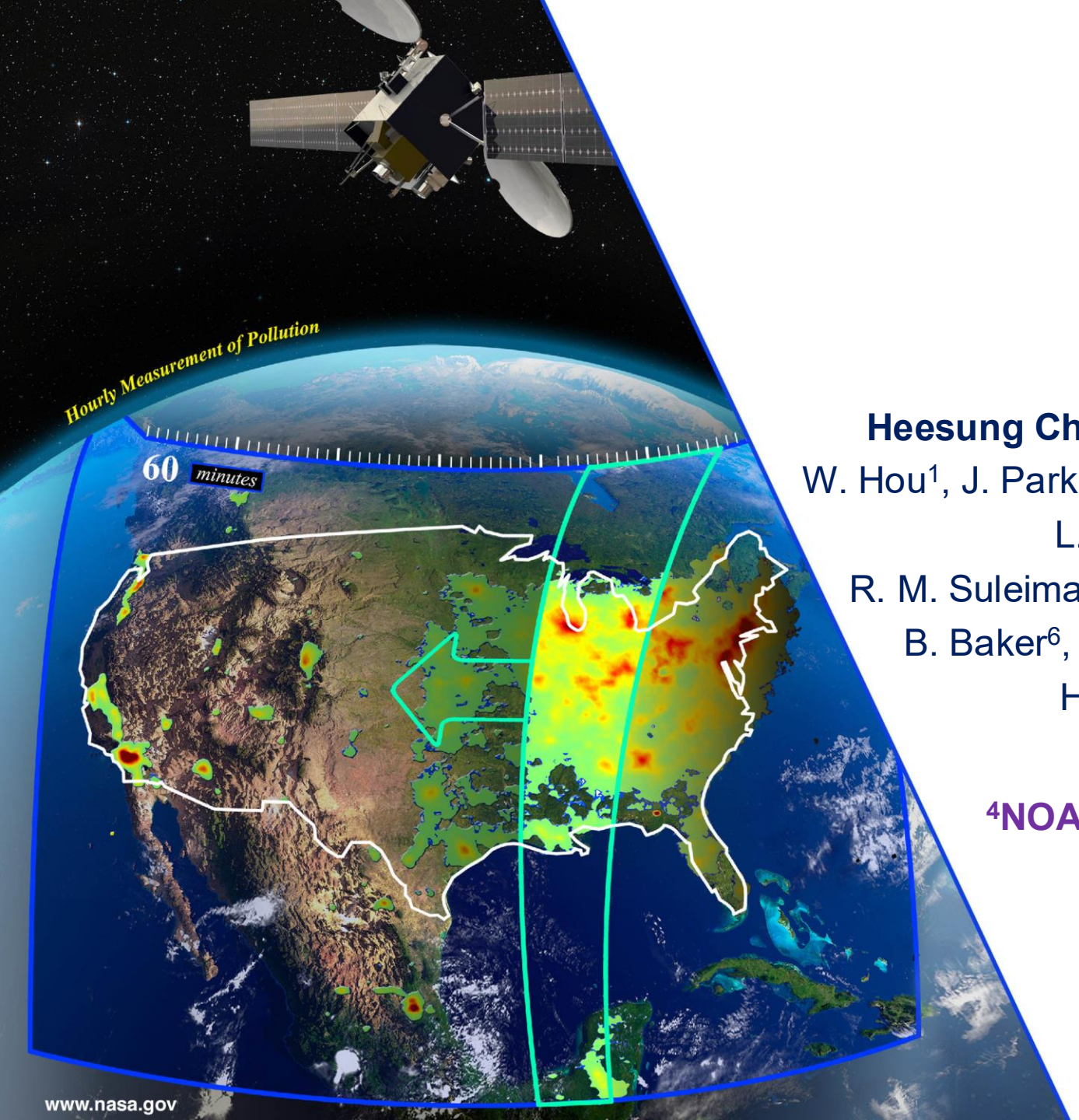


Tropospheric Emissions:
Monitoring of Pollution

TEMPO Level 1 Status

Heesung Chong[1], X. Liu[1], D.E. Flittner[2], J. Houck[1], J. Carr[3], W. Hou[1], J. Park[1], G. González Abad[1], C.R. Nowlan[1], H. Wang[1], L. Flynn[4], S. Marchenko[5], J. Joiner[5], J. E. Davis[1], R. M. Suleiman[1], J. Fitzmaurice[1], L. Yatsuhashi[1], K. Chance[1], B. Baker[6], C. Seftor[5], G. Jaross[5], J. O. Robaidek[7], X. Wu[4], H. Xu[4], B. Basnet[4], Y. Bai[4], C. Cao[4], D. Doelling[2]

[1]SAO, CfA [2]NASA LaRC [3]Carr Astro.
[4]NOAA/NESDIS [5]NASA GSFC [6]BAE [7]UW–Madison

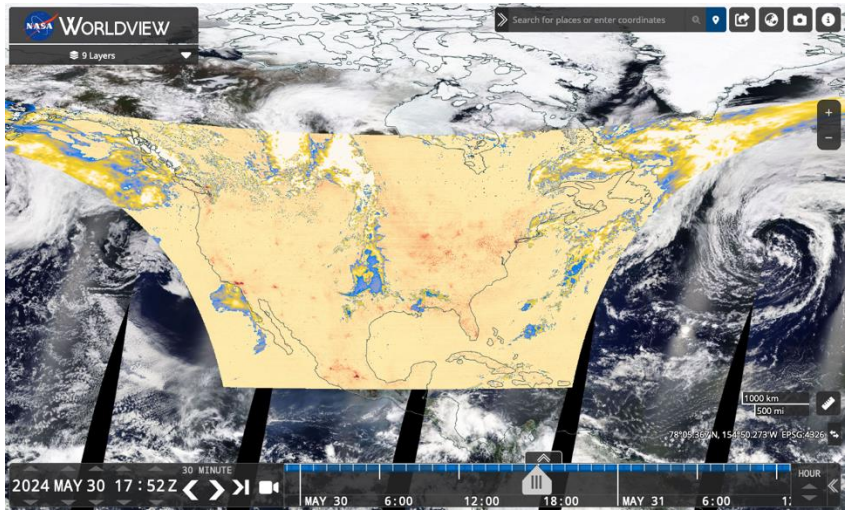
September 12, 2025

Smithsonian

TEMPO Mission Status

Date	Details
2023/04/07	Launch
2023/06–07	TEMPO power on + dry-out, cool down, etc.
2023/08/01–02	First light
2023/10/19	Nominal operations
2025/06/18	**Prime mission ends, review on 2025/10/10**
2026/09	**First extended mission ends, further extension via NASA senior reviews (2026/03)**

Public Release	Date	Details
V03	2024/05	L1 updated, Level 2/3 cloud, NO_2, HCHO, total O_3 V3 O_3 profile (ASDC 6/9/2025, not for the public)
V04	**2025/09/17**	**Release ozone profile (beta), updated L1 + other L2/L3 (provisional)**
NRT V02	**2025/09/17**	**L1, Level 2/3 cloud, NO_2, HCHO (funded by SNWG)**



ASDC TEMPO

Updates in Version 4 Level 1 products

- **Radiometric calibration updates**
  - Diffuser transmittance correction
  - Magnitude adjustment for the radiometric calibration coefficients
  - Diffuser goniometry correction
  - Etalon fringe correction

- **Image processing + Spectral calibration updates**
  - Stray light correction
  - Smear correction
  - Solar irradiance wavelength calibration

Diffuser transmittance

Issue to resolve in Version 3: **Positive bias in Sun-normalized radiance (on the order of 10%)**

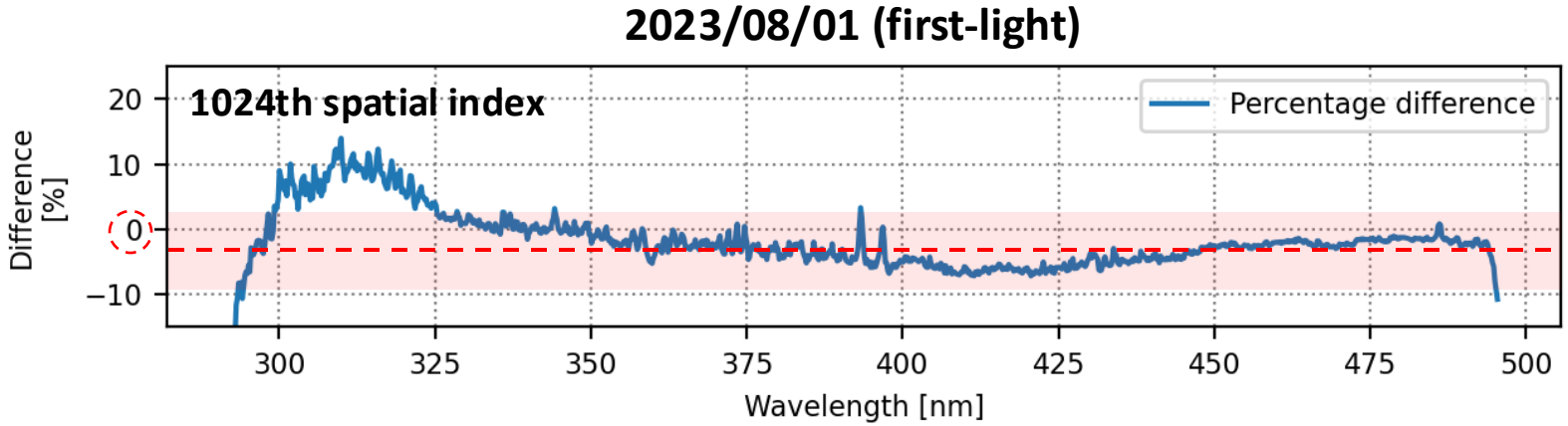
$$\text{(Sun-normalized radiance)} = \frac{\text{(Earth radiance)}}{\text{(Solar irradiance)}}$$

$$= \frac{\text{(Earth-radiance electric current)} * \text{(Calibration coefficient)}}{\text{(Solar-irradiance electric current)} * \text{(Calibration coefficient)} / (\textbf{Diffuser transmittance})}$$

Approach: **Adjust the solar diffuser transmittance.**

Diffuser transmittance

(TEMPO Version 3 irradiance) – (TSIS-1 reference irradiance)



Why did the transmittance bias <u>not</u> appear in Version 3? → Biases in calibration coefficients

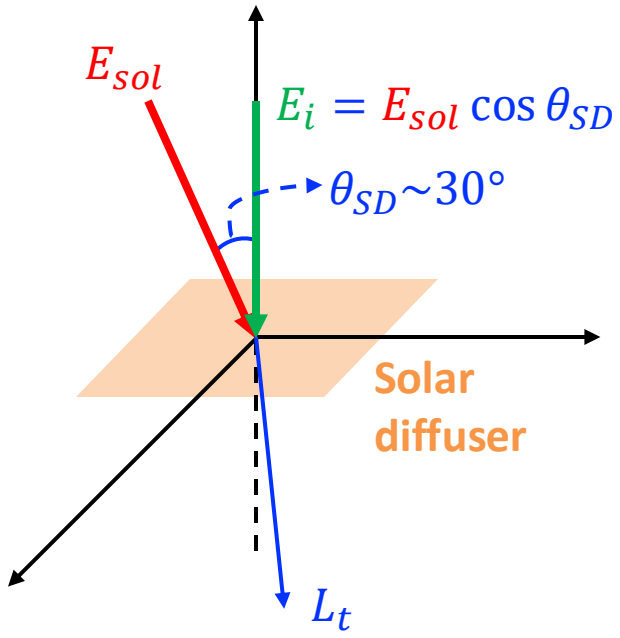
(Solar irradiance) = (Solar-irradiance electric current) * (Calibration coefficient) / (Diffuser transmittance)

How to verify the hypothesis? → Earth radiance

(Earth radiance) = (Earth-radiance electric current) * (Calibration coefficient)

Diffuser transmittance

Update in BTDF (Bidirectional Transmittance Distribution Function) data interpretation



- Definition of BTDF at GSFC during on-ground calibration

$$\beta_t^{GSFC} = \frac{L_t}{E_i}$$

- Definition of BTDF in TEMPO algorithm

$$\beta_t^{TEMPO} = \frac{L_t}{E_{sol}} = \frac{L_t}{E_i} \times \cos\theta_{SD}$$

$$\sim \frac{L_t}{E_i} \times 0.866$$

- Use of β_t^{GSFC} in TEMPO algorithm

  - **Version 3**: $\beta_t^{GSFC} \rightarrow \beta_t^{TEMPO}$

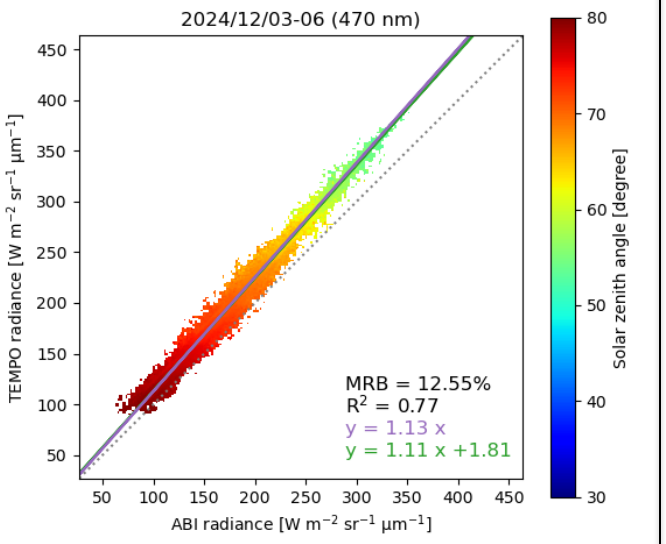
  - **Version 4**: $\beta_t^{GSFC} \rightarrow \frac{L_t}{E_i}$

Applying $\cos\theta_{SD}$ in Version 4 will decrease Sun-normalized radiances by ~13.4%.

Radiometric calibration coefficients

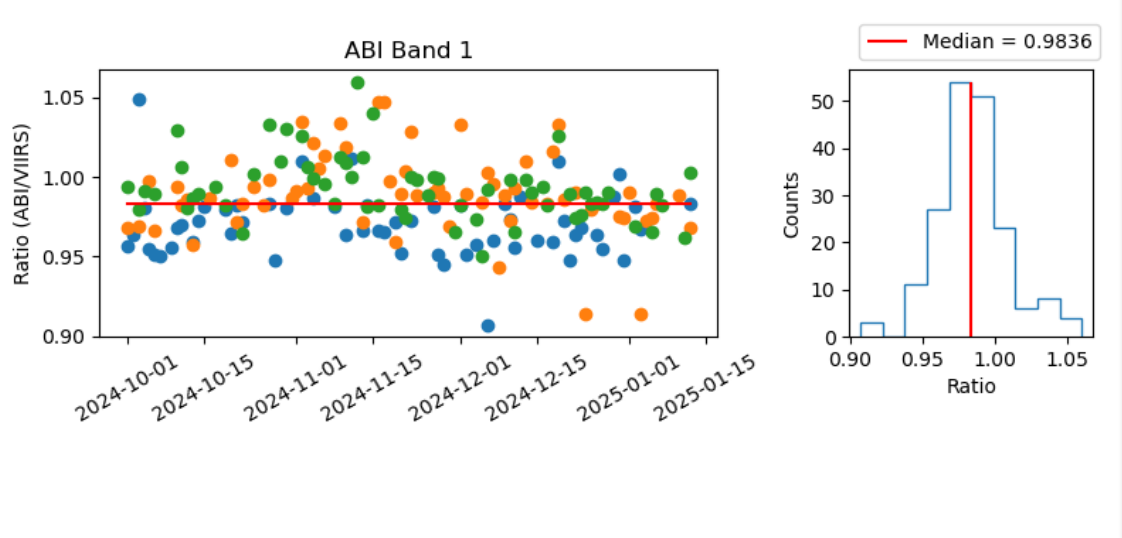
Earth radiance intercomparison (TEMPO vs. ABI vs. VIIRS)

Example: 470 nm (UV), GOES-19



$$\frac{TEMPO}{ABI} = 1.1255$$

$\times$



$$\frac{ABI}{VIIRS} = 0.9836$$

$$\rightarrow \frac{\boldsymbol{TEMPO}}{\boldsymbol{VIIRS}} = \mathbf{1.1070}$$

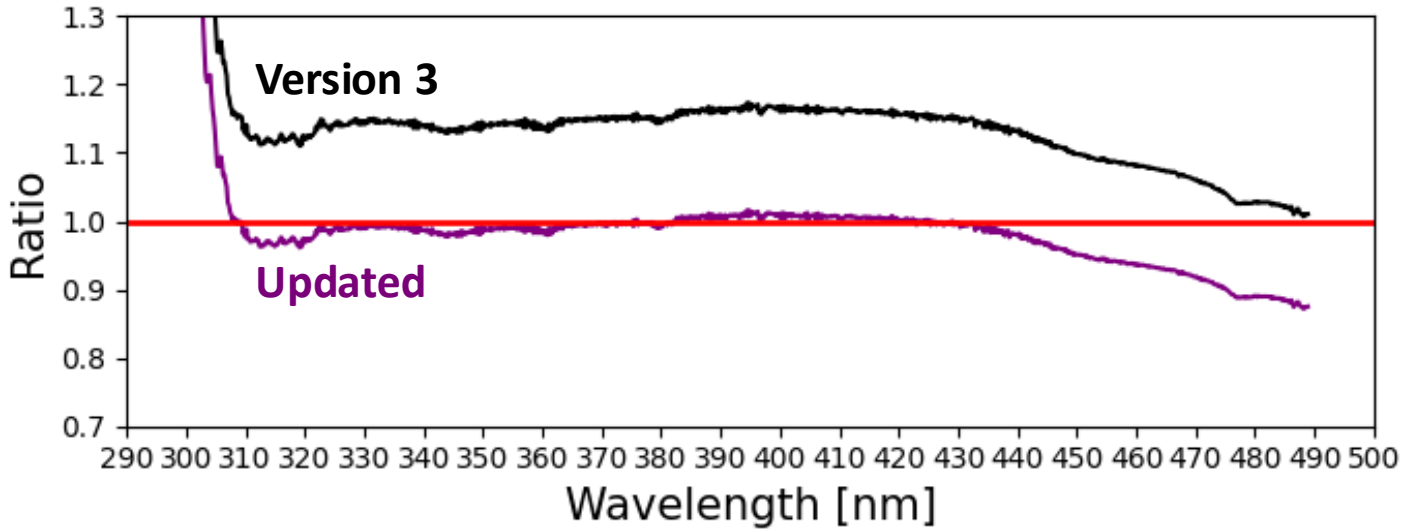
In Version 4, the UV and visible calibration coefficients will be reduced by 11% and 7%, respectively.

Absolute calibration

Sun-normalized radiance (Version 3 → Version 4)

Ratio: TEMPO / VLIDORT simulation

2023/11/06, scan 009, granule 02



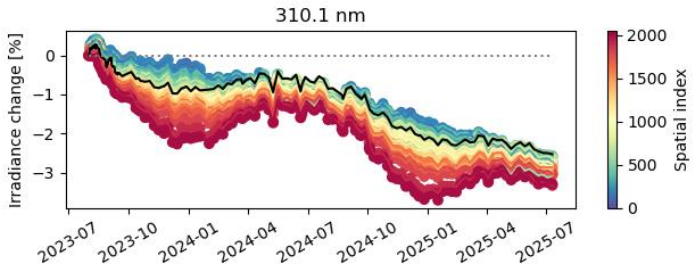
*Note: Spectral-independent, constant surface albedo (0.074) was used.

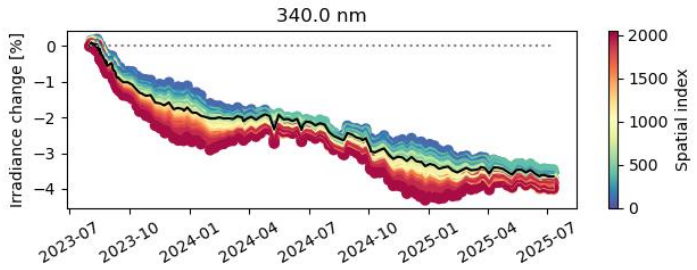
[Credit: Junsung Park]

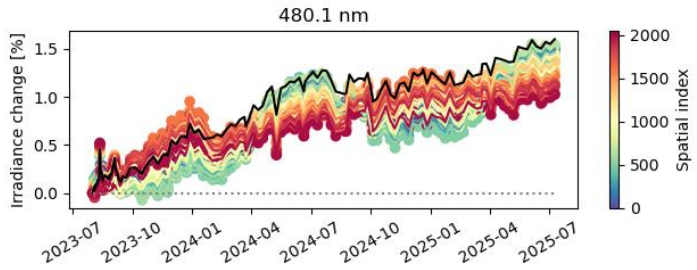
Most significant outcome: Cloud fraction bias will be significantly reduced.

Diffuser goniometry correction

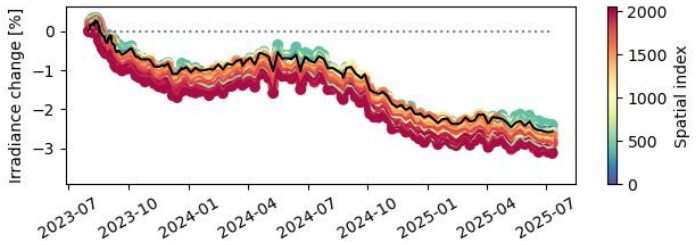
V03 UV

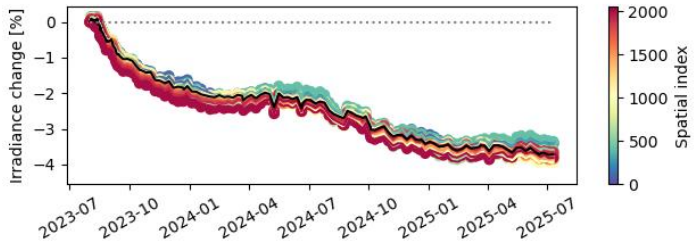


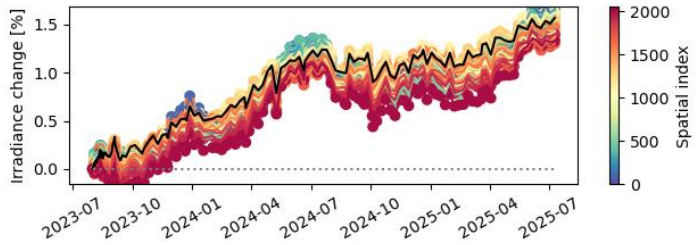




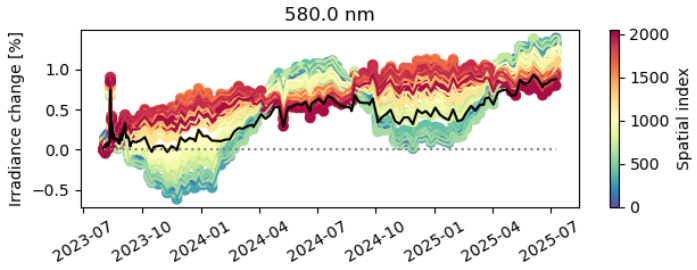
V04 UV

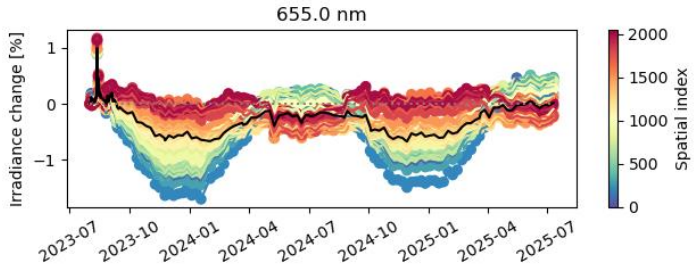


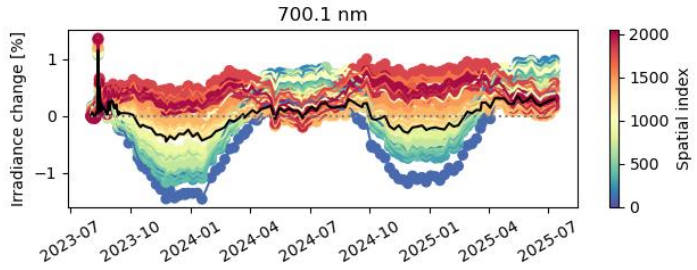




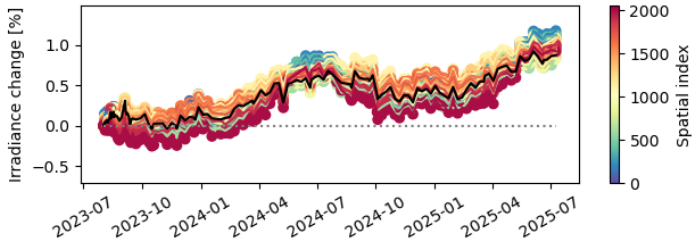
V03 VIS

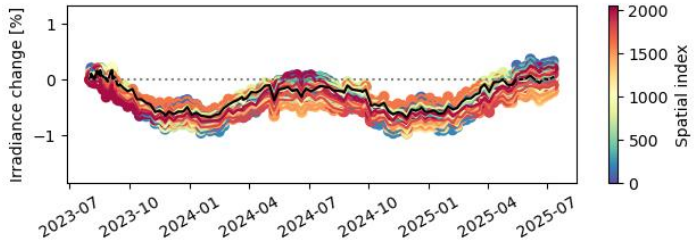


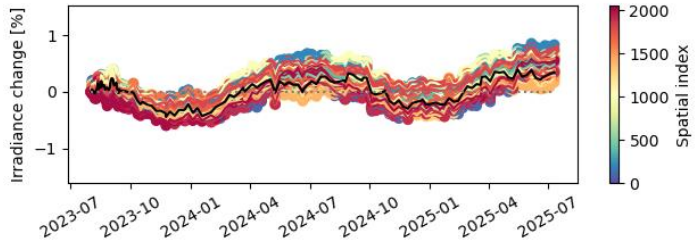




V04 VIS





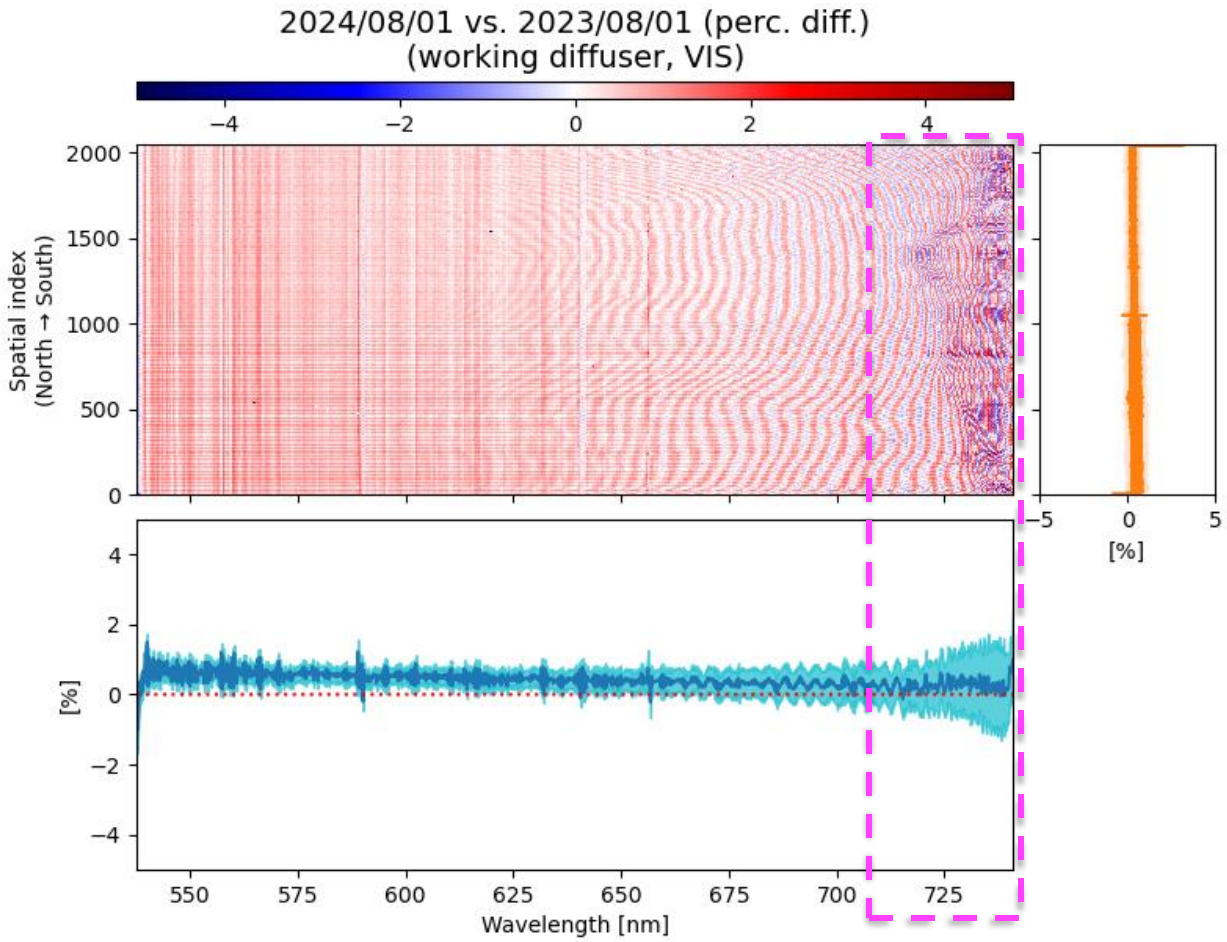


Note the seasonal variability that appears even at the center spatial position (black).

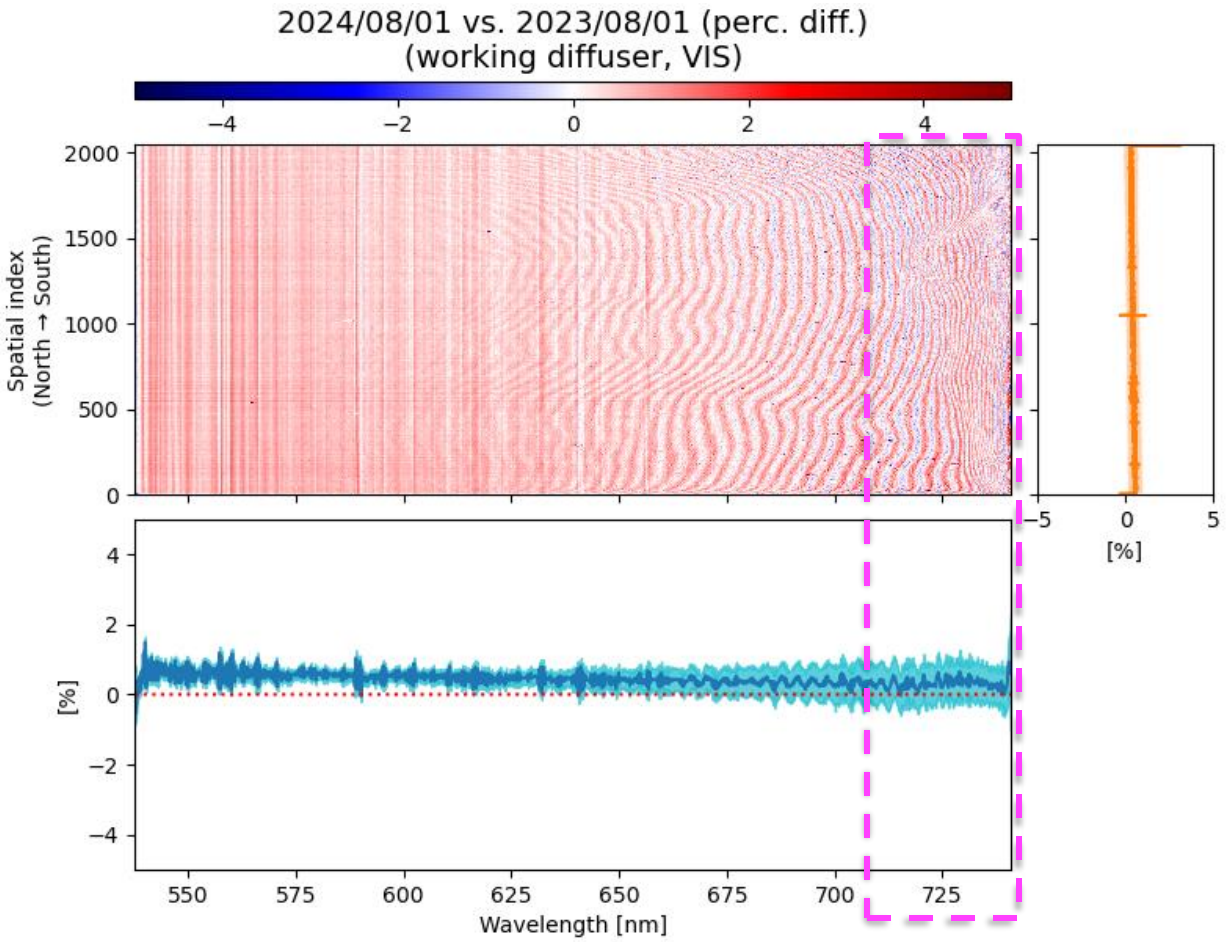
Etalon fringe correction

[etaloning] = f([depletion region thickness], [wavelength of incident light], [CCD temperature])

Version 3



Version 4



Summary

- For Version 4, we have enhanced
  - Diffuser transmittance correction
  - Magnitude adjustment for the radiometric calibration coefficients
  - Diffuser goniometry correction
  - Etalon fringe correction
  - Stray light correction
  - Smear correction
  - Solar irradiance wavelength calibration
- Calibration work will continue.

Thank you for your attention!

Stray light correction

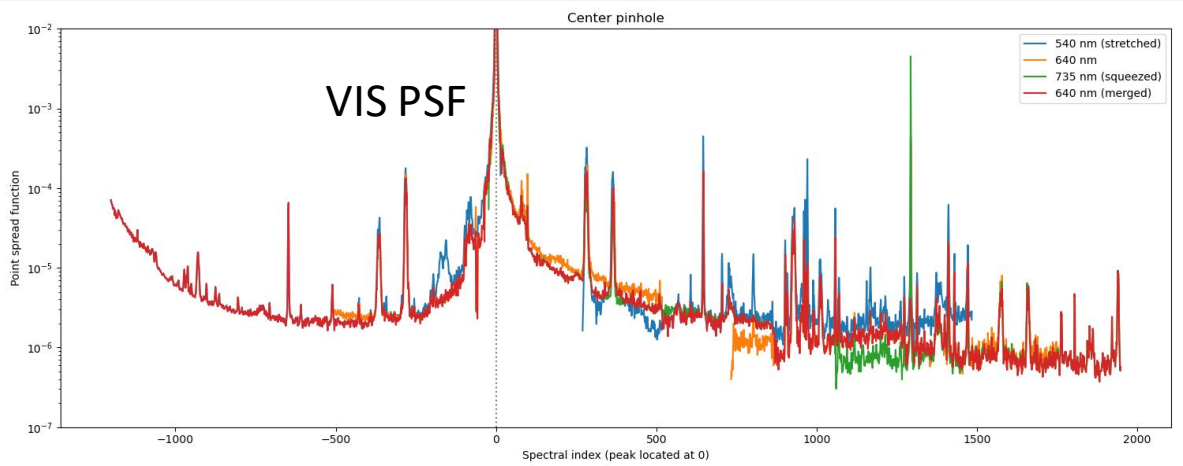
Issues to resolve in Version 3:

(1) Overcorrection at short wavelengths

(2) Background stray light remaining in the UV channel

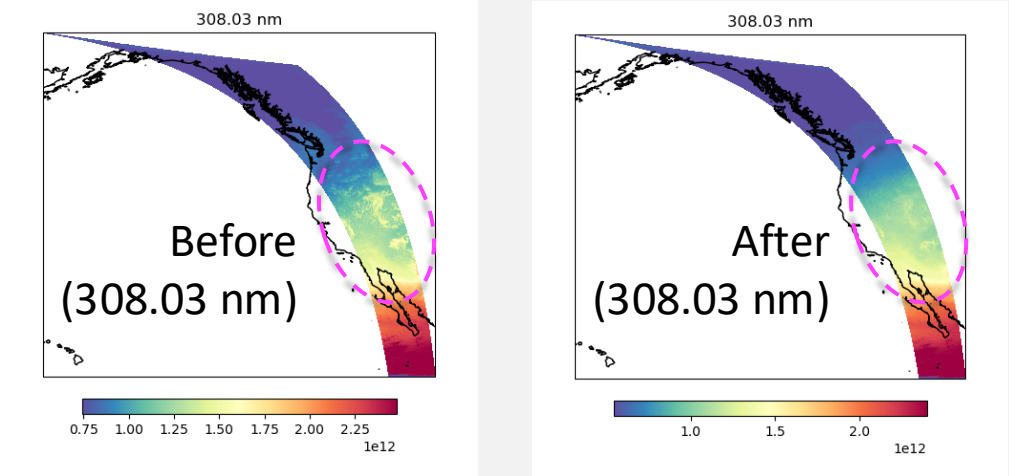
Approach 1

Update PSFs (Point Spread Functions).



Approach 2

Implement a background stray light correction.

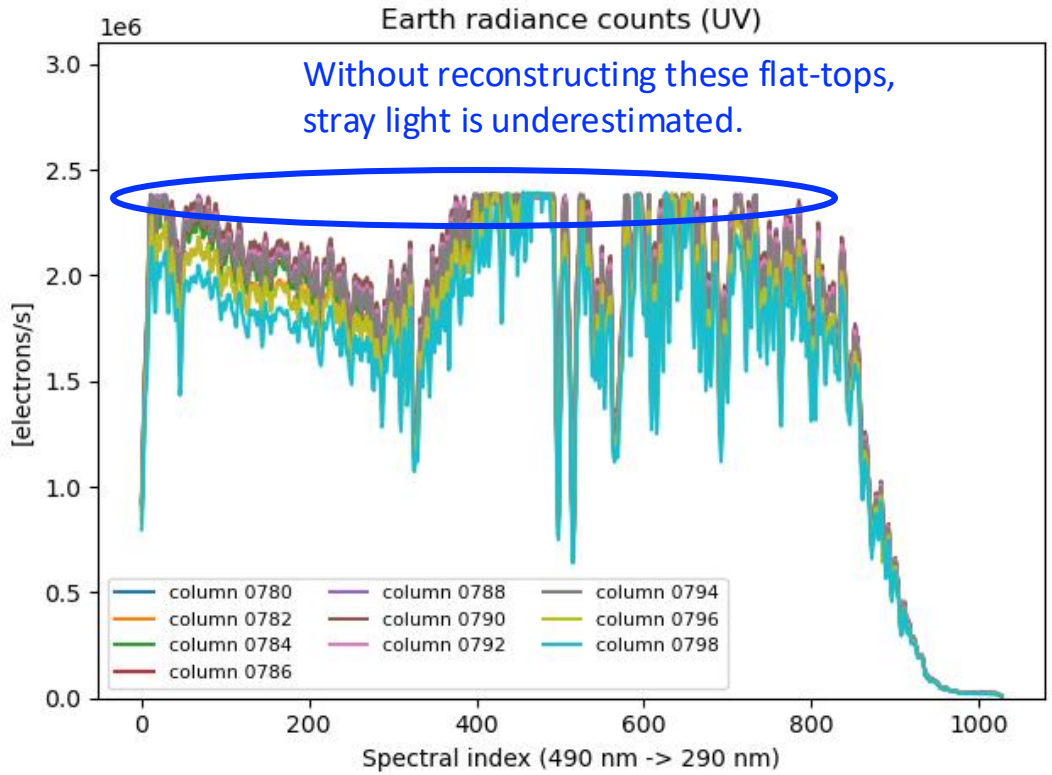


Most significant outcome: Ozone profile retrieval will be stabilized.

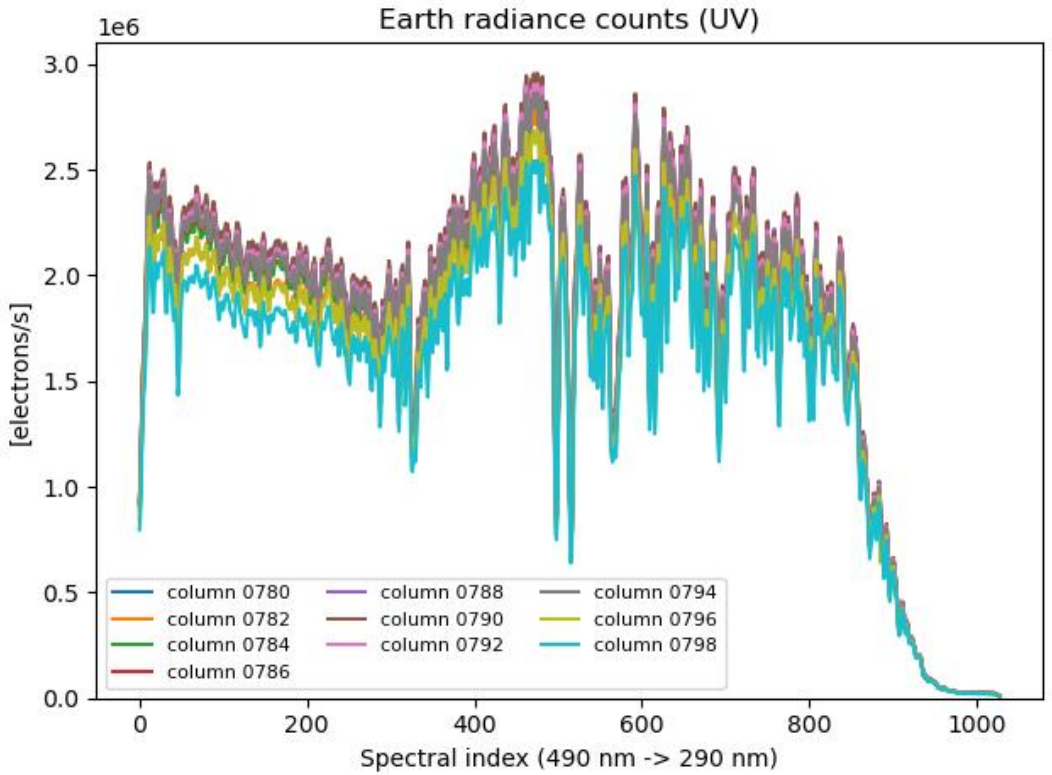
Stray light correction

Approach 3: Reconstruct radiances for CCD pixels with signal saturation.

Before reconstruction



After reconstruction



Most significant outcome: Positive biases in formaldehyde retrieval over cloudy pixels will be mitigated.

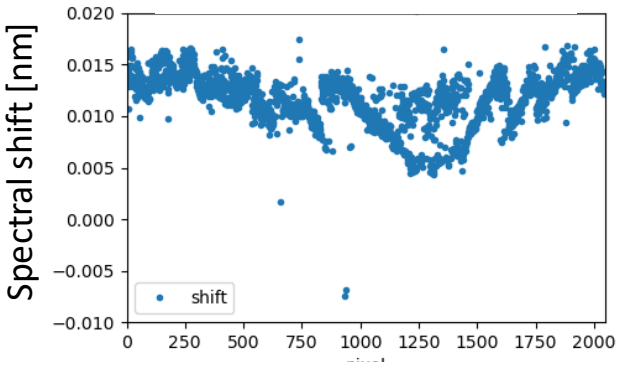
Spectral calibration

Issue to resolve in Version 3: Spatial variability (North-South) in wavelength registration

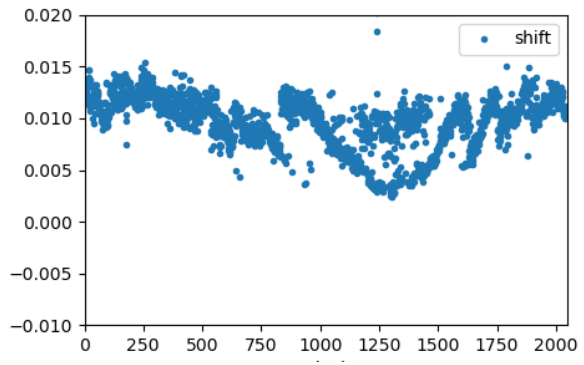
Approach: Remove the slit-function asymmetry factor from the fitting to increase stability.

Version 3

NO_2 fitting window



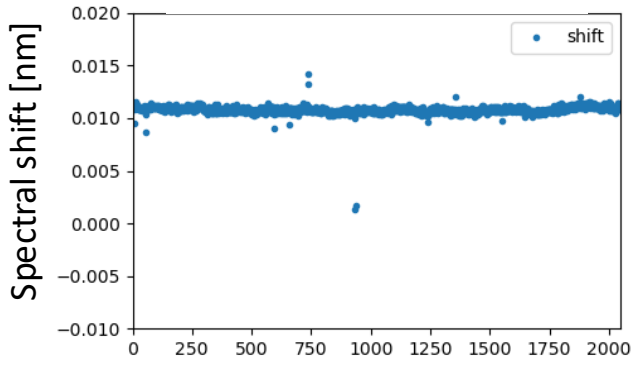
HCHO fitting window



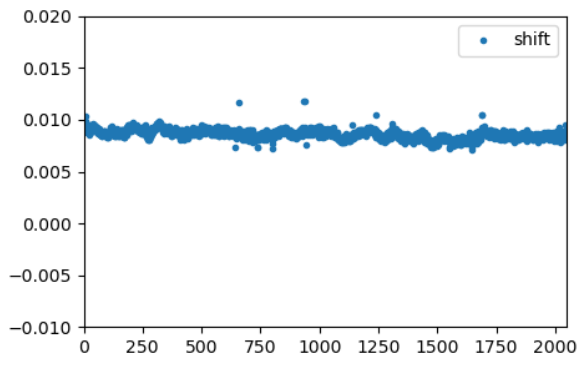
CCD spatial index (North → South)

Updated

NO_2 fitting window



HCHO fitting window



CCD spatial index (North → South)

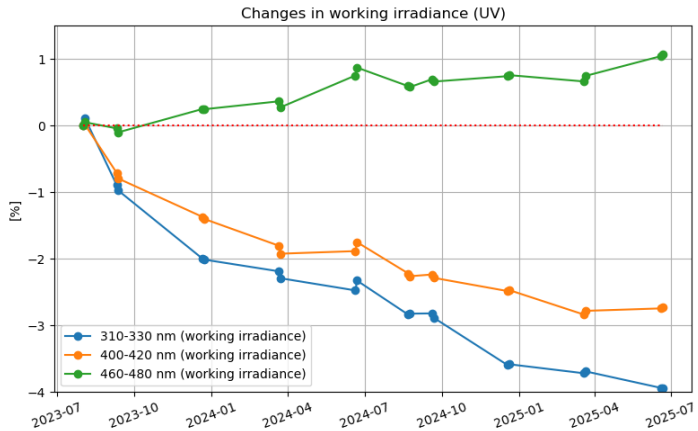
[Image credit: Gonzalo González Abad]

Most significant outcome: The Level 1 calibration will capture spectral changes with enhanced accuracy.

Trending

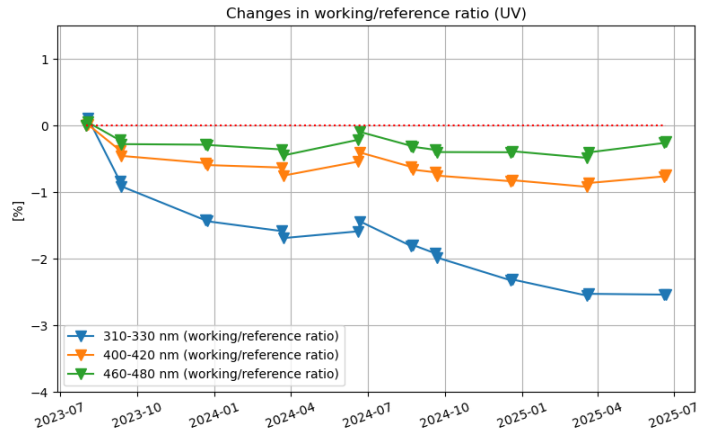
UV

Working irradiance changes



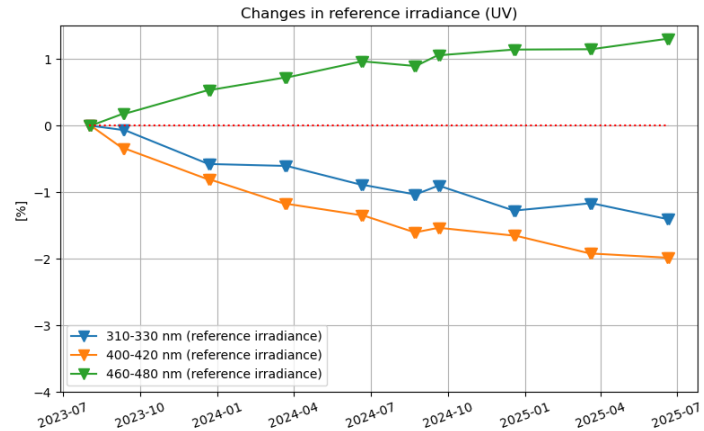
=

Proxy for working diffuser changes



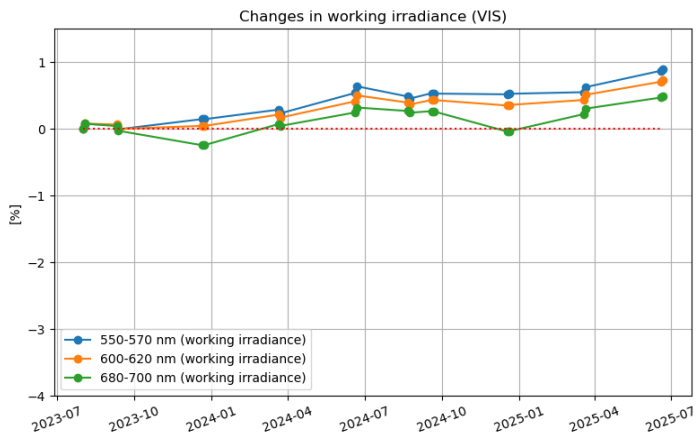
+

Proxy for optics+detector changes



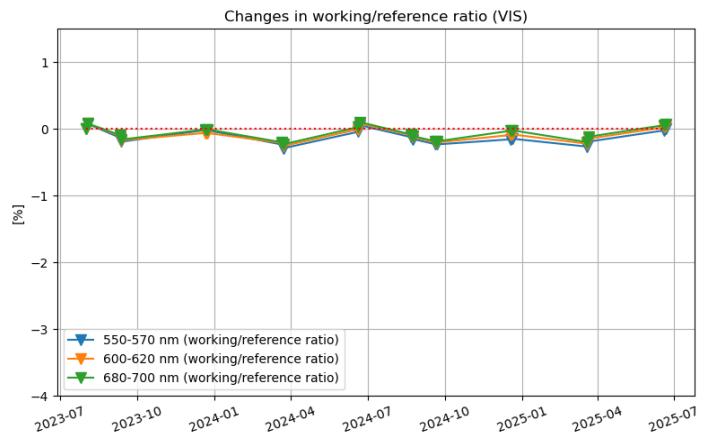
VIS

Working irradiance changes



=

Proxy for working diffuser changes



+

Proxy for optics+detector changes