EARTH SYSTEM SCIENCE
INTERDISCIPLINARY CENTER

Evaluation of the potential of Sentinel-3 SLSTR data for bias correction of NOAA's high-resolution global sea surface temperature analysis

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Satellite-based SST Analyses

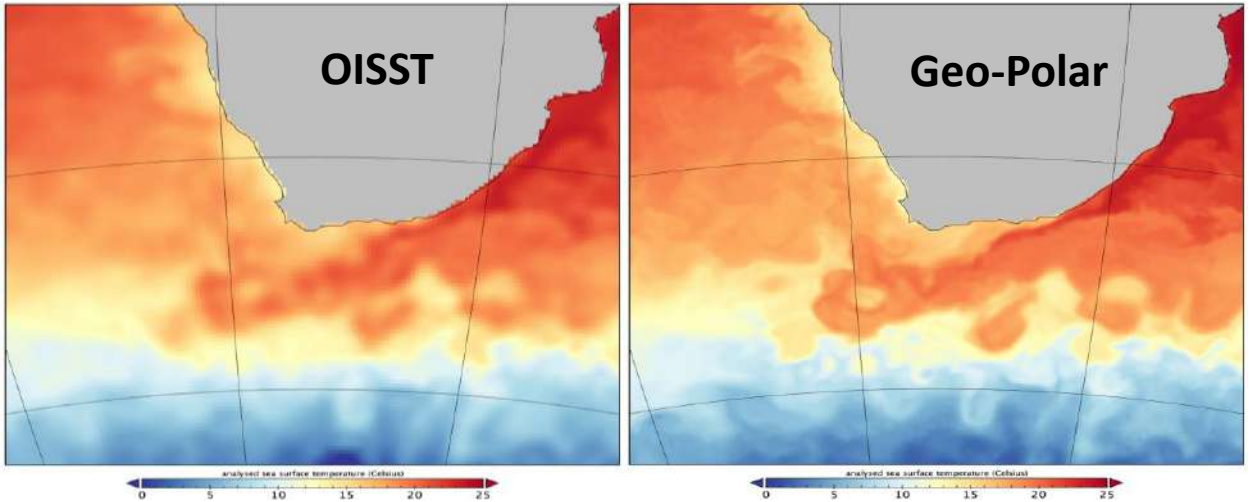
- A key geophysical parameter in a **convenient format**
  - Reduces many millions of satellite observations onto a regular global grid
  - Ranked as the most important oceanographic variable
- Wide range of downstream applications
  - Climate, environmental monitoring, forecasting, ecology, etc.
- Similar SST analyses are produced by a substantial number of national agencies
  - Some agencies produce more than one flavor, e.g. NOAA (Extended Reconstruction Analysis, Daily Optimal Interpolation SST, Geo-Polar Blended, Near-Surface Sea Temperature)
  - Different resolutions (or rather grid spacing…)

Geo-Polar Blended SST

- **1/20° analysis produced daily from 24 hours of Polar- & Geo-SST**
  - MetOp-B,C AVHRR, S-NPP & N20 VIIRS
  - GOES-E/W Imager (75°W, 135°W), Himawari-8/9 Imager (140°E), Met-8/11 SEVIRI (41.5°E, 0°E)
  - **Does not use buoy data**
- **Multi-scale OI –** Mimics Kalman Filter (*Khellah et. al., 2005*)
- **3 stationary priors –** Short, intermediate and long correlation lengths, interpolation based on local data density **allows fine resolution where possible without introducing noise**

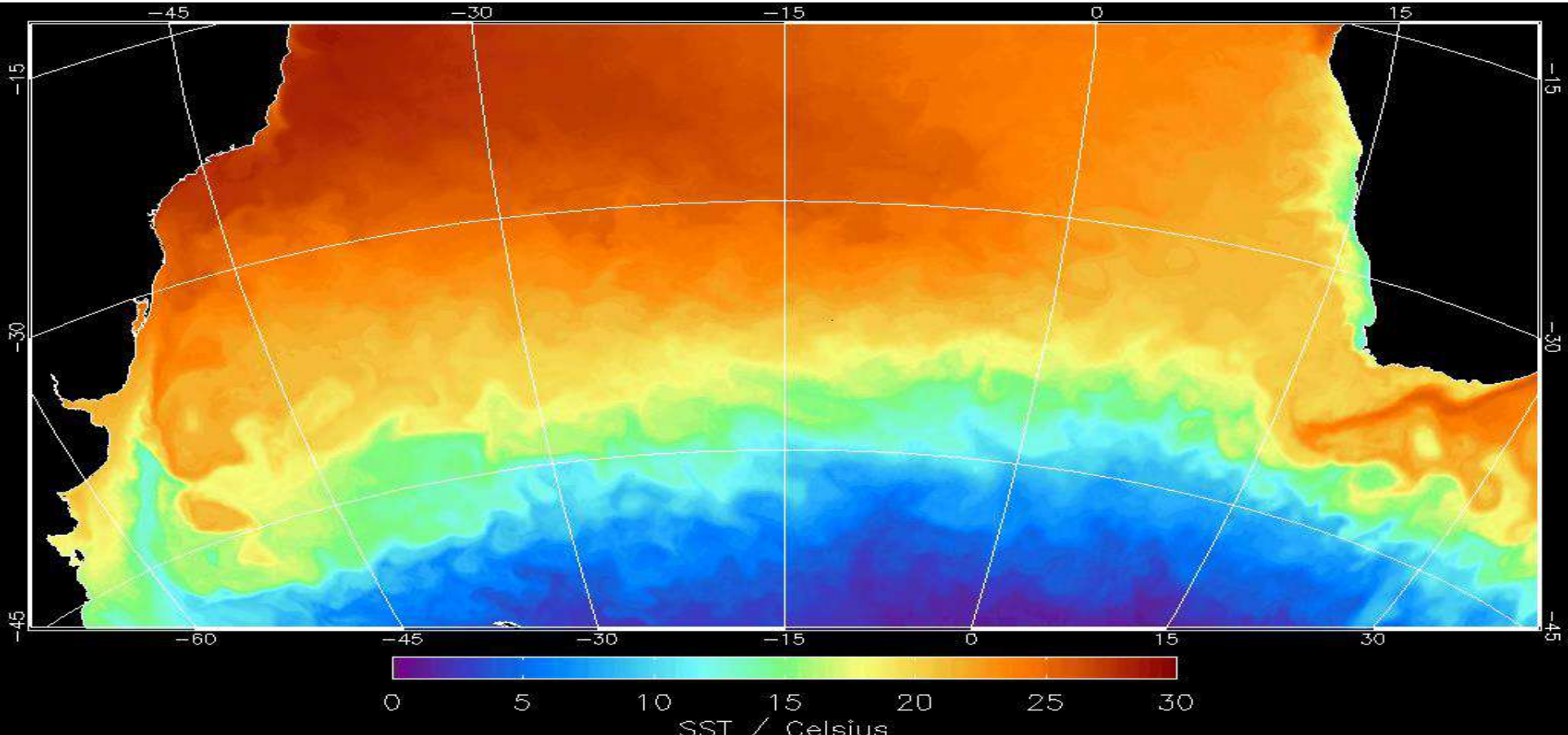
***Cf.* NOAA "Daily-OI"**
- ¼°, only AVHRR
- Ingests buoy+Argo
- ~40 year record
- **Widely cited**

GPB source dataset for CRW 5-km product suite



Ser

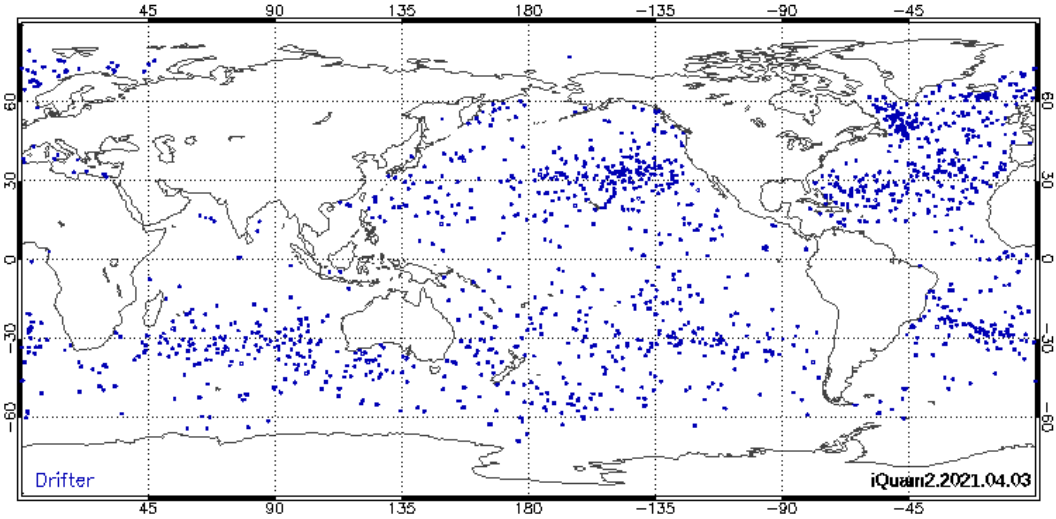
GPB Product Example



Key Challenges

- Many millions of satellite observations dominate the record
  - *Cf*. *in situ* is a few thousand buoy observations per day
- Satellite instruments don't measure SST, they retrieve it
  - **Retrievals have spatiotemporal biases**
- Traditional correction uses widely-spaced in situ as reference (e.g. Daily-OISST)

Drifting buoys



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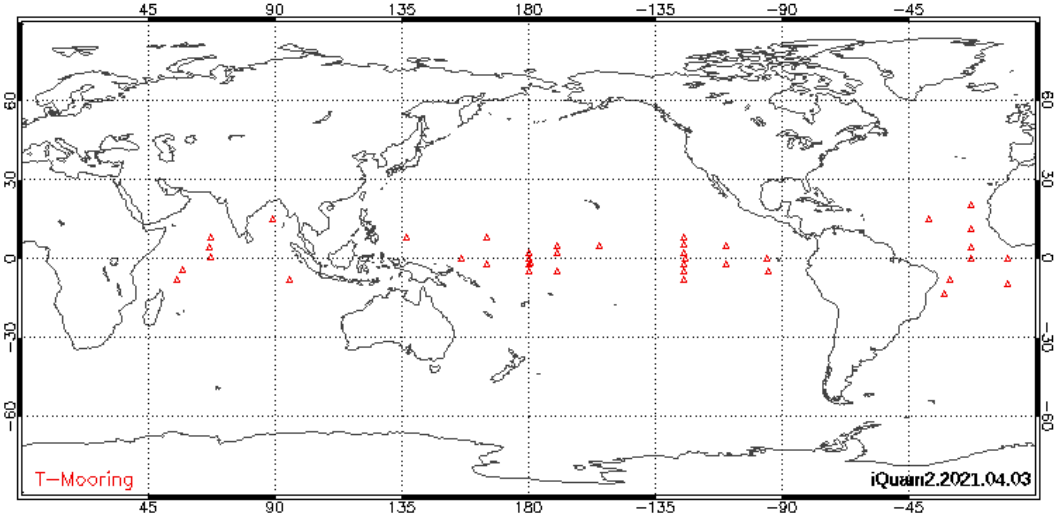
Tropical moorings



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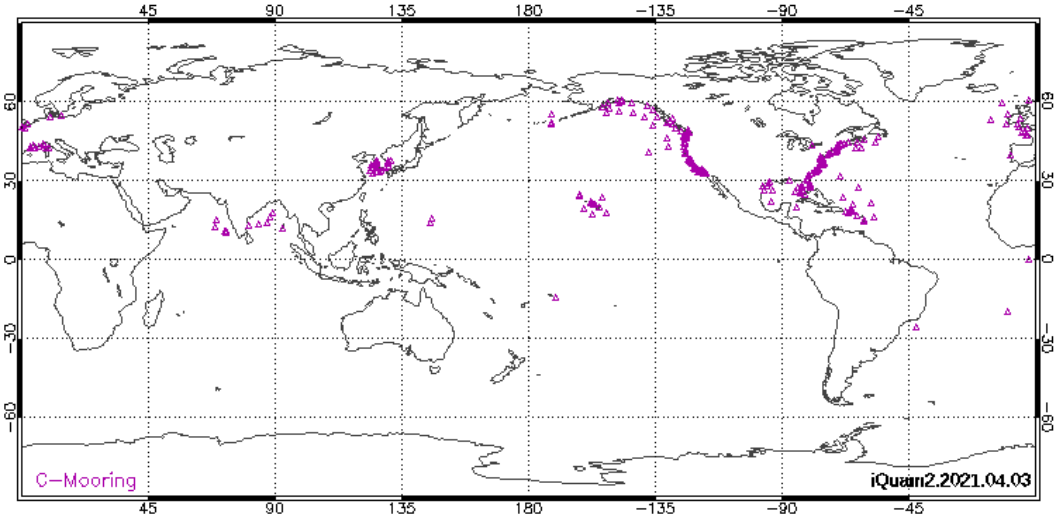
Coastal moorings



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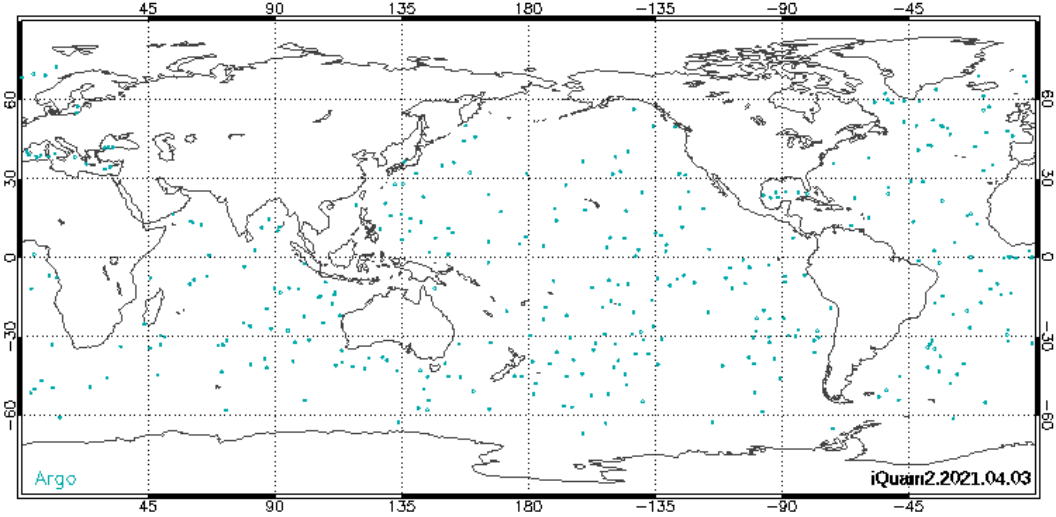
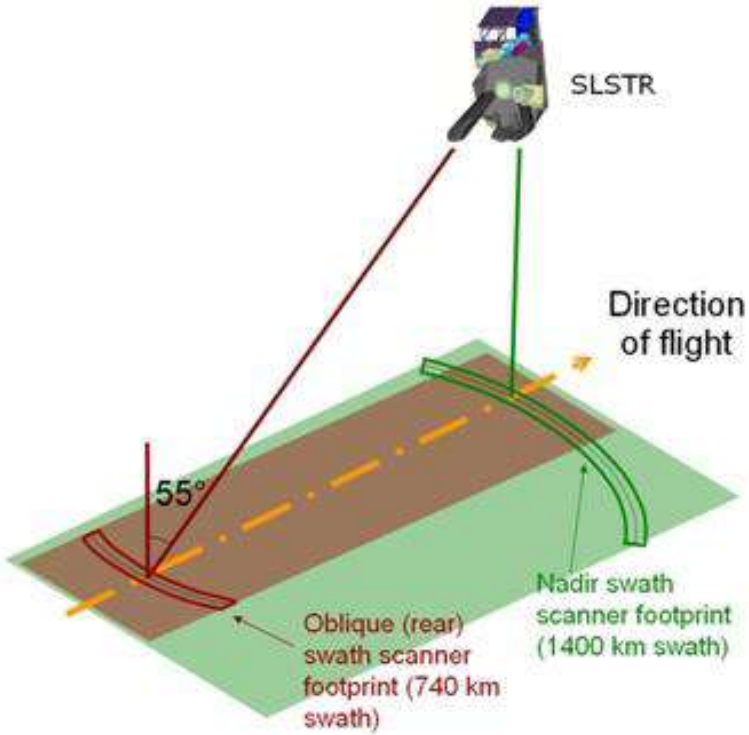
Argo floats



SLSTR: a climate quality reference

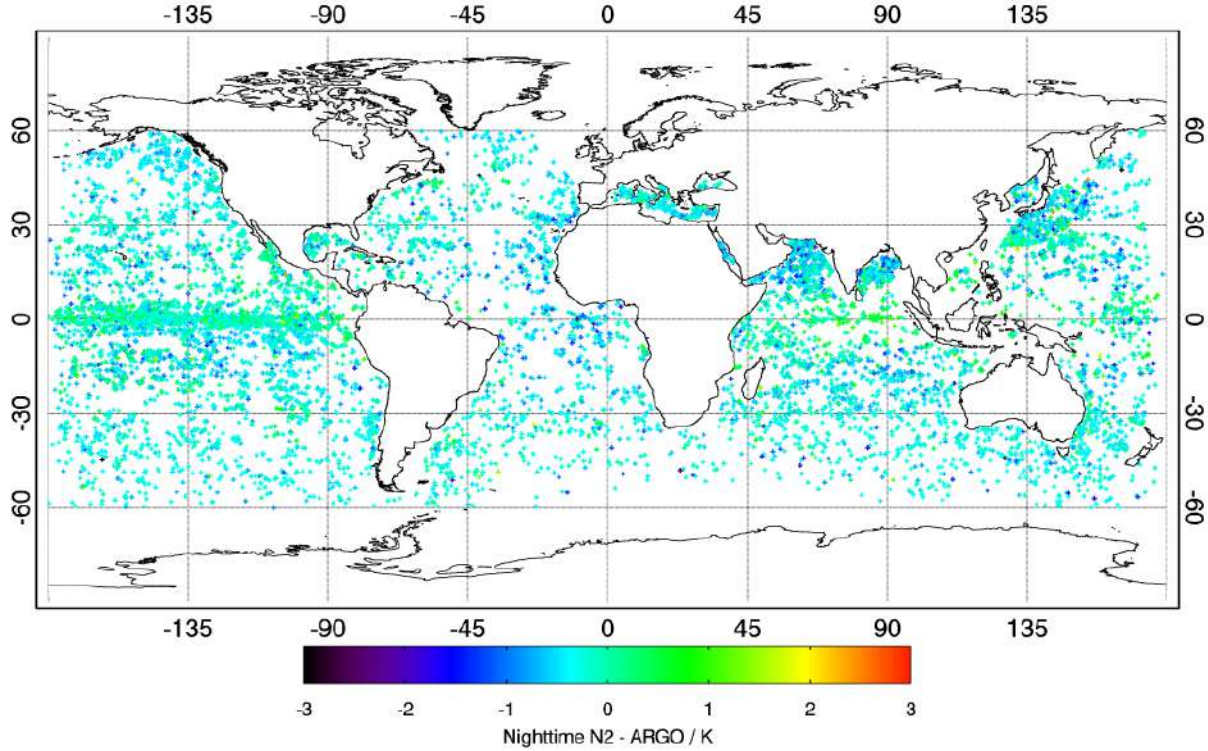
- SLSTR – continuation of (A)ATSR series
- Instrument characteristics
  - Dual-view to provide robust & accurate SST
  - Highly accurate thermal calibration (<0.03 K/decade)
  - Low thermal detector noise due to active cooling
- 4 different products/algorithms
  - Nadir 2-channel (N2), Nadir 3-channel (N3)
  - Dual 2-channel (D2), Dual 3-channel (D3)
- **Validation *vs.* Argo**



Nighttime N2 – S3A SLSTR

Warm bias in tropics

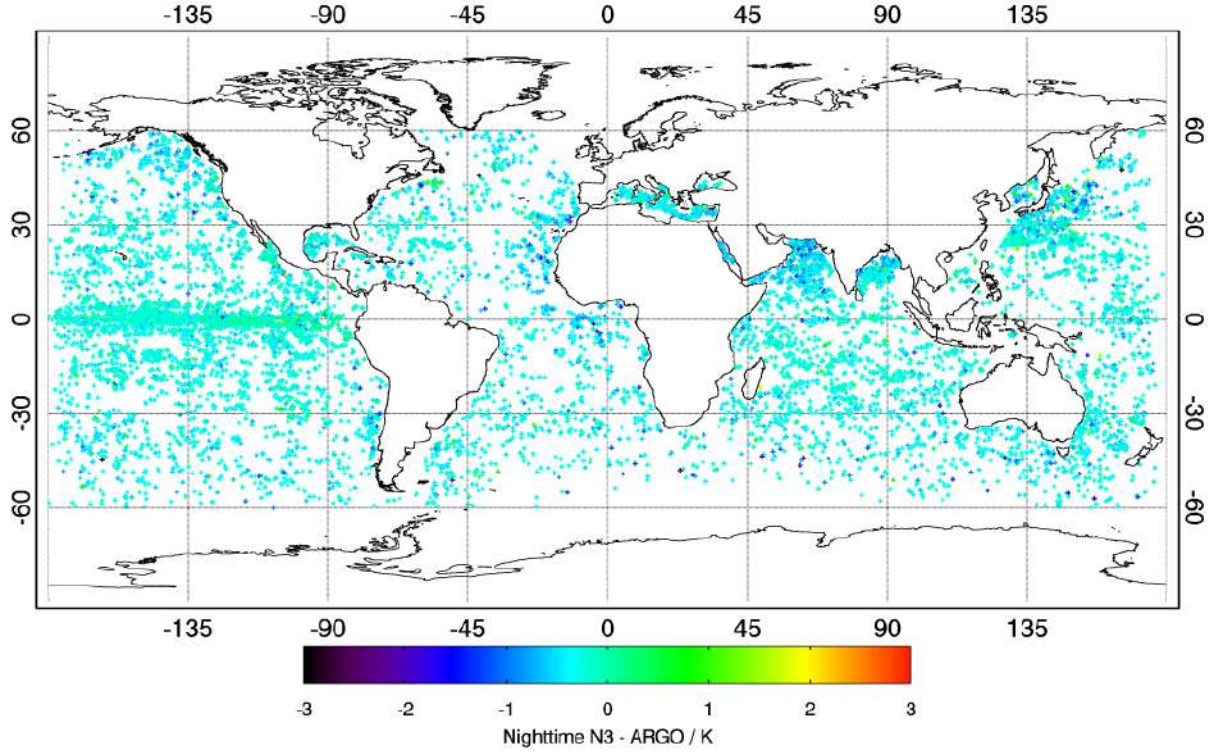
Cool aerosol bias evident



Nighttime N3 – S3A SLSTR

Reduced regional differences

Some aerosol-related bias still evident

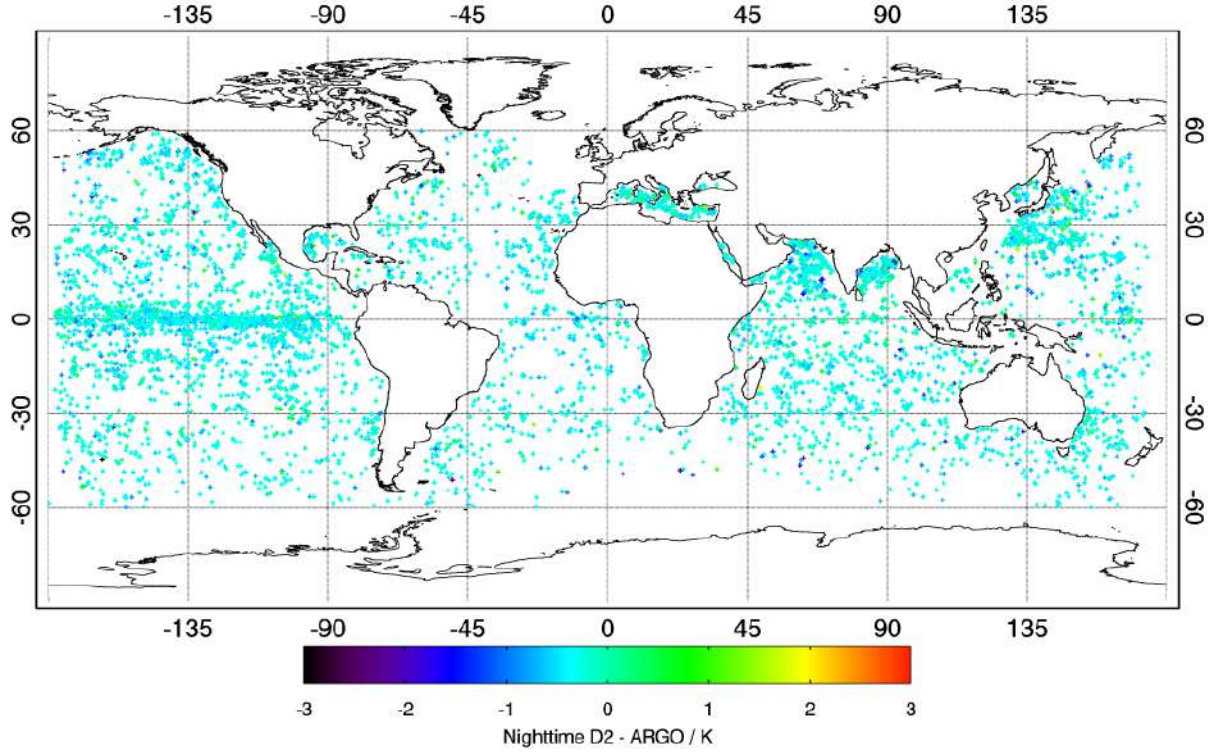


Nighttime D2 – S3A SLSTR

Fewer matches (narrower swath)

Greatly reduced aerosol-related bias

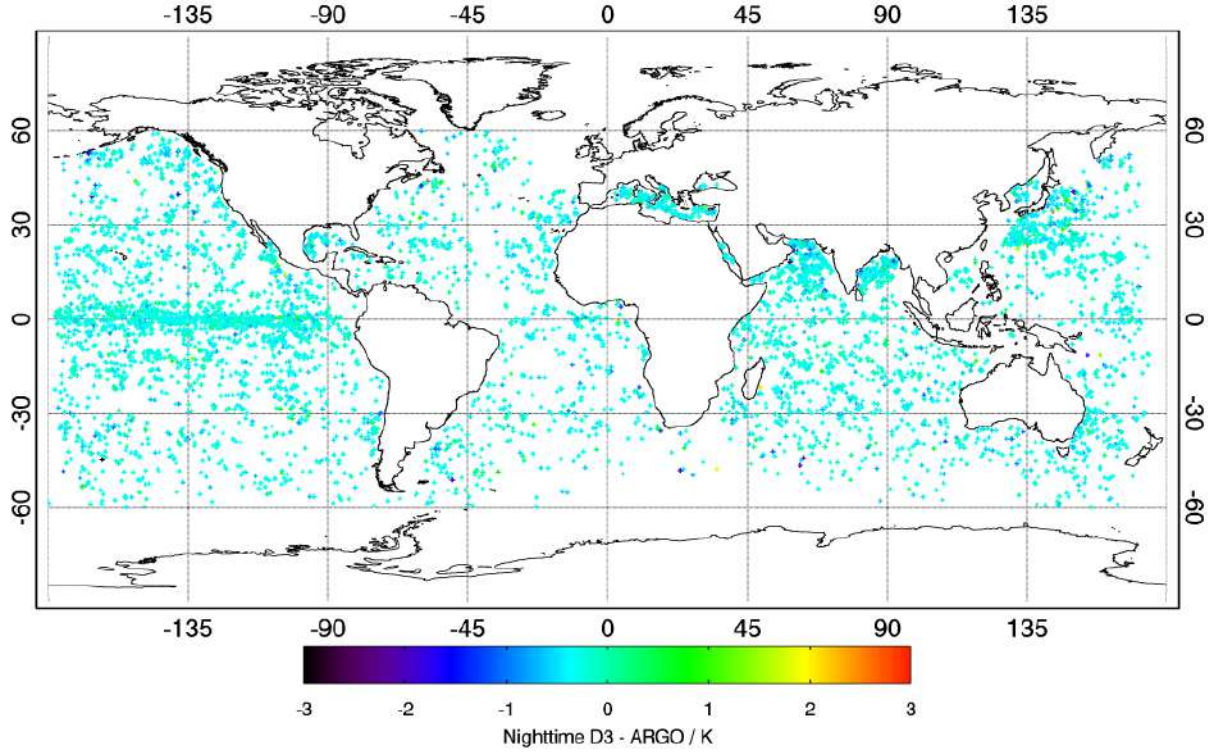
Still some regional biases



Nighttime D3 – S3A SLSTR

Issues largely resolved

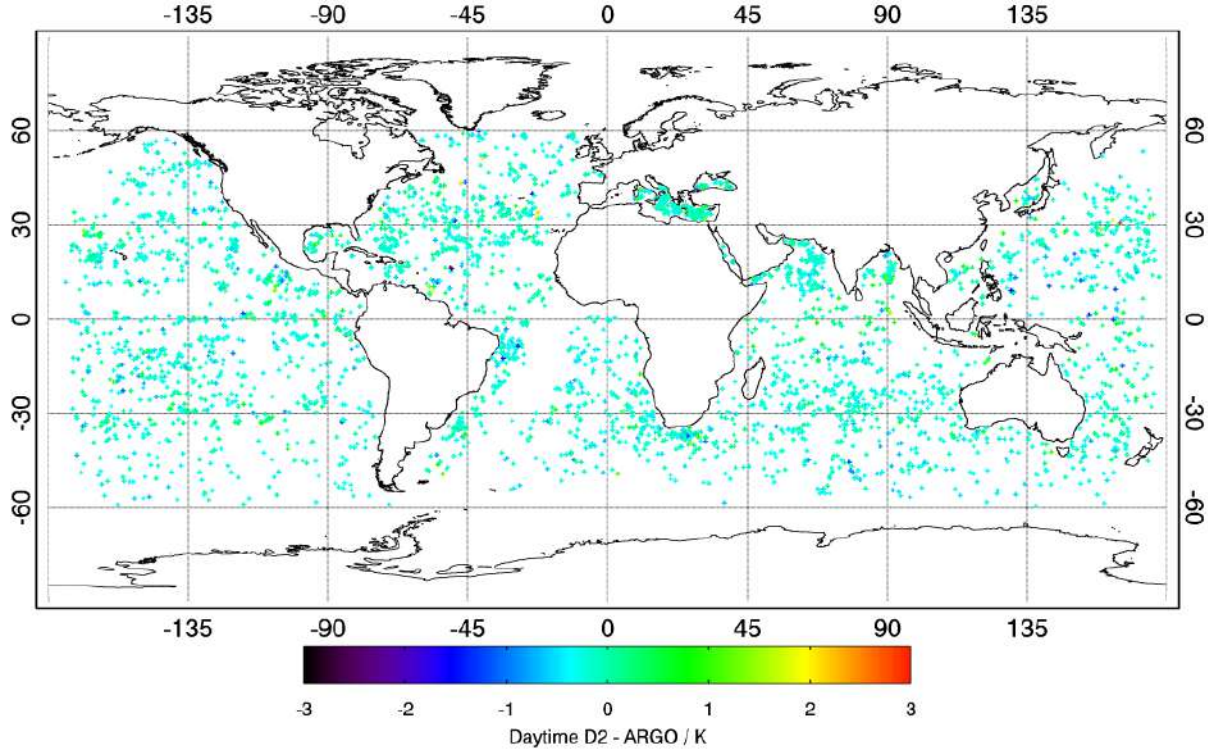
Low noise



Daytime D2 – S3A SLSTR

Subtle regional biases still evident

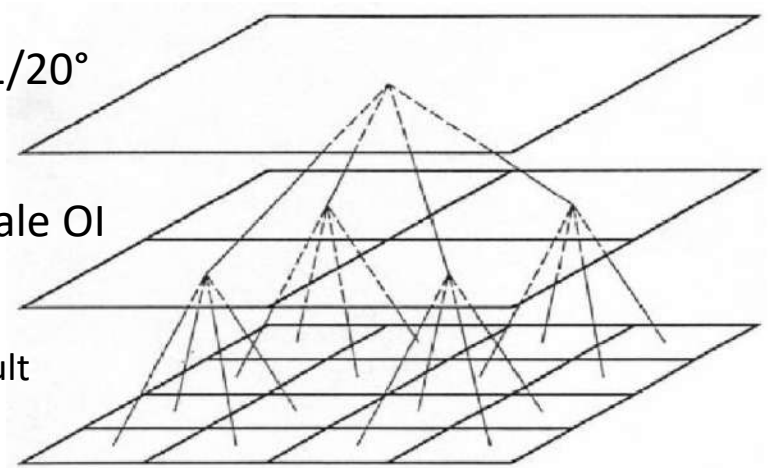
Aerosol issue largely managed



Estimation of bias w.r.t SLSTR

- Use night (D3) and day (D2) S3A & S3B SLSTR (*i.e.* 4 reference datasets)
  - Superob each onto individual 1/20°×1/20° grids
  - Screen daytime obs wind<5 $m.s^{-1}$
- Superop each trial dataset onto individual 1/20°×1/20° grids
  - **N20 VIIRS**, **MetOp-B/C AVHRR**, day & night
- Superob differences at 1/20° and perform multiscale OI on 1/4° grid
  - Match @1/20° to minimize representativeness issues
  - Stationary priors at 2°, 6°, 12° and interpolate final result based on local observation density
  - Allows “fine” bias correction where data can support it
  - Add thinned (1°×1°) low-weight bias from previous day, relaxed to zero by a factor of 0.9

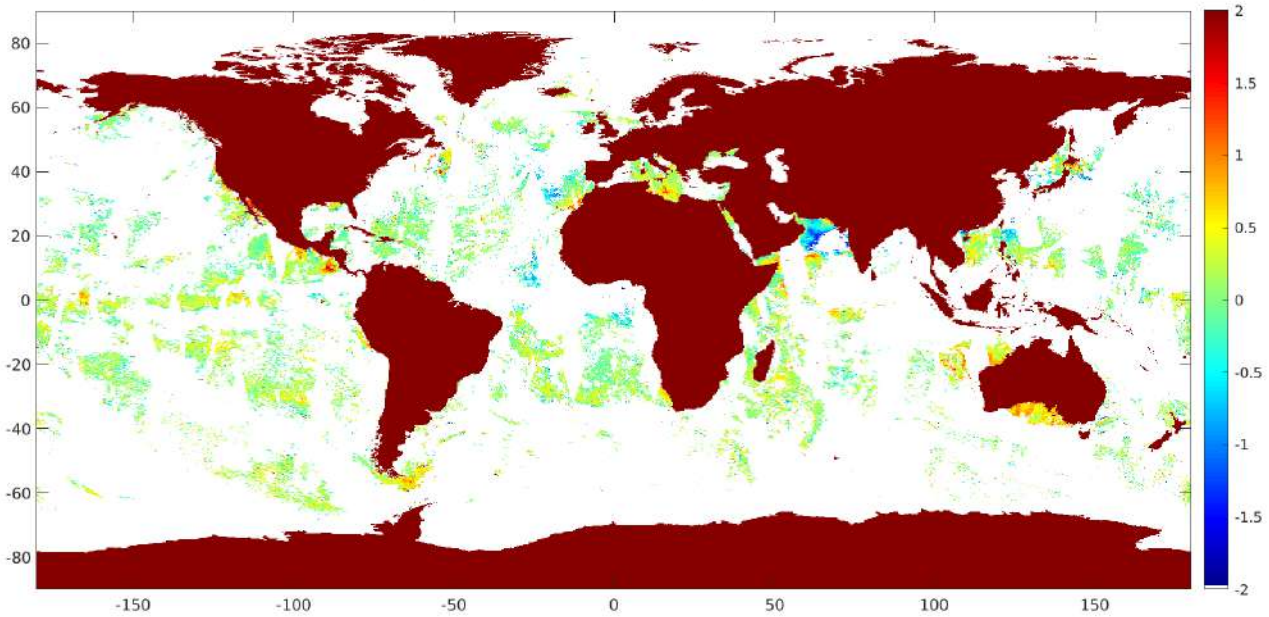
Quad-tree multiscale OI for speed



Examples of bias w.r.t SLSTR

MetOp-B – SLSTR A/B day+night

MetOp-B Daytime April 1st 2021

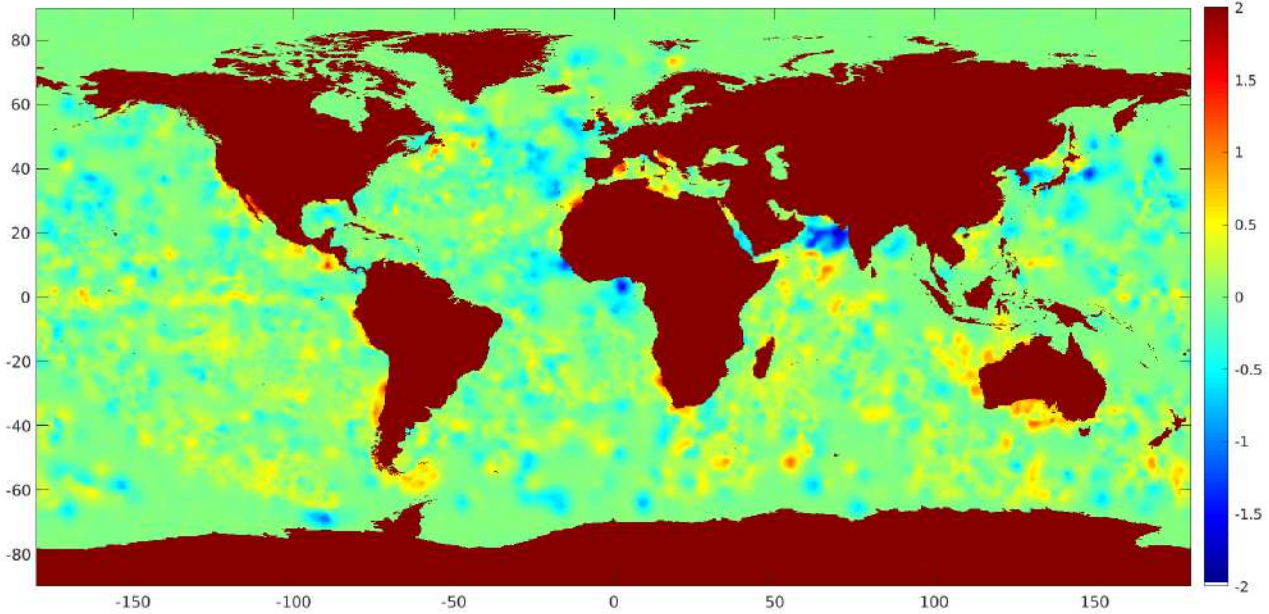


Examples of bias w.r.t SLSTR

MetOp-B – SLSTR A/B day+night

Estimated bias

MetOp-B Daytime April 1st 2021



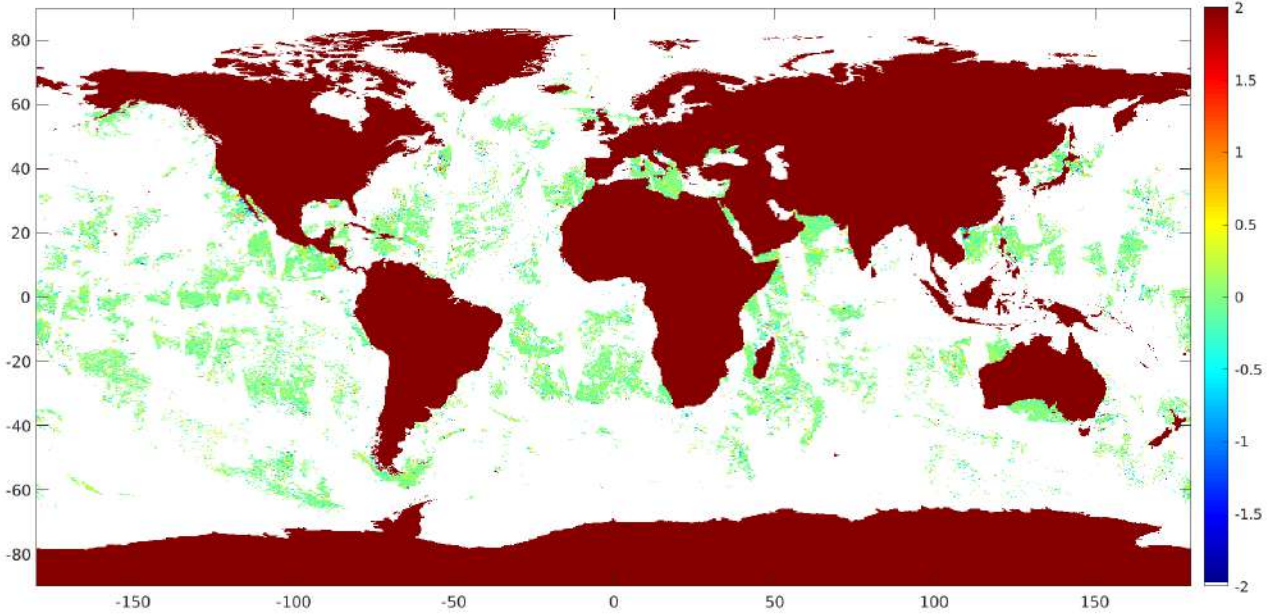
Examples of bias w.r.t SLSTR

MetOp-B – SLSTR A/B day+night

Estimated bias

Corrected MetOp-B - SLSTR

MetOp-B Daytime April 1st 2021



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Estimated bias

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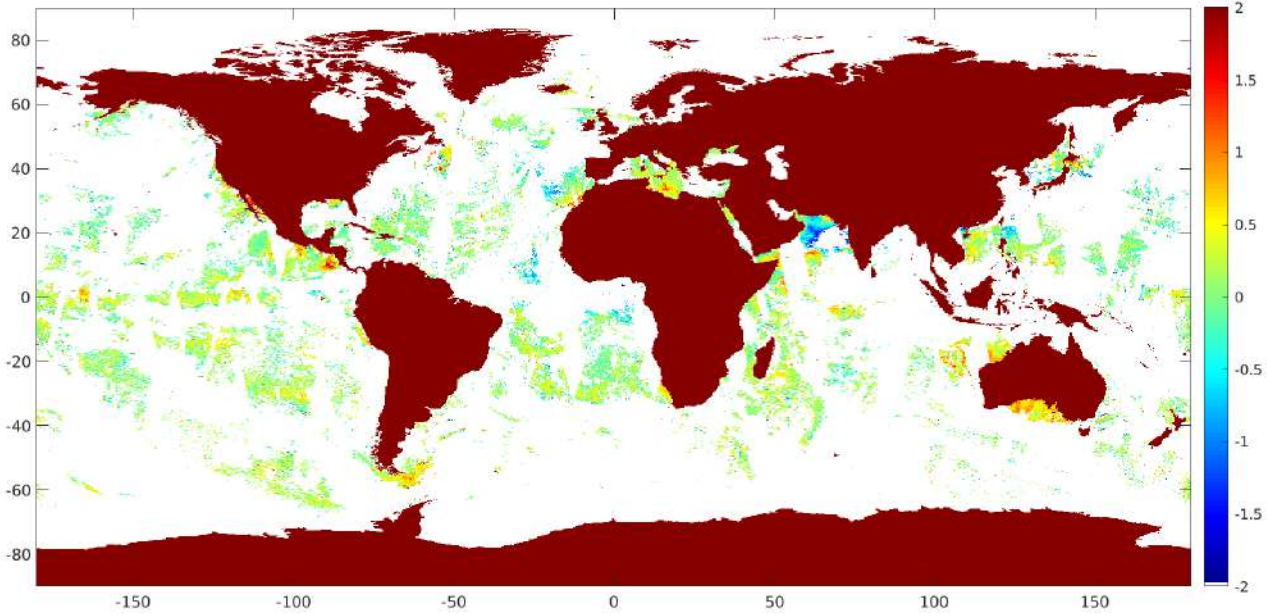
MetOp-B Daytime April 1st 2021



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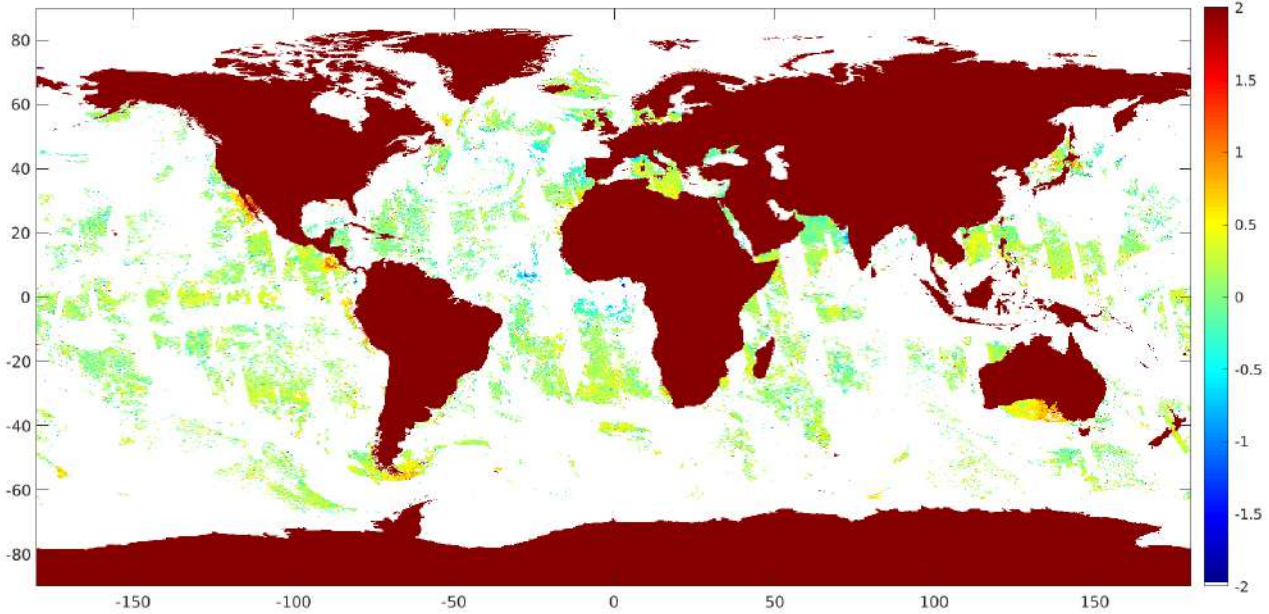
MetOp-B – SLSTR A/B day+night

MetOp-B Nighttime April 1st 2021



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Estimated bias

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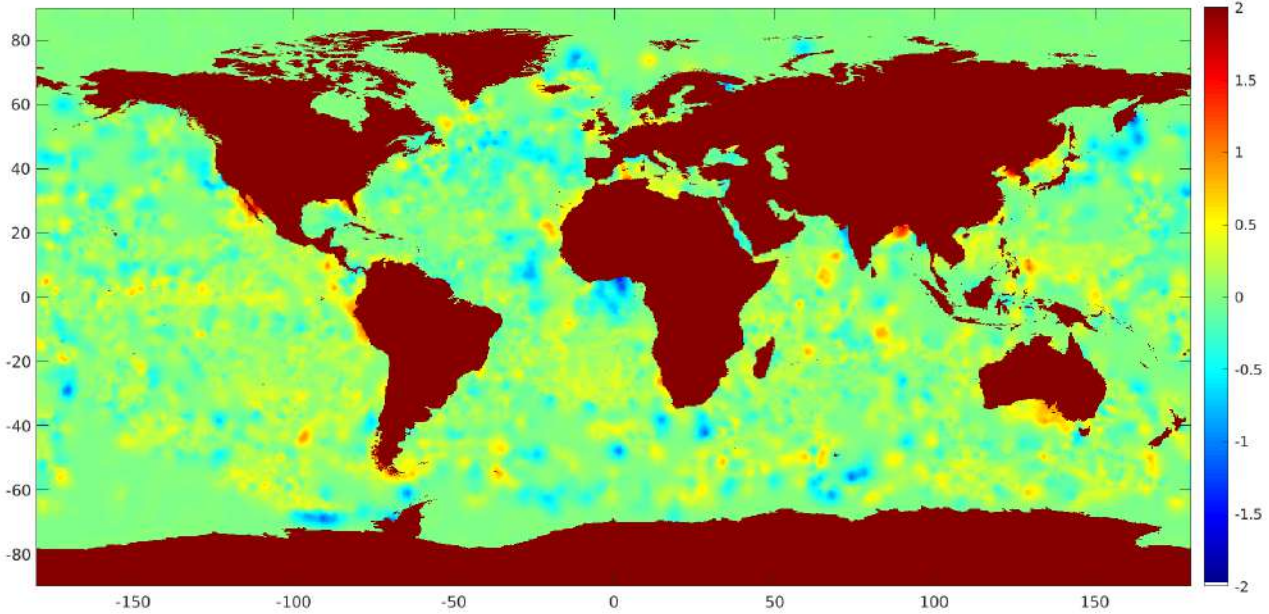

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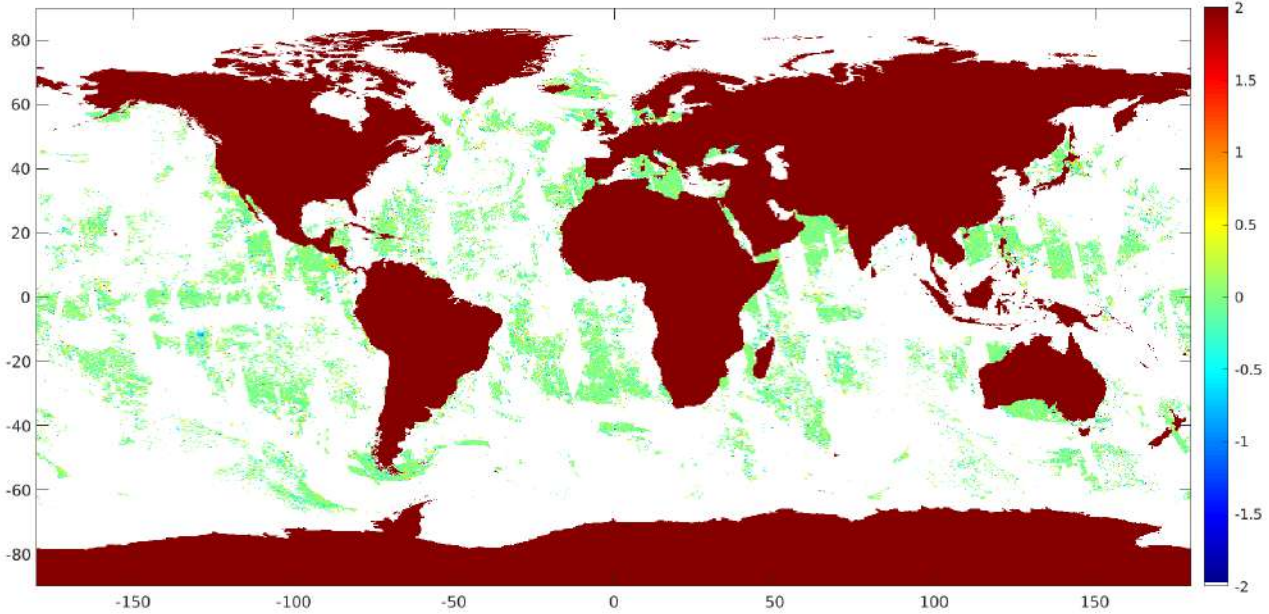

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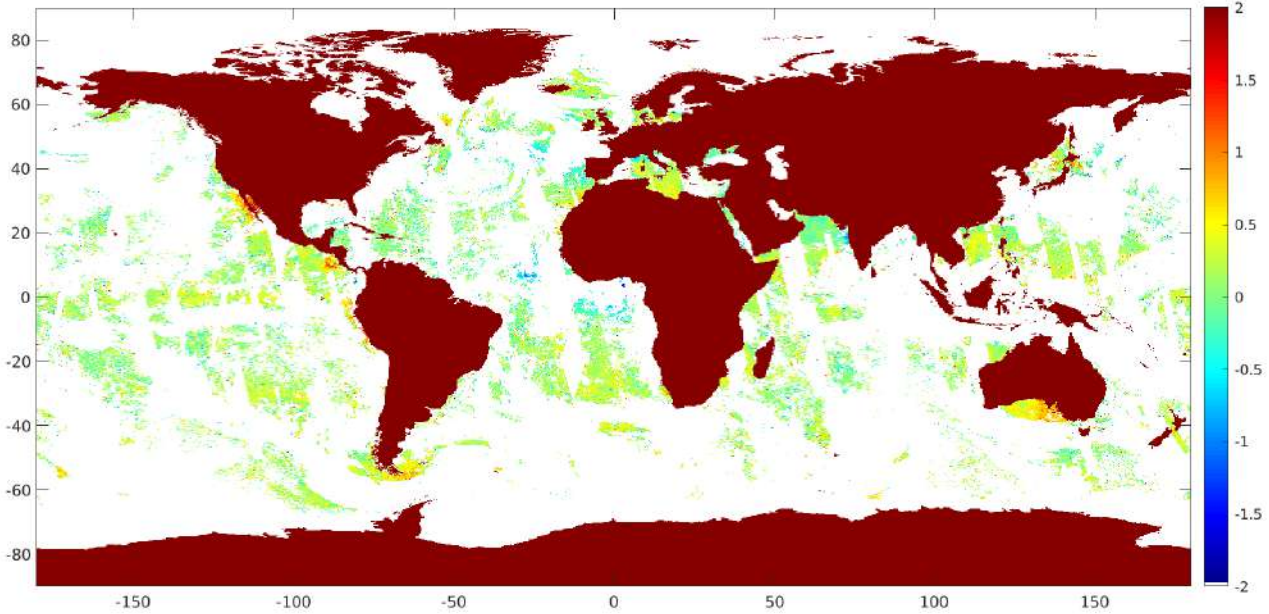
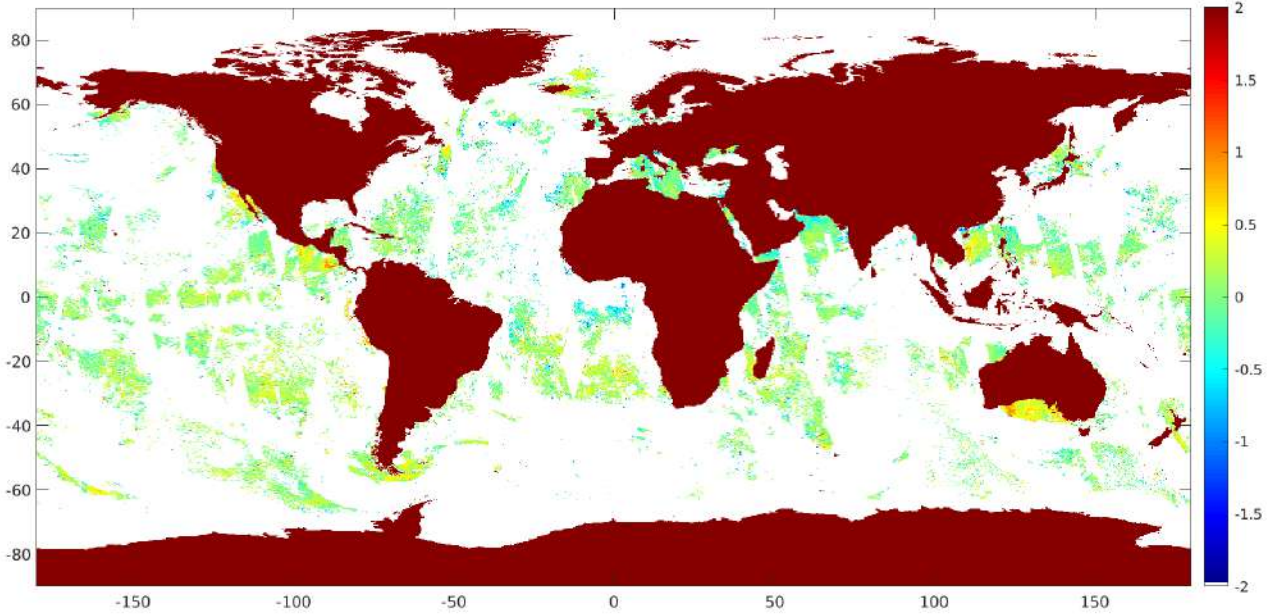


Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

NOAA-20 Nighttime April 1st 2021



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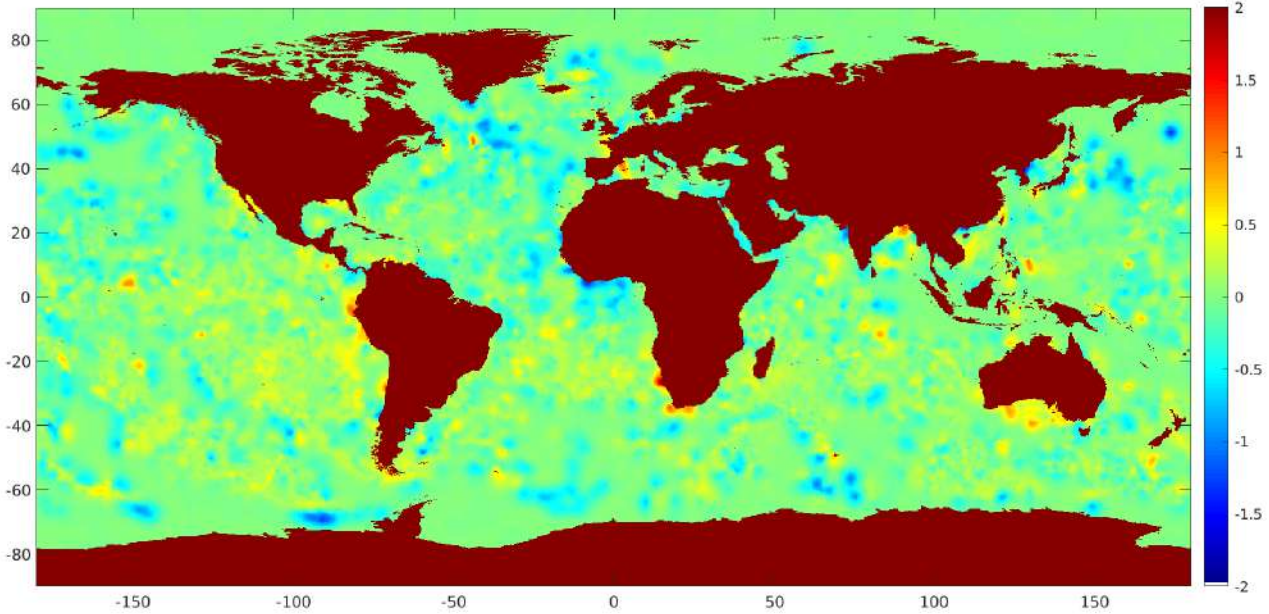
NOAA-20 – SLSTR A/B day+night

Estimated bias

NOAA-20 Nighttime April 1st 2021



Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

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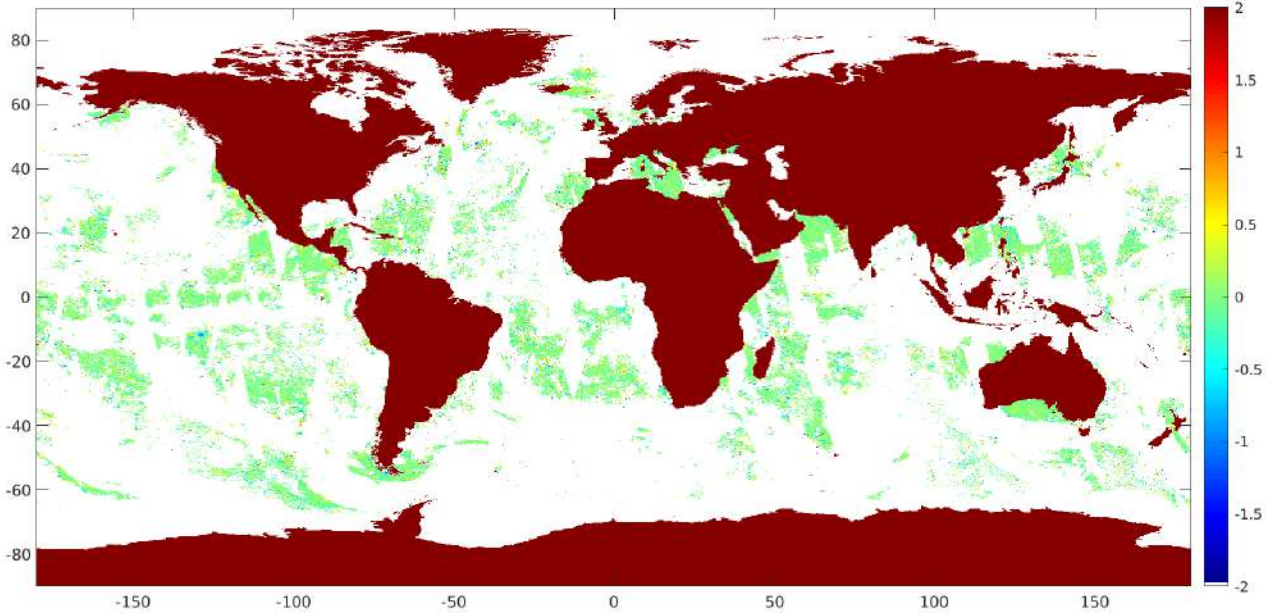
NOAA-20 Nighttime April 1st 2021



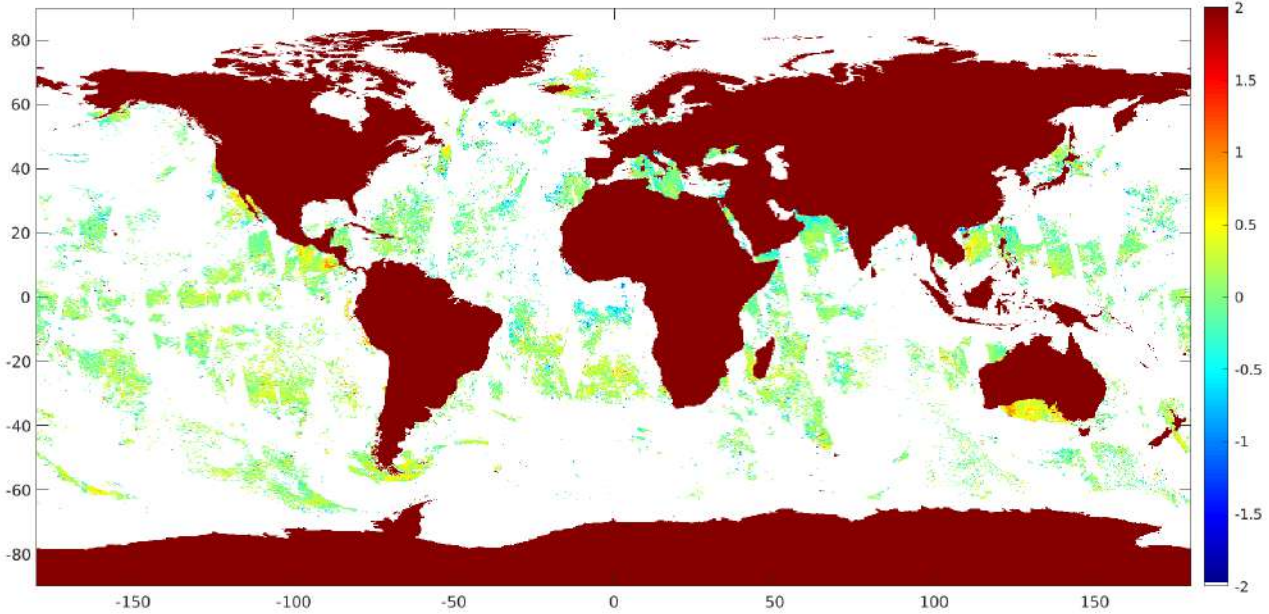
Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

Corrected NOAA-20 - SLSTR

NOAA-20 Nighttime April 1st 2021



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NOAA-20 – SLSTR A/B day+night

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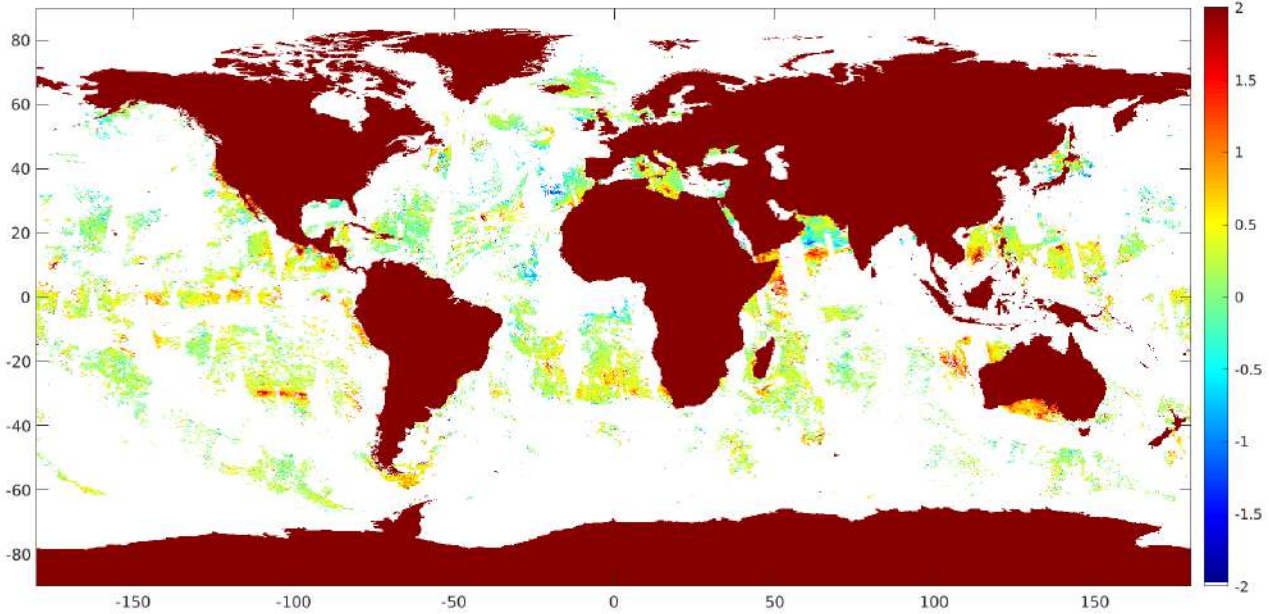

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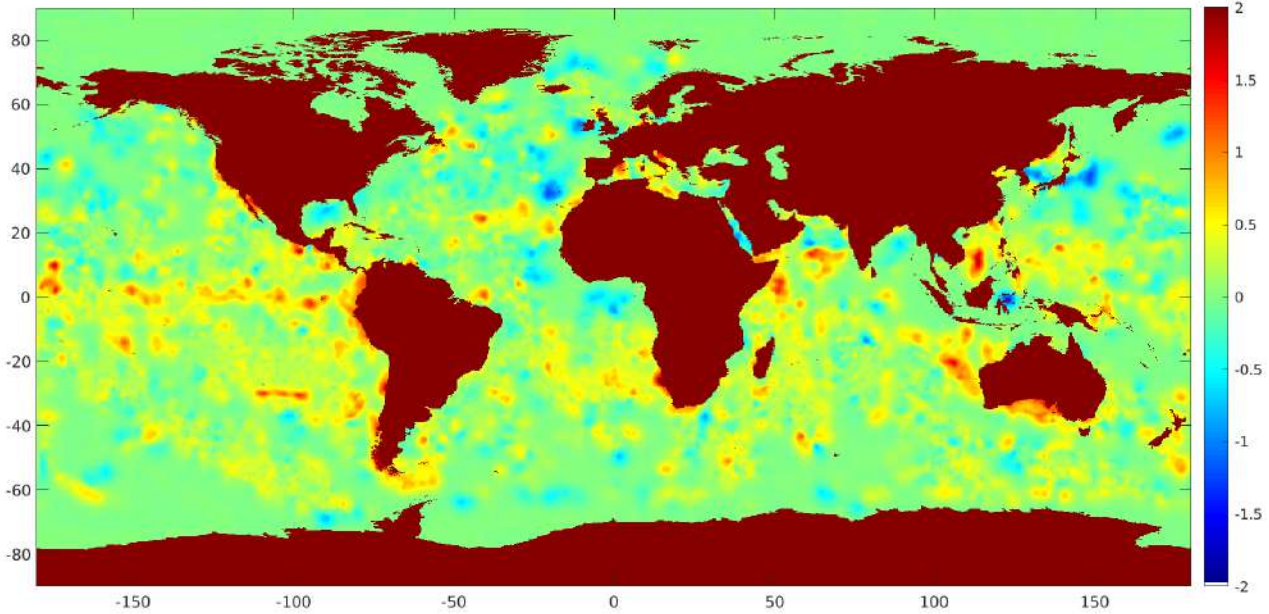

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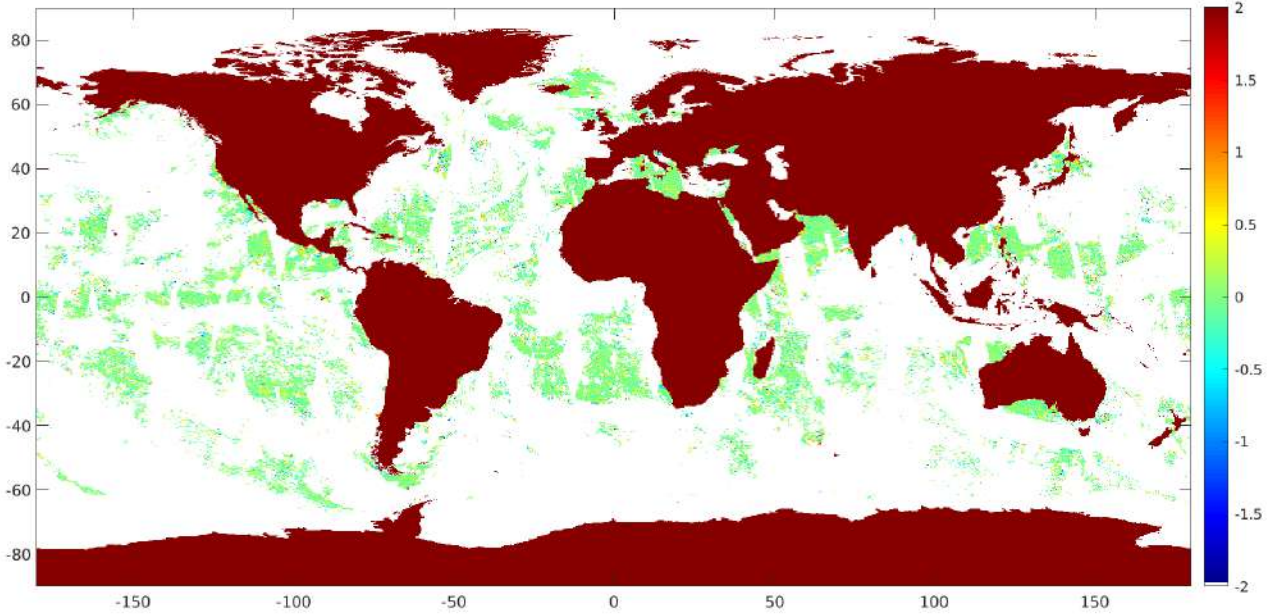

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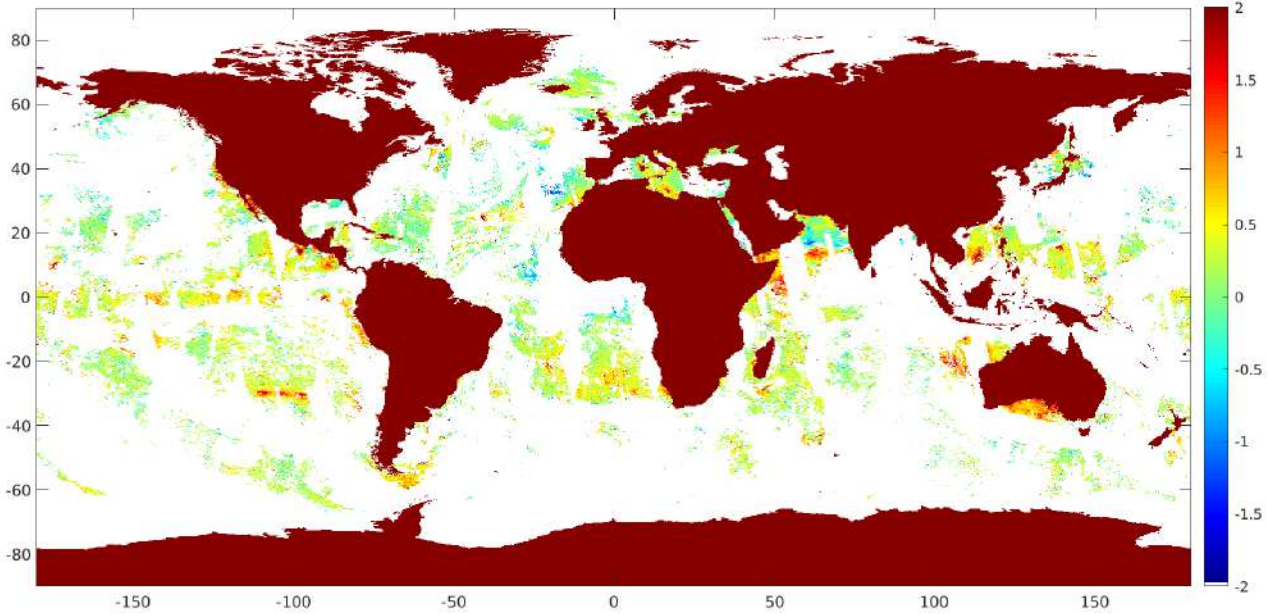
NOAA-20 – SLSTR A/B day+night

Estimated bias

Corrected NOAA-20 - SLSTR

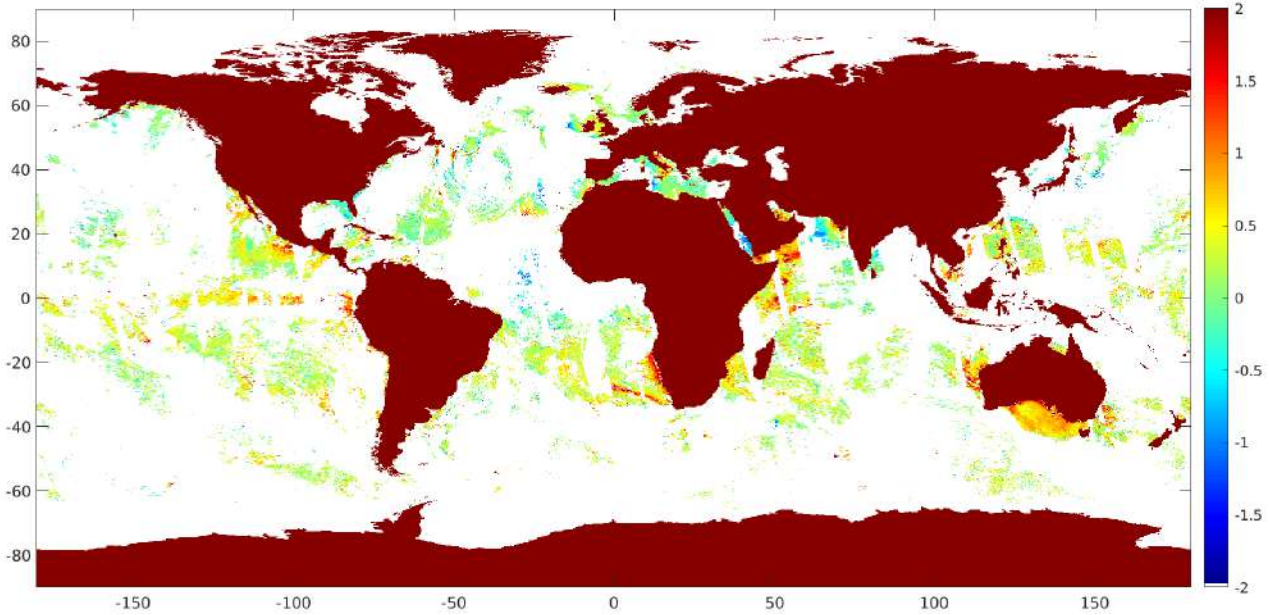
NOAA-20 Daytime April 1st 2021



Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

NOAA-20 Daytime April 2nd 2021

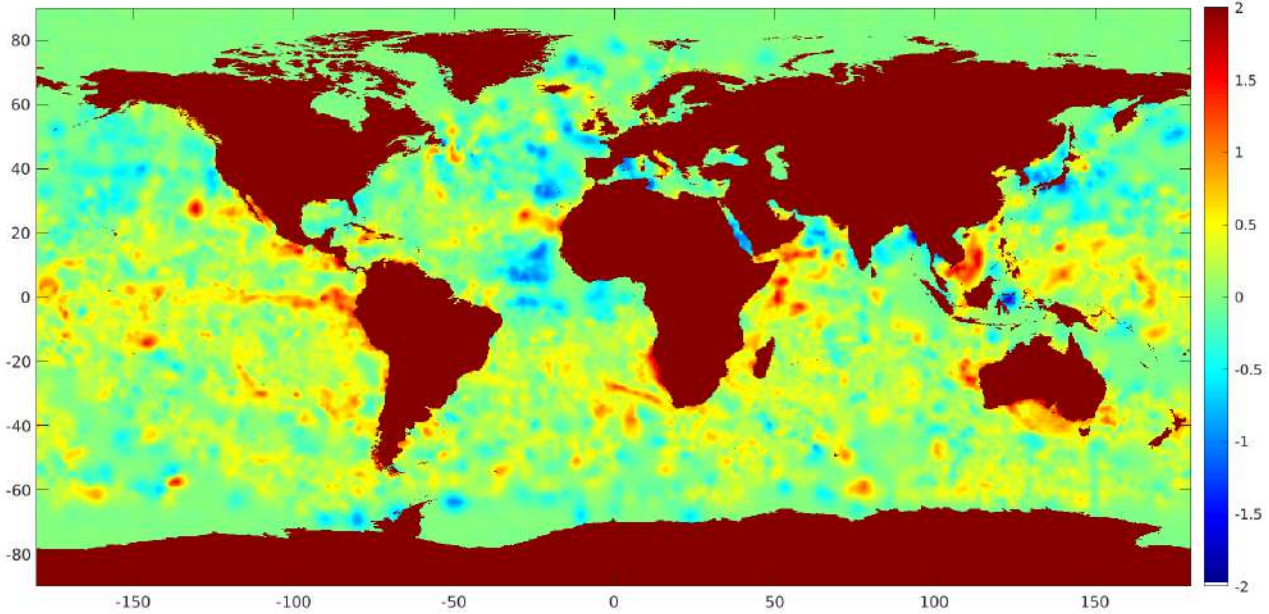


Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

NOAA-20 Daytime April 2nd 2021



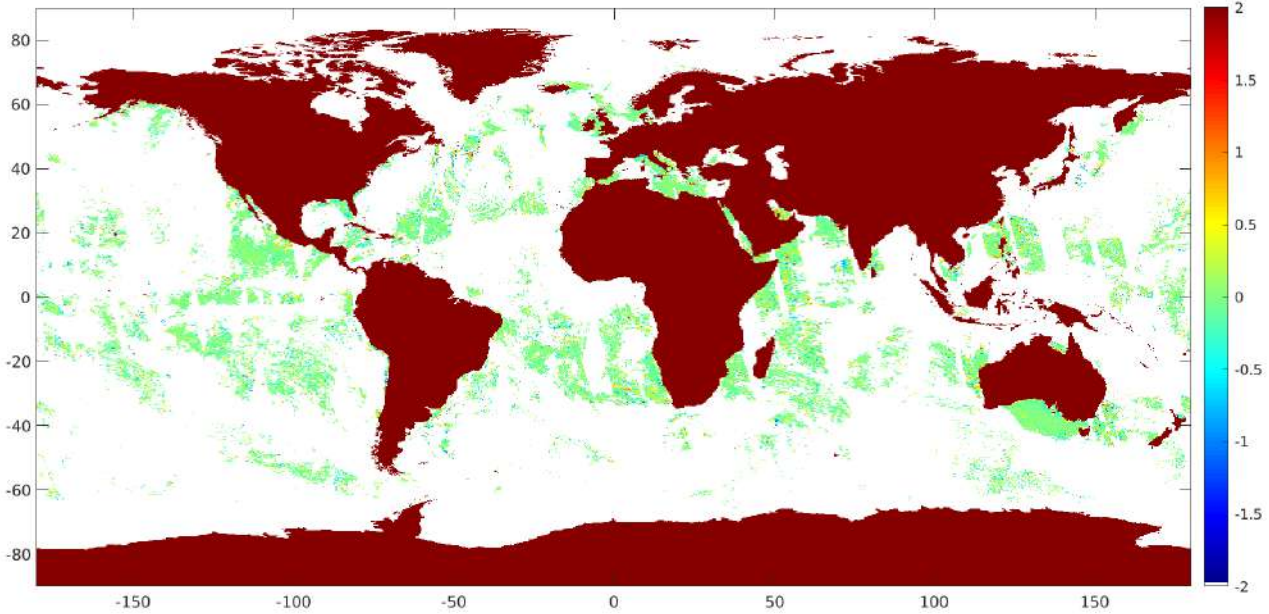
Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

Corrected NOAA-20 - SLSTR

NOAA-20 Daytime April 2nd 2021



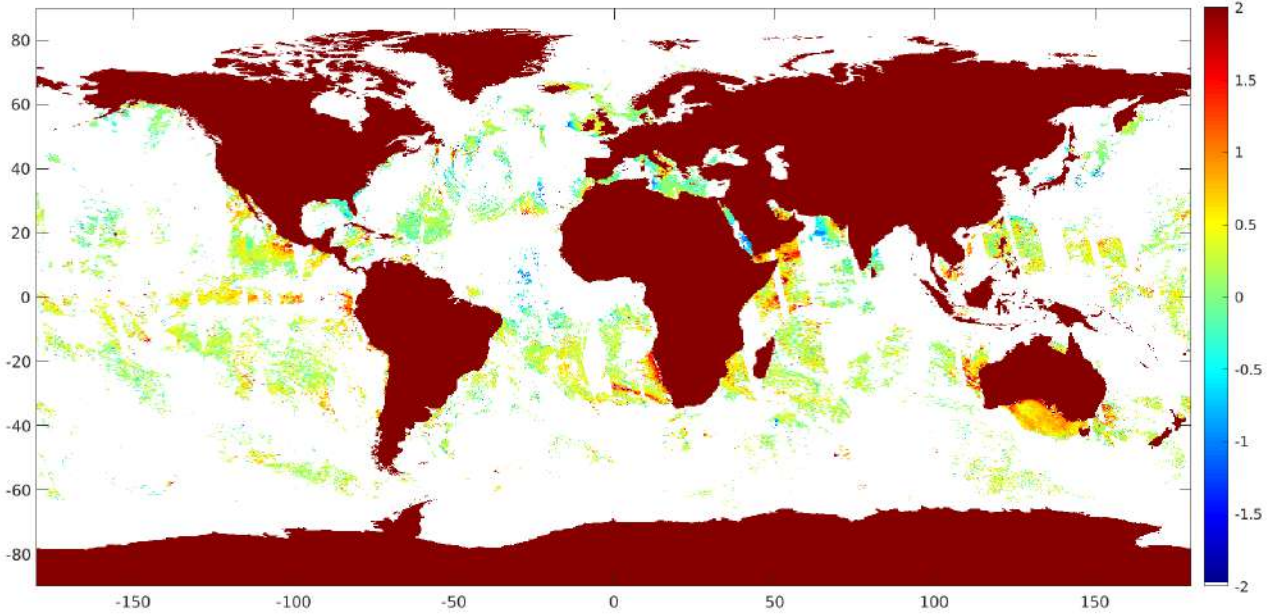
Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

Corrected NOAA-20 - SLSTR

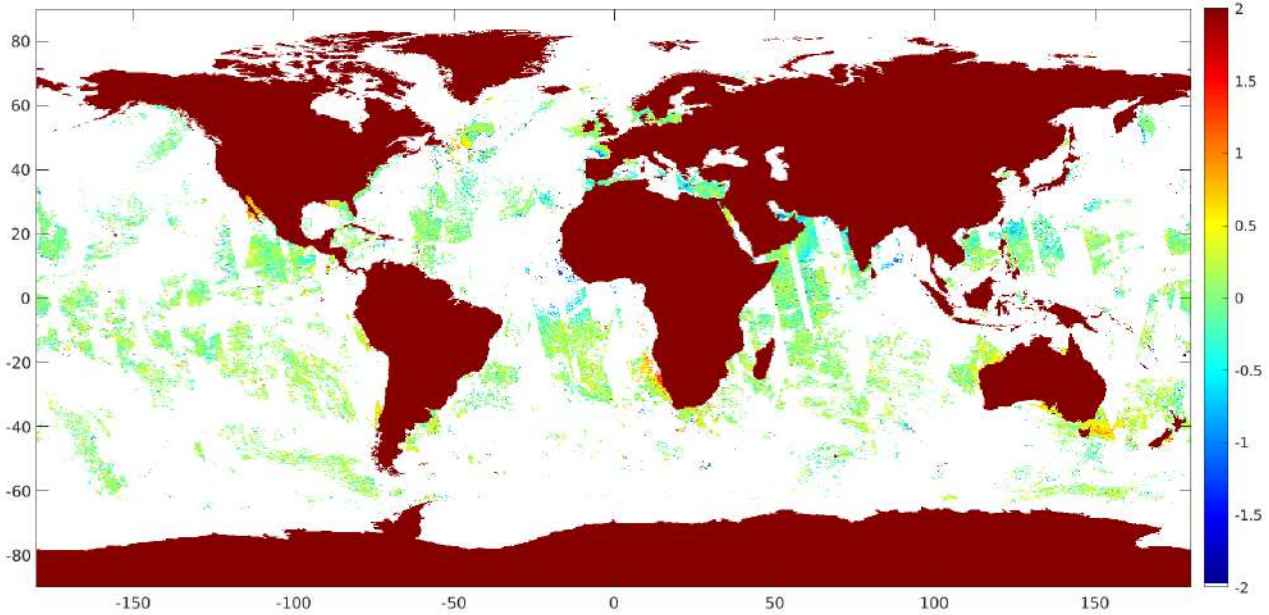
NOAA-20 Daytime April 2nd 2021



Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

NOAA-20 Nighttime April 3rd 2021

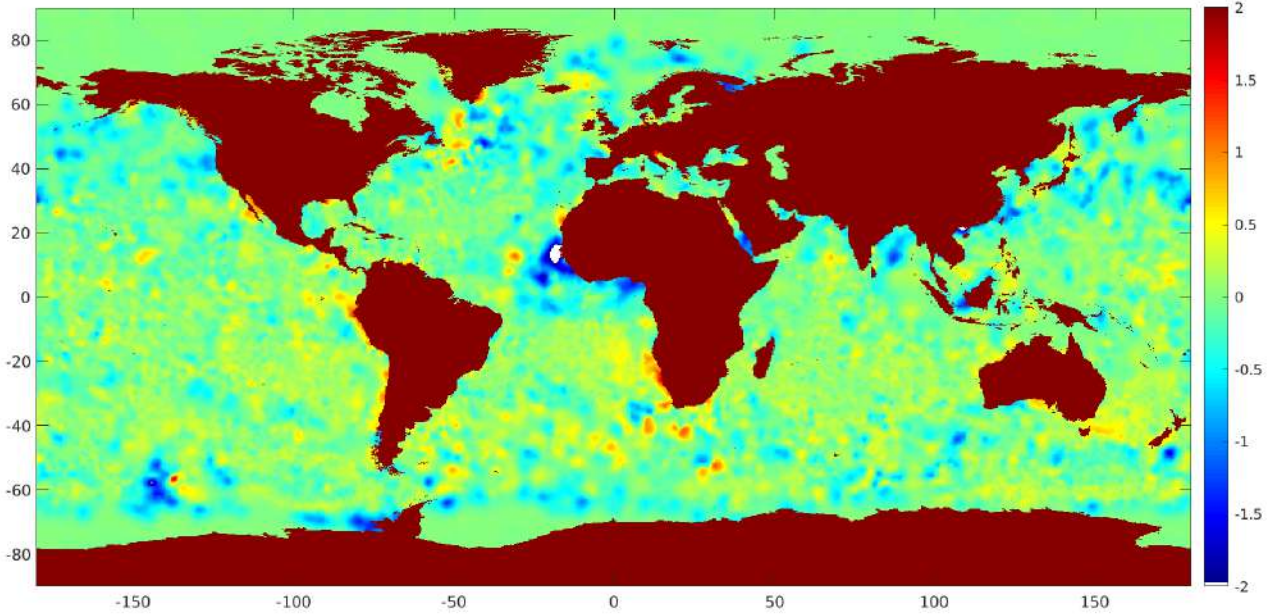


Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

NOAA-20 Nighttime April 3rd 2021



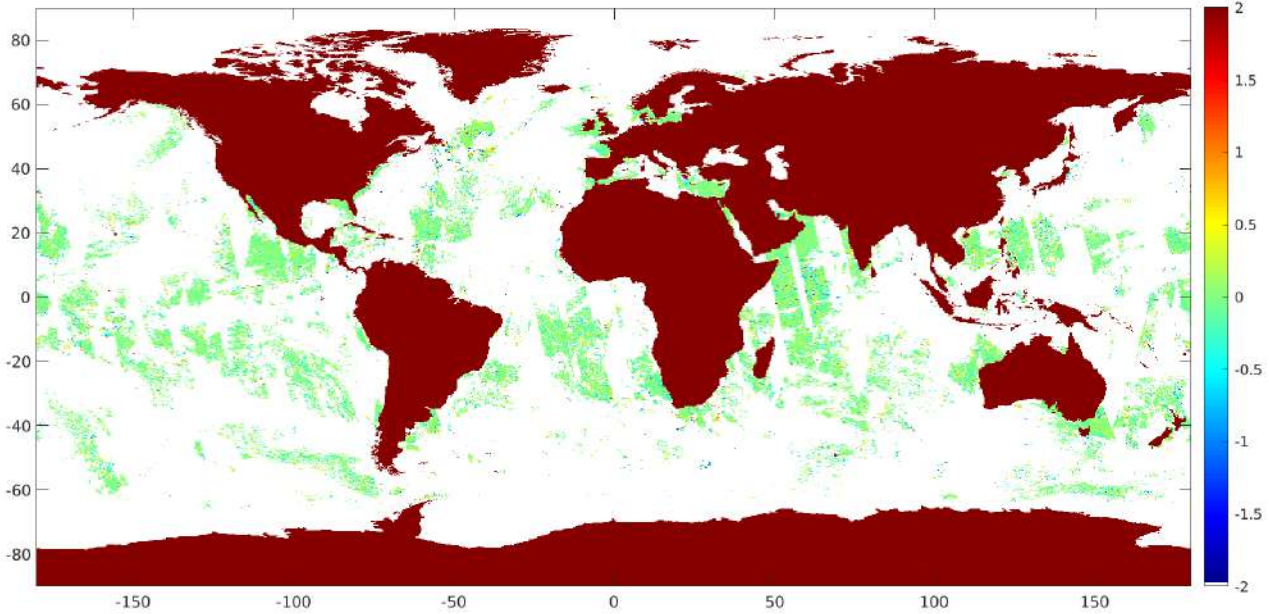
Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

Corrected NOAA-20 - SLSTR

NOAA-20 Nighttime April 3rd 2021



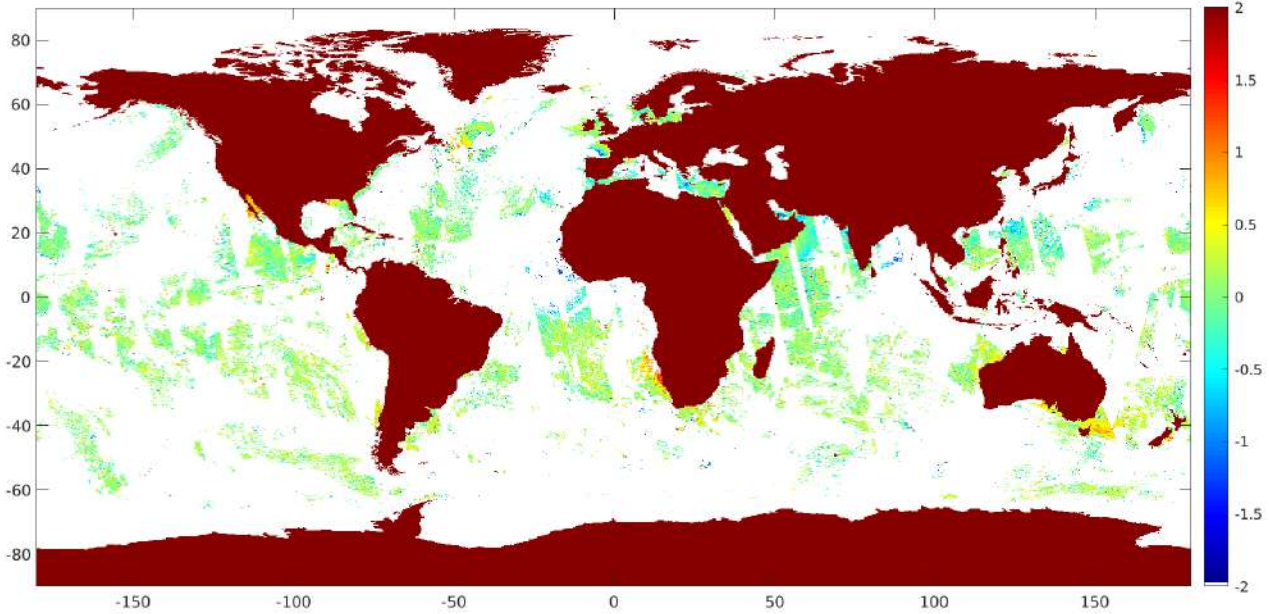
Examples of bias w.r.t SLSTR

NOAA-20 – SLSTR A/B day+night

Estimated bias

Corrected NOAA-20 - SLSTR

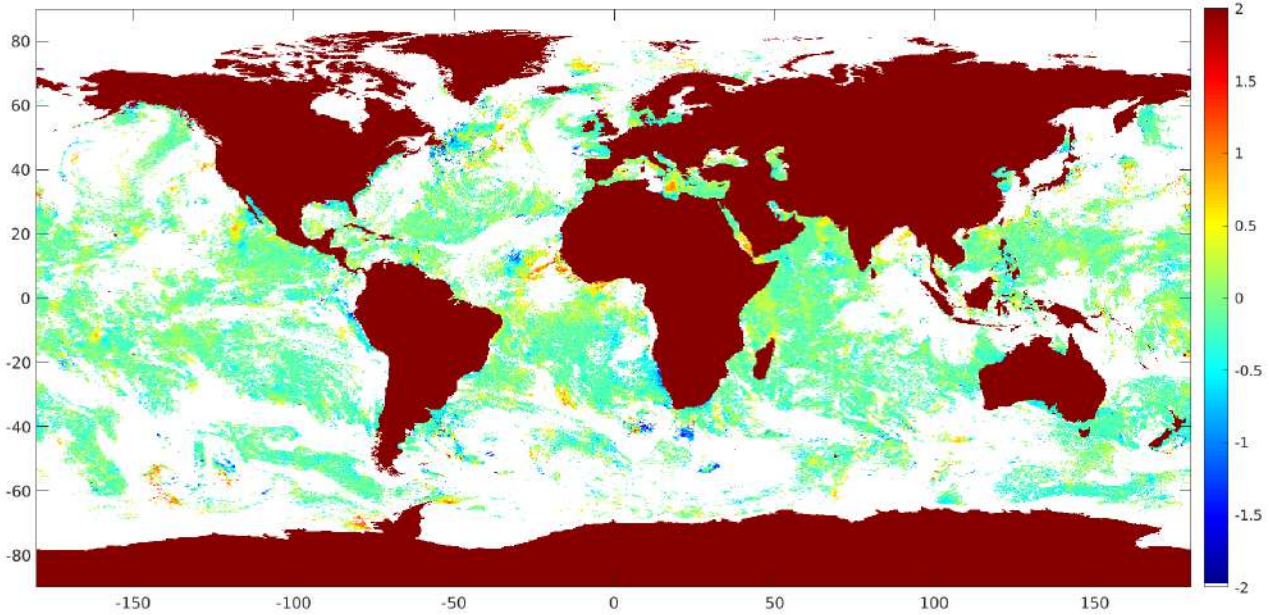
NOAA-20 Nighttime April 3rd 2021



Examples of bias w.r.t SLSTR

Corrected NOAA-20 – OSTIA

NOAA-20 Nighttime April 3rd 2021

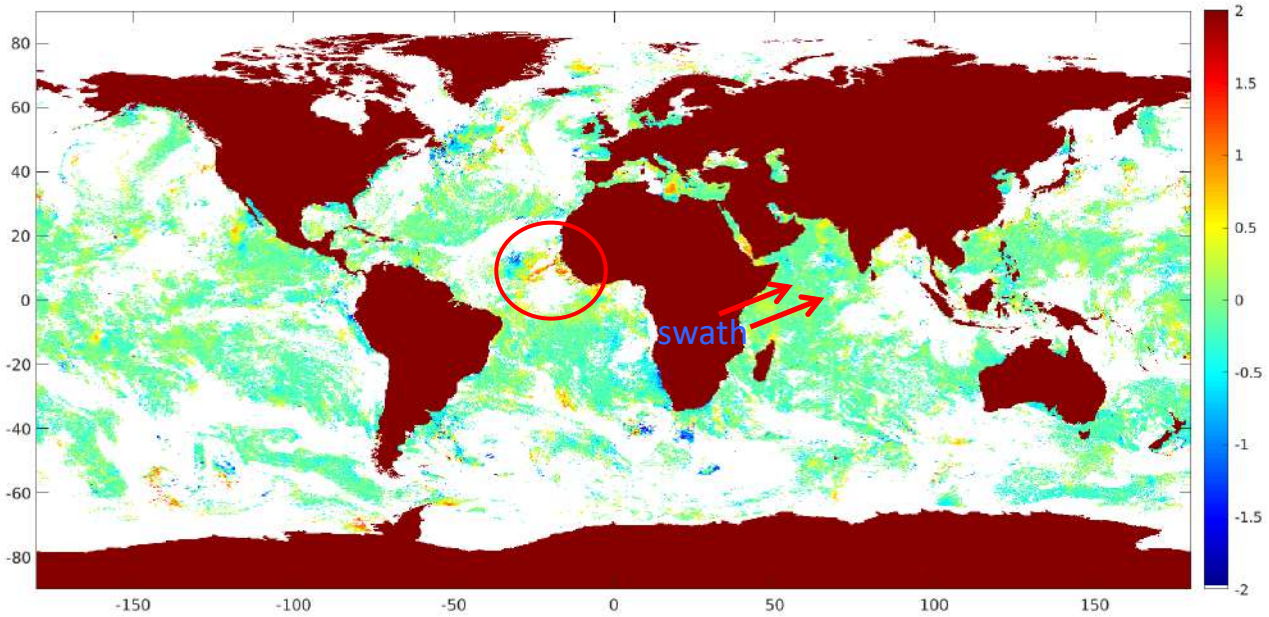


Examples of bias w.r.t SLSTR

Corrected NOAA-20 – OSTIA

Evidence of effect of SLSTR swaths/gaps…

NOAA-20 Nighttime April 3rd 2021



Examples of bias w.r.t SLSTR

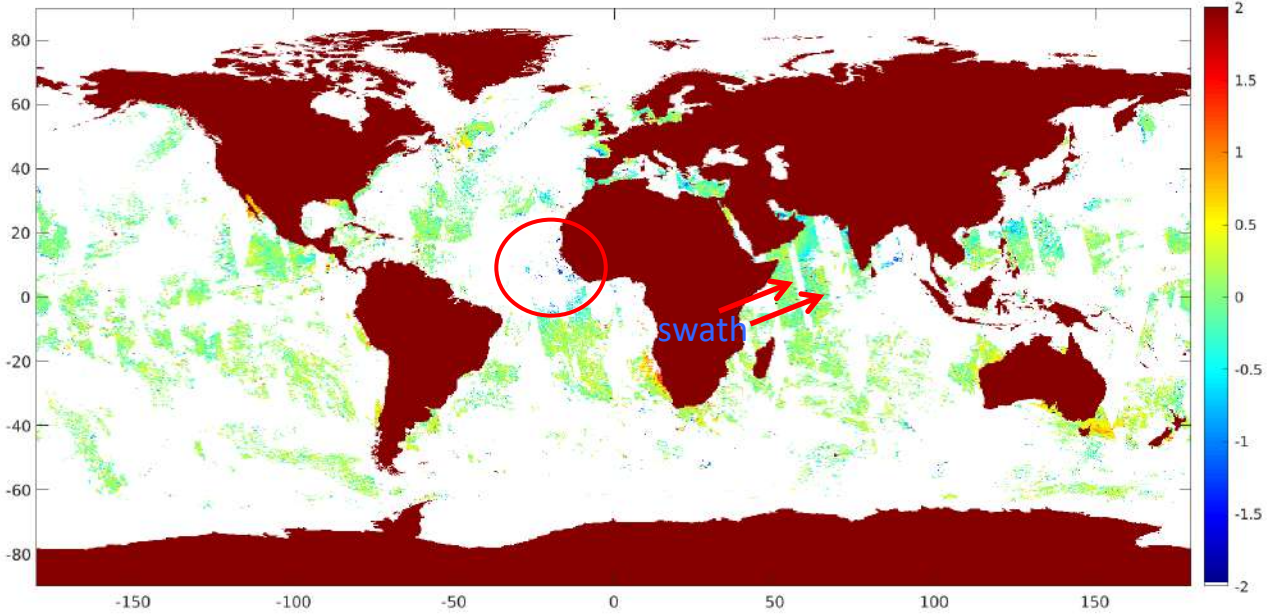
Corrected NOAA-20 – OSTIA

Evidence of SLSTR swaths/gaps…

…are confirmed

(also visible on NOAA SQUAM validation page)

SLSTR-A/B day+night April 3rd 2021

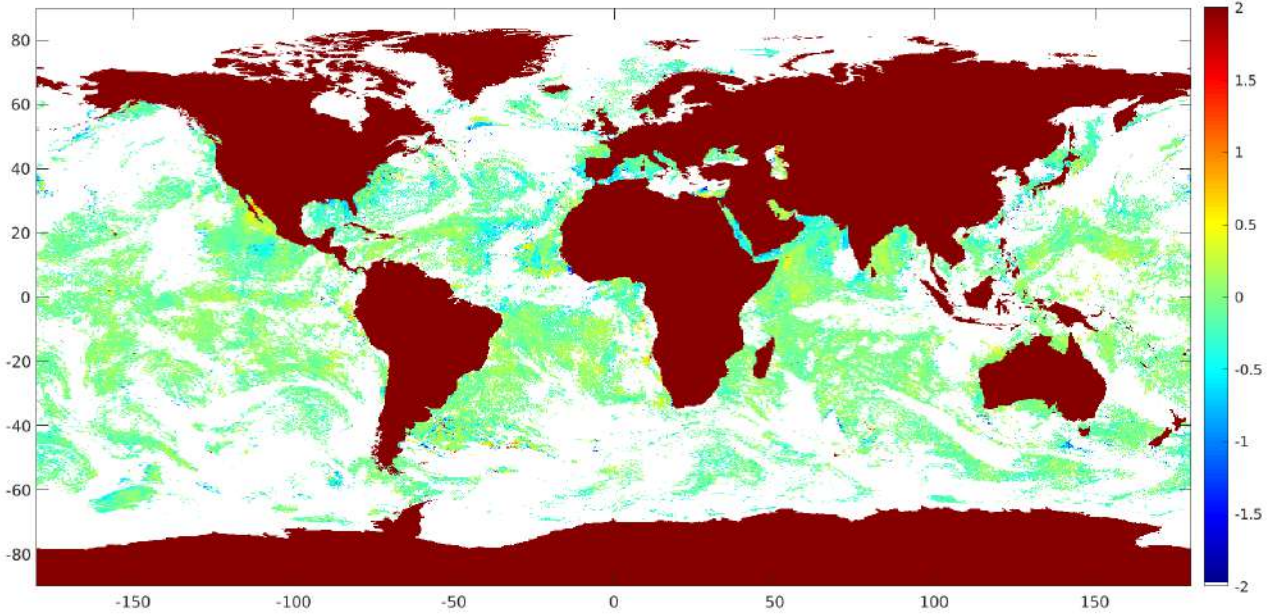


Examples of bias w.r.t SLSTR

<u>Uncorrected</u> NOAA-20 – OSTIA

(N.B. with SSES bias applied)

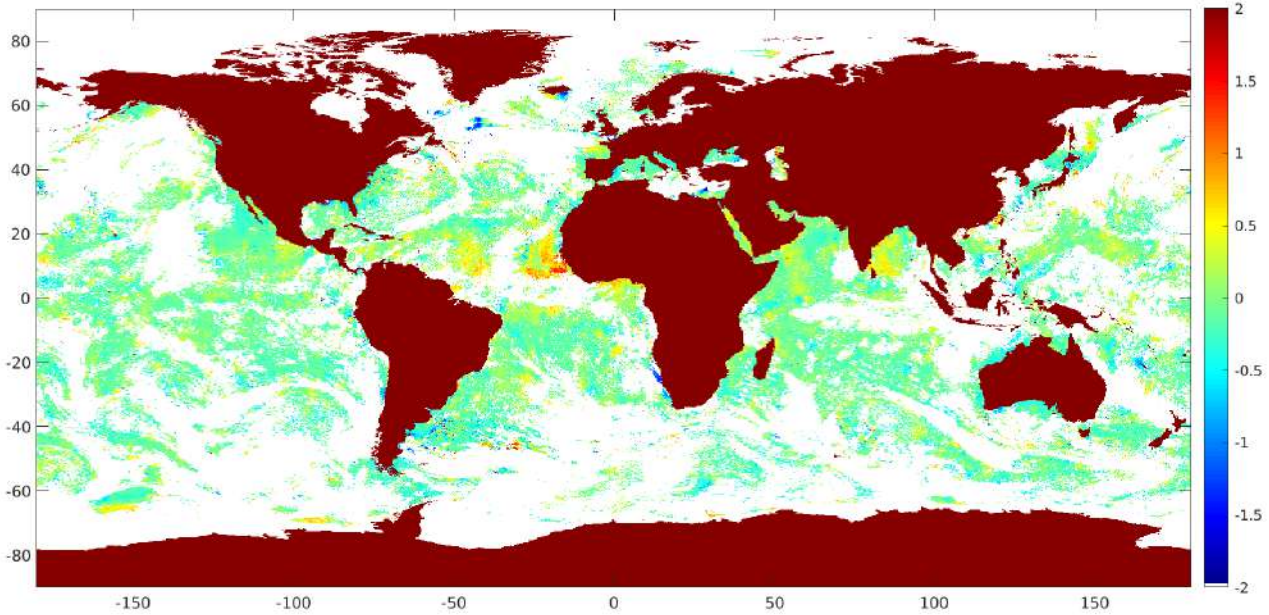
NOAA-20 Nighttime April 5th 2021



Examples of bias w.r.t SLSTR

<u>Corrected</u> NOAA-20 – OSTIA

NOAA-20 Nighttime April 5th 2021

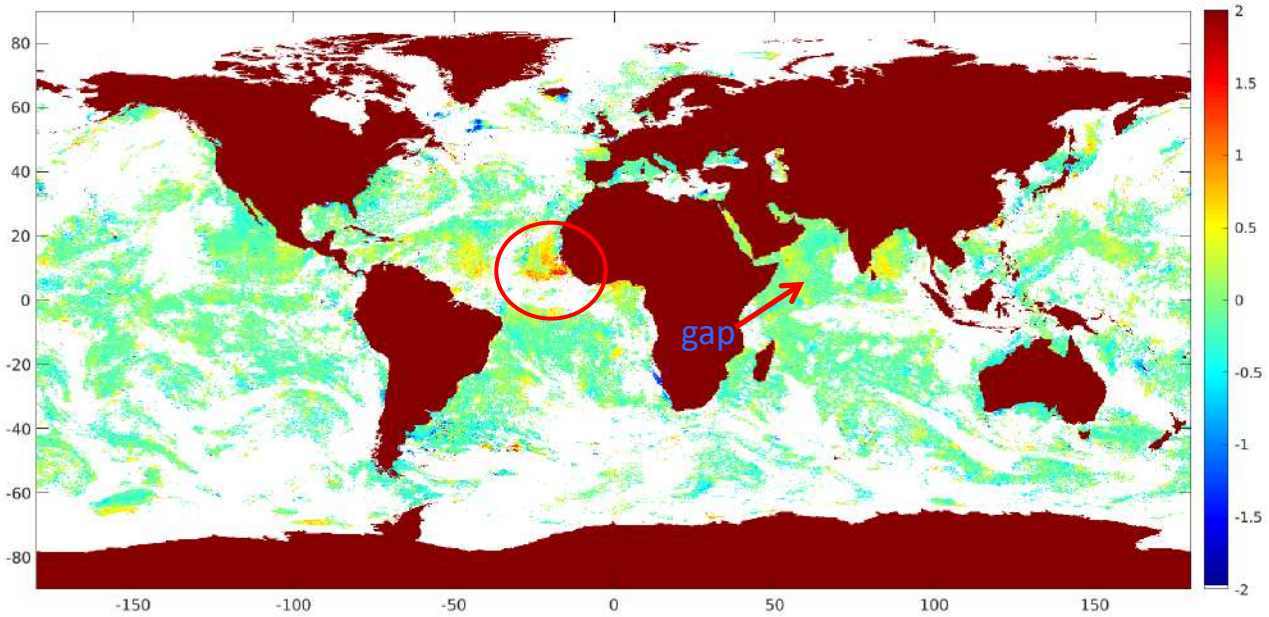


Examples of bias w.r.t SLSTR

Corrected NOAA-20 – OSTIA

Again, evidence of effect of SLSTR swaths/gaps…

NOAA-20 Nighttime April 5th 2021



Examples of bias w.r.t SLSTR

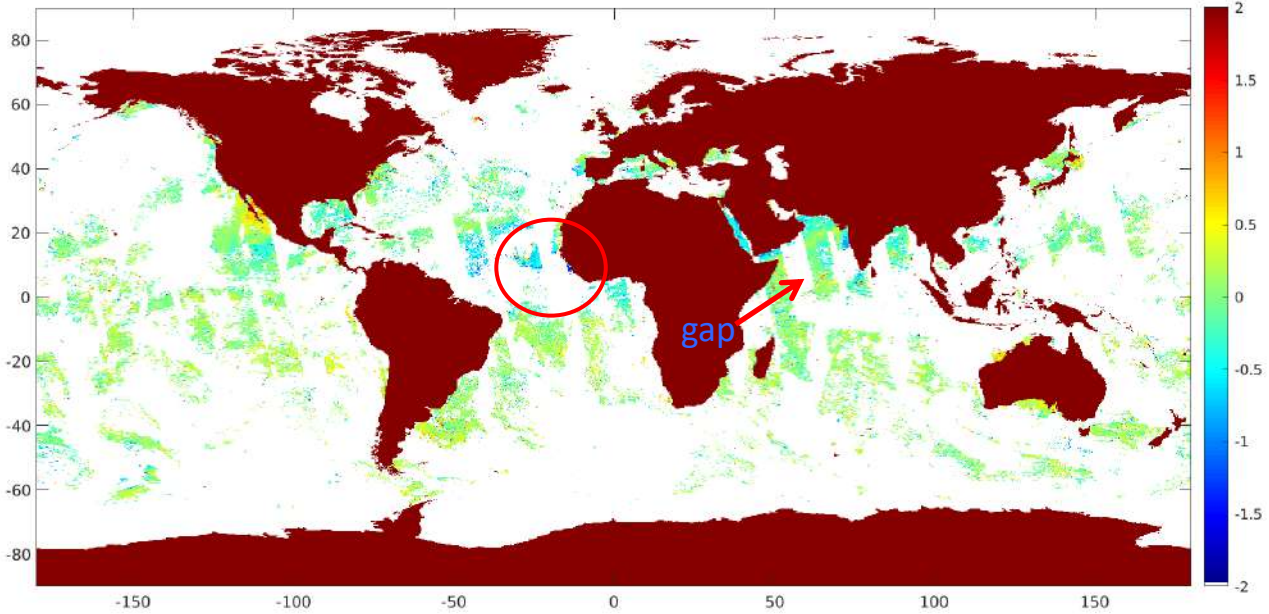
Corrected NOAA-20 – OSTIA

Evidence of SLSTR swaths/gaps…

…are confirmed

(also visible on NOAA SQUAM validation page)

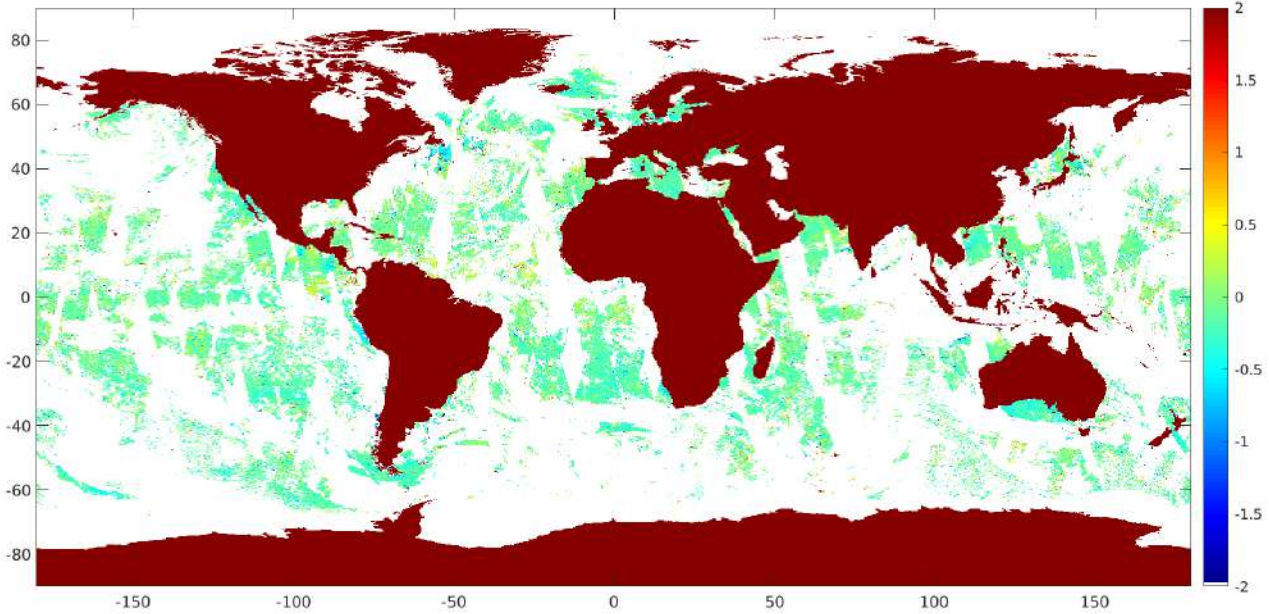
SLSTR-A/B day+night April 5th 2021



SLSTR – OSTIA

S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS <u>with SSES bias</u>

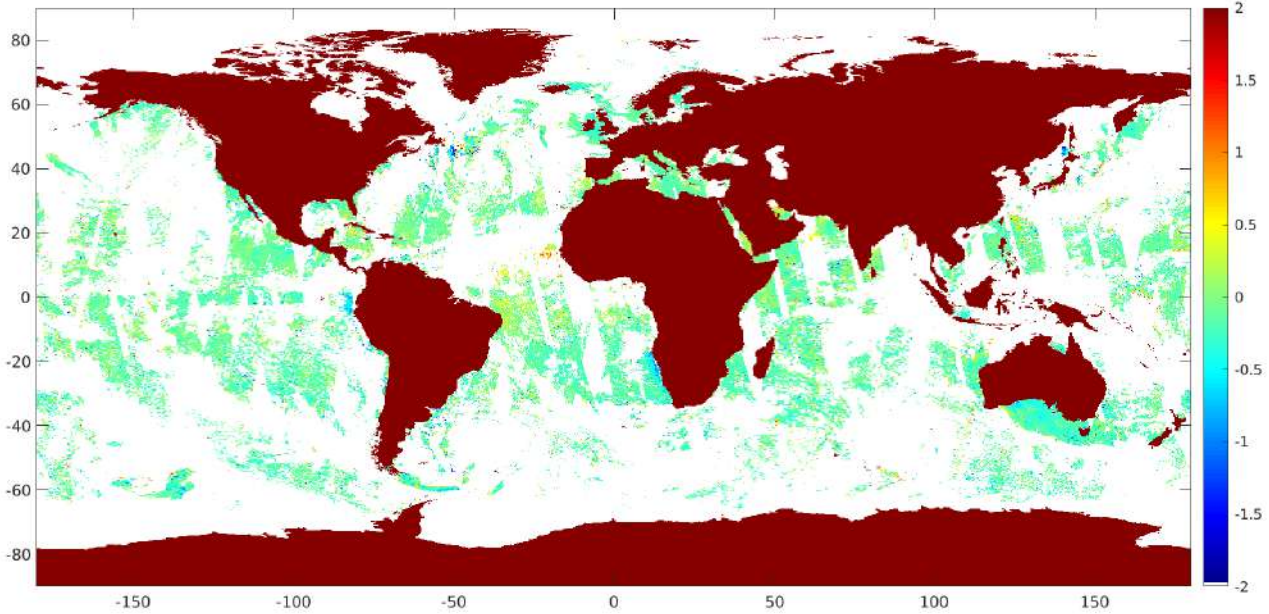
S3A&B SLSTR – OSTIA, April 1st 2021



SLSTR – OSTIA

S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS <u>with SSES bias</u>

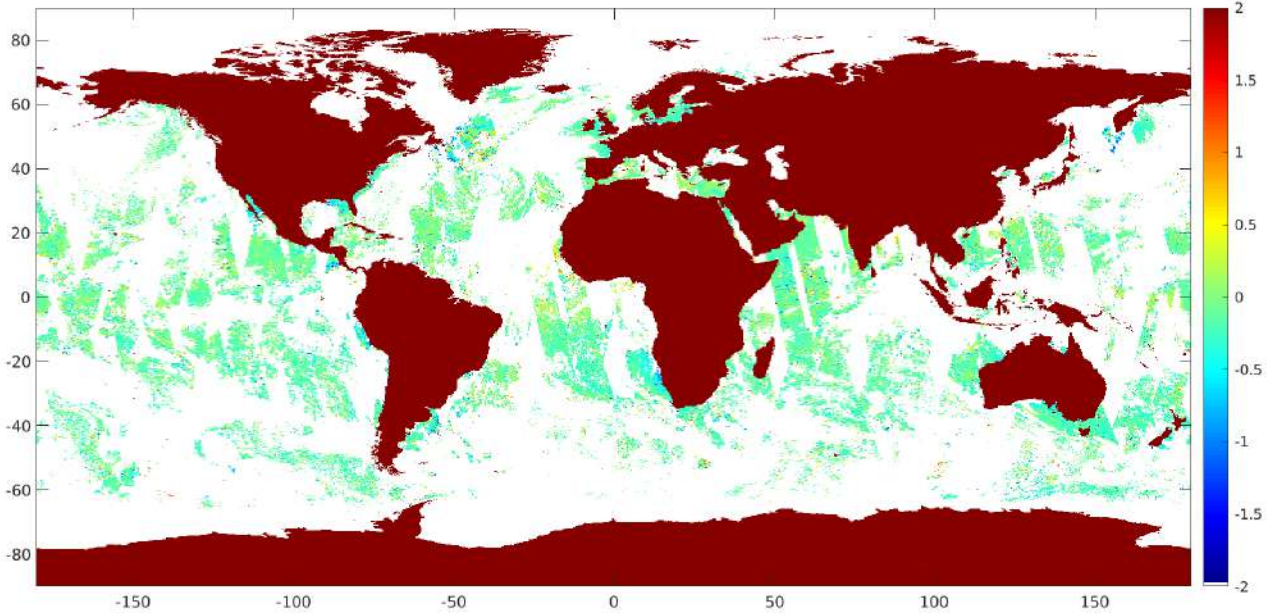
S3A&B SLSTR – OSTIA, April 2nd 2021



SLSTR – OSTIA

S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS <u>with SSES bias</u>

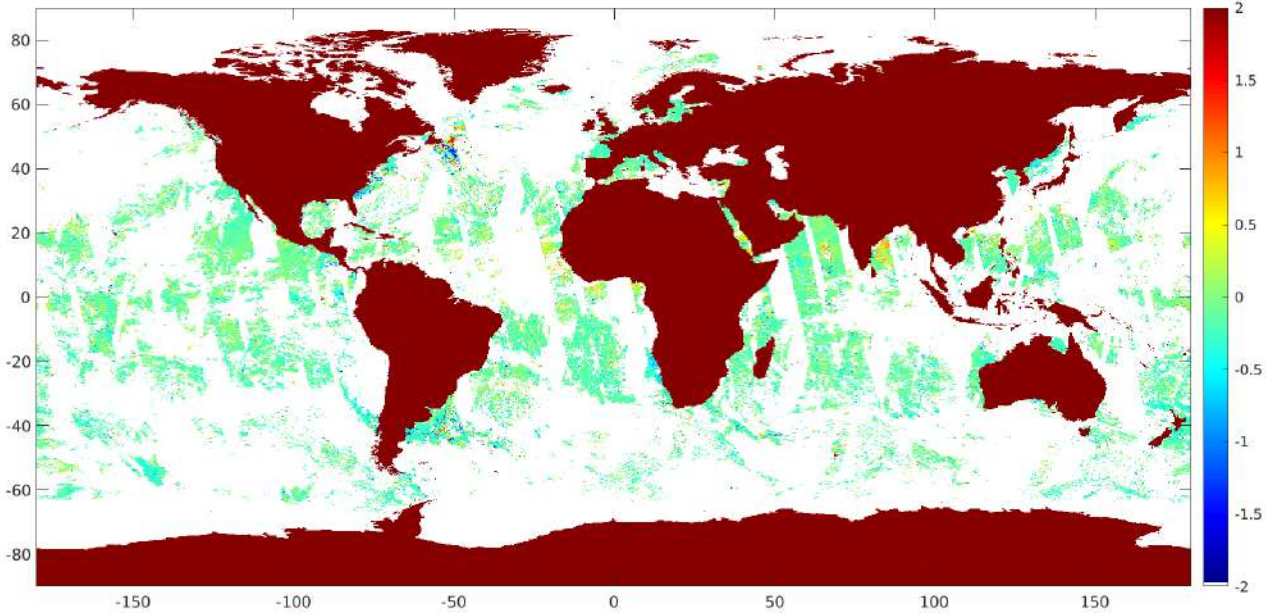
S3A&B SLSTR – OSTIA, April 3rd 2021



SLSTR – OSTIA

S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS <u>with SSES bias</u>

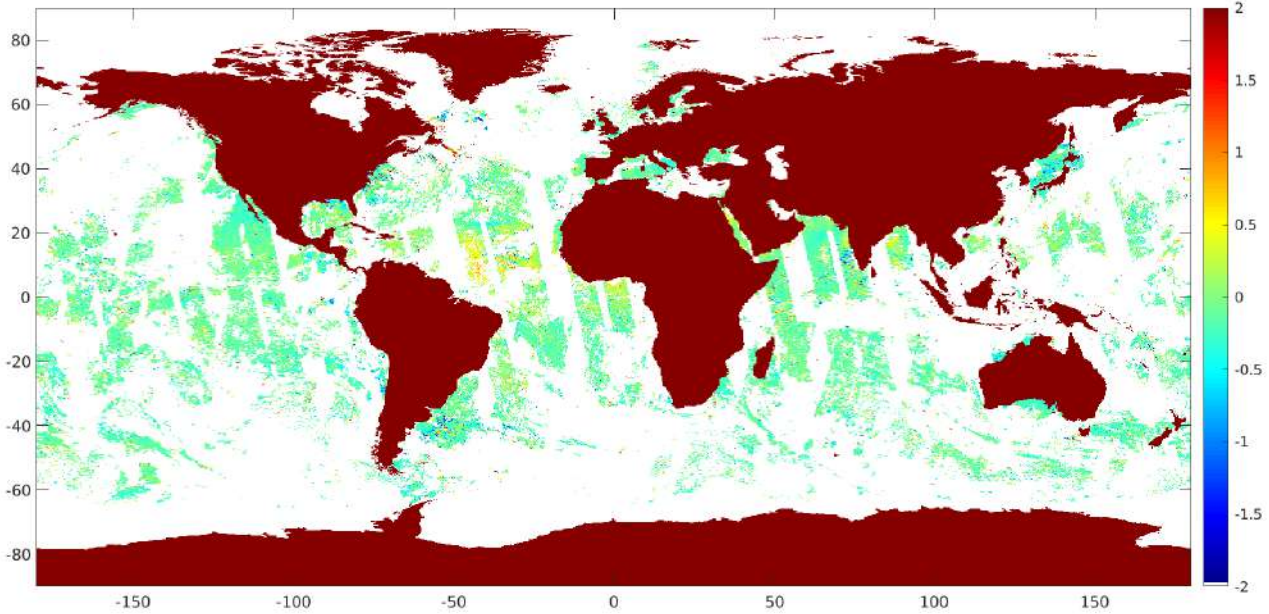
S3A&B SLSTR – OSTIA, April 4th 2021



SLSTR – OSTIA

S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS <u>with SSES bias</u>

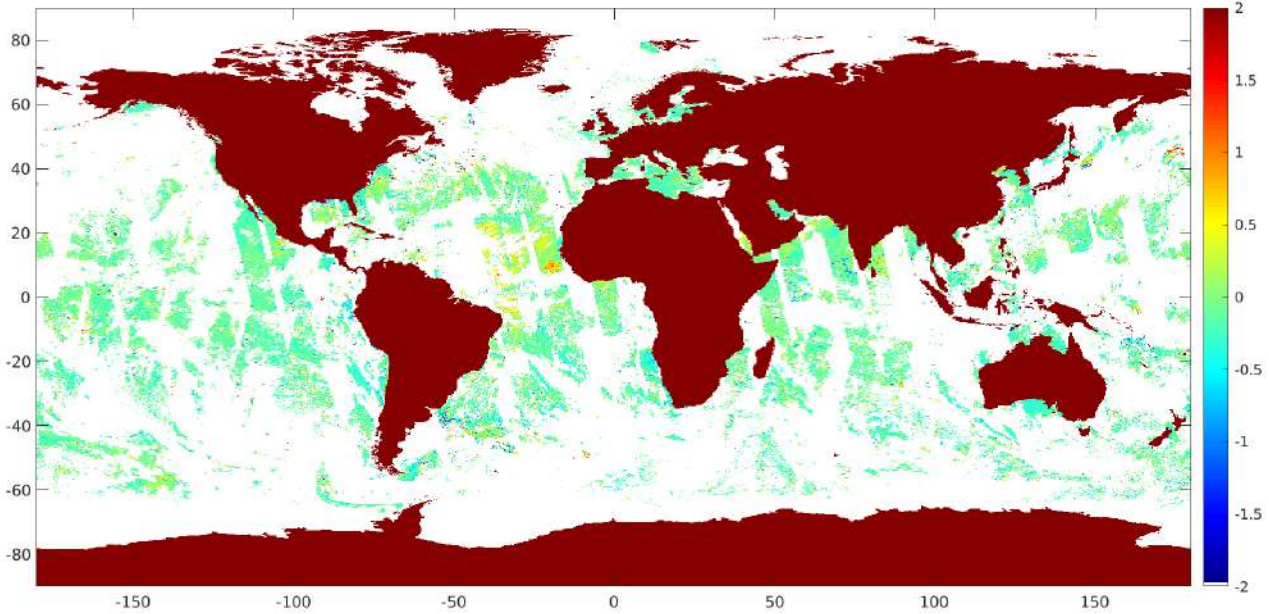
S3A&B SLSTR – OSTIA, April 5th 2021



SLSTR – OSTIA

S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS <u>with SSES bias</u>

S3A&B SLSTR – OSTIA, April 6th 2021

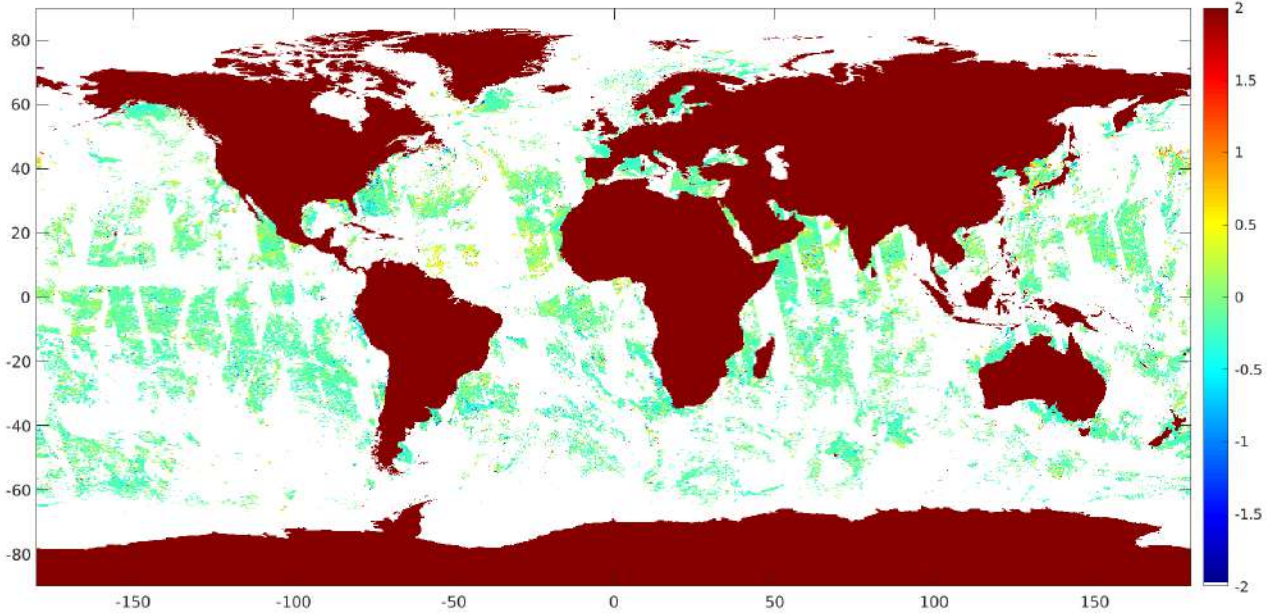


SLSTR – OSTIA

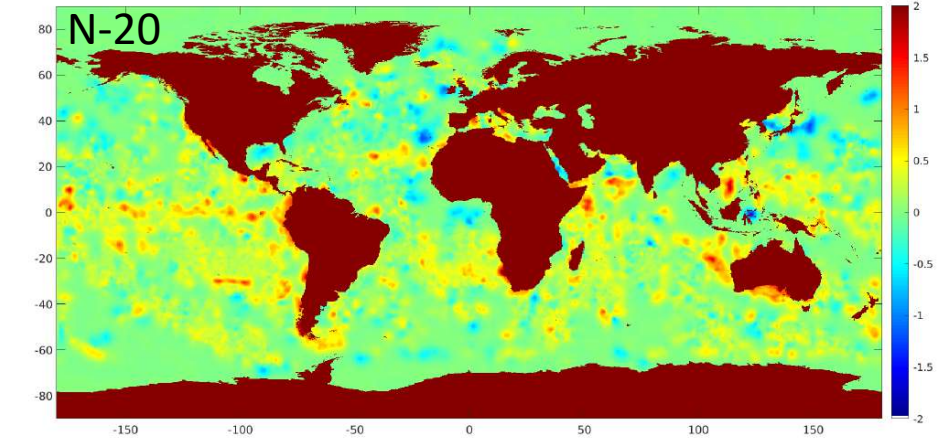
S3A&B SLSTR are used in OSTIA bias correction, along with much wider swath nighttime VIIRS with SSES bias

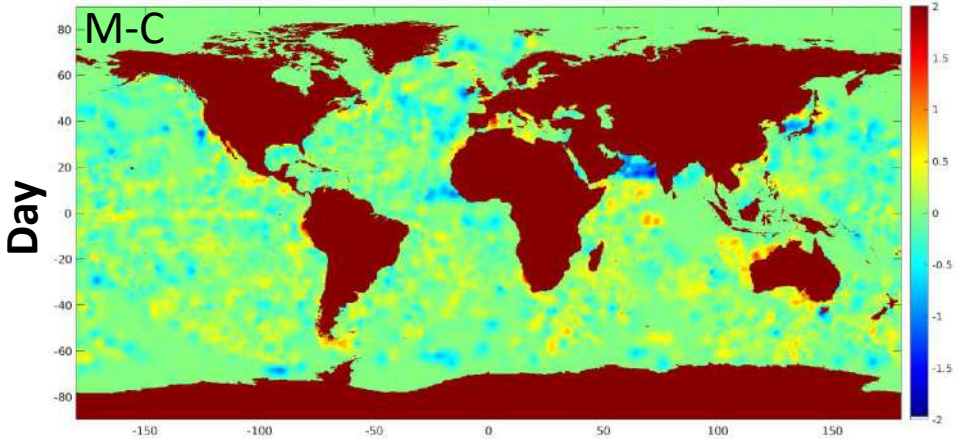
Where SLSTR & VIIRS agree, expect ~zero bias

S3A&B SLSTR – OSTIA, April 7th 2021

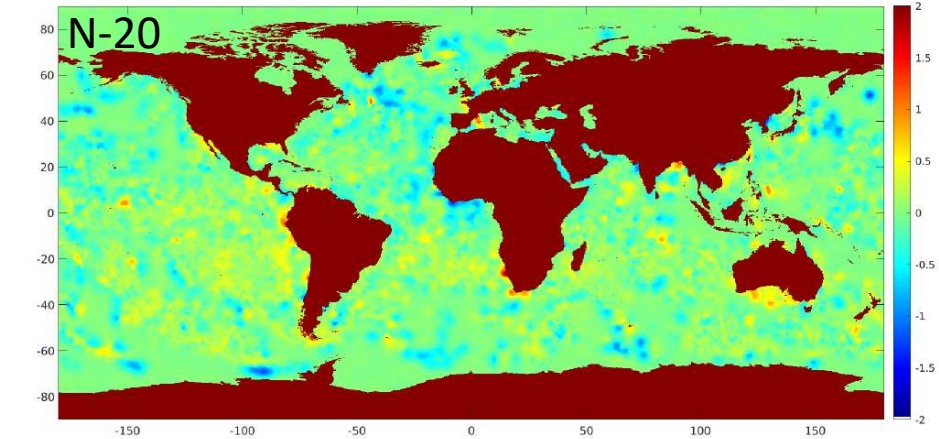


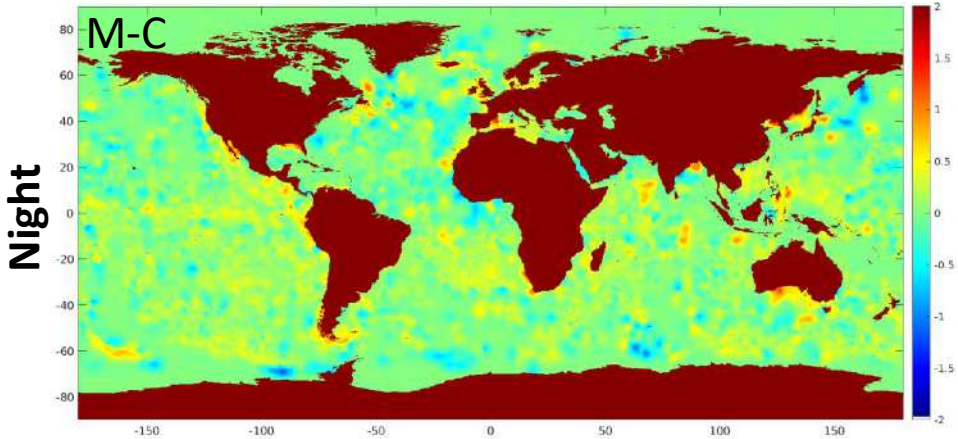
Bias Maps – April 1, 2021





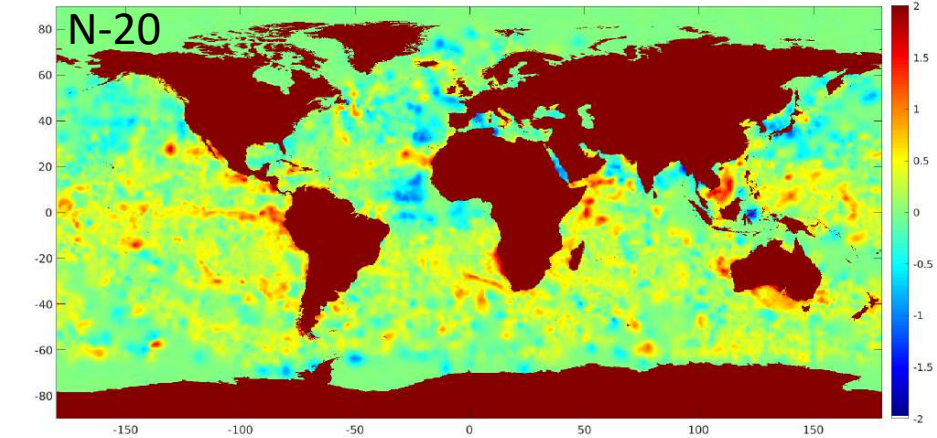
Day

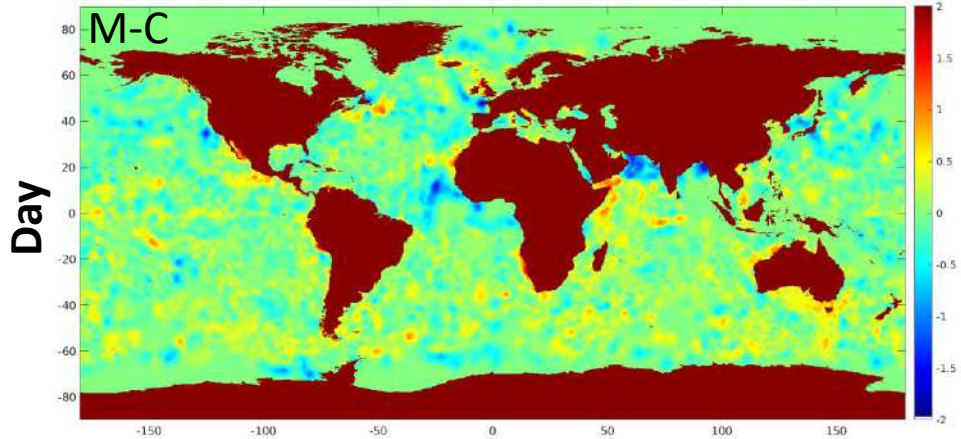




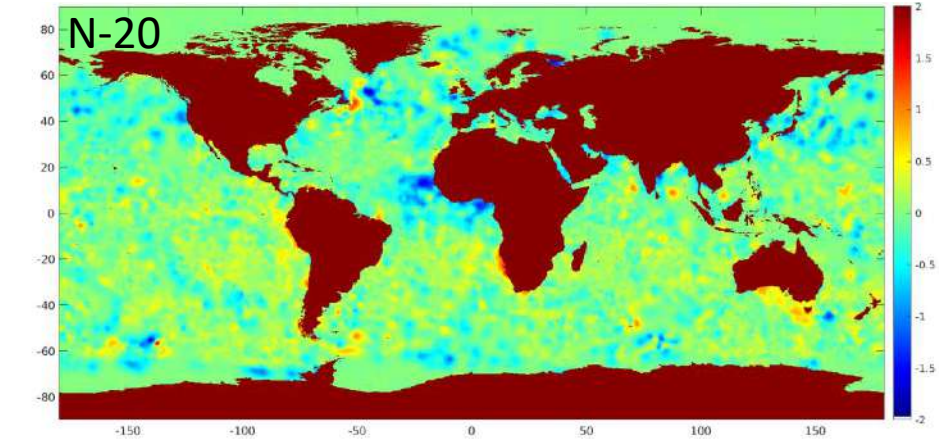
Night

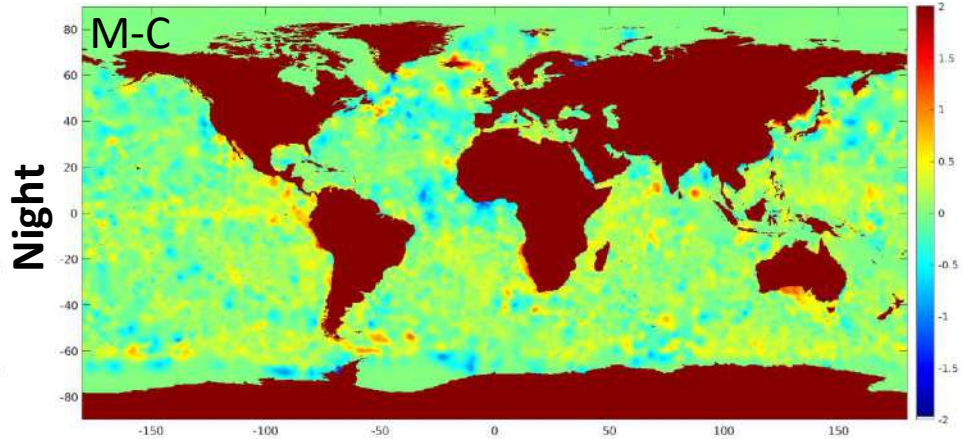
Bias Maps – April 2, 2021





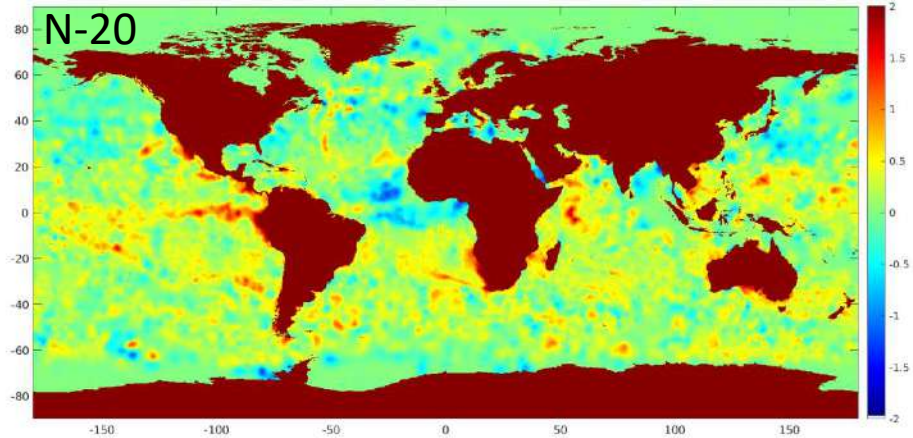
Day

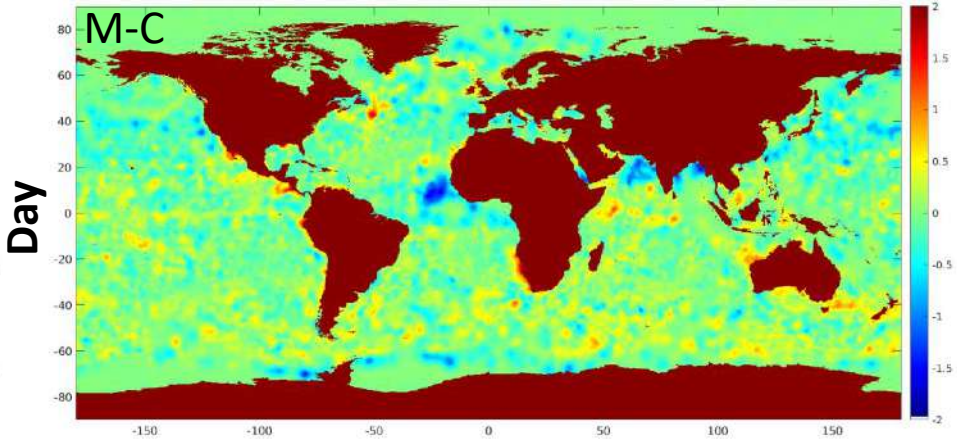




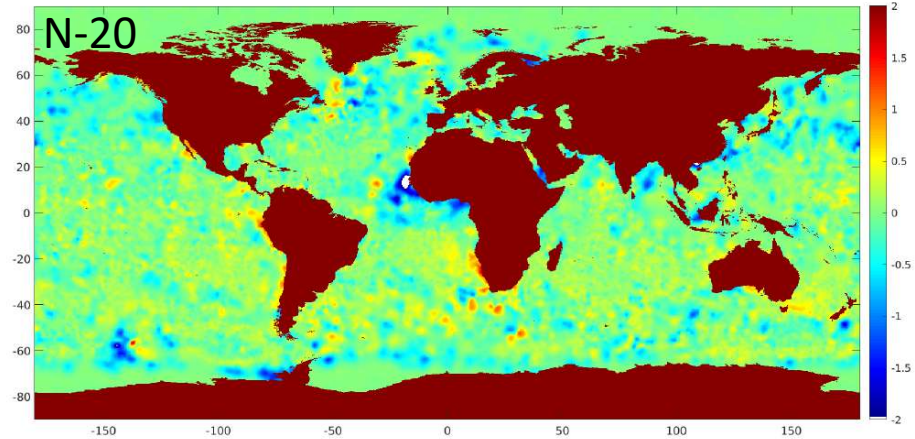
Night

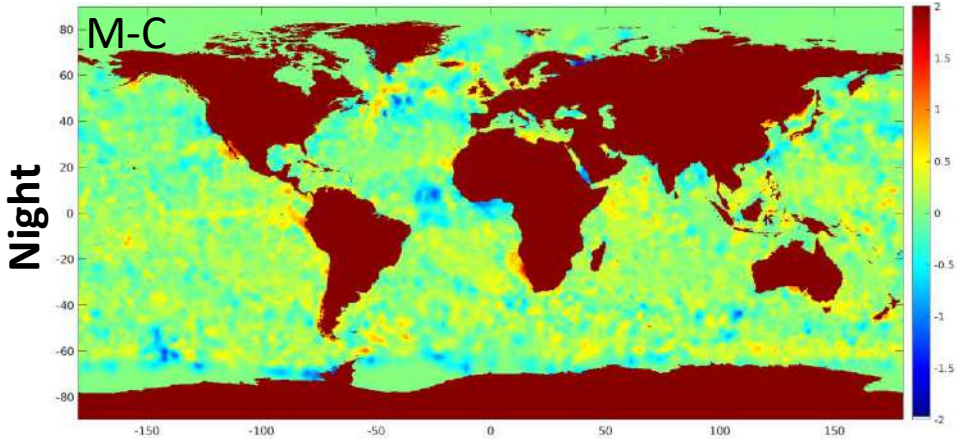
Bias Maps – April 3, 2021





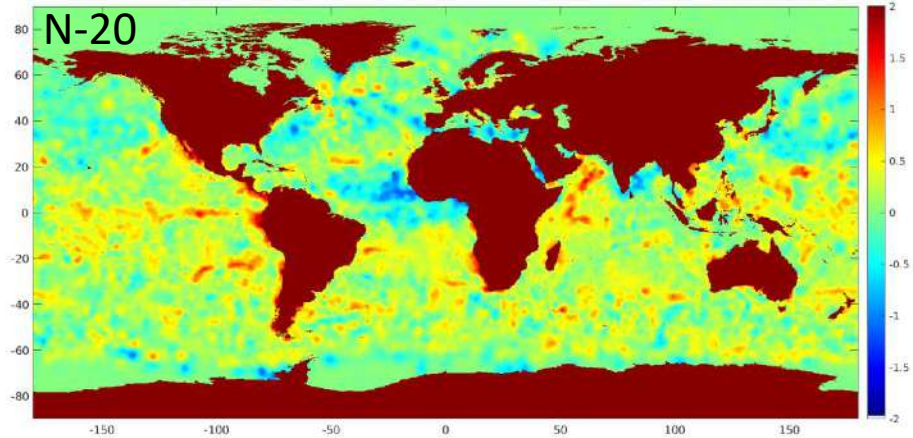
Day

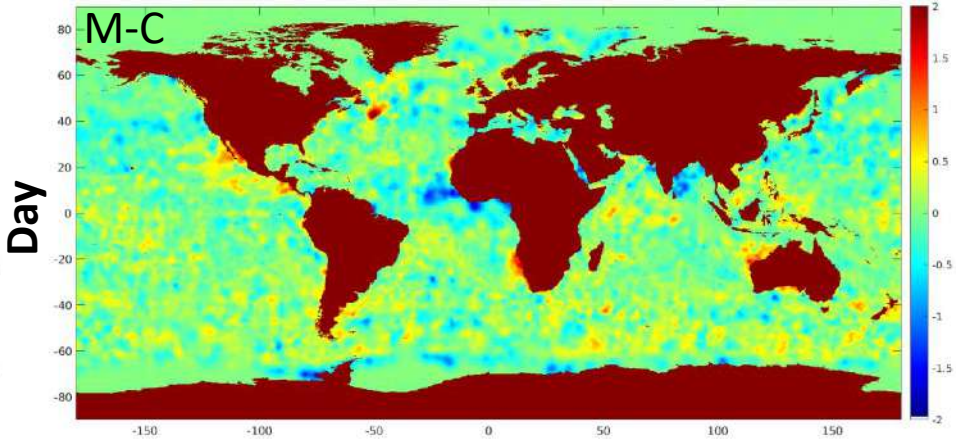




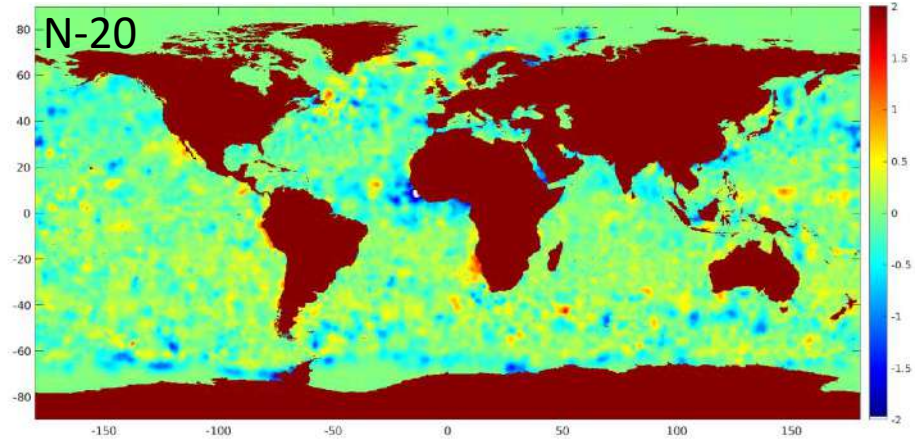
Night

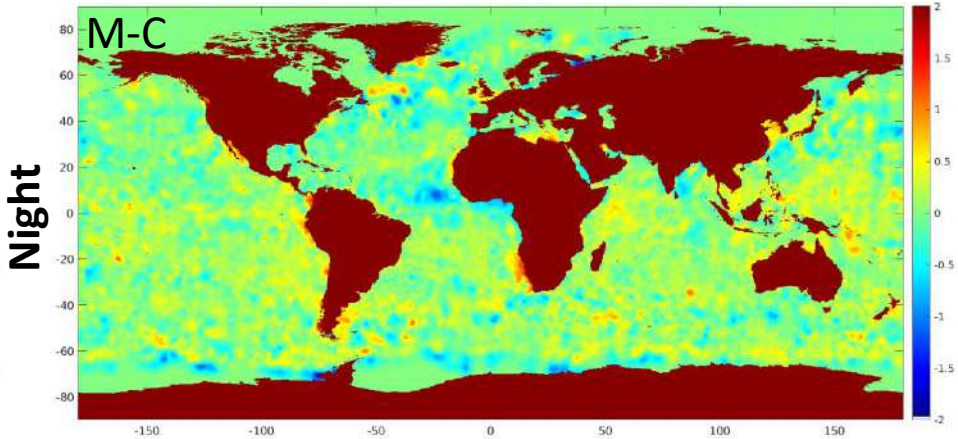
Bias Maps – April 4, 2021





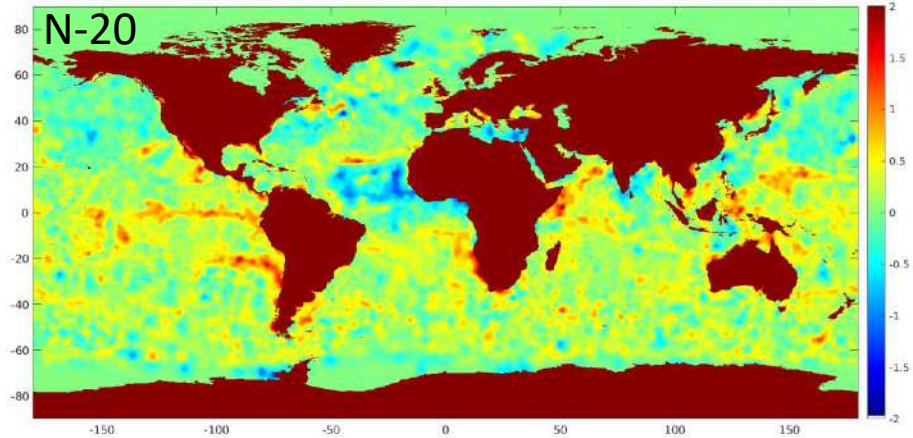
Day

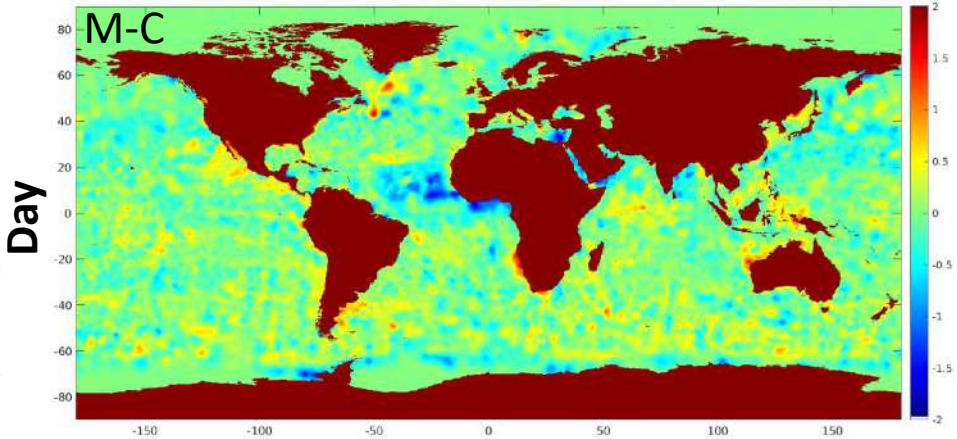




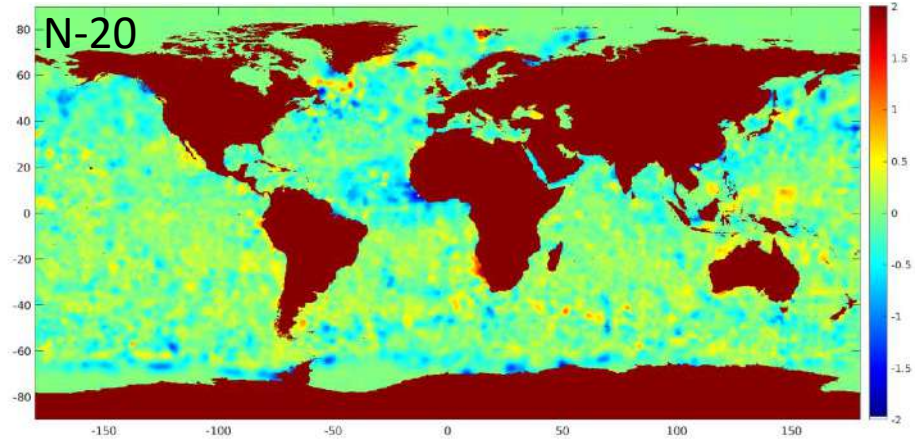
Night

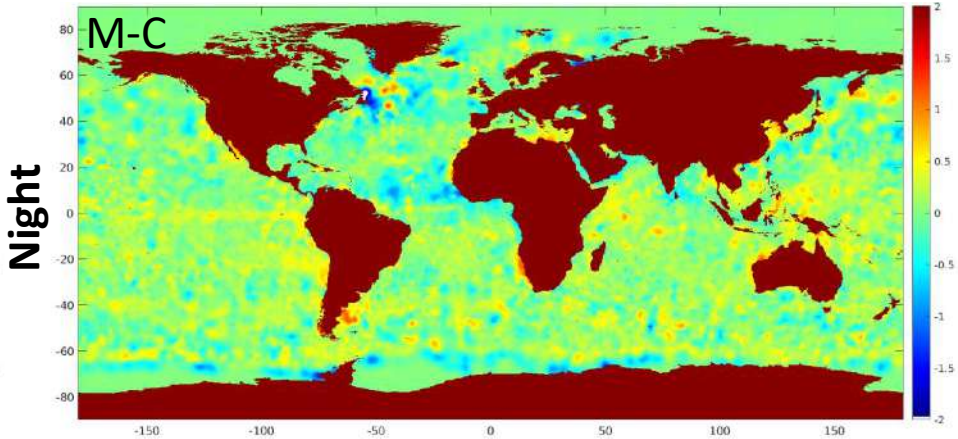
Bias Maps – April 5, 2021





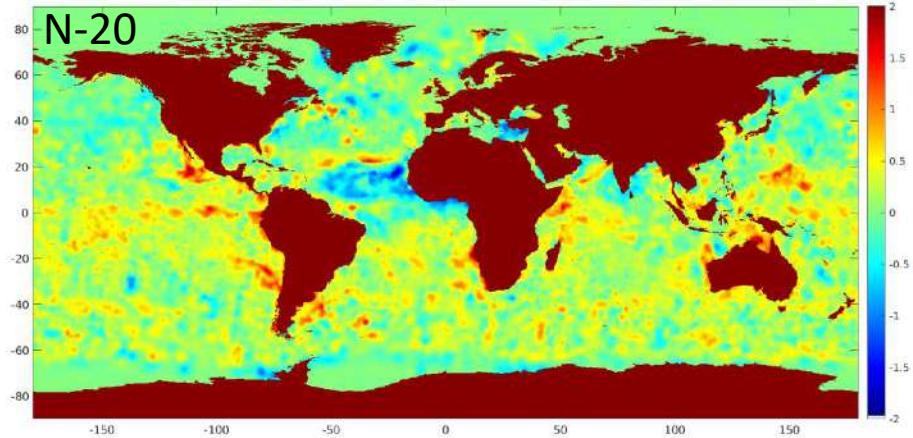
Day

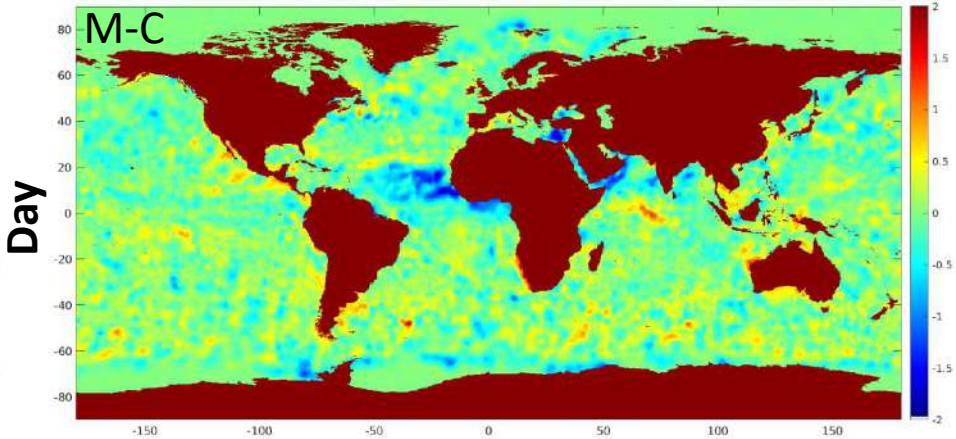




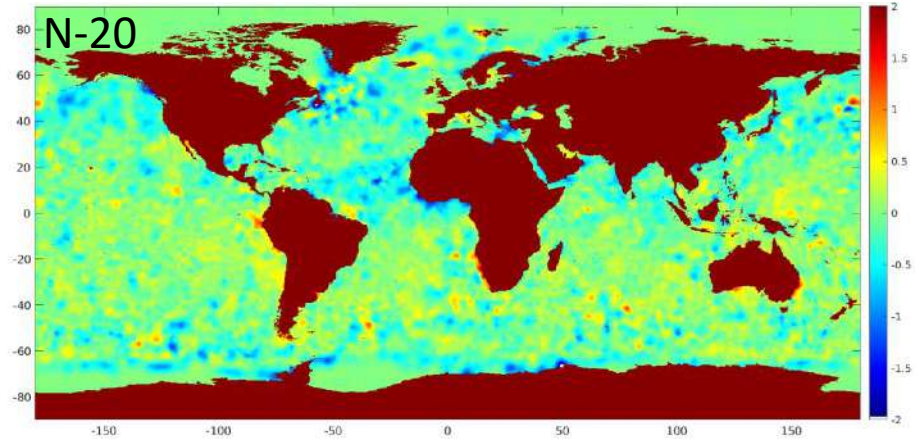
Night

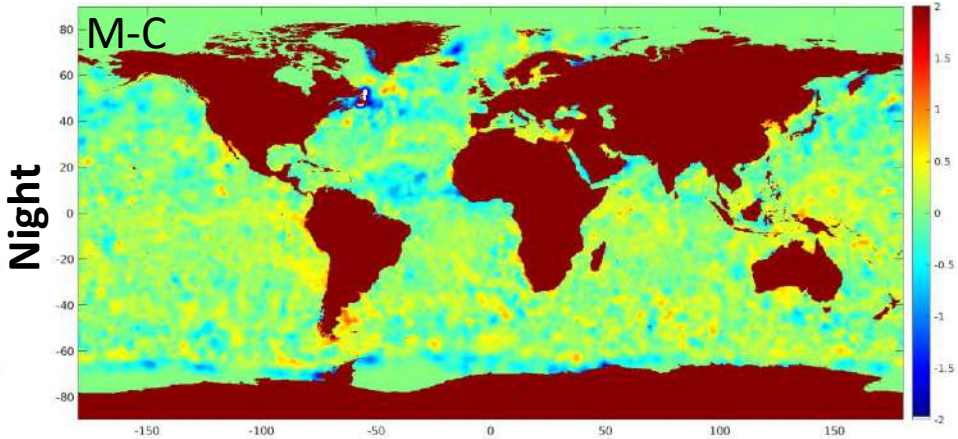
Bias Maps – April 6, 2021





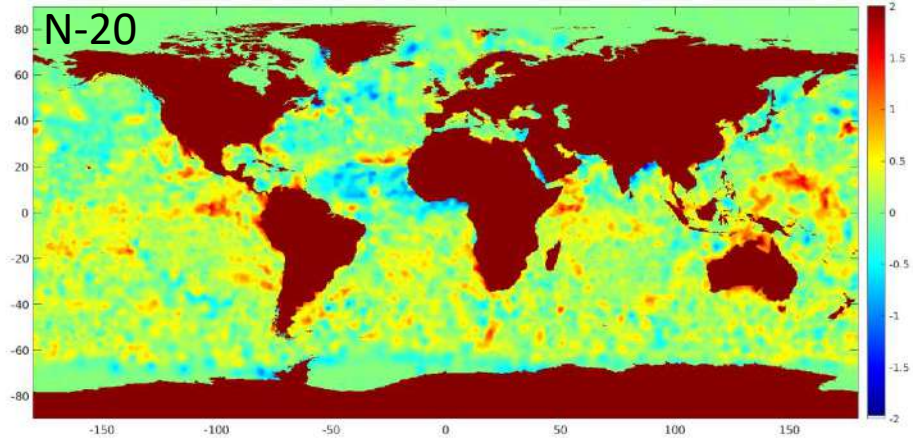
Day

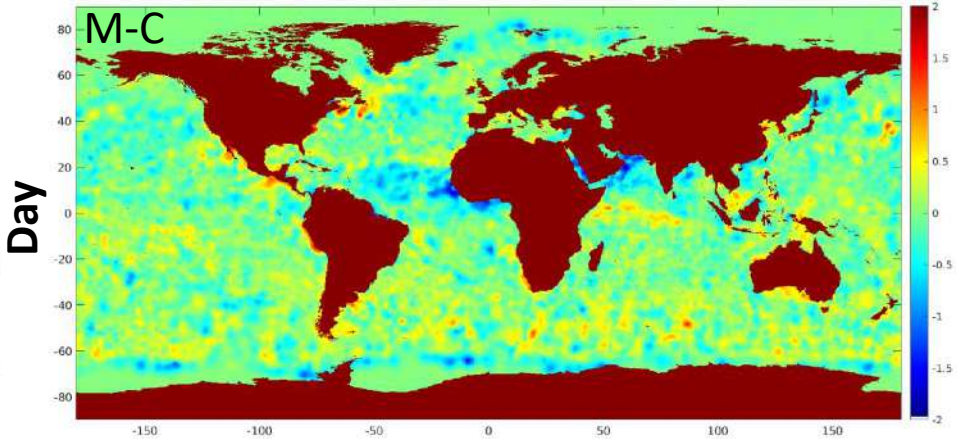




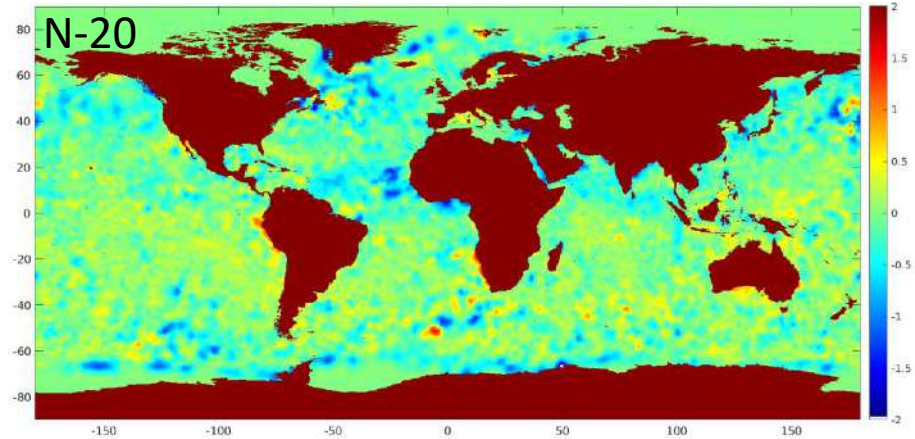
Night

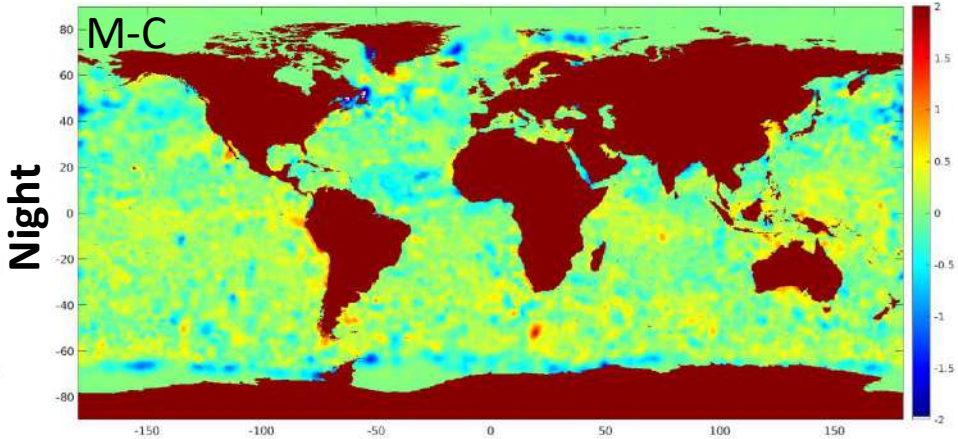
Bias Maps – April 7, 2021





Day





Night

Conclusions

- **S3A/B SLSTR offers a powerful method of correcting bias**
  - Dual-view is essential to mitigate effects (esp. aerosol – just wait 'til there is a **big volcano**…)
- **2 platforms ½ orbit apart mitigates effect of narrow (740 km) dual-view swath**
  - Still significant gaps due to cloud
  - Does restricting SLSTR to QL=5 miss significant aerosol?
- **Reference sensor approach has been used by other analyses (i.e. OSTIA)**
  - Use of nighttime VIIRS with SSES bias adjustment – may not work so well
- **Not all reference sensors are equal**
  - Perhaps a multi-stage approach to first correct the wider swath (e.g. VIIRS) data with SLSTR
- **Important to consider the persistence of different forms of bias**
  - Diurnal warming can vary considerably from day-to-day (N.B. wind <5 m/s screened for SLSTR)
  - Aerosol clouds may develop/advect relatively quickly
- **Consider using physical modeling (e.g. diurnal layer) and proxy information (e.g. aerosol)**
  - Avoid putting entire burden on statistical methods

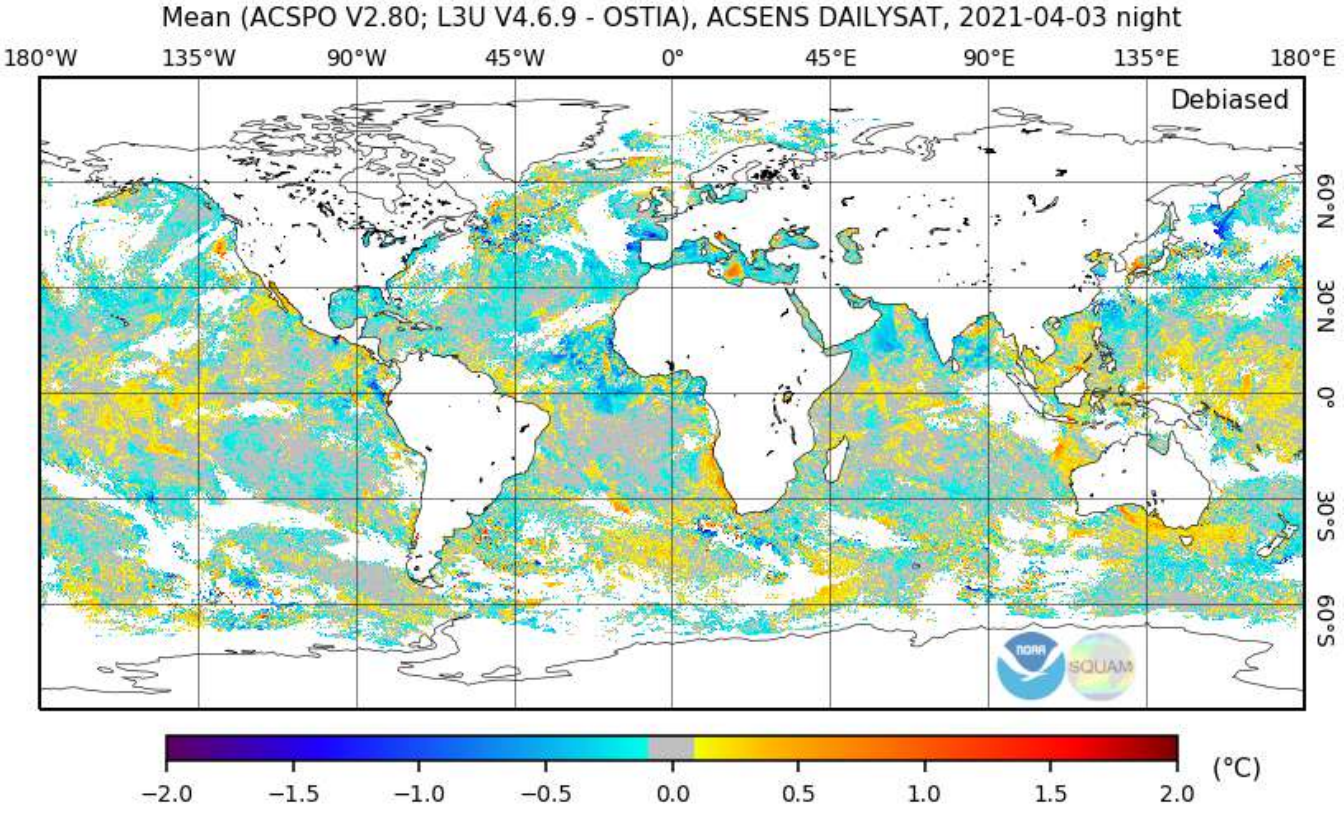
Conclusions

- **Current bias correction methods simply may not be adequate**
  - A lot of aerosol presentations this week illustrate the prevalence of one of the major issues
- **(A)ATSR series allows dual-view correction back to 1991**
- **Train proxy corrections using data from Pinatubo period**
  - Apply to AVHRR record from 1981-1991
  - Maybe AI/ML?
- **Preliminary indications are that, for such a key climate parameter with a long heritage, there remain <u>significant unanswered questions</u>**

Thank You

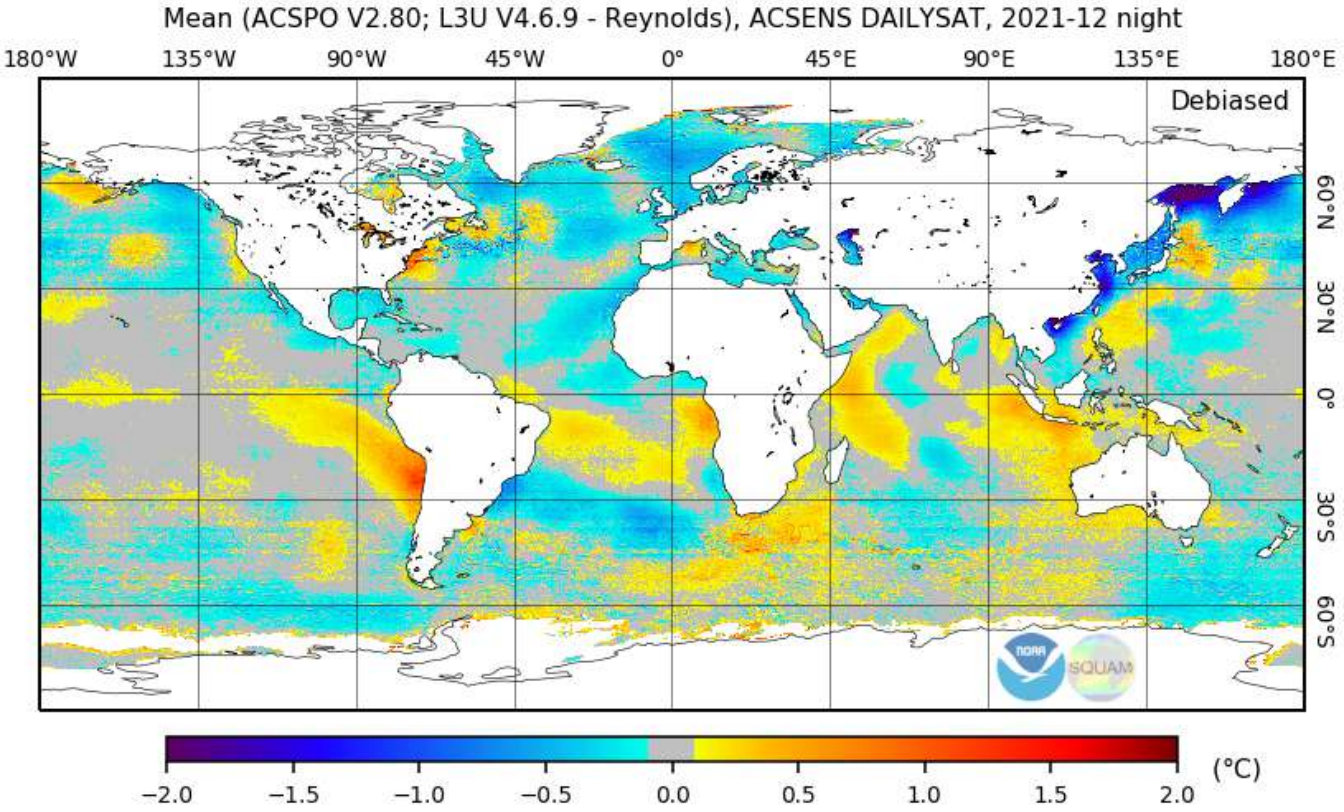
Backup Slides

Visible on NOAA SQUAM intercomparison page



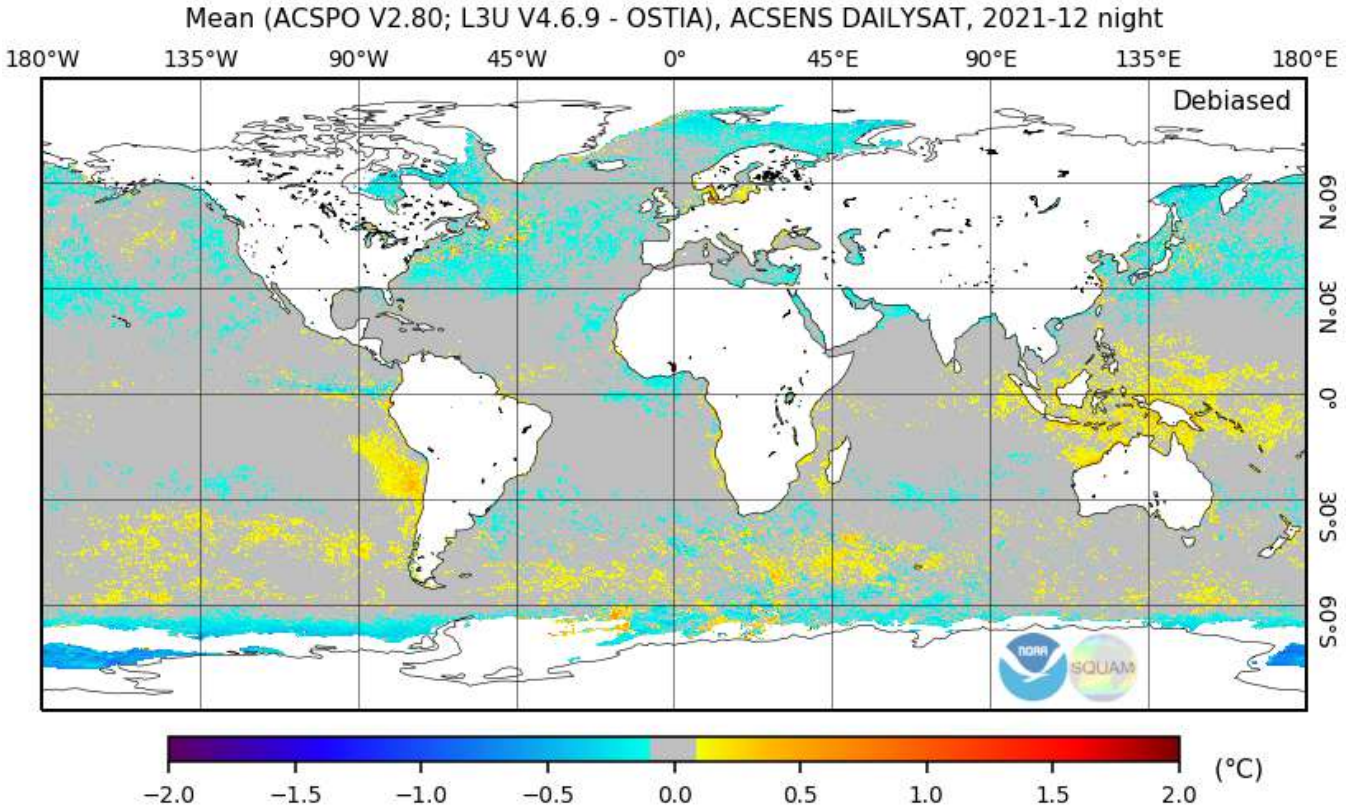
Backup Slides

VIIRS Daily Composite – Daily-OISST (December 2021)



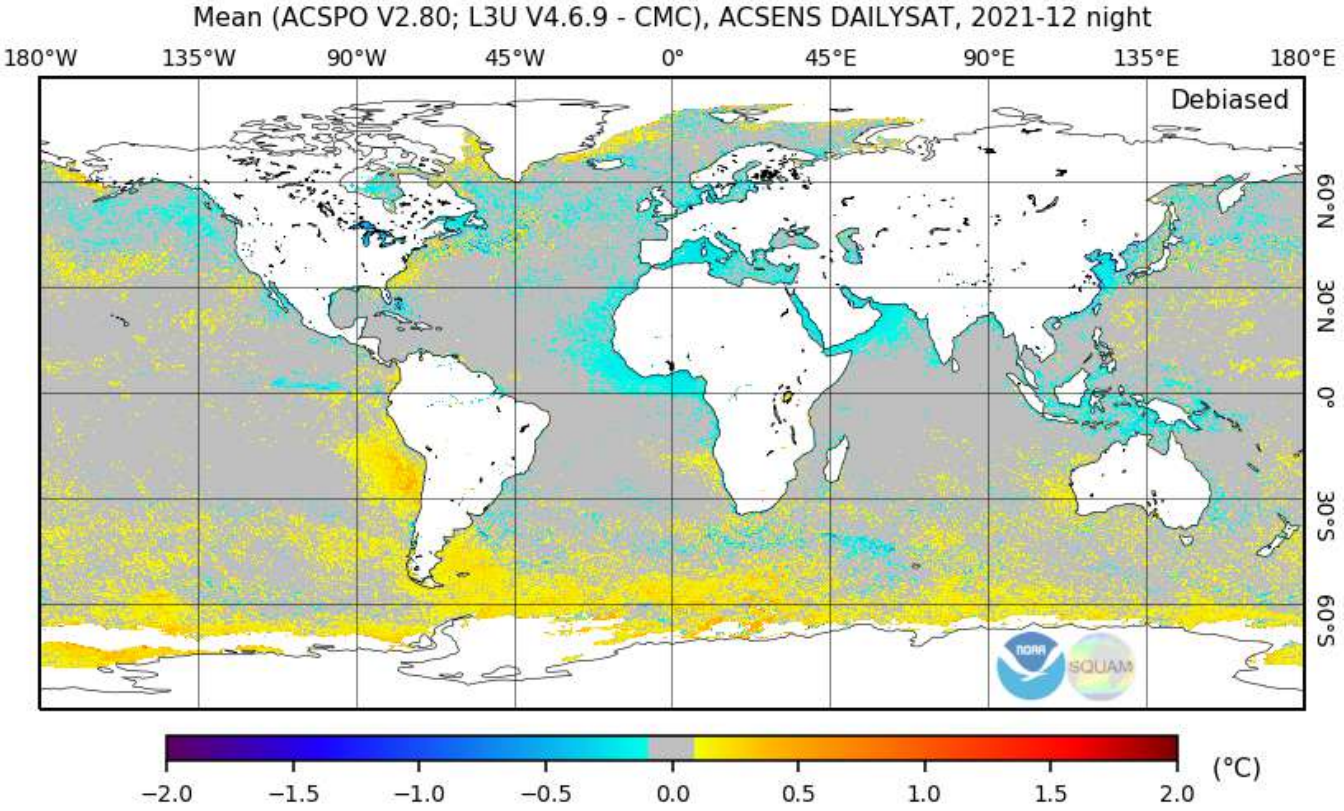
Backup Slides

VIIRS Daily Composite – OSTIA (December 2021)

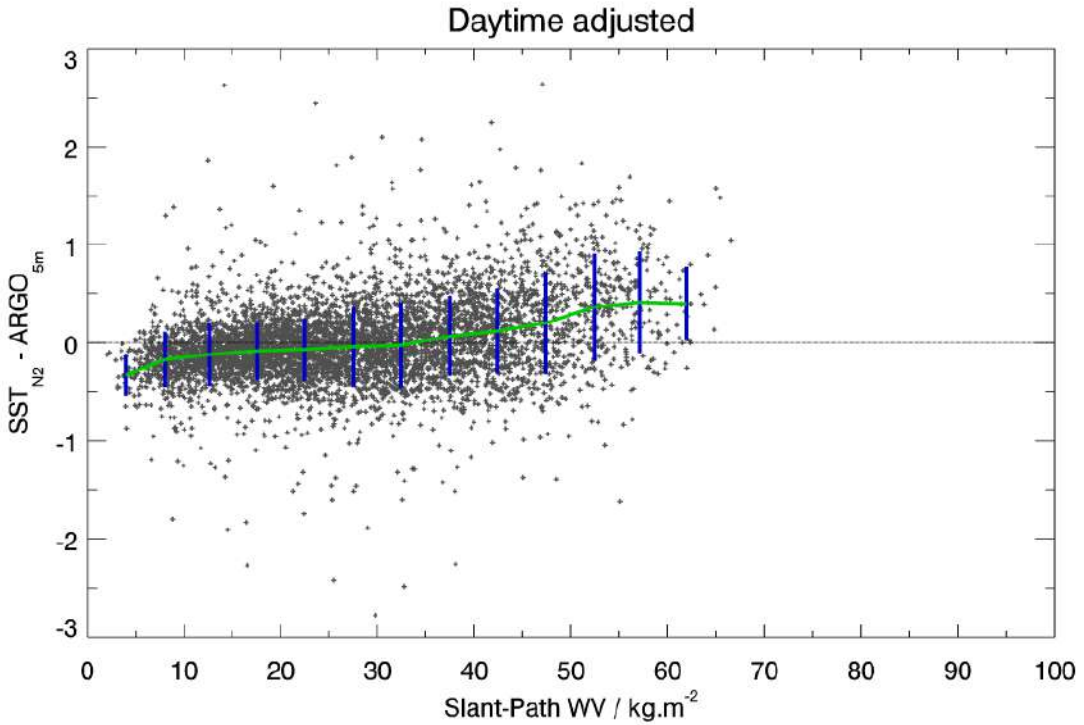


Backup Slides

VIIRS Daily Composite – CMC (December 2021)



Dependence on slant-path WV



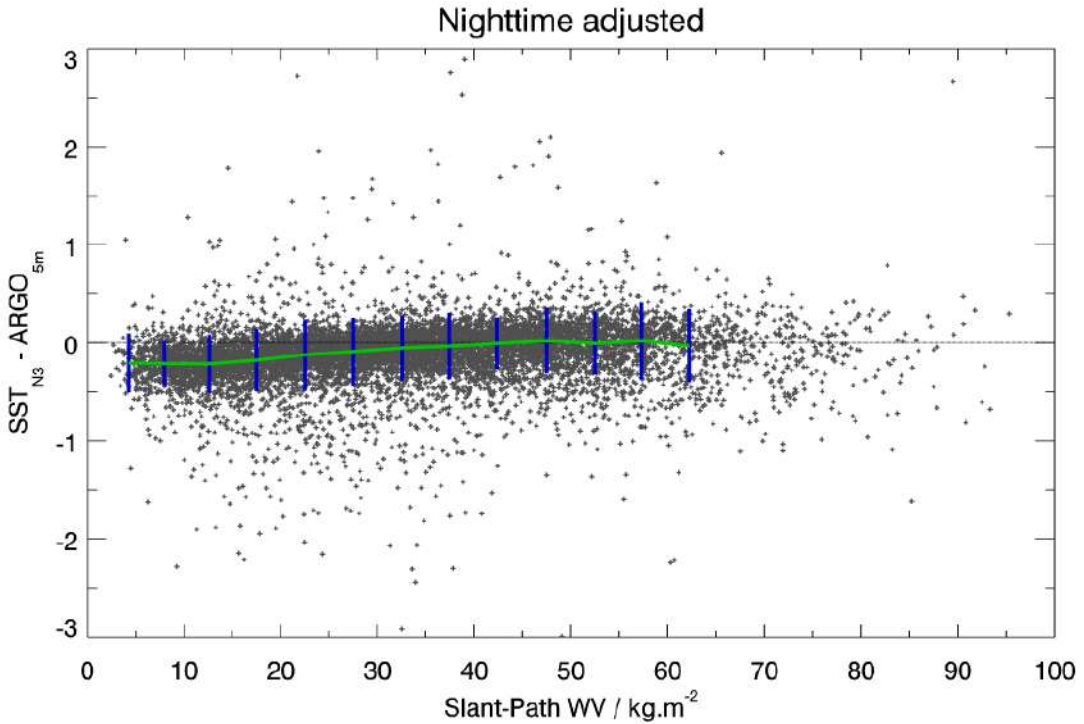
Daytime 2-channel

Again, distinct trend with higher water vapour

Fewer matches, less slant-path WV

N.B. Using WST QL

Dependence on slant-path WV

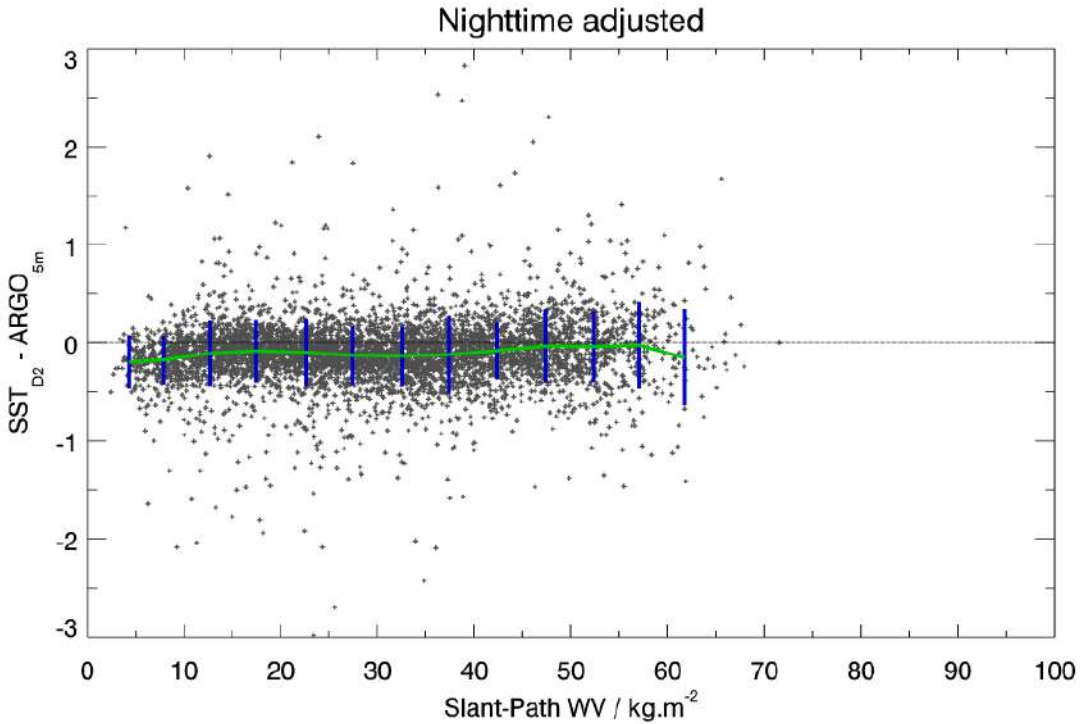


Nighttime 3-channel

Some trend with WV

N.B. Improved noise and linearity due to inclusion of 3.7 μm channel

Dependence on slant-path WV

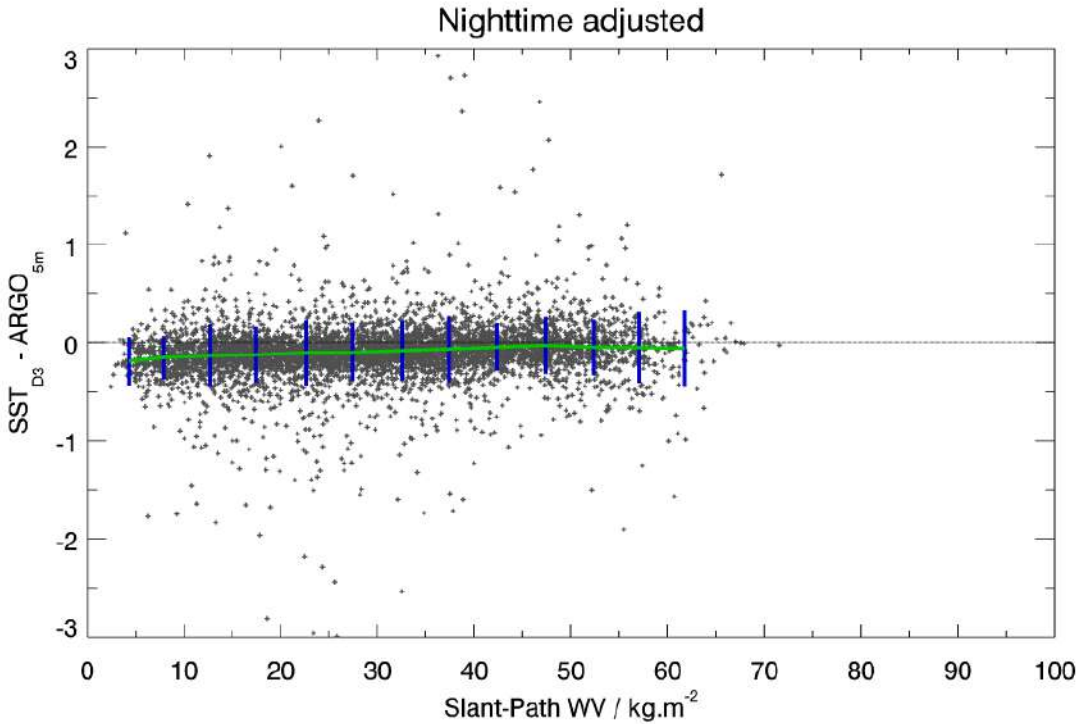


Nighttime Dual-2

Some structure due to WV (warmer at high values)

Note reduced range of slant-path WV

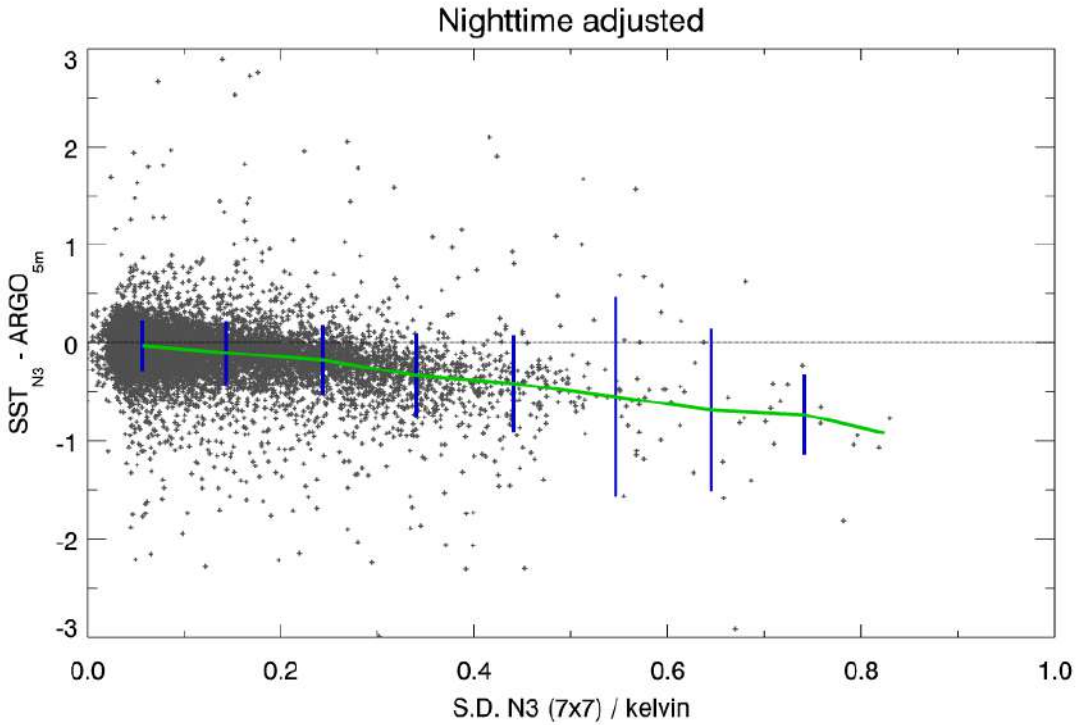
Dependence on slant-path WV



Nighttime Dual-3

About 0.2 K trend from low to high WV

Dependence on S.D. 7x7

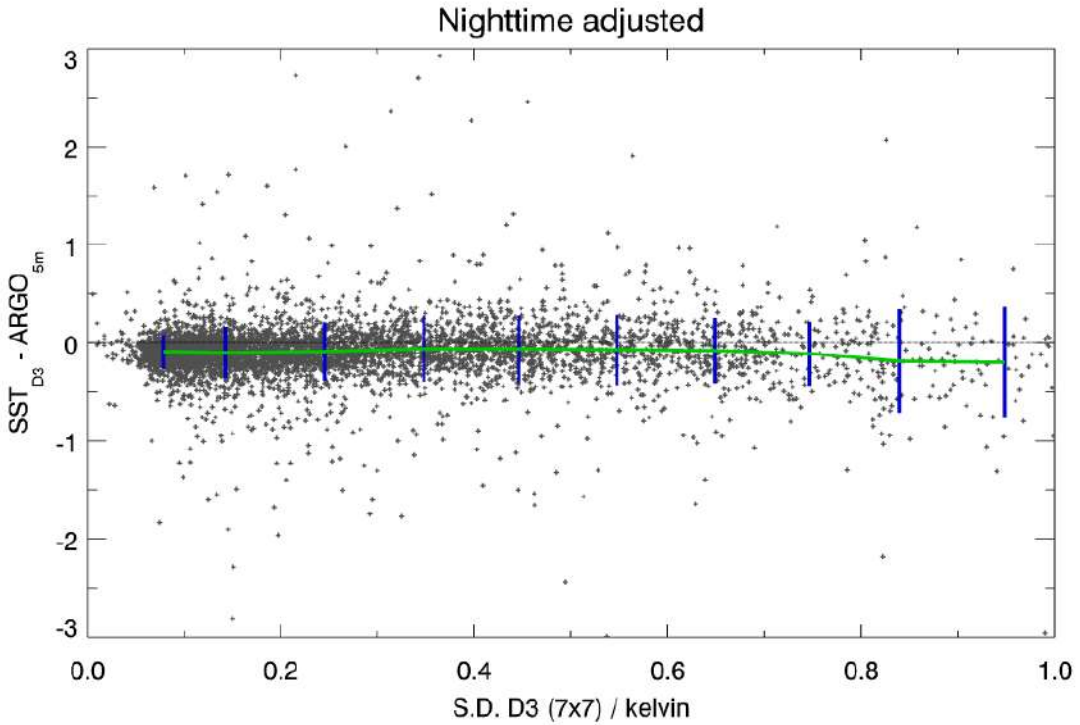


Nighttime 3-channel

Some trend w.r.t. S.D. in 7x7 box

Suggests residual cloud?

Dependence on S.D. 7x7



Nighttime Dual-3

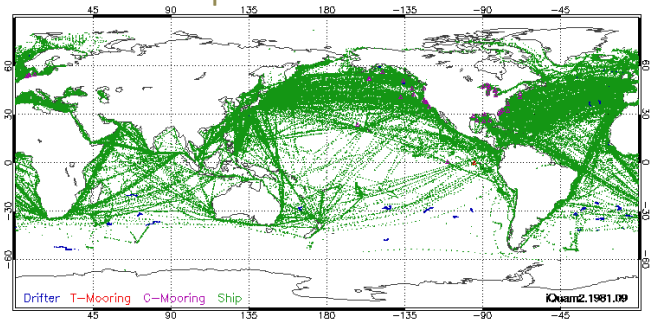
Virtually no trend w.r.t. S.D. in 7x7 box

N.B. Residual cloud in oblique view will produce warm bias

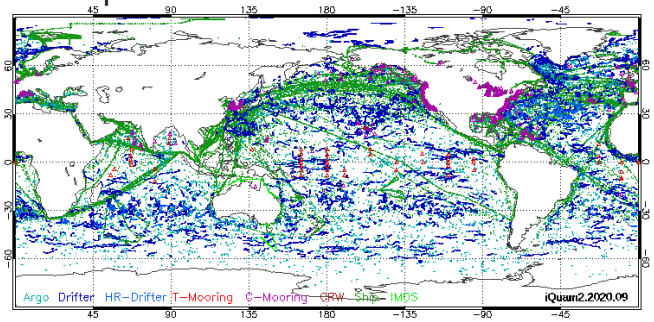
Reprocessing – the Bias Issue

- Cannot expect product to have uniform accuracy throughout 40-year period
- Should aim to ensure that biases remain ~consistent on appropriate time (~1 month) and space (~5°) scales
- Daily-OI uses in situ data (primarily buoys) to provide bias-free reference, but very sparse in early years of the record…

September 1981

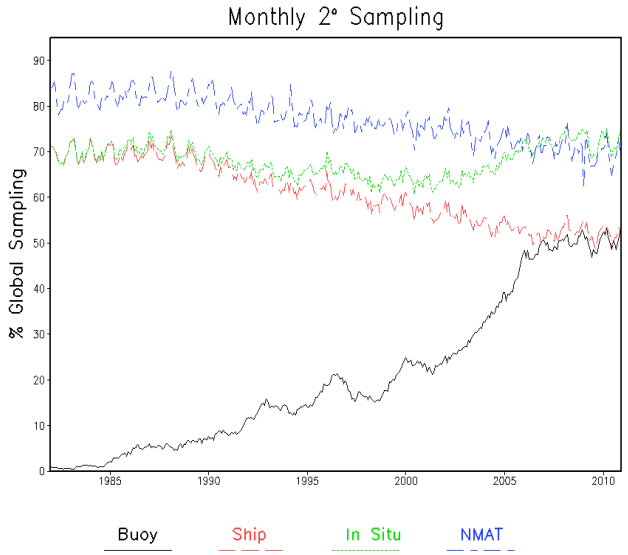


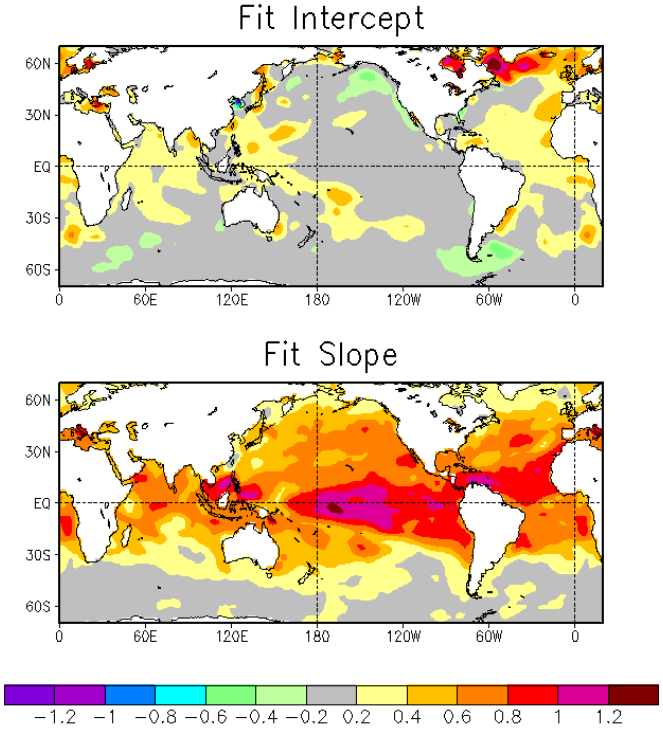
September 2020



Plots from NOAA SQUAM https://www.star.nesdis.noaa.gov/socd/sst/squam/

Reprocessing – Bias adjustment

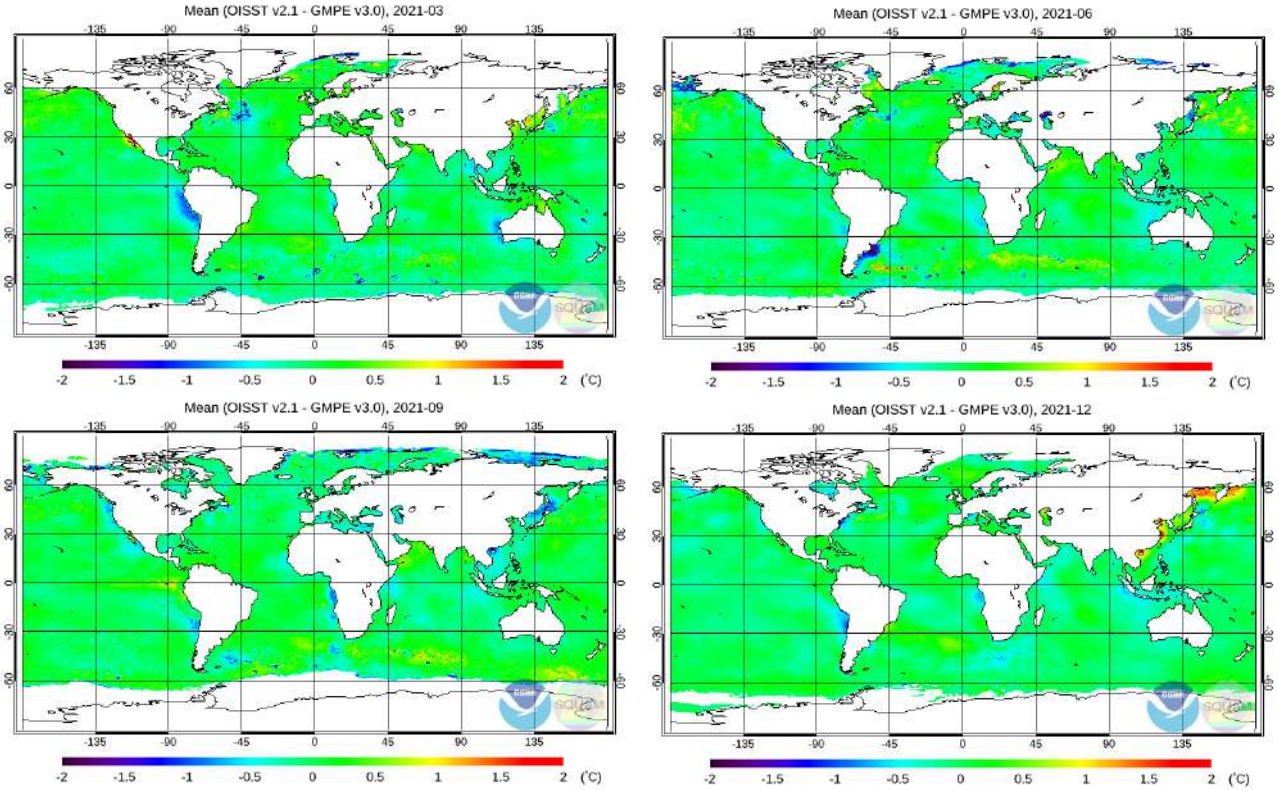




- *Tom Smith* proposal to include Night Marine Air Temperature (NMAT)
- Strength of coupling varies, but is potentially predictable via reanalysis & radiative transfer

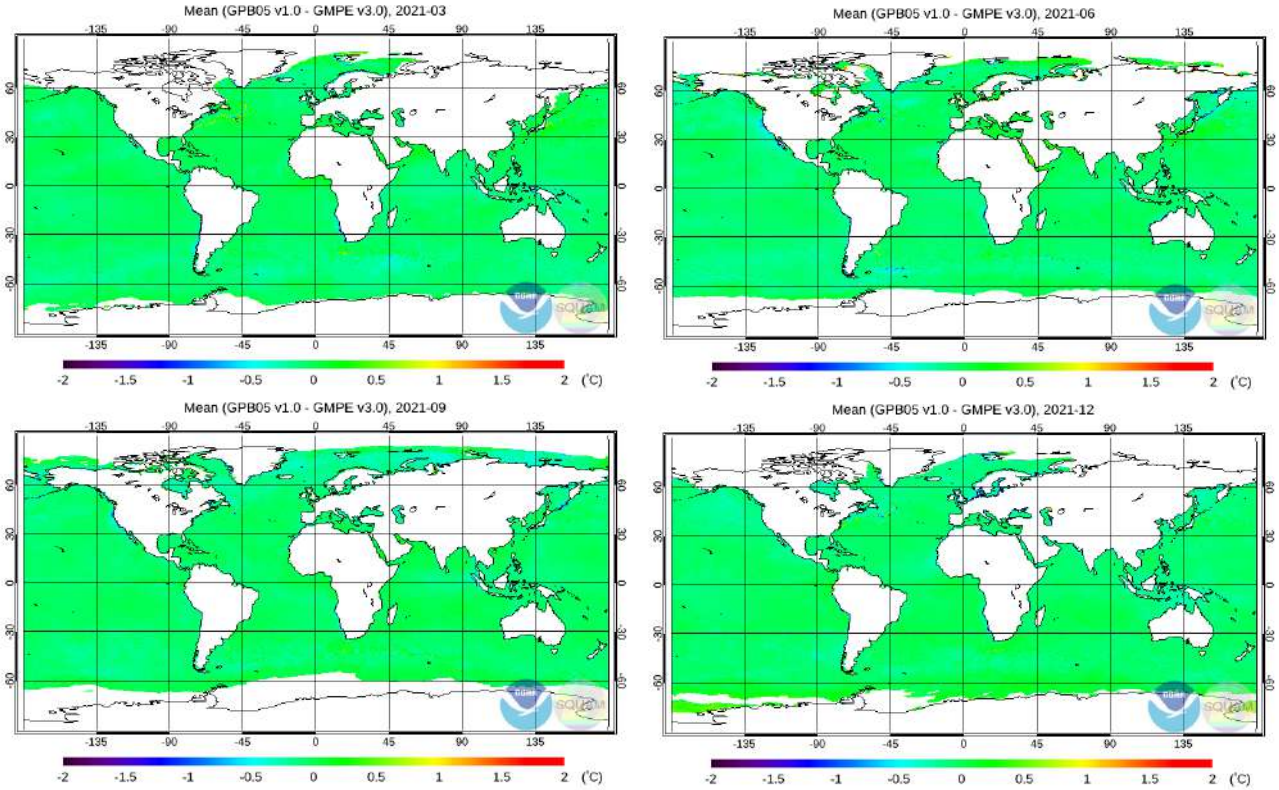
Will this be good enough?

Regional monthly biases



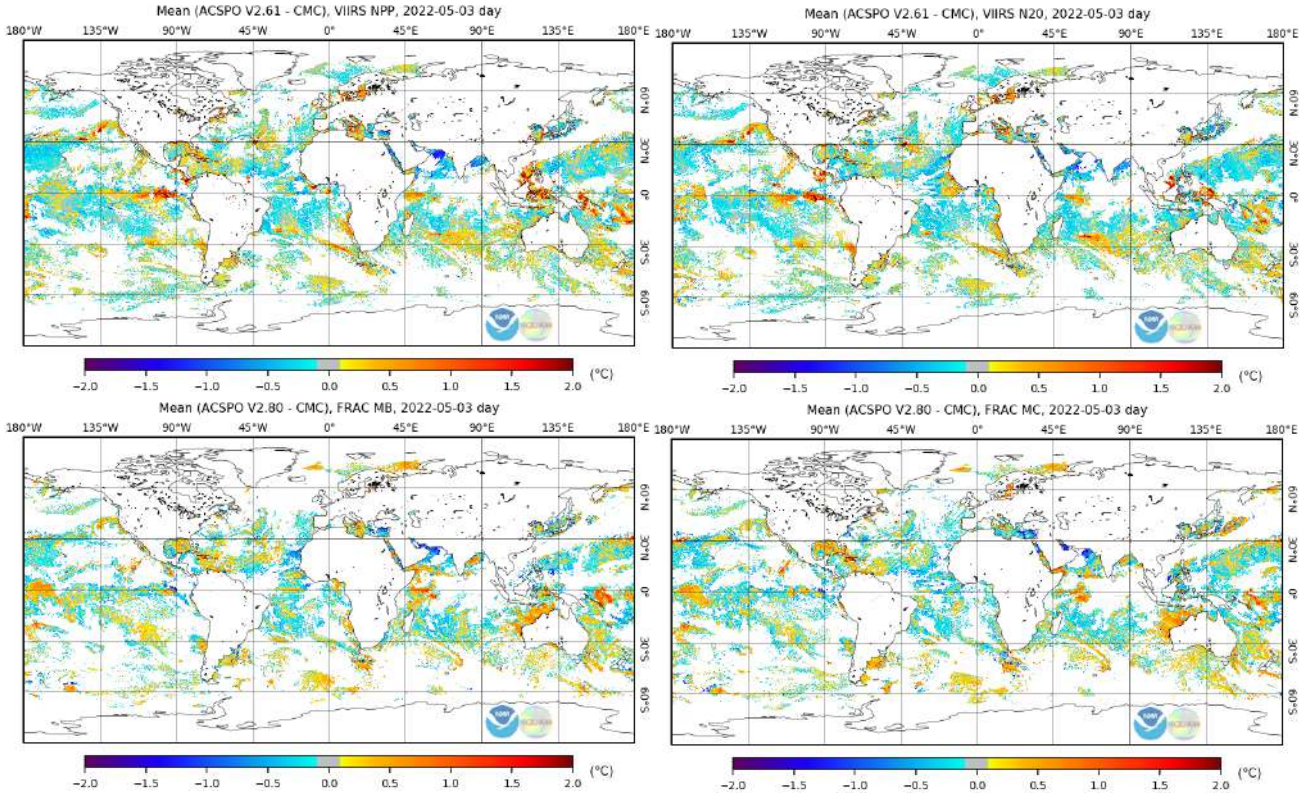
Daily-OI v2.1 bias w.r.t. GMPE Median, 03-06-09-12 2021

Regional monthly biases



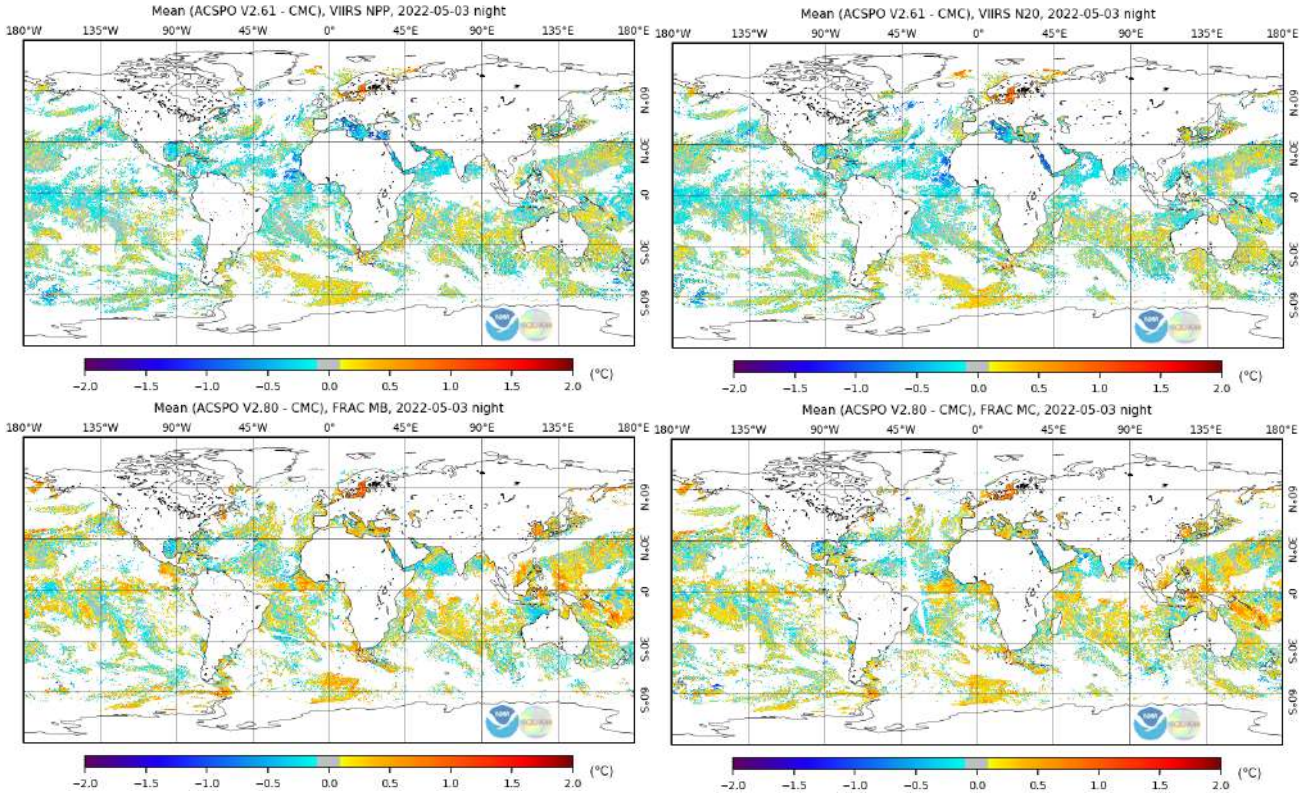
Geo-Polar Blended SST bias w.r.t. GMPE Median, 03-06-09-12 2021

Daytime biases w.r.t. CMC



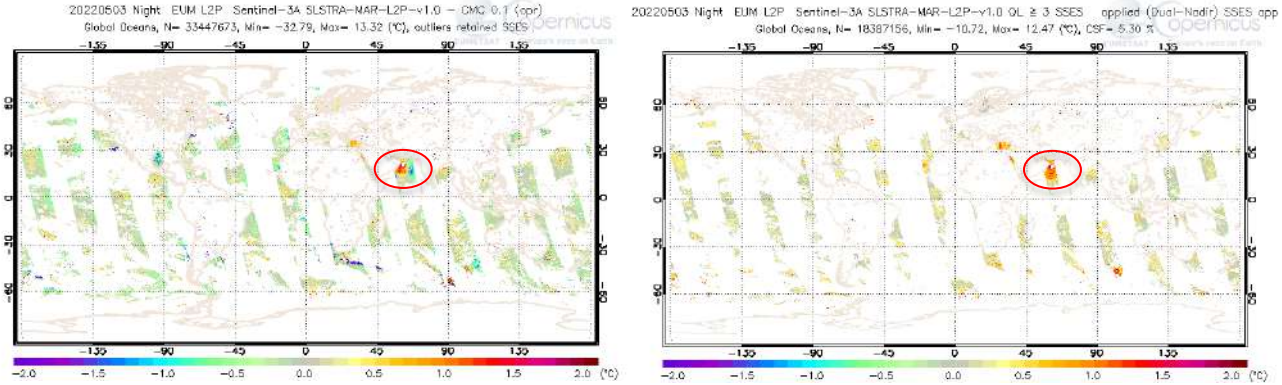
Top: S-NPP & NOAA-20 VIIRS Bottom: MetOp-B & C AVHRR

Nighttime biases w.r.t. CMC



Top: S-NPP & NOAA-20 VIIRS Bottom: MetOp-B & C AVHRR

Bias adjustment w/ reference sensor



- Use highest quality satellite data to fill in gaps & provide higher resolution bias correction field
- Propose Sentinel-3 A&B SLSTR (2016 – present)
  - (A)ATSR 1991 – 2012
  - Aerosol-capable retrieval (e.g. MODIS, Koner & Harris, 2016)?
  - Predictors from ancillary data (e.g. TOMS, HIRS), trained/validated on Pinatubo period