Sea Surface temperature reprocessing of Himawari-8 archive

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24th GHRSST Science Team Meeting, Ahmedabad, India

and online, 16th to 20th October 2023

Himawari-8/9 Geostationary satellite

- Operated by JMA

- located at 140.7°E and observes the Earth from 80°E to 160°W and from 60°N to 60°S

- Himawari-8: operational for 7th July 2015 -11th December 2022, Himawari-9: operational from 12th December 2022-present

The optical radiometer, advanced Himawari imager (AHI), on board Himawari-8 and Himawari-9 provides full disk images:

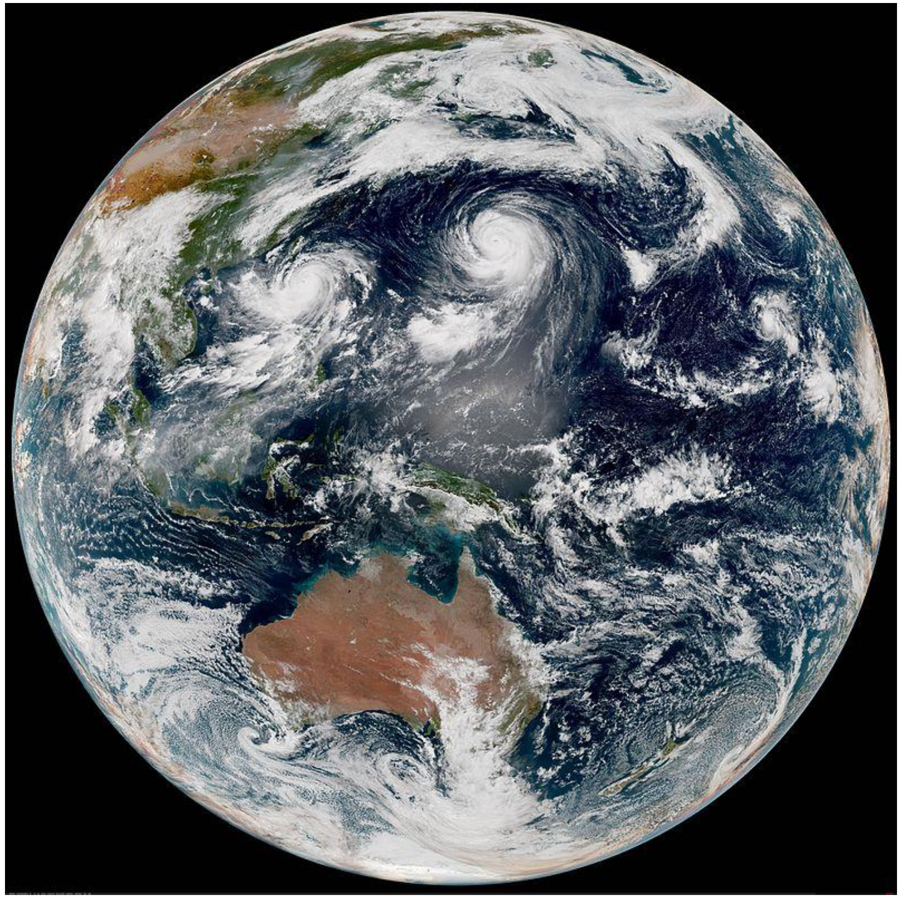
- Every 10 minutes, 2 km spatial resolution for infra-red (IR) frequency data at nadir.

- 16 spectral bands for visible-infrared wavelengths

Our SST retrieval method is based on the ESA CCI SST code (Merchant et al., 2019) :

➢ Radiative Transfer Model
➢ Bayesian cloud clearing method
➢ Empirical Bias model based on in-situ SSTs

Rayleigh-corrected, true-colour full disk Himawari-8 image
https://en.wikipedia.org/wiki/Himawari_8#/media/File:Himawari_8_Full_Disk_Aug_21_2015_0210Z.jpg



Radiative Transfer Model (RTTOV12.3)

- Simulates top-of-atmosphere radiances from brightness temperatures (BTs) for thermal channels and reflectances for solar affected channels.
- Uses an atmospheric profile of temperature, water and surface properties as state vectors

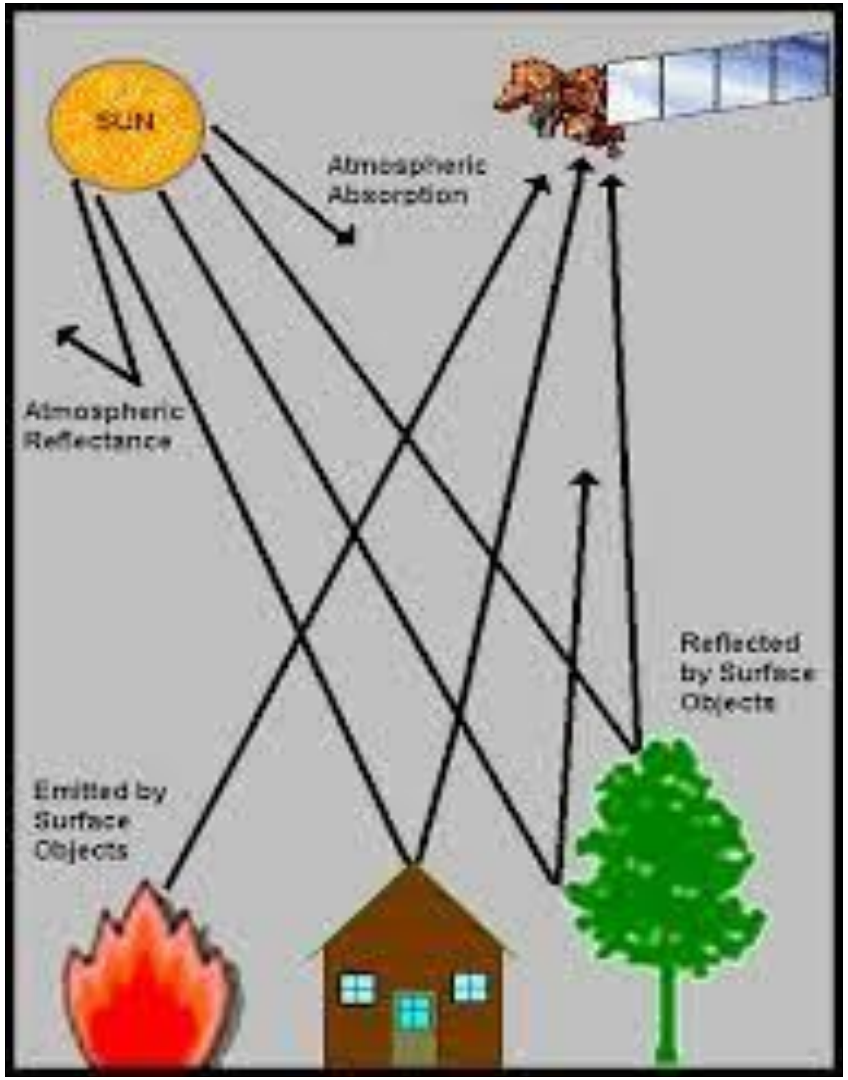
Data used:

- Himawari-8 Channels:

  Day-time: 3, 4, 13, 15 [0.64, 0.86, 10.4, 12.4 μm]

  Twilight: 13, 15 [10.4, 12.4 μm]

  Night-time: 7, 13, 15 [3.9, 10.4, 12.4 μm]
- ACCESS-G Analysis and forecast data
- OSTIA L4 Ice data
- GAMSSA SST Analysis



Picture taken from web

Cloud detection

- Physically-based, probabilistic Bayesian approach has been used for cloud detection to determine clear sky conditions
- Satellite observations and prior knowledge of the surface conditions are used to estimate clear-sky probabilities

$$P(c|\mathbf{y}, \mathbf{x}) = \frac{P(\mathbf{y}|\mathbf{x}, c)P(\mathbf{x}|c)P(c)}{P(\mathbf{y}|\mathbf{x})P(\mathbf{x})}$$

Where,
c- clear sky
y - observation vector
x - state vector (the meteorological condition)

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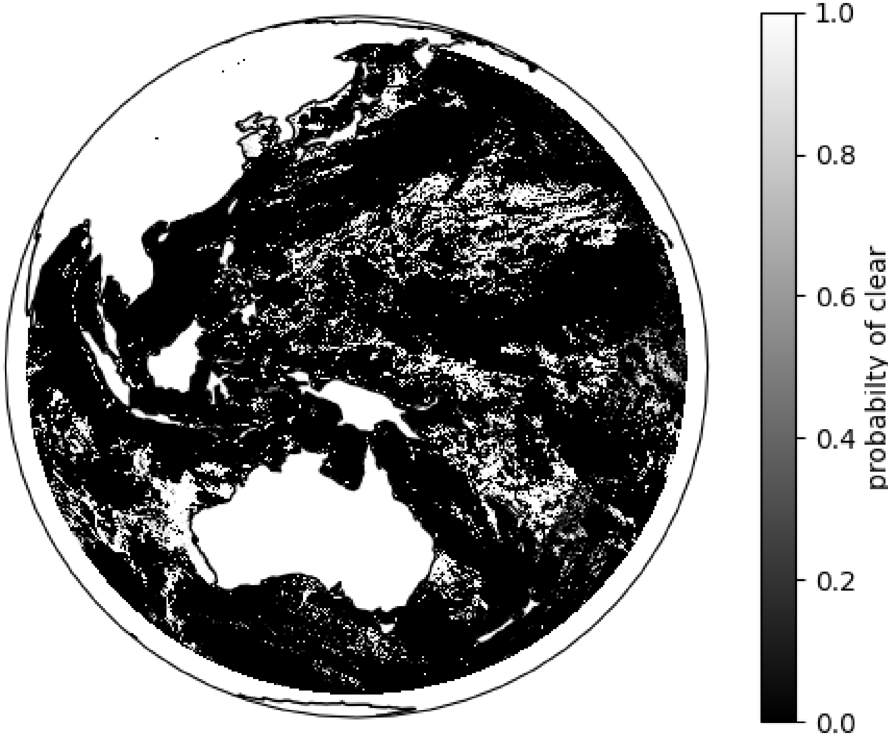
Probability of pixel being clear



- The pixels with probability greater than 0.9 are considered clear

The incidence of both missed cloud and false detection of cloud are significantly less in Bayesian approach than traditional approach to cloud screening (Embury et al., 2012).

SST retrieval

The SST was retrieved using an optimal estimation (OE) scheme:

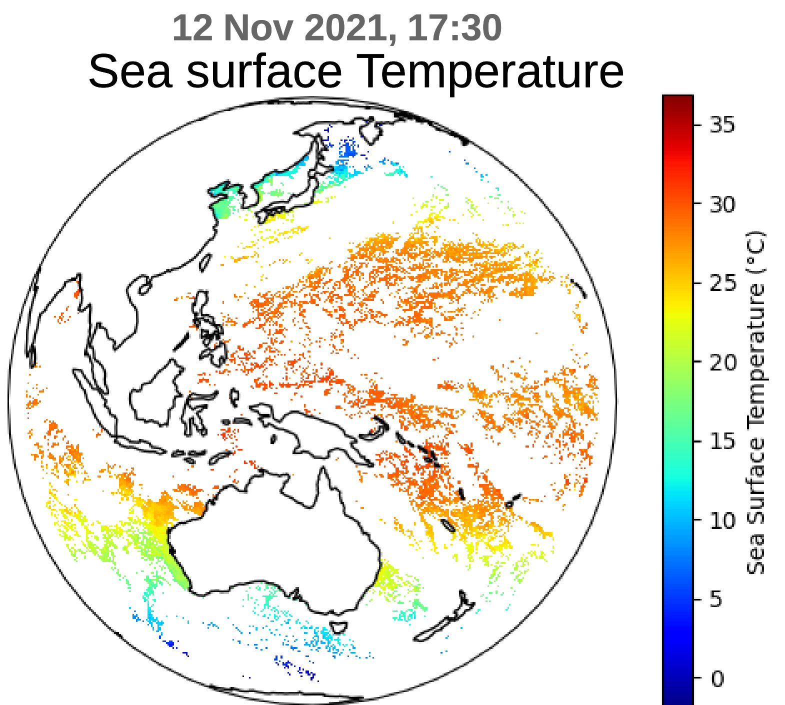
a priori knowledge

observation-simulation difference

$$\mathbf{z} = \mathbf{z}_a + \mathbf{S}_a\mathbf{K}^{\mathrm{T}}(\mathbf{K}\mathbf{S}_a\mathbf{K}^{\mathrm{T}} + \mathbf{S}_{\varepsilon})^{-1}(\mathbf{y} - \mathbf{F}(\mathbf{x}_a))$$

RTTOV

error covariance of observations and simulations



Where, z is a matrix with the retrieval results of SSTskin and TCWV,
z_a is a matrix with the background SSTskin and TCWV,
y is satellite observed BT,
$F(x_a)$ is simulated BT calculated by RTTOV12.3
K is a tangential vector, consisting of the partial derivative of the simulated BT to background SSTskin and TCWV,
S_ε is the covariance matrix of the satellite observed BT and the simulated BT,
S_a is the error of the background SSTskin and TCWV.

Quality Levels

QL =1 : Pclr < 0.5, sst sensitivity < 0.5, OE chi^2 > 3.

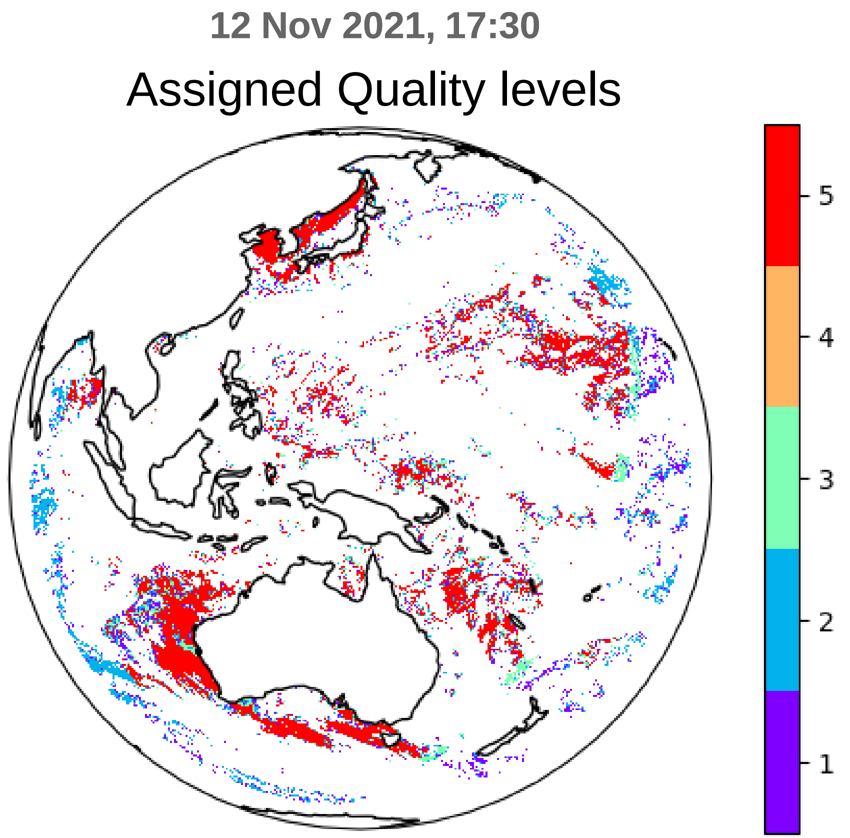
QL = 2 : Pclr < 0.8, sst sensitivity < 0.9. OE chi^2 > 2

QL = 3 : Twilight, Pclr < 0.9, sst sensitivity < 0.95, OE chi^2 > 1

QL = 4 : Dust detected

QL = 5 : Pclr > 0.9, sst sensitivity > 0.95, OE chi^2 < 1

where,
Pclr - clear sky probability,
sst sensitivity - sensitivity of the retrieval to the real sst,
OE chi^2 - chi squared of the deviations of the observed BTs relative to the modelled BTs



SSES bias model

- Empirical model based on in-situ SST data
- Rolling 1 month window adjusted every 5 days
- 6-d model based on time of day, satellite zenith angle, quality level, longitude, latitude and age
- Least squares regression to highly correlated components
- per pixel
- similar for GEO and LEO

$$n = n_{\text{swath}} g_n$$

$$\mu = \mu_{\text{swath}} + g_\mu$$

$$\sigma = \sigma_{\text{swath}} g_\sigma$$

Swath, or "Field of view" Component:
- Satellite Zenith Angle
- Solar zenith angle
- Quality level

Geographic Component:
- Latitude
- Longitude
- Time
- Quality Level

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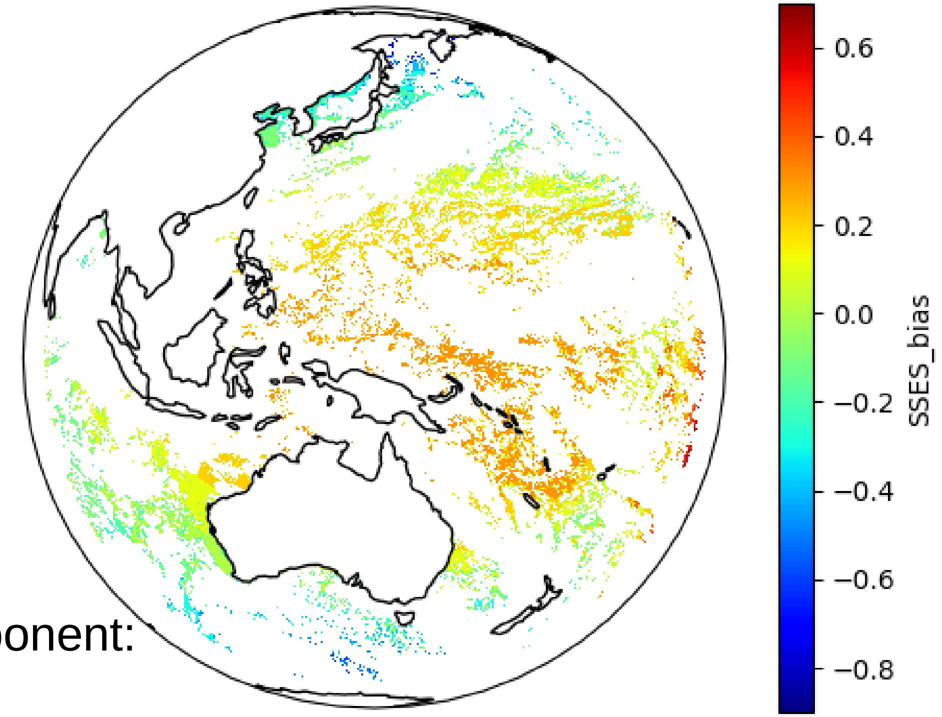
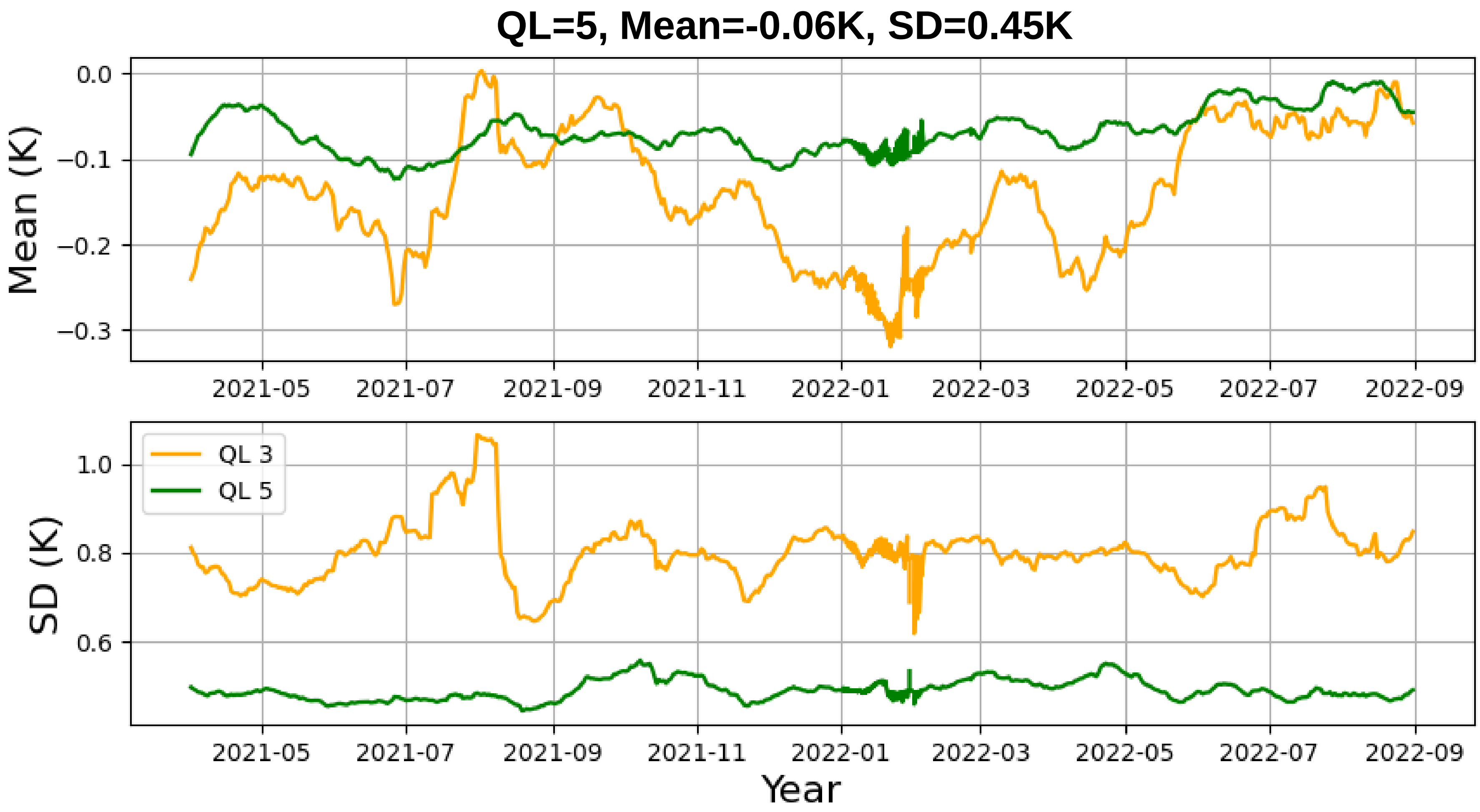
SSES_bias calculated with our model



Validation of Himawari-8 L2P against in-situ (drifting buoys and tropical moorings) from GTS

Monthly statistics, Apr 2021 - Aug 2022, Mean = SSTskin - in situ SSTdepth + 0.17 (in Kelvin),
Match-up thresholds: < 10 km distance and ± 6 hours. Criteria: Wind speed > 6 m/s (day), > 2 m/s (night)



Himawari-8 L3C SST Products

Method:

Hourly uses 10-minute L2P SST
Choose the observation closest to the linear interpolation of the T-60min … T+0min 10 minute SST to the time in question. Goal is to choose an observation, not compute an SST.

4 Hourly uses hourly SST
Choose the observation closest to the linear interpolation of the T-240min … T+0min hourly SST to the time in question. Goal is to choose an observation, not compute an SST.

Night uses hourly SST
Night L3C is determined by choosing the latest hourly SST after local sunset that has the best quality.

Resolution: Hourly, 4-hourly and Daily night-time, 0.02º x 0.02º

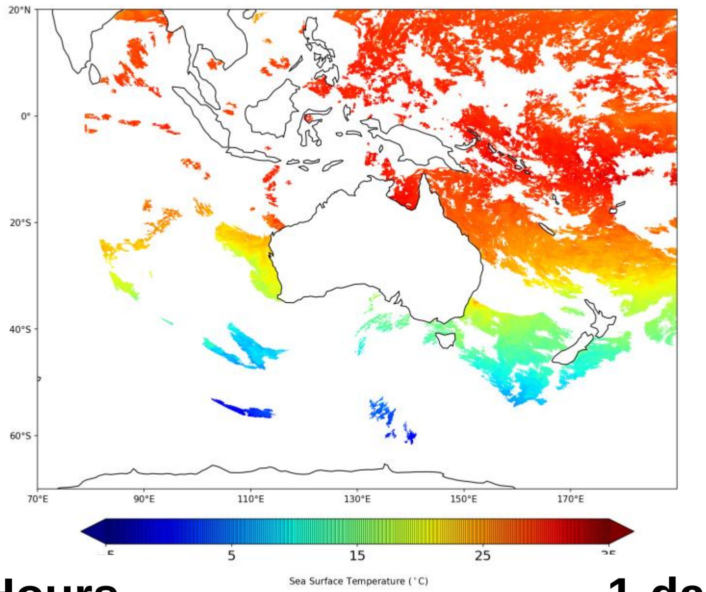
Available: Sep 2015 - Dec 2022

Access: http://portal.aodn.org.au and

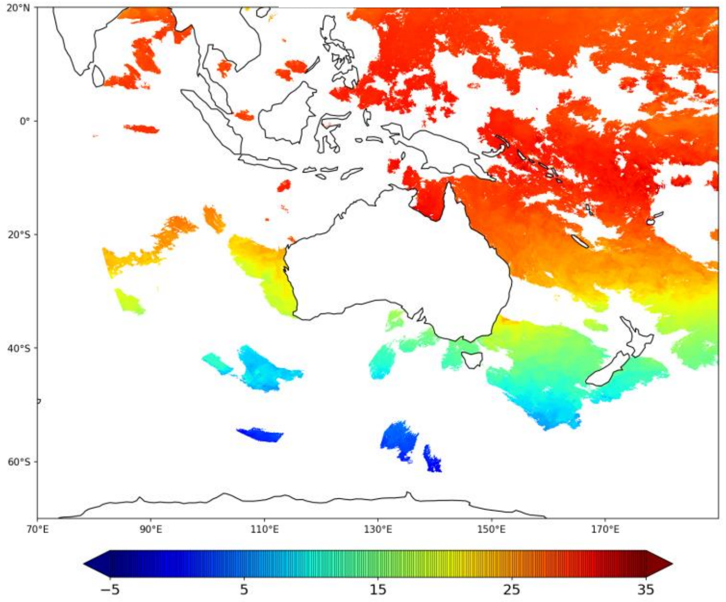
https://geonetwork.nci.org.au/

15 Mar 2020 H-8 L3C SSTskin for QL ≥ 3

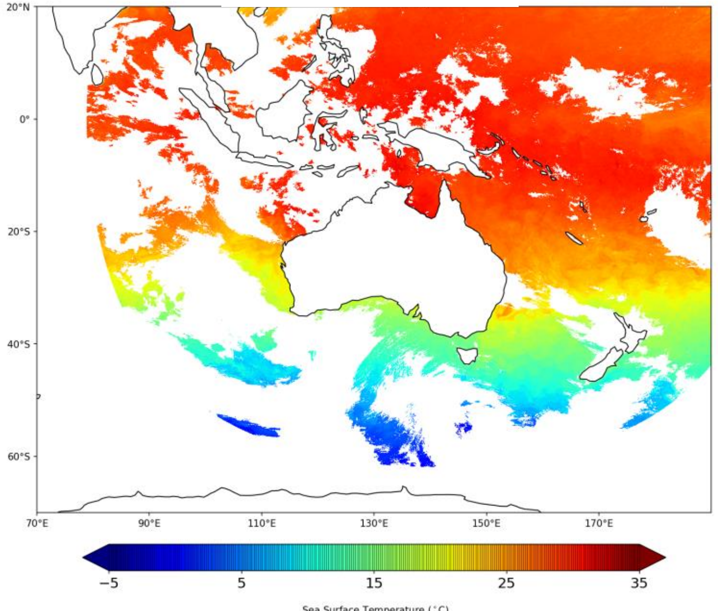
1-Hour



4-Hours



1-day night

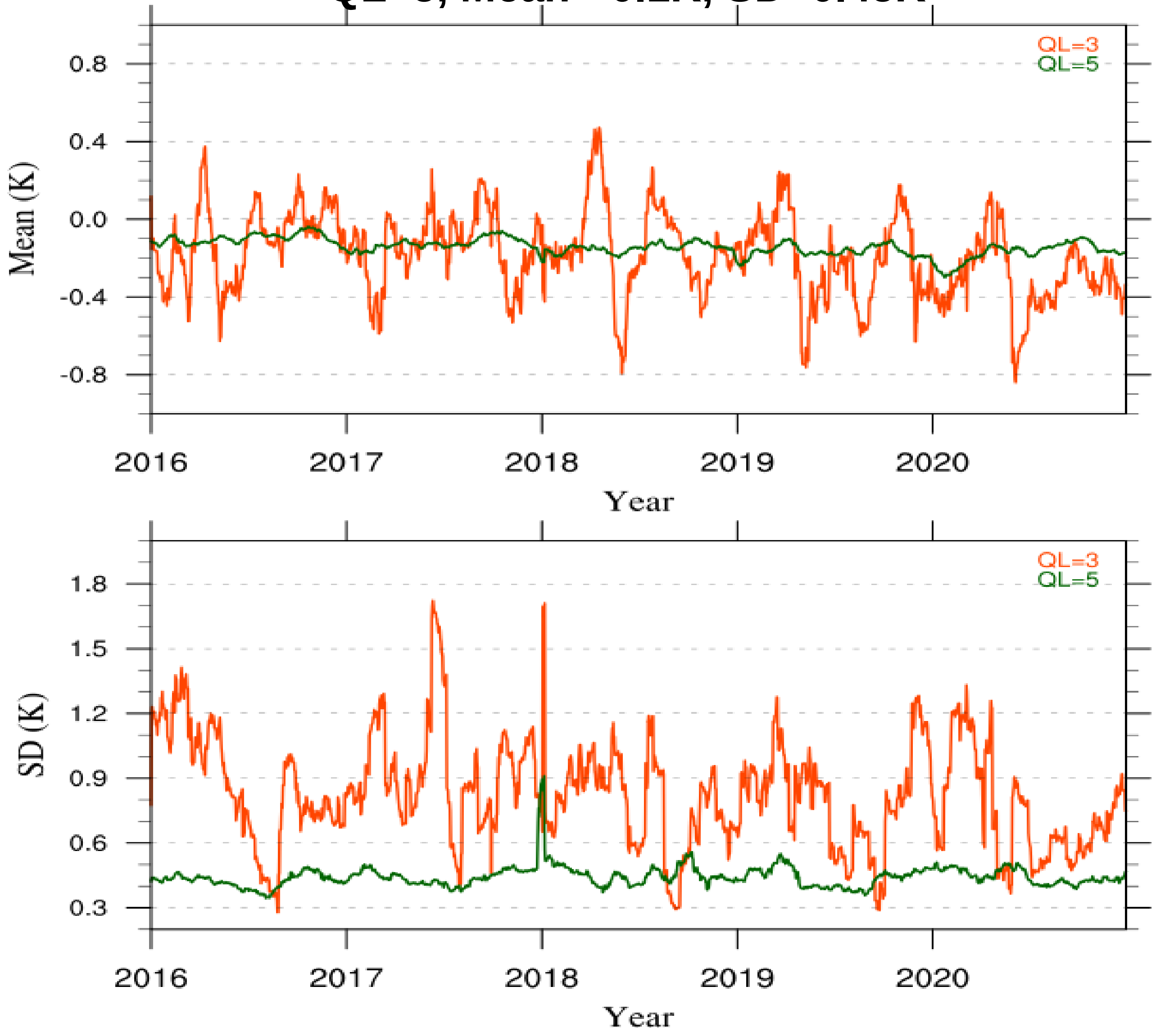


Himawari-8 night L3C SST Validation against buoy SST

L3C-01day, night only, monthly statistics, Jan 2016 - Dec 2020

Note: Mean bias = SSTskin - in situ SSTdepth + 0.17 (in Kelvin), Match-up thresholds: < 10 km distance and ± 6 hours

QL=5, Mean=-0.1K, SD=0.45K



GeoPolar Multi-Sensor L3S products

Method: L3C data are composited to L3S using an equal area weighted averaging method based on quality level, SSES bias and SSES standard deviation. See Govekar et al. (2022) for more details.

Inputs: L3C SSTs from NOAA-18, MetOp-B, Suomi-NPP, NOAA-20 and Himawari-8

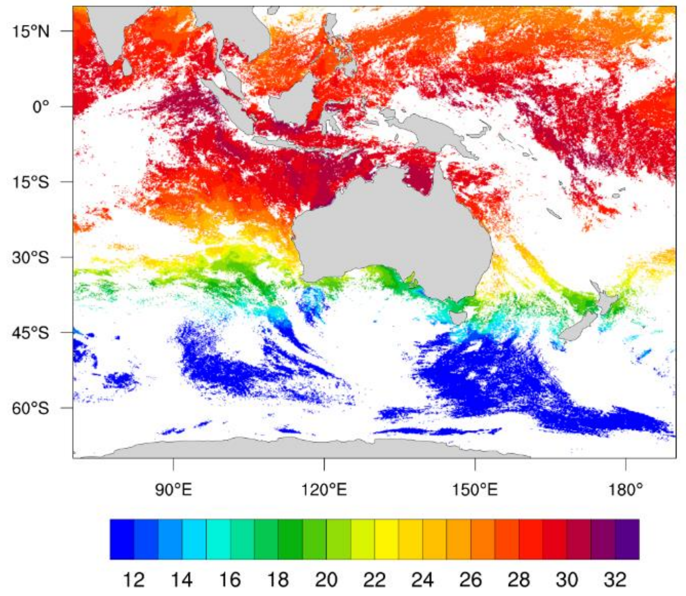
Available: Sep 2015 - Dec 2022

Access: http://portal.aodn.org.au and

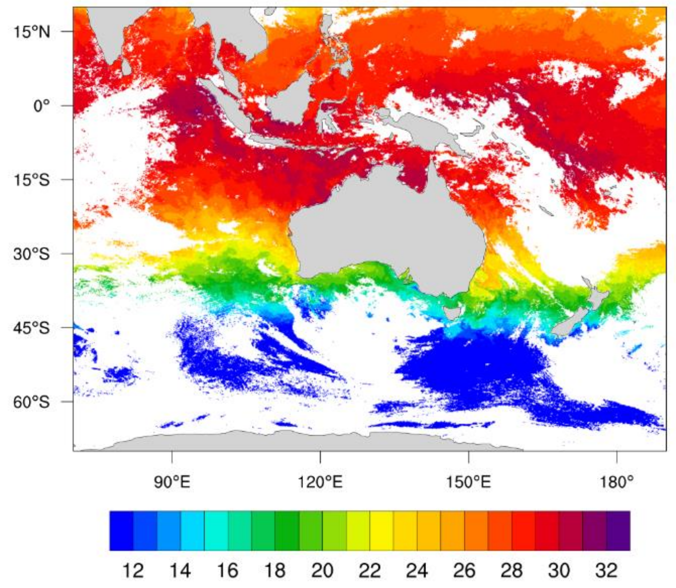
https://geonetwork.nci.org.au/

15 Mar 2020

1-day night Multi-Sensor L3S SST



1-day night GeoPolar Multi-Sensor L3S SST



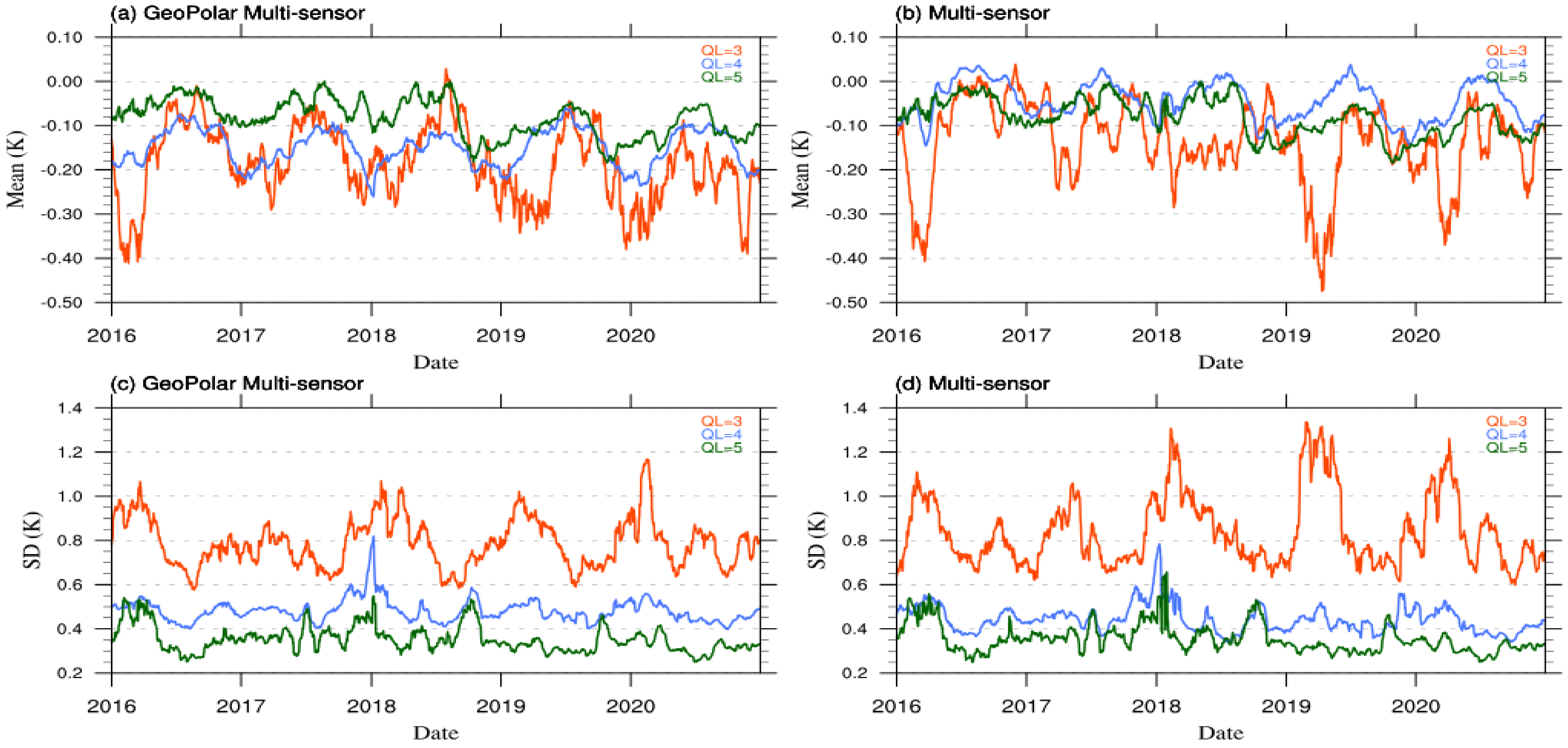
Multi-sensor L3S SST Validation against buoy SST

L3S-01day, night only, monthly statistics, Jan 2016 - Dec 2020

Note: Mean bias = SSTskin - in situ SSTdepth + 0.17 (in Kelvin), Match-up thresholds: < 10 km distance and ± 6 hours

GeoPolar Multi-Sensor L3S

Multi-sensor L3S



Future work

- Update the Himawari-8 SST processing method for Himawari-9, in collaboration with University of Reading

- Real time production of Himawari-9 SST products with use of new updated method by June 2024.

- Inclusion of NOAA-21 and MetOp-C in operational systems

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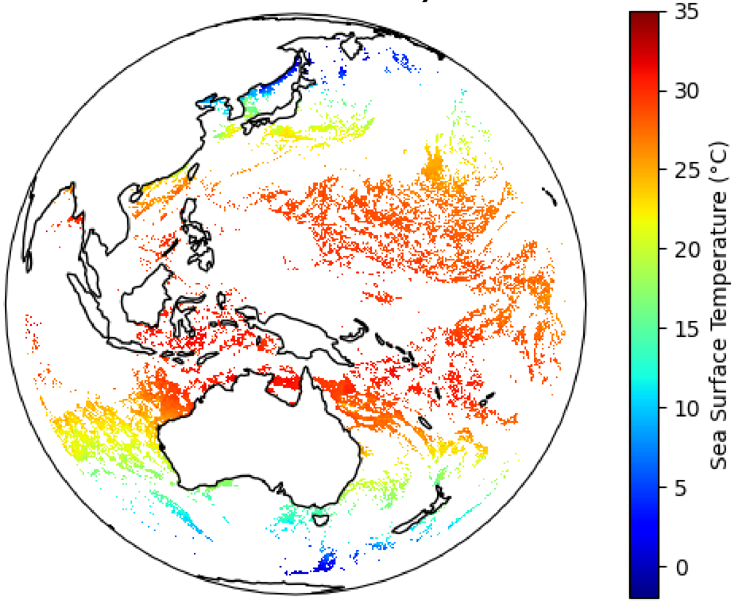
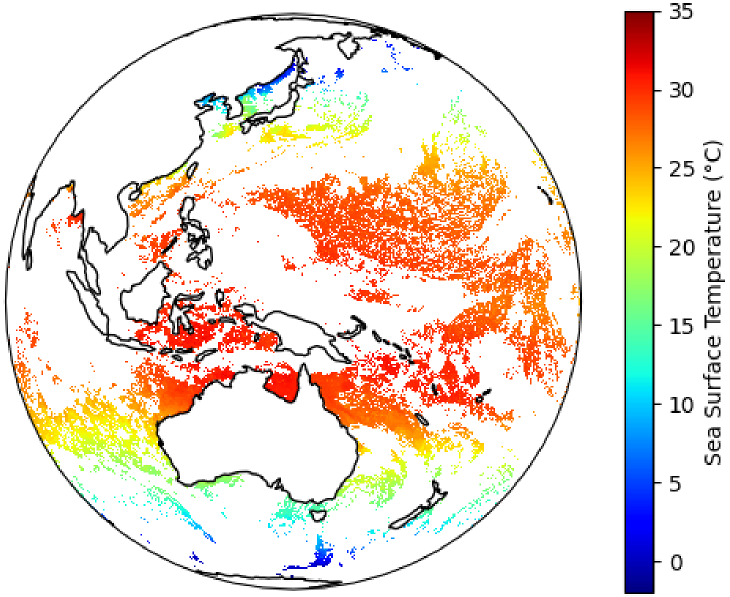
Himawari-8,



Himawari-9 with improved method

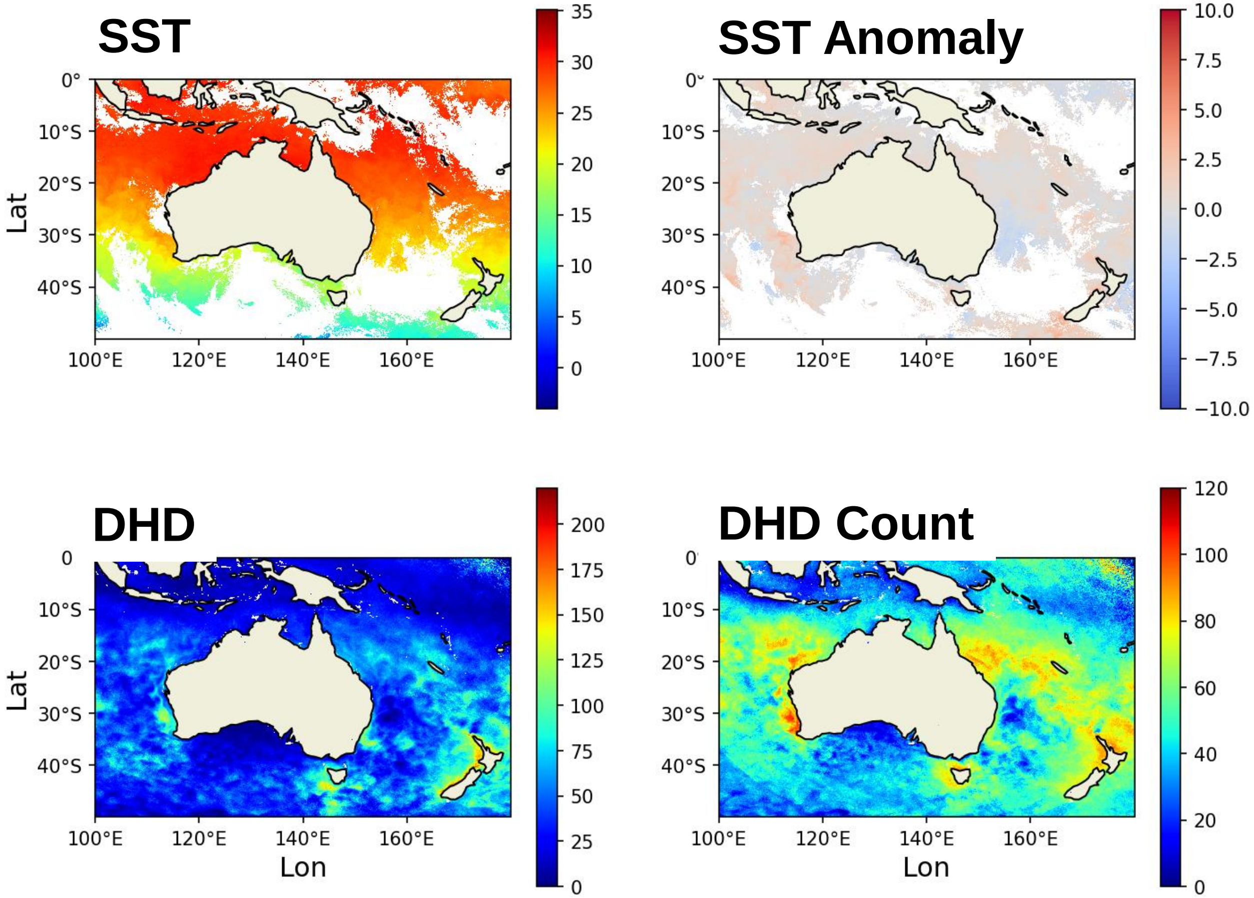


Future work

Develop downstream applications:

Use L3S SST products to generate marine heatwave and thermal stress monitoring metrics such as anomaly, percentiles, Degree Heating Days, Marine Heatwave Category, etc.

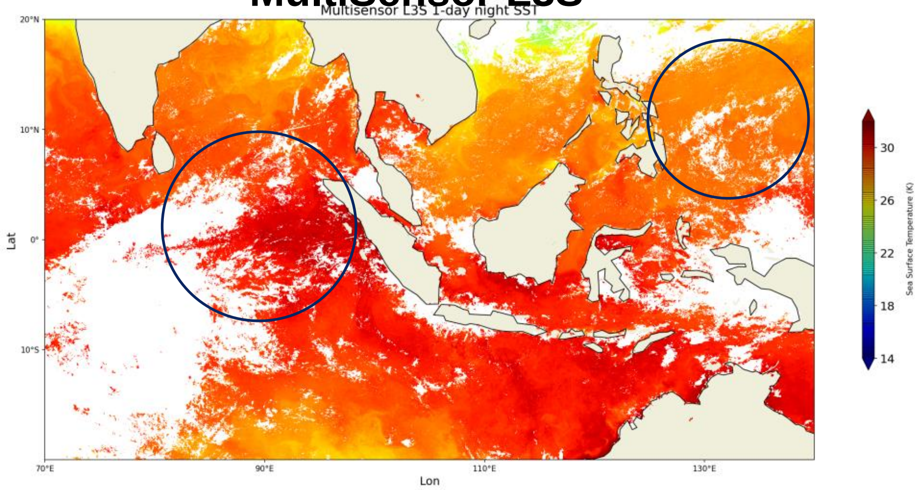
End of Summer 2021-22 season, 31 March 2022



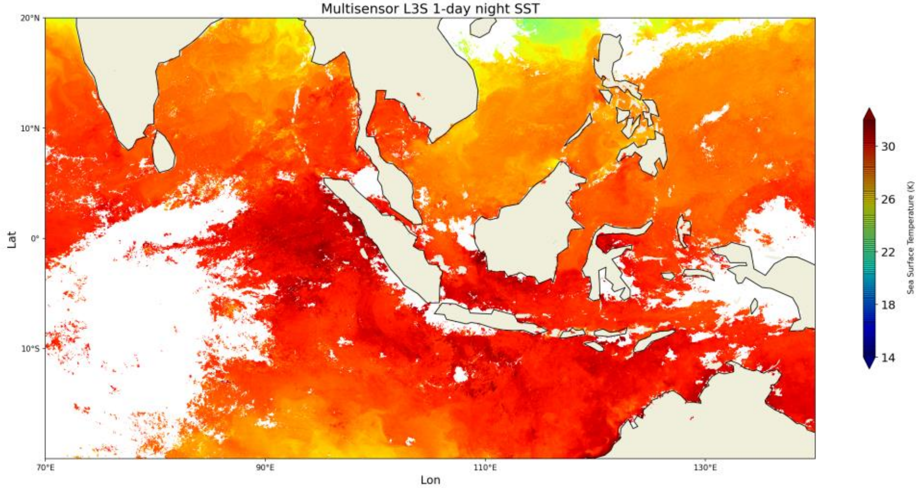
Summary

- In collaboration with University of Reading, we are developing more accurate Himawari-8/9 level 2 SST products which enable us to produce new level 3 SST products with enhanced temporal resolution (hourly, 4-hourly) and improved spatial coverage (Multi-sensor L3S including Himawari-8)
- Reprocessed Himawari-8 L2P, L3C data are available for 2015-2022
- Experimental Himawari-9 L2P files are available on NCI for testing, contact ghrsst@bom.gov.au
- All other IMOS SST products are available from https://geonetwork.nci.org.au (search for "Bureau of Meteorology Satellite SST Collection") and some from AODN (https://portal.aodn.org.au/).

MultiSensor L3S



GeoPolar MultiSensor L3S



Addition of Himawari-8 data to AVHRR+VIIRS L3S SST improves data coverage for 15th March 2020 - areas near "fast moving clouds" are filled in!

Thank you

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The Bureau of Meteorology

Supplementary slides….

Himawari-8 L2P SST Product

- ## Legacy method:

Bureau has produced Himawari-8 SST products in near real time from 2016 but they have not been sufficiently accurate.

➢ Retrieved by regressing against one day of VIIRS data in 2015

➢ GEOCAT clouds

➢ No bias model

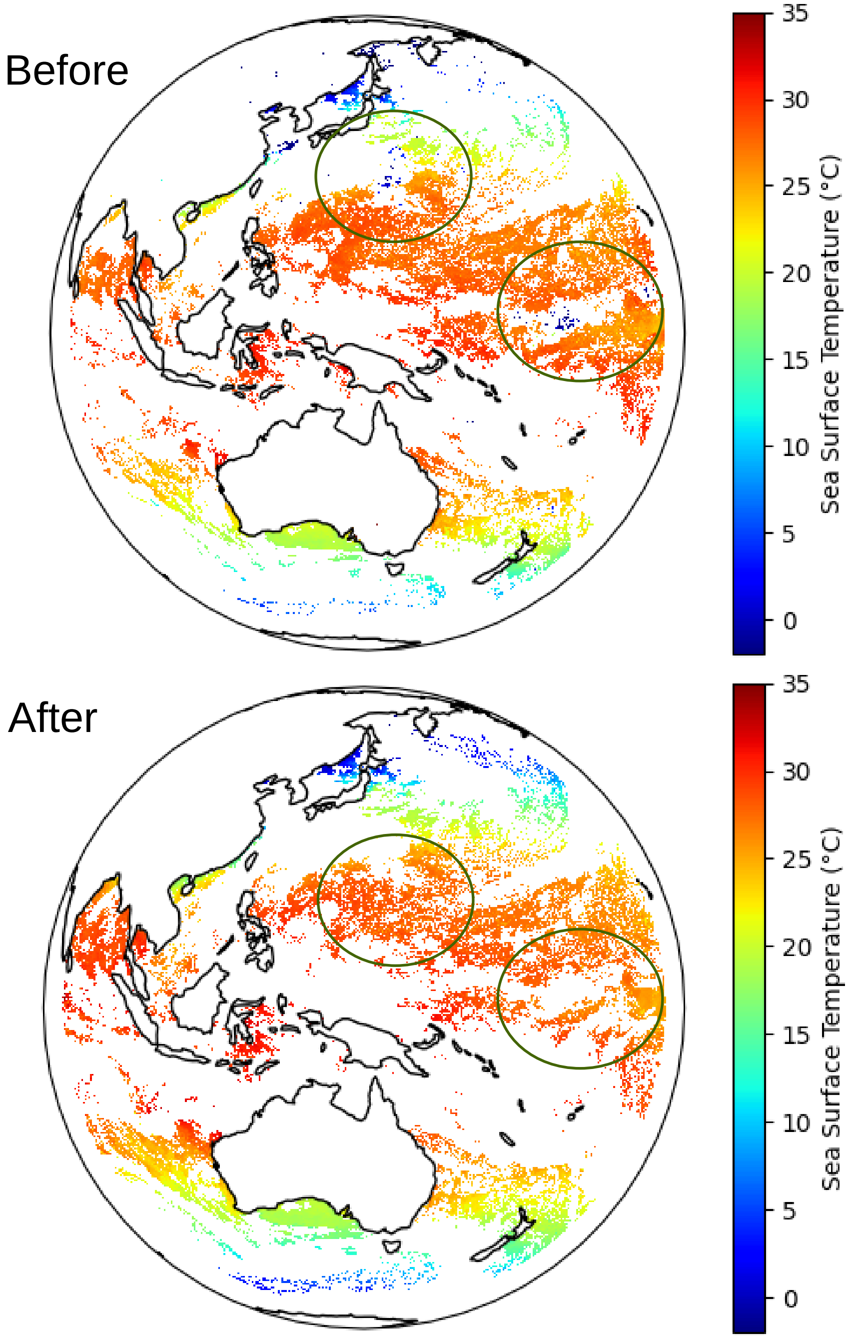
- ## New Method:

Based on the ESA CCI SST code (Merchant et al., 2019) in collaboration with the University of Reading:

➢ Radiative Transfer Model

➢ Bayesian cloud clearing method

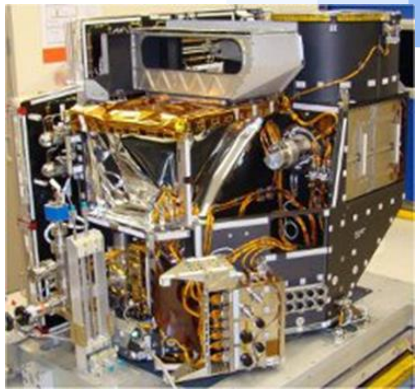
➢ Empirical Bias model based on in-situ SSTs



Advanced Himawari Imager (AHI)

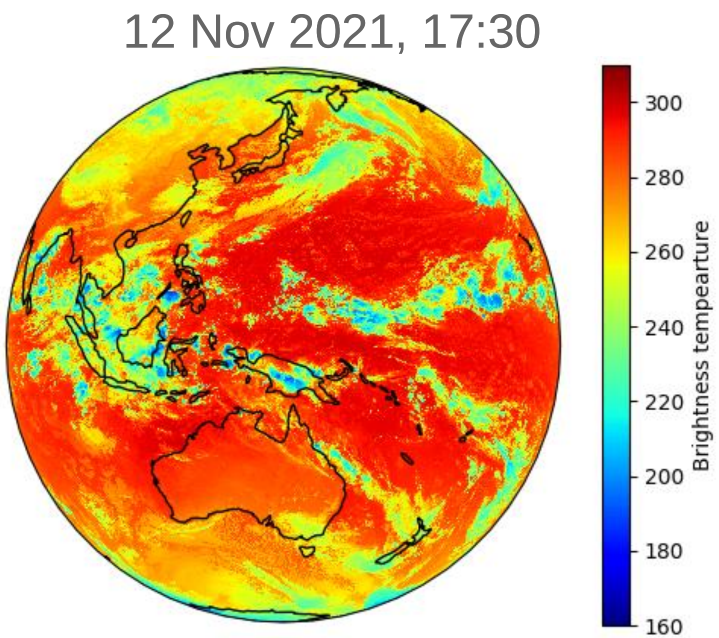
The optical radiometer, advanced Himawari imager (AHI), on board Himawari-8 and Himawari-9 provides full disk images:

- Every 10 minutes
- 2 km spatial resolution for infra-red (IR) frequency data at nadir.
- 16 spectral bands for visible-infrared wavelengths
- IR bands centered at 3.9, 8.6, 10.4, 11.2, and 12.4 μm are able to sense SSTs.



AHI sensor on Himawari-08

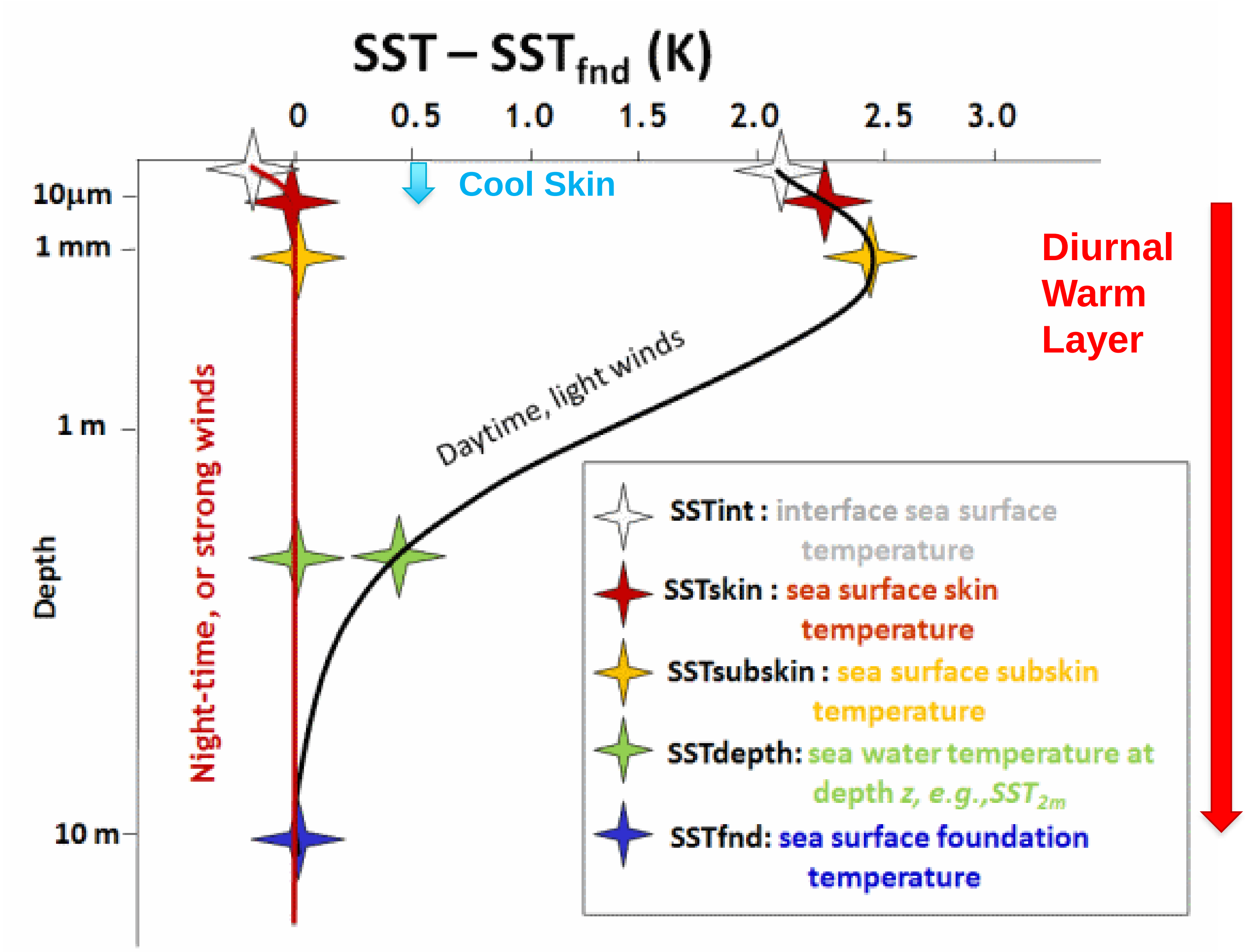
https://www.data.jma.go.jp/mscweb/en/himawari89/space_segment/spsg_ahi.htm



Channel 13 Brightness Temperature (K) values for the Full Disk (FLDK) observations of Himawari-8 AHI.

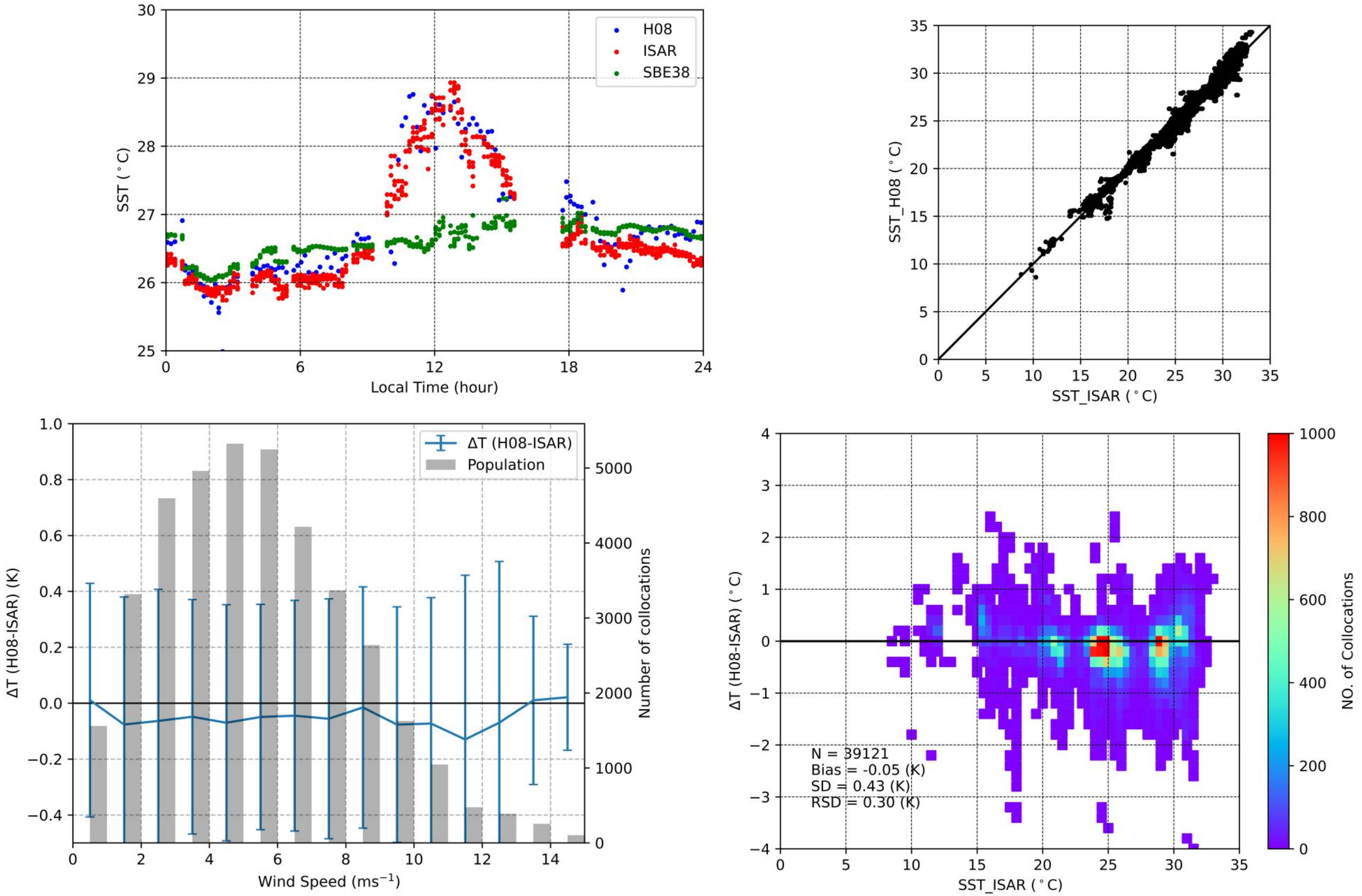
GHRSST definitions of SST depth

www.ghrsst.org



Validation of Himawari-8 L2P against ISAR

(Zhang et. al., 2023, Remote Sensing – see Presentation Session 3)



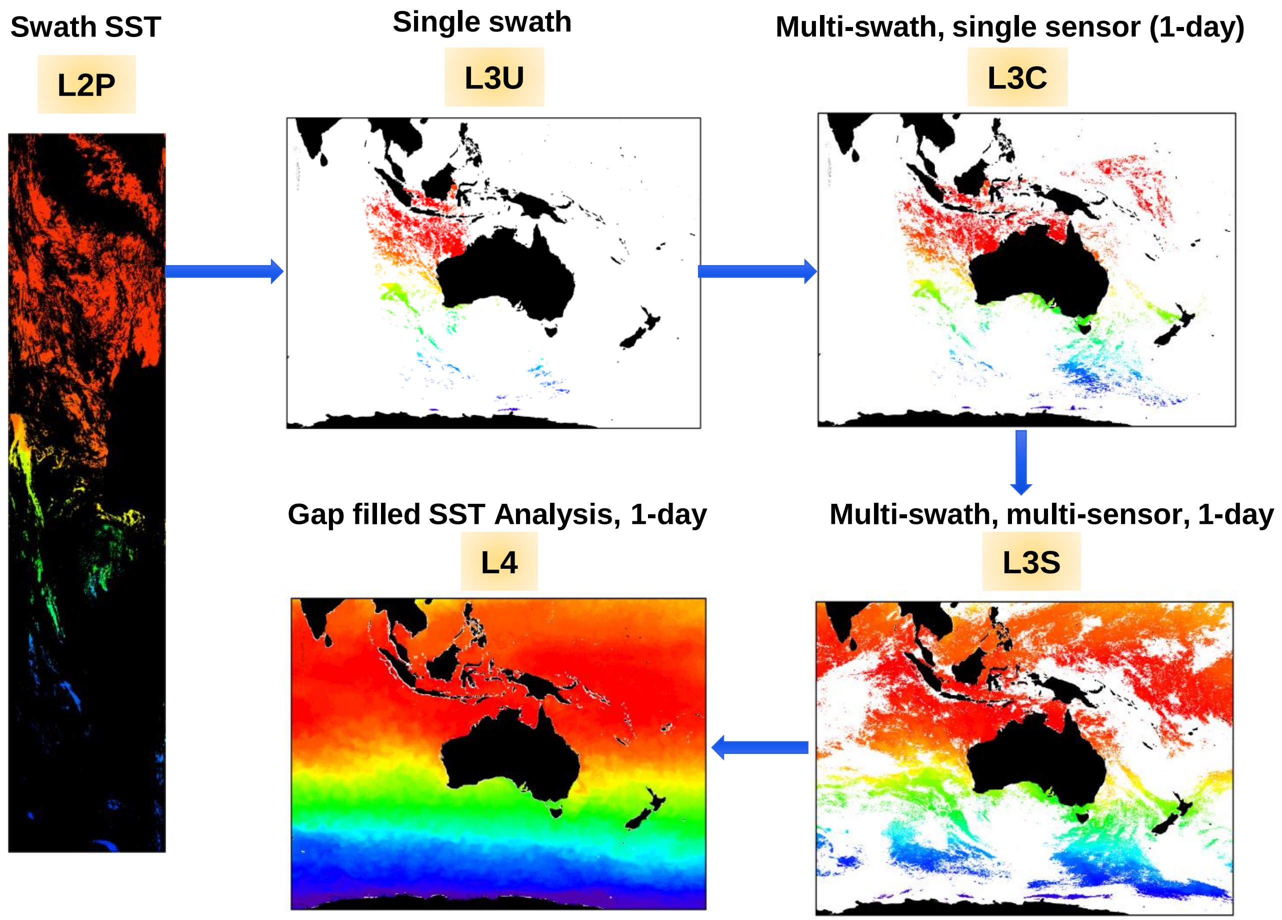
Different SST products

Through IMOS Project, the following SST products for each of the available satellite sensors are available:

- L2P (geolocated, native resolution of sensor)
- L3U (single swath/scene, gridded)
- L3C (multiple swath/scene, single sensor, gridded)
- L3S (multiple IR sensors, gridded)

We provide these SST products at 2 depths:

- Skin (SSTskin) at ~10 µm depth sensitive to diurnal warming
- Foundation (SSTfnd) equivalent to several meters depth and not affected by diurnal warming



Operational Multi-Sensor L3S products

Composites of SST data from AVHRR sensors on NOAA-18 and MetOp-B, and VIIRS sensors on Suomi-NPP and NOAA-20:

Resolution: 0.02º x 0.02º; 1, 3, 6 days and 1 month

Available: 2012 to present from http://portal.aodn.org.au and https://opus.nci.org.au/

Uses:

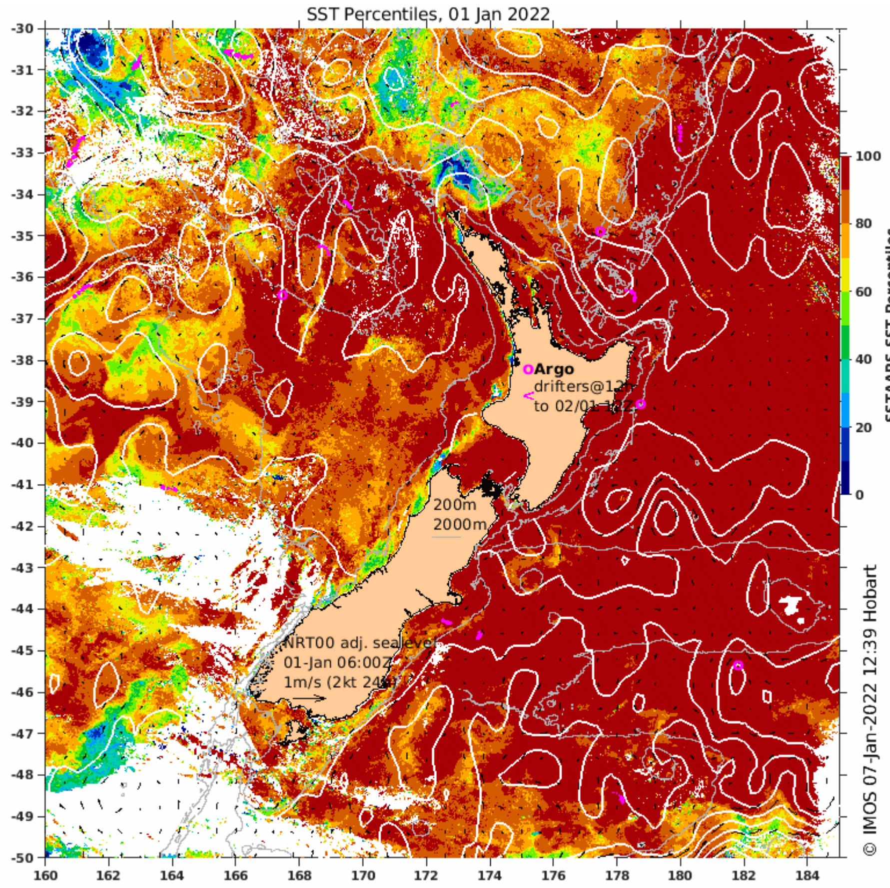
- BoM ReefTemp NextGen Coral Bleaching Risk Monitoring

http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml

- IMOS OceanCurrent SST and Percentile Maps

http://oceancurrent.imos.org.au

SST Percentiles from 6-day Multi-Sensor L3S – 1 Jan 2022



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Composites of SST data from AVHRR sensors on NOAA-18 and MetOp-B, and VIIRS sensors on Suomi-NPP and NOAA-20:

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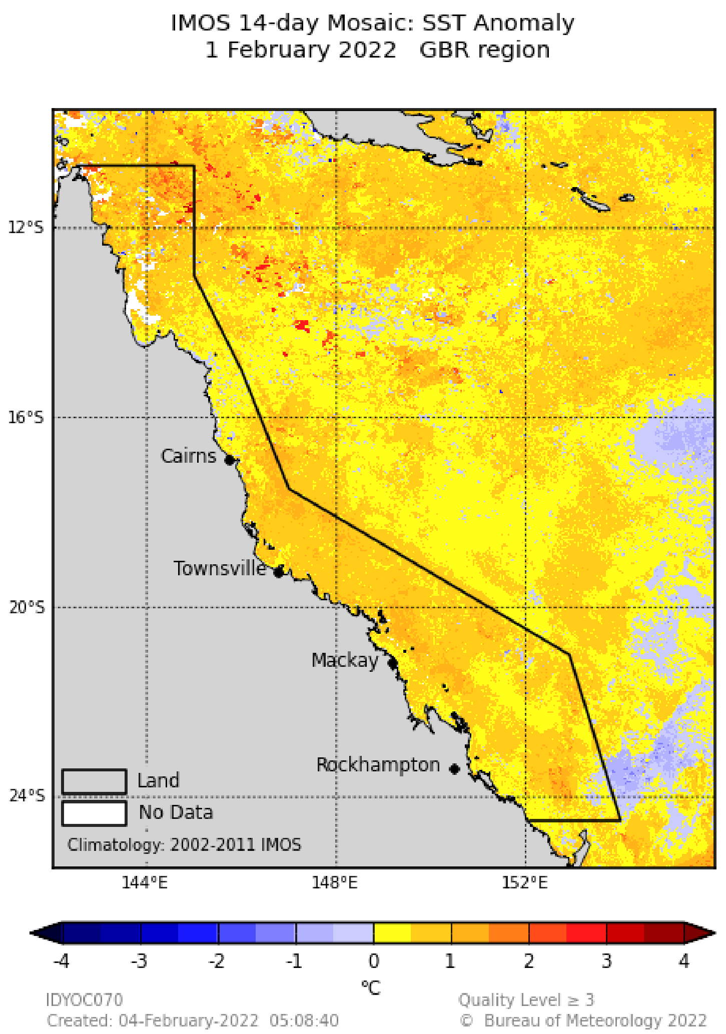
ReefTemp SST Anomaly Map from 1-day Multi-Sensor L3S



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Useful sites for information on IMOS SST products

- GHRSST products: https://www.ghrsst.org/quick-start-guide/
- Chapter on how to select an SST product: Beggs (2021)
- Overview of IMOS GHRSST products: https://opus.nci.org.au/pages/viewpage.action?pageId=141492230
- Access to IMOS GHRSST products: https://opus.nci.org.au/pages/viewpage.action?pageId=141492235 and http://portal.aodn.org.au
- AODN Toolbox: https://help.aodn.org.au/aodn-data-tools/
- IMOS HRPT AVHRR GHRSST Products: http://imos.org.au/facilities/srs/sstproducts/sstdata0/
- IMOS Multi-sensor GHRSST Products: Govekar et al. (2022) https://doi.org/10.3390/rs14153785
- Maps of BoM L4 SST: http://www.bom.gov.au/marine/sst.shtml
- IMOS OceanCurrent maps of IMOS L3U and L3S products: http://oceancurrent.imos.org.au
- GHRSST L4 (inc GAMSSA) Validation/Inter-comparison: http://www.star.nesdis.noaa.gov/sod/sst/squam
- Regional SST Maps (inc RAMSSA L4, IMOS L3S and other GHRSST L2P, L3U, L4 products): https://www.star.nesdis.noaa.gov/sod/sst/arms/
- Introduction to users on the set of GHRSST products: https://zenodo.org/record/6957658

Applications of IMOS GHRSST Products

…requiring high spatial resolution and less gaps than L3C

L3S (2 km gridded, multiple sensor)

Nowcasting coral bleaching

- ReefTemp NextGen uses 1-day night L3S

Australian 2 km SST climatologies

- SSTAARS (Wijffels et al., 2018) uses 1-day night AVHRR L3S
- Roughan et al. (2022) uses 1-day night Multi-sensor L3S

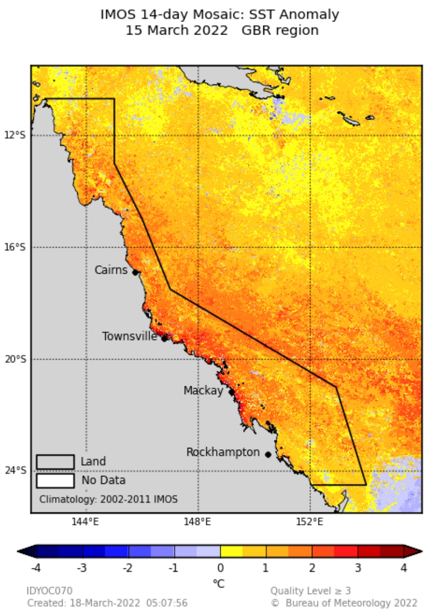
Nowcasting Marine Heat Waves

- IMOS OceanCurrent uses 1/3/6-day and 1-month night L3S for SST anomaly and percentile maps

Research on marine heatwaves, marine ecology, acquaculture, coastal oceanography and climate change

- e.g., Meng et al., 2022; Rykova et al., 2022; Layton et al., 2022; Hu et al., 2021; Xie et al., 2021; Heidemann & Ribbe, 2019; Ismail et al., 2018

ReefTemp 15 Mar 2022 1-day SST Anomaly



SSTAARS Daily Climatology 15 March