Validated Maturity Science Review
For NOAA-20 VIIRS VI and GVF Products

JPSS STAR Land Science Team
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JPSS NOAA NASA

VI/ GVF Cal/Val Team Members

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	Yunyue Yu	NOAA/NESDIS/STAR	EDR Lead, algorithm development/improvement, calibration/validation, team management
	Corinne Carter	NOAA Affiliate, UMD/CISESS	product monitoring and validation; algorithm development/improvement
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NCEP	Stan Benjamin	NOAA Federal	HRRR model
	Tanya Smirnova	NOAA Affilate	HRRR model

JPSS Data Products Maturity Definition

1. Beta

- Product is minimally validated, and may still contain significant identified and unidentified errors.
- Information/data from validation efforts can be used to make initial qualitative or very limited quantitative assessments regarding product fitness-for-purpose.
- Documentation of product performance and identified product performance anomalies, including recommended remediation strategies, exists.

2. Provisional

- Product performance has been demonstrated through analysis of a large, but still limited (i.e., not necessarily globally or seasonally representative) number of independent measurements obtained from selected locations, time periods, or field campaign efforts.
- Product analyses are sufficient for qualitative, and limited quantitative, determination of product fitness-for-purpose.
- Documentation of product performance, testing involving product fixes, identified product performance anomalies, including recommended remediation strategies, exists.
- Product is recommended for potential operational use (user decision) and in scientific publications after consulting product status documents.

3. Validated

- Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).
- Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.
- Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.
- Product is ready for operational use based on documented validation findings and user feedback.
- Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument.

Outline

- Product Overview/Requirements
- Evaluation of algorithm performance to specification requirements
  - Global and regional comparison of NPP and NOAA20 VI
  - Comparison of global NPP VIs to other satellite data sets
  - Comparison of in-situ PhenoCam data to NOAA20 VI time series
  - Evaluation of NOAA20 VI through comparison to in-situ Railroad Valley RadCalNet site
  - Global and site-based comparison of NPP and NOAA20 GVF
  - Comparison of PhenoCam data to NOAA20 GVF time series
  - Validation of NOAA20 GVF using GVF derived from Google Earth images
- User Feedback and Downstream Products
- Risks, Actions, and Mitigations
- Documentation (Science Maturity Check List)
- Conclusion
- Path Forward

VIIRS VI Product overview

NPP and NOAA 20 VIIRS VI Derivation

- VIs are reflectance ratios indicating the presence of green vegetation
- Global 4km and regional 1km grids
- Top of atmosphere (TOA) and top of canopy (TOC) normalized difference vegetation index (NDVI)

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$

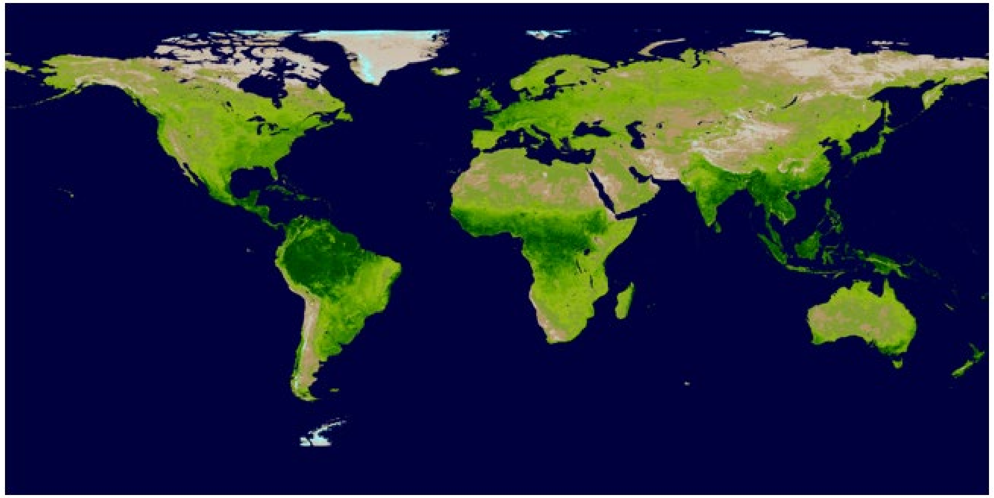
- Top of canopy enhanced vegetation index (TOC EVI)

$$EVI = 2.5 * \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + 6.0\rho_{red} + 7.5\rho_{blue} + 1.0}$$

Operational Status

- Has been available in CLASS since 11/20/2019

  Updated version v1r4 is implemented in CLASS.



Global 4km TOC EVI

Regional 1km TOC EVI

VI Product Requirements

Attribute	Threshold	Observed/validated
Geographic coverage	Clear, land (not ocean), daytime only	
Horizontal Cell Size	1km (regional), 4km (global)	1 km (regional), 4km (global)
Mapping Uncertainty	4km threshold, 1km objective	1km
Measurement Range (TOA NDVI, TOC NDVI, TOC EVI)	-1.0 to 1.0	-1.0 to 1.0
Measurement Accuracy (TOA NDVI)*	0.05 VI units (threshold), 0.03 VI units (objective)	0.01
Measurement Accuracy (TOC NDVI)*	0.05 VI units	0.03
Measurement Accuracy (TOC EVI)*	0.05 VI units	0.01
Measurement Precision (TOA NDVI, TOC NDVI, TOC EVI)*	0.04 VI units	0.04
Refresh	At least 90% coverage of the globe every 24 hours (monthly average)	Criterion has been met

*For the purpose of these requirements, “accuracy” is defined as absolute value of mean difference, and “precision” as RMS of (difference – mean difference), no matter the source of the reference data

VIIRS Green Vegetation Fraction Product Overview

NOAA-20 VIIRS Green Vegetation Fraction (GVF) Algorithm

- VIIRS GVF algorithm is a modified version of Gutman and Ignatov's (1998) GVF algorithm
- VIIRS GVF algorithm uses VIIRS I1, I2 and M3 TOC reflectances as input
- VIIRS GVF is derived form EVI

The Enhanced Vegetation Index (EVI)

$$EVI = G\frac{\rho_{\mathrm{NIR}} - \rho_{\mathrm{red}}}{\rho_{\mathrm{NIR}} + C_1 \cdot \rho_{\mathrm{red}} - C_2 \cdot \rho_{\mathrm{blue}} + 1}$$

The Green Vegetation Fraction

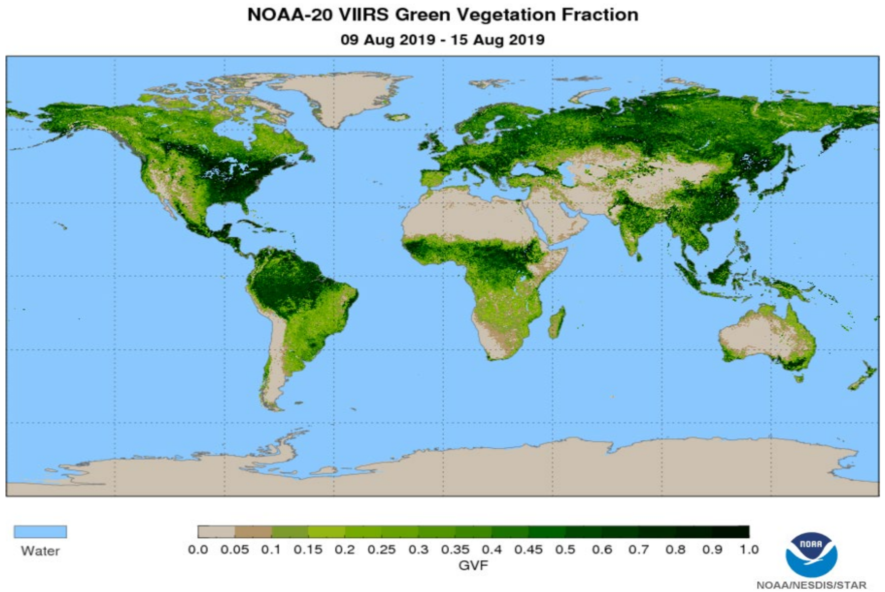
$$GVF = \frac{EVI - EVI_0}{EVI_\infty - EVI_0}$$

The NVPS VIIRS GVF system generates two products

1. *Weekly Global GVF at 4 km res*
2. *Weekly Regional GVF at 1 km res*

(Lat 7.5°S to 90°N, Lon 130°E to 30°E)

- Weekly (updated daily) GVF products
- Projection: Lat/Lon
- Output file format: NetCDF4
- VIIRS GVF available at NOAA/CLASS



GVF Product Requirements

Attribute	Threshold	Objective
Horizontal Cell Size	16 km	1 km (regional), 4km (global)
Vertical Reporting Interval	NS	NS
Mapping Uncertainty, 3 Sigma	4km	1km
Measurement Precision*		
Global	15%	8%
Regional	15%	8%
Measurement Accuracy*		
Global	12%	5%
Regional	12%	5%
Refresh	24 hours	24 hours

*For the purpose of these requirements, “accuracy” is defined as absolute value of mean difference, and “precision” as RMS of (difference – mean difference), no matter the source of the reference data

VI algorithm updates (1)

NVPS VI Version	Effective Date	Changes made
v1r1	Oct. 10, 2017 Implemented and tested in NDE	•Embed enterprise VI algorithms •Ingest enterprise upstream inputs (surface reflectances, cloudmask, aerosol) •Change output format from hdf into netcdf4
v1r2	Feb.12, 2018 Implemented and tested in NDE	•Kept all features of version v1r1 •Figured out resource leaks • Assigned values on uninitialized automatic variables • Used configuration file to replace hard coded numbers in scripts •Added check codes on untrusted inputs including array boundary, string length and division by zero •Changed running scripts so as to do single day running and batch running in multiple days and various modes.

VI algorithm updates (2)

v1r3	Sept. 26, 2018 Operational production for SNPP	•Kept all features of previous versions •Changed metadata • Added geolocation coordinate into output • Added grid-mapping information into output. • Changed source codes in C++ to be independent of input file name change
v1r4	Jun. 4,2019 Operational production for NOAA-20	•Kept all features of previous versions •Modified VI codes to be independent of platforms (SNPP, NOAA-20) •Reduced output storage by 30% through changing previous 2-dimensional Latitude/Longitude coordinates in outputs into 1-dimensional ones •Reduced the running time of biweekly compositing algorithm of VI by 75% through using previous 2 weekly composites and recent 2 daily intermediate results instead of 16 daily intermediate results • Environmental variables are specified in a PCF to make local running consistent with NDE running • VI running driver can match both local and NDE operational environments

GVF algorithm updates (1)

NVPS GVF Version	Effective Date	Changes made
v1r0	2012~2017 Implemented and tested in OSPO	•Embed GVF algorithms •Ingest enterprise IDPS-based inputs (surface reflectances) •input SR data format in HDF
v2r0	Feb. 10, 2018 Implemented and tested in NDE	•Embed enterprise GVF algorithms •Ingest enterprise NDE-based inputs (surface reflectances) •Change input SR data format from hdf into netcdf4
v2r1	Sept 26, 2018 Operational production for SNPP	•Kept all features of version v2r0 •Figured out resource leaks • Assigned values on uninitialized automatic variables • Used configuration file to replace hard coded numbers in scripts •Added check codes on untrusted inputs including array boundary, string length and division by zero

GVF algorithm updates (2)

v2r2	Jun 4,, 2019 Operational production for SNPP & NOAA-20	•Kept all features of previous versions •Changed metadata to be independent of platforms (SNPP, NOAA-20) • Added geolocation coordinate into output • Added grid-mapping information into output. • Changed source codes in C++ to be independent of input file name change
v2r3	Sept 17,2019 Operational production for NOAA-20 Oct 2, 2019 Fixed parameter.h	•Kept all features of previous versions •Reduced output storage by 30% through changing previous 2-dimensional Latitude/Longitude coordinates in outputs into 1-dimensional ones • GVF running driver can match both local and NDE operational environments

Algorithm improvement and evaluation

- Algorithm improvements since provisional review
  - Platform independence (NPP/ NOAA20)
  - Reduced output storage
  - Reduced volume of required inputs
  - Consistency with NDE
- Algorithm performance evaluation
  - Validation data sets (type, periods, coverage)
  - Validation strategies / methods
  - Validation results
  - Long term monitoring readiness

VI algorithm performance evaluation – Satellite data comparison

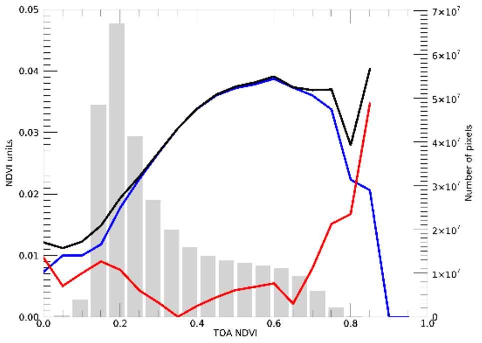
- Allows for evaluation of data across entire global and regional geographic ranges
- SNPP and NOAA 20 VIIRS VI consistency (daily, weekly and biweekly; global and regional; TOA NDVI, TOC NDVI, and TOC EVI*)
  - Results from SNPP and NOAA20 VIIRS instruments should be consistent with each other because both are in afternoon orbit, instruments are similar, and algorithms are identical
- Global biweekly NVPS NPP VIIRS TOC NDVI and TOC EVI comparison with NASA NPP VIIRS TOC NDVI and TOC EVI
  - NVPS NPP VIIRS VI and NASA NPP VIIRS VI come from the same instrument, but are processed using slightly different algorithms. Good consistency expected.
- Global biweekly NVPS NPP VIIRS TOC NDVI and TOC EVI comparison with MODIS TOC NDVI and TOC EVI
  - MODIS and VIIRS instruments are similar, but differ more than NPP and NOAA20 VIIRS. Bands are similar enough that VIs should still be consistent.

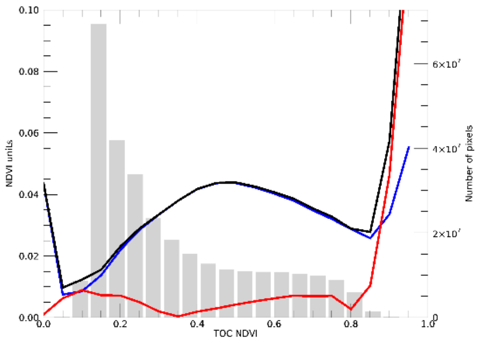
*TOA NDVI = top of atmosphere normalized difference vegetation index
TOC NDVI = top of canopy normalized difference vegetation index
TOC EVI = top of canopy enhanced vegetation index

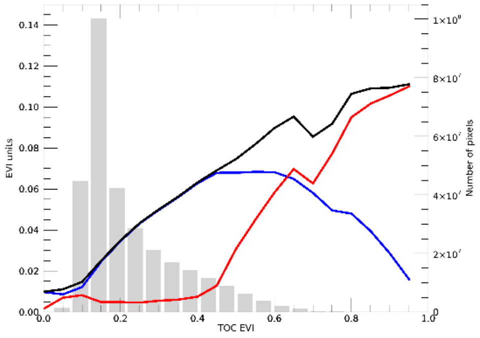
NOAA 20 VIIRS VI vs SNPP VIIRS VI (1)

Daily global TOA NDVI | Daily global TOC NDVI | Daily global TOC EVI

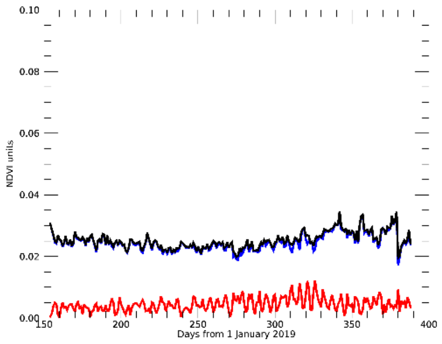
Stratified by NPP VI

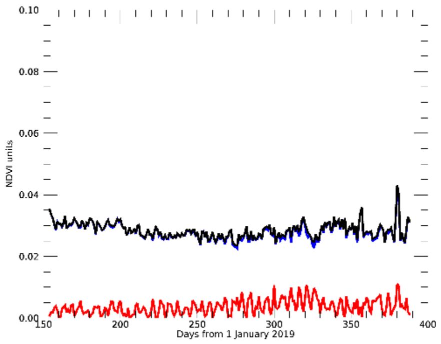


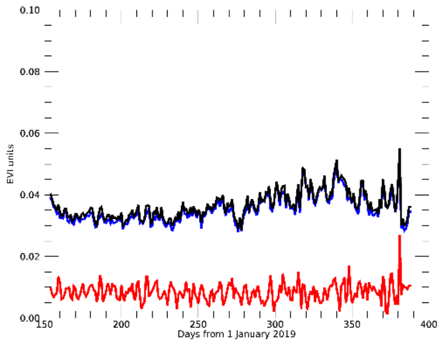




Time series







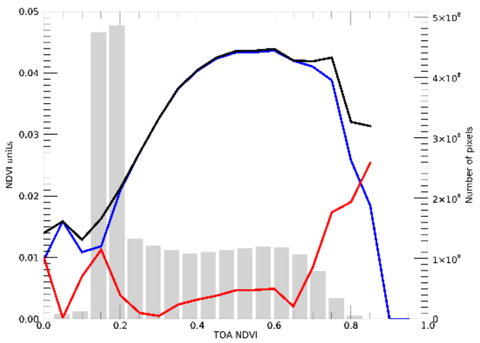
	TOA NDVI	TOC NDVI	TOC EVI
Accuracy	0.0042	0.0031	0.0083
Precision	0.0246	0.0284	0.0349
Uncertainty	0.0250	0.0285	0.0359

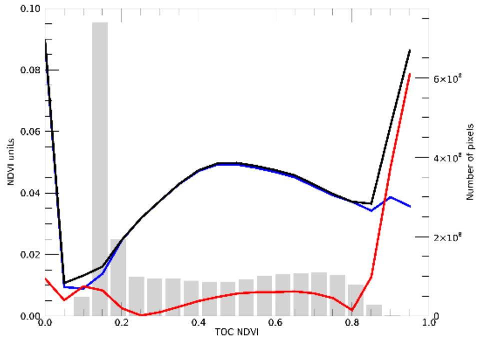
- Time period: June 2019 through January 2020
- 234 pairs of data files
- Analysis carried out for pixels flagged as high quality only
- Global accuracy and precision meet specifications overall and across time series
- VI values are clustered at low values. Accuracy and precision at low VI values meet specifications.
- Higher accuracy and precision values for the small number of high VI pixels should be investigated.

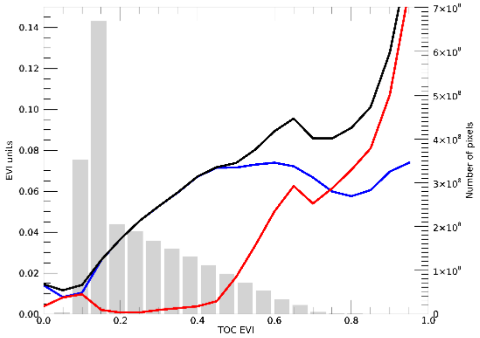
NOAA 20 VIIRS VI vs SNPP VIIRS VI (2)

Daily regional TOA NDVI | Daily regional TOC NDVI | Daily regional TOC EVI

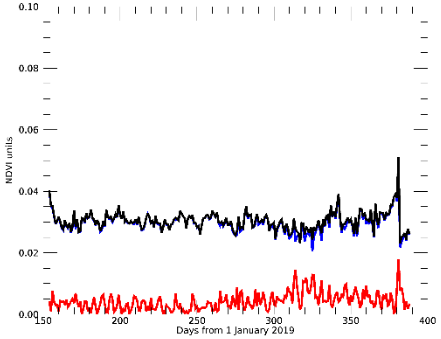
Stratified by NPP VI

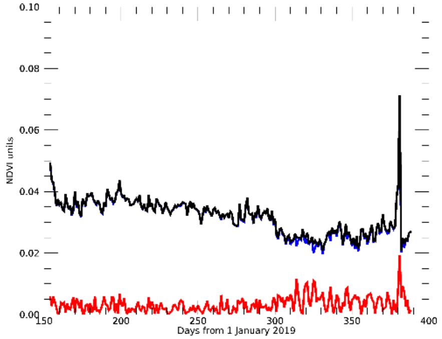


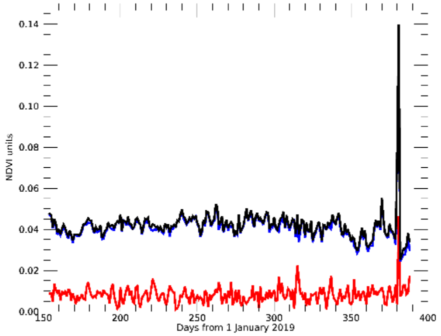




Time series







- Time period: June 2019 through January 2020
- 235 pairs of data files
- Analysis carried out for pixels flagged as high quality only
- Regional accuracy and precision meet specifications overall and across time series

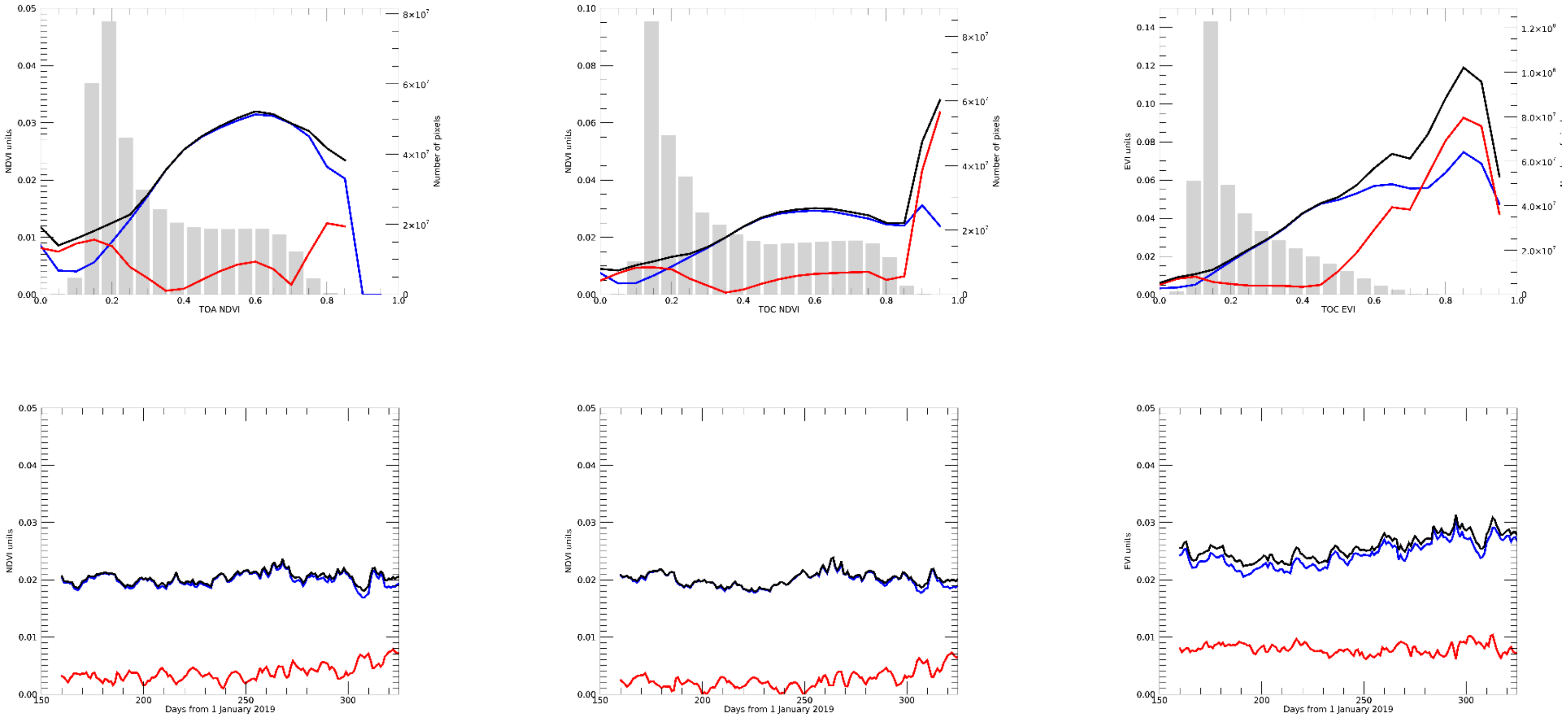
	TOA NDVI	TOC NDVI	TOC EVI
Accuracy	0.0035	0.0017	0.0080
Precision	0.0302	0.3301	0.0411
Uncertainty	0.0304	0.0331	0.0419

NOAA 20 VIIRS VI vs SNPP VIIRS VI (3)

	Weekly global TOA NDVI	Weekly global TOC NDVI	Weekly global TOC EVI

Stratified by NPP VI

Time series



	TOA NDVI	TOC NDVI	TOC EVI
Accuracy	0.0040	0.0028	0.0080
Precision	0.1967	0.0197	0.0238
Uncertainty	0.0201	0.0198	0.0251

- Time period: June 2019 through January 2020
- 222 pairs of data files
- Analysis carried out for pixels flagged as high quality only
- Global accuracy and precision meet specifications overall and across time series

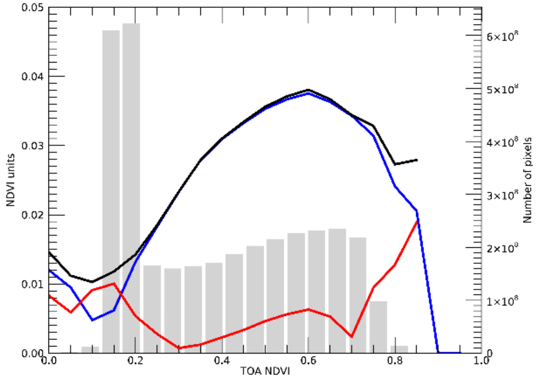
NOAA 20 VIIRS VI vs SNPP VIIRS VI (4)

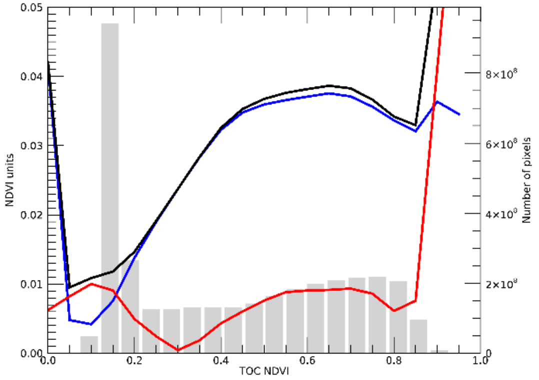
Weekly regional TOA NDVI

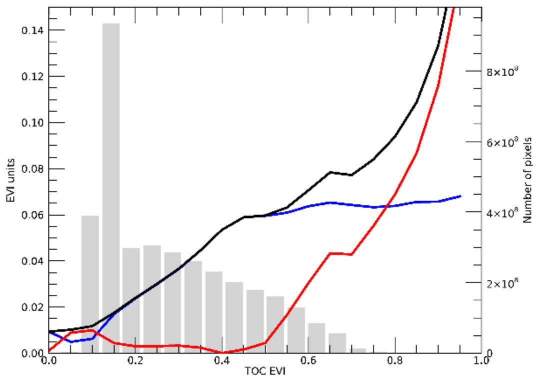
Weekly regional TOC NDVI

Weekly regional TOC EVI

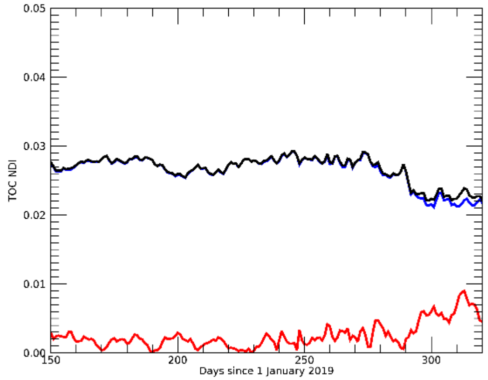
By NPP VI value

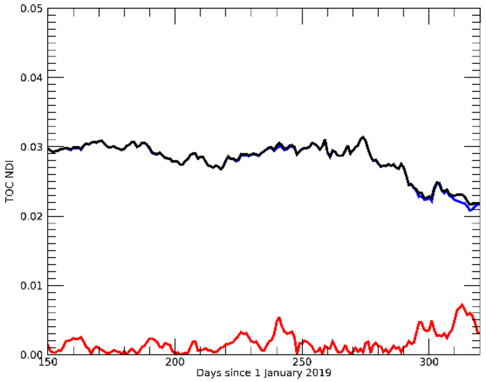


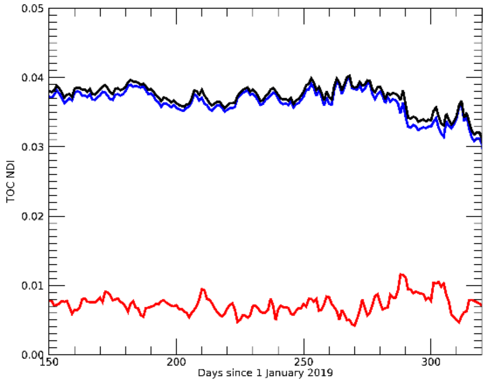




Time series

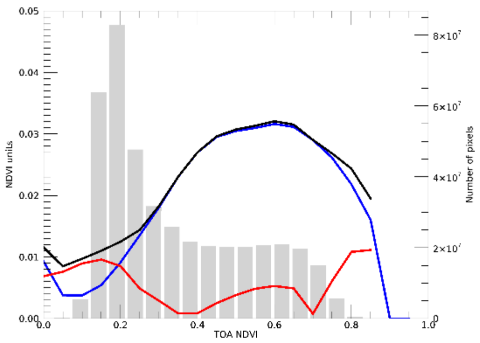
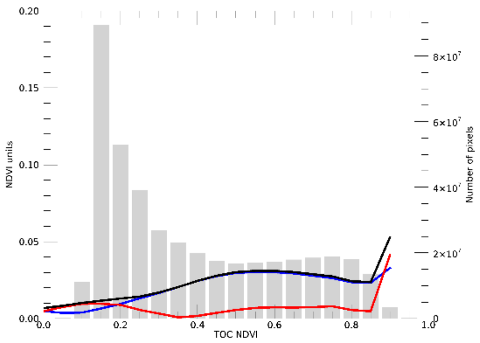
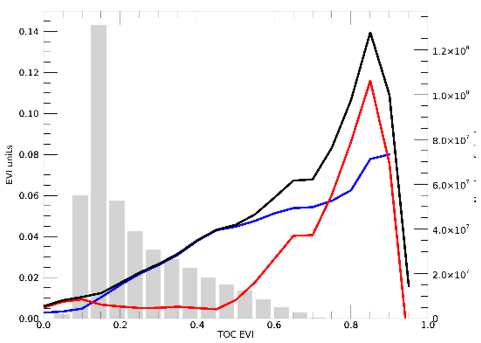
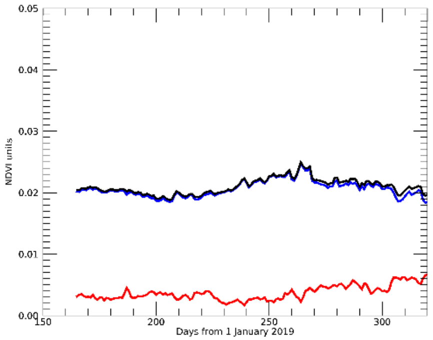
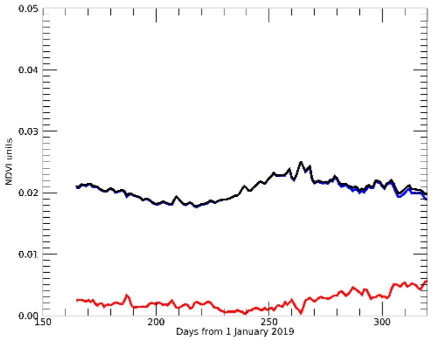
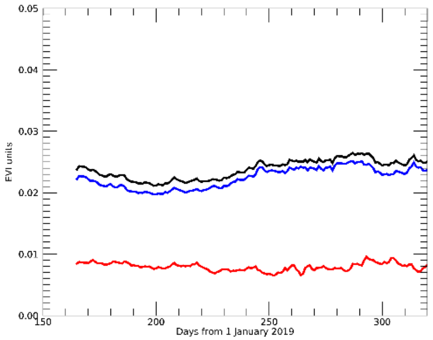






	TOA NDVI	TOC NDVI	TOC EVI
Accuracy	0.0025	0.0003	0.0073
Precision	0.0264	0.0280	0.0355
Uncertainty	0.0265	0.0280	0.0363

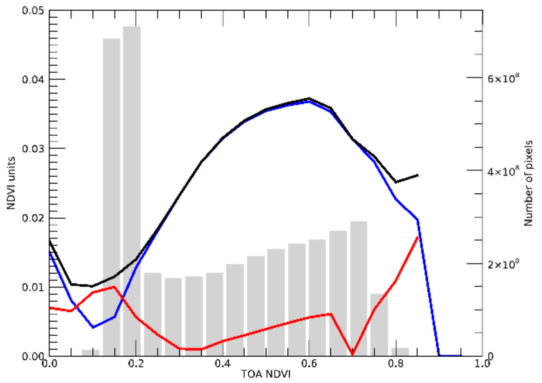
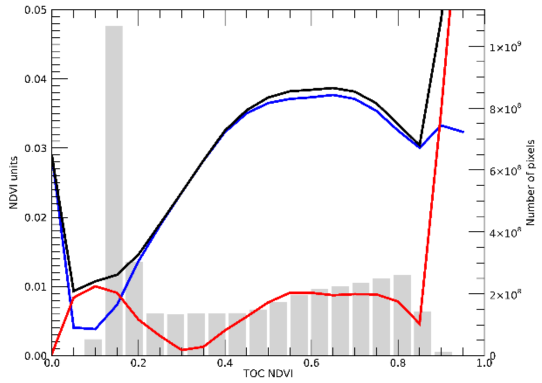
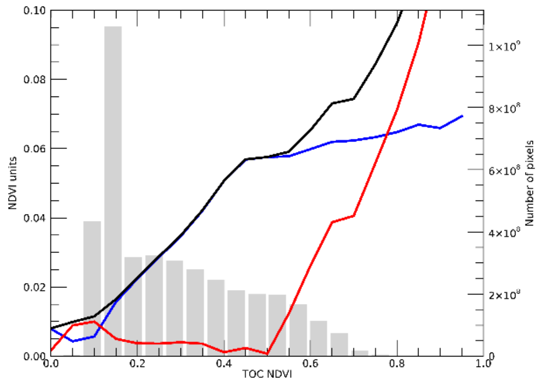
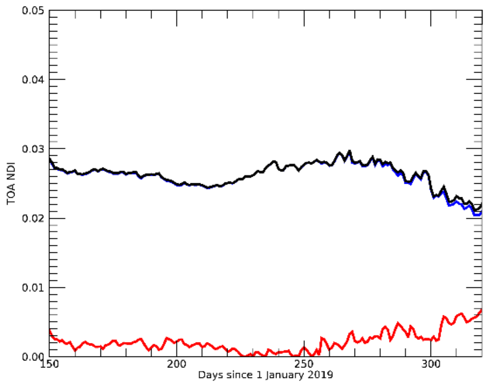
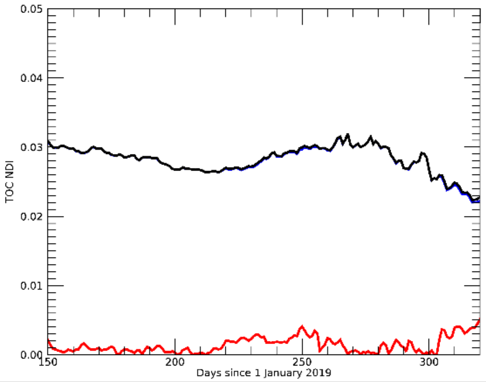
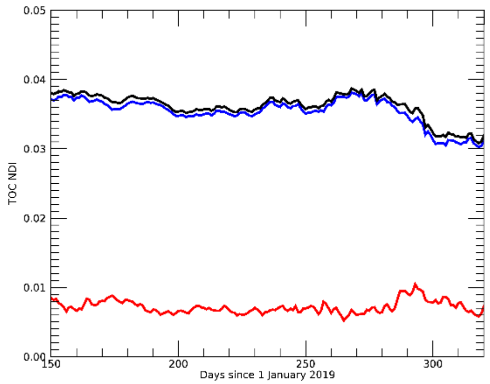
NOAA 20 VIIRS VI vs SNPP VIIRS VI (5)

	Biweekly global TOA NDVI	Biweekly global TOC NDVI	Biweekly global TOC EVI
Stratified by NPP VI			
Time series			

- Time period: June 2019 through January 2020
- 211 pairs of data files
- Analysis carried out for pixels flagged as high quality only
- Global accuracy and precision meet specifications overall and across time series

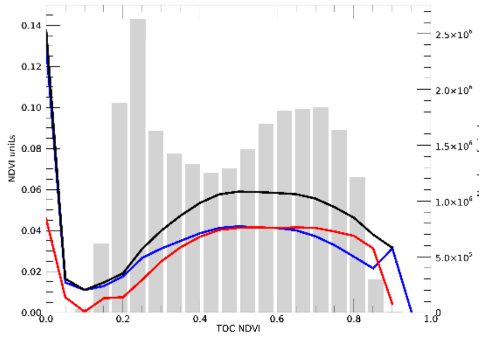
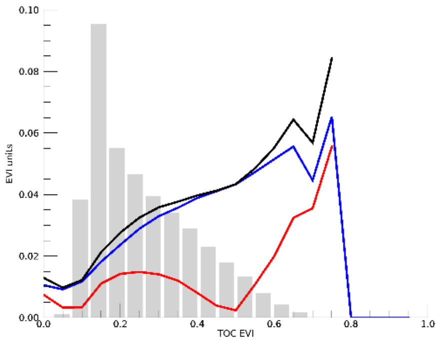
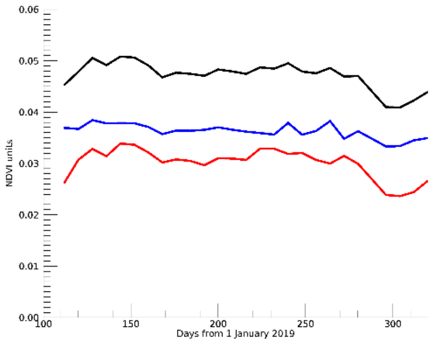
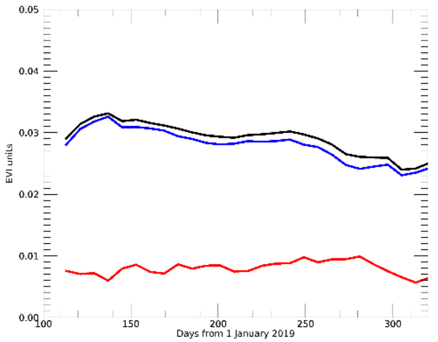
	TOA NDVI	TOC NDVI	TOC EVI
Accuracy	0.0039	0.0026	0.0080
Precision	0.2031	0.0202	0.0219
Uncertainty	0.0207	0.0203	0.0233

NOAA20 VIIRS VI vs SNPP VIIRS VI (6)

	Biweekly regional TOA NDVI	Biweekly regional TOC NDVI	Biweekly regional TOC EVI
By NPP VI value			
Time series			

	TOA NDVI	TOC NDVI	TOC EVI
Accuracy	0.0025	0.0003	0.0074
Precision	0.0258	0.0278	0.0344
Uncertainty	0.0259	0.0278	0.0352

NVPS NPP VIIRS vs NASA NPP VIIRS VI

	Global TOC NDVI	Global TOC EVI
Stratified by NVPS VI value		
Time series		

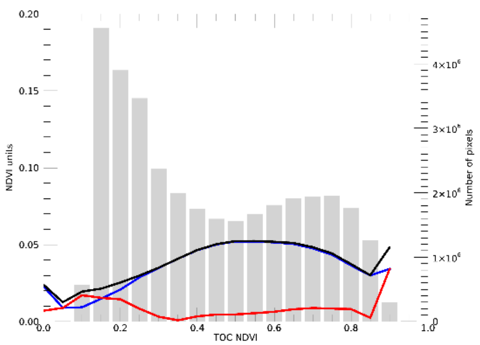
	TOC NDVI	TOC EVI
Accuracy	-0.0298	-0.0077
Precision	0.0361	0.0287
Uncertainty	0.0468	0.0276

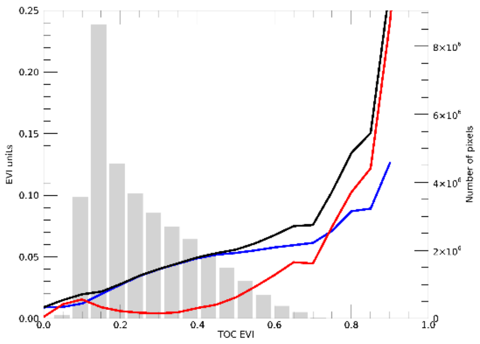
- Time period: April 2019 – January 2020
- 34 pairs of data files
- NASA produces global biweekly NPP VIIRS VI data only (one biweekly data file every week)
- NASA does not produce NPP VIIRS TOA NDVI.
- Accuracy and precision statistics meet specifications for time period investigated
- Accuracy and precision statistics meet specifications for all VI value stratifications except high TOC EVI, where there are few values.

NVPS NPP VIIRS vs MODIS VI

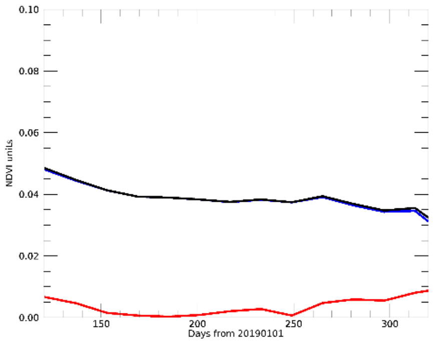
	Global TOC NDVI	Global TOC EVI

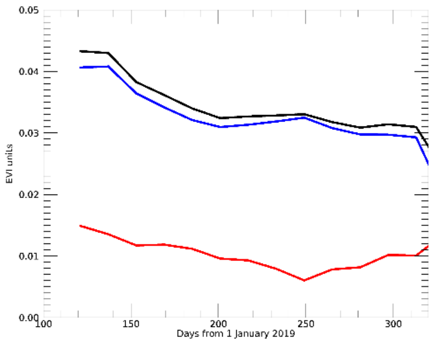
Stratified by NVPS VI value





Time series





	TOC NDVI	TOC EVI
Accuracy	0.00340756	0.010696
Precision	0.03820736	0.032214
Uncertainty	0.03835857	0.033943

- Time period: June 2019-January 2020
- 17 pairs of data files
- NASA produces global biweekly MODIS VI data only (one biweekly data file every 2 weeks)
- NASA does not produce MODIS TOA NDVI.
- Accuracy and precision statistics meet specifications for most of time period investigated
- Accuracy and precision statistics meet specifications for all VI value stratifications except high TOC EVI, where there are few values.

VI validation with PhenoCam data (1)

- The PhenoCam Network provides automated, near-surface remote sensing of canopy phenology across North America and Europe
- Images are uploaded to the PhenoCam server every half hour
- RGB images of the same view fields and regions of interest are taken regularly by cameras at PhenoCam sites
- Green Chromatic Coordinate (GCC) of RGB image is defined as

$$GCC = G / (R + G + B)$$

G is raw counts in green channel, R raw counts in red channel, and B raw counts in blue channel.

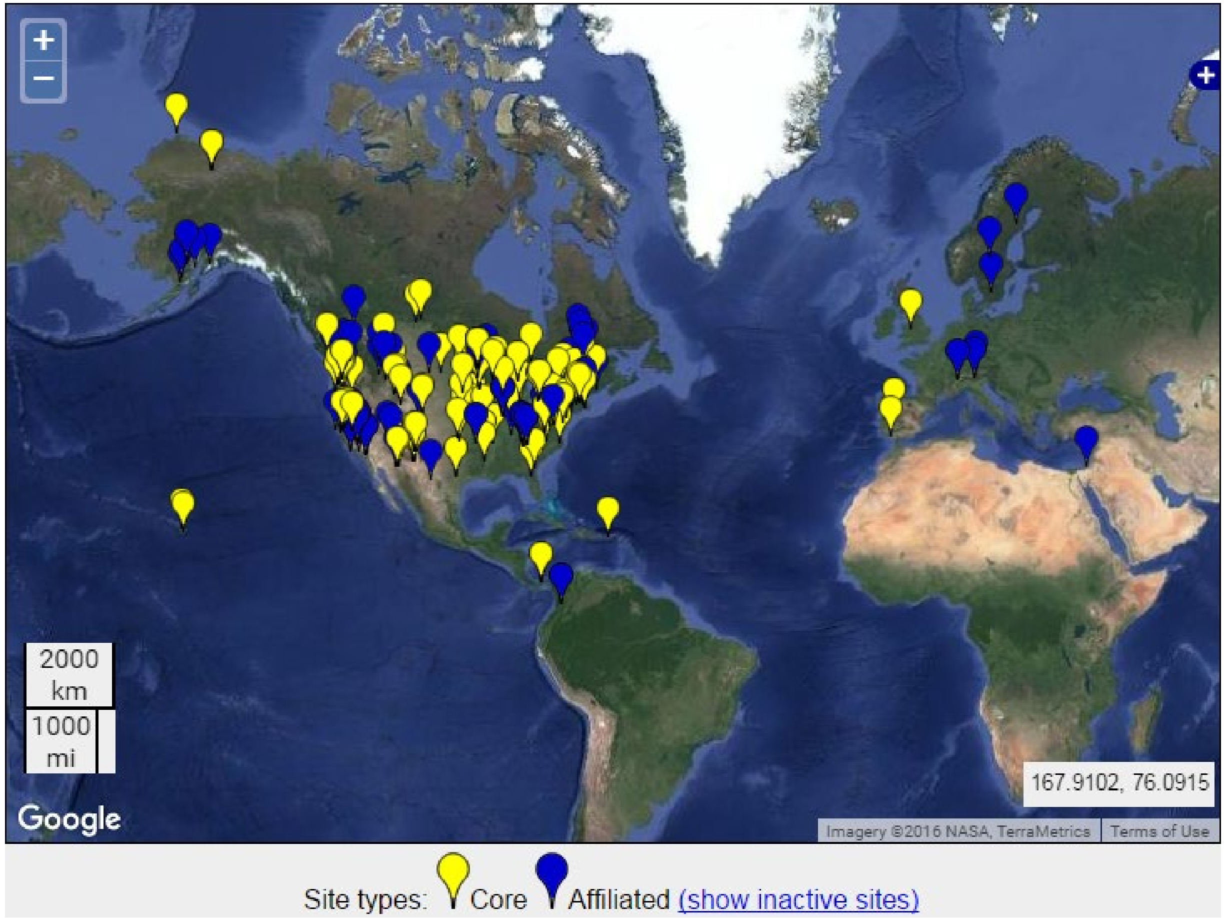
GCC=0.33 for white or grey pixels

GCC=0.4-0.5 for green pixels (green is the dominant channel)

- GCC is an indicator of green vegetation presence, but not identical to vegetation indices which include IR bands. Direct comparison of GCC and VI values is not valid.
- Since both are indicators of vegetation greenness, PhenoCam GCCs and VIIRS VIs from nearest- neighbor pixels can be expected to show trend correlation and similar seasonal variation

Phenocam sites

Phenocam site network is pictured below. Sites used in VI and GVF validation were selected from this network, representing a range of land cover and climate conditions.



https://phenocam.sr.unh.edu/webcam/network/map/

VI validation with PhenoCam data (2)

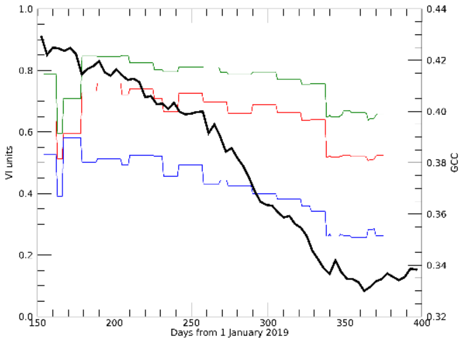
- Yan et al. (2019) have shown that PhenoCam GCC is correlated with Landsat and MODIS VI and with ground-measured GPP at a savanna site
- Richardson et al. (2018) found good agreement for PhenoCam and MODIS phenological transition dates "provided that the vegetation in the camera field of view was representative of the broader landscape", but not for evergreen forests
- We do not have enough data to demonstrate correspondence of phenological transition dates, but do have enough data to see trends in both GCC and VI. We expect these trends to be correlated.
- Our analysis demonstrates correlation coefficients of 0.6-0.7 or higher for many combinations of PhenoCam site GCC and NOAA20 VIs.
- Some of the weaker correlations can be explained by the small amount of variation in GCC or VI over time at some sites

Richardson, A.D., K. Hufkens, T. Milliman and S. Frolking. 2018. *Intercomparison of phenological transition dates derived from the PhenoCam Dataset V1.0 and MODIS satellite remote sensing.* Scientific Reports, 8: 5679. DOI: 10.1038/s41598-018-23804-6

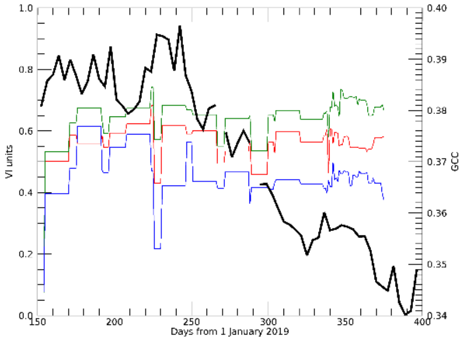
Yan, D., R. L. Scott, D. J. P. Moore, J. A. Biederman, W. K. Smith, 2019. *Understanding the relationship between vegetation greenness and productivity across dryland ecosystems through the integration of PhenoCam, satellite, and eddy covariance data.* Remote Sensing of Environment, 223: 50-62. DOI: 10.1016/j.rse.2018.12.029

VI validation with PhenoCam data (3)

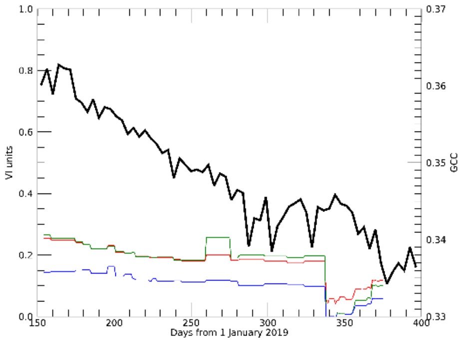
alligatorriver



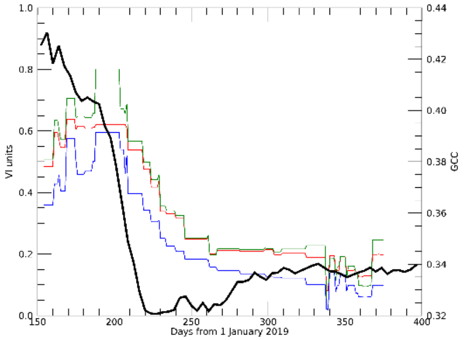
archboldpnot



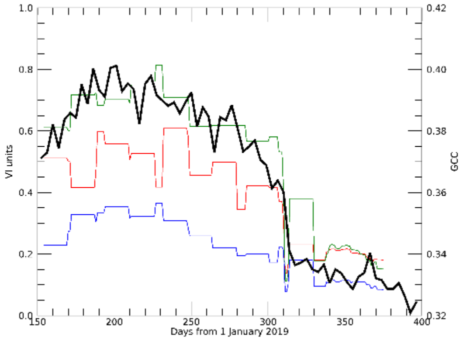
burnssagebrush



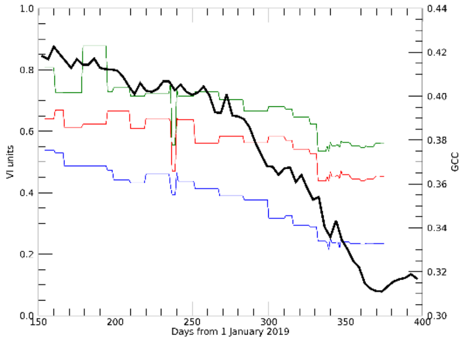
cafcookeastltar0



canadaOBS



dukehw



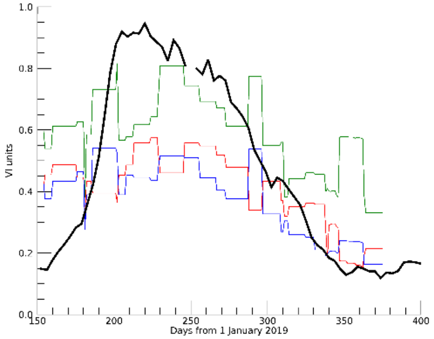
TOA NDVI TOC EVI
TOC NDVI GCC

- Time period: June – December 2019
- Validation results

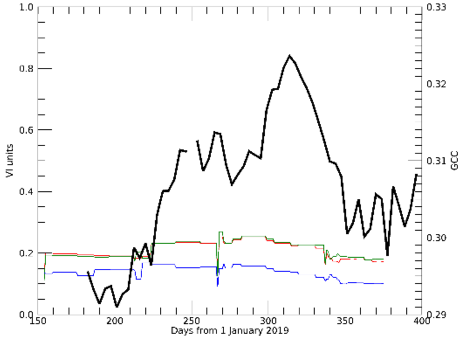
For most sites, both VI and GCC showed decreasing trend because time period is from northern hemisphere summer to winter. Some sites have limited variation in both VI and GCC. Not all sites show consistent trends due to factors such as spatial inhomogeneity.

VI validation with PhenoCam (4)

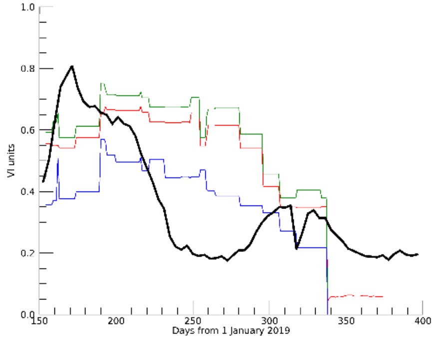
jurong



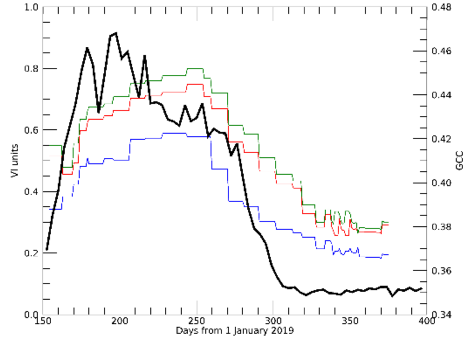
luckyhills



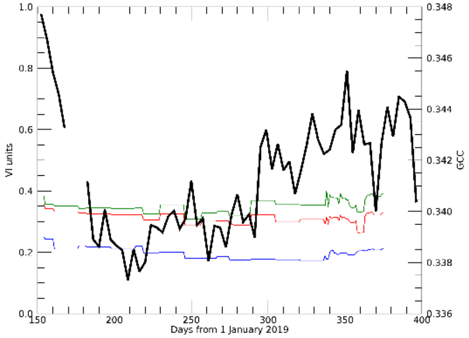
mandani2



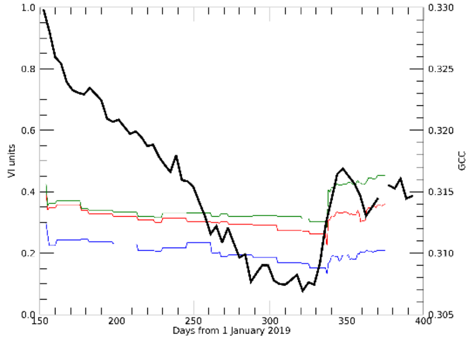
mead2



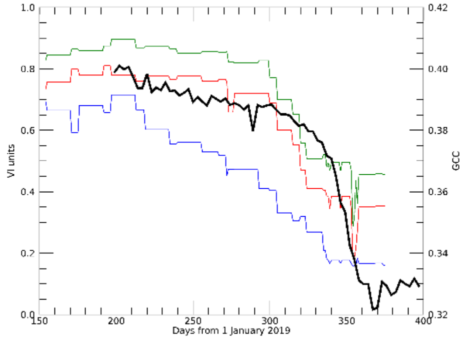
monteblanco



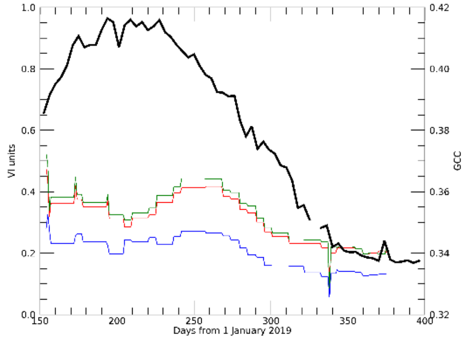
montenegro



morganmonroe



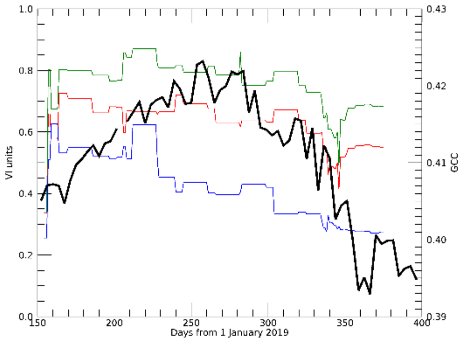
neon_d10_ARIK



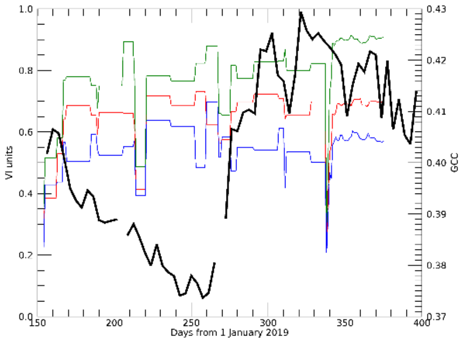
TOA NDVI
TOC NDVI
TOC EVI
GCC

VI validation with PhenoCam (5)

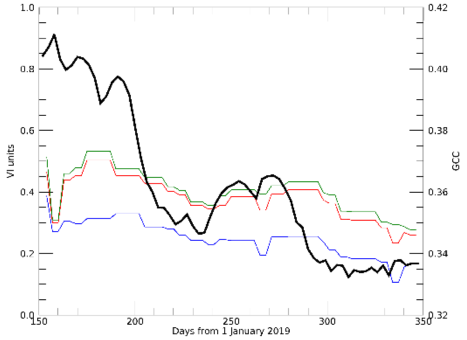
NEON_D08_TALL



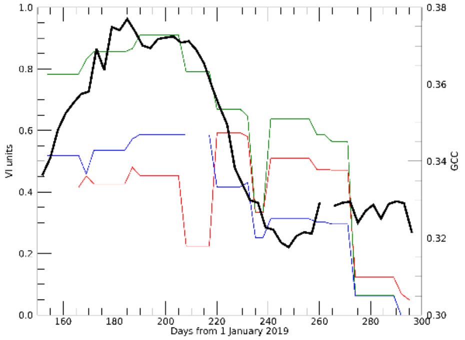
NEON_D04_GUAN



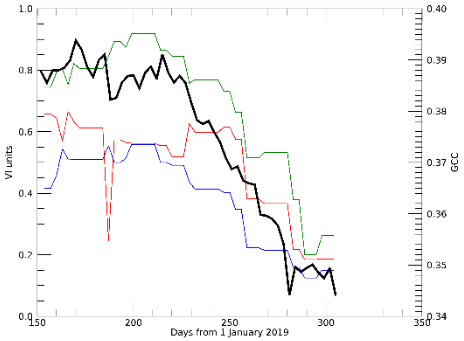
NEON_D11_OAES



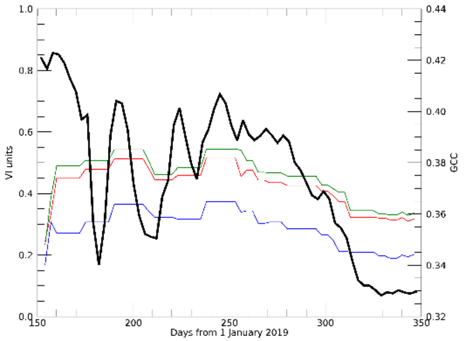
NEON_D18_TOOL



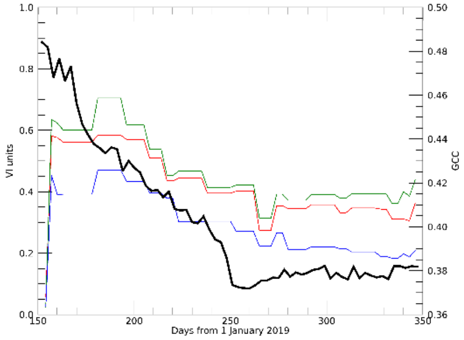
NEON_D19_BONA



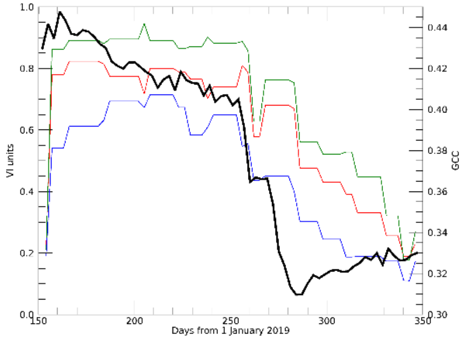
southerngreatplains



tworfta



willowcreek



TOA NDVI
TOC NDVI
TOC EVI
GCC

VI validation with PhenoCam (5)

- Brown et al. (2017)* found Spearman rank correlation coefficients (r_s) between MERIS TOC NDVI and PhenoCam GCC for 14 sites were positive except for one case, with a mean r_s value of 0.568 and standard deviation of 0.395
- This indicates that we should also see mostly positive correlations, with significant variability in the degree of correlation.
- r_s between GCC and TOC NDVI for 22 PhenoCam sites is shown below. Mean value = 0.564, standard deviation = 0.225
- This is very consistent with Brown et al. (2017).

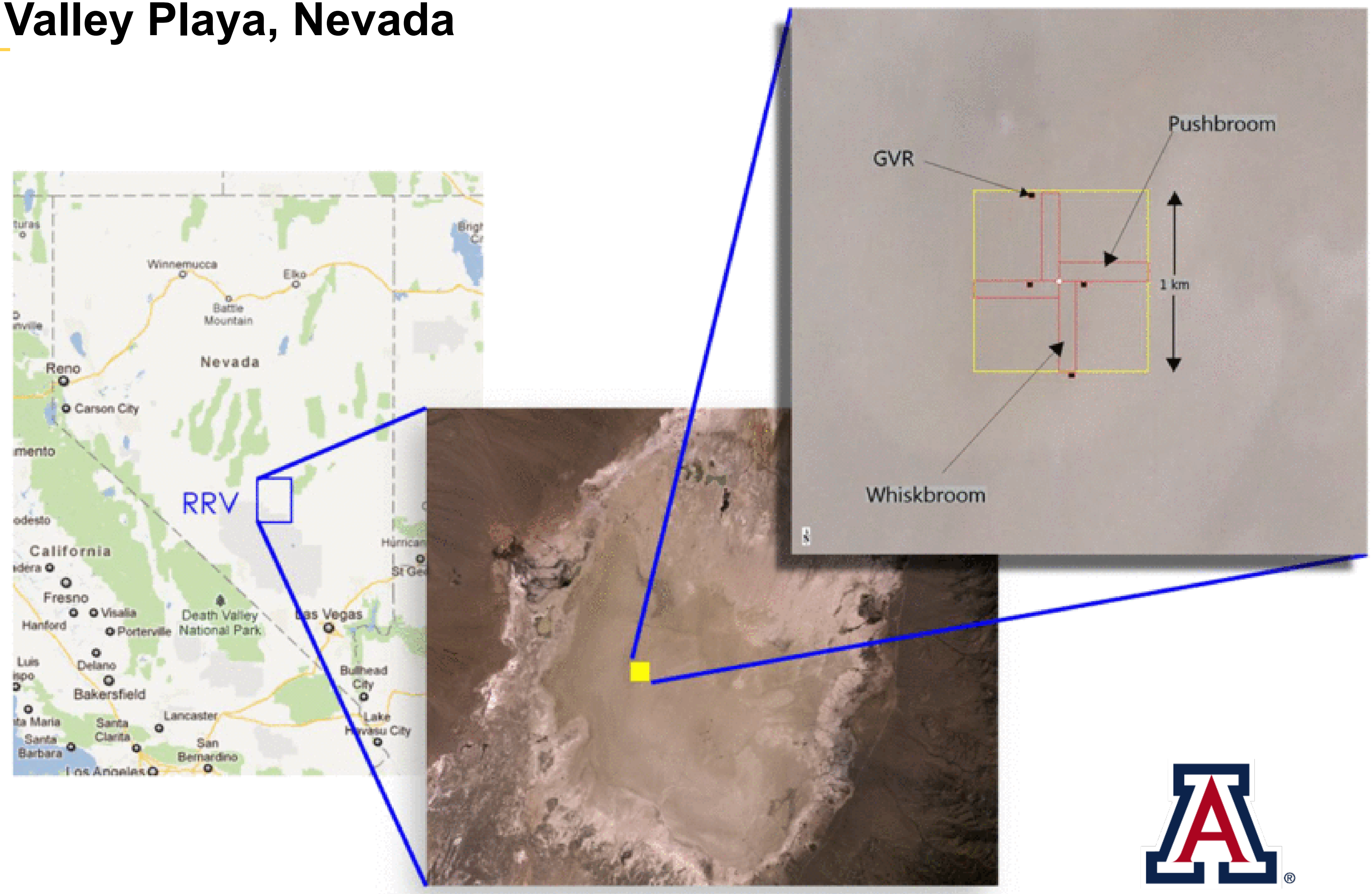
Site	$r_{s\_TOC\_NDVI}$		Site	$r_{s\_TOC\_NDVI}$
alligatorriver	0.399		montenegro	0.571
archboldpnot	0.106		morganmonroe2	0.724
burnssagebrush	0.462		NEON_D04_GUAN	0.339
cafcookeastltar01	0.118		NEON_D08_TALL	0.550
canadaOBS	0.849		NEON_D10_ARIK	0.408
dukehw	0.842		NEON_D11_OAES	0.690
jurong	0.667		NEON_D18_TOOL	0.857
luckyhills	0.779		NEON_D19_BONA	0.799
mandani2	0.246		southerngreatplains	0.578
mead2	0.554		tworfta	0.693
monteblanco	0.493		willowcreek	0.696

Brown, L. A., J. Dash, B. O. Ogutu, and A. D. Richardson, 2017. *On the relationship between continuous measures of canopy greenness derived using near-surface remote sensing and satellite-derived vegetation products.* Agricultural and Forest Meteorology, 247: 280-292. DOI: 10.1016/j.agrformet.2017.08.012

Validation of NOAA-20 VIIRS Vegetation Products at Railroad Valley Playa, Nevada

- Dried lakebed
- No vegetation
- Provision of
  - Surface reflectance
  - "Top-of-atmosphere" (TOA) reflectance

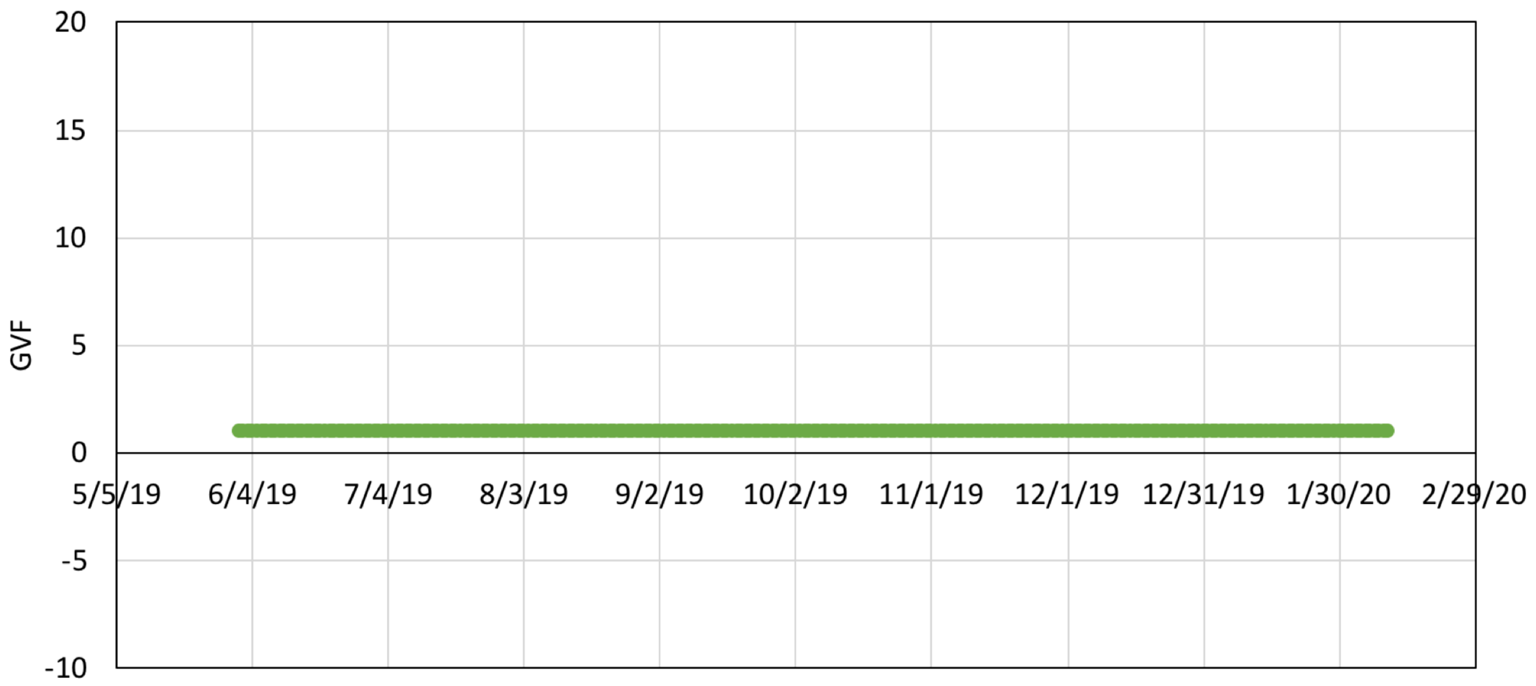
  representing a 1 km-by-1 km area at 30 min intervals
- *via* RadCalNet



(Source: Czapla-Myers et al., *JSTARS*, 2016)

NOAA-20 VIIRS GVF (Global)

- VIIRS GVF having its lowest value throughout the period examined (June 2019 – January 2020)



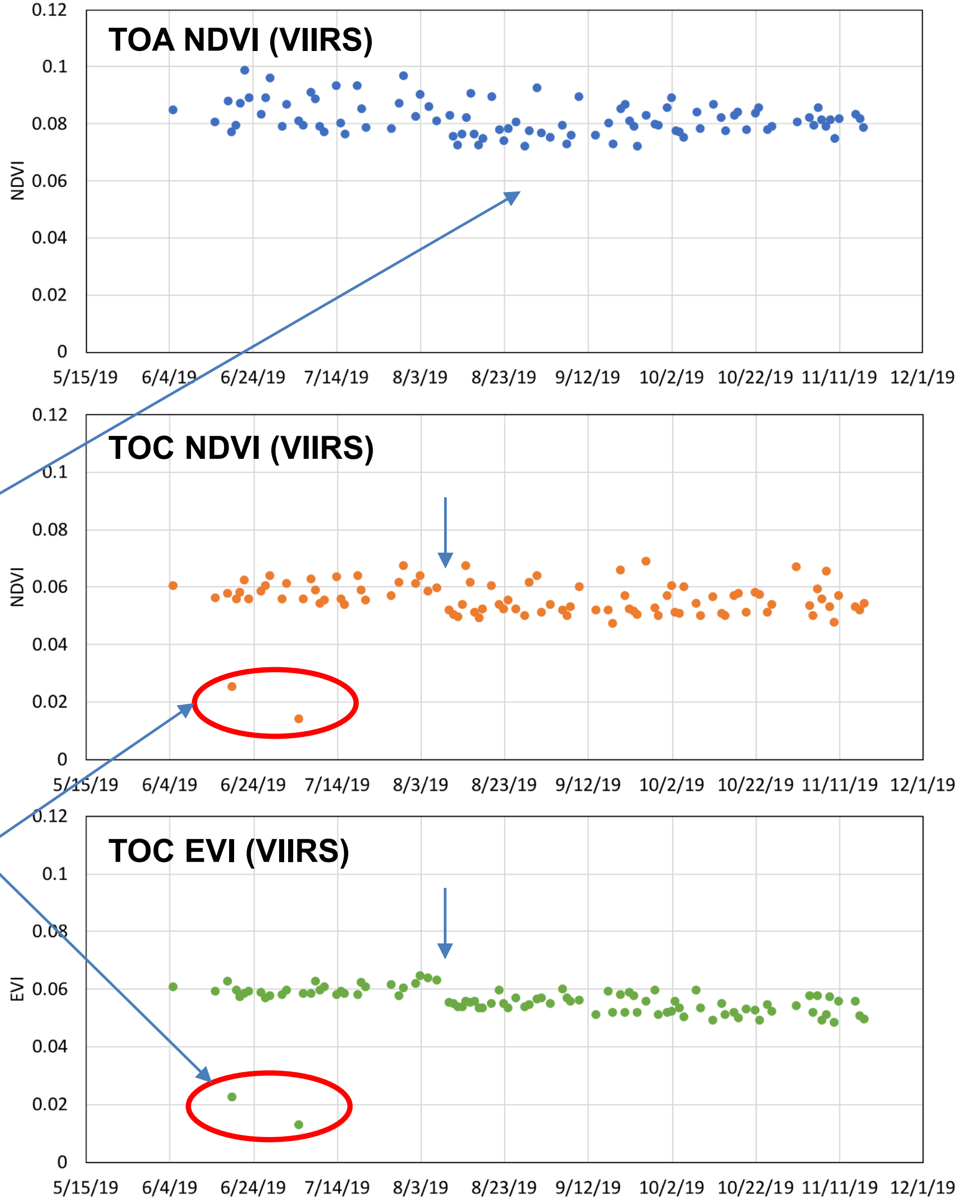
NOAA-20 VIIRS Vegetation Indices (Regional, Daily)

- Overall, N20 VIIRS and in situ measurements were comparable for all the three VIs
  - TOA NDVI
  - TOC NDVI
  - TOC EVI

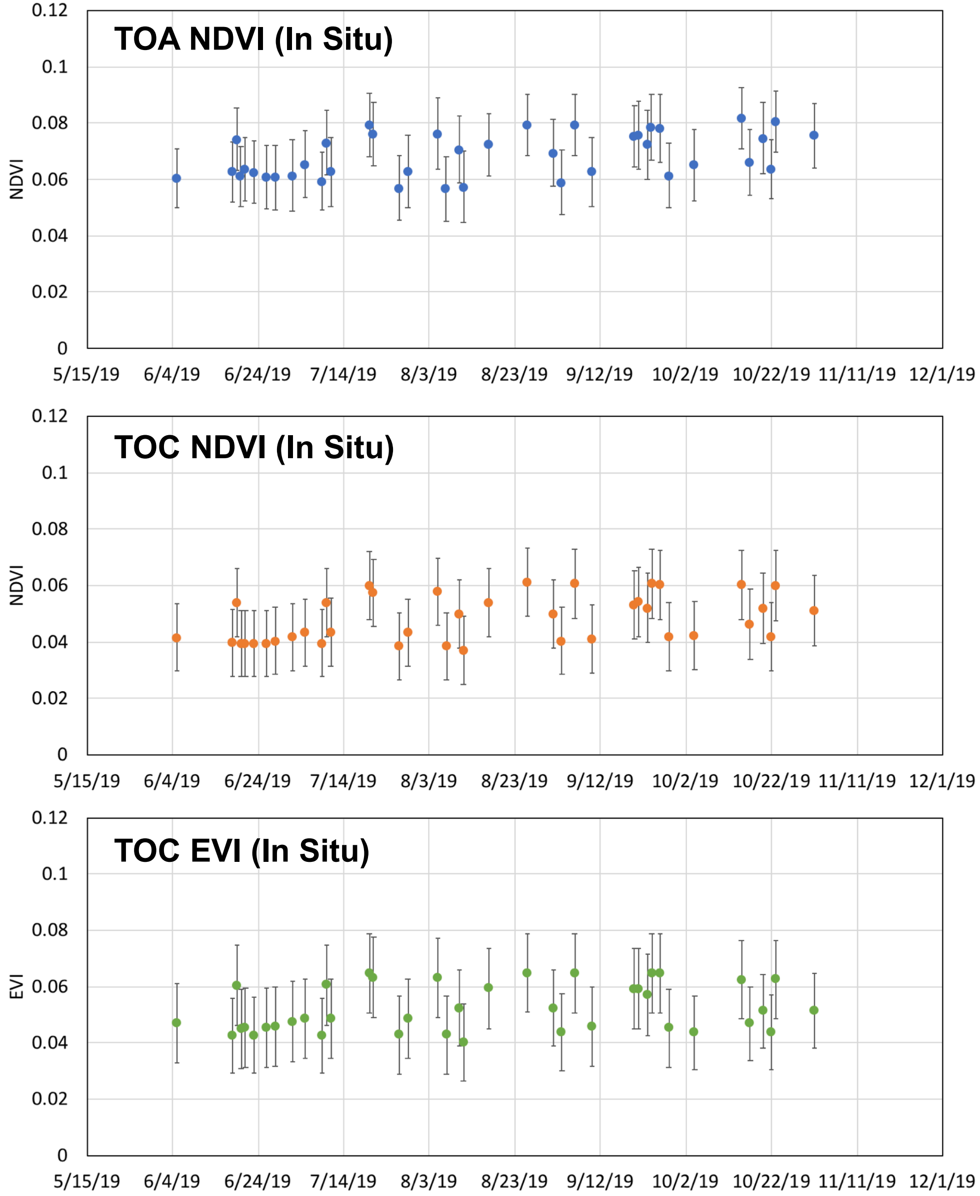
Small decrease in VI values
Consistent with seasonal cycle
seen in longer GVF time series

Atmospheric correction error
QF indicates "overall quality = high"

NOAA-20 VIIRS VI Data



In Situ Measured VI Data



APU Metrics: NOAA-20 VIIRS VIs (Regional, Daily)

Biophysical Parameters	Metric	Validation Result	L1 Requirement
TOA NDVI	Accuracy	0.015	0.05
TOA NDVI	Precision	0.011	0.04
TOA NDVI	Uncertainty	0.018	0.06
TOC NDVI	Accuracy	0.012	0.05
TOC NDVI	Precision	0.011	0.04
TOC NDVI	Uncertainty	0.016	0.06
TOC EVI	Accuracy	0.011	0.05
TOC EVI	Precision	0.012	0.04
TOC EVI	Uncertainty	0.015	0.06

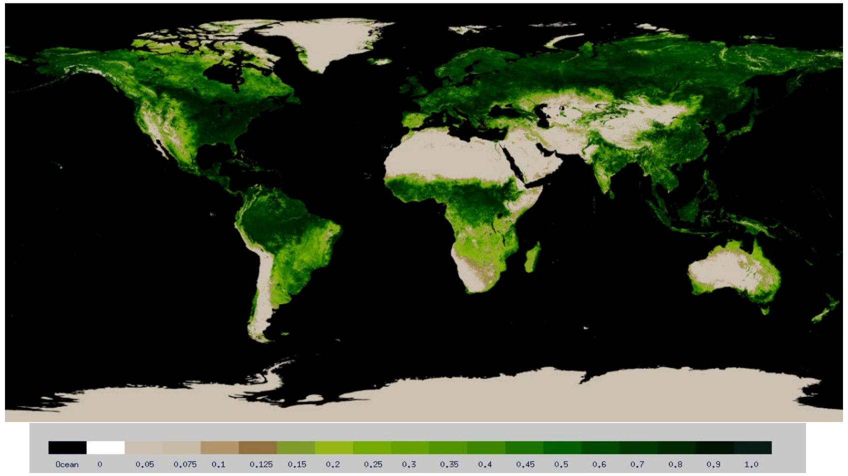
- For all the three VIs of TOA NDVI, TOC NDVI, and TOC EVI, all APU estimates from validation met and exceeded the corresponding L1 requirements.

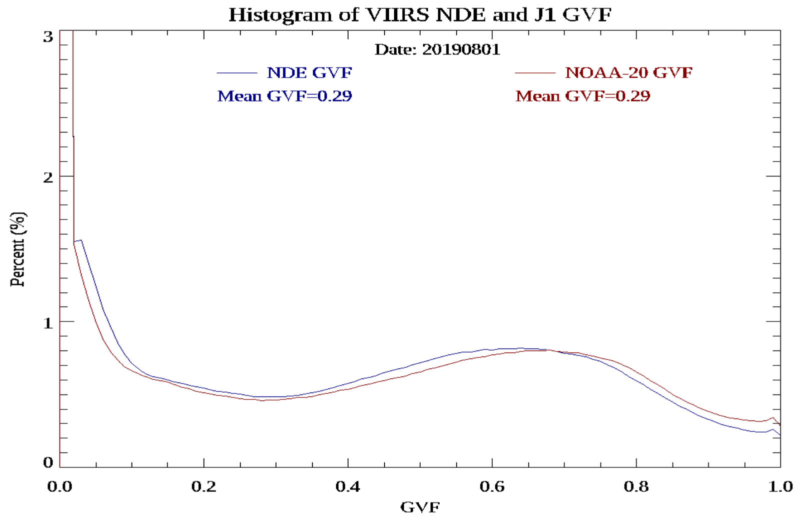
GVF algorithm performance evaluation

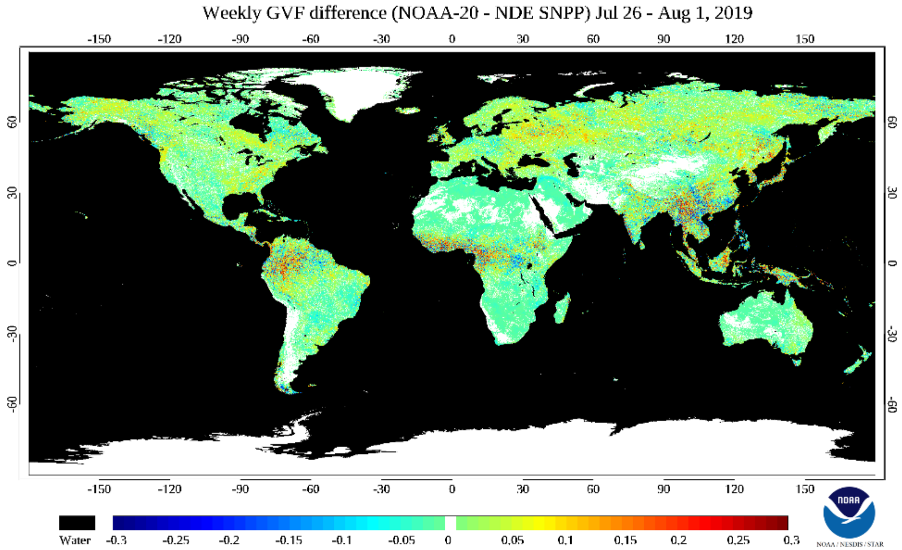
- NPP vs. NOAA20
  - NPP and NOAA20 GVF are generated with identically designed instruments in similar orbits, processed with the same algorithm. Values would be expected to be very close. This is demonstrated by
    - Histograms and differences for sample global data set
    - Site time series comparison (30 sites)
- NOAA20 time series vs. PhenoCam (48 sites)
  - Seasonal variations of GVF and GCC are expected to be similar. This is demonstrated by
    - Time series plots
    - Correlation coefficients
    - NOAA20 GVF correlations are higher than AVHRR climatology
- NPP and NOAA20 individual pixels vs. Google Earth images (77 sites)
  - High resolution (~1 m) Google Earth data are extracted for sample GVF pixel areas. Google Earth data are classified as vegetated or not vegetated.
  - GVF derived from Google Earth images are compared with VIIRS GVF values
  - Accuracy, precision and uncertainty of NOAA-20 GVF are calculated

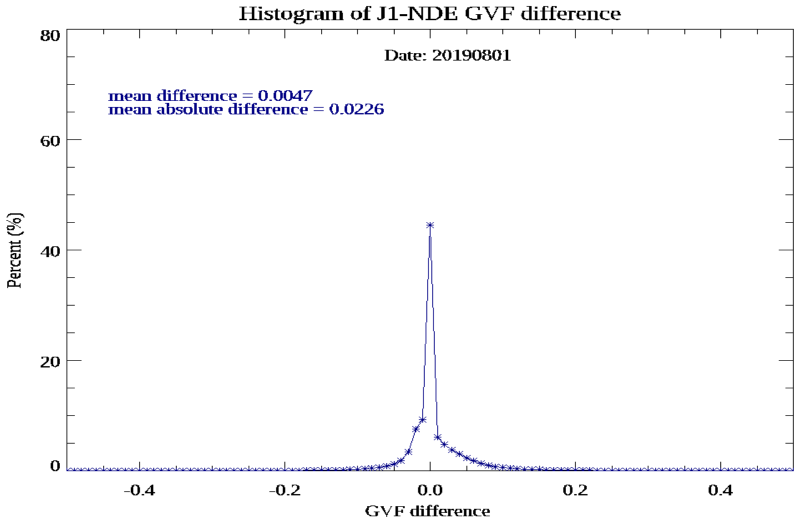
SNPP and NOAA-20 GVF comparison

NOAA-20 weekly GVF (Jul26-Aug 1, 2019)



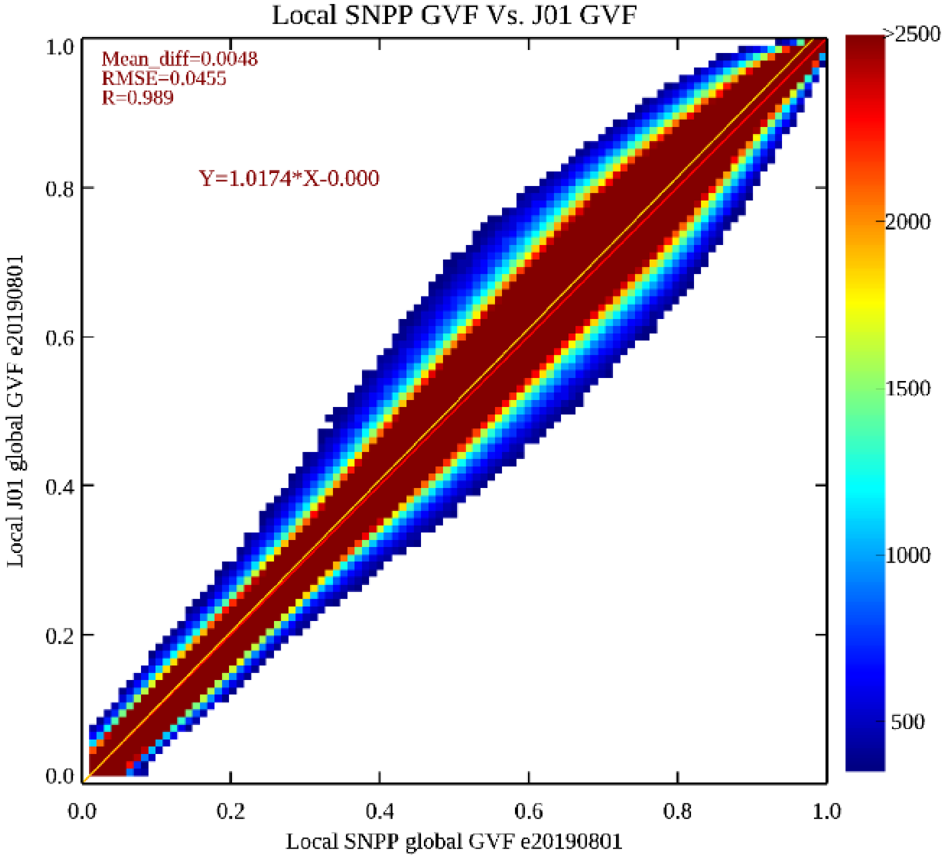


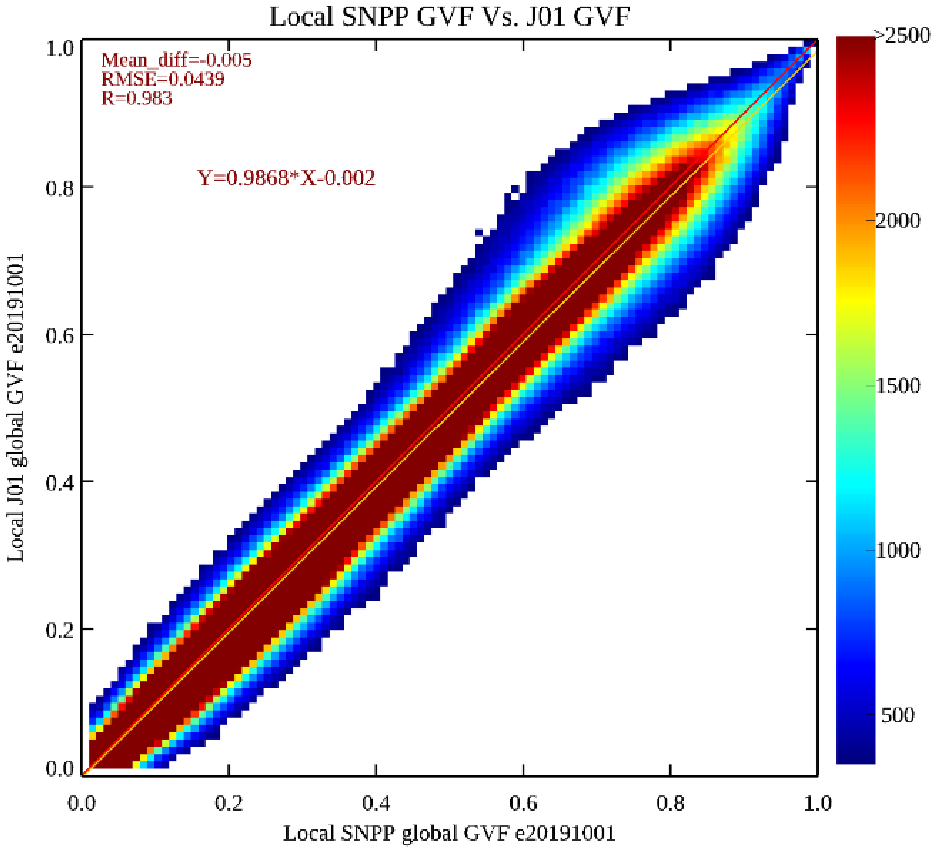




- GVF difference (SNPP-N20) map showed small difference between them with mean difference=0.004

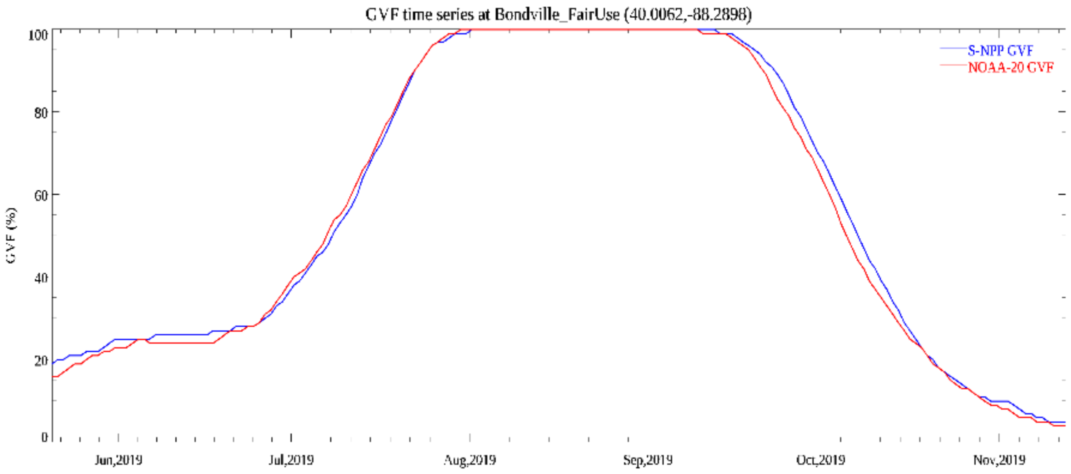
SNPP and NOAA-20 GVF comparison

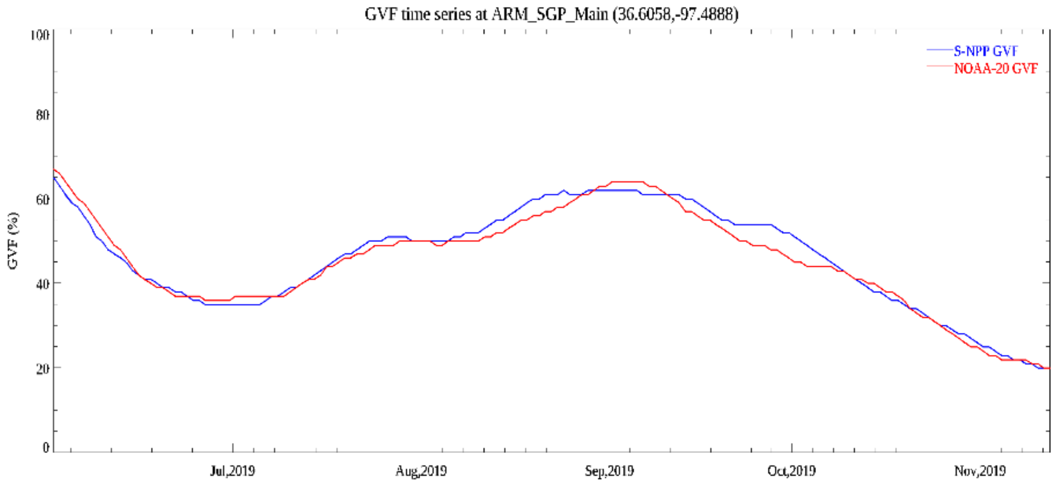


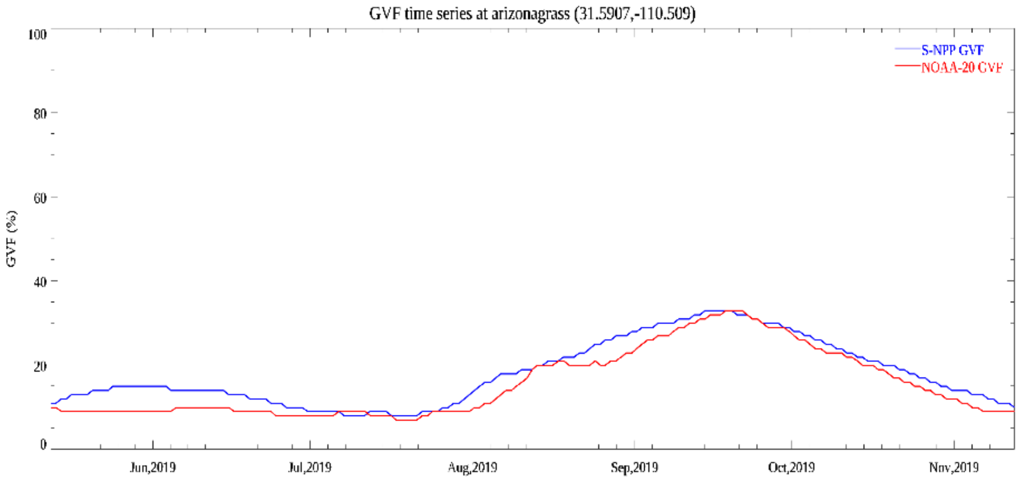


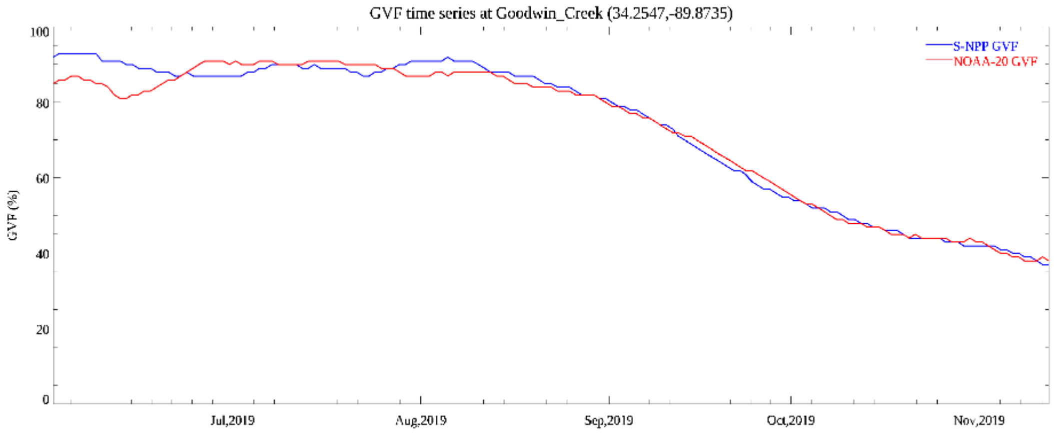
- Scatter plots between global SNPP and NOAA-20 GVF data showed strong agreement between them with RMSE=0.04 and R=0.98

SNPP and NOAA-20 GVF time series comparison examples (1)



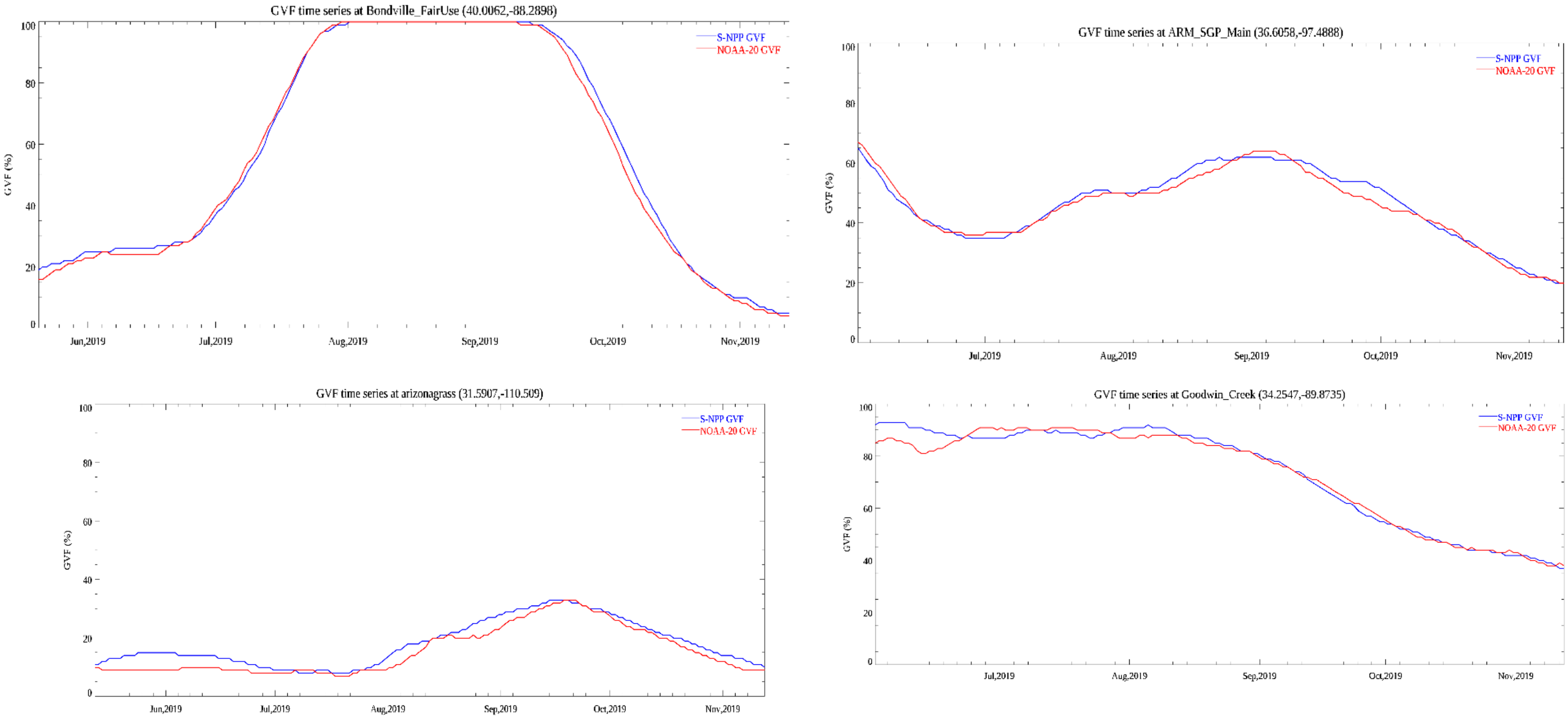






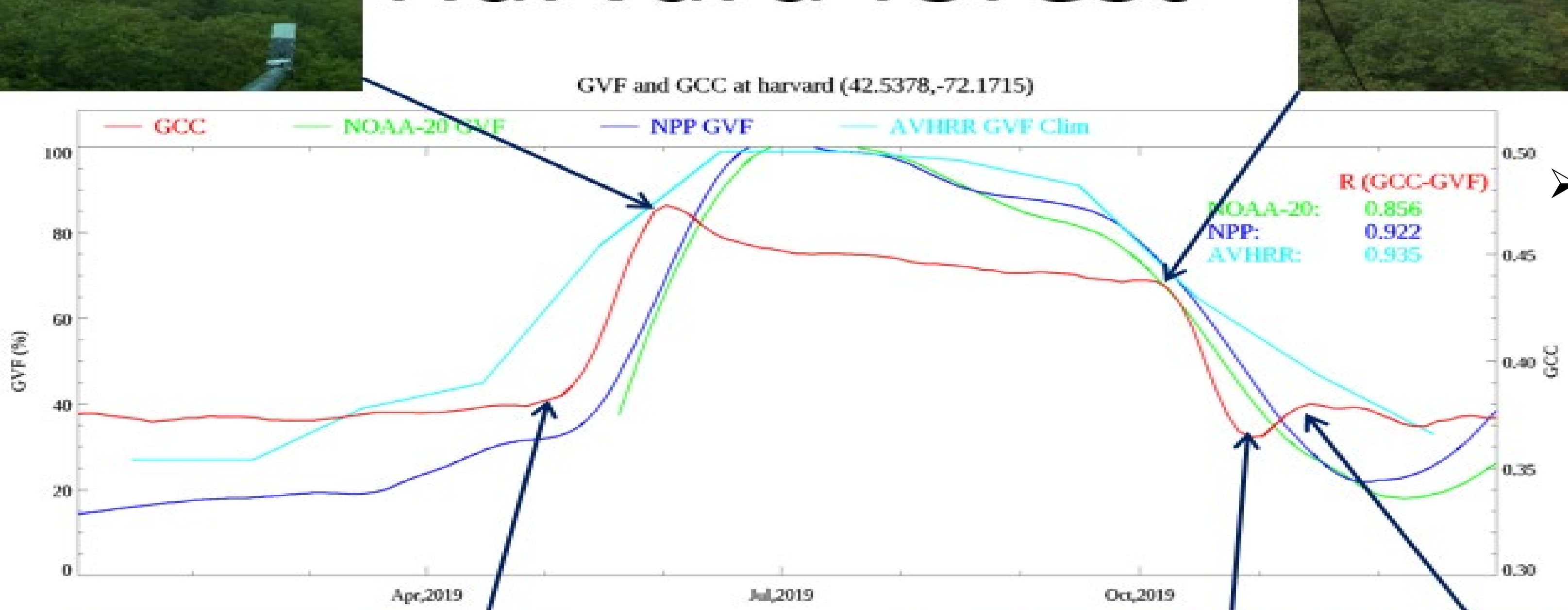
- Time series of SNPP and NOAA-20 GVF showed similar seasonal variation of different sites

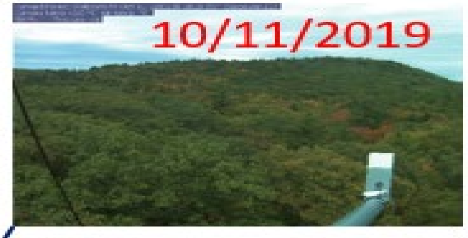
SNPP and NOAA-20 GVF time series comparison examples (2)



- Time series of SNPP and NOAA-20 GVF showed similar seasonal variation of different sites

Example of PhenoCam GCC and GVF time series comparison

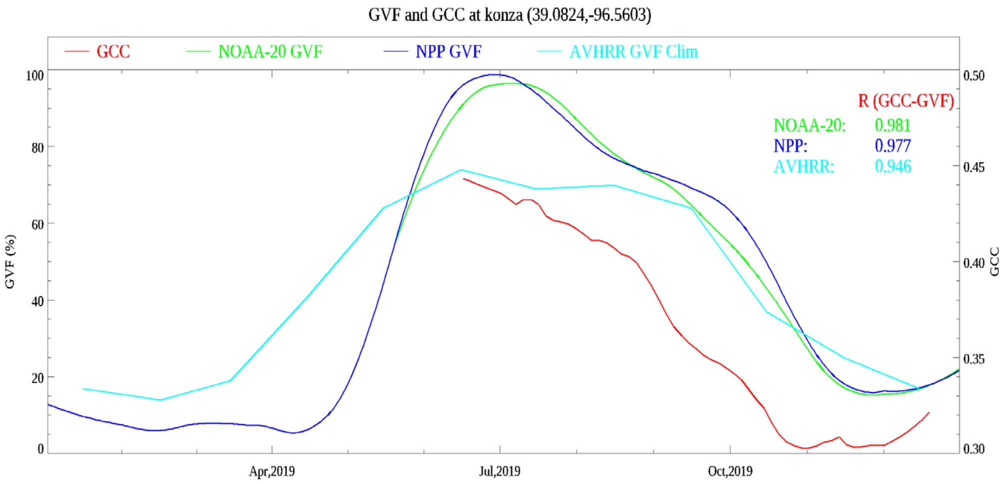


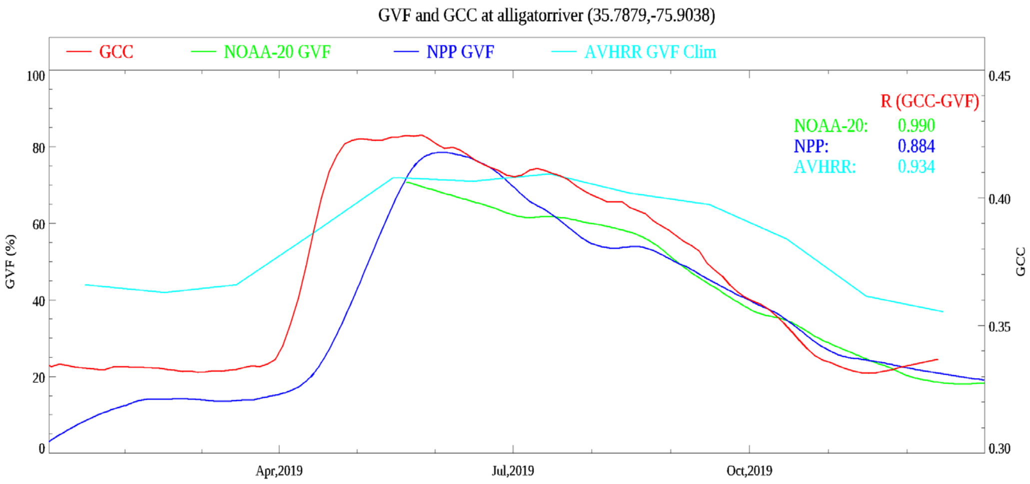


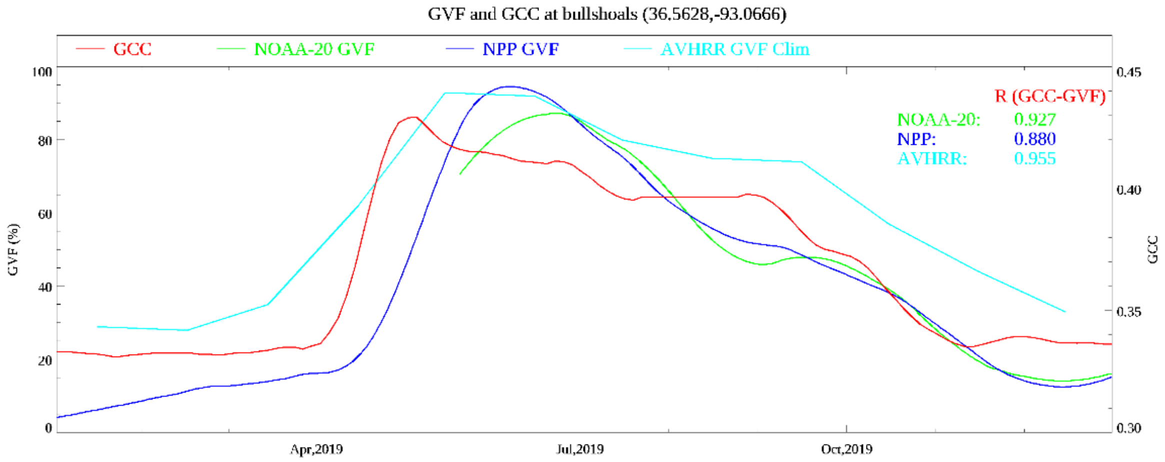
- High correlation coefficient (R) values between ground measured PhenoCam GCC and VIIRS GVF

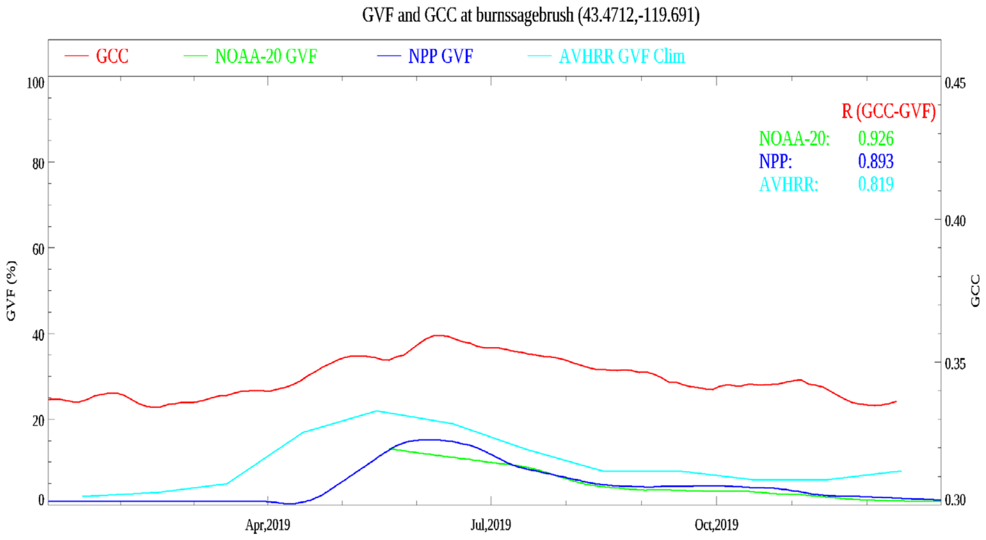
1. Ground measured PhenoCam GCC reflects seasonal green vegetation growth cycle
2. NPP and NOAA20 GVF followed the GCC seasonal cycles very well
3. AVHRR GVF climatology profile showed early green-up timing than GCC time series

VIIRS GVF vs. PhenoCam GCC plots and correlations (1)

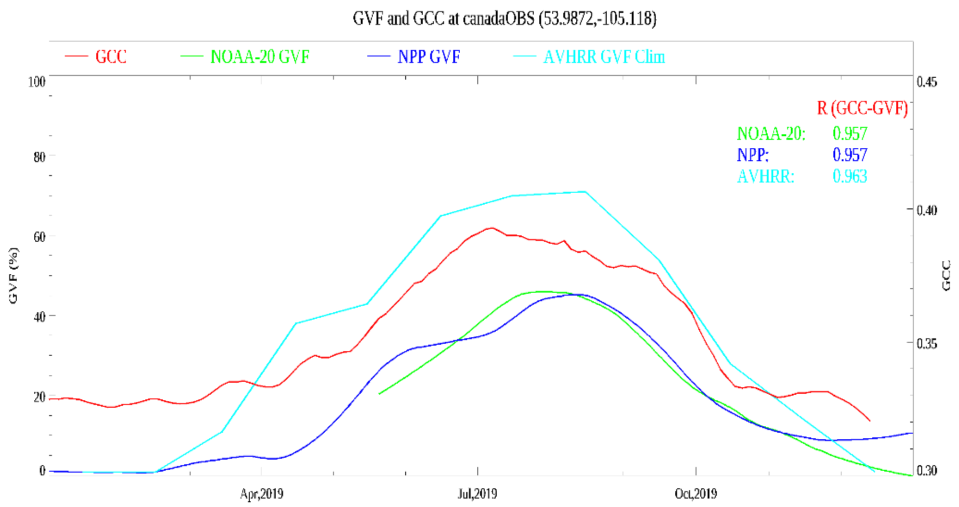


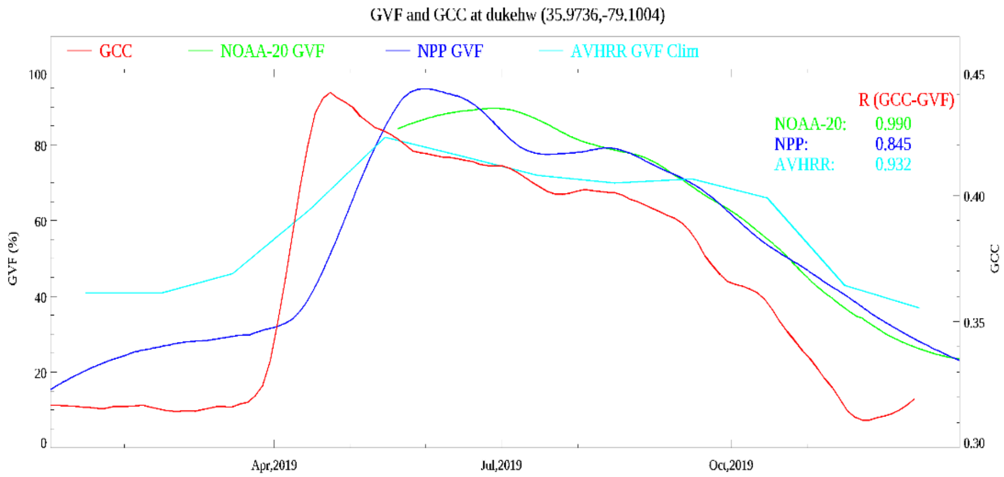


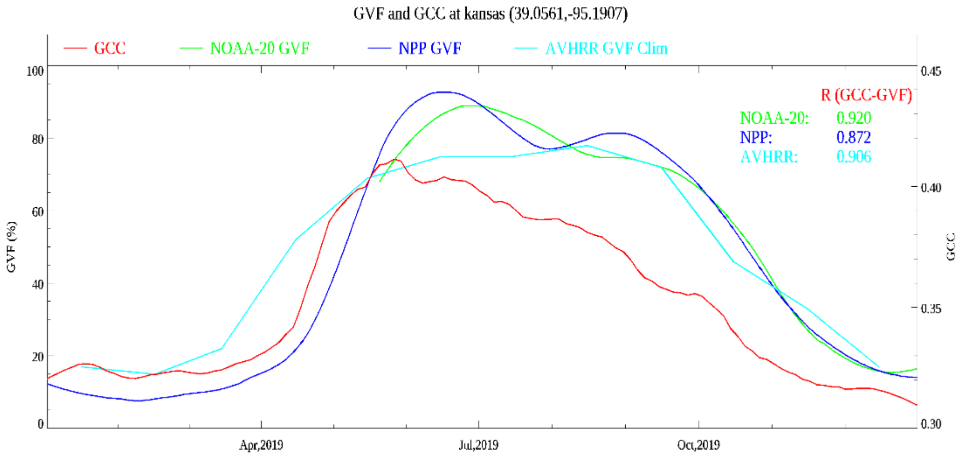


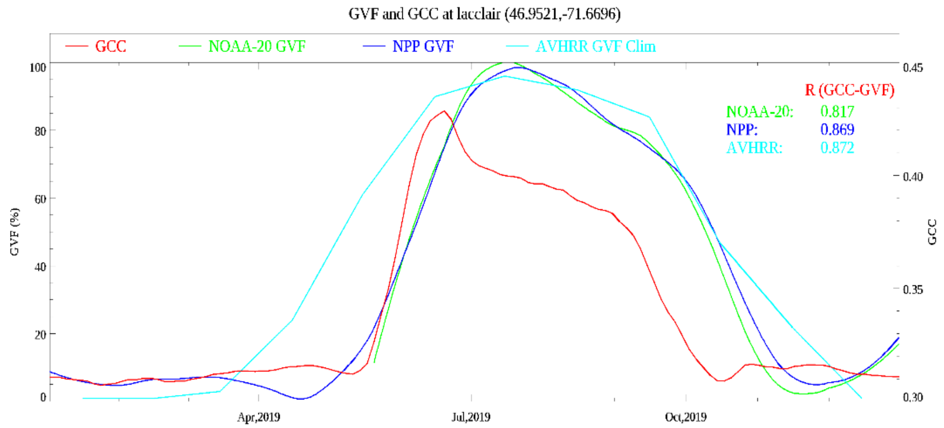


VIIRS GVF vs. PhenoCam GCC plots and correlations (2)

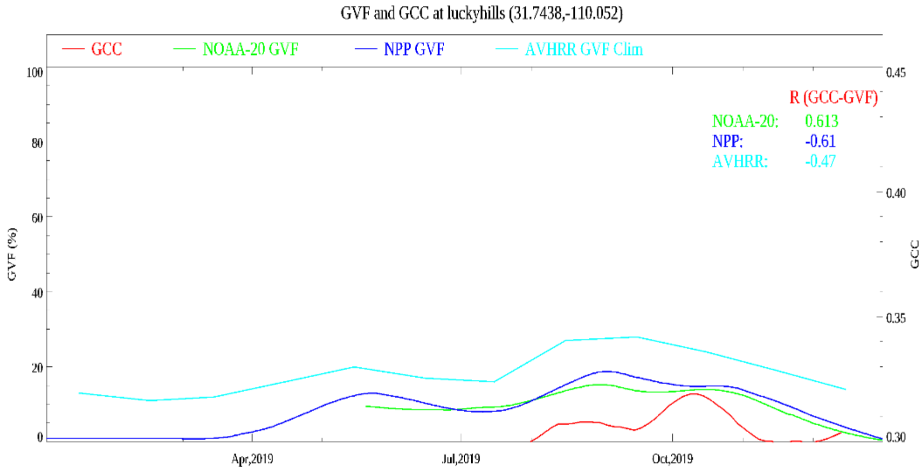


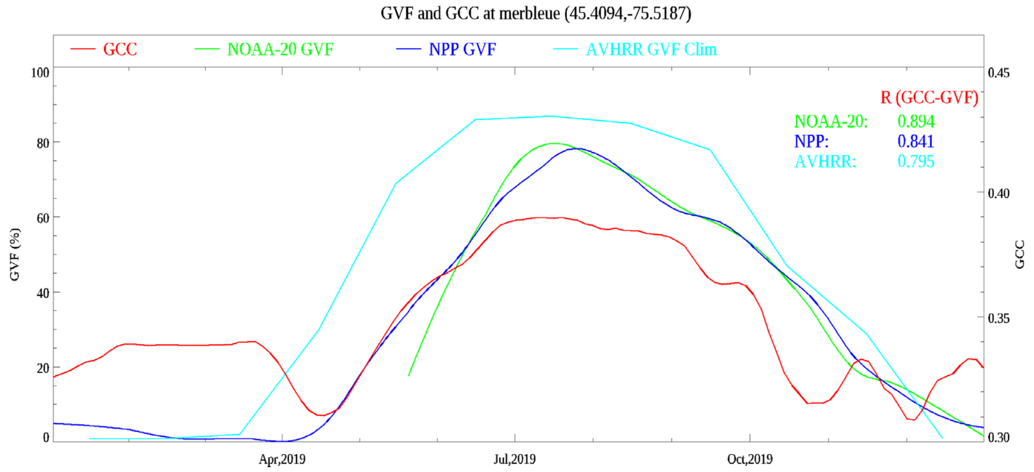


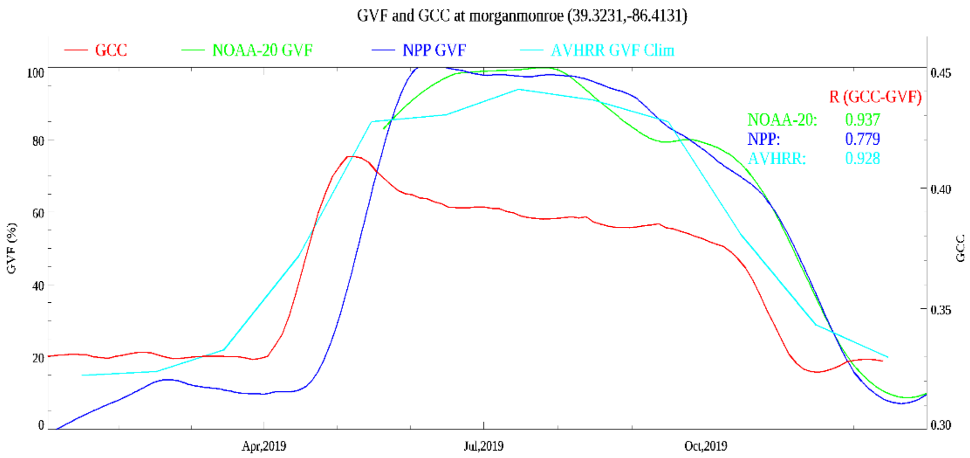


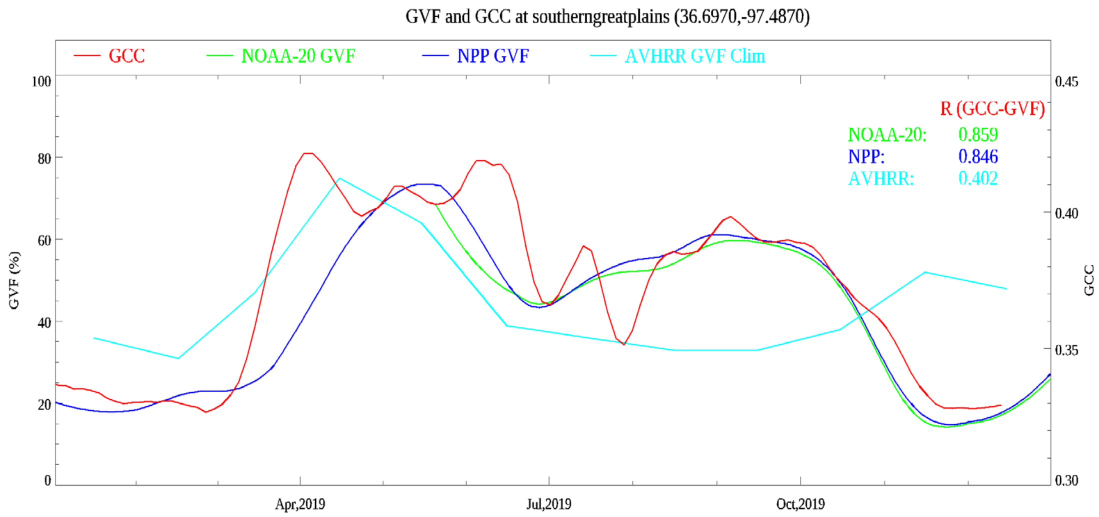


VIIRS GVF vs. PhenoCam GCC plots and correlations (3)

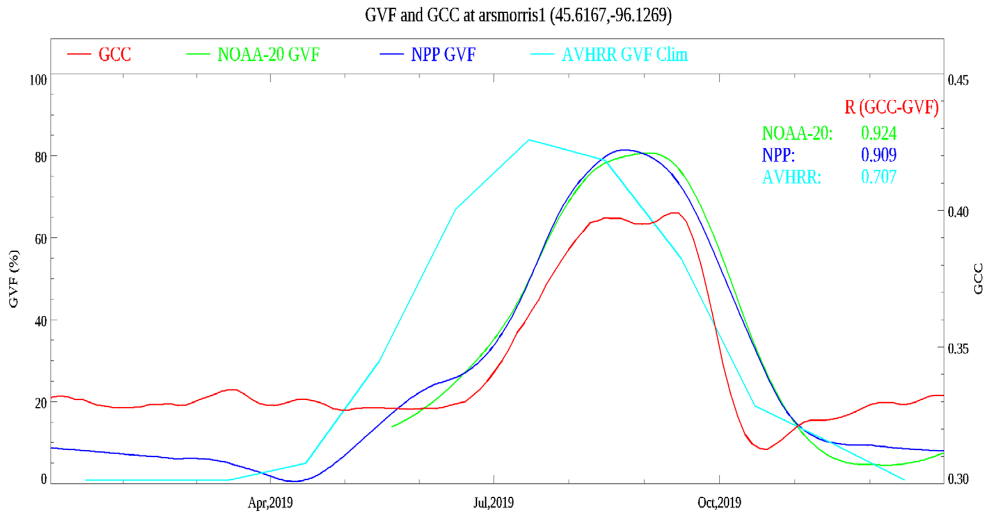


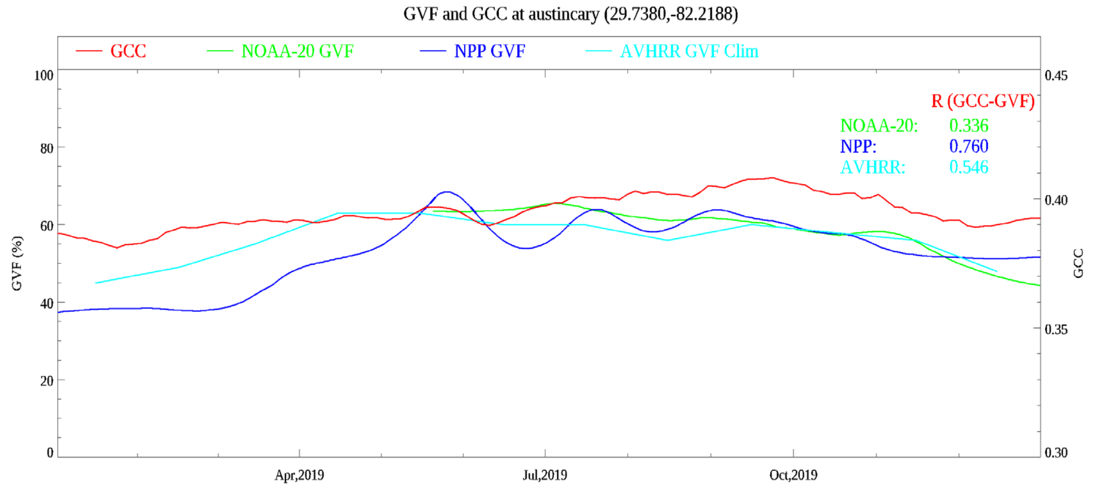


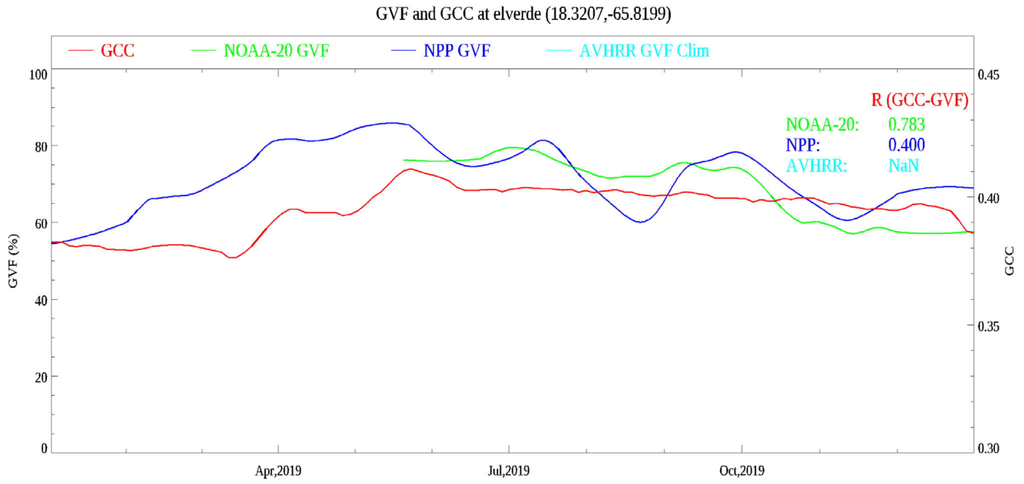


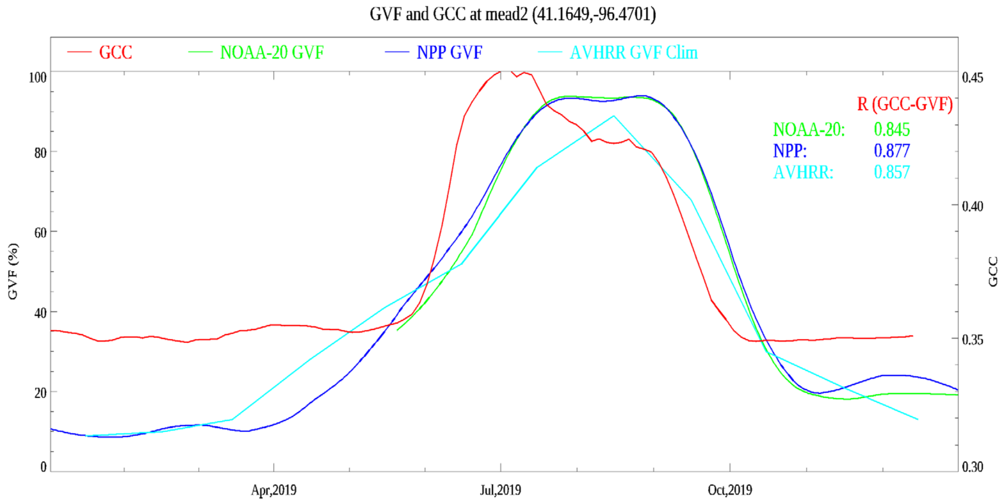


VIIRS GVF vs. PhenoCam GCC plots and correlations (4)









VIIRS GVF vs. PhenoCam GCC: Summary

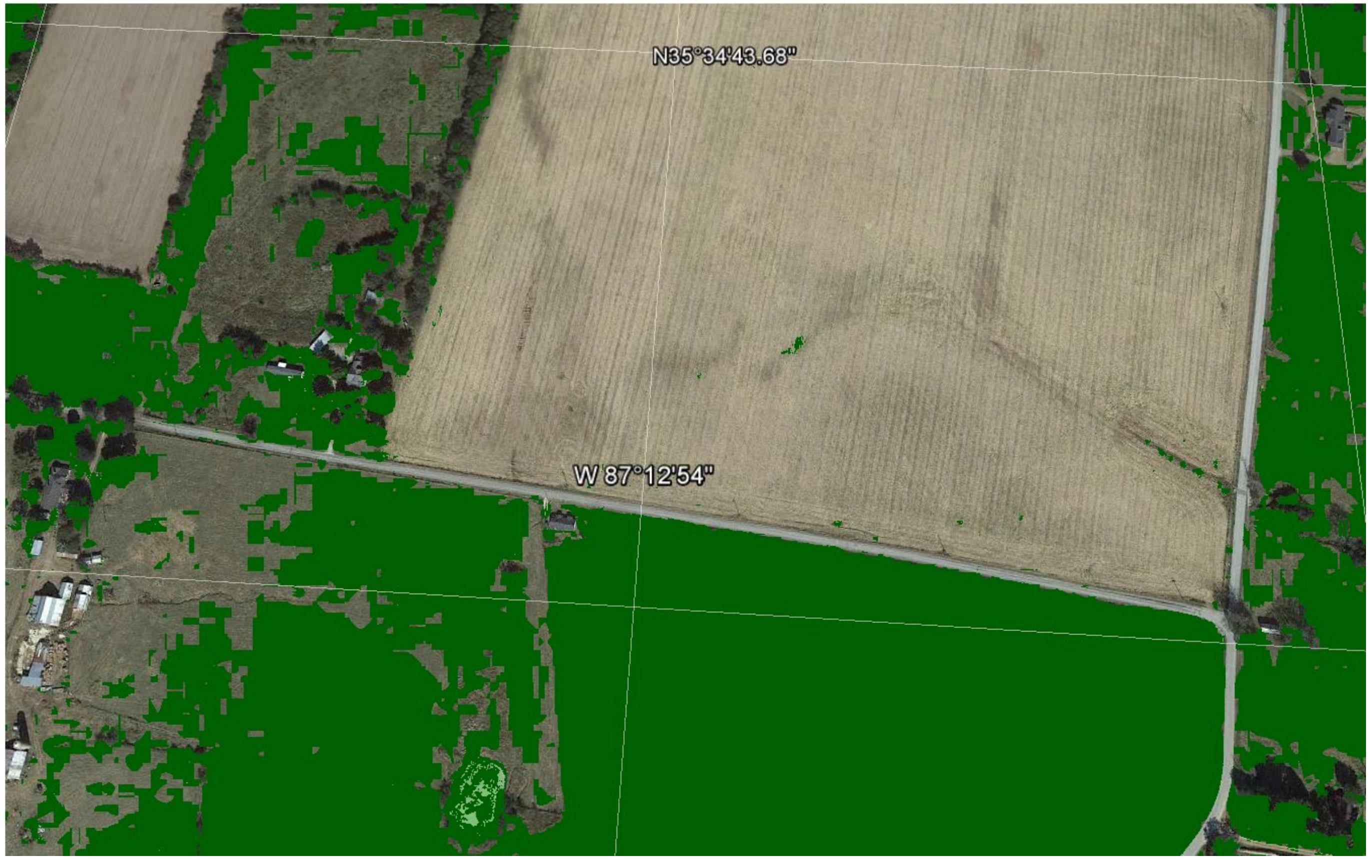
- PhenoCam images can be used for monitoring vegetation phenology and validating seasonal variation of GVF products
- VIIRS GVF seasonal cycles matched ground measured PhenoCam phenology
- PhenoCam GCC are highly correlated with VIIRS GVF. Correlations are higher with VIIRS GVF than AVHRR climatology GVF.
- AVHRR GVF climatology time series showed early green-up timing than GCC time series at some validation sites

GVF vs. Google Earth evaluation: Data and method

- High resolution (~1-m) RBG images with imagery dates are available on Google Earth
- Google Earth images over VIIRS GVF pixels, areas of 0.036° by 0.036°, were downloaded from Google Earth
- Green pixels on the high resolution Google Earth images were extracted by using a Green Color index (GCI)
    - GCI=3*Green-2*Red-Blue-20
    - If GCI>0 then pixel is classified as green
    - GVF=percentage of pixels where GCI>0
- GVF of Google Earth images were compared with VIIRS GVF
- 77 high resolution Google Earth images were downloaded from Google Earth for GVF validation

Google Earth example: Original Google Earth data

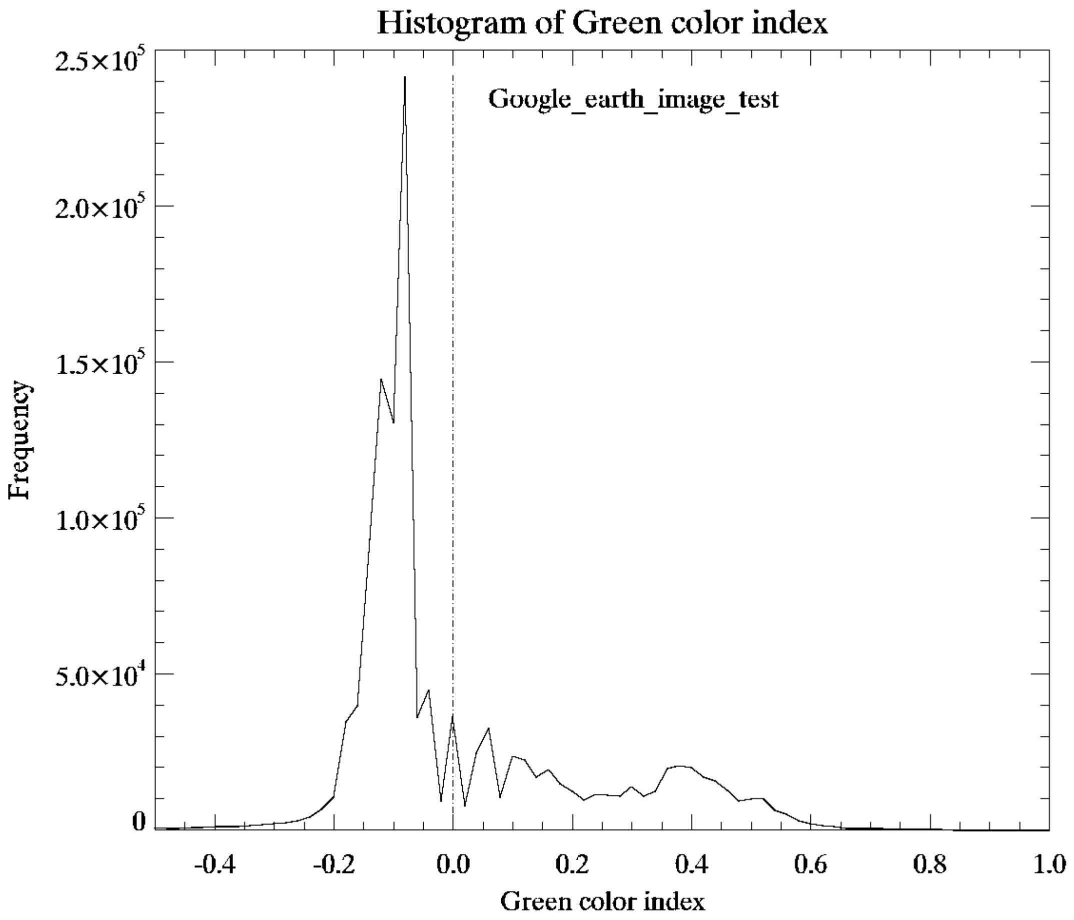
Google Earth example: Classification of data



GVF=0.34 (when threshold=30)

Google Earth example: Green pixels selected

Google Earth example: Green color index histogram



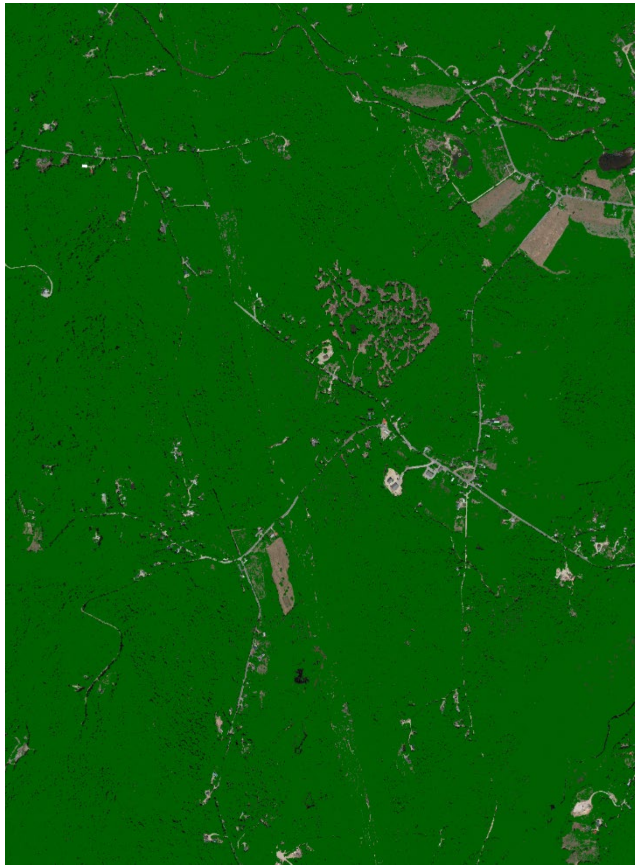
Google Earth results example: Alexandria

High resolution Google Earth image:

(6912×9472) pixels

Google Earth image over a 0.036-degree VIIRS GVF pixel

(7/7/2019)



Classified image (vegetation pixel: green)

Google Earth GVF=0.98
NPP GVF=0.90
J01 VIIRS GVF=0.97

Google Earth results example: Bellvue

High resolution
Google Earth image:

(6912×9216) pixels

Google Earth image over
a 0.036-degree VIIRS
GVF pixel

(7/17/2019)

Classified image
(vegetation pixel: green)

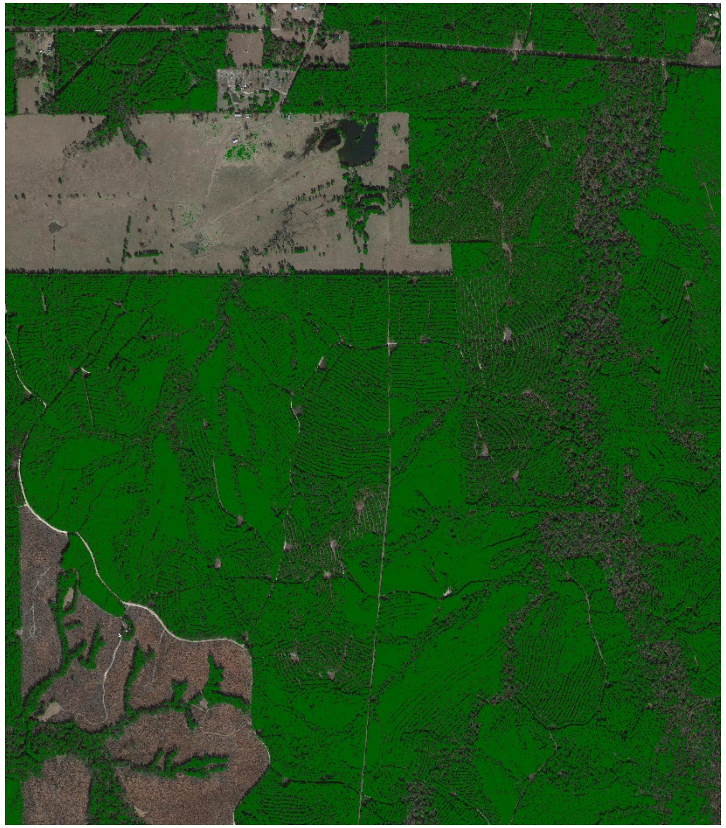
Google Earth GVF=0.427
NPP GVF=0.47
J01 GVF=0.45

Google Earth results example: Carmona

High resolution
Google Earth image:

(6912×7936) pixels

Google Earth image over a 0.036-degree VIIRS GVF pixel (11/17/2019)



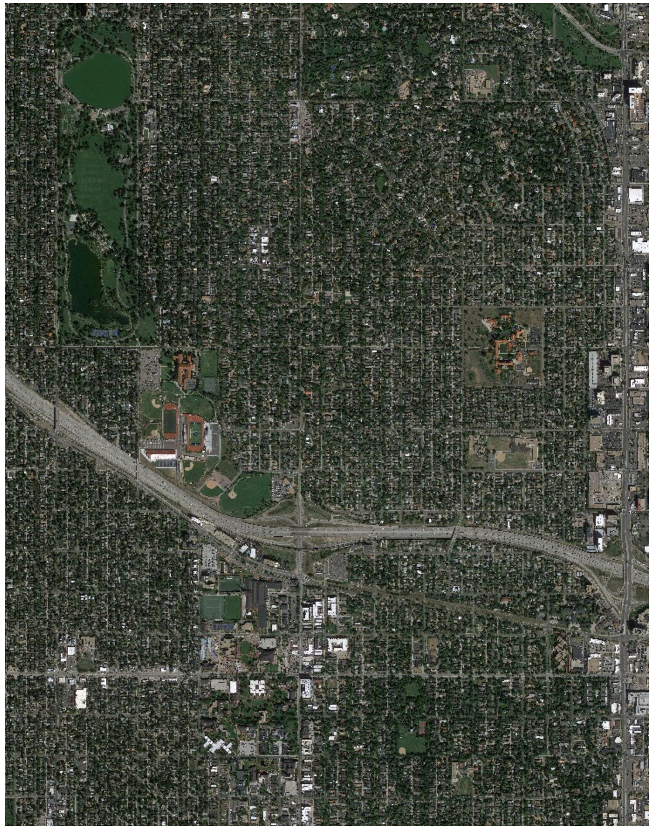
Classified image (vegetation pixel: green)

Google Earth GVF=0.492
NPP GVF=0.46
J01 GVF=0.48

Google Earth results example: Denver

High resolution
Google Earth image:

13824×17664 pixels



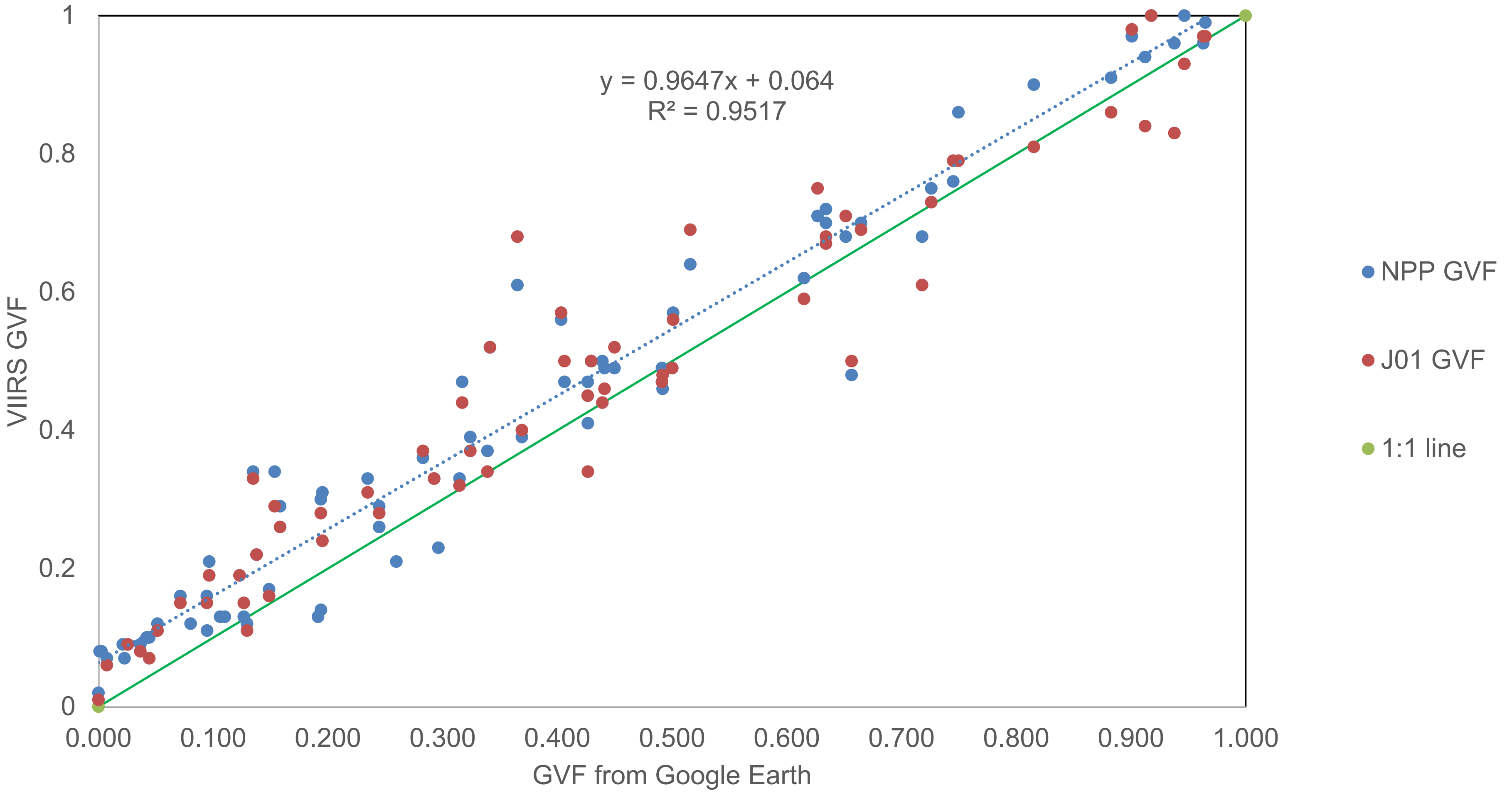
Google Earth image over a 0.036-degree VIIRS GVF pixel

(9/12/2019)

Classified image
(green vegetation: green)

Google Earth GVF=0.369
NPP GVF=0.39
J01 GVF=0.40

VIIRS 4-km GVF compared with Google Earth GVF



VIIRS GVF/ Google Earth validation statistics

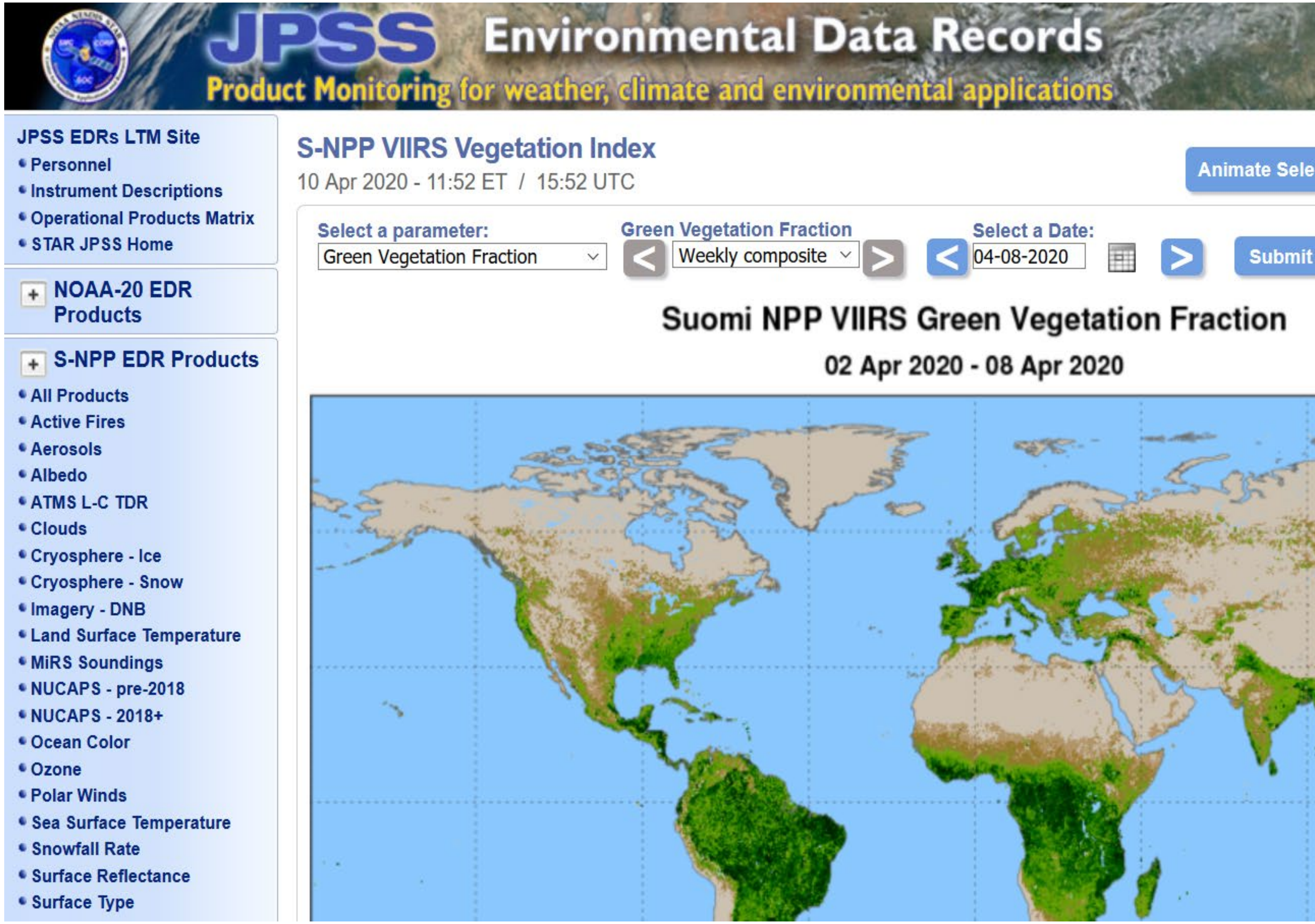
	Accuracy	Precision	Uncertainty
NPP GVF	0.051	0.063	0.081
NOAA-20 GVF	0.043	0.075	0.086
Requirement	0.12	0.15	0.17

VIIRS GVF/ Google Earth validation conclusion

- High resolution (~1m) green pixels can be identified using a green color index and GVF can be derived from Google Earth RGB images
- Good agreement was found between the VIIRS GVF and the GVF derived from Google Earth images with R^2=0.951
- The VIIRS GVF has low bias (0.05), and small uncertainty (0.08), indicating that NOAA20 GVF met the requirements

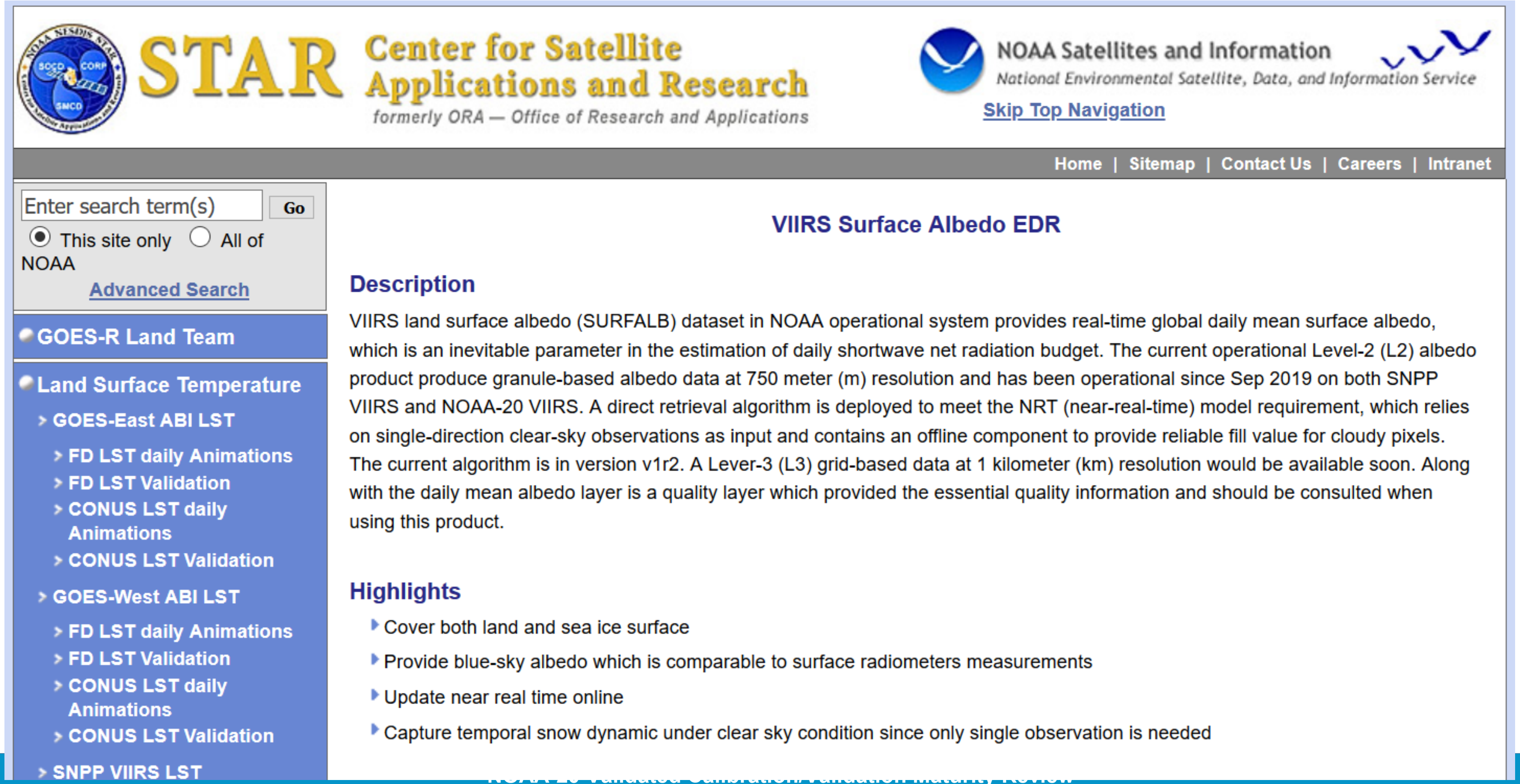
VIIRS VI / GVF Long term monitoring (1)

- Local long term monitoring tool is in development
- STAR monitoring tool is running for GVF (shown to right). STAR monitoring for VI is in development
- Images have been produced for STAR monitoring tool. So far, images have been produced for
  - NPP: 20180508 to 20200131
  - NOAA20: 20190604 to 20191204
- Image production for STAR monitoring tool is ongoing

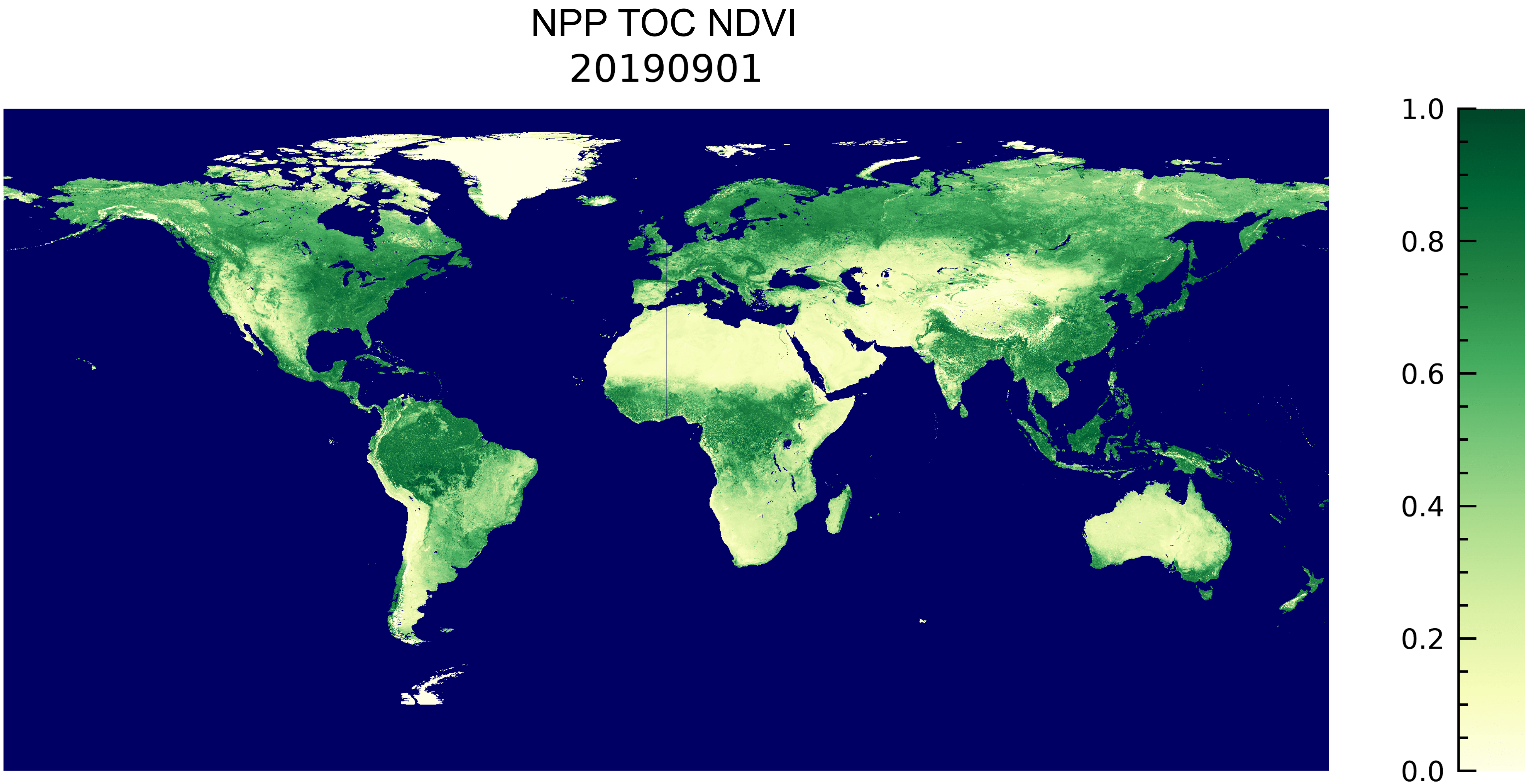


VIIRS VI and GVF Long term monitoring (2)

- A draft long term monitoring page has been developed by the VIIRS Albedo and LST teams: https://www.star.nesdis.noaa.gov/smcd/emb/land/snpp_lsa.php
- The page includes itemized known issues and data animations
- All land products will be included in this set of web pages. The page design will be adapted for use with VI and GVF data.
- As an example, the page for surface albedo is shown below.



Sample of animation to be used for long-term monitoring



User concerns for Vegetation Index

- Vegetation indices are widely used in many areas of agricultural, ecosystem, and global change research, but are not usually ingested into models
- TOA NDVI, TOC NDVI, and TOC EVI are among the most widely used vegetation indices.
- The purposes of the VIIRS VI products are continuity with previous AVHRR and MODIS records, and research into vegetation conditions and trends
- The format of the NVPS VI data sets is very similar to those of other available VI products. Their use should be straightforward to anyone familiar with VI data products.

Current Primary GVF Users:

- NOAA Earth System Research Lab/GSD, HRRR (Stan Benjamin, Tanya Smirnova)
- NCEP/EMC, Land Model (Jack Kain, Helin Wei)
- NESDIS/STAR, SMOPS (Xiwu Zhan)
- NDE downstream products: VIIRS LSE, LSA
- NASA /SPoRT Center (Jonathan Case)

Users and feedback (1)

Key User	Brief Summary
Helin Wei NCEP/EMC	GVF is one of the most important parameters to control land surface processes. The current GVF is monthly AVHRR-based 5-year climatology, which presents limitations such as that the annual cycle of vegetation is always represented in the same manner in models from year to year. Therefore the model produces the large bias in the anomaly years particularly during the seasonal transitions. To overcome this deficit, the new near real-time VIIRS GVF has been extensively tested in EMC NWP models and some positive results have been found. This new dataset has been planned to replace the old data in the next GFS implementation
Heshun Wang NOAA/STAR	GVF is an essential input data for NOAA LSE product, which is based on the vegetation cover method, VIIRS daily rolling weekly GVF is used to account for the LSE dynamic variation. The LSE product has been operationally used in the VIIRS LST product and will be incorporated into the GOES16/17 ABI LST product in the near future.
CLASS	VIIRS VI and GVF product archive and distribution

Users and feedback (2)

Tanya Smirnova NOAA/ESRL	Here at ESRL, we develop WRF-based operational Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) with the main focus on severe weather that have an impact on aviation operations. This summer we started testing the real-time VIIRS-GVF to replace the MODIS climatology to explore if this product can improve RAP/HRRR surface predictions. I ran in parallel two version of RAP for a couple of weeks: one with the MODIS climatology from WRF and another with real-time VIIRS GVF. I have noticed substantial differences between the two products in the SW US and also in Canada and Alaska. We plan to introduce VIIRS GVF into the next implementation of RAP and HRRR (RAPv4 and HRRRv3) at NCEP. We greatly appreciate your work on producing this real-time product. (Note: RAPv4 and HRRRv3 were implemented in operations on July 12, 2018. The VIIRS GVF is in operational use in these models now.)
Jonathan Case NASA/SPoRT	Based on a 3-yr preliminary analysis that I presented at the National Weather Association annual meeting, the VIIRS GVF product over the CONUS responded realistically to anomalies in weather/climate regimes I have transitioned the VIIRS GVF into NASA/SPoRT's real-time Noah land surface model runs using the NASA Land Information System framework. Visualization of the VIIRS GVF product over Eastern Africa has shown good behavior in depicting the variation in greenness in response to seasonal changes in the ITCZ location and corresponding rainfall.

Downstream products

- VIIRS GVF is an input to the NOAA Land Surface Emissivity (LSE) product, which in turn is used in the production of VIIRS Land Surface Temperature (LST).
- VIIRS GVF will be incorporated as an input of the GOES16/17 ABI offline LSE, which will be used in the ABI LST product in the near future
- Vegetation indices may be used as input for the generation of Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation absorbed (FPAR) data products

Risks, Actions, and Mitigations

Identified Risk	Description	Impact	Action/Mitigation and Schedule
Less than a full year of data used to conduct validation	Reprocessed NPP VI is available beginning March 26, 2019 and reprocessed NOAA20 VI beginning May 20, 2019. CLASS data are available from November 20, 2019 to present. Less than a full year of data was used in the validation analysis, which for most ecosystems means that the full phenological cycle was not represented.	low	**Open.** As more data are produced by CLASS, validation analyses can be repeated using longer time series.
Good quality pixels may be flagged as low quality	A relatively low percentage of pixels are flagged as high quality. Only pixels flagged as high quality have been shown to meet spec. More pixels than are now flagged may actually be sufficiently high quality to meet spec.	medium	**Open**. Quality flags have been reconfigured to indicate finer gradations of product quality. Analysis must be done to evaluate performance for pixels in different quality categories. .
Small number of high VI value pixels have higher accuracy and precision statistics	A small fraction of high VI pixels have accuracy and precision statistics over the spec values .	low	**Open**. Investigation of the cause of these greater accuracy and precision values will be conducted. As cal/ val continues, more high value data VI will be available to be investigated.
Running time is not fast enough to allow easy reprocessing	Current run time is sufficient for operations, but is an issue for reprocessing the entire record	medium	**Open**. Current work on next version is expected to significantly reduce run time.

Documentations (Check List, 1 slide)

Science Maturity Check List	Yes ?
ReadMe for Data Product Users	**Yes**
Algorithm Theoretical Basis Document (ATBD)	**Yes**
Algorithm Calibration/Validation Plan	**Yes (Update needed)**
External Users Manual	**Yes**
System Maintenance Manual (for ESPC products)	**Yes**
Peer Reviewed Publications (Demonstrates algorithm is independently reviewed)	**Draft manuscript is in production**
Regular Validation Reports (at least annually) (Demonstrates long-term performance of the algorithm)	**Yes**

Check List - Validated Maturity

Validated Maturity End State	Assessment
Product performance has been demonstrated over a large and wide range of representative conditions (i.e., global, seasonal).	**Yes**, direct comparison with long-term in-situ measurements, cross-comparison between NPP and NOAA20 VIIRS data, and comparison to NASA VIIRS and MODIS VIs have been conducted.
Comprehensive documentation of product performance exists that includes all known product anomalies and their recommended remediation strategies for a full range of retrieval conditions and severity level.	**Yes**, all potential issues have been included in the ATBD, review reports, and readme files.
Product analyses are sufficient for full qualitative and quantitative determination of product fitness-for-purpose.	**Yes**, a series of analyses have been conducted, from checking of input to evaluation of all output layers. The content has contained all common points that the users want to know.
Product is ready for operational use based on documented validation findings and user feedback.	**Yes**, the current product has met the requirements and ready for use. Continuous effort will be invested for further improvements.
Product validation, quality assurance, and algorithm stewardship continue through the lifetime of the instrument	**Yes**, the product will be monitored through the instrument lifetime for periodic and regular validation and calibration.

Requirement Check List – Vegetation Indices

DPS	Requirement	Performance
DPS-425	The Vegetation Indices shall provide top-of-atmosphere (TOA) normalized difference vegetation index (NDVI), top-of-canopy (TOC) enhanced vegetation index (EVI), and top-of-canopy normalized difference vegetation index; 4 km globally and 1 km regionally over land; in daytime; in clear conditions; at the daily refresh rate	Yes
DPS-426	The Vegetation Indices shall provide TOA NDVI with a measurement accuracy of 0.05	Yes, see validation results (Slides 15-22, 33)
DPS-427	The Vegetation Indices shall provide TOA NDVI with a measurement precision of 0.04	Yes, see validation results (Slides 15-22, 33)
DPS-428	The Vegetation Indices shall provide TOC EVI with a measurement accuracy of 0.05	Yes, see validation results (Slides 15-22, 33)
DPS-429	The Vegetation Indices shall provide TOC EVI with a measurement precision of 0.04	Yes, see validation results (Slides 15-22, 33)
DPS-430	The Vegetation Indices shall provide TOC NDVI with a measurement accuracy of 0.05	Yes, see validation results (Slides 15-22, 33)
DPS-431	The Vegetation Indices shall provide TOC NDVI with a measurement precision of 0.04	Yes, see validation results (Slides 15-22, 33)

Requirement Check List – Green Vegetation Fraction

DPS	Requirement	Performance
DPS-62	The Green Vegetation Fraction product shall provide green vegetation fraction globally and regionally, daytime only, weekly with daily updates, 24 hours after the seven-day compositing period	Yes
DPS-75	The Green Vegetation Fraction product shall provide the green vegetation fraction globally with a cell size of 16 km. and associated 3-sigma mapping uncertainty of 4 km	Yes
DPS-66	The Green Vegetation Fraction product shall provide the green vegetation fraction with a measurement precision of 15%	Yes, see validation results (Slides 54-55)
DPS-69	The Green Vegetation Fraction product shall provide the green vegetation fraction with a measurement accuracy of 12%	Yes, see validation results (Slides 54-55)

Conclusion

The NVPS team recommends the NPP and NOAA20 VIIRS VI and GVF products validated maturity based on their performance in ground validation, global cross-satellite comparison, and long term monitoring capacity.

Some concerns:

- Run time needs to be reduced
- Relatively short data record
- Some pixels flagged as low quality may actually be high quality
- Worse accuracy and precision statistics for high VI values (which represent a small percentage of pixels)

Path Forward

- Planned improvements
  - Reduce processing time
  - Combined NPP and NOAA20 products
  - Produce leaf area index (LAI) and fraction of photosynthetically active radiation absorbed (FPAR)
- Future Cal/Val activities / milestones
  - Perform satellite data and ground site comparisons with longer time series
  - Explore validation with additional high quality ground observations such as those from the Ameriflux flux tower network. Ameriflux sites provide radiation and carbon uptake data at hundreds of ground sites covering North America and a few sites in South America.
  - Continue routine ground validation using PhenoCam.
  - Continue the long-term monitoring of the product quality. Analyze and resolve any abnormal results.
  - Promote VI and GVF applications and be actively involved in interactions with users