Enhanced Radiometric Characterization of Sonoran PICS for Vicarious Calibration of GOES Imagers

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CALCON MEETING
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Introduction

- The Sonoran Desert in the Western Hemisphere is a commonly used PICS
- Minimal spatial and temporal variations and high reflectivity
- Within the field-of-view of GOES-East and West Imagers (lacking onboard calibrators), and thereby applicable for their vicarious calibration
- GOES have been providing valuable information for global climate change studies observing the Western Hemisphere

Introduction

- NASA's CERES project utilizes the Sonoran Desert to uniformly scale GOES sensors to a common radiometric scale
- Current GOES sensors are directly calibrated against MODIS radiances using coincident and collocated ray-matched radiance pairs
- For pre-MODIS timeframe GOES sensors, the CERES GEO PICS methodology relies on an empirical daily exoatmospheric radiance model (DERM)
- DERM averages multiple years of observed local noon TOA radiances for each day of the year to predict the reference daily radiance to determine the stability across the GEO record

Problem Statement

- Current DERM methodology does not account for any inter-annual variability due to varying atmospheric conditions
- DERM uncertainty is larger at select wavelengths that are sensitive to atmospheric variability

Objective

- Enhance the Sonoran Desert DERM accuracy by correlating observed radiance variability with atmospheric parameters like precipitable water, ozone concentration, and surface pressure

Outline of the Study

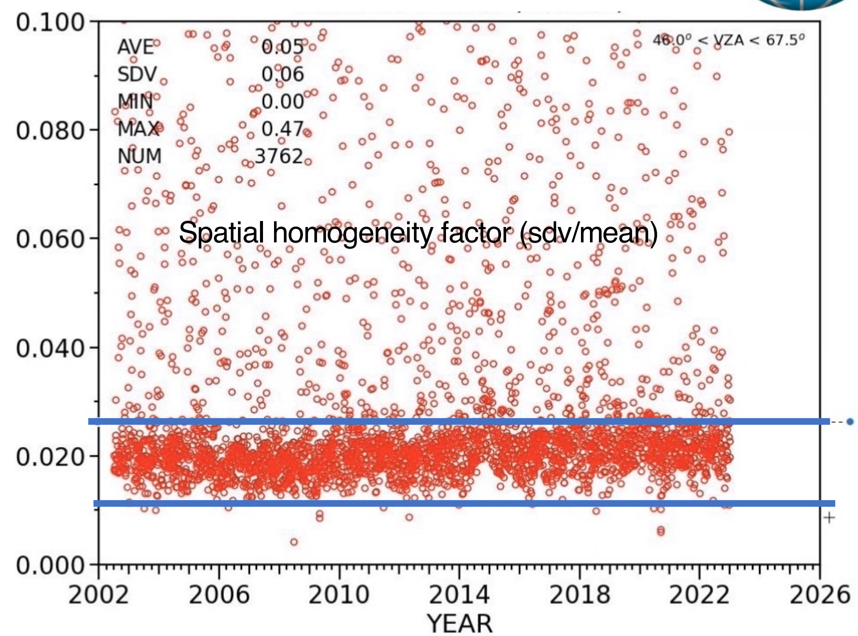
✓	MODIS over Sonoran	Characterization of Sonoran Desert using MODIS incorporating the atmospheric parameters under similar viewing conditions as GOES
✓	Traditional DERM	GOES-12 based DERM over Sonoran Desert
✓	Improved DERM	Traditional DERM + Atmospheric parameterization

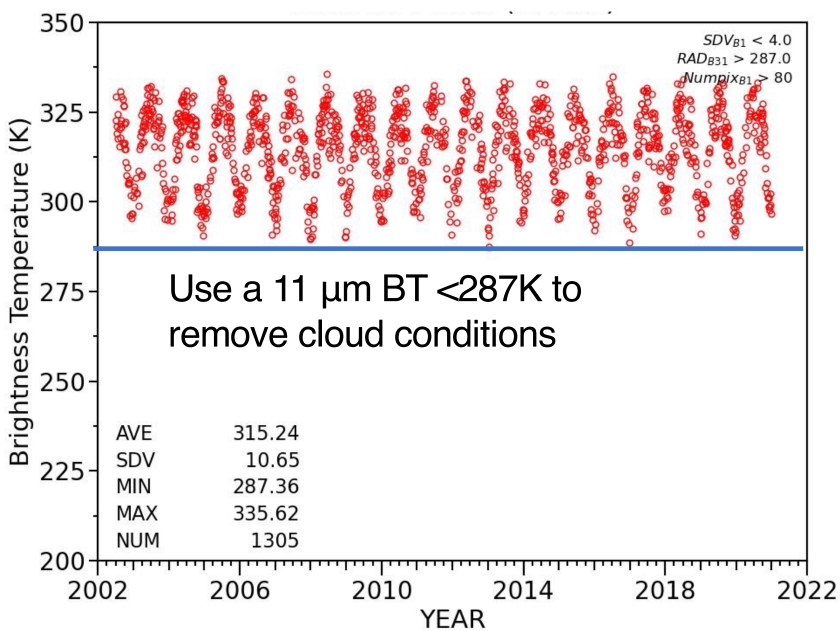
Aqua MODIS PICS Methodology

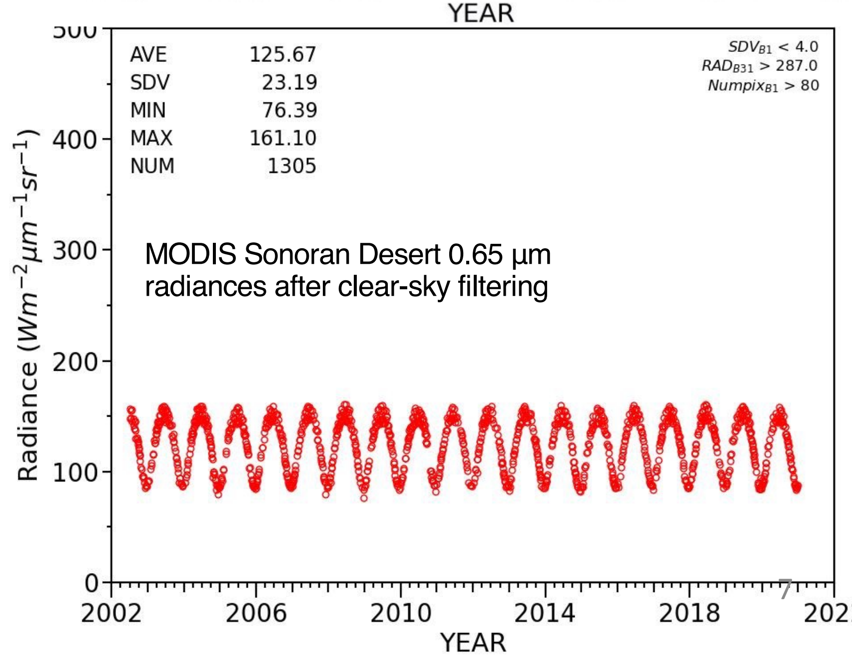
- Data Selection
  - Aqua MODIS Collection 6.1
  - Averaging the instantaneous MODIS pixel-level radiances that are located over the Sonoran ROI
- Clearsky filtering
  - ➢ 0.64µm radiance spatial homogeneity and brightness temperature within the ROI is used to identify pristine clear-sky observations
- Development of Directional Model
  - ➢ DM coefficients are derived that relate TOA reflectances with SZA and atmospheric parameters, which are used to predict the clear-sky reflectance over Sonora Desert
  - ➢ The atmospheric parameters are from the GSFC GMAO reanalysis product
- Dividing observed reflectance with the predicted reflectance to compute channel relative reflectance

Clear-sky Filtering MODIS Radiance over the Sonoran Desert

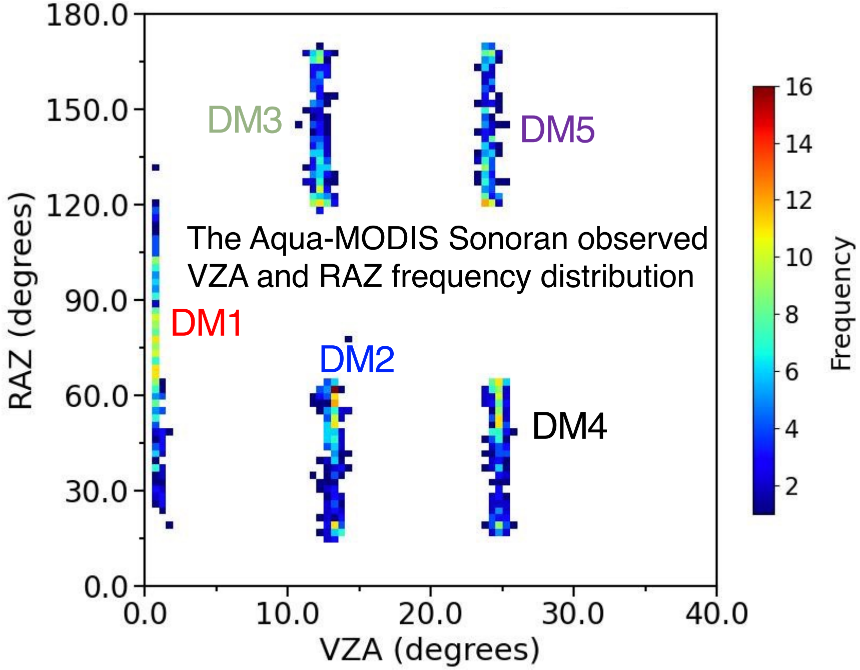
Clear-sky filtering using spatial homogeneity test and IR BT threshold



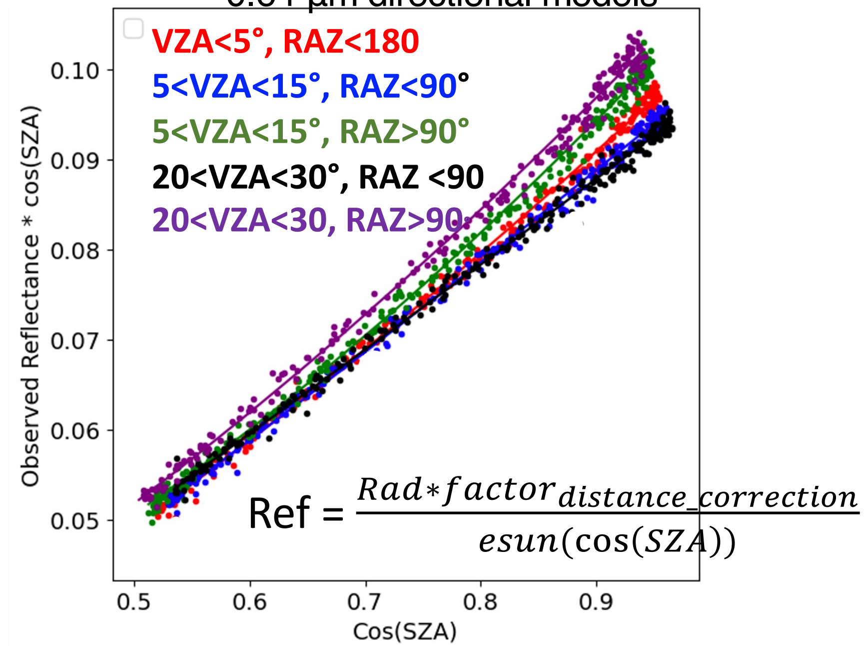




Development of Directional Models (VZA<30°)



Sonoran PICS Aqua-MODIS 0.64 µm directional models

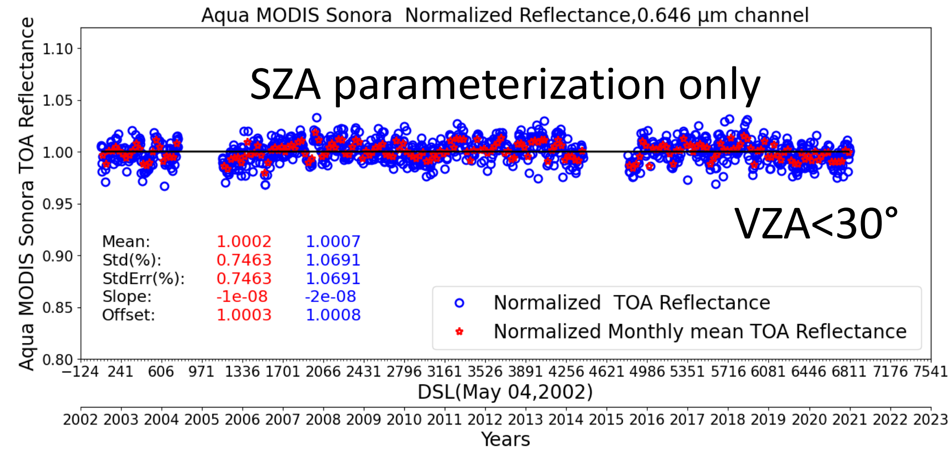


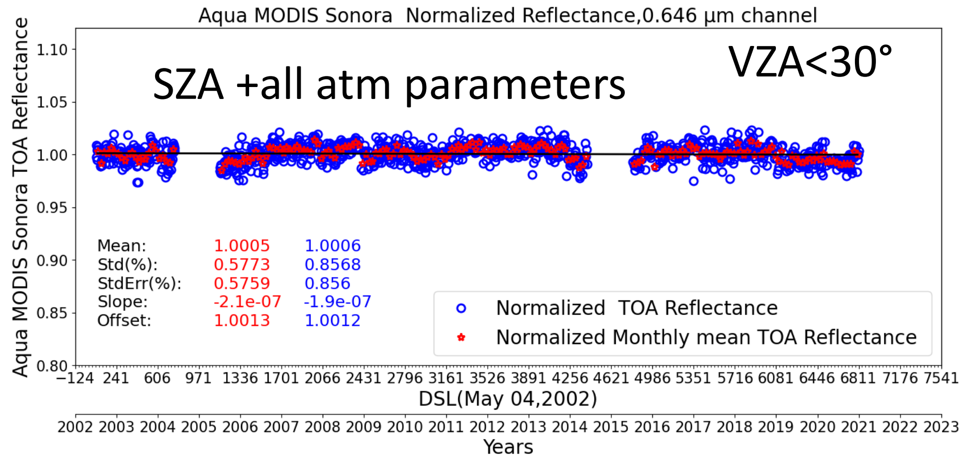
The Aqua-MODIS Sonora reflectance are regressed by applying regression fit

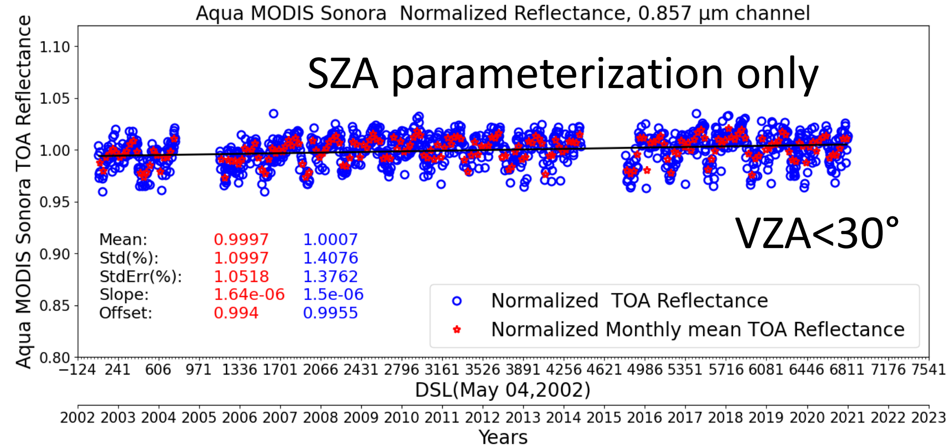
- With respect to cosine SZA, $\mathbf{Ref_{predicted} = g_0 + g_1 * cos(SZA)}$

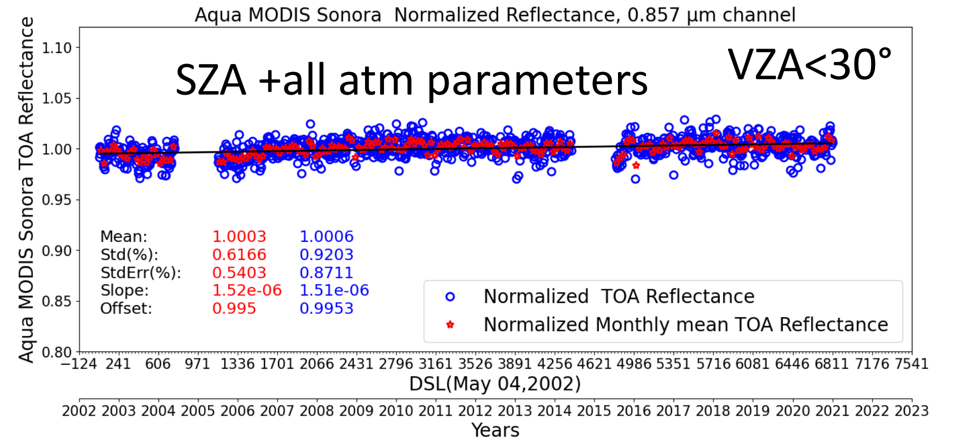
- Adding atmospheric parameters

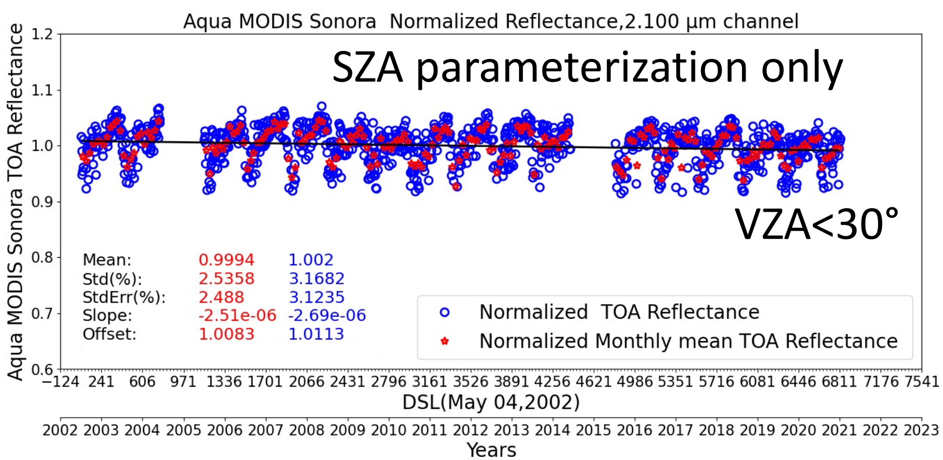
$$Ref_{predicted} = g_0 + g_1 * \cos(SZA) + g_2 * PW + g_3 * O_3 + g_4 * SP + g_5 * WS$$

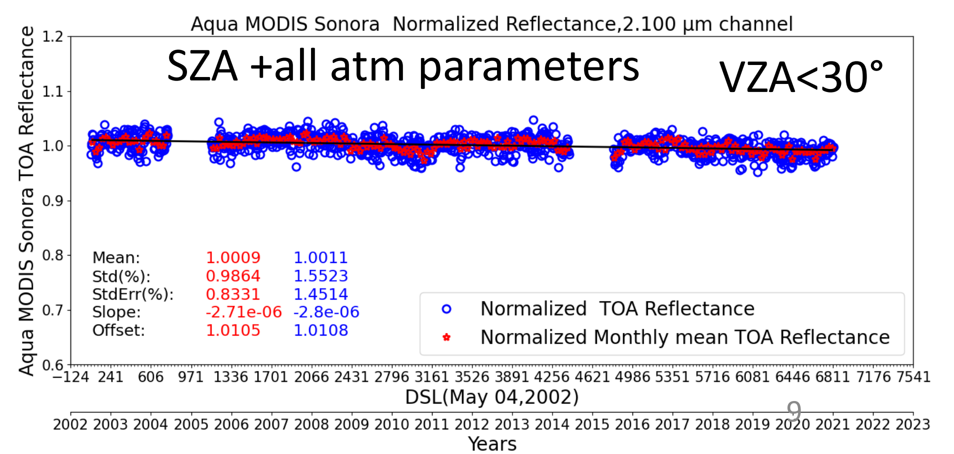

Aqua MODIS Sonora Normalized Reflectance,0.646 μm channel
SZA parameterization only
VZA<30°
Mean: 1.0002 1.0007
Std(%): 0.7463 1.0691
StdErr(%): 0.7463 1.0691
Slope: -1e-08 -2e-08
Offset: 1.0003 1.0008
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance,0.646 μm channel
SZA +all atm parameters
VZA<30°
Mean: 1.0005 1.0006
Std(%): 0.5773 0.8568
StdErr(%): 0.5759 0.856
Slope: -2.1e-07 -1.9e-07
Offset: 1.0013 1.0012
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance, 0.857 μm channel
SZA parameterization only
VZA<30°
Mean: 0.9997 1.0007
Std(%): 1.0997 1.4076
StdErr(%): 1.0518 1.3762
Slope: 1.64e-06 1.5e-06
Offset: 0.994 0.9955
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance, 0.857 μm channel
SZA +all atm parameters
VZA<30°
Mean: 1.0003 1.0006
Std(%): 0.6166 0.9203
StdErr(%): 0.5403 0.8711
Slope: 1.52e-06 1.51e-06
Offset: 0.995 0.9953
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance,2.100 μm channel
SZA parameterization only
VZA<30°
Mean: 0.9994 1.002
Std(%): 2.5358 3.1682
StdErr(%): 2.488 3.1235
Slope: -2.51e-06 -2.69e-06
Offset: 1.0083 1.0113
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance,2.100 μm channel
SZA +all atm parameters
VZA<30°
Mean: 1.0009 1.0011
Std(%): 0.9864 1.5523
StdErr(%): 0.8331 1.4514
Slope: -2.71e-06 -2.8e-06
Offset: 1.0105 1.0108
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years

Relative Reflectance Trend Standard Error (VZA<30°)

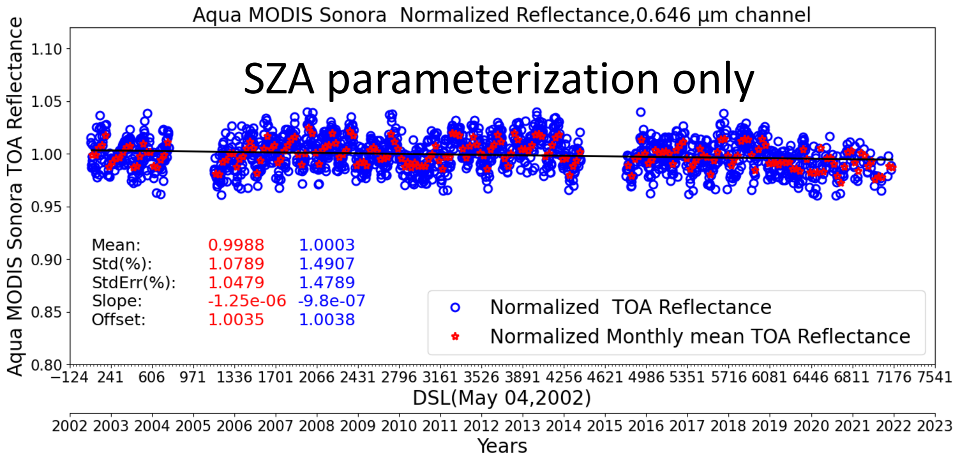
Parameters/Band(μm)	0.64 (%)	0.87 (%)	0.46 (%)	0.55 (%)	1.24 (%)	1.629 (%)	2.10 (%)
SZA	1.0691	1.3762	1.1251	0.9327	1.2718	0.885	3.1235
SZA+PW	**0.8992**	**0.8663**	**1.107**	0.9312	**0.794**	**0.7677**	**1.4611**
SZA+P_{SURF}	1.0634	1.3551	1.1152	0.9215	1.2622	0.8847	2.936
SZA+O_3	1.0708	1.3128	1.128	**0.9003**	1.2236	0.8776	2.9572
SZA+WS	1.0465	1.3102	1.1226	0.9336	1.2128	0.8871	2.8903
Comparison with SZA	15.90	37.05	1.61	3.47	37.57	13.25	53.22
SZA+PW+P_{SURF}+O_3+ WS	0.856	0.8711	1.0933	0.8989	0.7899	0.7624	1.4514
Comparison with SZA	19.93	36.70	2.83	3.62	37.89	13.85	53.53

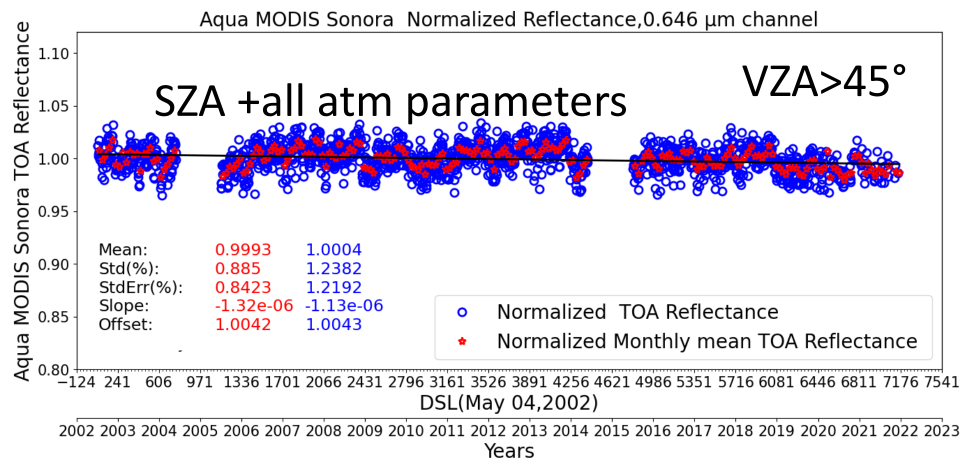
trend standard error with sza only

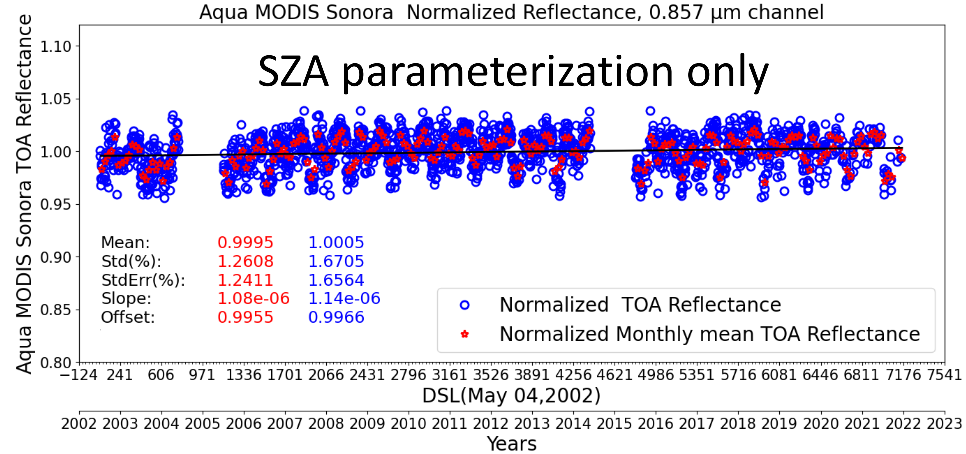
SZA and one other parameter trend standard error (smallest shown in bold)
Reduction when adding one parameter

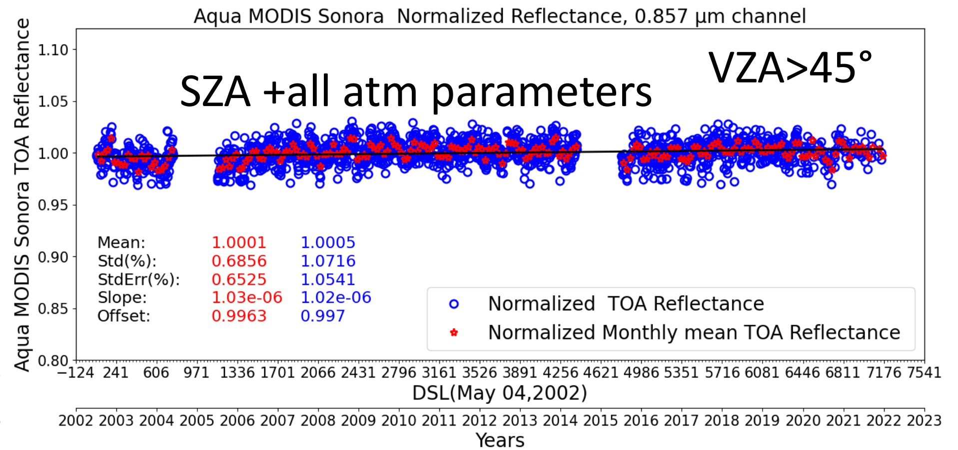
SZA ands all parameter standard error
Reduction when adding all the parameters

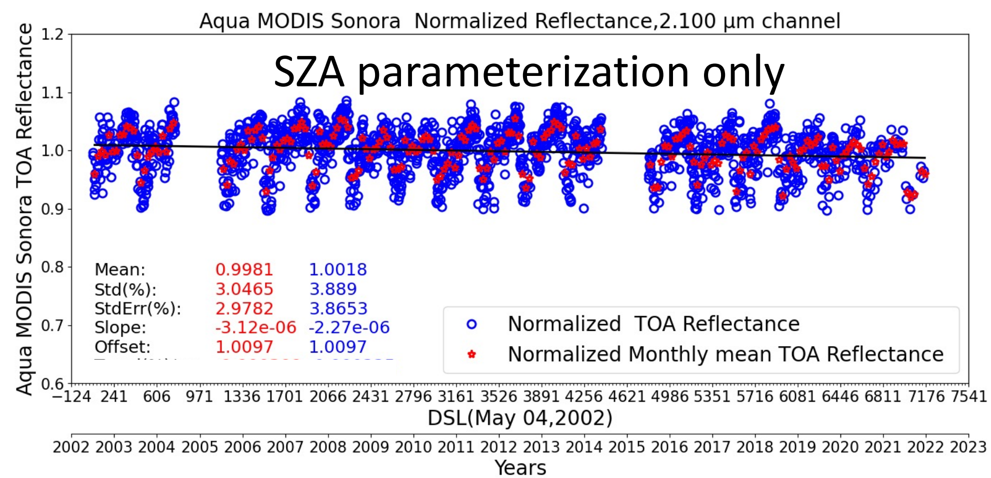
- The channels impacted by PW reduced the trend standard error between 15 to 50%

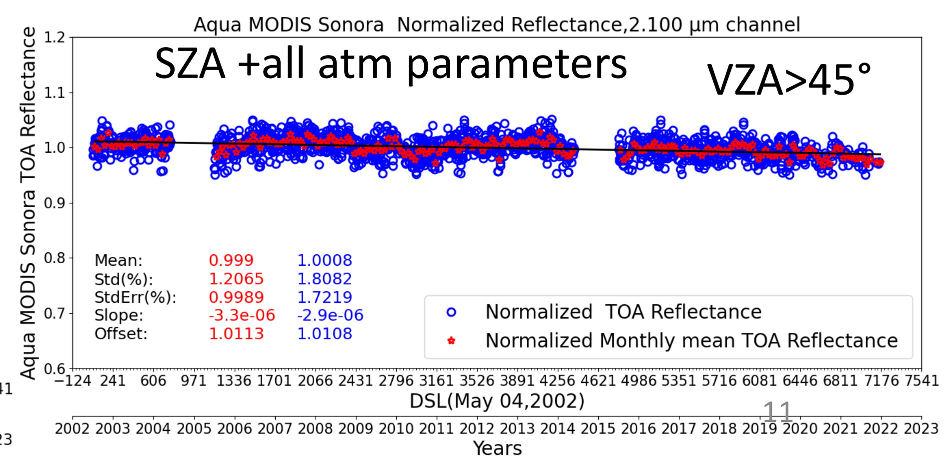

Aqua MODIS Sonora Normalized Reflectance,0.646 µm channel
SZA parameterization only
Mean: 0.9988 1.0003
Std(%): 1.0789 1.4907
StdErr(%): 1.0479 1.4789
Slope: -1.25e-06 -9.8e-07
Offset: 1.0035 1.0038
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance,0.646 µm channel
SZA +all atm parameters
VZA>45°
Mean: 0.9993 1.0004
Std(%): 0.885 1.2382
StdErr(%): 0.8423 1.2192
Slope: -1.32e-06 -1.13e-06
Offset: 1.0042 1.0043
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance, 0.857 µm channel
SZA parameterization only
Mean: 0.9995 1.0005
Std(%): 1.2608 1.6705
StdErr(%): 1.2411 1.6564
Slope: 1.08e-06 1.14e-06
Offset: 0.9955 0.9966
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance, 0.857 µm channel
SZA +all atm parameters
VZA>45°
Mean: 1.0001 1.0005
Std(%): 0.6856 1.0716
StdErr(%): 0.6525 1.0541
Slope: 1.03e-06 1.02e-06
Offset: 0.9963 0.997
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance,2.100 µm channel
SZA parameterization only
Mean: 0.9981 1.0018
Std(%): 3.0465 3.889
StdErr(%): 2.9782 3.8653
Slope: -3.12e-06 -2.27e-06
Offset: 1.0097 1.0097
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years


Aqua MODIS Sonora Normalized Reflectance,2.100 µm channel
SZA +all atm parameters
VZA>45°
Mean: 0.999 1.0008
Std(%): 1.2065 1.8082
StdErr(%): 0.9989 1.7219
Slope: -3.3e-06 -2.9e-06
Offset: 1.0113 1.0108
Normalized TOA Reflectance
Normalized Monthly mean TOA Reflectance
Aqua MODIS Sonora TOA Reflectance
DSL(May 04,2002)
Years

Relative Reflectance Trend Standard Error (VZA>45°)

Parameters/Band(μm)	0.64 (%)	0.87 (%)	0.46 (%)	0.55 (%)	1.24 (%)	1.629 (%)	2.10 (%)
SZA	1.4789	1.6564	1.942	1.4902	1.5162	1.0547	3.8653
SZA+PW	**1.3382**	**1.0999**	1.8799	1.464	**0.9887**	**0.9223**	**1.7624**
SZA+P_{SURF}	1.4618	1.6349	**1.8699**	**1.423**	1.4906	1.0315	3.6863
SZA+O_3	1.4627	1.6227	1.9217	1.4246	1.4834	1.0349	3.6919
SZA+WS	1.4579	1.5704	1.9406	1.4837	1.4454	1.0323	3.5917
Comparison with SZA	9.51	33.60	3.71	4.51	34.79	12.55	54.40
SZA+PW+P_{SURF}+O_3+ WS	1.2192	1.0541	1.8023	1.3678	0.9427	0.8759	1.7219
Comparison with SZA	17.56	36.36	7.19	8.21	37.82	16.95	55.44

trend standard error with sza only

SZA and one other parameter trend standard error (smallest shown in bold)
Reduction when adding one parameter

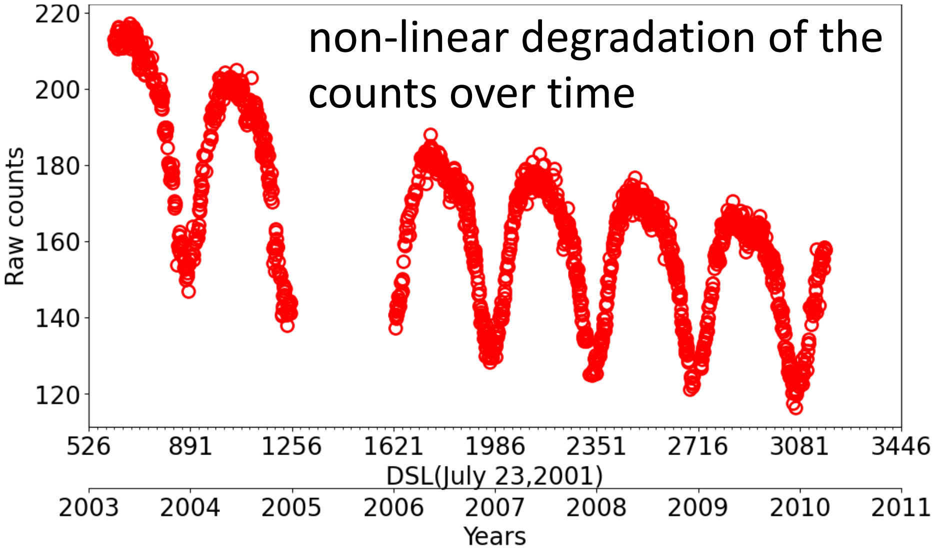
SZA ands all parameter standard error
Reduction when adding all the parameters

- The channels impacted by PW reduced the trend standard error between 15% to 50%
- Expect a 15% decrease in temporal noise adding in PW and other atmospheric parameters of the GOES observations

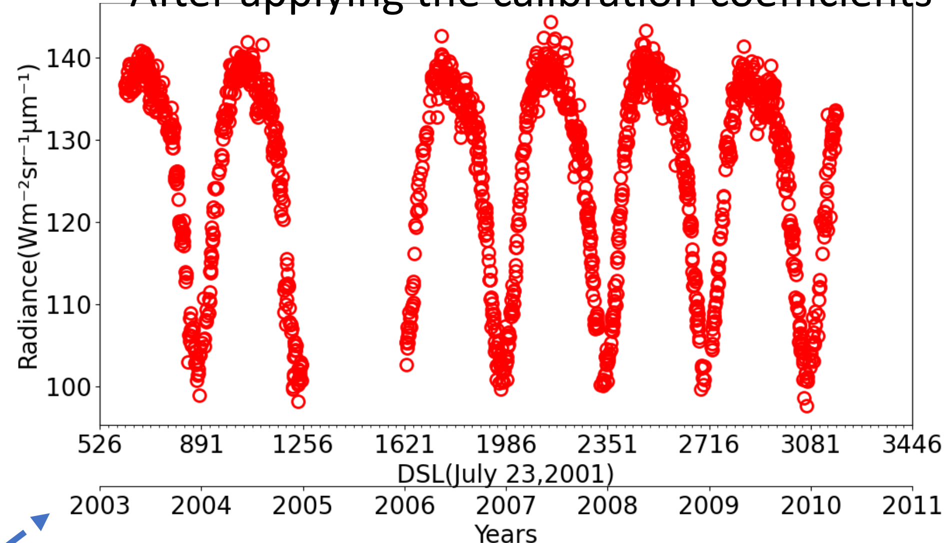
DERM Concept and Methodology

- This approach uses a PICS to transfer calibration from a reference GEO sensor to a target co-located GEO sensor.
- The reference GEO sensor calibration is obtained from its inter-calibration (ray-matching) with a matching Aqua MODIS band.
- The similar daily imaging schedules of the reference GEO provides consistent solar and azimuth angular conditions on a particular day of year.
- Multiple years of consistent-time daily TOA radiances observed from the reference GEO over the PICS are used to construct a daily-exoatmospheric radiance model (DERM).
- Near local noon-time data is chosen for maximum SNR.
- Since the daily angular conditions are repeated annually for any historical or successive co-located GEO, the reference GEO DERM is used to predict the TOA radiance of the co-located target GEO, and calibrate it.

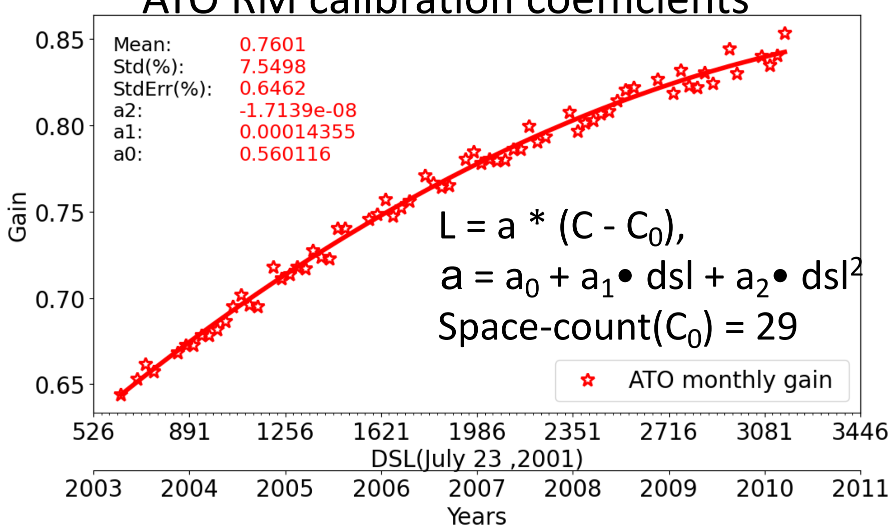
GOES-12 DERM



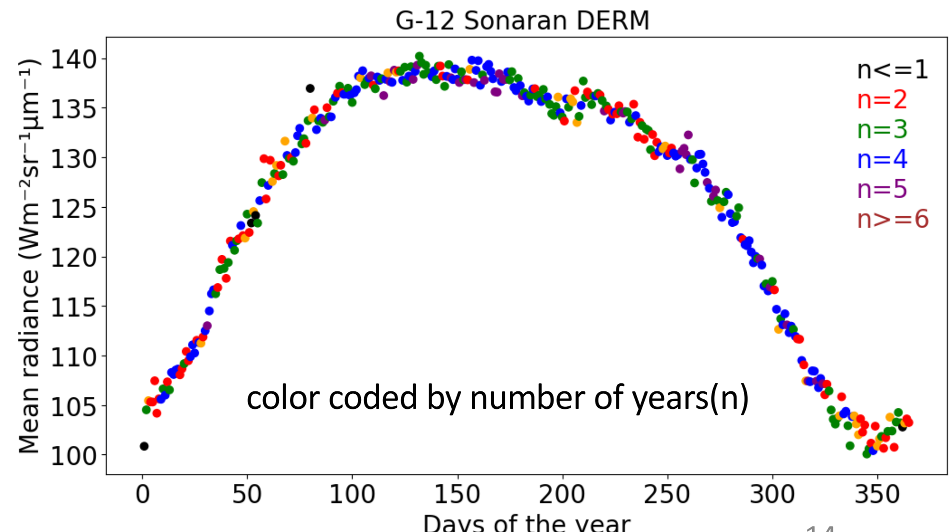
After applying the calibration coefficients



ATO RM calibration coefficients

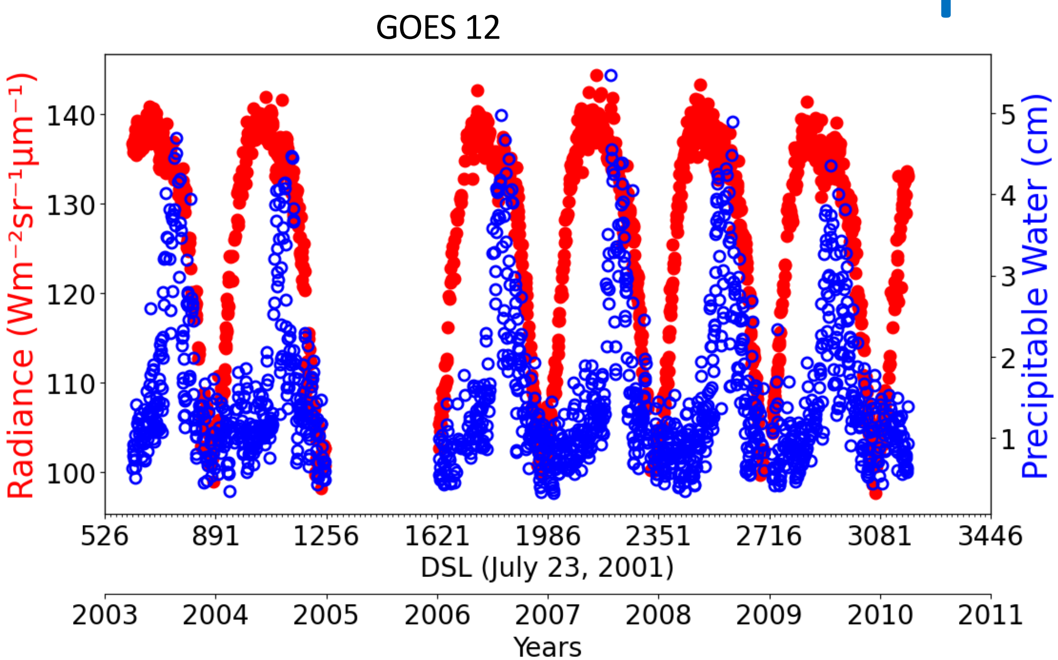


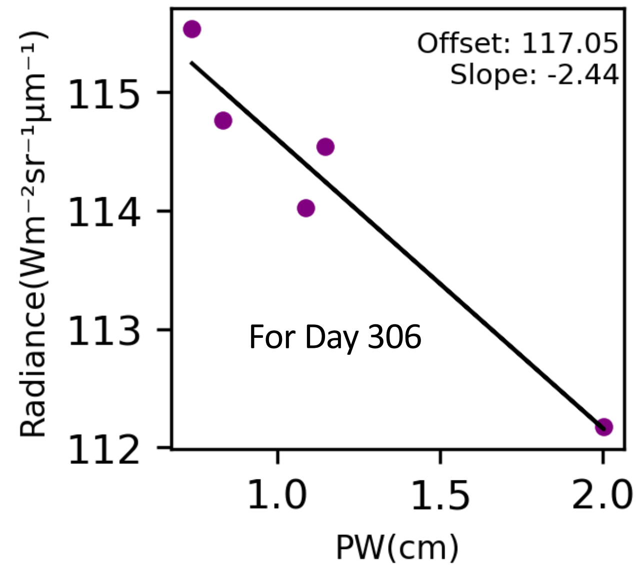
GOES-12 DERM after applying calibration coefficients



Doelling, D.R., C. Haney, R. Bhatt, B. Scarino, A. Gopalan, Geostationary Visible Imager Calibration for the CERES SYN1deg Edition 4 Product, Remote Sens. 2018, 10(2), 288, DOI:10.3390/rs10020288.

Account for Water vapor Absorption



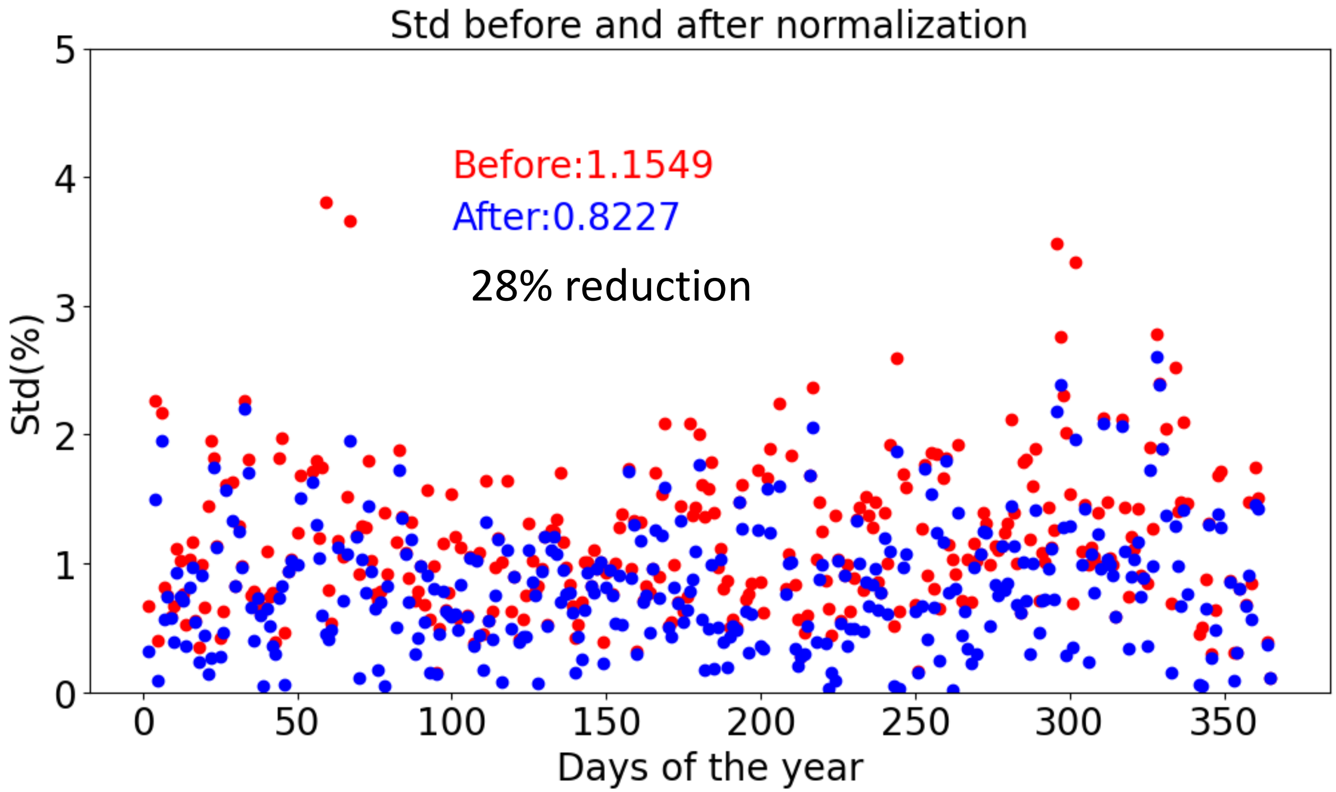


- PW oscillates with season, but has day to day variability in the PW that will impact the radiance
- Larger PW values correspond to smaller radiances, whereas smaller PW values correspond to greater radiances
- For each day, describe the radiance departure from DERM using a linear relationship based on PW $Predicted\_rad_{y-DDD}$ = slope* PW_{Y-DDD} +offset

G-12 DERM with Precipitable Water

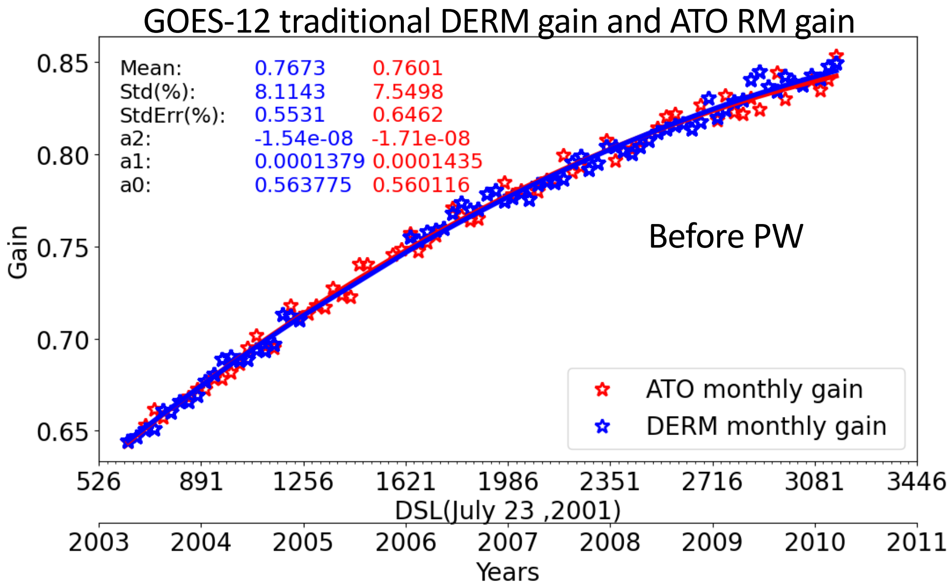
$Predicted\_rad_{y-DDD}$= Slope* PW_{Y-DDD} +Offset

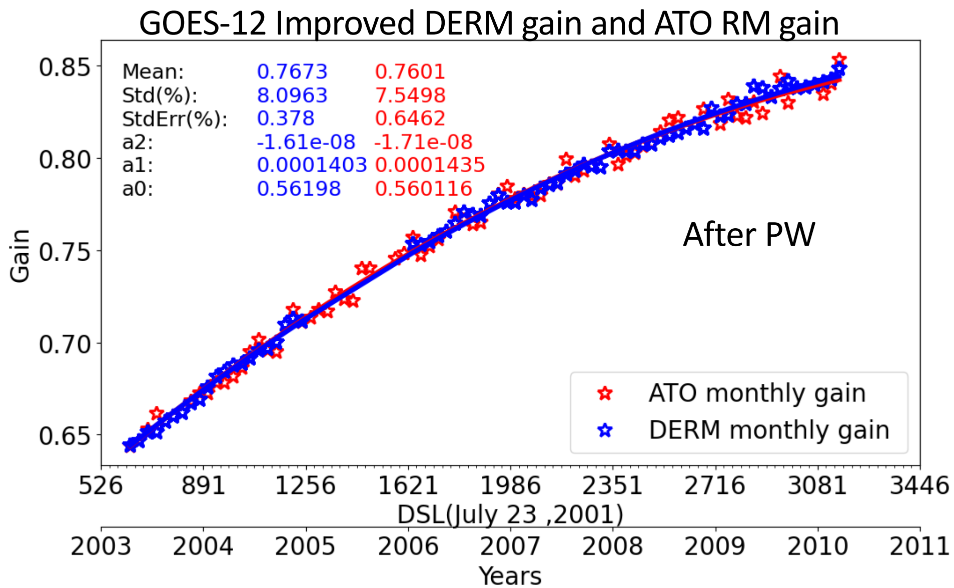
$$Normalized\_rad_{Y-DDD} = \frac{Observed\_rad_{Y-DDD}}{Predicted\_rad_{Y-DDD}} \text{ x } Rad_{mean\_PW\,DDD}$$



- By adding the PW-term the standard deviation , 28% reduction

G-12 DERM Validation





- GOES-12 gains derived from the DERM and Aqua ray-matching are consistent within 1% during the overlapping timeframe
- Improved DERM reduced error by ~30%

Conclusions

- DERM approach uses the consistent, repeating cycle of the PICS daily TOA radiance every year to inter-calibrate co-located GEO sensors
- The DERM results are consistent with GEO-to-MODIS ray-matching outputs
- Improved DERM incorporates the atmospheric parameters to mitigate inter-annual reflectance variability
- Correlating the MODIS observations with atmospheric parameters showed a significant reduction (up to 50%) of trend standard error, with PW having the greatest impact
- Improved DERM shows ~30% reduction in the natural variability of the daily TOA radiances
- The DERM approach has the potential to calibrate historical, current, and future co-located GEO sensors to the same calibration reference (MODIS or VIIRS)
- GOES-12 based improved DERM will be tested with additional GOES imagers, including the next-generation ones (e.g. GOES-16 ABI)