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Session 6

AATSR Validation
INTRODUCTION

The Advanced Along-Track Scanning Radiometer (AATSR) was launched on Envisat in March 2002. The AATSR instrument is designed to make precise and accurate global Sea-Surface Temperature (SST) measurements, which when added to the large data set collected from its predecessors, ATSR and ATSR-2, will provide a long term record of SST data (> 15 years) that can be used for independent monitoring and detecting of climate change. A description of the scientific aims and unique functionality of the AATSR instrument can be found in [1]. The data collected from the instrument is processed as part of the Envisat ground segment to Level 1b (calibrated, geolocated radiances) and Level 2 (geophysical products).

The AATSR instrument is self-calibrating, using two highly stable onboard blackbody reference targets for the thermal channels and an opal diffuser (illuminated once per orbit) for the visible and near-infrared channels. After launch, a three-month instrument-commissioning programme took place to confirm the instrument was performing nominally, as well as detailed algorithm verification of the processors used to produce the Level 1b and Level 2 products. The process of algorithm verification will be carried out throughout the lifetime of the AATSR instrument for long-term product assurance.

Validation of AATSR is defined as the assessment by independent means the quality of AATSR data products. Over sea, the primary product of AATSR is SST. Over land, because of the developmental nature of potential land products, namely Land Surface Temperature (LST) and NDVI, the primary product for validation purposes is considered to be top-of-atmosphere (TOA) visible and near infrared reflectances and thermal brightness temperatures. The objectives of the AATSR validation programme are therefore:

- To determine the accuracy of the global skin SST (± 0.3º C)
- To assess the accuracy of the AATSR data retrieved over land

This paper introduces the activities carried out so far in the validation of AATSR data, with the aim of providing assurance of data quality for applications such as climate change research.

An ideal validation programme is one in which in situ measurements are made of the parameters required for a) an end-to-end comparison between the geophysical quantity and its corresponding AATSR product and (b) for an analysis of any discrepancies between them (it will be difficult to carry out a proper analysis of SST results if information is not available, for example, on top of the atmosphere fluxes and atmospheric conditions such as water vapour content). Indeed, the ideal validation would be made over a range of sites and seasons, fully representative of conditions encountered by AATSR around the globe. For the purposes of the AATSR validation programme, such an ideal situation is labelled a Class 1 Validation. In total, three main classes have been defined, covering Class 1 (complete parameter set), Class 3 (reduced parameter set for point-to-point comparison only) and Class 5 (quality assurance). In addition two intermediate data sets, referred to as Class 2 (a mix of Class 1 and Class 3) and Class 4 (a mix of Class 3 and Class 5) are also defined. To date, the validation programme has been mainly Class 2; in the future it will be guided towards Class 1.

Whatever the level of validation, there must be confidence in the accuracy of the in situ measurements. Here, the emphasis is on the need for external, traceable calibration of all measuring equipment to ensure maximum exploitation of data obtained from validation campaigns. In addition to the evidence gathered from in situ campaigns, information from external sources (such as cross validation between satellites, use of analysis fields) and quality assurance using previously validated AATSR data products will be essential in gaining complete confidence in the AATSR data set.
SST VALIDATION

There are (effectively) two AATSR SST products that require validation: a gridded SST product referred to as ATS_NR__2P and a spatially averaged SST product, referred to as either ATS_AR__2P or ATS_MET_2P; the ATS_MET_2P is reduced Level 2 product in BUFR format specifically for meteorological users. The ATS_NR__2P product is imposed on a 1km grid, whereas the ATS_AR__2P product has cells of 10 arcmin (17km) or 30 arcmin (50km). Detailed information on these products and their content can be found in the AATSR product handbook [2]. It is the high resolution ATS_NR__2P product that is the primary geophysical quantity measured by AATSR. Validation of ATS_NR__2P product is therefore essential for validation of the AATSR instrument. For continuity with its predecessors, the ATS_NR__2P gridded product is also referred to as the GSST (Gridded Sea Surface Temperature) product and the ATS_AR__2P averaged product is also referred to as the ASST (averaged Sea Surface Temperature) product.

The AATSR instrument is sensitive to the temperature of the sea surface skin (the top few tenths of µm), which can differ from the bulk sea surface temperature (BSST) of the water just a few cm below the skin/surface by several tenths of a degree. Therefore, validation of the AATSR GSST product is carried out through comparisons with skin SST (SSST) measurements retrieved from high-precision radiometer measurements collected during in situ validation campaign. However, in certain circumstances (i.e. high wind speeds) BSST measurements can be used to add to the stock of data available for establishing the performance of AATSR, as it is believed that at sufficiently high wind speeds the skin effect breaks down [3]. The critical wind speed at which the skin effect becomes zero is a matter of much current debate, however most authors agree that at wind speeds of greater than 10 ms⁻¹ the skin effect can be considered negligible.

As other papers in these proceedings will show, four different radiometers have been used so far in the validation of the GSST product. The radiometers are the DAR011 operated by Ian Barton of CSIRO (Australia), the ISAR operated by Craig Donlon and Ian Robinson from SOC (UK), the M-AERI operated by Peter Minnett of the University of Miami (USA) and SISTeR operates by Tim Nightingale of RAL (UK). The precision and accuracy of each instrument is extremely important and should be traceable to a known standard radiometric standard. The radiometers were recently inter-compared with each other during the Miami Radiometer Intercomparison [4], the outcome being that no radiometer differed from any other radiometer by more than 0.1 K, as required for AATSR validation [5].

The ideal scenario is for observations to be made precisely at the time of overpass and directly under the satellite track. Observations outside this coincidence limit will introduce some additional error into the validation data set. For example, observations in the southern Norwegian Sea have shown that spatial separations of about 10km and time intervals of about 2 hours can introduce r.m.s. differences of 0.2K into the error budget of a satellite validation dataset [6]. The exact amount of error introduced by sampling away from overpass will vary according to the local conditions. In frontal regions the variability could be several degrees over just a few km, whereas in more stable regions the variability will be much less. In the case of the Norwegian Sea study [6], the measurements were made in a highly dynamic area, which will tend to promote large temporal and spatial errors. Validation match-ups observed away from exact coincidence will therefore require justification according to the local conditions before being included in the complete AATSR validation data set.

In addition to the validation of GSST products, validation of ATSR ASST products will provide essential information on the performance of the AATSR instrument. Many of the early errors in SSTs produced from ATSR and ATSR-2 data were detected using systematic comparisons with buoy data and SST analysis fields. This is a good method of detecting gross errors in SST at an early stage, and is advantageous in that it can be carried out at a global scale and without field data collection campaigns since the buoy data are provided operationally in an autonomous manner. A team from the UK Met Office (Anne O’Carroll, Lisa Horrocks, Roger Saunders and James Watts) has been validating the AATSR METEO product since its availability on the 19th August 2002. Since then, they have collected a very large data set of over 8500 match-ups. The University of Leicester and the UK Met Office have been comparing AATSR SST data with data from ATSR-2, MODIS, AVHRR, TMI and ECMWF analysis over long time periods. The comparisons between datasets are made of monthly mean SST data at half-degree resolution. Monthly mean datasets for AATSR data are calculated as the mean dual view SST from all available data (day and night) from the ASST product. Outputs from the comparisons include global and regional scale (as specified by the user) difference images, statistics and temperature difference distribution plots. Given a time series of data, changes in temperature difference between datasets can also be plotted and analysed.
VICAROUS VALIDATION OF VISIBLE REFLECTANCES

Vicarious validations of measured TOA radiances from AATSR’s visible and near infrared channels (0.55µm, 0.67µm, 0.87µm and 1.6µm) are carried out over stable land sites and over cloud. Several groups, including Dave Smith from RAL, Olivier Hagolle from CNES and Fred Prata from CSIRO are comparing AATSR and MERIS TOA reflectances over a range of desert regions and the Greenland ice sheet and are monitoring the long-term stability of the two instruments. This will lead to a robust characterisation of the in-orbit performance of the instruments and the on-board calibrators; similar spectral channels on AATSR and MERIS enables direct comparisons of two instruments on the same orbiting platform to be made. In addition, the AATSR ad MERIS reflectances are inter-compared with reflectances from other sensors such as ATSR-2, AVHRR, POLDER and SeaWiFS. A range of desert sites with stable and well-known surface characteristics is used. The BRDF of the desert sites is initially characterised using field equipment and through bi-directional TOA measurements from other sensors. Finally, Brian Kerridge from the Rutherford Appleton Laboratory has been comparing AATSR with ATSR-2, GOME and SCIAMACHY.

VALIDATION OF AATSR LAND SURFACE TEMPERATURE

Part of the AATSR validation programme to date has been devoted to a prototype Land Surface Temperature (LST) product. The Level 2 gridded product (ATS_NR__2P) produced by the ENVISAT payload data segment does not currently contain a LST. It has a placeholder for such a value over land but at the current time, this field contains the 11 µm brightness temperature over land. Fred Prata from CSIRO has proposed a prototype AATSR LST retrieval [7], and during the ENVISAT Commissioning Phase, this retrieval is to be tested in the AATSR Prototype Processor. Following an initial evaluation of the prototype retrieval, a decision was made to add the retrieval to the Operational Processor used in the ENVISAT payload data segment, sometime in early 2004. It should be noted that at present, there would be no spatially averaged LST retrieval. This will be considered once the retrieval in the 1 km product has been optimised. Prototype LST retrievals are currently being validated over Australia (Fred Prata, CSIRO), Greenland (Julienne Stroeve, University of Colorado) and Spain (Cesar Coll and Jose Sobrino, University of Valencia). In addition, Lake surface temperature, which is considered to be a type of Land surface rather than sea surface owing to topological effects on the retrieval, is validated over Lake Tahoe in the USA (Simon Hook, JPL).

RESULTS

The results of the AATSR validation campaign collected so far are reported in other papers presented in these proceedings of the MAVT 2003 workshop and in the proceedings of the Envisat validation workshop that took place in December 2002 [8].

SUMMARY

A comprehensive validation programme for AATSR has been underway since May 2002. So far, an initial validation phase has been completed and has shown that the AATSR instrument is performing well and that the Level 2 geophysical products are within specification.

ACKNOWLEDGEMENTS

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REFERENCES


One Year's Validation of AATSR
Overview and highlights

David Llewellyn-Jones
AATSR Principal Investigator
Space Research Centre
University of Leicester, UK
AATSR data

September 2002

October 2002

Validation Workshop, 9-13th December 2002, ESRIN

University of Leicester
AATSR Validation – Overview & Highlights

- Requirements and General Approach
- Current status of overall programme
  - Reflectance measurements and MERIS Inter-comparisons
  - The new Land Surface Temperature Product
  - SST Validation
- Conclusions and future priorities
General Requirements

- *In situ* surface-leaving radiance measurements needed to establish ultimate accuracy of retrieval scheme
- In fact the atmospheric correction is the main ‘product’ we are formally validating
- Coincident Atmospheric profile information important for testing atmospheric corrections independently
- Error budgets needed for in situ measurement process
General Requirements

- Measurements of surface parameters e.g. soil temperature, bulk water temperature, canopy temperature etc. are not part of the formal level 2 validation.

- **But** – they are scientifically important – also needed by many users.

- They are often the recognised temperatures for those users.
Current status of overall programme

- Approx 15 data-collection projects have provided results
- Generally excellent accuracies established over land and sea, within specification
- Residual biases found in SST values, some global some reflecting regional differences
- Interesting and encouraging comparisons with data from other sensors
Validation of Reflectance – some highlights –

- Inter-comparison with MERIS show agreement within ~3%
- These are totally independent sensors viewing simultaneously from same platform
- Cloud-top measurements indicate AATSR reflectance's are correct within 2%
- Some issues concerning comparisons with other sensors
AATSR Land Surface Temperature

- New AATSR Product from ESA – due for implementation in next IPF update (Nov 2003??)
- Split-window nadir-only algorithm (Prata)
- Regional and seasonal retrieval coefficients, depending on surface type and atmospheric climatology – 14 surface types
- ‘Lake’ is one surface type
- Target accuracy – better than 1°C
AATSR Land Surface Temperature

- Validation results so far from 9 land sites and from Lake Tahoe (10 of 14 surface types covered)
- Results show good performance of algorithms under conditions tested
- Lake Tahoe results show interesting comparisons with MODIS lake product
- Need for validation data for all 14 surface types represented
AATSR - Requirements for SST Validation

- Demanding accuracy in SST – better than 0.3°C globally, with a ‘highest accuracy target’ of 0.1°C
- Therefore must be able to verify the accuracy globally
- Global validation requires representative seasonal and geophysical variation in observing sites
- Must be able to achieve higher levels of accuracy in selected areas
From the AATSR Performance Requirements:

“The AATSR instrument and ground processing system shall be able to produce SST retrievals routinely with an absolute accuracy of better than 0.3K (1-sigma limit) globally when averaged over areas of 0.5° longitude by 0.5° latitude, provided that >20% of samples within each area are cloud-free, with absolute accuracies close to 0.1K to be expected under certain favourable conditions.”

“The AATSR instrument and ground processing system shall be able to produce SST retrievals routinely to give SST for cloud-free samples to a relative accuracy of at least 0.3K (1-sigma limit) for all samples.”
AATSR - General Approach to SST Validation

Three levels:

1) Continuous checks of global fields by inter-comparison with drifting-buoy data and analysis fields, or data from other satellite sensors

2) Continuous Autonomous radiometric measurements of SST from ship-borne platforms

3) High-precision radiometric measurements at selected sites
SST Validation - some highlights

- UK Met Office, one year of near-continuous comparisons of global SST fields with \textit{in situ} buoy data (O’Carroll, Horrocks, Watts \textit{et al})

- Autonomous systems, namely ISAR (Donlon), MAERI (Minnett) demonstrated and produced high-accuracy data

- Precision \textit{in situ} radiometer samples from Indian Ocean (Nightingale) and from Gulf of Carpentaria (Barton)
AATSR Global Buoy Matchups

- Very consistent acquisition rate over one year – ~ 6,600 matchups
- Closest agreement between AATSR skin and buoy (bulk) values - unexpected
- This could suggest AATSR SST values could be warm by ~ 0.2°K

Where do these biases come from?
- Matchup RMSD values (~0.3- 0.4K) are consistent with expected buoy uncertainties
- Day/night differences are Very small
- Regional analyses under way
Distribution of matchups – ‘typical week’
Radiometric measurements

- Autonomous systems (Donlon, Minnett) successfully demonstrated

- Other systems (Nightingale, Barton) have produced high-quality matchups

- 30 Matchups with well-calibrated radiometers

- Small discrepancies and biases (positive and negative) can be seen. These are different for day and night – and may be regional in origin
Global comparisons with other sensors

- MODIS, AVHRR and (A)ATSR produce single view SST using near-identical channel wavelengths.

- Inter-comparisons with (A)ATSR dual-v-view SST show power of along-track scanning – essential for accurate SST in presence of aerosol.

- TMI (TRMM microwave Imager) uses microwave channels and is unaffected by aerosol.

- All inter-comparisons show biases – AATSR cooler – skin/bulk difference?
ATSR - AVHRR - 2 years' data
ATSR2 SST (dual-nadir) vs TOMS Aerosol Comparison
AATSR – TMI  *(TMI measures warmer)*  

One month’s data – Sept 2002
Conclusions and future priorities

- Excellent first year of results show AATSR can meet its specifications and data can be recommended for wide distribution
- Some problems require further attention—notably residual biases in SST
- Need for targeted regional campaigns in SST and in LST (to cover all classifications used)
- Global monitoring and autonomous systems required to detect drift
Acknowledgments are due to

• DEFRA, the UK Department of Environment, Food and Rural Affairs, who funded AATSR to support their programme of climate prediction and research, which in turn provides inputs to their policy-making processes

• Funding agencies in Australia and from NERC, the UK Natural Environment Research Council who made significant contributions

• The University of Leicester Physics Department Student Project programme

• The AATSR Validation team world-wide

• ESA for ENVISAT and associated support to the AOP
THE GLOBAL LAND SURFACE TEMPERATURE PRODUCT FROM ENVISAT'S AATSR: DESCRIPTION, VALIDATION AND APPLICATIONS

Dr Fred Prata, CSIRO Atmospheric Research, Australia
Dr Marianne Edwards, University of Leicester, UK.

With contributions from:
Dr Simon Hook, JPL, Dr Julienne Stroeve, U of Colorado, Dr Jose Sobrino, U of Valencia, Dr Cesar Coll U of Valencia, Dr Folke Olesen,
Summary of Presentation

The LST Algorithm

The Validation Protocol

• Detailed field campaigns (in progress)
• Continuous field site observations
• Global 1x1 degree match-ups
• Intercomparisons with other satellite instruments

Results from Uardry, Amburla, Thangoo & Tahoe

Results using NCEP data for other global regions (e.g. Borneo, Spain, Greenland, Sahara)

MODIS comparisons

Conclusions
AATSR LST Algorithm

- Regression based
- Global
- Uses 13 land surface types (emis. surrogate)
- Land cover fraction at 0.5° x 0.5° resolution
- NVAP water vapour
- Global 1 km DEM
Regression Algorithm

LST = a(f,pw,i) + b(f,i) (T_{11}-T_{12})^n + [b(f,i)+c(f,i)] T_{12}

\[ a(f,pw,i)=d_i[sec(\theta) - 1]pw + f a_{v,i} + [1 - f ] a_{s,i} \]

\[ b(f,i) = f b_{v,i} + [1 - f ] a_{s,i} \]

\[ c(f,i) = f c_{v,i} + [1 - f ] c_{s,i} \]

11,12 refer to 11 µm and 12 µm AATSR channels
\( a,b,c \) = regression coefficients
\( pw \) = precipitable water
\( f \) = fractional vegetation cover
\( i \) = land class number (1-14)*


Friday, March 26, 2004

MAVT Workshop
AATSR LST Algorithm – Validation Results

Global Land Type Classification Map

Greenland: Type=13
Kamchatka: Type=10
Tahoe: Type=14
Sahara: Type=11
Borneo: Type=1

Amburla -> 7
Thangoo -> 6
Uardry -> 9
The Validation Protocol

• Detailed comparisons with in situ radiometers at several field sites

• Global comparisons using NCEP data

• Cross-validation with other satellites (e.g. MODIS, ADEOS-II)

• Intensive field work at field sites in collaboration with other researchers
AATSR LST Algorithm – Validation Results

CIGSN Sites

Thangoo

Amburla

Hay

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MAVT Workshop
Uardry Field Site, Hay, NSW
AATSR LST Algorithm – Validation Results

Friday, March 26, 2004

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Thangoo field site
Broome, WA

Friday, March 26, 2004

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Friday, March 26, 2004

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Amburla Field Site

Atmospheric Research
20.4.1999

CSIRO

Thangoo Scanning Radiometer

Uardry Tower Radiometers

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# LST Validation sites and key contacts

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of Products</th>
<th>Investigator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tahoe</td>
<td>15</td>
<td>Simon Hook</td>
</tr>
<tr>
<td>Uardry</td>
<td>9</td>
<td>Fred Prata</td>
</tr>
<tr>
<td>Amburla</td>
<td>16</td>
<td>Fred Prata</td>
</tr>
<tr>
<td>Thangoo</td>
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<td>Fred Prata</td>
</tr>
<tr>
<td>Borneo</td>
<td>3</td>
<td>Fred Prata</td>
</tr>
<tr>
<td>Spain</td>
<td>7</td>
<td>Cesar Coll</td>
</tr>
<tr>
<td>Kamchatka</td>
<td>2</td>
<td>Fred Prata</td>
</tr>
<tr>
<td>Greenland</td>
<td>7</td>
<td>Julienne Stroeve</td>
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<tr>
<td>Finland</td>
<td>3</td>
<td>Jose Sobrino</td>
</tr>
<tr>
<td>Sahara</td>
<td>21*</td>
<td>Fred Prata</td>
</tr>
</tbody>
</table>

*L1b data only. Processed to LST using CSIRO processor*
LST Product for Uardry, NSW

Grid cell mean=287.06K
Grid cell s.d. = 1.89K

HOME
Grid cell mean = 307.37K
Grid cell s.d. = 2.53K

LST Product for Amburla, NT
AATSR LST Algorithm – Validation Results

Grid cell mean=309.16K
Grid cell s.d. = 2.18K

LST Product for Thangoo, WA

Grid-cell problem near coastal boundaries now resolved
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LST Product for Greenland (J. Stroeve)

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Grid cell mean = 289.34K
Grid cell s.d. = 1.62K

Lake Tahoe

LST Product for lake Tahoe (S. Hook)
AATSR LST Algorithm – Validation Results

LST Product for Finland (J. Sobrino)
AATSR Validation at Uardry, NSW.

Mean (radiometer-AATSR) = +0.2 K
Std. Dev. = ±0.9 K

Bottom panel: NCEP analyses
(see later)
AATSR Validation at Amburla, NT.
Lake Tahoe validation site (Simon Hook)

- Net Radiation
- Solar Panel
- Air Temperature and Relative Humidity
- Skin Temperature
- Power Supply
- Bulk Temperature

Dimensions: 2.4 m
# AATSR Validation at lake Tahoe

<table>
<thead>
<tr>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period Evaluated</td>
</tr>
<tr>
<td>Minimum scene temperature</td>
</tr>
<tr>
<td>Maximum scene temperature</td>
</tr>
<tr>
<td>Number of Acquisitions</td>
</tr>
<tr>
<td>Number of cloudy scenes</td>
</tr>
<tr>
<td>Number of blank scenes</td>
</tr>
<tr>
<td>Number of matchups</td>
</tr>
<tr>
<td>AATSR LST Accuracy (bias)</td>
</tr>
<tr>
<td>AATSR LST Precision</td>
</tr>
<tr>
<td>AATSR LST Uncertainty</td>
</tr>
</tbody>
</table>
Global validation using NCEP data

- Re-analysis - independent data source
- 1x1 degree resolution
- 6-hourly
- ‘Surface temperatures’
- Global
Air temperature can be used to validate LST globally at night

Air temperature and surface temperature are almost the same at night
Sampling problem with NCEP data

AATSR LST retrievals

Sahara, 30 to 31°N 0 to 1°E. NCEP 1° x 1° (4x daily) Surface Temperatures, 15-Sep to 21-Nov 2002.
Greenland, 71 to 74 °N -44 to -34 °E. NCEP 1° x 1° (4x daily) Surface Temperatures

Bias = 0.23K
Standard deviation = 1.36K
AATSR LST Algorithm – Validation Results

NCEP comparisons for Spain
### Summary of Global NCEP comparisons

(Nighttime only)

<table>
<thead>
<tr>
<th>Site</th>
<th>Bias NCEP-AATSR (K)</th>
<th>St.dev (K)</th>
<th>Range</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>Amburla</td>
<td>+1.4</td>
<td>3.2</td>
<td>280-300</td>
<td>7</td>
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<tr>
<td>Uardry</td>
<td>+1.3</td>
<td>1.9</td>
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<tr>
<td>Thangoo</td>
<td>−0.5</td>
<td>2.5</td>
<td>290-300</td>
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<td>not enough data</td>
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<td>1.4</td>
<td>240-260</td>
<td>13</td>
</tr>
<tr>
<td>Spain</td>
<td>+0.2</td>
<td>3.1</td>
<td>270-290</td>
<td>12</td>
</tr>
</tbody>
</table>
Intercomparisons with MODIS

Uardry radiometers

Demonstrates that there is no bias in the Uardry radiometer data. Can use data to compare AATSR and MODIS LST products - cross-validation
AATSR LST Algorithm – Validation Results

Uardry Tower Radiometers - Hay, NSW, Australia. 22/09/01

- Nadir view \[T_s=306.77K\] s.d.=0.83K
- 30 degree view \[T_s=305.23K\] s.d.=0.84K
- 55 degree view \[T_s=304.57K\] s.d.=0.98K
- Air temperature (15 m)

Temperature (°C)

Time (hours)

MODIS-Terra overpass
## AATSR LST Algorithm – Validation Results

### Uardry Intercomparison with MODIS/Terra

<table>
<thead>
<tr>
<th>Date/Time</th>
<th>MODIS</th>
<th>Uardry radiometers</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>µ</td>
<td>σ</td>
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<tr>
<td>Year Mon Day Hr Mn Ss</td>
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<tr>
<td>2000 03 27 00 41 48</td>
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<td>2000 07 01 00 41 31</td>
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<td>2000 08 02 00 40 27</td>
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<td>2000 10 05 00 40 10</td>
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<td>2001 09 22 00 32 19</td>
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</tr>
</tbody>
</table>

- **Nadir** Bias = +0.51 K S.d. = ±1.35 K
- **30 degrees** Bias = −0.54 K S.d. = ±1.04 K
Conclusions

• Validation at Australian sites and at Lake Tahoe show that the regression algorithm is working within specification.

• Validation using NCEP data suggests that the global coefficients are delivering surface temperatures within ±2 K over the range 240-300 K. More data are needed.

• Intercomparisons with MODIS not complete, but we expect AATSR to perform better.

• Lake surface temperature coefficients working well.

• Cloud flag over land is a problem.
Validation of AATSR Land Surface Temperature Product at Lake Tahoe CA/NV, USA

Simon J. Hook & Fred J. Prata
Agenda

• Location of study site
• Study site instrumentation
• Period validated and data issues
• Validation procedure
• Results
• Cross comparison with MODIS
• Conclusions.
Measurements at each Buoy

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Manufacturer</th>
<th>Model #</th>
<th># of sensors</th>
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Cross Comparison of Radiometers at Miami
Cross Comparison of Radiometers at Miami

Date and Time (GMT)

Temperature (°C)

- JPL - kinetic
- salinograph (D)
- Hard Hat (E)
- DAR011 (F)
- MAERI (H)
- SISTer (I)
Means and standard deviations of the estimated skin SST differences between pairs of radiometers for the entire cruise period, and for each half of the cruise

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<tr>
<th>Radiometer Pair</th>
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<td>Std.Dev (K)</td>
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<td>0.114</td>
<td>148</td>
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Period Validated and Data Issues

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<th>Matchups</th>
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<tr>
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<td>10</td>
<td>3</td>
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<tr>
<td>August</td>
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<td>September</td>
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<tr>
<td>October</td>
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<table>
<thead>
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<tr>
<td></td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>65</td>
</tr>
</tbody>
</table>

- Blank scenes continue to be delivered, occasionally with matching complete scene e.g. July 03.
- Data delivery is inconsistent, some months complete others no data. Majority of data for winter.
- Radiometer problems in Jan-Mar prevented validation of the few clear scenes.
Validation Methodology

• Hook and Prata used Lake Tahoe site with ATSR2 to develop regression coefficients for retrieving water skin and bulk temperatures. Algorithms were developed for two channel case, day and night (Hook et al. 2003).

• Regression coefficients used in AATSR LST algorithm for water bodies. Two channel day and night skin temperature algorithm was implemented.

• Validation involved extracting pixels from AATSR data over buoys at Lake Tahoe site and using coefficients to derive skin temperature which was then compared with the measured skin temperature.
Difference between AATSR LST and Vicarious Skin Temperature at Lake Tahoe
CA/NV CY 2002-2003 (Split-Window Eq. For Full Dataset)
Difference between AATSR LST and Vicarious Skin Temperature at Lake Tahoe
CA/NV CY 2002-2003 - Night Only (Split Window Eq. for Full Dataset)

Delta Temperature

Overpass Date

Night
Difference between MODIS LST (MOD011) and Vicarious Skin Temperature at Lake Tahoe CA/NV CY 2000-2002 v2.4.1, v3.0.1, v3.1.4, v4.0.0

Overpass Date

MOD011 - Vicarious skin temp.
Difference between MODIS Products (MOD02 and MOD11) and Vicarious Measurements at Lake Tahoe CA/NV CY 2000-2002

- Delta skin temperature (MOD011 - Vicarious)
- Delta at sensor brightness temp. (Vicarious - Band 31)
Results using Hook et al. 2003 equations

<table>
<thead>
<tr>
<th>Dataset and Errors</th>
<th>Equation Form</th>
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<th>Split Window</th>
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<tr>
<td></td>
<td>Ts=a + b<em>T11 + c</em>T12</td>
<td></td>
<td>Ts=T11-b(T11-T12) + c</td>
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<tr>
<td><strong>Day and Night Equation (full dataset)</strong></td>
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<tr>
<td>Bias (predicted minus measured)</td>
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<tr>
<td>Precision (predicted minus measured)</td>
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<td>99</td>
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<tr>
<td><strong>Day only Equation (day dataset)</strong></td>
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<td>Bias (predicted minus measured)</td>
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## Summary

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<td>Number of blank scenes</td>
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</tr>
<tr>
<td>Number of matchups</td>
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<td>AATSR LST Accuracy (bias)</td>
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<td>AATSR LST Precision</td>
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<td>AATSR LST Uncertainty</td>
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<td>MODIS LST Accuracy (bias)</td>
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<td>MODIS LST Uncertainty</td>
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</tbody>
</table>

* MODIS precision calculation method differs from AATSR
Future work

• Have not received a full year of data. Data sent primarily from winter months. Need full year of data to maximize number of matchups.
• Certain scenes are blank (empty). Problem identified but not resolved. Some of blank scenes supplied as blank and as complete scene (different processors?).
• Need to compare MODIS LST algorithm and AATSR algorithm using same processing methodology.
Status of the Operational AATSR Land Surface Temperature Product

Andrew R. Birks

Working Meeting on MERIS and AATSR Calibration and Geophysical Validation

ESRIN, Frascati
2003 October 23
Simple Outline of Algorithm

• Basic algorithm for LST retrieval:
  \[ LST = a_0 + b_0 T_{11} + c_0 T_{12} \]  
  (1)
  where
  – \( a_0, b_0 \text{ and } c_0 \) are the retrieval coefficients
  – \( T_{11} \) is the 11 micron nadir view brightness temperature
  – \( T_{12} \) is the 12 micron nadir view brightness temperature

• In practice, to allow additional tuning of the algorithm, Equation (1) is replaced by
  \[ LST = a_0 + b_0 (T_{11} - T_{12})^n + (b_0 + c_0)T_{12} \]
  \[ n = 1 / \cos(\theta / m) \]  
  (2)
  where \( \theta \) is the zenith angle of observation, and \( m = 5 \)
  \( E\text{qn. (2) reduces to } E\text{qn. (1) when } n = 1 \)
Retrieval Coefficients

- Retrieval coefficients $a_0, b_0, c_0$, depend on surface characteristics and atmospheric water vapour via look-up tables.
- For each cell of dimension $0.5\degree \times 0.5\degree$, tables define:
  - Surface classification. The cell is assigned to one of 14 surface types, represented by an integer in the range 1 to 14.
  - Vegetation fraction $f$ ($0 \leq f \leq 1$). Seasonal variation is represented by 12 values of $f$, one for each calendar month.
  - Monthly mean precipitable water $pw$ at the centre of the cell. Again 12 monthly values are given to represent the seasonal variation.
- Four sets of regression coefficients $a, b$ and $c$ (vegetation / soil, day / night) are specified for each surface type.
Extended Reference Processor

- This LST algorithm has been implemented in a version of the Level 2 Reference Processor (the Extended Reference Processor)
  - 2 channel regression on 11 and 12 micron channels
  - Coefficients depend on surface type and season via LUTs
- Implemented for full resolution (GST) product only
  - Implementation for AST not added at this stage owing to resource limitations
- Principal modifications to L2 processor
  - Addition of interpolation of satellite elevation
  - Input of extended LUTs
  - LST calculation for clear land pixels if LUTs supplied
- Used for validation during commissioning phase

Andrew R. Birks
MAVT-2003
Testing of ERP

• System Testing: 10 tests including
  – Correct implementation of LST in nadir field
  – Agreement with RP where unchanged (AST product)
  – Backwards compatibility when LST auxiliary file not supplied
  – Performance

• Acceptance testing
  – Based on subset of system tests supplemented by comparisons with independent IDL calculations

• Final Acceptance Test Meeting held on 2002 May 13
  – No discrepancies found; performance OK
  – Processor deemed acceptable to proceed to Phase 2
Auxiliary file contents

- The LST auxiliary file (ATS_LST_AX) includes the following data sets:
  - General Parameters for LST Retrieval: 3 parameters
  - Index Data for LST Retrieval: $1440 \times 360$ array
  - Vegetation fraction for LST Retrieval: $1440 \times 360 \times 12$ array
  - Climatology records for LST retrieval: $1440 \times 360 \times 12$ array
  - Topographic variance flag for LST retrieval: $1440 \times 360$ array
  - LST Retrieval Coefficients:
    - $16 \times 2$ (night/day) $\times 2$ (vegetation / soil) coefficient sets
Auxiliary file versions

- Two versions of the auxiliary file ATS_LST_AX have been used to date:
  - May 2002
    - Original look-up tables as used for acceptance testing
    - Used for initial analysis of Australian sites
  - February 2003
    - New coefficients
    - New surface type mask including inland lakes
    - Used for volunteers’ sites
- New file to be supplied for use with Operational Processor
  - New surface type mask defines coastal cells as land
Revised Surface Type Mask

• In the original Surface Type Mask coastal cells were flagged as sea
  – No retrieval coefficients were defined for land pixels within the cell
  – No LST retrieval was possible for sites within these cells
• New surface type mask now supplied by CSIRO identifies coastal cells as land
• New auxiliary file ATS_LST_AX to be supplied for use with Operational Processor will include this mask
Operational Implementation

• Implementation in AATSR Operational Processor now well advanced
  – Expected in next release of Level 2 IPF
  – Revised Surface Type Mask

• Experimental product so open issues remain:
  – Processing Over Lakes
  – Cloud Clearing
  – Pixels flagged as Cloudy
  – Image Smoothing
Processing Over Lakes

- Current auxiliary file includes
  - Lakes class in surface type mask
  - Corresponding lake retrieval coefficients
- However, AATSR land/sea database flags inland lakes as sea
  - LST is only retrieved for pixels flagged as land
  - Therefore lake retrieval is not attempted in the current implementation
- Solution not yet prescribed; options include
  - Checking all sea pixels against land surface type database (inefficient)
  - Radical restructuring of AATSR land/sea database to include a separate lake type
Cloud Clearing

- AATSR cloud clearing optimised for sea, so performance over land is not reliable
- Some simple changes to the present scheme that might improve cloud clearing over land have been identified:
  - Enable gross cloud test
  - Disable spatial coherence test
- More comprehensive approach required in the longer term, but outside the scope of current work programmes
Pixels flagged as Cloudy

- AATSR Level 2 (GST) product is ‘switchable distributed’, meaning that the contents of the pixel fields depend on the land/sea and cloud flags
  - LST is only calculated for pixels flagged as clear land, not cloudy land pixels
  - Pixels wrongly flagged as cloud contain 11 micron BT
- Proposed to calculate LST regardless of cloud state. This might be done by introducing an additional class of ‘invalid’ or ‘marginal’ land
- Requires revision of confidence flags, but given the limitations of the current cloud clearing scheme is viable
- (Similar to what happened in ATSR products over sea)

Andrew R. Birks
MAVT-2003
Image Smoothing

- CSIRO have proposed a smoothing algorithm for retrieved LST to remove discontinuities at cell boundaries.
- No smoothing in present implementation, but discontinuities do not appear to be intrusive.
- For adjacent cells having the same land type and vegetation fraction, the tropospheric water vapour interpolation is exactly equivalent to the proposed smoothing algorithm, and so no discontinuities are expected in this case.
Summary

- LST algorithm, based on that developed by F. Prata at CSIRO, has been defined for the AATSR processors
- Extended Reference Processor has been used for LST retrievals to date
- Implementation in AATSR Operational Processor now well advanced
  - Expected in next release of Level 2 IPF
  - New Surface Type Mask with revised coastal cells
- Further developments to address the open issues currently under review
NEAR-REAL TIME VALIDATION OF THE AATSR METEO PRODUCT SEA-SURFACE TEMPERATURE AT THE MET OFFICE

A G O’Carroll, J G Watts, L A Horrocks, R W Saunders, N A Rayner

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FitzRoy Road, Exeter, EX1 3PB, United Kingdom
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ABSTRACT

A full year of the Advanced-Along Track Scanning Radiometer (AATSR) Meteo product is now available from 19 August 2002. These data have been downloaded from an ESA FTP server in near-real time as BUFR formatted files. Validation has been performed on these data at the Met Office on a daily basis, with a 2-day lag from data receipt. Meteo product skin Sea Surface Temperatures (SST) have been compared to point measurements of buoy SST; a 1 degree climate SST analysis field compiled from in situ measurements and AVHRR SSTs; plus a 5 degree 5 day averaged in situ data-set. Comparisons of the AATSR Meteo product against TMI SSTs are presented. These validation activities have confirmed the Meteo product skin SST to be of a good quality.

From August 2002, only a maximum of 10 orbits of AATSR Meteo product BUFR formatted files were available, which increased to the full 14 orbits per day from November 2002. During the first 6 months of data receipt, it was not unusual for around 2 orbits per day to be unavailable. Data availability has become more reliable from February 2003 onwards.

Comparisons of the AATSR Meteo skin SST against buoy SSTs, from 19 August 2002 to 31 July 2003, give a mean (AATSR – buoy) of 0.07K (standard deviation = 0.35K) during night-time, and a mean of 0.03K (standard deviation = 0.46K) during the day. Analyses have shown that there is no cool skin effect observed in the night-time observations as would be expected, implying that the 3-channel Meteo product skin SST may be 0.1-0.2K too warm.

1. INTRODUCTION

The AATSR (Advanced Along Track Scanning Radiometer) instrument upon the Envisat satellite aims to observe Sea Surface Temperature (SST) to within 0.3K accuracy in order to continue the collection of data begun by the ATSR-1 and ATSR-2 instruments upon the ERS 1 and 2 satellites since 1991. Data has been gathered in near-real time at the Met Office from AATSR since 19th August 2002 via the ESA ftp servers. Daily monitoring of these AATSR skin SSTs has been carried out at the Met Office, and further validation against various climate datasets has been performed. A skin to bulk correction is estimated using the Fairall [1] model to account for the difference in SST from the surface skin SST to a depth of around 1m. These bulk SSTs make more suitable measurements when compared against buoy SSTs and other in situ based climate datasets.

Other validation activities involve the production of mean global SST time series, and the comparison of ESA skin SSTs against SSTs observed from the TRMM microwave imager (TMI). Whilst the Met Office gathers and monitors ESA skin SSTs, it also separately calculates the skin SST from brightness temperatures received from ESA using the coefficients supplied by ESA to calculate their own skin SST. These values of skin SST, calculated separately, are compared at the Met Office on a daily basis to ensure consistency of the ESA processing.

Along with the skin to bulk calculations, a diurnal thermocline model is ran at the Met Office, based on the Kantha & Clayson model [2] in order to gain knowledge of possible diurnal surface warmings, which are then flagged within the output data. These typically occur more frequently in low-latitudes, and in scenarios of high insolation and low wind-speeds. SSTs influenced by these surface warmings are less characteristic of the overall heat budget of the ocean and so should be excluded or corrected before being assimilated into climate SST datasets. This paper details the validation carried out on AATSR skin SSTs from 19th August 2002 to August 2003, and displays the results. Additional discussions are reported on SST algorithm comparisons, bias’s in SSTs, and finally future work and conclusions.
2. DATA AND METHODOLOGY

2.1 AATSR Meteo product

The AATSR Meteo product (ATS_MET_2P, [3]) is a fast-delivery level 2 product designed for use in meteorological studies, which contains spatially averaged channel brightness temperatures and sea surface temperatures (SSTs) in 10 arc minute cells. The contents of this product are extracted from the 10 arc minute average surface temperature product (ATS_AR_2P, [3]) for clear sea views. SST is retrieved using ESA’s pre-launch coefficient set, for both the nadir view and for the dual-view combination. In each case, only 11µm and 12µm data are used during the day, and valid 3.7µm data are also included during the night. The product validation described here has used only the dual-view SST both for day and night time.

Meteo product files are written individually, with each encoded in Binary Universal Form for the Representation of data (BUFR). The Meteo product BUFR version does not include a record quality indicator. However, the number of clear pixels in the nadir and dual views, which, in addition to a record quality indicator, has been included in the Meteo product throughout the Envisat validation phase, was added to the BUFR version of the product from 14 February 2003. A full list of the elements of data supplied in the BUFR version of the Meteo product from this date is shown in Table 1.

Table 1. Elements of data supplied in the BUFR version of the AATSR Meteo product

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<td>Second Second</td>
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<td></td>
</tr>
<tr>
<td>005001</td>
<td>Latitude Degrees 1/6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>006001</td>
<td>Longitude Degrees 1/6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>007002</td>
<td>Height or altitude Metres 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012180</td>
<td>Averaged 12µm Brightness Temperature for all Clear Pixels in Nadir View Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012181</td>
<td>Averaged 11µm Brightness Temperature for all Clear Pixels in Nadir View Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012182</td>
<td>Averaged 3.7µm Brightness Temperature for all Clear Pixels in Nadir View Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012183</td>
<td>Averaged 12µm Brightness Temperature for all Clear Pixels, Forward View Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012184</td>
<td>Averaged 11µm Brightness Temperature for all Clear Pixels, Forward View Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>002185</td>
<td>Averaged 3.7µm Brightness Temperature for all Clear Pixels, Forward View Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>002173</td>
<td>Mean Across Track Pixel Number</td>
<td>Numeric</td>
<td></td>
</tr>
<tr>
<td>021086</td>
<td>Number of Pixels in Nadir only, Average Numeric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012186</td>
<td>Mean Nadir Sea Surface Temperature Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>021087</td>
<td>Number of Pixels in Dual View, Average Numeric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>012187</td>
<td>Mean Dual View Sea Surface Temperature Kelvin 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>033043</td>
<td>Average Surface Temperature Confidence Flag table</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Supply of data from ESA

Envisat makes 14 orbits of the Earth each day, of which up to 10 can be downloaded data directly to the Kiruna receiving station. Meteo product BUFR files for these data have been made available in near-real time (NRT) on the Kiruna FTP site from 19 August 2002. The remaining orbits are generally out of the receiving range of the Kiruna station (these are Kiruna-blind) and their data are not added to the Kiruna FTP site.
The Kiruna-blind orbits have resulted in an absence of night-time observations over most of the Atlantic and part of the east Pacific Ocean (and a corresponding lack of daytime data across parts of the Indian and the west Pacific Oceans). However, the Svalbard receiving station was introduced into the data distribution chain on 7 November 2002, receiving the Kiruna-blind orbits which have been sent in NRT to a second FTP site at ESRIN. The Kiruna-blind orbits prior to the introduction of the ESRIN FTP site, which comprise approximately 5.4% of all orbits in the validation period, have yet to be released by ESA. The remaining orbits whose BUFR Meteo product were readily available and clearly readable comprise approximately 74% of the total number of orbits during the validation period.

A few gaps in the availability have resulted from instrument switch-offs and ground-based technical problems, as detailed in Table 2. Aside from these outages, the data coverage has occasionally been incomplete, with fewer orbits than expected on the servers, resulting in the absence of data from approximately 10% of the orbits in the period of 19 August 2002 to 31 August 2003 (referred to in this paper as the validation period), although the bulk of these were within the first 6 months. If outages in provision are not backfilled within 4 days, the Met Office experiences a permanent gap in its archive due to storage limitations, and approximately 1.0% of orbits’ Meteo product data are missing from our validation as a result. An additional 1.2% of orbits could not be used due to anomalies in the coding of the BUFR Meteo product received. Figure 1 shows the number of daily global observations of AATSR SST for the period 19 August 2002 to 20 August 2003.

Table 2. AATSR Meteo product availability between 19 August 2002 and 31 August 2003

<table>
<thead>
<tr>
<th>% of orbits:</th>
<th>Reason for unavailability</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>Switch off for platform manoeuvres</td>
<td>8 – 12 September 2002, 17 – 18 December 2002, 18 – 21 May 2003</td>
</tr>
<tr>
<td>2.0</td>
<td>Switch off for outgassing events</td>
<td>31 January – 3 February 2003, 31 July – 4 August 2003</td>
</tr>
<tr>
<td>0.6</td>
<td>Switch off for meteor shower</td>
<td>18 – 20 November 2002</td>
</tr>
<tr>
<td>1.6</td>
<td>Other instrument switch-offs</td>
<td>25 August 2002, 15 – 19 March 2003</td>
</tr>
<tr>
<td>10.0</td>
<td>Occasional missing orbits, cause unknown</td>
<td>Various</td>
</tr>
<tr>
<td>1.2</td>
<td>BUFR coding errors / poor communication</td>
<td>11 – 12 October 2002, 1 January 2003, 12 – 14 February 2003</td>
</tr>
<tr>
<td>1.0</td>
<td>Late provision of data to FTP sites</td>
<td>19 – 22 March 2003</td>
</tr>
<tr>
<td>5.4</td>
<td>Kiruna-blind orbits, before ESRIN FTP site available</td>
<td>19 August – 7 November 2002</td>
</tr>
</tbody>
</table>
It is our intention to provide a more complete AATSR archive for climate monitoring purposes, for which the release by ESA of all re-processed data, with the exception of that missing due to instrument switch-offs, could increase the coverage to 90% of all orbits in this validation period.

2.3 Buoy data

In this study, AATSR skin SSTs, converted to a bulk SST at around 1 m in depth, have been compared to both moored buoys and ships, plus drifting buoy SST measurements. These buoy matchups are extracted on a weekly basis from the Global Telecommunications System, after which the buoy matchup processing at the Met Office [4] is performed and analysed. The buoy matchup dataset is a collection of 79 different fields detailing the buoy observations, AATSR observations and atmospheric and sea surface conditions. The dataset from which these analyses are presented in this paper are from 19 August 2002 to 20th August 2003.

A weekly quality control of individual buoys was performed, in which the mean difference between reported SST and the Met Office NWP background SST field was considered. Buoys which showed a mean weekly bias of more than 1.2K or standard deviation of greater then 0.6K compared to NWP were screened out. Additionally, each single buoy SST report was required to agree within gross limits (8K) with climatology. On the basis of these tests, up to 25% of the buoy reports received each week could be filtered out.

The matching up of the two observation types involves choosing buoy observations which are located within the 10arc-minute resolution grid box of the AATSR observation. The time difference between the two data types must be within ±3 hours. In the event that 2 buoy SSTs are matched up to the same AATSR observation, the buoy observation closest in time to the AATSR observation will be chosen. Efforts to screen out cloudy observations are made by checking the quality control (QC) word calculated during the Met Office processing of the AATSR skin and bulk SSTs. Additionally, careful screening of duplicate matchups, where the same AATSR observation matched with consecutive reports from a single buoy, were performed. The number of matchups per week varied according to gaps in AATSR provision, but could be up to ~ 200.

2.4 MOHSST and HadISST analyses

Two of the climate data sets for global SST provided by the Hadley Centre are used routinely in AATSR validation: the Met Office Historical Sea Surface Temperature (MOHSST) and the Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST). MOHSST [5] is a gridded data set of sea temperatures at a depth of 1 – 10 metres. Its data are quality controlled in situ observations from ships and buoys, averaged at 5° spatial resolution.
A 5-day average version of the MOHSST data set is available in near-real time to provide a gross validation of AATSR every 5 days. The 10 arc minute AATSR SSTs are averaged over the same 5-day periods at 5˚ spatial resolution for their validation against MOHSST.

The HadISST [6] data set is a globally complete 1˚ spatial resolution sea-ice and SST analysis field, produced on a monthly basis. The SST data which contribute to HadISST come from ships, buoys and the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) satellites. The ship and buoy data is averaged into a 1˚ latitude / longitude globally complete field, from which a night-time AVHRR SST field is subtracted. The difference is smoothed to create a field for which the AVHRR data can be corrected. The corrected AVHRR and in situ fields are then averaged together onto a 2˚ latitude / longitude grid which is reconstructed as a 1˚ spatial resolution field, with gaps covered by reduced space optimal interpolation and sea ice fields added to produce the HadISST1 field.

AATSR comparisons have been made against the monthly HadISST1 fields for each calendar month from September 2002 to August 2003 inclusive. The 10 arc minute AATSR SSTs are subtracted from daily climatology SST fields which are at 1˚ spatial resolution. The anomalies are averaged to daily 1˚ spatial resolution and subsequently averaged over the monthly period. A climatological SST normal, averaged over the same period at 1˚ resolution, is added to this, creating a monthly AATSR SST, whose spatial resolution matches the HadISST1 analyses.

2.5 TRMM Microwave Imager (TMI)

The TMI instrument is onboard the Tropical Rainfall Monitoring Mission (TRMM), a joint NASA and NASDA mission, was launched in November 1997. The TRMM satellite moves from west to east in an inclined orbit providing data at various local times between latitudes 40ºS and 40ºN. The TMI is a conical scan microwave radiometer with channels at five separate frequencies: 10.7, 19.4, 21.3, 37 and 85.5GHz and a spatial resolution of about 50km. The 10.7GHz channel is used to retrieve SST as it is insensitive to water vapour and cloud. This gives an advantage over infrared sensors as cloudy (although non-precipitating) coverage can be viewed with TMI. In addition to precipitation, the TMI does have sensitivities to sea surface roughness and so the microwave SST retrieval attempts to account for these effects. Details of the physical retrieval algorithm, which aims to derive SST to an accuracy better than 0.5K, are given in [7]. Figure 2 shows the monthly averaged TMI SST for July 2003. This study includes comparisons of AATSR SSTs against TMI SSTs. The TMI SSTs have been retrieved as daily averaged files from the Remote Systems Website http://www.ssmi.com between –40 and 40 degrees latitude.

![Fig. 2. Monthly averaged SST from the TRMM Microwave Imager](image)

2.6 Met Office processing of skin to bulk SST differences

The Met Office receives the Meteo product containing skin SST, brightness temperatures and other related information in near-real time. On a daily basis, the skin SSTs at the Met Office are retrieved from BTs using ESA launch coefficients and compared to the ESA skin SST, which are retrieved using the same coefficients, and comparisons made to check for errors.
These Met Office derived skin SSTs are then processed to a bulk SST, which is the temperature of the ocean at around 1 metre in depth. This is done by using the Fairall [1] model and is necessary because the satellite observes a radiative skin temperature which is always cooler than the sub-skin by more than 0.1K. For obtaining SST for climate purposes we require the bulk temperature which provides a more comparable measurement when looking at other climate datasets, and is more representative of the overall heat capacity of the ocean.

At night the sub-skin SST is representative of the bulk SST at around ~1m in depth. However, during the day the sub-skin SST can become warmer than the bulk SST by several Kelvins, especially in cases of strong insolation & low wind speed where thermal stratification results. These locations are typically in low-latitudes, but can reach mid-latitudes if local atmospheric conditions are favourable. These diurnal warming effects are modelled at the Met Office, using the Kantha-Clayson [2] model to try to predict occurrences of warmings within the 10 arc minute resolution cells, with NWP fluxes and wind observations needed for inclusion in the models. Such predictions are flagged in the observation record and affected observations are not included in further analyses. A diagram showing the processing scheme at the Met Office and the how data is received from ESA is shown in figure 3.

![Diagram showing the processing scheme at the Met Office.](image)

**Fig. 3.** Meteo product data chain and the processing carried out at the Met Office.

The validation datasets used are measures of the bulk SST, and so comparisons of bulk SST against our validation datasets have been made to complement the skin SST analyses.

### 2.7 Error estimation

An error estimation field is evaluated within the Met Office processing of the AATSR Meteo product as an attempt to assess the possible error of the bulk SST retrieval according to whether the recommended retrieval is a 2-channel or 3-channel retrieval. It is intended as information to allow AATSR data to be assimilated into the HadISST1 analyses of the Hadley Centre. The method uses a variety of factors and is not intended to be static, but to evolve.

The error estimate for each observation is calculated as a possible error in degrees K, and has contributions as listed in Table 3. The final error (in degK) is computed as the square root of the sum of the squares of all the components of individual errors, in (1):-
Final error = $\sqrt{\sum error \text{ components}^2}$

(1)

or, in more detail, in (2):

$$Final \ error = \sqrt{(N_{\text{pixels\_error}}^2 + ice\_error^2 + \text{model\_error}^2 + bulk\_error^2)}$$

(2)

where $N_{\text{pixels\_error}}, ice\_error, model\_error$ and $bulk\_error$ are calculated from the tests listed in Table 3.

Table 3. List of contributions to final error estimation value.

<table>
<thead>
<tr>
<th>Tests to calculate error components</th>
<th>Error component</th>
</tr>
</thead>
<tbody>
<tr>
<td>The number of pixels making up each 10 arc minute cell.</td>
<td>$N_{\text{pixels_error}}$</td>
</tr>
<tr>
<td>Error contribution from SST algorithm.</td>
<td>Model_error</td>
</tr>
<tr>
<td>Error contribution due to type of skin model used.</td>
<td>Bulk_error</td>
</tr>
<tr>
<td>Do we consider that sea-ice exists within the observation cell?</td>
<td>Ice_error</td>
</tr>
</tbody>
</table>

3. METEO PRODUCT RESULTS

3.1 Dual view SSTs

Global plots of daily and monthly seas surface temperature from the Meteo product have been produced throughout the validation period. The dual view skin SST for 3 June 2003 is shown in Fig. 4. On this day, all 14 orbits of the satellite yielded SST data which was delivered in the Meteo product to the FTP sites.

![Fig. 4. Dual view skin SSTs from the Meteo product of 3 June 2003](image)

The monthly mean SSTs have been plotted globally for each of the 12 calendar months, September 2002 to August 2003 inclusive, in Fig. 5. One clear feature is the cool SST in the south-east Atlantic to the west of South Africa, and in the north-east Pacific near the west coast of USA, as is expected due to the cold Benguela and California currents respectively in the oceanic gyres. The seasonal variations in SST can be seen in both hemispheres and the gaps in monthly mean SSTs suggest areas of persistent cloud cover, such as that in the south-east Pacific near the coast of Peru.
3.2 SST Algorithm Comparison

Different retrieval coefficients are used to calculated the dual-view 2-channel skin SSTs (hereafter D2) & dual-view 3-channel skin SSTs (hereafter D3). A bias between these 2 retrievals has been observed to exist, showing that the night-time skin SSTs are not cooler than day-time skin SSTs, as would normally be expected due to diurnal warming, implying that D3 may be too warm.

From the period September 2002 to August 2003, results of mean differences show that D2 are cooler than D3 by ~0.14K (σ=0.2K, n=9511981), where all skin SSTs calculated at the Met Office (using ESA launch coefficients) which pass a data confidence word are used.

Comparisons of the dual-view skin SSTs against the HadISST1 climate dataset show that the D3 values are similar to HadISST, whilst the D2 are warmer (see Table 4). The subset of statistics are taken where good skin to bulk calculations are performed on the skin SSTs for September 2002 – August 2003.

Table 4. Results of Met Office dual-view skin SST minus HadISST1.

<table>
<thead>
<tr>
<th>Retrieval type</th>
<th>Mean (skin SST HadISST1), K</th>
<th>Standard deviation, K</th>
<th>Number in sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-channel</td>
<td>0.02</td>
<td>0.58</td>
<td>242224</td>
</tr>
<tr>
<td>2-channel</td>
<td>0.14</td>
<td>0.61</td>
<td>242383</td>
</tr>
</tbody>
</table>
3.3 Biases in Sea Surface Temperature retrievals

Biases in SST retrievals are caused by two factors. Firstly, retrieval errors are a contributor. These are state dependent. The retrieval errors vary with atmospheric state, as a different atmosphere was used by the radiative transfer model (RTM) used to calculate the retrieval coefficients, than the state at the time of satellite measurement. This leads to the retrieval errors varying with latitude, longitude and season. An example of the variation with latitude is shown in figure 7.
Secondly, there is a mean global offset between D2 and D3 retrievals due to errors in the RTMs used to calculate the retrieval coefficients. To estimate this offset, comparisons are made against night-only insitu measurements which have been adjusted to a skin SST measurement. For an AATSR sample from December 2002 to April 2003, D2 is 0.03K too warm and D3 is 0.19K too warm with regard to insitu observations.

4. VALIDATION RESULTS

4.1 Comparisons with buoy SSTs

Fig. 8 shows the coverage of buoy SSTs matched up with AATSR observations from 19 August 2002 to 20 August 2003. They were matched up when the buoy SST measurement is coincident in a 10 arc minute AATSR observation cell, and where the two measurements are taken within 3 hours of each other. A good spread of matchups has been obtained for the period, but with fewer in the Southern Oceans, as expected.

Table 5 shows statistics (using 3 sigma standard deviation test) from these analyses of buoy SSTs matched up with AATSR skin and bulk SSTs during this same period. The results display how a cool skin with respect to buoy SSTs are not observed at night, which leads to the conclusion that the night-time (3-channel) SST retrievals are too warm. The AATSR bulk SSTs are around 0.2K warmer than the buoy SSTs.

Fig. 9 shows the time series for the year for skin and bulk SSTs against buoy SSTs. The results show that the AATSR SSTs are mainly within the ±0.3K accuracy required for AATSR, with the skin SSTs displaying closer results to the buoy SSTs than the bulk SSTs.

Table 5. Statistics of co-located AATSR minus buoy SSTs for 19 August 2002 to 20 August 2003

<table>
<thead>
<tr>
<th>SST type</th>
<th>Subset</th>
<th>Mean (AATSR – buoy SST), K</th>
<th>Standard deviation, K</th>
<th>Number matchups</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESA Skin</td>
<td>Day + night</td>
<td>0.05</td>
<td>0.41</td>
<td>6691</td>
</tr>
<tr>
<td>ESA Skin</td>
<td>Day</td>
<td>0.03</td>
<td>0.46</td>
<td>3611</td>
</tr>
<tr>
<td>ESA Skin</td>
<td>Night</td>
<td>0.05</td>
<td>0.35</td>
<td>3080</td>
</tr>
<tr>
<td>Bulk</td>
<td>Day + night</td>
<td>0.21</td>
<td>0.40</td>
<td>5646</td>
</tr>
<tr>
<td>Bulk</td>
<td>Day</td>
<td>0.19</td>
<td>0.35</td>
<td>3028</td>
</tr>
<tr>
<td>Bulk</td>
<td>Night</td>
<td>0.23</td>
<td>0.34</td>
<td>2621</td>
</tr>
</tbody>
</table>

Fig. 8. Locations of buoy SSTs matched with AATSR SSTs from 19 August 2002 to 20 August 2003. (pink = moored buoys, blue=drifting buoys)
On 25 June 2003, a trough can be observed for the Met Office skin and bulk SSTs. The daily mean Met Office skin SST minus buoy SST is -0.49K. This anomaly is contributed to by three matchups on the same day (out of only 8 matchups which include Met Office skin SST), around 21:50 in the evening, all in the same local area of the Bay of Biscay. Differences are not too large limited to a maximum of around 1.6K. The indications are that the AATSR observations could be affected by cloud contaminated pixels making up the 10 arc minute cell. Table 6 displays the three matchups.
out of a total of 32 for this day which contribute to the anomaly. The AATSR ESA skin SST minus buoy SST is $-0.09K$
for this day. The ESA skin SST is comparable to the Met Office skin SST for the day, however a larger sample of
matchups is available for the ESA skin SSTs which reduces the anomaly. Fewer Met Office skin SSTs are available due
to the unavailability of Numerical Weather Prediction model fields.

Table 6. Anomalous AATSR/buoy matchups in the Bay of Biscay, 25 June 2003

<table>
<thead>
<tr>
<th>Buoy SST, K</th>
<th>Met Office skin SST, K</th>
<th>Latitude, degrees</th>
<th>Longitude, degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>292.6</td>
<td>291.9</td>
<td>46.7</td>
<td>-4.5</td>
</tr>
<tr>
<td>290.5</td>
<td>289.4</td>
<td>51.0</td>
<td>-7.8</td>
</tr>
<tr>
<td>290.6</td>
<td>289.9</td>
<td>48.3</td>
<td>-5.7</td>
</tr>
</tbody>
</table>

From AATSR/buoy matchups compiled from 19 August 2002 to 20 August 2003, only 8 daily mean values of ESA skin
SST minus buoy SST are greater than or less than 0.3K. Thus, most of the years results indicate that the AATSR
retrievals are with the boundaries required for AATSR SST data.

Regional samples of from the buoy matchup files have also been analysed in order to look for characteristics in the
main ocean basins. Table 7a displays the statistics for the analysed regions, and Table 7b describes the
latitude/longitude boundaries of the regions chosen for a matchup period of 19 August 2002 to 20 August 2003.

Table 7a. Statistics for AATSR SSTs compared to buoy SSTs for difference oceanic regions, between 19August 2002
and 20 August 2003

<table>
<thead>
<tr>
<th>Region</th>
<th>Sample</th>
<th>AATSR ESA skin SST – buoy SST</th>
<th>AATSR bulk SST – buoy SST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>difference, K</td>
<td>deviation, K</td>
<td>Number matches</td>
</tr>
<tr>
<td>Tropical Atlantic</td>
<td>Night</td>
<td>0.16</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>0.12</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Night/day</td>
<td>0.14</td>
<td>0.33</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>Night</td>
<td>0.10</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>0.08</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Night/day</td>
<td>0.09</td>
<td>0.31</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>Night</td>
<td>0.03</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>0.06</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Night/day</td>
<td>0.05</td>
<td>0.47</td>
</tr>
<tr>
<td>Southern Ocean</td>
<td>Night</td>
<td>0.02</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>-0.13</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>Night/day</td>
<td>-0.05</td>
<td>0.40</td>
</tr>
<tr>
<td>West Pacific</td>
<td>Night</td>
<td>0.01</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>-0.02</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>Night/day</td>
<td>0.01</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Table 7b. Latitude and longitude boundaries for oceanic areas used in regional analyses.

<table>
<thead>
<tr>
<th>Region</th>
<th>Latitude range (degrees)</th>
<th>Longitude range (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Atlantic</td>
<td>-20 to 20</td>
<td>-40 to 0</td>
</tr>
<tr>
<td>Indian Ocean</td>
<td>-20 to 0</td>
<td>60 to 80</td>
</tr>
<tr>
<td>North Atlantic</td>
<td>40 to 60</td>
<td>-40 to -15</td>
</tr>
<tr>
<td>Southern Ocean</td>
<td>-90 to -40</td>
<td>-180 to 180</td>
</tr>
<tr>
<td>West Pacific</td>
<td>-10 to 10</td>
<td>140 to 180</td>
</tr>
</tbody>
</table>

The results show that the AATSR skin SSTs in the North Atlantic, Southern Ocean and West Pacific are similar to the
matched up buoy SSTs during night-time. The corresponding AATSR bulk SSTs have a slightly higher mean difference
with buoy SSTs ranging from 0.12K to 0.33 K for these regions at night-time. The buoy SSTs have a better agreement
with the AATSR skin SSTs, than the bulk SSTs.
Results during night-time for the Tropical Atlantic and Indian Ocean regions show that the mean difference indicates that AATSR skin SSTs are warmer than the buoy SSTs by 0.16 and 0.1K respectively. These differences are slightly larger than for the other regions and for the overall global means. The statistics are only calculated on matchups where a diurnal thermocline is thought to not exist, and being night-time results this is more unlikely. The results do not indicate the possibility of aerosols affecting the results.

During the day, the mean (AATSR skin SST – buoy SST) for the Southern Ocean is –0.13K (standard deviation = 0.41K), so here the buoy SSTs are slightly warmer than the AATSR SSTs. Slight cloud contamination may contribute to this.

4.2 Comparisons against MOHSST and HadISST

AATSR skin SSTs have been converted to estimated bulk SSTs using the processing scheme described in Section 2.6. For comparisons against MOHSST, the skin and bulk SSTs have been averaged over 5-day periods (pentads) at 5º resolution and the corresponding MOHSST data sets have been subtracted from them. The global mean skin and bulk SST – MOHSST differences with standard deviation are plotted for each pentad of 19 August 2002 – 18 August 2003 in Fig. 10. No Meteo product was available during the pentad of 17-21 March 2003, and the mean differences for skin and bulk – MOHSST of -0.66 K and -0.48 K respectively on 17-21 December 2002 were calculated using only 96 means at 5º resolution, due to the low availability of AATSR data in this period. For the other 50 pentads, between 100 and 1000 grid cells at 5º were used to produce the global means, all of which lay within the ±0.3 K range for both skin and bulk SST comparisons against MOHSST. The high standard deviations can partly be attributed to the coarse resolution, as the largest differences tended to be found in regions of strong SST gradients such as the Gulf Stream, or regions where small numbers of in situ data contributed to MOHSST, such as the Southern Oceans. The fall in standard deviations during November 2002 coincided with the introduction of Kiruna-blind orbits into the data distribution chain, perhaps the existence of more uniform areas in the Kiruna-blind orbits led to this characteristic.

For comparisons against HadISST, the skin and bulk SSTs have been averaged monthly at 1º resolution and the monthly HadISST1 fields have been subtracted from them, using the method described in Section 2.4. Global plots of the monthly SST differences have been produced for each calendar month of the validation period, with the August 2003 skin SST minus HadISST1 plot in Fig. 11. This demonstrates that the SST differences are generally within ±1 K away from the poles, although many regions such as across the south Atlantic and north-west Pacific, where much of the AATSR data is significantly warmer or cooler than HadISST1, tend also to be regions where cloud detection has frequently resulted in the unavailability of AATSR SSTs. This suggests that cloud contamination may have affected the AATSR data in these regions. Comparisons against TMI data shown in section 4.4 support this.
Monthly and annual global differences between AATSR ESA skin or bulk SSTs and HadISST1 at 1° resolution and standard deviations are listed in Table 8. Results are presented for the ESA skin SST, whilst the bulk SST is derived from the Met Office derived skin SST. Statistics for bulk SST are only presented where a ‘good’ skin-bulk temperature difference has been calculated which is why a lower sample of bulk SSTs are included. Factors such as whether NWP model fields are available for a particular observation affect the calculation of the modelled skin minus bulk difference. The annual comparison takes a mean and standard deviation for all 1° spatial resolution comparisons in over each of the 12 months. The mean differences between AATSR skin SST and HadISST1 are generally closer to zero than the mean differences between AATSR bulk SST and HadISST1, although these results make no correction for the interalgorithm bias. The increase of standard deviation to 1.02K, for the ESA skin SST results for July 2003, coincides with a period where we observed anomalously cooler skin SSTs by about 1K in the global results when compared to bulk SST, possibly due to sampling errors.

Table 8. Monthly and annual comparisons of AATSR SST minus HadISST1

<table>
<thead>
<tr>
<th>Period:</th>
<th>AATSR ESA skin SST – HadISST1:</th>
<th>AATSR bulk SST – HadISST1:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean, K: Standard deviation, K:</td>
<td>Mean, K: Standard deviation, K:</td>
</tr>
<tr>
<td>September 2002</td>
<td>-0.06 0.70</td>
<td>32288 0.09 0.60</td>
</tr>
<tr>
<td>October 2002</td>
<td>-0.09 0.62</td>
<td>31663 0.06 0.60</td>
</tr>
<tr>
<td>November 2002</td>
<td>-0.07 0.61</td>
<td>30280 0.08 0.60</td>
</tr>
<tr>
<td>December 2002</td>
<td>-0.12 0.64</td>
<td>28866 0.02 0.67</td>
</tr>
<tr>
<td>January 2003</td>
<td>-0.09 0.60</td>
<td>31545 0.09 0.62</td>
</tr>
<tr>
<td>February 2003</td>
<td>-0.04 0.62</td>
<td>30644 0.11 0.61</td>
</tr>
<tr>
<td>March 2003</td>
<td>-0.03 0.59</td>
<td>33353 0.12 0.59</td>
</tr>
<tr>
<td>April 2003</td>
<td>-0.02 0.57</td>
<td>34012 0.14 0.57</td>
</tr>
<tr>
<td>May 2003</td>
<td>-0.04 0.60</td>
<td>33420 0.12 0.60</td>
</tr>
<tr>
<td>June 2003</td>
<td>-0.01 0.68</td>
<td>34114 0.15 0.67</td>
</tr>
<tr>
<td>July 2003</td>
<td>0.03 1.02</td>
<td>34321 0.14 0.69</td>
</tr>
<tr>
<td>August 2003</td>
<td>0.01 0.69</td>
<td>33697 0.15 0.64</td>
</tr>
<tr>
<td><strong>Annual: September 2002 – August 2003</strong></td>
<td><strong>-0.04 0.66</strong></td>
<td><strong>388223 0.11 0.62</strong></td>
</tr>
</tbody>
</table>
4.3 Impact of AATSR in HadISST

Section 4.2 concerns the HadISST1 product in which in situ SST data is used to correct a 1° gridded night-time AVHRR SST field. However, studies to produce a parallel version of the HadISST1 product using AATSR SST data in place of AVHRR have been made. Comparisons between the preliminary HadISST products for September 2003, constructed in the same way as described for the HadISST1 product in Section 2.4 (see also reference [6]) before the corrections are made for the ice fields, have produced the plots in Fig. 12. Here, the corrected AATSR field has been subtracted from the corrected AVHRR field, to a mean global difference of 0.01 K, standard deviation 0.12 K.

Larger differences between the two products can be detected clearly on regional scales. The east Atlantic, particularly near Africa, appears as an area where the HadISST product using AVHRR is cooler than that using AATSR. Comparison of the September HadISST product using AVHRR with and without the in situ SST correction, and the same comparison using AATSR data confirm that AVHRR requires a greater correction in the east Atlantic region than AATSR. The initial AVHRR data is more than 0.3 K greater than the corrected AVHRR data through much of this region, while the initial AATSR is generally within ±0.1 K of the corrected AATSR here. This provides evidence that the aerosol correction in AATSR SST data gives it an advantage over AVHRR.

The greatest differences between initial and corrected AATSR data are seen in the Southern hemisphere around 40° S, where the initial AATSR is around 0.4 K warmer than the corrected product in the south-west Indian Ocean, and around 0.3 K cooler than the corrected product in the south-west Pacific Ocean. However, these regions also require large corrections to their AVHRR SST data. Globally, the mean corrected AATSR data is 0.04 K cooler than its initial data, while the mean corrected AVHRR data is 0.03 K warmer than its initial data, but these differences have a standard deviation of 0.13 K for AATSR compared to 0.16 K for AVHRR, suggesting that AATSR SSTs are slightly more consistent than AVHRR SSTs in their comparison against in situ data.

![Fig. 12. Global differences between HadISST analyses using AVHRR and AATSR SST fields, September 2003](image)

4.4 Comparisons of AATSR against TMI

Comparisons of AATSR against TMI data have been made for June, July and August 2003. Table 9 displays the differences statistics, and Fig. 13 shows an AATSR skin 2 & 3-channel SST – TMI for July 2003. Only night-time AATSR data are included to avoid diurnal thermocline effects.

<table>
<thead>
<tr>
<th>Month</th>
<th>AATSR Skin 2-channel SST – TMI</th>
<th>AATSR Skin 3-channel SST - TMI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean, K</td>
<td>St.Dev, K</td>
</tr>
<tr>
<td>June 2003</td>
<td>-0.27</td>
<td>0.59</td>
</tr>
<tr>
<td>July 2003</td>
<td>-0.30</td>
<td>0.58</td>
</tr>
<tr>
<td>August 2003</td>
<td>-0.37</td>
<td>0.58</td>
</tr>
</tbody>
</table>

Fig. 13. Global map of mean AATSR channel-3 skin SST – TMI SST for July 2003

Overall, the results indicate that the AATSR skin 2-channel SST is ~ 0.3K cooler than TMI, and the AATSR skin 3-channel SST is ~ 0.2K cooler than TMI. However, there is a large regional variation in the differences, with SSTs warmer than TMI in the Northern Hemisphere and cooler than TMI in the Southern Hemisphere. The large negative differences south of 20 degrees South may be influenced by some residual cloud contamination in the AATSR data. Note that similar comparisons using ATSR-2 SSTs have given similar hemispheric patterns.

5. CONCLUSIONS AND FUTURE WORK

Comparison of the AATSR Meteo product against various SST datasets over a full year (August 2002 to August 2003) has confirmed that the AATSR instrument is performing satisfactorily. Comparisons against in situ buoy SSTs and the MOHSST and HadISST fields have confirmed that the AATSR skin and bulk SSTs are performing to the required 0.3K accuracy. However, the skin SSTs are too warm being closer to the buoy AATSR SSTs than the bulk SSTs, with the mean night-time AATSR skin SST – buoy SST at 0.05K and the mean night-time AATSR buoy SST – buoy SST at 0.23K. The same feature has been seen with HadISST1, as the mean AATSR skin SST – HadISST1 is -0.04K, compared to the mean AATSR bulk SST – HadISST1 of 0.11K.
A bias of ~0.14K in the mean between dual-view 3-channel SSTs and dual-view 2-channel SSTs has been confirmed for the years results, where the D3 SSTs are warmer than the D2. This confirms the behaviour reported in the validation report of December 2002. These biases were not removed during this work, and it is observed from comparisons that the D2 SSTs are closer to reality implying that the D3 SSTs are too warm. These differences indicate that actual day/night differences in SST from diurnal warming will be influenced by the biases in the two retrieval methods.

Future work should aim to provide a Meteo product SST which is unbiased between day and night, through empirical and theoretical studies. Firstly, the interalgorithm differences should be understood fully, and secondly a scientifically robust means of correcting them should be produced.

6. REFERENCES


7. ACKNOWLEDGEMENTS

TMI data and images are produced by Remote Sensing Systems and sponsored by NASA’s Earth Science Information Partnerships (ESIP): a federation of information sites for Earth Science; and by NASA’s TRMM science team.
Near-real time validation of the AATSR meteo-product at the Met Office

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Jim Watts, Roger Saunders, Lisa Horrocks, Nick Rayner
Met Office, U.K.

Outline

- Met Office contribution to AATSR validation
- Data chain, Met Office processing & Meteo-product availability
- AATSR validation
  - Meteo-product dual skin SSTs
  - Validation against buoys, another insitu dataset, and a climate SST dataset
- SST algorithm comparisons
- Conclusions and recommendations
AATSR validation at the Met Office

- Validation of AATSR meteo-product SST
  - against Met Office skin SSTs derived from Meteo-product BTs
  - gross checks on instrument performance in near-real time
  - comparisons against insitu buoy SSTs (weekly)
  - comparisons against MOHSST, 5 degree gridded insitu (pentads)
  - comparisons against HadISST, 1 degree global monthly SST analysis (monthly)
- Number of observations received
- Web-pages showing routine validation results
AATSR monitoring website


Password required:
Username: aatsruser
Password: sst4you

Updated daily at 0900 Monitoring plots provided two days behind time
Buoy matchups updated weekly
Monthly summary plots

If you have any queries please email AATSR_Team@metoffice.com

Glossary
AATSR Advanced Along Track Scanning Radiometer
SST Sea Surface Temperature
MOHSSST Met Office Historical Sea Surface Temperature dataset
HadISST Hadley Centre Sea Ice and Sea Surface Temperature dataset

Science performed on dual-view Skin SSTs

- AATSR is sensitive to radiative skin temperature
- insitu and HadiSST validation are measures of bulk SST (<1m)
- Skin - bulk differences arise from: skin effect; diurnal thermocline
- Skin always cooler than “sub-skin” by >0.1K
  - conduction through molecular surface layer
  - at night, sub-skin = bulk
- Diurnal-thermocline effects may be apparent during day in locations of strong insolation, low wind speed: esp at low latitudes
- Skin-bulk model applied to Met Office derived dual-view skin SSTs
- A bulk SST enables more appropriate comparisons against insitu datasets
Processing system

AATSR instrument on ENVISAT

Met Office

Processing

Second retrieval of skin SST
Obtain NWP heat flux/wind data
Skin effect model
Diurnal thermocline model
Error estimations

Bulk SST product

Validation

Buoy match-up
AATSR data averaging

Intercomparison of SSTs

Level 1b processing
Level 2 processing
— Cloud detection
— Spatial averaging
— Retrieval of skin SST
Meteo product extraction

BUFR encoding
FTP server
Meteo-product availability in near-real time

- Routine service of data from Kiruna via ESA ftp site from 19 Aug 02
  - only 8-10 orbits available per day for first ~2 months
- From 7 Nov, additional ~4 orbits per day available from ESRIN
- Some data gaps: various reasons

- Unavailability of orbits during 19 Aug 02 - 10 Sep 03 = 15.8% of total
- Product available from Kiruna or ESRIN ftp sites but NOT readable = 2.2% of total
  => product available and readable = 82% of total
- Reliability of the availability of the Meteo-product & communication of problems has improved greatly since the end of February.
Global AATSR timeseries

Number of daily global AATSR observations.

Total no. of daily AATSR obs
No. of QCed daily AATSR obs
AATSR bulk SST (2-channel retrieval)
AATSR coverage

ESA dual-view skin SST 31/08/2003 to 31/08/2003

Sea surface temperature (K)

273 281 289 297 305
Error estimates

- Each observation of estimated bulk SST assigned error estimate in Kelvins
- Use envisaged by Hadley Centre during assimilation into HadISST1

Contributions to error based on:
- number of pixels making up each 10 arc minute cell
- error contribution from SST algorithm
- error contribution due to type of skin-bulk model used
- is ice contamination a possibility within cell?

More work necessary to quantify these errors
AATSR compared to buoy SSTs

- Quality-controlled buoy data (reporting on GTS)
- Collocated to same 10 arcminute cell
- Coincident within 3 hours
- Coverage so far ~6700
- Calculate robust statistics (3-σ test)

20020819 to 20030820
AATSR compared to buoy SSTs (2)

Means for period 19 Aug 02 - 20 Aug 03:

**SKIN**
- all: 0.05 K (σ 0.41 K)
- night: 0.07 K (σ 0.35 K)
- day: 0.03 K (σ 0.46 K)

**BULK**
- all: 0.21 K (σ 0.4 K)
- night: 0.23 K (σ 0.34 K)
- day: 0.19 K (σ 0.45 K)
Regional buoy statistics (night)

- Tropical Atlantic, mean (AATSR - buoy) = 0.16K (sd=0.29, n=108)
- Indian Ocean, mean = 0.10 (sd=0.29, n=31)
- North Atlantic, mean=0.03K (sd=0.4, n=55)
- S Ocean, mean=0.02K (sd=0.38, n=237)
- W Pacific, mean=0.01K (sd=0.28K, n=77)
Validation against MOHSST
Validation against HadISST1
Validation against HadISST1

- Mean ESA skin SST - HadISST1 from 1 Sep 02 - 31 Aug 03:
  mean = -0.04K (standard dev = 0.66K)

- Mean AATSR bulk (D2d, D3n) SST - HadISST1:
  mean = 0.11K (standard dev = 0.62K)
AATSR vs TMI

Night-time, July 2003
AATSR (skin dual 3-ch) minus TMI
mean = -0.15K
S.D. = 0.56K
n = 17731

TMI data supplied by Remote Sensing Systems
Impact of AATSR in HadISST

HadISST1 reconstruction September 2003 with corrected AVHRR – with corrected AATSR

Met Office Hadley Centre for Climate Prediction and Research
Dual-view 2-ch skin SSTs compared to 3-ch skin SSTs

- Day night biases observed due to differences in D2, D3 retrievals
- Monthly mean differences:
  - D2 cooler than D3 by 0.14K (standard dev = 0.2K, number obs=9511981)
- Comparison against HadISST
  - D3 ~ HadISST (mean D3-HadISST = 0.02K, standard dev =0.58, n=242227)
  - D2 cooler than HadISST by ~ 0.14K (standard dev=0.61, n =242383)
- Comparisons against buoy SSTs
  - Cool skin not observed in night-time data, so warm bias
    » mean AATSR - buoy: 0.08K (night), 0.04K (day)
• Systematic retrieval errors result in differences between D3 and D2 AATSR SSTs

  • observed in comparisons of night-time data
  • leads to day-night biases
  • leads to AATSR SSTS biased against insitu

• Bias viewed in 2 components

  • “latitude dependent” bias (state dependent)
  • constant offset
AATSR D2-D3 SST difference

AATSR D2 minus D3, December 2002 – April 2003
Global mean = -0.16 K
Variation between -0.08 and -0.28 K
First order correlation with latitude, but note Indian Ocean
Bias against in situ

- Edinburgh coefficients
  - D2 is 0.17 K too warm
  - D3 is 0.15 K too warm => 0.02 K D2-D3 bias

- ESA pre-launch coefficients
  - D2 is 0.03 K too warm
  - D3 is 0.19 K too warm => -0.16 K D2-D3 bias

- Note: values calculated before correction of air-mass dependent retrieval error, so liable to change
Conclusions

- Meteo-product validates well against buoys and climate SST data, SSTs close to, or within expectation.
- D2, D3 algorithm difference within 0.15K
  - dual-view 3-channel skin SSTs may be slightly too warm
- Some evidence of undetected cloud in buoy matchups
Future work and recommendations

Future work:
- Continued monitoring and comparison of NRT AATSR Meteo-product
- Comparison of AATSR/ATSR2
- Comparison of AATSR/AMSR/TMI
- Continuation of processing of ATSR1&ATSR2 data to ensure ~15 year record of (A)ATSR SSTs

Recommend:
- further work to correct dual-view interalgorithm bias and implement in ESA processor
INTRODUCTION

The Advanced Along Track Scanning Radiometer (AATSR) is the third in a series of dual-view radiometers designed to measure sea surface temperature (SST) globally. The instrument concept [1] employs infra-red channels centred at 12, 8 and 3.7 µm (nighttime) to obtain intrinsic sensitivity to thermal emission from the surface and hence surface temperature; the 3.7 µm radiances in the daytime include reflected solar radiation. Atmospheric contributions to the signal are strongly reduced by the use of combined viewing of the same scene at nadir and at 55 degrees. Under conditions where the emissivity of the scene can be assumed to be angle independent and homogeneous in the field of view, then the difference between dual and nadir measurements is governed by the differing atmospheric path length. This assumption works well for ocean scenes from which SST can be derived with a target accuracy of 0.3 K globally (one sigma).

A particular driver for understanding the accuracy of AATSR SST data is the need to identify the following: (a) instrumental drift in order to be able to determine global trends of sea surface temperature over time with as high confidence as possible (0.1 K/decade knowledge of instrument drift required); (b) regional patterns of climate change in order to improve both knowledge of regional contributions to global trends and to improve “fingerprinting” of climate change. A complicating factor is that there are a number of regions of the world in which comparisons with other datasets reveal discrepancies and where AATSR measurements must be carefully validated. These potential variations in accuracy are a function of season and year (i.e. dependent on sea surface and atmospheric parameters such as water vapour, aerosol and cloud) and hence the validation must be performed over long timescales.

Although the AATSR instrument measures globally on each day through 14 orbits of 512 km swath, the most exacting validation is performed by precision radiometer measurements occurring under strict coincidence criteria and clear skies. However, it is important also to understand the characteristics of AATSR data globally and at regional scales in order to be able to test the quality of the data, to identify the components of uncertainty that dominate the error budget, and to determine the ultimate accuracy achievable with the AATSR instrument. Comparisons to other global satellite sensors and to operational analyses are an important mechanism for investigating these aspects of the datasets produced.

In identifying the global/regional characteristics of AATSR data, premium has been placed so far on the analyses of data during the initial validation period. One of the clear implications of these results was the need to understand the patterns observed for the period in the context of those expected from a longer time series. Work to construct such a series for AATSR is on-going but will take time and further data acquisition for a dataset of order two years or longer. In this paper, data from a predecessor instrument, ATSR-2, are also examined to provide a long-term context in which to place seasonal global comparisons. Eventually, the ATSR-2 comparison work will also be compared to the equivalent AATSR analyses to demonstrate consistency between the two instruments.

GLOBAL ANALYSES OF AATSR DATA

A number of global fields are available for comparison to the AATSR and ATSR-2 instruments. Satellite measurements include those of the Advanced Very High Resolution Radiometer (AVHRR), MODerate Resolution Imaging Spectroradiometer (MODIS) and the Thermal Microwave Instrument (TMI) instruments exploiting mainly infrared but also microwave measurements in the case of the TMI. Meteorological analyses are available and sea surface temperature calculated from the European Centre for Medium Range Weather Forecasting (ECMWF) model have been employed. The datasets considered have all been averaged to monthly means at half-degree resolution. For the purposes considered here, it is reasonable to average day and night data together since the comparison is performed...
to illustrate the mean characteristics of all AATSR data. However, it should be remembered that there can be biases between the two conditions, not least because the 3.7 µm channel can only be employed at night. The AATSR data employed have all been taken from the spatially averaged AATSR data that is produced at ten-arc minute resolution (ATS_AR_2P [2]) and averaged here to half-degree resolution. Outputs from the comparisons of AATSR with other instruments include global and regional scale difference images, statistics and temperature difference distribution plots. Given a time series of data, changes in temperature difference between datasets can also be plotted and analysed.

Preliminary global comparisons of AATSR data during the initial validation period have been performed with MODIS, TMI and ECMWF data. An example is shown here for AATSR compared to MODIS (V3) for September 2002; the MODIS data are derived from 11 and 12 µm channels. The plot shows that whilst there is reasonable agreement on average across the globe, there are significant areas of both positive differences and negative differences ranging up to 1.5 K in magnitude. Large positive differences can be seen off the west coast of Africa and in the Red Sea. Large negative differences can exist in the Southern Atlantic but possibly also in high Northern latitudes. The differences between AATSR and MODIS are approximately Gaussian in nature for global data and the mean is 0.4 K with a one sigma spread of values of about 0.6 K.

![Fig. 1: A comparison of AATSR and MODIS monthly means for September 2002. Positive numbers indicate that AATSR SSTs are warmer than those produced by MODIS.](image)

### TEMPORAL EVOLUTIONS OBSERVED IN ATSR-2 DATA

The comparison shown in Figure 1 is revealing because it suggests that there might be geophysical regimes associated with the observed differences. It was decided to examine ATSR-2 data to identify such regimes and to utilise seasonality to support identification of atmosphere/ocean effects as opposed to instrument effects. For the ATSR-2 instrument, the main source of data has been the spatially averaged product available at V3.21 at ten arc minute resolution. Fifteen months of data were averaged to monthly means at half-degree resolution starting from January 1999 and ending in January 2002. All data were compared to equivalent datasets from AVHRR (V4.1). The length of the dataset was sufficient to provide good coverage of the seasonal evolution of differences in sea surface temperature between the two instruments.

Examination of the difference fields over the full two years allowed a large number of regimes to be identified. These have been described using a series of boxes of specified latitude and longitude whose average behaviour can then be examined over time. The nature of the boxes is intended to isolate regimes of geophysical behaviour although it is possible that instrument performance could also significantly affect the results of a particular box. Thirty-eight boxes have been employed so far and these are displayed in Fig. 2. They include regions that display very good agreement between ATSR-2 and regions of poorer agreement.
Fig. 2: Thirty-eight boxes in latitude and longitude selected on the basis of regional differences between ATSR-2 and AVHRR data.

Fig. 3 shows results for Box 1, which isolates a region of the South Eastern Pacific. The plot displays the absolute monthly mean SST difference between AATSR and AVHRR. In this region, the agreement between ATSR-2 and AVHRR is excellent. The monthly error is less than 0.3 K consistently throughout the whole time period. Similarly excellent agreement is found for regions such as the South Atlantic to a large extent (a small departure from consistency was found for December 2000).

Fig. 3: Time evolution of the absolute monthly mean difference in SST observed for ATSR2 data minus AVHRR data. Data shown are for Box 1 in the South East Pacific.

Other areas show much stronger seasonal residual differences, with r.m.s. differences of up to 0.3 K between ATSR-2 and AVHRR. In this paper, two areas are discussed for which the effects of atmospheric aerosol are shown to be the controlling factor: Box 28 which extends from the West Coast of Africa westwards towards the Caribbean, and Box 14 covering the Red Sea.
Fig. 4: Time evolution of the absolute monthly mean difference in SST observed for ATSR2 data minus AVHRR data. Data shown are for box 28 in the tropical Atlantic Ocean to the west of Africa.

Fig. 4 shows the results for Box 28. The data show a strong seasonal effect to the residuals with strong peak differences in the time period from June to September in each year. Examination of maps revealed the westward progression of the anomalies and is consistent with the presence of Saharan dust aerosols, which have absorption features in the mid-infrared. The finding appears to be confirmed by the correlation with TOMS aerosol data for which a gradient of 0.474 +/- 0.002 was found. A similar gradient (0.471 +/- 0.001) is deduced from correlation of the ATSR-2 dual minus nadir SST fields, the assumption here being that ATSR-2 nadir data are similar in nature to MODIS data. The effects are also seen to the east of the Sahara desert. Fig. 5 shows the results for Box 14, which is centred on the Red Sea (and only contains “SST” values). Again a strong seasonality can be seen with strong peaks in the May to July of each year. Note the differences between the strength of the differences between the two years, which are in the opposite sense to those seen in Figure 4. A correlation with TOMS aerosol data reveals a very strong correlation with a gradient of 0.480 +/- 0.013 which is very close to that derived earlier for westward advected Saharan dust.

Fig. 5: Time evolution of the absolute monthly mean difference in SST observed for ATSR2 data minus AVHRR data. Data shown are for box 14 which covers the Red Sea.

SUMMARY

Global comparisons of AATSR with other sensors have been shown to be an important tool for understanding the quality of AATSR data on global and regional scales. It has been demonstrated that there are strong regional variations in the comparison between ATSR-2 and AATSR on the one hand and MODIS and AVHRR on the other hand. The instruments compare well globally and in regions such as the South Eastern Pacific. However this is less true of regions where Saharan dust aerosols are an influence. It has not been possible in this work to demonstrate that the (A)ATSR retains its accuracy when Saharan dust aerosol are present, but it has been possible to show, by analogy with ATSR dual and nadir STTs, that Saharan dust does cause errors in SST derived from single view instruments. The time dependence of the differences between instruments has also proved to be important, emphasizing that global comparisons and validation should be diagnosed over seasons and years at regional scales.
FUTURE WORK

A significant amount of work is planned to derive the full benefit from the global/regional analyses described above. Four main areas of work are envisaged.

1. Regular comparisons and diagnoses of global data fields will be performed using similar global fields from other sources e.g. AVHRR, MODIS, TMI and ECMWF. A key aim will be to identify and categorise regions of variability in the inter-comparisons and identify magnitudes of deviations, time dependences (e.g. seasonality) and geophysical regimes that lead to the differences.

2. Further diagnostic analysis of results already obtained will be carried out, especially with respect to regional and seasonal variations in performance of AATSR.

3. The regional results from comparisons of global fields will be extended to define priorities for field campaigns by examination of a) SST differences between AATSR and other sensors b) understandings of the effects through correlations with geophysical variables c) investigations of cloud cover frequencies.

4. Global field comparisons will also be extended to internal diagnostic tests. These are intrinsic aspects of validation that need further characterisation since errors in the internal quantities on a global or regional scales would indicate uncertainties in radiative transfer assumptions or instrument calibration issues. Ultimately such errors define the expected accuracy of AATSR for use in global and regional climate trend studies.

ACKNOWLEDGEMENTS

This work has been supported in part by a contract from the Department of the Environment, Food and Rural Affairs (Defra). The authors would like to thank Dr. G. Corlett (AATSR Validation Scientist) and the AATSR Validation Team for helpful comments and discussion. The authors would like to acknowledge the European Space Agency for the operation of ENVISAT and for access to the data.

REFERENCES


Global Comparison of (A)ATSR SST Datasets with other Sensors

John J. Remedios, J. Aylmer-Brewin, D. Levett, B. Mannerings, M. Edwards, and D. Llewellyn-Jones

EOS-SRC, Dept. of Physics and Astronomy
University of Leicester, U.K.
Why compare global datasets?

- Obtain a global figures of merit for the performance of the AATSR sensor
- Obtain global statistics on the comparison of AATSR to other instruments
- Determine regional characteristics of the AATSR datasets
- To provide information on the time evolution of regional tendencies.
- Isolate issue of atmospheric correction which may impact the quality of the data
- To deliver quantitative information for the planning of validation activities such as campaigns and regular cruises.
Comparison of global monthly mean AATSR SST data with:-

- MODIS (infra-red)
- TMI (microwave)
- ECMWF (meteorological assimilation analysis)

To date, comparisons performed between AATSR data and MODIS, ECMWF and TMI for September 2002

Data compared are monthly means, at half degree resolution

AATSR data used: spatially averaged product, dual view SST retrieval, all available data
- Mean global difference: -0.41 deg K (MODIS warmer)
- Tropical region (+/- 30 degrees)
  - Mean difference: -0.41 deg
  - Percentage of values between +/- 0.6 deg K: 65.63

MODIS: 36km, SST from 11 micron day/night
- Mean global difference: -0.38 deg K (TMI warmer)
- Mean absolute difference: 0.50 deg K
- Standard deviation: 0.55 deg K
- Tropical region (+/- 30 degrees)
  - Mean difference: -0.42 deg K
  - Standard deviation: 0.50 deg K
  - Percentage of values between +/- 0.6 deg K: 68.48

TMI data: 0.25 degree
Binned to half degree for comparison
Mean global difference: -0.05 deg K
Mean absolute difference: 0.88 deg K
Standard deviation: 1.43 deg K
Tropical region (+/- 30 degrees)
  • Mean difference: -0.40 deg K
  • Standard deviation: 0.88 deg K
  • Percentage of values between +/- 0.6 deg K: 55
AATSR dual view SST

AATSR minus MODIS

AATSR minus TMI

AATSR nadir only SST
AATSR dual SST minus AATSR nadir SST
- Important to place AATSR results in context of longer timescale of differences (evolution)

- The ATSR-2 data should display a similar behaviour to AATSR so a more detailed study has been performed with this dataset.

- Main comparison point here is AVHRR

- Concentrate on two effects
  - Time evolution
  - Aerosol

- Data compared are monthly means, at half degree resolution.

- ATSR-2 data used: spatially averaged product, dual view SST retrieval, all available data.
- Global difference fields analysed at regional level
- Histograms produced and mean differences examined over time.
Ability to analyse differences over several months

Average SST Difference Between ATSR-2 And AVHRR Over CUBA

07/2000  01/2001
Mean (absolute SST difference) over time

Average SST Difference Between atsr2 And avhrr Over box1

Area Distribution of Temperature Differences 2000Q4

Area Distribution of Temperature Differences 2000Q12

% +/-0.3K    % +/-0.6K    % +/-1.0K
85.040       98.203      99.812

% +/-0.3K    % +/-0.6K    % +/-1.0K
61.854       90.563      99.058

Validation Workshop, 23rd October 2002, ESRIN
Mean (absolute SST difference) over time
Mean SST difference over Time

Average SST Difference Between atsr2 And avhrr Over box0

Summer time peaks
Month of greatest agreement: 01/2000

Month of worst agreement: 07/1999

% +/-0.3K  % +/-0.6K  % +/-1.0K
50.969    88.075    99.092

% +/-0.3K  % +/-0.6K  % +/-1.0K
25.681    48.494    72.956
Mean SST difference over time

Winter time peaks
Box 8 - North Pacific

Average SST Difference Between atsr2 and avhrr Over Box8

-ve Differences
Followed by
+ve Differences

2000 Months 6&7
Box 8

2000 Months 6&7
Box 27
Mean SST difference versus Time

Correlation=0.79

TOMS Aerosol Index versus Time
Scatter Plot of Mean SST Difference versus Aerosol Index Over the Red Sea

Aerosol vs SST Difference for atsr2 minus avhrr

Gradient = 0.480 +/- 0.013
Intercept = 0.025 +/- 0.0093
Chi-squared = 610.05987

Pixel by Pixel Correlation = 0.544
Dust Storm over Red Sea
(MODIS) August 14th 2003

http://naturalhazards.nasa.gov/
DUAL-NADIR ATSR-2 SST

TOMS AEROSOL
TOMS aerosol index vs ATSR2 dual-nadir SST difference

Aerosol vs SST Difference for atsr2_dual minus atsr2_nad

Gradient = 0.471 +/- 0.002
Intercept = -0.194 +/- 0.0007
Chi squared = 15341.701
## SST-AOI comparisons

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<td>ATSR-2 Dual minus Nadir</td>
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Conclusions

- Preliminary comparisons performed for AATSR data and SST from ECMWF analyses, MODIS and TMI data, for September 2002
- Longer term context provided by ATSR-2 comparisons.
- Key aspects: areas of good agreement, areas of poor agreement.
- Need to include atmosphere and surface conditions in defining regimes of behaviour. These can often be of quite small scales.
- Comparisons with buoy data under similar box system would be revealing
- Comparisons with precision radiometers will also help
- Next steps:
  - Long term analyses of AATSR data
  - Campaign planning
ABSTRACT
Instruments mounted on Australian research vessels and an operational passenger ferryhave provided three extensive data sets that are used to assess the performance of the Advanced Along Track Scanning Radiometer (AATSR) instrument and the theoretical algorithms that are used to provide estimates of sea surface temperature (SST) from the AATSR data. The DAR011 infrared radiometer was deployed on the RV Lady Basten for four short cruises in mid-2002 and on the RV Southern Surveyor for a 32-day cruise in the Gulf of Carpentaria in mid-2003. The radiometer data were complemented with meteorological and bulk SST measurements throughout the cruises. For the 2003 cruise twenty AATSR scenes were obtained over the Gulf of Carpentaria and ten of these provided coincident data with the ship location. Four coincidences were cloud-free, providing good match-ups with the AATSR SST estimates. Infrared and microwave data were also collected from seven other satellite instruments (including ATSR-2) allowing comparisons with AATSR data on a larger spatial scale.
A radiometer and bulk SST measuring device have been installed on a passenger ferry that makes regular trips between the west Australian coast and Rottnest Island. 1134 transects have been made over the seven-month period between November 2002 and May 2003. While there have been some teething problems with the radiometer the bulk SST measurements have provided a large valuable data set for comparisons with AATSR measurements. 270 cloud-free coincidences between the AATSR and the ferry data were obtained.
Results from the three data sets confirm that the AATSR is providing SST estimates well within the required specifications.

INTRODUCTION
Australian scientists have been involved in the ATSR series of instruments since the start of the program in 1980. Part of that involvement has been in the supply of geophysical validation data for the sea surface temperature (SST) derived from these instruments. Details of such data collected for the first ATSR instrument are described in [1]. Further data were collected for ATSR-2 [2], and the latest contributions are for the AATSR on ENVISAT. Three separate activities have been undertaken to provide SST validation data for ongoing quality assessment of the AATSR SST products.

VALIDATION INSTRUMENTATION

DAR011 Infrared Radiometer
The DAR011 radiometer is a single-channel, self-calibrating, infrared radiometer developed and built within CSIRO. The radiometer has a heritage going back many years and is the culmination of developments leading to a reliable accurate instrument. Full details of the instrument are provided in [3]. A rotating 45 degree plane mirror sequentially views the sea, a hot black body calibration target, the sky, and finally an ambient temperature black body calibration target. The incoming radiation is physically chopped against a second ambient temperature black body and the chopped radiation is focused with a 45 degree parabolic front surfaced mirror onto a pyroelectric detector. Before reaching the detector the radiation passes through an interference filter that passes radiation with wavelengths between 10.5 and 11.5 µm. The temperatures of the two calibration black bodies are accurately monitored providing excellent absolute radiometric accuracy.
During 2001 the DAR011 radiometer was included in the Miami2001 infrared radiometer calibration and inter-
comparison. The radiometer was calibrated against a NIST-designed black body target, and compared against other 
similar instruments used for the validation of satellite-derived surface temperatures, and found to perform with a high 
degree of accuracy. Results from the Miami2001 exercise are reported in [4] and [5].

New TASCO-based Radiometer in Perth

A new radiometer system has been developed for the Perth-Rottnest Island ferry the “Sea Flyte”. The system is based 
on a TASCO radiometer which is mounted in a housing that allows a view of the water outside the ferry wake in normal 
operations. The radiometer section can be fully sealed when the ferry is in port allowing fresh-water washing of the 
system. While under way a fan provides a positive pressure within the housing and the air stream expressing from the 
view port prevents any water or spray from entering the unit, and a GPS system is included for navigation. Downwelling sky radiance is measured at a coastal site to give a correction for clear sky emissivity. Within the 
radiometer housing the TASCO radiometer is mounted in a detachable unit allowing easy replacement and laboratory 
calibration. The TASCO lenses are susceptible to degradation in a marine environment and are replaced at least once 
per month. Calibration is undertaken using a portable black body target. This can be done in situ (on the ferry) or in 
the laboratory. This radiometer system is still undergoing initial testing and has not yet been used in AATSR SST 
validation.

Bulk SST Measurements

A well-calibrated platinum resistance thermometer (PRT) was deployed from the RV Lady Basten during the 2002 
validation cruises. The PRT was mounted under a small wooden block and measured the water temperature at a depth 
of approximately 0.05 m.

A well-calibrated PRT is mounted in the engine water intake system of the “Sea Flyte” and provides the SST at a depth 
close to 1 m.

The bulk SST on the Southern Surveyor is measured continuously by the ship’s thermostalnograph with the water 
take being at a depth of 3 m.

THE RV LADY BASTEN CRUISES

The DAR011 radiometer was deployed on the RV Lady Basten for four cruises during the following periods –

- May 24 to June 02, 2002
- June 05 to 14, 2002
- September 19 to 28, 2002
- October 21 to 30, 2002.

ATSR-2 and AATSR data were obtained to cover these cruises and clear-sky match-ups extracted for validation 
analysis. The ATSR-2 results have already been reported in [6]. For AATSR a total of eight match-ups were obtained – one for each of the first three cruises and five for the last cruise. The DAR011 radiometer data were corrected for the non-unity emissivity of the ocean surface and then averaged over one-minute intervals. The AATSR brightness 
temperatures were used to provide SST estimates using two, three, four and six channels of data for night-time match-
ups, and two and four channels of data for the daytime. The results are presented in Table 1 and Fig. 1. The figure 
includes values for the bulk-skin temperature difference.

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THE PERTH FERRY DATA ANALYSIS

Underway data have been collected on the ferry “Sea Flyte” for the period November 2002 to May 2003. The ferry undergoes maintenance during the winter months of June and July and is expected to resume operations in the austral spring of 2003. The ferry undertakes several trips every day either to Rottnest Island or further north on whale-watching trips. On each transect the bulk temperature, as measured by the calibrated PRT, is recorded and the data logged to a data recorder. Data are downloaded each week and have been analysed to compare with satellite measurements.

The ferry data have initially been condensed into 1-minute averages along the transect. These data have then been further condensed by dividing each transect into five bands based on longitude. Data in the two bands that are closest to the mainland coast and next to Rottnest Island have been discarded, and the remaining data in each of the three longitude bands have been averaged for each transect. In the period between November 1, 2002 and May 31, 2003 there were 1134 ferry transects available for match-ups with AATSR SST estimates. The three bands used in the validation analysis are between longitudes 115.59 E, 115.62 E, 115.65 E, and 115.68 E. Usually between 3 and 5 one-minute readings are available in each longitude band.

The UK-PAC has supplied AATSR Level 2 SST data at 1 km spatial resolution. The data are included in the ATS_NR_2P data files and are supplied on CD-ROMs. The distributed SST products include data flags that indicate whether the value in the data file is an SST value or some other parameter. The flags also indicate whether the forward and nadir views were clear or cloudy. In this analysis only those SST values in which both the nadir and forward views were flagged as clear have been included in the analysis.

For each AATSR SST value the ferry data were scanned to obtain all measurements of bulk SST collected on the same day. In all 266 coincidences were obtained and the differences between the ferry and AATSR SST values are plotted in Fig. 2. The analysis was also restricted to differences between the ferry and AATSR measurement times of less than 2 and 1 hours. The results are plotted in Fig. 3 and Fig. 4 respectively. For the all-day data set the ferry minus AATSR data showed a bias of 0.31 K and an rmse of 0.54 K. For the 2-hour and 1-hour data sets the number of match-ups reduced to 142 and 78 respectively and in both cases the bias reduced to 0.19 K and the rmse to 0.48 K. In all three cases the bias values are acceptable as the comparison is between a skin SST estimate from AATSR and a bulk SST measurement from the ferry. Under normal conditions, with a well-mixed upper ocean layer, the bulk-skin temperature difference is expected to be between 0.15 and 0.3 K [7]. The three figures displaying these results show occasions when the differences are both larger and smaller than the expected value. For those cases in which the AATSR estimate

Fig. 1. SST validation results for the Lady Basten cruises of 2002.
is higher than the bulk temperature it is possible that there was some diurnal heating near the surface under light wind conditions. When a full data set of local wind speeds is available this possibility will be explored. In the other cases, when the AATSR estimate is too low, the possibility of cloud contamination of the AATSR data will be explored.

The above analysis also included AATSR SST values derived using the nadir data only. In all three cases the nadir-only AATSR SST was considerably warmer than the dual-view case. Fig. 5 shows the difference between the nadir-only and dual-view AATSR estimates for the < 2 hour data set. This difference, and its variation throughout the seven-month data collection period, needs further investigation.

THE GULF OF CARPENTARIA CRUISE

During May and June 2003 the RV Southern Surveyor was operating in the Gulf of Carpentaria to the north of Australia. The DAR011 radiometer [3] was installed on the vessel and radiometric measurements of the skin SST were obtained on most days at the local times of 0800-1200 and 2000-2400. The ship was fitted with a thermosalinograph and a full suite of standard meteorological instruments and data from these were collected for the entire cruise. AATSR data were supplied by the UK-PAC, and for this analysis the ATS_TOA Level-1B infrared brightness temperatures were used. Careful checks on the collocation of the nadir and forward views, using coastline features, occasionally led to some minor forward-view adjustments of no more than 1 pixel in both the across-track and along-track directions. The standard ESA AATSR SST algorithm coefficients were used with the brightness temperatures to produce the four SST estimates for the 2-, 3-, 4-, and 6-channel algorithms. These estimates were also averaged over 3x3 and 5x5 pixel windows giving a possible 12 SST values for each coincidence.
Table 2. AATSR SST validation results for the Gulf of Carpentaria cruise. T/S is the thermosalinograph bulk SST, DAR is the sky-corrected DAR011 skin SST, Pix is the AATSR pixel number, and the SSTn are the four AATSR SST values averaged over 5x5 pixels.

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Fig. 6. AATSR SST validation results for the Gulf of Carpentaria cruise.

The DAR011 radiometer measurements were corrected for non-unity sea surface emissivity and then averaged over 1-minute intervals. Coincidences between the AATSR data and the ship measurements were isolated and the AATSR brightness temperature fields were then scanned to ensure that the sky in the vicinity of the vessel was free from clouds. After this analysis was completed there were four occasions with coincident data from the AATSR and the DAR011. The data are presented in Table 2 and the AATSR-DAR011 differences are shown in Fig. 6.

In Table 2 the AATSR SST values are those averaged over 5x5 pixels. SST-3 and SST-6 are not produced for the daytime case. The results in Fig. 6 show that all the estimates for both AATSR and ATSR-2 are within the 0.3 K target and the mean difference is 0.12 K for both instruments. The data shown in Fig. 1 for the Lady Basten cruises suggests that the 6-channel algorithm provides higher values than the 4-channel case. If the daytime data point is excluded from the analysis then the 6-channel algorithm gives a mean difference of 0.08 K.

AATSR AND AVHRR IMAGE COMPARISONS

During the Gulf of Carpentaria cruise satellite data were also collected from seven other instruments providing estimates of SST. A full analysis and inter-comparison of these data sets will be undertaken in due course. For AATSR SST validation the SSTs derived for two different nights have been compared with those from the AVHRR on NOAA-16 over a 2.5° x 2.5° latitude-longitude area. The satellite SST images have been remapped onto a 0.01° x 0.01° grid (approximately 1 km) to enable easy comparison. For the night of May 28 the two satellite images are shown in Fig. 7. The differences between the SSTs from the two satellites are displayed in a simple histogram in Fig. 8. The histogram for a second night (25th May) is also shown in Fig. 9.
AVHRR data were collected throughout the cruise and analysed using the standard NOAA operational SST algorithms. Due to operational limitations DAR011 data were not collected during AVHRR overpass times so the SST data have been compared to those from the thermosalinograph. Comparisons with the AVHRR on NOAA-16 give a bias of -0.07 K (AVHRR warmer) and an rmse of 0.51 K. The 0.2 K difference between the AVHRR bulk SST and the AATSR skin SST as shown in Fig. 8 and Fig. 9 is consistent with the bulk –skin temperature difference observed during the night [7]. This is excellent agreement given that the AATSR data were recorded some 4 to 5 hours before the AVHRR. The spread of the difference histograms is also acceptable as the AVHRR brightness temperatures are 10-bit data - equivalent to approximately 0.1 K. With typical AVHRR SST algorithms this translates to a digitisation “noise” in the SST fields of 0.3 to 0.5 K.

**CONCLUSIONS**

The three Australian activities described in this paper have all produced valuable data to confirm that the AATSR is providing SST estimates well within the design specifications. Both the Lady Basten and Southern Surveyor (Gulf of Carpentaria) results suggest that AATSR estimates are 0.12 K colder than those from the DAR011 radiometer. The Perth ferry data analysis gives AATSR dual-view SST values that are, on average, 0.31 K colder than the ship bulk temperature measurement. This is consistent with a skin-bulk temperature difference of 0.2 to 0.3 K.
The AATSR analyses have shown some differences in the four different SST algorithms. The dual-nadir (4-channel vs 2-channel) algorithm differences observed in the Perth data set, and shown in Fig.5 needs urgent attention. The re are also differences between the 6- and 4-channel algorithms that also needs attention (see the Lady Basten results in Fig. 1 and the values listed in Table 2).

Finally, the abundant results from the Perth ferry show the advantage of installing instruments on regular ferry services instead of their use on occasional research voyages. When the new radiometer installation on the Sea Flyte is operational it is expected that the number of coincidences between AATSR SST estimates and radiometric skin temperature measurements will increase dramatically.

ACKNOWLEDGEMENTS

The Australian Institute of Marine Science has provided access to the RV Lady Basten and the assistance of the master and crew in the collection of the ship-based data is gratefully acknowledged. The DAR011 radiometer on the RV Southern Surveyor was operated by Stephen Thomas and Pamela Brodie, and their assistance in collecting the SS0403 data set is also gratefully acknowledged. The operators of the Sea Flyte ferry in Perth provide a wonderful platform for obtaining ground truth data for satellite comparisons. Their help and perseverance with this project is much appreciated. The TOA and NR AATSR data products have been supplied by ESA.

REFERENCES

Validation of AATSR-Derived SST in Australian Waters

Ian Barton$^1$ and Alan Pearce$^2$

$^1$CSIRO Marine Research, Hobart, Tasmania, Australia
$^2$CSIRO Marine Research, Perth, Western Australia

Presentation to the ENVISAT Validation Workshop
ESA/ESRIN, Frascati, Italy, 20-24 October 2003
AATSR SST Validation Campaigns


2. TASCO-based radiometer on the Rottnest Island ferry.

1. DAR011 Radiometer on the RV Lady Basten

Four cruises on the RV Lady Basten all Townsville-Townsville and operating near the Great Barrier Reef

- 24 May - 2 June, 2002  1  Val. points
- 5 - 14 June, 2002  1  Val. points
- 19 - 28 September, 2002  1  Val. points
- 21 - 30 October, 2002  5  Val. points
ATSR-2 validation results from 2 Lady Basten cruises

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<td>24.10</td>
<td>23.48</td>
<td>24.13</td>
<td>00.00</td>
</tr>
</tbody>
</table>

NOTES:
Dates and times are local. EST is 10 hours ahead of UTC.
PRT is bulk SST from Platinum Resistance Thermometer
DAR is sky-corrected skin SST from DAR011 radiometer
Tasco is sky-corrected skin SST from Tasco radiometer
NAD is nadir-only ATSR-2 SST from *.GSST-LXC file
DUA is dual-view ATSR-2 SST from *.GSST-LXC file
SST4* is four-channel ATSR-2 SST with manual alignment of two views
SST6* is six-channel ATSR-2 SST with manual alignment of two views

* Merchant SST coefficients used.
AATSR validation results from the Lady Basten cruises

<table>
<thead>
<tr>
<th>dd</th>
<th>mm</th>
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<th>Lat (S)</th>
<th>Lon. (E)</th>
<th>PRT</th>
<th>DAR</th>
<th>Pix</th>
<th>SST2</th>
<th>SST3</th>
<th>SST4</th>
<th>SST6</th>
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<td>25.72</td>
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</table>
2. Perth to Rottnest Island ferry

- Radiometer based on a TASCO radiometer
- Calibration using a portable black body target
- Ferry operates 4 to 6 times daily
- Bulk SST measured with water intake PRT
- Position logged with GPS
- Sky radiance from shore-mounted radiometer
Ferry transect – Hillarys to Rottnest Is.
Perth ferry data analysis

- AATSR SST values are those supplied in L2 data files named ATS_NR_2P with the quality flag showing clear sky in both views.
- Eight months of data - October 2002 to May 2003
- 1134 ferry transects mainly from Hillarys Marina to Rottnest Island – but some whale-watching trips.
- Bulk SST from the intake PRT. No radiometer data.
- Transects split into five longitude zones between Hillarys and Rottnest, and the PRT data were averaged in each of these zones for each transect. Usually 4 or 5 one-minute readings in each zone. First and last zone discarded to give three data points for each transect.
All day, n=265

* Nadir  Bias=-0.45, Std dev=0.62
X  Dual   Bias=+0.31, Std dev=0.54
DT < 2 hr, n=142

* Nadir  Bias=-0.56, Std dev=0.62
X Dual    Bias=+0.19, Std dev=0.48

Sample number. November 2002 to May 2003
dT < 1 hr, n=75

* Nadir  Bias=-0.56, Std dev=0.62
X  Dual   Bias=+0.19, Std dev=0.48

Sample number.  November 2002 to May 2003
dT < 2 hr
3. DAR011 on Southern Surveyor
SST Validation in the Gulf of Carpentaria

Acknowledgements to –
Pamela Brodie, Stephen Thomas (CSIRO) – for collecting the ship data
Chris Rathbone – for AVHRR data analysis
Ken Suber – for MODIS data analysis
NASDA – GLI data provision
NASA – MODIS data
Chelle Gentemann (RSS) – access to AMSR-E data
ESA/RAL – AATSR and ATSR-2 data
RV Southern Surveyor – Voyage SS0403

Cairns to Darwin, 9 May – 10 June

DATA SETS –
- DAR011 most days 0800-1200 & 2000-2400 EST
- Thermosalinograph – complete record
- Navigation - full record from GPS
- Met data – Licor, wind & ship velocity, Ta, Q
## Satellite data sets

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Total</th>
<th>Ship match-ups</th>
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</thead>
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<td>AVHRR</td>
<td>49</td>
<td>36</td>
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<td>NOAA-16</td>
<td>AVHRR</td>
<td>47</td>
<td>42</td>
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<tr>
<td>TERRA</td>
<td>MODIS</td>
<td>47</td>
<td>25</td>
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<tr>
<td>AQUA</td>
<td>MODIS</td>
<td>47</td>
<td>28</td>
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<tr>
<td></td>
<td>AMSR-E</td>
<td>30</td>
<td>8</td>
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<td>ADEOS-2</td>
<td>GLI</td>
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<td>ERS-2</td>
<td>ATSR-2</td>
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<td>4</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>AATSR</td>
<td>18</td>
<td>4</td>
</tr>
</tbody>
</table>
Gulf of Carpentaria
GLI  25 May 2003
Satellite-derived SST validation against ship data

- Bulk SST from the ship thermosalinograph is available for the entire cruise
- DAR measurements have been corrected for surface emissivity and averaged into 1-minute intervals
- AVHRR x 2, MODIS, MYDIS, AMSRE, and GLI have all been compared with Bulk SST
- AATSR and ATSR-2 have been compared with radiometric SST from the DAR011 radiometer
- A bias and standard deviation is given for each instrument.
ERS-2 ATSR-2    Mean diff = -0.09
ENVISAT AATSR    Mean diff = -0.12
TERRA MODIS
Bias 0.53  Std Dev 0.63

AQUA MYDIS
Bias 0.76  Std Dev 0.65

NOAA-12 AVHRR
Bias -0.42  Std Dev 0.77

NOAA-16 AVHRR
Bias 0.07  Std Dev 0.51
AQUA AMSR-E
Bias 0.05  Std Dev 0.67

ADEOS-2 GLI
Bias 0.10  Std Dev 0.25
Satellite image data inter-comparisons

- All infrared satellite data have been re-mapped onto a 0.01 x 0.01 degree latitude-longitude grid
- AMSR-E data at 0.25 degree resolution have been duplicated to provide a value at each 0.01 degree grid point
- Image areas of 2.5 x 2.5 degrees in latitude and longitude have been compared
- Histograms of SST differences from pairs of instruments have been plotted
- In some images an offset has been subtracted from the image data for image comparisons
Important factors

GLI - Using latest algorithm provided by Hiroshi Kawamura
  - De-striping factors are all unity
  - Bow-tie effects have been removed in L1B data

MODIS & MYDIS -
  - Bow-tie effects removed when re-mapped
  - Algorithms not the latest version

AATSR -
  - Uses the official ESA algorithms
  - Offsets of 1 pixel, 1 line often required in collocation
28 May 2003
Night - EST
AVHRR – 0300
AATSR – 2200
MODIS – 2230
AMSRE – 0200

15.5–17.0 °S
138.5–141.0 °E
AVHRR – AATSR = 0.2 °C

AVHRR – MODIS = -1.5 °C

AVHRR – AMSRE = -1.2 °C
25 May 2003
Night - EST
AVHRR – 0330
AATSR – 2200
MYDIS – 0200
GLI – 2230

15.5–17.0 °S
139.5–142.0 °E
AVHRR – AATSR = 0.2 °C

AVHRR – MYDIS = -1.5 °C

AVHRR – GLI = -0.3 °C
7 June 2003
Day - EST
AVHRR – 1500
MODIS – 1030
GLI – 1030
AMSRE – 1400
15.5–17.0 °S
138.5–141.0 °E
AVHRR – MODIS = -0.8°C

AVHRR – GLI = 0.0°C

AVHRR – AMSRE = 0.5°C
Summary from SS0403 data set

• Navigation of all instruments is very good
• AVHRR and AATSR show excellent agreement both with each other and with ship data
• MODIS instruments too warm by ~ 1 K (SST algorithm is under review)
• AMSR-E has shown a day/night anomaly – needs further checking
• GLI shows striping effects due to detector array as well as some slowly varying electronic effect. JAXA is working to remove these effects
• AVHRR – NOAA-12 is inferior to NOAA-16
Summary from the 3 Validation Campaigns

BIAS  AATSR against DAR011

<table>
<thead>
<tr>
<th>Ship</th>
<th>SST-4</th>
<th>SST-6</th>
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</thead>
<tbody>
<tr>
<td>Lady Basten</td>
<td>0.16 too cold</td>
<td>0.12 too warm</td>
</tr>
<tr>
<td>Sea Flyte*</td>
<td>0.19 too cold</td>
<td>*</td>
</tr>
<tr>
<td>Southern Surveyor</td>
<td>0.17 too cold</td>
<td>0.06 too cold</td>
</tr>
</tbody>
</table>

* Against Bulk SST
Conclusions from AATSR Validation campaigns

• ATSR-2 is still supplying high quality data after 7 years in orbit
• Initial comparison of AATSR SST estimates with ship data show excellent agreement
• AATSR SST (like SST from ATSR-2) and LST will need continuing validation
• Dual/nadir difference (SST4-SST2) during the day is a major concern
  Significant SST6-SST4 differences at night also occur
• Navigation of nadir view is excellent. However, occasionally some minor collocation corrections of no more than 1 pixel and 1 line are required
Abstract

A SISTeR validation radiometer was deployed on the RRS Charles Darwin in June and July 2002 in the Indian Ocean as a part of the ENVISAT AATSR validation effort. End-of-life validation data were also collected for the ERS-2 ATSR-2 instrument. Skin SSTs were collected under a total of seventeen ENVISAT and ERS-2 overpasses. ATSR-2 validations have been complicated by the degraded attitude control of the ERS-2 platform. Attitude correction files derived from the ERS-2 scatterometer have been incorporated into an ATSR-2 test processor. Significant geolocation errors are still present, particularly in the ATSR-2 forward view, but a validation has been attempted. Most differences between ATSR-2 and AATSR SSTs, and SISTeR SSTs are less than 0.3K.

Introduction

The Scanning Infrared Sea surface Temperature Radiometer (SISTeR) from the Rutherford Appleton Laboratory (RAL) is a compact, self-calibrating filter radiometer designed to measure the skin temperature of the sea surface. A SISTeR was deployed on the RRS Charles Darwin as a part of the SCIPIO cruise with support from an earth observation enabling grant from the UK NERC for the beginning-of-life validation of the AATSR sea surface temperature sensor on the ESA ENVISAT satellite and the end-of-life validation of the ATSR-2 sensor on ERS-2. The cruise took place in the Indian Ocean between the Seychelles and Mauritius, from the 1st June to the 11th July 2002.

The SISTeR Instrument

A SISTeR was mounted on the handrails on the port quarter of the Darwin’s foremast platform, facing outwards over the bow about 45° from the centre line. The SISTeR scan mirror was stepped out from the ship at small angular increments and the first clear view to the sea was identified at approximately 20° from nadir. A sea view at 25° was chosen for the standard scanning sequence, along with sky views at 50°, 25° and 0° from zenith. The views contained multiple radiance samples, each integrated for 0.8s. Skin SSTs were calculated from the sea view, with small corrections for reflected sky radiance from the 25° sky view¹.

The SISTeR calibration was checked repeatedly against a CASOTS portable black body ², both before shipping and aboard the Darwin before, during and after the cruise (Figures 1 and 2). The CASOTS black body consists of a thin-walled copper cavity immersed in a water bath. The bath temperature was monitored with a Thermometrics AS125 thermistor, S/N 2228 and a Hart Scientific 1504 bridge S/N A14282. The combined accuracy of the
thermistor and bridge was approximately 3mK at room temperature. The water in the CASOTS water bath was circulated with a 50W immersible pump, which doubled as a water heater, giving a temperature rise of approximately 3K every hour. The initial deviation of the brightness temperature recorded by the SISTeR from the thermometric temperature of the water bath was approximately 10mK near to ambient temperature, with a slope of –1.5mK/K over the measurement range. Measurement noise on a 0.8s sample increased slightly through the cruise from an initial 30mK or so as the optical surfaces degraded, but the calibration result was reproduced to within the experimental accuracy on each calibration check. The radiometric error attributable to SISTeR in its normal operating region (ambient deviation of -5K to 0K in Figures 1 and 2) was estimated to be less than 20mK.

**Figure 1** Calibration of SISTeR against a CASOTS black body at RAL on the 8th May 2002, just prior to shipping. The SISTeR ambient black body, BB1, was operated at approximately 26°C during these measurements.
Methodology

During the cruise, prospective ATSR-2 and AATSR overpasses were identified from time-tagged charts of the instrument swaths covering the immediate area in which the Charles Darwin was operating. The charts were interpolated from the ERS-2/ENVISAT reference orbit with an IDL program. Small modifications could be made to the cruise track to correct possible “near misses”, but in general the information was used to plan activities around the overpass time.

After the cruise, overpass points were refined to an “exact” time and position by considering the time-varying unit vectors $n_{\text{ship}}$ and $n_{\text{sat}}$, pointing respectively from the earth’s centre to the RRS Charles Darwin and to the satellites, ERS-2 or ENVISAT. The angle $\Theta$ between these vectors is at a minimum at the point of closest approach between the ship and the sub-satellite point. $\Theta$ is simply related to the dot product of the two vectors $n_{\text{ship}} \cdot n_{\text{sat}} = \cos \Theta$

so the overpass point can be found by searching for local maxima of the dot product $n_{\text{ship}} \cdot n_{\text{sat}}$. IDL code was written to perform a coarse search for local maxima, which were then refined by Newton-Rapheson iteration. $n_{\text{ship}}$ was derived from the ship’s GPS log and $n_{\text{sat}}$ either from the satellite reference orbit, from two-line elements or from the ATSR products themselves, once they had been generated. As the sub-satellite point moves far faster than the ship, the direction of closest approach is very nearly perpendicular to the satellite track. This allows a simple early test for viable overpasses: When the surface distance $R_{\text{earth}} \times \Theta$ is less than half of the ATSR swath width, or 256km, the point of closest approach will fall within the ATSR product.

The Validation Data Set

The SISTeR was operated for about half of the total cruise time, starting a couple of hours after leaving the Seychelles on the morning of the 1st June and finishing early on the morning of the 10th July, a day before making port in Mauritius. Skin sea surface temperatures varied between approximately 24°C and 28°C (Figure 3). Poor weather limited observations below approximately 10°S. Scattered cloud was generally present although there were sometimes clear skies, especially at night over the northern part of the cruise track.

Using ERS-2 and ENVISAT sub-satellite tracks propagated from reference orbits, ATSR-2 and AATSR product requests were generated for all overpasses that passed the half-swath test (Tables 1 and 2). Those for ATSR-2 were subsequently updated with navigation data from the products themselves. The cruise track coincided with the AATSR swath on seventeen occasions (Table 1, Figure 4), always near to 10.00am or 10.00pm local time, and with the ATSR-2 swath approximately half an hour earlier (Table 2). Of these, four or five fell within the clear intervals and were prospects for validations of the ATSR instruments. Balloon GPS sondes were also released for the 6am and 6pm UTC synoptic times that most closely coincided with the overpasses.

GBT and GSST images for four ATSR-2 overpasses (4, 6, 8 and 16) have been processed to Levels 1 and 2 on a test processor (T360) at RAL, incorporating attitude correction data derived from the ERS-2 scatterometer. These
are illustrated in Figures 5 – 8. There is an along track difference in registration of approximately 40km.
<table>
<thead>
<tr>
<th>Overpass</th>
<th>Julian Day UTC</th>
<th>Time UTC</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Across track Position (km)</th>
<th>Comments</th>
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<tbody>
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<tr>
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<tr>
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<td>155</td>
<td>06:42:12</td>
<td>5°14.08'S</td>
<td>57°17.29'E</td>
<td>164</td>
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<tr>
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<td>59</td>
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<tr>
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<td>05:59:37</td>
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<td>58°10.50'E</td>
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<td>Cloud</td>
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Table 1 ATSR-2 overpass analysis for CD141. The time and ship’s position at overpass is listed, along with the distance of the overpass from the centre of the ATSR-2 swath and a note on the conditions at overpass.

<table>
<thead>
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<th>Overpass</th>
<th>Julian Day UTC</th>
<th>Time UTC</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Across Track Position (km)</th>
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<td>63°26.86'E</td>
<td>132</td>
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</tr>
<tr>
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<td>166</td>
<td>17:55:58</td>
<td>17°49.54'S</td>
<td>62°45.08'E</td>
<td>107</td>
<td>Rain</td>
</tr>
<tr>
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<td>169</td>
<td>05:37:39</td>
<td>19°35.70'S</td>
<td>61°59.89'E</td>
<td>56</td>
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</tr>
<tr>
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<td>18°37.85'S</td>
<td>58°23.89'E</td>
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</tr>
<tr>
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<td>175</td>
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<td>7°59.96'S</td>
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</tr>
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</table>

Table 2 AATSR overpass analysis for CD141. The time and ship’s position at overpass is listed, along with the distance of the overpass from the centre of the AATSR swath and a note on the conditions at overpass.

the instrumental views for overpass 4. Across-track agreement is to approximately 5km. For overpass 6, the along track difference is of order 20km, with little discernable across track displacement. Overpass 8 appears quite well registered, with displacements of order 5km in both the along and across track directions. The views from overpass 16 are displaced by a similar amount.
Given the large amounts of nearby cloud, these displacements introduce significant problems in the calculation of dual view SSTs. Both overpasses 4 and 6 could well yield more substantial overpass data, but the along track misalignment causes large numbers of pixels to be masked in one or other view, when this would not be the case for better registered data. Some improvement may be possible with relative naked eye or corollative alignments of the forward and nadir views. The cloud base was generally less than 1,000m, so the cloud outlines should give a reasonable guide.

Figure 3 Summary of SISTeR skin sea surface temperatures for CD141.
Figure 4 The cruise track for CD141, showing the availability of SISTeR data and the positions of the seventeen ATSR-2 and AATSR overpasses (details in Tables 1 and 2).
The SISTeR skin SSTs at overpass (Table 3) in general correspond well to the various averages of ATSR-2 SST (Tables 4 and 5), to 0.3K or better in most cases. The mean deviations of the ATSR-2 50km nadir-only and dual view SSTs from the SISTeR 1 hour SSTs are +0.09K and −0.03K respectively. The SISTeR reported steady SST values and consistently low standard deviations across all of the averaging intervals for these points, so large area, long period comparisons may be permissible. The ATSR-2 SST standard deviations are, however, quite high for the dual view averages, suggesting that misalignment is a significant problem.

<table>
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<tr>
<th>Overpass</th>
<th>±1 min</th>
<th>±2 mins</th>
<th>±5 mins</th>
<th>±10 mins</th>
<th>±20 mins</th>
<th>±60 mins</th>
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<td>672</td>
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</table>

Table 3 SISTeR mean skin sea surface temperatures for overpasses 4, 6, 8 and 16, averaged over bins extending 1, 2, 5, 10, 20 and 60 minutes either side of the overpass time, with the number and standard deviation of SISTeR samples for each bin.

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<tr>
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<th>5 km</th>
<th>10 km</th>
<th>20 km</th>
<th>50 km</th>
</tr>
</thead>
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Table 4 ATSR-2 nadir-only mean skin sea surface temperatures, masked with the nadir cloud flag, for overpasses 4, 6, 8 and 16, averaged over bins extending 1, 2, 5, 10, 20 and 50 kilometres from the overpass point, with the number and standard deviation of ATSR-2 pixels for each bin.
Table 5 ATSR-2 dual view mean skin sea surface temperatures, masked with the nadir and forward cloud flags, for overpasses 4, 6, 8 and 16, averaged over bins extending 1, 2, 5, 10, 20 and 50 kilometres from the overpass point, with the number and standard deviation of ATSR-2 pixels for each bin.

AATSR Validation Results

Once again, the SISTeR skin SSTs at overpass (Table 6) in general correspond well to the various averages of AATSR SST (Tables 7 and 8), to 0.3K or better in most cases. The exceptions are where the numbers of averaged AATSR pixels are small and the pixels are remote from the overpass point (overpasses 10 and 12), and for the
Table 7: AATSR nadir-only mean skin sea surface temperatures, masked with the nadir cloud flag, for overpasses 4, 8, 10, 12, 16 and 17, averaged over bins extending 1, 2, 5, 10, 20 and 50 kilometres from the overpass point, with the number and standard deviation of AATSR pixels for each bin.

<table>
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<th>Overpass</th>
<th>1 km</th>
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<th>20 km</th>
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Table 8: AATSR dual view mean skin sea surface temperatures, masked with the nadir and forward cloud flags, for overpasses 4, 8, 10, 12, 16 and 17, averaged over bins extending 1, 2, 5, 10, 20 and 50 kilometres from the overpass point, with the number and standard deviation of AATSR pixels for each bin.

<table>
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<th>Overpass</th>
<th>1 km</th>
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<th>10 km</th>
<th>20 km</th>
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single daytime nadir SST (overpass 17) for which the value is derived only from two AATSR channels. The mean deviations of the AATSR 50km nadir-only and dual view SSTs from the SISTeR 1 hour SSTs are +0.32K and +0.15K respectively. If the marginal overpasses are excluded, these drop to +0.21K and +0.08K respectively.

Conclusions

Based on a limited number of coincident SST measurements with a SISTeR radiometer, we conclude that both ATSR-2 and AATSR high-resolution dual view SST products are meeting their accuracy specifications comfortably (less than 0.3K error). The mean ATSR-2 high-resolution nadir-only SST error is also small, but a small positive bias is detectable in the equivalent AATSR products.

Acknowledgements

The authors would like to thank the officers and crew of the RRS Charles Darwin for their cooperation and assistance during the cruise. This work was funded by Earth Observation Enabling Grant NER/T/S/2001/00971 from the UK Natural Environment Research Council.

References


Figure 5 ATSR-2 nadir (top) and forward (bottom) 11µm brightness temperature images for overpass 4 on the evening of day 156 (5th June, 2002). The position of the RRS Charles Darwin is shown with a red cross.
Figure 6 ATSR-2 nadir (top) and forward (bottom) 11µm brightness temperature images for overpass 6 on the evening of day 160 (9th June, 2002). The position of the RRS Charles Darwin is shown with a red cross.
Figure 7 ATSR-2 nadir (top) and forward (bottom) 11µm brightness temperature imagess for overpass 8 on the evening of day 163 (12th June, 2002). The position of the RRS Charles Darwin is shown with a red cross.
Figure 8 ATSR-2 nadir (top) and forward (bottom) 11µm brightness temperature images for overpass 16 on the evening of day 182 (1st July, 2002). The position of the RRS Charles Darwin is shown with a red cross.
SCIPIO – Validation of ATSR-2 and AATSR with SISTeR

Tim Nightingale
Rutherford Appleton Laboratory

This work was funded by an EO enabling grant from the UK NERC and was conducted in collaboration with Leicester University
A SISTeR radiometer was deployed on the RRS Charles Darwin as a part of the SCIPIO cruise, lead by Adrian New of the Southampton Oceanography Centre.

SCIPIO was a multidisciplinary investigation into the area surrounding the Mascarene ridge, a chain of islands and seamounts between the Seychelles and Mauritius in the Indian ocean.

Cruise activities included studies of the south equatorial current, regional bio-chemistry and large internal waves, and validation of the ATSR-2, AATSR and MERIS instruments.

SISTeR generated skin SST data sets to validate ATSR-2 at end of life and AATSR during its commissioning phase.
The RRS Charles Darwin departed Mahé, Seychelles on the 1\textsuperscript{st} June 2002.

Made an intermediate port call at Mauritius.

Arrived in Mauritius on the 12\textsuperscript{th} July 2002 (measurements finished on the previous day).

The Weather was often poor below 10\textdegree S – south-east trade winds brought rain and high seas.

There were seventeen AATSR and ATSR-2 overpasses, of which four are candidates for validation points.

Auxiliary data include full met measurements, bulk SSTs, long and short wave fluxes and radiosonde profiles.

The track of the RSS Charles Darwin for the SCIPIO cruise, showing the availability of SISTeR data (thickened line) and the positions of the seventeen ATSR-2 and AATSR overpasses.
SISTeR is a chopped, self-calibrating filter radiometer with infrared filters matching those in ATSR-2 and AATSR.

Near to ambient temperature and with the 10.8µm or 12.0µm filter, radiometric noise is approximately 30mK for a 0.8s sample and radiometric accuracy is of order 20mK.

SISTeR measures sea and sky radiances.
SISTeR Calibrations

Calibration of SISTeR against a CASOTS black body at RAL on the 8th May 2002, just prior to shipping. The SISTeR ambient black body, BB1, was operated at approximately 26°C during these measurements.

Calibration of SISTeR against a CASOTS black body on board the RRS Charles Darwin on the 10th July 2002, just prior to return. The ambient black body, BB1, was operated at approximately 27°C during these measurements.

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For a narrow band filter radiometer, SST can be calculated to a very good approximation from

\[ R_{up} = e \, B(SST) + (1 - e) \, R_{down} \]

where \( e \) is the emissivity of the sea surface and \( B(SST) \) is the black body radiance at the sea surface temperature, each integrated over the instrumental filter function and field of view, and \( R_{up} \) and \( R_{down} \) are the upwelling and complementary downwelling sea and sky radiances measured by the radiometer.
SISTeR Measurements

- SISTeR was installed on the foremast platform of the RRS Charles Darwin.
- Looked forward, about 45° from the ship’s centre line.
- Sea view to clear sea ahead of bow wave.
- Views at 25° from nadir (sea) and 0°, 25° and 50° from zenith (sky).
- The 25° sky view is used to correct for reflected sky radiance in the sea view.

SISTeR installation on the foremast platform of the RRS Charles Darwin

MAVT Workshop, ESRIN, 20-24 October 2003
SISTeR SSTs

- SISTeR operated for approximately half of the cruise period (shut down for bad weather for the remaining time).
- Most SISTeR skin SSTs fell between 24°C and 28°C.
- The SISTeR calibration was checked before, during and after the cruise, against a CASOTS black body reference. There was no change to within experimental error (~5mK) despite degradation of the optical surfaces.

SISTeR skin sea surface temperature record for the SCIPIO cruise

MAVT Workshop, ESRIN, 20-24 October 2003
Identifying Overpasses

- Calculate time-varying unit vectors pointing to ship (GPS) and satellite (product file or reference orbit).
  - \( \mathbf{n}_{\text{ship}} \cdot \mathbf{n}_{\text{sat}} = \cos T \)
- Closest approach when \( T \) is smallest.
- Look for local maxima of \( \mathbf{n}_{\text{ship}} \cdot \mathbf{n}_{\text{sat}} \)
- Refine maxima by Newton-Rapheson iteration.
- Sub-satellite point moves much faster than ship so the closest approach is very nearly across the satellite track.
- Choose overpasses where \( T \times R_{\text{earth}} < 256 \text{km} \).
There are significant problems with the geolocation of ATSR-2 products, particularly in the forward view, following the failure of the ERS-2 gyros in early 2001.

Absolute alignment of ATSR-2 images from the SCIPIO cruise using surface features is not possible, due to the lack of local land features.

An ATSR-2 test processor (T360), incorporating attitude correction data (pitch and yaw only) derived from the ERS-2 scatterometer, has been used to generate SCIPIO ATSR-2 products.

There are still significant residual geolocation errors.

It may be possible to make further improvements to the location of the forward view by matching cloud outlines – the cloud base was generally low and parallax errors are likely to be small in comparison.
ATSR-2 nadir (left) and forward 10.8µm gridded brightness temperature images for overpass 16 (red cross), geolocated with attitude correction files generated from the ERS-2 scatterometer.

Note the severe corrections to the forward view.
# ATSR-2 Overpasses

<table>
<thead>
<tr>
<th>Overpass</th>
<th>Julian Day UTC</th>
<th>Time UTC</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Across track Position (km)</th>
<th>Comments</th>
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<tbody>
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<td>56°31.87'E</td>
<td>220</td>
<td>Cloud</td>
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<tr>
<td>3</td>
<td>155</td>
<td>06:42:12</td>
<td>5°14.08'S</td>
<td>57°17.29'E</td>
<td>164</td>
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<td>7°12.98'S</td>
<td>58°19.62'E</td>
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</tbody>
</table>
ATSR-2 Overpass (5th June 2002)

MAVT Workshop, ESRIN, 20-24 October 2003
All four overpasses at night.

- Local cloud + geolocation problems, so long time (1 hour) and large area (50km radius) averages taken about overpass time
- SISTeR SST standard deviations very low – very good local uniformity.
- All ATSR-2 SSTs agree with SISTeR to within 0.3K.
- Mean nadir only bias +0.09K, mean dual view bias - 0.03K.
## AATSR Overpasses

<table>
<thead>
<tr>
<th>Overpass</th>
<th>Julian Day UTC</th>
<th>Time UTC</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Across Track Position (km)</th>
<th>Comments</th>
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<td>Cloud</td>
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<tr>
<td>3</td>
<td>155</td>
<td>06:13:44</td>
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<td>165</td>
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<tr>
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<td>58°11.94'E</td>
<td>18</td>
<td>Cloud</td>
</tr>
</tbody>
</table>
AATSR Overpass (5th June 2002)

CD141 SISTeR Temperatures (RRS Charles Darwin, 5th June 2002)

Sky Temperature (K)

Copyright: Rutherford Appleton Laboratory, Chilton, Oxon, 2002
Created: 15/12/2002

CD141 – SCIIPO (18:13:18 UTC, 5th June 2002)

MAVT Workshop, ESRIN, 20-24 October 2003
Five overpasses at night, one (17) during day.

Local cloud, so long time (1 hour) and large area (50km radius) averages taken about overpass time.

SISTeR SST standard deviations very low – very good local uniformity.

**All points**: Mean nadir only bias +0.32K, mean dual view bias +0.15K.

**Marginal excluded**: Mean nadir only bias +0.21K, mean dual view bias +0.08K.

<table>
<thead>
<tr>
<th>Overpass</th>
<th>SISTeR (± 1 hour)</th>
<th>AATSR Nadir (= 50km)</th>
<th>AATSR Dual (= 50km)</th>
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<td>4</td>
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<td>300.75K</td>
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<td>300.10K</td>
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<td>300.31K</td>
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<td>17</td>
<td>300.07K</td>
<td><strong>300.66K</strong></td>
<td>300.12K</td>
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</table>

MAVT Workshop, ESRIN, 20-24 October 2003
Conclusions

? The SISTeR radiometer maintained its calibration and operated without problems throughout the cruise.

? Validation conditions were not ideal – scattered cloud throughout and poor weather during the southern portion of the cruise.

? ATSR-2 night time nadir-only and dual view SSTs correspond well to SISTeR in-situ values.
   ? All nadir-only SSTs agree to within 0.3K, dual view to within 0.2K.
   ? Nadir-only SSTs are 0.09K warm on average.
   ? Dual view SSTs are 0.03K cold on average.

? AATSR night time nadir-only and dual view SSTs correspond well to SISTeR in-situ values.
   ? All nadir-only SSTs agree to within 0.4K, dual view to within 0.2K.
   ? Nadir-only SSTs are 0.21K warm on average.
   ? Dual view SSTs are 0.08K warm on average.

MAVT Workshop, ESRIN, 20-24 October 2003
Validation of the AATSR GSST product with \textit{in situ} measurements from the Marine Atmospheric Emitted Radiance Interferometer

E. J. Noyes\textsuperscript{1}, B. Mannerings\textsuperscript{1}, J. J. Remedios\textsuperscript{1}, M. C. Edwards\textsuperscript{1}, D. Llewellyn-Jones\textsuperscript{1}, G. K. Corlett\textsuperscript{1} & P. J. Minnett\textsuperscript{2}

\textsuperscript{1} Space Research Centre, University of Leicester, UK
\textsuperscript{2} RSMAS/MPO, University of Miami, US
Explorer of the Seas Cruise

• Sailing since 28 October 2000
• On board research laboratory

http://www.rsmas.miami.edu/rccl/eos.html
M-AERI Instrument

- Marine - Atmospheric Emitted Radiance Interferometer (M-AERI)
- Spectral range: 500 – 3300 cm\(^{-1}\) (3-18 µm)
- Resolution: 1.0 cm\(^{-1}\)
- Field of View: 1.3 °
- Measurement cycle: ~ 11 minutes
- Views ahead of the ship’s bow wave to avoid disturbance

http://www.rsmas.miami.edu/rccl/maeri.html
M-AERI SSTs

• SST calculated from 10 spectral points near 7.7 µm wavelength

• Corrected for reflected sky radiance and atmosphere between the sea surface and the M-AERI instrument (~1 km atmospheric path length)

• Emissivity value used in SST retrieval was derived from previous M-AERI measurements made at sea

• Calibration using two internal black bodies
M-AERI Accuracies

- Traceability to NIST through the NIST EOS Transfer Radiometer (TXR) and NIST traceable reference thermometers.
- Residual uncertainties <0.03K
Validation of the GSS1 Product (1)

- **Spatial Matchup Criteria**
  
  AATSR pixel with centre latitude and longitude closest to lat and long of in situ measurement

- **Temporal Matchup Criteria**
  
  AATSR Overpass

  -60 mins  -15 mins  +15 mins  +60 mins
Validation of the GSS1 Product (2)

• Confidence Flag Criteria
  – Bit 4 (pixel over land) NOT set
  – Bit 5 (nadir-view pixel is cloudy) NOT set
  – Bit 8 (forward-view pixel is cloudy) NOT set
  * Other flags set (e.g. cosmetic fill) recorded in ‘summary matchup file’ should further analysis be required.

• Data Time Period
  – September 2002 – June 2003 (10 complete months)
Notes about the Results

AATSR minus in situ SST

0.3 K limits

AATSR BIAS

AATSR – in situ SST

+ve bias = AATSR measures warm
AATSR BIAS
- all = +0.23 K
- ‘good’ = +0.14 K

Points < ±0.3 K
- all = 58%
- ‘good’ = 70%

Dual SST Matchups
- Sept ’02 – June ’03
- Overpass ± 15 min
- 12 valid matchups
- 2 unreliable in situ?

RMS M-AERI StDev
- all (12) = 0.11 K
- ‘good’ (10) = 0.08 K

RMS Differences
- all (12) = 0.41 K
- ‘good’ (10) = 0.33 K
Possible reasons for high standard deviation of *in situ* measurements

- Lack of stationarity over the time it takes to generate each set of interferograms (such as broken clouds, wave breaking at the surface)
- Radio frequency interference from ship (no convincing evidence)
- Temperature transients inside the instrument caused by sunlight entering the aperture (directly or reflected off the sea surface)
- Temperature transients in the BBs (e.g. colder air blowing into the aperture – may not be applicable in the Caribbean)
- Increase in stays from scattering elements on the scan mirror (e.g. salt crystals from spray prior to being cleaned)
Dual SST Matchups
- Sept ’02 – June ’03
- Overpass ± 15 min
- 12 valid matchups

Colour indicates standard deviation of 3x3 block of pixels
Dual SST Matchups
- Sept ’02 – June ’03
- Overpass ± 15 min
- 12 valid matchups

Problem Days:
- 01 Dec ’02
- 30 June ’03
1x1 Block:

Dual SST Matchups
- Sept ’02 – June ’03
- Overpass ± 15 min
- 12 valid matchups

- Nadir-view SST higher than dual-view SST for all matchups except for the two of the three low-noise outliers

Colour indicates nadir- minus dual-view SST for 1x1 block of pixels
AATSR Bias
- all = + 0.14 K
- ‘good’ = + 0.07 K

Points < ± 0.3 K
- all = 66%
- ‘good’ = 77%

RMS Differences
- all (15) = 0.34 K
- ‘good’ (13) = 0.28 K

3x3 Block:
Dual SST Matchups
- Sept ’02 – June ’03
- Overpass ± 15 min
- 15 valid matchups
- 2 unreliable in situ?

RMS M-AERI StDev
- all (15) = 0.11 K
- ‘good’ (13) = 0.09 K

RMS Differences
- all (15) = 0.34 K
- ‘good’ (13) = 0.28 K
Dual SST Matchups

- Sept ’02 – June ’03
- Overpass ± 15 min
- 15 valid matchups

Problem Days:
- 01 Dec ’02
- 30 June ’03
RMS Differences

- 48 points = 0.41 K
- 39 points = 0.35 K

Dual SST Matchups

- Sept ’02 – June ’03
- Overpass ± 60 min
- 48 valid matchups
- 9 unreliable in situ?

RMS M-AERI StDev

- all (48) = 0.12 K
- ‘good’ (39) = 0.08 K

RMS Differences

- 48 points = 0.41 K
- 39 points = 0.35 K

AATSR BIAS

- all = + 0.18 K
- ‘good’ = + 0.11 K

Points < ± 0.3 K

- all = 58 %
- ‘good’ = 64 %
Nadir SST Matchups

- Sept ’02 – June ‘03
- Overpass ± 60 min

30 June 2003
Dual SST Matchups
- Sept ’02 – June ’03
- Overpass ± 60 min
- 48 valid matchups

Problem days:
- 01 Dec ’02
- 30 June ’03
1x1 Block:

Dual SST Matchups
- 30 June 2003
- Overpass ± 60 min

Key - matchups:
☐ - within ± 0.3 K
X - > ± 0.3 K
⋆ - AATSR cloud

Colour indicates dual-view SST
**1x1 Block:**

**Matchups**
- 30 June 2003
- Overpass ± 60 min

- AATSR dual-view SST
- AATSR dual-view SST (3x3 block)
- AATSR nadir-view SST
- M-AERI SST
• 30 June 2003
• 512 x 512 km image
• Colour scale (K) is nadir minus dual-view SST
• White areas are invalid or cloudy pixels
### Dual-View SST Statistics

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<th>Block Size</th>
<th>1x1</th>
<th>3x3</th>
<th>1x1</th>
<th>3x3</th>
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<td>± 60</td>
<td>± 60</td>
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<tr>
<td>Number of matchups</td>
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<tr>
<td>% within ± 0.3 K</td>
<td>all</td>
<td>58</td>
<td>66</td>
<td>58</td>
</tr>
<tr>
<td>‘reliable’*</td>
<td>70</td>
<td>77</td>
<td>64</td>
<td>67</td>
</tr>
</tbody>
</table>

* ‘Reliable’ denotes in situ measurements with relatively low standard deviation
Conclusions (1)

1. Similar pattern of results obtained using 1x1 and 3x3 blocks of pixels with ± 15 and ± 60 minute temporal brackets.

2. Poor quality matchups are confined to two days:
   - 01 December 2002
   - 30 June 2002

3. Poor-quality dual-view SST matchups generally appear to correspond to:
   - High standard deviation of M-AERI measurement
   - Nadir-SST higher than dual-view SST (anomalous atmospheric conditions?)
4. Quality of matchups appears to be independent of SST and the heterogeneity of SST (neighbouring pixels).

5. **Best results:** 3x3 block of AATSR pixels with M-AERI measurements made within 15 minutes of the AATSR overpass excluding unreliable *in situ* measurements
   - RMS difference = 0.28 K  (0.33 K = 1x1 block)
   - 77 % of matchups within ± 0.3 K  (70 % = 1x1 block)

6. AATSR generally measures warm (0.07 – 0.23 K)
Acknowledgments

- Kevin Maillet, Chip Maxwell, Don Cucciara at RSMAS for M-AERI support
- NASA
- NERC
- DEFRA
Infrared Sea
Surface Temperature
Autonomous Radiometer

Craig Donlon and Ian Robinson
ESA AO 9081/2

First presented at the ENVISAT validation Workshop, ESA/ESRIN, Italy, October, 2003.
Outline

- Review of validation activities
- Presentation of results
- Particular concerns
- Future validation work into 2004 and beyond
- Summary
AO-9081/2: ISAR

Project Structure

PIs: C. Donlon (9081) & I. Robinson (9082)  CoPIs: M. Reynolds (BNL) & T Nightingale (RAL)

Project Manager: G. Fisher

Data collection

Instrumentation
- C. Donlon (JRC)
- G. Fisher (SOC)
- M. Reynolds (BNL)
- R. Edwards (BNL)
- T. Nightingale (RAL)

ISAR system
- Design, build, Test systems

Ancillary instruments

Data logging
- Software development and maintenance

Calibration

Operations
- G. Fisher (SOC)
- R. Collins (SOC)
- C. Donlon (SOC)
- BF and P&O

Liaison with
- Brittany Ferries and P&O

Installation
- Software maintenance
- Hardware maintenance
- Data collection and backup

Data analysis

Data management
- D. Poulter (SOC)
- G. Fisher (SOC)
- C. Donlon (JRC)
- SOC-LSO data management team

In situ data and archive
- AATSR data archive and processing
- Software development and maintenance

Analysis
- C. Donlon (JRC)
- D. Poulter (SOC)
- I. Robinson (SOC)

Software development and maintenance
- AATSR-ship colocation
- NILU database
- Report to VS
- Validation loop (VS & DQG)

Operations
- G. Fisher (SOC)
- R. Collins (SOC)
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Installation
- Software maintenance
- Hardware maintenance
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- I. Robinson (SOC)

Software development and maintenance
- AATSR-ship colocation
- NILU database
- Report to VS
- Validation loop (VS & DQG)
In situ data collection

Data/instrumentation:
- ISAR radiometer: SSTskin
- SSTdepth sensors: SSTdepth
- Solarimeter, anemometer

2 demonstration “operational” activities in the Bay of Biscay/E. Channel area:
- M/V Val de Loire
  - May 15th - June 26th 2002
- M/V Pride of Bilbao and EU FerryBox project
  - August 16th 2002 - Present
Infrared Sea

AO-9081/2: ISAR

Ship tracks in the experiment area

- Rich SST dynamics
- Varied atmospheric structure
  - Polar/Tropical maritime
  - Polar/Tropical continental
- Ease of access to ships with good coverage
- Aerosol presence
- COOL SST’s !!
- Unique in the radiometer validation activities

MV Val de Loire May-July 2002
M/V Pride of Bilbao August 2003-
An autonomous in situ IR radiometer:

- Self protecting; optical rain gauge
- Triggers a shutter that seals the system
- Target: 3 months at sea unattended
- Self Calibrating (2BB); +/-0.1K rms
- Spectral window 9.6-11.5μm
- Dedicated real time data log system
ISAR Installation: Val de Loire

ISAR5C Mount bracket shown in place on the bridge wing.

ISAR-5C radiometer and ScTi MiniORG rain sensor.
ISAR installation: Pride of Bilbao

New ISAR mount bracket
New Cable run
New Rain Gauge mount bracket
Solarimeter
Sonic Anemometer

Kipp&Zonen CM11 pyranometer
Gill Windmaster 3 axis sonic anemometer (u,v,z @ 1 sec)

AO-9081/2: ISAR
AATSR data

- AATSR data delivered from UK PAC on CDROM over an area
  - PLEASE can we have DVD!!
  - Archive is difficult to manage

- Processed all data collocated with each ship

- 4 match-up data sets
  - Of which only 2 have both dual view SST retrievals
Results
Val de Loire Results

May 15th - June 26th 2002

AO-9081/2: ISAR
Val de Loire: Day 140 (+/- 10 mins.)

AO-9081/2: ISAR
Val de Loire: Day 143 (+9.3 hrs)

AO-9081/2: ISAR
Val de Loire: Day 153 (+/- 10 mins)

AO-9081/2: ISAR
Val de Loire: Day 155 (+2.6 hours)
## Summary of VDL match-up data

<table>
<thead>
<tr>
<th>TIME (SDay)</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>ISAR SSTskin (K)</th>
<th>AATSR Combined SSTskin (K)</th>
<th>ΔSSTskin AATSR - ISAR (K)</th>
<th>AATSR Nadir SSTskin (K)</th>
<th>ΔSSTskin AATSR - ISAR (K)</th>
<th>ΔTime (ISAR - AATSR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>140.9</td>
<td>46.676N</td>
<td>4.8646W – 4.71131W</td>
<td>286.75 (0.37)</td>
<td>287.12 (0.34)</td>
<td>-0.37</td>
<td>286.96 (0.385)</td>
<td>-0.21</td>
<td>+/- 30 mins</td>
</tr>
<tr>
<td>140.9</td>
<td>46.508N</td>
<td>4.8133W</td>
<td>286.8</td>
<td>286.8</td>
<td>0</td>
<td>286.3</td>
<td>0.5</td>
<td>+/-10 mins.</td>
</tr>
<tr>
<td>143.5</td>
<td>45.255N</td>
<td>4.27336W</td>
<td>285.88</td>
<td>--</td>
<td>--</td>
<td>285.8</td>
<td>-0.08[2]</td>
<td>9.3 hours</td>
</tr>
<tr>
<td>153.45</td>
<td>49.995N-50.009N</td>
<td>4.164W – 4.171W</td>
<td>285.55 (±0.1)</td>
<td>285.50</td>
<td>0.05</td>
<td>285.8</td>
<td>0.2</td>
<td>+/- 10 minutes</td>
</tr>
<tr>
<td>155.5</td>
<td>44.791N - 44.924N</td>
<td>4.1286W – 4.17017W</td>
<td>285.53 (0.197)</td>
<td>--</td>
<td>--</td>
<td>285.32 (0.114)</td>
<td>0.21</td>
<td>2.68 hours</td>
</tr>
</tbody>
</table>

About a 15% return on total number of validation match-up possibilities

AO-9081/2: ISAR
22-26 October 2002

😊 No chance: Cloudy sky ($BT_{sky} > 260$ K)
😊 Effort Index=$\text{NaN}$
The Future...
Recent Pride of Bilbao ship refit has improved the ISAR system infrastructure aboard the ship:
- New robust cables and power supply
- New installation of Anemometer on main Mast
- New installation of Solarimeter on Top deck (98% free of infrastructure shadow), space for other instruments
- Tested and all OK.
- Small grant application for optical radiometry (PML)
- Ad hoc CO2 possibility (based on instrument availability CASIX)

Resources assumed, an interface to an existing real time satellite data transmission service will be made in 2004:
- ISAR data will be available in real time every 10 minutes at the FerryBox web site http://www.soc.soton.ac.uk/ops/ferrybox_index.php

Data available to everyone free of charge
FerryBox NRT service

- Real-time underway data via Satellite link
- Thermosalinograph and Flourimeter
- ISAR will be fully interfaced to the FerryBox system in January 2003
- Cable problems...

AO-9081/2: ISAR
Collaboration with University of Miami under the NOPP
- ISAR will be installed aboard the M/W Falstaff operating on a trans-Atlantic operational service.
- Additional Ocean/Atmosphere (including CO₂) sensors will also be available
- Inter-comparisons with other radiometers

More ISAR radiometers are being solicited
- USA has commissioned 1 ISAR
- New Zealand in discussion
- USA has 1 ISAR already

Discussions to make dedicated IR and MW radiometer measurements with the Meteorological Research Flight, MetOffice
- June-July 2005 (indicative) Canary Is. 1 week campaign (in discussion)

Medspiration (ESA-DUE) will require operational validation data hence the need for SOO approach
Falstaff route

The current track of the MV Falstaff

MV Falstaff
Wallenius Shipping Co. car carrier, 6-week cycle

AO-9081/2: ISAR
Particular concerns

- Validation is not a 6 month only experiment;
  - At sea logistics are extremely challenging, unpredictable and expensive
  - Experimental lead times are great; can’t just ‘go out and do some validation’ if a low funding line is provided
  - Planning and careful liaison with ship operators is essential to success in a SOO environment

- Validation is an important (but often overlooked) satellite mission component;
  - When satellite SST data sets have accuracies better than 0.3 K (e.g., AATSR) the quality of the in situ measurement is the critical factor
  - Without accurate and complete in situ data, it is impossible to demonstrate the accuracy of AATSR SSTskin products!
Proposal for operational monitoring

The Global Ocean Data Assimilation Experiment (GODAE) High Resolution SST Pilot Project (GHRSST-PP) has a component dedicated to SST validation.

How can the AATSR validation team work with the GHRSST-PP?

Within the GHRSST-PP High Resolution Diagnostic Data Set!

- Request that the HR-DDS global areas are extracted by ESA for validation and inter-comparison experiments in an operational manner.
Based on output of the 2nd, 3rd & 4th GHRSSST-PP Science Team workshop feedback. Fully documented in the HR-DDS Implementation Plan (GHRSSST/14)
HR-DDS: Science and Applications

- Provides time series plots of data values
- Provides browse imagery
- Move making is possible
- Dynamic statistics
- Browse imagery
- Very interactive and dynamic (see WWW example)

AO-9081/2: ISAR
Infrared Sea
Surface Temperature
Autonomous Radiometer

AO-9081/2: ISAR