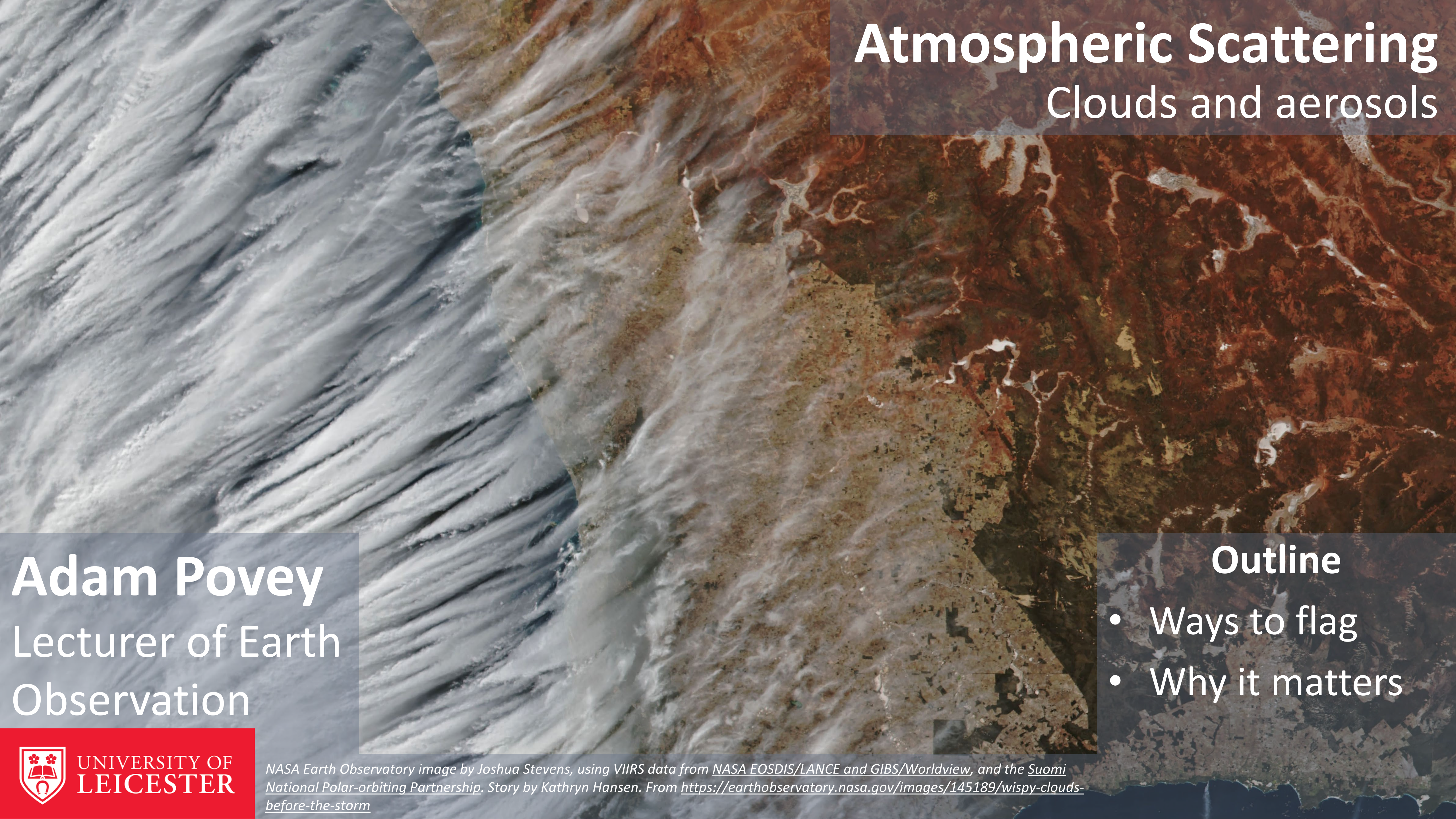


Atmospheric Scattering

Clouds and aerosols

Adam Povey

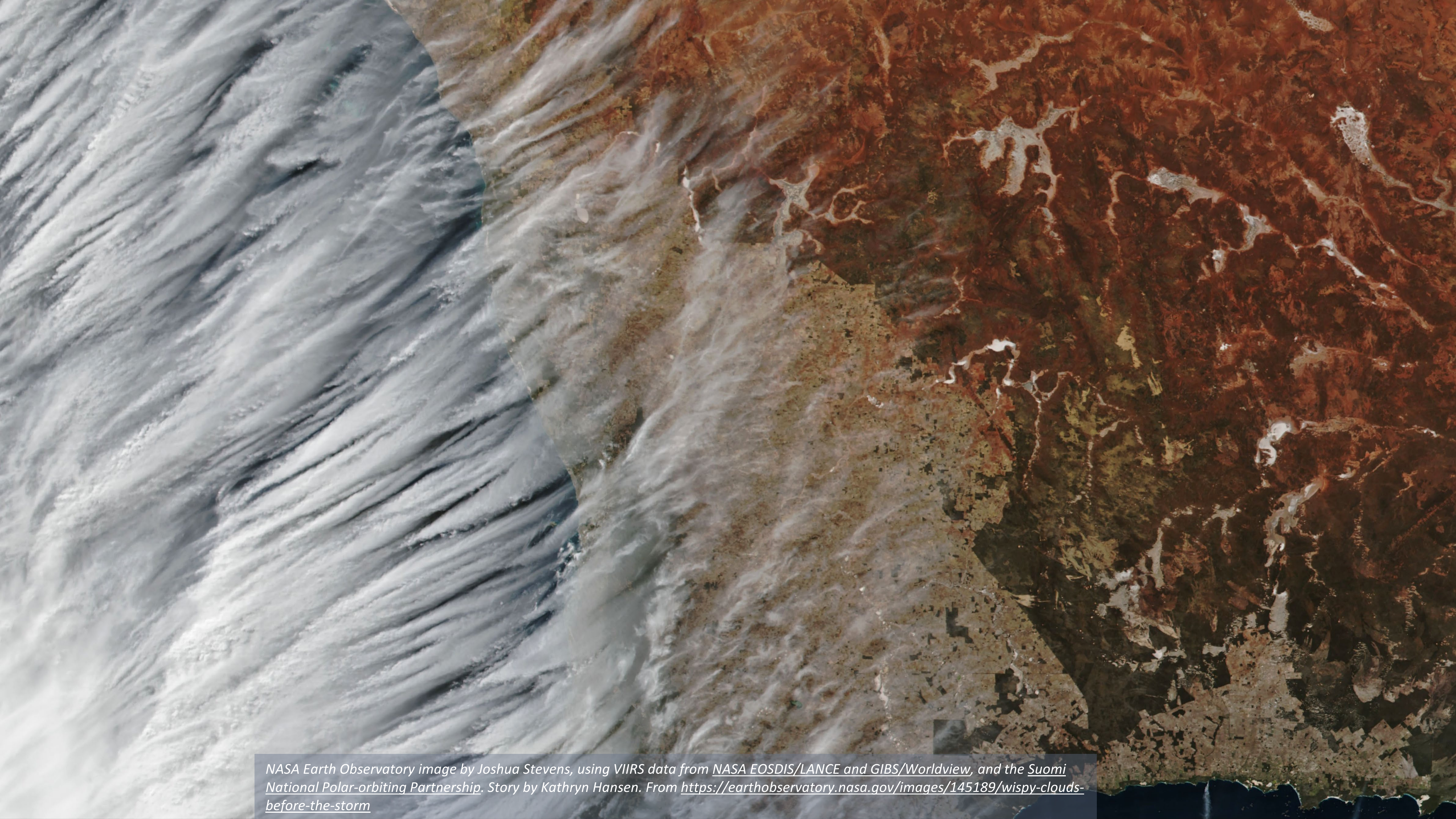
Lecturer of Earth Observation

UNIVERSITY OF LEICESTER

Outline

- Ways to flag
- Why it matters

NASA Earth Observatory image by Joshua Stevens, using VIIRS data from NASA EOSDIS/LANCE and GIBS/Worldview, and the Suomi National Polar-orbiting Partnership. Story by Kathryn Hansen. From https://earthobservatory.nasa.gov/images/145189/wispy-clouds-before-the-storm



NASA Earth Observatory image by Joshua Stevens, using VIIRS data from NASA EOSDIS/LANCE and GIBS/Worldview, and the Suomi National Polar-orbiting Partnership. Story by Kathryn Hansen. From https://earthobservatory.nasa.gov/images/145189/wispy-clouds-before-the-storm

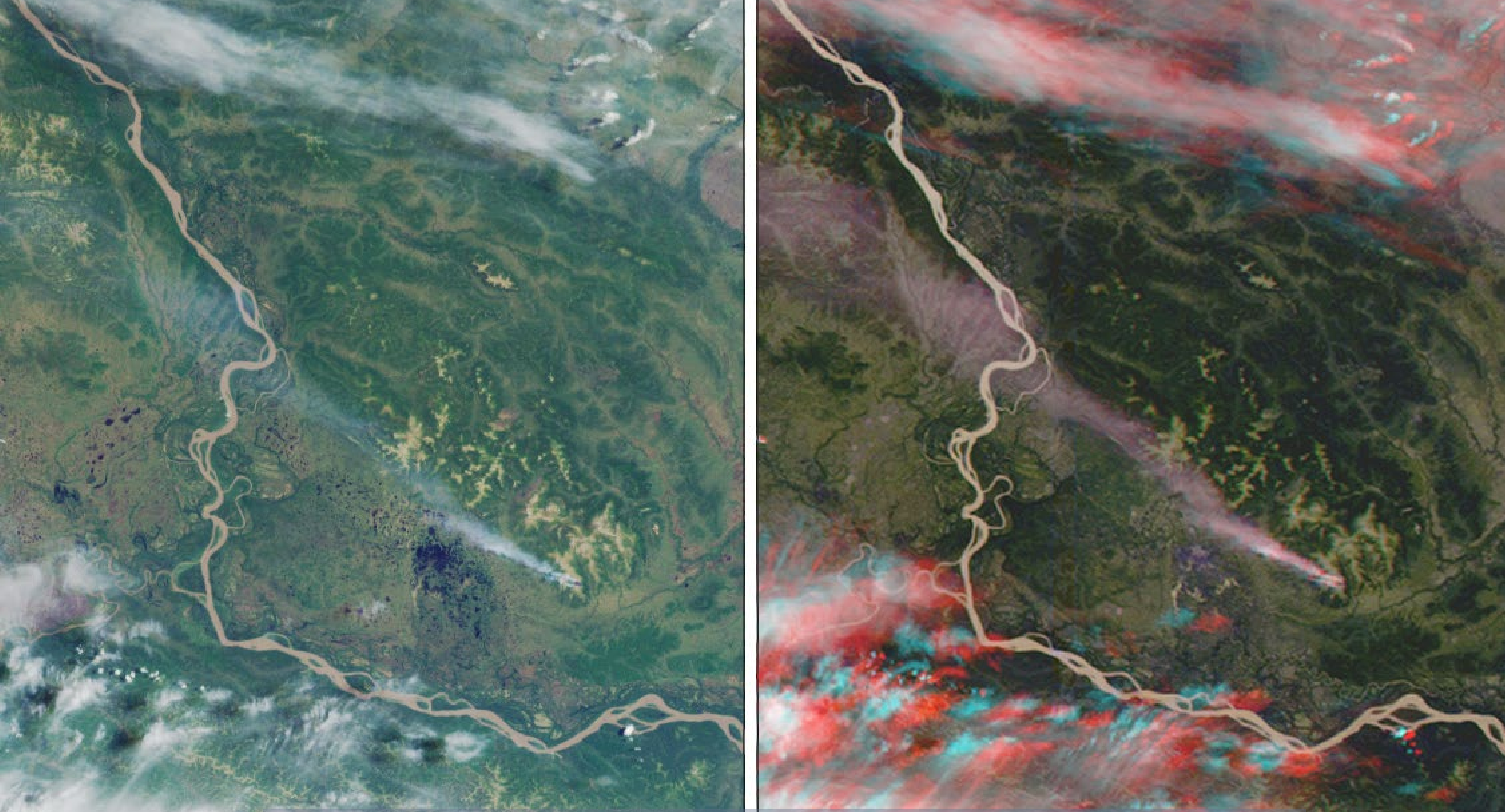


Image Credit: NASA/GSFC/JPL, MISR Science Team. https://earthobservatory.nasa.gov/images/849/misr-stereo-imaging-distinguishes-smoke-from-cloud

Can detect cloud from its parallax in imagery

- When observed at an angle, high objects will appear to move relative to nadir imagery.
- This scene shows smoke and cloud over western Alaska.
  - MISR takes images of each scene at 9 different angles and 4 wavelengths.
  - Left is the nadir visible image.
  - Right is a stereo anaglyph, combining the 45 and 60⁰ cameras for viewing with red/blue lenses.
- Note lack of parallax for the low smoke plume compared to high cloud.

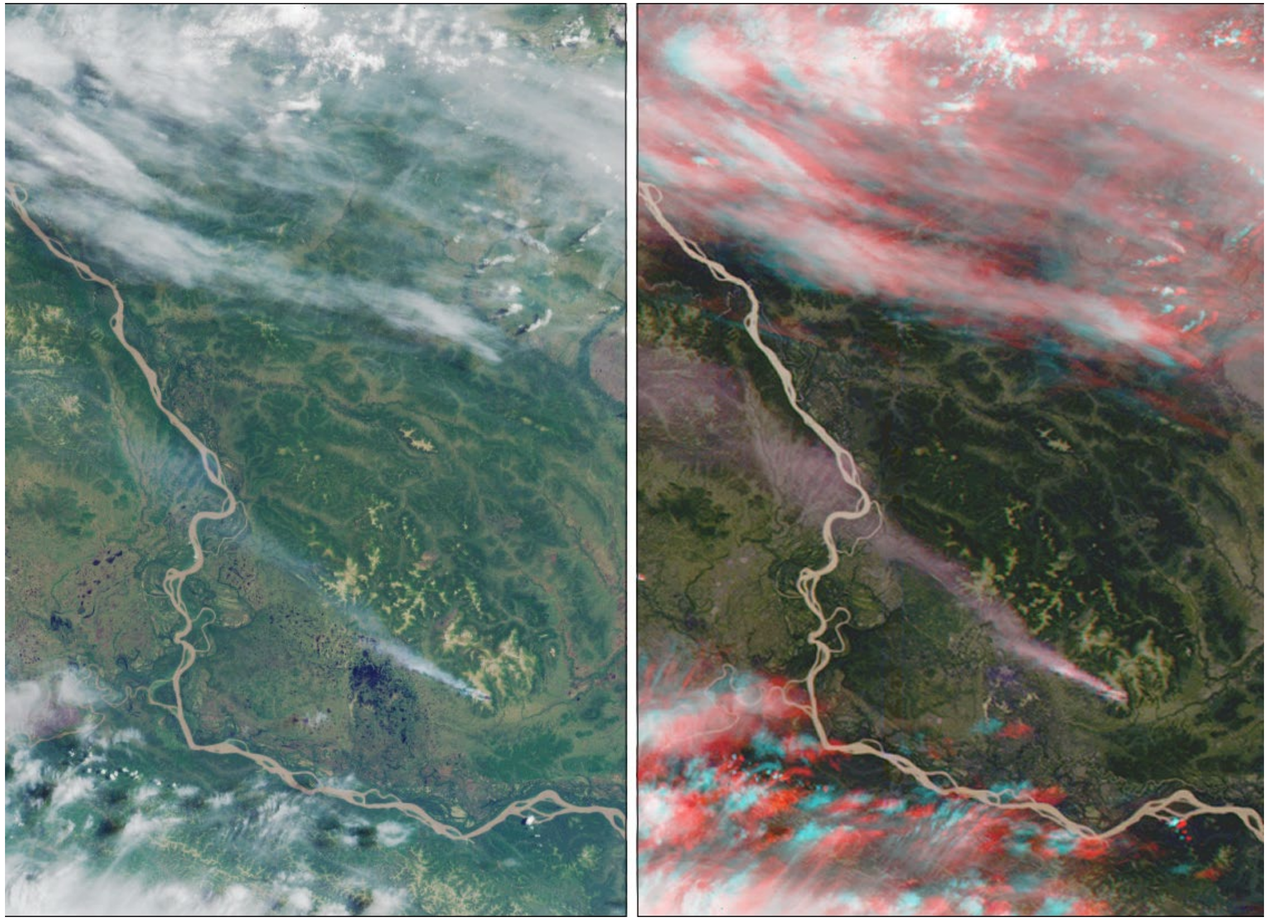
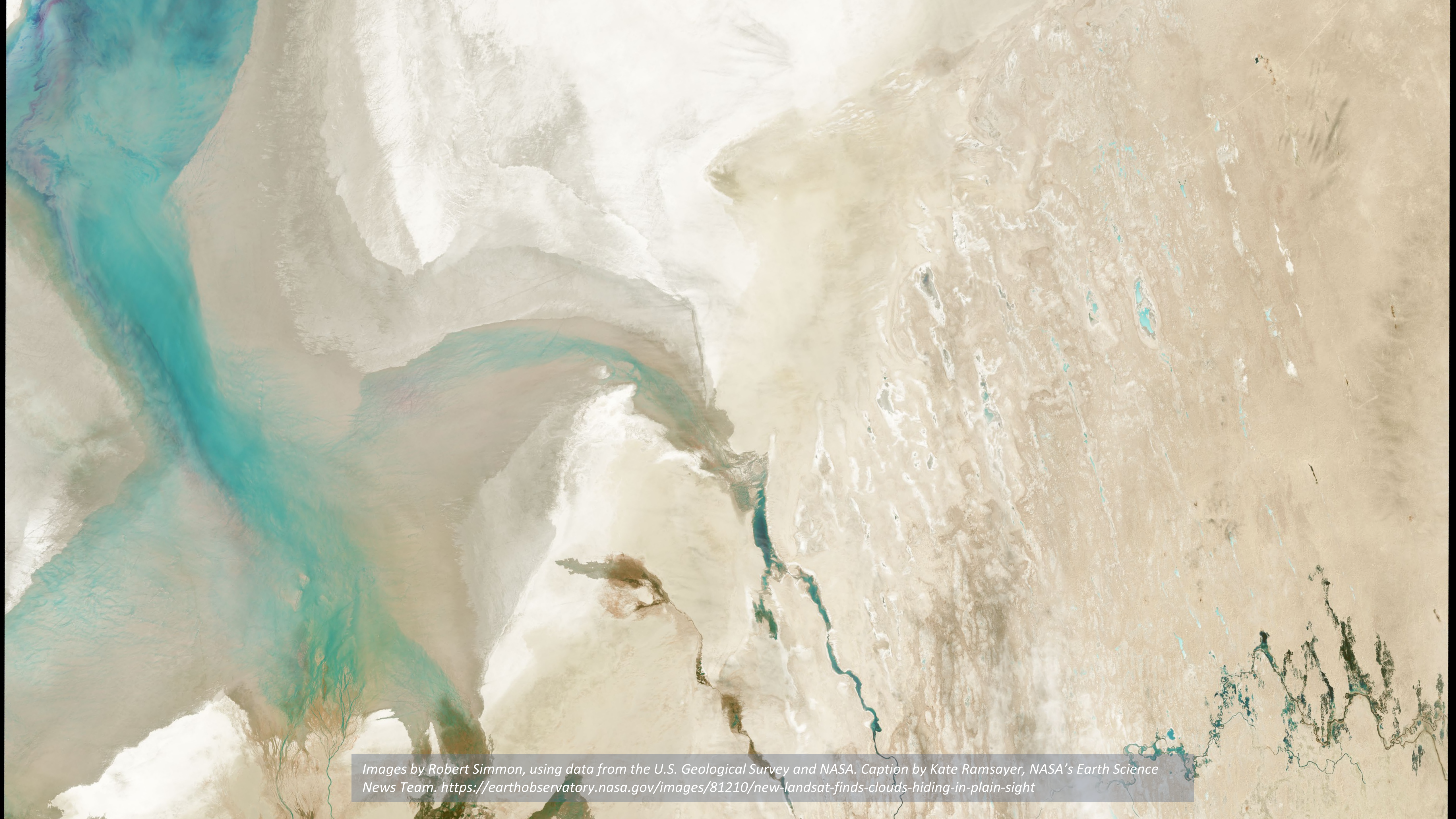
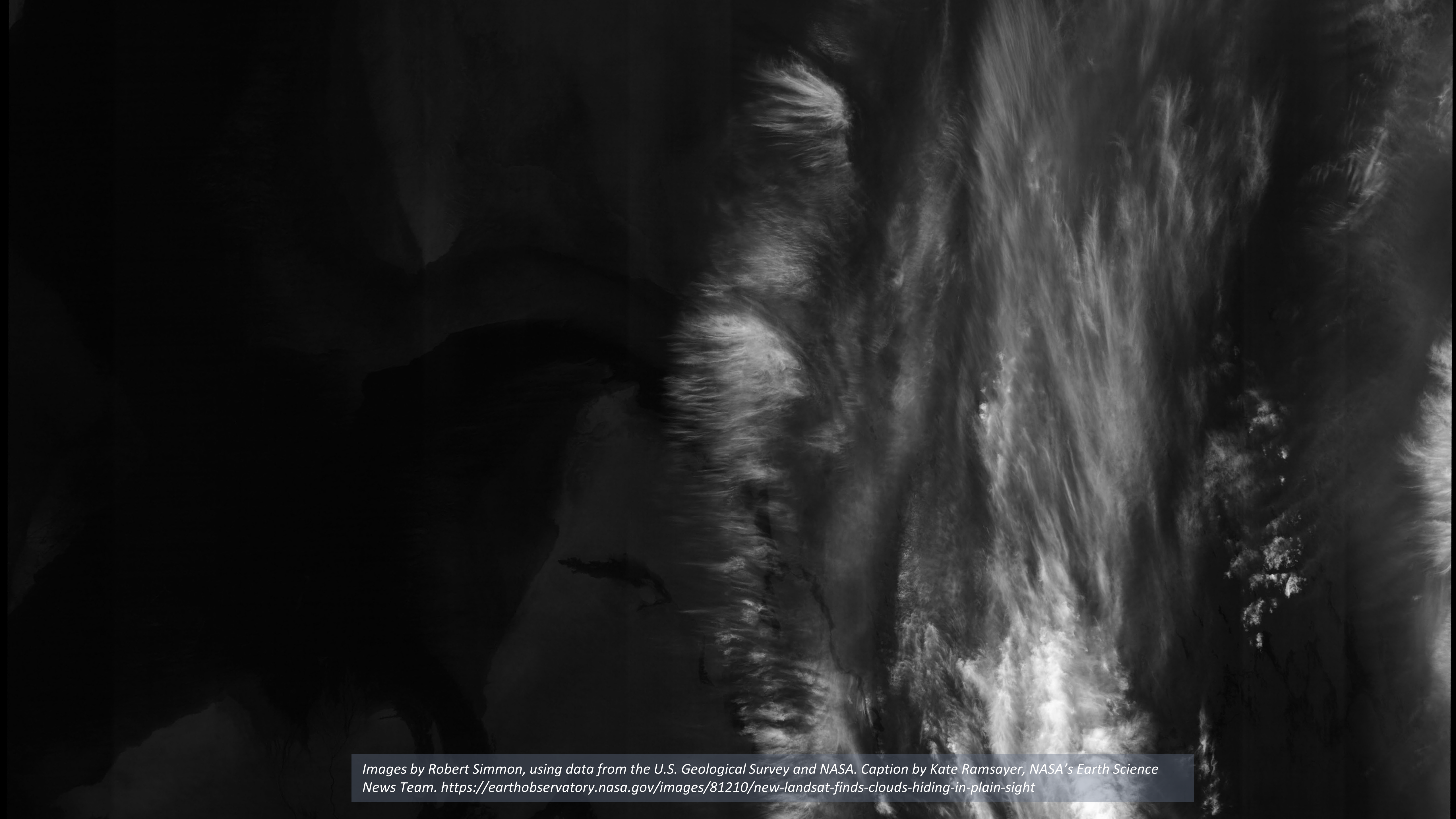


Image Credit: NASA/GSFC/JPL, MISR Science Team.
https://earthobservatory.nasa.gov/images/849/misr-stereo-imaging-distinguishes-smoke-from-cloud

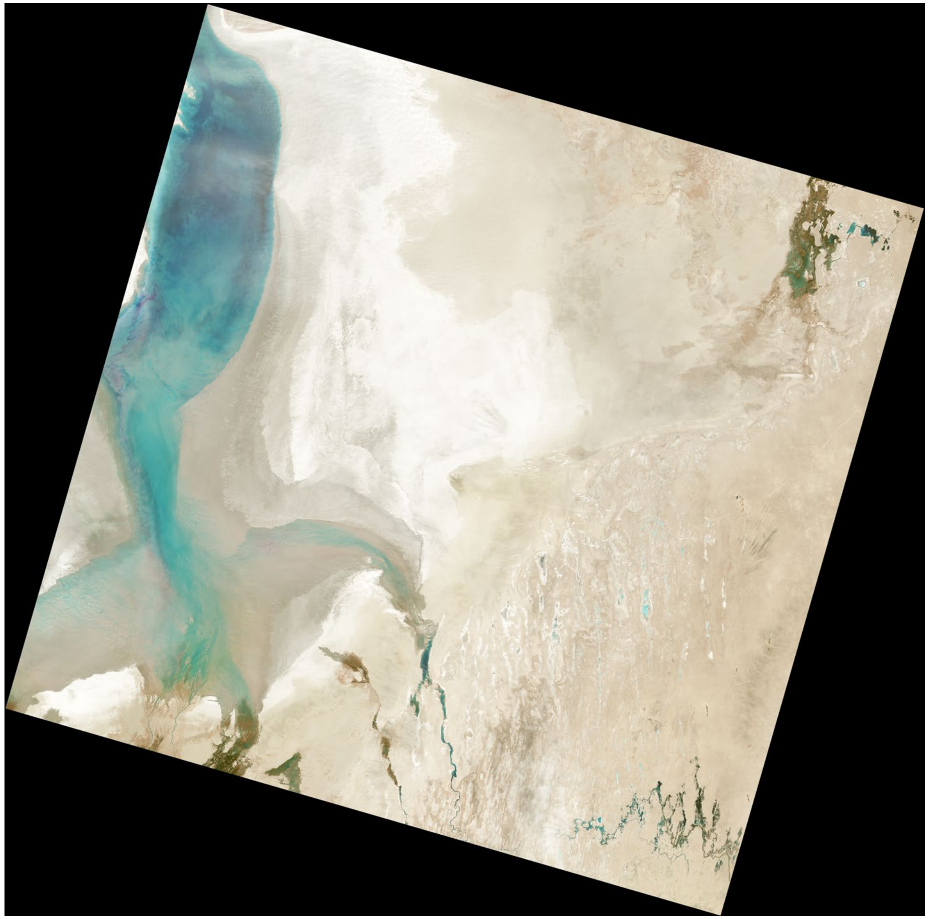


Images by Robert Simmon, using data from the U.S. Geological Survey and NASA. Caption by Kate Ramsayer, NASA's Earth Science News Team. https://earthobservatory.nasa.gov/images/81210/new-landsat-finds-clouds-hiding-in-plain-sight



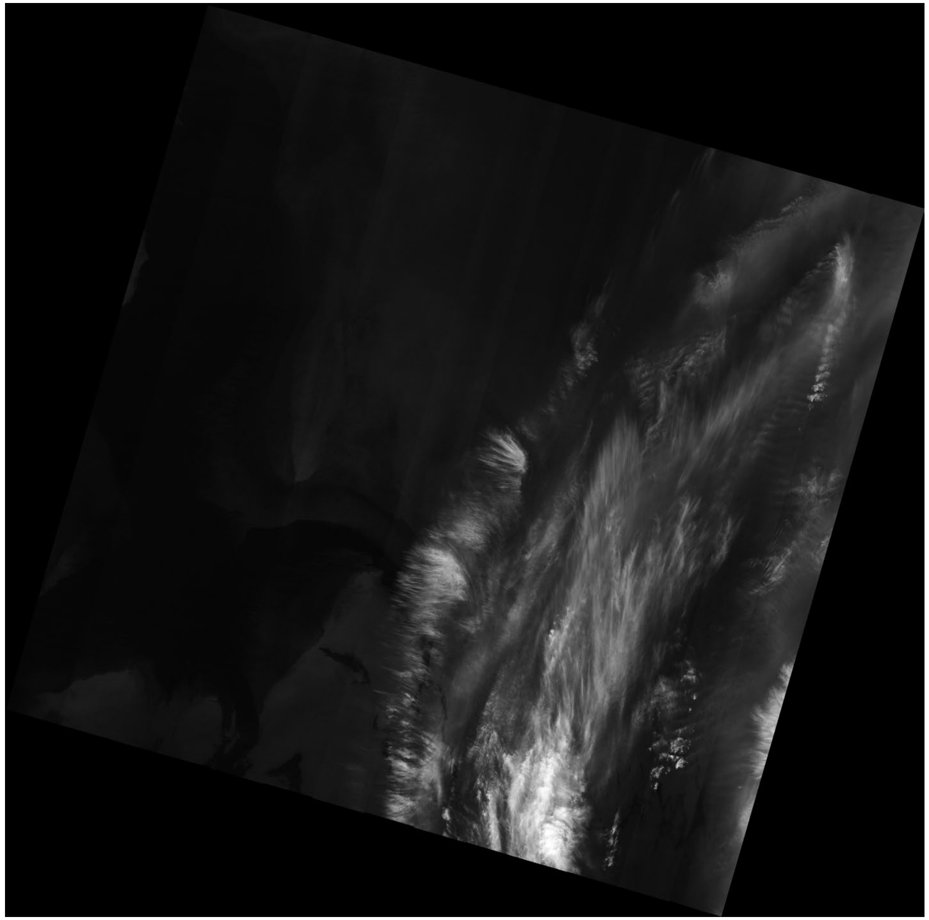
Images by Robert Simmon, using data from the U.S. Geological Survey and NASA. Caption by Kate Ramsayer, NASA's Earth Science News Team. https://earthobservatory.nasa.gov/images/81210/new-landsat-finds-clouds-hiding-in-plain-sight

Can detect cloud through channel selection



Left: True-colour image of the Aral Sea in 2013 from LCDM. **Right**: 1.38µm reflectance from the same scene, highlighting cirrus clouds as there is strong water absorption in this band. This channel has only available since Landsat 8.

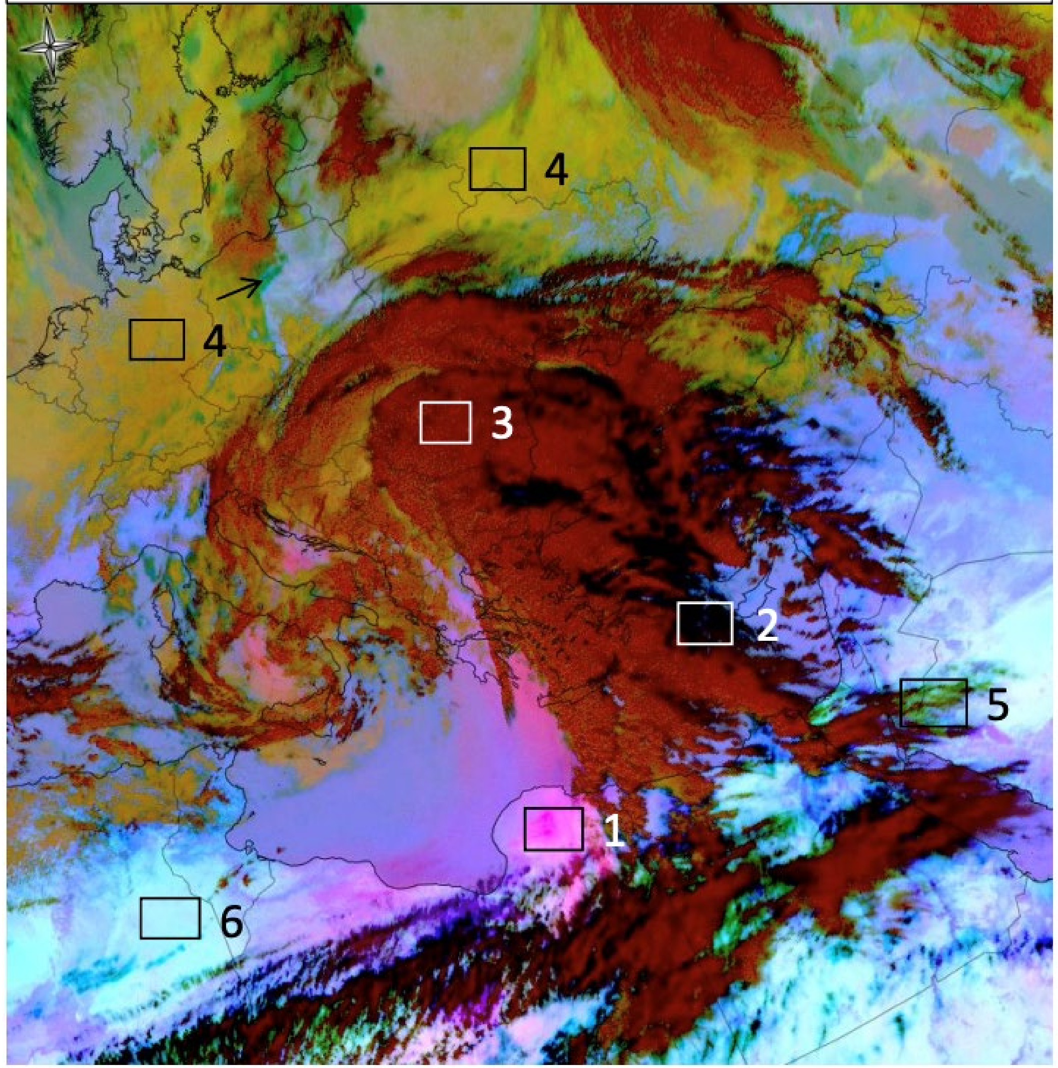
Cirrus contamination is a major source of systematic error for virtually all Earth observation data.



Images by Robert Simmon, using data from the U.S. Geological Survey and NASA. Caption by Kate Ramsayer, NASA's Earth Science News Team. https://earthobservatory.nasa.gov/images/81210/new-landsat-finds-clouds-hiding-in-plain-sight

Manual classification uses various combinations of radiances, brightness temperatures and their differences

SEVIRI Dust RGB, 23 March 2016, 12:00 UTC



Colour	Channel [µm]	Physically relates to	Smaller contribution to the signal of	Larger contribution to the signal of
Red	IR12.0–IR10.8	Cloud optical thickness Thin dust	Thin ice clouds	Dust
Green	IR10.8–IR8.7	Cloud phase	Thin ice clouds Dust	Water clouds Deserts
Blue	IR10.8	Temperature	Cold clouds	Warm surface Warm clouds

Colour Interpretation

1	Dust or ash clouds. The colour of dust clouds varies from pink to violet, ash clouds are more reddish.
2	Cirrus clouds with no clouds below are black or dark blue.
3	Thick, high and cold ice clouds.
4	Thick mid-level clouds. Thin mid-level clouds appear green (black arrow).
5	Thin cirrus clouds over deserts appear green.
6	Hot sandy deserts, dry air mass.*
7	Humid air in lower levels.* (~ 700 hPa)
8	Dry air in lower levels.*

** Colours can vary considerably depending on surface temperature.*

Images from Eumetsat; see https://eumetview.eumetsat.int/static-images/MSG/RGB/ for more examples

Operational products tend to mimic those choices

<u>SEVIRI Operational Cloud Mask</u>

https://navigator.eumetsat.int/product/EO:EUM:DAT:MSG:CLM

15th June 2020   07:12 UTC

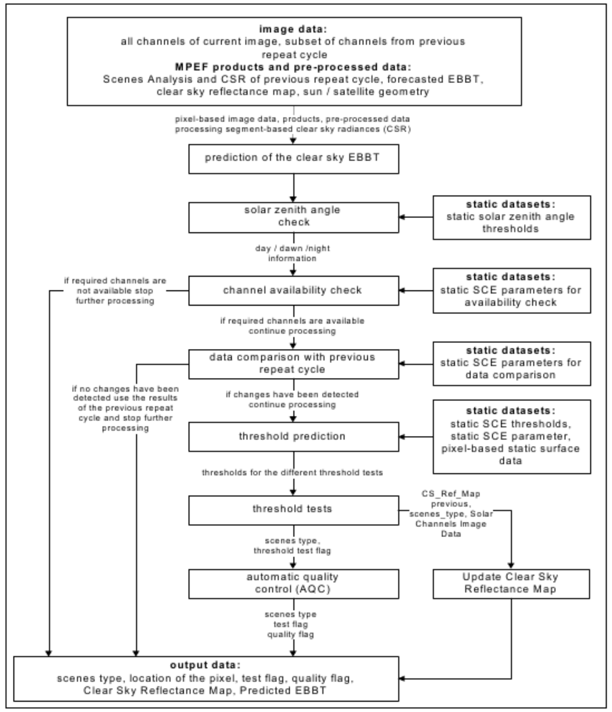
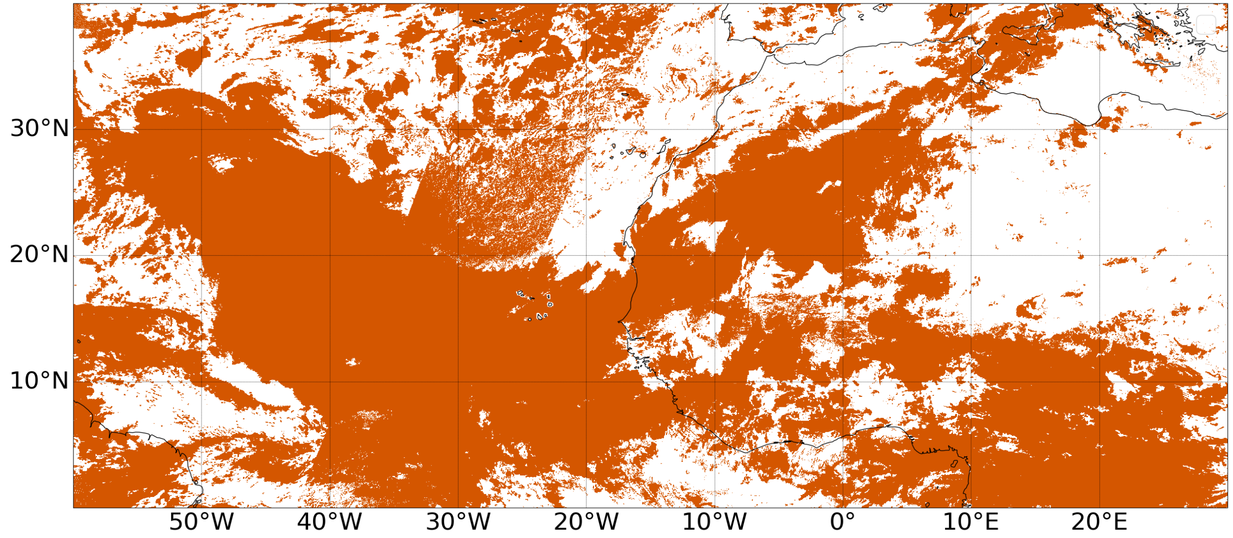
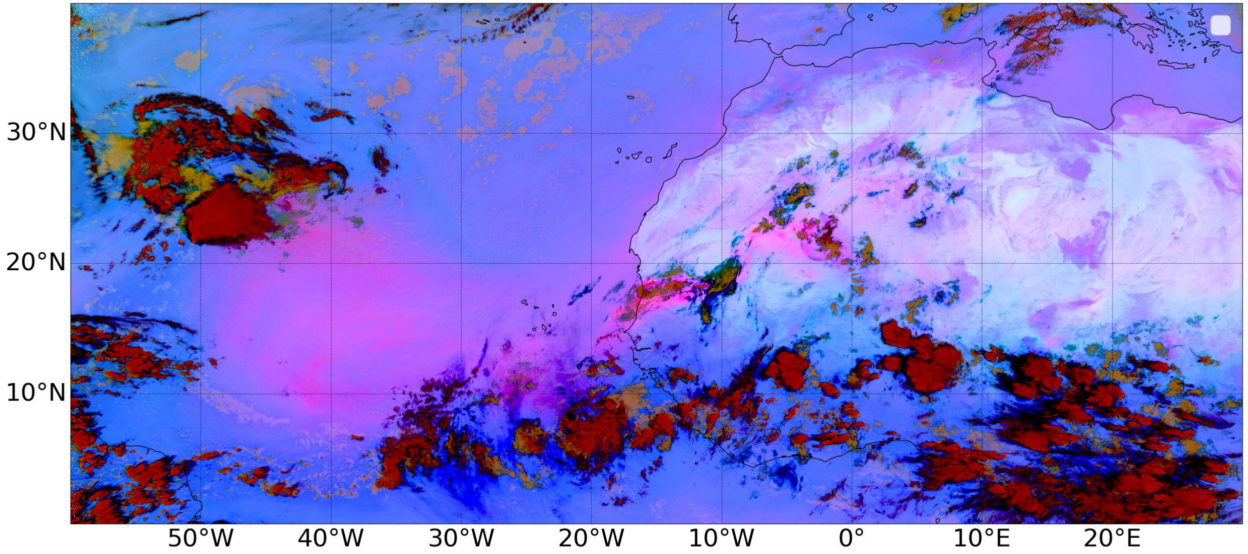


Figure 4: Scenes Analysis SCE Processing

https://www.eumetsat.int/media/38993



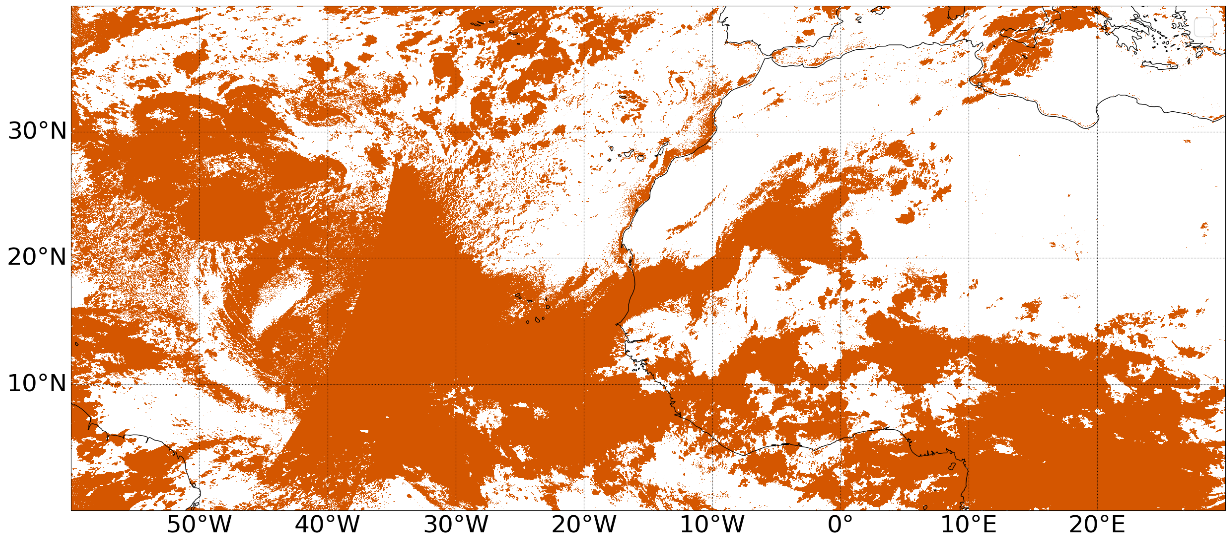


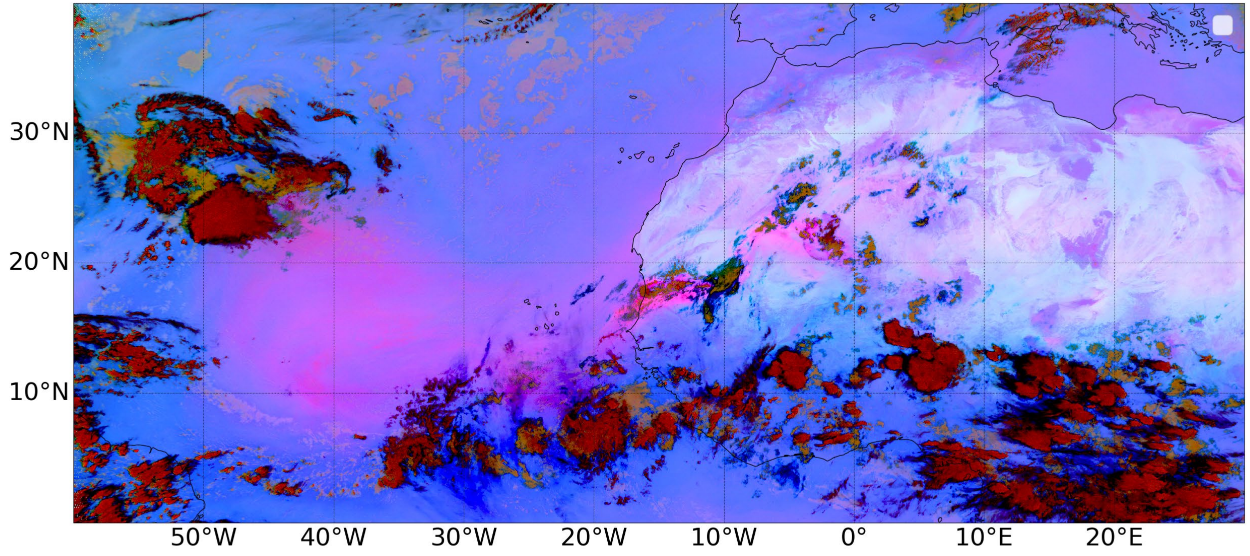
Images generated by Rui Song; see doi:10.5194/amt-17-2521-2024

Operational products increasingly automate decisions

<u>SEVIRI Machine Learning Cloud Mask</u>
https://navigator.eumetsat.int/product/EO:EUM:CM:MSG:CMA_SEVIRI_V001

15th June 2020   07:12 UTC





Images generated by Rui Song; see doi:10.5194/amt-17-2521-2024

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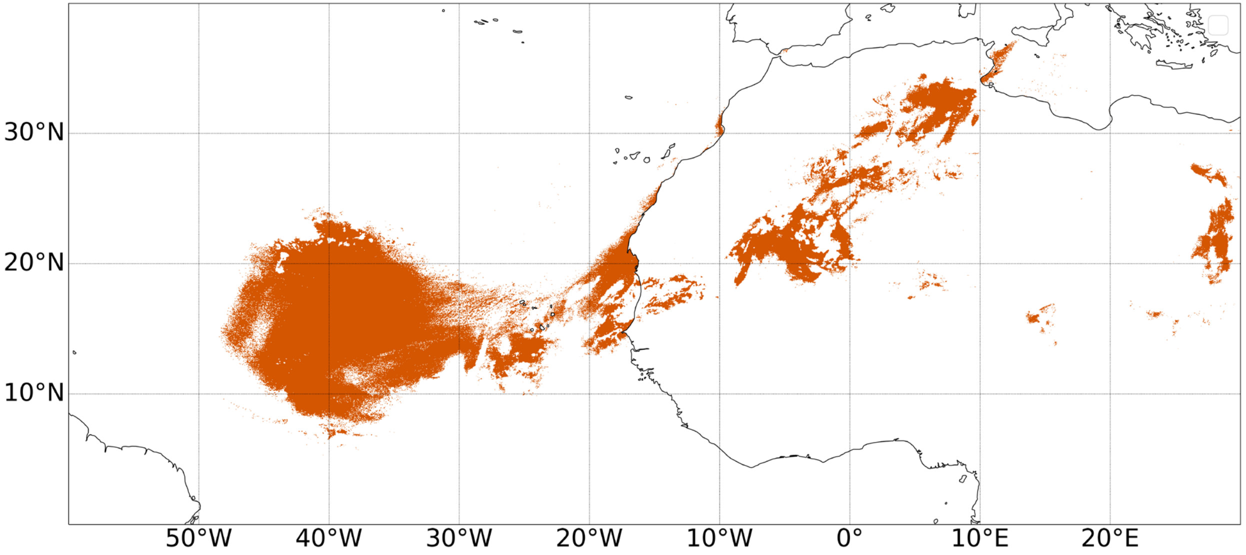
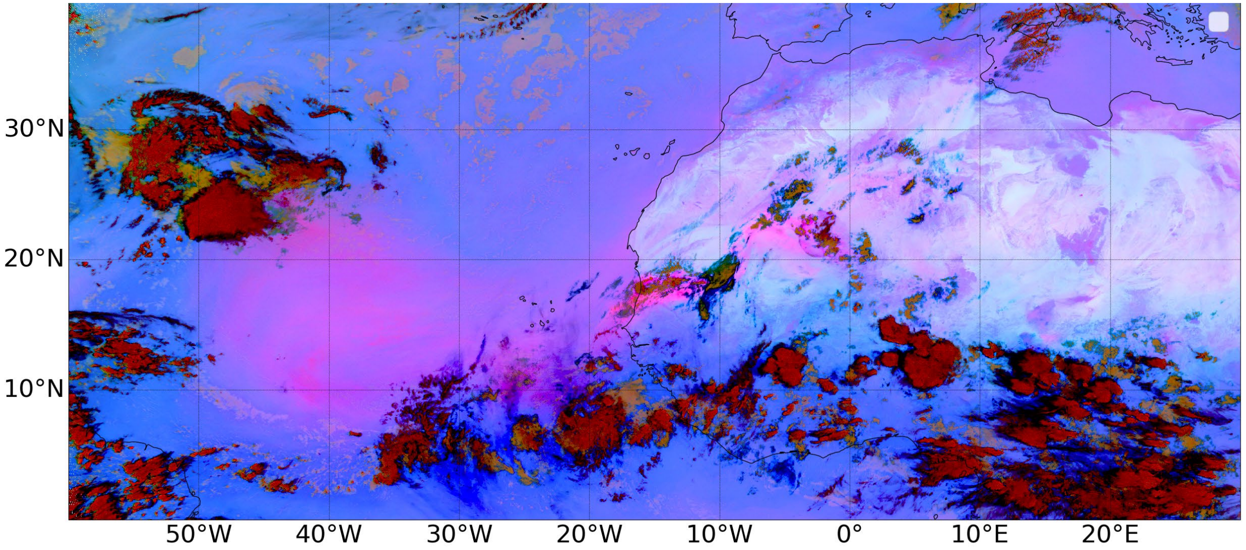
Research products have a long heritage of decision trees

<u>SEVIRI Dust Flag</u>
Ashpole, I., and Washington, R. (2012), J. Geophys. Res., 117, D08202, doi:10.1029/2011JD016845.

19th June 2020   19:42 UTC

$$T_{108} \geq 285$$
$$T_{120} - T_{108} \geq 0$$
$$T_{108} - T_{087} < 10$$
$$T_{108} - T_{087} - \langle T_{108} - T_{087} \rangle < -2$$





Images generated by Rui Song; see doi:10.5194/amt-17-2521-2024

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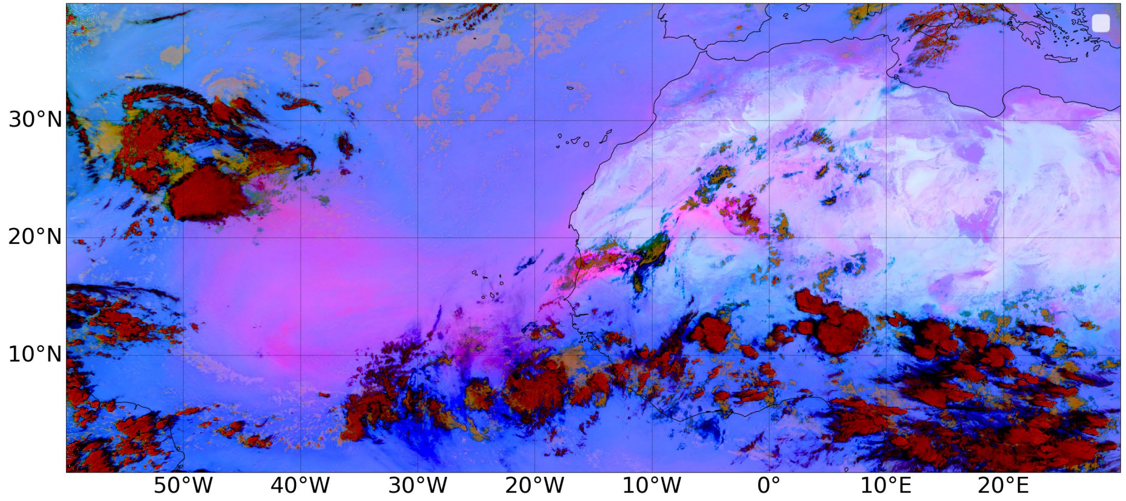
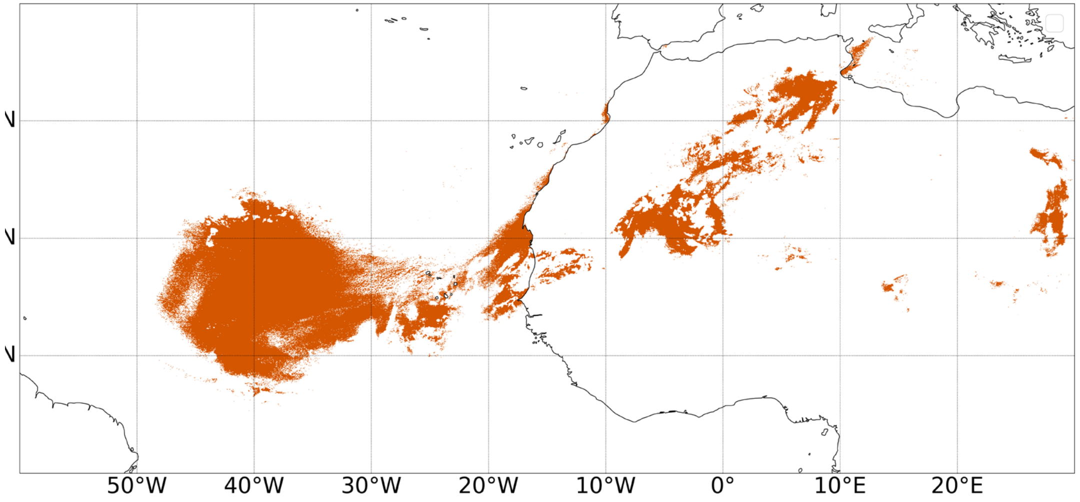
19th June 2020   19:42 UTC

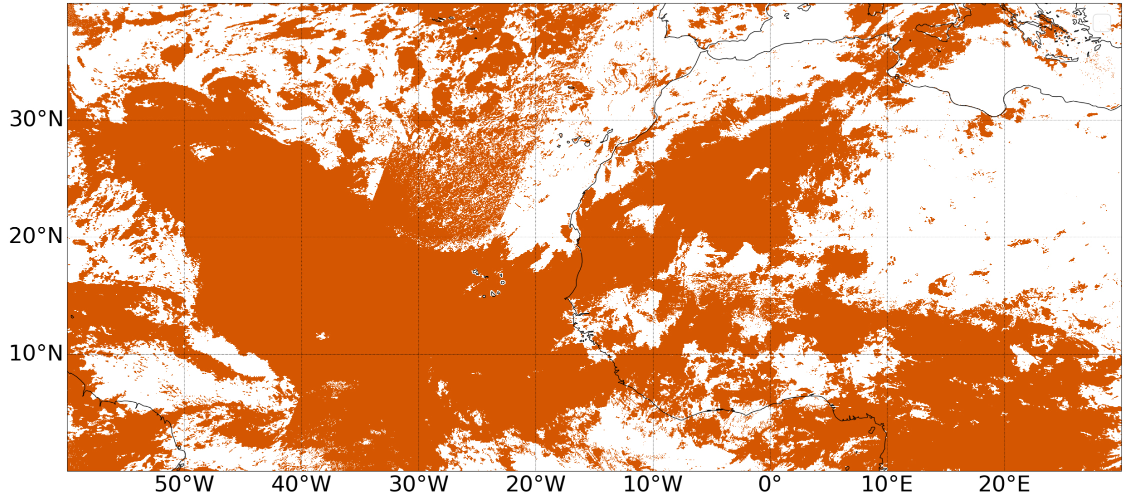
SEVIRI Dust RGB



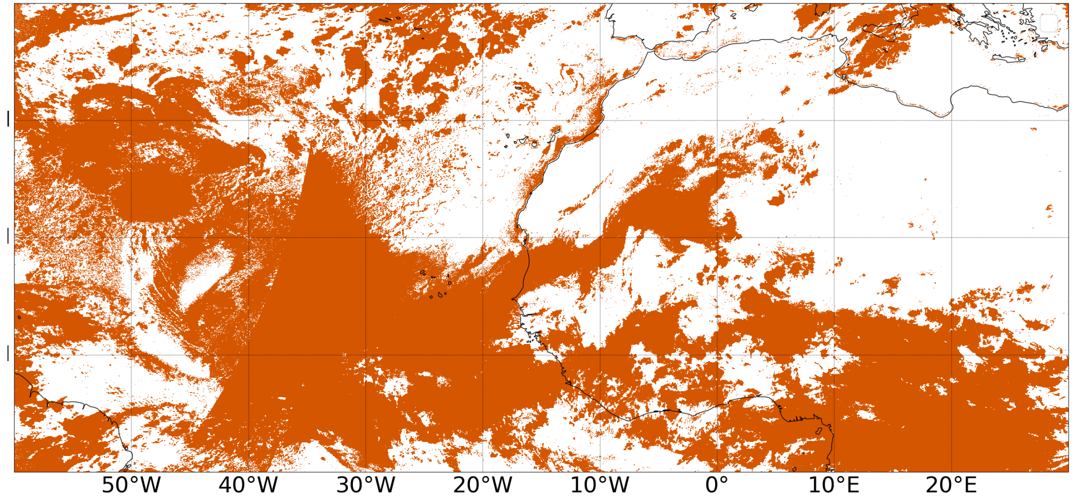
SEVIRI Dust Mask



SEVIRI Cloud Mask



SEVIRI Cloud Mask (machine learning)



Images generated by Rui Song; see doi:10.5194/amt-17-2521-2024

Neural networks can be quantitative rather than classification based, applying a threshold to convert to a flag

- Region on the SE coast of Australia from a Himawari scene for 1 January 2020 at 03:30 UTC.
  - *Top*) False-colour composites of the scene are presented in the left-hand column, showing (a) true-colour, (c) natural-colour and (e) dust RGBs.
  - *Bottom*) Neural network classifications (b) the NN continuous cloud mask, (d) NN binary cloud mask and (f) a comparison of the three binary masks for the scene.

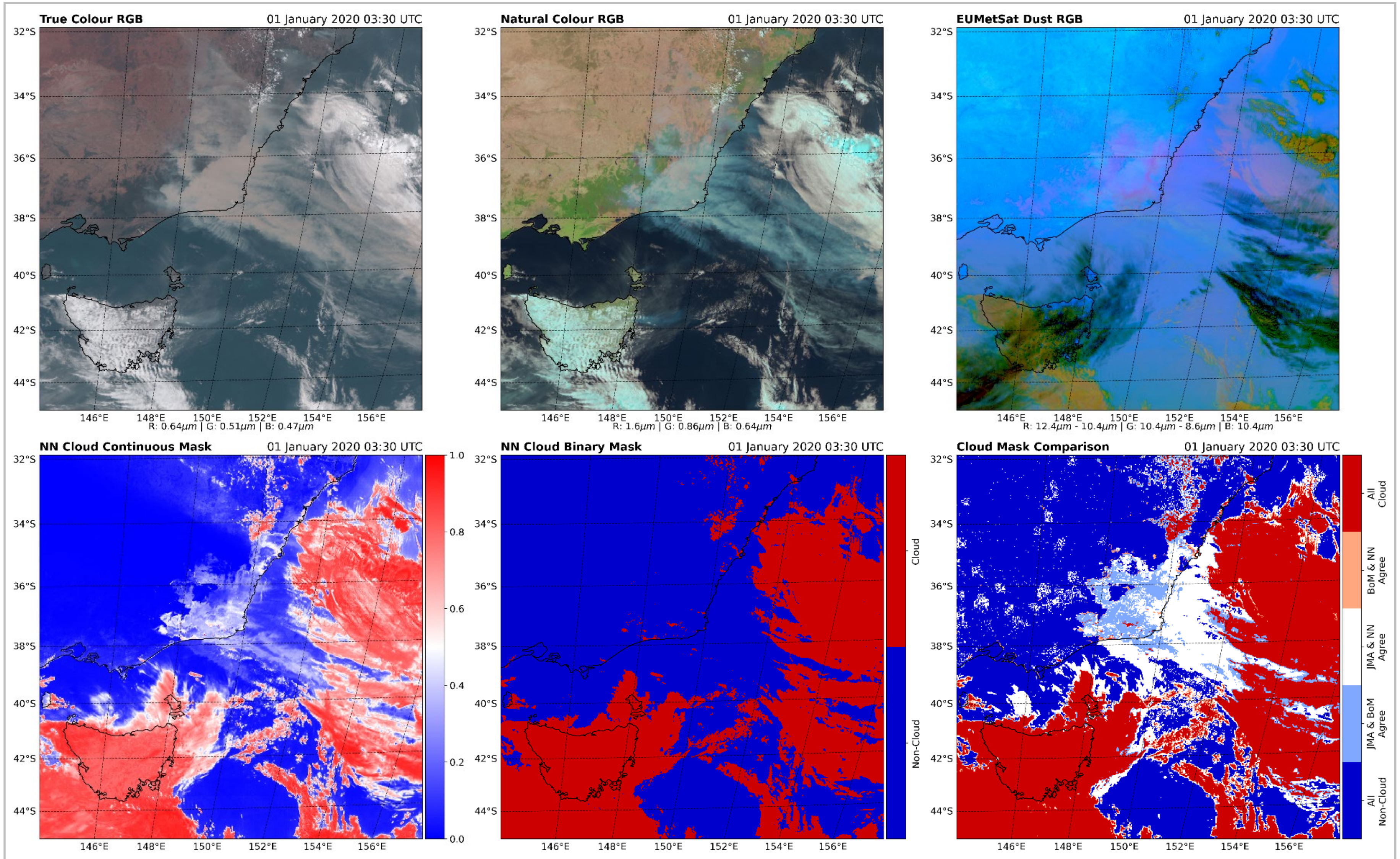
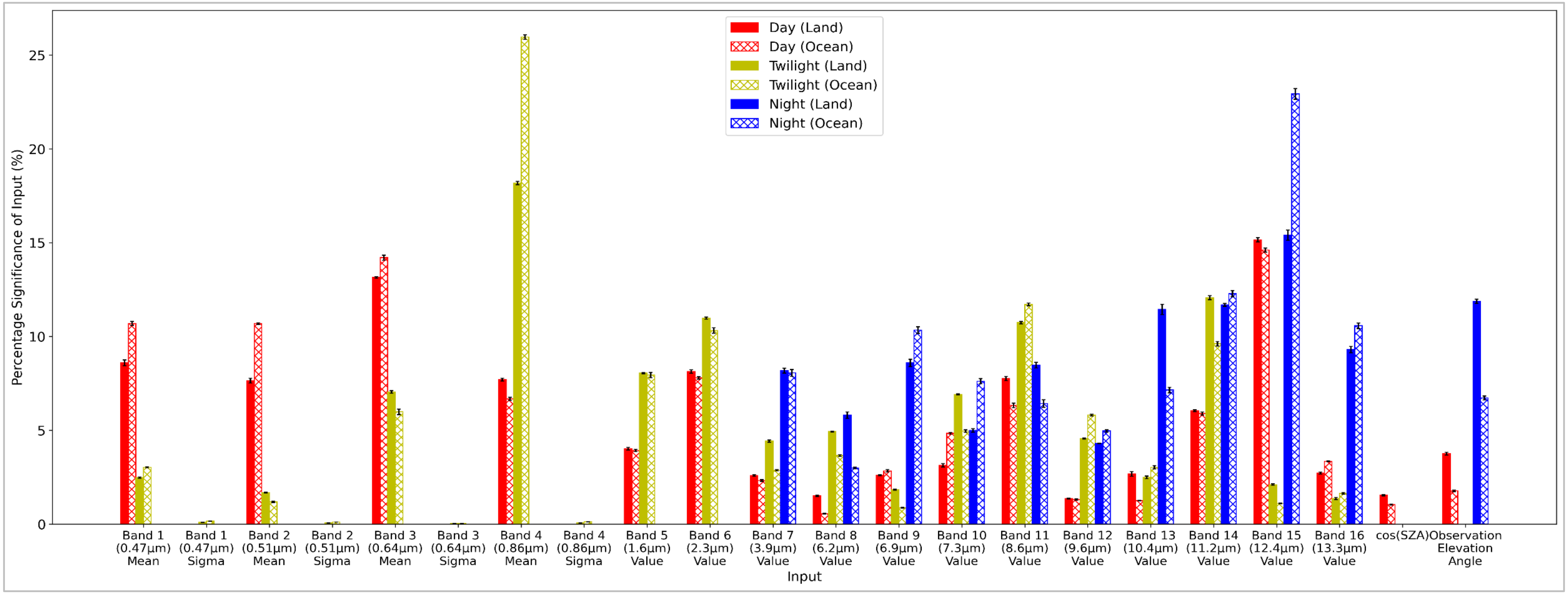


Fig. 10 of Robbins et al. 2023 doi:10.5194/amt-15-3031-2022

MONASH University

Neural networks are basically doing a decision tree



SHAP analysis of network sensitivity. Fig. 6 of Robbins et al. 2023 doi:10.5194/amt-15-3031-2022

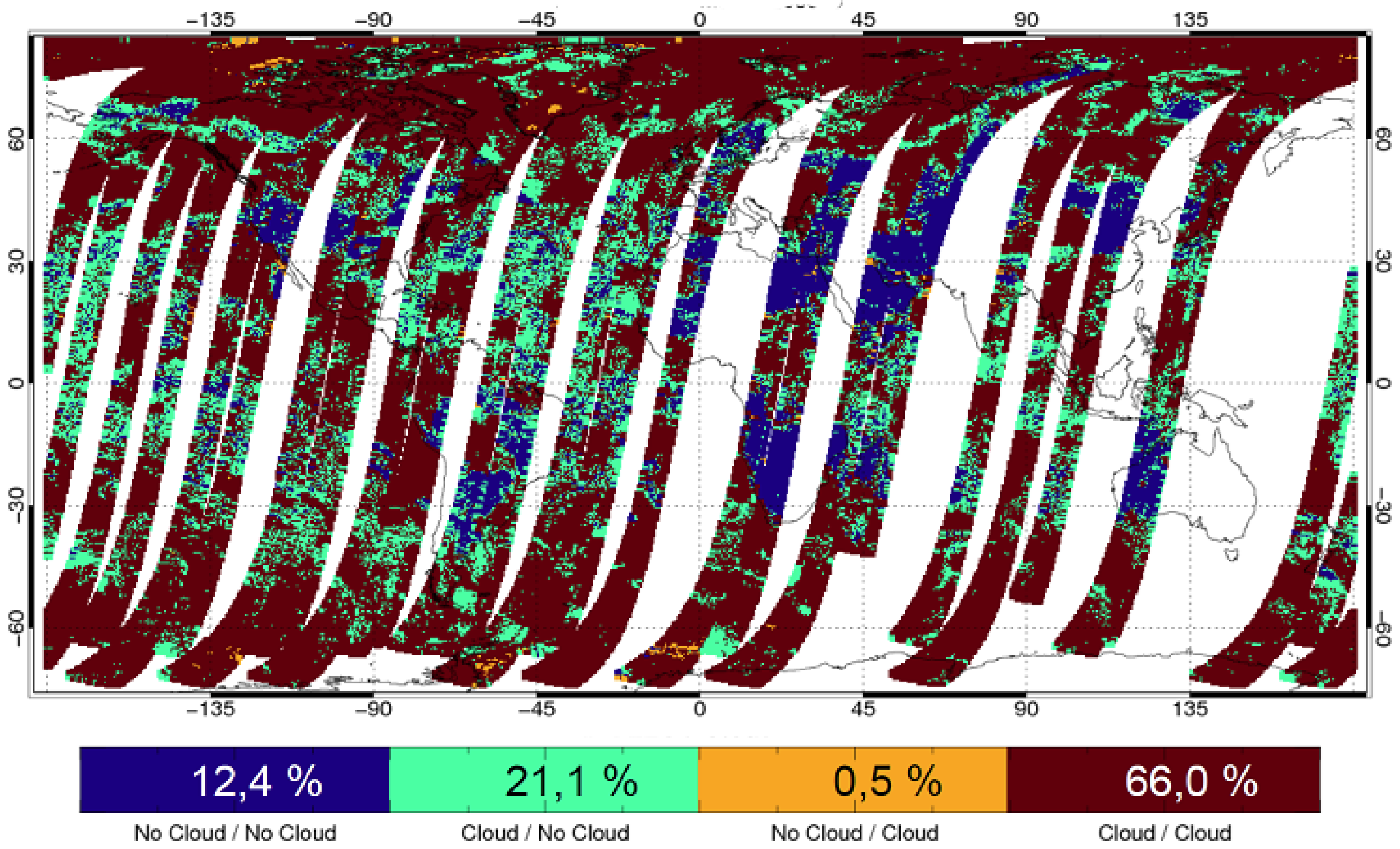
The difference between "is cloud" and "is not aerosol" **excludes up to 20% of observations** from datasets

Coverage from one day of AATSR observations combining classifications from Cloud and Aerosol CCI

Blue/**Red** are where the masks agree

Green/**Orange** are where they disagree

Image produced by Thomas Popp and researchers in Aerosol CCI



Aerosol CCI Cloud Flag/Cloud CCI Cloud Flag

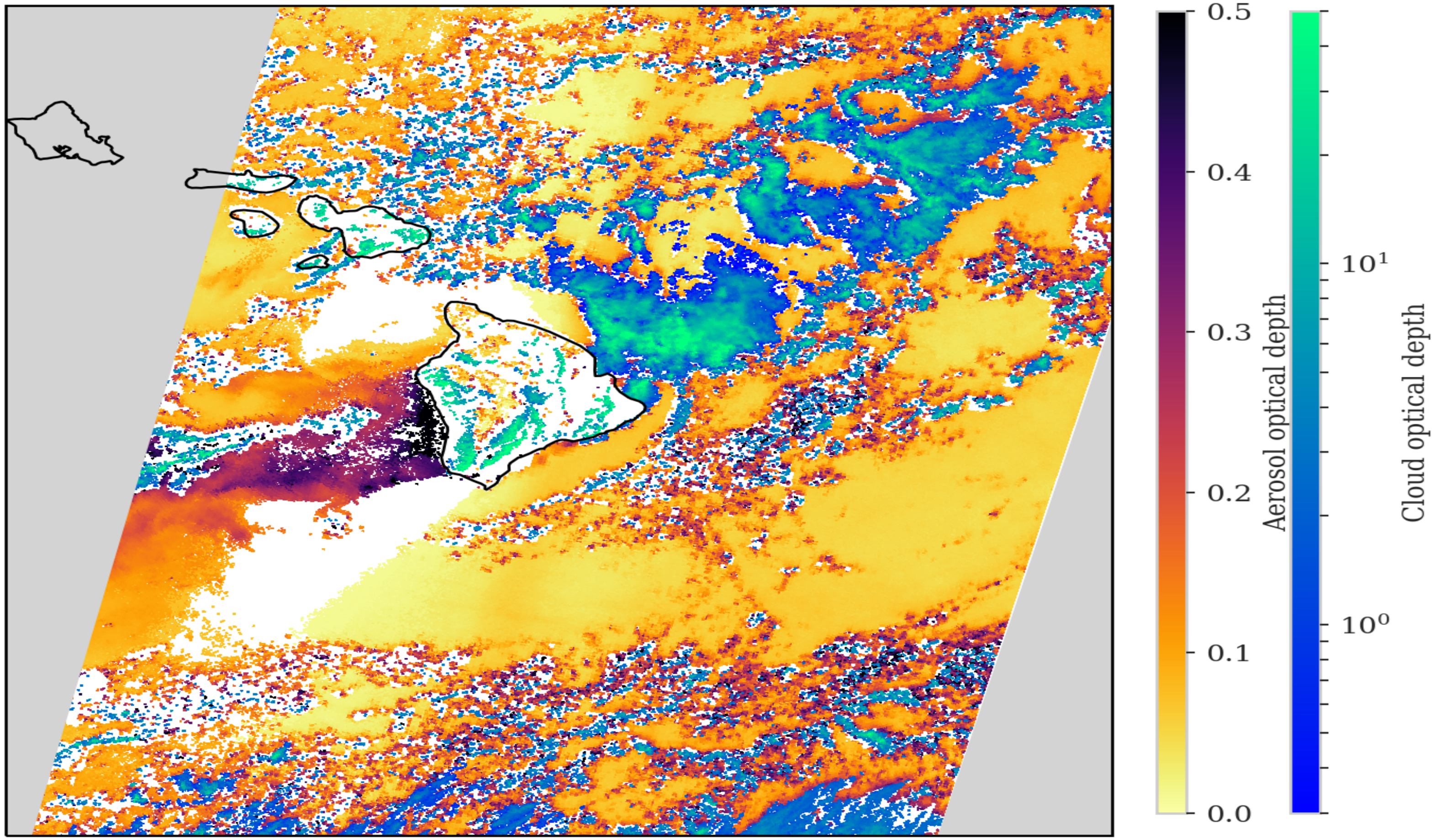
Nearby clouds can contaminate observations even when not included within the observation

 16

Retrievals of aerosol (**red-orange**) and cloud (**blue-green**) around Mt. Kilauea on 9 Sep 2008 as seen by AATSR and processed by ORAC.

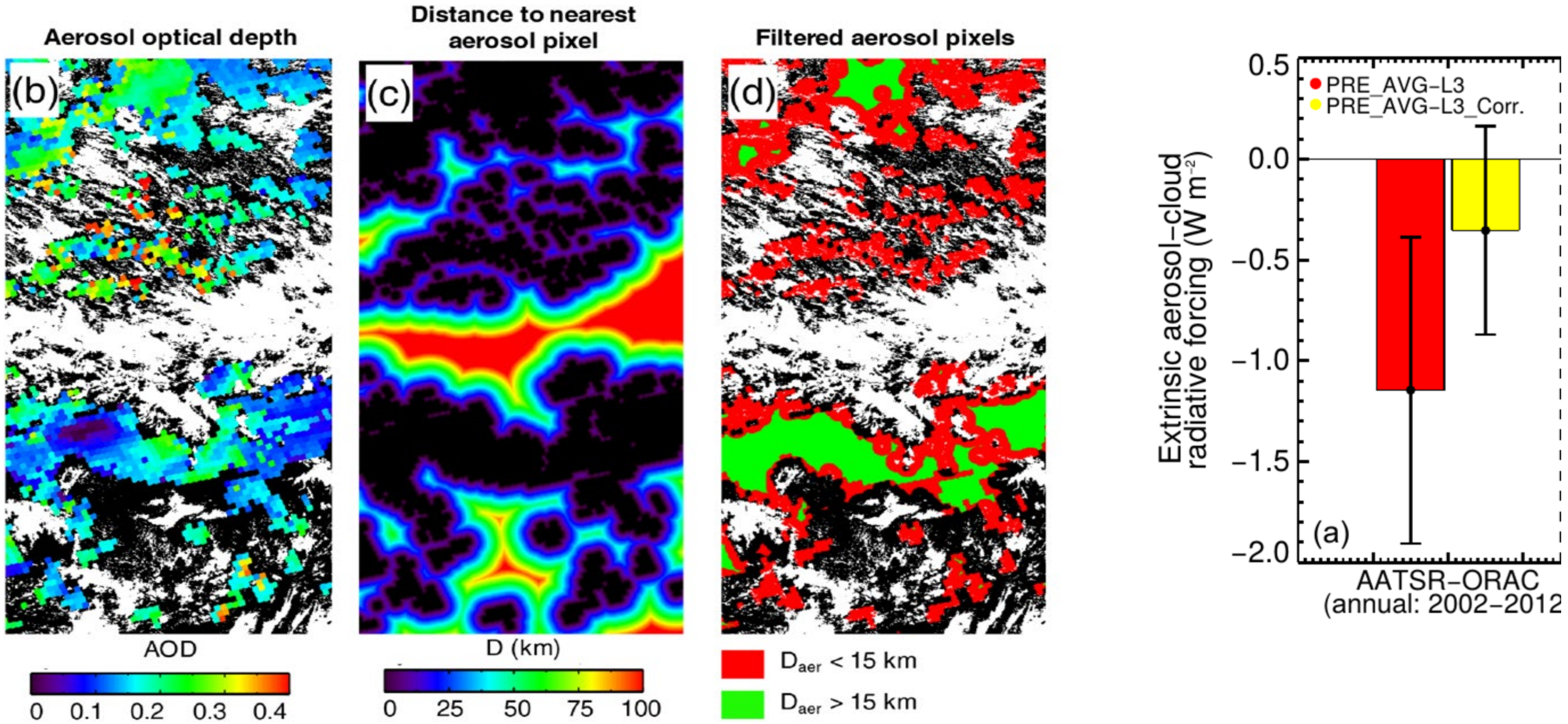
- Note the increase in aerosol optical depth as one approaches a cloud.

- Missing data (white) is common at the interface.



17

Nearby clouds can contaminate observations
and the filtering method affects downstream analyses



Figs. 1 & 9 from Christensen et al. 2017, doi:10.5194/acp-17-13151-2017

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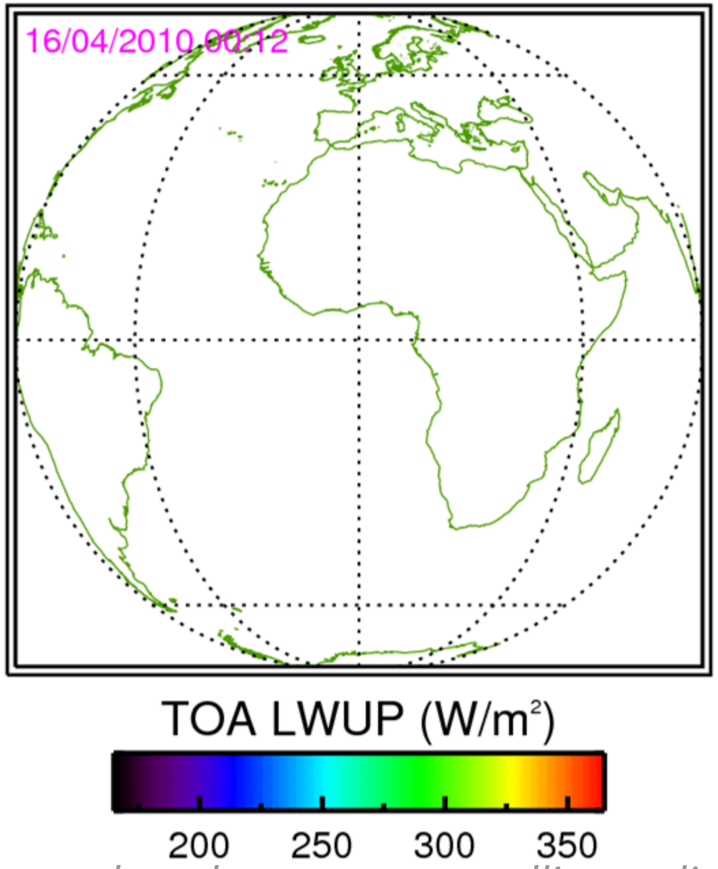
Summary

- Masking clouds or aerosols from an image is a common first-step in quality assurance in Earth observation processing.
- Many cloud masks rely on decision trees comparing various visible and/or infrared wavelengths.
  - Neural networks increasingly automate the process but their performance is limited by the completeness of the training data.
- Clouds can "contaminate" nearby observations even if there isn't strictly cloud present.



Top-of-atmosphere long-wave upwelling radiation from SEVIRI, by Matt Christensen.

General radiative transfer

Wikipedia says the radiative transfer equation is,

Spatial change, often written ∂I/∂τ

Gain due to emission

$$\frac{1}{c}\frac{\partial}{\partial t}I_\nu + \hat{\Omega}\cdot\nabla I_\nu + \left(k_{\nu,s} + k_{\nu,a}\right)\rho I_\nu = j_\nu \rho + \frac{1}{4\pi}k_{\nu,s}\rho\int_\Omega I_n \, \mathrm{d}\Omega$$

Temporal change, usually ignored

Loss due to scattering and absorption

Light coming from the rest of the atmosphere

where I_ν is spectral radiance with the subscript denoting frequency, c is the speed of light, t is time, Ω is solid angle on the unit hemisphere, j is the emission coefficient, k_s is the scattering opacity, k_a is the absorption opacity, ρ is mass density.

Solar and thermal radiative transfer

In practice, for each waveband we tend to consider which processes are significant.

- Shown is a schematic of radiative transfer in the retrieval I work with.

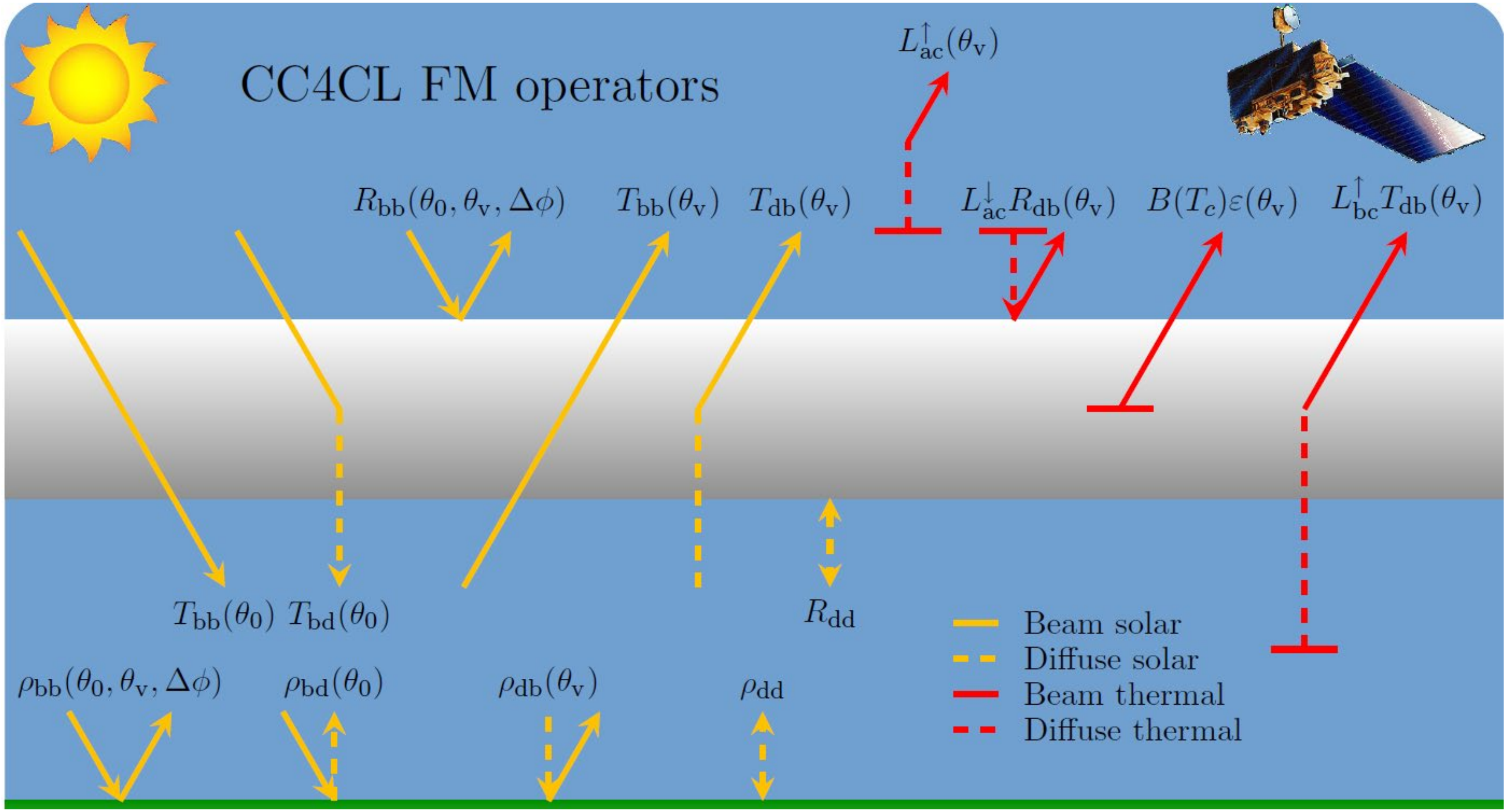


Fig. 1 from doi:10.5194/amt-11-3397-2018