REPORT FROM THE AUSTRALIAN RDAC TO GHRSST-XX

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ABSTRACT

This is a report of progress during the past 12 months in the Australian Regional Data Assembly Centre at the Bureau of Meteorology (BoM), relating to the provision and validation of Group for High Resolution Sea Surface Temperature (GHRSST) products, and related SST research.

1 Overview

As a contribution to the Integrated Marine Observing System (IMOS), the Australian Bureau of Meteorology produces several real-time and delayed mode (reprocessed), GHRSST format products (GHRSST Science Team, 2012) for a range of operational and research applications, using locally received and overseas sea surface temperature (SST) data sets obtained from polar-orbiting and geostationary satellites (Beggs, 2019). In summary, they are:

1.1 Operational Real-time GDS1.6

- Daily Regional 1/12º SSTfnd L4 ("RAMSSA") over 60ºE to 190ºE, 70ºS to 20ºN (Figure 1(a))
- Daily Global 0.25º SSTfnd L4 ("GAMSSA") (Figure 2(b))

(a) (b)

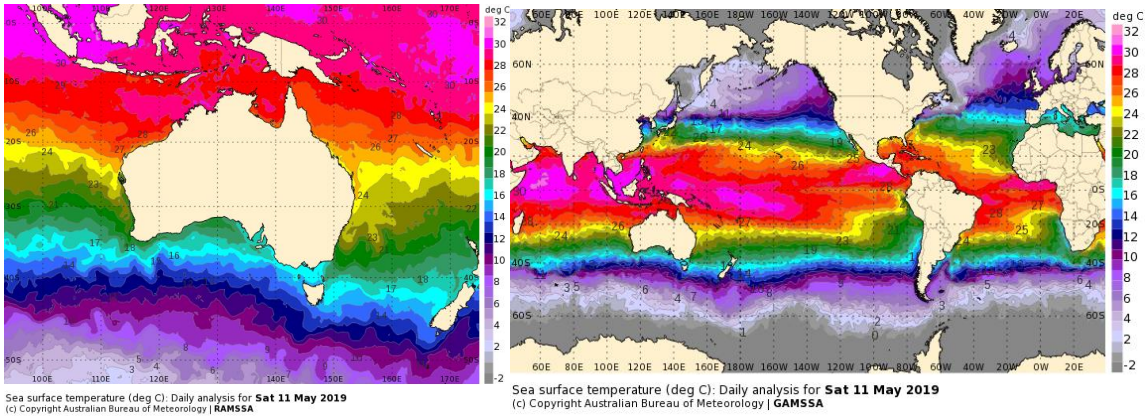


Figure 1: Example of foundation SST for 11th May 2019 from BoM Daily L4 analyses (a) RAMSSA and (b) GAMSSA, formed from NAVOCEANO GAC AVHRR L2P (MetOp-A, MetOp-B), JAXA AMSR-2 and in situ SST (ships, buoys).

1.2 Operational Real-time GDS2.0

- Daily Regional 1/12º SSTfnd L4 ("RAMSSA") over 60ºE to 190ºE, 70ºS to 20ºN

- Daily Global 0.25º SSTfnd L4 ("GAMSSA")
- 1 km SSTskin L2P from High Resolution Picture Transmission (HRPT) Advanced Very High Resolution Radiometer (AVHRR) data (NOAA-15, NOAA18, NOAA-19)
- 0.02º SSTskin L3U and day/night L3C over Australia (70ºE to 190ºE, 70ºS to 20ºN) and Southern Ocean (2.5°E to 202.5°E, 77.5°S to 27.5°S) from HRPT AVHRR data (NOAA15, NOAA-18, NOAA-19) and ACSPO Visible Infrared Imaging Radiometer Suite (VIIRS) L3U data (Suomi-NPP)
- 0.02º day/night SSTskin and day+night SSTfnd L3S over Australia (70ºE to 190ºE, 70ºS to 20ºN) and Southern Ocean (2.5°E to 202.5°E, 77.5°S to 27.5°S) from
    - AVHRR-only: HRPT AVHRR data (NOAA-18, NOAA-19)
    - Multi-sensor: HRPT AVHRR data (NOAA-18) and VIIRS data (Suomi-NPP) (Figure 3(a))
- 2 km 10-minute Himawari-8 AHI SSTskin L2P

1.3 Experimental Real-Time GDS2.0

- 0.02º SSTskin L3U and day/night L3C over Australia (70ºE to 190ºE, 70ºS to 20ºN) and Southern Ocean (2.5°E to 202.5°E, 77.5°S to 27.5°S) from OSI-SAF Full Resolution Area Coverage (FRAC) AVHRR L2P (MetOp-B) and ACSPO VIIRS L3U data (NOAA-20)
- 0.02º day/night SSTskin and day+night SSTfnd L3S over Australia (70ºE to 190ºE, 70ºS to 20ºN) and Southern Ocean (2.5°E to 202.5°E, 77.5°S to 27.5°S) from
    - Multi-sensor: HRPT AVHRR data (NOAA-18), FRAC AVHRR data (MetOp-B) and VIIRS data (Suomi-NPP, NOAA-20) (Figure 3(b))
- 0.02º Hourly, 4-hourly and Daily night-only SSTskin L3C over Australia (70ºE to 190ºE, 70ºS to 20ºN) from Himawari-8 AHI

1.4 Reprocessed GDS2.0

- HRPT AVHRR L2P/L3U/L3C/L3S from 1992 to 2016 (NOAA-11 to NOAA-19 satellites)
- AVHRR and VIIRS L3U/L3C/L3S from 2012 to 2016 (NOAA-18, NOAA-19, MetOp-A, MetOp-B, Suomi-NPP)
- MTSAT-1R Hourly 0.05º L3U (2006 to 2010)

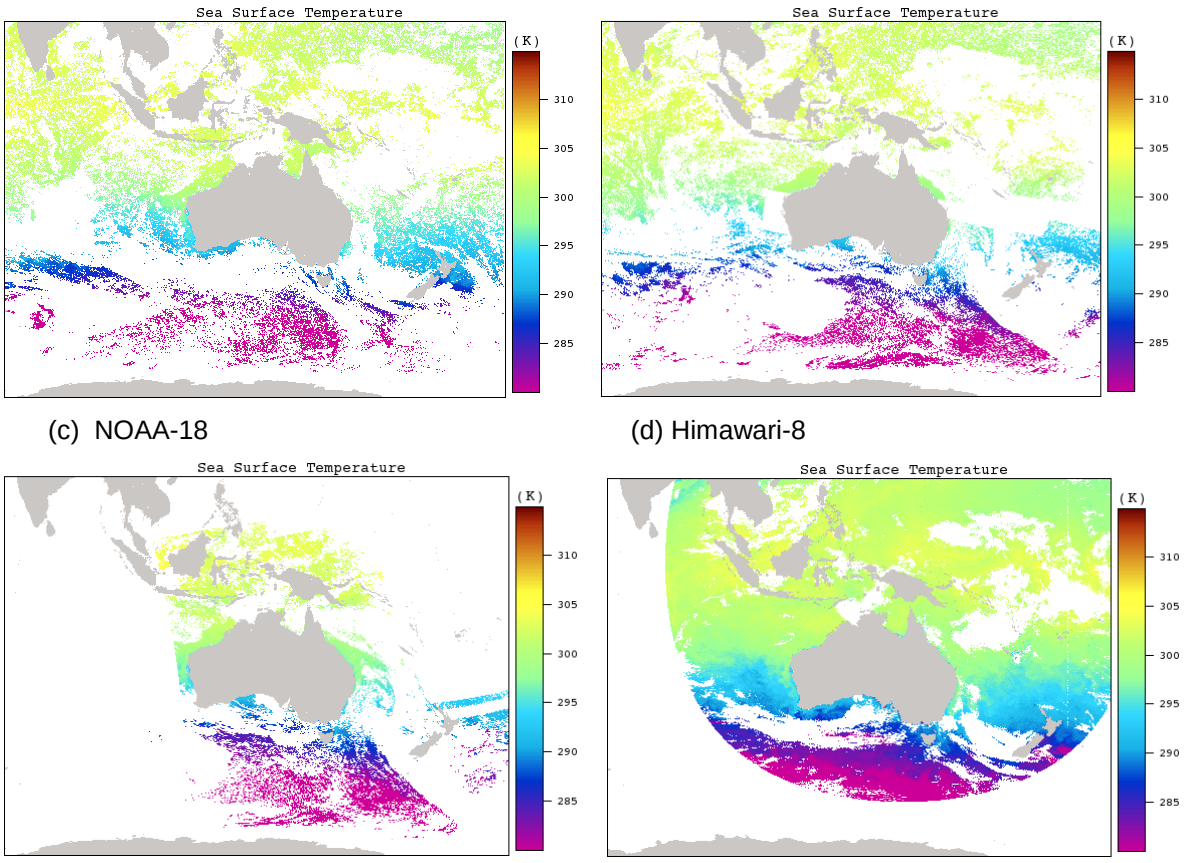
2 Data availability

2.1 Real-time GDS1.6

- Operational daily L4 (RAMSSA/GAMSSA) are available within 6 hours of final observation back to 2008 from JPL PO.DAAC (http://podaac.jpl.nasa.gov/dataset/ABOM-L4HRfnd-AUS-RAMSSA_09km and http://podaac.jpl.nasa.gov/dataset/ABOM-L4LRfnd-GLOB-GAMSSA_28km), NOAA/NCEI (https://www.nodc.noaa.gov/SatelliteData/ghrsst/accessdata.html) and Bureau OPeNDAP server.

(a) MetOp-B

(b) NOAA-20



(c) NOAA-18

(d) Himawari-8

Figure 2: Example of skin SST for 11th May 2019 from IMOS 1-day L3C products formed from (a) daytime MetOp-B FRAC AVHRR, (b) night-time NOAA-20 VIIRS, (c) night-time NOAA-18 HRPT AVHRR and (d) night-time Himawari-8 AHI L3U SST.

(a) Operational Multi-sensor

(b) Experimental Multi-sensor

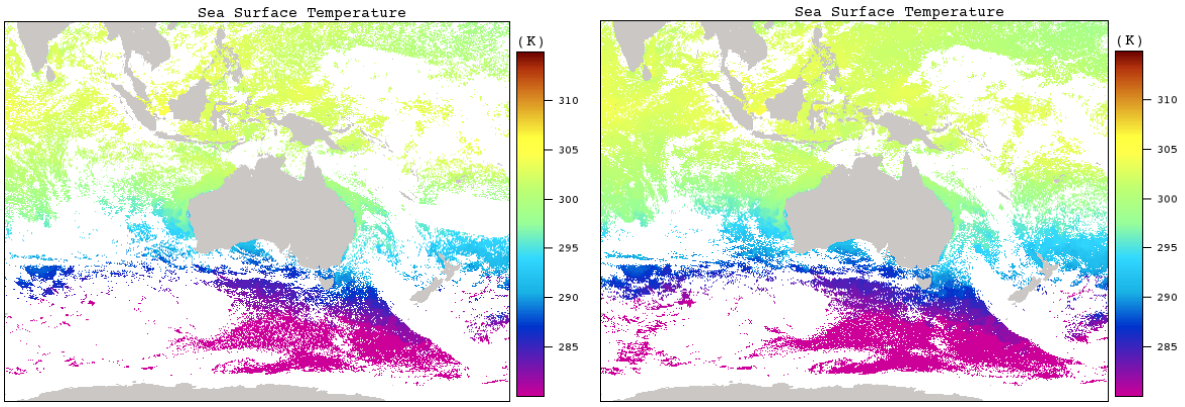


Figure 3: Example of skin SST for 11th May 2019 from IMOS 1-day night-time Multi-sensor L3S products formed from (a) NOAA-18/AVHRR and Suomi-NPP/VIIRS and (b) NOAA-18/AVHRR, MetOp-B/AVHRR, Suomi-NPP/VIIRS and NOAA-20/VIIRS L3C SST.

2.2 Real-time GDS2.0

- Operational daily L4 (RAMSSA/GAMSSA) are available within 6 hours of final observation back to 2006/2008 from the Australian Ocean Data Network (AODN) Thredds Server at http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/SST/ghrsst/L4/catalog.html
- Operational IMOS fv01 HRPT AVHRR (available 2015 to present)
    - L2P: OPeNDAP server (contact ghrsst@bom.gov.au)
- Operational IMOS fv01 HRPT AVHRR L3U/L3C/L3S (available 2015 to present): http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/SST/ghrsst/catalog.html
- Experimental IMOS fv01 MetOp-B, NOAA-20 L3C and Multi-sensor L3S: OPeNDAP servers (contact ghrsst@bom.gov.au**)**
- BoM AHI Himawari-8
    - L2P: (available 24 March 2016 to present) Contact ghrsst@bom.gov.au
    - L3C: (available 1 October 2017 to present) Contact ghrsst@bom.gov.au

2.3 Reprocessed GDS2.0

- IMOS fv02 HRPT AVHRR (available 1992 to 2016)
    - L2P: http://dapds00.nci.org.au/thredds/catalog/rr5/satellite/GHRSST/v02.0fv02/L2P/catalog.html
    - L3U/L3C/L3S: http://portal.aodn.org.au and http://dapds00.nci.org.au/thredds/catalog/rr5/satellite/GHRSST/v02.0fv02/Continental/catalog.html
- IMOS AVHRR and VIIRS L3U/L3C/L3S (available 2012 to 2016): Contact ghrsst@bom.gov.au
- IMOS MTSAT-1R L3U (available Jun 2006 to Jun 2010): IMOS Thredds server at

http://rs-data1-mel.csiro.au/thredds/catalog/imos-srs/sst/ghrsst/L3U/mtsat1r/catalog.html

3 Progress since GHRSST-XIX

3.1 Issues with NOAA-18 and NOAA-19 AVHRR SST

Orbital decay of NOAA-18 and NOAA-19 in recent years has affected the accuracy of real-time AVHRR SST products during some months, particularly since April 2017 for NOAA-18 and November 2017 for NOAA-19 (NOAA NESDIS, 2019). From 22 May 2018, Global Area Coverage (GAC) AVHRR NOAA-18 L2P SST data has no longer been ingested into BoM ocean models and SST analyses. IMOS NOAA-18 L3C SSTs are still ingested into IMOS L3S as errors are relatively small since August 2018 (BoM, 2019). BoM removed NOAA-19 SST data from ocean models (7 August 2018), Daily L4 (24 October 2018), IMOS Multi-sensor L3S (7 September 2018) and IMOS AVHRR L3S (1 October 2018).

3.2 Issues with change in GTS format of Drifting Buoy SST

Since 2nd November 2016 the number of 5-digit WMO ID drifting buoys providing SST data to GTS has steadily decreased, with new drifting buoys all having 7-digit IDs. BoM started ingesting 7-digit ID drifting buoy SSTs into IMOS SST systems from 9th December 2016 and SST analyses from 1st July 2018. The decrease in drifting buoy SST ingested from 2nd November 2016 to 30th June 2018 has had no noticeable impact on RAMSSA or GAMSSA SST analysis accuracy compared with independent Argo SST(5m) data (https://www.star.nesdis.noaa.gov/sod/sst/squam/analysis/l4/).

3.3 Operational SST Analyses

3.3.1 Overview

BoM produces regional 1/12º ("RAMSSA") and global 1/4º ("GAMSSA") operational daily foundation L4 SST analyses in near real-time based on an optimal interpolation method. For more information on RAMSSA see Beggs et al (2011) and for GAMSSA see Zhong and Beggs (2009) and Beggs et al (2011). RAMSSA and GAMSSA are available in both GDS1.6 (Beggs and Pugh, 2009) and GDS2.0 L4 format (GHRSST Science Team, 2012) (Section 2).

SST inputs:

- 1 km IMOS fv01 HRPT AVHRR (NOAA-18, -19) L2P SSTskin (Paltoglou et al., 2010) (Stopped 21st October, 2018)
- 9 km NAVOCEANO GAC AVHRR GHRSST-L2P SST1m (NOAA-18, NOAA-19, MetOp-A, MetOp-B) (NOAA-18 stopped 22 May 2018, NOAA-19 stopped 24 October 2018)
- ~50 km AMSR-2 (GCOM-W) L2P SSTsubskin (since 1 December 2014)
- GTS Buoy and ship in situ SSTdepth (Argo and CTD SSTdepth ingested only into RAMSSA)

Sea Ice inputs: NOAA/NCEP Daily 1/12º sea-ice concentration analysis (Grumbine, 1996)

Background:

- RAMSSA: Formed from a combination of previous day's RAMSSA analysis and BoM Global Weekly 1º SST analysis (Smith et al., 1999).
- GAMSSA: Formed from a combination of previous day's GAMSSA analysis and Reynolds and Smith (1994) Monthly 1º 1961 – 1990 SST climatology.

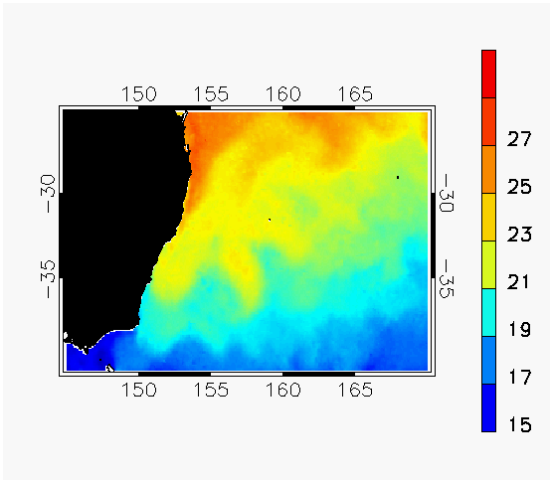
Applications: Boundary condition for NWP models, validating ocean forecasts and MetEye. In addition, GAMSSA contributes to the GHRSST Multi-Product Ensemble.

3.3.2 Progress

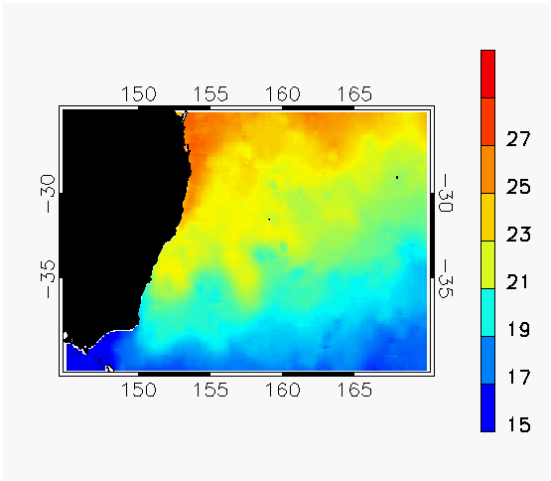
ACSPO 0.02º Suomi-NPP VIIRS L3U SST data is being ingested into experimental, near real-time daily SST analyses (1/4º GAMSSA and 1/12º RAMSSA). Night-only ACSPO VIIRS L3U (quality level 5) data are collated to daily 1/4º and 1/12º L3C SSTfnd. Data are then further thinned by striding to 1/2º (GAMSSA) and 1/3º (RAMSSA). The thinned VIIRS SSTs are ingested along with NAVOCEANO GAC AVHRR, JAXA AMSR-2 and in situ SSTfnd into test RAMSSA and GAMSSA analyses. In order to reduce innovation STD compared with drifting and tropical moored buoy SSTfnd, the background correlation length scales have been increased from 12 km to 20 km (RAMSSA) and from 50 km to 80 km (GAMSSA). An additional change to experimental GAMSSA is that the background field is now formed from a weighted combination of the previous day's GAMSSA analysis and the BoM Global Weekly 1º SSTblend analysis.

Examples of the operational and test RAMSSA and GAMSSA SST maps are shown in Figure 4(a)-(d). For comparison, the Canadian Meteorological Centre (CMC) 0.1º daily foundation SST analysis (Brasnett and Surcel Colan, 2016) is also shown (Figure 4(e)).

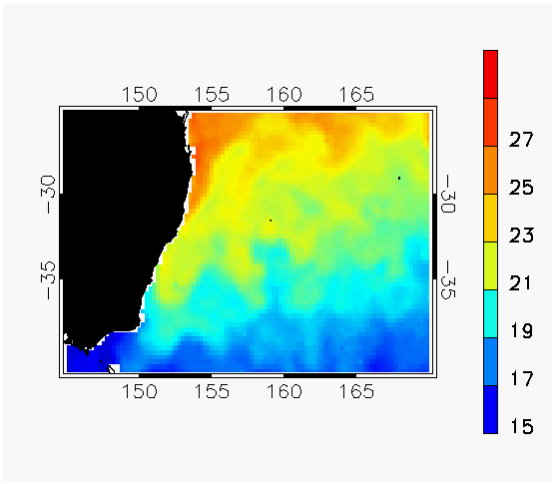
(a) Operational RAMSSA



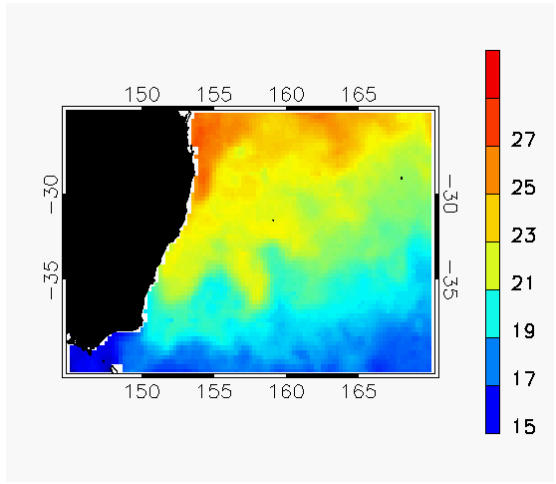
(b) Experimental RAMSSA



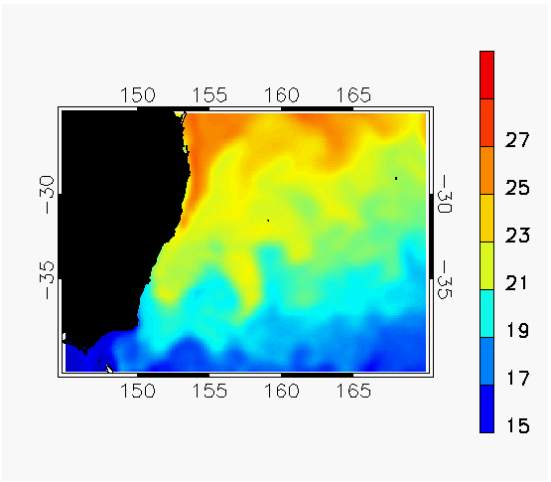
(c) Operational GAMSSA



(d) Experimental GAMSSA



(e) CMC 0.1deg



(f) Experimental GSAS v20

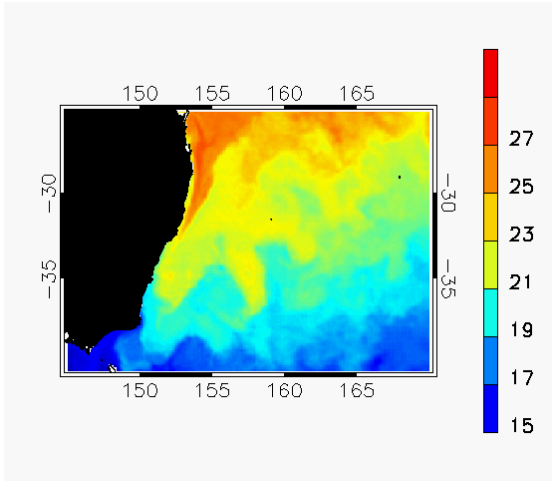


Figure 4: Example of foundation SST in the East Australian Current for 11th May 2019 from daily Multi-sensor L4 analyses (a) operational RAMSSA, (b) experimental RAMSSA (ingesting VIIRS L3U SST), (c) operational GAMSSA, (d) experimental GAMSSA (ingesting VIIRS L3U SST), (e) CMC0.1deg (ingesting VIIRS L3U SST) (Brasnett and Surcel Colan, 2016), and (f) experimental GSAS version 20 (ingesting VIIRS L3U SST).

3.4 Experimental Ensemble Optimal Interpolation SST Analysis (GSAS)

3.4.1 Overview

The BoM operational optimal interpolation SST analysis systems (GAMSSA, RAMSSA and Global Weekly) are based on Fortran code developed in the 1980s. Ensemble Kalman Filter data assimilation C code (EnKF-C; Sakov, 2014) is currently used for data assimilation into the BoM operational ocean model (OceanMAPS v3.2; BoM, 2017). Based on EnKF-C, an Ensemble Optimal Interpolation (EnOI) Global SST Analysis System (GSAS) has been developed, and is currently being tested and modified to eventually replace RAMSSA and GAMSSA. GSAS is a daily near-global (±75ºN) foundation SST analysis on a 0.1º x 0.1º grid. It ingests similar satellite SST inputs as operational GAMSSA (GAC AVHRR L2P and AMSR-2 L2P), with the addition of ACSPO VIIRS L3U night-only SST, strided to 0.04º. Unlike RAMSSA and GAMSSA, no in situ SST or sea ice data are currently ingested. The EnOI system uses background ensemble error covariances formed from the OFAM3 ocean model, with a support localisation radius (LOCRAD) of 100 km, RFACTOR to 0.33, and KFACTOR to 1 (Sakov, 2014). In addition, the latest GSAS test version (v20) uses a relaxation to CSIRO Atlas of Regional Seas (CARS) 2009 climatology (https://researchdata.ands.org.au/csiro-atlas-regional-cars-2009/15210) with e-folding time of 60 days. An example of the GSAS v20 SST is shown in Figure 4(f). Spectral analysis of GSAS v19 (without AMSR-2 data ingested) performed by the UK Met Office indicates that GSAS has slightly lower spectral density in boundary current regions to the current operational OSTIA but higher spectral density than CMC0.1deg (*Simon Good, pers. com.*). Globally, it has 0.02K higher RMS error compared with independent Argo SST(5m) observations than CMC0.1deg (*Simon Good, pers. com.*).

Future work in 2019/20 will concentrate on developing GSAS regional 0.1º SST analysis to replace RAMSSA, involving ingesting a sea-ice analysis, and improving the climatology and land mask.

3.5 IMOS GHRSST AVHRR and VIIRS Composite Products

3.5.1 Overview

As part of the Integrated Marine Observing System (IMOS: www.imos.org), BoM in collaboration with CSIRO, produces a range of HRPT AVHRR GDS2.0 L2P, L3U, L3C and L3S products from the series of NOAA Polar Orbiting Environmental Satellites (NOAA-11 to NOAA-19). Following methods documented in Griffin et al. (2017), SST values are derived by regressing brightness temperatures against regional drifting buoy SST observations at ~0.2 m depth, error estimates obtained using matchups with buoy data, and quality levels defined from proximity to detected cloud. The 0.02º resolution level 3 products are available in a range of averaging periods from single orbit to 1 month to suit different applications (Beggs, 2019). All products are available in real-time (within 3 to 24 hours of final observation) (Paltoglou et al., 2010) and have also been reprocessed to cover the period from 1992 to 2016 (Griffin et al., 2017). For more information see IMOS (2018) and AODN (2019).

Applications: BoM operational coral bleaching nowcasting service (ReefTemp NextGen: http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml), regional maps of ocean currents and SST (http://oceancurrent.imos.org.au/), SST climatologies (Wijfells et al., 2018), and research/monitoring SST diurnal variation, Marine Heat Waves and coastal upwelling (Beggs, 2019).

3.5.2 Progress

From 2018, NOAA officially replaced the AVHRR sensor program with the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor program, after a long trial which began with the first VIIRS sensor launched in 2012 aboard the Suomi National Polar-Orbiting Partnership (NPP) platform. The VIIRS sensor provides higher spatial resolution (0.75 km at nadir) and lower noise than AVHRR, and has better orbital stability, with daily global SST coverage in cloud-free conditions at around 01:20 and 13:20 local time. The NOAA Office of Satellite and Product Operations (OSPO) produce real-time VIIRS L3U SST on the IMOS 0.02º x 0.02º grid (NOAA CoastWatch, 2018). The Bureau of Meteorology (BoM) have composited the OSPO VIIRS L3U data, following the method in Griffin et al. (2017), to produce daily day/night L3C composites of VIIRS data on the IMOS grid and domain. The NPP VIIRS L3U data are composited based on quality and uncertainty estimates with AVHRR SST data from NOAA-18 and NOAA-19 to construct the new IMOS "Multi-sensor

L3S" product suite (Griffin et al., 2017), resulting in improvements to overall quality, accuracy and coverage (Beggs et al., 2019a). These new products, produced operationally at BoM since 16 November 2018 (e.g. Figure 3(a)), are intended to be drop-in replacements for the existing AVHRR-only L3S product set, with similar file format. Validation of the night-time 1-day Multi-sensor L3S SST against *in situ* SST indicates incorporating VIIRS data significantly reduces the standard deviation of the 30-day differences from typically 0.4-0.7°C to 0.2-0.5°C for highest quality level L3S SSTs (BoM, 2019).

Real-time, operational, Multi-Sensor L3S netCDF files containing average SSTs over periods of 1, 3, 6 days and 1 month are available back to 1st January 2018 from the AODN Thredds server at http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/SST/ghrsst/catalog.html in the L3SM-1d, L3SM-3d, L3SM-6d and L3SM-1m sub-directories, and from the AODN portal (http://portal.aodn.org.au). Maps of these Multi-sensor composite SSTs are available for various Australian regions from IMOS OceanCurrent (http://oceancurrent.imos.org.au/index.php) back to 1st January 2018. Since 21st November 2018, the IMOS Multi-sensor 1-day nighttime L3S SSTs have been ingested into the Bureau of Meteorology's ReefTemp NextGen coral bleaching nowcasting system (http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml).

Experimental real-time Multi-sensor L3S products (e.g. Figure 3(b)) have also been developed that ingest additional SST data from OSI-SAF MetOp-B Full Resolution Area Coverage (FRAC) AVHRR L2P and ACSPO NOAA-20 VIIRS L3U. The Multi-sensor L3S products are also being reprocessed from 2012 to 2018 to incorporate all available MetOp-A and MetOp-B FRAC AVHRR L2P, NOAA-18 and NOAA-19 HRPT AVHRR L2P and NPP and NOAA-20 VIIRS L3U data. Example plots of the experimental 1-day night-only Multi-sensor L3S SSTskin can be viewed in the NOAA/NESDIS ACSPO Regional Monitor (e.g. https://www.star.nesdis.noaa.gov/sod/sst/arms/?datatype=none&data_lev=L3U&satt=VIIRS_NPP&daynight=night&variable=sst&date=2019-08-11&region-selected=AU&curr_slide=0&last_slide=0&masked=true&sses=true&front=false&cmp=true&cmp_to=MultiSensor&polar_slide=0).

3.6 Himawari-8 L3C SST

3.6.1 Overview

BoM, in collaboration with JMA and NOAA/NESDIS/STAR, have since 24 March 2016 produced operational real-time Himawari-8 L2P skin SSTs on the GEOS grid, by regressing against ACSPO VIIRS L3U SSTsubskin measurements for a single date (21 July 2015), followed by subtracting 0.17 K to convert from subskin to skin SST. Currently, the Sensor Specific Error Statistics (SSES) values are estimated using a function based on AHI brightness temperature variability on 21 July 2015, and require further work to correct for sensor changes over time. Quality level values are derived for each SST value based on the Griffin et al. (2017) method, using a combination of proximity to cloud, identified using the GEOCAT method (http://cimss.ssec.wisc.edu/csppgeo/geocat.html), and size of the estimated error, estimated on "local SST variability". Possible quality levels are 0 to 5, with 5 identifying the most cloud-free pixels.

The 10 minute Himawari-8 L2P SST values are composited to hourly L3C files on the GEO projection by selecting the best quality spatially and temporally consistent SST. For the daily, night-time L3C composition, the retrieval is selected from the hourly retrievals, such that it is the best quality, closest in time to local sunrise. The hourly, 4-hourly or daily L3C data on the GEO projection is further mapped to the IMOS 0.02° x 0.02° grid using sub-pixel area weighted averaging of any overlapping pixels. An example of the Himawari-8 daily night-time L3C SSTskin over the IMOS domain (70°S to 20°N, 70°E to 190°E) is shown in Figure 2(d). The Himawari-8 SST composition method involves no smoothing or interpolation.

Experimental Himawari-8 L3C GDS2.0 files from 1st October 2017 to present are available via OPeNDAP on request. Near real-time validation plots of Hourly and Daily L3C against drifting and tropical moored buoy SSTs are available at BoM (2019).

Applications: Himawari-8 L2P files are ingested into IMOS 4-hourly SST composite maps (http://oceancurrent.imos.org.au/product.php?product=fourhour), L3C files are used for research into coastal upwelling (Beggs et al., 2019b).

4 Plans for 2019/2020

During the coming 12 months, the Bureau of Meteorology plans to:

- Tune optimal interpolation of ACSPO VIIRS L3U SSTs into RAMSSA and GAMSSA daily SST analyses before operational release
- Continue to develop new "GSAS" L4 product in order to replace RAMSSA and GAMSSA as operational SST analyses
- Add NAVOCEANO MetOp-C GAC AVHRR L2P and ACSPO NOAA-20 VIIRS L3U data to BoM L4 and ocean models
- Investigate ingesting EUMETSAT Sentinel-3A/B SLSTR L2P and L3C SST to IMOS Multi-sensor L3S, GSAS L4 and BoM ocean models
- In collaboration with Jon Mittaz (Uni Reading), improve cloud-clearing and SSES of BoM Himawari-8 SST prior to ingesting into IMOS Multi-sensor L3S

5 References

AODN (2019). Australian Ocean Data Network Satellite SST Products Help Page: https://help.aodn.org.au/satellite-sst-data/

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