Biological Background (3 min)

**Photic Zone**

Phytoplankton growth: increase in biomass without compromising the fitness of successive generations1

* Can continue in perpetuity under the given environmental conditions

It requires:

* Inorganic sources of C, N, P, S, & other essential nutrients1
* Energy input as photons
* Light is scattered and absorbed as it passes through water
  + decrease in photosynthetically active radiation with depth
* The area where there’s enough light for photosynthesis is referred to as the photic zone
  + The accepted bottom limit of the photic zone is 1% of surface irradiance1
    - Equivalent to 2-20 umol photon m-2 s-1

**Light Constraint at the Poles**

At the poles, light availability is constrained by2,3:

* Sun elevation angle
  + Changes due to the obliquity (tilt) of the earth as it moves around the sun
  + At the poles, you see the polar night and midnight sun
* Thickness of ice/snowpack
  + Snow has very high light attenuation properties
    - Think about the blinding snowbanks in the winter

**Psychrophilic Phytoplankton**

Regardless, some phytoplankton exhibit next growth under the ice in the winter, through photosynthesis at extremely low light levels3

* Evidence of growth below >1 m of snow and 1 m of sea ice3
* 0.17 umol photons m-2 s-1
* 10-120x below the accepted lower limit
* The theoretical minimum for phytoplankton growth is 0.01 umol photons m-2 s-1.2

**Primary Production**

* Surviving and maintaining an intact photosystem under the ice in the winter has important implications for spring blooms
  + Spring blooms are the highest primary production of the year
* Right now, blooms are changing in terms of both total annual productivity and seasonal peaks due to climate change4,5
  + Since blooms= base of food web, will have important ecological consequences for the whole arctic system

**Carbon Cycling**

* Psychrophilic phytoplankton also have important implications for carbon cycling and sequestration3
  + Thermohaline circulation: dense/cold water sinks at poles5
    - Major carbon export pathway from surface waters to the deep ocean

Biophysical Background (3 min)

**Energy Partitioning**

Light energy absorbed by the photosynthetic pigments of PSII (primarily chlorophyll-a) is distributed variably among three pathways6:

1. Photochemistry (photochemical quenching of ChlF)
2. Dissipation as heat (non-photochemical quenching of ChlF)
3. Re-emission at longer wavelengths as fluorescence (ChlF)

**S-State Cycling**

When a photon is absorbed, PSII undergoes a charge separation, which extracts an electron from the Mn cluster of the WOC. As successive photons are absorbed, it induces increasingly oxidized states, known as s-states. Once four photons have been absorbed and the Mn cluster has lost 4é, it replaces them by oxidizing 2 water molecules to 1 oxygen.

Energy partitioning changes between s-states due to changes in free energy. So, by following changes in ChlF, we can follow the s-state cycling.

A complete water oxidation cycle during oxygenic photosynthesis requires the absorption of four photons and the successive accumulation of four oxidizing equivalents7–9.

PSII charge separation extracts an electron from a manganese cluster in the Oxygen Evolving complex. After the manganese cluster loses 4 electrons, it replaces the electrons by oxidizing 2 H2O to 1 O2O2.

(Figure) Pathway of s-state cycling and the electron transfer chain in PSII. Successive PSII charge separations extract electrons from the Mn cluster of the water-oxidizing/oxygen-evolving complex, inducing four increasingly oxidized states. Following the accumulation of four oxidizing equivalents, 2 H2O are oxidized to 1 O2.

The four successive s-states are reflected by an oscillation in chlorophyll fluorescence, as it varies with the free energy of the water-oxidizing complex 10.

**Recombination**

* Recombination is when electrons flow back from QA- or QB- instead of continuing through the ETC, resulting in
  + Evolved as a mechanism of photoprotection from the ROS that are formed when PSII receive excess light
  + Also important for the formation of chlorophyll molecules11
* However, backflow results in a loss of charge separation12

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