Météo-France update : evolution of the MOCAGE model and research results

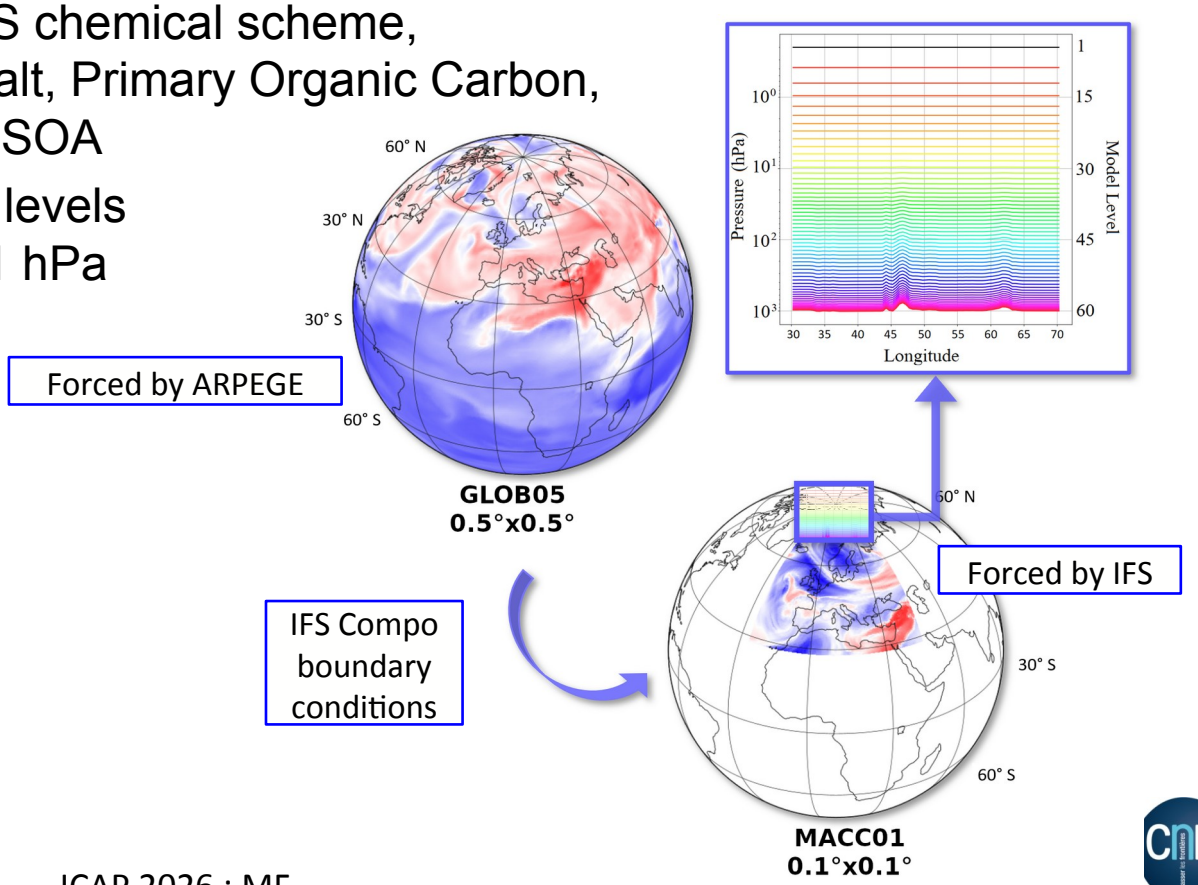
Jonathan Guth jonathan.guth@meteo.fr
+ colleagues from team COMPO

CNRM, Météo-France and CNRS
Modelling, Assimilation, Surface for Atmospheric Composition and Air Quality

MOCAGE operational configuration

MOCAGE general features

- Off-line chemistry transport model
  - Semi-Lagrangian advection scheme with convection and diffusion parametrization
  - RACM+REPROBUS chemical scheme, Desert Dust, Sea Salt, Primary Organic Carbon, Black Carbon, SIA, SOA
  - 60 σ-hybrid vertical levels from surface to 0.01 hPa



MOCAGE general features

Global domain is used for:

- ICAP → Connection with this community, help to improve our model
- Participation to forecast of the WMO Dust Regional Center (Northern Africa-Middle East-Europe)
- UV Index forecast for French territory (ozone column)
- Volcanic Ash and SO_2, and other aerosol forecast for the aviation safety
- Aerosol forecast for national defence

Regional domain is used for:

- CAMS-atmosphere regional air quality ensemble forecast
- French national air quality platform Prev'Air
- Higher horizontal resolution of some global duties (defence and aviation)

Other uses:

- Weather forecasters try to evaluate the impact of atmospheric composition on weather (for example when a dust cloud pass over Europe)

Data assimilation system in operations

- 3D-Var algorithm using 1h windows :
  - Global domain assimilation :
    - MODIS AOD (will be terminated in August at the latest)
    - VIIRS AOD (SNPP, NOAA-20, NOAA-21)
    - TROPOMI SO2 for volcanic event
      - IASI SO2 in monitoring
    - IASI and CrIS radiances for O_3 and CO
  - Regional domain assimilation:
    - TROPOMI SO2 for volcanic event
      - IASI SO2 in monitoring
    - 6 Lidars from Météo-France network (Mini-MPL)
    - E-profile ceilometers (CHM15K at 1064nm, CL31 and CL51 at 910nm
  - !! Assimilation for aerosols only updates 3D total mass:
    no information on aerosol type or size !!

Towards an operational in-line chemistry model

- Large effort in the past years at Météo-France to gather all processes for gaseous and aerosols compounds used in various models (MOCAGE, ARPEGE climate model, Meso-NH, AROME-dust) into a single library
  - **A**erosols and **C**hemistry **LIB**rary → ACLIB

- ACLIB is already interfaced with:
  - CTM MOCAGE
  - Climate models ARPEGE-ESM and AROME-RCSM
  - Numerical Weather Prediction models AROME and ARPEGE
  - Research model Meso-NH

- Development into the model MOCAGE are going on as input for ACLIB, but also as operational readiness
- We started developing an instance if the ARPEGE model called ARPEGE-Compo aimed at replacing MOCAGE (global domain)

Let’s have a look into research studies

MOCAGE SOA

@Americ J.

- Secondary organic aerosol (SOA) schemes implemented in MOCAGE are based on several papers offering different levels of complexity :
  - Castro et al. (1999) [*operational in MOCAGE*] : SOA are deduced from emitted primary organic aerosols (POA), following a simple linear relationship based on organic compounds measurements in Europe
  - Spracklen et al. (2011) [*available in MOCAGE and IFS-COMPO*] : SOA are produced from many sources (anthropogenic, biogenic and biomass burning) based on the irreversible condensation of volatile organic compounds (VOCs), following a fixed aerosol yield method
  - Sartelet et al. (2019, 2026) [*under evaluation in MOCAGE*] : SOA are produced by SSH-aerosol, a partitioning model based on a molecular approach enabling the explicit description of several processes related to the condensation of VOCs (absorption into an aqueous phase, hygroscopicity, non-ideality, oligomerization…), coagulation and nucleation of particles

Currently in progress : comparison of the 3 methods by conducting global-scale simulations at a resolution of 0.5°, covering several years (2018-2022), and assessment with available observations

Towards an operational in-line chemistry model

@Guth J.

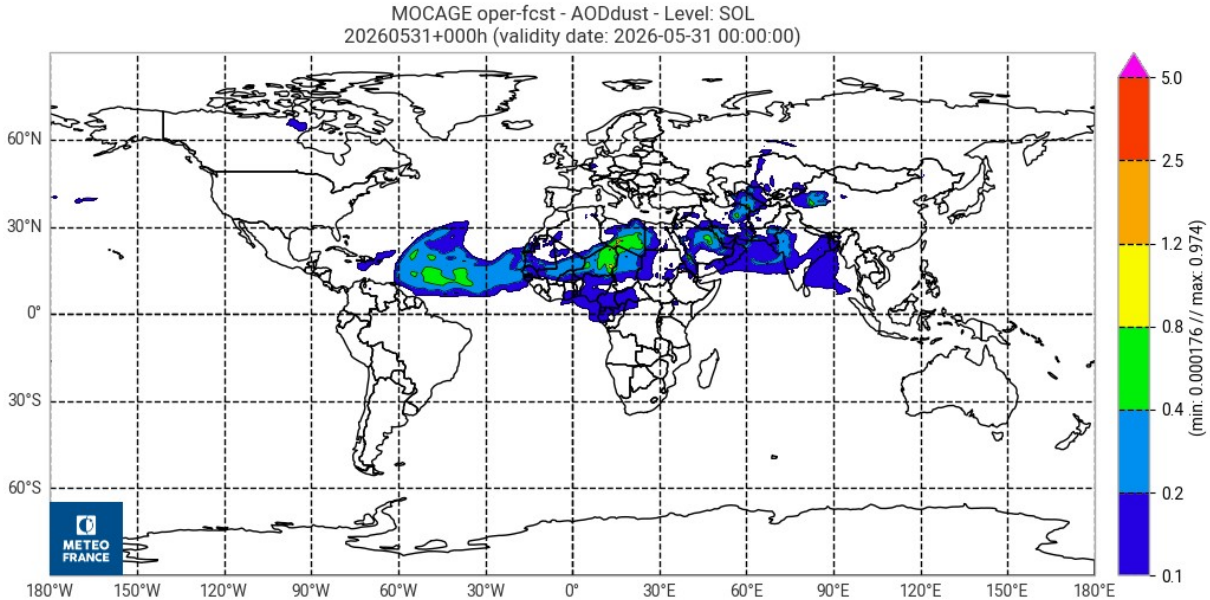
- A near real time experiment of ARPEGE-Compo based on cy49T1 is running since March 2026 :
  - For now only desert dust are represented using the TACTIC scheme
    - Michou et al. (2015); Nabat et al., (2015)
  - Results are encouraging but not yet validated
  - Next step is to add carbonaceous aerosols especially to follow biomass burning events

Towards an operational in-line chemistry model

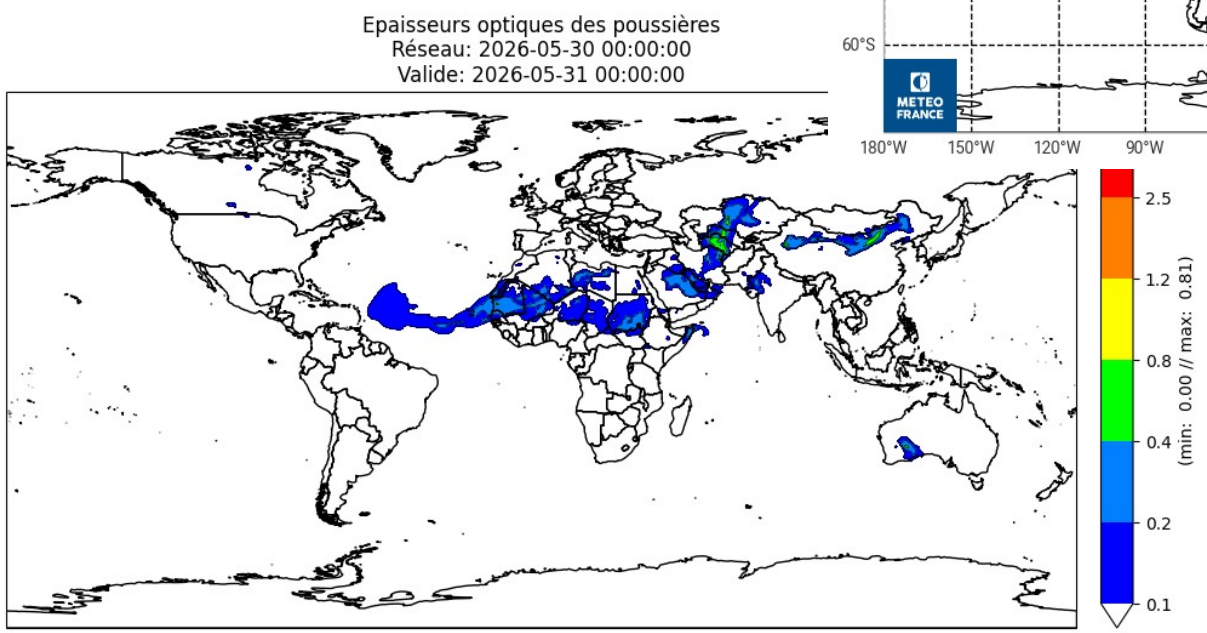
@Guth J.

- Desert Dust AOD for 31st May 2026

MOCAGE (with DA)



ARPEGE-Compo (no DA)



SO_2 volcanic data assimilation with plume altitude in the regional domain : Icelandic eruption on 23 August 2024

@Bacles M.

In operation : assimilation of TROPOMI with assumptions about plume altitude (from 3 to 10 km).

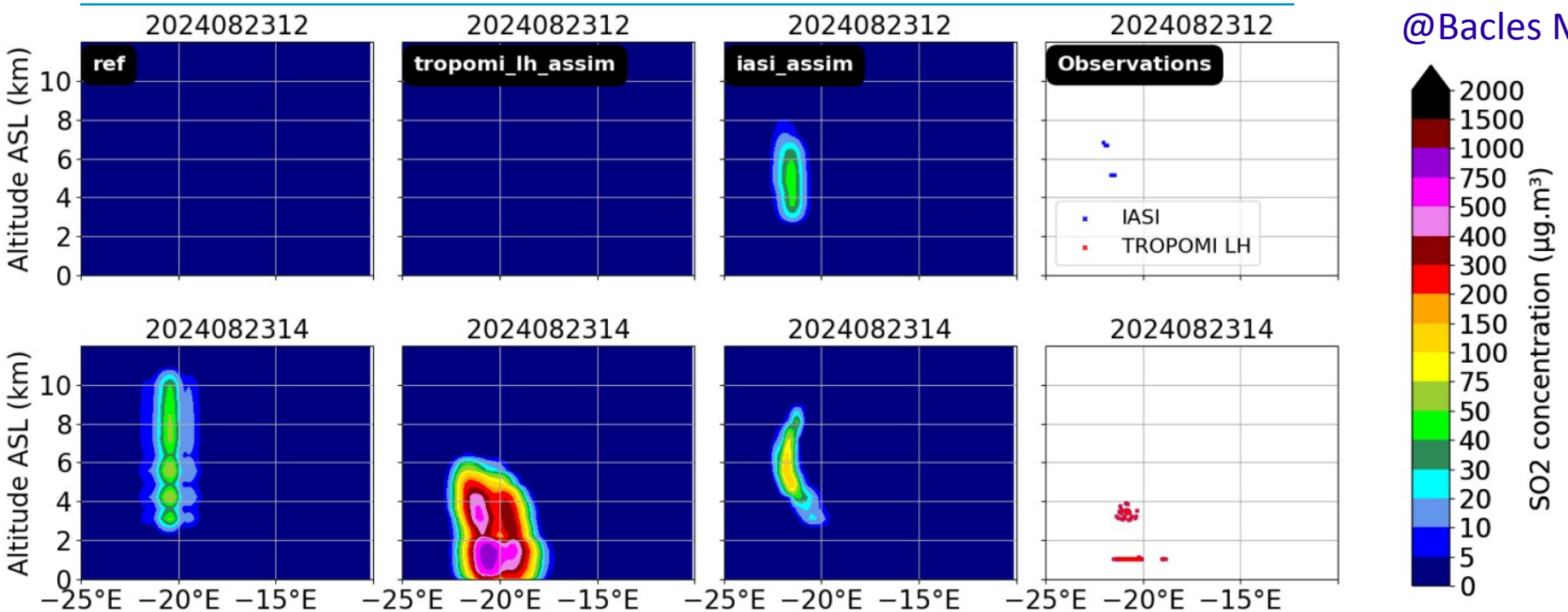
Wrong altitudes of the plume in MOCAGE during some eruptions.

Observations : plumes altitudes can be provided by IASI and TROPOMI LH (for observations > 15 DU).

Assumption : All of the SO2 detected is located within a 2-kilometre-thick layer centred on the altitude indicated by the observations.

Case study : - Icelandic eruption on 23 August 2024

SO_2 volcanic data assimilation with plume altitude in the regional domain : Icelandic eruption on 23 August 2024

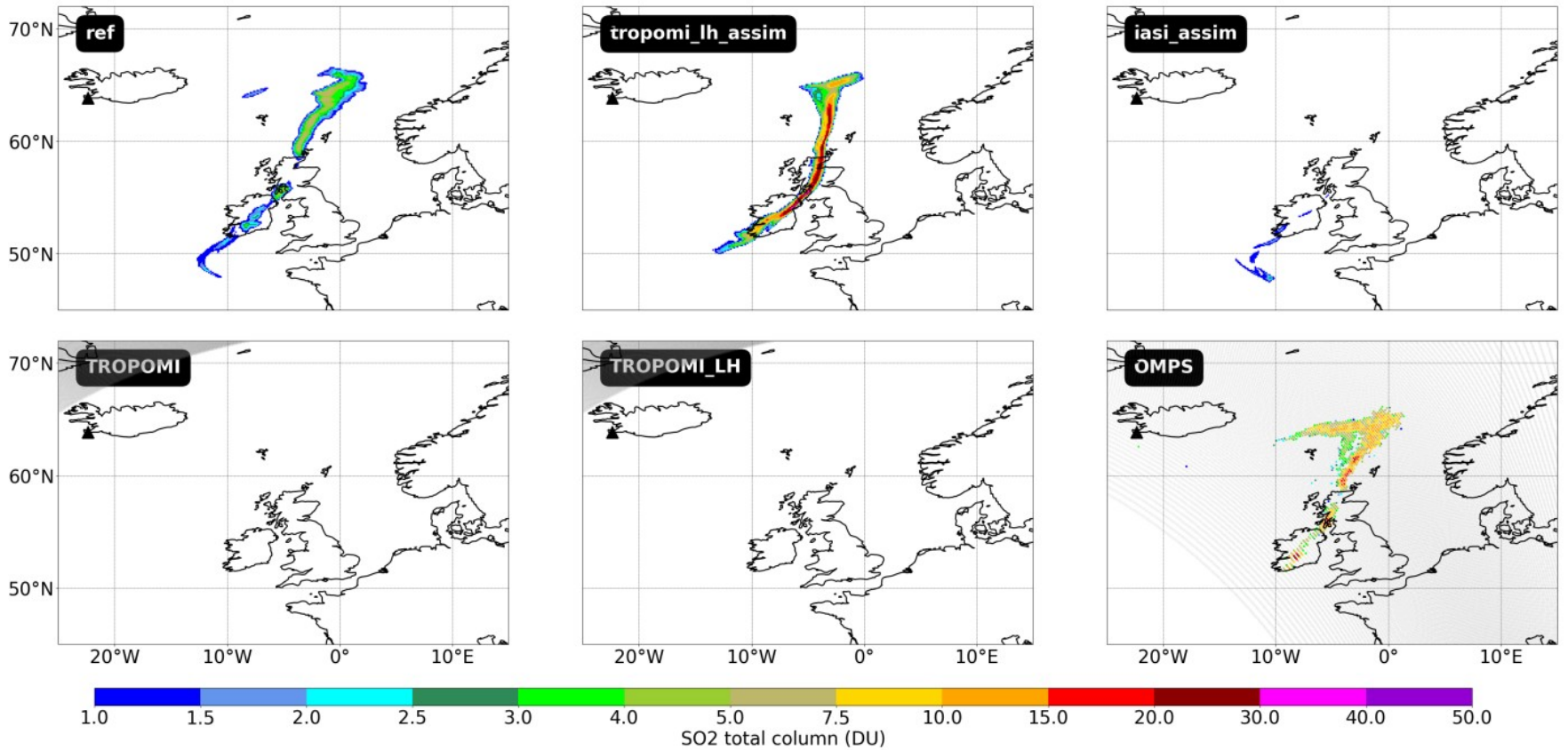


@Bacles M.

- In ref experiment (=operational settings), plume is between 3 and 10 km (assumptions).
- **Assumption in assim exps** : All of the SO2 detected is located within a 2-kilometre-thick layer centred on the altitude indicated by the observations.
- Simulated plume altitude is consistent with the observed altitude.
- Significant differences between IASI and TROPOMI LH in terms of altitude, due to the presence of clouds (IASI) .

Results on 24 August 2024 at 13 UTC

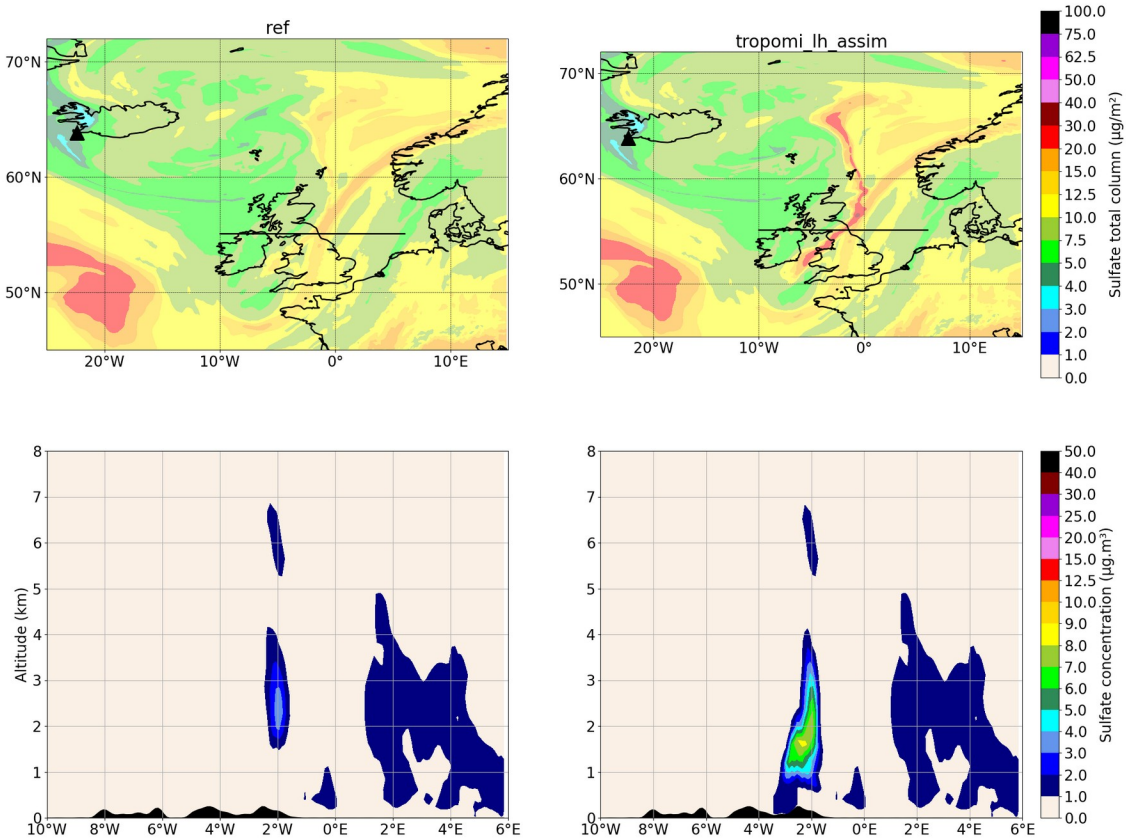
@Bacles M.



- TROPOMI LH observations are assimilated on 23 August. The shape of the plume is consistent with OMI observations. SO2 total columns are overestimated.
- Observations from TROPOMI are assimilated on 24 August and correct the shape of the plume.

Impact on sulfate aerosols

@Bacles M.

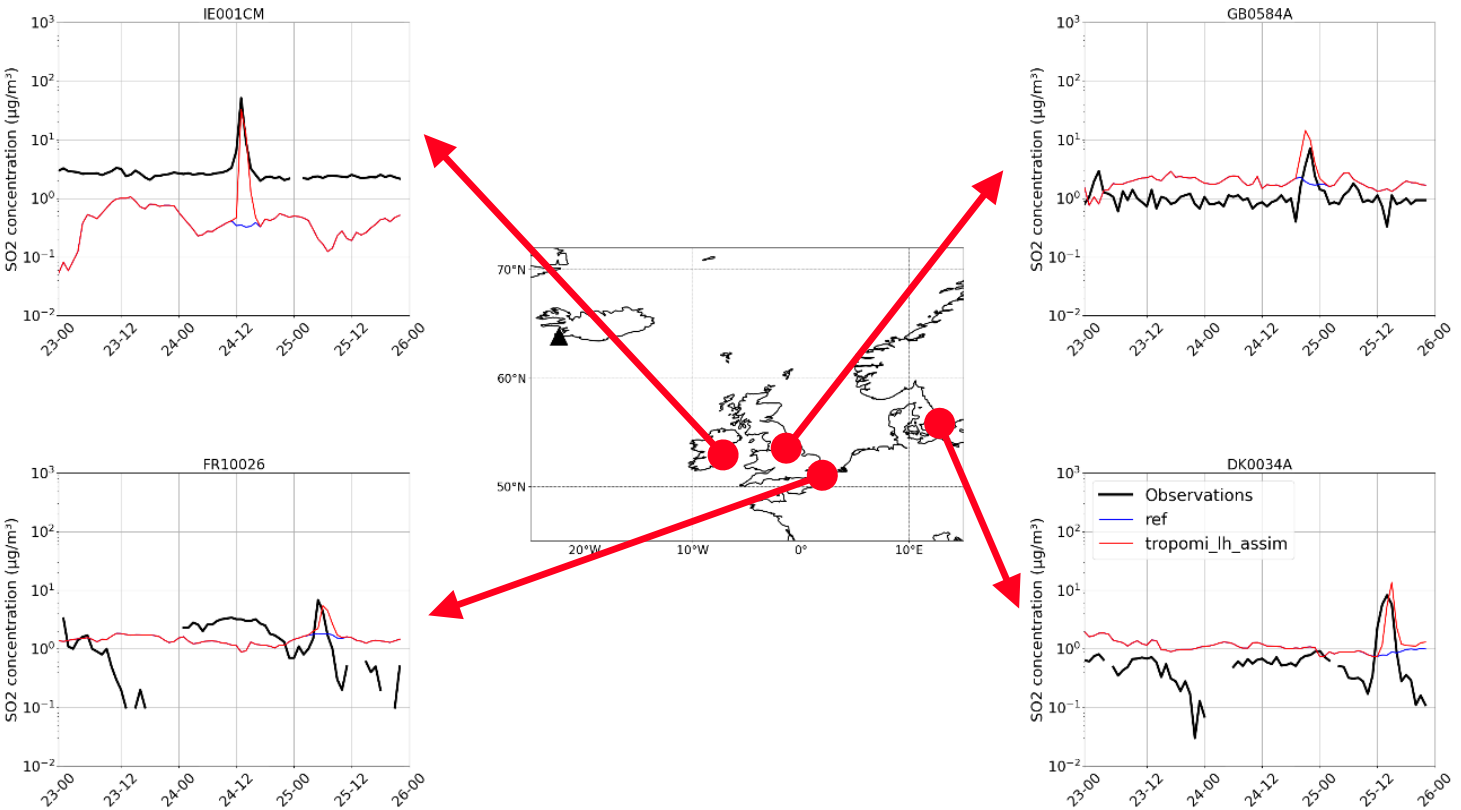


- Looking at sulfate aerosols one can see an enhancement on total column and sulfate aerosols vertical profile
- Nevertheless there are no validation data able to help evaluate sulfates

Preprint Bacles & Guidard, 2026 at AMT
https://doi.org/10.5194/egusphere-2026-2098

Impacts at surface

@Bacles M.



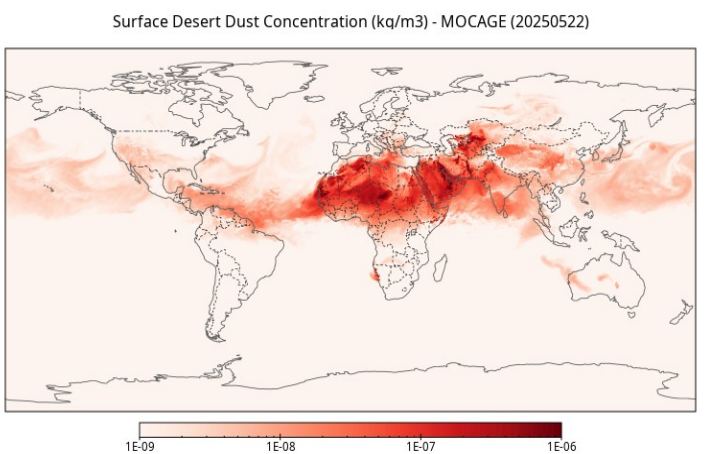
The assimilation of TROPOMI LH (red) shows an increase of surface SO_2 concentration which is also observed by EEA stations (black) compared to the reference simulation (blue)

Assimilation of EarthCare data

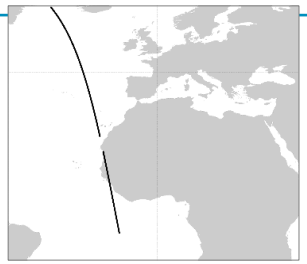
@El Amraoui L.

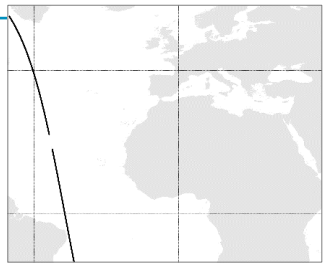
- Motivations :
  - Assess the contribution of lidar measurements to better constrain the model outputs in a global assimilation system (vertical constraint).
  - EarthCARE provides information on each type of aerosol enabling the possibility of assimilating each type separately.
  - Assess the impact on other parameters that are not directly observed: AOD, aerosol concentration, etc.

- Experiment (Test of EarthCARE added value within a CTM) :
  - Assimilation exercice: May - July 2025 (coincides with a desert dust event)
  - EarthCARE observations (Backscatter coefficient)
  - Assimilation within MOCAGE model: 60 levels ; 0.5° X 0.5° (lon, lat)



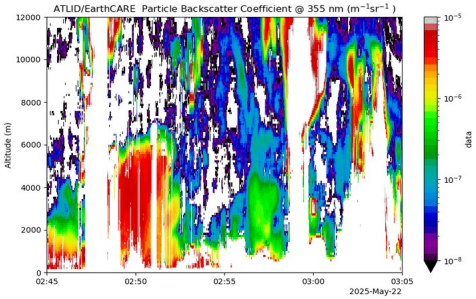
Model vs Assimilated EartCARE (Backscatter coefficient @ 355 nm)



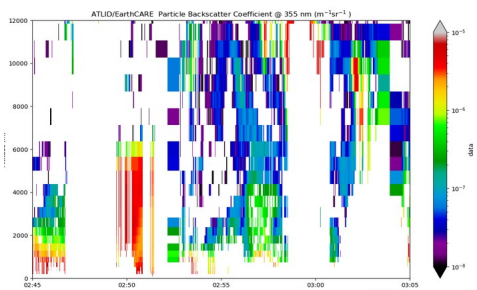


@El Amraoui L.

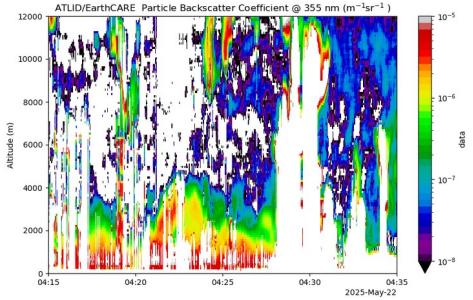
Obs. EarthCARE



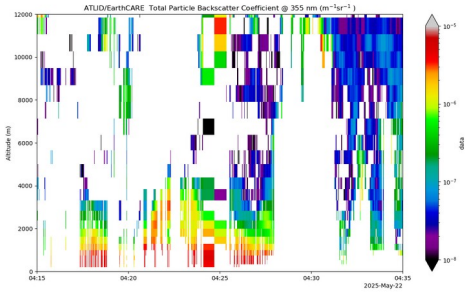
Obs (Model grid)

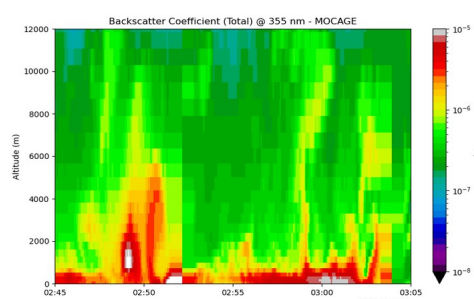


Obs. EarthCARE

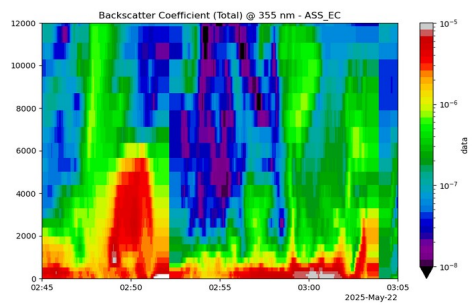


Obs (Model grid)

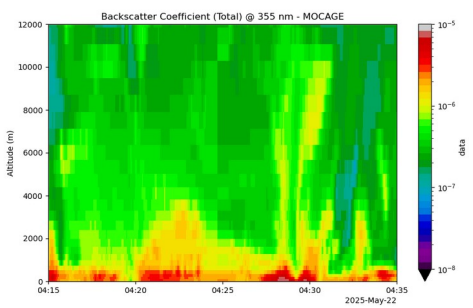




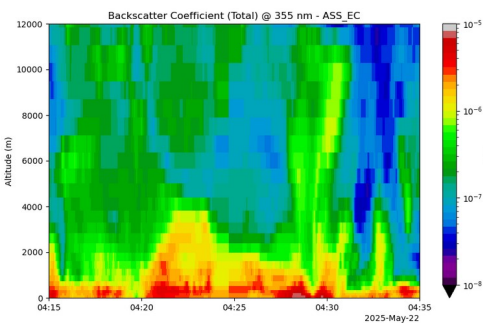
Model



Assim.



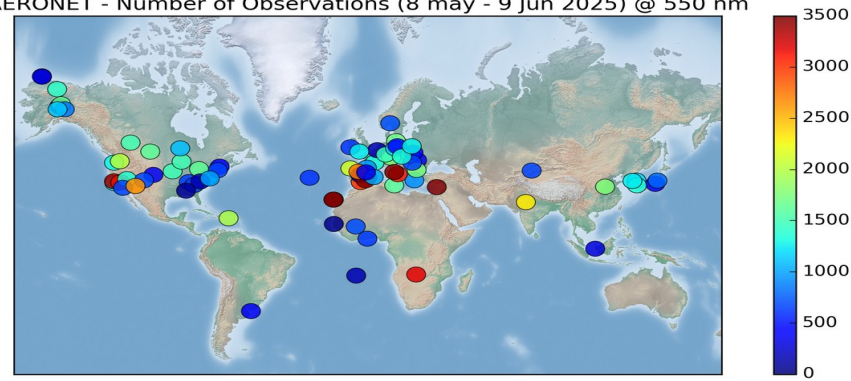
Model

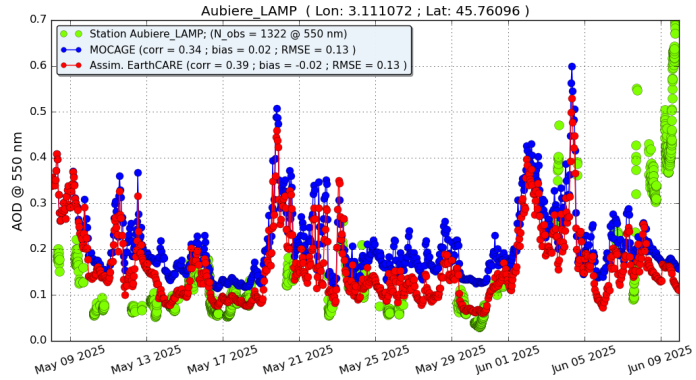


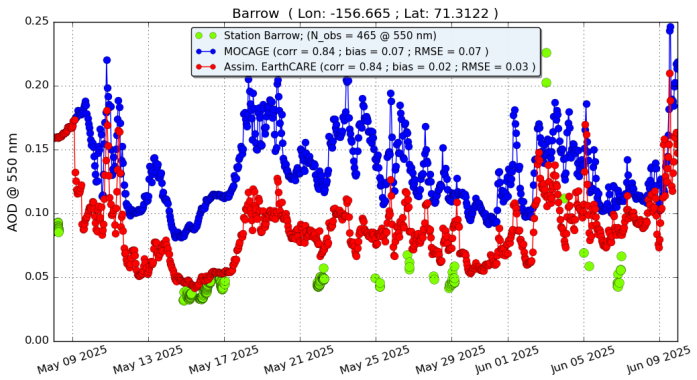
Assim.

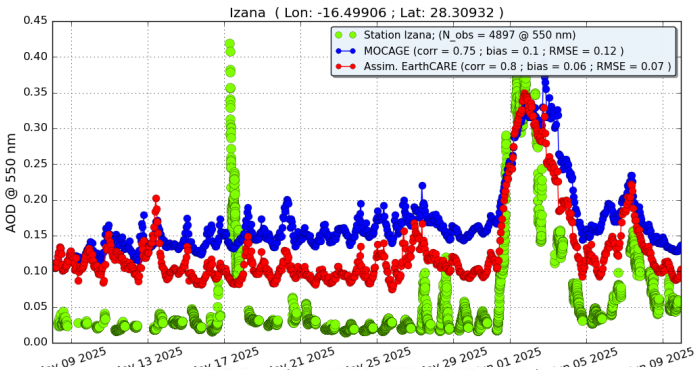
Validation vs AERONET AOD @ 550 nm

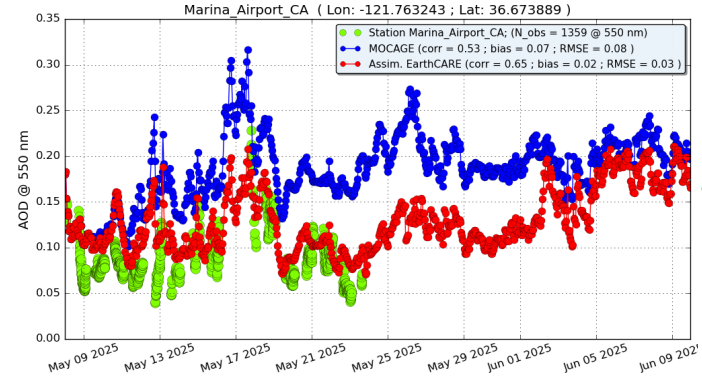
- **AERONET AOD level 2.0 (V3)**
- **Période: 8th May – 9th June 2025**

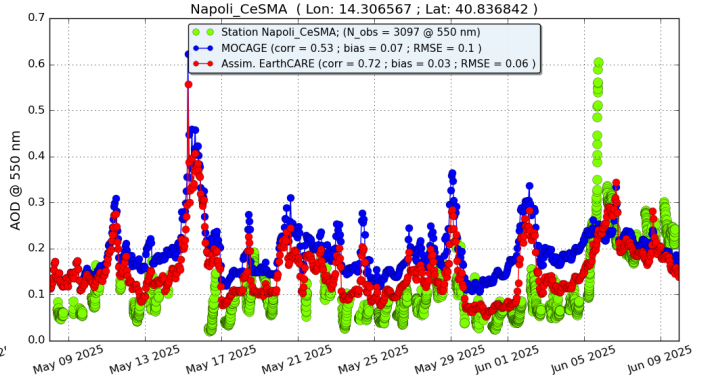


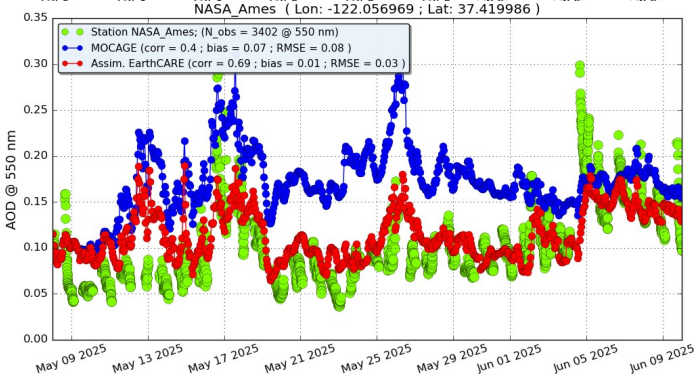






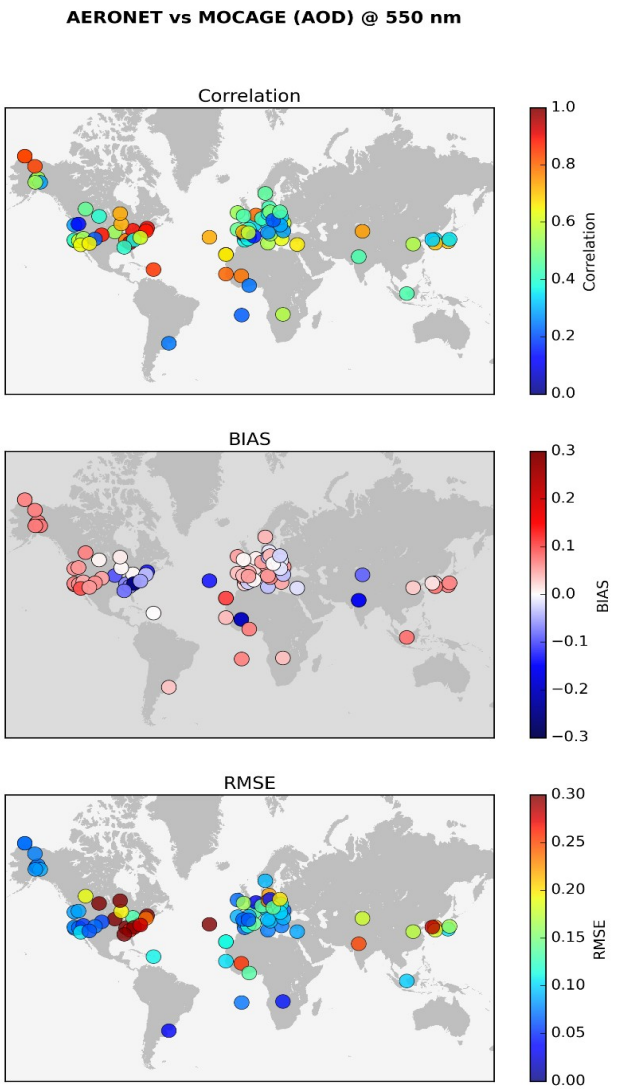


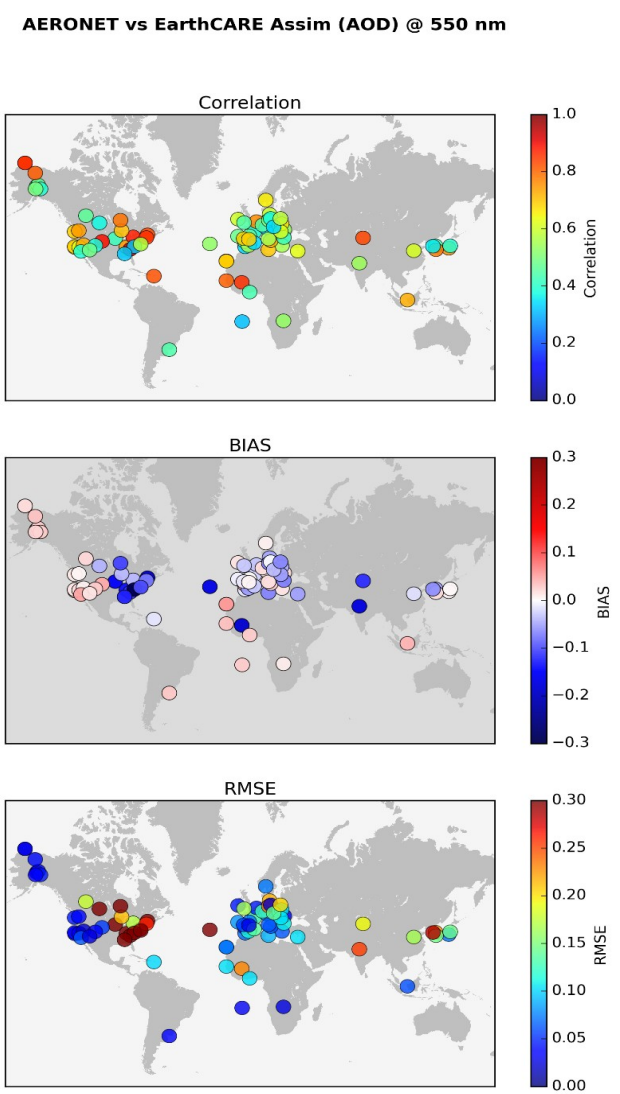


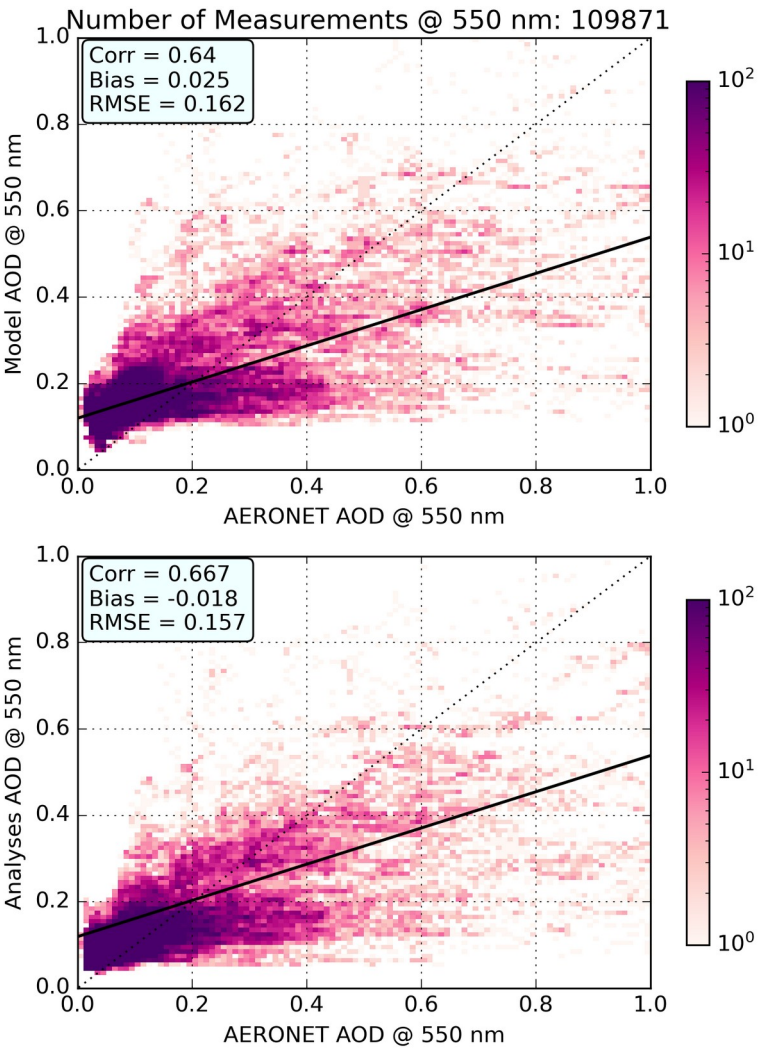


Validation vs AERONET AOD @ 550 nm

@El Amraoui L.



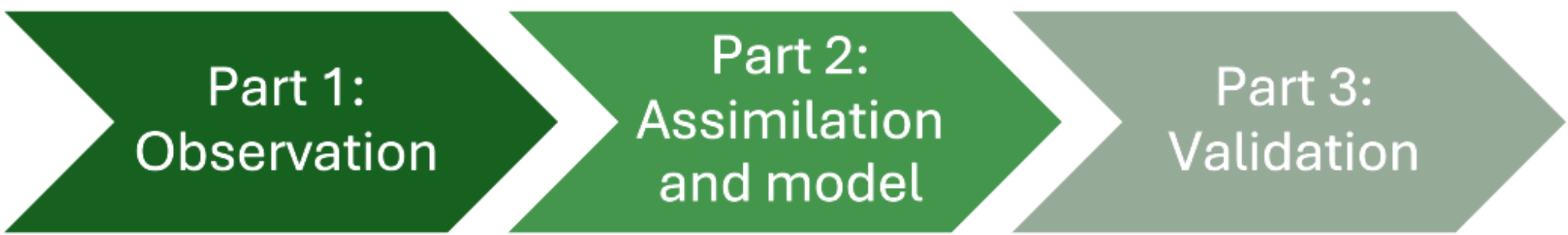




Assimilation of infrared sensors for desert dust

- Several sensors in different projects:
  - IASI vs IASI-NG in CTM MOCAGE (Etienne Gruet's PhD, funded by CNES-MF)
  - IASI in ARPEGE-Compo (Horizon Europe project CAMAERA)
  - IRS in AROME-Compo (Auguste Maillot's PhD, funded by TAS-MF)

- 3 parts:



Hyperspectral sensors : Big data

Part 1: Observation

@Gruet E.

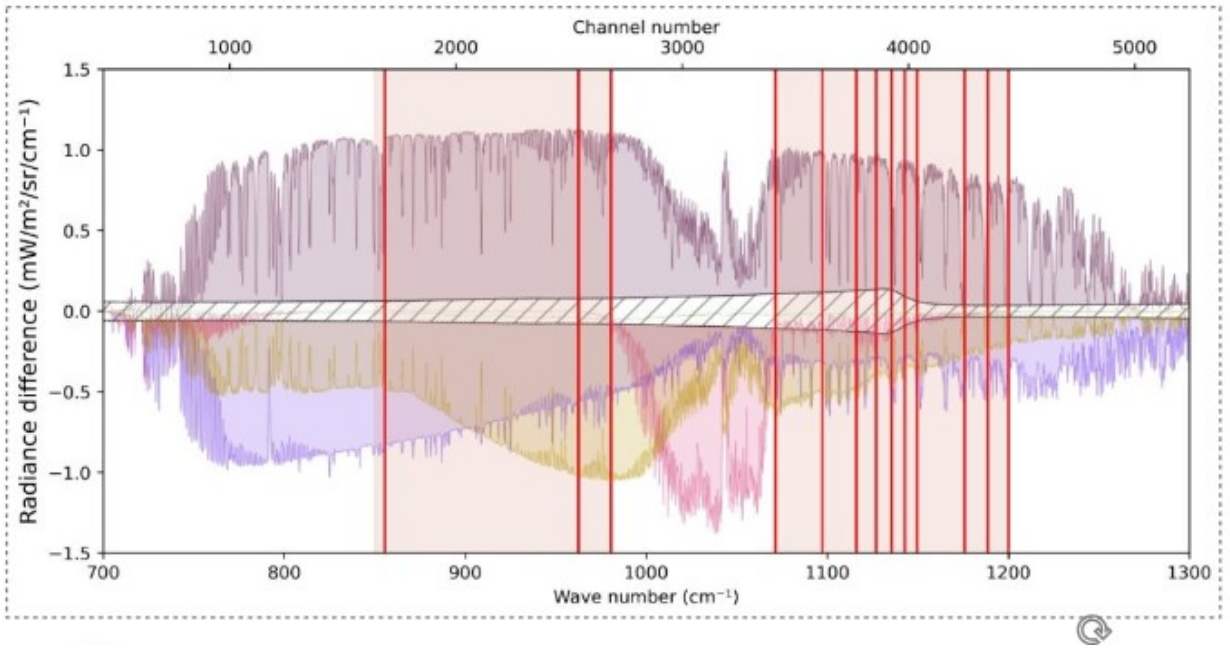
- **The huge amount of data requires a selection of a subpart of them.**
  - Use of a Degree of Freedom for Signal algorithmm to maximize the information using the fewest channels

IASI-NG sensitivity to dust

Part 1: Observation

@Gruet E.

- Aim : Select the channels that are most sensitive to dust and least sensitive to other atmospheric compounds



13 most sensitive channels by dust determine by DFS (0.08% of IASI-NG channels)

IASI-NG noise
Dust bin 1
Dust bin 2
Dust bin 3
Skin temperature
Ozone
Water vapor

Most sensitive zone by dust and the least affected by other

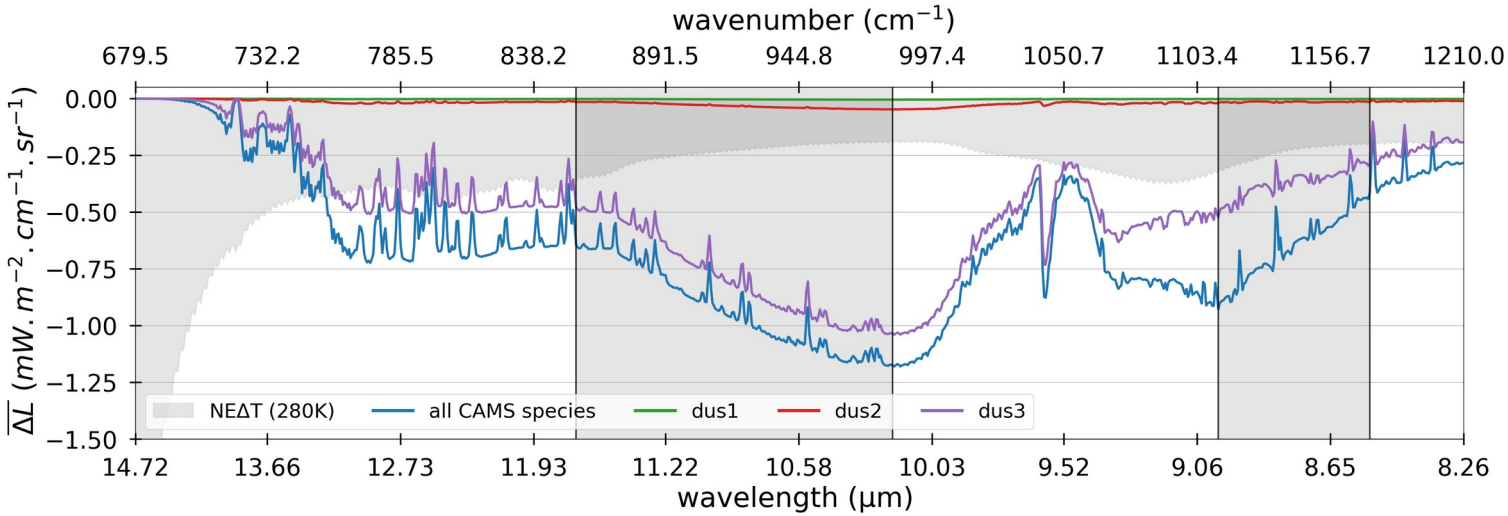
See you in at the Eumetsat Conference for assimilation results!

IRS Sensitivity analysis

Part 1: Observation

@Maillot A.

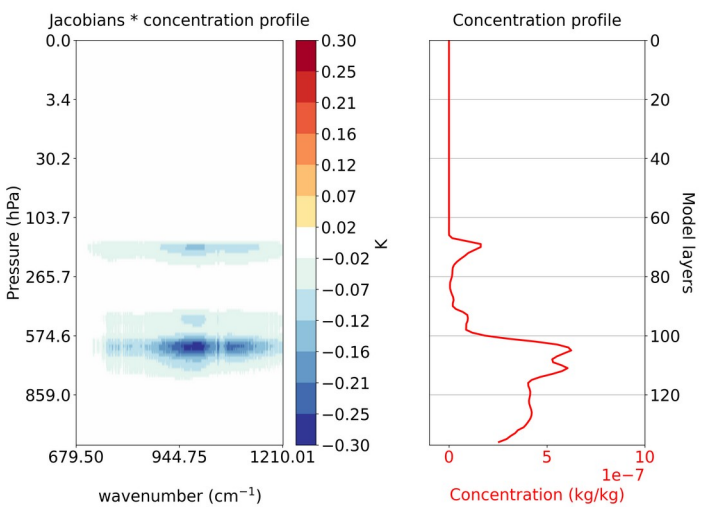
Brightness temperature difference between IRS simulated observations with activated and deactivated aerosols



Two spectral windows

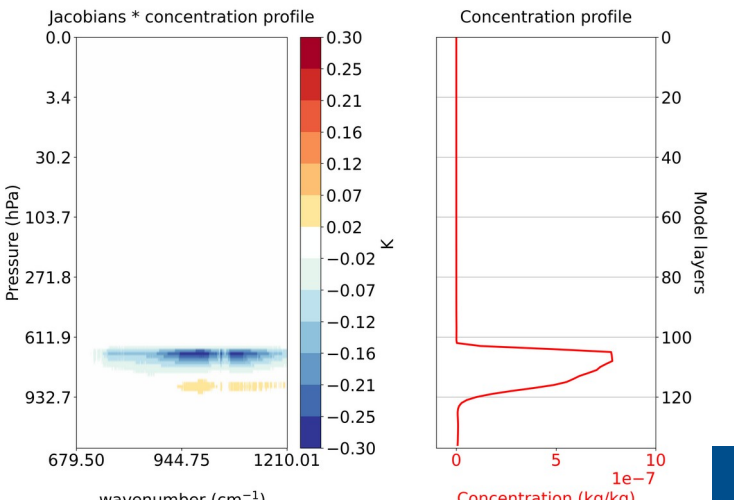
A. 210 channels
855.7 – 982.3 cm^{-1}

B. 101 channels
1112.5 – 1173.1 cm^{-1}



Dust jacobians

For 2 typical dust profiles



Initial tests – identify dusty pixels

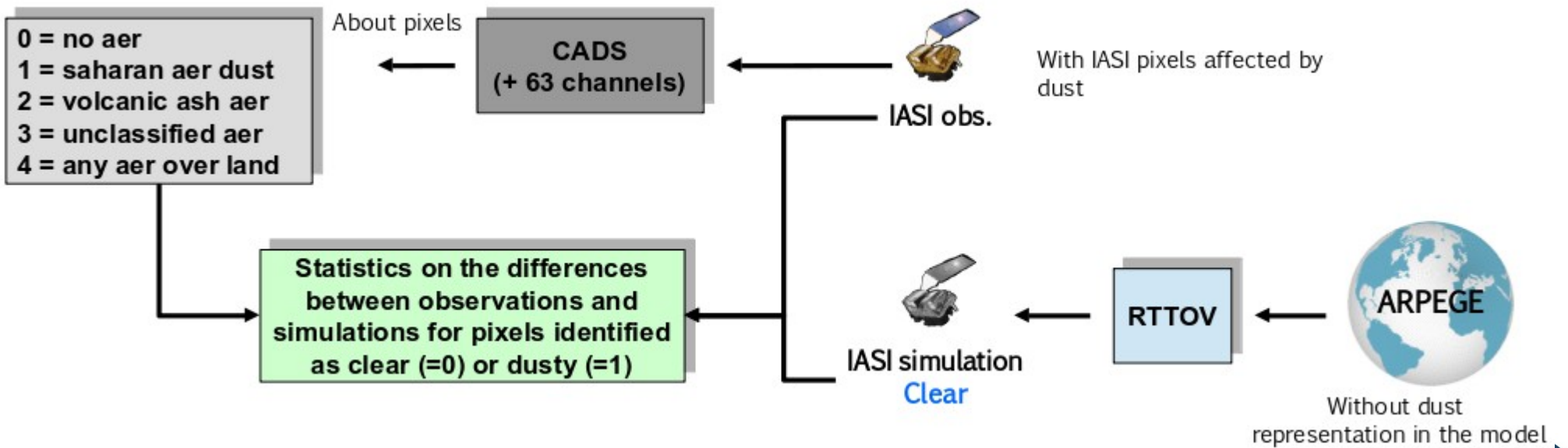
Part 1: Observation

@Coopmann O.

- **Construction of an experiment with activation of the CADS algorithm to identify IASI pixels affected by dust.**

→ ARPEGE NWP experiment on a 49t1 operational configuration

→ Study period between December 18 and 29, 2024, with a strong dust episode coming from West Africa.



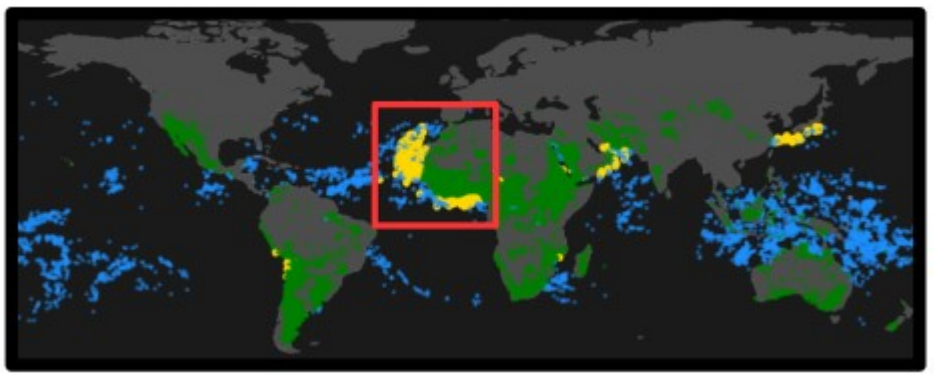
Initial tests – identify dusty pixels

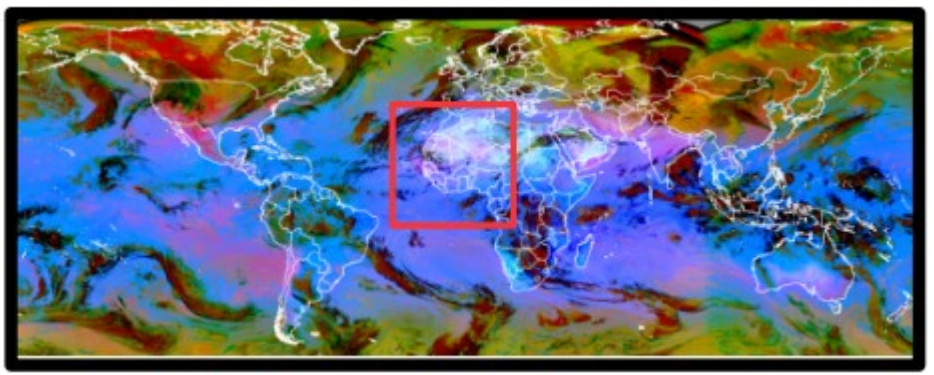
Part 1: Observation

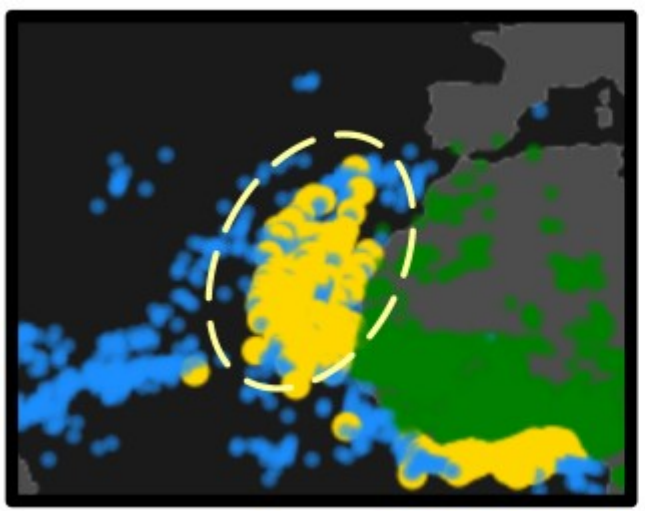
@Coopmann O.

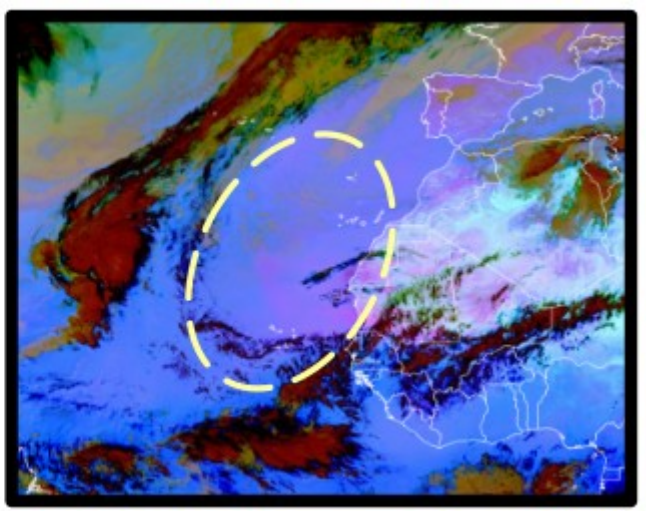
- **Comparaison with EUMETSAT products**

→ The case from December 18 compared to the product (Geostationary Ring Dust RGB)









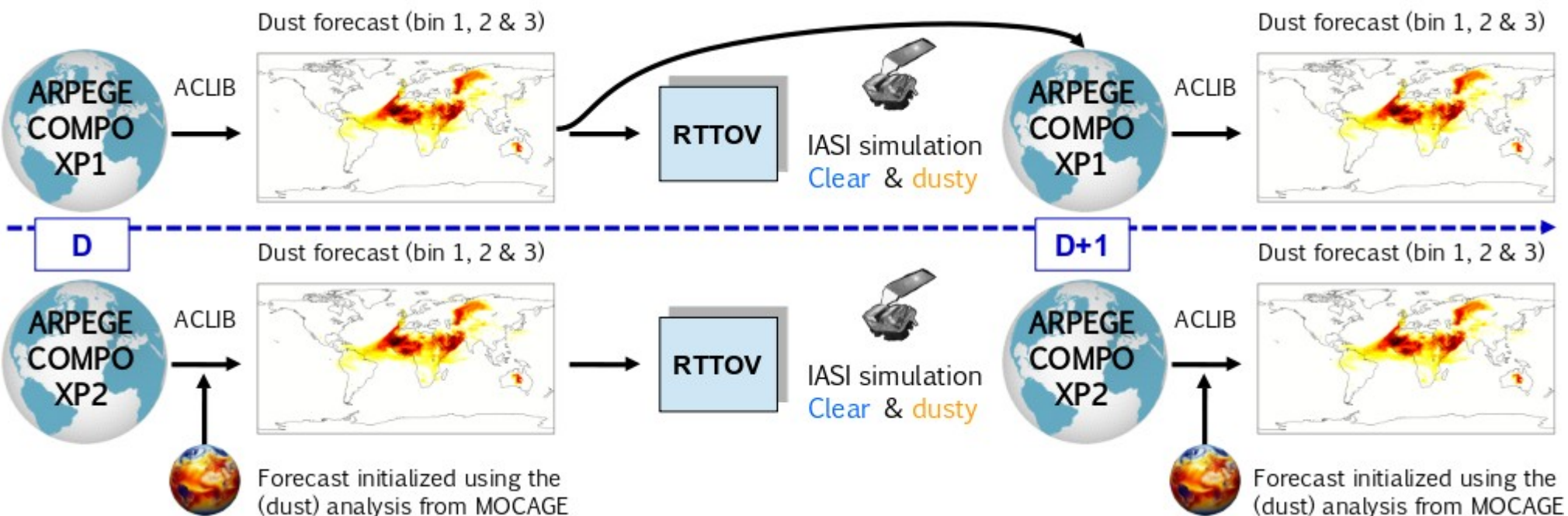
ARPEGE-Compo with dusts

Part 2: Assimilation and model

@Coopmann O.

- **Setting up an ARPEGE-COMPO configuration with interactive dust**

→ Testing of two experiments with implementation of the ACLIB library for activation and forecast of dusts in ARPEGE-COMPO : **XP1** (forecast cycle) & **XP2** (initialization using MOCAGE dust at the start of each forecast)



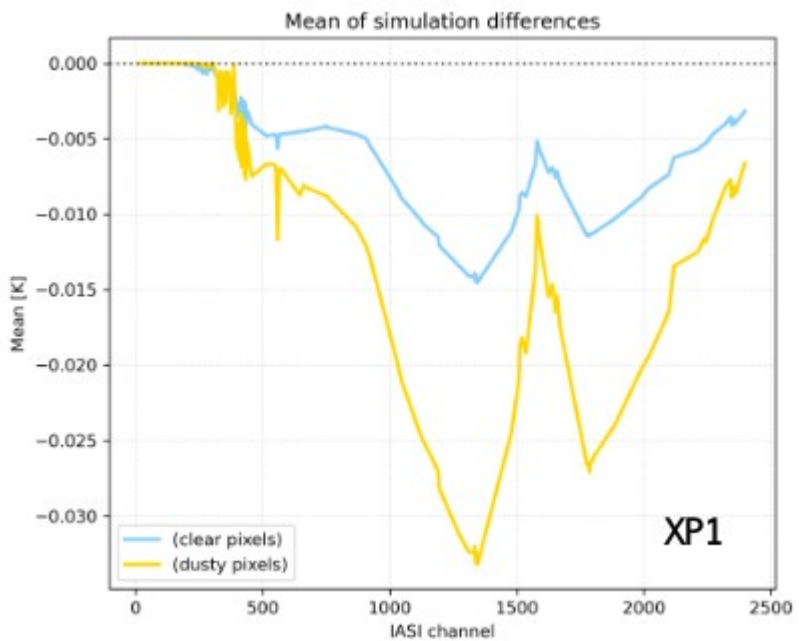
ARPEGE-Compo with dusts

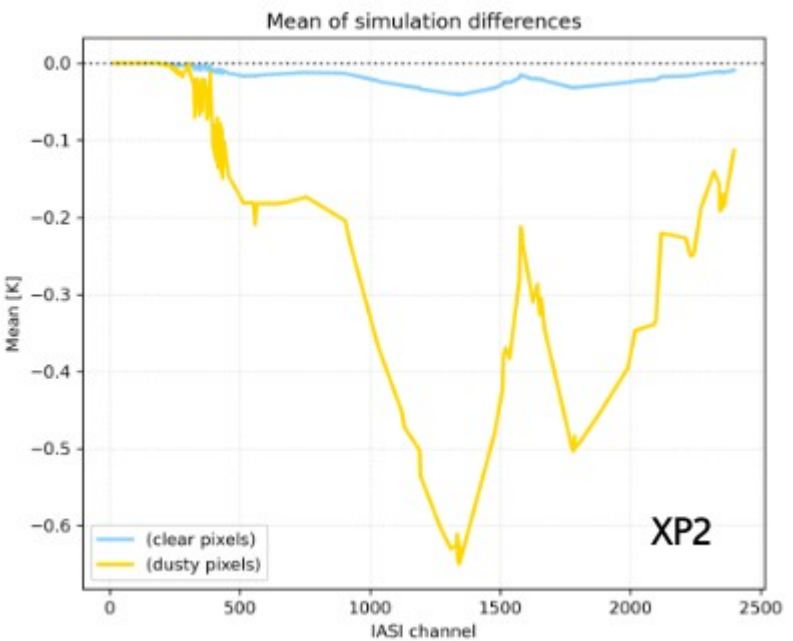
Part 2: Assimilation and model

@Coopmann O.

- **Impact on RTTOV simulations (clear and dusty)**

→ Statistics on the differences between the clear and **dusty** (activation of aerosol parametrization) radiative transfer simulations over the entire period for pixels identified as clear (**blue line)** and dusty (**orange line**) for **XP1** (left) & **XP2** (right).





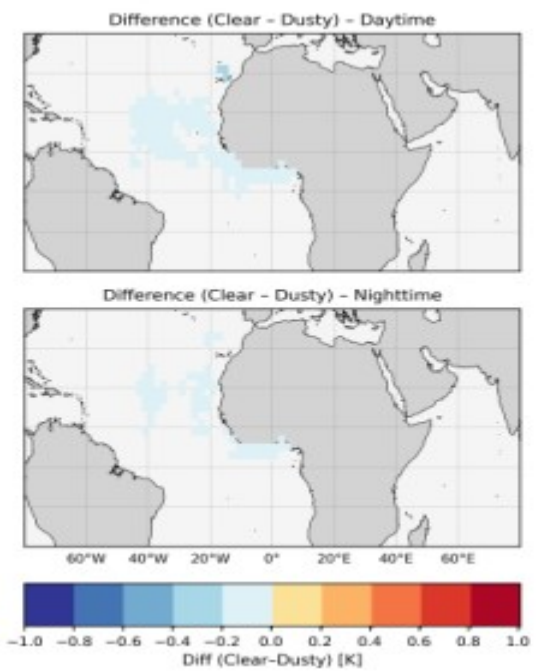
ARPEGE-Compo with dusts

Part 2: Assimilation and model

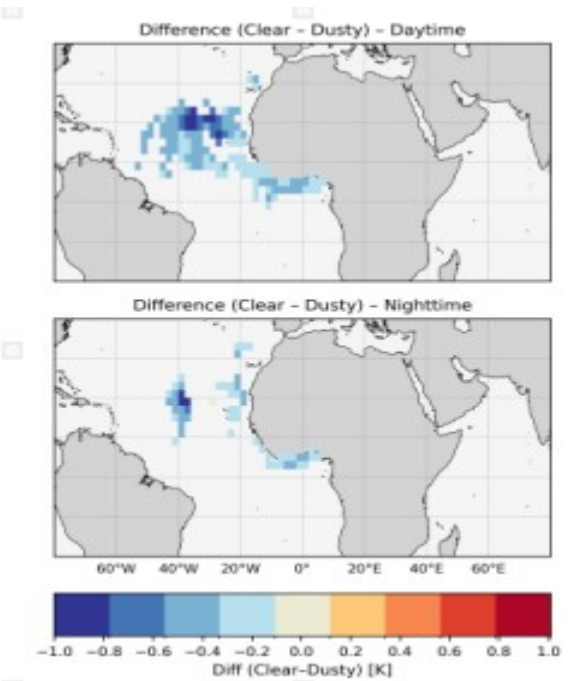
@Coopmann O.

- **Impact on RTTOV simulations (clear and dusty)**

→ Statistics on the differences between the clear and **dusty** (activation of aerosol parametrization) radiative transfer simulations over the entire period for pixels identified as dusty for **XP1** (left) & **XP2** (right) for channel 1027 sensitive to desert aerosol.



XP1



XP2

Conclusion and perspectives

- Modelisation
  - A new modelisation path for SOA is on its way in MOCAGE and ACLIB that will offer new study opportunities
  - The first bricks of our new on-line atmospheric composition model based on ARPEGE and ACLIB
- Assimilation
  - First tests on Earthcare data assimilation for aerosols are promising. Their assimilation along with other data but also the use of the aerosol speciation are scientific objectives.
  - The assimilation of radiances for dust aerosols is a project based on several satellite instruments and models that is really promising, especially in a context of joint weather and aerosol prediction.
- Interactions
  - Moving towards aerosols of the day in NWP ARPEGE and AROME from MOCAGE (not shown)

During the Pride month, CNRM is proud to highlight diversity and the actions taken throughout the year to stand with LGBTQIA+ colleagues

Météo-France update : evolution of the MOCAGE and ARPEGE models and research results

Jonathan Guth jonathan.guth@meteo.fr
+ colleagues from team COMPO

CNRM, Météo-France and CNRS
Modelling, Assimilation, Surface for Atmospheric Composition and Air Quality