Satellite Land Surface Temperature production at STAR

Team Lead: Yunyue Yu

NOAA/NESDIS/STAR

Team Members: Yuling Liu, Peng Yu, Heshun Wang, Yuhan Rao, and Zhen Song

UMD/CICS

Funded by the GOES-R AWG, GOES-R Proving Ground, STAR JPSS, and NGGPS

Outline

- LST Basics
- VIIRS LST EDR
- VIIRS L3 LST development
- GOES-R LST development
- Emissivity product development
- LST Long Term Monitoring
- Summary

LST Basics

Definition: Land Surface Temperature (LST) is the mean radiative skin temperature derived from thermal radiation of all objects comprising the surface, as measured by remote sensing ground-viewing or satellite instruments.

Benefits:

- plays a key role in describing the physics of land-surface processes on regional and global scales
- provides a globally consistent record from satellite of clear-sky, radiative temperatures of the Earth's surface
- provides a crucial constraint on surface energy balances, particularly in moisture-limited states
- provides a metric of surface state when combined with vegetation parameters and soil moisture, and is related to the driving of vegetation phenology
- an important source of information for deriving surface temperature in regions with sparse measurement stations

VIIRS LST EDR: Granule Product, moderate resolution, Split-window/Surface-type (17 IGBP) Dependent Regression Algorithm;

GOES-R LST: Full Disk, CONUS, MESO, Split-window/Emissivity Explicit Regression Algorithm.

Mission Requirement:

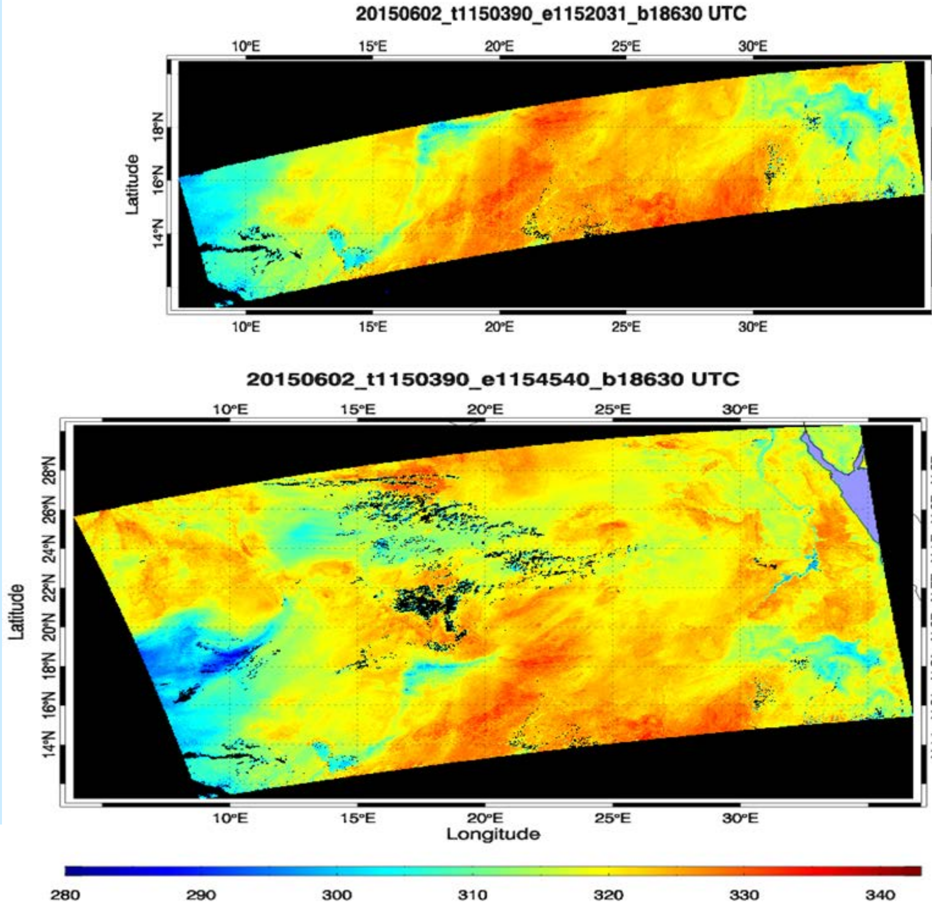
SNPP VIIRS : H = 1 km, T = Daily, A = 1.4 K, Uncertainty = 2.5 K

GOES-R ABI : H = 2/10 km, T = Hourly, A = 2.5 K, Uncertainty = 2.3 K

VIIRS LST EDR

Basics: Current S-NPP VIIRS LST Operational Product

- Operational Products
  - Single 1.5 min granule data
  - Combined 4 x 1.5 min granule data
- Production team
  - STAR Science Team : Scientific development and validation
  - JPSS DPE (Data Product Engineering) : Production



- Web sites
  - CLASS: http://www.nsof.class.noaa.gov/saa/products/welcome (search for JPSS VIIRS EDR)
  - Team site : http://www.star.nesdis.noaa.gov/jpss/lst.php
  - NASA site: http://viirsland.gsfc.nasa.gov/Products/LSTEDR.html
- Monitoring: http://www.star.nesdis.noaa.gov/jpss/EDRs/products_LST.php

Validation Status

- **Validated V1 review – December, 2014**

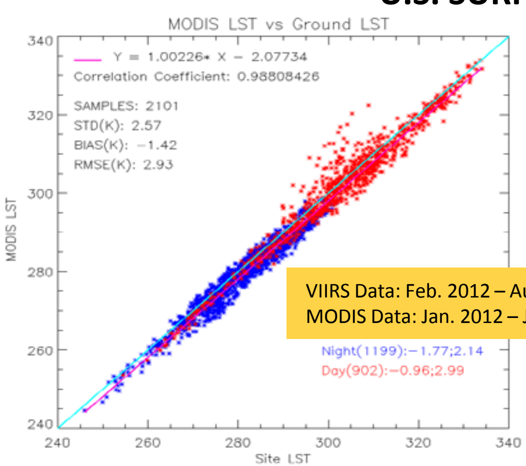
Validation summaries of the LST EDR are shown in Table (**right**); validated 1 maturity approval in Dec. 2014. Marginally meet the requirement with limited "in-situ" data

Validation details of the VIIRS LST comparisons against the SURFRAD station data are shown in the plots (**bottom-left**) and in the tables (**bottom-middle, bottom-right**).

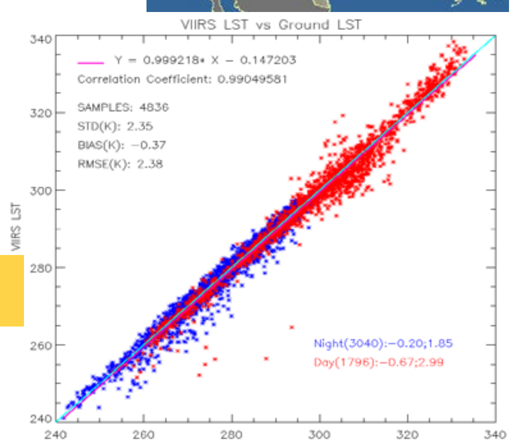
Attribute Analyzed	L1RD Threshold	Validation Result	Description
In-situ Validation	1.4K (2.5K)	**-0.37 (2.35)**	Results are based on the VIIRS data over SURFRAD sites for over 2.5 years . The error budget estimation is limited by ground data quality control, cloud filtering procedure and upstream data error.
R-based Validation	1.4K (2.5K)	0.47(1.12)	A forward radiative transfer model is used, over 9 regions in globe, representing all 17-IGBP types over the seasons. The error budget estimation is limited by profile quality, cloud screening procedure and sampling procedure.
Cross satellite Comparison		0.59(1.93): daytime 0.99(2.02): nighttime	The results are based on comparisons to MODIS LST, over 100 scenes, over low latitude, polar area and CONUSThe error budget estimation is limited by the spatial and temporal difference, sensor difference, angle difference etc.

U.S. SURFRAD stations

Season	Samples	Overall		Day		Night	
		Bias	STD	Bias	STD	Bias	STD
Spring	1297	-0.54	2.78	-0.69	3.82	-0.46	1.97
Summer	1403	-0.1	2.43	-0.87	3.68	0.26	1.39
Fall	1160	-0.28	1.9	-0.32	2.04	-0.24	1.79
Winter	976	-0.65	2.01	-0.83	1.65	-0.53	2.21



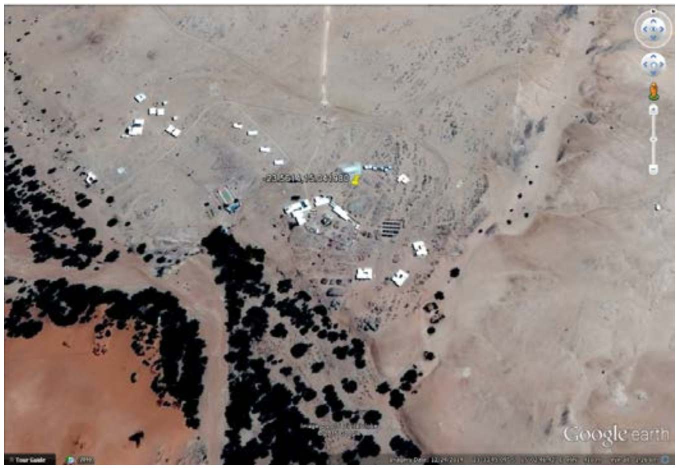
VIIRS Data: Feb. 2012 – Aug. 2014
MODIS Data: Jan. 2012 – Jul. 2013



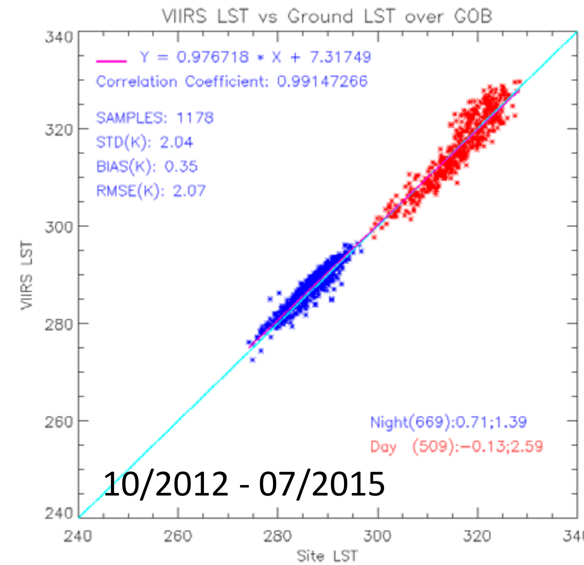
IGBP type	Samples	Overall		Day		Night	
		Bias	STD	Bias	STD	Bias	STD
4	18	-1.41	3.01	-1.82	2.66	-1.26	3.22
6	96	-0.98	1.41	-0.5	1.88	-1.32	0.84
7	955	-0.2	1.59	0.24	2.06	-0.61	0.79
8	286	0.19	2.56	-1.7	2.6	1.38	1.66
10	1048	-0.49	1.81	-0.85	2.3	-0.37	1.59
12	1238	-0.35	2.68	-0.63	3.8	-0.22	1.91
14	857	-0.28	2.54	-1.28	2.4	0.19	2.47
15*	189	-1.72	4.31	-1.72	4.31		
16	149	-0.23	1.55	0.87	1.67	-1.04	0.75

Towards Comprehensive Validation

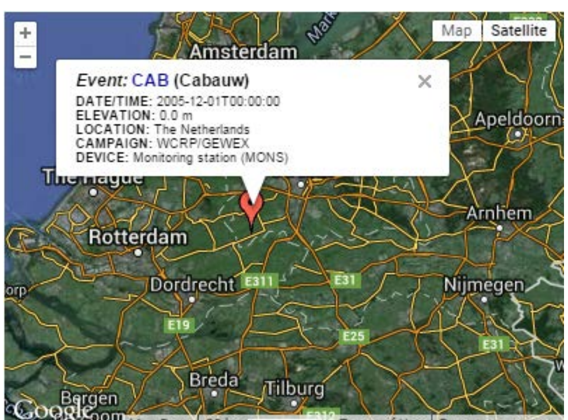
Validation with BSRN

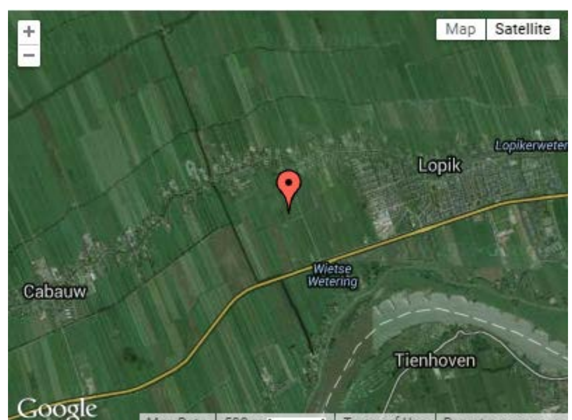


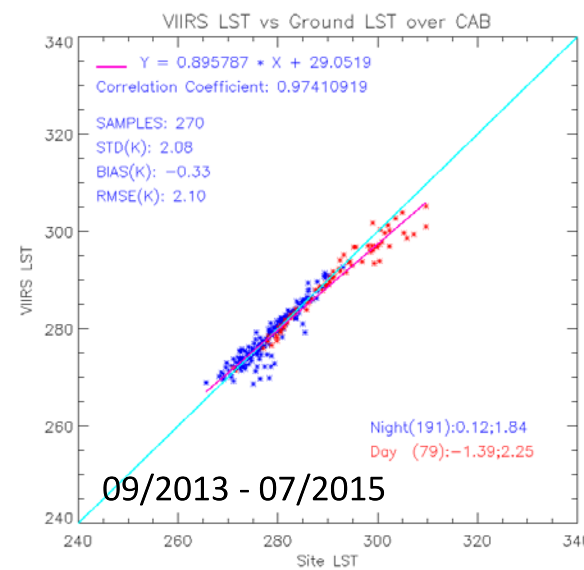
Gobabeb, Namibia



Cabauw, Netherlands

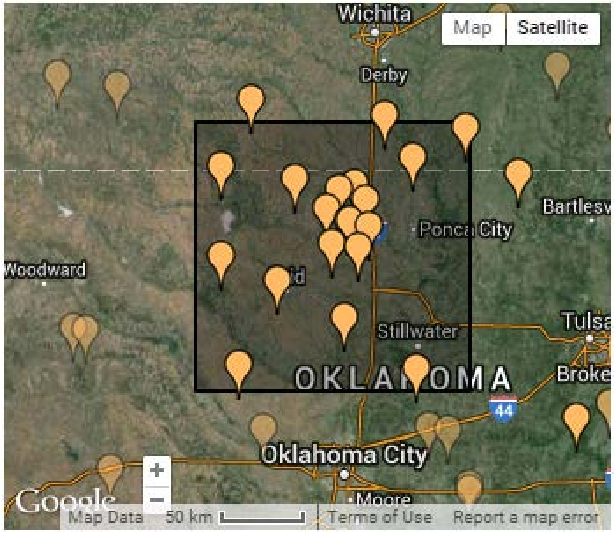


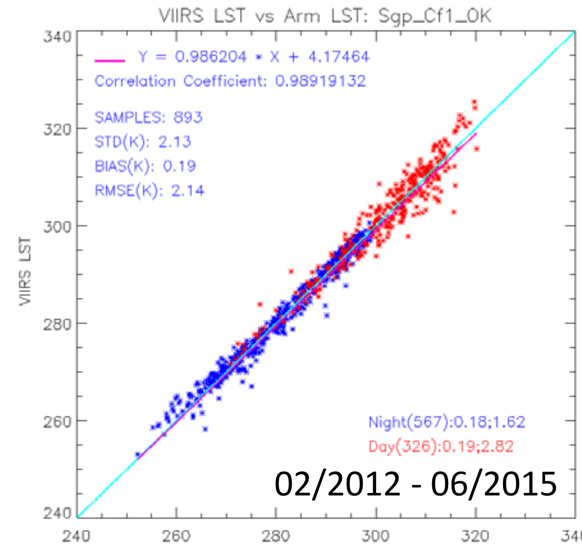




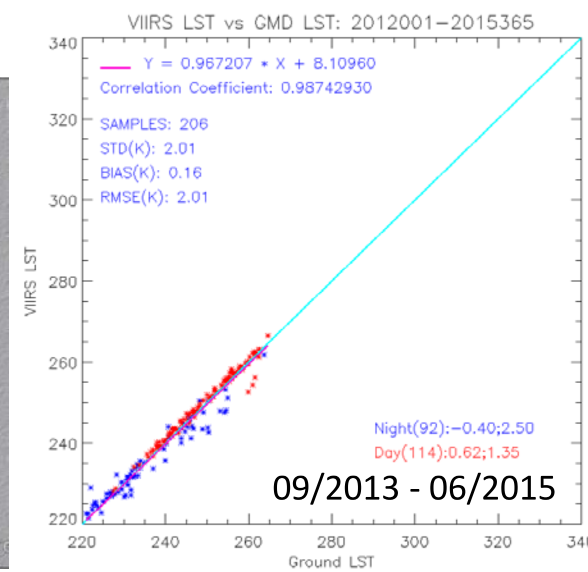
Towards Comprehensive Validation

SGP_CF1



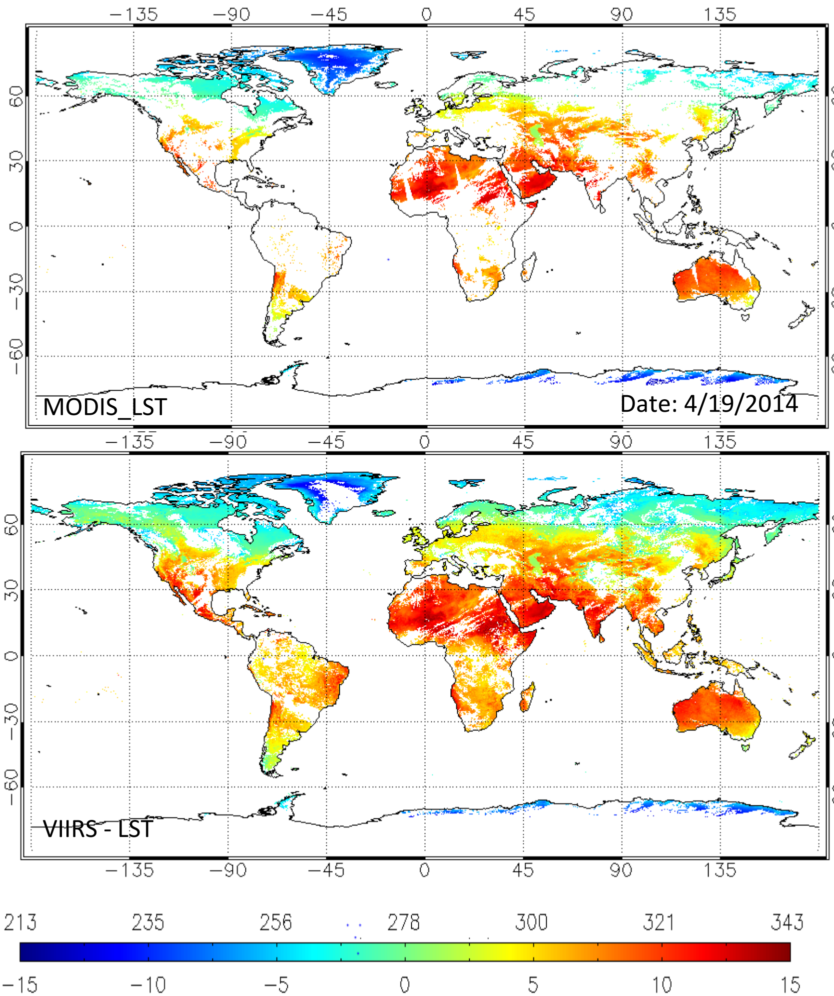


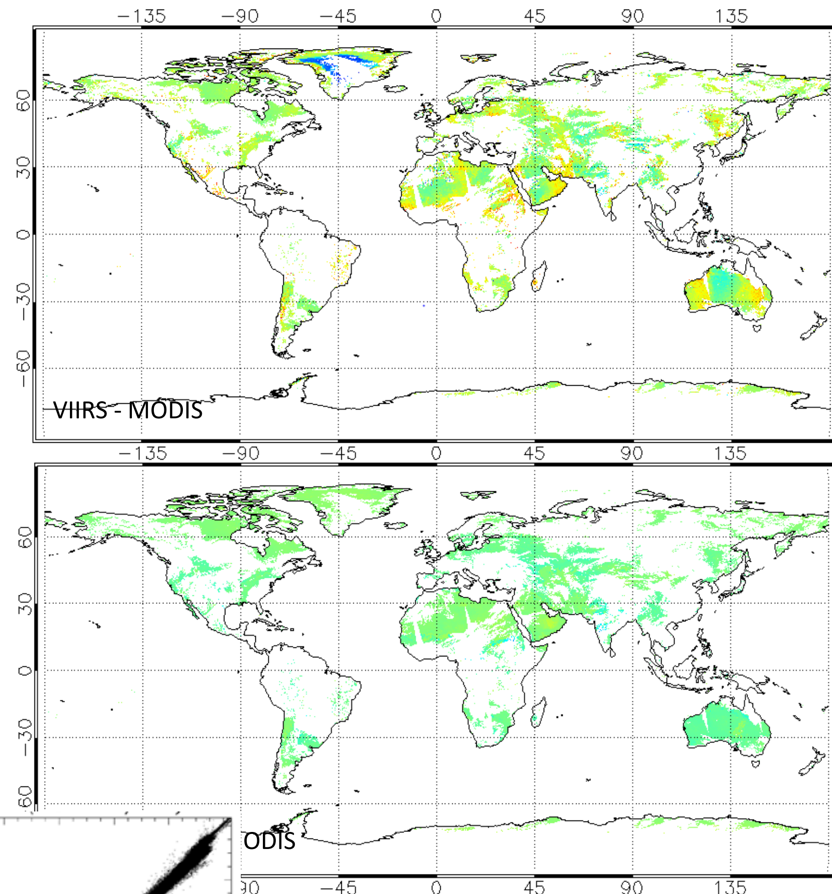
GMD, Summit, Greenland

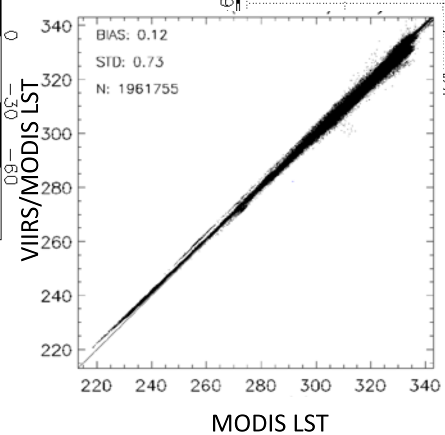


Cross-satellite Comparisons

Cross-satellite Comparison: dataset difference



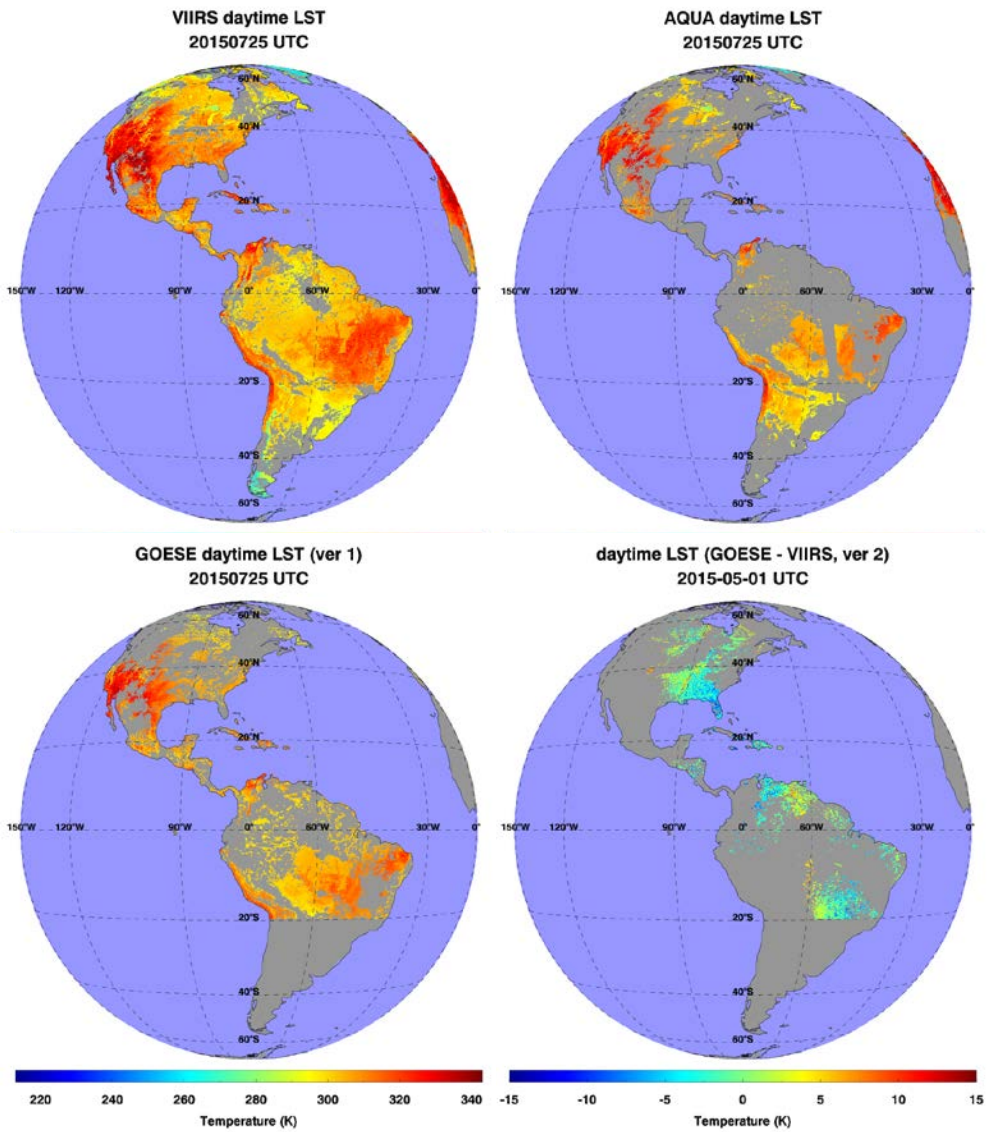




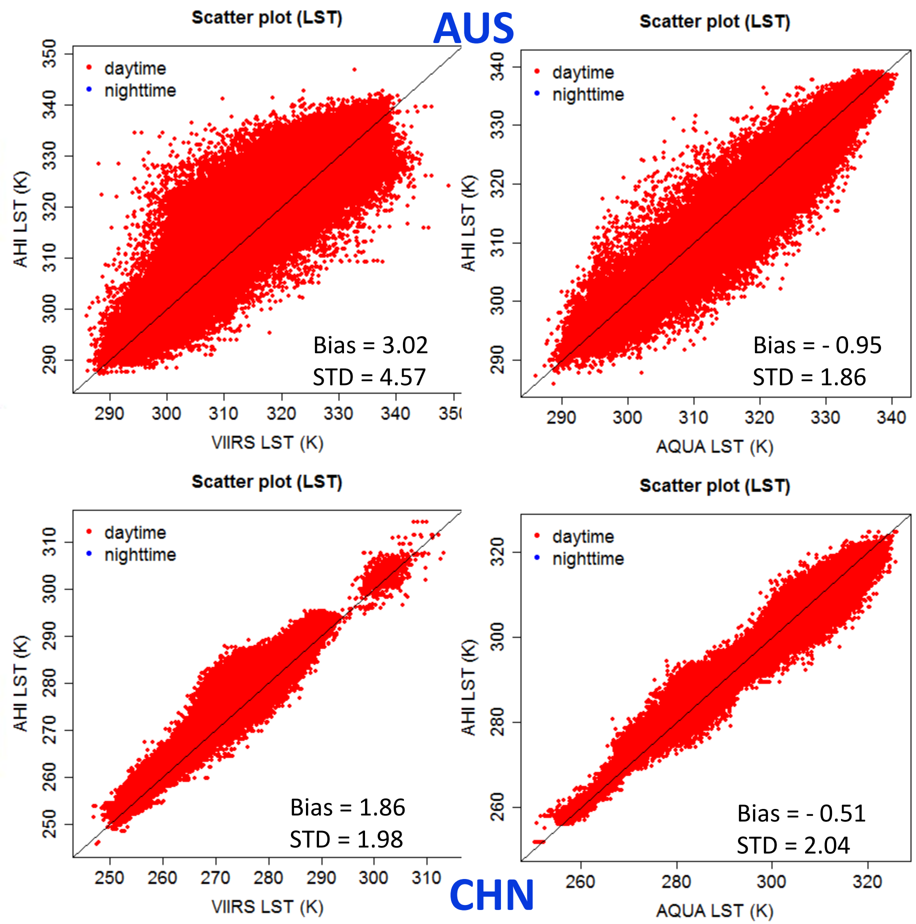
Cross-satellite LST comparison is used in VIIRS LST evaluation.

Caution: Time difference is a significant impact; granule level comparison is needed.

Cross-satellite Comparisons



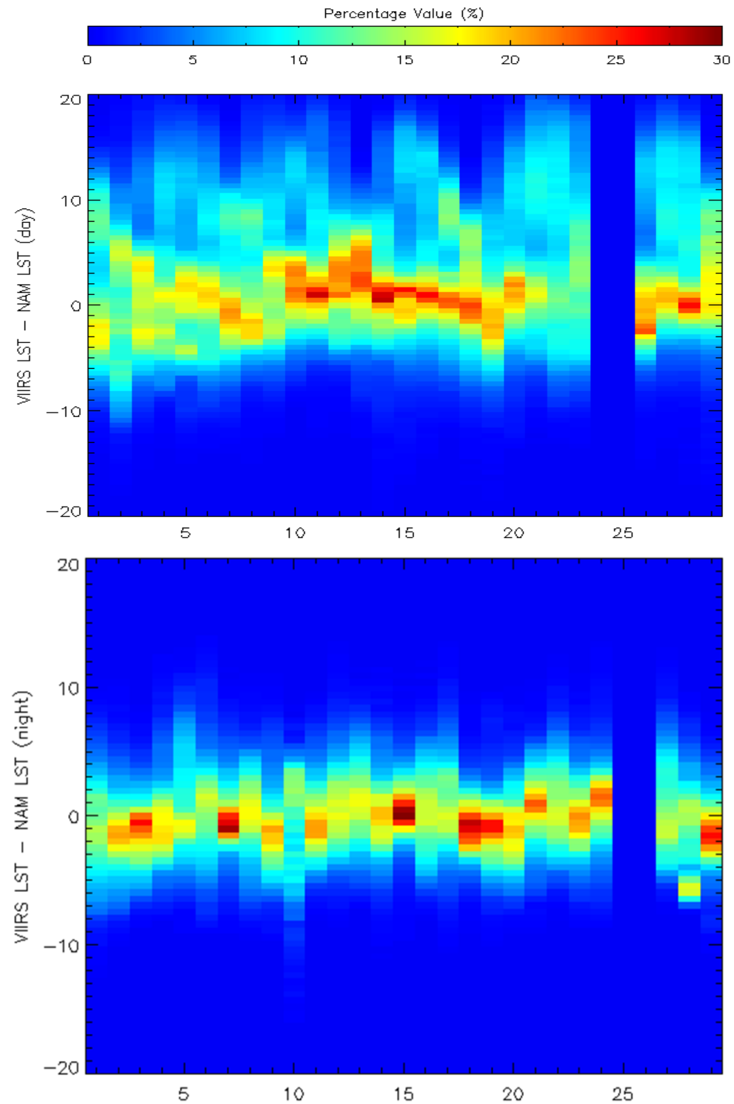
Geo-Leo LST comparisons



JPSS LST for EMC model evaluation

Project on-going: Incorporation of near-real-time S-NPP JPSS Land Surface Temperature data into the NCEP Land modeling suite

- Performed comparison of VIIRS LST data and NAM model data
  - Period: March 2012
  - Resolution: 0.05 deg
- Results
  - ✓ VIIRS LST and NAM LST agree with each other better in nighttime.
  - ✓ The monthly mean biases are 0.47 and 3.76 during nighttime and daytime, respectively.
  - ✓ Granule level comparisons show that the VIIRS-NAM difference over west region is higher than that over east region.
- Current effort: new data format needed
  - Gridded 1 km data
  - Projection and data format matches to the EMC model run needs
  - Time label and QFs for each grid
  - Tools to convert a popular L3 LST data format into a rather specific EMC requested data format
  - Analysis of the JPSS and Model LST differences



Day and night, March 2012

VIIRS L3 LST development

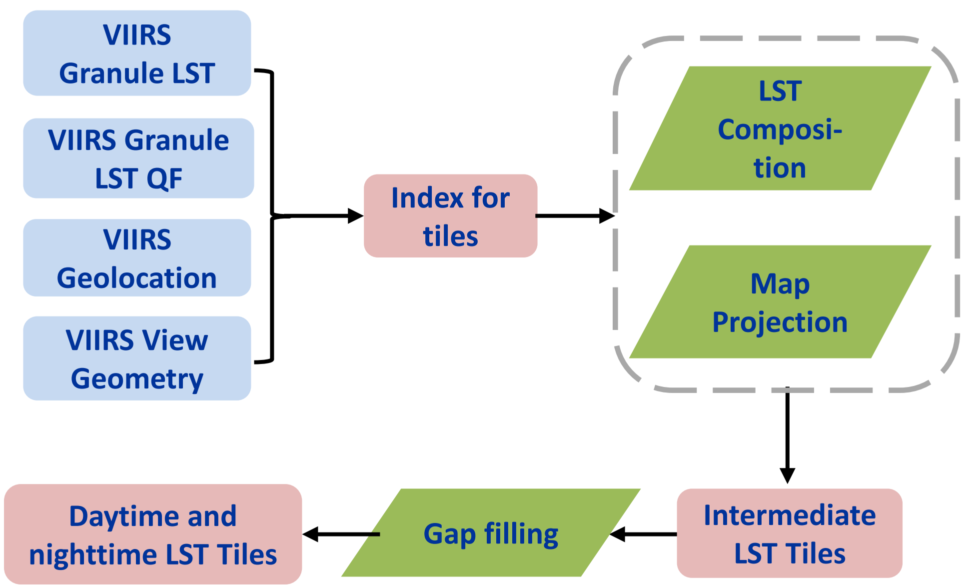
VIIRS L3 Global Gridded Daily LST

- Current VIIRS LST EDR: granulized instantaneous product;
- Regular-grid LST product is highly demanded;
- Level-3 VIIRS Gridded LST features:
  - Global coverage with 0.01 degree spatial resolution
  - Gridded with tile system management
  - Gap-filled at invalid pixel
  - Daily product at daytime and nighttime

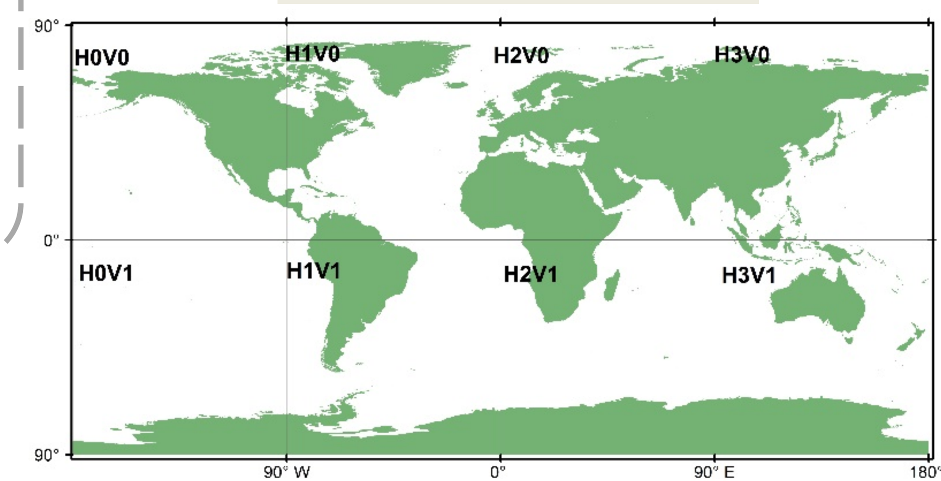
Data fields of VIIRS Gridded LST

Variable Name	Long Name	Number Type	Units	Valid Range	Fill Value	Scale Factor	Offset
LST_Day	Daily daytime Land Surface Temperature	uint16	K	0, 65527	65533-65535	0.0025455	183.2
QC_Day	Quality Control for daytime LST	uint16	none	Details to QA	NA	NA	NA
View_Time_Day	Time of Daytime LST Observation	uint16	second	0, 43200	65535	2	0
View_Angle_Day	View zenith angle of Daytime LST	uint8	deg	0, 180	255	1	-90
LST_Night	Daily nighttime Land Surface Temperature	uint16	K	0, 65527	65533-65535	0.0025455	183.2
QC_Night	Quality Control for nighttime LST	uint16	none	Details to QA	NA	NA	NA
View_Time_Night	Time of Nighttime LST Observation	uint16	second	0, 43200	65535	2	0
View_Angle_Night	View zenith angle of Nighttime LST	uint8	deg	0, 180	255	1	-90

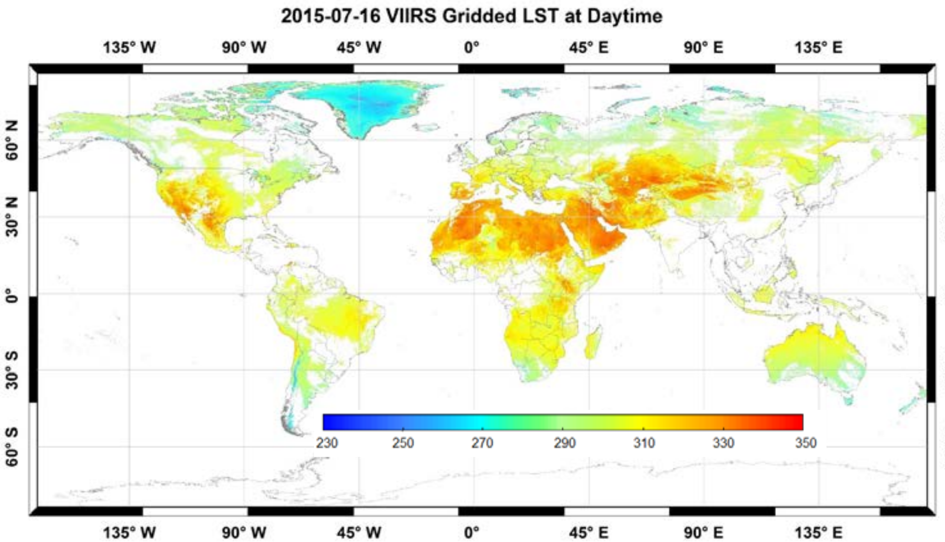
Processing Diagram



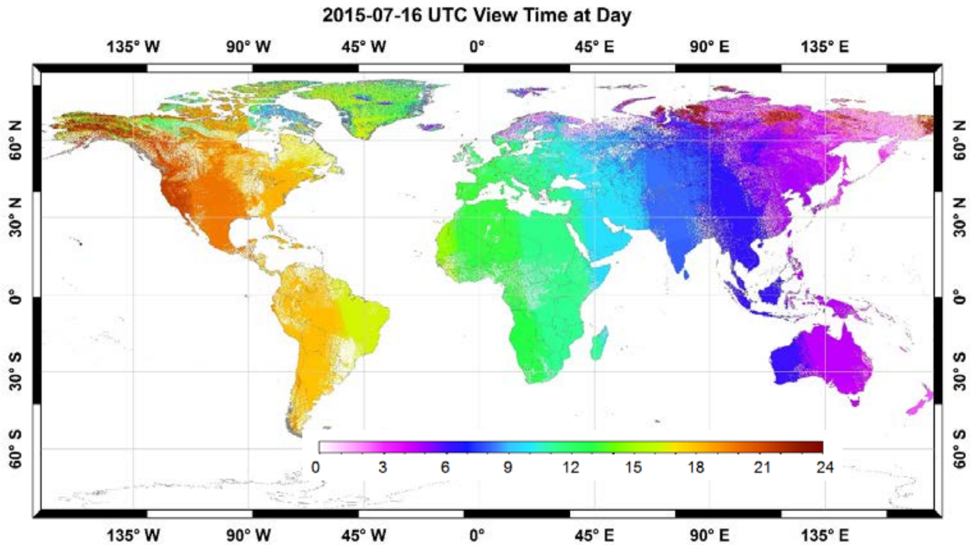
4 by 2 tiles (90D * 90D)



VIIRS L3 Global Gridded Daily LST



Example data



Two-bytes QC Field

Bits	Long Name	Key
1 & 0	Data quality flag	00= High; 01= Median; 10= Low; 11= No retrieval
3&2	Mandatory QA flags	00=Pixel produced; 01=Pixel produced but from filled value; 10=Pixel not produced due to cloud effects or invalid land surface; 11=Pixel not produced due to other reasons
5 & 4	Cloud Confidence Indicator	00: Confidently Clear; 01: Probably Clear; 10: Probably Cloudy; 11: Confidently Cloudy
6	Active Fire	0 = no active fire 1 = active fire
7	AOT Condition	0 = within range, (AOT $\leq$ 1.0) 1 = outside range
10-8	Land/Water Background	Bit 2 Bit 1 Bit 0 0 0 0 = Land and Desert 0 0 1 = Land / No Desert 0 1 0 = Inland Water 0 1 1 = Sea Water 1 0 1 = Coastal
15-11	Surface Type	1: Evergreen Needleleaf Forests; 2: Evergreen Broadleaf Forests; 3: Deciduous Needleleaf Forests; 4: Deciduous Broadleaf Forests; 5: Mixed Forests; 6: Closed Shrublands; 7: Open Shrublands; 8: Woody Savannahs; 9: Savannahs; 10: Grasslands; 11: Permanent Wetlands; 12: Croplands; 13: Urban and Build-up; 14: Cropland/Natural Vegetation Mosaics; 15: Snow and Ice; 16: Barren; 17: Water; 31: Fill

GOES-R LST development

GOES-R ABI LST Product

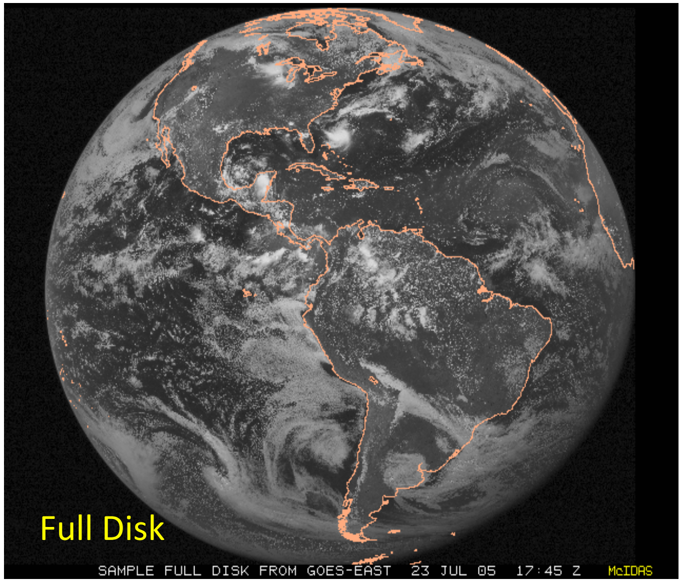
- The ABI Land Surface Temperature (LST) algorithm generates the baseline products of land surface skin temperatures in three ABI scan modes: *Full Disk, CONUS, and Mesoscale*;
- Has a good heritage; will add to the LST climate data record;

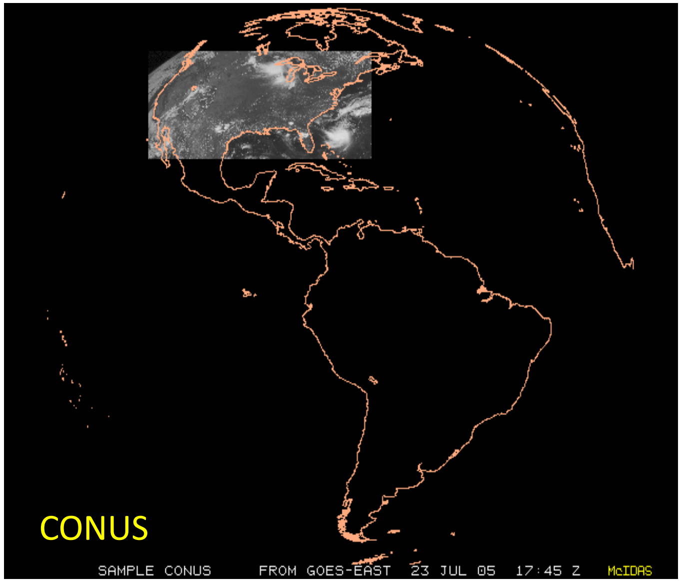
Products

Product	Accuracy	Precision	Range	Refresh Rate	Resolution
LST (CONUS)	2.5 K	2.3 K	213 ~ 330 K	60 min	2 km
LST (Full Disk)	2.5 K	2.3 K	213 ~ 330 K	60 min	*10 km*
LST (Mesoscale)	2.5 K	2.3 K	213 ~ 330 K	60 min	2 km

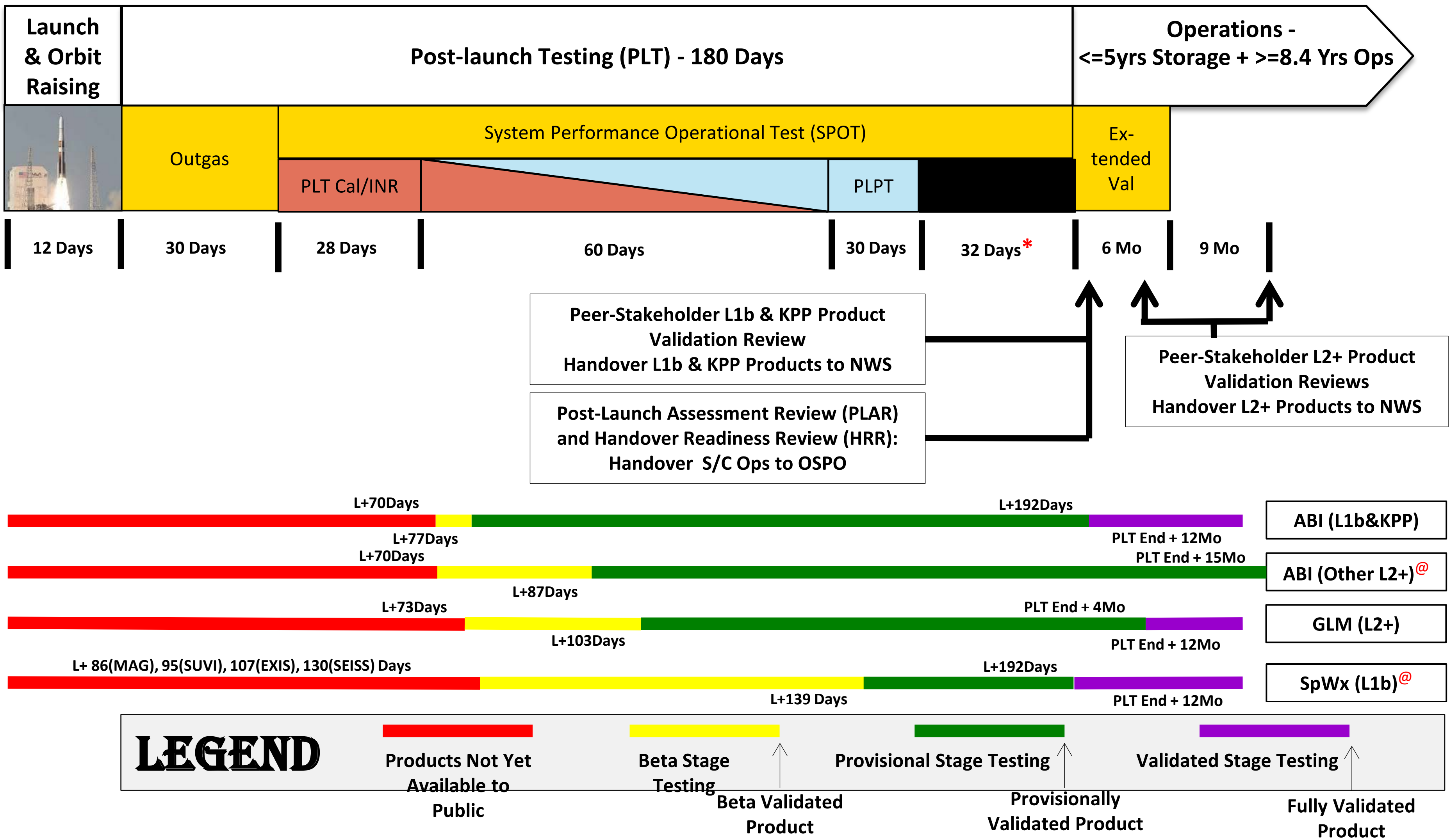
Qualifiers

Product	Temporal Coverage	Product Extent	Cloud Cover Conditions	Product Statistics
LST (CONUS)	Day and Night	LZA < 70	Clear Conditions associated with threshold accuracy	Over specified geographic area
LST (Full Disk)	Day and Night	LZA < 70	Clear Conditions associated with threshold accuracy	Over specified geographic area
LST (Mesoscale)	Day and Night	LZA < 70	Clear Conditions associated with threshold accuracy	Over specified geographic area





PLPT Zoom-In Schedule



@ Maturity level may vary for each product, as product availability is driven by maturity of algorithm implementation, as well as, the existence of science phenomena and associated ground-truth data.

GOES-R ABI LST Validation

Components of LST Validation

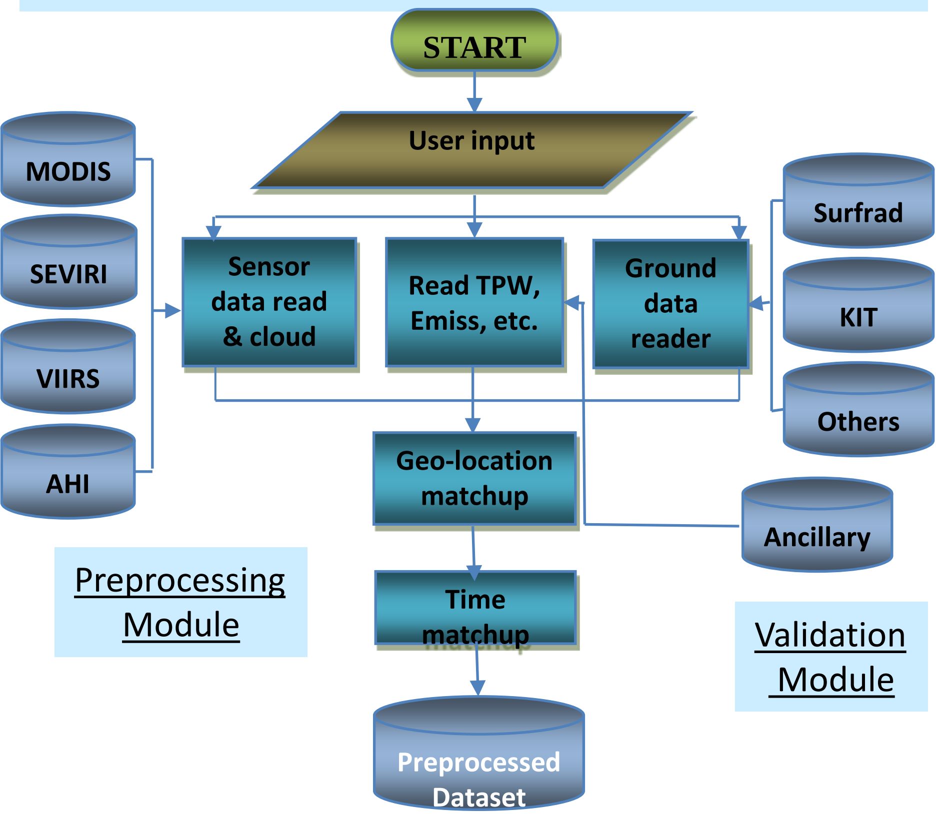
- In-situ measurement comparisons and analyses
- Cross-satellite comparisons and analyses
- Successful applications –users promotion

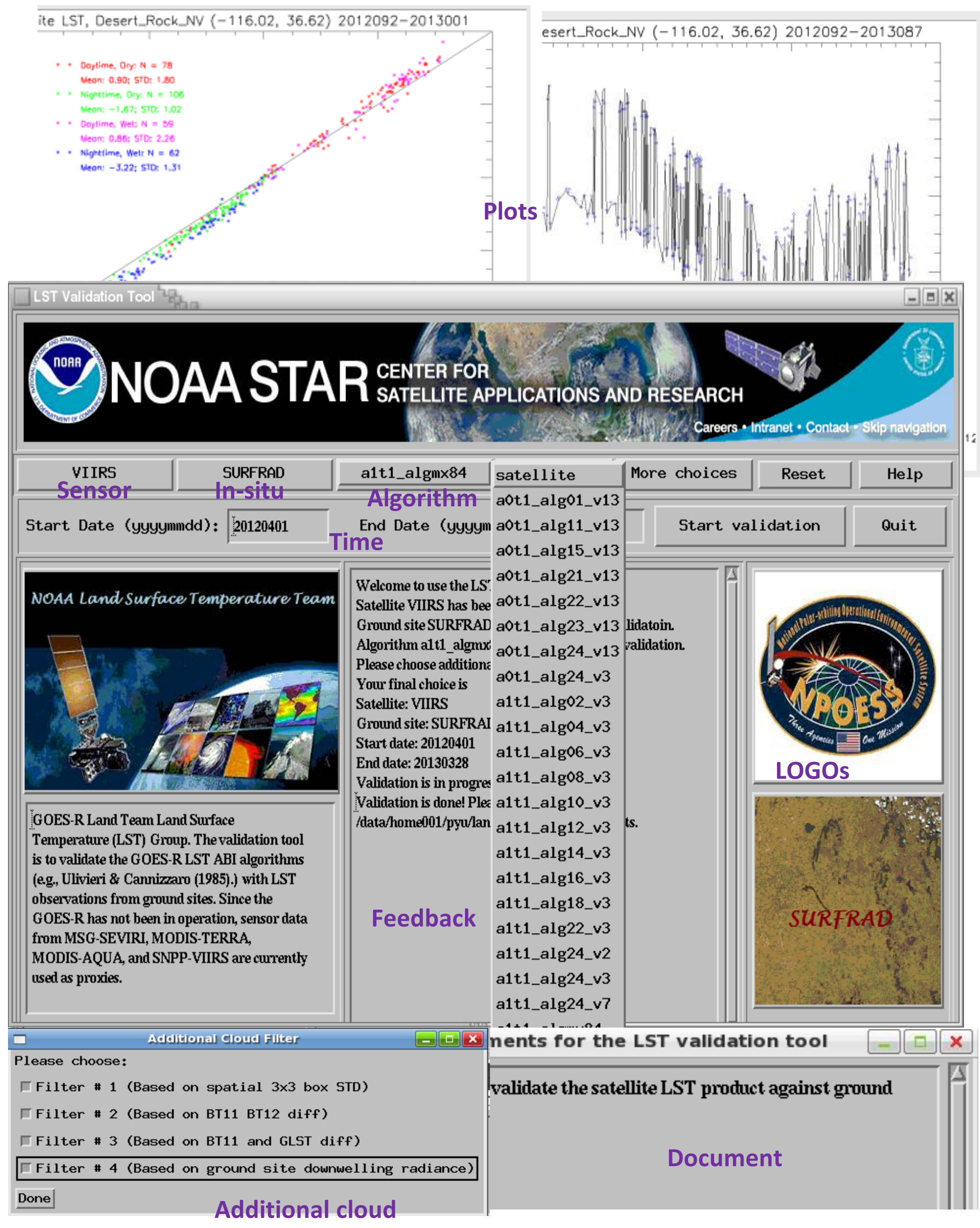
Strategy of In-situ measurement comparisons and analyses

- Existing ground station observations (e.g. SURFRAD Network), as long-term data source
- Field campaign data plays three important roles
  - ❑ High quality observations for direct comparison and analysis
  - ❑ Calibrating co-site ground station observations
  - ❑ Characterizing heterogeneity feature of co-site ground station
- Towards the field campaign readiness
  - ❑ Platform: low altitude, small unmanned aerial vehicle (UVA)
  - ❑ Instrument readiness : accurate infrared radiometers covers ABI bands
  - ❑ Site selection: better to cover SURFRAD/CRN station
  - ❑ Data processing and algorithms: noise filtering, spatial characterization, calibration to station data, etc.
  - ❑ Coordination with the Field Campaign Team.

LST Validation Tool

- Modularized design: preprocessing and validation modules
- Reader: Reads satellites, ground sites, and auxiliary data
- Spatial and temporal match-up
- Apply satellite cloud mask if available
- Satellite and ground site LST estimation/extraction
- Preprocessed data set (relevant variables; 33 variables)
- User friendly, efficient
- Multiple sensor, in-situ, algorithm; ease of extension
- Additional cloud filtering option
- Easy to be combined with the monitoring system and the algorithm generation tool





Algorithm Evaluation – VIIRS proxy

cics-md

- VIIRS data as proxy
- Replacement of the ST-dependent algorithm
- Common retrieval algorithm for different sensors;
- Emissivity Development

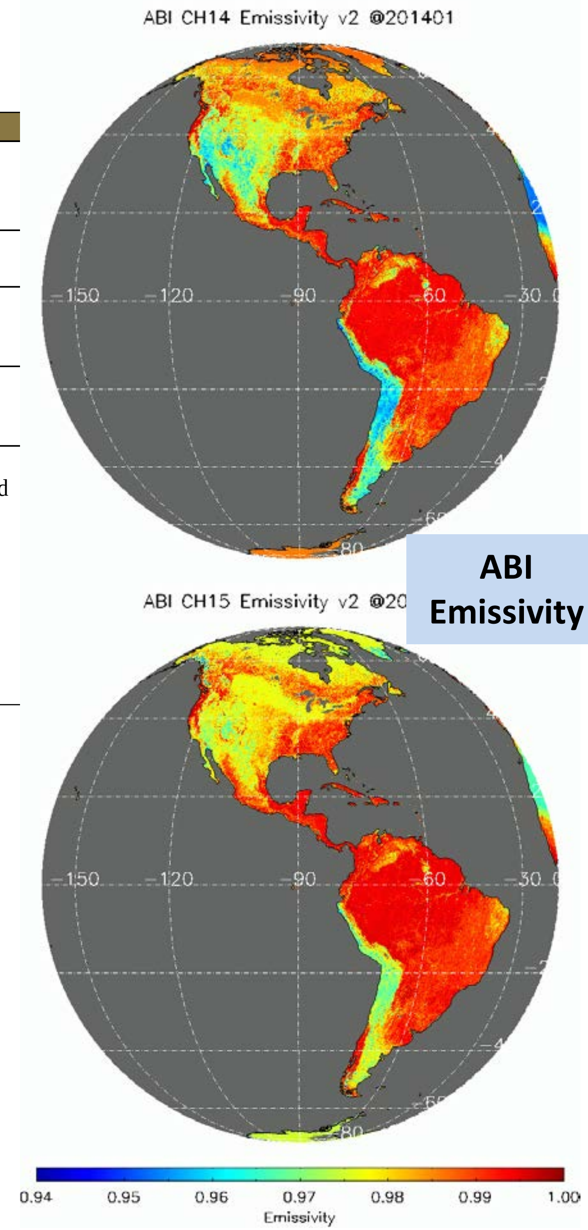
Algorithm Candidates

No	Formula#	Reference
1	$T_s = C + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}+T_{12}) + (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})(T_{11}-T_{12}) + D(T_{11}-T_{12})(\sec\theta-1)$	Wan & Dozier (1996); Becker & Li (1990).
6	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + D(T_{11}-T_{12})(\sec\theta-1)$	Ulivieri & Cannizzaro (1985).
10	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12}) + A_5(T_{11}+T_{12})\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta-1)$	Ulivieri & Cannizzaro (1985) modified 1.
11	$T_s = C + A_1T_{11} + A_2(T_{11}-T_{12}) + A_3\varepsilon + A_4\varepsilon(T_{11}-T_{12}) + A_5\Delta\varepsilon + D(T_{11}-T_{12})(\sec\theta-1)$	Ulivieri & Cannizzaro (1985) modified 2.

#Note:
T_{11} and T_{12} represent the top-of-atmosphere brightness temperatures of ABI channels 14 and 15, respectively;
$\varepsilon=(\varepsilon_{11}+\varepsilon_{12})/2$ and $\Delta\varepsilon=(\varepsilon_{11}-\varepsilon_{12})$, where ε_{11} and ε_{12} are the spectral emissivity values of the land surface at ABI channels 14 and 15, respectively;
θ is the satellite view zenith angle.
C, A_1, A_2, A_3, A_4, A_5, A_6, and D are algorithm coefficients.
Modified versions: $D(T_{11}-T_{12})(\sec\theta-1)$ is removed and the retrieval is carried out in different satellite view zenith angle ranges, *i.e.*, [0, 25, 45, 55, 65, 75]

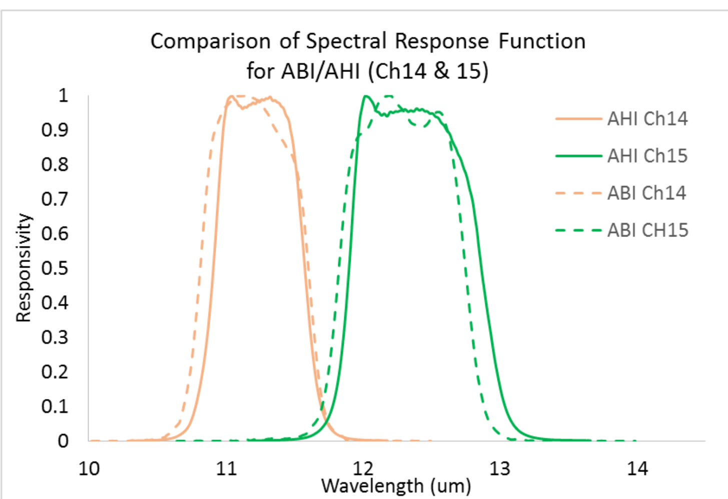
Validation results with three years VIIRS data as proxy and AWG emissivity

Alg	BON	TBL	DRA	FPK	GWN	PSU	SXF	Overall
IDPS	0.06/1.79	-0.23/1.34	-0.59/1.63	0.37/1.89	0.99/2.03	0.64/1.74	-0.02/2.07	0.05/1.87
1	0.27/1.75	-0.64/1.50	-0.82/1.70	0.20/1.81	0.77/2.06	0.36/1.75	0.25/1.67	-0.05/1.84
1’	0.32/1.72	-0.59/1.44	-0.72/1.59	0.24/1.76	0.79/2.04	0.37/1.72	0.29/1.65	0.00/1.79
6	0.26/1.75	-0.62/1.50	-0.87/1.73	0.22/1.80	0.78/2.07	0.36/1.75	0.26/1.68	-0.06/1.86
6’	0.31/1.73	-0.56/1.45	-0.77/1.64	0.26/1.76	0.80/2.05	0.38/1.72	0.31/1.66	-0.00/1.81
10	0.26/1.74	-0.64/1.49	-0.89/1.67	0.20/1.80	0.77/2.06	0.36/1.75	0.25/1.67	-0.07/1.84
10’	0.32/1.72	-0.58/1.44	-0.78/1.58	0.24/1.76	0.80/2.04	0.37/1.72	0.30/1.65	-0.01/1.79
11	0.27/1.75	-0.64/1.49	-0.88/1.68	0.20/1.80	0.77/2.06	0.36/1.75	0.26/1.67	-0.07/1.84
11’	0.32/1.72	-0.59/1.44	-0.79/1.58	0.24/1.76	0.80/2.04	0.38/1.72	0.30/1.65	-0.01/1.79



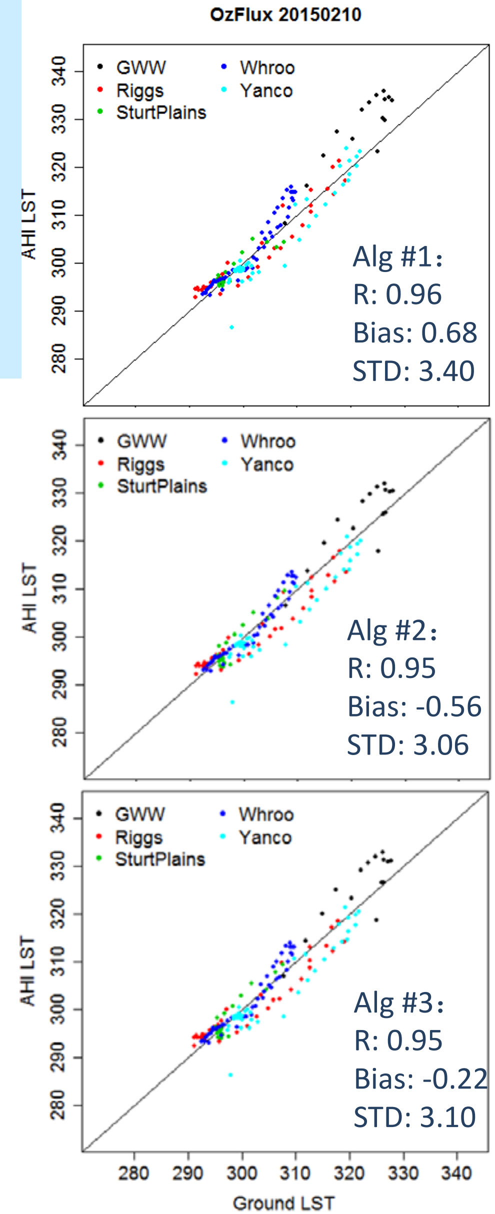
Algorithm Evaluation – AHI proxy

Channel	Himawari-8 AHI Wavelength	Himawari-8 AHI Bandwidth	GOES-R ABI Wavelength	GOES-R ABI Bandwidth
1	0.47	0.04	0.47	0.04
2	0.51	0.03	0.64	0.1
3	0.64	0.08	0.865	0.04
4	0.86	0.03	1.378	0.015
5	1.61	0.04	1.61	0.06
6	2.26	0.04	2.25	0.05
7	3.88	0.2	3.9	0.2
8	6.24	0.82	6.19	0.83
9	6.94	0.4	6.95	0.4
10	7.35	0.19	7.34	0.2
11	8.59	0.37	8.5	0.4
12	9.63	0.38	9.61	0.38
13	10.4	0.42	10.35	0.5
14	11.24	0.67	11.2	0.8
15	12.38	0.97	12.3	1
16	13.28	0.56	13.3	0.6

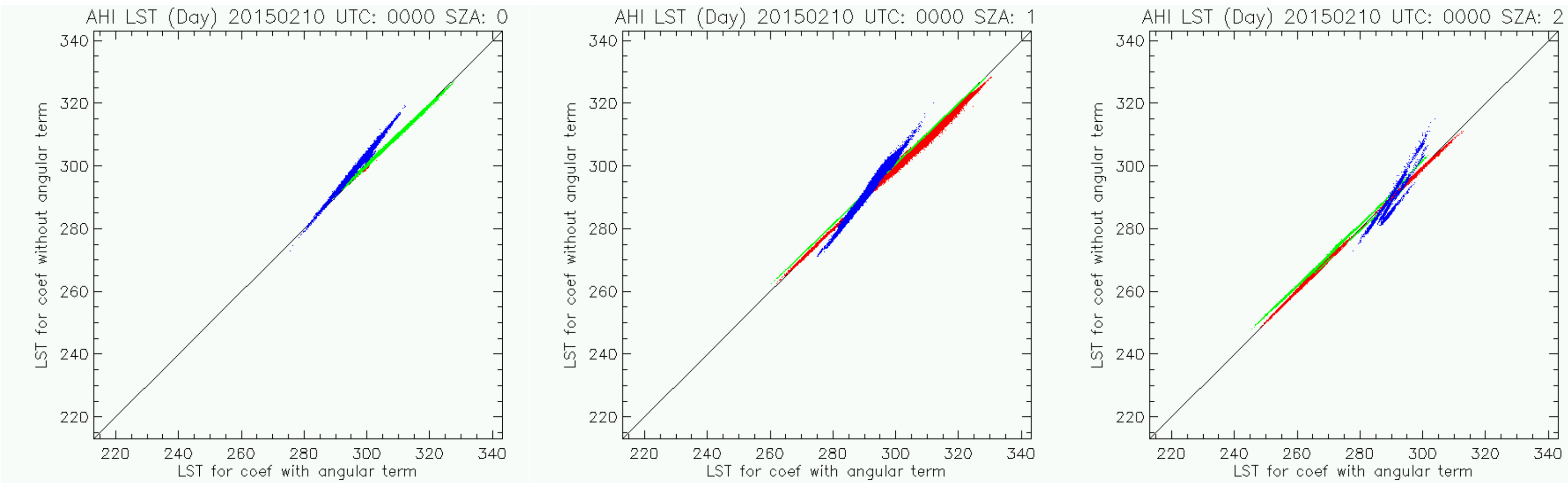


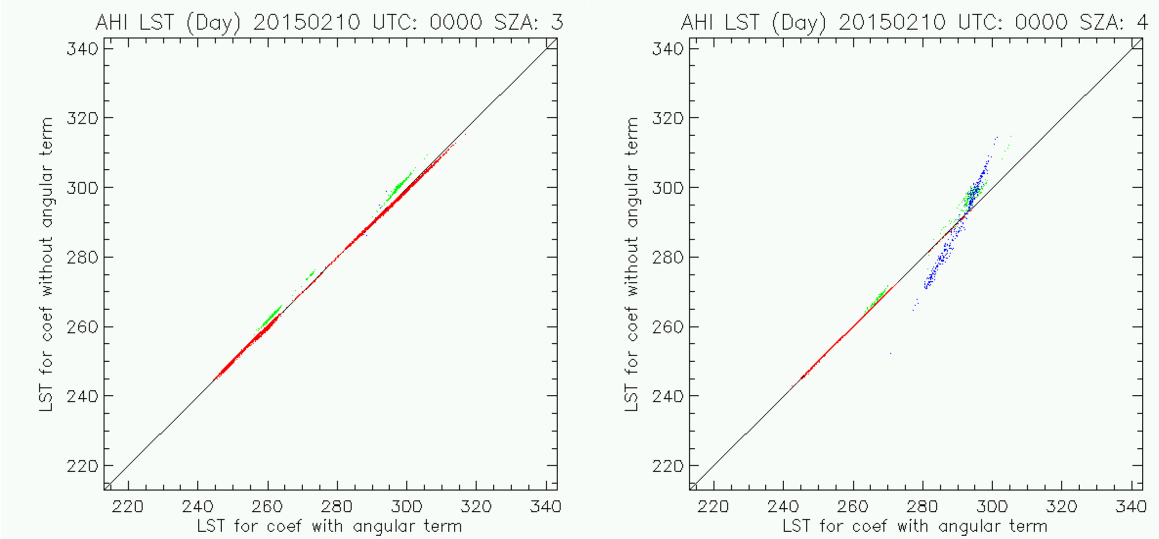
- Himawari-8 AHI data as proxy
- Similar sensor characteristics with GOES-R ABI
- Preliminarily validated using Australia ground measurements
- Multiple algorithms: 1) ABI; 2) Modified SZA correction; 3) emissivity difference

Site	Lat	Lon	Vegetation
GWW	-30.191	120.654	Woodland
Riggs	-36.656	145.576	Pasture
Sturt Plains	-17.151	133.35	Grasslands
Whroo	-36.673	145.029	Woodland
Yanco	-34.988	146.291	NA



Algorithm Evaluation – AHI proxy





		SZA				
		0-25	25-45	45-55	55-65	65-75
Bias	0-1.5	0.73	1.18	-0.03	0.23	-0.04
	1.5-4	0.11	-0.44	-1.04	-2.15	-2.44
	4-5	-3.18	-0.41	2.67	-0.85	0.91
STD	0-1.5	0.12	0.48	0.39	0.37	0.07
	1.5-4	0.26	0.58	0.71	0.43	1.81
	4-5	1.02	2.01	2.27	2.18	5.71

- Proposing new coefficients for different satellite zenith angle

Emissivity product development

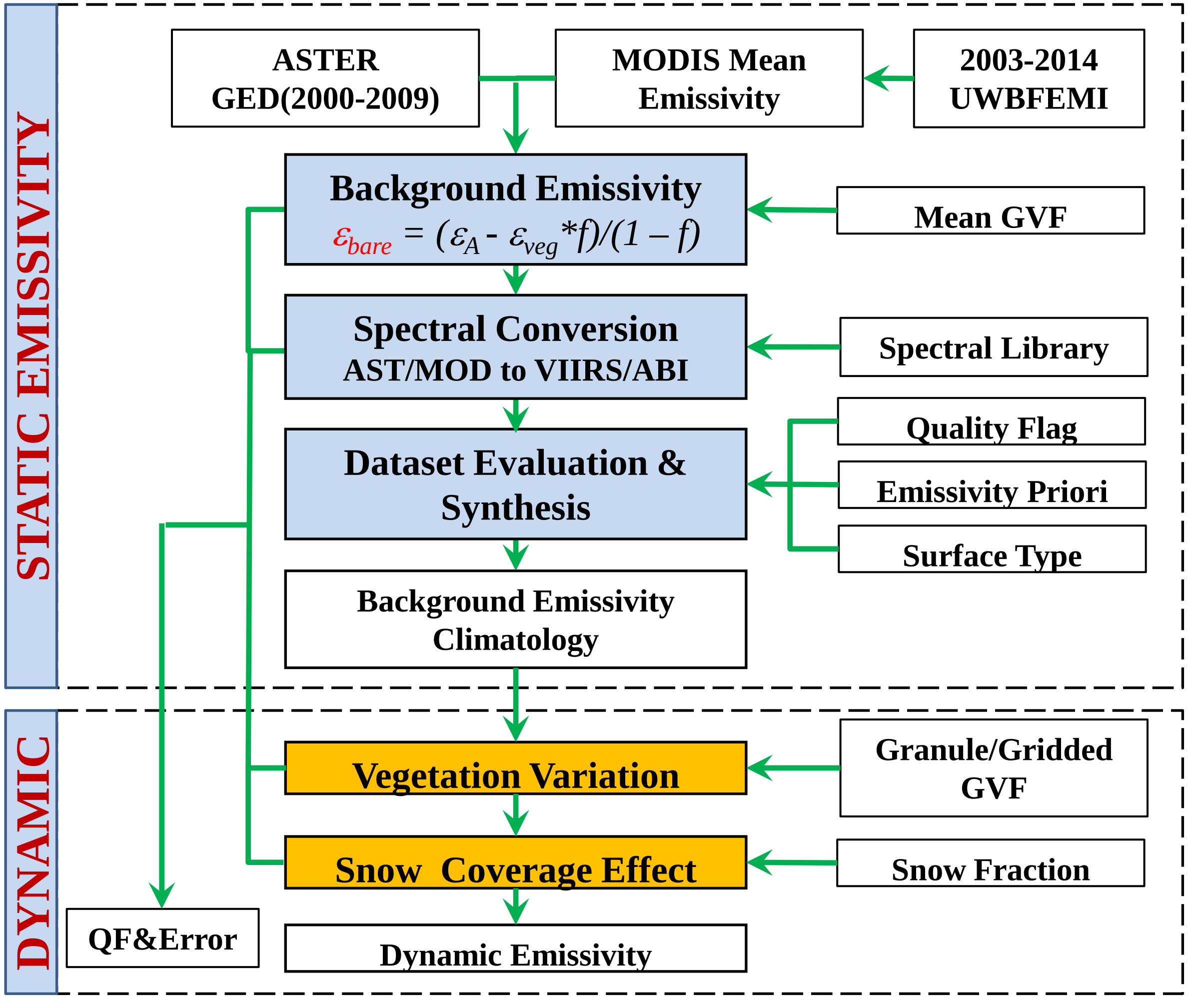
Land Surface Emissivity

Purpose:
- Enhance LST retrieval and validation
- Support the forecasting model

Method:
- Dividing a land pixel into three components (soil, vegetation and snow).
- Using historic emissivity product to generate background (soil or snow) emissivity climatology
- Using real time vegetation and snow information to adjust the static emissivity.

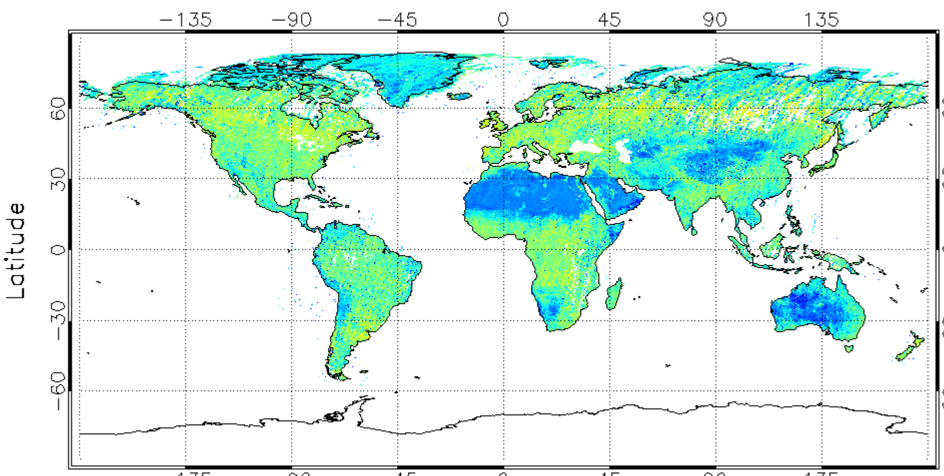
Main Features:
- Daily global gridded dataset
- VIIRS Swath and GOES-R full disk.
- Up to 1 km resolution
- QF for each grid

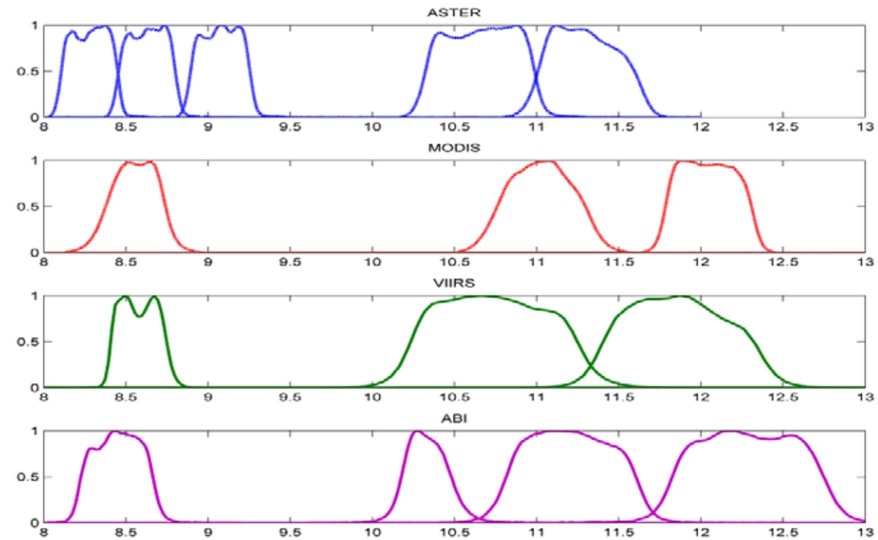
Algorithm Flowchart



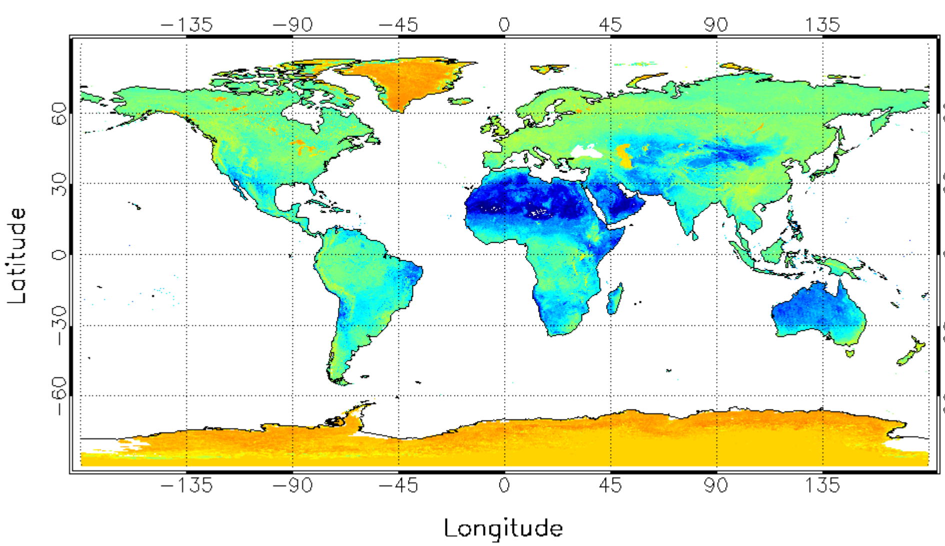
Static Emissivity

ASTER GED Emissivity (11.3um)

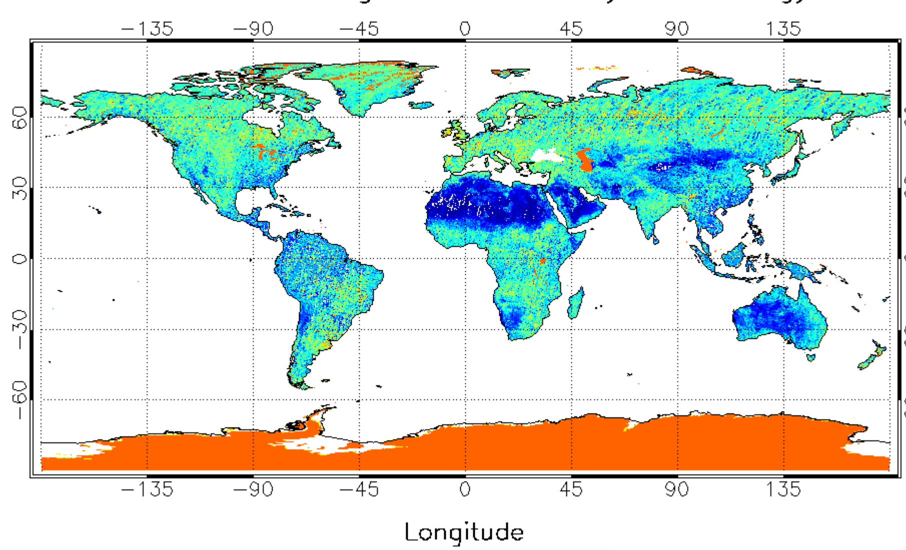


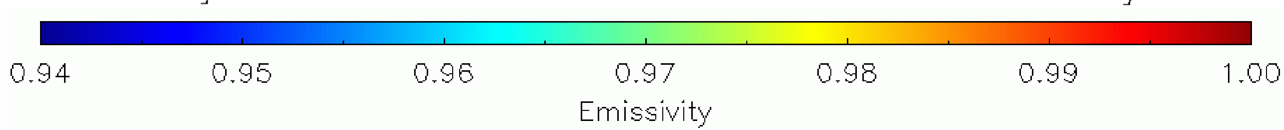


MODIS Emissivity Climatology (11.3um)



VIIRS M15 Background Emissivity Climatology



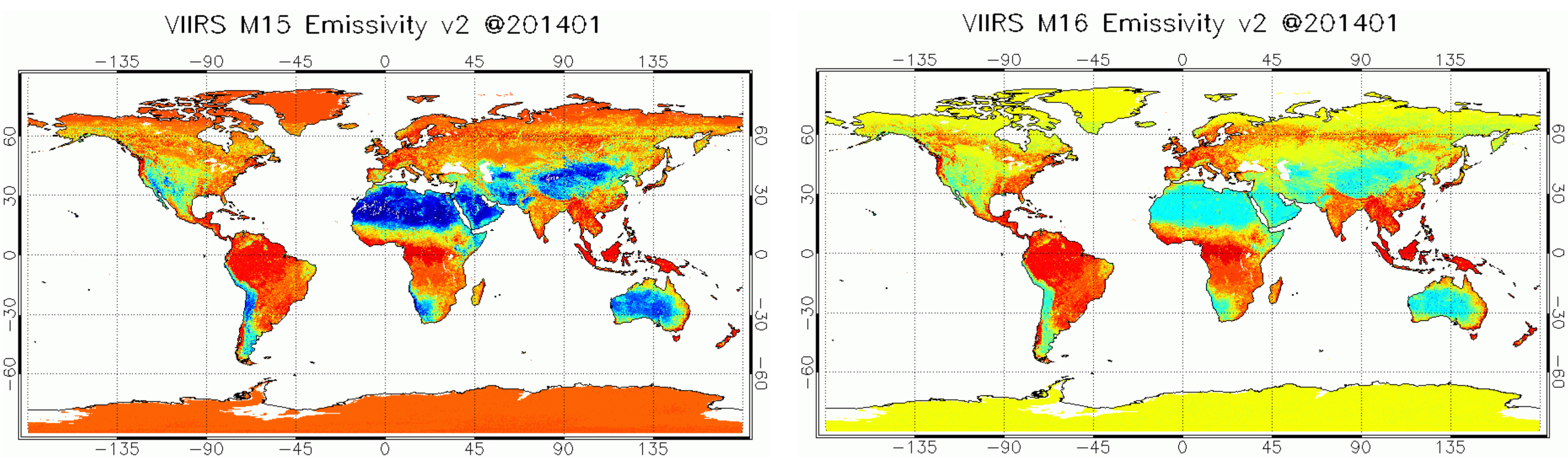


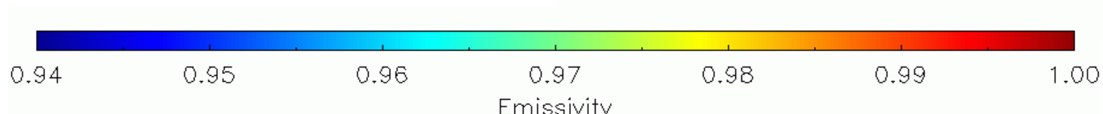
Dynamic Emissivity

Emissivity Products	Spatial Resolution	Temporal Resolution	Spectral coverage	Uncertainty
Global Gridded	0.01° x 0.01°	8-day, 2 days latency	8.55, 10.75,12.0 µm, BBE	<1.5%
VIIRS Granule	750m @nadir	Swath, daily	8.55, 10.75,12.0 µm	<1.5%
GOES-R Full disk	2km @nadir	Full disk, daily	8.4, 10.3, 11.3, 12,3µm	<1.5%

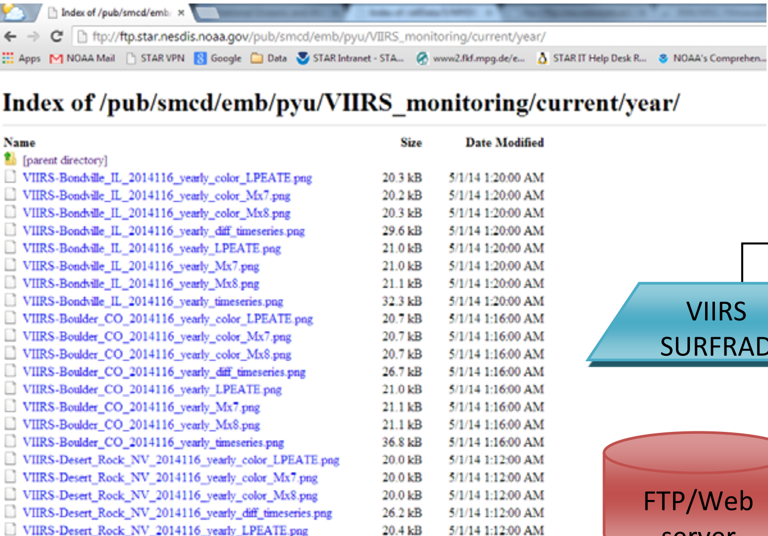
Future work:

- Incorporate the emissivity into LST retrieval and evaluate the accuracy.
- Investigating the soil moisture impact on the emissivity and add this effect to the dataset.





LST Long Term Monitoring



Index of /pub/smcd/emb/pyu/VIIRS_monitoring/current/year/

Name	Size	Date Modified
[parent directory]		
VIIRS-Bondville_IL_2014116_yearly_color_LPEATE.png	20.3 kB	5/1/14 1:20:00 AM
VIIRS-Bondville_IL_2014116_yearly_color_Mx7.png	20.2 kB	5/1/14 1:20:00 AM
VIIRS-Bondville_IL_2014116_yearly_color_Mx8.png	20.3 kB	5/1/14 1:20:00 AM
VIIRS-Bondville_IL_2014116_yearly_diff_timeseries.png	29.6 kB	5/1/14 1:20:00 AM
VIIRS-Bondville_IL_2014116_yearly_LPEATE.png	21.0 kB	5/1/14 1:20:00 AM
VIIRS-Bondville_IL_2014116_yearly_Mx7.png	21.0 kB	5/1/14 1:20:00 AM
VIIRS-Bondville_IL_2014116_yearly_Mx8.png	21.1 kB	5/1/14 1:20:00 AM
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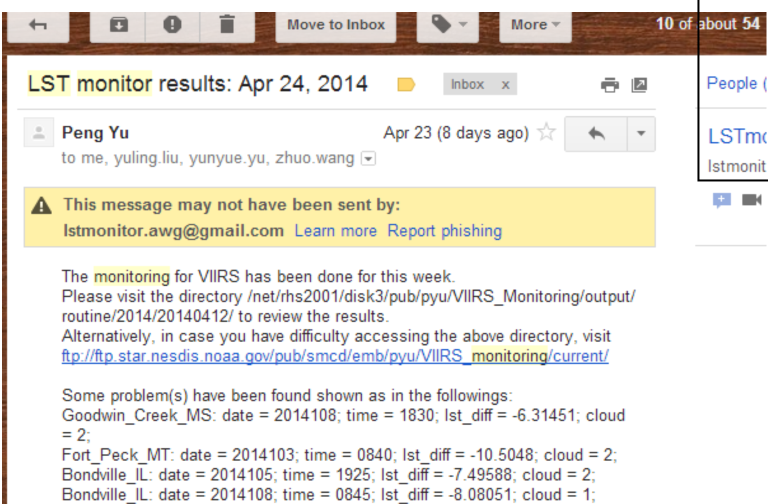


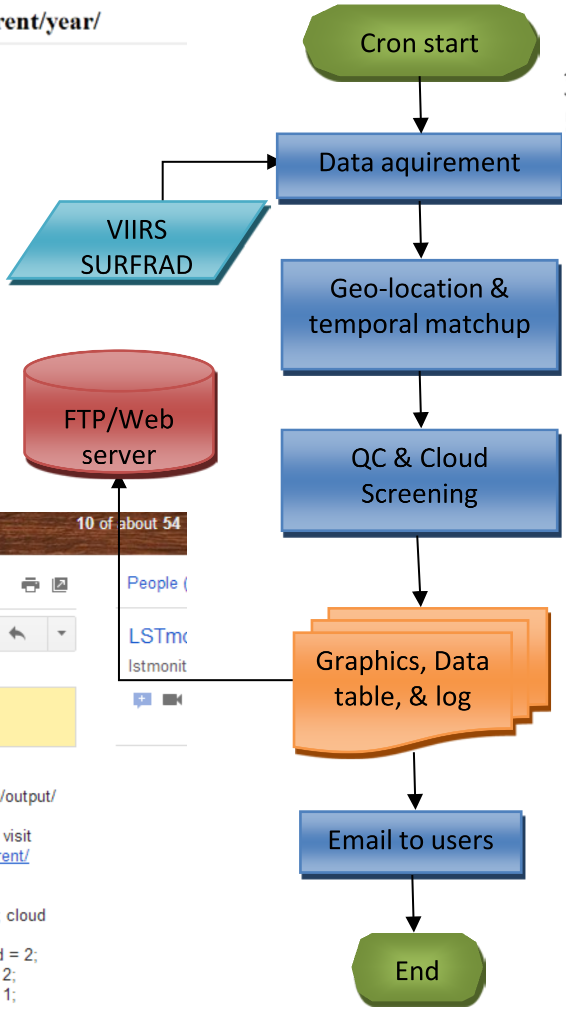
LST monitor results: Apr 24, 2014

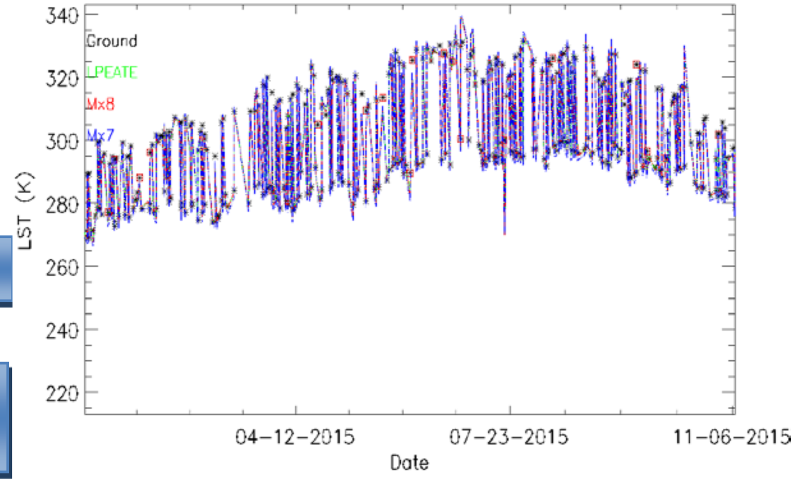
Peng Yu — Apr 23 (8 days ago)
to me, yuling.liu, yunyue.yu, zhuo.wang

This message may not have been sent by: lstmonitor.awg@gmail.com Learn more Report phishing

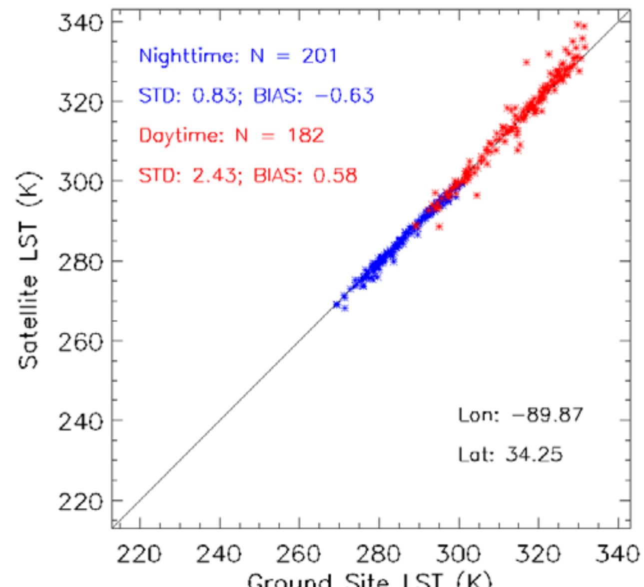
The monitoring for VIIRS has been done for this week.
Please visit the directory /net/rhs2001/disk3/pub/pyu/VIIRS_Monitoring/output/routine/2014/20140412/ to review the results.
Alternatively, in case you have difficulty accessing the above directory, visit ftp://ftp.star.nesdis.noaa.gov/pub/smcd/emb/pyu/VIIRS_monitoring/current/

Some problem(s) have been found shown as in the followings:
Goodwin_Creek_MS: date = 2014108; time = 1830; lst_diff = -6.31451; cloud = 2;
Fort_Peck_MT: date = 2014103; time = 0840; lst_diff = -10.5048; cloud = 2;
Bondville_IL: date = 2014105; time = 1925; lst_diff = -7.49588; cloud = 2;
Bondville_IL: date = 2014108; time = 0845; lst_diff = -8.08051; cloud = 1;





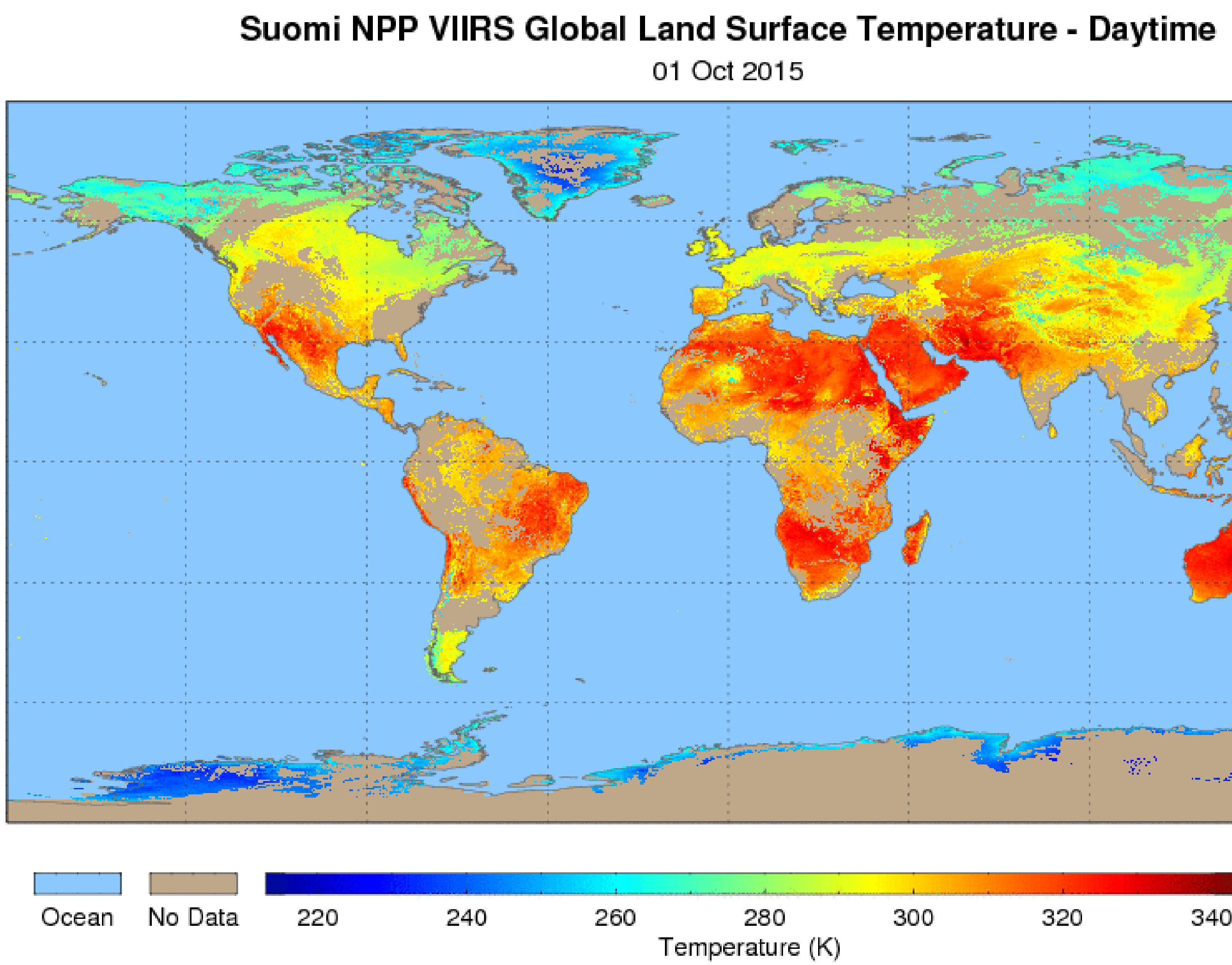
Desert Rock: 2015001-2015311



ftp://ftp.star.nesdis.noaa.gov/pub/smcd/emb/pyu/VIIRS_monitoring/current/year/

VIIRS LST LTM - Global

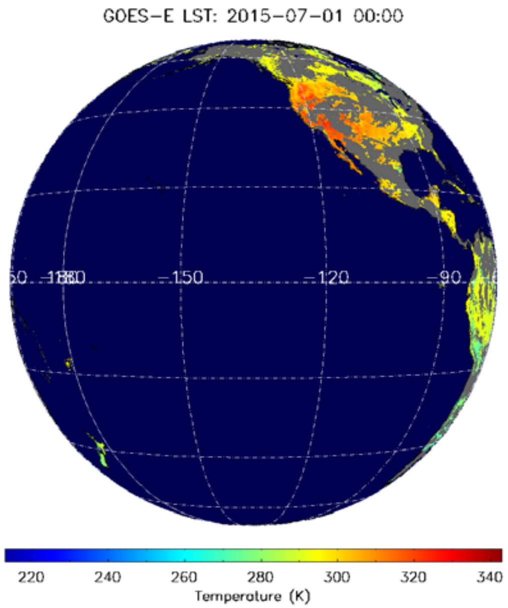
- Near real-time;
- Daytime Nighttime;
- Global composite;
- 5 km resolution;

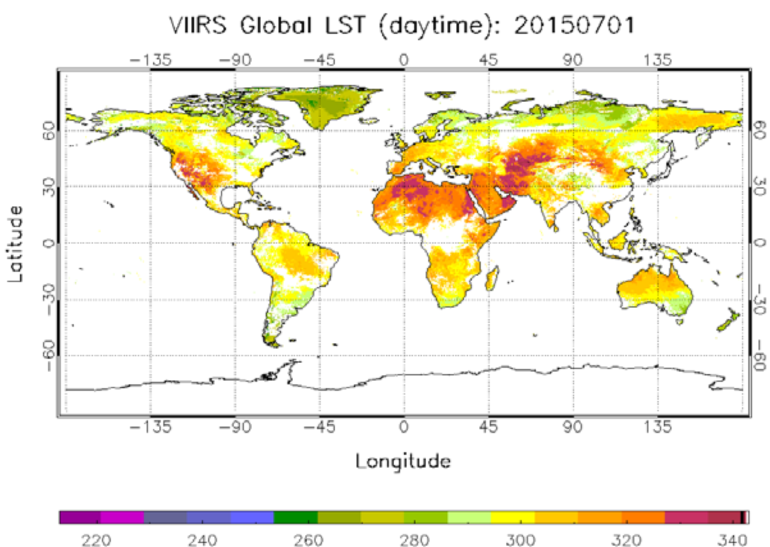


NOAA/NESDIS/STAR

http://www.star.nesdis.noaa.gov/jpss/EDRs/products_LST.php#

Monitoring -- Animation of Time Series





Summary

- S-NPP VIIRS LST EDR
  - reached V1 validated status
  - more comprehensive validation with extended in-situ observation is ongoing
- GOES-R LST
  - Flexible validation tool has been established
  - Retrieval algorithm is tested with multiple proxy sensors, *e.g.*, Himawari AHI
- A high resolution emissivity data is being developed
  - Global coverage
  - Algorithm for different satellite sensors
- A Level-3 daily global 0.01° gridded LST product is being developed
- Sophisticated LST monitoring system for multiple sensors was constructed
  - In-situ validation alerting/notification
  - Cross satellite comparison, single sensor product monitoring

Thank You!