REPORT TO GHRSST14 FROM AUSTRALIA – BLUELINK AND IMOS

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ABSTRACT

Since June 2012 there have been a number of new and updated sea surface temperature (SST) products released by the Australian Bureau of Meteorology with support from the Bluelink Project and the Integrated Marine Observing System (IMOS). In addition to upgrades to the operational regional and global SST analyses (RAMSSA and GAMSSA) contributed to the GHRSST Global Data Assembly Centre (GDAC) and the GHRSST Multi-Product Ensemble Project, the Bureau is also producing operational real-time and reprocessed High Resolution Picture Transmission (HRPT) AVHRR SST in GDS v2.0 L2P, L3U, L3C and L3S formats which we intend to supply to the GDAC before December 2013. Other new products produced by the Bureau over the past year which may be of interest to the GHRSST community are the reprocessed MTSAT-1R skin SST L3 files for the GHRSST TWP+ Project, validation-quality, near real-time SSTdepth data from eighteen ships of opportunity and a high resolution, operational coral reef stress monitoring system, ReefTemp NextGen. This report summarises the advances made in the research and development of new SST products by Bluelink and IMOS from 1 June 2012 to 1 June 2013 and plans for the coming year.

1. Introduction

For the past ten years, the Australian Government, through the Australian Bureau of Meteorology (Bureau, http://www.bom.gov.au), Royal Australian Navy and CSIRO have contributed to Bluelink Ocean forecasting Australia (Brassington et al., 2007; http://wp.csiro.au/bluelink), a project to deliver ocean forecasts for the Australian region. Bluelink includes ocean model, analysis and assimilation systems, and provides timely information and forecasts on oceans around Australia. Phases I and II of the project have completed and Phase III will run until June 2014. Operational high resolution (0.1° horizontal resolution) ocean analyses and forecasts are available as maps from http://www.bom.gov.au/oceanography/forecasts/ and netCDF files from http://godae.bom.gov.au.

One of the aims of Bluelink has been to provide the best possible SST products for ingest into and validation of research and operational Numerical Weather Prediction (NWP), ocean and atmosphere-ocean coupled models. To this end it was decided at the commencement of Bluelink I to align with many of the goals of the Group for High Resolution SST (GHRSST: http://www.ghrsst.org) and modify the Bureau's existing operational SST analysis and direct broadcast Advanced Very High Resolution Radiometer (AVHRR) SST processing systems to produce a range of products in GHRSST formats containing uncertainty estimates for each SST value. These satellite SST products have been produced in various GHRSST file formats ranging from geolocated SST from one satellite to gridded SST from multiple satellites (L2P, L3U, L3C, L3S and L4 – see Casey et al., 2011) at various spatial and temporal resolutions designed for a wide range of research and operational applications (Beggs, 2010; Beggs et al., 2011a; Garde et al., 2013).

Commencing in 2007, the Bluelink support for development of GHRSST products has been strongly augmented by funding from the Integrated Marine Observing System (IMOS, http://www.imos.org.au), a nation-wide collaborative program designed to observe the oceans around Australia, with guaranteed funding until September 2014, likely to be extended until June 2015.

The main Bluelink and IMOS contribution to GHRSST is through an Australian Regional Data Assembly Centre (RDAC) system based at the Bureau of Meteorology, delivering the following types of GHRSST data products:

- MTSAT-1R hourly, 1/20° resolution, SST L3U (gridded, single scene) files using different algorithms for day and night and reprocessed for the GHRSST TWP+ Project using the same algorithm for day and night (Section 3)
- Locally received High Resolution Picture Transmission (HRPT) Advanced Very High Resolution Radiometer (AVHRR) SST L2P (geolocated, single swath), L3U (gridded, single swath), L3C (gridded, single sensor) and L3S (gridded, multiple sensor) files using different algorithms for day and night and a recently improved method for deriving sensor specific error statistics (Section 4)
- L4 (gridded, gap-free) files from "RAMSSA", the operational, daily, 1/12° resolution, SST analysis over the region 20°N to 70°S, 60°E to 170°W (Section 5), and the operational, global, daily, 1/4° resolution SST analysis system ("GAMSSA") (Section 6).

Other SST-related contributions include:

- Quality assured *in situ* SST available via the GTS and IMOS Ocean Portal in near real-time from vessels of the Australian Volunteer Observing Fleet (AVOF) fitted with Automatic Weather Stations and other ships of opportunity and research vessels in the Australian region (Section 2)
- Quality assured meteorological, SSTdepth and calculated air-sea flux data available via the IMOS Ocean Portal (http://imos.aodn.org.au/webportal) from three research vessels in the Australian region (http://imos.org.au/airseaflux.html)
- Quality assured *in situ* meteorological, SSTdepth and calculated air-sea flux data available via the IMOS ocean portal in near real-time from a Southern Ocean mooring (http://imos.org.au/asfs.html)
- Provision of in situ and satellite SST and NWP and wave model forecasts for the GHRSST Tropical Warm Pool Diurnal Variability (TWP+) Project (https://www.ghrsst.org/ghrsst-science/science-team-groups/dv-wg/twp/; Section 7)
- Research into the frequency and amplitude of diurnal warming events over the Tropical Warm Pool using TWP+ data from multiple satellites (Section 7)
- Testing the impact of assimilating WindSat GHRSST-format L2P-gridded SSTsubskin data into the Bureau's Operational ocean model, OceanMAPS 2.1 (Huang, 2012) - decreased standard deviation of OceanMAPS analysis SST2.5m with respect to buoy SSTfnd by 0.1 to 0.2°C over region 90°E – 180°E, 70°S – 15°N
- Developing an operational coral reef stress monitoring system for the Great Barrier Reef, "ReefTemp NextGen", based on the GHRSST-format IMOS HRPT AVHRR L3S products (Garde et al., 2013)
- Ten years of global, daily, 1/10° resolution, Bluelink Ensemble-based SST (BESST) re-analyses (Beggs et al., 2012b)
- Regional hourly and Global 3-hourly skin SST analyses in a GHRSST L4-like format ("RAMSSA_skin" and "GAMSSA_skin": Beggs et al. 2009 and Beggs et al., 2011b) – available from http://godae.bom.gov.au
- Evaluating the use of hourly RAMSSA_skin SSTs in the data assimilation cycle of the Bureau of Meteorology's regional ACCESS NWP system (Puri et al., 2010). (It is hoped that the use of realistic diurnally varying SSTs will have a positive impact on the quality control of satellite radiance observations, and therefore on forecast skill.)

2. SST from Ships of Opportunity

Typically, SST observations from engine intake sensors on volunteer observing ships (VOS) in the Australian region are significantly noisier than those obtained from drifting buoys. Until recently, the more accurate SST observations from Australian research vessels have been difficult to access in a timely manner in consistent formats. Therefore, prior to 2010, ship SST observations in the Australian region have not been used for near real-time validation of satellite SST observations. From 2008, the IMOS Project has enabled accurate, quality controlled, SST data to be supplied in near real-time (within 24 hours) to the Global Telecommunications System (GTS) from VOS, passenger ferries and research vessels in the Australian region.

As part of IMOS, the Bureau of Meteorology (Bureau) has instrumented eight Australian commercial vessels with hull temperature sensors (Sea Bird SBE 48), supplying high-quality bulk SST observations every hour. In addition, the Bureau has provided near real-time access to one minute averaged SST and salinity data streams from seven research vessels (RV Southern Surveyor, RSV Aurora Australis, RV L'Astrolabe, RV Solander, RV Cape Ferguson, RV Tangaroa and RV Linnaeus), two tourist ferries (PV SeaFlyte and PV Fantasea One) and one commercial vessel (MV Pacific Celebes). In total, eighteen vessels have

contributed near real-time data to IMOS and the GTS (Table 1 and Figure 1). Due to sales of vessels over the years, currently only 12 of these vessels provide data to IMOS and the GTS.

Table 1. *Details of IMOS Ship SST Data Available Via the GTS and IMOS Ocean Portal*

Vessel	Callsign	Data Start	SST Sensor
RV Southern Surveyor	VLHJ	4 Feb 2008	SBE 3
RV L'Astrolabe	FHZI	30 Dec 2008	SBE 38
RSV Aurora Australis	VNAA	12 Oct 2008	SBE 38
PV SeaFlyte (Rottnest Is Ferry)	VHW5167	30 Apr 2008	SBE 38
PV Fantasea One (Whitsunday Ferry)	VJQ7467	5 Nov 2008	AD590
PV Spirit of Tasmania II (Bass Strait Ferry)	VNSZ	10 Dec 2008	SBE 48
MV Portland	VNAH	20 Jun 2009	SBE 48
MV Stadacona	C6FS9	10 Aug 2009	SBE 48
MV Highland Chief	VROB	30 Sep 2009	SBE 48
MV Iron Yandi	VNVR	10 Feb 2010	SBE 48
PV Pacific Sun	9HA2479	12 Dec 2010	SBE 48
RV Solander	VMQ9273	24 Feb 2010	SBE 38
RV Cape Ferguson	VNCF	5 Dec 2010	SBE 38
RV Tangaroa	ZMFR	27 Apr 2011	SBE 38
MV Pacific Celebes	VRZN9	11 May 2008	Aanderaa 4050
RV Linnaeus	VHW6500	21 Dec 2011	SBE 38
MV Xutra Bhum	HSB3402	3 Jul 2012	SBE 48
MV Wana Bhum	HSB3403	5 Aug 2012	SBE 48

All SST data are quality assured (Beggs et al., 2012a) and placed in real-time on the Global Telecommunications System (GTS) as either SHIP or TRACKOB reports. The quality controlled (QC'd) SST data are also available in netCDF format with QC flags and metadata via the IMOS ocean data portal (http://imos.aodn.org.au/webportal) or directly from http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-SST/catalog.html , http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-ASF/catalog.html or http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-TRV/catalog.html.

Comparisons between AATSR, AVHRR, buoy and IMOS ship SST observations indicate that at least twelve of the IMOS ship data streams, including all those from hull temperature sensors, have comparable errors to those obtained from drifting buoys (Beggs et al. 2012a). In waters with little or no coverage by buoys, satellite SST validation and bias-correction should be improved by using IMOS ship SST observations in addition to available drifting buoy SST data.

The IMOS ship SST data have been used in real-time SST analysis systems (including RAMSSA and GAMSSA) and for validation of satellite SST, SST analyses and ocean models (Beggs et al., 2012a).

There are plans to provide quality assured SSTskin data to IMOS from an autonomous "ISAR" SST radiometer to be installed in early 2014 on Australia's new research vessel, RV Investigator.

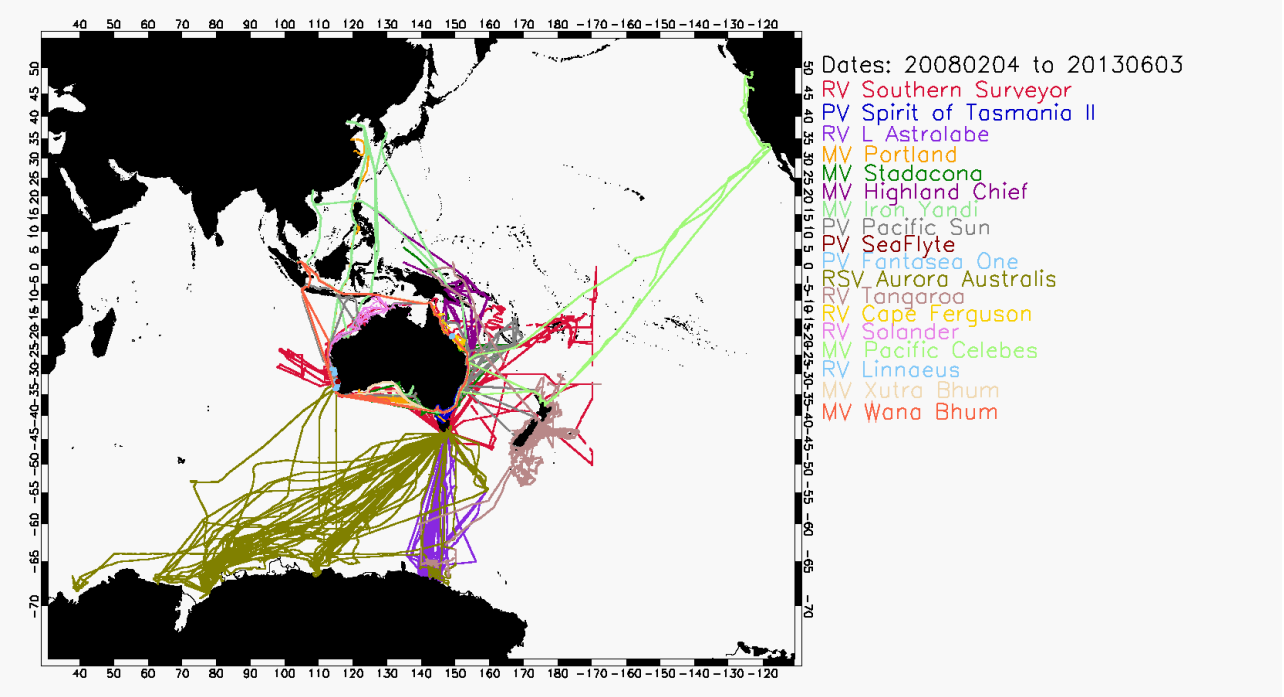


Figure 1. *Locations of all IMOS QC'd ship SST observations to 3 June 2013 from 18 vessels.*

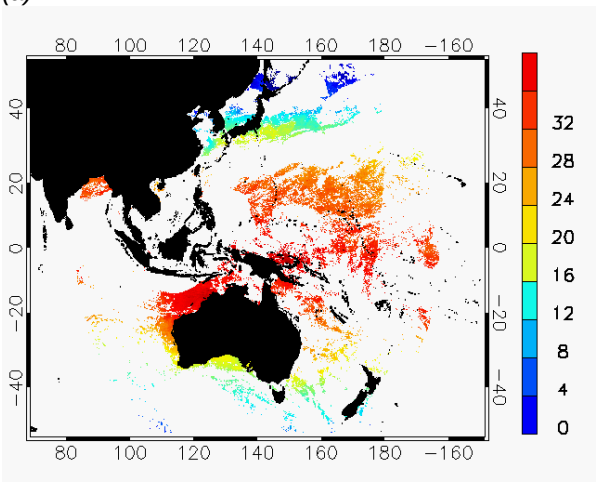
3. Geostationary MTSAT-1R skin SST

The MTSAT-1R satellite is in geostationary orbit above 140°E and carries the Japanese Advanced Meteorological Imager (JAMI) on board. JAMI captured full-disc imagery on an hourly basis during the period 2005-2010 in five spectral channels (0.6-12.0 µm). The observations from spectral channels centred at 3.7, 10.8 and 12.0 µm were used to calculate SST. Since mid-2007, the Bureau has routinely generated SSTskin products from the MTSAT-1R, using the NOAA-developed Geostationary Satellite Derived Sea Surface Temperature Processing System (Maturi et al., 2008). The software has been modified at the Bureau to accept locally generated NWP fields, University of Edinburgh/NOAA Baysean cloud clearing and use regression against drifting buoy SST rather than physical retrieval to convert from brightness temperatures to SST (version 4).

The v4 MTSAT-1R SSTskin 0.05° x 0.05° gridded, single scene L3U files (Figure 2) back to June 2006 are available via ftp://aodaac2-cbr.act.csiro.au/imos/GHRSST/L3U/ABOM-L3U_GHRSST-SSTskin-MTSAT_1R/.

Initial comparison to the network of drifting buoys indicated that the difference between MTSAT-1R and buoy SST observations varied spatially and temporally, with biases on the order of ±0.2 K and standard deviations on the order of 0.8-1.2 K. Additionally, the use of different algorithms for day (2-channel) and night (3-channel) scenes introduced hour-to-hour differences in the bias of > 0.2 K. This order of uncertainty reduces the utility of the data for temporal studies of diurnal variability.

(a)



(b)

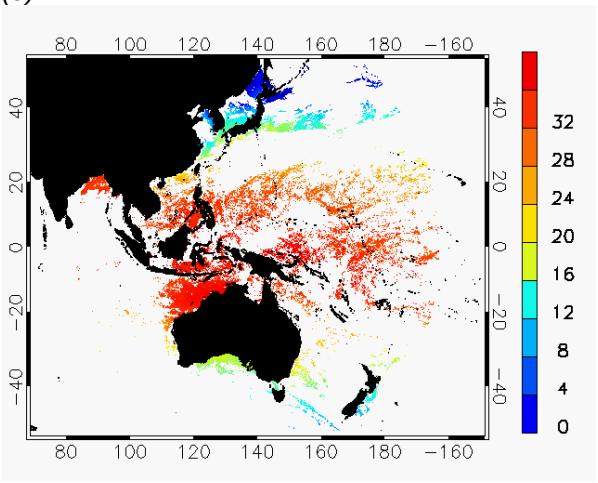


Figure 2. *An example of the output from the v4 MTSAT-1R processing system of L3U SSTskin for (a) 0530 UT (day) and (b) 1630 UT (night) on 10 April 2009. SST is plotted for cloud-free pixels (quality level = 3 to 5).*

In order to reduce the temporal and spatial biases in the MTSAT-1R SST data, the following correction factors were developed from a number of geometric and temporal properties, including pixel/line position, observation hour, solar declination and Earth-Sun distance.

$$Corrected\ \ SSTskin = SSTskin + GFAC + DFAC + TFAC \quad (1)$$

Where *DFAC* is the SST correction caused by the solar declination/earth sun distance, *TFAC* is a correction for the time of day and *GFAC* is a correction associated with the scan pattern and these various SST components are parameterised thus:

$$SSTskin = p_0 T_4 + p_1(T_4 - T_5) + p_2(T_4 - T_5)\sec\theta \quad (2)$$

$$GFAC = p_3(XIDX - p_4)^2 + p_5 YIDX^2 \quad (3)$$

$$DFAC = p_6 DECL + p_7(ESDIST - 1) \quad (4)$$

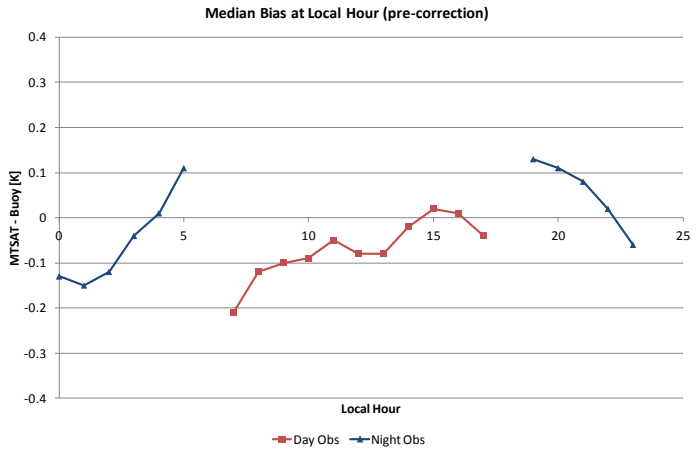
$$TFAC = p_8 \sin(\pi OBSHOUR/12) + p_9 \sin(2\pi OBSHOUR/12) \quad (5)$$

Where
T_4 = Brightness temperature of Channel 4 (11 micron channel)
T_5 = Brightness temperature of Channel 5 (12 micron channel)
θ = satellite zenith angle,

XIDX = pixel number in longitude direction
YIDX = pixel number in latitude direction
DECL = solar declination
ESDIST = distance between Earth and Sun
OBSHOUR = Integer hour of observation in UTC

The application of these correction factors reduced the spatial and temporal differences between buoy and MTSAT-1R SST observations (Figure 3). The resulting bias is < 0.1 K with a standard deviation of ~0.7 K and hour-to-hour differences < 0.1 K.

(a)



(b)

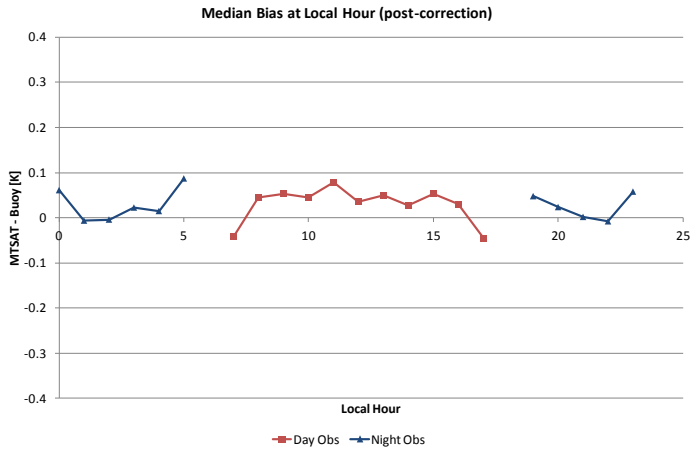


Figure 3. *MTSAT-1R SSTskin – buoy SSTskin versus local sidereal time in hours for the entire study period and MTSAT-1R domain (a) without correction and (b) with the correction described in equation 1. Note: The buoy SSTdepth measurements were converted to SSTskin by subtracting 0.17ºC.*

The corrected version 5 MTSAT-1R SSTskin values were converted to the GHRSST Tropical Warm Pool Diurnal Variability (TWP+) Project L3 format for the period 1 January to 30 April 2010 and released for testing by the TWP+ Project Team in January 2013. Preliminary results of their use to quantify diurnal warming in the Tropical Warm Pool region are described in Section 7.

4. Locally Received AVHRR SST

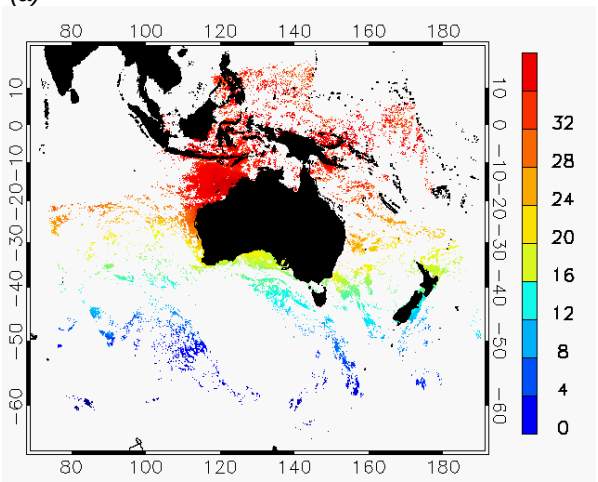
The highest resolution (1.1 km) data from Advanced Very High Resolution Radiometer (AVHRR) sensors on the NOAA series of polar-orbiting meteorological satellites can only be obtained through receiving direct broadcast High Resolution Picture Transmission (HRPT) data from the satellite as these data are not stored onboard. In Australia HRPT data is received by a consortium of agencies (Bureau of Meteorology, WASTAC, AIMS and CSIRO) at ground-stations located in Darwin, Townsville, Melbourne, Hobart, Perth and

Alice Springs and in Antarctica at Casey and Davis Stations. As part of the IMOS Project the Bureau of Meteorology, in collaboration with CSIRO Marine and Atmospheric Research, produces real-time, HRPT AVHRR SSTskin data (Paltoglou et al., 2010) from operational NOAA polar-orbiting satellites in the GHRSST GDS v2.0 L2P, L3U, L3C and L3S formats (Casey et al., 2011).

During the past 12 months, the Bureau has tested revised SST regression algorithms based on modified Non-Linear SST (NLSST – Walton et al., 1998) algorithms. The dataset has a number of features and processing methodologies which target a range of user expertise, and attempt to provide a consistent, accurate record. These features include a dynamic retuning of SST regression algorithms, dynamic estimates of sensor specific error statistics (SSES - based on matchups with SST from drifting buoys), multi-swath, multi-instrument composites over time periods from single day to monthly, and a consistent evaluation of day/night SST (Griffin et al., 2013).

The SSESs (bias and standard deviation of the median SST compared with drifting buoys) are a function of the estimated proximity to cloud in kilometers, latitude, longitude, satellite zenith angle and whether day or night, with daytime defined as sun zenith angle < 90º. Recently, the method used to calculate the SSES statistics for gridding and merging multiple SSTs from the same sensor as well as SSTs from multiple sensors has been modified to better reflect the matchup accuracy of the data sources (Griffin et al, 2013).

(a)



(b)

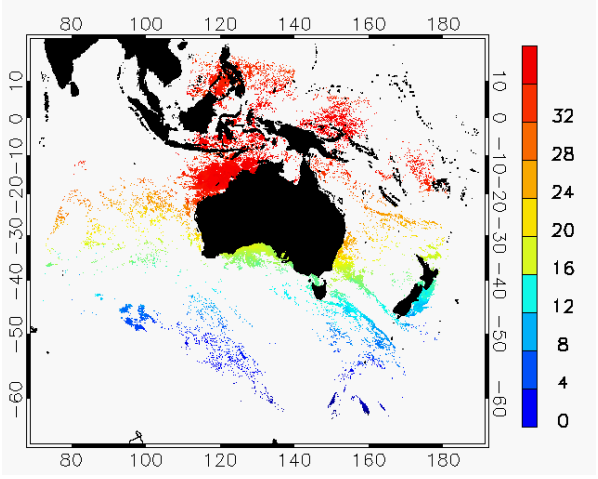


Figure 4. *Example of 1-day (a) day (~1330 LT) and (b) night (~0130 LT) 0.02° x 0.02° L3C SSTskin from NOAA-18 HRPT AVHRR SST data for 10 April 2009. SST is plotted for cloud-free pixels (quality level ≥ 3).*

Each L2P file is gridded to a cylindrical equidistant projection (0.02° latitude x 0.02° longitude) over the region 70ºE to 190ºE, 70ºS to 20ºN to form a GDS v2.0 format L3U file (Casey et al., 2011). These L3U files

are in turn combined to form single sensor day/night L3C and Multiple sensor (one, three, six, fourteen and monthly) day/night and day+night L3S composite 0.02° x 0.02° resolution HRPT AVHRR SSTskin files in GHRSST GDS v2.0 formats (Casey et al., 2011) over the region 70ºE to 190ºE, 70ºS to 20ºN (eg. Figure 4). Each gridded cell contains the average of all the highest available quality SSTs that overlap with this cell, weighted by area of overlap. Only quality level ≥ 2 SSTs are included in the L3U, L3C or L3S products.

Using the Paltoglou et al (2010) methodology, HRPT AVHRR SSTskin GDS v2.0 L2P and L3U files from NOAA-15, 16, 17, 18 and 19 (back to 1998) are currently available from the IMOS FTP server (ftp://aodaac2-cbr.act.csiro.au/imos/GHRSST/) with L3C available back to 2009 and L3S files (from NOAA-15, 17, 18 and 19) available back to 2002. Using the new SST algorithms and SSES method described in Griffin et al. (2013), the archived raw HRPT AVHRR data from all operational NOAA polar-orbiting satellites over the Australian and Antarctic regions back to 1992 will be progressively reprocessed into day/night SSTskin L2P, L3U, L3C and L3S files, and day+night SSTfnd L3S files, by June 2014.

The IMOS AVHRR L2P products are being ingested into several SST analysis systems (Bureau's RAMSSA, GAMSSA, JPL OurOcean's G1SST and Medspiration's ODYSSEA Great Barrier Reef analysis). The L3U and L3S products are used for real-time mapping of meso-scale ocean currents in the Australian region (http://oceancurrent.imos.org.au/). The L3C products are being used in the GHRSST TWP+ project (https://www.ghrsst.org/ghrsst-science/science-team-groups/dv-wg/twp/). The L3S products are used within the Bureau for the ReefTemp NextGen coral bleaching nowcast system (Garde et al. 2013).

Future work for the period to June 2014 will include:

- Routinely validating HRPT AVHRR SST against drifting buoys and IMOS in situ SST data (eg. ships, Argo, seals)
- Providing real-time HRPT AVHRR SSTskin L3U files from Casey Antarctic station
- Providing reprocessed (back to 1992) HRPT AVHRR SSTskin L2P, L3U, L3C and L3S files incorporating Australian and Antarctic data via IMOS and the GHRSST GDAC – all ready providing real-time files from Australian ground stations via IMOS and Bureau OPeNDAP servers

5. RAMSSA – Regional Australian Multi-Sensor SST Analysis

A real-time, high-resolution, Regional Australian Multi-Sensor Sea surface temperature Analysis (RAMSSA) system has been developed at the Australian Bureau of Meteorology as part of the Bluelink Ocean Forecasting Australia project, and has been operational since 13 June 2007. The pre-existing operational, 1/4° resolution, regional SST analysis system (Smith et al., 1999) was modified to produce 1/12° resolution, daily SST analyses over the Australian region (20°N - 70°S, 60°E - 170°W) (Figure 5).

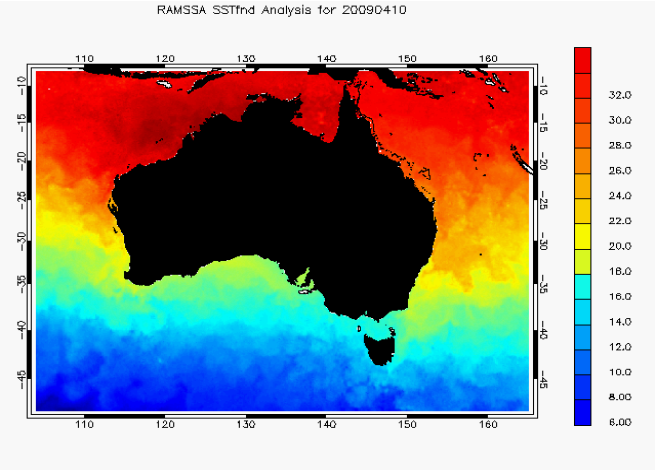


Figure 5. *An example of the RAMSSA v1.3 daily regional 1/12° resolution SST analysis for 10 April 2009.*

Over the years, the RAMSSA system has combined SST data from infrared (AVHRR and AATSR) and microwave (AMSR-E/WindSat) sensors on polar-orbiting satellites with in situ (ship, buoy, Argo and XBT) measurements to produce daily foundation SST estimates (SSTfnd), largely free of nocturnal cooling and diurnal warming effects (Beggs et al., 2011c). REMSS AMSR-E L2P stopped being ingested on 10 October

2011 and ESA AATSR L2 SST on 12 April 2012. On 11 December 2012, REMSS WindSat L2P-gridded SSTsubskin data started to be ingested into the operational RAMSSA analyses. The various data streams that have been used to form each daily RAMSSA analysis are listed in each L4 file header. By ~0400 UT each day, the operational analyses of the previous day's observations can be downloaded as GDS v1.7 netCDF3 L4 files from the GHRSST GDAC (via ftp://podaac-ftp.jpl.nasa.gov/allData/ghrsst/data/L4/AUS/ABOM/RAMSSA_09km/) or viewed as maps of SST and SST anomalies from http://www.bom.gov.au/marine/sst.shtml. Archived RAMSSA L4 files back to 12 June 2006 are available from http://godae.bom.gov.au/ and back to 1 April 2008 from the GHRSST Long-Term Stewardship Facility at NODC (ftp://ftp.nodc.noaa.gov/pub/data.nodc/ghrsst/L4/AUS/ABOM/RAMSSA_09km/).

The RAMSSA analyses are used in real-time as the boundary condition for the Bureau's regional numerical weather prediction models (ACCESS-R, ACCESS-A and ACCESS-C) and to validate the Bluelink operational ocean model (OceanMAPS2) SST(2.5m) forecasts/analyses (Huang 2012). They are used experimentally in regional skin SST analyses (Beggs et al., 2009b) and the GHRSST TWP+ experiment.

Future work on RAMSSA in 2013/2014 will include updating the file format to GDS2 netCDF4 L4 (Casey et al., 2011) and investigating the ingestion of new GHRSST L2P and L3U files from AMSR-2 (on GCOM-W1), VIIRS (on S-NPP), AVHRR (on METOP-B) and possibly Himawari-8.

6. GAMSSA – Global Australian Multi-Sensor SST Analysis

A real-time Global Australian Multi-Sensor Sea surface temperature Analysis (GAMSSA) system was developed at the Australian Bureau of Meteorology as part of the Bluelink project, and has been operational since 2 October 2008. The operational, RAMSSA 1/12° resolution, regional SST analysis system (Beggs, 2007; Beggs et al., 2011c) was modified to produce 1/4° resolution, daily global foundation SST analyses (Beggs, 2008; Zhong and Beggs, 2008) (Figure 6).

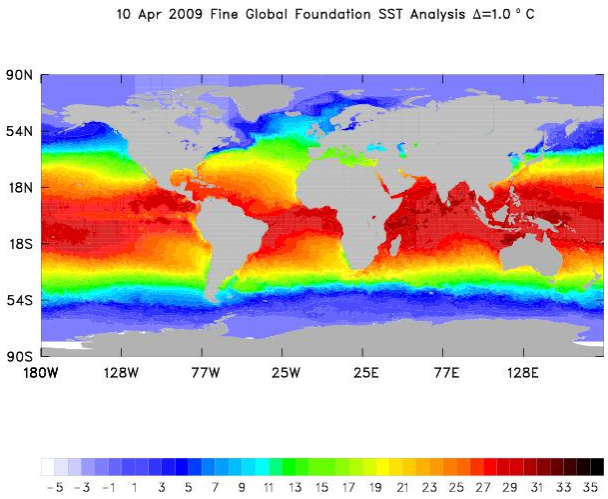


Figure 6. *An example of the GAMSSA v1.1 daily global 1/4° resolution SSTfnd analysis for 10 April 2009.*

The operational GAMSSA analysis system currently uses the following data streams
(i) REMSS WindSat L2P-gridded SSTsubskin (since 11 Dec 2012)
(ii) IMOS HRPT AVHRR L2P SSTskin from NOAA-18 and NOAA-19
(iii) NAVOCEANO GAC AVHRR SSTblend from NOAA-18, NOAA-19 and METOP-A
(iv) in situ SST from the GTS (ships and buoys)

By ~0500 UT each day, the operational analyses of the previous day's observations can be downloaded as GDS v1.7 L4 files from the GHRSST GDAC (via ftp://podaac-ftp.jpl.nasa.gov/allData/ghrsst/data/L4/GLOB/ABOM/GAMSSA_28km/). Archived GAMSSA L4 files back to 23 July 2008 are available from http://godae.bom.gov.au/ and back to 24 August 2008 from the GHRSST

Long-Term Stewardship Facility at NODC (ftp://ftp.nodc.noaa.gov/pub/data.nodc/ghrsst/L4/GLOB/ABOM/GAMSSA_28km/).

Prior to 11 December 2012, the input satellite SST data streams were corrected for global biases by subtracting the SSES_bias_error values from SSTs in the GDS v1.6 format files. However, it was unclear whether applying this bias correction was reducing errors, so since that date no bias correction has been applied to the operational GAMSSA (or RAMSSA) systems. Figure 7 shows the results of applying and not applying the bias-correction to the input data streams for the period 1 January to 30 April 2013. It would appear from this small study that applying the bias-correction reduces the bias in the NAVOCEANO GAC AVHRR SST data streams but increases the bias in the REMSS WindSat SST data. It was reported at the 14th GHRSST Science Team Meeting that the calculation of SSES_bias_error in WindSat L2P-gridded files was modified in early June 2013. The Bureau intends to evaluate these updated SSES_bias_error values later in 2013 before applying the bias-correction to the WindSat SST values ingested into the GAMSSA and RAMSSA systems.

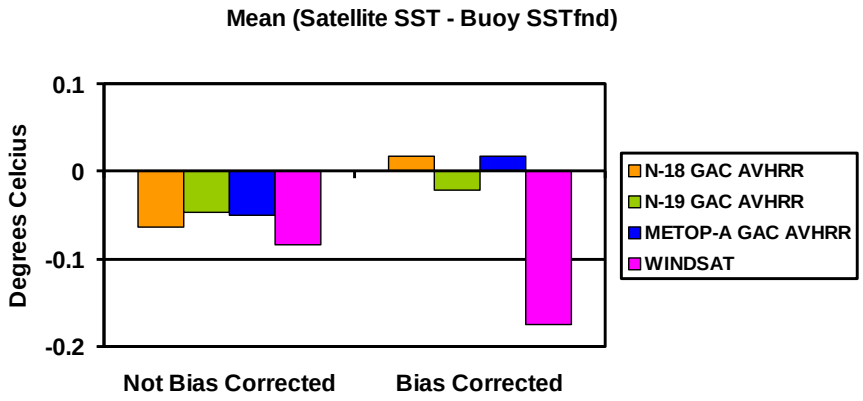


Figure 7. *Global satellite SST inputs to GAMSSA with and without applying the correction SST – SSES_bias_error for the period 1 January to 30 April 2013.*

Since 10 March 2009, GAMSSA analyses have contributed as one of 11 global SST analyses to the GHRSST Multi-Product Ensemble (GMPE: Martin et al., 2012) and Analysis Intercomparison Project (http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/daily/ens/index.html). During 2010, the GAMSSA SSTfnd analyses contributed the third highest percentage of SST values to the GMPE median SST (10.3%) compared with the Canadian Meteorological Centre (CMC) 0.2º SSTfnd analysis (12.9%) and Met Office OSTIA SSTfnd analysis (12.3%) (Martin et al., 2012). Global match-ups with independent SST observations from Argo floats indicate that during 2010 GAMSSA had a standard deviation of 0.49ºC compared with 0.46ºC from CMC and OSTIA analyses (Martin et al., 2012). Although globally GAMSSA was on average only 0.03°C colder than Argo SST during 2010, it was on average 0.13°C warmer than Argo SST over the Southern Ocean (Matthew Martin, pers. com., 2011).

Hovmöller diagrams of L4 minus L4 analyses produced by the NOAA SST Quality Monitor (L4-SQUAM: http://www.star.nesdis.noaa.gov/sod/sst/squam/L4/index.html) show that GAMSSA SSTfnd is on average between 0°C and 0.5°C warmer than the GMPE daily SSTblend analysis over the Southern Ocean (Dash et al., 2012). It has been shown that the AVHRR and AMSR-E L2P SST data streams ingested into GAMSSA are on average biased warm by between 0°C and 0.3°C south of 40°S between 60°E and 170°W (Beggs et al., 2011c).

The GAMSSA analyses are used in real-time as the boundary condition for the Bureau's operational global NWP model (ACCESS-G: Puri et al., 2010) based on the Met Office's Unified Model. They are also used to initialise the Bureau's seasonal forecast model (POAMA 2.0: http://poama.bom.gov.au).

Future work on GAMSSA in 2013/2014 will include updating the file format to GDS2 netCDF4 L4 (Casey et al., 2011) and investigating the ingestion of new GHRSST L2P and L3U files from AMSR-2 (on GCOM-W1), VIIRS (on S-NPP), AVHRR (on METOP-B) and possibly Himawari-8.

7. Using the TWP+ Data Set to quantify diurnal variation over the Tropical Warm Pool

A new comprehensive dataset, the TWP+, has been compiled by the Australian Bureau of Meteorology (BoM) in collaboration with the Group for High Resolution SST (GHRSST), Australian Integrated Marine Observing System (IMOS), Météo-France, University of Edinburgh (UoE) and Remote Sensing Systems (REMSS) for the study of diurnal variability over the Tropical Warm Pool region. The TWP+ data set comprises satellite and *in situ* SST observations and high-resolution model forecasts of ocean/atmospheric parameters at the ocean surface over the region 25°S to 15°N, 90°E to 170°E for the periods 1 January to 30 April 2009 and 1 January to 30 April 2010. The data set contains SST observations ranging in depth from 20 cm to several metres from drifting and moored buoys and ships, and the following gridded skin (~10 μm depth) or subskin (~ 1 mm depth) SST data from radiometers on polar-orbiting and geostationary satellites:

- UoE ATSR Reprocessing for Climate (ARC) AATSR on EnviSat (skin, 0.1° resolution)
- IMOS/BoM HRPT AVHRR on NOAA-17, NOAA-18 and NOAA-19 (skin, 0.02° resolution)
- EUMETSAT FRAC AVHRR on METOP-A (skin, 0.025° resolution)
- IMOS/BoM Imager on MTSAT-1R (skin, 0.05° resolution)
- REMSS AMSR-E version 7 on Aqua (subskin, 0.25° resolution)
- REMSS WindSat version 7 on Coriolis (subskin, 0.25° resolution)

Other SST products included are a gridded, daily, composite of "foundation" (pre-dawn) SST using night-time MTSAT-1R skin SST data for the hours 10 pm to 5 am LST (at native 0.05° resolution and regridded to 0.375° resolution), and a gridded, daily, gap-free analysis of satellite and *in* situ SST approximating a foundation SST (RAMSSA) (at native 1/12° resolution and regridded to 0.375° resolution). Forecast products included in TWP+ are the Bureau's hourly, 0.375° resolution, ACCESS-R Numerical Weather Prediction forecasts of surface parameters (short-wave and long-wave flux, friction velocity, sensible and latent heat flux, wind stress, accumulated precipitation, winds, pressure, air temperature and humidity) (Puri et al., 2010), and the Bureau's AUSWAM 12-hourly, 0.5º resolution forecast of sea state parameters (significant wave height and direction, wind speed and direction and peak wave period).

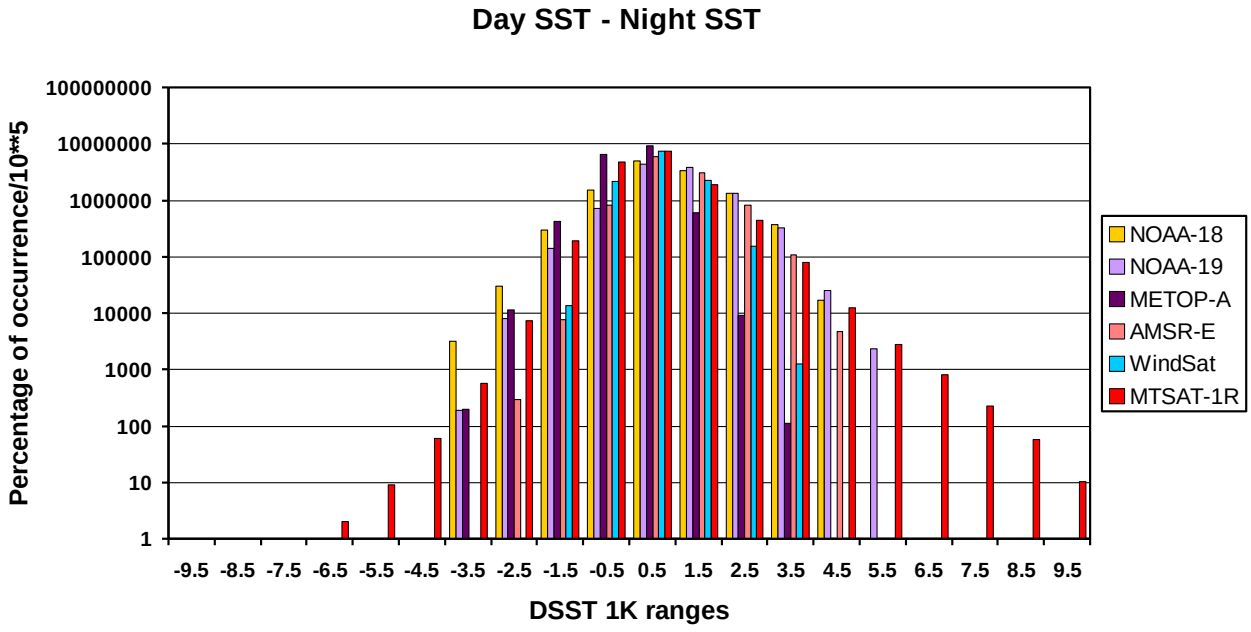


Figure 8. *Percentage occurrence/100,000 of 1°C ranges of daytime SST – night-time SST for the various TWP+ satellite data streams, for the period 1 January to 30 April 2010 over the region 25°S to 15°N, 90°E to 170°E. The data were filtered for 2 x 2 good SSTs using the proximity_confidence levels in each L2P, L3U or L3C file. A mininum proximity_confidence of 4 was used for SSTs from NOAA-18 and NOAA-19 AVHRR, 2 for AMSR-E/WindSat and 5 for MTSAT-1R.*

The TWP+ data are currently being used to quantify diurnal warming events and test diurnal variation models as part of the GHRSST Tropical Warm Pool Diurnal Variability (TWP+) Project

(https://www.ghrsst.org/ghrsst-science/science-team-groups/dv-wg/twp/). Recent studies show that different satellite sensors measure different diurnal warming events due to differing spatial coverage and observation times. For the period 1 January to 30 April 2010 over the TWP+ domain daytime minus night-time SSTs of up to 6°C were measured using multiple satellite sensors for NWP wind speeds less then 3 m/s (Figure 8), implying that models need to be able to predict diurnal warming up to at least 6°C.

All TWP+ data are available to TWP+ project collaborators in netCDF format from the Bureau of Meteorology OPeNDAP server. Contact h.beggs@bom.gov.au for access.

8. Future Plans for Bluelink and IMOS SST Products (2012-2013)

10.1 SST Products

As part of the next phase of the IMOS and Bluelink-III Projects (June 2013 – June 2014), the Bureau of Meteorology aims to:

- Provide reprocessed (back to 1992) HRPT AVHRR SSTskin L2P, L3U, L3C and L3S files incorporating Australian and ***Antarctic*** data via IMOS and the GHRSST GDAC – all ready providing real-time files from Australian ground stations via IMOS and Bureau OPeNDAP servers
- Provide real-time HRPT AVHRR SSTskin L2P, L3U and L3C files from Casey Antarctic station
- Provide reprocessed hourly, 0.05º x 0.05º gridded, v5 MTSAT-1R SSTskin L3U files for 2006 to 2010
- Upgrade operational RAMSSA and GAMSSA to GDS2 L4 format and to incorporate new GHRSST L2P and L3U data streams as they become available
- Provide quality-assured SSTskin data from an autonomous radiometer on Australia's new research vessel, RV Investigator.

10.2 SST-related Research

Over the coming year the Bureau of Meteorology plan to:

- Evaluate hourly RAMSSA_skin SSTskin analyses for quality control of satellite sounder data being assimilated into ACCESS-R NWP analyses
- Write a paper on using the TWP+ satellite SST data set (AVHRR, AMSR-E, WindSat and MTSAT-1R) and ACCESS-R winds to quantify the frequency and extent of diurnal warming events over the TWP
- Write a paper on producing an HRPT AVHRR SST data set using a consistent 3-channel algorithm for day and night

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10. References

10.1 Links to Web Pages, OPeNDAP and FTP Servers

Bureau of Meteorology Operational SST Analysis Web Page: http://www.bom.gov.au/marine/sst.shtml

Bluelink Ocean Forecasting Australia Project Web Site: http://wp.csiro.au/bluelink/

Bluelink SST Products Research Web Page:
http://www.cawcr.gov.au/projects/SST/SST_external.html

Bureau of Meteorology GODAE OPeNDAP Server: http://godae.bom.gov.au

Bureau of Meteorology Seasonal Forecast Model (POAMA) Web Site: http://poama.bom.gov.au.

Bureau of Meteorology Web Site: http://www.bom.gov.au

Group for High Resolution SST (GHRSST) Web Site: http://www.ghrsst.org

GHRSST Global Data Assembly Centre Web Page: http://ghrsst.jpl.nasa.gov

GHRSST Long-Term Stewardship Facility at NODC Web Site: http://ghrsst.nodc.noaa.gov/

GHRSST Multi-Product Ensemble (GMPE) and Analysis Intercomparison Project Web Page: http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/daily/ens/index.html

GHRSST Tropical Warm Pool Diurnal Variability (TWP+) Project Web Page: https://www.ghrsst.org/ghrsst-science/science-team-groups/dv-wg/twp/

Integrated Marine Observing System (IMOS) Web Site: http://www.imos.org.au

IMOS GHRSST SST Products Web Page: http://imos.org.au/sstproducts.html

IMOS Ocean Data Portal: http://imos.aodn.org.au/webportal

IMOS Remote Sensing Data Web Page: http://imos.org.au/srs_data.html

IMOS Remote Sensing FTP Server for GHRSST data: ftp://aodaac2-cbr.act.csiro.au/imos/GHRSST

IMOS Research Vessel Air-Sea Fluxes web page: http://imos.org.au/airseaflux.html

IMOS Research Vessel Meteorological, SST and Flux Data OPeNDAP site: http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-ASF/catalog.html

IMOS Ship of Opportunity SST web page: http://imos.org.au/sst.html

IMOS Ship of Opportunity SST Data OPeNDAP site: http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-SST/catalog.html

IMOS Southern Ocean Flux Station Web Page: http://imos.org.au/sofs.html

IMOS Tropical Research Vessel Data OPeNDAP site: http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-TRV/catalog.html

NOAA/NESDIS SST Quality Monitor Site (SQUAM): http://www.star.nesdis.noaa.gov/sod/sst/squam/index.html

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