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Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS)

ESA Contract No. 4000113848_15I-LG

OP-60: Scientific and Technical Meeting Report: *Toward Field Intercomparison Exercise for Ice Surface Temperature*

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ESA Craig Donlon Technical Officer	Digitally signed by Device Identity 9c6f8ccd4f5eaa531db70b0929b3d2a06f1e6010 Location: Noordwijk, The Netherlands Date: 2018.06.27 13:14:37 +02'00' *Signature*	**NPL** Andrew Brown Project Manager	Andrew Brown, NPL *Signature*

INTRODUCTION

An international workshop was held at the National Physical Laboratory, the UK national metrology institute on October 16-18, 2017. The aim of the workshop was to review the current state of the art in both satellite derived and surface based measurements and consider their adequacy to meet the varied needs of the user community, now and the foreseeable future. In particular, results of the recent set of comparisons of instruments and methods used for satellite validation carried out under the auspices of CEOS through the ESA funded project FRM4STS were presented and discussed. The workshop was structured to consider input from invited presentations spanning the domains of land, water and ice and through facilitated discussion come to a consensus view on priorities for each domain.

This report contains the presentation and summarizes the key results at the workshop within the radiometer field inter-comparison exercise for Ice Surface Temperature and the discussion that followed the presentation.

SUMMARY OF KEY FINDINGS

A field inter-comparison experiment over sea ice was conducted in March-April, 2016 on the sea ice off Qaanaaq, in Northwest Greenland. The experiment and the campaign followed the procedures and protocols for Ice temperature radiometer comparisons that have been developed within the FRM4STS project to ensure traceability and repeatability of the experiment.
Six different thermal infrared radiometers participated in the inter-comparison, the first of its kind over sea ice, including two Fiducial Reference Measurements Thermal Infrared Radiometers (FRM-TIR). The weather conditions were typical for a high Arctic environment, with surface temperatures between -30^{o}C and -10^{o}C and low wind speeds. Pairwise comparisons of the 10 minute averaged brightness temperatures from the radiometers showed mean differences between 0.13 and 1.0 K and standard deviation from 0.05 to 1.20 K. Inter-comparison of the sky brightness temperatures showed that a lower limit of ~173 K was reached with both FRM-TIR instruments during cold sky conditions. Several other experiments have been conducted during the field campaign, such as spatial variability study, a freeze-up experiment and an angular dependence experiment. All these experiments are described here and contribute to the understanding of the radiometers inter-comparison experiments.
The radiometer installed on the DMI automatic weather station was used for validating the four most used satellite Ice surface Temperature products for a period of four months. Root mean square differences ranged from 1.4 K to 3.5 K, where the Metop_A AVHRR and MODIS Terra products showed the smallest differences to the radiometer observations. The experiment was the first time with several radiometers and a focus upon SI traceability.

DISCUSSIONS AND WAY FORWARD

The extreme conditions under which the experiment has been conducted in caused difficulties to several of the instruments. In addition, the lessons learned during this pilot experiment are valuable for future field campaigns. The presentation at the workshop thus ended with a concluding slide and suggestions for a way forward, followed by a discussion with the scientific experts present at the meeting. The discussions during the meeting were focused upon identifying gaps and challenges to the existing in situ observational network and on proposing a way forward.

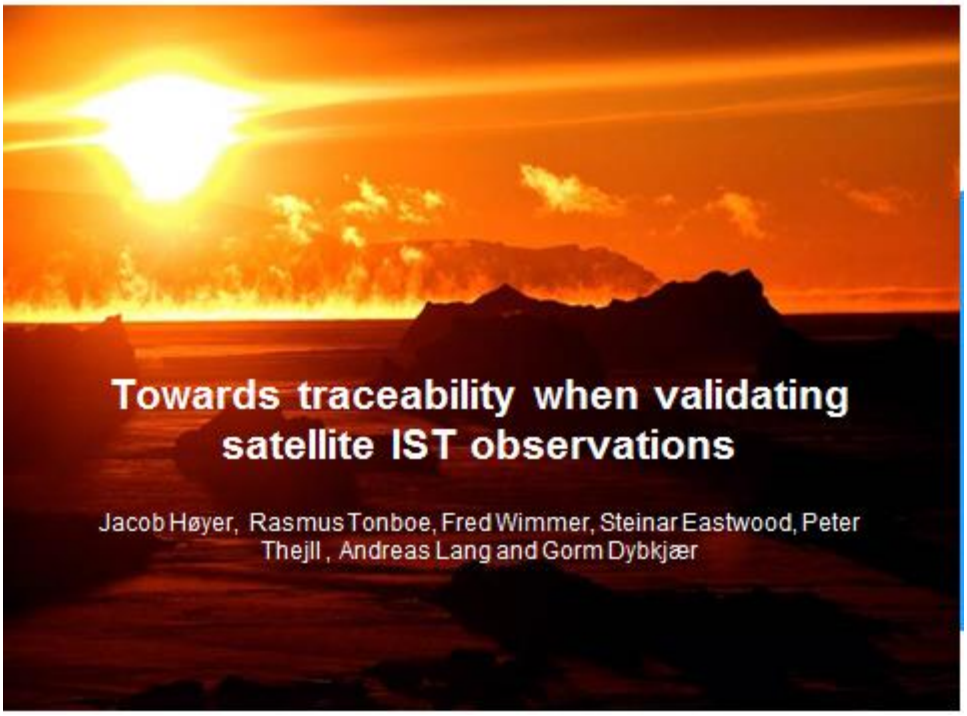
The main Recommendations from the discussion were:

- It was recognized that the experiment was a successful pilot campaign. It was the first of its kind and provided unique observations and experience. It is very important to repeat the campaign to establish the results obtained and to optimize and improve on the lessons learned.
- Future experiments could include The FRM TIR calibration experiments in cold conditions, to improve the results.
- Assessing the spatial variability within a footprint proved to be very difficult using a sledge on the sea ice. A drone experiment equipped with a thermal camera would be better suited for this experiment to assess the spatial variability in ice surface temperature within a satellite footprint of typically 1 km^2
- The different surface conditions at the sea ice surface are associated with emissivity changes that are hard to quantify, as these are not large. However, with the dry and cold atmosphere, the impact on the observed IST might still be significant. It is therefore important to conduct surface emissivity measurements to understand the variations in IST.
- The existing uncertainty models associated with FRM TIR observations have been derived for SST. These should be evaluated for IST observations in much colder conditions.
- At present, there are no reference radiometer observations that can be used for all-year validation of the satellite IST products. This is a serious challenge to algorithm developments and to routine monitoring of the satellite performance over ice. It is therefore recognized that there is an urgent need for an all-year maintained TIR FRM radiometer at, e.g. Summit or Dome C.
- Systematic inter-comparison should be performed for of all satellite IST products using Simultaneous Nadir Overpasses (SNOs) to monitor and quality assess the different satellite IST products.

The conclusion from the discussion above was thus, that FRM4STS has made a significant contribution to advance the fiducial IST measurements and that these achievements should be followed up with additional initiatives in order to keep momentum.

PRESENTATION

The slides from the presentation '*Towards traceability when validating satellite ice surface temperature observations'* are reproduced on the following pages.



Motivation

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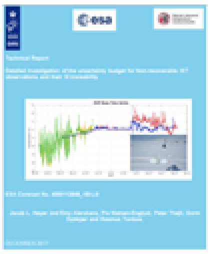
- Little use of Satellite IST despite large potential
  - Limited IST validation studies
    - Lack of reference data
    - Lack of understanding the uncertainty budgets
- Need for a reference data set for validation and calibration of satellite IST
- Here: Investigate the implications of using:
  - iSVP buoys
  - Radiometers observations
  - T2m air observations
- Developed automatic quality control procedures
- Purchased two iSVP buoys to put out in Qaanaq Western Greenland



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Motivation

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- 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

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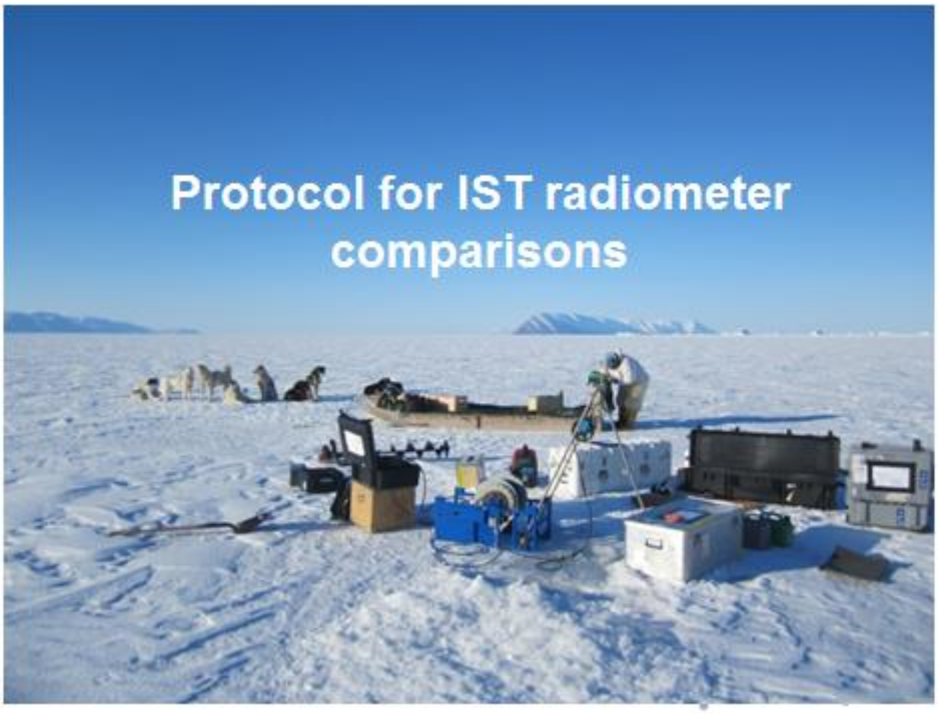

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Protocol for IST radiometer comparisons

- Developed for the IST FICE
  - Guidelines for IST radiometer experiment
- General purpose experiment:
  - Can be used for other camaigns

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Field Inter-Comparison Experiment (FICE) for Ice surface- temperature

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IST FICE introduction

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- 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

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Site

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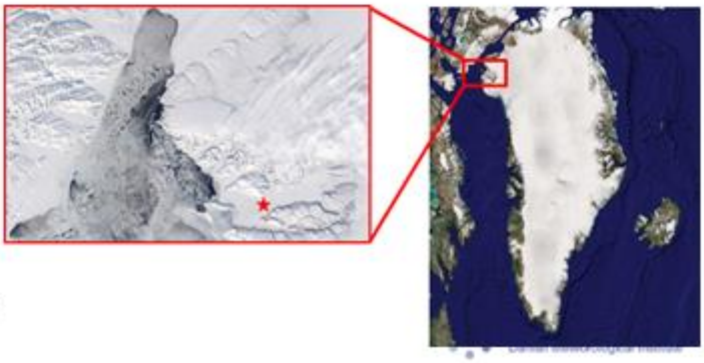
- *Inglefield Bredning, off Qaanaaq*
- *High Arctic environment*
- *1 meter of sea ice*
- *9 cm of snow*
- *4 km from the coast*
- *DMI field campaigns since 2011*



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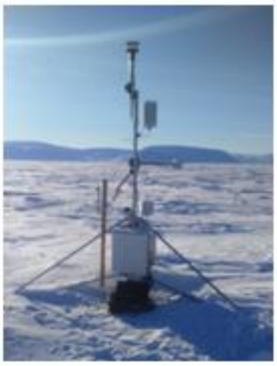
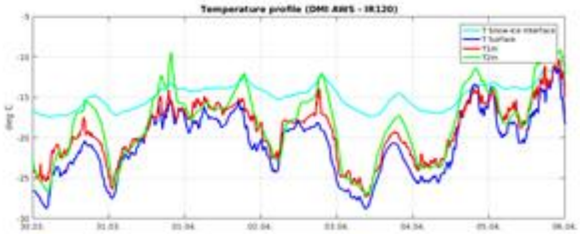
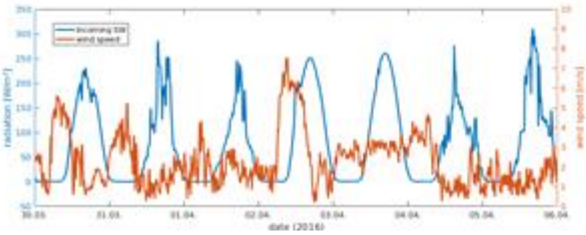
Weather conditions

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







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Instrumentation

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Radiometers	Institution	Ice sampling rate	Spectral range (μm)	Measured parameters
ISAR08	DMI	2-3 minutes	9.8-11.5	Radiometric IST/Sky temp
ISAR03	NOCS	2-3 minutes	9.8-11.5	Radiometric IST/Sky temp
KT15.85 II	DMI	1 sec	9.6-11.5	Radiometric IST
IR120 WS	METNO	1 min	8-14	Radiometric IST
IR120 CS	METNO	1 min	8-14	Radiometric IST
IR120 AWS	DMI	10 min	8-14	Radiometric IST
Other instruments				
DMI AWS	DMI	10 minute		-Wind -Radiation (short/long, in/out) -Humidity -T_{2m}, T_{1m}, $T_{snow/ice}$ - Radiometric IST (IR120, see top of table)
WS	METNO	1 min		-Radiation (long,in) - Radiometric IST (IR120, see top of table)
IMB	SAMS/DMI	2 hourly		Vertical Snow and Sea Ice temperature (every 2 cm)

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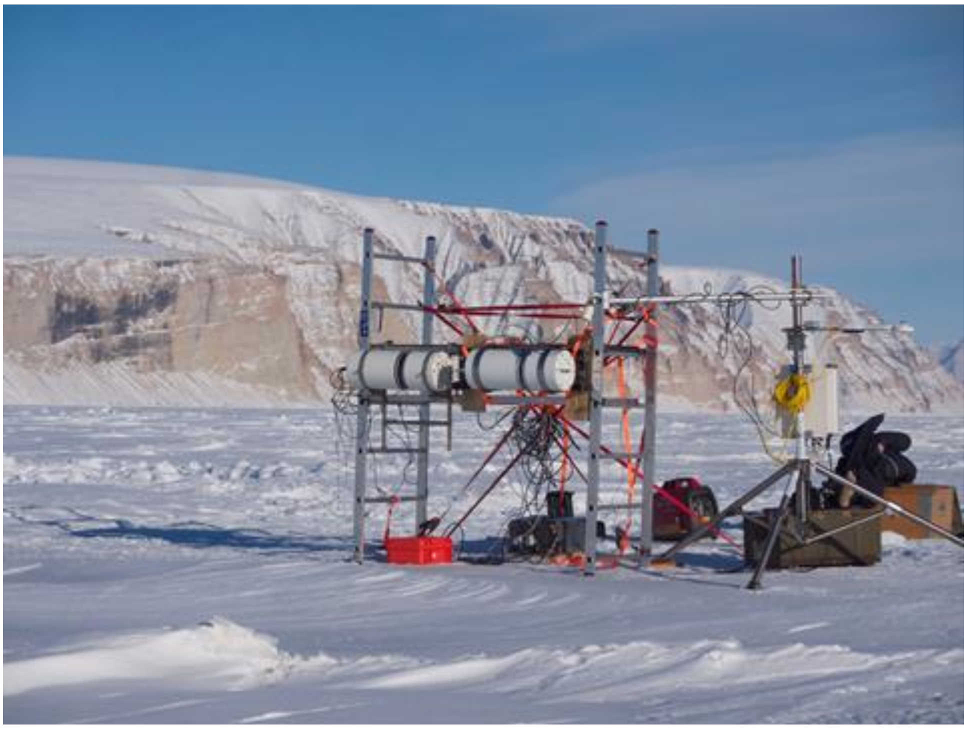

Intercomparison experiment

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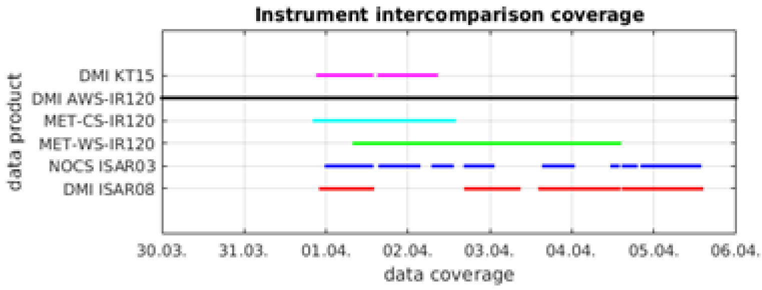
- All instruments worked during intercomparison experiment
- Cold conditions challenging for setup and instruments



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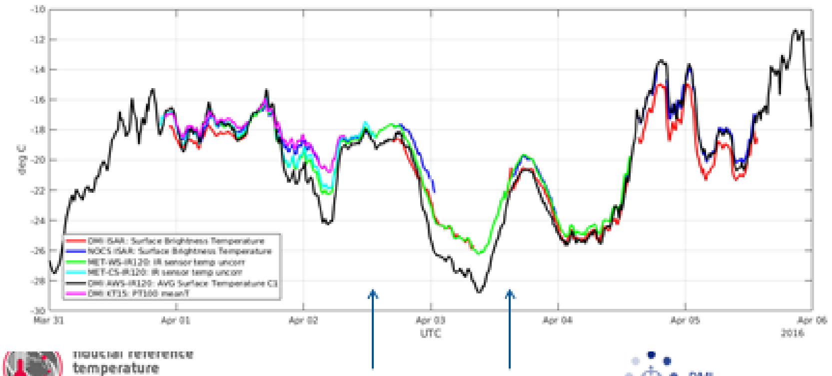
Radiometer results, Brightness temperatures

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



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Pairwise intercomparison, Mean

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

mean difference [deg C]

	DMI ISAR	NOC ISAR	DMI AWS	DMI KT15	MetNO CS	MetNO WS
net.no WS	-0.41	0.36	-0.90	0.83	0.21	
met.no CS	-0.61	0.14	-0.49	0.47		-0.21
DMI KT15	-0.86	-0.27	-1.00		-0.47	-0.83
DMI AWS	-0.13	0.58		1.00	0.49	0.90
NOC ISAR	-0.93		-0.58	0.27	-0.14	-0.36
DMI ISAR		0.93	0.13	0.86	0.61	0.41

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Pairwise intercomparisons, stddev

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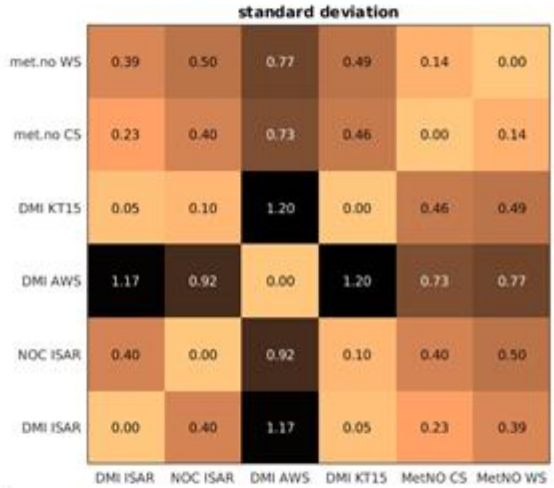
- AWS stands out due to 10 minute subsampling versus 10 minut averaging
- Stddev within 0.5 degrees C



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ISAR comparison

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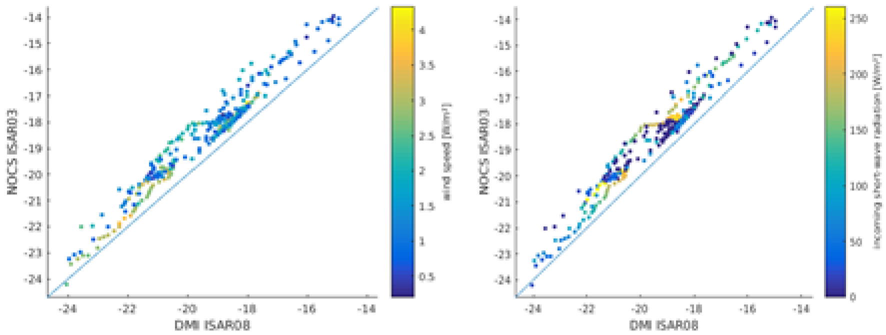
- No apparent dependencies on temperature, wind speed or insolation
- Differences might be due to: reference thermistor noise, window contamination effects and scan drum misalignment.



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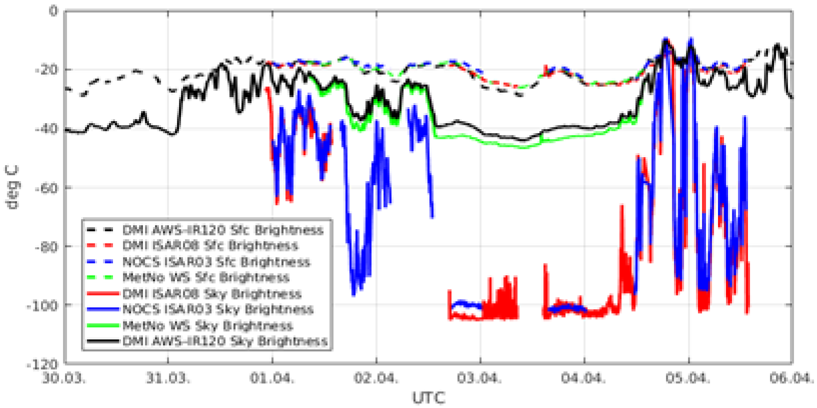
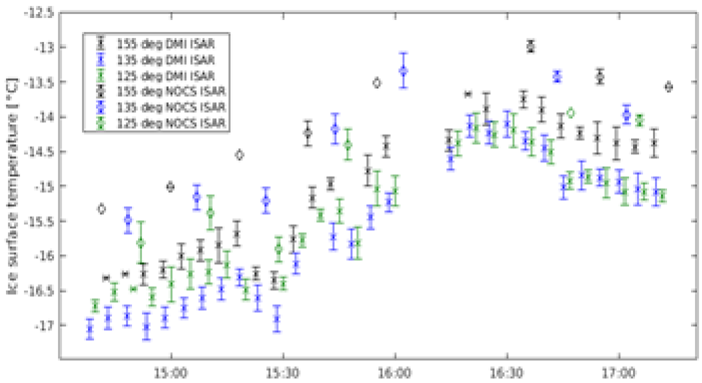
SKY TEMPERATURES

- Large variability
- Agreement between DMI and NOCS ISARs
- -100 °C temperatures appears is the lower limit for KT15



ANGULAR DEPENDENCY

- 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

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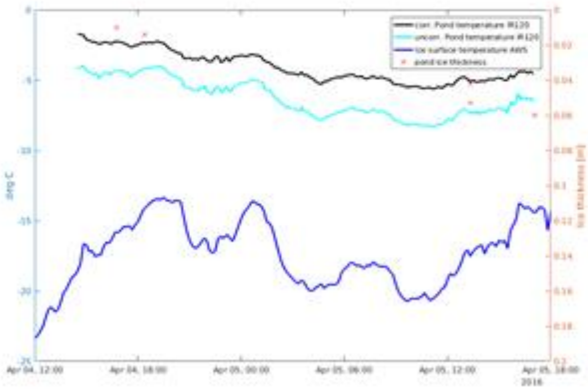
- First large hole filled over night
- New experiment last day
- One radiometer (MetNo)
- Smaller hole with ice contamination from sides



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Example of validation of satellite IST with radiometer comparisons

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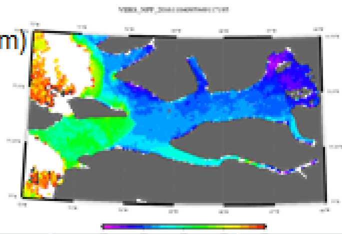
SATELLITE VALIDATION

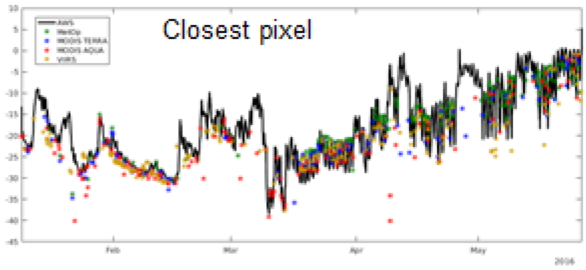
- Validated againt DMI TIR on AWS
  - 4.5 months (Jan-June, 2016)
  - Cambell Scientific IR120 (8-14 μm)
  - 10 minute observations

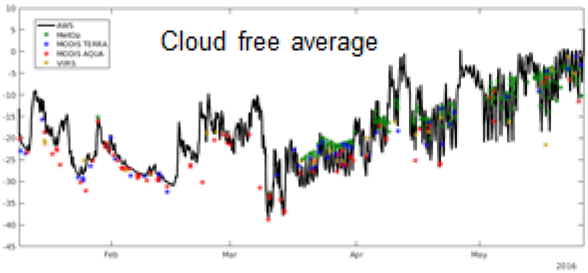


Satellite product	Spatial resolution	File granule	Data Provider
Metop_A AVHRR OSI 205	1.1 km	3 min	EUMETSAT OSI-SAF
NPP SUOMI VIIRS	750 m	5 min	NOAA
MODIS TERRA (MOD29.006)	1 km	5 min	NASA-GSFC
MODIS AQUA (MYD29.006)	1 km	5 min	NASA-GSFC

SATELLITE VALIDATION

- Only best quality included
- Cold outliers in all products





SATELLITE VALIDATION

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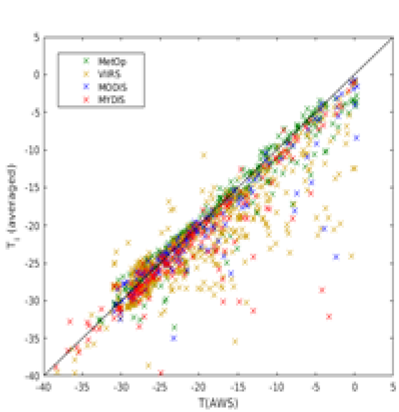

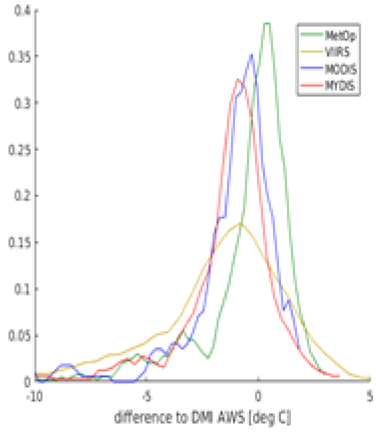

- Cold tail evident in all products
- OSI-SAF Metop AVHRR looks OK.
- VIIRS_NPP shows a broad peak.

EXAMPLES, WITHIN 3H14MIN

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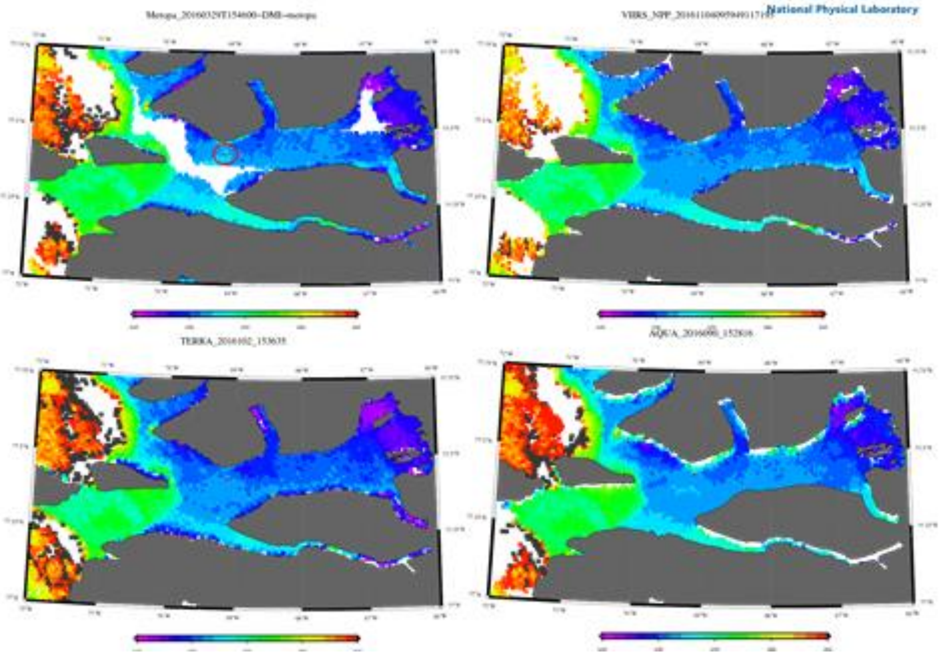

SATELLITE VALIDATION

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

Cloud-free average	Metop_A AVHRR	VIIRS	MODIS TERRA	MODIS AQUA
Mean difference	-0.2 K	-0.9	-0.6 K	-1.7 K
Median abs difference	0.8 K	1.0 K	0.7 K	1.1 K
RMSE	1.7 K	2.8 K	1.4 K	3.5 K
stdv (differences)	1.7 K	2.7 K	1.3 K	3.1 K
N(matches)	173	26	52	75

CONCLUSIONS

- A successfull pilot IST FICE conducted
- Challenging environmental conditions
- Mean radiometer differences between 0.21 and 1 ºC
- Satellite validation against TIR:
    - All products have diffuculties 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: 0.25-0.5ºC

- FICE report available, paper in preparation

Data for this phase of the project is available here: [Phase 2C - Ice Surface Temperature]