ACSPO Clear-Sky Mask (ACSM)

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The Evolution of the ACSPO Clear-Sky Mask Concept

- ACSPO initially adopted the "Clouds from AVHRR, extended" (CLAVR-x, by A. Heidinger) - a set of cloud tests relying mainly on radiative properties of clouds
- Eventually, the focus in the ACSPO Clear-Sky Mask (ACSM) has been shifted from cloud properties to predictors more relevant to SST:
  - ✓ SST increments:

    $\boldsymbol{\Delta T_S}$ = Retrieved SST **-** Reference SST

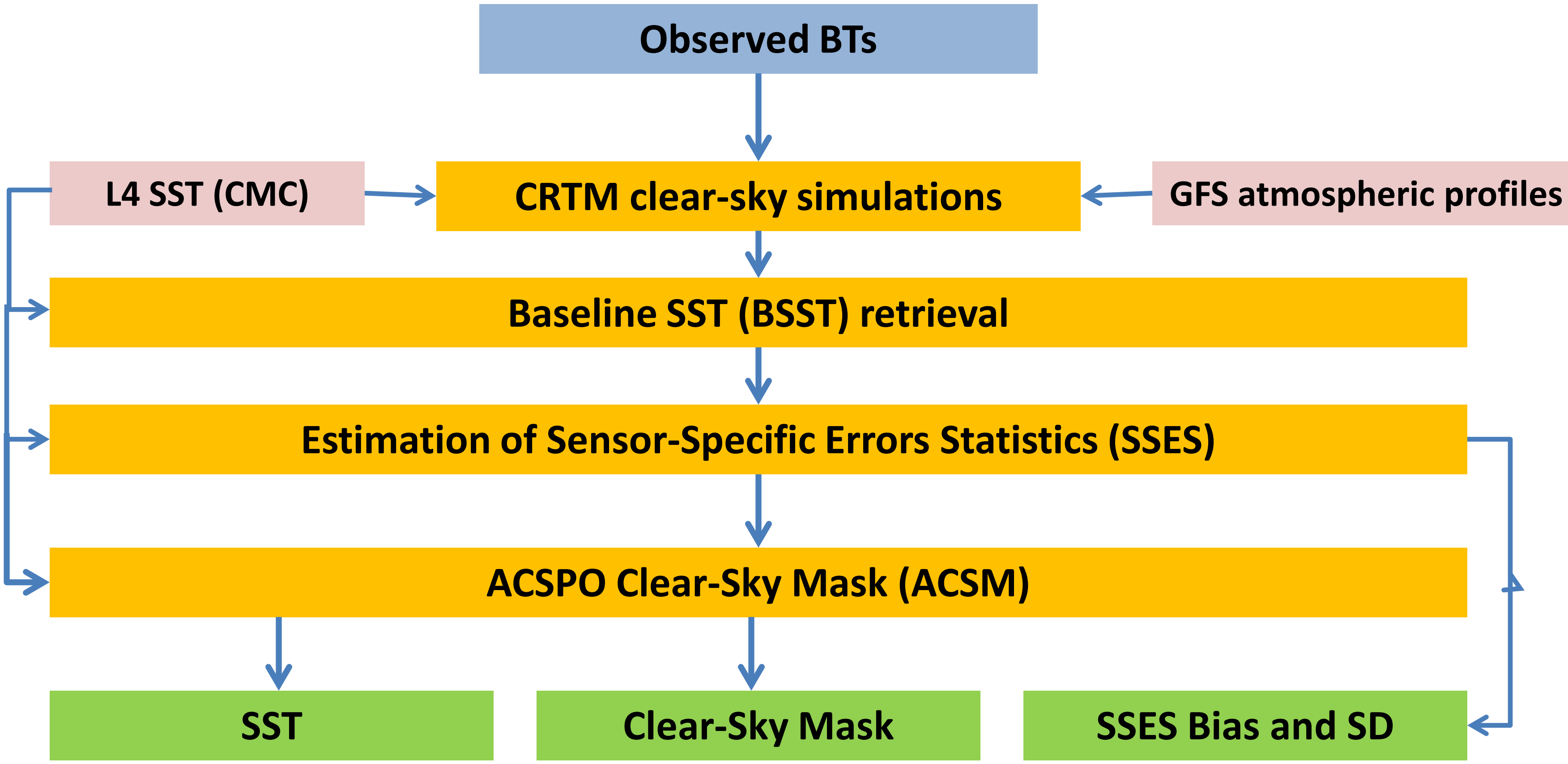
    Currently, Reference SST is L4 SST by the Canadian Meteorological Center (CMC)
  - ✓ Reflectance ***R*** in the visible bands *(daytime only)*
  - ✓ Spatial uniformity of retrieved SST
  - ✓ BT increments:

    $\boldsymbol{\Delta T_B}$ = Observed BTs – Simulated clear-sky BTs

    Clear-sky BTs are simulated in ACSPO with the Community Radiative Transfer Model (CRTM), using as input Reference SST and GFS atmospheric profiles.
    The latest ACSM versions do not use $\boldsymbol{\Delta T_B}$ *pending more accurate input to CRTM*

<u>*Reference:*</u> *Petrenko B., A. Ignatov, Y. Kihai, A. Heidinger, Clear-sky mask for the Advanced Clear-Sky Processor for Oceans. J. Atmos. Ocean. Technol.* ***2010****, 27, 1609–1623.*

The ACSPO Flow Chart



Unlike other SST systems (e.g., OSI-SAF), ACSPO performs Clear-Sky BT simulations and SST retrievals in all ocean pixels before the ACSM. This allows using ΔT_S and ΔT_B as clear-sky predictors

The ACSM Filters for Himawari-8 AHI and GOES-16 ABI

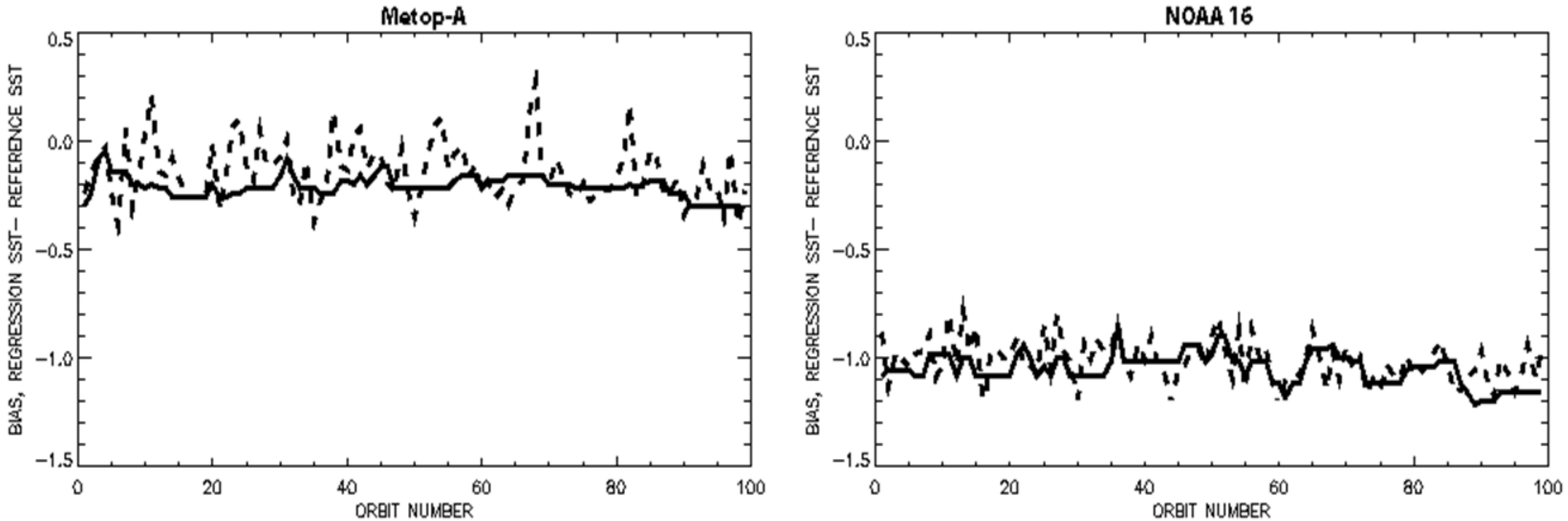
- **All filters are binary:**
  - ✓ **Filters 1 - 3 classify pixels into "Clear" or "Cloudy"**
  - ✓ **Filters 4 and 5 classify pixels into "Clear" or "Probably Cloudy"**
- **Filters 3 and 5 are for daytime only**

ACSM filter	Predictor	Comments
1. Static SST	ΔT_S	•Rejects colder ΔT_S using static threshold. •Under certain conditions, rejects large warm ΔT_S caused by warm stratus clouds. •Provides the first guess for filter 2.
2. Adaptive SST	ΔT_S	Refines the cloud detection by filter 1 analyzing local ΔT_S statistics for "clear" and "cloudy" pixels
3. Reflectance	$R_{0.86}$ in AHI/ABI band 4	Detects brighter $R_{0.86}$ values during day
4. Uniformity	Spatial SD of T_S - median(T_S)	Detects subpixel clouds by SST variability above the noise level.
5. SST/Reflectance Cross-correlation	Correlation between ΔT_S and $R_{0.86}$	Detects subpixel clouds by SST variability below the noise level during day

The ACSPO Quality Levels are linked to the ACSM Output

Quality Level	Meaning	Conditions
5	Clear	All filters show “clear”
4	Probably Cloudy	Filters 1-3 show “clear”, Uniformity filters 4 or 5 show “probably cloudy”
3	Cloudy	At least one of the filters 1-3 shows “cloudy”
1, 2		Not used
0	Invalid	Invalid (Land, ice etc.)

Accounting for global biases in SST (BT) increments

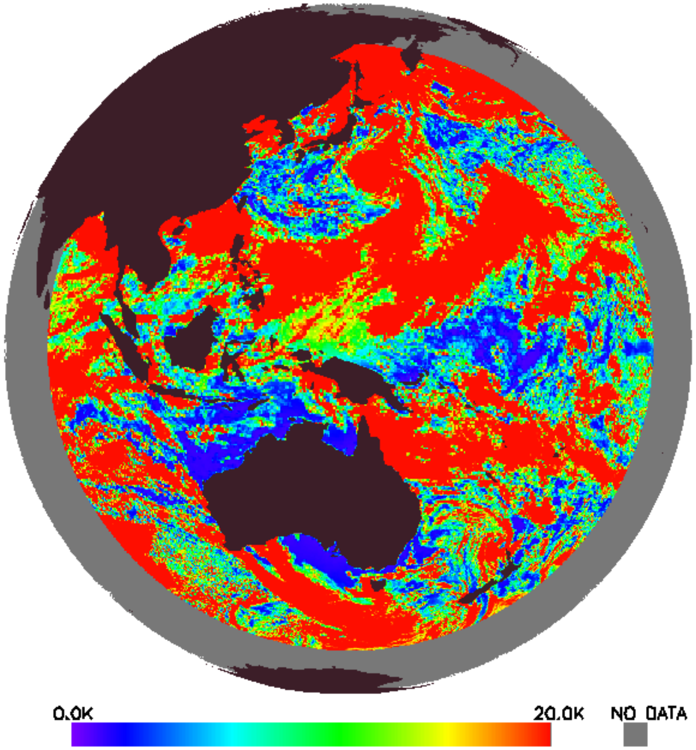


Solid lines:	Positions of peaks of ΔT_S histograms
Dashed lines:	Biases, estimated as average SST anomaly over "clear" pixels

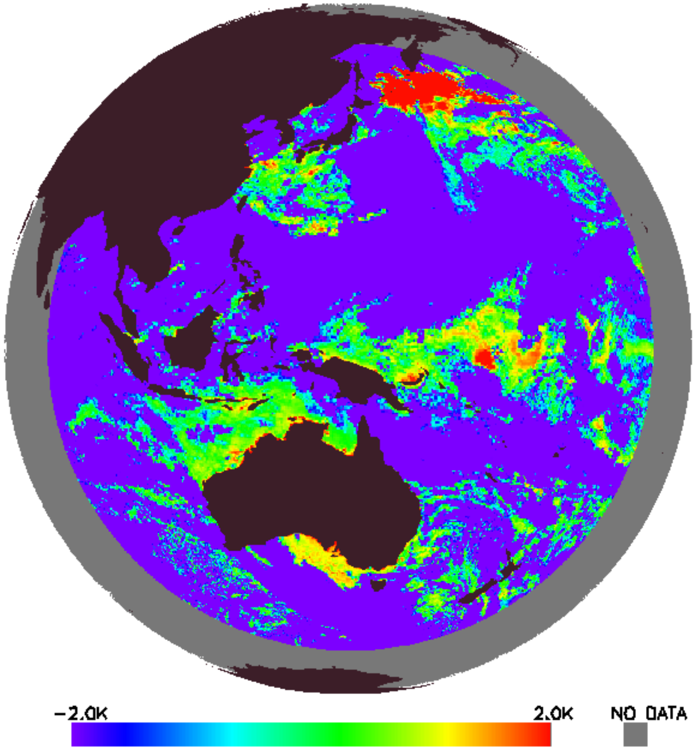
- ***ΔT$_S$*** may be biased due to sensor calibration or algorithm errors
- Using biased ***ΔT$_S$*** as a predictor may cause cloud leakages/false cloud detections
- The global biases are estimated as positions of maxima of histograms of increments, accumulated during the past ~12 to 24 hrs over "all-sky ocean" pixels
- No crosstalk between estimated biases and the ACSM output
- Accounting for global biases stabilizes the ACSM output

All-sky AHI images (no ACSM), 08/15/2016, 3:10 UTC

$R_{0.86}$



ΔT_S : Bias=-15.5 K, SD=21.3K, CF=100%*



**   CF is clear-sky fraction – a clear-sky part of all ocean pixels in %*

*** The ACSPO AHI SST is defined for view zenith angles < 67^o*

Cold (and, sometimes, warm) large SST deviations, and 0.86 µm reflectance (during day) are used as cloud predictors

Static SST filter

$\Delta T_S - D_{SST} > T_{static}(\vartheta)$ or $\Delta T_S - D_{SST} > T_{warm}(\vartheta)$?

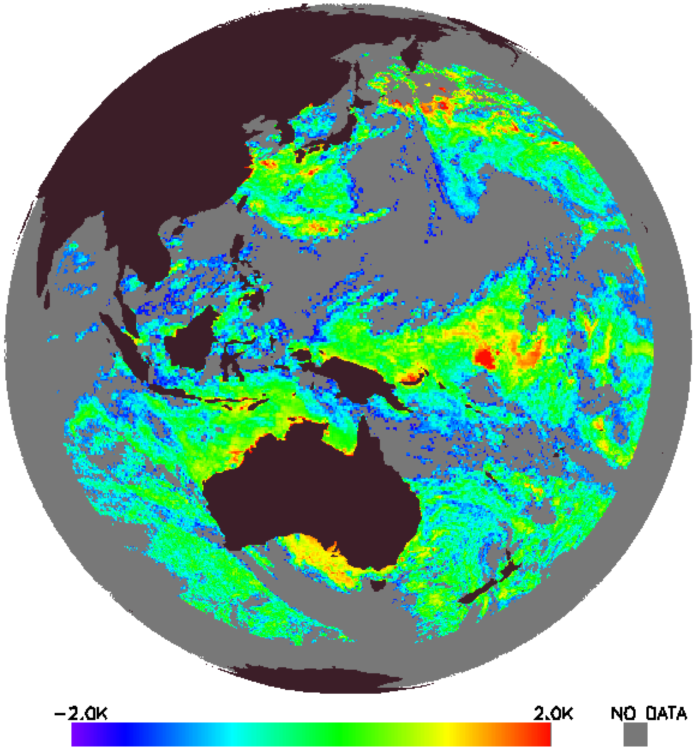
- If Yes then the pixel is "cloudy"

If $T_0 < 293$ K and $T_{ATM12} - T_S^0 > -12$ K ?

- If Yes, then $T_{warm} = T_{static}$
- Otherwise $T_{warm} = \infty$

$T_{static}(\vartheta)$	Static threshold
Θ	View zenith angle
T_0	L4 SST
T_{ATM12}	Simulated upwelling atmospheric temperature at 12.3 µm
D_{SST}	estimated bias

ΔT_S: Bias=0.07 K, SD=0.96K, CF=36%



- The filter rejects most obvious cloud effects on ΔT_S

Adaptive SST filter

$P_{clear}(\Delta T_S) > P_{cloud}(\Delta T_S)$?

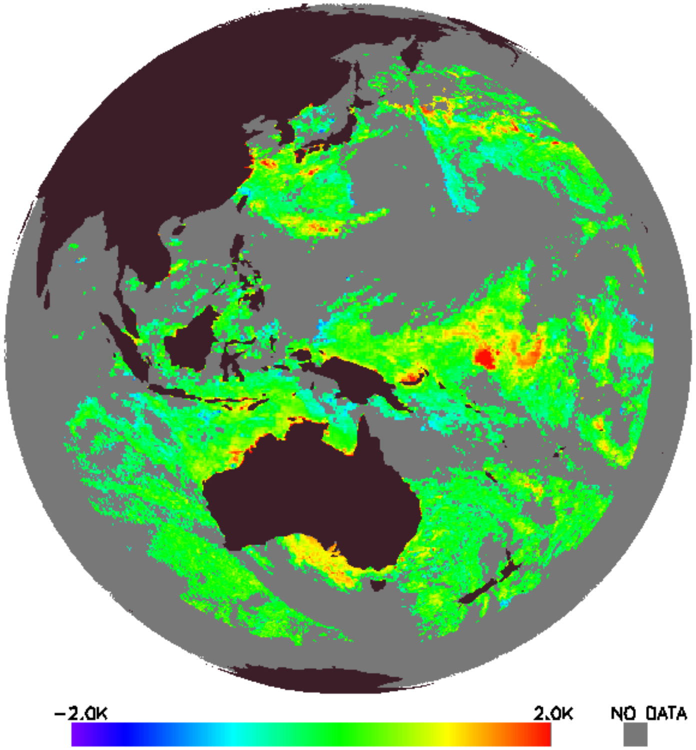
If yes, then the pixel is "Clear", otherwise it's "Cloudy"

ΔT_S is SST increment at tested pixel

P_{clear} and P_{cloud} are "clear-sky" and "cloudy" PDFs of ΔT_S within the moving 17×17 window

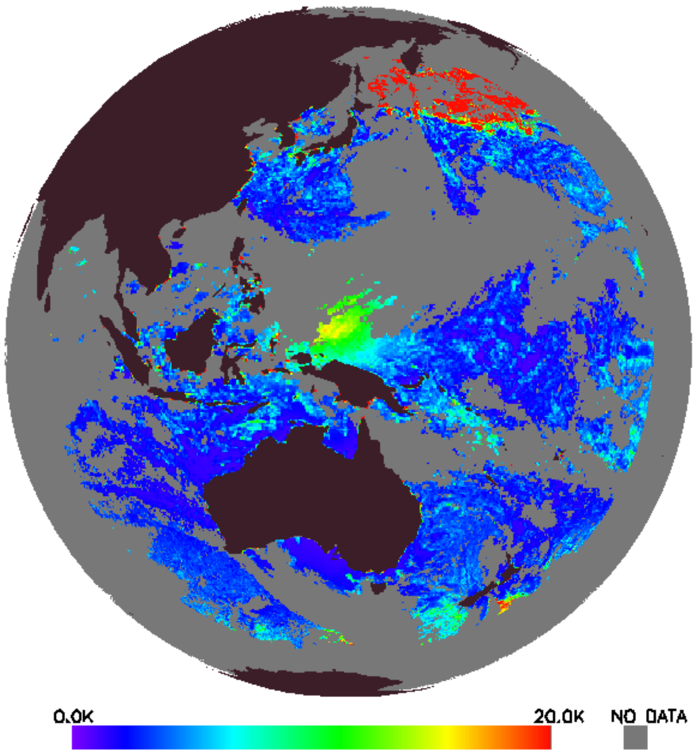
- The first guess P_{clear} and P_{cloud} are derived from the output of the Static SST filter
- On each iteration, the pixels within the window are reclassified into "clear" and "cloudy" based on the current PDFs, and the PDFs are recalculated
- The iterations are repeated 3 times unless the tested pixel becomes "cloudy" earlier

ΔT_S: Bias=0.43 K, SD=0.61K, CF=26%

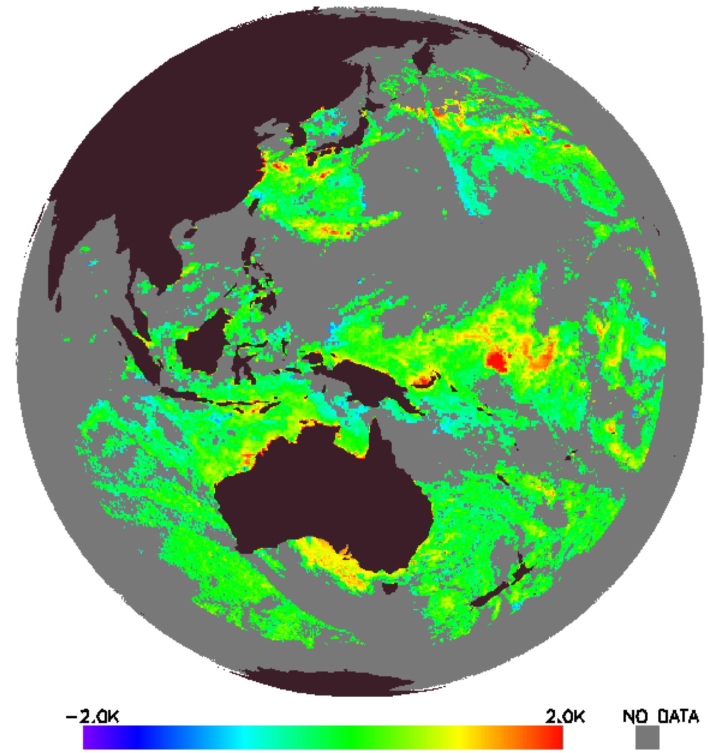


0.86 µm Reflectance and SST-CMC
<u>before</u> the Reflectance filter

$R_{0.86}$



ΔT_S: Bias=0.43 K, SD=0.61K, CF=26%

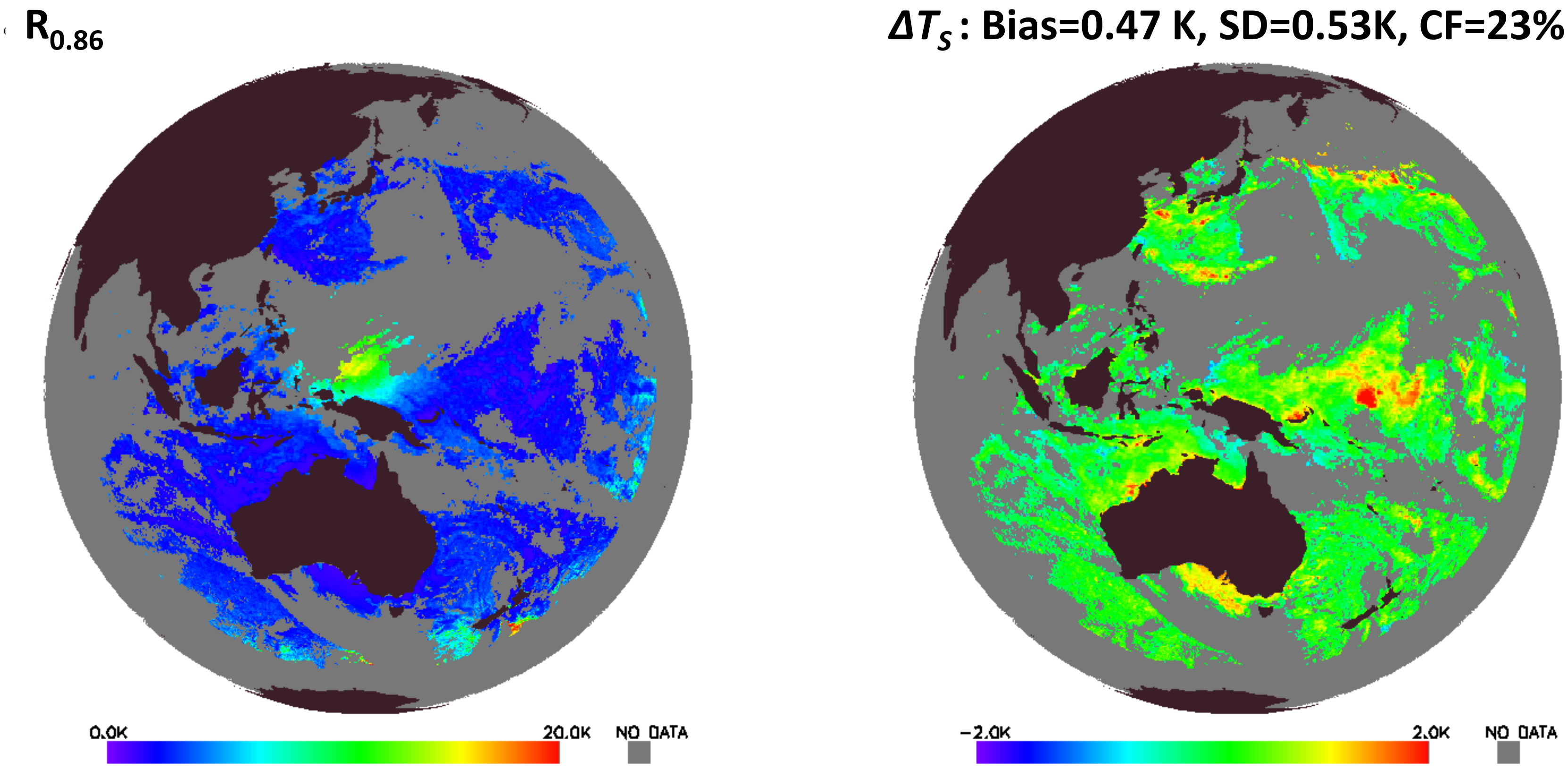


$R_{0.86}<T_R(\Theta_{solar},\Theta_{glint})$? - If yes, the pixel is "clear", otherwise it is "cloudy"

Θ_{solar} is solar zenith angle,

Θ_{glint} is glint angle

0.86 µm Reflectance and SST-CMC
after the Reflectance filter



The threshold is set as a function of Θ_{solar} and Θ_{glint} to preserve the glint area and ensure smooth transition between day and night

The Uniformity and CC filters

The Spatial Uniformity filter:

Σ(X) < η? - If yes then the pixel is clear;
Otherwise, it's cloudy

$X = T_S - median(T_S)$

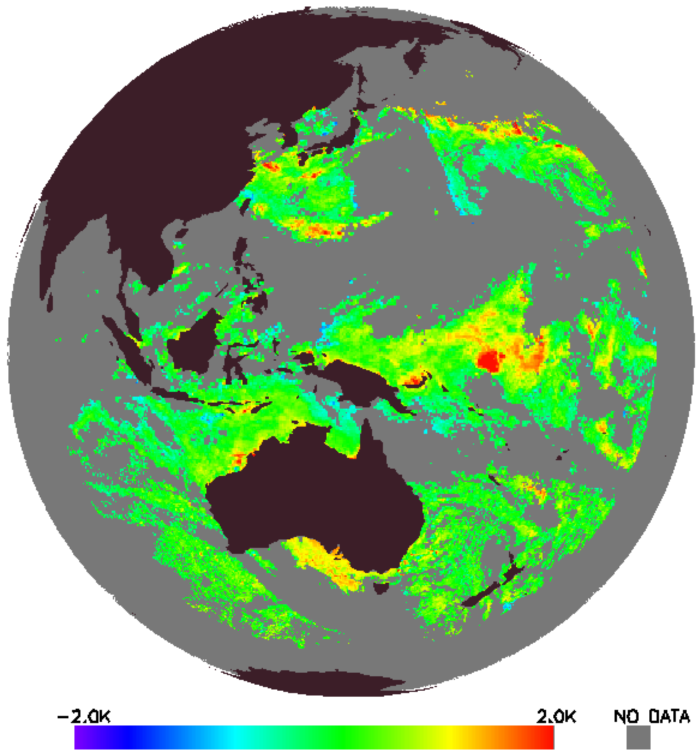
Σ(X)	spatial standard deviation within 3 × 3 window
η	threshold
$median(T_S)$	spatial median of SST

The Cross-Correlation filter (daytime):

$r^2D(T_S) < \gamma$? - If yes then the pixel is "clear"
otherwise it's "cloudy"

r	spatial correlation of T_S and $R_{0.86}$
$D(T_S)$	spatial variance of SST
γ	threshold

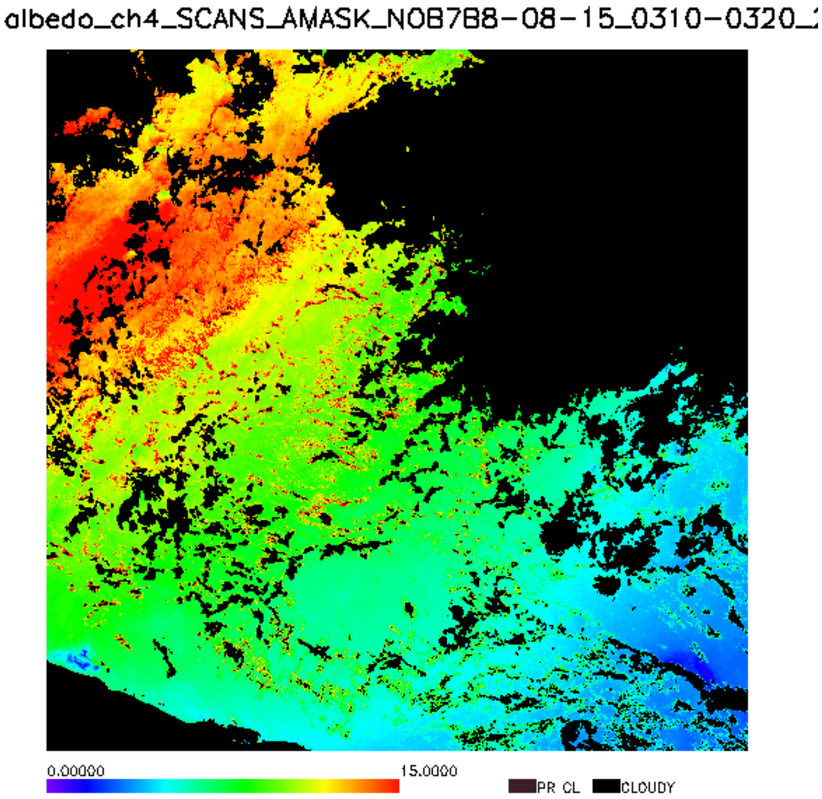
ΔT_S, Bias=0.53 K, SD=0.52K, CF=17.7%

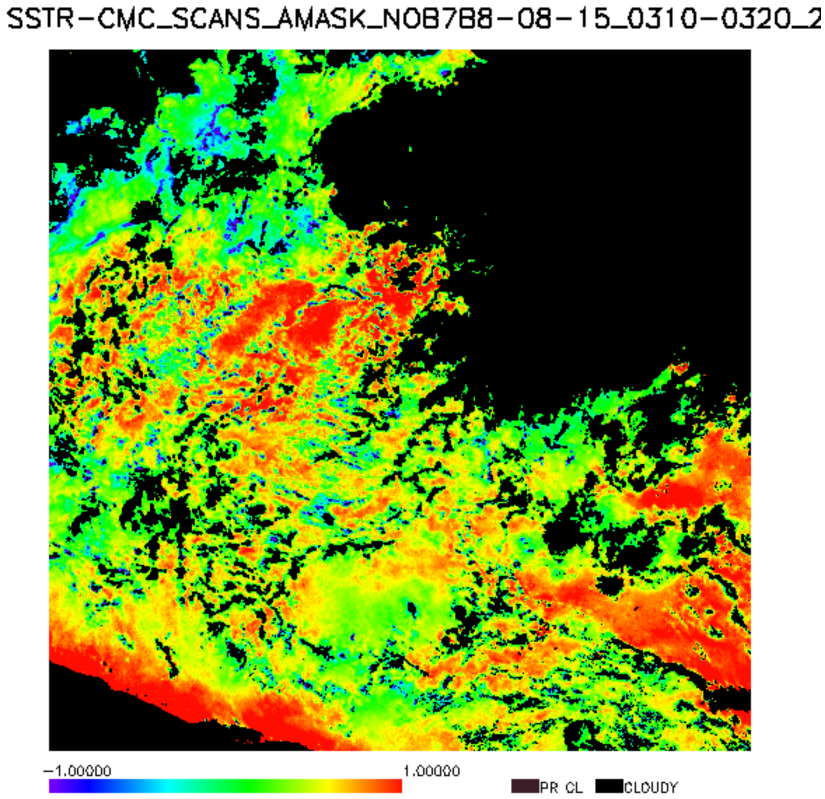


- The ACSPO Uniformity filter detects subpixel cloud above the noise level, preserves high SST gradients
- The Cross-Correlation filter detects subpixel cloud below the noise level
- The spatial uniformity and CC filters warm up bias & reduce clear-sky fraction, slightly change SD

AHI 0.86µm reflectance and SST-CMC, 2016-08-15, 3:10 UTC

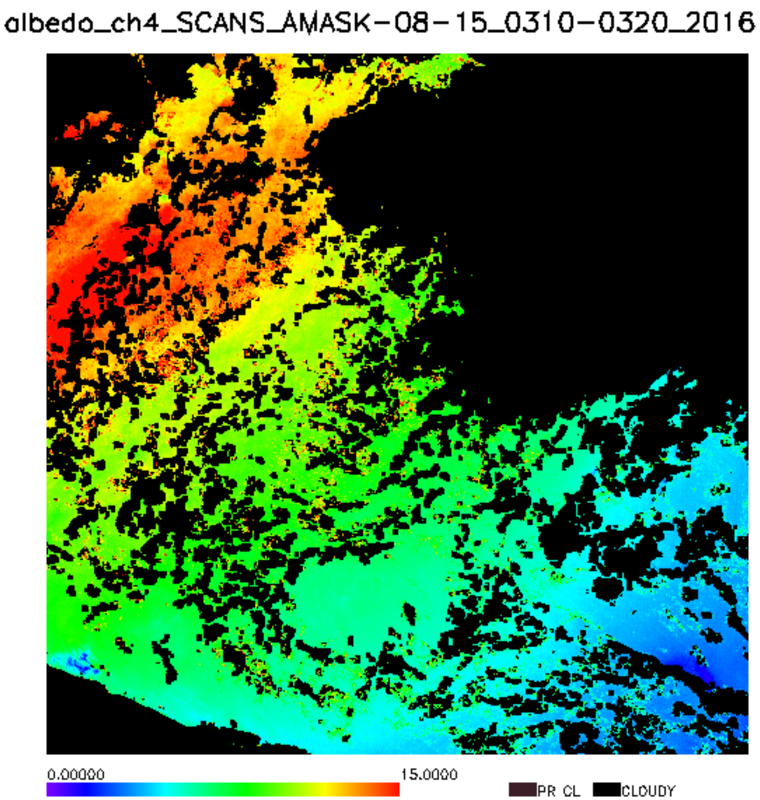
Before the Uniformity and CC filters

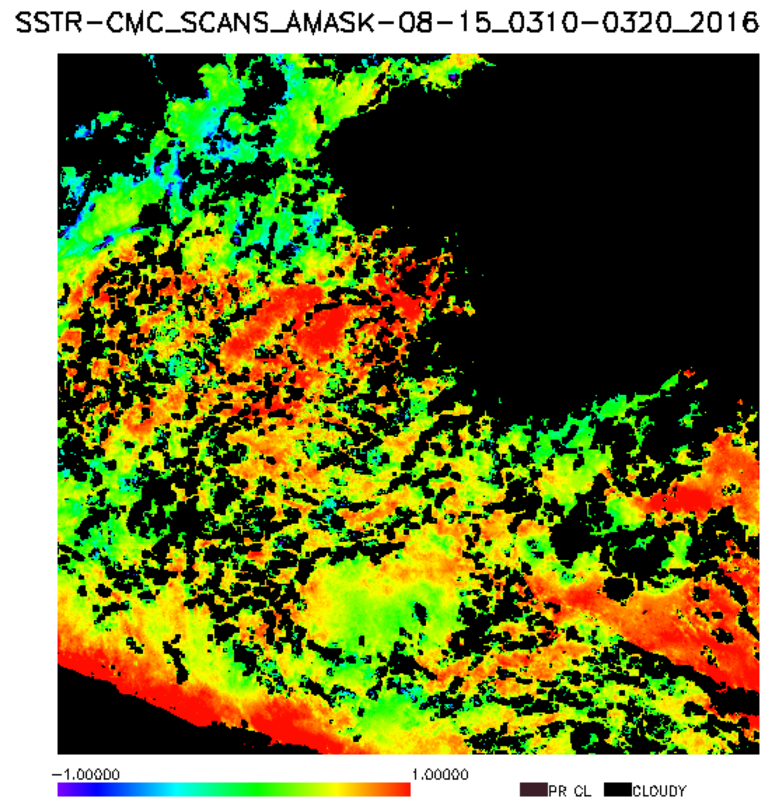




- Subpixel cloud shows itself both in $R_{0.86}$ and ΔT_S
- The effect of subpixel cloud on $R_{0.86}$ is comparable with the effect of sun glint

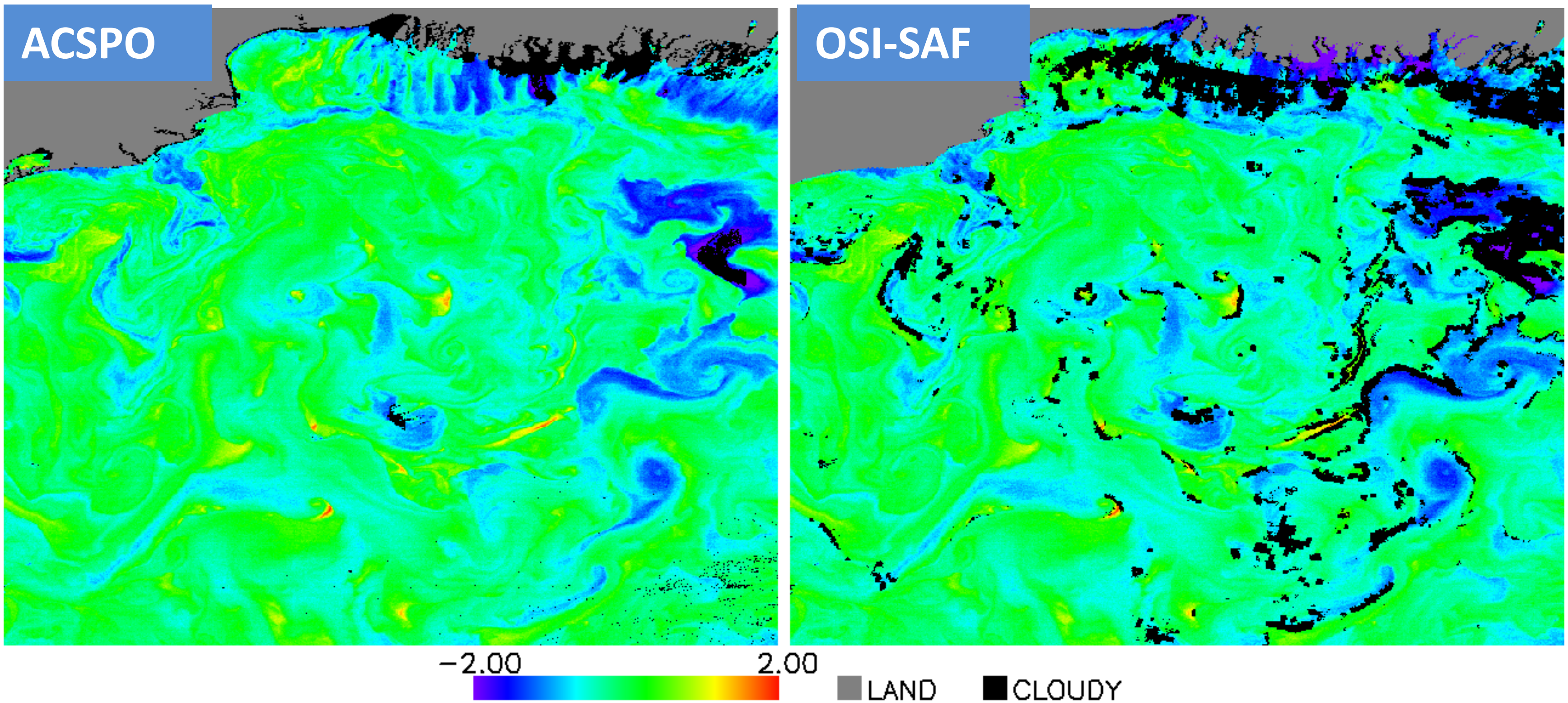
AHI 0.86μm reflectance and SST-CMC, 2016-08-15, 3:10 UTC
<u>After</u> the Uniformity and CC filters





- The Uniformity filter rejects spatial ΔT_S variations exceeding the noise level
- The CC filter rejects less intensive variations in ΔT_S by their correlation with R_8

SST - CMC in Bay of Bengal by ACSPO and OSI-SAF
MetOp-A, Feb 3, 2013, Night



- The Uniformity filter in the OSI-SAF cloud mask hides high SST gradients
- The Uniformity filter in ACSPO preserves SST gradients due to using as input

$$\boldsymbol{X = T_S - median(T_S)},$$

rather than $\boldsymbol{T_S}$

Comparison of the performances of the ACSM and other cloud masks

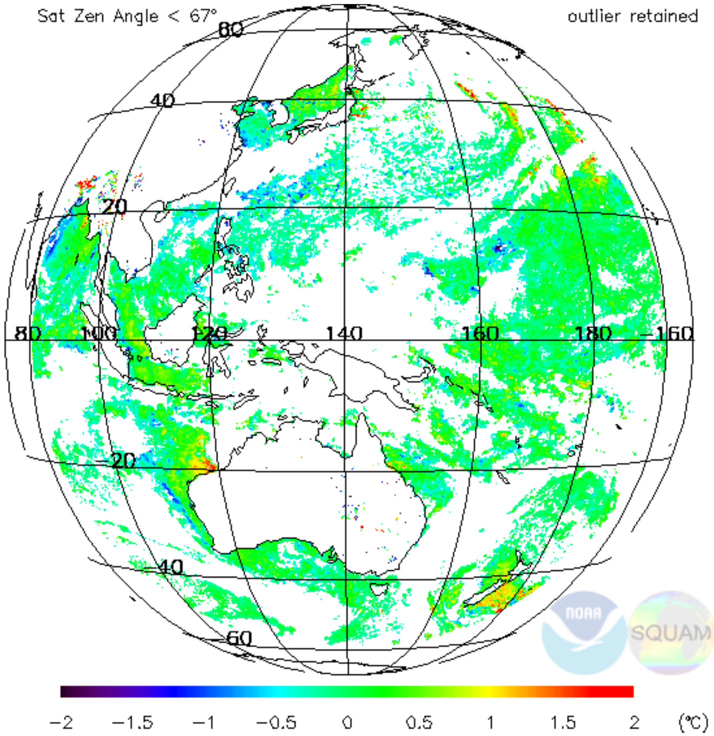
The performances of the cloud masks are compared in terms of global statistics:

1. Global bias with respect to CMC and *in situ* SST
2. Global SD with respect to CMC and *in situ* SST
3. The number N of clear-sky observations or Clear-sky fraction of all ocean pixels (CF)

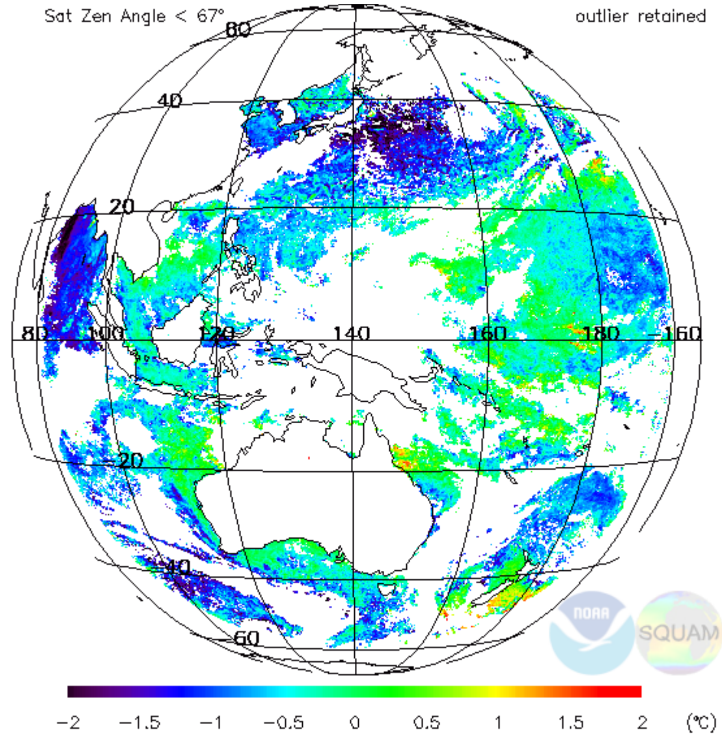
- In general, more conservative cloud mask produces warmer bias, smaller SD and smaller number of clear-sky pixels

AHI SST – CMC by ACSPO and JAXA
(2017-03-17, 00:00 Local Solar Time, night)

ACSPO: Bias=0.06 K, SD=0.44 K, CF=21.6%



JAXA: Bias=-0.48 K, SD=0.62K, CF=23.1%*

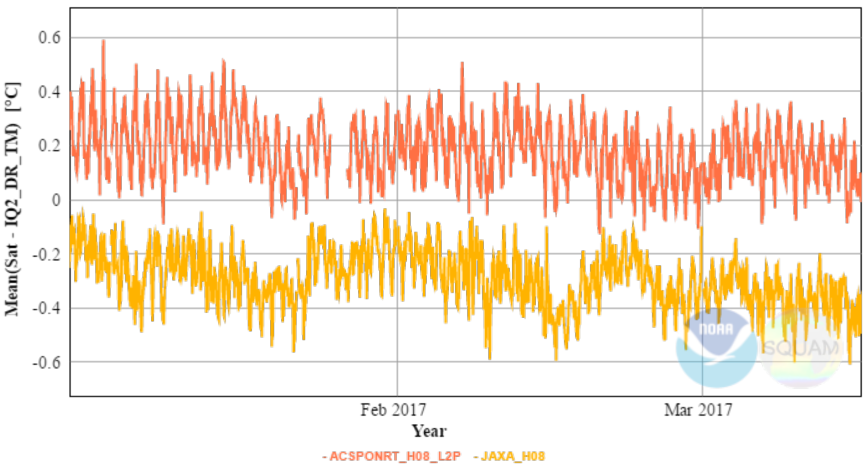


CF is clear-sky fraction – a clear-sky part of all ocean pixels in %

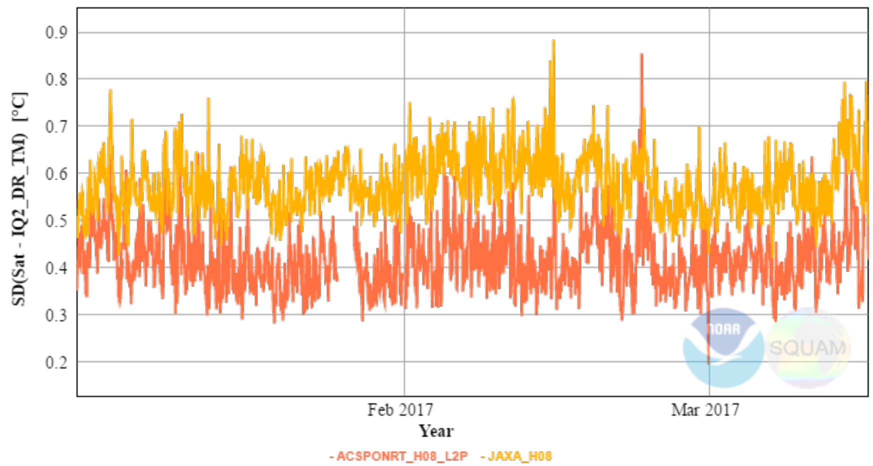
JAXA produces ~12% more clear-sky pixels, significantly colder bias and larger SD

AHI: Bias and SD wrt *in situ* SST and the Clear-Sky fraction by ACSPO and JAXA

Mean, SST-*in situ* SST



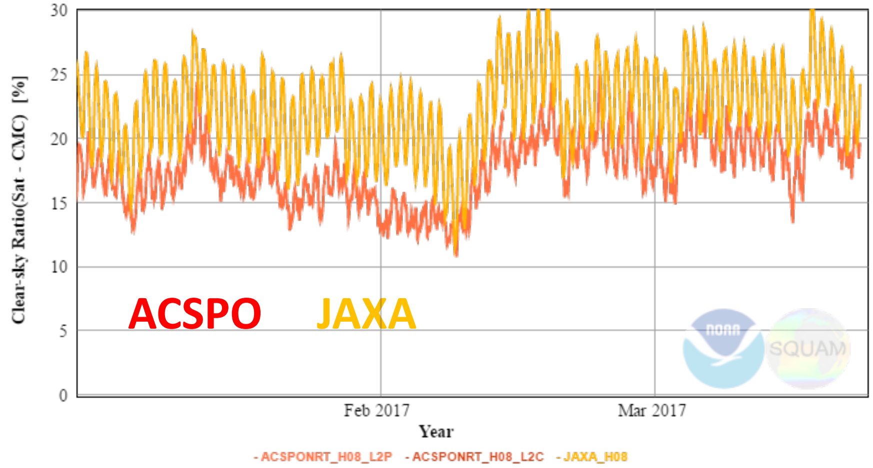
SD, SST-*in situ* SST



JAXA vs ACSPO:

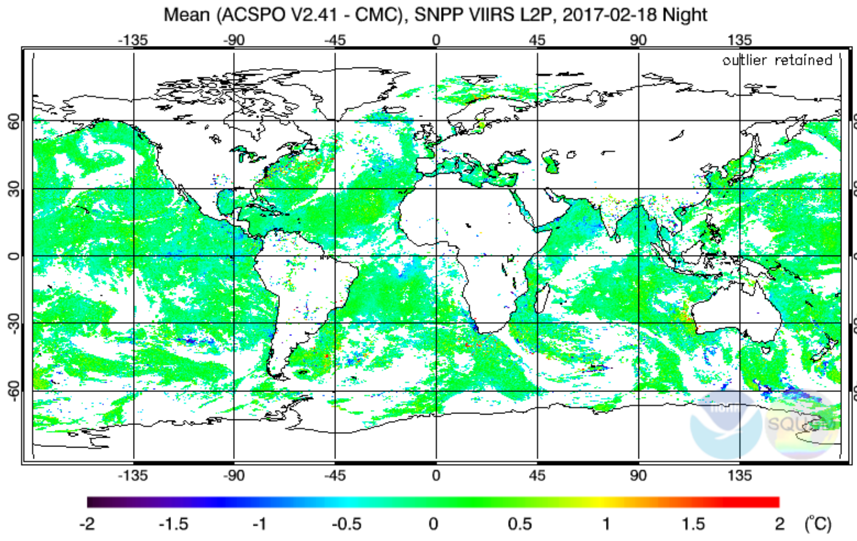
- ✓ Negative biases wrt *in situ* SST, during both day and night
- ✓ Larger SD wrt in situ SST
- ✓ Larger and more variable clear-sky fraction

Clear-Sky Fraction

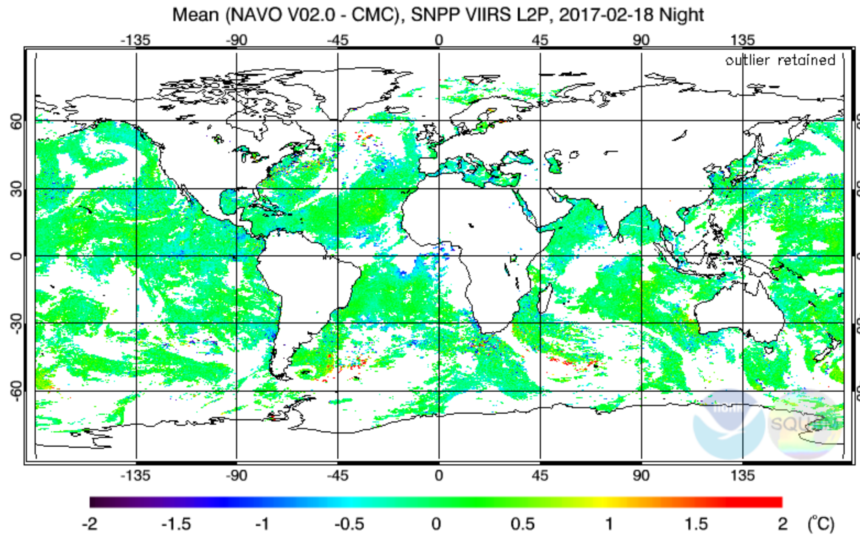


Nighttime composite maps of VIIRS SST minus CMC by ACSPO and NAVO (2017-02-18)

ACSPO: Bias=0.05 K, SD=0.33 K, CF=18.7%

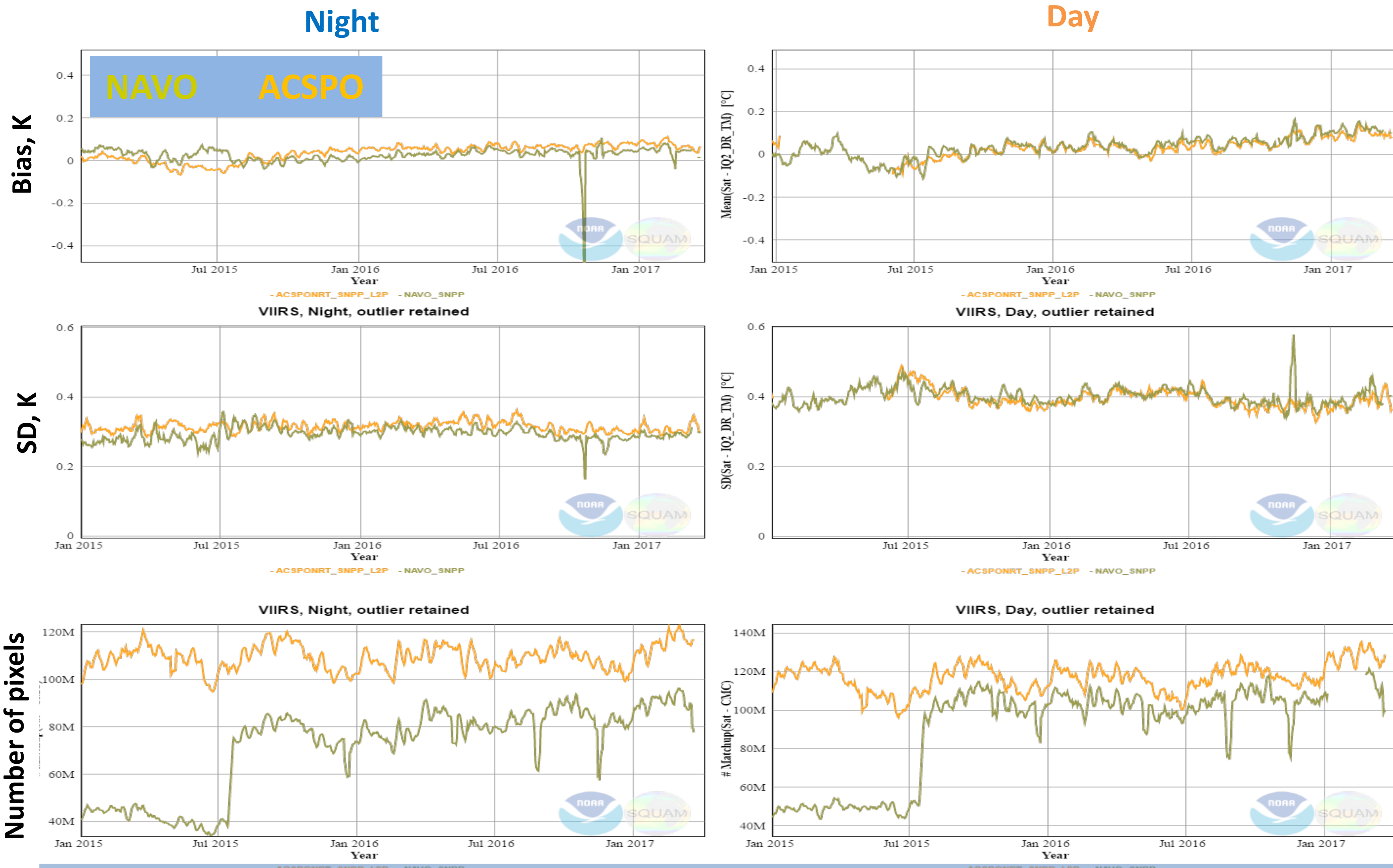


NAVO: Bias=0.03 K, SD=0.32K, CF=14.3%



- ACSPO VIIRS SST has been reported in full-swath since the beginning of the processing in January 2012
- NAVO VIIRS SST went full-swath in July 2015
- Currently, the statistics for both products are comparable although the clear-sky fraction is larger for ACSPO

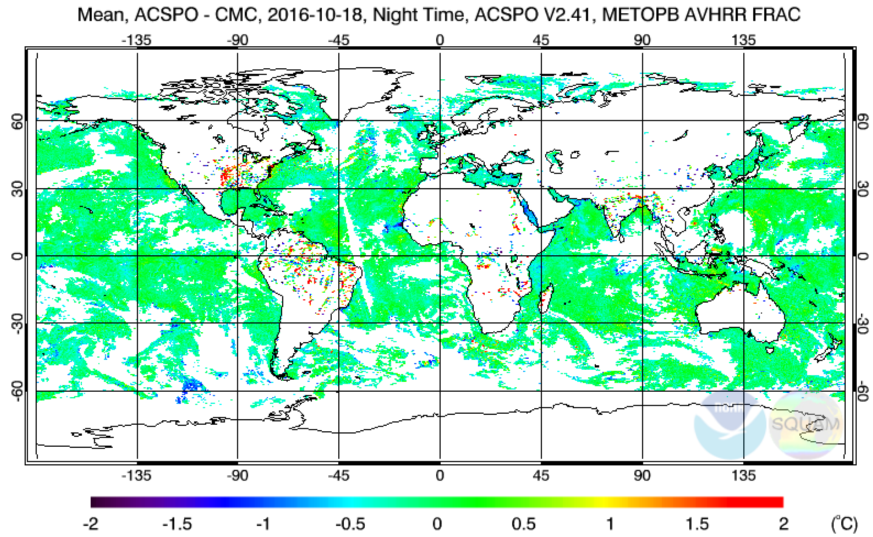
VIIRS: Time series of bias and SD wrt in situ SST and Numbers of clear-sky pixels by ACSPO and NAVO



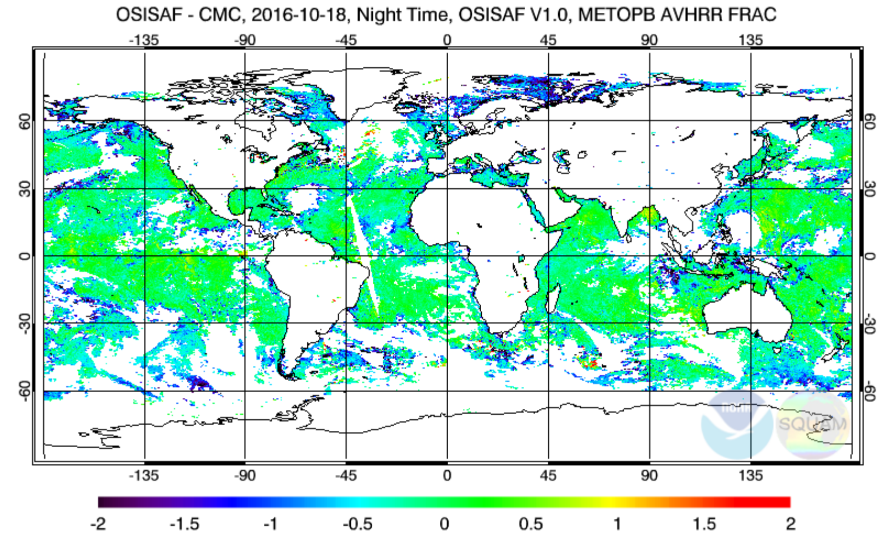
- Nighttime SDs of NAVO SST are somewhat smaller; daytime SDs for NAVO & ACSPO are close
- NAVO produces less clear-sky pixels during both day and night

Nighttime composite maps of METOP-B AVHRR (FRAC) SST minus CMC by ACSPO and OSI-SAF (2017-10-18)

ACSPO: Bias=0.02 K, SD=0.33 K, CF=21.8%



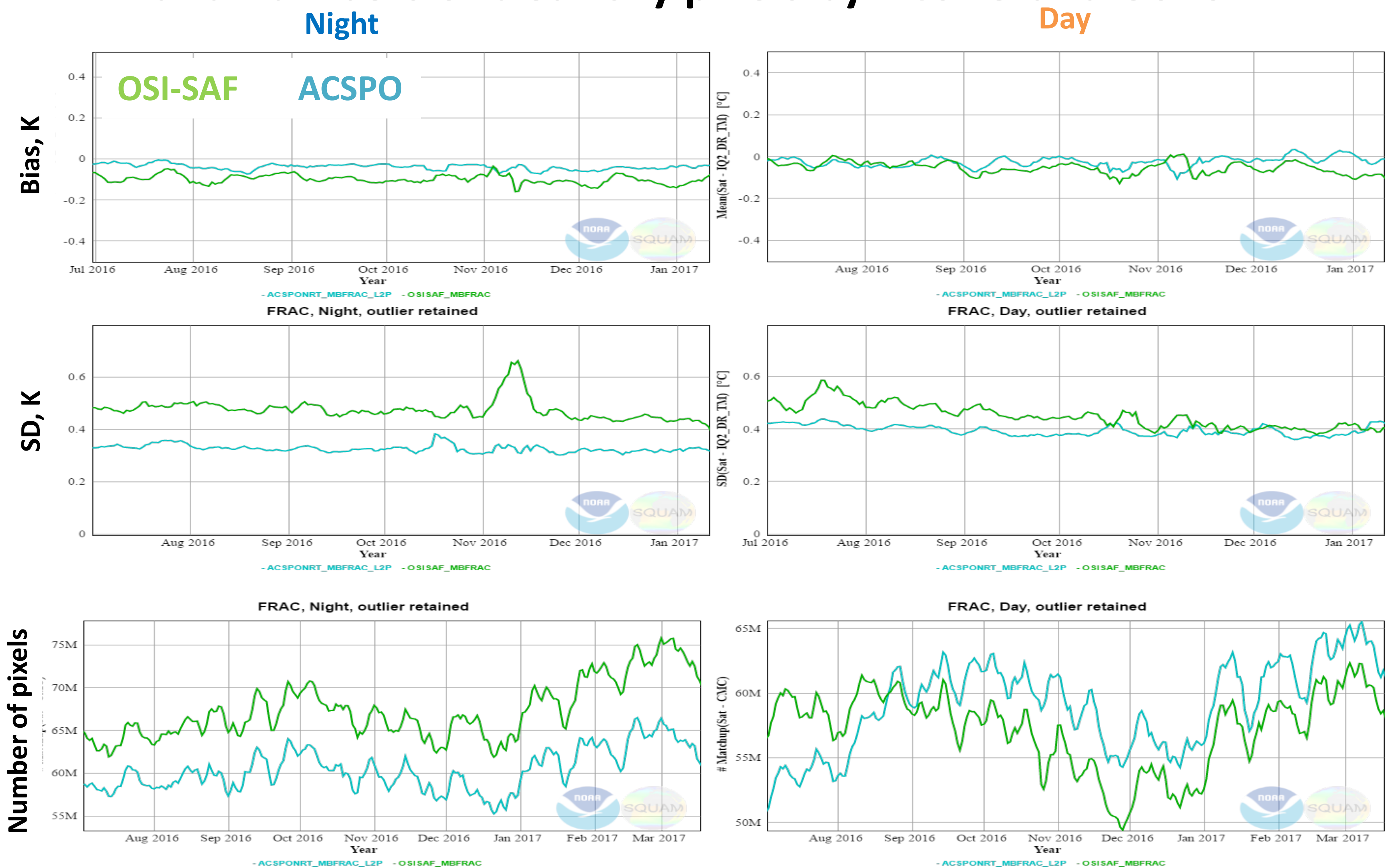
OSI-SAF: Bias=-0.05 K, SD=0.43K, CF=22.7%



OSI-SAF MetOp-B (FRAC) SST vs. ACSPO:

- Larger SD
- Larger clear-sky fraction
- More noticeable cloud leakages

MetOp-B: Time series of bias and SD wrt in situ SST and numbers of clear-sky pixels by ACSPO and OSI-SAF

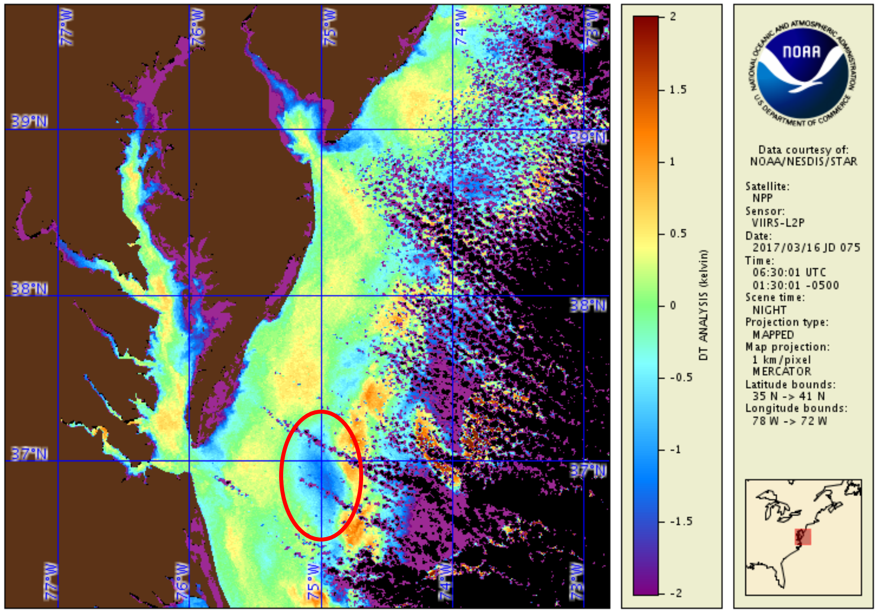


- During night, OSI-SAF produces more clear-sky pixels and larger SD
- During day, OSI-SAF produces less clear-sky pixels and larger SD

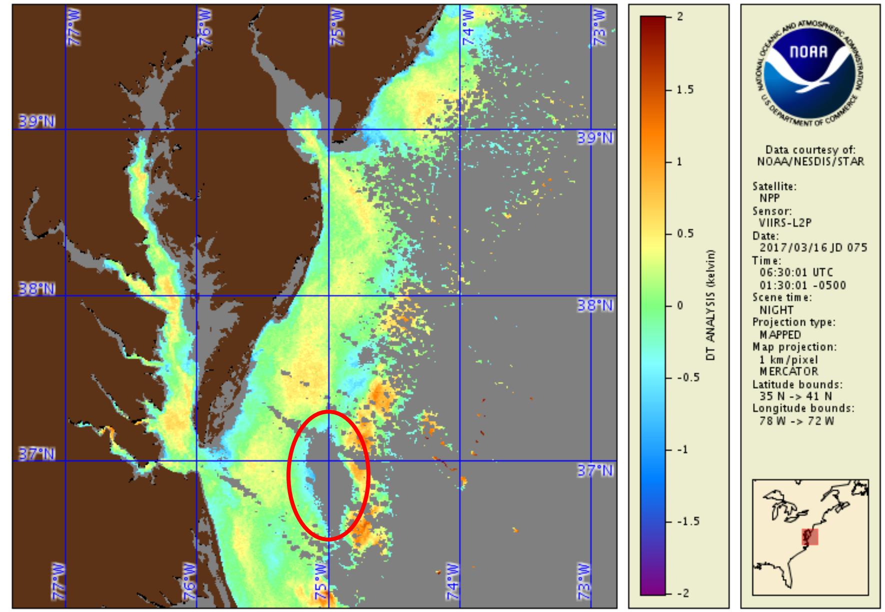
False cloud detections in ACSM

Nighttime VIIRS SST-CMC, the Chesapeake Bay, 2-17-03-16

All pixels



Clear-Sky pixels only



- The ACSM uses $\boldsymbol{\Delta T_S}$ as efficient predictor and, therefore, relies on accuracy of the reference SST.
- L4 SST may be inaccurate in dynamic zones with high SST variability, e.g. due to shifted SST gradients.
- The local inaccuracies in L4 SST may cause false cloud detections
- This problem will be addressed with upcoming ACSM developments

Future ACSM development

- The most important future ACSM enhancements will use new powerful sources of information:
  - ✓ Temporal variability between sequential AHI and ABI images
  - ✓ The difference between the shapes of SST anomalies caused by thermal fronts and clouds in the dynamic zones (using the pattern recognition methods)
- *See presentations by Irina Gladkova*
- Additional clear-sky filters may be explored based on clear-sky simulations of sensor brightness temperatures

Thank you