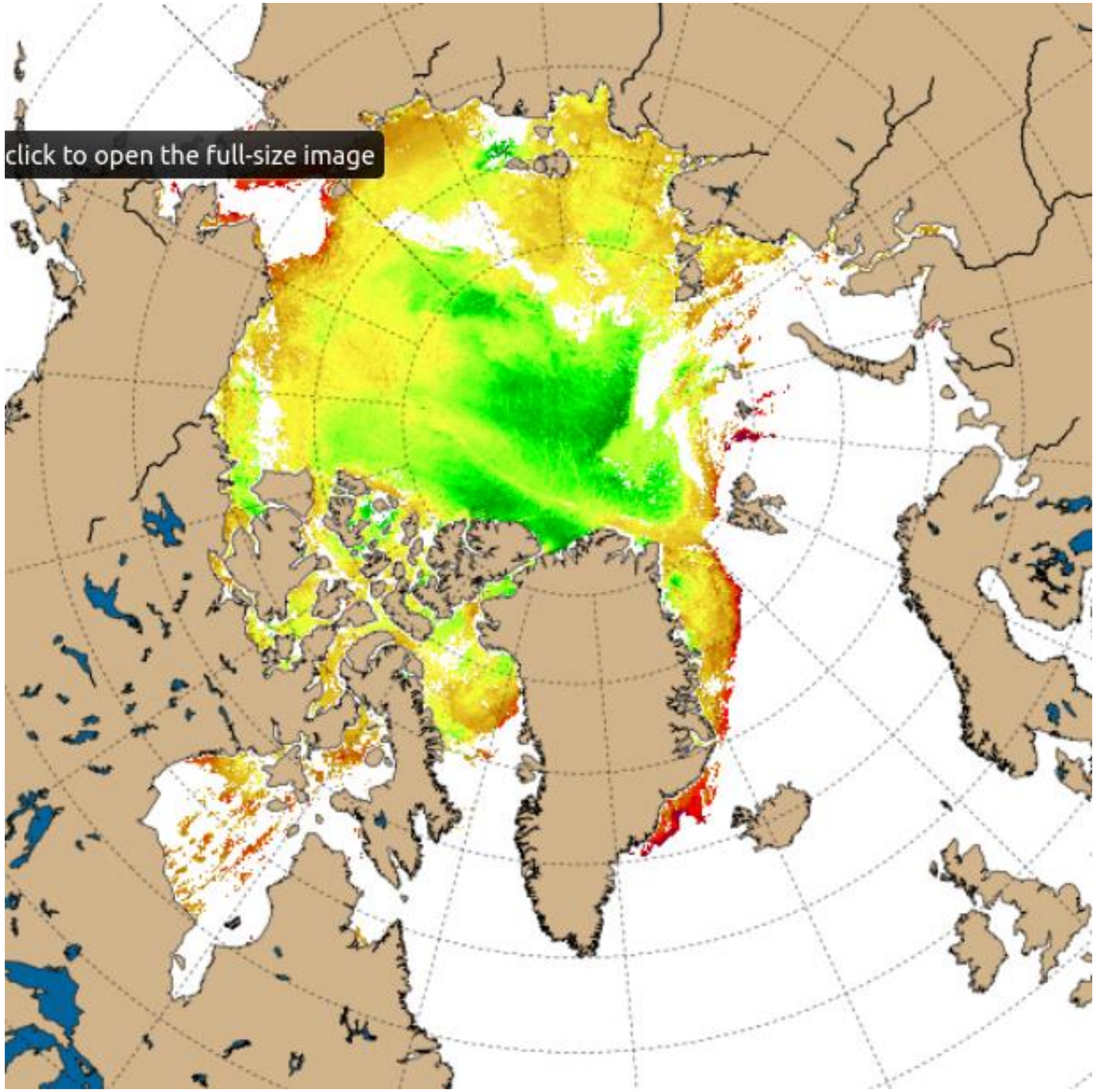
The Danish Meteorological Institute

Sea Ice- and Marginal Ice Zone Surface Temperature retrieval

- from Sentinel-3 Sea and Land Surface Temperature Radiometer.



Project Contributers and Partners

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Final project presentation, December 14, 2020 (on web)

Project Objective

Issues

Sea Ice Surface Temperatures IST influences the surface energy balance and affecting the atmospheric boundary layer structure, turbulent heat exchange and ice growth rate. Modeling of these processes all benefit from operational, near real time satellite products of IST, in particular in areas with sparse and inferior observation network coverage.

Purpose

To provide near real time satellite products of IST to model communities in areas with poor ground data coverage. In addition climate applications benefit from better global and long term coverage of surface temperature from satellites at high latitudes.

Outcome

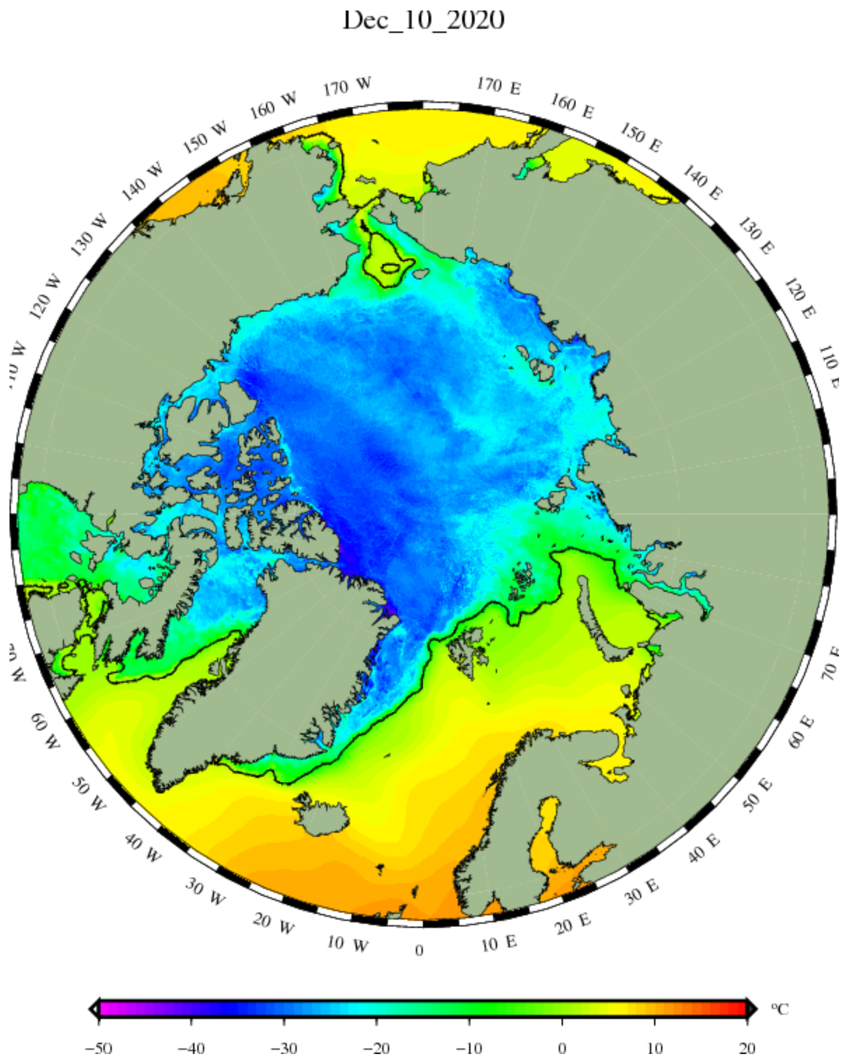
A prototype processor for sea-ice and marginal ice zone temperature retrieval for the Copernicus Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR).

Talk outline

- Background on Ice Surface Temperature (IST) monitoring and perspectives
- Modelers need for IST
- Special challenges with IST retrieval and evaluation
- SLSTR data
- Requirements for SLSTR IST and Match-up data
- Algorithm
- Performance
  - Sea ice
  - 1 year evaluation
  - Comparison with OSISAF IST
  - SLSTR A vs B
  - QL and Uncertainties
- Prototype Processor sketch
- Conclusions and future work

Back ground and status of Ice surface temperature monitoring

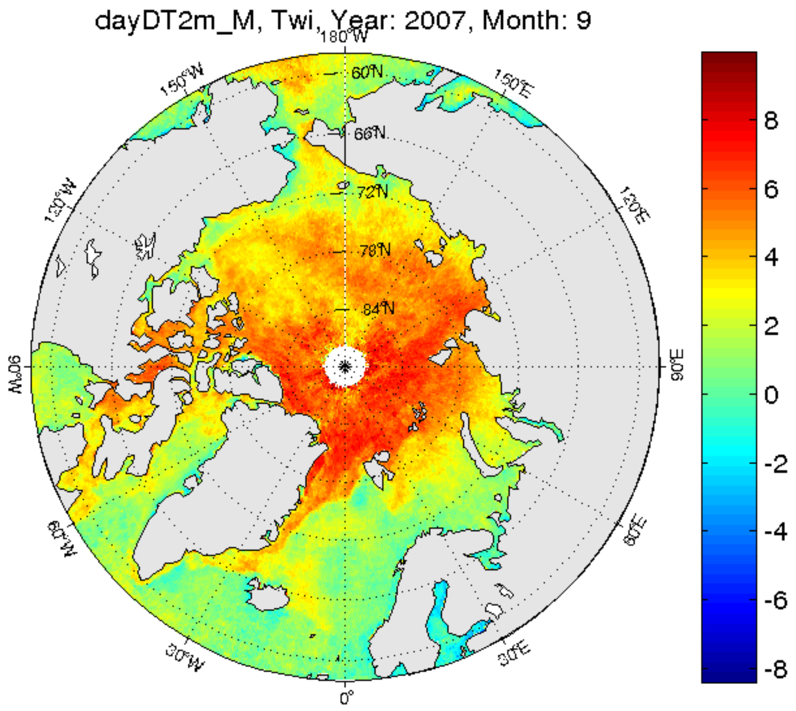
- In the past four decades, satellite-based land, sea and ice surface temperature retrieval has bee carried out.
- Sea Surface Temperature (SST) and Land Surface Temperature (LST) are both recognized as Essential Climate Variables by the Global Climate Observing System (GCOS).
- Sometimes Sea Ice Surface Temperature (IST) retrieval is not covered, sometimes it is covered by LST communities and sometime by SST communities.
- IST needs its own community, with its own issues…
- IST is not (yet) an ECV, but an application is send to GCOS and is currently under review to be part of the 'club'.



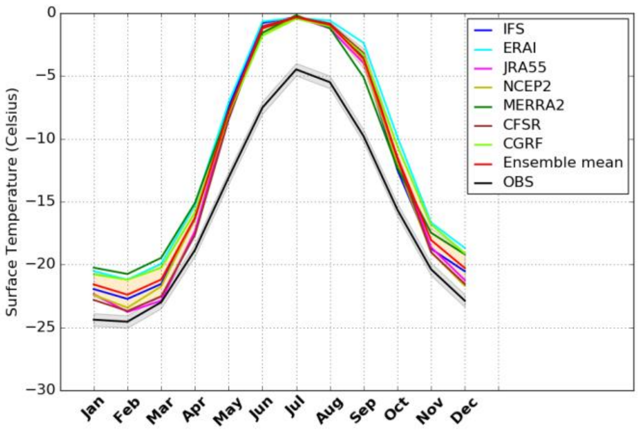
DMI Level 4 HL SST and IST product, Based on OSISAF IST/SST

Why is satellite IST important for model builders

- Up to 10 K bias in monthly mean data. Not only the for ERA-interim – also valid for e.g. ERA-5, NAOSIM...
- Large impack on ice growth and melt – snow thickness
- Large geograpical variability
- Valuable for for ice model tuning, assimilation and validation



Mean temperature difference between modelled skin temperatures (ERA-interim) minus satellite observed skin temperatures (AASTI), September 2007 (G.Garric, Mercator)

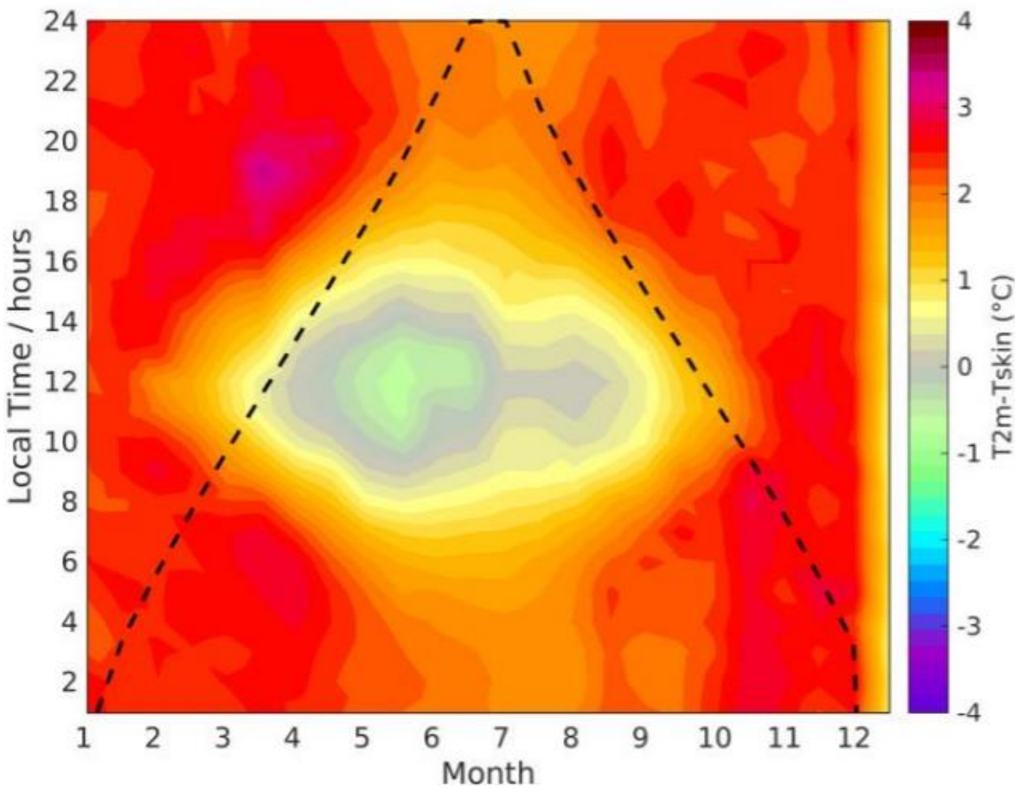


AASTI v1 vs model surface temperatures +80 N (Gilles Garric , Mercator)

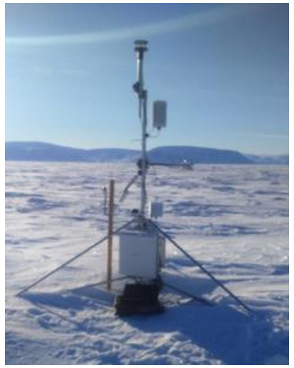
SKIN TEMPERATURE VS AIR TEMPERATURE CONVERSION IS COMPLICATED

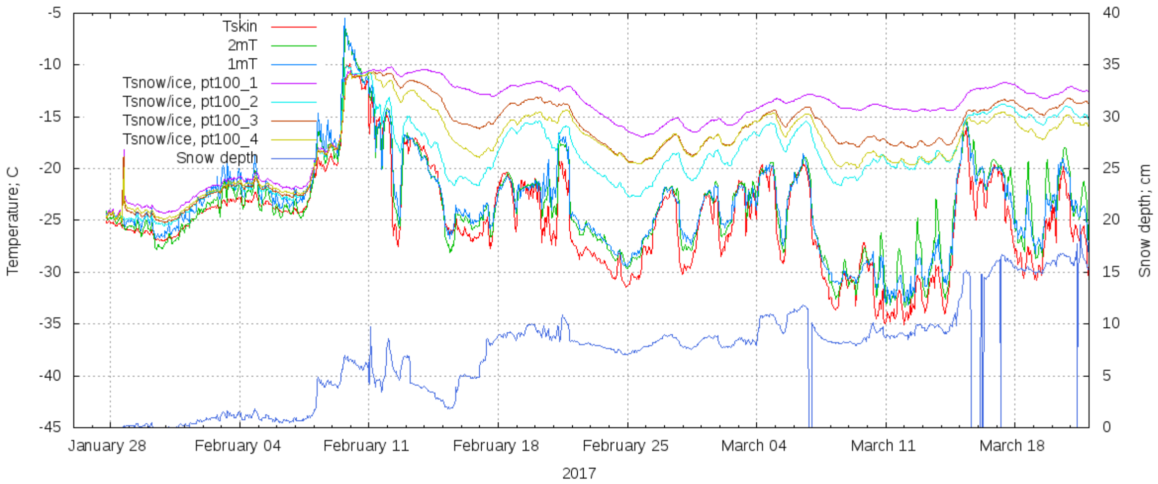
Ground measurements - challenges

- Ice surface temperature measurements on sea ice poorly represented by traditional buoys.
- Skin and air temperatures difference change with time of day and season
- Large errors are observed when traditional in situ instruments are snow covered – which is a common occurence on sea ice.



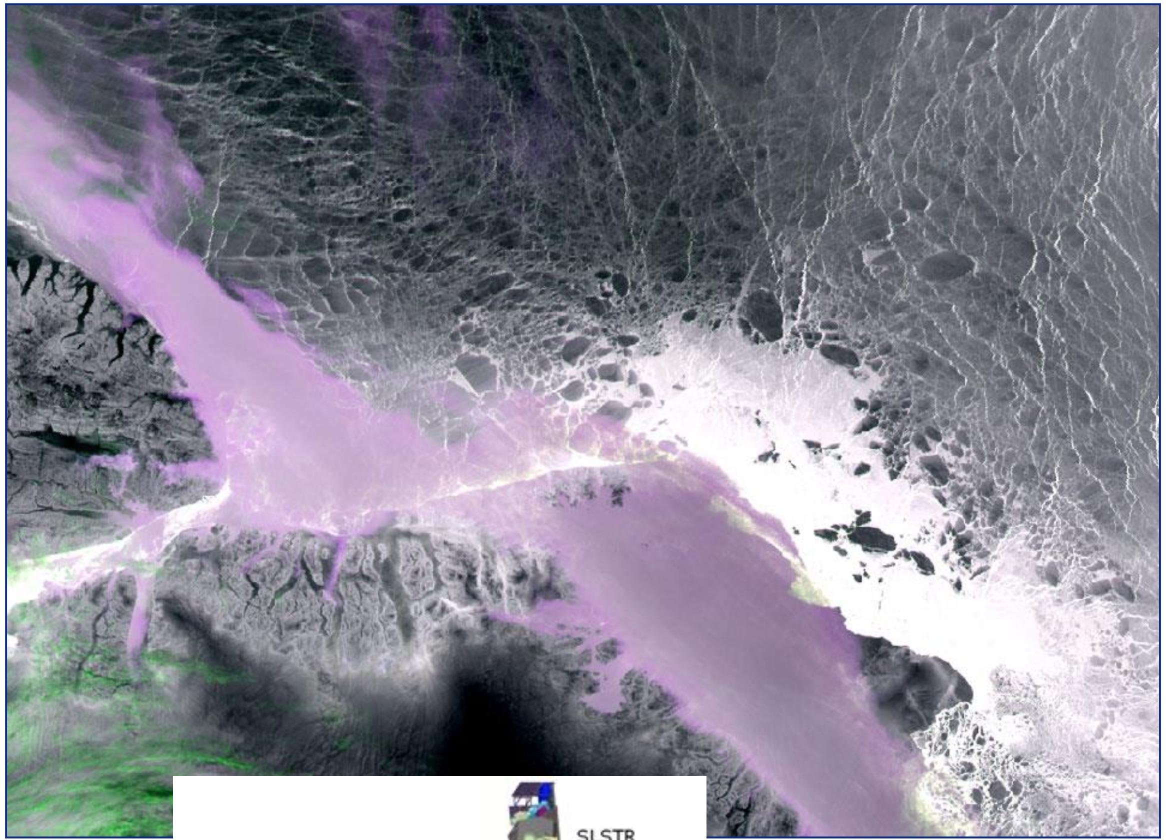
Mean Month 2 mT – skinT for clear sky conditions at PROMICE Kangerlussuaq, upper ice cap (Nielsen-Englyst et al., 2018)

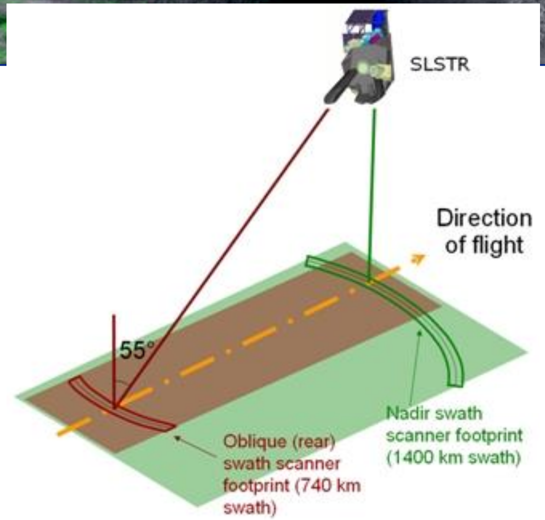




SLSTR Instrument

- Level 1 data stream provide 2x9 channels (S1-S9) from Visible to thermal infrared, for IST (S8+S9) algorithm and cloud screening.
- All channels are in dual view, Oblique and nadir.
- Cloud products are part of the level 1 data stream.





Spectral channel centre (µm)	VIS	0.554 (S1); 0.659 (S2) 0.868 (S3)
	SWIR	1.374 (S4); 1.613 (S5); 2.25 (S6)
	MWIR/TIR	3.742 (S7); 10.85 (S8); 12.02 (S9)

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Requirements for the SLSTR IST processor

- The satellite based IST performance requirement is in principle the product performance compared with the perfect temperature measure of the area mean skin temperature, with no time lag.
- Therefor – performance values must be corrected for uncertainties of the reference temperature

Δx (km)	Δt (min)	Δz (m)	$\mu_{in\ situ}$ (°C)	$\mu_{\Delta x}$ (°C)	$\mu_{\Delta t}$ (°C)	$\mu_{\Delta z}$ (°C)	$\sqrt{\mu^2_{in\ situ} + \mu^2_{\Delta x} + \mu^2_{\Delta t} + \mu^2_{\Delta z}}$ (°C)
1.0	10	IST_{skin}	0.2	0.12-0.25	0.34	0	0.41-0.47
1.0	30	IST_{skin}	0.2	0.12-0.25	0.71	0	0.75-0.78
1.0	60	IST_{skin}	0.2	0.12-0.25	1.11	0	1.13-1.16
1.0	10	T_{2m}	0.05	0.12-0.25	0.34	1.45 - 2.38	1.49-2.42
1.0	30	T_{2m}	0.05	0.12-0.25	0.71	1.45 - 2.38	1.62-2.50
1.0	60	T_{2m}	0.05	0.12-0.25	1.11	1.45 - 2.38	1.83-2.64
1.0	10	T_{buoy}	0.05	0.12-0.25	0.34	3.27 - 4.95	3.29-4.97
1.0	30	T_{buoy}	0.05	0.12-0.25	0.71	3.27 - 4.95	3.35-5.01
1.0	60	T_{buoy}	0.05	0.12-0.25	1.11	3.27 - 4.95	3.46-5.08

Variability within:
* 1 km^2
* dt = 30 min
* dz = -0.1 to 2 m

Radiometric measurement

2 m air measurement

Traditional buoy measurement

Uncertainty budget for In-Situ measurements to represent skin temperature (Høyer et al. 2018)

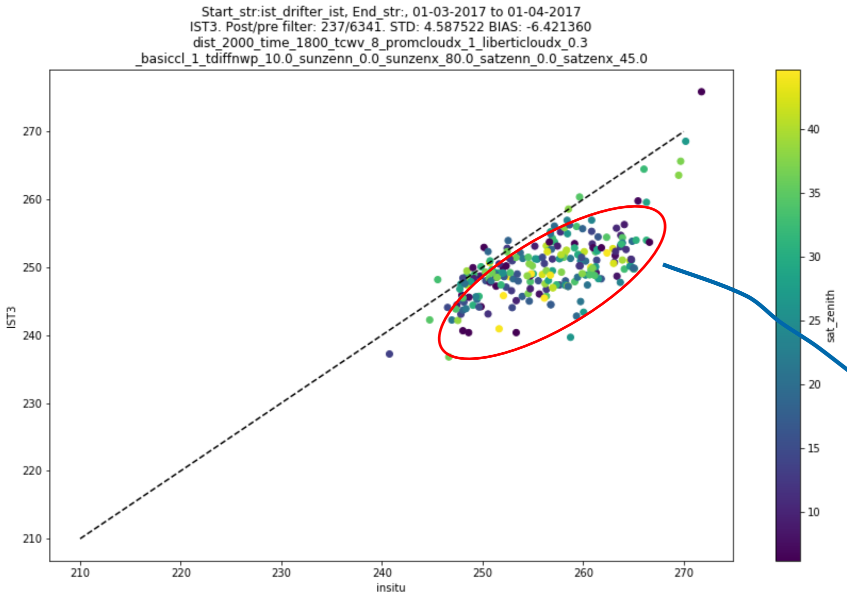
IDENTIFICATION		
Product name	SLSR IST	
Satellite Input data	SLSTR L1b data stream	
Other input	SLSTR WCT/WST SST, OSISAF Ice Conc.	
Method	Multi Spectral Algorithm for skin temperature retrieval.	
Dissemination means	EUMETCAST ? (TBD)	
Dissemination format	L2P, NetCDF	
Timeliness	NRT: 15 minutes processing time + time for level 1 availability at production centre.	
Spatial Coverage	Global: Pole wards of 50 N and 50 S.	
Spatial sampling	1 km	All processing is performed for the 1 km SLSTR grid
Projection	Swath	Adapted to 1 km SLSTR grid
Threshold accuracy	Bias=2.5 K STD= 2.0 K	Against high quality skin or air (at surface) temperature measuremens only
Target accuracy (Best realistic requirement)	Bias=1.5 K STD= 1.5 K	
Optimal accuracy	Bias=0.5 K STD= 0.5-1.0 K	
Data range	160 K - 300 K	
Verification method	Compared with radiometer or other high quality in situ data.	STD and mean error
Users	Met services, operational analysis and ocean model communities, reserch and climate studies and environmental studies.	

Match Up DB with In situ

Despite a lot of ground and aerial observation data from planes, ships and ice – we ended up using PROMICE AWS data from the Greenland ice cap to minimize noise and other undesired effects for evaluation of IST algorithms.

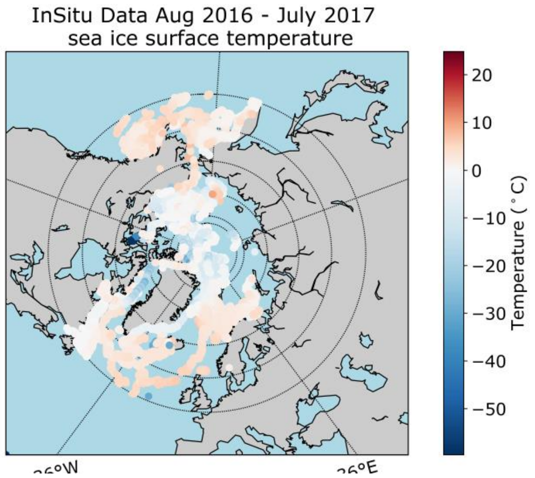
PROMICE data are hourly surface temperatures throughout the year and quality ensured every 1-2 years.

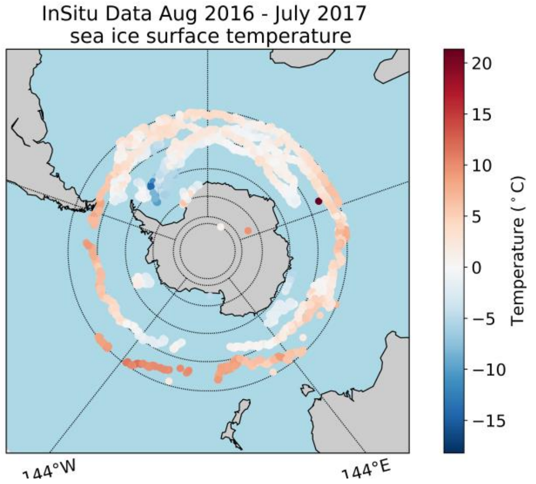
Drawback: Only few sea ice data used in algorithm evaluation.

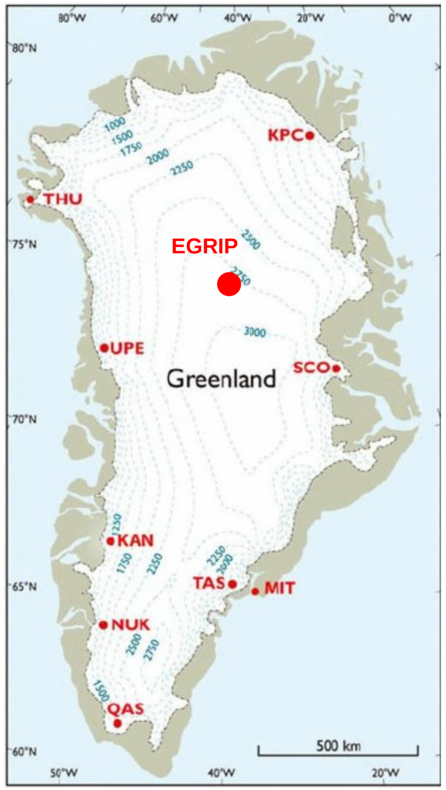


Scatterplot of IST3 versus traditional sea ice drifter temperatures (day time, March 2017)

Warm buoy temperature observations that most likely originate from snow covered sensors.







SLSTR IST and MIZT algorithms

Two algorithms selected from preliminary studies of 15 algorithms. Selection is based on accuracy, precision and stability

- ***IST Algorithm1*** *– a traditional split window based on nadir view only*

$$= a_0 + a_1 Tb_{11_{nadir}} + a_2 Tb_{12_{nadir}} + a_3 \left((Tb_{11_{nadir}} - Tb_{12_{nadir}}) \left(\frac{1}{\cos\theta} - 1 \right) \right)$$

- ***IST Algorithm2*** *– a dual view algorithm*

$$= a_0 + a_1 Tb_{11nadir} + a_2 Tb_{11oblique}$$

- ***Marginal Ice Zone algorithm***

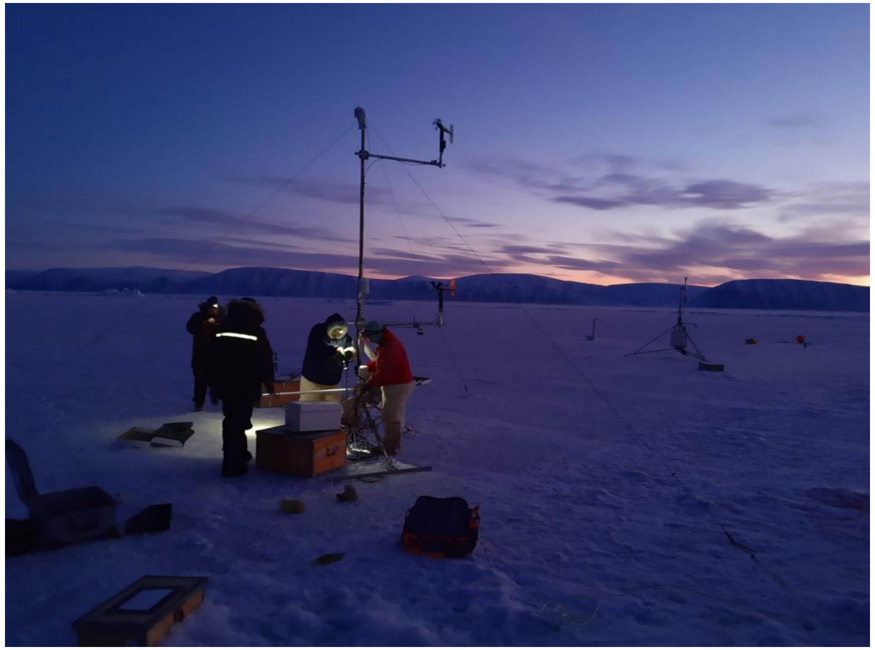
$$= 0.5(Tb_{11nadir} - 268.95) * SST - 0.5 * (Tb_{11nadir} - 270.95) * IST$$

Algorithm coefficients are calculated from regression analysis on Radiation Transfer Model simulations (RTTOV), with incidence angle dependent emissivity.

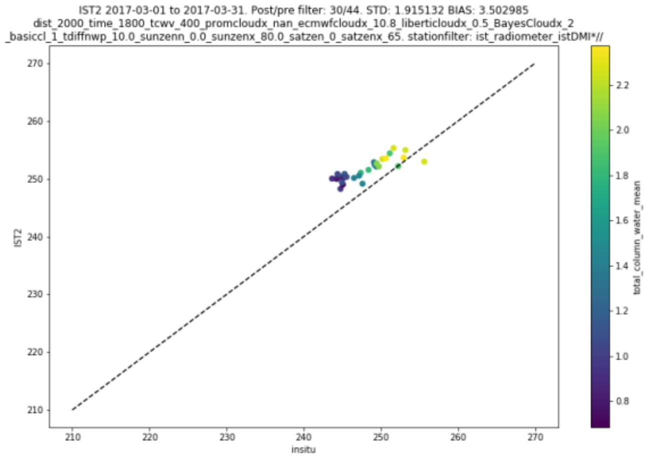
$Tb_{11nadir/oblique}$	**Tb 10.854 µm**	**S8_BT_i[n/o]**
$Tb_{12nadir/oblique}$	**Tb 12.023 µm**	**S9_BT_i[n/o]**

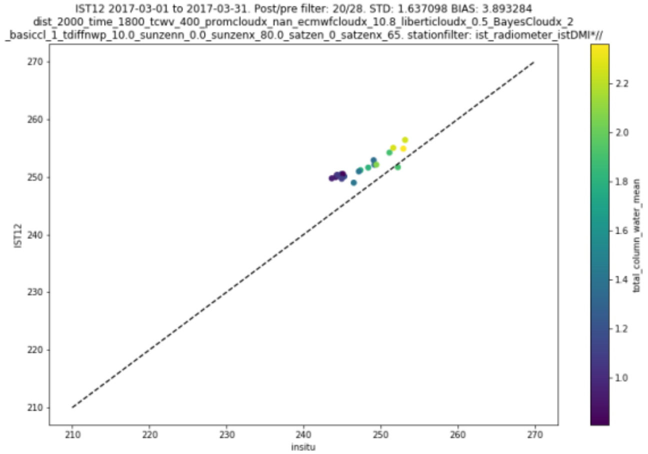
Validation – sea ice

- STD against DMI fiducial skin temperature measurements 1.9 K and 1.6 K for IST2 and IST12, respectively.
- Bias correspond to emissivity that is not corrected for in the in situ temperature – i.e. in situ observation is the brightness temperature.



DMI Winter Observatory, Qaanaaq NW Greenland.
Deployment of two AWS's on the Sea Ice, January 2019.

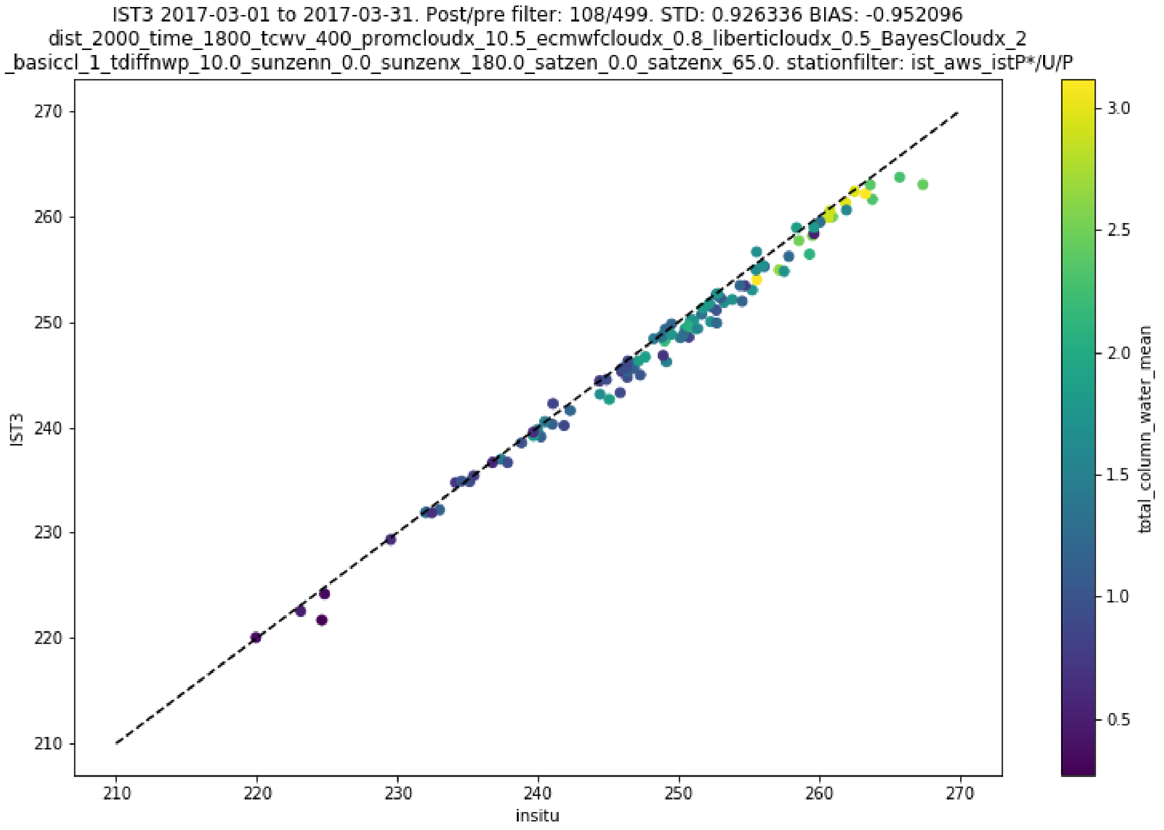




Scatter plots of IST2 (top) and IST12 (bottom) against DMI sea ice radiometric thermal infrared brightness temperatures from day time in March 2017

Validation – 1 month scatterplot

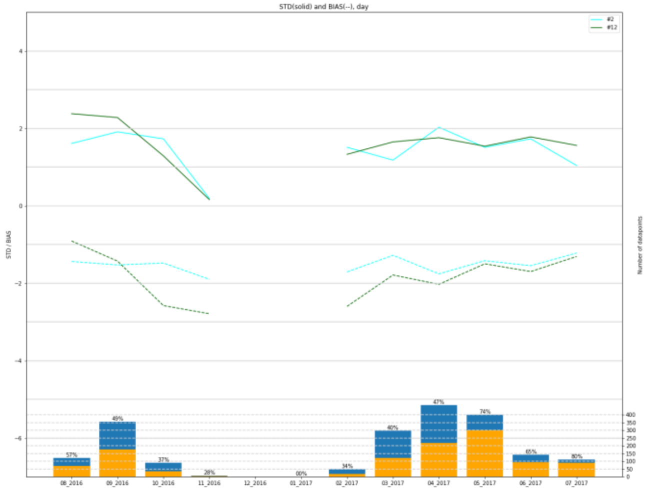
- Best quality data without night data
- High performance below goal requirement threshold, taking into observation uncertainty into account



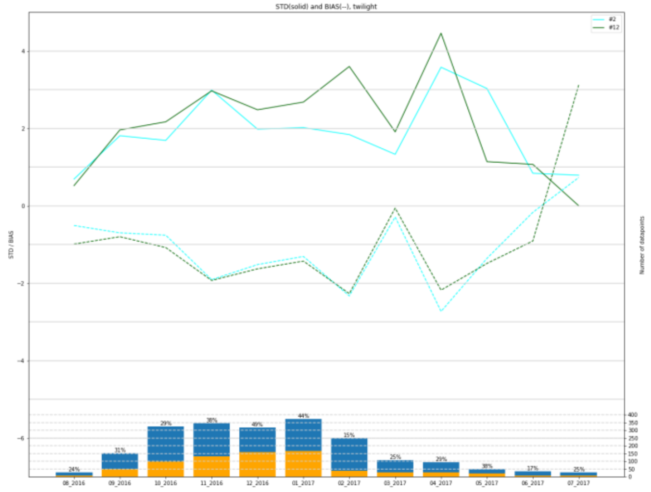
IST2 – approximate 1 year values	Day time	Twilight	Night time
STD (K)	1.4	1.9	2.6
BIAS (K)	-1.5	-1.1	-1.4

Validation (STD and Bias) – 1 year performance against PROMICE surface temperature

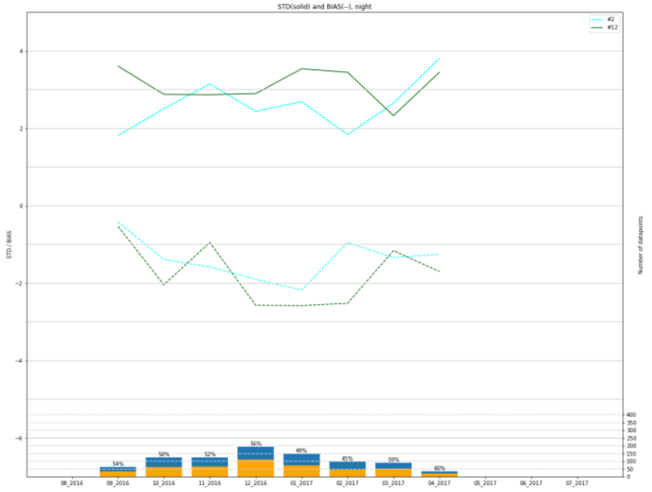
IST12 – approximate 1 year values	Day time	Twilight	Night time
STD (K)	1.6	2.3	3.1
BIAS (K)	-1.9	-1.3	-1.8



Day time



Twilight

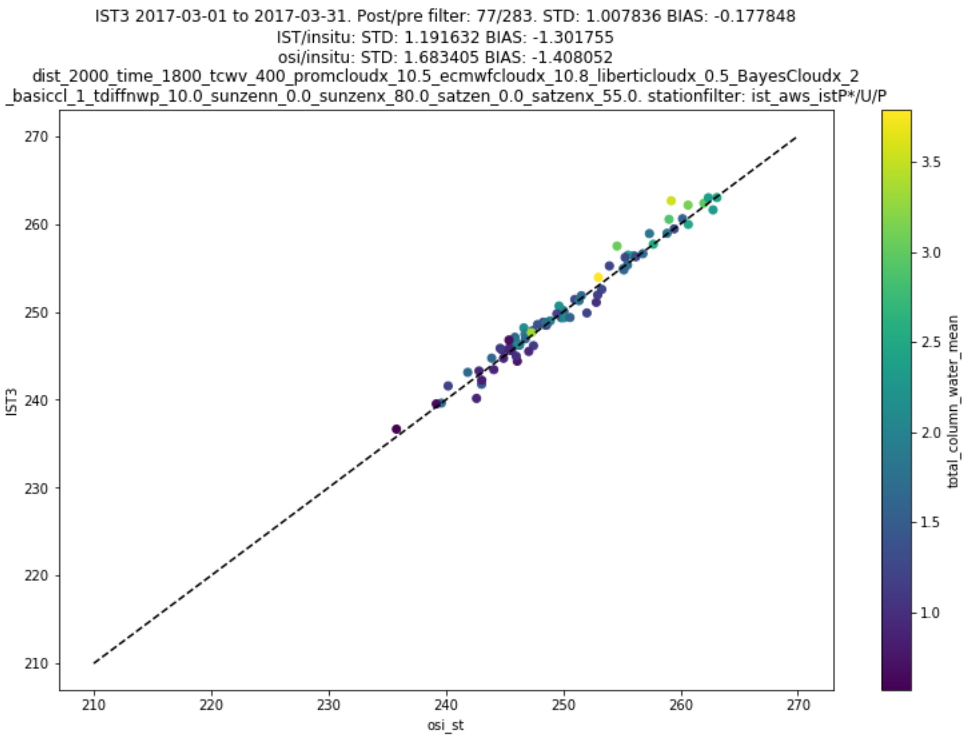


Night time

Performance of IST 2 (Turquoise) and IST12 (Green) (Solid lines are STD and punctured lines are Bias). Bars indicate the number of data points before and after masking for IST2 (blue and yellow, respectively

Validation vs OSISAF IST

- Match-up criteria's are 2 km and 30 minutes
- SLSTR IST and OSISF IST nearly unbiased - OSISAF is slightly colder than SLSTR IST.
- SLSTR IST3 STD=1.19 K
- OSISAF IST STD=1.68 K

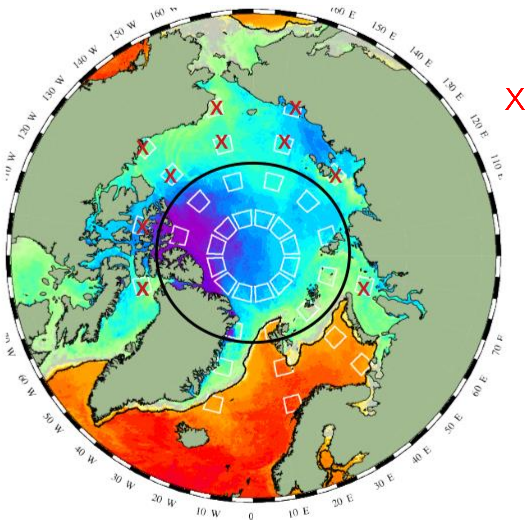


SLSTR IST3 matchup with OSISAF IST, March 2017.

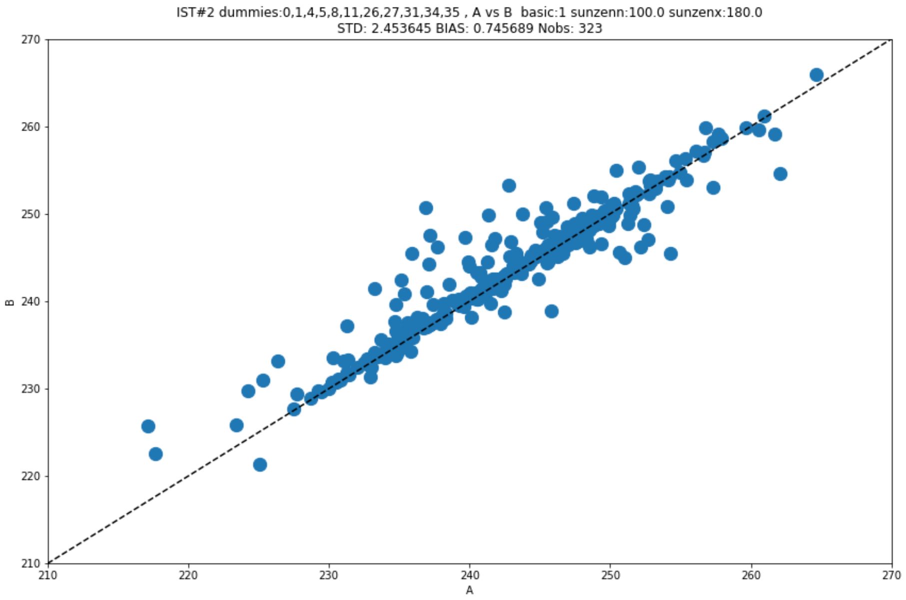
A RELATIVE COMPARISON

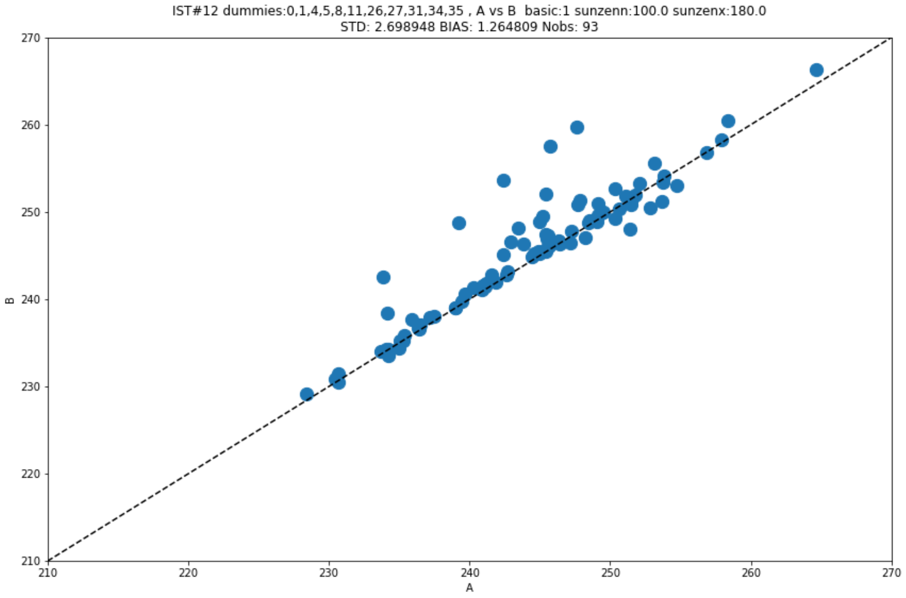
SLSTR A vs B

- Both IST2-A and IST12A algorithms are positively biased relative to SLSTR-B IST – mainly caused by scattering
- It is not clear why scattering tend to give a warm B-bias
- It is recommended to run the IST processer with SLSTR-A and SLSTR-B in parallel for a period to evaluate precision and accuracy against one or more trustworthy ground observation records. This is essential in order for both products to be used together as an operational two/multi sensor IST product.



X - dummy match up areas





Inter-comparison of SLSTR-A IST (IST2 top;IST12 bottom) with SLSTR-B IST, night data with no cloud-mask applied.

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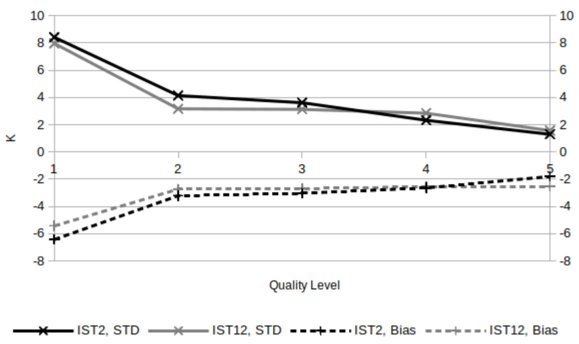
Quality Level assignment

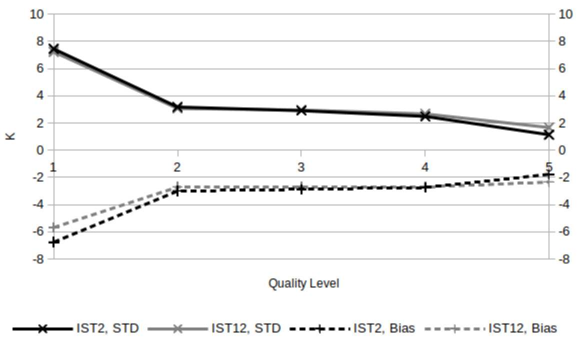
- QL assignment works as intended – better performance with increasing QL
- Too little dynamic in QL 2-4

Recommended for future development.

Test Name	Test Description	Penalty for failed test
IST	The IST estimate is within 10 K of the corresponding NWP surface temperature value.	1
Sat-Zenith	The scan angle is less than 55 degrees	1
Sun-Zenith	The sun elevation is less than 80 degrees	1
Cloud	The pixel is cloud free. Test against the nadir cloud product for IST2 and test against both nadir and oblique cloud product for IST12	6
CAF	The NWP cloud area fraction is less than 0.8	1
TCWV	The total column water vapour is less than 3 kg m^{-2} according the associated NWP TCWV	1

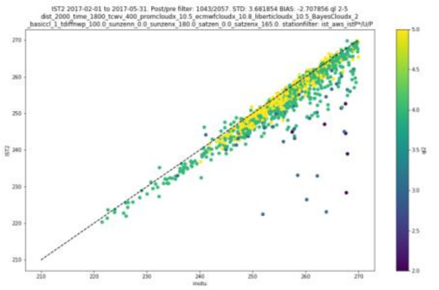


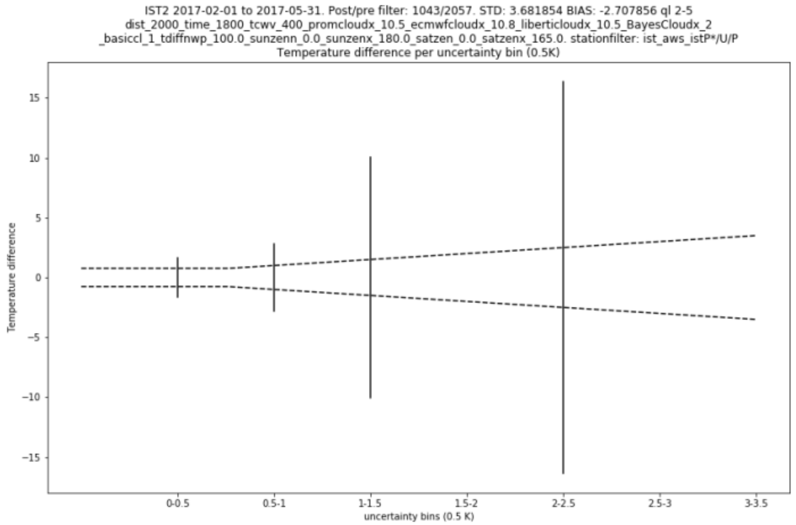
February-March-April



August-September-October

Quality Level	Description	Penalty points
QL 0	No Data. Missing or corrupt data	--
QL 1	Bad Data. Not cloud free according to cloud mask	> 5
QL 2	Worst Quality	4 - 5
QL 3	Low Quality	3
QL 4	Acceptable Quality	1 - 2
QL 5	Best Quality	0





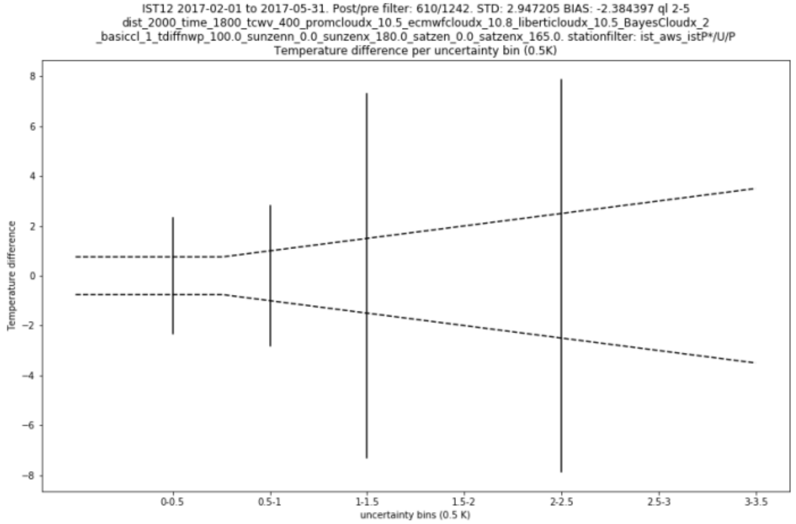
IST2 – nadir, split window

Uncertainty – algorithm and evaluation

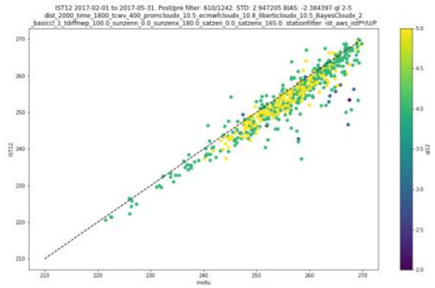
- *Random uncertainty, geolocation and Instrument Noise,* $U_{rnd} = \sqrt{U_{geo}^2 + U_{NEdT}^2}$
- *Local scale uncertainty, emissivity and residual of cal. Fit,* $U_{loc} = \sqrt{U_{emis} + U_{fmt}}$
- *Global scale uncertainty, Expert judgement from quality level.*

Total theoretical uncertainty

- $U_{tot} = \sqrt{U_{rnd}{}^2 + U_{loc}{}^2 + U_{glob}{}^2}$



Recommended for future development jointly with QL assignment algorithm.



IST12 – dual view

Cloud Mask Performance

- Liberti Cloud: for day time cloud screening
  - Good: Works very well in normal arctic sea ice conditions (88% and 75% correctly classified in September and March, respectively)
  - To be solved: cloud screening in very cold conditions

- Basic Cloud: For day time cloud screening
  - Good: Works generally well
  - To be solved: Non detected clouds (40% and 20% undetected in March and September, respectively

(Reference PROMICE Cloud Area Fraction)

Alternative can be..

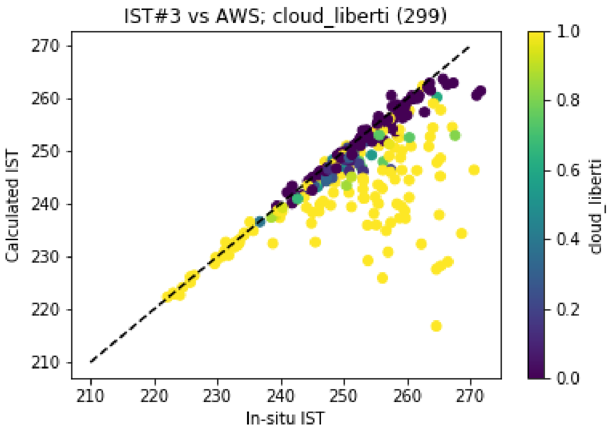
- University of Leicester Cloud all time cloud
  - Decision: Undecided (more work needed)

01-9-2016 to 30-9-2016

Promice Upper & EGP Day N.330	Liberti No Cloud	Liberti Cloud (>30%)
Promice No Cloud	0.427273	0.0181818
Promice Cloud (>30%)	0.10303	0.451515

01-3-2017 to 31-3-2017

Promice Upper & EGP Day N.258	Liberti No Cloud	Liberti Cloud (>30%)
Promice No Cloud	0.418605	0.108527
Promice Cloud (>30%)	0.135659	0.337209



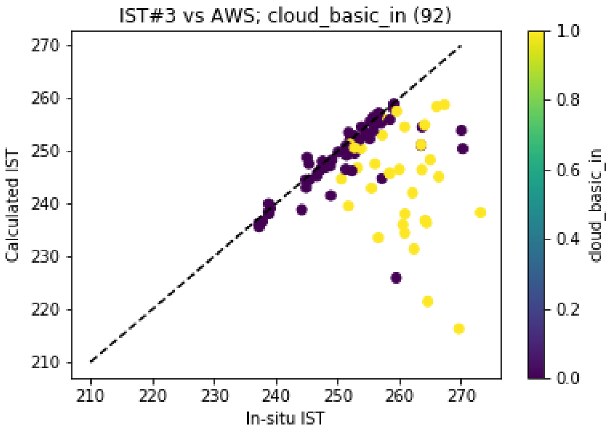
Day time, March 2017, PROMICE Upper Liberti cloud mask

01-9-2016 to 30-9-2016

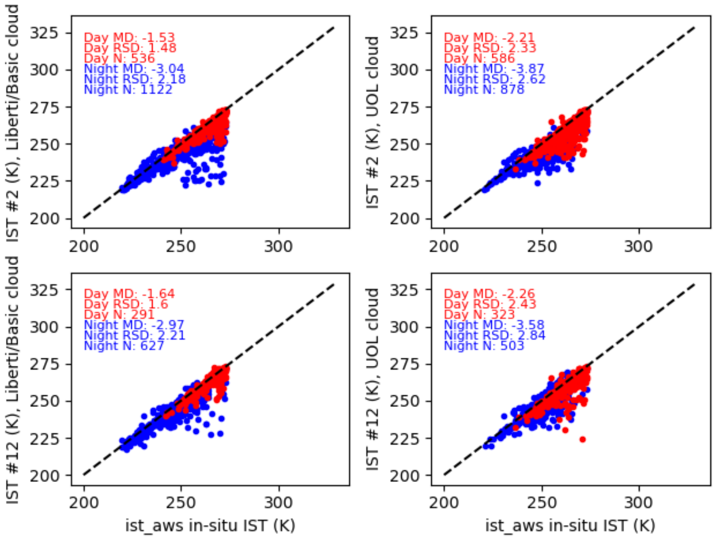
Promice Upper & EGP Night N.85	Basic No Cloud	Basic Cloud
Promice No Cloud	0.317647	0.0588235
Promice Cloud (>30%)	0.2	0.423529

01-3-2017 to 31-3-2017

Promice Upper & EGP Night N.98	Basic No Cloud	Basic Cloud
Promice No Cloud	0.255102	0.0510204
Promice Cloud (>30%)	0.397959	0.295918



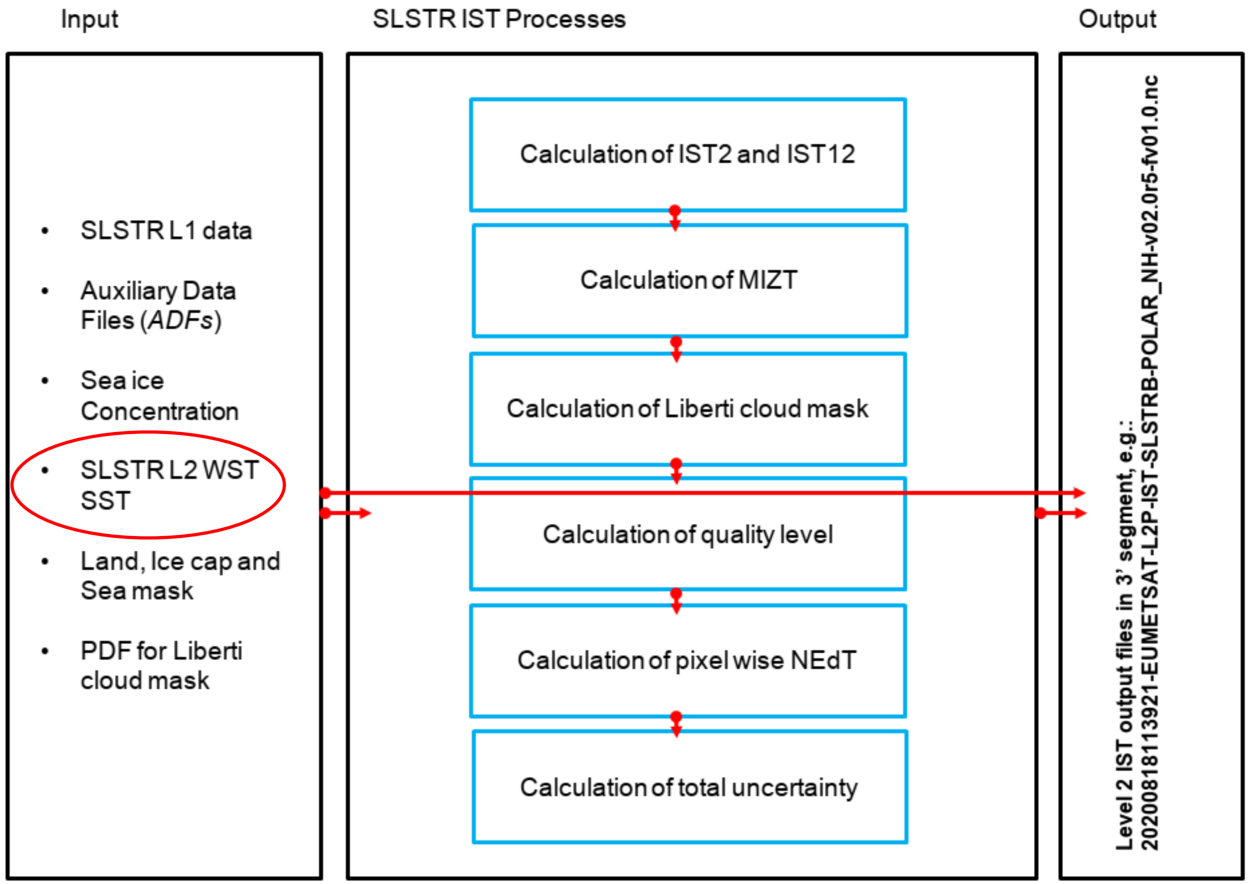
Night time, March 2017, OBS PROMICE Upper Basic cloud mask



IST2 (top) and IST12 (bottom) SLSTR retrievals masked with the Liberti/Basic (left) and UoL (right) cloud masks compared to PROMICE Upper and EGP between August 2016 and July 2017

The SLSTR IST Processor

- The NRT SLSTR prototype processor consists of 3 elements
  - Compiling and linking to external static and dynamical input data sets
  - Calculation of all output and intermediate variables
  - Generation of the L2P output file



May at some point be integrated in processor

Conclusions

- The SLSTR IST processor provide IST output from two different algorithms
- produce IST products that perform equally or superior to existing state-of-the-art operational products
- SLSTR IST retrievals is well under threshold requirement for the highest quality data
- the SLSTR IST products is shown to be a robust measure through time and across seasons over 1 year
- Cloud screening consists of a combination of the native Basic cloudmask (nighttime) and the Liberti cloud mask (day time).
    - Night time cloud screening is troublesome

Future works

- To develop means and facilities for fiducial sea ice temperature observations
  - One solution is IMB’s but they are expensive - New and easy deployable means are needed (see notes in appendix in validation report, D13)
- Focus on SLSTR cloud masking
  - UoL cloud
  - Liberty (in particular very cold surfaces)
  - PPS NWC SAF
- S3-A and S3-B ist show good compliancy.
  - Comparison against absolute temperature references is needed.
- Quality level assignment and uncertainty algorithms need to be revisited.
  - Effects from the quality level algorithm.
  - These two algorithms need to be jointly improved.
- Algorithm development must always have focus
  - 15 different algorithms perform generally well so improvements on algorithms will provide limited performance improvements
  - Cloud issues must be in focus for TIR IST products in general
- Validation on sea ice under different atmospheric and Marginal Ice Zone performance must be evaluated
- Integration of SLSTR IST and SST processors should be considered for future developments