Towards an independent time series of sea surface temperature from satellite observations

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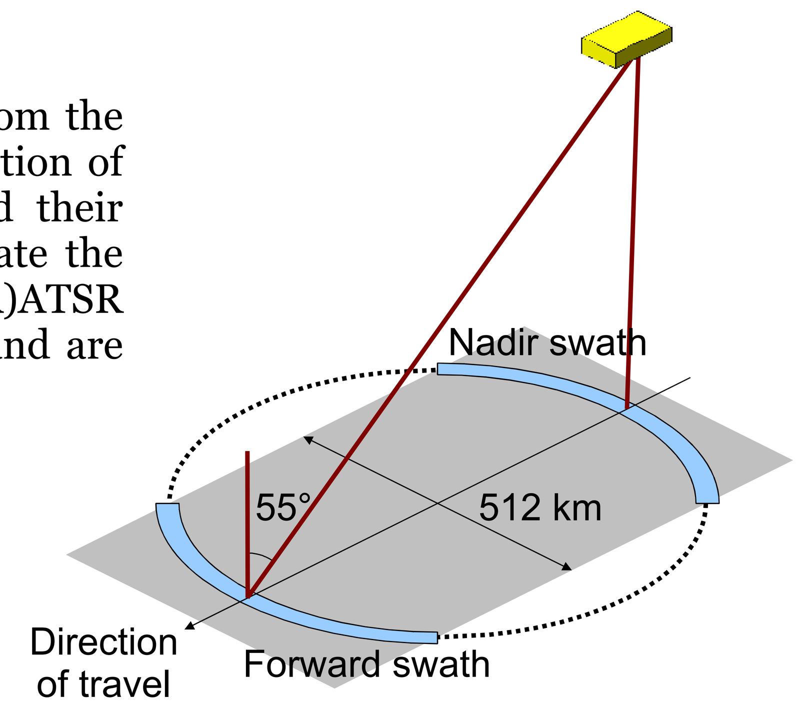
Introduction

The (A)ATSR Reanalysis for Climate project aims to produce a new, high quality record of sea surface temperature suitable for climate change research from the (A)ATSR multi-mission archive. All (A)ATSR data will be reprocessed using modern cloud screening techniques and improved SST retrieval algorithms. In order to be suitable for climate change research, the completed record must have:

- Independence from other records
- At least 15 years global coverage
- Regional biases < 0.1 K
- Stability of 0.05 K per decade
- Both skin and bulk SSTs
- Comprehensive error characterization

These requirements are challenging but feasible using data from the (A)ATSR series of instruments. Due to the exceptional calibration of the (A)ATSR instruments using two black body targets and their unique dual view capability it is possible to accurately estimate the SST without any use of in-situ data for calibration. Current (A)ATSR SSTs are recognised as the most accurate satellite retrievals and are used as the reference InfraRed sensor for GHRSST-PP.

(A)ATSR data do not currently meet out requirements for climate. However many of the remaining sources of error are now known and the possibility exists to correct them though new algorithms and techniques.



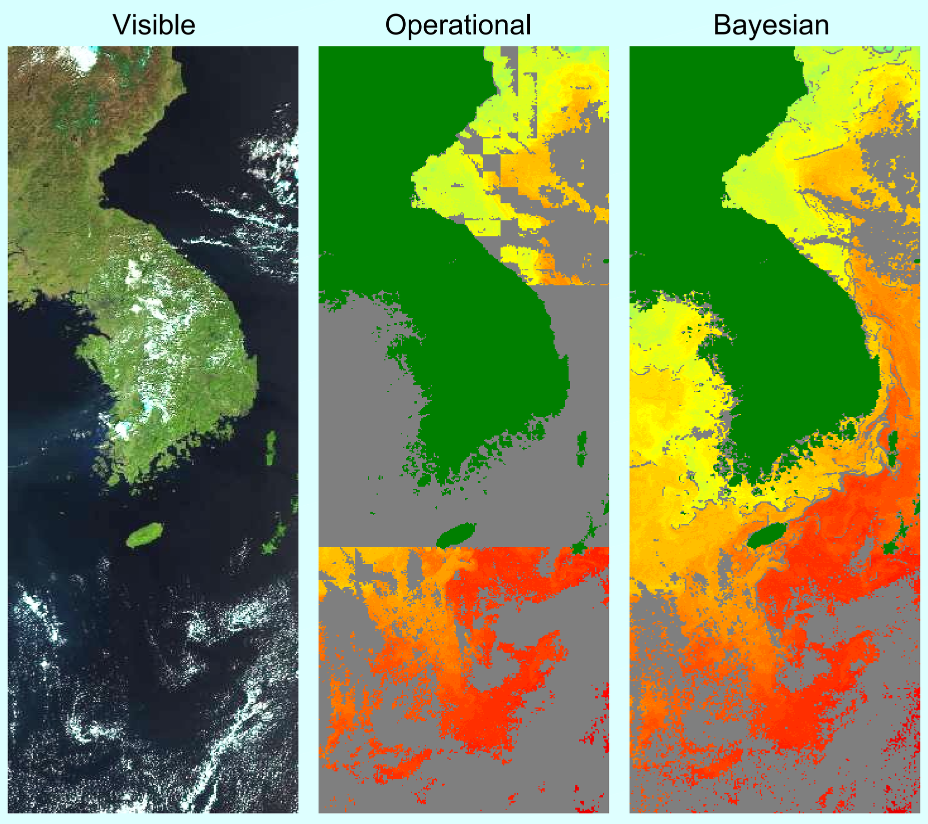


Figure 1. Comparison of operational and Bayesian cloud masks. Bayesian cloud mask calculated using 11 and 12 micron nadir channels.

Cloud Detection

The original (A)ATSR Cloud detection scheme was based on a threshold approach developed from the algorithms of Saunders and Kriebel (1989). However, as with all threshold based approaches, minimising the False Alarm Rate while maximising the Hit Rate rapidly becomes difficult as the complexity of the scheme increases.

Existing issues include failure to detect thin cloud and cloud edges where Brightness Temperature impacts are smaller than the pre-set thresholds; incorrect flagging of ocean gyres as cloud where the sea surface is colder than the pre-set threshold; and complete failure of the cloud mask in the presence of strong ocean fronts.

A new probabilistic cloud detection scheme has been developed which uses Bayes' theorem to calculate the probability that each pixel is clear using a forward model to predict expected brightness temperatures from a Numerical Weather Prediction Model prior. Tests using the new scheme show a significant improvement in both hit rate and reduction in false alarms.

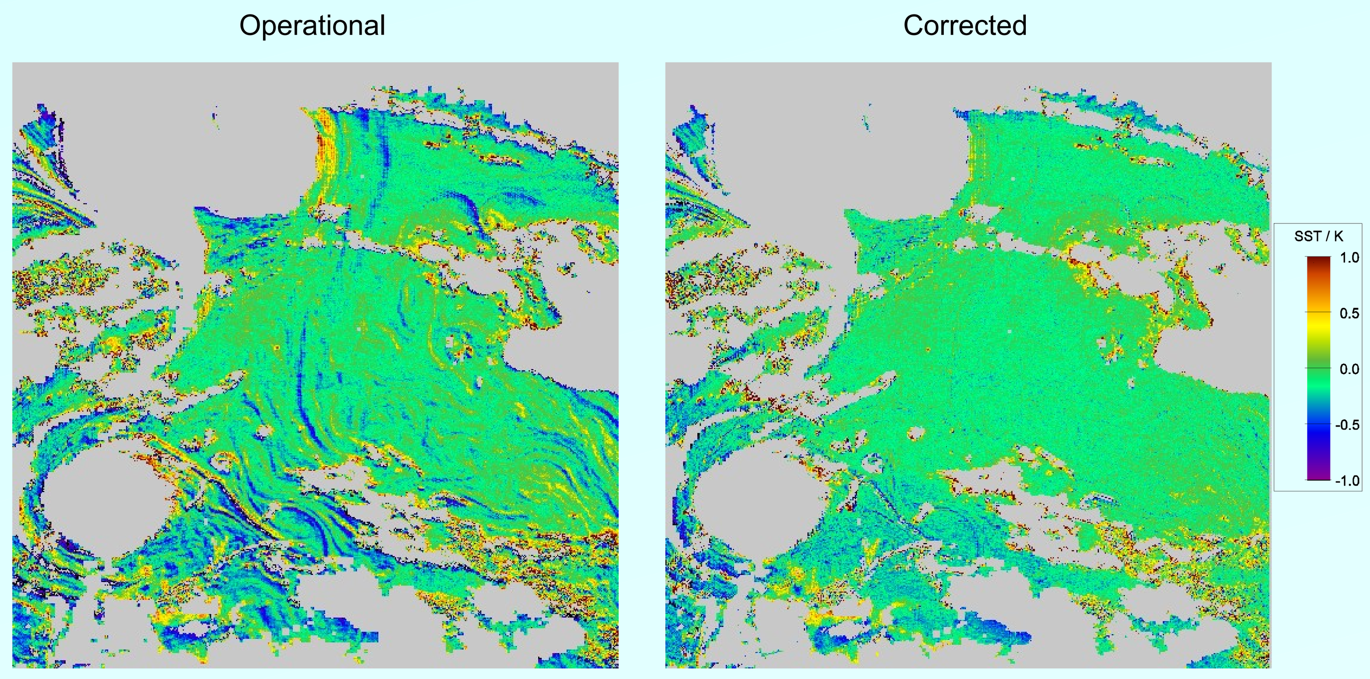


Figure 2. Difference between Dual view SST retrieval and Nadir only retrieval showing effect of forward view offset. Left – current state (2 pixel offset between views). Right – forward view offset corrected.
Operational cloud mask shown (incorrect flagging of ocean gyres, and failure to flag cloud edges)

Saharan Dust

Saharan dust outbreaks can cause biases upto 1 K in (A)ATSR SSTs and can affect large areas of the Atlantic Ocean and Mediterranean Sea. Previous work with Meteo France lead to the development of a night-time Saharan Dust Index (SDI) which can be used to both detect and correct Saharan Dust related biases.

This method has now been extended by the University of Leicester to function with (A)ATSR utilising the dual view capability to also operate during the day.

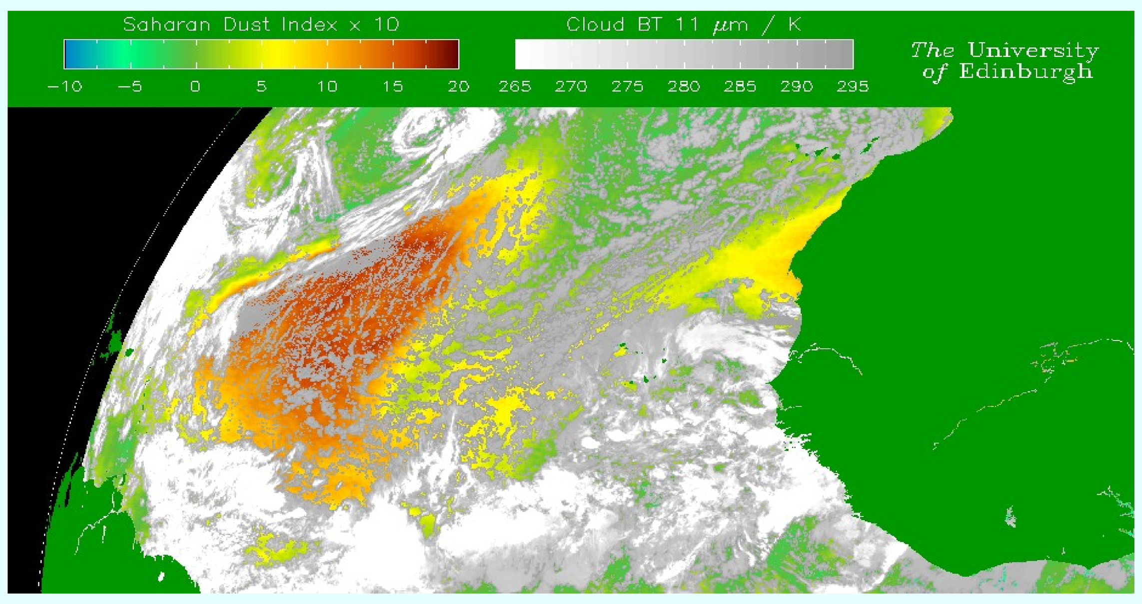


Figure 3. Saharan dust in night-time thermal imagery. C. Merchant, O. Embury, P. LeBorgne, B. Bellec, "Saharan dust in nighttime thermal imagery: Detection and reduction of related biases in retrieved sea surface temperature" Rem. Sens. Environ. 104(1), 15-30 (2006)

Geolocation

(A)ATSR pixels are geolocated to an absolute accuracy of ~1-2 km, while the relative accuracy between neighbouring pixels is much higher the relative accuracy between the two views is not. In the case of AATSR there is an approximate 2 km offset (both across and along track) between the forward and nadir views. Although this offset is not much larger that the size of a forward view pixel, it can lead to significant errors in the dual view retrieval as the two views are no longer observing the same footprint on the ocean surface.

In the presence of strong ocean fronts the relative offset can lead to artefacts >0.5 K. These can be seen in Fig. 2 which shows the difference between the dual view retrieval and nadir-only. Correcting the offset can eliminate these visual artefacts.

The forward view offset also impacts the spatially averaged SST product. Assuming a 16 km grid size, correcting the 2 km offset is equivalent to removing noise with a magnitude between 0.1 and 0.15 K.

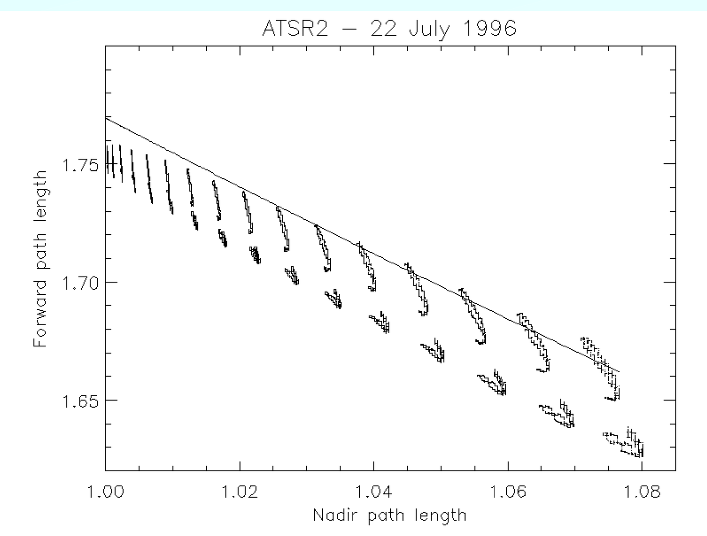


Figure 4. Assumed (solid line) and actual ATSR viewing geometry.

Viewing Geometry

Current (A)ATSR SST retrievals assume a fixed relationship between across track pixel number and satellite zenith angle (both forward and nadir views). Retrieval coefficients are calculated for 'centre' and 'edge' of swath and interpolated between using the (assumed) nadir path length. However in practice the relation changes throughout the satellites orbit as shown in Fig. 4.

The current method leads to biases in the Dual view retrieval ~0.1 K at night, and ~0.2 K during day. Fig. 5 shows the biases as a function of across track pixel number. The 'm' shape of the graph is due to the use of only two interpolation points for centre and edge, while the overall slope and variation with latitude is due to the assumption that the relation is fixed.

However by increasing the number of interpolation points and using the actual path lengths rather than across track pixel number, it is possible to reduce these biases to less than 0.001 K

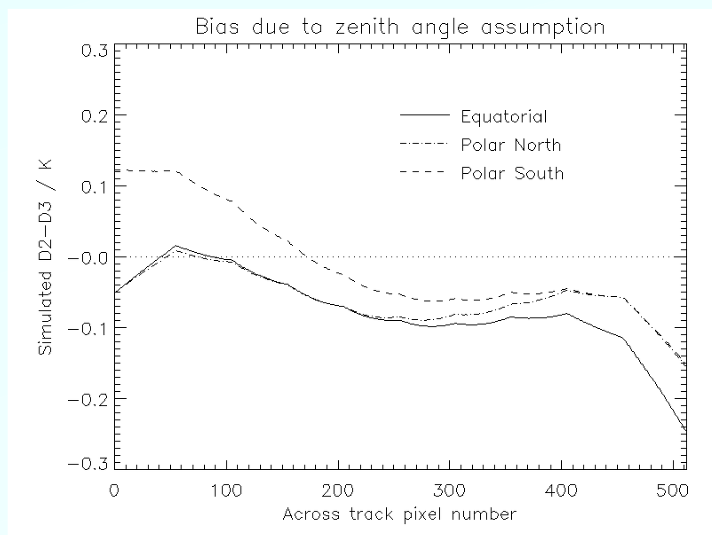


Figure 5. Biases due to viewing angle assumption.

Self Consistency

The AATSR mission up to end of 2007 was re-processed using a dedicated computer cluster located at the UK Natural Environment Research Council (NERC) Earth Observation Data Centre (NEODC). The input dataset comprises approximately 20,000 GB of L1B top-of-atmosphere Brightness Temperatures. The output is spatially averaged SST on a 0.1 degree grid.

Self consistency is asserted by comparing nadir-only and dual-view retrievals shown in Fig. 6. Along with improvements to the biases between dual and nadir SSTs, the new retrieval has significantly reduced the standard deviation from ~0.3 K to 0.15 K.

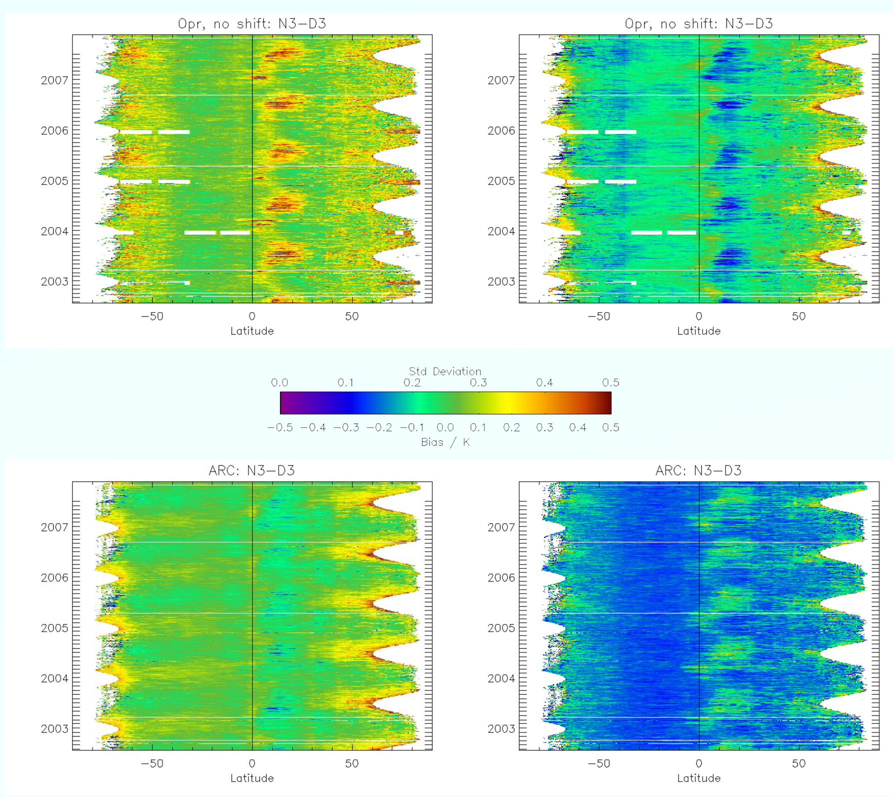


Figure 6. Nadir – Dual night time differences for operational retrieval (top) and (A)RC retrieval (bottom). Left column shows bias; right shows standard deviation.

Validation Using Buoys

Validation was also performed against co-located data from the Met Office Marine Data Bank. Plots of satellite retrieval – buoy measurement are shown in Fig. 7.

In all cases the new (A)RC retrievals show significantly reduced noise levels; especially in the dual-view retrievals (D2/D3) where standard deviations are reduced by more than 0.1 K.

The retrieval biases are also improved indicating that the new radiative transfer modelling is better. With the N2 bias now consistent with other retrievals.

Dual-view retrievals show reduced north-south bias due to new treatment of zenith angle. This is clearest in D3 which is least affected by prior and non-linearity error.

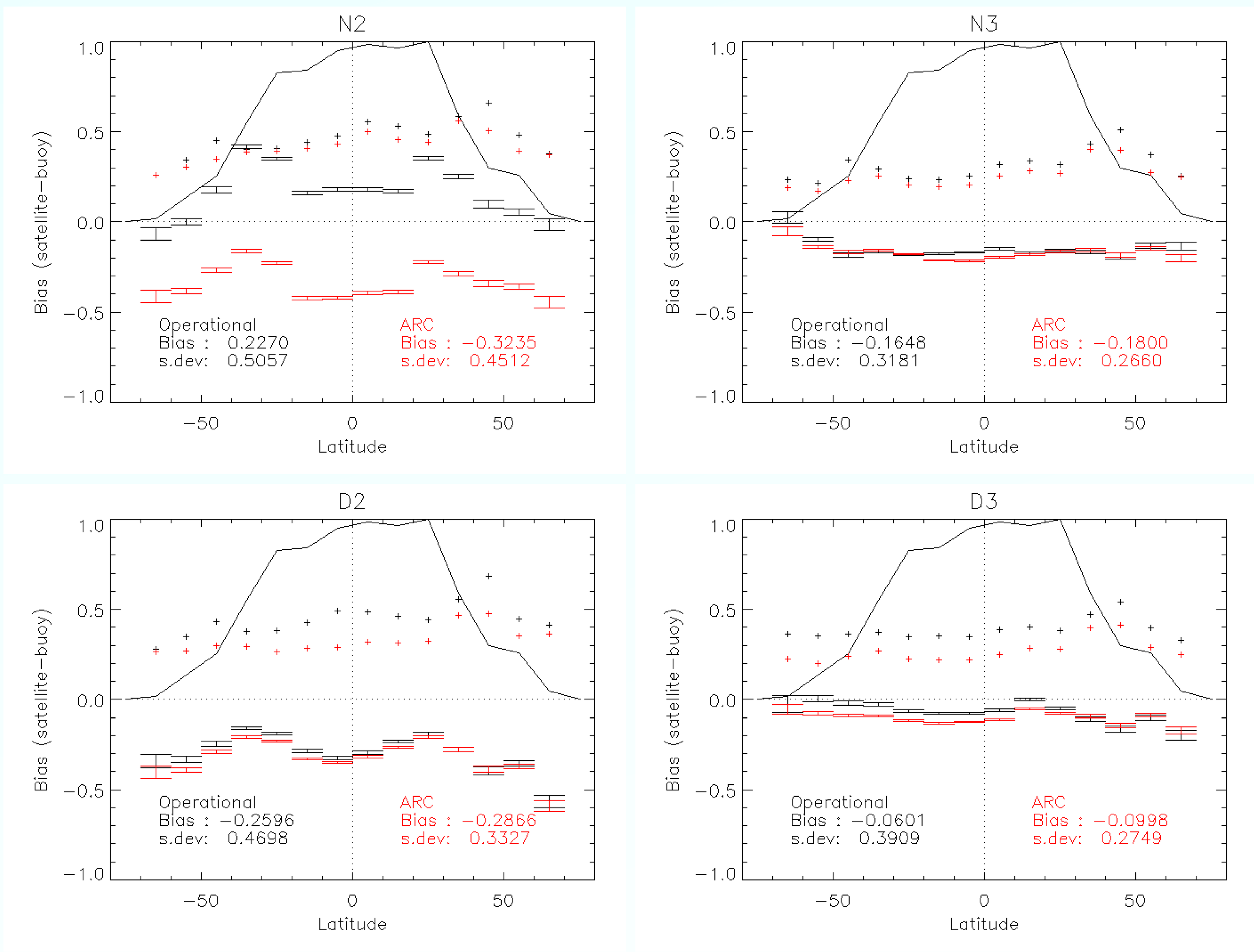


Figure 7. Validation against *in situ* buoy data plotted against latitude. Error bars show mean ± standard error in each bin. Crosses indicate standard deviation. Solid line indicates frequency distribution of data points.
NOTE – all data are night-time with no skin to bulk correction so expected bias is approximately -0.2 K