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Further developments of ACSPO SST: approaching SST_{skin} and SST_{depth}

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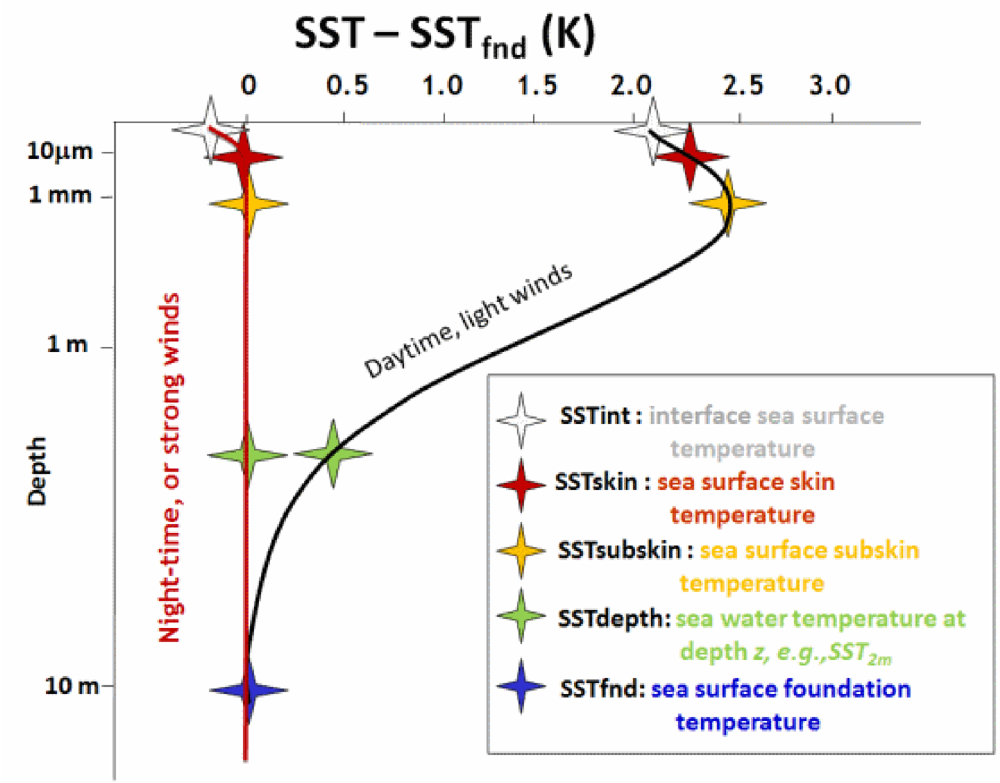
Definitions of SST_{skin} and SST_{depth}



The figure is from https://www.ghrsst.org

- Satellite brightness temperatures are sensitive to SST_{skin} - the temperature of the upper ~10 µm ocean layer
- Regression SST is trained and validated against SST_{depth} measured by drifting and moored buoys at ~1-2 m depth
- The magnitudes of diurnal variations in SST_{skin} are larger than in SST_{depth}

Objectives

- The superior performance of the Himawari-8 AHI and GOES-16 ABI enables continuous monitoring of the diurnal cycle (DC) in SST.
- However, besides instrument capabilities, the quantitative DC monitoring requires optimization of SST algorithms
- In general, retrieved SST mixes the properties of SST_{skin} or SST_{depth}, which requires more specific targeting of retrievals at SST_{skin} or SST_{depth}.
- The current ACSPO v.2.41 already produces certain approximations of SST_{skin} and SST_{depth}:
  - Baseline SST (BSST), aka “sub-skin” SST, is sensitive to SST_{skin}
  - De-biased SST (DSST) precisely fits SST_{depth} with SD ~0.25 K.
- This presentation discusses the performance of the ACSPO v.2.41 SSTs in terms of DC monitoring and the upcoming modifications of SST products in ACSPO v.2.50.

AHI/ABI BSST equation

$$T_S = a_0 + a_1 T_{11} + a_2(T_{11}-T_8) + a_3(T_{11}-T_{10}) + a_4(T_{11}-T_{12}) +$$
$$+[a_5 + a_6 T_{11} + a_7(T_{11}-T_8) + a_8(T_{11}-T_{10}) + a_9(T_{11}-T_{12})]S_\vartheta +$$
$$+ [a_{10}(T_{11}-T_8) + a_{11}(T_{11}-T_{10}) + a_{12}(T_{11}-T_{12})]T_S^0$$

- The BSST is currently the closest approximation of SST_{skin}
- On average, BSST is reasonably precise wrt *in situ* SST (SST_{depth}) and sensitive* to SST_{skin}
- The DC monitoring requires accurate estimation of spatial and temporal SST variations. This, in turn, requires minimization of spatial and temporal variations in BSST biases and sensitivity

*SST sensitivity μ is RTM-based metric, which characterizes response of retrieved SST to variations in SST_{skin} *(Merchant et al., GRL, 2009)*.

Training BSST regression coefficients

- Initially (since May 2015) AHI BSST coefficients were trained with the conventional Least-Squares (LS) method:

$$<(T_S - T_{IS})^2> = min \qquad (1)$$

T_S retrieved SST
T_{IS} *in situ* SST
<*> denotes averaging over MDS

- The sensitivity of AHI BSST with LS-estimates of coefficients was found too low

- Since April 2016, the AHI BSST coefficients are retrained with the Constrained Least-Squares method (CLS), which poses a constraint on the mean sensitivity over the MDS *(Petrenko et al., SPIE, 2016)*:

$$\begin{cases} <(T_S - T_{IS})^2> = min \\ <\mu> = \mu_0, \end{cases} \qquad (2)$$

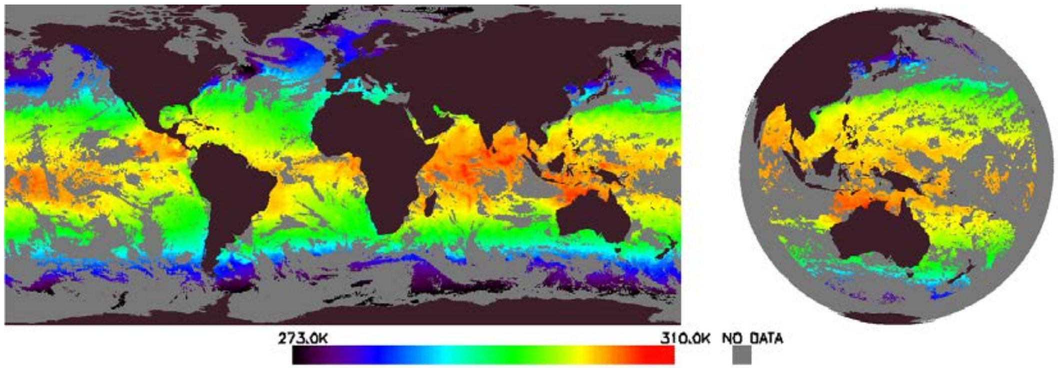
μ_0 predefined value of mean sensitivity

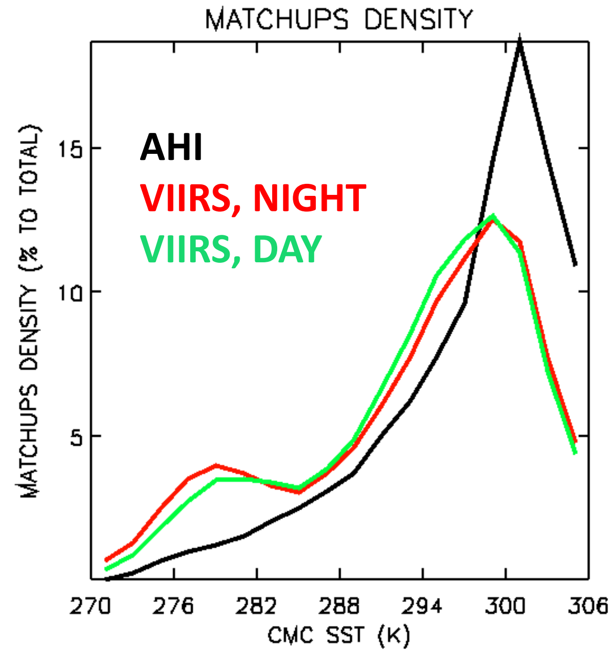
- The adjustment of mean sensitivity makes BSST biases and sensitivity even more non-uniform.
- To limit this non-uniformity, BSST coefficients are trained with μ_0= 0.95, rather than with μ_0 = 1

SST_{skin}

The effect of narrow SST histogram on AHI BSST sensitivity

S-NPP VIIRS **Himawari-8 AHI**





- Unlike the polar-orbiting sensors, AHI mainly observes low-latitude regions with relatively warm SST
- The SST histogram is narrower for AHI than for VIIRS, which means lower SNR
- Training AHI SST coefficients with the LS method results in much lower <***μ***> than for VIIRS

Mean sensitivities over the MDS
For VIIRS and AHI

Instrument	VIIRS (day)	VIIRS (night)	AHI (LS)	AHI (CLS)
<*μ*>	0.83	0.90	0.64	**0.95**

The Experimental PWR SST_{skin} in ACSPO v.2.50

•The experimental PWR SST_{skin} was designed to reduce the non-uniformity of biases and sensitivity:

- ✓ Unlike BSST, the PWR SST_{skin} uses PWR approach based on segmentation of the SST domain in the ***R***-space, similarly to DSST in v.2.41
- ✓ Unlike DSST, the PWR SST_{skin} coefficients for each segment are trained with the CLS method under the constraint $\langle \boldsymbol{\mu} \rangle = 1$.

- The PWR SST_{skin} has been implemented as an experimental algorithm in ACSPO v.2.50

Training of BSST and PWR SST_{skin} coefficients in ACSPO v. 2.41

SST_{skin}

- ✓ Global coefficients for BSST and local coefficients for PWR SST_{skin} are trained with the CLS method

- ✓ The offsets in the regression equations are adjusted to meet on average the nighttime relationship between SST_{skin} and SST_{depth} *(Donlon et al., 2002)*:

$$SST_{skin} - SST_{depth} = -0.14 - 0.30\exp(-\boldsymbol{V}/3.7)$$

V is surface wind speed from the NOAA Global Forecast System (GFS), https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs

Selection of matchups for SST_{skin}

- Matching <u>absolute</u> SST_{skin} against *in situ* SST is problematic because of significant and variable difference between SST_{skin} and SST_{depth}, depending from many factors
- However, the DC monitoring requires estimation of <u>temporal and spatial variations</u> in SST_{skin}, rather than its absolute values.
- Therefore, it is sufficient to use those matchups only, for which the difference between SST_{skin} and SST_{depth} is relatively stable
- We used matchups with ***V***> 6 m/s, for which the relationship between SST_{skin} and SST_{depth} is "well characterized … by a cool bias of -0.17±0.07 K" *(Donlon et al., 2002*)

Training MDS:

510296 matchups for January-December 2017

318662 matchups with ***V***>6 m/s

Validation MDS:

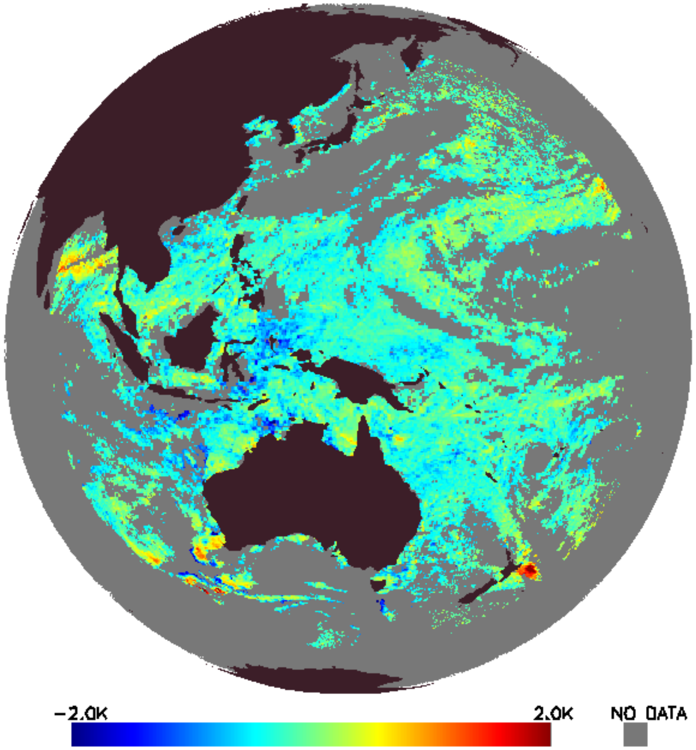
103 064 matchups for January-March 2017

63574 matchups with ***V***>6 m/s

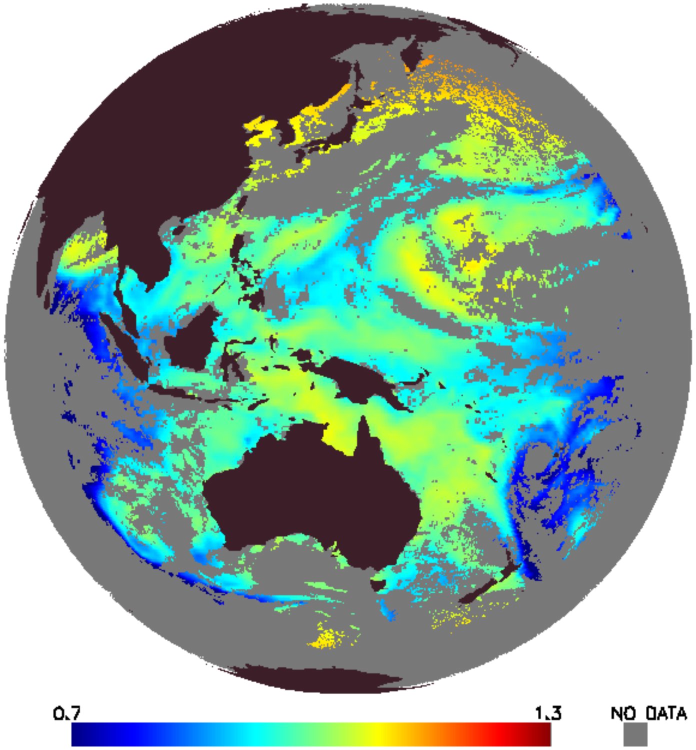
(See iQuam-2 presentations by X. Zhou)

BSST: Bias wrt CMC and sensitivity (AHI, 01-08-2016, 18:00 UTC, Night)

BSST-CMC: Bias=-0.18 K, SD=0.41 K



Sensitivity: Mean=0.97, SD=0.07, P*=64%

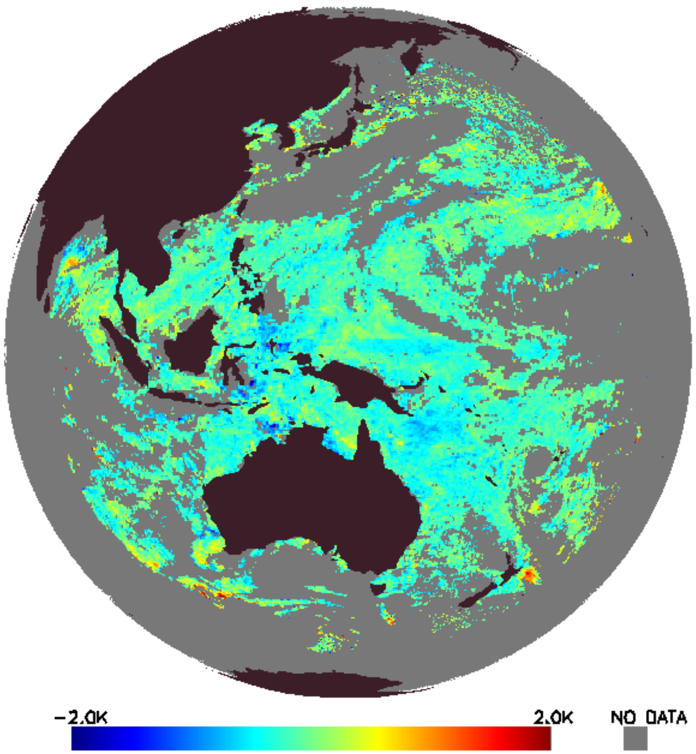


*P is the fraction of clear-sky pixels with $0.95 < \mu < 1.05$

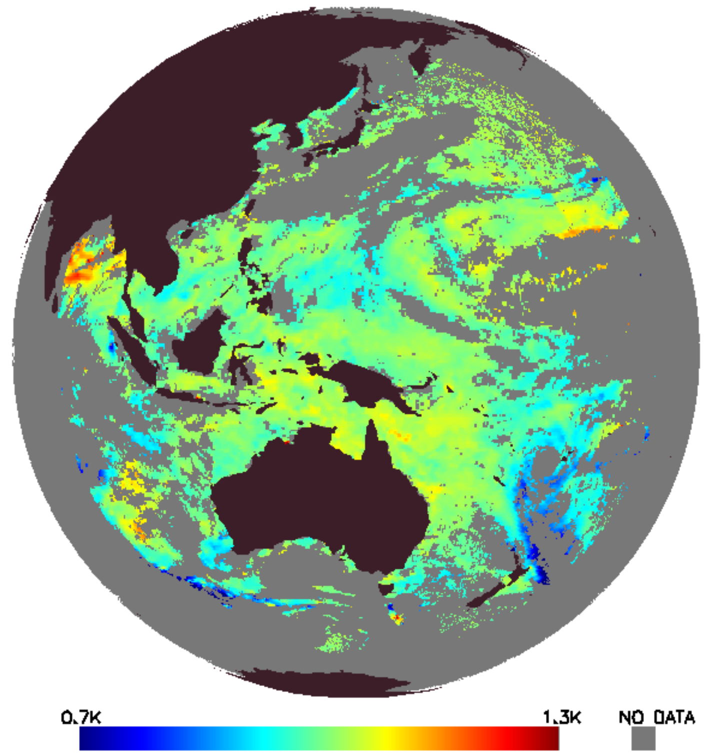
SST_{skin}

PWR SST_{skin}: Bias wrt CMC and sensitivity (AHI, 01-08-2016, 18:00 UTC, Night)

PWR SST_{skin}-CMC: Bias=-0.18 K, SD=0.33 K



Sensitivity: Mean=1.01, SD=0.04, P=84%



- PWR SST_{skin} reduces global SD from 0.41 to 0.33, which suggests reduction in regional biases
- The PWR SST_{skin} sensitivity is closer to optimal and less variable; P increased from 64% to 84%

Statistics of BSST and PWR SST_{skin} wrt *in situ* SST

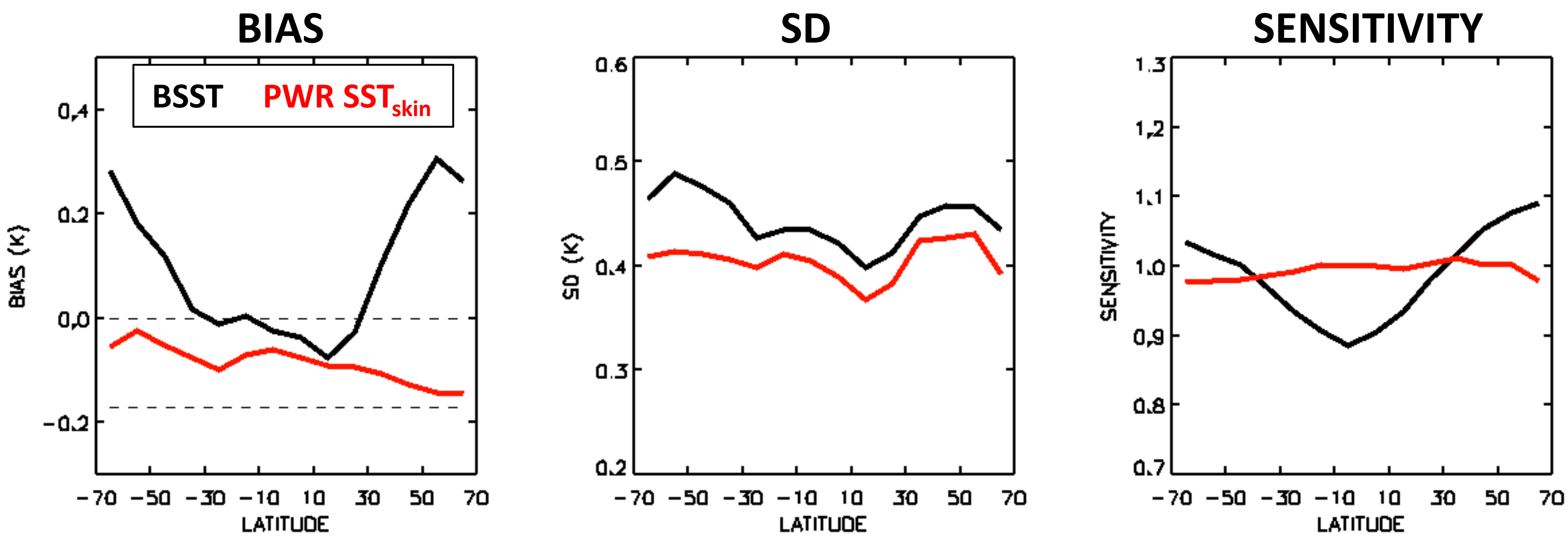
Validation MDS (*V*>6 m/s)

Algorithm	Bias	SD	Mean sensitivity	SD of sensitivity
		Night		
BSST	-0.08 K	0.45 K	0.95	0.09
PWR SST_{skin}	-0.13 K	0.41 K	1.00	0.07
		Day		
BSST	0.08 K	0.42 K	0.95	0.09
PWR SST_{skin}	-0.03 K	0.37 K	1.00	0.06

- PWR SST_{skin} :
  - ✓ Reduces global SD during both day and night, which suggest more uniform regional biases
  - ✓ Keeps mean sensitivity less variable and closer to optimal
  - ✓ Reduces the difference between daytime and nighttime biases from 0.16 K to 0.10 K (suggesting that BSST overestimates the DC magnitude due to variable biases and sensitivity)

Statistics of BSST and PWR SST_{skin} wrt in situ SST as functions of latitude

Validation MDS, *V*>6m/s



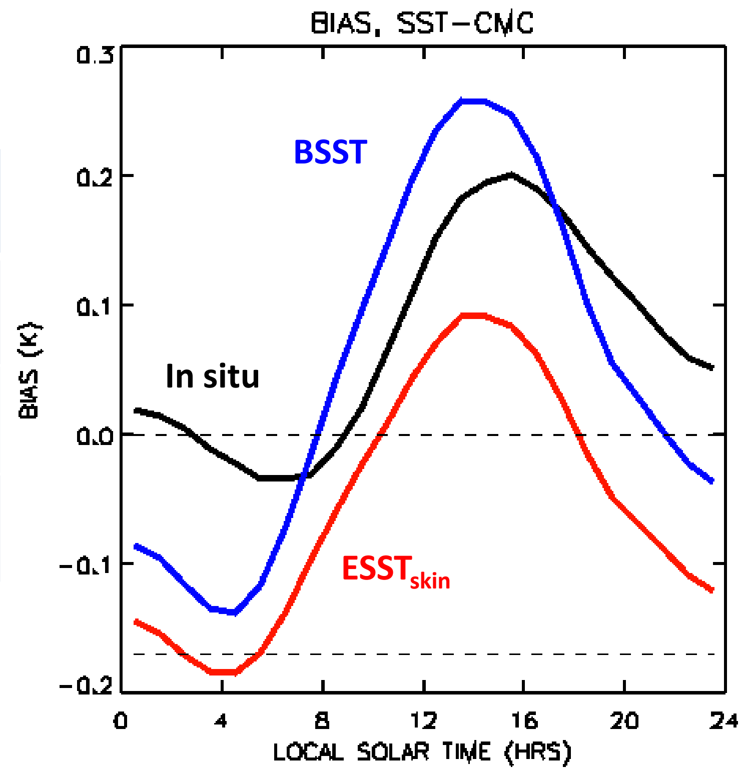
- •BSST biases and sensitivity increase from low to high latitudes

- •PWR SST_{skin}:
  - ✓Produces more uniform biases
  - ✓Smaller SDs
  - ✓More uniform and close to optimal sensitivity

Biases of *in situ* SST, BSST and PWR SST$_{skin}$ wrt CMC as functions of Local Solar Time

Validation MDS, all matchups

Statistics	BSST (CLS)	PWR SST$_{skin}$	*In situ* SST
DC magnitude	0.40 K	0.28 K	0.24 K
Time of minimum	4:30	4:30	6:30
Time of maximum	13:30	13:30	15:30



- Minima and maxima of BSST and PWR SST$_{skin}$ happen ~2 hrs earlier than for *in situ* SST
- DC magnitude in ESST$_{skin}$ is reduced from 0.40 K to 0.28 K

Improving approximation of SST_{depth} with De-biased SST (DSST)

- Current De-biased AHI SST precisely fits SST_{depth} with SD ~0.25 K.
- However, since DSST is retrieved from BTs, sensitive to SST_{skin}, the shape of DC in DSST is closer to SST_{skin} than to SST_{depth}.
- The consistency between DSST and SST_{depth} can be improved by accounting for those variables which drive the difference between SST_{depth} and SST_{skin}.
- Two of such variables are available at the time of L2 processing:
  - ✓ Surface wind speed ***V***
  - ✓ Local solar time (LST).

Modified $DSST_{depth}$ in ACSPO v.2.50

The DSST of ACSPO v.2.41 was modified to $DSST_{depth}$ in ACSPO v. 2.50 as follows:

$$T_S = a_0 + a_1 T_{11} + a_2(T_{11}-T_8) + a_3(T_{11}-T_{10}) + a_4(T_{11}-T_{12}) +$$
$$+ [a_5 + a_6 T_{11} + a_7(T_{11}-T_8) + a_8(T_{11}-T_{10}) + a_9(T_{11}-T_{12})]S_\vartheta +$$
$$+ [a_{10}(T_{11}-T_8) + a_{11}(T_{11}-T_{10}) + a_{12}(T_{11}-T_{12})]T_S^0 + a_{13}V$$

$DSST_{depth}$:

- Similarly to DSST in ACSPO v. 2.41, exploits segmentation of the ***R***-space and LS-estimates for coefficients
- Adds ***V*** as a regressor to the equation
- The dependency from LST is more complicated than from ***V***
- The offsets of the SST equations for each segment are corrected for specific LST hours using the corresponding matchups. During L2 processing, the offsets are interpolated to actual LST.

SST_{depth}

Statistics of ACSPO AHI SSTs wrt *in situ* SST and CMC

- Training MDS: 510298 matchups for January-December 2016
- Validation MDS: 103064 matchups for January-March 2017

Validation MDS, all wind speeds

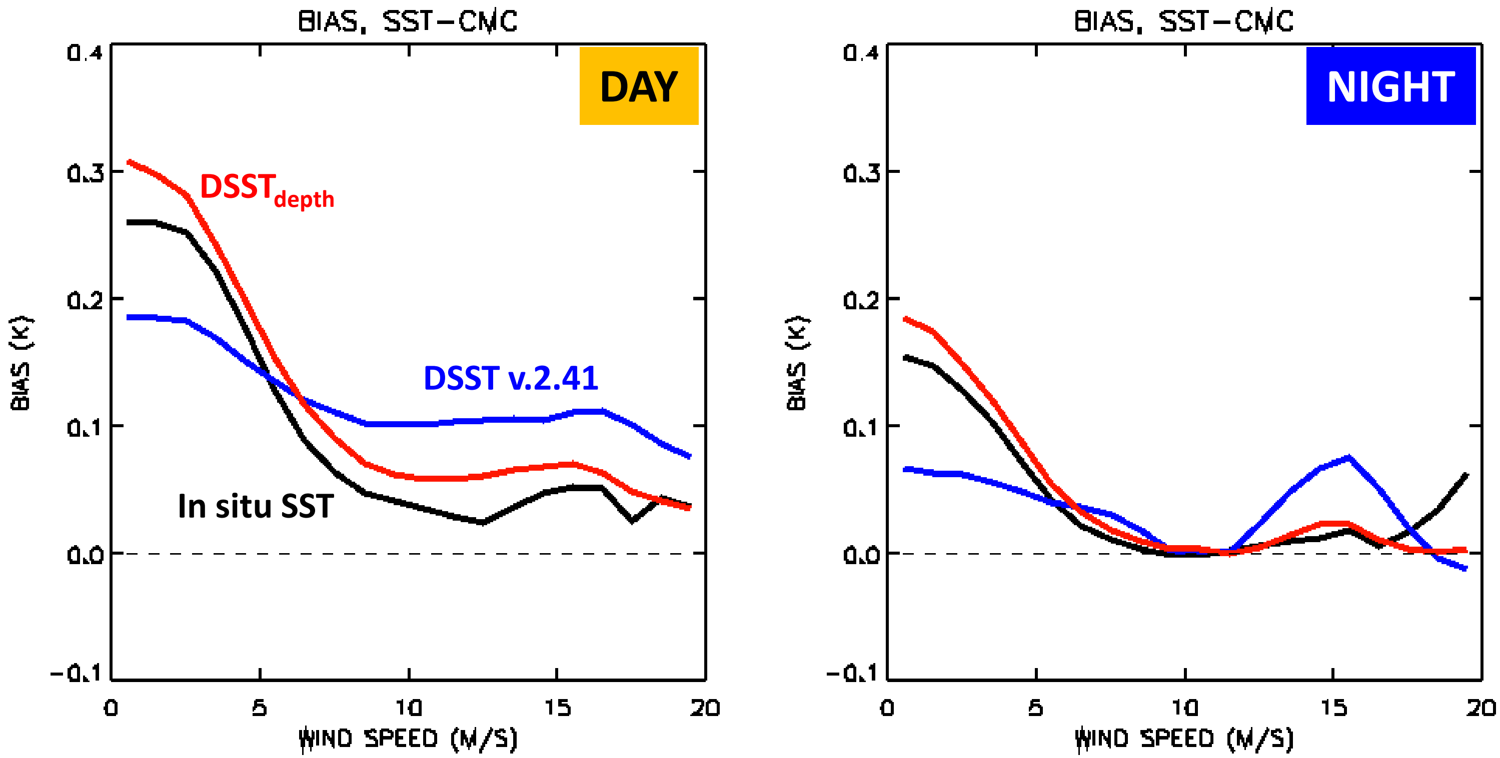
SST	SST-*In situ* SST		SST-CMC	
	Bias	SD	Bias	SD
In situ SST	-	-	0.07	0.279
DSST v.2.41	0.02	0.254	0.09	0.173
$DSST_{depth}$ v. 2.50	0.02	0.249	0.09	0.200

- SD of $DSST_{depth}$ wrt *in situ* SST is smaller than for DSST in ACSPO v.2.41
- However, $DSST_{depth}$ SD wrt CMC is larger

Nighttime and daytime SST bias wrt CMC as functions of surface wind speed

SST_{depth}

Validation MDS, all matchups



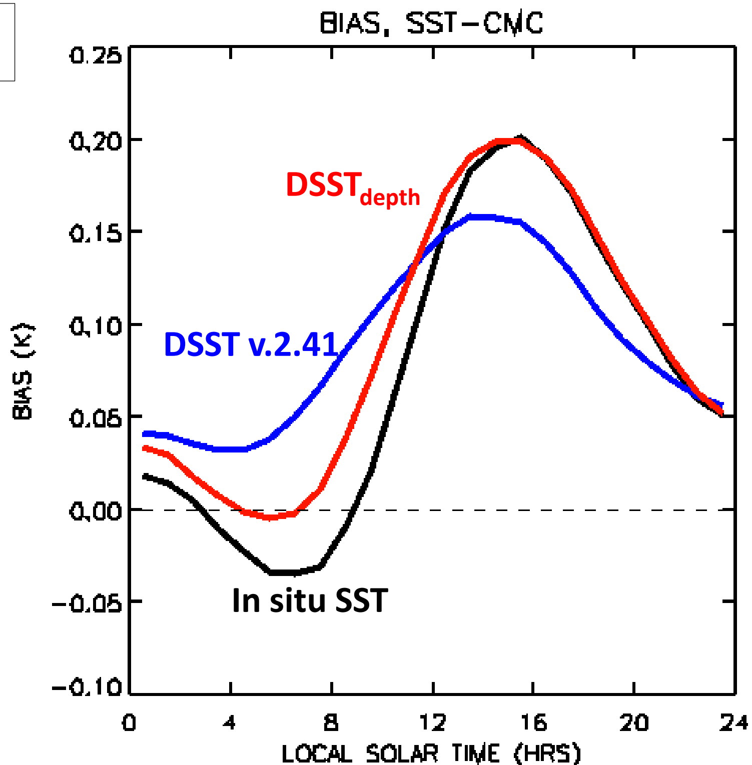
- The dependency of $DSST_{depth}$ bias from wind speed is more consistent with *in situ* SST than the same dependency for DSST in v.2.41

SST_{depth}

Bias wrt CMC as function of Local Solar Time (validation MDS)

Validation MDS, all matchups

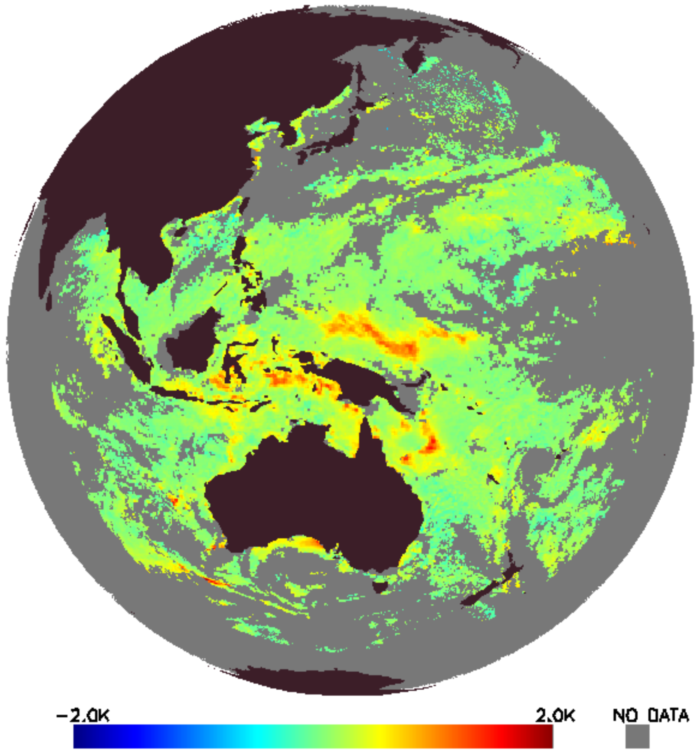
Statistics	*In situ* SST	DSST	$DSST_{depth}$
DC magnitude	0.24 K	0.13	0.20 K
Time of minimum	6:30	4:30	5:30
Time of maximum	15:30	13:30	14:30



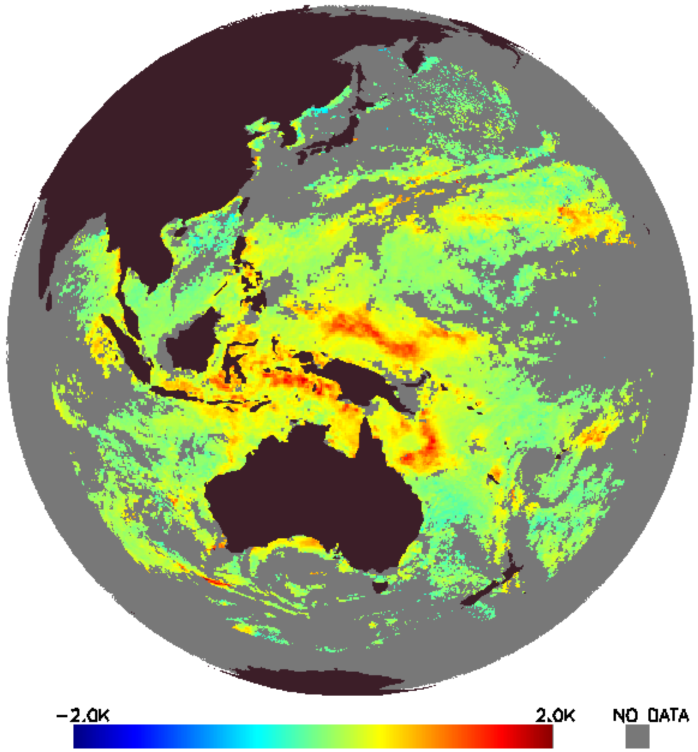
- The DC magnitude in $DSST_{depth}$ is larger and closer to *in situ* SST
- The times of maximum and minimum of bias in DSST v.2.41 are the same as for SST_{skin} (cf. slide 15)
- The times of maximum and minimum of bias in $DSST_{depth}$ are closer to *in situ* SST
- Overall, the $DSST_{depth}$ brings the DC shape and magnitude closer to *in situ* SST

Deviations of DSST and $DSST_{depth}$ from CMC (January 8 2016, 5:00 UTC - Day)

DSST-CMC: Bias=0.26 K, SD=0.23 K



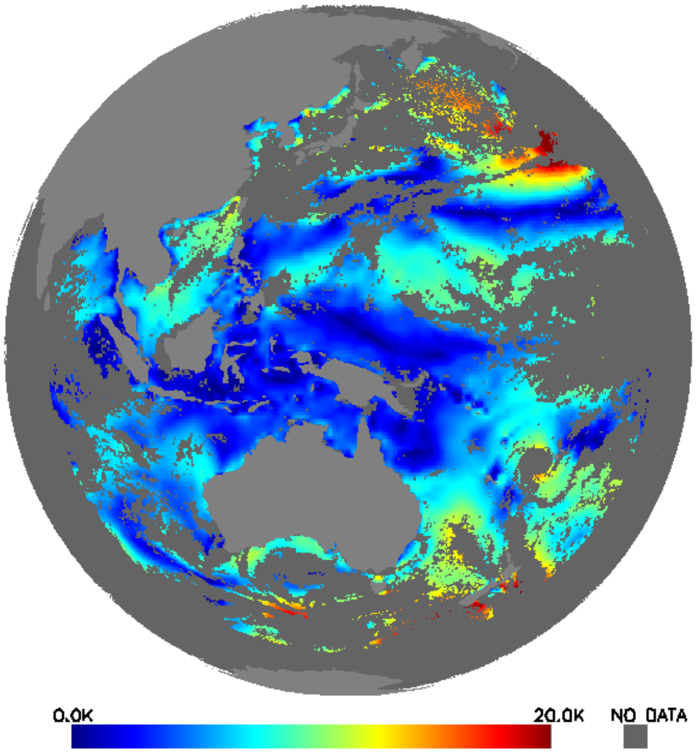
$DSST_{depth}$-CMC: Bias=0.39 K, SD=0.29 K



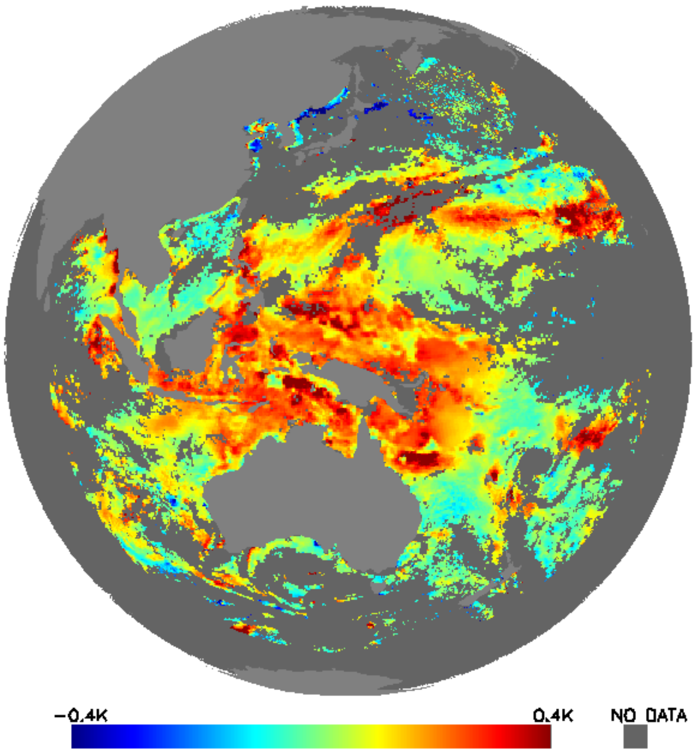
Accounting for wind speed and LST dependencies warms up daytime $DSST_{depth}$ bias, increases SD wrt CMC

GFS wind speed and the difference DSST-$DSST_{depth}$ (January 8 2016, 5:00 UTC - Day)

GFS Wind speed



$DSST_{depth}$-DSST v.2.41



$DSST_{depth}$ increases daytime deviations from CMC in the regions with low wind speed

Time series of bias and SD of Baseline SST, PWR SST_{skin} and $DSST_{depth}$ wrt CMC in ACSPO v.2.50 (5 – 9 January 2016)

PWR SST_{skin}:

✓DC magnitude reduces from ~0.6 K (for BSST) to ~0.4 K

✓SD reduces from 0.45 -0.55 K (for BSST) to 0.35K-0.45 K

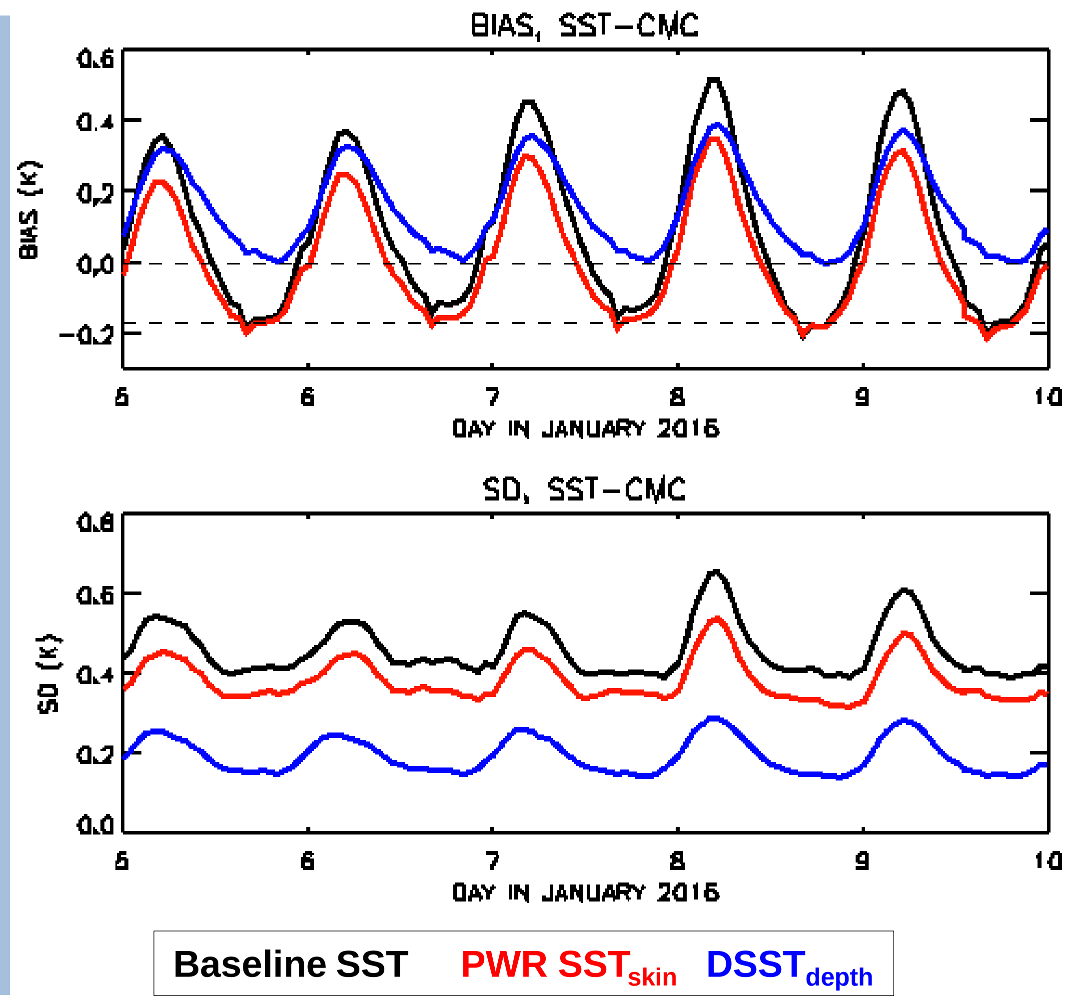
✓Nighttime PWR SST_{skin} is closer to expected bias wrt CMC of -0.17 K

$DSST_{depth}$:

✓Shows the DC magnitude of ~0.15-0.2 K

✓Shifts DC minima and maxima late compared with BSST and PWR SST_{skin}

✓Fits CMC with SD of ~0.15 – 0.25 K



Summary and future work

- In version 2.50 of ACSPO, the capabilities of the quantitative DC monitoring will be explored by more specific targeting SST algorithms at SST_{skin} and SST_{depth}.
- The approximation of SST_{skin} will be improved by:
  - ✓Using the piecewise regression, to make regional biases and sensitivity more uniform
  - ✓Training regression coefficients under the optimal constraint on mean sensitivity
- The approximation of SST_{depth} will be improved by accounting for variables driving the SST_{skin}/SST_{depth} difference, such as GFS wind speed and Local solar time.
- The new SST_{skin} algorithm is implemented in ACSPO v. 2.50 as "experimental"
- The new SST_{depth} algorithm replaces the current ACSPO DSST
- The future work will be focused at extensive validation and further enhancement of the ACSPO SST_{skin} and SST_{depth} products.

Thank you