Towards Global L3S-LEO Products at NOAA

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Motivation for Super-Collated (L3S) SST Product at NOAA

- NOAA provides high resolution SST products from multiple satellites/sensors using its Advanced Clear Sky Processor for Oceans (ACSPO) enterprise system.
  - LEO (low earth orbiters): Hi-Res ~1km@nadir: NPP/N20 VIIRS, Metop-A/B/C AVHRR FRAC, Terra/Aqua MODIS. *In 2022, J2/VIIRS & Metop-SG/MetImage will be launched.* Lo-Res (~4km): NOAA-07 to -19 AVHRR GAC.
  - GEO (geostationary orbit): Hi-Res (~2km/nadir) G16/17 ABI & H08 AHI. *In 2021, GOES-T/ABI & MTG/FCI will be launched.*
- Users are faced with an overwhelming data volumes and number of files. Moreover, they are left to deal with regional, angular and cross-sensor biases in SST retrievals. Often, they don't know the specifics of the products they are trying to fuse.
- As a result, they often resort to using gap-free level 4 (L4) analyses (MUR, OSTIA, GPB, Reynolds OISST), despite their degraded feature resolution.
- **Our answer is data fusion** – ACSPO L3S: Global Gridded Super-Collated (multi-sensor) Products.

Overview of Current and Future ACSPO L3S Products

- Experimental L3S data available on NOAA CoastWatch site [1].
- Two lines of L3S products are in development: L3S-LEO & L3S-GEO.
- L3S-LEO includes PM (afternoon orbits) and AM (mid-morning orbits) SST products.
- Figure 1 shows histograms of normalized number of observations as a function of local solar time for both PM and AM products (day and night), demonstrating their potential to cover of a large portion of the diurnal cycle.
- L3S-GEO will be organized into 24 hourly files, capable of resolving the diurnal cycle
- Table 1 shows overview of **Current/Future** products and estimated data volumes.

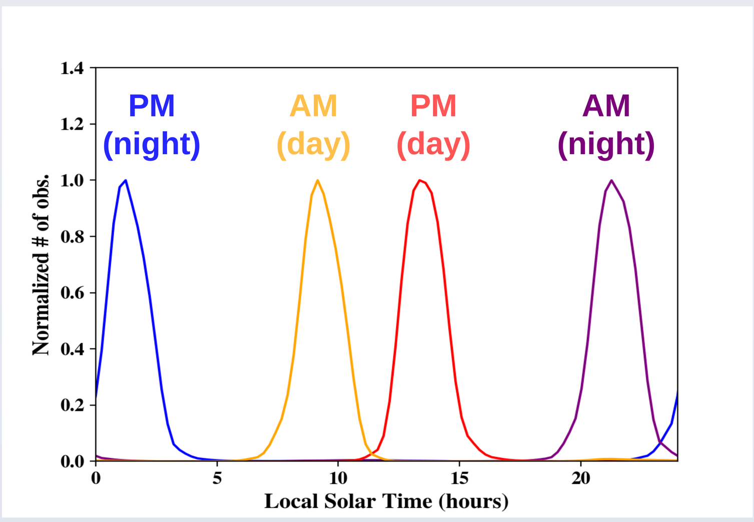

Figure 1. Normalized histograms of number of observations as a function of local solar time. (Based on aggregated data from January 2020.)

L3Ss	Satellites	Number of files per day	Volume (GB/Day)
LEO-PM	NPP/N20/Aqua	2 (day/night)	0.6
LEO-AM	METOP-A/B/C, Terra, Metop-SG	2 (day/night)	0.6
GEO	G16, G17, H08, MTG	24 (hourly)	~2

Table 1. Summary of current (black) and planned (grey) ACSPO L3S products.

Example: L3S-PM SST Imagery

- Mid-Atlantic Coast, US (figure 2).
- Four VIIRS overpasses available: Improved coverage in L3S compared to L3U.
- Feature resolution preserved/improved but gaps due to clouds are not filled.
- Images shown here are taken from the ARMS online system [2]

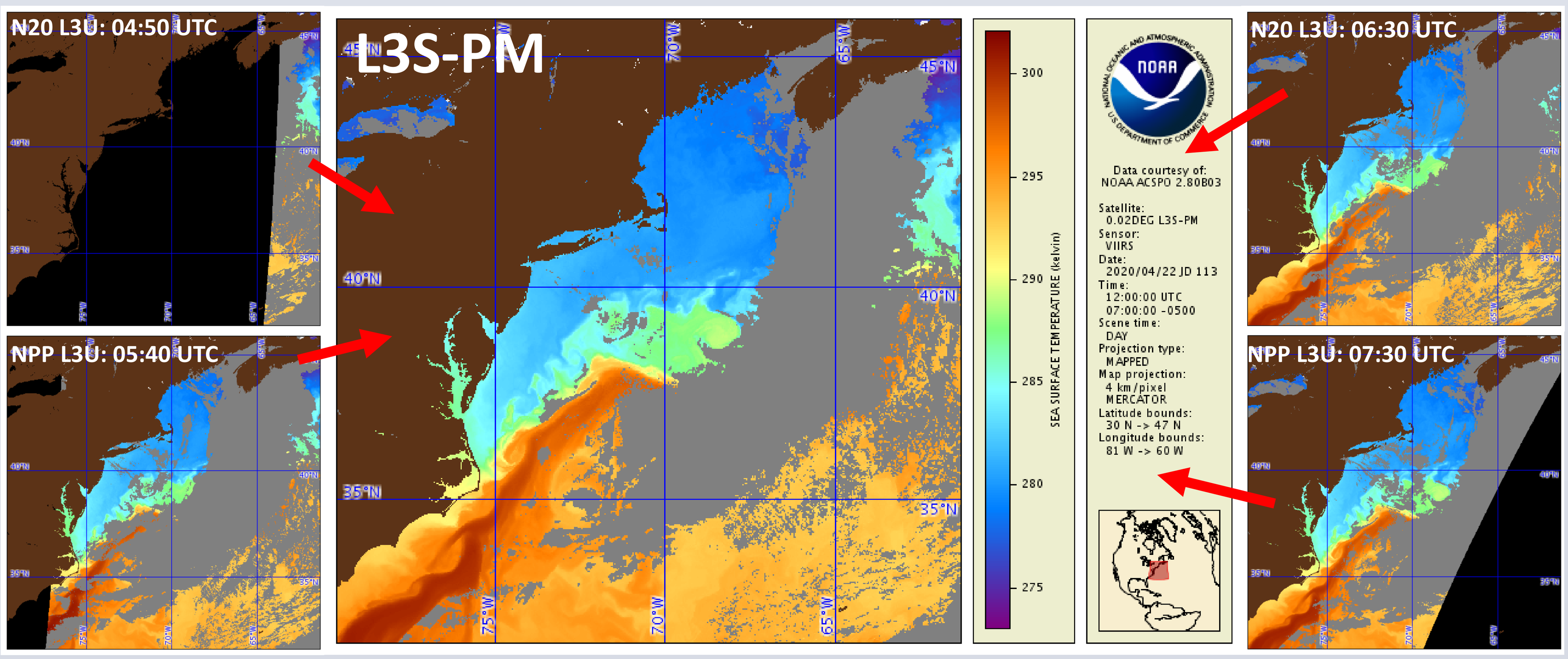

Figure 2. ACSPO night-time sub-skin SST imagery. Center panel shows the L3S-PM product while the four corners panels show individual L3U overpasses by NPP and N20 VIIRS. Grey pixels denote ocean pixels covered by cloud and black pixels denote ocean pixels outside of the sensor swath.

Overview of the ACSPO Collation Algorithm

The ACSPO collation algorithm comprises two steps (see further info in Refs. [3] and [4]):

1. Angular Debiasing/Normalization

- Satellite SST data are subject to residual intra-/inter-sensor biases between consecutive overpasses that depend strongly on view zenith angle (VZA).
- The ACSPO collation algorithm mitigates those by creating a low-resolution, satellite-based lowest VZA (LVZA) "SST reference" produced by combining near-nadir data from multiple overpasses.
- SST reference is used to debias input L3U data while maintaining feature resolution.
- Figure 3 demonstrates improved NPP/N20 consistency after LVZA debiasing.

References

[1] https://coastwatch.noaa.gov/cw/satellite-data-products/sea-surface-temperature/noaa-acspo/l3s-leo.html
[2] https://www.star.nesdis.noaa.gov/socd/sst/arms
[3] Jonasson, *et al*. "Progress With Development of Global Gridded Super-Collated SST Products from Low Earth Orbiting Satellites (L3S-LEO) at NOAA," Proc. SPIE 11420, Ocean Sensing and Monitoring XII, 1142002 (2020).
[4] Gladkova, *et al*. "Towards high-resolution multi-sensor gridded ACSPO SST product: reducing residual cloud contamination," Proc. SPIE 11014, Ocean Sensing and Monitoring XI, 110140L (2019).
[5] https://www.star.nesdis.noaa.gov/socd/sst/squam/
[6] Xu and Ignatov, "*In situ* SST Quality Monitor (*i*Quam)," *JTECH*, **31**, 164-180 (2014).

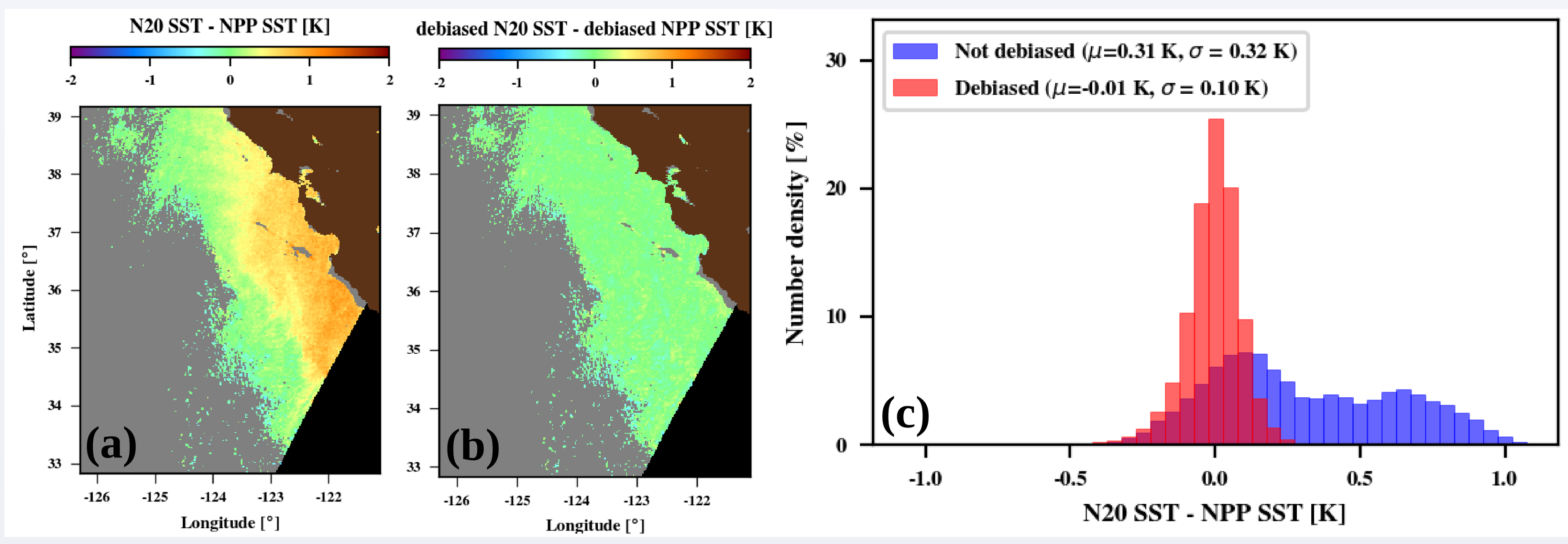

Figure 3. Panels (a) and (b) show difference in night-time sub-skin SST between consecutive overpasses between N20 (11:00 UTC) and NPP (10:10 UTC) (a) with and (b) without the LVZA debiasing. The NPP overpass was near nadir, while the N20 overpass was near swath edge and was biased warm. After debiasing (b), the agreement is greatly improved. Panel (c) shows histograms of differences with and without debiasing demonstrating improved agreement in terms of shape of the histogram (more Gaussian), and comparison statistics (mean, standard deviation). Imagery location is off the Coast of California on 4 Feb'2020.

2. Adaptive SST Weighting

- Each L3U pixel (from step 1) is weighted, using an iterative adaptive weighting procedure, which preserves features, suppresses noise and minimized spatial discontinuities.
- SST values more consistent with surrounding are weighted higher (reduces impact of cloud contaminated pixels). Figure 4 demonstrates improvement in imagery (a) with adaptive weighting compared to (b) simple average weighting.
- Measurements made at lower VZAs are weighted higher. This preference is greater in dynamic regions, to minimize smoothing of SST contrasts such as thermal fronts. Figure 5 demonstrates improvement in imagery due to (a) VZA weighting compared to (b) simple average weighting.

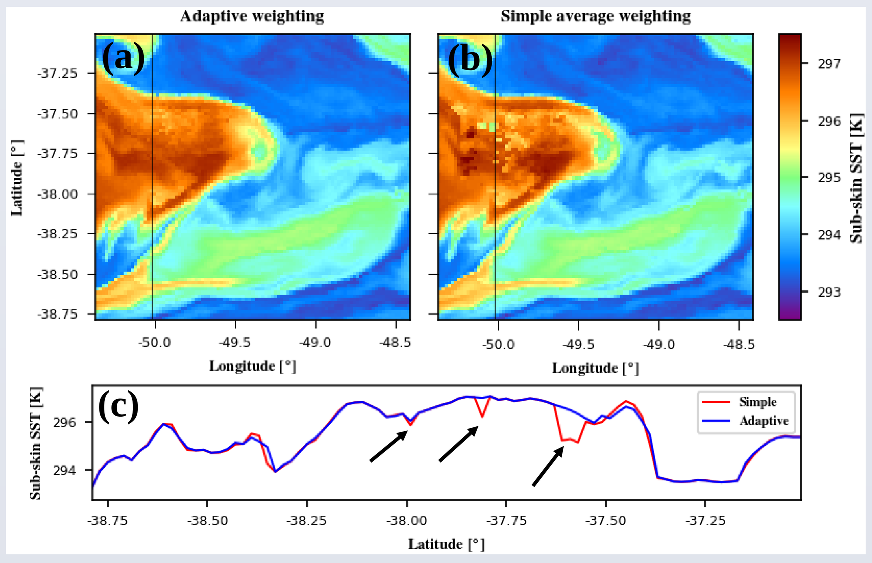

Figure 4. L3S-PM (night; Feb. 2, 2020) sub-skin SST imagery from the South Atlantic Ocean (Brazil Current). (a) Using adaptive weighting. (b) Using simple average weighting. Panel (c) shows a slice of (a) and (b) at a constant longitude marked by black vertical lines. Black arrows denote cloud contaminations that are mitigated by adaptive weighting.

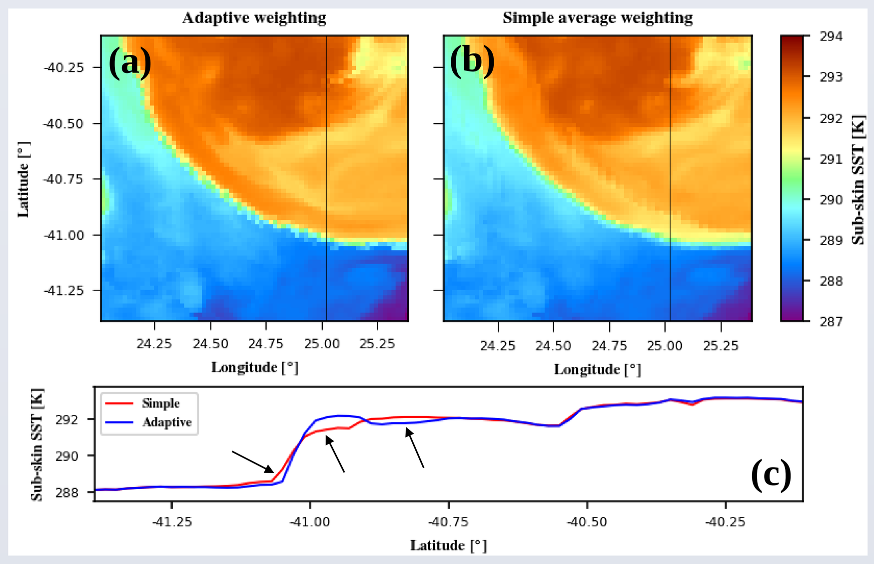

Figure 5. L3S-AM (night; Feb. 2, 2020) sub-skin SST imagery from the Indian Ocean (Agulhas Current). (a) Using adaptive weighting. (b) Using simple average weighting. Panel (c) shows a slice of (a) and (b) at a constant longitude marked by black vertical lines. Black arrows denote sharp thermal fronts that are degraded in magnitude with simple average weighting.

Global Validation

- We evaluated the L3S-PM SST product and compared to individual-sensor L3Us.
- Validation is performed using the SQUAM online system [5] using match-ups with in-situ data (drifters and tropical moorings) from the *i*Quam online system [6].
- Evaluation period between Nov'1 2029 and Apr' 9 2020.
- Table 2 below summarizes validation statistics for sub-skin and depth SST.

	PM L3S (sub-skin)	NPP L3U (sub-skin)	N20 L3U (sub-skin)	PM L3S (depth)	NPP L3U (depth)	N20 L3U (depth)
Night						
Bias, K	**+0.029**	+0.038	+0.050	**-0.009**	-0.007	-0.006
SD, K	**0.293**	0.328	0.334	**0.259**	0.284	0.292
Clear Ratio, %	**34.8**	25.8	25.8	**34.8**	25.8	25.8
Day						
Bias, K	**-0.030**	-0.023	-0.029	**+0.008**	+0.006	-0.001
SD, K	**0.322**	0.353	0.351	**0.256**	0.272	0.273
Clear Ratio, %	**34.9**	26.2	26.2	**34.9**	26.2	26.2

Table 2. Global mean biases and standard deviations (SDs) of ACSPO L3S/L3U minus iQuam SSTs and corresponding clear sky ratios. Results are given for sub-skin SST (calculated using global regression) and depth SST (calculated using piece-wise regression).

- L3S standard deviations are reduced across the board (0.02-0.04 K decrease).
- Significant improvement in clear-sky coverage: ~(34±1)% relative increase.
- L3S-AM improvements (not shown here) were similar except for even greater improvement in coverage ~(57±11)% due to availability of 3 platforms (METOP-A/B/C).

Summary

- ACSPO L3S algorithm for collation of L3U SSTs from hi-res LEO sensors (VIIRS and AVHRR FRAC) has been proposed and implemented.
- Collation is a three-step process: 1) create ACSPO reference (low VZA composite); 2) debias input L3U data; 3) weight using an adaptive weighting procedure that mitigates cloud leakages and attempts to maintain L3U feature resolution.
- L3S coverage significantly improved compared to individual sensor L3Us.
- Incremental improvements in precision (0.01-0.04 K reduction in SD w.r.t. in-situ).

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