19th GHRSST Science Team Meeting

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ACSPO Hourly SST Products from GOES-R ABI & Himawari-8/9 AHI

Irina Gladkova[1,2,3], Alexander Ignatov[1],
Matthew Pennybacker[1,3], Olafur Jonasson[1,3], Yury Kihai[1,3]

[1] STAR, NOAA Center for Weather and Climate Prediction (NCWCP), USA
[2] City College of New York, USA
[3] Global Science and Technology, Inc., USA

Thanks to our colleagues for help

- **Yanni Ding:** Monitoring geo L2/3C in ARMS
- **Xinjia Zhou, Kai He:** Providing *i*Quam *in situ* data; Monitoring L2C in SQUAM
- **Maxim Kramar:** Routine geo ACSPO testing/processing in STAR
- **Boris Petrenko:** Recalculating NLSST coefficients and SSES LUT's for L2C
- **Andrew Fitzgerald:** Rewriting prototype MatLab L2C code into initial C++ implementation

Motivation for Geo Collated SST

- The new geostationary sensors, ABI and AHI onboard GOES-16 (G16) and Himawari-8 (H08) have a 15/10min refresh rate, providing a wealth of temporal information
- In conjunction with high spatial resolution (2km @nadir) this results in huge data volumes
- For many users of diurnally resolved SST, a product with a lower time resolution (e.g., hourly) is often sufficient
- In response to users' needs, NOAA has developed hourly "collated" SST product (L2C; in L1b projection) and its gridded counterpart (L3C; in 0.02º equiangular projection)

Compositing/Collation Options

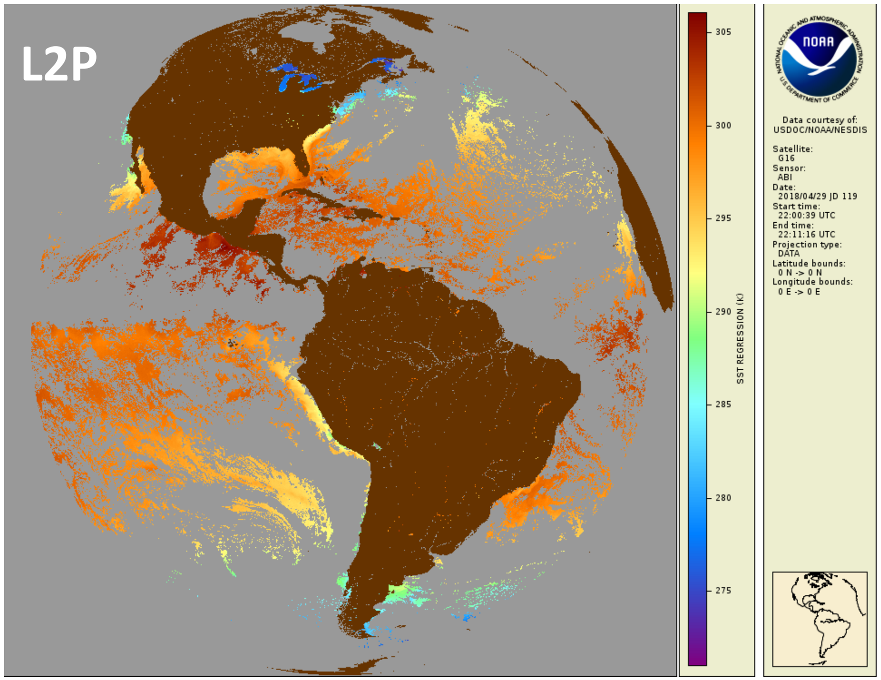
Type	Methodology	Drawbacks
Time-based sampling	keep data at selected times (i.e. subsampling at hour UTC)	• Fails to take the advantage of frequent in time observations
Averaging	(weighted) average of all data within chosen time-frame	• may propagate cloud leakages • may suppress diurnal signal • May affect thermal front location
Value-based sampling	e.g. selecting warmest SST, to suppress cloud leakages	• may be subject to outliers (e.g., due to cloud/land contamination) • may be subject to warm biases
Time-based selection	keeping one (e.g. last) clear sky observation within specified time interval	• may propagate cloud leakages • may be subject to outliers

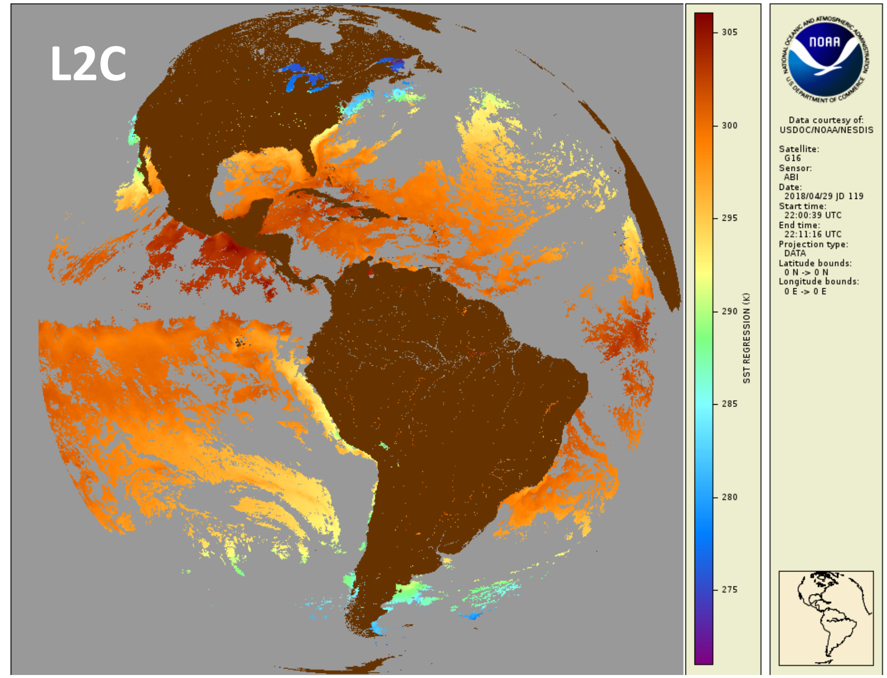
ACSPO "Collation" process was specifically designed for geo SST products, taking into account many aspects of SST retrievals and masking into consideration

ACSPO Hourly Collated L2/3C Products

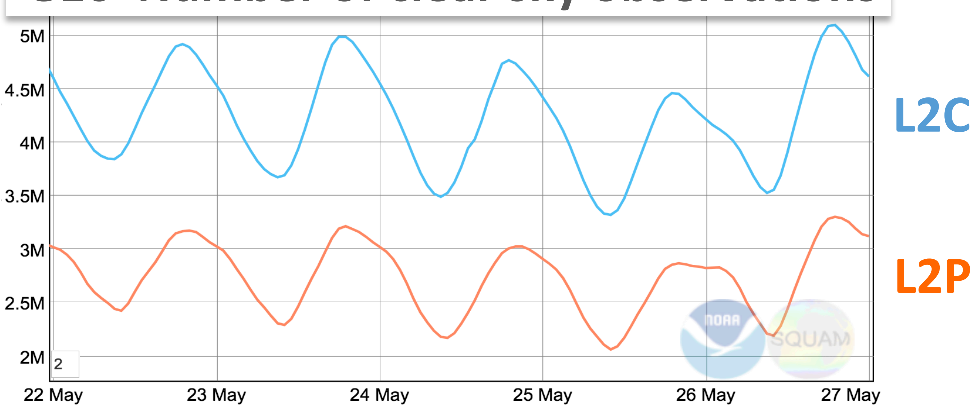
1. L2C product is produced from all L2P files with native time/space resolution and reported in original L1b (swath) projection, 24 hourly files per day, with a total data volume of ~6GB/day
2. Collation algorithm is designed to meet the following objectives:
   - Improve spatial coverage
   - Improve temporal consistency
   - Reduce cloud leakages & false alarms
   - Reduce spatial/temporal noise
   - Maximally preserve (1) native spatial feature resolution; and (2) temporal information content
3. ACSPO also produces L3C (L2C projected onto 0.02º equilateral grid), 24 hourly files per day, with a total data volume of ~0.6GB/day

Larger spatial coverage of L2C vs L2P





G16 Number of clear sky observations



Number of SST OBS increases by
- ~40% for G16 ABI
- ~50% for H08 AHI

Cloud move during the 1 hr interval, revealing more clear-sky pixels

Cloud masking considerations

The current ACSPO mask is subject to 2 misclassifications:

- Cloud leakages (residual cloud)
- False alarms (wrongly screened clear pixels)

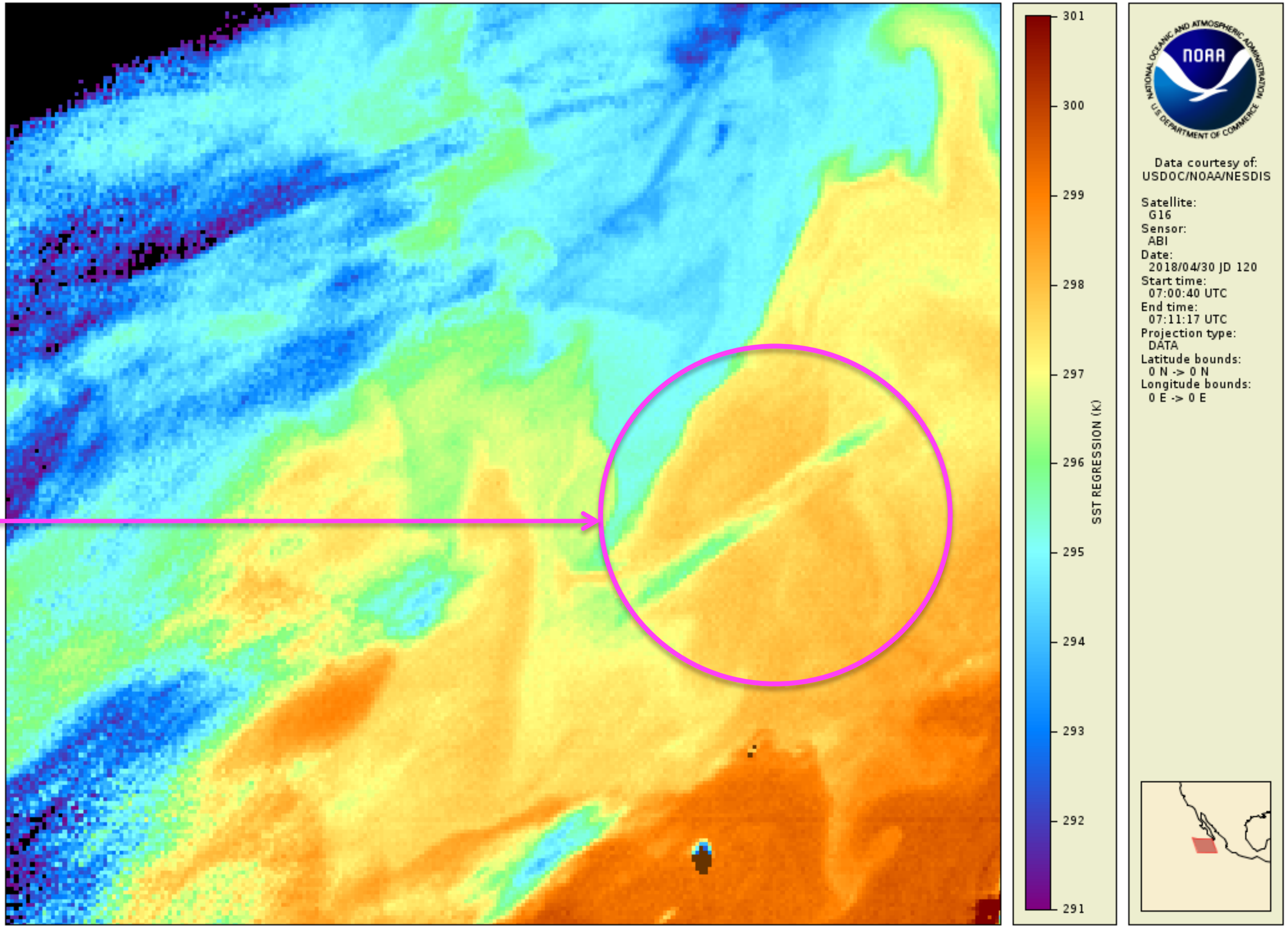
Compositing using the current mask:

- Needs additional QC to screen-out cloud leakages
- Many dynamic areas are lost, due to false alarms in L2P mask

Therefore the collation process should be performed assuming that the retrieved L2P SSTs may be subject to occasional cloud leakages, as well as over screened clear-sky regions.

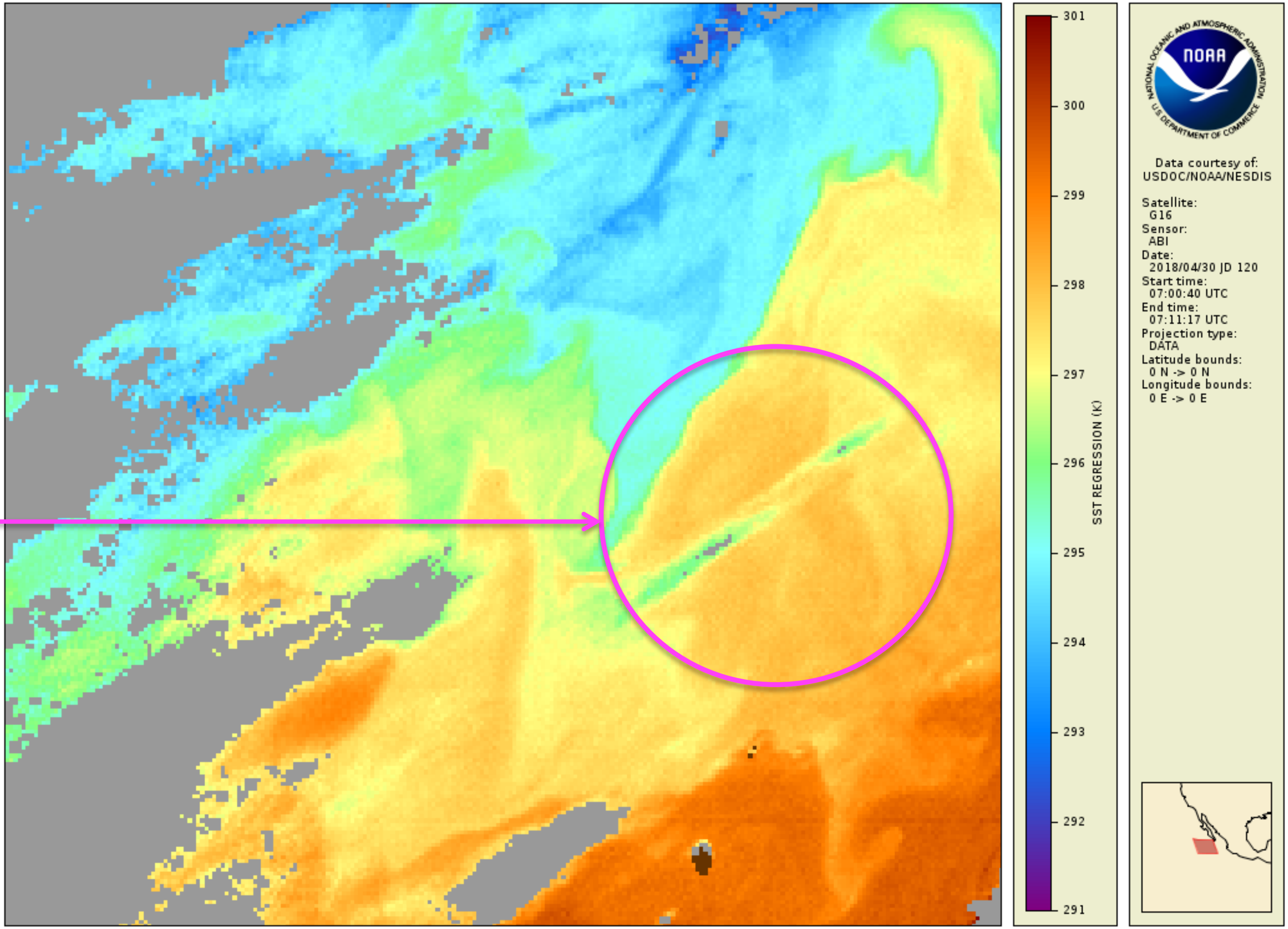
G16/ABI: L2P SST, 30 April 2018 at 07:00UTC

Typical cloud challenging to detect from BT's at particular time instance



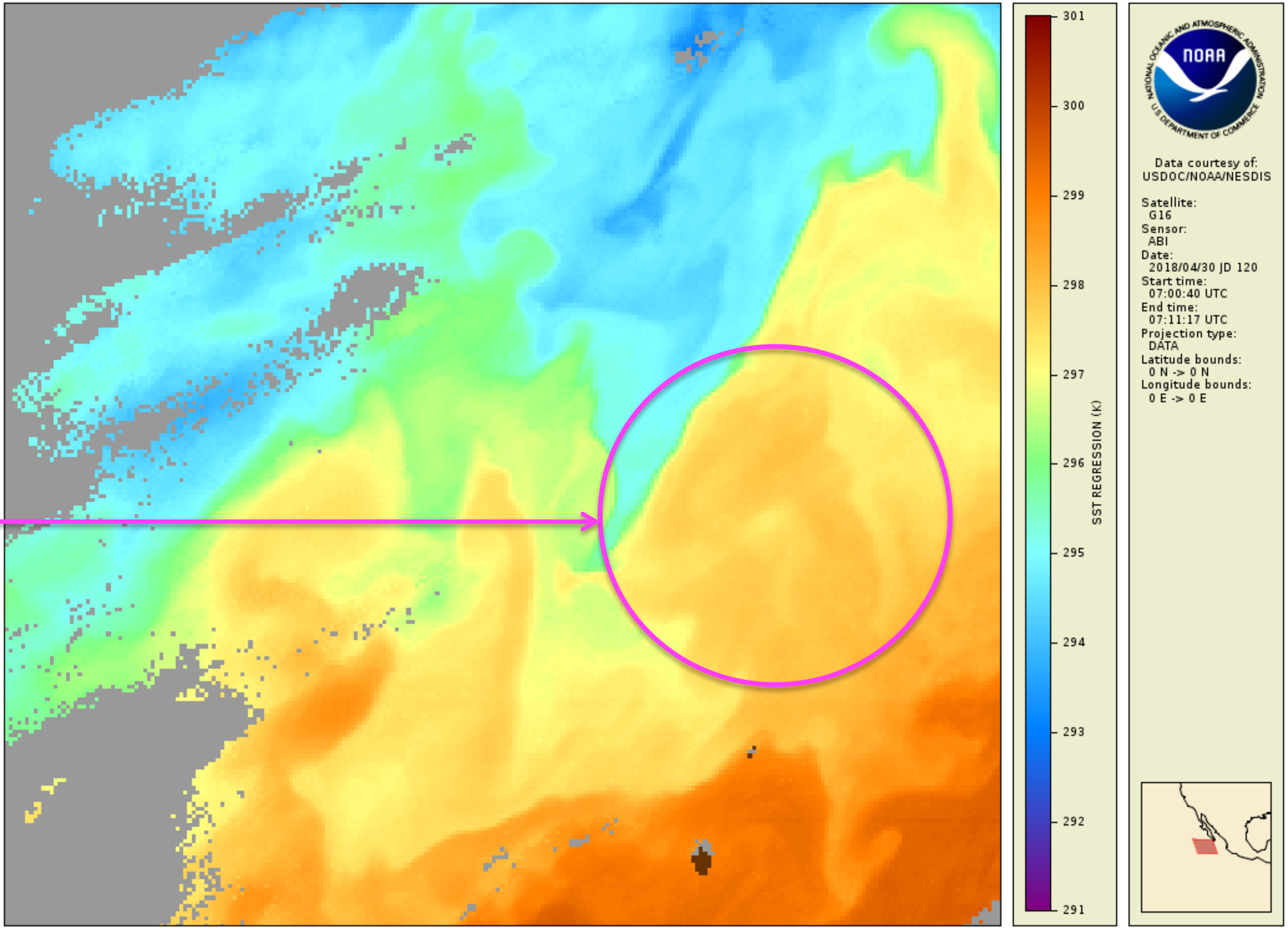
L2P with ACSPO L2P cloud mask

Typical cloud leakage In L2P

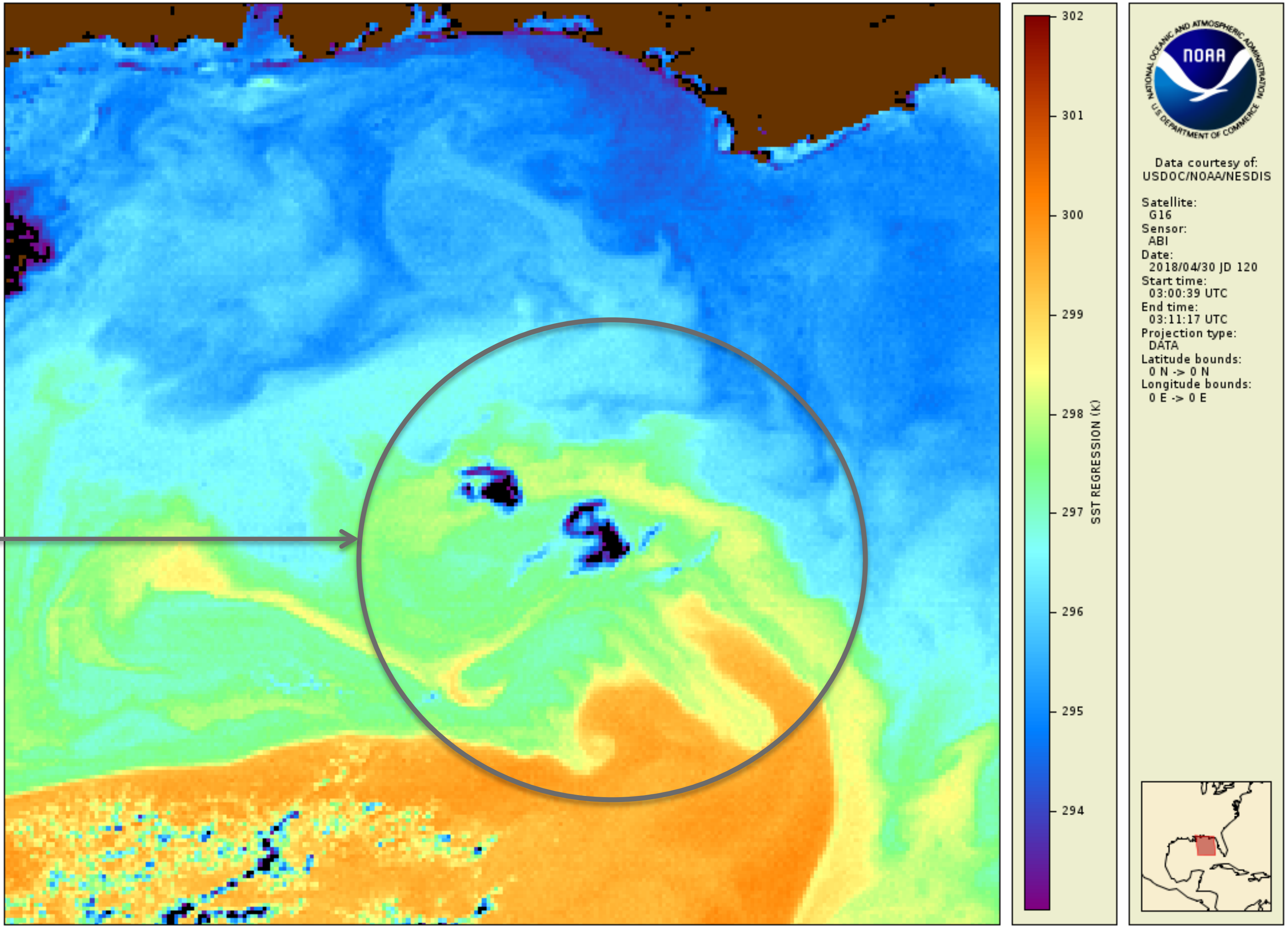


Example of hourly collated SST

Moving cloud should not affect L2C



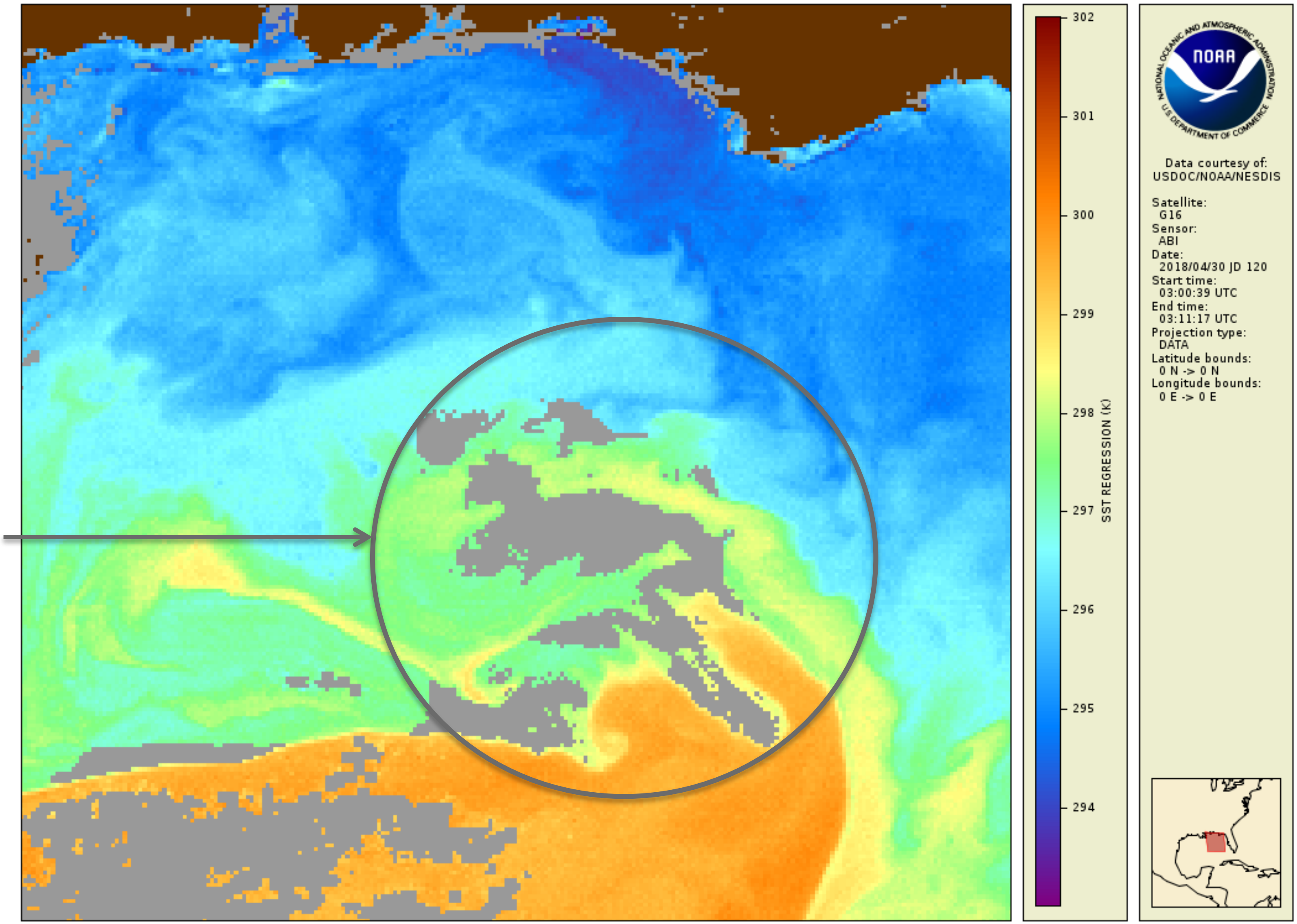
G16/ABI: L2P SST, 30 April 2018 at 03:00UTC



Clear sky dynamic region ..

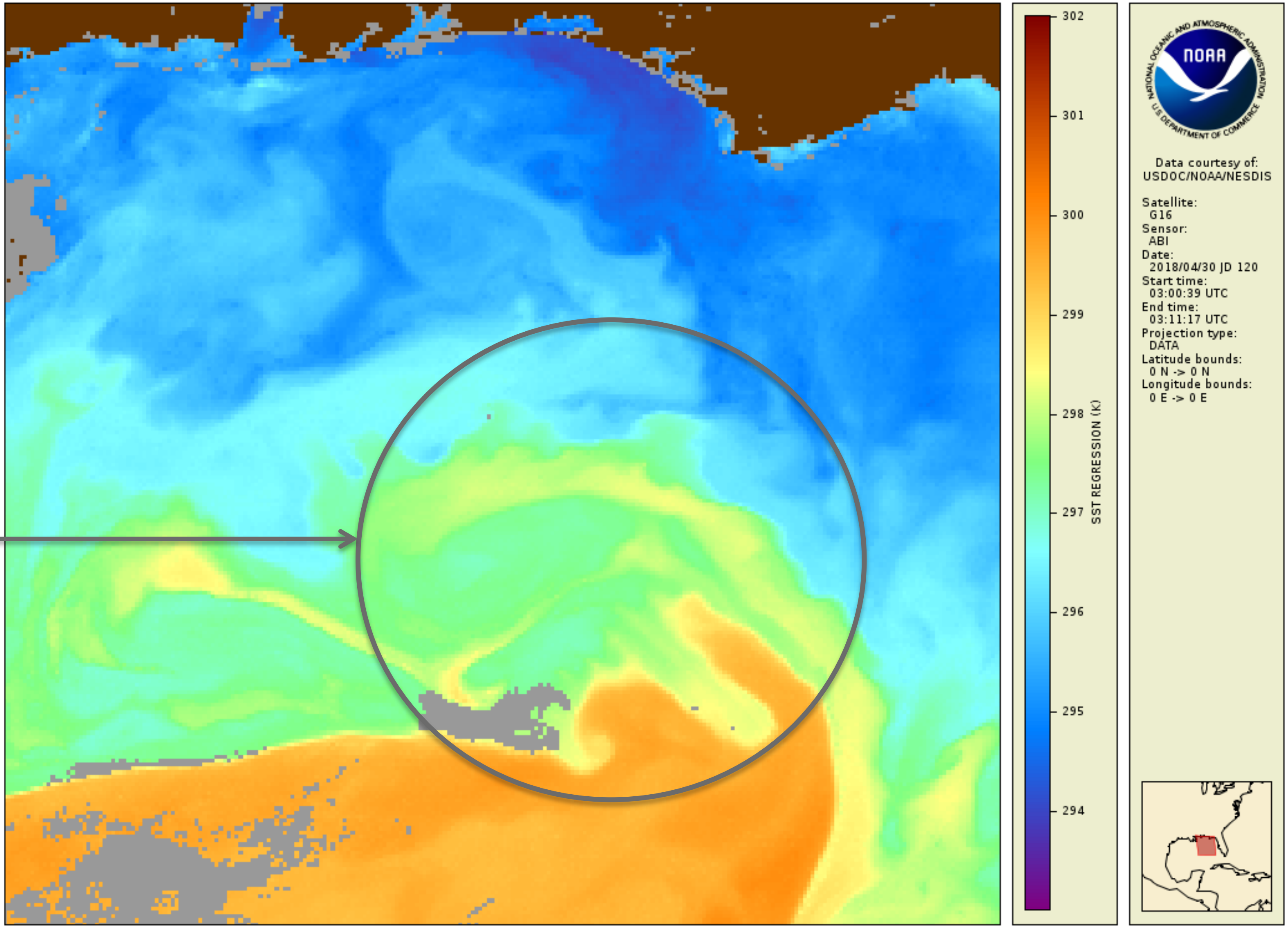
L2P with ACSPO L2P cloud mask

..Is over-screened



Example of hourly collated SST

..but mostly **restored in L2C**

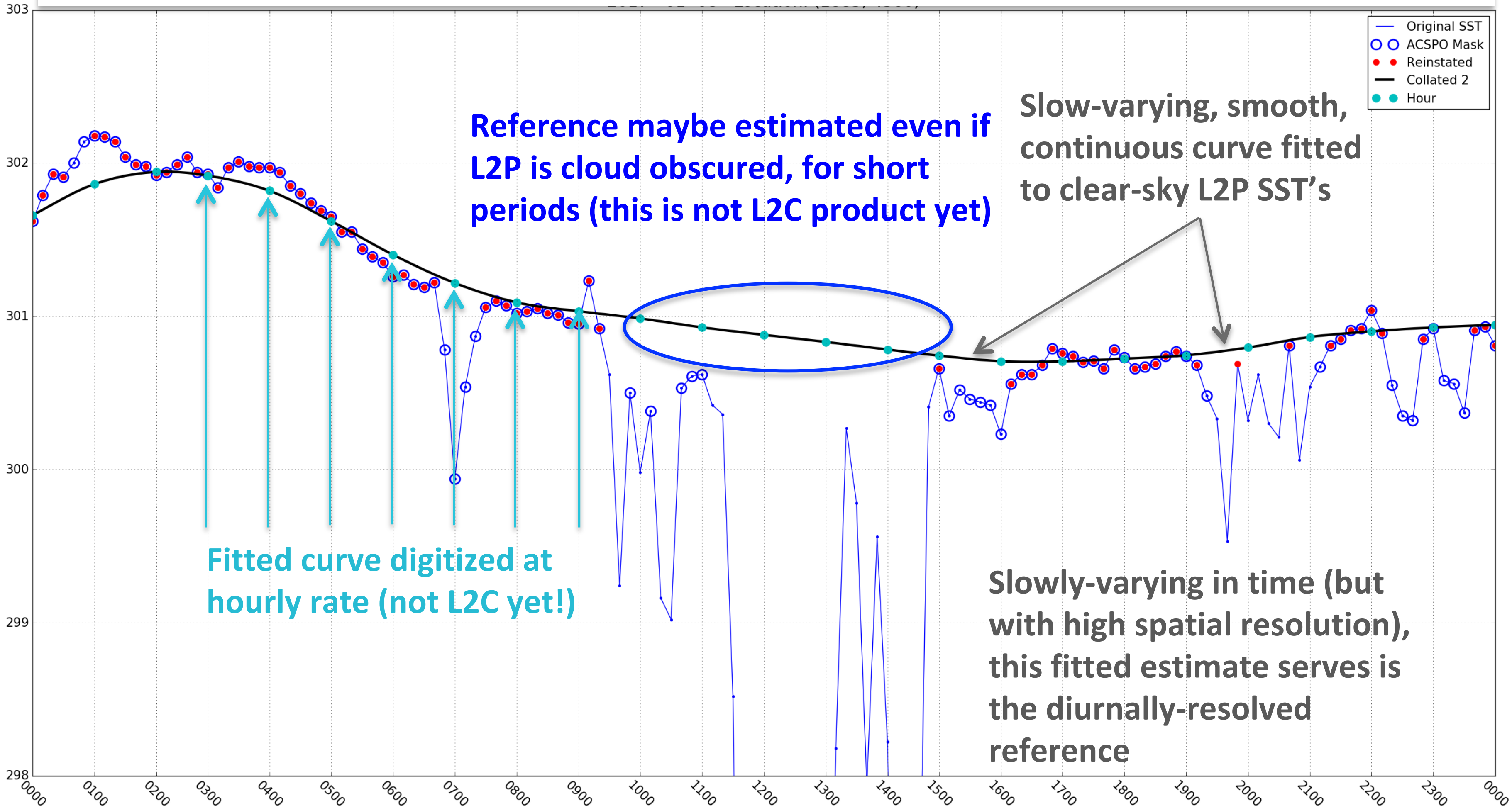


Main Steps of ACSPO L2C Approach

- Use the current ACSPO clear-sky mask as a first-guess, assuming that it may be (and often, it is) subject to occasional cloud leakages and false alarms
- Remove residual cloud leakages based on temporal information
- Estimate diurnally-resolved reference (for locations with clear-sky observations available during the considered period of time)
- Use the computed reference to identify false alarms and return wrongly screened-out pixels back to clear-sky domain
- Aggregate the new clear-sky SSTs at 1 hr increments (taking into consideration that identified SST values can be still contaminated by cloud)

New Diurnal-Cycle Resolved Reference

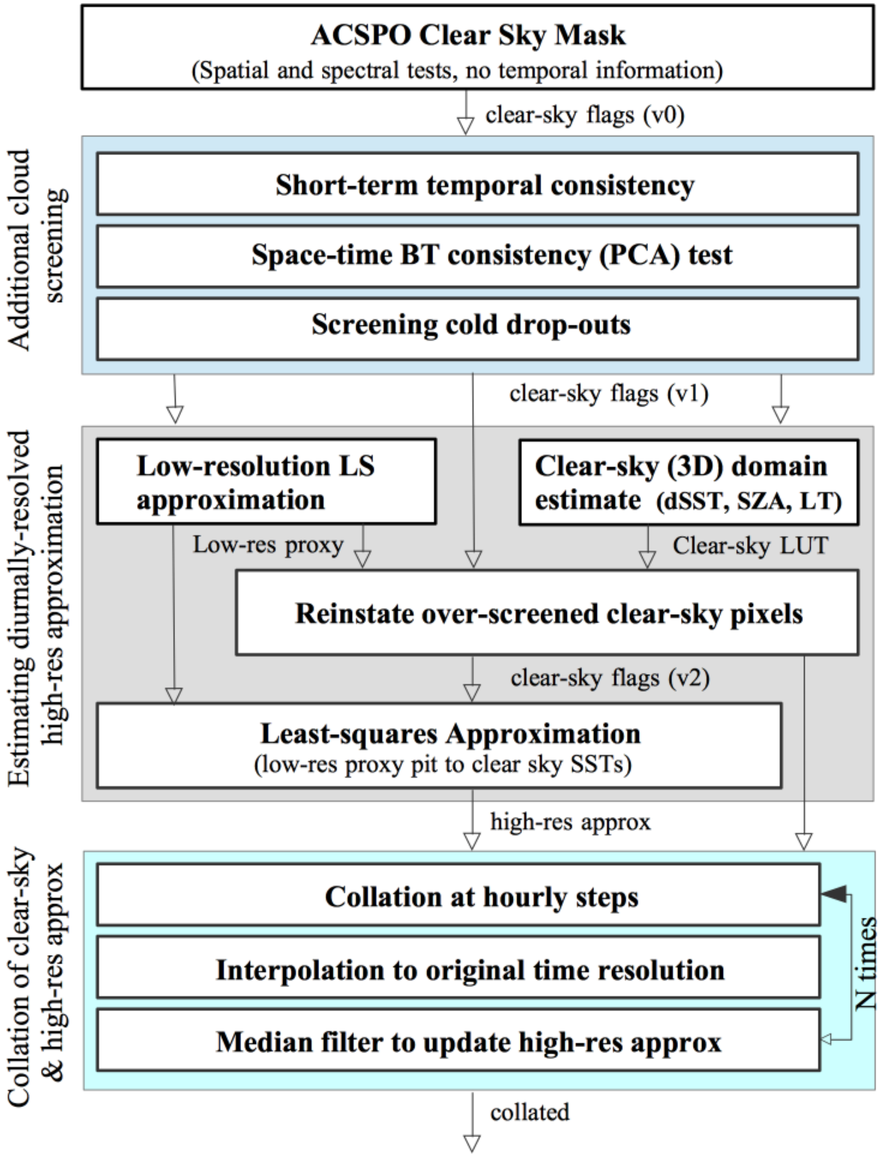
Example: January 8, 2017 (16.5°N, 173.8°E), Himawari-8/AHI



Near real-time processing compromise

- Original approach was developed with daily chunks in mind
- Memory usage (~1 GB/L2P granule + overhead) required shortening this to processing in smaller chunks. Testing found that global statistics and coverage were degraded using fewer than 25 granules
- NRT version of the code is processing 6 hr chunks with 5 hrs of history for ABI (3 hrs for AHI) and 1 hr of future data
- Current implementation takes ~6 min on our development systems, making L2C product for N:00 UTC available 6 min after (N+1):00 UTC L2P granule is obtained

Block Diagram: Main Steps



0. Initiate with current L2P mask

1. Perform additional cloud screening (series of temporal tests that sequentially reduce clear-sky domain)

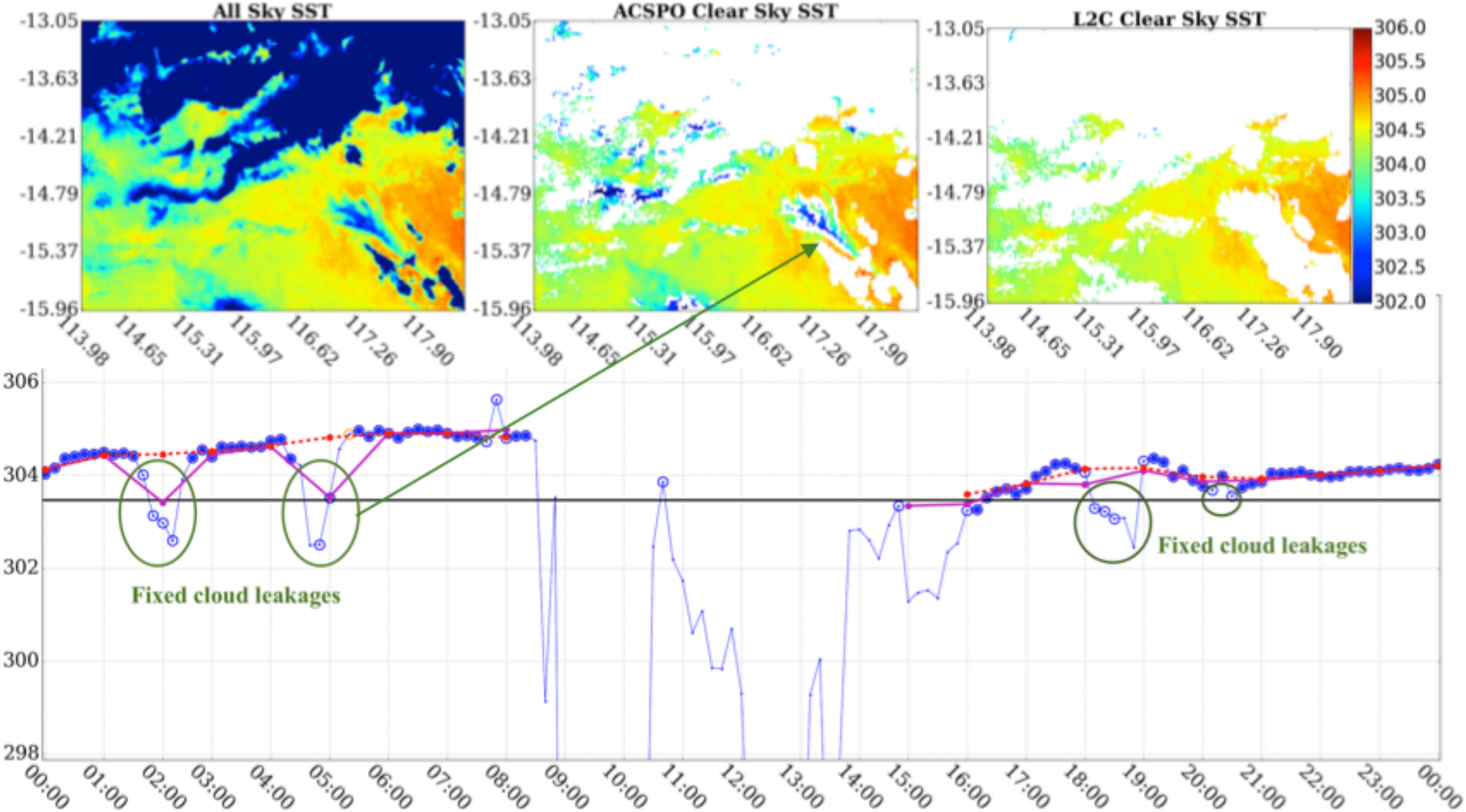
2. Estimate hi-res proxy in 2 steps:
   - estimate low-res/slow varying component;
   - fit low-res model to clear-sky observation, in each pixel;

3. Collate clear-sky observations with hi-res proxy, by iterative refinement of the proxy

Block 1: additional cloud screening based on temporal information

Tests	Variables used	Window row X col X time
1-step forward and backward difference	SST	1x1x2 (temporal only)
Deviation from average	SST	1x1x3 (temporal only)
Cold drop-out test	SST	1x1x6 (temporal only)
Local min test	SST	1x1x3 (temporal only)
Space-time BT consistency (PCA) test	BT08, BT10, BT11, BT12	3x3x3 (space/time/spectra)

Example of cloud screening improvement, using temporal information

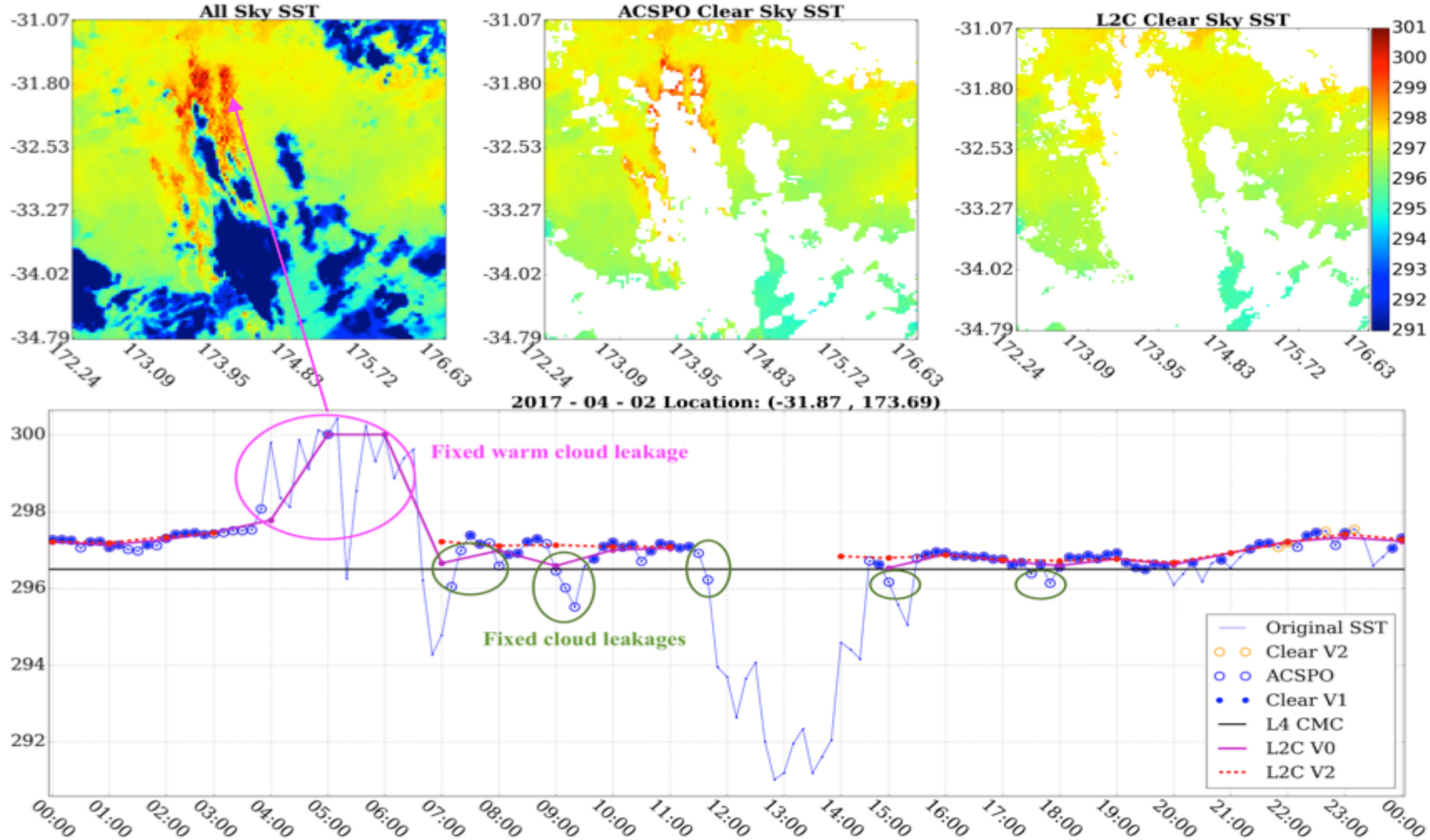


Examples of cold clouds missed by the current ACSPO mask.

Magenta line corresponds to hourly collated SST without additional could screening.

Red line represents L2C SST with cloud screening using temporal filters and robust collation.

Cloud screening example: warm cloud

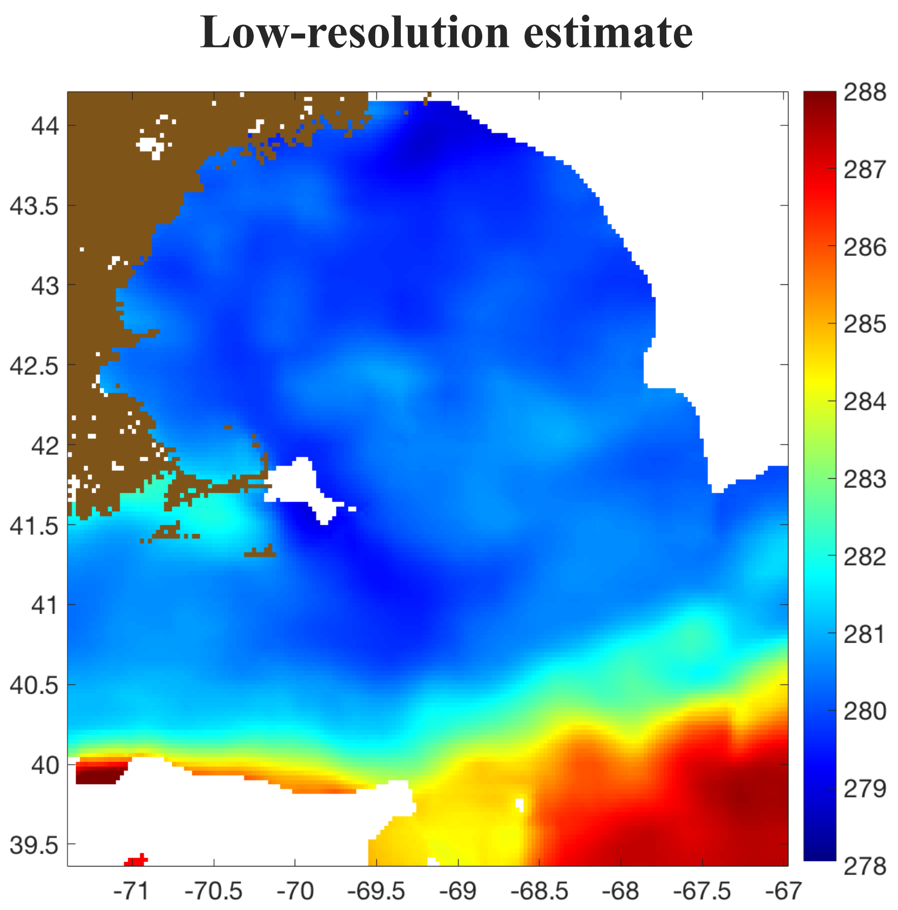


Blue circles: Pixels identified by ACSPO mask as "clear";

Magenta ovals: Pixels obscured by warm clouds;

Green ovals: Cold clouds missed by the current L2P ACSPO mask.

Block 2: Low-resolution component



For each row/col location of the FD at each time instance, the retrieved SST value can be represented as

$$T_r = T_s + T_f$$

T_r is retrieved SST value which is affected by atmospheric component

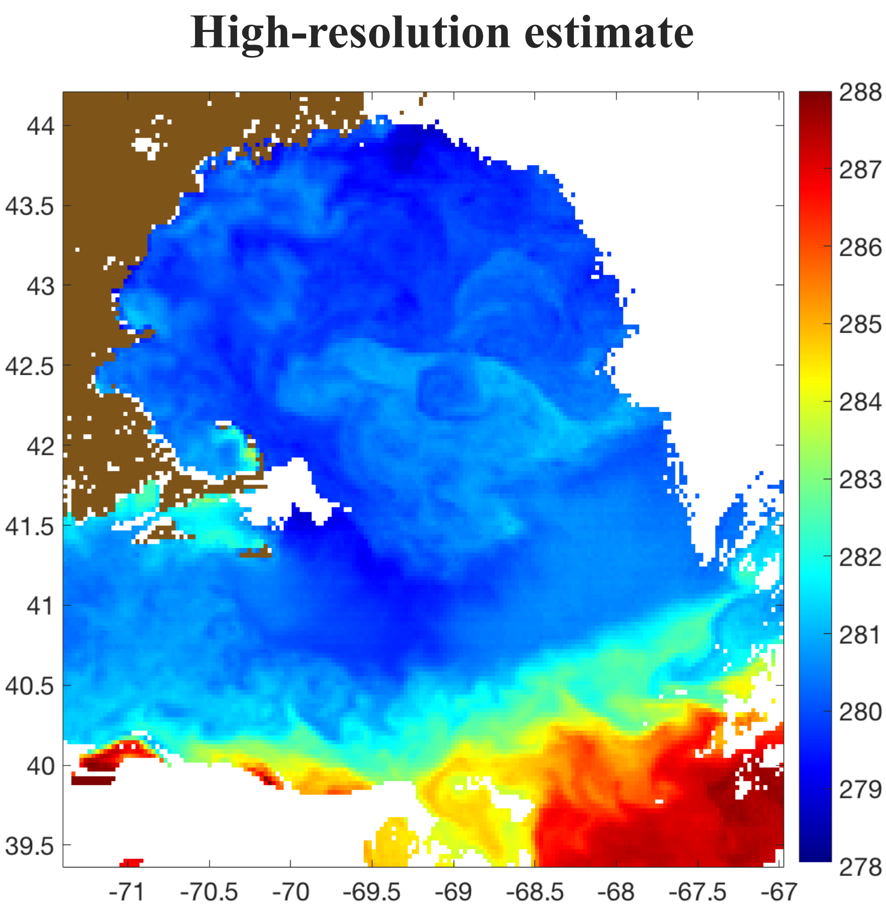
T_s is a component varying slower in time than T_f

The least square setting

$$\underset{T_s}{\operatorname{argmin}} \left(||T_s - T_r||_2^2 + \gamma \sum_{k=1}^{K-1} (T_s(t_k) - T_s(t_{k+1}))^2 \right)$$

with T_r representing an average in space/time window can then be used to estimate a slow-varying in time component T_s by penalizing large differences between sequential in time values.

Block 2: High-resolution estimates



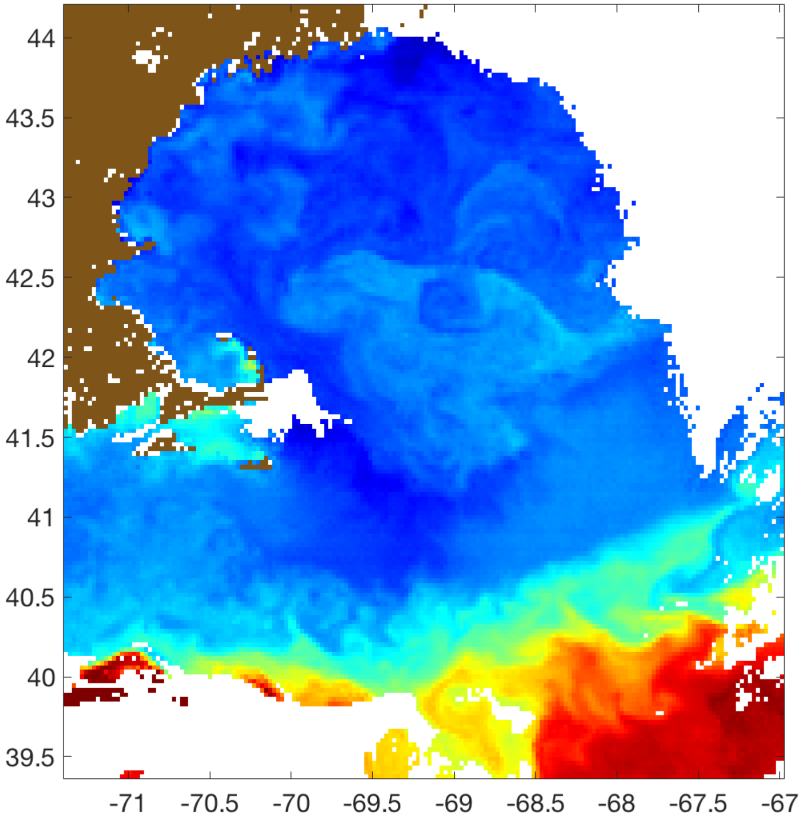
Each row/col of the FD have slow-varying in time component T_s .

This local time-dependent shape T_s is then fitted to the clear-sky sst's in each pixel.

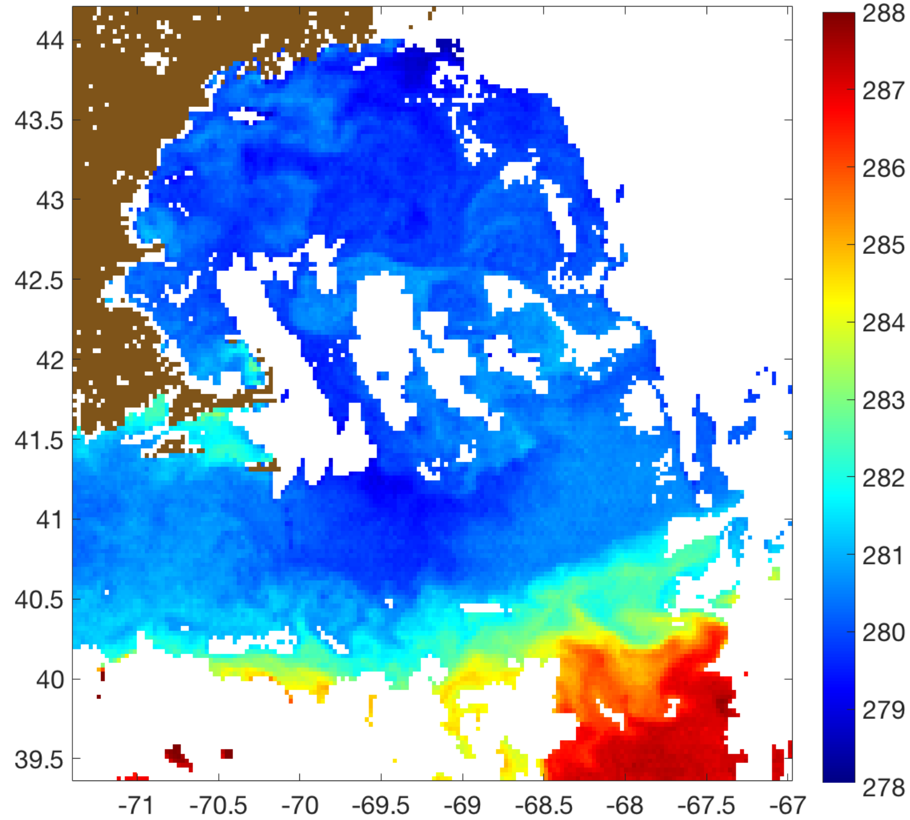
Resultant high-resolution in space but slowly varying in time estimation can then be used as diurnally resolved proxy for refined cloud screening and for collation steps.

L2P and L2C (ABI, April 30, 07:00UTC, 01:00 LT) for comparison with high-res proxy

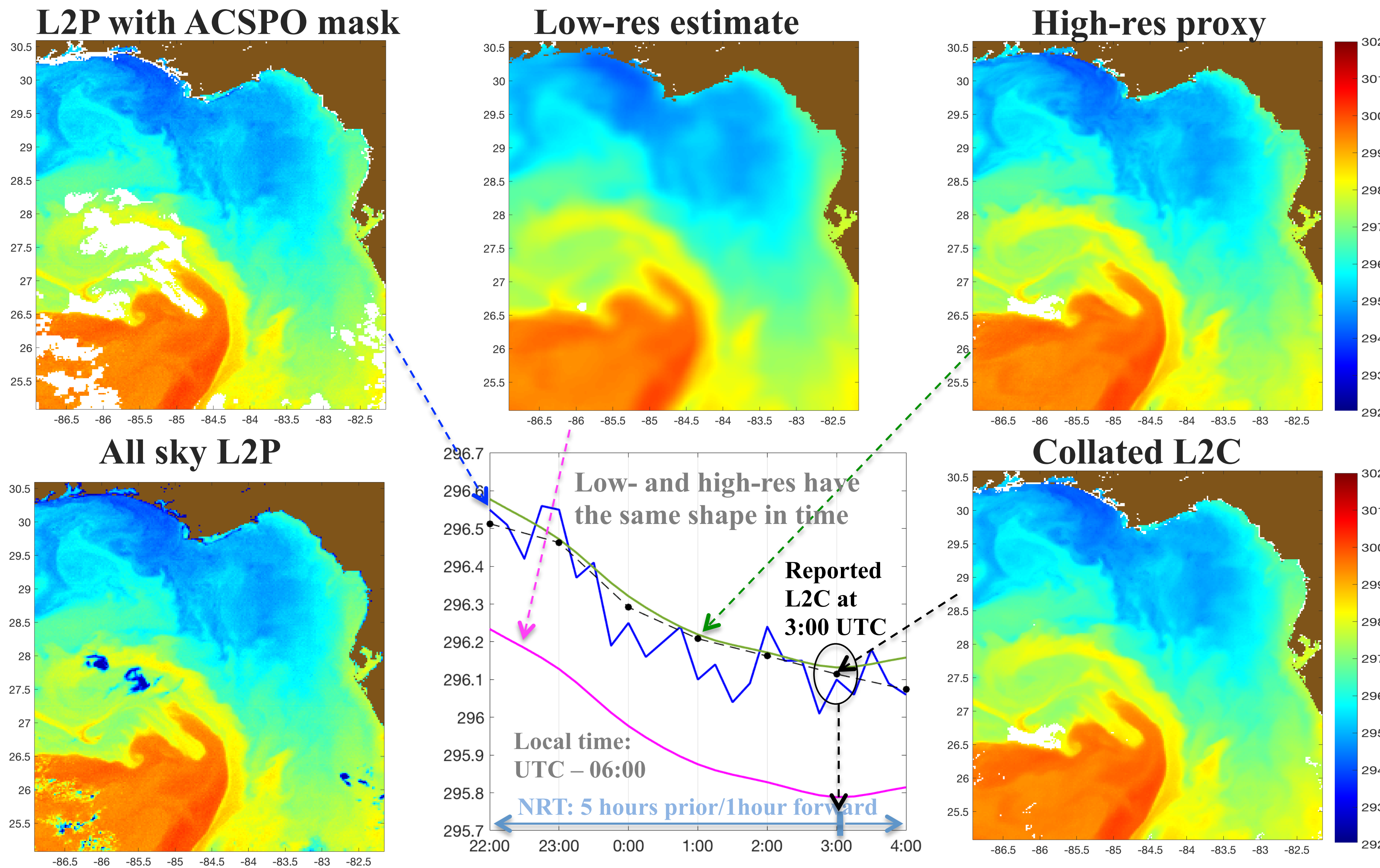
Collated L2C SST



L2P with original ACSPO mask

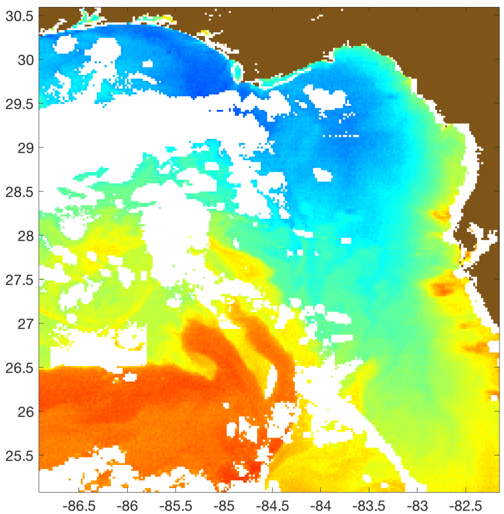


Block 3: High-res & clear sky collation (April 30, 03:00UTC , 21:00 LT)

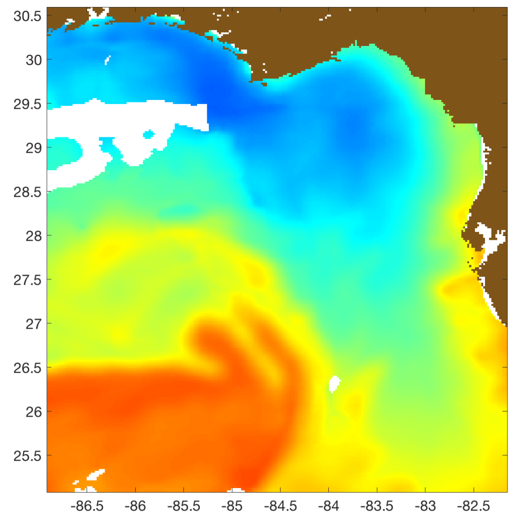


Block 3: High-res & clear sky collation (April 30, 18:00UTC , 12:00 LT)

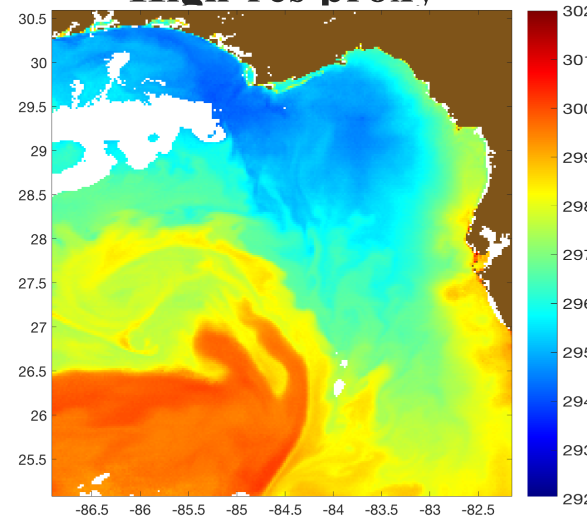
L2P with ACSPO mask

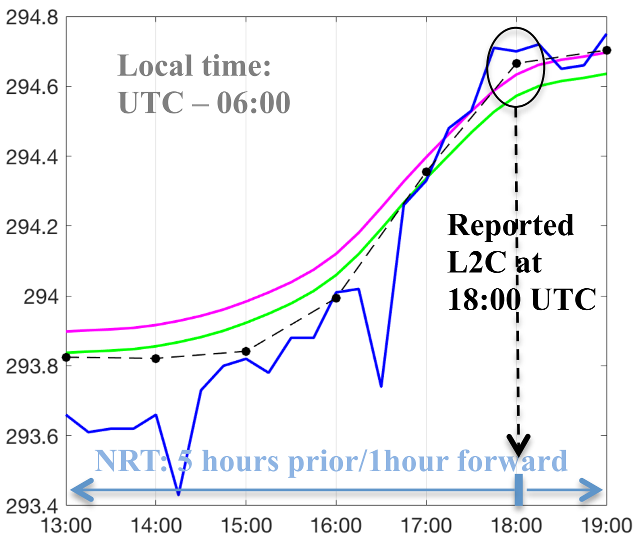


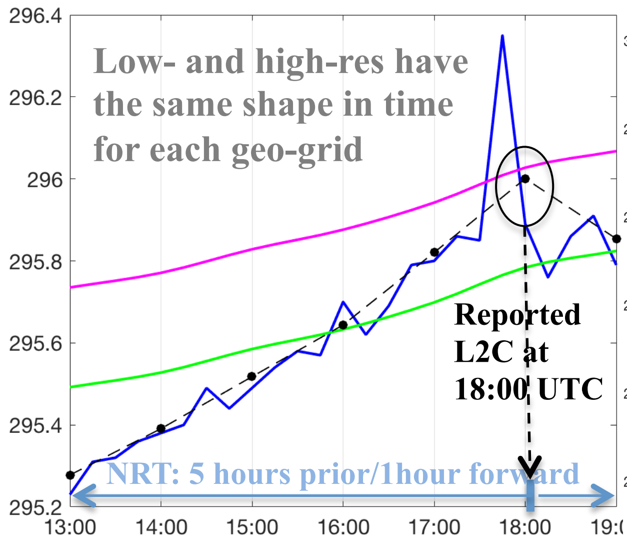
Low-res estimate



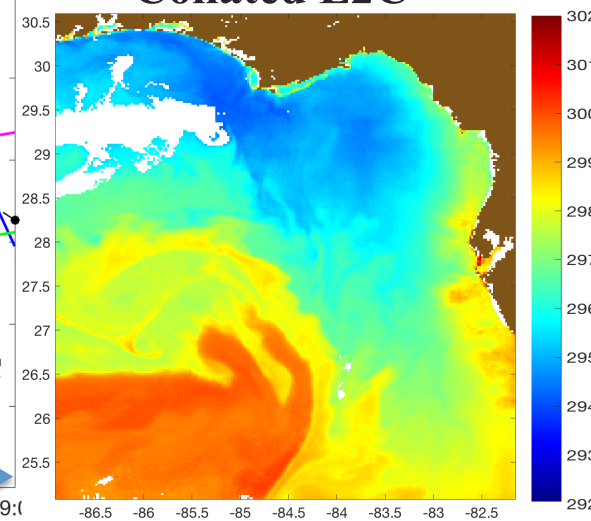
High-res proxy





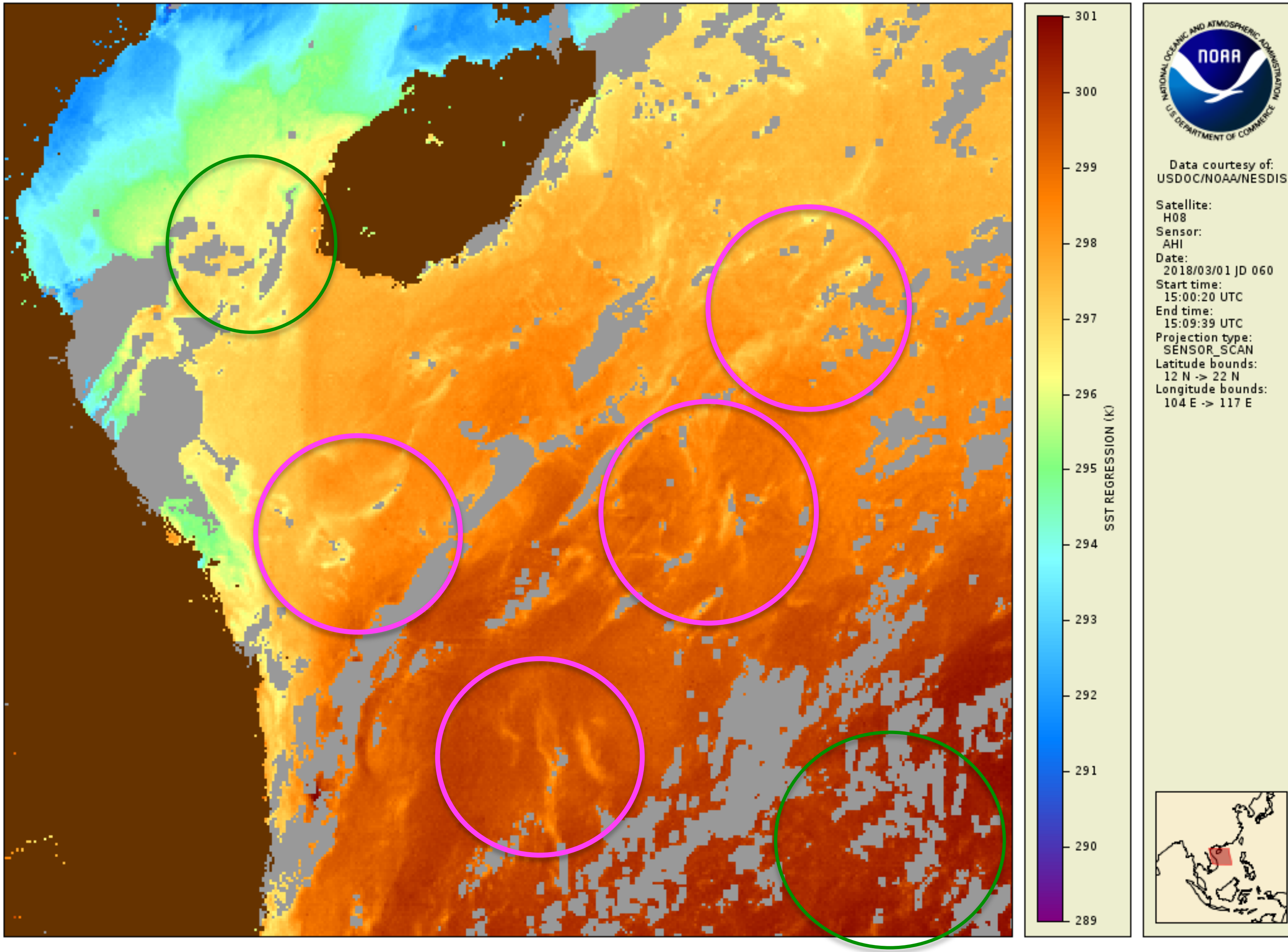


Collated L2C



L2P/L2C Examples:
Improved coverage,
Improved image quality
and
(partial) recovery of false cloud detection in
dynamic region

H08/AHI: L2P SST over Great Barrier Reef



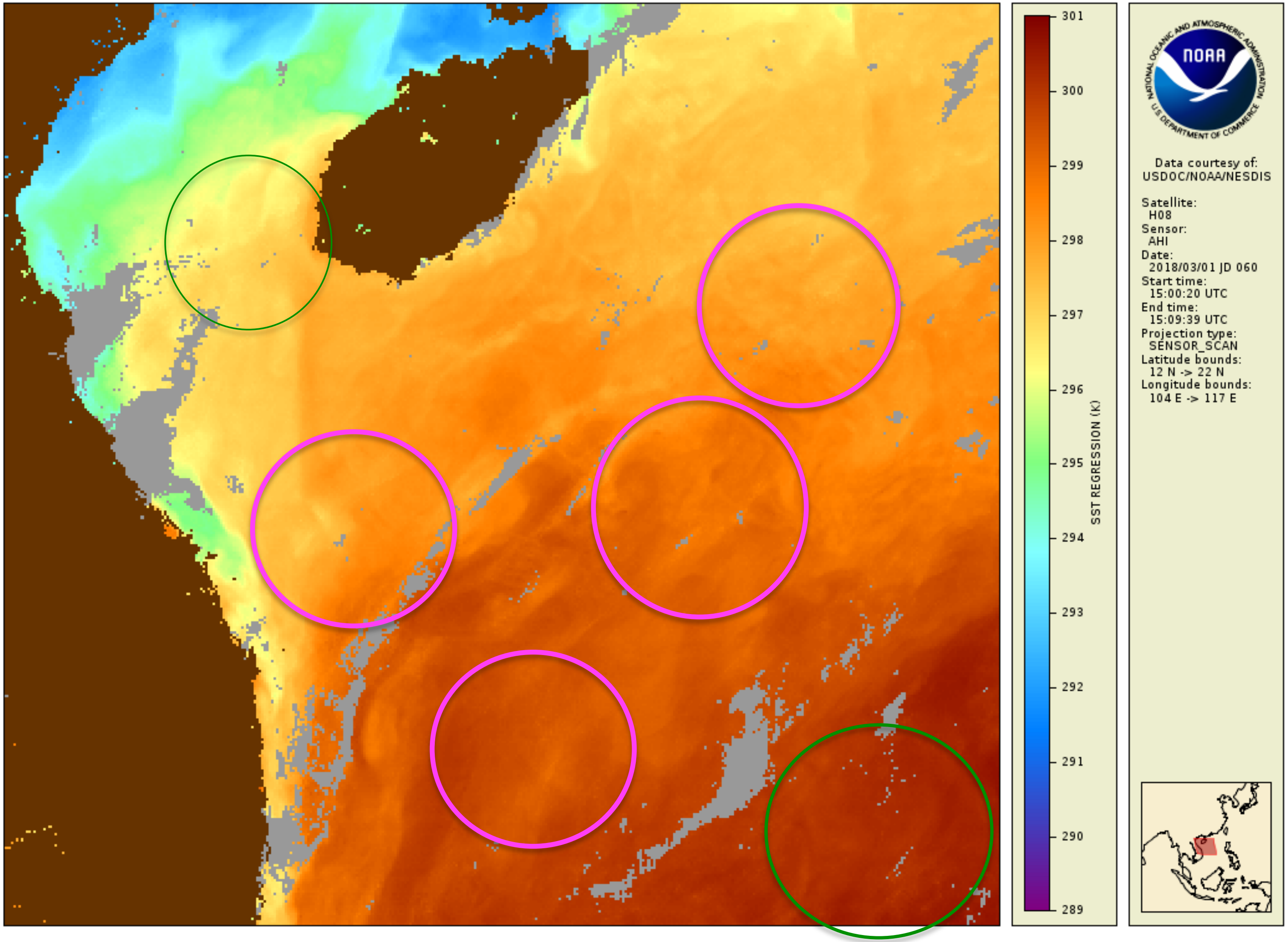
Typical Cloud Leakage in L2P

Cloudy at selected time

Collated Hourly L2C

Cloud Leakages in L2P reduced

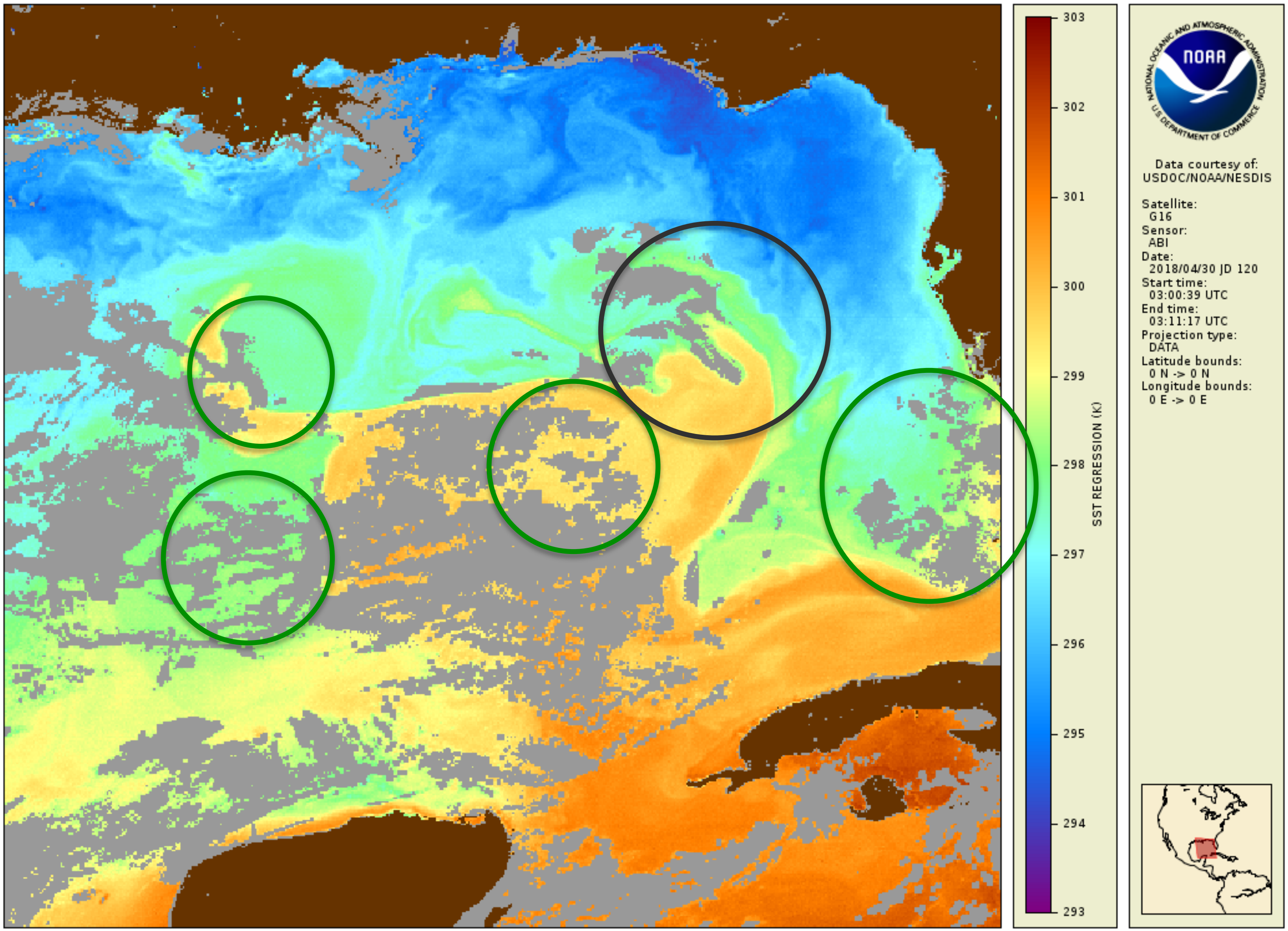
Clear-sky at least once during 1hr window



G16/ABI: L2P (night-time) SST over Gulf of Mexico

Lost dynamic region

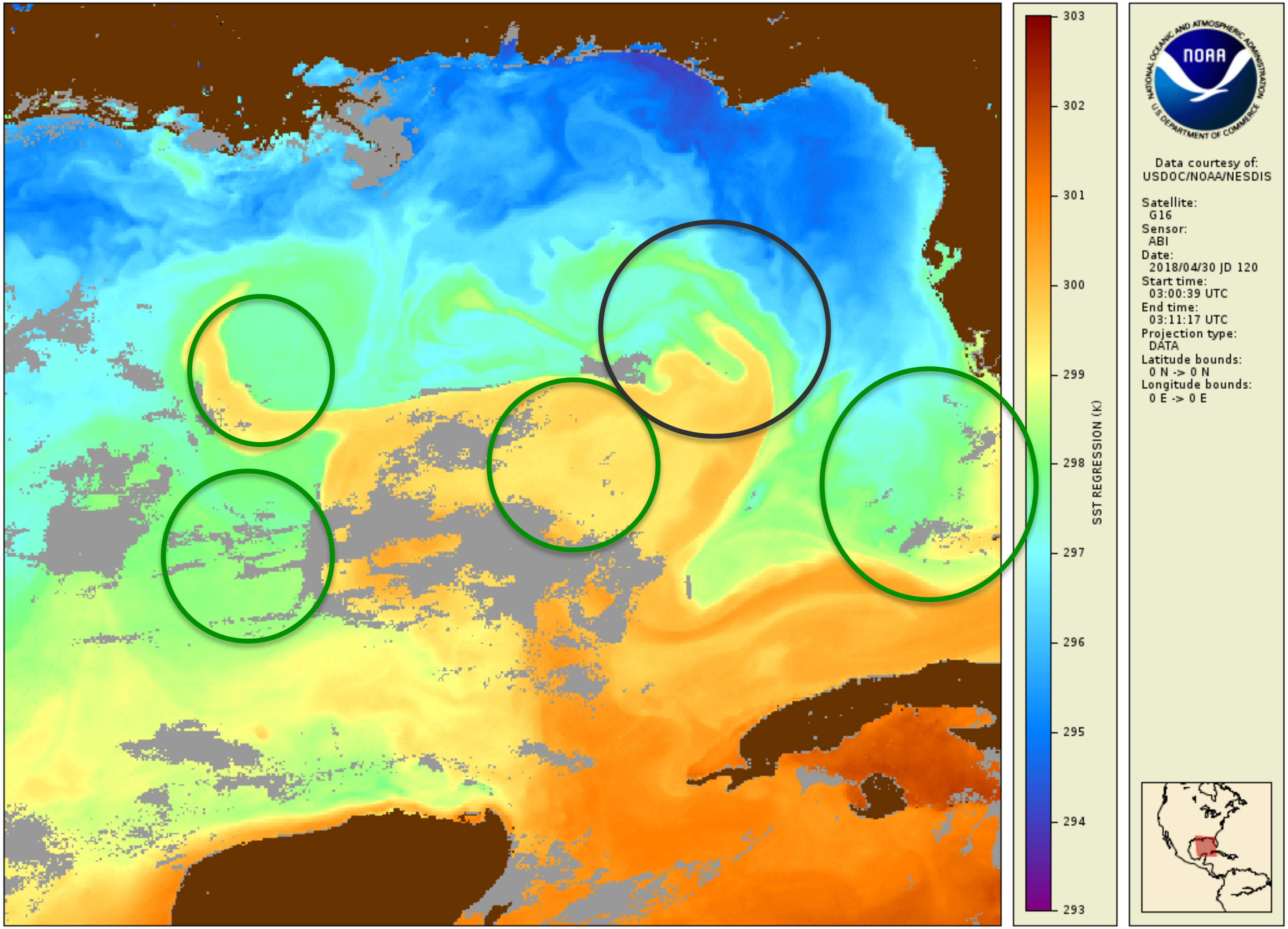
Cloudy at selected time



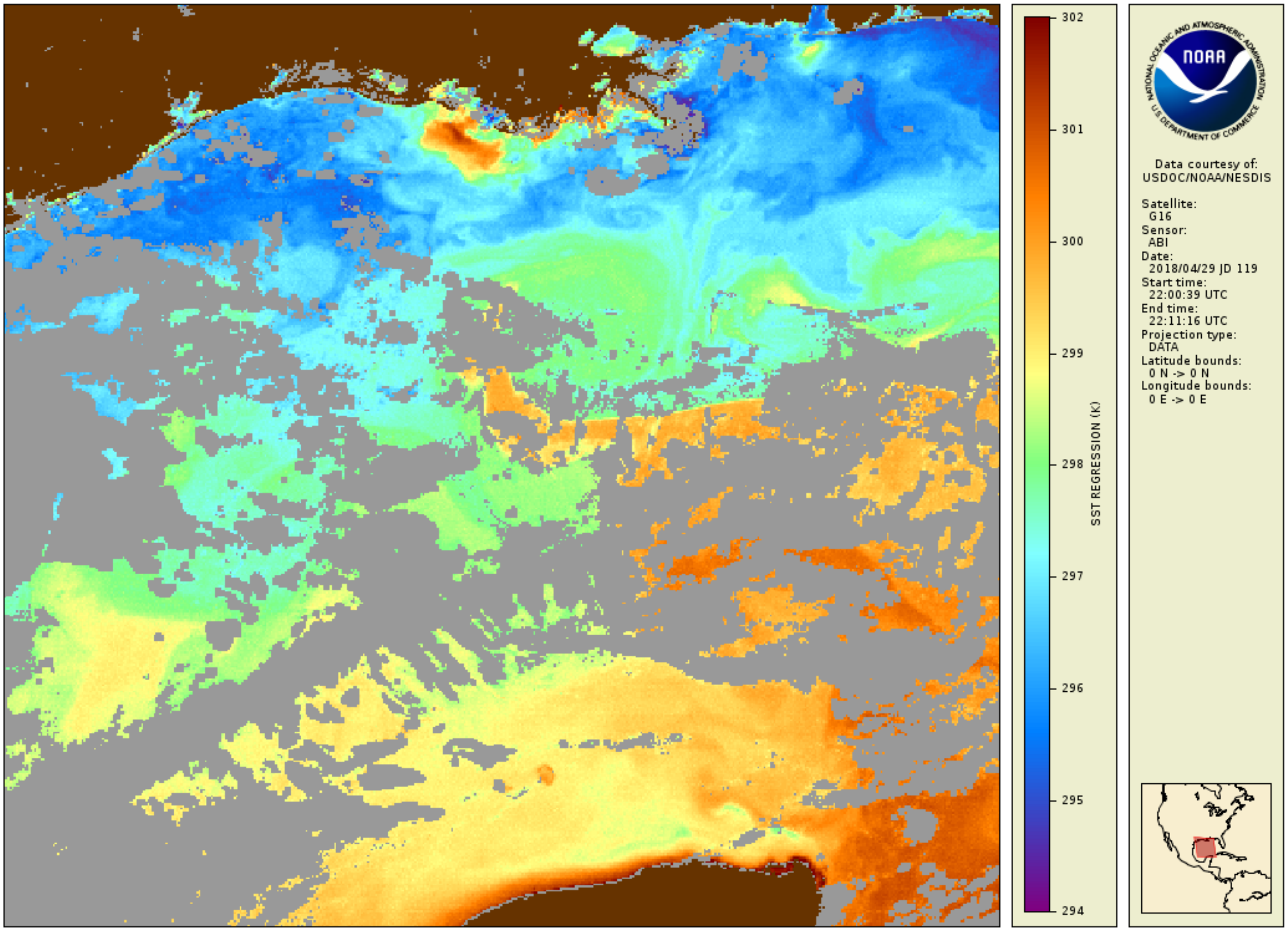
Collated Hourly L2C

Recovered dynamic region

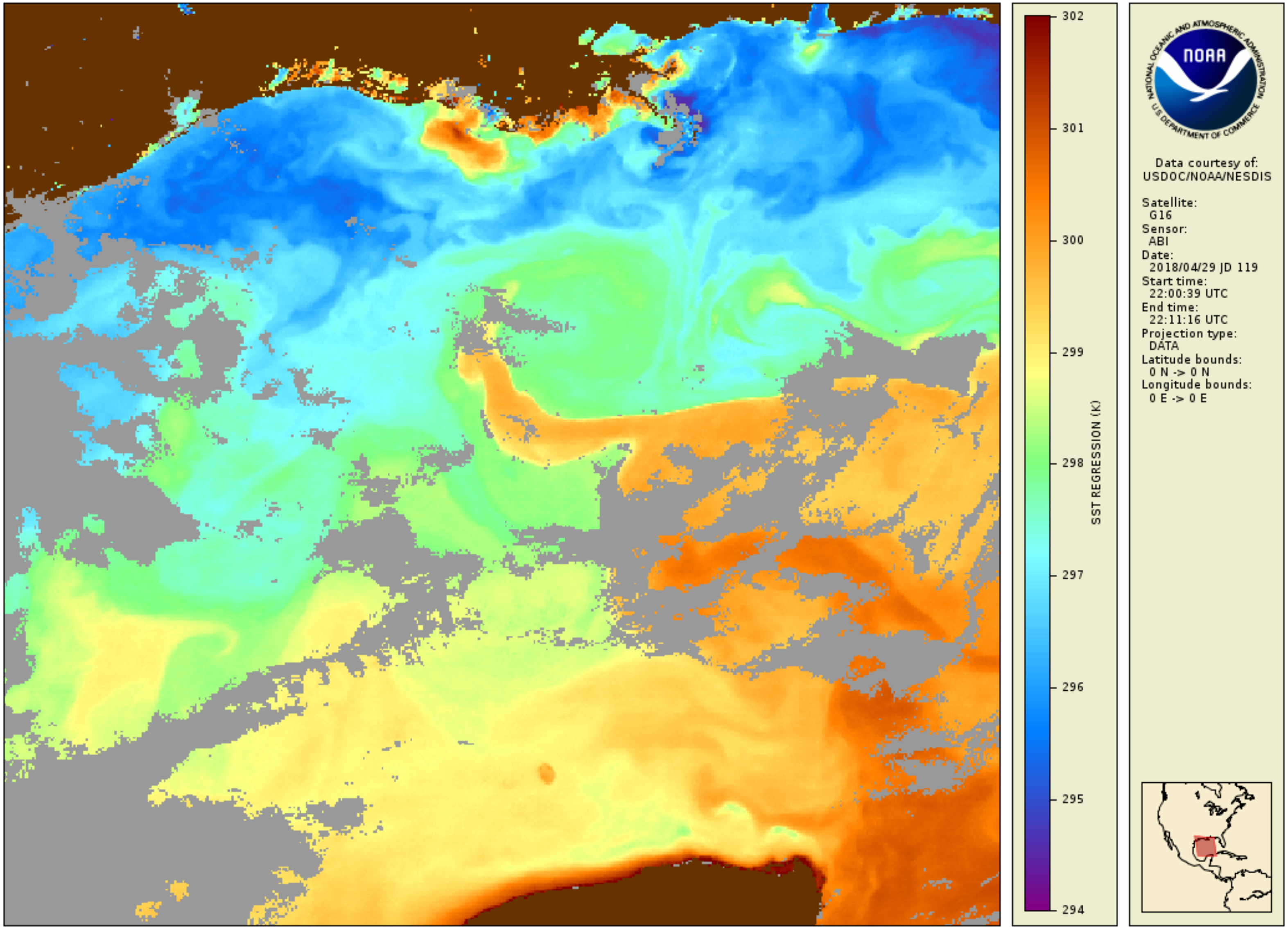
Clear-sky at least once during 1hr window



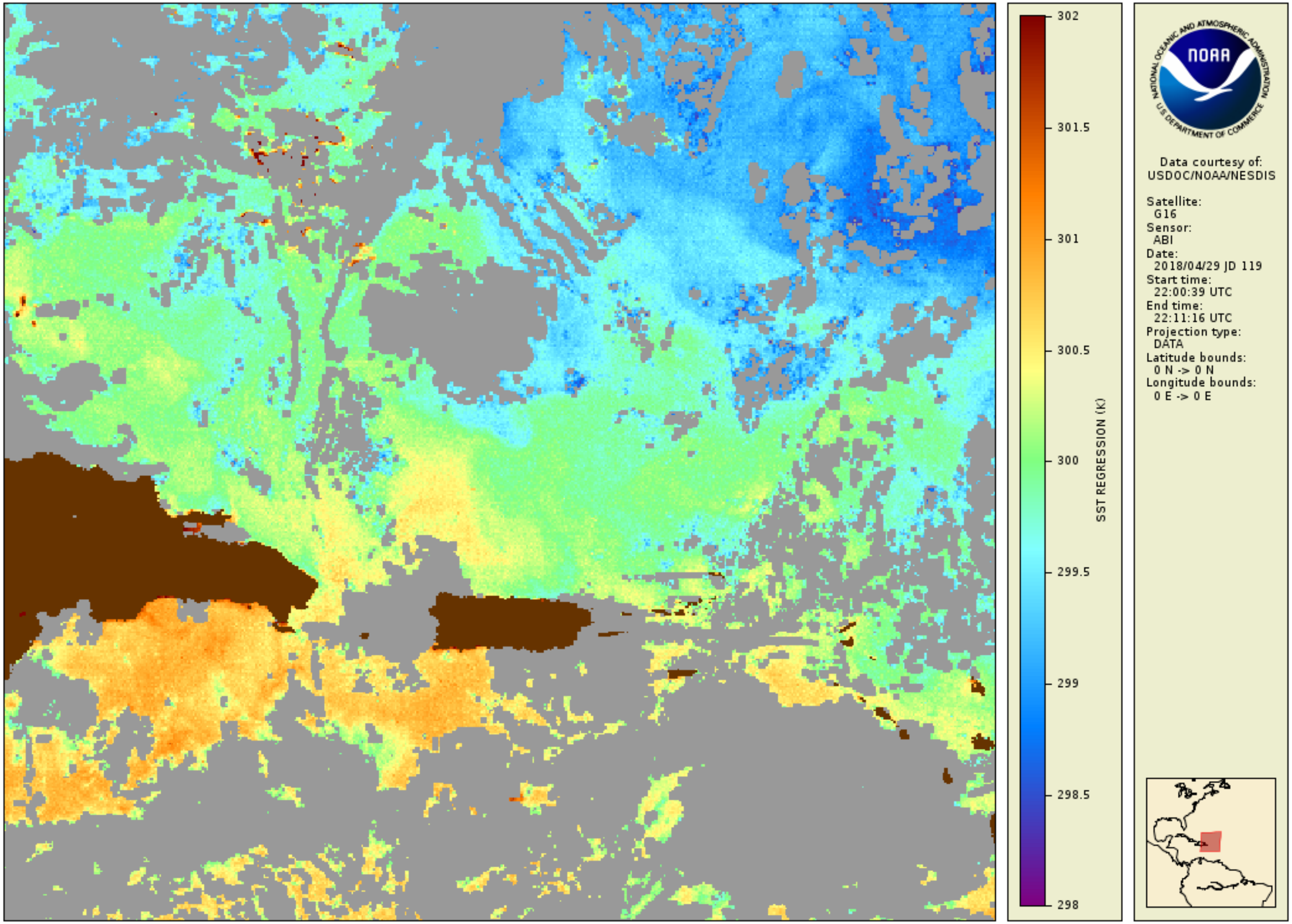
G16/ABI: L2P SST (day-time) over Gulf of Mexico



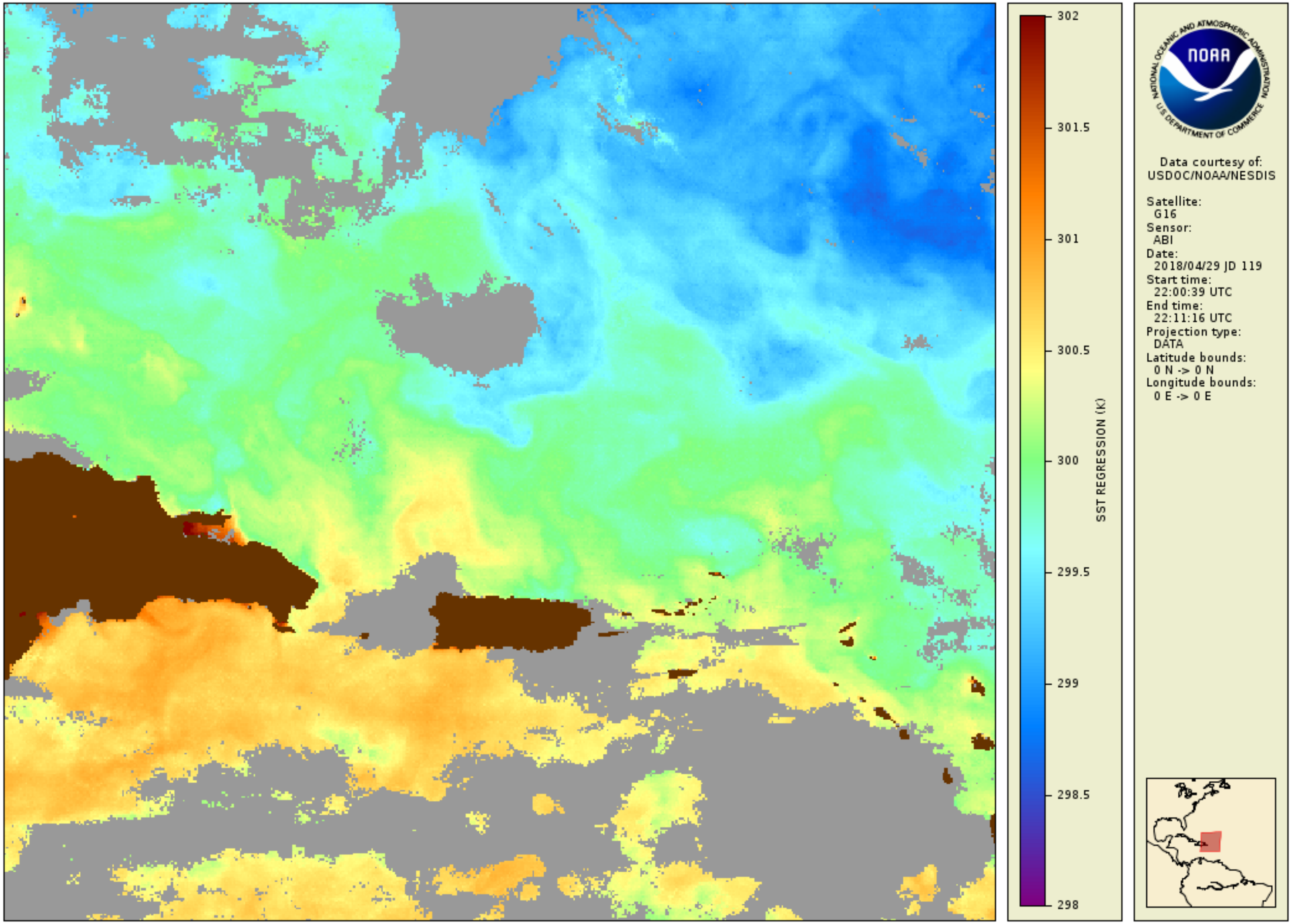
Collated Hourly L2C: Significantly larger coverage



G16/ABI: L2P SST over Caribbean (numerous small clouds)



Collated Hourly L2C: Significantly larger coverage



Monitoring the performance

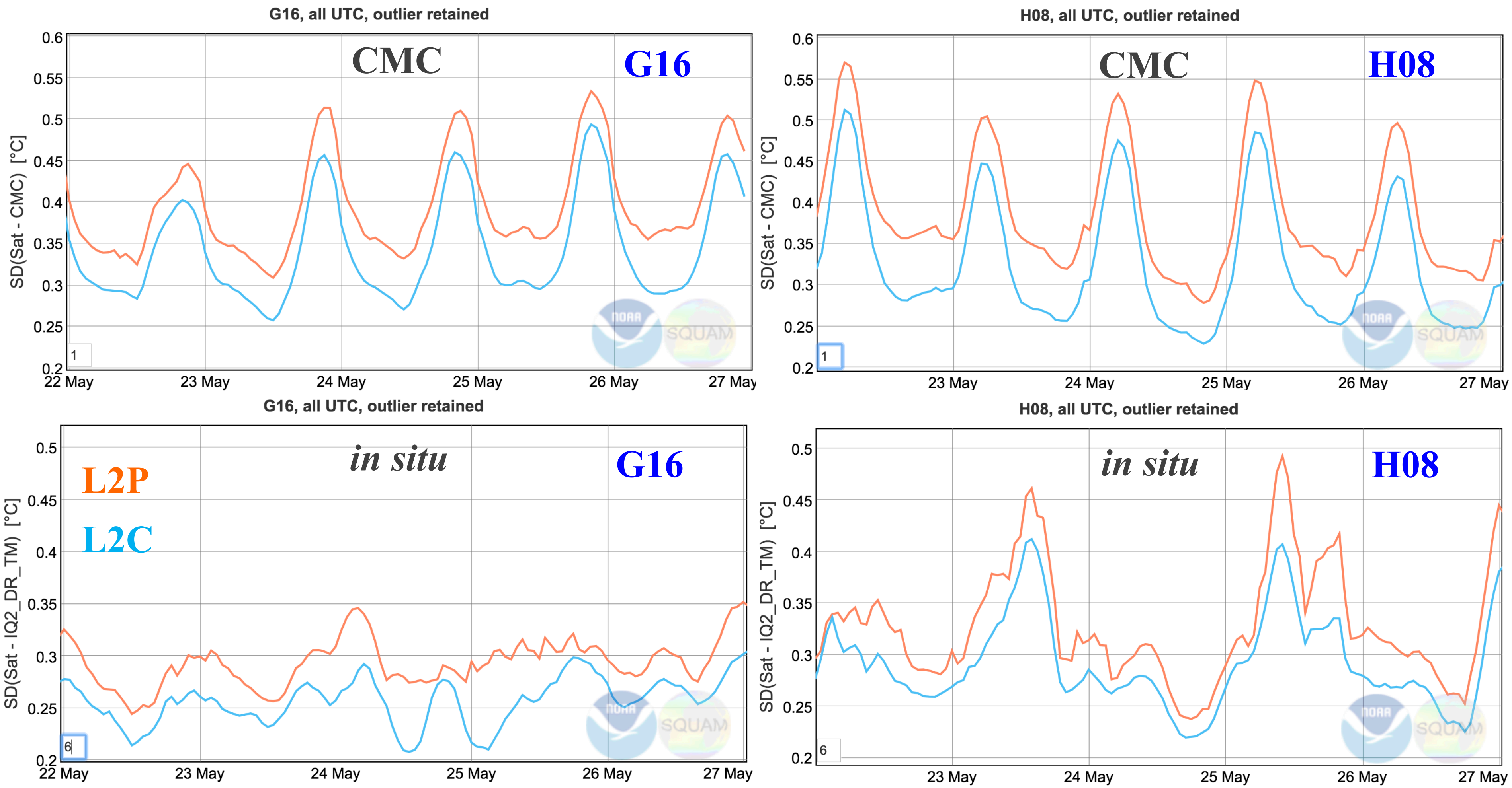
The new L2C products (both, G-16 and H-08) has been monitored and validated using NOAA SST monitoring systems (internal pages during testing stage):

- SQUAM (SST quality monitoring)
- ARMS (ACSPO regional monitor for SST)

Evaluations in SQUAM against reference (CMC) and against in situ measurements (drifters, tropical mooring buoys, ARGO floats) show the superior performance of the L2C compared to original L2P in terms of global statistics.

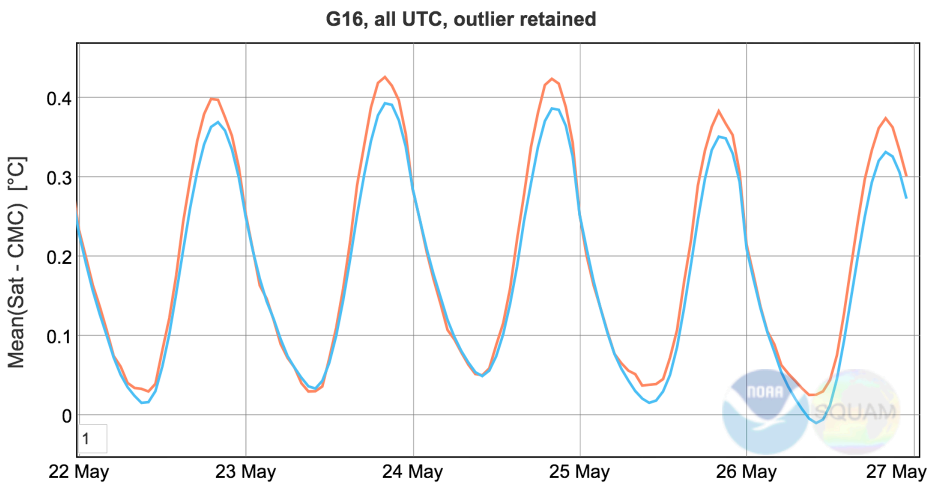
Evaluations in ARMS show improved image quality, larger (and more consistent in time) coverage and significantly smaller presence of cloud-obscured values

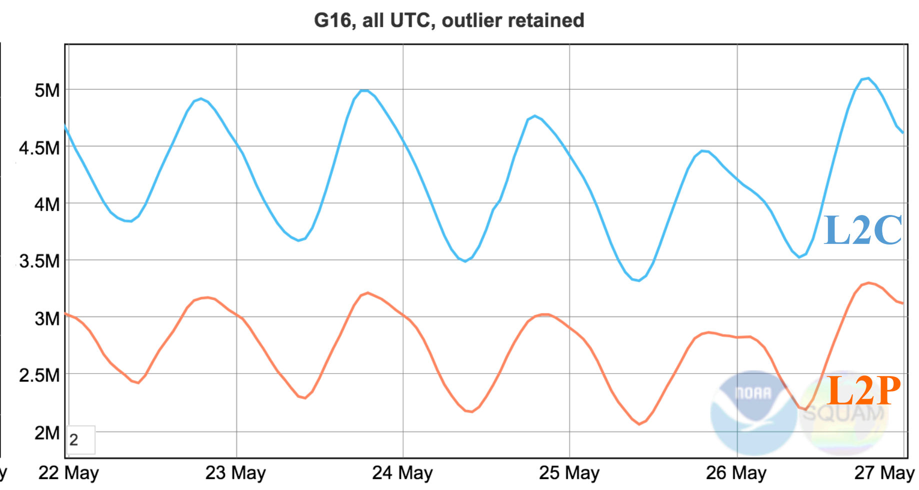
Standard deviation

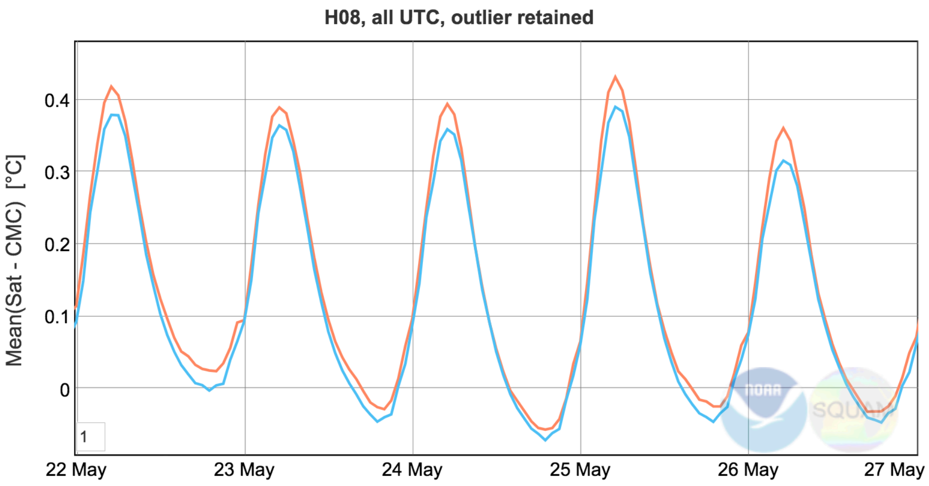


Standard deviations with respect to (top) reference (CMC) and (bottom) *in situ* measurements (drifters + tropical moorings) are consistently lower for L2C than L2P

Duirnal Cycle







- Mean difference and Standard deviation with respect to reference (CMC) retain the same diurnal shape as original L2P data.
- The coverage is ~40% larger for L2C than L2P

Options Considered

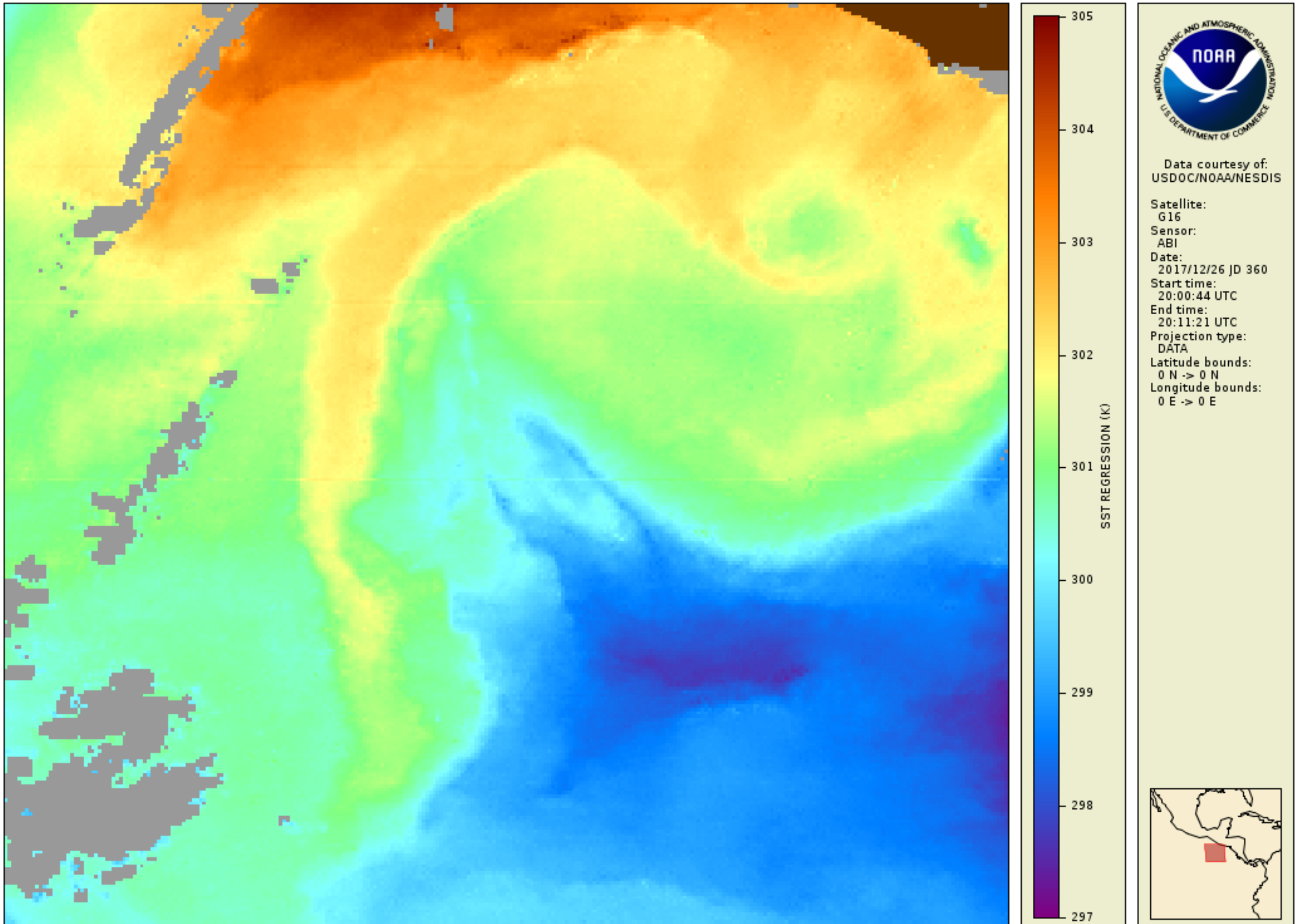
Two options were considered:

1) Collating L2P SST values
2) Collating brightness temperatures and retrieving SST from collated temperatures

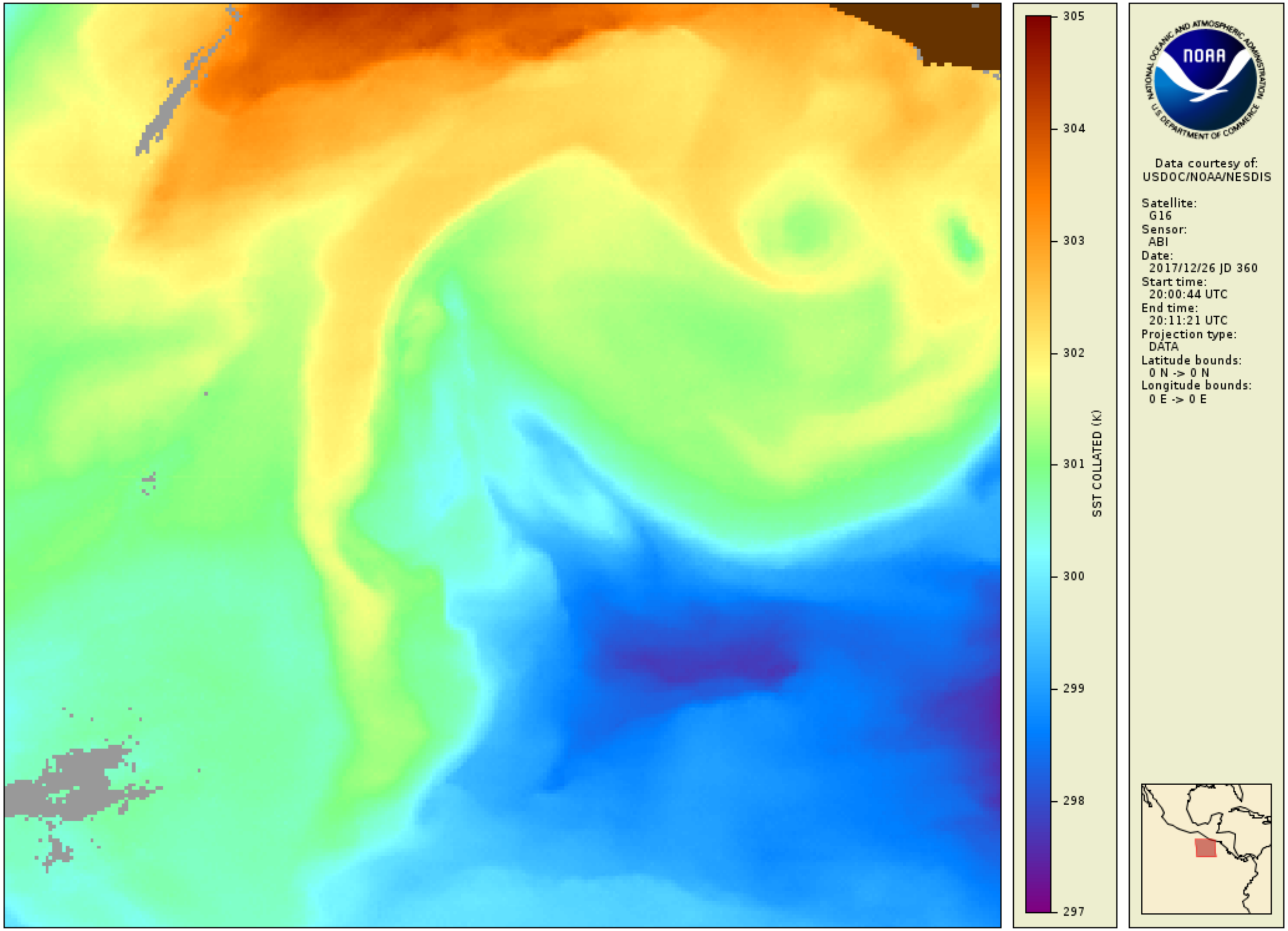
Option-2 allows estimation of SSES bias and standard deviation while the first version (Option-1) only provided L2C SST and brightness temperatures computed independently.

Retrieving SST from collated BT's required new set of coefficients, which at some point were calculated and now used to produce L2C SST.

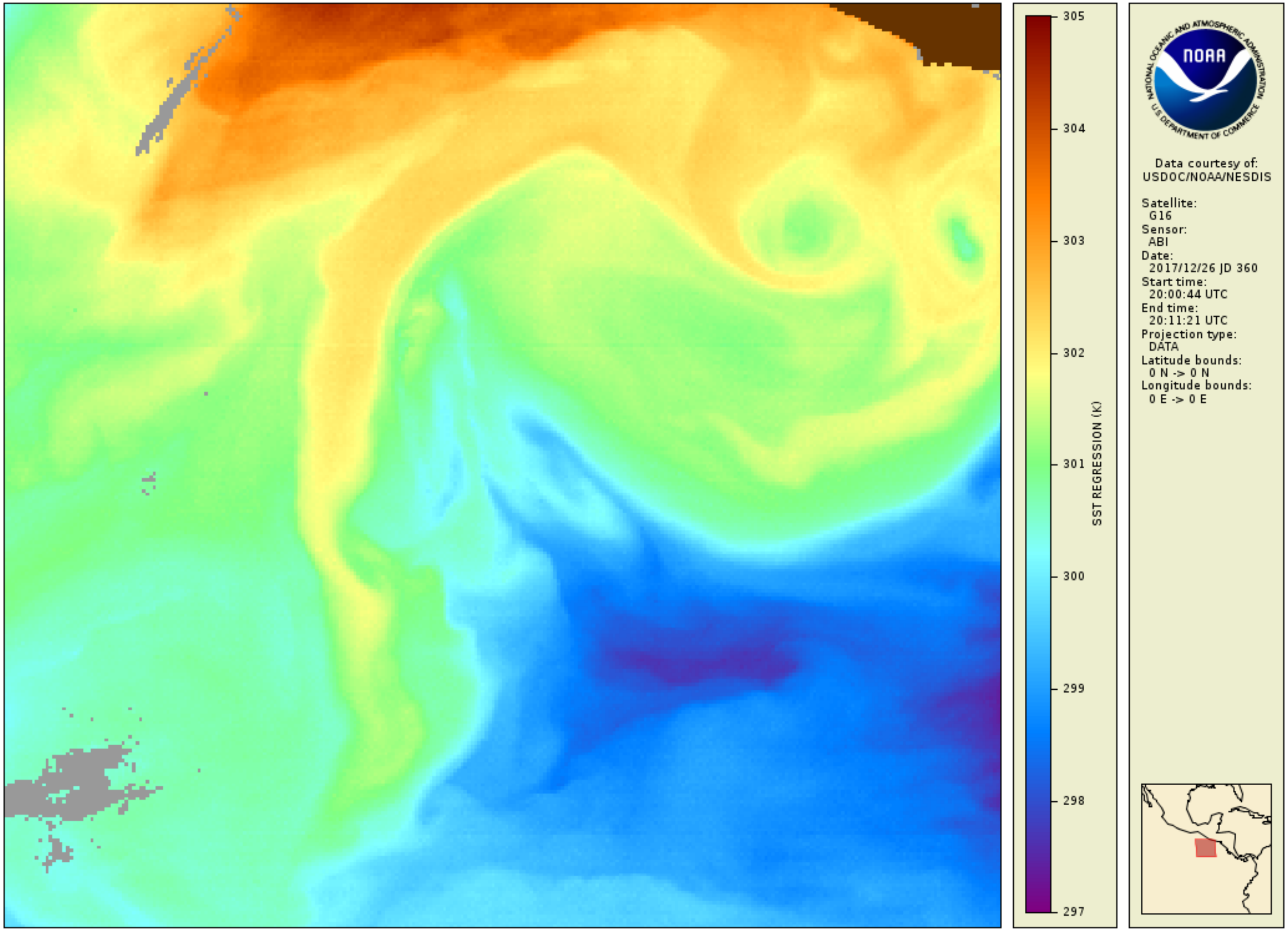
Original L2P



L2C SST Collated directly from L2P

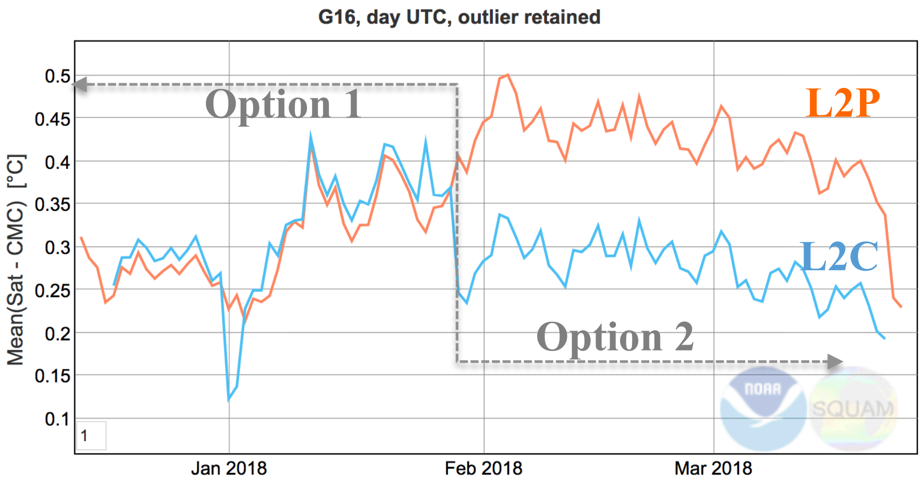


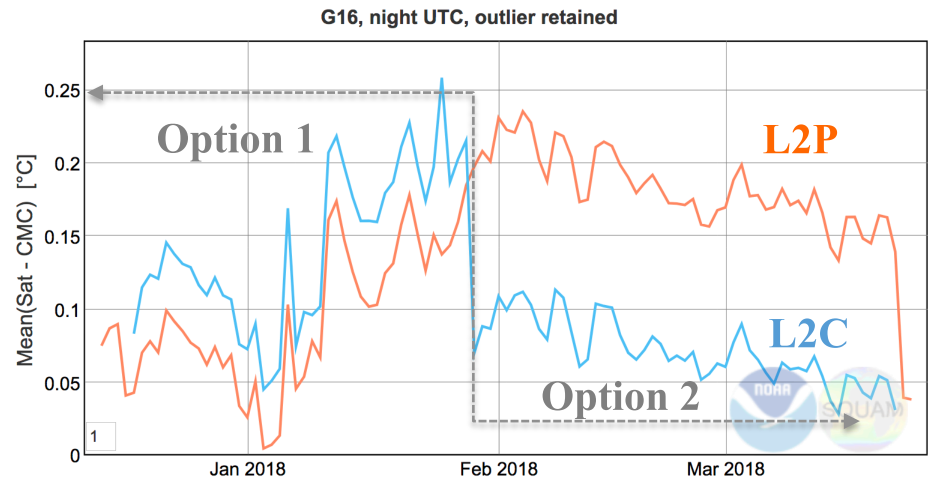
L2C SST's retrieved from collated Brightness Temperatures



Option1: Collating L2P SST values;

Option2: Collating BT's and retrieving SST from collated temperatures

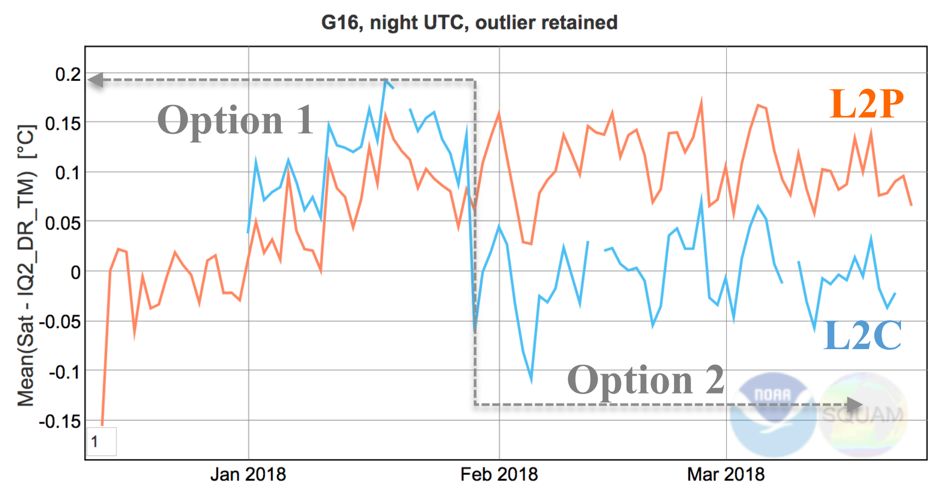




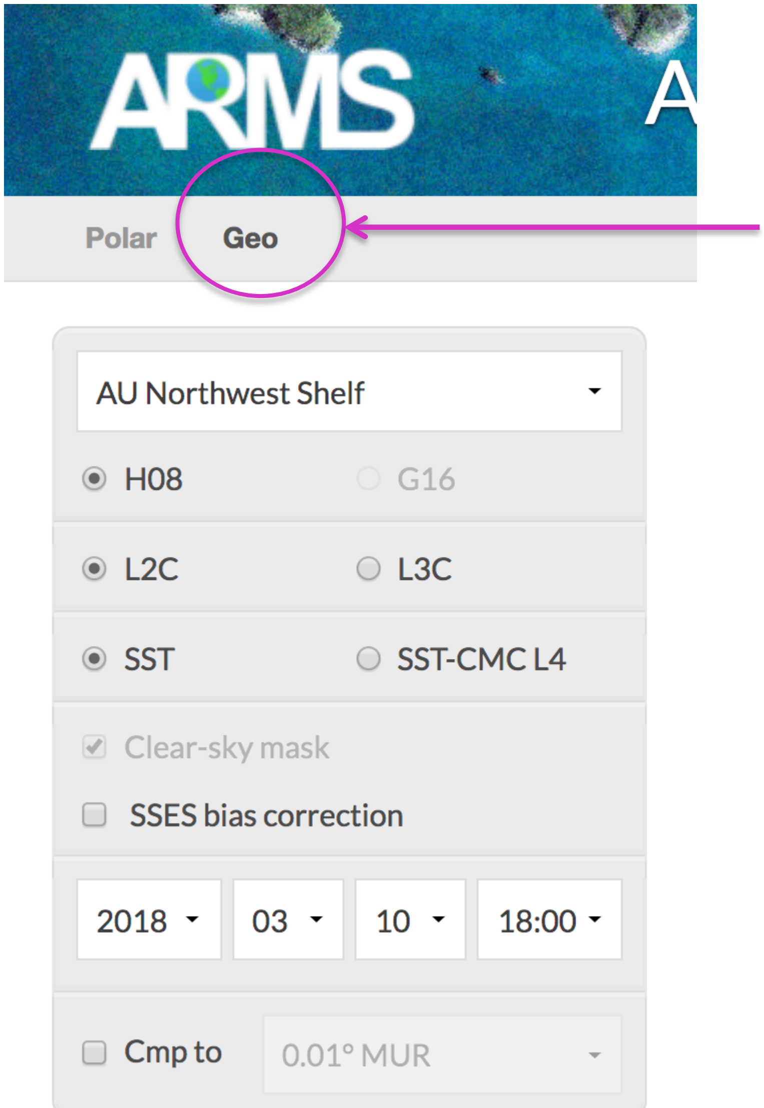
Collated SSTs were warmer than L2P, due to less contamination by residual cloud

NLSST using collated BT's needs a different set of coefficients

Mean difference became consistently lower for L2C, after coefficients were recalculated



Evaluating image quality (regional scale)



ACSPO Regional Monitor for SST (ARMS) has been updated to include evaluation of the geo SSTs

New features, such as “play movie” button for geo platforms allows to evaluate temporal consistency of L2C product

Advantages of the collated products are especially visible in the regions with persistent small, scattered clouds

Conclusion

- We have developed and implemented a geo collation algorithm, which employs a combination of various time-space windows, to better discriminate clear sky from cloud-obscured observations, and to more accurately identify valid SST retrieval domain
- Several adjustments have been made to the initial design, resulting in more robust and faster performance
- The generated collated L2C product has been added to NOAA monitoring systems and performs better than the L2P

Future Work

The major issue that needs to be addressed in the future is:

- Massive false alarms (large clear sky regions, screened out by the current ACSPO L2P mask) results in a significant data loss in dynamic/coastal regions
- The large lost areas cannot be restored by the L2C
- The false alarms are mainly due to threshold-based decisions, based on comparison with daily L4s which
    - Do not resolve diurnal cycle
    - Have much cruder spatial grid than satellite pixels
    - Have even cruder feature resolution than stated grid size

Rethinking/Reevaluation of the current ACSPO L2P clear-sky mask as initial seed into the algorithm, may be needed