

Observing Tidewater Glacier Variability: Progress and Challenges



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Motivation and Challenges

- Transfer of mass at the **glacier-ocean boundary** plays a significant role in ice sheet dynamics, mass balance and sea level rise.
- Processes operating at the ice-ocean boundary operate on a range of **temporal** (seconds to years) and **spatial** (mm to km) scales.
- Some processes are **known** to be important but are **poorly understood**; other important processes might still be **unknown**.

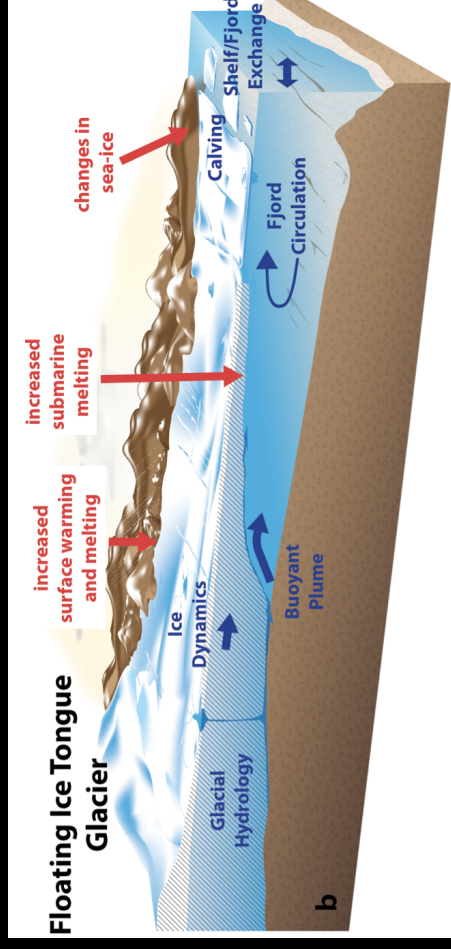
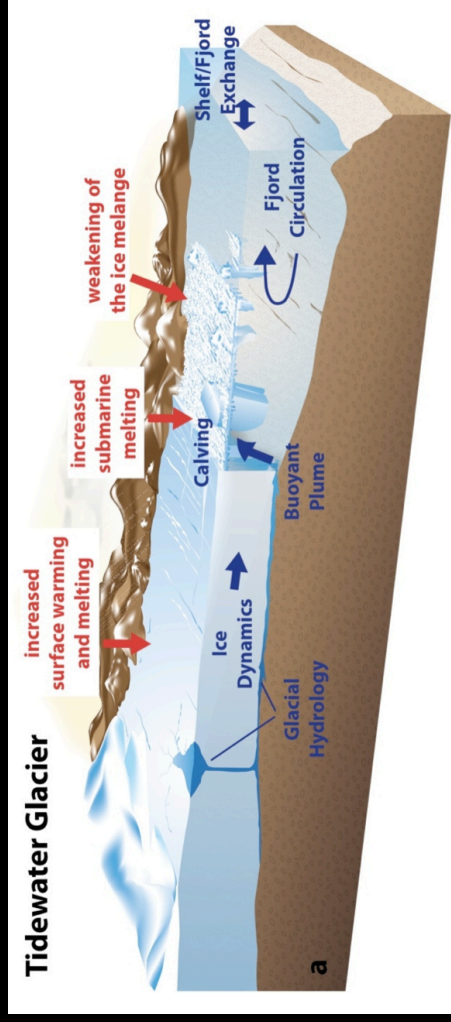
What parameters (do we think) are important?

glaciology

ice flow
calving
surface balance
hydrology

oceanography

hydrography
circulation
mélange



[GRISO, 2012]

geometry

ice thickness
bathymetry

climate/meteorology

temperature
winds

How do we observe these parameters?

glaciology

ice flow - **RS**, **in situ**

calving - **RS**, *in situ*

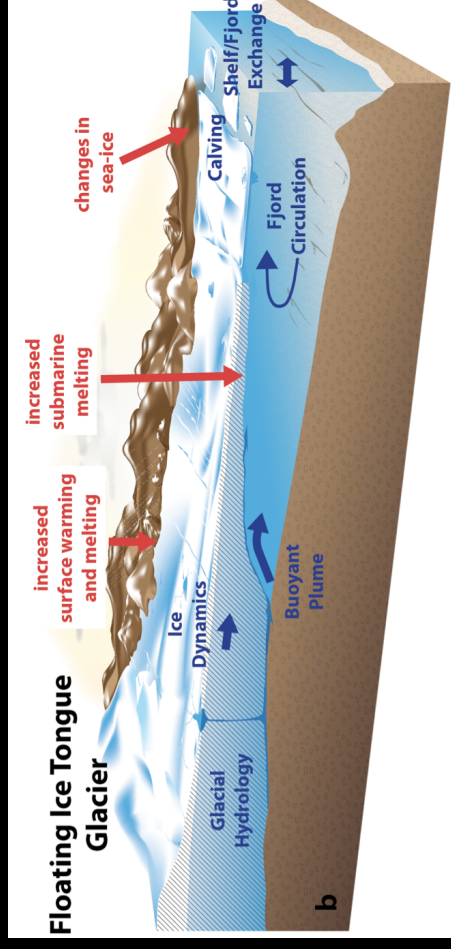
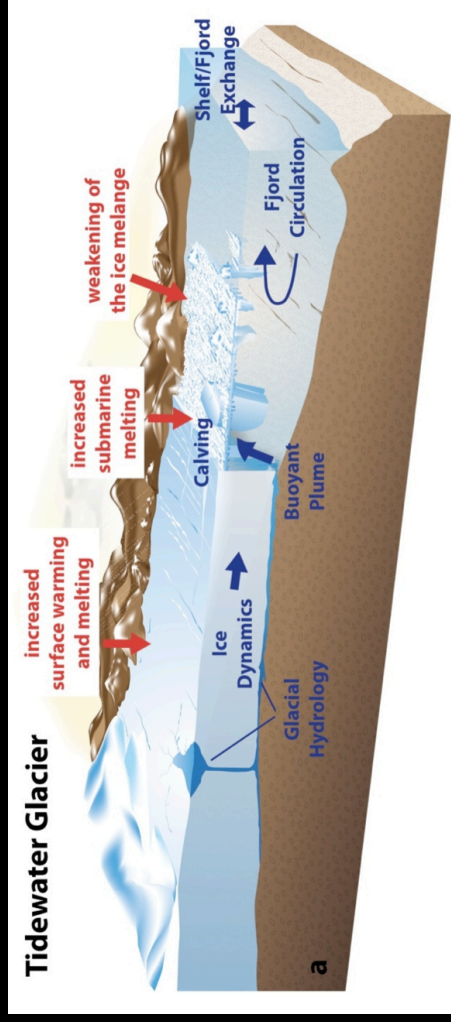
surface balance - **RS**, **in situ**
hydrology - *in situ*

oceanography

hydrography - *RS*, **in situ**

circulation - **in situ**

mélange - *RS*, *in situ*



bold = well-developed

italics = less well-developed

[GRISO, 2012]

geometry

ice thickness - **surveys**

bathymetry - **surveys**

climate/meteorology

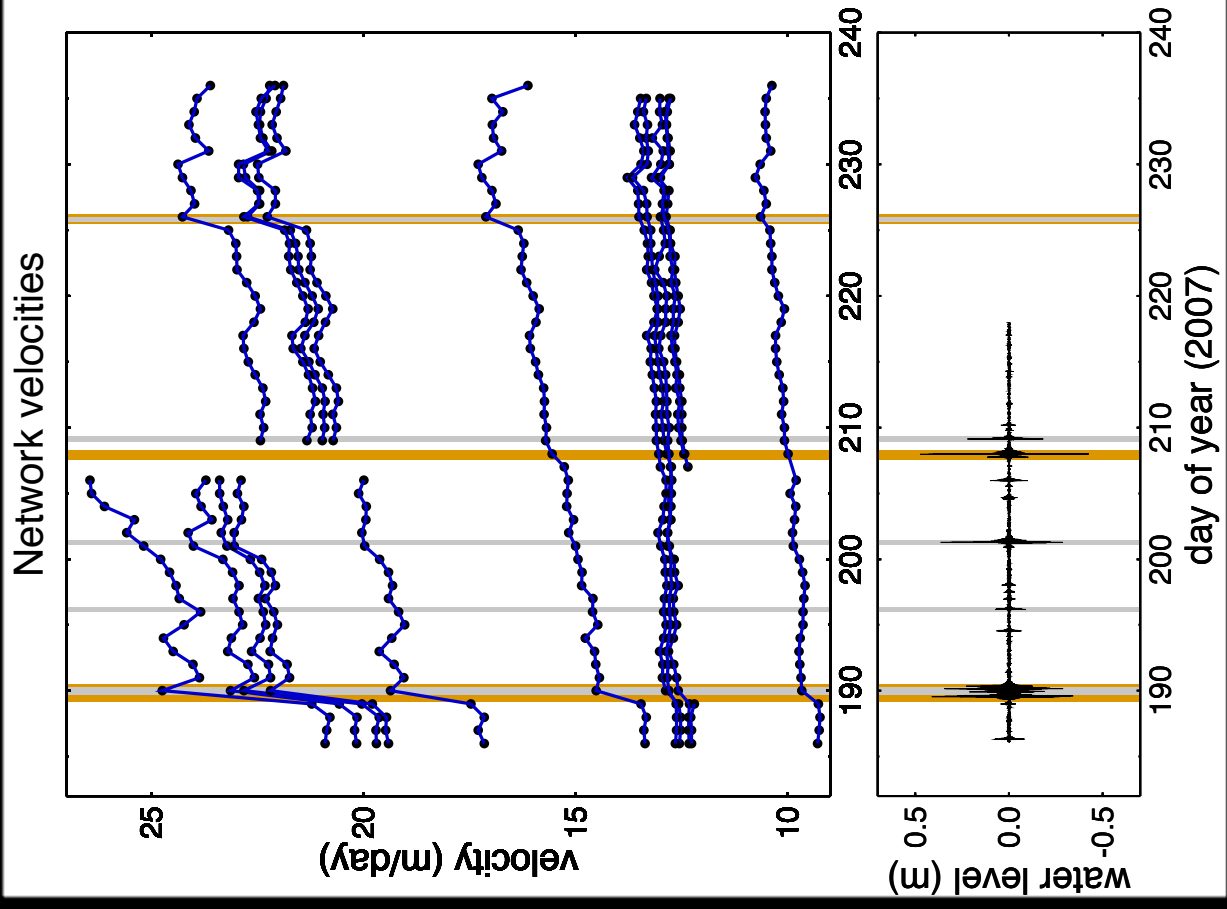
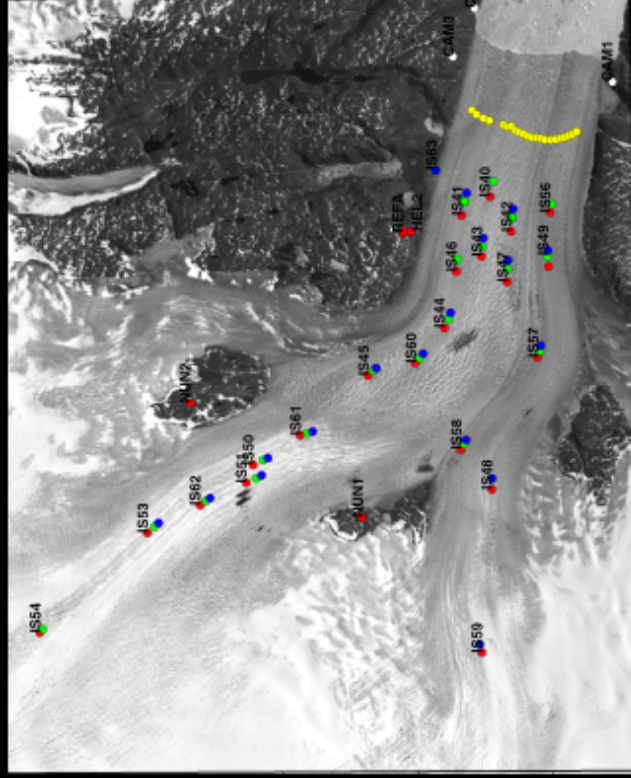
temperature - **in situ**

winds - *RS*, **in situ**

Figure 1 is a line graph showing ice velocity (m/yr) on the y-axis (ranging from 2000 to 12000) versus along-flow distance (km) on the x-axis (ranging from 0 to 30). The graph displays ice velocity data for various years and seasons, categorized by color and line style. The legend indicates the following data series:

- 2001 summer (red dashed line with open circles)
- 2001/01 winter (red dashed line with open circles)
- 2003 summer (orange dashed line with open circles)
- 2004 summer (June) (green dashed line with open circles)
- 2004 summer (July) (blue dashed line with open circles)
- 2005 summer (cyan dashed line with open circles)
- 2005 summer (GFS) (cyan dashed line with open circles)
- 2005/06 winter (blue dashed line with open circles)
- 2006 summer (purple dashed line with open circles)
- 2006 summer (GFS) (purple dashed line with open circles)
- 2006/07 winter (purple dashed line with open circles)
- 2007 summer (magenta dashed line with open circles)
- 2007 summer (GFS) (magenta dashed line with open circles)
- 2007/08 winter (magenta dashed line with open circles)
- 2008 summer (GFS) (magenta dashed line with open circles)
- 2008/09 winter (magenta dashed line with open circles)
- 2009 summer (GFS) (magenta dashed line with open circles)
- 2009 (Jan-Feb) (black solid line with open circles)
- 2009 (April-May) (black solid line with open circles)
- 2009 (June) (black solid line with open circles)
- 2009 (Aug-Sept) (black solid line with open circles)
- 2009 (Oct-Nov) (black solid line with open circles)
- 2010 summer (black solid line with open circles)
- 2010 (April-May) (black solid line with open circles)
- 2010 (July) (black solid line with open circles)
- 2010 (Sept) (black solid line with open circles)
- 2010 (Nov) (black solid line with open circles)
- 2012 summer (black solid line with open circles)

The graph shows that ice velocity generally increases with along-flow distance, with a notable peak around 15 km. The 2001/01 winter data (red dashed line with open circles) shows the highest velocities, reaching over 12000 m/yr at 30 km. The 2009 summer (GFS) data (magenta dashed line with open circles) shows the lowest velocities, generally below 4000 m/yr. An inset map in the top left corner shows the location of the study area in the Arctic, with a red line indicating the along-flow distance.



[Nettles et al, 2008]

in situ vs. remote sensing observations

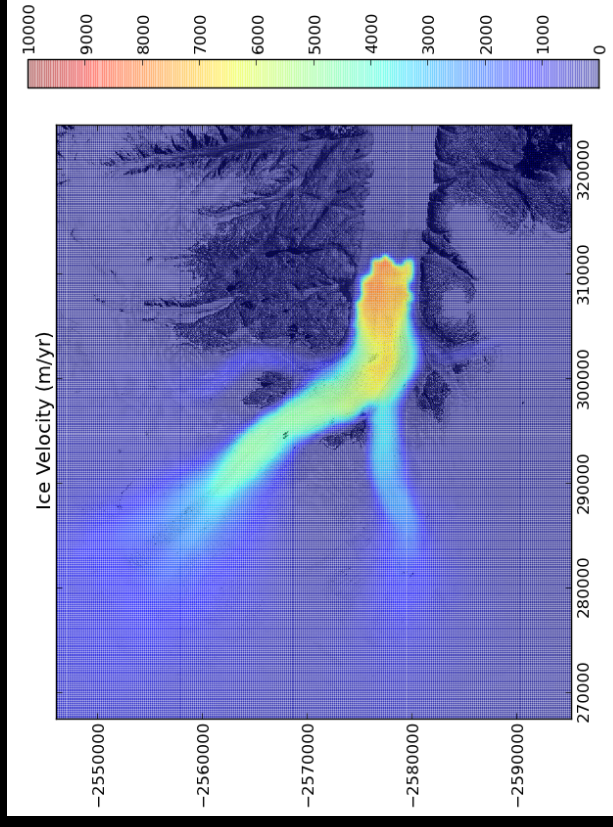
in situ:

- **continuous sampling**
- *spatially limited*
- *difficult to incorporate into models*
- *expensive, challenging*

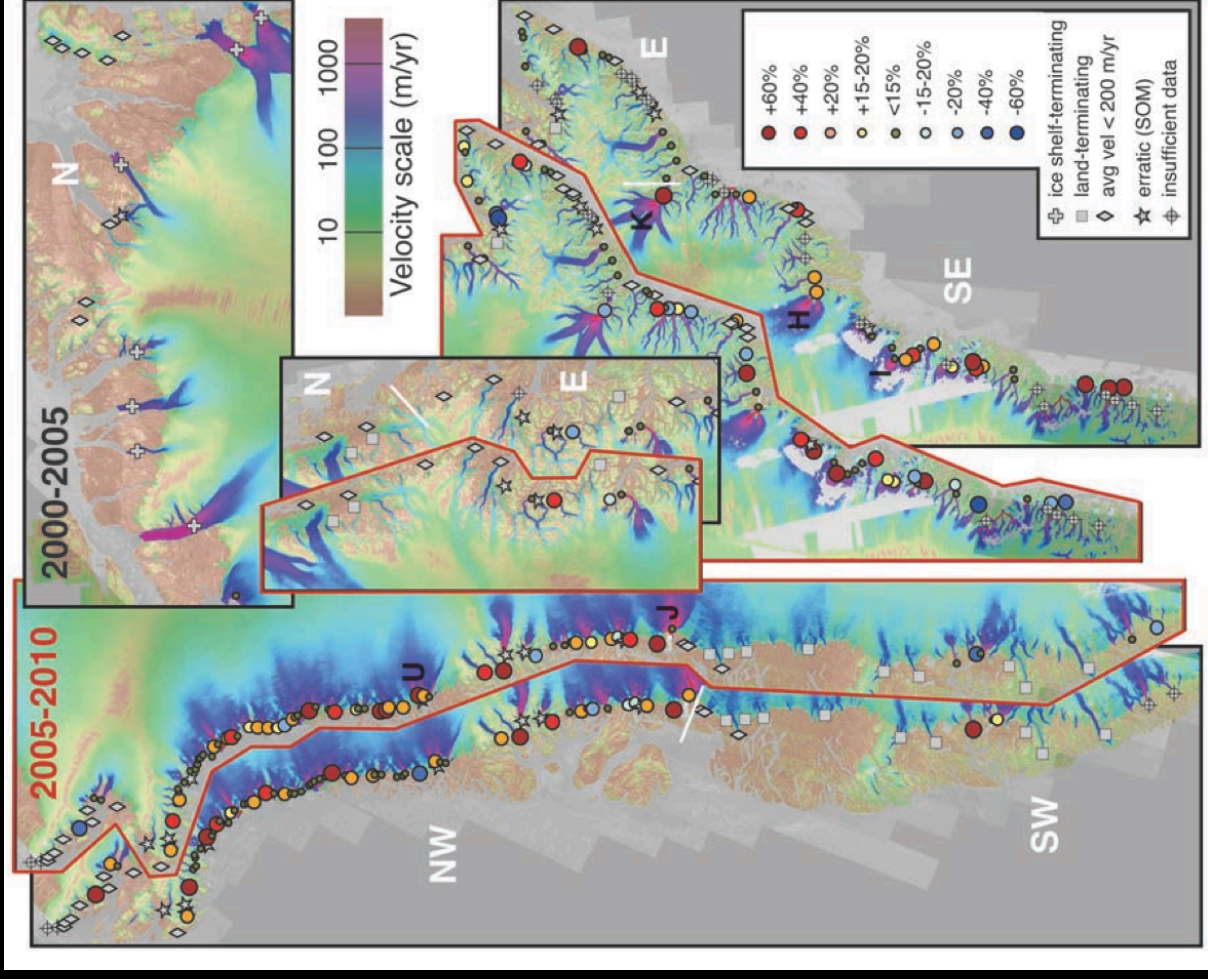


remote sensing:

- **spatially extensive**
- **easier to incorporate into models**
- **cheap and ‘easy’**
- *periodic sampling*



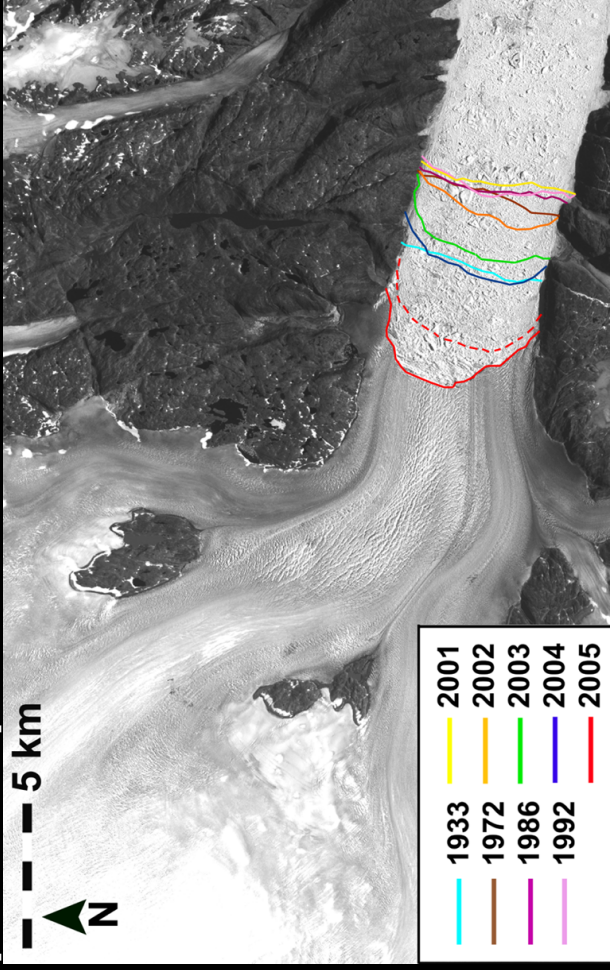
continuous sampling vs. spatial extent



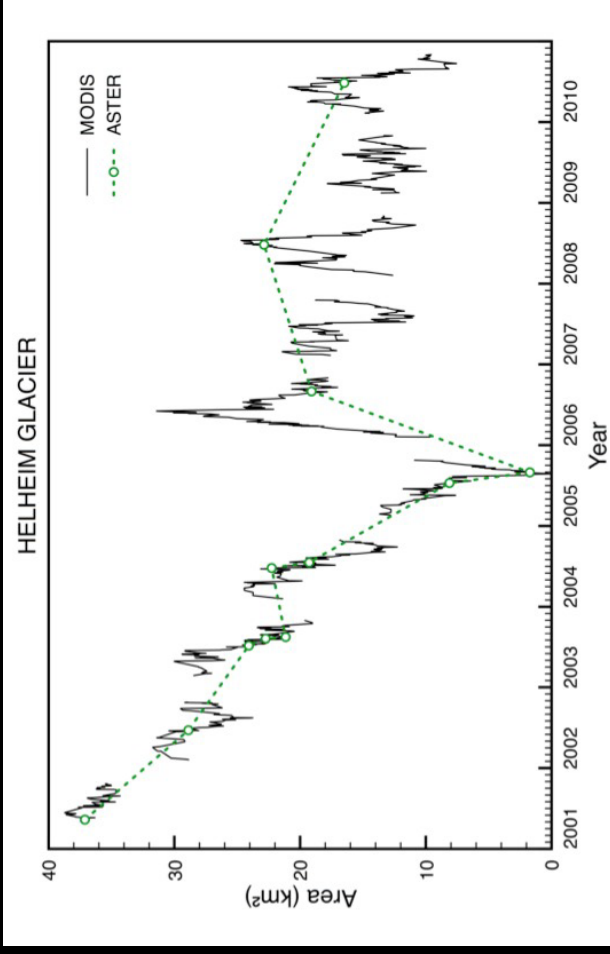
[Moon et al., 2012]

How important is temporal resolution?

[Stearns, 2008]



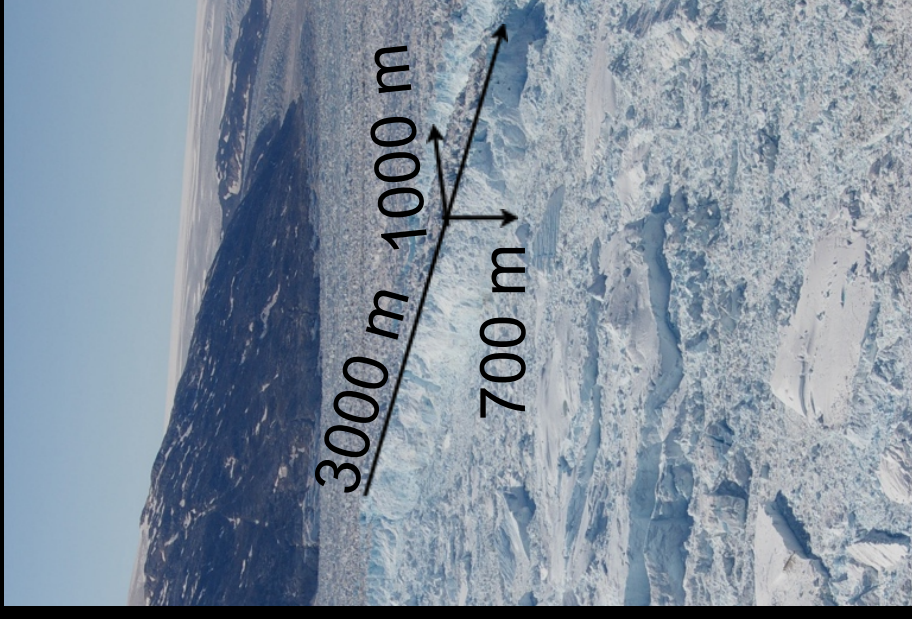
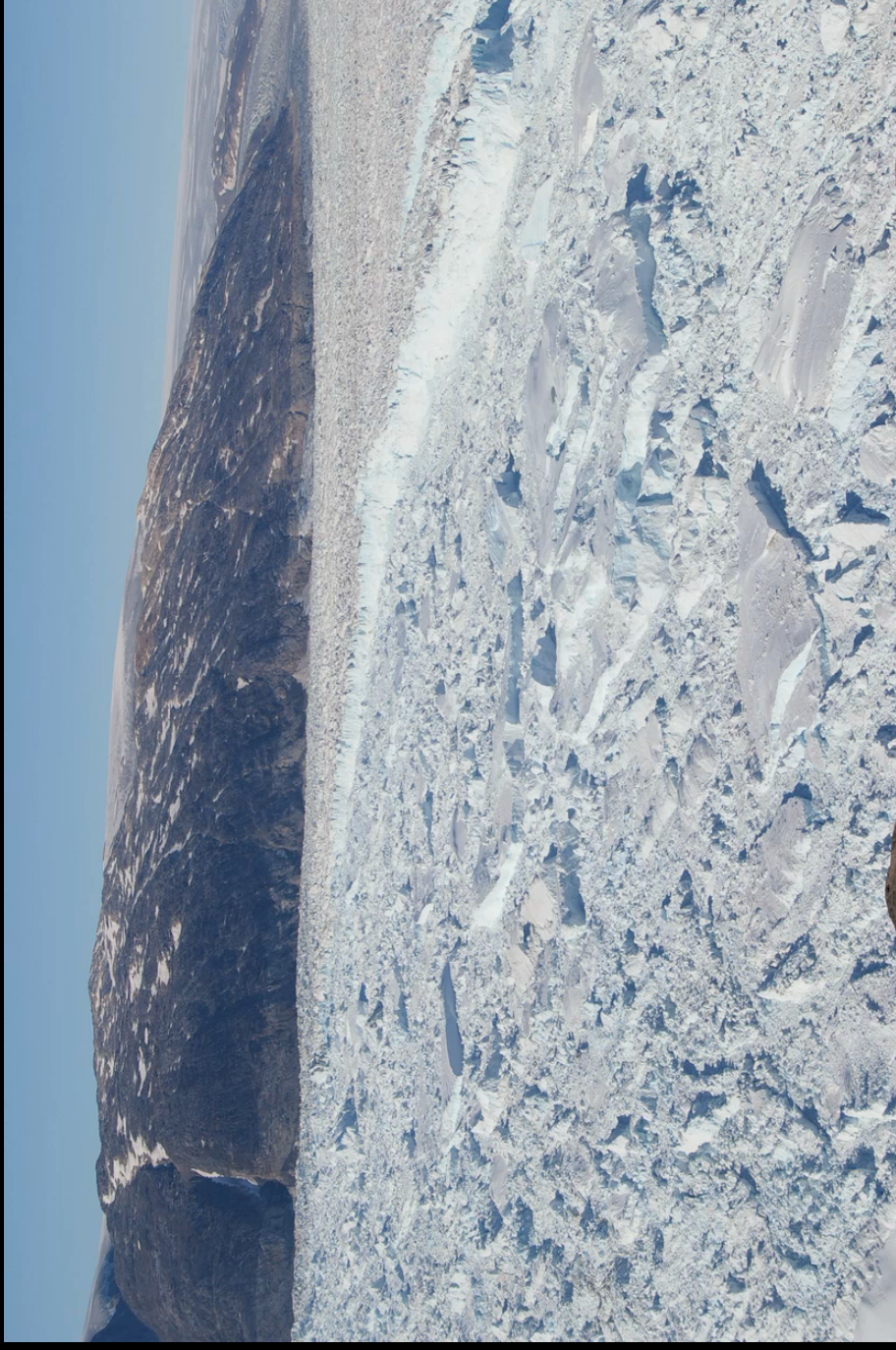
[Schild,



minimum position each
year

~daily
positions

How important is temporal resolution?



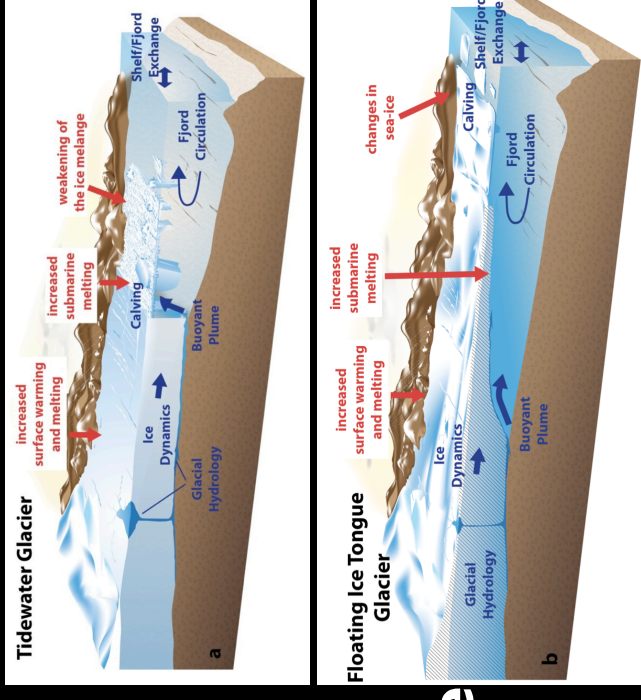
1-Aug-2008; 1000-1530 UTC; 4 minutes between frames

continuous sampling vs. spatial extent

mechanisms that initiate acceleration and retreat:

- 1. increased submarine melting**
 - ice geometry and roughness
 - subglacial discharge of surface melt
 - oceanic properties and circulation
- 2. reduction/weakening of ice melange**
 - ice properties/thickness
 - atmospheric and thermodynamic forcing
 - oceanic mechanical or thermodynamic forcing
- 3. increased crevassing and reduced ice strength due to surface warming**

- surface melt



Where do we need innovation and improvement?

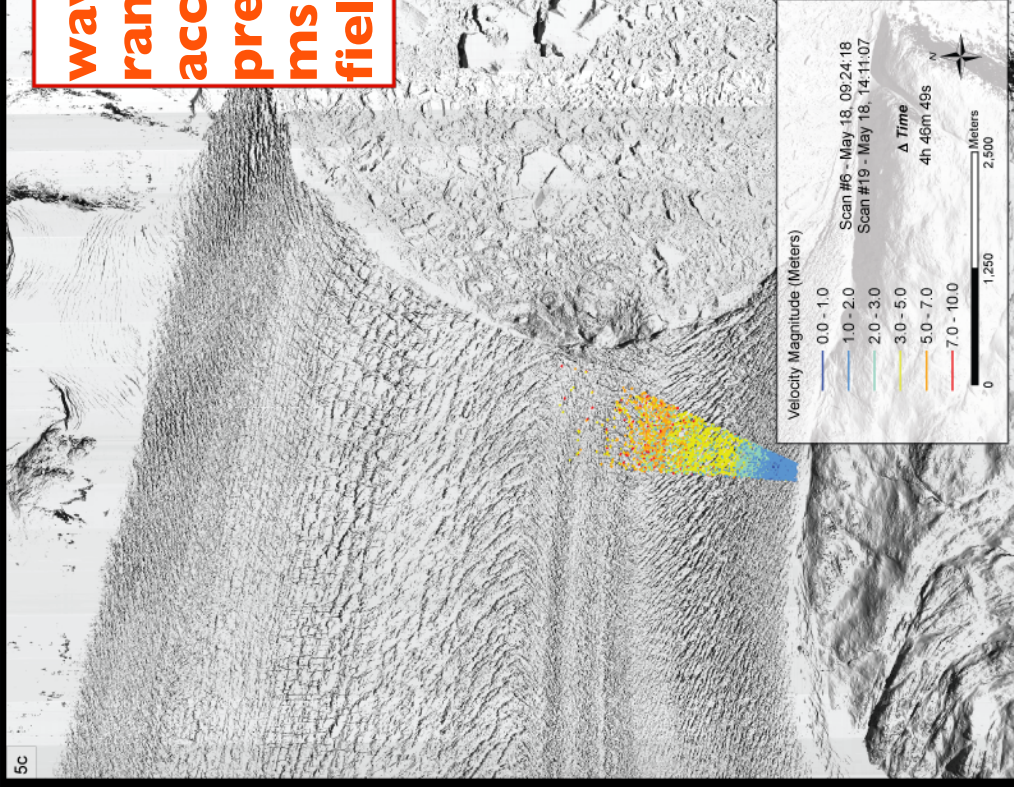


in situ methods:

- robust, low-cost GPS receivers
- radio/satellite telemetry
- innovative data processing/analysis methods

Where do we need innovation and improvement?

Riegl LPM-321

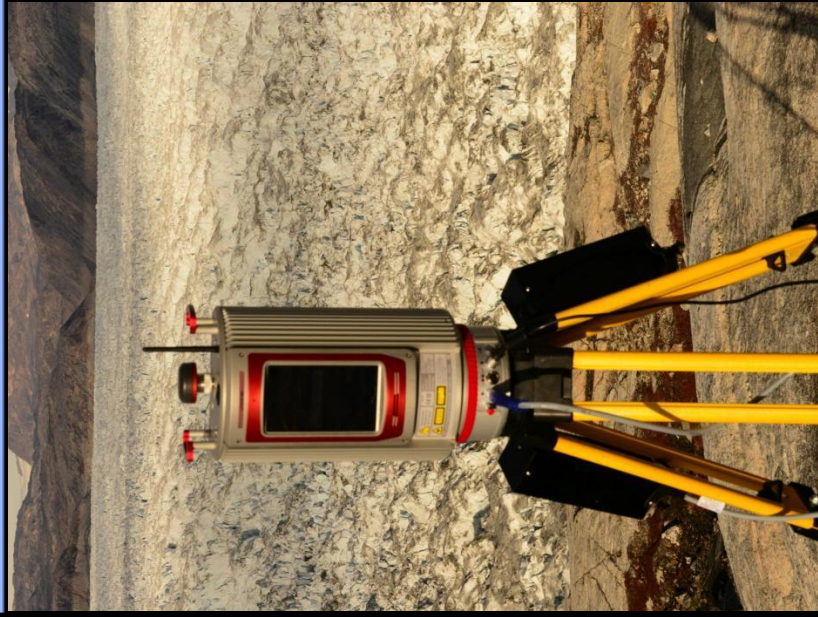


wavelength: 1550 μm
range: 1 - 6 km (not ice)
accuracy: 25 mm
precision: 15 mm
msmt. rate: 10 - 1000 Hz
field of view: 360°h x 150°v

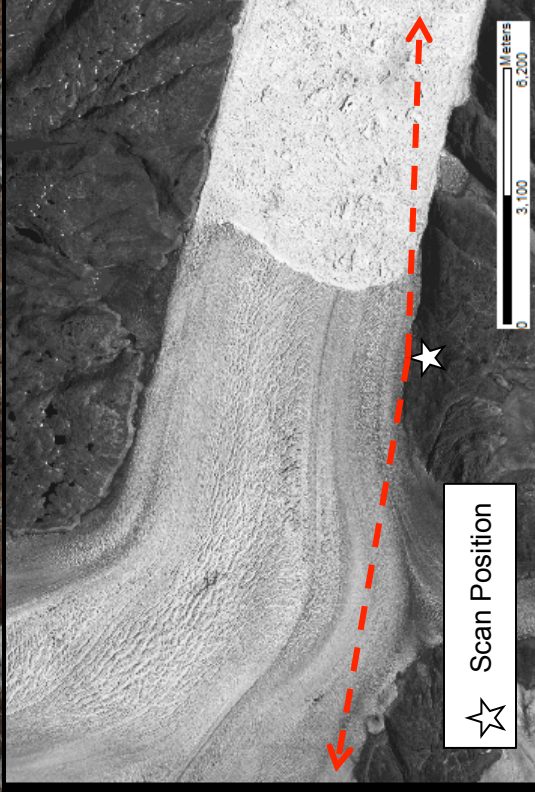
near situ methods:

- unattended operation
- high spatial and temporal resolution
- TLS, GBRI, time-lapse cameras

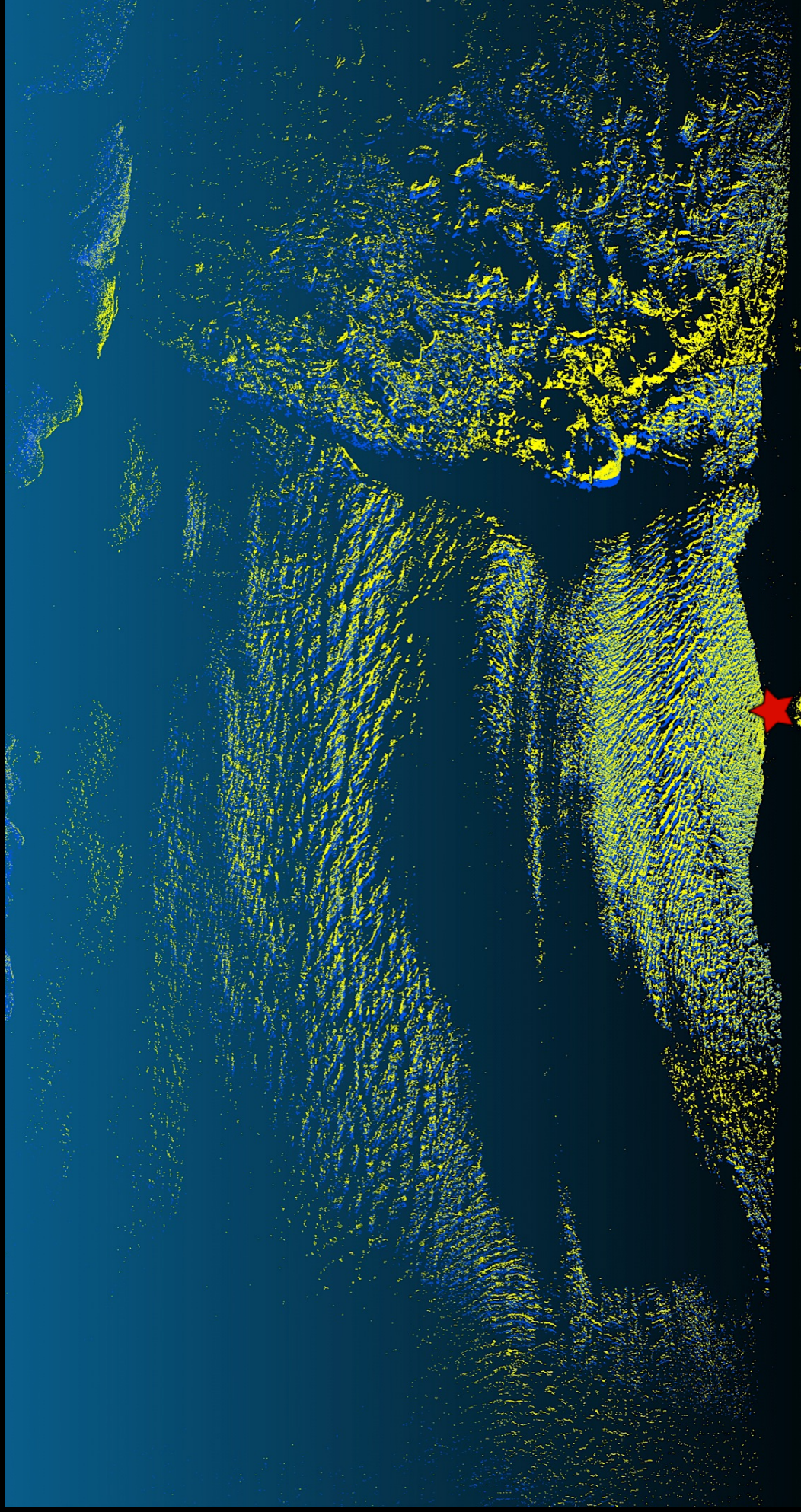
Where do we need innovation and improvement?



wavelength: 1064 μm
range: 6 - 10 km
accuracy: 15 mm
precision: 10 mm
msmt. rate: 222 kHz
field of view: $360^\circ\text{h} \times 60^\circ\text{v}$



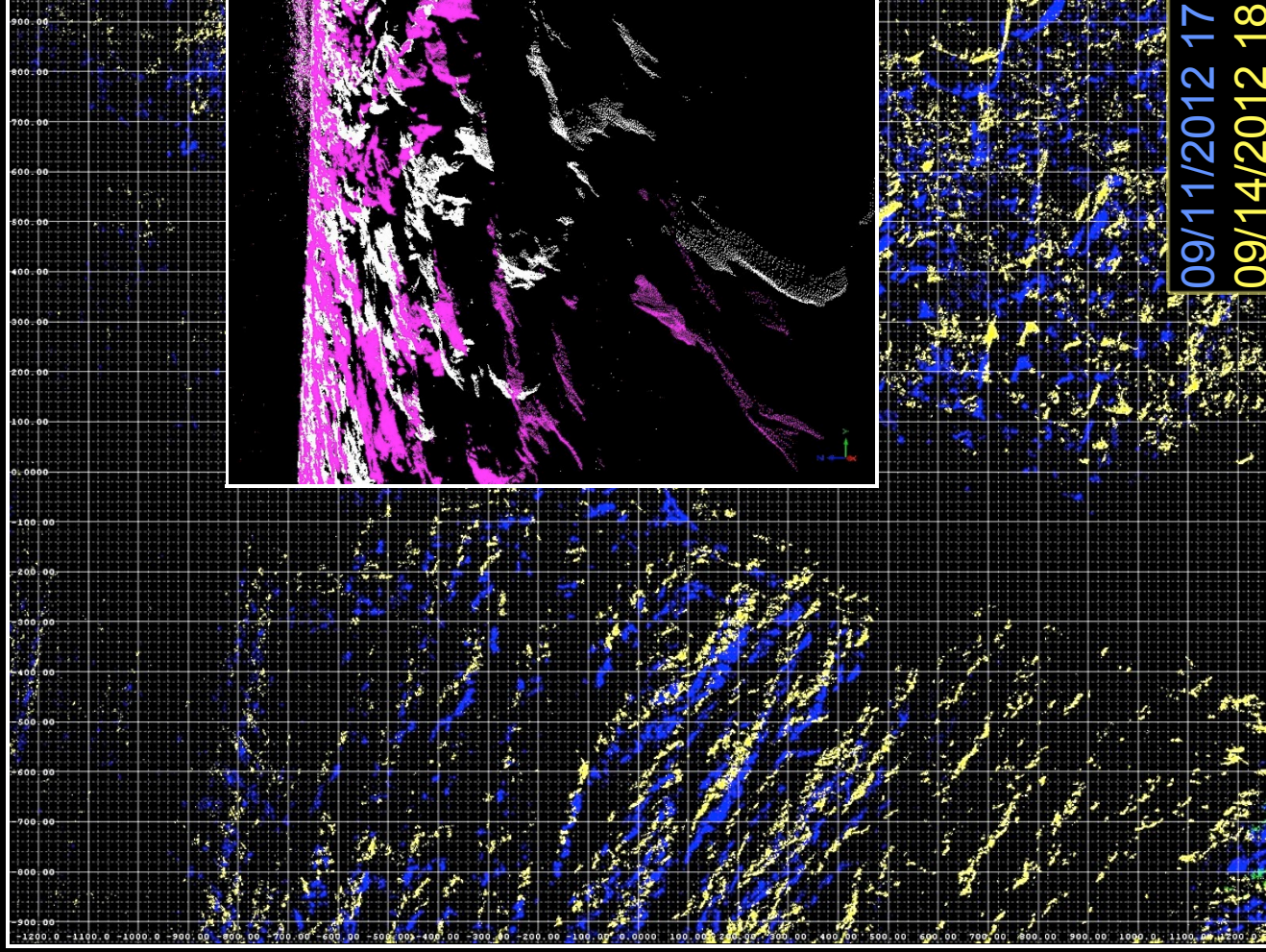
Where do we need innovation and improvement?



scan
position

09/11/2012 17:24:59 - blue
09/14/2012 18:38:10 - yellow

Where do we need innovation and improvement?



09/11/2012 17:24:59 - blue
09/14/2012 18:38:10 - yellow

Where do we need innovation and improvement?

ground-based radar interferometer



Where do we need innovation and improvement?



wavelength: Ku-band and C-band

range resolution: 75 cm

azimuthal resolution:

- **1 km:** 7m (Ku-band); 24 m (C-band)

- **10 km:** 70 m (Ku-band); 240 m (C-band)

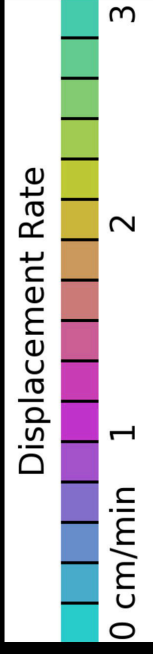
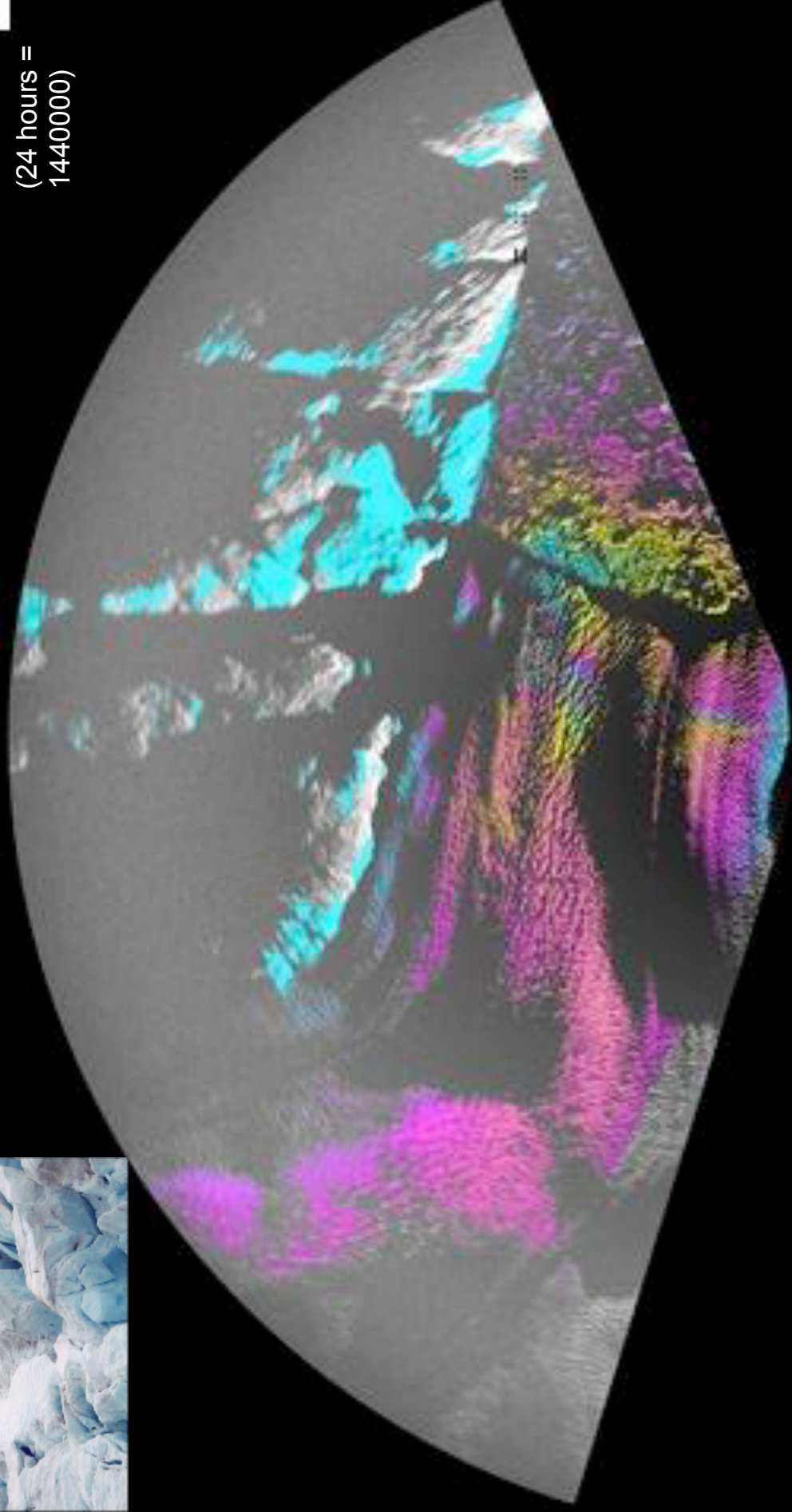
scan rate: 1 min/scan



ve need innovation and improvement?

0001001

(24 hours =
1440000)



(2 cm/min $\approx$ 10

1-minute interferograms from September 10-13, 2012.
Ku-band radar (~ 16 mm wavelength)

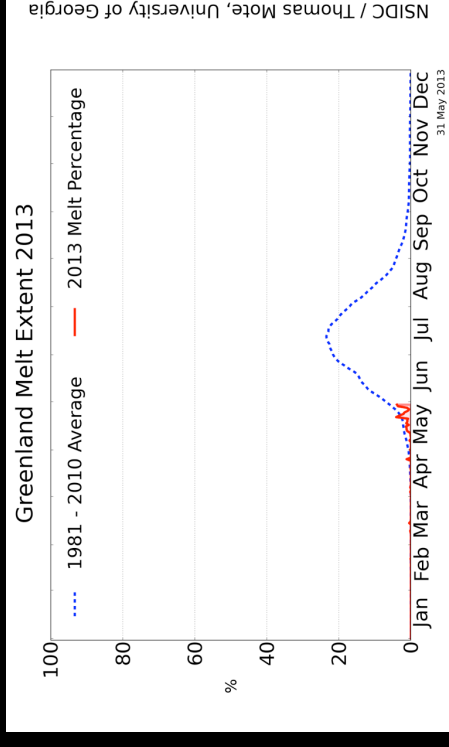
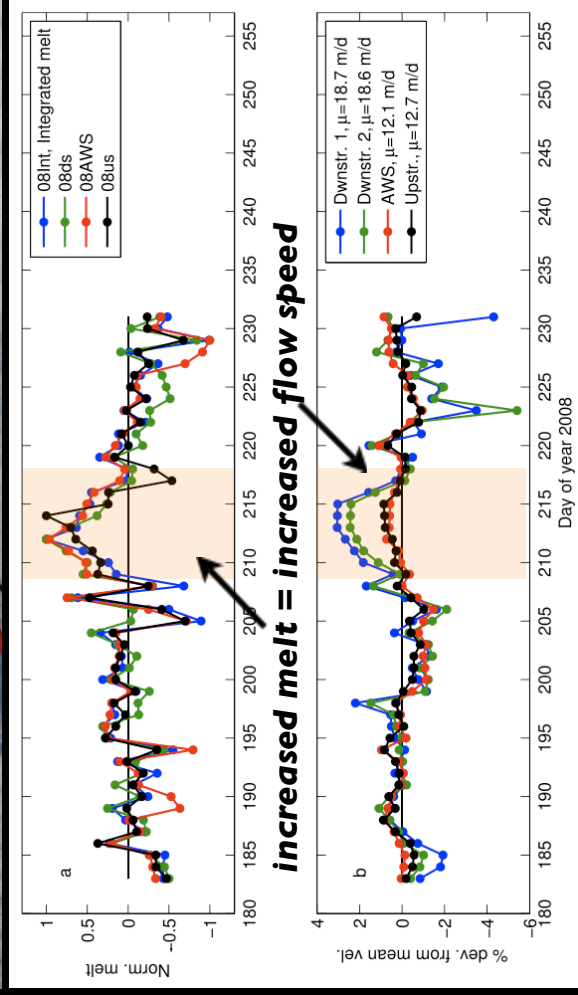
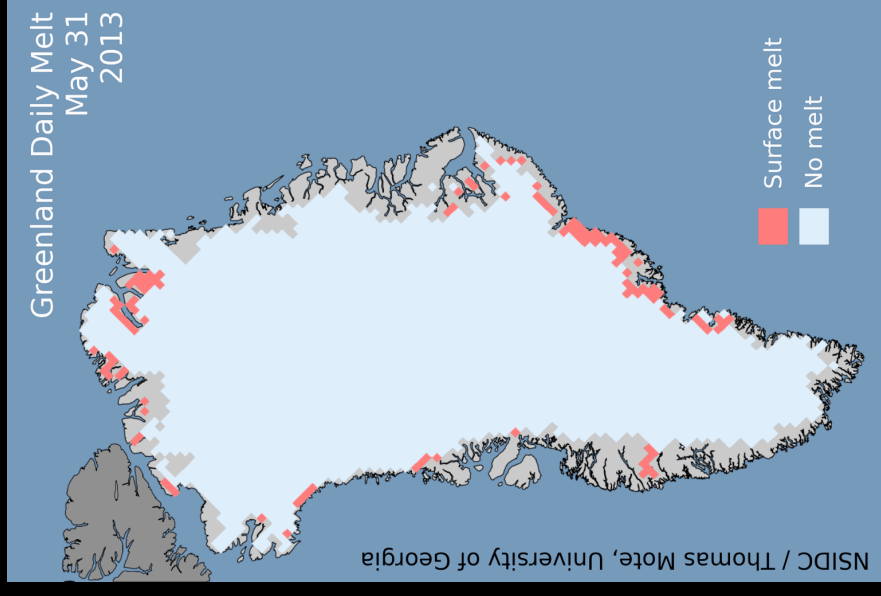
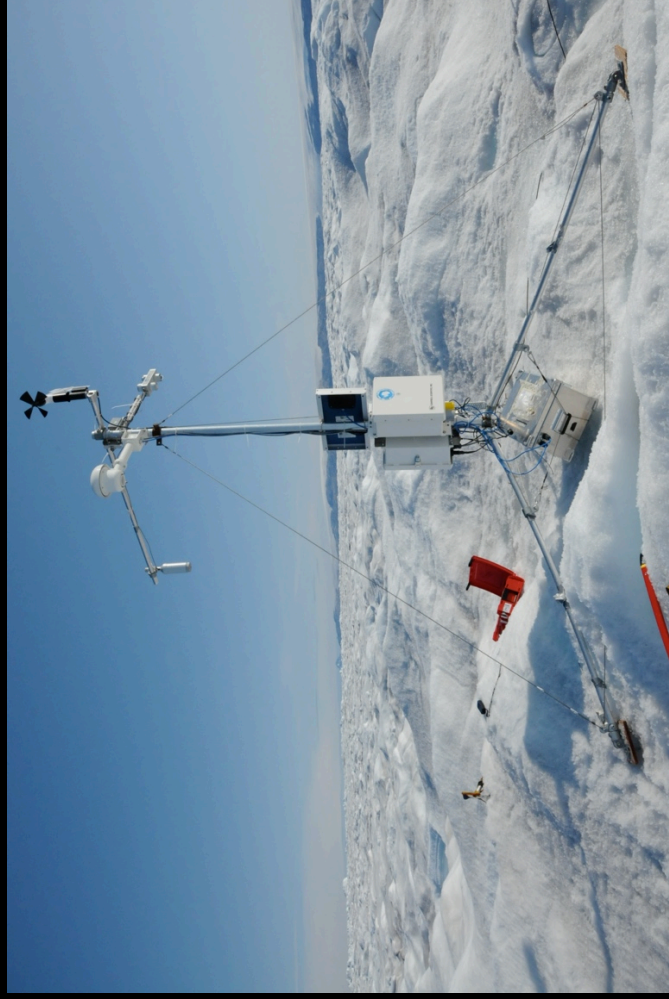
Conclusion

Our ideal ice-ocean observing platform should combine *in situ*, *near situ* and satellite remote sensing measurements.

In some cases, improved remote sensing techniques and platforms reduce the need for extensive networks of *in situ* instruments (e.g. ice flow, calving).



Problem of Scale (spatial and temporal)



[Andersen et al., 2010]