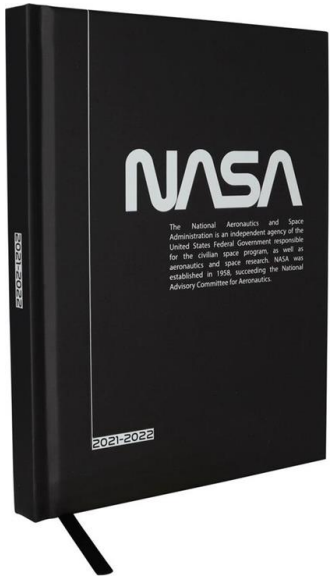
National Aeronautics and Space Administration

Finding your TEMPO: An introduction to the mission, products, and data services for air quality observations over N. America

Caroline Nowlan, Center for Astrophysics
Gonzalo González Abad, Center for Astrophysics
Daniel Kaufman, ASDC
Hazem Mahmoud, ASDC
05/29/2024

Agenda

- Mission introduction
- Data product details
- Accessing TEMPO data on Earthdata Search
  - Finding documentation
  - Searching and filtering
  - Subsetting and concatenating
- Additional TEMPO information resources
- Asking questions on Earthdata Forum
- How to learn more
- Q&A



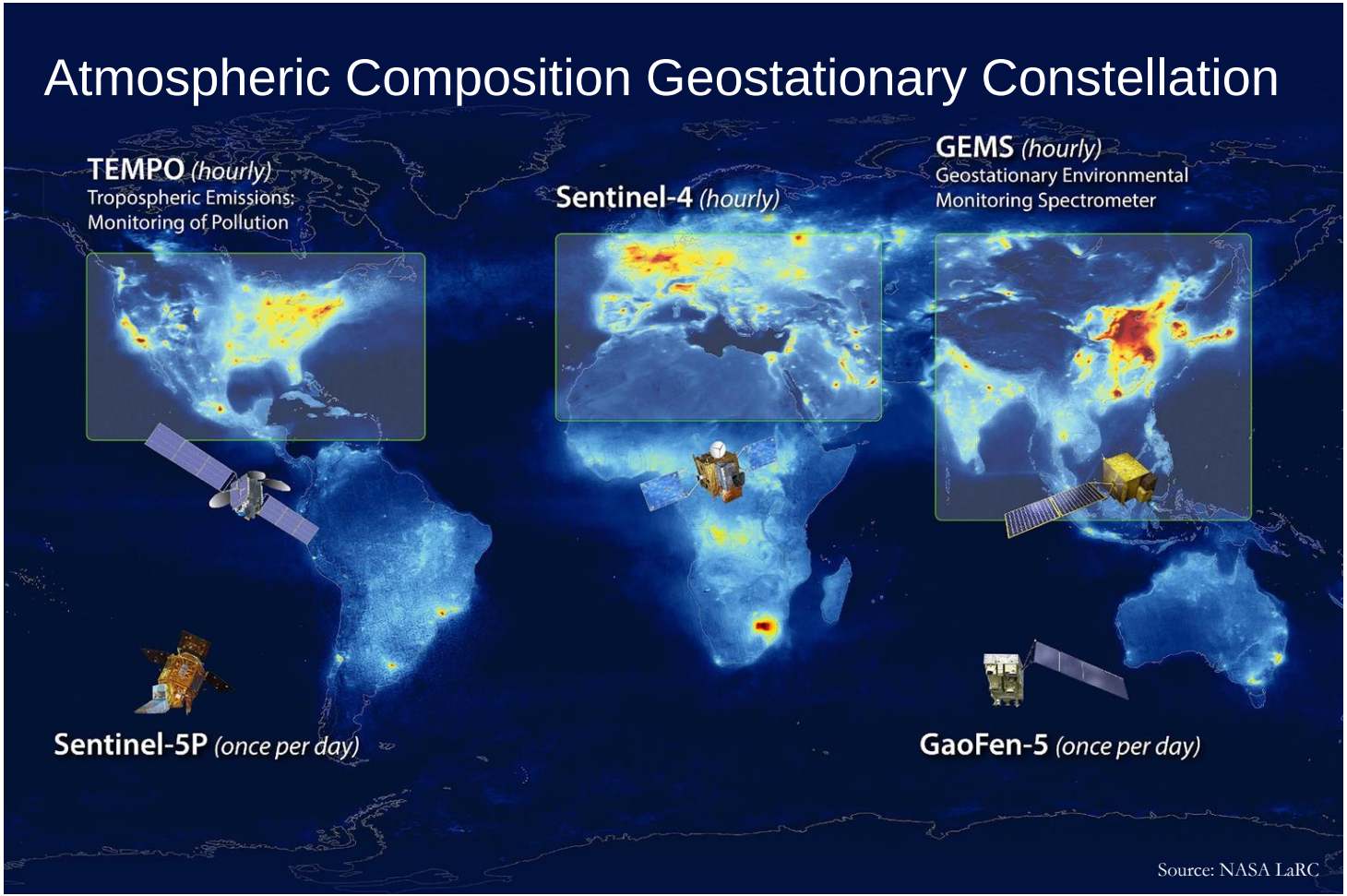
Mission Intro

Tropospheric **E**missions: **M**onitoring of **Po**llution

- Hourly daytime air pollution measurements over North America
- NASA's first Earth Venture Instrument (EVI), selected in 2012
- **Geostationary orbit** means TEMPO can scan the continent continuously
  → High temporal resolution
  → High spatial resolution
- Baseline data products:
  - Ozone
  - Nitrogen dioxide
  - Formaldehyde

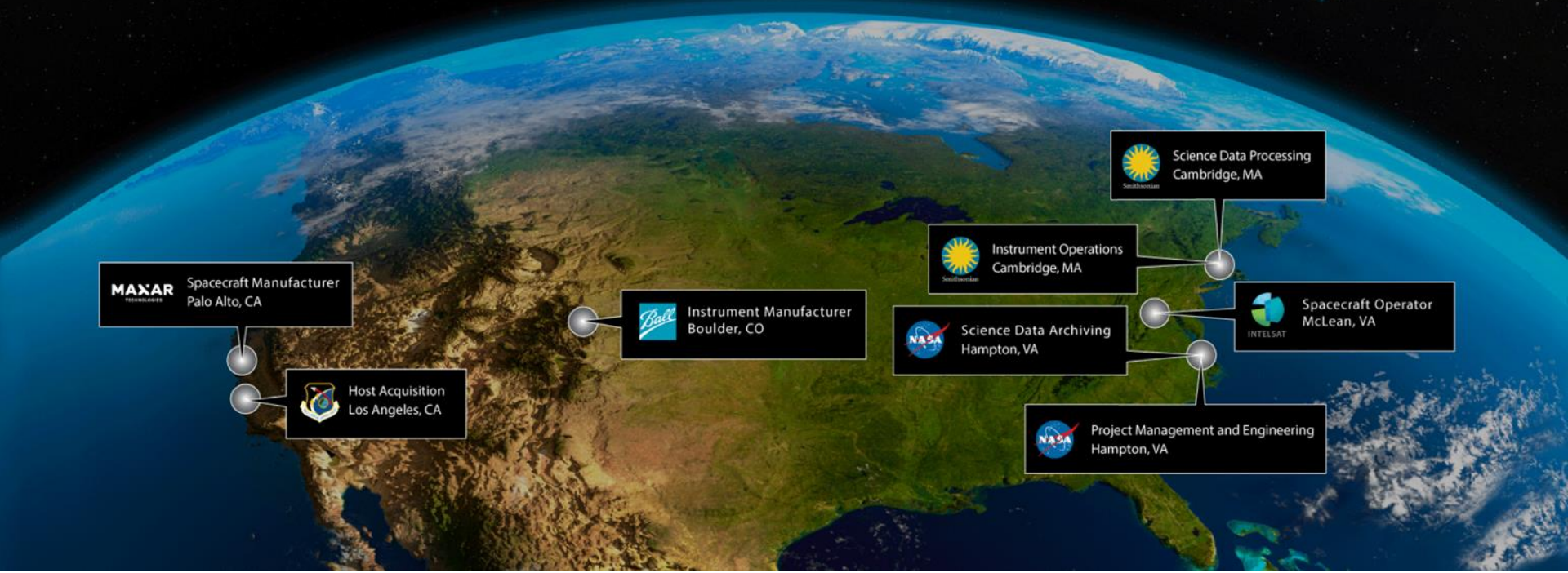
Credit: NASA's Scientific Visualization Studio

Atmospheric Composition Geostationary Constellation



PI: Xiong Liu (Smithsonian Astrophysical Observatory)
Founding PI: Kelly Chance

Multiple partners, 600+ early adopters



TEMPO Timeline

Kick-off	January 2013
Instrument delivered	November 2018
Integrated to Intelsat 40e	June 2022
Launch	7 April 2023
First light	2 August 2023
Nominal operations	October 2023
Radiances and 3 weeks of unvalidated trace gas files released to public	February 2024
Public data release	May 2024
Near real time products	Mid-2025

* Baseline mission is 20 months, then up for extensions through NASA Senior Reviews

TEMPO Operations

Nominal scans

- 2048 North/South pixels
- 1181 East/West steps per hour
- 2 x 4.75 km^2 at center of field of regard

Optimized scans

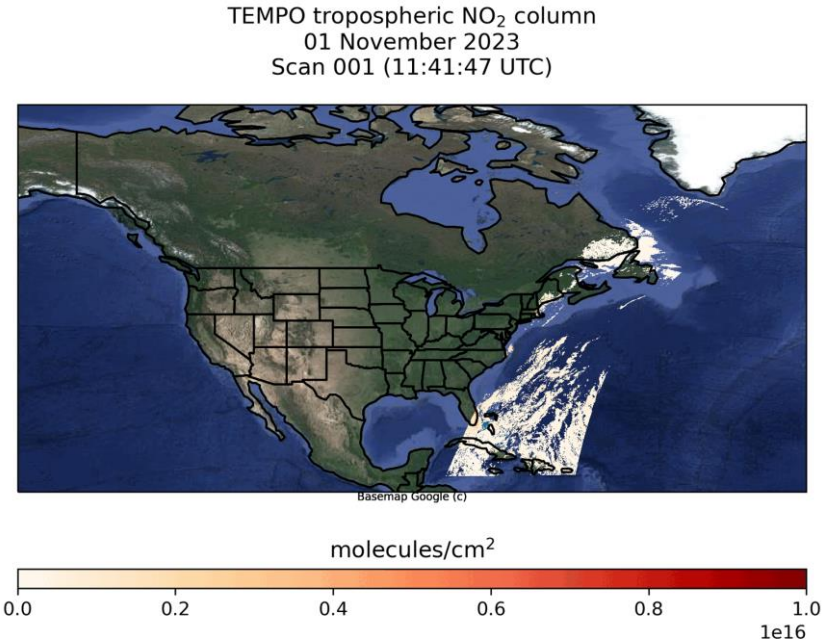
- Higher temporal resolution AM and PM scans over coasts (40 minutes)

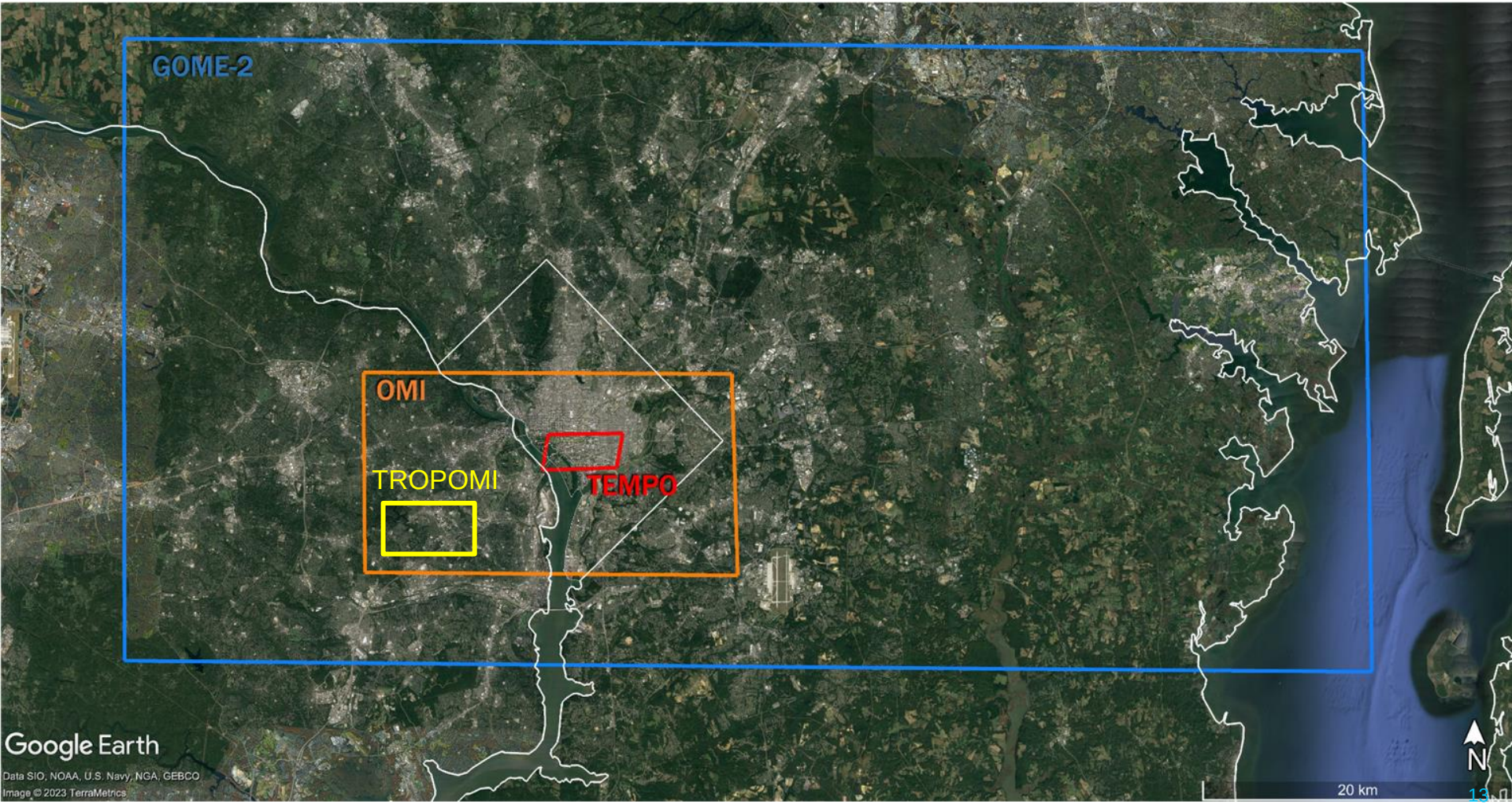
Twilight scans (city lights)

- Performed during darkness, before morning scans

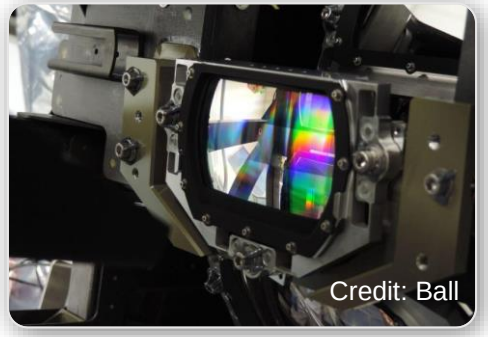
High-time scans

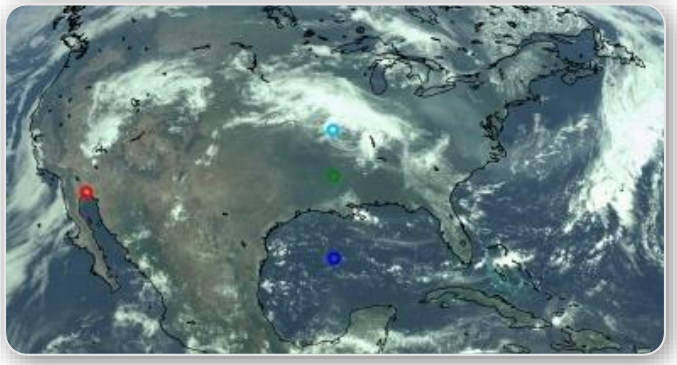
- Frequent scans (5 to 10 minutes) over selected longitudes
- Rare → can be requested but require science team approval

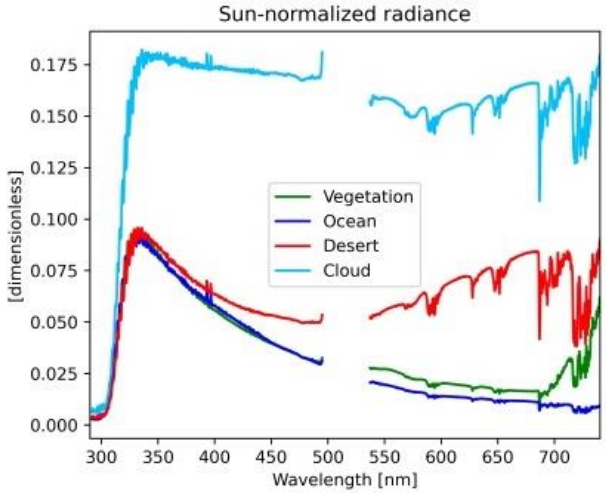



GOME-2
OMI
TROPOMI
TEMPO
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2023 TerraMetrics
N
20 km

TEMPO Spectra







Data Products

TEMPO Level 1 products

Product	Level	Description	Nominal sampling frequency	Maturity level
DRK	1a	Dark exposure	Variable (typically sampled before the beginning of the other types of exposure)	Beta
RAD	1b	Geolocated Earth radiances	Once per hour or more frequent (during daylight hours)	Beta
RADT	1b	Geolocated Earth radiances (twilight)	Variable	Beta
IRR	1b	Solar irradiance (working diffuser)	Once per week	Beta
IRRR	1b	Solar irradiance (reference diffuser)	Once per 3 months	Beta

Beta: “The product is minimally validated but may still contain significant errors;... publication of research based on Beta maturity products is not recommended and highly discouraged”

TEMPO Level 2 & Level 3 products

Product	Level(s)	Description	Most relevant variables in level 2 and level 3 file	Maturity level
NO2	2 & 3	Nitrogen dioxide total, tropospheric, and stratospheric columns	vertical_column_troposphere, vertical_column_stratosphere	Beta
HCHO	2 & 3	Total formaldehyde columns	vertical_column	Beta
O3TOT	2 & 3	Total ozone columns	column_amount_o3	Beta
CLDO4	2 & 3	Cloud parameters	cloud_fraction, cloud_pressure	Beta

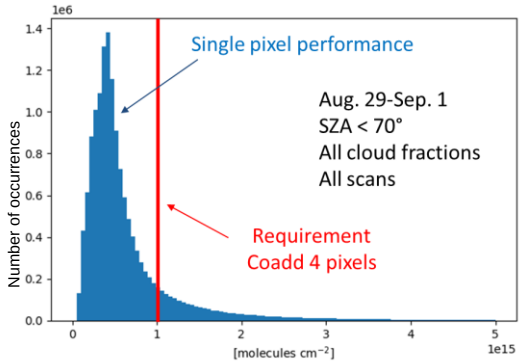
Level 2: Information provided at TEMPO's native resolution (hourly sampling frequency or less; ~10 km^2); usually one hour East-West scan is broken in 9 to 10 level 2 files.
Level 3: All level 2 data from a TEMPO East-West scan on a regular grid (0.02° x 0.02°)

Level 2 product requirements

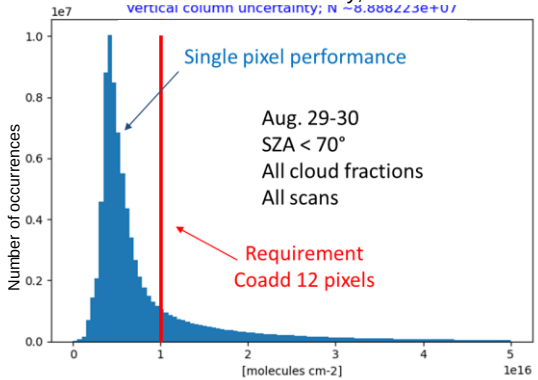
Product	Required precision	Temporal revisit*
0-2 km O_3 (selected scenes)	10 ppbv	2 hour
Tropospheric O_3	10 ppbv	1 hour
Total O_3	3%	1 hour
Tropospheric NO_2	1 x 10^{15} molecules cm^{-2}	1 hour
Tropospheric HCHO	1 x 10^{16} molecules cm^{-2}	3 hour

* number of hourly measurements to be averaged to achieve required precision

NO_2 tropospheric column uncertainty; N~2x10^7



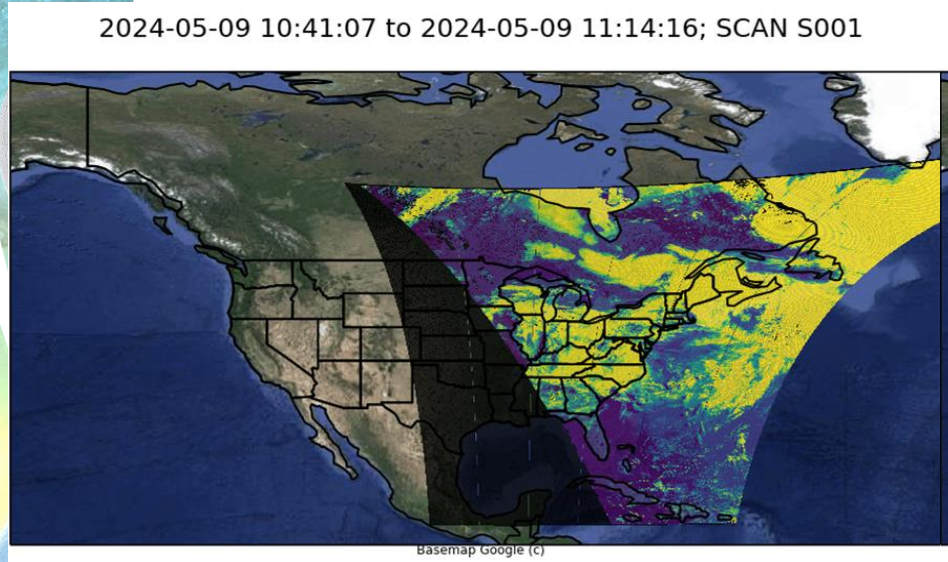
HCHO column uncertainty; N~8x10^7



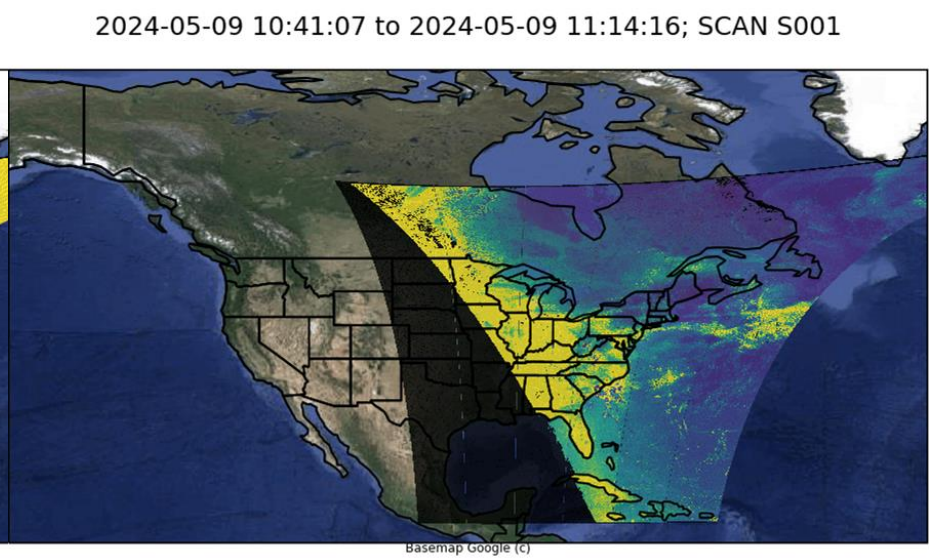
There are ongoing efforts to expand the suite of TEMPO operational products with aerosol information (AOD, layer height, UVAI) and traces gases (SO_2, CHOCHO, BrO, H_2O and HONO) in the near future.

One day of HCHO retrievals: filtering data

To perform qualitative studies it is essential to perform quality control on the data; multiple variables in the level 2 and level 3 files (main_data_quality_flag, cloud_fraction, vertical_column_uncertainty, snow_ice_fraction…) provide suitable information to filter data depending on the user's application.



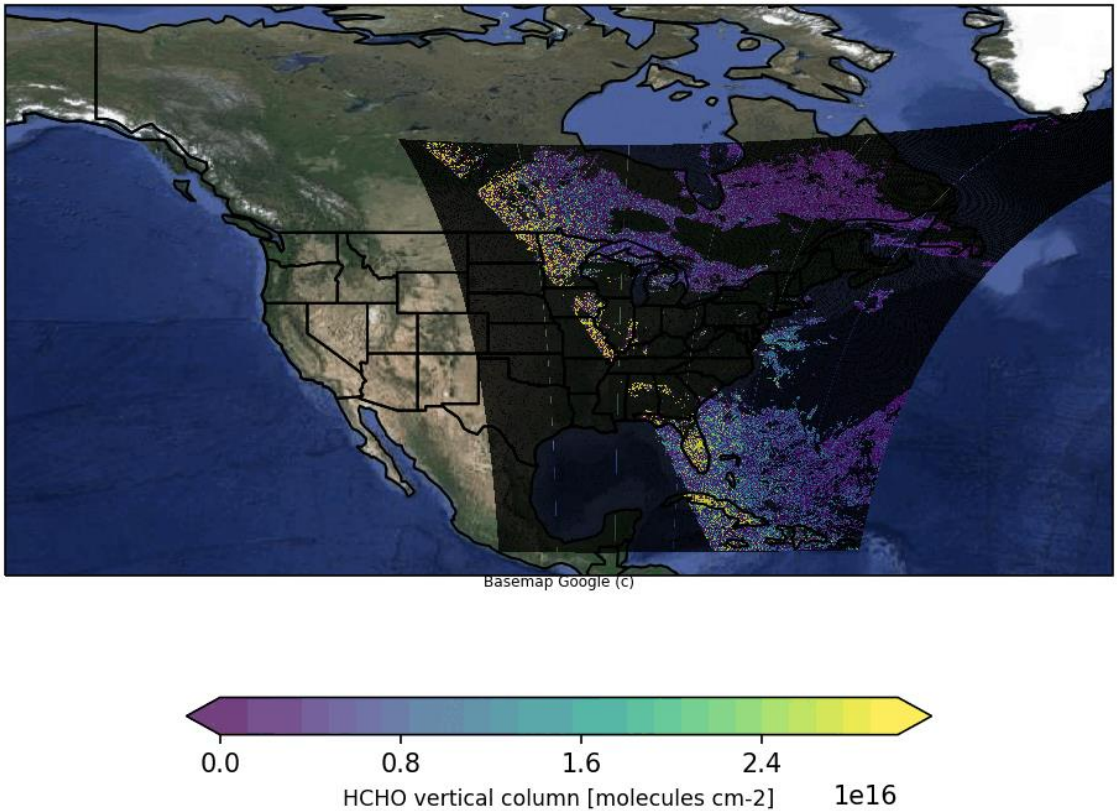
Cloud fraction



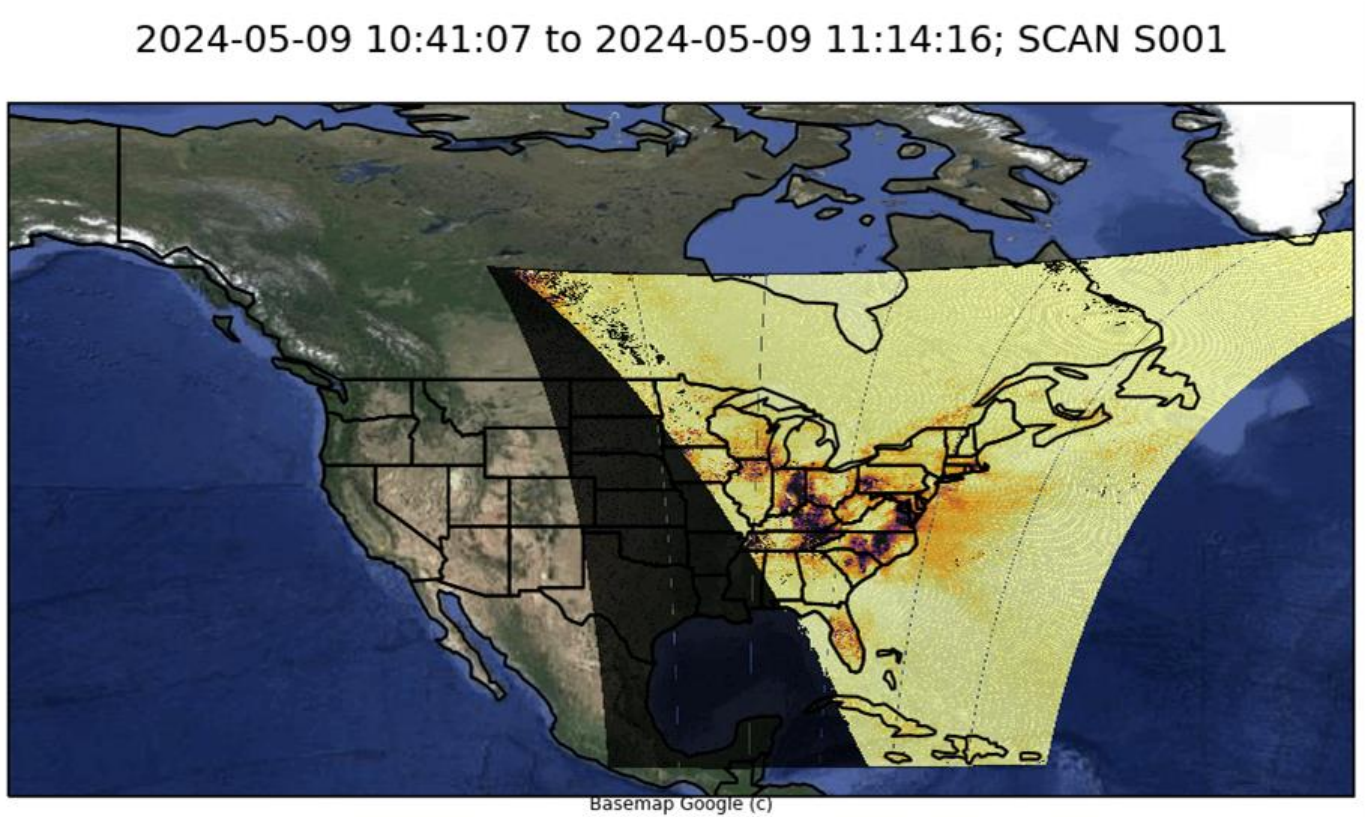
Vertical column uncertainty

One day of HCHO retrievals showing data only with cloud fraction < 0.25

2024-05-09 10:41:07 to 2024-05-09 11:14:16; SCAN S001



One day of NO_2 retrievals (unfiltered)

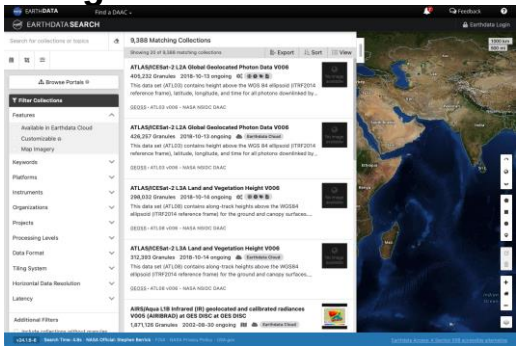


As mentioned previously it is important to filter data using the criteria described in the user guides

How to find TEMPO data products on Earthdata Search

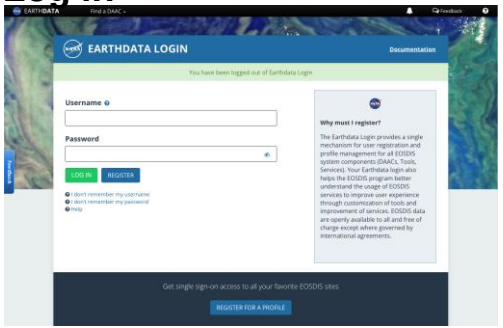
Summary

Navigate to *Earthdata Search*

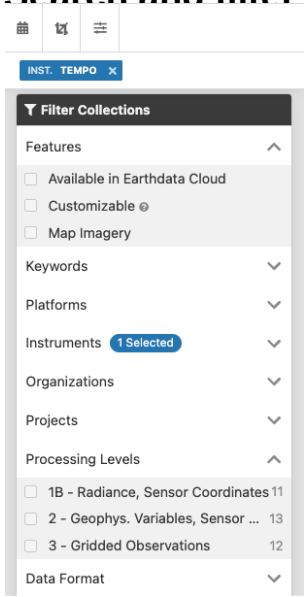


search.earthdata.nasa.gov/

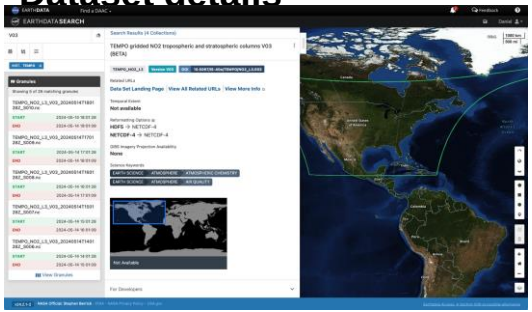
Log in



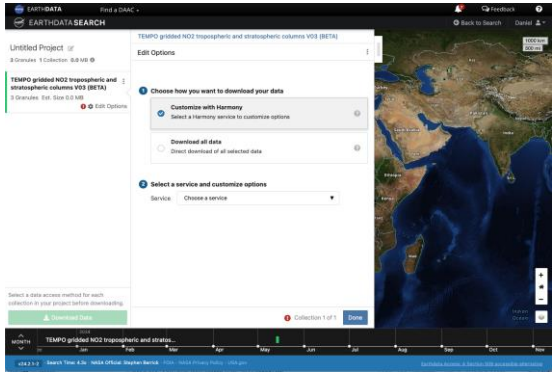
Search and filter



Dataset details



Customizing the download or access



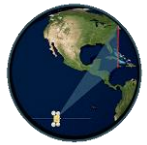
Demonstration

Demonstration Links - for reference

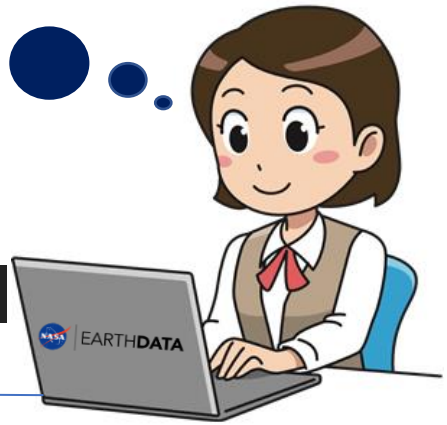
- **Earthdata Search:** https://search.earthdata.nasa.gov
- **TEMPO Project landing page:** https://asdc.larc.nasa.gov/project/TEMPO
- **NASA Earthdata Cloud information:** https://www.earthdata.nasa.gov/eosdis/cloud-evolution
- **NASA CMR STAC API tutorial:** https://nasa-openscapes.github.io/2021-Cloud-Hackathon/tutorials/02_Data_Discovery_CMR-STAC_API.html
- **Panoply:**

  https://www.giss.nasa.gov/tools/panoply/

TEMPO Resources at ASDC



EARTHDATA Forum



Amazon EC2

> 100 Gbps

EARTHDATA CLOUD

+/- 30 Mbps

NASA WORLDVIEW

EARTHDATA

aws

Earthdata Harmony

-SAMBAH
-HOSS

Earthdata GIS

COMMON METADATA REPOSITORY

OPeNDAP

REMOTE SENSING INFORMATION GATEWAY RSIG

Amazon S3

NASA EDPub

Database

CUMULUS EOSDIS

Application Services

amazon web services

Networking

Security

Atmospheric Science Data Center

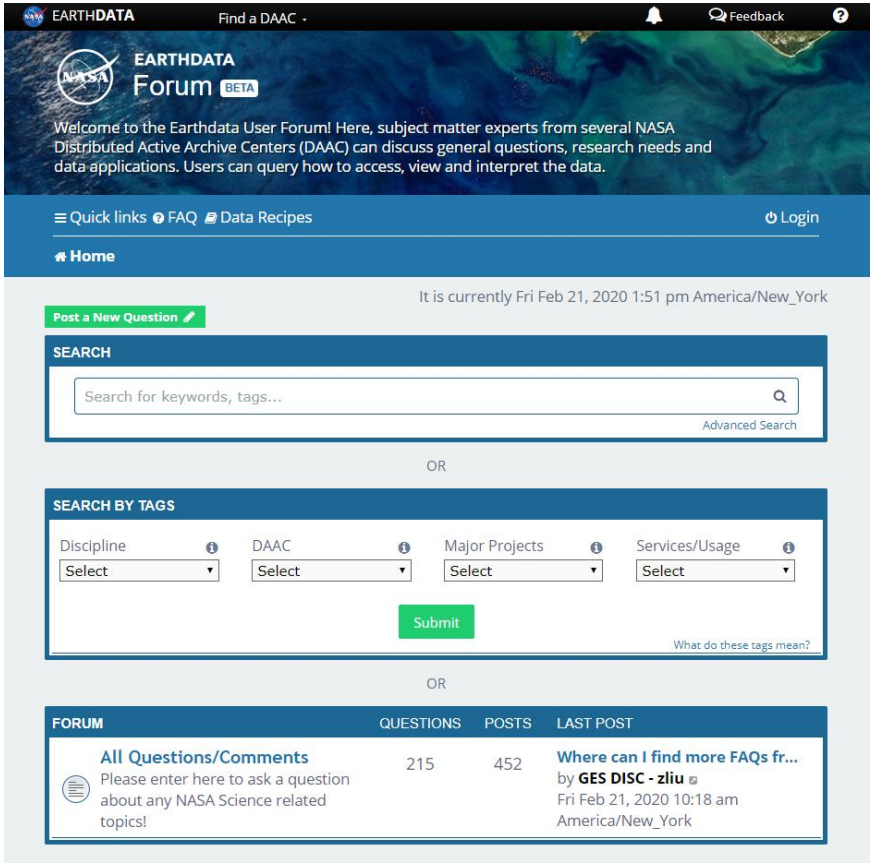
Earthdata Forum

Science Data Users can seamlessly search for information even if they do not know which DAAC the data belongs to.

Scientists & Data Providers can effectively assist their user community in more accurately using their products.

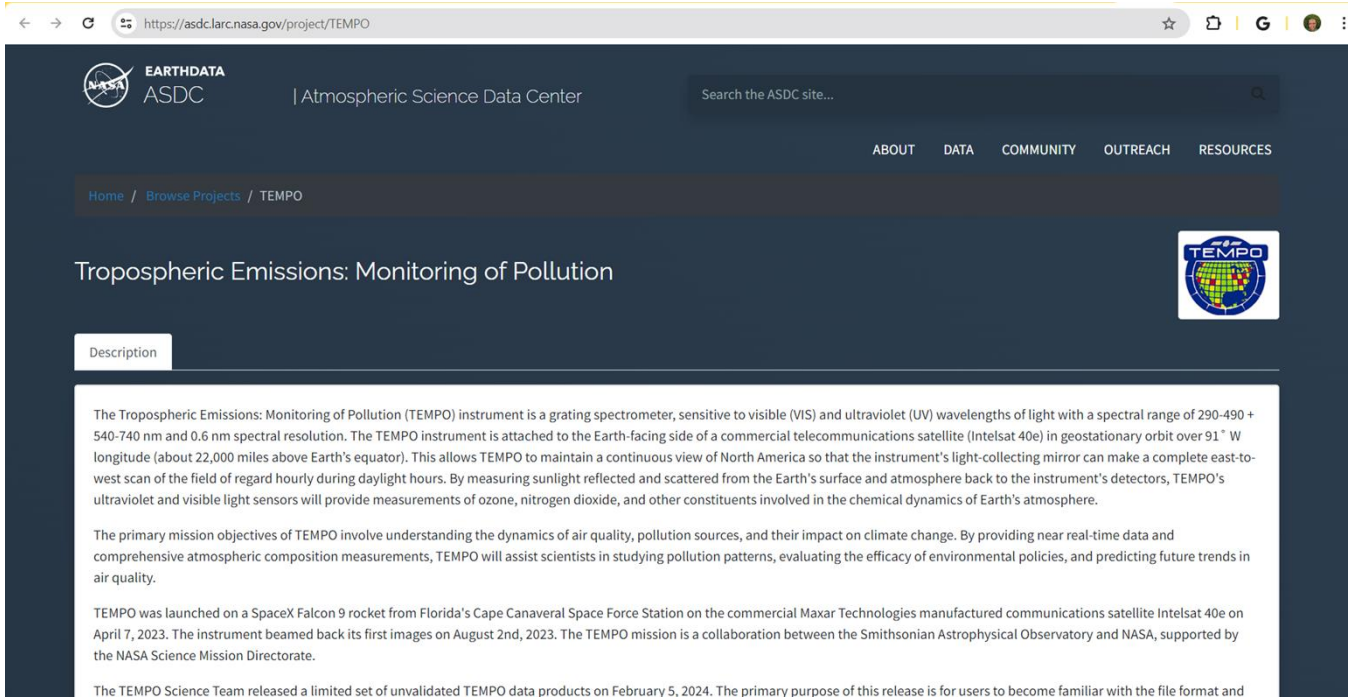
DAACs & Subject Matter Experts (SMEs) can quickly link users to existing resources.

DAAC User Services can swiftly provide inquirers with an authoritative source related to DAAC data products & services.



https://forum.earthdata.nasa.gov/

ASDC Webpage

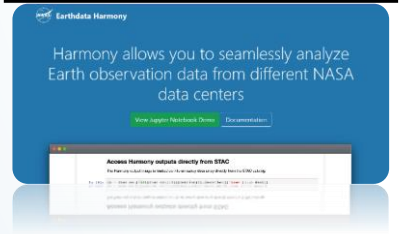


https://asdc.larc.nasa.gov/project/TEMPO

Additional Resources

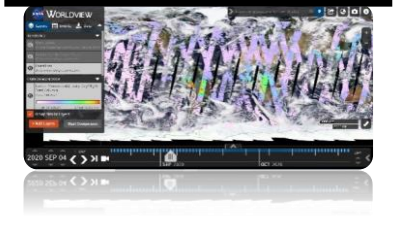
Harmony Services

https://harmony.earthdata.nasa.gov/



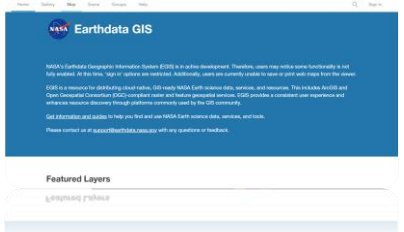
Worldview

https://worldview.earthdata.nasa.gov/



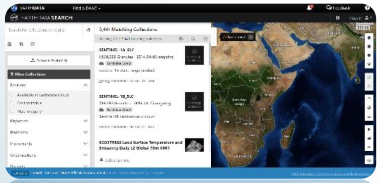
Earthdata GIS EGIS

https://gis.earthdata.nasa.gov/portal/



Earthdata Search

https://search.earthdata.nasa.gov/search

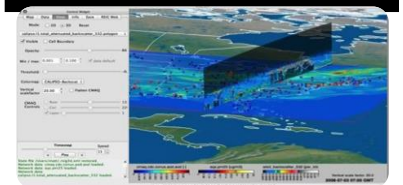


OPeNDAP

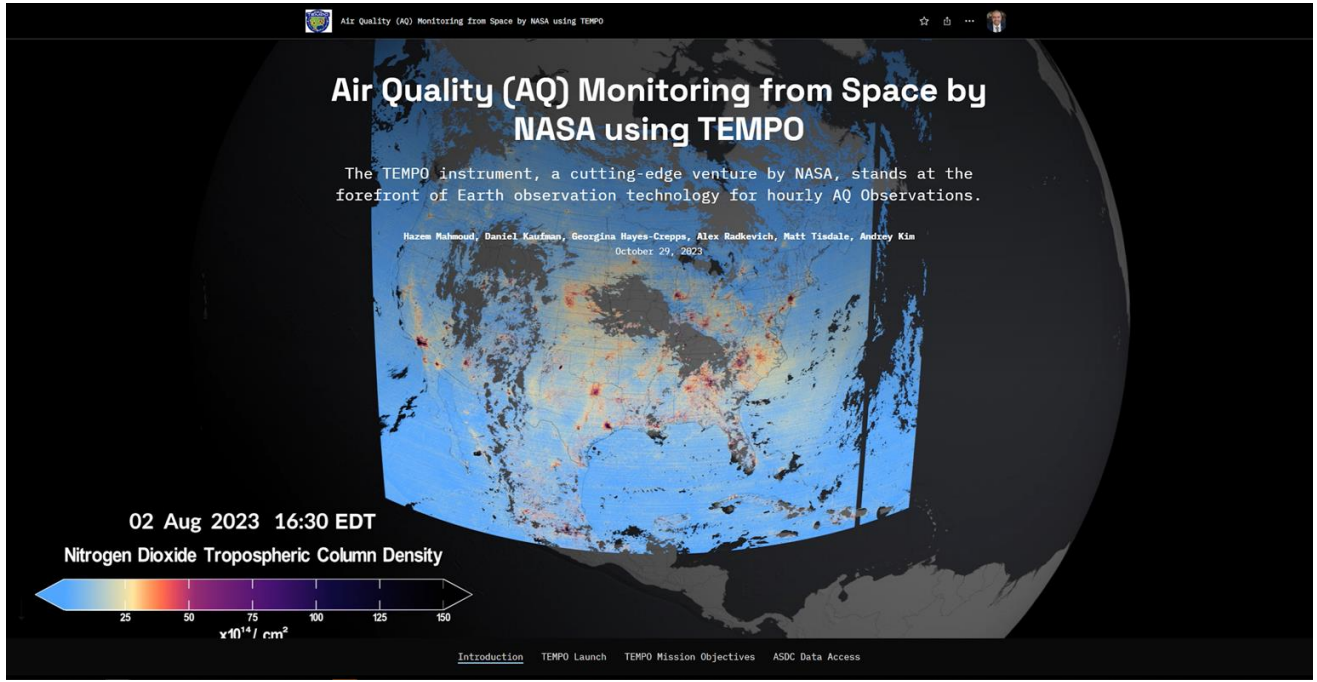
https://opendap.earthdata.nasa.gov/

Remote Sensing Information Gateway

https://www.epa.gov/hesc/rsig3d-data-inventory



TEMPO Storymap



Atmospheric Science Data Center
NASA Langley Research Center
Hampton, Virginia (USA)
https://asdc.larc.nasa.gov/
support-asdc@earthdata.nasa.gov

Extra Slides Follow

Daily Log

[TEMPO_nominal-operation_data-products_daily_log - Google Docs]

•([http://github.com/JeanFitzmaurice/TEMPO-Observation-Log])

TEMPO Daily Log during Nominal Operation (10/17/2023-present)

Jean Fitzmaurice, John Houck, Xiong Liu

Last updated on 3/21/2024

Date	Log
10/17/2023	**SDPC v4.1** operational processing started (9 hrs)
10/18/2023	Frequent data dropouts (missing data), INR might fail and no subsequent data products
10/19/2023	**Solar cal Working Diffuser (WD)** Frequent data dropouts (missing data), INR might fail and no subsequent data products
10/20/2023	Frequent data dropouts (missing data), INR might fail and no subsequent data products
10/21/2023	Frequent data dropouts (missing data), INR might fail and no subsequent data products
10/23/2023	Some data dropout
10/26/2023	**Solar cal WD**
10/29/2023	Bad INR almost all day (**no L2 data products**) (R2.3.8 restart issue), will be reprocessed later with SDPC v4.2.

Additional Resources

- Point to programmatic access tools (ASDC GitHub, earthaccess, Harmony-py)
- Opendap access
- Worldview GIBS
- Imagery in AGOL
- Training, tutorials, storymap, rsig to share

Questions?

deadlines

Webinar Date: 05/29/24 2pm EDT

Presenter Training: April 29 through May 3, 2024

First Dry Run- Week of May 13-17,2024

Second Dry Run- Week of May 20-24,2024

05/02/24:

- Agenda,
- Webinar banner imagery,
- Title and Talk Abstract,
- Name, professional title, bio, and photo(s) of the speaker(s)

05/09/24: List of invitees

05/24/24: Polling questions (short answer, multiple choice, multiple answer)

Hazem Mahmoud
Science Lead at NASA LaRC ASDC ADNET

Bio: Dr. Hazem Mahmoud, the DAAC Scientist at the Atmospheric Science Data Center, brings a wealth of expertise in geophysics and environmental engineering to his role. His primary focus lies in utilizing both orbital and suborbital instruments for remote sensing of the Earth's atmosphere. Dr. Hazem specializes in analyzing radiation budget, cloud formations, aerosol distribution, and tropospheric composition. His ultimate goal is to achieve near real-time air quality monitoring from space and study the impact of the air we breathe on our health. His passion for this field ignited when he confronted the challenge of limited Earth data availability early in his career, compelling him to dedicate his research to remote sensing applications. He firmly advocates for the integration of remote sensing data into scientific endeavors, believing it to be a crucial step in advancing global research efforts.

Name: Caroline Nowlan
Job Title: Atmospheric Physicist / Center for Astrophysics | Harvard & Smithsonian
Bio: Dr. Caroline Nowlan is an atmospheric physicist at the Center for Astrophysics | Harvard & Smithsonian, where she works on remote sensing of the Earth's atmosphere using satellite and aircraft instruments. She is a member of the team leading the Smithsonian/NASA next-generation air quality monitoring instrument TEMPO (Tropospheric Emissions: Monitoring of Pollution), which recently began making measurements of air pollutants over North America from geostationary orbit. Dr. Nowlan is also responsible for global formaldehyde measurements from a suite of NASA/NOAA satellite instruments, and has been an investigator on projects examining urban air pollution in the U.S. and South Korea using remote sensing of the atmosphere from aircraft. She holds a Ph.D. in physics from the University of Toronto.

Name: Gonzalo Gonzalez Abad
Job Title: Atmospheric Physicist / Center for Astrophysics | Harvard & Smithsonian
Bio: Gonzalo Gonzalez Abad received his B. Sc. degree in physics in 2008 from the Universidad de Valencia, Spain and a Ph.D. in Chemistry from the University of York, York, UK in 2012. He is currently a physicist at the Center for Astrophysics | Harvard & Smithsonian, in Cambridge, Massachusetts, USA. His main research interest is the development of trace gas retrieval algorithms applicable to observations by space-borne ultraviolet and visible solar light backscattered spectrometers. He leads the development of Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite instrument formaldehyde retrievals and is a member of the Atmospheric Composition Instrument (ACX) science team.

Name: Daniel Kaufman

Job Title / Affiliation: ASDC TEMPO Lead Data Scientist / Booz Allen Hamilton

Bio: Dr. Daniel Kaufman received his B.Sc. in physics from the University of Maryland and a Ph.D. in Marine Science at the Virginia Institute of Marine Science, College of William and Mary. Daniel's research and data science work has included analyses and assimilation of biogeophysical data from autonomous ocean gliders, formulating diagnostics of atmospheric carbon dioxide concentrations as simulated in global climate models, and the development of a large-scale mathematical optimization model and decision support tool for watershed pollution management. Daniel supports NASA's Atmospheric Science Data Center (ASDC) as one of the center points of contact for TEMPO, serves as a Center Champion for NASA's Transform to Open Science (TOPS) initiative, and co-develops tools that provide user-friendly access to satellite-based atmospheric science data.

TEMPO Resources at ASDC

- (~5 min)
  - Data pages
  - Data log
  - https://asdc.larc.nasa.gov/project/TEMPO
  - https://docs.google.com/document/d/1X06_F2FjVGgwad3Ya70_GSxbpausgak04_M8bUYkiO0/edit
  - https://storymaps.arcgis.com/stories/01e82aefbc8b4d7a951fe089c818bc0c