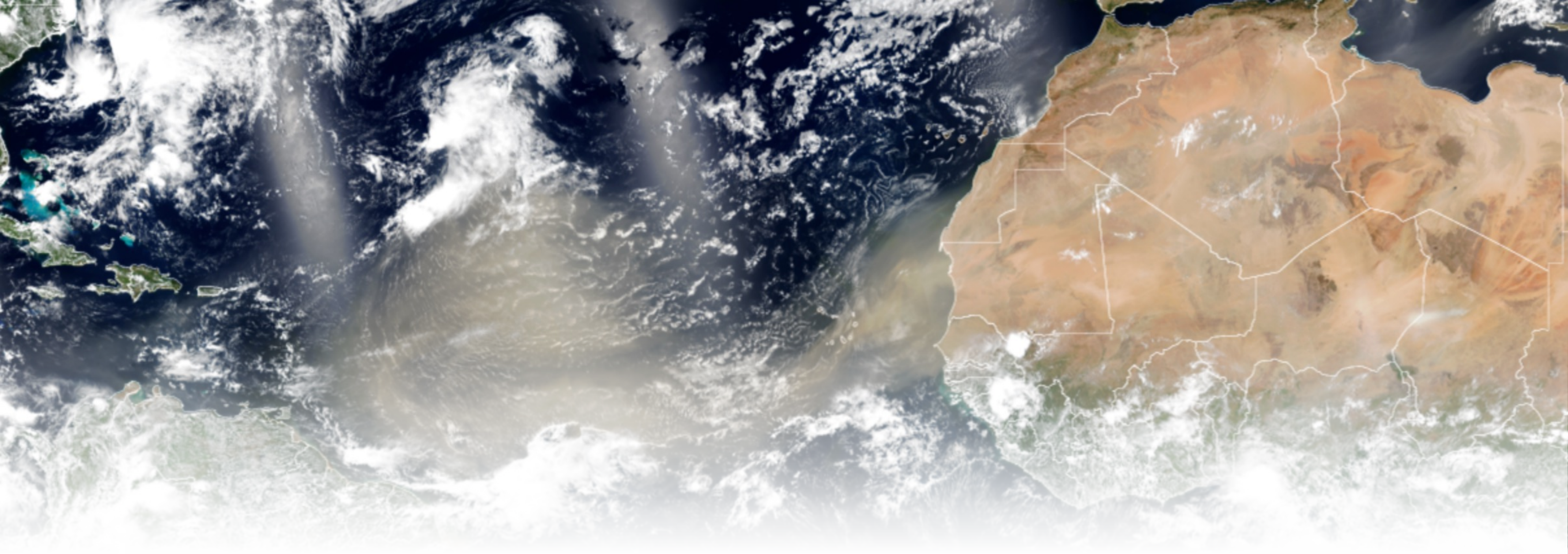

Introduction to satellite data

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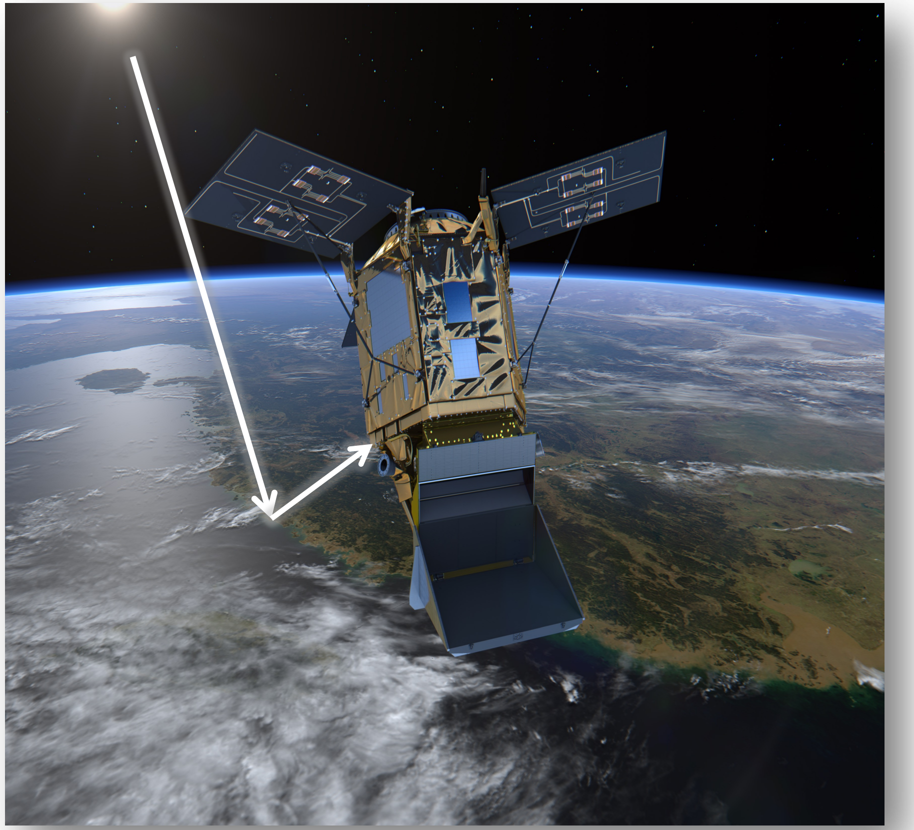
ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

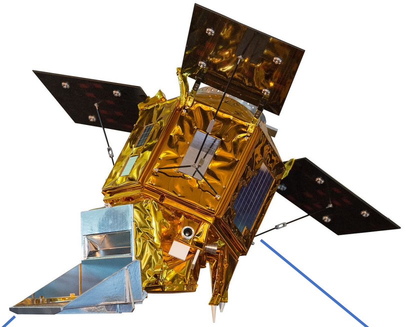
EUMETSAT
AC SAF
ATMOSPHERIC COMPOSITION MONITORING

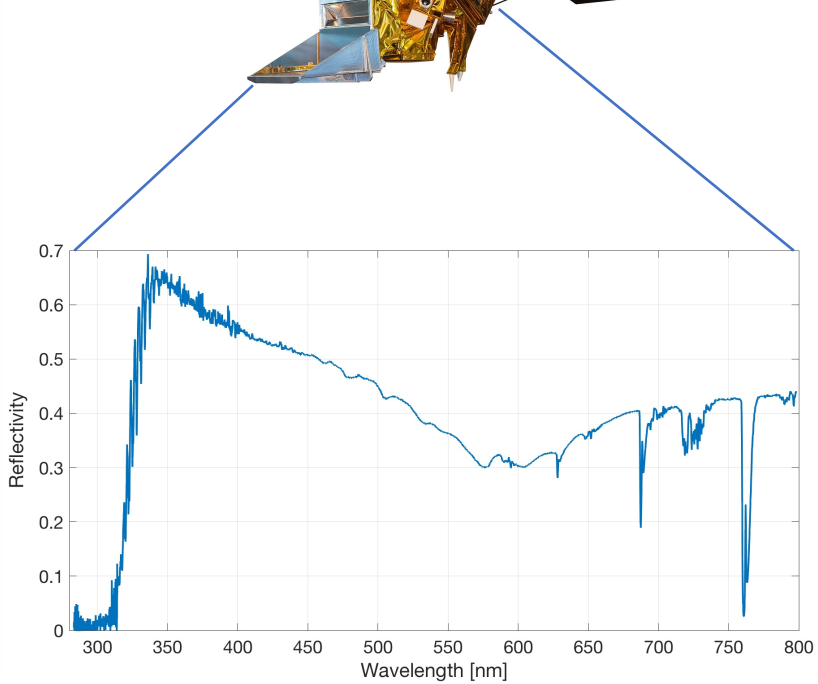
Contents of the lecture

- Basic principles of passive satellite measurements
- True color RGB images from satellites
- RGB composites and other (level 1) dust products
- Aerosol Optical Depth
- Absorbing Aerosol Index
- Absorbing Aerosol Height

Basic principle of a passive satellite measurement







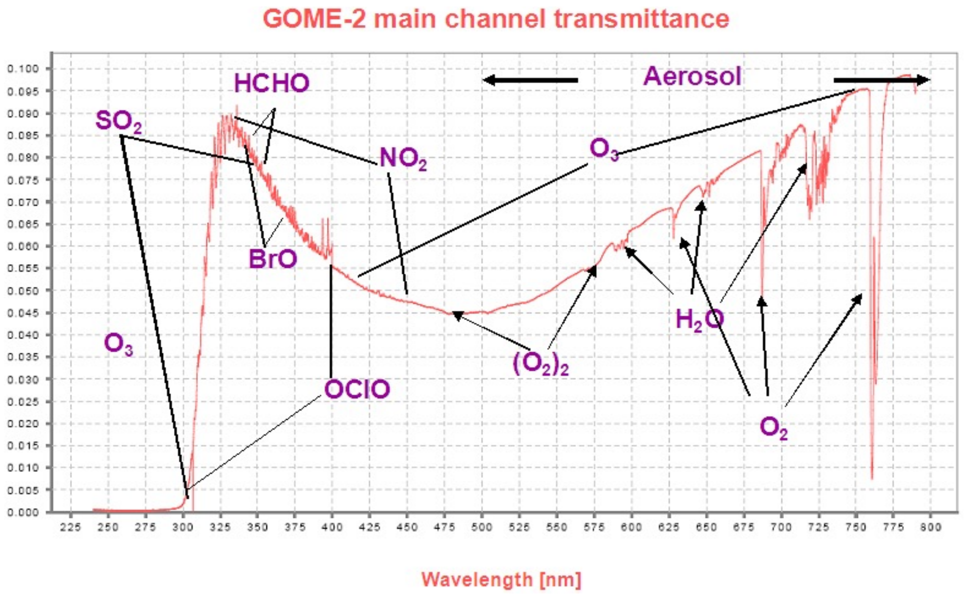
- Passive satellite instruments measure
  - Solar radiation that is reflected back to the space from Earth surface and the atmosphere.
  - Thermal radiation that is emitted from the Earth and the atmosphere

- Satellite observations of atmospheric components are **always indirect:** satellites measure radiation, not concentrations.

Basic principle of a passive satellite measurement

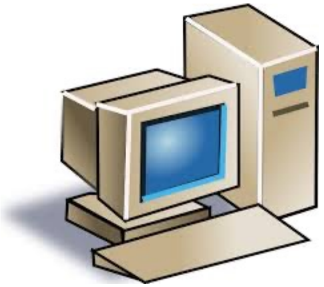
- Passive satellite instruments measure reflected radiation at selected wavelengths
- The key is the "fingerprint" that different gases and aerosols leave on the measured radiation
  - By selecting different wavelengths channels, different gases / aerosols can be observed.

Satellite measurement

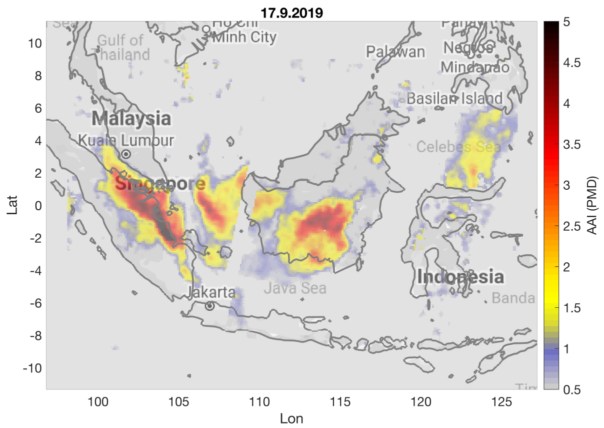


Level 1 data

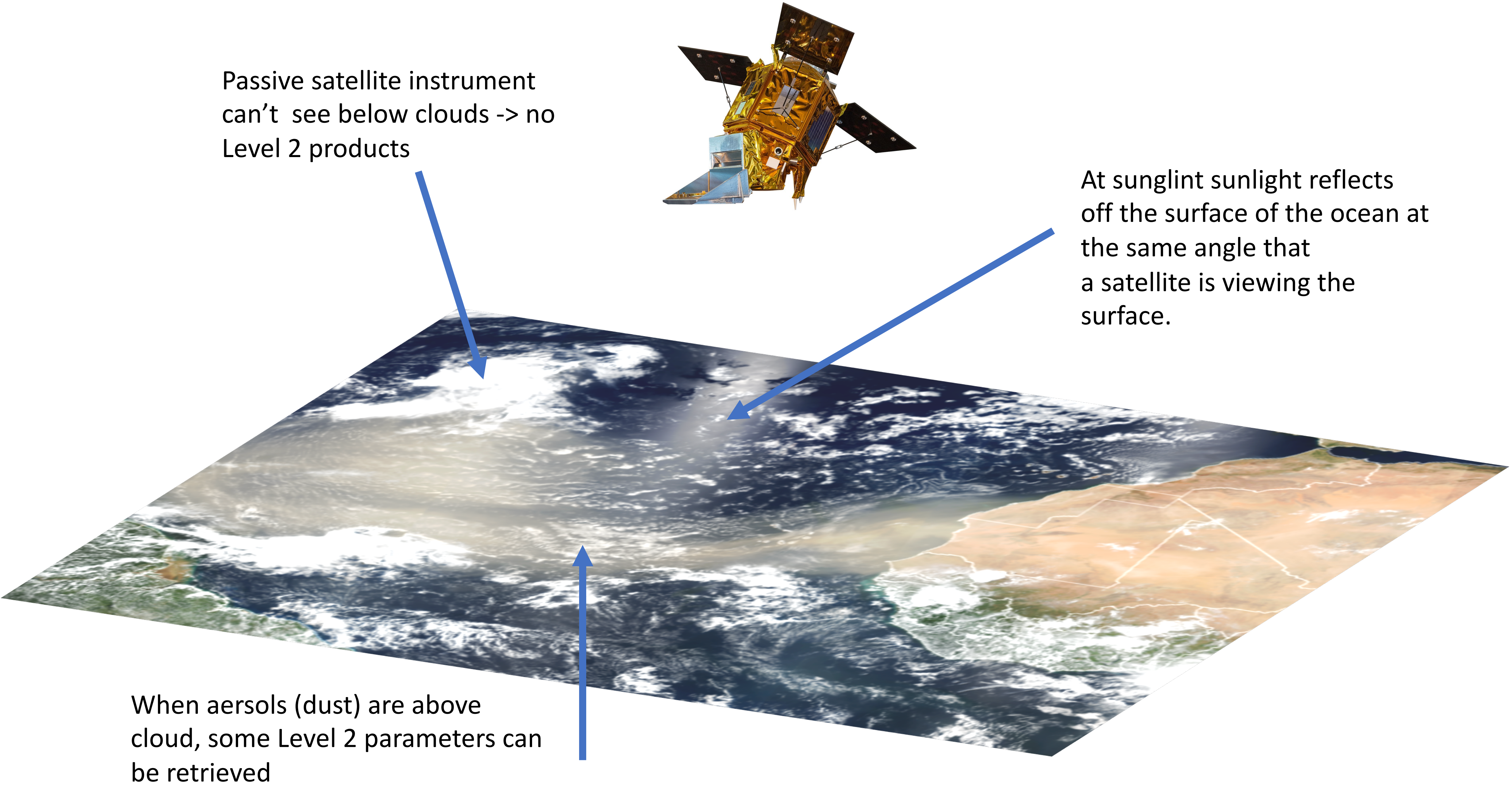
Retrieval algorithm



Satellite observations of atmospheric components



Level 2 data

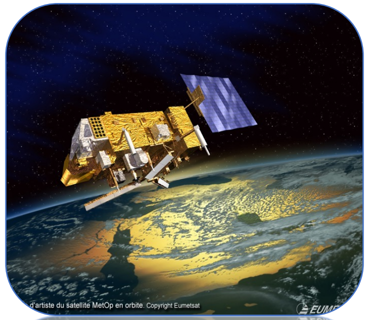

Passive satellite instrument can’t see below clouds -> no Level 2 products
At sunglint sunlight reflects off the surface of the ocean at the same angle that a satellite is viewing the surface.
When aersols (dust) are above cloud, some Level 2 parameters can be retrieved

Examples of current operational satellite instruments monitoring atmospheric composition

OMI
NASA AURA

- Since 2004
- Polar orbit
- Trace gases, **aerosols,** clouds, UV- radiation
- FMI as the co-PI institute with KNMI

GOME-2 and IASI
Metop-A, B. and C



- Since 2006, 2012, and 2018
- Metop-A decommissioning has started, no data after Oct/Nov. 2021
- Polar orbit
- Trace gases, **aerosols,** methane, clouds, UV-radiation

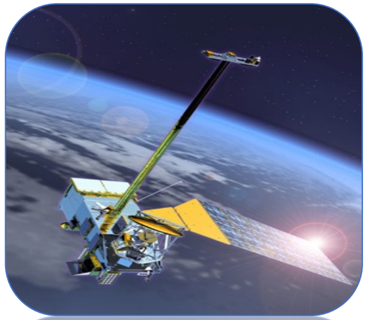
TROPOMI
Copernicus sentinel 5p

- Since 2017,
- Polar orbit
- Trace gases, **aerosols**, clouds, UV- radiation, methane

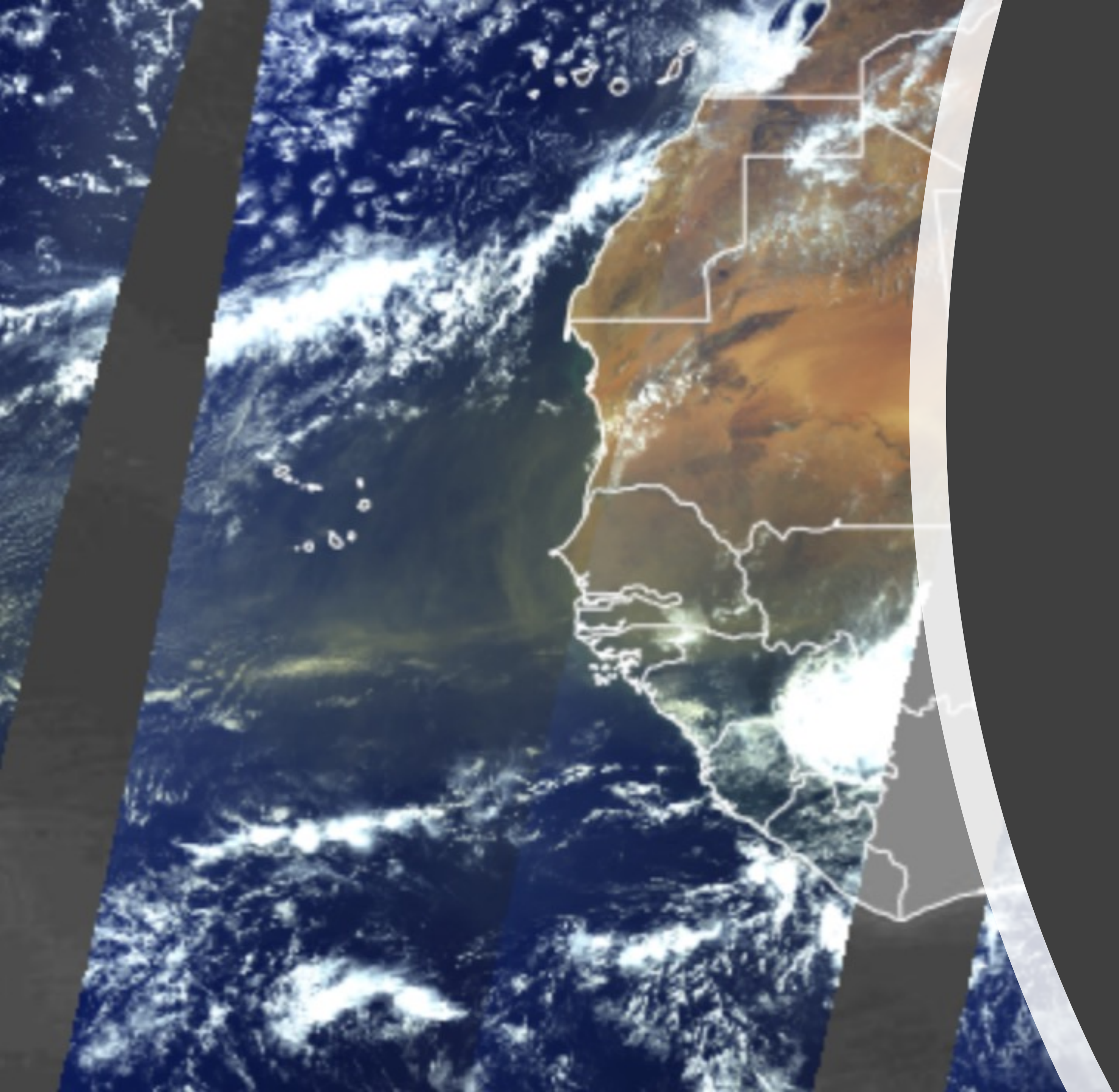
MODIS
NASA Terra and Aqua

- Since 1999, and 2002
- Polar orbit
- **Aerosols,** clouds, fire detection

VIIRS NOAA/NASA
SNPP and JPSS



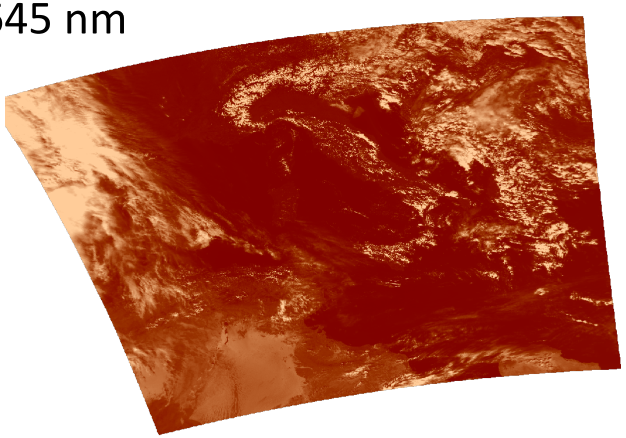
- Since 2011, and 2017
- Polar orbit
- **Aerosols**, clouds, fire detection



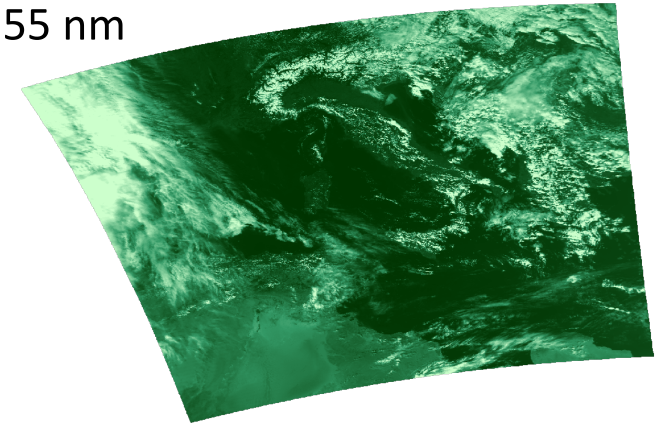
True color RGB images

Example: MODIS

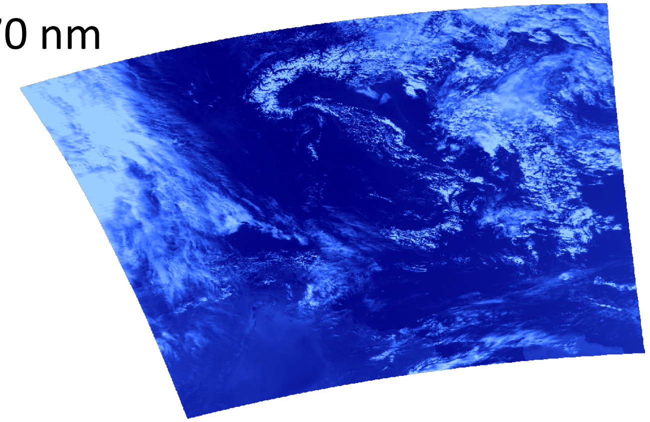
645 nm



555 nm

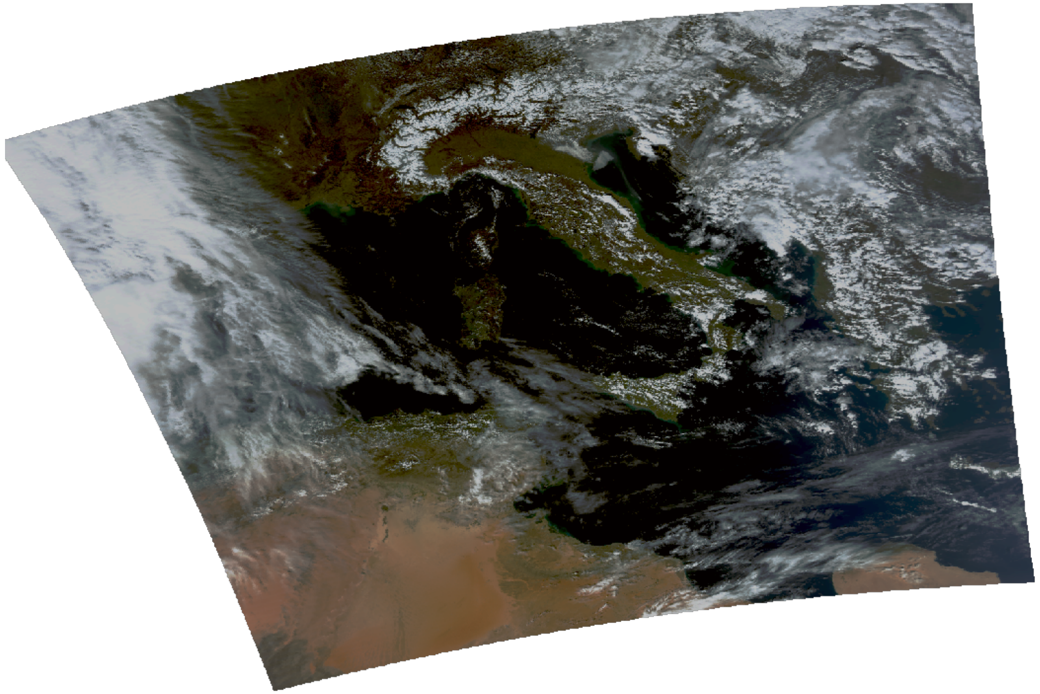


470 nm



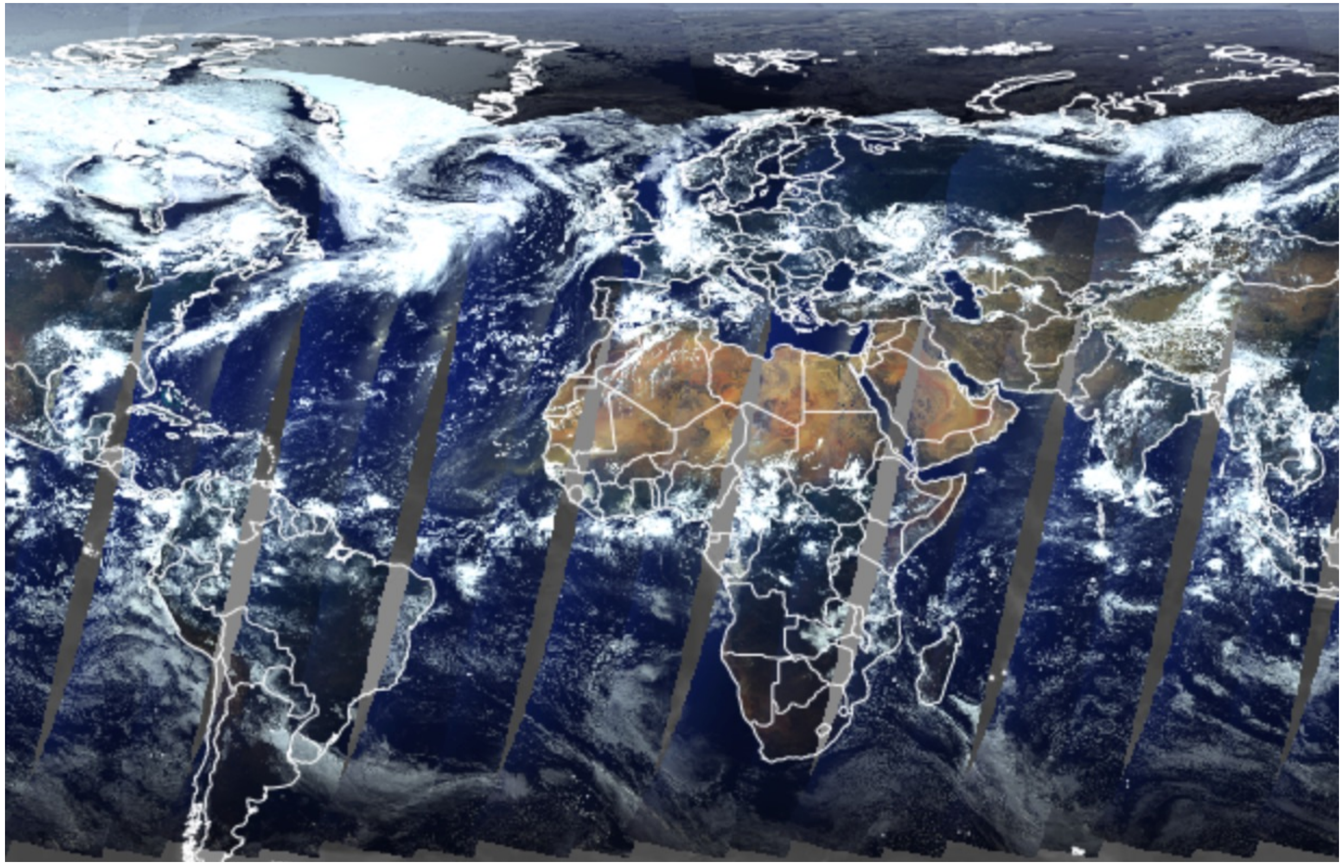
RGB “True color” images

- RGB image composite is a technique to display the color imagery by using the property of the three primary colors of the light.
- RGB image from satellite observations is created from (calibrated) radiances, i.e. Level 1 data.
- To create proper RGB images from satellite data, some enhancement factors etc. might be needed.
- There are codes available e.g. in Python (find with Google), that plots an RGB image from MODIS L1B file.



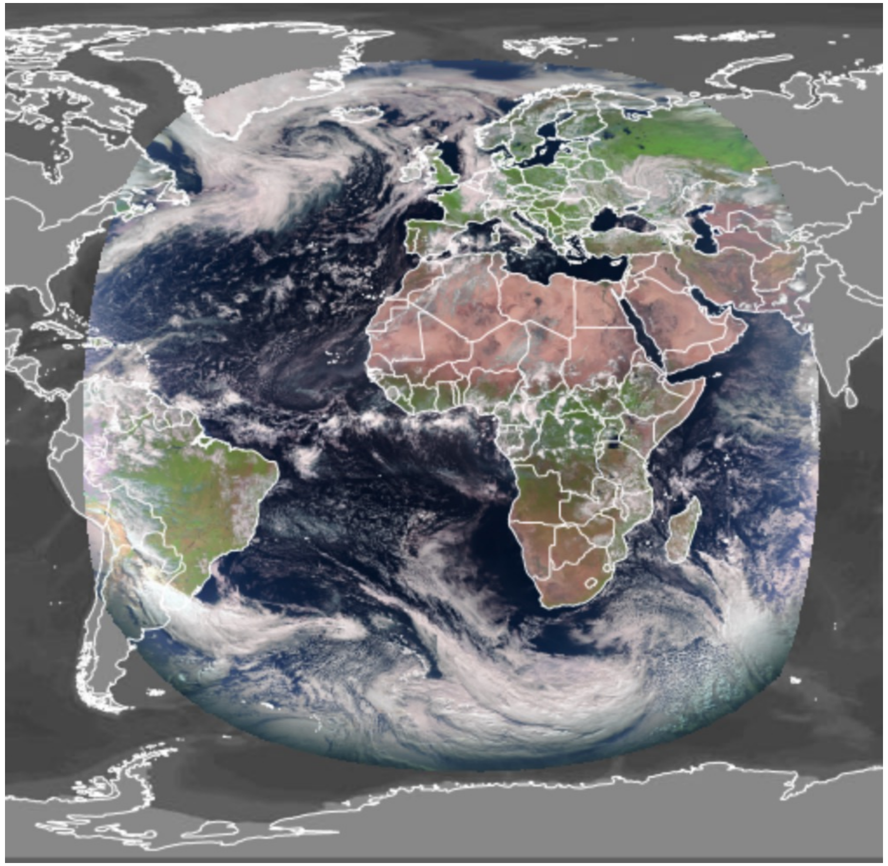
Polar orbiting satellite:
Sentinel-3 OLCI

- Observations about once per day / location at about same local time.
- Global coverage



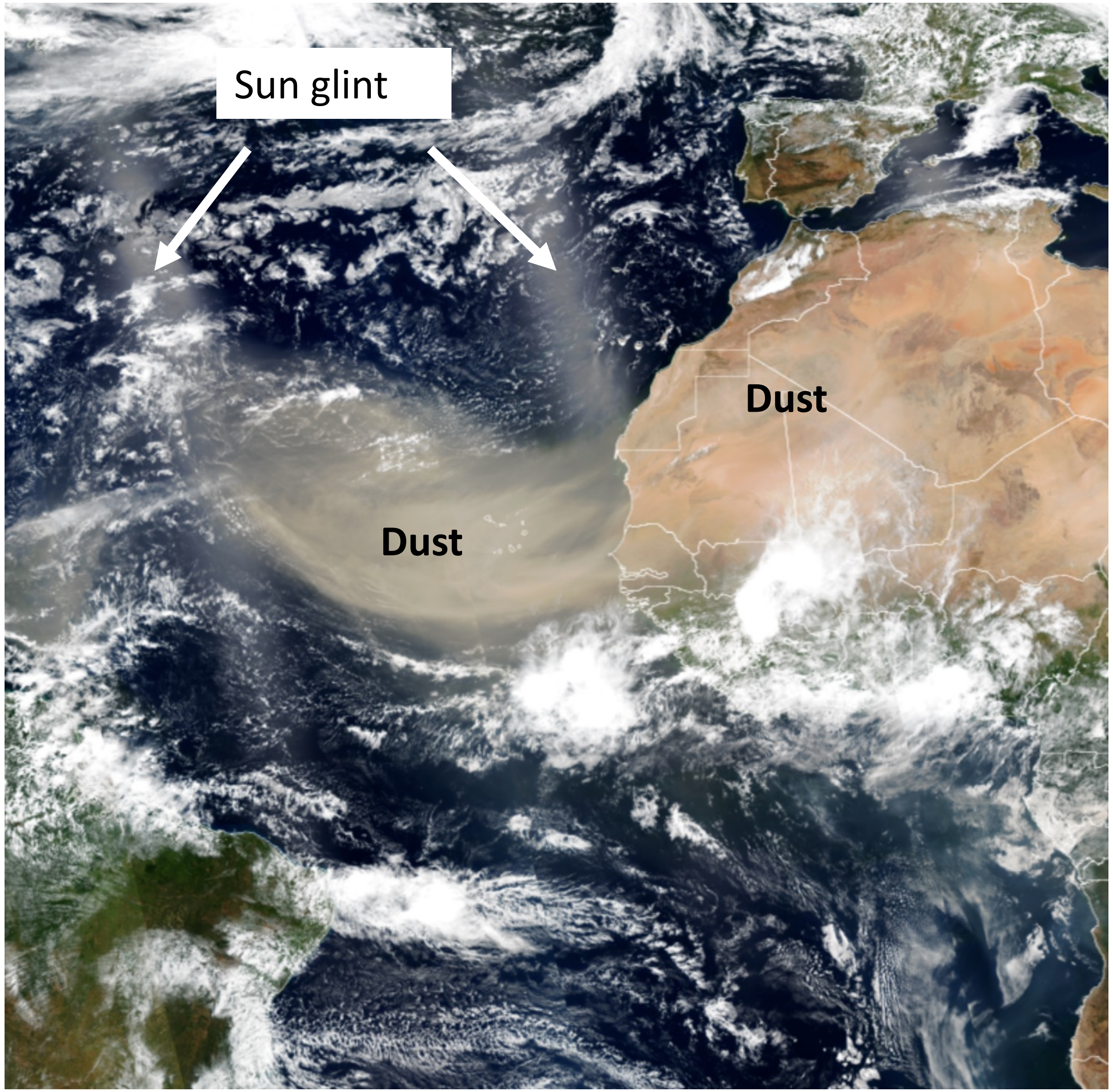
Geostationary satellite:
MSG Seviri

- Observations every 15 minutes during daytime (true color RGB based on solar channels)
- Covers only restricted area

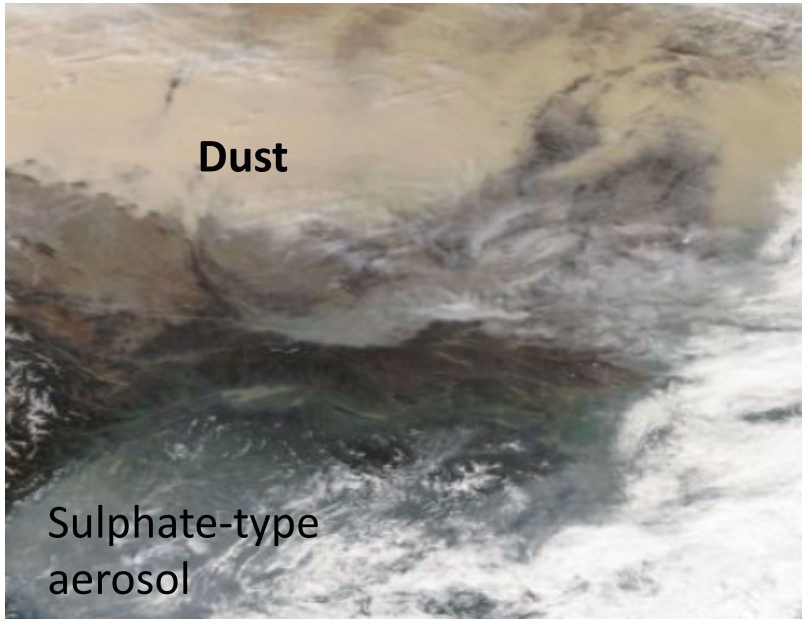


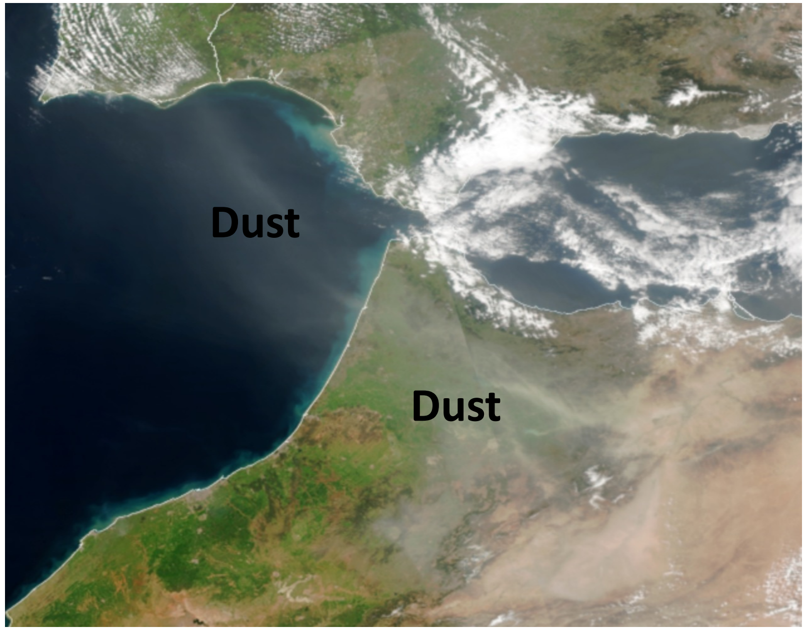
Dust in RGB images

Polar orbiting satellites



Observation time always at about same local time (sun synchronous)



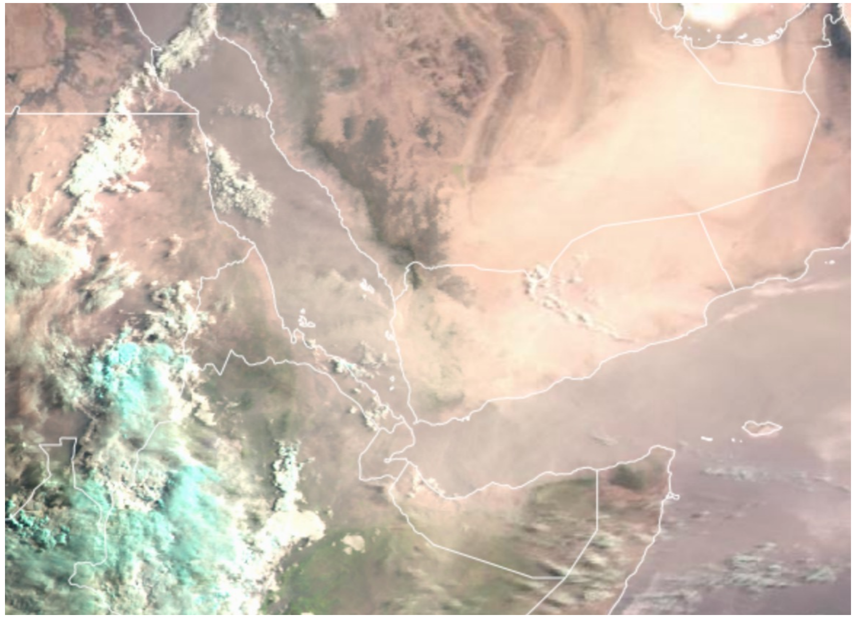


Dust in RGB images
Geostationary satellite

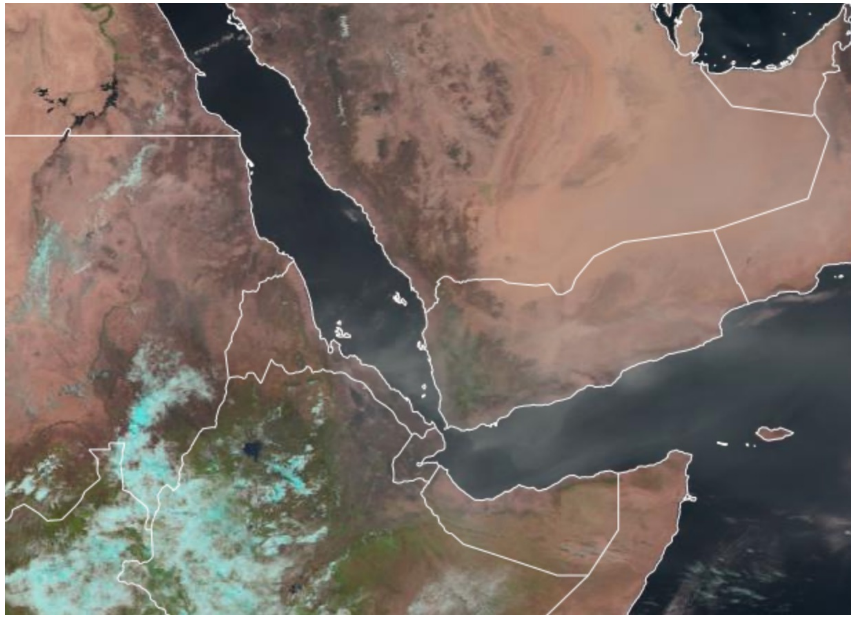
Example: MSG Seviri RGB True color product

Observation time changes -> solar angle change

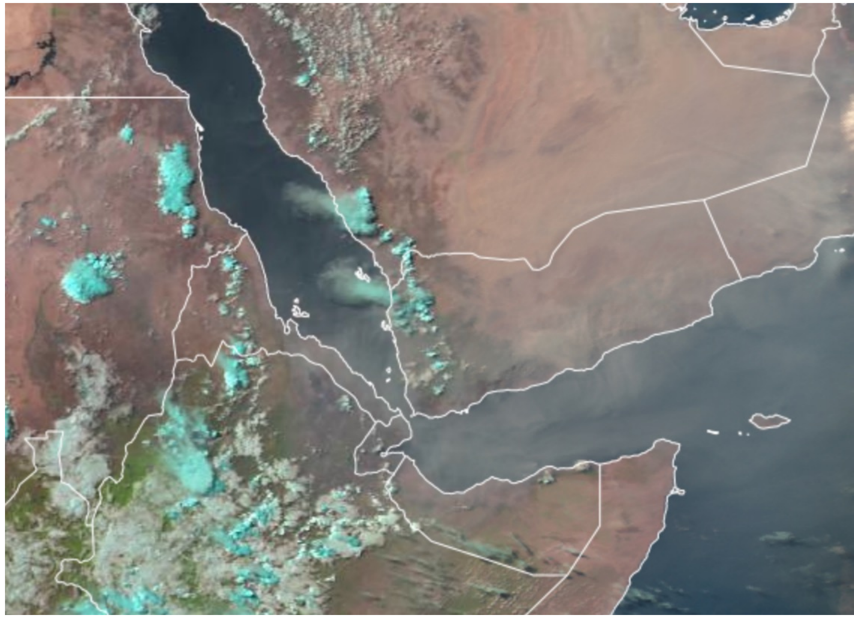
"Early morning"

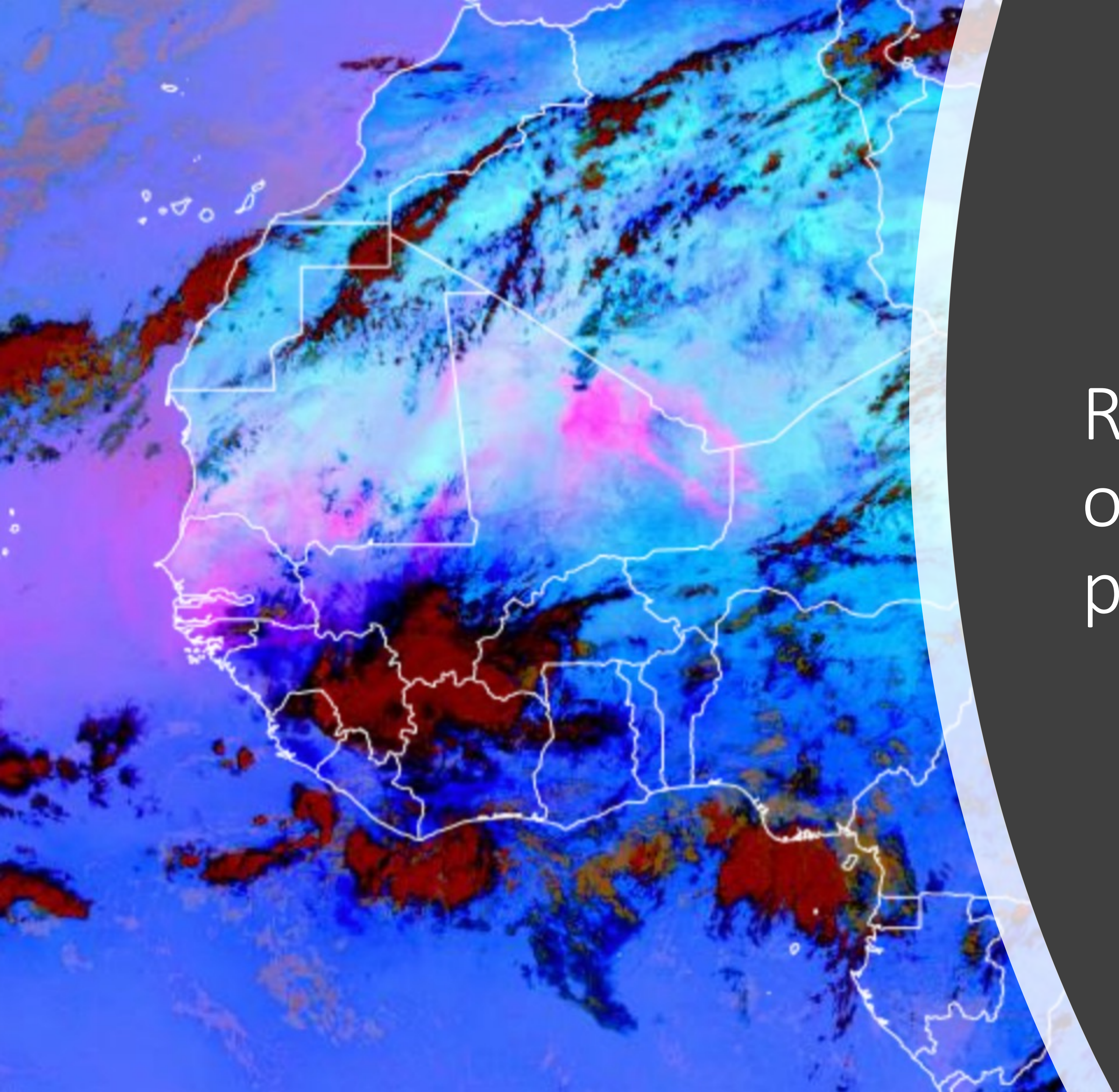


"Close to noon"



"Late afternoon"

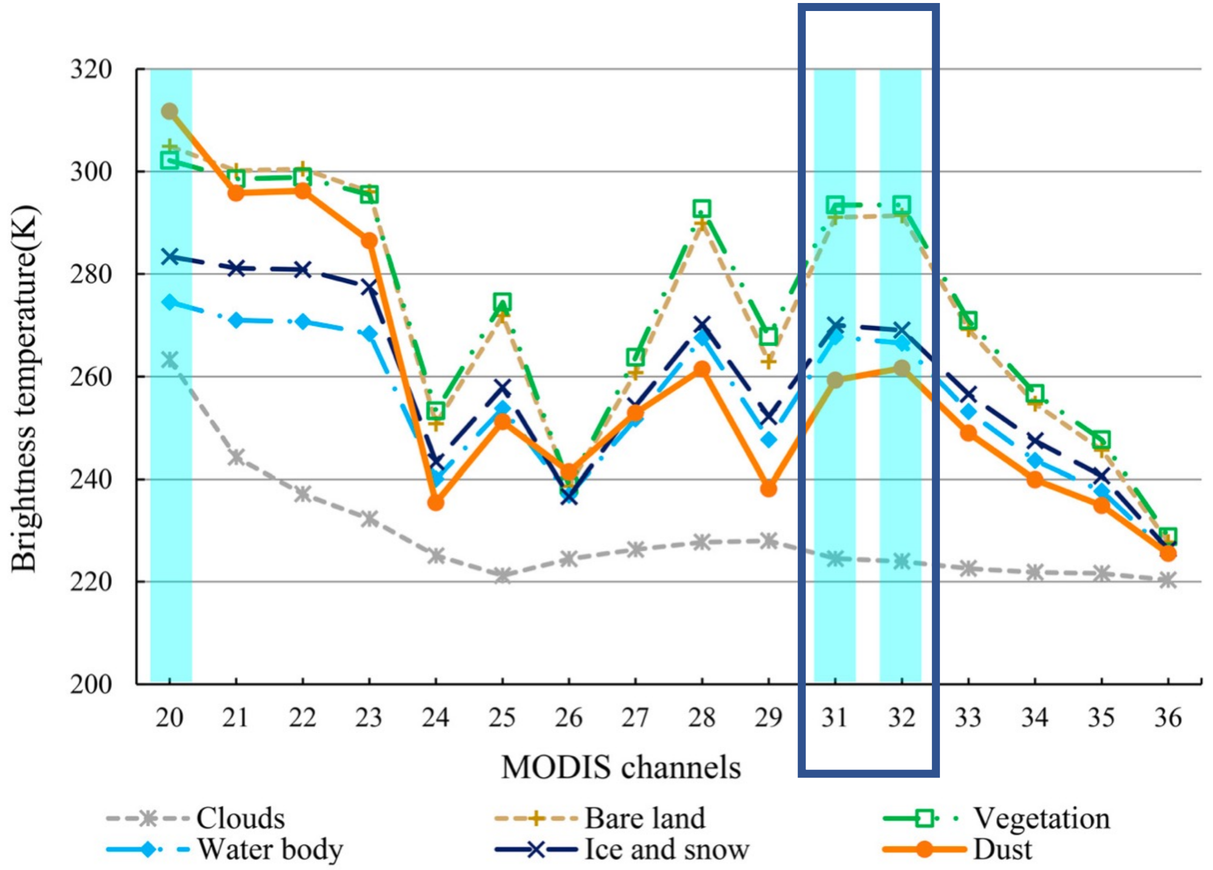




RGB composites and other (level 1) dust products

Dust indexes based on Brightness Temperature

- Based on spectral characteristics of dust in thermal channels
- Typically these indexes are obtained by very simple “band calculations”



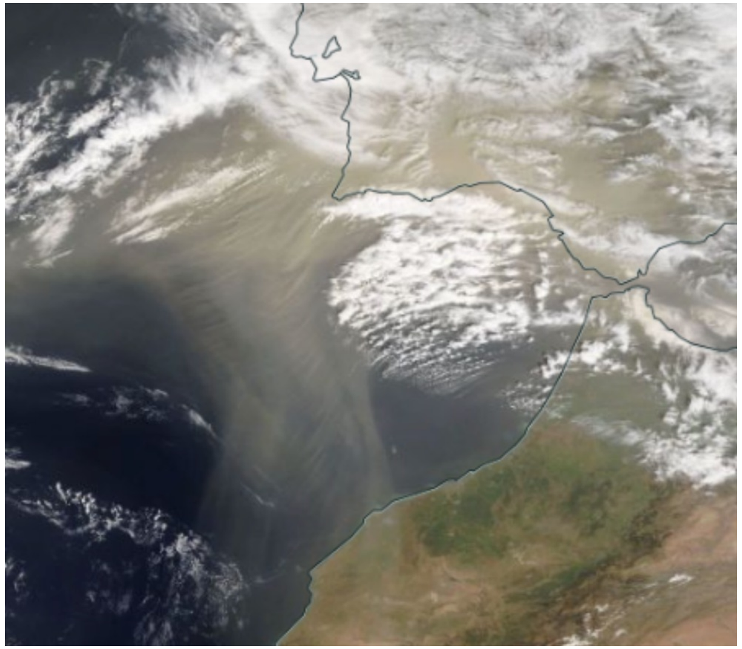
Example: MODIS Brightness temperature difference at 11 (31) and 12 micron (32):

DBT= BT32-BT31

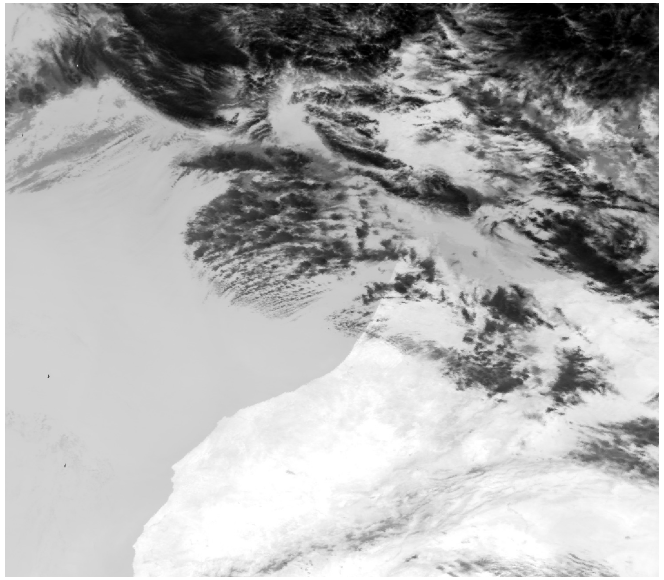
For dust BT32 should be slightly higher than BT31, opposite to clouds

From Yue et al. *Int. J. Appl. Earth Obs. Geoinf, 57,* 166–176, 2017

Example of MODIS Brightness Temperature Difference to detect dust

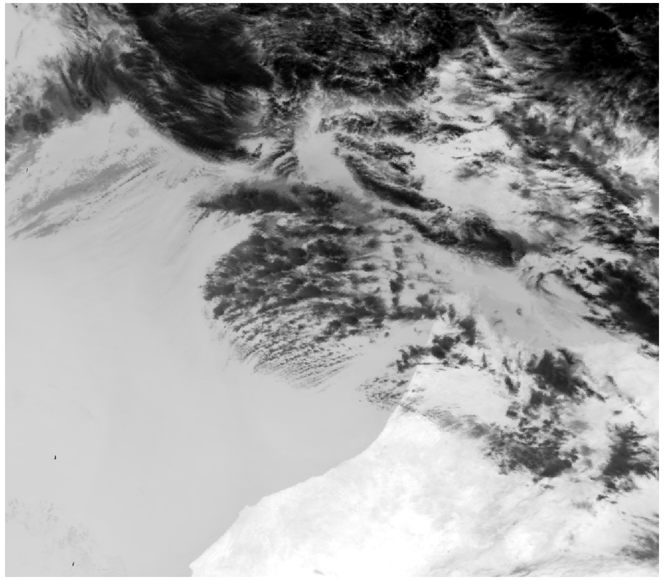


BT32



−

BT31



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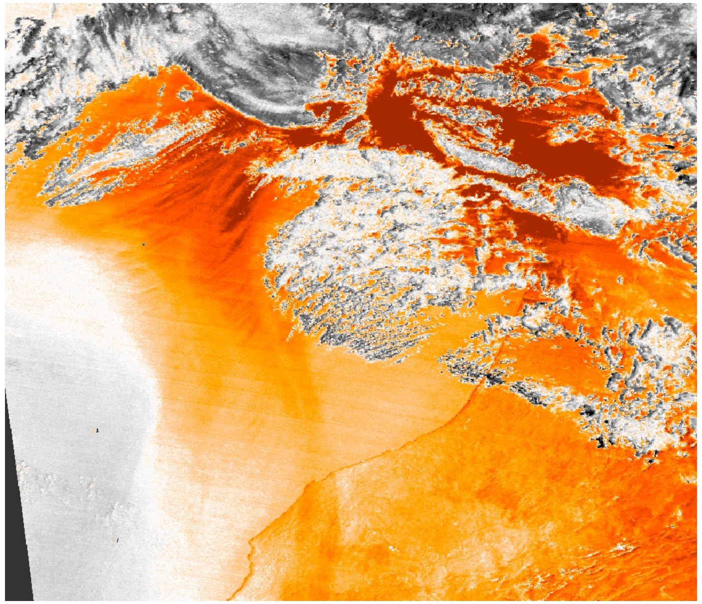
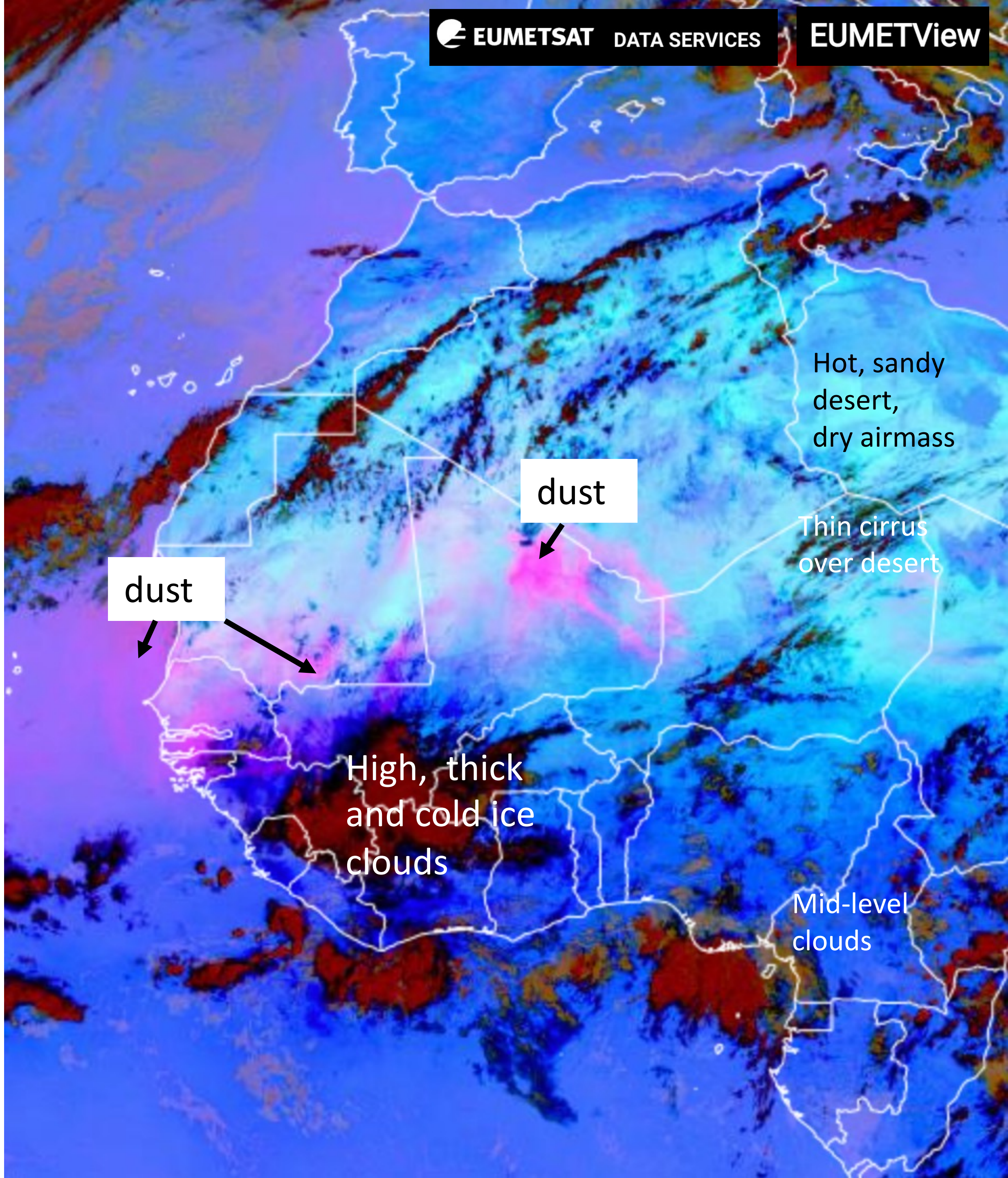


(black “cold”, white “warm”)

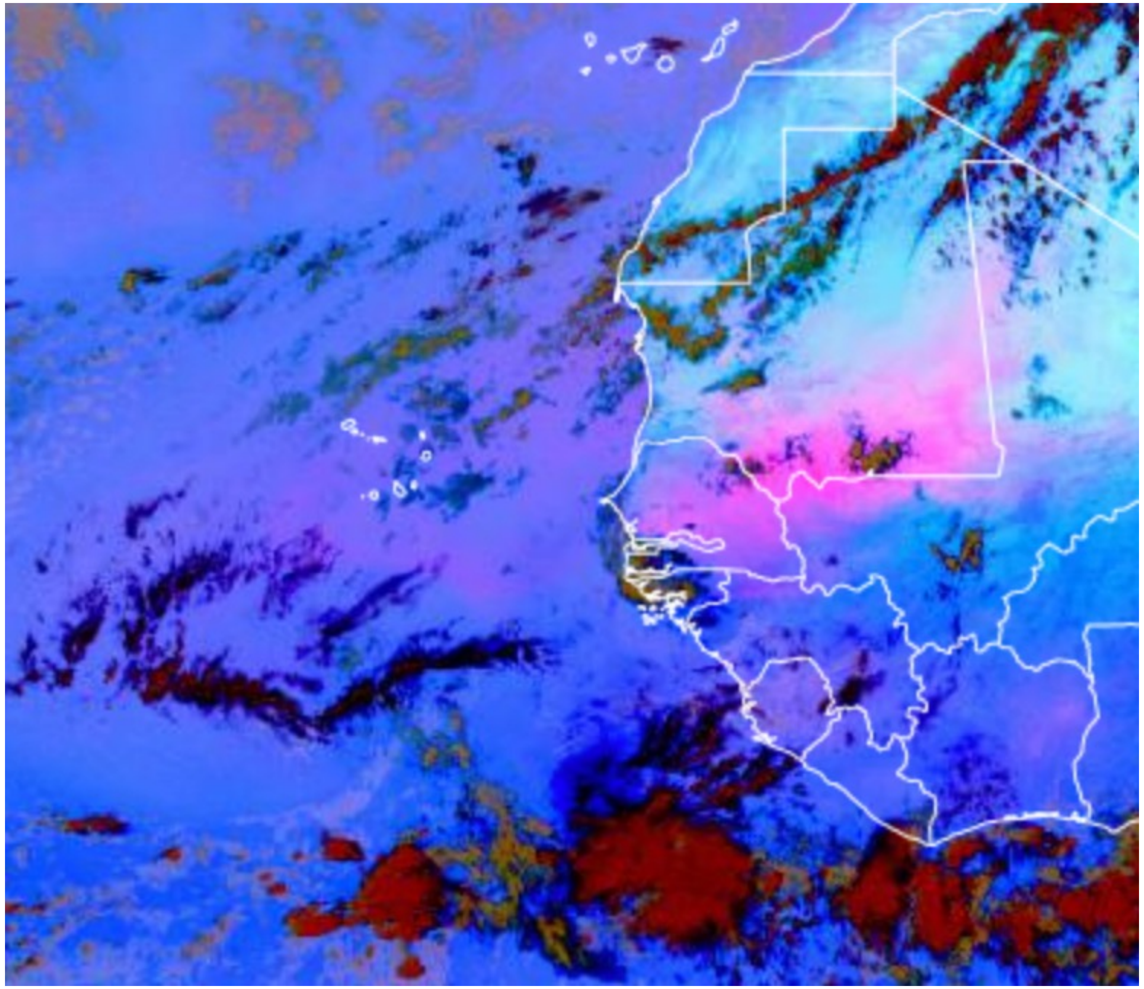
Orange BTD > 0 -> dust

MSG Seviri Dust RGB composite product

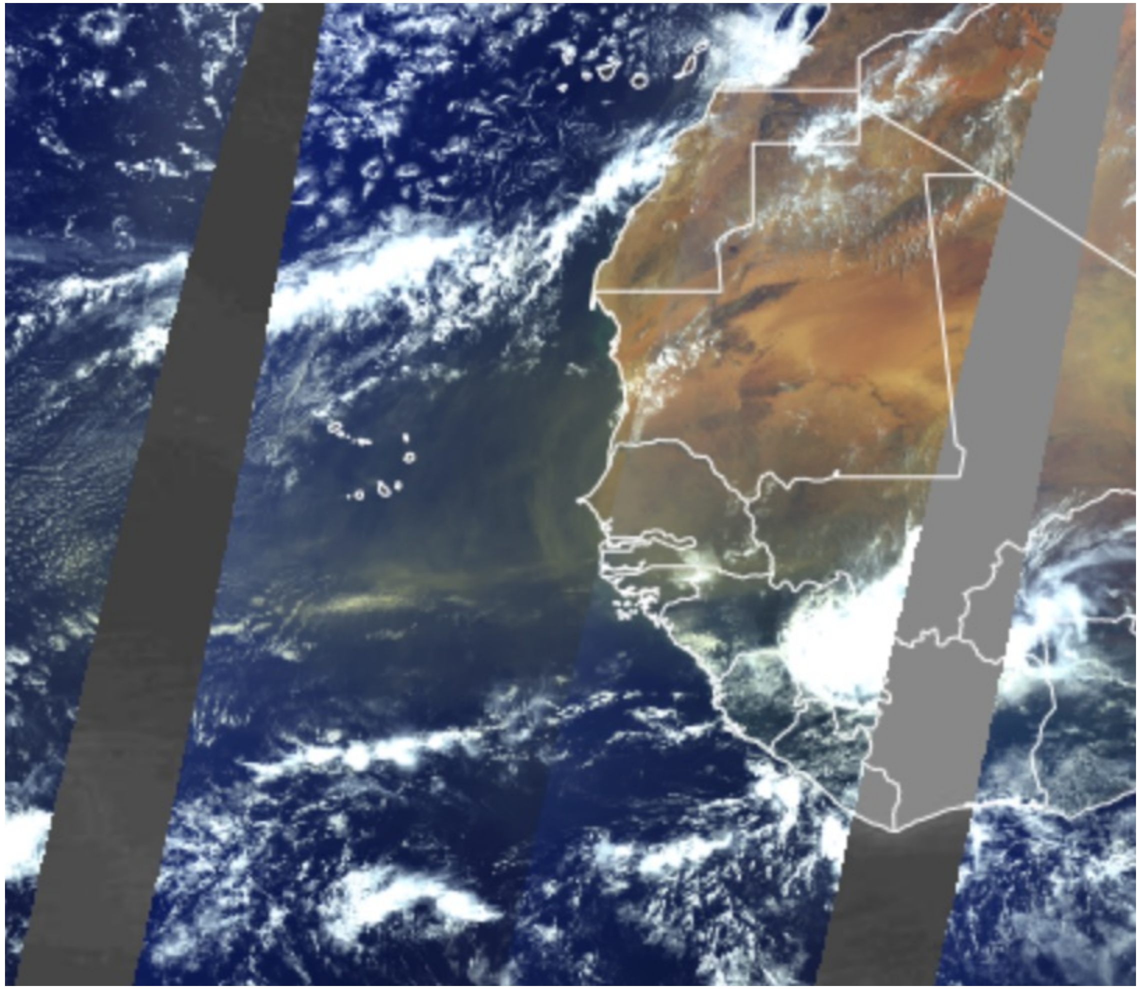
- Based on combining measurements from three different ***infrared*** channels:
  - Red: IR12 – IR10.8
  - Green: IR10.8-IR8.7
  - Blue: IR10.8
- Benefits:
  - Available night and day at 15 min temporal resolution near real time
  - Easy and quick to use in EUMETSAT online services
  - Additional info on cirrus clouds or dry/humid air masses
- Limitations:
  - Dust RGB doesn't indicate the concentration or height of the dust plume
  - Color shades can vary, interpretation not always straightforward
  - Thin or low level dust over ocean difficult to detect
  - For more detailed analysis with dust RGB recommended to use other satellite products
- Interpretation (roughly):
  - **Pink/violet :** Dust
  - **Orange/brown**: thick high/mid-level clouds
  - **Black**/ **dark green**: thin cirrus

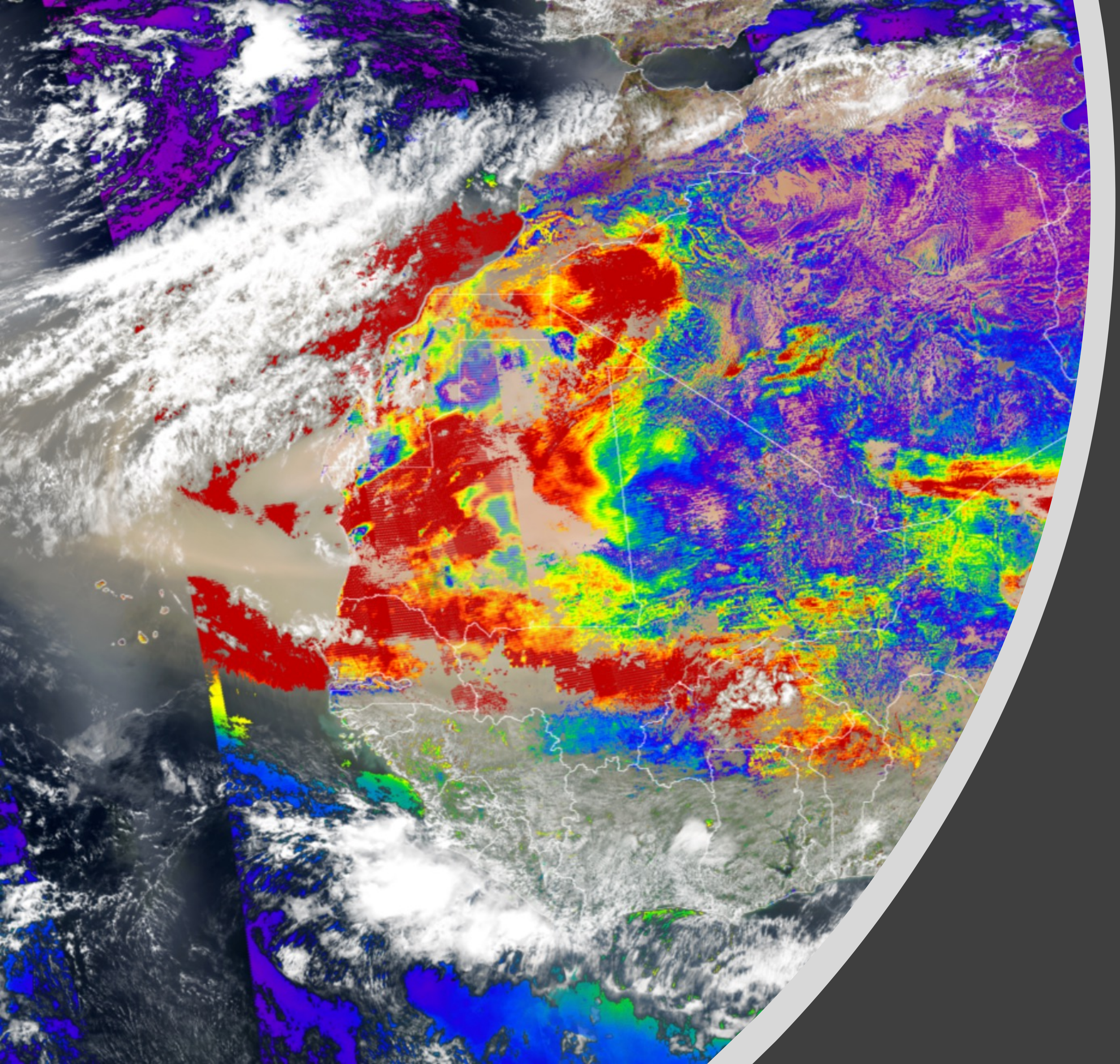


MSG Dust RGB 5.6.2021 (12 UTC)



Sentinel-3 OLCI RGB 5.6.2021



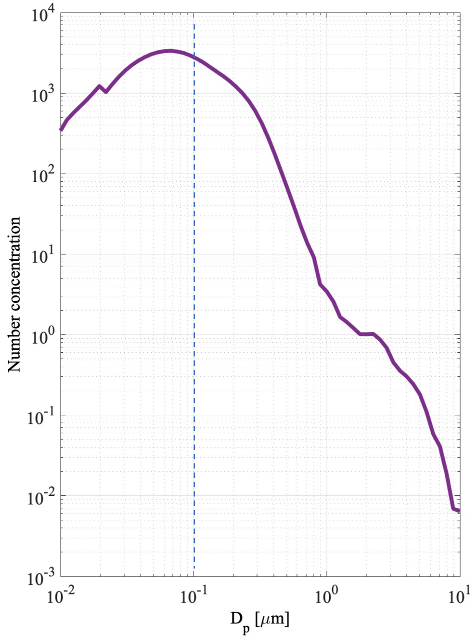


Aerosol Optical Depth

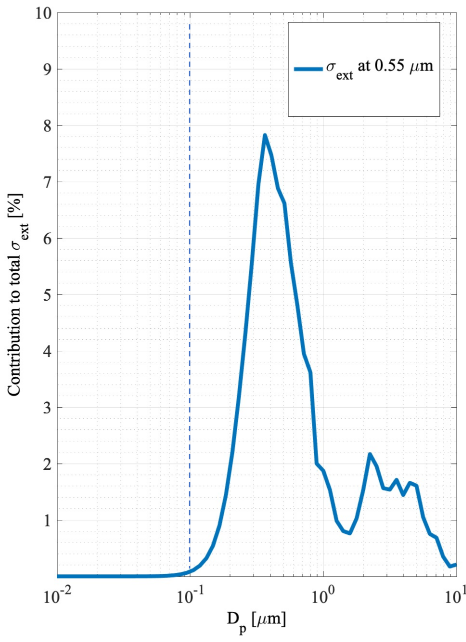
Aerosol optical depth (AOD)

- Also known as aerosol optical thickness (AOT)
- AOD is *related to the amount* of (optically active) aerosols in the total atmospheric column.
- Retrieved from satellite- and ground-based instruments
- Extinction coefficient: $\beta_e = \beta_a + \beta_s$ units of inverse length [m^{-1}]

Measured aerosol size distribution



Contribution of each particle size to the total extinction at 550 nm



AOD is defined as the sum of aerosol extinction at all atmospheric levels, from surface up to the top of the atmosphere

$$AOD = \int_{surf}^{TOA} \beta_e(s)\,ds$$

[unitless]

AOD retrievals

$$\rho_\lambda^{\mathrm{TOA}}(\tau,\theta_0,\theta,\varphi) = \rho_\lambda^a(\tau,\theta_0,\theta,\varphi) + \frac{T_\lambda(\tau,\theta_0)\,T_\lambda(\tau,\theta)\rho_\lambda^s}{1 - s_\lambda(\tau)\rho_\lambda^s}$$

Reflectance at TOA measured by satellite

Atmospheric path reflectance:
- aerosols
- molecules

Surface contribution

TOA reflectance measured by the satellite

↓

Cloudscreening

↓

Rayleigh correction

↓

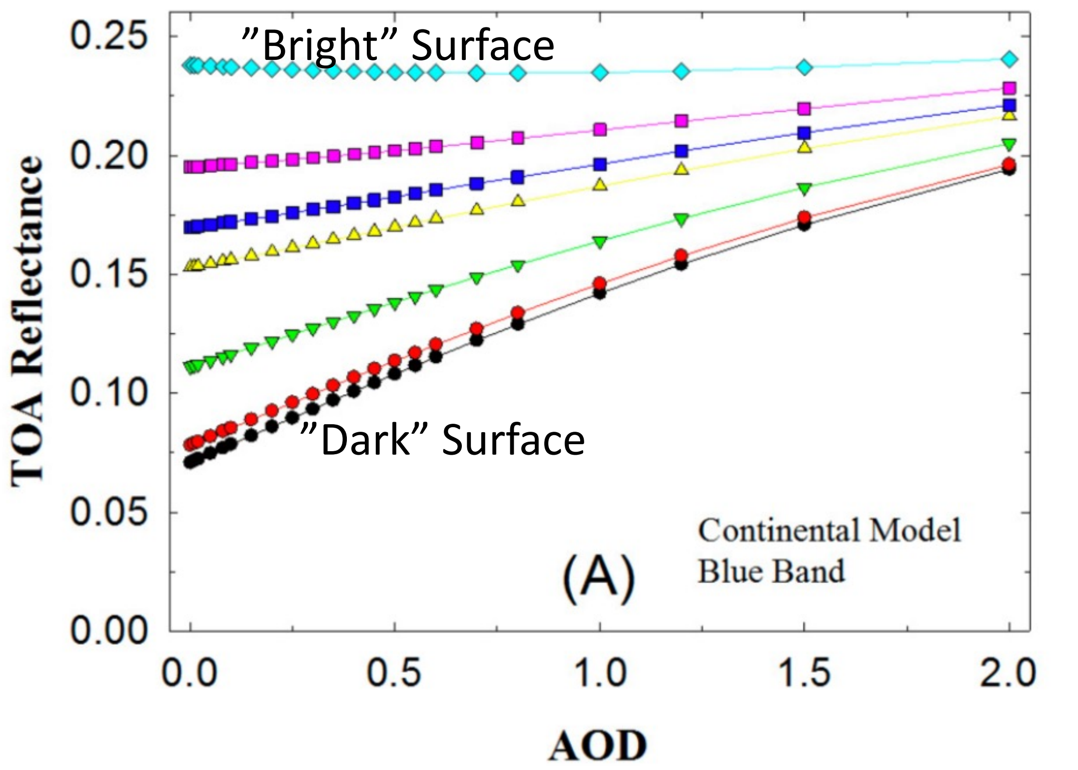
Surface correction

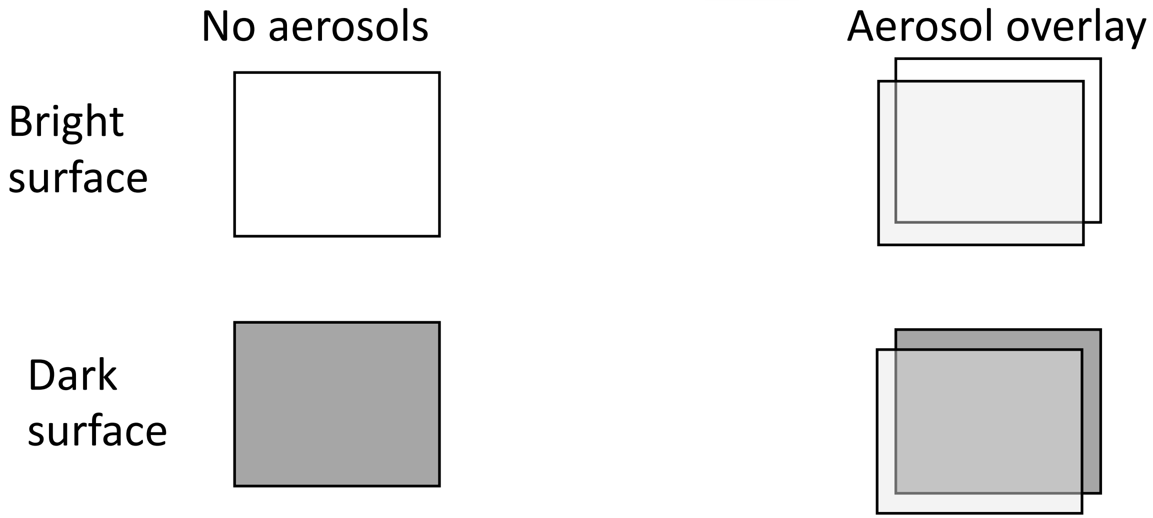
↓

Aerosol contribution

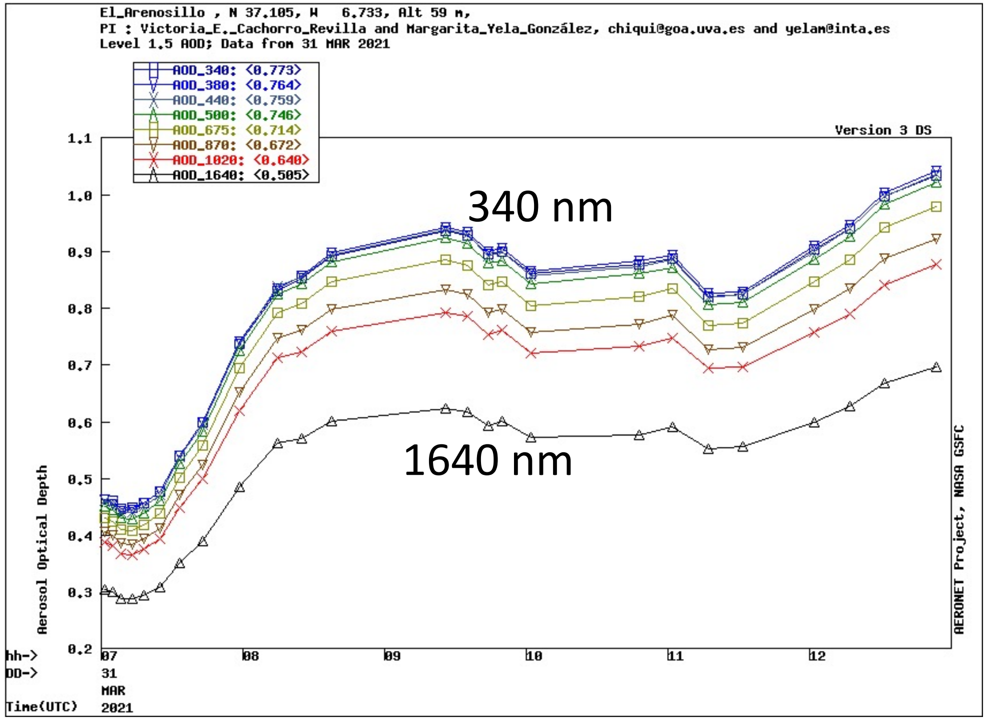
Note! All AOD algorithms do not retrieve AOD over bright surfaces (desert)

From Tian & Sun, 2016

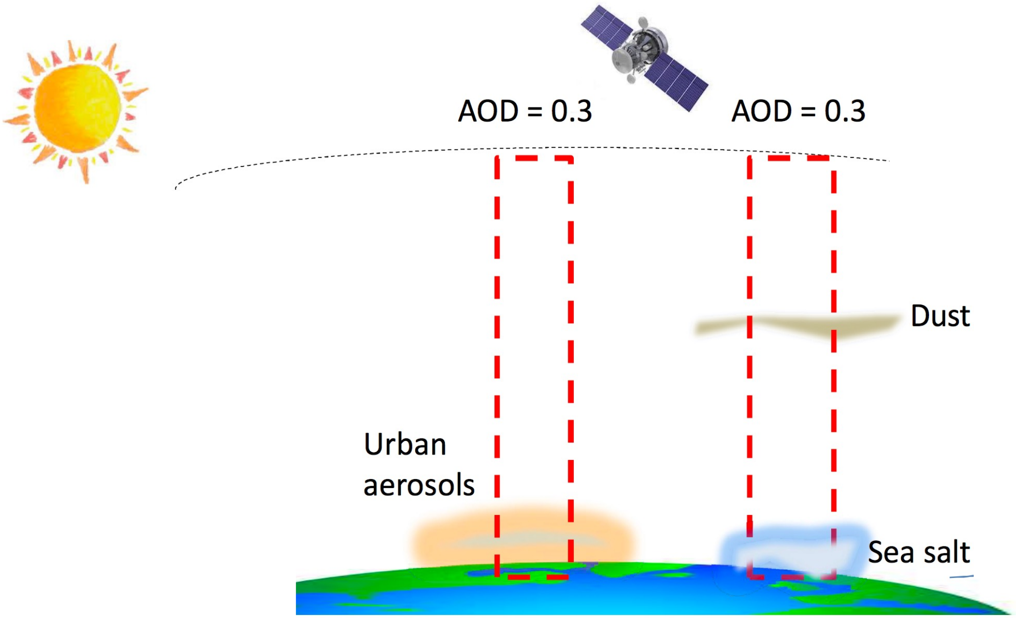




- AOD is wavelength dependent, often products give AOD e.g. at 550 nm
- With spectral information on AOD some rough estimations about aerosol type can be made
- Typical for dust cases is elevated AOD at longer wavelengths also

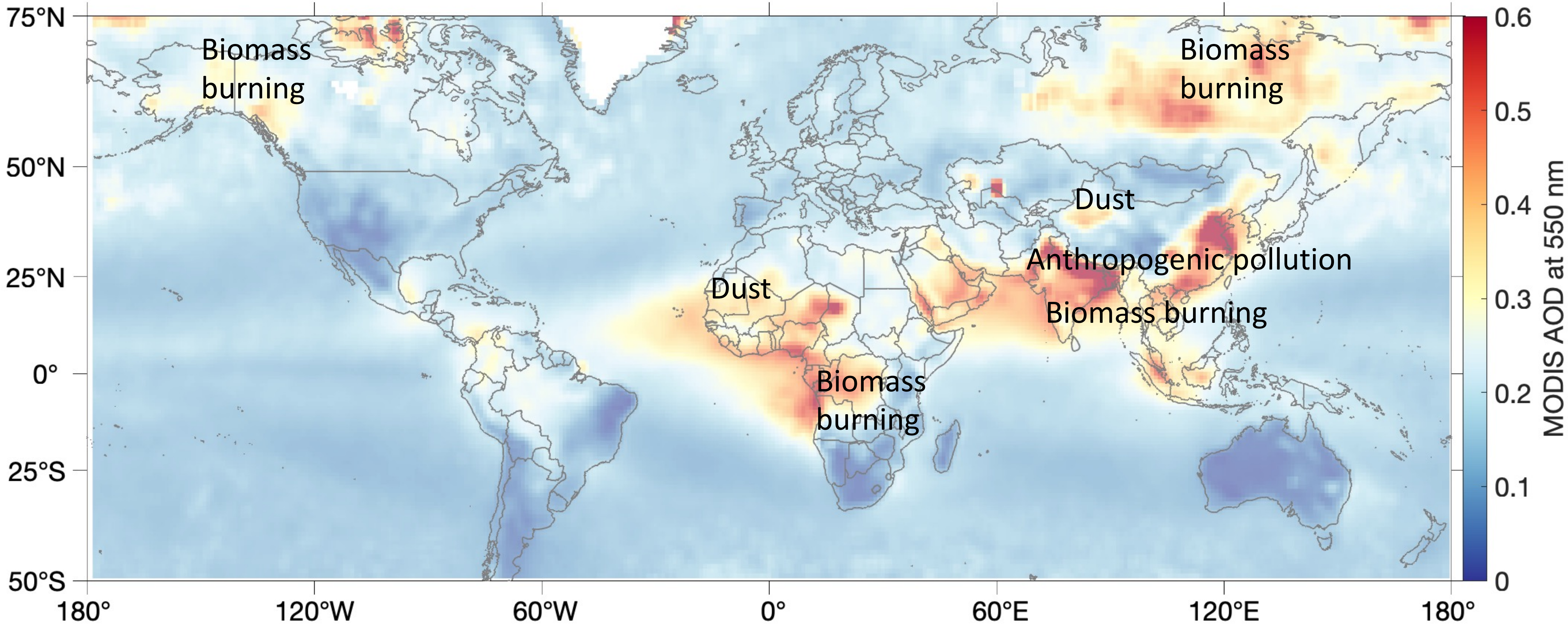


- AOD from passive satellite instruments doesn’t indicate what is the vertical distribution of aerosols
    - “same” AOD can be obtained for very different cases



Satellite AOD is available from several instruments (and wavelengths), e.g.:

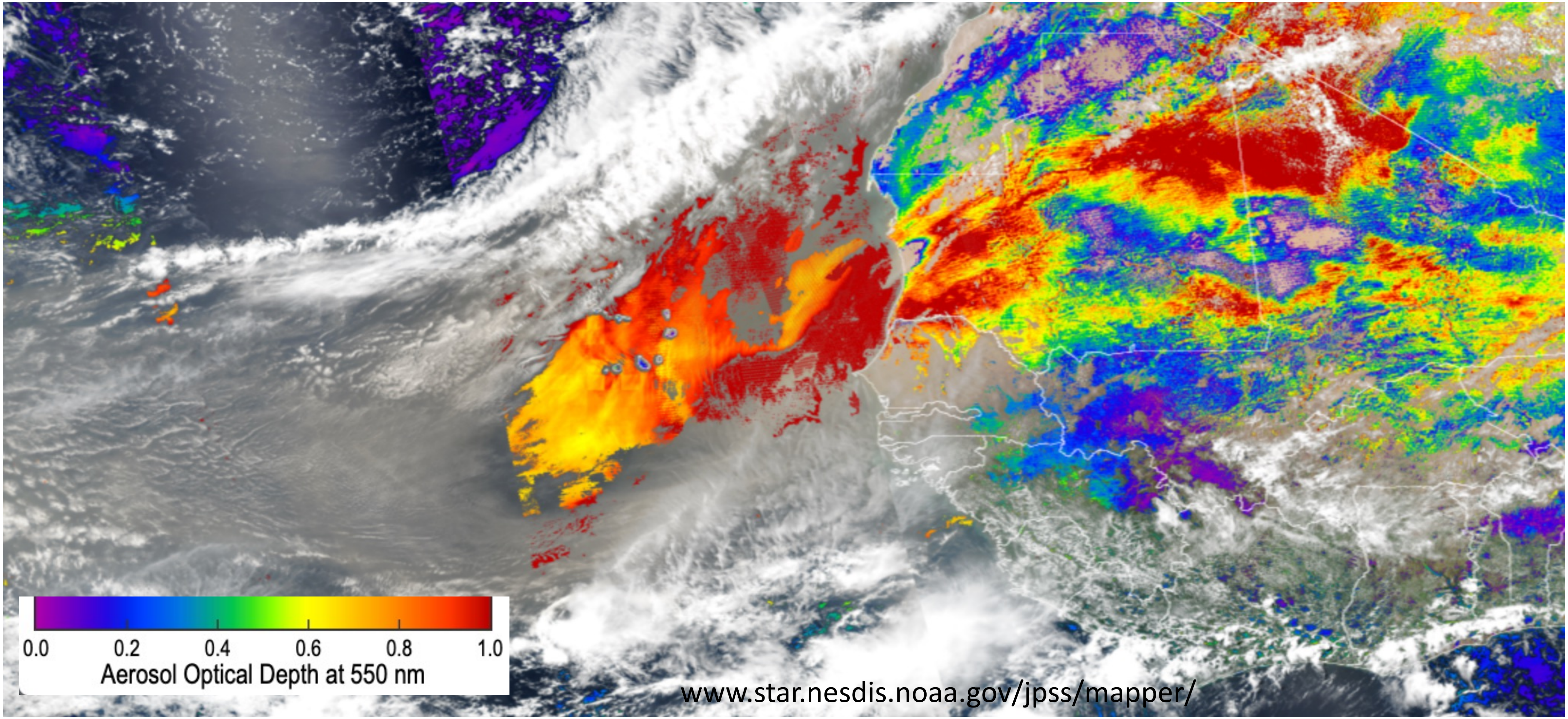
- OLCI, SLSTR (Sentinel 3), AATSR (Envisat, until 2012)
- E.g. MODIS (Aqua, Terra), MISR (Terra), VIIRS (Suomi NPP, NOAA 20), SeaWIFS,
- Multi-instrument products such as PMAp (combining information from GOME-2, AVHRR, IASI)



MODIS Terra 2019 / Deep Blue Algorithm

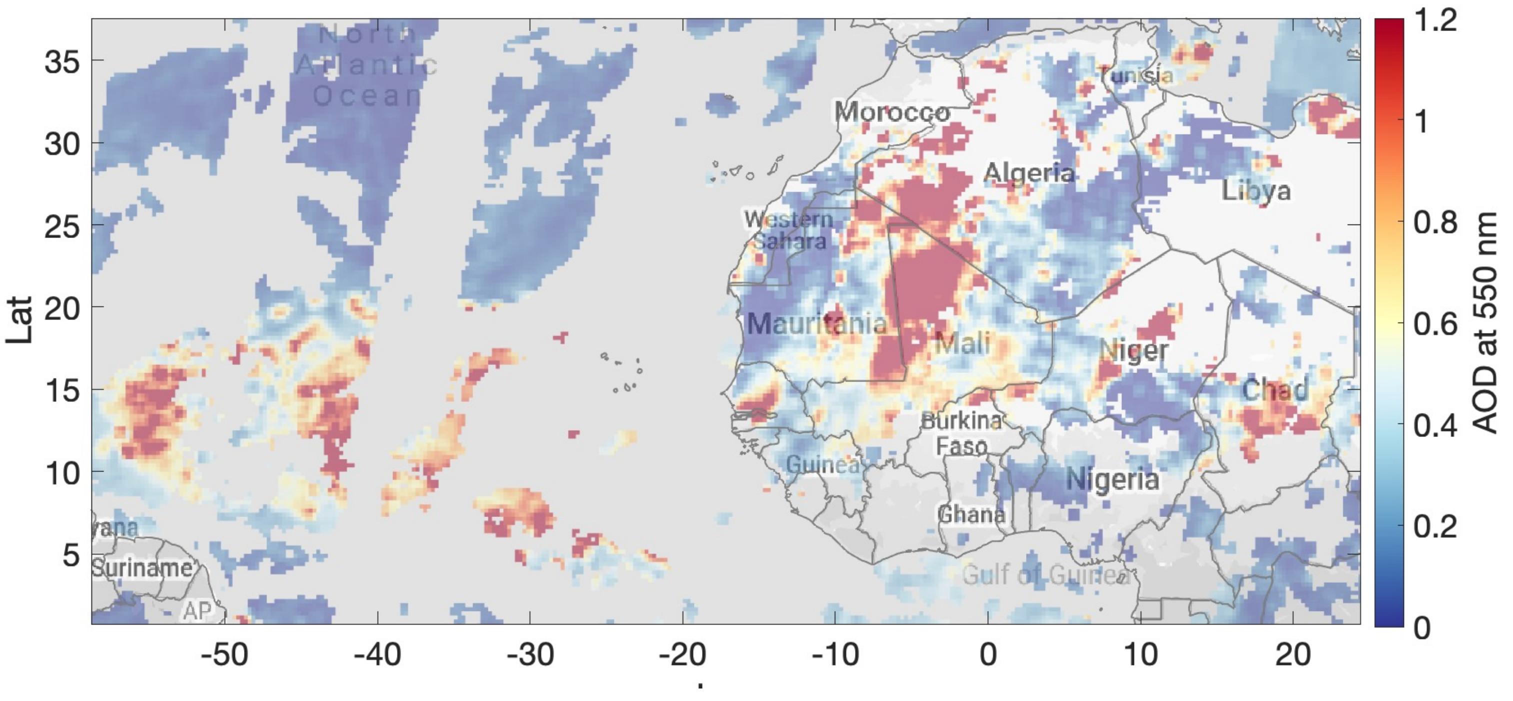
AOD at 550 from VIIRS instrument 7.6.2021

- AOD is not retrieved for cloudy cases
  - thickest parts of dust plumes can be interpreted as clouds -> AOD is not provided
- AOD is not provided at sunglint



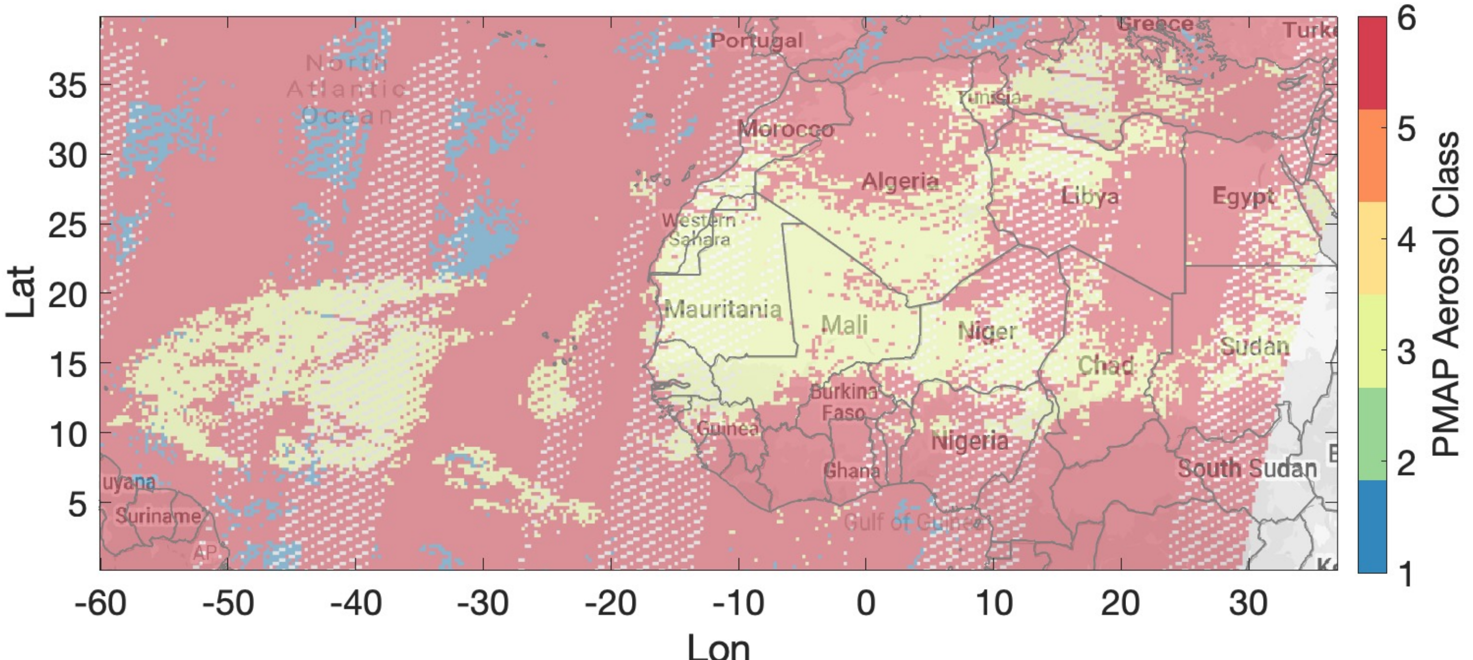
PMAP AOD and aerosol class 7.6.2021

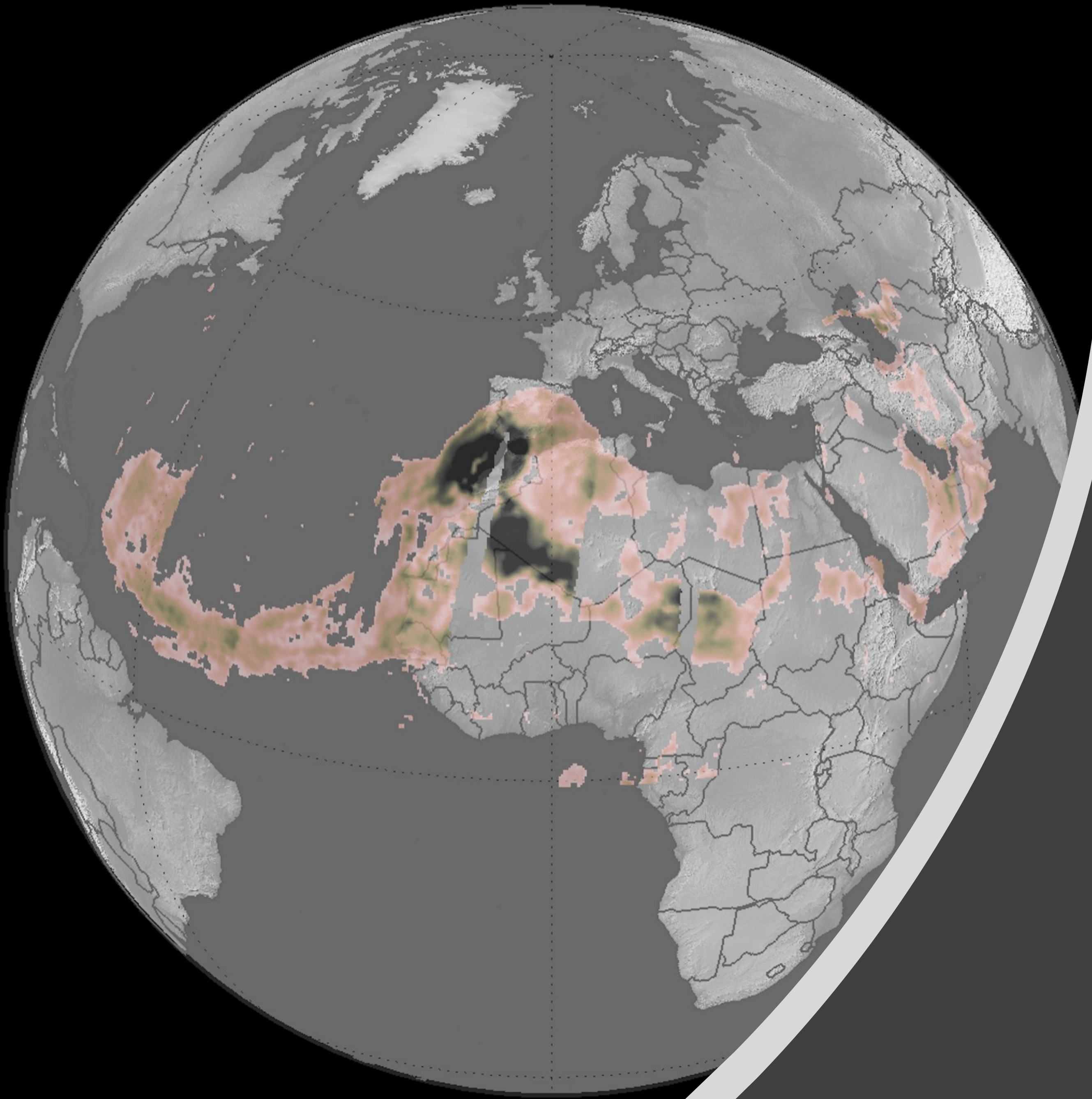
- Level 2 AOD files often include several other "byproducts" that can be useful for determining e.g. aerosol type



PMAP Aerosol class

1=Coarse mode (ocean)
2=Thick smoke
3= Dust
4= Thick Volcanic ash / dust
5= Volcanic ash
6= in this image including PMAP classes 10, 11, 15, aerosol cont. cloud, no class.

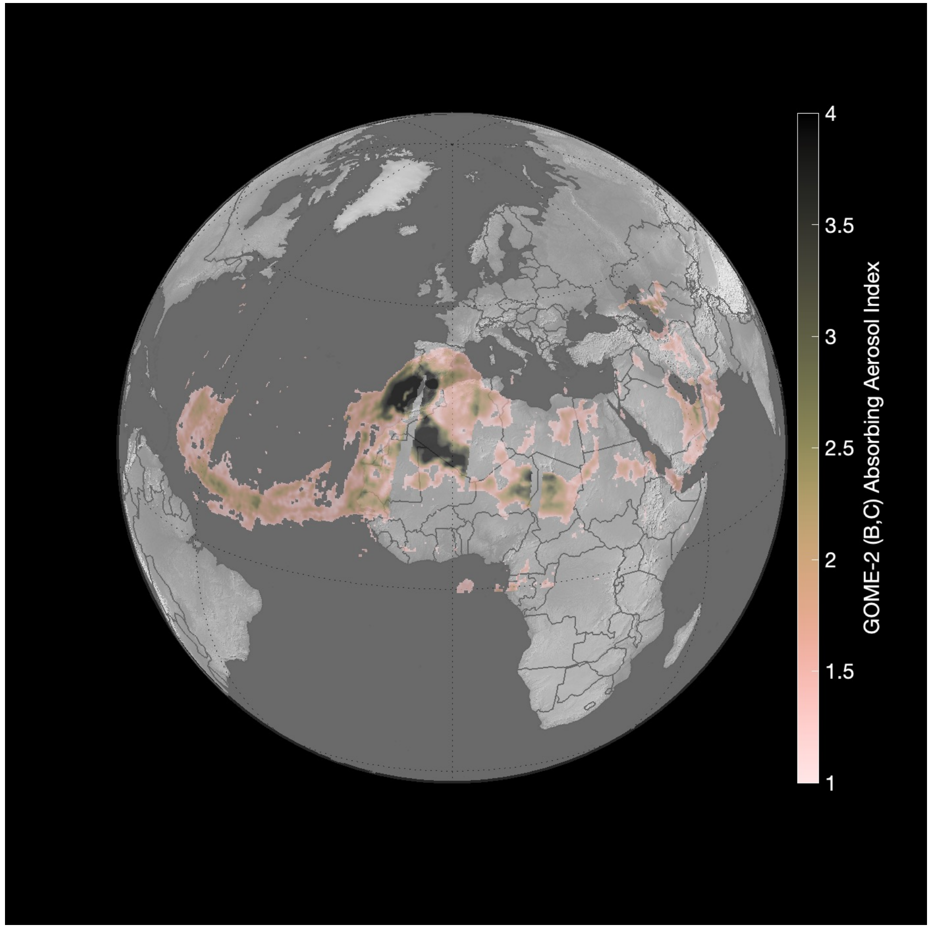




Absorbing Aerosol Index

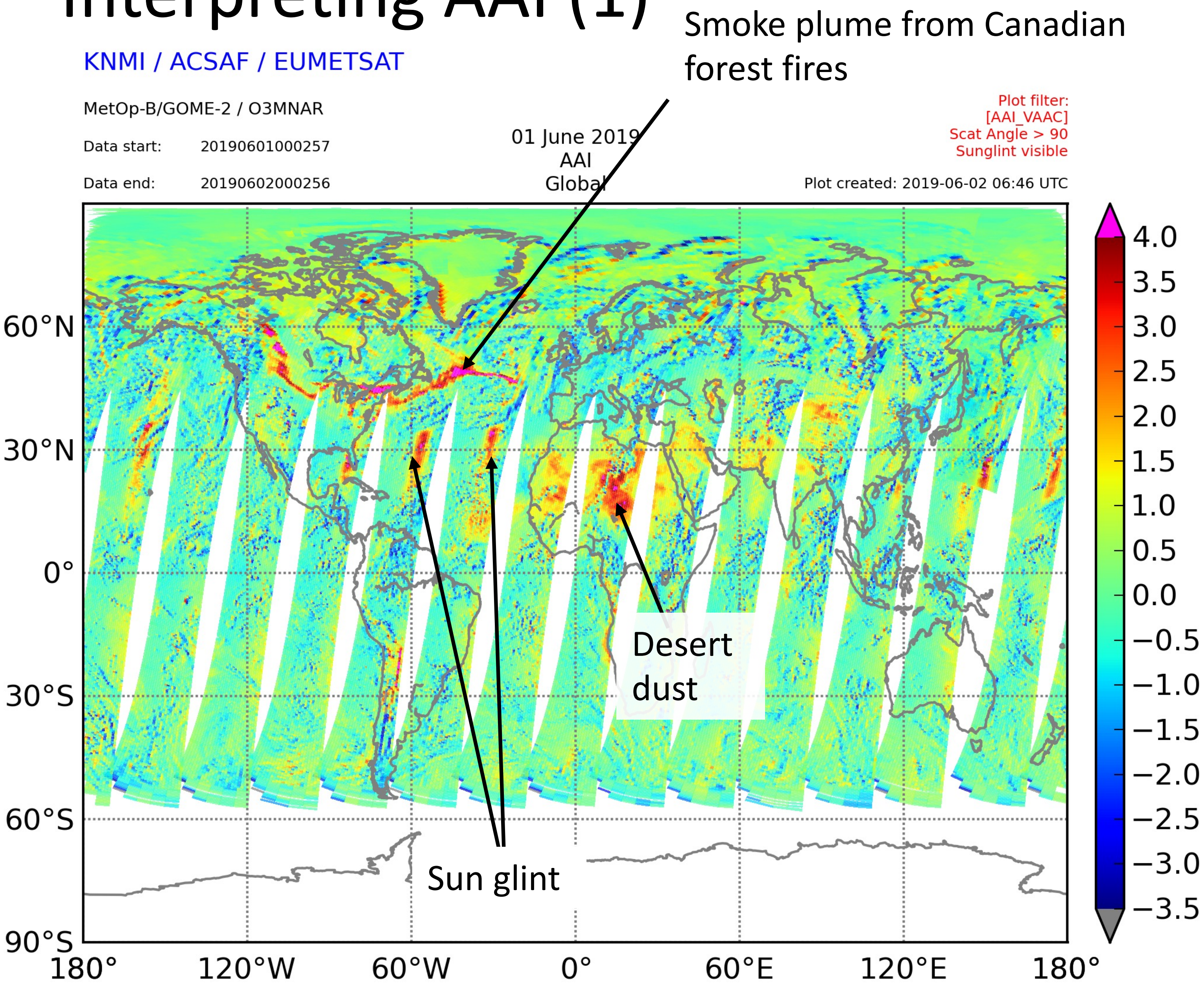
Absorbing Aerosol Index (AAI)

- Also known as UV Aerosol Index (UVAI)
- Defined using UV-wavelengths (typically 340 – 380 nm; **GOME-2, TROPOMI**, OMI, OMPS)
- Sensitive to absorbing aerosols: smoke, volcanic ash, desert dust
- AAI separates the spectral contrast at two UV wavelengths caused by aerosol extinction from that of other effects (e.g. molec. scattering)
- Can be obtained also for cloudy scenes, where aerosols are on top of clouds.



AAI is a good tracer for dust, smoke and ash plumes

Interpreting AAI (1)



- **Positive AAI values** indicate **presence of absorbing aerosols**
  - For clouds (or scattering aerosols) AAI is close to zero or negative
  - Also sunglint over ocean causes positive values but that is often filtered out from the data.

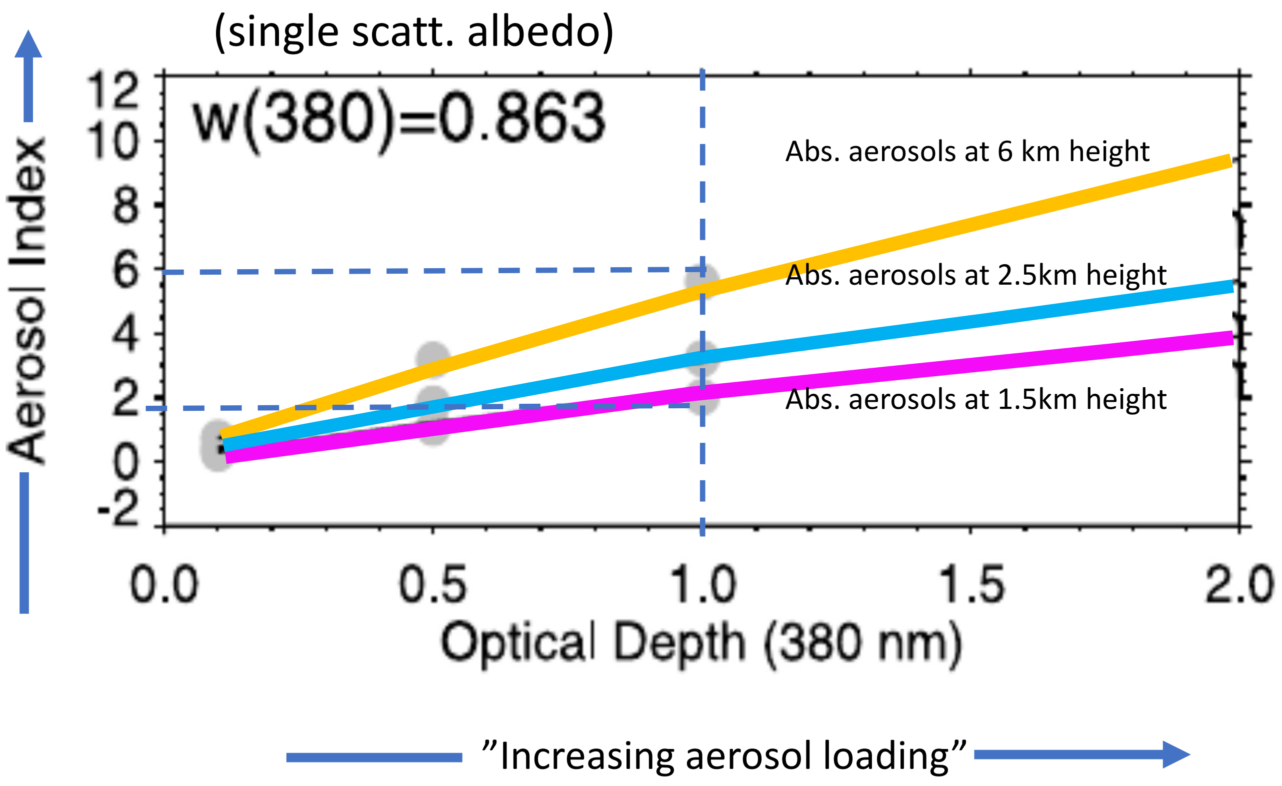
- For abosorbing aerosol plumes typically AAI > 1.0
  - Background slightly positive

AAI is available from several instruments:

- GOME-2 (A,B,C)
- TROPOMI
- OMI, OMPS
- Multi-instrument AAI (> 40 year time series!)

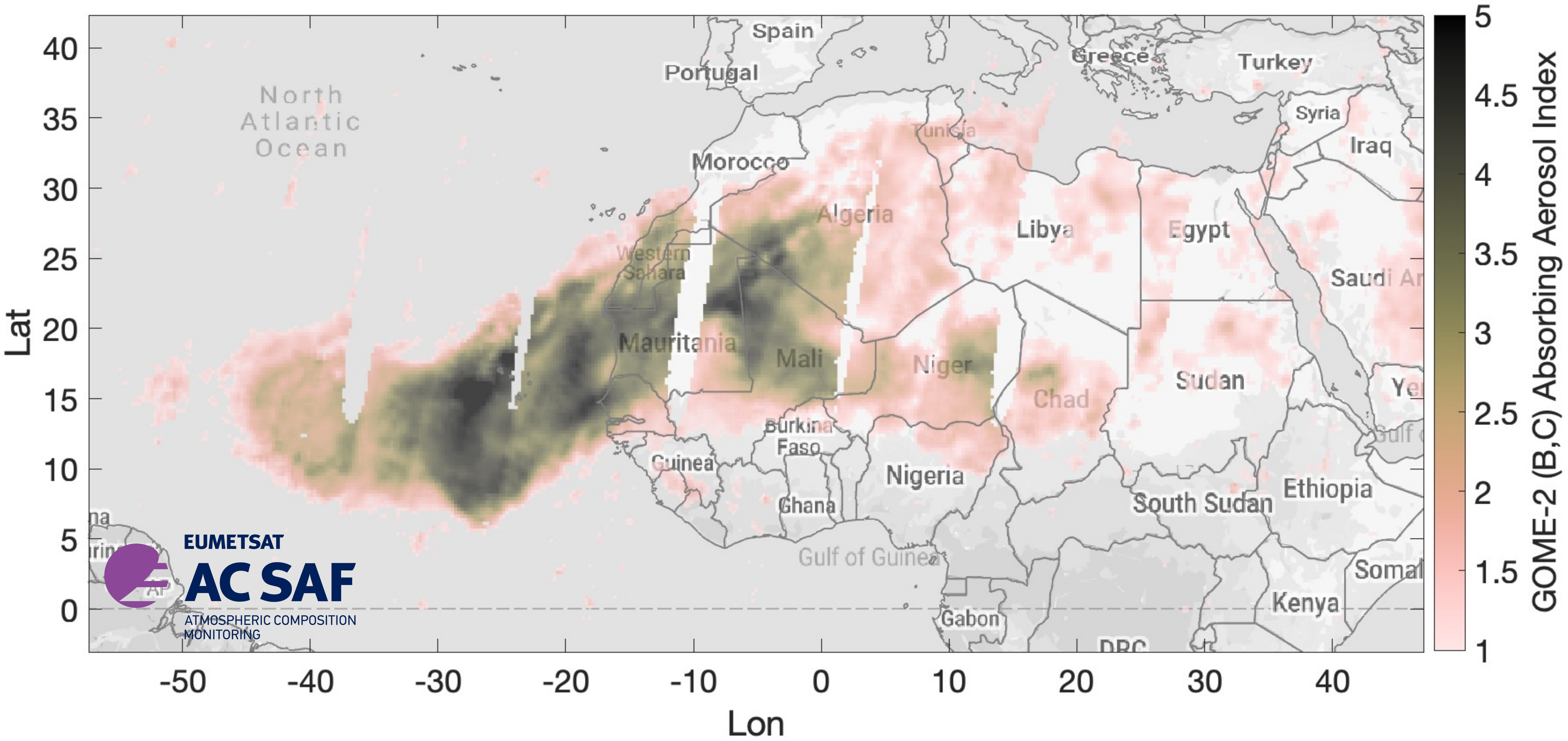
Interpreting AAI (2)

- AAI values depend on various factors
  - Comparing different cases with each other is not straightforward!
- Not a ”direct” measure of aerosol loading
- With **AAI you typically see an elevated plume**
  - For assessing air quality at the surface, additional information (model, in situ, lidar) is recommended.

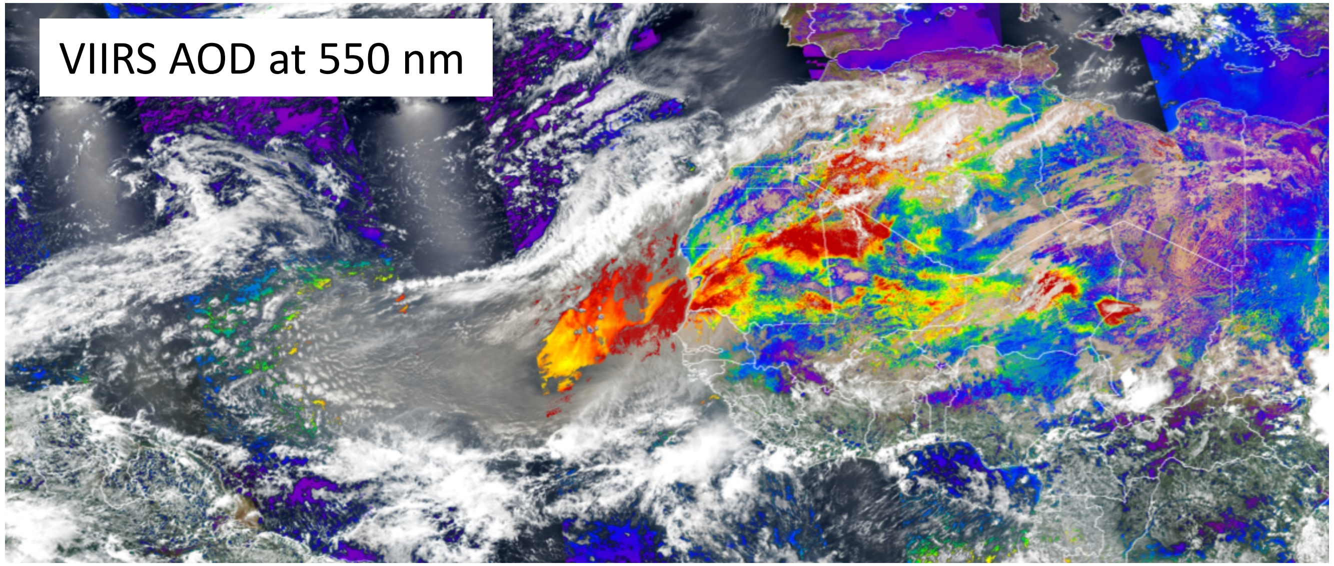


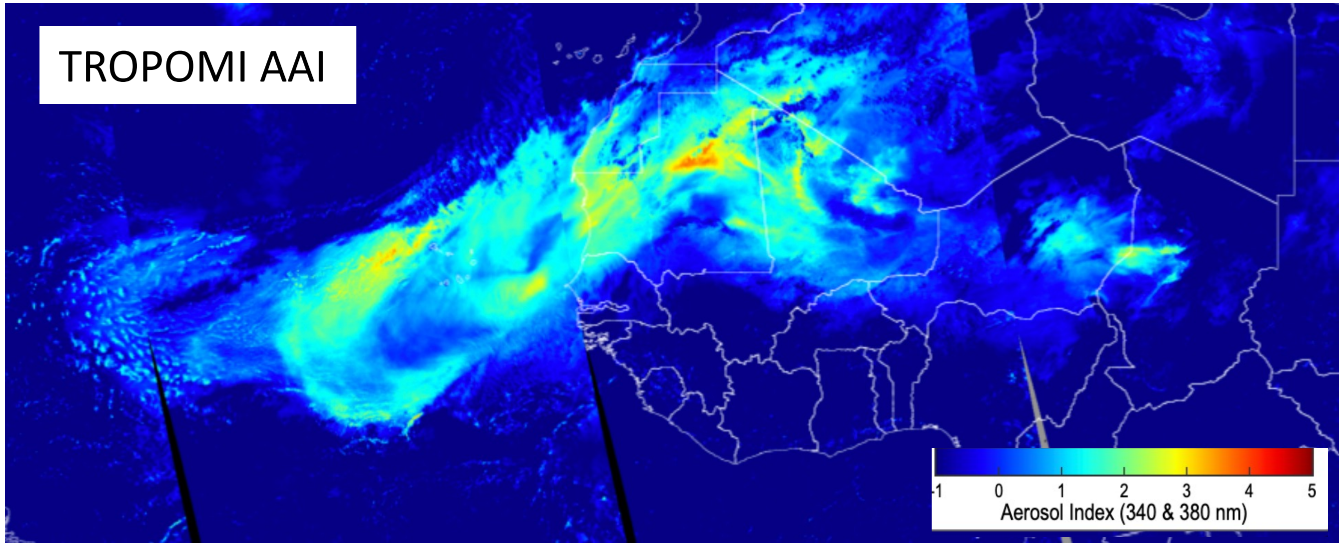
From: Ginoux & Torres, JGR, 2003

GOME-2 B & C AAI 7.6.2021



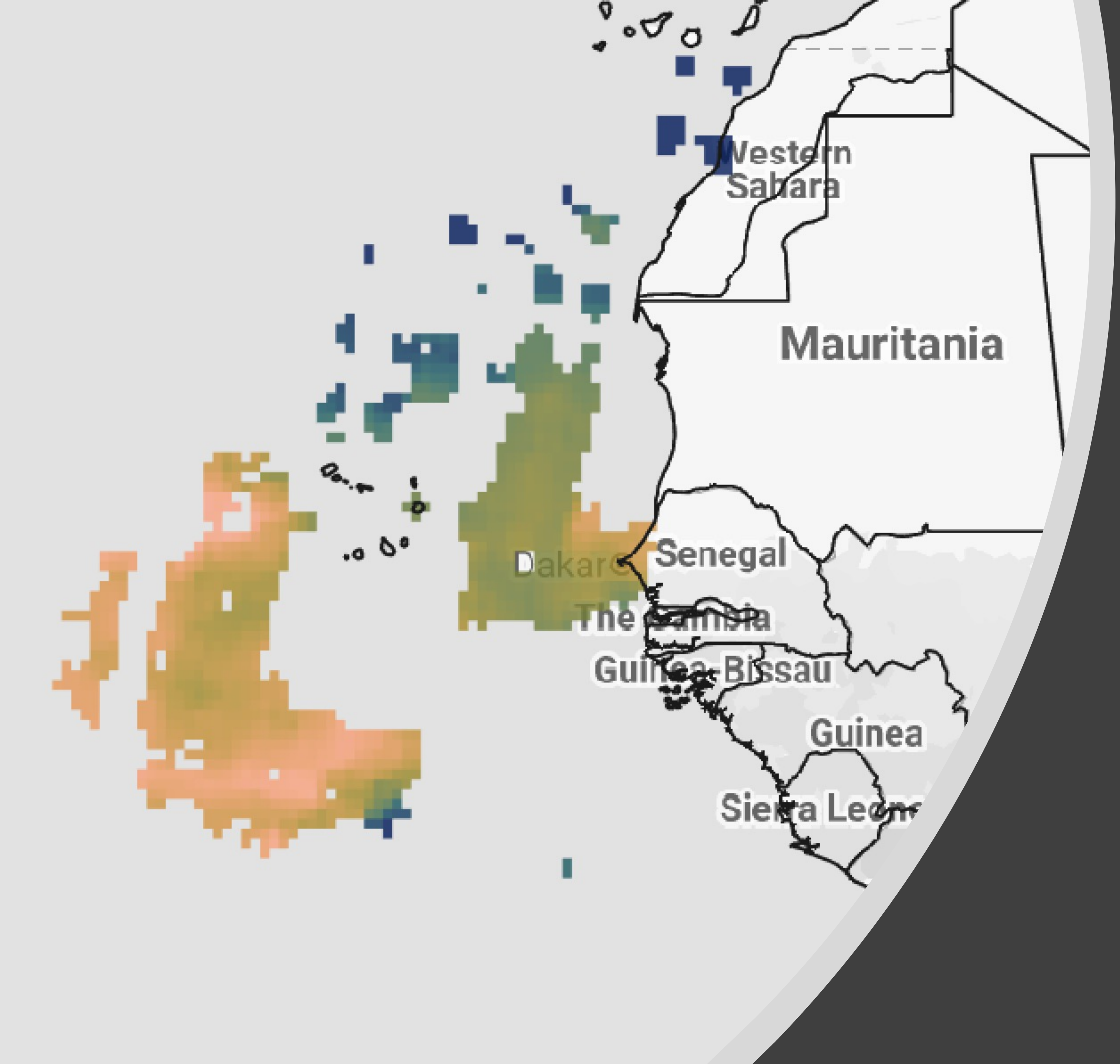
Comparison of TROPOMI AAI and VIIRS AOD 7.6.2021





- Combining information from AOD and AAI can give more detailed view on the dust plume
- AOD gives more detailed info on spatial variation of aerosol loading, also for places where dust is close to surface
- AOD "misses" parts of the plume, also cloudy/ partly cloudy scenes
- AAI gives more complete view of the extent of the plume, also for cloudy/partly cloudy scenes, but does not directly indicate the amount of aerosols.

(images from NOAA Jstar mapper service)



Absorbing Aerosol Height

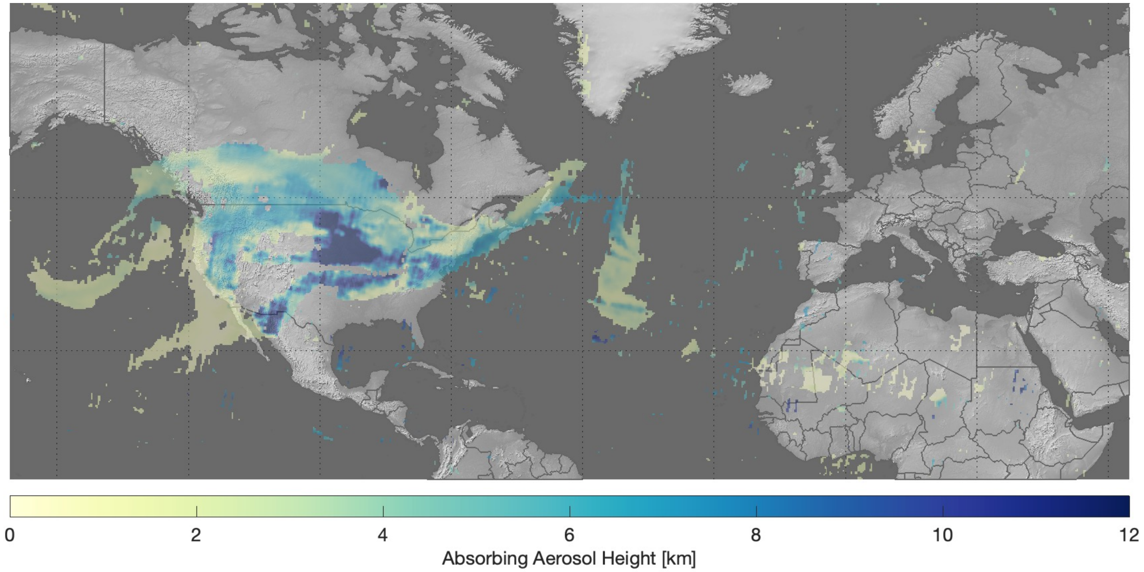
GOME-2 Absobing Aerosol Height

EUMETSAT AC SAF
ATMOSPHERIC COMPOSITION MONITORING

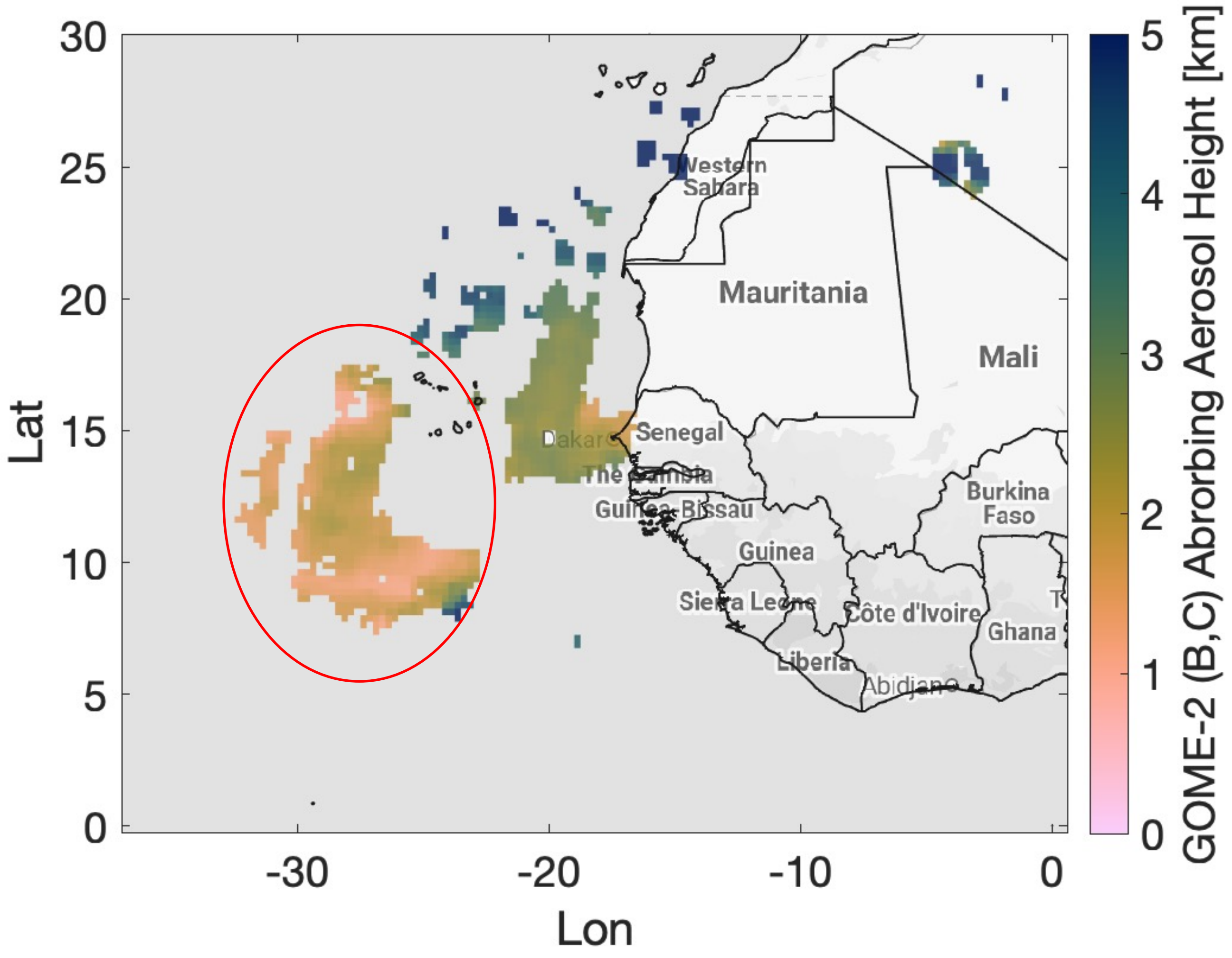
- Retrieval is based on Oxygen A-band and information derived from FRESCO cloud algorithm.
- AAH is provided from GOME-2 and can be obtained via AC SAF FMI server.
- AAH should be analysed with AAI:
    - AAI < 2 correspond to scenes with too low amounts of aerosol to result in a reliable AAH -> pixels have fill value.
    - 2 < AAI < 4: aerosol layer is not in all cases thick enough for a reliable retrieval, but AAH estimate is given, should be used with caution.

- AAH also available from TROPOMI

Example of GOME-2 (A,B,C) AAH

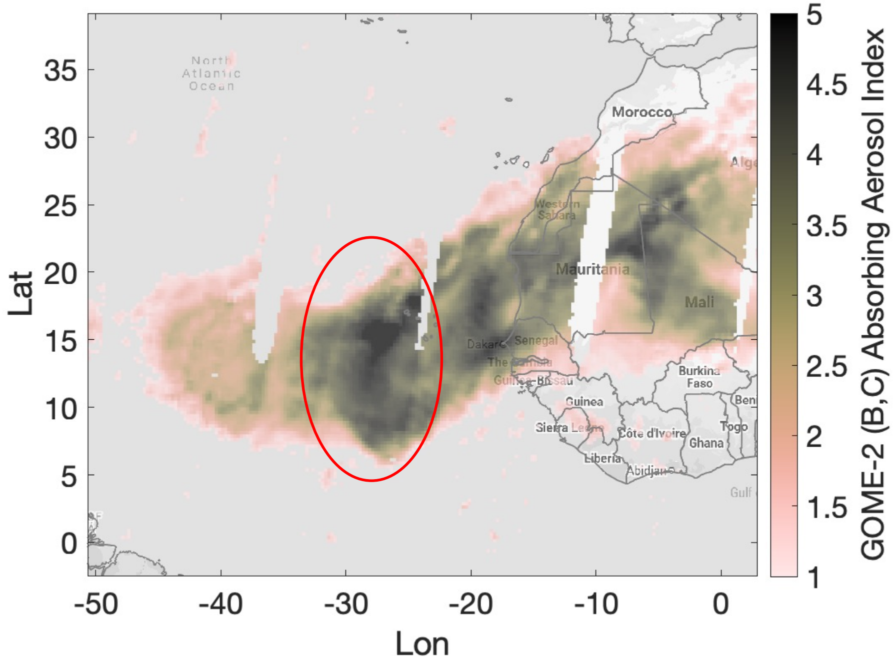


Absorbing Aerosol Height
7.6.2021

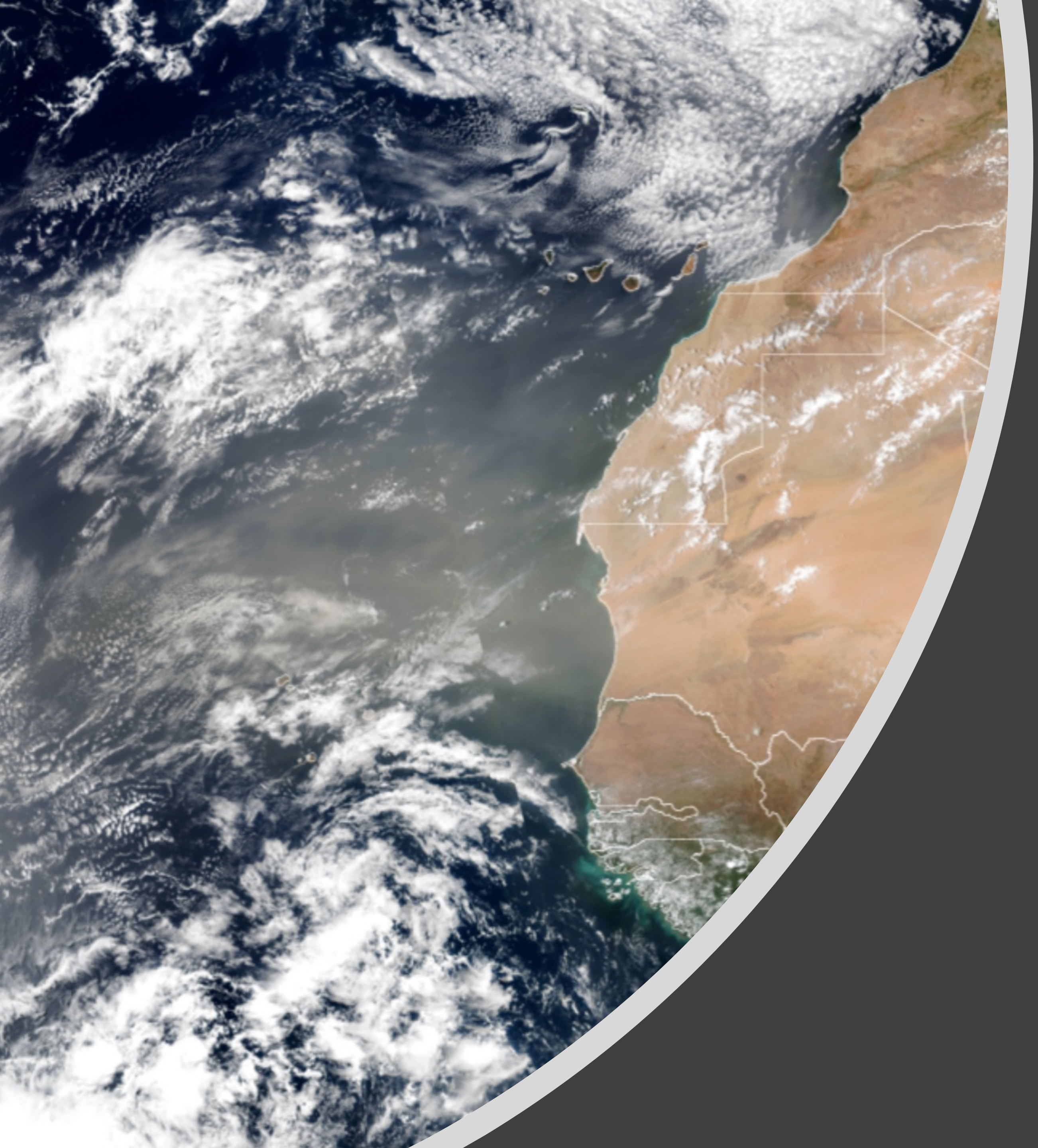


- High quality AAH can be retrieved only for pixels where AAI is high enough
- Typically AAH is retrieved only parts of the plume

Absorbing Aerosol Index
7.6.2021



EUMETSAT AC SAF ATMOSPHERIC COMPOSITION MONITORING

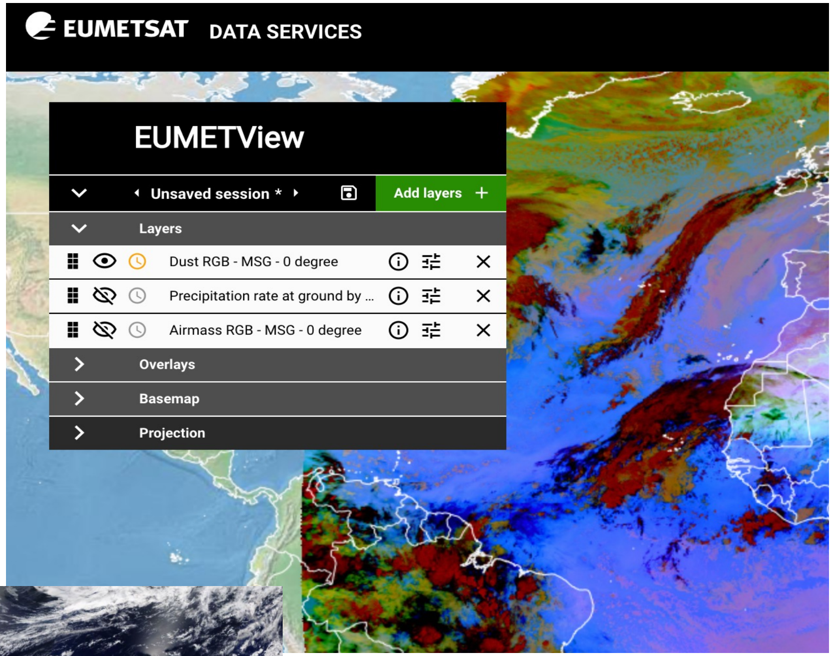


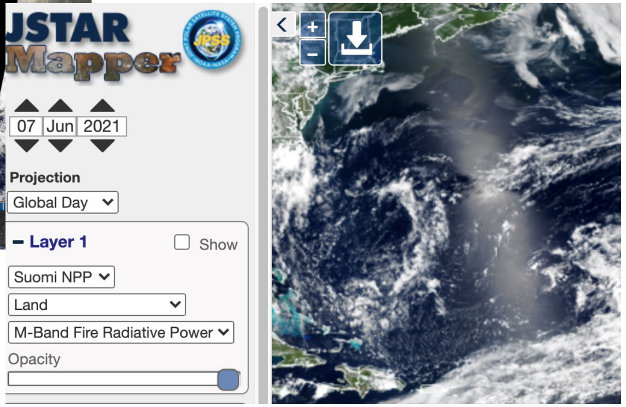
Take home messages

- Passive satellite observations provide various parameters for monitoring dust events
- True color RGB and RGB composite images are available at several web-based services in near real time
  - Easy to use but interpretation not always straightforward
- Aerosol optical depth provides an estimate on aerosol loading of all aerosol types
- Absorbing Aerosol Index indicates the presence of absorbing aerosols (elevated plumes), including dust
- Absorbing Aerosol Height gives an estimate on the height of an absorbing aerosol layer, when the signal is ”strong” enough
- Comprehensive view on dust episodes can be obtained by combining observations of RGB, AOD, AAI and AAH!

Resources where to obtain RGB and composite images (near real time):

- **EUMETVIEW by EUMETSAT**
  - https://view.eumetsat.int/
  - MSG true color and RGB Dust composites
  - OLCI true color RGB
- **NOAA JSTAR Mapper**
  - https://www.star.nesdis.noaa.gov/jpss/mapper/
  - VIIRS True color RGB
- **NASA World View**
  - https://worldview.earthdata.nasa.gov/
  - MODIS, VIIRS True color RGB





Resources to obtain aerosol observations

Web services for viewing data (no data download or processing needed):

- MODIS AOD, OMI & OMPS AAI: https://worldview.earthdata.nasa.gov/
- VIIRS AOD & TROPOMI AAI: https://www.star.nesdis.noaa.gov/jpss/mapper/
- GOME-2, OMI & TROPOMI AAI: https://sacs.aeronomie.be/nrt/index.php

Actual data download examples (incomplete list)

- PMAP AOD: EUMETSAT EO portal, **https://eoportal.eumetsat.int/**
- MODIS AOD: Nasa Earthdata services, https://ladsweb.modaps.eosdis.nasa.gov/
- GOME-2 AAI and AAH: AC SAF data portal, **https://safserver.fmi.fi/index.html**