The Conversion of ATSR Sea Surface Temperatures for Use in a Climate Database

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Abstract

The high accuracy of `skin' sea surface temperature measurements from ATSR make them a valuable source for global databases used in climate studies. To compliment existing records measured from ships and buoys, it is necessary to convert the observations to a bulk surface temperature at a depth of about 1 metre. A method is being developed to do this at the United Kingdom Meteorological Office (UKMO), which includes quality control tests to reject observations with cloud and aerosol contamination. Skin to bulk temperature algorithms are currently being tested using meteorological data from the UKMO's Global Model. The output from the algorithms are compared with drifting buoy temperature measurements, with the aim of developing the best conversion for different surface windspeed regimes under different solar radiation conditions. This paper will review the skin vs bulk SST issues, will show the necessity for full quality control of the satellite data, and results from the latest conversion algorithms.

Keywords: SST, ATSR, Climate Change

Introduction

An important tool for climate change studies is a global historical dataset of SSTs. Such a dataset can be used both in modelling studies and in the detection of climate change. The Global Sea-ice and Sea Surface Temperature (GISST) dataset is produced at the Hadley Centre (Rayner *et al*,1996) and consists of monthly SST fields from 1903 onwards.

The accuracy of SST measurements from ATSR make them suitable for use in the GISST dataset and allows global coverage of the oceans. As ATSR measures the radiation emitted from the top few microns of the sea surface the retrieved temperature is the skin SST. Measurements made using buoys or from ships are at a depth of about 1m or more; this is the bulk SST. Typically the skin SST is cooler than the bulk SST by up to 1K. For satellite measurements to compliment data from ships and buoys without bias each satellite skin SST needs to be converted to a bulk SST. The object of the work presented here is to develop a method which quality controls the 0.5° SST product from ATSR and converts each observation to a bulk SST which represents what would be measured in situ. The ATSR data analysed here has been produced using the SADIST-1 processing scheme. Although the most accurate SSTs are from dual retrievals a proportion of the dataset (about 10%) are from a single view only. In order to obtain global coverage for climate use single view SSTs are used where a dual retrieval is not available.

Quality Control of SSTs

The two most important sources of error in satellite observations are due to cloud and aerosol contamination, both of which lead to an underestimation of the SST. As observations without bias are required for climate use it is necessary to remove contaminated observations.

Testing for cloud contamination in SADIST-1 data

A simple method to check for cloud contamination in satellite retrievals is to compare them with an existing SST dataset. In this case the GISST dataset is used, which is particularly useful as in its production higher weighting is given to surface observations than to satellite data. To highlight differences each satellite observation in March 1992 was compared with the corresponding position in the GISST March 1992 dataset. A histogram of results is shown in Figure 1 along with corresponding statistics in Table 1. Results using SSTs derived from both single and dual view retrievals are shown. The mean of each comparison is negative highlighting the cool skin measured by the satellite compared with the GISST dataset which represents bulk SST. Each histogram shows a cool tail where ATSR observations are significantly cooler than the corresponding value in the GISST dataset. These observations contain cloud contamination and are cooler than the GISST values by up to 20K. For SSTs derived from dual view retrievals the amount of cloud contamination is very low with around 2% of the data outside of 3K from the corresponding GISST SST. Data outside of this 3K limit is considered to contain cloud contamination and the amount of this data in dual view retrievals is about the same for March 1992 and March 1995. Results also show that whilst there are extra observations from single view retrievals they are more likely to be cloud contaminated. It is hoped that new cloud tests developed for the SADIST-2 processing scheme will lower the amount of contamination. Similar results can also be found when comparing ATSR observations with a second SST monthly mean dataset created from the UKMO daily analyses of SST.

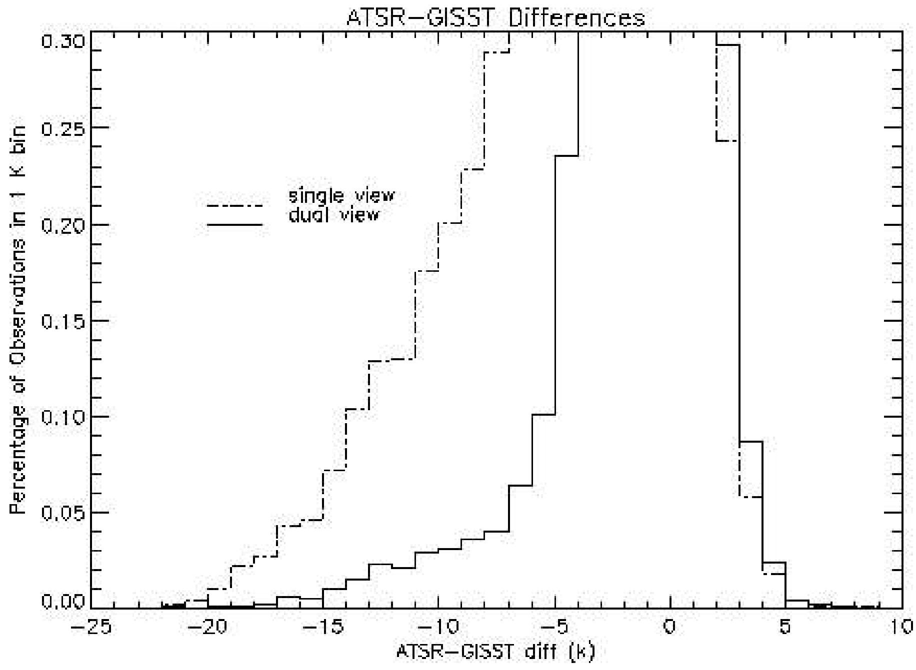

Figure 1: A histogram of ATSR-GISST SST difference for observations during March 1992.

Time Period	Retrieval Type	No of Observations	ATSR-GISST (K)		
			mean	sd	% of obs outside ± 3K
March 1992	Dual View	556977	-0.64	0.98	1.6
March 1992	Single view	640600	-1.13	1.58	4.5
March 1995	Dual View	609643	-0.85	1.03	2.4

Table 1: Results of the Comparison between ATSR SSTs and the monthly GISST dataset for both March 1992 and March 1995.

Testing for Aerosol Contamination in SADIST-1 Data

The eruption of Mount Pinatubo in June 1991 released a large amount of aerosol into the atmosphere, one month before the launch of ERS-1. Analysis carried out by Murray *et al*,1996 shows that whilst night-time 3-channel dual view retrievals are robust with respect to the aerosol, day-time dual view retrievals are subject to a cold bias of up to 0.5K. The work also demonstrated that dual view retrievals are more robust in the presence of large amounts of aerosol than single view retrievals.

Recognising that a dual view retrieval is more accurate allows a crude aerosol test to be performed by looking at the dual-single view difference for the same observation. What is observed, particularly for the night observations in 1992, is that the single view SST is very cool with respect to the dual view SST. From analysis of the data an observation is considered to have significant amounts of aerosol contamination if the dual-single view difference is greater than +1K. The results of this test are shown in Table 2.

Time Period	% of night observations failing the test	% of day observations failing the test
March 1992	4.68	1.02
March 1993	0.85	0.36
March 1994	0.68	0.22
March 1995	0.28	0.25

Table 2: Results of the dual-single view test for aerosol contamination

As the observation period moves away from 1992 the number of observations failing the test decreases. The big decrease for night observations between 1992 and 1993 is partly due to the Pinatubo aerosol falling out and partly due to the change to a 2-channel retrieval (after the loss of the 3.7 μm channel). By March 1995 low rejection rates suggest that most of the aerosol has fallen out of the atmosphere and data failing this test is probably due to the presence of large amounts of water vapour.

Comparison between SADIST-1 SSTs and Drifting Buoy Data

In order to investigate the bulk-skin SST difference, measurements of SST from buoys were co-located in time and space with the ATSR observations. The buoy measurements were obtained from the drifting buoy archive held at the UKMO which totals about 17000 observations a week. Since the buoy measurements are made at about the 1m level in the ocean they represent bulk SST. The period from January to March 1995 was chosen as the satellite observations should be free from aerosol contamination due to Pinatubo. The following criteria were used when making each buoy ATSR matchup:

ATSR SST from a dual retrieval
Both measurements made within 5 hours from each other
Buoy SST located within the 0.5 ATSR pixel
GISST cloud contamination test on ATSR SST
Dual-Single view aerosol contamination test on ATSR SST
GISST test on buoy SST
Both measurements made during night-time or day-time (using the ATSR record and a solar elevation test for the buoy)

The GISST test on each buoy SST consisted of evaluating the GISST-buoy difference which acted as a filter to reject faulty buoy observations or areas of the ocean with strong gradients of SST. Analysis of one complete week of buoy observations showed that 80% of the data is within ± 1K of the GISST dataset. This was used as the rejection limit. The total number of matchups found in the period January to Match 1995 which satisfied the above criteria were 1343 and the mean differences are shown in Table 3 along with a histogram of the data in Figure 2.

Observation	number of matchups	Buoy-ATSR difference (K)	
		mean	σ
all observations	1343	0.51	0.31
night observations	644	0.56	0.29
day observations	699	0.48	0.31

Table 3: Results of buoy-ATSR differences for matchups in the period January to March 1995.

On average for both day and night data each buoy measurement is warmer than the corresponding ATSR measurement which again highlights the cool skin of the ocean. Only about 4% of the matchups show warm skin where the ATSR measurement is warmer than the buoy observation. The range of the data is consistent with current estimates of the range of the bulk-skin difference using shipbourne radiometers.

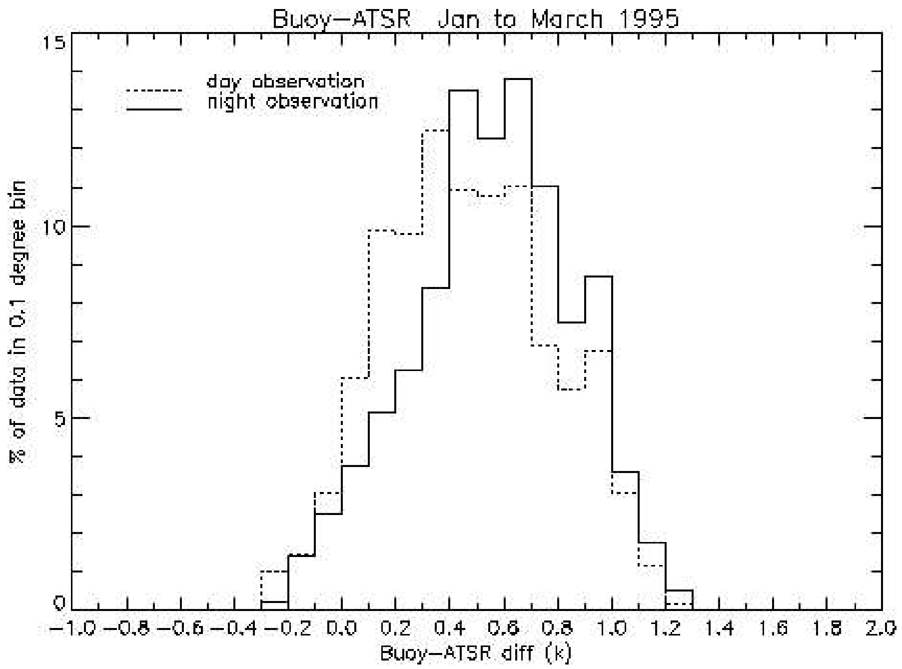

Figure 2: A histogram of buoy-ATSR SST difference (observed Δ T) for matchups during the period January to March 1995.

Testing Skin to Bulk Algorithms

Introduction

There are several models which attempt to describe the temperature difference across the thermal skin of the ocean where heat is transferred by molecular conduction. The depth of this layer is governed by the stress of the wind on the ocean's surface. Below this layer the surface of the ocean is considered to be well mixed. Table 4 outlines the properties of some of the algorithms.

Algorithm	***model type***	***Comments***
Saunders (1967)	forced convection	
Hasse (1971)	forced convection	includes effect of solar radiation
Katsaros (1977)	free convection	models low windspeed regime
Soloviev-Schlüssel (1994)	renewal model	models low to high windspeed regime

Table 4: Skin to bulk algorithms

As well as windspeed the bulk-skin temperature difference is also driven by the total heat flux out of the ocean, Q. At night this is made up of the following terms:
$Q=L+H+\lambda_{ir}$

Where:

L=Latent heat flux
H=Sensible heat flux
λ_{ir} =Net long wave radiation.

During the daytime the net solar flux can also be included, although most of the algorithms neglect its effect. Since under clear skies the net solar flux is typically 600W/m² inclusion of it in the total heat flux tends to dominate the direction, predicting a warm skin. However only 4% of the buoy ATSR matchups show a warm skin. This is because the actual percentage of the net solar flux which is absorbed in the conduction layer is very small (about 2% for a layer 1mm thick). So an approximation of zero solar heating can be made. Only the Hasse algorithm explicitly includes the effects of solar radiation.

In order to calculate the bulk-skin temperature difference to correct the satellite observations the best estimates of the windspeed and the total heat flux at the point on the surface where the observation is made are required. Analysis fields of surface fluxes and 10m windspeed generated by the UKMO's global model are used as the source for this data. The fields are created every 6 hours with a resolution of 0.83° lat. x 1.25° long. Linear interpolation is carried out using data from the nearest analysis time which is in the same part of the diurnal cycle as the observation.

Figure 3 shows the predictions of the bulk-skin SST difference (model Δ T) using the Saunders algorithm for the matchup locations during the night. The general trend is a reduction in Δ T with increasing windspeed. The outlier in the dataset, which is a prediction of 1K, is due to a large latent heat flux at that location.

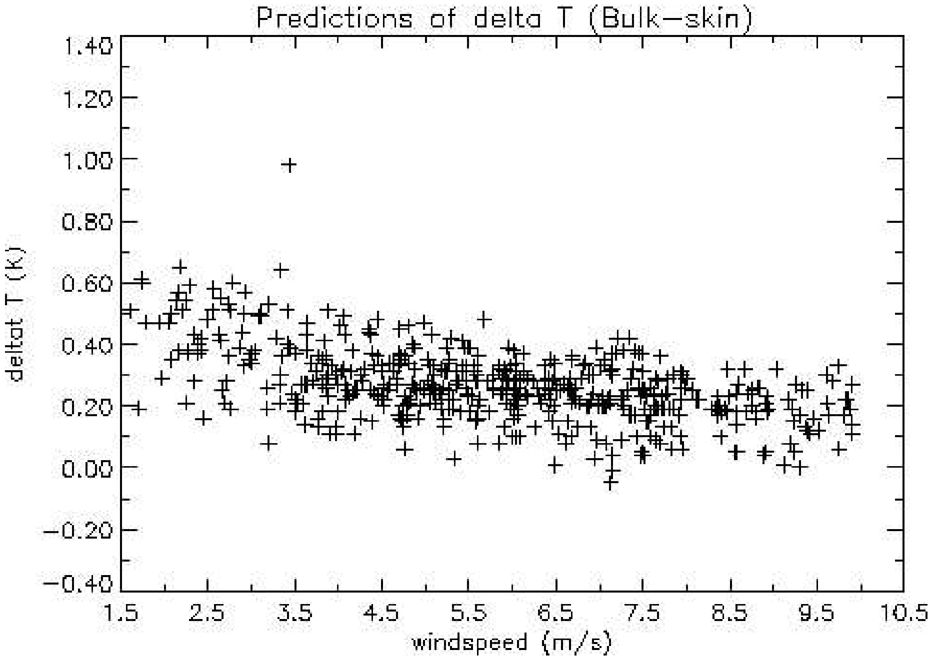

Figure 3: Predictions of the bulk-skin SST difference (model △ T) using the Saunders algorithm for night-time locations in the surface windspeed range 1.5-10 m/s

Comparison of Observations with Predictions: Moderate to High Windspeed

Using the global windspeed data it was found that over 80% of the buoy ATSR matchups occur with a windspeed range of 1.5 to 10 m/s at the surface. For each matchup in this windspeed range the observed bulk-skin SST difference (observed △ T) was compared with the model △ T from each algorithm. Results are shown in Table 5 for both night and day data. Figure 4 shows the observed △ T night-time data with windspeed, which has a much larger variation than the corresponding predictions by the Saunders algorithm in Figure 3.

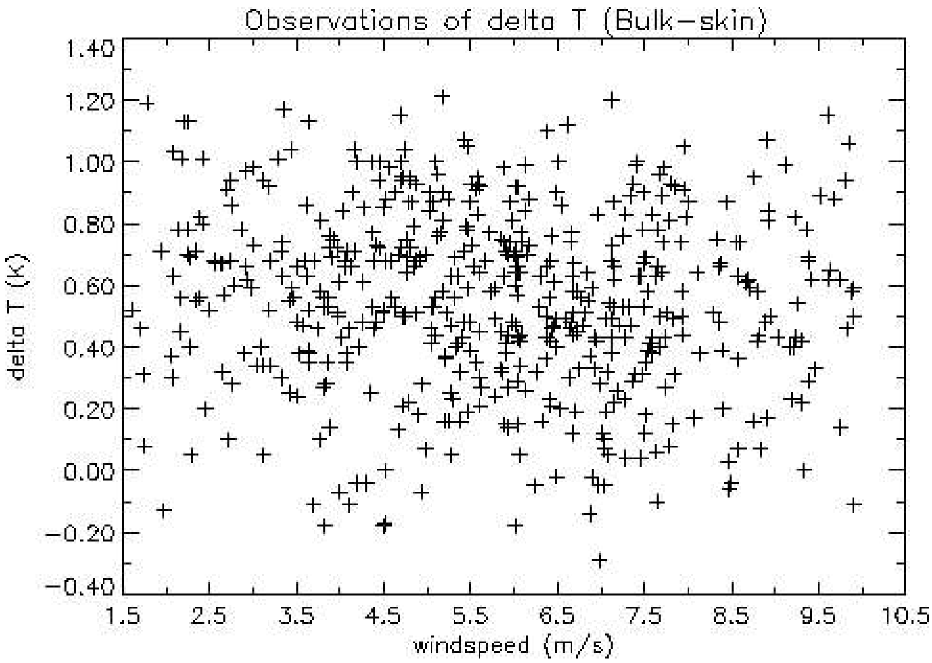

Figure 4: Observations of the bulk-skin SST difference (observed △ T) for night-time locations in the surface windspeed range 1.5-10 m/s.

Algorithm	***Bulk-Skin Prediction (K) (Model △ T)***		***Observed △ T- Model △ T (K)***	
	mean	σ	**mean**	σ
Saunders day	0.27	0.11	0.19	0.32
Soloviev-Schlüssel day	0.25	0.08	0.21	0.31
Hasse day	0.40	0.21	0.07	0.37
Observed △ T day	0.46	0.31		
Saunders night	0.27	0.12	0.28	0.30
Soloviev-Schlüssel night	0.24	0.08	0.32	0.29
Hasse night	0.50	0.24	0.05	0.36

Observed Δ T night	0.55	0.29		

Table 5: A comparison of the difference between observed Δ T and model Δ T using different algorithms. The windspeed range is 1.5-10 m/s. The statistics for observed Δ T are also included for comparison.

If an algorithm accurately describes the observed Δ T for each point in the dataset it would be expected that both the value and spread of the observations would be reduced by application of the algorithm. The difference between the observed Δ T and model Δ T gives a measure of how good the predictions are. When comparing these differences it can be seen that none of the algorithms reduce the standard deviation of the observed Δ T for either the night or day observations. This suggests that none of the algorithms can fully account for the spread of the values of observed Δ T. The best algorithm for this windspeed range appears to be the Soloviev-Schlüssel algorithm, whilst the algorithm due to Hasse actually increases the standard deviation of the observed Δ T.

Comparison of Observations with Predictions: Low windspeed

As the windspeed drops the depth of the conduction layer at the surface increases. Below a certain windspeed this depth becomes too large and heat is transferred by free convection. In order to investigate the boundary between free and forced convection the values of model Δ T and observed Δ T were averaged into windspeed bins of 0.5m/s. Due to a lack of observations at low windspeed both night and day observations were used. Measurements using shipbourne radiometers (Kent *et al*,1996) showed that at low windspeed the solar flux becomes important in the formation of a near surface thermocline at a value greater than 800 W/m². To simplify the analysis any day observations with a surface solar flux greater than this value were rejected. From the results shown in Figure 5 it can be seen that the Saunders algorithm overestimates Δ T at windspeeds below 1.0m/s compared to the free convection models and the observations. Although not shown in Figure 5 the predictions from the Hasse algorithm below 1.0m/s are even greater than those from the Saunders algorithm. At a windspeed of about 1.5m/s the predictions from the Katsaros (free) and Saunders (forced) algorithms coincide. This suggests that below this windspeed free convection becomes dominant as the mechanism of heat transfer and either the Katsaros or Soloviev-Schlüssel algorithm should be used to convert observations from skin to bulk SST.

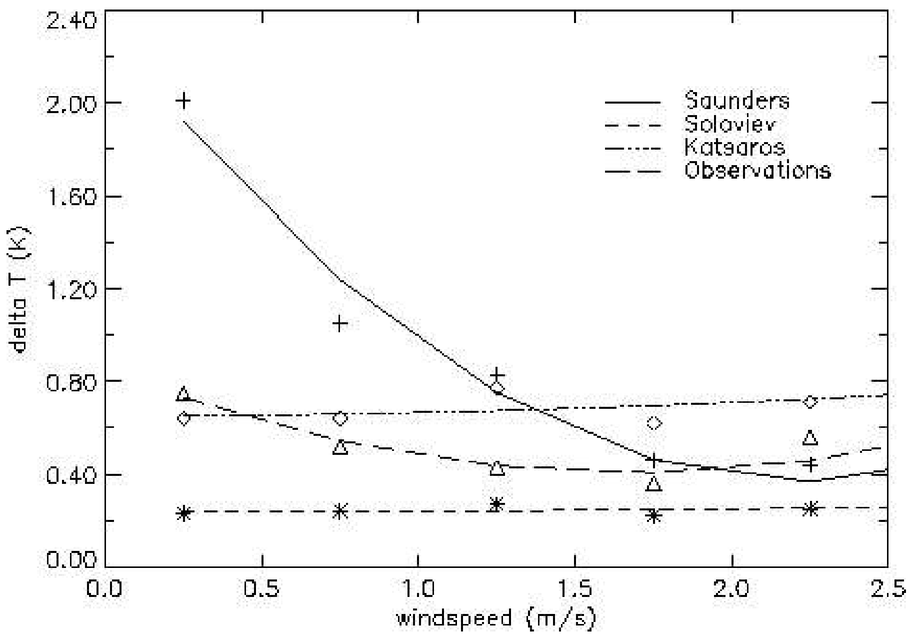

Figure 5: A comparison of bulk-skin predictions (model Δ T) from each algorithm at low windspeeds. The data has been averaged into 0.5 m/s windspeed bins.

Conclusions

SSTs from ATSR have been passed through a quality control scheme and matched with buoys to produce observations of bulk-skin temperature difference . These observations have been compared with predictions from several algorithms. It has been shown that at low windspeed an algorithm which models free convection should be used. In the moderate to high windspeed range the Soloviev-Schlüssel algorithm gives the best predictions for both night-time and day-time conditions. However the algorithms do not reduce the spread of the observed bulk-skin difference. This may be due to other effects on the data (such as residual cloud contamination) which are more dominant. SSTs from the SADIST-2 scheme will soon be available. The work will be repeated with these improved SST observations in order to determine the best algorithms to convert ATSR data from skin SST to bulk SST. The bulk SSTs can then be used as part of the observations required to form a database for climate use.

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