Calibration of UV/Vis Spectrometers for Aerosol Products

L. Flynn (NOAA) drawing upon work by Z. Zhang, J. Niu, D. Liang, C. Seftor, G. Jaross, M. Bali, M. Goldberg, A. Heidinger and C. Cao

CEOS AC-VC Meeting, October 26, 2023

Disclaimer

"The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect those of NOAA or the Department of Commerce.“

The following Publication has been Approved:

Title	Calibration of UV/Vis Spectrometers for Aerosol Products
Author	LAWRENCE FLYNN
Outlet	CEOS (Committee on Earth Observing Satellites) AC-VC-19 (Atmospheric Compostion - Virtual Constellation) Meeting, October 26, 2023.
Document Id	23849

Global Space-based Inter-Calibration System

https://gsics.wmo.int/en/welcome

- **What is GSICS?**
  - Global Space-based Inter-Calibration System
  - Initiative of CGMS and WMO
  - Effort to produce consistent, well-calibrated data from the international constellation of Earth Observing satellites
- **What are the basic strategies of GSICS?**
  - Improve on-orbit calibration by developing an integrated inter-comparison system
    - Initially for GEO-LEO Inter-satellite calibration
    - Extended to LEO-LEO
    - Using external references as necessary
  - Best practices for calibration & characterisation
- **This will allow us to:**
  - Improve consistency between instruments
  - Provide adjustment coefficients if needed.
  - Reduce bias in Level 1 and 2 products
  - Provide traceability of measurements
  - Retrospectively re-calibrate archived data
  - Better specify future instruments
  - Develop a cadre of experts in calibration
  - Easy access to the health of observing systems.

EUMETSAT CNES JMA

NOAA CMA KMA

ISRO NASA WMO

USGS NIST JAXA

ESA ROSHYDROMET IMD ROSCOSMOS

GSICS Activities – GSICS Quarterly Newsletter

https://www.star.nesdis.noaa.gov/smcd/GCC/newsletters.php

Over the last year, we published four new Issues of the GSICS Newsletter

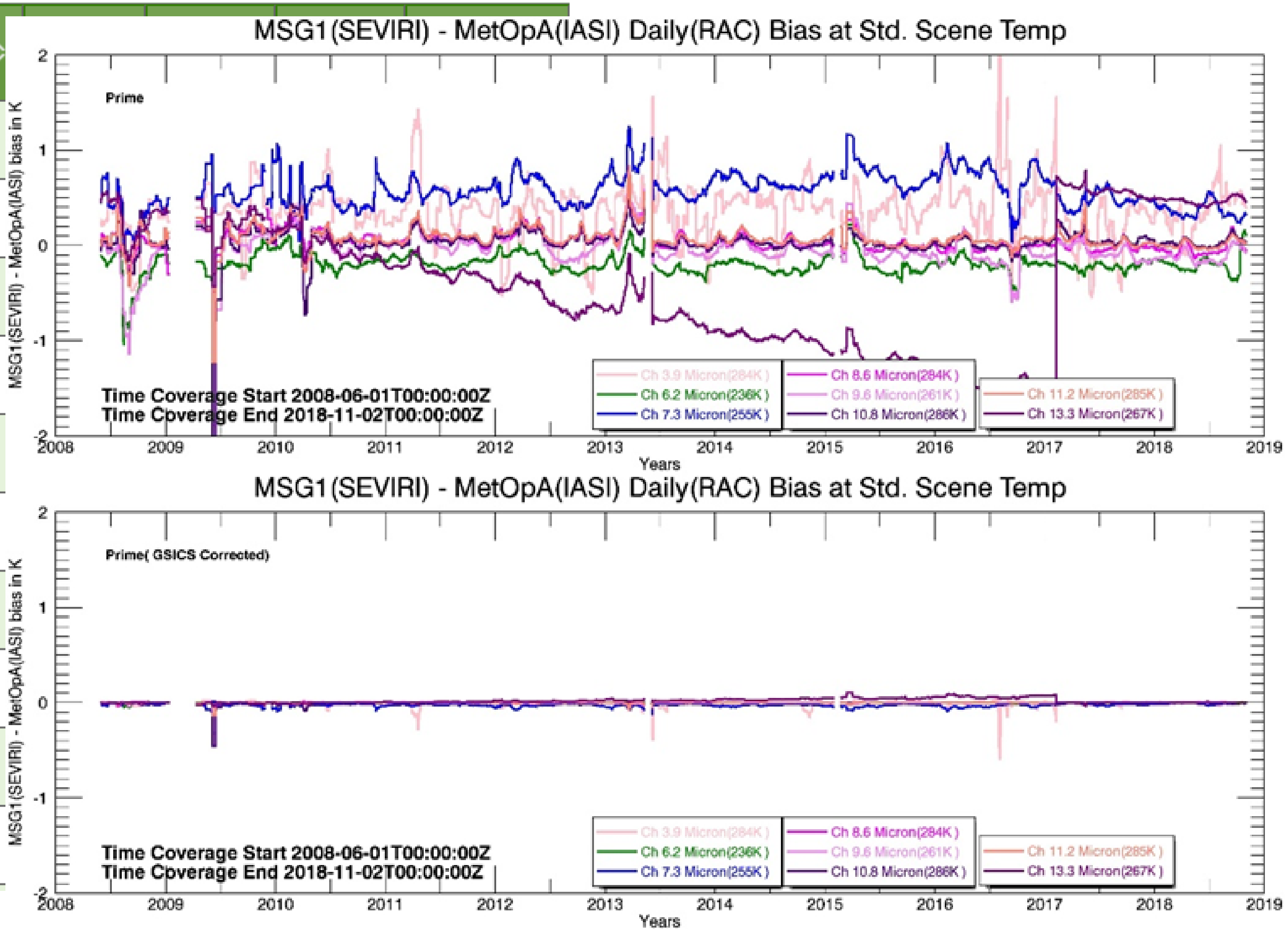
- 12 Research Articles and seven Topics of News to which
- Approximately 70 Scientists contributed as Authors & Co-Authors.
- Contributions from non-GSICS members has increased.

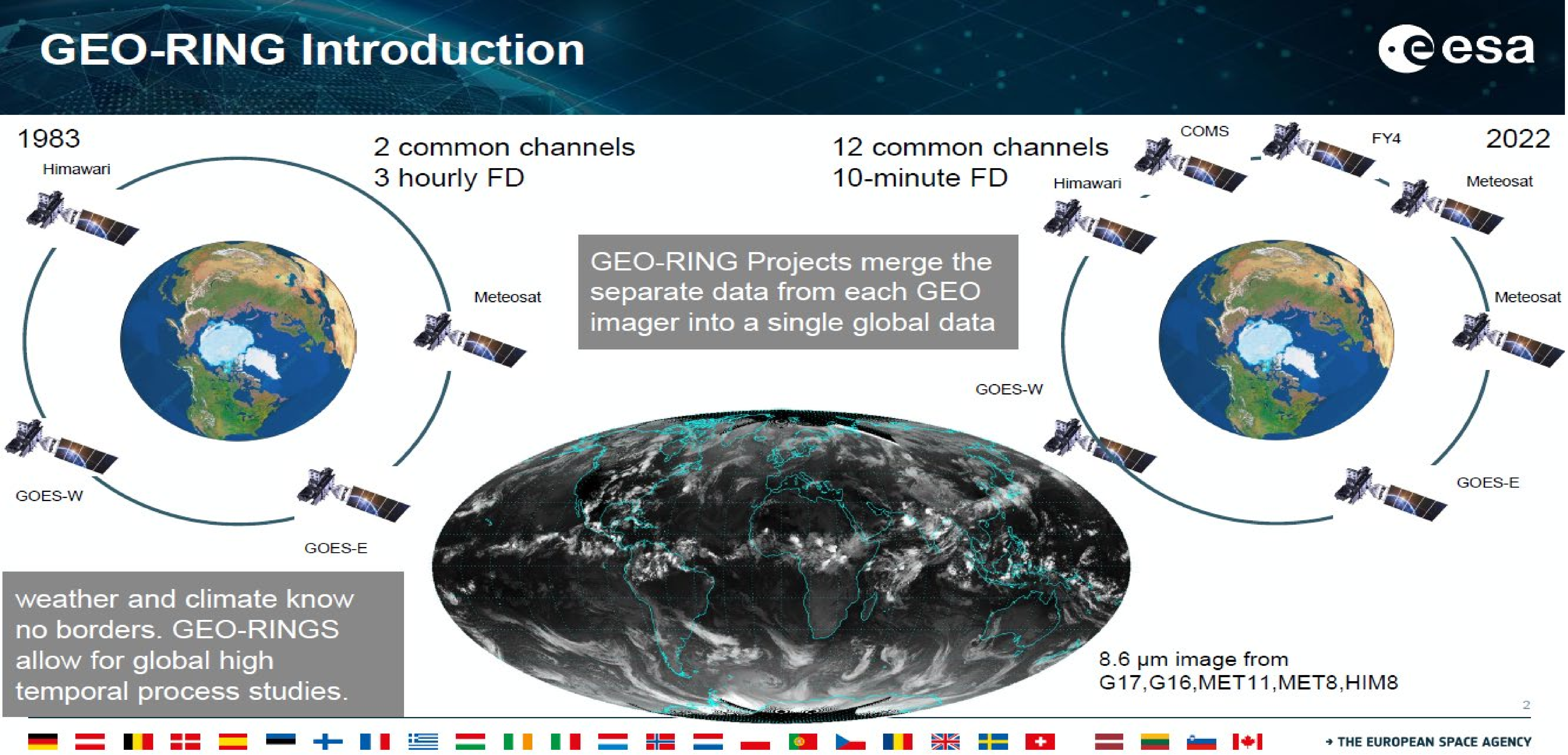
GSICS Newsletter Editorial Board
Manik Bali, Editor
Lawrence E. Flynn, Reviewer
Lori K. Brown, Tech Support
Fangfang Yu, US Correspondent.
Tim Hewison, European Correspondent
Yuan Li, Asian Correspondent

New Visualization Feature on the GSICS Product Catalog more than 70 products have been accepted

https://www.star.nesdis.noaa.gov/smcd/GCC/ProductCatalog.php

Product Type	Algorithm Type	Data Producer	Maturity Level	Monitored Instrument	Reference Instrument
Prime Re-analysis correction	GEO-LEO Prime IR	EUMETSAT	Demonstration	MSG-1 SEVIRI	IASI-A
Prime Re-analysis correction	GEO-LEO Prime IR	EUMETSAT	Demonstration	MSG-2 SEVIRI	IASI-A
Prime Re-analysis correction	GEO-LEO Prime IR	EUMETSAT	Demonstration	MSG-3 SEVIRI	IASI-A
Prime Re-analysis correction	GEO-LEO Prime IR	EUMETSAT	Demonstration	MSG-4 SEVIRI	IASI-A
Re-analysis Correction	GEO-LEO IR	EUMETSAT	Demonstration	MSG-1 SEVIRI	IASI-A
Re-analysis Correction	GEO-LEO IR	EUMETSAT	Operational	MSG-2 SEVIRI	IASI-A
Re-analysis Correction	GEO-LEO IR	EUMETSAT	Operational	MSG-3 SEVIRI	IASI-A
Re-analysis Correction	GEO-LEO IR	JMA	Demonstration	Himawari-8 AHI	Aqua AIRS
Re-analysis Correction	GEO-LEO IR	JMA	Demonstration	Himawari-8 AHI	IASI-A
Re-analysis Correction	GEO-LEO IR	JMA	Demonstration	Himawari-8 AHI	IASI-B





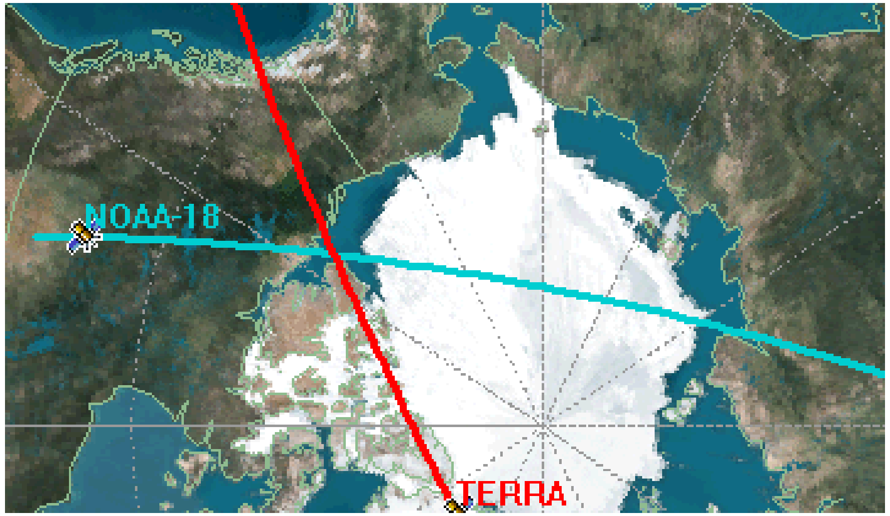
GEO versus LEO instruments under-flights has led to a GEO Ring – ISCPP NG is leveraging this set of intercalibrated instruments. From **Status of the Next Generation of the International Satellite Cloud Climatology (ISCCP-NG) , A. Heidinger**

https://earth.esa.int/living-planet-symposium-2022-presentations/27.05.Friday/RhineLobby/1040-1220/02_Heidinger.pdf

Simultaneous Nadir Overpass (SNO) Method

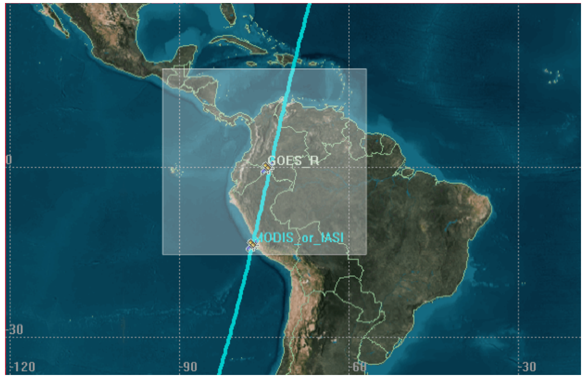
-a core component in the Integrated Cal/Val System

POES intercalibration



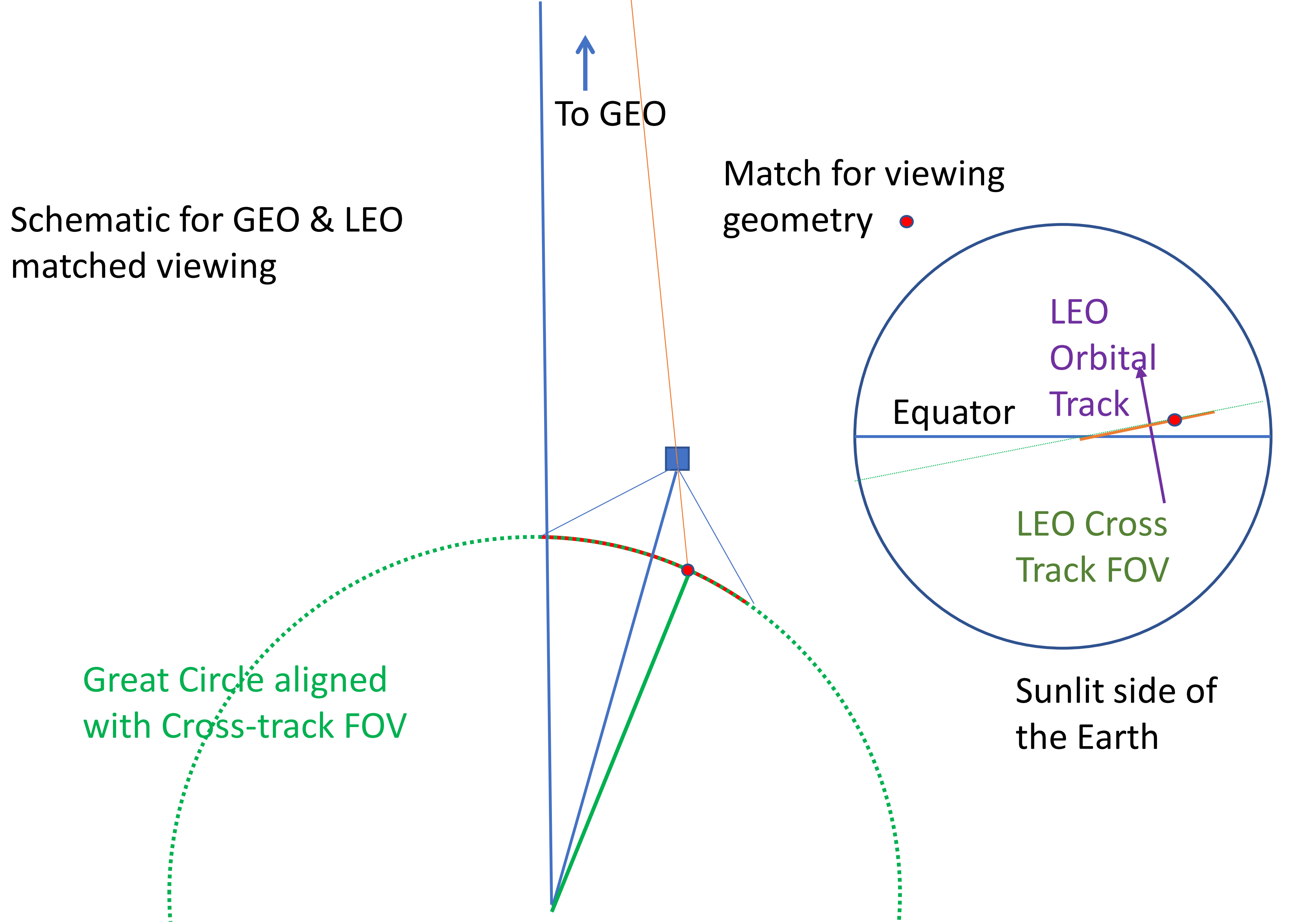
- Useful for remote sensing scientists, climatologists, as well as calibration and instrument scientists
- Support new initiatives (GEOSS and GSICS)
- Significant progress are expected in GOES/POES intercal in the near future

- Capabilities developed at NESDIS
- Has been applied to microwave, vis/nir, and infrared radiometers for on-orbit performance trending and climate calibration support
- Capabilities of 0.1 K for sounders and 1% for vis/nir have been demonstrated in pilot studies
- Method has been adopted by other agencies



GOES vs. POES

Slide from a 2006 presentation by C. Cao, NOAA.
These methods have been used extensively by the GSICS Community and are creating bias monitoring products for the IR and Visible sensors on LEO an GEO platforms. The success has created a GEO-Ring of intercalibrated satellite instruments. There are related efforts for UV spectrometers and EPIC, GEMS and TEMPO are expanding the LEO / GEO studies.



Simultaneous View Path (SVP) match up between GEO and LEO. Matches will be present for an instrument on a GEO platform with one in a LEO orbit as the LEO orbital tracks pass near the GEO sub-satellite point, e.g., 1200 at GEO sub-satellite point, 1330 at LEO sub-satellite point.

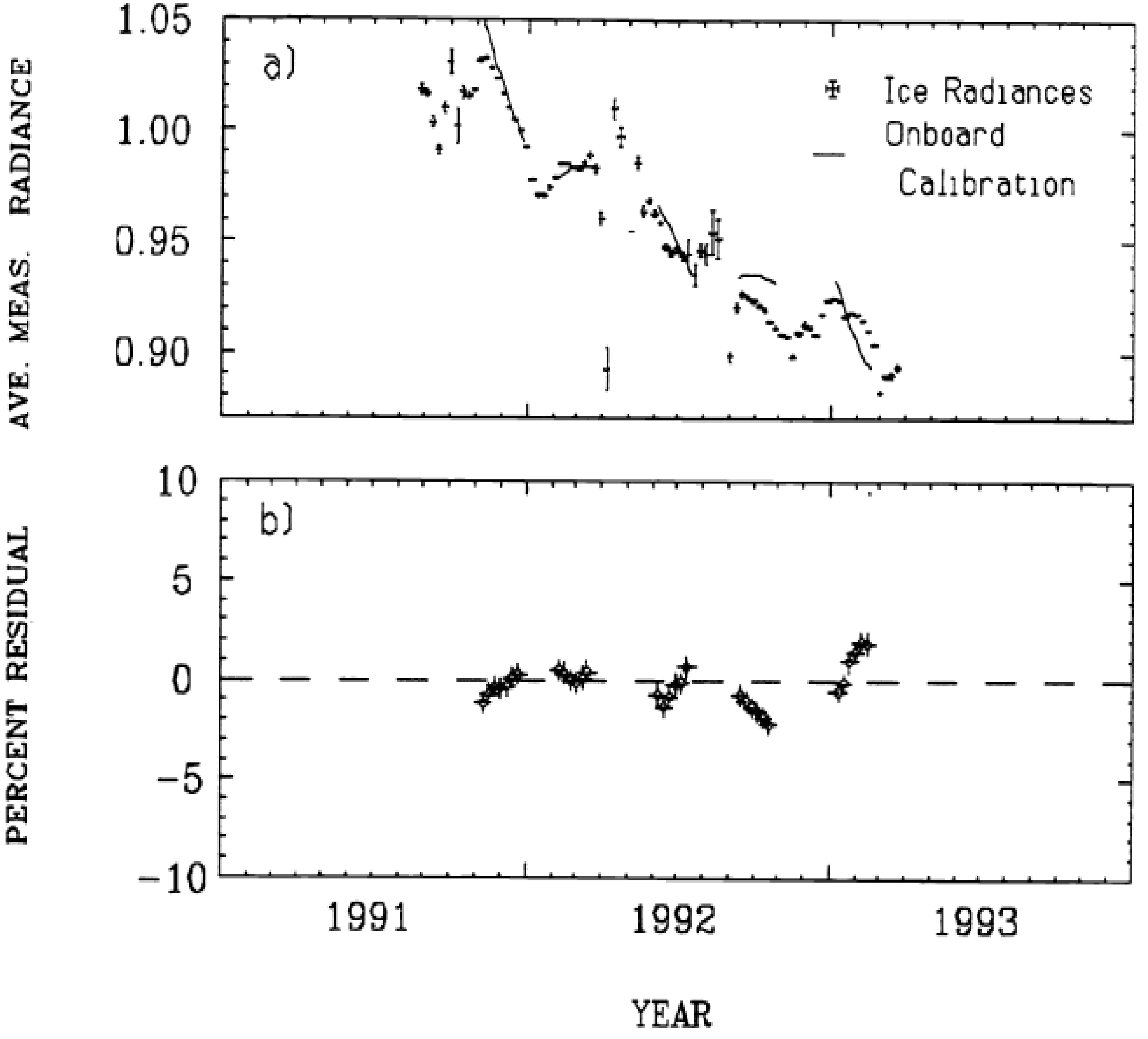


Figure 3 a) Weekly average Antarctic and Greenland radiance measured by Meteor-3/TOMS. Data are normalized to the calibrated sensitivity on day 355, 1991. Residuals **b)** relative to the calibrated sensitivity are shown as well.

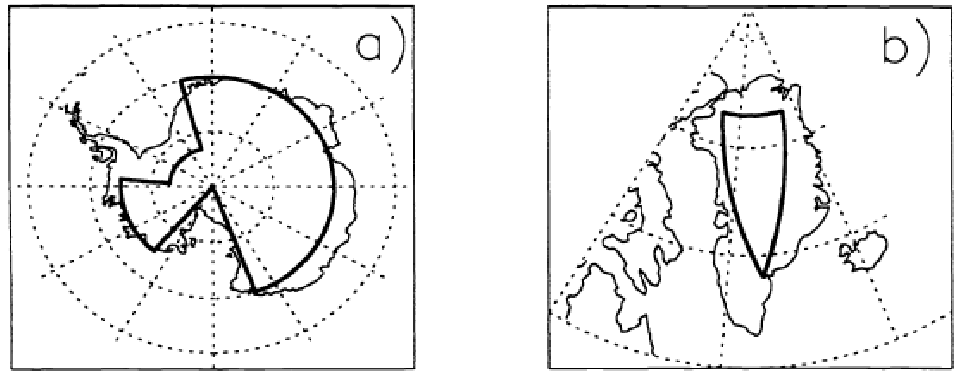
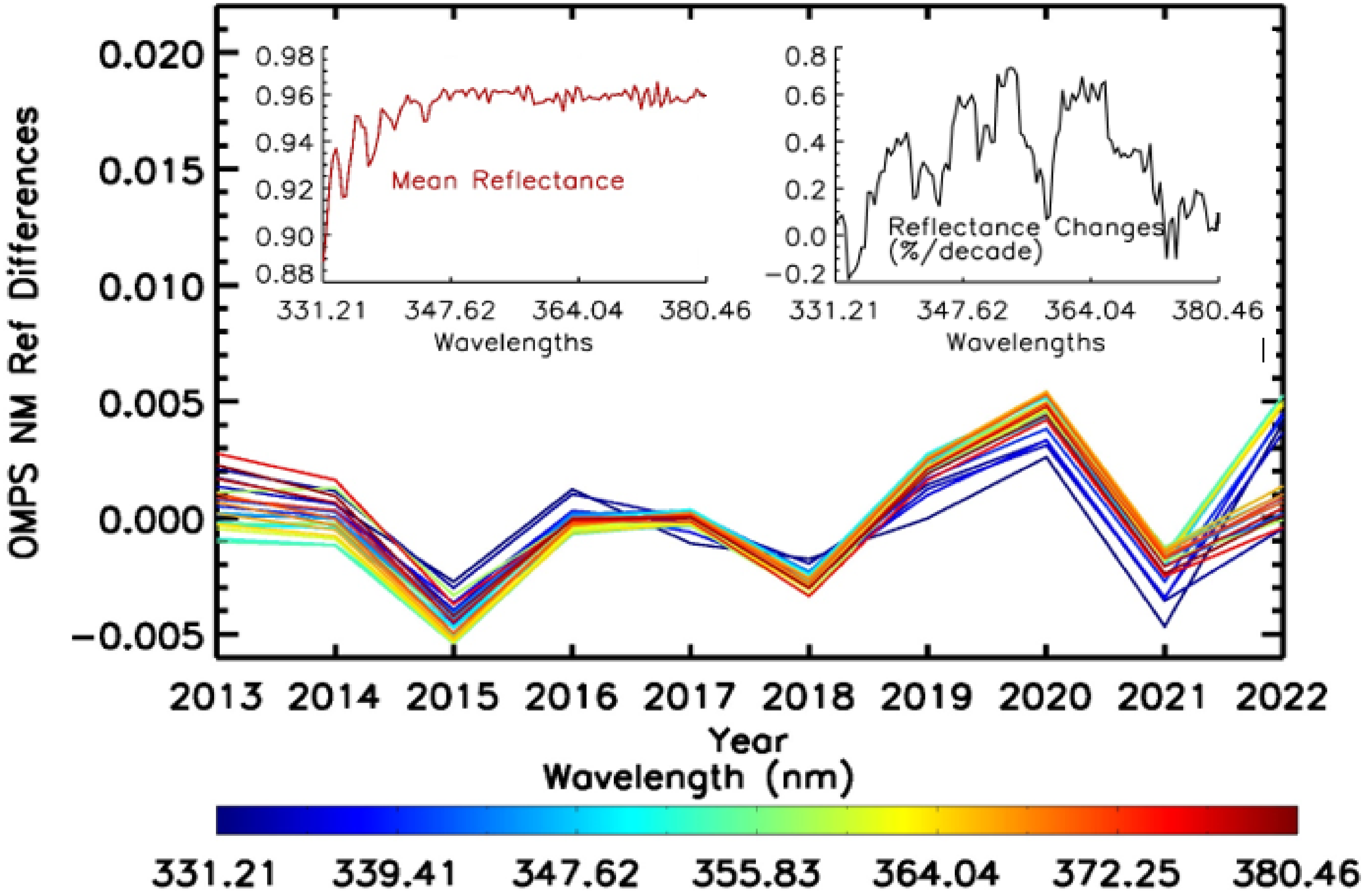


Figure 1 Geographic location of the **a)** Antarctica and **b)** Greenland sample areas. The maximum extent of the nadir view is shown.

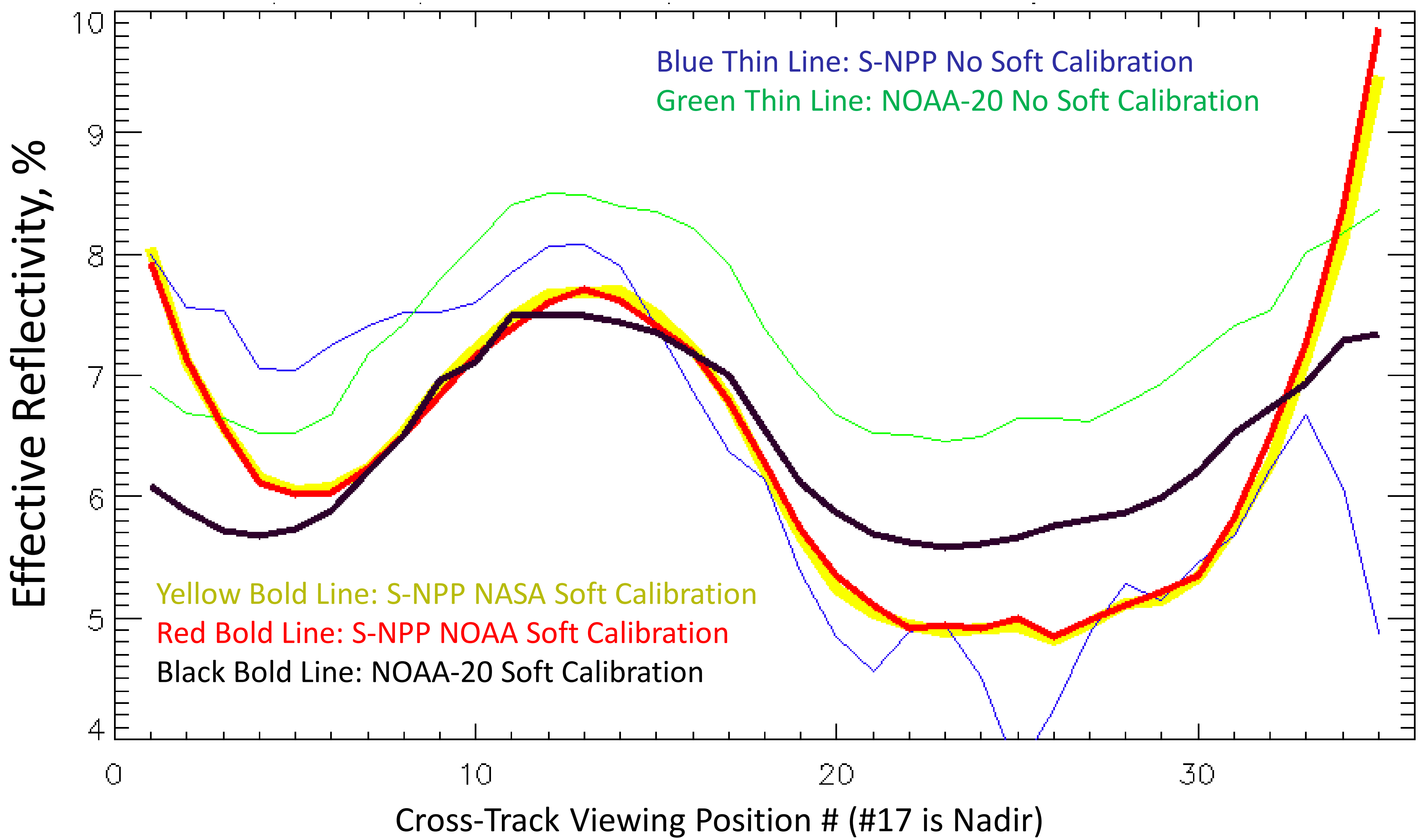
Figures from "Ice radiance method for BUV instrument monitoring," 1993 by G. Jaross and A. Kreuger NASA.

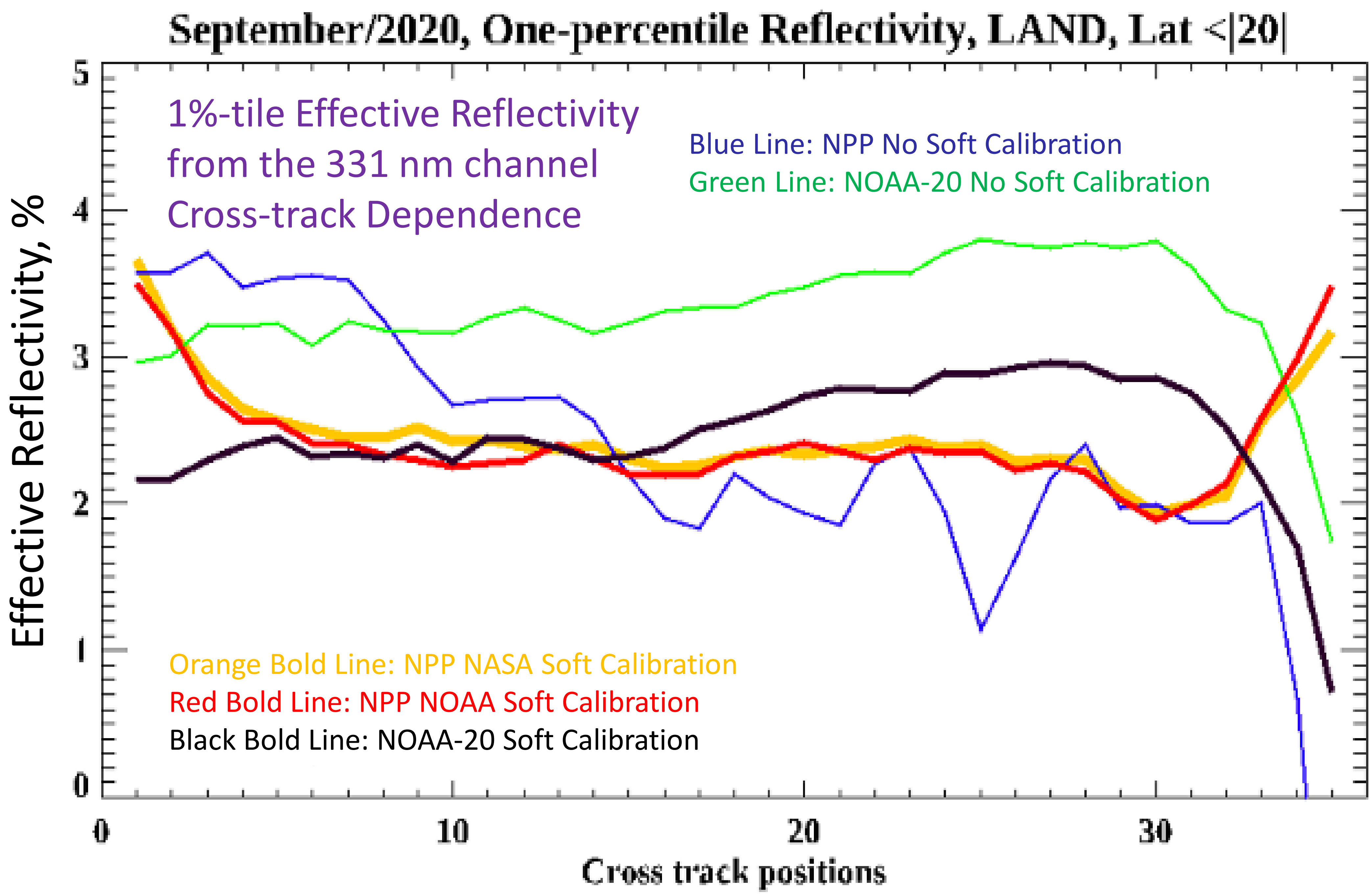
Models have been developed to give estimates of the expected radiances over Antarctica and Greenland. These have be used to estimate calibration biases and maintain calibration consistency over time for reflectivity channels for TOMS, OMI and OMPS instruments.



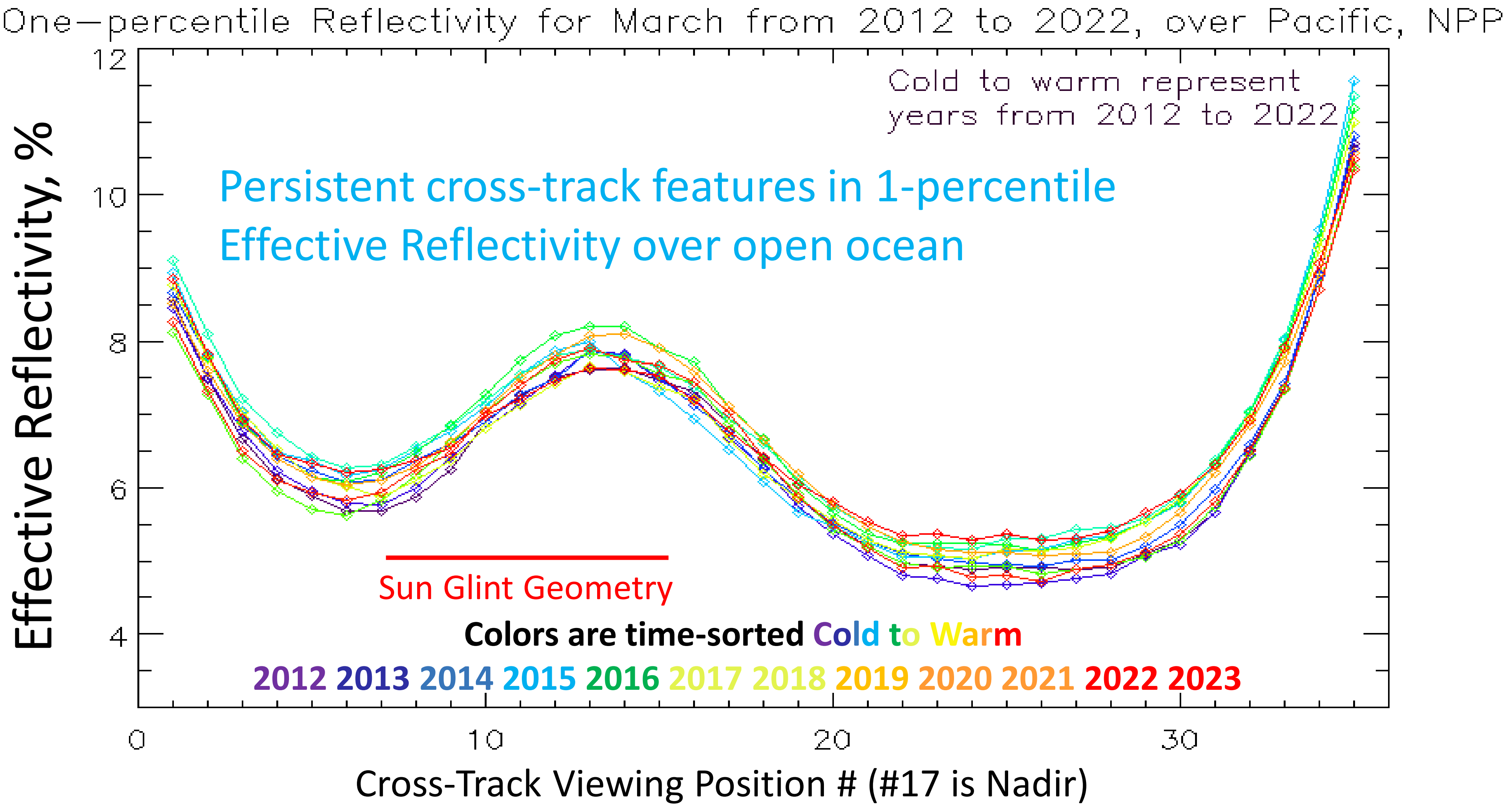
OMPS NM monthly mean Deep Convective Cloud reflectance in March from 2013 to 2022 for wavelengths between 331.21nm and 380.46nm with the long-term average for each wavelength removed. The left insert is long-term mean reflectance for each wavelength. The right insert is estimate of reflectance changes over ten years. 1-Sigma uncertainties on the trend estimates are 0.3%/decade.

Cross-track Dependence of the One-Percentile Effective Reflectivity from the 331 nm Channel for September 2020 over a Latitude / Longitude Box in the Equatorial Pacific

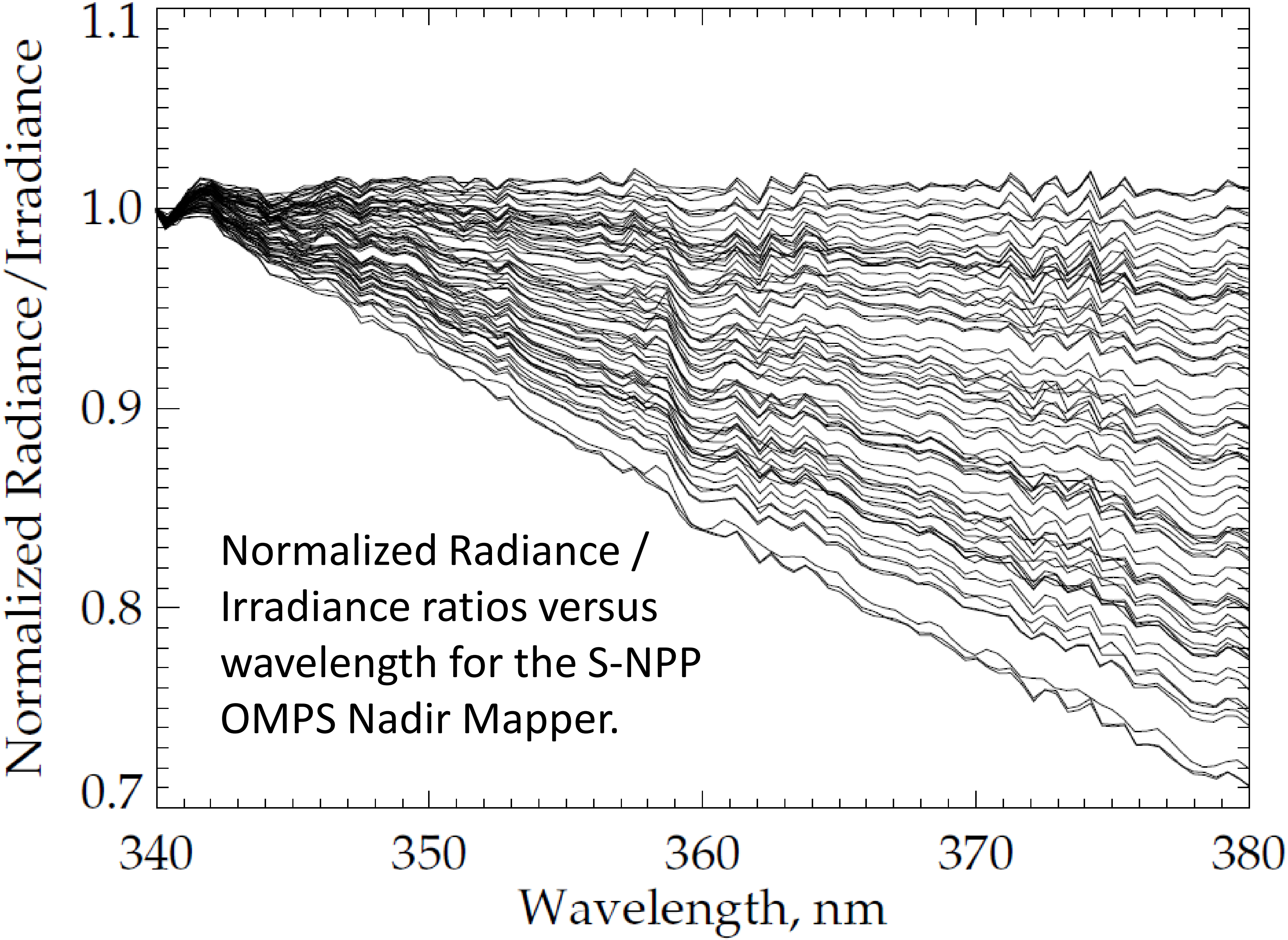




September/2020, One-percentile Reflectivity, LAND, Lat <|20|
1%-tile Effective Reflectivity
from the 331 nm channel
Cross-track Dependence
Blue Line: NPP No Soft Calibration
Green Line: NOAA-20 No Soft Calibration
Orange Bold Line: NPP NASA Soft Calibration
Red Bold Line: NPP NOAA Soft Calibration
Black Bold Line: NOAA-20 Soft Calibration
Effective Reflectivity, %
Cross track positions
0
1
2
3
4
5
0
10
20
30



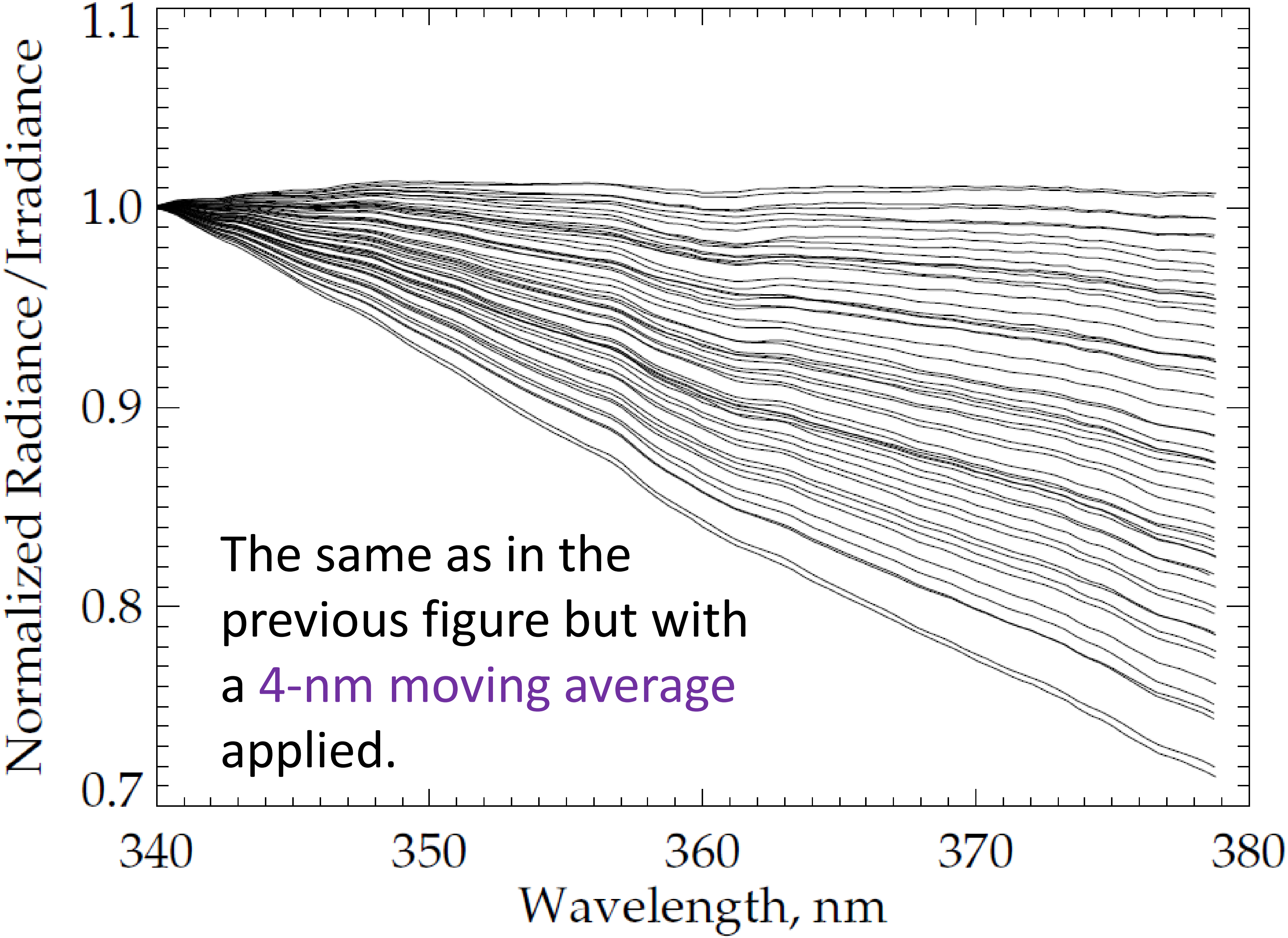
Cross-track dependence over the Equatorial Pacific of one-percentile March V8TOz Effective Reflectivity for S-NPP for 11 years. Colors are time-sorted Cold to Warm. The cross-track pattern for one-percentile reflectivity is very stable year-after-year, and the absolute values are stable at the 1% level. While we use Effective Reflectivity values from comparisons over the same time periods to make our soft calibration adjustment estimates, this suggests that there is also value to comparing the absolute results over time as a stability check.



Normalized Radiance / Irradiance ratios versus wavelength for the S-NPP OMPS Nadir Mapper.

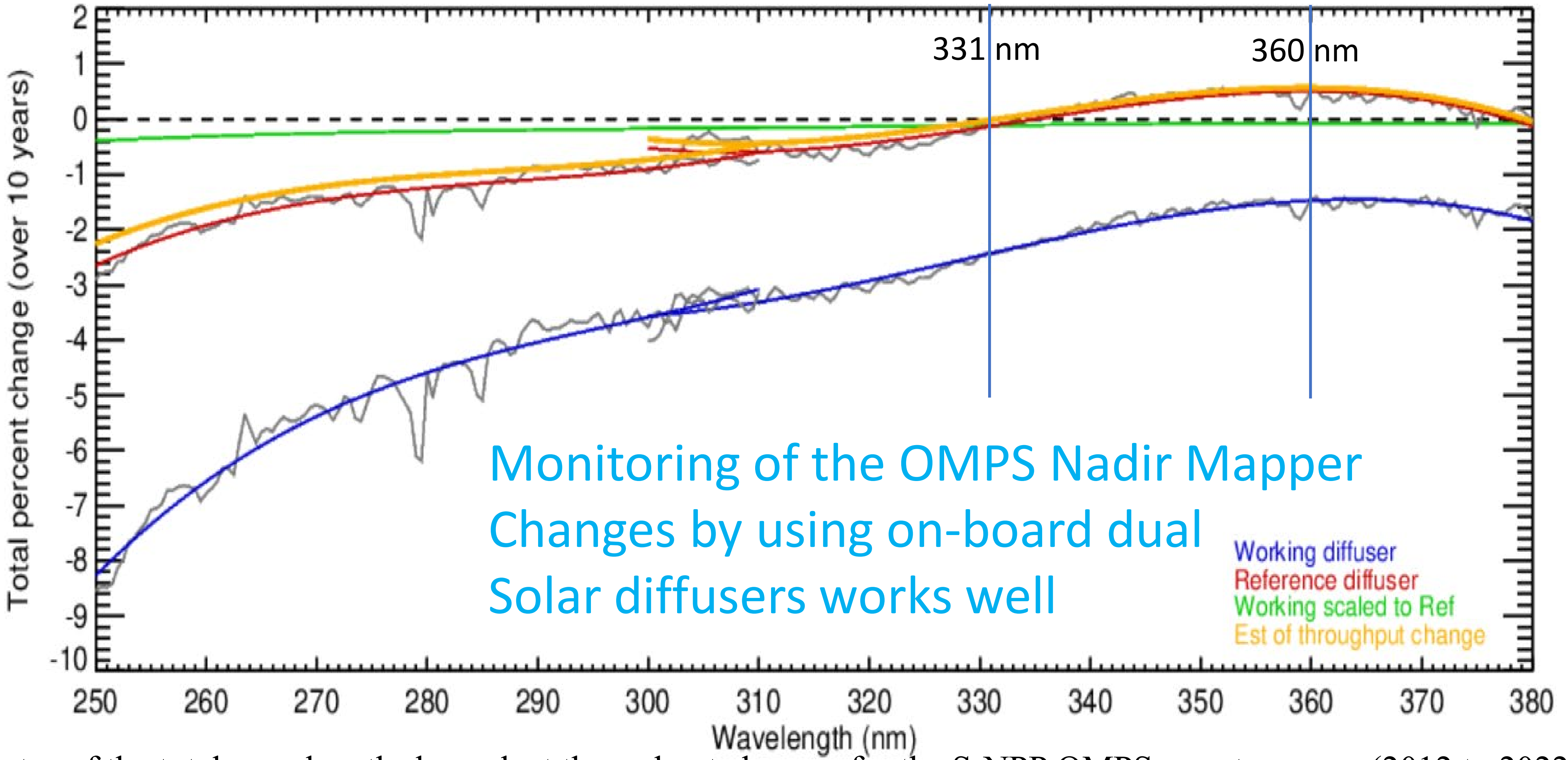
The clouds, Rayleigh scattering and absorbing aerosol signals create the broad wavelength dependence in the radiances as scenes and viewing and solar angles vary.

The small scale features are produced by Ring Effect, trace gas absorption, wavelength scale shifts and stray light.

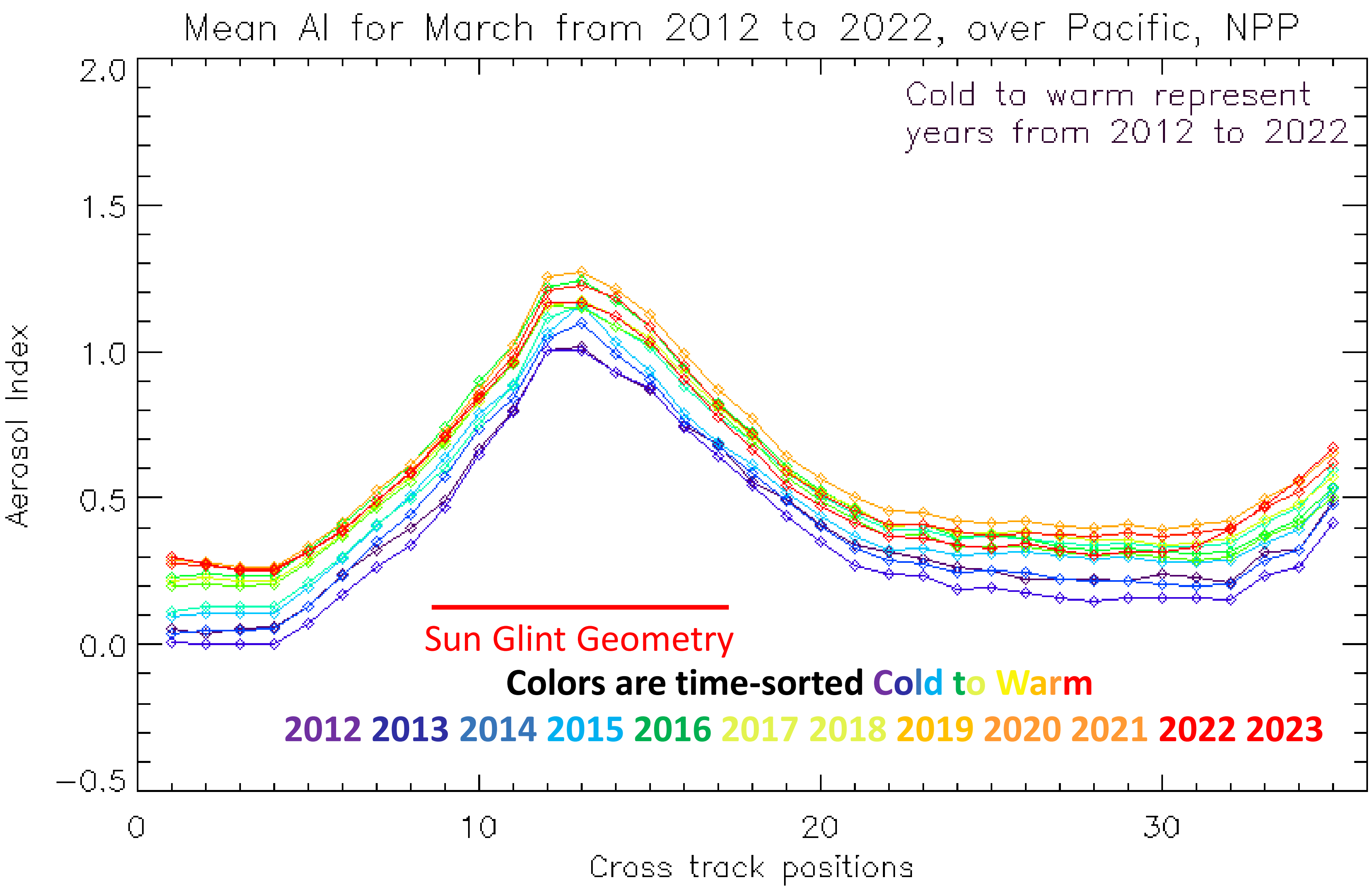


The absorbing aerosol signals are preserved but small scale features are greatly reduced.

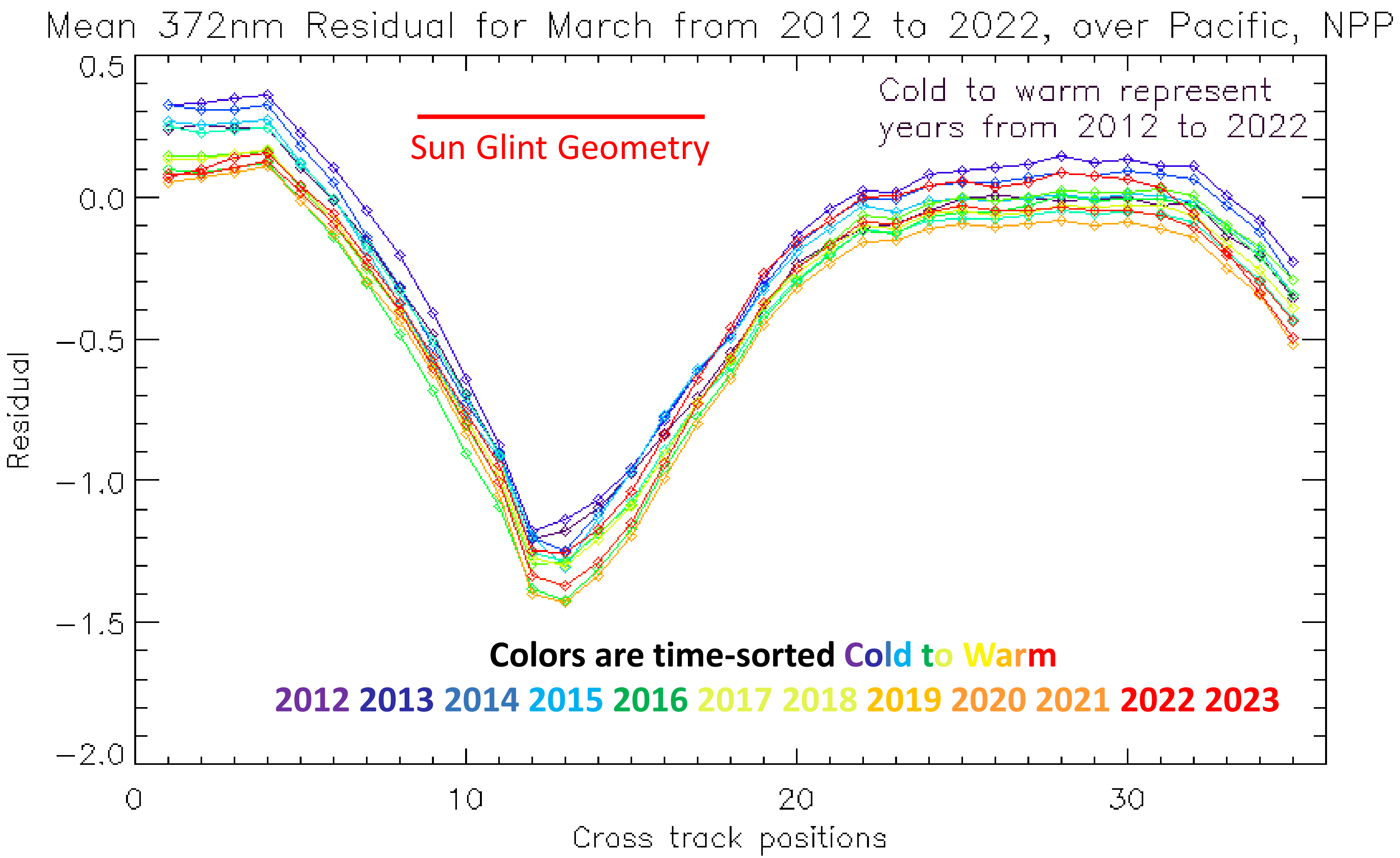
For retrievals of some aerosol properties, we can degrade the spectral resolution and treat OMPS and other spectrometer as a filter instruments.



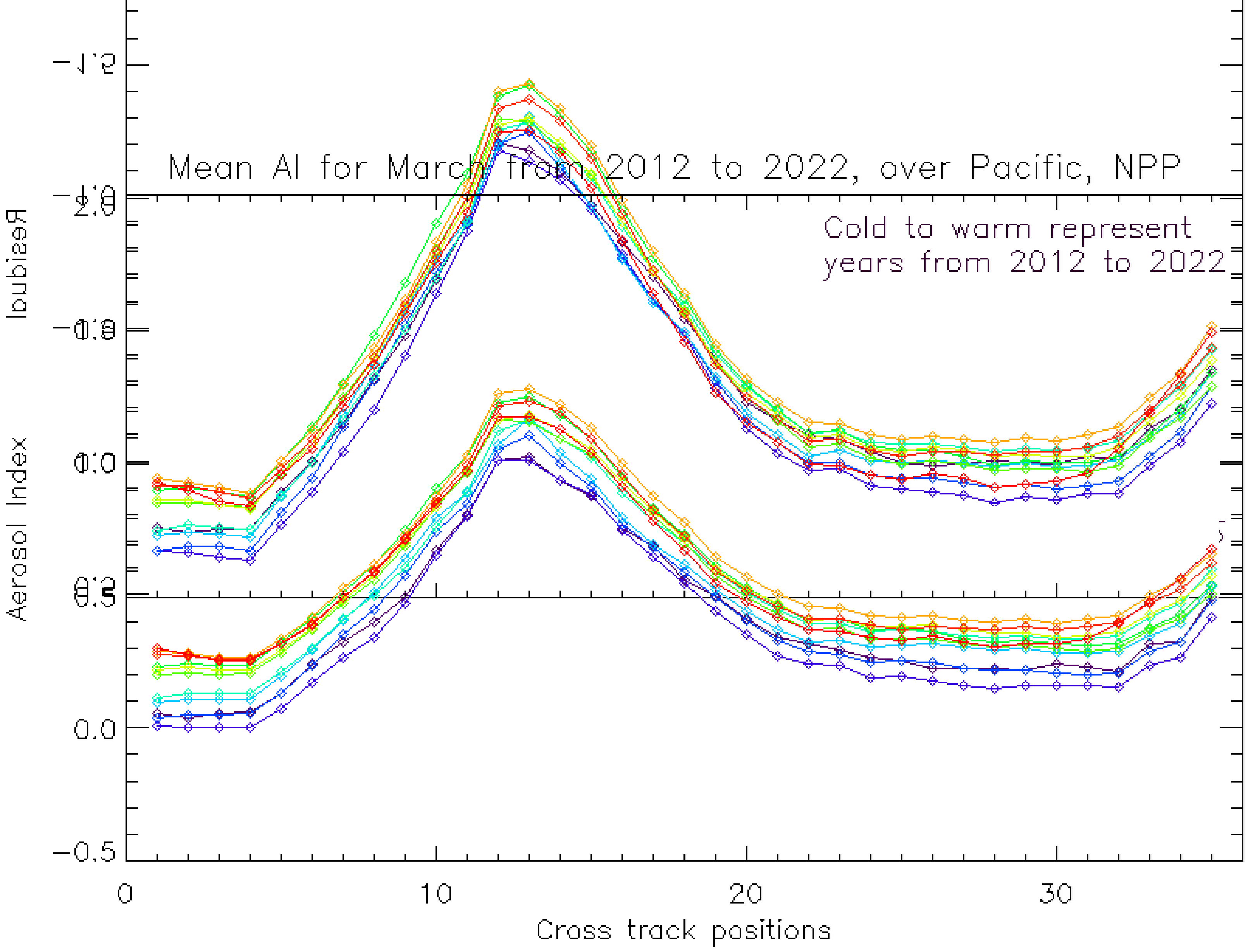
Estimates of the total wavelength-dependent throughput changes for the S-NPP OMPS over ten years (2012 to 2022). The blue curve is from linear fits of the changes of the bi-weekly solar measurements from the working diffuser. The red curve is from linear fits of the changes of the annual solar measurements from the reference diffuser. The green curve is a scaling of the blue curve accounting for the difference in exposure frequency for the reference versus the working diffusers. The orange curve is the red curve minus the green curve. It gives an estimate of the throughput degradation for the shared optical path for the radiance measurements. Notice that the instrument throughput changes for the OMPS NM (300 nm to 380 nm) are well within the +-1% level. (This figure was created and provided by Colin Seftor of SSAI for the NASA GSFC Ozone Team.)



Cross-track dependence over the Equatorial Pacific of the Aerosol Index for S-NPP for March for 11 years Cold to Warm. The cross-track pattern for the Aerosol Index is also very stable year-after-year and the absolute values are stable at the 0.4 level. The figure on the slide before does show a trend in the instrument throughput for the 360 nm channel relative to the 331 nm one which has not been adjusted in any calibration, so some time dependence in this figure is not unexpected.



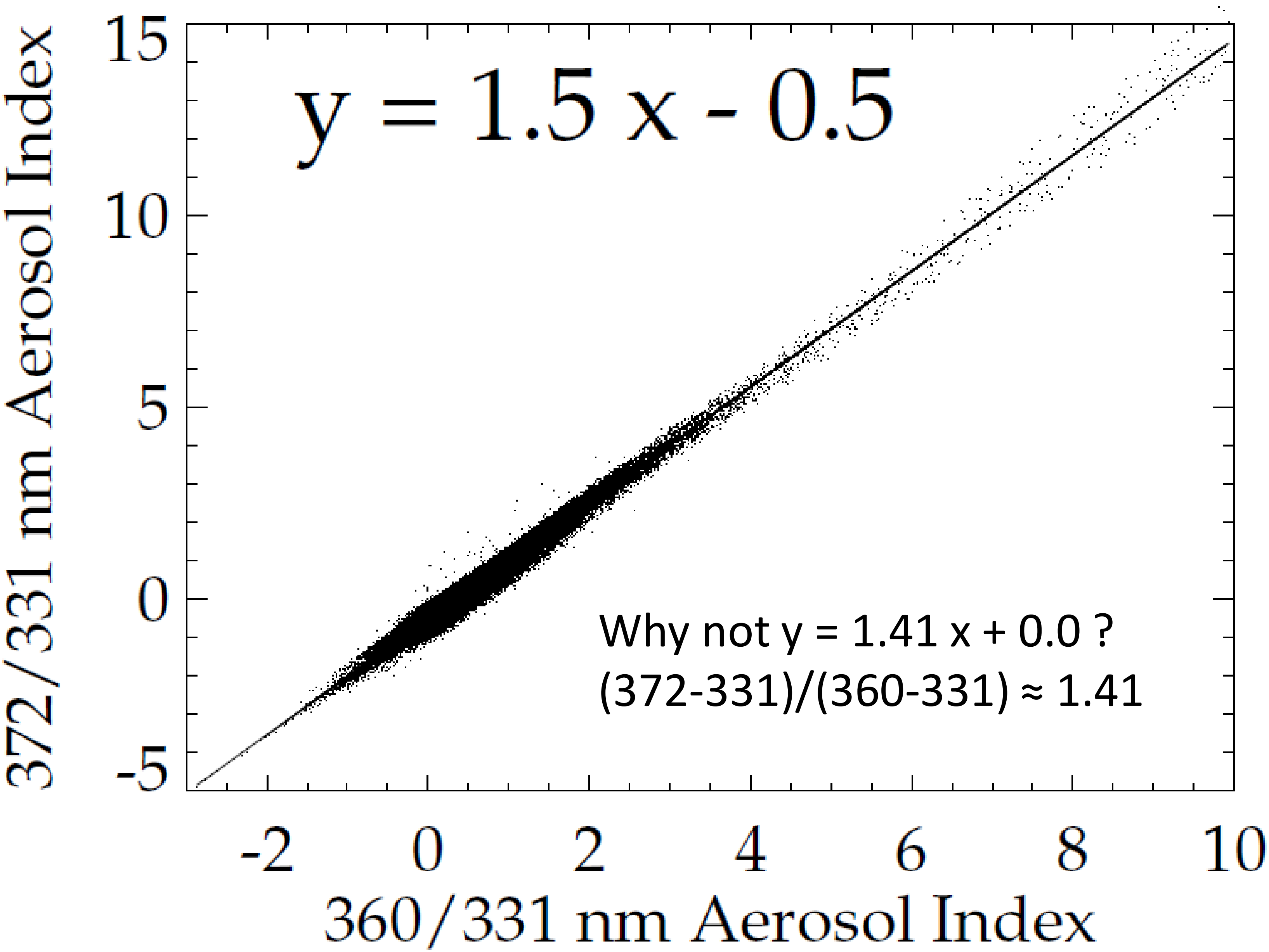
Cross-track dependence over the Equatorial Pacific of the 372 nm residual for S-NPP for March for 11 years Cold to Warm. The cross-track pattern for this alternate Aerosol Index is also very stable year-after-year and the absolute values are stable at the 0.4 level.



Here is a comparison of the negative of the 372 nm residuals plotted over the 360 nm Aerosol Index. They show very similar changes over time. The sun-glint effect is a little larger for the 372 nm channel as expected.

Cross-track dependence over the Equatorial Pacific of the Aerosol Index (Negative of the 360 nm residual using the 331 nm Effective Reflectivity) and the negative of the 370 nm residual for S-NPP for March for 11 years Cold to Warm.

Scatter plot for one day of two Aerosol Indices



Possible Topics for Discussion

- Calibration
  - Absolute versus stability
  - Relative
    - To another product, e.g., a ground-based network such as AeroNet
    - To another satellite instrument – What is the best choice for a reference?
    - Internal consistency, e.g., de-striping. Solar Zenith and Viewing Zenith Angles
    - To a retrieval algorithm or forward model
  - Spectrometers versus broad bandpass measurements – Aerosols are broad signals
- Relative Calibration Bias and Adjustments using targets and scenes
  - Open Ocean and Sunglint
  - Dark Vegetation and Land (PICS)
  - Ice Radiances
  - Deep Convective Clouds
  - Using aerosol-free scenes as zero references
- UV Absorbing Aerosol Indices
  - Wavelength pair choice
  - Cross-track dependence, Satellite Viewing Angle, Solar Zenith Angle.
  - Reflectivity model impact
- Beyond an Index – Angstrom coefficient, height, phase function
  - Polarization information
  - Height information
    - Oxygen A Band (750-780 nm)
    - O2-O2 near 477 nm
    - Ring Effect / Inelastic Scattering (Solar features and Solar Activity)
- GEO and L1 versus LEO instruments under-flights – leading to a GEO Ring – ISCPP NG
  - https://earth.esa.int/living-planet-symposium-2022-presentations/27.05.Friday/RhineLobby/1040-1220/02_Heidinger.pdf

Should we establish a Reference Instrument for UV Spectrometers?

- OMI
  - Pros – Extensive calibration and trending, good spectral resolution and coverage
  - Cons – Row Anomaly, nearing end-of-life
- OMPS
  - Pros – Fully functioning dual diffuser system characterizes small degradation
    - Three instruments flying with two more launches scheduled over the next decade
  - Cons – Limited wavelength range and 1.0 FWHM resolution
- Tropomi
  - Pros – Good spectral coverage, large set of validated products
- EPIC
  - Pros – Everyone flies underneath it with matching LOS possibilities
  - Cons – limited number of filter channels
- Other LEO or GEO?
- Future SITSats? TRUTHS, CLARREO and LIBRA
- Currently IASI and CriS are IR references and VIIRS are Visible references.

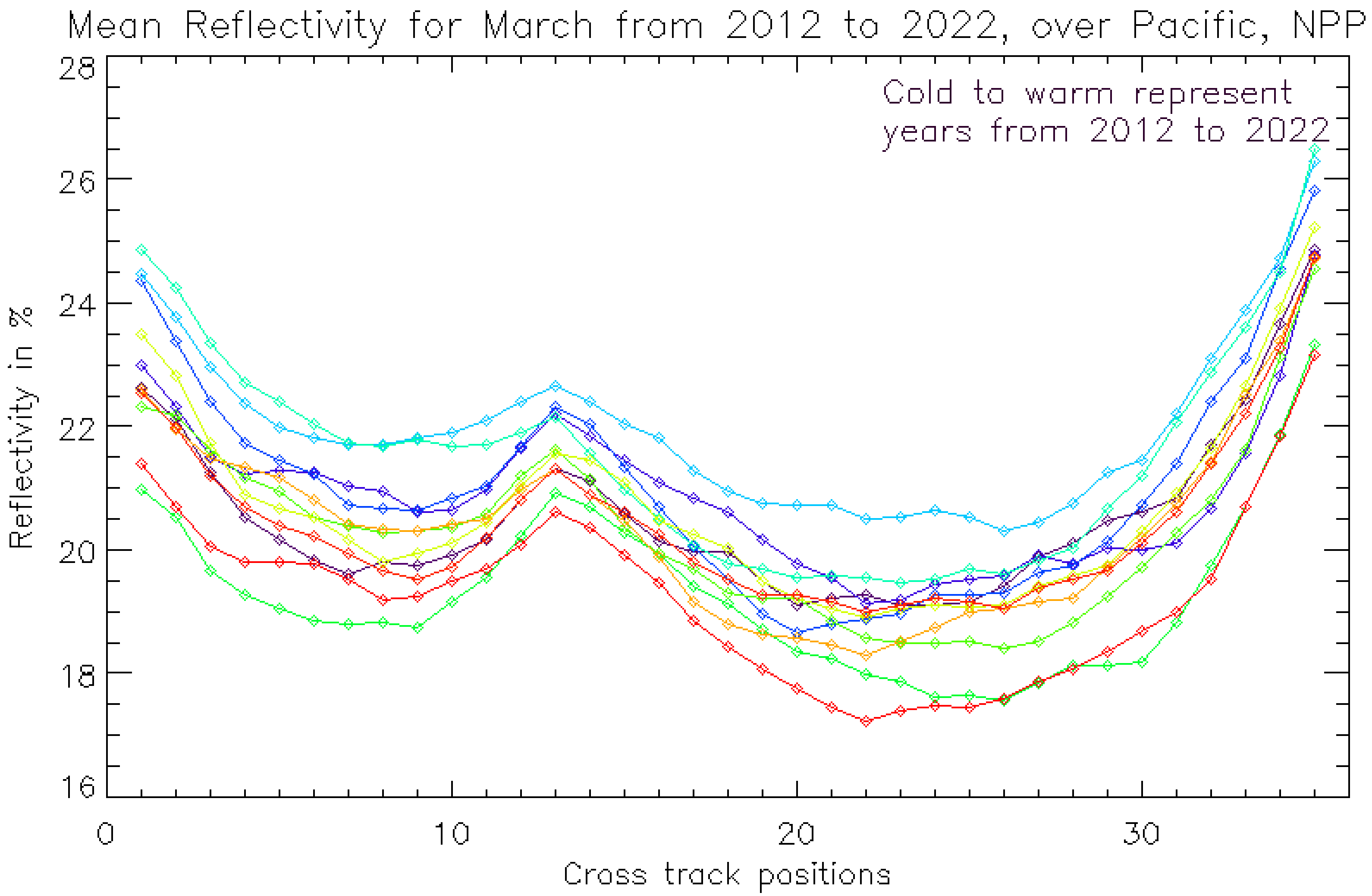
Summary and Conclusions

- GSICS Methods are being applied to characterize instruments used for aerosol retrievals.
- More work should be conducted to homogenize UV/Vis instrument records.
- The new Geostationary instruments can use the GEO/LEO methods already applied to imagers.

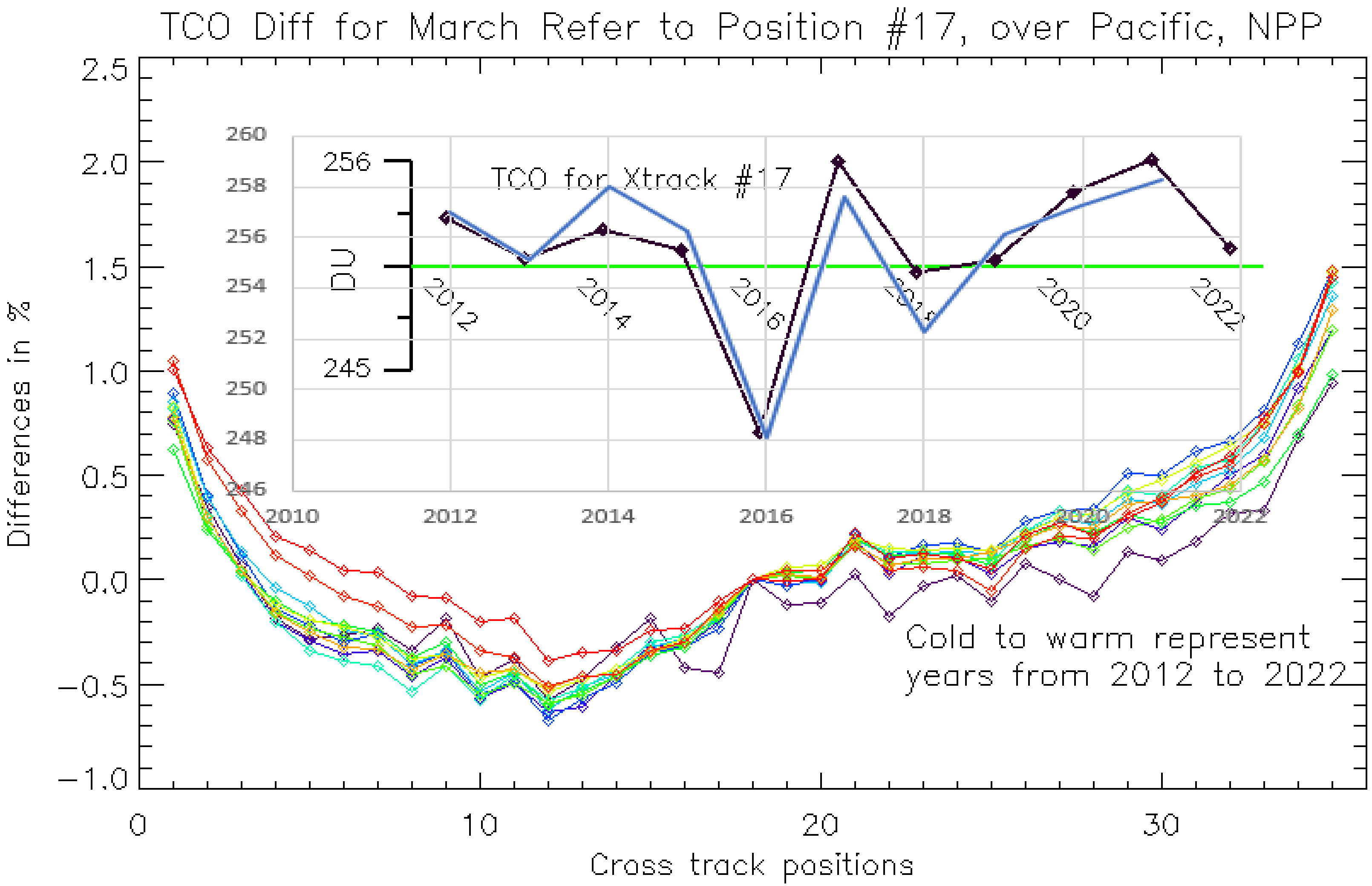
References

- GSICS Meetings http://gsics.atmos.umd.edu/bin/view/Development/MeetingsAndConferences
- GSICS Product Catalog https://www.star.nesdis.noaa.gov/smcd/GCC/ProductCatalog.php
- GSICS Quarterly Newsletter https://www.star.nesdis.noaa.gov/smcd/GCC/newsletters.php
- **Status of the Next Generation of the International Satellite Cloud Climatology (ISCCP-NG),** 2022 , A. Heidinger, https://earth.esa.int/living-planet-symposium-2022-presentations/27.05.Friday/RhineLobby/1040-1220/02_Heidinger.pdf
- **Ice radiance for BUV Instrument Moniroting,** G. Jaross & A. Krueger, 1993, https://docserver.gesdisc.eosdis.nasa.gov/repository/Mission/TOMS/3.3_ScienceDataProductDocumentation/3.3.6_ProductApplication/Jaross_Krueger_ice_radiance_method.pdf
- **Integrated Satellite Instrument Calibration/Validation System Preliminary Design Review**, 2006, C. Cao & F. Weng https://www.slideserve.com/huyen/changyong-cao-fuzhong-weng-noaa-nesdis-star-star-calibration-team-september-20-2006
- Feasibility Analysis of OMPS NM SDR Data Long-Term Stability Assessment using Deep Convective Cloud targets," 2023, Ding Liang et al.
- "The Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP) Version 1 Aerosol Extinction Retrieval Algorithm: Theoretical Basis" 2017, R. Loughman et al., https://amt.copernicus.org/preprints/amt-2017-299/amt-2017-299-manuscript-version5.pdf,

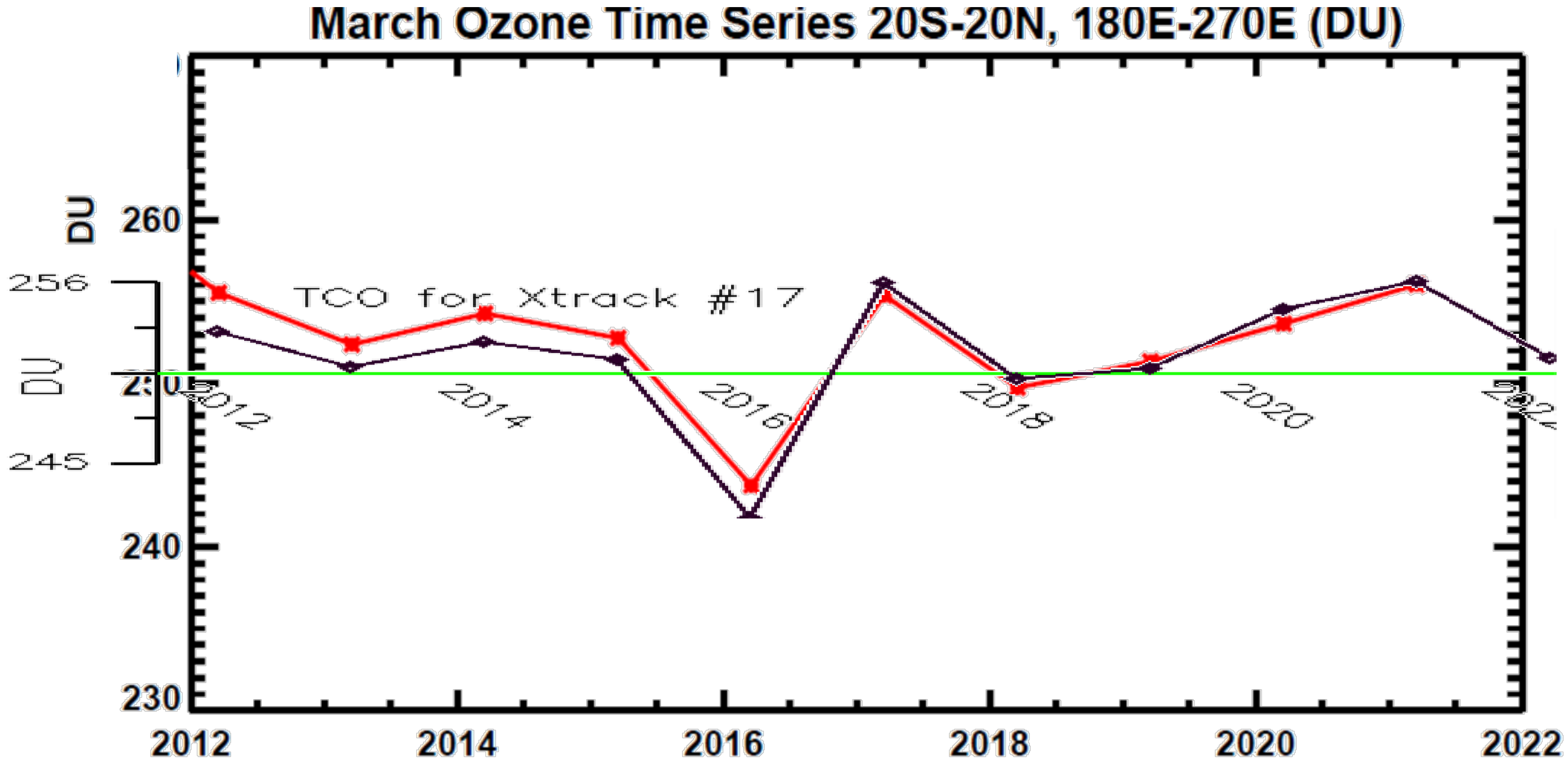
Backup



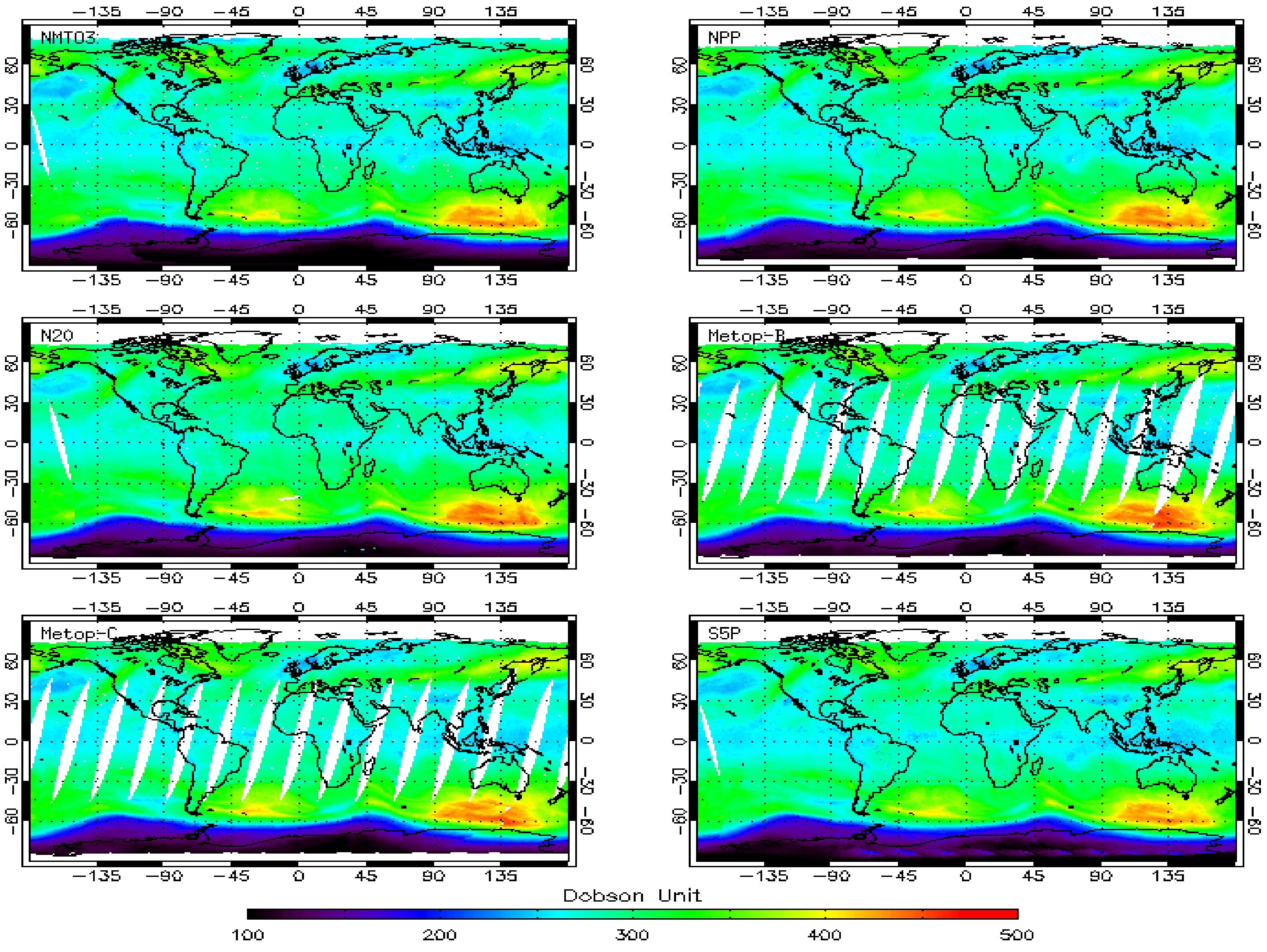
Cross-track dependence over the Equatorial Pacific of average March V8TOz Effective Reflectivity for S-NPP for 11 years. Colors are Cold to Warm. The range of values here is larger than that on the previous slide for the one-percentile reflectivity, and the order of the years from higher to lower values is different.



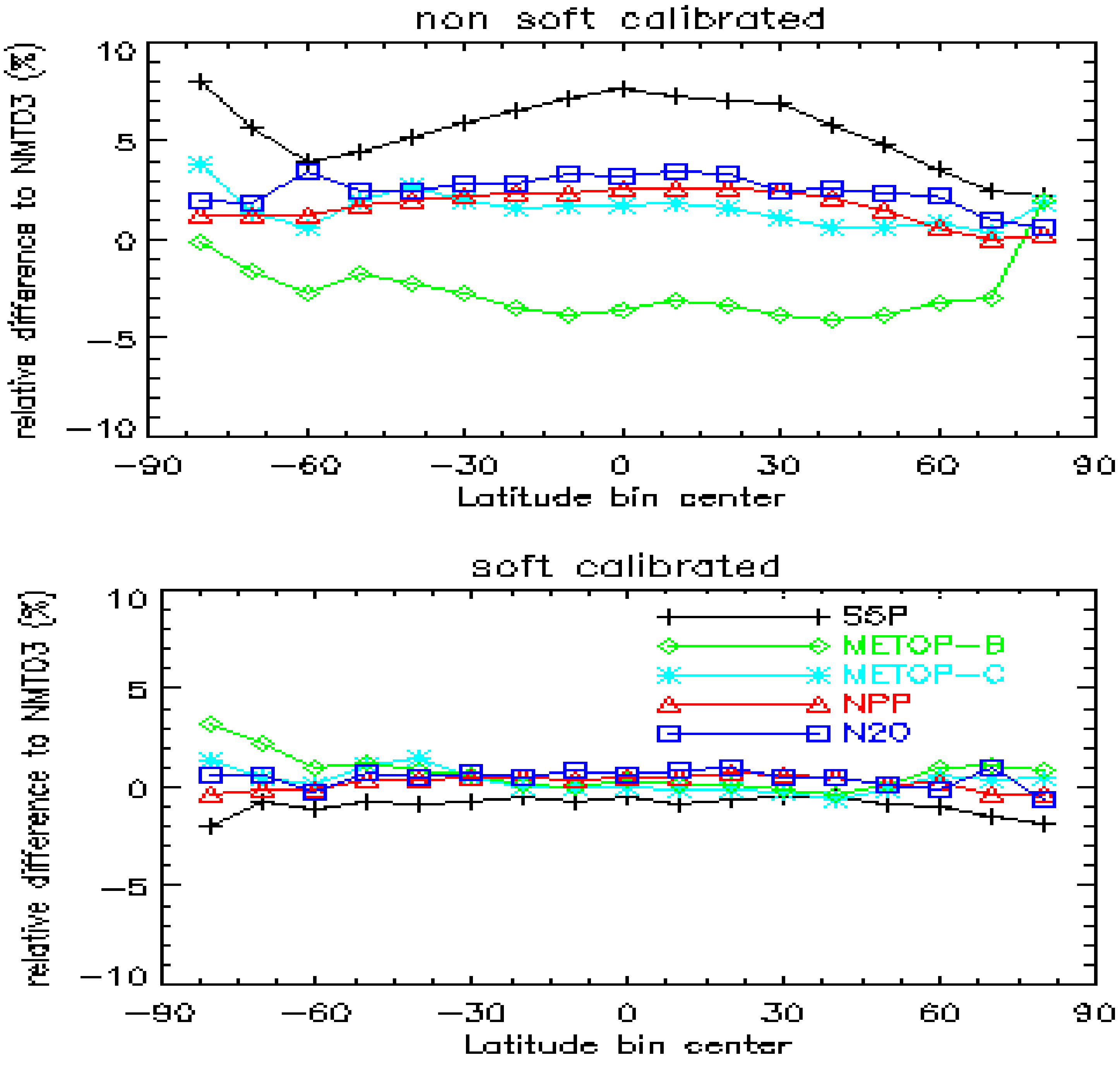
Cross-track dependence over the Equatorial Pacific of the average March V8TOz Total Column Ozone for S-NPP for 11 years Cold to Warm. This figure shows that the cross-track pattern for the total column ozone over the Equatorial Pacific box is also stable year-after-year. The values are given relative to cross-track position 17 for each individual year. The average TCO values for position 17 over the 11 years vary by 7% with no specific trend as shown in the inset time series. One expects variations for this region related to dynamics such as the Quasi-Biennial Oscillation.



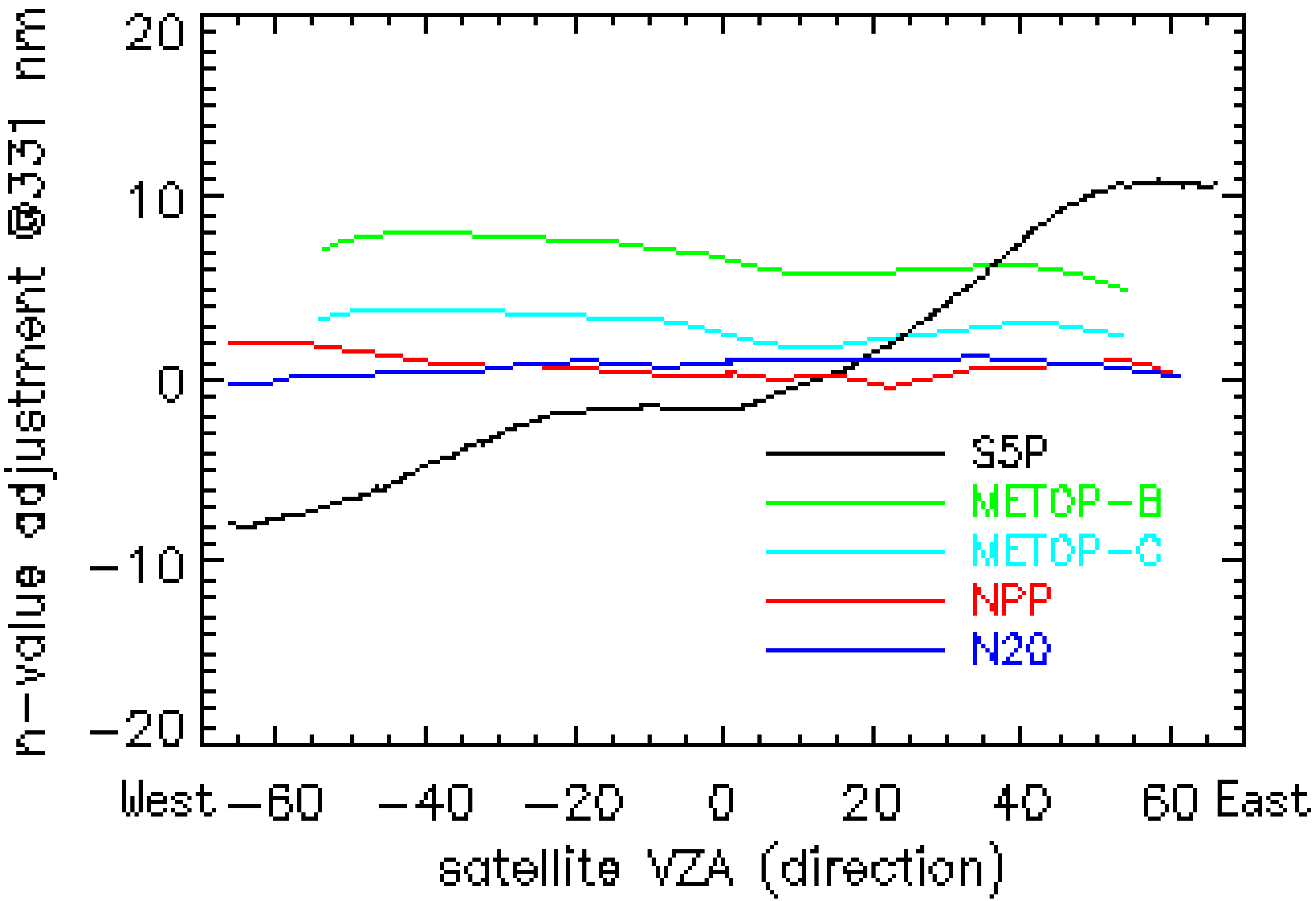
Equatorial Pacific of average March total column ozone for S-NPP the Nadir-View for 11 years. Black is the V8TOz product and Red is a V8Pro product.



Six maps demonstrate consistent retrievals of baseline products and EV8TOz products from measurements made by OMPS NPP, NOAA-20, GOME-2 on Metop-B and -C, and TROPOMI on the 7th of October 2021.

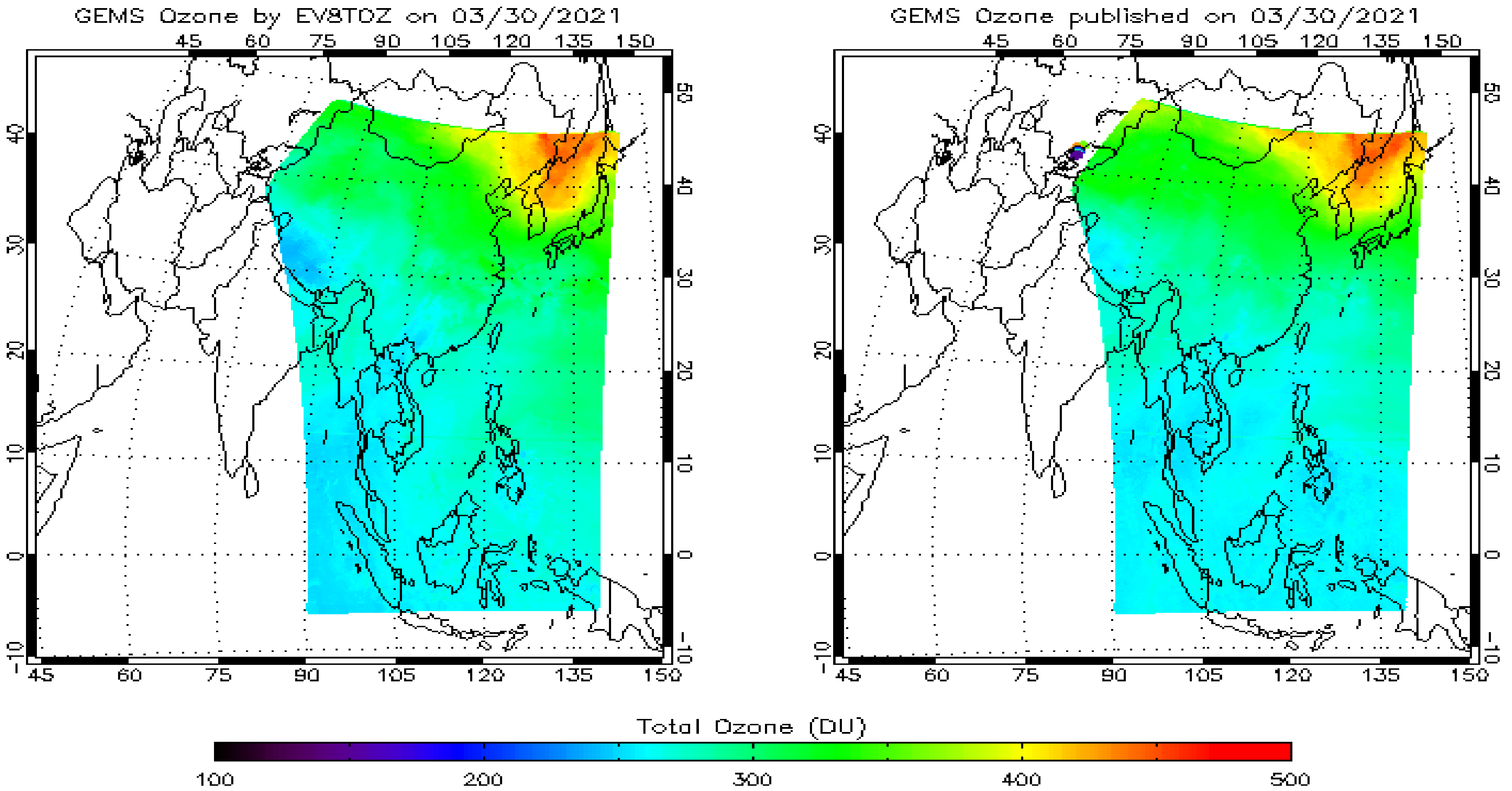


The zonal means of all five TOZ products on 7 October 2021 are computed within ±85° Latitude span. Their differences relative to the baseline are illustrated for the cases without soft calibration (upper), and with soft calibration (lower).

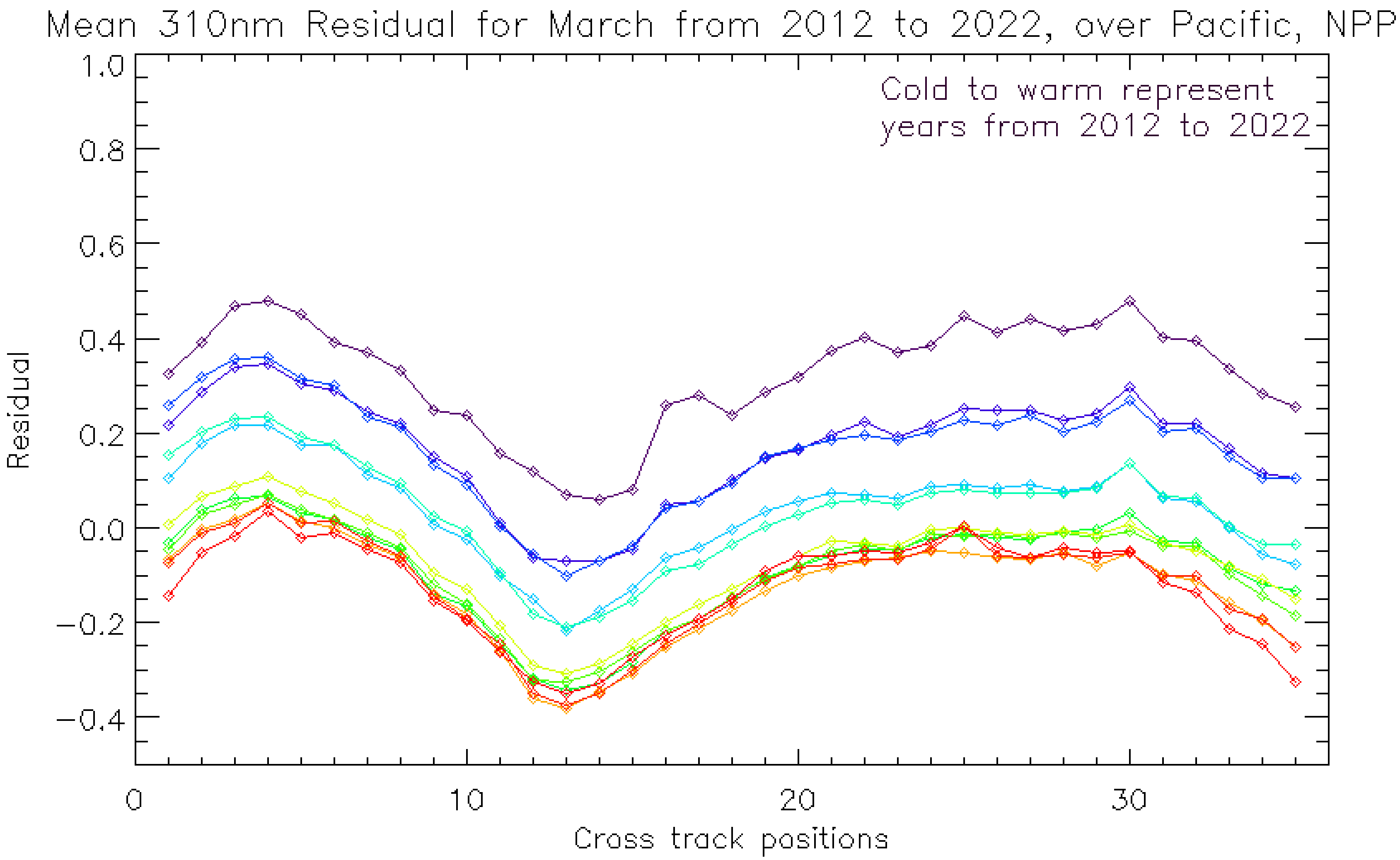


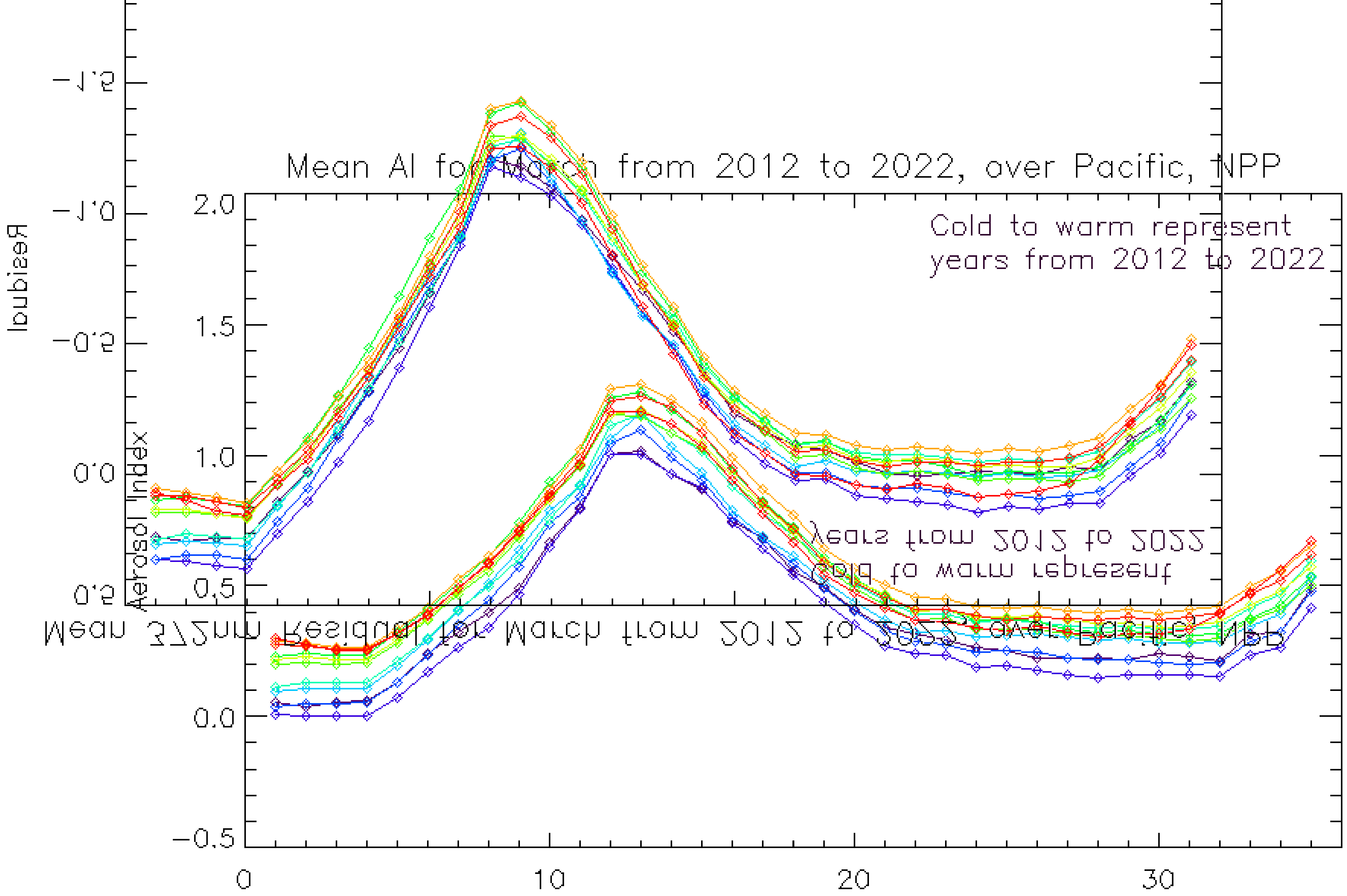
Five sensors' N-value adjustments in soft calibration tables for 331 nm channel are illustrated as a function of satellite viewing angle (VZA). The VZAs toward West are defined as negative.

NOAA EV8TOz & GEMS Team V9TOz Retrieved Total Column Ozone for 20210330_0145



Is the GEMS Team using the latest reflectivity and aerosol version of the V9TOz retrieval algorithm?


Mean 310nm Residual for March from 2012 to 2022, over Pacific, NPP
Cold to warm represent
years from 2012 to 2022
Residual
Cross track positions
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0
10
20
30

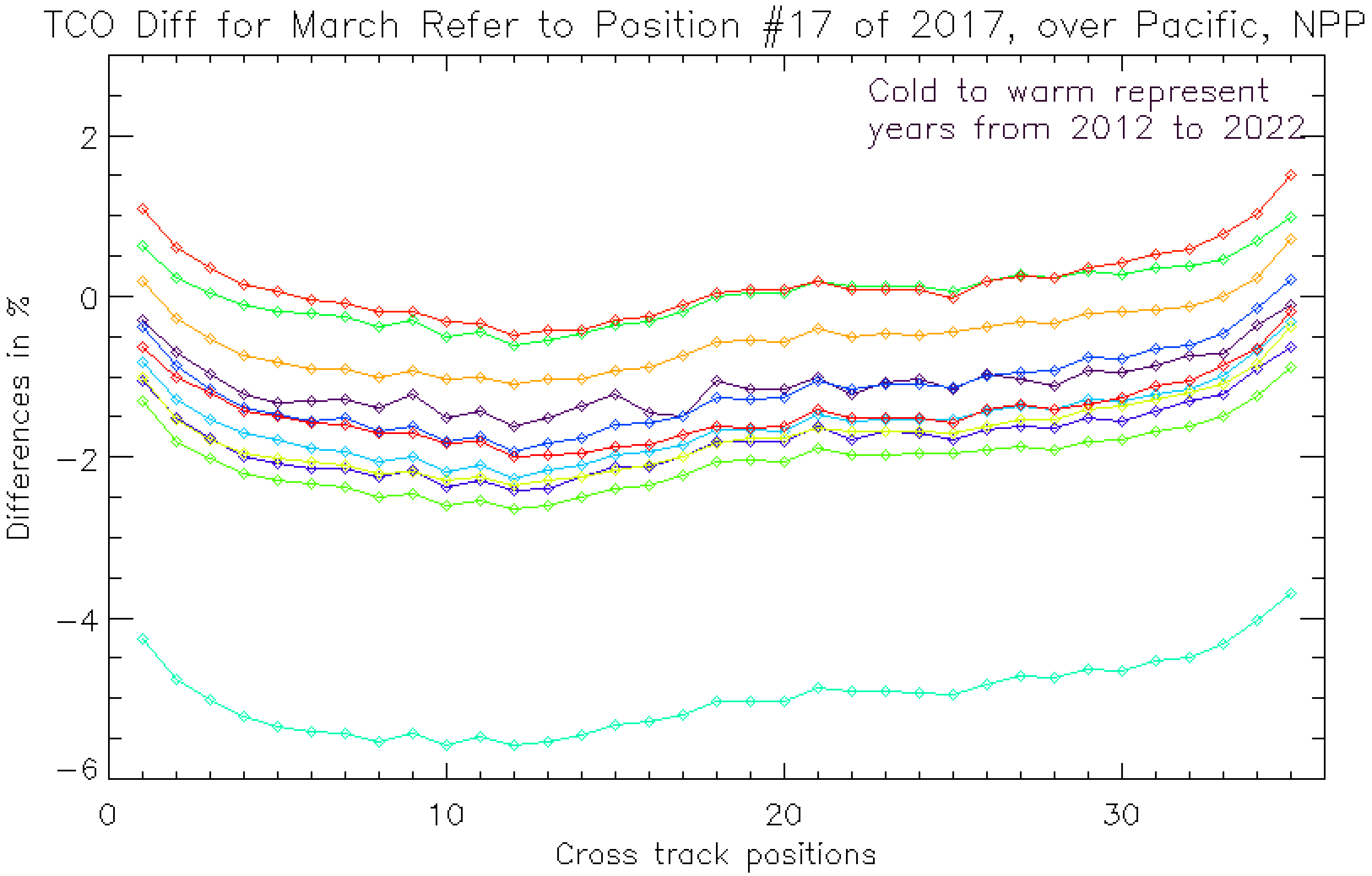


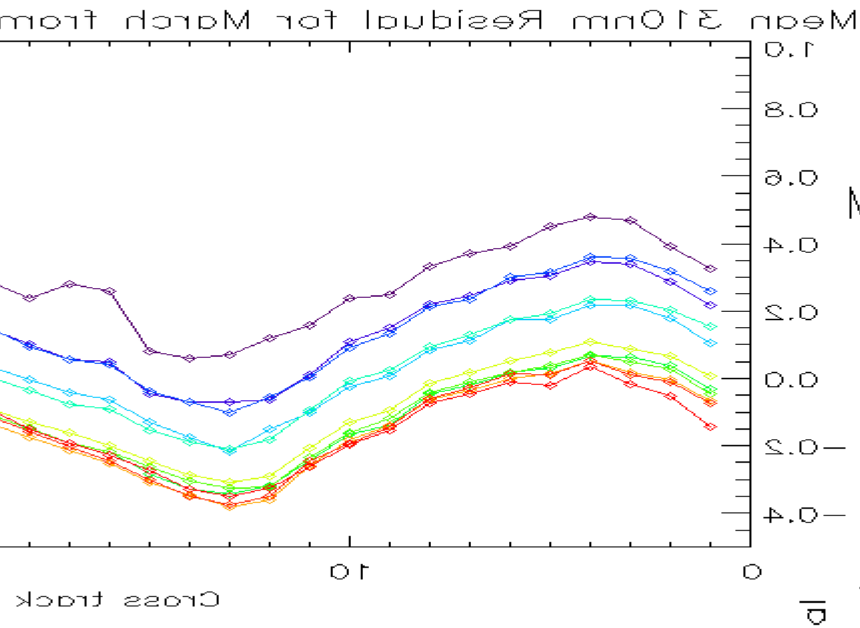
Just to check, I put the negative of the 372 nm residuals over AI. They show very similar changes over time. The sun-glint effect is a little larger.

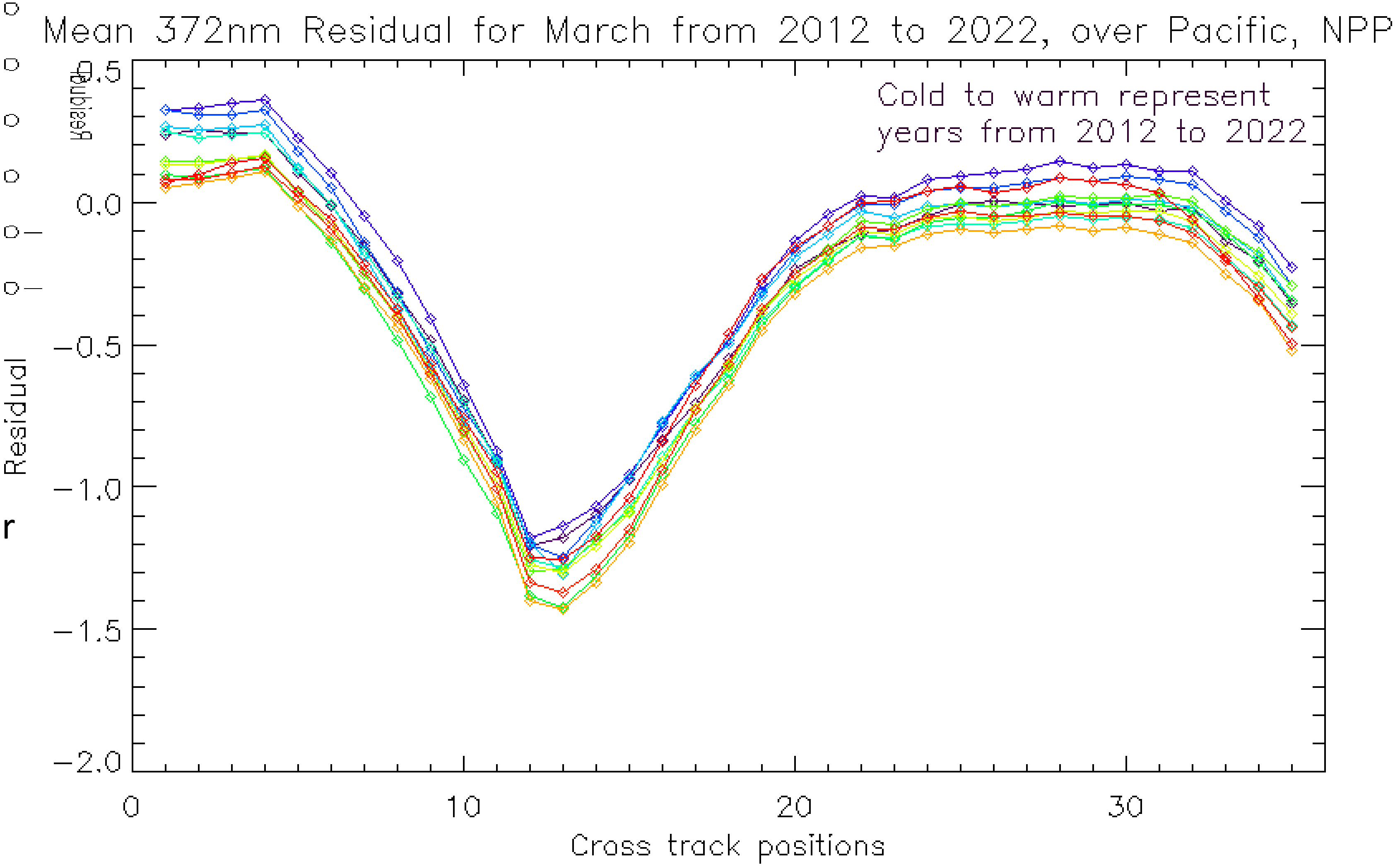
Can you make a scatter plot like Figure 12 comparing the AI with the negative of the 372 nm residual for one day for NPP? Maybe three plots one for nadir and one for positions 4 and 32. You do not need to grid the values as they are for the same granules.

Figure X.b. Cross-track dependence over the Equatorial Pacific of the Aerosol Index for S-NPP for March for 11 years Cold to Warm.

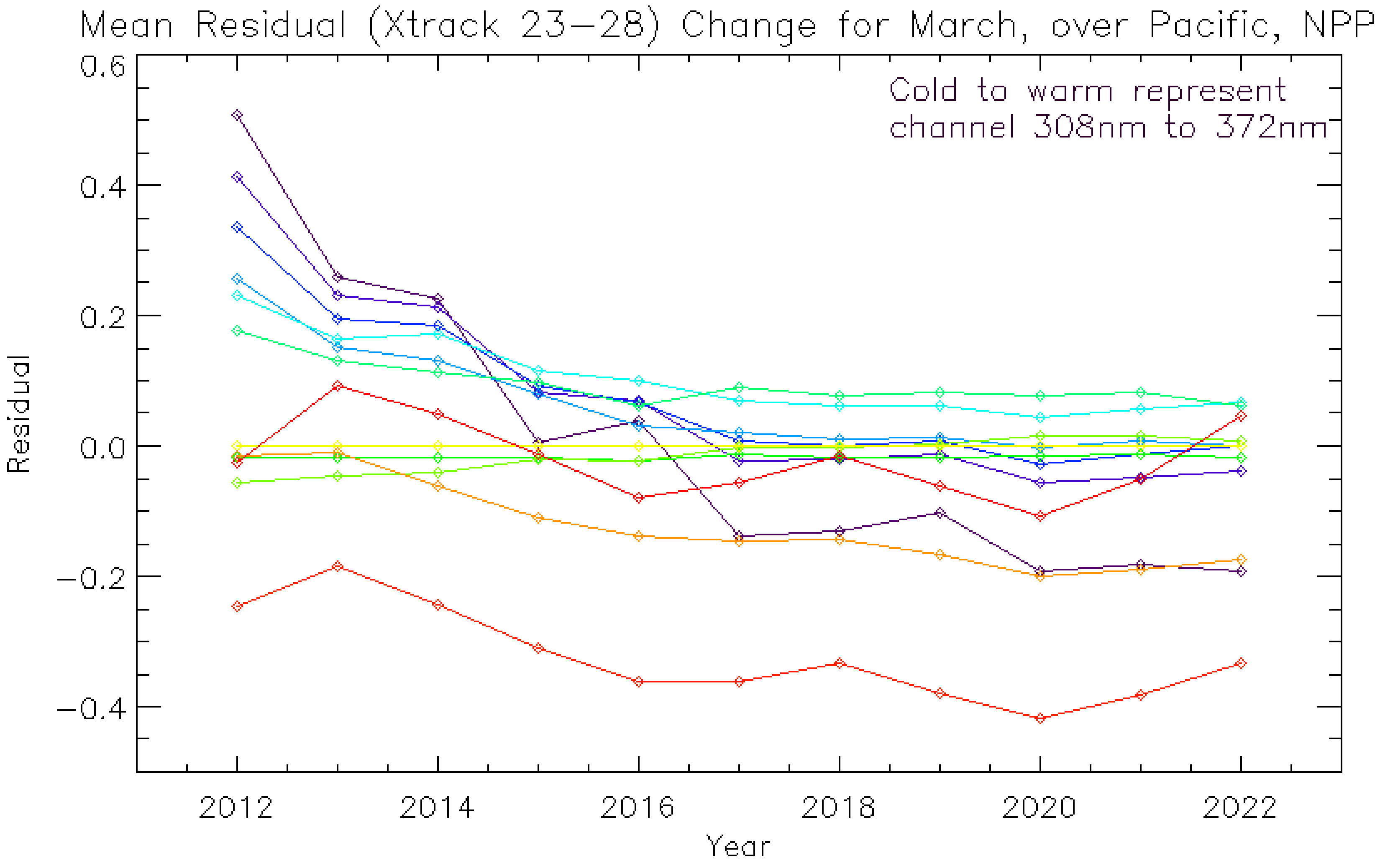
Figure X.b shows that the cross-track pattern for the Aerosol Index is also very stable year-after-year and the absolute values are stable at the 0.4 level. Figure 1 does show a trend in the instrument throughput for the 360 nm channel relative to the 331 nm one which has not been adjusted in any calibration, so some time dependence in this figure is not unexpected.

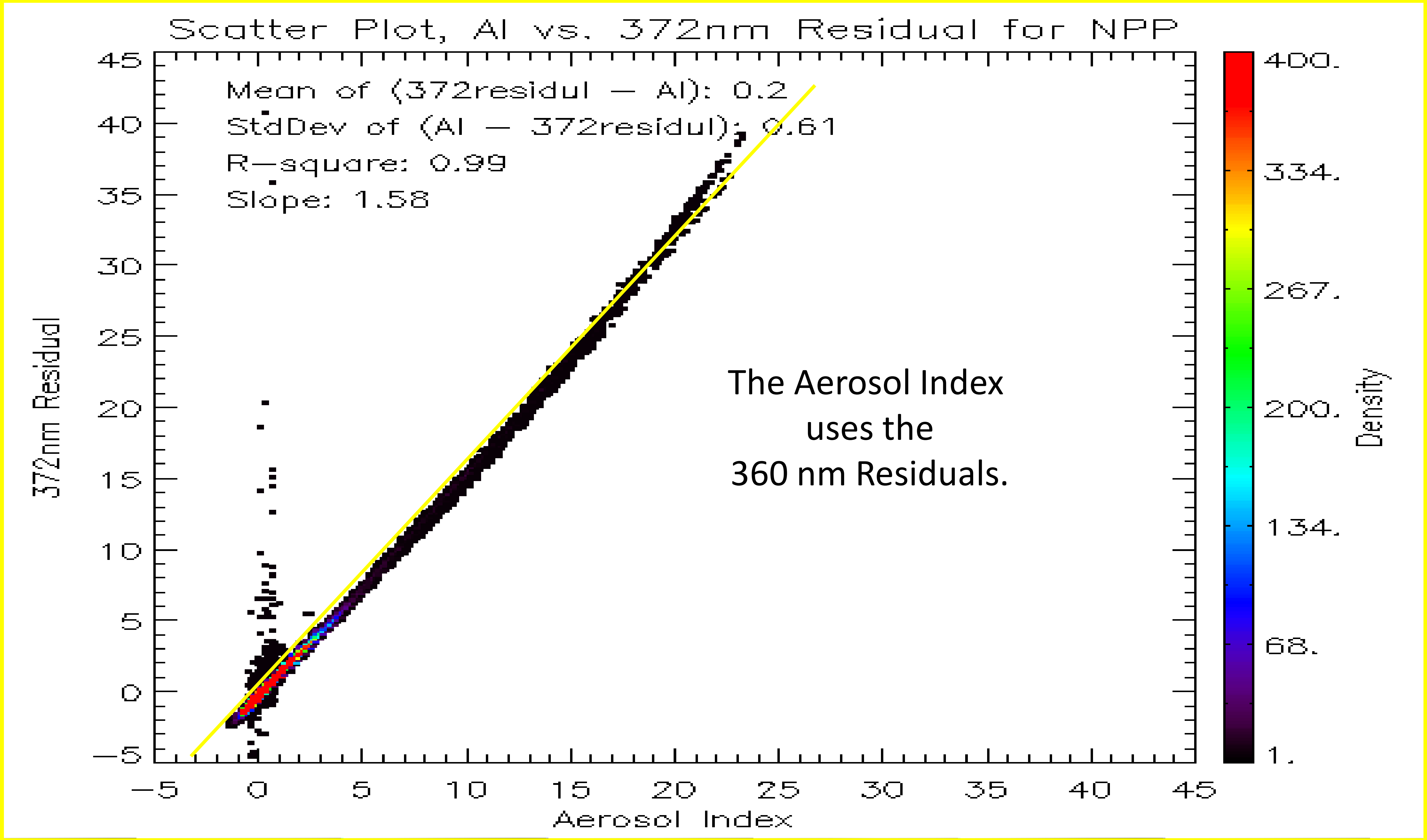

TCO Diff for March Refer to Position #17 of 2017, over Pacific, NPP
Cold to warm represent
years from 2012 to 2022
Differences in %
2
0
−2
−4
−6
0
10
20
30
Cross track positions





It's interesting that the residuals for 310 nm show a similar cold to hot trend as the 372 nm ones.


Mean Residual (Xtrack 23–28) Change for March, over Pacific, NPP
Cold to warm represent
channel 308nm to 372nm
Residual
0.6
0.4
0.2
0.0
−0.2
−0.4
2012
2014
2016
2018
2020
2022
Year



Scatter Plot, AI vs. 372nm Residual for NPP
Mean of (372residul – AI): 0.2
StdDev of (AI – 372residul): 0.61
R–square: 0.99
Slope: 1.58
The Aerosol Index
uses the
360 nm Residuals.
372nm Residual
Aerosol Index
Density
400.
334.
267.
200.
134.
68.
1.