Wildfires in the Arctic

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Daniela Meloni, Tatiana Di Iorio, Virginia Ciardini - *ENEA*
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Giovanni Muscari - *INGV*
Silvia Becagli - *Univ. Florence*
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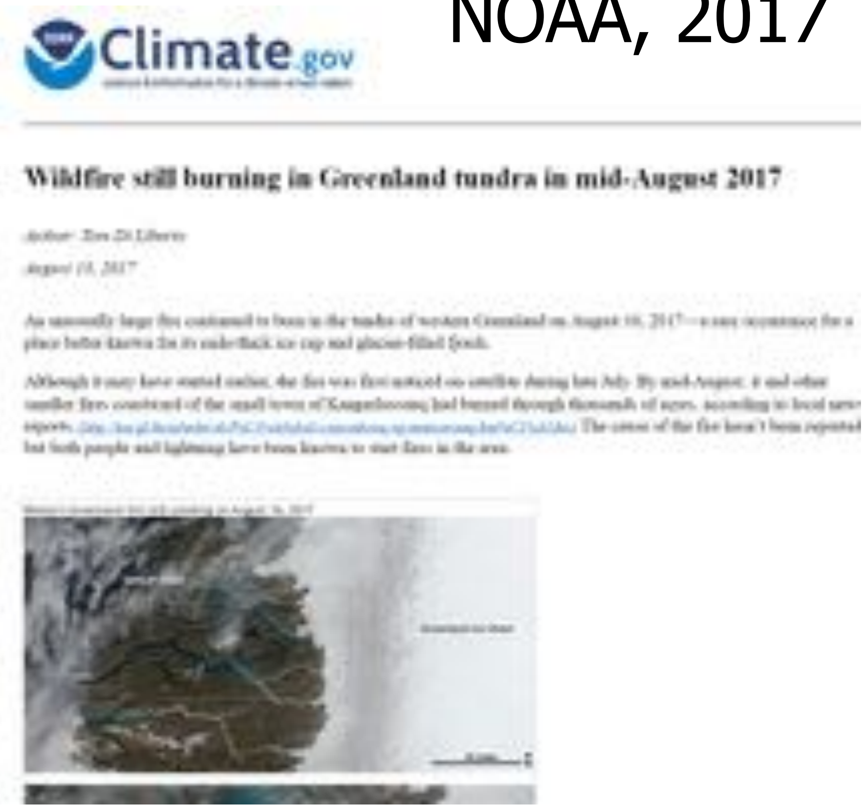
James W. Hannigan, Ivan Ortega - *NCAR*
Brent N. Holben - *NASA/GSFC*

Megafires such as this one in Canada's Northwest Territories last year are transforming the boreal forest. PHOTO: KYLE THOMAS

New Scientist, 2017

NOAA, 2017



WMO, 2019

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Aerosols emitted from wildfires

could significantly affect global climate

*through perturbing **global radiation balance**.*

From *Impacts of Wildfire Aerosols on Global Energy Budget and Climate: The Role of Climate Feedbacks*, Jiang Y. et al., 2020

https://www.nationalgeographic.org/encyclopedia/wildfires/

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Aerosols emitted from wildfires

could significantly affect global climate

through perturbing ***global radiation balance****.*

The feedback **mechanisms** between fire and climate interactions **are still a great challenge and remain fundamentally uncertain**

From *Impacts of Wildfire Aerosols on Global Energy Budget and Climate: The Role of Climate Feedbacks*, Jiang Y. et al., 2020

https://www.nationalgeographic.org/encyclopedia/wildfires/

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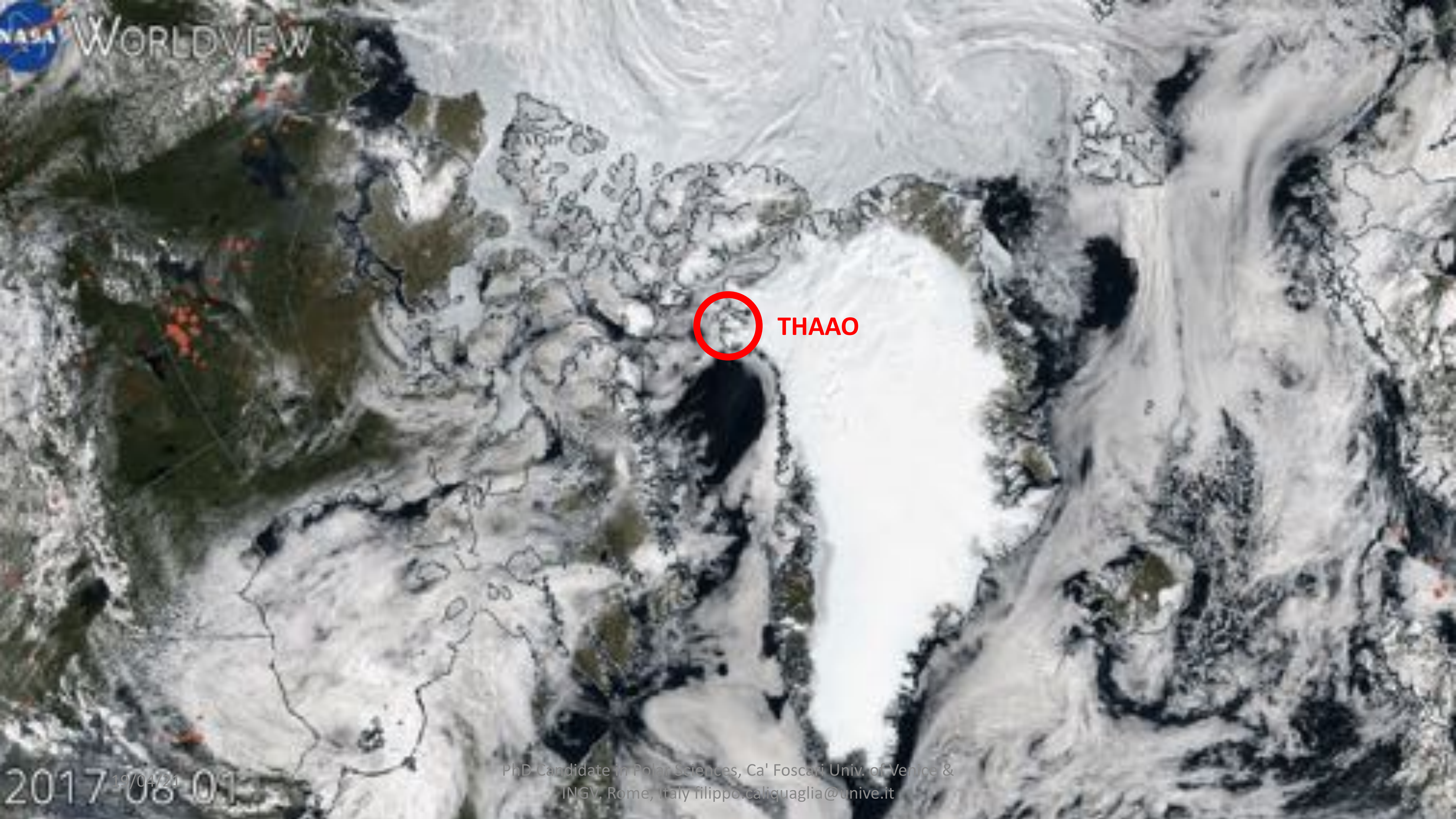

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Objective

Draw an overall picture of the sources and radiative effects of wildfires burning in August 2017 at THAAO and in the Arctic

Achieved through a multi faceted approach: taking into considerations observations concerning the chemistry and physics of the atmosphere, as well as modelling.

- Having the chance to observe two atmospheric states (normal condition and "wildfires" condition)
  - Measure the atmospheric parameters which are involved in radiative budget
  - Model the atmosphere in a point location for which all these observations are available
  - Use obtained modelling parameters (formulating some hypotheses) to extend the impact assessment to a wider geographical area affected by wildfires

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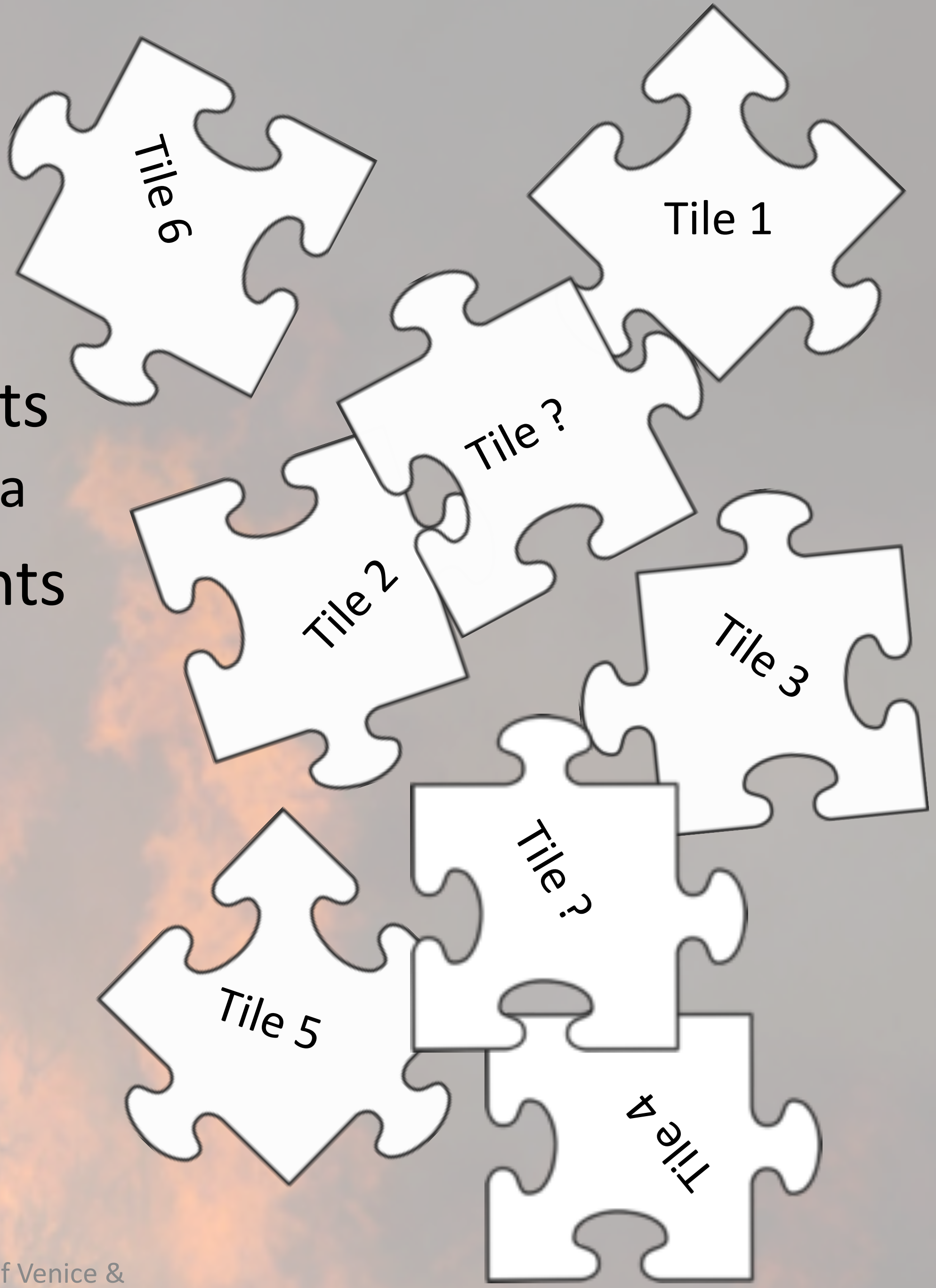
Outline

- Tile 1: Radiation from ground measurements
  - AOD (sun-photometer), SW, PAR, all-sky camera
- Tile 2: Chemistry from ground measurements
  - Air sampling, FTIR
- Tile 3: Chemistry from satellites
- Tile 4: Modelling of back trajectories
- Tile 5: Modelling of atmospheric chemistry
- Tile 6: Modelling of radiative impacts
  - Spatial extrapolation



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THAAO
Thule High Arctic Atmospheric Observatory
(76.5°N, 68.8°W)

http://www.thuleatmos-it.it

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Instruments

Meteorological sensors (NCAR/INGV)
Radiosondes (INGV/ENEA)
Pyrheliometer (ENEA)
Solar/IR radiometers for downwelling radiation (ENEA)
Solar/IR radiometers for upwelling radiation (ENEA)
FTIR Spectrometer (NCAR)
Aerosol/temperature lidar (Univ. Roma/ENEA)
VESPA22 mm-wave spectrometer (INGV)
Microwave profiler (ENEA)
Cimel Sun photometer (AERONET; NASA)
SolData Sun Photometers (ENEA)
PM10 sampler (Univ. Firenze/ENEA)
H_2O isotope analyzer (Univ. Alaska)
Pyrometer (ENEA)
All-sky camera (ENEA)
Ceilometer (ENEA)

Ground-based measurements

https://www.britannica.com/science/wildfire

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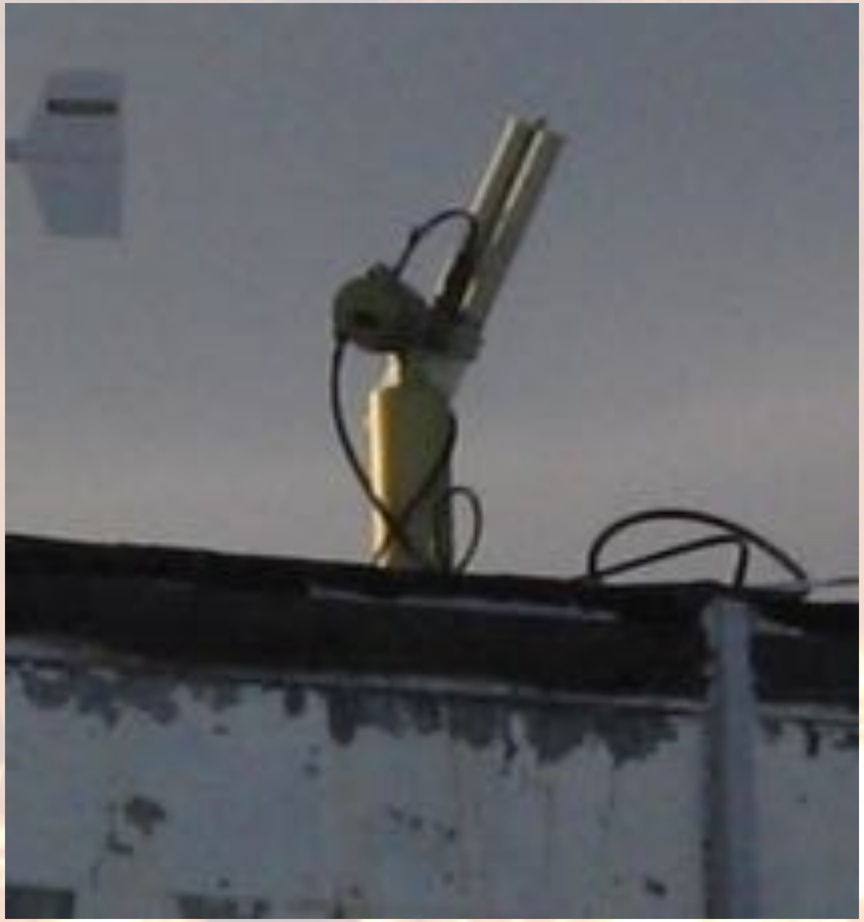
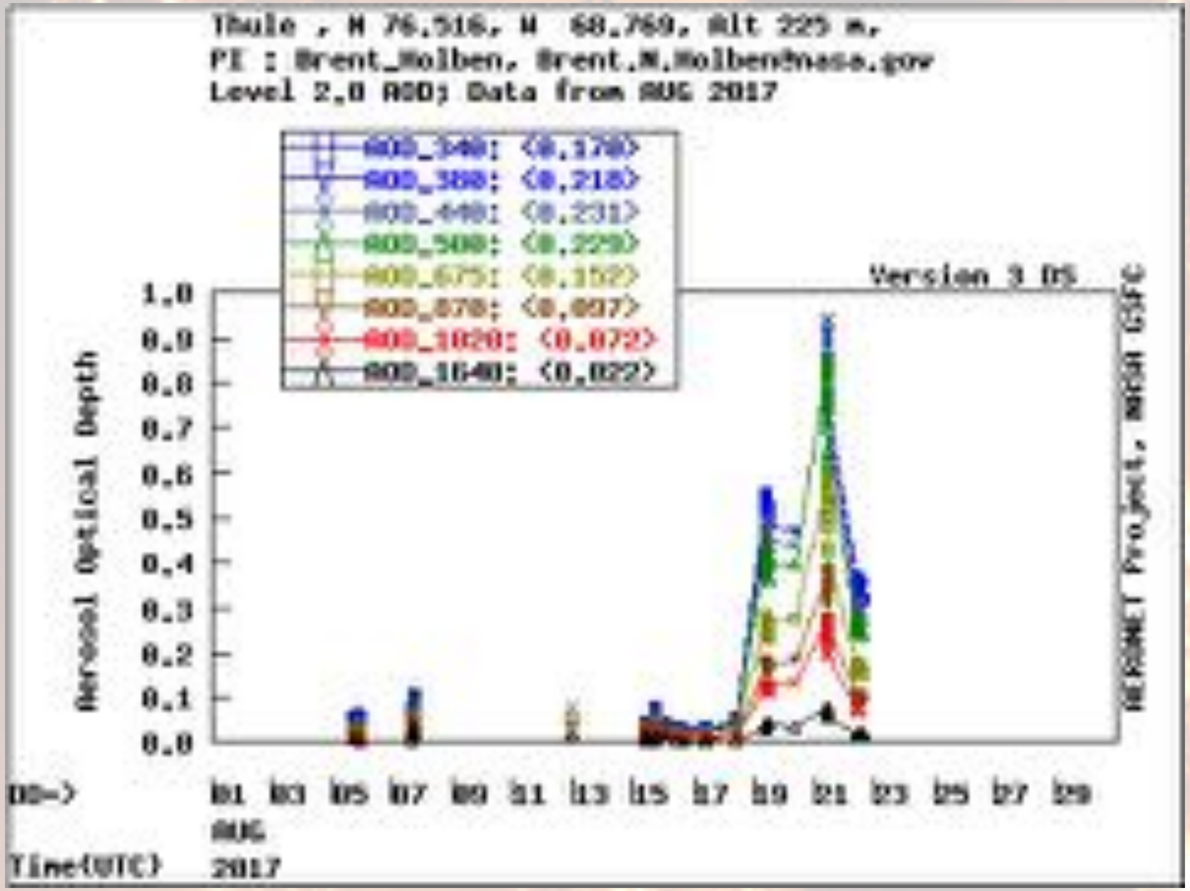
AOD for different lambda





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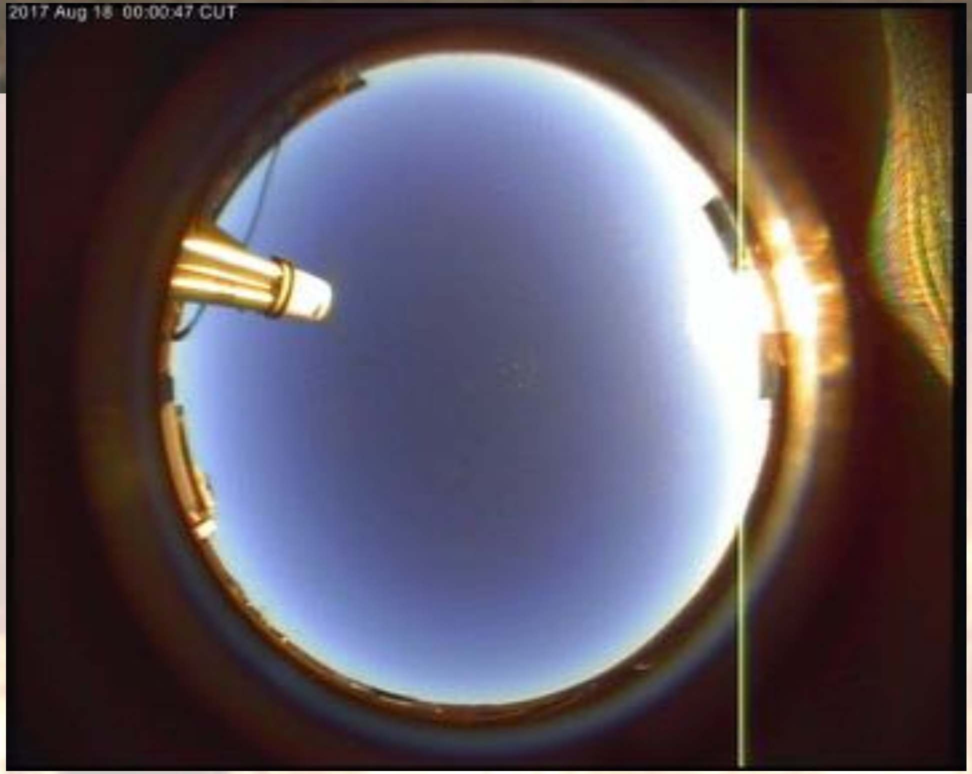
All sky camera @THAAO

18 August 2017 – 1h frames



21 August 2017 – 1h frames

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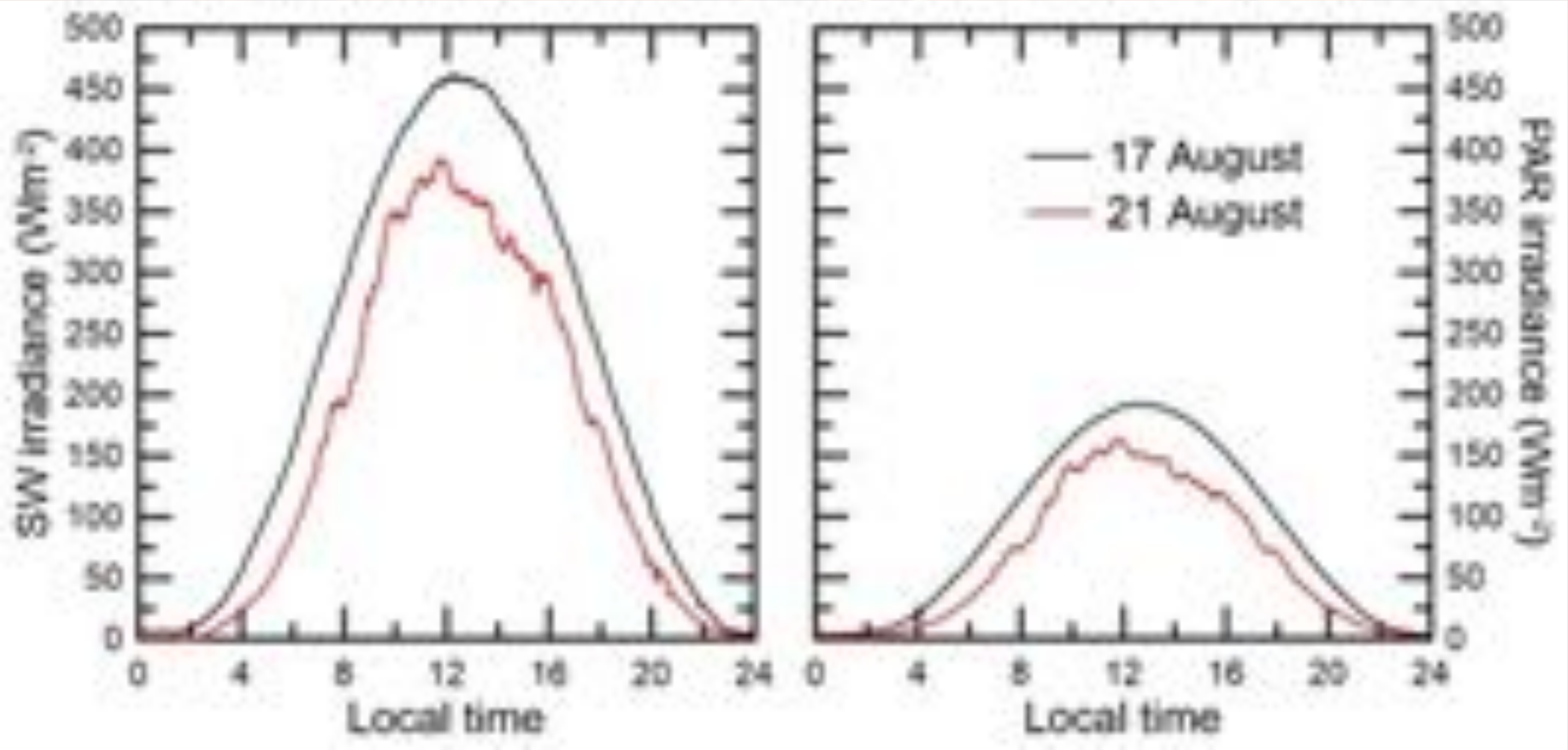
SW and PAR radiation comparison



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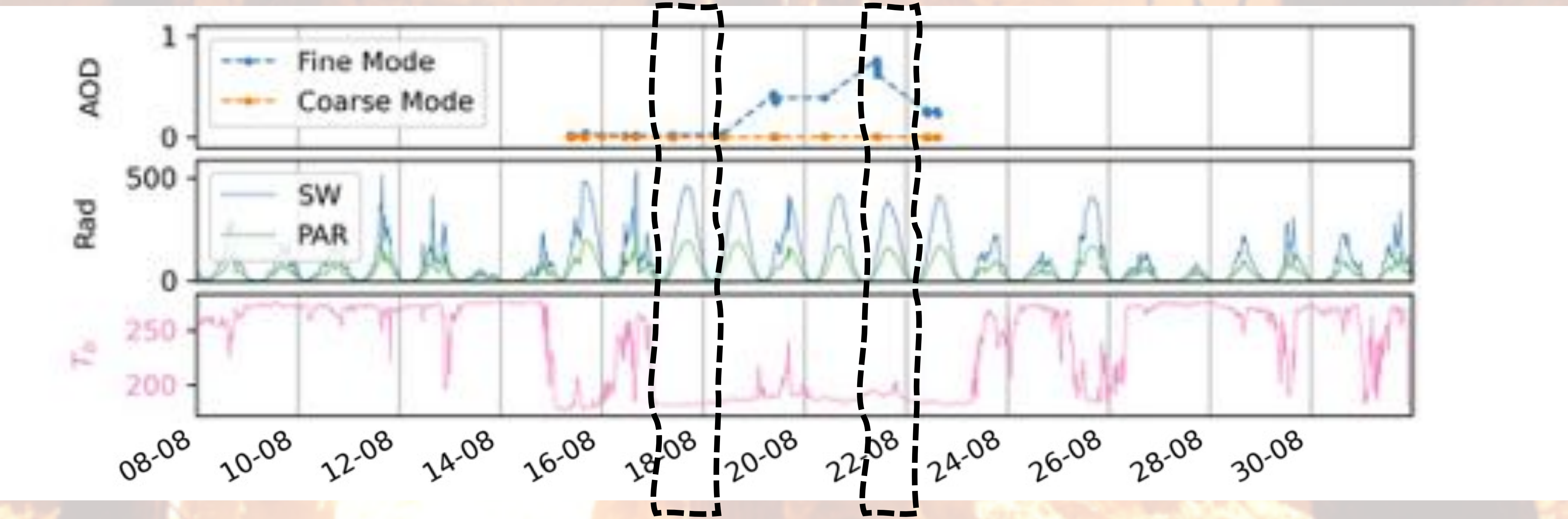
Radiation: summary

Tile 1



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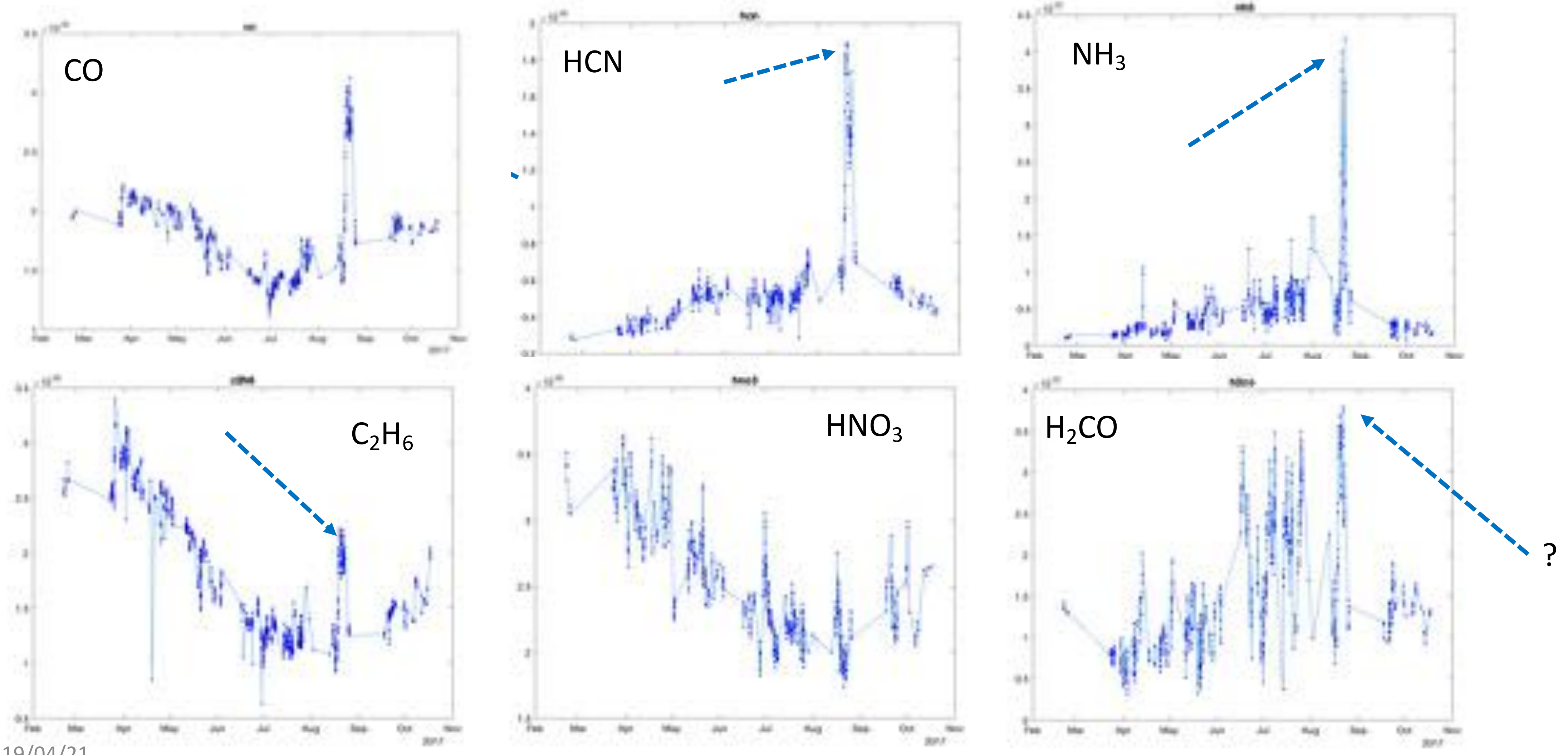
Chemistry of the atmosphere from FTIR



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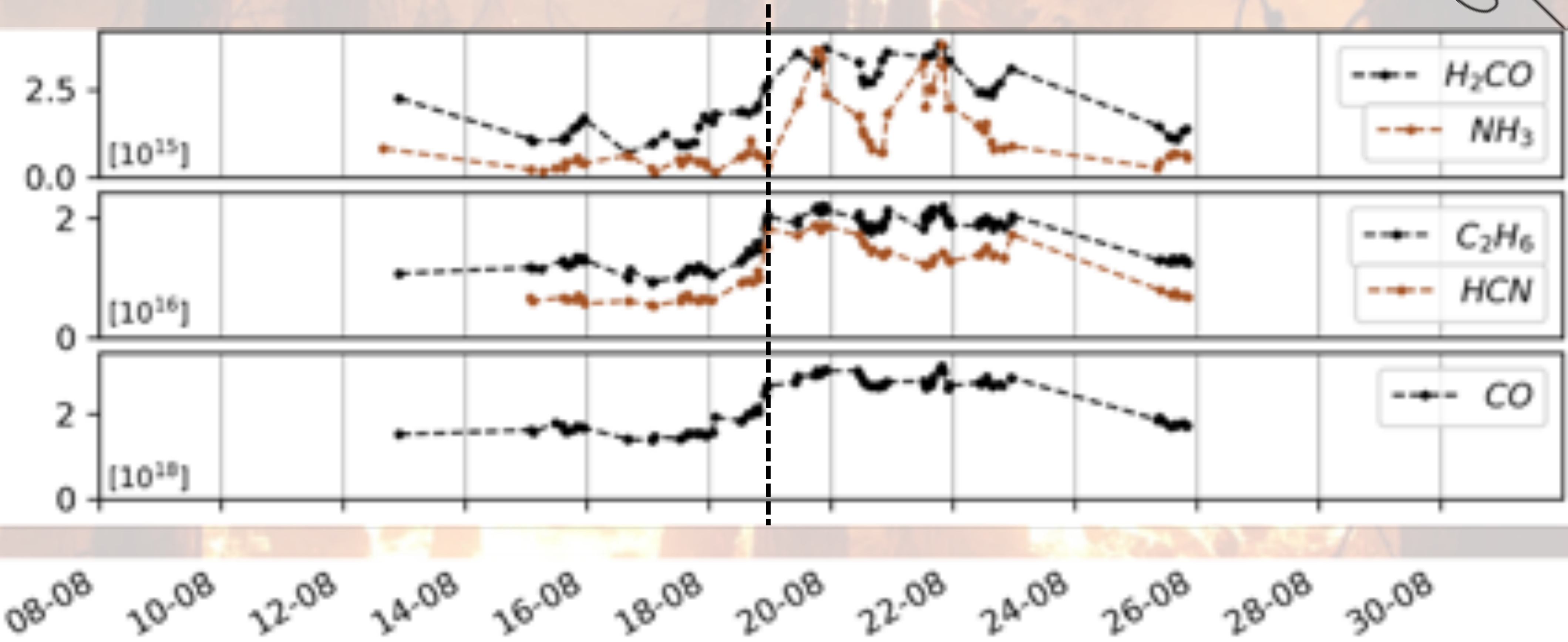
Chemistry of the atmosphere: FTIR

Tile 2



NH_3 -> Ammonia
H_2CO -> Formaldehyde

C_2H_6 -> Ethane
CO <- Carbon Monoxyde
HCN -> Cianidric Acid

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Chemistry of the atmosphere: air sampling

PM10 sampling head, with an airflow of 2.3 m^3/h

Automatic continuous measurements every 48 hours

Teflon filters are then 47 mm in diameter, with 2.0 µm nominal porosity, shipped frozen.

PM10 mass is determined by the difference of the filters weight before and after the sampling.

Filters are cut in two halves for ions (ion chromatography) and the metal determination (ICP-AES).

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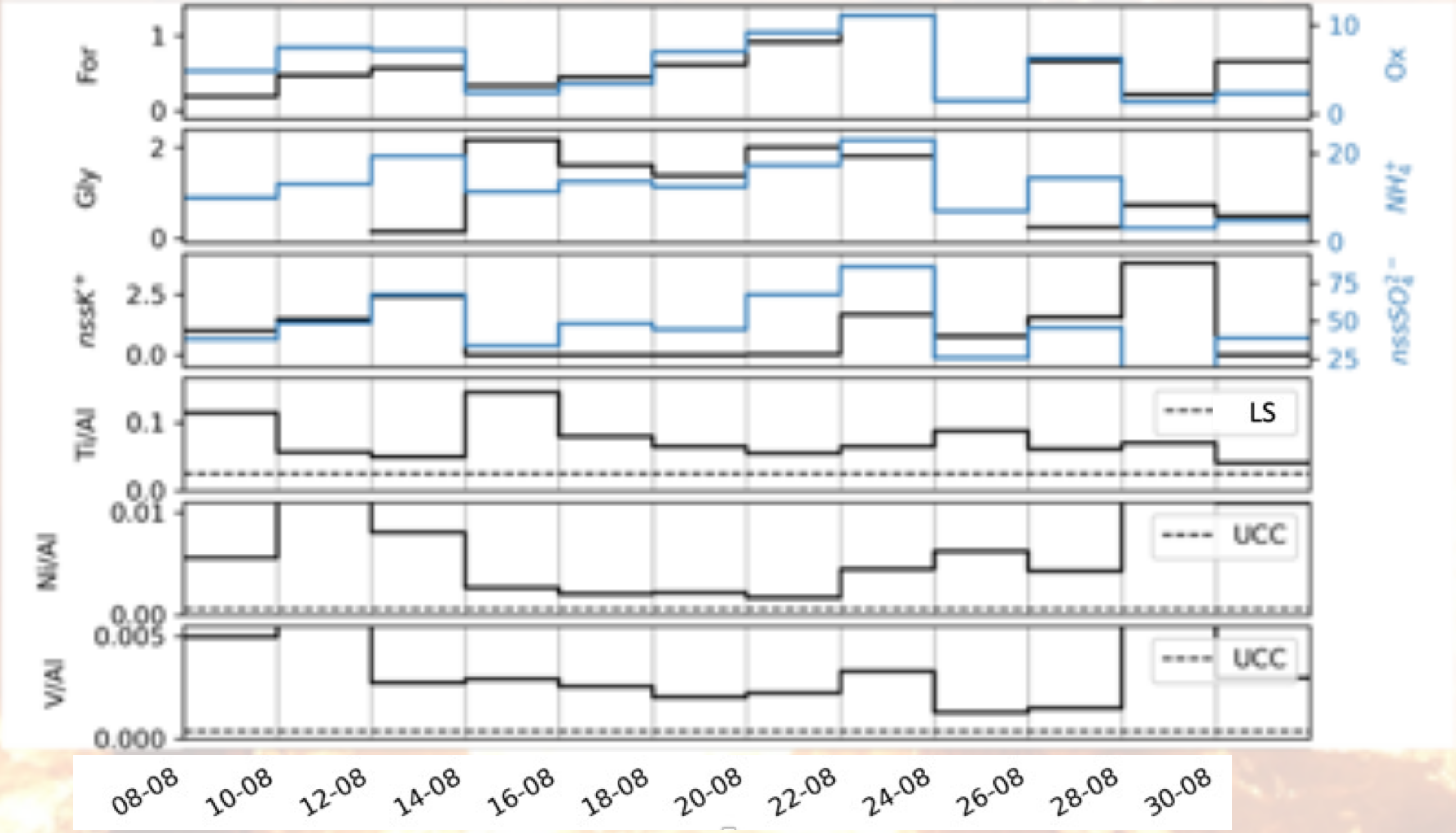
Chemistry of the atmosphere: ground measurements

Tile 2



- More complex interpretation
- UCC = Upper Continental Crust
- LS = Local Soil reference

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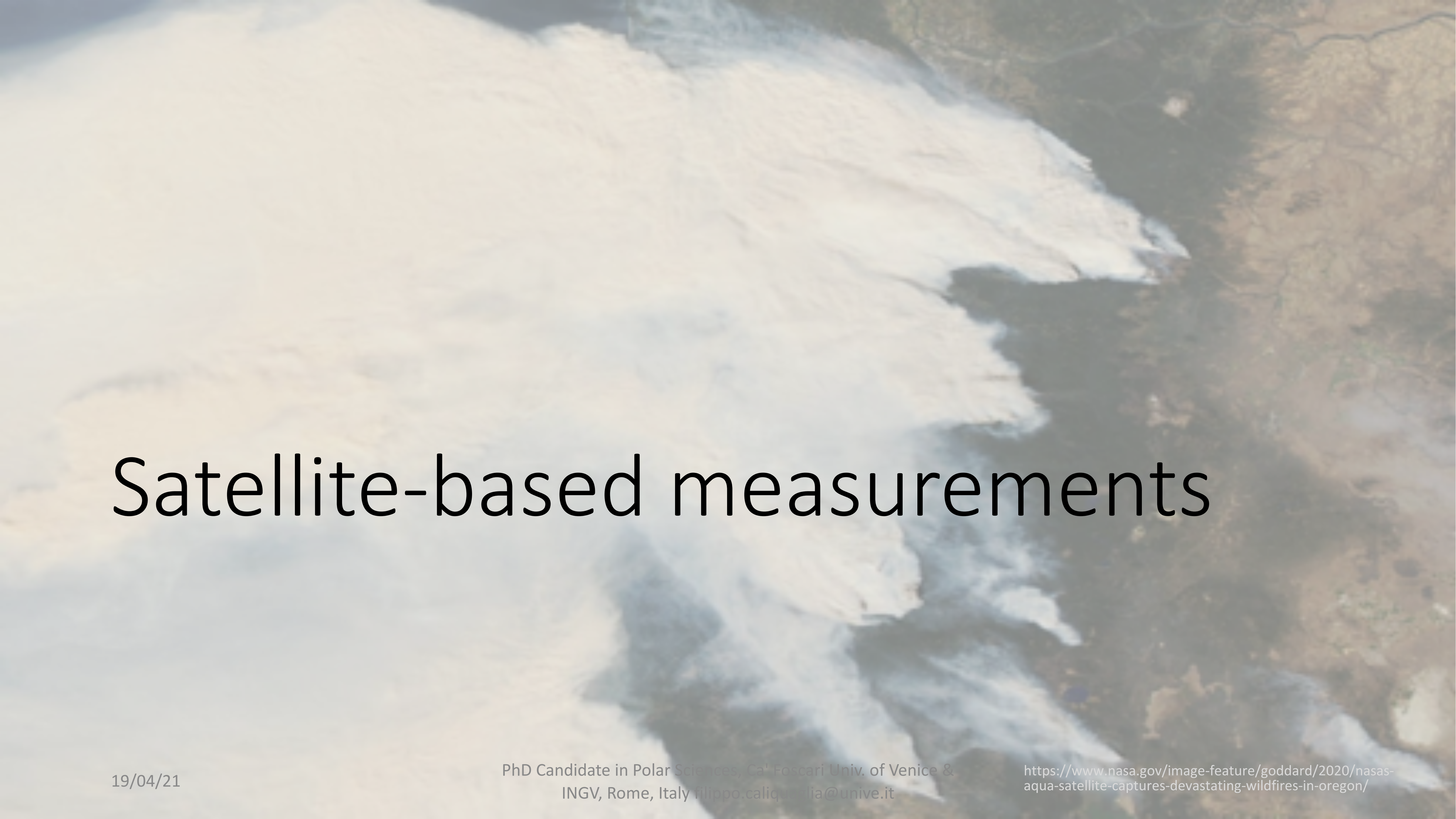

Satellite-based measurements

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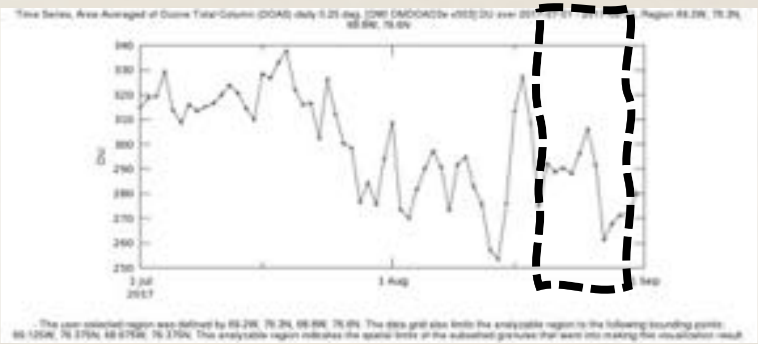
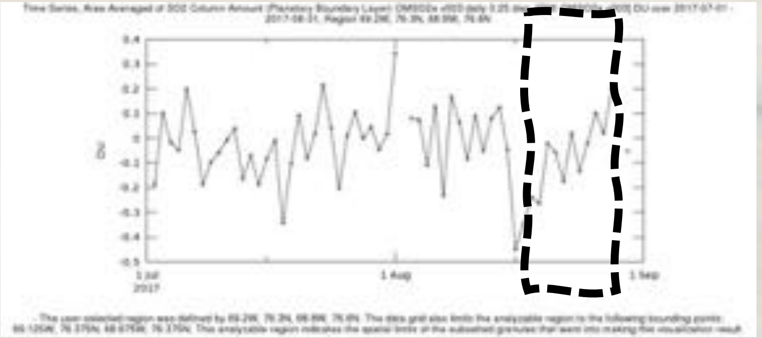
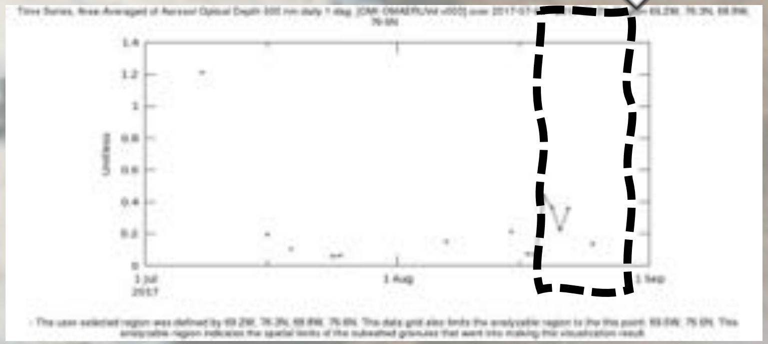
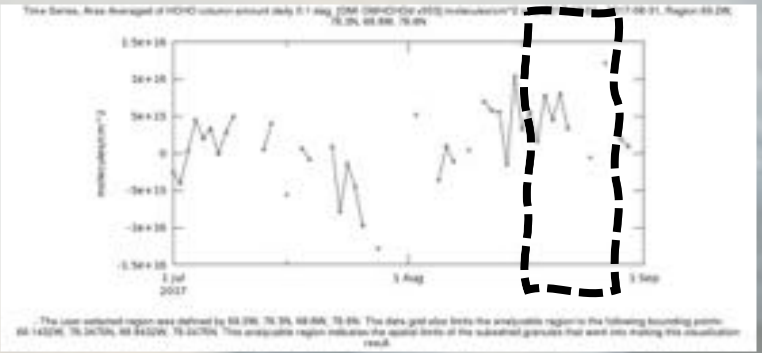
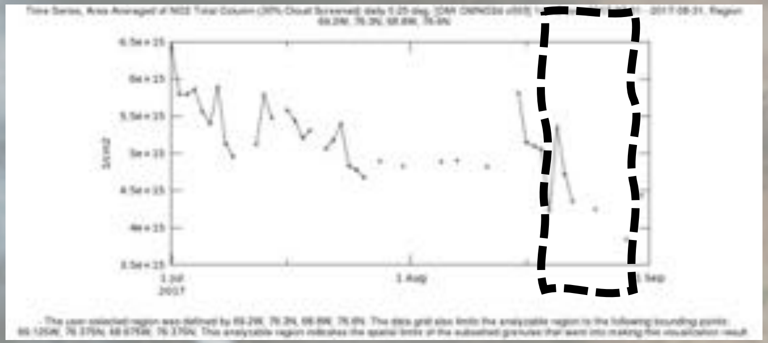
https://www.nasa.gov/image-feature/goddard/2020/nasas-aqua-satellite-captures-devastating-wildfires-in-oregon/

Chemistry of the atmosphere from satellites

Tile 3

- Area-averaged
- Column averaged

From “Giovanni” platform
giovanni.gsfc.nasa.gov/giovanni/

Since 2019 also TROPOMI onboard Sentinel 5P

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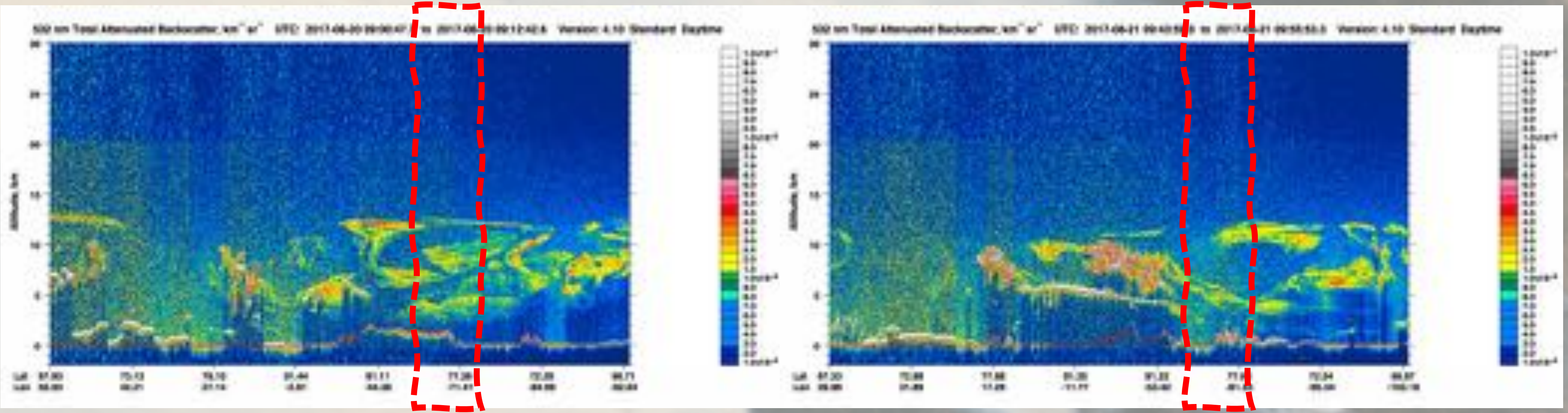
CALIOP - Aerosol backscatter profile

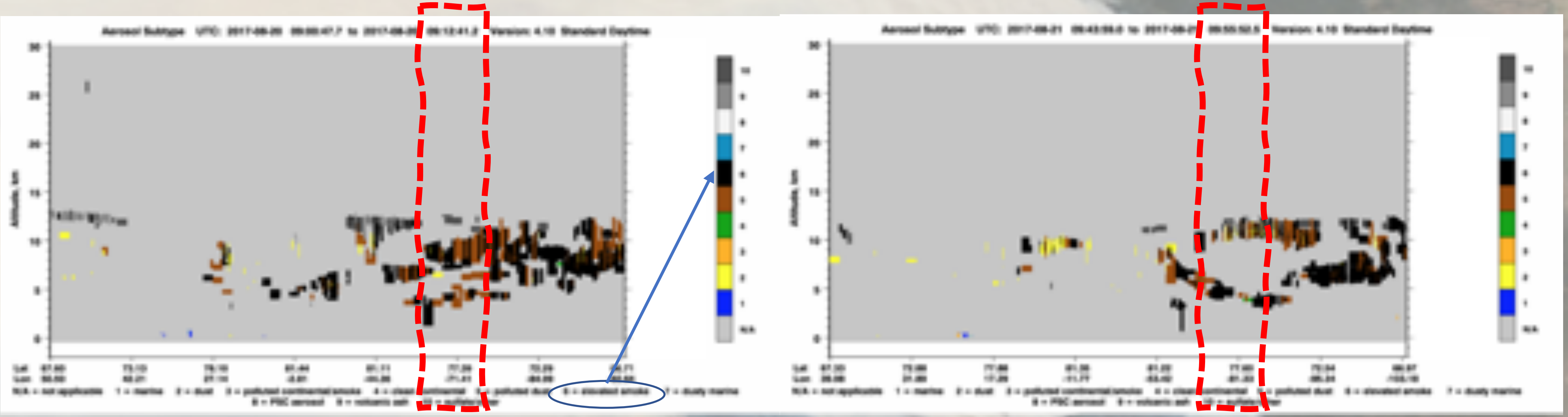
Level 1 CALIOP data (v. 4.10, Vaughan et al. (2004)) were used to retrieve the aerosol backscatter profile. CALIOP attenuated backscatter data were averaged over a horizontal path of about 50 km, and a 300 m running average was calculated along the vertical coordinate.

20 August 2017 21 August 2017



CALIOP - Aerosol type attribution

20 August 2017 21 August 2017



Elevated smoke and polluted dust

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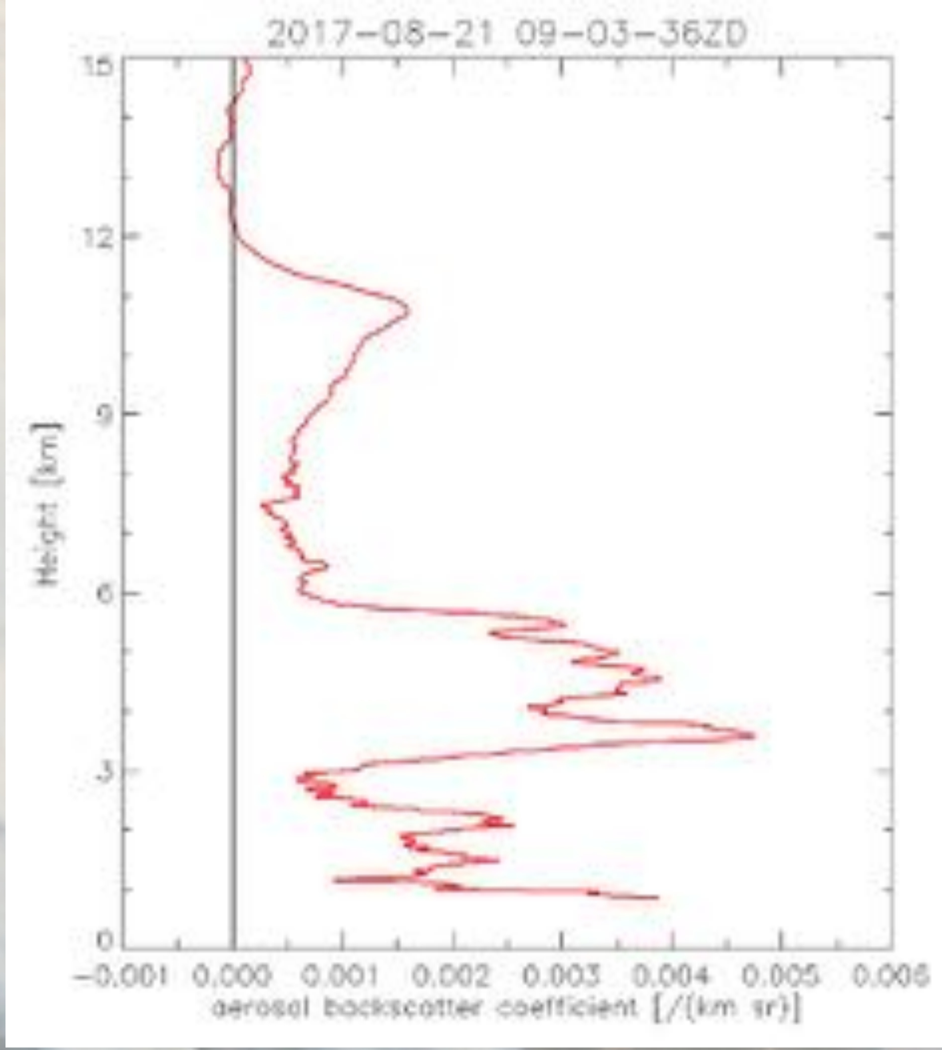
CALIOP retrievals

- Two aerosol layers around 3 and 11 km of elevation



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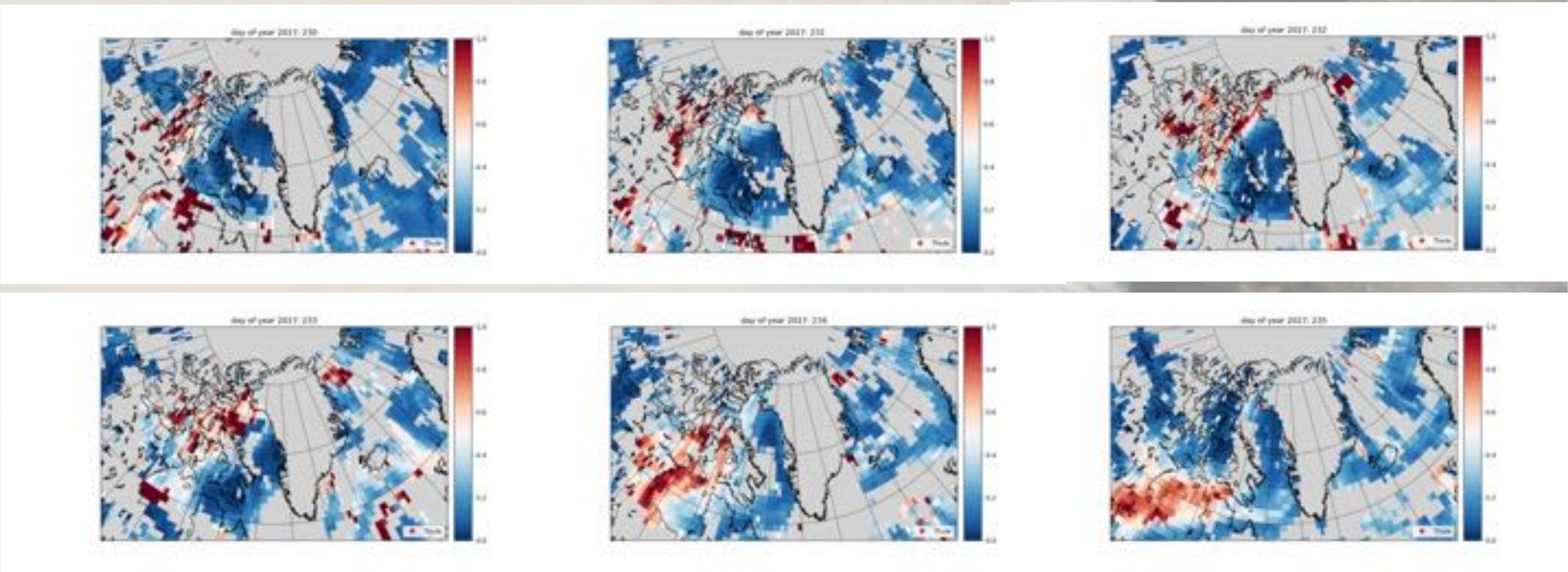
MODIS AOD



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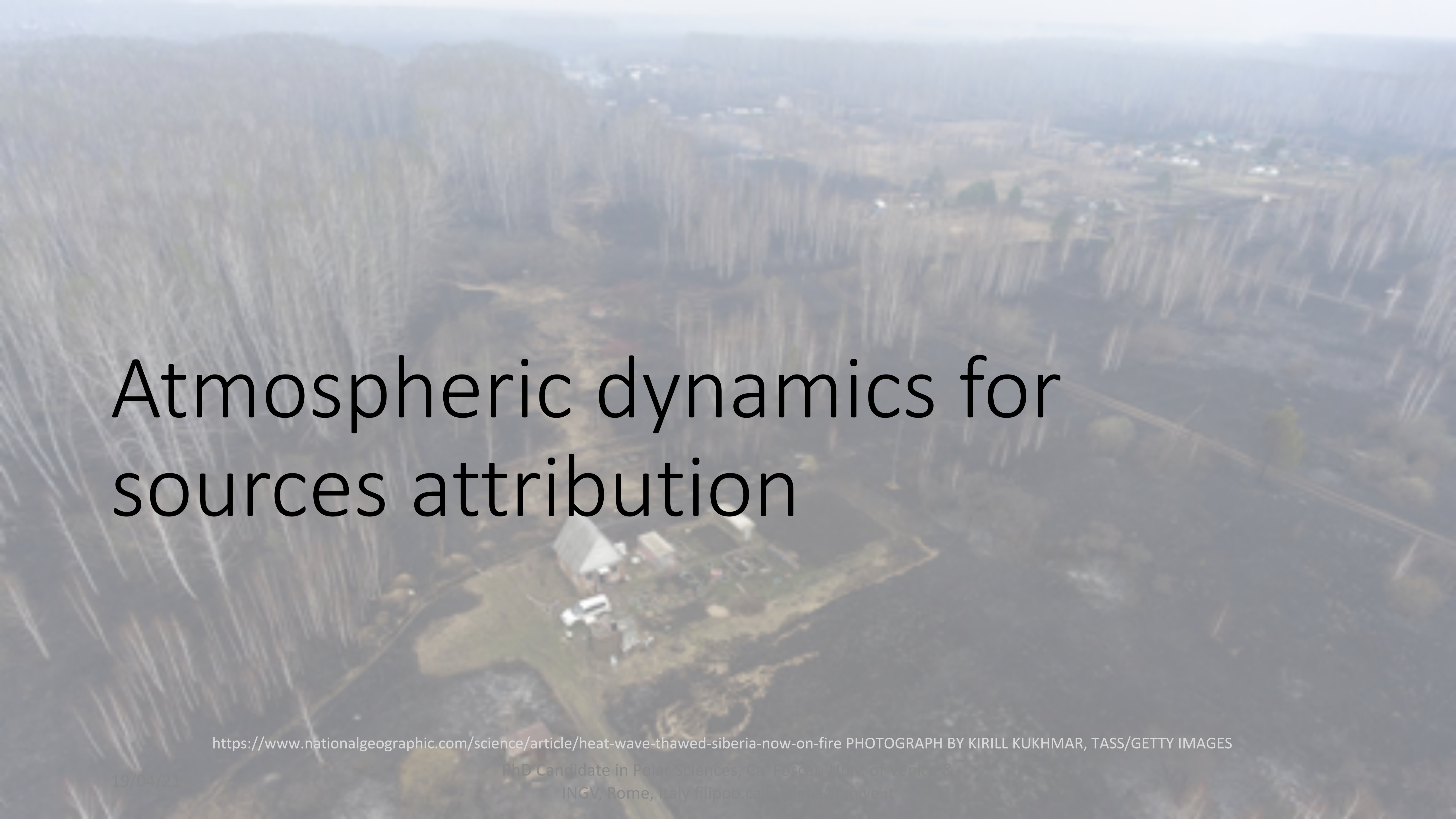

Atmospheric dynamics for sources attribution

https://www.nationalgeographic.com/science/article/heat-wave-thawed-siberia-now-on-fire PHOTOGRAPH BY KIRILL KUKHMAR, TASS/GETTY IMAGES

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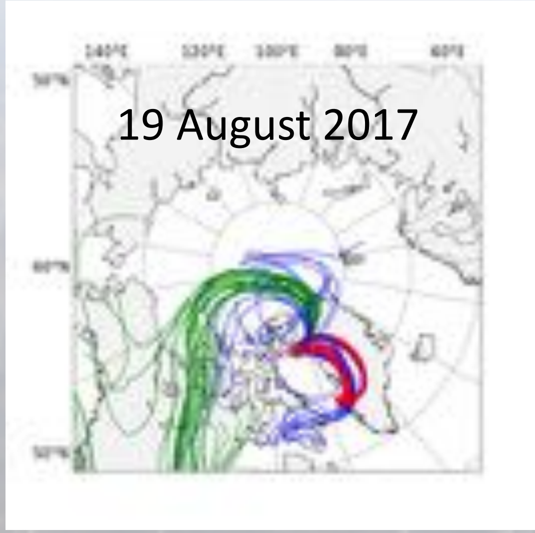
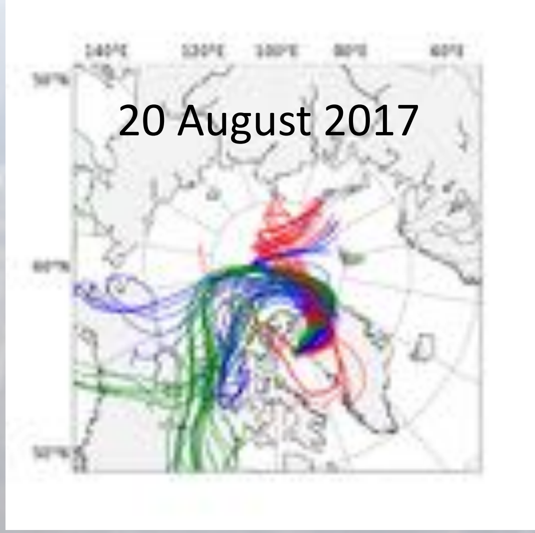
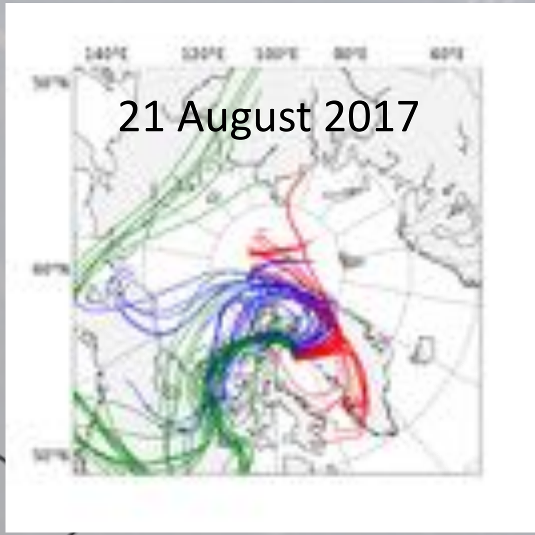
HYSPLIT





- Trajectories obtained from HYSPLIT model
  - a) 19 August 2017 (69 trajectories)
  - b) 20 August 2017 (67 trajectories)
  - c) 21 August 2017 (69 trajectories)
- NCEP dataset was employed as the meteorological reanalysis input
- 144 hours backwards in time
- 3-hourly time-step.
- Subdivided into three classes according to their altitude:
  - lower troposphere: 250, 500, 750 m asl in **red**;
  - mid-troposphere: 1000, 2000, 3000 m a.s.l. in **blue**;
  - upper troposphere: 7000, 8000, 9000 m asl in **green**.



Tile 4

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Radiative Transfer modelling

https://calmatters.org/explainers/californias-worsening-wildfires-explained/

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MODTRAN objective

- Simulation of the SW irradiance components (upward and downward)
- Calculation the Aerosol Radiative Effect (ARE) and the Atmospheric Heating Rate (AHR) profile.

$$ARE = (SW\downarrow - SW\uparrow)_{aer} - (SW\downarrow - SW\uparrow)_{no\_aer}$$

IN GENERAL

Radiative Effects represents the instantaneous radiative impact of atmospheric particles on Earth’s energy balance

Radiative Forcing is calculated as the change of Radiative Effects between two different periods (e.g., preindustrial and present-day)

[or, in our case, with or without aerosols]

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MODTRAN input I

- AOD values from AERONET Sunphotometer (340, 380, 440, 500, 675, 870, 1020, and 1640 nm, then fitted with 4th order polynomial to retrieve missing values in the SW interval 340-300 nm and 1640-3000 nm)
- The IWV was adjusted to the value measured by the HATPRO microwave radiometer.
- The total ozone content was set equal to the value measured by the Ozone Monitoring Instrument (OMI)
- Broadband surface albedo measured at THAAO
- The vertical aerosol extinction profile was derived from the CALIOP backscattering profile
- AOD value at 500 nm is 0.63
- The standard sub-Arctic summer atmosphere (McClatcheyet al., 1972) was chosen for the vertical profiles of meteorological and gas profiles (below 10 km the HATPRO temperature profile was used)
- The spectral aerosol absorption and scattering properties, i.e. single scattering albedo (SSA) and asymmetry factor (g), were derived from the literature after RT simulations in the aerosols-free case

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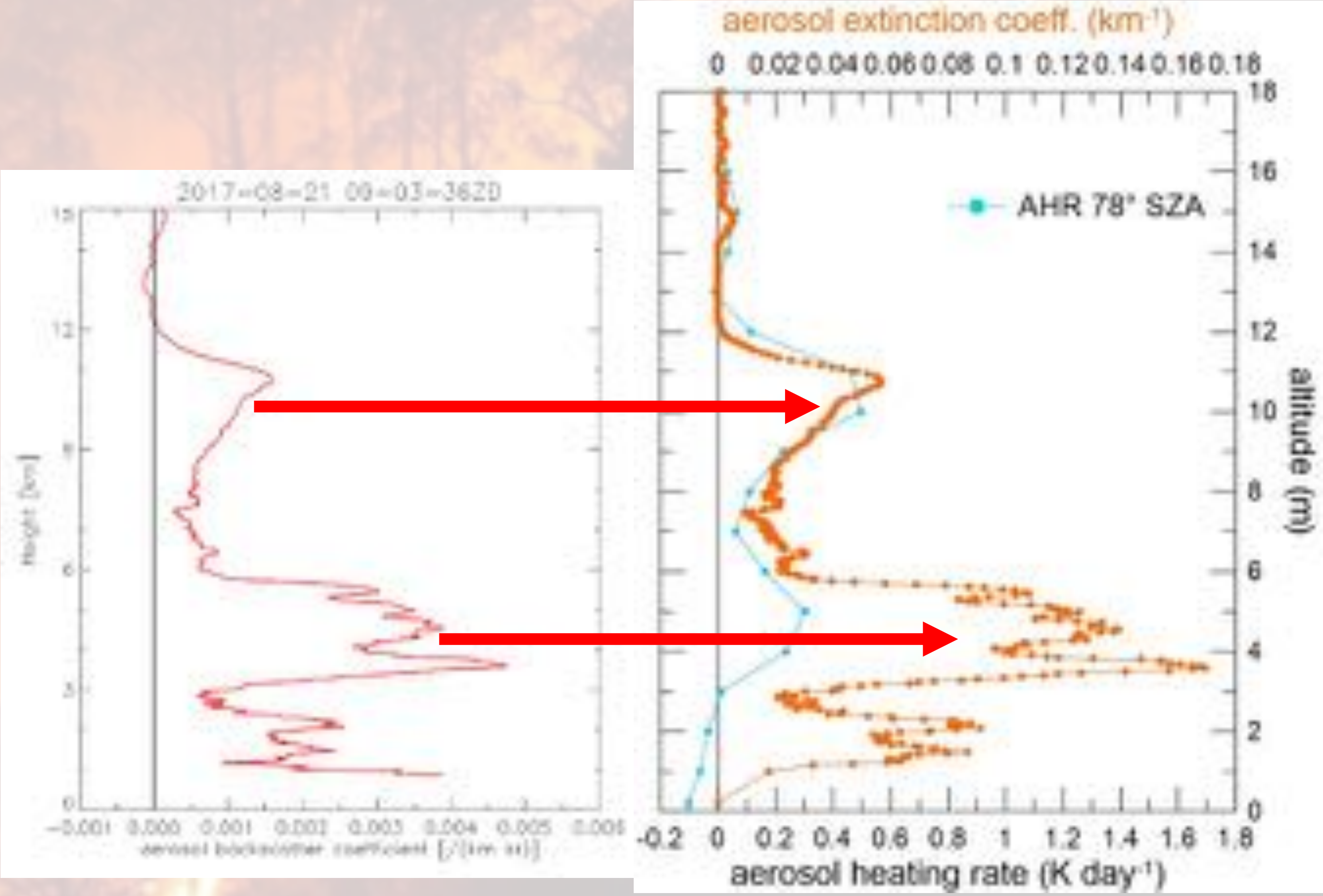
MODTRAN input II

- Extinction: is the sum of scattering and absorption, so it represents total effect of medium on the radiation passing through it
- Fixed extinction to backscatter coefficient using a value compatible for the presence of dust and smoke particles
- The CALIPSO profile was truncated at 1 km to eliminate possible contamination of the signal due to surface reflection in the lowermost section of the atmosphere

CALIPSO retrieval

MODTRAN retrieval



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MODTRAN settings

- Highest spectral resolution (0.1 cm^{-1}) in the 0.3-2.8μm interval
- The vertical resolution is 1 km up to 25 km, 5 km up to 60 km, and 10 km up to 100 km
- 78° SZA → the smallest angle with AOD measurements on 21 August 2017

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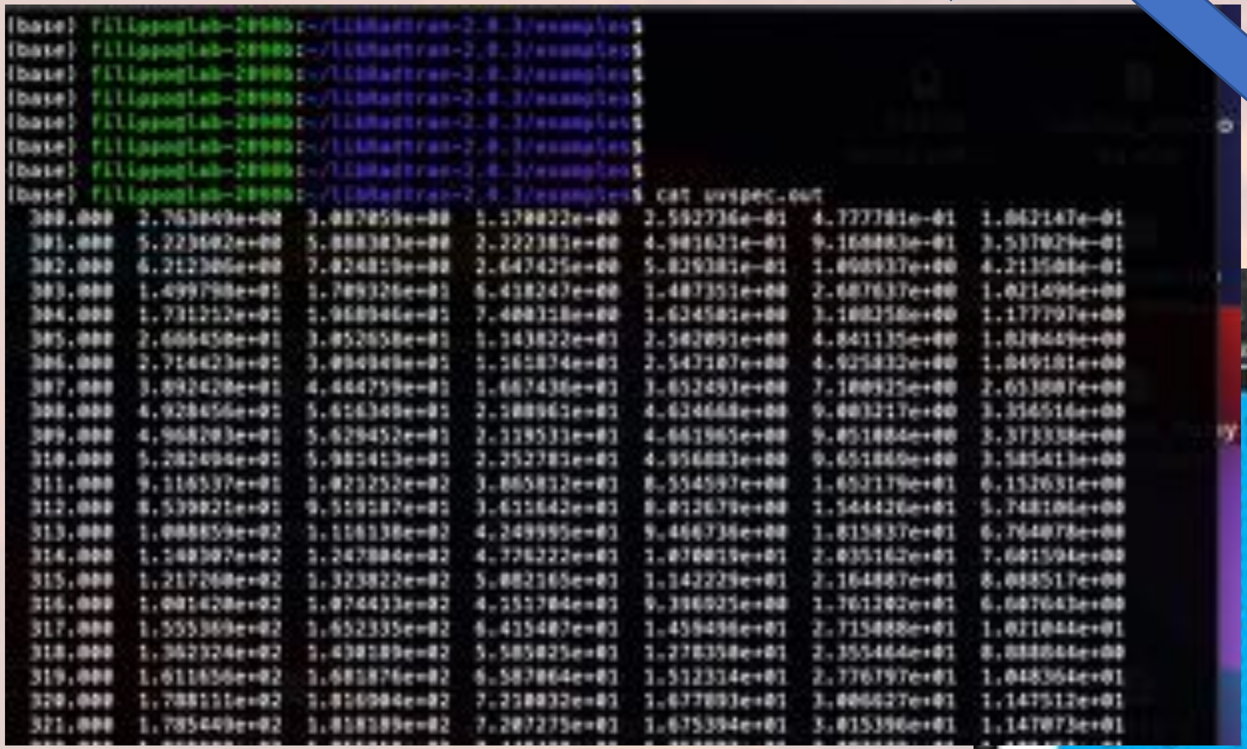
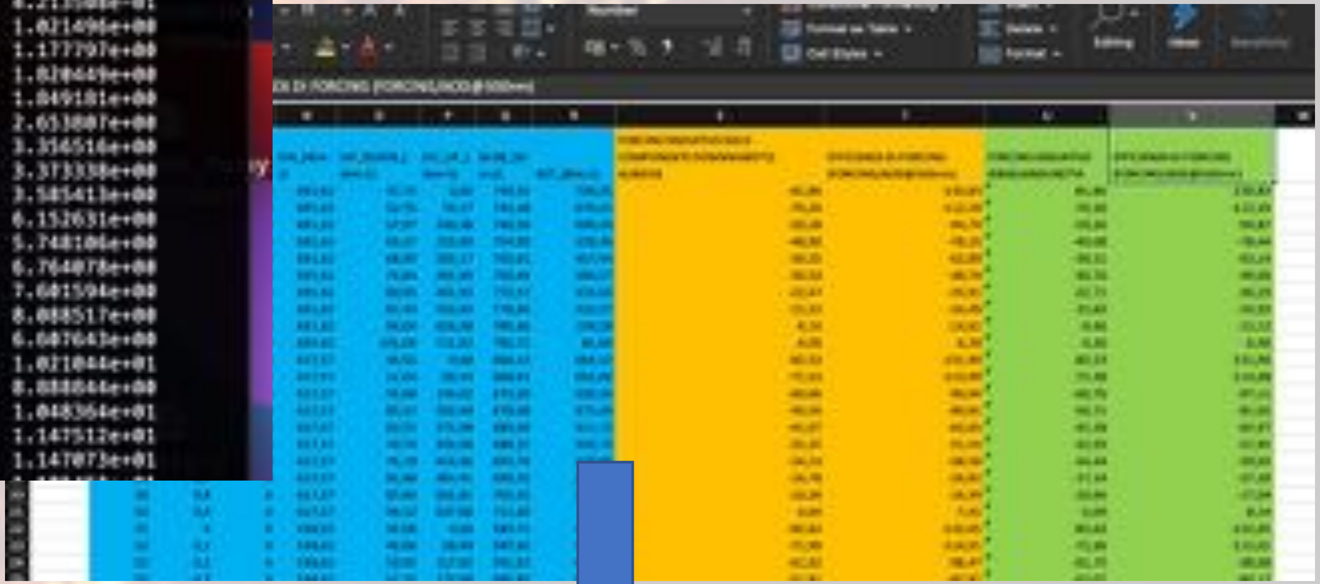
MODTRAN processing





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MODTRAN results: aerosols-free case

MODTRAN aerosols-free case was run to estimate:

- The best modelling parameters not available from measurements

And then to:

- the Atmospheric Radiative Effect
- the Atmospheric Heating Rate profiles up to the top of the aerosol layer detected by CALIOP

$$ARE = (SW\downarrow - SW\uparrow)_{aer} - (SW\downarrow - SW\uparrow)_{no\_aer}$$

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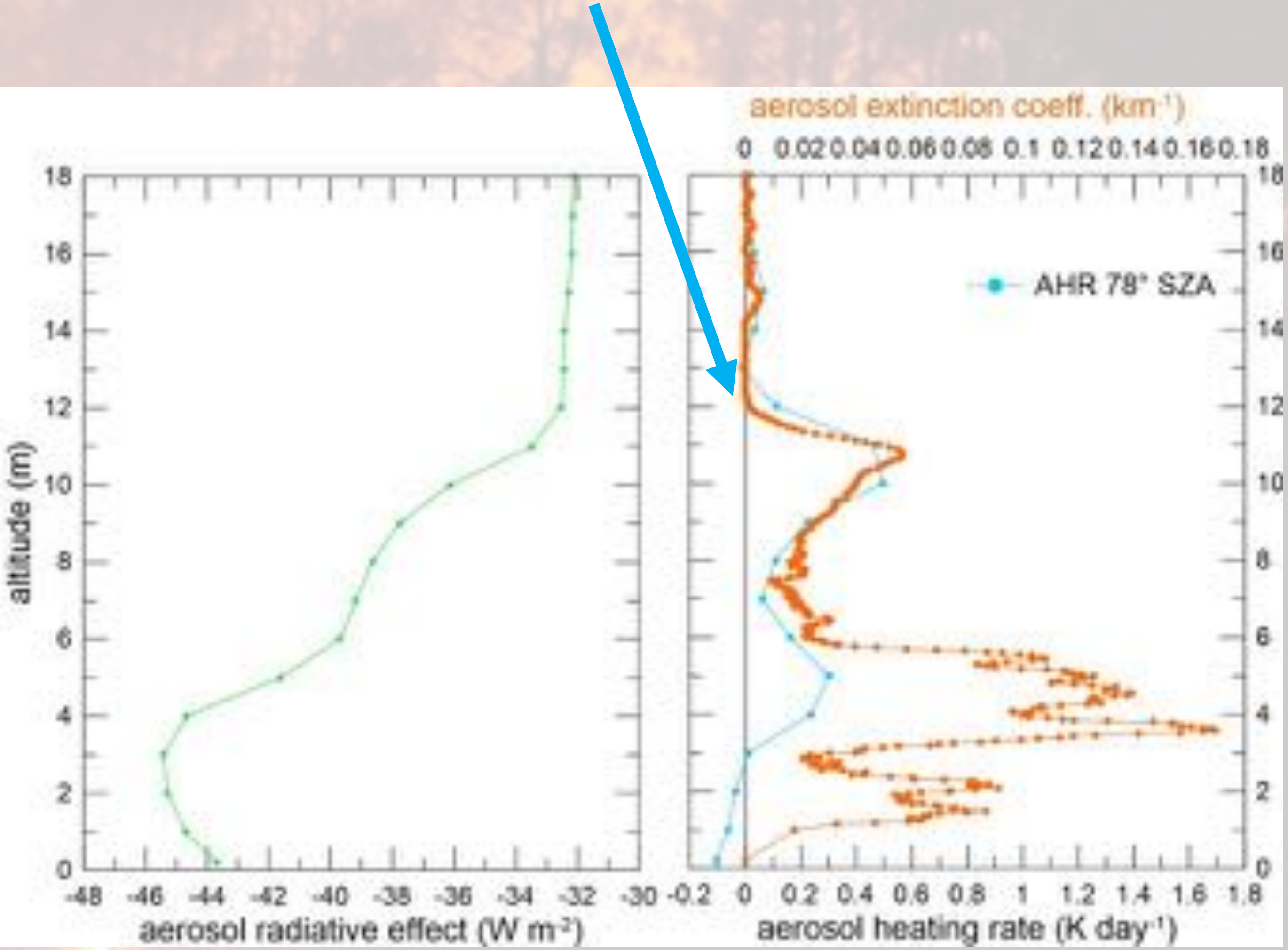
MODTRAN results: the 21 August simulation

- The largest AHR values (+0.50 K/day) are found between 8 and 12 km
- The largest extinction in the CALIPSO profile is between 3 and 6 km.

This behaviour is due to the dependence of the ARE on the SZA. For very low Sun, scattering and absorption by aerosol are more effective at higher altitude.



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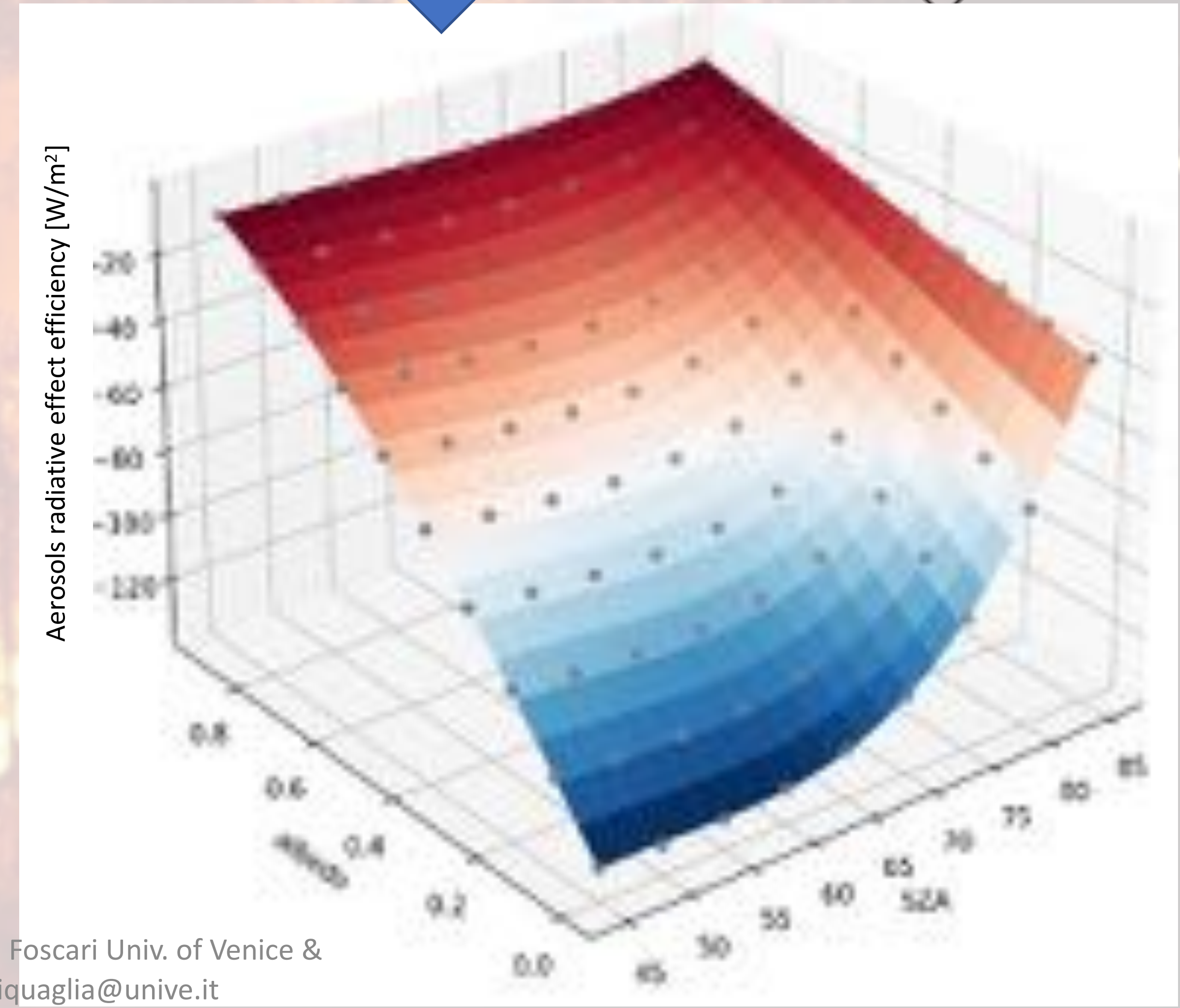
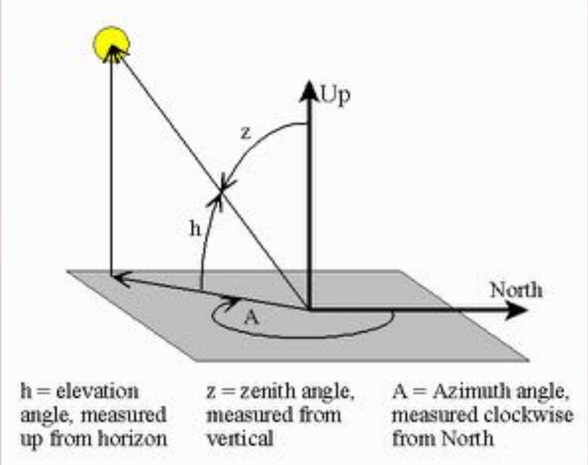
MODTRAN results

Tile 5

- The AREE is ARE per unit of AOD at 500 nm
- For highly reflecting surfaces the AREE is very low and nearly constant
- The impact of absorbing BB aerosols, being locally produced or transported mainly in summer, when larger surfaces are free of snow, may be remarkable for the Arctic surface radiation budget.





Meysam Mahooti (2021). NREL's Solar Position Algorithm (SPA) MATLAB Central File Exchange. Retrieved March 18, 2021.

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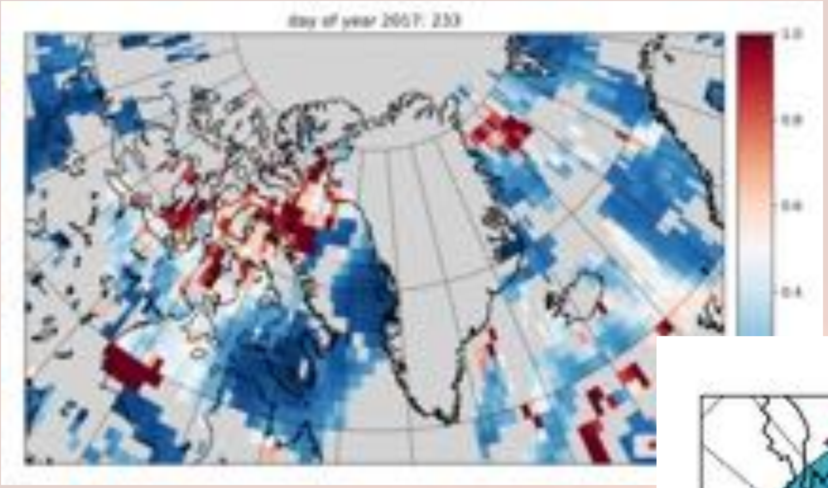
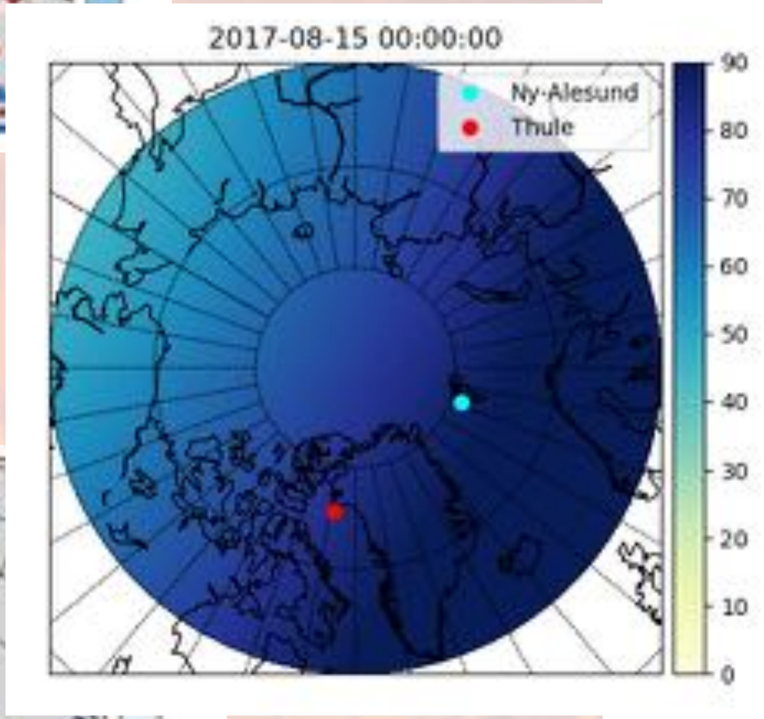
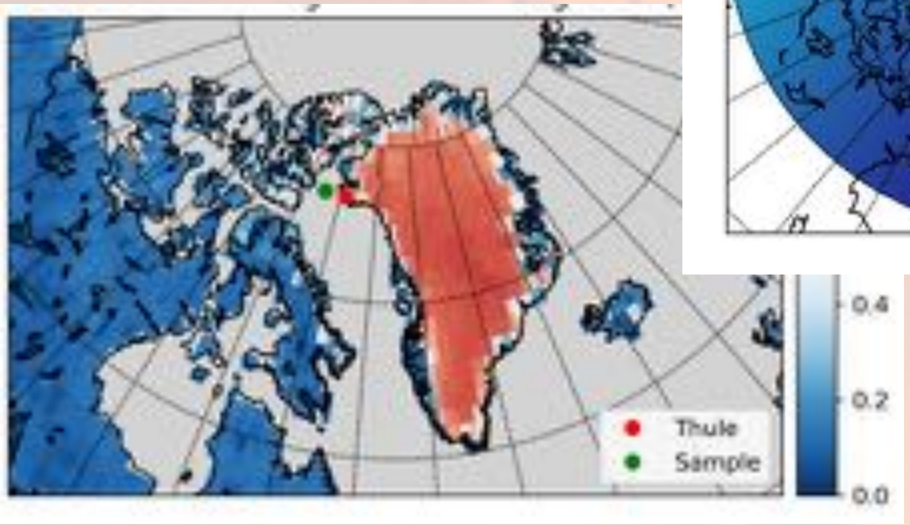
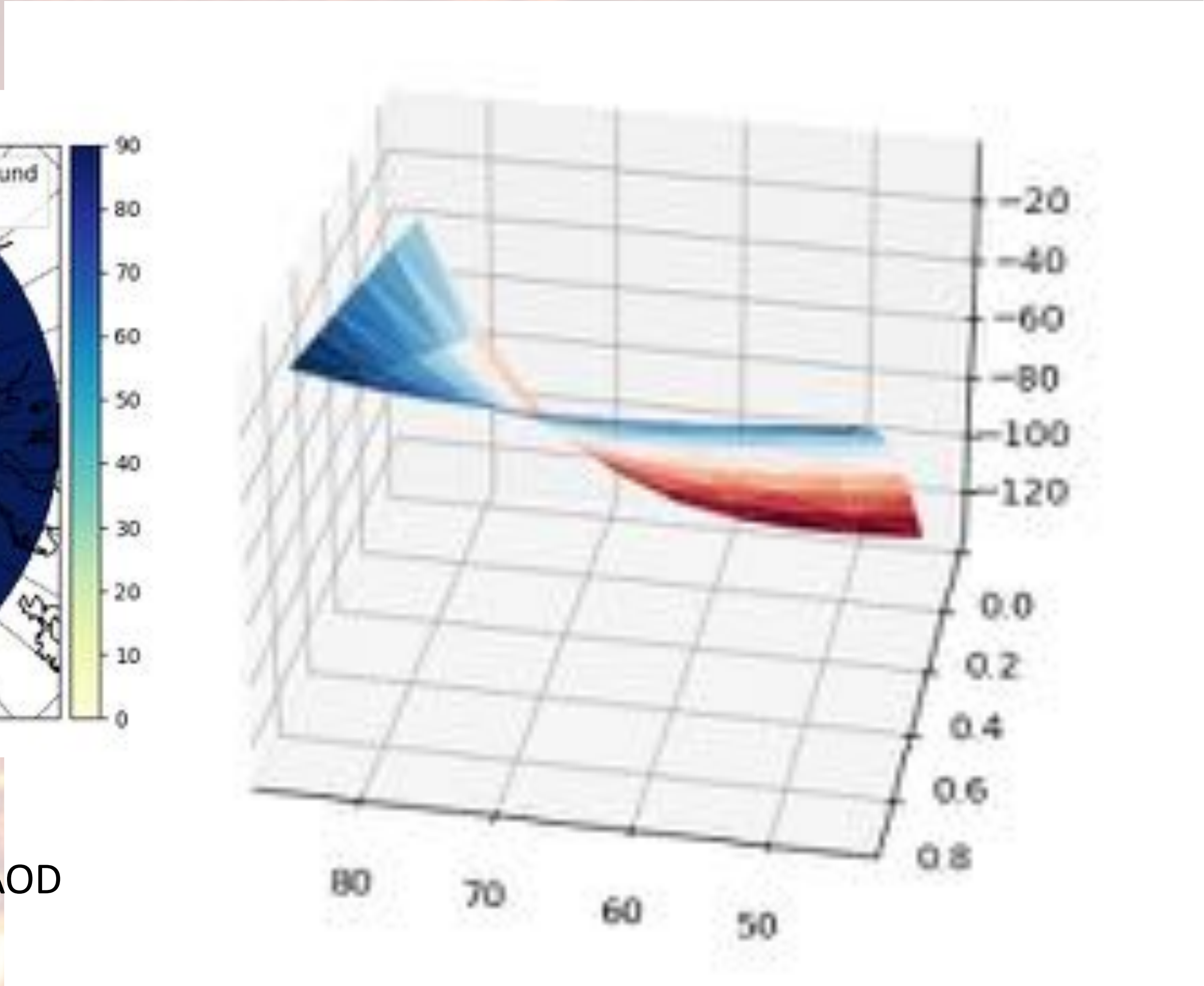
Albedo, SZA, AOD









ARE = AREE *AOD

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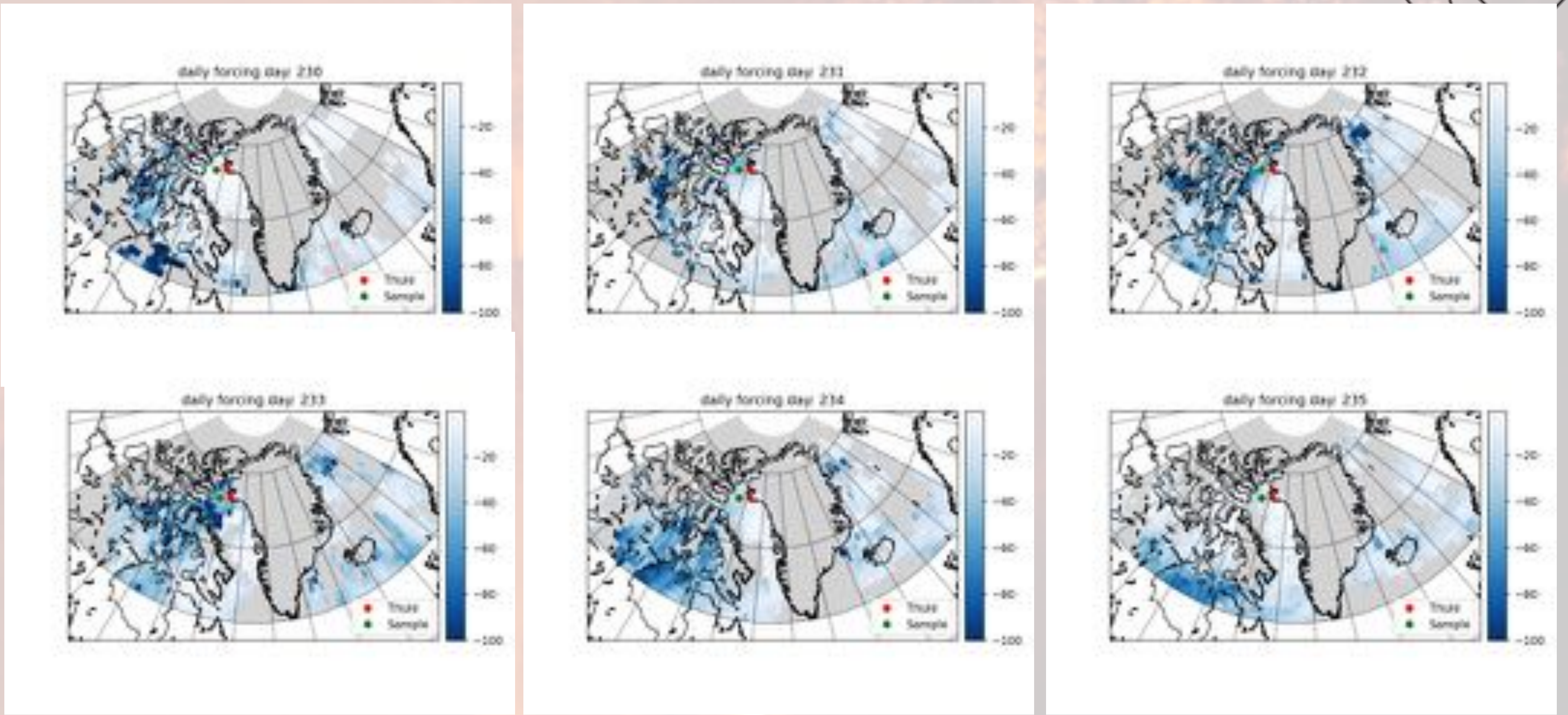
Aerosol Radiative Effect

Tile 6



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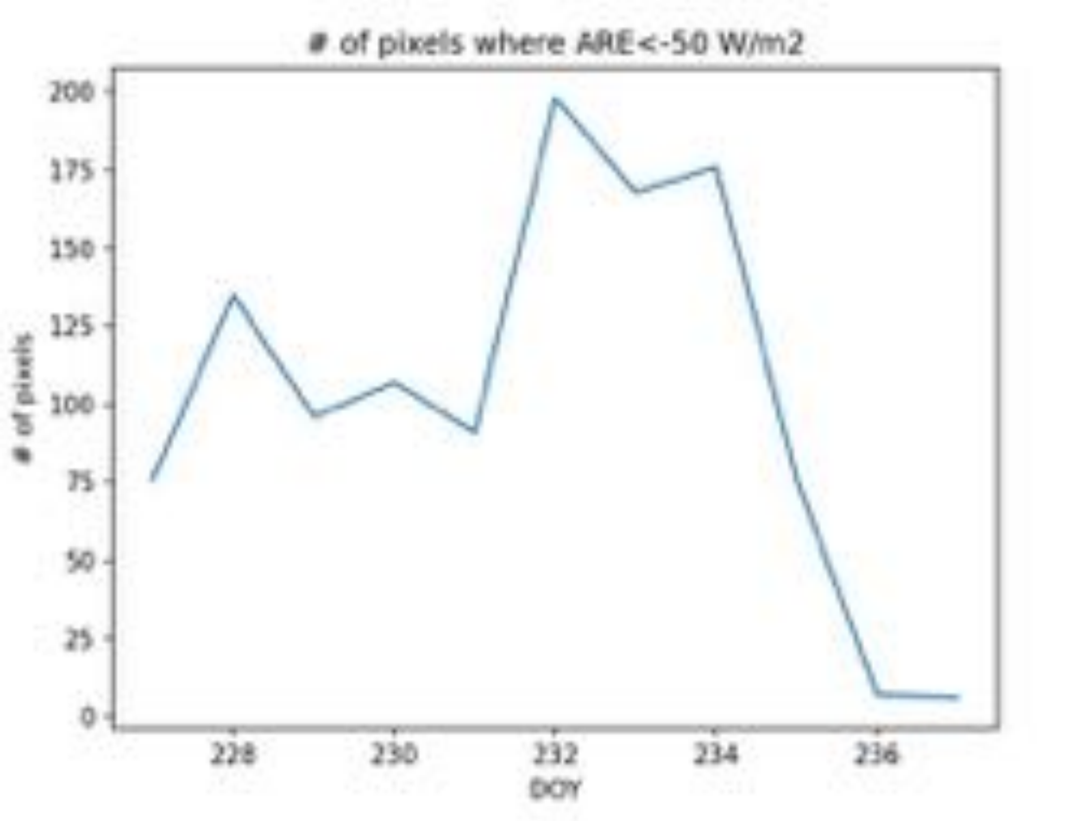
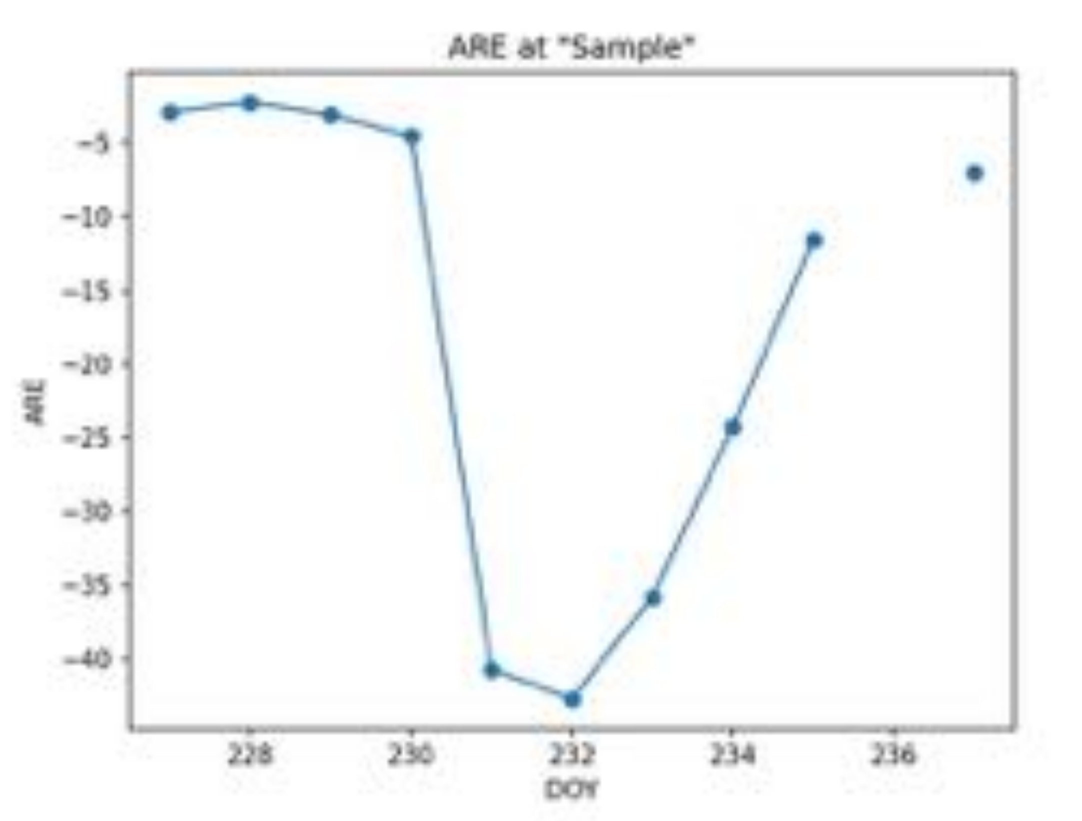
Zoom in

OVERALL AREA



"SAMPLE" location



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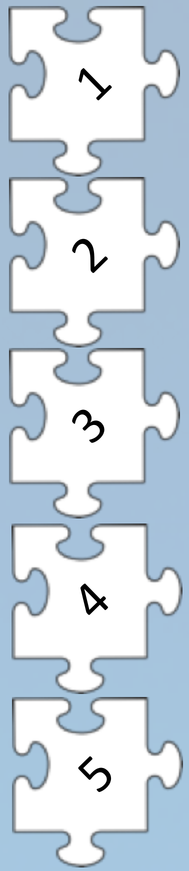
Summary & Conclusions



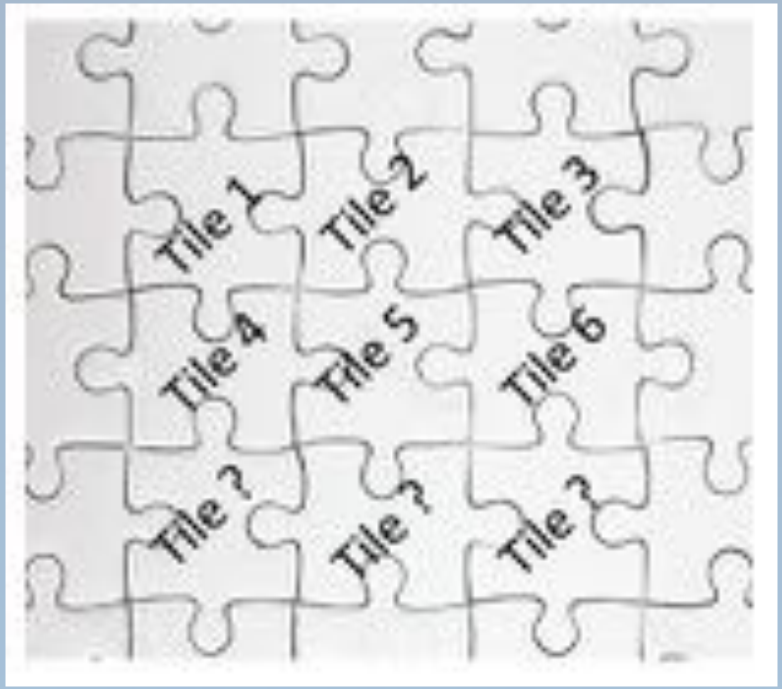
Radiation

Chem of atm [ground]

Chem of atm [sat]

Chem/Phys Modelling

Rad modelling



1. Sources of wildfires have been investigated through air sampling and model back-trajectories
2. Radiative modelling of the atmosphere and of the event of August 2017 at Thule High Arctic Atmospheric Observatory has been performed and compared to previous findings in literature
3. Spatial extrapolation has been applied to assess the radiative effect over a wider area

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Megafires such as this one in Canada's Northwest Territories last year are transforming the boreal forest. PHOTO: KYLE THOMAS