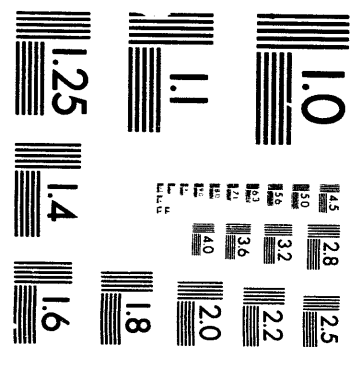

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BNL-49690
Conf-931023I--1

THE VALIDATION OF ATSR MEASUREMENTS WITH *IN SITU* SEA TEMPERATURES.

P. J. Minnett[1] and K. L. Stansfield[2]

[1]Oceanographic and Atmospheric Sciences, Brookhaven National Laboratory, P.O. Box 5000, Upton, N.Y. 11973-5000;
[2]Marine Sciences Research Center, State University of New York, Stony Brook, N.Y. 11794-5000

tel. (516) 282 5983
fax. (516) 282 3246
OMNET P.MINNETT
email minnett@bnl.gov

October 8, 1993

To appear in Proceedings of the Second ERS-1 Symposium, 'Space at the service of our environment', Hamburg, Germany, 11-14 October, 1993. To be published by the European Space Agency.

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Abstract

The largest source of uncertainty in the retrieval of SST (sea-surface temperature) from space-borne infrared radiometric measurements is in the correction for the effects of the intervening atmosphere. During a research cruise of the R/V *Alliance* measurements of sea-surface temperature, surface meteorological variables and surface infrared radiances were taken. SST fields were generated from the ATSR data using pre-launch algorithms derived by the ATSR Instrument Team (A.M. Zavody, personal communication), and the initial comparison between ATSR measurements and SST taken along the ship's track indicate that the dual-angle atmospheric correction is accurate in mid-latitude conditions.

Keywords: Infrared radiometry, ATSR, atmospheric correction, sea-surface temperature, shipboard measurements.

1. INTRODUCTION

During October and November, 1991, the NATO Research Vessel Alliance sailed from Amsterdam into the western Mediterranean Sea and during this time measurements were made for the validation of ATSR data. This reports the initial comparison between ATSR measurements and sea-surface temperatures (SSTs) taken along the ship's track by an *in situ* thermometer at a depth of about 3m.

2. ITINERARY

The ship sailed from Amsterdam on October 1 arriving at La Spezia on October 9. Apart from when the ship was in port from the 9 to 15 October, 18 October, and 21 to 24 October, measurements were made continuously until November 9.

The track of the ship for this period is shown in Fig. 1.

3. SHIP-BOARD INSTRUMENTATION

Measurements of sea-surface temperature, surface meteorological variables and surface infrared radiances were taken by a set of instruments mounted on the ship and logged by computers.

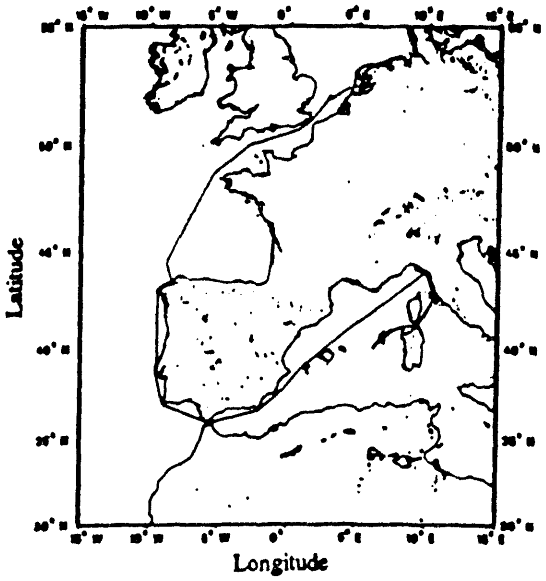

Figure 1. Track of the R/V Alliance, 1 October to 9 November, 1991.

The surface temperatures used here are from a Sea-Bird CTD (Conductivity-Temperature-Depth sensor) which was mounted through the hull so that it extended beyond the ship's boundary layer, at a depth of about 3m. It is acknowledged that these data are not ideal for the validation of ATSR as they may be decoupled from the true surface temperature by the skin effect and possible diurnal thermoclines, but at the time of writing they provide the temperatures in which I have most confidence. One minute averages of 1-second samples are used. At present, the data from the ship radiometer (R.A.L./S.I.L. type) are not ready for use, although it is anticipated that these will form the basis of a validation of ATSR using skin temperatures.

Atmospheric profiles of temperature and humidity were made using radiosondes, launched, when possible, so their ascents coincided with satellite overpasses when the sky was reasonably clear of cloud.

Latitude, longitude, ship's speed, heading (gyrocompass reading) and course made good derived by the ship's navigation computer were archived at int[illegible]als of about one minute.

4. ATSR ON ERS-1

The ATSR/M is a scanning four-channel infrared radiometer incorporating a two channel nadir-pointing microwave radiometer and is the first satellite instrument to have been designed for the accurate measurement of sea-surface temperature. (Refs. 1, 2). It uses the same infrared channels as the AVHRR (Advanced Very High Resolution Radiometer on the NOAA series of polar-orbiting satellites), but has a novel approach to the correction of the effects of the intervening atmosphere, in that the same 500 km swath of the ocean surface is measured twice through different atmospheric path lengths (Ref. 3). This information, coupled with the multichannel measurements, permits an improved atmospheric correction. In addition, rigorous pre-launch calibration (Refs. 4, 5), and improved internal black-body calibration targets (Ref. 6) enable a more accurate in-flight measurement, and detectors refrigerated to liquid nitrogen temperatures improve the signal to noise level.

5. ATSR DATA

Six scenes of level 1.5 (brightness temperature) data were provided by RAL from the period of this cruise. Of these, only two contain the position of the ship, at the time of the satellite overpass, under clear skies. One of these is a daytime overpass (October 2), and the other is at night-time (October 6). Note that the time taken for the ship to complete the track across the image is nearly one day and comparisons must be restricted to that part of the ship's track close to the ship's position at the time of the satellite overpass (Ref. 7).

5.1. Image navigation

The geographic location of individual pixels was calculated by bi-linear interpolation between the 25km grid provided in the image files. The accuracy of the grid was confirmed by overlaying coastal outlines; corrections were made where necessary.

5.2 Atmospheric correction

The pixels along the position of the ship's track were sampled to extract the ATSR measured brightness temperatures in the nadir and forward views at 10.8 μm and 12 μm. Plots of these, as a function of longitude are shown together with the -3m SST in Figures 2 and 3. SSTs were calculated from these brightness temperatures using coefficients calculated by Albin Zavody (ATSR Project, Rutherford Appleton Laboratory, U.K.), for both the nadir swath multichannel split-window algorithm and the dual-angle multichannel algorithm. The coefficients as supplied were applicable to 50-km wide subswaths symmetrically placed on each side of the sub-satellite track. These coefficients were used to generate values that change smoothly across the swath by a least-squares fourth-order polynomial fit. The resulting SST traces along the ship's track are shown in Figures 4 and 5.

Cloud free areas, about 50x50 km square, were selected in each scene and the differences between the nadir swath multichannel split-window algorithm and the dual-angle multichannel algorithm were calculated (Table 1). These are a function of the state of the atmosphere, and have mean values in excess of 0.5K. Drawing on the result of the comparison with the *in situ* measurements (see below), it is likely that the dual-angle multichannel algorithm produces a more accurate result.

Table 1. Discrepancies in SSTs between the nadir-only and dual-angle split-window retrieval in cloud-free areas.

	Boundary of box		ΔSST
	pixels	lines	mean ± 1 s.d.
October 2.			
	30: 89	150:209	0.670 ± 0.258
October 6.			
	10: 59	230:279	-0.439 ± 0.441
	110:159	110:159	-0.376 ± 0.213
	260:309	150:199	-0.426 ± 0.215
	235:284	245:294	-0.545 ± 0.276
	370:419	180:229	-0.404 ± 0.230
	450:499	420:469	-0.004 ± 0.325

6. DISCUSSION

As a consequence of cloud cover, and also of the relatively narrow swath of the ATSR, the number of usable coincidences of satellite and ship data is distressingly small.

6.1 General performance

The brightness temperature images are apparently free of instrumental noise. The temperature features observable in the ocean appear realistic and uncontaminated by instrumental effects.

6.2 Brightness temperatures

The traces of brightness temperatures along the ship's track appear to be entirely credible. The decreasing brightness temperatures with increasing wavelength and increasing atmospheric path length are as expected. The relative effects of the spectral brightness temperature gradient and the atmospheric path length gradient are different in the two cases reported here, due to the different atmospheric conditions on the two days. On October 2, the brightness

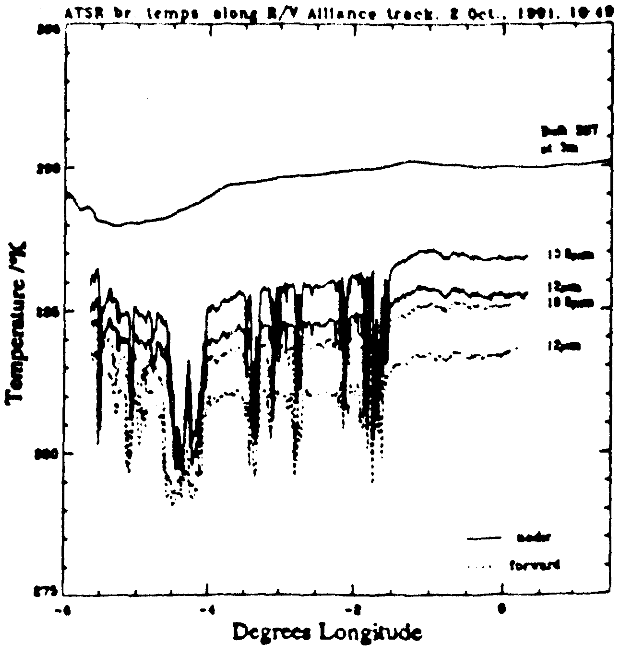

Figure 2. ATSR brightness temperature sections with the 3m *in situ* SST along the track of the ship for the image taken on October 2, 1991.

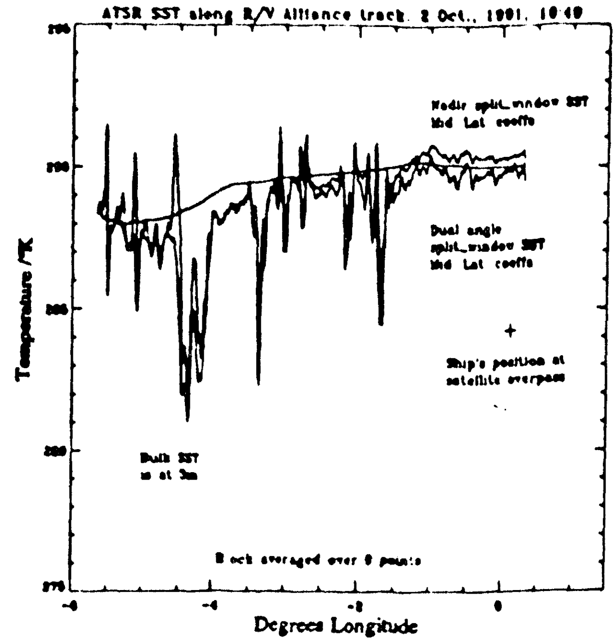

Figure 4. SSTs derived with the nadir split-window and dual-view split-window algorithms, smoothed by block averaging over 9 samples along the track. Mid-latitude atmospheric correction coefficients have been used. The 3m bulk temperature trace is also shown. The data are for the October 2 case.

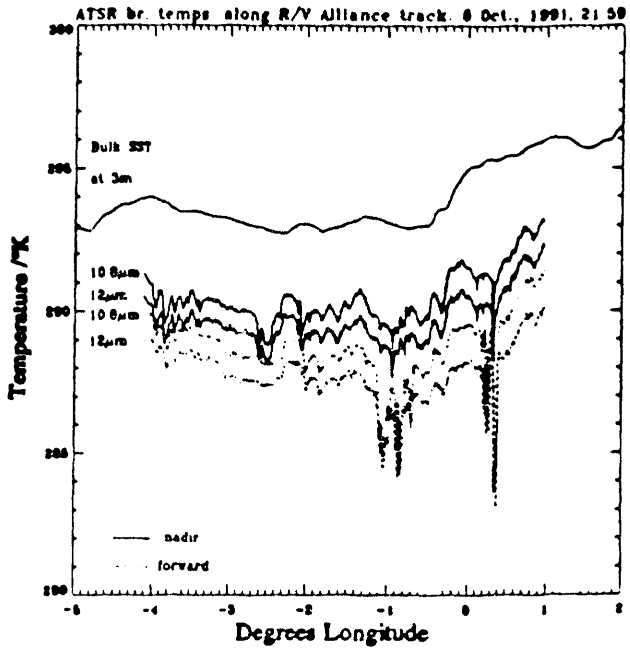

Figure 3. ATSR brightness temperature sections with the 3m *in situ* SST along the track of the ship for the image taken on October 6, 1991.

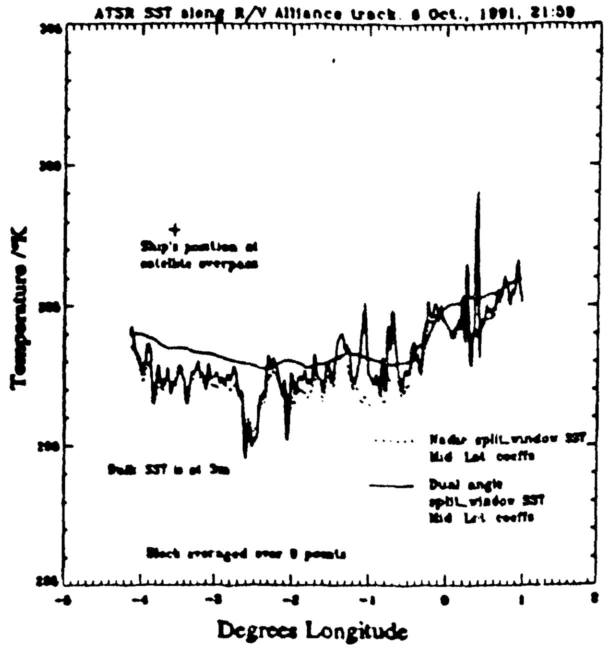

Figure 5. SSTs derived with the nadir split-window and dual-view split-window algorithms, smoothed by block averaging over 9 samples along the track. Mid-latitude atmospheric correction coefficients have been used. The 3m bulk temperature trace is also shown. The data are for the October 6 case.

temperature difference between the 10.8μm and the 12μm nadir measurements is comparable to that between the nadir and forward measurements at 10.8μm (Figure 2). Towards the west the atmospheric conditions change and the 10.8μm measurement becomes colder than that at 12μm at nadir. Towards the east, the radiosonde launched from the ship shows that the atmosphere was anomalously dry at mid levels, between 1 and 2 km height. On October 6 (Figure 3), the brightness temperature difference between the 10.8μm and the 12μm nadir measurements is only about half of that between the nadir and forward measurements at 10.8μm. The atmosphere was anomalously dry at higher levels, between 3 and 4 km height.

6.3 SST comparison

Comparison of ship SST and ATSR derived SST is encouraging. In the October 2 case, the split-window retrieval overcompensates the effect of the atmosphere and produces an SST retrieval that is warmer than the -3m bulk measurement (Figure 4). Given that the skin temperature is expected to be lower than the bulk temperature by a few tenths of a degree, the dual-angle SST retrieval looks to be very accurate indeed. The discrepancy between the two ATSR SST retrievals diminishes towards the west as the atmospheric conditions change. Note that the ship measurements can not be used to validate the satellite retrieval here because of the excessive time interval between the ship and satellite measurements. The comparison on October 6 does not show a clear advantage of the dual-angle retrieval (Figure 5).

The differences between the nadir-only and dual-angle SST retrievals can be significant (Table 1); it is presumed, but not demonstrated here, that the dual-angle retrieval is more accurate.

6.4 Noise levels in the SST fields

The nadir-only split-window SST images (not shown) are very clean and noise-free. The dual-angle split-window SST retrievals are significantly noisier than those derived from the nadir scans alone. This results from at least three effects: the SST is derived by the combination of four channels of information instead of two, and each channel contributes some noise to the retrieval; the coefficients in the dual-angle retrieval are larger than in the nadir-only retrieval and these magnify the noise levels; and the mismatch in the pixel sizes in the forward and nadir swaths. The last effect may be the most important, and is most readily corrected, as instead of mapping the forward view pixels into the nadir swath, which requires oversampling of the forward-view information, the nadir swath pixels could be mapped into the forward view image. Although this would lead to a loss of resolution it may reduce the noise level.

6.5 Effects of spatial averaging

Averaging the SST traces may produce a more stable estimate of the SST (Figure 6), but the standard deviation

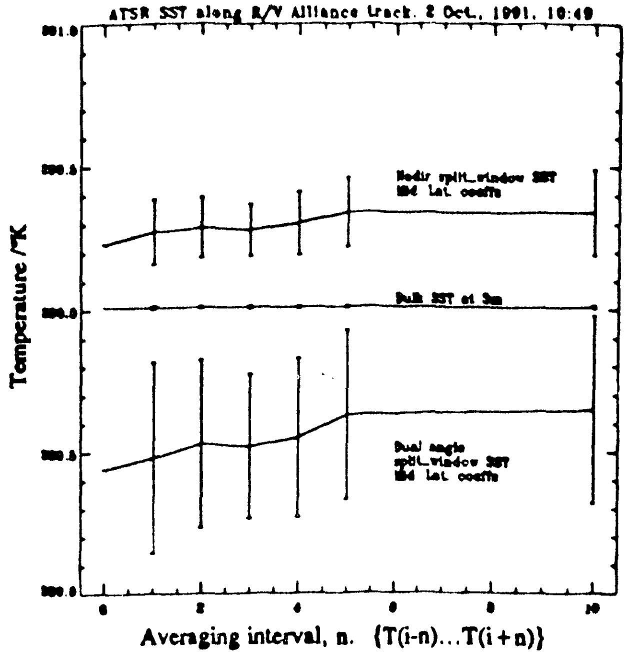

Figure 6. Effect on SST estimates of averaging along the track of the ship for the October 2 case. The error bars are the ±one standard deviation in the averaging interval.

of the derived SSTs is consistently higher for the dual-angle retrieval compared to the split-window retrieval, by about a factor of two.

6.6 Effects of clouds

The effects of clouds are more pronounced in the dual angle retrievals. This is an inevitable consequence of the parallax in the forward view measurements.

7. CONCLUSIONS

The ATSR is performing well, and the atmospheric correction coefficients derived by Albin Zavody appear to function very well, although the sample presented here is too small to draw firm conclusions.

The inclusion of the information of the dual view in the atmospheric correction can result in changes in the estimate of the SST by over 0.5K. While it is presumed that the dual-view retrieval is more accurate, that cannot be demonstrated with this small data set. More comparisons must be made to confirm the benefits of the dual-angle atmospheric correction technique.

The variance of the SST in a given area is greater when the SST field has been derived using a dual-angle atmospheric correction, than that when using the nadir-only atmospheric correction.

8. ACKNOWLEDGEMENTS

The support during the cruise of the ship's officers and crew and technical staff from the SACLANT Undersea Research Centre is appreciatively acknowledged. The ATSR data (©1991 by ESA and SERC) were provided by the ATSR Project Team at RAL. Support from the National Oceanic and Atmospheric Administration, Grant NA26GP0266-01, is acknowledged. This document was prepared under the auspices of the United States Department of Energy under Contract No. DE-AC02-76CH00016.

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