ARC SST v1.1

Along-Track-Scanning-Radiometer Reprocessing for Climate (ARC) Sea Surface Temperature (SST)

1. Intent of This Document and Point of Contact

1a. This document summarizes essential information needed for using the ARC SST data in climate applications. References are provided at the end of this document to additional information.

Dataset File Names:

tos_ATSR_L3_ARC-v1.1.1_199701-201112.nc

tosAnom_ATSR_L3_ARC-v1.1.1_199701-201112.nc

1b. Technical point of contact for this dataset:

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1c. Recommended citation:

MacCallum, Stuart N; Merchant, Christopher J; Embury, Owen. (2013). ATSR Reprocessing for Climate: Sea Surface Temperature (ARC-SST) v1.1 - Global 1 Degree Monthly Average – Obs4MIPs, 1997-2011 [Dataset]. University of Edinburgh.

2. Data Field Description

CF variable name and units:	*tos*, K *tosNobs*, number of observations *tosStddev*, K tosAnom, K
Spatial resolution:	1.0° latitude-longitude grid
Temporal resolution and extent:	Monthly averaged, from 01/01/1997 to 31/12/2011
Coverage:	Global oceans excluding sea-ice, on full-globe grid. All longitudes. Latitude range with data approximately -78°S to 85°N

3. Data Origin

3a. Source

Skin Sea Surface Temperature (SST-skin) is a directly retrieved variable. It is inferred from brightness temperatures (BTs, i.e., radiometric temperatures) observed by the series of Along Track Scanning Radiometers (www.atsrsensors.org). Relationships between SST and satellite BTs are simulated using physics of radiative transfer, knowledge of variability and trends in greenhouse gases, and knowledge of sensors[i]. Inversion of BTs to SST is achieved by a weighted combination of BTs, the weights being defined by analysis of the simulated BT-

SST relationships[ii]. An important property of the data set for climate applications is therefore that is independent of in situ SST observations[iii].

SSTs at a depth of 20cm (SST-20cm, corresponding to the GHRSST naming convention[iv]) are estimated from the SST-skin observations via physical models. An adjustment to a consistent local equatorial crossing time of 10.30/22.30 h is also applied.

SST anomalies, used in quality control, are determined relative to daily climatology derived from ARC SST v1.1 observations over the period 1992 to 2008.

The daily 0.1° resolution v1.1 ARC SST data, from which this Obs4MIPs dataset is derived, are available at www.neodc.rl.ac.uk/browse/neodc/arc and is described in more detail in the references[i, ii, iii, v].

3b. Simplified processing steps

1. Pre-processing of level 1b geolocated calibrated images (ATSR archive version 2.0). Some image shifting and adjustment of BTs is done to offset known systematic errors in ATSR level 1b v2.0. Level 1b data consist of calibrated top-of-atmosphere brightness temperatures, geolocated and projected onto a latitude-longitude grid for each individual satellite orbit.

2. Cloud detection, where pixels in satellite image are eliminated if their probability of being cloud-affected exceeds a threshold. This is done at full (1 km) resolution.

3. Inversion from clear-sky BTs to skin SSTs at full resolution, with associated estimation of SST uncertainty due to radiometric noise and intrinsic retrieval error[ii]. Dual-view 3-channel (3.7 μm, 11 μm, and 12 μm) retrievals (D3) are used at night, while dual-view 2-channel (11 μm and 12 μm) retrievals (D2) are used for daytime observations.

4. Estimation of 20 cm depth SSTs using skin and stratification models[v].

5. Averaging clear-sky pixel SSTs to 0.1° resolution cells, keeping day and night separate, and calculating SST uncertainty per cell.

6. Calculation of daily SST anomaly (SSTA) field relative to ARC SST climatology.

7. Spatial and temporal averaging of the daily 0.1° resolution SST (and SSTA) fields to monthly 1° resolution.

8. Averaging of day and night-time SST (and SSTA) fields. Note that day or night-time cells are excluded where the day-night difference is outside 2.5σ from the mean (the colder SST is excluded on the assumption that most outliers are the result of cloud contamination) and where the SST < -2 °C.

9. Application of a median filter. Cells are excluded where the difference from the median of a 7x7 cell area is > 3σ from the average difference. This filtering is only applied at latitudes higher than 30 °S and 60 °N, to avoid excluding strong temperature gradient features such as the Gulf Stream.

3c. Assumptions and use of prior data

SST-skin retrieval is wholly independent of in situ SST observations.

Cloud detection/screening[vi] utilizes information from numerical weather prediction fields (ERA 40[vii] and ECMWF operational[viii]), which seems to influence results at the <0.1 K level in SST in coastal regions.

Adjustment to SST-depths involves modeling the surface skin effect and diurnal variability, using models forced by ERA-interim flux and wind fields.

3d. Merging data of more than one instrument

Observations are merged across three sensors (designated, ATSR-1, ATSR-2 and AATSR). Note that ATSR-1 observations are not provided in this dataset but are incorporated in the reference climatology.

Inter-satellite BT homogenisation has been undertaken to make SSTs from all three sensors correspond to what would be observed from AATSR using observations at 3.7 and 11 μm in two views. This was achieved by using satellite overlap periods to match BTs between sensors, accounting for the real differences between instruments.

SST estimates are obtained by adding the calculated adjustments to SST values. For AATSR, these adjustments include correction for the half-hour local orbit time difference between AATSR and the previous sensors, in order to eliminate aliasing of the diurnal cycle into the record.

3e. Sampling used in creating the source, 0.1° resolution, gridded product

All pixels in the 0.1° cell that are designated as clear-sky are used in the average.

The number of pixels contributing to a cell therefore varies between 1 and the maximum possible at that latitude (approximately 125 for the equator).

The uncertainty in SST attached to the cell appropriately reflects the number of pixels used in forming the average.

3f. Spatial and temporal averaging used in creating the final gridded product

Spatial and temporal averaging to produce SST (and SSTA) products on a 1° resolution grid is performed using the regridding tool developed for the ESA SST Climate Change Initiative (CCI) project (http://www.esa-sst-cci.org/).

4. Validation and Uncertainty Estimate

Validation of the 0.1° resolution v1.1 ARC SST data been undertaken (to date) using drifting buoys, moored buoys, routine ship observations and a global SST analysis (HadSST3[ix,x]). Because of the nature of the radiometer, various channel combinations can be used to estimate SST, and all have been validated. Assessments of ARC v1.1 SSTs for accuracy (bias), precision (scatter) and inter-annual stability (trends in bias) have been undertaken. In addition, the SST sensitivity[xi] has been evaluated in simulation and the spatial SST variability inspected. The following sections provide a summary of these assessments[iii] of the 0.1° resolution v1.1 ARC SST data from which this Obs4MIPS dataset is derived.

4a. Assessment of accuracy of 0.1° resolution v1.1 ARC SST data

The target accuracy for ARC v1.1 SSTs is for bias to be less than 0.1 K, for all regions (assessed on ~1000 km scales). This is statistically demonstrable globally against drifting buoy observations for AATSR SST-20cm (sufficient number of drifters in this era), and is demonstrable for some areas for earlier in the record (Fig. 1).

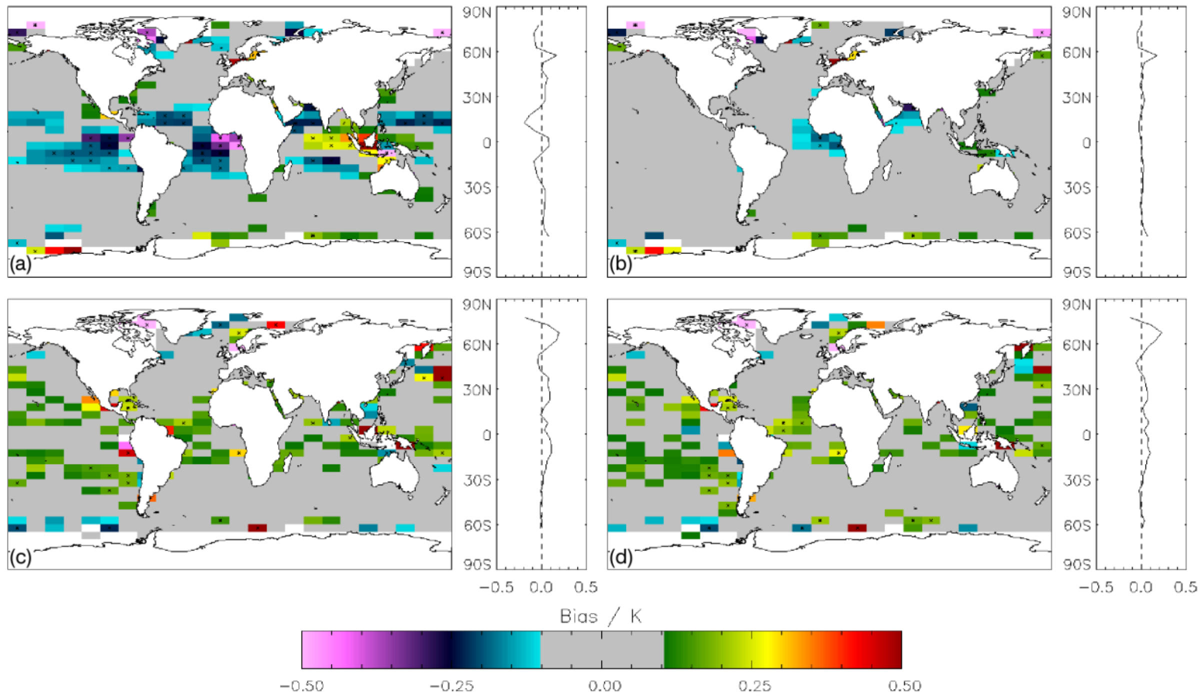

Figure 1 Median difference between estimated $SST_{0.2m}$ and in situ drifters for (a) AATSR D2, (b) AATSR D3, (c) ATSR-2 D2, and (d) ATSR-2 D3. X symbols indicate the difference exceeds 0.1 K with a significance of 90%, * symbols indicate the bias exceeds 0.1 K with a significance of 99%. Significance is calculated with a Student's t-test using the number of unique drifters in each cell.

Global median differences and robust (outlier-tolerant) standard deviations of AATSR and ATSR-2 SST-20cm compared to drifters are given in Table 1. Comparable accuracy is found for ATSR-2 and AATSR, although fewer drifting buoys make assessments of ATSR-2 less statistically robust.

ATSR	**Day / Night (D2 / D3)**	**Number of matches**	**Median difference (RSD) (K)**
ATSR2	Day	47590	0.014 (0.268)
ATSR2	Night	38876	0.026 (0.216)
AATSR	Day	534255	0.042 (0.185)
AATSR	Night	419594	0.023 (0.171)

Table 1 Global ARC estimated $SST_{0.2m}$ – drifter in kelvin. Statistics are median difference with robust standard deviation (RSD) in parentheses.

Accuracy has also been explored as a function of various parameters. Figure 2 shows the accuracy and precision (relative to drifting buoys) as a function of latitude, TCWV, wind speed, and across-track pixel for AATSR SST-20 cm data. In all cases the dual-view SSTs exhibit accuracy within the 0.1 K target across almost the entire parameter range.

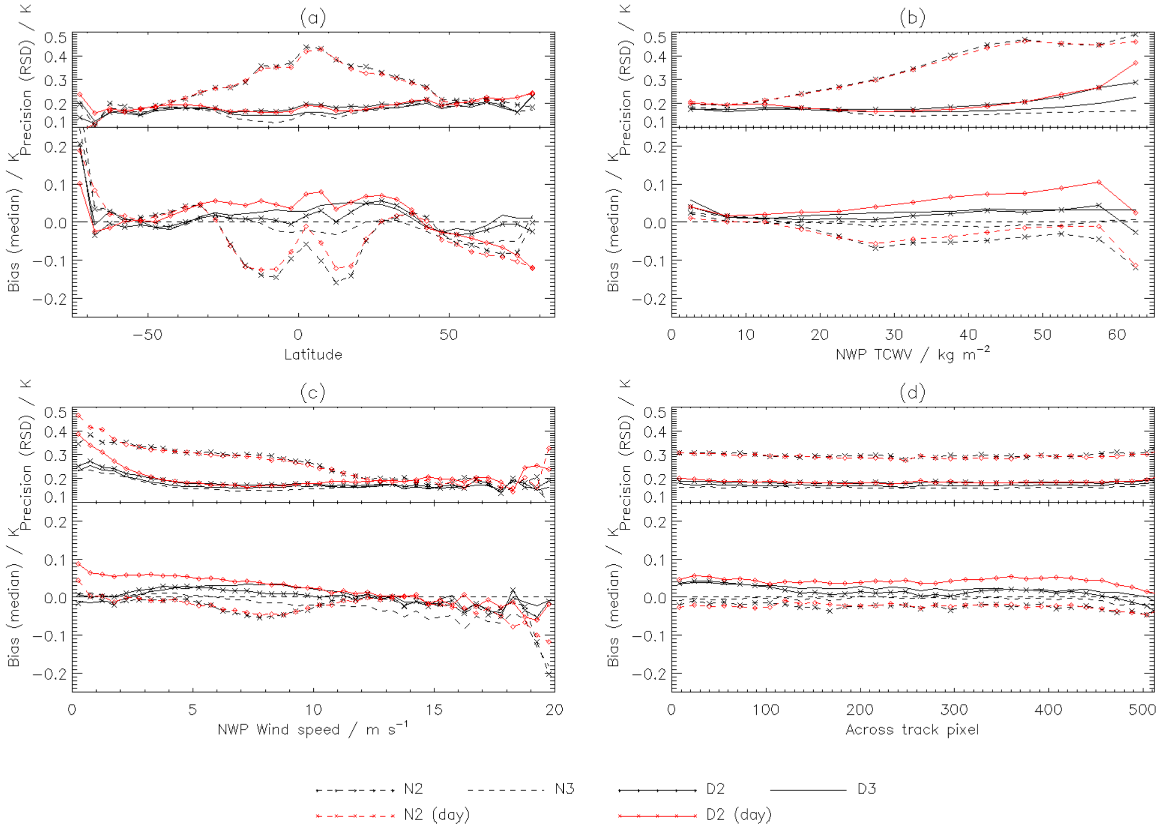

Figure 2 AATSR estimated SST0.2m – in situ drifter as a function of (a) latitude, (b) NWP total column water vapour, (c) NWP wind speed, and (d) across track pixel number. Solid with symbol – D2; solid – D3. Black lines used for night-time data; red (with X symbol) used for day-time data. Although not used in this Obs4MIPs dataset, results are also presented for two alternative retrievals (dashed with symbol – N2; dashed – N3). These use the same channels as D2 and D3 retrievals but only use the nadir-view.

4b. Assessment of precision of 0.1° resolution v1.1 ARC SST data

The precision (quantified by the standard deviation of unsystematic errors) is only partly controllable by algorithm design and also depends on instrumental characteristics. Therefore, there is no target for precision other than to be as precise as possible.

A three-way error analysis is possible for AATSR, exploiting drifting buoys and co-incident passive microwave observations, which can separate out their precisions. Results show that D3 SST-1m SSTs at 0.1° spatial resolution have a precision of 0.14 K (which is better than drifting buoys themselves).

An indication of precision is also given by the standard deviation of comparisons with tropical moored buoys, since these are of higher accuracy than drifting buoys (although there is some in situ contribution to error meaning that the results are pessimistic about the precision). These suggest that D2 is ~0.18 K for ATSR2 and AATSR. For D3, the results are consistent in suggesting precision of around 0.12 K.

ATSR	**Day / Night (D2 / D3)**	**Number of matches**	**Median difference (RSD) (K)**
ATSR2	Day	12358	0.043 (0.193)
ATSR2	Night	8936	0.025 (0.119)
AATSR	Day	21436	0.030 (0.164)
AATSR	Night	16338	0.019 (0.128)

Table 2 Global ARC estimated $SST_{1.0m}$ – tropical moored buoys in kelvin. Statistics are median difference with robust standard deviation in parentheses

4c. Assessment of stability of 0.1° resolution v1.1 ARC SST data

The target long-term stability (having homogenized data across sensors and removed diurnal aliasing) is for trend artefacts over the time series to be less than 0.05 K/decade in magnitude.

A statistically robust assessment of stability of ARC v1.1 SSTs against tropical moored buoy SSTs in the Pacific Ocean has been undertaken — see Figure 3.

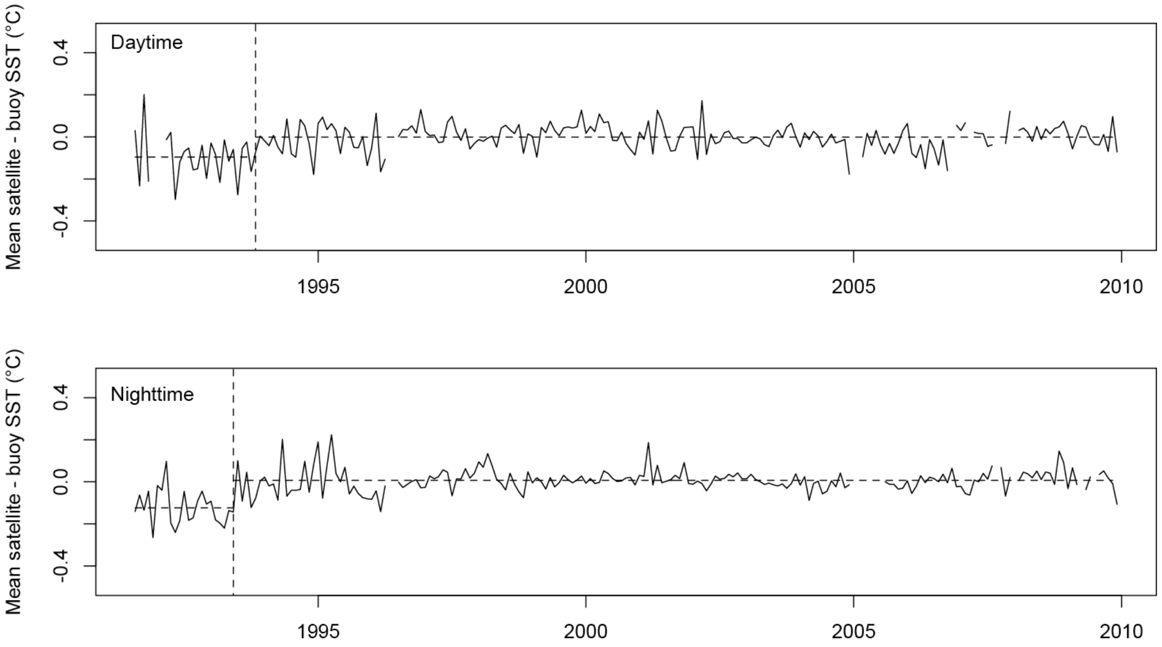

Figure 3. Analysis of stability of the full series of ARC observations against tropical moored buoys, using a technique for identifying step changes objectively. Upper panel: daytime monthly mean discrepancies; lower panel, night time. The early step change is apparently associated with the dissipation of the post-Pinatubo stratospheric aerosol.

With the exception of the early years of ATSR-1, where a bias of order -0.1 K is evident, the data are extremely stable, as quantified in Table 3.

Region	**Period**	**Time of day**	**Trend (°C $decade^{-1}$)**	**95% confidence interval (°C $decade^{-1}$)**
Tropics	*1991 – 2009*	*Day*	*0.026*	*0.006 < trend < 0.045*
Tropics	*1991 – 2009*	*Night*	*0.044*	*0.020 < trend < 0.069*
Tropics	1993 - 2009	Day	-0.006	-0.026 < trend < 0.015
Tropics	1993 - 2009	Night	0.010	-0.014 < trend < 0.034

Table 3. Trends and their significance in the full ARC timeseries (D2 SSTs).

All the full-period trends are within the 0.05 K/decade target. Including 1991 and 1992, there is a statistically significant upward trend arising from the early post-Pinatubo bias, of order 0.04 K/decade. For 1993 to 2009, the analysis demonstrates stability to be within about 0.03 K/decade of zero with a very high statistical confidence.

In extra-tropical areas, moored buoys of somewhat lower accuracy are available, principally coastal moorings. Against these data, step changes of order a few cK are evident in the data, and seem to be associated with changes to the re-analysis/NWP fields used for cloud detection. Coastal cloud detection therefore seems to have a greater dependence on re-analysis/NWP than in the open ocean, and that dependence is sufficient to affect SST via differences in the level of residual cloud contamination of pixels designated "clear-sky".

It may be that the long term stability in the extra-tropics away from coastal regions is poorer than the <0.03 K/decade results for the tropics, but we have not been able to assess this because of lack of stable in situ comparison points.

Stability around the seasonal cycle is difficult to assess and likely varies considerably geographically. The best information comes from fitting an annual cycle to monthly mean differences between ARC SSTs and moorings. We refer to this as the "seasonal bias cycle", although the *in situ* contributions to the amplitude are not known. The median seasonal bias cycle is found to be 0.08 K peak-to-peak for tropical moorings. For the (predominantly coastal) moorings outside the tropics, the equivalent number is found to be 0.3 K for day-time data and 0.2 K for night-time data. The range of seasonal cycle in difference relative to moorings is from essentially zero to a worst case of 1.5 K. Comparisons with HadSST3 suggest a peak-to-peak season bias cycle in the N Pacific (~50° N) of around 0.5 K, probably associated with poorly understood difficulties in cloud detection for this region.

4d. Sensitivity to true changes in SST

The ARC SST-skin retrievals are designed to have the property that a 1 K change in SST, all other factors being equal, gives very close to 1 K change in retrieval. This means that the magnitude of differences across fronts, for example, should be faithfully represented, which is not always the case in satellite SST data.

4e. Spatial distribution of variability

An example of the spatial distribution of variability of monthly ARC SSTs is shown in Figure 4. The ARC v1.1 field seems geophysically plausible, and in some regions is less noisy and more plausible than in the *in-situ*-based data set used as a comparison. Extremely good agreement is seen in the N Atlantic (well sampled *in situ*). An exception is that N Pacific variability appears to be exaggerated in the ARC data by cloud-detection related biases in some months.

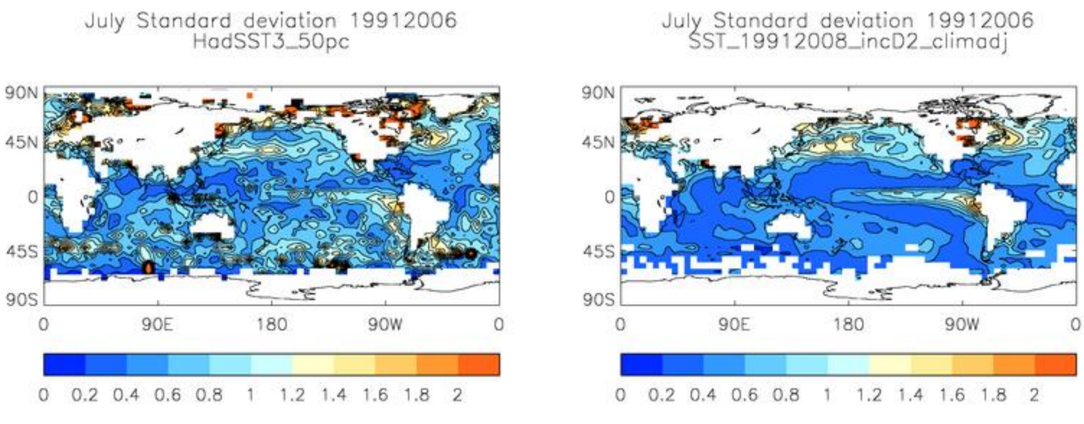

Figure 4. Comparison of the standard deviation of July-average SSTs from 1991 to 2006 in (left) the median of the HadSST3 ensemble and (right) the ARC v1.1.

5. Considerations for Model-Observation Comparisons

Due to the nature of the ERS-2/ENVISAT orbit, observations have been standardized to a local time of day (local equatorial crossing time of 10.30/22.30 h). The sampling of the diurnal cycle is therefore consistent through the record and any risk of aliasing the diurnal cycle into long-term changes has been minimized. Sampling the diurnal cycle at these times gives SST approximately equal to the daily mean SST.

SST observations are only made for clear-sky scenes, therefore the data sample only cloud-free viewing conditions. The implications of this for representativity uncertainty in a monthly-mean SST-depth estimate are not fully clear, but are not thought to be significant.

Data gaps for any given month are the result of satellite swath limitations and exclusion of cloudy areas. Despite lower coverage than for other satellite datasets such as AVHRR, there is evidence that SST variability associated with phenomena such as ENSO is cleanly captured in the ARC dataset[iii].

6. Instrument Overview

ATSRs were designed specifically to deliver SSTs of a quality relevant to climate. ATSRs are dual-view radiometers, by virtue of along-track scanning, which provides greater information content for SST and atmospheric variability than a single view. They have two onboard high-accuracy black bodies for improved calibration over the range of SST relevance. Active cooling of detectors gives low noise at pixel level (of order 5 cK). Relative to other similar instruments, such as AVHRR, the dual-view retrievals from ATSRs provide SST estimates with higher accuracy, precision and robustness against atmospheric anomalies including aerosol events[iii].

7. References

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8. Revision History

Rev 0 – 5th April 2013 - This is a new document and dataset.

Rev 1 – 3rd July 2013 – Recommended citation added.

Rev 2 – 7th March 2014 – SST anomaly data file added and contact email updated.