

Air Quality Satellite Monitoring by TROPOMI on Sentinel-5P

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Abstract

The latest launched Sentinel satellite mission, the Sentinel-5 Precursor (Sentinel-5P) is one of the European Space Agency's (ESA) new mission family – Sentinels. The sole payload on Sentinel-5P is the TROPospheric Monitoring Instrument (TROPOMI), which is a nadir-viewing 108 degree Field-of-View push-broom grating hyperspectral spectrometer, covering the wavelength of ultraviolet-visible (270 nm to 495 nm), near infrared (675 nm to 775 nm), and shortwave infrared (2305 nm - 2385 nm). Sentinel-5P is the first of the Atmospheric Composition Sentinels and is providing measurements of ozone, NO₂, SO₂, CH₄, CO, formaldehyde, aerosols and cloud at high spatial, temporal and spectral resolutions. The NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) is one of the 12 Distributed Active Archive Centers (DAACs) within NASA's Earth Observing System Data and Information System (EOSDIS). The GES DISC archives and supports over a thousand data collections in the Focus Areas of Atmospheric Composition, Water & Energy Cycles, and Climate Variability. Under the End User License Agreement between NASA and ESA, GES DISC is curating TROPOMI Level-1B and Level-2 products and providing information services through enhanced tools and services that offer facile solutions for complex Earth science data and applications. This presentation will demonstrate up-to-date TROPOMI products including earthview radiance, solar irradiance, aerosol layer height, Carbon Monoxide, Nitrogen Dioxide, and cloud, as well as easy ways to access, visualize and subset TROPOMI data.

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NASA/Goddard Earth Sciences Data and Information Services Center (GES DISC)

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Introduction

The recently launched Sentinel satellite mission, the Sentinel-5 Precursor (Sentinel-5P), is one of the European Space Agency's (ESA) new mission family – Sentinels. The sole payload on Sentinel-5P is the TROPospheric Monitoring Instrument (TROPOMI), a nadir-viewing 108° field-of-view push-broom grating hyperspectral spectrometer, covering the wavelengths of ultraviolet-visible (270 nm - 495 nm), near infrared (675 nm - 775 nm), and shortwave infrared (2305 nm - 2385 nm). Sentinel-5P is the first of the Atmospheric Composition Sentinels, and is providing measurements of atmospheric chemistry, aerosols, and clouds at high spatial, temporal, and spectral resolution.

The NASA Goddard Earth Sciences Data and Information Services Center (GES DISC) supports over a thousand data collections in the focus areas of Atmospheric Composition, Water & Energy Cycles, and Climate Variability. Sentinel-5P TROPOMI Level-1B (L1B) and Level-2 (L2) products are curated at the GES DISC. Sentinel-5P data are provided by the European Union and the European Space Agency (ESA) through an agreement between ESA and NASA.

Through its convenient and enhanced tools/services, such as OPeNDAP and L2 Subsetting, GES DISC offers the air quality remote sensing user community facile solutions for using complex Earth science data and applications.

This presentation will demonstrate up-to-date TROPOMI products including EarthView (EV) radiance, solar irradiance, Aerosol Index, Carbon Monoxide, Total column Ozone, Nitrogen Dioxide, and cloud, as well as easy ways to access, visualize and subset TROPOMI data.

Instrument Specification

Table 1: Instrument Specification Comparisons between Sentinel-5P TROPOMI, Aura OMI, and S-NPP OMPS

Satellite	Sentinel-5P	S-NPP	Aura
Sensor	TROPOMI	Nadir Mapper (NM)	Nadir Profiler (NP)
Spectrometer	Push-broom grating spectrometer 2D CCD	Push-broom grating spectrometer 2D CCD	Push-broom grating spectrometer 2D CCD
Spectral coverage	UV-VIS: 270–495 nm NIR: 675–775 nm SWIR: 2305–2385 nm	300 – 380 nm	250 – 310 nm
Spatial resolution	7 X 3.5 km near nadir	50 X 50 km at nadir	250 X 250 km
Field-of-View	108° (2600 km)	110° (2800 km)	16.6°
Spectral resolution	0.23 – 0.5 nm	1.1 nm	1.1 nm
Ascending node equator local crossing time	~13:30	~13:30	~13:45



Figure 1: This figure demonstrates the satellite footprint size comparison between Aura/OMI and S5P/TROPOMI. The Airborne Prism Experiment (APEX) was an airborne flight campaign held in Antwerp, Brussels, and Liege in Belgium. TROPOMI's wide spectral coverage and the 3.5km by 7km spatial resolution bring space-based atmospheric chemistry remote sensing capability to a new, improved level (Frederick Tack et. al.).

Acknowledgment: The authors acknowledge ESA for the S5P/TROPOMI products. Acknowledgment also goes to S5P/TROPOMI and S-NPP/OMPS L1B calibration/validation and L2 Science Teams for the science algorithms.

Available Products

S5P/TROPOMI has eight L1B radiance orbital products, corresponding to TROPOMI's eight spectral bands. The spatial resolution for L1B radiance is 7 x 3.5 km, except for band 1, band 8, and band 9. Compared to S-NPP OMPS L1B radiance (figure 2a), which has 50 by 50 km spatial resolution, TROPOMI allows perception of structures in cloud, atmosphere, and surface data in much finer detail (figure 2b). Another noticeable improvement is the cross-orbital continuity, especially for longer wavelengths (figure 2c).

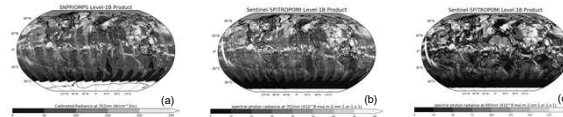


Figure 2: EV radiance on July 1st 2018. (a) S-NPP OMPS radiance at 352nm; (b) TROPOMI radiance at 352nm; (c) TROPOMI radiance at 693nm.

S5P/TROPOMI L1B solar irradiance has two daily products, one in the UV-VIS-NIR spectrum range (figure 3a), and the other in the shortwave infrared spectrum range (figure 3b). Currently, TROPOMI L1B calibration is experiencing certain issues, one of which is the discrepancy between band 2 and band 3 (figure 3c). However, TROPOMI L2 retrieval algorithms prefer to use the ratio of radiance and irradiance, which cancels out the influence of the absolute irradiance drifts.

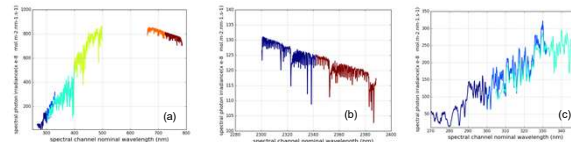


Figure 3: Solar irradiance on October 1st 2018. (a) UV-VIS_NIR spectrum; (b) shortwave infrared spectrum; (c) Band 2 and band 3 discrepancy.

As an atmospheric chemistry satellite instrument, S5P/TROPOMI's main L2 products are closely related to air quality monitoring, including trace gases, aerosols, and also clouds. Scientists are avidly exploring many potential utilizations of the information that S5P/TROPOMI provides.

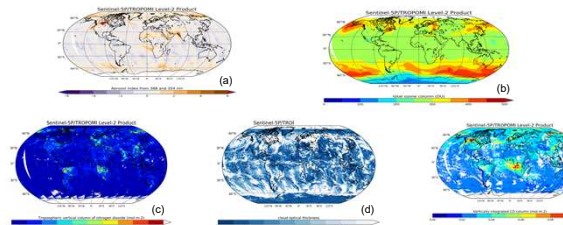


Figure 4: S5P/TROPOMI L2 product samples - (a) UV Aerosol Index, 10/25/2018; (b) Total Column Ozone, 10/25/2018; (c) Tropospheric Vertical Column Nitrogen Dioxide, 8/15/2018; (d) Cloud Optical Thickness, 10/25/2018; (e) Vertical Integrated Column Carbon Monoxide, 7/1/2018.

Current Tools for S5P/TROPOMI

• Search the data via GES DISC UI page (<https://disc.gsfc.nasa.gov/>) using keyword "S5P" or "s5p" to browse all the available products. This is the most direct and convenient way.

• For each specific data collection, users are able to:

- See and download all the data files on GES DISC public data servers via HTTPS;
- Use the Earthdata Search across multiple data centers;
- Search for specific regions and/or time periods by using the GES DISC search engine.

• Via OPeNDAP protocol

OPeNDAP is a Web-based visualization tool for online data in Data Pools. Users are able to view data field structures defined in the metadata. Users can also choose to download specific variable(s) in either NetCDF-4 or ASCII format.

Application Use Case

In mid-August 2018, the western United States and Canada experienced deadly blazes that destroyed structures and affected the lives of millions of people. Figure 5a is the true color image from S-NPP VIIRS. S5P/TROPOMI detected high densities of carbon monoxide (CO, Figure 5b) and high positive UV aerosol index (Figure 5c), which could indicate absorbing black carbon aerosols caused by biomass burning. Figure 5b also shows that UVAI can detect aerosols when clouds are present. Figure 5d-e demonstrate how the atmospheric effects of this huge biomass burning event spread throughout southern Canada and the northern USA.

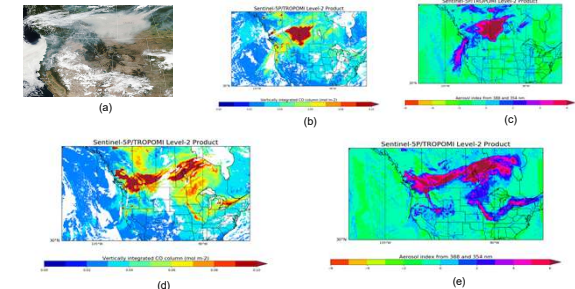


Figure 5: The wildfire event in mid-August of 2018 in the northwestern United States and southwestern Canada. (a) is the S-NPP/VIIRS true-color image in the interested region; (b) and (c) are S5P/TROPOMI CO and UVAI in North America on August 15th, 2018; (d) and (e) are S5P/TROPOMI CO and UVAI in North America on August 18th, 2018.

Huge Saharan dust plumes in late June and early July of 2018 passed over Mauritania, Senegal, Gambia, and Guinea-Bissau before moving out over the Atlantic Ocean. The dust plumes were clearly seen in the S5P/TROPOMI UV AI image (figure 6c) but did not appear in the CO image (figure 6b), proving the absorbing aerosols are non-smoke particulates. Figure 6a shows the NASA Goddard Earth Observing System Model, Version 5 (GEOS-5) model simulation.

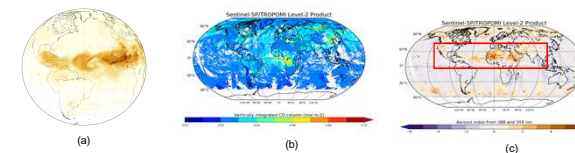


Figure 6: The transatlantic dust plumes (in the red box) on July 1st, 2018. (a) is the GEOS-5 simulation. (b) and (c) are S5P/TROPOMI CO and UVAI L2 products.

Summary and Future Work

- S5P/TROPOMI L1B and L2 products are currently available at NASA/GES DISC. For the air quality user community, TROPOMI's high spatial/spectral resolution and its wide spectral coverage are very useful for many applications.
- More S5P/TROPOMI L2 products will be available in late 2018 and mid 2019. These products will include Sulfur Dioxide, Formaldehyde, Tropospheric Ozone, Full Ozone profile, Tropospheric Ozone profile, and Aerosol Layer Height.
- S5P/TROPOMI L1B data processing will attempt to improve along-track spatial resolution to 5.5km.
- S5P/TROPOMI is providing both the UV Aerosol Index and the vertical integrated CO column products. The combination of these two products can be used to separate biomass burning aerosols from non-smoke aerosols.

Reference: Tack, Frederick & Merlaud, Alexis & Iordache, Marian-Daniel & Danckaert, Thomas & Yu, Huan & Fayt, Camille & Meuleman, Koen & Deutsch, Felix & Fierens, Frans & Van Roozendael, Michel. (2017). High-resolution mapping of the NO₂ spatial distribution over Belgian urban areas based on airborne APEX remote sensing. Atmospheric Measurement Techniques. 10. 1665-1688. 10.5194/amt-10-1665-2017.