Effects of surface light modulation on vertical phytoplankton flow dynamics
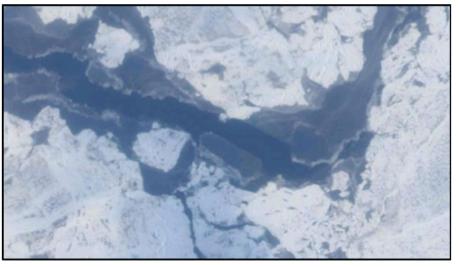
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Under-ice phytoplankton blooms

(a) Melt-ponded sea ice
(c) Sea ice with leads
(b) Under-ice phytoplankton bloom
(d) Low phytoplankton biomass beneath sea ice
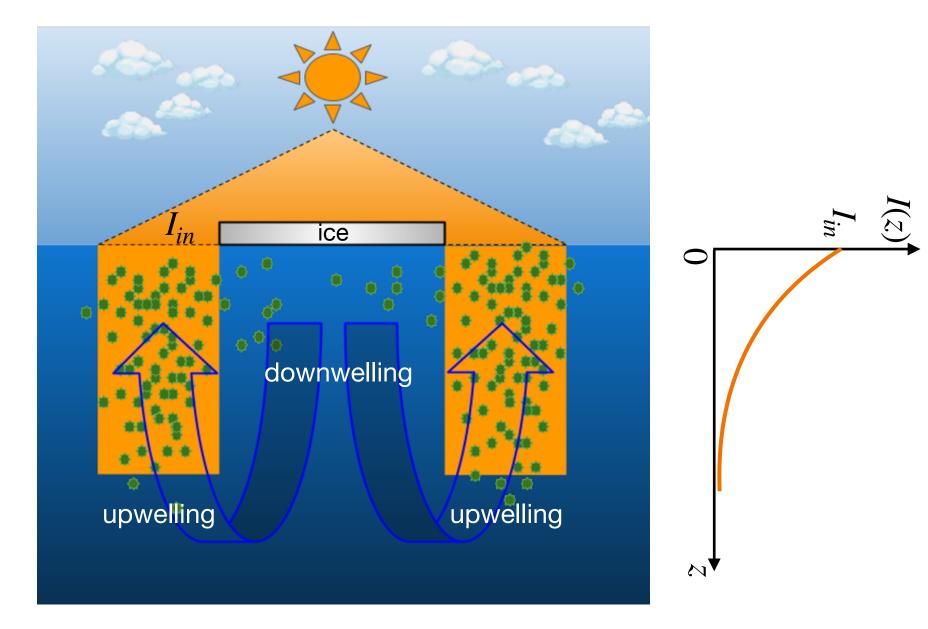
Lowry et al., JGR (2018)

Possible controlling factors:
Increase of light availability in ice-free regions
Convective fluid motions
Nutrient availability

Expected to become more frequent in the Arctic ocean
Impact on primary production and marine ecology

Idealized 2D advection-reaction-diffusion model

$$\partial_t \theta = [p(I) - l]\,\theta - \mathbf{v} \cdot \nabla \theta + D\,\nabla^2 \theta$$

Vertically heterogeneous growth rate [light absorption, $I = I(z)$]
No light below obstacles (ice) $\Rightarrow p(I) = 0$ there
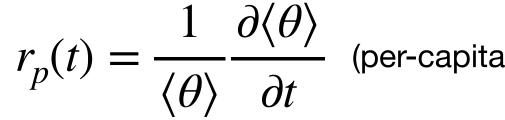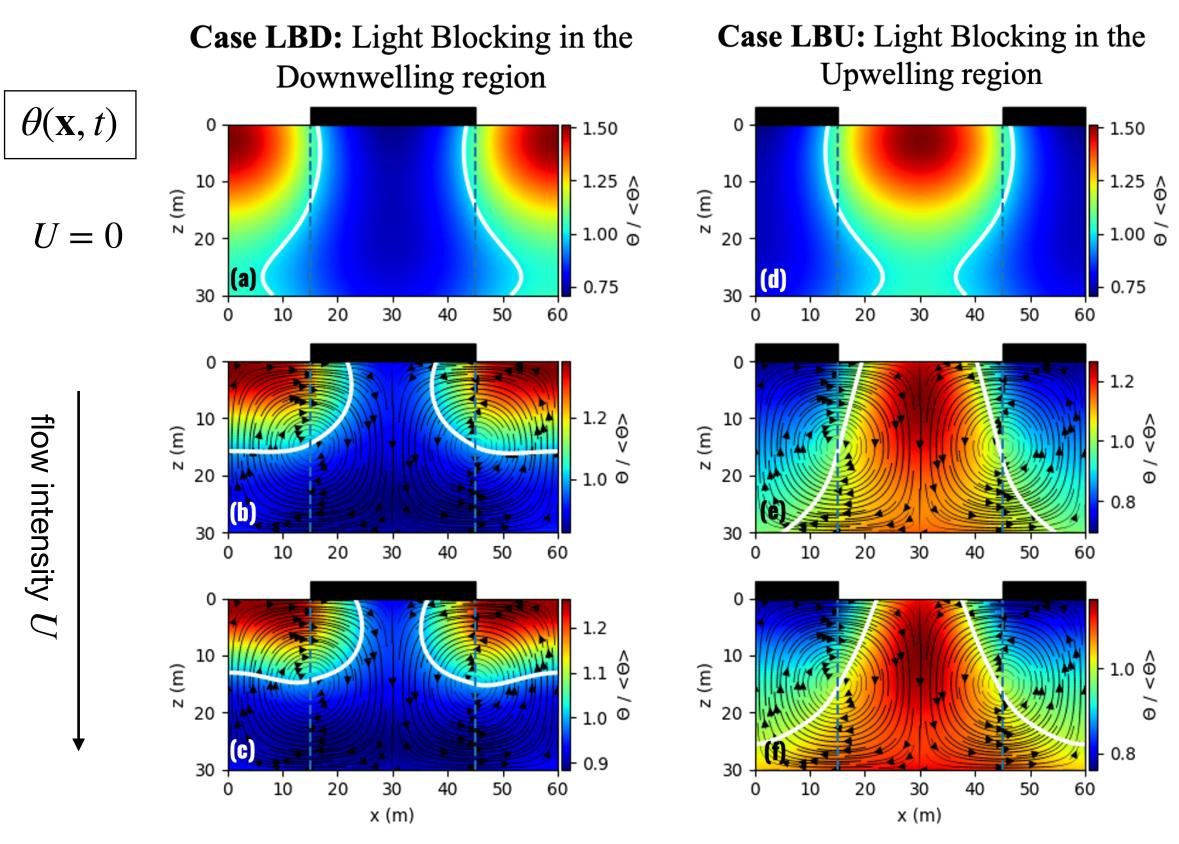Advection by kinematic cellular flow & sinking

Population survival/extinction

$$r_p(t) = \frac{1}{\langle\theta\rangle}\frac{\partial\langle\theta\rangle}{\partial t}$$ (per-capita growth rate)

Light absorption at the surface and convective flows

Role of sinking

Case LBD: Light Blocking in the Downwelling region

Case LBU: Light Blocking in the Upwelling region

$\theta(\mathbf{x}, t)$
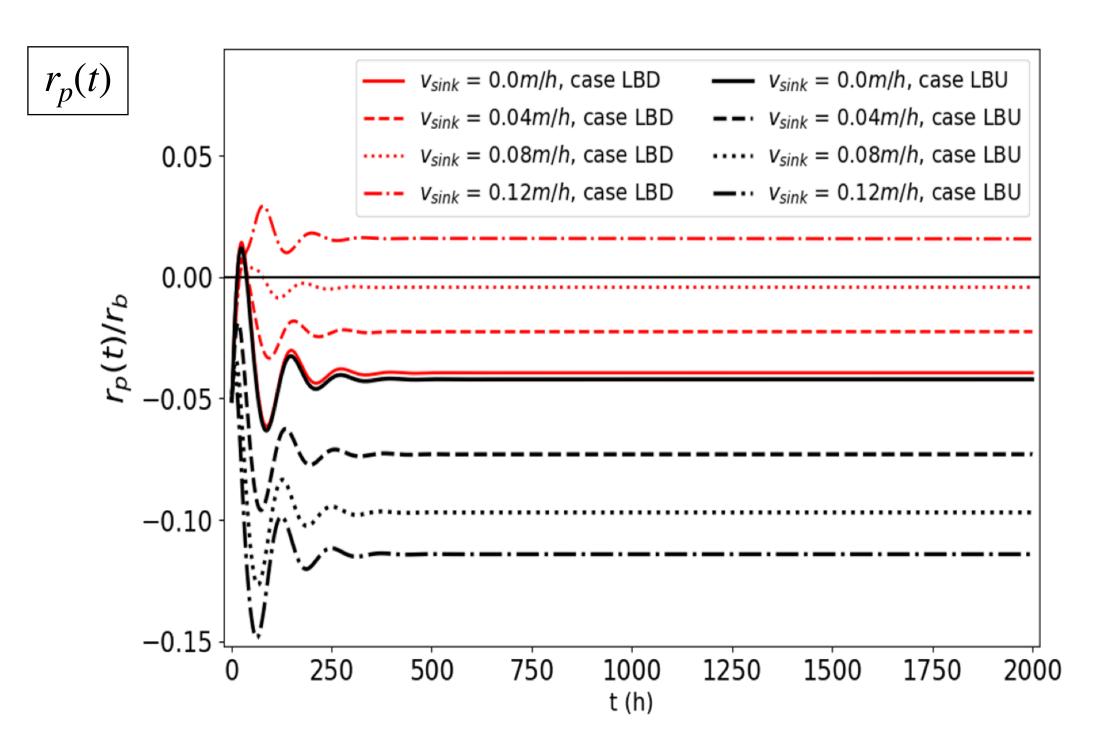
$U = 0$

flow intensity U

$r_p(t)$

The main effect of advection is to hinder phytoplankton growth, but its importance depends on the obstacle position with respect to the upwelling and downwelling regions of fluid motion. Survival is more difficult in the LBU case, in the presence of flow.

The sinking speed, while small, also plays an important role, which depends on how it sums to the flow. In the downwelling (upwelling) region of LBU (LBD) case, it reduces (increases) the residence time in the well-lit upper layer.

Perspectives: more realistic description of fluid flows beneath ice-covered regions (ice melting, mixed layer)