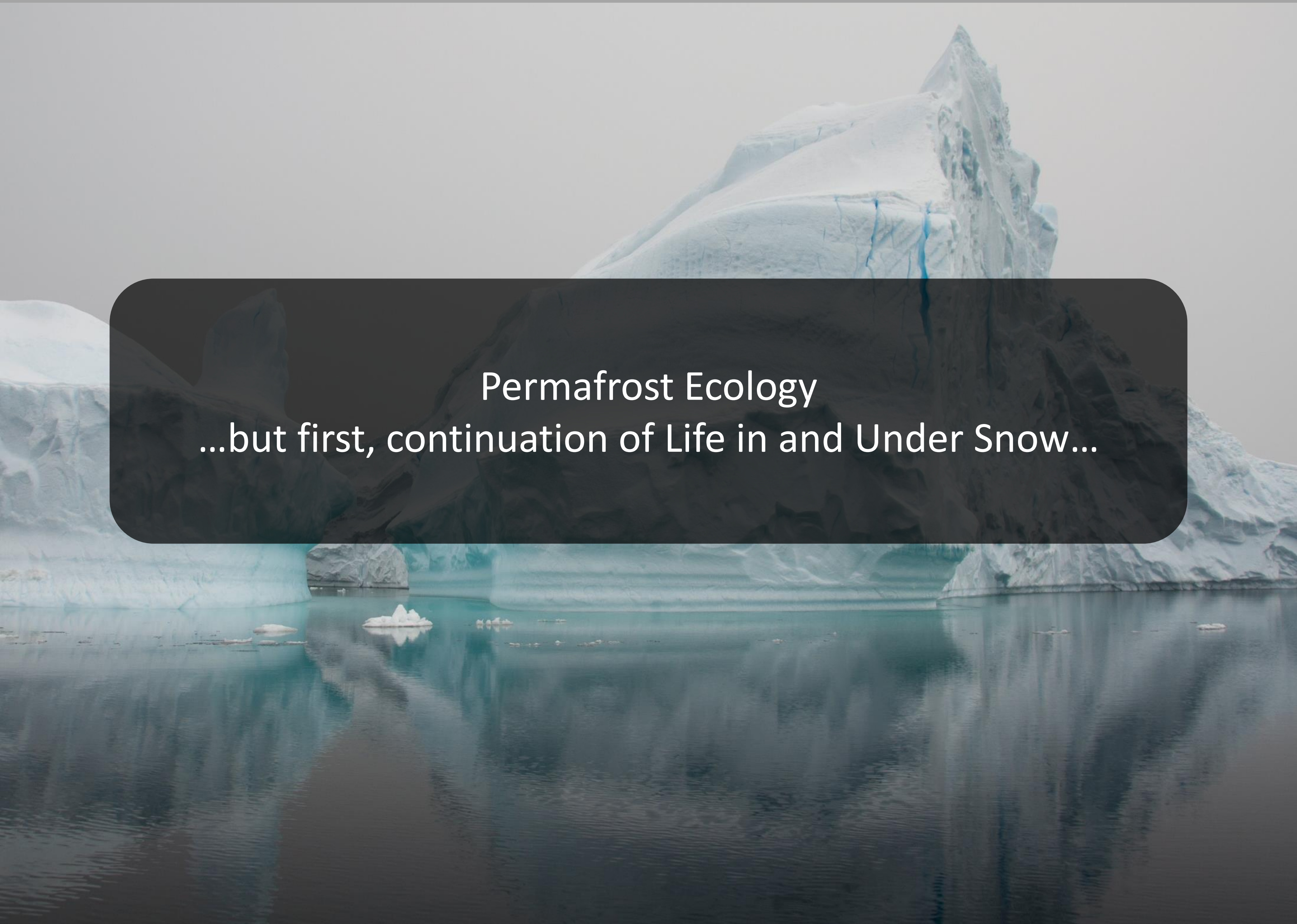


Permafrost Ecology
…but first, continuation of Life in and Under Snow…

Announcements

- Questions on annotated bibliography, presentations…

1. Which of the following organisms are potential mixotrophs; diatoms, dinoflagellates, ciliates?

   Dinoflagellates and ciliates

2. DMS, a byproduct of DMSP catabolism, does what in the atmosphere?

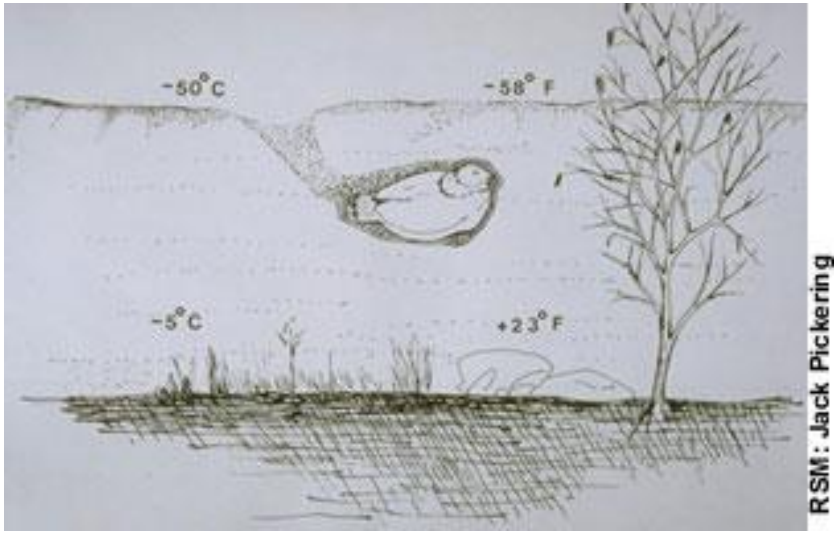
   Serves as a cloud condensation nuclei

3. Which of the following undergo respiration: bacteria, diatoms, dinoflagellates, ciliates?

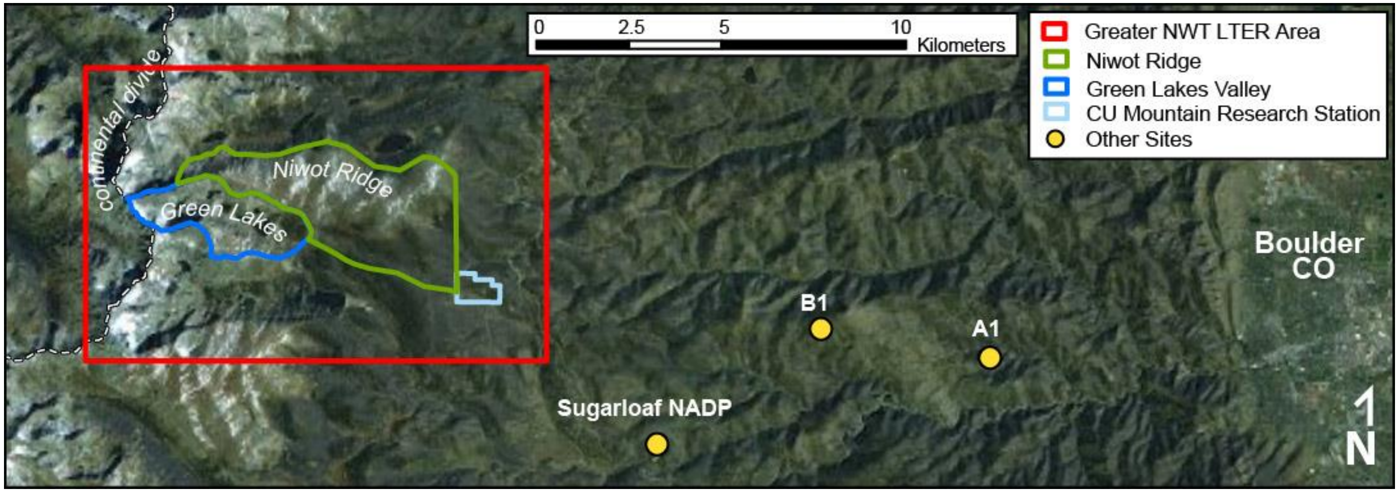
   All of the above!

1. From where does the *Chlamydomonas* bloom originate each year?
2. List three reasons the snow surface is a more harsh environment than the ice-water interface.
3. Why might snow algae blooms be enhanced near penguin rookeries?

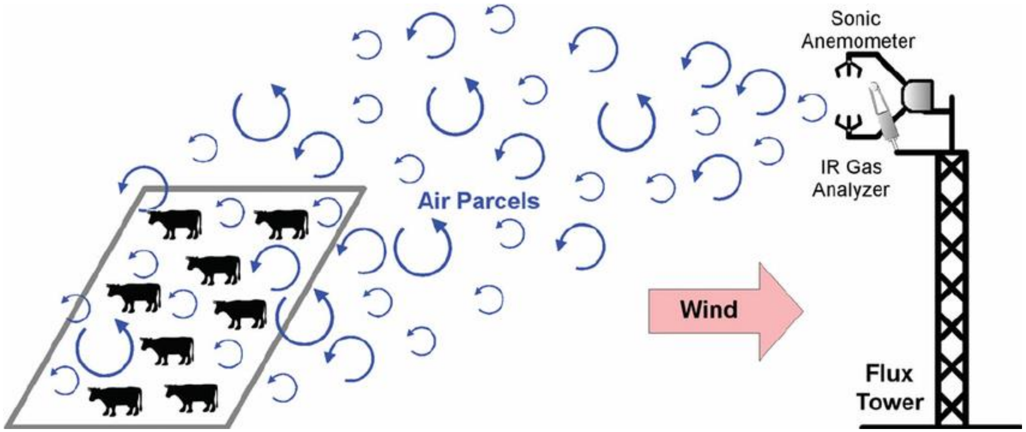
Subnivial environment



- The base of the snowpack is comparatively warm, and high in nutrients and organic matter
- These trends extend to the soil below the snowpack, which remains biologically active throughout winter



- The Niwot Ridge LTER site in Colorado is one of the best-studied temperate snow ecosystems
- Eddy-flux covariance towers at the site allow observations of the inorganic carbon exchange between the atmosphere and soil/biomass



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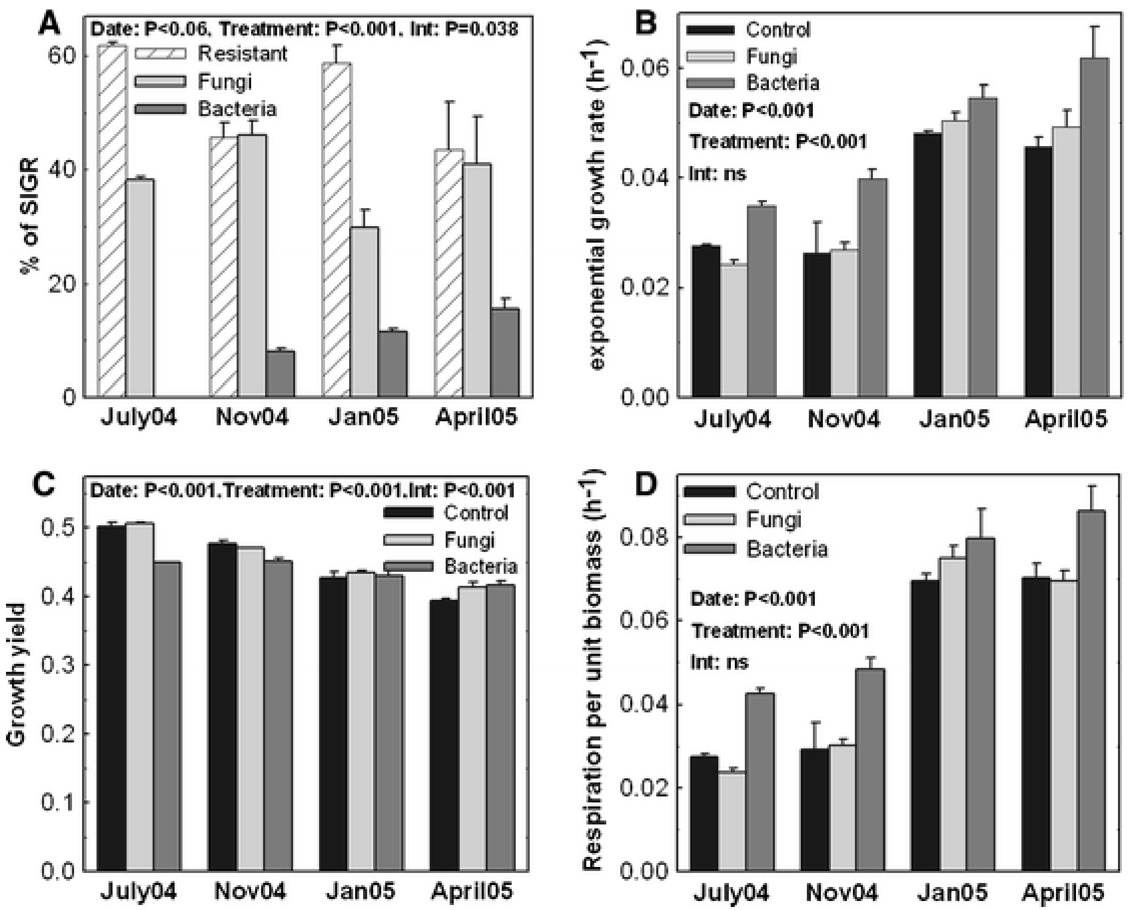
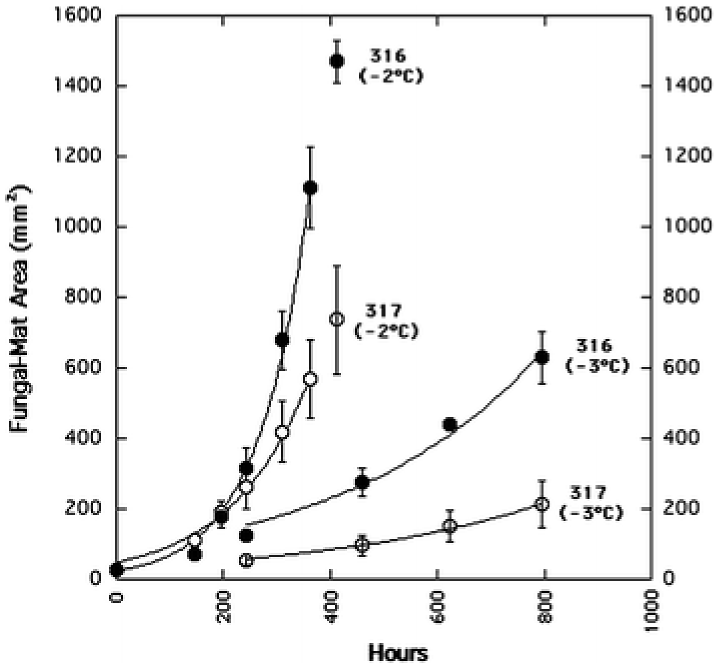
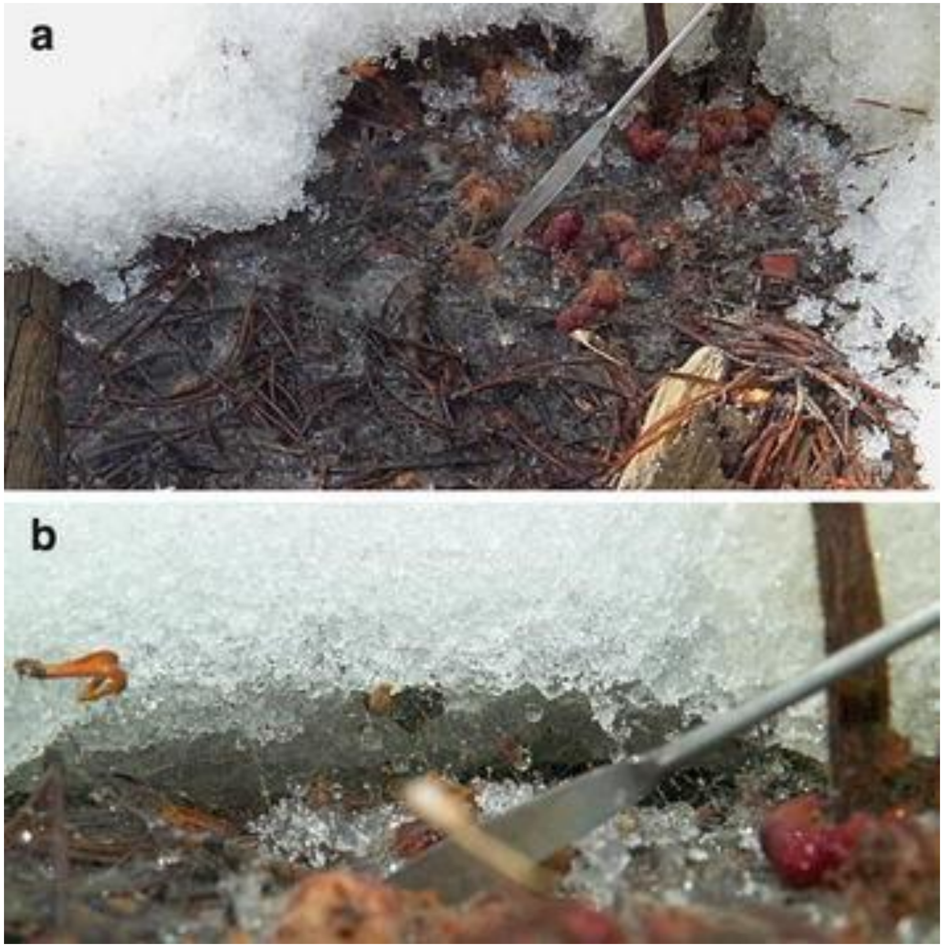


Lipson et al., 2009

- Fungal and bacterial respiration remains high during winter





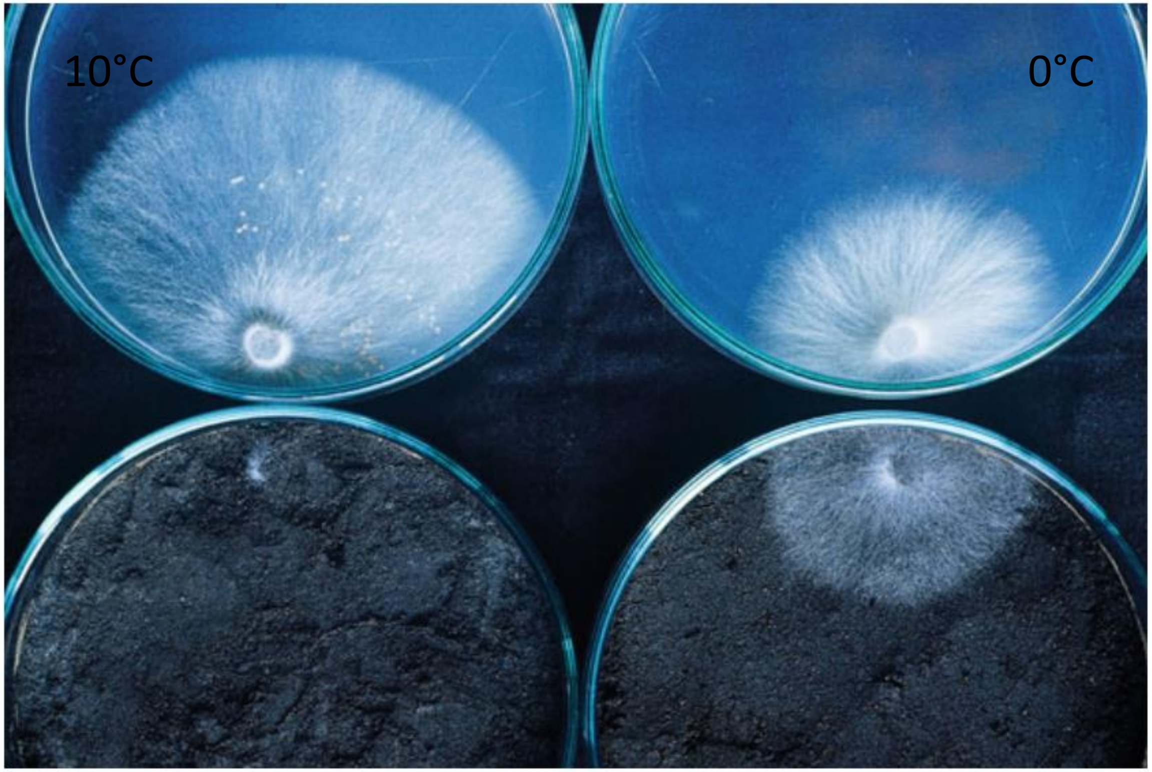
Lipson et al., 2009

- Fungi (snow molds) are a major component of the subnivial environment
- Snow molds are extremely sensitive to temperature change
- Q: Does this imply a high or low Q10 value?

Fig. 1.2 Turfgrass damage in a golf course nursery induced by *Typhula ishikariensis*. Fungicide applications prior to snow cover protected plants from damage, and the plants greened up quickly after snow melt (*left-side* plot). Leaves were killed, but later green shoots appear indicating that crowns and roots were not also entirely killed (*right-side* plot)

- Ecologically snow molds are good, because they re-mineralize organic matter
- However, snow molds are a significant plant pathogens
- Opportunistically attack plants when they become resource limited at the end of winter

Matsumoto and Hsiang, 2018



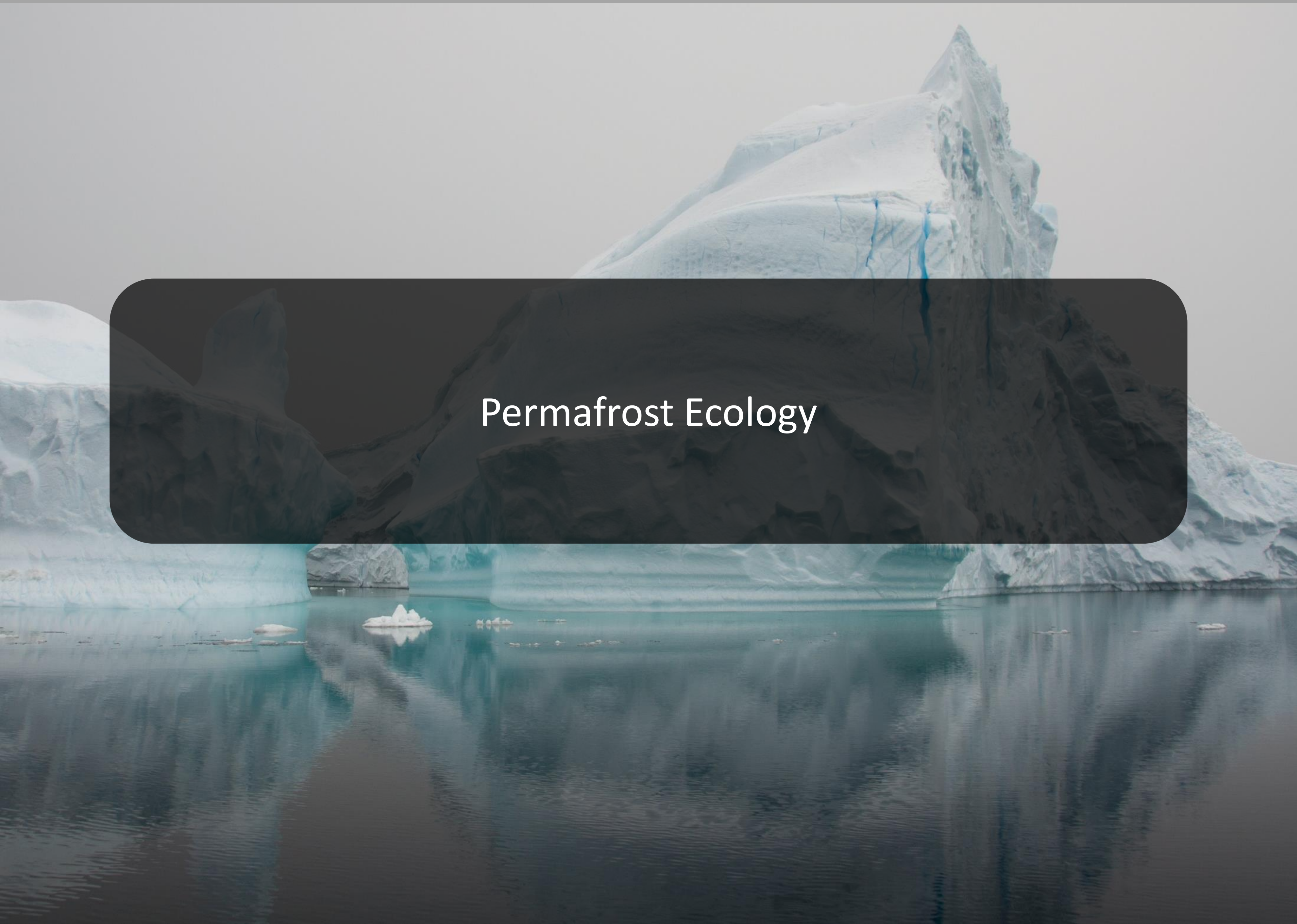
- Experiments with snow molds demonstrate *enhanced* growth well below optimal growth temperature – why?
- This is an excellent example of the complicated relationship between temperature and competition

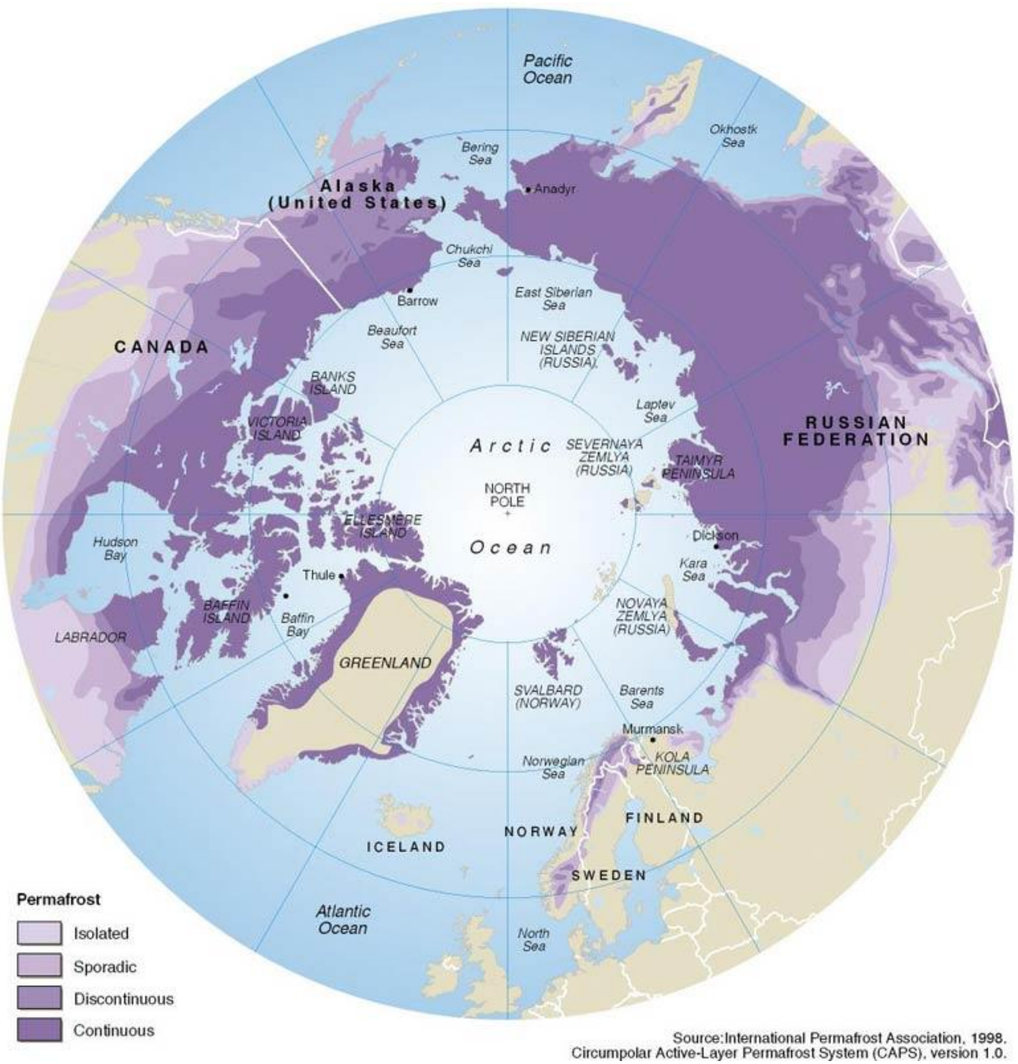
Matsumoto and Hsiang, 2018

- Hair ice caused by the fungus *Exidiopsis effuse*
- Fungal metabolites inhibit ice recrystallization similar to ice binding proteins
- The process is still not well understood…

Hoffman et al., 2015

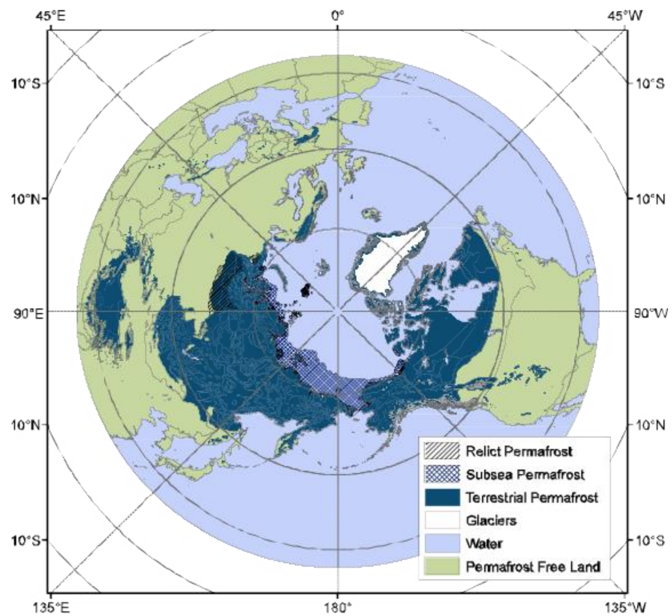
Permafrost Ecology

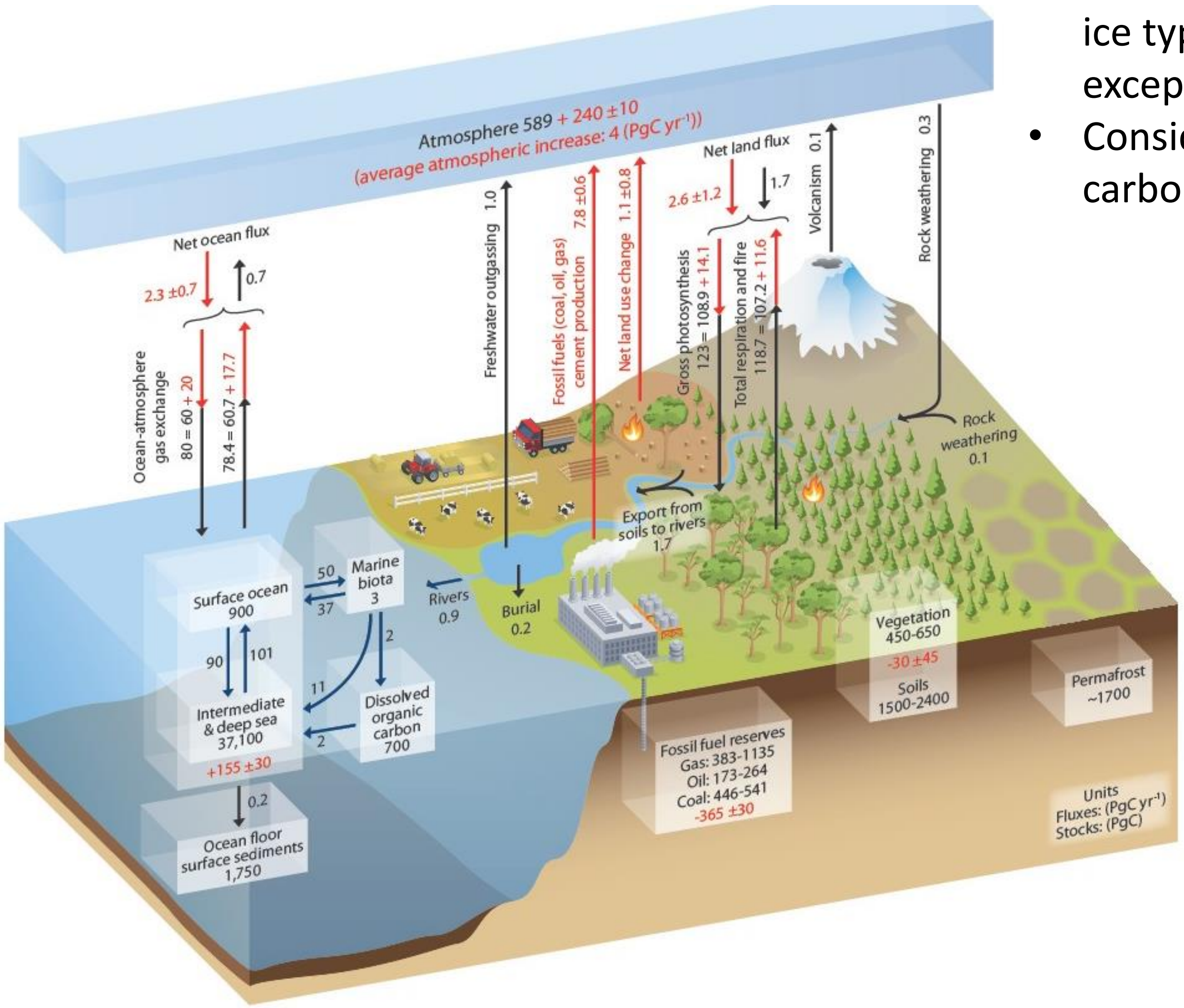




Permafrost: soil frozen for more than two consecutive years

- More widespread in the northern hemisphere
- Present at the periphery of the Antarctic, and at high altitudes throughout the world
- Q: Is there permafrost below glacial ice?





- Permafrost is similar to other ice types we've discussed, except:
- Considerably more organic carbon

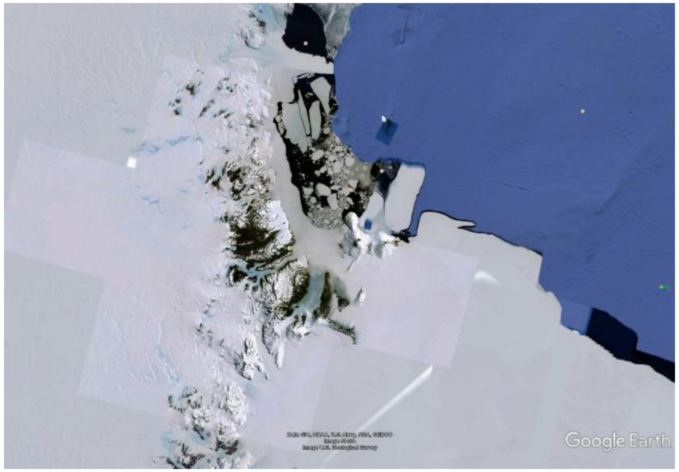
- Permafrost exists in the Arctic and Antarctic, but is much more widespread in the Arctic
- We will focus our discussion on the Arctic – why?

ARTICLE

Received 16 Aug 2011 | Accepted 14 Dec 2011 | Published 7 Feb 2012 DOI:10.1038/ncomms1645

Rapid microbial response to the presence of an ancient relic in the Antarctic Dry Valleys

Grace Tiao[1,2], Charles K. Lee[1], Ian R. McDonald[1], Donald A. Cowan[3] & S. Craig Cary[1,4]



and reducing ultraviolet exposure. In a unique, multi-year mummified seal transplantation experiment, we found that endemic Dry Valley microbial communities responded to these changes within 3 years, resulting in a sevenfold increase in CO_2 flux and a significant reduction in biodiversity. These findings challenge prevailing ideas about Antarctic Dry Valley ecosystems and indicate that current and future environmental conditions may strongly influence the ecology of the dominant biota in the Dry Valleys.

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Table 1 | Radiocarbon dating of seal tissue samples near Miers Valley.

Sample	Lab code	$F^{14}C$* (%)	Age† (BP‡)	Corrected§ age (BP)
Seal C, tooth	Wk-22932	79.4±0.2	1,854±32	764±32
Seal I‖, muscle	Wk-22933	84.4±0.2	1,365±32	275±32
Seal W, muscle	Wk-22935	84.0±0.2	1,398±34	308±34
Seal V, bone	Wk-22934	83.2±0.2	1,476±34	386±34
Cape Evans seal hair (circa 1901–1904)	Wk-22936	86.2±0.2	1,197±30	107±30

Calculations of conventional radiocarbon are based on a Libby half-life of 5,568 years with correction for isotopic fractionation applied; the corrected age takes into account the marine reservoir effect. Means are provided with ±1s.d.

*pMC, percent modern carbon.

†Conventional radiocarbon age[27].

‡Before present.

§Corrected using the radiocarbon and actual ages of a seal carcass outside the Cape Evans hut, killed during the *Discovery* expedition.

‖Seal I was used for the movement study.

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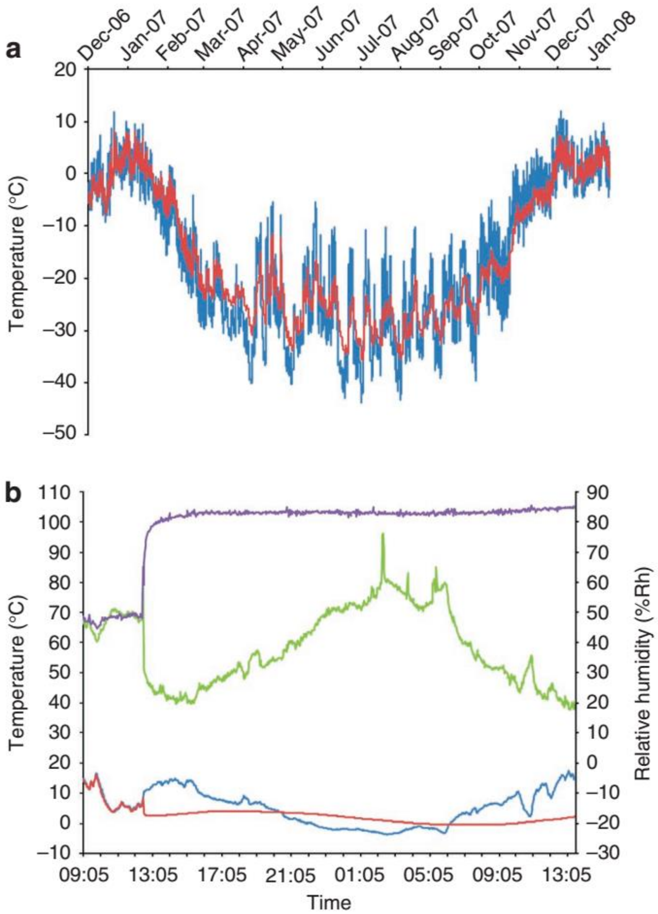

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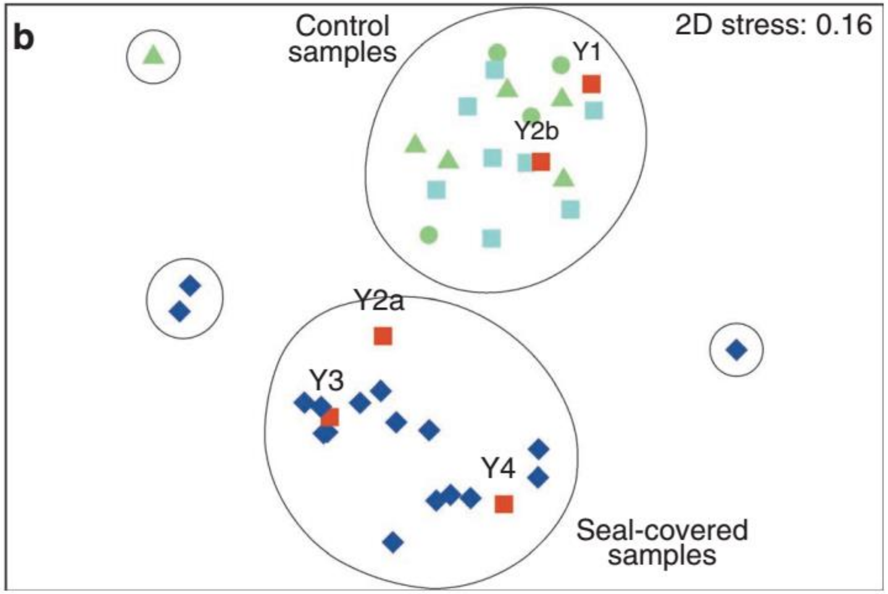
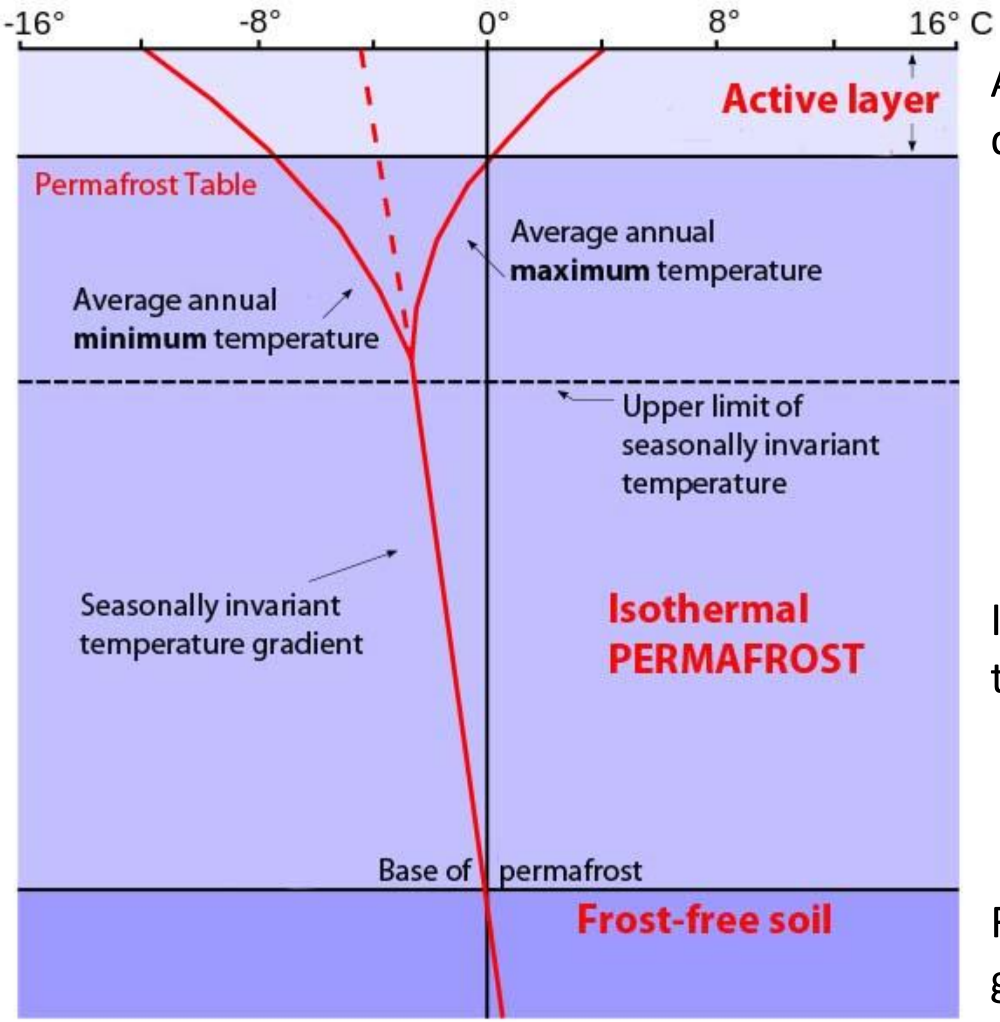


- After 3 years, samples below seal transplant begin to look like samples below the seal at the original location.
- Antarctic permafrost is active – even at the surface – things just happen very slow!

- Arctic permafrost is altogether different: wetter, with a seasonally warm active layer

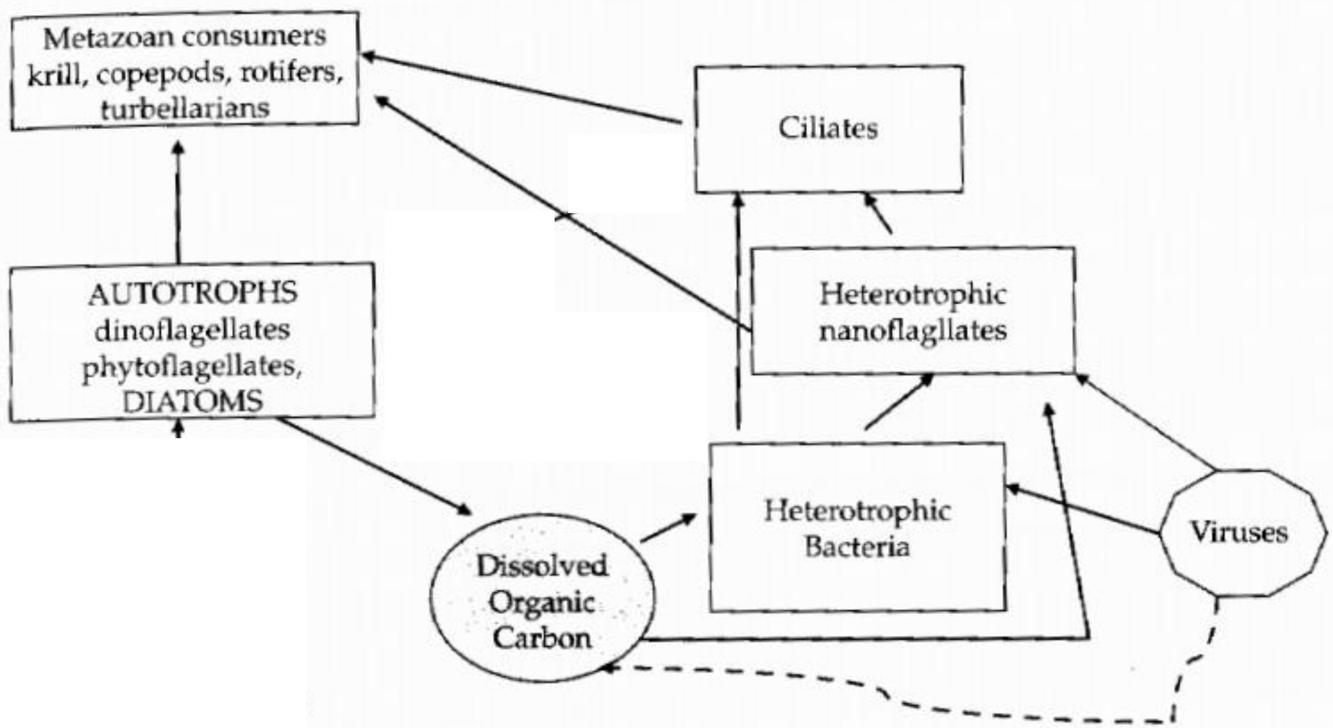
Q: Where is the "sweet spot" for life and why?



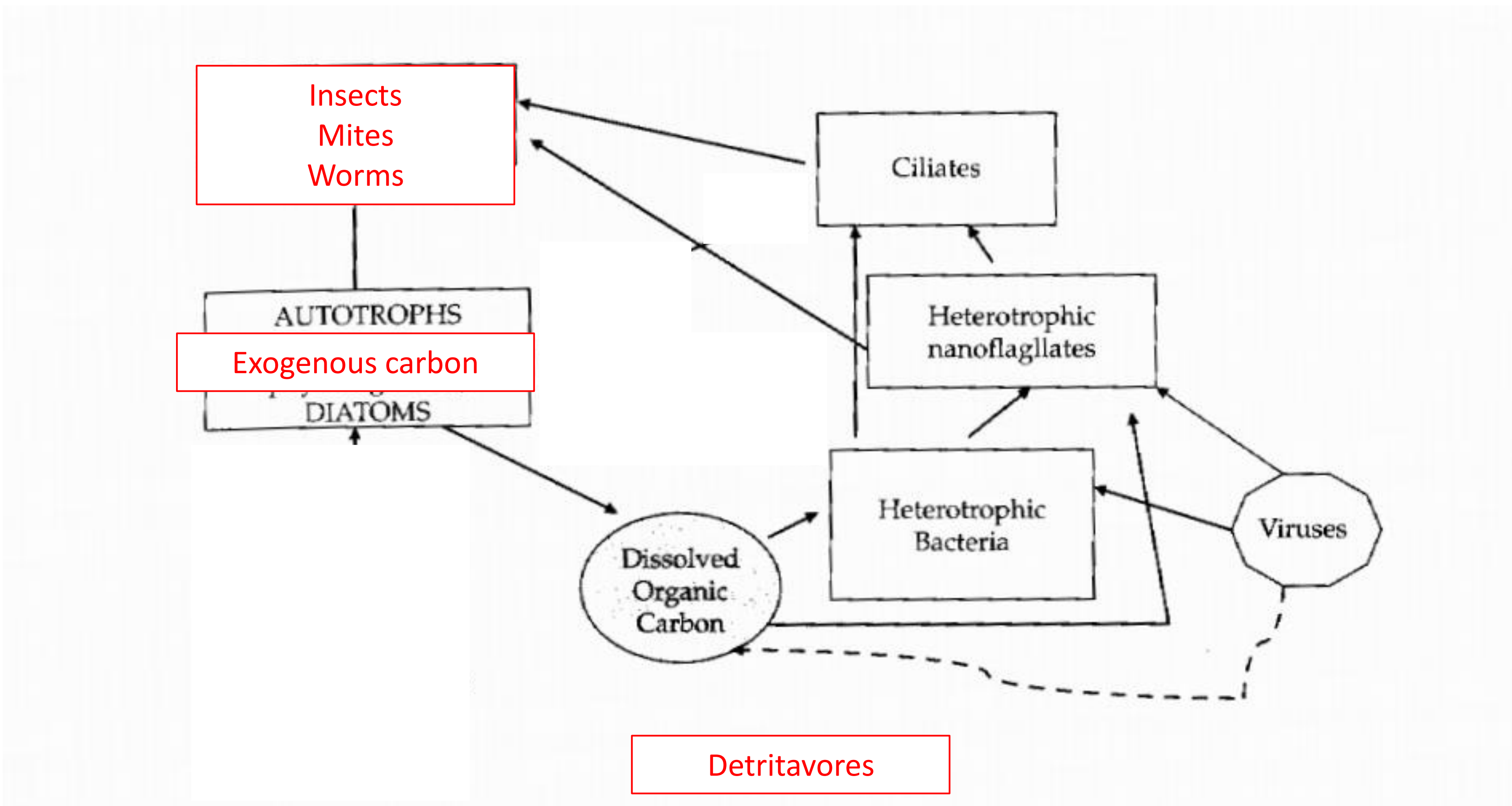
Active layer: warms above freezing during the summer

Isothermal permafrost: not prone to season warming.

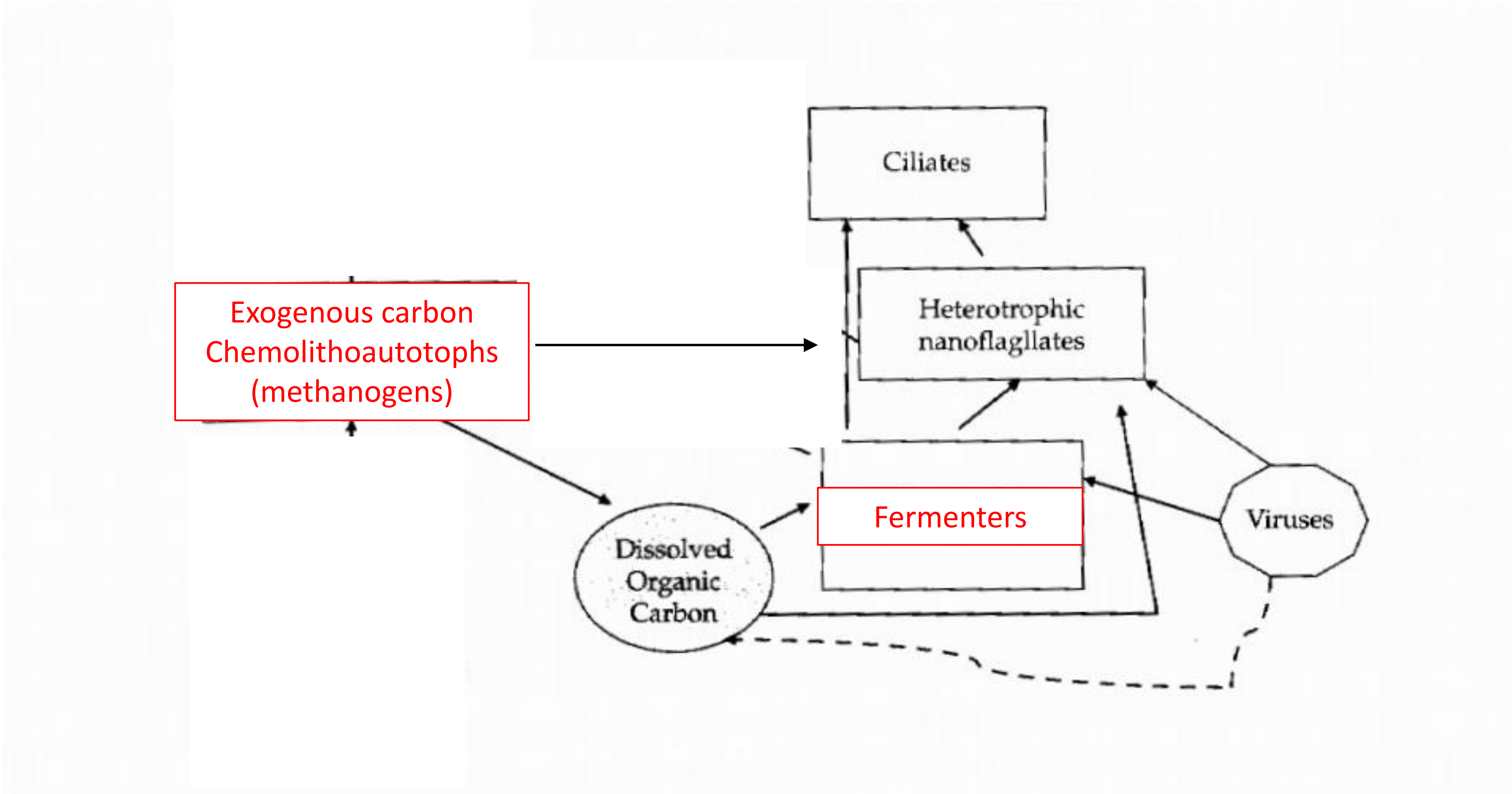
Frost-free soil warmed by geothermal energy.


Metazoan consumers
krill, copepods, rotifers,
turbellarians
Ciliates
AUTOTROPHS
dinoflagellates
phytoflagellates,
DIATOMS
Heterotrophic
nanoflagllates
Heterotrophic
Bacteria
Viruses
Dissolved
Organic
Carbon

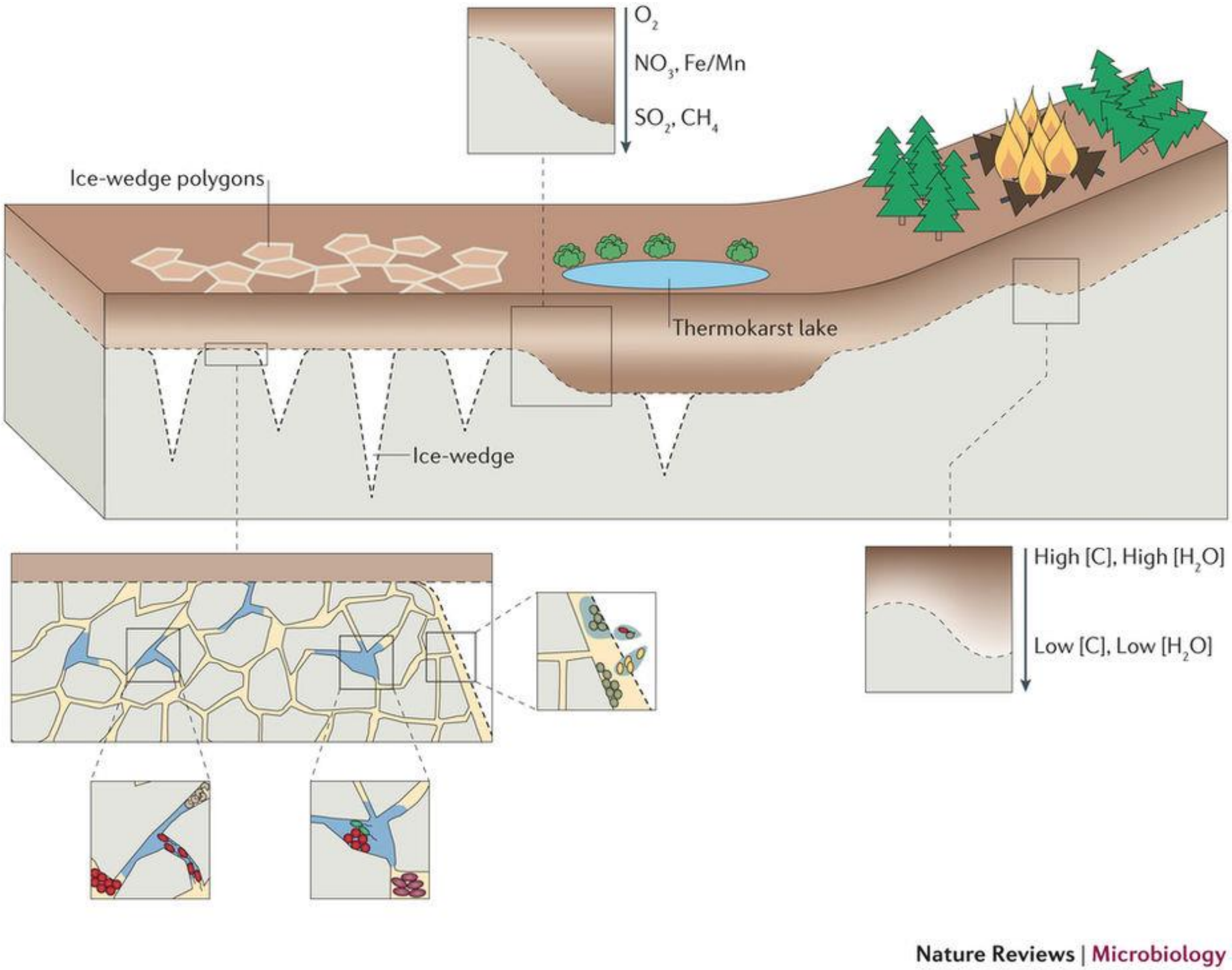
Permafrost foodweb, active layer



Permafrost foodweb, permafrost table



- The further you get from the oxidized atmosphere, the more *reduced* the environment

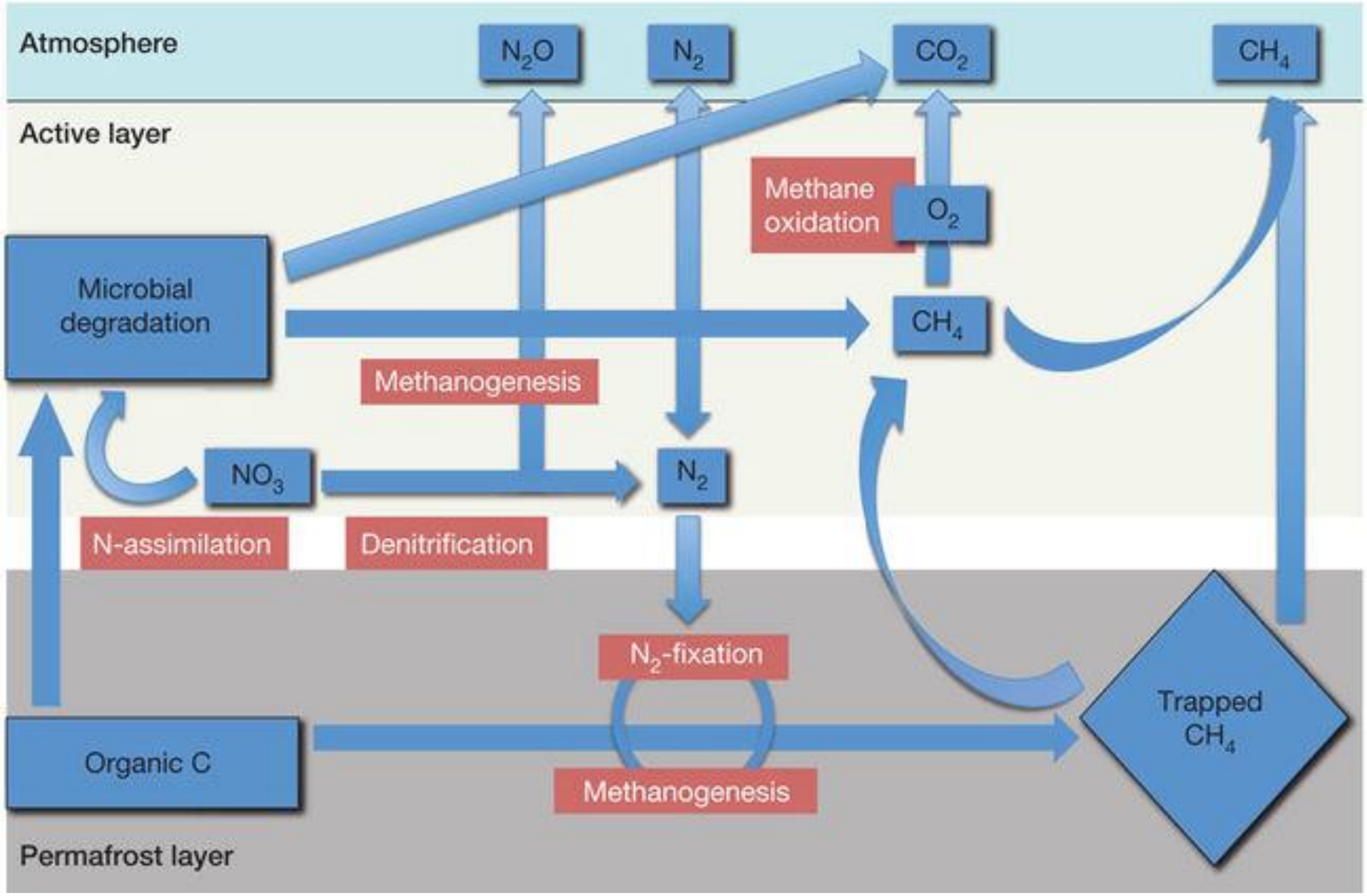


Jansson and Tas, 2014

- The further you get from the oxidized atmosphere, the more *reduced* the environment
- Compounds have lower affinities for electrons, and the difference in electron affinity is reduced
- At some point this becomes limiting for life, because the different in electron affinity is what provides proton motive force and enables ATP synthesis

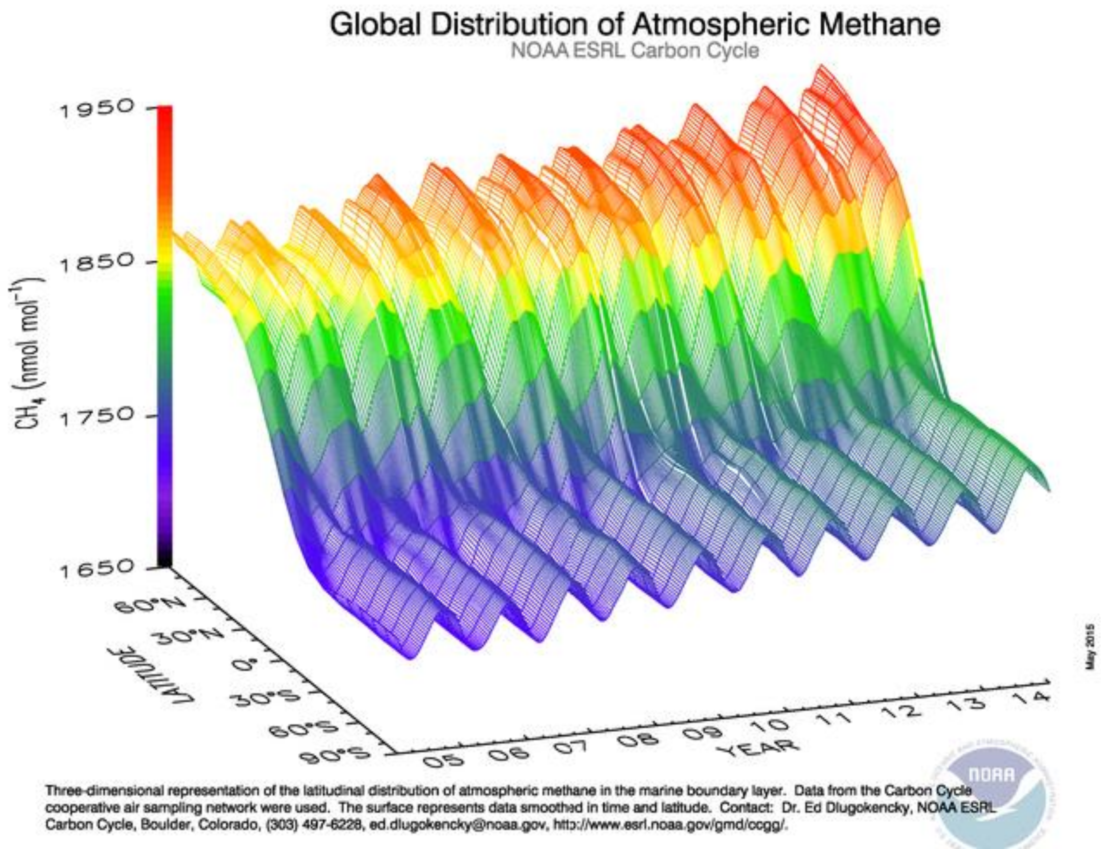
Common electron donors	Common electron acceptors
CH_2O	Oxygen
CH_4 Methanotrophy	Nitrate
NH_4^+	Mn(IV)
H_2	Fe(III)
Fe(II)	Sulfate
	CO_2 Methanogenesis

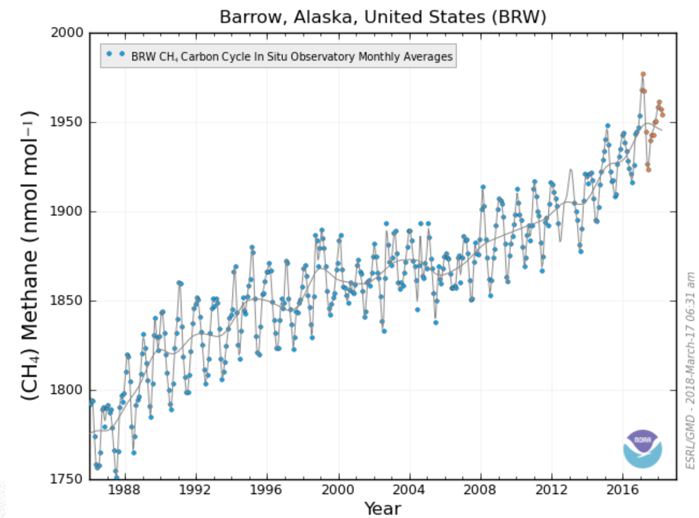
- Among the key permafrost metabolisms are those involving methane, including *methanogenesis* and *methanotrophy*



- Among the key permafrost metabolisms are those involving methane, including *methanogenesis* and *methanotrophy*
- Q: Why are methane metabolisms of particular interest?

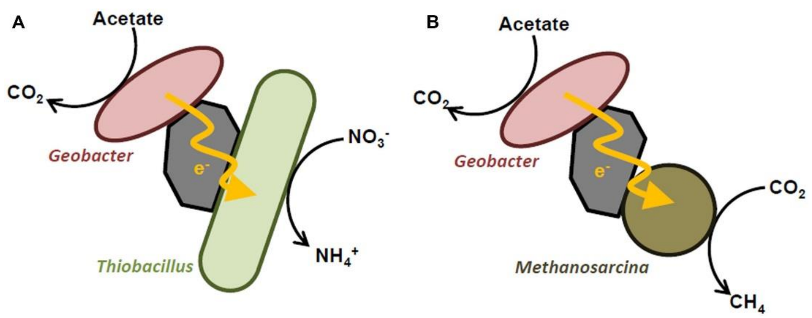
Mackelprang et al., 2011



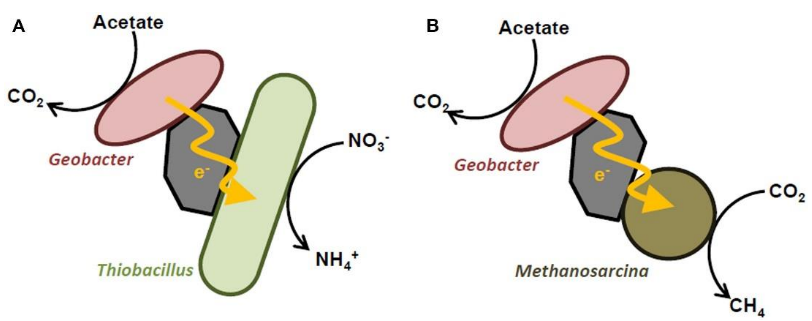


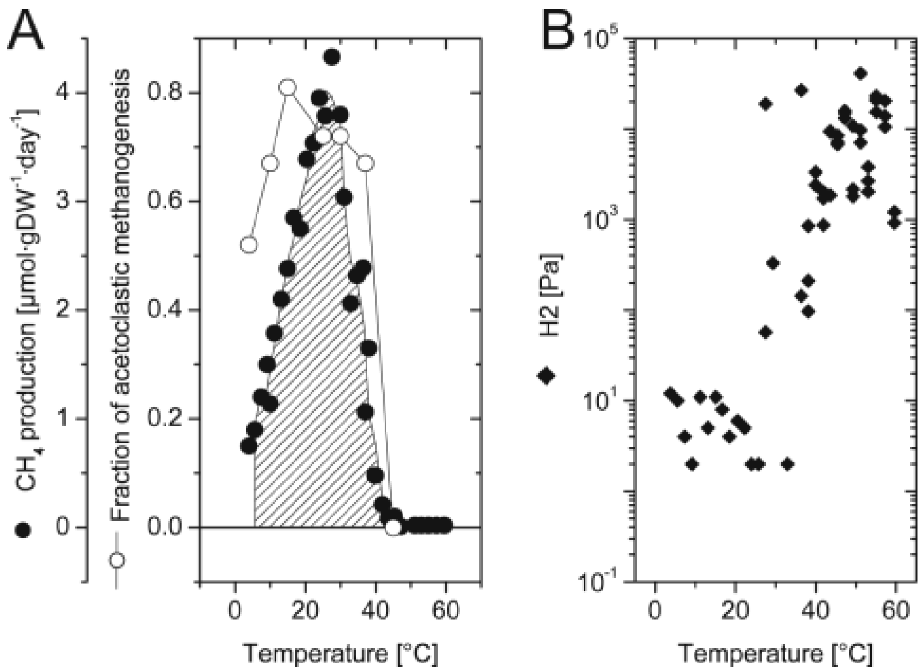
- Methane is 28x as efficient as trapping infrared radiation as CO_2. Fortunately for us it is more reactive, and has a short residence time in the atmosphere.
- Subject to a strong positive feedback

- Methanotrophy is relatively straightforward: CH_4 + electron acceptor -> CO_2
- Methanogenesis takes diverse forms, and can be much more complicated
  - Hydrogenotrophic methanogenesis: $H_2 + CO_2$ -> CH_4
    - But where does the hydrogen come from?



- Methanotrophy is relatively straightforward: CH_4 + electron acceptor -> CO_2
- Methanogenesis takes diverse forms, and can be much more complicated
  - Hydrogenotrophic methanogenesis: $H_2 + CO_2 \rightarrow CH_4$
    - But where does the hydrogen come from?
  - Acetoclastic methanogenesis: $CH_3COOH \rightarrow CO_2 + CH_4$
    - Dominates when C comes from carbohydrates
  - Balance between these is also temperature dependent

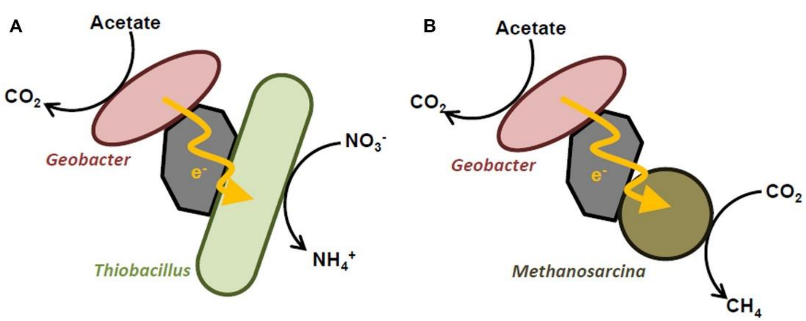


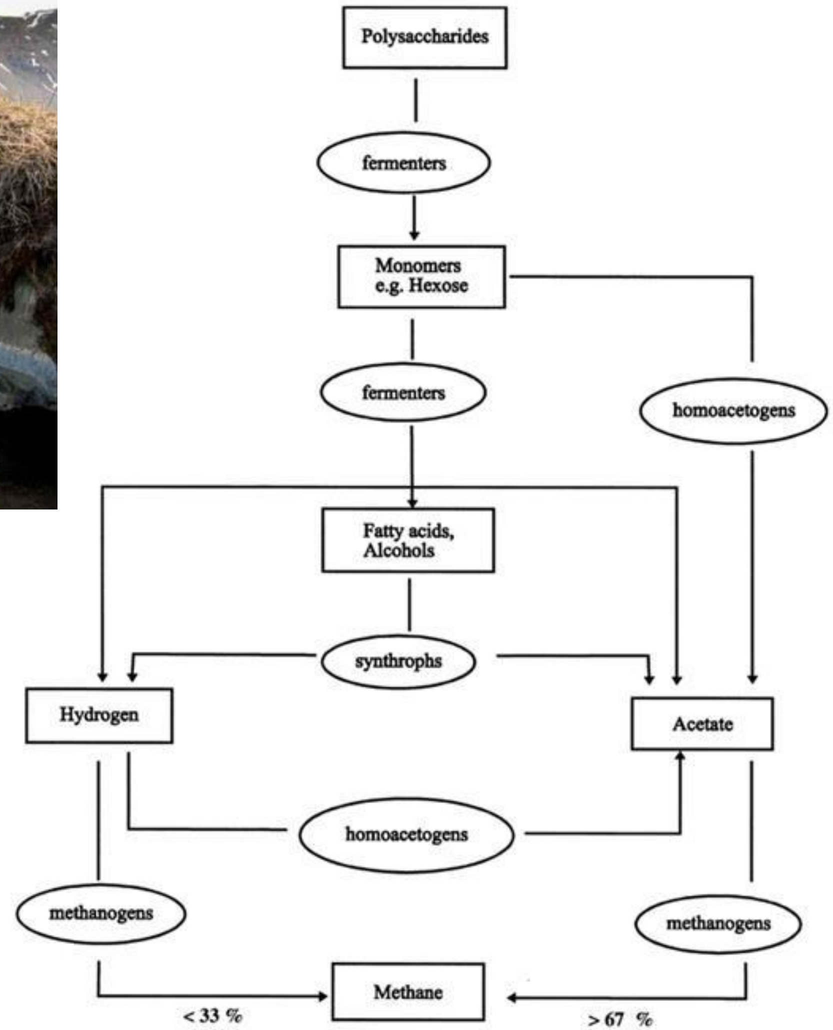


Open: fraction methane from acetate
Closed: methane production rate

Metje et al., 2007

SIO 121, Lecture 8: Permafrost ecology





Conrad et al., 1999

- Methanogenesis is significant wherever (wet) permafrost is found…
- Hypothesis: as permafrost melts tundra drains, reducing methane emissions
  - Evidence does not support this!

Environmental Science & Technology Article

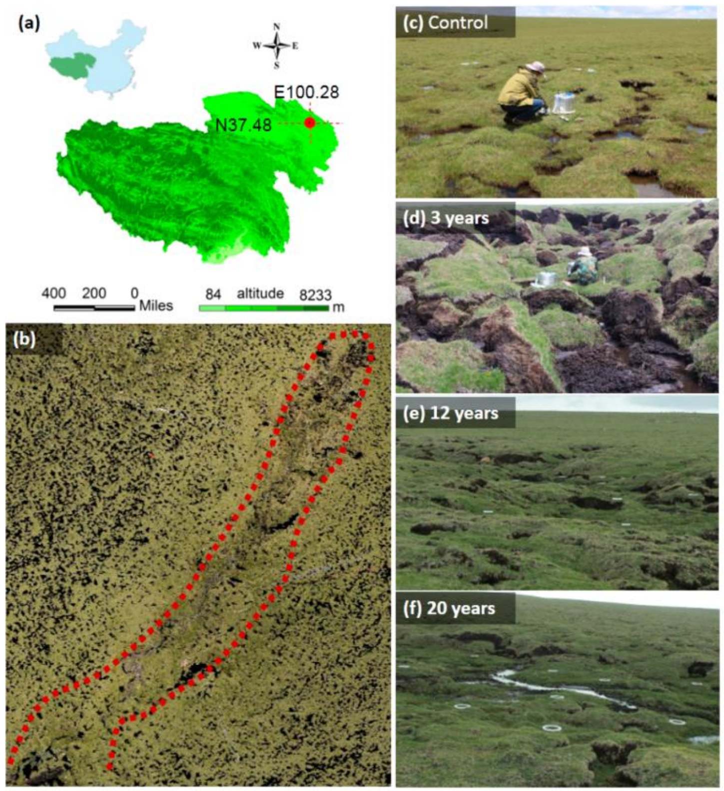
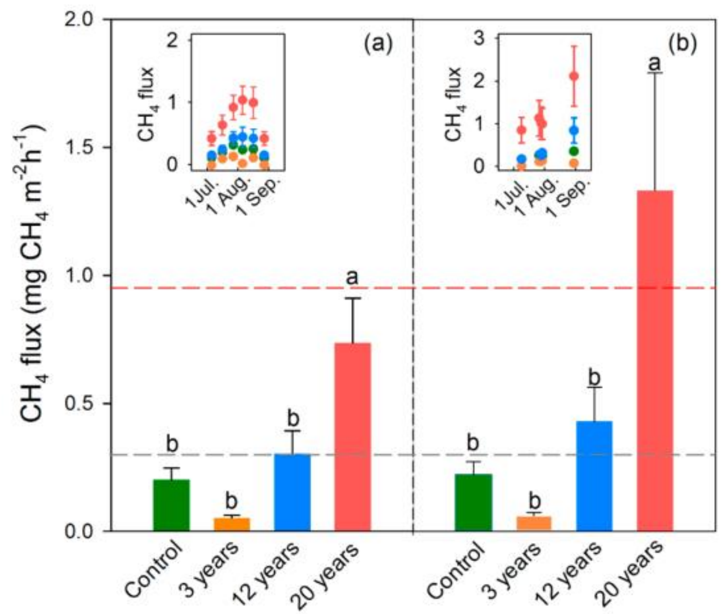
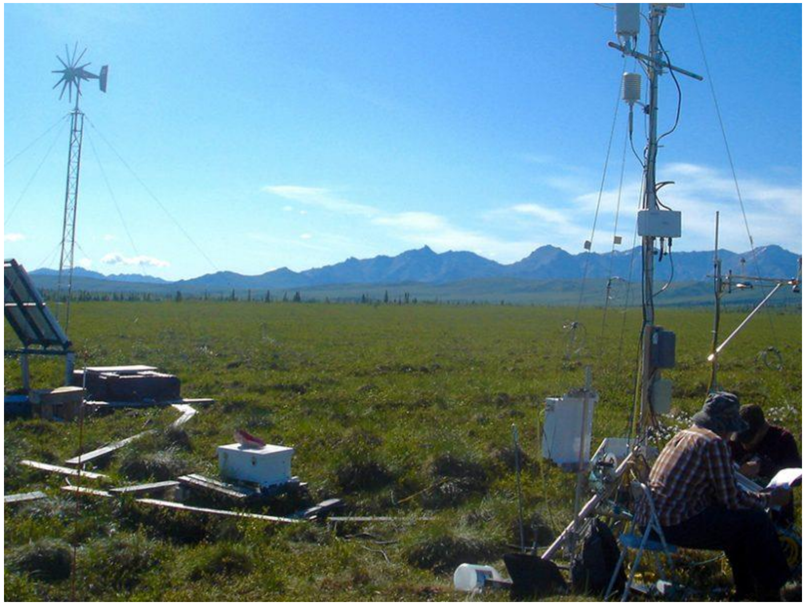


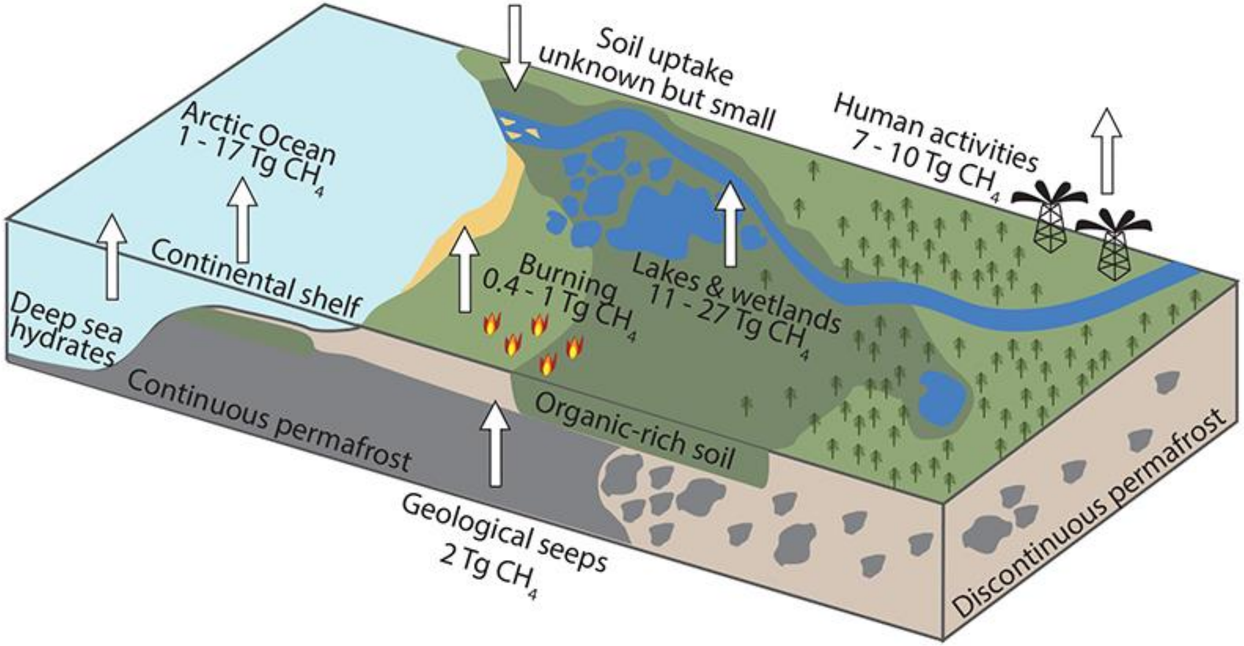
Figure 1. Location map of the study area (a), image of the thermo-erosion gully (b), and photographs of the different thaw stages (c−f). The red dot indicates our study site, and the image of the thermo-erosion gully was obtained by a high-resolution topographic model with LiDAR (VZ-400, Riegl, Horn, Austria, analyzed with Riscan pro 2.0 software).



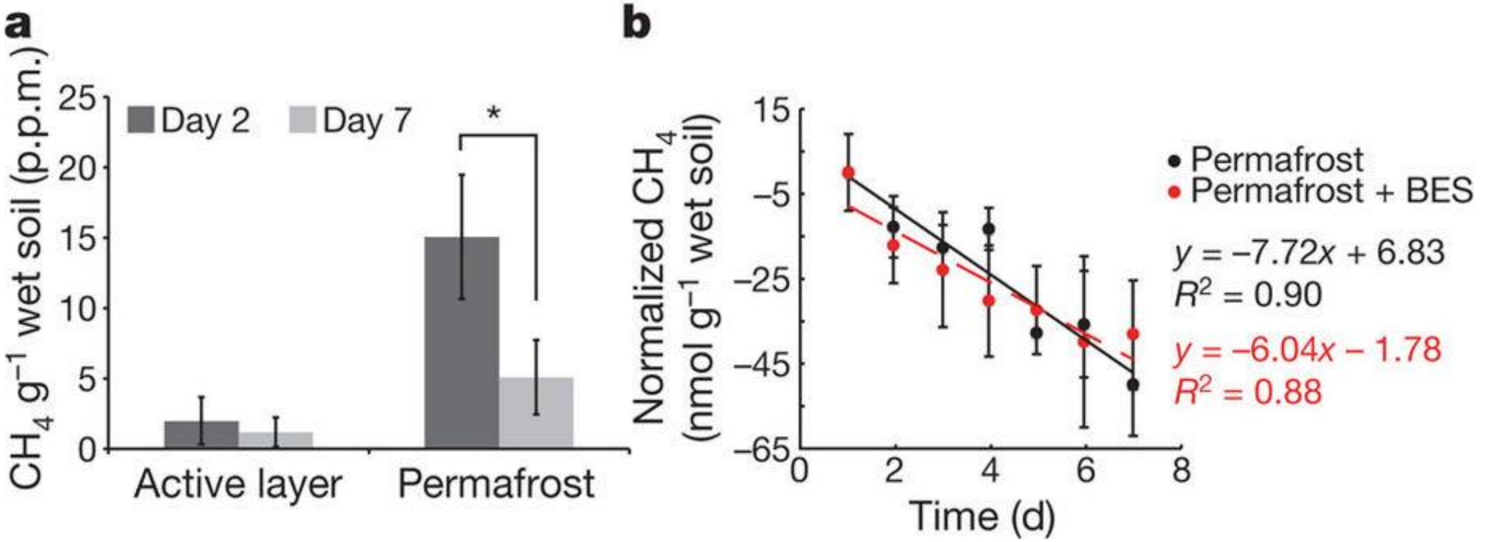
Yang et al., 2018



- ~6 Pg (6000 Tg) methane in atmosphere
- But we are NOT in steady state!
- Sources exceed sinks by ~25 Tg yr^{-1}



- What about the soil biological sink term?
- Very poorly constrained!



Mackelprang et al., 2011

- Back to the sunlit surface… concurrent with permafrost decay the Arctic is undergoing "Arctic Greening", also known as borealization

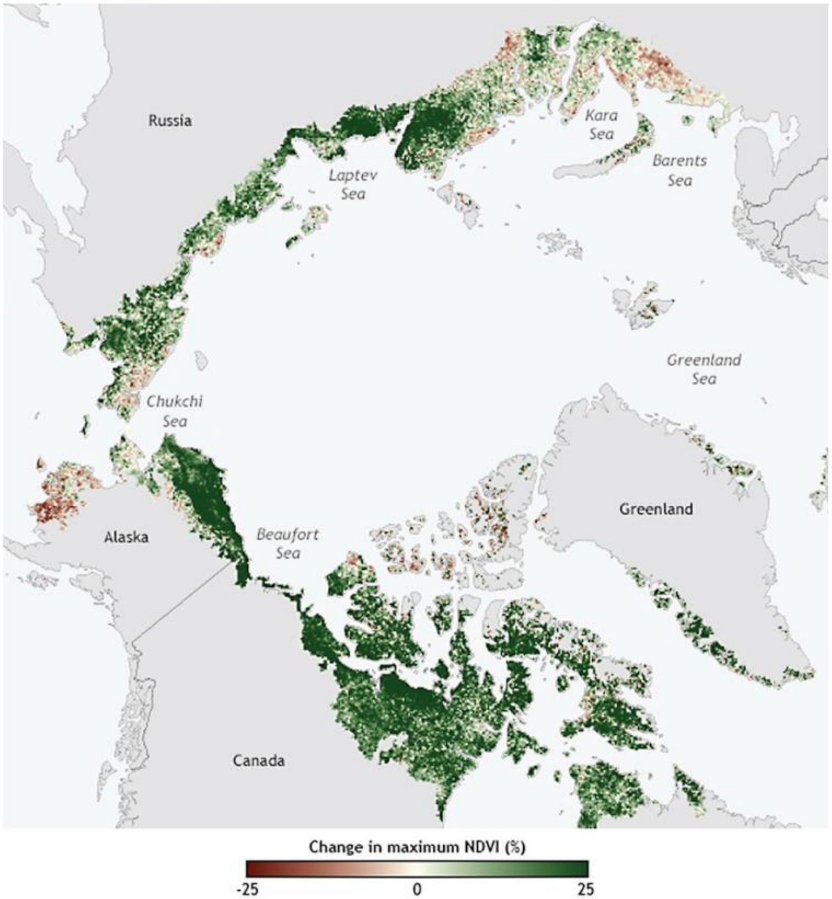


FIGURE 3.6 Land areas adjacent to newly opened water in the Arctic are becoming "greener." Since observations began in 1982, Arctic-wide tundra vegetation productivity has increased. In the North American Arctic, the rate of greening has accelerated since 2005. SOURCE: NOAA.