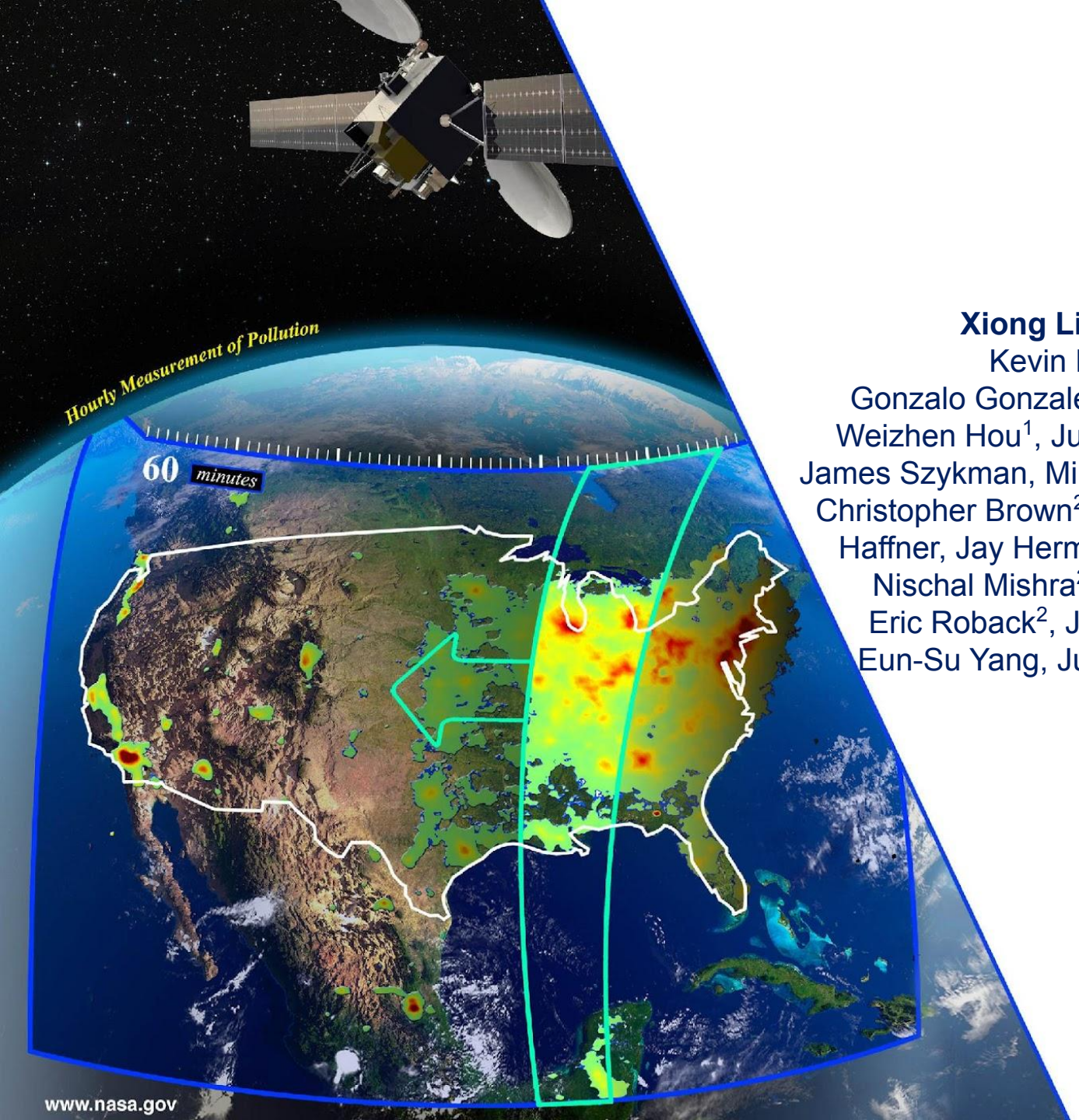



Tropospheric Emissions:
Monitoring of Pollution

# TEMPO Status Update

**Xiong Liu**[1], Kelly Chance[1], Raid Suleiman[1], John Houck[1], John Davis[1], Kevin Daugherty[2], David Flittner[2], David Rosenbaum[2], Crystal Fenn[2], Gonzalo Gonzalez Abad[1], Caroline Nowlan[1] , Huiqun Wang[1], Heesung Chong[1], Weizhen Hou[1], Junsung Park[1], Christopher Chan Miller[1], Juseon Bak[1], Jim Carr, James Szykman, Mike Newchurch, Aaron Naeger, Ronald Cohen, Zolal Ayazpour[1], Christopher Brown[2], Zachary Fasnacht, Jean Fitzmaurice[1], Jeffrey Geddes, David Haffner, Jay Herman, Joanna Joiner, Laura Judd, Emma Knowland, Xuming Lei, Nischal Mishra[2], Robert Neece[2], Ewan O'Sullivan[1], Brad Pierce, Wenhan Qin, Eric Roback[2], Justin Strickland[2], Robert Spurr, Luke Valin, Alexander Vasilkov, Eun-Su Yang, Jun Wang, Barron Henderson, Katherine Travis, Prajjwal Rawat, Jerry Ziemke, Stacey Frith, Natalya Kramarova, Colin Seftor, and the TEMPO Team

[1]CfA | Harvard & Smithsonian

GeoXO ACX STM

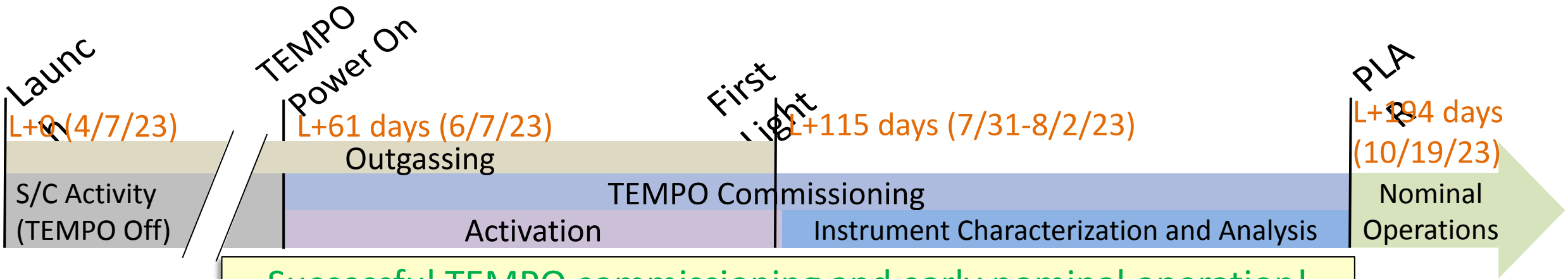
College Park, MD

May 7, 2024

Smithsonian

# TEMPO Commissioning and Early Nominal Operation

- **TEMPO commissioning: SAO + LaRC + Intelsat + Maxar + Ball + Carr Astronautics**
  - ✔ TEMPO power on 6/7, Dry out (6/9-7/9) and cool down (7/10-7/12)
  - ✔ First light (7/31-8/2): working/reference diffuser solar & Earth imaging
  - ✔ Instrument Characterization and Analysis (ICA) activities
  - ✔ Coordinate with AGES+ campaigns in Aug. and Coastal Texas Air Quality Field Campaign in Sep. (no Earth imaging for only 6 days, special observations over LA and Texas)
- **Nominal operation: after the Post Launch Acceptance Review (PLAR) on 10/18-19/2023**
  - ✔ Weekly commanding, no special observations before L2/3 public release
  - ✔ Optimize off-nominal twilight observations: city lights=>lighting types, Aurora, gas flaring, moonlight
  - ✔ Overall very smooth operation except for some data dropouts, scan mirror stuck midway
  - ✔ Safe mode: 9/8/23 (thruster firing, down 1 day); 1/24/24 (GPS/pointing error & out of sync, down for 7 days)



# Baseline Line Mission & Data Products Public Release Timeline

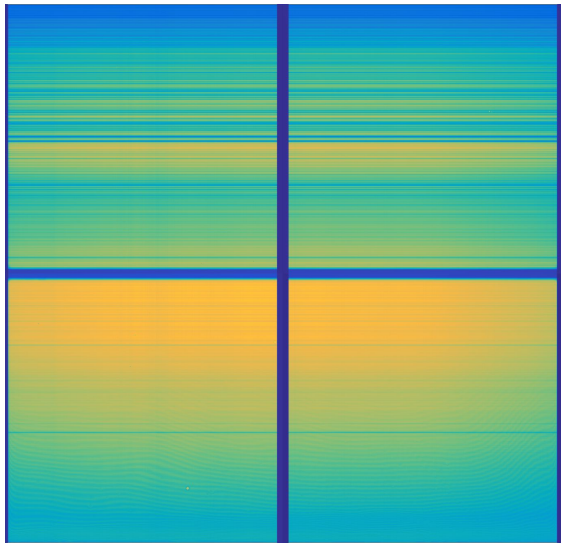
| Data Product | Description | Time beyond On-Orbit Checkout (OOC) to deliver initial data | Maximum data latency after first release for ≥ 80% of products |
|---|---|---|---|
| Level 0 | Reconstructed, Unprocessed Instrument Data | 2 months | Within 2 hours of receipt at SAO |
| Level 1b | Calibrated, Geolocated Radiances | 4 months | Within 3 hours of Level 0 and ancillary data receipt at SAO |
| Level 2 | Derived Geophysical Data Products | 6 months | Within 24 hours of production of Level 1 at SAO |
| Level 3 | Derived Gridded Geophysical Data Products | 6 months | 1 month after completion of data accumulation required for individual geophysical products |

- Baseline mission (Phase E, 20 months, 10/2023-6/2025), will be continued with NASA extension / senior review
- Data products sent to ASDC for archival & distribution before nominal operation
- Early access to TEMPO Science and Validation team members. Bi-weekly L2 Cal/Val meeting led by Jim Szykman & Brad Pierce
- Mini release (Dec. 17-30, 8 days during Aug. commissioning) on Feb. 05, 2024
- Beta Level 1 public release: Feb. 27,2024
- Level 2/3 public release: May 20, 2024

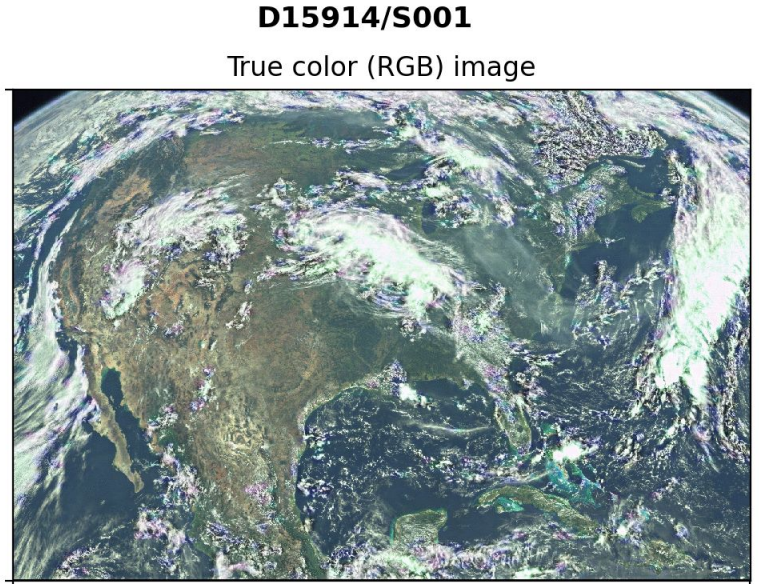
We are nearly on track to release the data products to the public!

# TEMPO Instrument & First Light (8/1-2/2023)

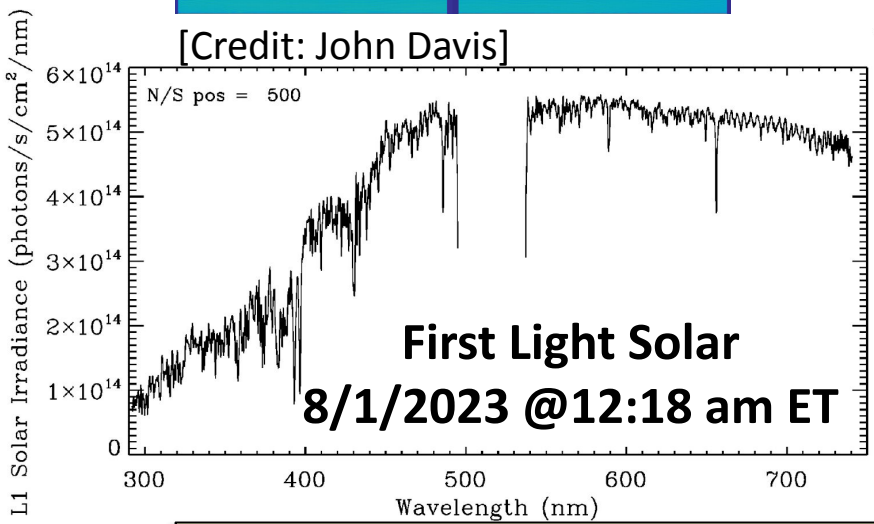
- **Imaging spectrometer measuring solar irradiance and solar backscattered Earth radiance**



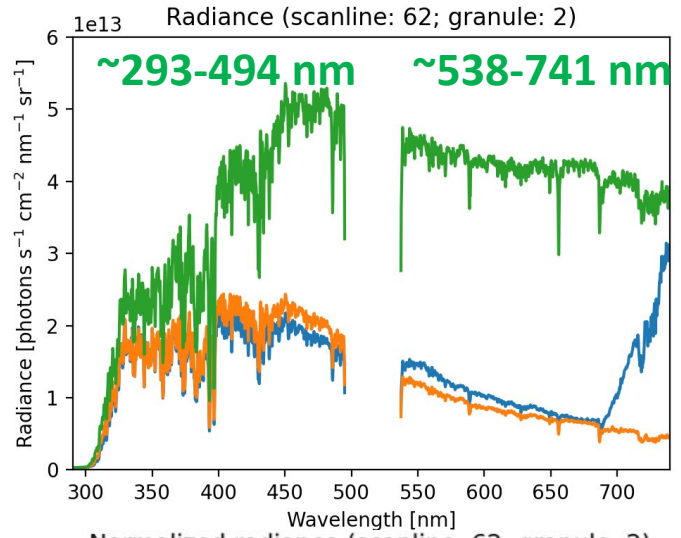
[Credit: John Davis]

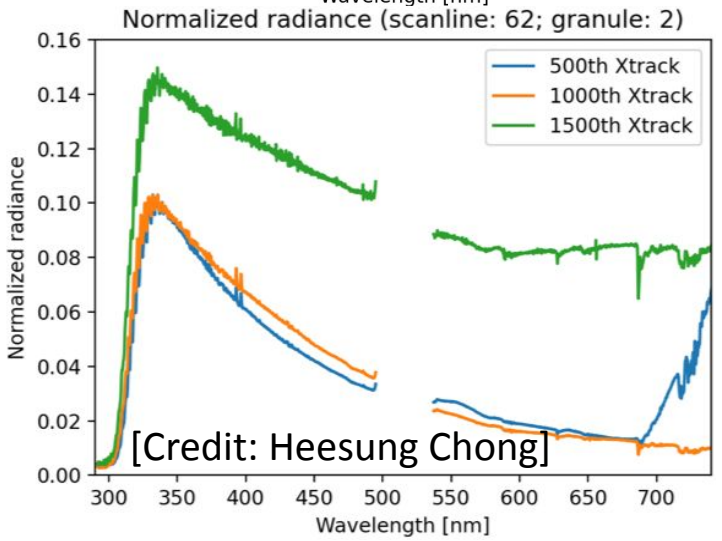



**First Light Earth 8/2/2023 @11:13-17:16 ET RGB Images**




**First Light Solar 8/1/2023 @12:18 am ET**




[Credit: Heesung Chong]

TEMPO First light and NRT checking showed that TEMPO is working very well!

# Baseline and Threshold Measurements Requirements

| Species/Products | Required Precision | Temporal Revisit* |
|---|---|---|
| 0-2 km $O_3$ (Selected Scenes) Baseline only | 10 ppbv | 2 hour |
| Tropospheric $O_3$ | 10 ppbv | 1 hour |
| Total $O_3$ | 3% | 1 hour |
| Tropospheric $NO_2$ | $1.0 \times 10^{15}$ molecules $cm^{-2}$ | 1 hour |
| Tropospheric $H_2CO$ | $1.0 \times 10^{16}$ molecules $cm^{-2}$ | 3 hour |

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

- Mission duration: 20 months for baseline, 12 months for threshold
- Spatial resolution: < 60 $km^2$ for baseline (4 native pixels coadded), < 300 $km^2$ for threshold
- AOD, SO2, and CHOCHO removed at KDP-C.

Reduced list of baseline data products due to cost cap!

# TEMPO Data Products
## Baseline + SNWG TEMPO NRT

| Level | Product | Algorithm | Major Outputs | A Priori (L2) | Res km$^2$ * | Freq/Size | Val. Status (5/20/2024) |
|---|---|---|---|---|---|---|---|
| **L0** | **Digital counts** | Raw to L0 | Reconstructed/reformatted DN | | 2.0 x 4.75 | Daily/hourly | |
| **L1** | **Irradiance** NRT | SAO L0-1 | Calibrated & quality flags | | | weekly | **Beta** |
| | **Radiance** NRT | SAO L0-1 | Geolocated, calibrated, viewing, geolocation & quality flags | | 2.0 x 4.75 | Hourly, granule | **Beta** |
| | **City lights** | SAO L0-1 | Geolocated & calibrated | | 2.0 x 4.75 | Variable, granule | **Beta** |
| **L2** | **Cloud** NRT | OMI $O_2$-$O_2$ | Cloud fraction, cloud pressure | GEOS-CF | 2.0 x 4.75 | Hourly, granule | **Beta** |
| | **$O_3$ profile** | SAO $O_3$ profile | $O_3$ profile, total/strat/trop/0-2 km $O_3$ column, errors, a priori, AKs | Climatology+ GEOS-CF | >= 8.0 x 4.75** | Hourly, granule | **Unvalidated** |
| | **Total $O_3$** | TOMS V8.5 | Total $O_3$, AI, cloud fraction | Climatology | 2.0 x 4.75 | Hourly, granule | **Beta** |
| | **$NO_2$** NRT | SAO trace gas, BU strat./trop. sep. | SCD, strat./trop. VCD, error, shape factor, scattering weights | GEOS-CF | 2.0 x 4.75 | Hourly, granule | **Beta** |
| | **HCHO** NRT | SAO trace gas | SCD, VCD, error, shape factor, scattering weights | GEOS-CF | 2.0 x 4.75 | Hourly, granule | **Beta** |
| **L3** | **Gridded L2** | SAO L2-3 | Same as L2 | | 2 x 2 | Hourly, scan | |

* Spatial resolution at center of FOR. ** Might be at 8 x 9.5 km$^2$

Research **aerosols**, **$SO_2$**, **ocean color** products

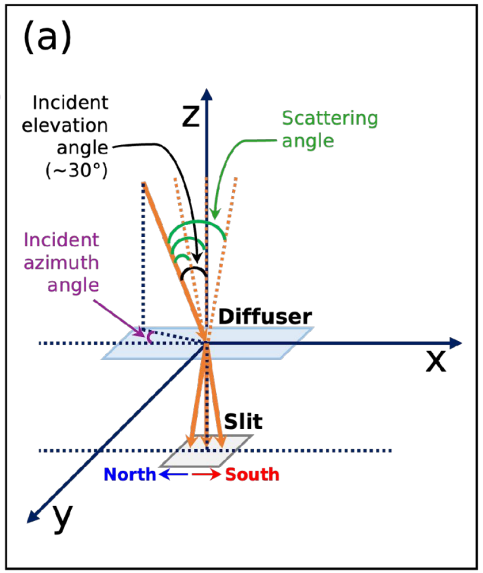
Satellite Needs Working Group (SNWG) funded TEMPO NRT products (L2 products < 3 hours from observation time): 3/26/2024-3/25/2026, NOAA GeoXO team to produce TEMPO/GOES-R NRT aerosol products

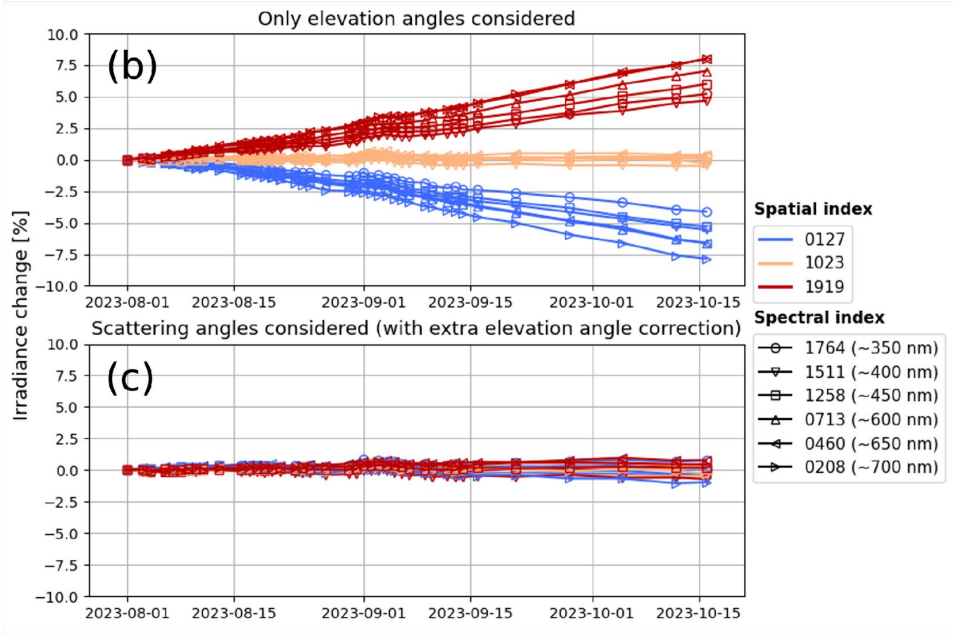
# Algorithm/Data Products Development Timeline

- **First Light $NO_2$ Images Release (8/24): updates to pre-launch (SDPC v4.0) (offline/development):**
  - ✔ Use initial wavelength grid for radiance from calibrated first light working solar irradiance
  - ✔ No straylight correction and polarization correction
  - ✔ Optimized Image Navigation and Registration (INR) for first light
  - ✔ Optimization to clouds & $NO_2$ algorithms
- **First official SDPC update: SDPC v4.1 (V1 data products) approved on 10/16, operational on 10/17, L0-1b, cloud, $NO_2$, HCHO, total $O_3$ produced and sent to ASDC**
  - ✔ INR: working well meeting science requirements.
  - ✔ L0-1b: gain/non-linearity, bad pixel map, improved saturation flagging, Octant phase (odd/even)
  - ✔ Further optimization in cloud and $NO_2$
  - ✔ Major changes to HCHO: radiance reference, and background/reference correction
  - ✔ $O_3$ profile not ready due to absolute radiometric calibration
- **SDPC v4.2 (V1): approved on 11/17, operational on 11/18**
  - ✔ INR: remove UV/Visible biases, accurate at subpixel level, tested to work for special observation
  - ✔ Data processing pipeline: more robust, automatically recover from INR crash, other minor updates
  - ✔ Used to reprocess TEMPO commissioning observations

# Algorithm/Data Products Development Timeline

- **SDPC v4.3 (V2) & Level 1 release: approved on 2/23/2024, operational 2/26/2024**
  - ✔ **Level 1 Beta Public Release:**
    - ❖ Scattering angle dependent BTDF correction, removing time- and across-track dependent biases
    - ❖ Improved CCD image processing steps (electronic offset correction, smear correction, dark current correction after accounting for temperature dependence)
    - ❖ Improved solar wavelength calibration, use latest solar irradiance wavelength for radiance
  - ✓ **Critical updates to $NO_2$, HCHO, and cloud algorithms: GLER interpolation issues, snow/ice, missing data due to cloud radiance wavelength calibration failure, $NO_2$ tropopause layer selection bug, temperature correction in total $NO_2$ AMF**
  - ✓ **Change L3 resolution from $0.05°\times0.05°$ to $0.02°\times0.02°$**




[Credit: David E. Flittner]

# Algorithm/Data Products Development Timeline

- **SDPC v4.4 (V3) & Level 2-3 release: May 20, 2024**
  - ✔ Improved Level 1 & new Level 1 city lights
    - Add nominal geolocations for city lights & Improve the robustness for INR
    - Improve FPA temperature sampling and temperature-dependent dark current correction
    - Add straylight correction (1-D PSF)
    - Add radiance wavelength calibration
  - ✔ Improved Level 2 & 3 and likely ozone profile (UV only) product for public release
    - Update GLER (v6.0->v6.1, snow free + 100% snow, quality flag 2-> 5, fill in gaps via interpolation)
    - Perform retrievals up to SZA 90
    - Update main data quality flag (AMF > 6 as suspect), Revisit convergence flag & AMF diagnostic flag
    - Add temperature profile to output (for AMF)
    - Cloud: SCD fitting optimization, SCD T correction, ECF/OCP iteration, wavelength shifts to ECF
    - Ozone profile: Update the use of GEOS-CF meteorology and ozone profile + Derive soft calibration

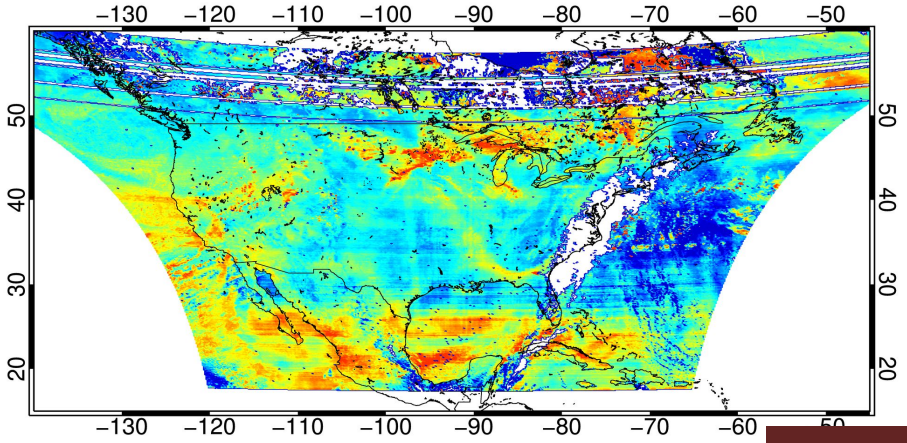
Power/cooling issues at our data center

- **After the May 2024 L2/3 public release --- end of baseline mission:**
  - ✔ Reprocessing for all data products (except for ozone profile product)
  - ✔ Updates to science algorithms & calibrations as needed based on validations and feedback
  - ✔ Update $O_3$ profile retrieval with UV only
  - ✔ Release UV/Visible to improve retrieval sensitivity to 0-2 km $O_3$

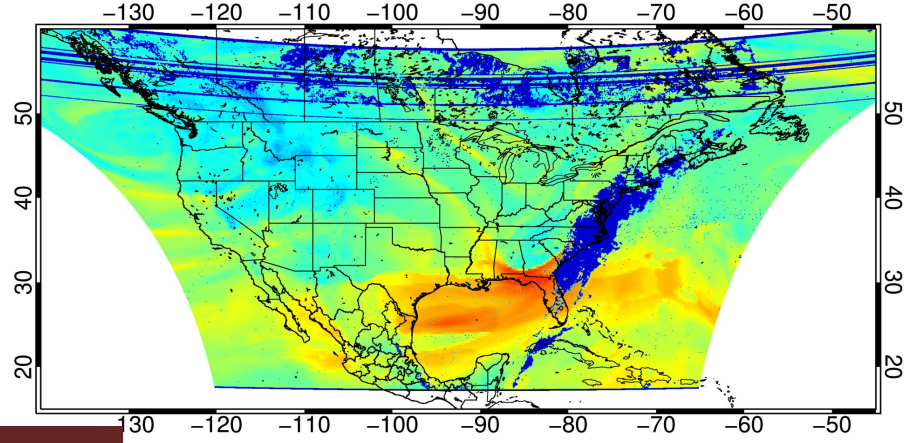
# TEMPO O3PROF (3/28/2024 Scan 008)

**Earlier version from 2 weeks ago!**

**Tropospheric O3 from TEMPO O3PROF**

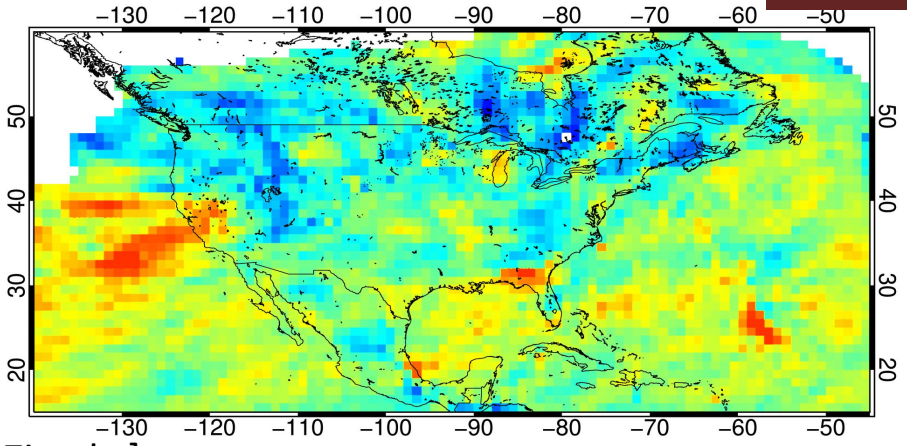



**Tropospheric O3 from GEOS-CF**



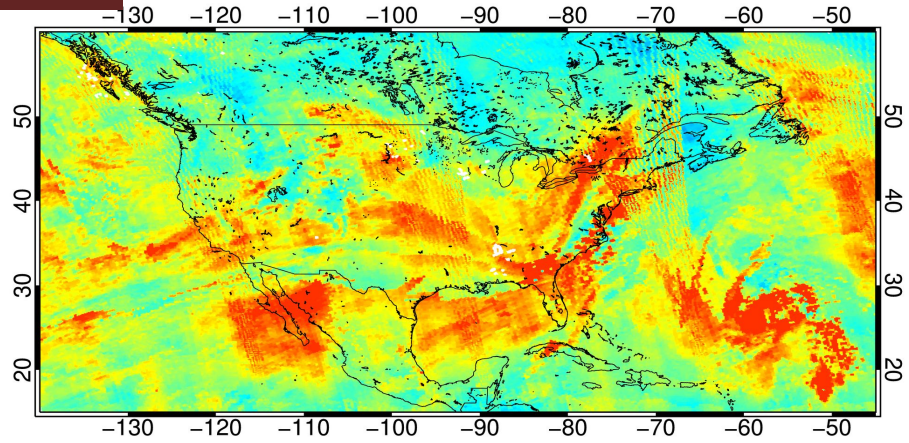

PRELIMINARY!

**Tropospheric O3 from EPIC**



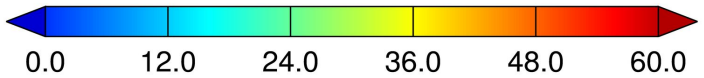

[Credit: Jerry Ziemke]

**Tropospheric O3 from TROPOMI**




[Credit: Junsung Park]

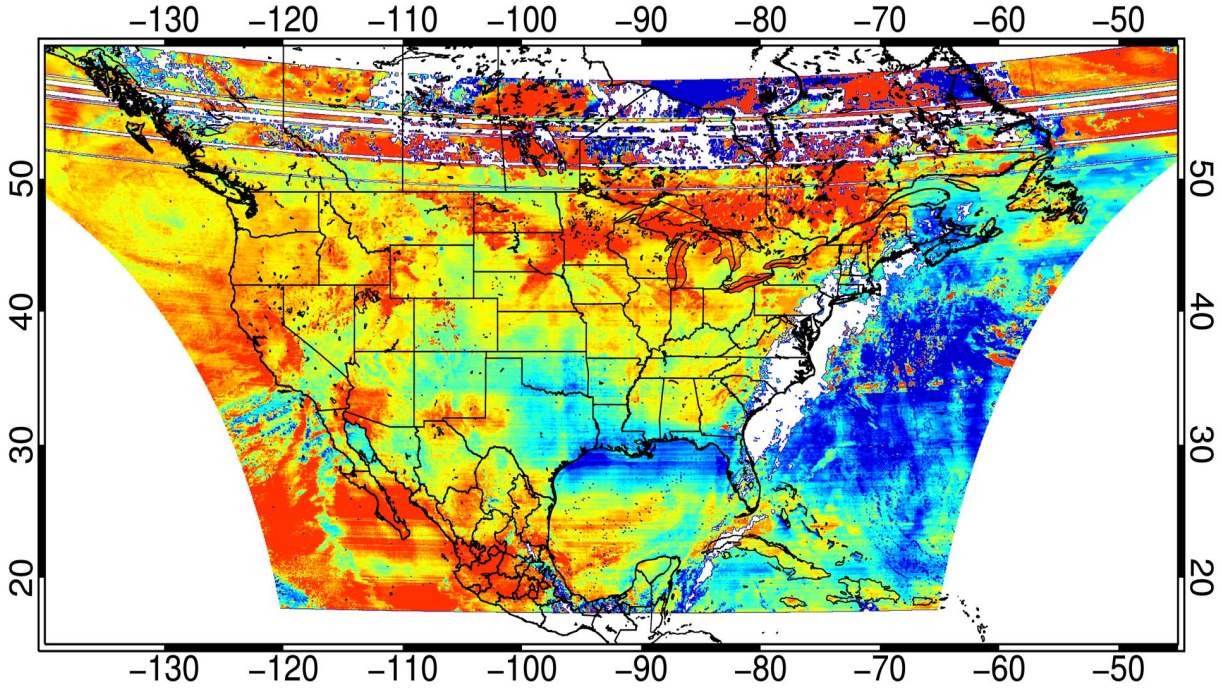
**Dobson Unit**



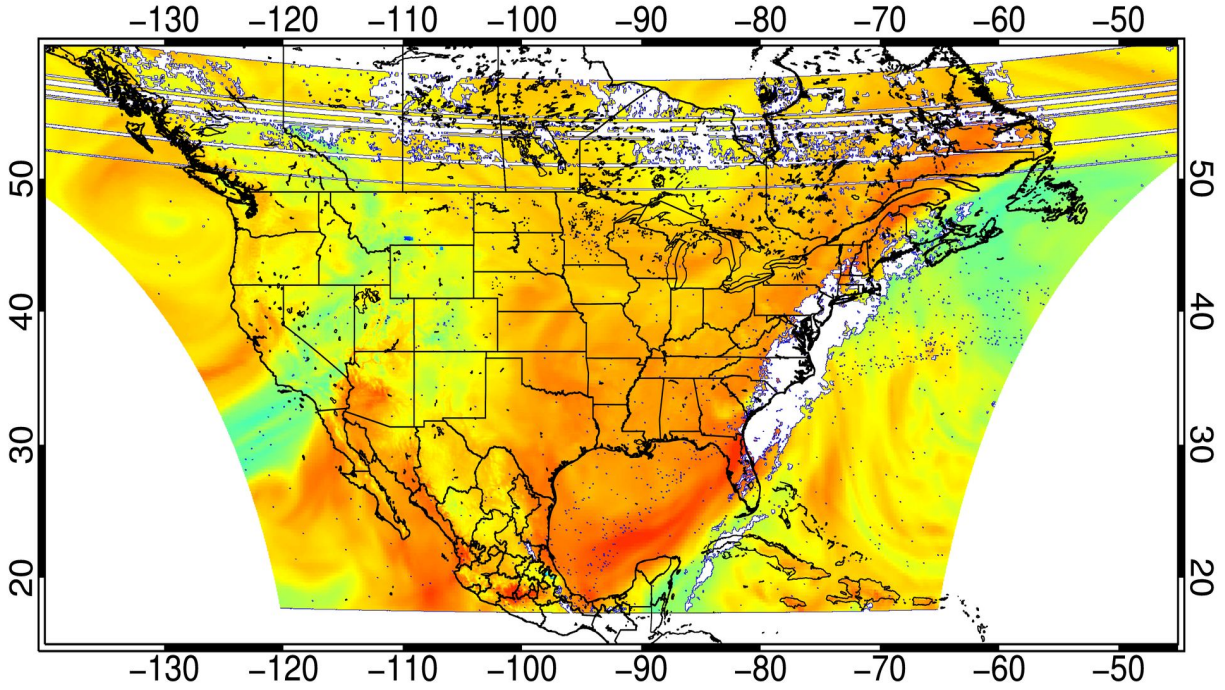

**Note different tropopause pressure from EPIC/TROPOMI!**

# TEMPO O3PROF (3/28/2024 Scan 008)

**Surface to 2 km O3 from TEMPO O3PROF**




**Surface to 2 km O3 from GEOS-CF**



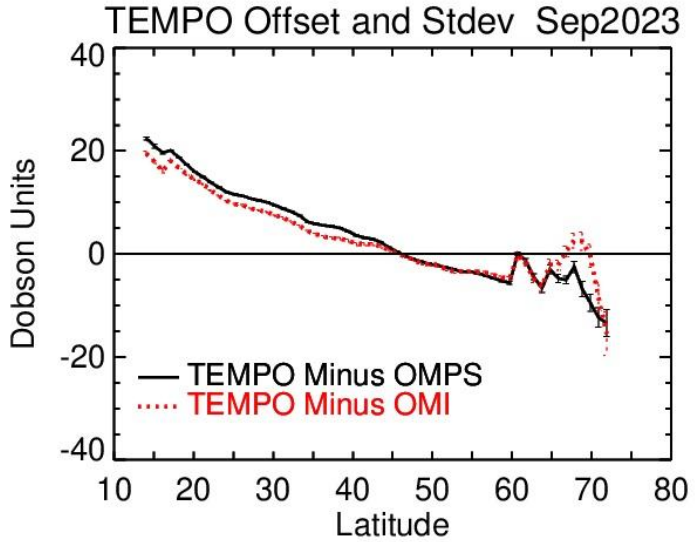

[Credit: Junsung Park]

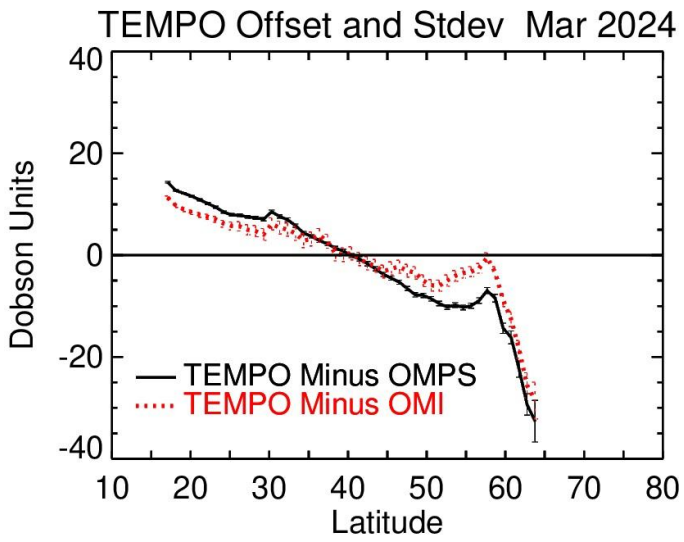

**Dobson Unit**

PRELIMINARY!

# TEMPO Total Ozone (V2): Comparison with OMPS and OMI

*Credit: Jerry Ziemke & Stacey Frith, NASA GSFC*

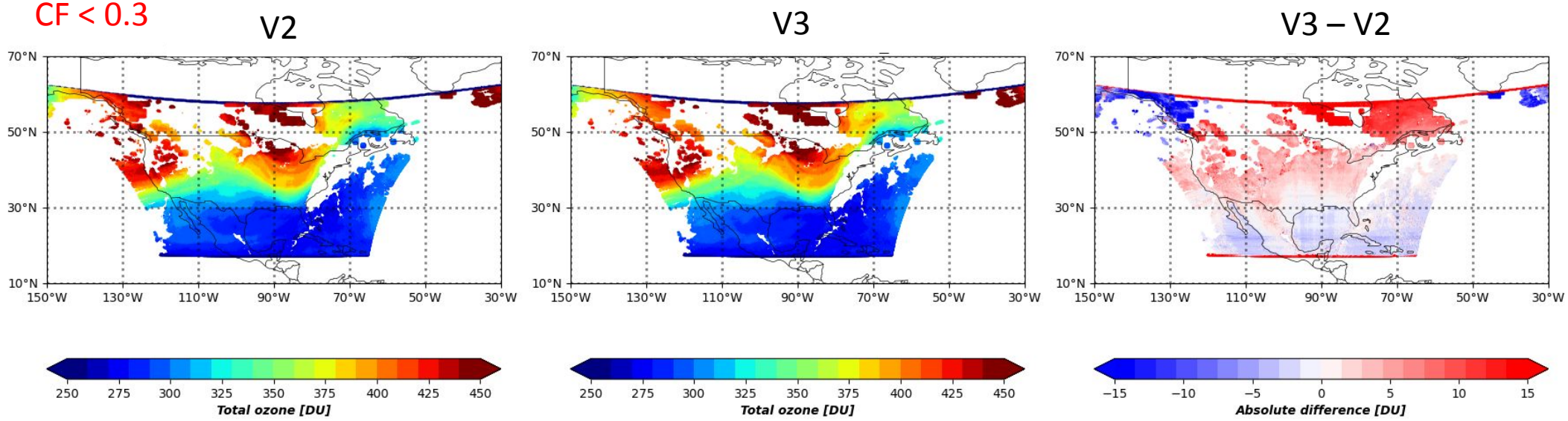



OMPS and OMI within ±3 hr overpass with TEMPO with all data binned to 1° × 1° daily averages

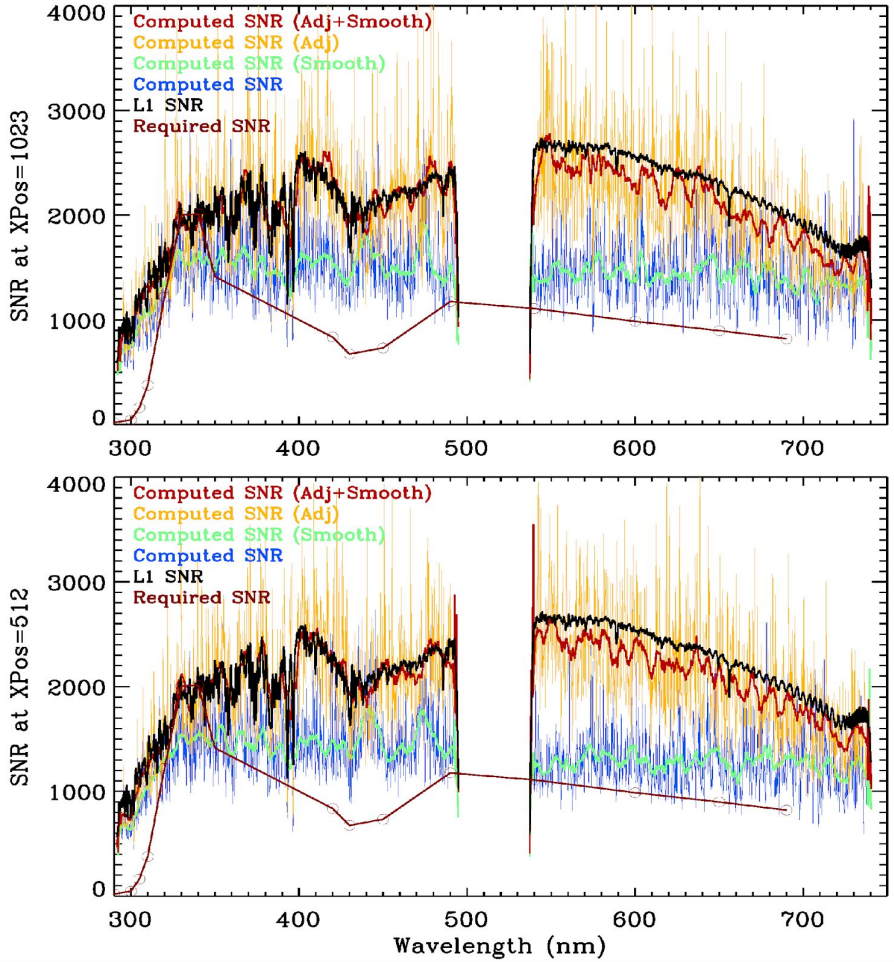
**20240328, S008**

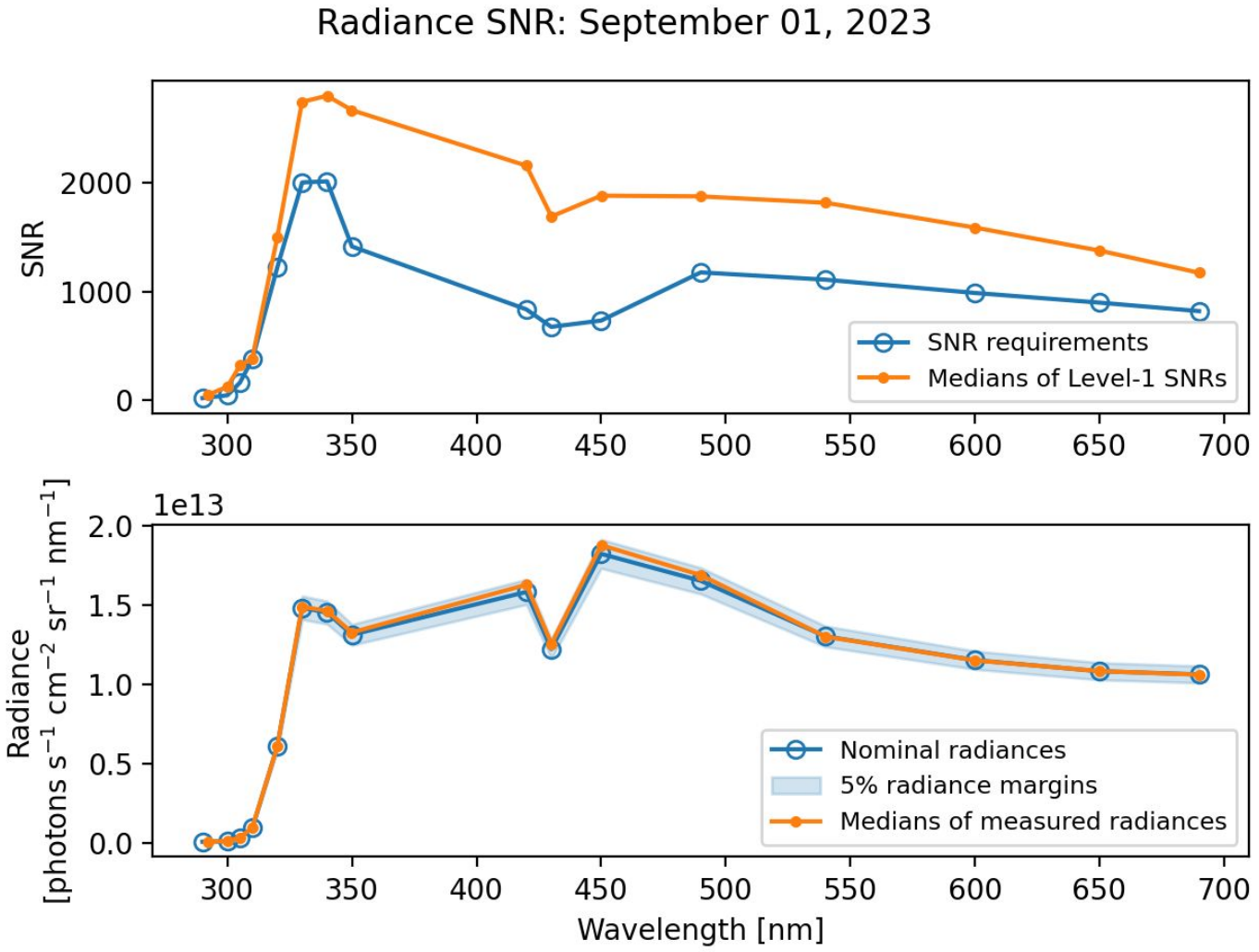
CF < 0.3



# Solar Irradiance and Radiance SNR

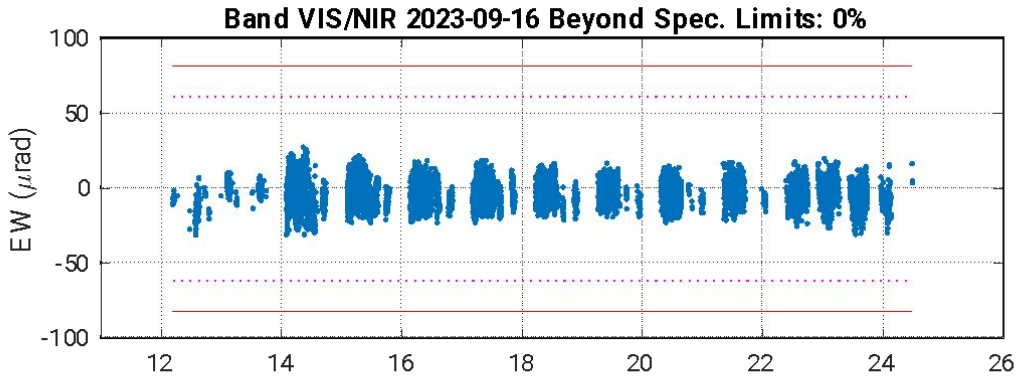
- **15 frames of working solar diffuser measurements on 8/17 for SNR verification.**

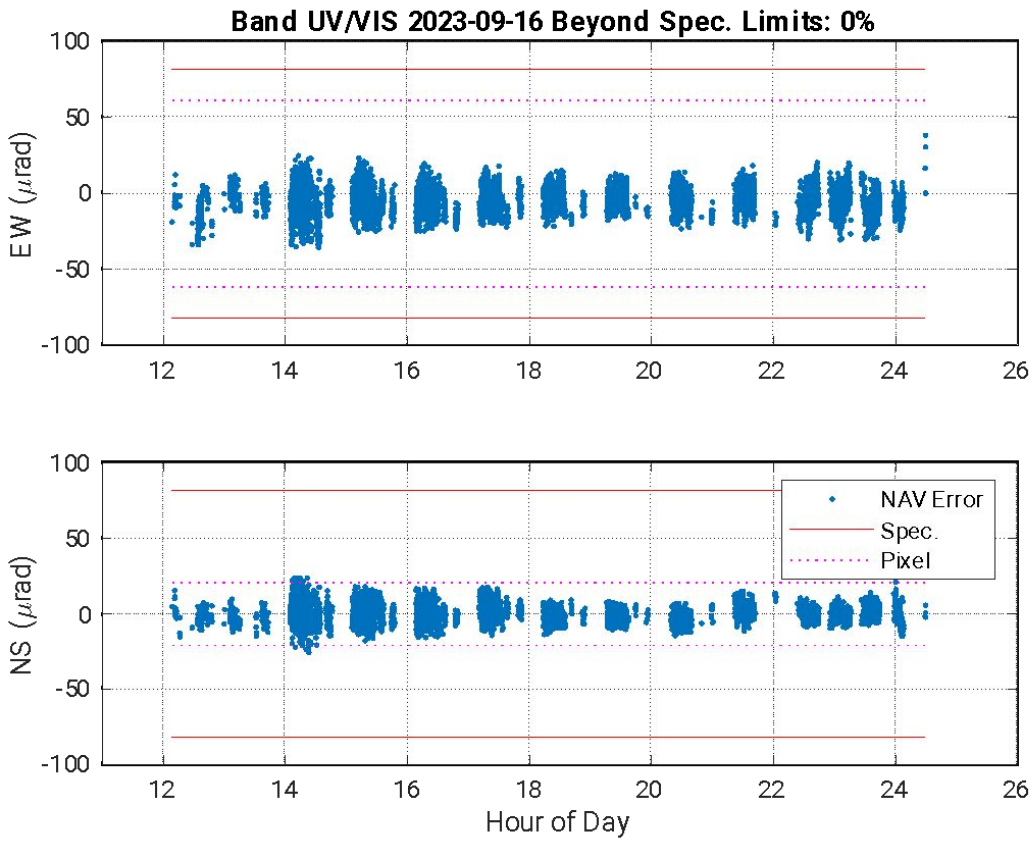



TEMPO solar irradiance and radiance meet instrument SNR requirements as predicted!

# INR Accuracy
# Optimized Scanning (GPSR): September 16

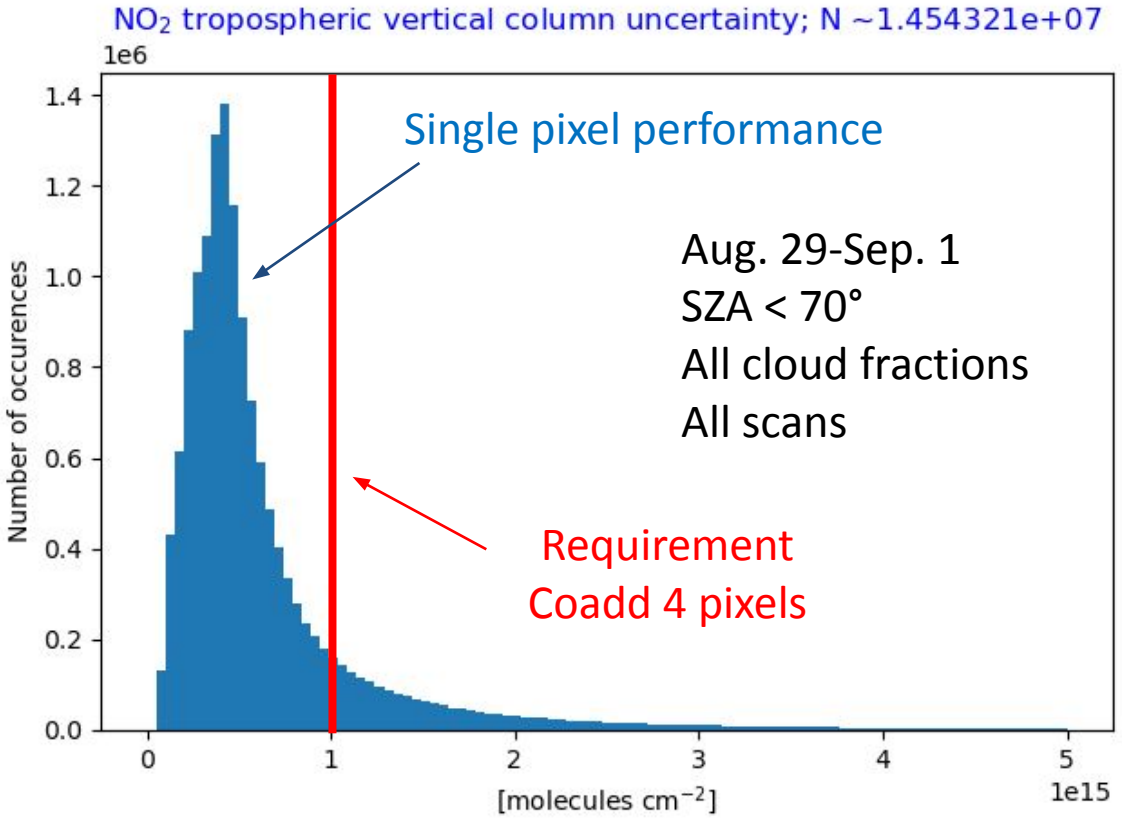


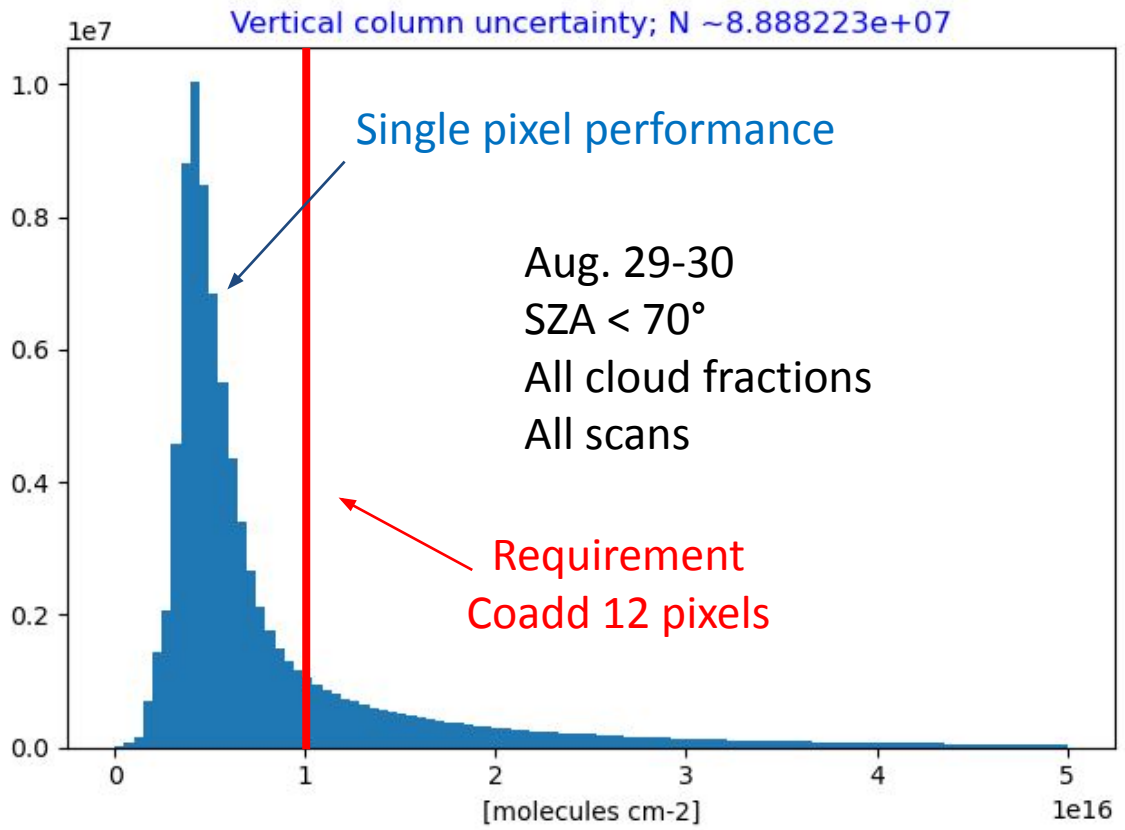




| | EW Mean | EW Std | NS Mean | NS Std | Out of Limit |
|---|---|---|---|---|---|
| VIS/NIR | -2.0981 | 6.0594 | -1.4832 | 4.1732 | 0 |
| UV/VIS | -3.3226 | 6.1935 | -0.128 | 4.3225 | 0 |

TEMPO INR (geolocation) is accurate at sub-pixel level for both UV and Visible Channels!

# $NO_2$ Tropospheric Column & HCHO Column Fitting Uncertainties



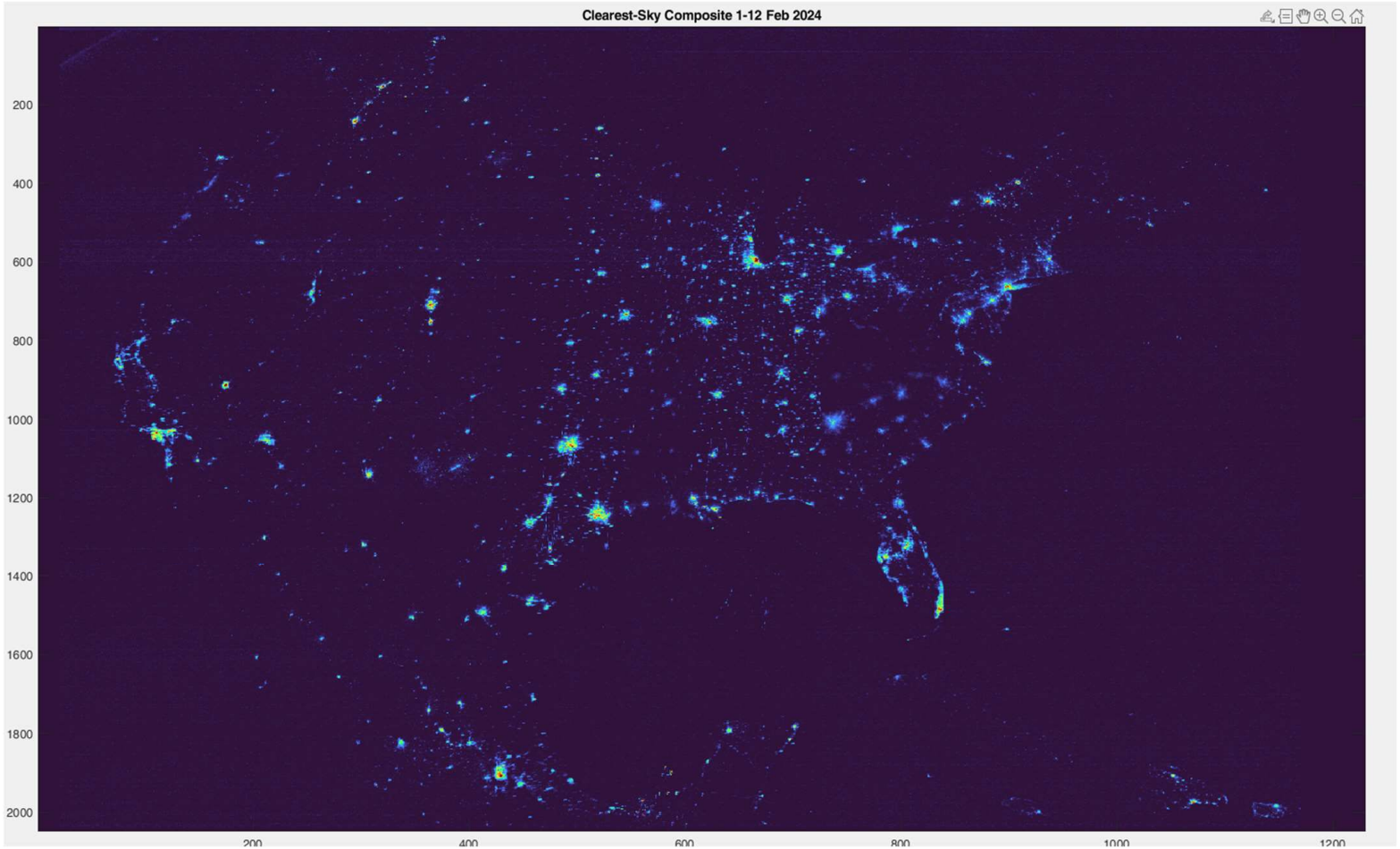




- **$NO_2$ Median uncertainty = 0.46 × $10^{15}$ molecules/$cm^2$ (SZA < 70°, all clouds)**
- **HCHO Median uncertainty = 5.5 x $10^{15}$ molecules/$cm^2$ (SZA < 70°, all clouds)**

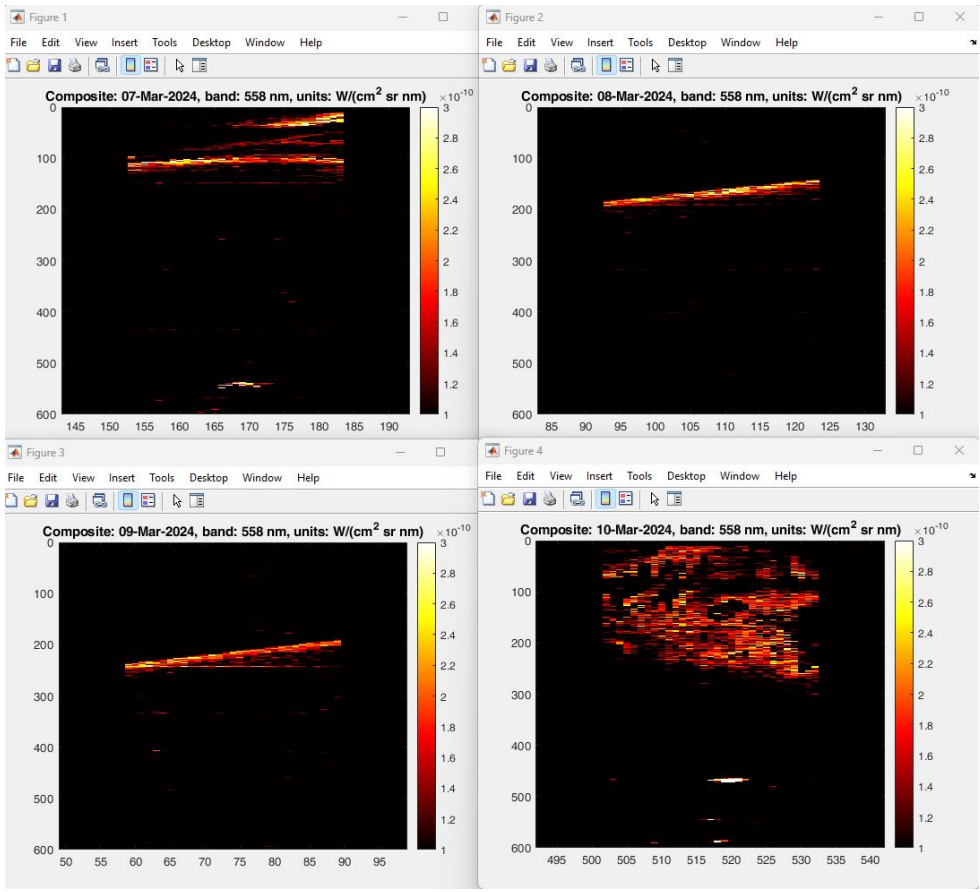
TEMPO $NO_2$ & HCHO meets requirement for >90% of cloud-free scenes with **no pixel coadding**!

# City Lights & Aurora

## Clearest-Sky Composite 1–12 February 2024




## Oxygen at 558 nm

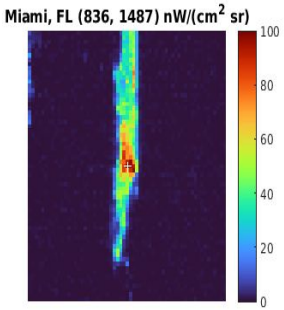


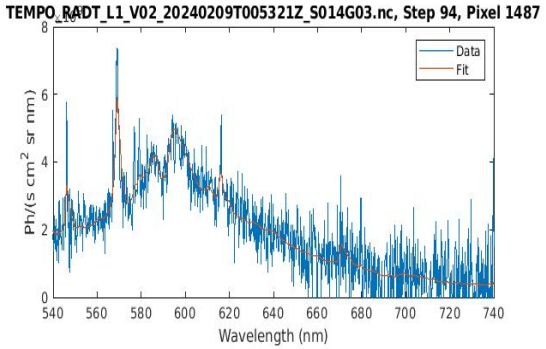

Radiance derivation □ Post-processing (de-speckling, de-streaking, etc.) □ Composite

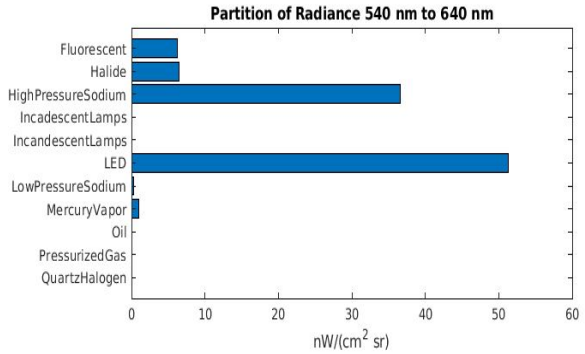
[Credit: Jim Carr]

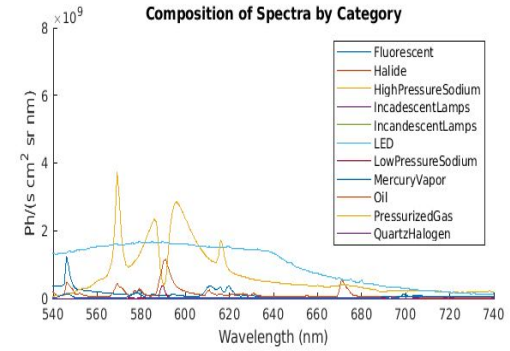
# City Lights Spectral Classification

## Miami, Fl

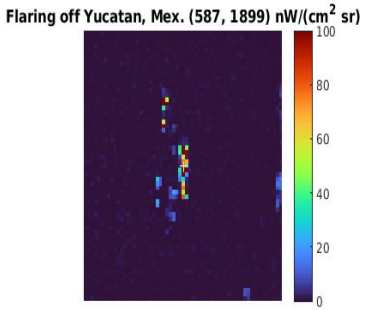


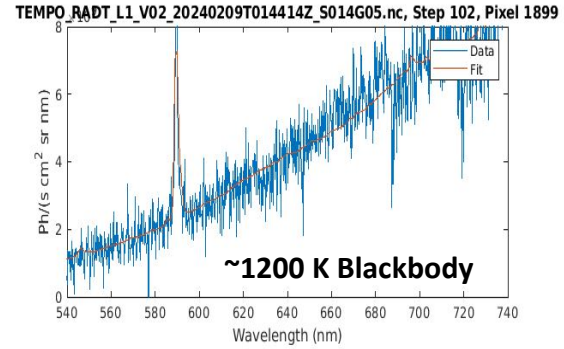



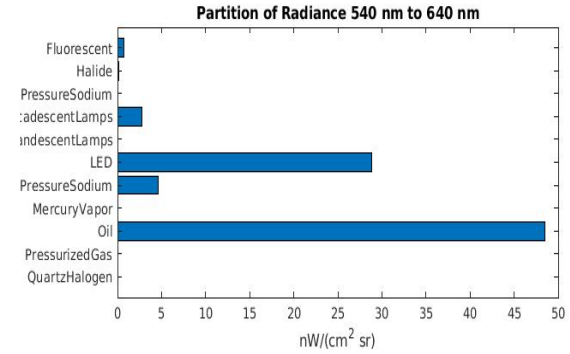



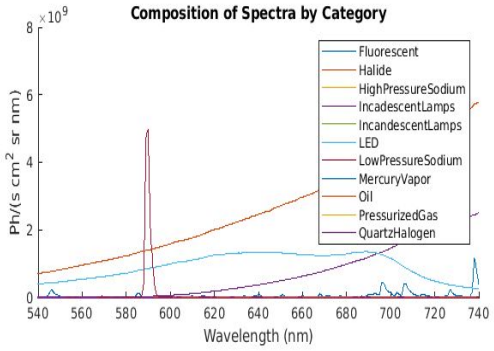




## Offshore Flaring




[Credit: Jim Carr]

# Proposal for Special Collection in AGU Journals
# TEMPO Data Products, Science, and Applications

- Editors: Jun Wang, Xiong Liu, Kelly Chance, Joanna Joiner, Shobha Kondragunta, James Szykman
- We invites articles covering a wide range of topics:
  - ✔ Development, calibration, and validation of TEMPO data products
  - ✔ Societal or operational applications of TEMPO data products
  - ✔ Data assimilation or analysis of TEMPO data products to improve understanding and prediction of Earth and atmospheric processes
  - ✔ Synergy of TEMPO data products with other satellite data products
  - ✔ Interdisciplinary research utilizing TEMPO data to study atmospheric greenhouse gases, land surface processes (such as crop growth and yield, fire combustion and emission, soil and canopy emission), air quality, public health, environmental justice, and hazard surveillance
  - ✔ Contributions aimed at enhancing TEMPO data usage through machine learning or citizen science approaches are of great interest.
- Primary Journals: Earth and Space Science; Journal of Geophysical Research – Atmosphere
- Other Journals: AGU Advances; Geophysical Research Letter; GeoHealth; Community Science; Journal of Advances in Modeling Earth's Systems (?)
- Estimated # of articles: ~30
- Open for 1.5-2 years

# Summary

- TEMPO commissioning and nominal operation have gone on very well
- TEMPO is providing revolutionary hourly daytime atmospheric pollution measurements at high spatial resolution over North America
- Most data products (L1b, cloud, $NO_2$, HCHO, total $O_3$) are in good quality at this early stage, showing that the TEMPO instrument and science algorithms are working very well.
- We are on track to release the L2/3 data products to the public (likely including the UV only ozone profile product)

**On track to release TEMPO data products that are acceptable to enable meeting baseline science requirements!**

*Acknowledgements:* Funding from NASA (Contract No. NNL13AA09C )

*Thank you!*

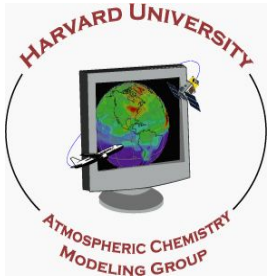

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN


MAXAR












SAINT LOUIS UNIVERSITY











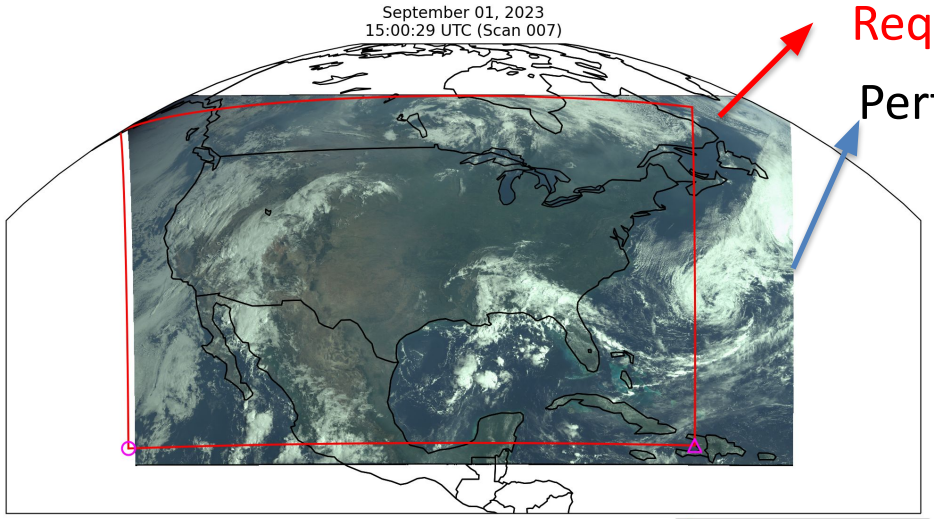



Environment and Climate Change Canada

Environnement et Changement climatique Canada

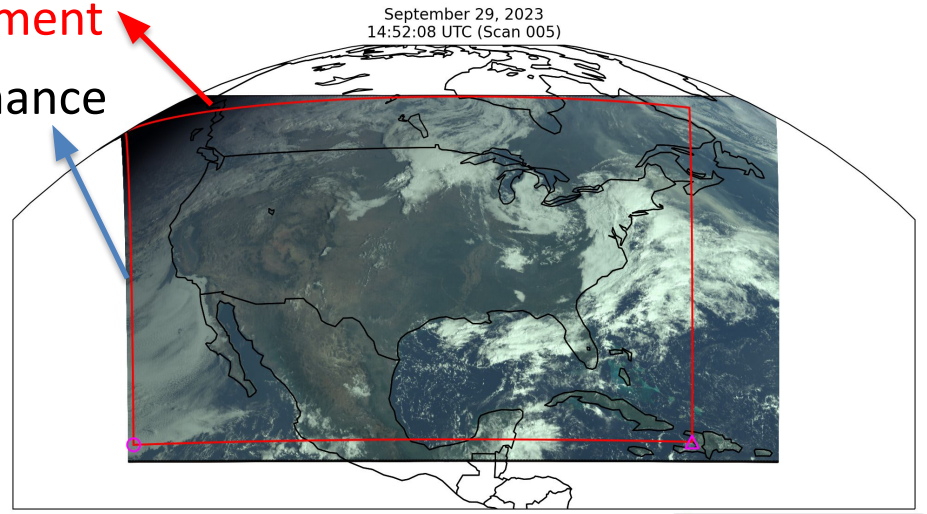

TEMPO

# Field of Regard




Requirement

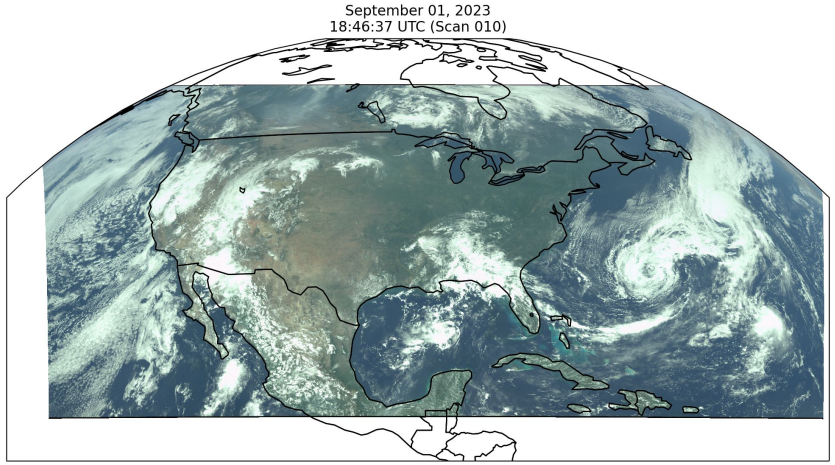
Performance

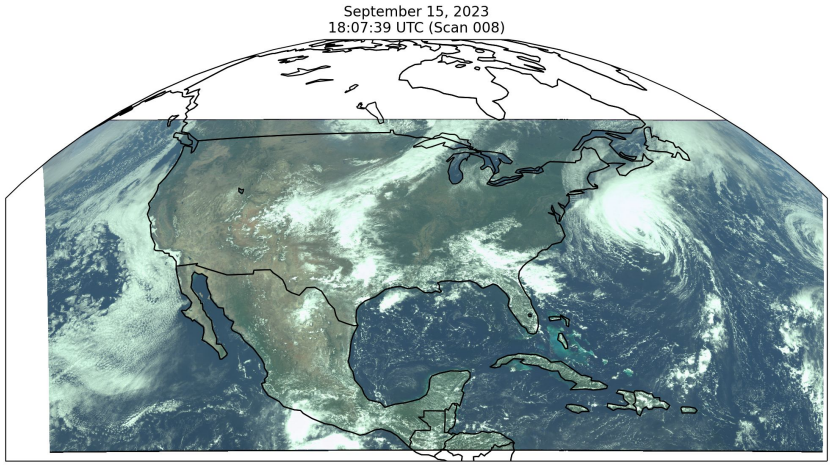


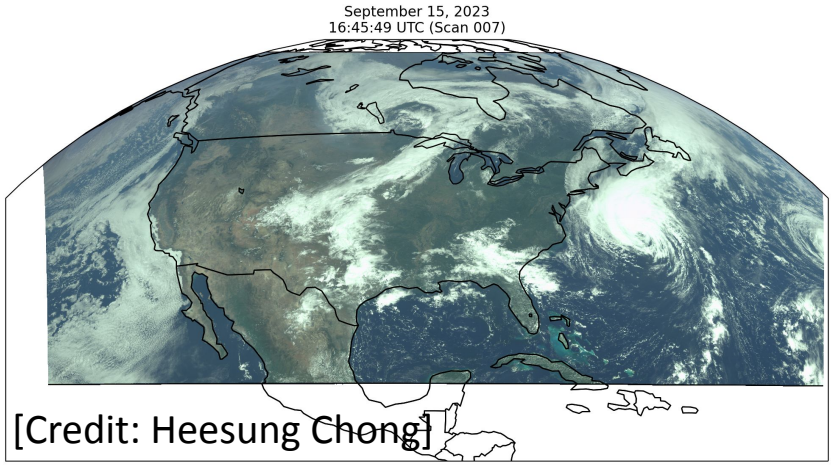

**First light 8/2** field of Regard: 62.7 mins
(100 ms integration time, 26 coadds, 61.5 µrad)

**Optimized** field of Regard in late Sep.: 59.75 mins
(100 ms integration time, 26 coadds, 64 µrad)

**Fields of regard characterization (FOR mapping) with different N-S SMA angles**

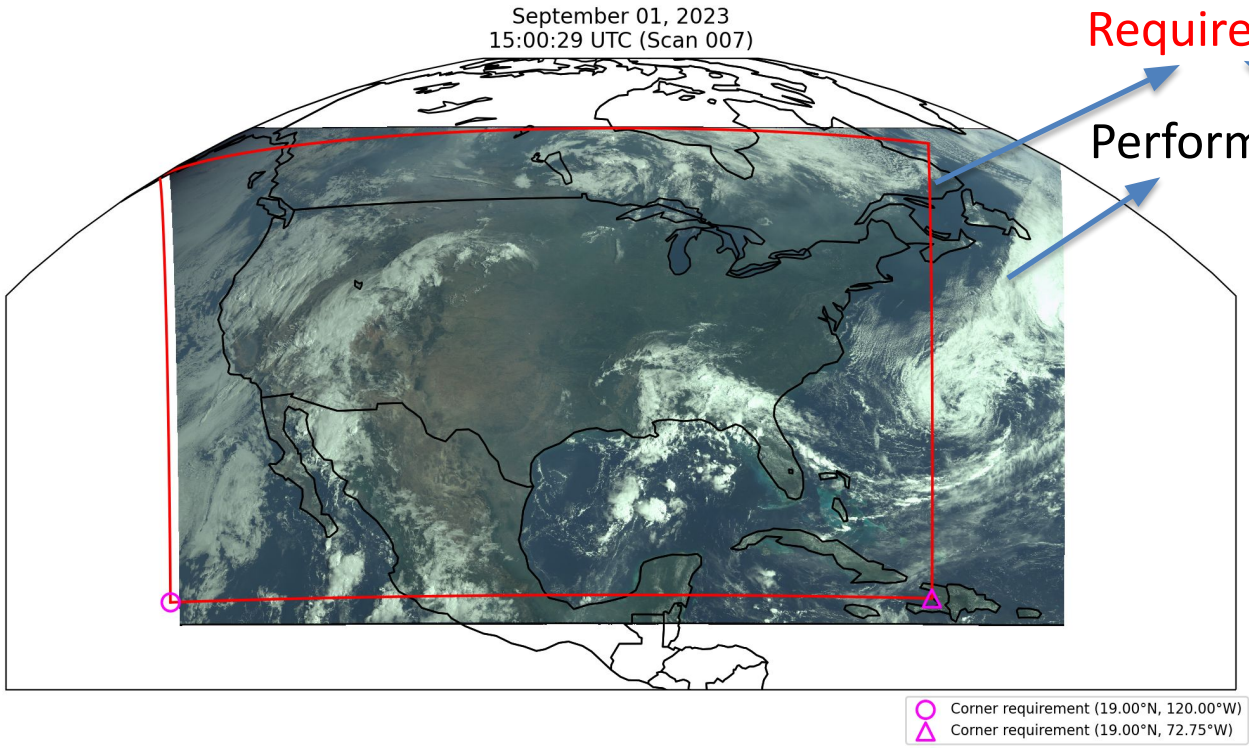


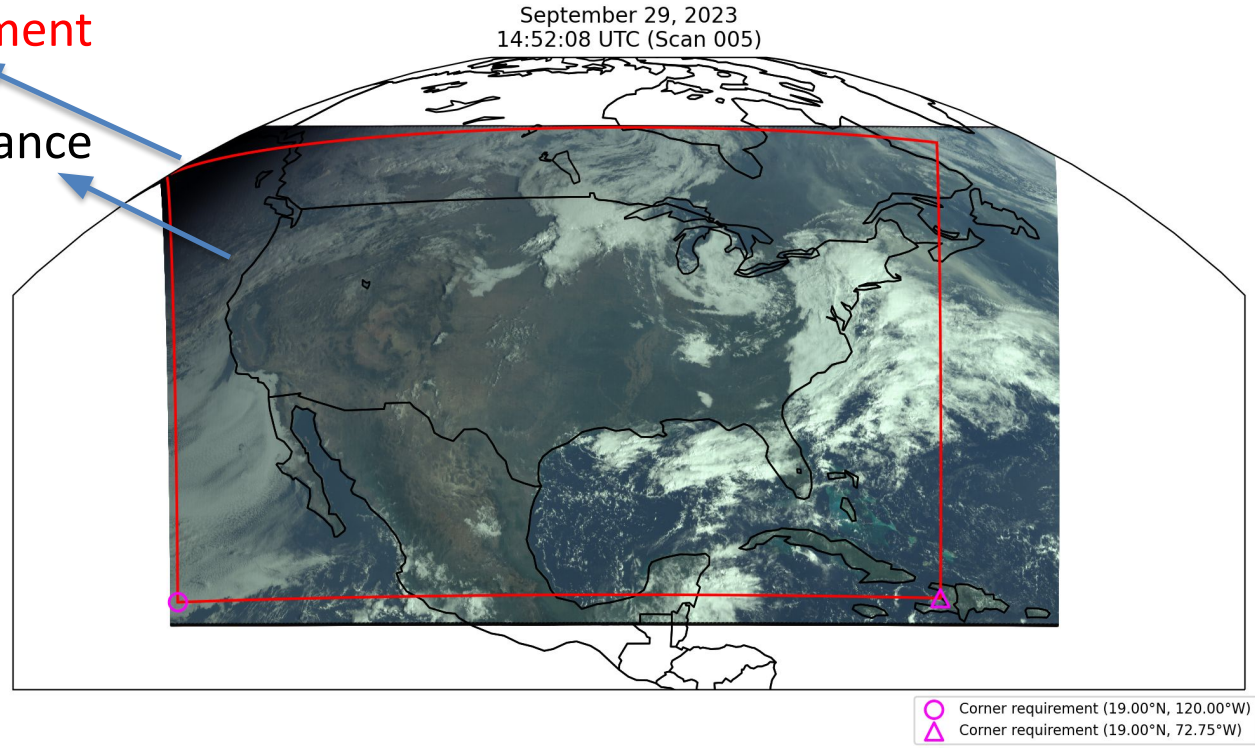

[Credit: Heesung Chong]

# Field of Regard




Requirement

Performance



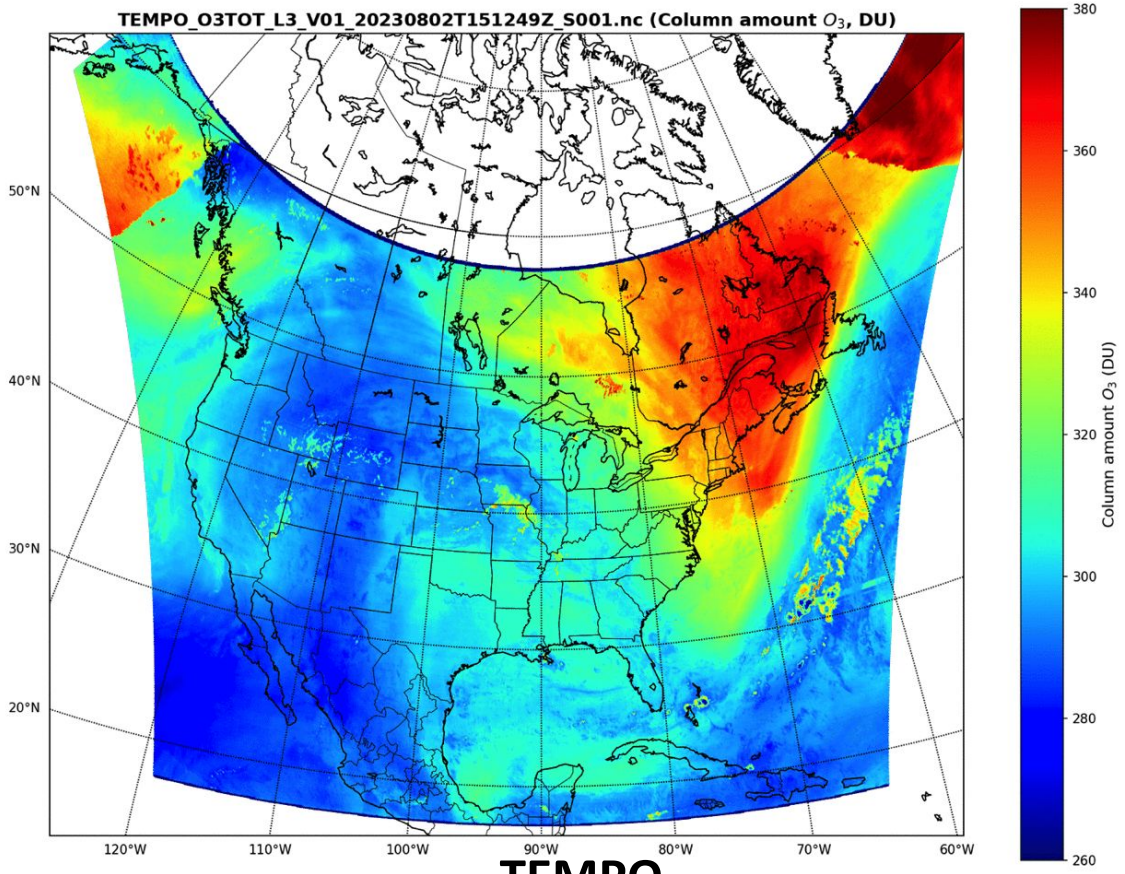

First light field of Regard: 62.7 mins
(100 ms integration time, 26 coadds, 61.5 µrad)

Optimized field of Regard: 59.75 mins
(100 ms integration time, 26 coadds, 64 µrad)

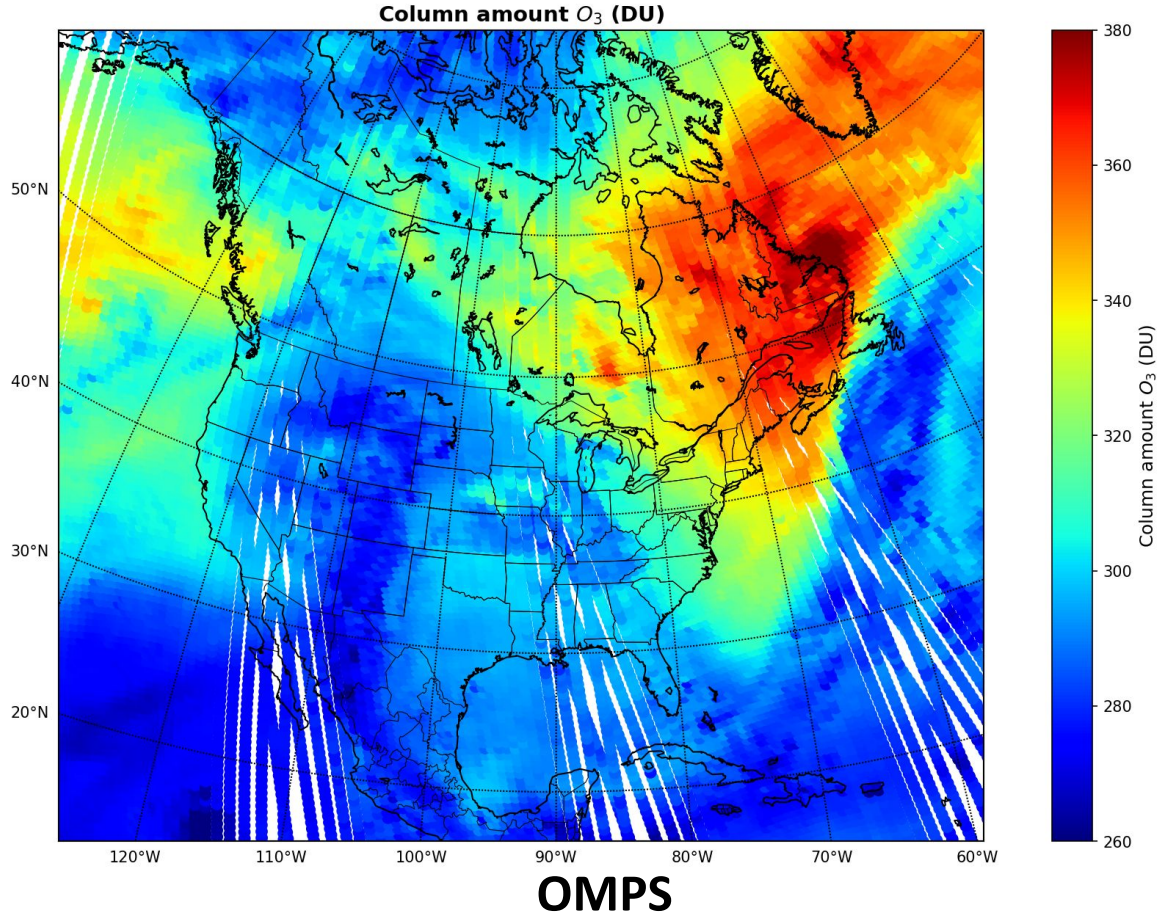
TEMPO is now operating with optimal parameters to support long-term science data collection!

# First Light Total Ozone (02 August 2023)

- Similar spatial distribution with OMPS total ozone
- Total ozone were further improved with improved wavelength calibration & radiometric calibration (e.g., BTDF correction, straylight correction)



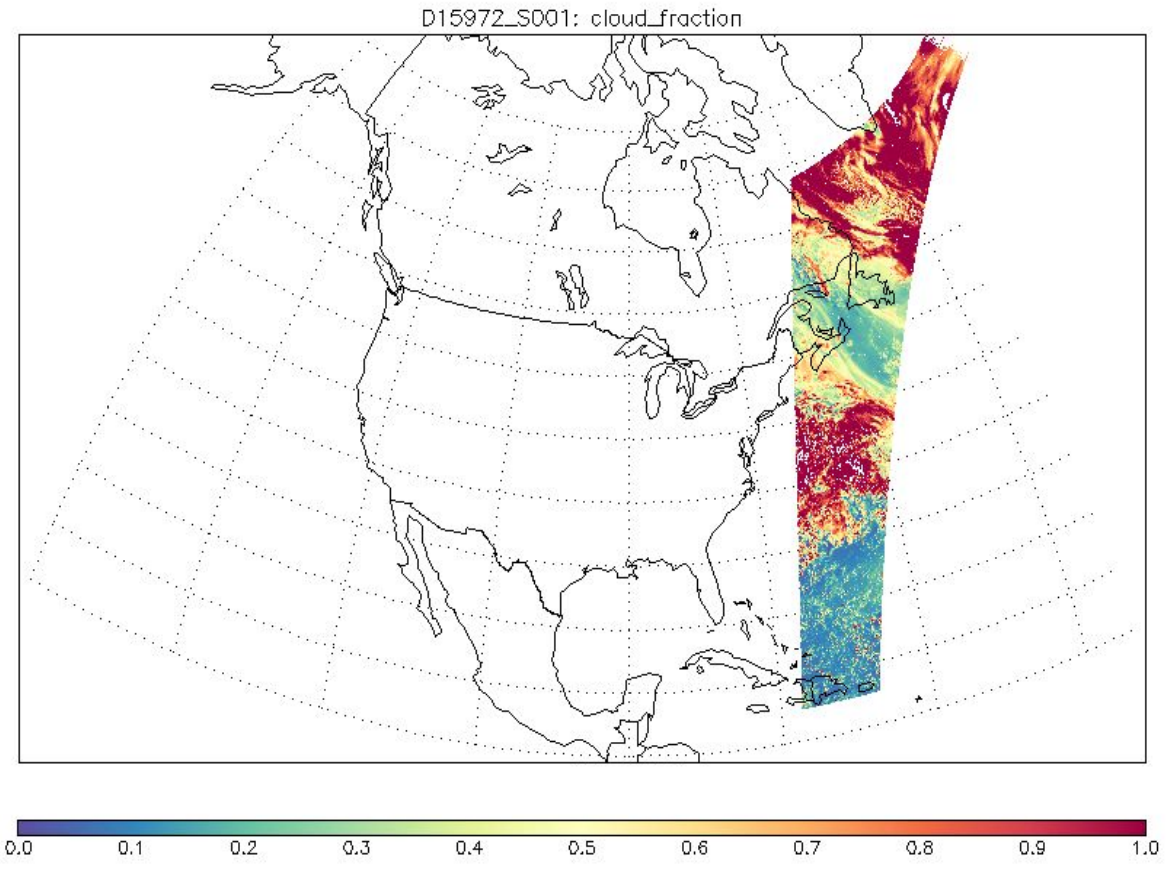

TEMPO



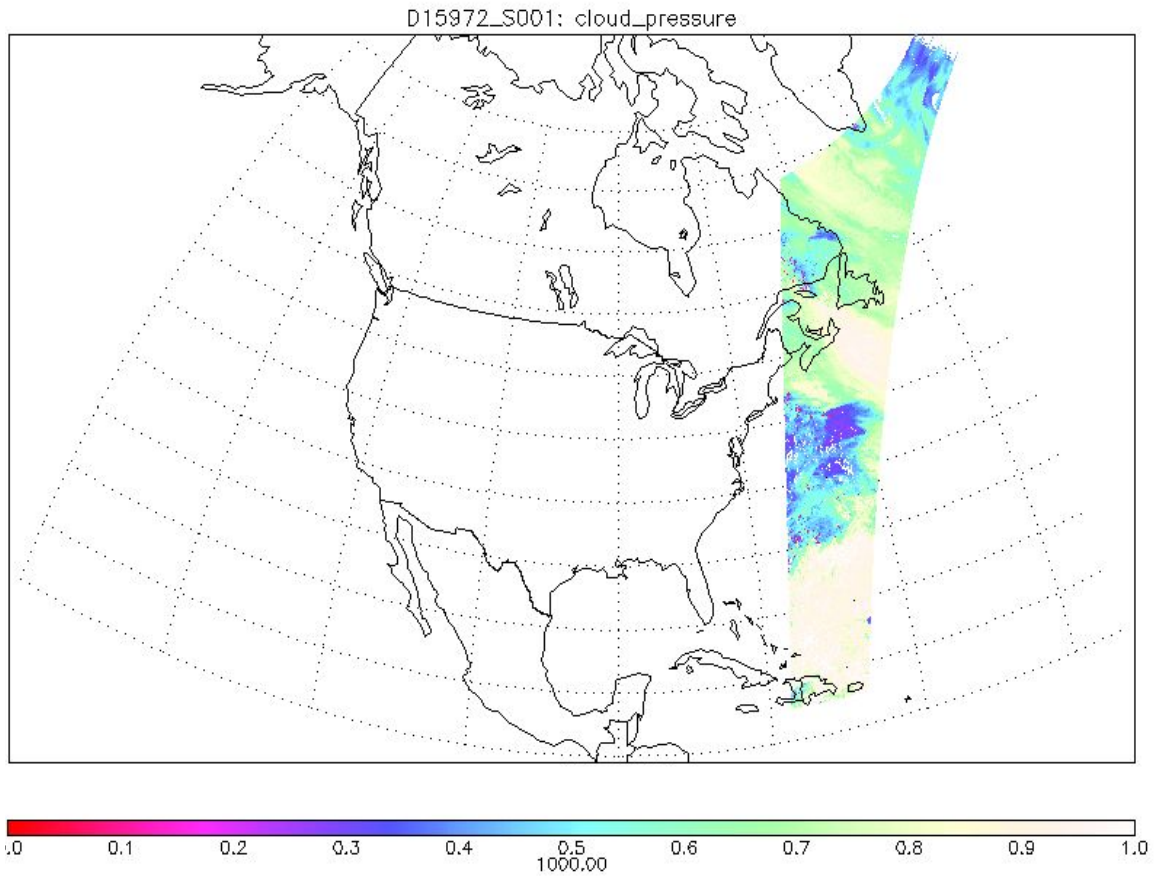

OMPS

# Cloud Products (29 September 2023)

**Cloud fraction**



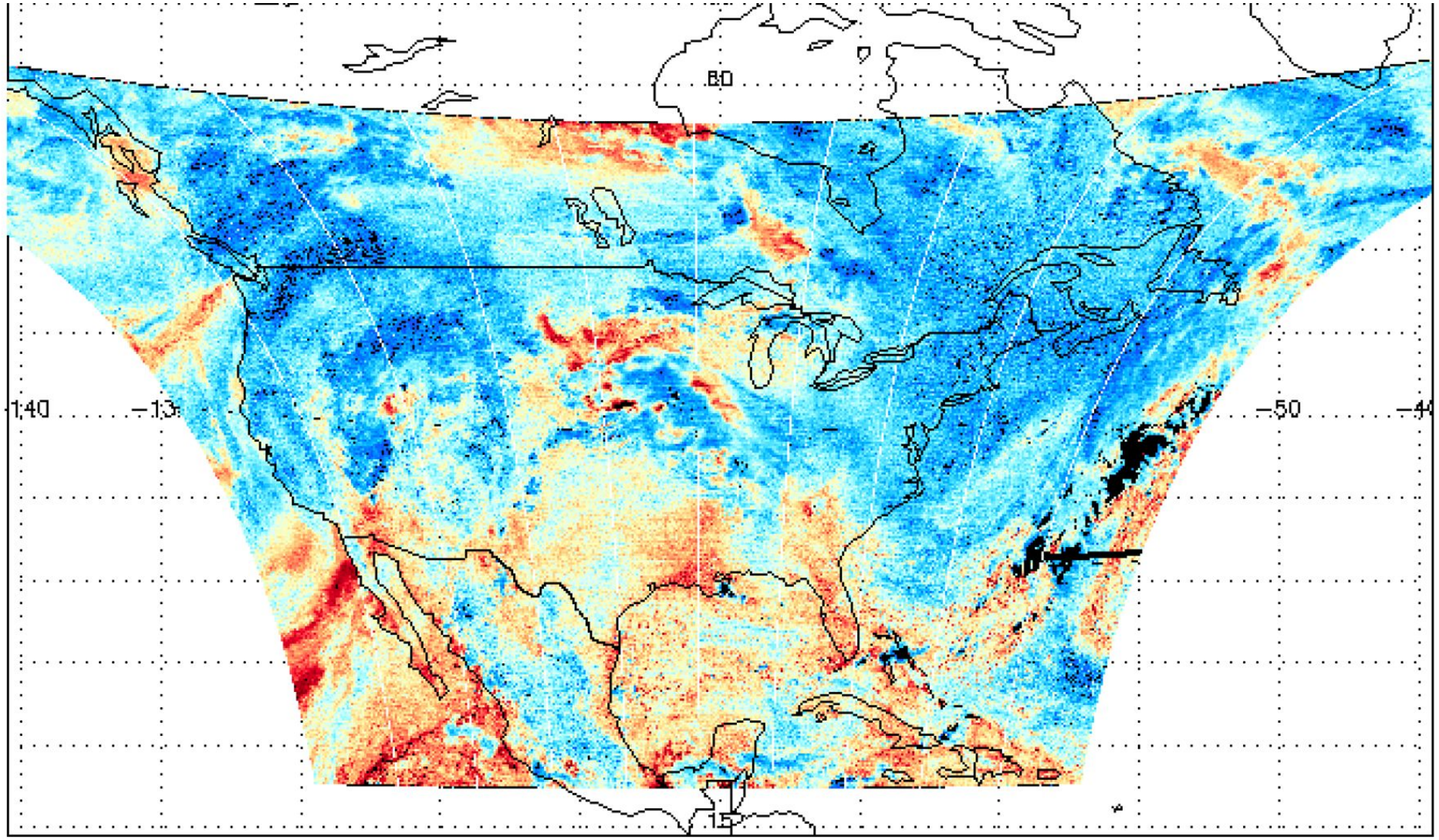

**Cloud pressure**



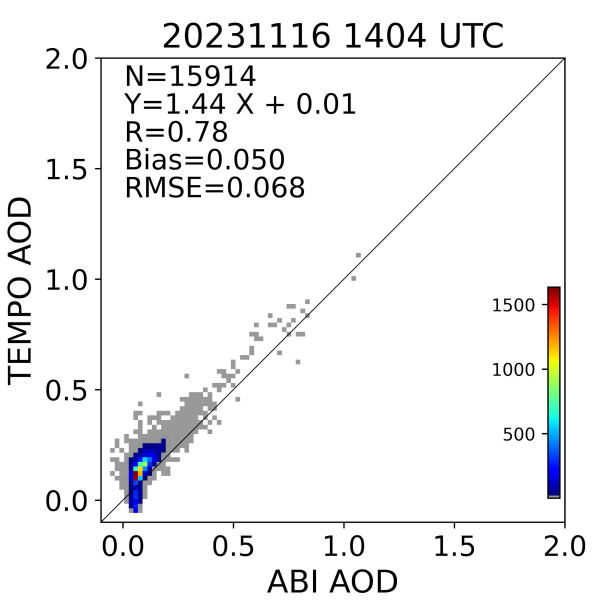

- **Saturation causes no retrieval under very cloudy conditions.**

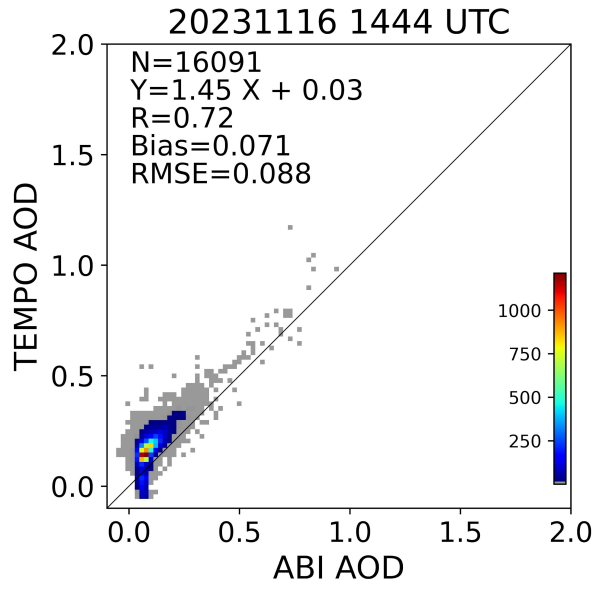
[Credit: Huiqun Wang]

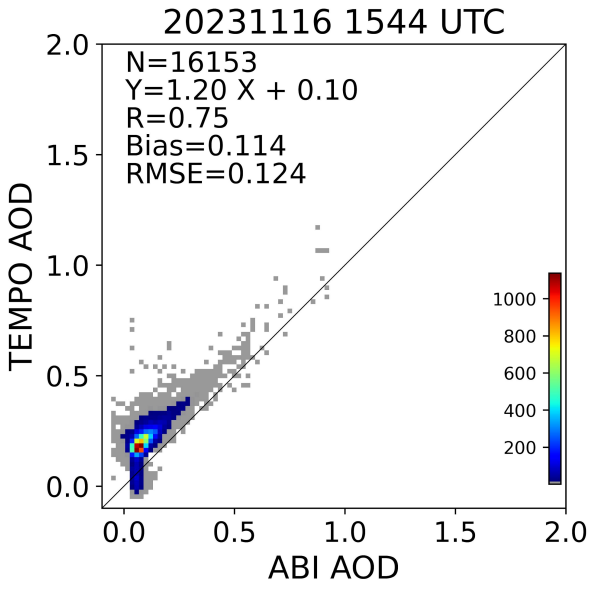
# First Light $H_2O$ SCD (2 August 2023)

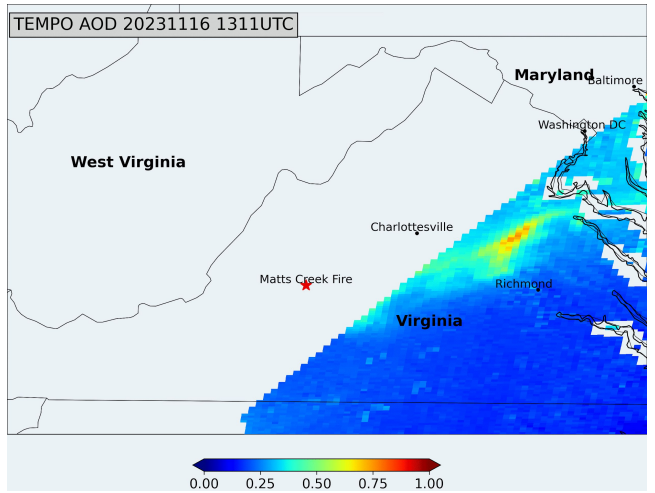


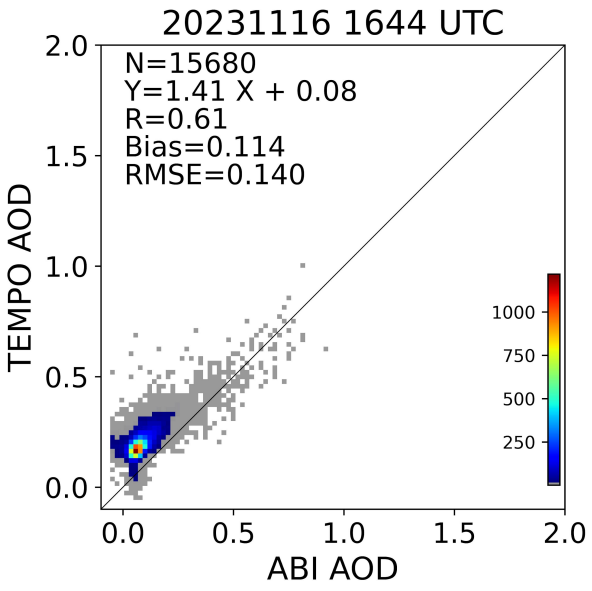
# TEMPO AOD vs ABI AOD in the VA fire region

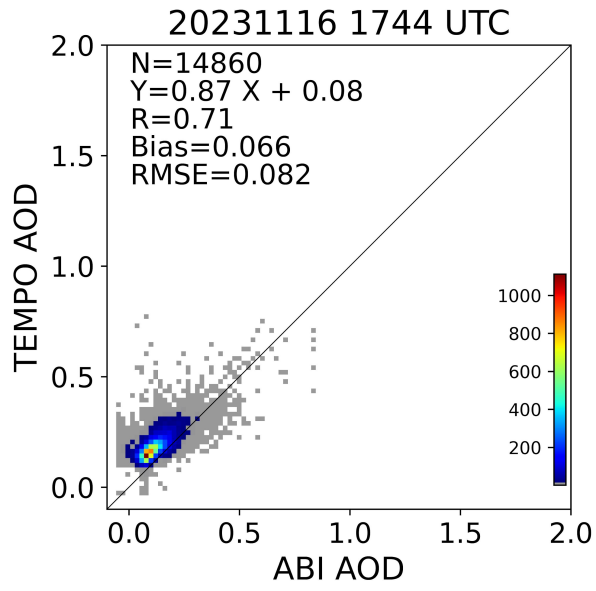


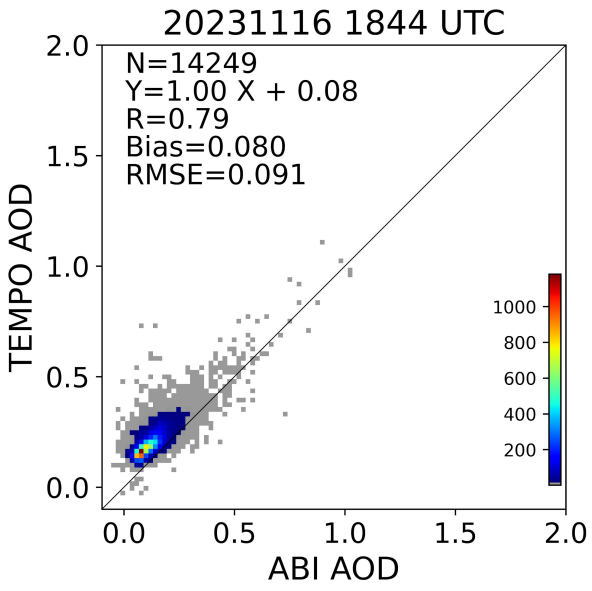



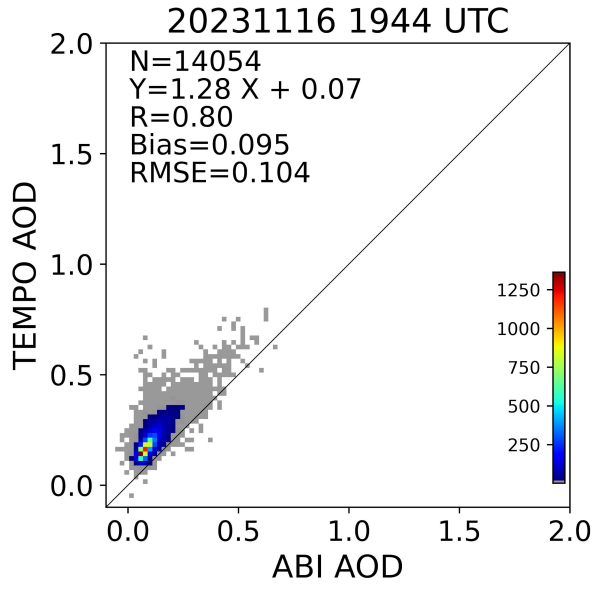



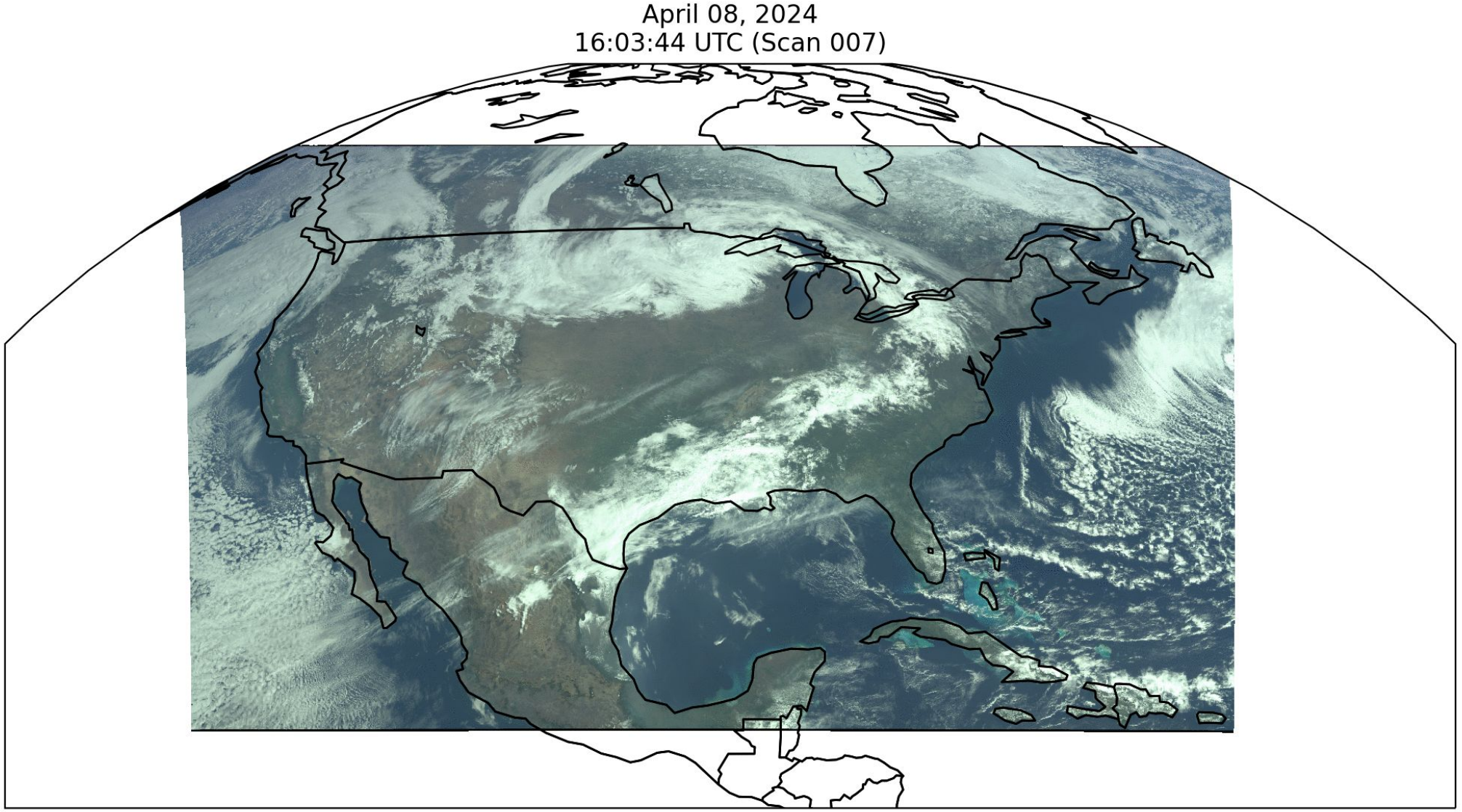




**Credits: NOAA GeoXO Team, Pubu, Hai, Zigang and Shobha**

# TEMPO Observation of Solar Eclipse




[Credit: Heesung Chong]

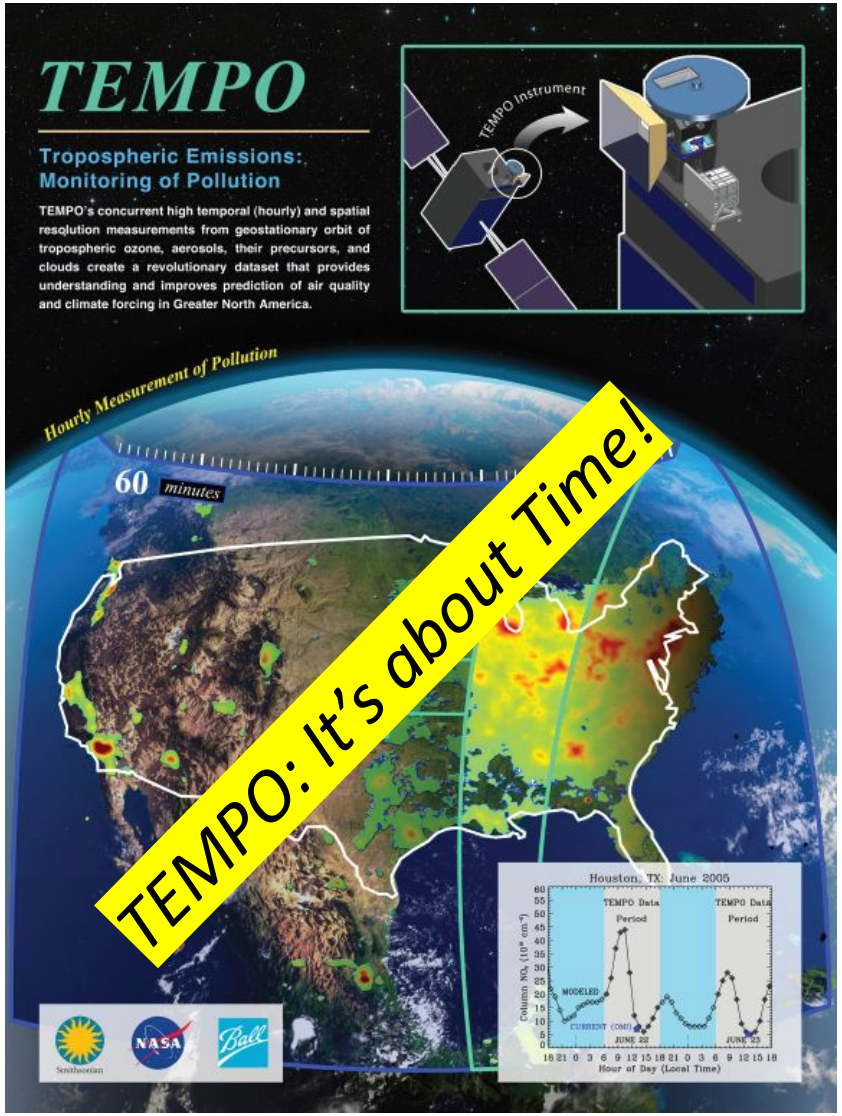
# Introduction to TEMPO

## NASA's first Earth Venture Instrument (EVI) selected in 2012

- ✔ **PI:** Kelly Chance, Smithsonian Astrophysical Observatory (SAO): Science team, ground systems, science data processing center
- ✔ **Instrument Project Management:** NASA LaRC → **SAO (Phase E)**
- ✔ **Instrument Development:** Ball Aerospace
- ✔ **Other Institutions:** NASA GSFC, NOAA, EPA, NCAR, Harvard, UC Berkeley, St. Louis U, UAH, U Iowa, Sitting Bull College, RT Solutions, Carr Astronautics
- ✔ **International collaboration:** Mexico, Canada, Cuba, Korea, U.K., ESA, Spain

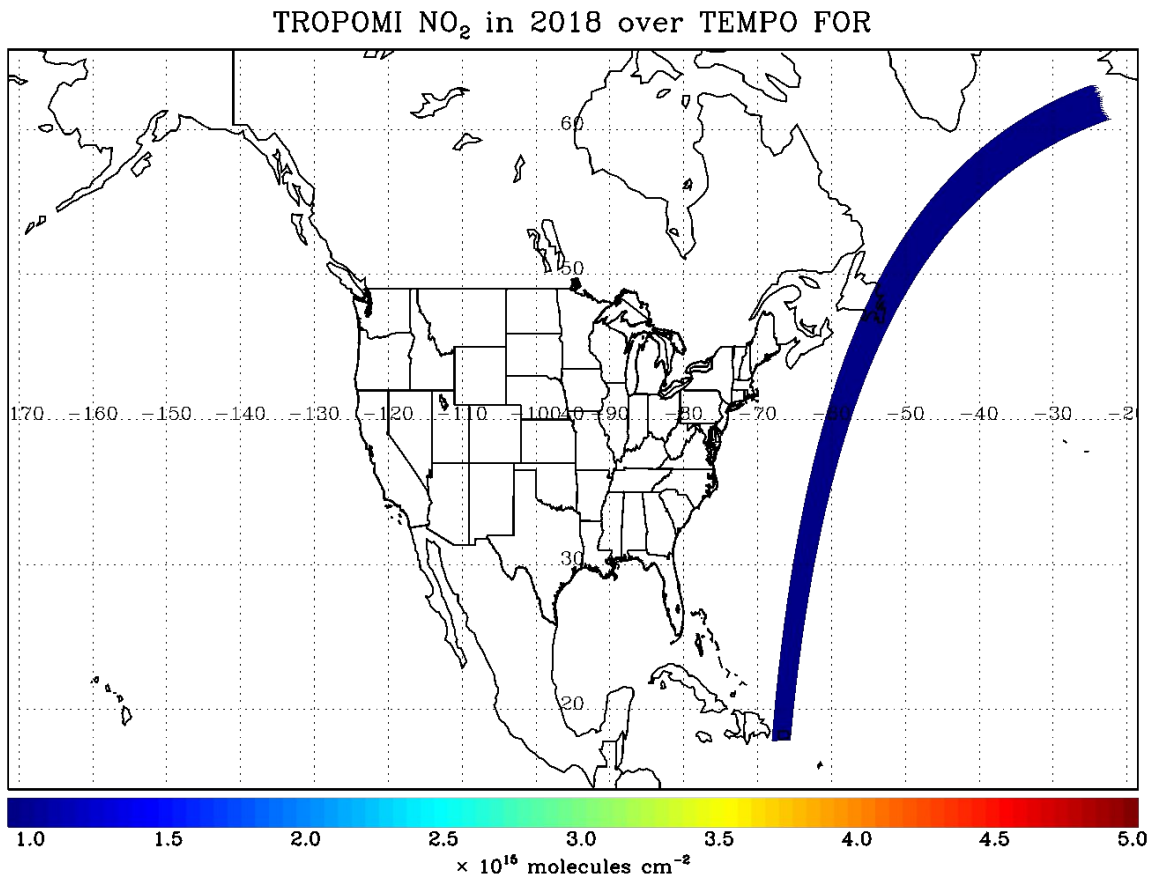
## NASA's first host payload

- ✔ **Mission Project Management:** NASA LaRC
- ✔ **Host Satellite Provider:** Maxar Technologies
- ✔ **Satellite Host:** Intelsat (IS-40e)
- ✔ **Launch:** SpaceX



# TEMPO Operation

## Operate on geostationary communications satellite Intelsat 40e (IS-40e) at 91 ° W




- Field of regard is optimized to cover both Puerto Rico and Canadian tar sands.
- S5p-TROPOMI $NO_2$ product oversampled by Kang Sun.

- **Nominal:** Scan Field of Regard (FOR) in 1 hour
  - ~ 2K N/S pixels × ~1200 steps/hr
  - 2 × 4.75 $km^2$ @center of FOR
- **Optimized scan**: in the early morning and late afternoon, daylight portion, higher temporal resolution (~40 mins)
- **Special Observations (up to 25%):**
  - ✓ **High-time scan**: selected portion at higher temporal res. (e.g., <= 10 mins)
  - ✓ Oversample to effectively increase spatial resolution
  - ✓ Change FOR
  - ✓ No Special observations before April release

**Request special observation** https://weather.ndc.nasa.gov/tempo/green_paper.html

# TEMPO Software/Algorithm Teams

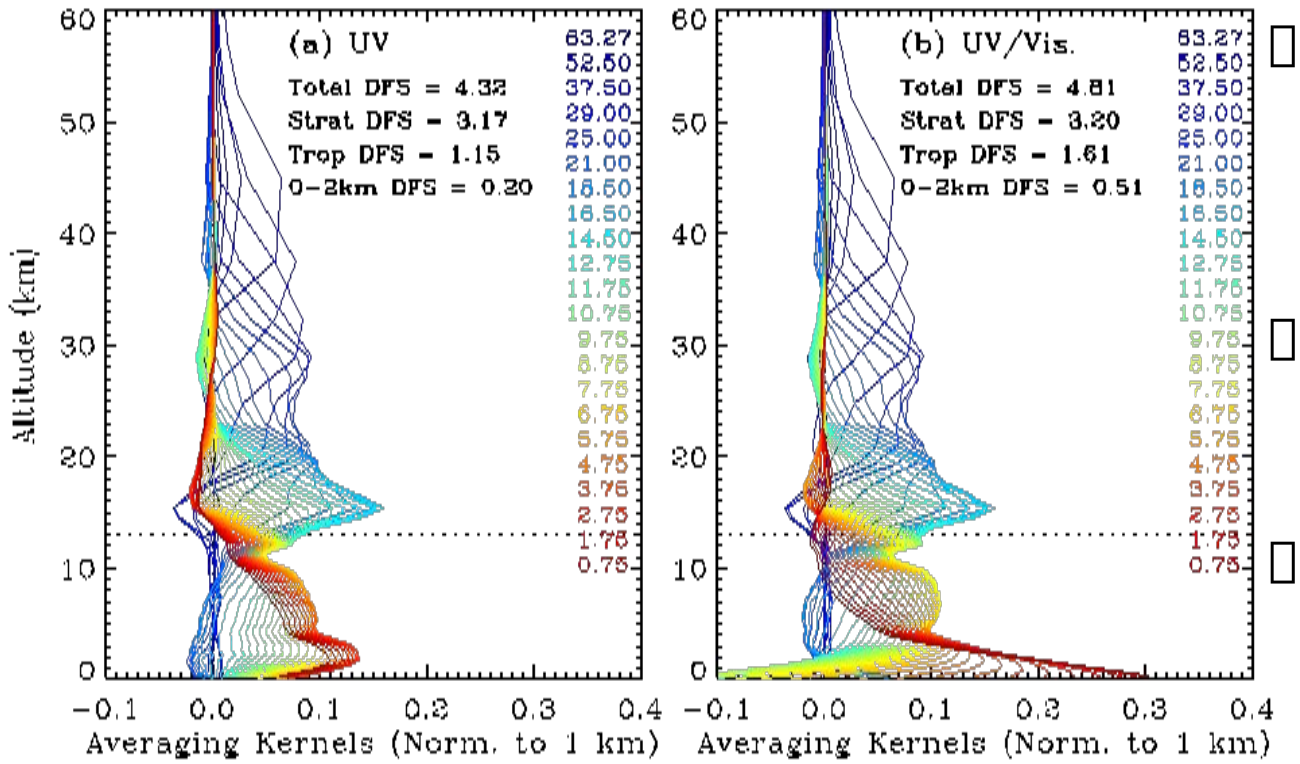
| Operational Algorithm | Personnel |
|---|---|
| **Instrument Operation Center (IOC) including Raw-L0** | John Davis |
| **L0-1b** | **Heesung Chong**, John Houck, Weizhen Hou, Xiong Liu, Dave Flittner, Jim Carr |
| **Ozone profile** | Junsung Park, Xiong Liu |
| **Total ozone** | GSFC / Junsung Park + Xiong Liu |
| **Nitrogen dioxide** | **Caroline Nowlan**, Gonzalo González Abad |
| **Formaldehyde** | **Gonzalo González Abad**, Caroline Nowlan |
| **Clouds** | **Huiqun (Helen) Wang**, Eun-Su Yang, Alexander Vasilkov, Joanna Joiner |
| **Science Data Processing Center Operational Implementation & Processing Pipeline** | John Houck |

# Science Algorithms

- **Launch-ready Science Data Processing Center (SDPC) V4 software completed in Mar 2023**
- **Algorithm mostly based on OMI heritage algorithms except for new L0-1b processor including Imaging Navigation and Registration (INR) using GOES-R by Carr Astronautics**
- **SAO trace gas algorithm (HCHO, $NO_2$): spectral fitting to derive Slant Column Densities (SCDs), calculate air mass factor (AMFs) and derive Vertical Column Densities (VCDs)**
  - ✔ $NO_2$ requires stratospheric/tropospheric separation based on spatial filtering method (Geddes et al., 2018)
- **Cloud algorithm: SAO $O_2$-$O_2$ fitting + NASA GSFC's $O_2$-$O_2$ cloud at ~477/466 nm**
- **Total ozone algorithm: heritage TOMS V8.5, using ozone absorbing and non ozone absorbing pairs to derive total ozone column**
- **Ozone profile algorithm: heritage SAO OMI $O_3$ profile, using 290-340, 540-650 nm, retrieve $O_3$ profile at 24 layers, including total, stratospheric, tropospheric, and 0-2 km $O_3$**
- **Main L1-2 algorithms updates include:**
  - ✔ NASA GMAO's GEOS-CF trace gas profiles and meteorology
  - ✔ Hourly resolved monthly mean Geometry-dependent Lambertian Equivalent Reflectivity (GLER) climatology

# First Light $NO_2$ (2 August 2023)

# Including Visible to Improve Tropospheric Ozone Retrieval Sensitivity



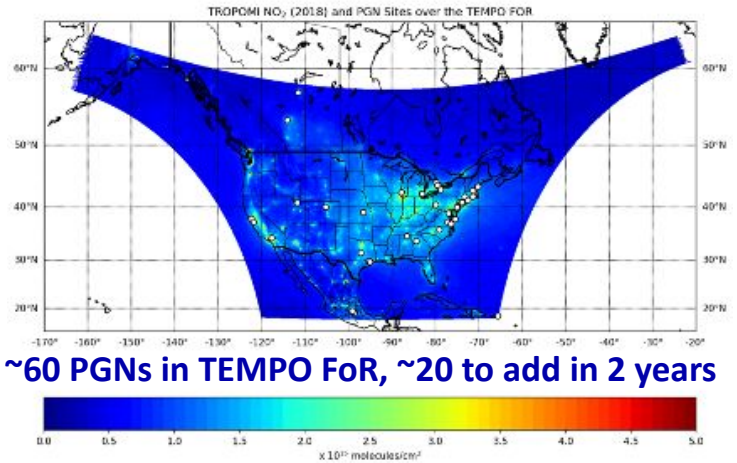

- This example is for solar zenith angle =25, viewing zenith angle 45, relative azimuthal angle 86, Signal to noise Ratio (SNR) with 4 pixels coadded
- Add visible to improve retrieval sensitivity in the lower troposphere and help separate free tropospheric $O_3$ from boundary layer $O_3$
- Under ideal conditions: 3-5 total Degree of Freedom for Signal (DFS) with up to ~1.5 in the troposphere, and up to ~0.5 DFS in 0-2 km

- Adapted from OMI (Liu et al., 2010): Spectral fitting + VLIDORT + Optimal Estimation (OE) from Fitting windows: 293-345 nm, 540-650 nm
- Retrieve partial $O_3$ columns at ~24 layers (bottom layer is 0-2 km above the surface) as well as total, stratospheric, and tropospheric $O_3$ columns, other trace gases, and auxiliary parameters.
- A priori: a combination of tropopause-based climatology (Bak et al., 2013) with diurnally-resolved GEOS-CF data

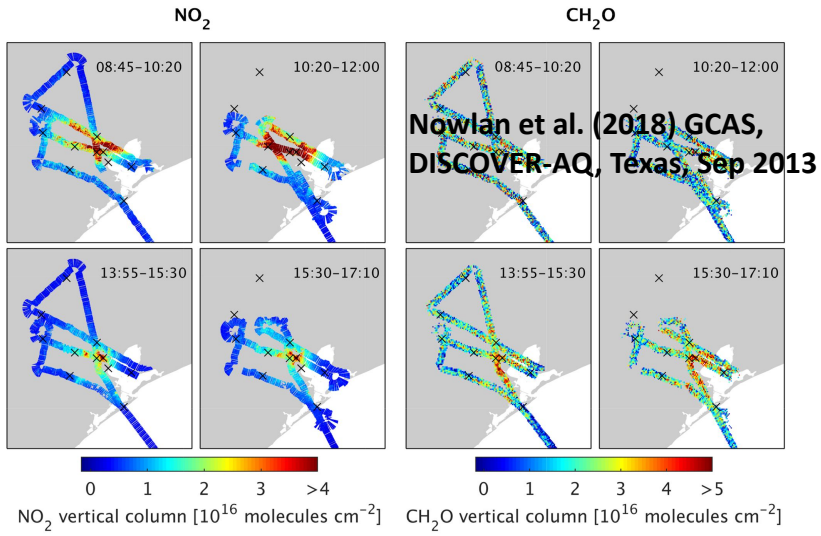
# TEMPO L2 Science Validation Plan

- TEMPO PLRA has a bare minimum validation requirements (3 Pandoras, 1 month per season)
- Jim Szykman has led the development of best-efforts basis validation plan: beta, provisional, full
- Use satellite observations (i.e., LEO and EPIC/DSCOVR) for cross validations
- Pandora & Pandonia Global Network (PGN): validate $NO_2$, HCHO, total $O_3$ and diurnal variation
- TOLNet: 8 LIDAR instruments by time of launch to validate tropospheric $O_3$ & 0-2 km $O_3$ and diurnal variation

https://www.pandonia-global-network.org/

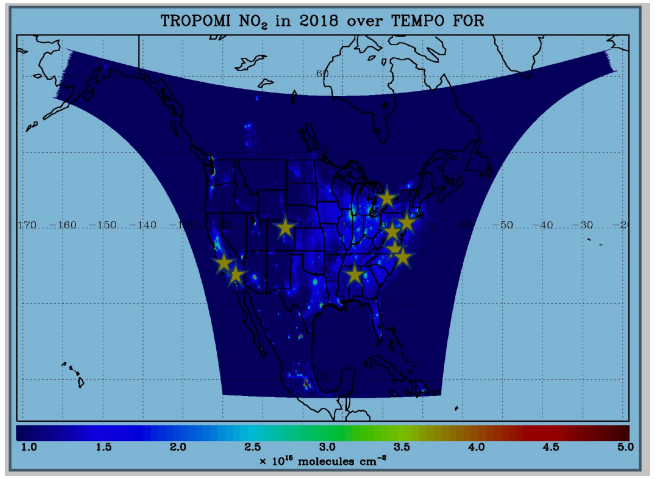



**~60 PGNs in TEMPO FoR, ~20 to add in 2 years**




**Nowlan et al. (2018) GCAS, DISCOVER-AQ, Texas, Sep 2013**

www-air.larc.nasa.gov/missions/TOLNet/




- Airborne instruments: GEO-TASO, GCAS, HSRL-2, IAGOS, SeaRey UAV
- Other instruments: ozonesonde, Dobson/Brewer, MAXDOAS, FTIR, AERONET, …
- Planned flight campaigns AGES+ (e.g., STAQS, AEROMMA+CUPiDS, GOTHAAM) during June-Aug 2003, provide integrated approaches linking TEMPO science, applications, and validation
- Evaluation with chemistry transport models and data assimilation.

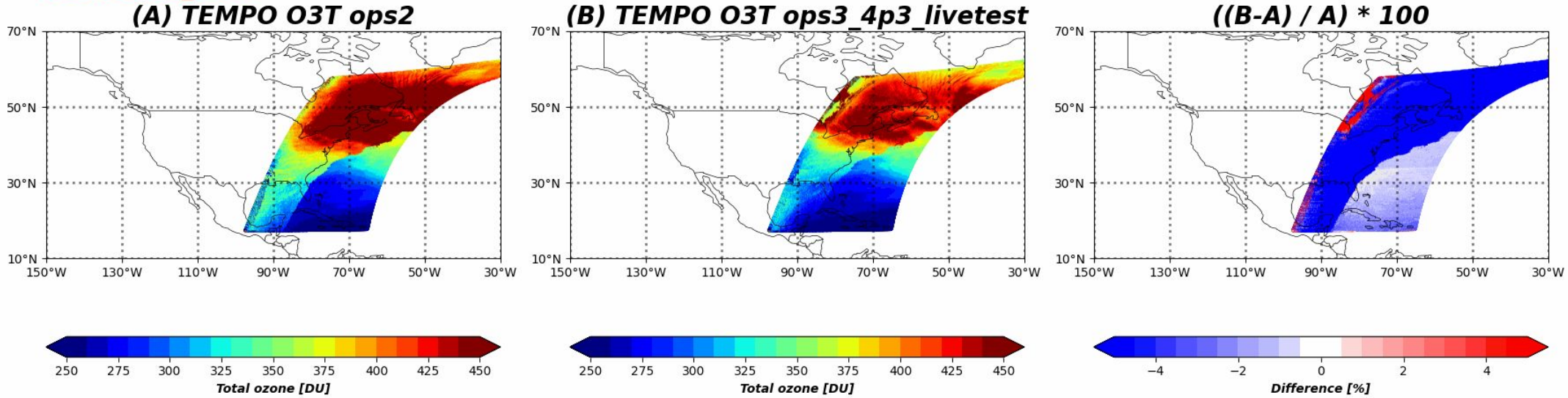
# Calibration and L1b Validation

- Verify and update image correction steps in the L0-1 processing during Commissioning Phase (~L+1~L+3 months, ~90 days)
  - System linearity, zero-input, relative gains, saturation blooming, dark current variation and temperature-dependent correction, check quality flags, evolution of solar diffuser, noise calculation, straylight
- Assess wavelength calibration and its performance
  - Will assess performance of routine processing (wavelength calibration in both L0-1b & L1-2 via high-resolution solar reference and atmospheric absorption)
  - Pre-launch measured instrument line shape will be compared with that derived from solar irradiance
- Assess radiometric calibration using a multi-pronged approach
  - Internal assessment of images, Assess performance of routine processing
  - Comparison solar irradiance with solar reference and correlative contemporaneous sensors (e.g., OMPS, TROPOMI, GOME-2, EPIC, MODIS, VIIRS)
  - Comparison with radiative transfer simulation
- Assess geo-location methodology with Image Navigation and Registration (INR) during commissioning phase, accuracy and uncertainty
  - Imagery: assess registration offset of fiducial points not used in INR, using other reference imagery
  - L2: assess bias and variance in registration offset of known point sources of $NO_2$

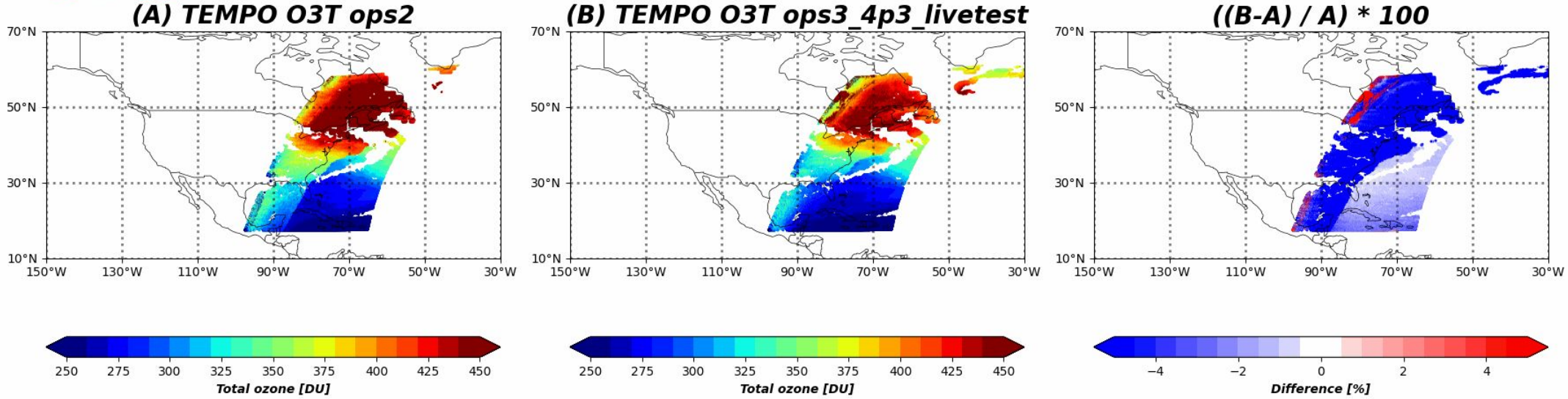
# TEMPO O3TOT comparison between V1.0 and V2.0

FEB 16, 2024

20240216_S002



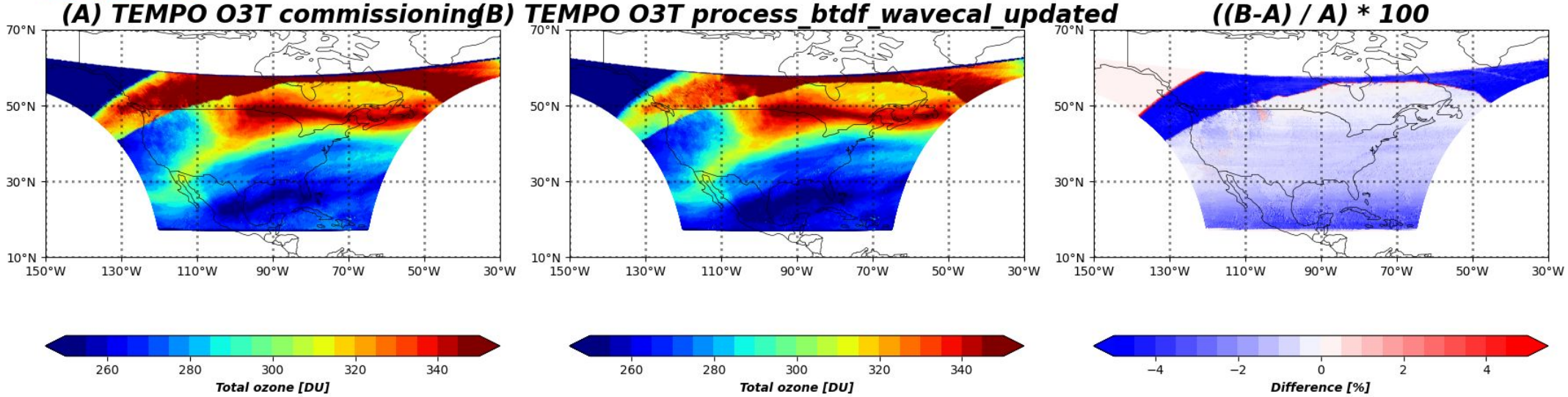

CF <= 0.3



# TEMPO O3TOT comparison between V1.0 and V2.0

S006 NOV 11, 2023

**No filtering**




**CF <= 0.3**