The view from above Arctic snow at 89-325 GHz: What can surface emissivity on these channels tell us about snowpack stratigraphy?

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Royal Met Society Meeting

21 November 2018

Collaborators

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- Matt Purslow, Summer Student, Reading University
- Mo Smith, FAAM

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Contents

- FAAM aircraft and microwave radiometers
- Motivation
- MACSSIMIZE flights
- Initial results from snow emissivity flights
- Future analysis and implementation plans

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The Facility for Airborne Atmospheric Measurements

NERC Centres for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

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MARSS, MHS demonstrator

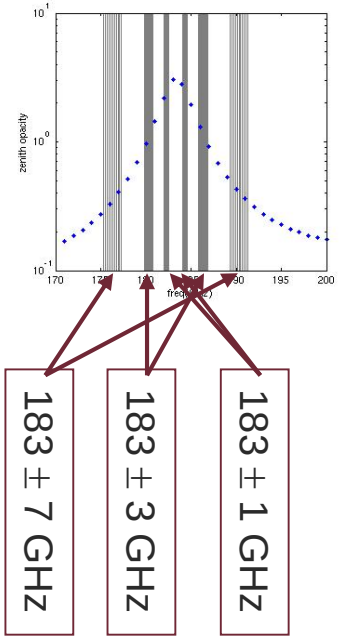
MHS is a humidity sounder on MetOp-series satellites.

- Provides important profile information about humidity which is assimilated into NWP systems

MARSS is a microwave radiometer on FAAM

MARSS and MHS

- Measure T_B at 89, 157, and 183 GHz.
- 3 channels centred at 183 GHz: Allows simultaneous retrieval of emissivity and effective temperature



Microwave Capability

MARSS, MHS simulator

- Five channels at three frequencies
- Simultaneous retrievals of surface temperature and emissivity at 183 GHz
- Sensitive to gradients in snow pack characteristics=> snow pack layering

Channels (GHz)	Passband offsets (GHz)
88.992	**±1.1**
118.75	±1.1,±1.5,±2.1,±3.0,±5.0
157.05	**±2.6**
183.31	**±1,±3,±7**
243.2	±2.5
325.15	±1.5,±3.5,±9.5
424.7	±1.0,±1.5,±4.0
448	±1.4,±3.0,±7.2
664	±4.2
874.4	±6.0

Microwave Capability

MARSS, MHS simulator

- Five channels at three frequencies
- Simultaneous retrievals of surface temperature and emissivity at 183 GHz
- Sensitive to gradients in snow pack characteristics=> snow pack layering

ISMAR's channels mimic those of the Ice Cloud Imager an instrument selected for the Post-EPS generation of meteorological satellites due for launch in the 2020s.

- Lower frequencies useful for remotely sensing surface.

118 GHz and 183 GHz

=> simultaneous retrieval of surface temperature and emissivity.

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Motivation for MACSSIMIZE Campaign

Year of Polar Prediction

“The Year of Polar Prediction (YOPP) is one of the key elements of the WMO’s Polar Prediction Project. YOPP is scheduled to take place from mid-2017 to mid-2019**.**

Mission: Enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, verification, user-engagement and education activities.” (see http://www.polarprediction.net/yopp for more details)

Why are snow and sea ice emissivity important?

- Emissivity is important as we need to know it to make appropriate use of satellite microwave sounding data.
- Assimilation of such data is the backbone of global NWP.
- MW sounding limited to channels peaking in the upper troposphere in the Arctic due to variability in emissivity and surface temperature.
- Snow covers a large part of the Arctic which is an important data-sparse region.
- Profile data could be provided by MW sounders if snow emission characterised sufficiently.
- Snow emissivity studied in two previous campaigns lead by Met Office.

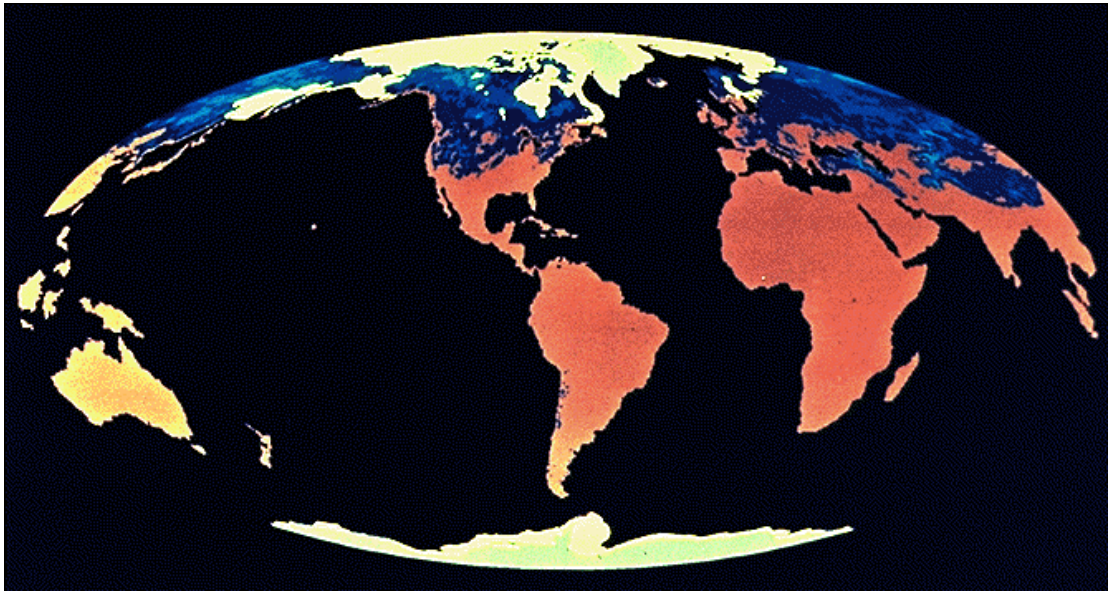
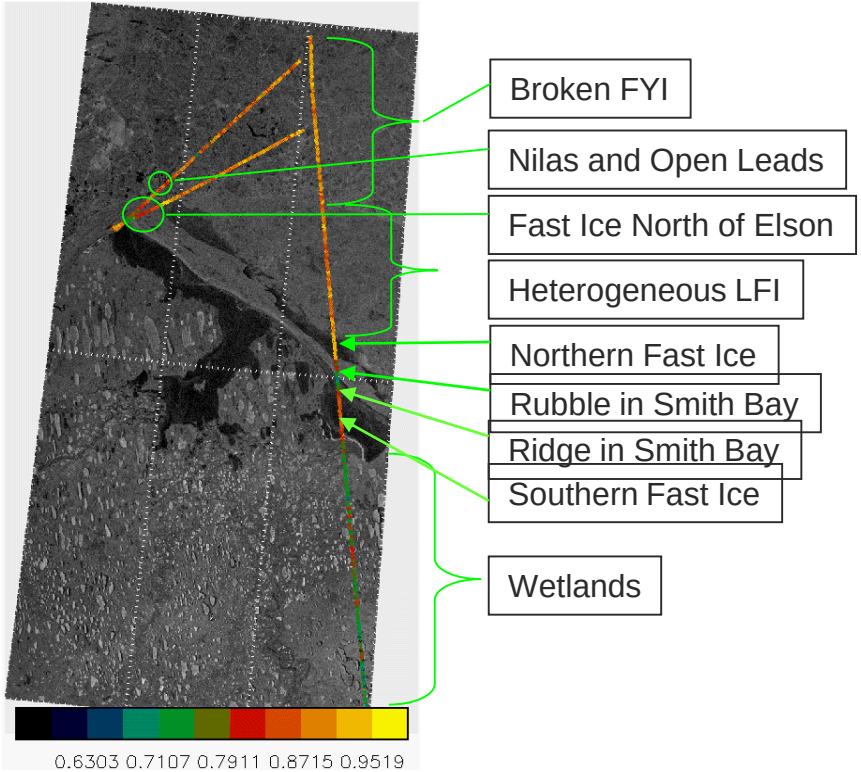


Figure: Snapshot of NH snow (blue) and sea ice cover (pale yellow)

POLEX and CLPX-II campaigns

- Both campaigns focused on emissivity
- POLEX (2001) yielded
  - an excellent survey of variability over FYI and MYI sea ice types.
  - No ground truth snow properties which are needed to evaluate emissivity models.
- CLPX-II (2008) had good ground truth of density and overall depth but measurements of snow microstructure were mediocre. Some evaluation still carried out.
- Both campaigns generated a good knowledge of emissivity variability and the processes determining it.



Actual emissivities quite variable

Figure shows emissivity spectra from Harlow (2011) based on 24 surface types from 7 flights from CLPX-II and POLEX.

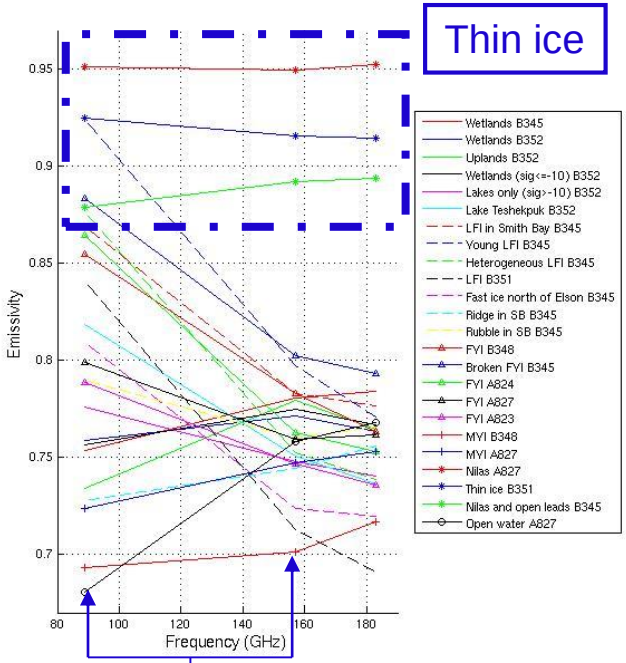
Emissivities of thin ice flat and near .9 or above.

Emissivities of thick ice types quite variable

- More so at 89 GHz than higher freq.

Repetition of spectral shape related to surface conditions.

- Thermodynamic
- Depositional history (snowfall)
- Wind speed history



G157-89

Stratigraphy effects emissivity

Typical tundra snowpacks are stratified into three main components

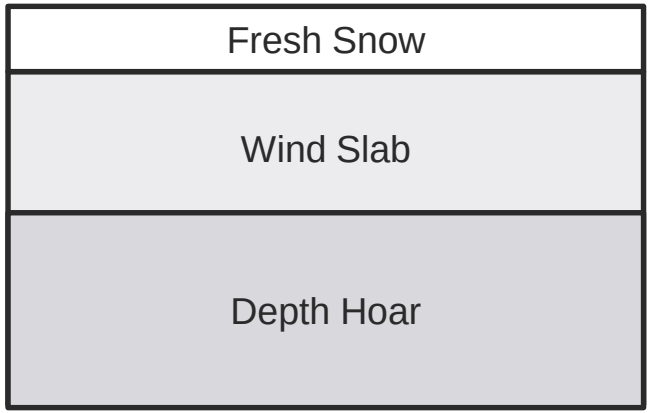
- Fine grained, loosely packed **Fresh Snow** on top of:
- Fine grained, densely packed **Wind Slab** on top of:
- Coarse grained, porous **Depth Hoar**
- Thermal and mechanical forcing determine relative thickness of these layers. Fresh snow quickly modifies Fresh Snow into Wind Slab.

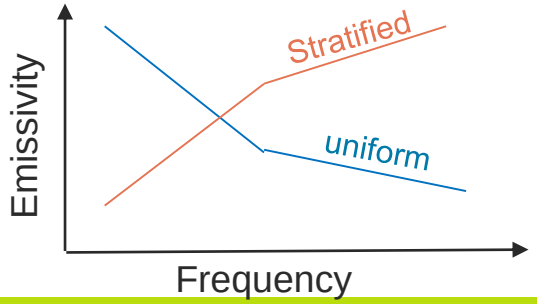
Emissivities change with frequency

- Penetration decreases with increasing frequency
- Strength of scattering increases with increasing frequency

Snowpacks with uniform/stratified grain size profiles

=> monotonic decreasing/increasing emissivity with frequency



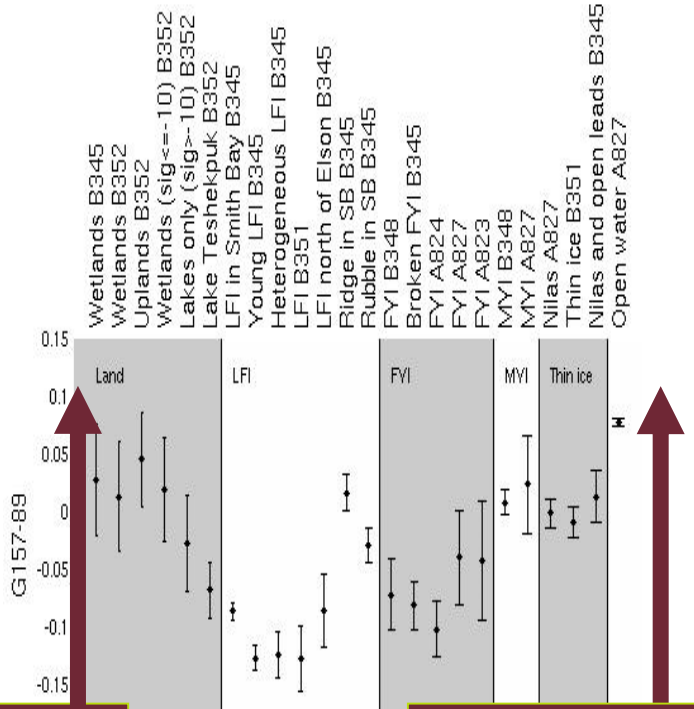


mm-wave emissivities effected by surface type

Broad surface classes in alternating grey and white

mm-wave emis can be related to surface type (Harlow, 2011)

- 157–89 GHz emis difference sensitive to snow depth and statigraphy.
- 89 GHz radiation penetrates 10 – 20 cm in pack.
- Penetration at 157 GHz shallower.
- Insensitive to ice surface roughness and salinity



Increasing surface roughness

Increasing snow depth and depth hoar fraction

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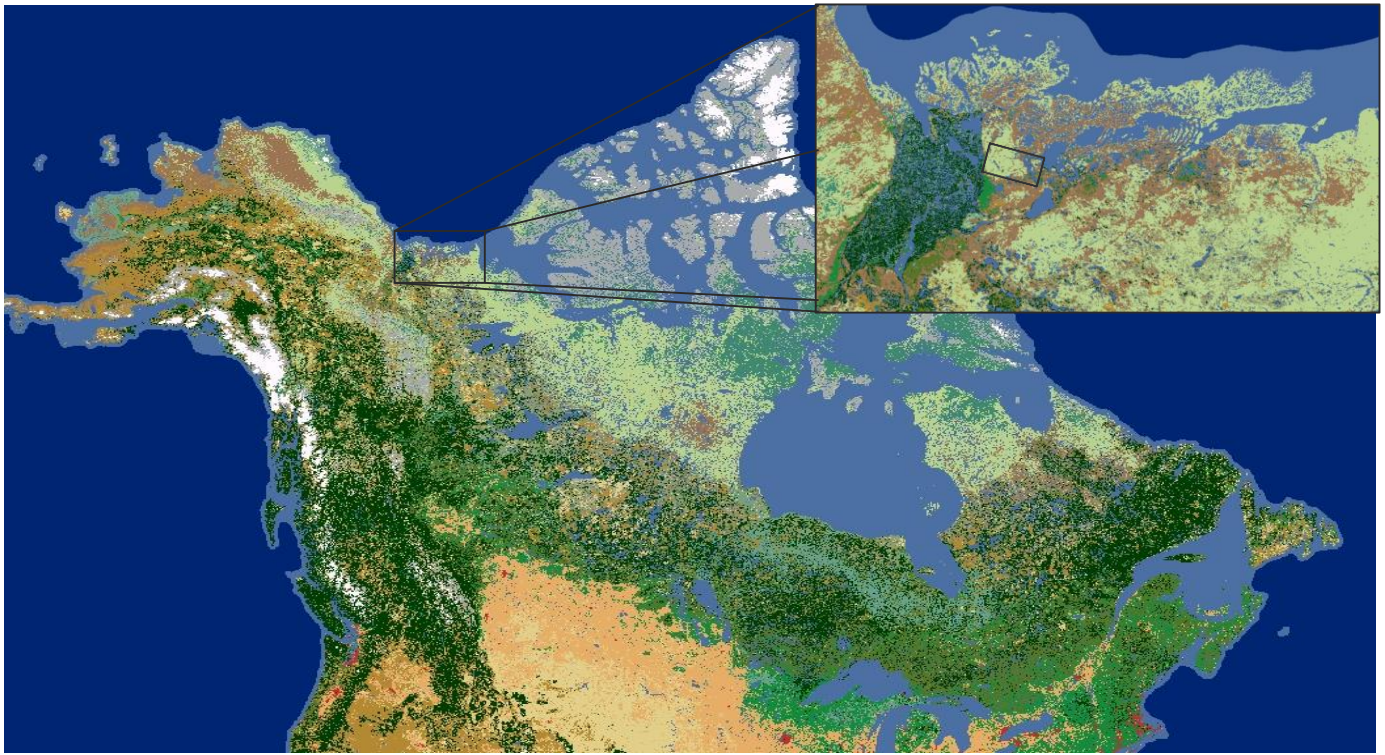
MACSSIMIZE

- March 2018
- Measurements of Arctic Cloud, Snow, and Sea Ice nearby the Marginal Ice ZonE
- Combined objectives from cloud physics, boundary layer and radiation groups.
- This talk focuses on radiation objectives: airborne measurements of emissivities at Trail Valley Creek in NWT, Canada.
- Only able to retrieve emissivities because we have radiometers that measure both up and down and we can fly at low level. [Harlow (2009) and Harlow (2011)]

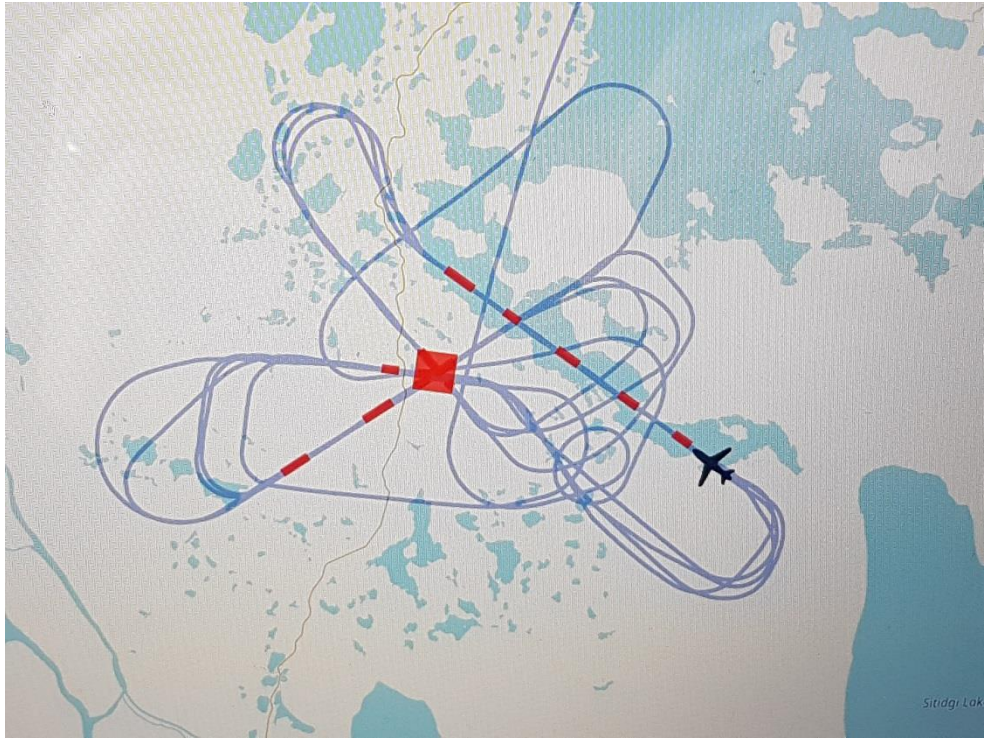
Why Trail Valley Creek?

- Well characterized tundra site
- **Tundra snow** as classified in Sturm et al (1995) makes up majority of general snow over arctic.
- Dominated by strong winds and strong internal thermal gradients
- Most of pale green and gray as well as ice fit this description.



Snow Pit Flights –

- Low level circuits over Trail Valley Creek
- Boxes were snow pits were being dug
- Microwave data collected at nadir while over the boxes; zenith and cals stopped.
- Variety of snow types sampled including snow on lake ice and tundra with variable slopes and veg types.



Snow Emissivity Flights

11 March 2018- C085

16 March 2018- C087

- Snow measurement Crew arrive at TVC; report ice layer under wind slab and on top of depth hoar; ice from rain in Jan.

18 March 2018- C089- mostly cloudy

20 March 2018- C090

- Fresh snow with surface hoar

22 March 2018- C092

- last day for snow measurement crew at TVC
- Snow highly sculpted from strong winds the previous day.

C087 & C090

- Some cloud overhead on both flights but plenty of contrast between downwelling and upwelling.
- Signs of wind scouring during C090 (right); less so on C087 (left).
- Ground crew reported layer of low density snow deposited between these two flights.

C092 – wind sculpted snow

- Ground crew report of massive resculpturing of the snowpack:
- "*scoured down to the ice layer in many patches, with the removed snow ending up as sharp sastrugi in exposed areas or a smooth and loose surface on lee slopes*".
- More snow on southern end of lake than northern end.

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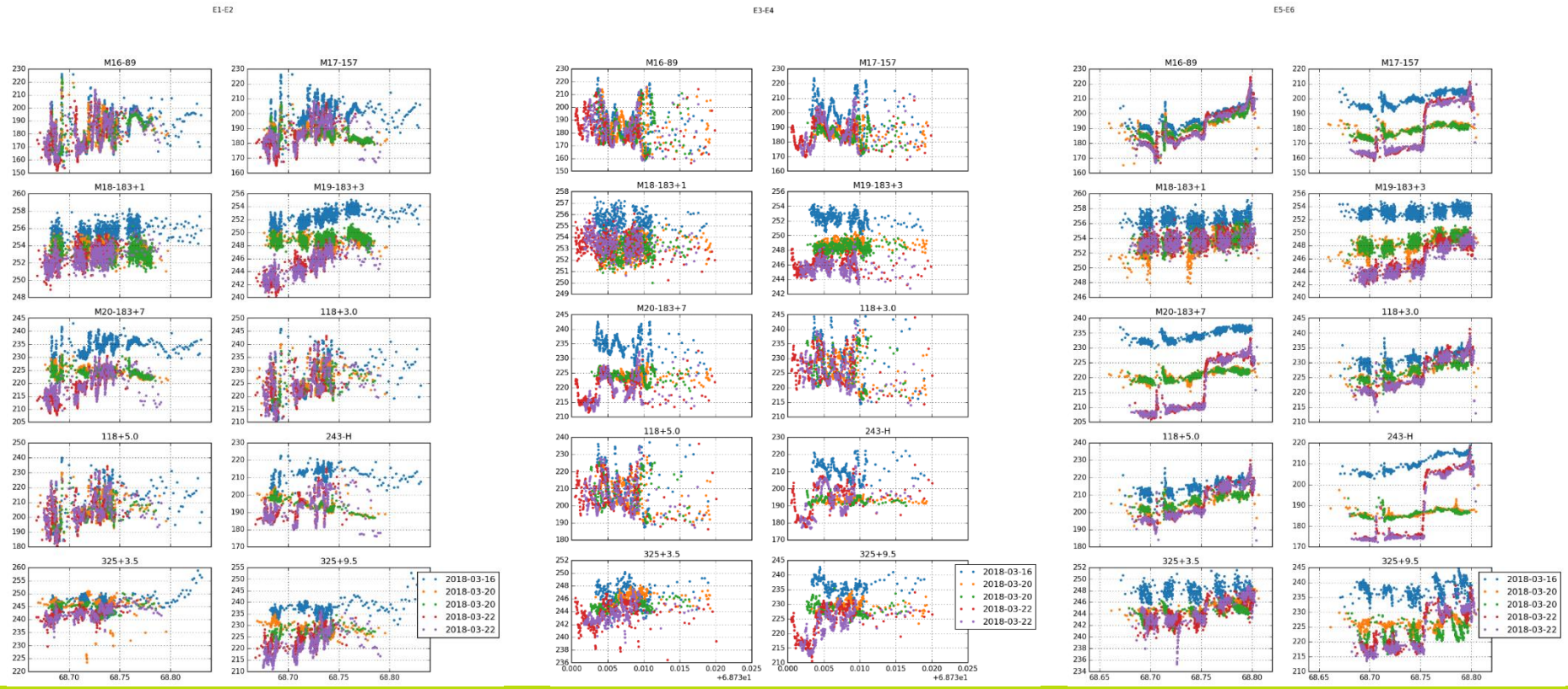
Measured nadir brightness temperatures



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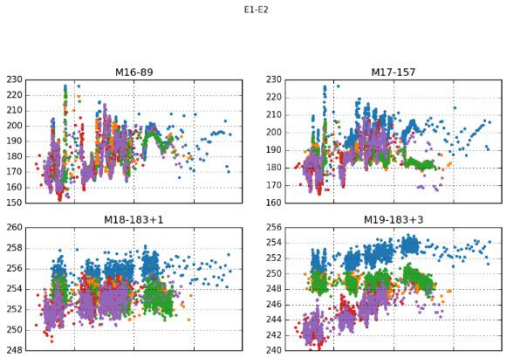
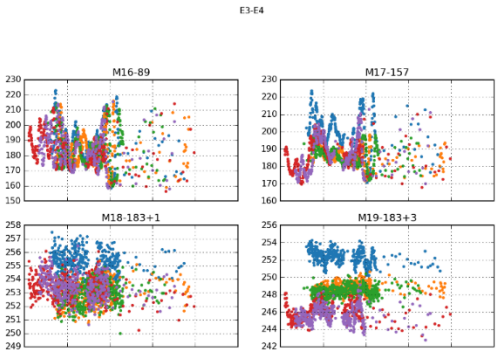
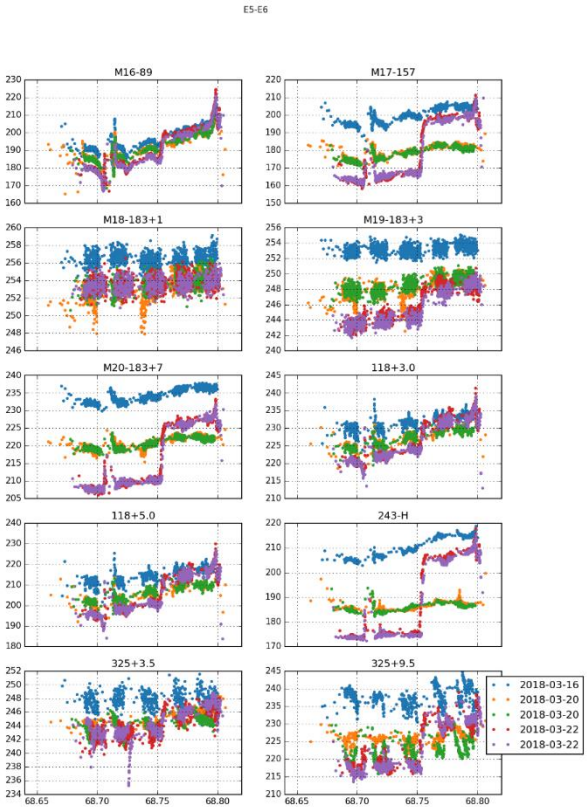


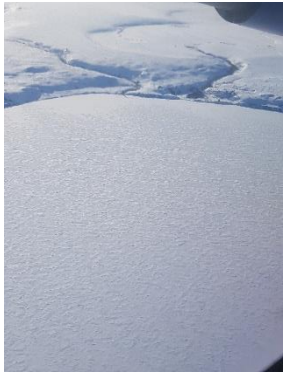


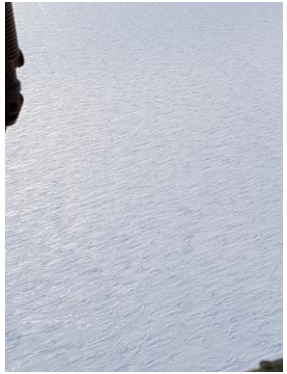


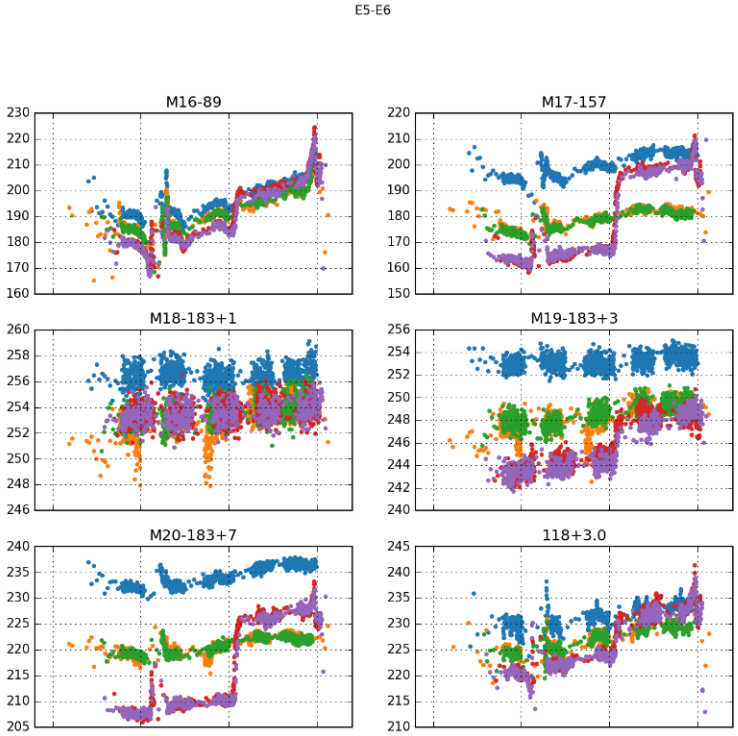
- Broadly repeatable patterns in T_B from run to run and flight to flight.
- T_B decreases through the week with decreases strongest at higher frequencies. Emissivity effect likely in response to changes in snowpack stratigraphy.
- Strong change on last flight over E5-E6 likely due to scouring and denuding of lake ice at northern end of lake. Emissivity effect.
- Surface effects in T_B up to 325±9 GHz.

Lake run most interesting of all

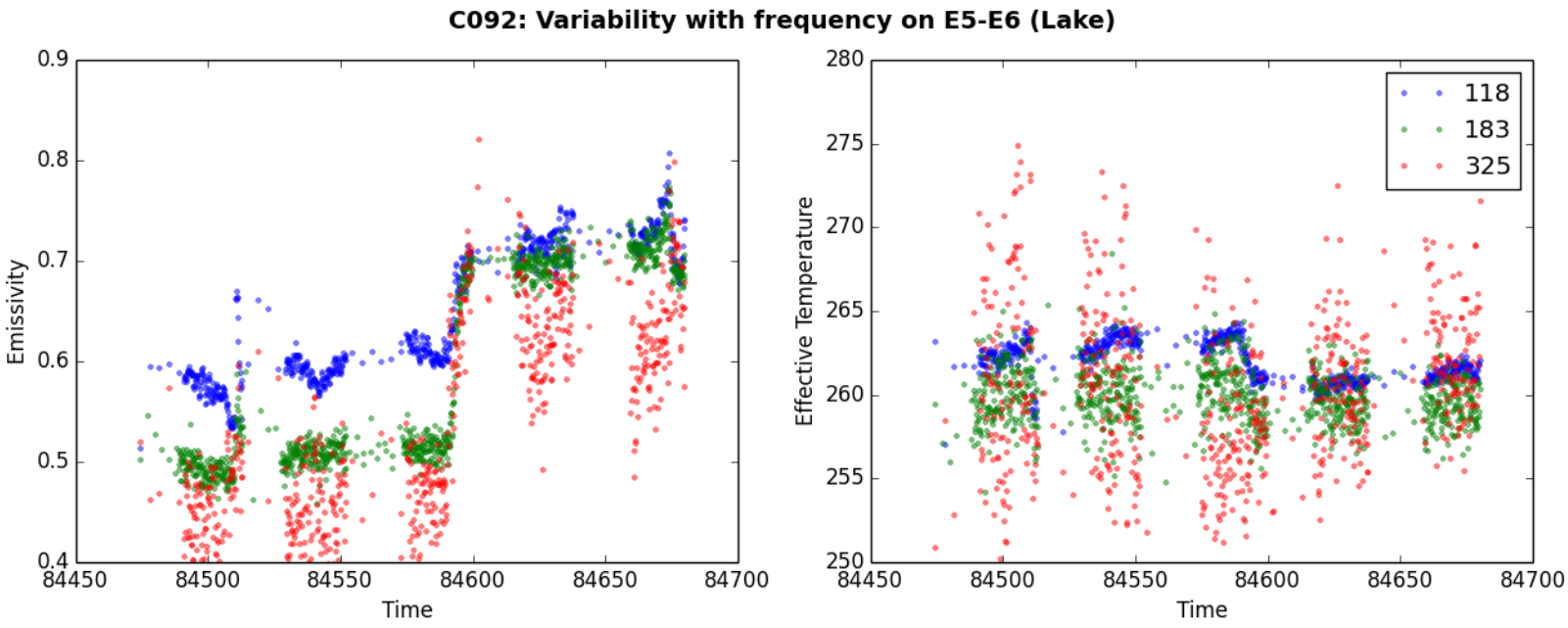
- Knee 2/3 of way along run on 22 March seen in both runs in both MARSS and ISMAR.
- Likely due to changes in snow stratigraphic properties.
- Surface of lake ice (left below) very similar in appearance to smooth land-fast sea ice (right).







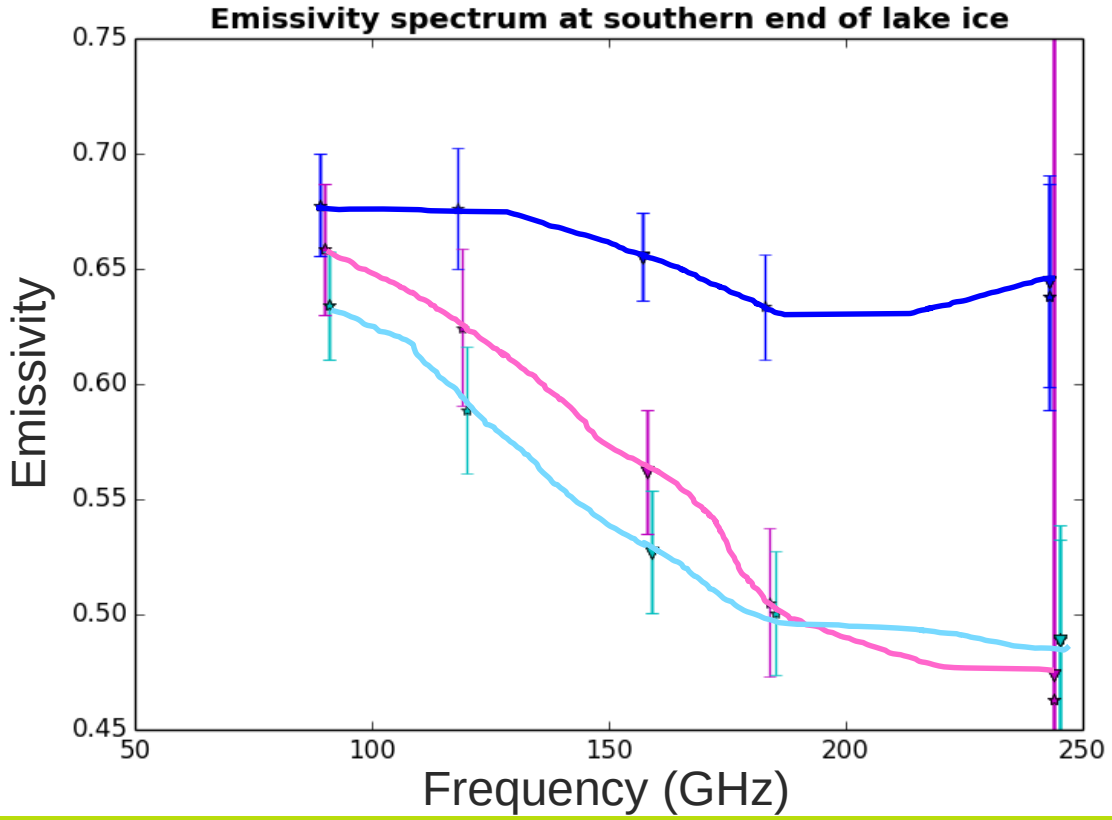
Retrieved Emissivities



- Note low values retrieved, near 0.5, are likely due to the buried ice lens.

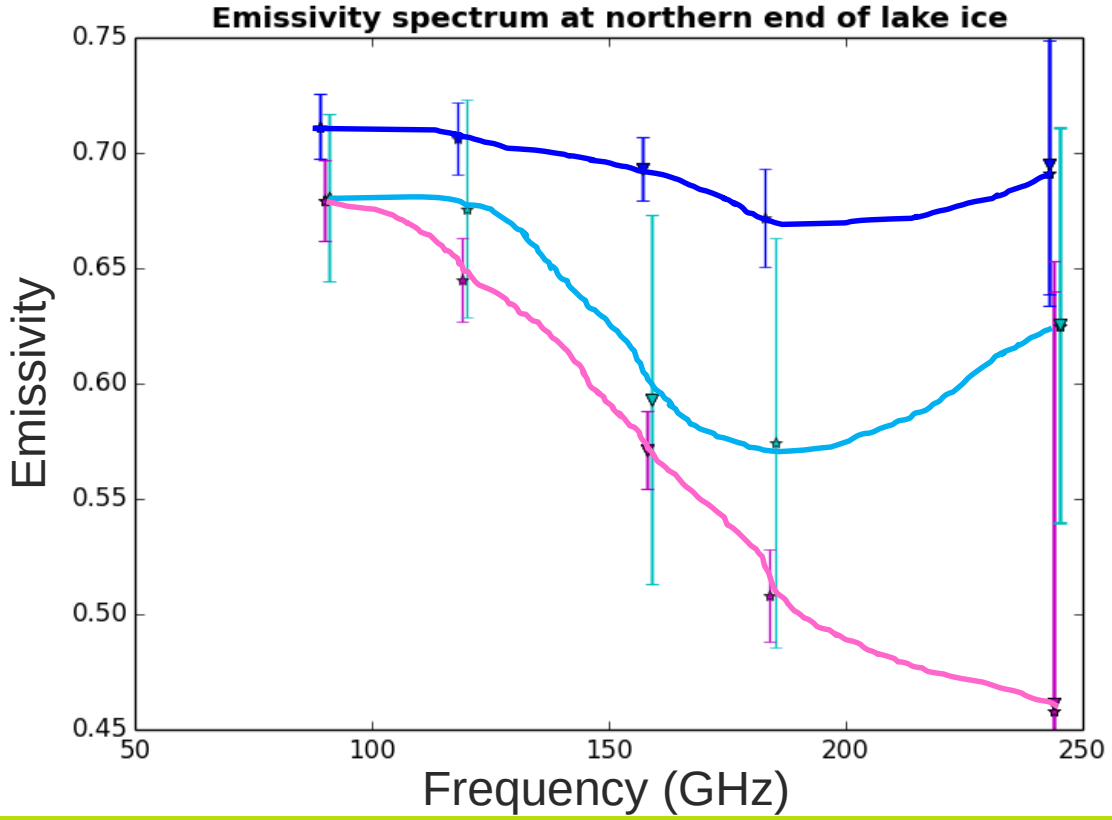
South end of Lake

- Snow deposition area
- Flat emissivity at beginning: aged, stratified snow pack (blue)
- Emissivity decreases with time at all frequencies: deposition of fresh snow on top of aged snow.

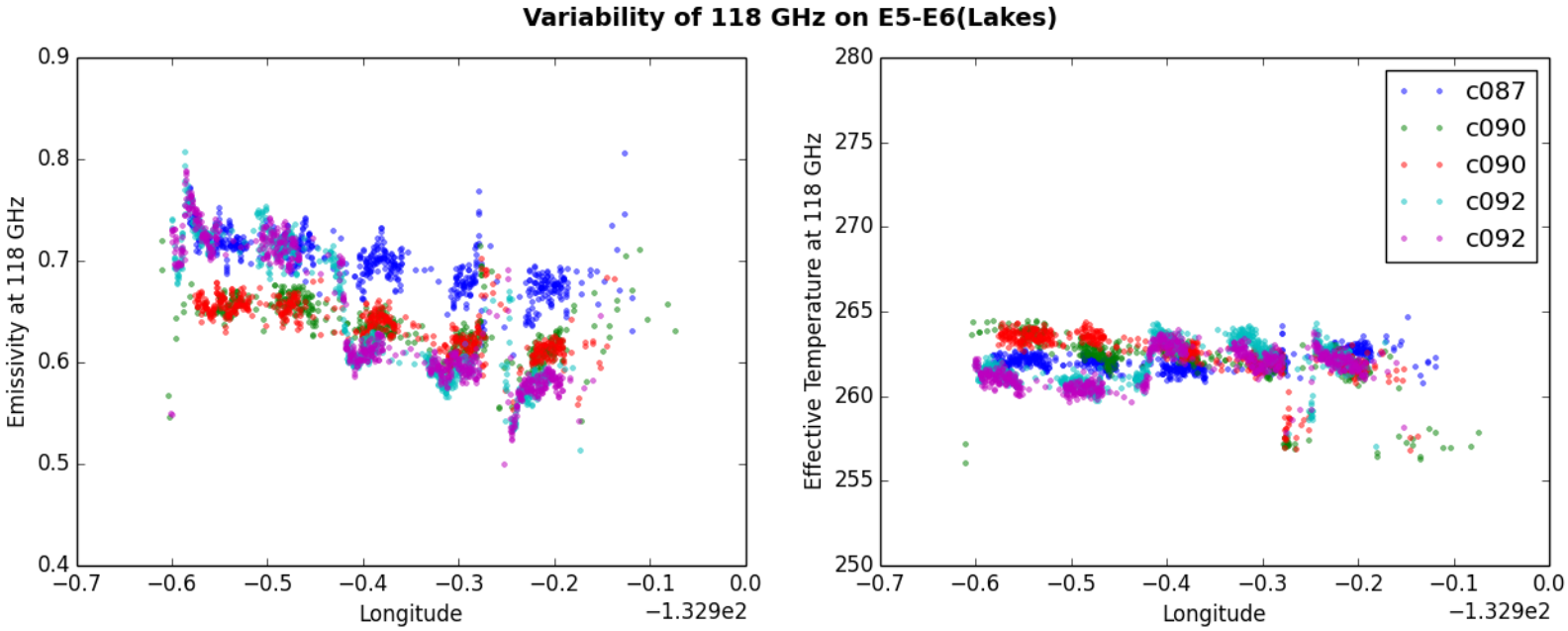


North end of Lake

- Snow scoured away on last day (cyan).
- Similar spectral shape as south end during first flight (blue)
- Deposition of fresh snow leads to monotonic decrease of emissivity with frequency (magenta).
- Removal of snow (except barchans) (cyan)



Lake ice an interesting test case: Real work starts with data over land



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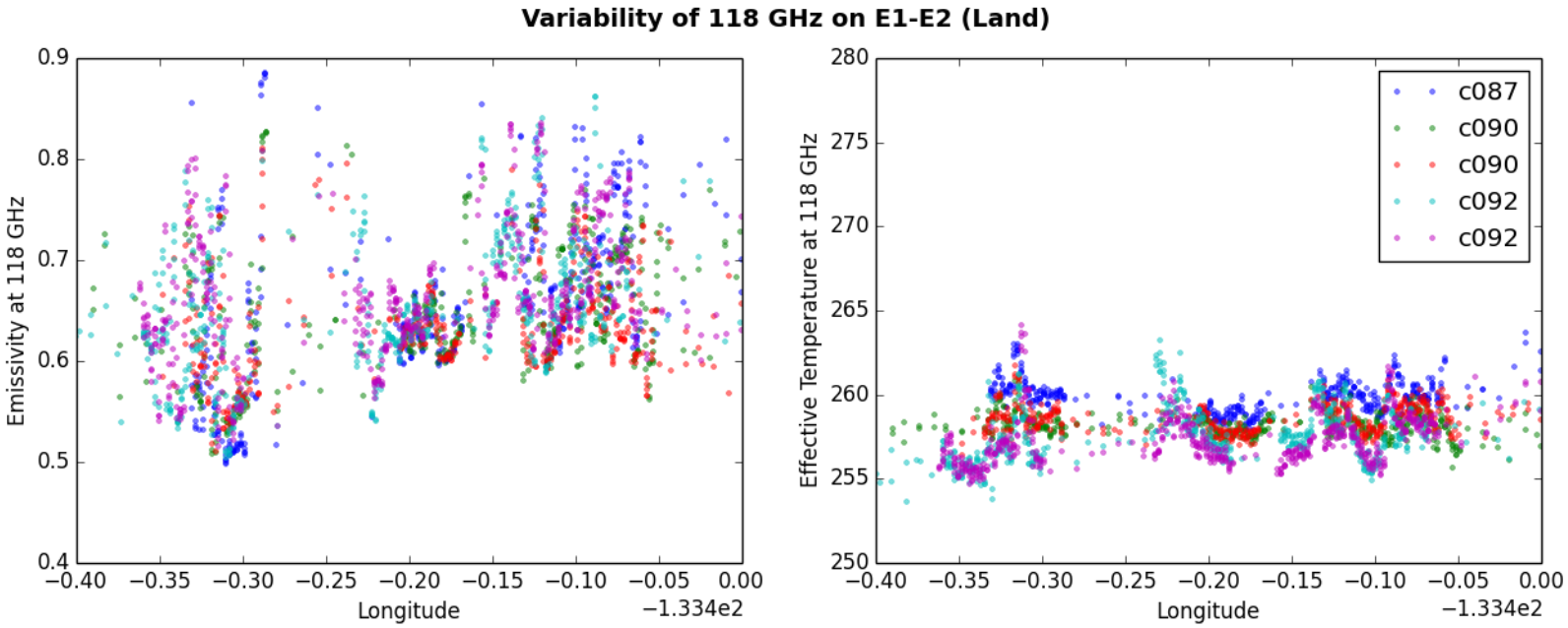

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Met Office

Analysis Plans

1. Retrieval of MW and IR emissivities and effective temperatures of surfaces overflown.
2. Development of JULES snow module with processes important in Arctic snow.
3. Evaluation of microwave emissivity models with campaign data.
4. Coupling of emissivity models to JULES.
5. Evaluation of coupled model within the Met Office Observation Processing System
6. DA trials

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Questions?

R.C. Harlow (2009), “Millimeter microwave emissivities and effective temperatures of snow covered surfaces: Evidence for Lambertian surface scattering,” *IEEE Trans. Geosci. Remote Sens*., Vol. 37, No. 7, pp.1957-1970, July 2009.

R.C. Harlow (2011), “Sea ice emissivities and effective temperatures at MHS frequencies: An analysis of airborne microwave data measured during two Arctic campaigns,” *IEEE Trans. Geosci. Remote Sens*., vol. 49, no. 4, pp. 1223 - 1237, April 2011.

R.C. Harlow and R. Essery (2012), “Tundra snow emissivities and effective temperatures at MHS frequencies: An analysis of airborne microwave data measured during CLPX-II,” *IEEE Trans. Geosci. Remote Sens*., Vol. 50, No.11, pp. 4262-4278, November 2012

Comparison between IR and MW $T_{surface}$