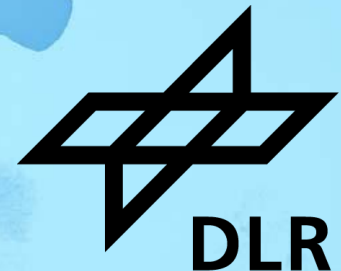# SENTINEL-4 OPERATIONAL PRODUCTS

Diego Loyola, Ronny Lutz, German Aerospace Center (DLR)

Teams from Sentinel-4 L2OP and AC-SAF

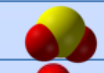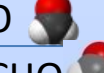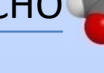ATMOS Conference, Bologna, Italy, 1st July 2024
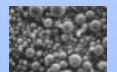
DLR

1

Sentinel-4 Geophysical Level-2 Products

- Copernicus L2 Products

- AC-SAF L2 Products

Sentinel-4 Copernicus Geophysical Level-2 Products

Sentinel-4 Copernicus Products		
Species	**Parameter**	**Algorithm**
O_3	Total column	DOAS + iter. AMF
	Tropospheric column	OE
NO_2	Total column	DOAS
	Tropospheric column	S4 & CAMS
SO_2	Total column	DOAS (COBRA)
HCHO	Total column	DOAS
CHOCHO	Total column	DOAS
Cloud	Cloud fraction	OCRA
	Optical depth	ROCINN
	Cloud height	ROCINN
Aerosol	Index	UVI
	Optical depth	GRASP
	Layer Height	OE
Surface	BRDF & ws. albedo	GRASP

- Development: ESA with DLR as prime
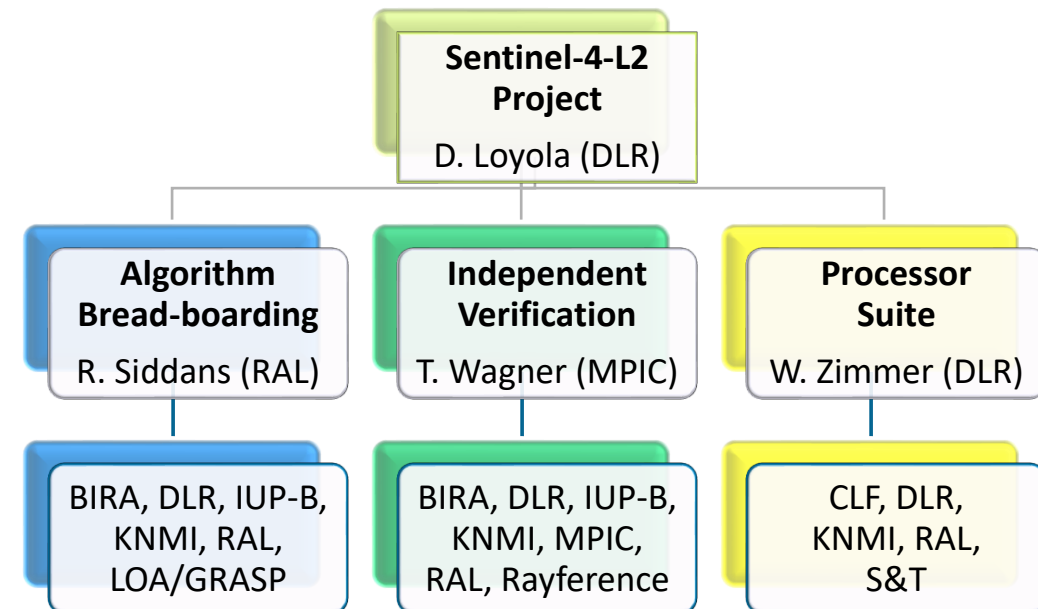
- Operations: EUMETSAT

Sentinel-4 Copernicus – Total Ozone (O$_3$)

- **Heritage**
  - GOME/SCIA/GOME-2: DOAS with iterative AMF/VCD (Van Roozendael et al., JGR 2006; Loyola et al., JGR 2011; Hao et al., AMT 2014)
  - TROPOMI:
    - OCRA/ROCINN Cloud as Layer (CAL) Loyola et al., AMT 2018
      - No need of ghost-column corrections
    - Retrieval of surface properties GE_LER Loyola et al., AMT 2020

- Sentinel-4 algorithm
  - AMF computed using Sentinel-4 BRDF and OCRA/ROCINN CAL

ozone_geometrical_vertical_column
01:45

GEMS DLR O$_3$

ozone_geometrical_vertical_column ()

200.0   270.0   340.0   410.0   480.0   550.0

K.-P. Heue (DLR)

4
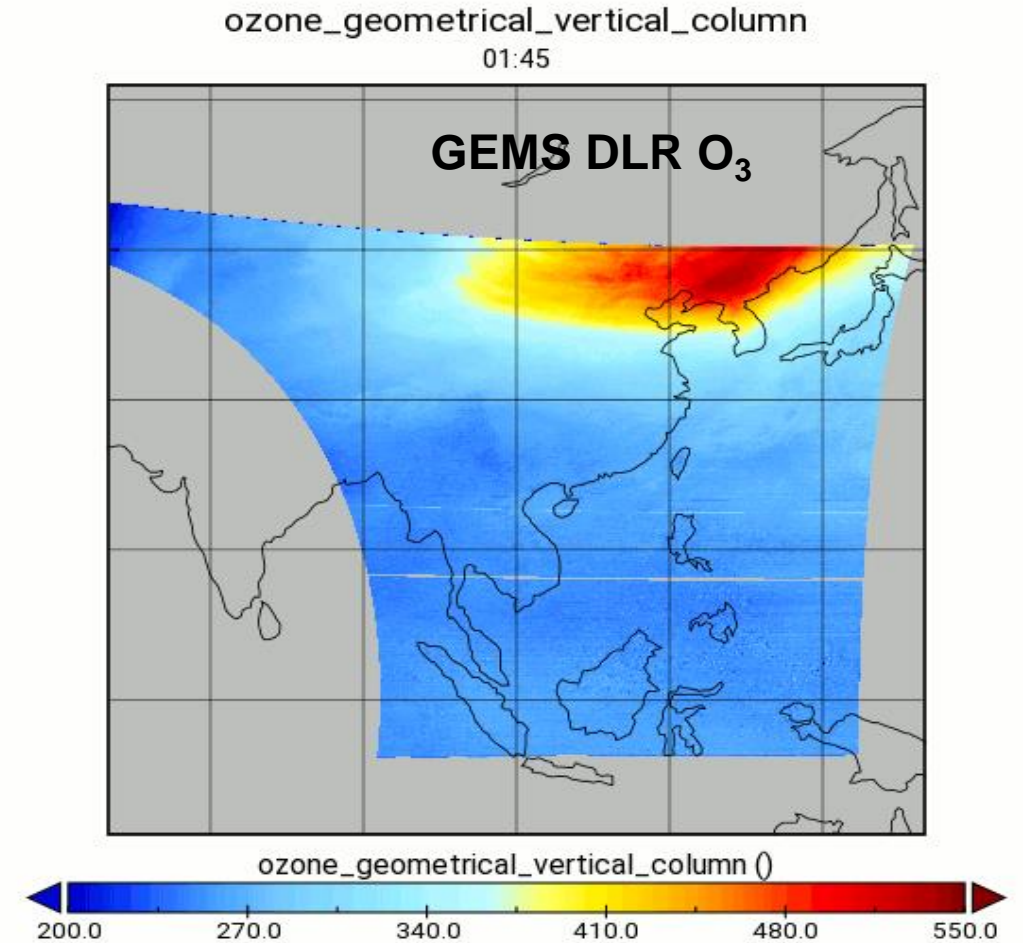
Sentinel-4 Copernicus – Tropospheric Ozone (O$_3$)

- **Heritage**: ozone profile algorithm developed for GOME
  - Specific emphasis on tropospheric ozone information in the Huggins bands
- ESA CCI-ozone uses this scheme to provide full record from GOME, SCIAMACHY, GOME-2, OMI and TROPOMI
- Sentinel-4 has no measurements of Hartley band below 305 nm, which provides stratospheric profile information in all previous UVN missions

GEMS RAL trop. O$_3$

K.-L. Chan (RAL)
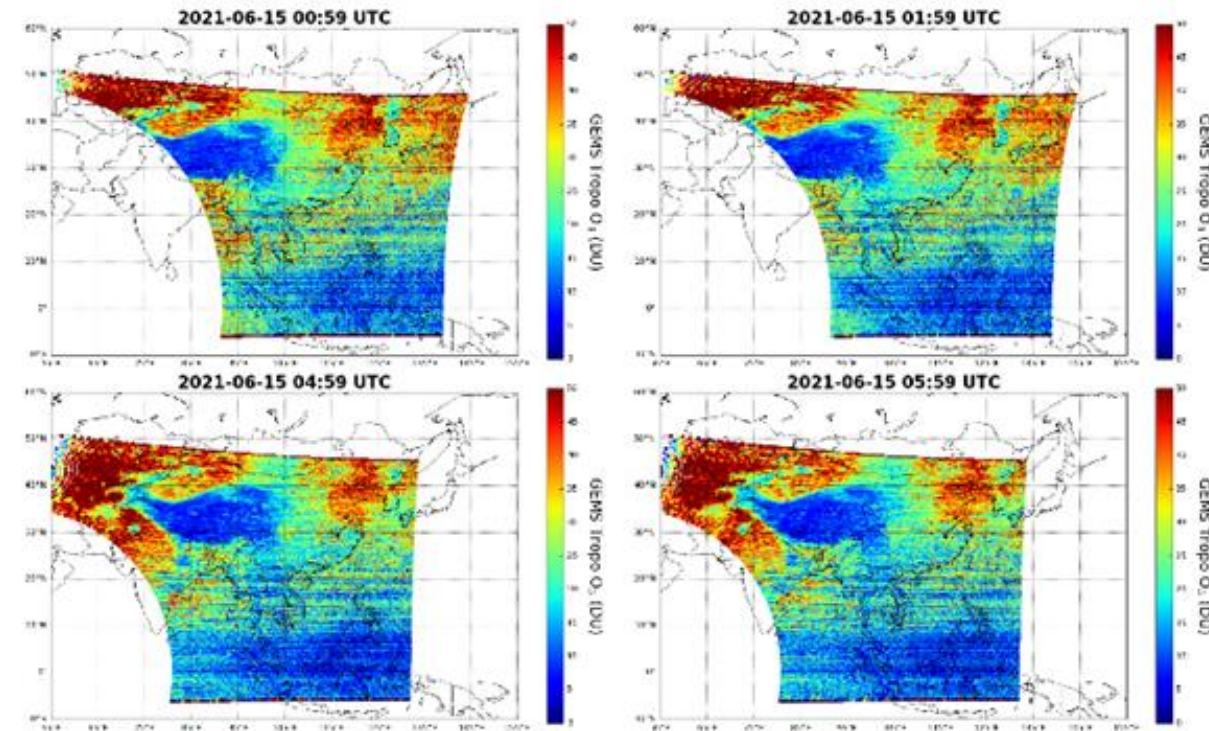
S4 Copernicus – Tropospheric Nitrogen Dioxide (NO$_2$)

- **Heritage**: Standard DOAS retrieval from GOME, SCIAMACHY, GOME-2 , OMI and TROPOMI
  - Stratospheric correction to determine tropospheric slant columns
  - Application of AMFs to determine tropospheric vertical columns

- Sentinel-4 algorithm
  - Stratospheric fields from CAMS based on assimilation of S5(P) and Sentinel-4 data
  - AMFs based on Sentinel-4 BRF product
  - A priori NO$_2$ profiles from high-resolution regional CAMS forecast

GEMS IUP trop. NO$_2$

October 2021 04:45,
no cloud correction

A. Richter (IUP-B)

6
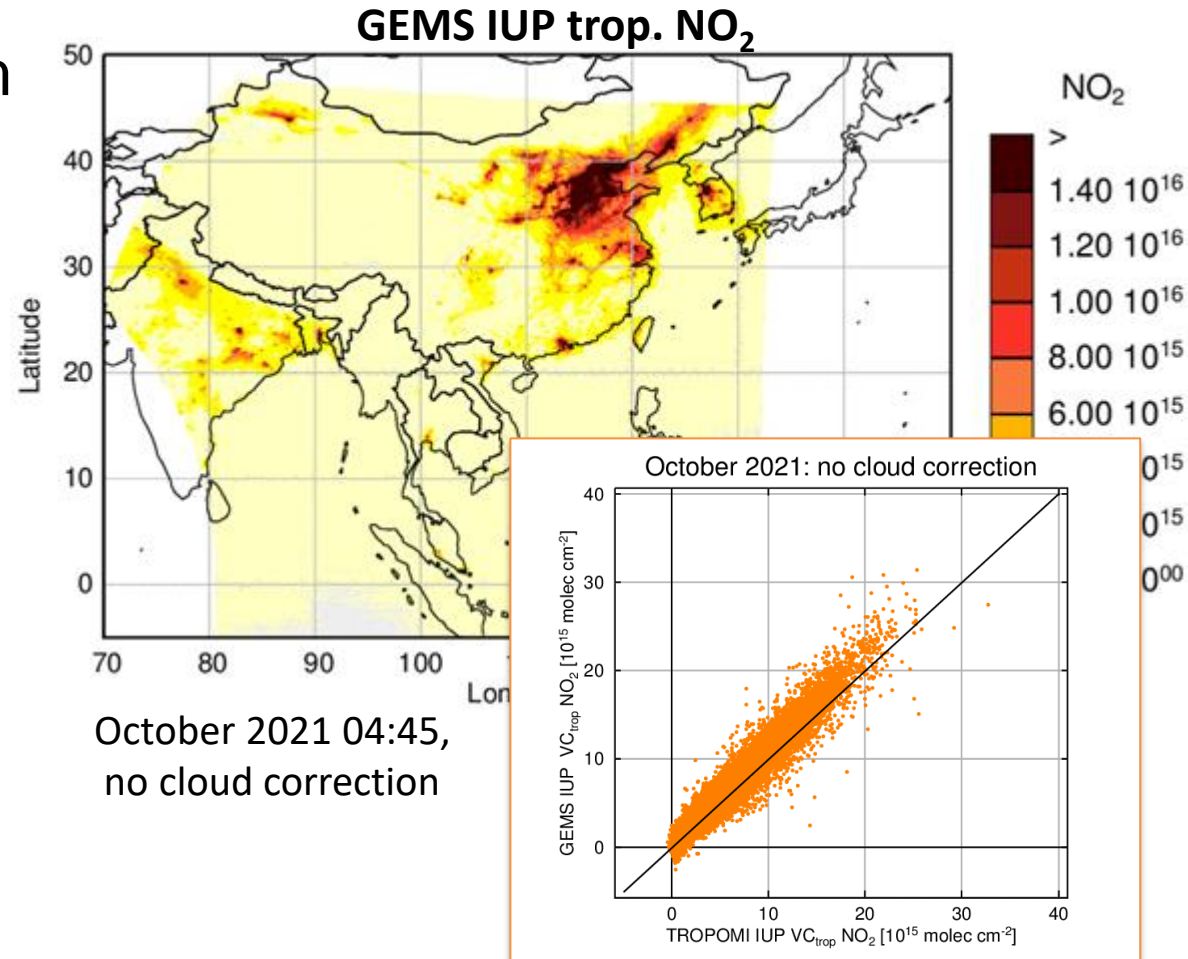
Sentinel-4 Copernicus – Sulfur Dioxide (SO$_2$)

- **Heritage**: DOAS with one baseline fitting windows plus two alternative windows for high SO$_2$ (currently operational for S5P)

- Sentinel-4 algorithm
  - Background offset correction with screening of volcanic plumes and heavy pollution
  - Conversion to VCD by means of an AMF dependent on other Sentinel-4 L2 products: BRF, clouds and aerosol index

- Research algorithm COBRA
  - Operational for TROPOMI end 2024

GEMS COBRA 2021.03.21 0045

GEMS BIRA COBRA SO$_2$

N. Theys (BIRA)
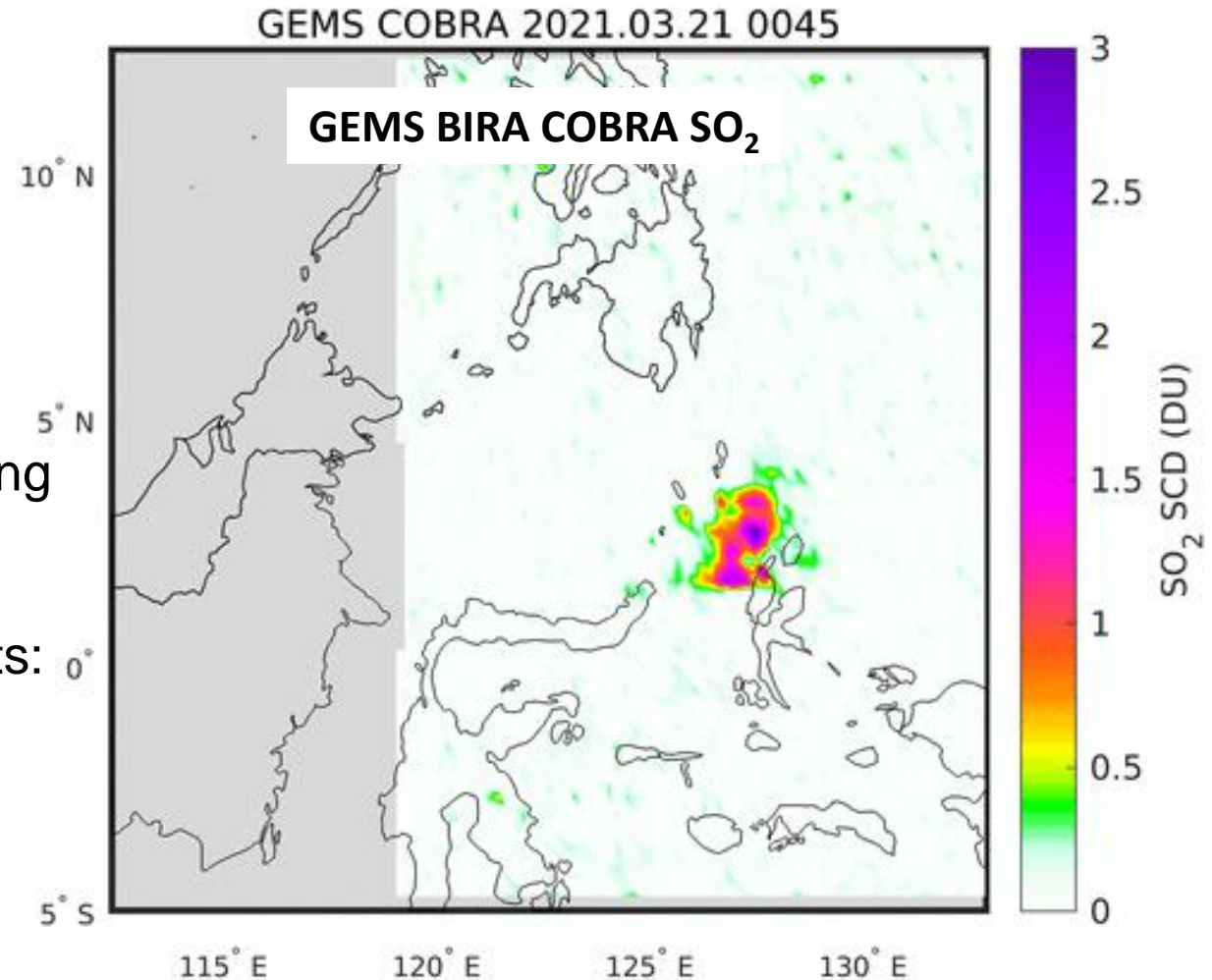
Sentinel-4 Copernicus – Formaldehyde (HCHO)

- **Heritage:** Two-window DOAS ([BrO] and [HCHO]), operational for S5P

- Sentinel-4 algorithm
  - Background offset correction
  - Conversion to VCD by means of an AMF dependent on other Sentinel-4 L2 products: BRF, clouds and aerosol index
  - Ocean region does not suffice for background correction

GEMS BIRA HCHO

Oct.2021

Mar.2022

Aug.2022

0445 Oct. 2021 , GEMS HCHO VCD x10^{+15} molec.cm

0445 Mar. 2022 , GEMS HCHO VCD x10^{+15} molec.cm^{-2} N

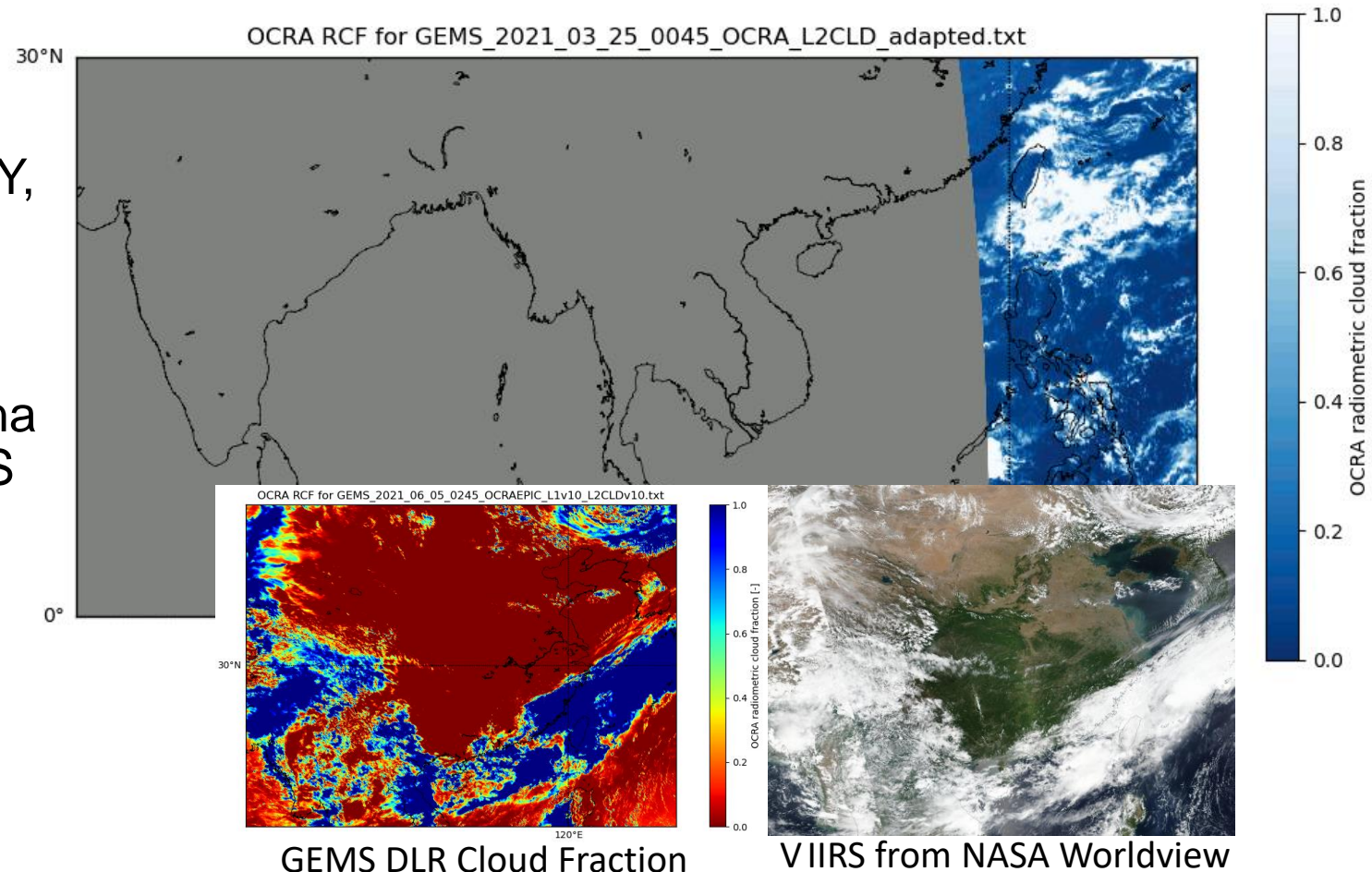0445 Aug. 2022 , GEMS HCHO VCD x10^{+15} molec.cm^{-2} NIER L2 V1.0
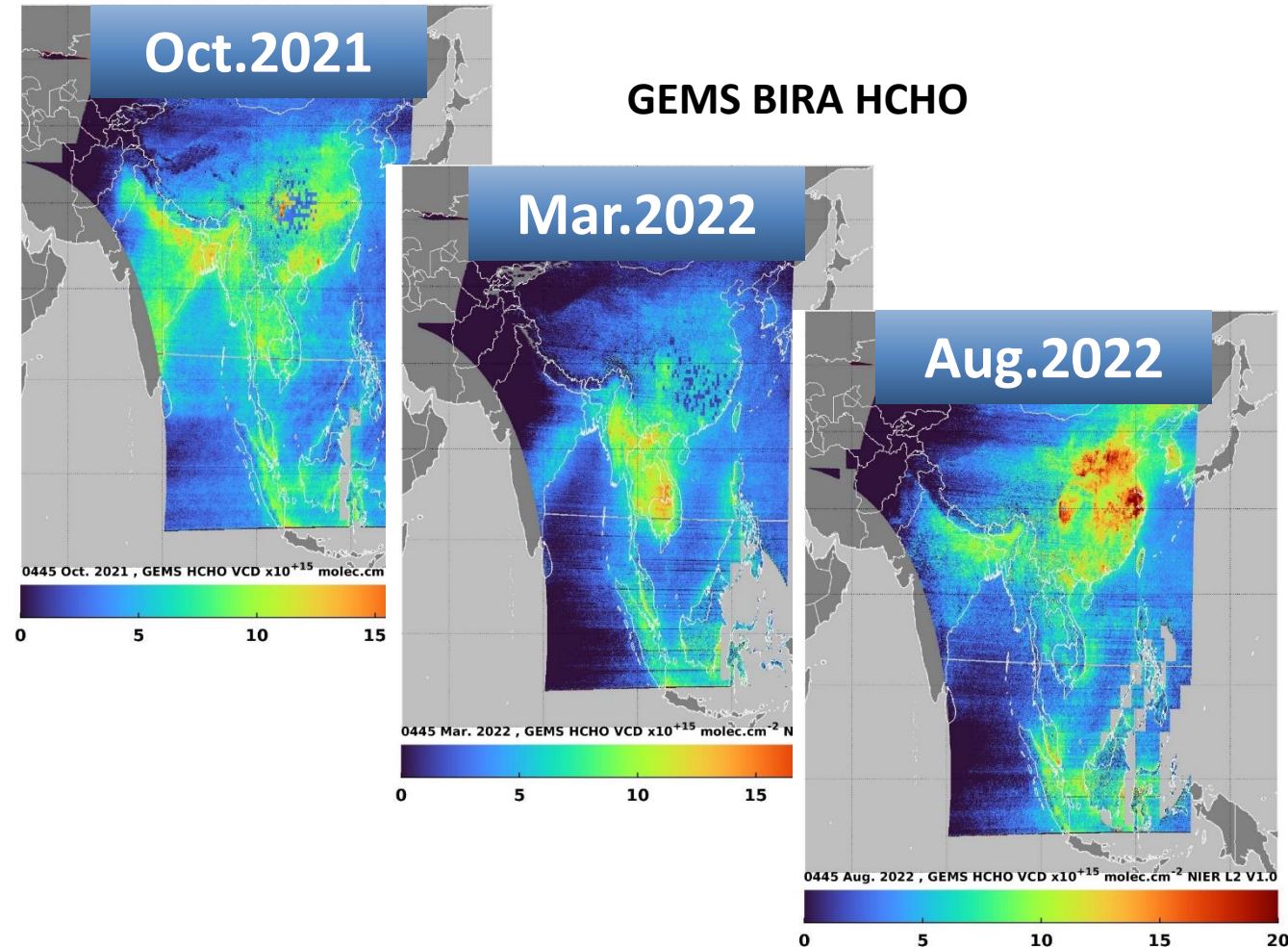
I. De Smedt (BIRA)

Sentinel-4 Copernicus – Clouds

- **Heritage:** OCRA/ROCINN algorithms used operationally for **GOME** (Loyola et al., TGRS 2007; Loyola et al., IJRS 2010), SCIAMACHY, **GOME-2** (Lutz et al., AMT 2016), and **TROPOMI** (Loyola et al., AMT 2018; Compernolle et al., AMT 2021)

- Applied to OMI, EPIC/DSCOVR (Molina Garcia et al., JQSRT 2018) and GEMS

- **Sentinel-4 algorithm**
  - OCRA (UV) for cloud fraction
  - ROCINN (NIR)
    - CAL: cloud optical thickness & top height
    - CRB: cloud albedo & height

GEMS DLR Cloud Fraction

OCRA RCF for GEMS_2021_03_25_0045_OCRA_L2CLD_adapted.txt

OCRA RCF for GEMS_2021_06_05_0245_OCRAEPIC_L1v10_L2CLDv10.txt

GEMS DLR Cloud Fraction

VIIRS from NASA Worldview

R. Lutz (DLR)

Sentinel-4 Copernicus – Surface and AOD

Heritage: GRASP
- Multi-day retrieval approach, each day with multi-hours measurements
  - Stable and accurate surface reflection retrieval

Sentinel-4 algorithm
- Products for cloud free conditions:
  - Surface **BRDF** (BRF, DHR, White Sky Albedo)
  - **AOD**
- Daily Gapless Surface Reflectance
  - Surface **BRDF** for following wavelengths: 342, 367, 410, 443, 490, 755 nm
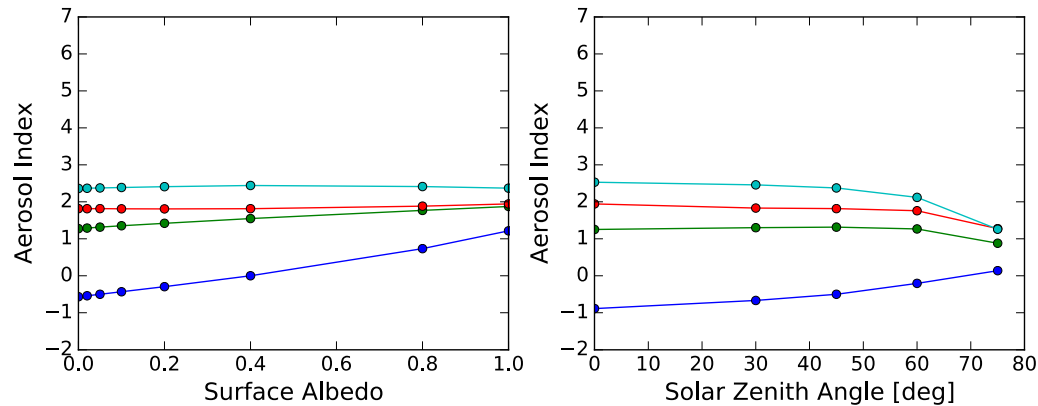
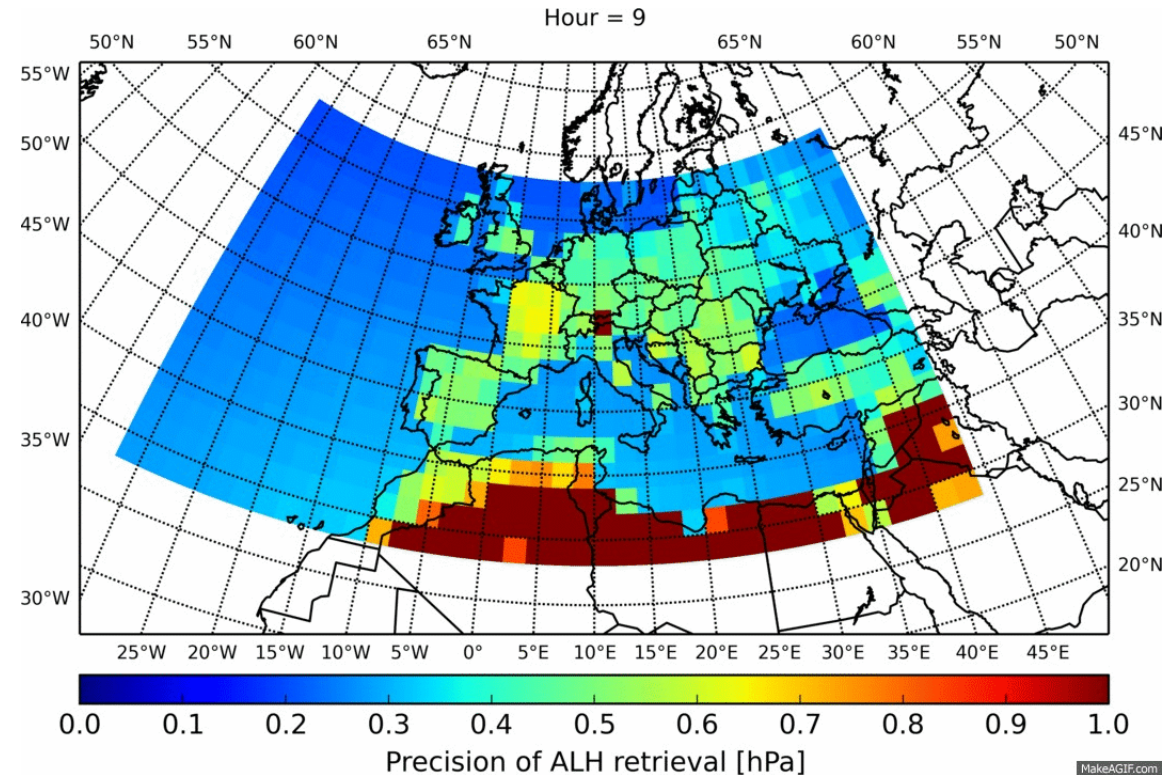**GEMS GRASP AOD & BRDF**
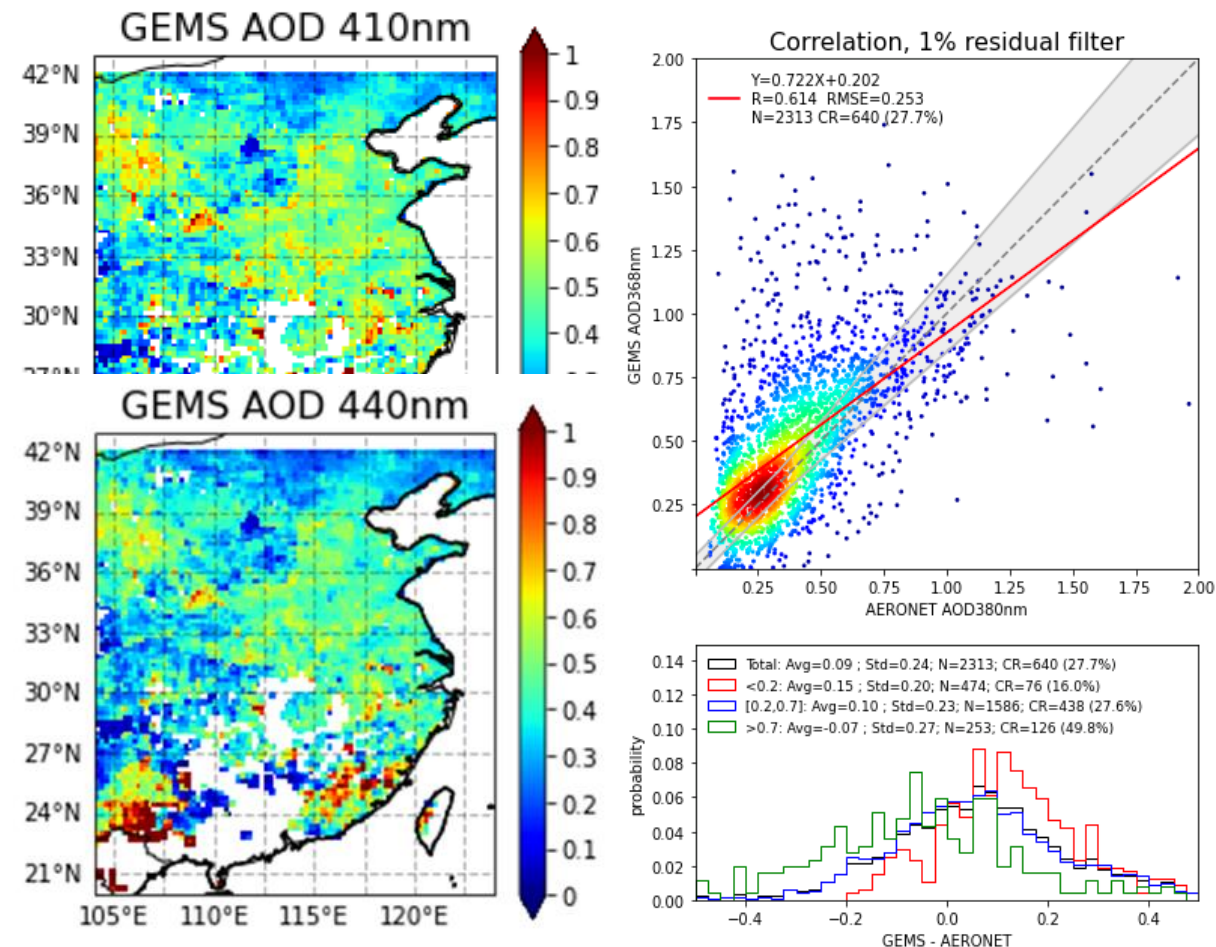
P. Litvinov (GRASP), A. Hangler (CLF)

10

Sentinel-4 Copernicus – Aerosol Layer Height (ALH) and Aerosol Index (AI)
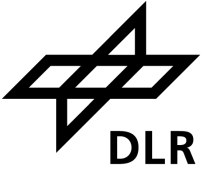
- **Heritage:**
  - ALH algorithm from S5P using information from the O2 A-Band

  - AI algorithm from TOMS using two different pairs

ALH Diurnal Variability of the Retrieval Error

Hour = 9

Precision of ALH retrieval [hPa]
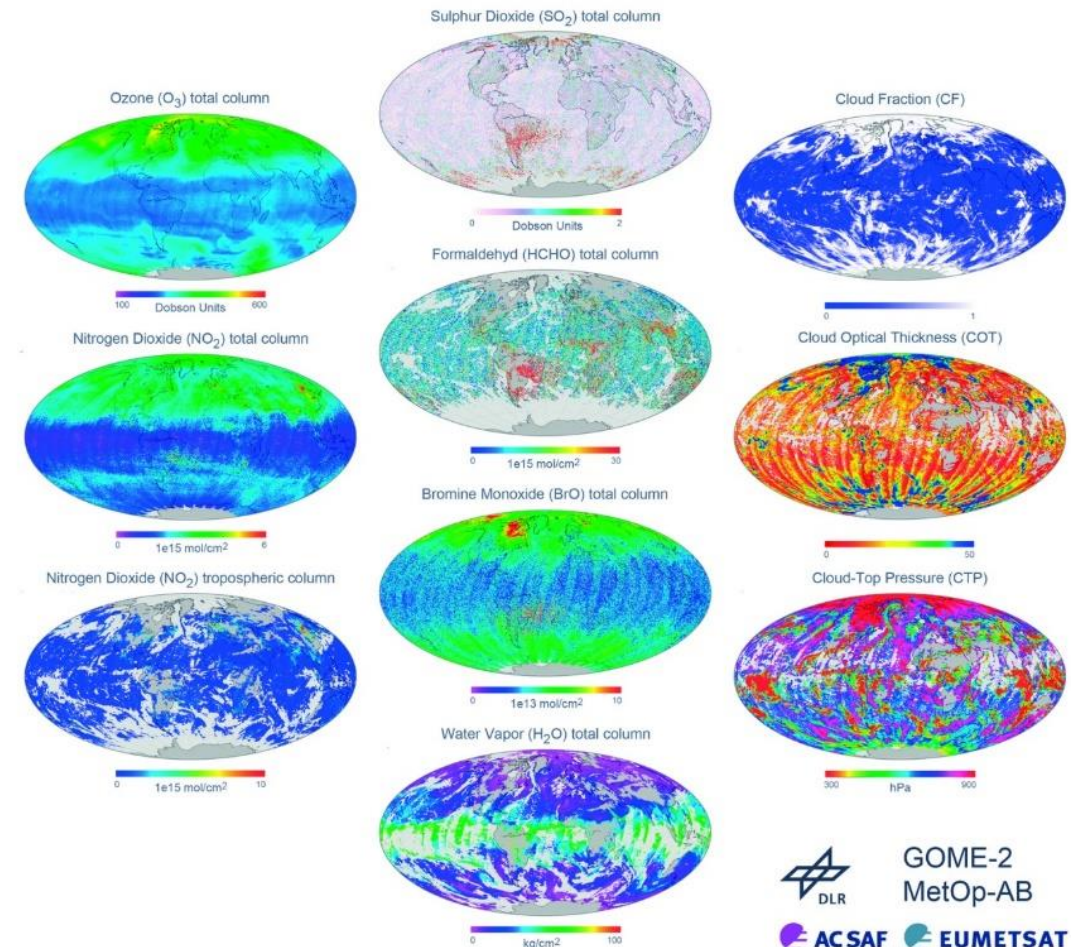
M. de Graaf (KNMI)

Sentinel-4 Geophysical Level-2 Products

- Copernicus L2 Products

- **AC-SAF L2 Products**

Sentinel-4 Products		
Species	**Parameter**	**Algorithm**
Operational		
H_2O	Total column	DOAS + iter. AMF
SO_2	Layer Height	FP_ILM
Research		
Surface	GE_LER	FP_ILM
BrO	Tropospheric column	DOAS
HONO	Nitrous acid during wildfires	DOAS
…		

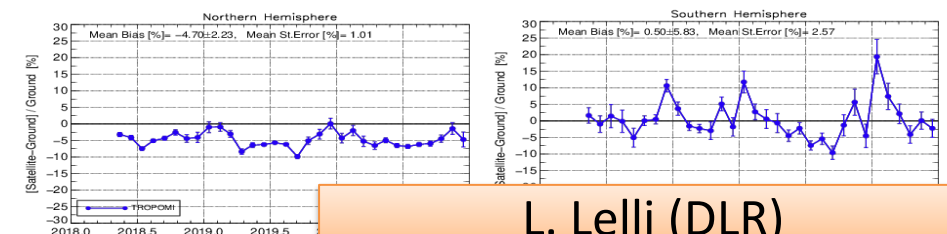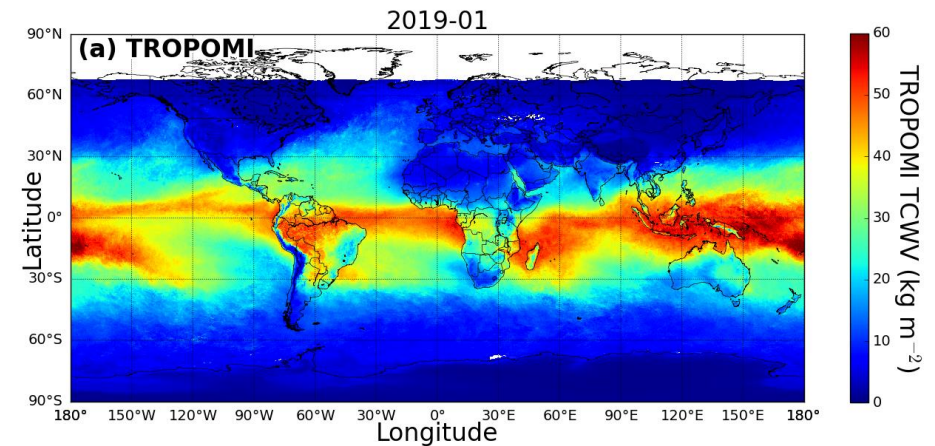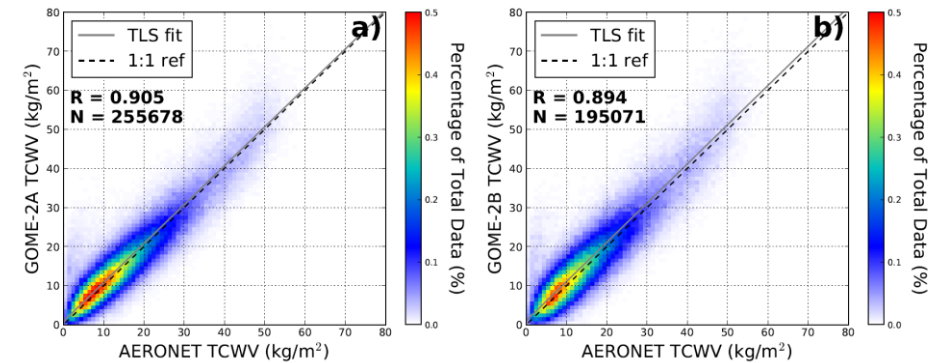Development & Operations: DLR and EUMETSAT AC-SAF

Sentinel-4 AC-SAF – Water Vapor

- **Heritage:**
  - DOAS fitting in the blue band
  - Iterative AMF/VCD calculation
    - WV profile climatology classified as function of TCWV based on 11 years of ERA-Interim

- Applied to:
  - GOME-2/MetOp
    - Chan et al. 2020, Vaquero et al., 2022
  - TROPOMI/S5p
   - Chan et al. 2021, Garane et al., 2023

L. Lelli (DLR)

Sentinel-4 AC-SAF – SO$_2$ Layer Height

Cumbre Vieja & Etna 2021

- **Heritage**: FP_ILM (Full-Physics Inverse Learning Machine)
  - PCA + Neural Network retrieval
  - Extremely fast and accurate SO$_2$ LH
  - Processing speed: ~3ms / pixel

- Applied to:
  - GOME-2/MetOp
    - Efremenko et al. 2017
  - TROPOMI/S5p
    - Hedelt et al. 2019
    - Inness et al. 2022
    - Koukouli et al. 2022
  - OMI/AURA
    - Fedkin et al. 2021

P. Hedelt (DLR)
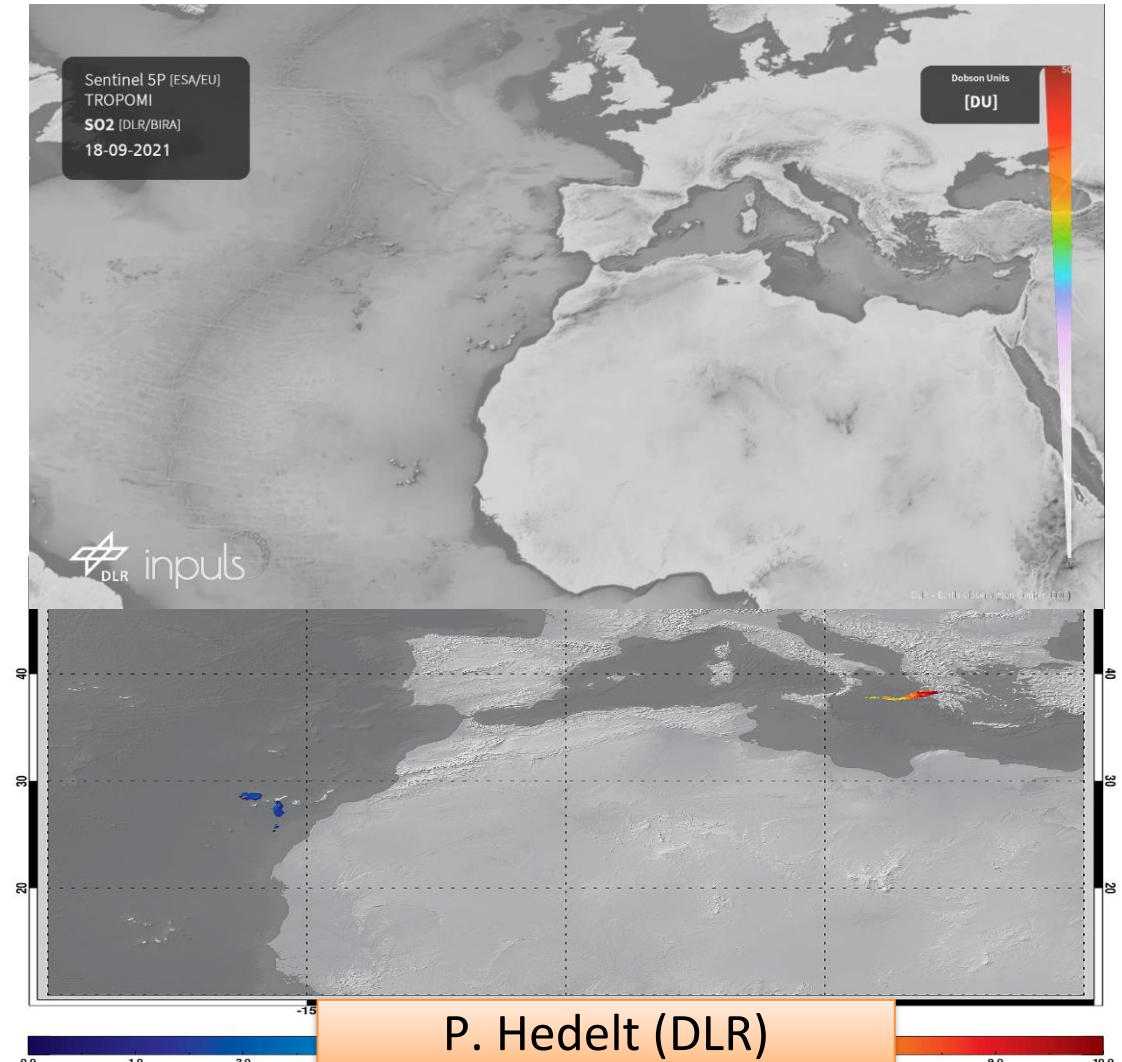
- HONO is a source of hydroxyl radical (OH) which can lead to enhanced VOC oxidation, formation of ozone and aerosols.

- Until recently, measurements of HONO mostly using in-situ and spectroscopic techniques from instruments on the ground or onboard aircrafts

- First satellite mapping of HONO in fire plumes using TROPOMI, Theys et al. 2020.

- **Potential added-value information on HONO using geostationary satellites (GEMS, TEMPO, Sentinel-4)**

GEMS 2021/03/01 - 2021/04/30

N. Theys (BIRA)
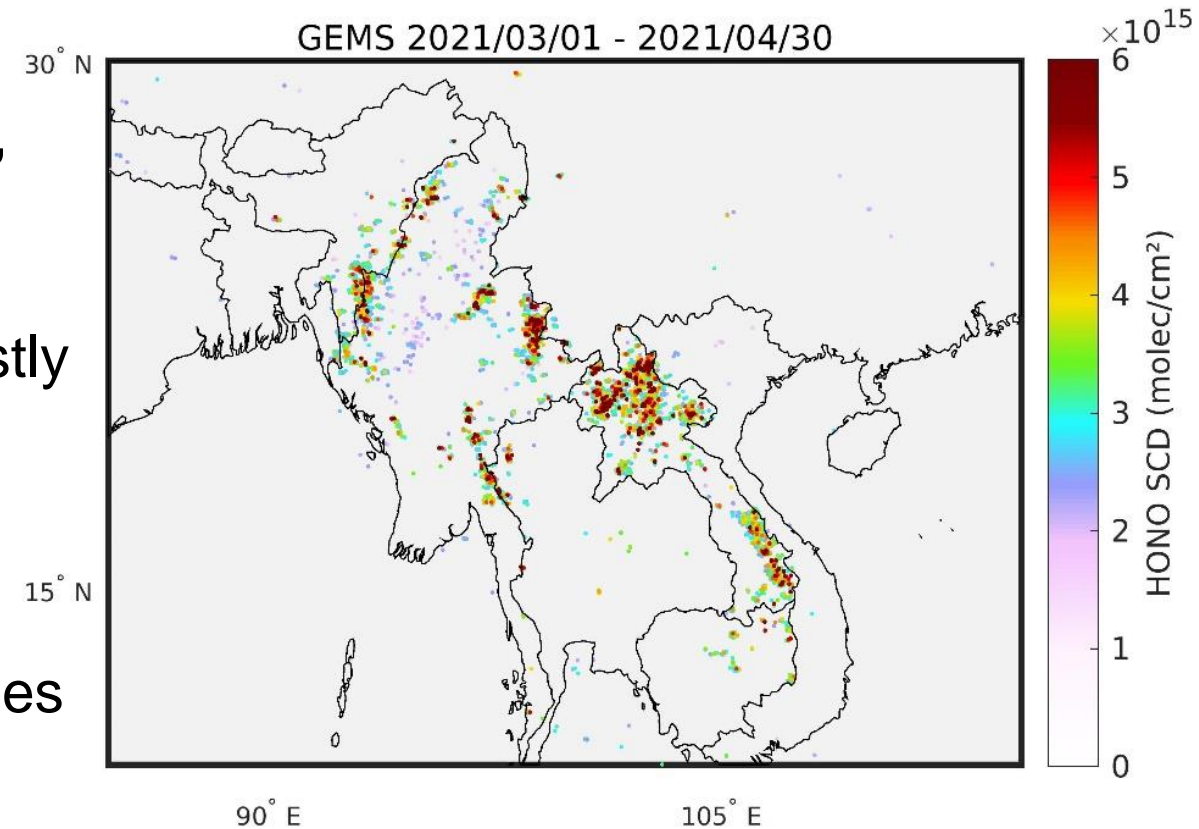
Acknowledgements

Sentinel-4 L2OP

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ESA: Giorgio Bagnasco, Olivier Le Rille, Ben Veihelmann, Shimon Machluf

GRASP: Pavel Lytvynov, Anton Lopatin

IUP-B: Andreas Richter, Lisa Behrens

KNMI: Pepijn Veefkind, Martin De Graaf, Maarten Sneep

LOA: Oleg Dubovik

MPIC: Thomas Wagner, Steffen Beirle, Janis Pukite, Simon Warnach

S&T: Daniele Fantin, Frank Vonk

RAL: Richard Siddans, , Ka Lok Chan, Andy Smith

RAY: Yves Govaerts, Marta Luffarelli

EUMETSAT: Lothar Schueller, Rasmus Lindstrot, …

FMI: Seppo Hassinen

DLR: Birgit Wunschheim, Pascal Hedelt, Klaus-Peter Heue, Stephan Kiemle, Luca Lelli, Suryakiran Maruvada, Julian Meyer-Arnek, Walter Zimmer