Observing the cryosphere:
What do we measure and why?

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Today’s goals

What are the variables of interest in cryospheric research?

How are these variables measured now, and how have they been historically? What are the advantages of different observation methods?

What is the basis for remote sensing, and what are the current remote sensing techniques used in cryospheric research?
Motivating flux problem

What do we measure and why?

What controls ice flux through a horizontal gate in our glacier?
Motivating flux problem

Model

\[
\frac{du}{dz} = A(T)\tau^3
\]

\[
u = A(T)\tau^3 H
\]

What do we measure and why?
Motivating flux problem

\[ \frac{du}{dz} = A(T)\tau^3 \]

\[ u = A(T)\tau^3 H \]

\[ uH = A(T)\tau^3 H^2 \]

What do we measure and why?
Motivating flux problem

\[ \frac{du}{dz} = A(T)\tau^3 \]
\[ u = A(T)\tau^3 H \]
\[ uH = A(T)\tau^3 H^2 \]
\[ \tau = \rho g H \alpha \]
Motivating flux problem

What do we measure and why?

\[ \frac{du}{dz} = A(T) \tau^3 \]

\[ u = A(T) \tau^3 H \]

\[ uH = A(T) \tau^3 H^2 \]

\[ \tau = \rho g H \alpha \]

\[ uH = A(T) \rho g \alpha H^5 \]
Motivating flux problem

What do we measure and why?

What controls ice thickness and ice-thickness change when we can ignore glacier sliding?
What do we measure and why?

Motivating flux problem

What controls ice thickness and ice-thickness change when we can ignore glacier sliding?

External forcing and glacier geometry
In Situ Measurements vs. Remote Sensing

Directly collecting information about a system at a point of interest. This requires *that the instrumentation be located directly at a point of interest* for the system and *be in contact with the point of interest*. Collecting information about a system at a distance. This requires *transmission of information* from the system to the instrument *without direct contact*. What do we *measure* and why?
In Situ Measurements vs. Remote Sensing

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Accumulation

To derive total accumulation, you measure change in snow thickness + deposited snow density
What do we measure and why?
Melt

To derive total melt in the ablation zone, you just have to measure changes in ice thickness.
Glacier-thickness change

What do we measure and why?

DEM courtesy David Shean
Glacier-thickness change

Menunos et al 2019
Ice-shelf thickness change
Ice-shelf thickness change

What do we measure and why?

Dutriuex et al 2014
Shean et al 2016
Motivating flux problem

What do we measure and why?

What controls ice thickness and ice-thickness change?

External forcing and glacier geometry
How do we measure ice thickness?
Radar-system timescales

What do we measure and why?
How do we measure ice thickness?
Ice-sheet thickness observations

What have we measured and why?
In Situ Measurements vs. Remote Sensing

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The Physics of Observation
Gravity

Newton’s Law of Universal Gravitation:
F: The force due to gravity
G: Universal Gravitational Constant
m: Masses of the objects
d: Distance between their centers of mass

\[ F = G \frac{m_1 \times m_2}{d^2} \]
Wave Theory

The Wave Equation:
- $u$: The propagating perturbation
- $t$: Time
- $c$: The wave speed

1D Solution to the Wave Equation:
- $u$: The propagating perturbation
- $t$: Time
- $x$: Distance in the propagation direction
- $k$: Wavenumber
- $f$: Frequency
- $c$: The wave speed

$$\frac{\partial^2 u}{\partial t^2} = c^2 \nabla^2 u$$

$$u(t, x) = \sin(kx - 2\pi f * t + \phi)$$

$$c = \frac{\lambda}{f}, \quad k = \frac{1}{\lambda}$$

Wave Reflection
- $R$: Reflection Coefficient
- $Z$: Electric / Acoustic Properties

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$
Black Body Radiation

Planck’s Law:
L: Radiance (outgoing energy)
h: Planck’s Constant
f: Frequency
c: Speed of Light
k: Boltzmann’s Constant
T: Temperature

Brightness Temperature Equations:
$T_B$: Brightness Temperature
$\varepsilon$: Emissivity
$T_s$: Surface Temperature

$$L_f = \frac{2hf^3}{c^2}(e^{\frac{hf}{ekT}} - 1)^{-1}$$

$$L_f \approx \frac{2kTf^2}{c^2} \quad \text{(Microwave Approximation)}$$

$$T_B = \varepsilon T_s$$
Remote Sensing

- Ice Thickness / Material Properties
- Changes in Ice Mass
- Sea Ice Presence / Skin Temperature
- Surface Changes and Ice Flow Speeds
Return to silly-putty model

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Importance of sliding
Radar interferometry

t=t_1
Radar interferometry

t=t_{2}
Radar interferometry

Time series courtesy Nick Holschuh