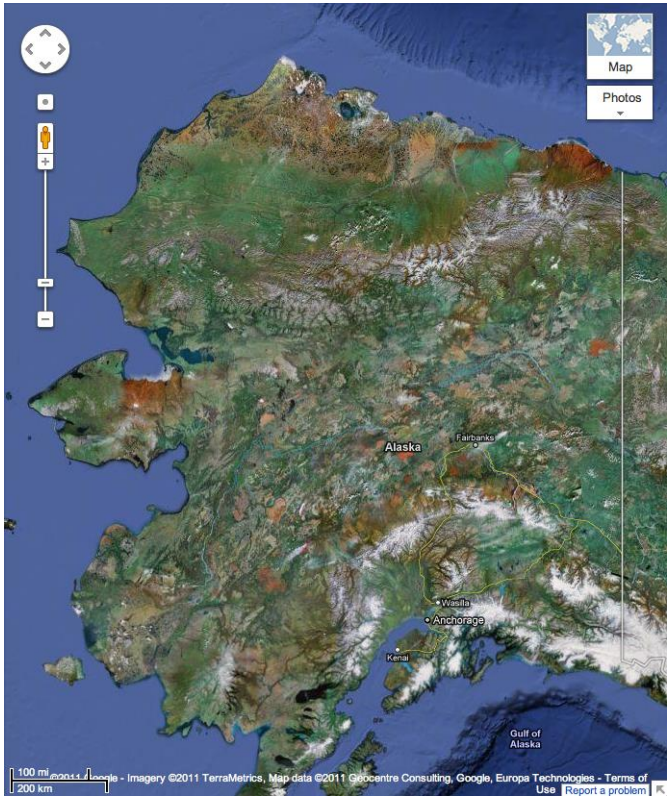
Andrew Juhl
Lamont Doherty Earth Observatory

Orientation

- Samples collected from
  near shore seasonal fast ice
  near Barrow, AK



Orientation

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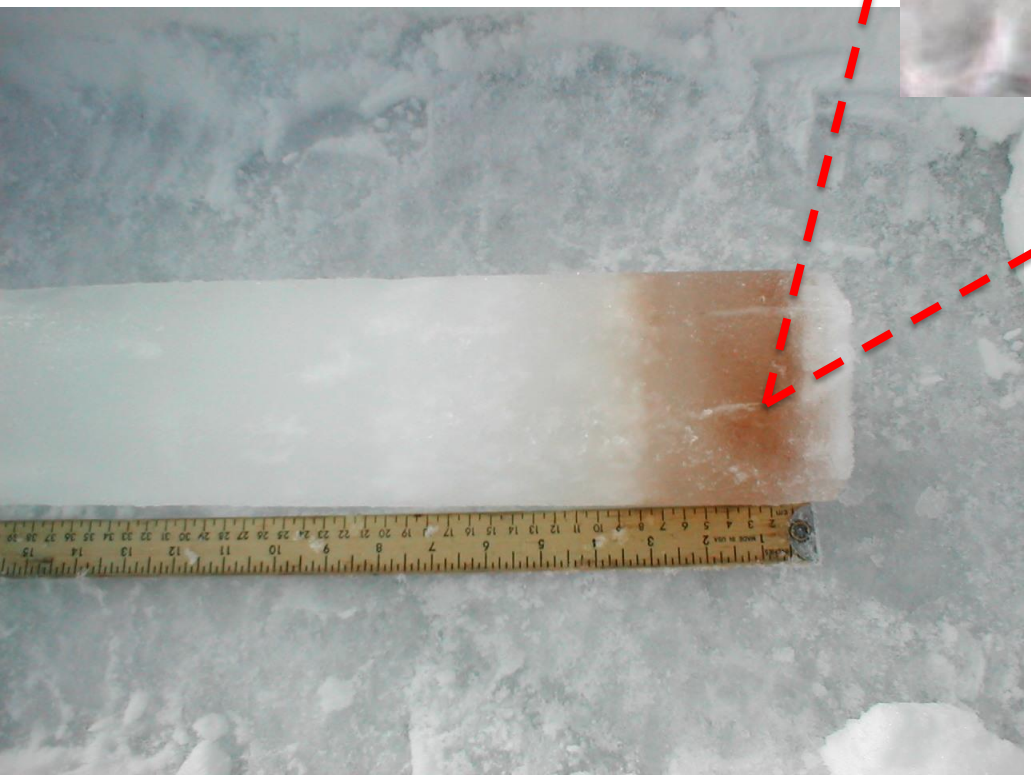
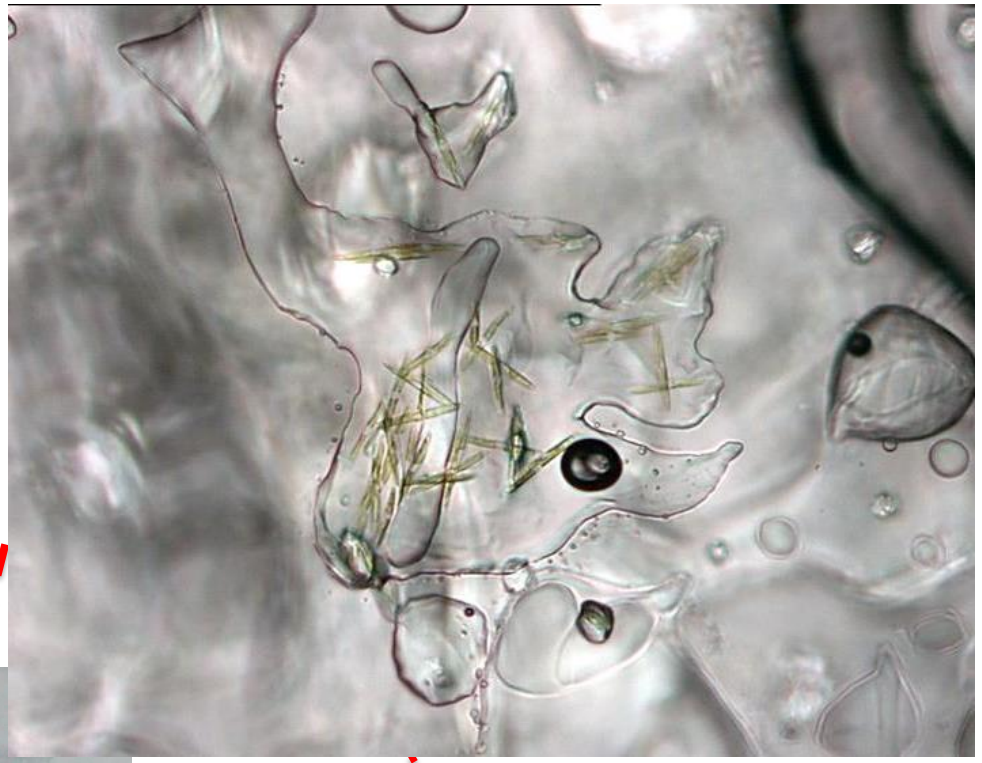
Sundown over the Chukchi Sea in April





- On average, sea ice covers more than 25 million km^2 (9.5 million mi^2)
  - ~5% Northern Hemisphere
  - ~8% Southern Hemisphere

- Fluctuates both seasonally and annually

  (NASA Earth Observatory)

- In a warming climate, Arctic sea ice still forms every winter, but less survives through the year, so Arctic changing to more 1 year old ice, and there is more open water in the summer

April 2014

September 2014

What are some challenges to living in sea ice?

- Habitable space?
- Cold temperatures
- Darkness

Living Inside Ice?

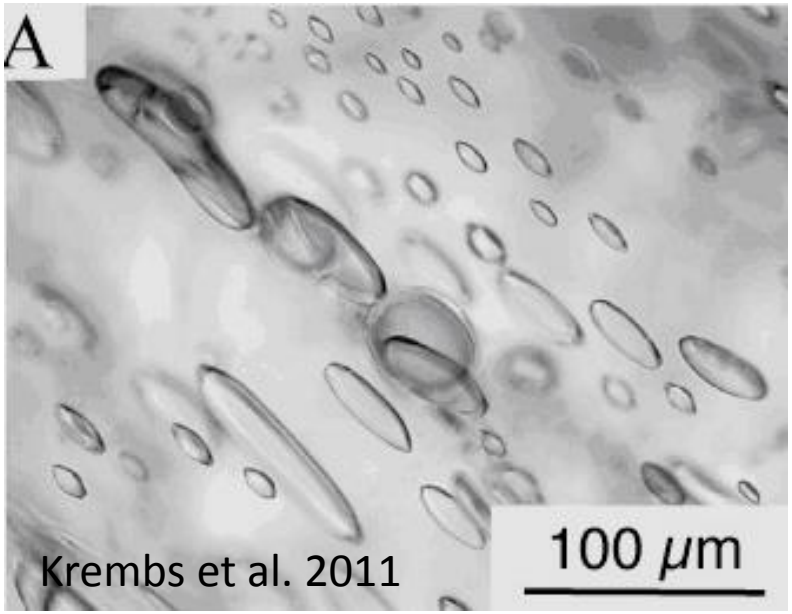
- Growth of algae and other microorganisms does not happen in freshwater ice

- Saltwater and freshwater ice are different

Fresh vs. Saltwater Ice

Saltwater ice and freshwater ice are “clearly” different

Sea Ice is Porous



Krembs et al. 2011

Thin section showing pores in frozen, artificial seawater

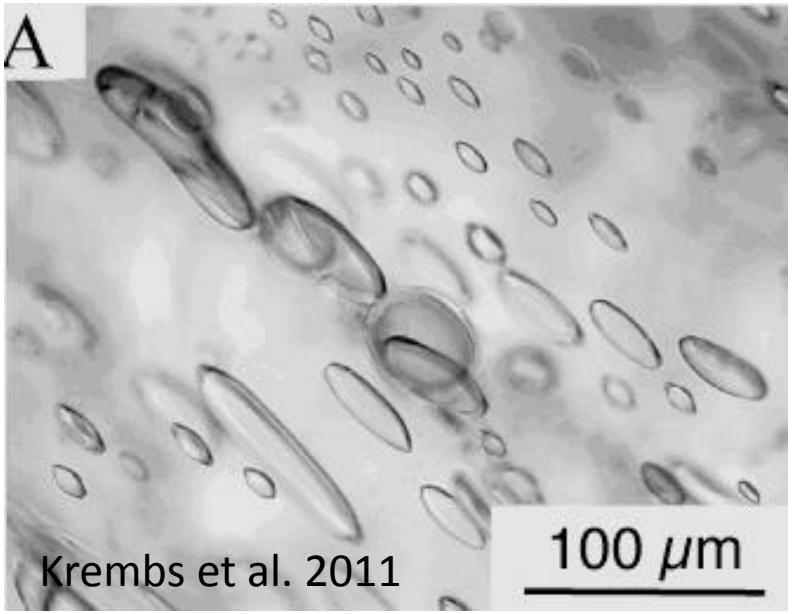
Salt is the key

During freezing, ions are excluded, remaining water becomes saltier, depressing freezing point

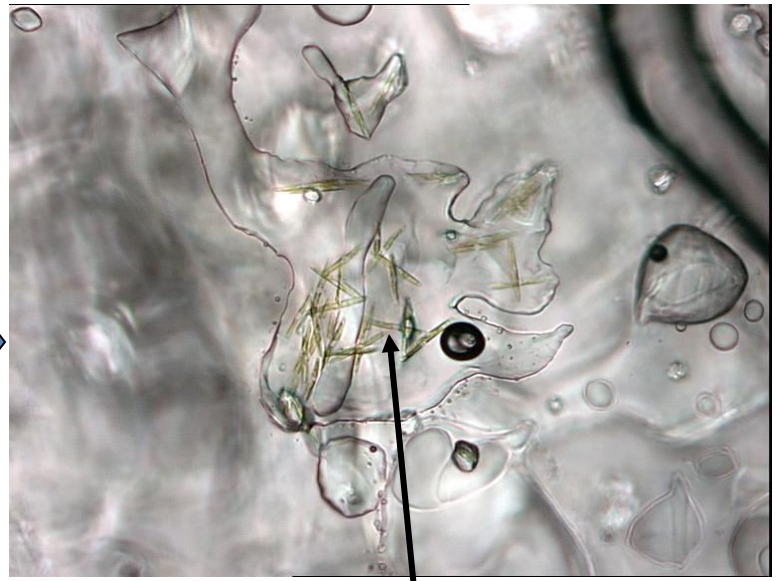
Salt acts sort of like antifreeze

Sea Ice is Porous

The presence of liquid water within the ice, as well as the crystal substrate, create a habitat for a microbial biofilm dispersed throughout the ice



Pores in frozen, artificial seawater



Diatom cells

How do algae get inside the ice?

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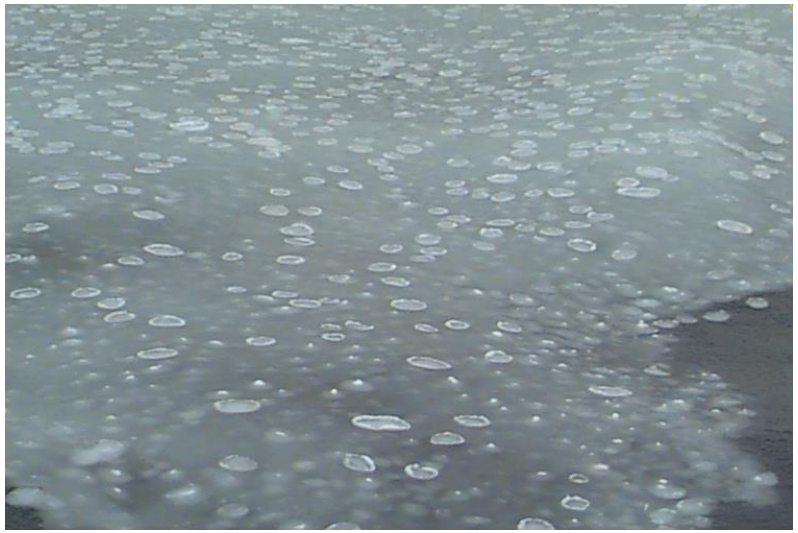
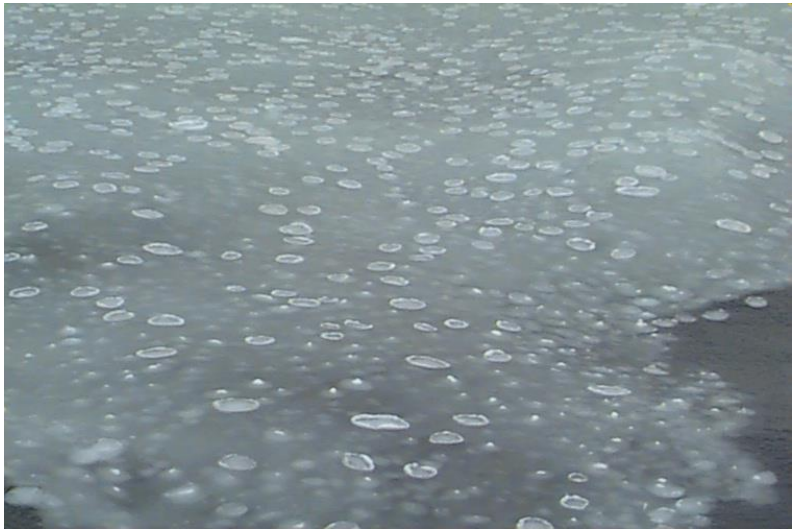
How do algae get inside the ice?



Ice formation process

- Ice crystals form in the water and rise to the surface making “Grease ice”
- Grease ice coalesces into “pancake ice”
- Pancakes grow and join to form pack ice
- Pack ice then continues to grow downward if the air above is cold enough

How do algae get inside the ice?



During the “grease ice” phase
(ice only hours to days old)

- Chlorophyll and algae cell counts are highly elevated relative to the surrounding water
- This could be the colonization step?
- Some ice algae produce “ice-binding” proteins that could help them stick to newly formed ice crystals
- However, ice formation occurs in the fall, the algae species in the water are different from those found in the ice in spring.
- Algae of the “right” species frozen into the ice in fall would have to survive in the ice all winter

It’s Cold Out There

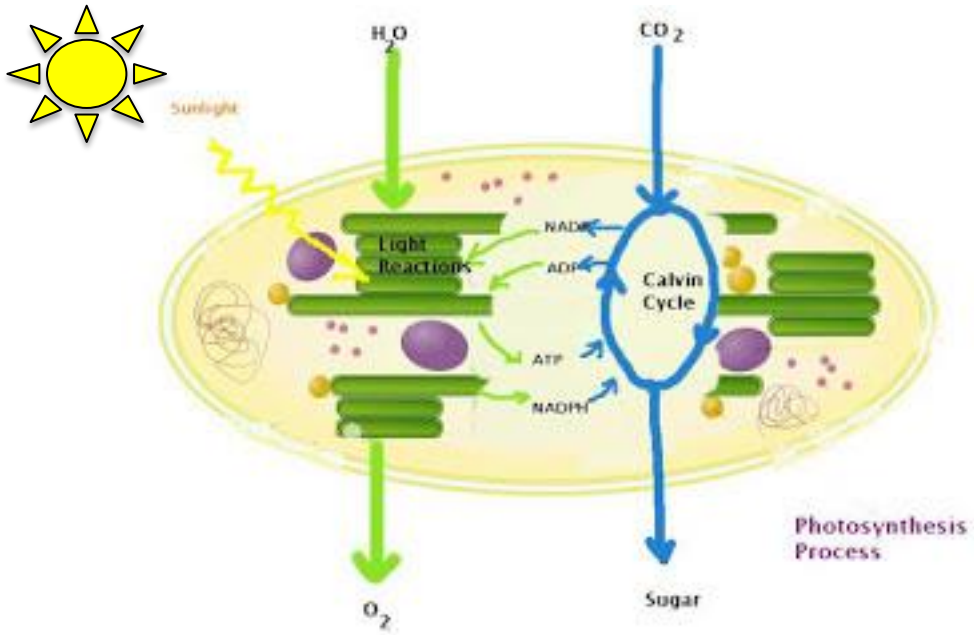
How cold?

Sea ice usually -20 to -2˚C

Usually warmer than the air above

Water below ice is always around -2˚C

It’s Cold Out There – but is that always a bad thing?



Algae are photosynthetic – use light energy to fix C as sugars and other biological products (and release oxygen)

Some of those products are used to make more algae, but a lot is respired

Although they produce their food from sunlight, they still have to eat some of it

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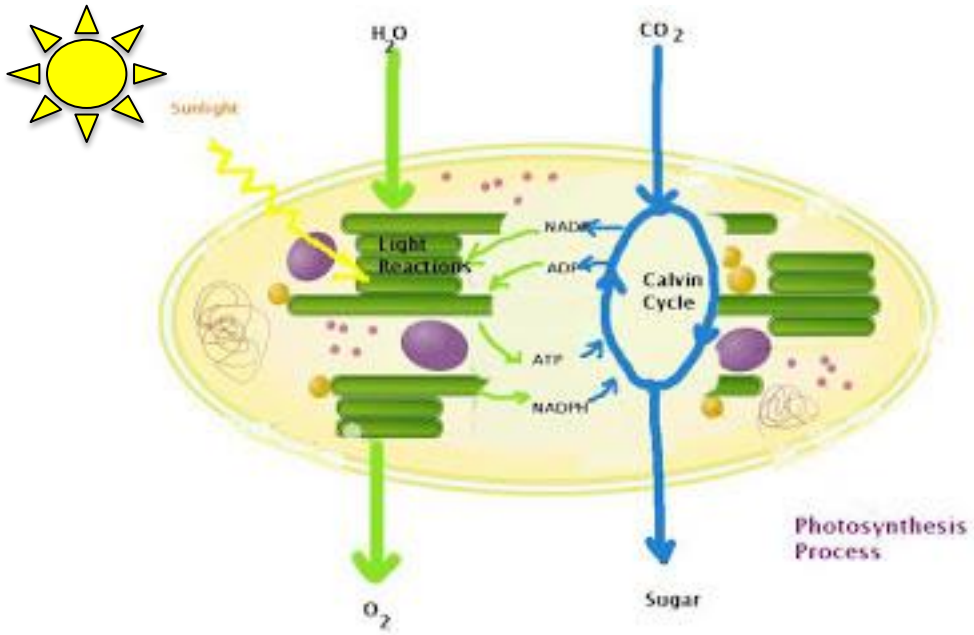

$6\ CO_2 + 6\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2$ Photosynthesis

$6\ CO_2 + 6\ H_2O \leftarrow C_6H_{12}O_6 + 6\ O_2$ Respiration

But respiration is very low at cold temperatures

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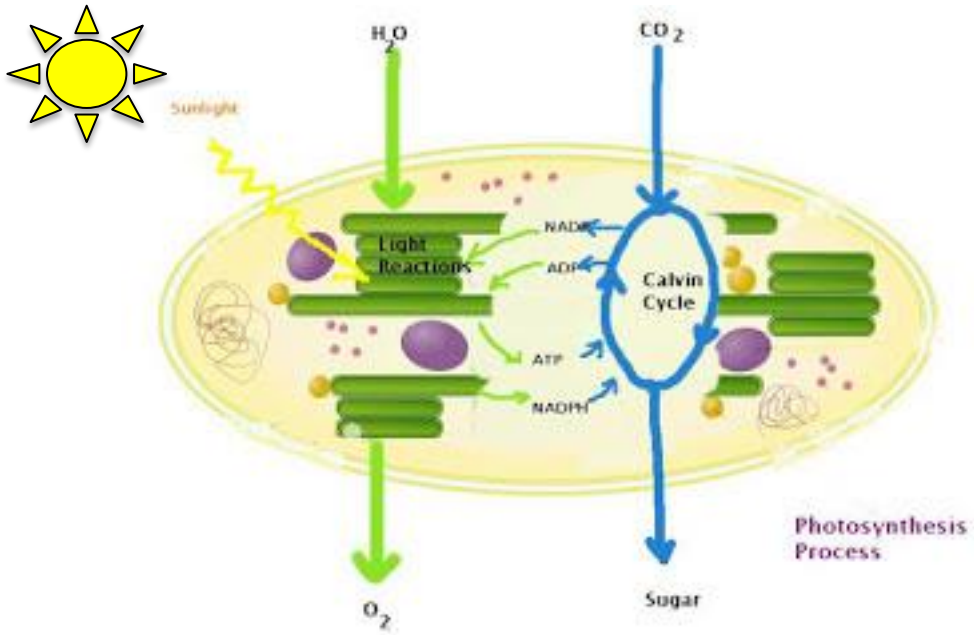

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But respiration is very low at cold temperatures

b/c respiration is low, ice algae can survive even if photosynthetic rates are low

It’s Cold Out There – what can algae do?

One reason biological processes move more slowly when its colder is because enzyme activity slows down.

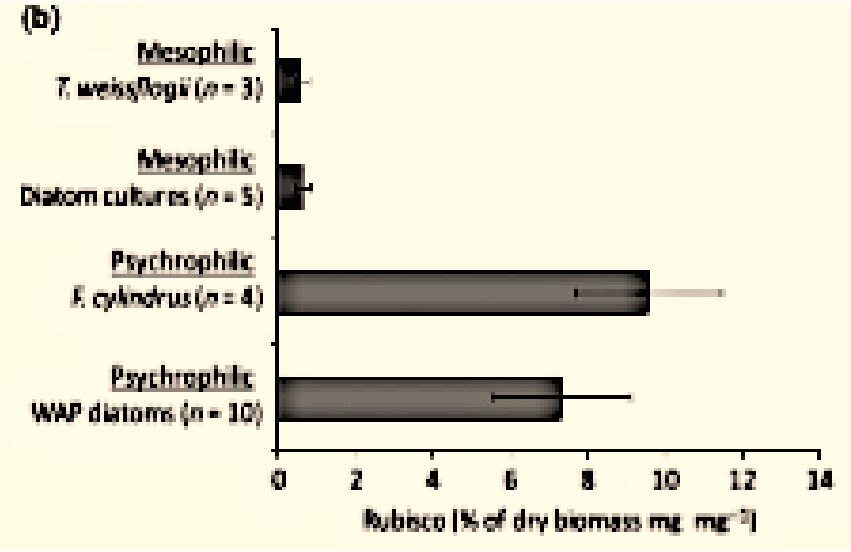
One key enzyme in photosynthesis is Ribulose-1,5-bisphosphate carboxylase (the enzyme that actually “fixes” C from CO2 into an organic form) -> “Rubisco”

Rubisco activity is slower at low temperatures

Is there a way to avoid that problem?

It's Cold Out There – what can algae do?

How about make a lot more Rubisco?



Cultured, medium temp diatoms
Grown warm

Cultured, Antarctic diatom

Antarctic diatoms in field

} Grown cold

Young et al. 2015

What are some challenges to living in sea ice?

- Habitable space? -> Liquid water-filled brine channels

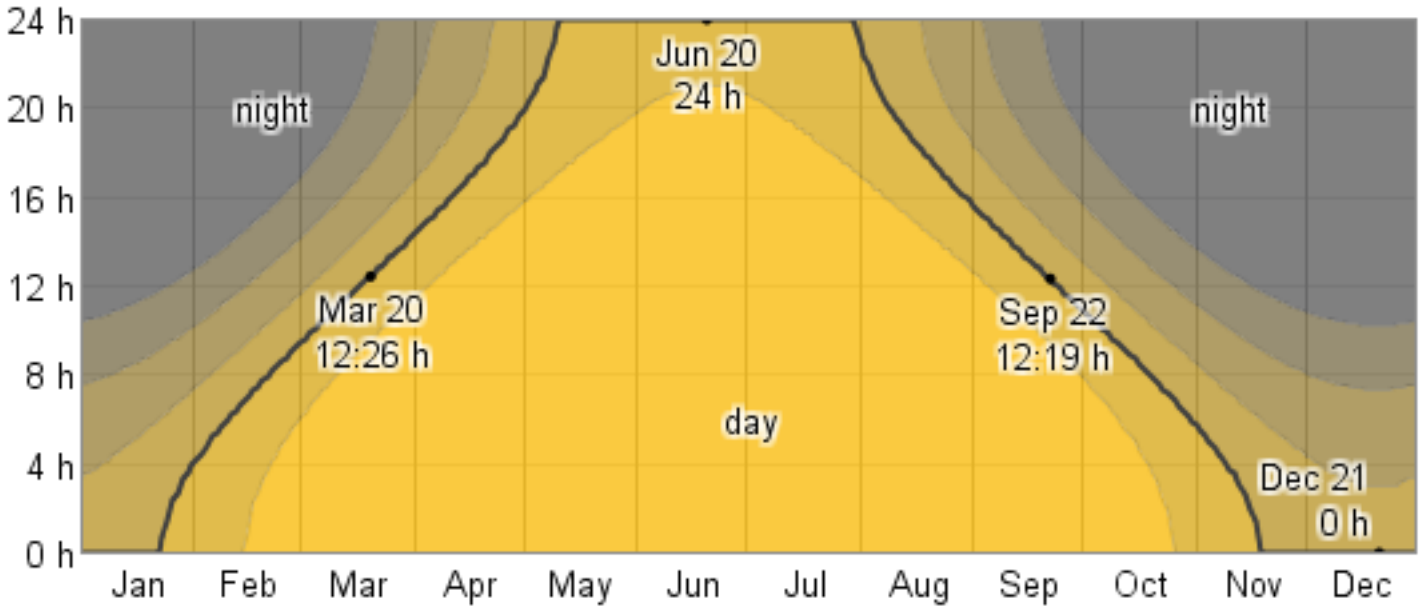
- Cold temperatures -> a variety of ways to compensate

- Darkness

What are some challenges to living in sea ice?

- Habitable space? -> Liquid water-filled brine channels
- Cold temperatures -> a variety of ways to compensate
- Darkness -> polar regions are dark for months

Annual cycle of day length in Barrow, Alaska



24 hour sunshine - May, June, and July
24 darkness – Nov, Dec, and Jan

So, actually about the same hours of sunshine as elsewhere, but distributed more unevenly

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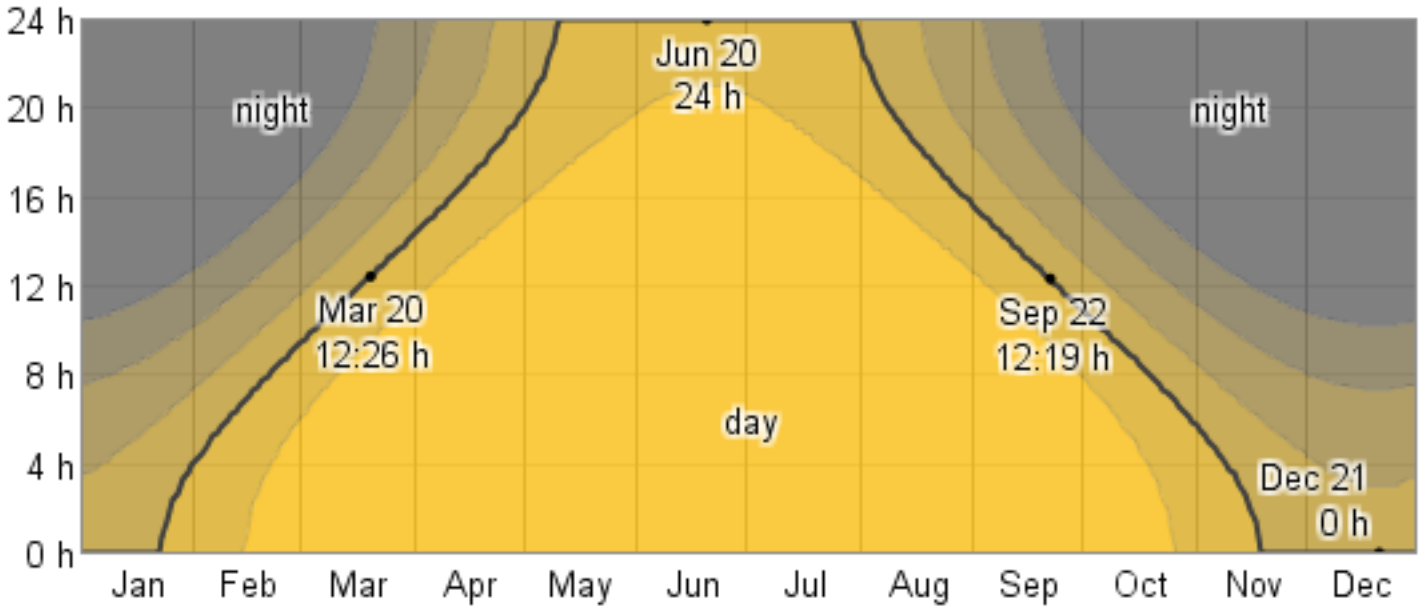

Plenty of sun in summer, no sun in winter

For algae, this means a very uneven food supply

Other Polar Organisms

- The extreme seasonality of polar environments subjects many other organisms to periods of plenty, followed by periods of starvation

Polar Bears, Bowhead Whales, and other organisms (incl. Ice Algae) deal with this challenge in the same way

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Polar Bears, Bowhead Whales, and other organisms (incl. Ice Algae) deal with this challenge in the same way -> they get fat

Other Polar Organisms

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The annual food cycle is different for different organisms

Fat Diatoms

- Ice Diatoms can be 30-60% lipid by dry weight
- Other algae typically 10-20%
- Relative production of lipids increases with light level (Smith et al. 1989)
- Make hay (or lipids) when the sun shines

Table 3. Allocation of ^{14}C-labeled photosynthate among intracellular pools in arctic ice algae, as a function of the PFD (μmol quanta m^{-2} s^{-1}) during incubation (avg of 11 experiments). Low-molecular-weight pool of photosynthate—LMW. Standard SE for these mean values ranged between 10 and 15%.

	Percent of photosynthate			
PFD	LMW	Lipid	Protein	Polysaccharide
33.0	36.3	23.1	19.6	21.8
15.5	42.9	19.0	19.3	20.0
6.5	41.7	16.1	25.3	18.4
3.5	38.0	10.9	37.3	16.5

Light

What are some challenges to living in sea ice?

- Habitable space? -> Liquid water-filled brine channels
- Cold temperatures -> a variety of ways to compensate
- Darkness -> store up lipids when the sun is up