The effects of ice-shelf melt on the biological productivity of Antarctic coastal polynyas

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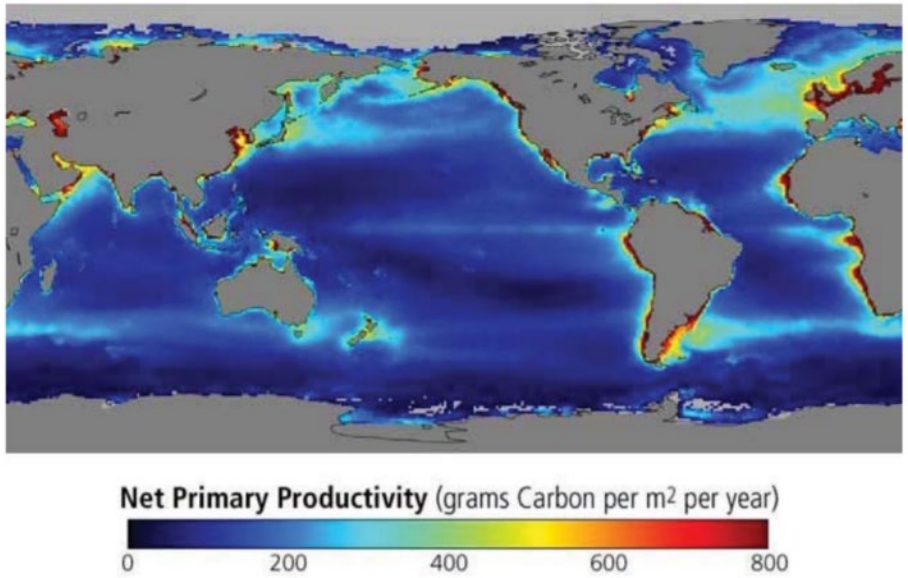
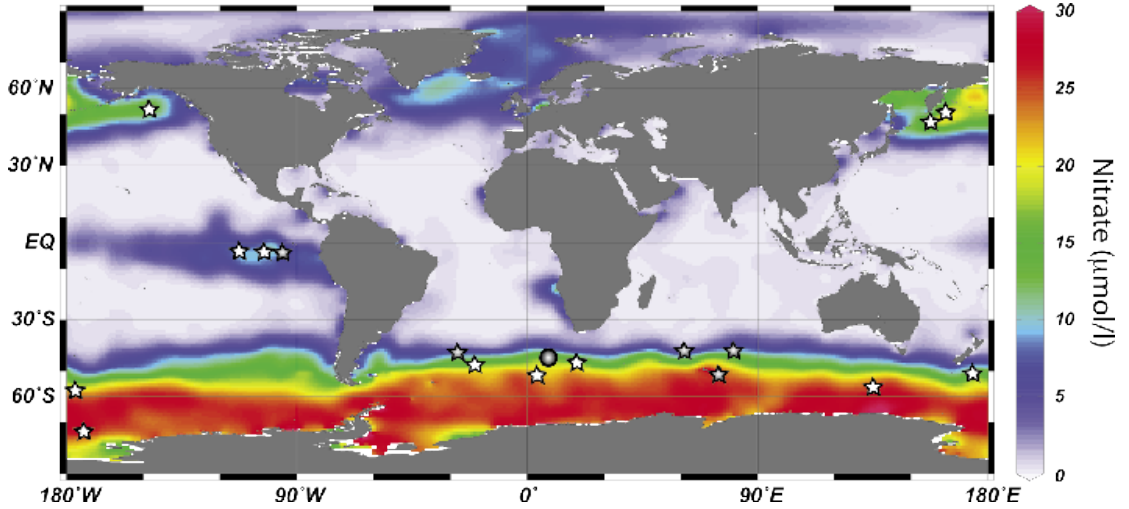
NATURAL ENVIRONMENT RESEARCH COUNCIL

The Southern Ocean and Biological Productivity

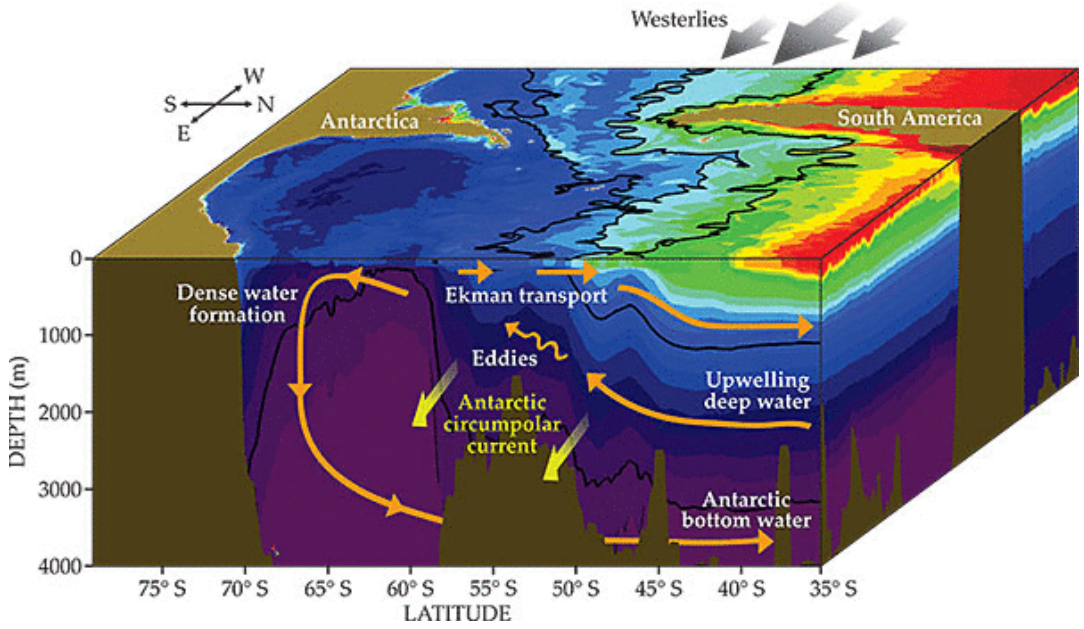


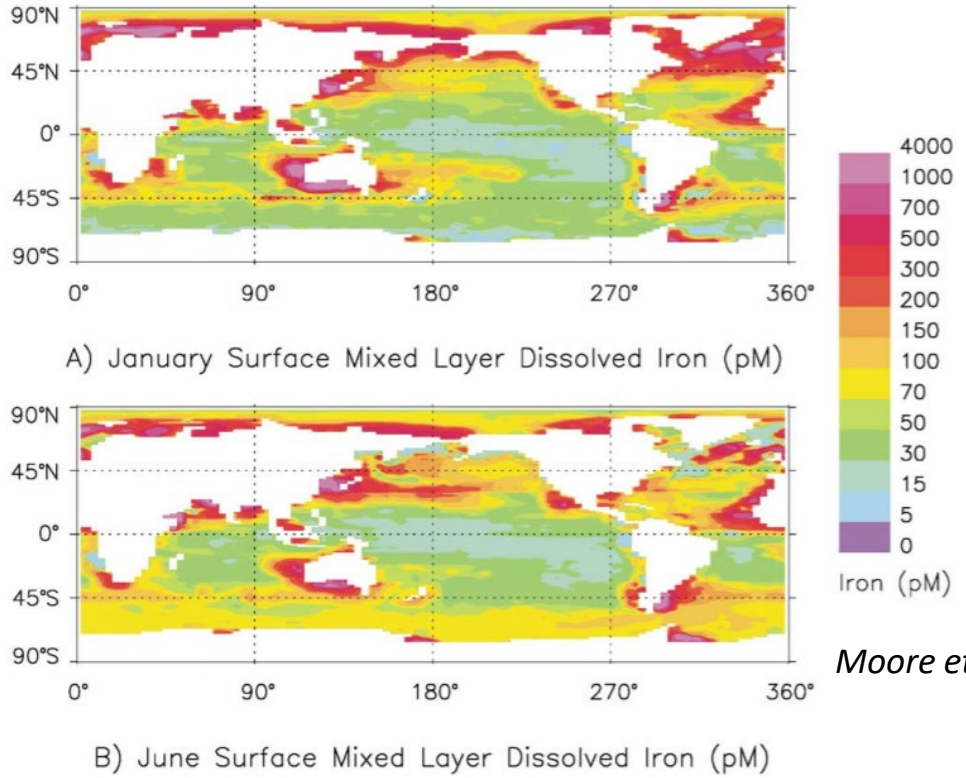
nasa.earthobservatory.gov



- Net primary productivity (fixing of Carbon by photosynthesis) is relatively low in the Southern Ocean – despite abundance of nutrients

High Nutrient, Limited Chlorophyll

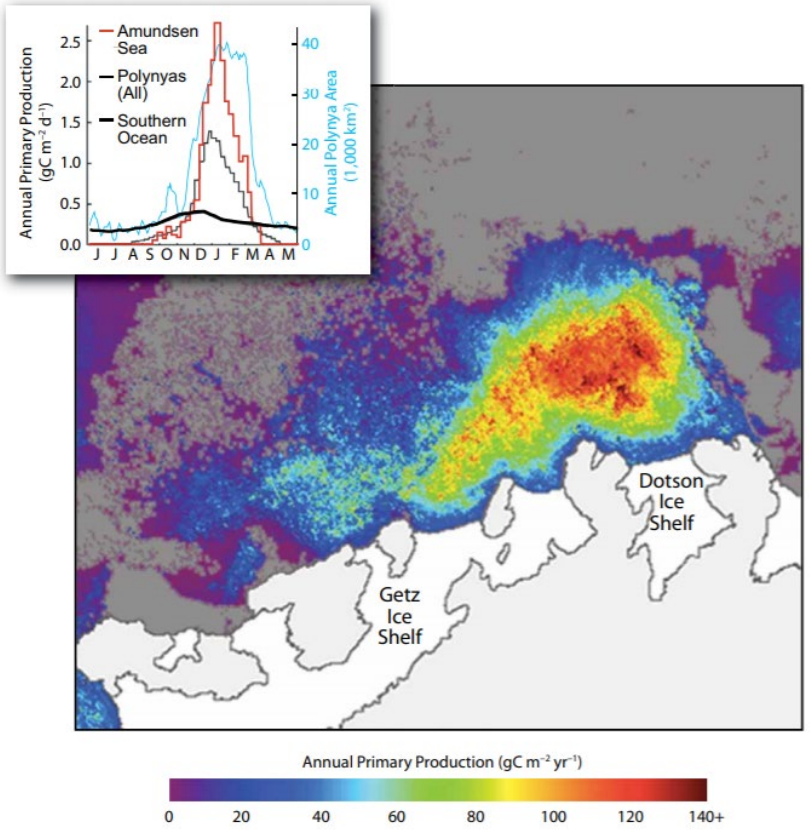




Moore et al, 2007

- Due in part to limiting of *iron* (needed as catalyst in photosynthesis)
- Upwelling of NADW brings nutrients, but little dust deposition due to remoteness

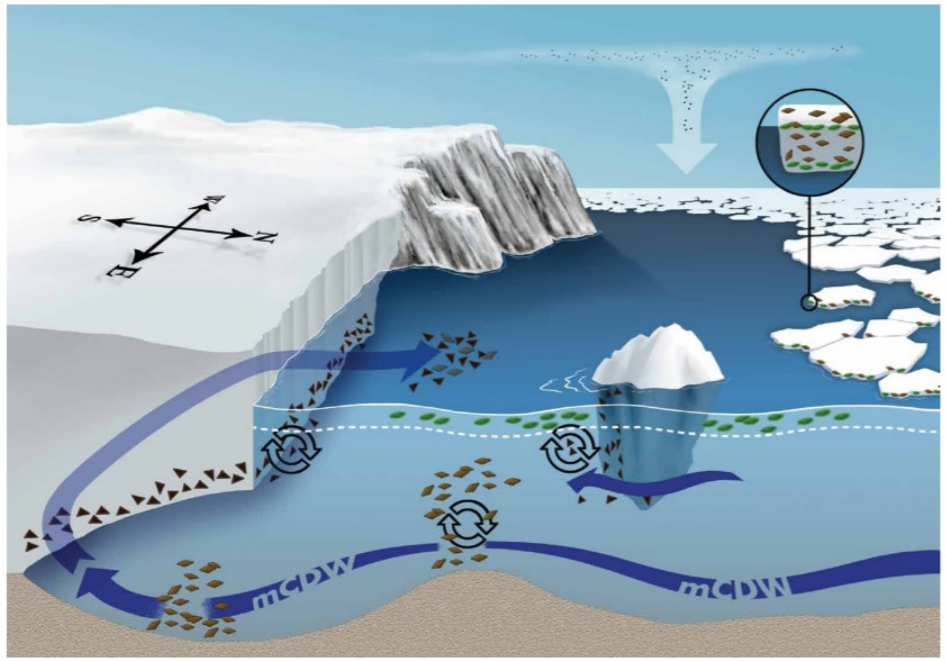
Productivity in Coastal Polynya



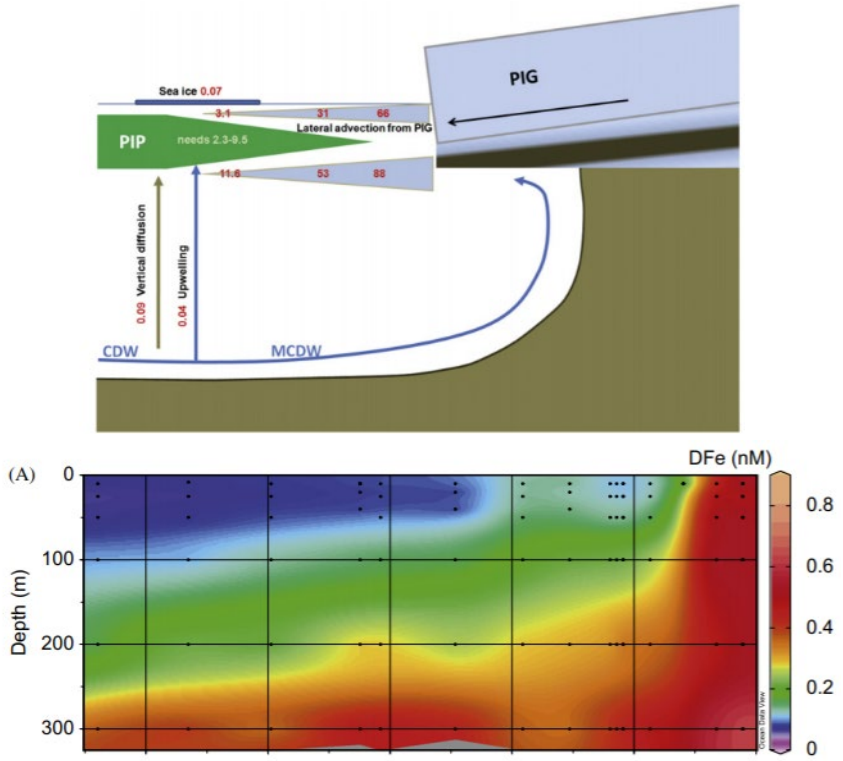
Yager et al, 2012

- Coastal polynyas are some of the most productive regions in Southern Ocean
- Amundsen and Pine Island Polynyas rates an order of magnitude above that of open ocean
- Limited ice cover, but also due to source of micronutrients (i.e. iron)

Ice shelves as source of biological iron



Yager et al, 2012



Gerringa et al, 2012

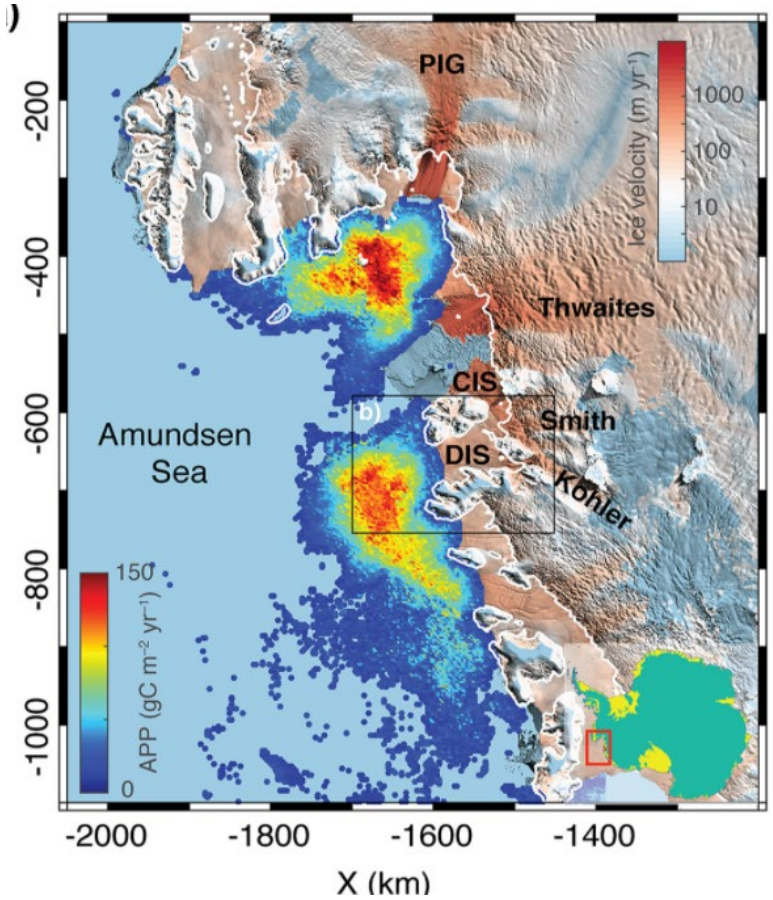
- Ice-shelf melt has been implicated as important source of iron in upper ocean
  - Melting of ice-entrained sediment
  - Transport of iron in deep water

Aims of research

1. Determine degree to which ice-shelf melt plays a role in Polynya productivity

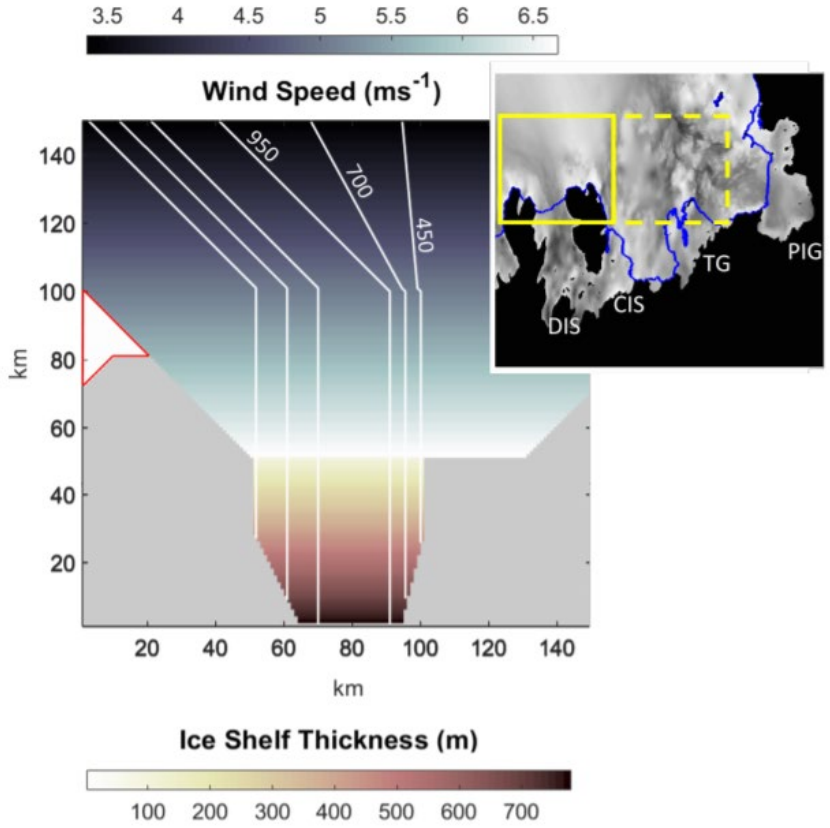
2. Investigate competing effects of iron and light limitation

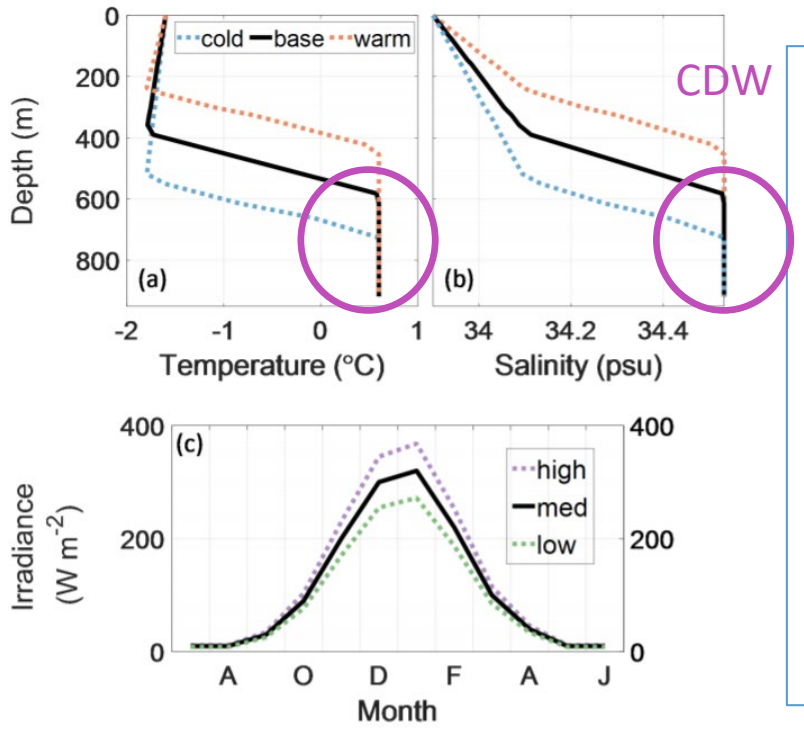
3. Investigate response to differing levels of irradiance (light) and ocean temperature



Idealised study with MITgcm-BLING

Twelves, A. G., et al (**2020**). Self-shading and meltwater spreading control the transition from light to iron limitation in an Antarctic coastal polynya. *Journal of Geophysical Research: Oceans*

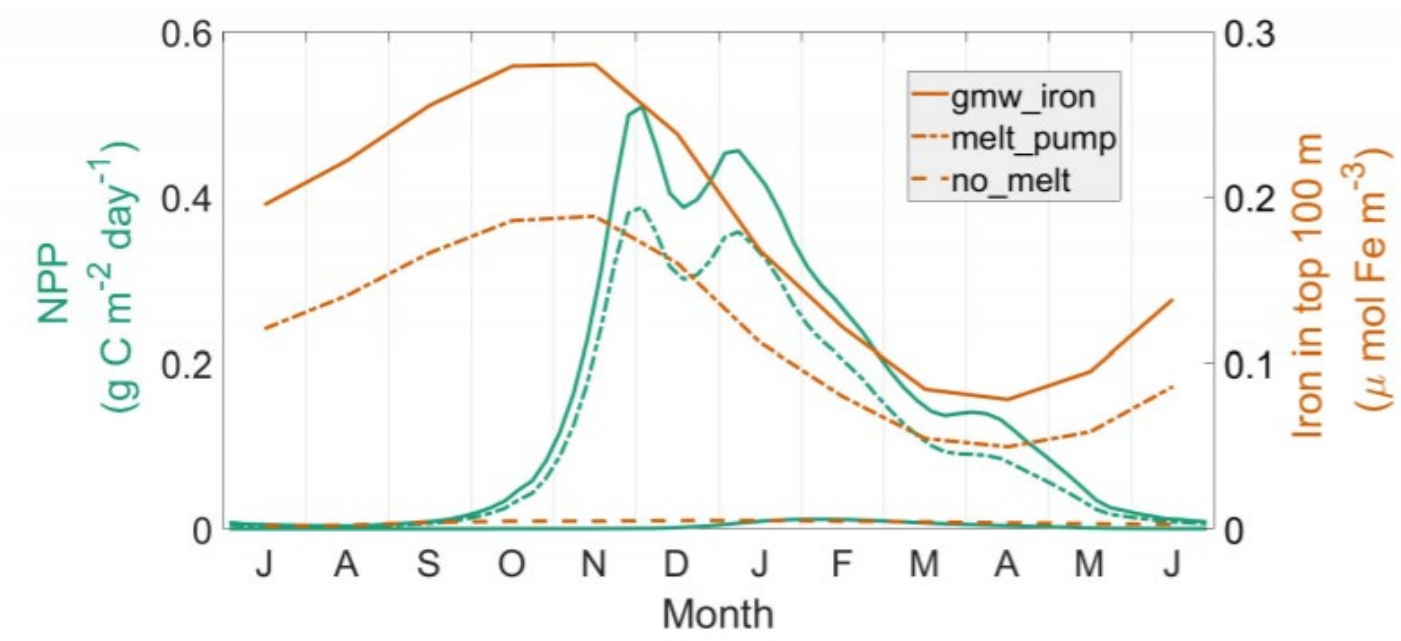




Boundary Conditions

- MITgcm coupled with BLING (Biogeochemistry with Light, Iron, Nutrient and Gas; Galbraith et al 2010;Verdy and Mazloff, 2017)
- Dynamic/thermodynamic sea ice component, ice shelf-ocean interactions
- Idealised domain/forcing allows larger number of experiments

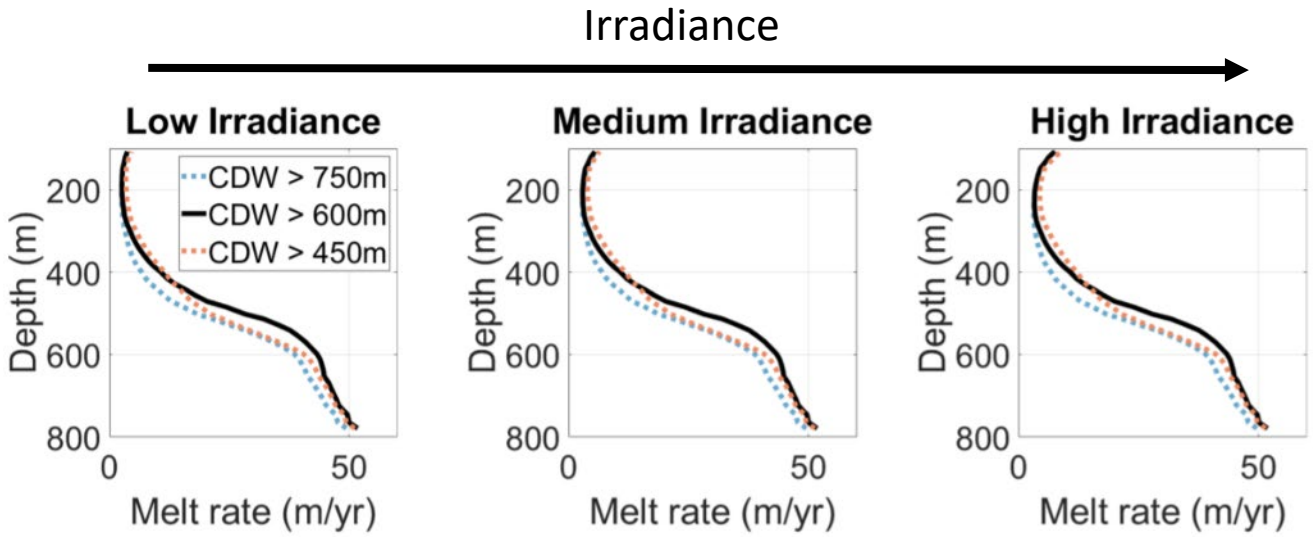
Results: Different sources of iron



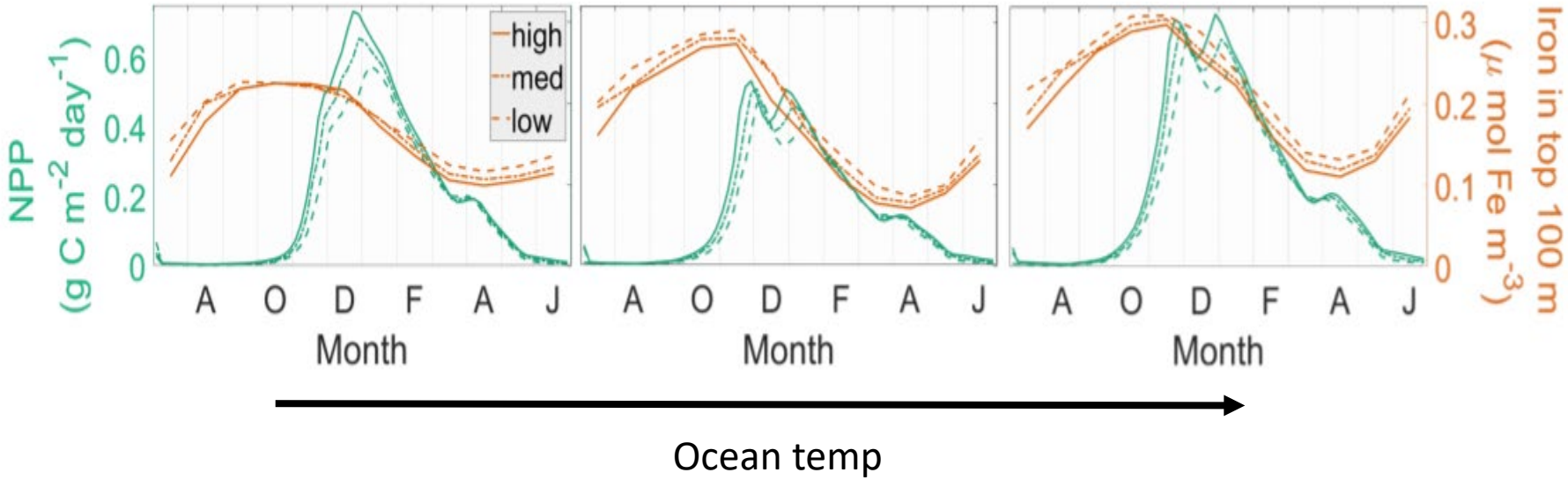
melt_pump = Iron in CDW only
gmw_iron = Iron in CDW and ice-shelf melt

- "turning off" melting yields negligible productivity
- Dual sources of iron (GMW and CDW)
- Addition of GMW leads to 50% greater iron concentrations – but only ~20% greater productivity

Results: Varying irradiance and Oce. Temp.

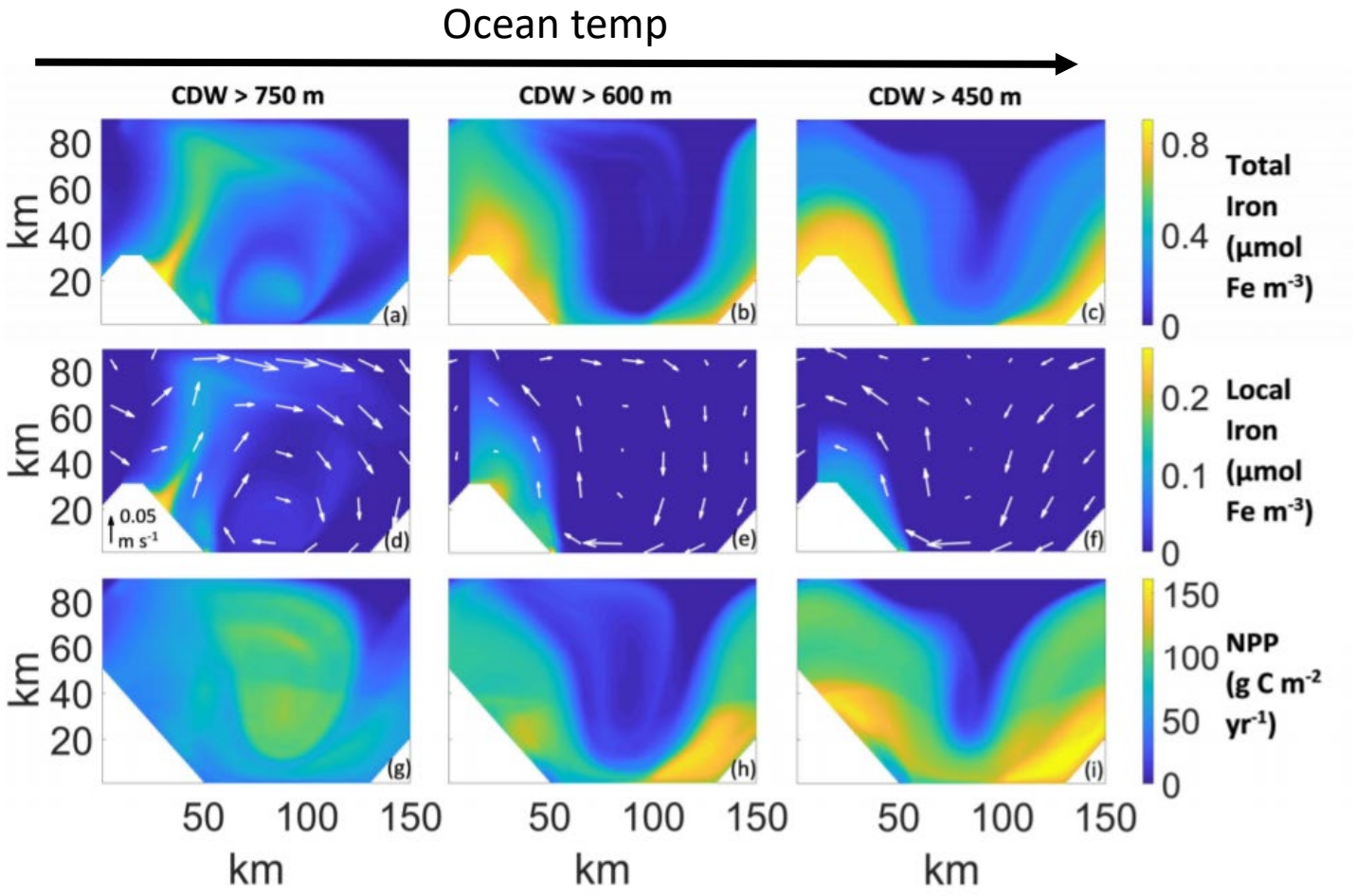


- Effect of ocean temp on melt rates varies with depth
- Bulk melt rates “linear” /symmetric in ocean thermocline depth change
- Small impact of irradiance…

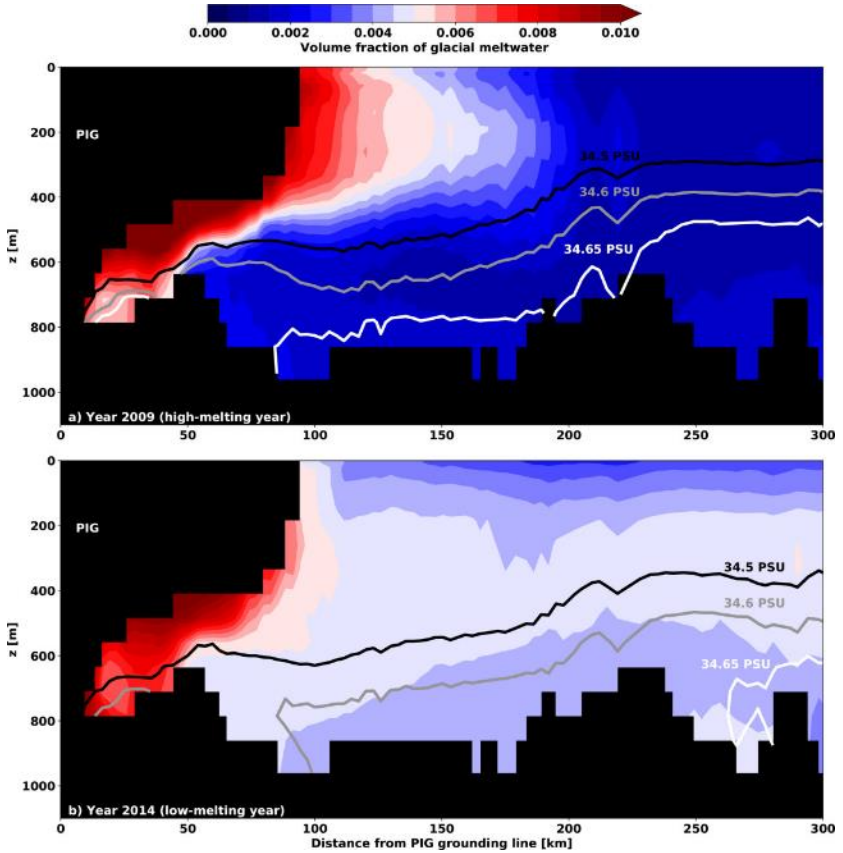


- Productivity linear in irradiance change
- However, very nonlinear in ocean thermocline change (counter to effects on iron)

Melt-regulated spreading of Nutrients



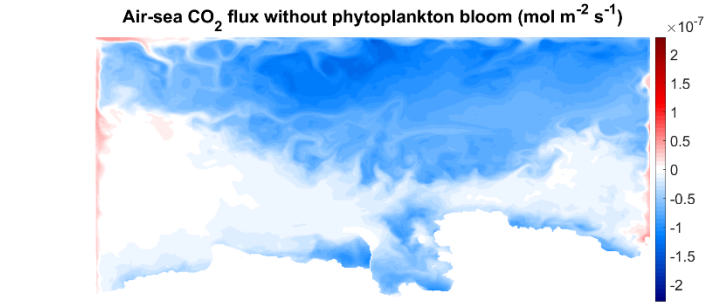
Effects seen in realistic ocean models (Kimura et al 2017)

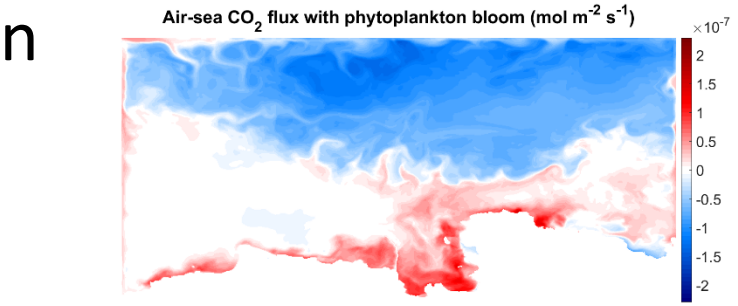


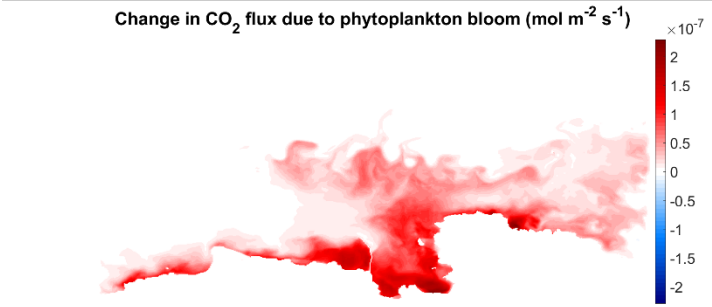
- Strong melt leads to strong boundary current
- Absence of strong current leads to circulation of surface waters by gyre

Conclusions and Further Work

- Ice-shelf melt shown to be crucial in upwelling of iron in coastal polyna
- Feedbacks of melt on ocean circulation can influence surface “spreading” of nutrients and productivity
- Importantly – interannual variability of winds may be important, but not investigated here



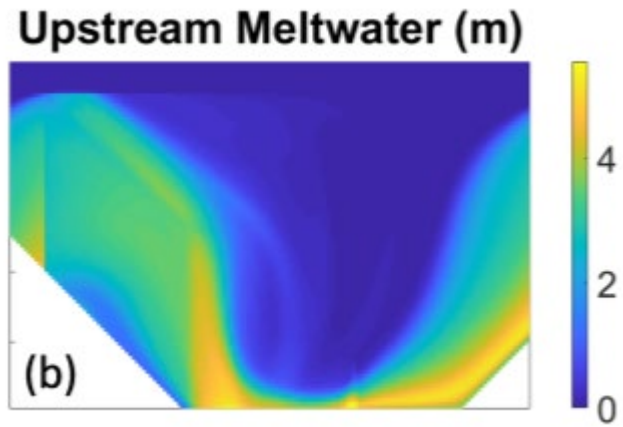


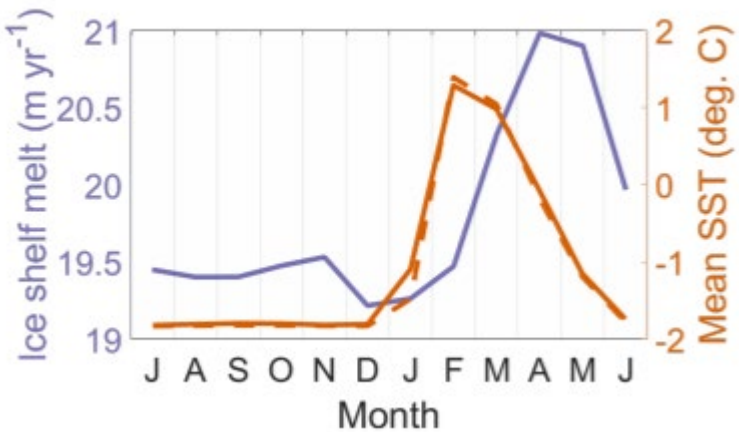


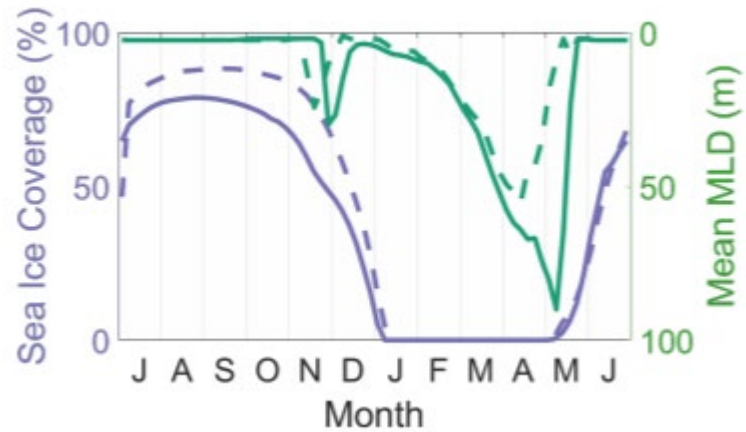
<u>Ongoing work</u>

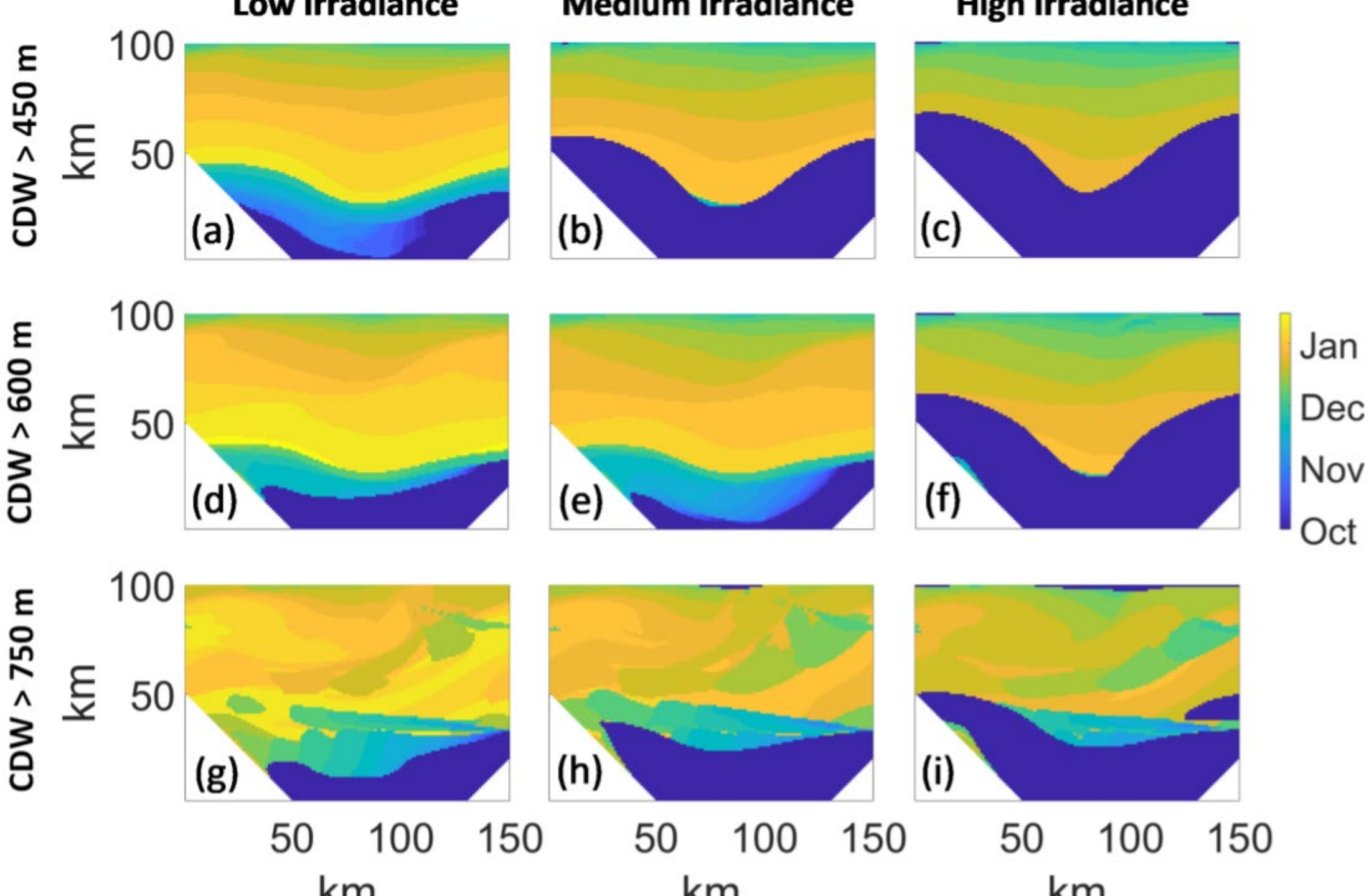
BLING coupled with realistic physical model of Amundsen (with P Holland)

Preliminary results: impact of biology on CO2 fluxes

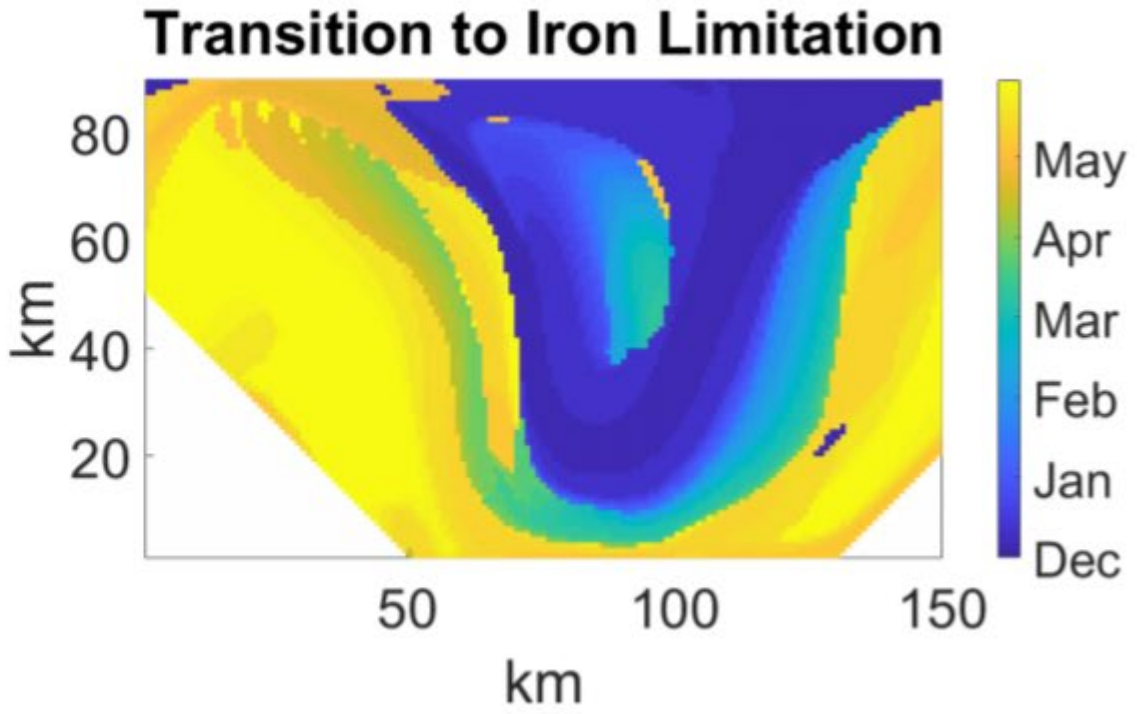

Upstream Meltwater (m)
(b)
4
2
0


Ice shelf melt (m yr^{-1})
21
20.5
20
19.5
19
Mean SST (deg. C)
2
1
0
-1
-2
J A S O N D J F M A M J
Month


Sea Ice Coverage (%)
100
50
0
Mean MLD (m)
0
50
100
J A S O N D J F M A M J
Month


Low Irradiance
Medium Irradiance
High Irradiance
CDW > 450 m
CDW > 600 m
CDW > 750 m
100
50
km
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
Jan
Dec
Nov
Oct
50
100
150
km

Results: Light and Iron limitation



- Effects of limiting factors (Iron, light) can be examined, by treating them as **nonlimiting**
- Seasonal transition from light to iron limiting – **timing of transition depends on location**