Satellite Aerosol Optical Depth (AOD) Monitoring within the Copernicus Atmospheric Monitoring Service (CAMS) Data Assimilation System

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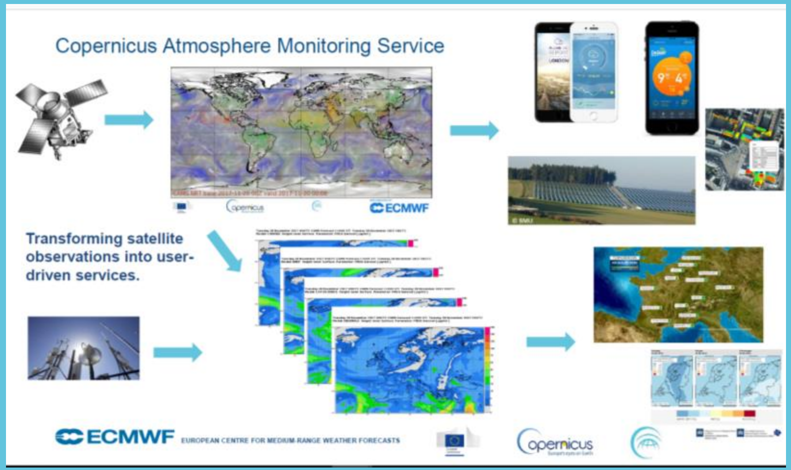

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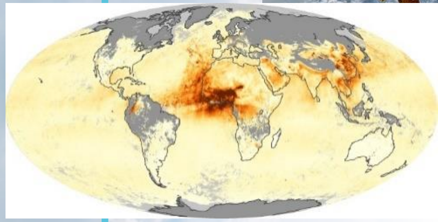
INTRODUCTION

- Needs for new observational data streams
  - More accurate observations.
  - Enhanced spatial and temporal coverage.
  - Increased resilience to instrument failure (e.g. recent failure of AQUA).

- Use of data assimilation system to evaluate aerosol satellite products
  - Inherent spatial and temporal collocation
  - Global and regional statistics.
  - Model comparisons: e.g. first guess departure, bias correction.
  - Identify AOD retrieval deficiencies and inconsistencies between products.

CAMS AEROSOL DATA ASSIMILATION SCHEME

Satellite AOD
MODIS (AQUA, TERRA)
PMAp (METOP A,B,C)



4D VAR data assimilation

Integrated Forecasting Sytem (IFS)

Atmosp. model

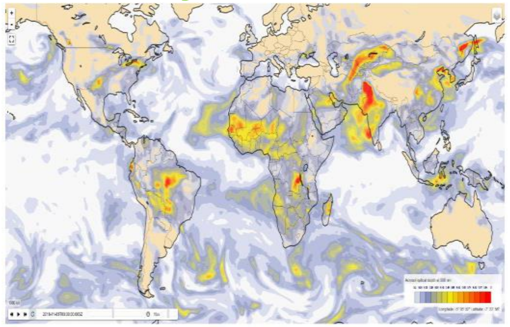
- Semi-Lagrangian advection model
- 137 atm levels
- 40 km horizontal resolution

AER model:

- Bulk-bin scheme
- Species: sea salt, dust, organic matter, black carbon, sulfate, nitrate, amomium
- Emission sources: biomass burning (GFAS), CAMS_GLOB dataset

Remy et al., 2019 GMD

5 day forecast, reanalysis



AOD, aerosol concentration, PM2.5, PM10

SATELLITE AOD USED IN CAMS system

Assimilated products

- **MODIS**
  - AQUA, TERRA
  - C6
  - DB+DT product
  - 10 km
  - Land and ocean

- **PMAp**
  - METOP-A,B,C
  - From GOME-2+IASI+AVHRR
  - V2.1
  - 40*10 km
  - Assimilated over ocean only

Monitored product

- **SLSTR**
  - S3a and S3b
  - V2 (released Aug 2020)
  - 9.5 km
  - Ocean only

- **NOAA-EPS VIIRS**
  - NOAA-20 and S-NPP
  - V2r1
  - 6 km
  - Land and ocean

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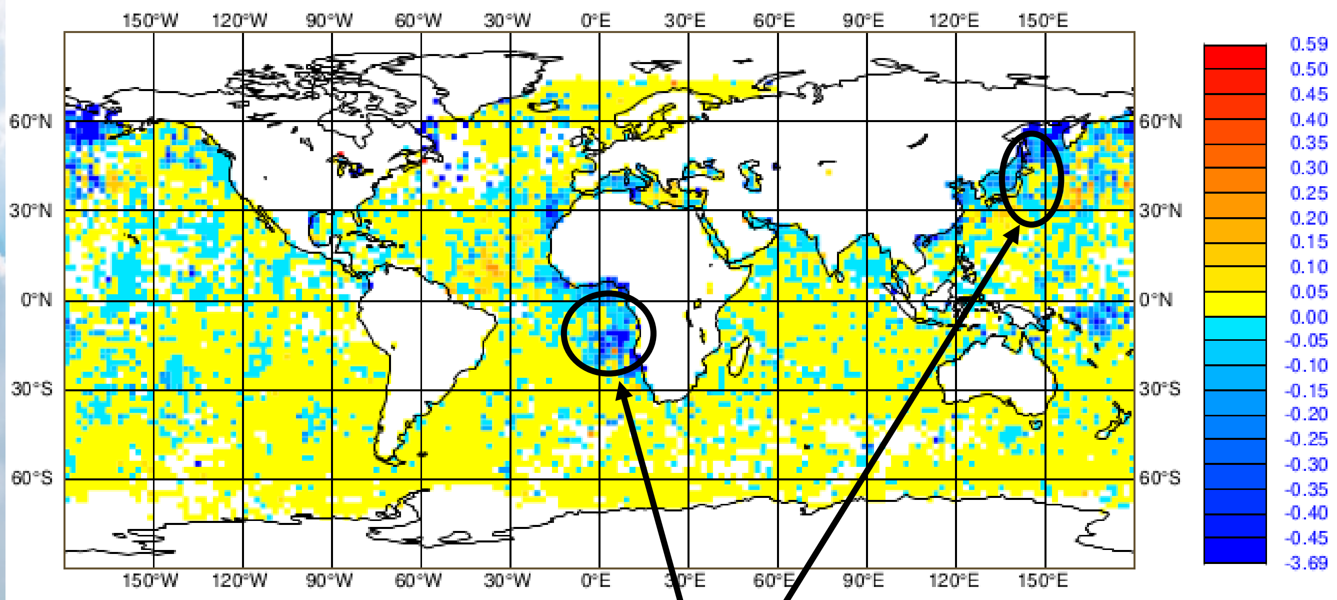
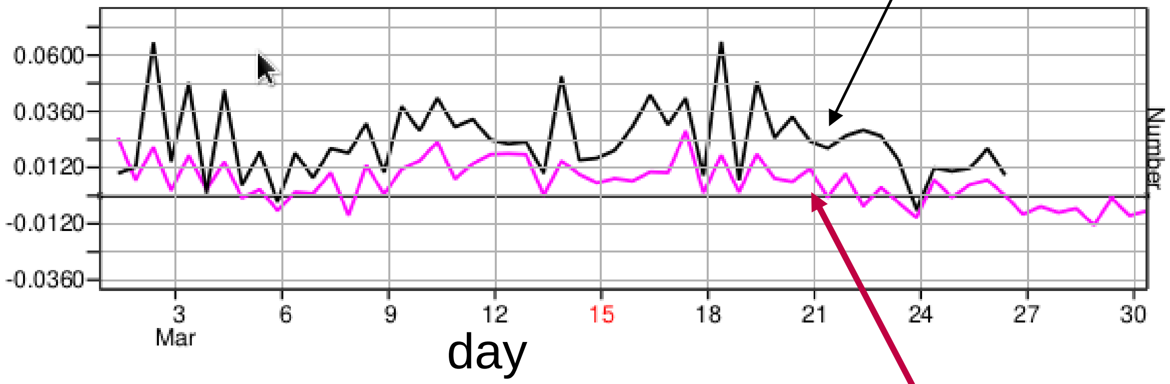
PMAp-B: version 2.2.3 versus 2.2.2

March 2015

PMAp-B V2.2.3 (new) – PMAp v2.2.2 (old)



Satellite – modelled AOD



Old version 2.2.2

New version 2.2.3

reduction of unrealistic AOD hotspots

Reduction of departure between observation and modelled AOD

Impact of cloud contamination

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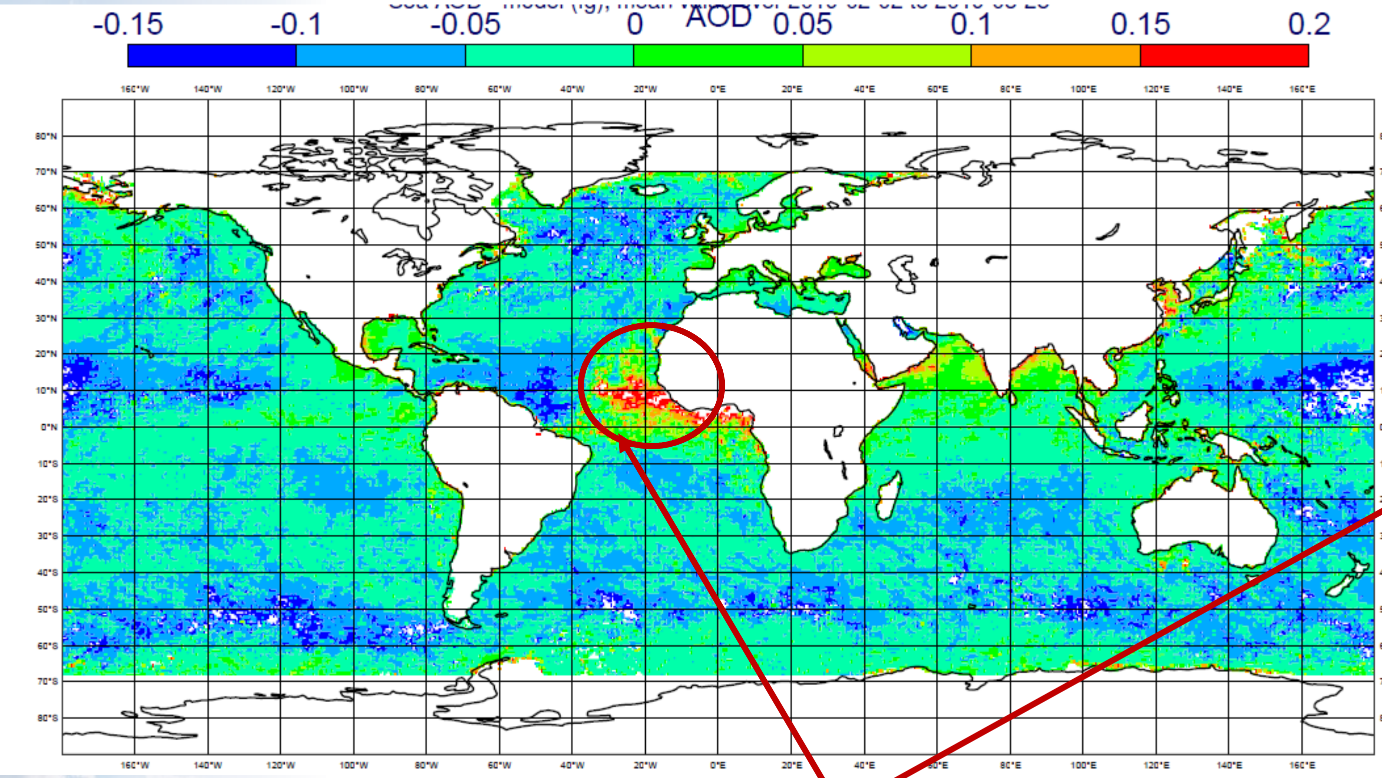
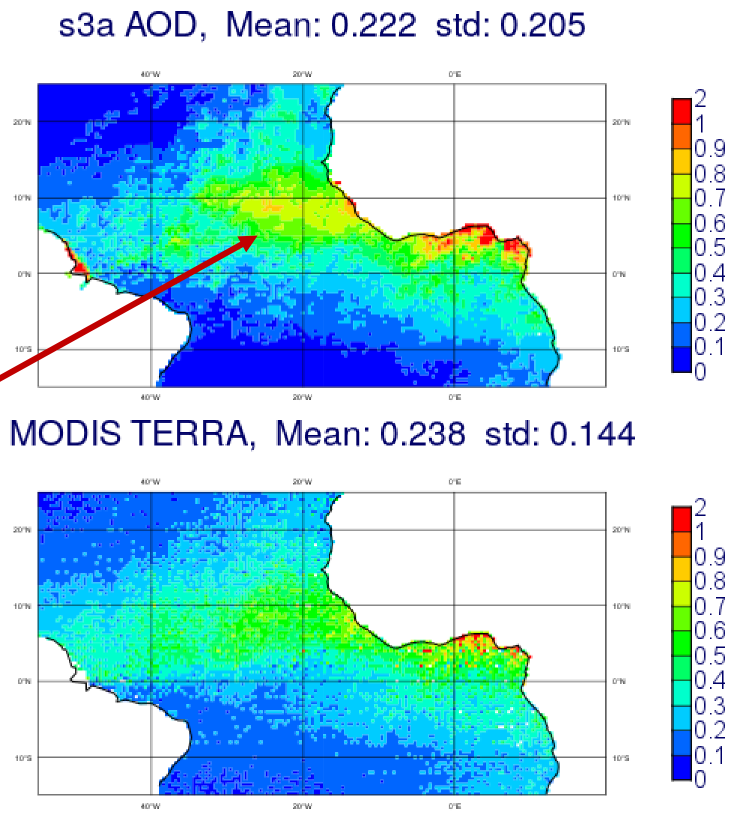
SENTINEL-3/SLSTR (S3a) over Ocean

S3a satellite AOD – modelled AOD



Comparison with MODIS

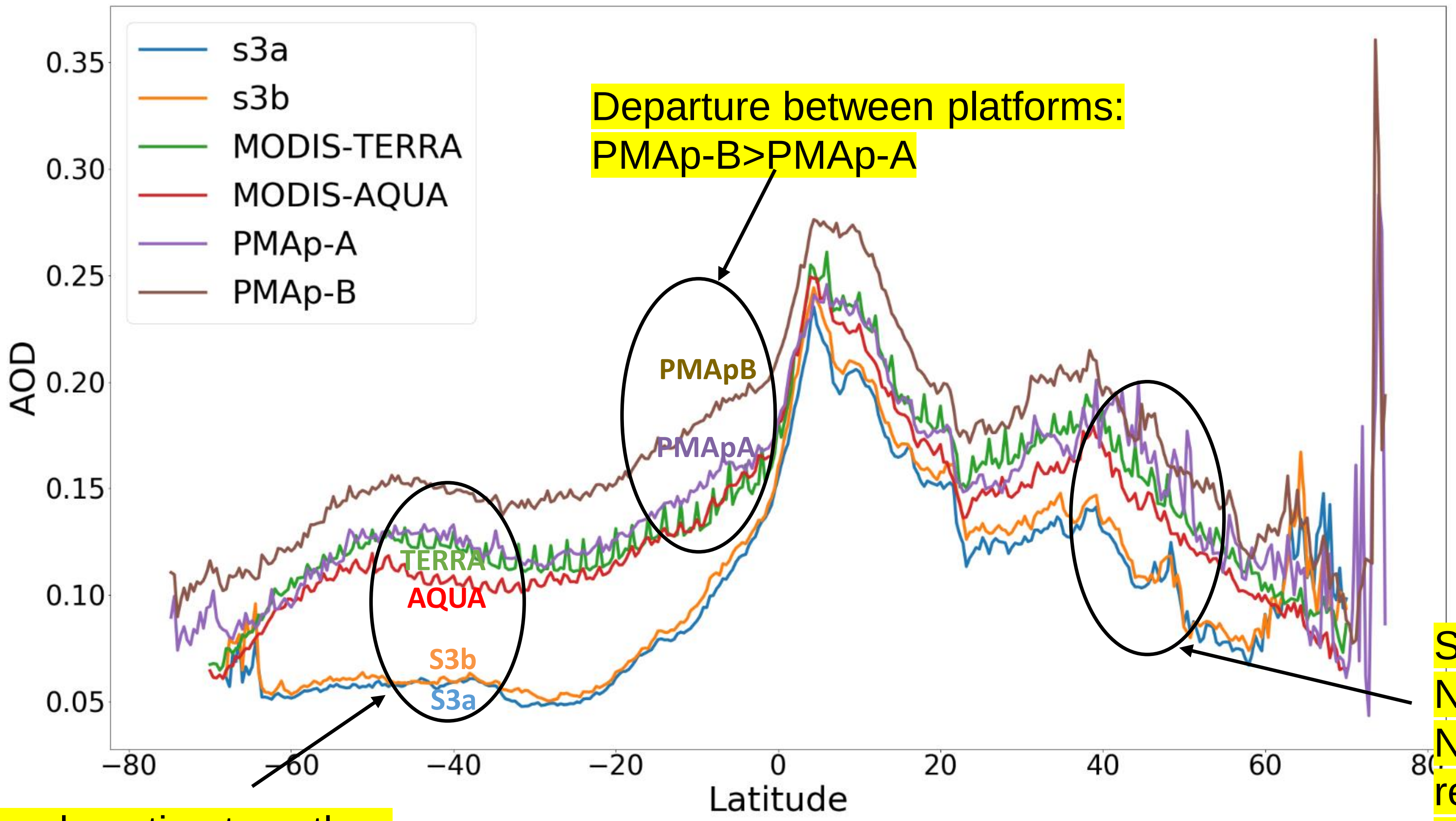


Feb-March 2019

Overestimation of dust AOD

Impact of radiance calibration in the SWIR

S3/SLSTR, TERRA, AQUA, PMAp over ocean



Feb-March 2019 average over ocean

Departure between platforms: PMAp-B>PMAp-A

Smaller departure in NH:
NH/SH structure related to S3 geometry ?

S3 underestimates other products in SH oceans

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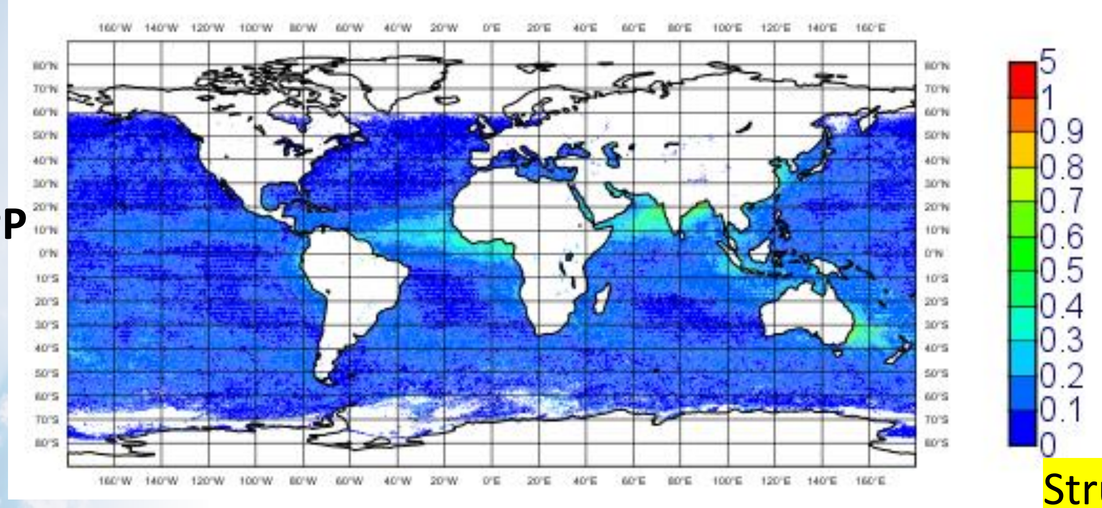
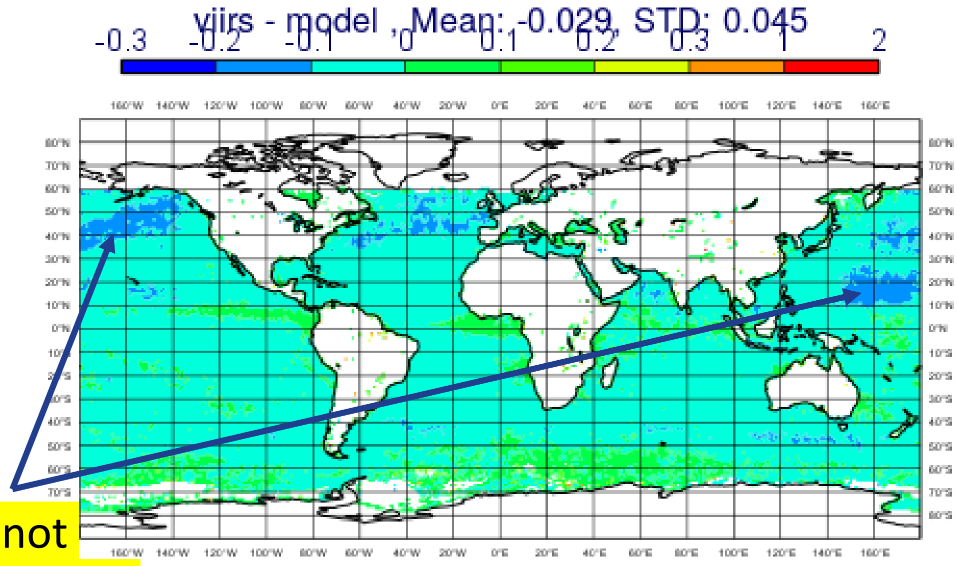
VIIRS/S-NPP vs MODIS and model over ocean

OBSERVATION (OBS)

OBS-MODEL

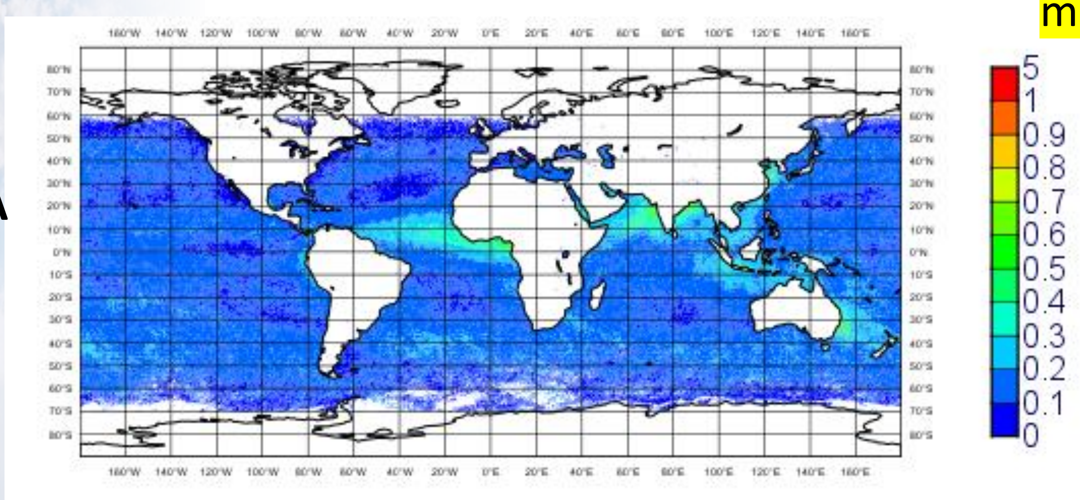
VIIRS/S-NPP

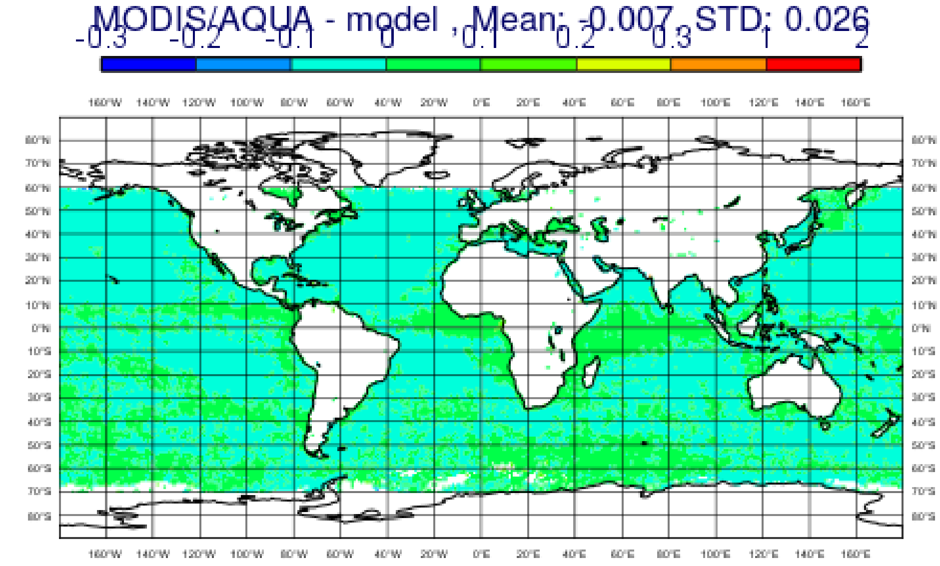




Structures not seen in MODIS or model

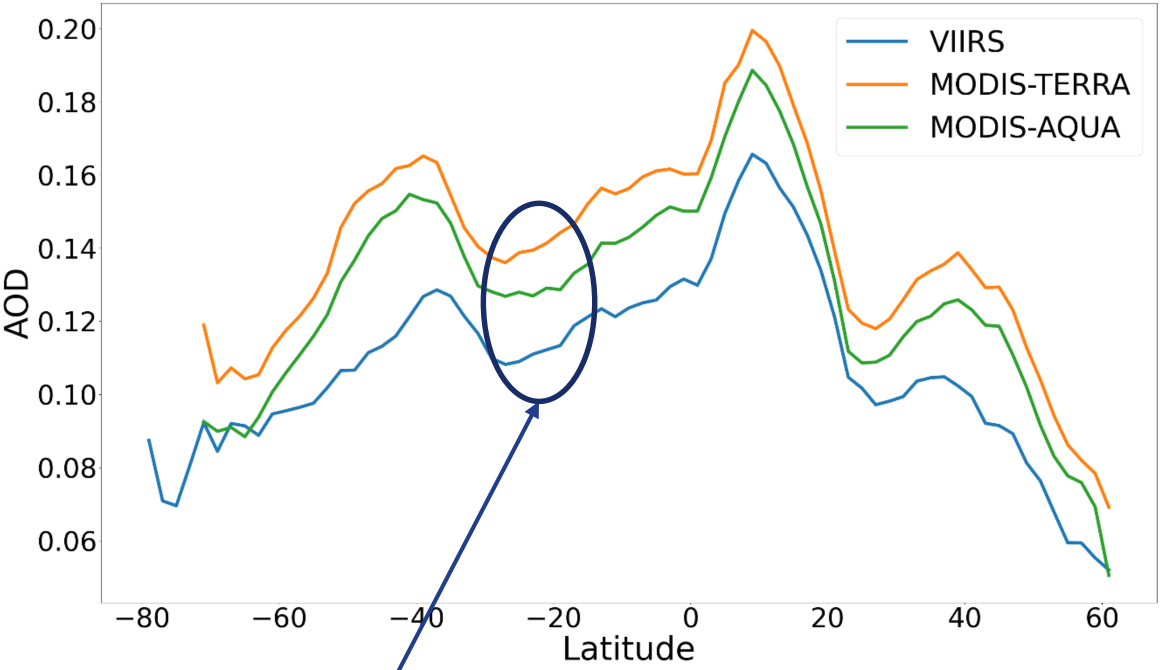
MODIS/AQUA



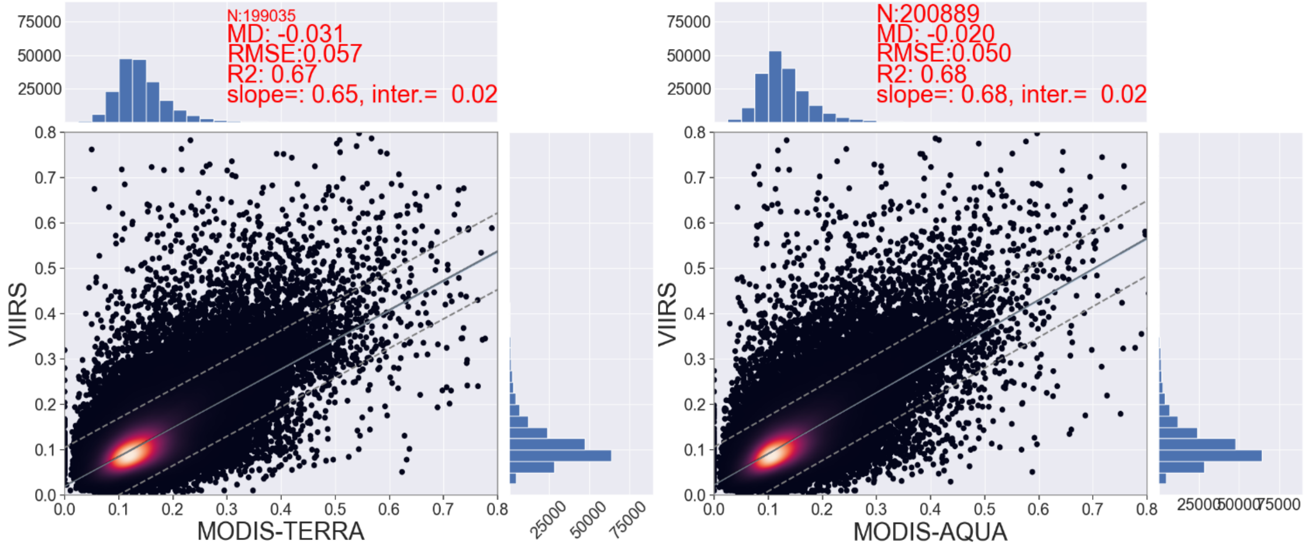


VIIRS AOD < MODIS over ocean

VIIRS/S-NPP vs MODIS over ocean



VIIRS<MODIS, particularly for SH ocean



Overall good consistency between VIIRS and MODIS

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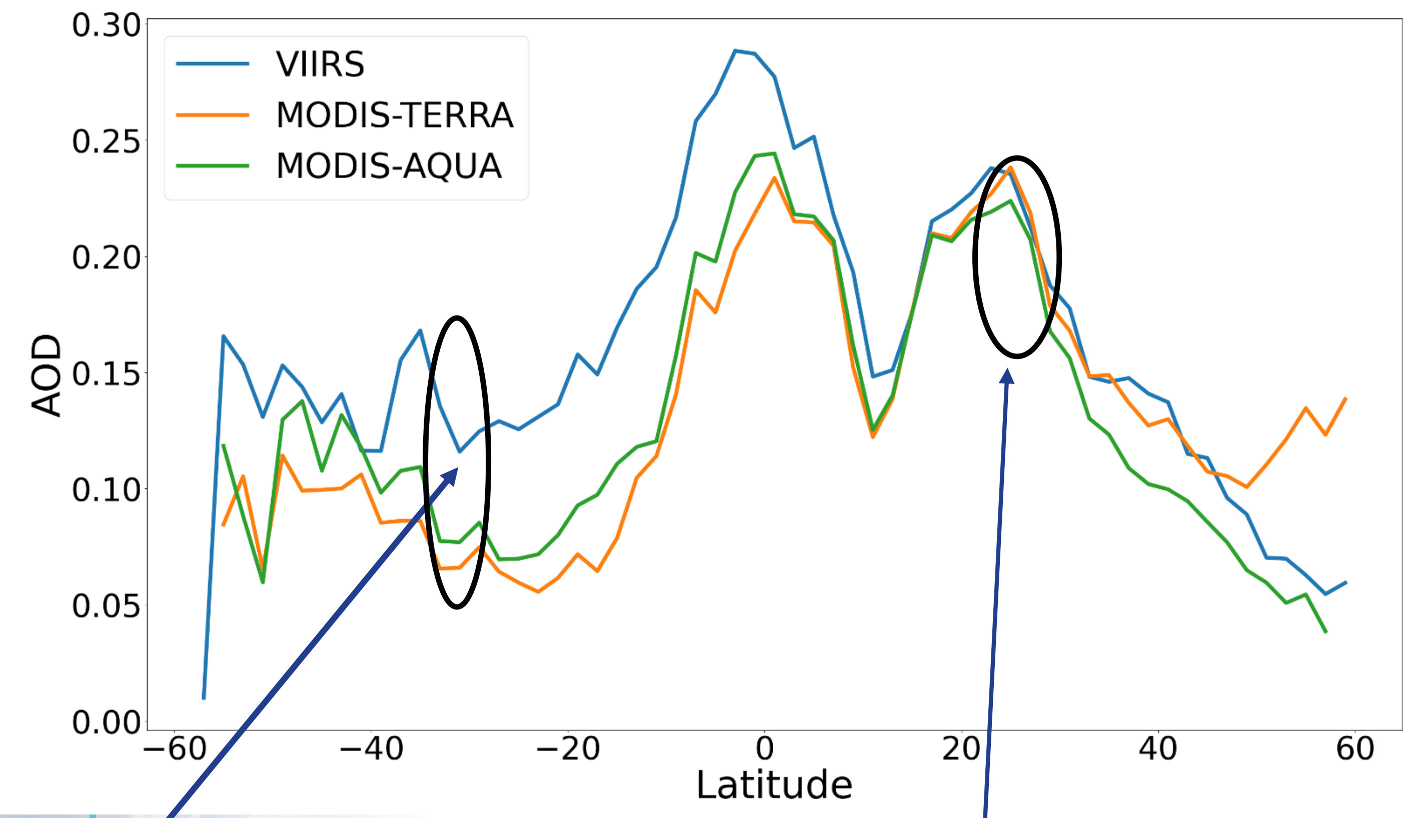
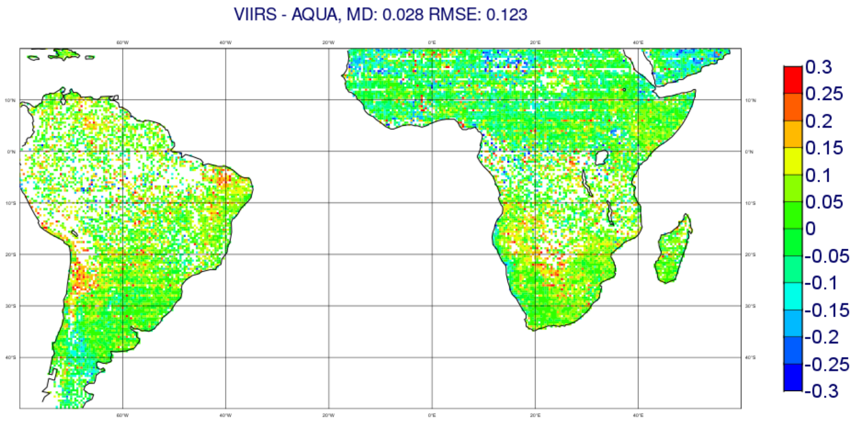
VIIRS/S-NPP vs MODIS over land

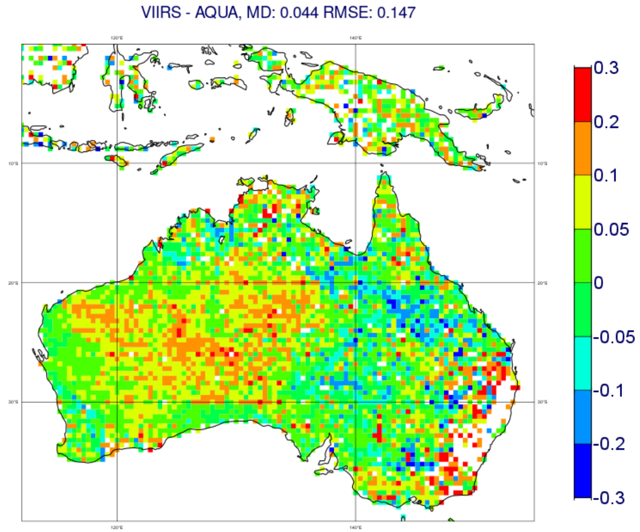


VIIRS>MODIS for SH

Better consistency for NH

VIIRS – MODIS/AQUA





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TAKE HOME MESSAGES

➢ Potential of data assimilation (DA) system

- **Consistent comparison of multi-satellite and simulated AOD.**
- **Identify deficiencies in satellite AOD products:** bias and their spatiotemporal structures
- **Need to evaluate observation error.**

➢ Study on intercomparing NRT satellite AOD within DA systems

- **Various DA systems to encompass model and DA method variability**
- **Assess the impact of satellite observation diversity on the analysis**
- **Interactions between model diversity and satellite observations**
- **Strategies for assimilating multiple satellite AOD**: bias correction, adaptive thinning …
- **Case studies: extreme fire and dust event ?**

IMPLEMENTED BY ECMWF

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ADDITIONAL SLIDES

INTRODUCTION

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- Satellite AOD uncertainties
  - **Algorithm > instrument** (Kokanovsky et al., 2007, Schutgens et al., 2020).
  - Pre-processing (e.g. **cloud screening**, land/sea mask, QA).
  - **Radiative transfer model** and assumptions (e.g. surface reflectance model).
  - **Aerosol model** (e.g. spatiotemporal distribution of aerosol optical properties).
  - **Surface type** (e.g. sunglint and whitecap over ocean, bright surfaces over land).

- Satellite AOD and model intercomparison
  - **Indicator of retrieval uncertainty** (Sogacheva et al. 2020 , Schutgens et al., 2020)
  - **Larger departures between products over land than ocean** (Schutgens et al., 2020)
  - **Needs to evaluate the observation error estimates** (Sayer et al., 2020).

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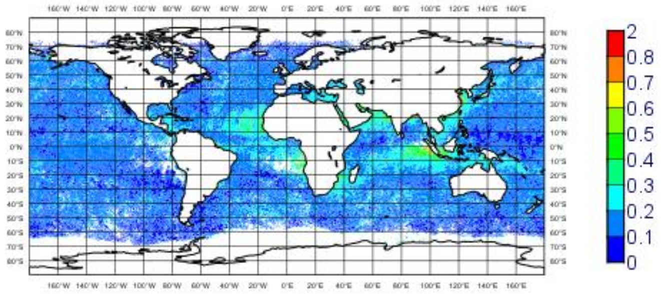
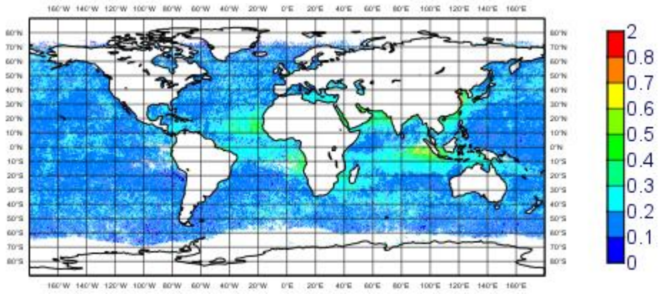
PMAp-A

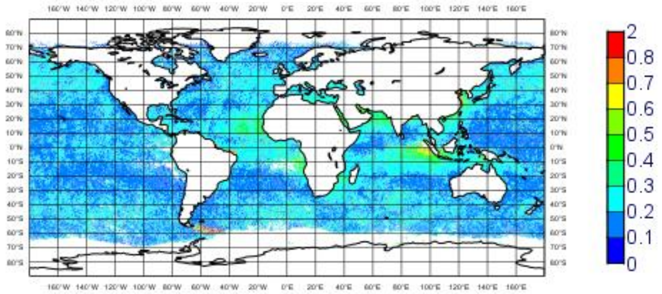
October 2019



PMAp-B

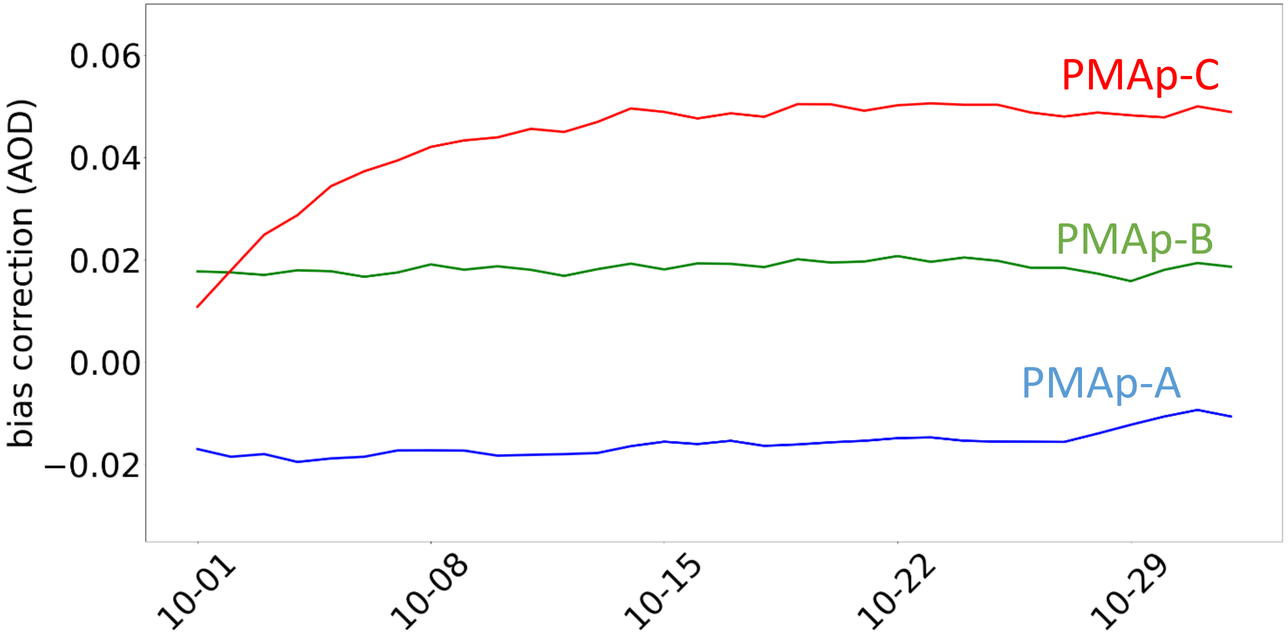


PMAp-C



PMAp-C > PMAp-B>PMAp-A

Time evolution of bias correction for PMAp-A,B,C



Larger bias for PMAp-C

Impact on differences in satellite AOD on the assimilation

DISCUSSION SLIDES

Discussion (1/5)

- Best practices to integrate information from satellites and modelling
  - Implementation of a new NRT product in DA system requires two steps
    - Step1: Passive monitoring
    - Step2: Active (assimilation) monitoring
  - Step 1
    - Needs further documentation on
      - uncertainty in each individual AOD product
      - multi-satellite product consistency/discrepancies
      - Spatiotemporal structure of observation uncertainties (spatial and temporal length scales)
    - Not enough for NRT products
    - International effort using AEROSAT platform:
      - Evaluation carried out at data provider level prior their use in DA system
      - DA system can help to
        - evaluate the product during its development phase and provide feedbacks
        - quantify the impact of product uncertainty on the analysis

Discussion (2/5)

- Best practices to integrate information from satellites and modelling
  - DA system provides a consistent framework
    - Account for observation error and model errors
    - Inherent temporal and spatial collocation of observations and model in observation space
  - Key aspects
    - Data thinning strategies: adaptive thinning, super-obbing
    - Bias correction to ensure better consistency between model and observation
    - Choice of an anchor
    - Prognostic observation error
    - Well documented QA
    - Background error covariance matrix

Discussion (3/5)

- **What are conditions of high/low consistency within satellite data/modelling and between both**
  - Modelling consistency
    - Uncertainty/accuracy for aerosol mass diagnostics: ground networks
    - Model biases
    - Impact of resolution
  - Observation uncertainty
    - Expected uncertainty and accuracy of 0.03 – 0.05
    - Spatial and temporal consistency between products (minimized spatiotemporal structures of deviation between products)
    - Documentation of uncertainties: function of aod, type of aerosols, regions, seasonal variations
  - Observation - model departure
    - small (bias correction scheme may be needed)
    - Consistent temporal variations: diurnal cycle, seasonal evolution…

Discussion (3/4)

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- Development priorities
  - **Strategy for assimilating multi-satellite AOD**
    - Bias correction and selection of an anchor
    - Observation error: prognostic one at pixel level
    - Thinning : adaptive thinning (use QA)
  - **Needs for specific case studies on evaluating multi satellite AOD within DA systems**
    - Monitoring observations and asses the impact on the analysis
    - Encompassing a range of models and assimilation methods,
    - Evaluation needs to include AOD and observation error
    - Extreme cases (fire, dust) for NRT applications
  - **Consider assimilating level-1 (radiances) product versus retrievals**:
    - Discrepancies can be larger at retrieval (level-2) level
    - Should provide better consistency with aerosol models defined in the model
    - First results encouraging but needs further research to improve observation operator, pre-processing (cloud screening..)

Discussion (4/4)

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- Best way to compare different products and resolve differences for data assimilation
  - Essential to verify the consistency or inconsistency with observations already assimilated
  - Differences between products propagate in the analysis and the diagnostics in a complex way:
    - E.g: assimilating only AQUA or only TERRA, assimilating PMAp versus no PMAp-> can generate large differences in PM2.5
    - Complex interactions between
      - Different level of uncertainties between products
      - Departure between products vary across regions (challenging surfaces: South ocean for sea, African dust, large variability of aerosol in China) and seasons
      - Difference in temporal (overpass time …) and spatial (spatial resolution) sampling
  - Difficulty to disentangle the impact of the assimilation versus model structure