Suomi National Polar-orbiting Partnership (S-NPP)

NASA Science Team Assessment of S-NPP VIIRS Ocean Color Products

Kevin R. Turpie,
Barney Balch, Bruce Bowler, Bryan A. Franz, Robert Frouin, Watson Gregg, Charles R. McClain, Cecile Rousseaux, David Siegel, Menghua Wang

8 May 2013
International Ocean Color Science (IOCS) Meeting
Darmstadt, Germany

QUICK BACKGROUND

TRANSLATING BETWEEN PARADIGMS: NOAA AND NASA DATA PRODUCTS

NOAA Operational Data Products	NASA Evaluation Data Products	
Raw Data Record (RDR)	Level 0	
Sensor Data Record (SDR)	Level 1b	Uncorrected Level 1b or “Pseudo” Level 1a
Environmental Data Records (EDR)	Level 2	
	Level 3	

NASA SCIENCE TEAM TASKS

Activities can be separated into three areas:

- **"New" Algorithms –** development of new products or continuity products.
- **Data Collection –** to develop/validate new products and validate EDRs.
- **Product Evaluation –** analysis to answer the following questions :

Q1: Will the Ocean Color EDR products meet NASA science objectives for data continuity with the SeaWiFS and MODIS Aqua missions?

Q2: Does the VIIRS measurements provide sufficient quality data to meet said NASA science objectives?

NASA SCIENCE TEAM OBJECTIVES

NASA ST Evaluation at GSFC involved two components :

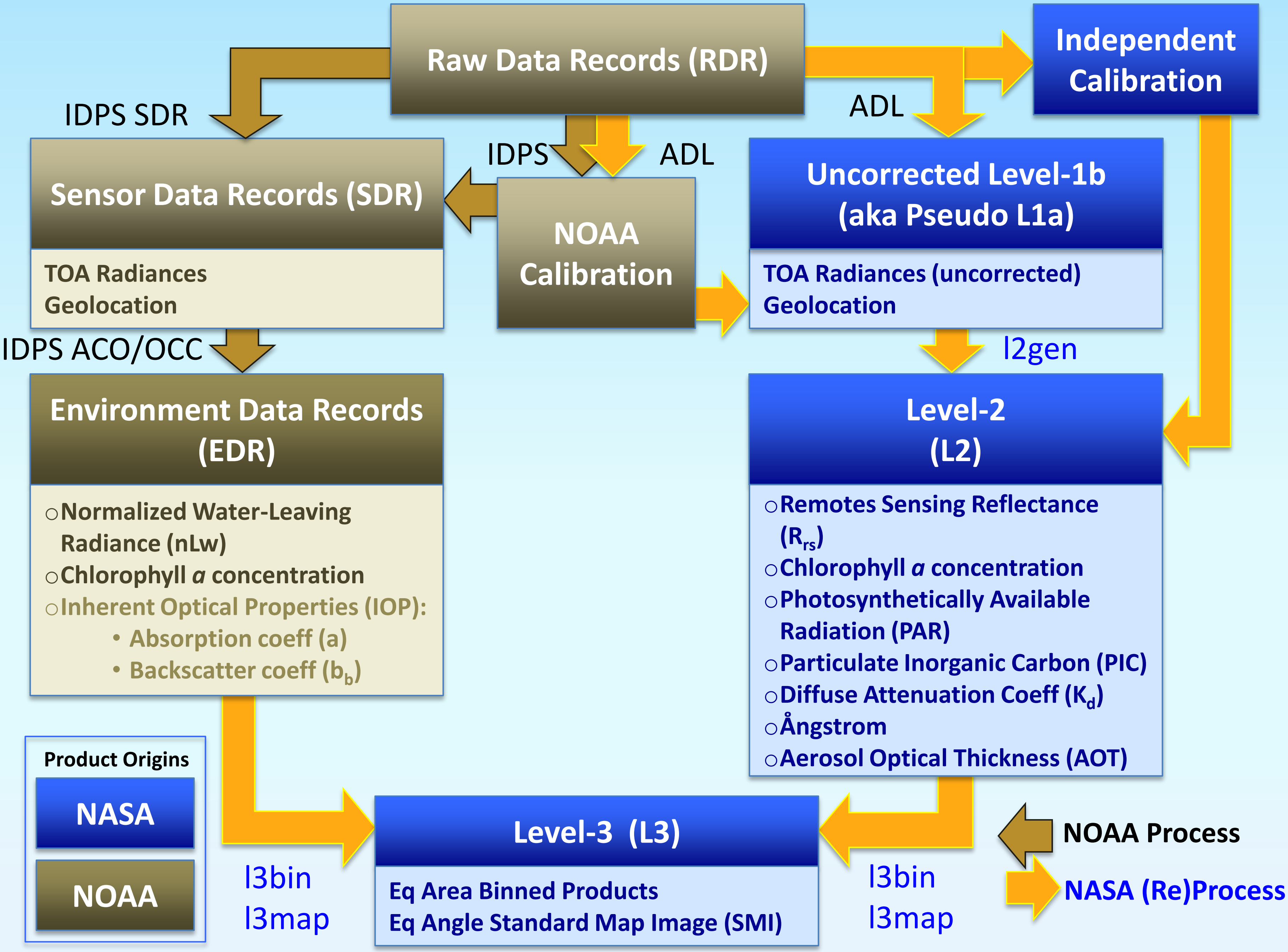
- **Evaluation (Re)Processing,** and

- **Independent Calibration.**

NASA Evaluation (Re)Processing

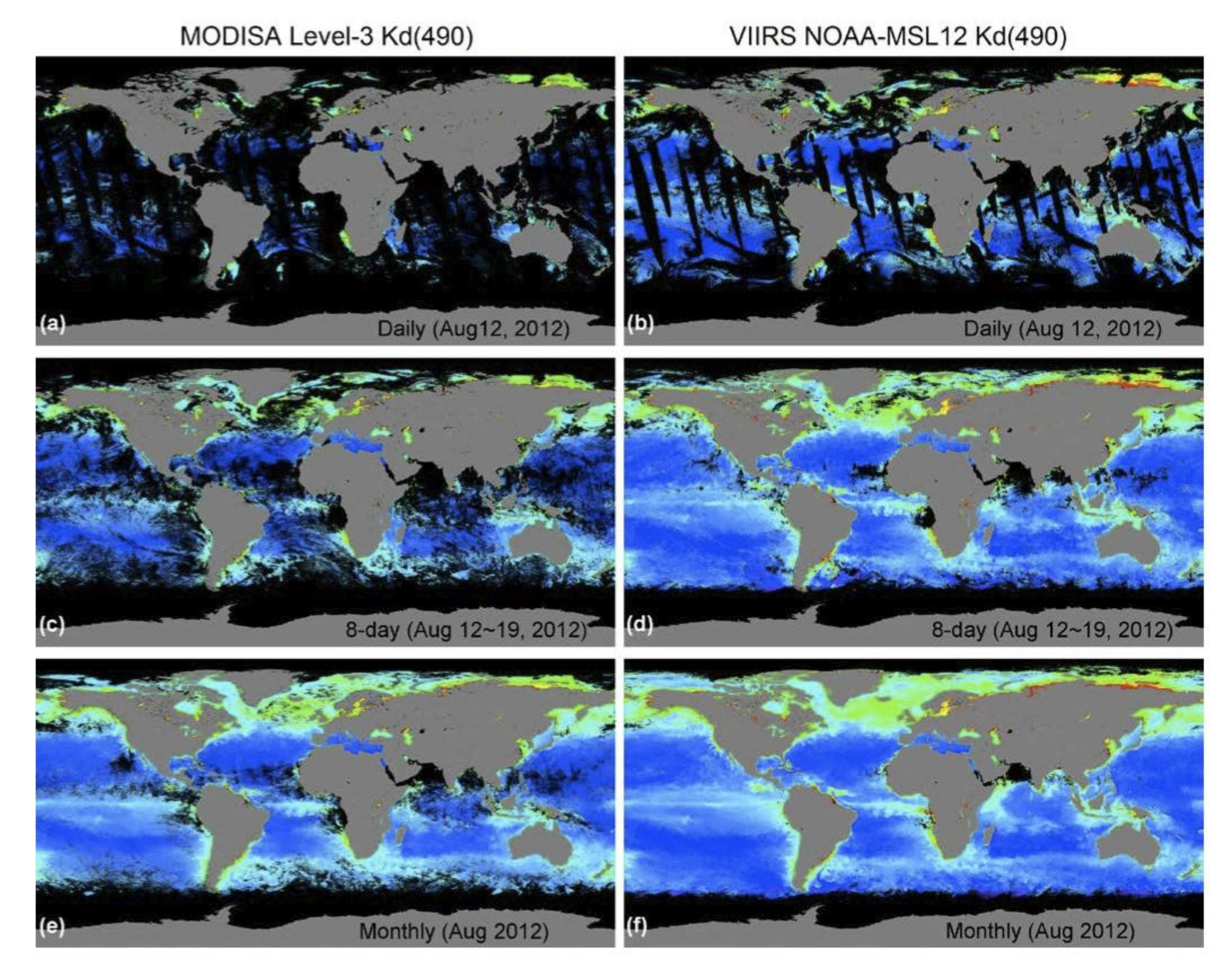
ADVANTAGES :

- Production of NASA evaluation products provides an opportunity to look at VIIRS performance using NASA algorithms common to the NASA OC CDR established with SeaWiFS and MODIS.
- The NASA approach records changes in calibration with time so that the data can be easily and consistently reprocessed.
- Evaluation processing provides a longer time series during the early mission, thus accelerating evaluation of VIIRS potential.
- Facilitates the production of new and continuity data products not supported by the operational data processing system.
- Facilitates generation of L3 data products, which is not supported by the operational processing stream.


Raw Data Records (RDR)
Independent Calibration
IDPS SDR
ADL
IDPS
ADL
Sensor Data Records (SDR)
TOA Radiances
Geolocation
NOAA Calibration
Uncorrected Level-1b (aka Pseudo L1a)
TOA Radiances (uncorrected)
Geolocation
IDPS ACO/OCC
l2gen
Environment Data Records (EDR)
○Normalized Water-Leaving Radiance (nLw)
○Chlorophyll *a* concentration
○Inherent Optical Properties (IOP):
• Absorption coeff (a)
• Backscatter coeff (b_b)
Level-2 (L2)
○Remotes Sensing Reflectance (R_{rs})
○Chlorophyll *a* concentration
○Photosynthetically Available Radiation (PAR)
○Particulate Inorganic Carbon (PIC)
○Diffuse Attenuation Coeff (K_d)
○Ångstrom
○Aerosol Optical Thickness (AOT)
Product Origins
NASA
NOAA
l3bin
l3map
Level-3 (L3)
Eq Area Binned Products
Eq Angle Standard Map Image (SMI)
l3bin
l3map
NOAA Process
NASA (Re)Process

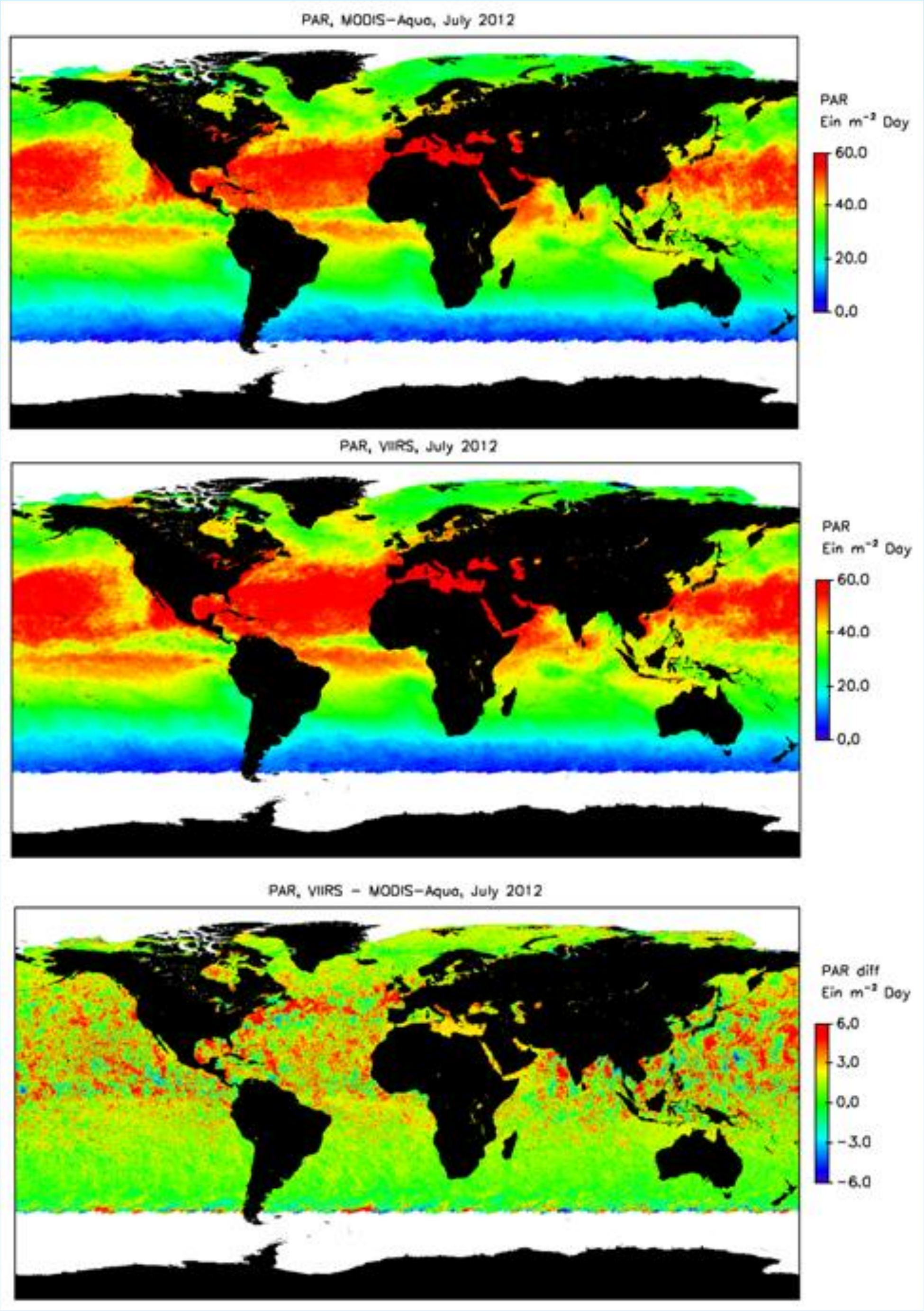
“NEW” ALGORITHMS

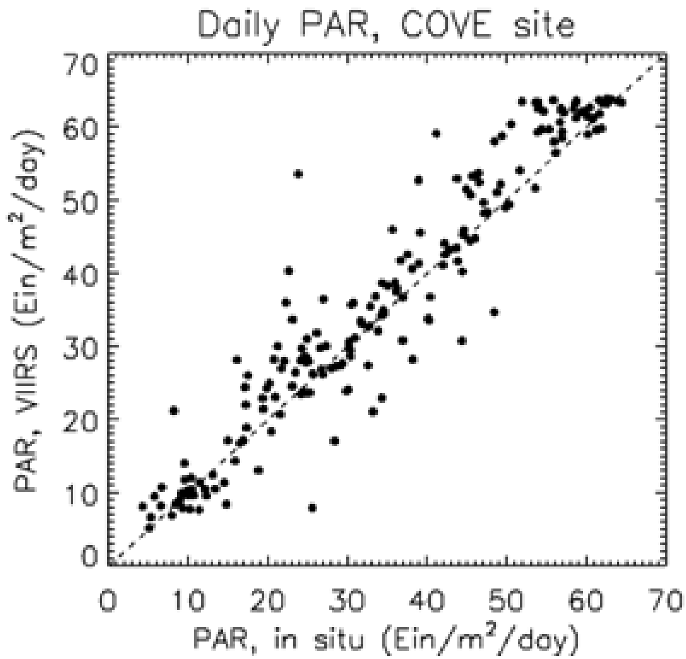
$K_d(490)$ – MODIS to VIIRS Comparison

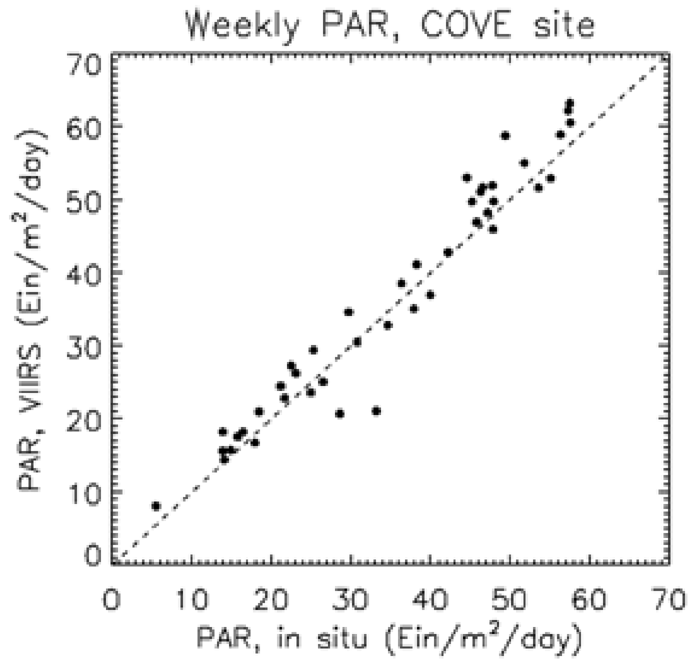


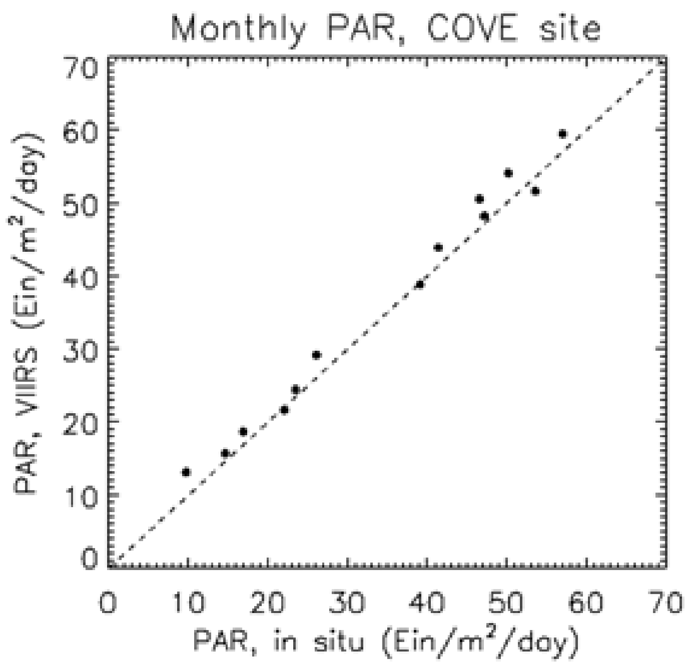
VIIRS and MODIS $K_d(490)$ compare well, but coverage is better for VIIRS.

PAR Monthly Avg Comparison Between VIIRS and MODIS





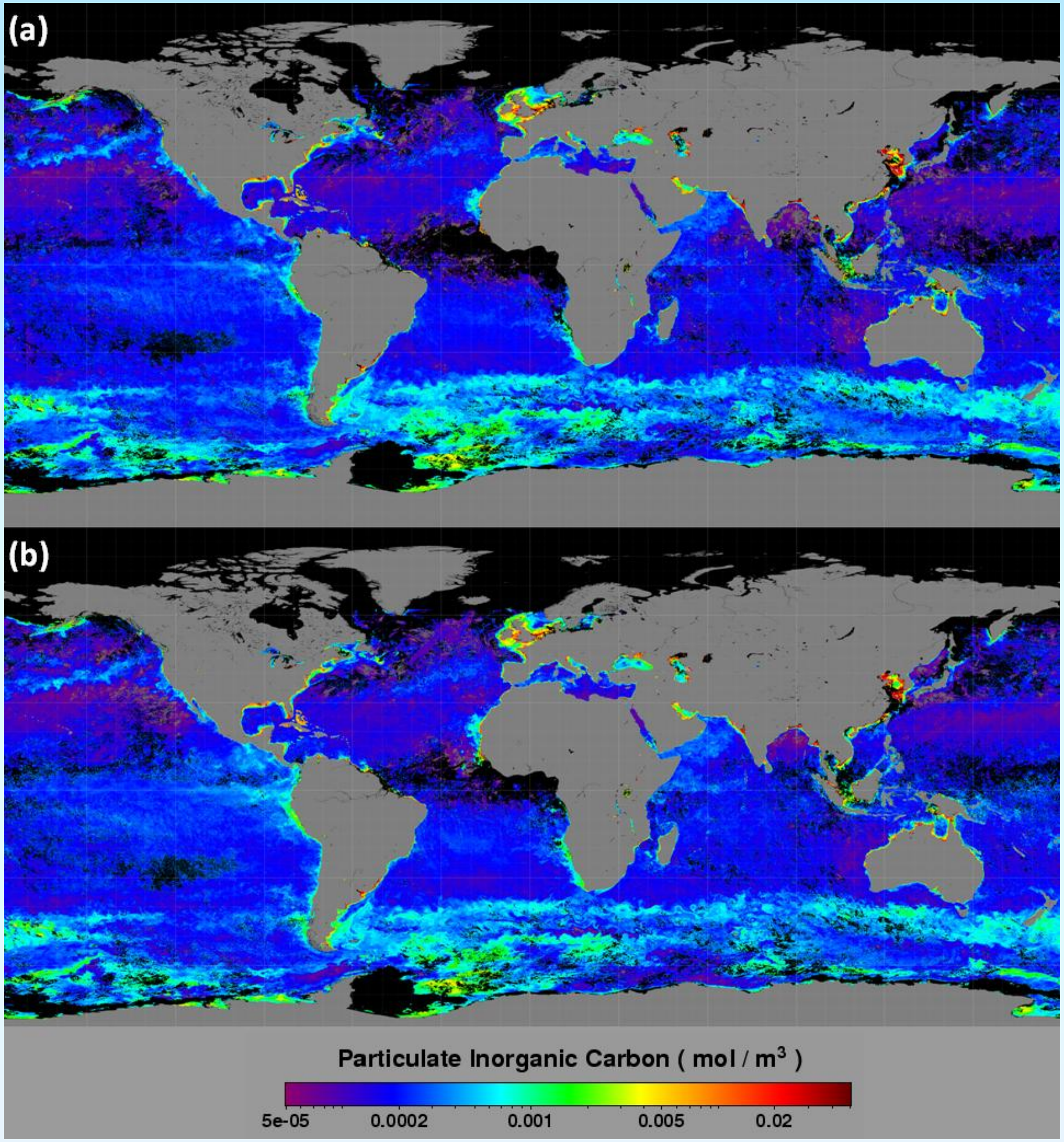




VIIRS PAR compares very well with *in situ* data.

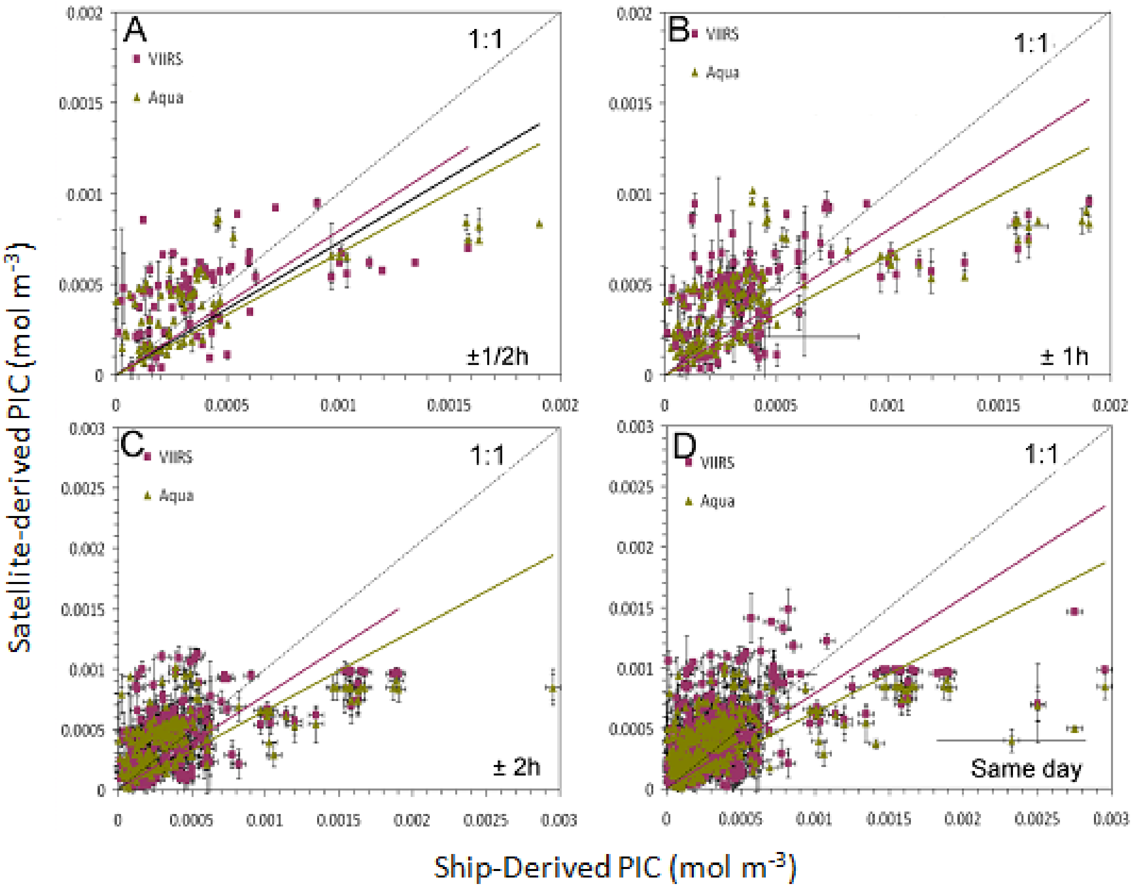
r^2	*Bias ($E/m^2/d$)*	*RMS ($E/m^2/d$)*
0.910	1.93 (5.6%)	5.81 (16.8%)
0.949	1.43 (4.2%)	4.05 (11.8%)
0.990	1.46 (4.5%)	2.32 (7.2%)

PIC – MODIS to VIIRS Comparison



VIIRS and MODIS PIC compare well.

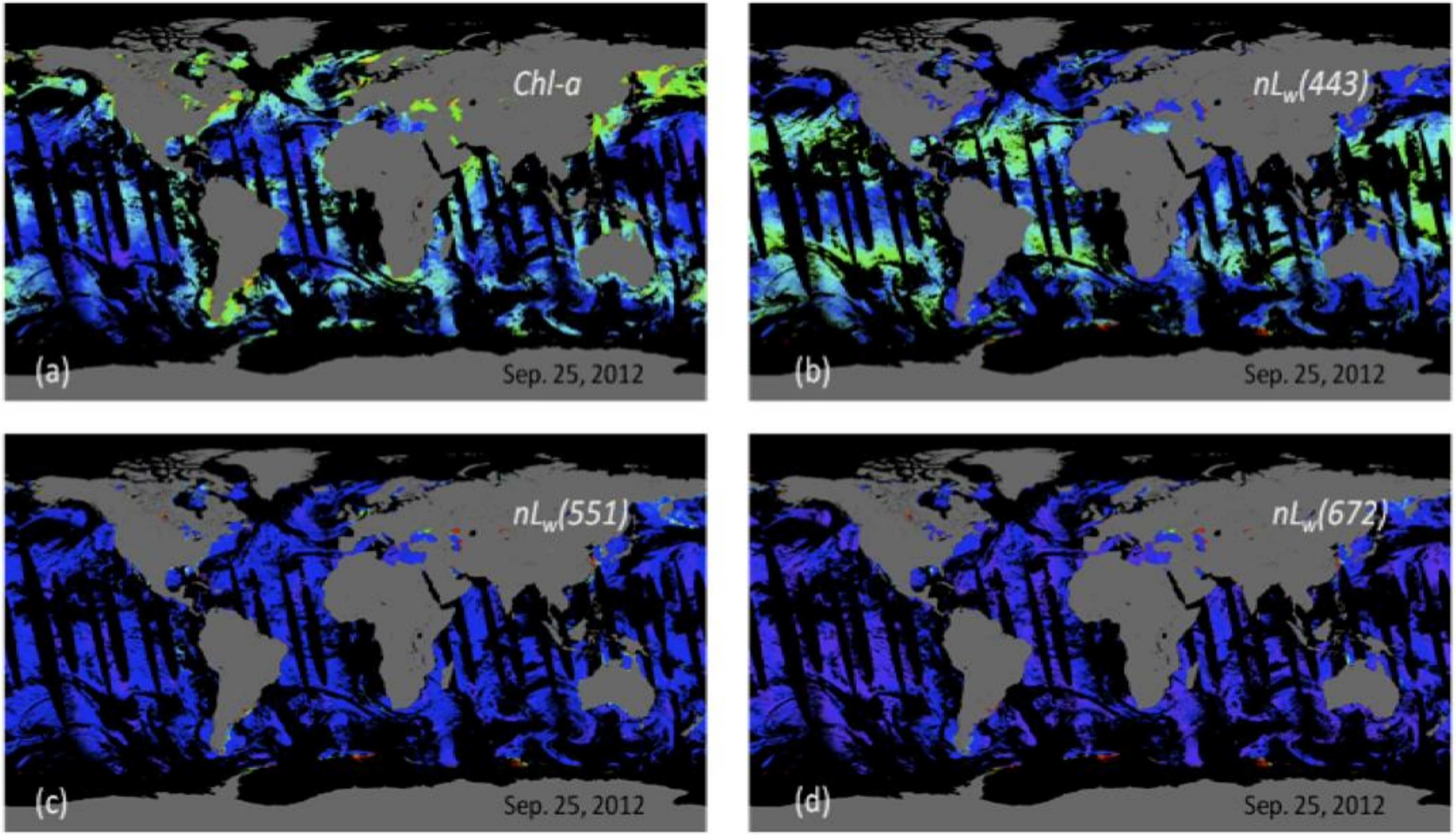
PAR Satellite to *In Situ* Comparison for VIIRS and MODIS



		Equation	R^2	*DF*	*F*
a	VIIRS	y[±2.71E-4]=0.792[±0.0614]x	0.692*	74	166.4
	Aqua	y[±2.43E-4]=0.668[±0.052]x	0.682*	66	165.1
b	VIIRS	y[±2.82E-4]=0.800[±0.045]x	0.681*	147	313
	Aqua	y[±2.57E-4]=0.658[±0.037]x	0.717*	123	311
c	VIIRS	y[±2.92E-4]=0.785[±0.033]x	0.685*	267	582
	Aqua	y[±2.82E-4]=0.658[±0.032]x	0.665*	217	430
d	VIIRS	y[±3.08E-4]=0.791[±0.026]x	0.653*	501	943
	Aqua	y[±2.82E-4]=0.634[±0.026]x	0.610*	387	604

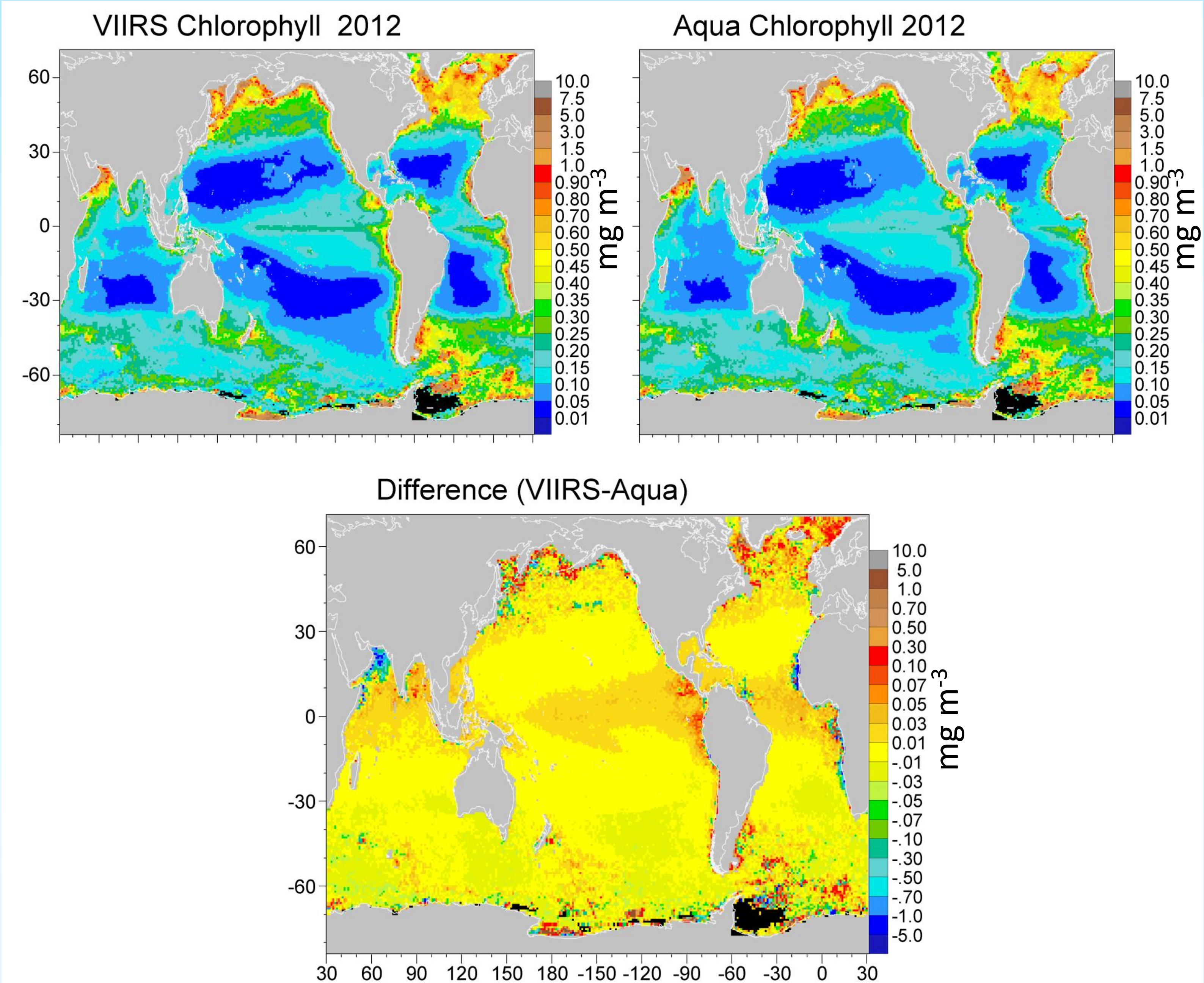
VIIRS and MODIS show comparable performance.

Application of the SWIR Band for Atmospheric Correction



- (a-d) Daily L3 VIIRS products using with SWIR band.
- This are close to MODIS values (not shown).

Assimilation Methods – Annual Median Chlorophyll and Difference.



GSFC PRODUCT EVALUATION
Calibration Assessment

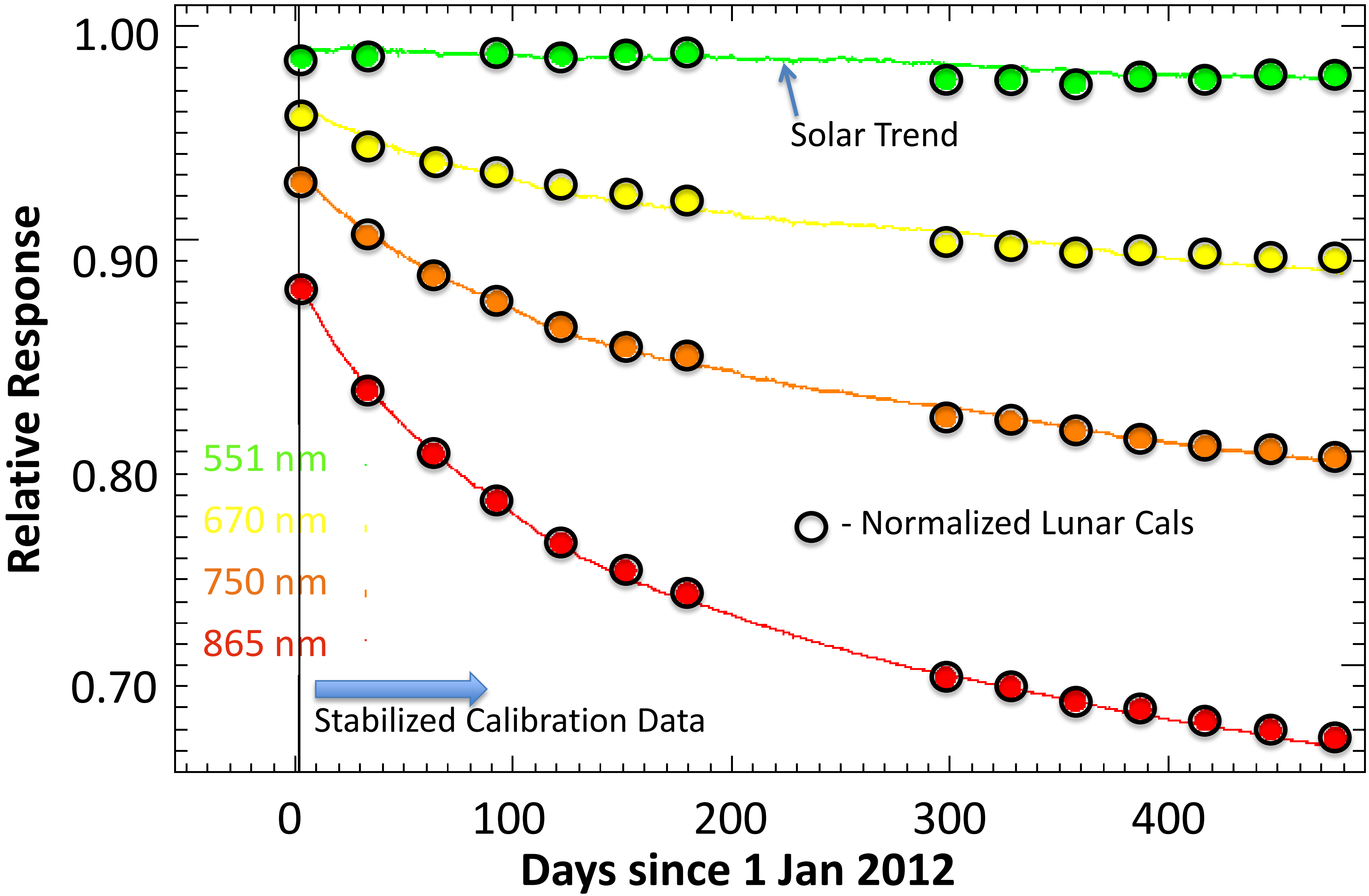
Independent Calibration

ADVANTAGES :

- Facilitates evaluation (re)processing.
- Independent verification of operational calibration.
- Can apply lessons learned from heritage instruments.
- Provided flexible and direct access to calibration data for product evaluation.

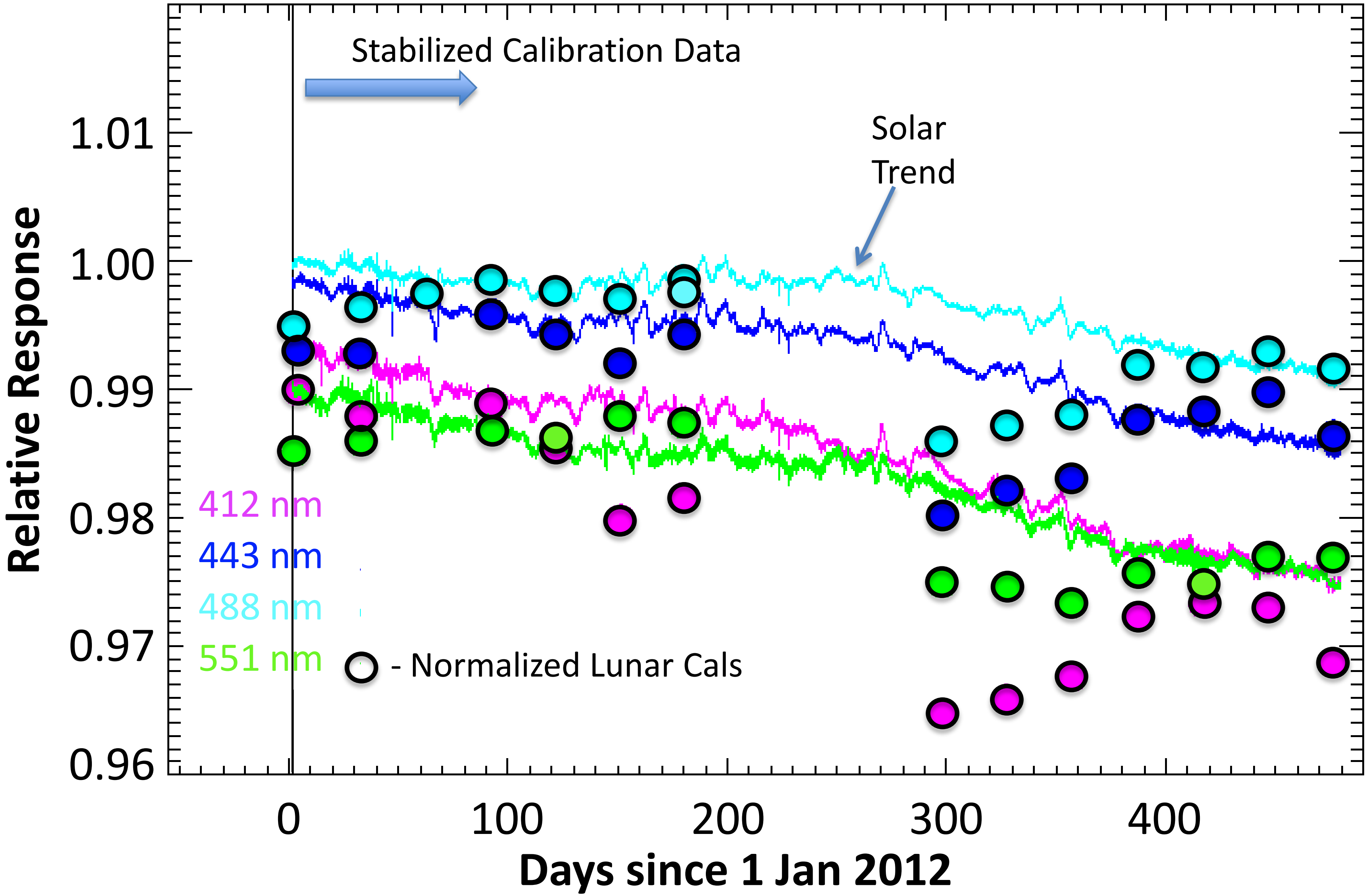
NASA VIIRS SOLAR CALIBRATION

with Verification of Lunar Measurements



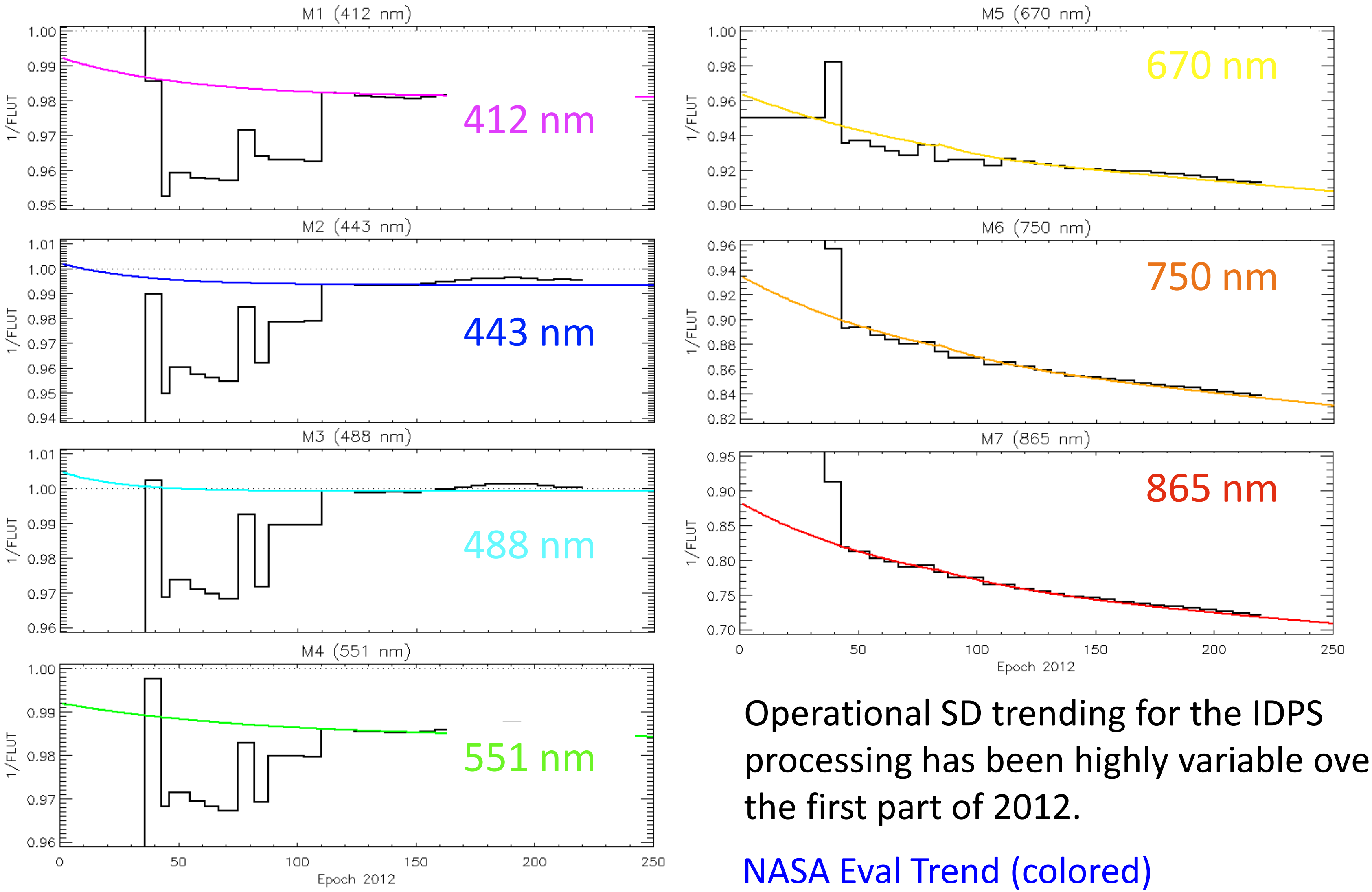
NASA VIIRS SOLAR CALIBRATION

with Verification of Lunar Measurements



EVALUATION OF OPERATIONAL CALIBRATION

COMPARISON TO OPERATIONAL SOLAR TRENDING FOR 2012

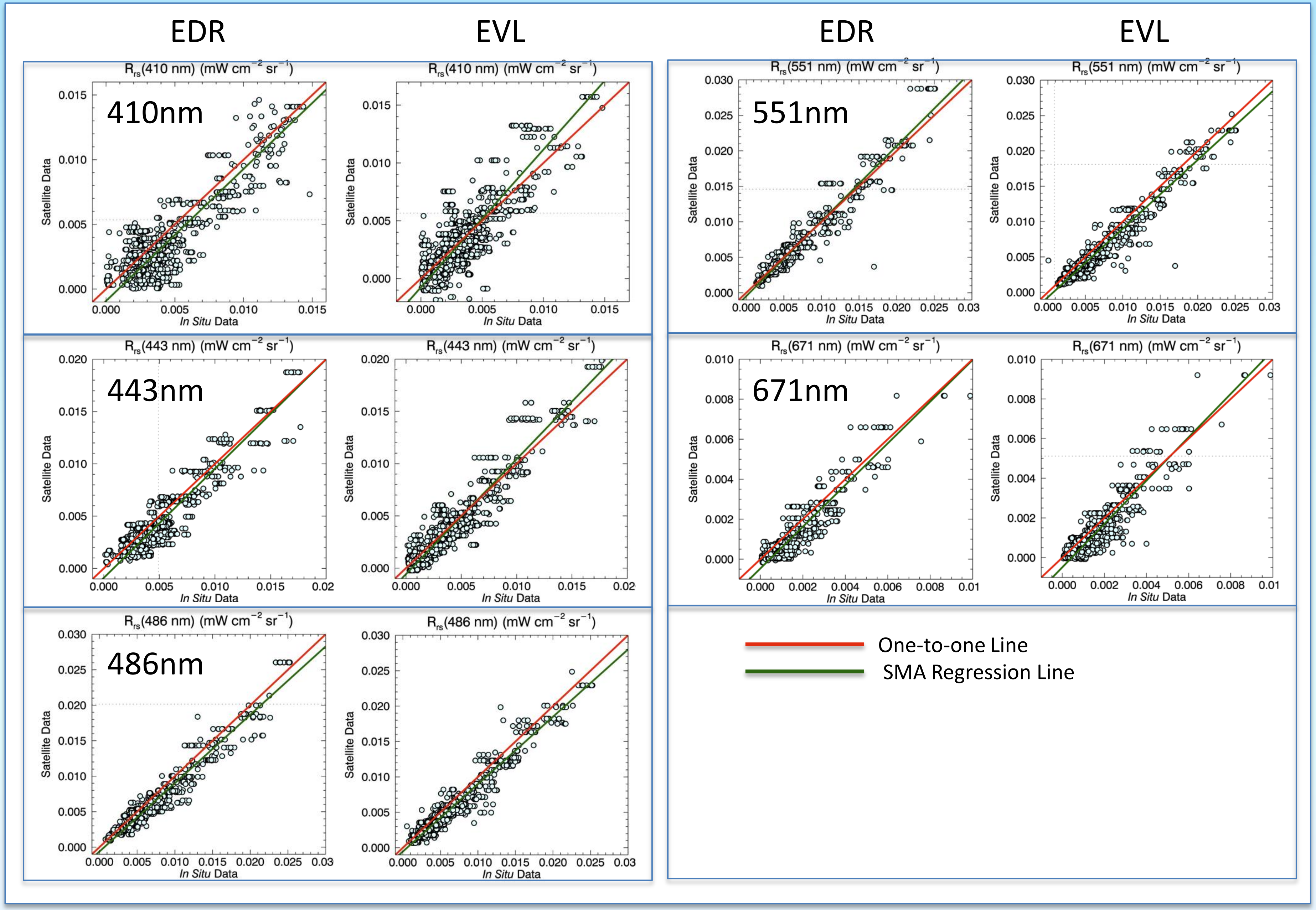


Operational SD trending for the IDPS processing has been highly variable over the first part of 2012.

NASA Eval Trend (colored)

NOAA Oper Trend (black)

GSFC PRODUCT EVALUATION
Product Assessment



EDR
EVL
EDR
EVL
410nm
443nm
486nm
551nm
671nm
Rrs(410 nm) (mW cm-2 sr-1)
Rrs(443 nm) (mW cm-2 sr-1)
Rrs(486 nm) (mW cm-2 sr-1)
Rrs(551 nm) (mW cm-2 sr-1)
Rrs(671 nm) (mW cm-2 sr-1)
Satellite Data
In Situ Data
One-to-one Line
SMA Regression Line

Eval and EDR Rrs Regression Stats

NASA Evaluation Data Products (L2) Match-Up Analysis (R2013.0)

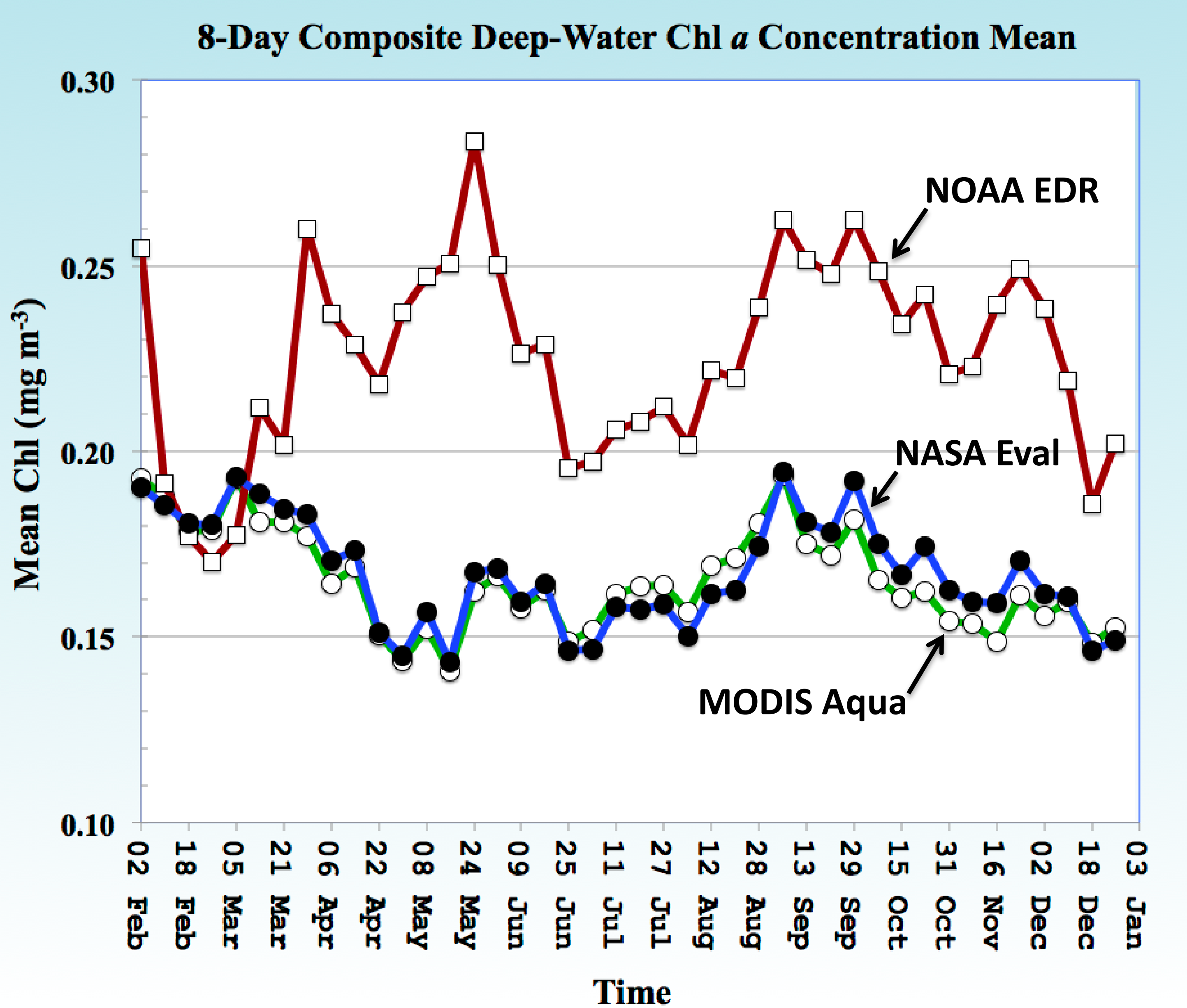
			Confidence Interval				Confidence Interval			
Rrs(l) nm	Slope	Std Err	Lower Bnd	Upper Bnd	Intercept	Std Err	Lower Bnd	Upper Bnd	No.	R^2
410	**1.19**	1.78E-02	1.16E+00	1.23E+00	-7.6E-04	8.00E-05	-9.10E-04	-6.10E-04	1399	**0.69**
443	**1.10**	1.18E-02	1.08E+00	1.12E+00	-5.7E-04	6.00E-05	-6.90E-04	-4.50E-04	1188	**0.86**
486	0.95	6.43E-03	9.39E-01	9.64E-01	-5.3E-04	5.00E-05	-6.20E-04	-4.40E-04	1399	**0.94**
551	0.97	6.60E-03	9.59E-01	9.84E-01	-7.1E-04	5.00E-05	-8.00E-04	-6.10E-04	1389	**0.94**
671	**1.09**	1.32E-02	1.07E+00	1.12E+00	-4.9E-04	2.00E-05	-5.30E-04	-4.40E-04	1249	**0.82**

NOAA Environmental Data Records (EDR) Match-Up Analysis

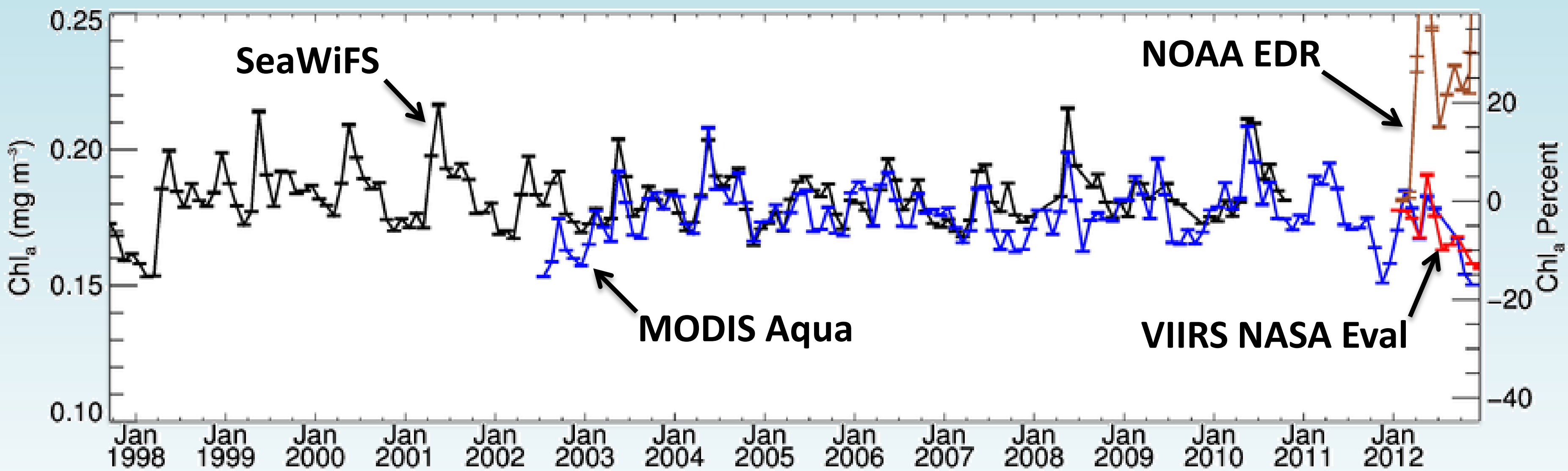
			Confidence Interval				Confidence Interval			
Rrs(l) nm	Slope	Std Err	Lower Bnd	Upper Bnd	Intercept	Std Err	Lower Bnd	Upper Bnd	No.	R^2
410	1.02	1.65E-02	9.88E-01	1.05E+00	-9.2E-04	9.00E-05	-1.09E-03	-7.50E-04	1006	0.74
443	1.04	1.42E-02	1.02E+00	1.07E+00	-9.0E-04	8.00E-05	-1.07E-03	-7.40E-04	**840**	**0.85**
486	0.96	8.20E-03	9.47E-01	9.80E-01	-6.2E-04	7.00E-05	-7.50E-04	-4.90E-04	**963**	**0.93**
551	1.06	8.86E-03	1.04E+00	1.08E+00	-4.8E-04	7.00E-05	-6.20E-04	-3.50E-04	**957**	**0.93**
671	1.04	1.44E-02	1.01E+00	1.07E+00	-4.6E-04	3.00E-05	-5.20E-04	-4.10E-04	**881**	**0.83**

The R2013.0 Evaluation Products appear to perform a little worse than the EDR in the blue and red bands.

Common Bin Comparison for 2012



Comparison of the EDR and NASA Evaluation Product Against the Long-Term Record



B. Franz 2013

Deep Water Monthly Composite Average for Chlorophyll *a* Concentration

VIIRS Product Evaluation

CONCLUSIONS

- VIIRS evaluation production supports the development of new or continuity algorithms.
- Analysis showed that the EDR product flags and masks reduced data coverage, undermining the product's usefulness, but are being improved.
- *In situ* match-ups show that both operational and evaluation radiometric products are in general agreement with the AERONET-OC data.
- Up to present, NOAA EDR chlorophyll *a* concentration deep water average time series runs much higher than the long-term NASA record and NASA evaluation product.
- Currently, EDR chlorophyll *a* concentration will likely be improved with the application of vicarious calibration, but the previous record will remain reprocessed.

VIIRS Product Evaluation

CONCLUSIONS

- A significant portion of the NOAA ocean color record remains insufficient to meet NASA's research objectives. **(Q1)**
- Conversely, NASA record agrees with MODIS Aqua remarkably well, thus VIIRS has potential for NASA data continuity. **(Q2)**

Danke Schön

BACKUP SLIDES

Ocean Color Team Members

David Siegel

Data Collection – Plumes & Blooms

(New Algorithm – GSM)

Robert Frouin

Data Collection – SIMBADA

New Algorithm – Photosynthetically Available Radiation (PAR)

Barney Balch

Data Collection – AMT, GBII, Gulf or Maine

New Algorithm – Particulate Inorganic Carbon (PIC)

Watson Gregg

New Algorithm – Consistent Global Maps of Chlorophyll using Data Assimilation

Menghua Wang

Evaluation of VIIRS Ocean Data – NOAA Operational EDR

Kevin Turpie

Evaluation of VIIRS Ocean Data – NASA Continuity Algorithms and Recommendations.

Peter Minnett

Evaluation of VIIRS SST Data

“New” Algorithms

Balch – Development of the Particulate Inorganic Carbon (**PIC**) algorithm* for VIIRS.

Frouin – Development of the Photosynthetically Available Radiation (**PAR**) algorithm* for VIIRS.

Gregg – Development of techniques using oceanic modeling and data assimilation to improve the mapped record of chlorophyll *a* concentration.

Siegel – Development and evaluation of the **GSM** analytic model for in-water optical constituents. This is an experimental SeaWiFS and MODIS product.

* - Standard products with SeaWiFS and MODIS.

Data Collection

Balch – Collected data from the Atlantic and southern oceans for evaluation of VIIRS data products and to support development of the PIC algorithm.

Frouin – Collected radiometric data with his SIMBADA instrument for evaluation of VIIRS and to support development of this PAR algorithm.

Siegel – Collected data from coastal waters for evaluation of VIIRS in coastal and to support analysis with the GSM model.

All data are being archived in the SeaWiFS Bio-optical Archive and Storage System (SeaBASS).

Validation is also using several hundred radiometric data points from the AErosol RObotic NETwork - Ocean Color (AERONET)

Product Evaluation

TWO PRONGED APPROACH :

NASA - To determine whether NOAA EDR = NASA CDR, and evaluate VIIRS potential to met NASA science requirements, the **GSFC team** created NASA evaluation products using :

- **Evaluation (Re)Processing** – the NASA-selected algorithms used in generating current NASA CDR with full reprocessing capability.
- **Independent Calibration** – based on NASA-developed techniques combining lunar and solar trending.

NOAA – To generally evaluate operational NOAA EDR quality, **Menghua Wang** performed independent processing using his software (NOAA-msl12) and collaborated with the Navy Research Laboratory, who produced products with their software (NRL-APS, which based on NASA software).

In both cases, VIIRS results were compared to *in situ* data and other spaceborne sensors.

Background

DEFINITIONS AND TEAM OBJECTIVE

Climate Data Record (CDR) – "a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.[1]"

Earth System Data Record (ESDR) – "a unified and coherent set of observations of a given parameter of the Earth system, which is optimized to meet specific requirements in addressing science questions....[2]"

ESDR and CDR – "Long-term, high-accuracy, stable, environmental observations…[3]"

- **Decadal Span**
- **High Accuracy**
- **Stability**
- **Consistency**
- **Continuity**

Objective – Evaluate operational NOAA Environmental Data Products (EDR) "to demonstrate the suitability of these data sets for use as ESDRs and CDRs[3]" and "…evaluate the accuracy with which the operational algorithms … can extend the time series of science-quality data records begun with NASA's EOS and earlier satellite systems.[3]"

1-National Research Council (2004). Climate Data Records from Environmental Satellites, National Academies Press, Washington, D.C.
2-Maiden and Ramapriyan (2009). NASA's MEaSUREs Program: Making Earth System Data Records for Use in Research Environments. Presentation.
3-ROSES10 Announcement, Appendix A.22, Section 1.1.

Background

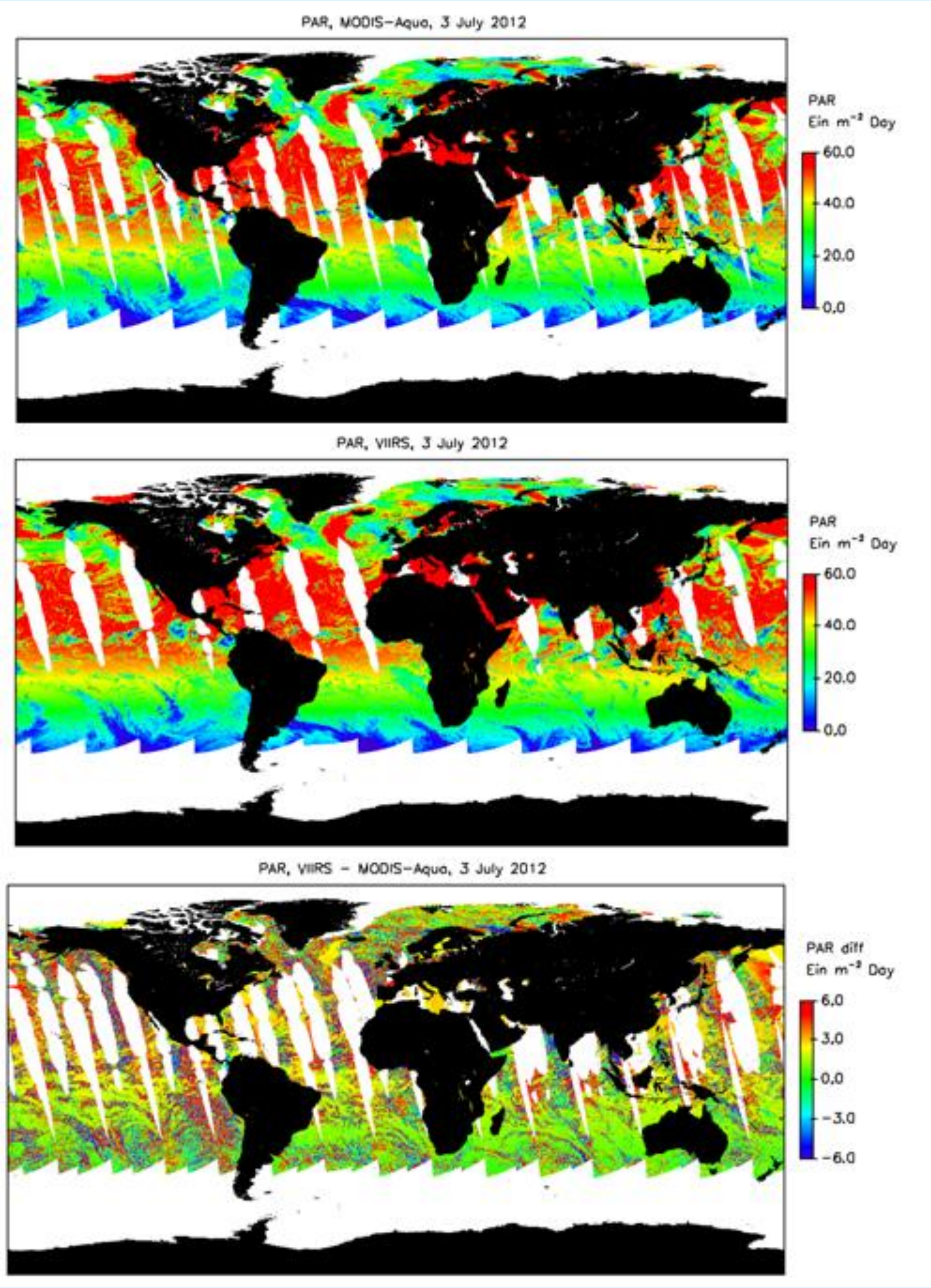
NINE KEY OCEAN COLOR CDR MISSION COMPONENTS

1. High-Performance Sensor	Prelaunch calibration, characterization, and performance assessment.
2. Computational and Data Infrastructure	• (Re)Processing, • Storage, and • Distribution
3. Algorithms	Accurate, community-accepted calculations for atmospheric correction, derived products, and mapping (e.g., Level-3 products).
4. Calibration	Postlaunch instrument recalibration for changes and on-orbit artifacts.
5. Maneuvers	Roll (lunar cal); Yaw maneuver (solar calibrator); Pitch (thermal RVS)
6. Reprocessing	Apply algorithms and calibration consistently over multiple missions.
7. Validation	Assess product quality based on *in situ* data, comparisons to existing space or airborne assets, and artifact monitoring.
8. *In situ* Data Collection	To support data product quality assessment and develop remote sensing models.
9. User Tools and Input	Important to supply the community with common tools to apply the data; vital to facilitate and respond to input from the community regarding data quality.

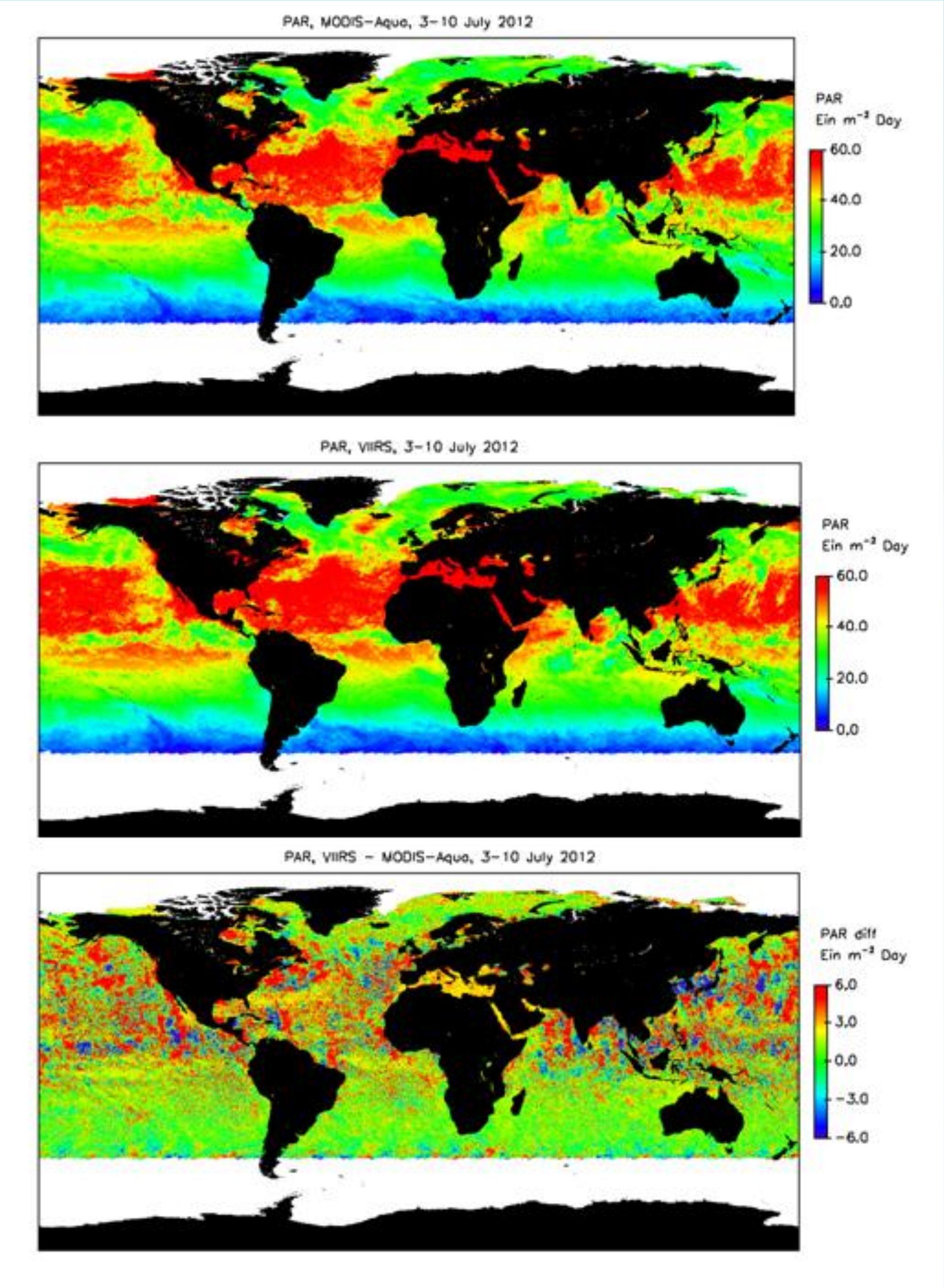
OCEAN PEATE SCIENCE TEAM SUPPORT

TEAM	INVESTIGATION	OCEAN PEATE PRODUCTS	OPERATIONAL SUPPORT
Balch (PI) Bowler	**New Algorithm** **Data Collection**	L2 Evaluation R_{rs}(l) (algorithm input)	**Algorithm Implementation:** Particulate Inorganic C (PIC) Particulate Organic C (POC) **New Product Generation:** L2 & L3 Evaluation PIC & POC **Available Services:** SeaBASS Archival Support
Frouin (PI) Deschamps	**New Algorithm** **Data Collection**	L2 Evaluation R_{rs}(l) (algorithm input)	**Algorithm Implemention:** Photosynthetically Available Radiation (PAR) **New Product Generation:** L2 Evaluation PAR **Available Services:** SeaBASS Archival Support
Gregg (PI) Casey Rousseaux	**New Algorithm**	L3 Evaluation Chl *a* L3 Operational Chl *a*	**Available Services:** SeaBASS Archive Retrievals and Match-up
Minnett (PI) Evans Turpie	**SST Evaluation**	L1 Evaluation (Thermal Bands)	**Available Services:** Match-up Support
Siegel (PI) Nelson	**New Algorithm** **Data Collection**	L2 Evaluation R_{rs}(l)	**Available Services:** SeaBASS Archival Support
Turpie (Sci PI) McClain (PI) Franz	**OC Evaluation**	L2 & L3 Evaluation R_{rs}(l), Chl *a,* Angstrom, AOT L2 & L3 Operational nLw(l), Chl *a*	**Available Services:** Independent Solar and Lunar Calibration Support Regional Time Series Tool Scan Angle Artifact Detection Tool SeaBASS Match-up Tool
Wang	**OC Evaluation**	L3 MODIS Products	none

PAR Daily Comparison Between VIIRS and MODIS



PAR 8-Day Avg Comparison



Independent Calibration

COLLABORATIVE EFFORT :

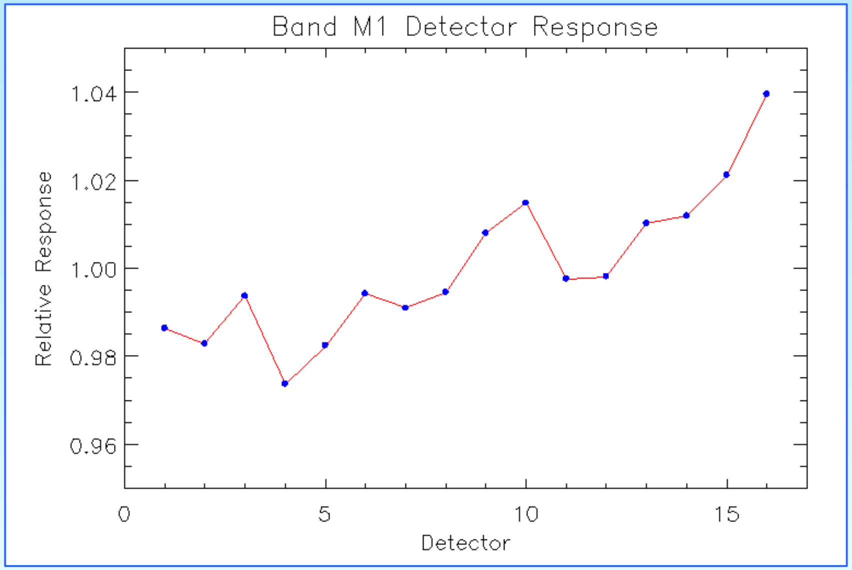
- The off-line calibration processing and analysis was developed by Gene Eplee of the OBPG.
- Additional system development and analysis provided by Wayne Robinson and Gwyn Fireman (OBPG).
- Shared and discussed findings with the NASA VIIRS Calibration Support Team's (VCST).
- Collaborated with NASA Science Team member, Tom Stone (USGS), for application of the ROLO model for lunar trending.
- Bob Barnes and Fred Patt (OBPG) worked with VCST and Mission Ops to plan calibration roll maneuver.
- Applied NASA VCST's transmission and BRDF tables based on yaw maneuvers.
- Shared results at scientific conferences and technical papers.

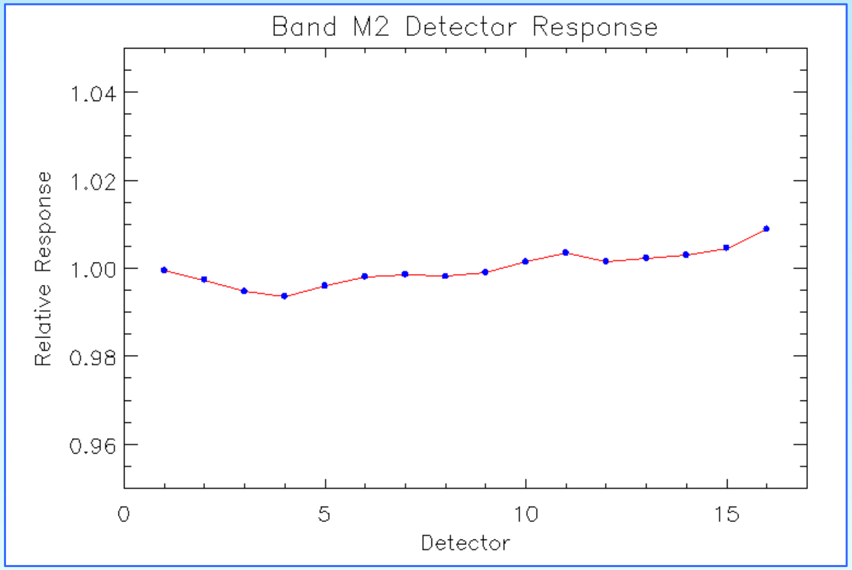
Independent Calibration

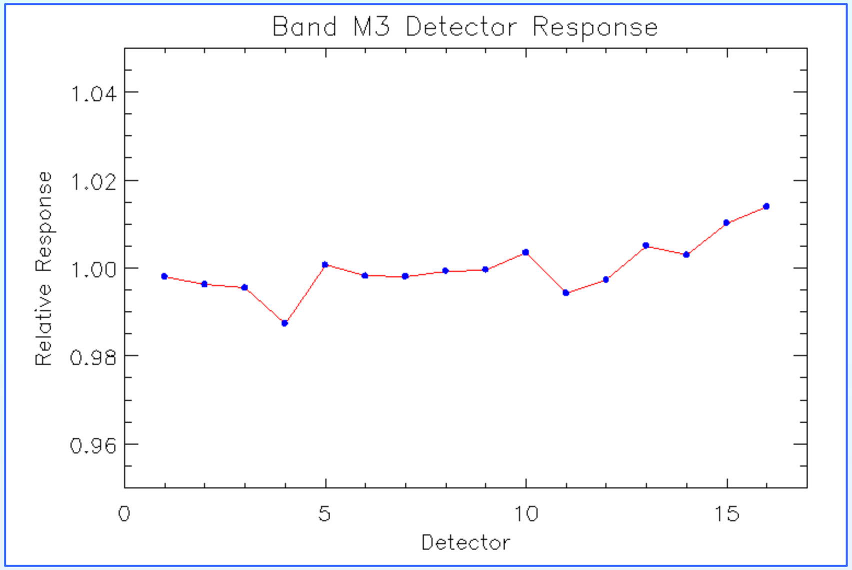
APPROACH :

- Linearize prelaunch counts-to-radiance conversion.
- Track and trend instrument relative response change with respect to VIIRS measurements of
    - the on-board solar diffuser (SD) and
    - the moon (facilitated by roll maneuvers and ROLO model).
- Track and correct for changes in SD by trending measurements by the SD Stability Monitor (SDSM).
- SD trending addresses relative changes in instrument response. Vicarious calibration is used to remove static calibration biases.
- Use lunar trends to identify and possibly correct artifacts in the solar trends.
- Use on-board solar diffuser (SD) to determine and remove gross detector-to-detector and mirror-side differences.

DETECTOR-TO-DETECTOR RESPONSE VARIATION







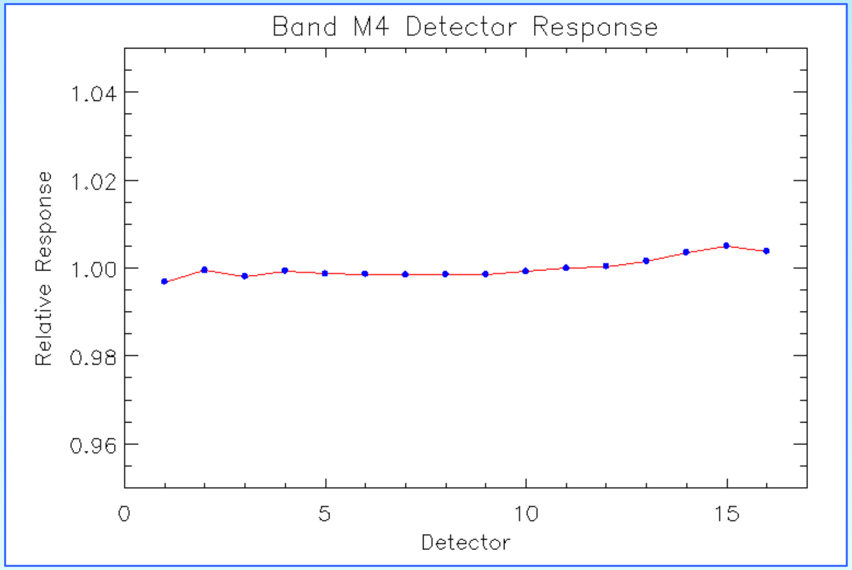
SD STRIPING CORRECTION

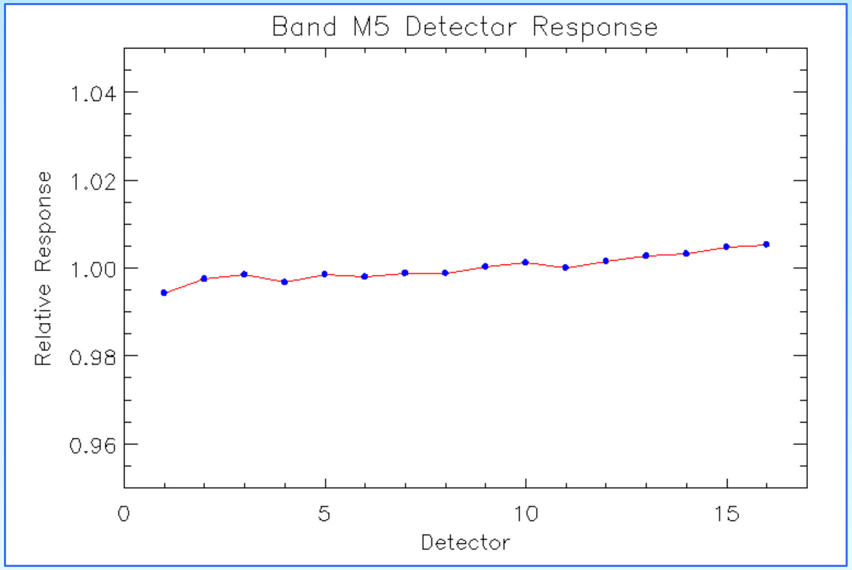
Using the SD over the mission, we identify and remove 1st order striping effects.

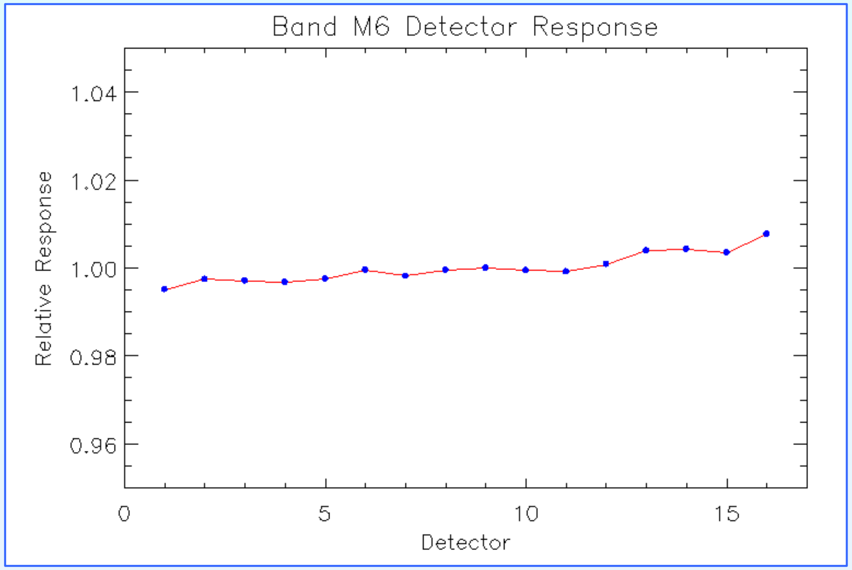
These effects are likely embedded in the prelaunch characterization of the counts-to-radiance conversion.

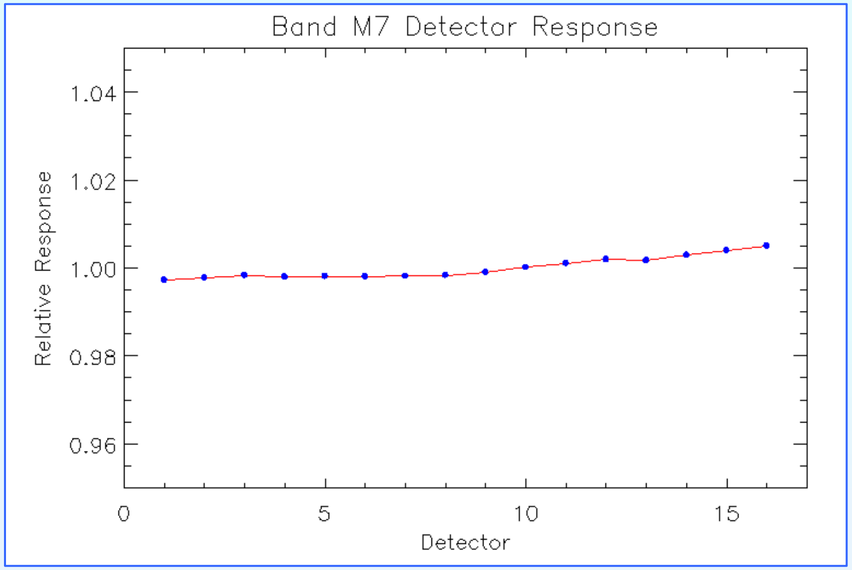
They appear to be stable over the year.

DETECTOR-TO-DETECTOR RESPONSE VARIATION

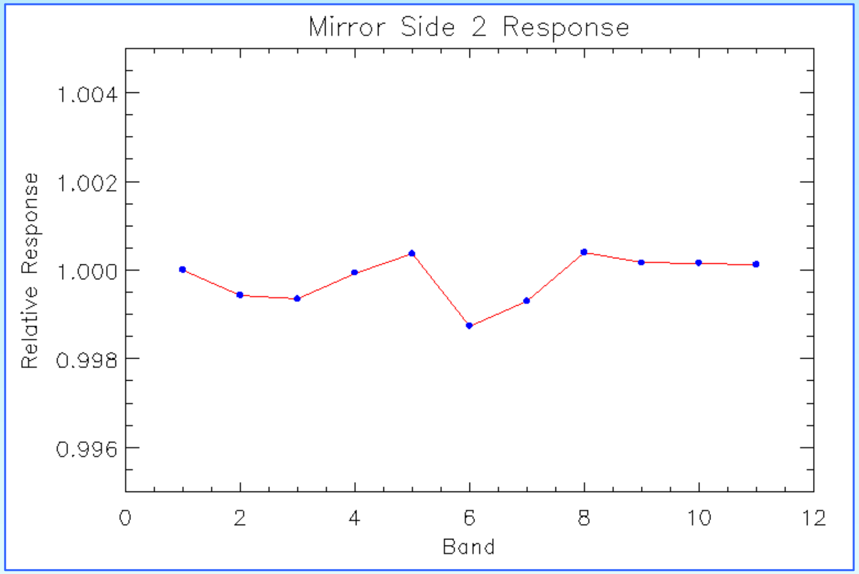


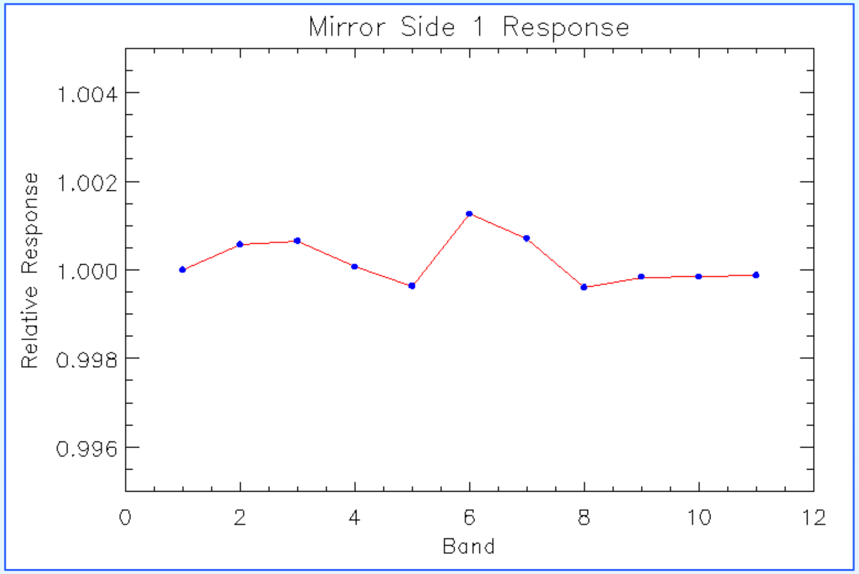






MIRROR-SIDE RESPONSE DIFFERENCES



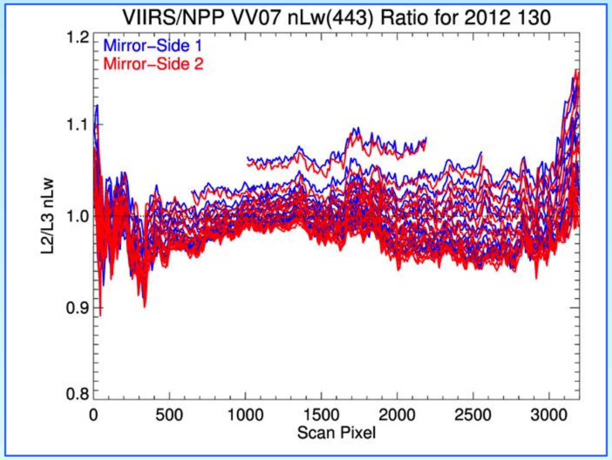


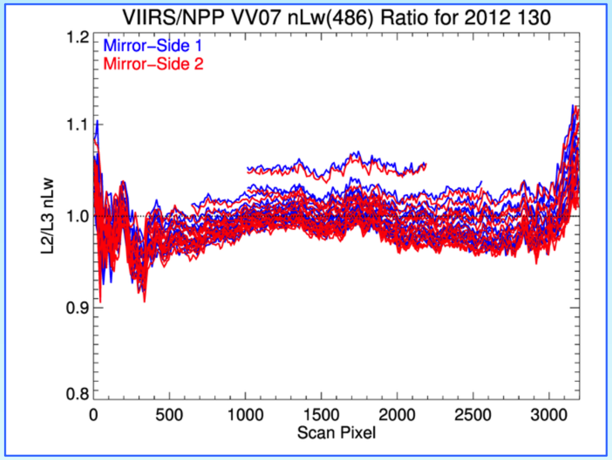
<u>SD MIRROR-SIDE CORRECTION</u>
Using the SD over the mission, mirror-side effects are identified and removed.

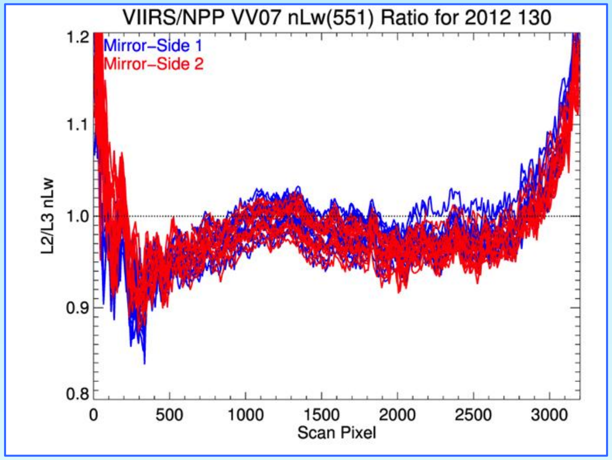
These effects are also likely embedded in the prelaunch characterization of the counts-to-radiance conversion and also appear to be stable over the year.

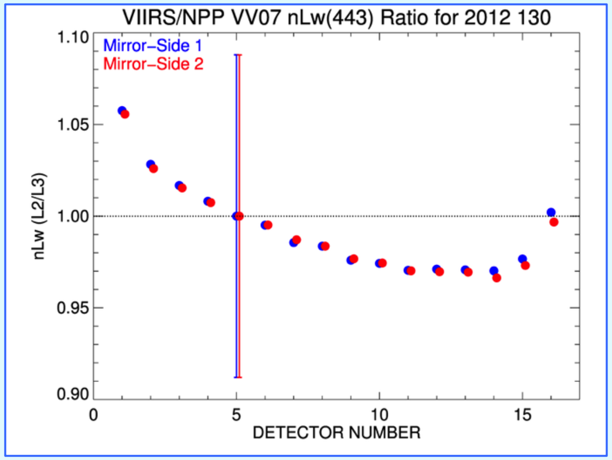
Response behavior across bands between mirror sides is complementary.

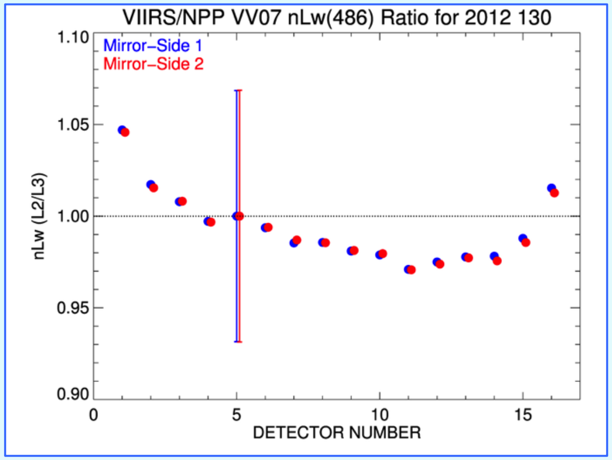
VARIATION IN nLw ALONG SCAN AND TRACK

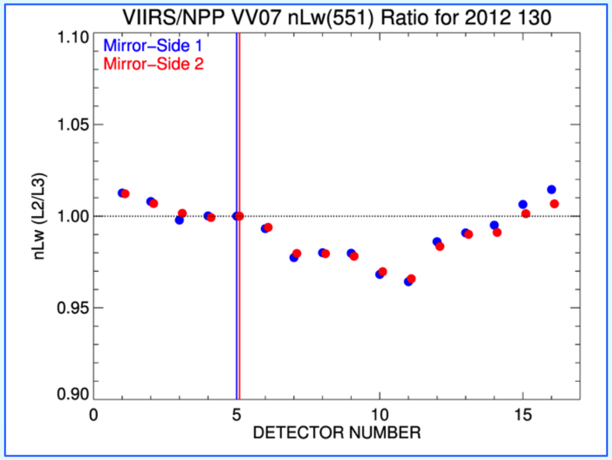






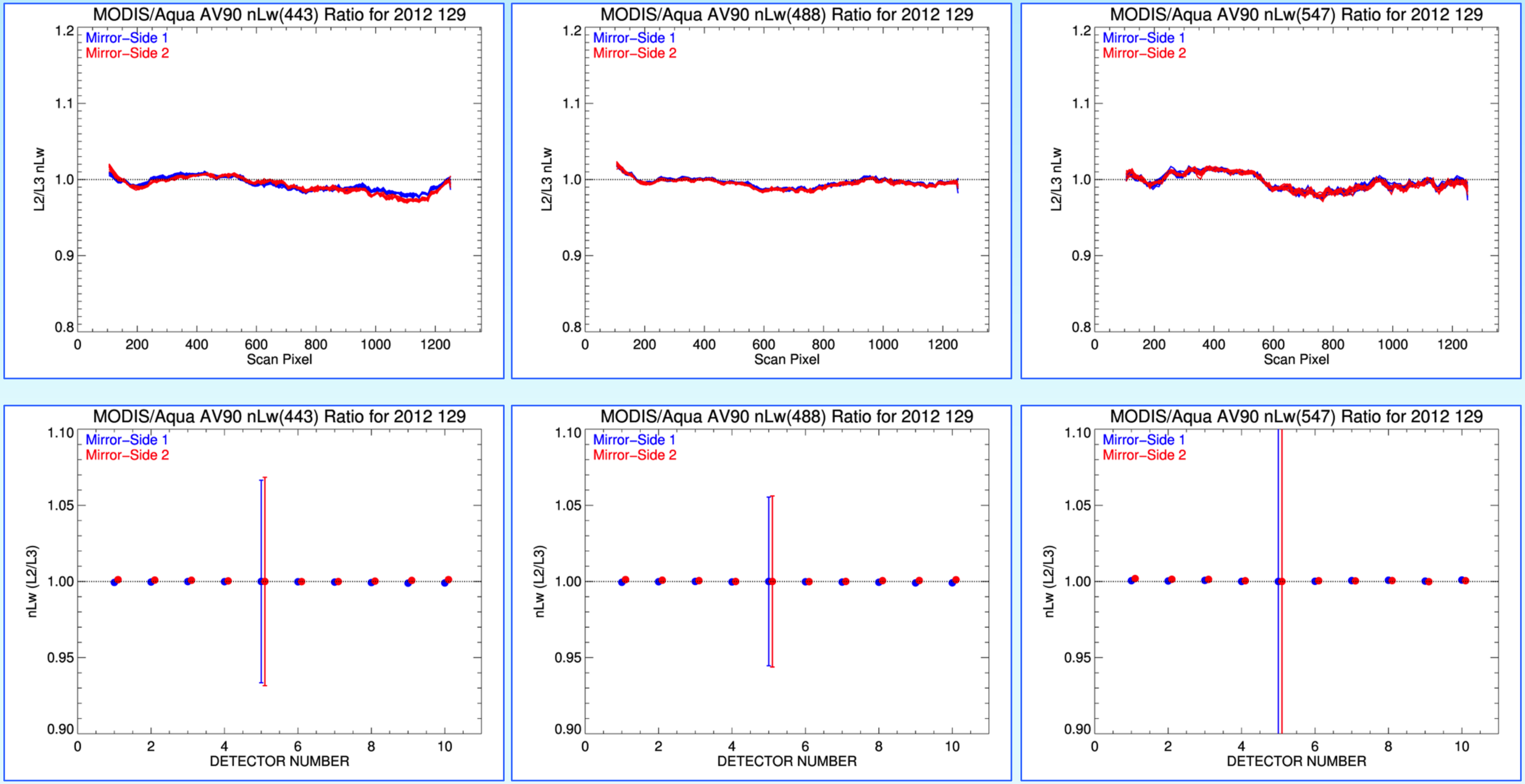






- In L2 to L3 comparison, less than 10% variation in the evaluation normalized water-leaving radiance (nLw) can be seen along scan, the 551nm band being most notable.
- Along track, significant residual striping can still be seen in nLw, esp. edge dets.
- **Comparable nLw striping has been observed in the EDR.**

VARIATION IN nLw ALONG SCAN AND TRACK



- Similar analysis for MODIS show much smaller effects, esp for striping.

Calibration Assessment

CONCLUSIONS :

- Comparisons between the operational IDPS calibration and the independent calibration show the former was not stable this year.
- However, a consistent calibration can be achieved with VIIRS, but it may take years to reach heritage quality.
- Corrections for residual striping and scan effects should be applied.
- Improvements in the operational calibration stability are expected.
- However, the operational algorithm change process is necessarily dilatory.
- Therefore, given the lack of a reprocessing capability, delays can cause lengthy, permanent epochs in the data record.

VIIRS Product Evaluation

COMPARISON TO *IN SITU* DATA

- Several hundred match-ups were found between VIIRS satellite data and AERONET-OC data with a 3-hr window. No other *in situ* sources were found.
- AERONET-OC sites are mostly northern hemisphere coastal.
- Data includes only remote sensing reflectance (R_{rs}). No chlorophyll *a* concentration match-ups were found.
- Match ups with MOBY were excluded because that source was used in the vicarious calibration.
- SeaBASS currently can match up the VIIRS Evaluation Products only. Match ups with EDR data must be done by hand.

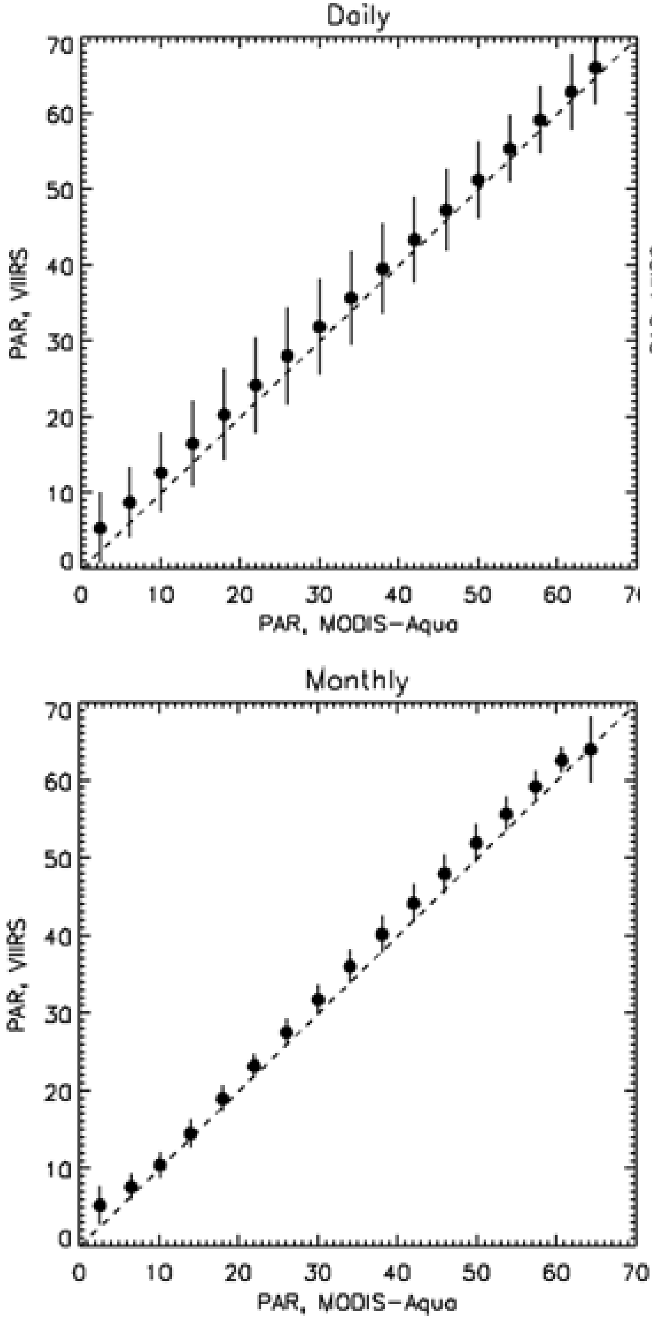
VIIRS Product Evaluation

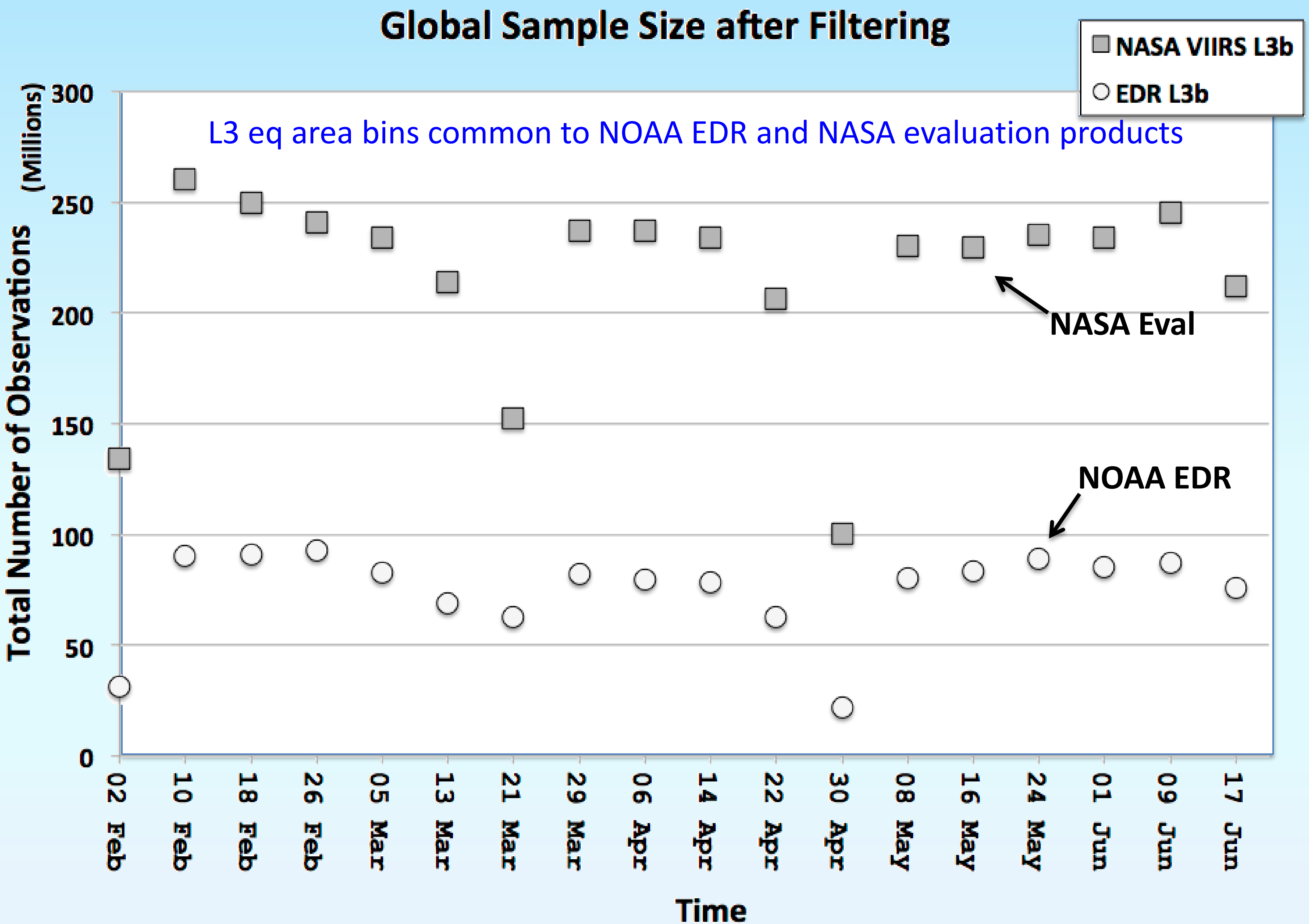
Locations of AERONET-OC site used in match-up analysis.

VIIRS Product Evaluation

FLAG AND MASK EVALUATION :

- Bad flagging undermines filtering data for analysis or validation.
- Bad masking removes data and they cannot be recovered.
- Masking issues :
  - All inland waters are masked (e.g., Great Lakes),
  - Pixels are masked whenever any single band has negative normalize water-leaving radiance, losing gyre data, and
  - EDR pixels within 650 km of scan end.
- Masks and flags significantly and systematically reduce spatial coverage and the number of observations within each L3 bin.
- Reduction in spatial sampling can introduce significant noise into the EDR L3 statistics.
- Generally, EDR flags and masks showed poor performance, but improvements later in the year have been observed.


Daily
PAR, VIIRS
PAR, MODIS-Aqua
Weekly
PAR, VIIRS
PAR, MODIS-Aqua
Monthly
PAR, VIIRS
PAR, MODIS-Aqua



Global Sample Size after Filtering
NASA VIIRS L3b
EDR L3b
L3 eq area bins common to NOAA EDR and NASA evaluation products
Total Number of Observations (Millions)
300
250
200
150
100
50
0
NASA Eval
NOAA EDR
02 Feb
10 Feb
18 Feb
26 Feb
05 Mar
13 Mar
21 Mar
29 Mar
06 Apr
14 Apr
22 Apr
30 Apr
08 May
16 May
24 May
01 Jun
09 Jun
17 Jun
Time

VIIRS Product Evaluation

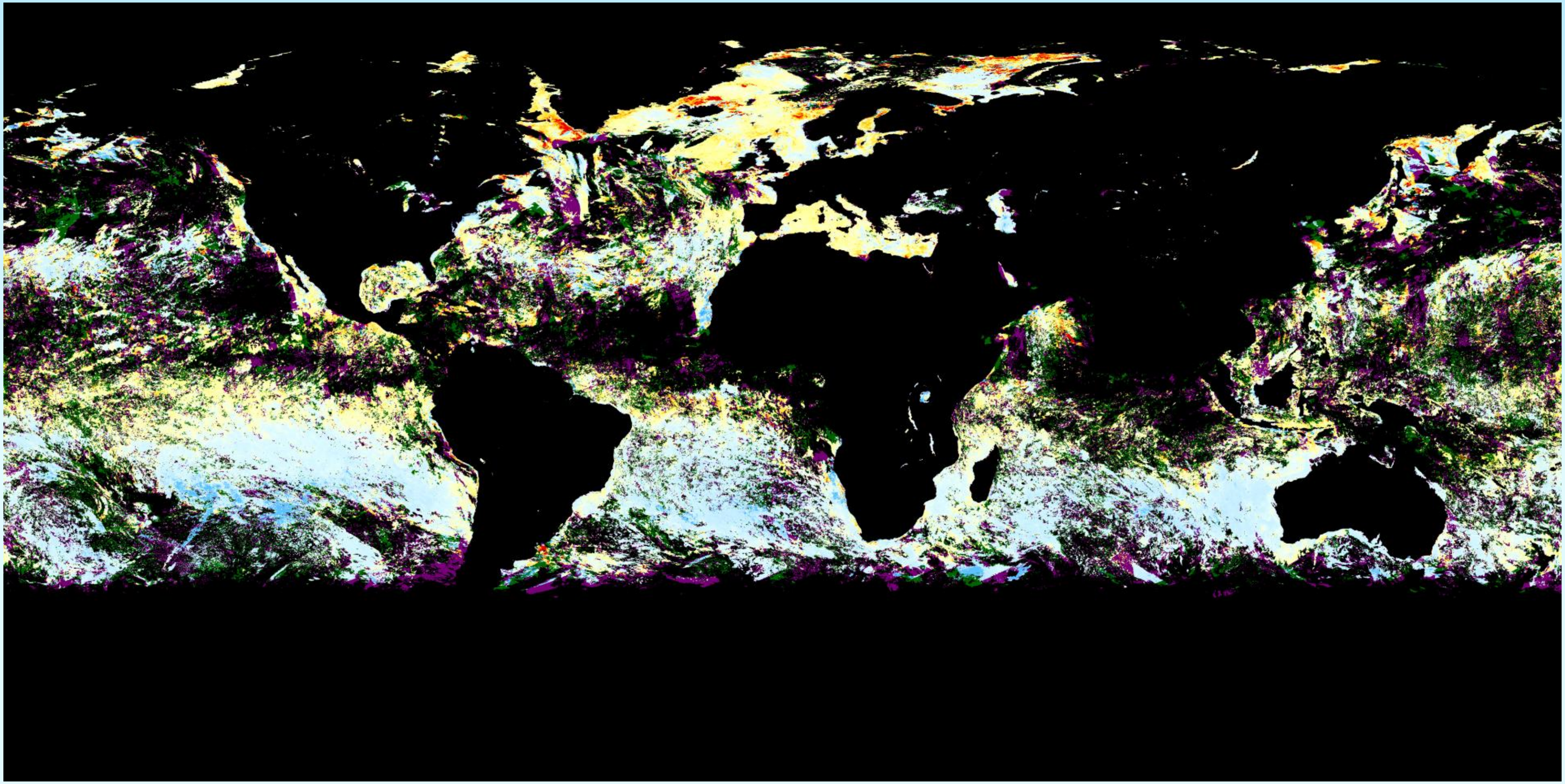
COMPARISONS TO MODIS Aqua

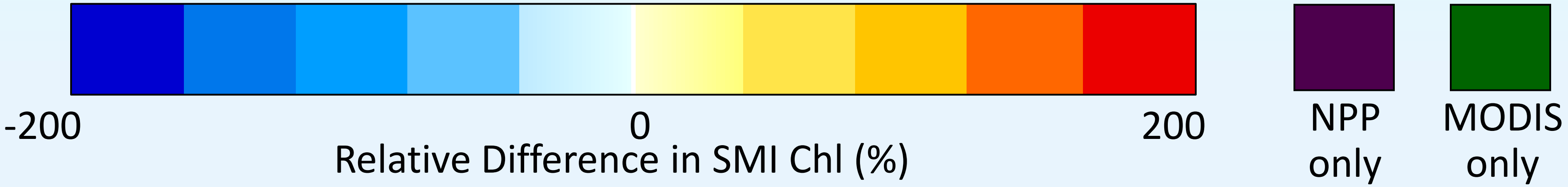
- NASA evaluation and NOAA EDR chlorophyll *a* concentration time series for global deep waters was compared to data from MODIS Aqua. ☆
- Maps were create showing the relative differences between :
  - NASA evaluation chlorophyll *a* concentration and MODIS Aqua data and
  - NOAA EDR chlorophyll *a* concentration and MODIS Aqua data.
- L2 imagery for chlorophyll *a* concentration were compared between NASA evaluation chlorophyll *a* concentration and NOAA EDR chlorophyll *a* concentration.

Relative Difference Map

NASA Eval VIIRS – MODIS Aqua

8-Day composite – 24-31 May 2012

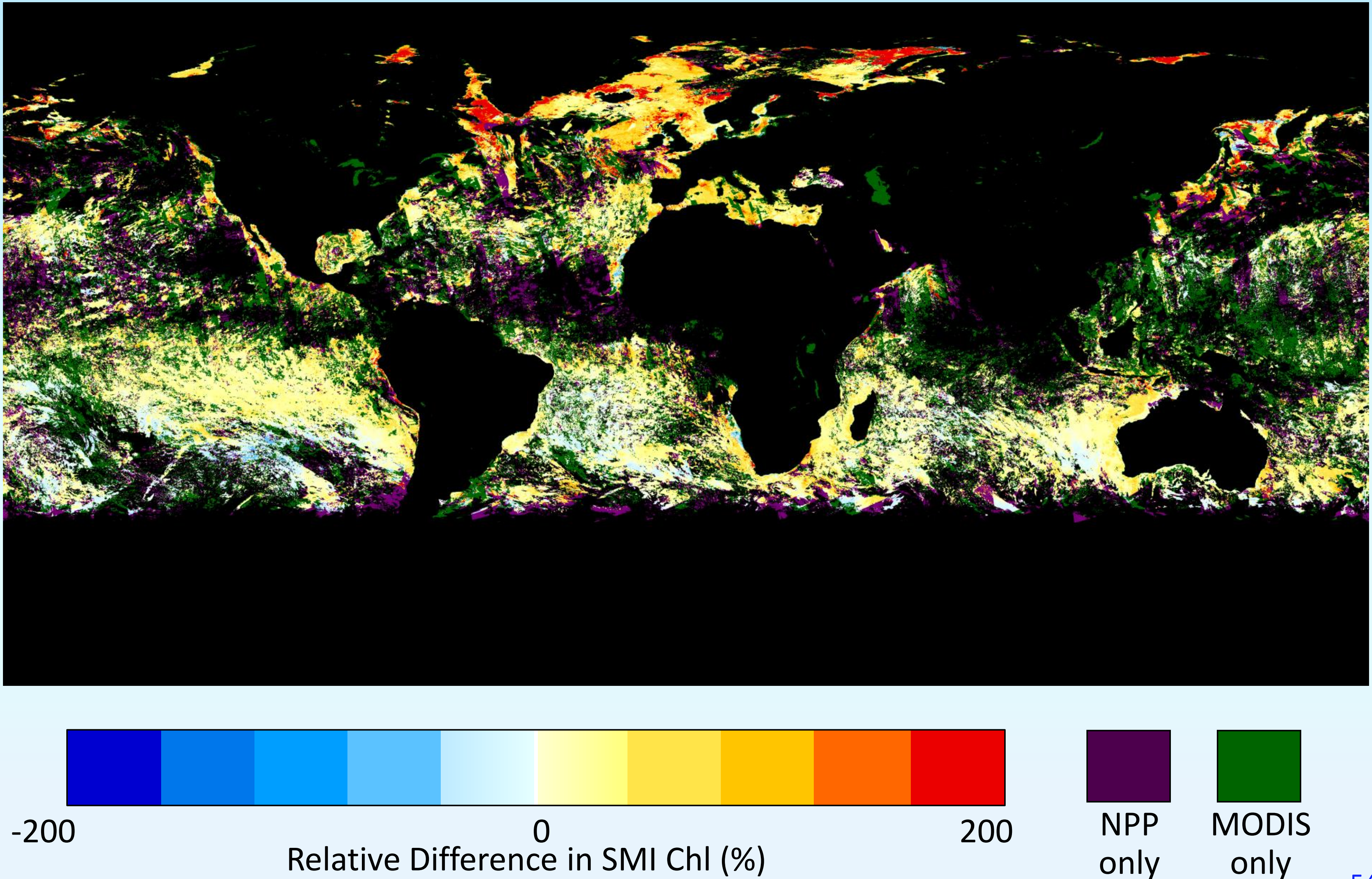


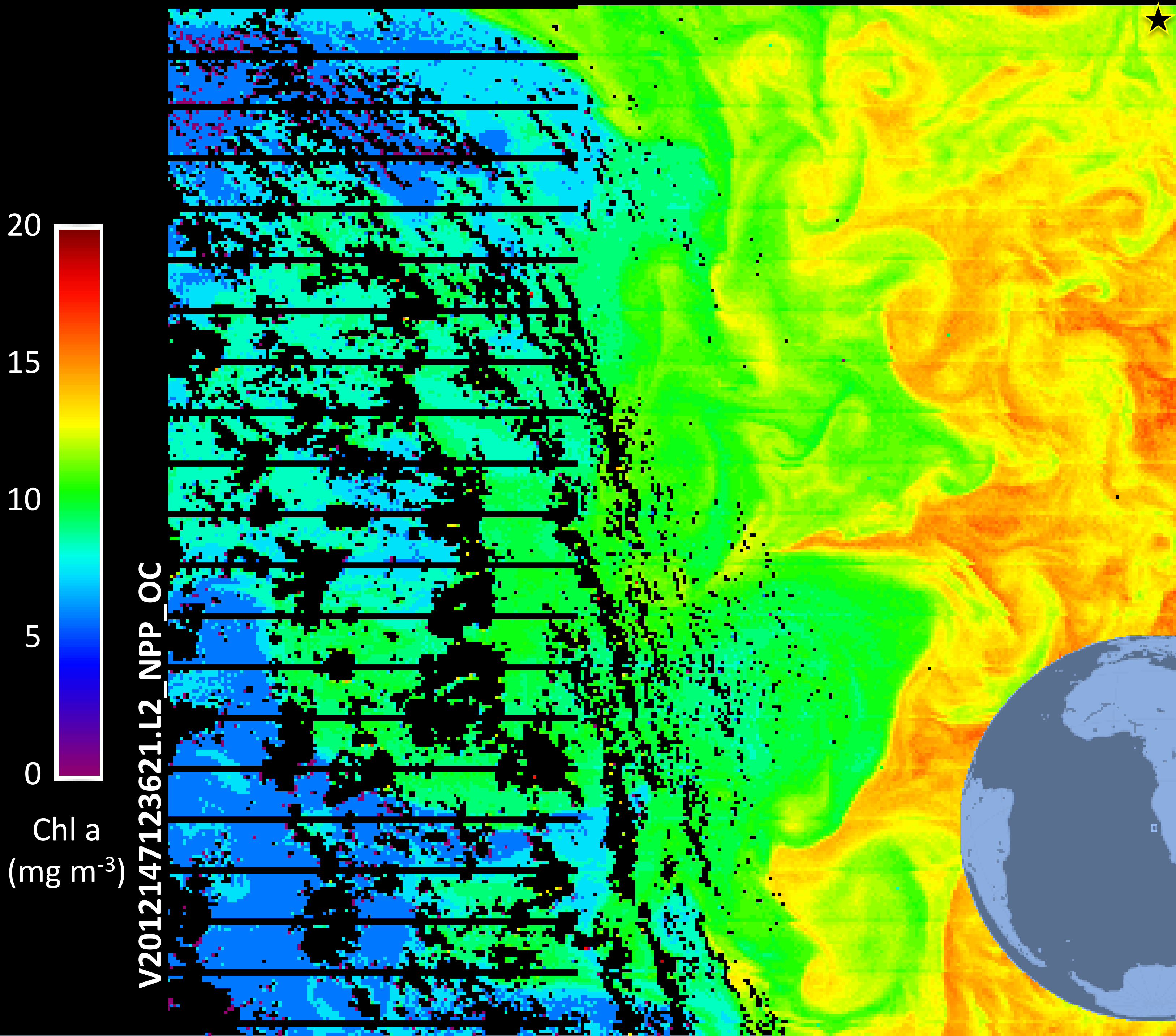


Relative Difference Map

NOAA EDR – MODIS Aqua

8-Day composite – 24-31 May 2012



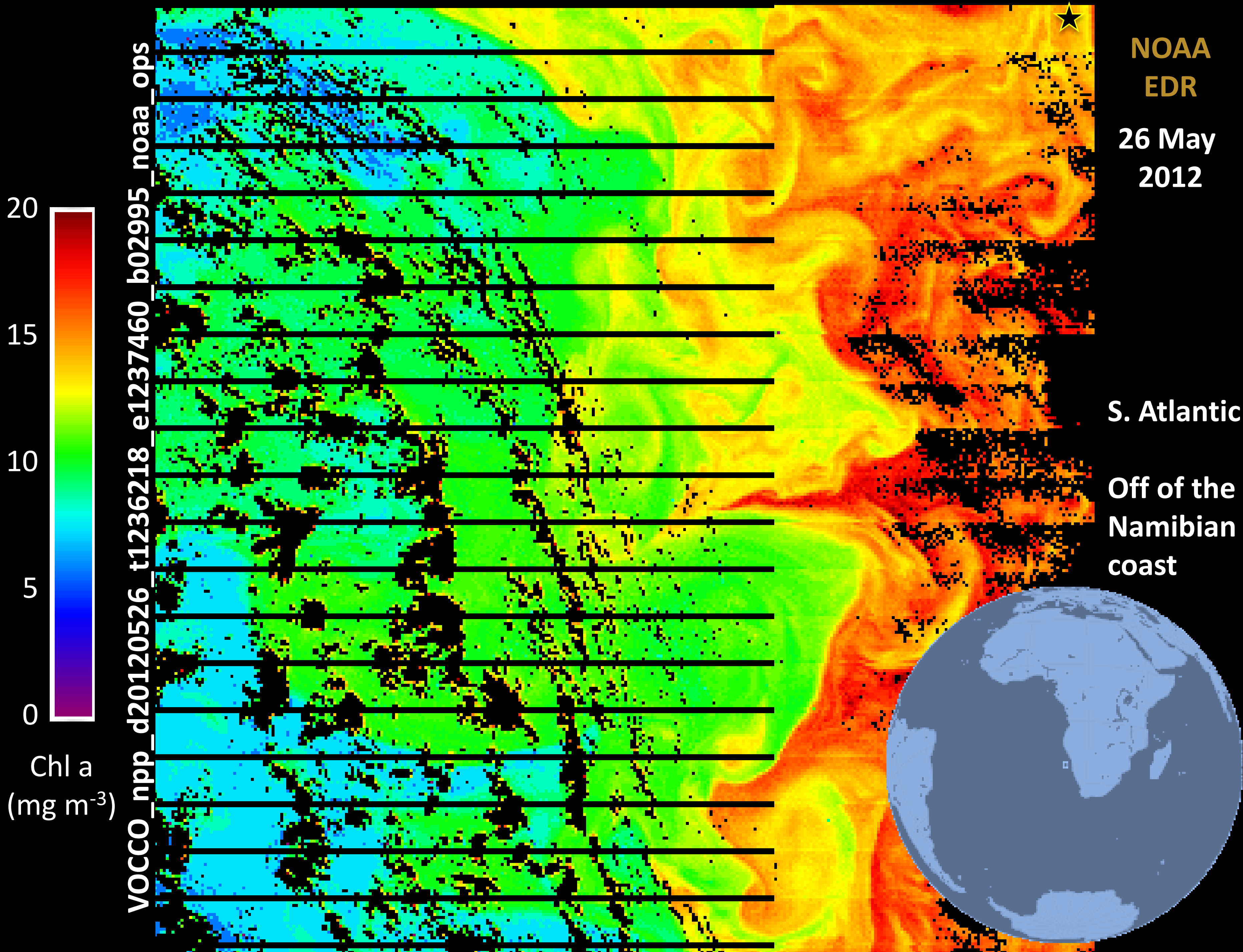


NASA
L2

26 May
2012

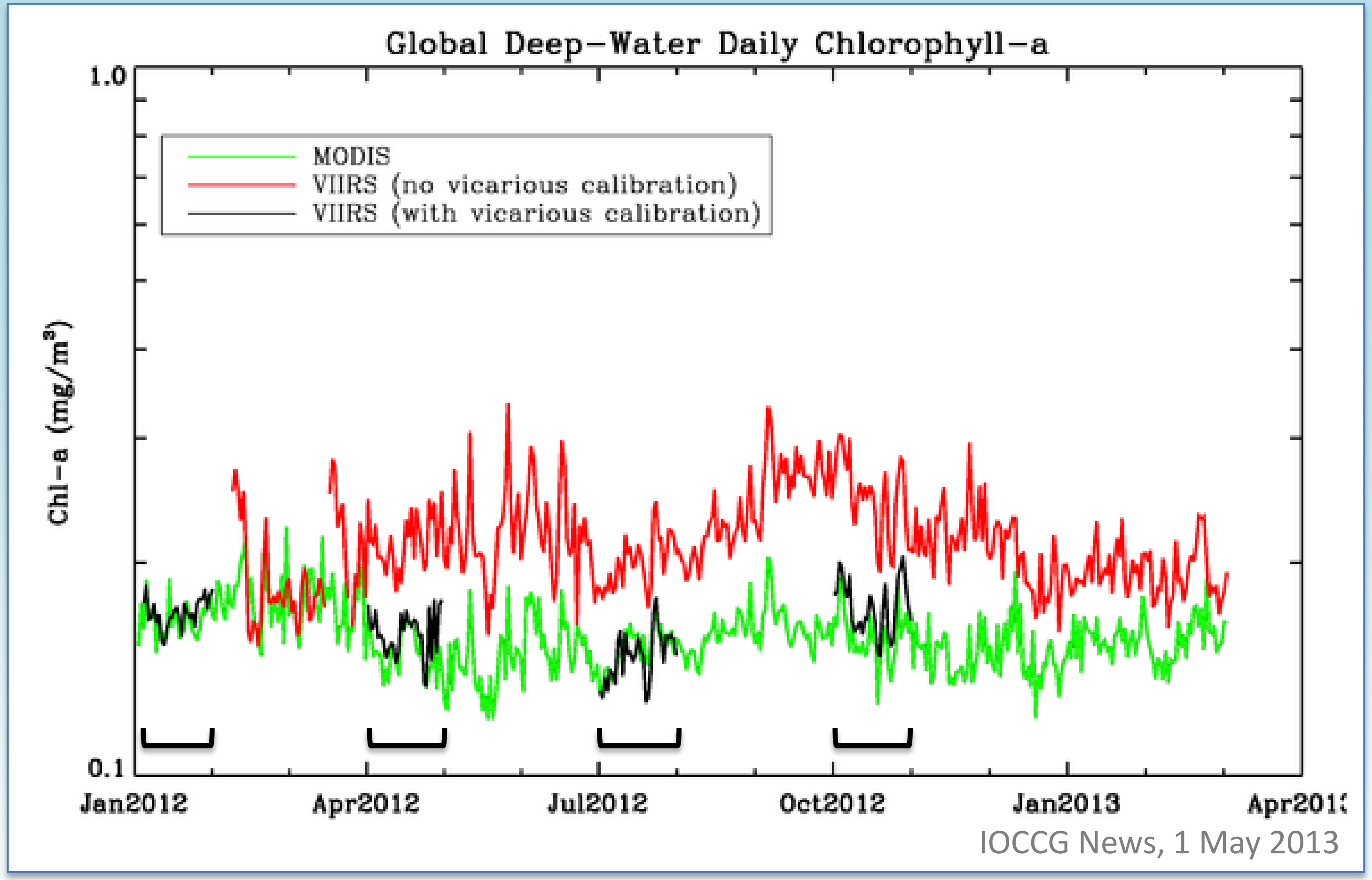
S. Atlantic

Off of the
Namibian
coast



NOAA
EDR
26 May 2012
S. Atlantic
Off of the Namibian coast
VOCCO_npp_d20120526_t1236218_e1237460_b02995_noaa_ops
20
15
10
5
0
Chl a (mg m^{-3})

EDR Vicarious Calibration



- Vicarous calibration coefficients are expected to be inserted into the operational processing stream shortly.
- Brings the chlorophyll product back in family with MODIS.
- The plot above was produced outside of the operational processing.
- The distributed NOAA product has not been reprocessed.