Towards traceability when validating satellite IST observations

Jacob Høyer, Rasmus Tonboe, Fred Wimmer, Steinar Eastwood, Peter Thejl, Andreas Lang and Gorm Dybkjær
Outline

- Motivation
- Protocols
- FRM IST intercomparison experiment
  - Satellite validation
- Uncertainty budget
- Conclusions and way forward
Motivation

- IST ranked 4 out of 22 parameters in SI CCI survey
- Several satellite products are available:
  - Metop
  - Modis
  - Viirs
  - AVHRR-GAC reanalysis
- In situ observations very difficult to use
  - Sparse
  - Representativeness effects often larger than product uncertainty
  - No SI traceability
Protocol for IST radiometer comparisons
Protocol for IST radiometer comparisons

• Developed for the IST FICE
  • Guidelines for IST radiometer experiment
• General purpose experiment:
  • Can be used for other campaigns
Field Inter-Comparison Experiment (FICE) for Ice surface-temperature

Report from Field Inter-Comparison Experiment (FICE) for ice surface temperature

Jacob L. Høyer and Andreas M. Lang, Rasmus Tonboe, Steinar Eastwood and Warenfrid Wimmer

Danish Meteorological Institute
IST FICE introduction

- March 30 – April 7, 2016
- 3 research teams and 6 TIR radiometers
  - 2 x ISARs (DMI + NOCS)
  - 1 x KT 15.85II (DMI)
  - 3 x Cambell IR 120 (DMI + 2 Metno)
- All instruments mounted on sea ice for intercomparison
- Additional experiments:
  - Spatial variability
  - Freeze up experiment
  - Angular emissivity experiment
Site

- **Inglefield Bredning, off Qaanaaq**
- **High Arctic environment**
- **1 meter of sea ice**
- **9 cm of snow**
- **4 km from the coast**
- **DMI field campaigns since 2011**
Weather conditions

- Typical conditions for transition season:
  - Cold and calm
  - Pronounced daily variation
  - Uneven snow distribution
  - Favourable conditions for field work
# Instrumentation

<table>
<thead>
<tr>
<th>Radiometers</th>
<th>Institution</th>
<th>Ice sampling rate</th>
<th>Spectral range (μm)</th>
<th>Measured parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISAR08</td>
<td>DMI</td>
<td>2-3 minutes</td>
<td>9.8-11.5</td>
<td>Radiometric IST/Sky temp</td>
</tr>
<tr>
<td>ISAR03</td>
<td>NOCS</td>
<td>2-3 minutes</td>
<td>9.8-11.5</td>
<td>Radiometric IST/Sky temp</td>
</tr>
<tr>
<td>KT15.85 II</td>
<td>DMI</td>
<td>1 sec</td>
<td>9.6-11.5</td>
<td>Radiometric IST</td>
</tr>
<tr>
<td>IR120 WS</td>
<td>METNO</td>
<td>1 min</td>
<td>8-14</td>
<td>Radiometric IST</td>
</tr>
<tr>
<td>IR120 CS</td>
<td>METNO</td>
<td>1 min</td>
<td>8-14</td>
<td>Radiometric IST</td>
</tr>
<tr>
<td>IR120 AWS</td>
<td>DMI</td>
<td>10 min</td>
<td>8-14</td>
<td>Radiometric IST</td>
</tr>
</tbody>
</table>

Other instruments

<table>
<thead>
<tr>
<th>DMI AWS</th>
<th>DMI</th>
<th>10 minute</th>
<th>- Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Radiation (short/long, in/out)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Humidity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- T₂m, T₁m, Tsnow/ice</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Radiometric IST (IR120, see top of table)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WS</th>
<th>METNO</th>
<th>1 min</th>
<th>- Radiation (long,in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Radiometric IST (IR120, see top of table)</td>
</tr>
</tbody>
</table>

| IMB          | SAMS/DMI    | 2 hourly          | Vertical Snow and Sea Ice temperature (every 2 cm) |
Intercomparison experiment

- All instruments worked during intercomparison experiment
- Cold conditions challenging for setup and instruments
Radiometer results, Brightness temperatures

- Sampling intervals for different radiometers: 1Sec – 10 min
- DMI AWS placed about 40 meters away
Pairwise intercomparison, Mean

- Very different sampling intervals for different radiometers (1Sec – 10 min)
- For intercomparison, interpolated to minute observations and averaged every 10 minute
Pairwise intercomparisons, stddev

- AWS stands out due to 10 minute subsampling versus 10 minute averaging
- Stddev within 0.5 degrees C

<table>
<thead>
<tr>
<th></th>
<th>DMI ISAR</th>
<th>NOC ISAR</th>
<th>DMI AWS</th>
<th>DMI KT15</th>
<th>MetNO CS</th>
<th>MetNO WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>met.no WS</td>
<td>0.39</td>
<td>0.50</td>
<td>0.77</td>
<td>0.49</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>met.no CS</td>
<td>0.23</td>
<td>0.40</td>
<td>0.73</td>
<td>0.46</td>
<td>0.00</td>
<td>0.14</td>
</tr>
<tr>
<td>DMI KT15</td>
<td>0.05</td>
<td>0.10</td>
<td>1.20</td>
<td>0.00</td>
<td>0.46</td>
<td>0.49</td>
</tr>
<tr>
<td>DMI AWS</td>
<td>1.17</td>
<td>0.92</td>
<td>0.00</td>
<td>1.20</td>
<td>0.73</td>
<td>0.77</td>
</tr>
<tr>
<td>NOC ISAR</td>
<td>0.40</td>
<td>0.00</td>
<td>0.92</td>
<td>0.10</td>
<td>0.40</td>
<td>0.50</td>
</tr>
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<td>DMI ISAR</td>
<td>0.00</td>
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<td>0.05</td>
<td>0.23</td>
<td>0.39</td>
</tr>
</tbody>
</table>
ISAR comparison

- No apparent dependencies on temperature, wind speed or insolation
- Differences might be due to: reference thermistor noise, window contamination effects and scan drum misalignment.
SKY TEMPERATURES

- Large variability
- Agreement between DMI and NOCS ISARs
- -100 °C temperatures appears is the lower limit for KT15
• Brightness temperatures
• Angles from Zenith (25, 45, 55 incident)
• TBs at 125° about 0.25-0.5°C colder than at 155°,
• Differences can be more than 1°C.
FREEZE UP EXPERIMENT

- First large hole filled over night
- New experiment last day
- One radiometer (MetNo)
- Smaller hole with ice contamination from sides
Example of validation of satellite IST with radiometer comparisons
SATELLITE VALIDATION

- Validated against DMI TIR on AWS
- 4.5 months (Jan-June, 2016)
- Cambell Scientific IR120 (8-14 μm)
- 10 minute observations

<table>
<thead>
<tr>
<th>Satellite product</th>
<th>Spatial resolution</th>
<th>File granule</th>
<th>Data Provider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metop_A AVHRR OSI 205</td>
<td>1.1 km</td>
<td>3 min</td>
<td>EUMETSAT OSI-SAF</td>
</tr>
<tr>
<td>NPP SUOMI VIIRS</td>
<td>750 m</td>
<td>5 min</td>
<td>NOAA</td>
</tr>
<tr>
<td>MODIS TERRA (MOD29.006)</td>
<td>1 km</td>
<td>5 min</td>
<td>NASA-GSFC</td>
</tr>
<tr>
<td>MODIS AQUA (MYD29.006)</td>
<td>1 km</td>
<td>5 min</td>
<td>NASA-GSFC</td>
</tr>
</tbody>
</table>
SATELLITE VALIDATION

- Only best quality included
- Cold outliers in all products
• Cold tail evident in all products
• OSI-SAF Metop AVHRR looks OK.
• VIIRS_NPP shows a broad peak.
EXAMPLES, WITHIN 3H14MIN
## SATELLITE VALIDATION

<table>
<thead>
<tr>
<th>Closest pixel</th>
<th>Metop_A AVHRR</th>
<th>VIIRS</th>
<th>MODIS TERRA</th>
<th>MODIS AQUA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean difference</td>
<td>-0.4 K</td>
<td>-1.7 K</td>
<td>-1.4 K</td>
<td>-1.9 K</td>
</tr>
<tr>
<td>Median abs difference</td>
<td>0.8 K</td>
<td>1.5 K</td>
<td>0.8 K</td>
<td>1.1 K</td>
</tr>
<tr>
<td>RMSE</td>
<td>2.0 K</td>
<td>3.6 K</td>
<td>3.5 K</td>
<td>4.8 K</td>
</tr>
<tr>
<td>stdv (differences)</td>
<td>1.9 K</td>
<td>3.2 K</td>
<td>3.3 K</td>
<td>4.4 K</td>
</tr>
<tr>
<td>N(matches)</td>
<td>227</td>
<td>197</td>
<td>122</td>
<td>165</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cloud-free average</th>
<th>Metop_A AVHRR</th>
<th>VIIRS</th>
<th>MODIS TERRA</th>
<th>MODIS AQUA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean difference</td>
<td>-0.2 K</td>
<td>-0.9</td>
<td>-0.6 K</td>
<td>-1.7 K</td>
</tr>
<tr>
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<td>1.0 K</td>
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<td>1.7 K</td>
<td>2.7 K</td>
<td>1.3 K</td>
<td>3.1 K</td>
</tr>
<tr>
<td>N(matches)</td>
<td>173</td>
<td>26</td>
<td>52</td>
<td>75</td>
</tr>
</tbody>
</table>
Uncertainty budget for traditional in situ IST observations
Motivation

- Operational satellite products require operational in situ observations for monitoring and validation.
- iSVP Buoy observations available from IABP through GTS

Task: How can we best use the GTS observations for satellite validation?

- Deploy iSVP buoys
  - Perform inter-comparison of iSVP observations
  - Assess the different uncertainty components when validating satellite IST
  - Automatic QC procedures to identify representative observations
Satellite vs. In situ

- Differences include:
  - Uncertainty on iSVP sensor
  - Uncertainty on satellite IST product
  - Spatial difference (footprint vs. point)
  - Temporal difference
  - Vertical difference (skin vs. snow, 1m or 2m air temp)
Spatial Variability

<table>
<thead>
<tr>
<th>Part</th>
<th>N(obs)</th>
<th>Distance</th>
<th>Duration</th>
<th>Stdv (°C)</th>
<th>Bias to AWS</th>
<th>Spatial stdv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1</td>
<td>718</td>
<td>4.08 km</td>
<td>00:59:45</td>
<td>0.69 °C</td>
<td>-0.01 °C</td>
<td>0.25 °C</td>
</tr>
<tr>
<td>(Apr-02)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 2</td>
<td>709</td>
<td>3.04 km</td>
<td>00:59:00</td>
<td>0.42 °C</td>
<td>0.50 °C</td>
<td>0.12 °C</td>
</tr>
<tr>
<td>(Apr-03)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Temporal difference

- Large hourly variability, compared to SST
- Three years of AWS data, + Tara + ARMS data
Vertical difference

- AWS Qaanaaq, 2015-2017
  - $T_{2m} - T_{skin}$
  - Large wind speed dependency
iSVP buoys

- Two iSVP buoys deployed in January 2017, at AWS site
- Wrong software, reporting -5°C!
- Two new deployed in April, 2017
- New buoys recovered in June
- Old buoys left on ice -> ocean
Buoy inter-comparison with AWS

- Buoys 2-4 degrees warmer than IST
- Stddev 3-5 degrees, lowest for new buoys
CONCLUSIONS

• A successful pilot IST FICE conducted
• Challenging environmental conditions
• Mean radiometer differences between 0.21 and 1 °C
• Satellite validation against TIR:
  • All products have difficulties detecting the clouds
  • Metop_A had highest data return and showed best performance

• iSVP buoys within 1 meters showed up to 20 degrees C difference
• Sampling effects much larger than algorithm effects

• Effect of angular dependency: 0.25-0.5°C

• FICE report available, paper in preparation
Way forward

- Repeat campaign:
  - Additional FRM TIR calibration experiments in cold conditions
  - Spatial variability experiment with drones
  - Freeze-up experiment with larger basin
  - Measurement of surface emissivity

- Uncertainties on FRM TIRs should be evaluated
- Need for an all-year maintained TIR FRM radiometer at, e.g. Summit
- Systematic intercomparison of all satellite IST products (SNOs)
Questions ?