JAWS: Harmonized Automated Weather Station Data

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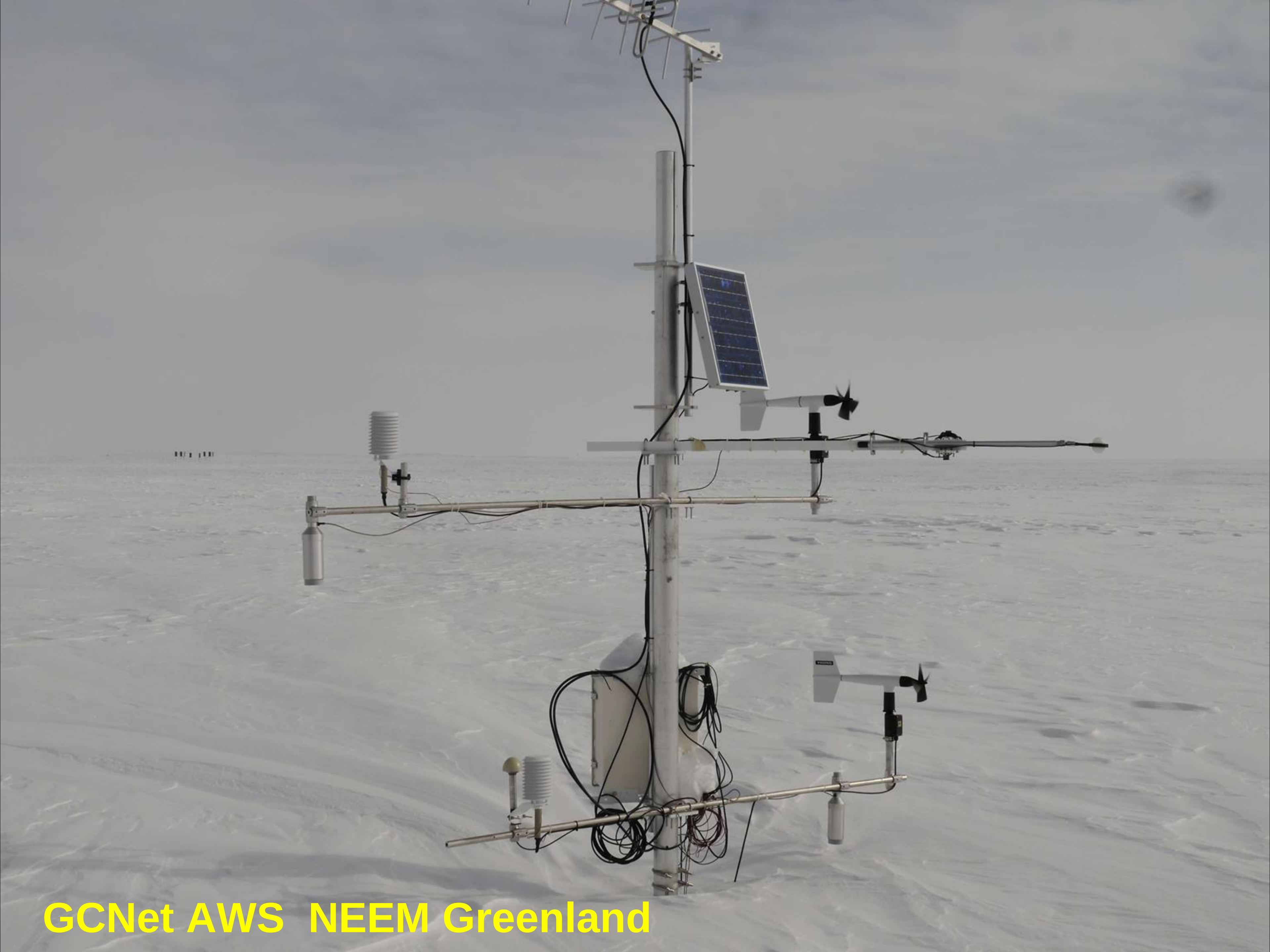
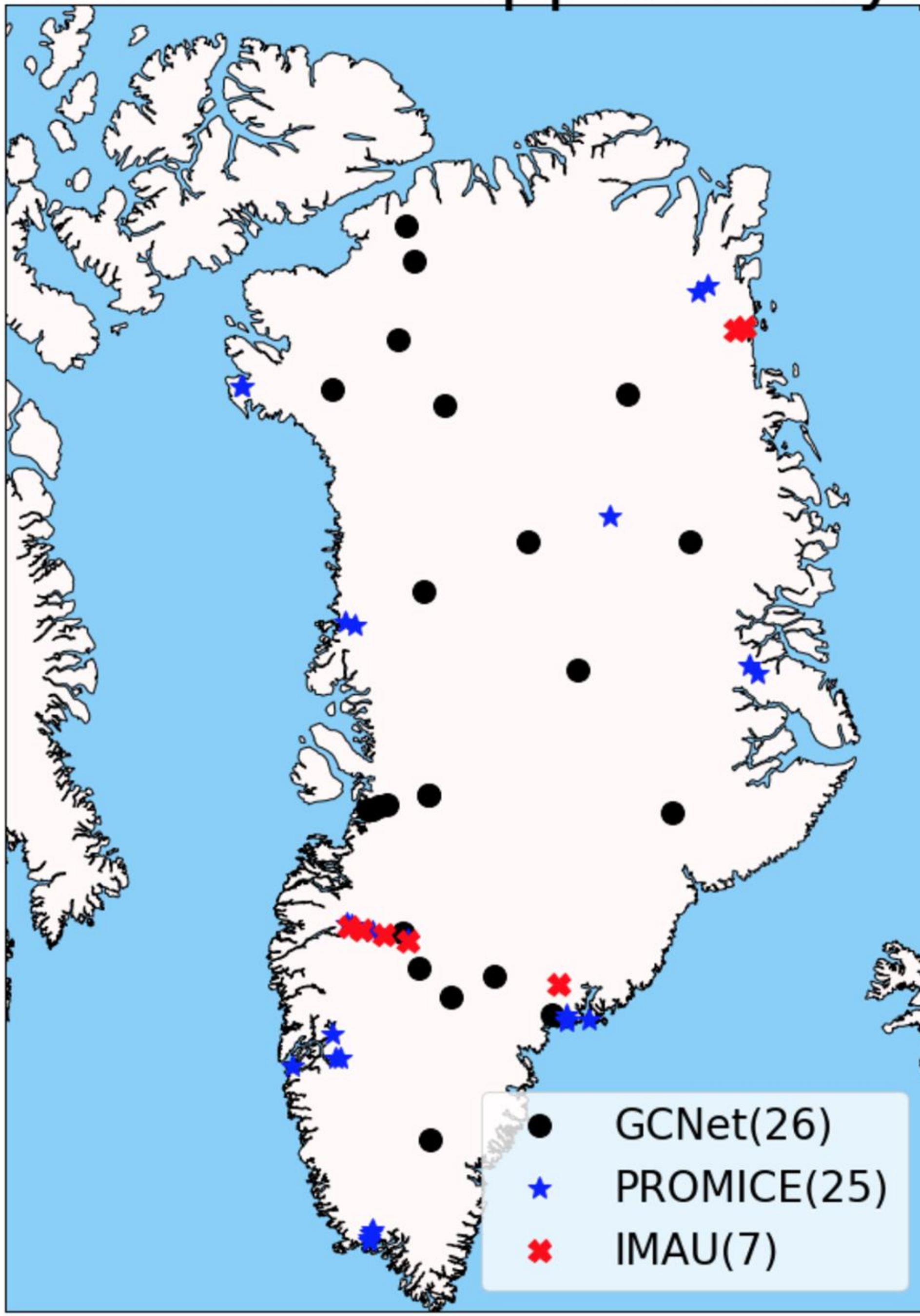
2016 Summer @ Thule, Greenland


PROMICE AWS THU-L


GCNet AWS Saddle


GCNet AWS NEEM Greenland

Greenland AWS supported by JAWS



Science Enabled by Polar AWS and JAWS

- Numerical Weather Prediction
- Ground Truth for Satellite/Model/Analyses
- Ice Velocity
- Measure Surface Energy Budget:
  - Heat
  - Precipitation
  - Radiation
- Estimate:
  - Cloud Radiative Effects
  - Snow/Ice Melt
  - Firn Densification
  - Ice Shelf Hydrofracture

Most AWS Data is Idiosyncratic 1980s-era ASCII CSV

```
zender@aerosol:~/data/aist$ head -n 3 aist_promice.txt
Year MonthOfYear DayOfMonth HourOfDay(UTC) DayOfYear DayOfCentury AirPressure(hPa) AirTemperature(C) AirTemperatureHygroClip(C) RelativeHumidity_wrtWater(%) RelativeHumidity(%) W
indSpeed(m/s) WindDirection(d) ShortwaveRadiationDown(W/m2) ShortwaveRadiationDown_Cor(W/m2) ShortwaveRadiationUp(W/m2) ShortwaveRadiationUp_Cor(W/m2) Albedo_theta<70d LongwaveRa
diationDown(W/m2) LongwaveRadiationUp(W/m2) CloudCover SurfaceTemperature(C) HeightSensorBoom(m) HeightStakes(m) DepthPressureTransducer(m) DepthPressureTransducer_Cor(m) IceTemp
erature1(C) IceTemperature2(C) IceTemperature3(C) IceTemperature4(C) IceTemperature5(C) IceTemperature6(C) IceTemperature7(C) IceTemperature8(C) TiltToEast(d) TiltToNorth(d) Time
GPS(hhmmssUTC) LatitudeGPS((dd)mm.mmmmm) LongitudeGPS((dd)mm.mmmmm) ElevationGPS(m) HorDilOfPrecGPS LoggerTemperature(C) FanCurrent(mA) BatteryVoltage(V)
2008 9 1 0 245 3167 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -99
9 -999 -999 -999 -999 -999 -999
2008 9 1 1 245 3167 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -999 -99
9 -999 -999 -999 -999 -999 -999
zender@aerosol:~/data/aist$ echo

zender@aerosol:~/data/aist$ tail -n 3 aist_gcnet.txt
3 2014 143.5000 497.00 159.44 39.36 -17.86 -17.86 -17.62 -17.36 78.40 75.58 8.63 9.09 147.2 155.5 999.0 999.0000 1.9269 -15.49 -7.48 999.00 1.29 999.00 -37.47 -42.80 -15.06 -33.8
2 -5.32 13.57 595.60 46.32 20.72 -17.43 -17.45 -18.37 -18.35 9.94 10.37 0.54 0.55 -16.30 7.46 9.73 5.89 4.89 0.65 59.43 11111118 87711121 21212111 116
3 2014 143.5417 629.00 200.65 999.00 -16.78 -16.82 -16.45 -16.27 75.63 73.02 7.63 8.03 148.9 156.7 999.0 999.0000 1.9369 -13.14 -3.99 999.00 1.54 999.00 -38.29 -42.24 -14.18 -32.
66 -4.11 13.55 678.80 66.09 7.04 -16.21 -16.22 -17.44 -17.46 8.88 9.42 0.57 0.58 -14.99 6.60 8.60 5.88 4.88 0.65 56.40 11911118 87711921 11111111 116
3 2014 143.5833 672.00 212.88 999.00 -15.83 -15.86 -15.51 -15.28 75.07 72.04 7.62 8.02 150.5 156.3 999.0 999.0000 1.9459 0.89 0.31 999.00 1.69 999.00 -38.41 -41.39 -13.28 -31.51
-2.73 14.60 704.20 48.26 6.88 -15.38 -15.42 -16.19 -16.23 8.92 9.25 0.48 0.48 -13.62 6.59 8.60 5.87 4.87 0.65 54.30 11911118 87711991 11111111 116
zender@aerosol:~/data/aist$ echo

zender@aerosol:~/data/aist$ head -n 3 aist_imau.txt
2007,240.62515,1500,313.97601,160.79336,323.00318,315.64155
2007,240.66682,1600,332.7952,177.30627,323.03752,316.18789
2007,240.70848,1700,363.79151,196.44834,320.38994,316.72297
zender@aerosol:~/data/aist$
```

Figure 2: Three records (usually hourly sensor measurements) of data from three different AWS networks as distributed in their respective L2 ASCII formats by: a) PROMICE, b) GC-Net, c) IMAU.

JAWS: Justified Automatic Weather Station Data

Objective

Interoperability: Enable automated analyses (statistics, subsets, assimilation, intercomparison) and discovery of AWS-like data

Strategy

Harmonize idiosyncratic L2 ASCII formats into L3 netCDF format with standardized metadata and value-added data

Implementation

Python code stack at http://github.com/jaws/jaws

> conda install -c conda-forge jaws
> pip install jaws
> jaws L2_in.txt L3_out.nc

README.md

Justified Automated Weather Station (JAWS) Software

build passing | build passing

Install with conda | Anaconda Cloud 0.4.1 | Last updated 24 May 2018 | Platforms linux-64,osx-64,win-64,noarch | license Apache_Version_2_0

downloads 1k total

JAWS-processed data is CF & ACDD-compliant

```
ajay@ajay-VirtualBox:~/Desktop$ ncks --cal -v air_temp,latitude,longitude,time,time_bounds AAWS_AGO-4_20161130.nc
netcdf AAWS_AGO-4_20161130 {
  dimensions:
    nbnd = 2 ;
    time = UNLIMITED ; // (24 currently)

  variables:
    float air_temp(time) ;
      air_temp:_FillValue = 9.96921e+36f ;
      air_temp:long_name = "Air Temperature" ;
      air_temp:standard_name = "air_temperature" ;
      air_temp:units = "kelvin" ;
      air_temp:cell_methods = "time: mean" ;
      air_temp:coordinates = "longitude latitude" ;

    double latitude ;
      latitude:long_name = "Latitude" ;
      latitude:standard_name = "latitude" ;
      latitude:units = "degrees_north" ;

    double longitude ;
      longitude:long_name = "Longitude" ;
      longitude:standard_name = "longitude" ;
      longitude:units = "degrees_east" ;

    double time(time) ;
      time:long_name = "Time" ;
      time:standard_name = "time" ;
      time:units = "seconds since 1970-01-01 00:00:00" ;
      time:bounds = "time_bounds" ;
      time:calendar = "standard" ;

    double time_bounds(time,nbnd) ;

  data:
    air_temp = 236.65, 237.45, 238.35, 238.95, 239.55, 240.25, 240.95, 241.45, 241.75, 241.75, 241.75, 241.65, 241.55, 241.05, 240.85, 240.35, 239.55, 239.05, 238.05, 237.45, 237.25, 237.45, 237.55, 237.75 ;

    latitude = -82.01 ;

    longitude = 96.76 ;

    time = "2016-11-30", "2016-11-30 01:00:00", "2016-11-30 02:00:00", "2016-11-30 03:00:00", "2016-11-30 04:00:00", "2016-11-30 05:00:00", "2016-11-30 06:00:00", "2016-11-30 07:00:00", "2016-11-30 08:00:00", "2016-11-3
0 09:00:00", "2016-11-30 10:00:00", "2016-11-30 11:00:00", "2016-11-30 12:00:00", "2016-11-30 13:00:00", "2016-11-30 14:00:00", "2016-11-30 15:00:00", "2016-11-30 16:00:00", "2016-11-30 17:00:00", "2016-11-30 18:00:00",
 "2016-11-30 19:00:00", "2016-11-30 20:00:00", "2016-11-30 21:00:00", "2016-11-30 22:00:00", "2016-11-30 23:00:00" ;

    time_bounds =
    "2016-11-29 23:00:00", "2016-11-30",
    "2016-11-30", "2016-11-30 01:00:00",
    "2016-11-30 01:00:00", "2016-11-30 02:00:00",
    "2016-11-30 02:00:00", "2016-11-30 03:00:00",
    "2016-11-30 03:00:00", "2016-11-30 04:00:00",
    "2016-11-30 04:00:00", "2016-11-30 05:00:00",
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    "2016-11-30 07:00:00", "2016-11-30 08:00:00",
    "2016-11-30 08:00:00", "2016-11-30 09:00:00",
    "2016-11-30 09:00:00", "2016-11-30 10:00:00",
    "2016-11-30 10:00:00", "2016-11-30 11:00:00",
    "2016-11-30 11:00:00", "2016-11-30 12:00:00",
    "2016-11-30 12:00:00", "2016-11-30 13:00:00",
    "2016-11-30 13:00:00", "2016-11-30 14:00:00",
    "2016-11-30 14:00:00", "2016-11-30 15:00:00",
    "2016-11-30 15:00:00", "2016-11-30 16:00:00",
    "2016-11-30 16:00:00", "2016-11-30 17:00:00",
    "2016-11-30 17:00:00", "2016-11-30 18:00:00",
    "2016-11-30 18:00:00", "2016-11-30 19:00:00",
    "2016-11-30 19:00:00", "2016-11-30 20:00:00",
```
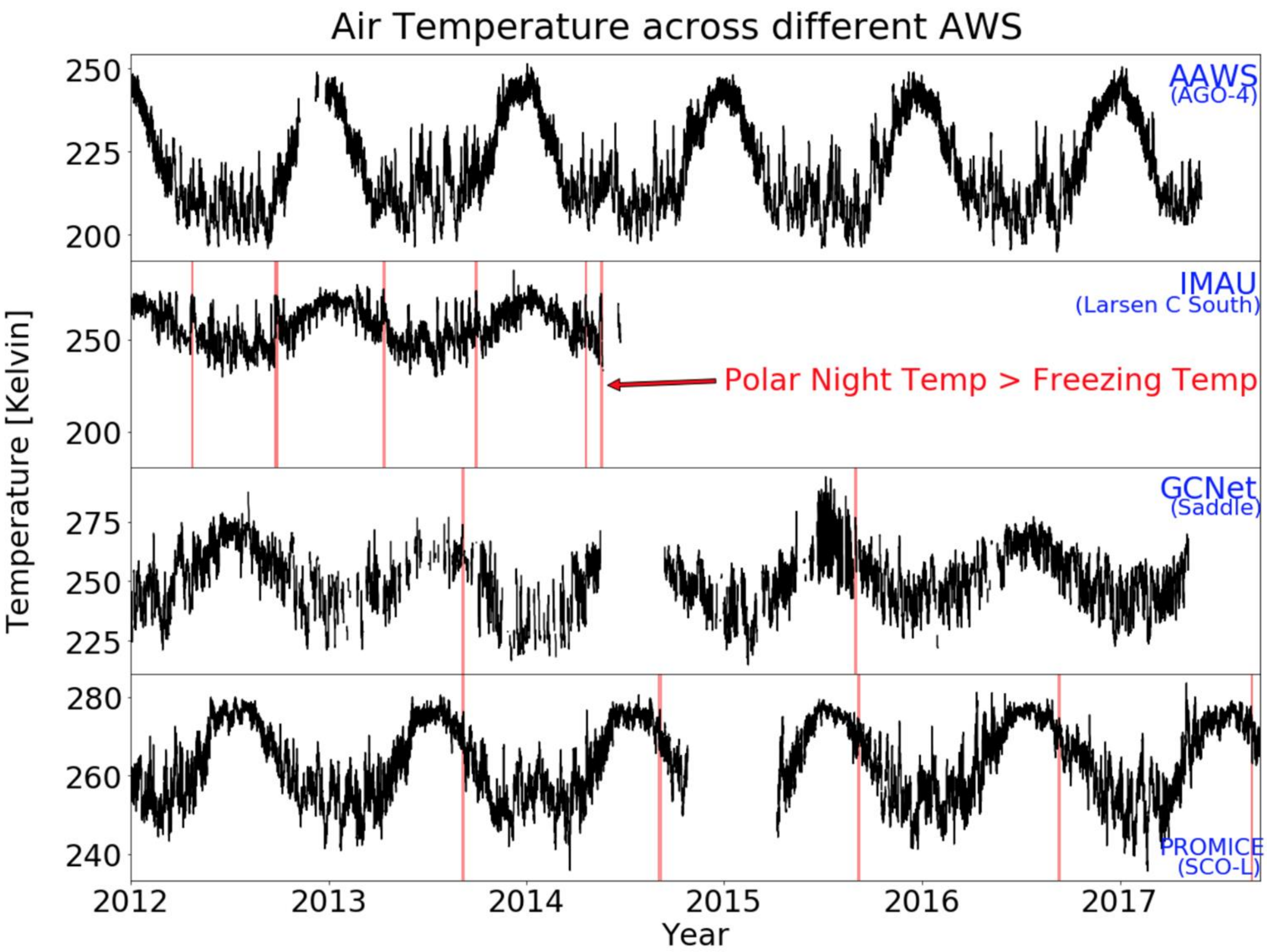
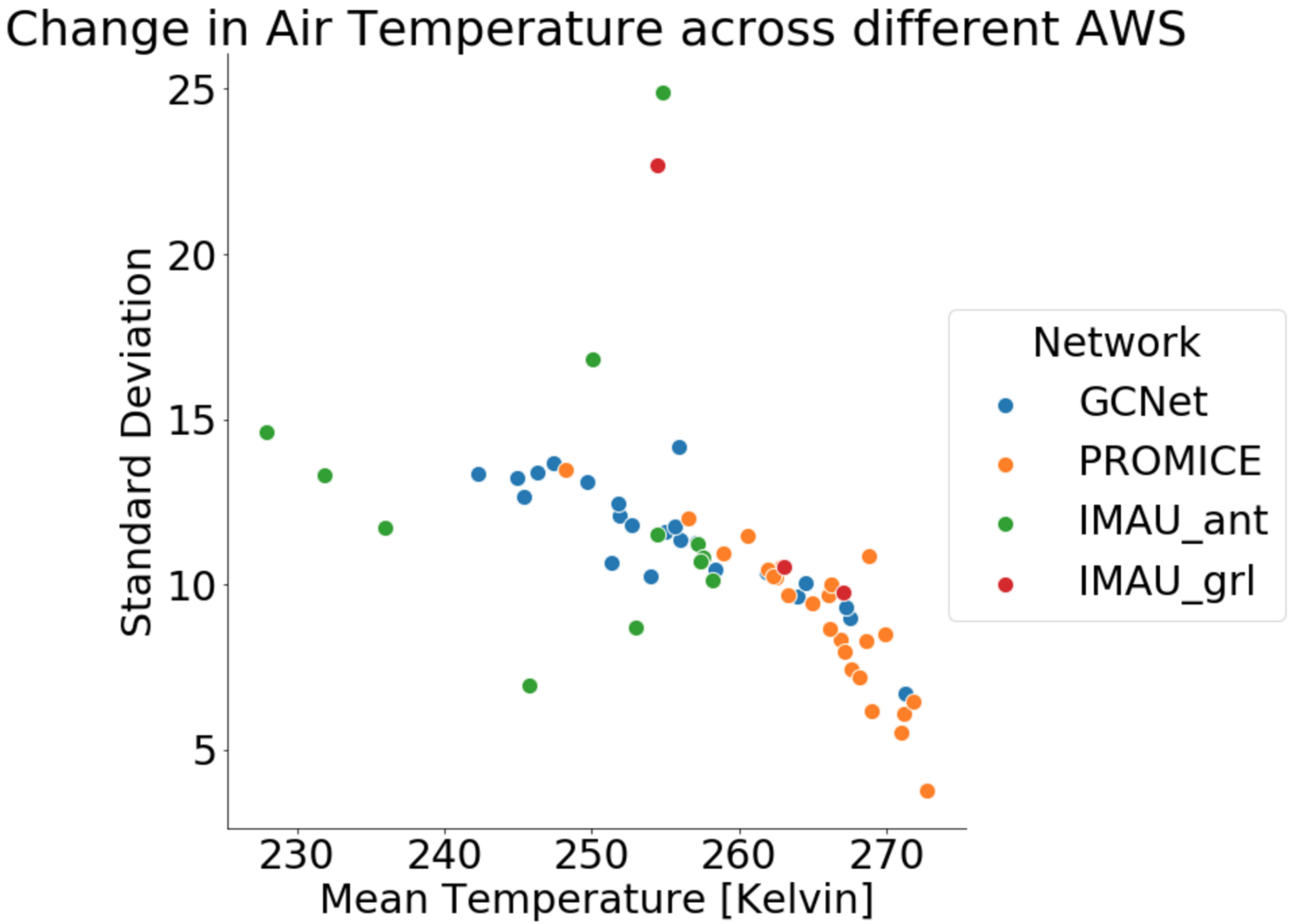
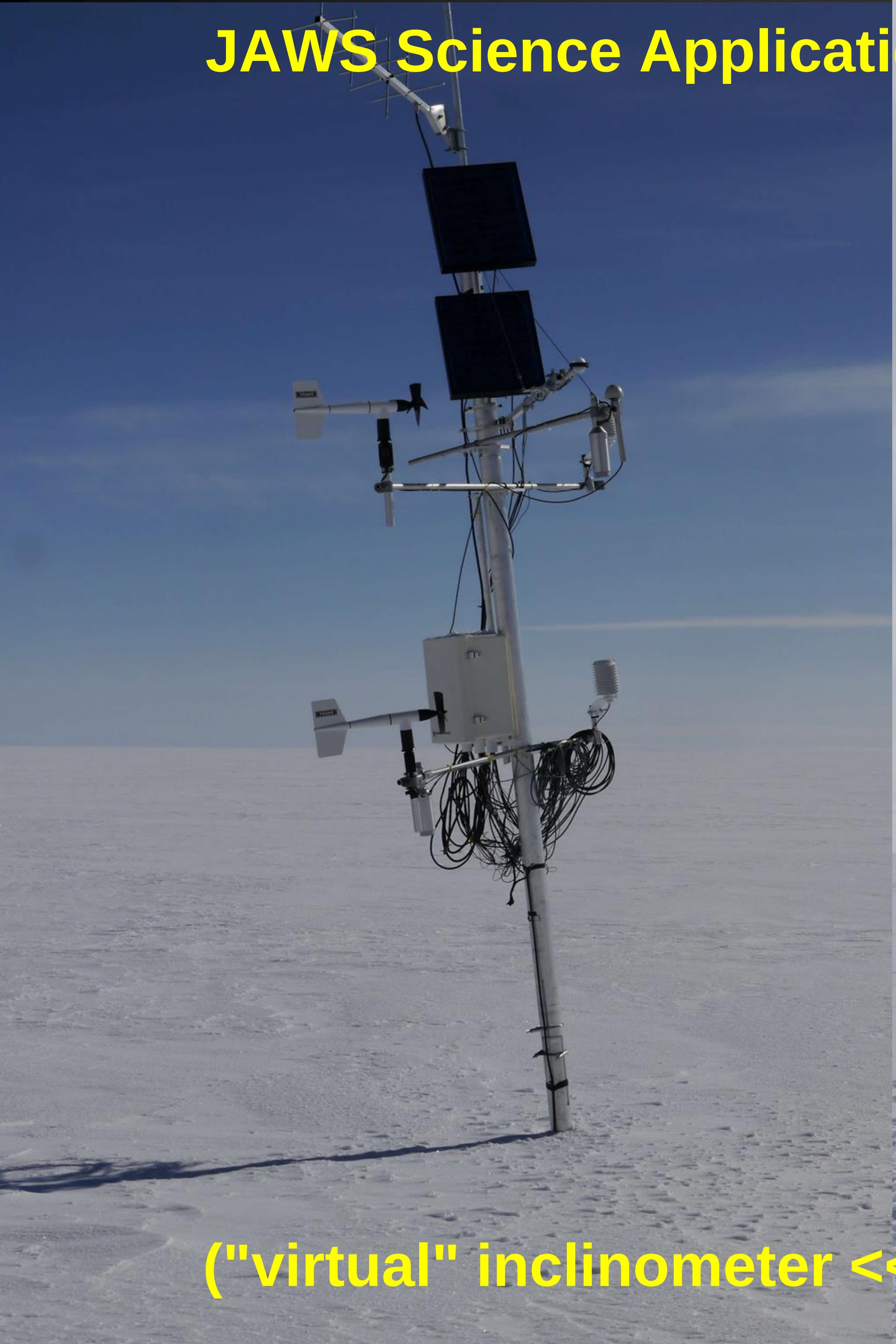

JAWS-processed data is intercomparable across networks



Intercomparability (from JAWS) for Outlier Detection



JAWS Science Application: Adjust Radiometry for Tilt




("virtual" inclinometer << $$$ than physical retrofit)

Tilted Radiometry Biases Surface Energy Budget

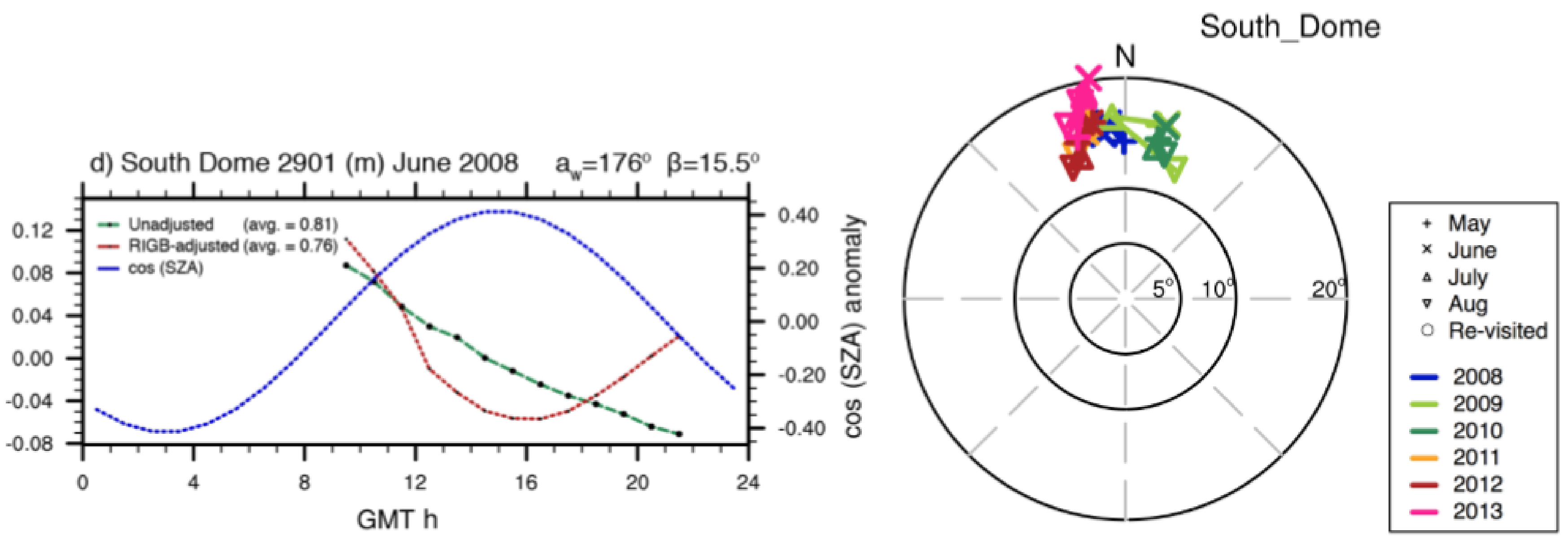
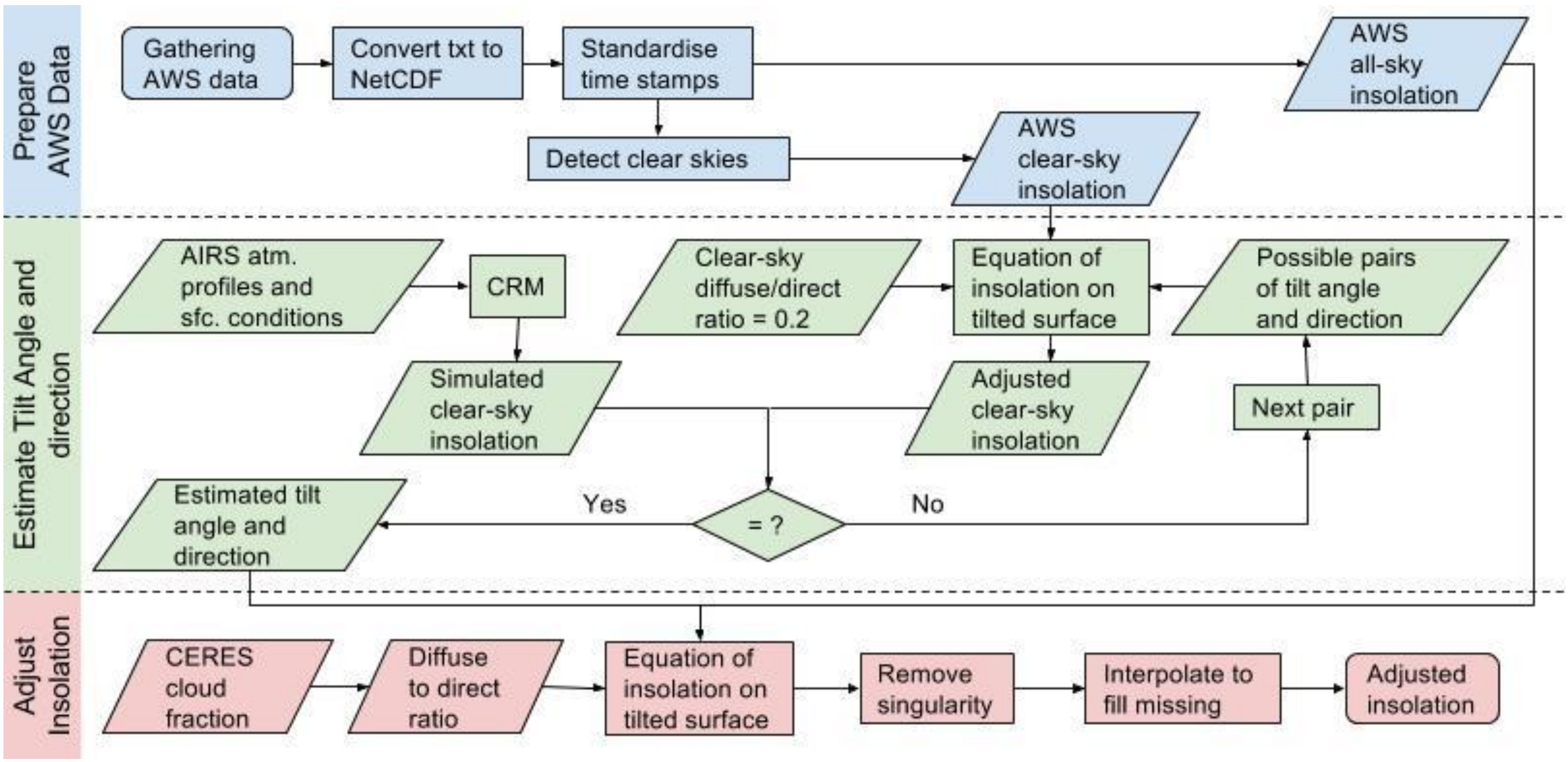


Figure 4: a) June 2008 tilt correction results at South Dome station. Top labels show elevation, month, and RIGB-derived tilt direction a_w and tilt angle β. Curves show albedo anomaly (monthly average of difference between hourly and daily albedo) for unadjusted (green) and adjusted (red) data. b) Estimated tilt angle (distance to circle center) and direction at South Dome station from 2009–2013.

Use RT with Satellite+AWS Data to Infer Tilt, Rotation



JAWS Tilt-Correction Improves Accuracy ~11 W/m2

The Cryosphere, 10, 727–741, 2016
www.the-cryosphere.net/10/727/2016/
doi:10.5194/tc-10-727-2016

The Cryosphere
Open Access
EGU

A Retrospective, Iterative, Geometry-Based (RIGB) tilt-correction method for radiation observed by automatic weather stations on snow-covered surfaces: application to Greenland

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[2]Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
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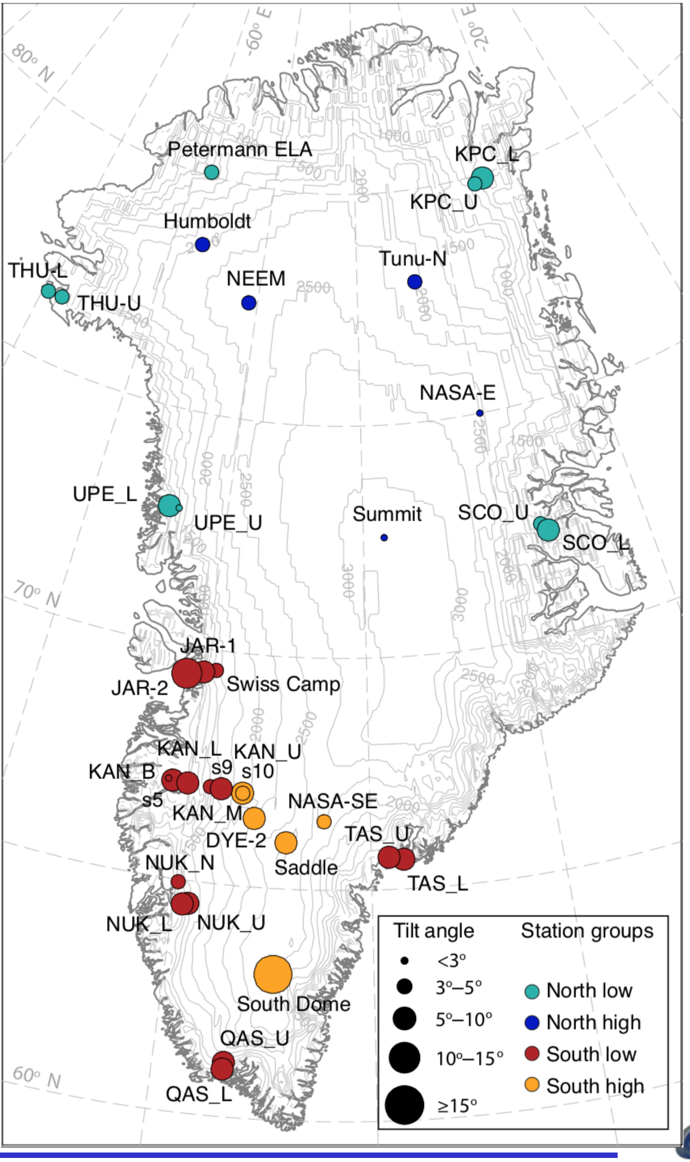
Received: 28 September 2015 – Published in The Cryosphere Discuss.: 3 November 2015
Revised: 11 February 2016 – Accepted: 11 March 2016 – Published: 24 March 2016

Abstract. Surface melt and mass loss of the Greenland Ice Sheet may play crucial roles in global climate change due to their positive feedbacks and large fresh-water storage. With few other regular meteorological observations available in this extreme environment, measurements from automatic weather stations (AWS) are the primary data source for studying surface energy budgets, and for validating satellite observations and model simulations. Station tilt, due to irregular surface melt, compaction and glacier dynamics, causes considerable biases in the AWS shortwave radiation measurements. In this study, we identify tilt-induced biases in the climatology of surface shortwave radiative flux and albedo, and retrospectively correct these by iterative application of solar geometric principles. We found, over all the AWS from the Greenland Climate Network (GC-Net), the Kangerlussuaq transect (K-transect) and the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) networks, insolation on fewer than 40 % of clear days peaks within ±0.5 h of solar noon time, with the largest shift exceeding 3 h due to tilt. Hourly absolute biases in the magnitude of surface insolation can reach up to 200 W m^{-2}, with respect to the well-understood clear-day insolation. We estimate the tilt angles and their directions based on the solar geometric relationship between the simulated insolation at a horizontal surface and the observed insolation by these tilted AWS under clear-sky conditions. Our adjustment reduces the root mean square error (RMSE) against references from both satellite observation and reanalysis by 16 W m^{-2} (24 %), and raises the correlation coefficients with them to above 0.95. Averaged over the whole Greenland Ice Sheet in the melt season, the adjustment in insolation to compensate station tilt is ∼ 11 W m^{-2}, enough to melt 0.24 m of snow water equivalent. The adjusted diurnal cycles of albedo are smoother, with consistent semi-smiling patterns. The seasonal cycles and inter-annual variabilities of albedo agree better with previous studies. This tilt-corrected shortwave radiation data set derived using the Retrospective, Iterative, Geometry-Based (RIGB) method provide more accurate observations and validations for surface energy budgets studies on the Greenland Ice Sheet, including albedo variations, surface melt simulations and cloud radiative forcing estimates.

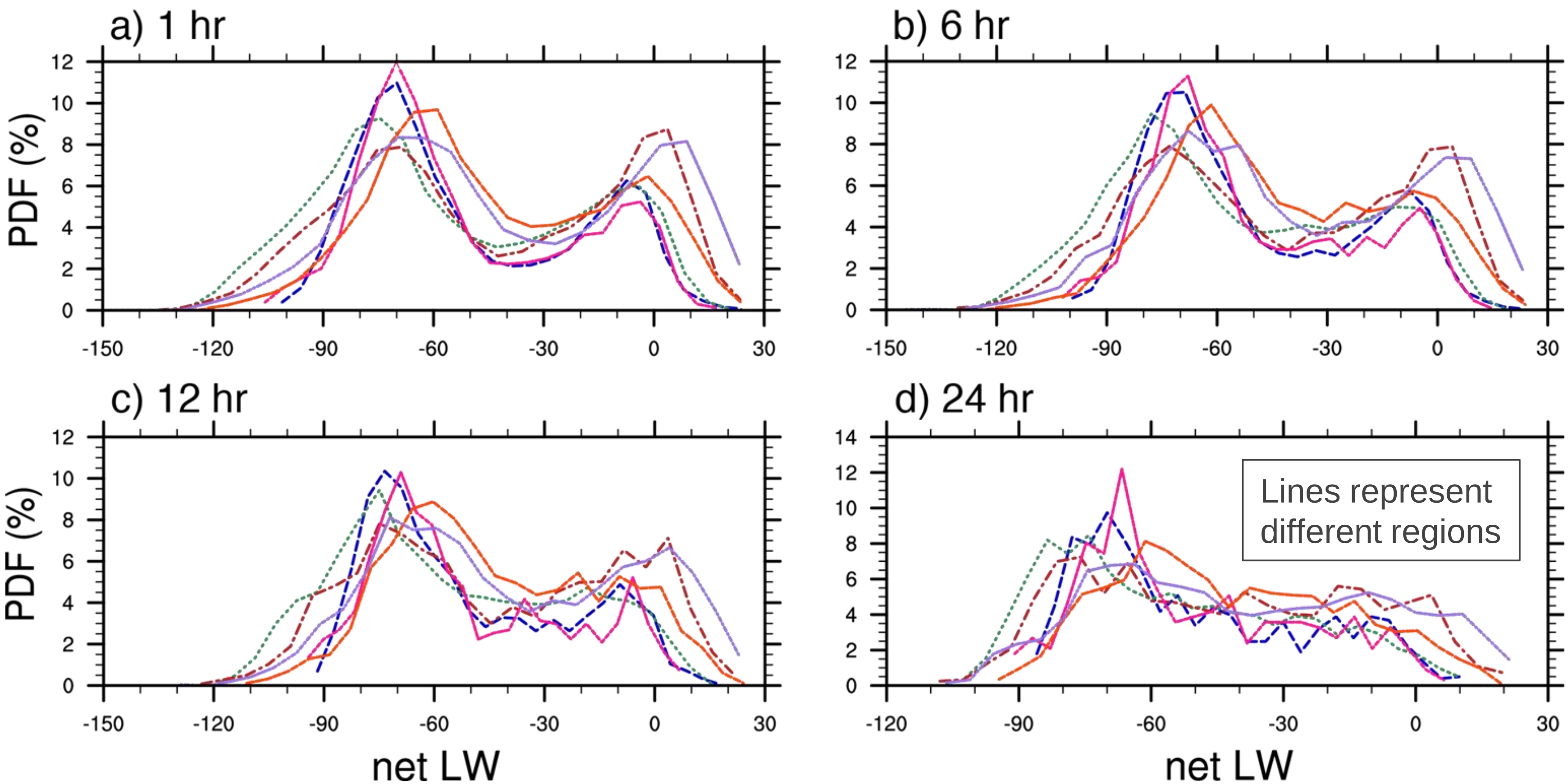
1 Introduction

The Greenland Ice Sheet has experienced dramatic mass loss and frequent massive melt events in the past 30 years (Nghiem et al., 2012; Tedesco et al., 2013; Velicogna and Wahr, 2013). At least half of the mass loss can be attributed to surface mass balance (van den Broeke et al., 2009; Enderlin et al., 2014; Andersen et al., 2015), which is in turn controlled by solar radiation (van den Broeke et al., 2011). Therefore, reliable measurements of surface radiative flux are essential for climate change studies in this sensitive area (Pithan and Mauritsen, 2014). In this study, we correct the station tilt problem to produce more consistent shortwave radiation (thereafter, SW) measured by the automatic weather stations (AWS).



ESTO
Earth Science Technology Office

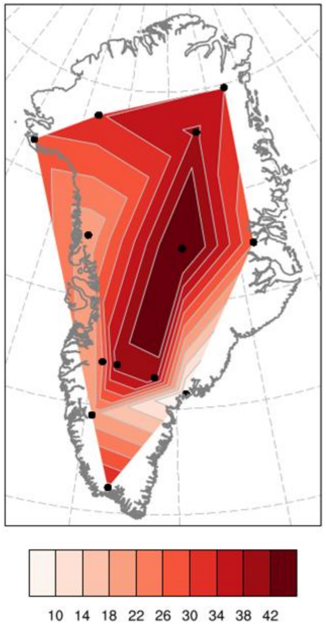
JAWS helps resolve short-timescale surface processes

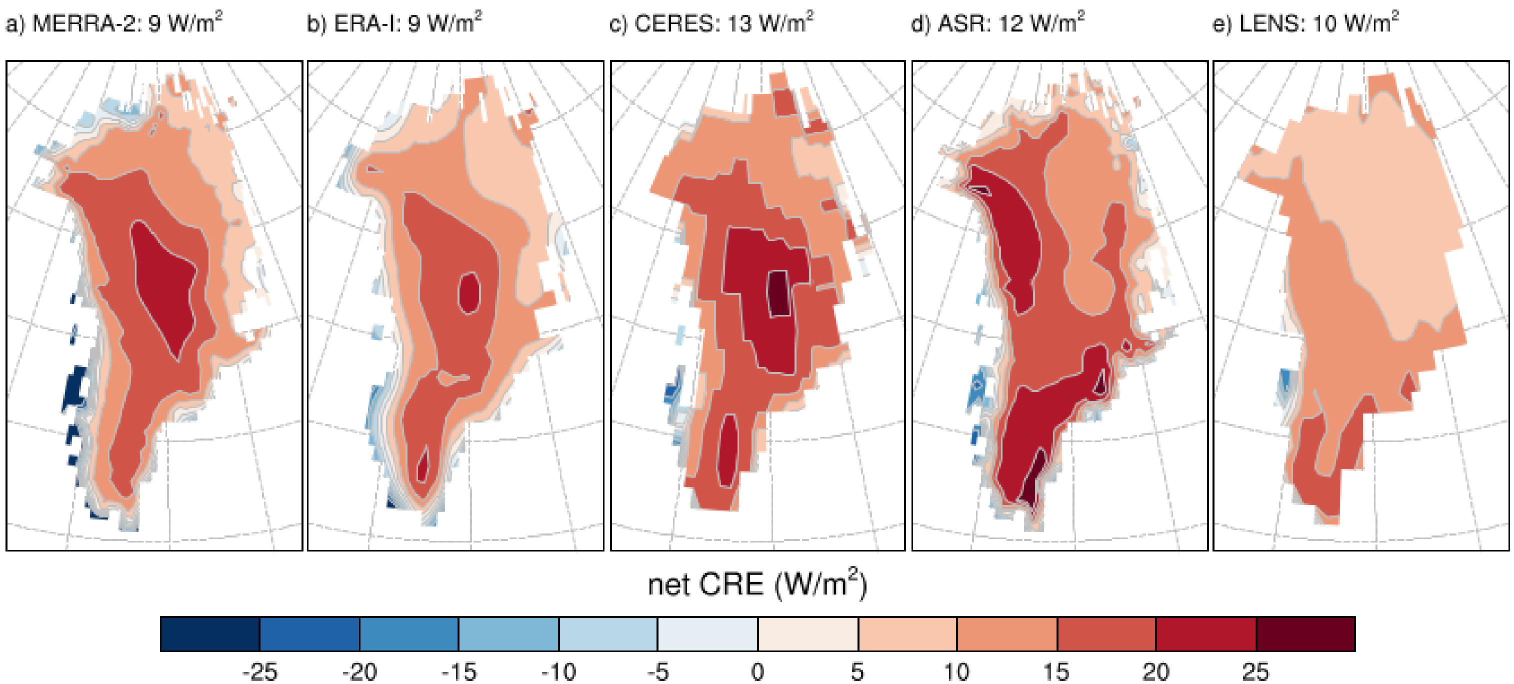


Temporal Characteristics of Cloud Radiative Effects on Greenland's Surface Energy Budget During Melt Season: Discoveries from Multi-year Automatic Weather Station Measurements (Submitted to *JGR*)

JAWS helps to ground-truth satellites, models, reanalyses

Cloud Radiative Effects "Warm center" distribution:



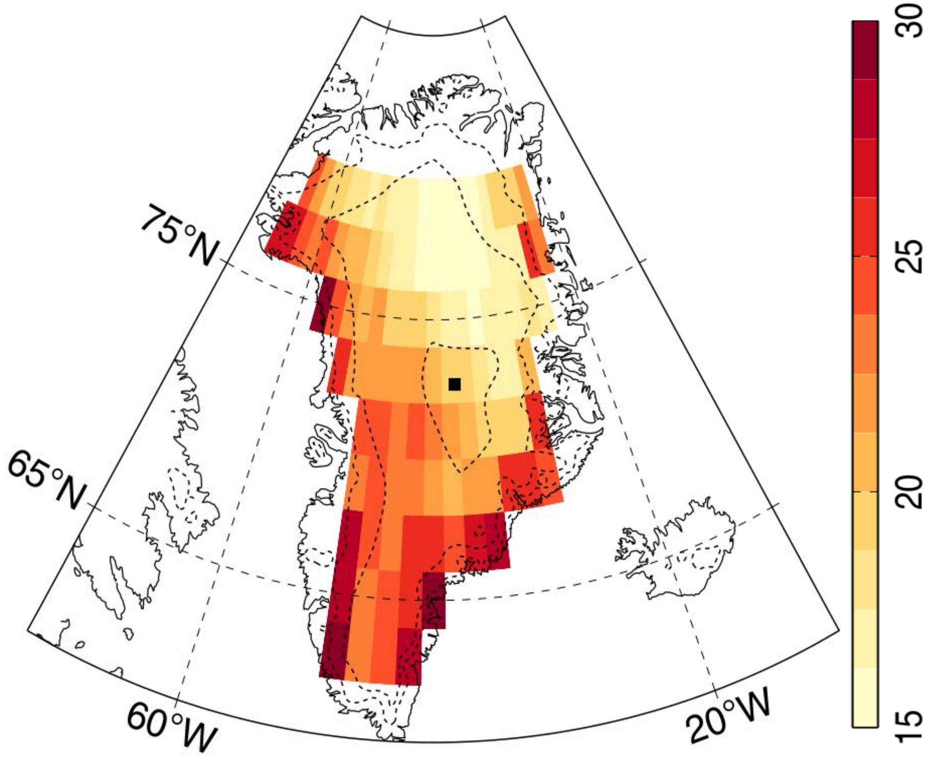


AWS ✓ ✓ ✓ ? ?

Spatial distribution of melt-season cloud radiative effects over Greenland: Evaluating satellite observations, reanalyses, and model simulations against in situ measurements (Submitted to *JGR*)

“Warm L-shape” in CALIPSO

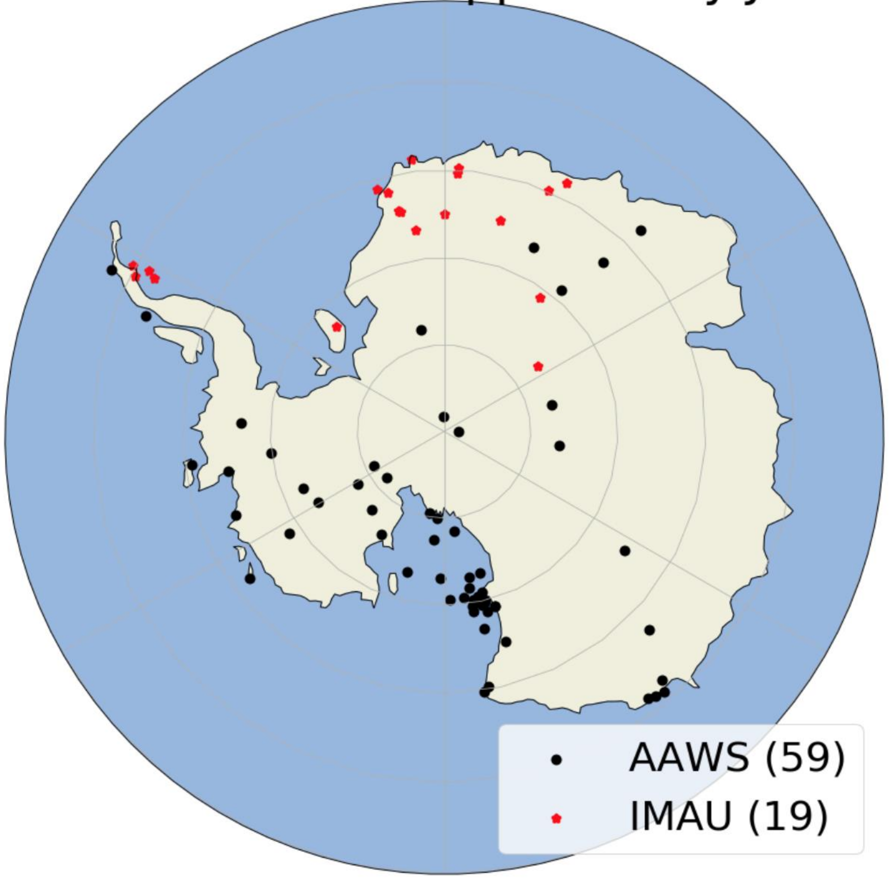
Annual CRE CALIPSO/CloudSAT (W/m²)

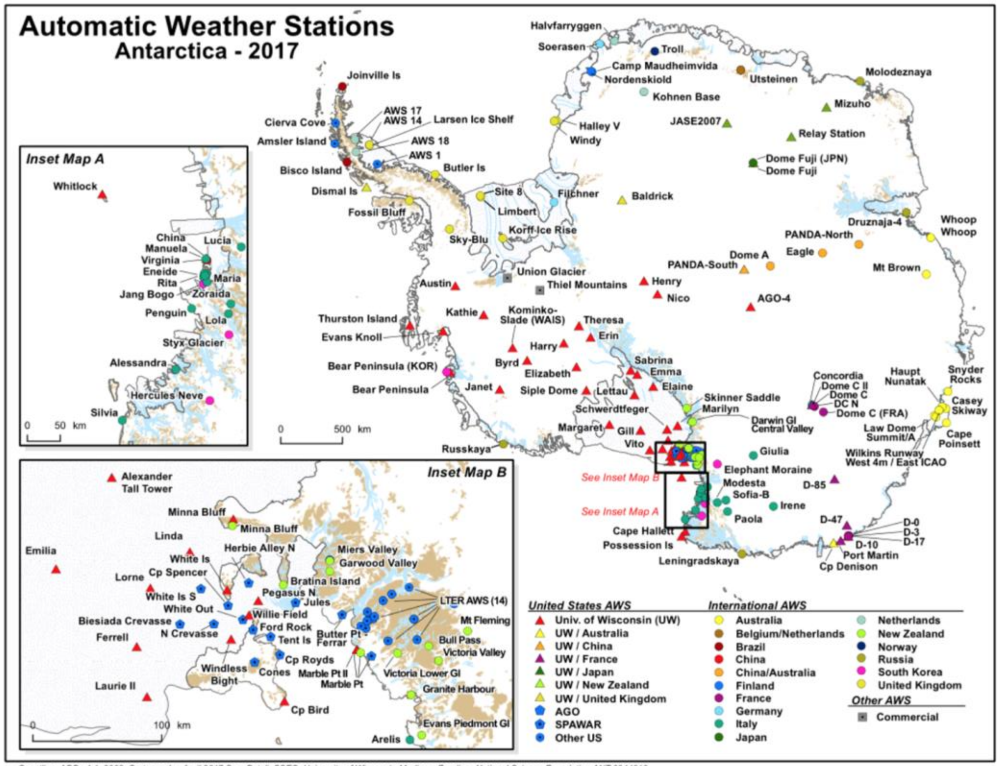


van Tricht *et al.* 2016

JAWS Processes ~50% (and counting) of Antarctic AWS

Antarctica AWS supported by JAWS





Coastline: ADD v4.1, 2003; Cartography: April 2017 Sam Batzli, SSEC, University of Wisconsin-Madison; Funding: National Science Foundation ANT-0944018

Larsen C Ice Shelf is vulnerable to disintegration

Credit: PRI

JAWS Helps Show ~25% Larsen C Annual Melt in Polar Night

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Geophysical Research Letters

RESEARCH LETTER

10.1029/2018GL077899

Key Points:
- Wintertime surface melt occurs frequently in the Antarctic Peninsula
- Winter melt heats the firn to a depth of about 3 m, retarding or reversing winter cooling
- Increased greenhouse gas concentrations could increase the occurrence of winter surface melt

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Citation:
Kuipers Munneke, P., Luckman, A. J., Bevan, S. L., Smeets, C. J. P. P., Gilbert, E., van den Broeke, M. R., et al. (2018). Intense winter surface melt on an Antarctic ice shelf. *Geophysical Research Letters, 45*. https://doi.org/10.1029/2018GL077899

Received 12 MAR 2018
Accepted 21 APR 2018
Accepted article online 2 MAY 2018

Intense Winter Surface Melt on an Antarctic Ice Shelf

P. Kuipers Munneke[1], A. J. Luckman[2], S. L. Bevan[2], C. J. P. P. Smeets[1], E. Gilbert[3,4], M. R. van den Broeke[1], W. Wang[5], C. Zender[5], B. Hubbard[6], D. Ashmore[7], A. Orr[3], J. C. King[3], and B. Kulessa[2]

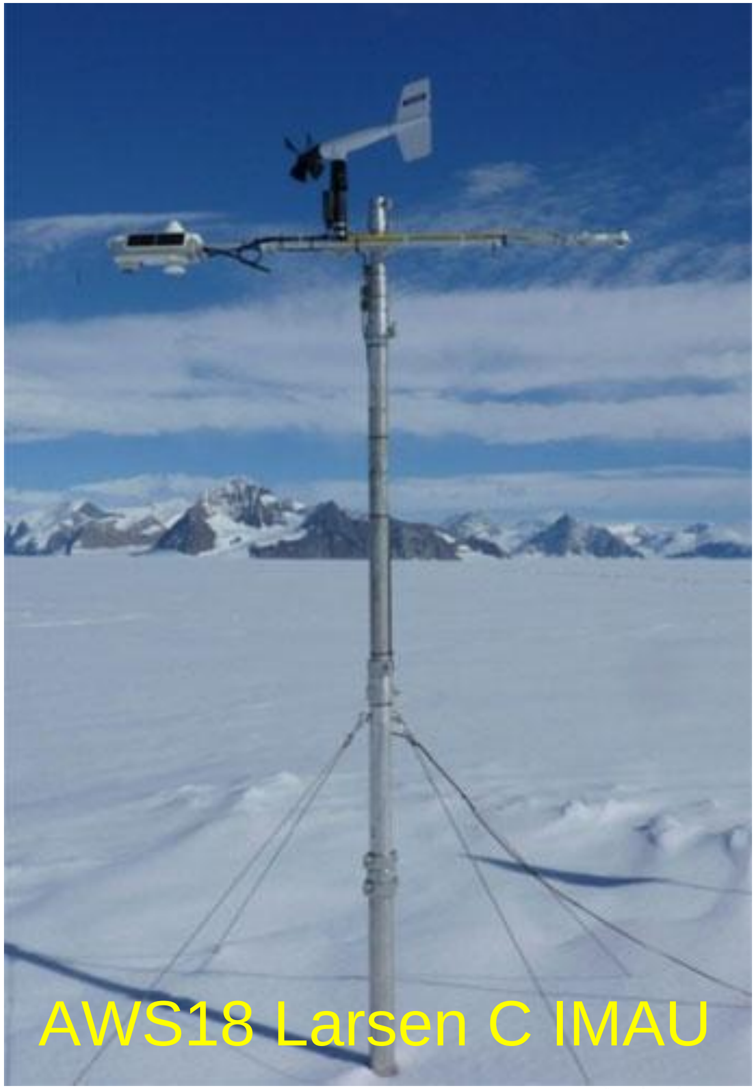
[1]Institute for Marine and Atmospheric research Utrecht, Utrecht University, Utrecht, Netherlands, [2]Department of Geography, Swansea University, Swansea, UK, [3]British Antarctic Survey, Natural Environment Research Council, Cambridge, UK, [4]School of Environmental Sciences, University of East Anglia, Norwich, UK, [5]Department of Earth System Science, University of California, Irvine, CA, USA, [6]Centre for Glaciology, Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, UK, [7]School of Environmental Sciences, University of Liverpool, Liverpool, UK

Abstract The occurrence of surface melt in Antarctica has hitherto been associated with the austral summer season, when the dominant source of melt energy is provided by solar radiation. We use in situ and satellite observations from a previously unsurveyed region to show that events of intense surface melt on Larsen C Ice Shelf occur frequently throughout the dark Antarctic winter, with peak intensities sometimes exceeding summertime values. A regional atmospheric model confirms that in the absence of solar radiation, these multiday melt events are driven by outbreaks of warm and dry föhn wind descending down the leeside of the Antarctic Peninsula mountain range, resulting in downward turbulent fluxes of sensible heat that drive sustained surface melt fluxes in excess of 200 W/m^2. From 2015 to 2017 (including the extreme melt winter of 2016), ~23% of the annual melt flux was produced in winter, and spaceborne observations of surface melt since 2000 show that wintertime melt is widespread in some years. Winter melt heats the firn layer to the melting point up to a depth of ~3 m, thereby facilitating the formation of impenetrable ice layers and retarding or reversing autumn and winter cooling of the firn. While the absence of a trend in winter melt is consistent with insignificant changes in the observed Southern Hemisphere atmospheric circulation during winter, we anticipate an increase in winter melt as a response to increasing greenhouse gas concentration.

Plain Language Summary Around the coast of Antarctica, it gets warm enough in summer for snow to start melting, and the sun provides most of the energy for that melt. Almost all meltwater refreezes in the snowpack, but especially on floating glaciers in Antarctica, it has been observed that meltwater forms large ponds. The pressure exerted by these ponds may have led to ice shelves collapsing into numerous icebergs in recent decades. It is therefore important to understand how much meltwater is formed. To find out, we installed an automatic weather station on a glacier in Cabinet Inlet, in the Antarctic Peninsula in 2014. The station recorded temperatures well above the melting point even in winter. The occurrence of winter melt is confirmed by satellite images and by thermometers buried in the snow, which measured a warming of the snow even at 3 m depth. Between 2014 and 2017, about 23% of all melt in Cabinet Inlet occurred in winter. Winter melt is due to warm winds that descend from the mountains, known as föhn. We have not seen the amount of winter melt increasing since 2000. However, we expect winter melt to happen more frequently if greenhouse gas continues to accumulate in the atmosphere.

1. Surface Melt in Antarctica

Current mass loss of the Antarctic Ice Sheet is made up almost entirely of ice shelf basal melting and iceberg calving (Depoorter et al., 2013). Although supraglacial and englacial runoff has been widely observed, especially in regions of low albedo such as blue ice and bare rock (Bell et al., 2017; Kingslake et al., 2017; Lenaerts et al., 2016), models suggest that only a small fraction (<1%) of the ~115 Gt (1 Gt = 10^{12} kg) of surface meltwater produced annually (Trusel et al., 2013; Van Wessem et al., 2017) runs off directly into the ocean. Instead, it is refrozen within underlying snow and firn layers (Kuipers Munneke, Picard, et al., 2012). The indirect impact of meltwater is profound, however, as an important role for meltwater-induced fracturing is implicated in the collapse of coastal ice shelves (Banwell et al., 2013; Scambos et al., 2000). Observed collapse following

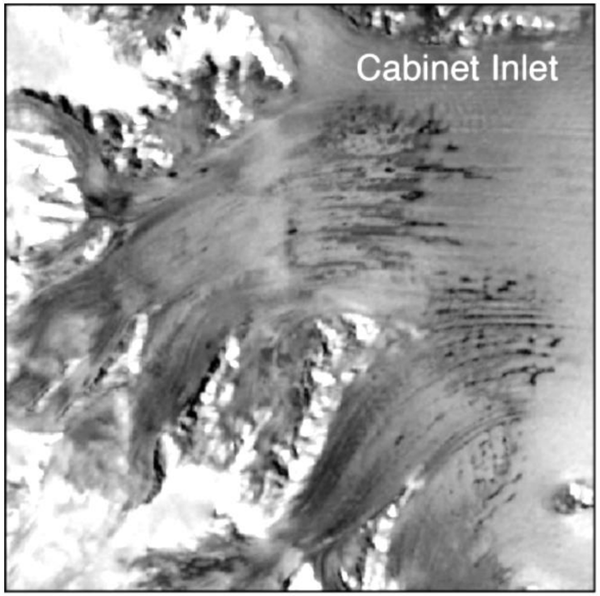


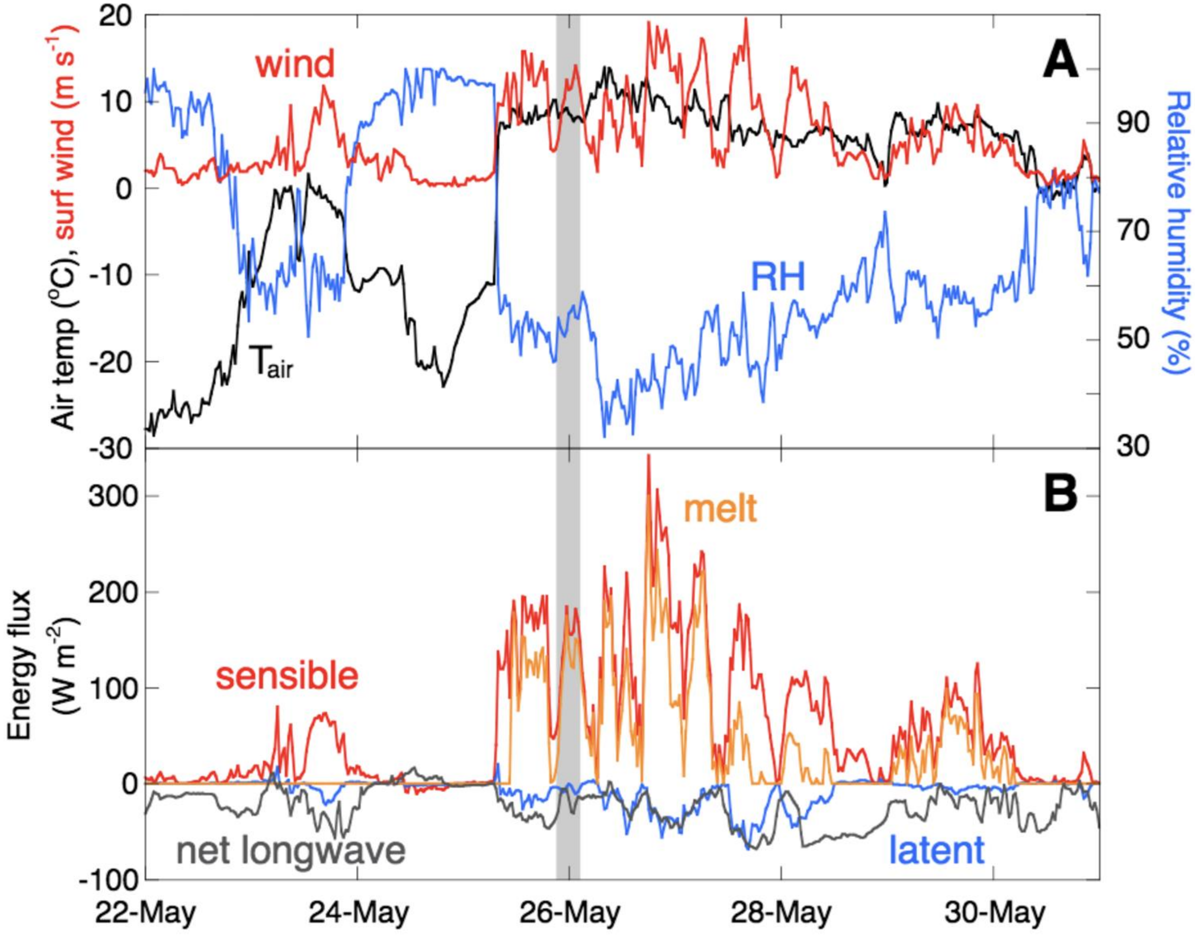
ESTO Earth Science Technology Office

Discovery of polar night melt (GRL, 2018)

Automatic Weather Station (AWS) 18

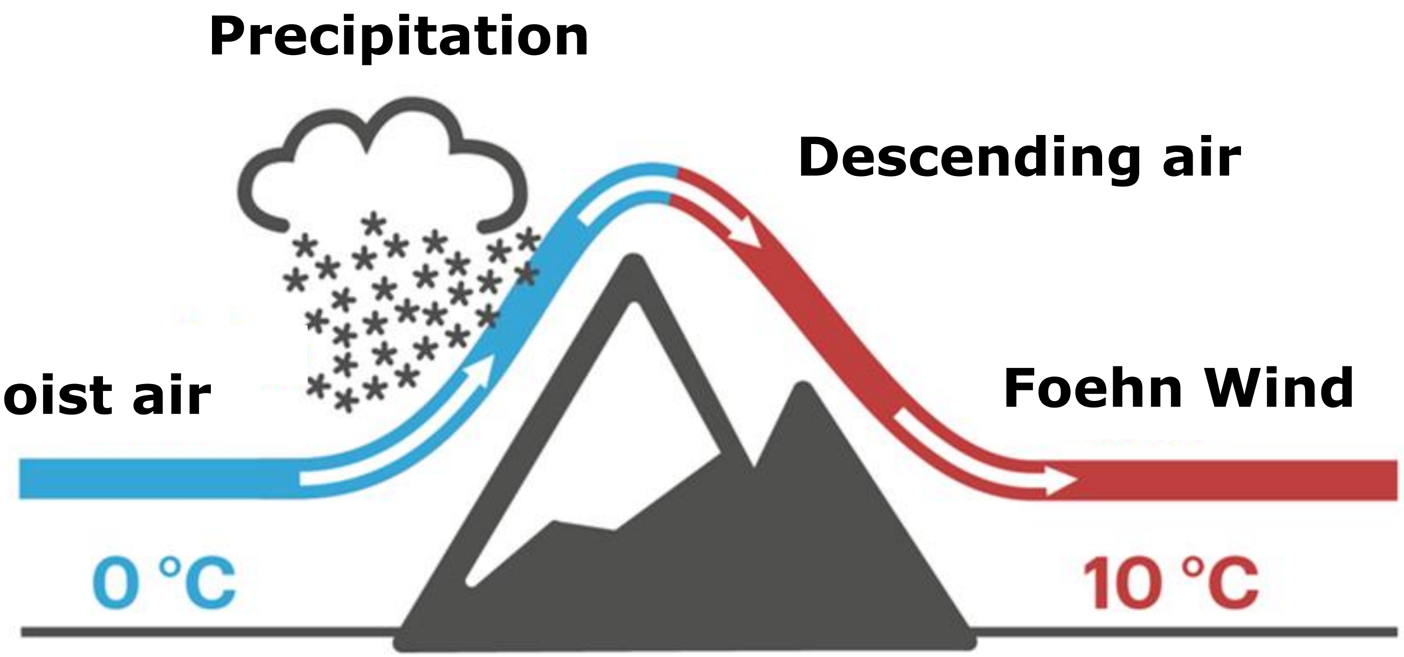
Between 2014 and 2017 **23%** of all melt **occurred in winter**





Kuipers Munneke et al., 2018

Foehn winds warm due to latent heat release



With limited shortwave radiation in polar night, melt occurs through downward turbulent fluxes of sensible heat from foehn wind

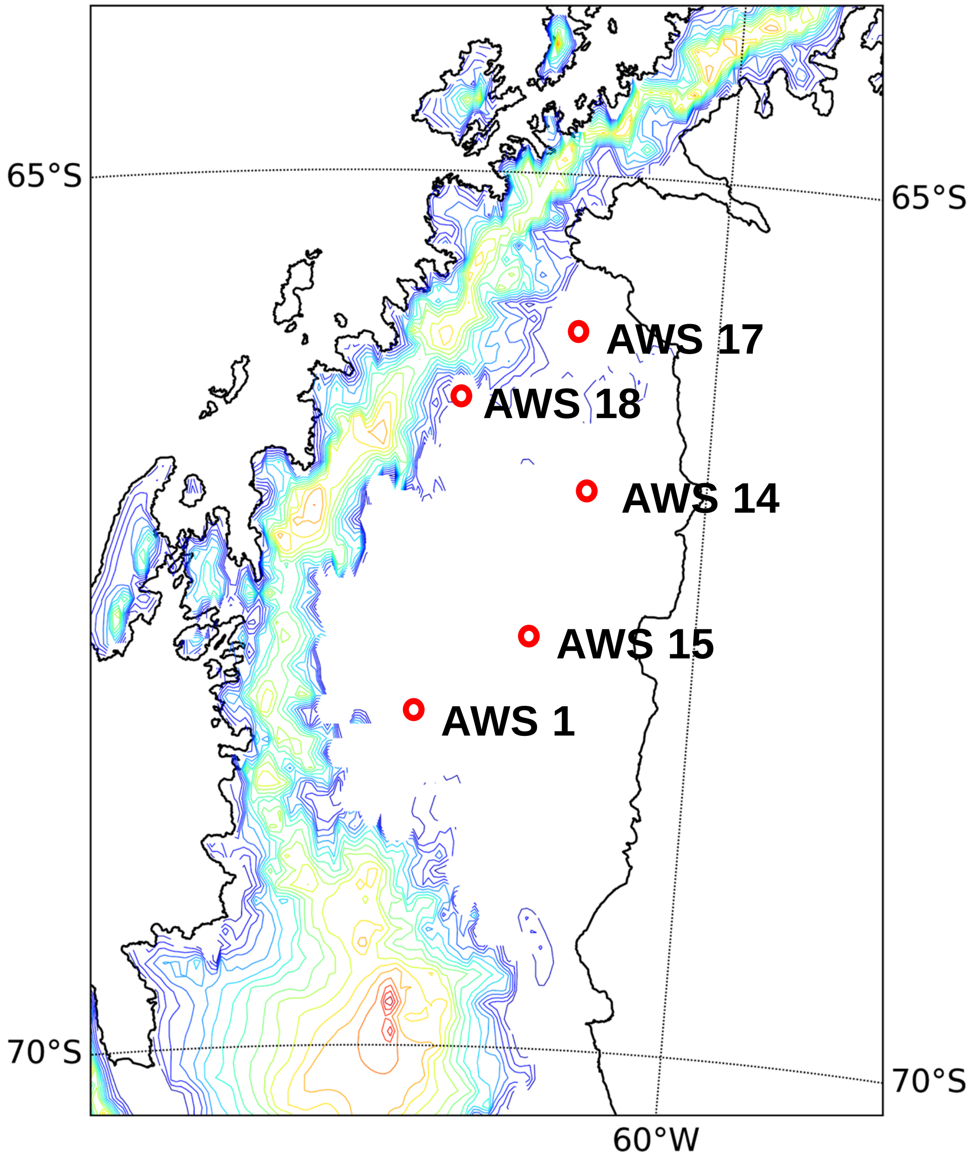
What we don't know...

- Spatial distribution/variability of polar night surface melt
- Temporal variability of polar night surface melt
- Vulnerability of Larsen C

How can we expand on this knowledge?

AWS data

MERRA-2 Reanalysis data



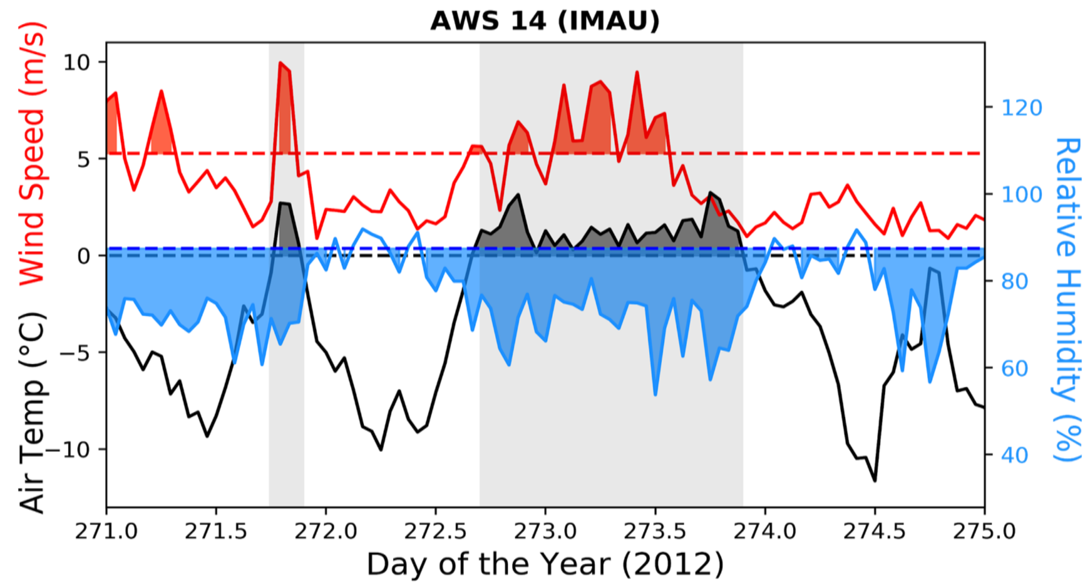
JAWS foehn detection algorithm (FonDA)

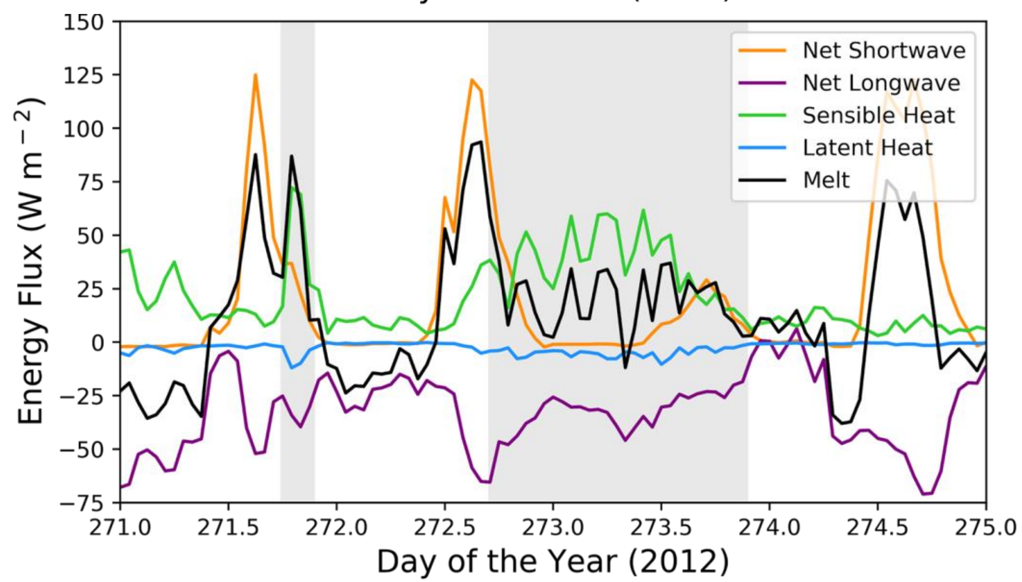
FonDa variable thresholds

- Temp > 0 ℃
- RH < 65th percentile
- Wind > 75th percentile

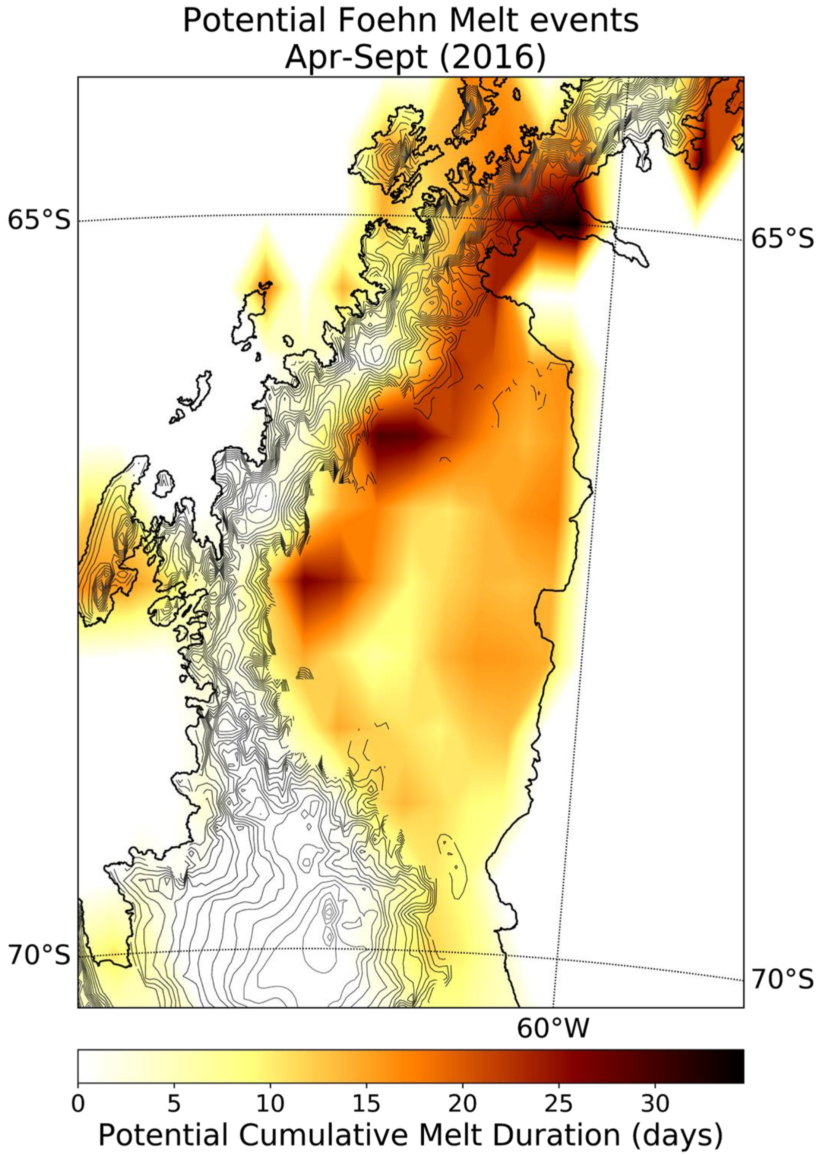
Ice Surface Energy Budget

Melt = SW_{net} + LW_{net} + Sens + Lat





MERRA-2 (FonDA) preliminary results



Supplementary Slides