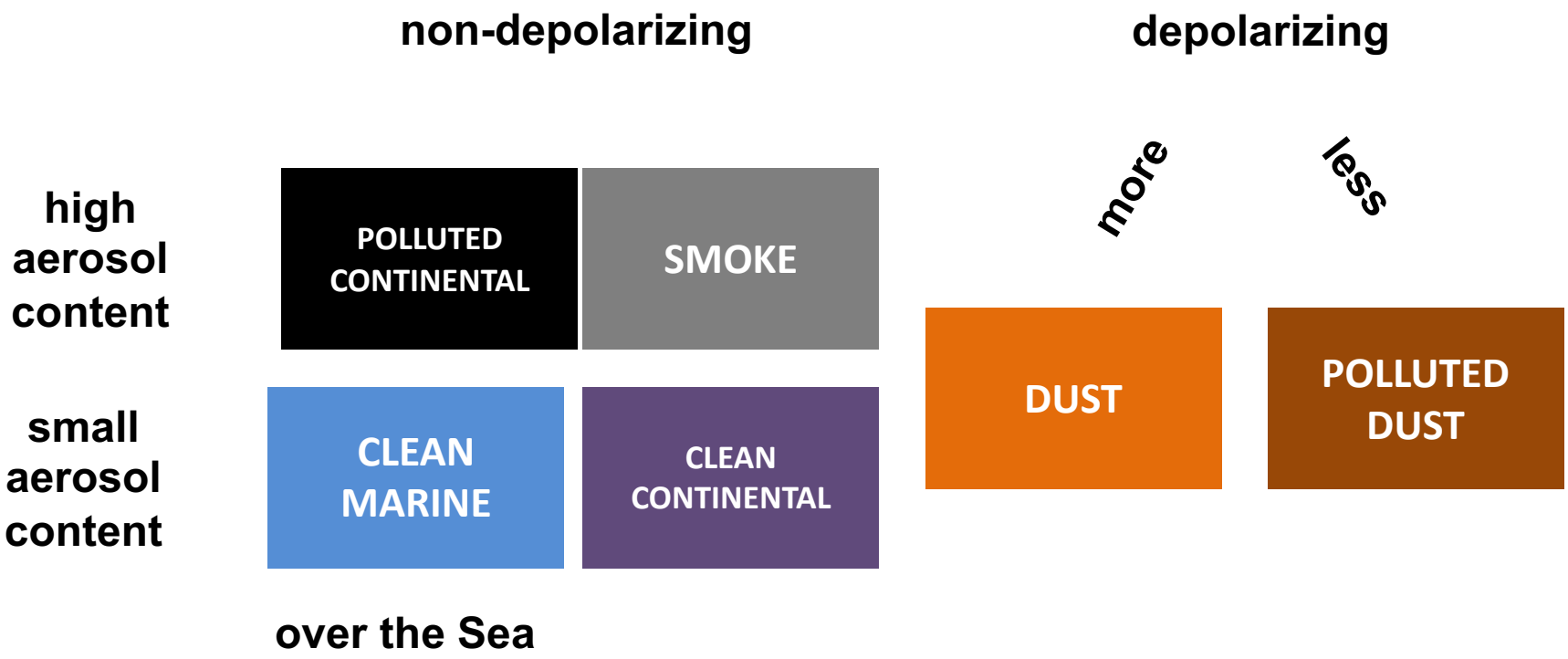
HOW?

Look up table on the base of aerosol typing

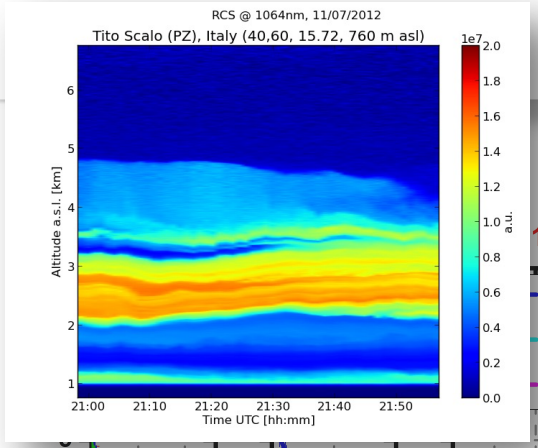
So the **products** (extinction and backscatter) **are the result of the typing scheme**

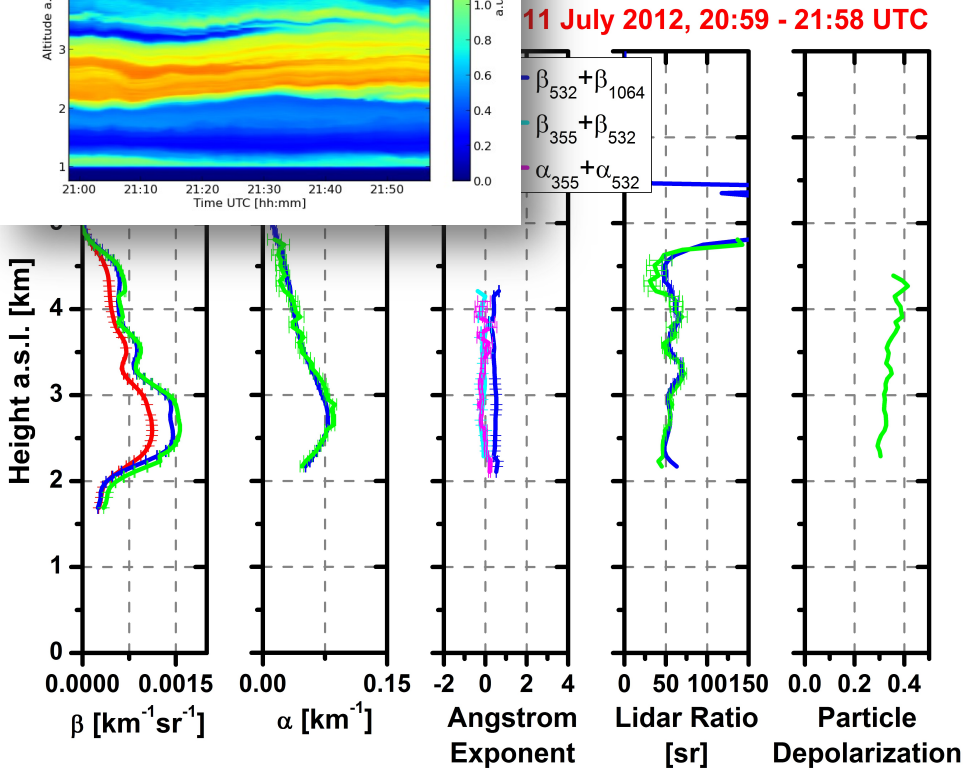
An example: CALIPSO

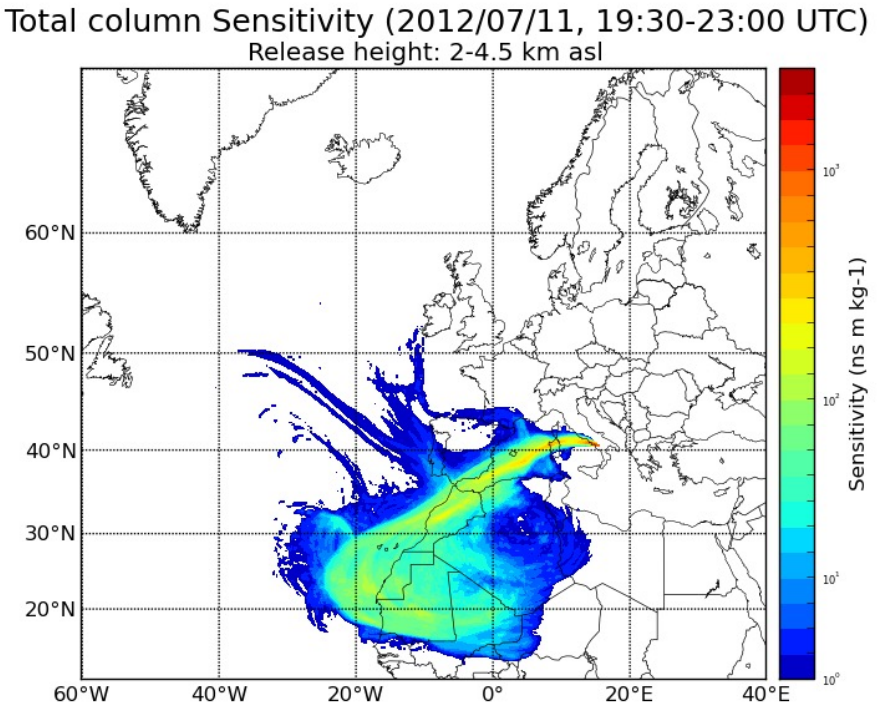
CALIPSO typing based on assumptions and needed for retrievals



GB lidar typing methods







- AE indicates coarse particles (values around 0) ➔ could be dust
- LR mean values of 56.7±6.1 and 54.1±10.1 sr, for 355 and 532 nm in respective ➔ probably dust

- Linear particle depolarization ratio of 34±3 % consolidates the hyp➔ Dust
- Finally, backward trajectory analysis indicates the pathway travelled of air masses ➔ foothills of Atlas

How to know about aerosol types
The general approach

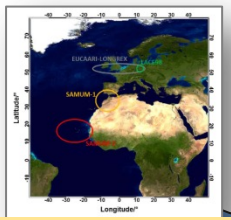
Identify the source for defining the aerosol characteristics

Investigate characteristics for understanding the source

More common in Ground Based observations

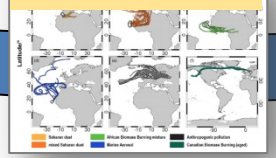
More common in satellite observations

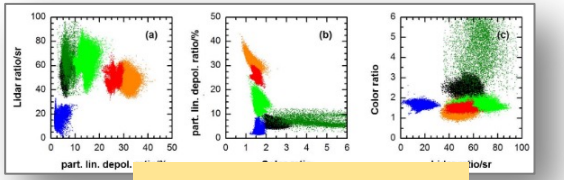
Input for defining automatic procedures for typing



Measurements

Sources

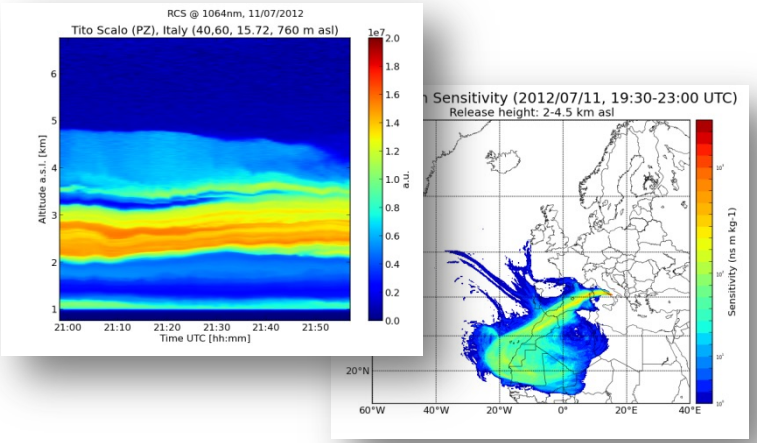




Procedures

Optical classification scheme

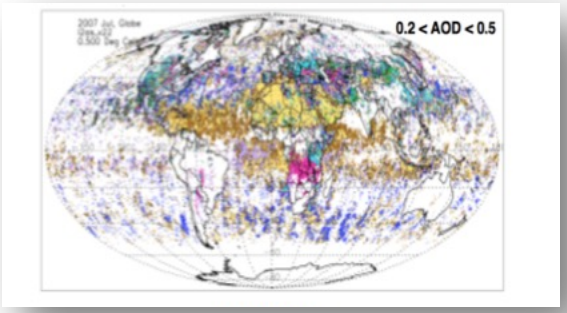
- GB observation + info for source determination allows for clustering observed optical properties respect to the source



- Unique “assured” information are ones related to optical measured properties



Kahn & Gaitley JGR 2015



- Satellite retrievals often rely on inferred types

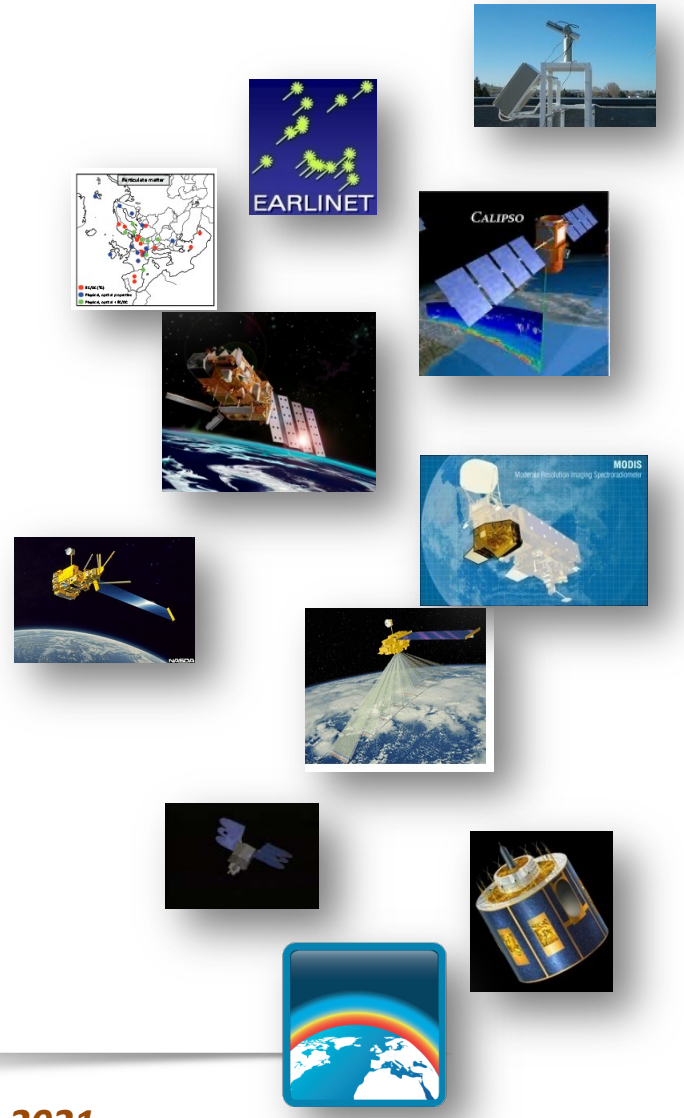
AEROsat Aerosol typing working group

- The International Satellite Aerosol Science Network (a.k.a. **AEROSAT**) is an initiative to help strengthen collaboration between different research groups around the world working on satellite aerosol retrieval.
- AEROSAT is an unfunded activity intended to be of **mutual benefit to the scientific work** of the network participants.
- **Aerosol typing WG:** Review methods to retrieve information on aerosol type from satellite and ground-based remote sensing.

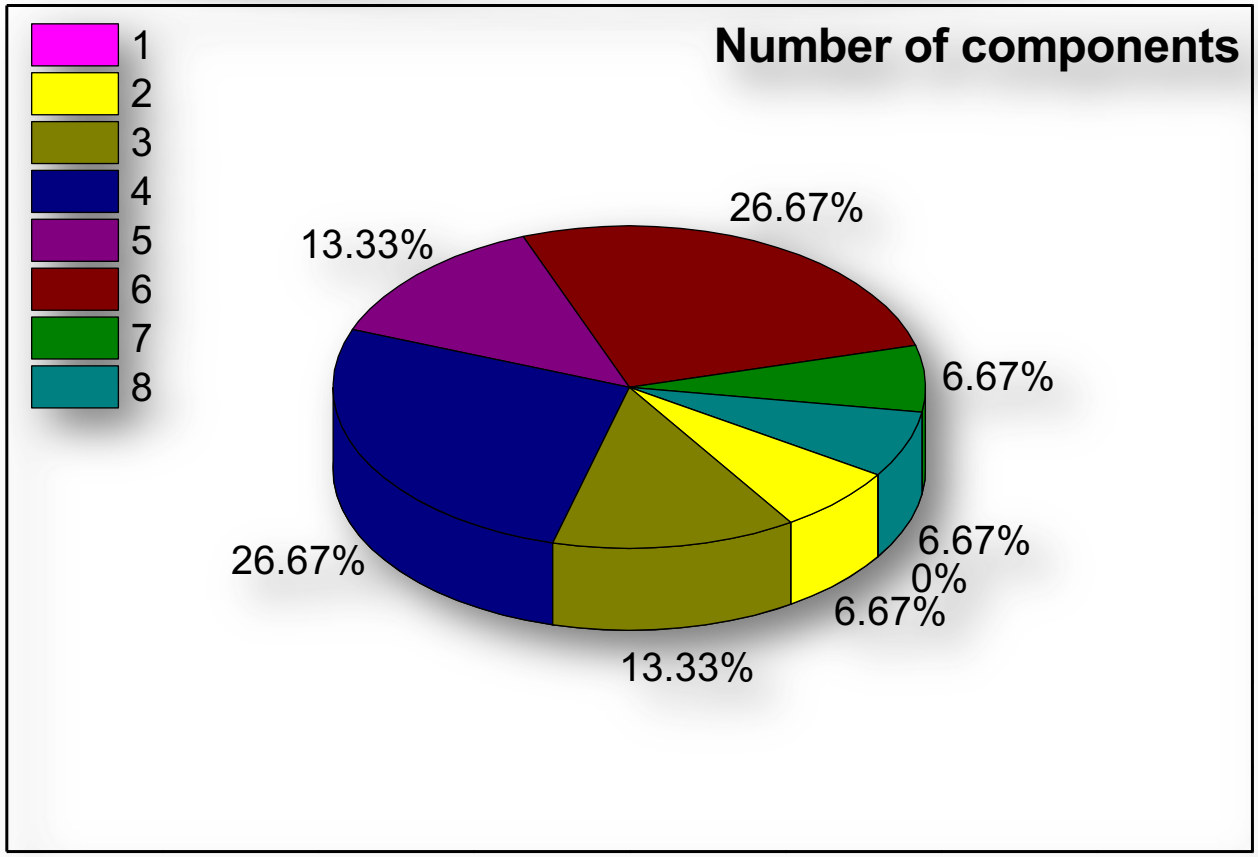


Overview of typing procedures

- 21 aerosol typing procedures included in the review
- 15 classify particles in source classes with an interpretative scheme
- 6 stays with the optical observables

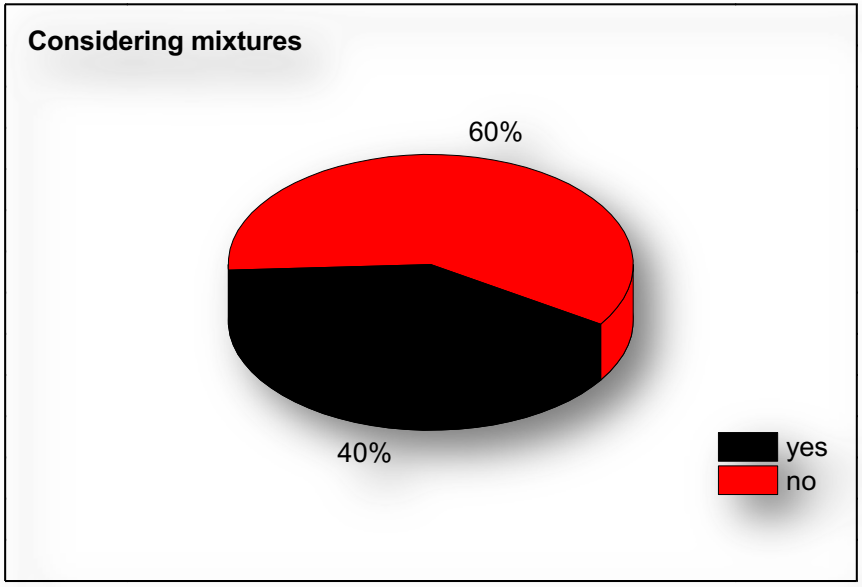


Review of typing procedures



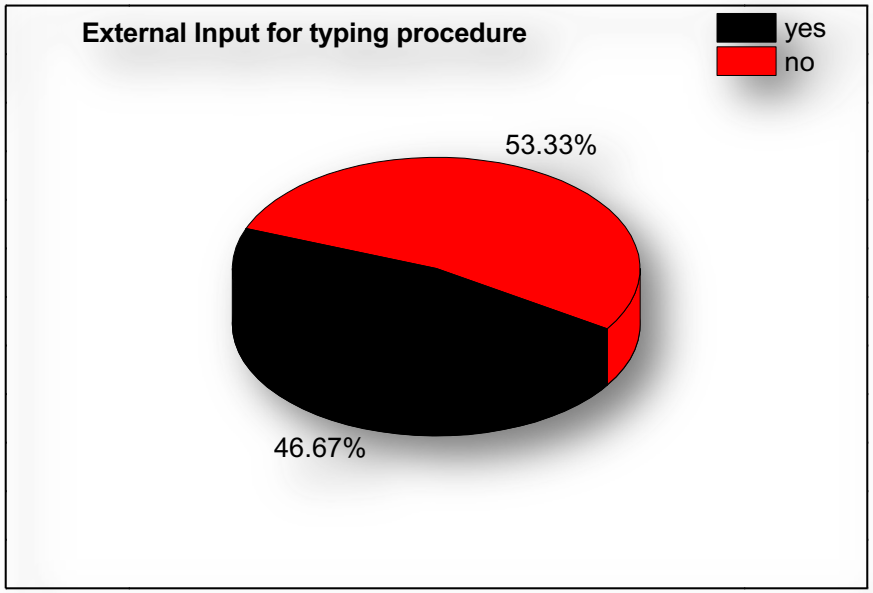
Even if different the aerosol typing procedures typically classify aerosol in 4-6 types. Never exceeding 8 components.

Review of typing procedures



Some algorithms take into account the possibility of mixtures between components.

Typically external inputs are datasets from GB measurements or from models + in some cases info about the locations



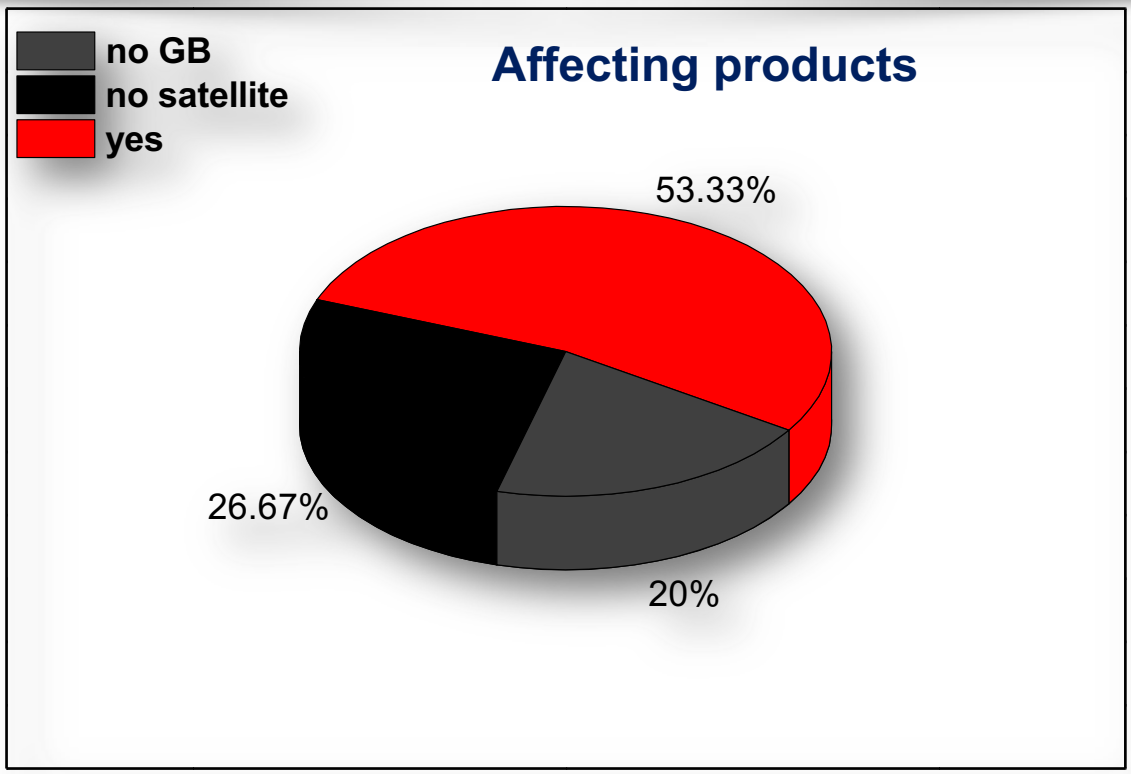
Nomenclature issue

The nomenclature is very heterogeneous among different platforms.



6 main classes could be identified grouping the different nomenclatures.

Review of typing procedures



Typically, aerosol retrievals from satellite measurements make a priori assumptions about aerosol type, and the accuracy of the derived aerosol products strongly depends on the reliability of these assumptions.

NOMENCLATURE

Different platforms use different names for “the same” aerosol type.

Just one easy example:



In some cases different names are also indicating some differences in physical meaning.

One example: DUST

DUST *word is used very often to mean desertic particles....*
but ***DUST*** *is also used in different community for coarse particles in general*



Important to avoid not-needed confusion

- Within remote-sensing community
- With respect to near-surface and modelling communities
- Taking into account “external” user

One example: DUST

DUST *is typically identified thanks to its asphericity and dimension.*

- Angstrom exponent + Angstrom exponent curvature [AERONET-Gobbi 2007]
- Desert region [AERONET-Catrall 2005]
- Particle Depolarization Ratio + Attenuated Backscatter+ Location [CALIPSO-Omar 2009]
- Particle Depolarization Ratio [EARLINET- Gross]
- Particle depolarization Ratio + Angstrom +Lidar Ratio + Backtrajectories [EARLINET Wandinger 2010]
- Brigthness temperature at 800 and 1200 cm−1+ clean scenario reference [IASI Clarisse 2013]
- Radiances /models for AOD + Angstrom + SSA [MISR Kahn 2015]
- Reflectance at 440, 412 and 2130 nm [MODIS, Ciren 2013]

One example: DUST

- Different observables
- Same observable : Different “thresholds”?

Linear Depolarization Ratio 0.3-0.35 Pure Dust [HSRL Burton]
Linear Depolarization Ratio >0.2 Pure Dust [Omar et al., 2009]

- Combination of observables
- External constraints

How change the different observables with particles properties changes?

Typing procedures - overview

- Confusing and misleading **nomenclature**
- Remote-sensing can provide **optical constraints** interpreted as **particle size, shape, and indices of refraction**
- A further **interpretative step**, entailing additional assumptions, reports particle **Source/Chemical Composition**
- **Validation Data** for aerosol type are very **limited**
- **Model** simulations and **in situ** measurements can help



Needs

- Making clear the variety of typing meanings, names, procedures
- Review the differences and try to explain them
- Identify gaps and further needs
- Comparing algorithms
- Overcoming limitation in reference datasets

AEROSAT plans



Identify a set of observation for typing

- **Comparing typing procedures**

(for this we should probably try to start from ground-based measurements, which are limited datasets, and check for satellite matches)

-Providing a reference dataset and a **link with the modeling community**

(also models typing and outputs could be relevant for this kind of database)

-collecting a set of measurements from each sensor for each aerosol type to be used as a **Reference database for aerosol typing** (REDAT)

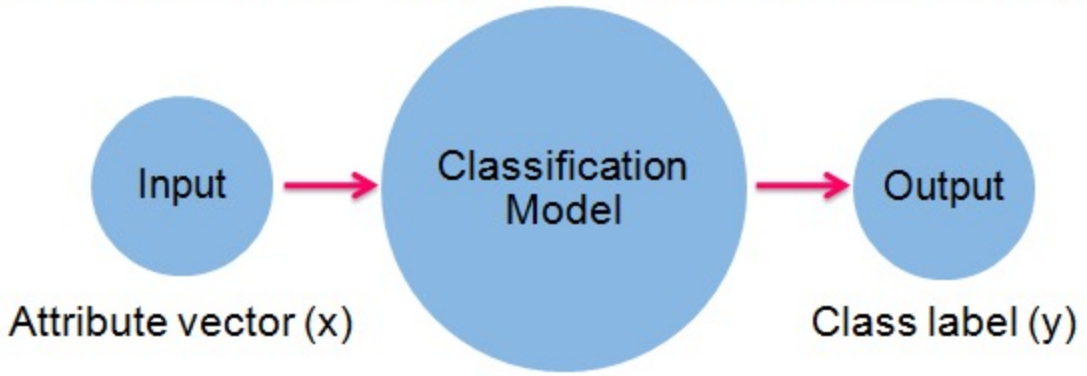
Comparing typing procedures

Aerosol typing within EARLINET/ACTRIS

A lidar stand-alone procedure has been realized in harmonization efforts with aerosol typing from HSRL lidar in US.

Method:
a distance-based multivariate analysis depending only on lidar intensive properties [Burton et al., 2012].

The method is set up using a training dataset and then results of the method are compared vs manual typing of the data (backtrajectories analysis + model inputs + satellite images).

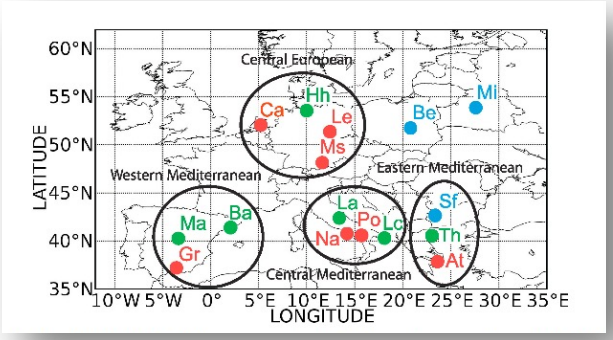


Papagiannopoulus et al., ACP 2018

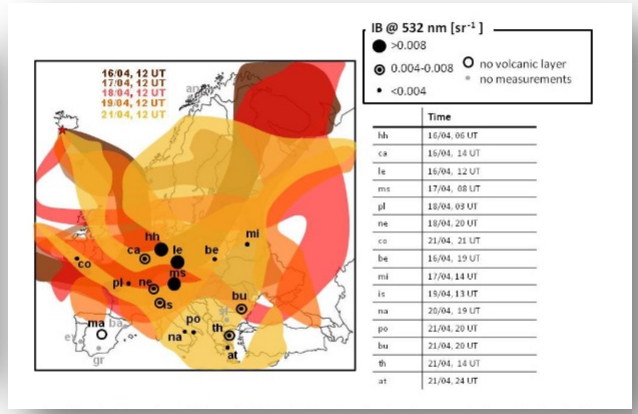
EARLINET/ACTRIS Reference dataset

Using published and full characterized data

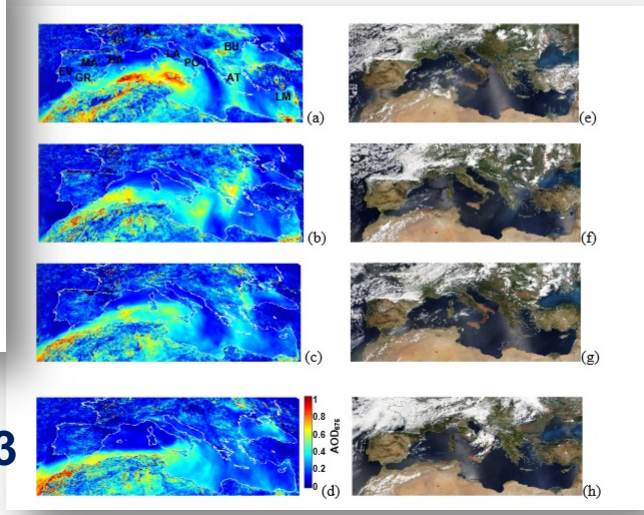
1. **CALIPSO- EARLINET dataset**
2. **Eyja volcanic eruption EARLINET dataset**
3. **ACTRIS summer 2012 campaign**



1. Pappalardo et al., JGR 2010



2. Pappalardo et al., ACP 2013

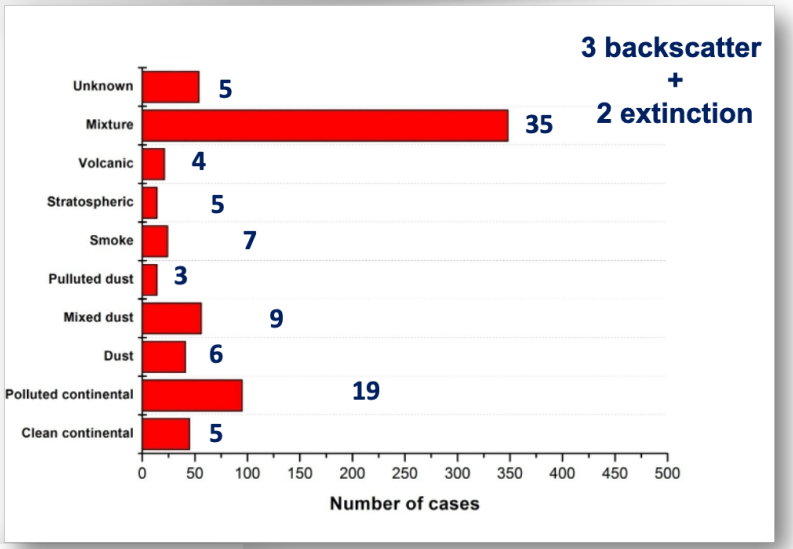


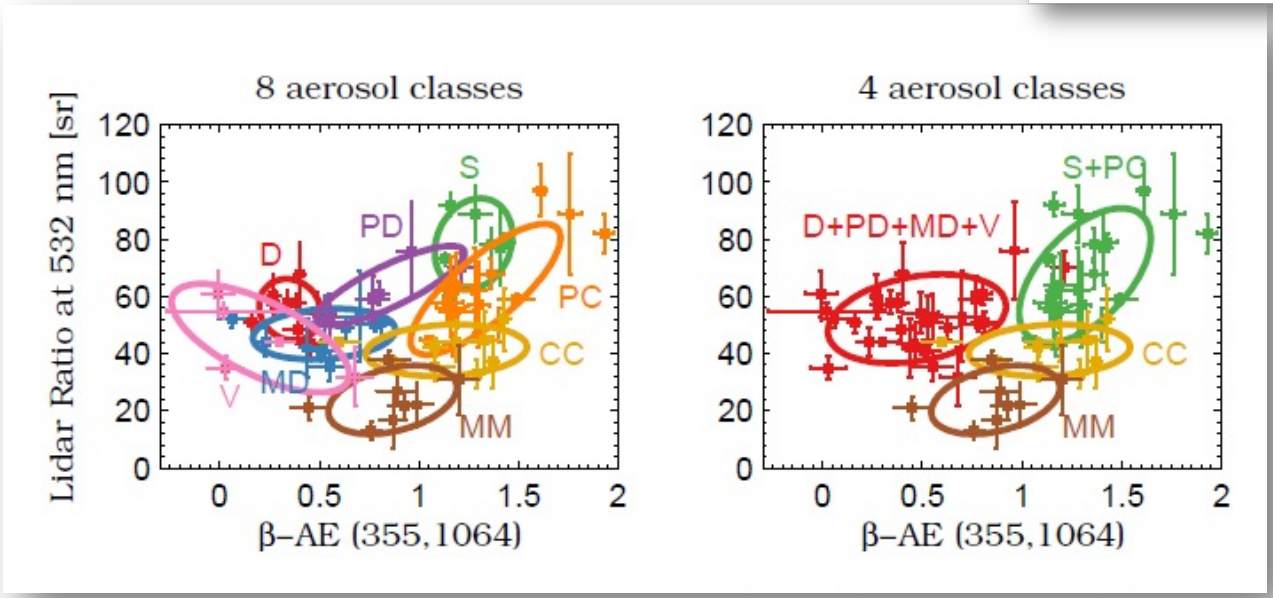
Papagiannopoulus et al., ACP 2018

3. Sicard et al., AMT 2015

EARLINET/ACTRIS Reference dataset

712 cases in total





Papagiannopoulus et al., ACP 2017

Aerosol typing within EARLINET/ACTRIS

Backscatter Angstrom 355/1064 nm + Lidar Ratio at 355nm + Ratio of lidar ratio 355/532 nm

4 clusters

Clean continental	Mixed marine	Absorbing particles	Dust & dusty mixture	Good 87%

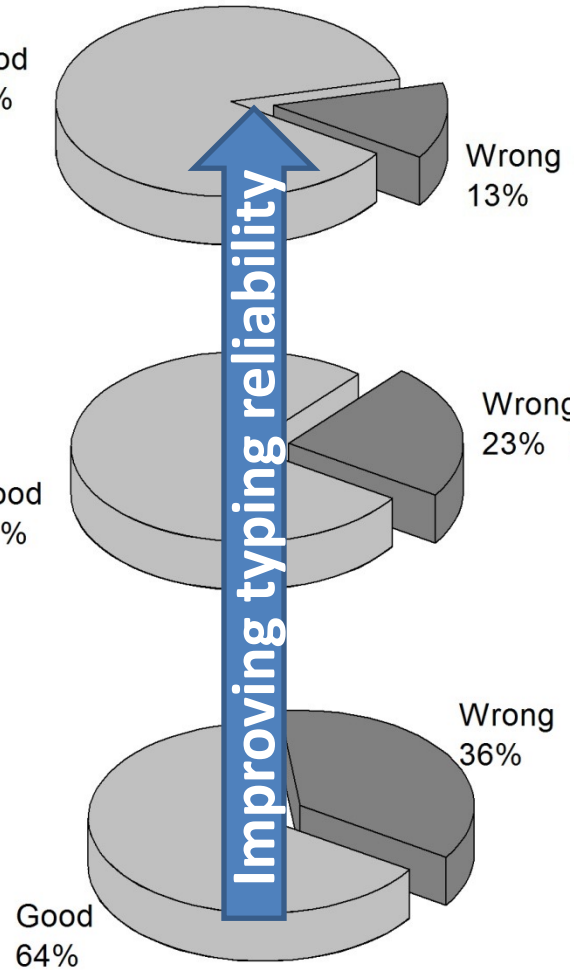
6 clusters

Clean ontinental	Mixed marine	Absorbing particles	Dust Polluted dust Mixed dust	Good 77%

7 clusters

Clean ontinental	Mixed marine	Polluted continental Smoke	Dust Polluted dust Mixed dust	Good 64%

Improving insight



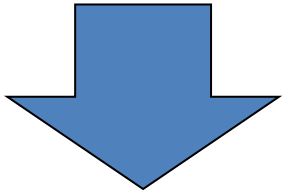
Aerosol typing in EARLINET/ACTRIS

Different procedures within EARLINET ACTRIS:

This stand-alone method

Neural network based on observations trained on real data and modelled data

Cluster identification based on obs +models



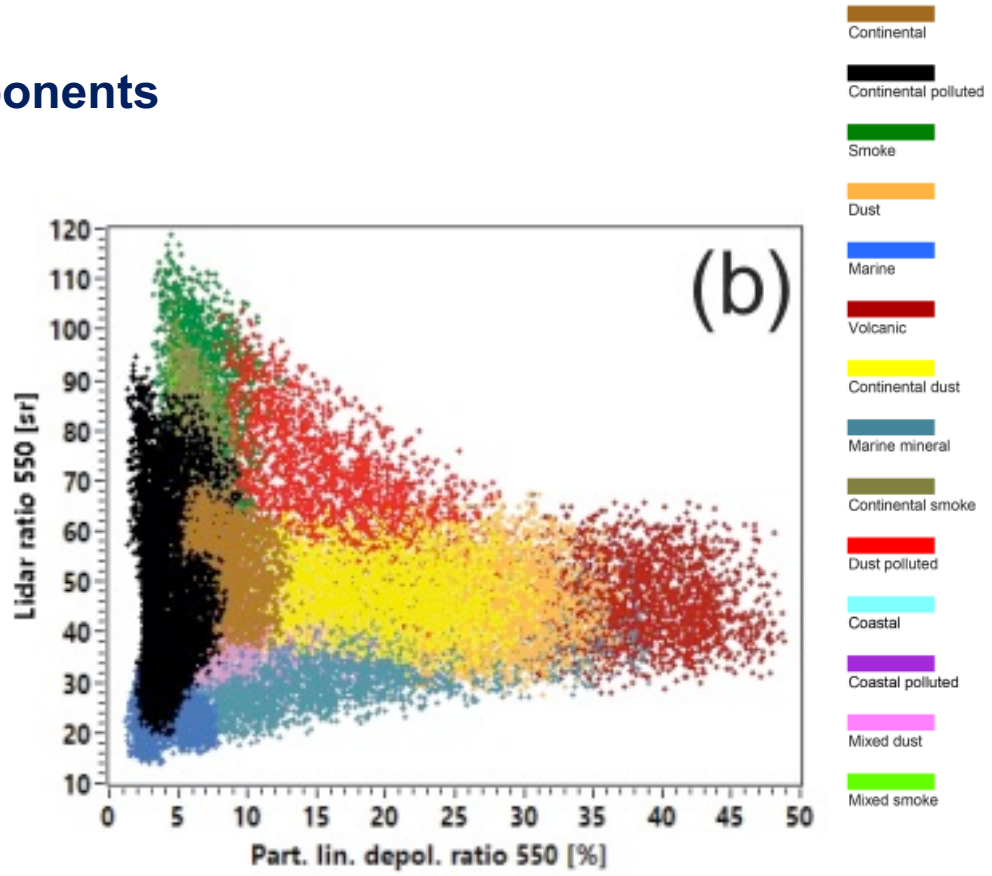
Comparisons for improving reliability knowledge

Comparing Aerosol typing in EARLINET/ACTRIS

NATALI- Neural network aerosol typing algorithm based on aerosol lidar data

Neural network algorithm based on OPAC + RH,
GDAC microphysics
Mischenko spheroidal model
Linear mixing of different components

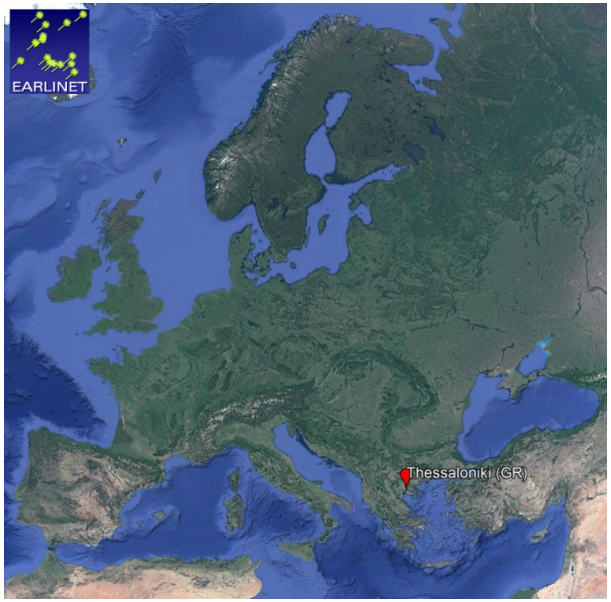
Nicolae et al., ACP 2018



Comparing Aerosol typing in EARLINET/ACTRIS

Systematic comparison of the 2 EARLINET algorithms on

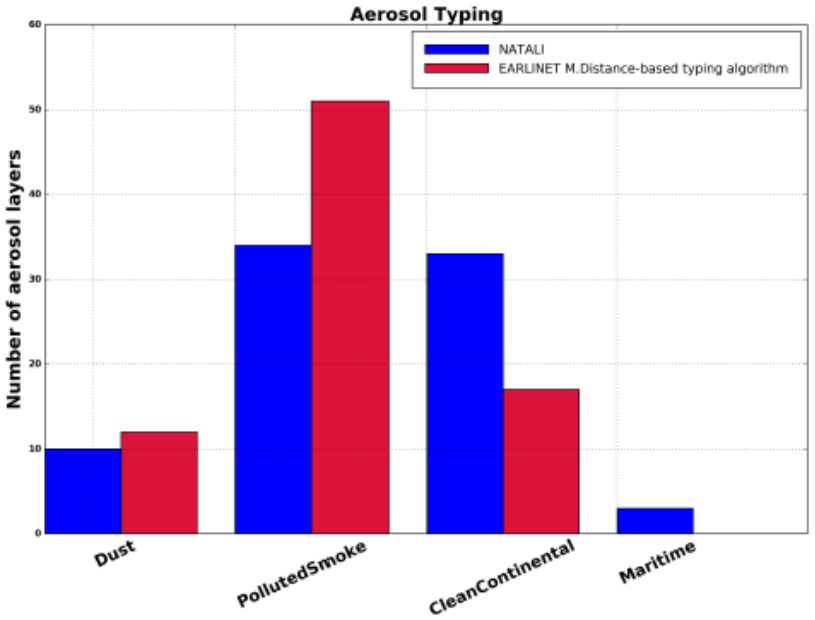
- 54 Raman lidar cases of aerosol measurements (backscatter coefficient profiles at 1064nm, 532nm and 355nm, as well as the extinction coefficient profiles at 532nm and 355nm)
- Thessaloniki
- period 2012-2015



The 2 methodologies agree on the Thessaloniki characteristics in terms of typical aerosol content

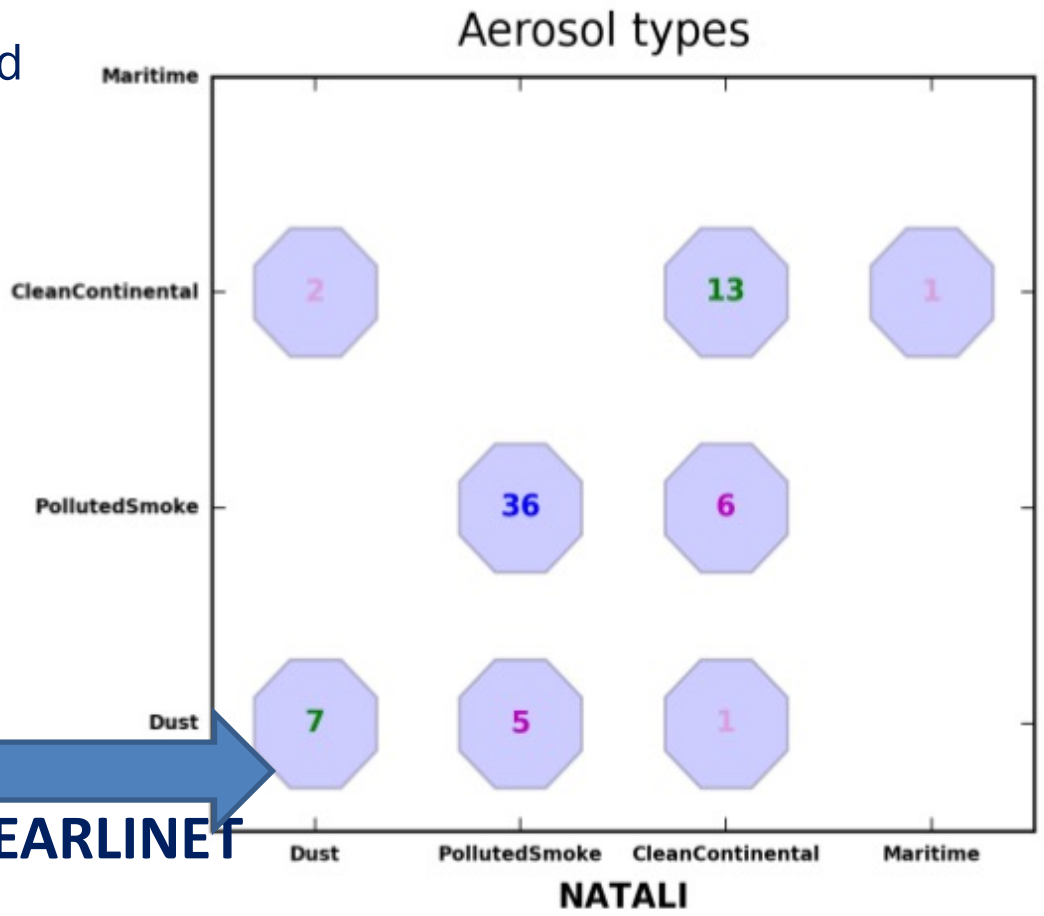
Vodouri et al., submitted ACPD 2018

Classes rearranged for doing the "comparison"



Comparing Aerosol typing in EARLINET/ACTRIS

- Comparison not trivial
- Mahanalobis method affected by the low number observed cases for maritime and clean continental cases in training dataset
- Typing difficulties in discriminating dust and polluted/smoke

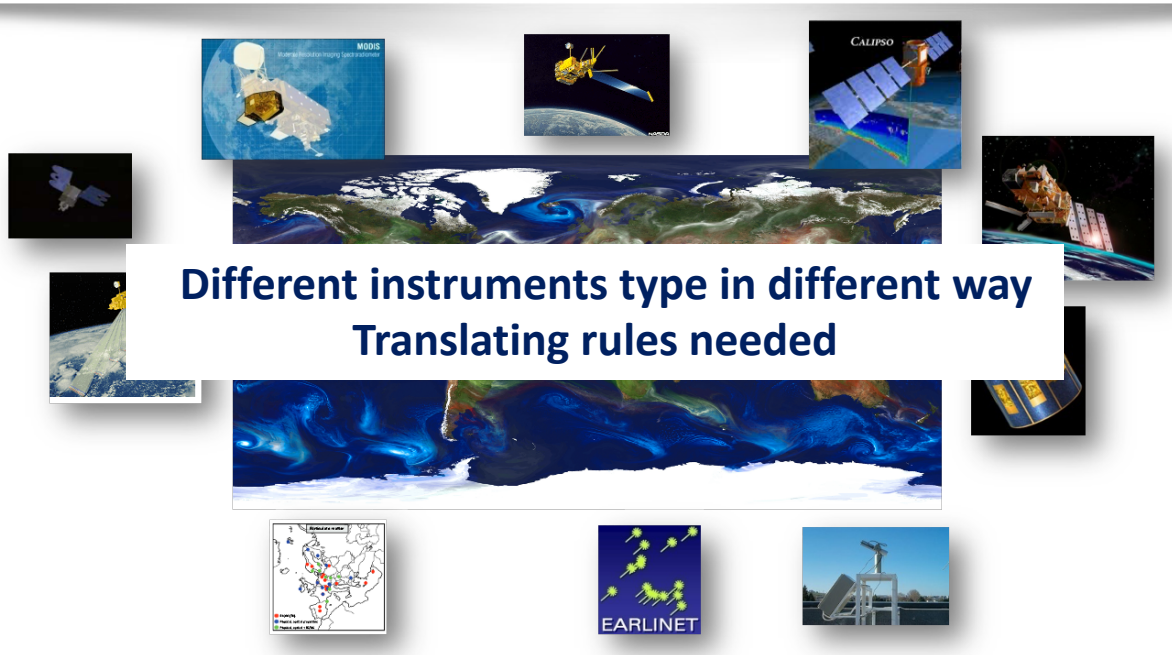


A real case:
Regional performance at an EARLINET urban station over 3y data

Voudouri, et al., Atmos. Chem. Phys., 2019

Model and observations for typing

Model as common base for typing comparison

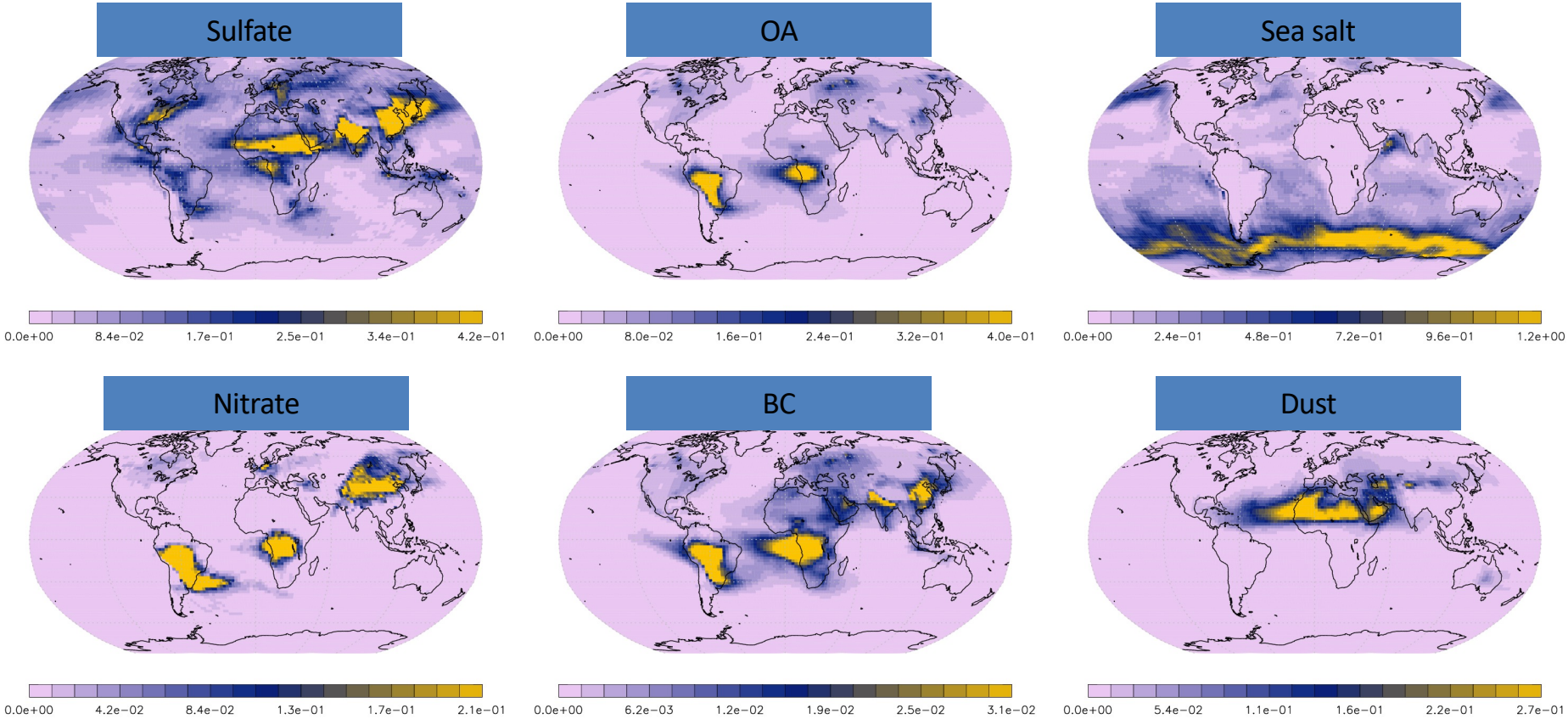


Co-located datasets can be used for a direct comparison, but limited in number

Models can have the role of a common ground where the typing procedures are compared

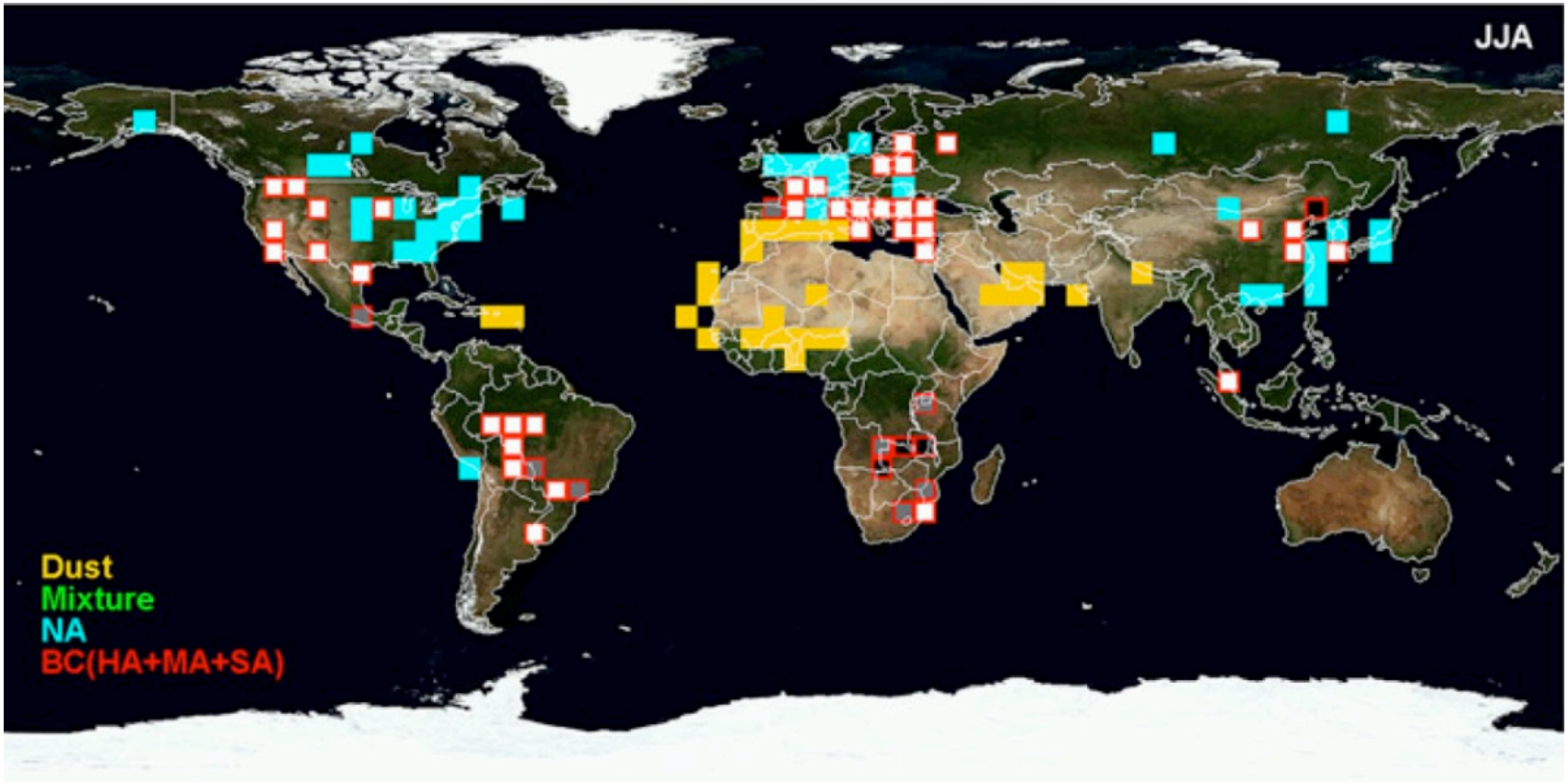
Information collected in AEROSAT as base for such investigations

What a model calculates (GISS ModelE, OMA, August 2010)



Note different scales

AERONET typing - Lee et al., 2010 (JJA 2005-2007)



Dust

Non-absorbing

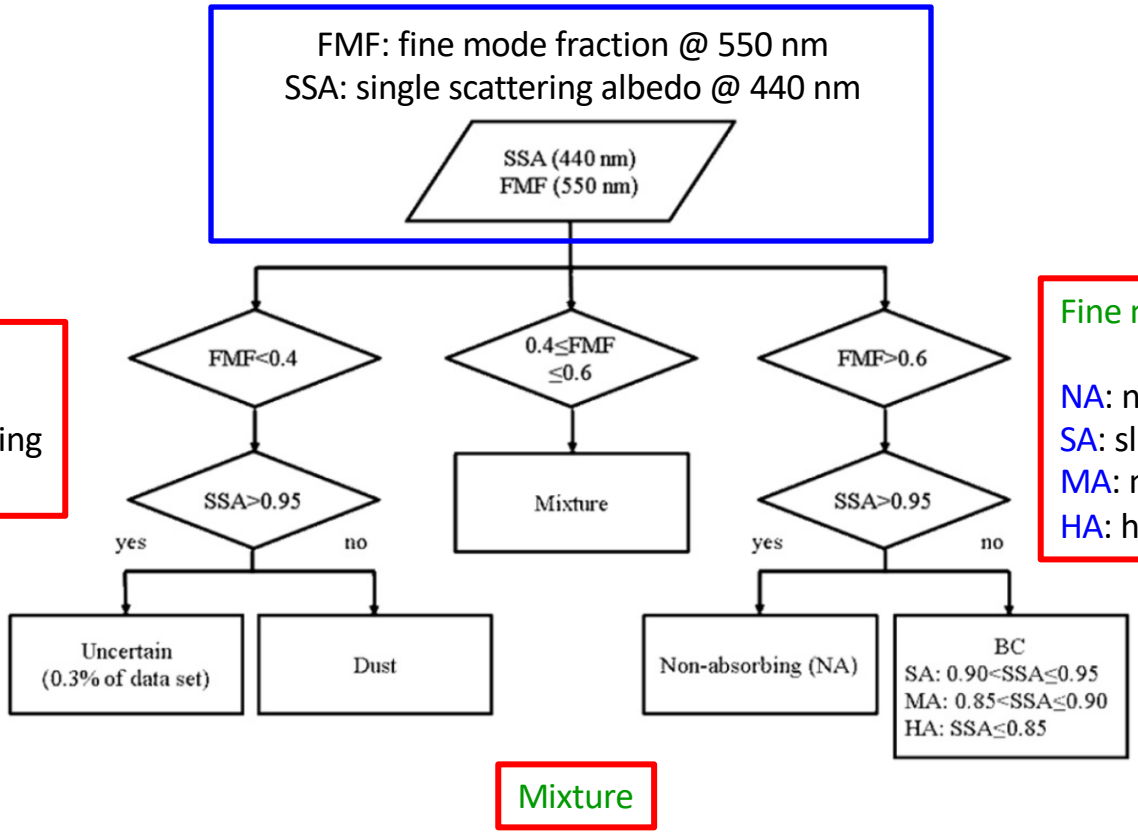
Mixture

Absorbing

Lee et al., Atm. Env., 2010

Example of an aerosol classification algorithm for AERONET

Lee et al., Atm. Env., 2010



Coarse mode aerosols

Uncertain: non-absorbing
Dust: absorbing

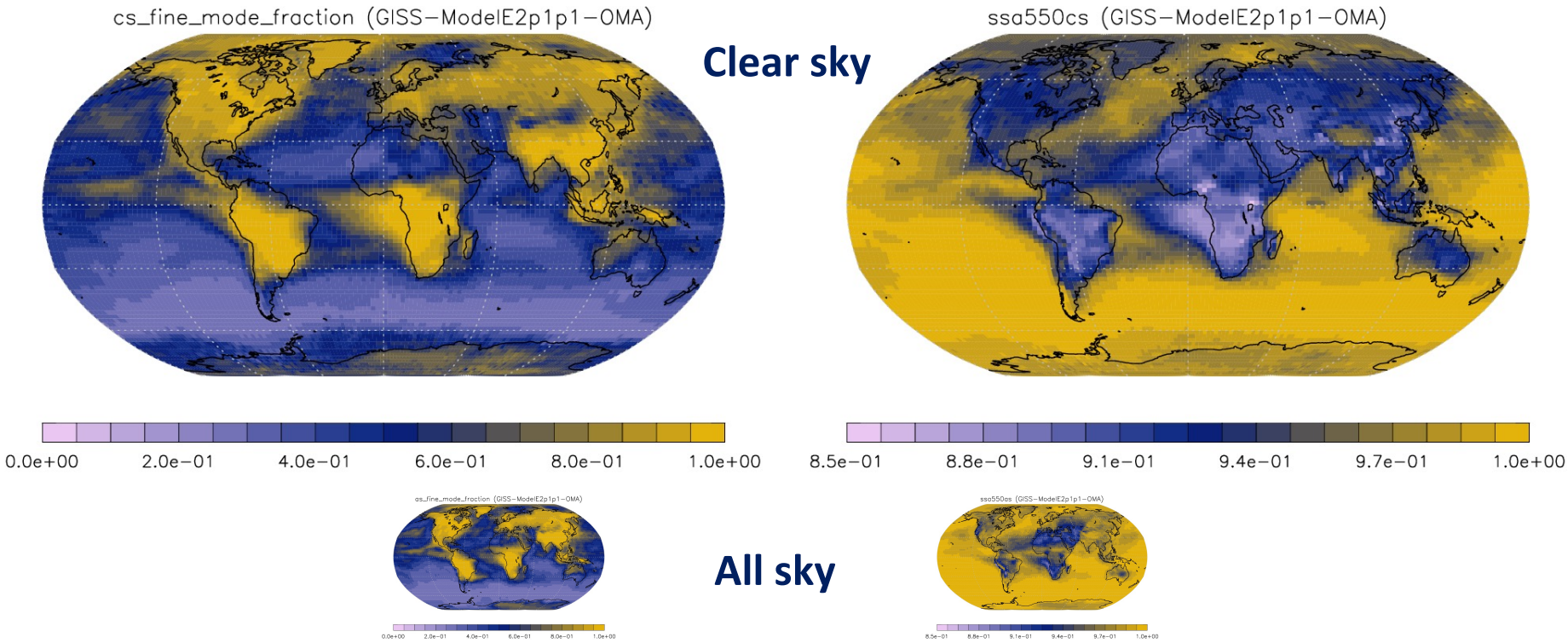
Fine mode aerosols

NA: non absorbing
SA: slightly absorbing
MA: moderately absorbing
HA: highly absorbing

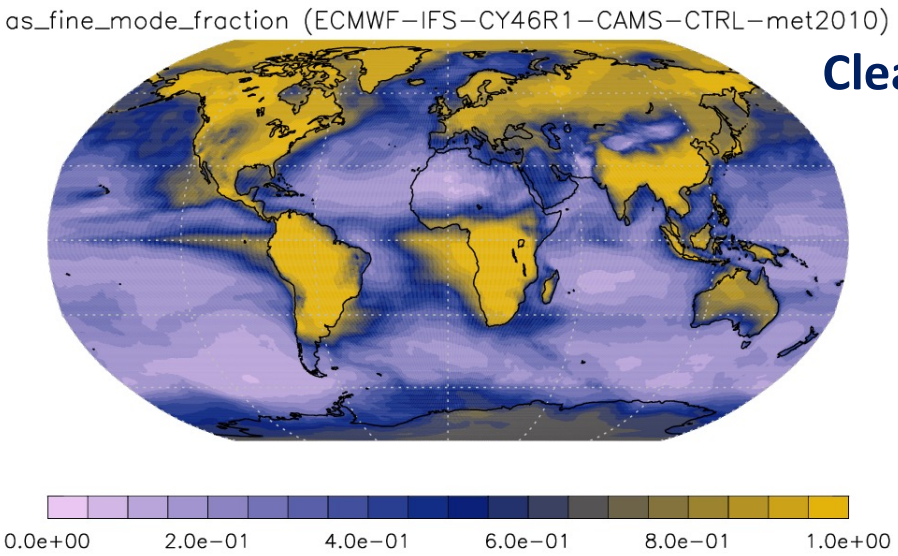
Mixture

GISS ModelE – Dimension and absorbing status

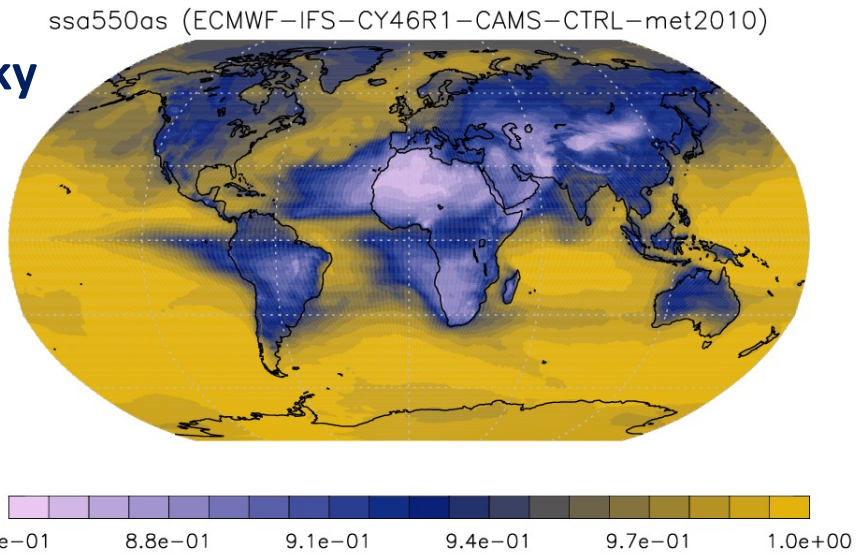
FMF and SSA @ 550 nm

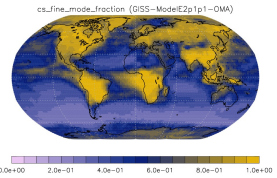


FMF and SSA @ 550 nm

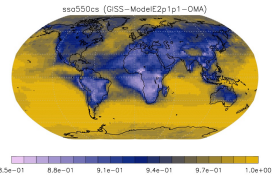


Clear sky



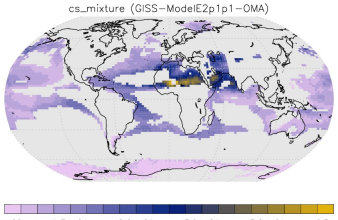


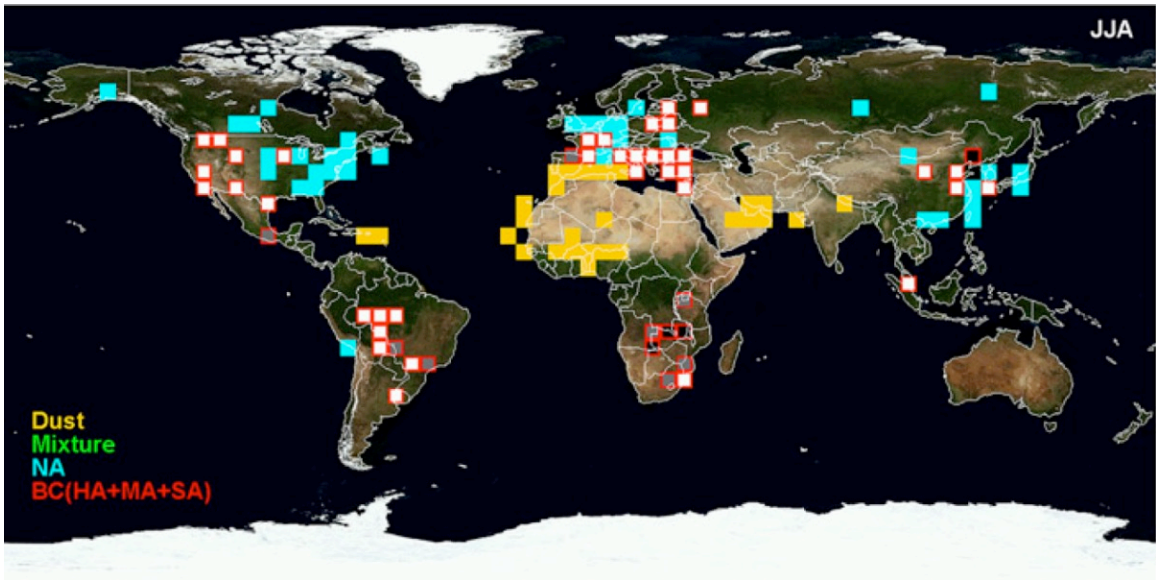
All sky



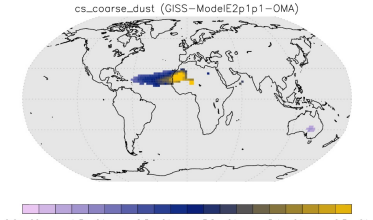
Model against Lee et al., 2010 (JJA 2005-2007)

Mixture

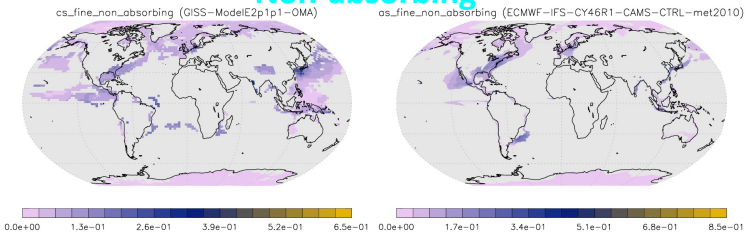




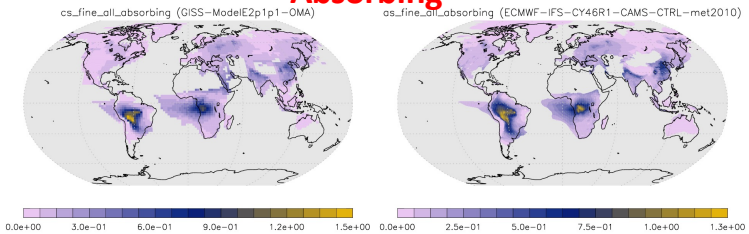
Dust



Non-absorbing



Absorbing



Model vs Observation: first thoughts

- When applying the Lee et al. (2010) criteria to GISS ModelE (2x2.5) :
  - Most “uncertain coarse mode” is sea salt.
  - There is very little coarse dust.

- A much higher resolution model (ECMWF-IFS-CY46R1-CAMS, ~0.35x0.35) is shockingly similar.

- Maybe finer temporal resolutions contain more structure?

- How can we deal with quantities that we don’t model, e.g. depolarization?

Next steps

- Comparison of typing procedure on climatological basis for ONE species
- **Dust** as the most abundant
- … and “easier” to track

Potential datasets

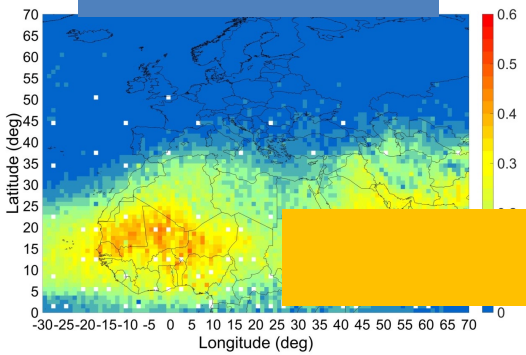
- Dust speciation method reviewed for **Mona et al., BAMS paper**: *Observing Moneral Dust : an European perspective on current capabilities and challenges ahead* (under revision)
- Datasets selected for BSC reanalysis evaluation in the **DUSTCLIM project** - Domain: 0-70 N- -30-70E 2006-2016

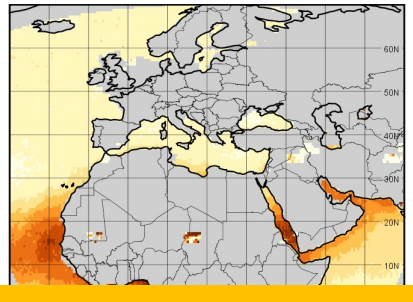


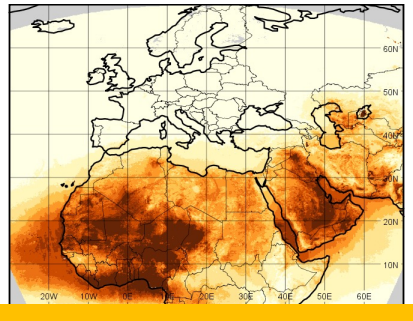
- AEROCOM models in 2010

Dust particles

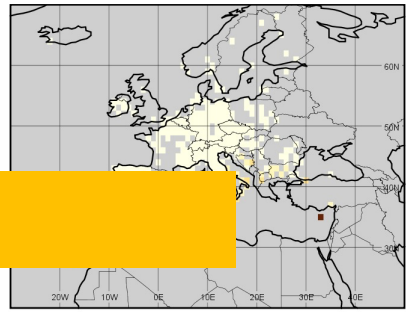
LIVAS-CALIPSO





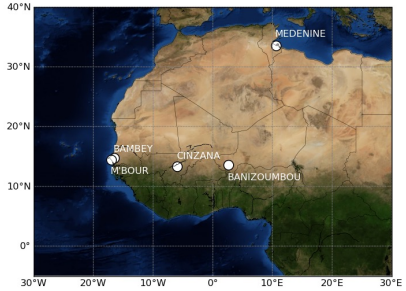


DustClim

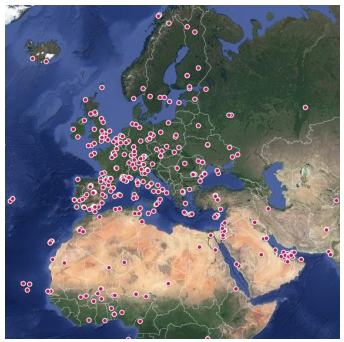


MIDAS -MODIS

work in progress…



INDAAF



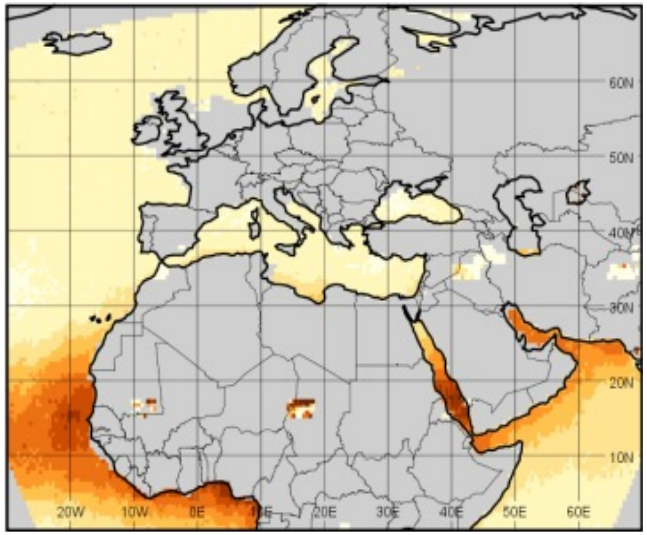
AERONET



ACTRIS_EARLINET

Dust particles

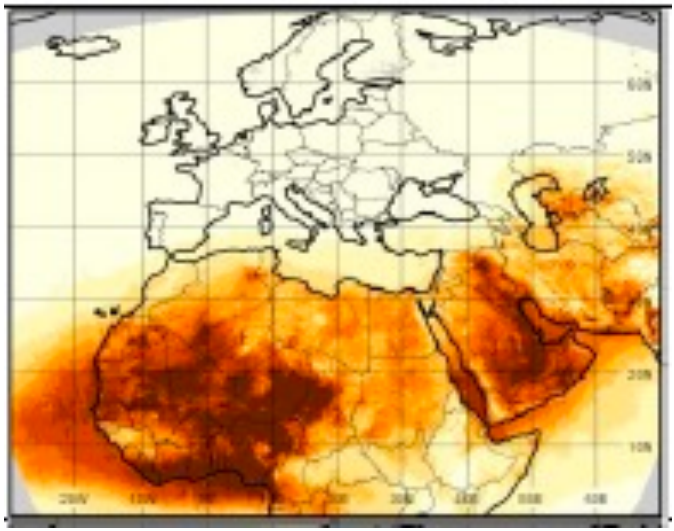
MISR



Kahn et al., JGR 2008

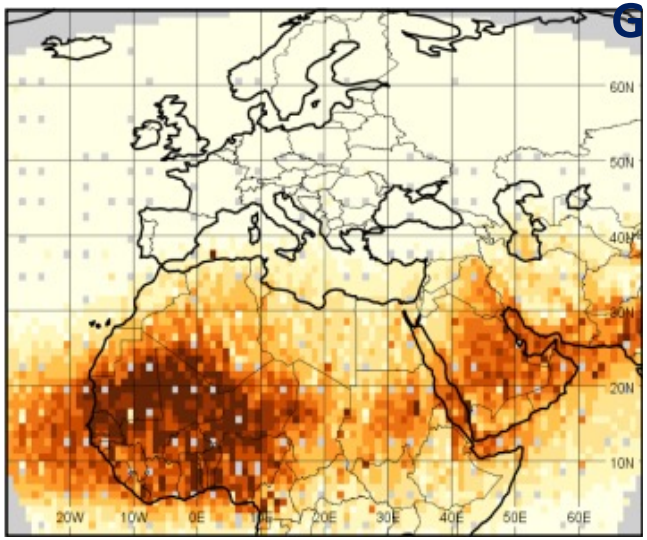
2011-2016

MIDAS



Gkikas et al., et al., AMT 2021

LIVAS



Amiridis et al., ACP 2015

DustClim

Conclusions

- Aerosol typing is a **key parameter**
- Many differences in concept makes **complex** the comparison
- **Models** can act as a common ground for comparison
- Measurements in **controlled conditions** can support the efforts
- Methodology to be still furthermore elaborated
- Large community effort needed!!!

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