Developing Enterprise Algorithm for Land Surface Temperature Product

Presenter
Yunyue Yu, STAR

Contributors:
Yuling Liu, Peng Yu, Heshun Wang,
UMD/CICS

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Team Members /Users

	Name	Institute	Function
JPSS-STAR	Ivan Csiszar	NOAA/NESDIS/SATR	Land Lead, Project Management
	Yunyue YU	NOAA/NESDIS/SATR	TEDR Lead, algorithm development, validation, team management
	Yuling Liu	*NOAA Affiliate, UMD/ESSIC*	*product monitoring and validation ; algorithm development*
	Heshun Wang	*NOAA Affiliate, UMD/ESSIC*	*algorithm improvement*
	Peng Yu	*NOAA Affiliate, UMD/ESSIC*	*product validation tool*
	Marina Tsidulko	*NOAA Affiliate, SciTech/IMSG*	*System Framework Design/Development*
	Jerry Zhan	NOAA/NESDIS/SATR	Surface Type, Soil Moisture application
NCEP-EMC			
	Michael EK	NOAA/EMC/NCEP	user readiness
	Jesse Meng	NOAA Affiliate	user readiness
	Weizhong Zheng	NOAA Affiliate	user readiness
	Yihua Wu	NOAA Affiliate	user readiness

External Users of LST product (Point of Contact)

– USDA Agricultural Research Services(Martha Anderson)

– USDA Forest Service (Brad Quayle)

– Academy – Univ. of Maryland (Konstantin Vinnikov, Shunlin Liang, Cezar Kongoli)

– Army Research Lab (Kurt Preston)

– EUMETSAT LSA SAF LST group (Isabel Trigo, Project Manager)

– ESA/ESRIN, Italy (Simon Pinnock & Olivier Arino)

– Univ. Of Edinburgh, UK (Chris Merchant)

– OBSPM, and LSCE, France (Catherine Prigent & Carlos Jimenez, and Catherine Ottlé)

– Universitat de les Illes Balears, Spain (Maria Antonia Jimenez Cortes)

– eLEAF, The Netherlands (Henk Pelgrum & Wim Bastiaanssen)

– Centre for Ecology and Hydrology, UK (Rich Ellis)

– Institute of Geodesy and Cartography, Poland (Katarzyna Dabrowska-Zielinska)

Requirements Summary

Product Requirements from JPSS L1RD and GOES-R L1RD

	GOES-R		JPSS
Products	Full Disc	CONUS	Swath
Accuracy	2.5 K	2.5 K	1.4 K
Precision	2.3 K	2.3 K	2.4 K
Range	213 – 330 K	213 – 330 K	213 – 343 K
Refresh Rate	60 mins	60 mins	Daily
Horizontal Resolution	10 km	2 km	1 km

Background: LST Basics

<u>Definition</u>: 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.

<u>Benefits</u>:

- 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

<u>VIIRS LST EDR</u>: Granule Product, moderate resolution, Split-window/Surface-type (17 IGBP) Dependent Regression Algorithm;
<u>GOES-R LST</u>: Full Disk, CONUS, MESO, Split-window/Emissivity Explicit Regression Algorithm.

Background: Challenges

– Algorithm/product Challenge

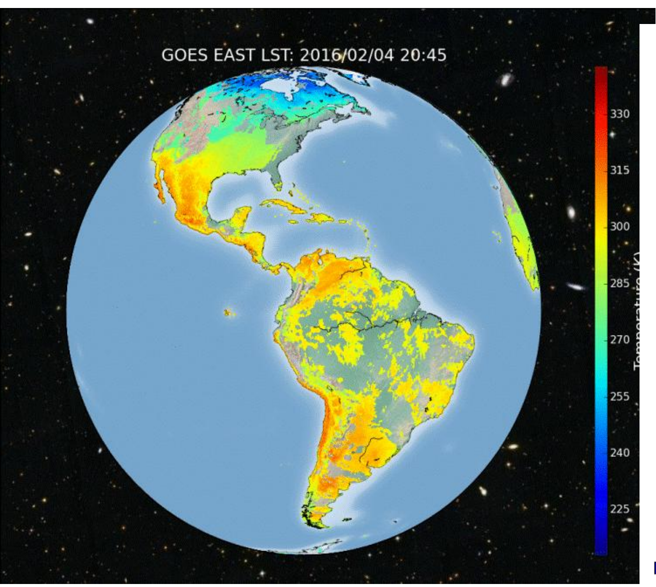
- consistency between the satellite missions
- Characterization of uncertainties associated with retrieved LSTs. Practical uncertain is significantly larger than the theoretical analysis.
- High accurate dynamic emissivity dataset
- Water vapor data resolution and forecast accuracy

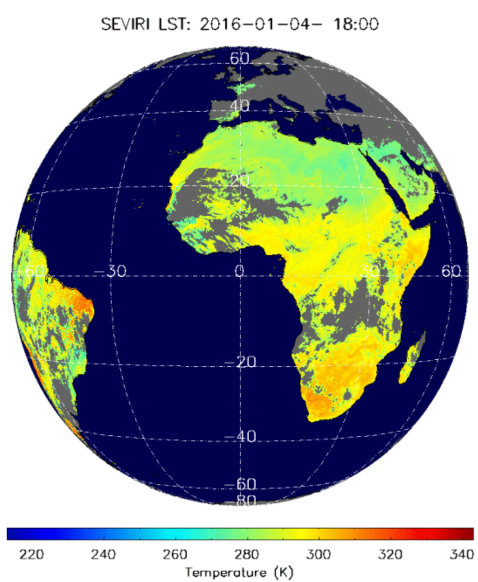
– Validation Challenge

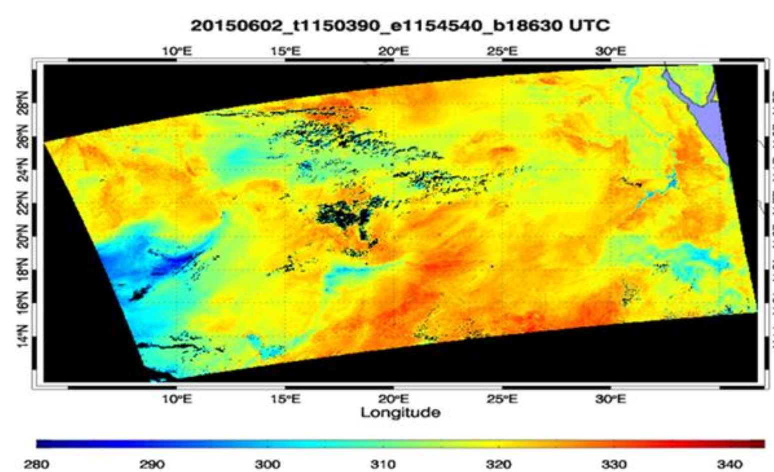
- Quantitative and qualitative limitations of validation dataset. The CalVal performed only with limited data, mostly with SURFRAD data. Global and seasonal representativeness of the validation are needed.
- High quality spot measurements
- Surface heterogeneity
- Cloud contamination impact is significant

Current Operational Product (L2)

	VIIRS (IDPS)	MODIS	GOES	SEVIR	ABI
Product	Granule , 1.5 min, 4x1.5 mins	Granule, 5 mins	Disk, 3 hour	Disk, 15 mins	Disk, 1 hr
Methodology	TIR Split-window	TIR Split-window	IR dual window	TIR Split-window	TIR Split-window
Algorithm	Regression, Surface Type Dependent coeffs	Regression, emissivity explicit	Decision Tree Regression, emissivity explicit	Regression, emissivity explicit	Regression, emissivity explicit







Enterprise LST Algorithm

Development Strategy

A unified LST retrieval algorithm is necessary for consistent LST production with different satellite missions

- Better Cross-satellite evaluation
- Better global validation effort
- Engineering and maintenance easiness

Consideration of enterprise algorithm development

- Simplify
- Robustness
- Applicable to both GEO and LEO satellite missions
- Consistent quality flags for users and for evaluation analysis
- Rely on thermal split window for best accuracy

Enterprise LST Algorithm

Sensor	LST Retrieval Algorithm
VIIRS	$LST_i = a_0(i) + a_1(i)T_{15} + a_2(i)(T_{15} - T_{16}) + a_3(i)(\sec\theta - 1) + a_4(i)(T_{15} - T_{16})^2$
MODIS	$LST = A_0 + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})\frac{(T_{11}+T_{12})}{2} + (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})\frac{(T_{11}-T_{12})}{2}$
ABI	$LST = C + A_1T_{11} + A_2(T_{11} - T_{12}) + A_3\varepsilon + D(T_{11} - T_{12})(\sec\theta - 1)$
GOES	Daytime: $LST = a_0 + a_1T_{11} + a_2(T_{11} - T_{3.9}) + a_3(T_{11} - T_{3.9})^2 + a_4(\sec\theta - 1) + a_5T_{3.9}\cos\theta_s + a_6(1-\varepsilon)$
	Nighttime: $LST = a_0 + a_1T_{11} + a_2(T_{11} - T_{3.9}) + a_3(T_{11} - T_{3.9})^2 + a_4(\sec\theta - 1) + a_5(1-\varepsilon)$
SEVIRI	$LST = A_0 + (A_1 + A_2\frac{1-\varepsilon}{\varepsilon} + A_3\frac{\Delta\varepsilon}{\varepsilon^2})\frac{(T_{11}+T_{12})}{2} + (A_4 + A_5\frac{1-\varepsilon}{\varepsilon} + A_6\frac{\Delta\varepsilon}{\varepsilon^2})\frac{(T_{11}-T_{12})}{2}$

The determined Algorithm

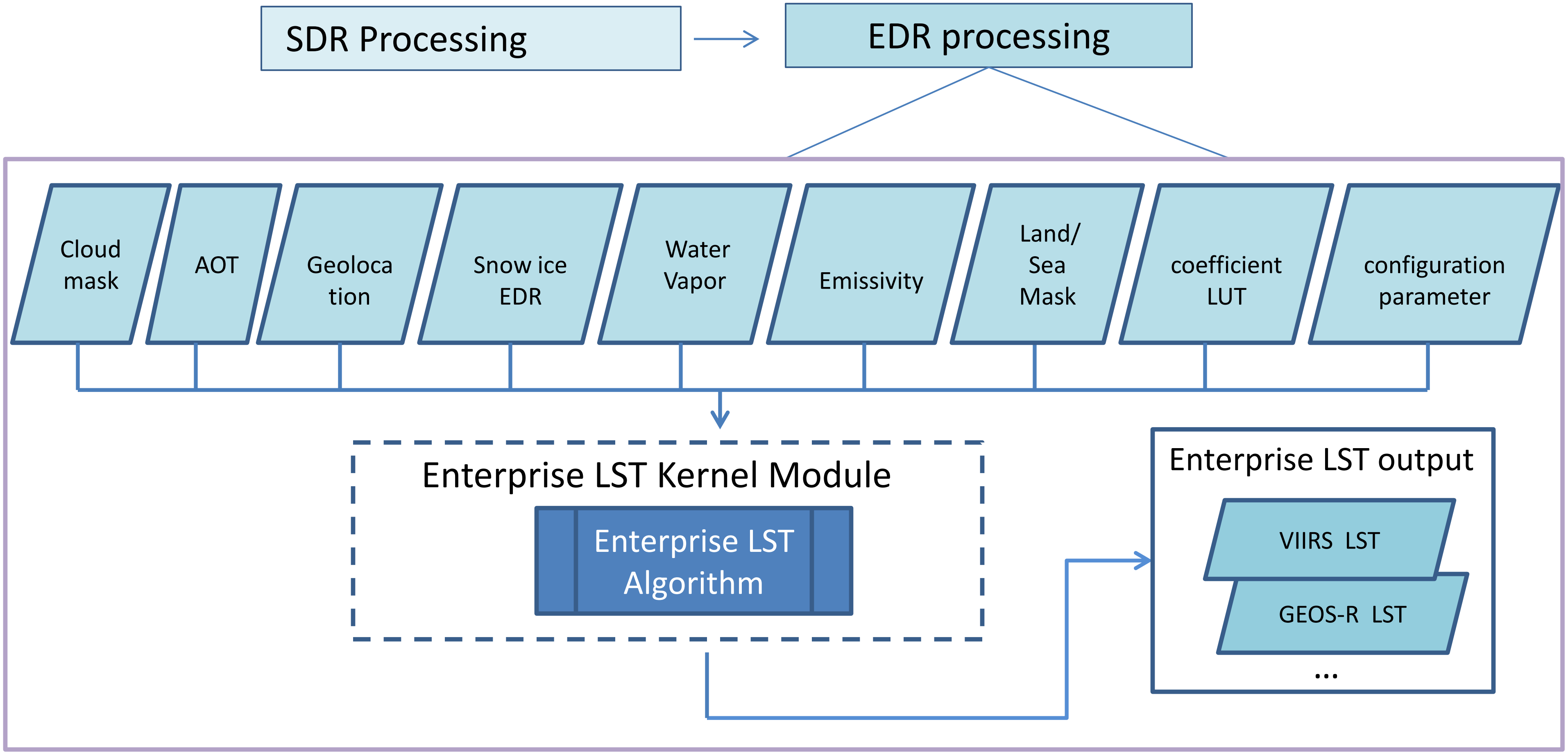
$$T_S = C_0 + C_1T_{11} + C_2(T_{11} - T_{12}) + C_3\varepsilon + C_4\varepsilon(T_{11} - T_{12}) + C_5\,\Delta\varepsilon$$

T_{11} and T_{12} : the TIR split-window channel BTs

ε and $\Delta\varepsilon$: mean emissivity at the TIR spectrum, and the emissivity difference

LUT {C} dimension: Day/night, View Zenith Angle, Total Column Water Vapor

High Level Data Flow

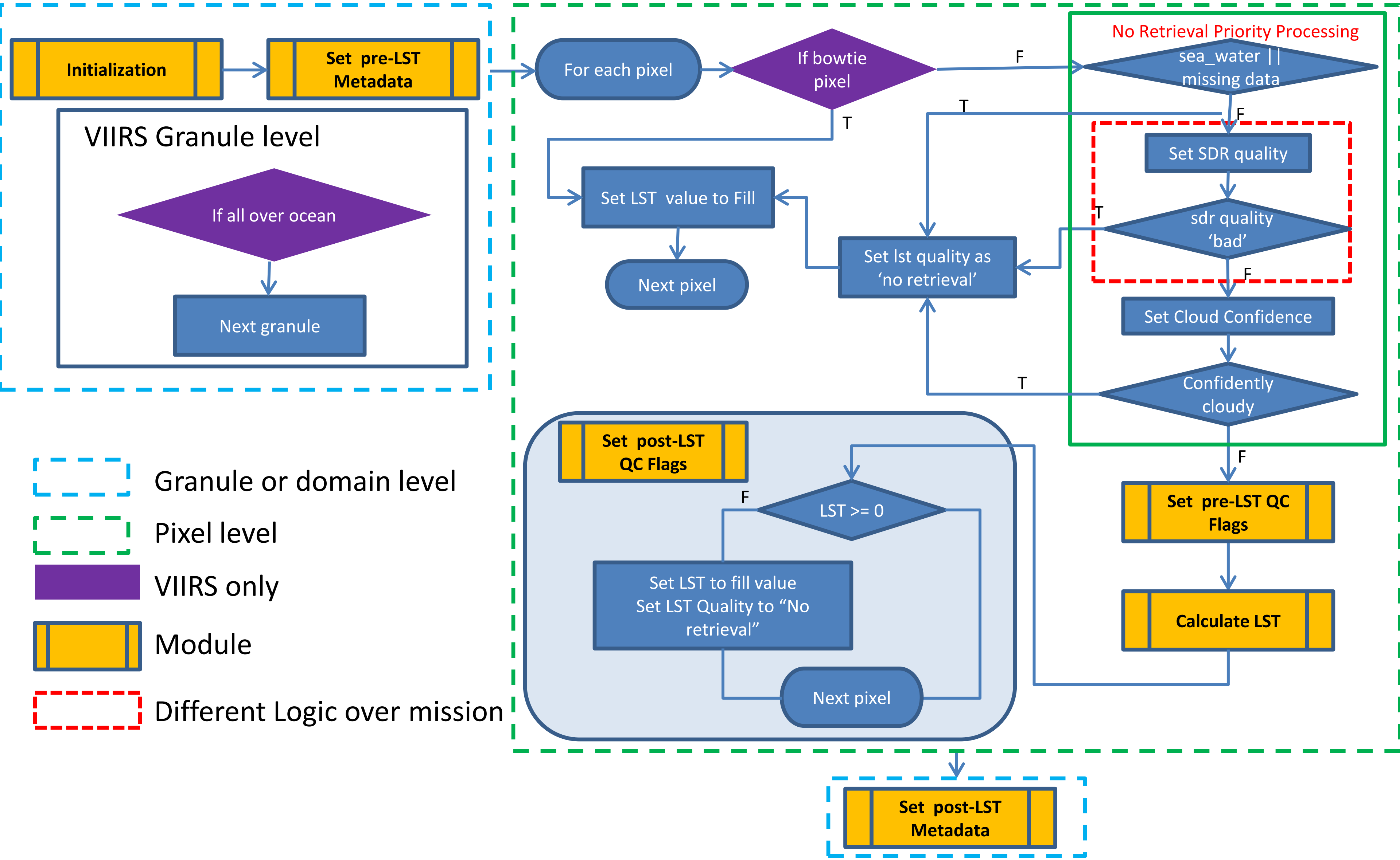


This algorithm can potentially support all available instruments such as VIIRS, GOES-R , SEVIRI, AHI etc. However, only VIIRS and GOES-R will be considered in the current frame.

Table of Input List

Name	Type	Description	Dimension	Unit
Primary Sensor Data(SDR)				
Brightness temperature 11µm	input	brightness temperature at 11µm	grid (xsize, ysize)	K
Brightness temperature 12µm	input	brightness temperature at 12µm	grid (xsize, ysize)	K
Latitude	input	Pixel latitude	grid (xsize, ysize)	Degree
Longitude	input	Pixel longitude	grid (xsize, ysize)	Degree
Solar zenith	input	solar zenith angles	grid (xsize, ysize)	Degree
View Zenith	input	Satellite view zenith angle	grid (xsize, ysize)	Degree
SDR QC flags	Input	Level 1b data quality	grid (xsize, ysize)	unitless
Space mask	Input	Out of space indicator(GOES-R only)	grid (xsize, ysize)	unitless
Derived Sensor Data				
Cloud mask	Input	Cloud mask data	grid (xsize, ysize)	unitless
Snow/ice mask	Input	Level 2 snow/ice mask data	grid (xsize, ysize)	unitless
Land/sea mask	Input	Level 2 land/sea mask data	grid (xsize, ysize)	unitless
water vapor	Input	For ABI: ABI baseline TPW;For VIIRS: NCEP tpw data	grid (xsize, ysize)	mm(cm)
Emissivity	Input	Land surface emissivity	grid (xsize, ysize)	unitless
AOT	Input	Level2 AOT data	grid (xsize, ysize)	unitless
LUT and Configuration File				
Coefficients LUT	Input	Algorithm coefficient file	2(day/night)*3(wv)*5(stz)* 7(coef items)	Unitless
Configuration file	Input	Configuration values		Unitless

Enterprise LST Kernel Module Flow Chart



LST QF

Flag	JPSS	GOES-R	Descriptions
LST quality	x		High,medium,low,no retrieval
Algorithm	x		Split; dual split
Day/night	x	x	0-night;1-day
SWIR availability	x		M12 amd M13 in range or not
LWIR availability	x		M15 and M16 in range or not
Active fire	x		0-no fire; 1-fire
Thin cirrus	x		0-no thin cirrus; 1-thin cirrus
Degradation	x	x	0-no degradation; 1-degradation(VIIRS: STZ > 40; ABI: STZ > 55)
LST out of range	x	x	VIIRS: 0-within range(213-343); 1-out of range ABI: 00-normal, 01-cold surface(213-250),10-out of range(213-330)
Cloud property	x	x	0-confidently clear; 1-probabaly clear; 2-pro cloudy; 3-confi cloudy
AOT condition	x		0-within range(aot <1); 1- out of range
HOI	x		Horizontal reporting interval. 0-within range (stz<53); 1-out of range
Sun glint	x		0-no sun glint; 1-sun glint
Terminator	x		0-beyond; 1-inside terminator(85 < soz <= 100)
Land water	x	x	VIIRS: 000-land and desert; 001-land no desert; 010-inland water;011-sea water;101-coastal ABI: 00-land,01-snow/ice;10-in land water,11-sea water
Surface type	x	x	VIIRS: 17 IGBP type including snow/ice surface ABI: included in the land water flag
TPW condition		x	(00=dry atmosphere (wv<=1.5g/cm2); 01=moist atmosphere(wv>2.0g/cm2); 10= very moist(wv>5.0/cm2
SDR Quality		x	00-normal;01-out of space;10-bad data;11-missing data
Emissivity quality		x	0-normal ; 1-historical emissivity

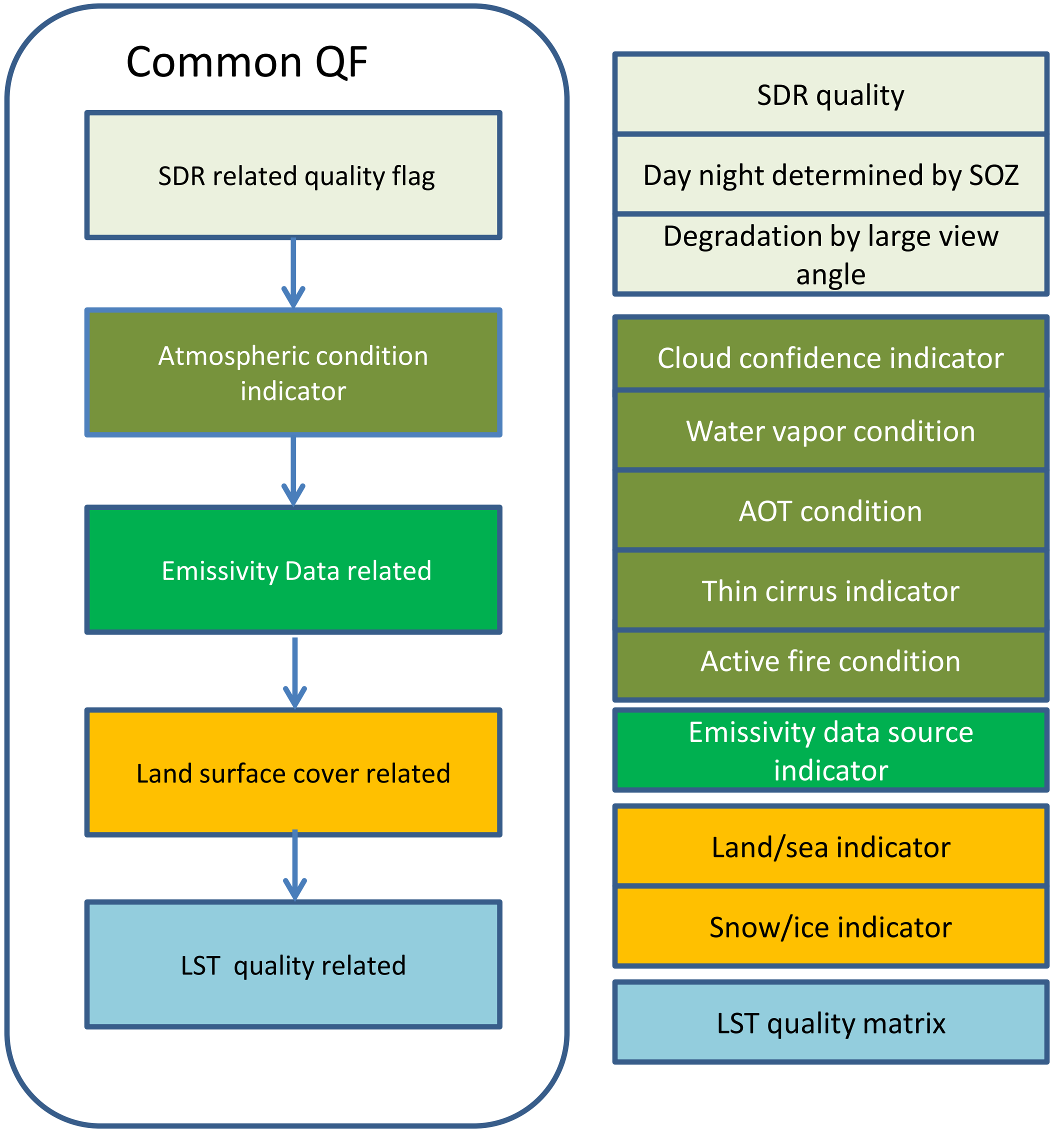
Quality Flag list

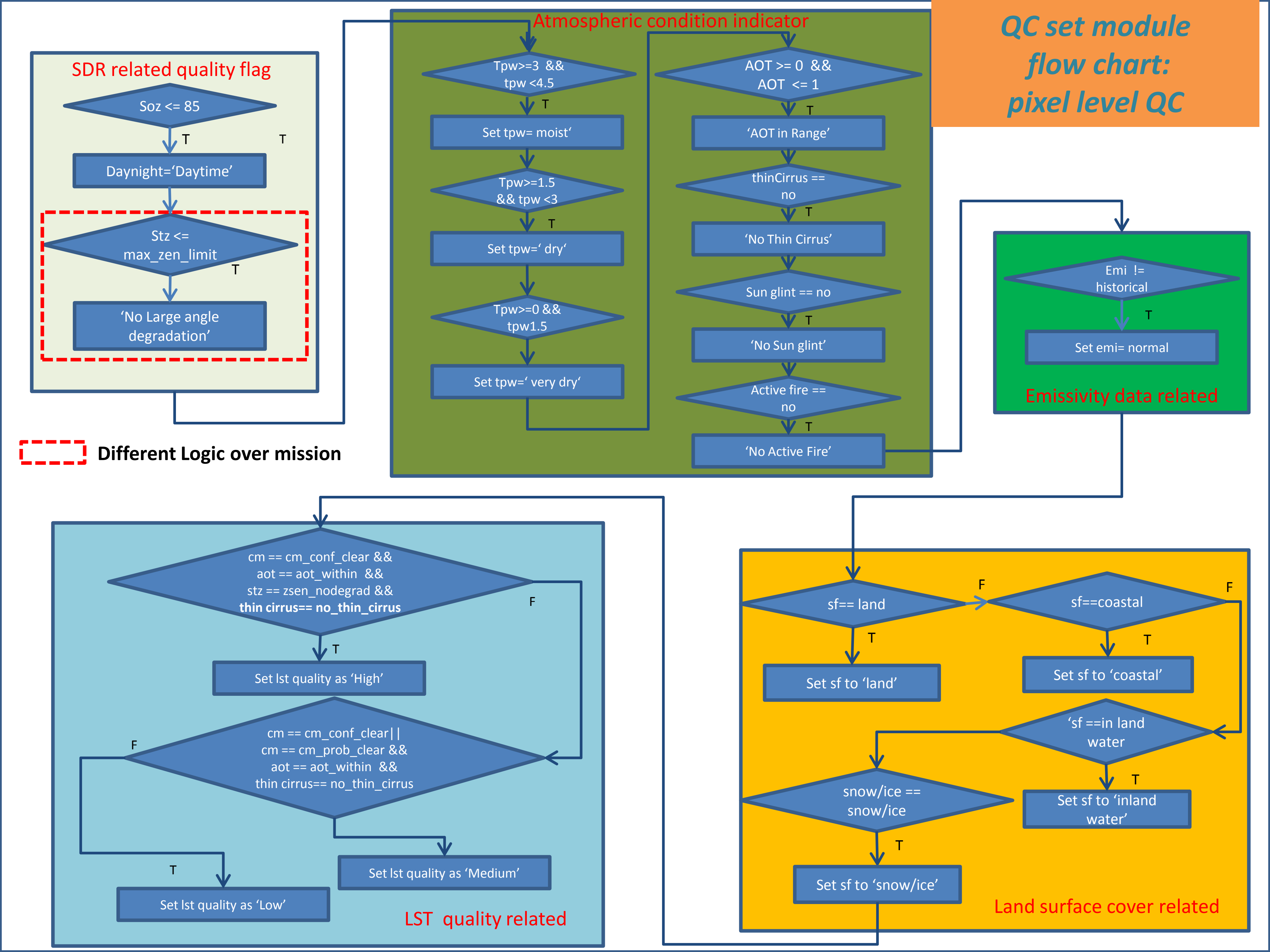
byte	bit	Flag	Source	description
1	0-1	LST quality	LST	00=high, 01=medium, 10=low, 11=no retrieval
	2-3	Cloud condition	Cloud mask	00=confidently clear, 01=probably clear,10=probably cloudy,11=confidently cloudy
	4	SDR quality	SDR	0=normal, 1=bad data VIIRS: (bad , missing , not calibrated) GOES-R: (bad , missing , not calibrated, out of space)
	5	Aerosol Optical Thickness at 550 nm (slant path)	AOT	0=within range(AOT<=1.0);1=outside range (AOT >1)
	6-7	Land surface cover	land/sea mask snow/ice mask	00=land;01=snow/ice;10=in land water;11=coastal
2	0-1	Water vapor condition	Tpw input	00=very dry atmosphere(wv<1.5g/cm^2) ; 01= dry [1.5,3); 10=moist atmosphere(3,4.5]; 11= very moist[4.5+)
	2	Emissivity availability	Emissivity	0=normal, 1=historical emissivity
	3	Degradation by large viewing angle	SDR	0=no degradation, 1=large view degradation (VIIRS: 40 degree, GOES-R: 55 degree)
	4	Day/night flag	SDR	0=night(solar zenith angle > 85degree), 1=day
	5	Thin cirrus*	Cloud Mask	0= no thin cirrus, 1= thin cirrus
	6	Active fire*	Cloud mask	0= no active fire, 1= active fire
	7	Reserved		Reserved for future use

Note: * Definition clarification or available of nighttime thin cirrus and active fire are to be requested.

QF set module flow chart: pixel level QF

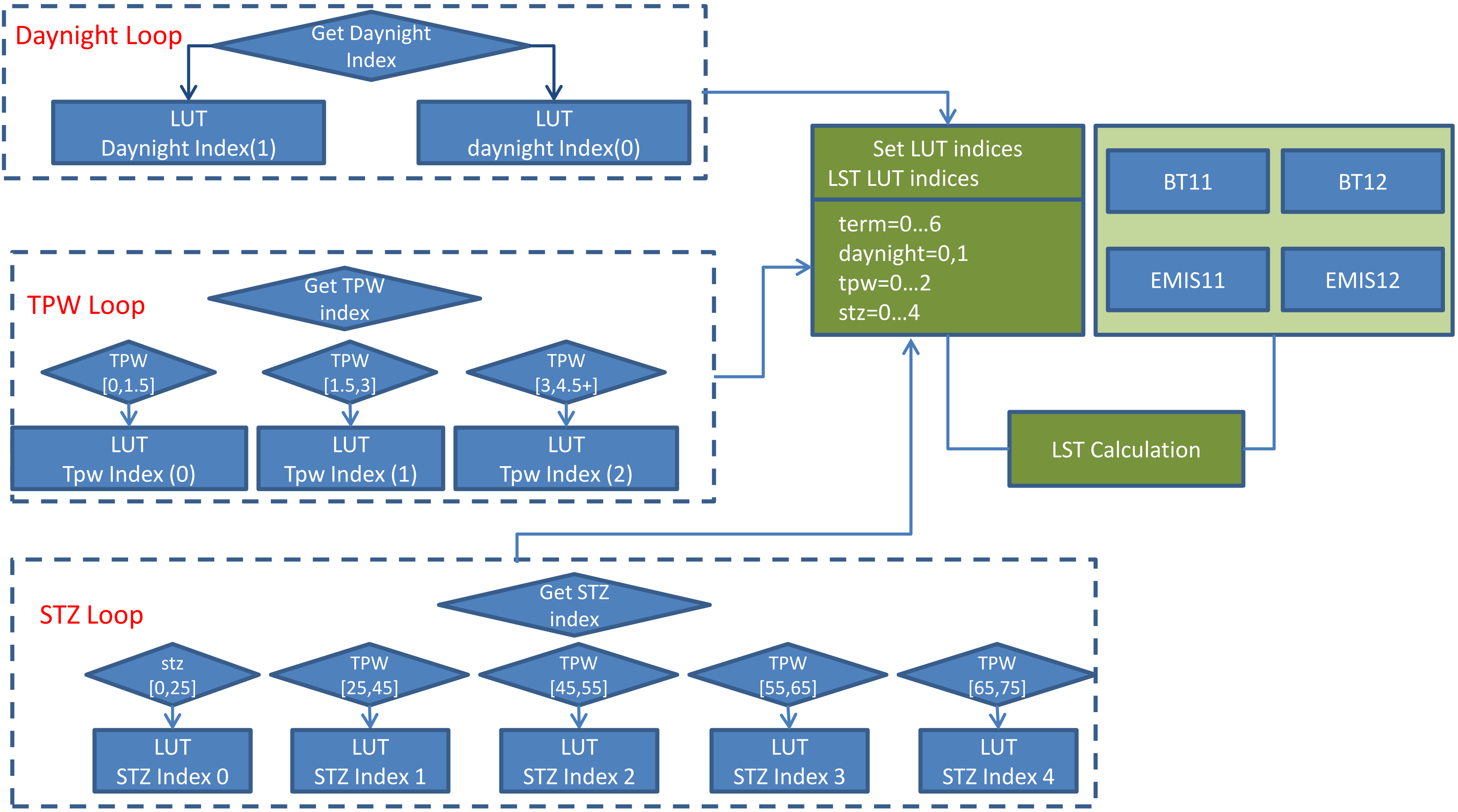
Threshold used in quality flag are configurable. Some thresholds are same but some are different among the missions.





QC set module flow chart: pixel level QC
SDR related quality flag
Soz <= 85
T
T
Daynight='Daytime'
Stz <= max_zen_limit
T
'No Large angle degradation'
Different Logic over mission
Atmospheric condition indicator
Tpw>=3 && tpw <4.5
T
Set tpw= moist'
Tpw>=1.5 && tpw <3
T
Set tpw=' dry'
Tpw>=0 && tpw1.5
Set tpw=' very dry'
AOT >= 0 && AOT <= 1
T
'AOT in Range'
thinCirrus == no
T
'No Thin Cirrus'
Sun glint == no
T
'No Sun glint'
Active fire == no
T
'No Active Fire'
Emi != historical
T
Set emi= normal
Emissivity data related
cm == cm_conf_clear && aot == aot_within && stz == zsen_nodegrad && thin cirrus== no_thin_cirrus
F
T
Set lst quality as 'High'
cm == cm_conf_clear|| cm == cm_prob_clear && aot == aot_within && thin cirrus== no_thin_cirrus
F
T
Set lst quality as 'Medium'
Set lst quality as 'Low'
LST quality related
sf== land
F
sf==coastal
F
T
Set sf to 'land'
T
Set sf to 'coastal'
'sf ==in land water
T
Set sf to 'inland water'
snow/ice == snow/ice
T
Set sf to 'snow/ice'
Land surface cover related

LST Calculation module flow chart: pixel level



Emissivity Development Strategy

➢ Propose a new emissivity algorithm

- Using historical emissivity products to generate background emissivity climatology.
- Employing the relationship between emissivity and GVF & Snow fraction to account for the dynamic change.
- Produce high resolution (0.009 degree) daily emissivity product for JPSS and GOES-R missions.

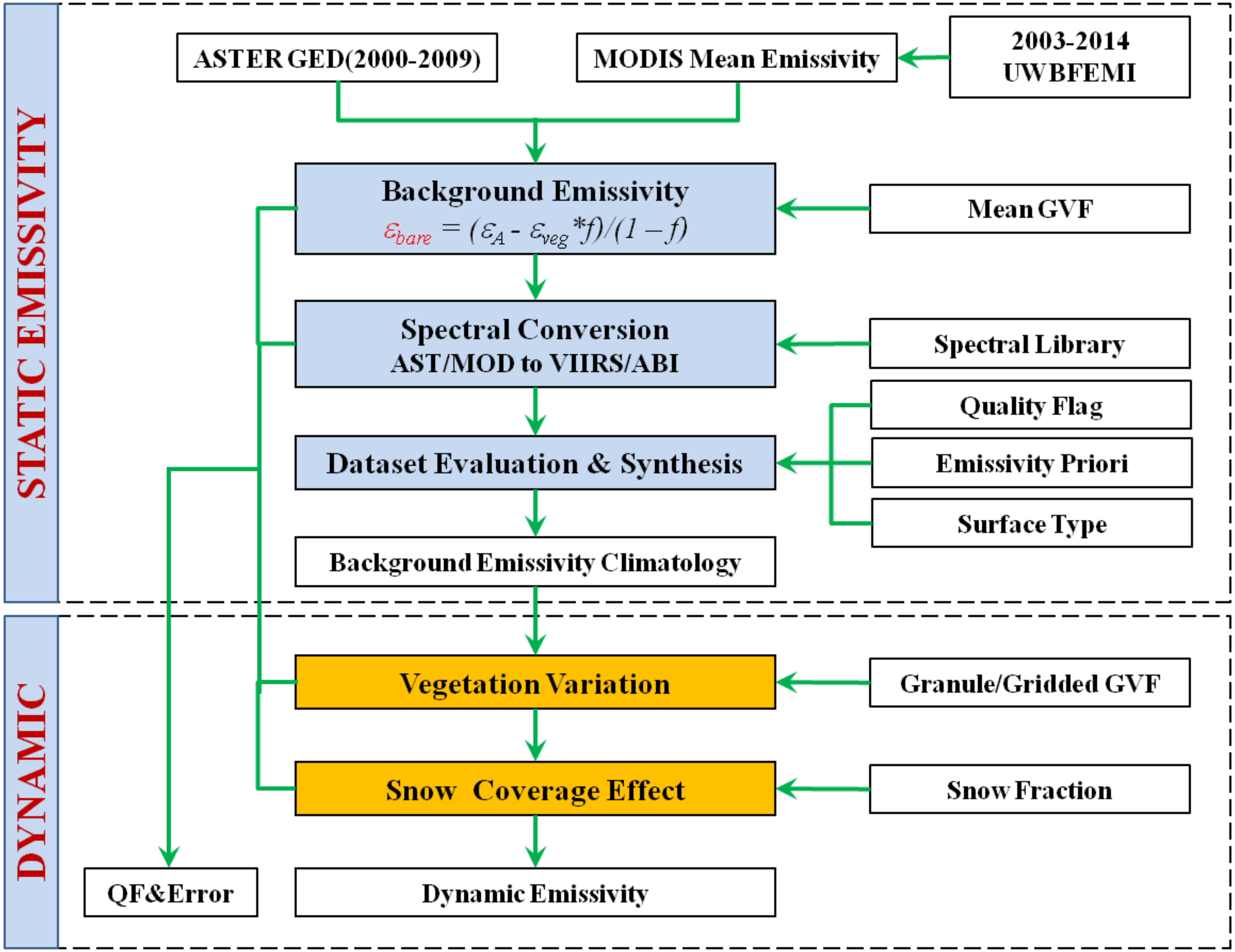
➢ Advantages

- Satellite emissivity products could provide more accurate soil emissivity than empirical method
- High resolution GVF & Snow product could well reflect the emissivity change.

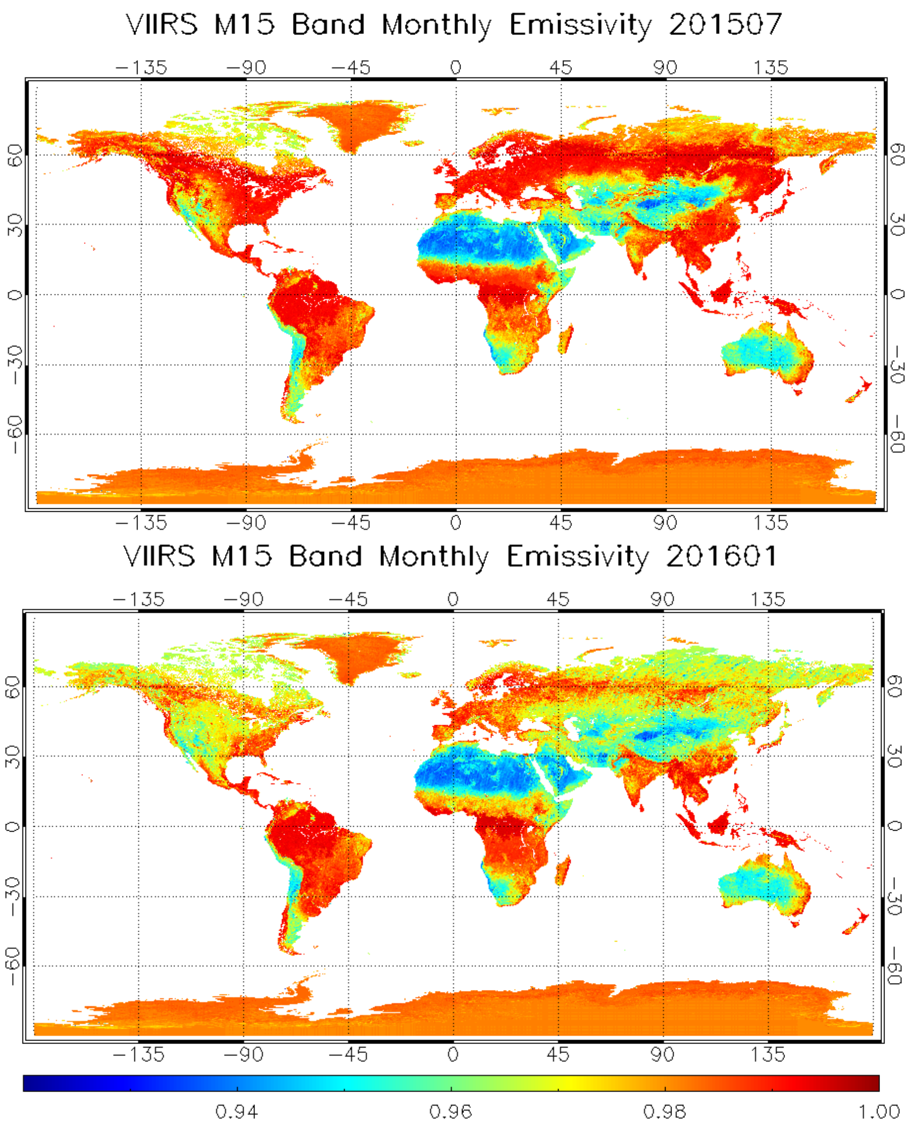
➢ Limitations

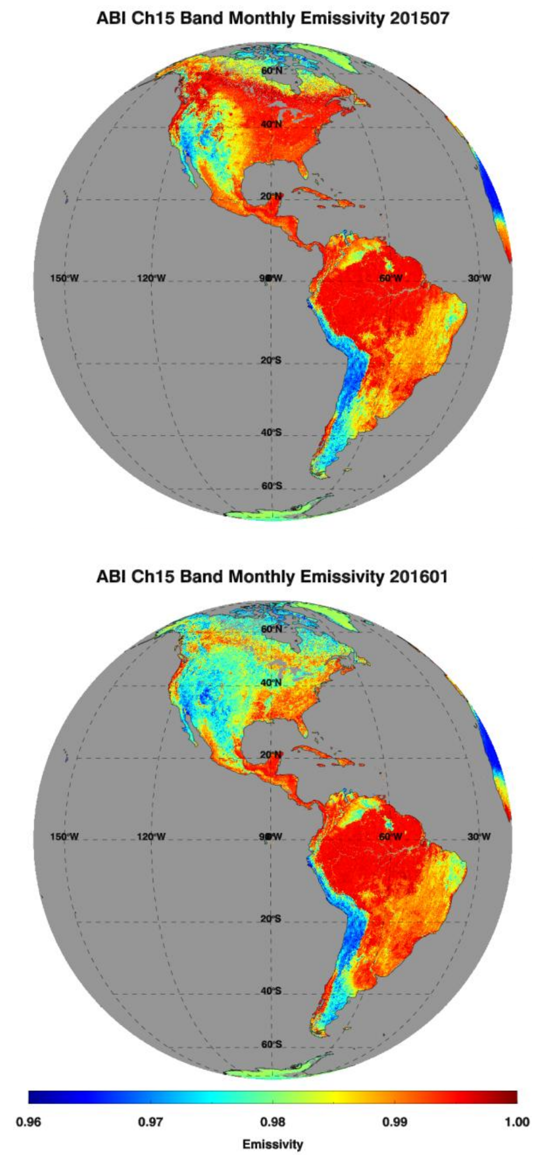
- The new emissivity product only include thermal infrared channels

High Level Process Flow



VIIRS and ABI Emissivity Product





Testing and Validation

How will product be tested/validated

- Ground data evaluation
  - Enterprise VIIRS LST
    - SURFRAD
    - BSRN
    - GMD
  - Enterprise SEVIRI LST
    - Ground data in Gobabeb, Namibia
  - Enterprise AHI LST
    - Ground data in Australia
- Cross satellite comparison
  - Enterprise VIIRS LST vs SEVIRI LST
  - Enterprise VIIRS LST vs AQUA LST
  - Enterprise VIIRS LST vs Enterprise AHI LST

Schedules and Milestones

Enterprise LST Algorithm Development		2016 (Calender Year)				2017				2018			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development Phase	Primary strategy, prototype, task plan												
	Initial Algorithm descriptive docs												
	Critical Design Review (CDR)												
Pre-operational Phase	Science code development and test												
	Framework Integration												
	Unit Test Readiness Review (UTRR)												
	Initial DAP												
	Initial ATBD, Software Review				ATBD V0								
	Algorithm Readiness Review (ARR)												
	Final DAP delivery												
Operational Phase	Operational Readiness Review												
	Operational Phase Begins in NDE												
Cal/Val Phase	Validation and LM monitoring												
	ATBD Update									ATBD V1			
	Maintenance and further improvement												

Risks

Potential risks

1. Algorithm in common vs mission specific features may introduce additional work in design and implementation.
2. Separated system maintenance may still needed for different satellite missions.
3. Quality of the product may be different between the missions, particularly between LEO and GEO missions (due to differences of resolution, sensor spec., angular effect etc.)
4. Limited high quality ground in-situ data is critical for enterprise algorithm validation.
5. It is not straight forward for users to switch from the current existing baseline LST product to the enterprise product due to the format change, QF logic update etc.

Summary and Recommendations

Summary

- A new emissivity explicit, TIR split-window regression approach is adapted as an enterprise algorithm for JPSS VIIRS LST production, which later can be applied for GOES-R ABI LST production as well.
- A consistent QF set is defined
- Emissivity production needed is in development
- Preliminary test demonstrates that it is feasible to implement the enterprise algorithm in multiple sensors.

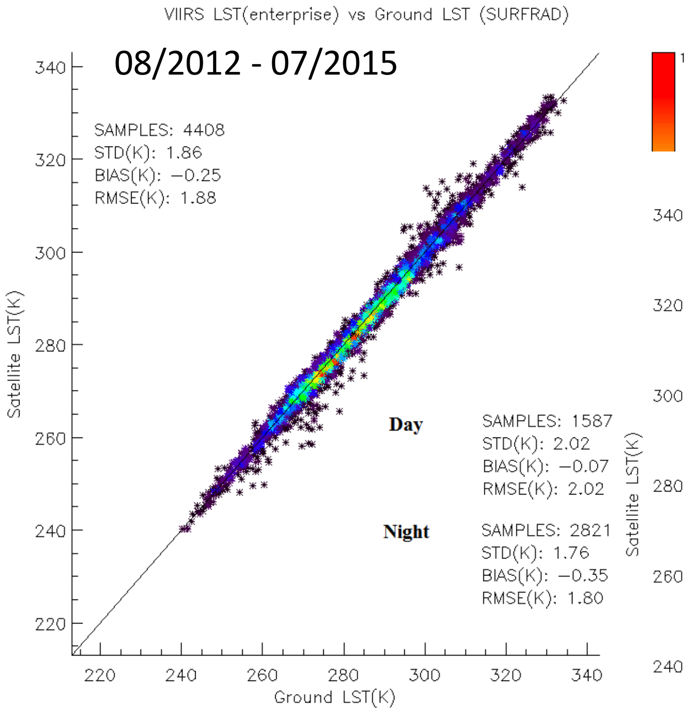
Recommendations

- The object-oriented programming in scheme for enterprise system design and development
- Maintenance separation for different missions
- Improvement of global representativeness of the validation data collection

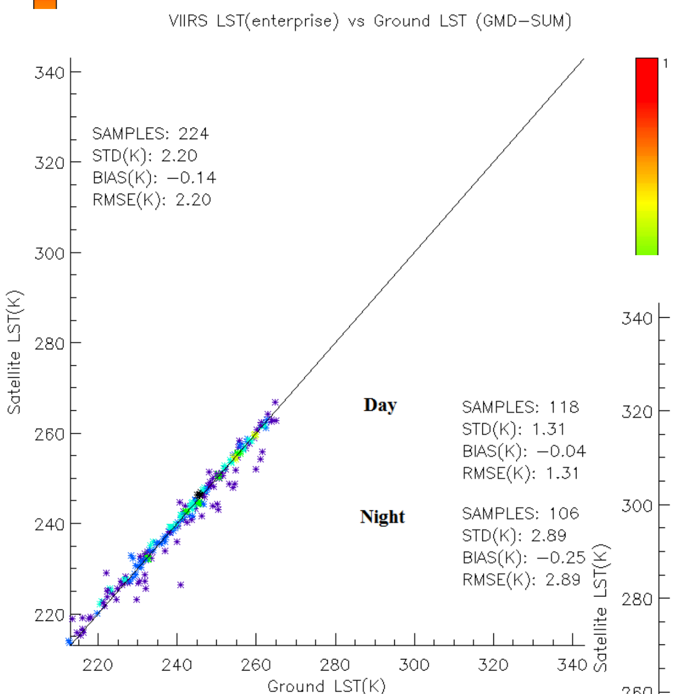
- Back-ups

Testing and Validation

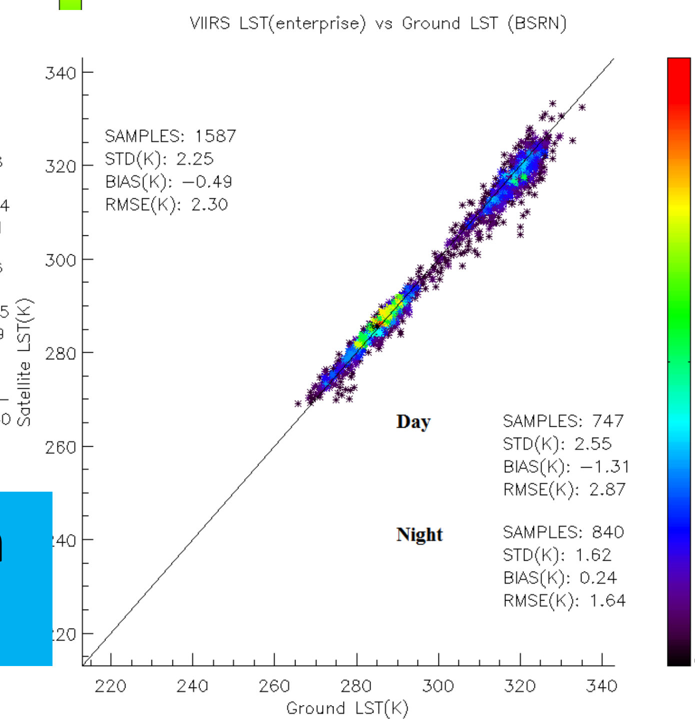
- Ground data evaluation



09/2013 - 06/2015

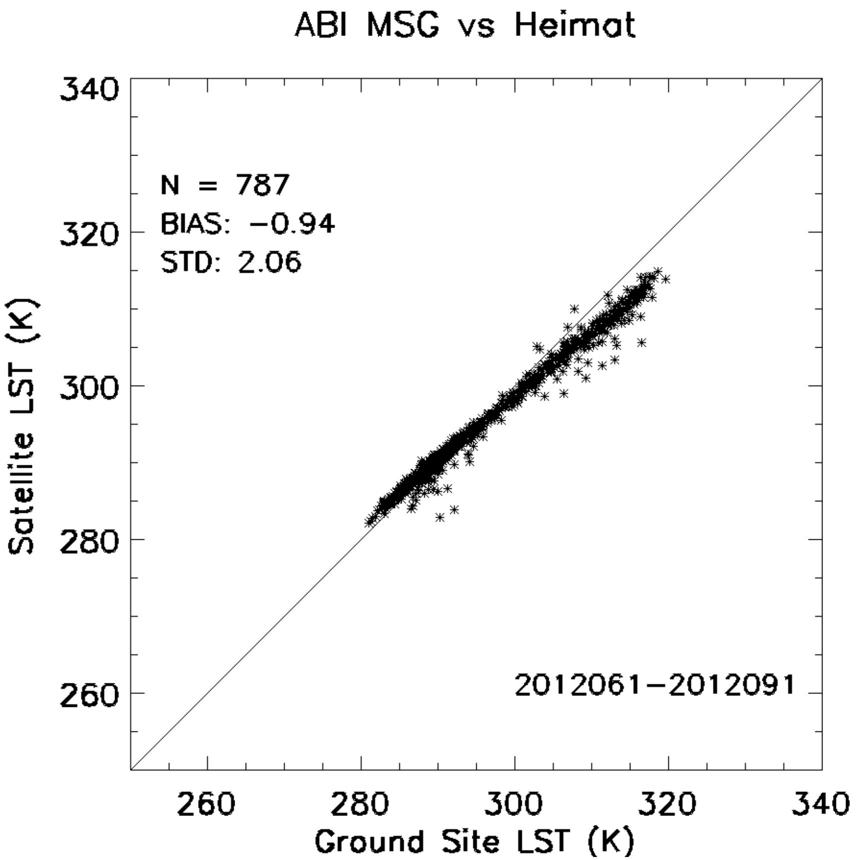


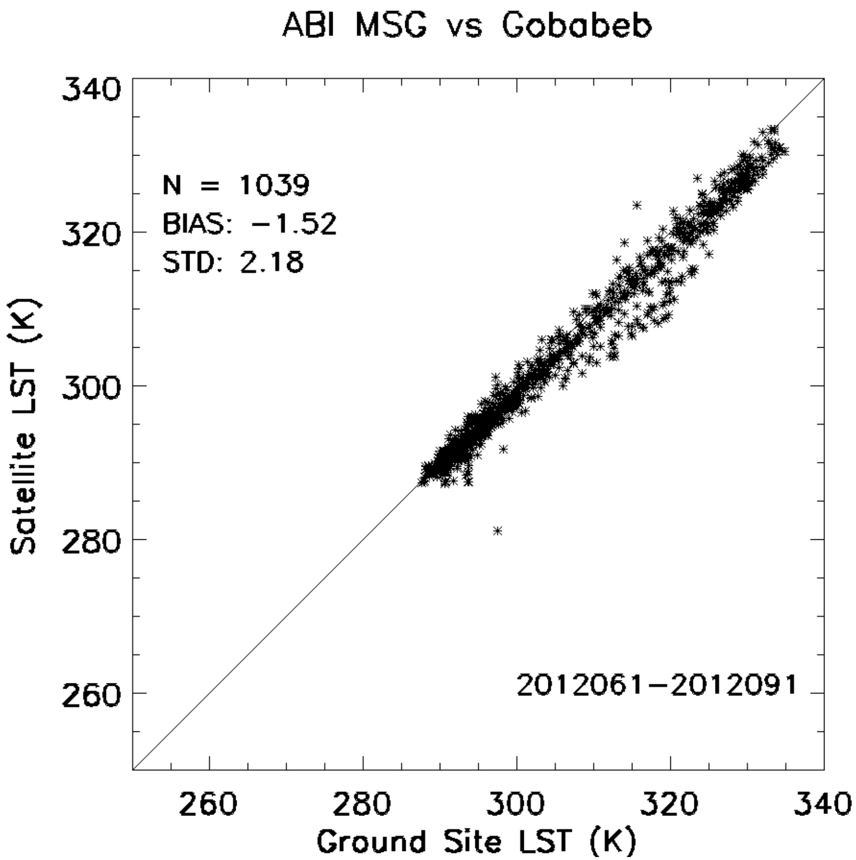
09/2013 - 07/2015



Enterprise VIIRS LST against ground data from SURFRAD, BSRN and GMD

Testing and Validation

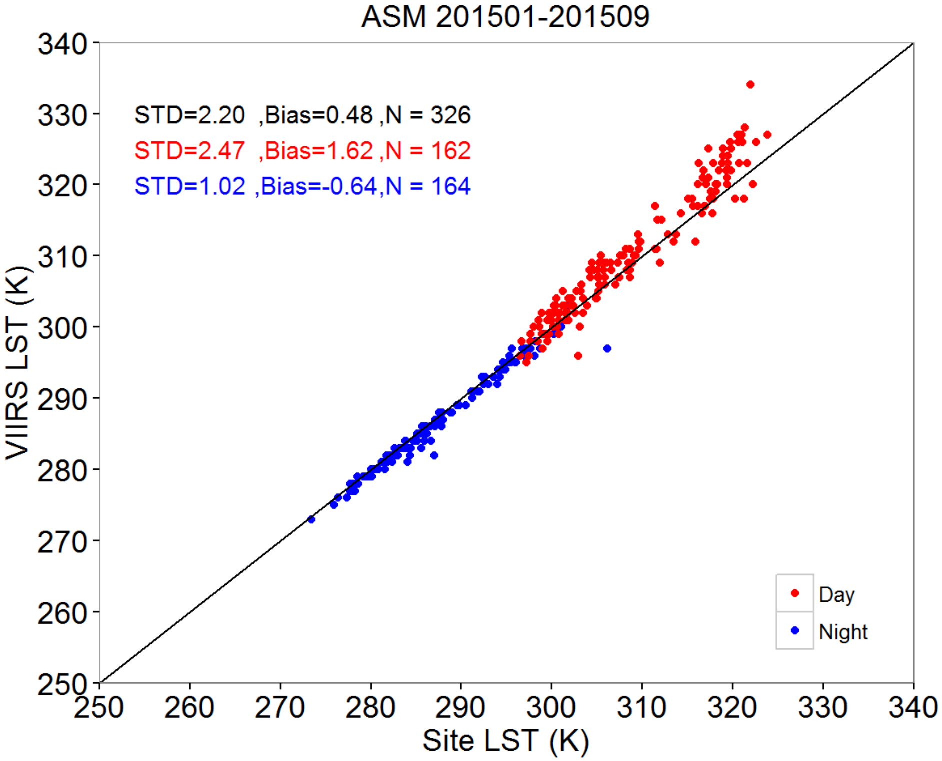


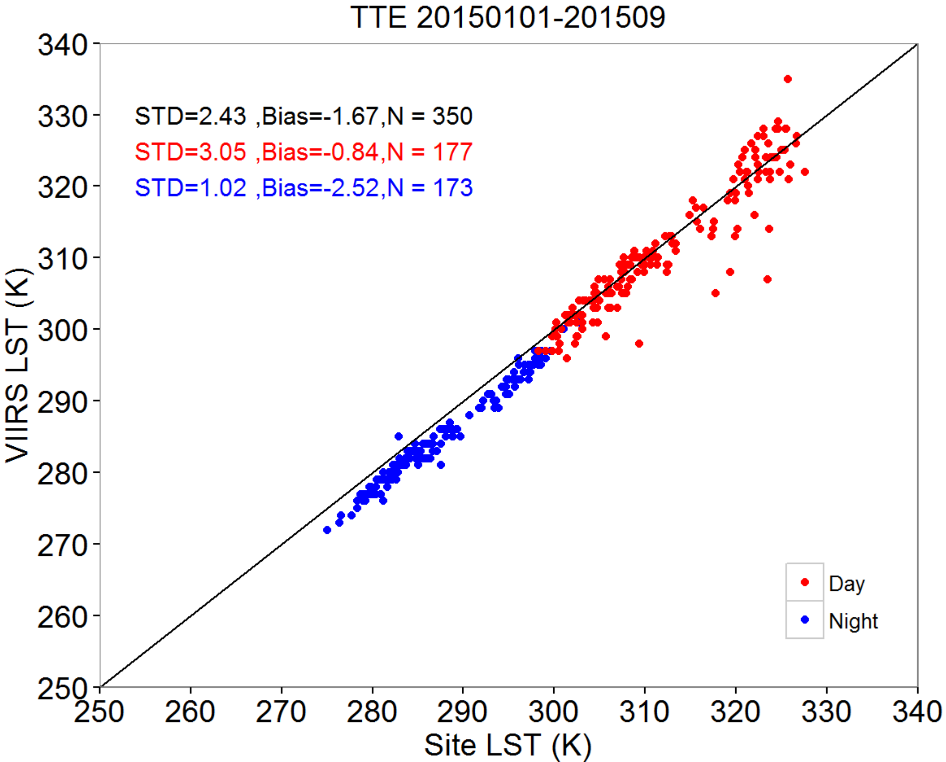


Enterprise SEVIRI LST against ground data in Gobabeb and Heimat, Namibia for the time period in March, 2012

Acknowledgement: The ground data is from Goettsche, Frank at AIT

Testing and Validation

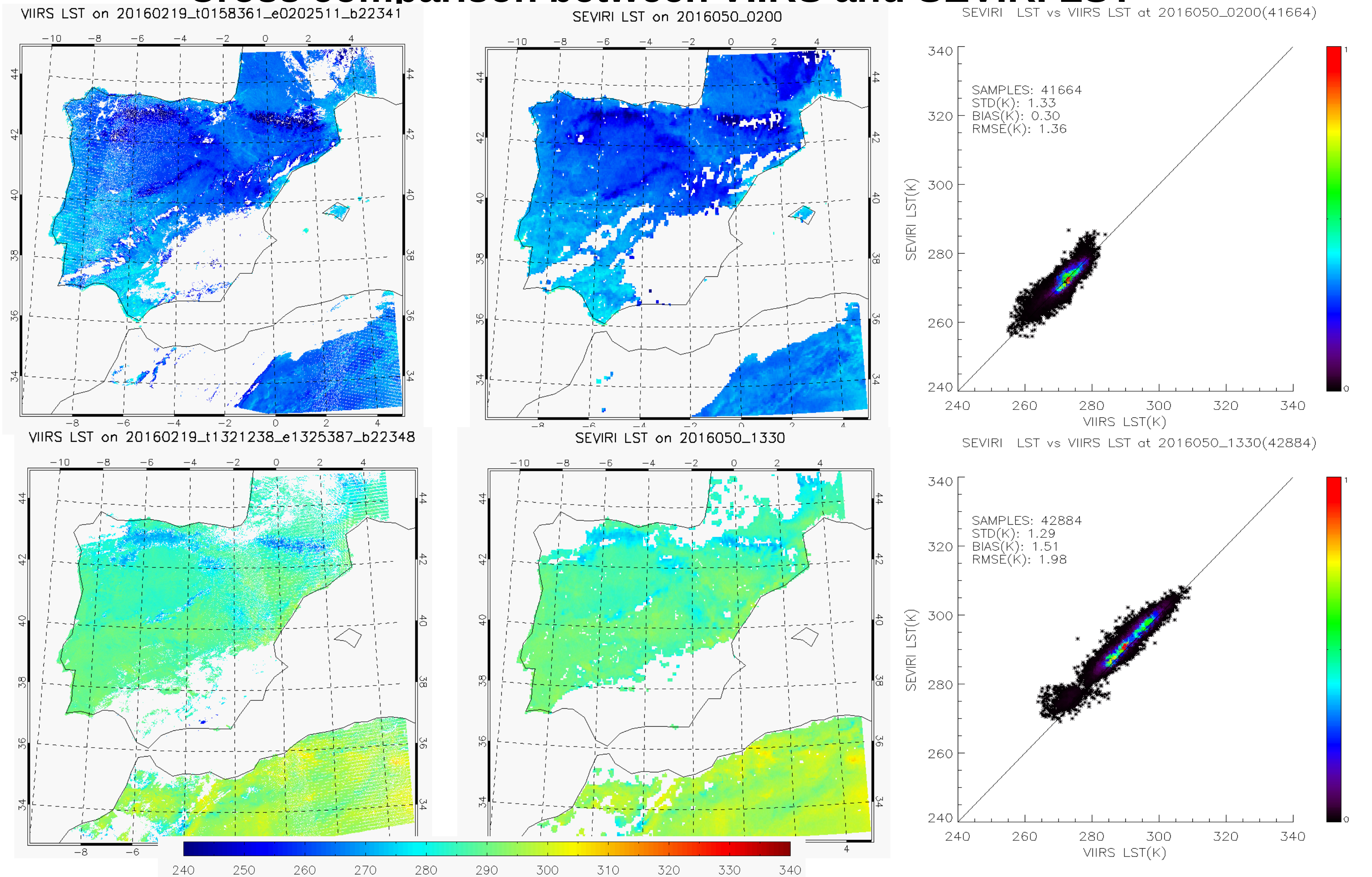




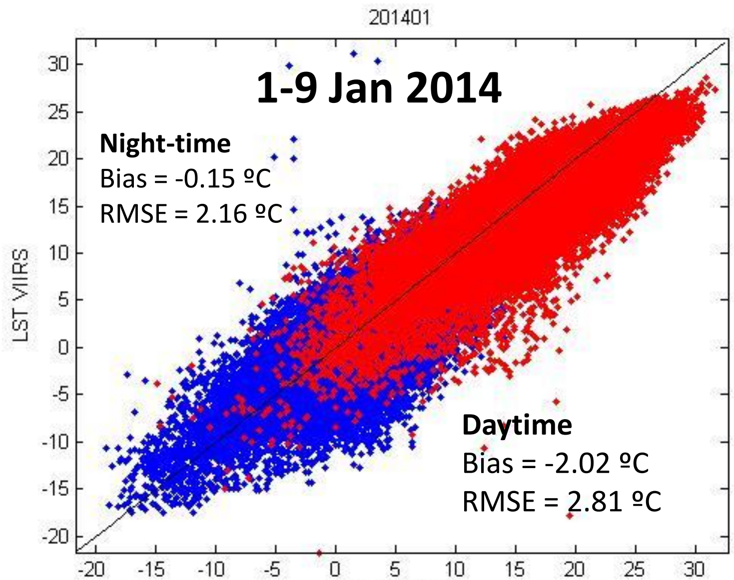
Enterprise AHI LST against ground data from Australia OzFlux network

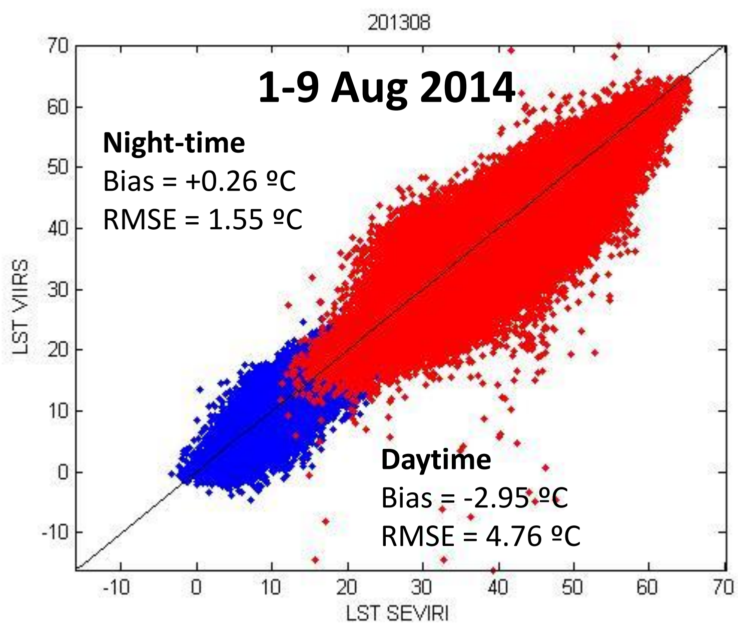
Testing and Validation

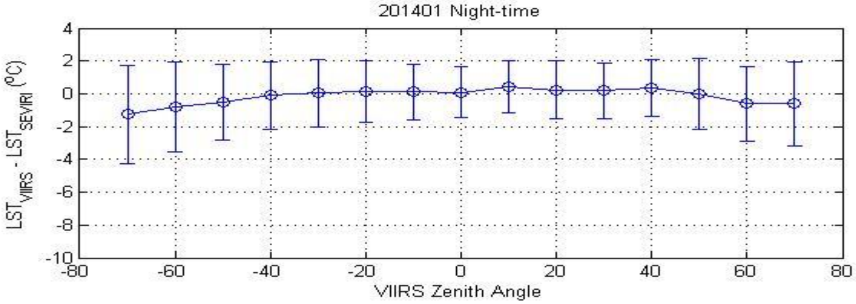
Cross comparison between VIIRS and SEVIRI LST

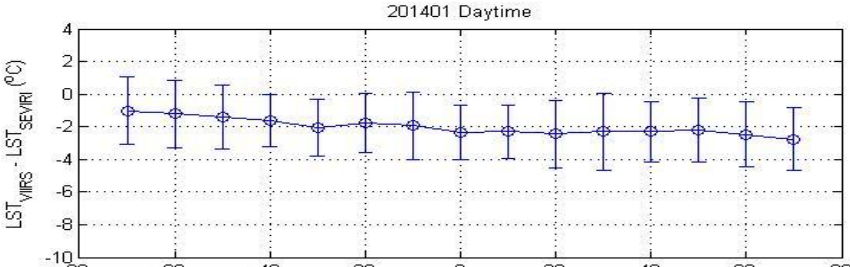


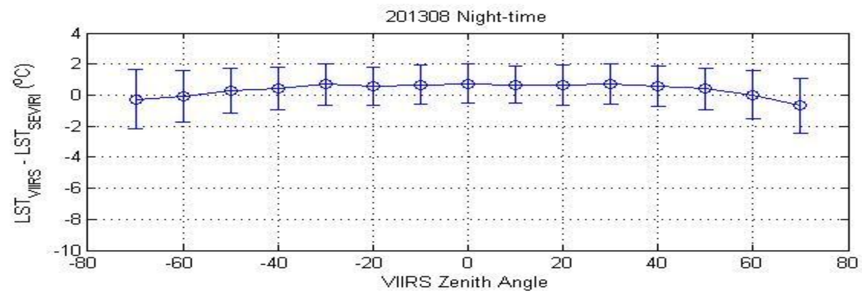
Quality analysis/validation (Cross satellite comparison)

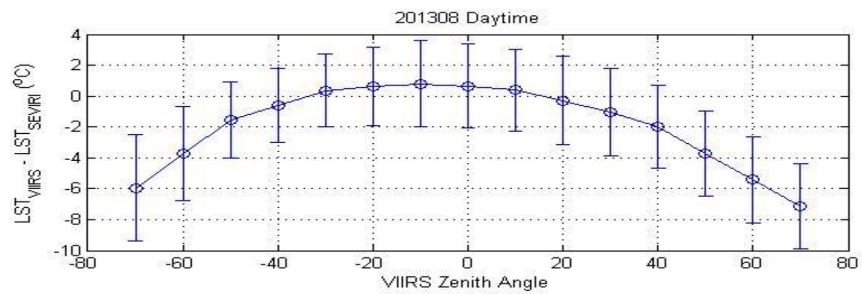






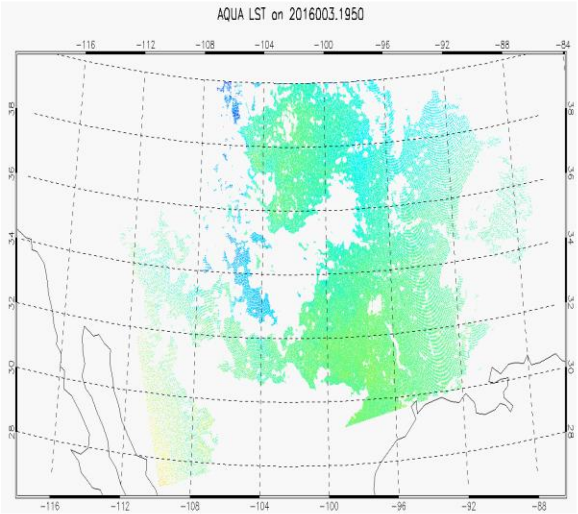


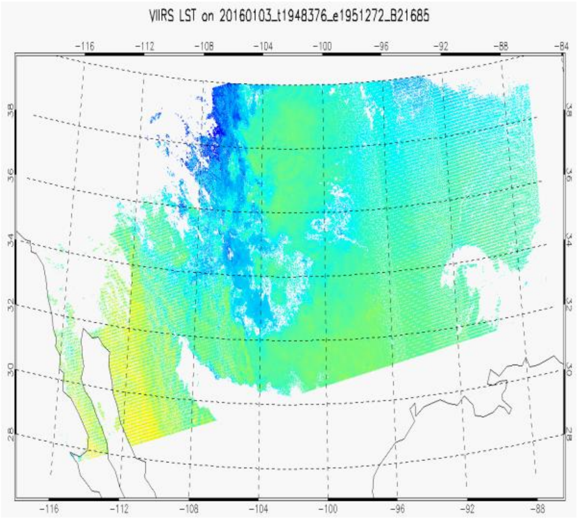


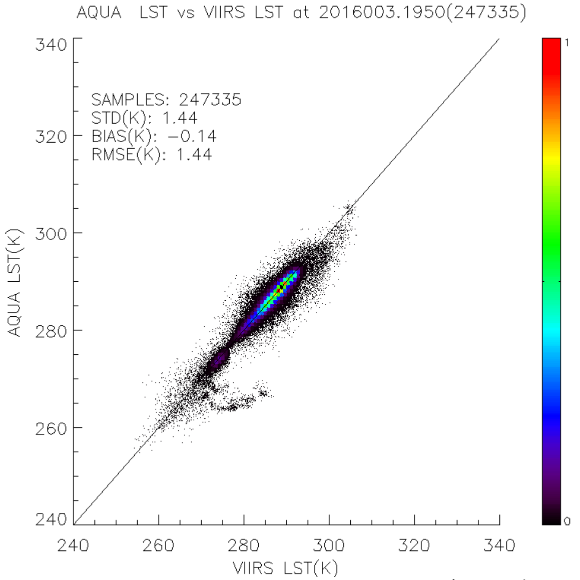


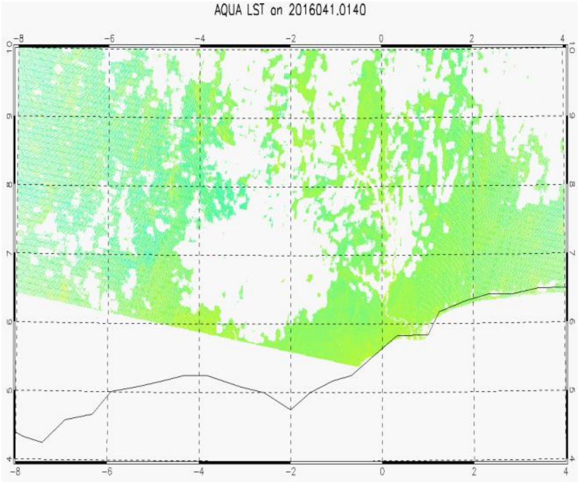
Testing and Validation

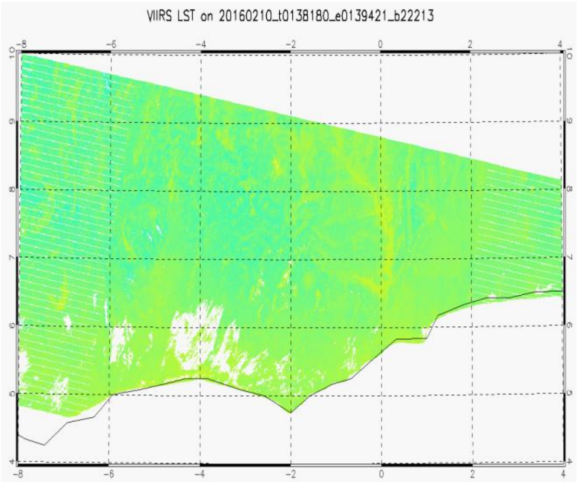
Cross comparison between VIIRS and AQUA LST

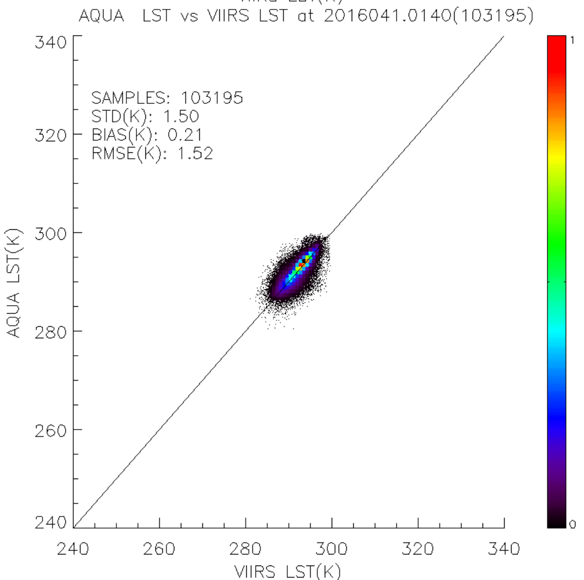


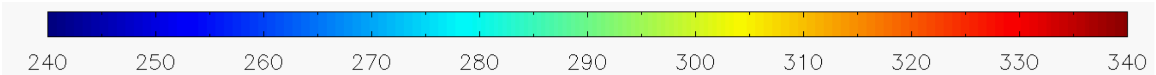












Testing and Validation

Cross comparison between VIIRS and AHI LST