# Cloud Retrieval for Passive Sensors in the UV-VIS-NIR for the Polar Sentinel-5P, Geostationary Sentinel-4 and Deep Space DSCOVR Missions

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ESA ATMOS 2021
Virtual Conference,
22-26 November 2021

# Motivation
-
# trace gas retrievals need cloud information

# Missions

# Sentinel-5 Precursor and Sentinel-4


**Orbit**
sun-synchroneous polar / geostationary

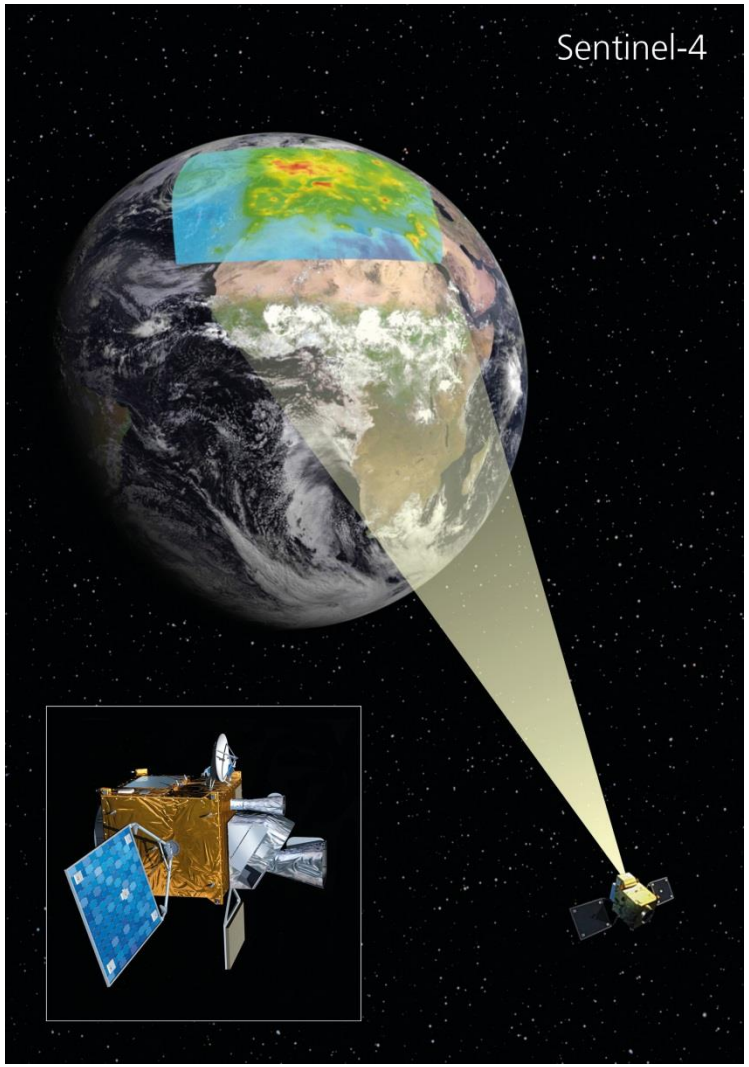
**Temporal resolution and coverage**
daily global / hourly Europe

**Instrument name**
TROPOMI / UVN

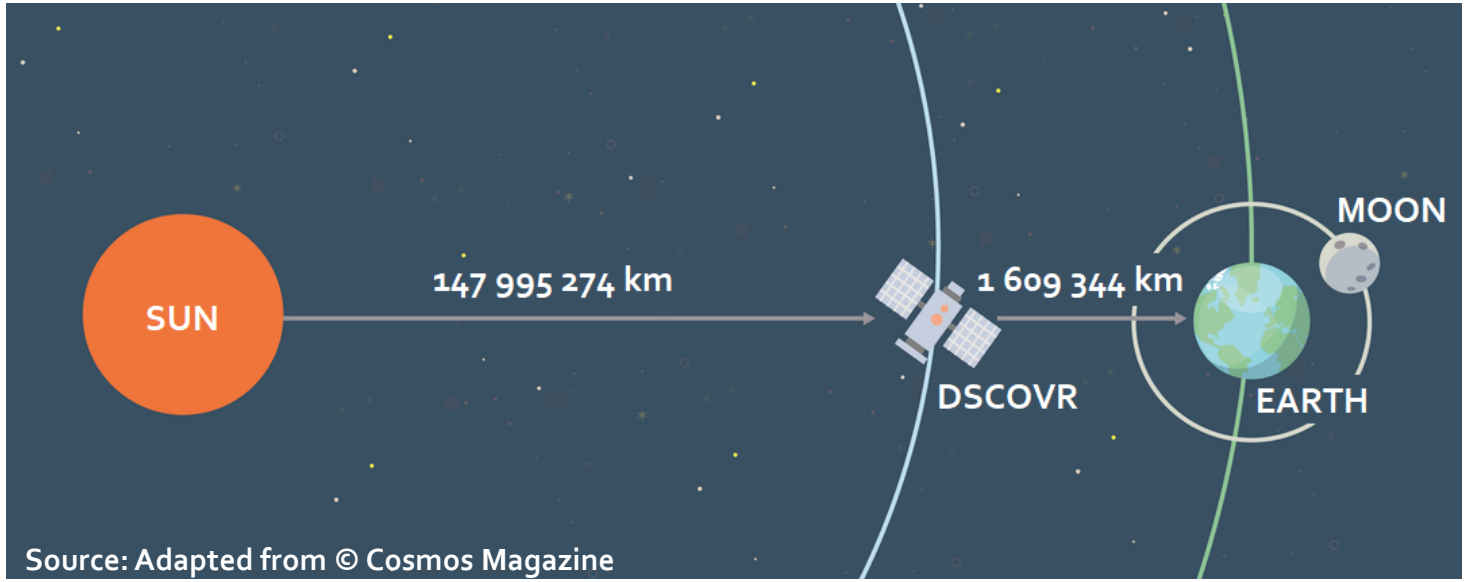
**Spatial resolution**
3.5 x 5.5 km² / 8 x 8 km²

**Spectral coverage**
UV-VIS-NIR-SWIR / UV-VIS-NIR

**Spectral resolution in the UVN**
0.25-0.5 nm / 0.12-0.5 nm



# DSCOVR – Deep Space Climate Observatory




EPIC/DSCOVR RGB images on 2015-07-16
Source: NASA

**Orbit**
Lagrange Point L1

**Temporal resolution and coverage**
10-22 full disk images per day

**Instrument name**
EPIC (Earth Polychromatic Imaging Camera)

**Spatial resolution**
12 km at nadir

**Spectral coverage**
10 channels across UV-VIS-NIR

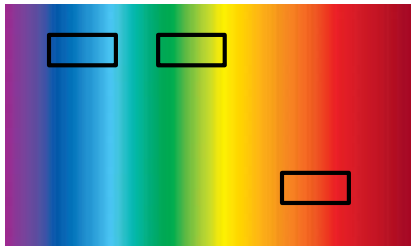
**Spectral resolution in the UVN**
bandwidth between 1-3 nm

DLR

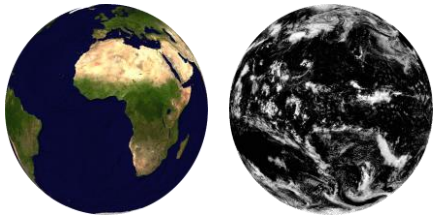
# The DLR Cloud Algorithms

# OCRA & ROCINN – Algorithm Overview

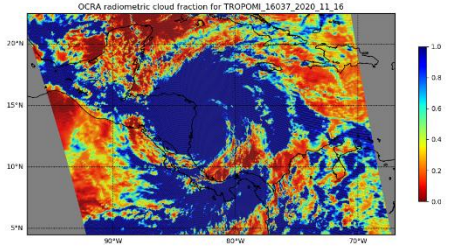
## OCRA
**Optical Cloud Recognition Algorithm**



color space approach



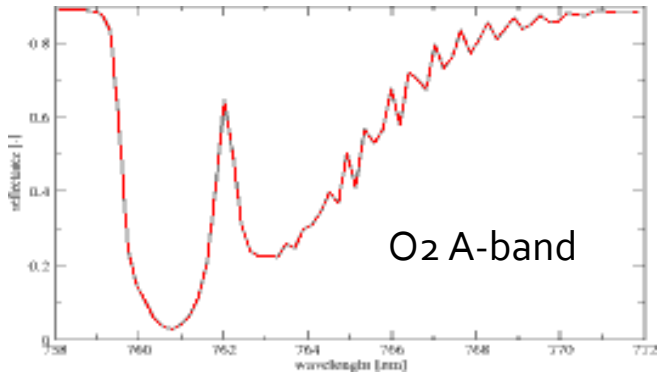
clear-sky composite

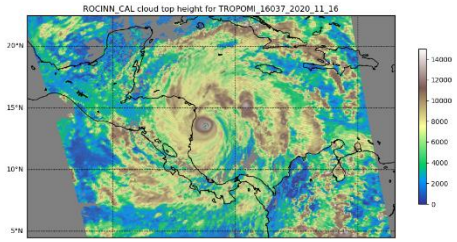



Radiometric cloud fraction

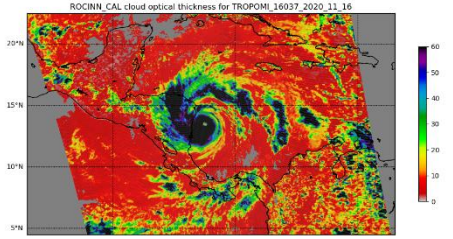
## ROCINN
**Retrieval of Cloud Information using Neural Networks**

neural network approach

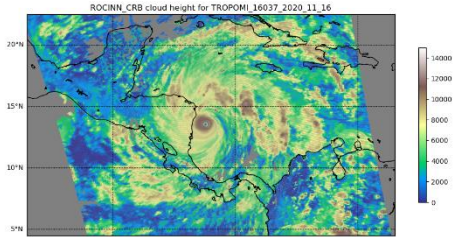


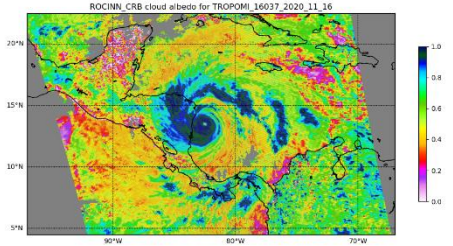

cloud top height




cloud opt. thickness




eff. cloud height

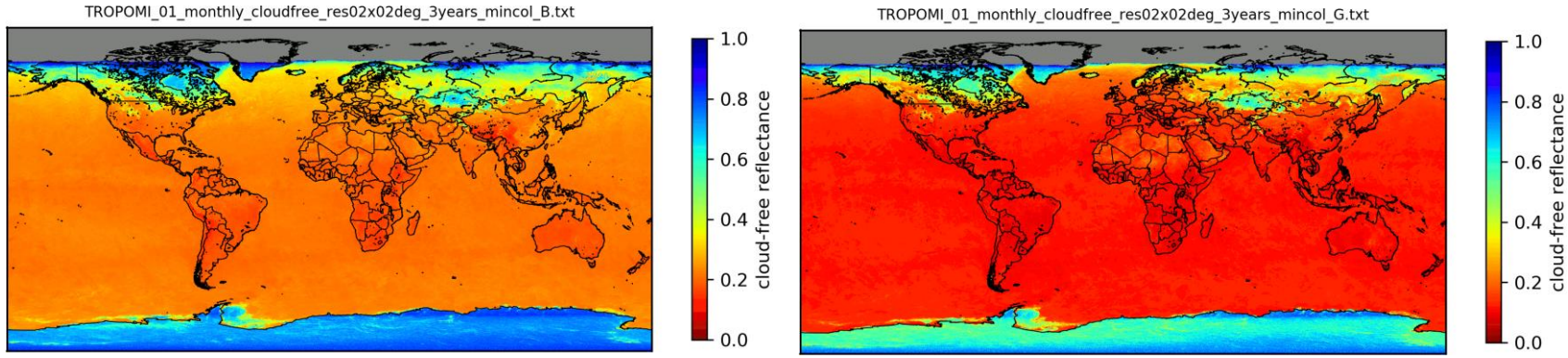


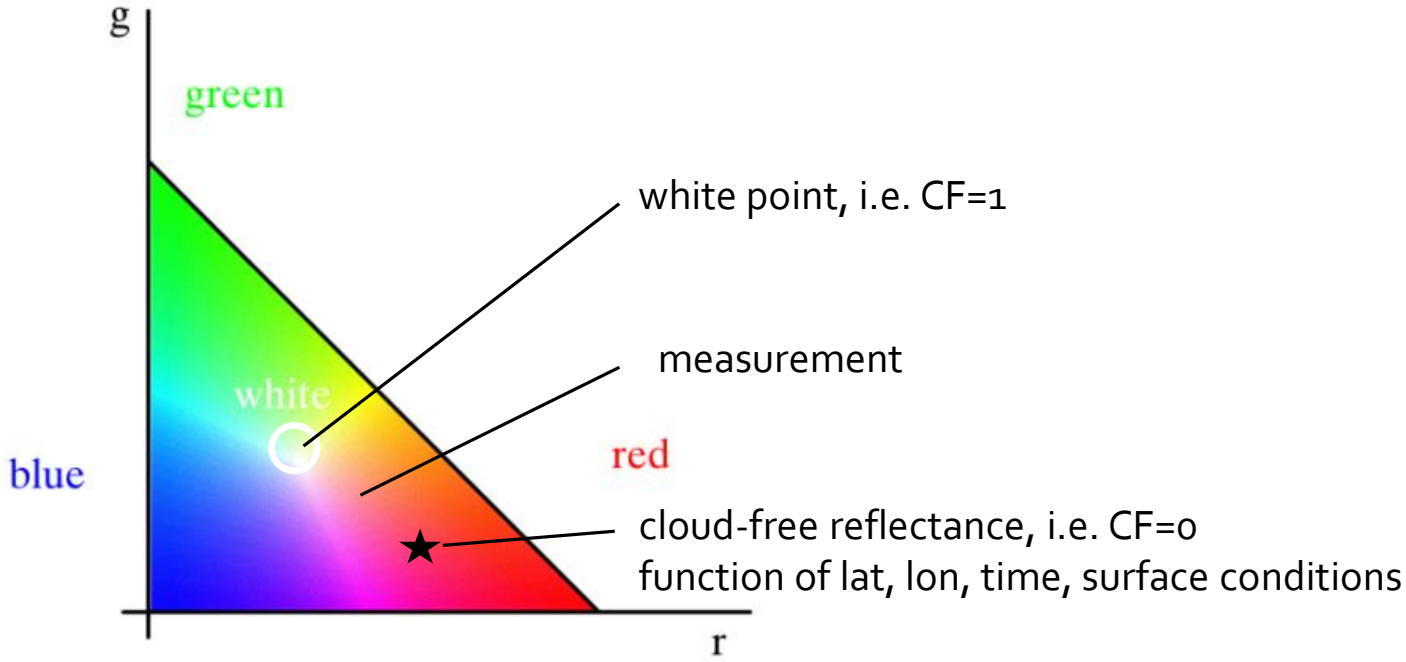

cloud albedo

Hurricane Iota
©NASA worldview

# OCRA Overview

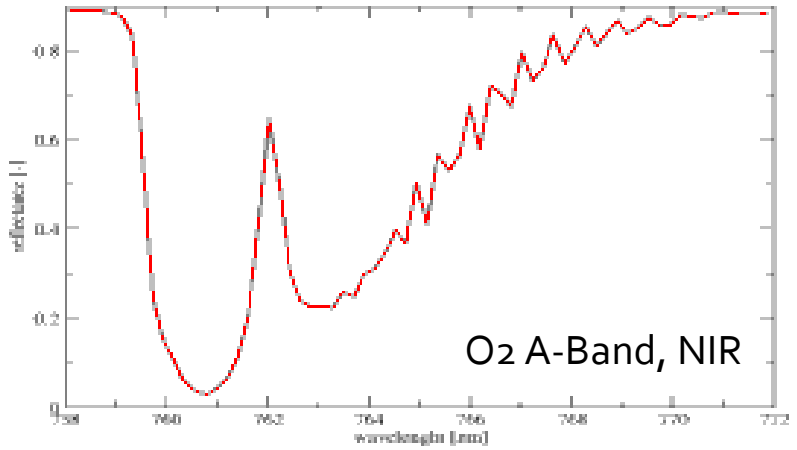
- generate cloud-free reflectance composite maps
- map measured reflectances to RGB color space
- assume cloud to be „white" in RGB space
- measured reflectance will be between white point and cloud-free point
- Radiometric cloud fraction scaled between cloud-free and white point



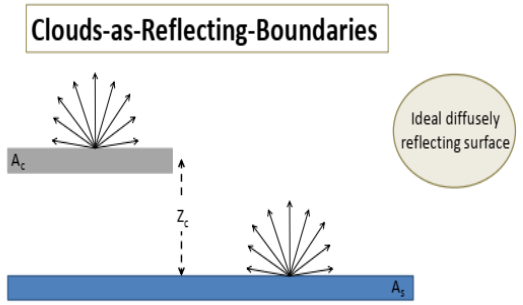

Lutz et al. (2016): OCRA radiometric cloud fractions for GOME-2 on MetOp-A/B, Atmos. Meas. Tech., 9, 2357-2379, https://doi.org/10.5194/amt-9-2357-2016

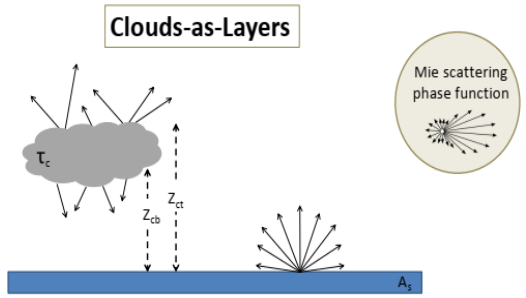
# ROCINN Overview




**Fitting window: [758-771] nm**

- two cloud models:
  **CRB**: clouds as reflecting boundaries (Lambertian reflector)
  **CAL**: clouds as layers (Mie-scattering liquid water droplets)



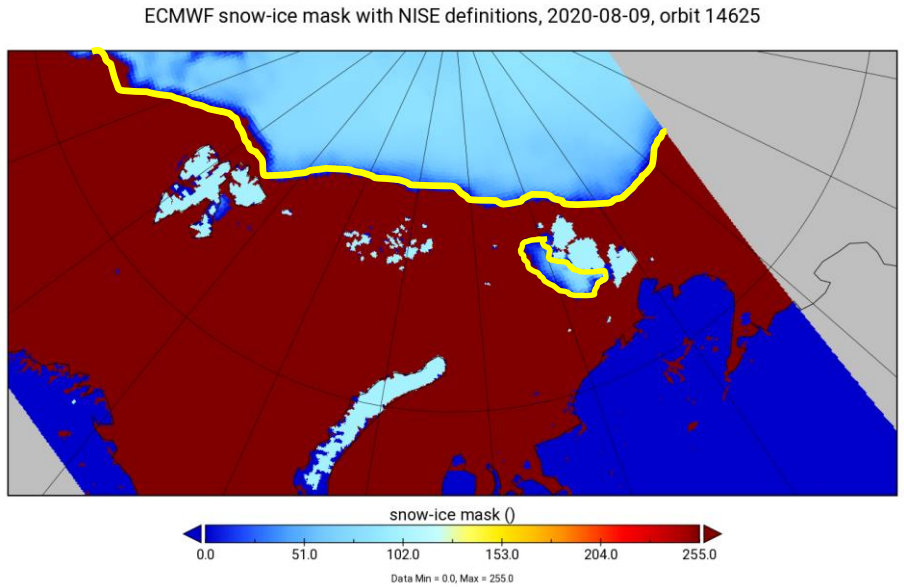




- forward model uses VLIDORT RT code
- neural network parametrized using smart sampling
- inversion using Tikhonov regularization

Loyola et al. (2018): The operational cloud retrieval algorithms from TROPOMI on board Sentinel-5 Precursor, Atmos. Meas. Tech., 11, 409-427. https://doi.org/10.5194/amt-11-409-2018
Loyola et al. (2016): Smart sampling and incremental function learning for very large high dimensional data, Neural Networks, Vol. 78, 75-87. https://doi.org/10.1016/j.neunet.2015.09.001

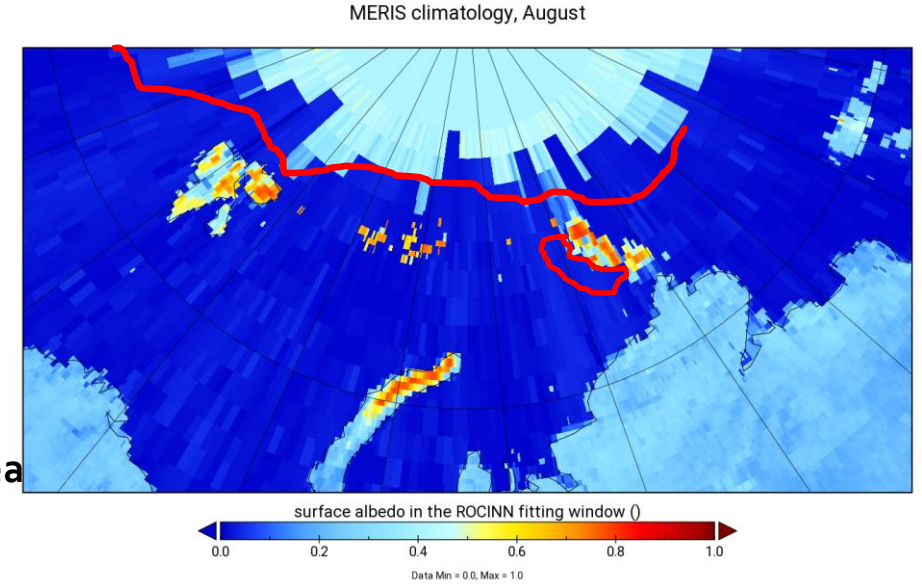
# recent improvements (I)

- surface albedo climatology is replaced by daily surface albedo retrieval (GE_LER) using TROPOMI measurements
- map is updated daily (G3_LER), but only for those grid cells which have a cloud fraction < 0.05




**Climatology:**

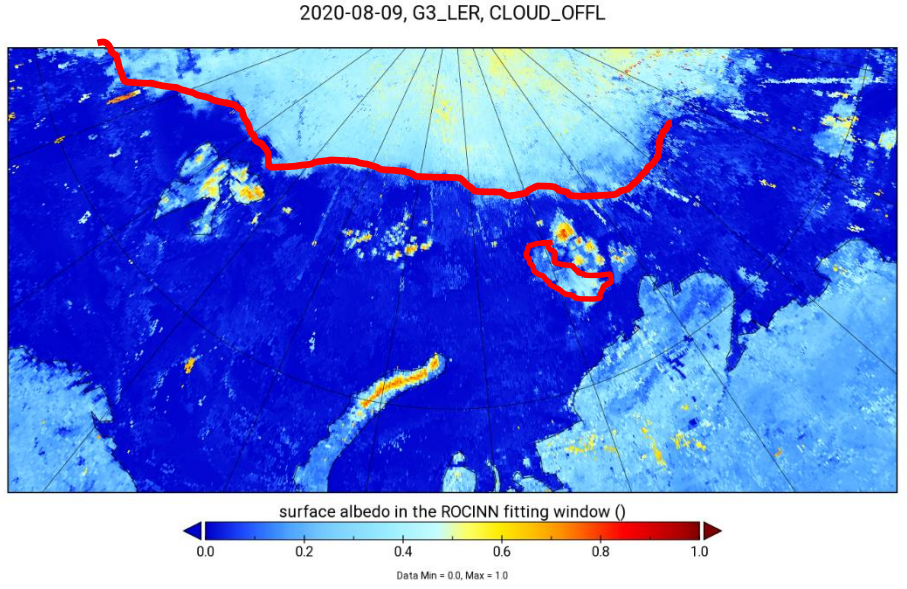
**- does not capture the actual ice border and sea ice**




**Daily G3_LER maps:**

**- better spatial resolution**

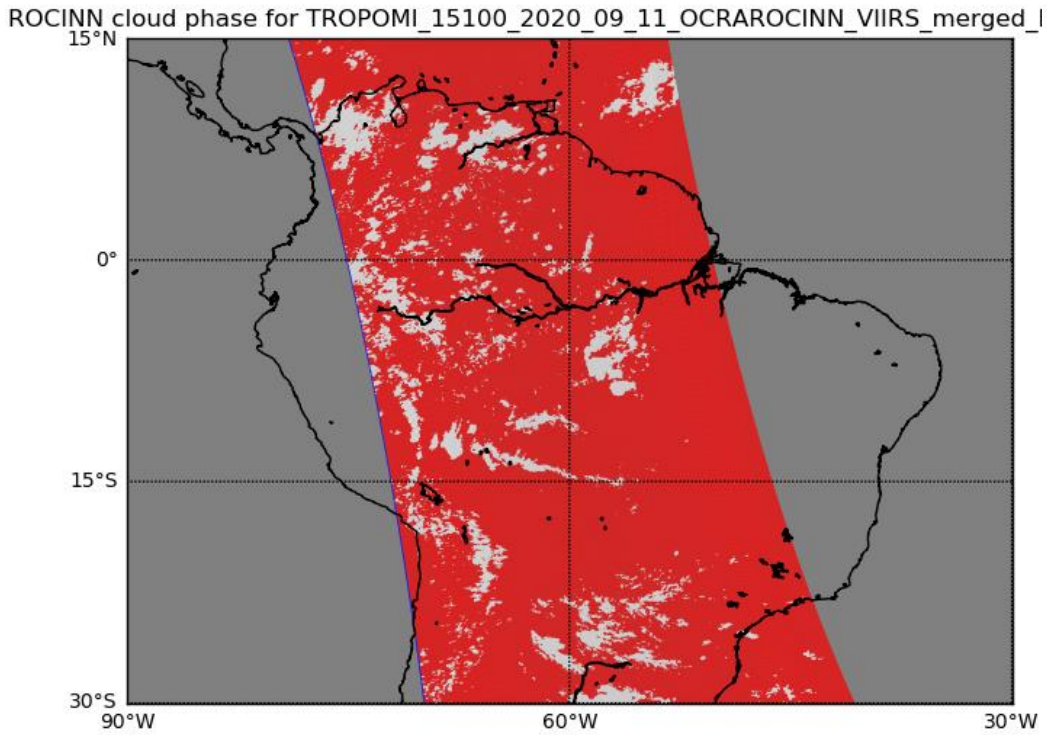
**- better representatation of actual surface conditions**



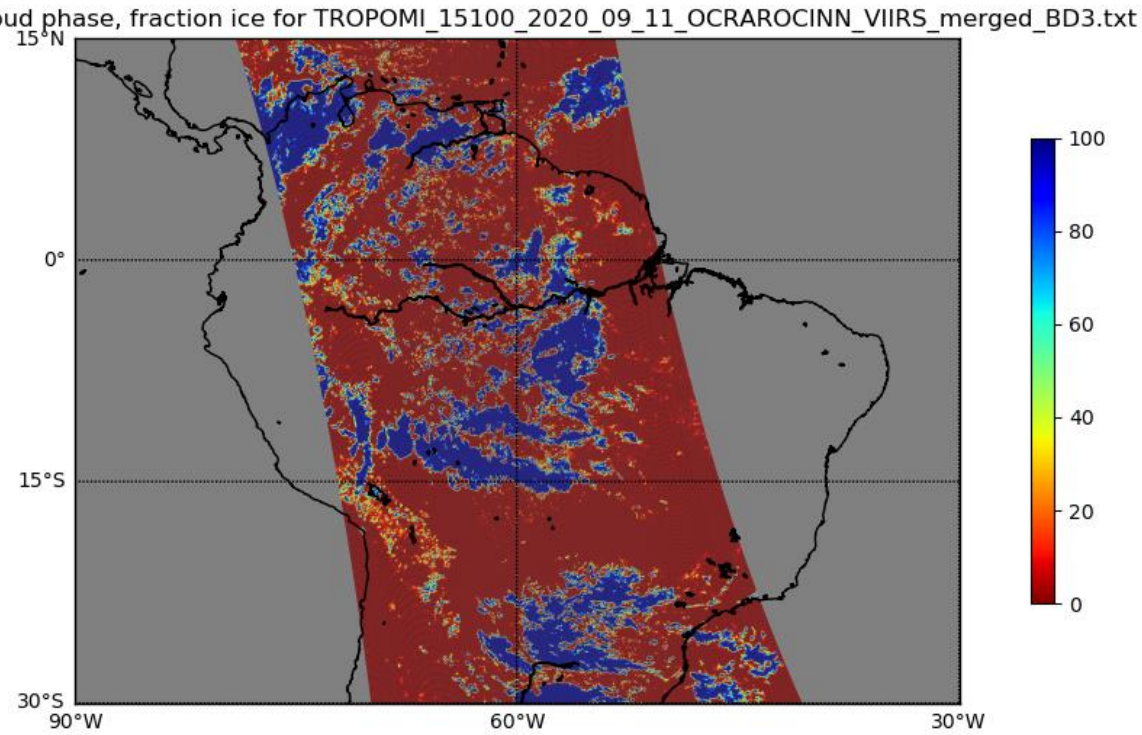

Loyola et al. 2019, https://doi.org/10.5194/amt-2019-37

# recent improvements (II)

- addition of an ice cloud detection flag to identify scenes not parameterized yet by ROCINN (only liquid clouds)




operational ROCINN ice cloud detection




VIIRS *cloud_phase_ice* fraction from the CloudPhase EDR

# recent improvements (III)

- ROCINN_CAL: ice cloud parameterization (VLIDORT 2.8.3)

  Spurr, R. J. D. VLIDORT: A linearized pseudo-spherical vector discrete ordinate radiative transfer code for forward model and retrieval studies in multilayer multiple scattering media, JQSRT, 102, 316-42, 10.1016/j/jqsrt.2006.05.005, 2006

  Bryan Baum et al.: Ice cloud single-scattering property models with the full phase matrix at wavelengths from 0.2 to 100 µm., JQSRT, 10.1016/j.jqsrt.2014.02.029, 2014

- Bulk properties and phase function of ice crystals of an effective diameter: Deff = 25 µm at 760 nm

- Simulated ice clouds have been retrieved with:

  - ROCINN_CAL for water clouds
    CTH errors between 0.3 and 5 km
    COT errors up to 90%

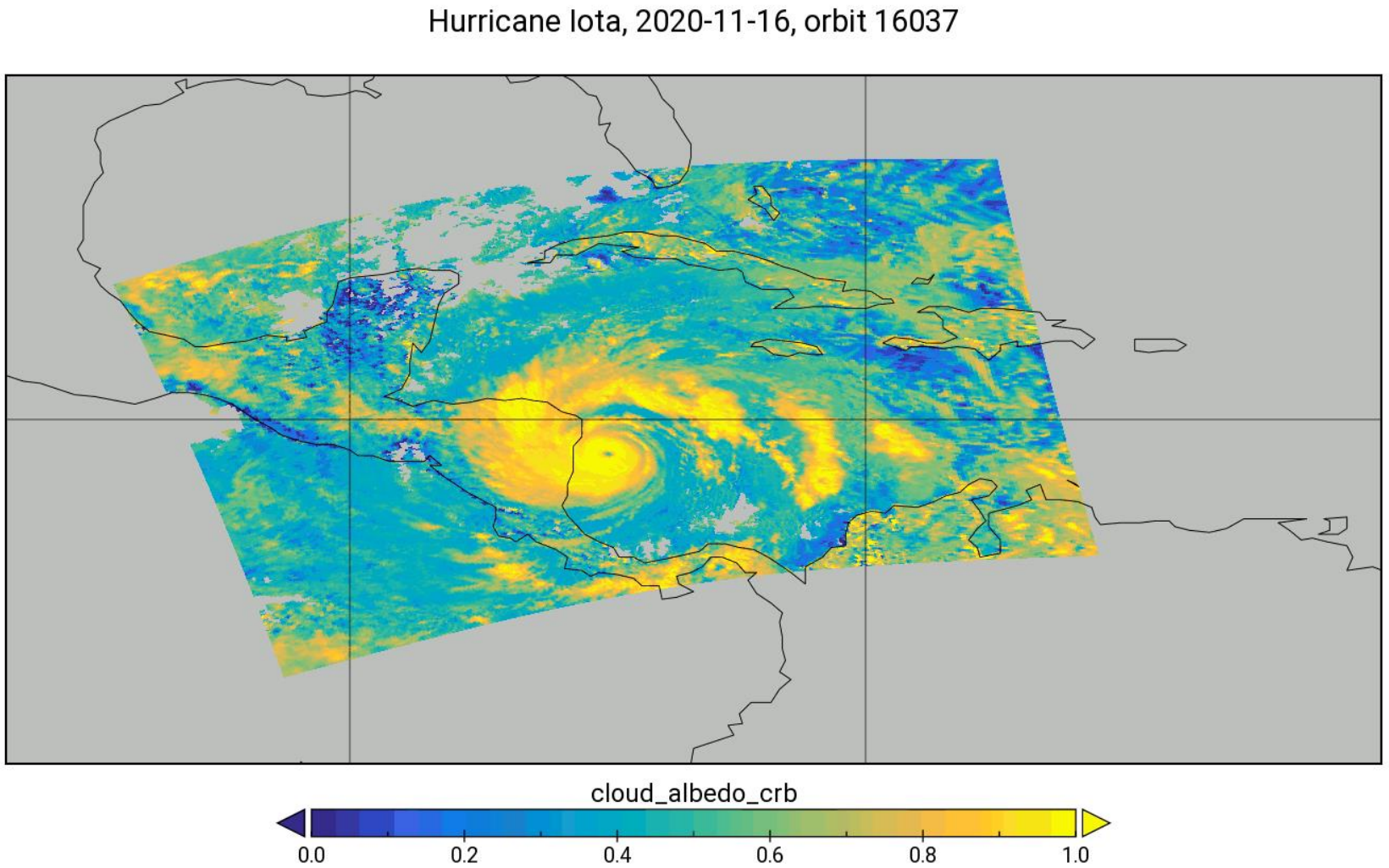
  - ROCINN_CAL for ice clouds
    CTH errors up to 0.1 km
    COT errors up to 10%

- When ice clouds are present, the **ROCINN_CAL_ice** implementation will considerably reduce the uncertainties



# Application Examples: S5P

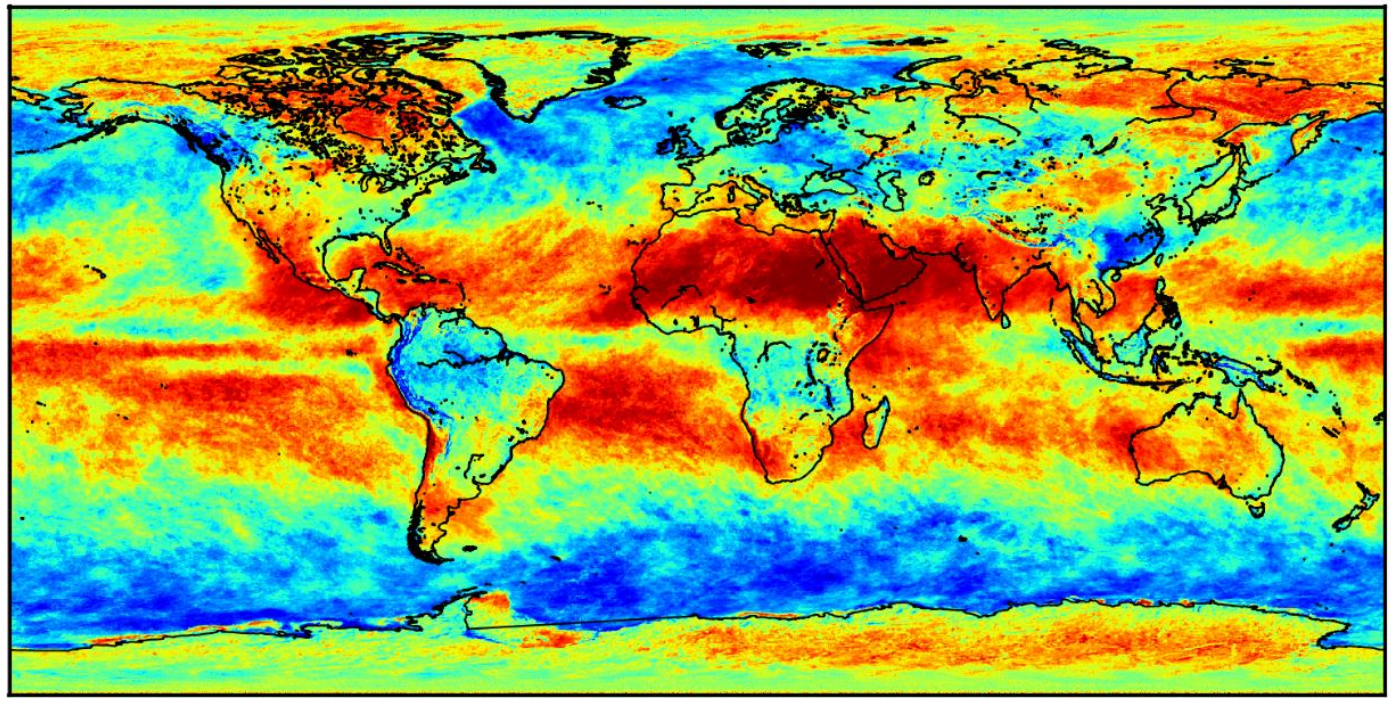
# S5P – operational cloud products

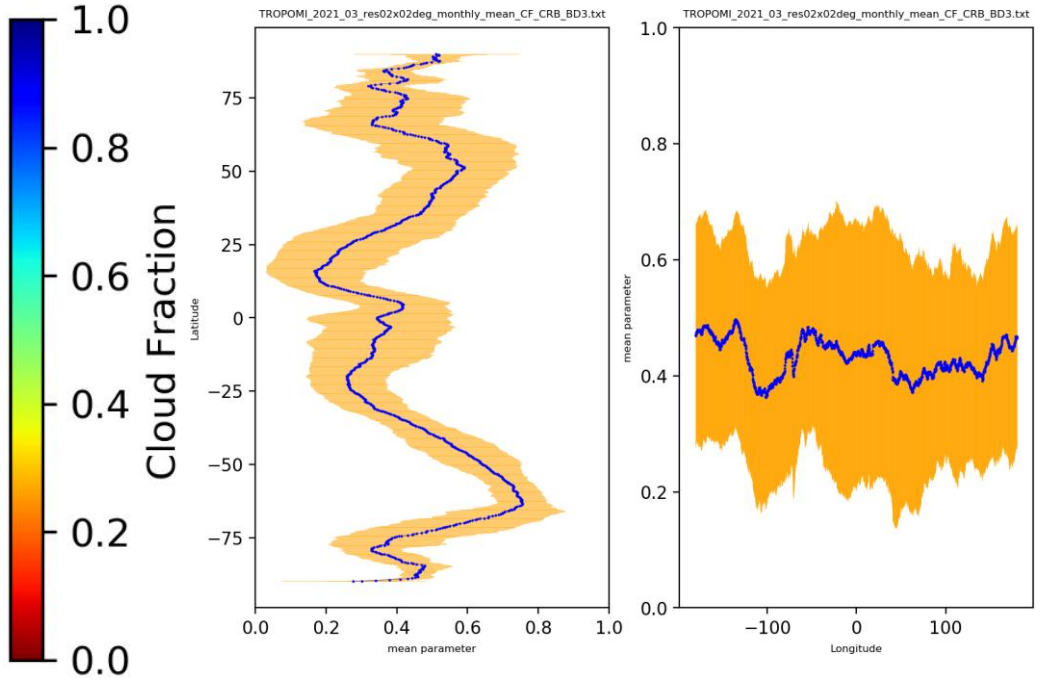



Hurricane Iota
©NASA worldview

# S5P – monthly mean maps and zonal/meridional means

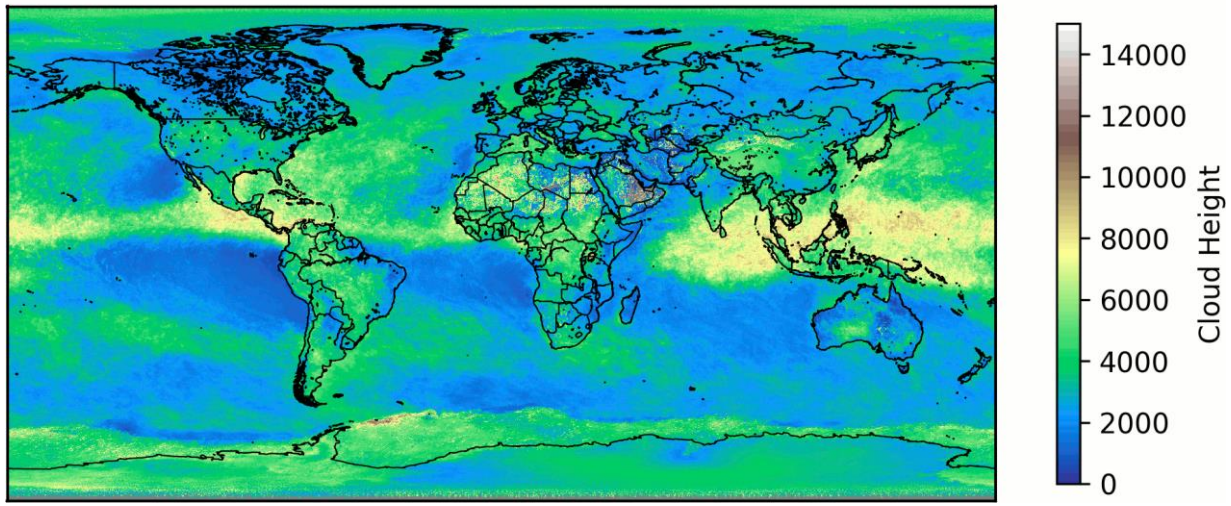
TROPOMI_2021_03_res02x02deg_monthly_mean_CF_CRB_BD3.txt



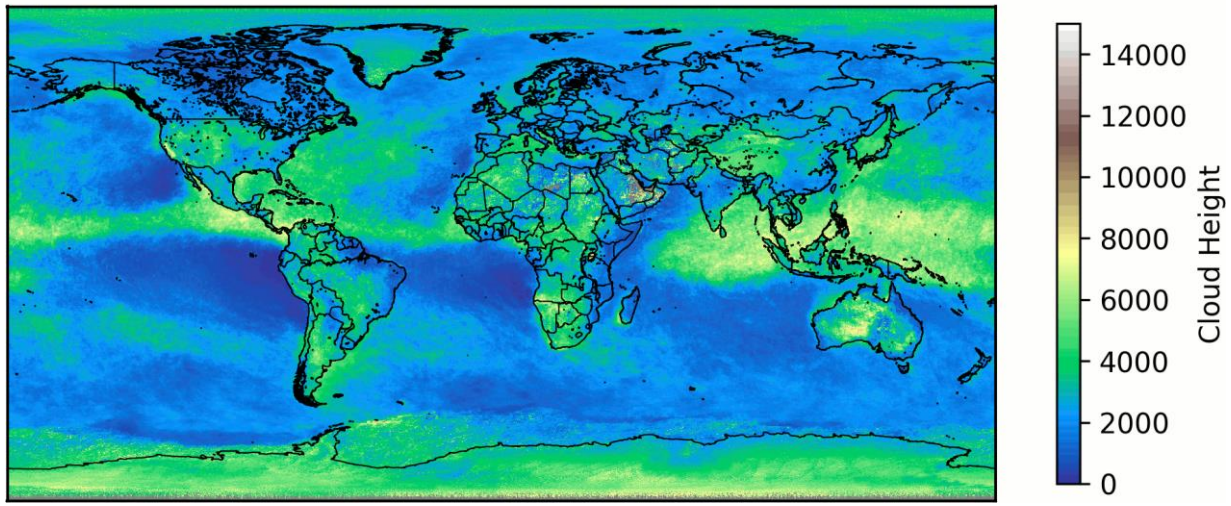


# S5P – yearly temporal evolution

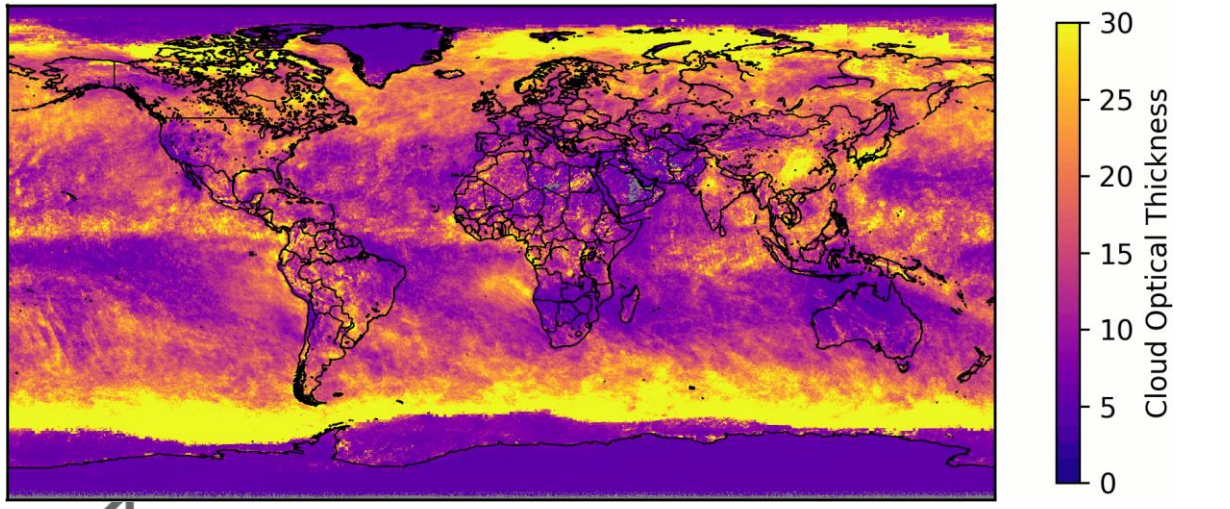
TROPOMI_2018_09_res02x02deg_monthly_mean_CTH_CAL.txt



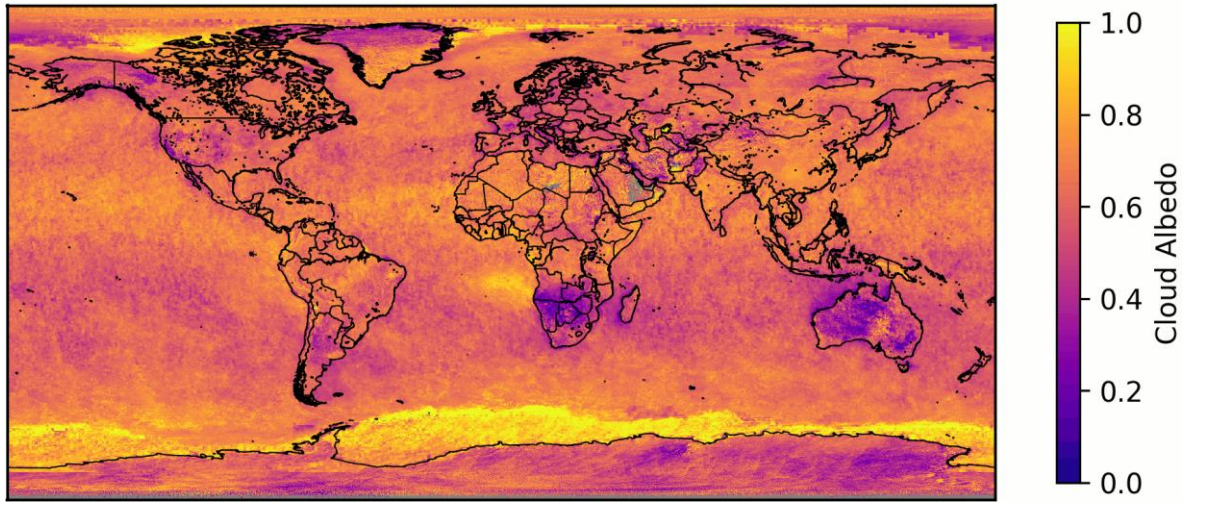

TROPOMI_2018_09_res02x02deg_monthly_mean_CH_CRB.txt



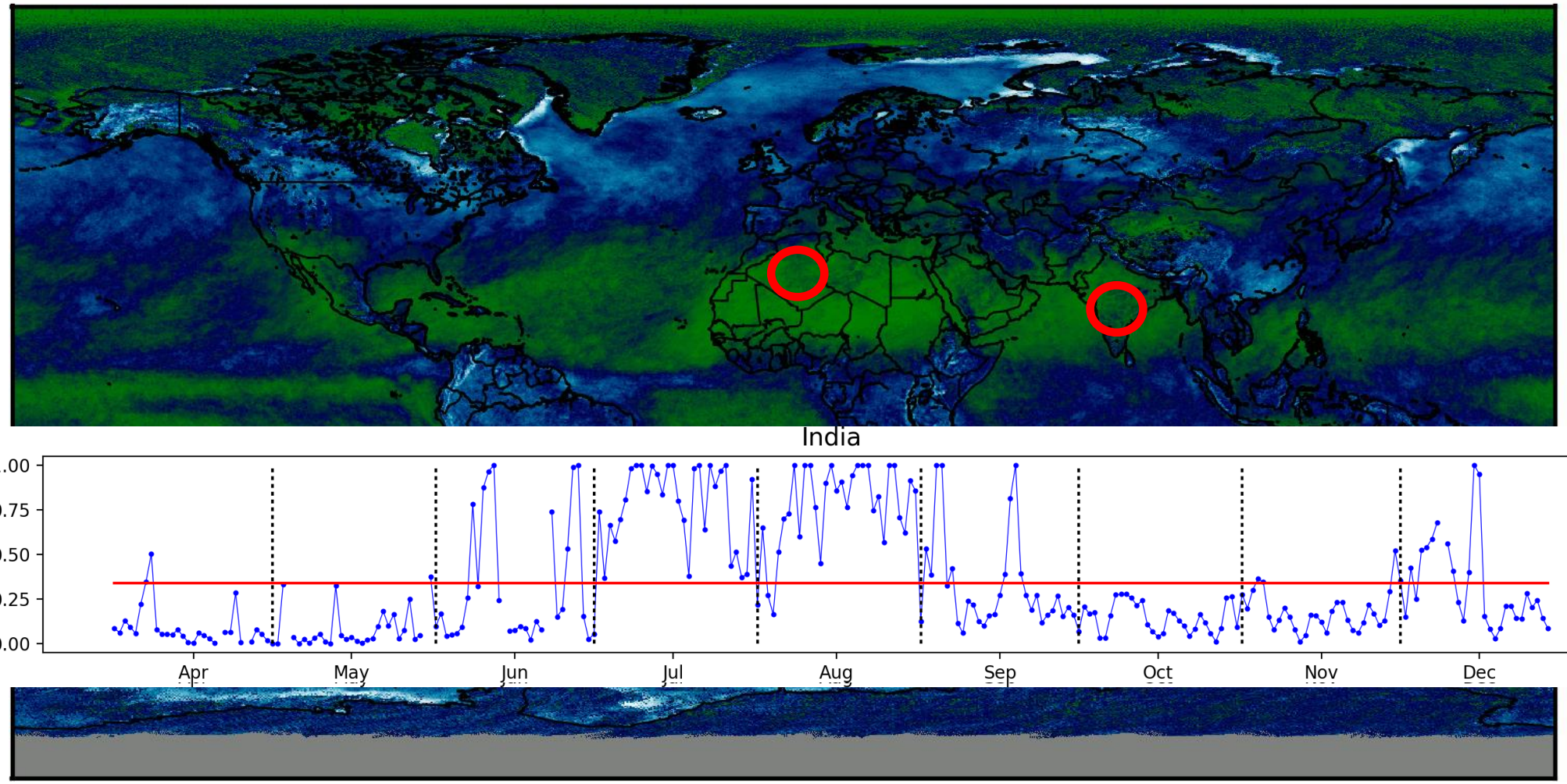

TROPOMI_2018_09_res02x02deg_monthly_mean_COT_CAL.txt




TROPOMI_2018_09_res02x02deg_monthly_mean_CA_CRB.txt



# S5P – time series for any given geolocation

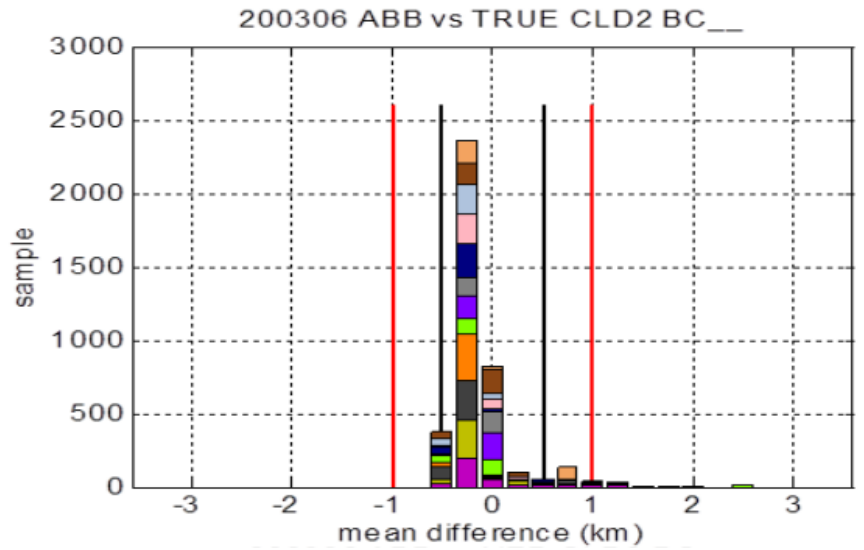


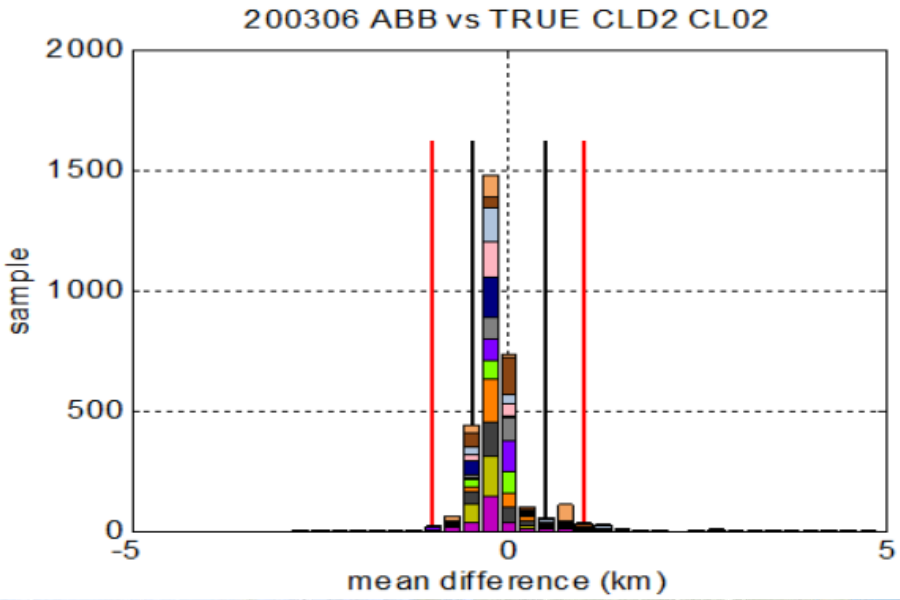
# Application Examples: S4

- no real data yet, launch early 2024
- synthetic data

# S4 – ROCINN applied to synthetic test data

- Test data for 17 locations across the S4 FOV
- Examples are shown for cloud top height (plots taken from S4L2 Verification report)
- Retrievals are within mission requirements for both
  - fully cloudy scenes (top panel)
  - partially cloudy scenes (bottom panel)



# Application Examples: DSCOVR

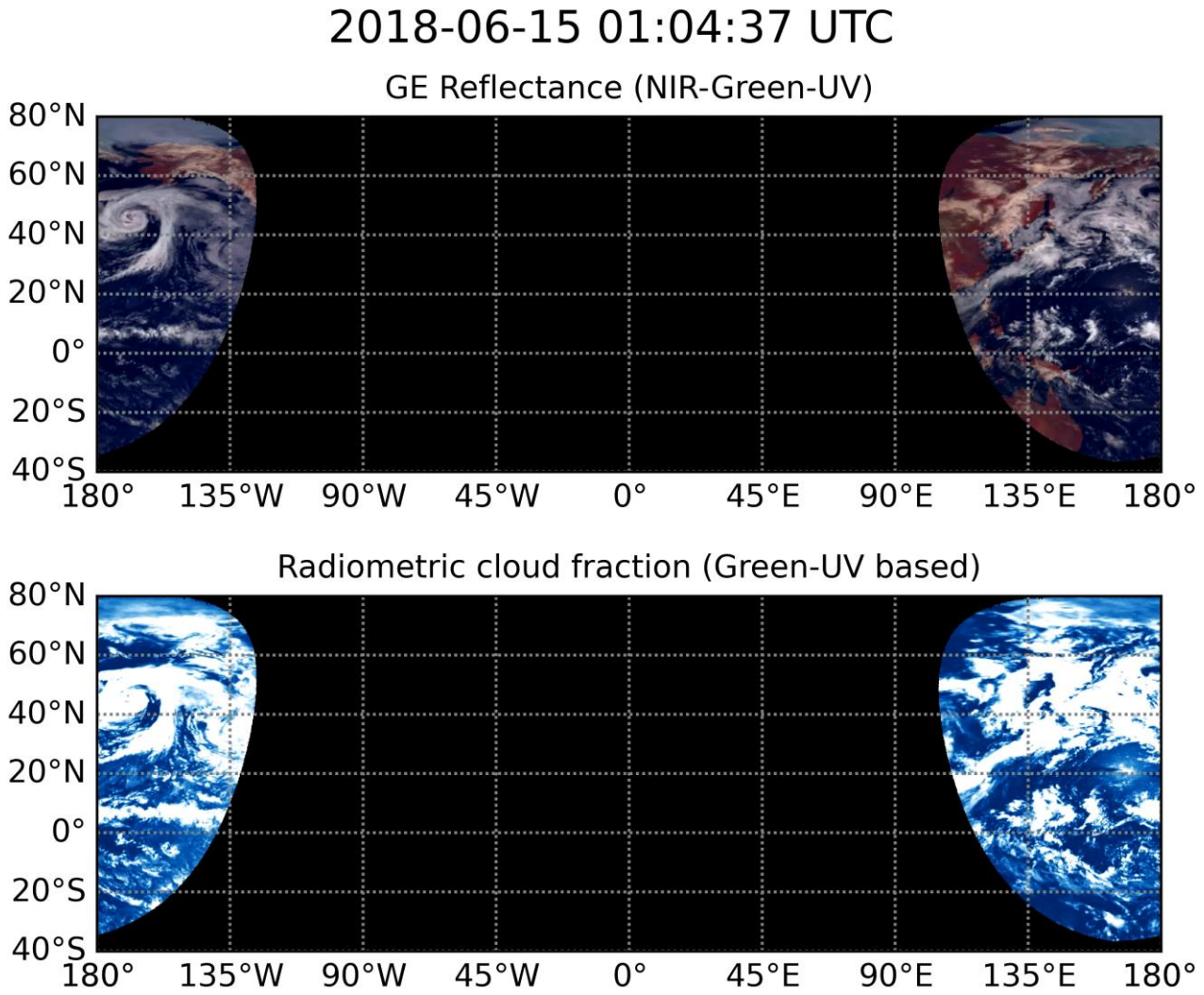
# DSCOVR – OCRA applied to EPIC

- Aggregation of daily maps in intervals of +/- 14 days with a small-percentile kernel and 0.2 deg resolution

Clear-sky maps for EPIC channels (780, 551, 388) nm

# DSCOVR – OCRA applied to EPIC

- True color (top) and OCRA radiometric cloud fraction (bottom) for 15 June 2018



# Conclusion and Outlook

## Conclusion

- OCRA/ROCINN has been **successfully implemented for Sentinel-5P** and is operational since more than three years and will also be used **operationally for the geostationary Sentinel-4**
- OCRA/ROCINN has been successfully applied to EPIC and OCRA to GEMS
- Validation against VIIRS, ground-based data (CLOUDNET) and synthetic data show good agreement

## Outlook

- OCRA/ROCINN cloud data records are already available for GOME, SCIAMACHY, GOME-2A/B/C
- Generate a **consistent, homogeneous multi-sensor cloud properties dataset** starting in 1995 and adding to the above also EPIC, S5P, GEMS and the upcoming S4, S5



***Thank you for your attention!***

**DLR-Atmos:**
*https://atmos.eoc.dlr.de/app/calendar*