The calibration of the short-wavelength channels of the ATSR series of Instruments

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Outline

• ATSR Instrument History
• Visible Calibration System
• Pre-Launch Calibration
• In-Orbit Calibration/Validation
• Long-Term Monitoring
• Primary aims
  – Measure global sea-surface-temperature to an accuracy of better than 0.3 K (1σ)
  – Provide a 15+ year dataset of global SSTs for climate modelling

• Additional aims for ATSR-2 and AATSR
  – Land Surface Temperature
  – Global vegetation monitoring
  – Cloud Properties
  – Aerosol Properties
ATSR – Design Features

- Conical Scan Geometry provides dual view
  - Allows atmospheric corrections

- Thermal IR channels at 12µm, 11µm and 3.7µm
  - Actively cooled to 80K using a Stirling cycle cooler
  - On-Board Blackbody sources (ε ~ 0.999) provide continuous calibration

- Visible/Near Infrared Channels at 1.6µm, 0.87µm, 0.66µm and 0.56µm
  - On-Board diffuser permits calibration once-per-orbit

The calibration of the short-wavelength channels of the ATSR series of Instruments
The calibration of the short-wavelength channels of the ATSR series of Instruments

ATSR - HISTORY

ATSR
- Development
  - Start: 1984
  - Calibration: Summer 1989
- AIT
  - Launch: 17 July 1991
- Operations
  - Nominal Operations End: June 1996
  - ERS-1 Fails: 10-March-2000

ATSR-2
- Start: 1990
- Calibration: Christmas 1992
- Launch: 27 April 1995
- 2006?

AATSR
- Start: 1994
- Launch: June 2001
- 2010?

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Visible Calibration System (VISCAL)

\[ r_{\text{VISCAL}} = \frac{A_{M2}}{A_{\text{AATSR}}} \cos(\pi/4) r_{M1} r_{M2} \tau_{UV} R_{\lambda}(0, \pi/4) \]
Calibration Algorithms

- Radiance detected by (A)ATSR from scene of reflectance $R_{\text{Scene}}$ is
  \[ L_{\text{scene}} = R_{\text{scene}} I_0 d\lambda \frac{\cos(\text{sza})}{\pi} = \alpha \frac{(C_{\text{scene}} - C_{\text{dark}})}{\text{SCP\_Gain}} \]

- Similarly the VISCAL unit produces a radiance $L_{\text{VISCAL}}$
  \[ L_{\text{VISCAL}} = R_{\text{VISCAL}} I_0 d\lambda / \pi = \alpha \frac{(C_{\text{VISCAL}} - C_{\text{DARK}})}{\text{SCP\_Gain}} \]

- Using this we can calibrate the AATSR raw counts to give a normalised top-of-atmosphere radiance such that
  \[ \text{VIS\_GBTR} = R_{\text{scene}} \cos(\text{sza}) = R_{\text{VISCAL}} \frac{(C_{\text{scene}} - C_{\text{dark}})}{(C_{\text{VISCAL}} - C_{\text{DARK}})} \]

- The aim of the pre-launch calibrations is to measure $\alpha$ and $R_{\text{VISCAL}}$

- Post launch calibration verifies $R_{\text{VISCAL}}$ and monitors long-term stability
Pre-Launch Calibration

• ATSR-2
  – Limited to measurement of radiometric responses $\alpha$ for 0.56 $\mu$m, 0.67$\mu$m and 0.87$\mu$m only
  – $R_{\text{VISCAL}}$ values derived from reflectance/transmission measurements of components
    • $r_{M1}, r_{M2}, \tau_{\text{UV}}, R_{\lambda}(0,\pi/4)$

• AATSR
  – Extensive pre-launch calibration performed
  – Response $\alpha$ and reflectance factor $R_{\text{VISCAL}}$ measured for all VNIR channels
  – Polarisation responses measured
  – Linearity measured
  – Calibration repeated under different conditions to measure effect of vacuum + operation of cryo-cooler.
AATSR Visible Calibration - Results

<table>
<thead>
<tr>
<th>Error in radiometric response</th>
<th>1.6µm</th>
<th>0.87µm</th>
<th>0.66µm</th>
<th>0.56µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error in VISCAL reflectance factor</td>
<td>9.0%</td>
<td>3.6%</td>
<td>3.4%</td>
<td>3.9%</td>
</tr>
<tr>
<td>S/N at 0.5% albedo</td>
<td>31:1</td>
<td>25:1</td>
<td>28:1</td>
<td>25:1</td>
</tr>
</tbody>
</table>

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ATSR-2 Calibration Studies & Campaigns

- First light check against pre-launch calibration
  - Smith, 1995 (RAL internal communication)

- In-Situ Validation Campaigns
  - La-Crau (Rondeaux, IJRS 1998 – measurements in 1995)
  - Hay, Amburla (Rondeaux & Prata, Private communication 1997)

- Polder Intercomparisons
  - Intercomparisons with Polder (with Cabot, Hagolle, and Henry 1999)

- Desert model (incl. comparisons with MISR, SEAWIFS)
  - Goaverts and Clerici, COSPAR 2002

- Comparisons with MISR, SEAWIFS (Goaverts and Clerici, COSPAR 2002)

- Long-Term Stability Monitoring
  - Smith, Mutlow & Rao, App. Optics. 2002

- GOME Intercomparisons
  - Stevens, 1997 (RAL internal communication)

- Cloud Models
  - Watts (RAL Internal Communication)

- Sun Glint (1.6um only)
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- Consistent results at 1.6µm
  - average of 1.06±0.03 applied to subsequent calibration tables

- Greater variation at shorter wavelengths
  - Most measurements show –ve bias
  - Effect of drift not considered in earlier measurements

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• Data from stable Desert and Ice targets used to determine long term drift

<table>
<thead>
<tr>
<th></th>
<th>0.56μm</th>
<th>0.66μm</th>
<th>0.87μm</th>
<th>1.6μm</th>
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<tbody>
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<td>1</td>
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<tr>
<td>Algeria - West</td>
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<td>1.3</td>
<td>1.3</td>
<td>0.4</td>
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<td>Arabia</td>
<td>1.4</td>
<td>0.8</td>
<td>1</td>
<td>0.5</td>
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<tr>
<td>Dunhuang *</td>
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<td>-0.1</td>
<td>0</td>
<td>-0.5</td>
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<td>1.1</td>
<td>0.9</td>
<td>0.3</td>
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<tr>
<td>Libya - 2</td>
<td>1.9</td>
<td>1.2</td>
<td>1</td>
<td>0.4</td>
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<tr>
<td>Libyan Desert</td>
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<td>0.9</td>
<td>0.1</td>
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<tr>
<td>Sechura Desert*</td>
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<td>-1</td>
<td>1.4</td>
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<tr>
<td>Sonora Desert*</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>0.8</td>
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<tr>
<td>Greenland</td>
<td>1.7</td>
<td>1.3</td>
<td>1.8</td>
<td>-</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>1.6</strong></td>
<td><strong>1.1</strong></td>
<td><strong>1.1</strong></td>
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<td><strong>0.3</strong></td>
<td><strong>0.1</strong></td>
</tr>
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</table>
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ATSR-2 Long Term Monitoring – After Drift Correction

Data from Libyan Desert

0.87μm Drift

Drift = 0.0003 Year⁻¹

October 2002 Data

0.86μm Drift

Drift = 0.0000 Year⁻¹
In-Orbit Calibration Approaches for AATSR

- Intercomparisons against other sensors
  - ATSR-2, MERIS, GOME
  - Whole orbit comparisons
  - Selected calibration sites (Desert, Ice)

- Calibration using Arctic stratus clouds
  - Compare measurements against modelled reflectances

- Long term trend analysis
  - Using stable desert and ice targets
Stable Calibration Targets

• Desert and Ice Targets used extensively for calibration and monitoring of AVHRR, ATSR-2, GOES, POLDER, Vegetation, MISR…

• Uniform reflectance over large area

• Long term-radiometric stability of the calibration sites
  - ensures long-term stability of the top-of-the atmosphere (TOA) albedo (and of seasonal variations, if any) or reflectance over large spatially uniform areas.

• High surface reflectance to maximise the signal-to-noise and minimise atmospheric effects on the radiation measured by the satellite

• Bi-directional reflectance factor (BRDF) due to surface anisotropy and other angular effects, and must be accounted for when determining long-term calibration trends.
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Calibration Targets

Desert - Sudan - Egypt

Ice - Greenland

AATSR GBTR image for 1st June superimposed on coincident MERIS Reduced Resolution Image
### Site Locations

<table>
<thead>
<tr>
<th></th>
<th>Lat center (°)</th>
<th>Long center(°)</th>
<th>lat-min</th>
<th>lat_max</th>
<th>long_min</th>
<th>long_max</th>
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<td>31.52</td>
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<td>25.55</td>
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<td>-113.54</td>
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<td>73.75</td>
<td>-40</td>
<td>70</td>
<td>77.5</td>
<td>-45</td>
<td>-35</td>
</tr>
</tbody>
</table>

Subset of ‘CNES’ calibration sites used + others
Results from Desert Comparisons

- Desert data for AATSR compared with:
  - Archive of ATSR-2 measurements for same view solar geometry
  - Near coincident ATSR-2 measurements

- Short wavelength (0.87µm, 0.67µm and 0.56µm) channels are high WRT ATSR-2

- 1.6µm shows good-agreement wrt. ATSR-2 after non-linearity corrections.
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1.6µm Nonlinearity

Pre-Launch Calibration Measurements showed
Non linear response for 1.6µm channel

AATSR vs. ATSR-2
desert targets

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Greenland AATSR vs. ATSR-2

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the ATSR series of Instruments

Greenland AATSR vs. MERIS

AATSR/MERIS Comparisons over Greenland

0.87μm

AATSR/MERIS 0.87μm = 1.05974

MERIS TOA Reflectance

60 70 80 90 100

AATSR TOA Reflectance

60 70 80 90 100

0.67μm

AATSR/MERIS 0.67μm = 1.05172

MERIS TOA Reflectance

60 70 80 90 100

AATSR TOA Reflectance

60 70 80 90 100

0.56μm

AATSR/MERIS 0.56μm = 1.09258

MERIS TOA Reflectance

60 70 80 90 100

AATSR TOA Reflectance

60 70 80 90 100

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GOME / SCIA / AATSR / ATSR-2 inter-comparison

- Inter-comparison requires
  - Spectral averaging of SCIA/GOME
  - Spatial averaging of AATSR/ATSR-2

- GOME & SCIA pixels not same size or coincident, therefore
  - Perform comparison for accurately co-located GOME/ATSR-2
  - Average SCIA to give scene comparable to GOME; compare to properly averaged AATSR
  - Associate nearest GOME/SCIA pixels to allow cross platform comparison; accept “noise” due to scene variation (time difference).
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Comparisons for 15th Dec 2002

SZAs for 6way comparison

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Comparison of AATSR, ATSR-2 and GOME
Reflectance : 0.56μm

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Comparison of AATSR, ATSR-2 and GOME
Reflectance : 0.67µm

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Cloud calibration: techniques

Forward scattering + Oblique path = High reflectance
ATSR along-track view

Side scattering + nadir path = Low reflectance
ATSR nadir view

Rayleigh layer + aerosol

+90 secs

Stratus: homogeneous, 'single layer': not too thick!
Ocean: black

High Northern latitude, descending node

Optically thin atmosphere above cloud 15 -18 Km
Optically thick, spectrally 'neutral' cloud
Non-reflecting surface
Ocean

Cloud optical depth not known, 
absolute calibration not possible.
Well defined spectral characteristics allows inter-channel calibration.
The calibration of the short-wavelength channels of the ATSR series of Instruments

<table>
<thead>
<tr>
<th>AATSR calibration factor</th>
<th>Nadir BDRF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.55μm</td>
</tr>
<tr>
<td>Baseline model (800hPa)</td>
<td>1.056</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AATSR relative calibration factor</th>
<th>Nadir 0.67μm / 0.55μm BDRF ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline model</td>
<td>0.982</td>
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</table>
Summary of Intercomparisons

<table>
<thead>
<tr>
<th>Ratio $R_{\text{AATSR}}/R_{\text{ref}}$</th>
<th>1.6</th>
<th>0.87</th>
<th>0.66</th>
<th>0.56</th>
</tr>
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<tbody>
<tr>
<td>AATSR vs. ATSR-2 Desert BRDF</td>
<td>1.01</td>
<td>1.08</td>
<td>1.08</td>
<td>1.13</td>
</tr>
<tr>
<td>AATSR vs. ATSR-2 Desert - Coincident Measurements</td>
<td>0.99</td>
<td>1.12</td>
<td>1.09</td>
<td>1.12</td>
</tr>
<tr>
<td>AATSR vs. ATSR-2 Greenland - BRDF</td>
<td>1.11</td>
<td>1.05</td>
<td>1.05</td>
<td>1.03</td>
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<td>AATSR vs. ATSR-2 Greenland - Coincidence</td>
<td>1.16</td>
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<td>AATSR vs. ATSR-2 Orbit Difference</td>
<td>1.12</td>
<td>1.08</td>
<td>1.08</td>
<td>1.08</td>
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<tr>
<td>AATSR-2 Average</td>
<td>1.00</td>
<td>1.12</td>
<td>1.08</td>
<td>1.09</td>
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<tr>
<td>Artic Stratus Clouds</td>
<td>1.02</td>
<td>1.02</td>
<td>1.06</td>
<td>1.06</td>
</tr>
<tr>
<td>GOME</td>
<td>1.01</td>
<td>1.01</td>
<td>1.01</td>
<td></td>
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<tr>
<td>MERIS</td>
<td>1.04</td>
<td>1.02</td>
<td>1.05</td>
<td></td>
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<tr>
<td>SADE (Cabot et al)</td>
<td>1.08</td>
<td>1.07</td>
<td>1.05</td>
<td></td>
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</tbody>
</table>

- AATSR agreement within 5% of MERIS GOME, & Cloud Comparisons
- AATSR 1.6µm channel agrees well with ATSR-2 after nonlinearity correction.
- AATSR SW channels approx 10% higher than ATSR-2

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Summary of AATSR reflectance comparisons

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Long Term Stability using Deserts

AATSR Reflectances normalised to BDRF for Libya1 Site

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Long Term Stability using Ice

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AATSR visible calibration drift rates for desert and ice targets

<table>
<thead>
<tr>
<th></th>
<th>1.6um</th>
<th>0.87um</th>
<th>0.67um</th>
<th>0.56um</th>
<th>Date Range</th>
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<tbody>
<tr>
<td>Algeria3</td>
<td>0.3</td>
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<td>Oct-02</td>
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<td>Algeria5</td>
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<td>1.1</td>
<td>1.1</td>
<td>1.6</td>
<td>May-95</td>
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</tbody>
</table>

Drift = exp(-rate*time)
Note: Drifts from Greenland measurements used – may be overcompensating
Drift Correction - Effect on Comparisons (2)

<table>
<thead>
<tr>
<th>Ratio $R_{AATSR}/R_{ref}$</th>
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<td>MERIS</td>
<td>1.02</td>
<td>0.99</td>
<td>0.99</td>
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</table>

- Long Term Drift correction reduces differences between MERIS, GOME and Cloud Measurements
- ATSR-2 Low compared to AATSR

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Conclusions

- Early intercomparisons with ATSR-2 show that 0.87µm, 0.67µm and 0.56µm are ~5% lower than other sensors
  - Although significant range of results

- Comparisons with AATSR show that ATSR-2 0.87µm, 0.67µm and 0.56µm channels ~ 10% lower than current measurements
  - Consistent with earlier calibration measurements

- AATSR 1.6µm shows agreement within 1% of ATSR-2
  - Note: dependent on pre-launch nonlinearity correction being applied.

- AATSR shows good agreement (< 3%) between AATSR, MERIS, GOME and Cloud models at 0.87µm, 0.67µm and 0.56µm

- Initial long-term drifts have been measured for AATSR and MERIS using Desert and Ice targets.

- Differences decrease (<1%) after applying long-term drift correction to AATSR reflectances.
Future Work

**AATSR**
- Continue comparisons with MERIS over desert and ice targets
  - Compare long term stabilities

- Aim to perform additional comparisons with GOME, SCIA (Barry Latter) & Arctic Stratus Calibration (Caroline Poulsen) including drift and nonlinearity corrections.

- Improve Long Term drift analysis using data for extended period
  - Current period Oct-2002 to Dec-2003

- Extend comparisons to include additional sensors (e.g. MODIS…)

**ATSR-2**
- Revisit early ATSR-2 inter-comparisons
  - Investigate effect of long-term drift