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IMOS Integrated Marine Observing System

Which IMOS GHRSST product should I use?

Helen Beggs*, Christopher Griffin, Pallavi Govekar, Leon Majewski, Lixin Qi and Aihong Zhong

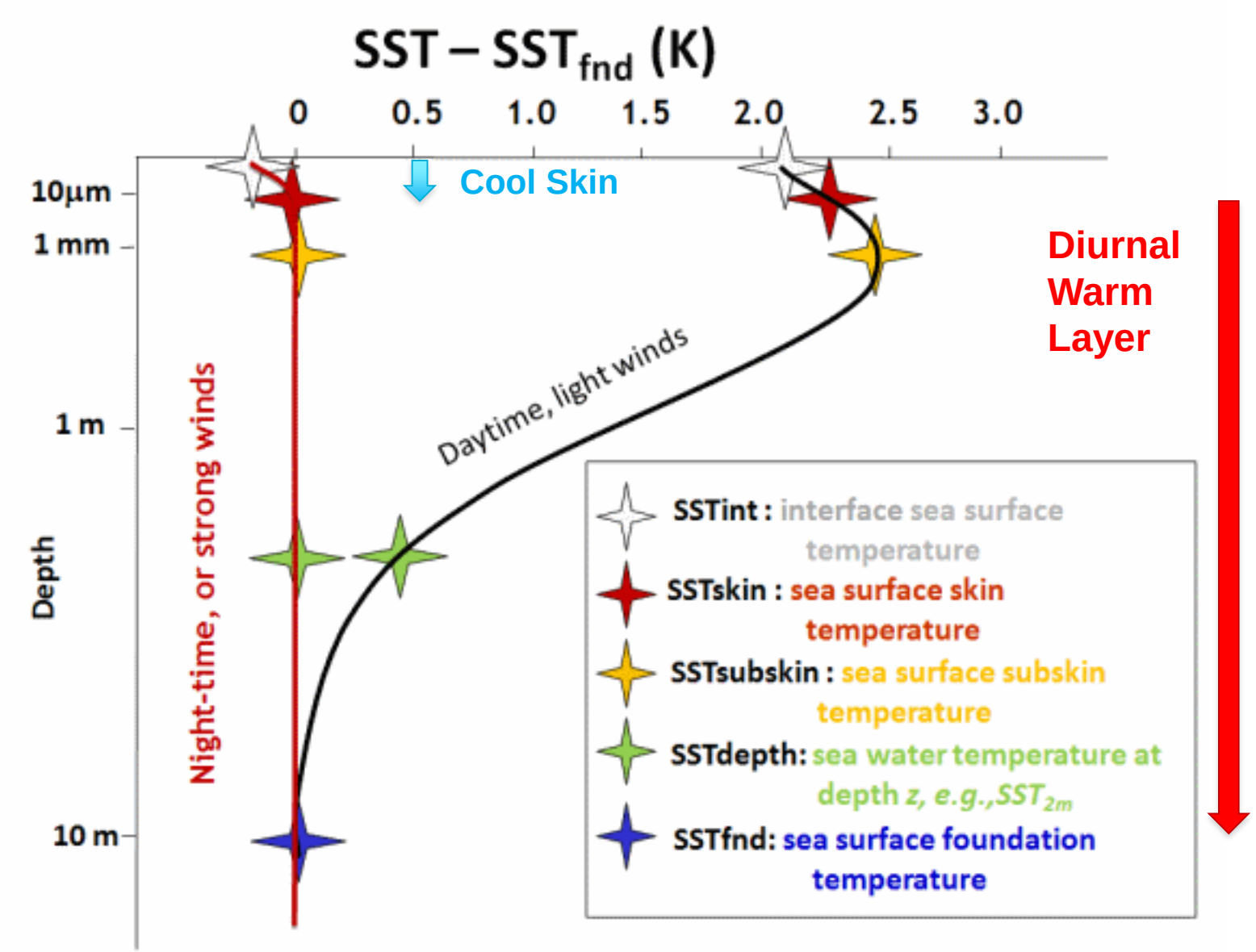
Bureau of Meteorology, Melbourne, Australia

*Leader, IMOS SRS SST Products Sub-facility

IMOS Data Workshop, Adelaide, 6th July 2018

Why SST depth is important

www.ghrsst.org



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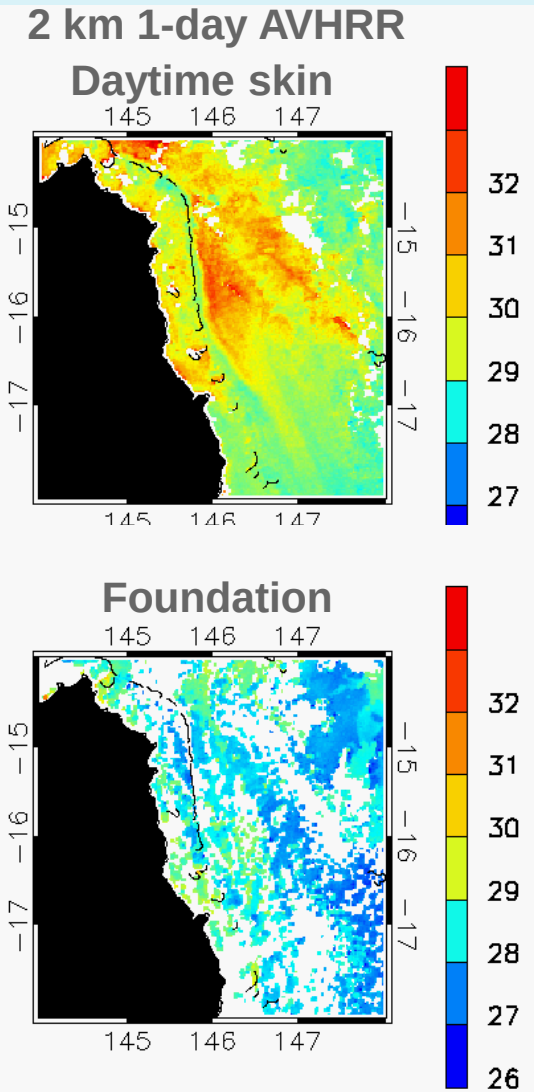
Things to consider when choosing an SST product…

- Depth – skin (~10μm), sub-skin or foundation (~10m)?
- Time – length/timeliness, local time of measurement
- Temporal resolution – what is characteristic time period of process?
- Spatial resolution of feature/process
- Spatial coverage – L3 composite vs L4 gap-free?
- Do you need microwave data to measure SST under cloud?
- Geolocation accuracy – native projection or gridded?
- SST accuracy – with respect to what reference?
- Quality level (cloud contamination)



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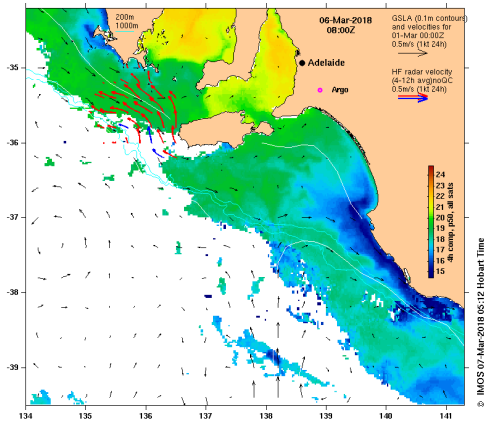
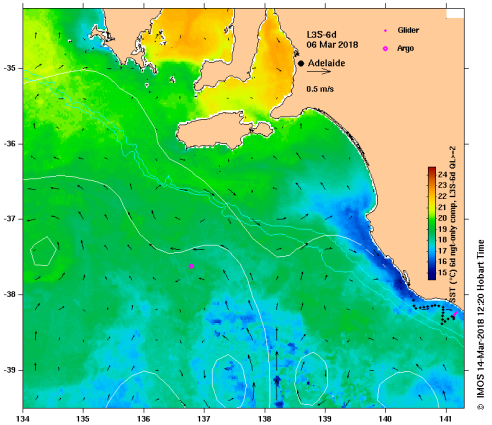
2 km
4-hour Multi-Sensor



6-day AVHRR



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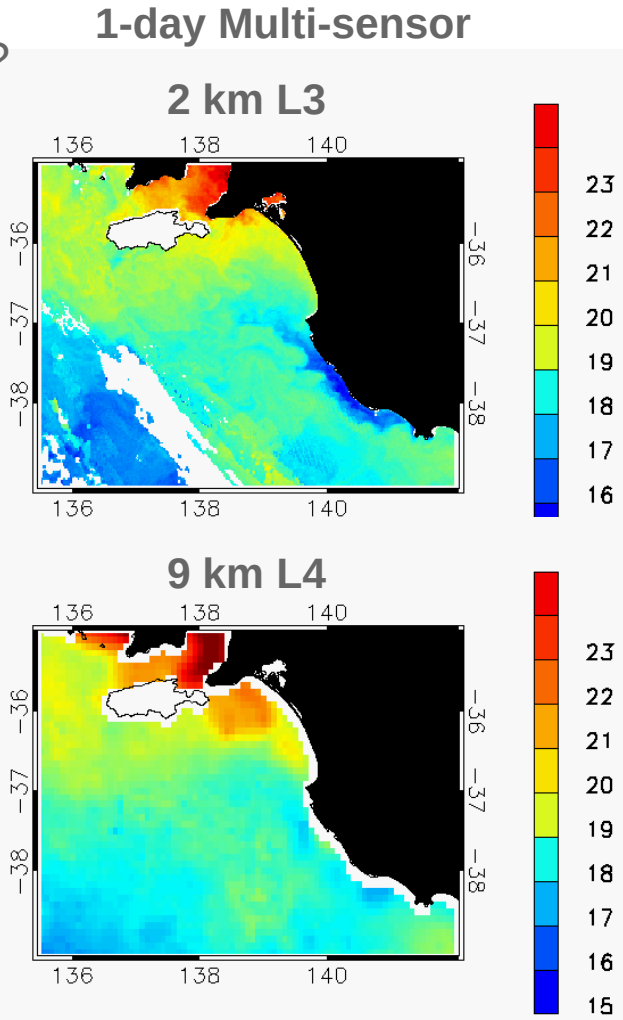

- International science group: 2000 – present
- Share high resolution satellite SST data products in common, CF-compliant netCDF4 formats
  - L2P (geolocated, native resolution of sensor)
  - L3U (swath, gridded)
  - L3C (multiple swath, gridded)
  - L3S (multiple sensor, gridded)
  - L4 (multiple sensor, statistically interpolated)
- More than 100 RT and reprocessed L2P/L3 products from most environmental satellites equipped with SST sensors
- More than 30 NRT daily, global (1-25 km) and regional (1–10 km), SST analysis (statistically interpolated) products (“L4”) and reanalyses
- SST information and data access: http://www.ghrsst.org

Bureau of Meteorology IMOS GHRSST products

Designed for different applications…

1-4 km AVHRR L2P SSTskin

2 km AVHRR L3U SSTskin

2 km 1/3-day AVHRR L3C SSTskin

2 km 1/3/6/14-day and 1-month AVHRR L3S SSTskin/SSTfnd

2 km VIIRS L3U SSTskin

2 km 1-day VIIRS L3C SSTskin

2 km 1/3/6/14-day and 1-month Multisensor (VIIRS+AVHRR) L3S SSTskin/SSTfnd

2 km 10-min Himawari-8 L2P SSTskin

2 km hourly Himawari-8 L3C SSTskin

5 km hourly MTSAT-1R L3U SSTskin

9 km Daily Regional RAMSSA L4 SSTfnd

25 km Daily Global GAMSSA L4 SSTfnd

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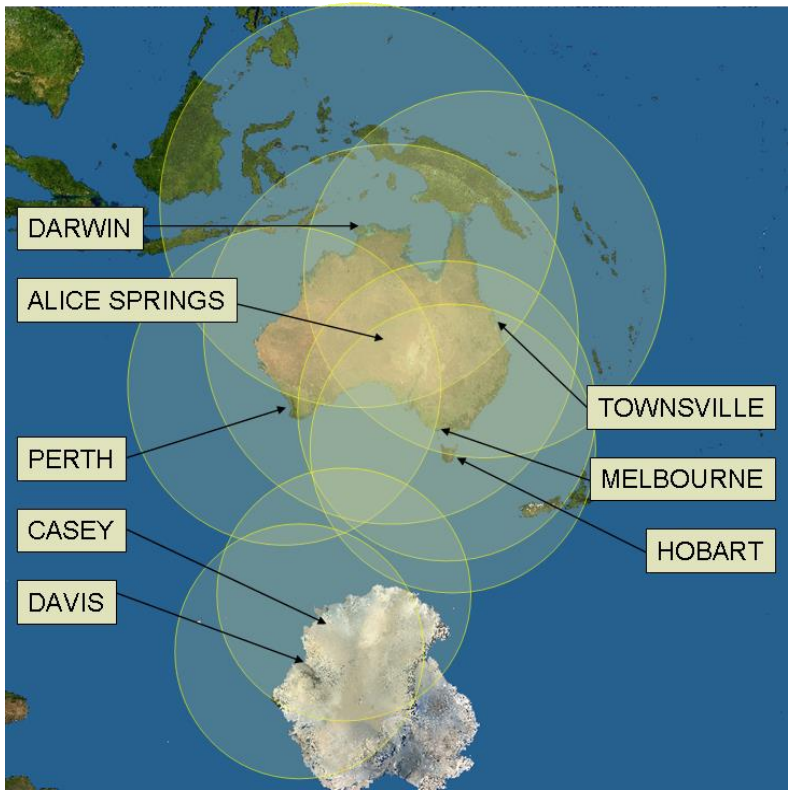
Why do we need 1 km resolution AVHRR SST Products?

Passive infra-red sensors on polar-orbiting satellites provide the highest resolution SST observations from space (~1 km) but cannot sense SST under cloud.

Pre-2002 (MODIS) the only wide swath, 1 km resolution, satellite SSTs available were direct-broadcast AVHRR skin SST from NOAA Polar-Orbiting Environmental Satellites (NPOES)

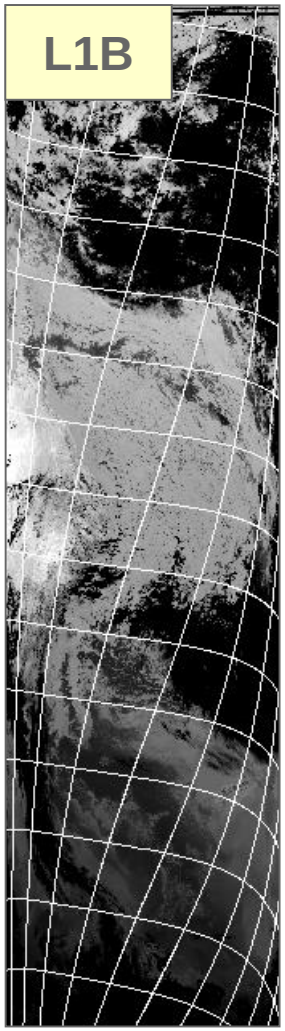
Australia has direct broadcast ("HRPT") AVHRR data back to ~1985 from reception stations in Australia and Antarctica.



IMOS-GHRSST AVHRR products

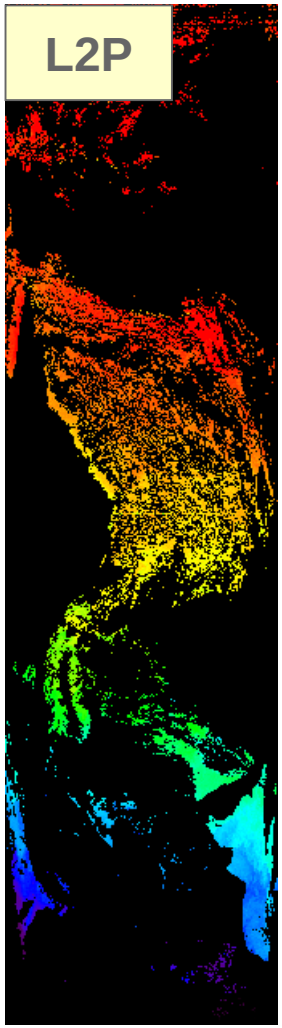
Swath BT

L1B



Swath SST

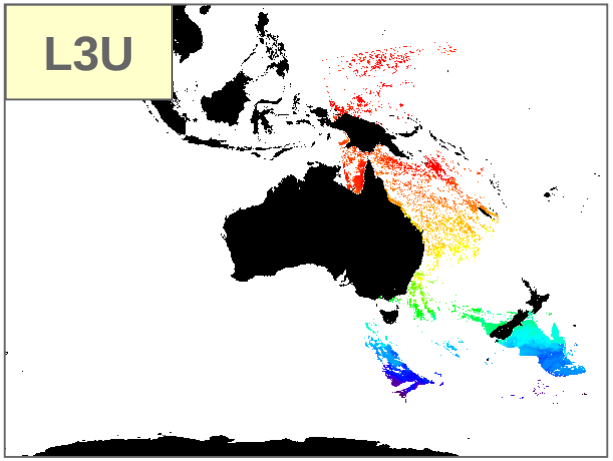
L2P



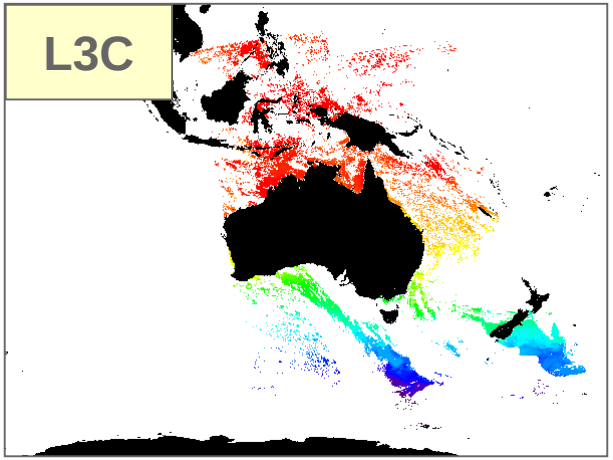
N18: 2011-04-30 04:01:33

single swath

L3U



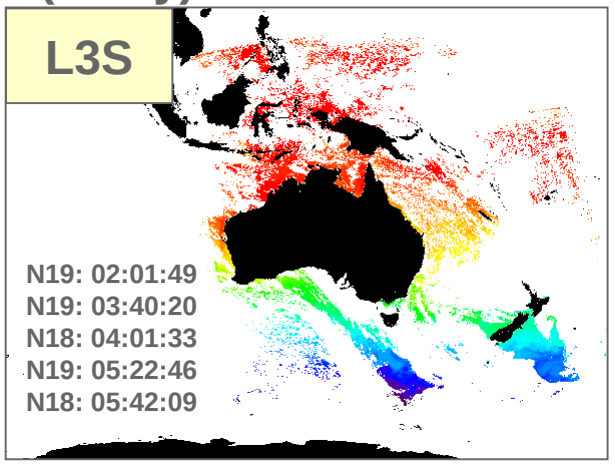
L3C



multi-swath, single sensor

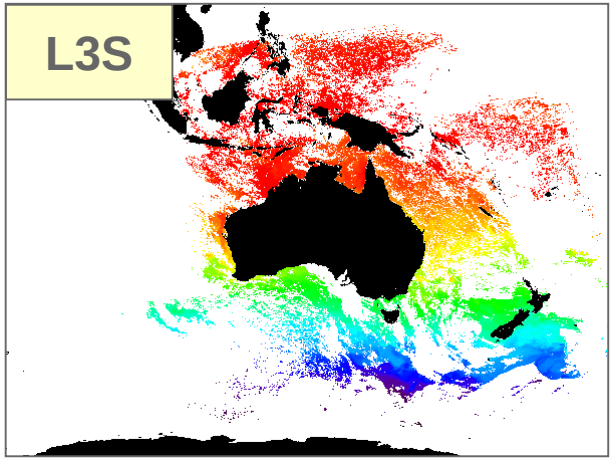
multi-swath, multi-sensor, (1-day)

L3S



N19: 02:01:49
N19: 03:40:20
N18: 04:01:33
N19: 05:22:46
N18: 05:42:09

L3S

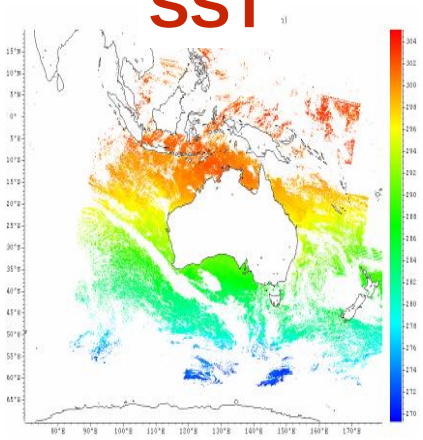


multi-swath, multi-sensor, multi-day (3-day)

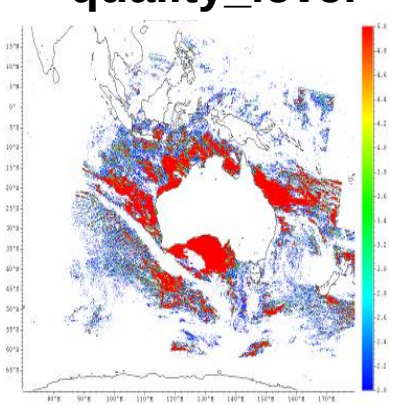
+ 6-day, 14-day, 1-month L3S

Useful pixel-by-pixel information (following GHRSST 2.0 format)

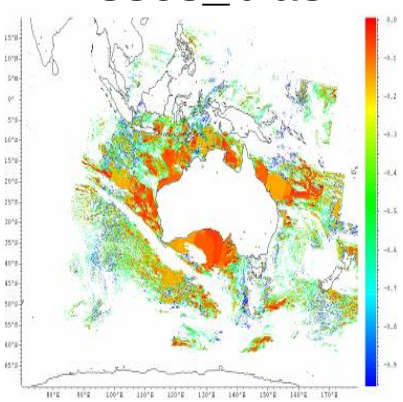
SST



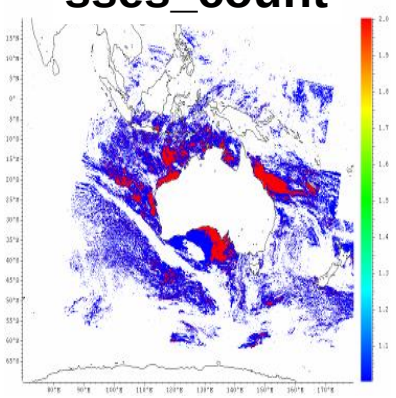
quality_level



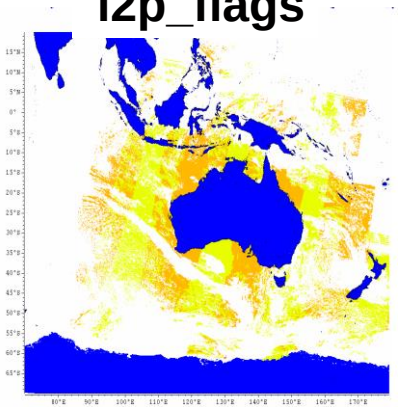
sses_bias



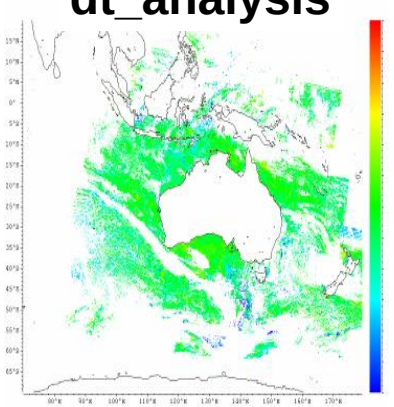
sses_count



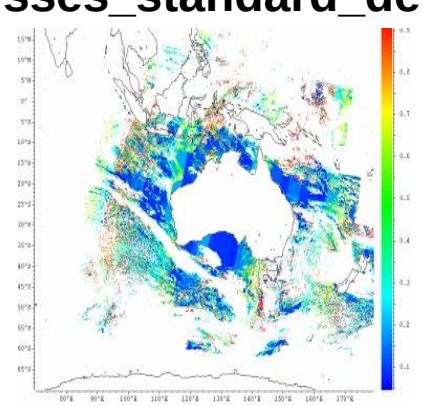
l2p_flags



dt_analysis



sses_standard_deviation



+ wind speed

+ aerosol optical depth

+ sea ice fraction

20131007 night composite from multiple satellites "L3S"
Quality Level (0 to 5) based on number of km to nearest cloud – 5 is best

IMOS HRPT AVHRR + VIIRS GHRSST products

Lead: H Beggs, L Majewski; Developers: C Griffin, P Govekar

http://imos.org.au/sstproducts.html

Resolution: L2P**:** 1.1 km^2 at nadir to 2x6 km^2 at edge of swath. L3U/L3C/L3S: 0.02º x 0.02º. L3S averaged over 1/3/6/14 days or 1 month

Depth: skin (day-only/night-only), foundation (day+night)

Available: 1992 to present over 2 domains (Australia and Southern Ocean)

Access: **L2P:** Contact ghrsst@bom.gov.au.

L3U, L3C, L3S: http://rs-data1-mel.csiro.au/thredds/catalog/imos-srs/sst/ghrsst/catalog.html

L3S (Australia only): AODN http://portal.aodn.org.au

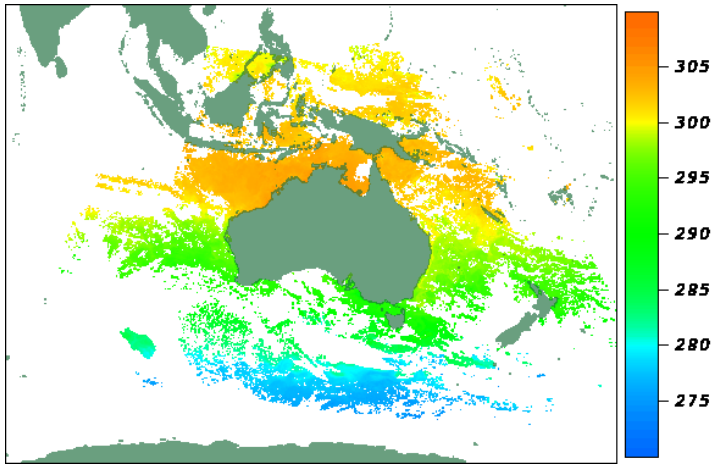
Method: SSTskin derived by regressing radiances against drifting buoy SST(0.2m) followed by subtracting 0.17ºC. Foundation SSTs derived from skin SSTs by rejecting observations for low NWP wind speeds and adding 0.17ºC.

Inputs: AVHRR radiances from NOAA-11 to NOAA-19

Info: Griffin et al (2017)
http://imos.org.au/facilities/srs/sstproducts/sstdata0/sstdata-references/

22 Feb 2016

1-day night AVHRR L3S



IMOS VIIRS and Multisensor GHRSST products

Lead: H Beggs; Developers: C Griffin, P Govekar

Resolution: L3U/L3C/L3S: 0.02º x 0.02º. **L3S** averaged over 1/3/6/14 days or 1 month

Depth: skin (day-only/night-only), foundation (day+night)

Available: 2012 to present over 2 domains (Australia and Southern Ocean)

Access: OPeNDAP: contact ghrsst@bom.gov.au

Method: Both AVHRR and VIIRS SSTskin derived by regressing radiances against drifting buoy SST(0.2m) followed by subtracting 0.17ºC. Foundation SSTs derived from skin SSTs by rejecting observations for low NWP wind speeds and adding 0.17ºC.

Inputs:

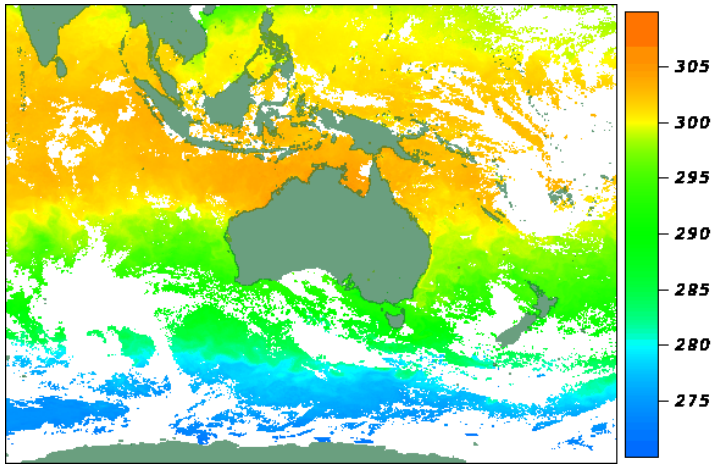
2 km IMOS AVHRR L3U from NOAA-15 to NOAA-19

2 km ACSPO S-NPP VIIRS L3U

Info: Griffin et al (2017)
http://imos.org.au/facilities/srs/sstproducts/sstdata0/sstdata-references/

22 Feb 2016

1-day night Multisensor L3S

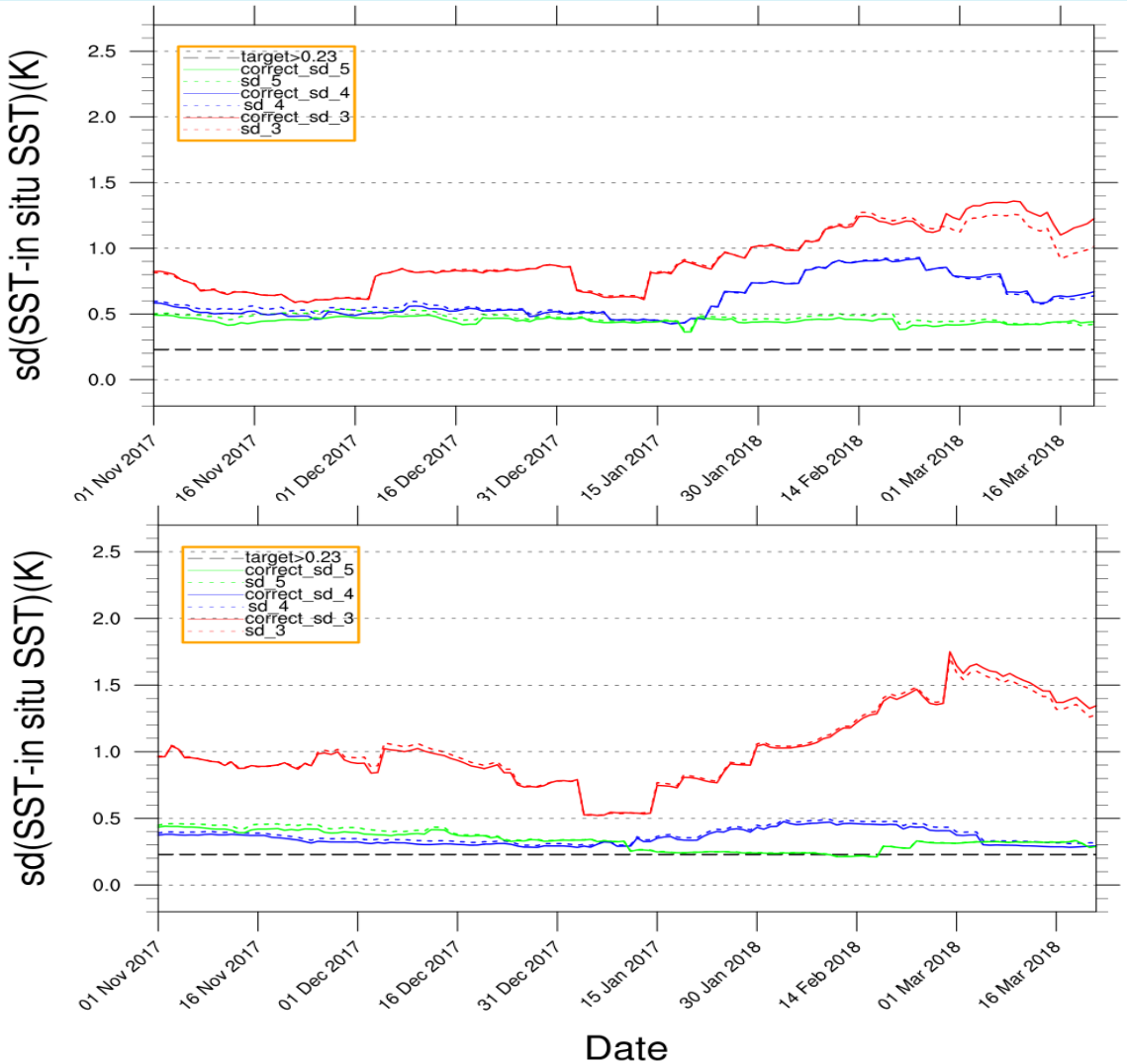


fv01 L3S SST on-line verification

Night StDev(L3S SSTskin – Buoy SSTskin)

L3S-01day, night only, monthly statistics, 1 Nov 2017-23 Mar 2018

Adding VIIRS to the IMOS night-time L3S products reduced standard deviation of QL=5 SSTs by ~ 0.1 to 0.2 K, and QL=4 SSTs by 0.2 to 0.4 K



IMOS MTSAT-1R L3U GHRSST Products

Developer: Leon Majewski in collaboration with
Eileen Maturi, Andy Harris and Jon Mittaz (NOAA/STAR)

Australian Government
Bureau of Meteorology

Resolution: 0.05º hourly

Depth: skin

Available: v2: Jun 2006 – Jun 2010 over full disk;
v3: Jan – Apr 2010 (TWP domain only)

Access: v2: http://rs-data1-mel.csiro.au/imos-srs/sst/ghrsst/L3U/mtsat1r

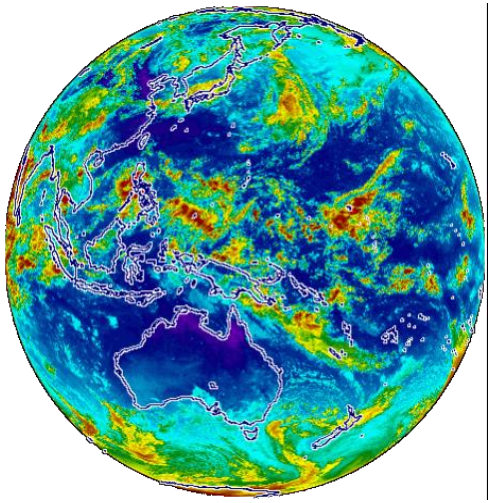
V3: OPeNDAP: Contact ghrsst@bom.gov.au

Inputs: ~4 km hourly radiances from JAMI radiometer on JMA's geostationary MTSAT-1R satellite

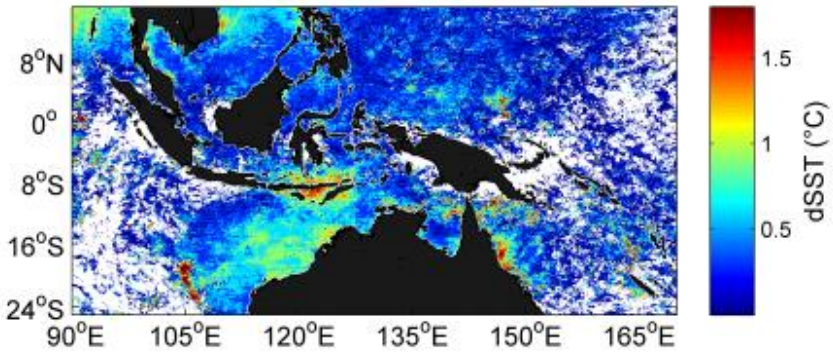
Uses: SST Diurnal Variation research

Ref: Zhang et al. (2018) JGR Oceans, 123

v2 MTSAT-1R SSTmax – SSTfnd over 1 day



Mean Mar 2010 v3 MTSAT-1R SSTmax - SSTfnd



BoM Himawari-8 L2P GHRSST Products

Lead/Developer: Chris Griffin

Australian Government
Bureau of Meteorology

Resolution: 10 min^{-1}, 2 km^2 at nadir, full disk

Depth: skin

Available: 8 Mar 2016 to real-time over full disk on H-8 GEO projection

Access: On NCI – contact ghrsst@bom.gov.au

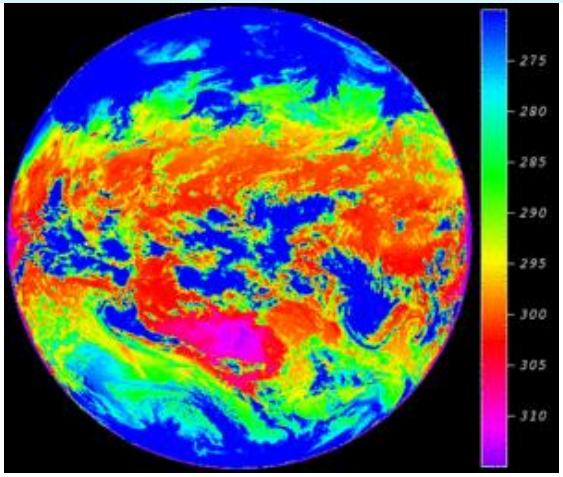
Method: JMA H-8 AHI radiances trained to ACSPO VIIRS L2P SST(0.2m) followed by subtracting 0.17ºC.

Inputs: ~2 km 10 min^{-1} radiances from AHI radiometer on JMA's geostationary Himawari-8 satellite

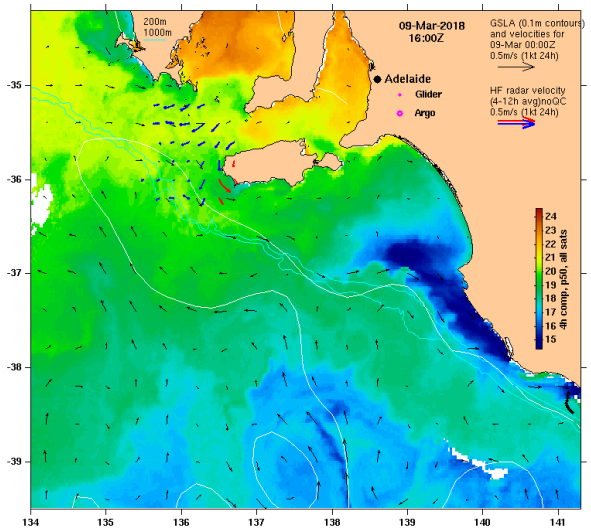
Uses:

- Ingesting into trial EnKF-C SST analysis and coastal ocean models
- Ingesting into CSIRO's IMOS OceanCurrent 4-hourly, 2 km L3 SST maps for Fisheries applications (http://oceancurrent.imos.org.au/four_hour.php)

H-8 L2P SSTskin



CSIRO 4-hrly L3 SSTsubskin



IMOS Himawari-8 L3C GHRSST Products

Lead: Helen Beggs, Developer: Chris Griffin

Australian Government
Bureau of Meteorology

1 Jan 2018 00 – 01 UTC

Resolution: Hourly, 0.02º SSTskin and Daily, 0.02º "pre-dawn" SSTfnd

Depth: skin, foundation

Domain: IMOS Australian grid (70ºE to 190ºE, 70ºS to 20ºN)

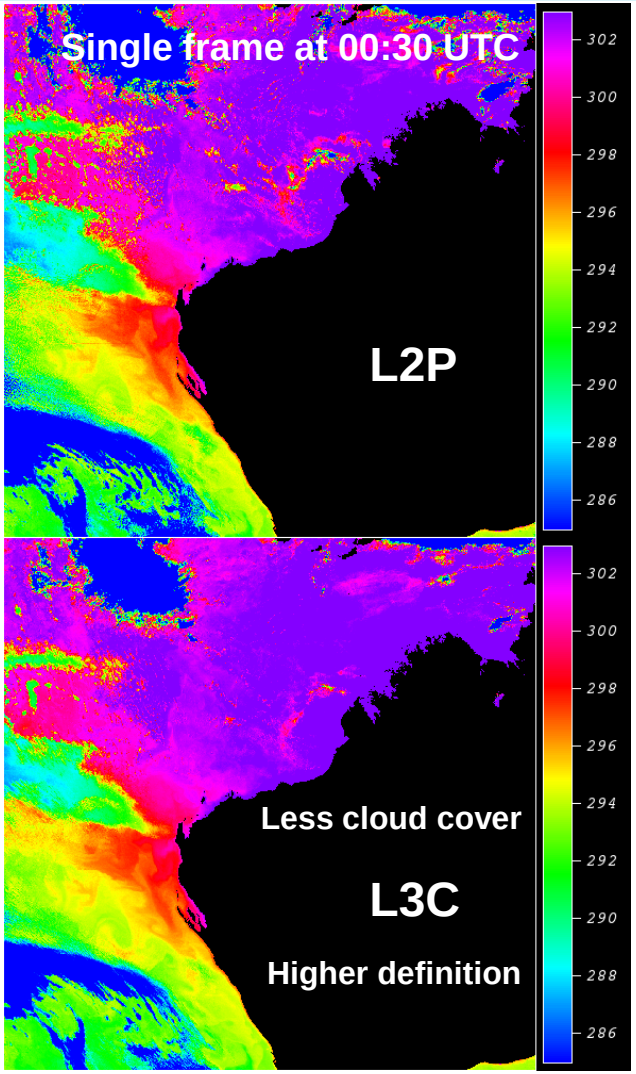
Available: RT hourly L3C products from 29 Jun 2018 to present. Aim to reprocess back to at least 1 Oct 2017.

Method: Composite BoM H-8 2 km 10-min L2P SSTskin to hourly L3C on GEO projection by selecting the "best" retrieval for each grid cell within the 1-hour period, based on pixel quality level, spatial and temporal consistency.

Composite L3C data on GEO projection to IMOS 0.02º L3C grid using weighted averaging of overlapping pixels.

Composition method involves no smoothing or interpolation.

Inputs: BoM H-8 L2P SSTskin, SSES and quality level



Daily Regional and Global Multi-Sensor SST analyses (RAMSSA and GAMSSA)

Developer: Helen Beggs; Contact: Lixin Qi, Pallavi Govekar

http://www.bom.gov.au/marine/sst.shtml

Resolution: 0.083º regional, 0.25º global daily

Depth: Foundation SST estimate

Available: RAMSSA: 2006 - present; GAMSSA: 2008 - present

Access: AODN Thredds server http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/SST/ghrsst/L4/catalog.html

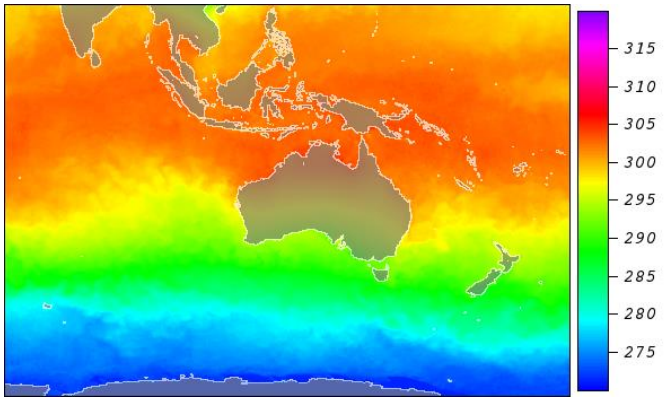
Method: Optimal interpolation (Beggs et al., 2011, AMOJ, 61)

Inputs:

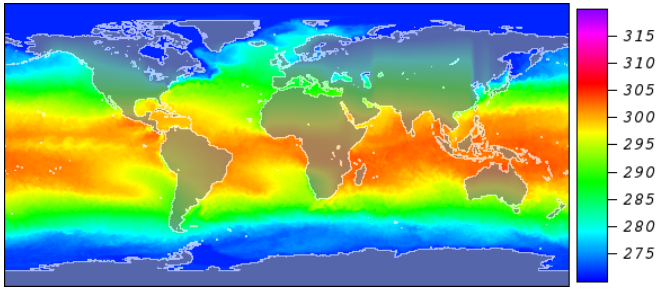
- 1-4 km IMOS HRPT AVHRR (NOAA-18/19) L2P SSTskin
- 9 km NAVOCEANO GAC AVHRR (NOAA-18/19, METOP-A/B) L2P SST1m
- ~50 km JAXA AMSR-2 (GCOM-W) L2P SSTsubskin
- Buoy and ship in situ SSTdepth (GTS)
- NCEP 9 km Sea Ice Analyses

Uses: BoM Numerical Weather Prediction models, MetEye, validating ocean models, GHRSST Multi-Product Ensemble

RAMSSA L4 SSTfnd (28 Feb 2018)



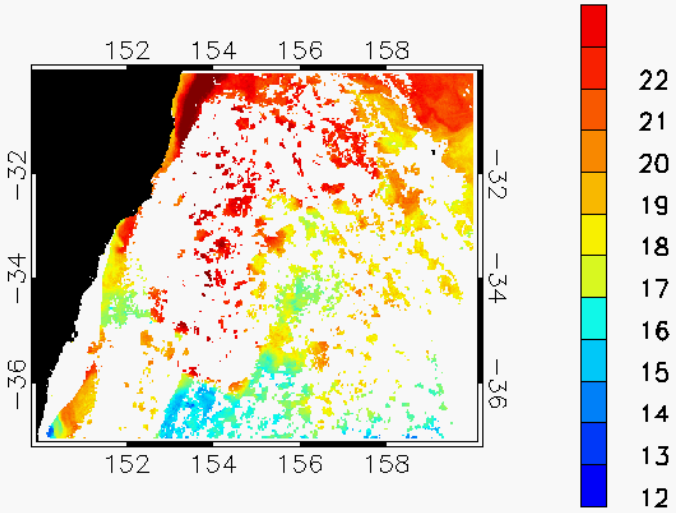
GAMSSA L4 SSTfnd (28 Feb 2018)



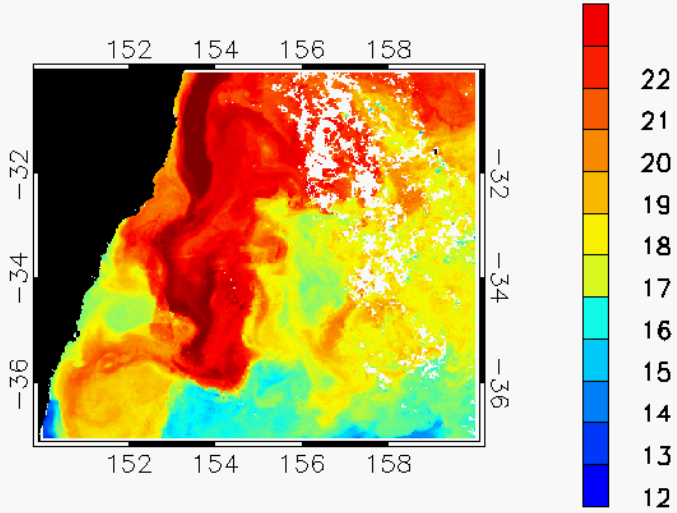
Temporal Averaging vs Spatial Interpolation

E.g. Multi-satellite day+night SSTfnd for 15 Aug 2013

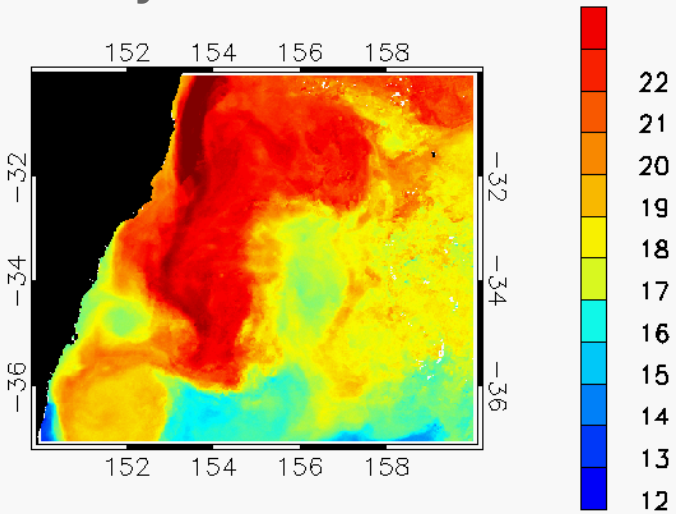
1-day 2 km L3S



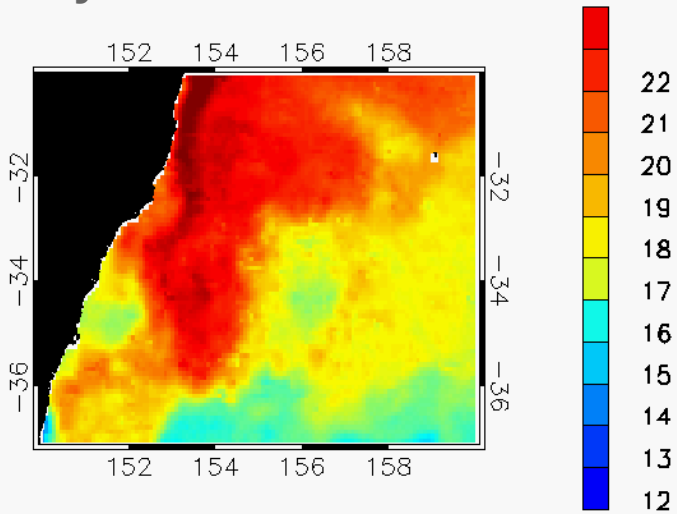
3-day 2 km L3S



6-day 2 km L3S



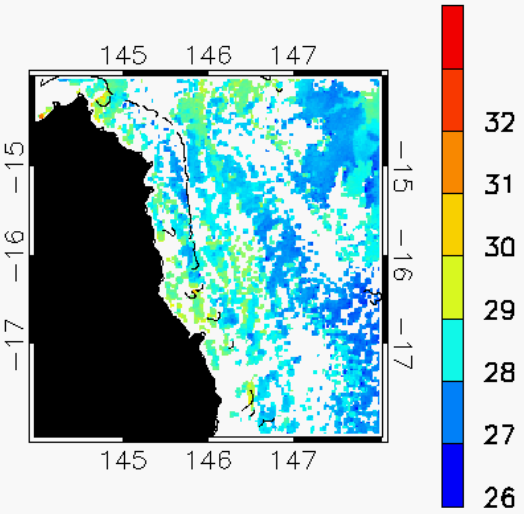
Daily 9 km RAMSSA L4



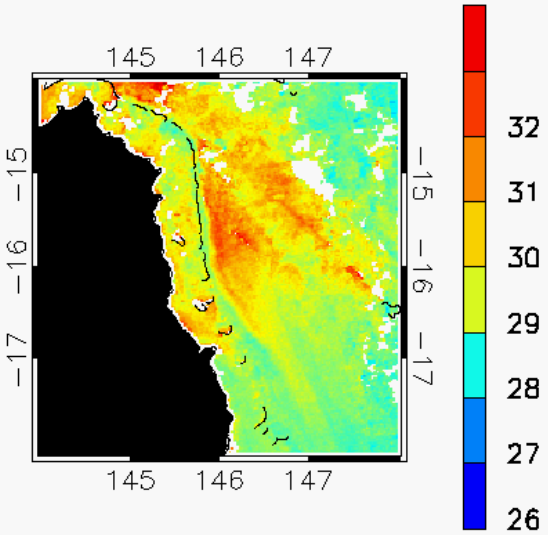
Why day-only, night-only and day+night L3S products?

1 Jan 2014

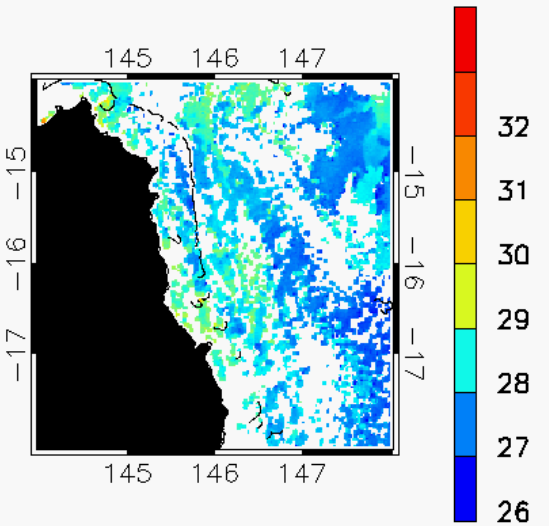
2 km IMOS day+night L3S



2 km IMOS day L3S



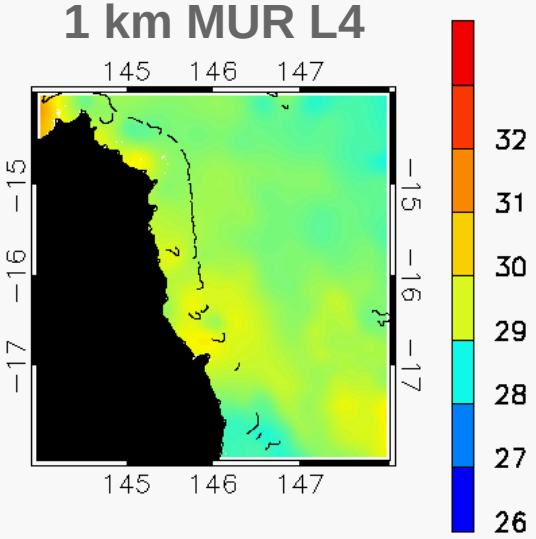
2 km IMOS night L3S



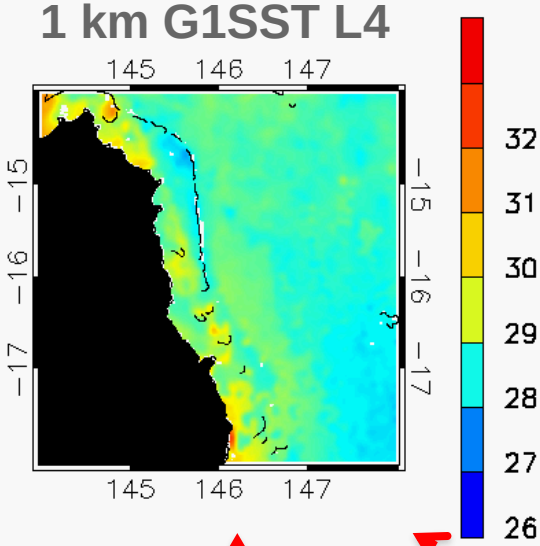
L4 interpolated SST vs L3S composite SST

L4 grid resolution ≠ Feature resolution!

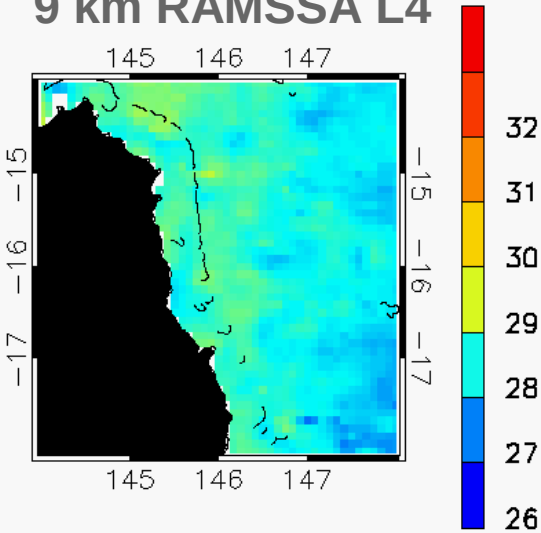
1 km MUR L4



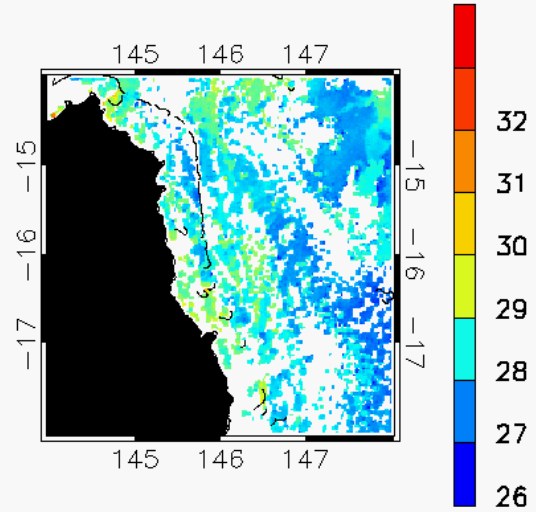
1 km G1SST L4



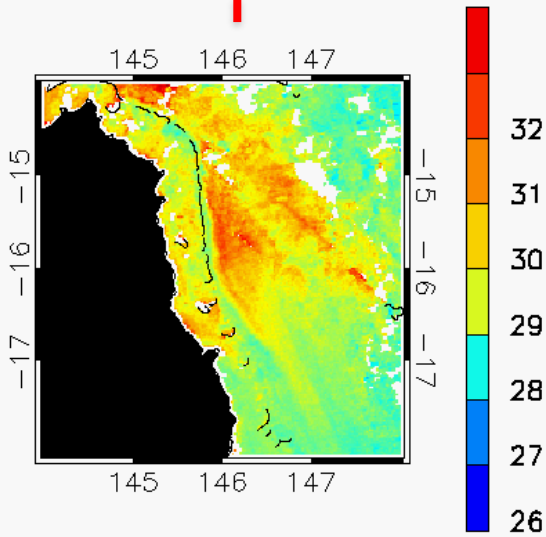
9 km RAMSSA L4



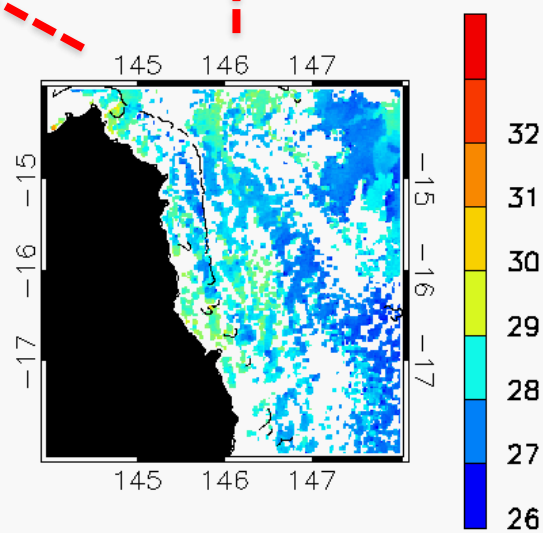
2 km IMOS day+night L3S



2 km IMOS day L3S



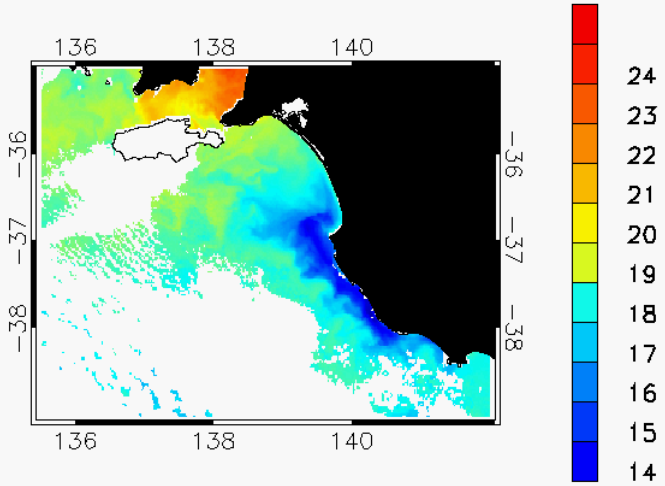
2 km IMOS night L3S



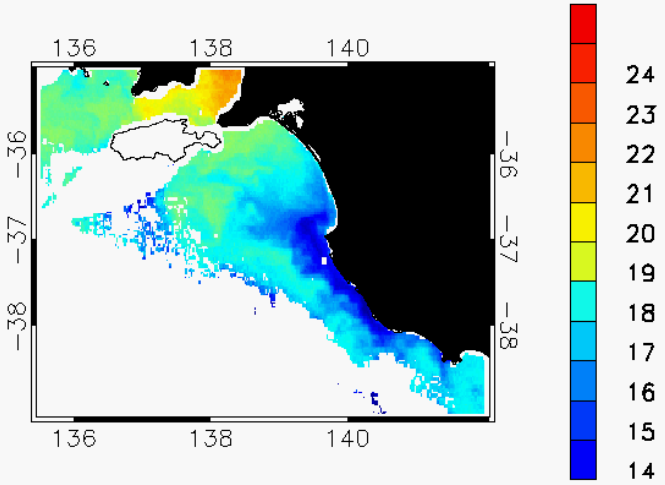
Accuracy vs temporal resolution in highly dynamic areas

Case Study: Bonney Coast 6 March 2018

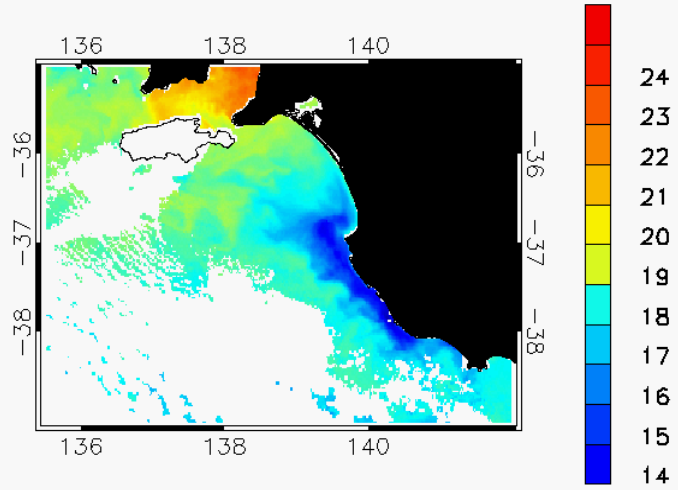
IMOS VIIRS Night L3C 15:20 UTC (QL ≥ 4)



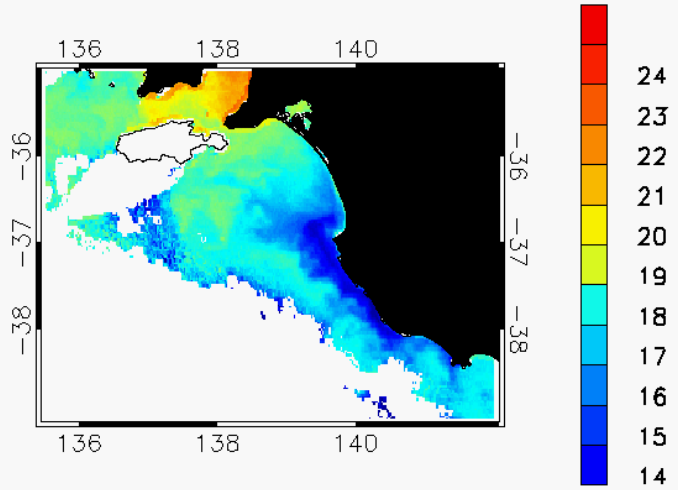
Himawari-8 Hourly L3C 15:30 UTC (QL ≥ 4)



IMOS Multisensor Night L3S 15:20 UTC (QL ≥ 4)



Himawari-8 Hourly L3C 15:30 UTC (QL ≥ 3)

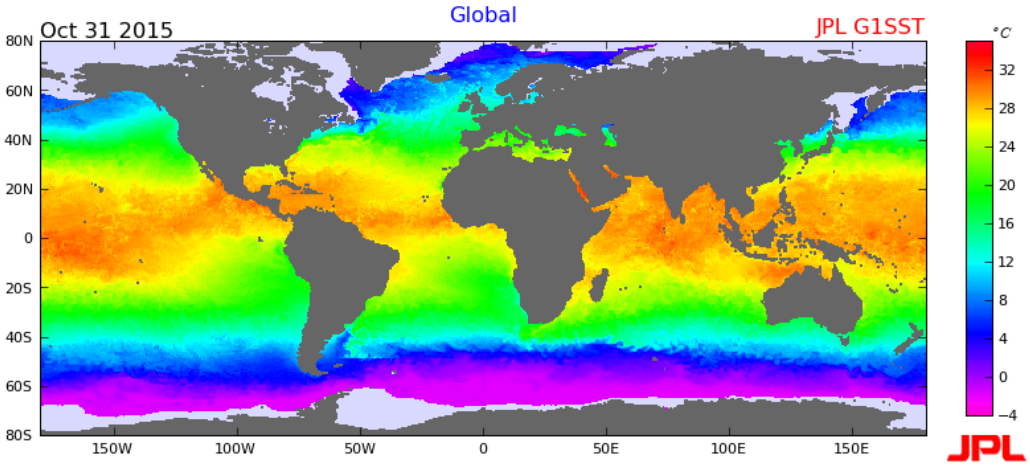


Applications of IMOS AVHRR GHRSST Products

L2P (geolocated swath)

- Ingested into “L4” SST analyses (RAMSSA, GAMSSA, G1SST)
- Ingested into CSIRO's IMOS OceanCurrent multi-satellite 4-hourly, 2 km L3 SST maps for Fisheries applications (http://oceancurrent.imos.org.au/four_hour.php)

JPL G1SST daily SSTdepth



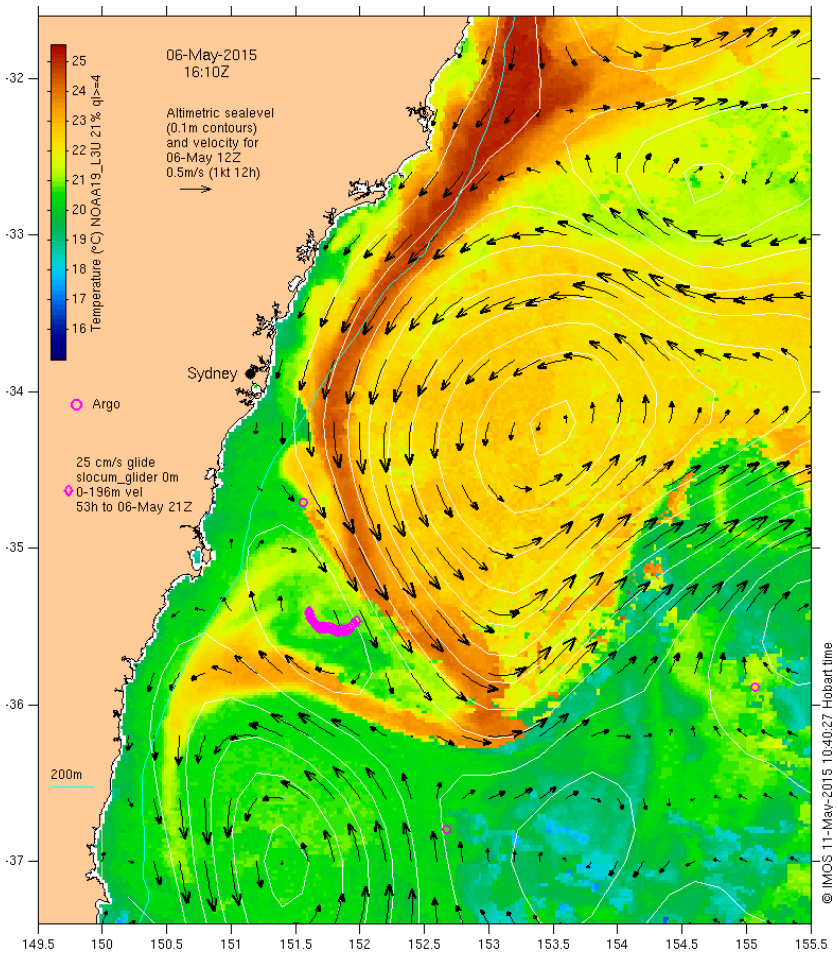
Applications of IMOS AVHRR GHRSST Products

L3U (2 km gridded, single swath)

Real-time SST maps

- www.fishtrack.com
- IMOS OceanCurrent (http://oceancurrent.imos.org.au/sst.php)

OceanCurrent SST Map 6 May 2015

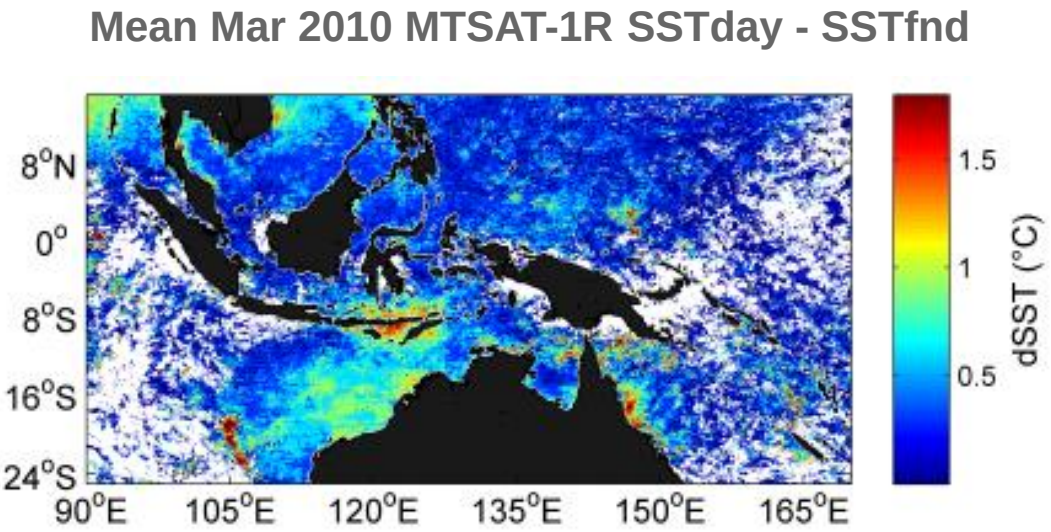


Applications of IMOS MTSAT-1R GHRSST Products

L3U (Hourly, 5 km gridded, single scene)

Research into diurnal warming

- Evaluation of dSST(0.5m) in GC2 coupled NWP experiments (José Rodriguez, UK Met Office)
- Great Barrier Reef (Xiaofang Zhu, PhD Uni of Miami)
- Tropical Warm Pool (Haifeng Zhang, PhD UNSW-Canberra) Zhang et al. (2016) Rem. Sens. Env., 183

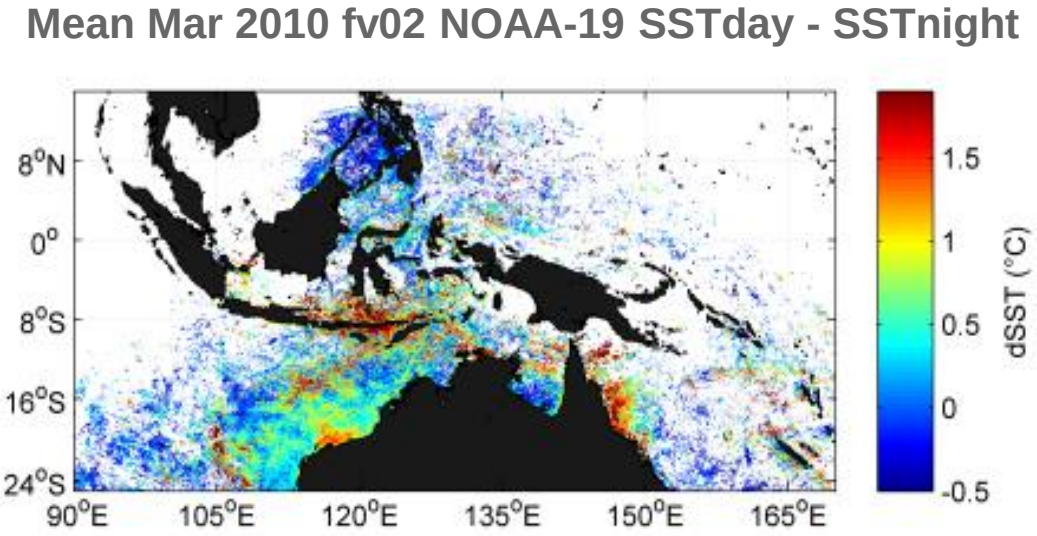


Applications of IMOS GHRSST Products

L3C (2 km gridded, multiple swath, night-only, day-only)

Research into diurnal warming

- Great Barrier Reef (Xiaofang Zhu, PhD Uni of Miami)
- Tropical Warm Pool (Haifeng Zhang, PhD UNSW-Canberra). See Zhang et al. (2016) JGR Oceans, 121



Applications of IMOS GHRSST Products

L3S (gridded, multiple sensor)

Nowcasting of coral bleaching

•ReefTemp NextGen uses night-only 1-day L3S Near RT maps of SST
http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml

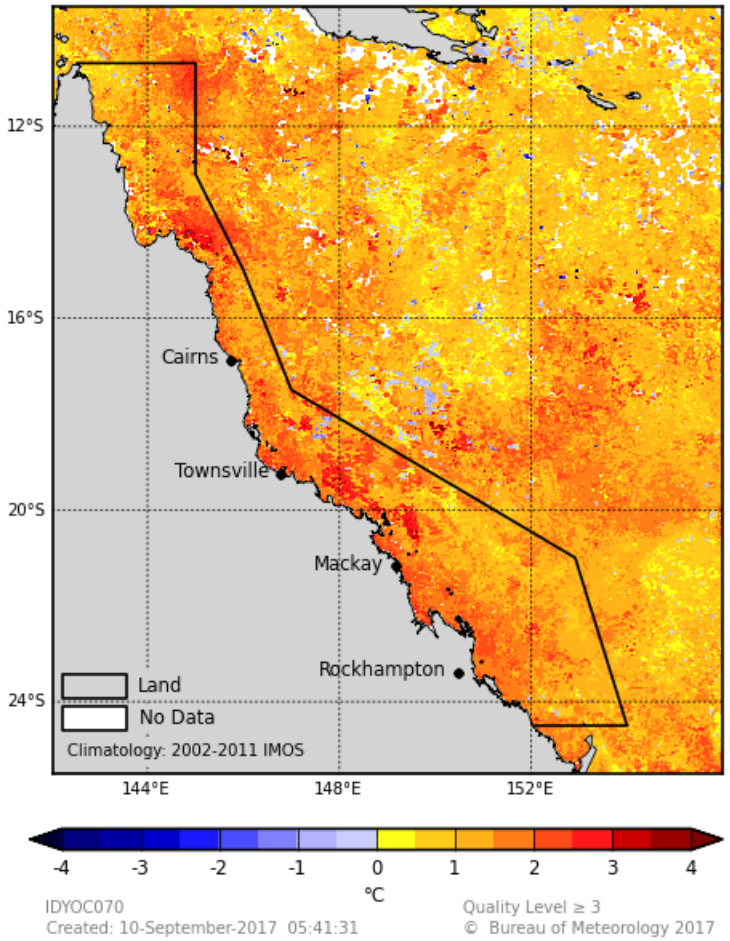
Coastal SST Maps

•IMOS *OceanCurrent* uses night-only 1 and 6-day L3S and night-only 1-month L3S
http://oceancurrent.imos.org.au/

2 km Australian SST climatology (SSTAARS) used night-only 1-day L3S

Access: http://portal.aodn.org.au (search for "SSTAARS")

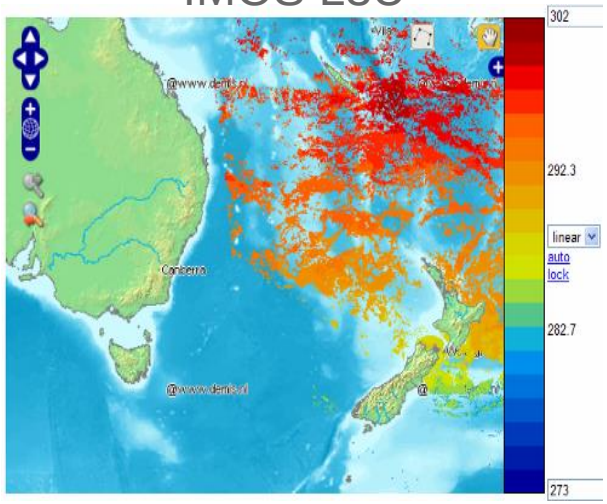
ReefTemp 1-day SST Anomaly
22 Mar 2017



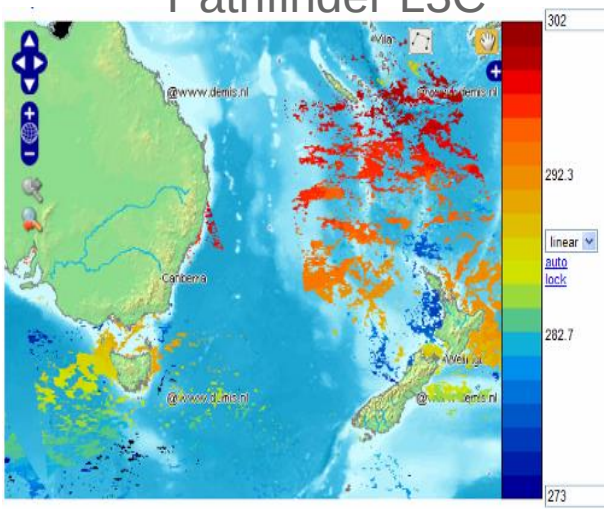
How does IMOS fv02 AVHRR L3C differ from Pathfinder AVHRR L3C SST?

- **Wider swath width**
- **Higher spatial resolution** - 1.1 km x 1.1 km cf 4.4 km x 1.1 km resolution at nadir
- **Resolves near-coastal gradients better**
- **More ancillary fields** - IMOS product has error estimates per pixel to comply with GHRSST spec
- **More satellites** - IMOS uses all available NOAA satellites, Pathfinder only one at a time
- IMOS back to 1992, **Pathfinder back to 1981**
- **IMOS real-time**, Pathfinder 3 months behind RT
- IMOS uses "adaptive calibration" and "adaptive error statistics" to "tune" AVHRR SSTs using regional in situ data to **minimise error**

IMOS L3U



Pathfinder L3C



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Useful sites for information on IMOS GHRSST products

Description of GHRSST products: https://www.ghrsst.org/quick-start/

Description of IMOS HRPT AVHRR GHRSST Products:
http://imos.org.au/facilities/srs/sstproducts/sstdata0/

How to read the IMOS HRPT AVHRR GHRSST Data:
http://imos.org.au/facilities/srs/sstproducts/sstdata0/reading-data/

Description of IMOS HRPT AVHRR GHRSST file variables:
http://imos.org.au/facilities/srs/sstproducts/sstdata0/sstdata-ghrsstfilefields/

IMOS GHRSST SST Validation:
http://opendap.bom.gov.au:8080/thredds/fileServer/abom_imos_ghrsst_archive-1/staticweb/sst-nrt-batch/index01.html and
http://imos.org.au/facilities/srs/sstproducts/sstdata0/sstdata-validation/

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/

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Summary

- Different SST products suit different applications…
- Be clear what SST depth you need (skin or foundation)
- Day or Night or Day+Night SST?
- How large is your ocean feature and how persistent?
- Weigh up spatial coverage vs accuracy
- L4 grid resolution ≠ ocean feature resolution ("sensitivity")
  - L3 will be more sensitive than L4 but has gaps
- Match the product temporal resolution to the process resolution (e.g. diurnal warming – 1 hour, coastal upwelling - 1 hour, meso-scale features in boundary currents - 1 day)
- **Contact:** helen.beggs@bom.gov.au

Additional slides for discussion

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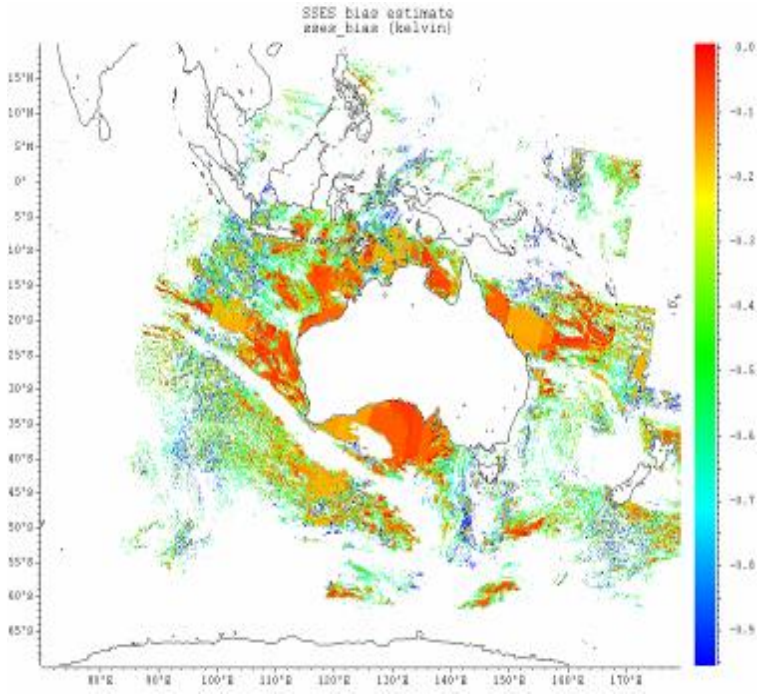
Adaptive Sensor Specific Error Statistics (SSES)

- Per platform basis
- Rolling 1 year window adjusted frequently (every 1 to 6 days)
- Measurements are weighted by time
(120 day time constant)
- Attributes considered (6-dimensions)
  - time of day,
  - satellite zenith angle,
  - quality level,
  - latitude, longitude, age

SSES_bias



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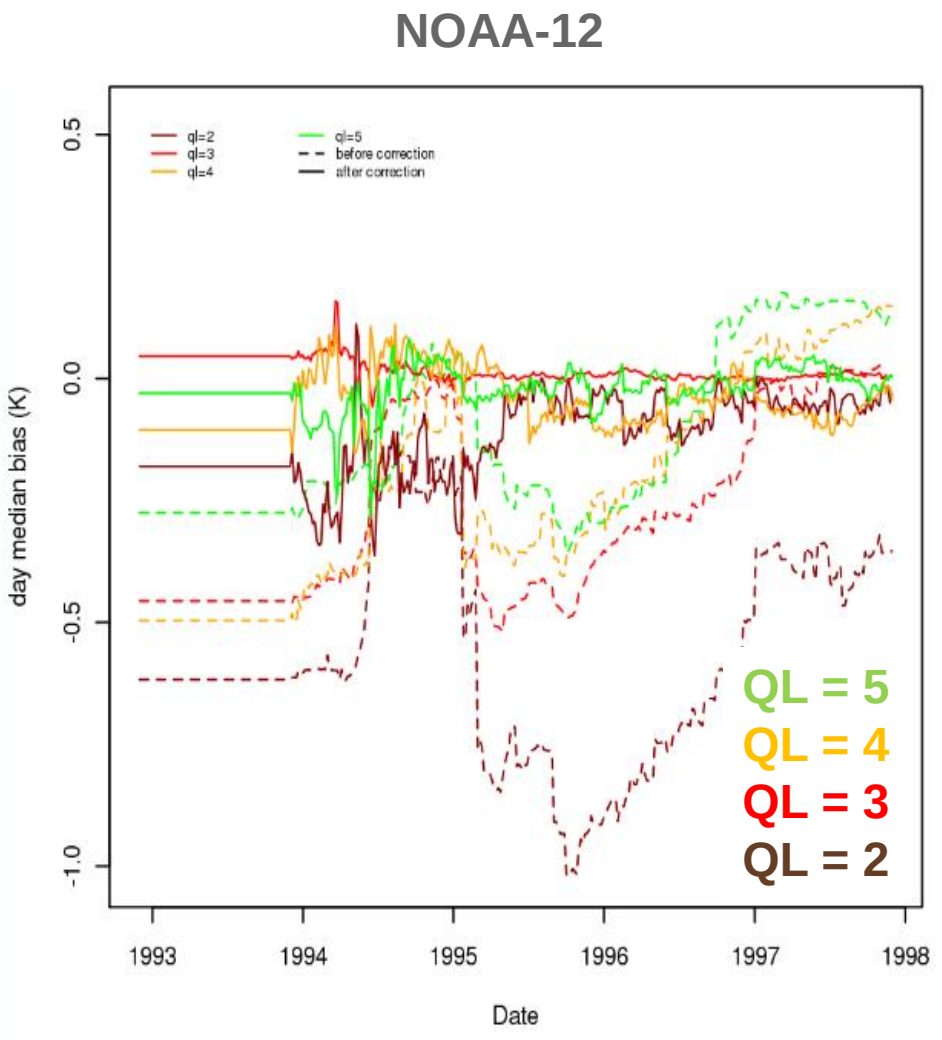
SSES Bias estimate performance

- Applying the bias correction improves the bias compared with *in situ* SST at all quality levels
- Dashed lines show before bias correction



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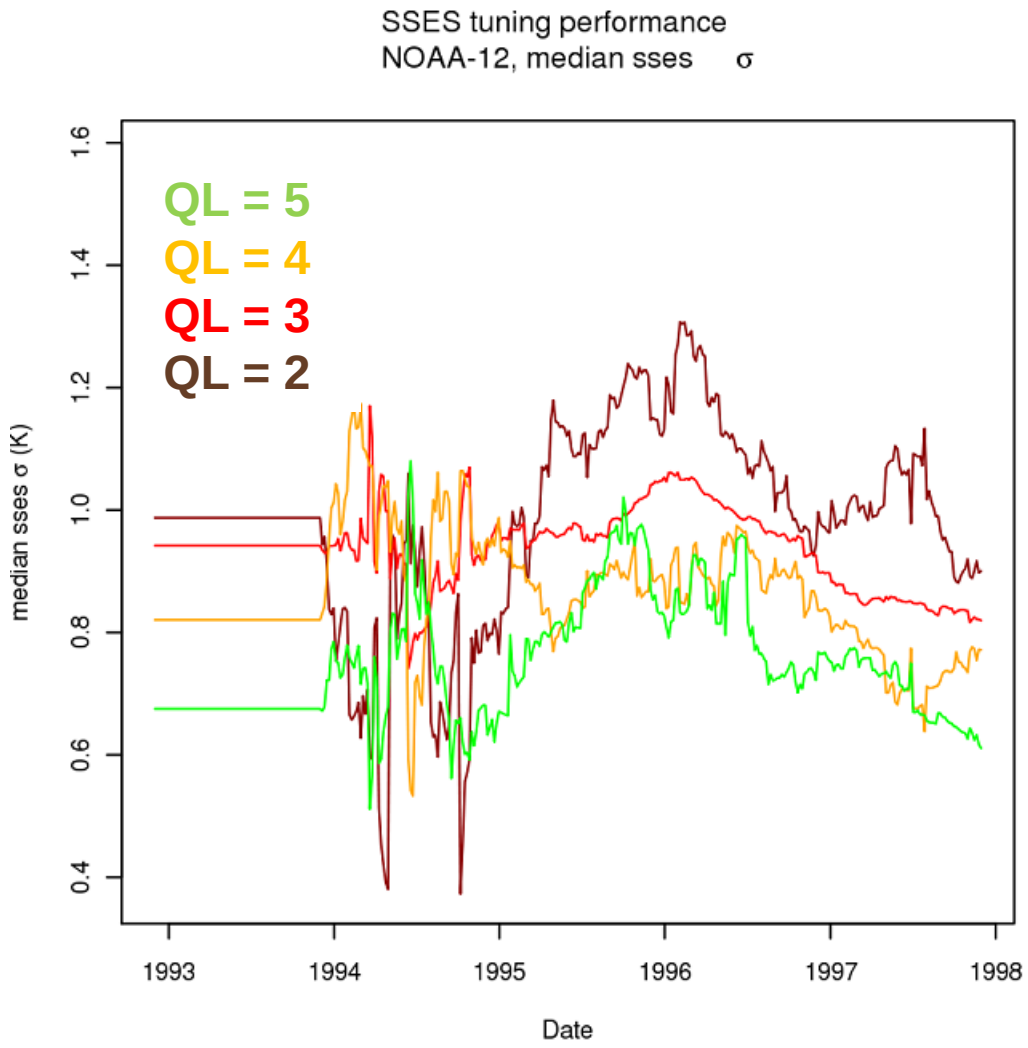
SSES Standard Deviation

- Standard deviation of AVHRR SSTs cf in situ SSTs at different quality levels are given in all IMOS SST files
- Variation over time (median standard deviation over the in situ matchups) is shown at the right for NOAA-12



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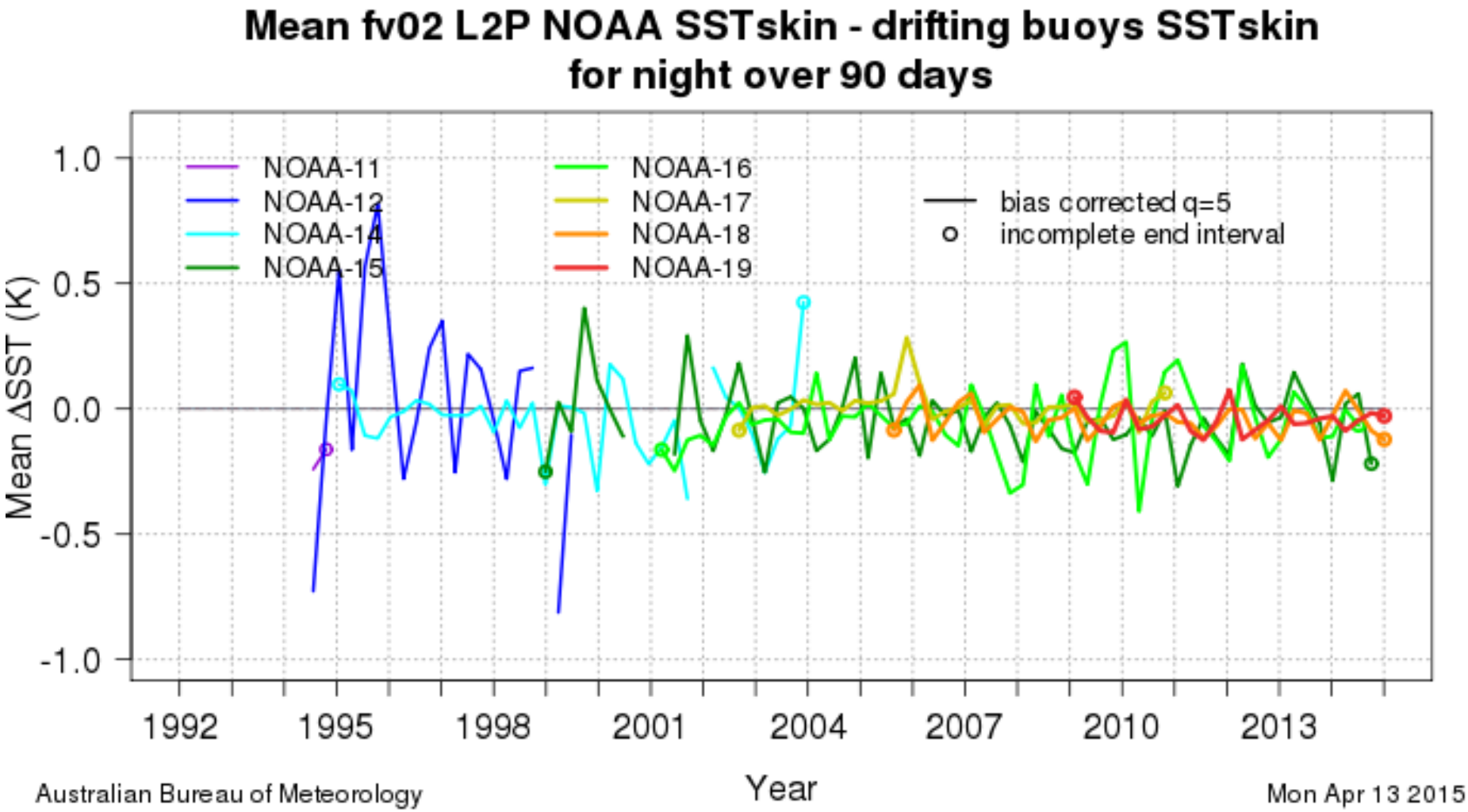
fv02 L2P SST on-line verification

http://opendap.bom.gov.au:8080/thredds/fileServer/abom_imos_ghrsst_archive/v02.0fv02/Validation/web/index.html



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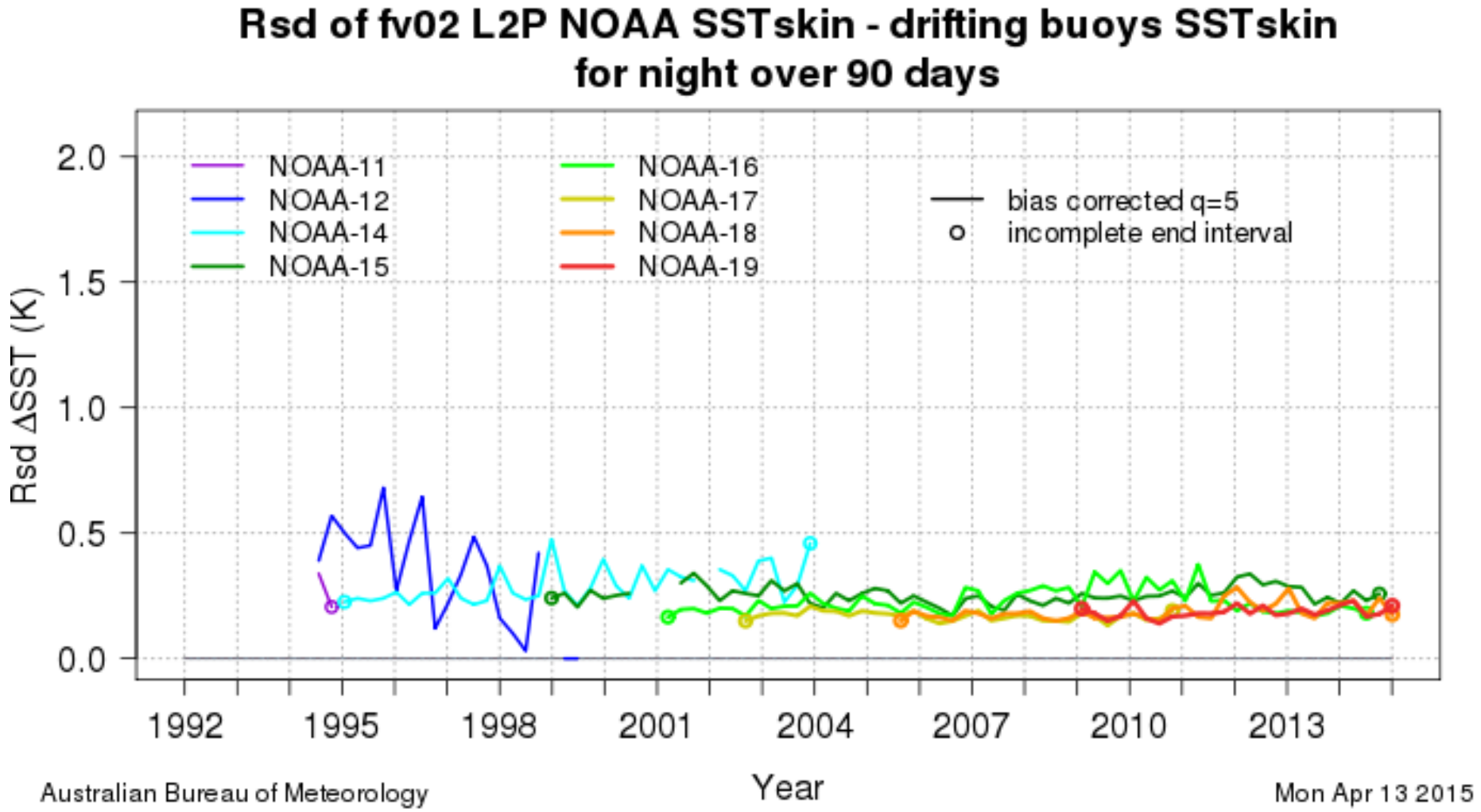
fv02 L2P SST on-line routine verification

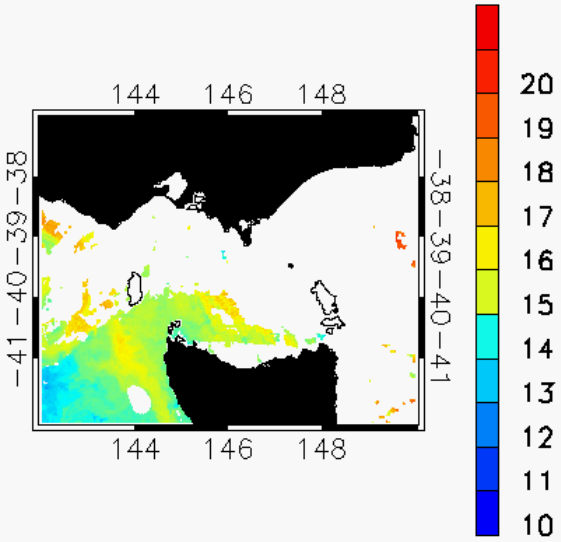
http://opendap.bom.gov.au:8080/thredds/fileServer/abom_imos_ghrsst_archive/v02.0fv02/Validation/web/index.html



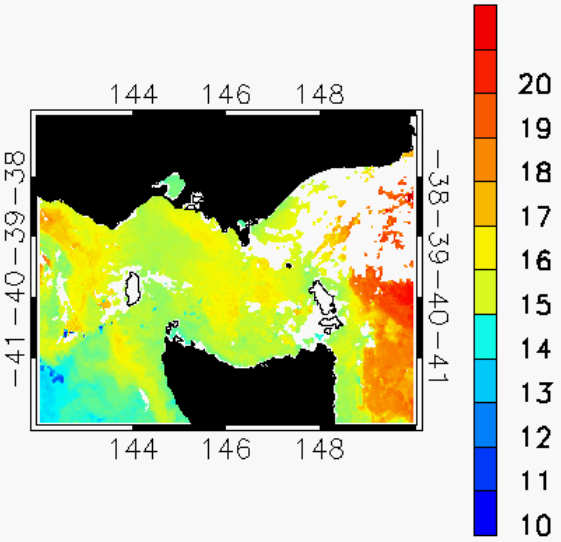
Temporal Averaging vs Spatial Interpolation

E.g. Multi-satellite day+night SSTfnd for 2 Jun 2014

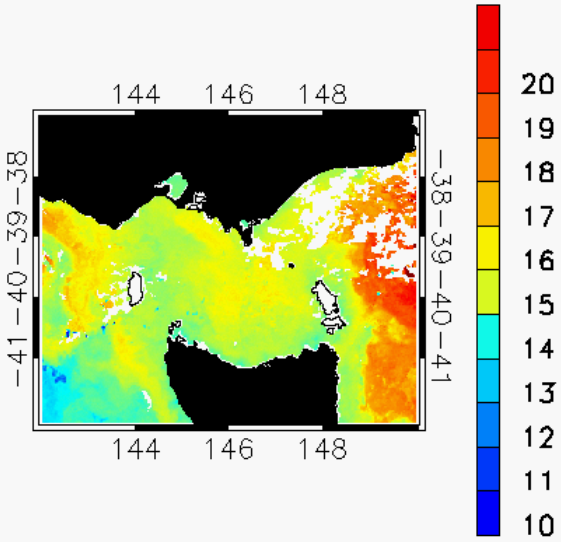
1-day 2 km L3S



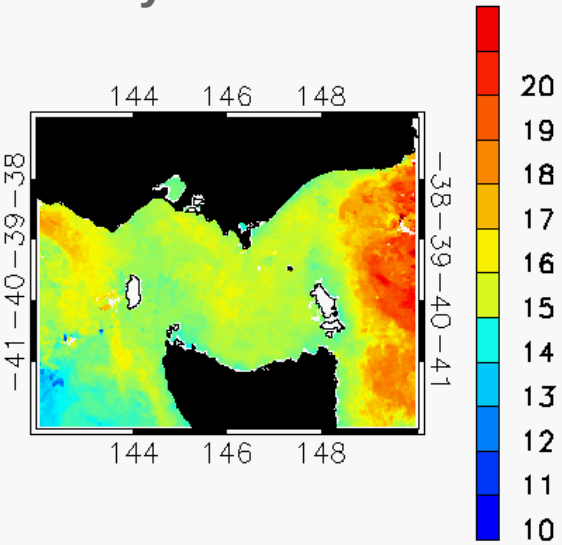
3-day 2 km L3S



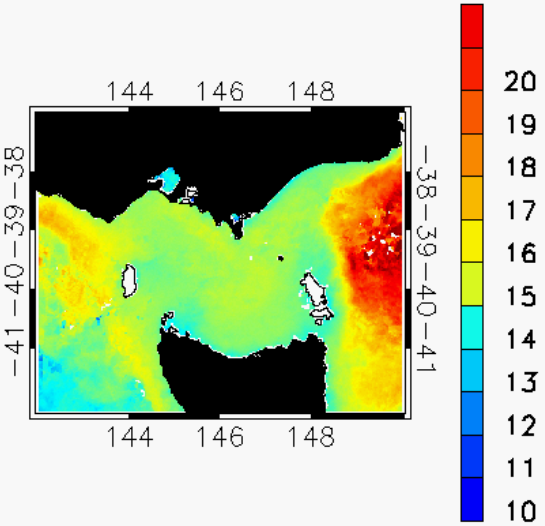
6-day 2 km L3S



14-day 2 km L3S



1-month 2 km L3S



Daily 1 km MUR L4