# IMOS SHIP SST FOR SATELLITE SST VALIDATION

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## ABSTRACT

We report on the Australian Integrated Marine Observing System (IMOS) ship SST data sets – nine years of in situ subsurface "SSTdepth" and two years of ship-based remotely sensed "SSTskin" quality-assured observations from ships of opportunity - and their application for satellite SST validation.

## 1 Ship SSTdepth

Since 2008, IMOS (http://www.imos.org.au) has enabled accurate, quality controlled (QC'd), in situ SST observations at several meters depth ("SSTdepth") below the surface to be supplied in near real-time from 21 Ships of Opportunity and research vessels in the Australian region. Nine vessels used SeaBird SBE 3 or SBE 38 temperature sensors, located in the water intake, and 12 used SBE 48 sensors positioned against the inside of the ship hull (http://www.seabird.com/). The data are valuable for satellite SST validation as they provide QC'd, in situ observations in coastal regions not sampled by either drifting buoys, moorings or Argo floats, and many of the vessels also provide QC'd meteorological observations, including wind speed. For more information see Beggs et al. (2012), http://imos.org.au/sstsensors.html and http://imos.org.au/airseaflux.html. Information on vessels, sensors and data streams is at http://imos.org.au/facilities/shipsofopportunity/sstsensors/sst-deployments/.

(a) (b)

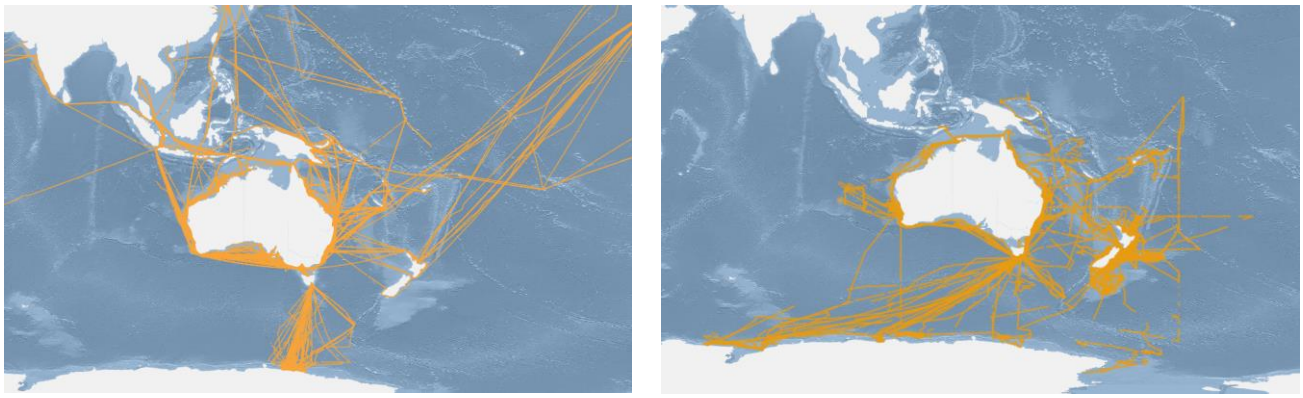

*Figure 1: Tracks of the (a) ships of opportunity that contributed SSTdepth data, and (b) research vessels that contributed meteorological, air-sea flux and SSTdepth data to the IMOS Project from January 2008 to June 2017 (accessed from https://portal.aodn.org.au on 29 June 2017).*

### 1.1 Quality Control

The Bureau of Meteorology employs an automated QC method based on the Shipboard Automated Meteorological and Oceanographic System (SAMOS: http://samos.coaps.fsu.edu/html/) for all IMOS ship meteorological and SST measurements. The QC tests in order of application are:

1. Known instrument malfunction (QC flag 'M')
2. Verify existence of time, latitude and longitude for every record (QC flag 'F')
3. Flag data not within physically possible bounds (QC flag 'B')

4. Flag non-sequential and/or duplicate times (QC flag ‘C’, ‘H’ or ‘T’)
5. Flag positions where vessel over land (QC flag ‘L’)
6. Flag unrealistic vessel speeds (QC flag ‘F’)
7. Low platform speed test (SST only): Flag data where ship speed is below 2.5 m/s (QC flag ‘Q’) (Note: does not apply to research vessels VLHJ, VLMJ, VNAA or ZMFR)
8. Climatology test: flag SST observation more than 3°C above/below Bureau's most recent daily foundation SST analysis (either RAMSSA or GAMSSA, Beggs et al., 2011). Different climatology tests are applied to other meteorological variables. (QC flag ‘G’)
9. Statistical test (1 minute data only): flag step, discontinuity or spike in data (QC flag ‘U’, ‘V’, ‘X’ or ‘Y’)

Once a flag is changed, it will not be altered further by any subsequent test. The IMOS QC system sets one QC flag for each variable for each time step. All data are retained in the final IMOS netCDF files but until 7th July 2017 only SST data that were flagged as having passed all QC tests (QC flag ‘Z’) were uploaded to the Global Telecommunications System (GTS) in “Trackob” (FM 62) format (see Section 1.3). After that date, SST data that had failed the climatology test (QC flag ‘G’) were also uploaded to the GTS, to permit near-coastal SSTs to be included.

## 1.2 Use in Satellite SST Validation

Comparisons with SST observations from satellites indicate that the IMOS ship SST data streams from the calibrated SBE 48 and SBE 38 sensors provide SSTdepth observations with comparable differences to those available from drifting buoys (Beggs et al., 2012), also demonstrated in Figure 2. The IMOS ship SSTdepth data are used in real-time by the Bureau of Meteorology as an independent data source for validating the IMOS Advanced Very High Radiometer (AVHRR) SSTs from NOAA polar-orbiting environmental satellites (http://imos.org.au/sstdata_validation.html).

(a) (b)

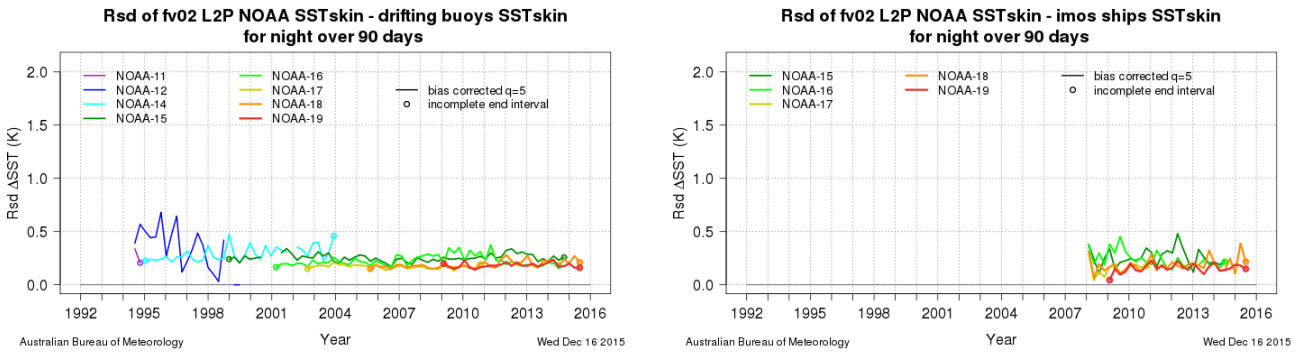


*Figure 2: Example plots of robust standard deviation of night-time IMOS “fv02” High Resolution Picture Transmission (HRPT) AVHRR level 2 pre-processed (L2P) SSTskin (from NOAA-11 to NOAA-19) minus (a) drifting buoy SST and (b) IMOS ship SST. The L2P SSTs have been filtered on quality_level 5 and bias-corrected by subtracting sses_bias (see http://imos.org.au/facilities/srs/sstproducts/sstdata0/). The drifting buoy and IMOS ship SSTdepth values have been adjusted to SSTskin by subtracting 0.17°C. Figure accessed from http://opendap.bom.gov.au:8080/thredds/fileServer/abom_imos_ghrsst_archive/v02.0fv02/Validation/web/index.html on 29 June 2017.*

## 1.3 Data Access

The IMOS ship SSTdepth data are available in near real-time from:

(i) GTS in ASCII format as hourly “SHIP” (FM 13) or 1-minute “Trackob” (FM 62) messages;

(ii) NOAA’s iQUAM v2 portal (http://www.star.nesdis.noaa.gov/sod/sst/iquam/v2/data.html) in “L2i” netCDF format (platform type = 7); and

(iii) IMOS THREDDS server (http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-SST/catalog.html and http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-ASF/catalog.html) in daily IMOS netCDF format files (containing navigation, meteorological and SST data, along with QC flags for each variable).

## 2 Ship SSTskin

Although the SSTdepth measurements from ships can be used for validation of remotely sensed SST measurements, this application is limited by the thermal stratification of the top few metres of the ocean, particularly in regions of high solar insolation and low winds. In October 2014, an Infra-red Autonomous Radiometer model 5D (ISAR: Donlon et al., 2008; http://www.isar.org.uk/), manufactured by National Oceanography Centre Southampton, was installed on Australia’s Marine National Facility, RV Investigator (Figure 3). The ISAR is a self-calibrating instrument measuring in situ ocean temperatures at the same depth as infrared radiometers on satellites (“SSTskin”), using wavelengths of 9.6 to 11.5 µm, accurate to around 0.1°C RMSE (Donlon et al., 2008).

(a) (b)

*Figure 3: Photos of the ISAR instrument as installed on RV Investigator, showing (a) view from port-side bridge deck during installation, and (b) view from above at sea.*

In order to measure SSTskin accurately from a ship, radiometric measurements of both the sea surface radiance ($L_{sea}$) and downwelling atmospheric radiance ($L_{sky}$) must be obtained and the value of seawater emissivity should be known accurately. The ISAR installation configuration used on RV Investigator is shown in Figure 4. The SST Radiometer is mounted on the port bridge wing, approximately 19.593 m above the summer load line. The emissivity is set as constant in the RV Investigator ISAR processing system, as 0.99164, based on a nadir viewing angle, $\theta$, of 25° (Werenfrid Wimmer, *pers. com.*, *25 March 2016*, after Niclos et al., 2009). Before and after each cruise, the radiometer is calibrated with reference to a CASOTS II National Oceanographic Centre Southampton manufactured black body, while immersed in a water bath controlled with a reference HART platinum resistance thermometer (http://www.isar.org.uk/calibration).

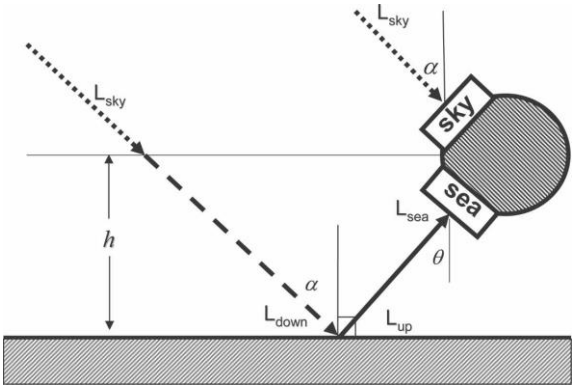


*Figure 4: Geometrical set up of the ISAR on RV Investigator (Figure taken from Donlon et al., 2008). In this case the nadir viewing angle, θ, is 25° and the height, h, above the ocean surface is typically ~19.6 m.*

## 2.1 Quality Control

The results of the June/July 2016 National Physical Laboratory (NPL) laboratory inter-comparison of the RV Investigator ISAR SST radiometer with a reference blackbody and 34 other ship-borne SST radiometers (from 12 agencies) were published in Barker-Snook et al. (2016). This report showed that the RV Investigator ("CSIRO") ISAR instrument compared very favourably with other similar radiometers within the SST measuring range (0°C to 45°C), being 0.04 to 0.15°C colder than the NPL reference blackbody. The results of a 5-day June/July 2016 side-by-side inter-comparison of 10 SST radiometers measuring surface temperatures of the Wraysbury Reservoir, UK, were published in Barker-Snook et al. (2017). This report showed that the RV Investigator ("CSIRO") ISAR measured surface water temperatures that were on average 0.189°C colder than the mean water temperatures of the 10 radiometers over the same 5-day period.

Following ISAR calibration after each RV Investigator cruise, the ISAR SSTskin data has been reprocessed using uncertainty code (v2.7.0) supplied by Dr Werenfrid Wimmer (Wimmer and Robinson, 2016). See Section 2.2 for data access. An example of the reprocessed ISAR SSTskin data is shown in Figure 5, along with the total expanded uncertainty for the ISAR radiometric skin SST ("TS2") value, being a combination of random (type A), systematic (type B), instrument and measurement uncertainty (Wimmer and Robinson, 2016). The ISAR expanded uncertainty is an estimate of the SST that differs from its true value by less than the stated uncertainty in 95% of cases, and can be considered as twice the standard deviation. Figure 5 illustrates the close agreement between the reprocessed ISAR SSTskin values (green line) and the SBE 38 SSTdepth values on the vessel, except during periods of diurnal warming of the surface ocean that are associated with low wind speeds (< 6 $ms^{-1}$) and at least moderate shortwave solar radiation (> 200 $Wm^{-2}$).

Both real-time and reprocessed ISAR data also undergo the QC procedure described in Section 1.1. Users wishing to study diurnal warming or cold upwelling events, where SSTskin may be more than 3°C above or below the corresponding foundation SST analysis, are advised to ignore the ISAR SST "value_exceeds_threshold" flag (TEMP_2_quality_control = 'G') in the IMOS format files.

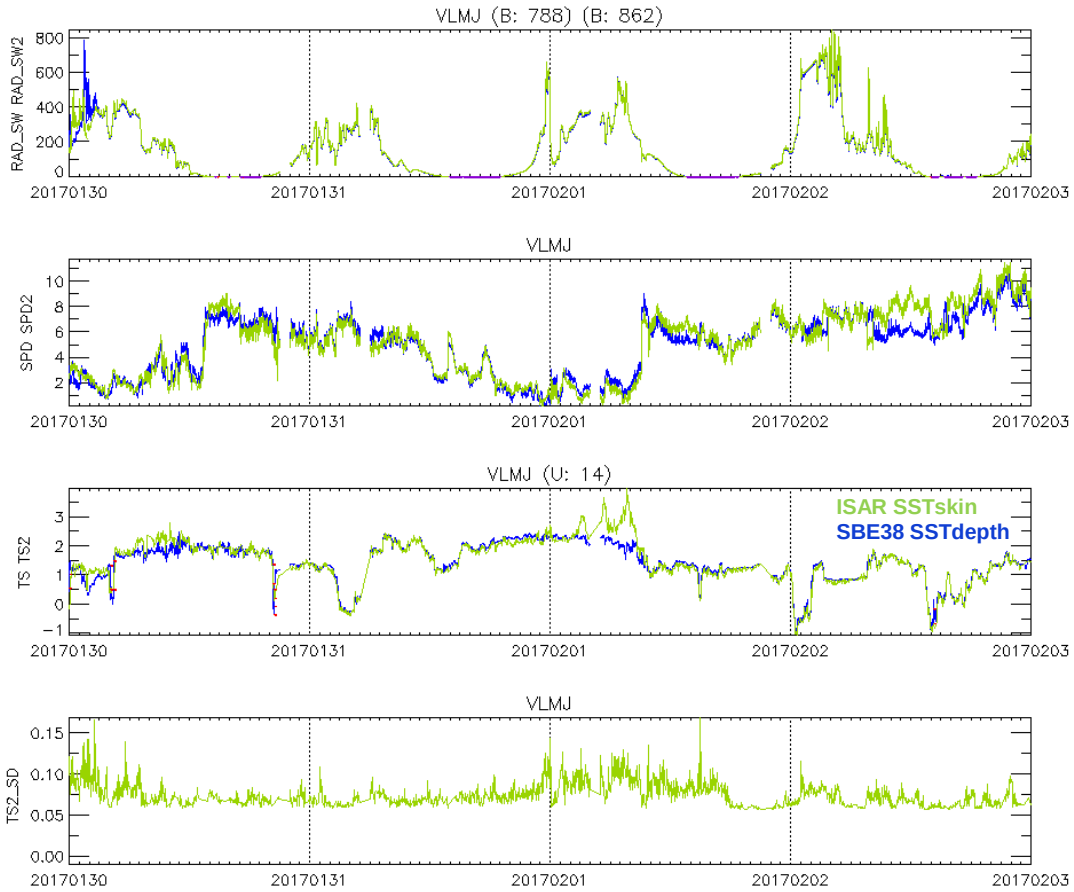


*Figure 5: Example time series (from top) of short-wave solar radiation ($Wm^{-2}$), wind speed ($ms^{-1}$), SBE 38 SSTdepth (blue) (°C), reprocessed ISAR SSTskin (green) (°C) and ISAR expanded uncertainty (2 x standard deviation) for Antarctic Cruise IN2017_V01 during 30th January to 3rd February 2017.*

## 2.2 Data Access

Real-time ISAR data has been available from the IMOS THREDDS server (http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-ASF/VLMJ_Investigator/meteorological_sst_observations/catalog.html) since 26 March 2016. As the ISAR calibration may vary throughout a deployment due to contamination of the ISAR optical system, the real-time data are less useful for satellite SST validation than the reprocessed data described in section 2.1. Figure 6 shows the locations of the real-time ISAR SST data for the period 24th March 2016 to 16 June 2017.

The reprocessed ISAR data (back to October 2014) are available in ASCII format from RV Investigator's ocean data archive (http://www.marlin.csiro.au/geonetwork/srv/eng/search#fast=index&from=1&to=10&any_OR_geokeyword=ISAR&hitsperpage=10). The reprocessed ISAR data are also available in IMOS netCDF files (containing navigation, meteorological and SST data, along with QC flags for each variable) for the period 31 August 2016 to 5 May 2017 from http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-ASF/VLMJ_Investigator/meteorological_sst_observations/2016/ISAR-QC/catalog.html and http://thredds.aodn.org.au/thredds/catalog/IMOS/SOOP/SOOP-ASF/VLMJ_Investigator/meteorological_sst_observations/2017/ISAR-QC/catalog.html. Additional data files back to March 2015 will be posted to these THREDDS directories in future. An example of some of the variables available from the reprocessed IMOS ISAR data set, useful for satellite SST validation, is shown in Figure 5. Other variables not shown are air temperature, humidity, air pressure, precipitation, sea surface salinity, long-wave radiation, photosynthetically active radiation, ship speed, latitude, longitude and heading.

Following release of updated ISAR processing code, we intend to reprocess the RV Investigator ISAR data to netCDF "L2r" format to contribute to the Shipborne Radiometer Network (http://www.shipborne-radiometer.org/).

On 14 March 2017 Ifremer and EUMETSAT ingested the reprocessed RV Investigator ISAR SSTskin data for the period 12 July to 15 November 2016 into the Sentinel-3 SLSTR SST Matchup Dataset v4.1 (http://www.ifremer.fr/cerweb/sentinel-3/mdb-slstr).

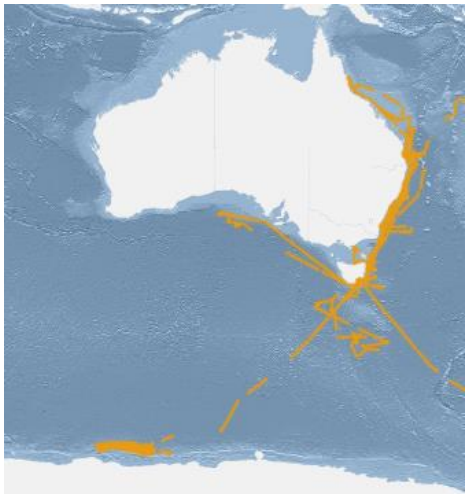

*Figure 6: Tracks of the RV Investigator (call sign: VLMJ) cruises that provided real-time ISAR SSTskin, SBE 38 SSTdepth and other meteorological data to the IMOS THREDDS server for the period 24th March 2016 to 5th May 2017 (accessed from https://portal.aodn.org.au on 30th June 2017).*

## 3 Plans for 2017/2018

- From 1st July 2017, Joel Cabrie (Marine Operations Manager, BoM) will take over leading the IMOS Ship SST Sensors Sub-facility from Helen Beggs.
- As at 30th June 2017, nine vessels provide near real-time, QC'd, SSTdepth data to the IMOS project – PV Spirit of Tasmania II, MV Stadacona, PV SeaFlyte, RTM Wakmatha, RSV Aurora Australis, RV Investigator, RV Tangaroa, RV Cape Ferguson and RV Solander. Additional ships are planned to be instrumented with SBE 48 sensors over the coming year.
- Future RV Investigator cruises will provide ISAR SSTskin data, provided the ISAR is operating on the voyage. Cruise plans (including voyage tracks) can be found at http://mnf.csiro.au/Voyages/Investigator-schedules/Plans-and-summaries.aspx .
- Minglun Yang (OUC PhD student) will participate in RV Investigator cruise IN2017_T01 from Hobart to Brisbane in April 2018, to estimate how the different sky view zenith or azimuth direction, surface roughness, time difference between sea and sky view measurements, or ship movement affect the accuracy of ISAR retrieved SSTskin.
- The IMOS ISAR data sets will be used to validate the BoM Himawari-8 SST data.
- All RV Investigator ISAR data (October 2014 to present) will be reprocessed to "L2r" netCDF format for upload to the Shipborne Radiometry Network database (http://www.shipborne-radiometer.org).

## 4 Acknowledments

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