Deriving Arctic near surface air temperature from satellites

Jacob L. Høyer, Pia Nielsen-Englyst and Kristine S. Madsen.

Danish Meteorological Institute
jlh@dmi.dk

DMI
Danish Meteorological Institute

EUSTACE has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no 640171

EUSTACE

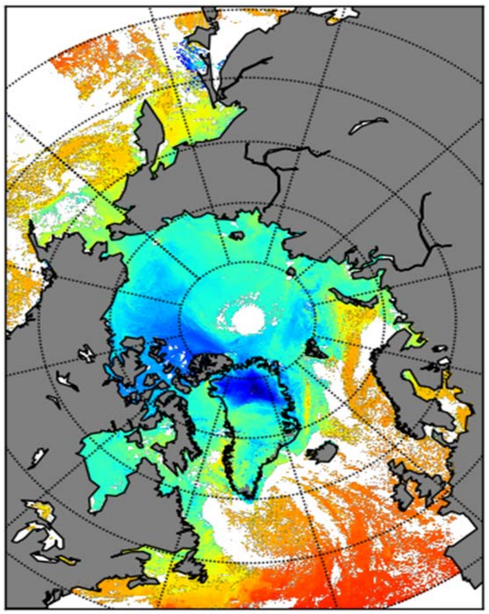
How do we achieve this?

- Analyse the variability of in-situ and satellite observations
- Relate satellite IST and 2-meter air temperature
- Set-up a regression model to estimate 2-meter air temperatures from satellite IST

DMI
Danish Meteorological Institute

EUSTACE

Satellite IST with uncertainties



- We use the DMI + Met.no IST reanalysis (AASTI; 2000-2009, will be extended) continued with the OSI-SAF Metop operational product to the present.
- Very good coverage in high latitudes
- Uncertainties added with 3 components:
  - Random (instrument noise, uncertainty due to mix of SST and IST in marginal ice zone).
  - Locally systematic (atmospheric effects, uncertain emissivity of varying ice and snow mixtures).
  - (large-scale) Systematic (follows overall flagging of data).

DMI
Danish Meteorological Institute

EUSTACE

3 hourly data coverage from satellite, 0.25 deg

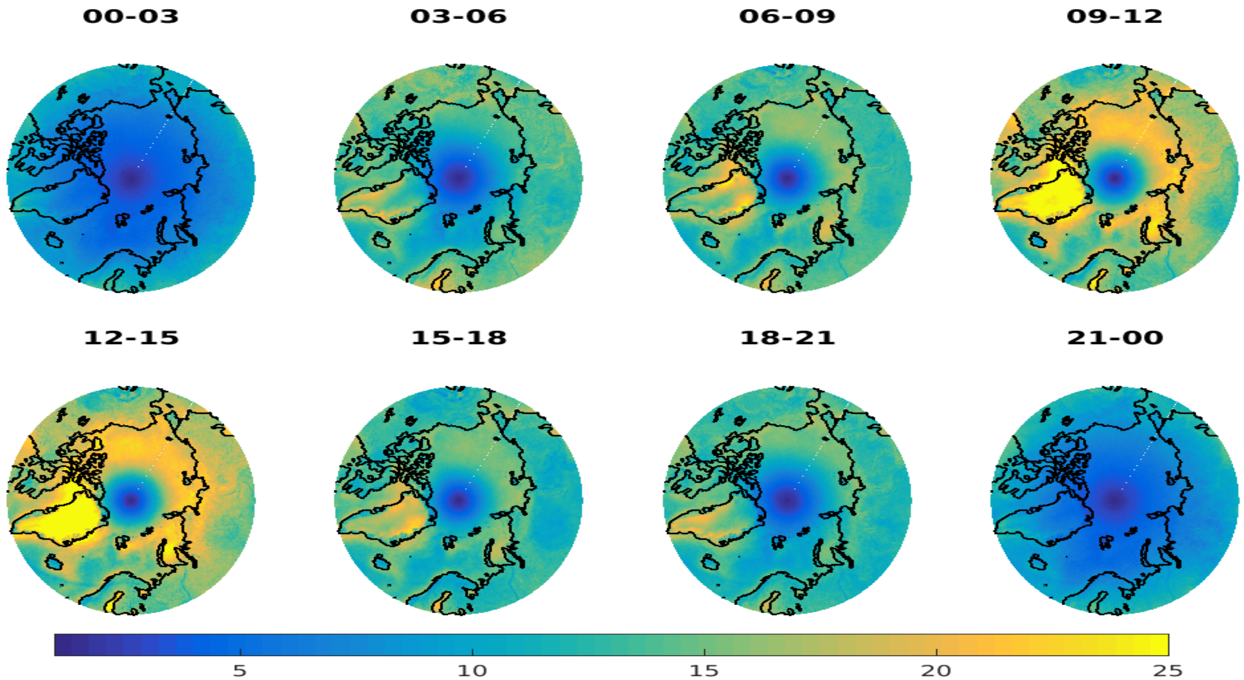


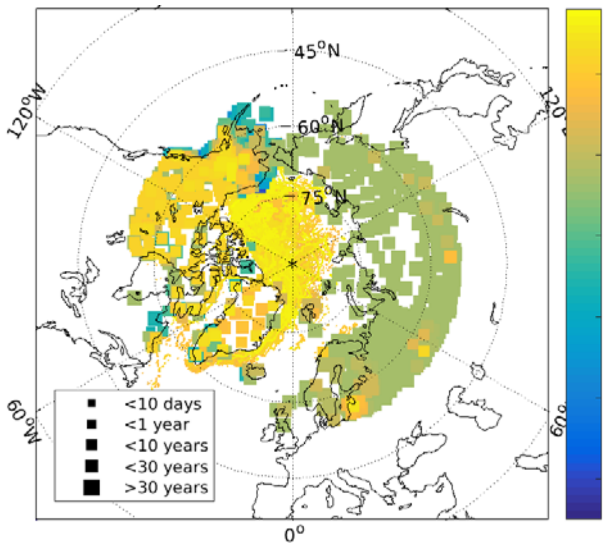
Figure: *Mean number of observations per day in each of the eight local solar time intervals. Northern Hemisphere averages 2000-2009 .*

DMI
Danish Meteorological Institute

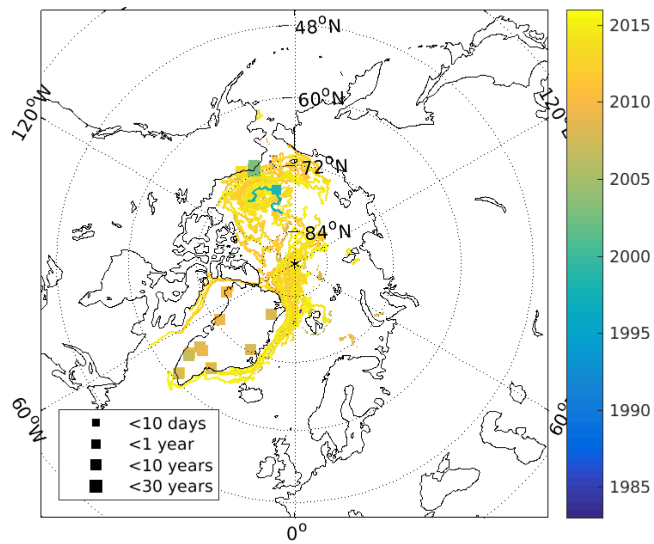
EUSTACE

In-situ dataset

T2m observations



IST observations



Overview of in-situ IST and T2m observations from land ice and sea ice in Arctic.

Colours show start year and marker size shows length of record.

All collected, quality controlled and converted to common CF-compliant NetCDF format

DMI
Danish Meteorological Institute

EUSTACE

Derived relationships between IST and 2-meter air temperature

Investigated dependencies:

- Latitude / solar height
- Shortwave radiation
- Clouds
- Wind
- Altitude
- Satellite measuring angle

Automatic weather station on sea ice in the fjord off Qaanaaq

DMI
Danish Meteorological Institute

PROMICE
Programme for Monitoring of the Greenland Ice Sheet

EUSTACE

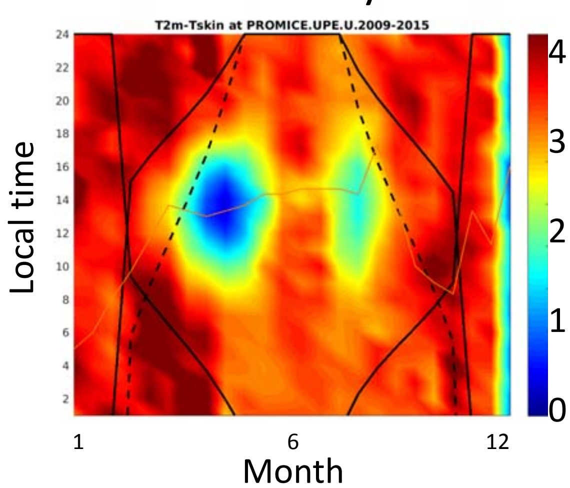
Relationship with clouds

- Difference between air and surface temperature for all sky conditions, cloud free conditions and cloudy conditions.

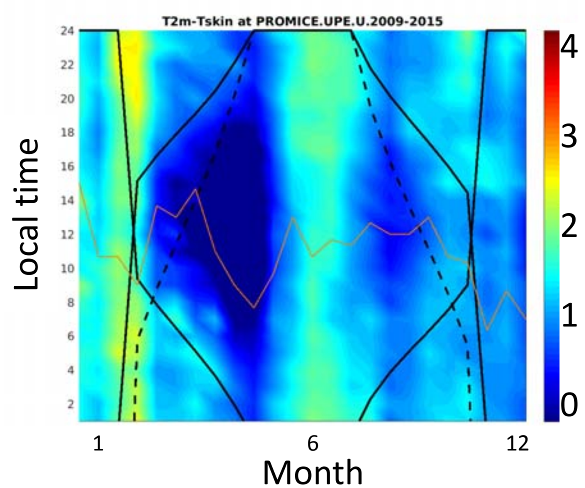
- Example from the Greenland Ice Sheet, Upernavik.

Data source: PROMICE

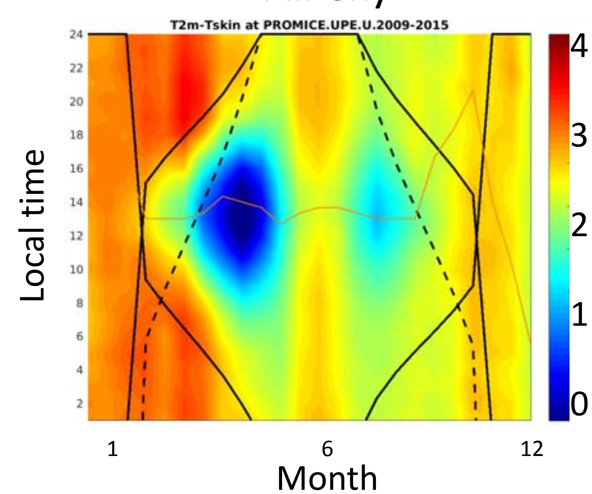
Clear-sky



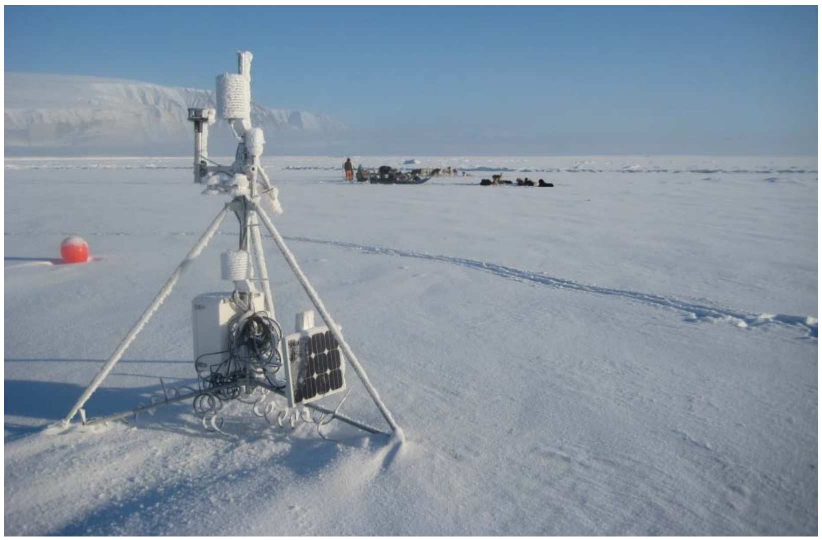
Overcast



All-sky

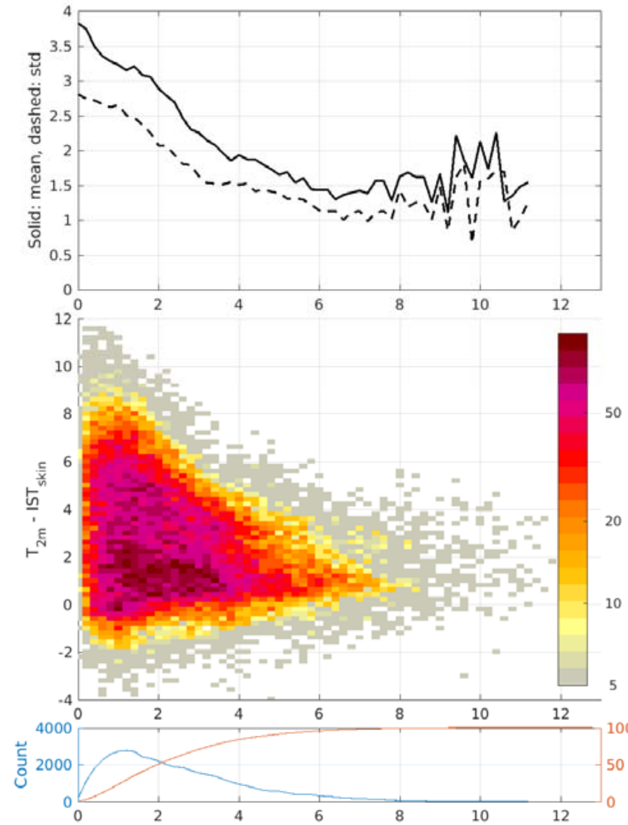


Relationship with wind



Automatic weather station on sea ice in the fjord off Qaanaaq

T2m - IST

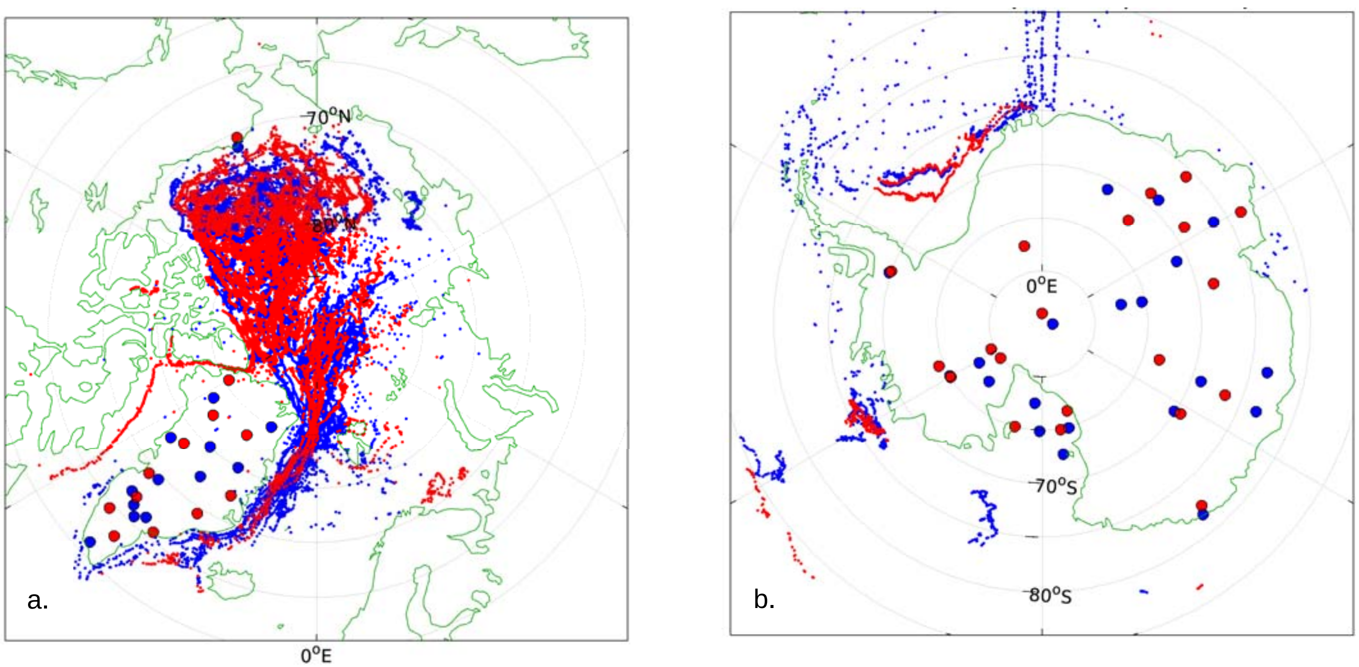


Wind speed m/s

EUSTACE

ICE-ARC

Matchup of satellite and in situ



red: analysis/training *blue: validation*

Deriving relationsship

DMI
Danish Meteorological Institute

EUSTACE

Key Issues

- Understanding the sampling characteristics of satellite and in situ data sets
  - Clear sky bias
  - Cloud contamination
- Focus has been on Taverage, but Tmin and Tmax also provided
- Additional tests have been applied to satellite data set
  - Ensure representativeness
  - Minimze impact of clouds not being removed

DMI
Danish Meteorological Institute

EUSTACE

Regression Analysis

Regression models: wind, latitude, altitude, shortwave radiation, seasonal cycle etc.

- Trained on in-situ data
- Validated against independent in-situ observations
- Correlation, bias and standard deviation

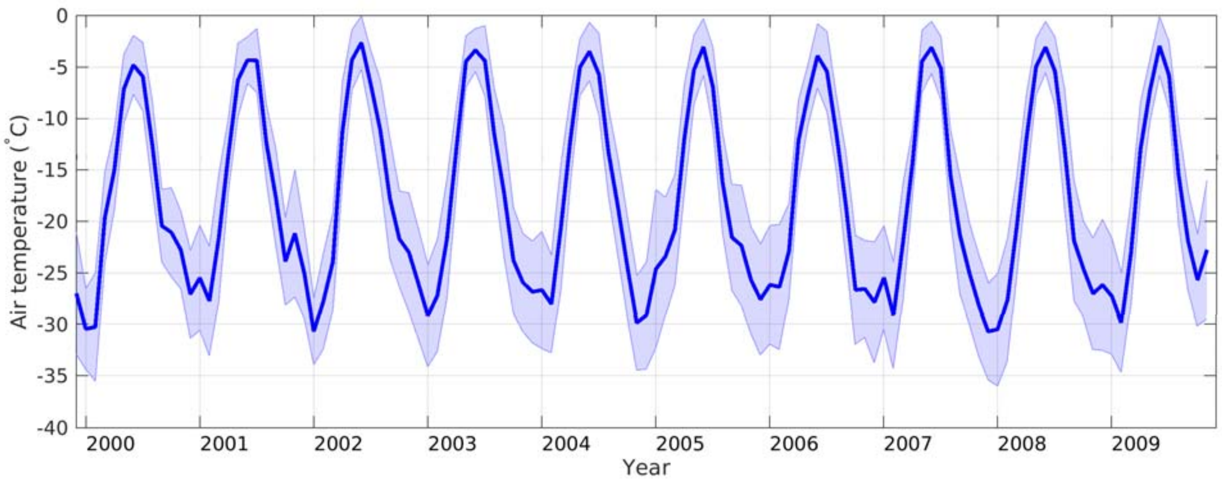
A seasonal cycle with fit of amplitude and phase:

$$T_{avg} = \alpha_0 + \alpha_1 \cdot IST_{avg} + \alpha_2 \cdot cos\left(\frac{time \cdot 2\pi}{1\ year}\right) + \alpha_3 \cdot sin\left(\frac{time \cdot 2\pi}{1\ year}\right)$$

DMI
Danish Meteorological Institute

EUSTACE

Estimated 2-meter air temperature - the Greenland Ice Sheet

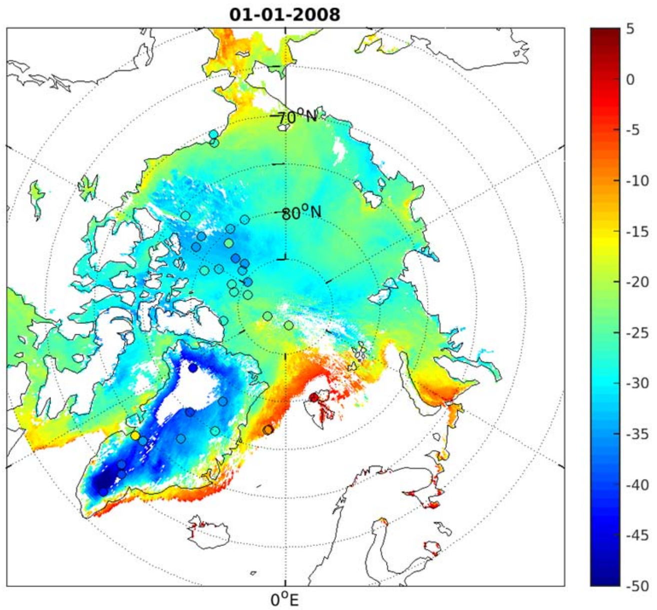


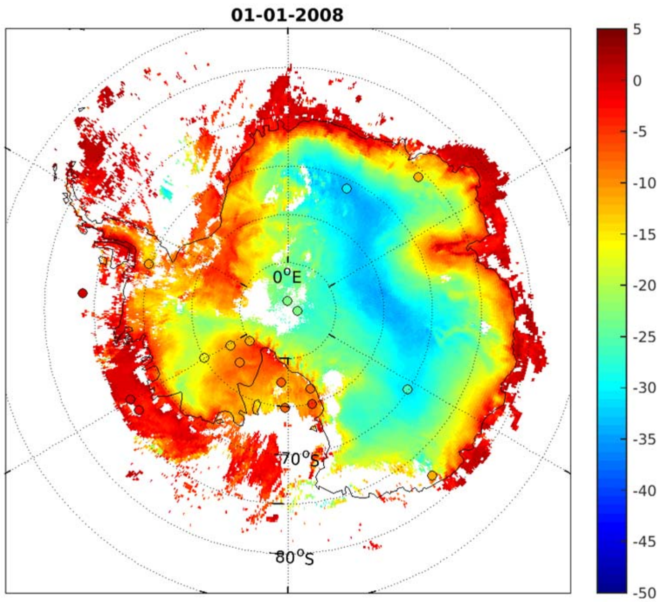
DMI
Danish Meteorological Institute

EUSTACE

Estimated 2-meter air temperatures

January



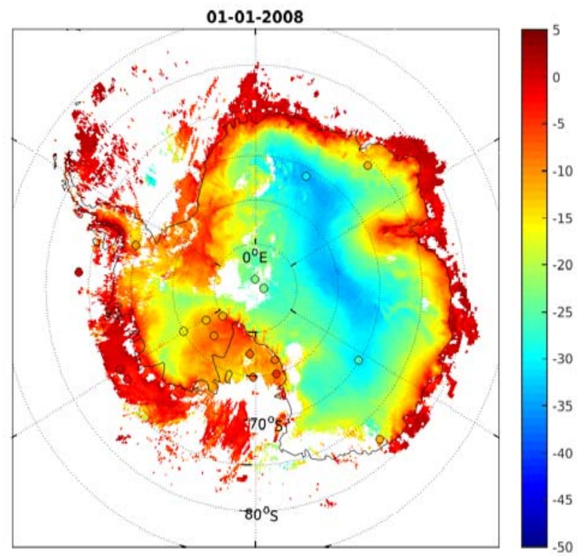


DMI
Danish Meteorological Institute

EUSTACE

FINAL T_{2M} FROM SATELLITE

- Daily fields in 0.25° by 0.25°, Arctic and Antarctic
- From 2000-2009
- Near surface air temperature: Average, Min and Max
- Uncertainties :
    - Random uncertainties
    - Synoptic scale correlated
    - Globally correlated w/wo cloud component
    - Total uncertainty, w/wo cloud component
- Sea ice concentration
- T2m –ERA Interim
- Wind speed –ERA Interim
- Tskin: TAvg, Tmin, Tmax
- Surface type mask



DMI
Danish Meteorological Institute

EUSTACE

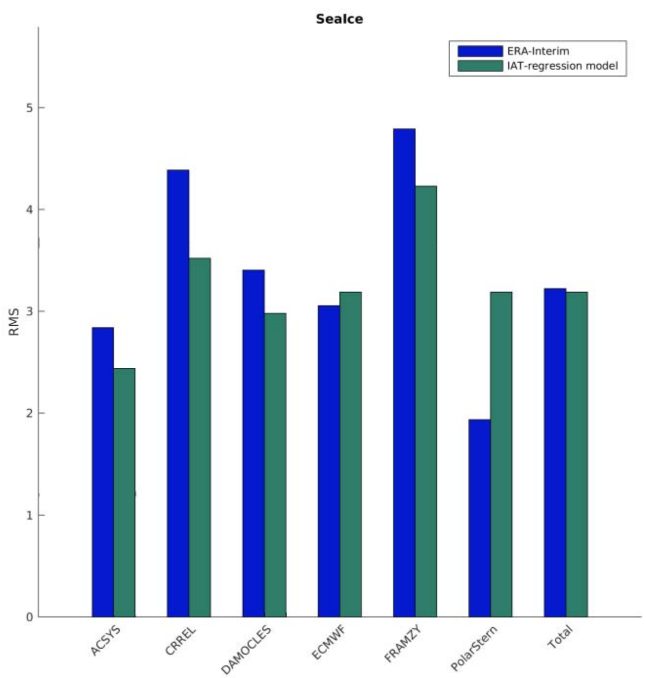
Validation of T2m

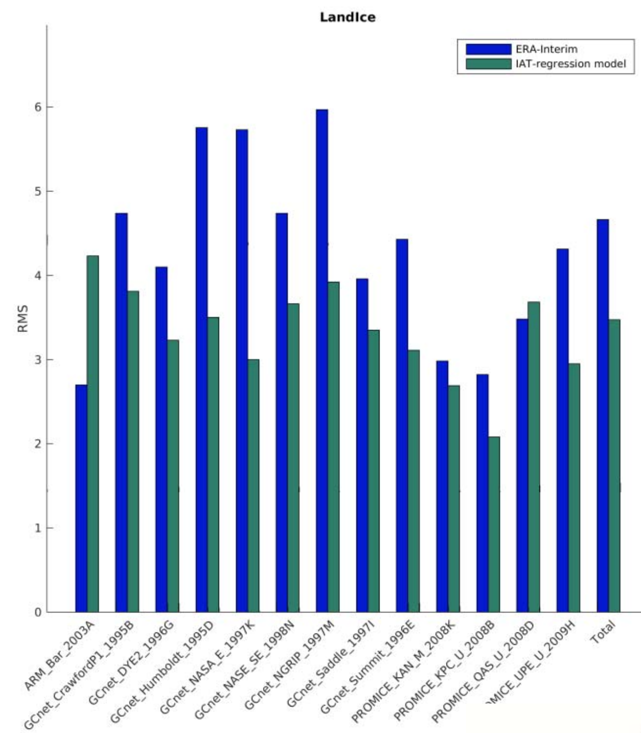
	Number of obser-vations	Corre-lation (%)	Bias (satellite derived – in situ , °C)	Standard deviation (°C)
Land ice Northern Hemisphere	20872	95.5	0.30	3.45
Sea ice Northern Hemisphere	16092	96.5	0.35	3.18
Land ice Southern Hemisphere	21327	97.3	0.12	3.11
Sea ice Southern Hemisphere	620	91.9	0.20	3.55

DMI
Danish Meteorological Institute

EUSTACE

Compared with ERA-Interim, NH

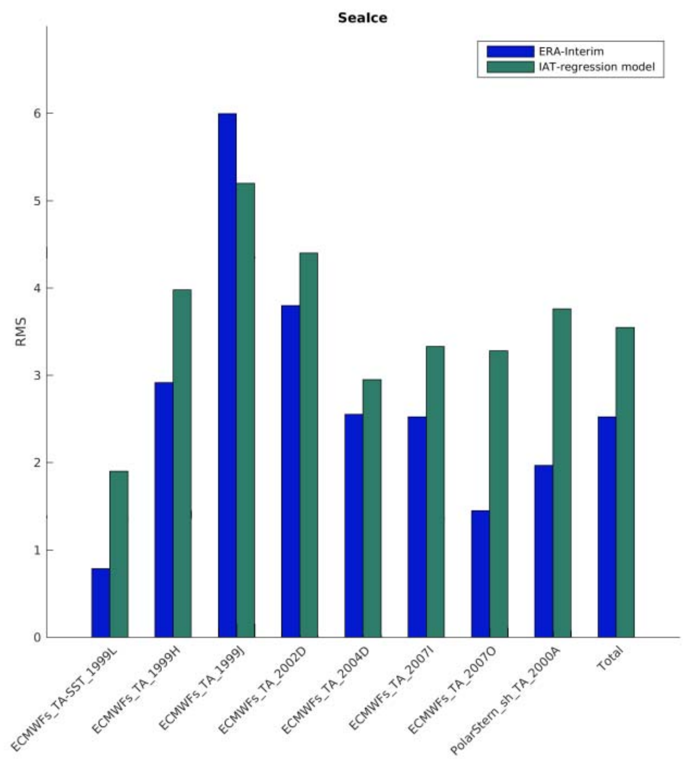


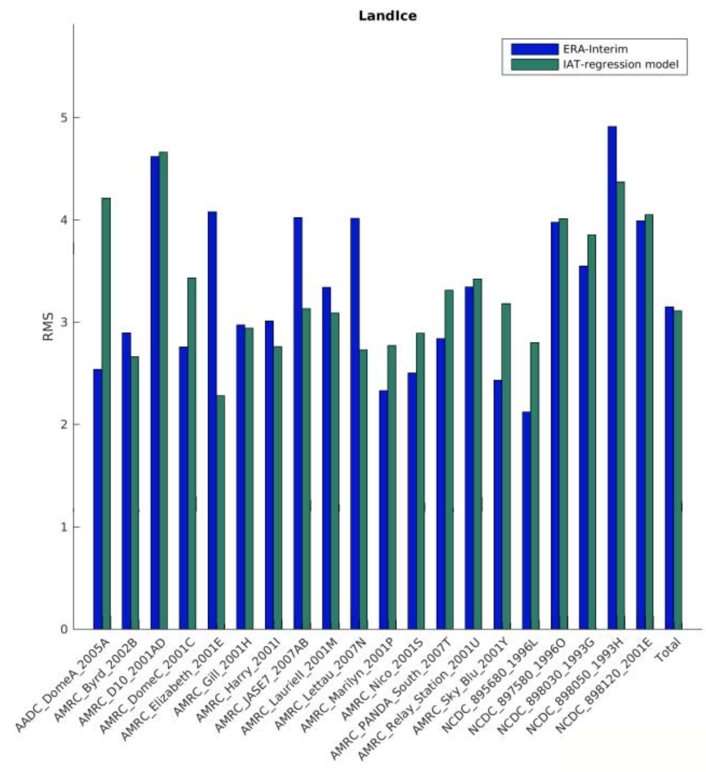


DMI
Danish Meteorological Institute

EUSTACE

Compared with ERA-Interim, SH





DMI
Danish Meteorological Institute

EUSTACE

Summary

- Relationships between IST and T2m have been developed.
- T2m has been estimated using daily satellite IST and a seasonal variation.
- The results have been validated against independent in-situ observations.
- Daily 0.25 degree T2m produced from 2000-2009 (Arctic + Antarctic).
- Satellite T2m better than ERA-Interim.
- Way forward:
  - better reference data
  - Extend satellite record 1982-2015)
  - Two papers in progress

DMI
Danish Meteorological Institute

Contact: jlh@dmi.dk

EUSTACE

ABSTRACT

Polar air temperature estimated from satellite ice surface measurements

Estimating the near surface air temperature from models or observations in the Polar Regions is challenging due to extreme conditions and the lack of in situ observations. The errors in near surface temperature products are therefore larger than for other regions of the world, and the potential for using Earth Observations is large. As part of the H2020 project EUSTACE, we have developed empirical models for the relationship between the satellite observed skin ice temperatures and 2m air temperatures. We use the Arctic and Antarctic Sea and sea ice Surface Temperatures from thermal Infrared satellite sensors (AASTI) reanalysis to estimate daily surface air temperature over land ice and sea ice for the Arctic and the Antarctic. Large efforts have been put into collecting and quality controlling in situ observations from various data portals and research projects. The reconstruction is independent of numerical weather prediction models and thus provides an important alternative to modelled air temperature estimates.

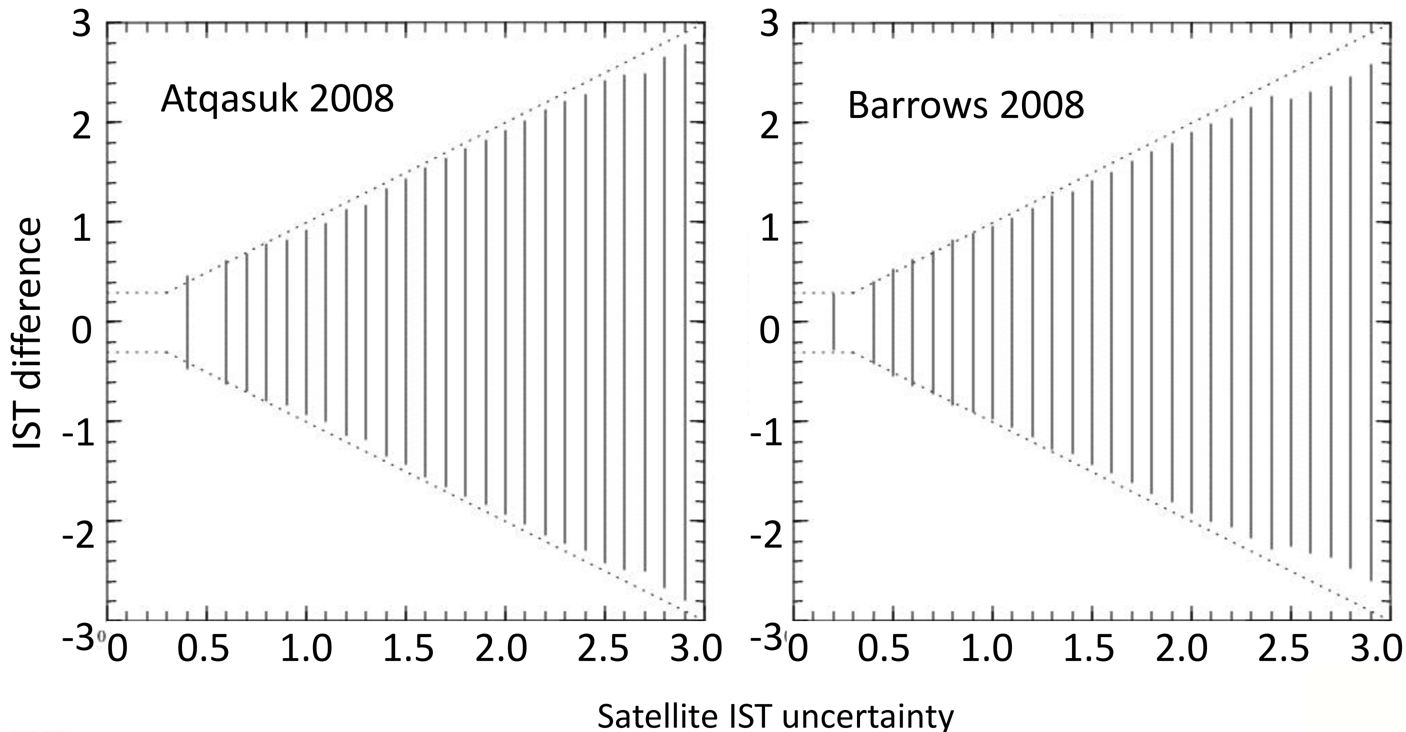
The new surface air temperature data record has been validated against more than 58.000 independent in situ measurements for the four surface types: Arctic sea ice, Greenland ice sheet, Antarctic sea ice and Antarctic ice sheet. The average correlations are 92-97% and average root mean square errors are 3.1-3.6°C for the four surface groups. The root mean square error includes the uncertainty of the in-situ measurement, which ranges from 0.5 to 2°C. A comparison with ERA-Interim shows a consistently better performance of the satellite based air temperatures than the ERA-Interim for the Greenland ice sheet, when compared against observations not used in any of the two estimates. This is encouraging and demonstrates the values of these products. In addition, the procedure presented here works on satellite observations that are available in near real time and this opens up for a near real time estimation of the surface air temperature over ice from satellites.

DMI
Danish Meteorological Institute

EUSTACE

AASTI uncertainty verification

Validation against independent radiometer observations from ARMS



Dashed lines: ideal uncertainty model

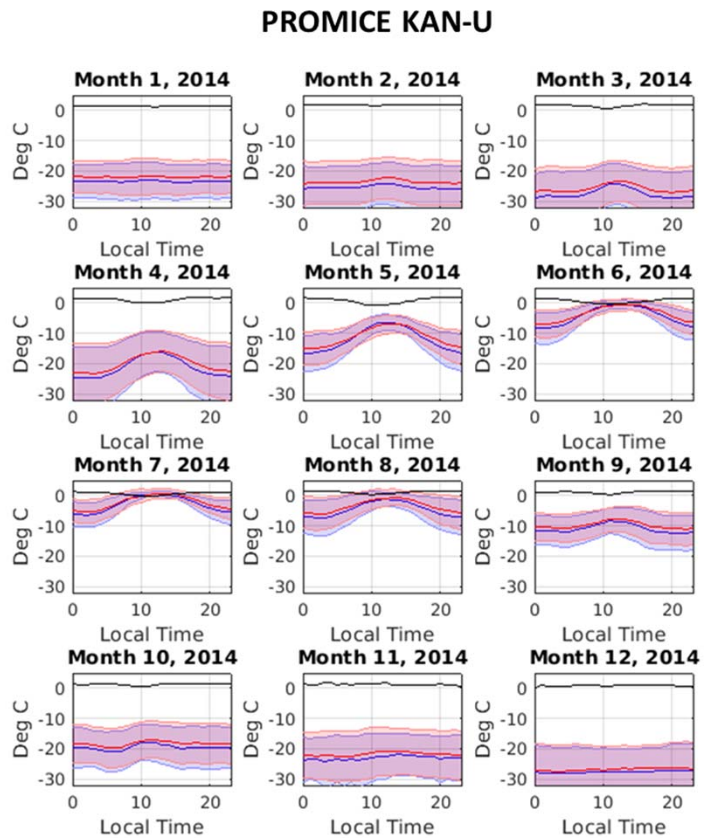
Solid lines: one standard deviation of satellite minus in situ IST differences for each 0.1 K bin.

Source: Darren Ghent, University of Leicester

DMI
Danish Meteorological Institute

EUSTACE

Diurnal and seasonal variation



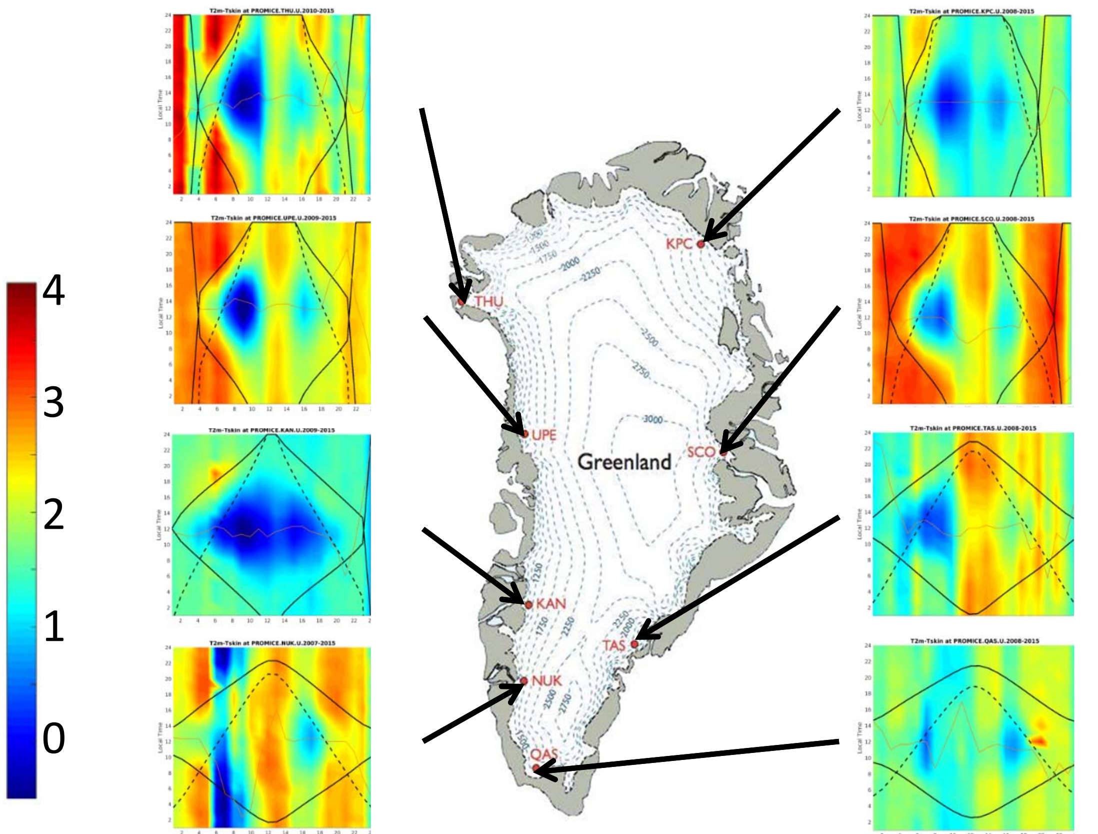
Red is air temperature, blue is ice surface temperature and black is the difference, T2m-IST.

Data source: PROMICE

DMI
Danish Meteorological Institute

EUSTACE

In-situ relationship between skin and air temperature



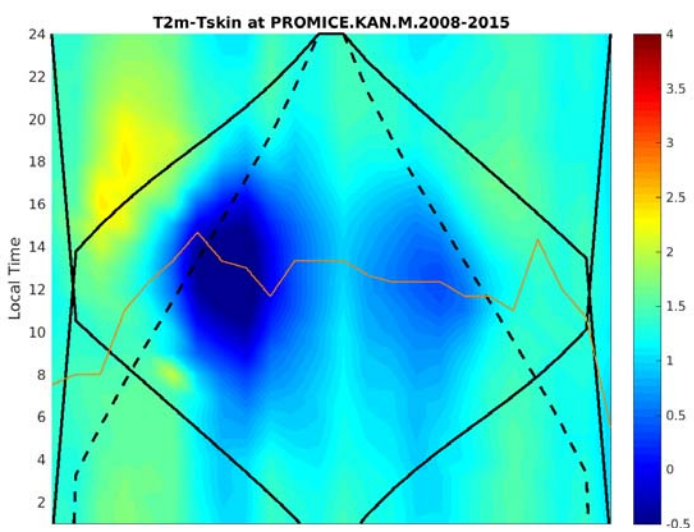
Air – skin temperature difference as a function of season and time of day

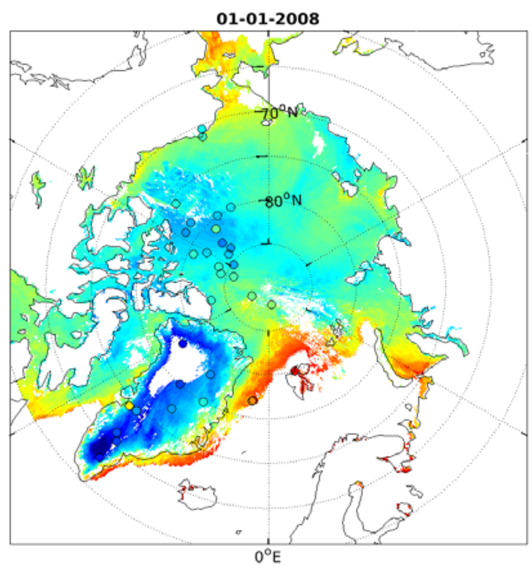
Data source: PROMICE

DMI
Danish Meteorological Institute

EUSTACE

Arctic satellite ice surface temperature variability and relationship to 2-meter air temperature





Pia N. Englyst , Jacob L. Høyer and Kristine S. Madsen.

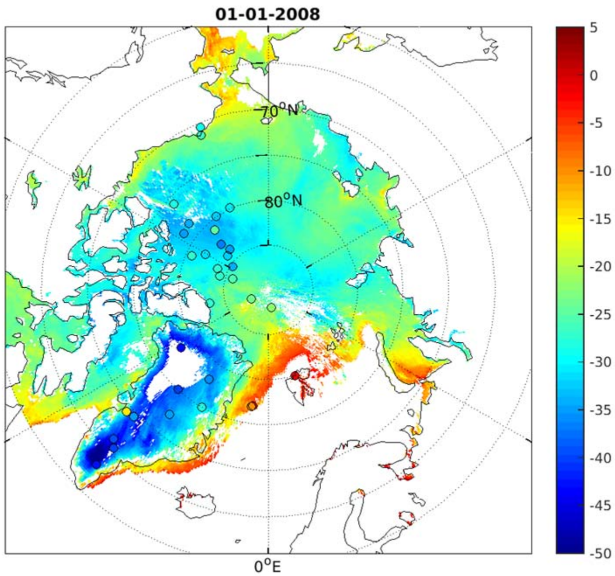
EUSTACE has received funding from the European Union's Horizon 2020 Programme for Research and Innovation, under Grant Agreement no 640171

DMI
Danish Meteorological Institute

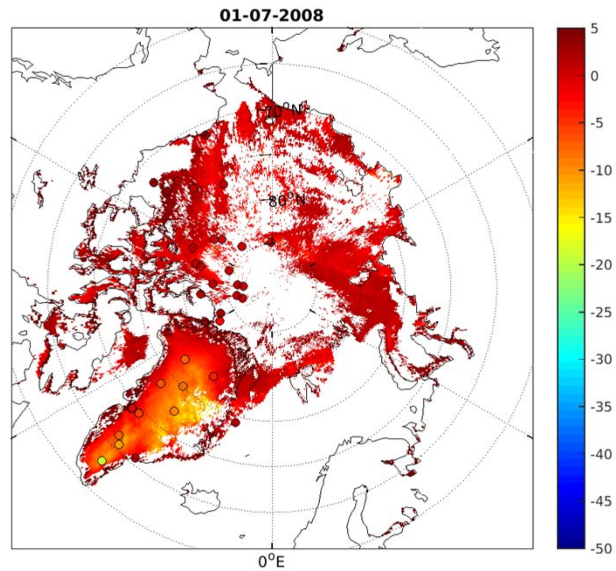
EUSTACE

Estimated 2-meter air temperatures

Winter 2008



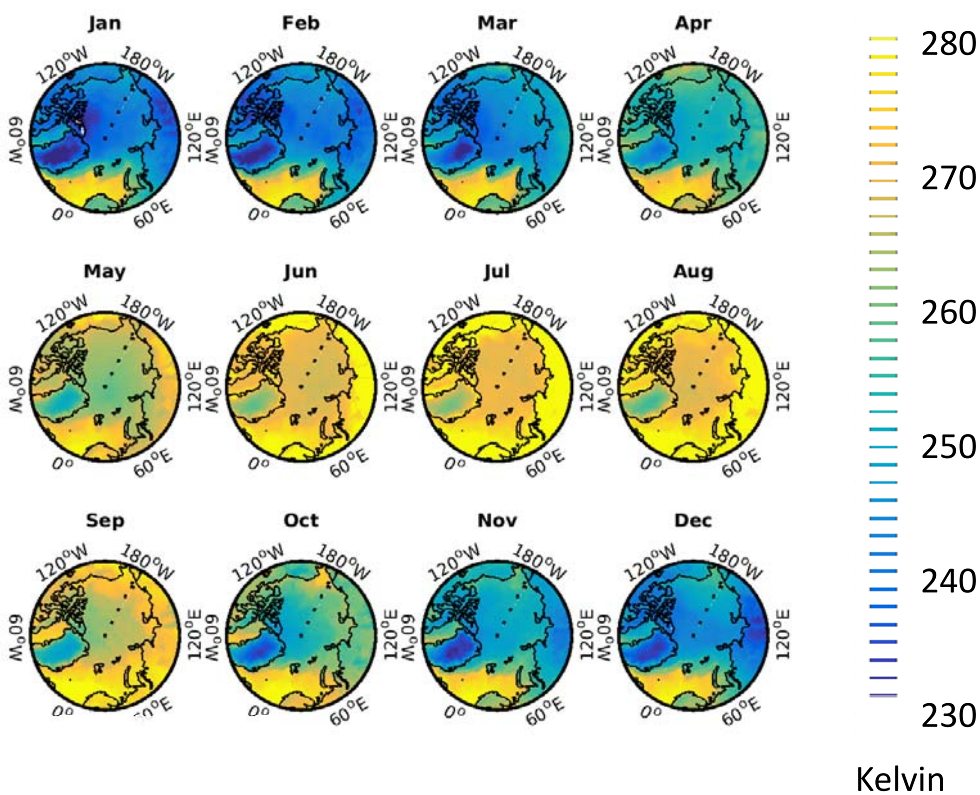
Summer 2008



DMI
Danish Meteorological Institute

EUSTACE

Satellite IST variability

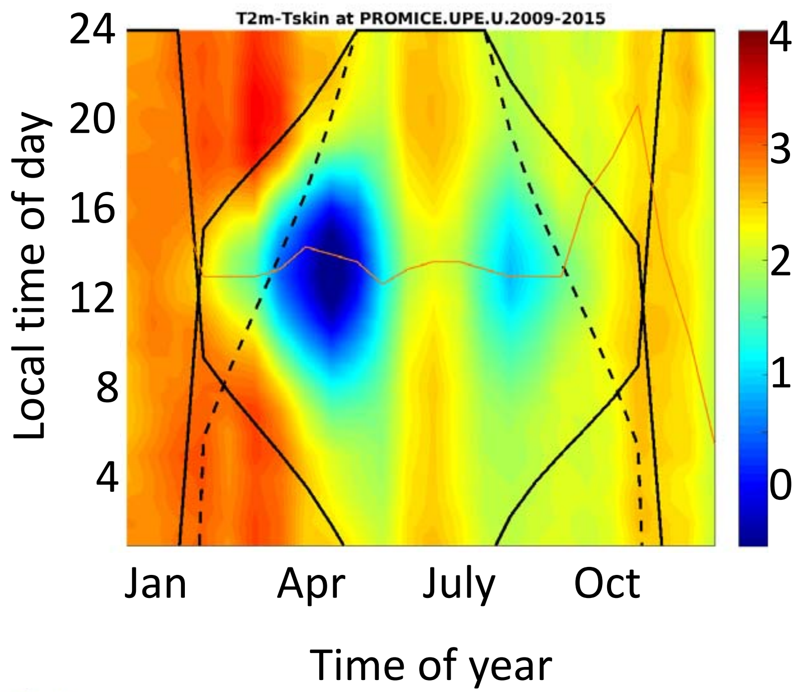


Average IST
in the Arctic region
each month (2008).

DMI
Danish Meteorological Institute

EUSTACE

In-situ relationship between skin and air temperature



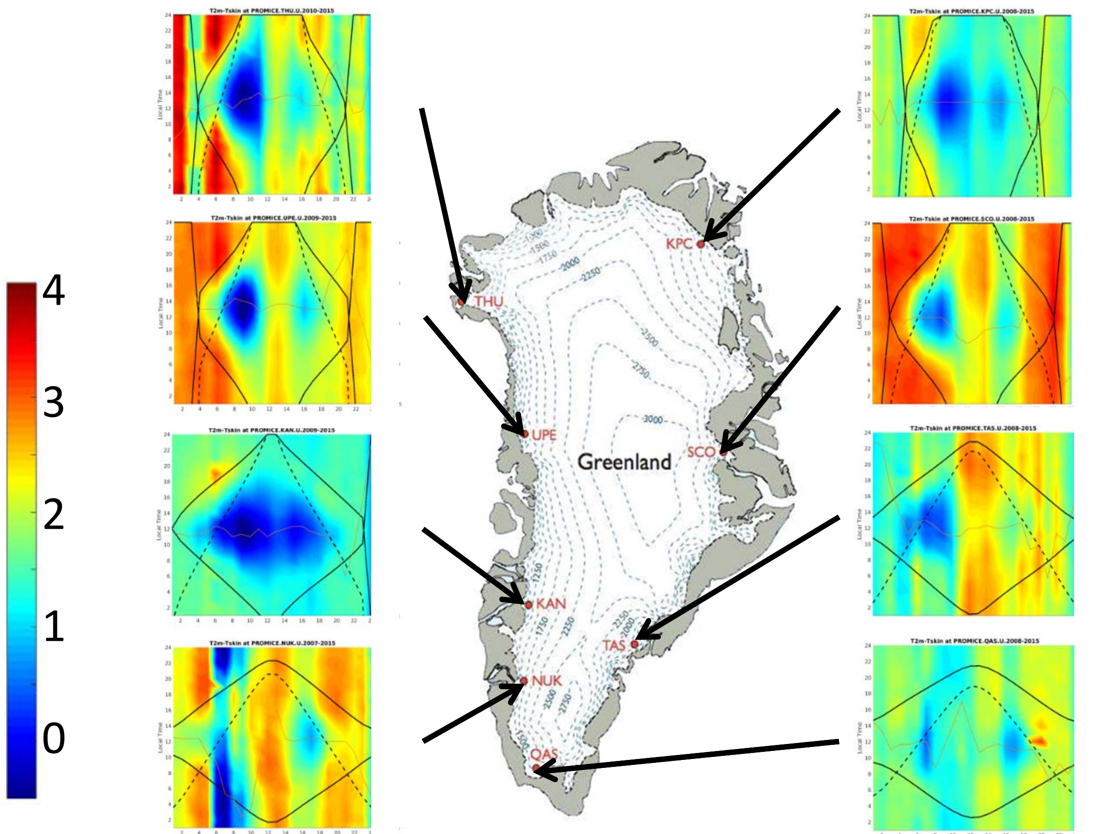
Air – skin temperature difference as a function of season and time of day.
Upernavik upper station, Greenland

Data source: Promice

DMI
Danish Meteorological Institute

EUSTACE

In-situ relationship between skin and air temperature



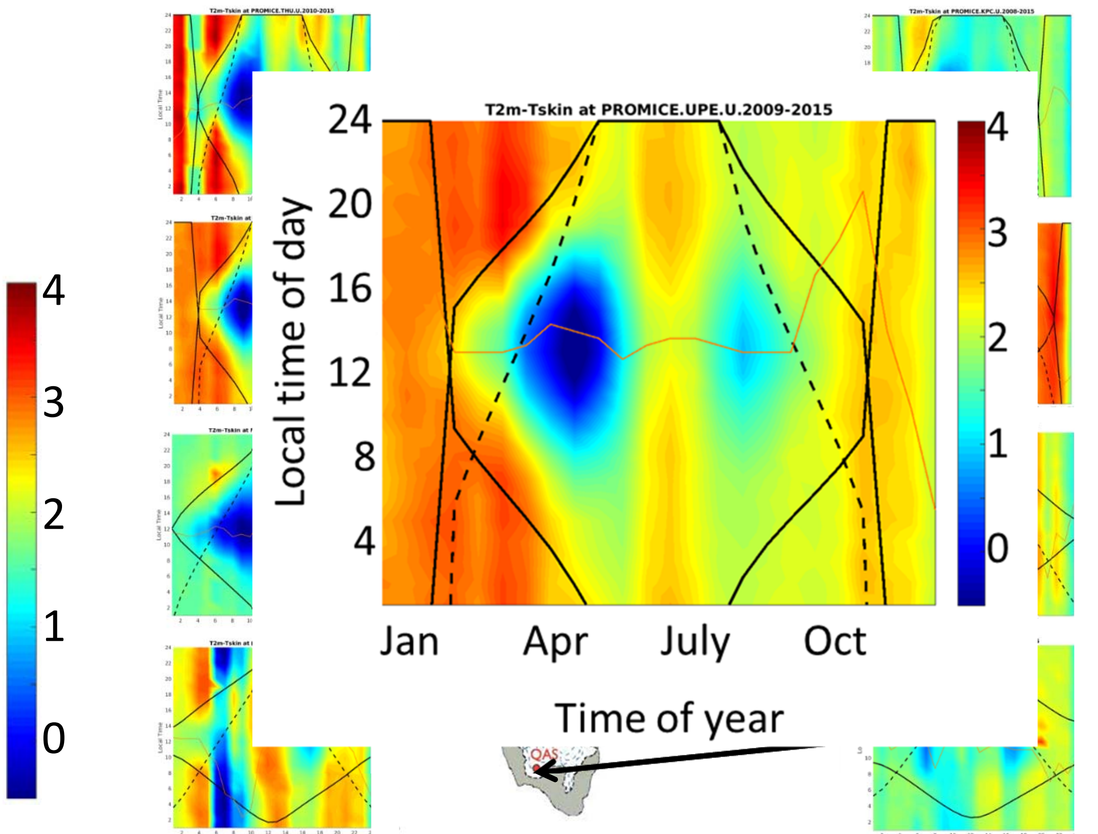
Data source: Promice

Air – skin temperature difference as a function of season and time of day

DMI
Danish Meteorological Institute

EUSTACE

In-situ relationship between skin and air temperature



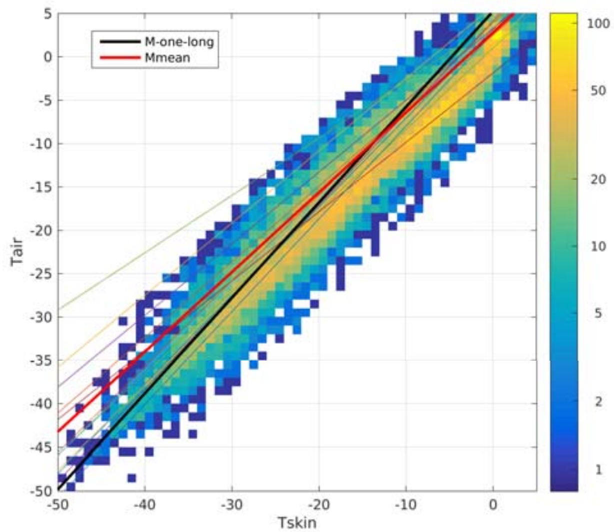
Data source: Promice

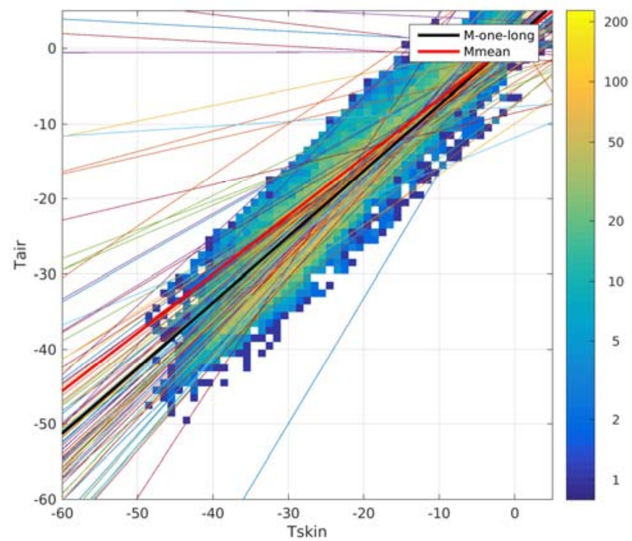
Air – skin temperature difference as a function of season and time of day

DMI
Danish Meteorological Institute

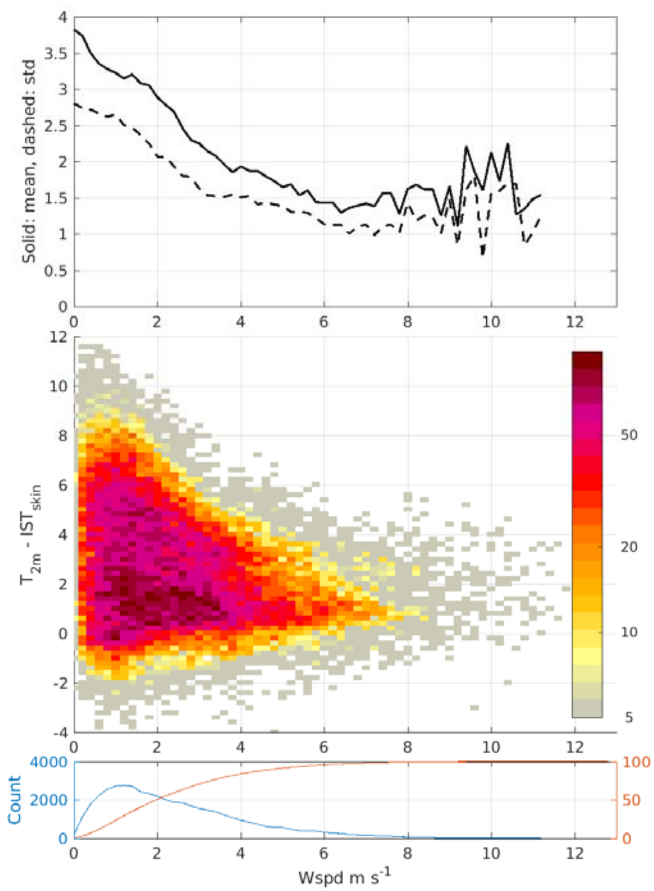
EUSTACE

Regression validation





AVG	N	CORR	BIAS	STD	RMS
LAND ICE NORTHERN HEMISPHERE	22884	95.3	0.37	3.54	3.91
SEA ICE NORTHERN HEMISPHERE	14337	96.6	0.36	3.17	3.19



Solid: mean, dashed: std
T2m - ISTskin
Count
Wspd m s-1

Satellite Data

- Greatest amount of AASTI observations around noon local time

In Situ Data

- Weakest vertical stratification around noon in summer months
- No significant inter-annual variability in air/surface temperature differences
- High solar irradiance weaken and in some cases reverses vertical stratification
- Overcast conditions weaken vertical stratification
- Strong winds weaken vertical stratification