Numerical Weather Prediction

Skin to bulk conversion of ATSR-2 sea surface temperature and comparisons with other ocean datasets

Forecasting Research Technical Report No. 324

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Conversion of ATSR-2 sea surface skin to bulk temperature for use in climate studies

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ABSTRACT

Over three years of bulk SSTs were derived using ATSR-2 cloud-cleared skin SSTs (averaged at a resolution of 0.5 degrees), using a skin to bulk temperature model. The algorithm is based on a physical skin model and covers all surface wind speed ranges. The near-surface diurnal thermocline is also modelled with the aim of rejecting those observations likely to have a strong thermocline.

This paper presents the results from comparisons of bulk SST with a climate dataset containing SSTs at 1 degree resolution. The dataset is maintained by the Hadley Centre at the Met. Office, and contains SST observations gathered from a combination of data including in-situ and Advanced Very High Resolution Radiometer (AVHRR) observations.

Recently new retrieval coefficients have been derived for the ATSR series. We investigate the impact of the coefficients on the observed bulk-skin SST difference.

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1. INTRODUCTION

The high accuracy and almost ten year time period of sea surface skin temperatures retrieved from the Along Track Scanning Radiometer (ATSR) series of instruments make them potentially useful observations for climate studies. However, for incorporation in current sea surface temperature (SST) analyses they need to be converted to represent bulk SST at a depth of around one metre in order to be consistent with other SST observations used such as from ships and buoys.

Cloud-cleared skin SSTs derived from ATSR-2 data were obtained from the Rutherford Appleton Laboratory (RAL) for June 1995 to February 1999. They were processed by RAL into a half degree product using the SADIST-2 scheme (Bailey,1995). No data is available from January 1996 to June 1996 due to scan-mirror problems on the ATSR-2 instrument.

The skin SSTs for the whole period have been converted into bulk SST using a processing scheme based on the Fairall skin model (Fairall et al, 1996) and the Kraus and Turner (1967) thermocline model. A comparison can be made to check the behaviour / accuracy of these bulk SSTs by comparing them with SSTs from buoys, which measure the bulk temperature of the ocean under the surface skin layer.

In this study, comparisons of the ATSR-2 bulk SSTs have been made with SSTs from buoys at fixed moorings which report on the GTS, and additionally, buoys from the Tropical Atmosphere Ocean (TAO) project in the tropical Pacific Ocean (McPhaden, 1995) which are also at fixed positions. No comparisons have been made using drifting buoys as experience has shown these measurements are more likely to be subject to larger errors. Additionally, global comparisons have been made between ATSR-2 bulk SST and the Global Ice and Sea Surface Temperature dataset (GISST) (Rayner et al, 1998). GISST is a climate dataset created and maintained by the Hadley Centre. It is based on in-situ and AVHRR SST data, is at a resolution of 1 degree and covers the period from 1961 to the present.

The aims of this study are to look at the characteristics and accuracy of the ATSR-2 bulk SSTs with respect to buoy sea surface temperatures and to examine any patterns emerging. The comparisons against the GISST dataset provide interesting insights due to the higher resolution and high spatial coverage of the satellite based observations. It is also instructive to look at the behaviour of the ATSR-2 SSTs over several years duration compared to the GISST dataset.

2. METHODOLOGY

2.1 Outline of how the skin SSTs were produced

The ATSR-2 skin SSTs used in this study were retrieved by the Rutherford Appleton Laboratory (RAL) from top-of-atmosphere radiances and coefficients determined by linear regression from brightness temperatures simulated using a radiative transfer model (Zavody et al, 1994). The coefficients are chosen to minimise the r.m.s. difference between the prescribed skin SSTs and retrieved skin SSTs in a diverse atmospheric profile dataset. During the day radiances from the nadir and forward views of the 11 and 12 micron channels were used to derive the skin SST and at night the 3.7 micron channel radiances are also used from both views with a different set of coefficients. The latter channel is more transparent to water vapour and so can be used to infer more accurate skin SSTs in the tropics.

2.2 Details on the production of the bulk product

The ATSR-2 skin SSTs have been used to generate a global product of bulk SST using a scheme developed at the Met. Office. The scheme involves a series of operations. First NWP model fields such as radiative surface flux and surface wind data are interpolated to provide an estimate of surface conditions for each observation. Then, the conversion of skin to bulk temperature can be performed using a skin-layer model. The skin model attempts to estimate the temperature difference across the ocean skin layer using the model surface conditions and the retrieved satellite SST.

Various models have been proposed to describe the temperature difference across the oceanic skin layer and for our purpose we require one which is applicable across all ocean conditions. Saunders (Saunders, 1967) derived a theoretical model for forced convection conditions by treating the skin layer as a fixed conduction layer whose depth depends on windspeed. It has the following form:

$$\Delta T = \frac{\lambda Q \nu}{\kappa \rho c_p \nu_*} \quad (1)$$

where Q represents the heat flux out of the ocean, ν_* is the friction velocity in water, κ is the thermal diffusivity, ρ is the density of water, c_p is the specific heat capacity of water, ν is the kinematic viscosity, and λ is a dimensionless constant. Fairall (1996) extended the model to cover low windspeed conditions by redefining λ as a function of flux and friction velocity:

$$\lambda = \lambda_0 f(\nu_*, Q) \quad (2)$$

where λ_0 is the value that λ will tend to as the free convection regime is approached. λ_0 has been estimated by various authors to be between 5 & 10. For the night-time a value of 4 was found to be optimal, and for the day-time a value of 7.5. Different values of λ_0 are use for day and night as different SST retrieval coefficients are used for the different day regimes. We can use λ_0 as a tuning constant to remove the residual bias between in-situ buoy SSTs and converted satellite bulk SSTs.

Fig. 1a shows the behaviour of the skin-layer model over a range of windspeeds. The example is for night-time and has been compiled using 1000 matchups of buoy SSTs with satellite SSTs. The main points to be emphasized are:

- A reduction in the observed delta T is observed with windspeed which follows the Fairall model.
- Fig. 1b displays day-time results compiled from 800 matchups and shows that the same pattern as seen in the night-time plot can also be seen but to a greater extent.

A subset of quality-controlled drifters were also used, where both the mean and standard deviation of the observed buoy SST minus background SST values for a buoy are less than 1K, and are thus considered to have good sensor calibration. These drifting buoys measure the temperature closer to the surface and gave better results in terms of the correlation of the observed delta T to predicted delta T. A thermocline model is used under day-time conditions, to predict the effects of diurnal heating. High insolation and low windspeed conditions may lead to the possibility of a thermocline developing, where a large temperature difference (delta T) below the skin layer up to a few deg K may occur.

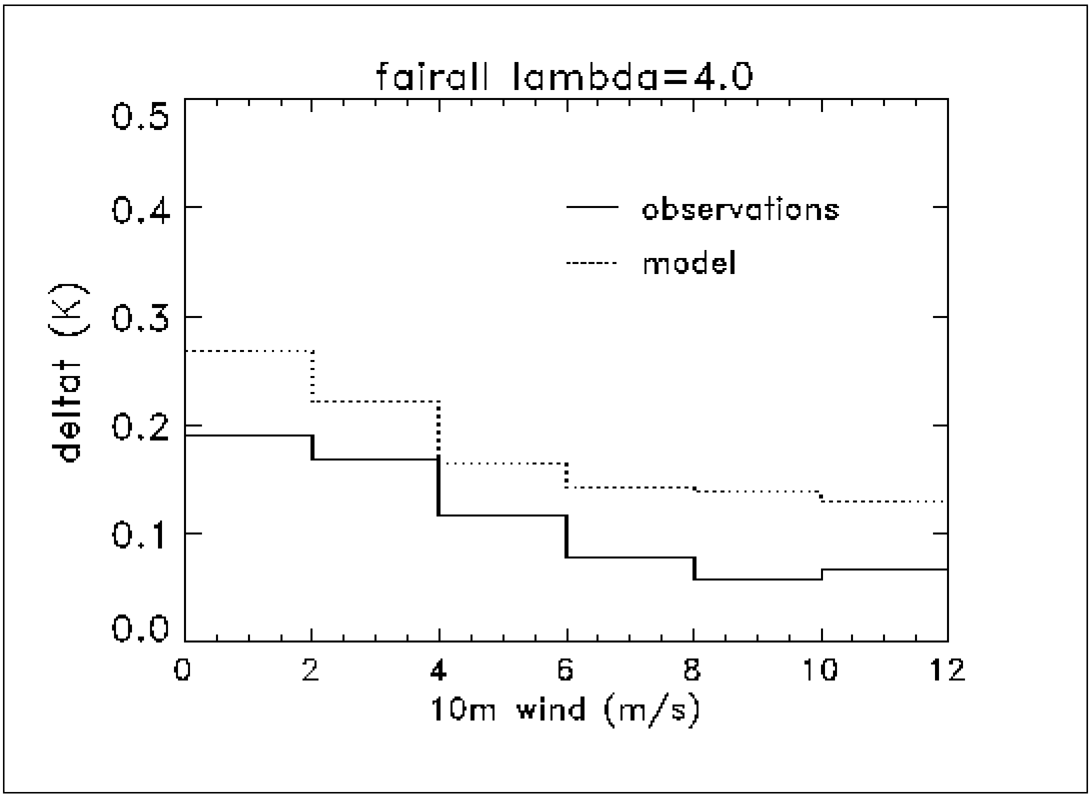

Fig. 1a Graph showing delta T (buoy SST minus satellite SST) against windspeed for night-time matchups to describe the skin effect.

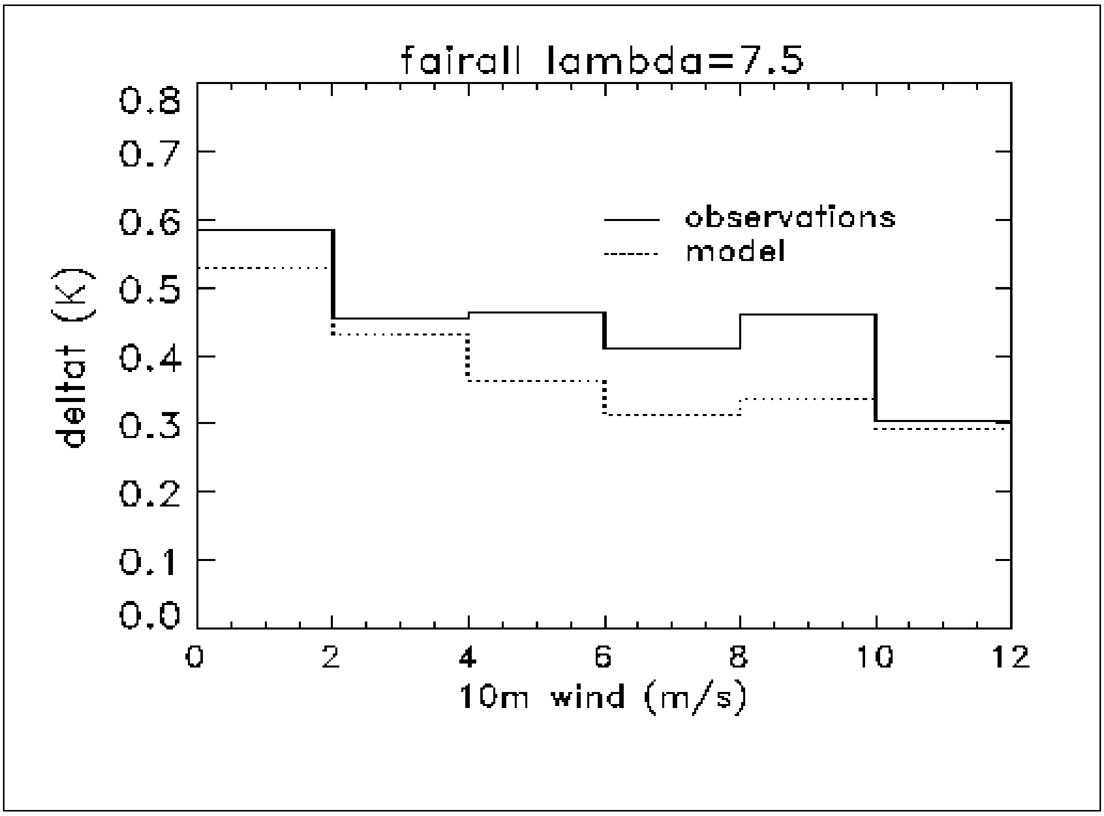

Fig. 1b. Graph showing delta T (buoy SST minus satellite SST) against windspeed for day-time matchups to describe the skin effect.

2.3 How the comparisons against in-situ data were compiled

2.3.1 Bulk SSTs vs. buoy SSTs

Statistics from comparisons of ATSR-2 SSTs with buoy SSTs were made to create means over 3-month periods and corresponding standard deviations from May 1995 to February 1999. This was done separately for day and night. In order to create day and night statistics, monthly matchup datasets were compiled which aimed to match ATSR-2 SSTs with those buoy locations which obeyed certain criteria. The criteria were tuned to select the best observations. A satellite skin SST is matched with a buoy SST if the circumstances in Table 1 are satisfied.

Criteria	Threshold	Effect
Matchup distance difference	Within same satellite grid box	-
Matchup time difference	< 1 hour	-
Number of 10 arc minute cells	> 5	To avoid cloud contaminated observations
RMS of 10 arc minute pixels	< 0.22 K	To avoid regions with large SST gradients
Inshore buoys: are screened out by the WMO ID and land tests on a 60x60 km square centred on the buoy position.		To avoid shallow water effects (eg tides)
Automatic light vessels: are screened out by the WMO ID.		Measurement depth unknown: avoids hull heating effects.
Reject if difference of dual minus nadir SST is	>1K	Aerosol test
Reject if GISST minus ATSR-2 SST is	>3K	Coarse cloud test

Table 1: Criteria for matching ATSR-2 SST with buoy locations.

The buoy matchup datasets contain information on the ATSR-2 SST, time, location, buoy type, buoy SSTs and buoy identifier, but also information on the surface fluxes, wind information and the time of day. The number of matchups per day ranged from approximately 30 to over 200.

For the analysis period of May 1995 to February 1999, ATSR skin SSTs were used which originated from three different SADIST 2 versions. However, there were no significant differences, only minor changes to the scheme which entailed slight modifications to quality control and cloud clearing tests. However, the SADIST 2 version for the final month of processing incorporated an improved SST retrieval algorithm and aerosol robust coefficients (Merchant et al, 1999). This may have the effect of improving the skin SSTs for the final month of this analysis period.

Within the skin SST to bulk SST processing scheme, NWP model flux and wind data were used throughout as inputs to the thermocline and skin models. Total column water vapour is also used within the skin to bulk conversion scheme to correct an observed bias in the bulk SSTs, which is caused by the skin SST retrieval not completely removing the effects due to water vapour absorption in the Tropics, which is due to sub-optimal SST skin temperature retrieval coefficients. However note that water vapour information was not available for 1995, so no correction was performed for this period.

Buoy data from the TAO array were used throughout the analysis period. Other fixed buoy data were also used throughout except for 1995 when none was available for technical reasons. A more stringent quality control process was performed on the months of July to September and November in 1996 and the months of March to July 1997, to enable drifting buoys to be used to increase the coverage in the southern hemisphere. Drifting buoys tend to undergo long periods at sea without maintenance, and are more likely to experience greater biases in their SSTs than fixed buoys and so the extra quality control is needed. The results were not significantly different for these months and so it is assumed the results for the remainder of the period with less quality control and coverage are still robust. Three monthly mean values of comparisons of ATSR-2 bulk SSTs against in-situ SSTs were calculated to provide a seasonal perspective on the results.

2.3.2 Bulk SST vs GISST

ATSR-2 bulk SSTs have also been compared with the GISST dataset. If there are more than 4 ATSR SSTs within a GISST 1 degree grid square, then the satellite SSTs are averaged before the mean value is compared with the GISST value. Comparisons of ATSR SST were made with the GISST dataset for the following regions:-

- Global: 90N, 180W to 90S, 180E over the oceans free of ice
- El Nino: 5N, 150 W to 5S, 90W

The regions will be referred to by the titles given above throughout this report.

3. RESULTS AND DISCUSSION

3.1 Comparisons of ATSR-2 bulk SSTs with GISST

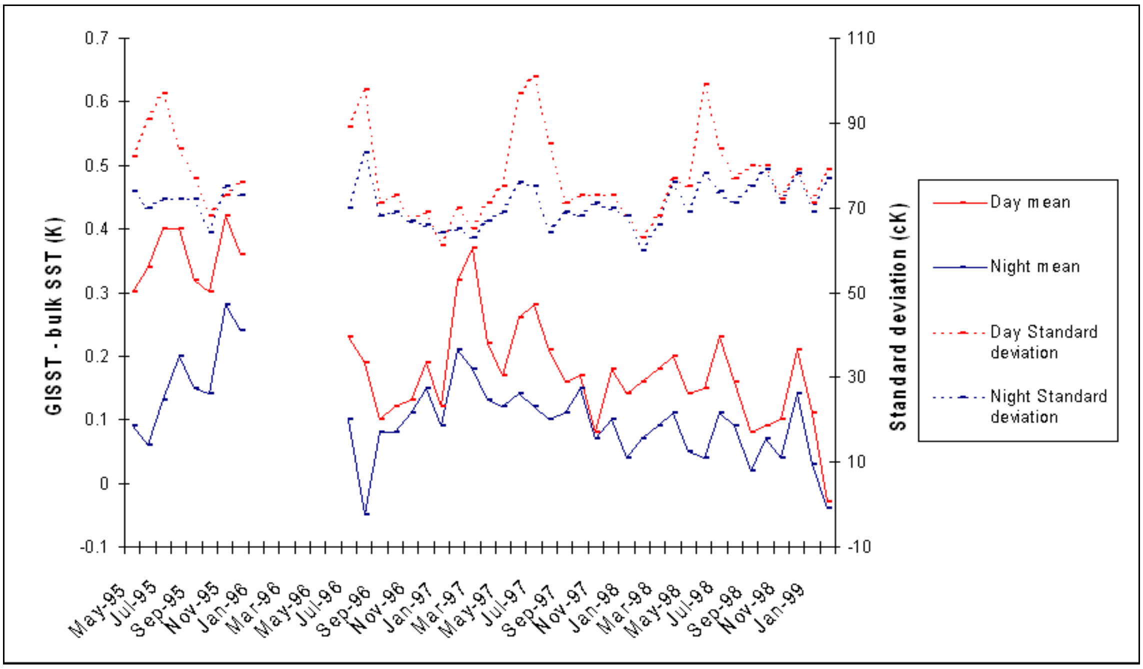

Fig. 2: Global monthly mean GISST minus ATSR-2 bulk SST from May 1995 to February 1999

A graph showing the comparison of ATSR-2 SSTs with the GISST dataset for the whole globe is shown in Fig. 2. Throughout the period, there is a cool bias in the satellite SSTs for both day and night, ranging from about 0 to +0.4K. Globally the cool bias is likely to be due to inadequacies in the cloud detection scheme causing the skin SSTs to be lower than the true value. In addition, the SST skin retrieval process is inadequately accounting for atmospheric water vapour in the tropics. Differences in the bias between day and night-time may be due to the night-time SST retrieval using 3 channels due to the 3.7µm channel being available, whilst the day-time SST retrieval uses only 2 channels which makes it more difficult to retrieve skin SSTs in the tropics. However, if the retrieval is optimal there should be no bias in either case, just an increase in variance for the 2 channel retrievals.

The 1995 period of Fig. 2 shows larger differences in the bias between day and night-time comparisons than the rest of the time series, and an overall cooler satellite SSTs with respect to GISST. This is due to there being no total column water vapour information available for 1995 and so this correction could not be performed. There is still a residual bias even when there is water vapour information available. This is because the retrieval coefficents were based on a sub-set of ATSR-2 SSTs with buoys which were biased towards the mid-latitudes.

There is a large improvement in the satellite SSTs with respect to GISST in February 1999 (the last month processed), when the satellite SSTs become warmer than GISST. This may be due to the fact that a new SADIST-2 version with improved cloud-clearing was used to produce the skin SSTs. There is a slight downwards trend in the bias i.e. improvement of the satellite retrieved SSTs with respect to GISST inferred from Fig. 2. Note that the day-time standard deviation of the differences are significantly larger for the northern hemisphere summer months. This is being investigated further.

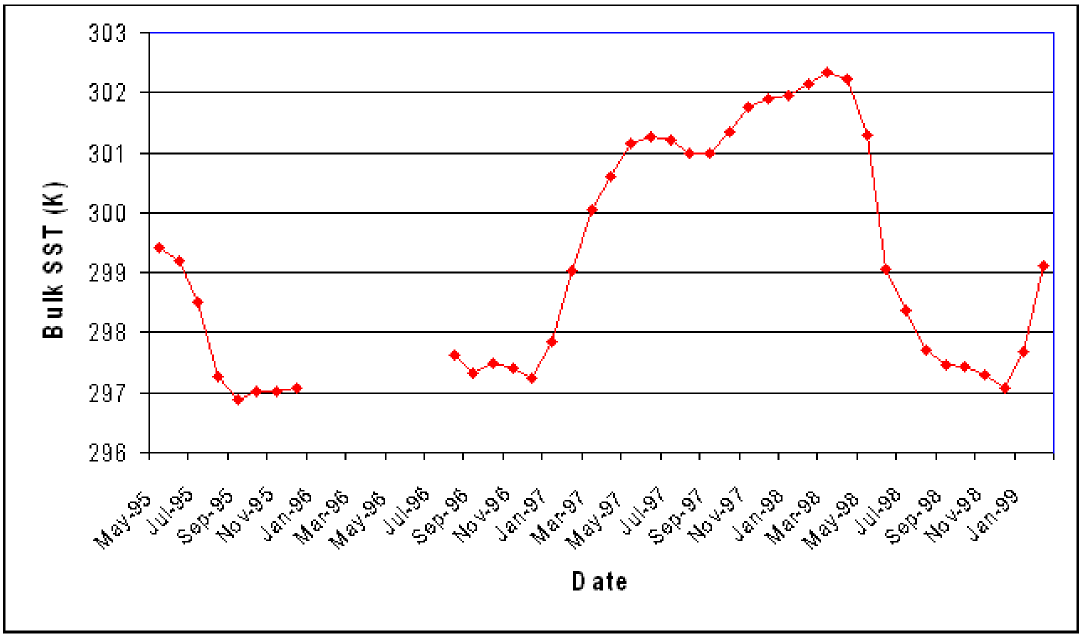

Fig. 3: Mean monthly bulk SST for the El Nino region from May 1995 to Feb 1999.

Fig. 3 shows time series of bulk SST for the El Nino region. The 1997/1998 El Nino can be clearly seen where the warmest peak in East Pacific SSTs is around March 1998. Fig. 4 shows monthly mean GISST minus ATSR-2 bulk SSTs for the El Nino region. There is an indication of a warm bias in the satellite SSTs coinciding with the timing of the 1997/1998 El Nino and a cool bias at other times. An increase in the standard deviations from May 1998 to January 1999 is evident and is being be investigated further.

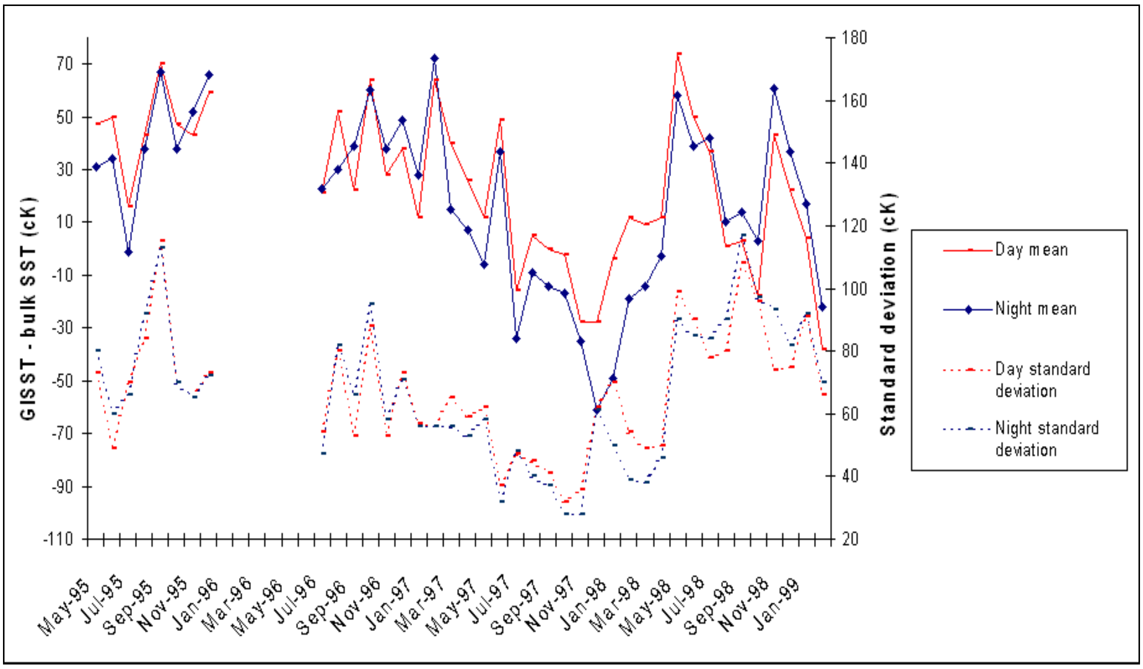

Fig. 4: Monthly mean GISST minus ATSR-2 bulk SSTs from May 1995 to February 1999 for the El Nino region

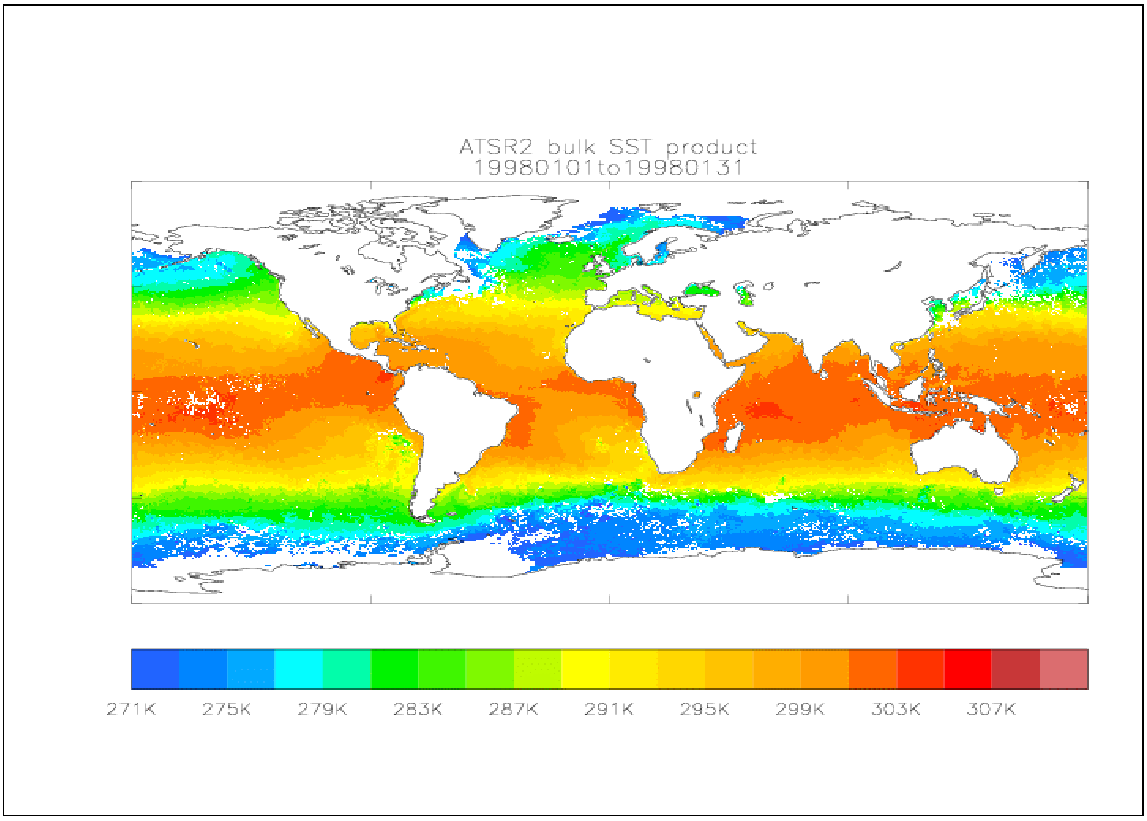

Fig. 5a: Global monthly mean ATSR-2 bulk SSTs for January 1998

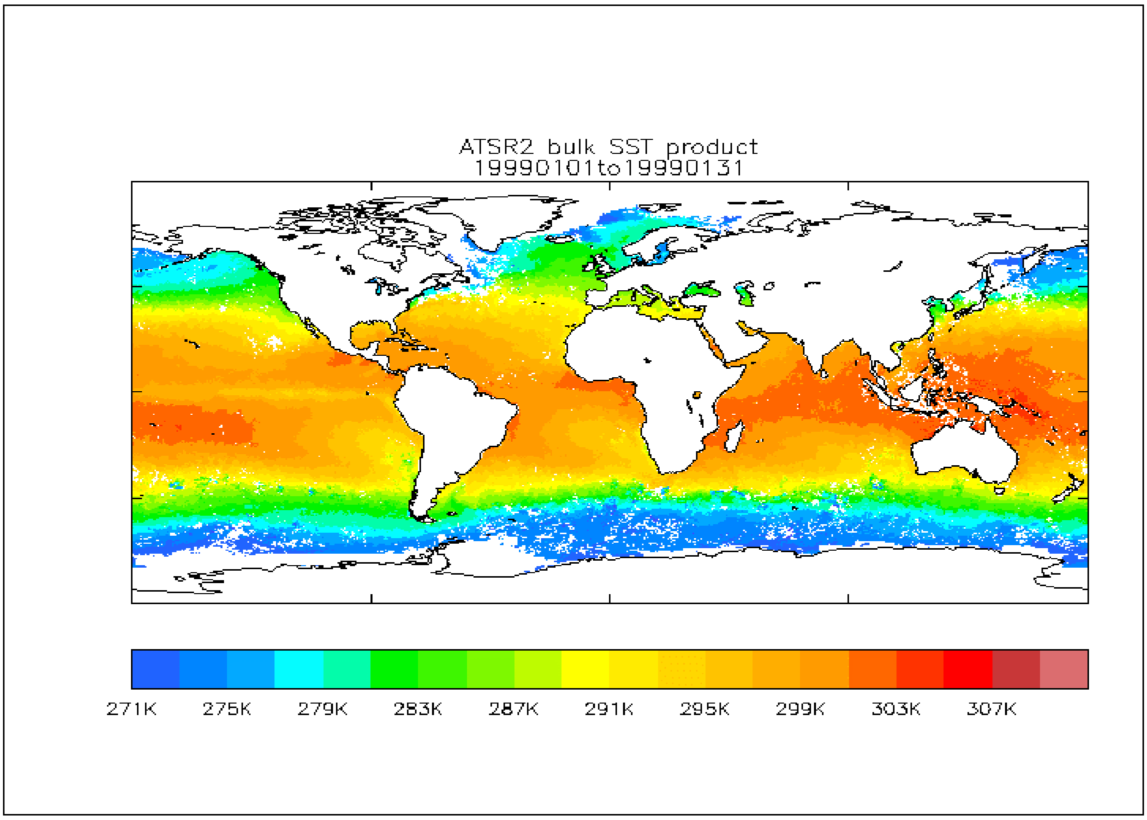

Figure 5b: Global monthly mean ATSR-2 bulk SSTs for January 1999

Fig. 5a displays the mean monthly bulk SSTs for January 1998, during the maximum of the latest El Nino. The figure shows that there is an area off the coast of Peru where very warm

SSTs are observed which are approximately 7K warmer than for the same month the following year. Fig. 5b shows the same figure for January 1999.

3.2 Comparison of ATSR-2 bulk SSTs with buoys

The comparisons of fixed buoy SSTs with ATSR-2 bulk SSTs gave a typical number of matchups at around 150 for each 3-monthly averaged period, ranging from ~50 to ~240. Slightly more matchups were made for night-time passes. Figure 6 shows the spread of buoy locations used for the 1996 matchups. This can be taken as typical for the other years also. The drifting buoy data were not used in this study as they were found to be too variable in quality.

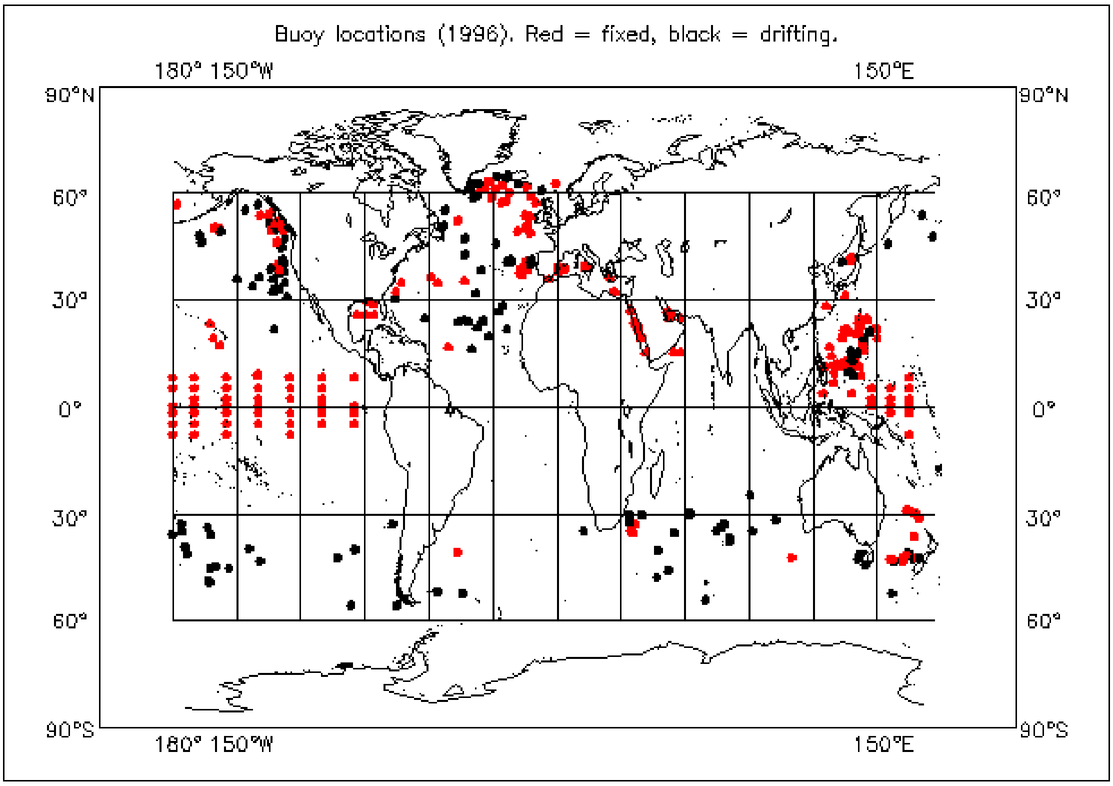

Figure 6: Drifting and fixed buoy locations used for 1996.

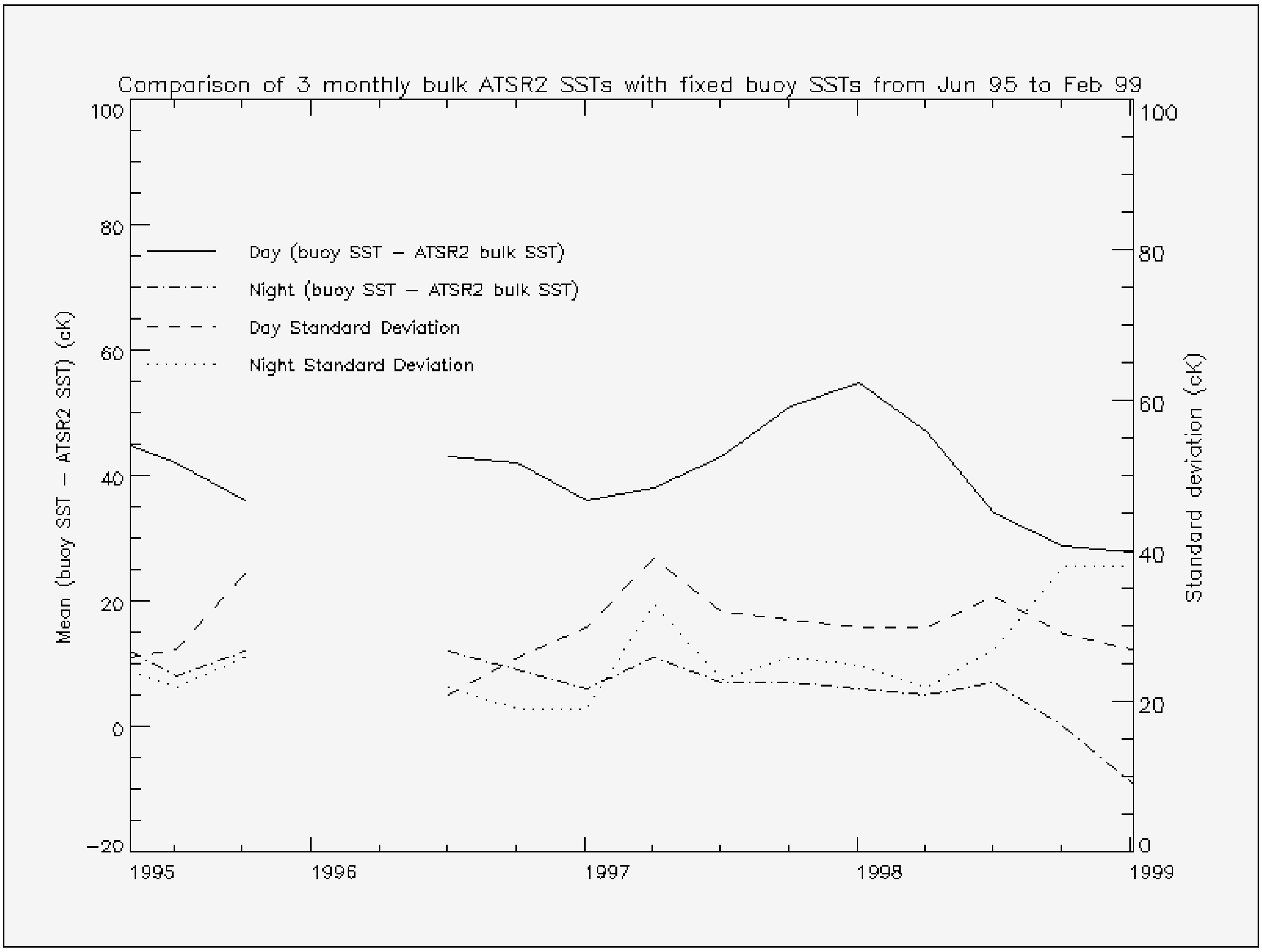

Fig. 7: Global three-monthly averaged comparisons of ATSR-2 bulk SSTs with fixed buoy SSTs from May 1995 to February 1999.

These plots show monthly means which have been averaged into 3-monthly periods to report only mean seasonal variations. As seen for the GISST comparisons there is a cool bias in the SSTs, with respect to buoys, which is more distinct for the daytime comparisons. The cool bias in the daytime ATSR-2 bulk SSTs ranges from ~0.3 to ~0.55 K. The cool bias in the night-time satellite SSTs is lower than for the day-time comparisons at around 0.1K. The daytime comparisons are more variable than the night-time results. A strong cool bias peak can be seen around January 1998, which coincides with the maximum in the 1997 / 1998 El Nino.

A small peak in the standard deviation for both the night-time and day-time plots of the 3-monthly mean value for April to June 1997 is observed. This has been investigated by plotting a histogram of the differences. The slightly higher standard deviation may be influenced by more undetected thermoclines and/or residual cloud contaminated observations for this period, but there is no obvious reason why there may be more in this period.

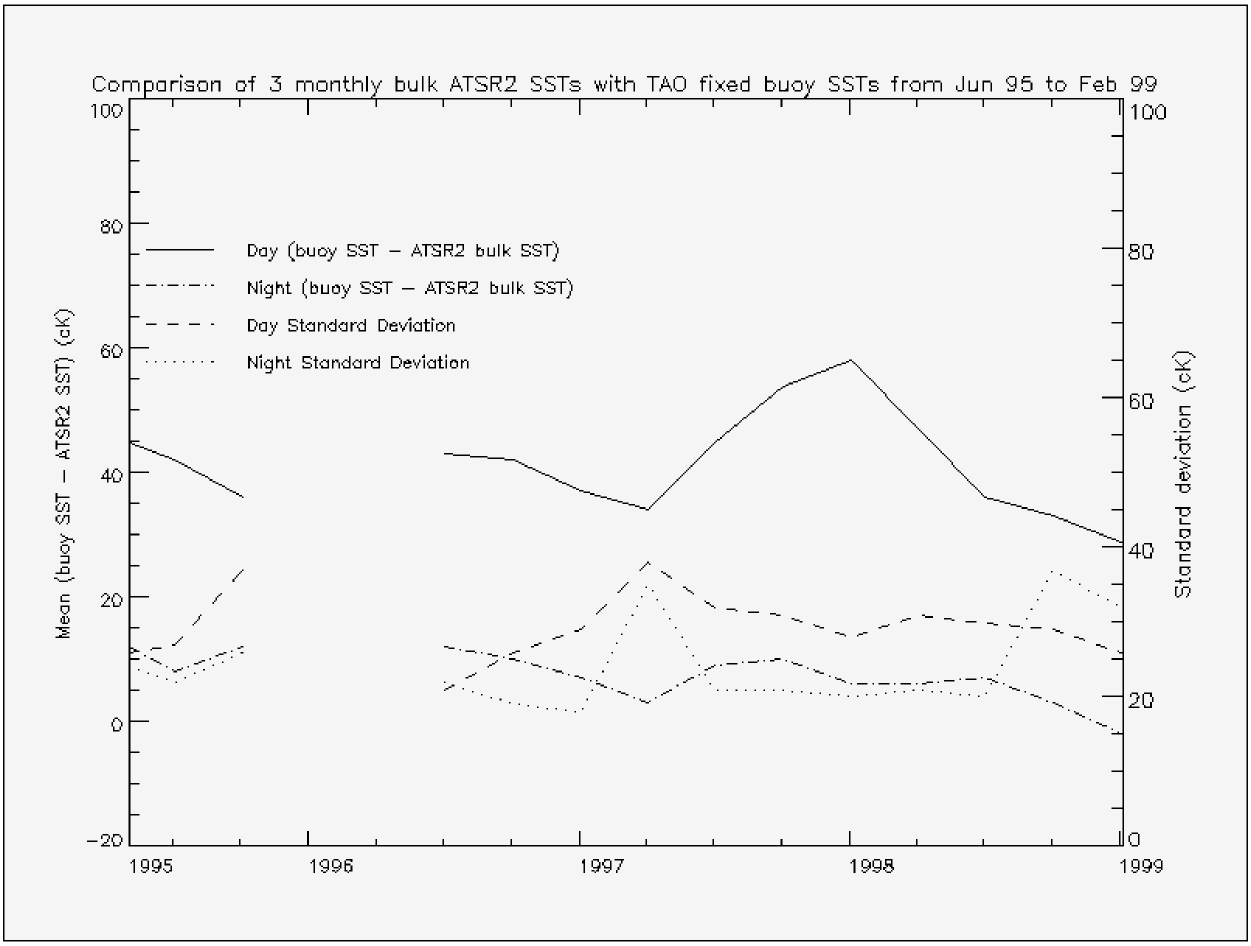

Fig. 8: Three-monthly averaged comparisons of ATSR-2 bulk SSTs with fixed buoy SSTs for the TAO array from May 1995 to February 1999

The same analysis as described above was made for comparisons using only fixed buoy data in the TAO array. Fig. 8 shows the comparisons of ATSR-2 bulk SSTs with TAO fixed buoys from May 1995 to February 1999 on a 3 monthly averaged basis which is very similar to the global plot in Fig. 7 showing that the tropics dominate the statistics.

4. Skin/Bulk Comparisons using the Merchant (1999) Coefficients

As noted earlier skin SST retrievals using the original (Zavody et al, 1994) coefficients appear to contain a cold bias with respect to the amount of water vapour in the path between the surface and satellite. We removed this using profiles of humidity from the Met Office model analyses coincident at the observation (in location and time) to estimate the water vapour loading and then applied a correction dependent on the amount. Recently Chris Merchant (University of Edinburgh) has derived a new set of coefficients for the two ATSR instruments in which he has attempted to improve both the treatment of aerosols and the water vapour continuum in the radiative transfer modelling (Merchant et al., 1999a). Using in-situ matchups this approach has demonstrated improved robustness to both high aerosol and water vapour loadings (Merchant et al., 1999b). This work focussed on data from the Tropical Pacific. We have repeated the buoy/satellite comparisons using our global matchup dataset as discussed in Section 2, with the satellite skin SSTs derived using the Merchant coefficients. Figure 9 shows a histogram of observed delta T for both night-time and day-time dual view 2-channel retrievals, both have a similar distribution with some evidence of the diurnal thermocline in the day-time.

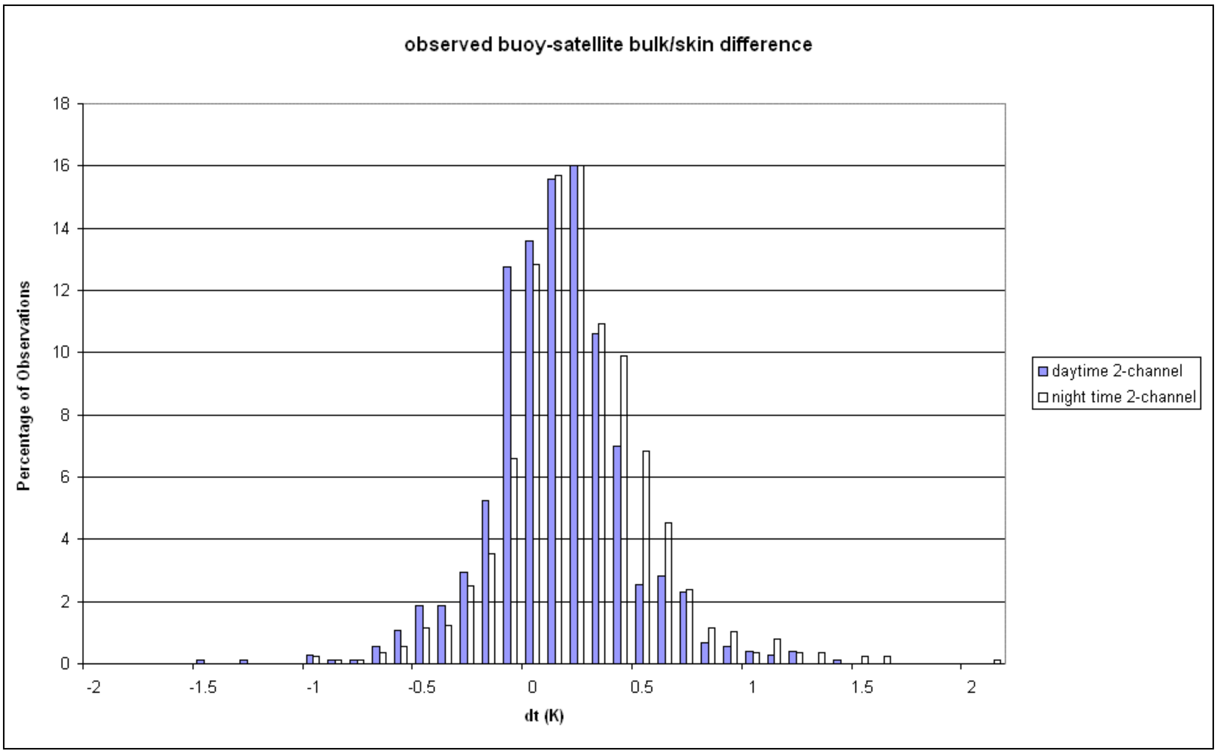

Figure 9. A histogram of observed buoy bulk SST - satellite skin SST difference. The satellite retrievals were derived using the Merchant coefficients.

The observations have also been compared to predictions from the Fairall model and Table 2 shows the results. In both night-time and day-time cases we find that the skin effect bias can be removed using the value of λ_0 proposed by Fairall (λ_0=6), without the need of an additional water vapour dependent correction. This is a significant improvement on the Zavody coefficients (also shown in the Table and without the water vapour correction).

Matchups	**Skin SST Coefficients**	**Observed dt (K)**		**Observed dt - skin model (K)**	
		Mean	**sd**	**Mean**	**sd**
Daytime	Merchant	0.15	0.31	-0.09	0.31
Daytime	Zavody	0.45	0.34	0.20	0.33
Nighttime	Merchant	0.25	0.33	0.00	0.33

Table 2 The observed bulk-skin SST difference and a comparison with the Fairall model prediction. Results are presented using two sets of retrieval coefficients applied to ATSR-2 two channel dual view retrievals.

These results with the Merhant coefficients appear encouraging and future work should look at the three channel dual view coefficients and also the use of a small latitude dependent offset which Merchant proposes.

5. CONCLUSIONS

ATSR-2 RAL processed (SADIST-2) skin SSTs have been processed to bulk SST and compared with the GISST SST analyses and in-situ buoy measurements. The comparisons show, for this version of the skin SST retrieval, the ATSR bulk SSTs have a mean bias of 0.5

degK for the daytime retrievals and 0.1K for the night-time retrievals. The night-time standard deviations of the differences are less than the daytime values as expected with the additional information from the 3.7µm channel. This is true for both the comparisons of ATSR-2 bulk SSTs against the climate dataset, GISST, and against fixed buoy data (for the global and TAO areas).

It is suspected that part of the cool bias for both day and night is caused by failings in the cloud detection. The daytime observations however are cooler than the night-time due to the use of a sub-optimal skin SST retrieval when only 2 channels are used in the retrieval process which degrades bulk SST retrievals in the tropics.

This suggests more work is needed to improve the accuracy of the two channel skin SST retrieval algorithm to remove the 0.5 degK bias in the tropics. In fact new coefficients recently developed at RAL (Merchant et al, 1999) have improved the SST skin retrieval method as can be seen for the February 1999 point in Fig.2. In parallel a new set of coefficients for the skin SST to bulk SST conversion model has been computed which removes the need for the integrated water vapour correction and it is planned to reprocess the ATSR dataset with these improvements. In addition the cloud detection algorithms also need to be critically reviewed and improved.

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