CO and CH_4 from TROPOMI on Sentinel-5 Precursor

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Copernicus
The European contribution to GEOSS

Services Component – led by EC

- Produces information services in response to European policy priorities in environment and security
- Relies on data from **in-situ** and **space component**

In-situ Component – led by EEA

- Observations mostly within national responsibility, with coordination at European level

Space Component – led by ESA

- Sentinels - EO missions developed specifically for Copernicus

Plus Contributing Missions - EO missions built for purposes other than Copernicus but offering part of their capacity to Copernicus

The Copernicus Mission Sentinel-5 Precursor

- Pre-operational, precursor to Sentinel-5
- Daily global observations of atmospheric composition
- Loose formation with Suomi-NPP/JPSS
- For air quality and climate services
- Payload = TROPOspheric Monitoring Instrument (TROPOMI)
- Jointly developed by Airbus Defense and Space Netherlands, KNMI, SRON and TNO, on behalf of the NSO and ESA.
- Planned launch date 2017
- 7 year design lifetime

TROPOMI on S5P

- UV-VIS-NIR-SWIR nadir view grating spectrometer
- Spectral range: 270-500, 675-775, 2305-2385 nm
- Spectral Resolution: 0.25-1.1 nm
- Spatial Resolution: 7x7km^2
- Global daily coverage at 13:30 local solar time

Assembled TROPOMI instrument

SWIR channel

S5P Level-2 Products (operational)

Species	Characteristics	expected accuracies
Ozone - O_3	vertical profile	10-30 % (6 km res.)
	total column	3.5 – 5 %
	tropospheric column	25%
Nitrogen dioxide - NO_2	total column	<10%
	tropospheric column	25-50%
Sulphur dioxide - SO_2	SO_2 enhanced	30 %
	total column	30 – 50 %
Formaldehyde - HCHO	total column	40 – 80 %
Methane - CH_4	total column	1.5 %
Carbon monoxide - CO	total column	< 15 %
Cloud	optical depth, fraction, height	<20 % (all parameters)
Aerosol	UV absorption index	~1 AAI
	layer height	< 100 hPa
Surface UV	spectral irradiance, UV index	TBD

+ Cloud data from VIIRS imager on Suomi-NPP

S5P Level-2 Products (research)

Species	Characteristics
Aerosol	fine mode optical depth
Glyoxal - CHOCHO	total column
Surface	effective reflectance
Water vapour - H_2O	total column
Bromine oxide - BrO	total column
Chlorine dioxide - OClO	total column
Iodine oxide - IO	total column
Semiheavy water - HDO	total column

…and potentially many others including e.g. SIF (solar induced fluorescence)

The 2.3 µm spectral range

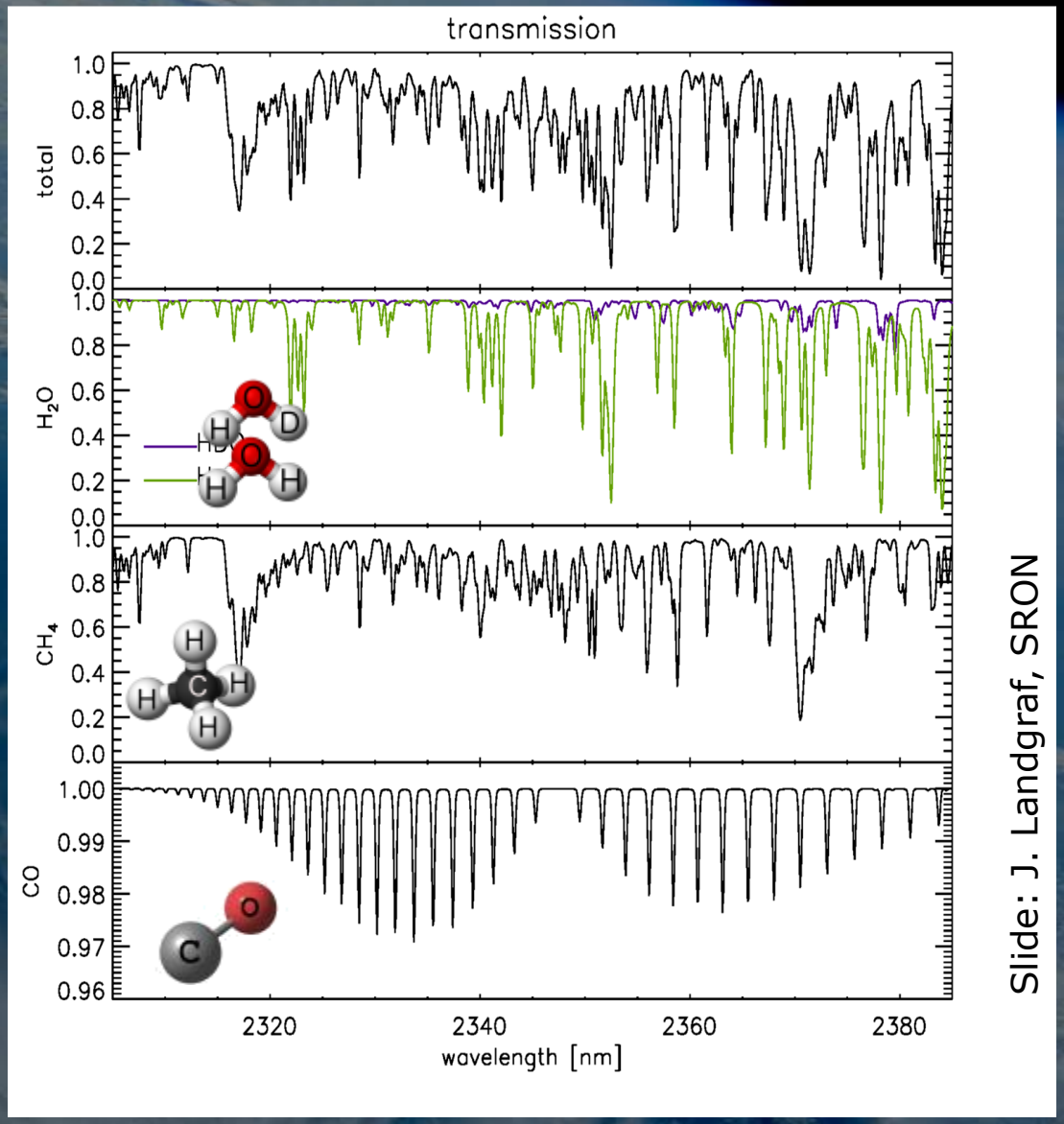
Spectral range contains information on:

- Water
- HDO
- Methane
- Carbon monoxide

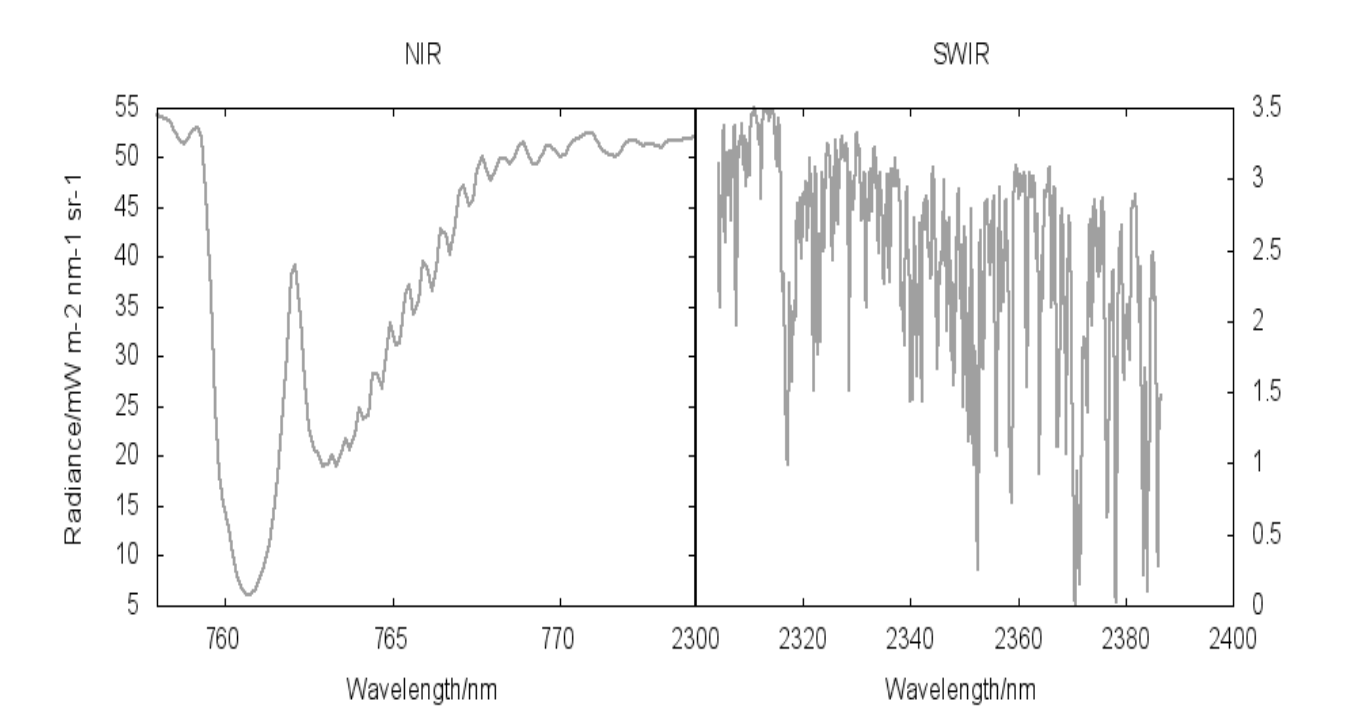
Quality requirement for operational data product:

CO: 10 % precision /
15 % accuracy

CH_4: 1 % precision /
1 % bias



Operational CH_4 algorithm: RemoTeC

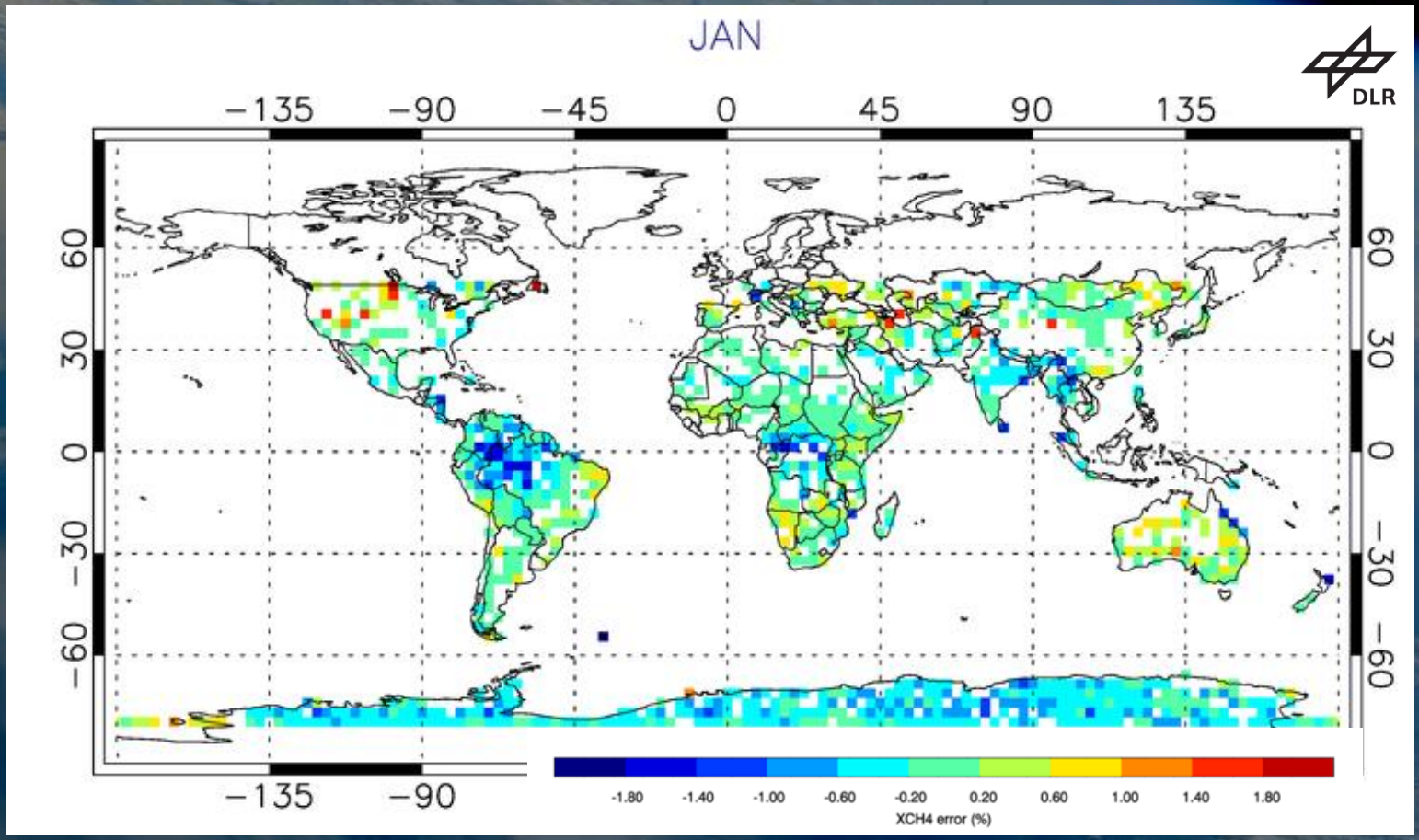


References:
Butz et al., 2009; 2010; 2011;
Schepers et al., 2012;2016
Guerlet et al., 2013;
Hu et al., 2016

- Cloud filtering using co-located VIIRS measurement
- Remaining scattering by aerosols and thin cirrus is accounted by the retrieval (O_2 A band in the NIR, and strong CH_4 bands in the SWIR)
- Height of a scattering layer, size and number of scattering particle, H_2O, CH_4, CO, surface albedo, spectral calibration, SIF
- 10 seconds per ground pixel

Slide: J. Landgraf, SRON

CH_4 bias estimate for four-day ensemble simulated clear sky measurements



Slide: J. Landgraf, SRON

➔ For 94 % of all cases bias < 1 %, rms error 0.55 %

Operational CO algorithm: SICOR

Band 1: 2315-2324 nm

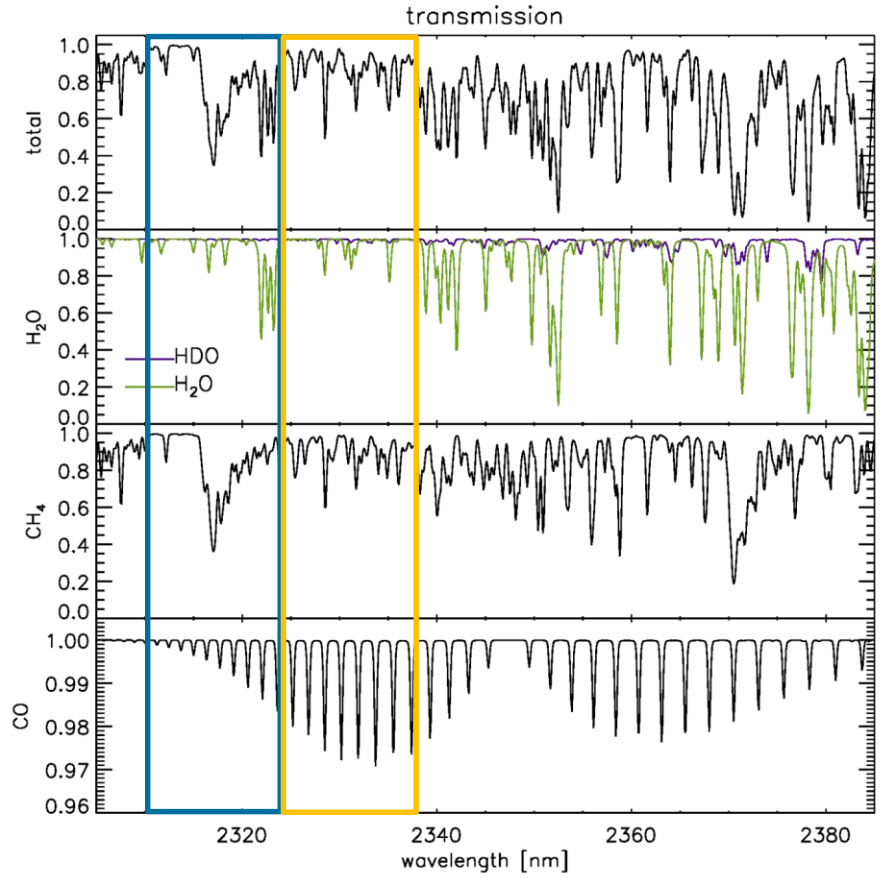
Non-scattering retrieval, difference between retrieved CH_4 and a priori knowledge used to filter on high and optically thick clouds

Band 2: 2324-2338 nm

Physics-based retrieval:

Fit parameters: CO, H_2O, scattering optical depth and scattering layer height, using a priori CH_4. Retrieval uses a two stream RTM.

➔ Processing time: 0.15 seconds per ground pixel



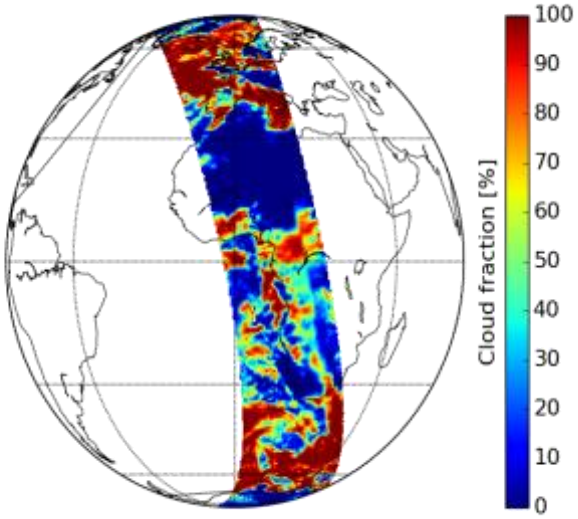
Slide: J. Landgraf, SRON

Reference:
Gloudemans et al., 2009 / Vidot et al., 2012,
Borsdorff et al., 2014, 2015
Landgraf et al., 2016

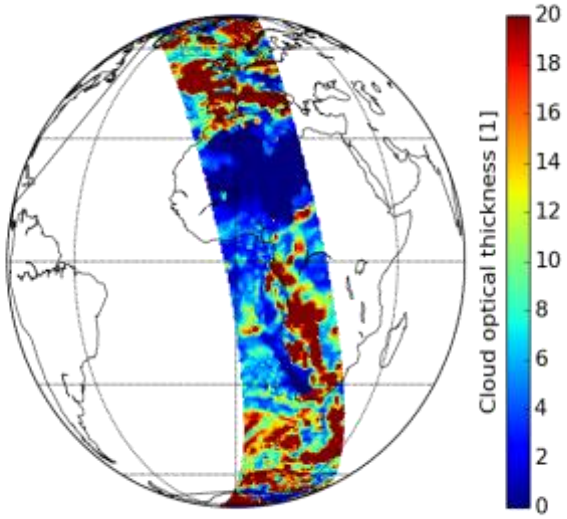
TROPOMI orbit ensemble (1)

simulated measurements with resampled MODIS cloud data to TROPOMI pixel size

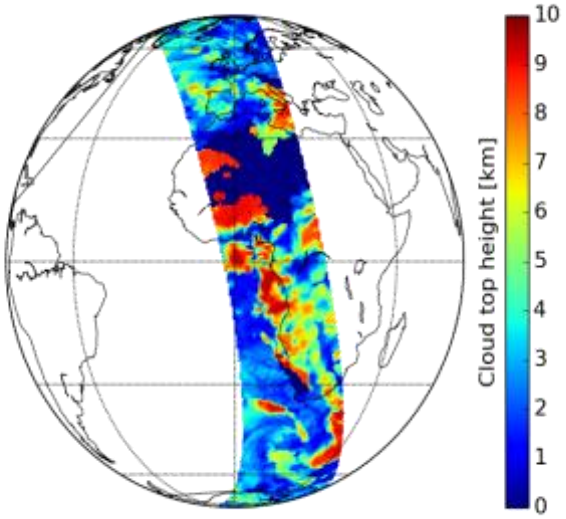
Slide: J. Landgraf, SRON



cloud fraction



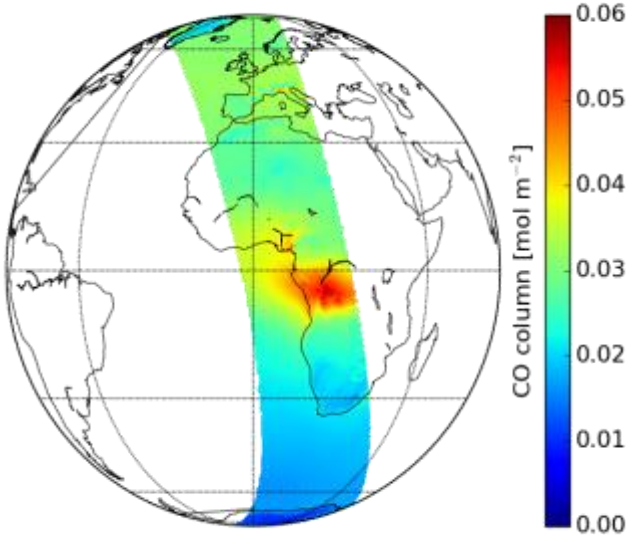
cloud optical depth



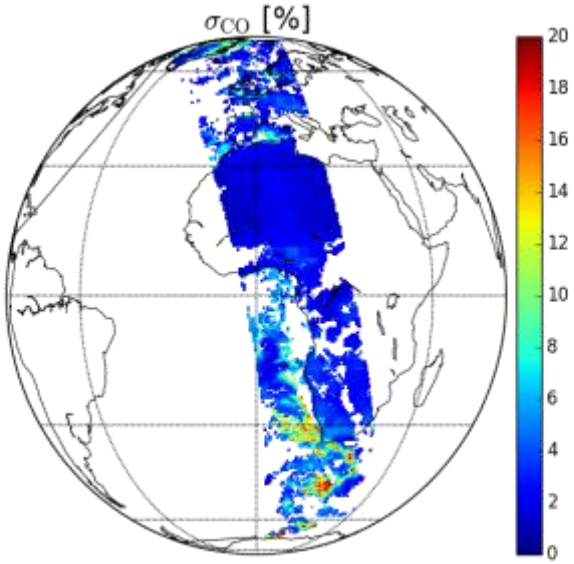
cloud top height

TROPOMI orbit ensemble – CO column

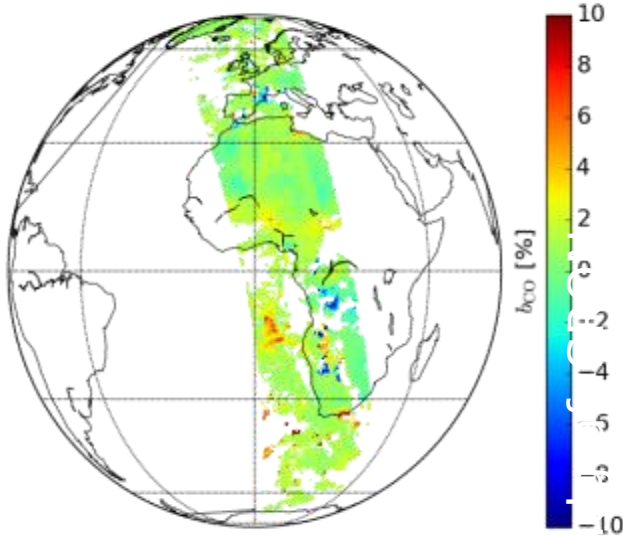
Slide: J. Landgraf, SRON



Biomass burning event central Africa



Overall very good precision



Small biases with some outliers <8% due to simple cloud model

Status of Sentinel-5P

Activity	Status
TROPOMI on-ground calibration and characterisation from Dec 2014 until Apr 2015	✓
Instrument into S5P satellite integration in May 2015	✓
Assembly, integration and testing (AIT) until early 2016	✓
Flight acceptance review (FAR) – Mar 2016	✓
Delivery to launch site (Plesetsk/Russia) – early 2017	?
Launch window opens end March 2017	?

S5P CalVal - Some Key Findings

- Ozone profile and total column well covered, except for the required measurement spatial representativity and specific environmental conditions
- Tropospheric ozone, NO_2 and formaldehyde well covered but lacking global validation and in particular for the tropics
- SO_2 lacks redundancies and validation capabilities for high SO_2 pollution
- CO and methane validation at risk, in particular as a result of funding issues for validation, e.g. TCCON
- Clouds and aerosol layer height well covered
- AAI validation only against other satellites
- Level 1b lack any redundancy and covering only UV/VIS

Conclusion

Sentinels-5P

- Embarks the UVNS instrument TROPOMI on a dedicated satellite
- Will provide global daily atmospheric composition observations incl. CO and CH_4
  - for the Copernicus Atmosphere Monitoring Service (CAMS)
  - for the Copernicus Climate Change Service (C3S)
  - for the future Emergency Management Service
- Is part of the CEOS AQ Constellation
  - acts as a "travelling standard" between the GEOs (TEMPO, S4, GEMS)
  - target common formats and static aux data, coordinated cal/val activities, reviews, …
- Bridges the gap between OMI on Aura and Sentinel-5
- Will fly in "loose formation" with Suomi NPP to use VIIRS for cloud clearing
- Is ready for launch, wait for launcher availability, launch scheduled in 1st Q 2017

Thank You

Any Questions?

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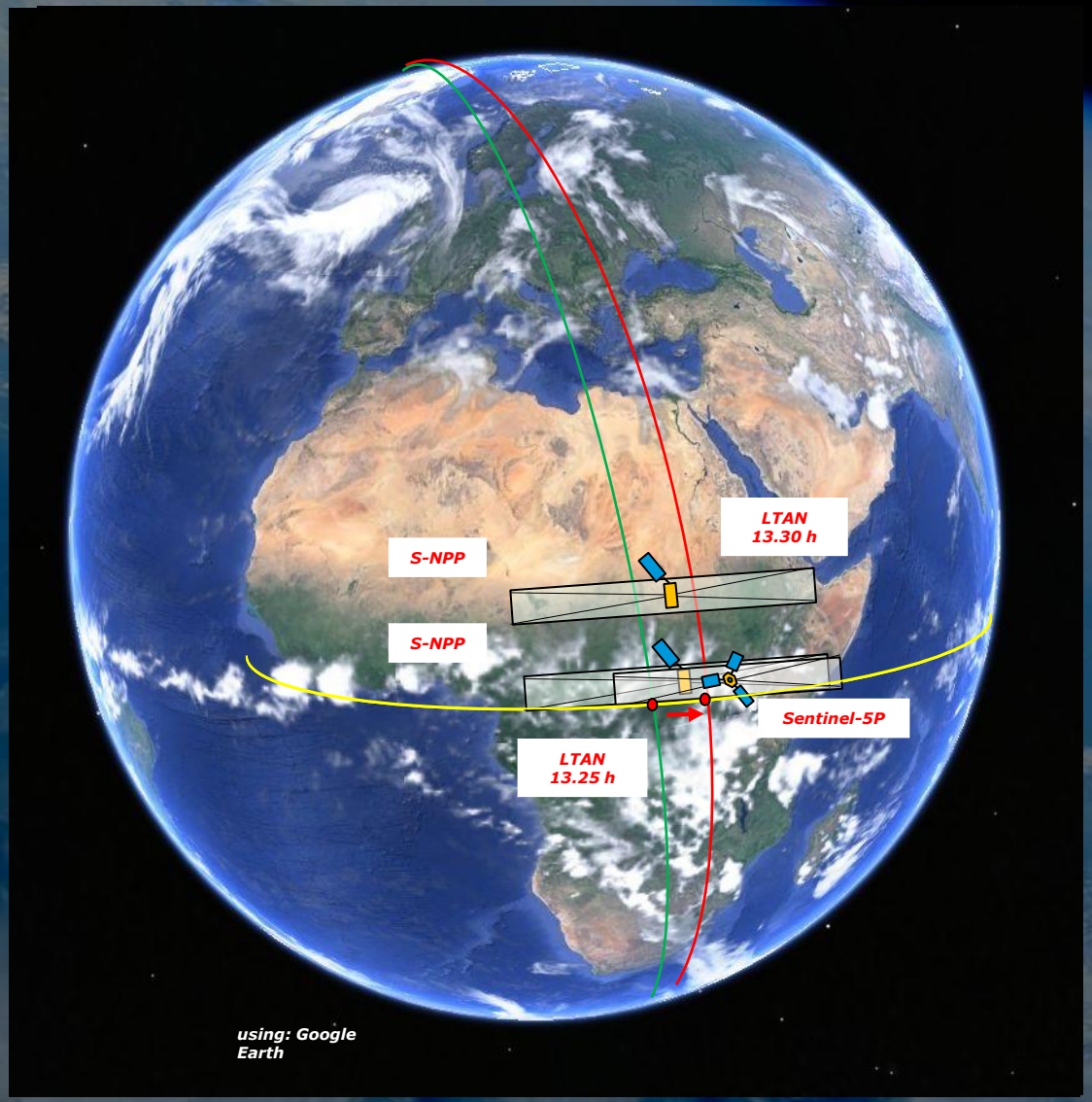
esa

sentinel-sp

Joint Operation of S5P with S-NPP

- TROPOMI SWIR channel L2 processing (CH_4) relies on accurate, high resolution cloud mask data
- phased operation with NASA's Suomi-NPP envisaged
- routine delivery of S-NPP/ VIIRS products to PDGS

Suomi-NPP: Launched Oct. 2011



S5P - Swath

Campaigns

Sep 2016 (presently on-going)

CINDI-2 Cabauw/NL - intercalibration of reference ground-based systems planned for NO_2, O_3, HCHO, O_4 → NDACC intercomparison, network setup

- Full suite of PANDORA, (MAX-)DOAS, Lidar, sunphotometer systems
- NO_2/O_3 sondes, in-situ systems, …

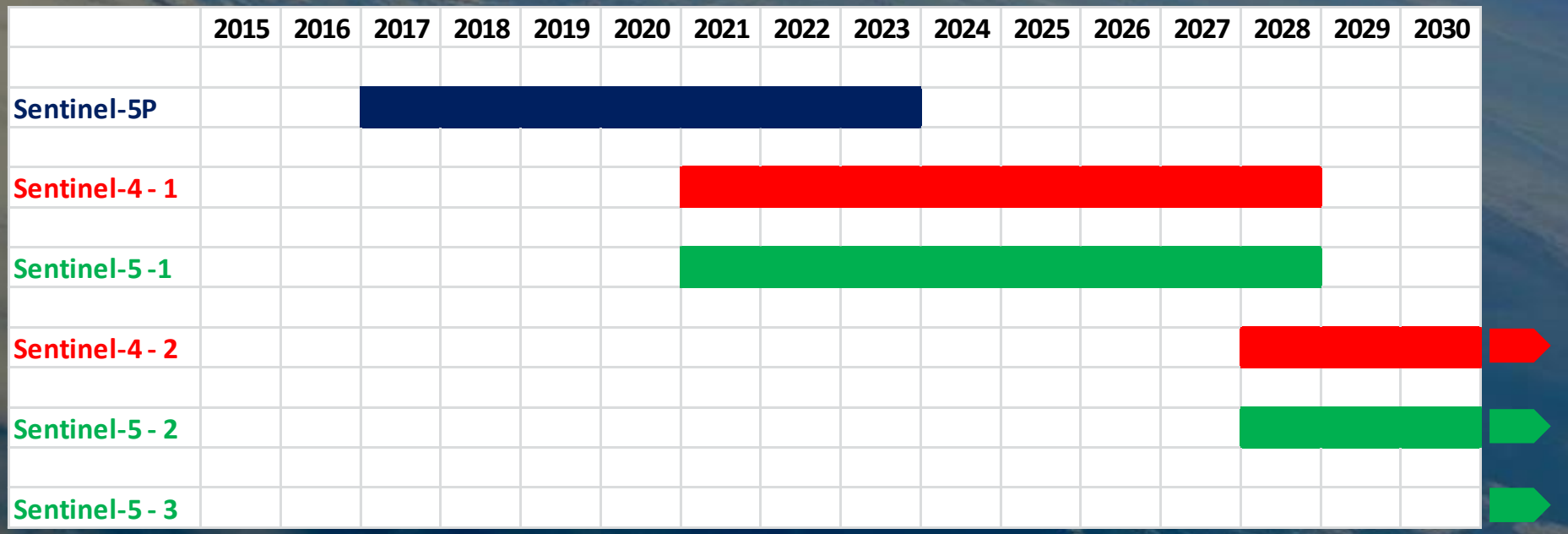
2018

(1) Deployment of suite of airborne and ground-based mobile/imaging systems for small scale variability analysis and TROPOMI validation in urban environment (NO_2, SO_2, HCHO, aerosol) → Romania, summer clear-sky

- AirMap, NO_2 sonde, SWING UAV, mobile DOAS, fast azimuth scan MAXDOAS, PANDORA, ground-based imaging DOAS, aerosol …

(2) Cloud impact campaign, instrumentation TBD → Cabauw/NL, Spring/summer/autumn

Launch Schedule of Atmospheric Sentinels



S5P and S5 = LEO
S4 = GEO

Overview: ESA's CAMS Related Missions

MetOp-SG B
- SCA
- MWI
- RO
- ICI
- Argos–4

MTG-S
- IRS
- Sentinel-4 UVN

Sentinel-5P
- TROPOMI

+SNPP

MetOp-SG A
- METimage
- IASI-NG
- MWS
- RO
- Sentinel-5 UVNS
- 3MI

MTG-I
- FCI
- LI

Graphics: ESA

S5P L-2 Algorithm Development

KNMI

DLR

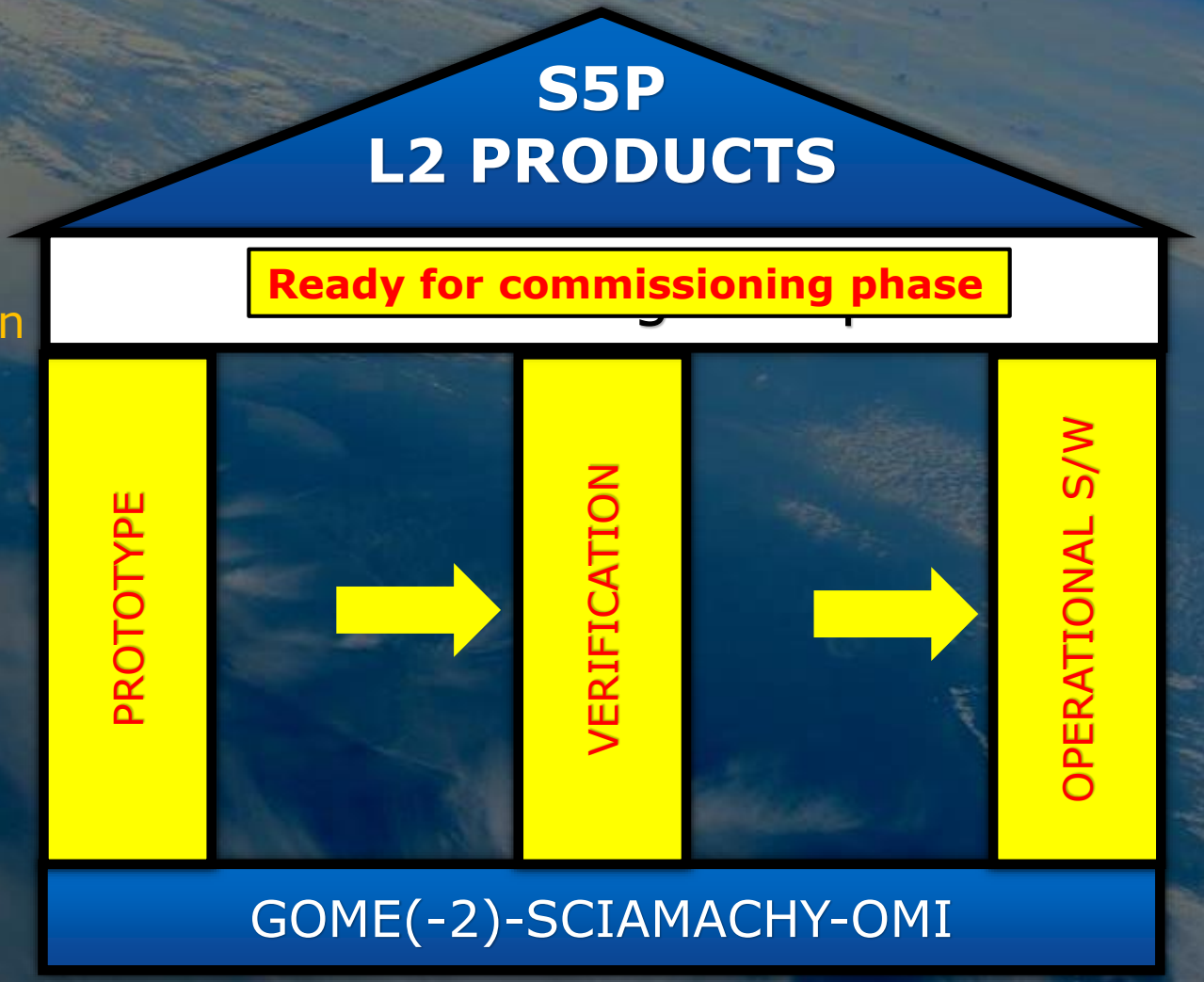
IUP-Bremen

BIRA

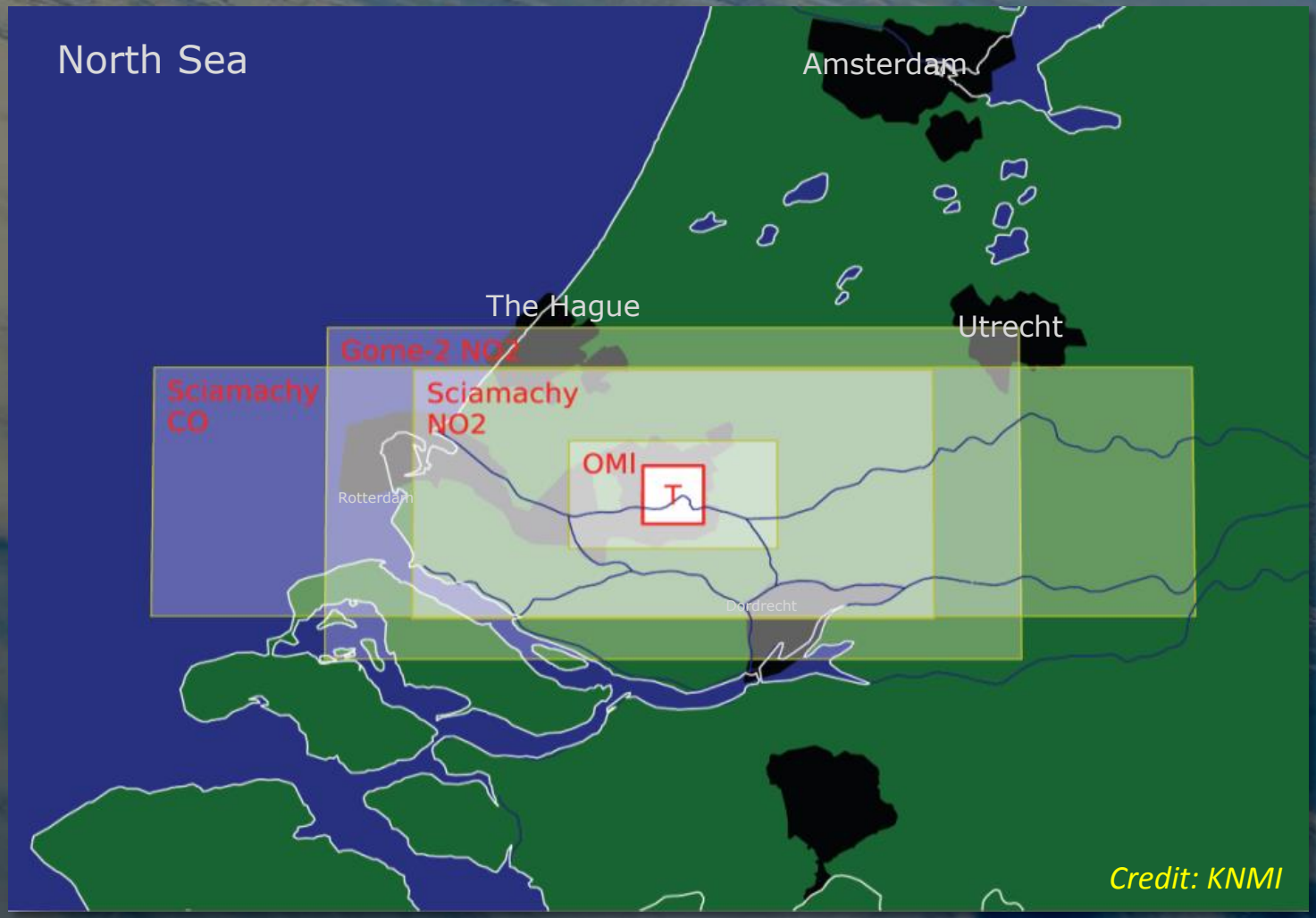
SRON

MPIC

RAL



S5P Spatial Resolution



Scia CO
120x30 km^2

Scia NO_2
60x30 km^2

GOME-2 NO_2
80x40 km^2

OMI
13x24 km^2

TROPOMI
7x7 km^2

Sentinel-5 Precursor Data Dissemination

- Data Volume:

Product type	GB per Orbit	GB per day
Level 1b Radiance NRT/OFL	(2 x) 35.6	(2 x) 504
Level 1b Irradiances OFL	0.03	0.42
Level 2 NRT	4.27	60.6
Level 2 OFL	5.24	74.3
Total	**45.1**	**639**

- Data Organisation
  - Level 1b radiance is provided as separate files for each of the 8 bands
    - Plus UV-UVIS-NIR and SWIR solar irradiance product
  - Each geophysical Level 2 parameter is provided in a dedicated product
  - Data format is netCDF-4 using Climate and Forecasting Metadata Standards
  - Data format harmonisation with heritage and future Sentinels

Sentinel-5 Precursor Data Access

- The Sentinel-5P core products list agreed with the Commission currently includes **Level-1** and **Level-2 products**

- Systematically provided on-line **to ALL users** in both Near-Real-Time (NRT, within 3 hrs from sensing, TBC) and Non-Time-Critical (NTC, within 14 days after sensing)
  - The relevant Copernicus Services will access the core products via the dedicated access point with strict guaranteed quality of service and associated Key Performance Indicators
  - Other users will access the core products via the Sentinels Scientific Data Hub. This will be provided without strict timeliness guaranteed albeit with expected nominal performances

Note:

expert users supporting the S5P commissioning and Cal/Val tasks will have access to the products (NRT and NTC) via specific mechanisms (e.g. open access data hub, dedicated data access points)