HiMAT U.S. Team meeting

Seattle, WA

March 20-21-22, 2018

Glacial Lake Assisted Melting (GLAM)

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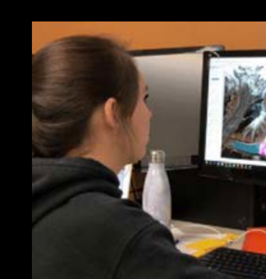
Univ. of Dayton



Acknowledgment: Thanks also to David Shean, Dan Jantzen, and Bob Yoder

A few key questions

How fast are Himalayan glacial lakes forming and growing?

How is suspended sediment implicated in radiative transfer, mass and energy balance of lakes and glaciers?

What is the energy and mass balance of glacial lakes and lakes' effects on glacier mass balance?

GLAM- Lakes (empirical- Shugar leads)

GLAM- Ice Flow (empirical-Haritashya leads)

GLAM- Icebergs (empirical-Watson leads)

GLAM- BioLith RT (numerical-Furfaro/Schiassi lead)

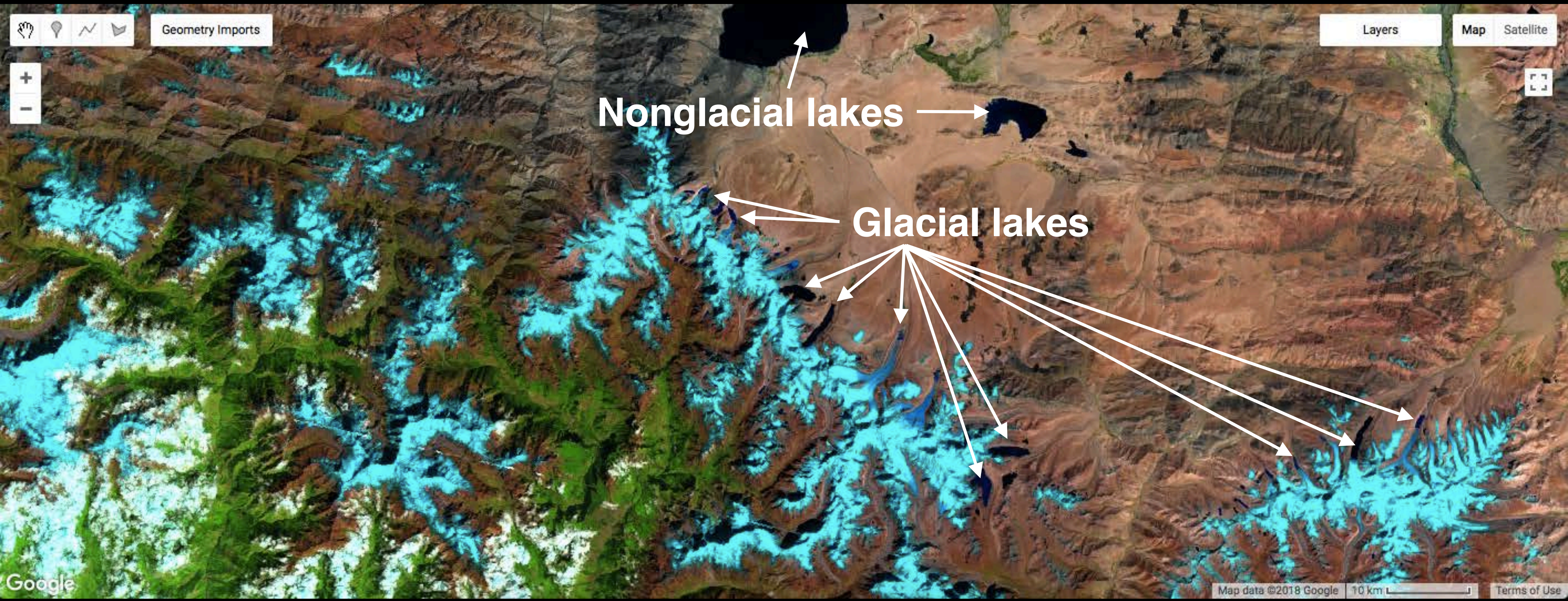
Today mostly this

GLAM- LITE (Lake, Icemass, and Thermal Energy Balance)(analytical- Kargel leads)

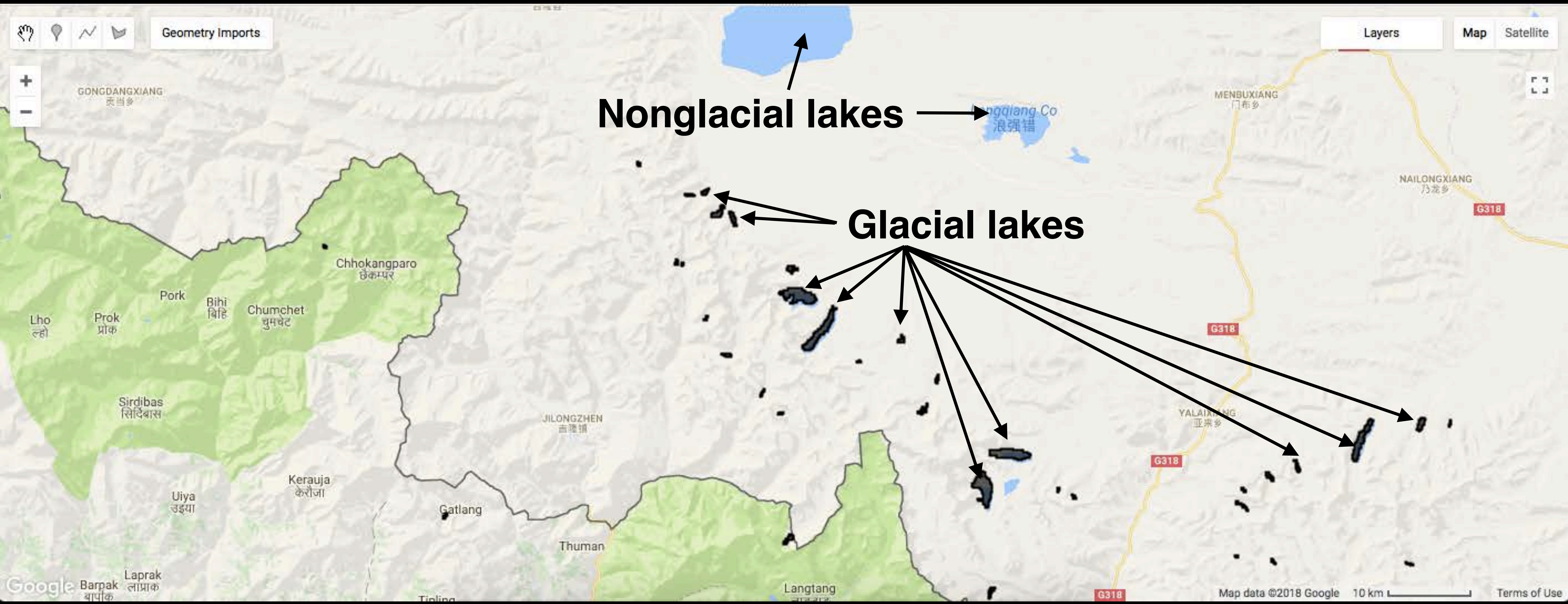
Spatio-temporal glacial lake mapping using Google Earth Engine

Dan H Shugar
& Aaron Burr

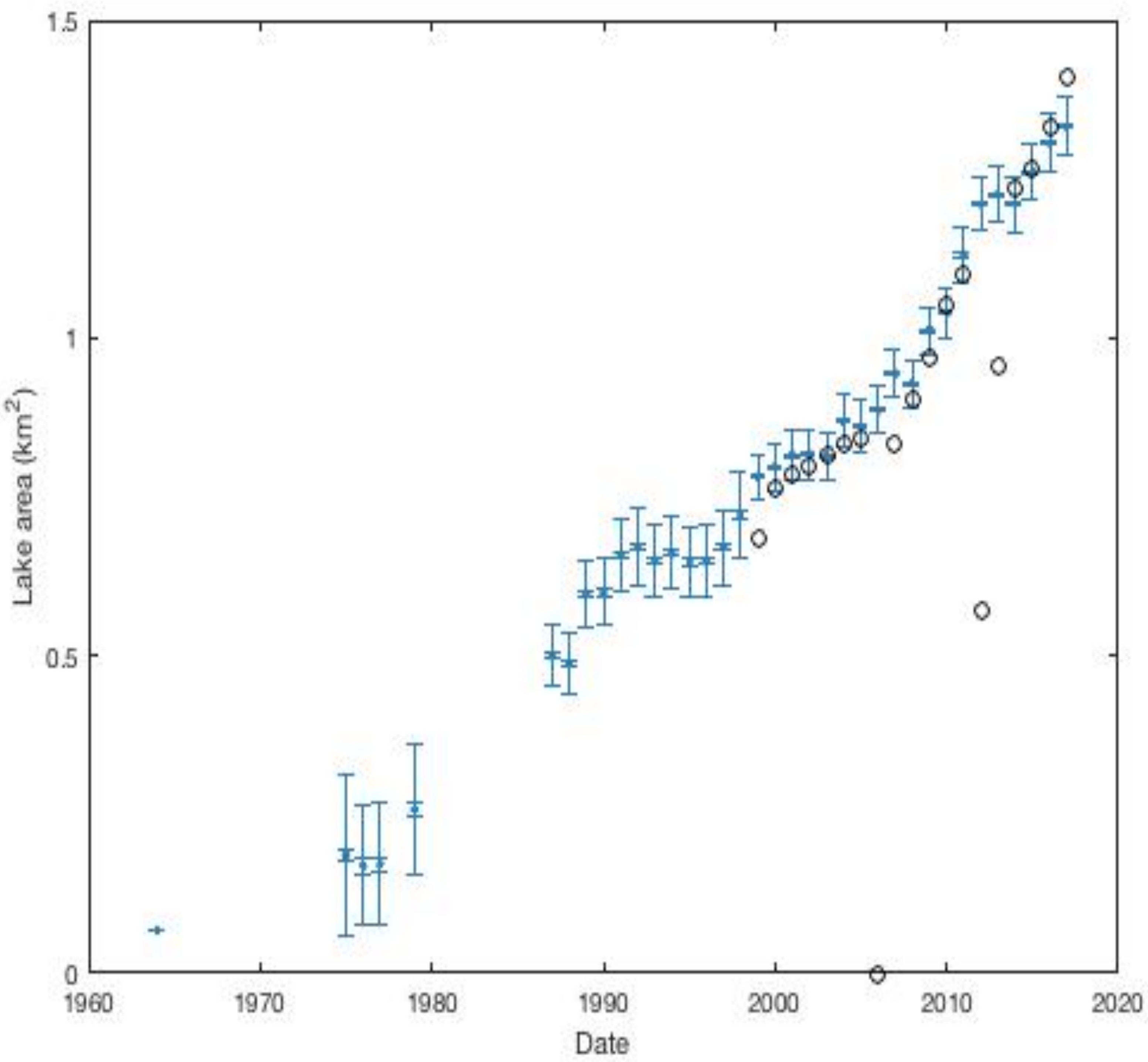
Goal: map only glacial lakes accurately, automatically



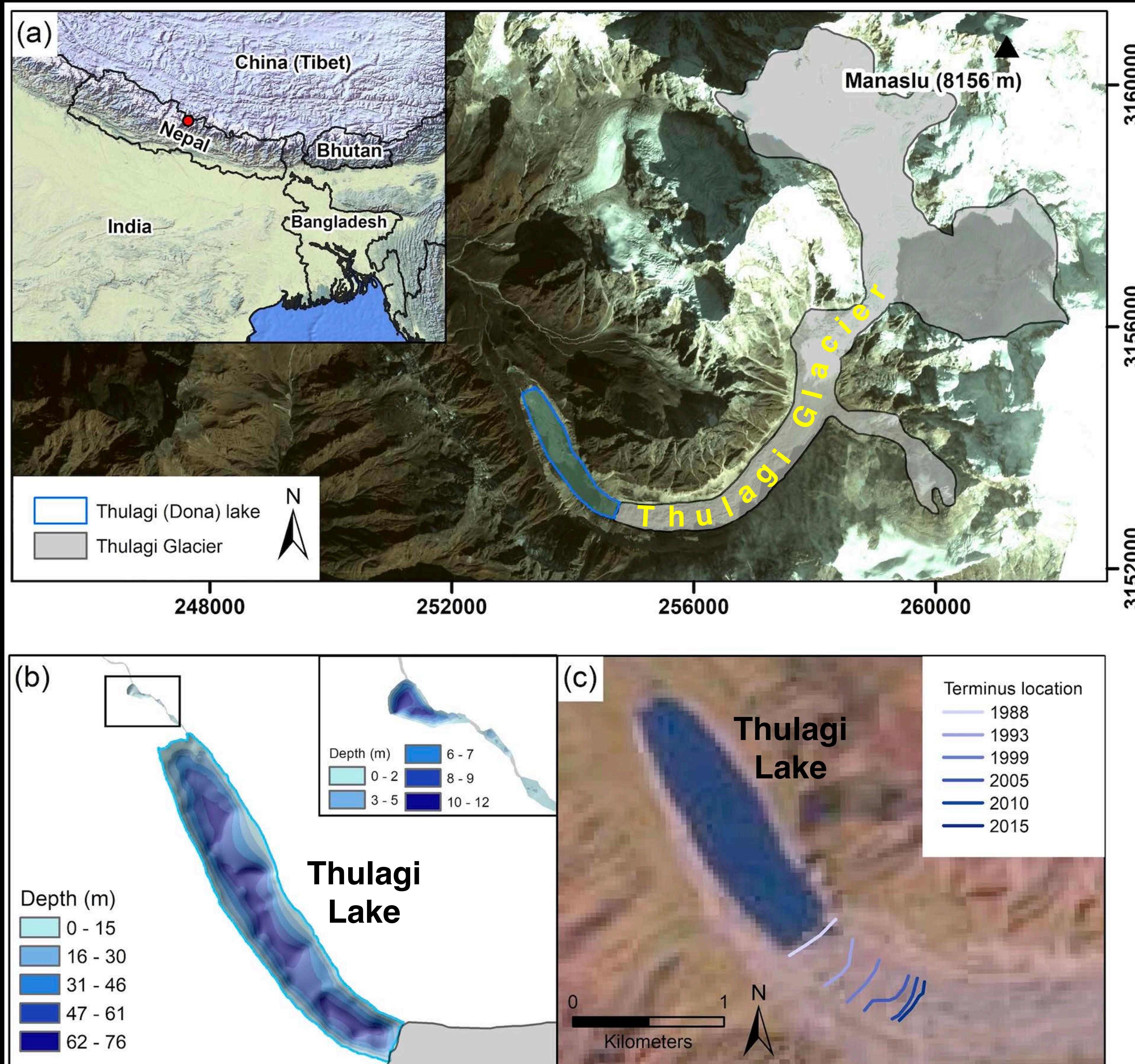
Goal: map only glacial lakes accurately, automatically



Automated & manual comparison at Imja Tsho



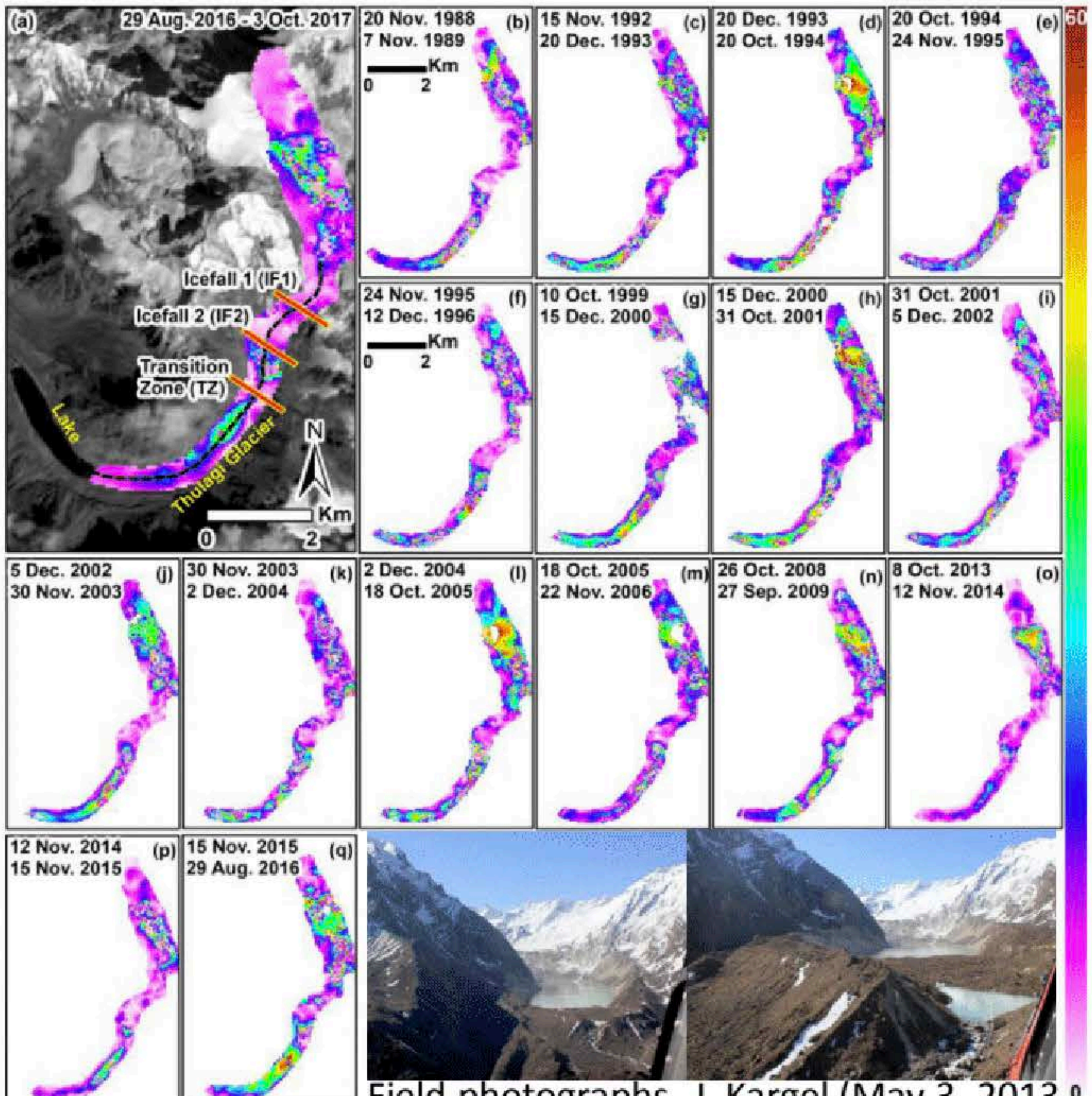
- **Generally good fit between manual (blue) and automated digitizing (black).**
- **Some errors due to brash ice, bergy bits, few cloud-free scenes in given year, etc.**
- **Next steps – incorporate ASTER, make code elegant so works across larger area through time.**



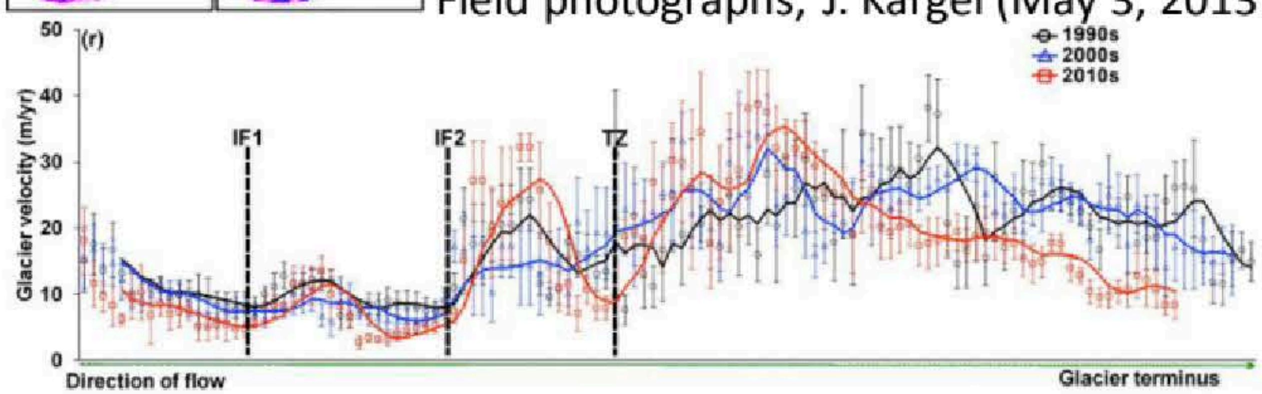
(a)
China (Tibet)
Nepal
Bhutan
Bangladesh
India
Manaslu (8156 m)
Thulagi Glacier
Thulagi (Dona) lake
Thulagi Glacier
N
248000
252000
256000
260000
3160000
3156000
3152000
(b)
Thulagi Lake
Depth (m)
0 - 15
16 - 30
31 - 46
47 - 61
62 - 76
Depth (m)
0 - 2
3 - 5
6 - 7
8 - 9
10 - 12
(c)
Thulagi Lake
Terminus location
1988
1993
1999
2005
2010
2015
0
1
Kilometers
N

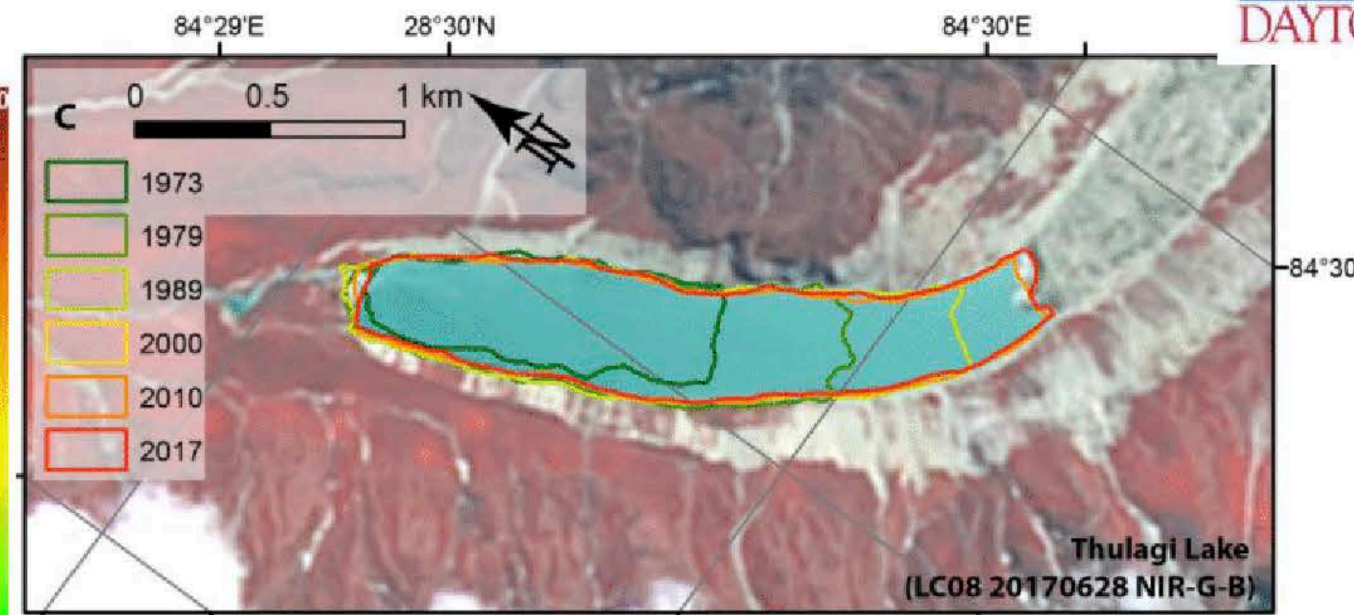
Thulagi Glacier Lake, Nepal

UNIVERSITY of DAYTON

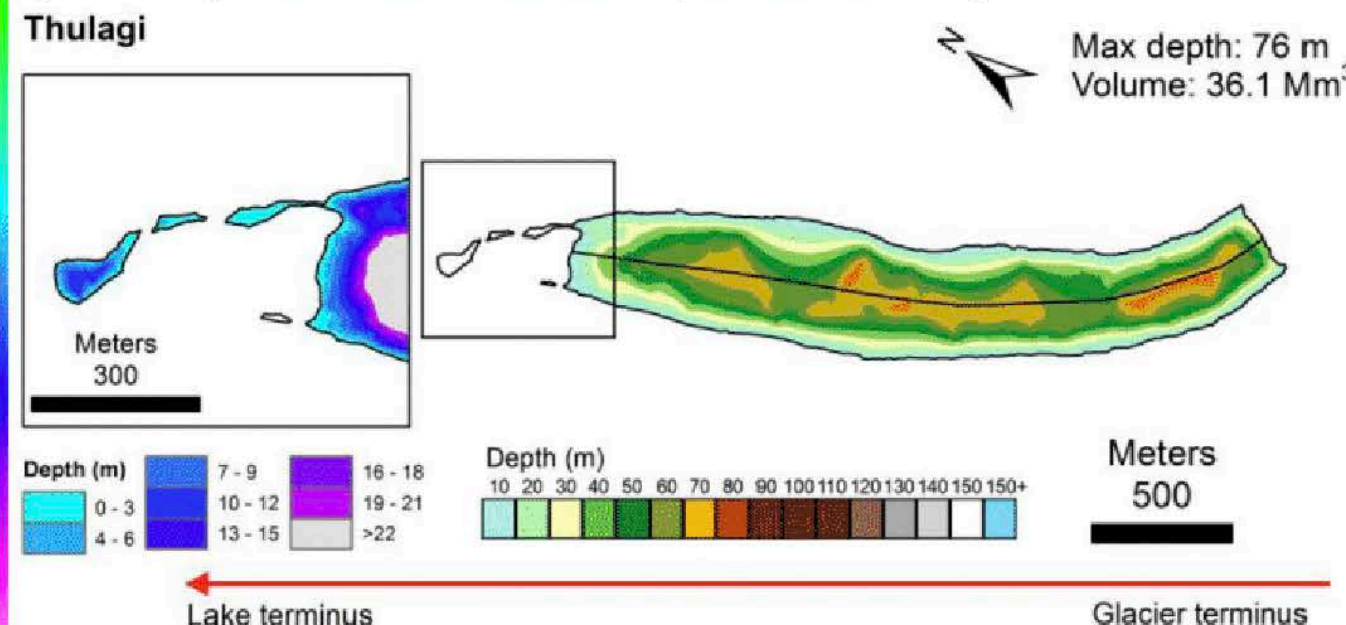


Field photographs, J. Kargel (May 3, 2013)

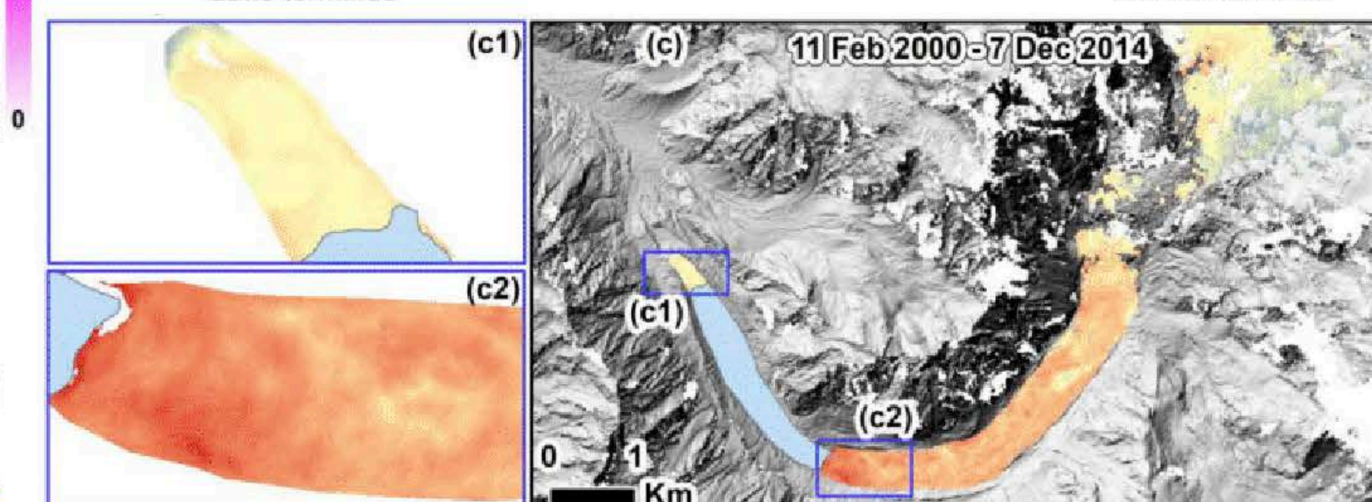




With D. Shugar

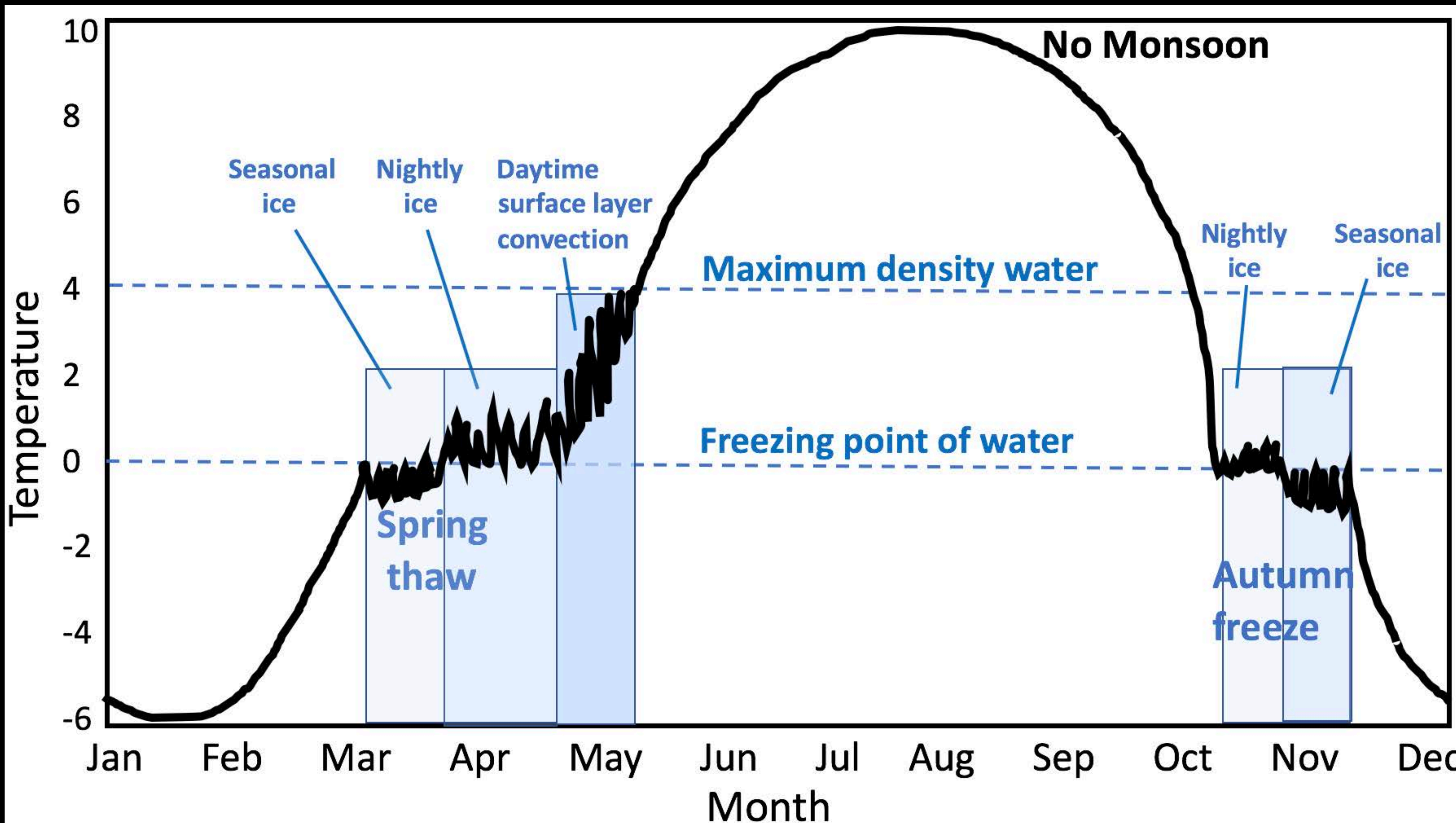


With S. Watson, J. Kargel

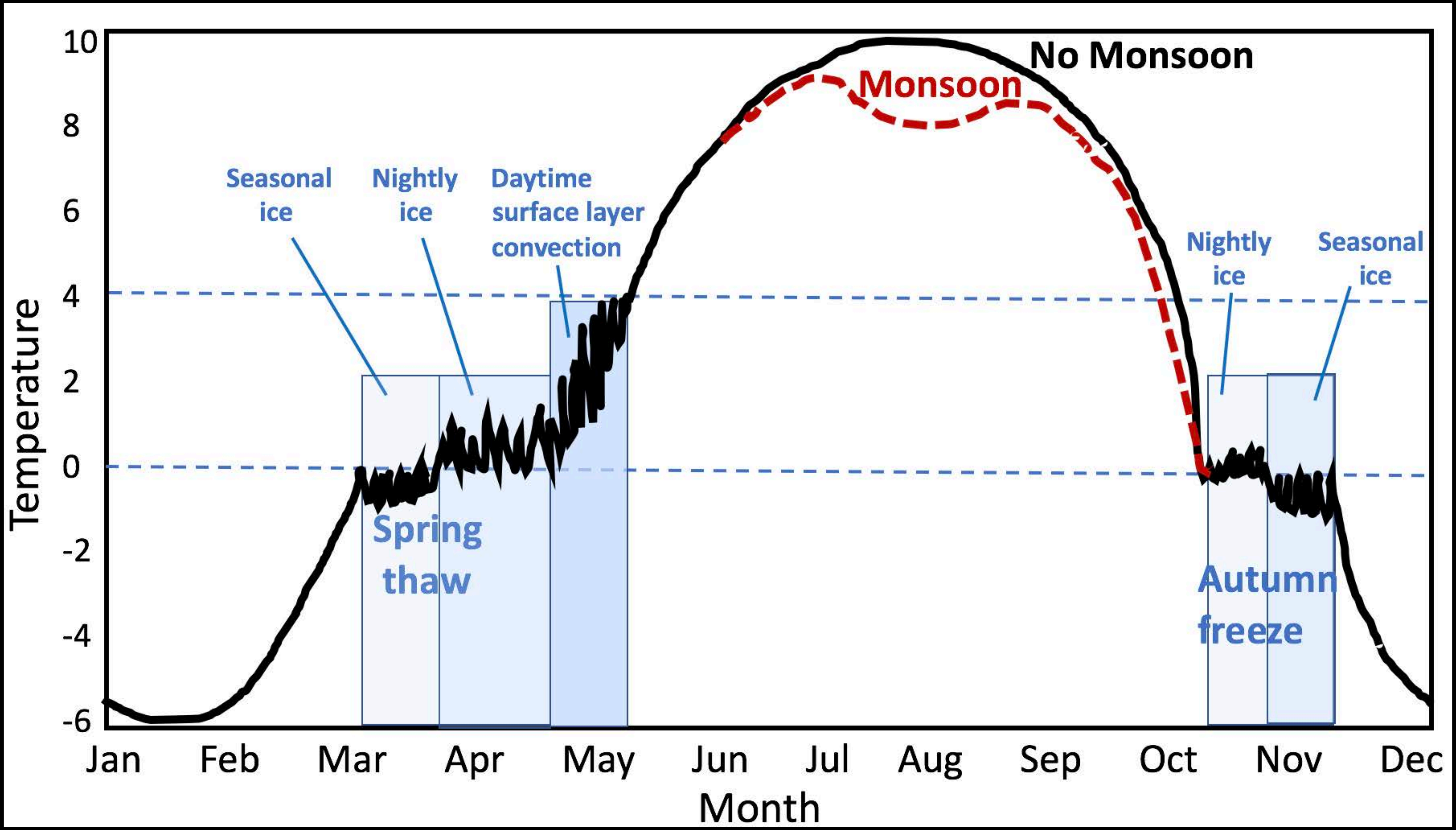


With D. Shean

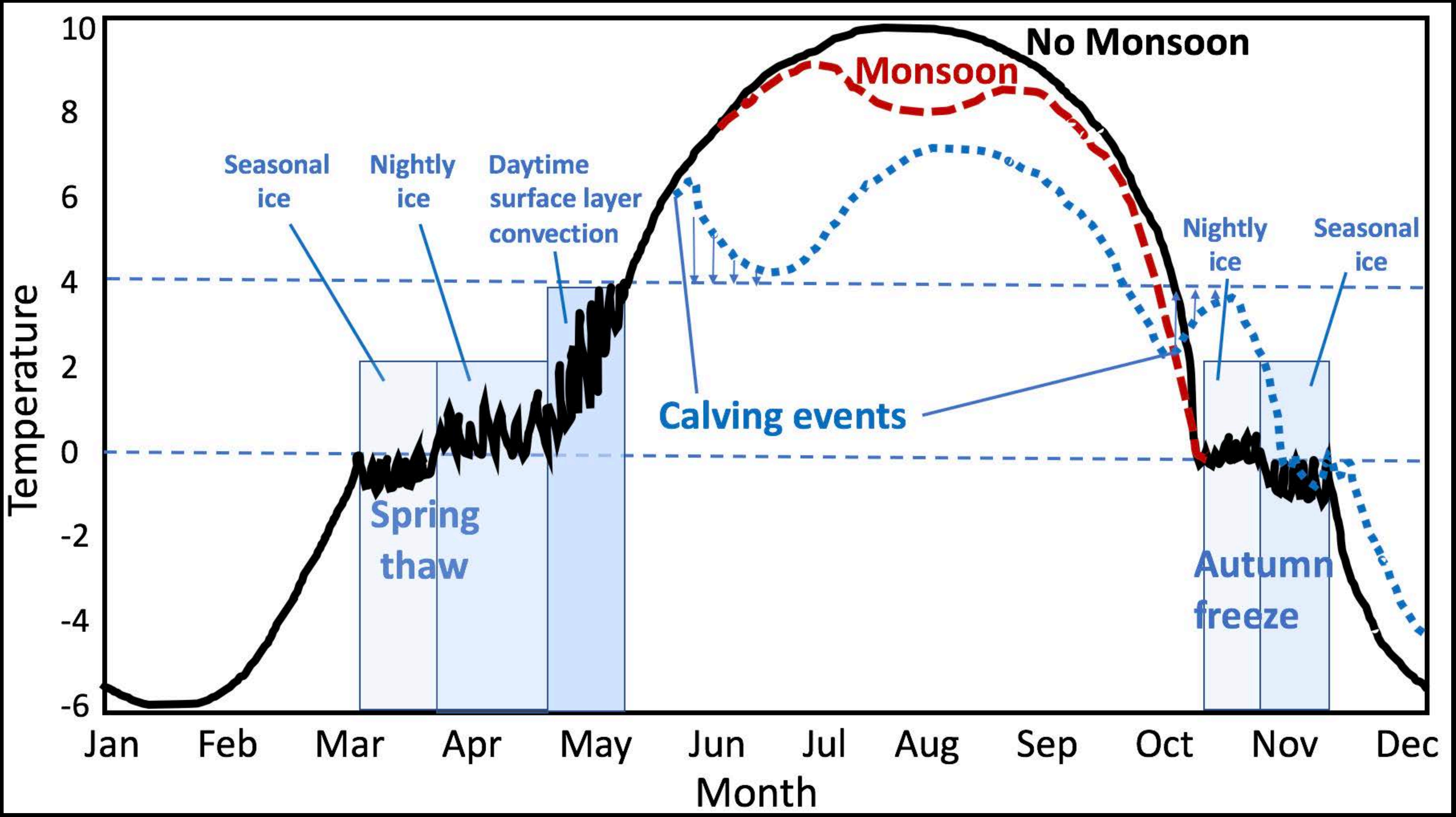
Umesh Haritashya and Katherine Strattman, Department of Geology, University of Dayton, Dayton, OH; Email: uharitashya1@udayton.edu



No Monsoon
Temperature
10
8
6
4
2
0
-2
-4
-6
Seasonal ice
Nightly ice
Daytime surface layer convection
Maximum density water
Freezing point of water
Spring thaw
Nightly ice
Seasonal ice
Autumn freeze
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

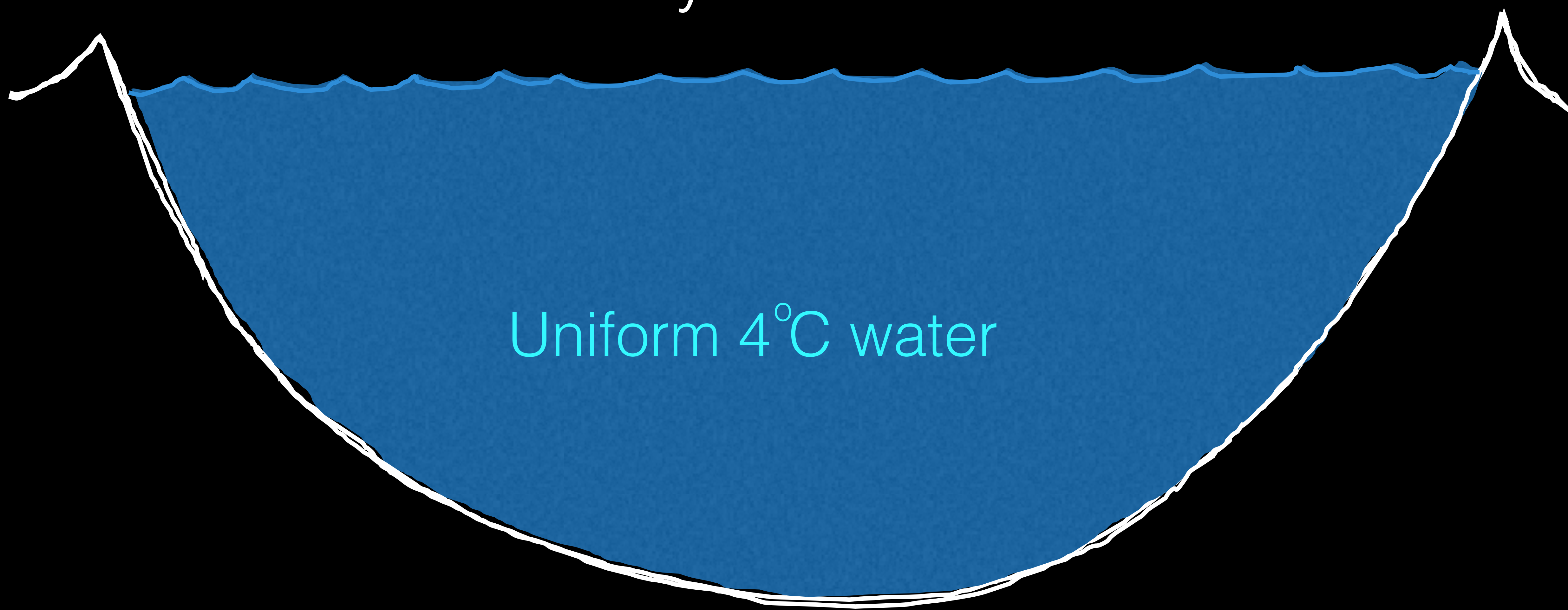


No Monsoon
Monsoon
Seasonal ice
Nightly ice
Daytime surface layer convection
Nightly ice
Seasonal ice
Spring thaw
Autumn freeze
10
8
6
4
2
0
-2
-4
-6
Temperature
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

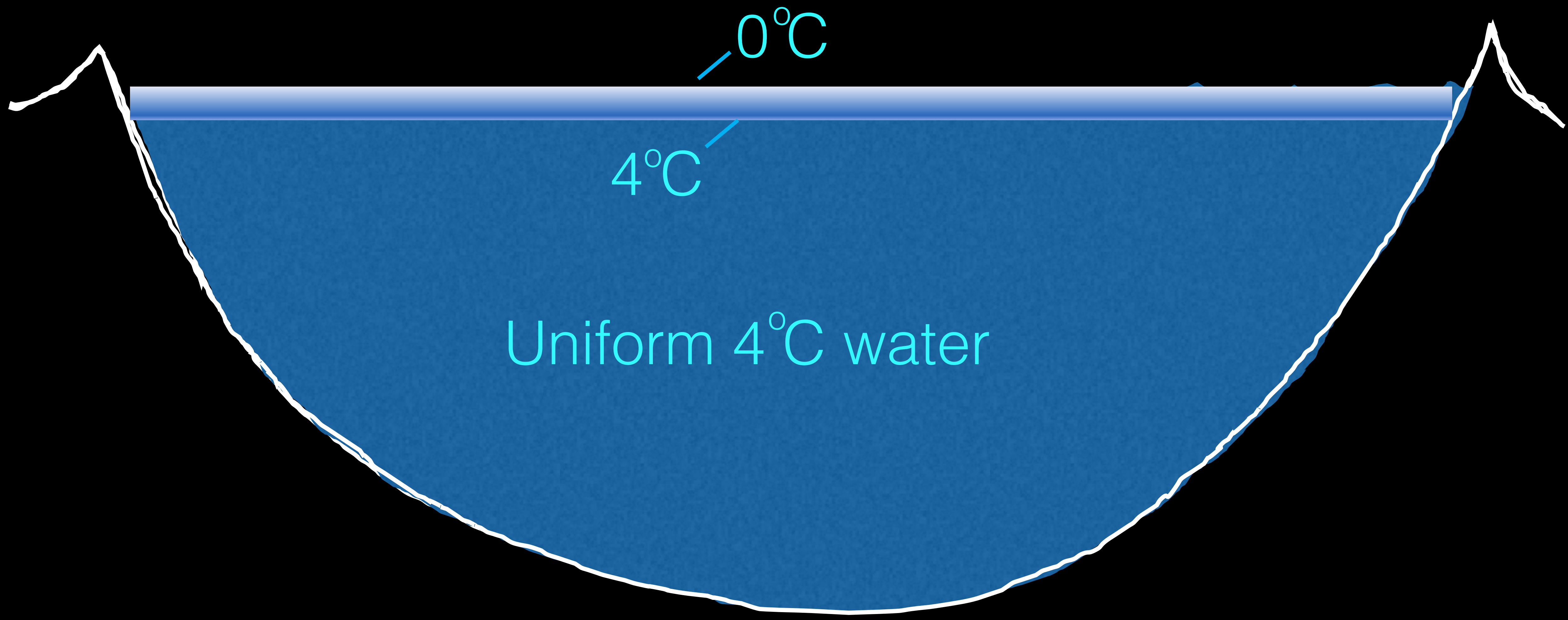


No Monsoon
Monsoon
Seasonal ice
Nightly ice
Daytime surface layer convection
Nightly ice
Seasonal ice
Calving events
Spring thaw
Autumn freeze
Temperature
10
8
6
4
2
0
-2
-4
-6
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

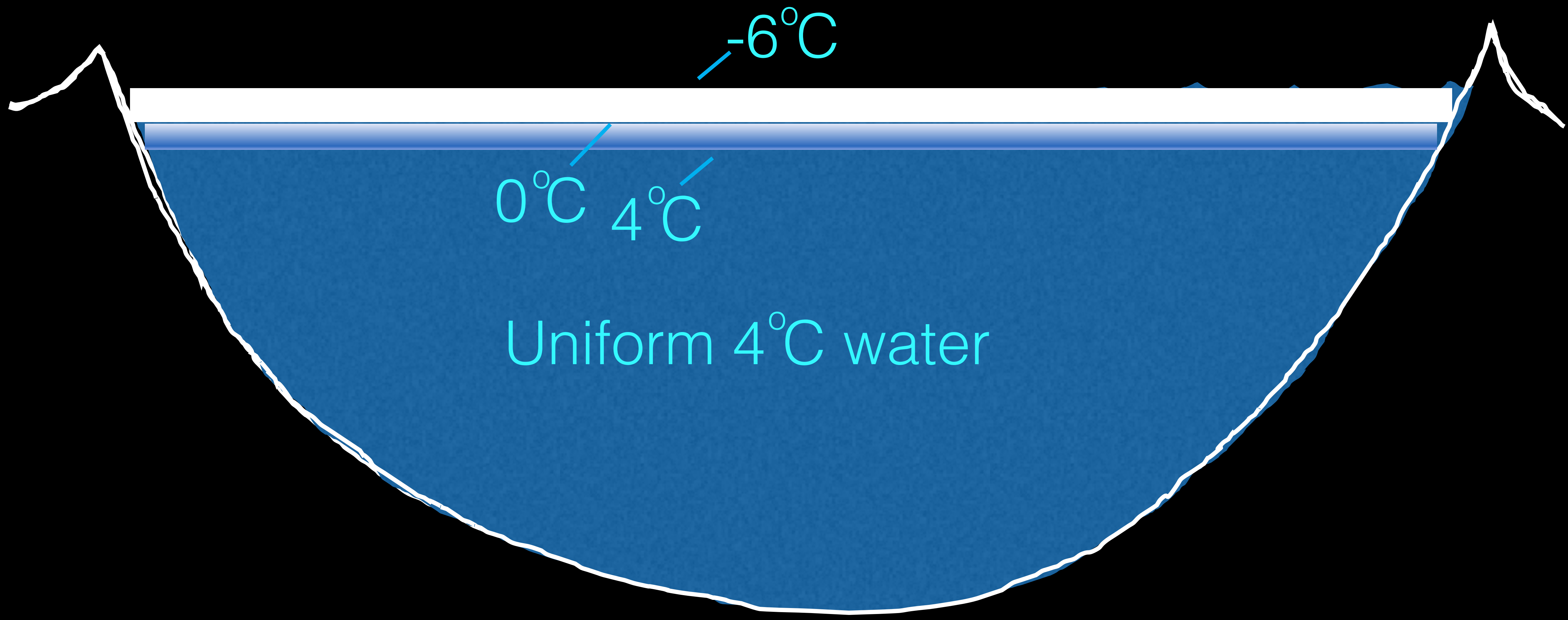
Early October



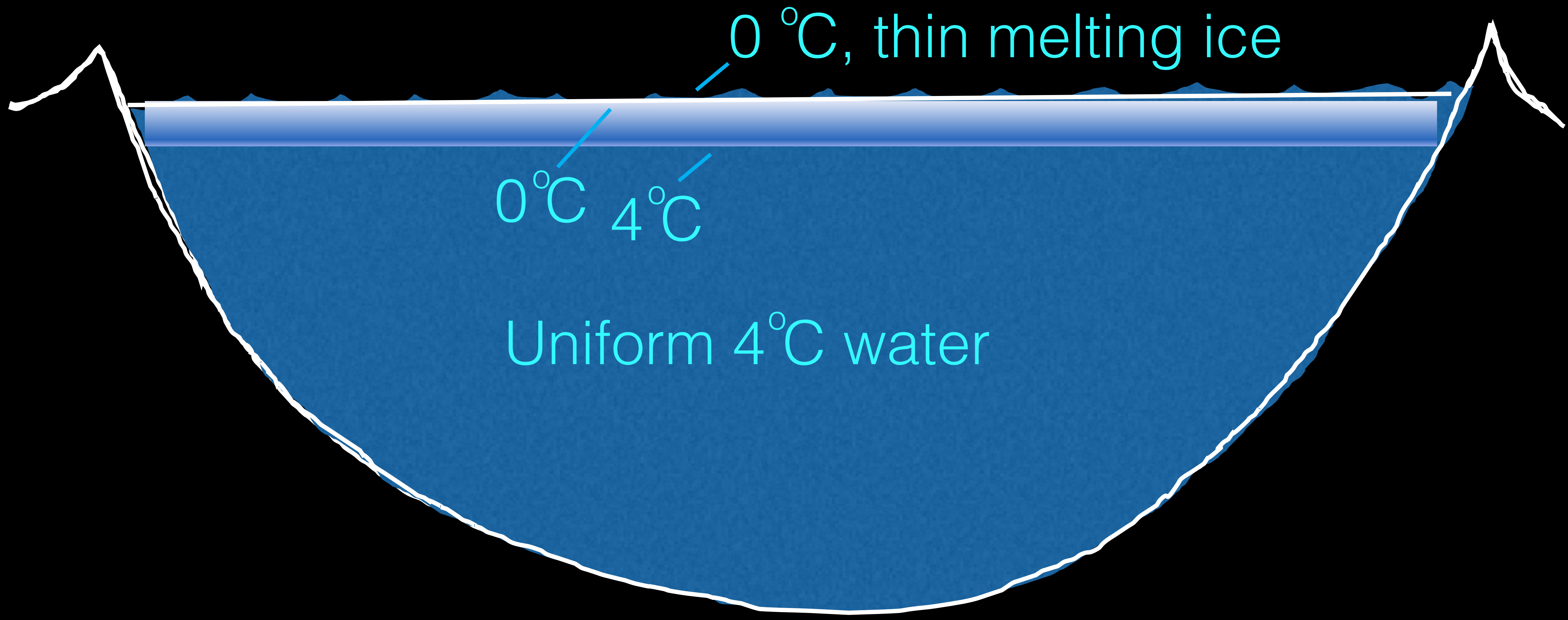
Early November first freeze



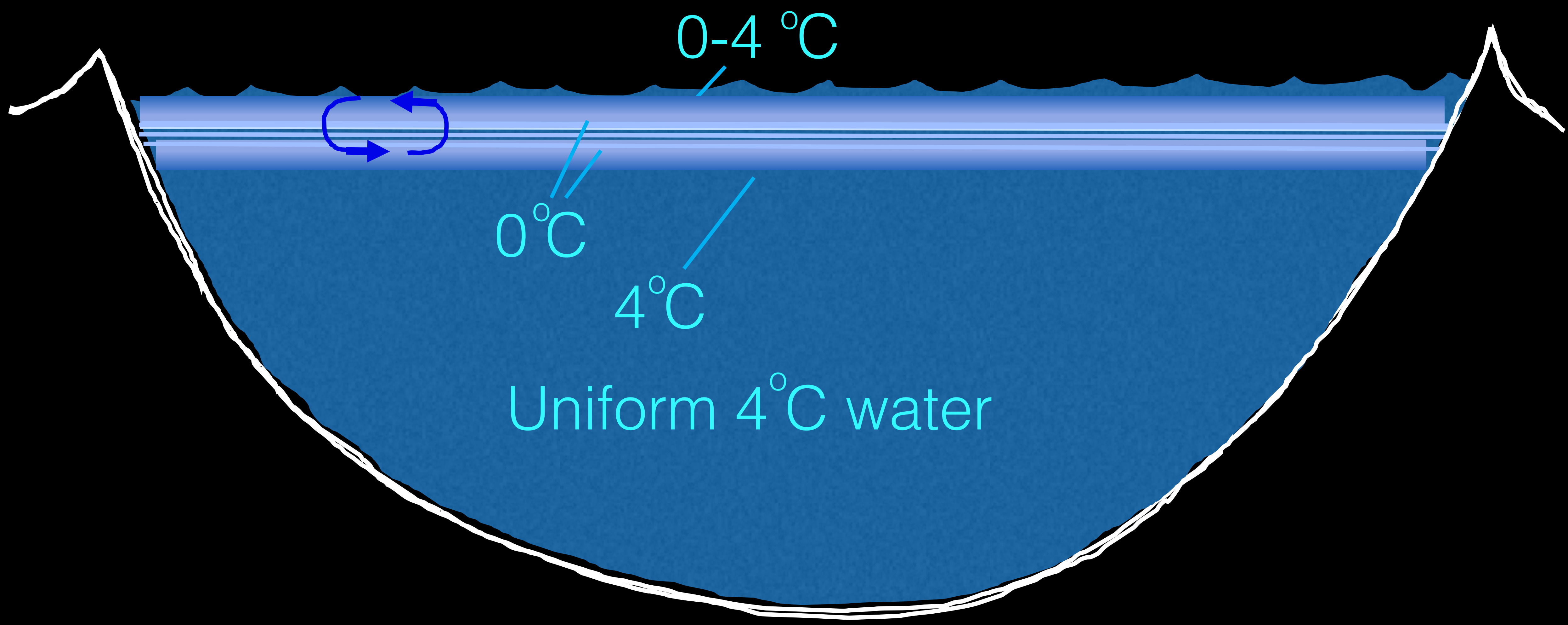
January thick lake ice



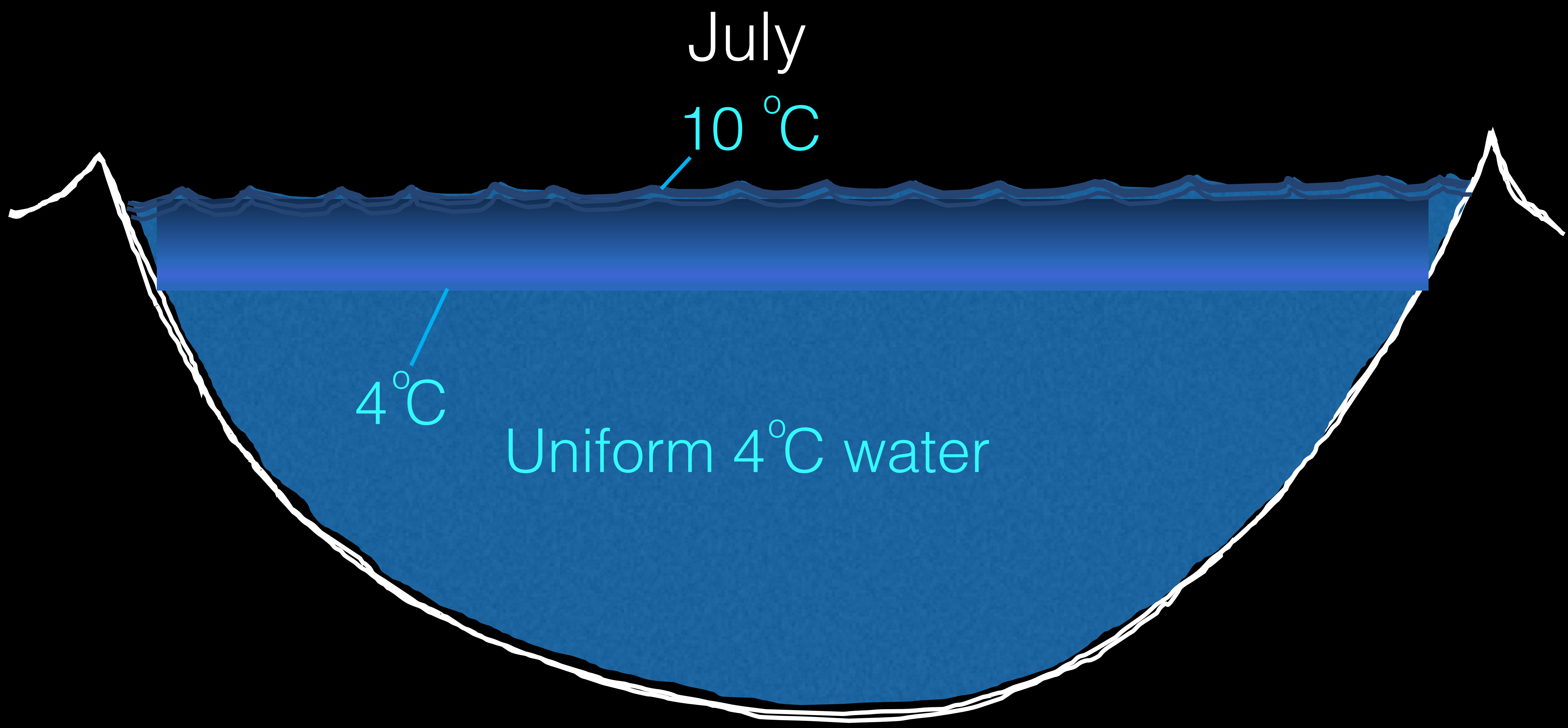
April thaw



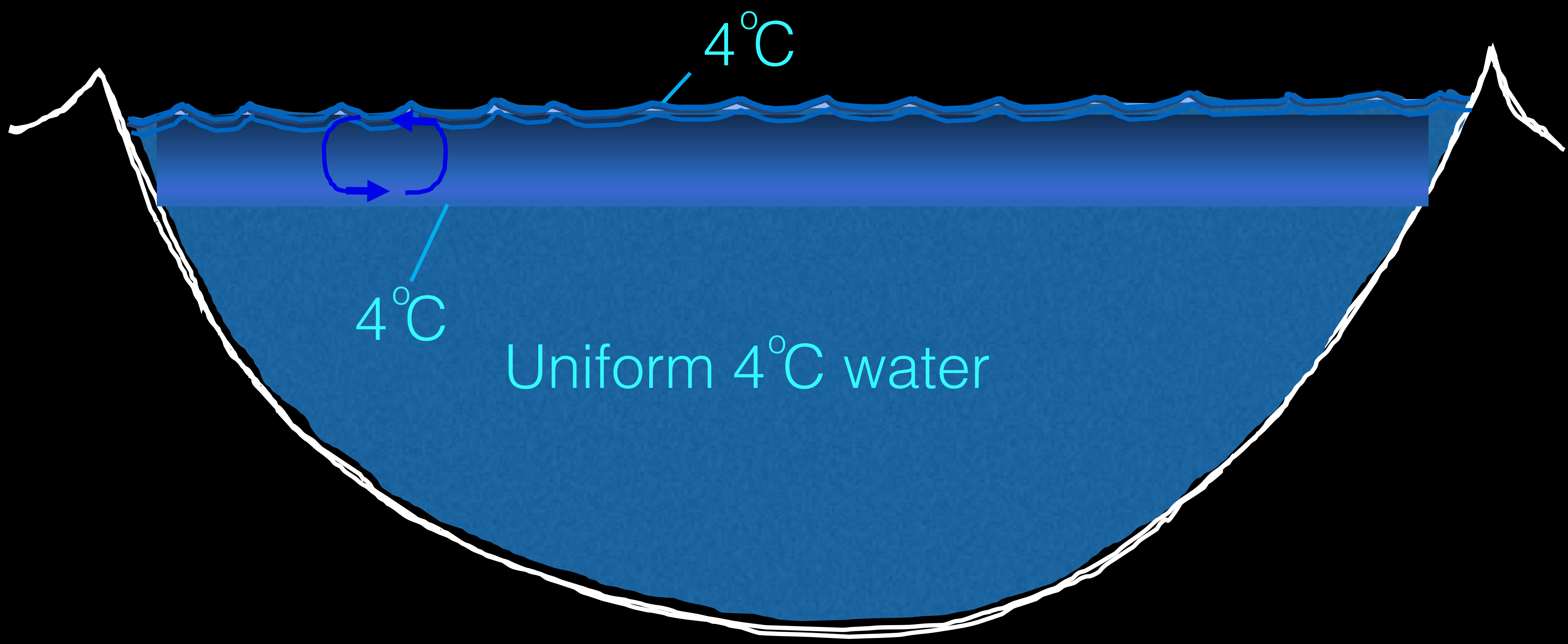
May warmup and free thermal convection



June

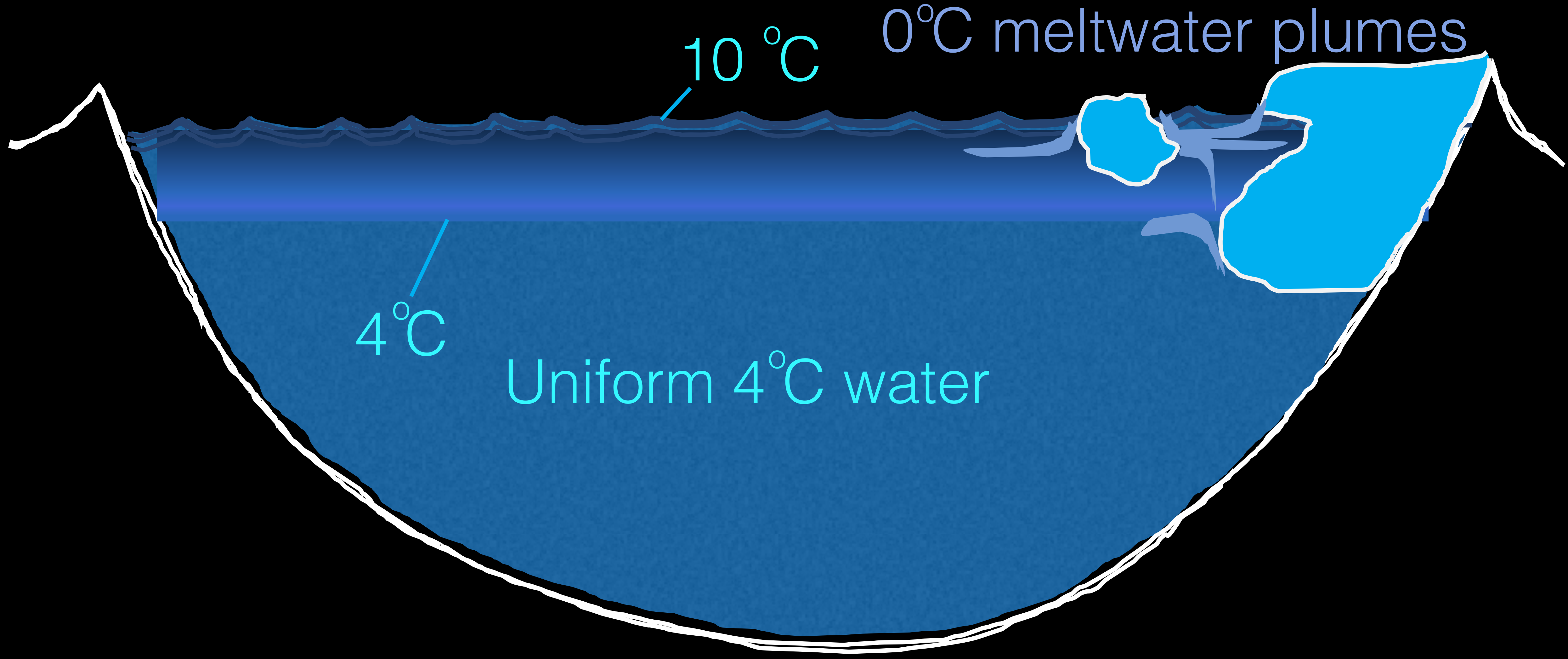

July
10 °C
4 °C
Uniform 4 °C water

Late September, Autumn free convection

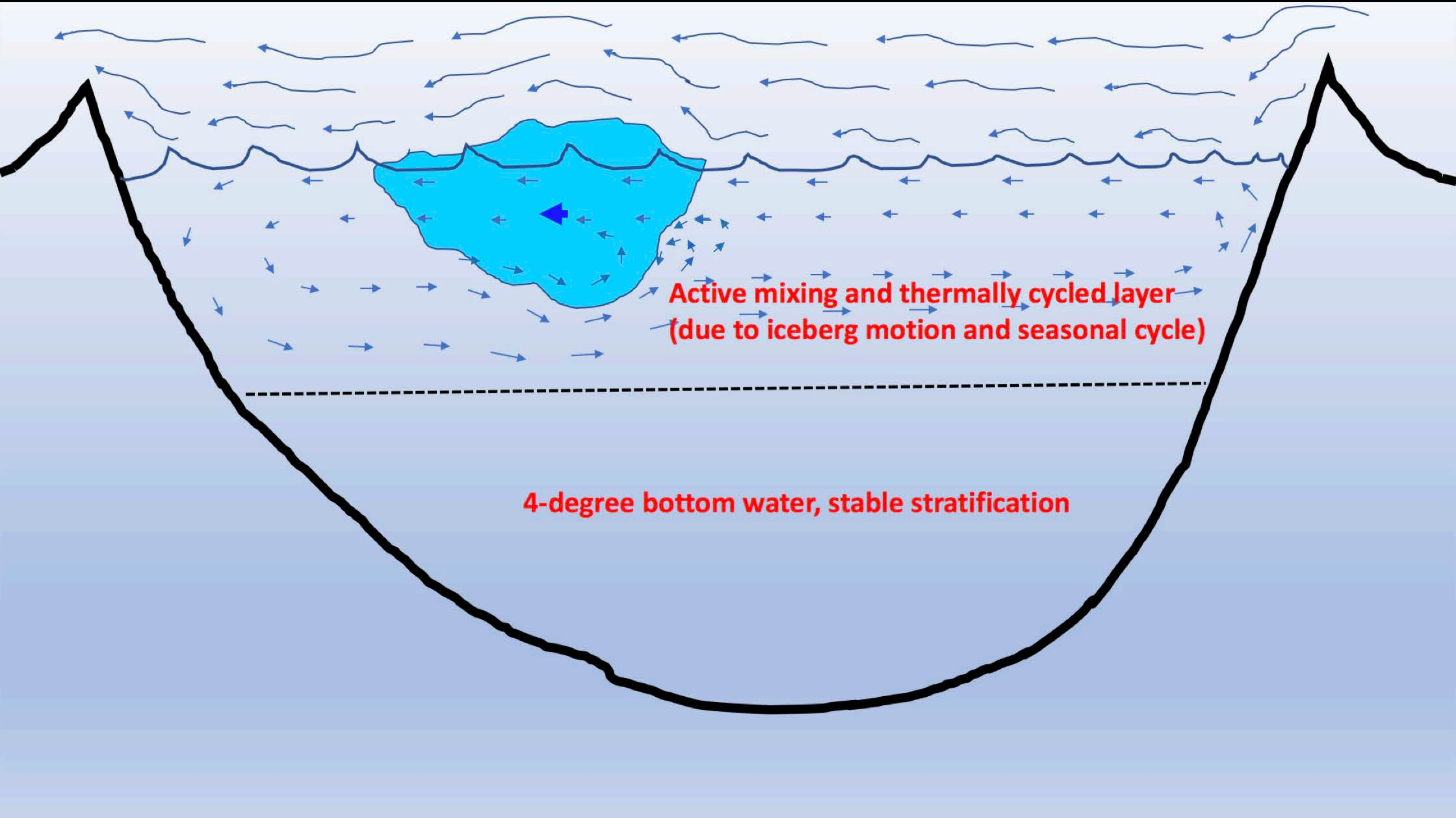


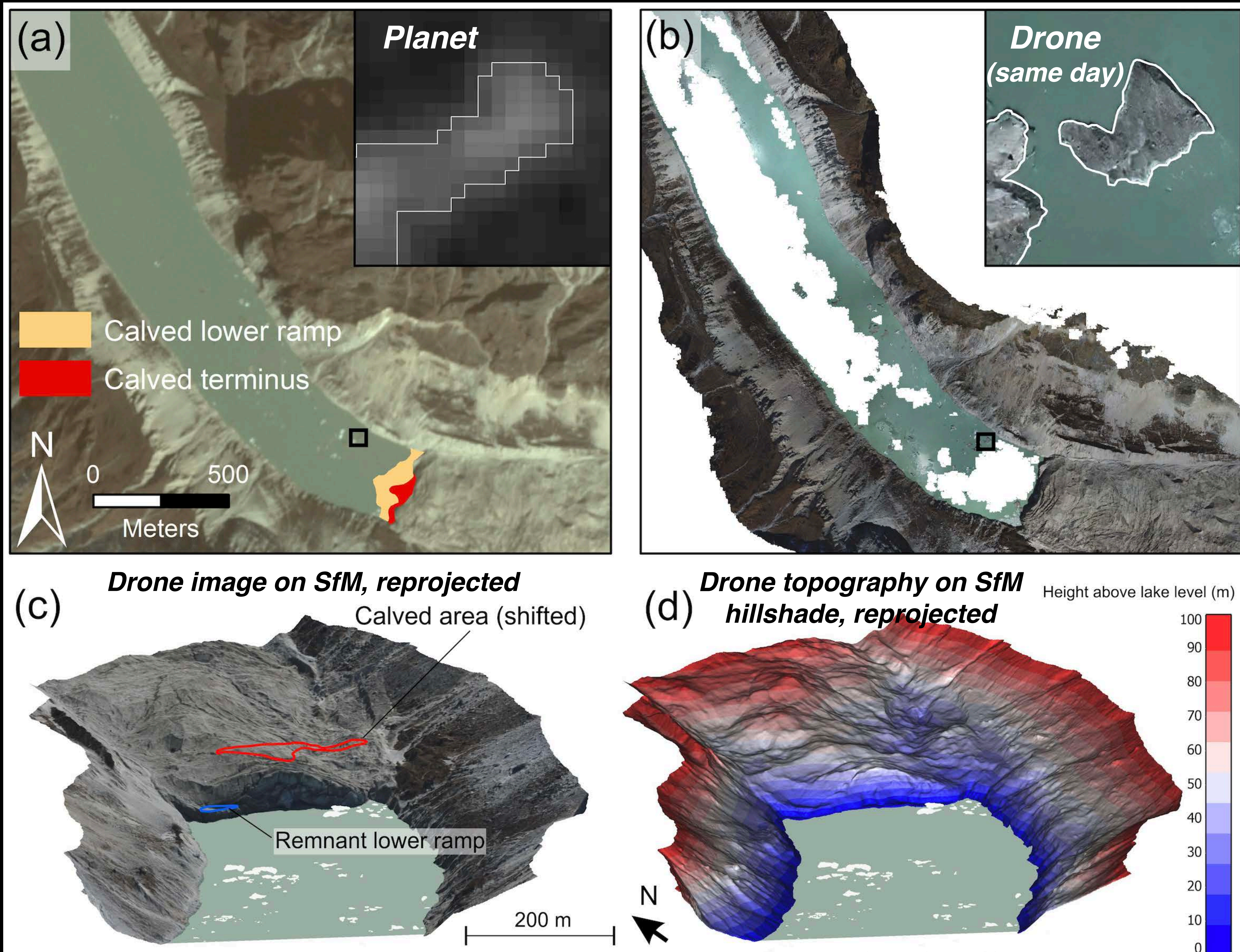
Early October

July- Glacier is present with metastable stratification



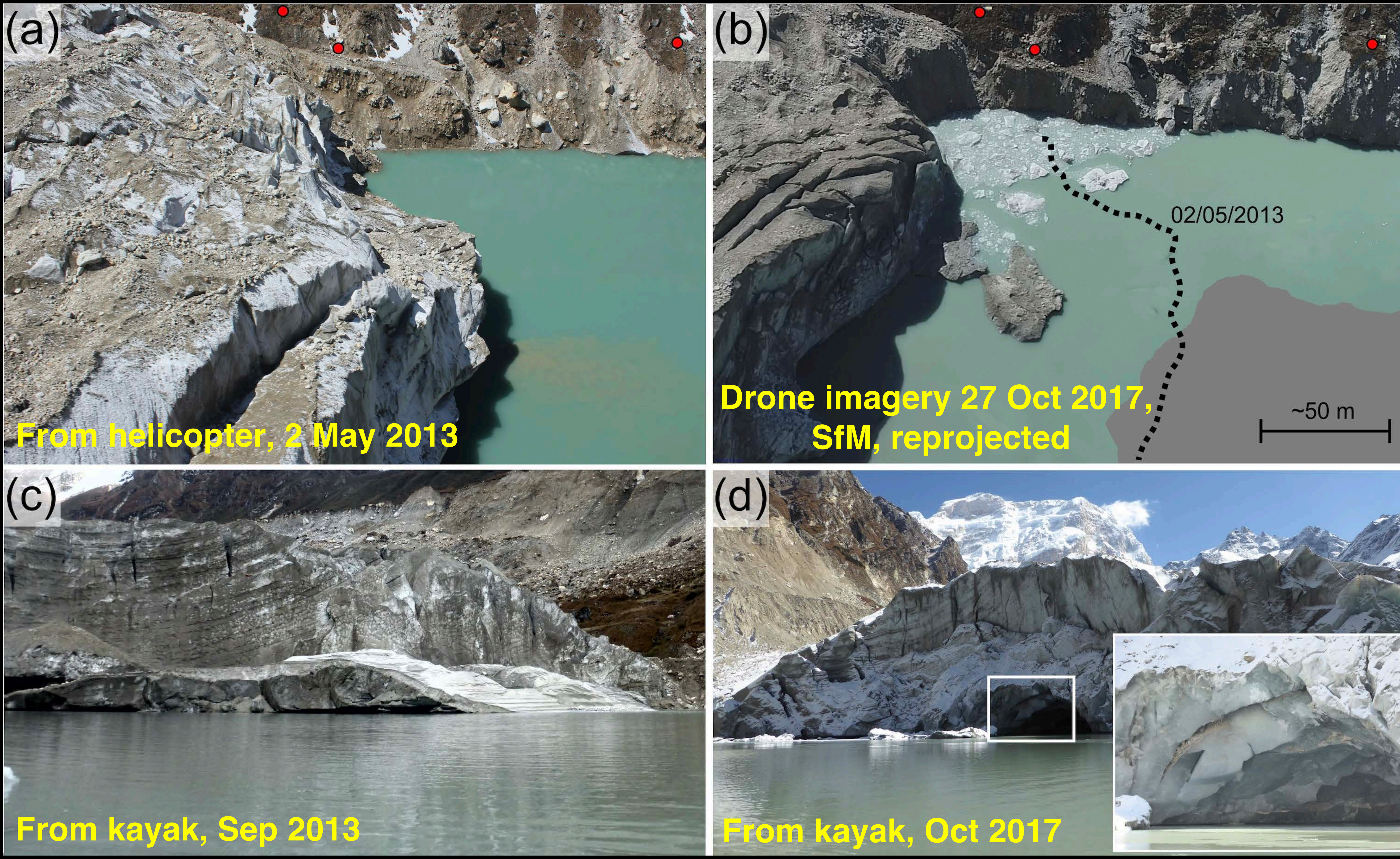
Wind-driven iceberg motion and forced convection mixes the lake down to iceberg roots



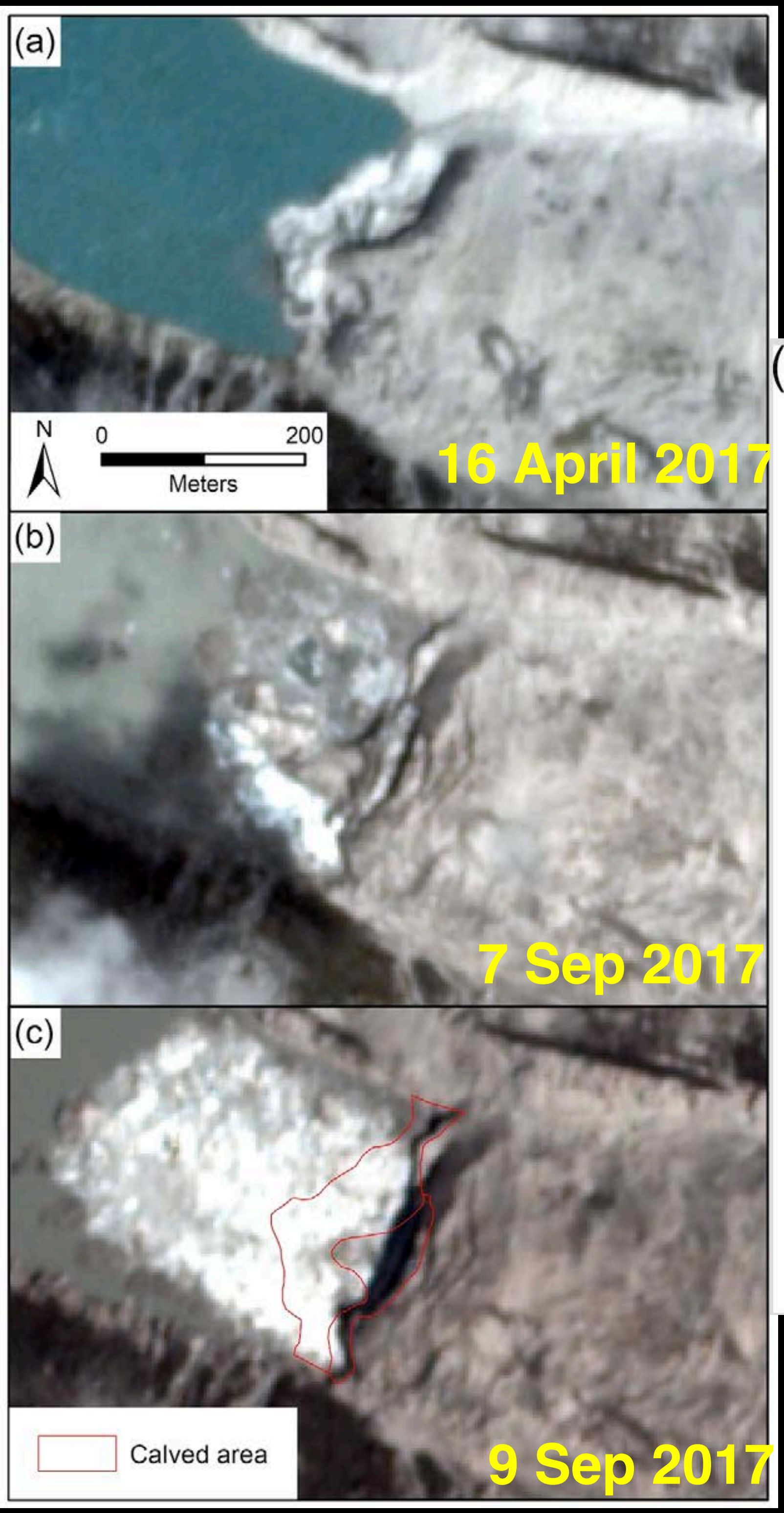


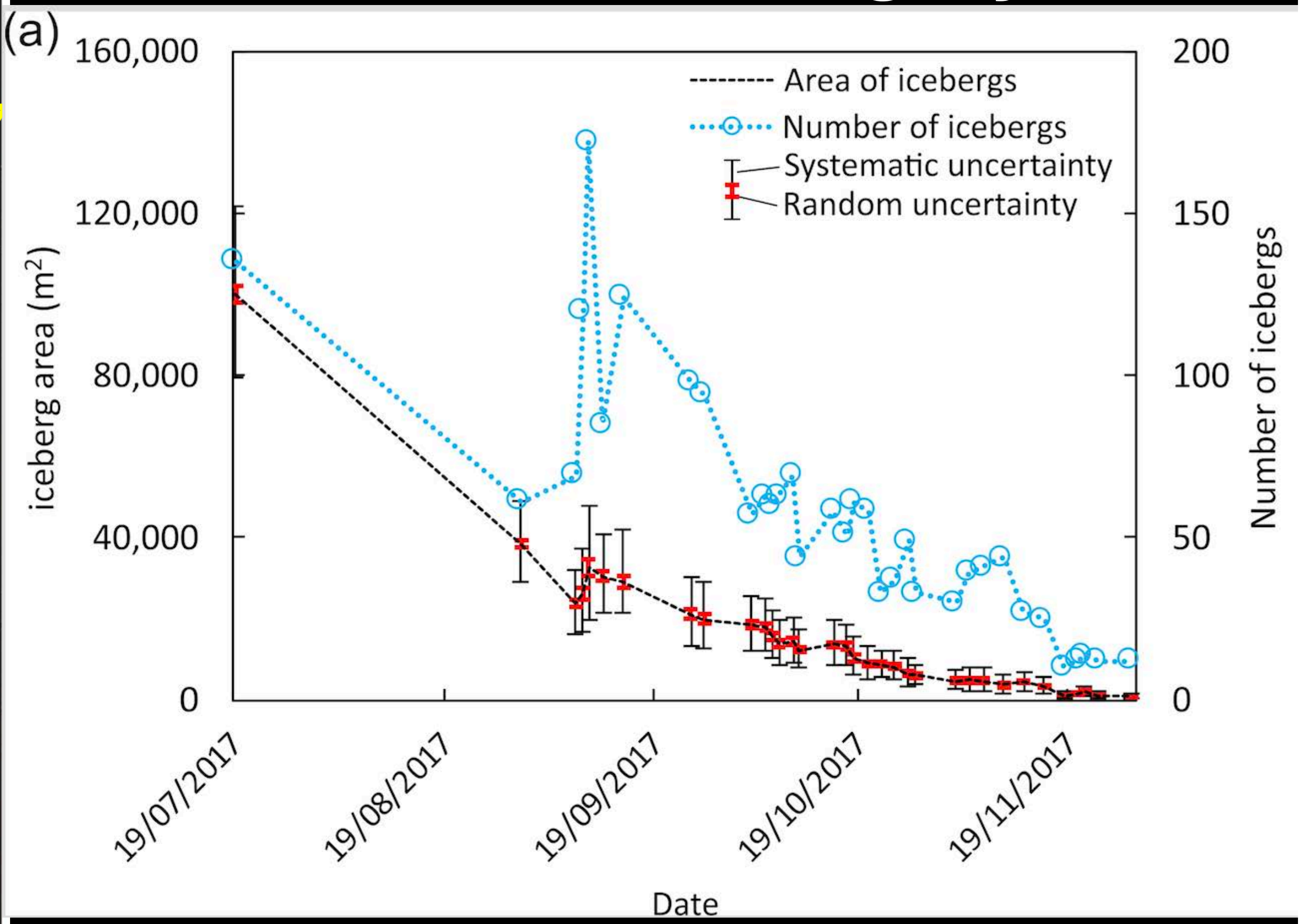
(a)
Planet
Calved lower ramp
Calved terminus
N
0
500
Meters
(b)
Drone
(same day)
(c)
Drone image on SfM, reprojected
Calved area (shifted)
Remnant lower ramp
200 m
N
(d)
Drone topography on SfM
hillshade, reprojected
Height above lake level (m)
100
90
80
70
60
50
40
30
20
10
0

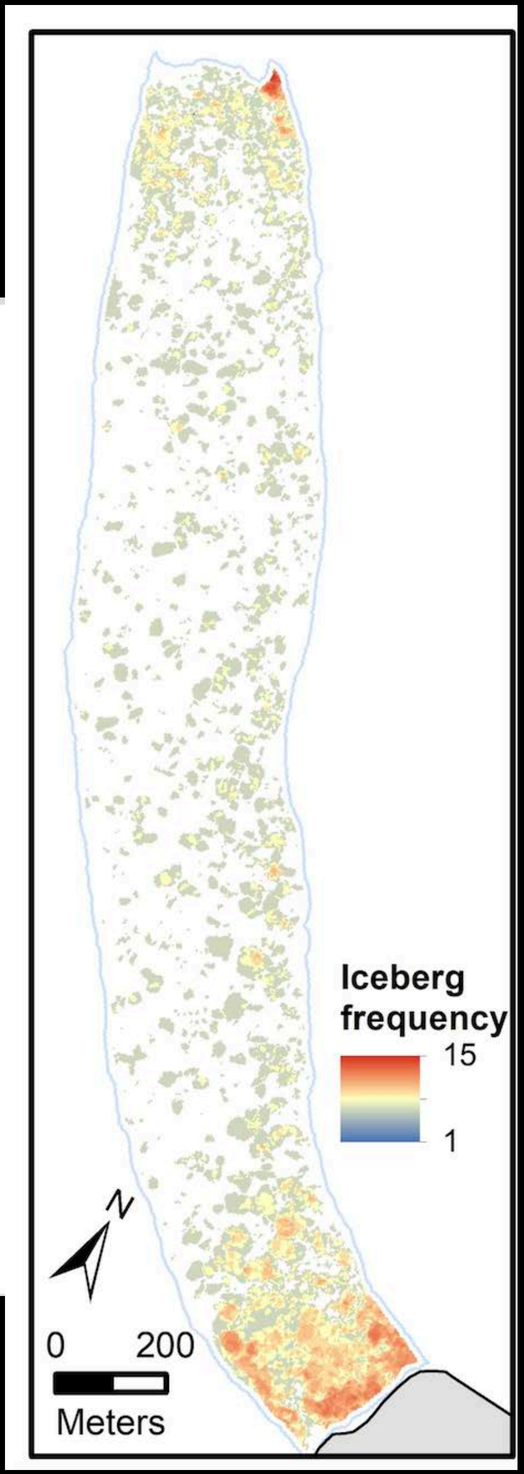
Thulagi Glacier/Lake



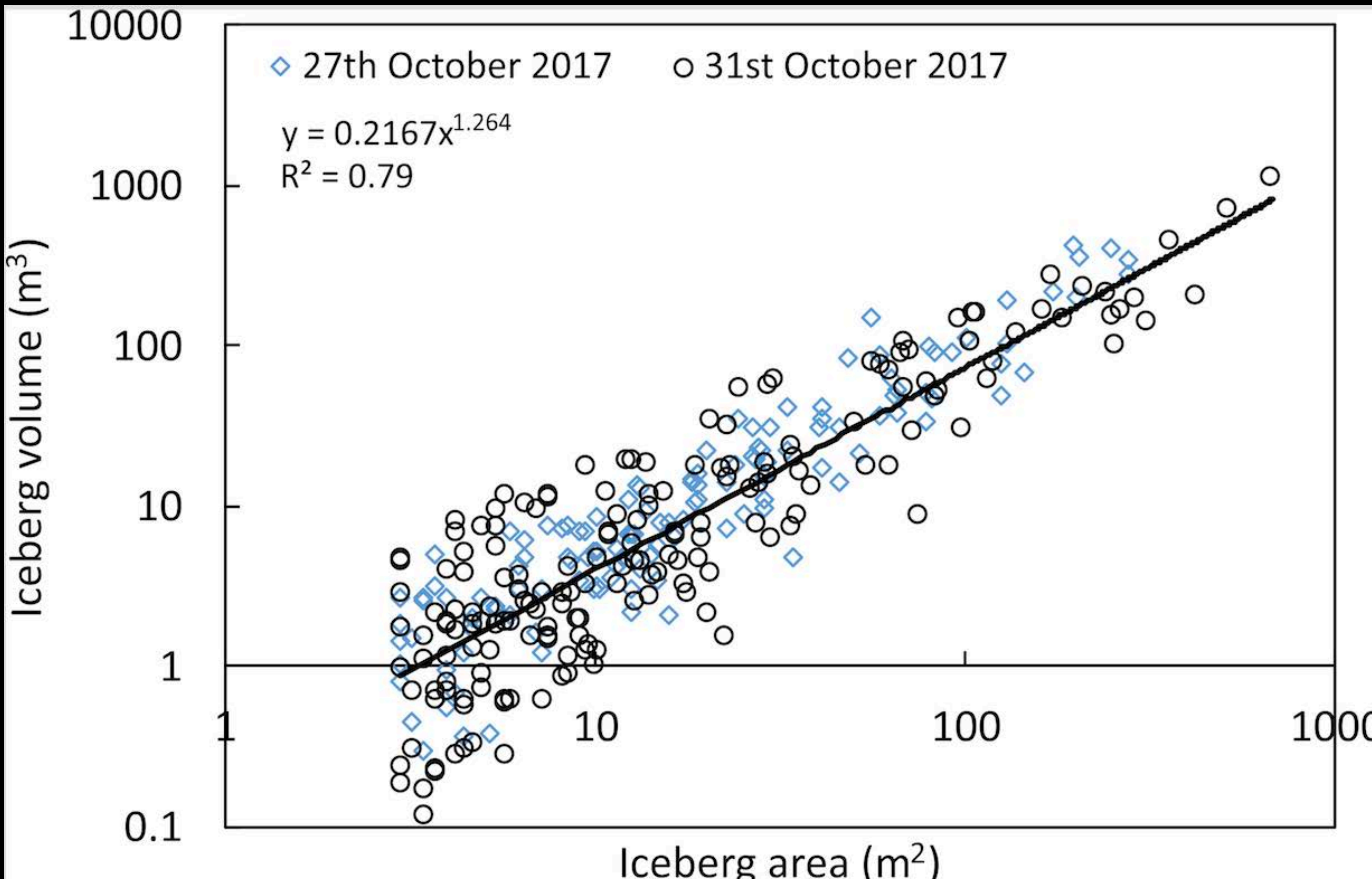
Thulagi Lake calving and icebergs, from *Planet* imagery







Thulagi Lake iceberg, area and above-surface volume, from drone imagery, SfM



Iceberg melting, figure of merit, I:

Thulagi Lake iceberg melting from the Sep 7-9 event. Ice mostly melted after 60 days.

The intial estimated 544,000 m^3 of calved ice = 4.99×10^8 kg would require 333,000 J/kg to melt = 1.66×10^{14} J.

How plausible is it that so much ice could melt in a few weeks?

MODEL 1: Heat comes from the deep lake thermal reservoir.

(1) Assume reservoir temperature = 4 °C.

(2) Reservoir volume = 6.75×10^7 m^3 = 6.75×10^{10} kg = 6.75×10^{13} g.

(3) Energy reservoir (above 0 °C) = 2.7×10^{14} Cal = 1.13×10^{15} J.

(4) CONCLUSION: The deep lake thermal reservoir is a factor of 7 greater than the energy needed to melt all that ice.

Iceberg melting, figure of merit, II:

Thulagi Lake iceberg melting from the Sep 7-9 event. Ice mostly melted after 60 days.
The intial estimated 544,000 m^3 of calved ice = 4.99 x 10^8 kg would require 333,000 J/kg to melt
= 1.66 x 10^{14} J.

How plausible is it that so much ice could melt in a few weeks?

MODEL 2: Heat comes from concurrent solar heating.

(1) Thulagi Lake area = 900,000 m^2.

(2) Assume 450 W/m^2 absorption for 4 hours daily for 60 days.

(3) Energy aborption = 3.1 x 10^{14} J.

(4) CONCLUSION: Concurrent solar heating would add twice as much energy as needed to melt all the calved ice.

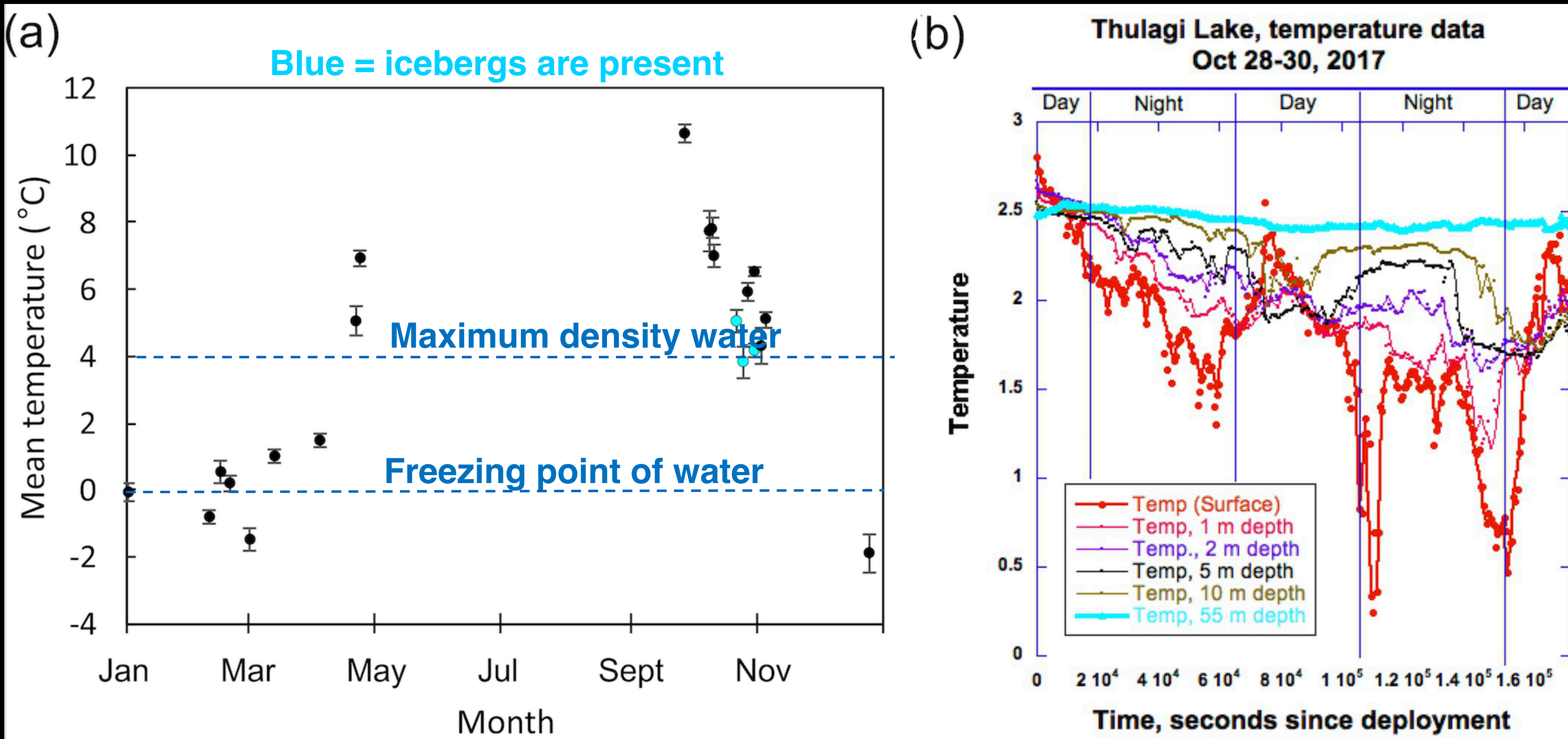
So there is plenty energy to melt the ice.

Where does the rest of the energy go?

So there is plenty energy to melt the ice.

Where does the rest of the energy go?

WE WILL TELL YOU NEXT YEAR!


(a)
Blue = icebergs are present
Mean temperature (°C)
Maximum density water
Freezing point of water
12
10
8
6
4
2
0
-2
-4
Jan
Mar
May
Jul
Sept
Nov
Month
(b)
Thulagi Lake, temperature data
Oct 28-30, 2017
Day
Night
Day
Night
Day
Temperature
3
2.5
2
1.5
1
0.5
0
Temp (Surface)
Temp, 1 m depth
Temp., 2 m depth
Temp, 5 m depth
Temp, 10 m depth
Temp, 55 m depth
0
2 10^4
4 10^4
6 10^4
8 10^4
1 10^5
1.2 10^5
1.4 10^5
1.6 10^5
Time, seconds since deployment

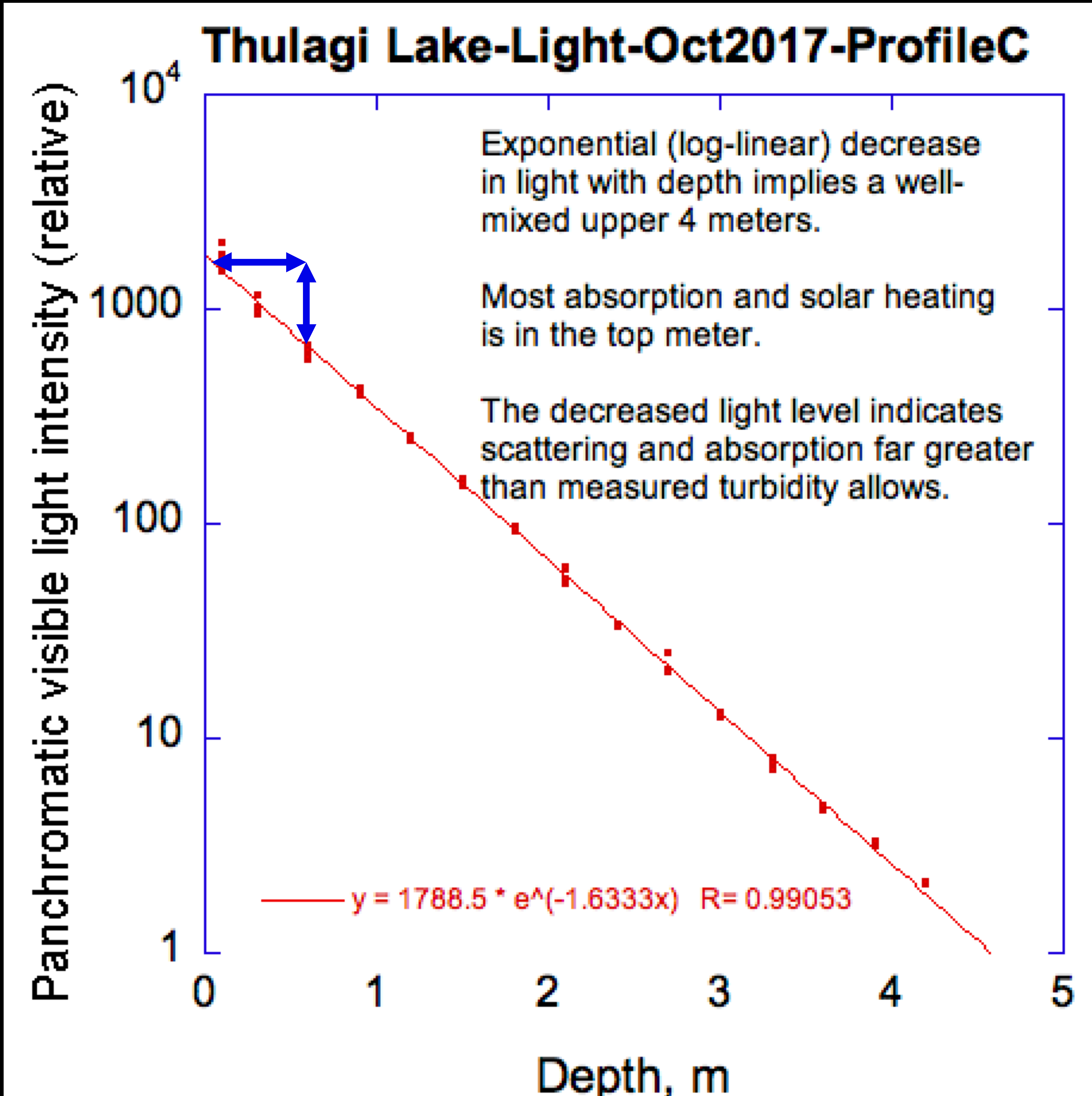


Figure of merit heating calculation.

Half of the incident unreflected sunlight is absorbed within the top 60 cm.

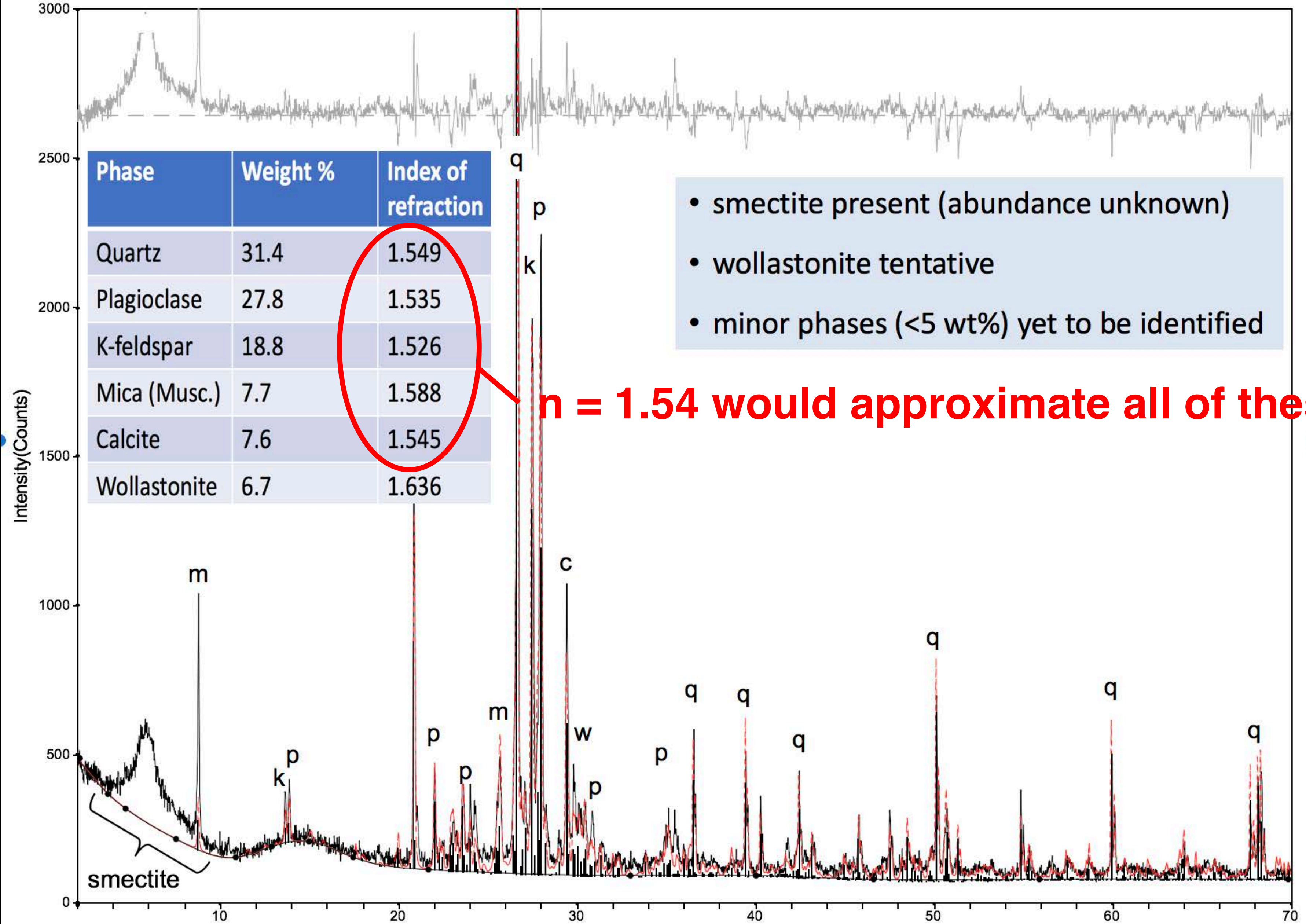
Incident refracted beam energy near the surface = 800 Watts/m^2 X 6 hours = 17.3 x 10^6 J.

Half is absorbed In upper 60 cm = 8.65 x 10^6 J = 2.06 x 10^6 Calories.

2.06 x 10^6 C/6x10^5 cm^3 = 3.4 C/cm^3.

Enough to raise the temperature by 3.4 degrees.

XRD results and optical index n for Thulagi Lake beach sand

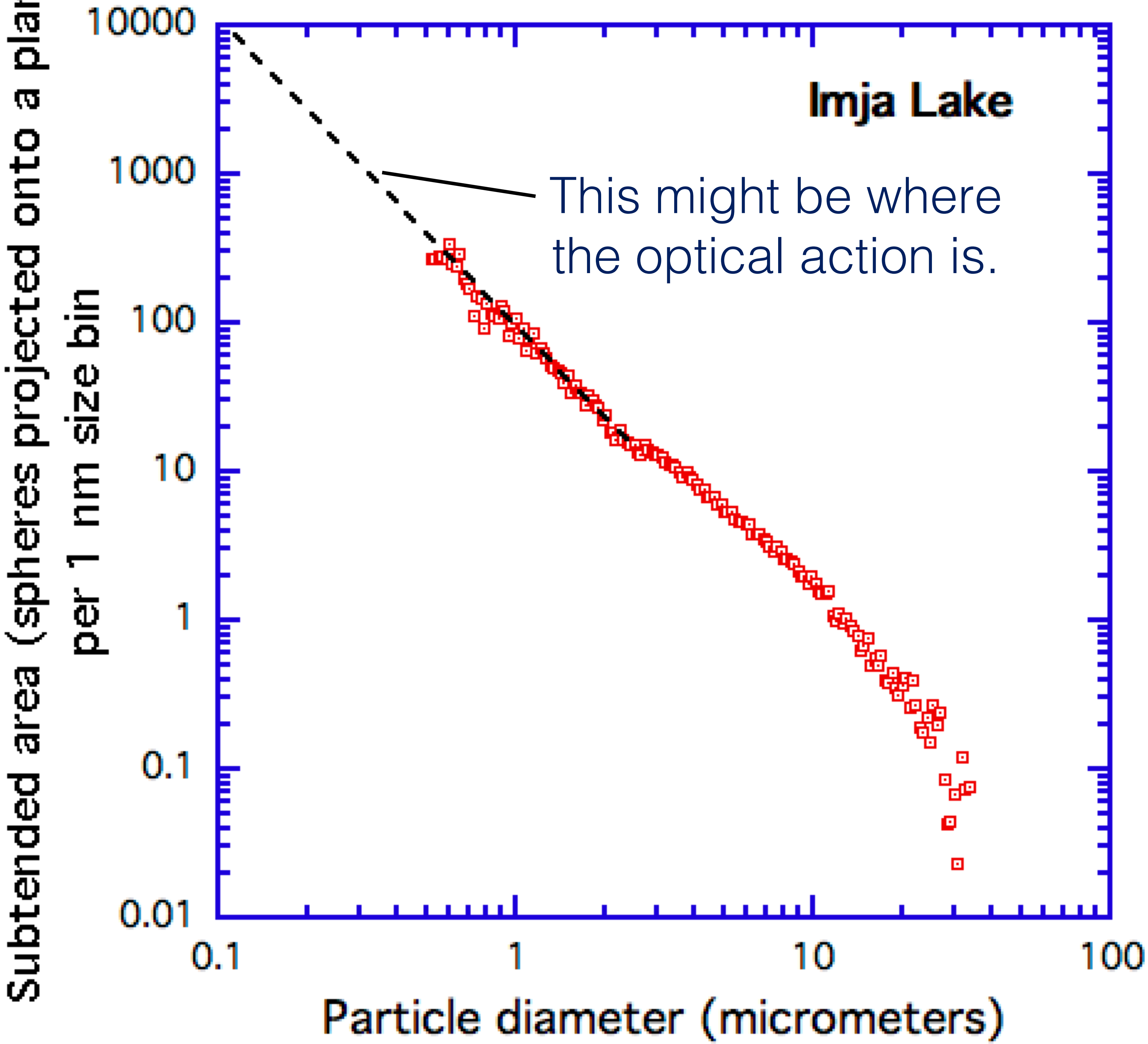


Phase	Weight %	Index of refraction
Quartz	31.4	1.549
Plagioclase	27.8	1.535
K-feldspar	18.8	1.526
Mica (Musc.)	7.7	1.588
Calcite	7.6	1.545
Wollastonite	6.7	1.636

- smectite present (abundance unknown)
- wollastonite tentative
- minor phases (<5 wt%) yet to be identified

n = 1.54 would approximate all of these

Suspended particle size-frequency distribution



Glacier Lake Assisted Melting (GLAM)

GLAM BioLith RT

Lakes Bio-Lithological Optical/RT Modeling, Water Components Concentration Retrieval/Mapping Effort, and Lake Temperature Distribution Simulations

Overview

- **IOPs, Physics occuring in the water**: Absorption coefficient, backscattering coefficient, extinction coefficient, and single scattering albedo are **Inherent Optical Properties (IOPs)** of a water body. They depend only on the medium composition

- **AOPs, what a satellite sees:** Radiance reflectance, **remote sensing reflectance**, and irradiance reflectance are **Apparent Optical Properties (AOPs)** of a water system. They also depend on the incoming light's geometric distribution

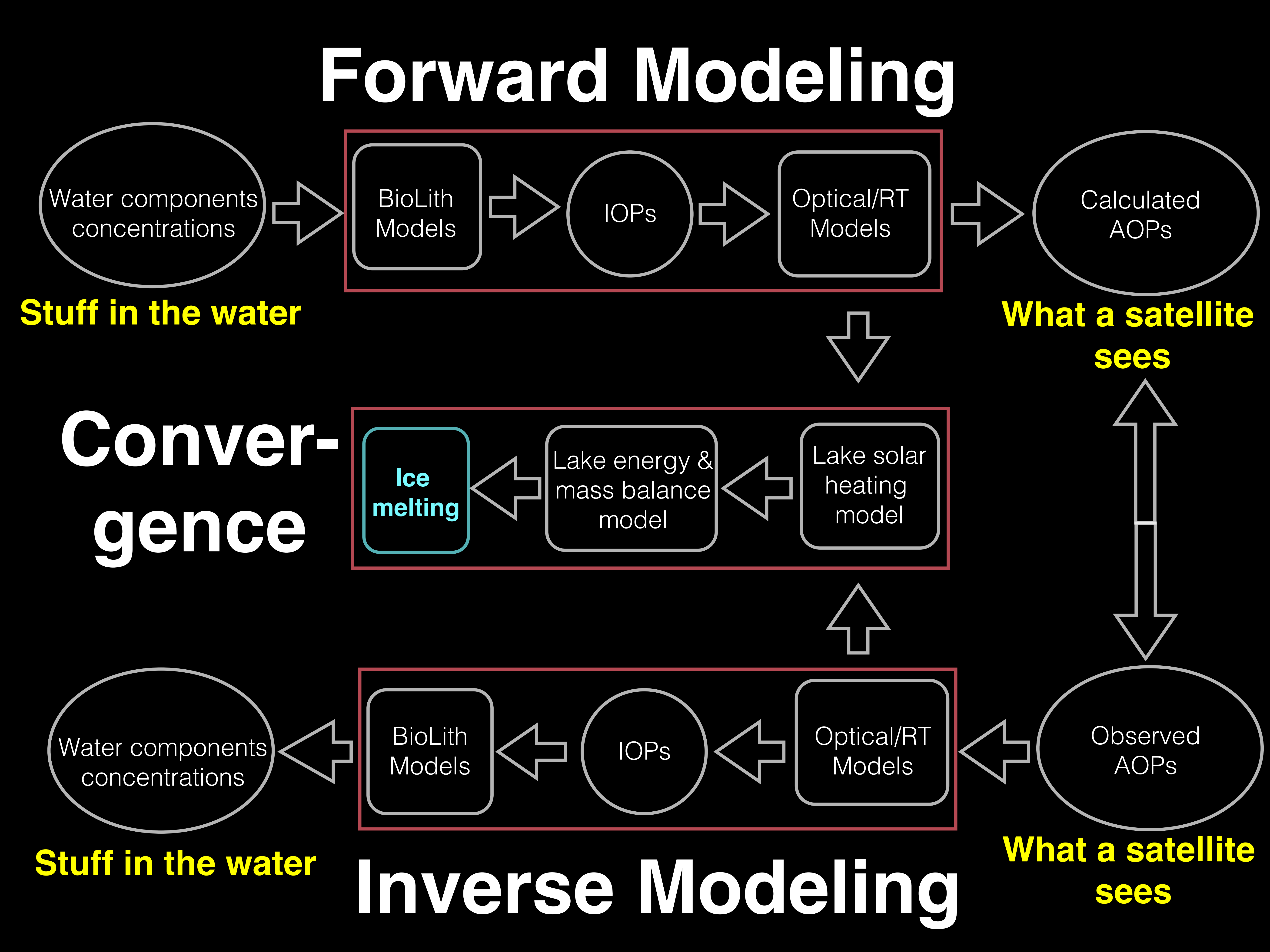
- **Stuff in the water (as well as the water itself):** Physical components such as **Phytoplankton**, **detritus**, colored dissolved organic matter, and **inorganic particles** that are present in the water body influence the IOPs; and hence the AOPs of the water column

- Water components concentrations, IOPs, and AOPs are related through mathematical equations called **Bio-Lithological Optical/Radiative Transfer (RT) models** [1]. **This is what we are building.**

- ***This is why we are building it:*** **The Radiative Transfer affects how much and where solar energy is absorbed by the water, hence heating of the lake:**

Goals

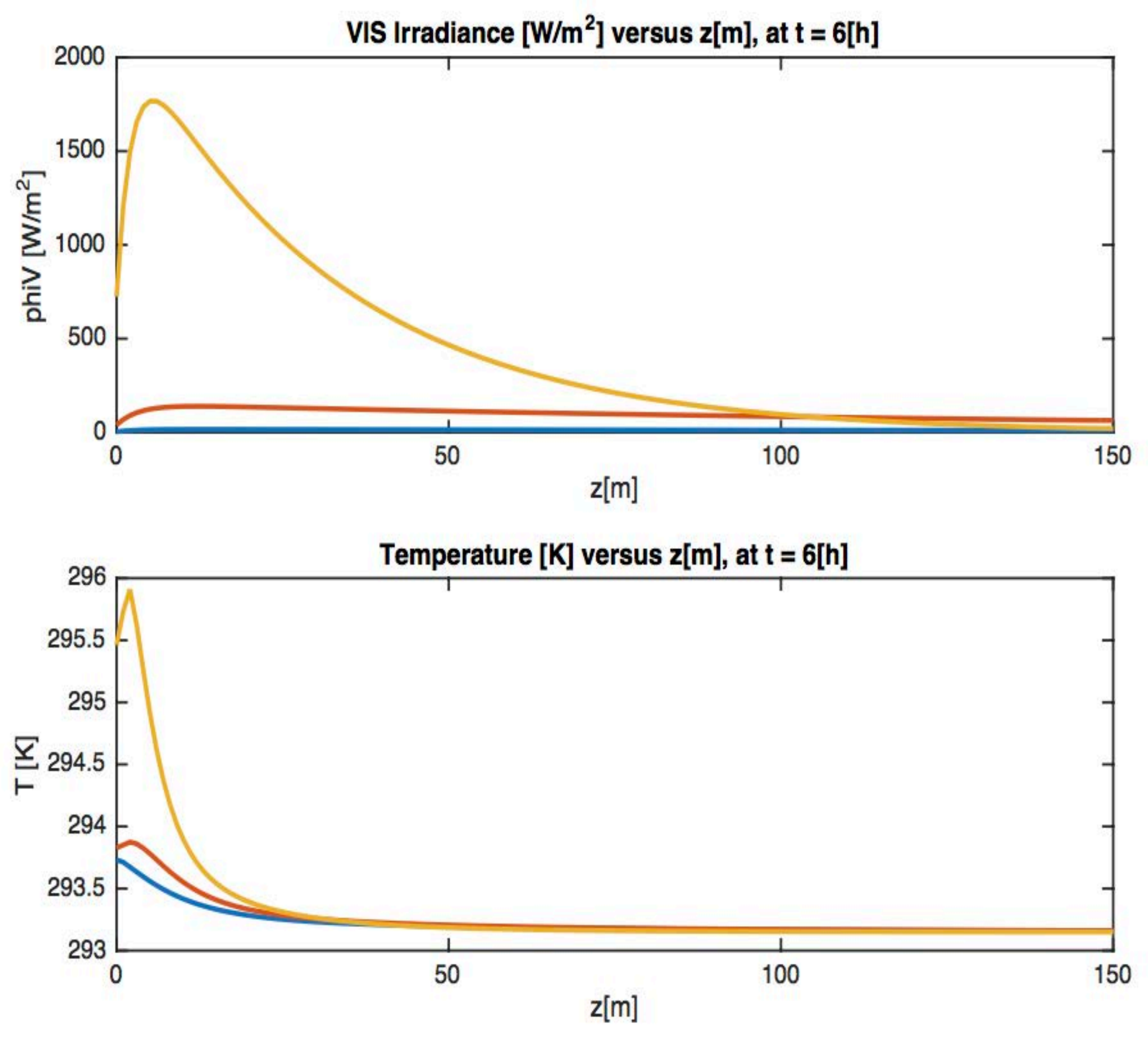
- Development of Bio-Lithological Optical/RT models for glacier lakes water (**forward modeling**)
- **Validation** of Bio-Lithological Optical/RT models via sensitive analysis and in-situ water samples (from Imja lake and Thulagi lake, Himalaya)
- Estimating the concentration of the physical components that are deposited into the lake due to glacier dynamics via Bio-Lithological Optical/RT model inversion (**inverse modeling**)
- Using the retrieved concentrations to run **temperature distribution simulation** for the lakes of interest


Forward Modeling
Water components concentrations
Stuff in the water
BioLith Models
IOPs
Optical/RT Models
Calculated AOPs
What a satellite sees
Conver-gence
Ice melting
Lake energy & mass balance model
Lake solar heating model
Water components concentrations
Stuff in the water
BioLith Models
IOPs
Optical/RT Models
Observed AOPs
What a satellite sees
Inverse Modeling

Achievements

- **GLAM BioLith RT**: Matlab code for Bio-Lithological Optical/RT forward and inverse modeling, based on [1,2,3,4]

- **Radiative Heat Transfer Equations (RHTEs)**: Matlab code for spherically visible irradiance and the temperature distributions in lake water simulations [8]



Coming next

- Water component concentrations retrieval via **GLAM-BioLith RT** inversion (classical and Bayesian)
- Temperature distribution simulation by using **RHTEs** with retrieved water component concentrations as inputs

References

- [1] Claudia Giardino, Gabriele Candiani, Mariano Bresciani, Zhongping Lee, Stefano Gagliano, Monica Pepe (2011), BOMBER: A tool for estimating water quality and bottom properties from remote sensing images, Computers & Geosciences
- [2] Claudia Giardino, Mariano Bresciani, Emiliana Valentini, Luca Gasperini, Rossano Bolpagni, Vittorio E. Brando (2014) Airborne hyperspectral data to assess suspended particulate matter and aquatic vegetation in a shallow and turbid lake, Remote Sensing of Environment
- [3] Peter Gege (2013) WASI-2D: A software tool for regionally optimized analysis of imaging spectrometer data from deep and shallow waters, Computers & Geosciences
- [4] Peter Gege (2015) The Water Color Simulator WASI, User manual for WASI version 4.1
- [5] Zhongping Lee, Kendall L. Carder, Curtis D. Mobley, Robert G. Steward, and Jennifer S. Patch (1998), Hyperspectral remote sensing for shallow waters. 1. A semianalytical modelb, Optical Society of America
- [6] Zhongping Lee, Kendall L. Carder, Curtis D. Mobley, Robert G. Steward, and Jennifer S. Patch (1999), Hyperspectral remote sensing for shallow waters: 2. Deriving bottom depths and water properties , by optimization, Optical Society of America
- [7] A. Albert, C.D. Mobley (2003), An analytical model for subsurface irradiance and remote sensing reflectance in deep and shallow case-2 waters, Optical Society of America
- [8] Enrico Schiassi, Roberto Furfaro, and Domiziano Mostacci (2016), Bayesian inversion of coupled radiative and heat transfer models for asteroid regoliths and lakes, Radiation Effects and Defects in Solids, 171:9-10, 736-745, DOI: 10.1080/10420150.2016.1253091