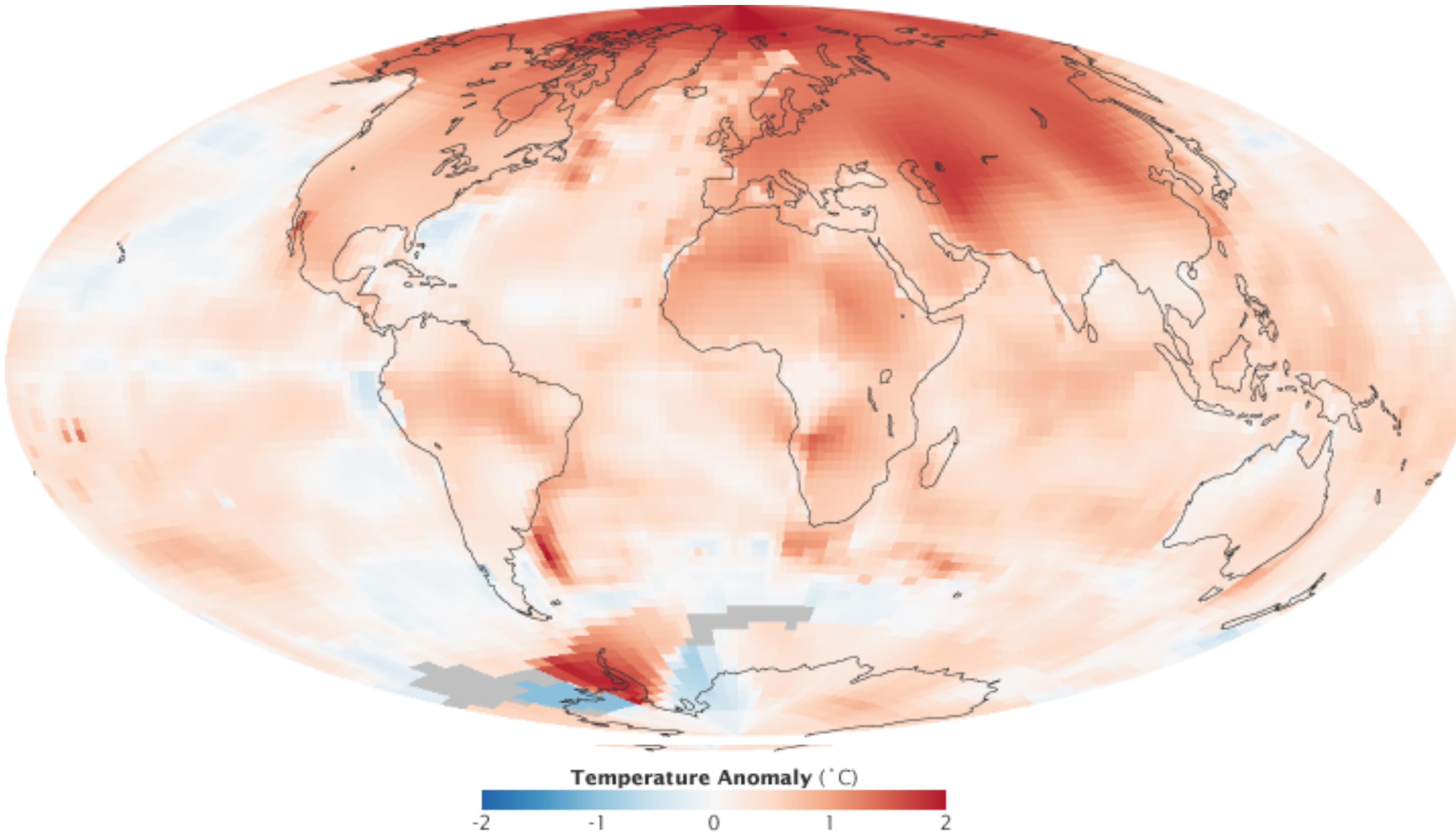
# Modes of Climate and Food Web Variability in High Latitude Oceans

**Kendra Daly**
**University of South Florida**




**5th International Zooplankton Production Symposium**
**Pucón, Chile**
**March 14-18, 2011**

http://earthobservatory.nasa.gov/IOTD/view.php?id=47628

## Outline

- ❖ Similarities and differences between Arctic and Antarctic systems
- ❖ Documented changes in Arctic and Antarctic systems
- ❖ Scenario testing: Combined field observations and models
- ❖ Path forward: Assessing climate impacts on ecosystems

## Outline

- ❖ Similarities and differences between Arctic and Antarctic systems
- ❖ Documented changes in the Arctic oceans and Southern Ocean
- ❖ Scenario testing: Combined field observations and models
- ❖ Path forward

**Session 6** Zooplankton in polar ecosystems and extreme environments

***Co-Convenors:***

*Angus Atkinson (British Antarctic Survey, UK)*

*Carin Ashjian (Woods Hole Oceanographic Institution, USA)*

**Monday 1400-1800**

*Similarities and differences between Arctic and Antarctic systems*

**Arctic and Antarctic zooplankton have evolved under conditions of**

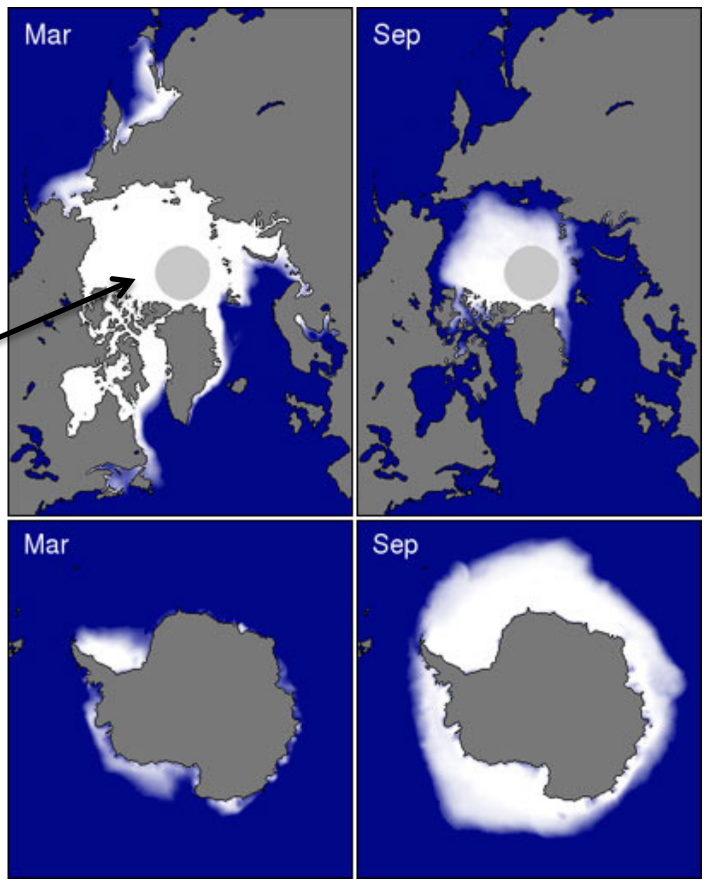
- Low seawater temperatures
- Highly seasonal variation in solar irradiance and primary production
- Arctic broad shallow shelves, with multiyear sea ice in some areas
- Southern Ocean deep continental shelves, often covered by annual sea ice

March September

Arctic

Limited satellite coverage

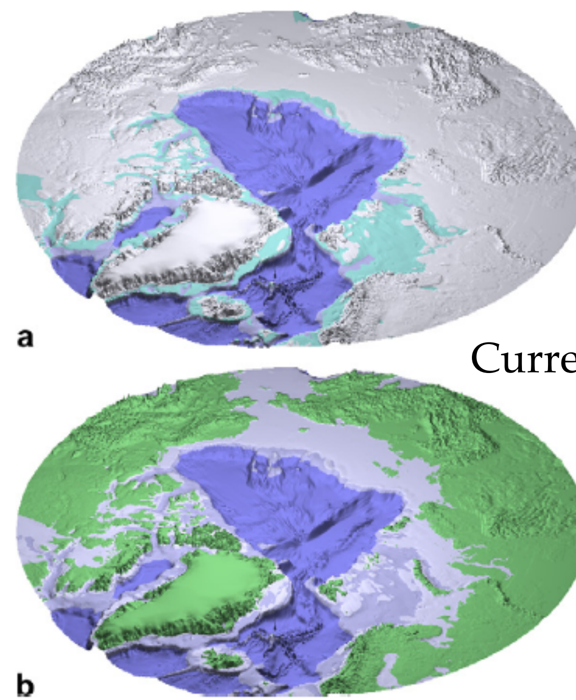
Antarctic




**http://nsidc.org/seaice/characteristics/difference.html**

Arctic Last Glacial Maximum

Current day




**Carmack & Wassmann (2006)**

*Similarities and differences between Arctic and Antarctic systems*

**High latitude physical environments also are influenced by multi-annual to decadal oscillatory atmospheric processes, which affects biological processes.**

Arctic systems

Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO) and Arctic Oscillation(AO)

Antarctic systems

El Nino Southern Ocean oscillations (ENSO), Southern Annular Mode oscillations (SAM)

*Similarities and differences between Arctic and Antarctic systems*
**Polar Zooplankton Communities, Rates, Life Histories**

## Similarities

- Ecologically-similar copepods are a dominate component in both systems
- Same genera of small copepods (*Oithona, Oncaea, Microcalanus*)
- Live 1-2 years
- Individual zooplankton feeding rates similar to boreal values

**Deibel & Daly (2007) Elsevier Oceanography Series 74**

### Antarctic


*Calanoides acutus, Calanus propinquus, Rhincalanus gigas, Metridia gerlacheii*

### Arctic

*Calanus hyperboreus*

*Calanus glacialis*

*Calanus finmarchicus*

*Metridia longa*

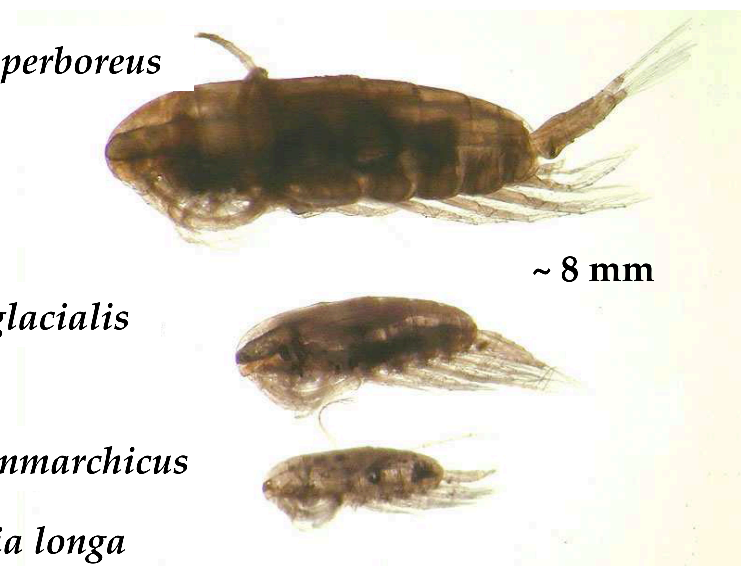



**Photo: P. Wassmann**

*Similarities and differences between Arctic and Antarctic systems*

**Polar Zooplankton Communities, Rates, Life Histories**

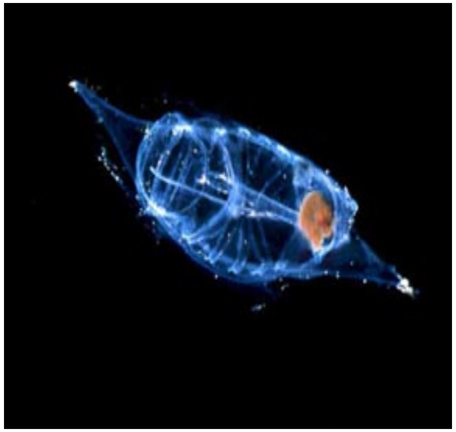
## Differences

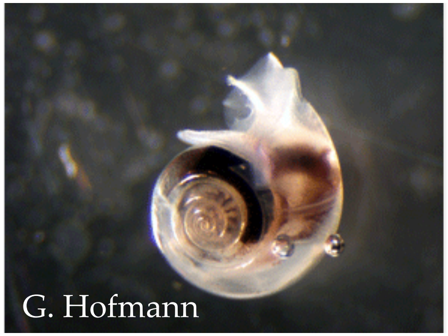
Euphausiids often dominant zooplankton biomass in the Southern Ocean
Euphausiids important in the western Arctic and the marginal seas

Appendicularians important as grazers & to vertical flux in Arctic
High abundances of pteropods & salps occur in the Southern Ocean

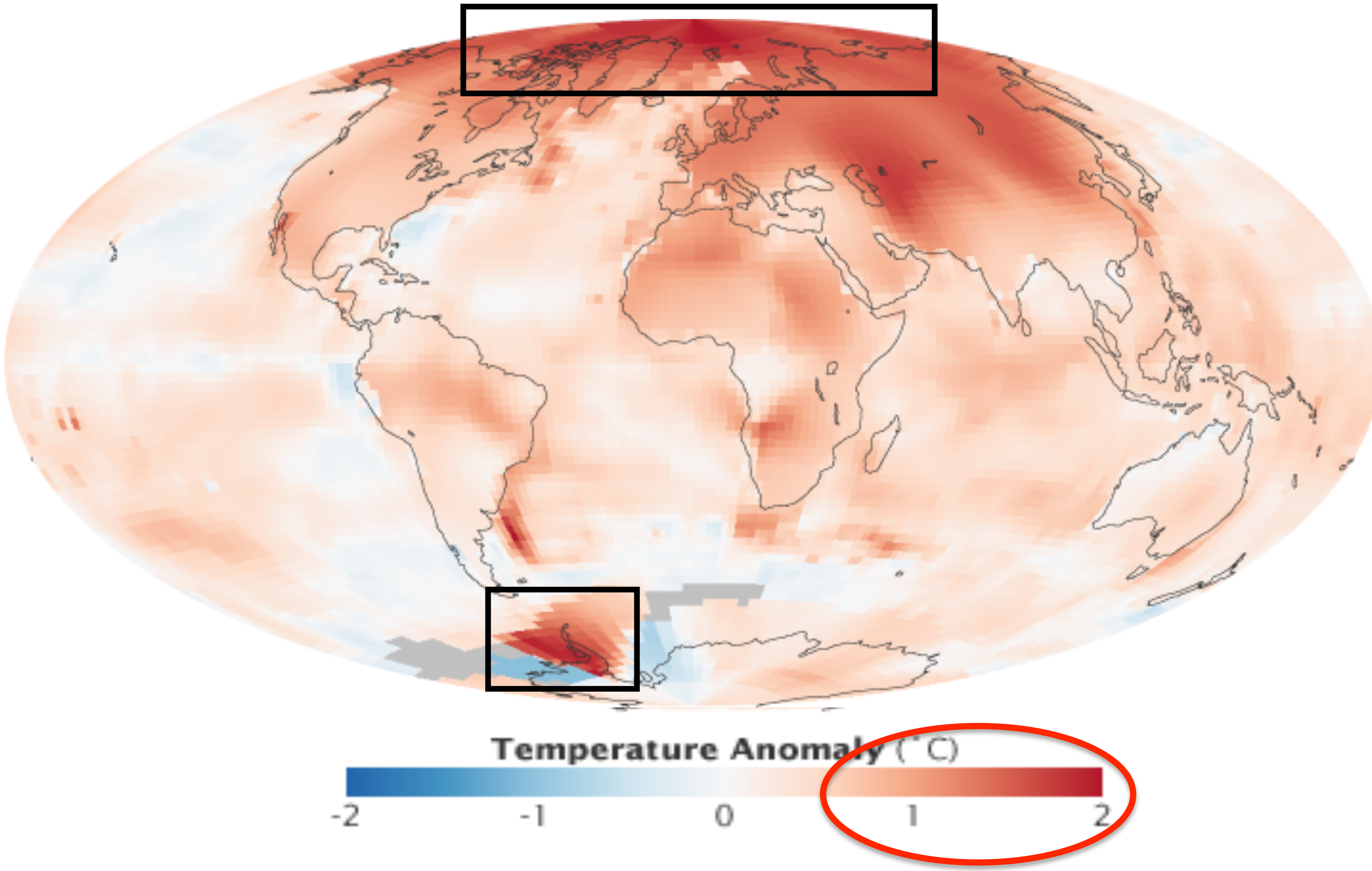
Most large calanoid copepods overwinter in diapause in Arctic
Some proportion of Antarctic copepods are active in surface waters in winter

**Deibel & Daly (2007) Elsevier Oceanography Series 74**



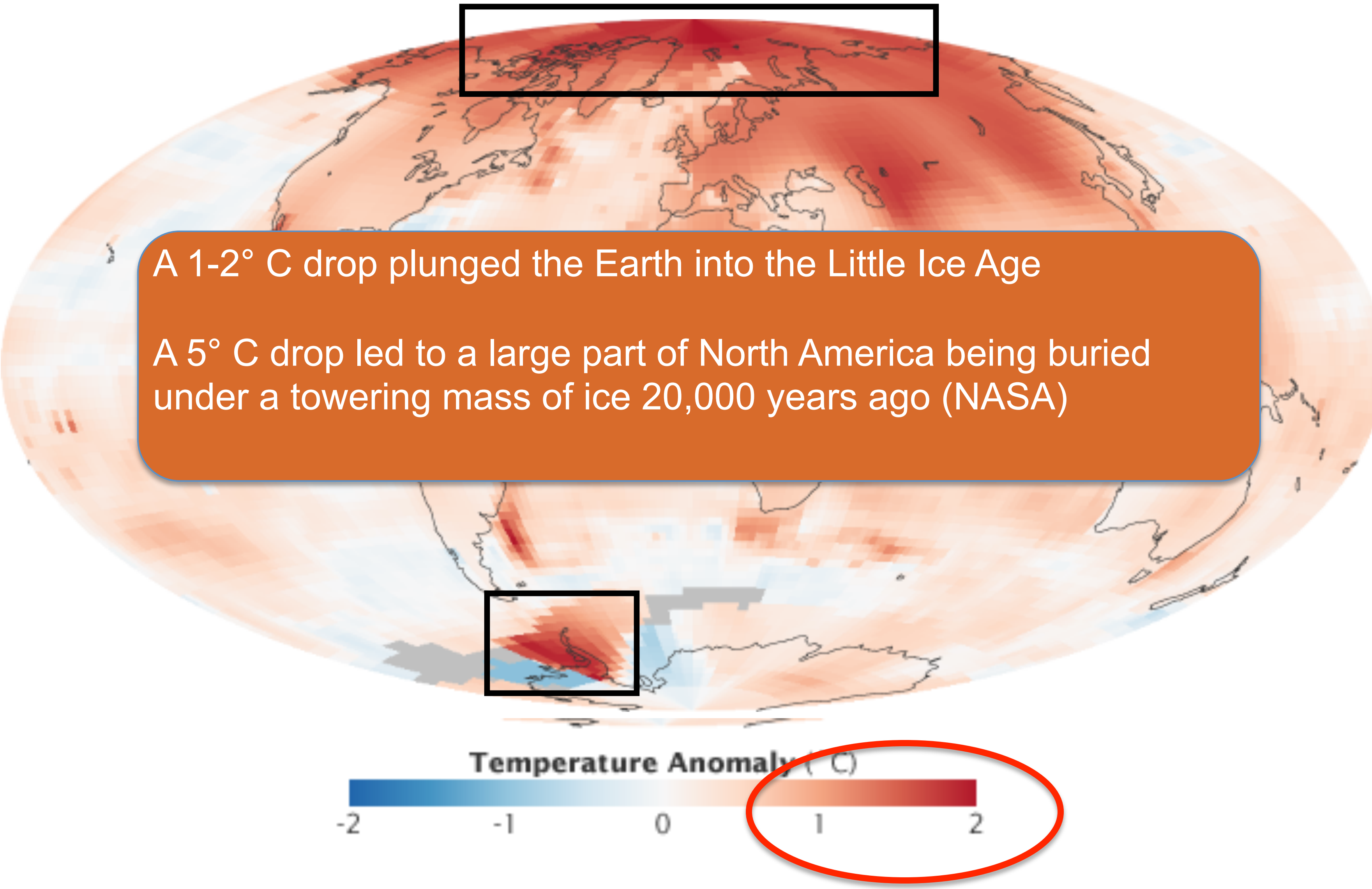



# Polar Regions Are Among the Fastest Warming Regions on the Planet




http://earthobservatory.nasa.gov/IOTD/view.php?id=47628

## Polar Regions Are Among the Fastest Warming Regions on the Planet




A 1-2° C drop plunged the Earth into the Little Ice Age

A 5° C drop led to a large part of North America being buried under a towering mass of ice 20,000 years ago (NASA)

http://earthobservatory.nasa.gov/IOTD/view.php?id=47628

## *Documented Changes in the Arctic and Marginal Seas*

- Atmospheric warming has increased Arctic Ocean temperature and resulted in decreased extent and thickness of sea ice (Comiso 2003; Kwok & Rothrock 2009).

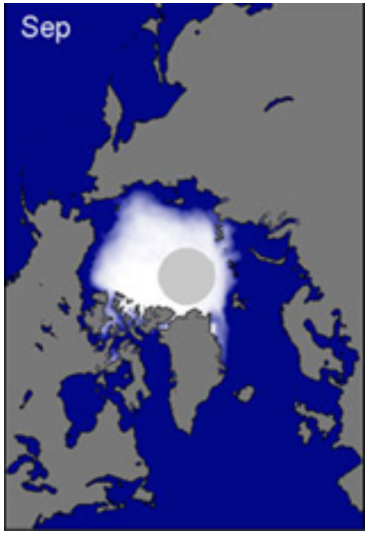
- Atmospheric warming combined with increased precipitation has lead to increased freshwater discharge into the Arctic Ocean from the six largest Eurasian rivers = increased stratification.

- Unprecedented amount of fresh water in the surface layer of the Arctic Ocean (e.g. Yamamoto-Kawai et al. 2009a) results in heating of surface layers up to 3ºC above average in ice-free regions that previously were ice covered (McPhee et al. 2009).

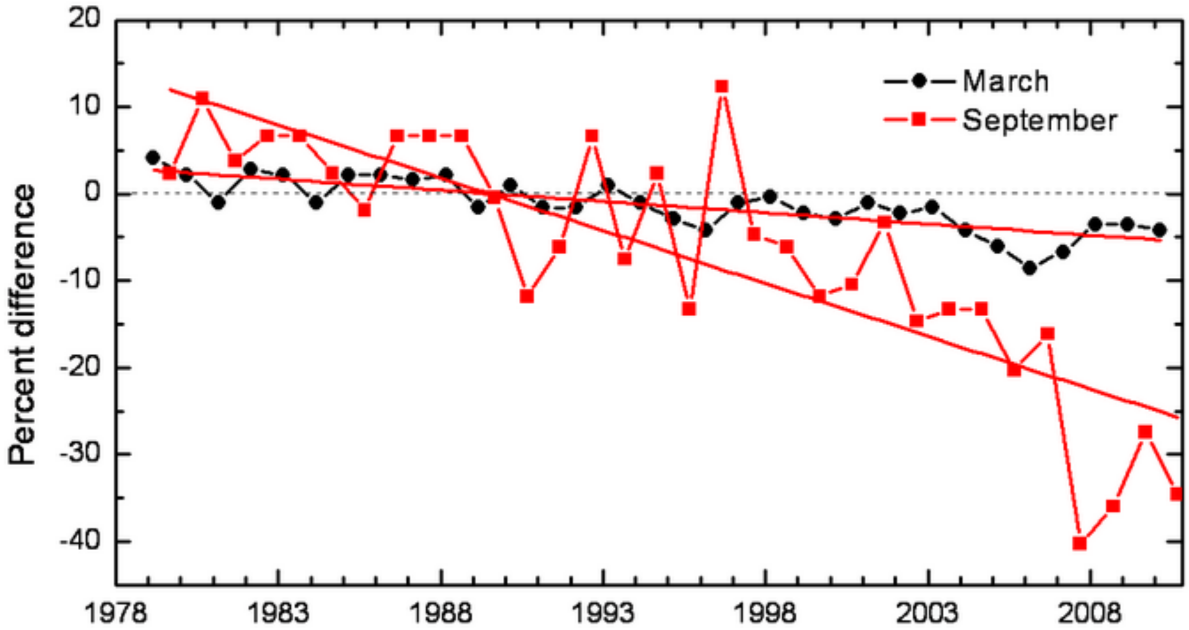
- Decrease in sea ice extent and age of sea ice

**Wassmann et al. 2011. Global Change Biology 17: 1235–1249**

*Documented Changes in the Arctic and Marginal Seas*




- The Arctic Sea ice extent has decreased about 11% per decade
- Half of the sea ice volume has disappeared
- More freshwater in the Arctic Ocean leads to more open water and increased stratification




http://www.arctic.noaa.gov/reportcard/seaice.html

## *Documented Changes in the Arctic and Marginal Seas*

❖ Substantial loss in older sea ice between 1988 and 2010

Blue: 1 year ice

Red: 5+ year ice

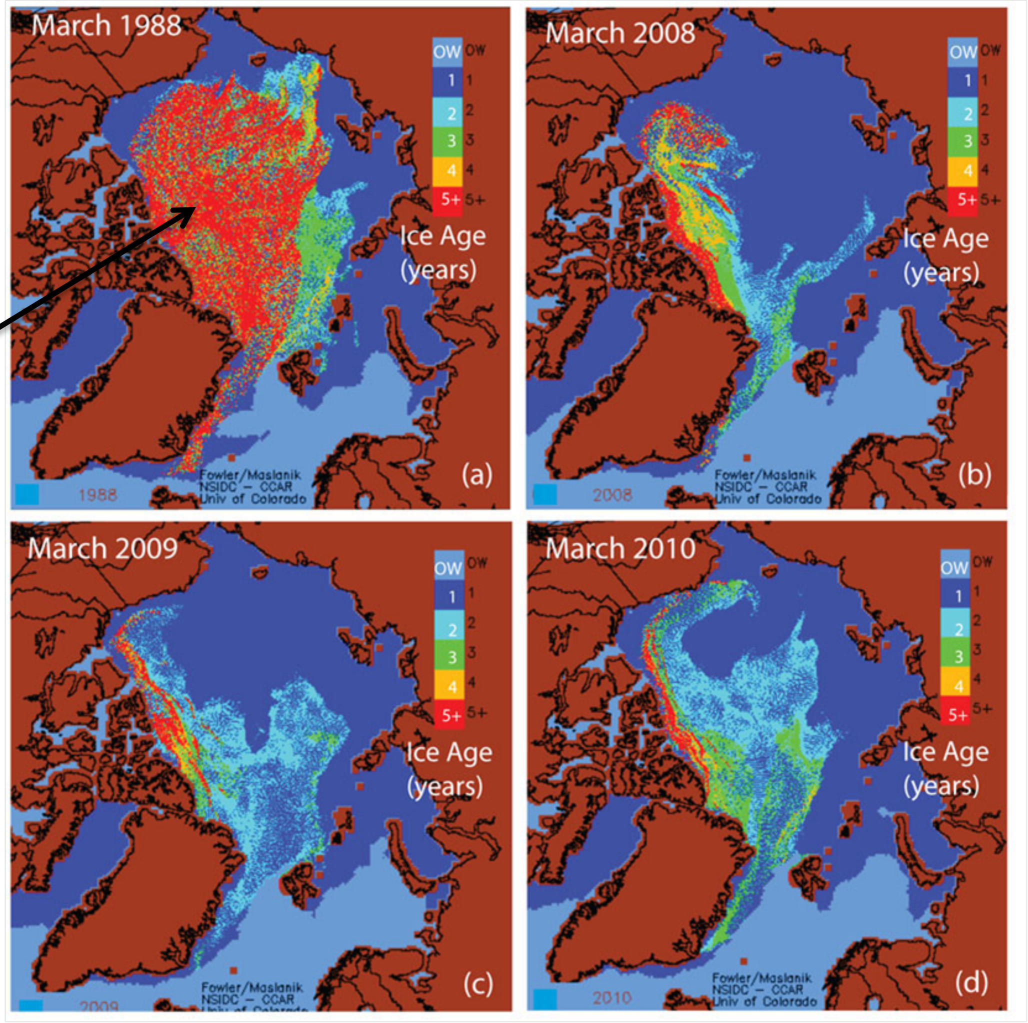



**Figure courtesy of National Snow and Ice Data Center, J. Maslanik and C. Fowler**

## *Documented Changes in the Arctic and Marginal Seas*

**Wassmann et al. (2011) Global Change Biology 17: 1235**

- **Documented 51 reports of changes in Arctic marine biota in response to climate change**, including range shifts and changes in abundance, growth/ condition, behavior/phenology and community/regime shifts. Most reports concerned marine mammals, particularly polar bears, and fish.

- Most reports are derived from subarctic locations (SW Greenland, the Bering Sea, the Barents Sea) and the Svalbard archipelago.

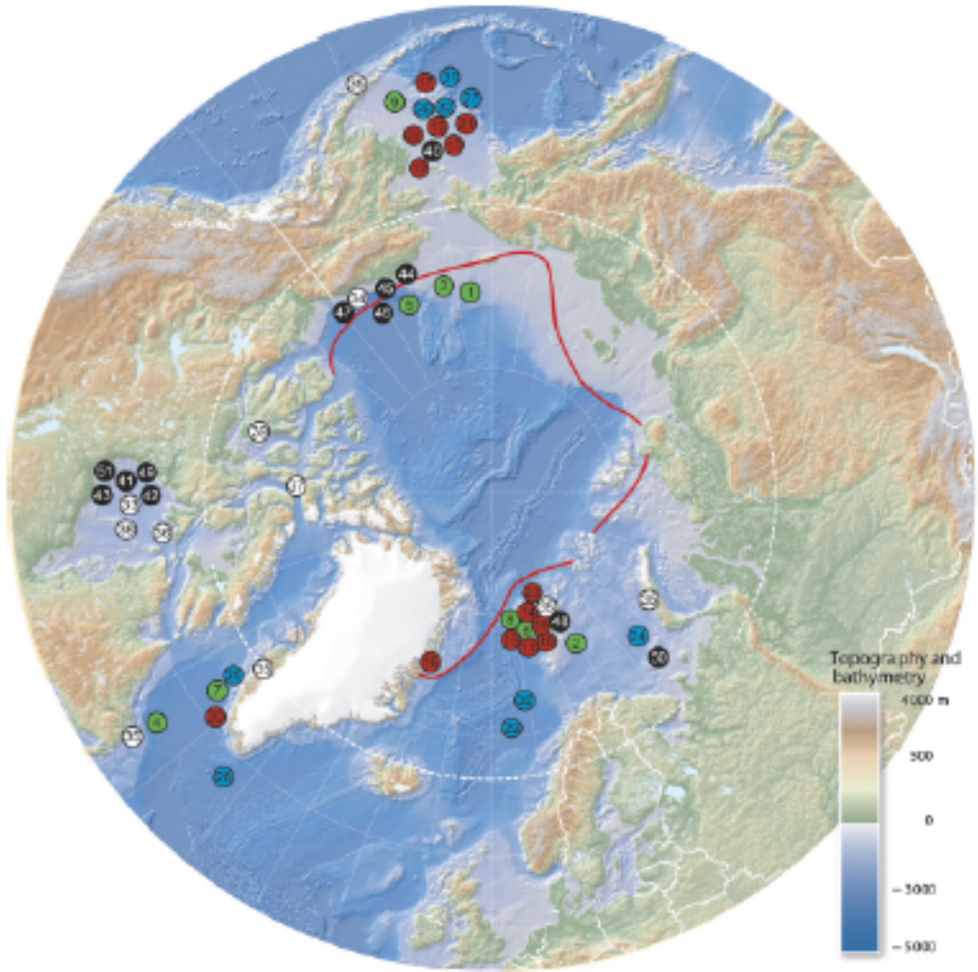
- The physical drivers include increased penetration of warm Atlantic and Pacific water into the Arctic Ocean, increased seawater temperature, reduced cover of sea ice, and increased submarine irradiance.

- The number of well-documented changes in planktonic and benthic systems is low.

- Evident losses of endemic species in the Arctic Ocean, and in ice algae production and associated communities, remain difficult to evaluate due to the lack of quantitative reports of its abundance and distribution.

*Documented Changes in the Arctic and Marginal Seas*

❖ Map showing where impacts of climate change on marine biota have been reported.




**Green: plankton**
**Red: benthos**
**Blue: fish**
White: birds
**Black: mammals**

**Wassmann et al. (2011) Global Change Biology 17: 1235**

*Documented changes in the Arctic and marginal seas*

- Recent evidence for increased phytoplankton biomass and primary production in the open Arctic Ocean, particularly the Pacific sector.
- The abundance of larger zooplankton and amphipod species associated with sea ice was reported to decline, while jellyfish abundance was reported to increase in some regions.

**Wassmann et al. (2011) Global Change Biology 17: 1235**

**Table 1** Reports of changes in Arctic plankton in response to climate change showing the organism and region investigated, the period of observation, and the response observed

| Subject | Region | Climatic driver | Footprint | References | Code |
|---|---|---|---|---|---|
| Primary production | Arctic Ocean | Ice changes | Increased annual primary production | Arrigo *et al.* (2008) | 1 |
| Phytoplankton biomass | Barents Sea | Ice changes | Increased phytoplankton biomass | Qu *et al.* (2006) | 2 |
| Primary production | Arctic Ocean | Ice changes | Increased primary production | Pabi *et al.* (2008) | 3 |
| Planktonic diatom | Labrador Sea | Altered circulation | Range shift of *Neodenticula seminae* | Reid *et al.* (2007) | 4 |
| Primary production | Beaufort Sea | Ice changes | Increased primary production | Mundy *et al.* (2009) | 5 |
| Amphipods | Kongsfjord, Svalbard | Altered circulation | Increasing proportion of *Themisto abyssorum* to *T. libellula* | Hop *et al.* (2006) | 6 |
| Zooplankton community | West Greenland | Warming | Changes in zooplankton abundance and composition | Pedersen & Rice (2002) | 7 |
| Copepods | Kongsfjord, Svalbard | Altered circulation | Increasing contribution of smaller copepods | Hop *et al.* (2006) | 8 |
| Jellyfish | Bering Sea | Warming | Increase in jellyfish biomass | Brodeur *et al.* (1999) | 9 |

The code number identifies the corresponding symbol in Fig. 3

*Documented changes in the Arctic and marginal seas*

❖ **Variable increases and decreases in ranges of fish stocks and spawning and recruitment, depending on species and region.**

**Wassmann et al. (2011) Global Change Biology 17: 1235**

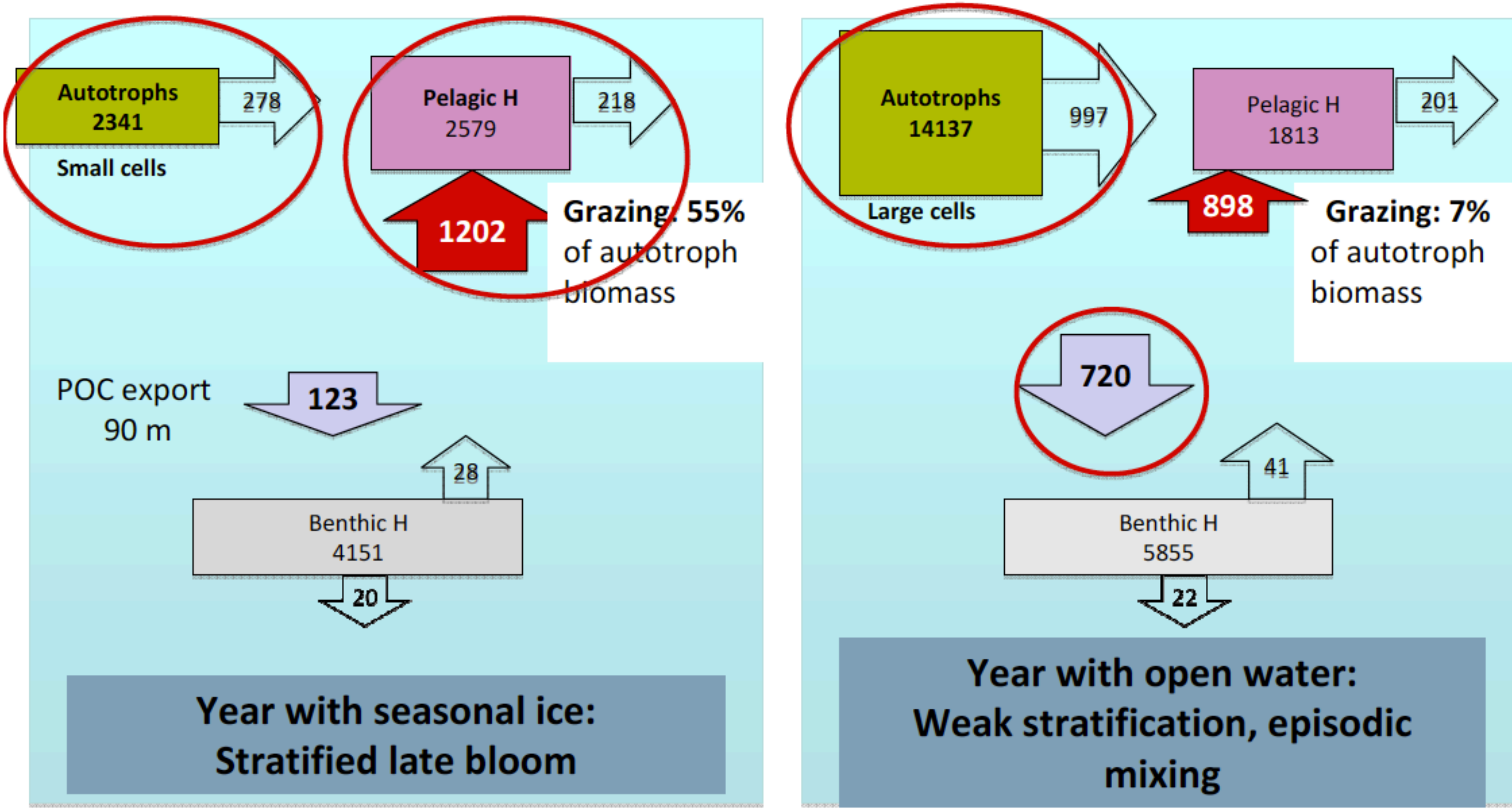
**Table 3** Reports of changes in Arctic fish in response to climate change showing the organism and region investigated, the period of observation, and the response observed

| Subject | Region | Climatic driver | Footprint | References | Code |
|---|---|---|---|---|---|
| Cod | Barents Sea | Warming | Increased cod recruitment and length | Overland *et al*. (2004) | 24 |
| Cod and Shrimp | West Greenland | Warming | Replacement of cod by shrimp | Hamilton *et al*. (2003) | 25 |
| Greenland Turbot | Bering Sea | Warming and ice changes | Increased spawning biomass | Overland & Stabeno (2004) | 26 |
| Pacific Cod | Bering Sea | Warming and reduced sea ice | Reduced spawning biomass | Overland & Stabeno (2004) | 27 |
| Cod | North Atlantic | Warming | Northward spread and increased spawning stock biomass and recruitment | Drinkwater (2009) | 28 |
| Cod | Barents Sea | NAO/temperature | Positive relation between cod recruitment and temperature | Ottersen & Stenseth (2001) | 29 |
| Snake Pipefish | W Svalbard | Warming | Northward range shift | Fleischer *et al*. (2007) | 30 |
| Walleye Pollock | Chukchi and Bering Seas | Warming | Northward range shift | Mecklenburg *et al*. (2007) | 31 |
| Walleye Pollock | Bering Sea | Warming and ice changes | Increased biomass | Overland & Stabeno (2004) | 32 |

The code number identifies the corresponding symbol in Fig. 3.

*Arctic Scenario testing: Combined field observations and models*

# Barents Sea shelf: Effect of stratification




**Ringstad et al. (2010) Prog. Ocean.**

Field based measurements
Units: mg C $m^{-2}$ $d^{-2}$, mg C $m^{-2}$

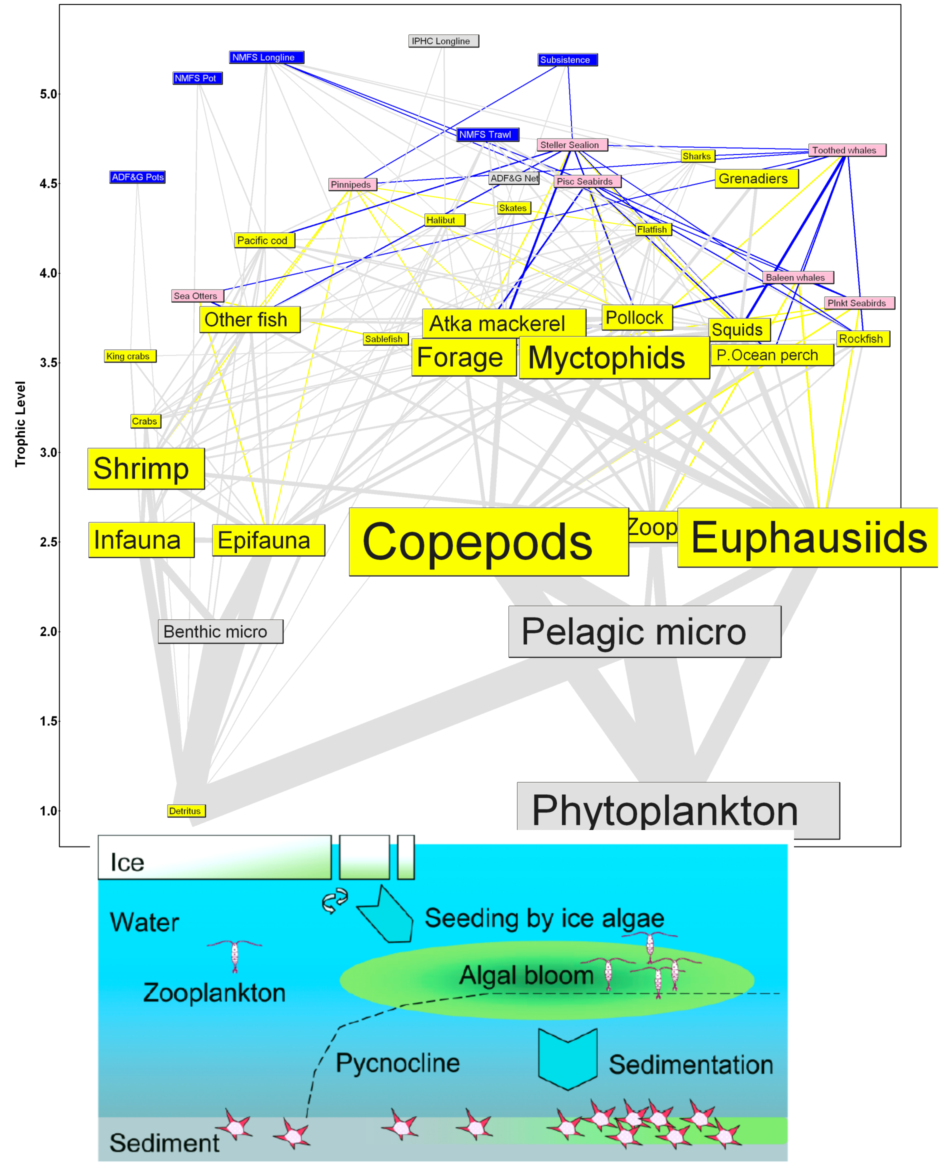
# *Arctic Scenario testing: Combined field observations and models*

## End-to-End food web model of the eastern Chukchi Sea

- Create mass-balance model of the eastern Chukchi Sea to characterize the trophic structure

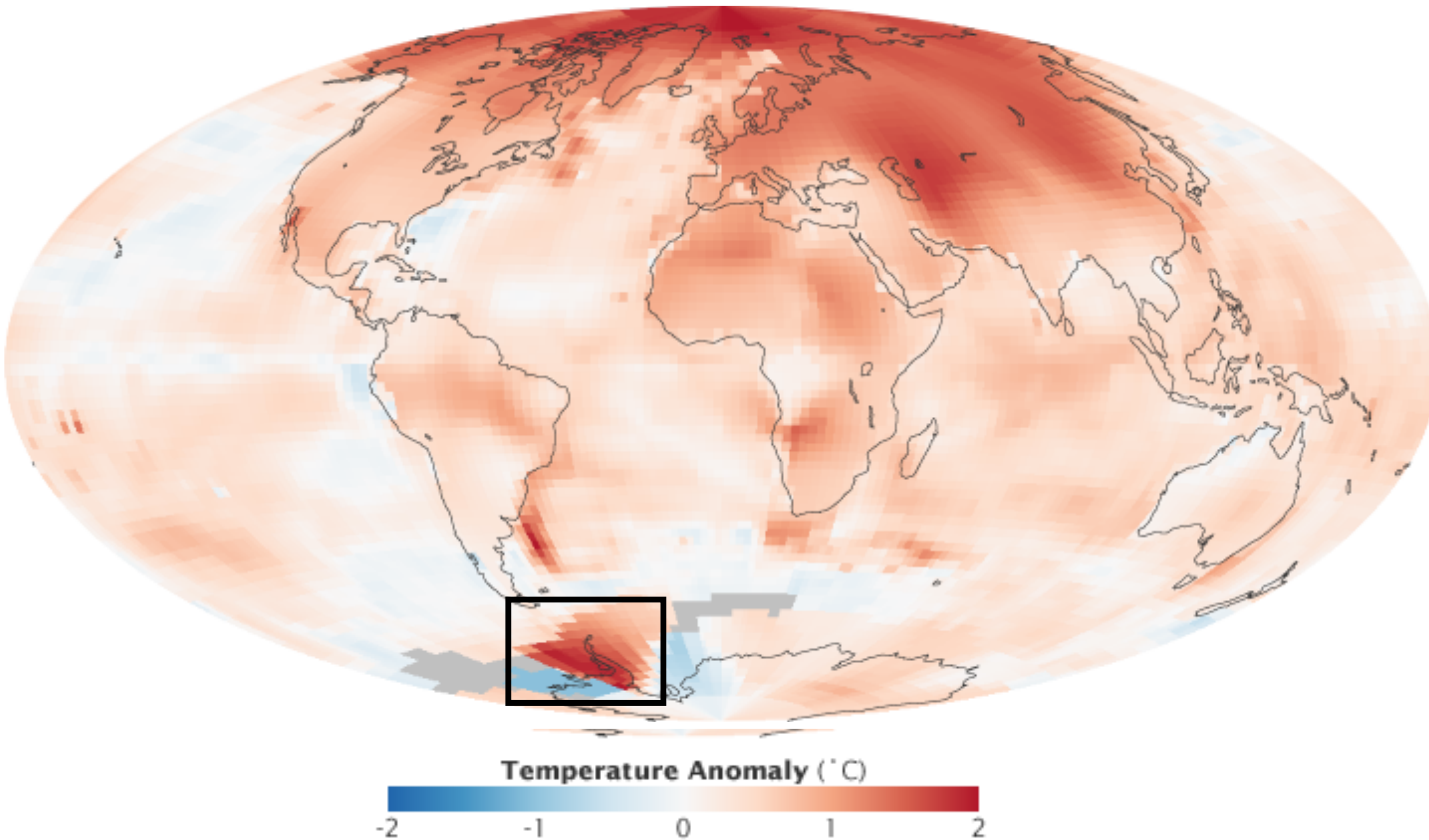
- Use simulations to investigate the impacts of introducing commercial fisheries for snow crab *(Chionoecetes opilio)* and/or arctic cod *(Boreogadus saida)*

- Identify key uncertainties about food web dynamics, investigate ecosystem stability and resilience




**Andy Whitehouse (UW and NOAA/NMFS)**

# Southern Ocean: Complex Landscape of Warming and Cooling

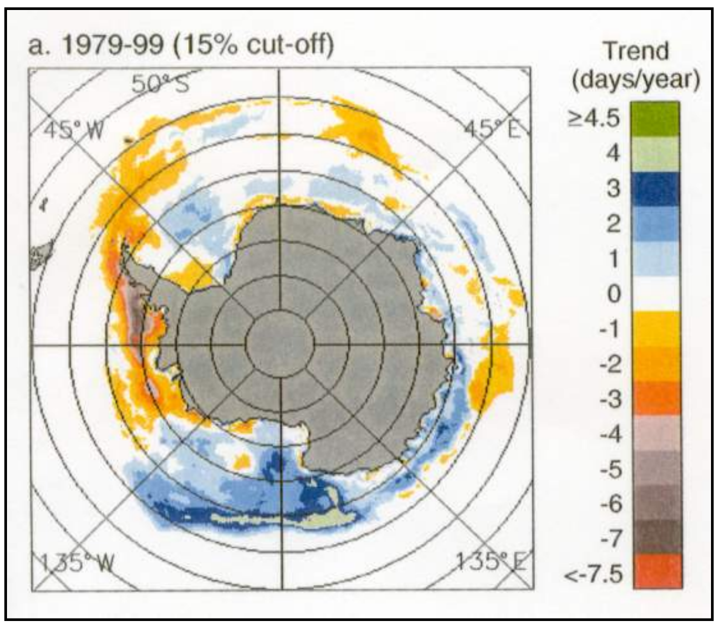


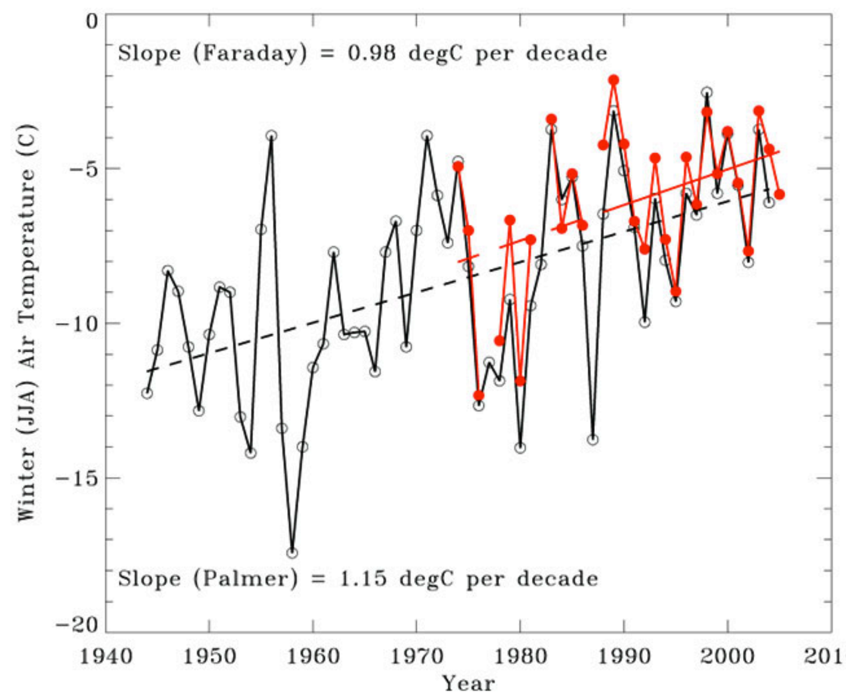

http://earthobservatory.nasa.gov/IOTD/view.php?id=47628

*Documented Changes in the Antarctic*

- Upper ocean temperatures have increased by 1ºC in the last 50 years (Gille 2002)

- Winter temperatures along the west Antarctic Peninsula have warmed 5.8ºC between1950-2005  - more than five times the global average (Vaughan et al. 2003).



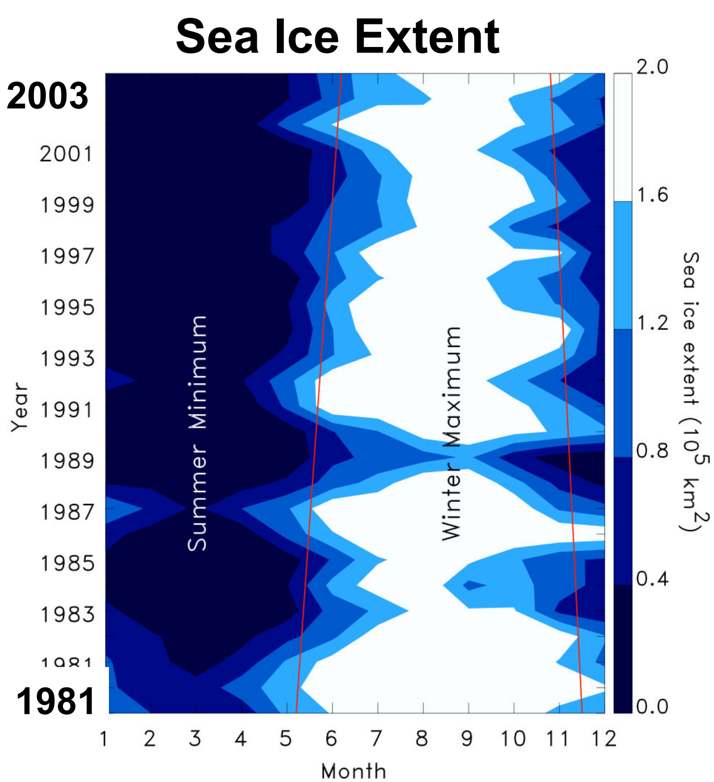



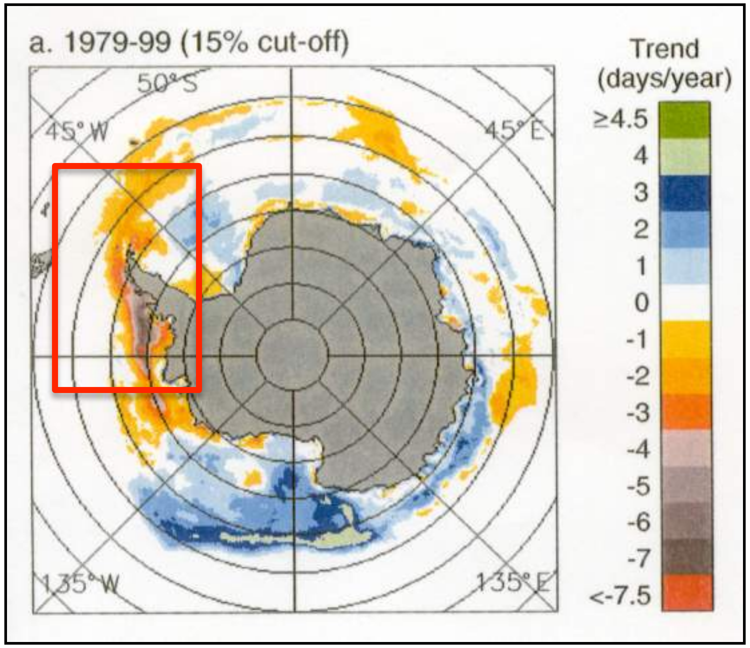
*Documented Changes in the Antarctic*

West Antarctic Peninsula and Bellingshausen Sea

- 87% of the glaciers are in retreat (Cook et al. 2005).

- Seasonal sea ice duration has decreased by about 90 days, related to a shift towards positive values of the Southern Annual Mode since the 1990s (Stammerjohn et al. 2008).

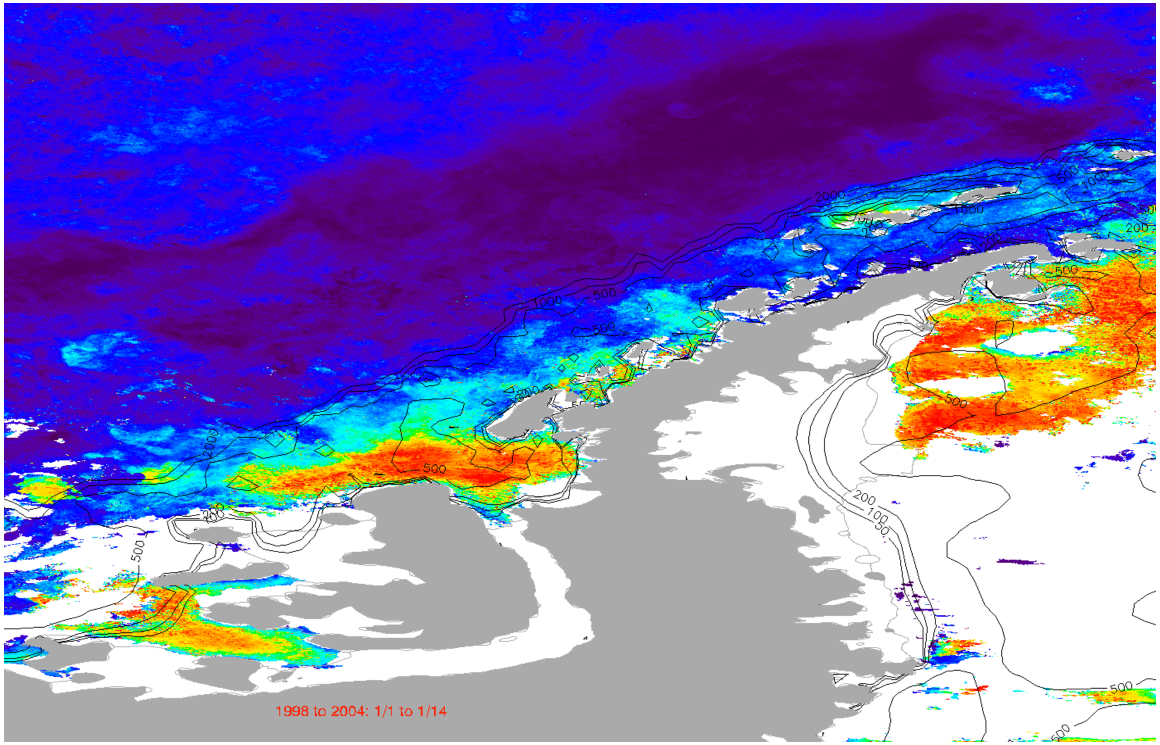


*Documented Changes in the Antarctic*

- Over last 30 years phytoplankton biomass has declined about 12% along the northern region of the Antarctic Peninsula (Montes-Hugo et al. 2009)

- In contrast, the southern Antarctic Peninsula (Marguerite Bay region) sustains persistent and long lasting blooms (Marrari, Daly, & Hu 2008)



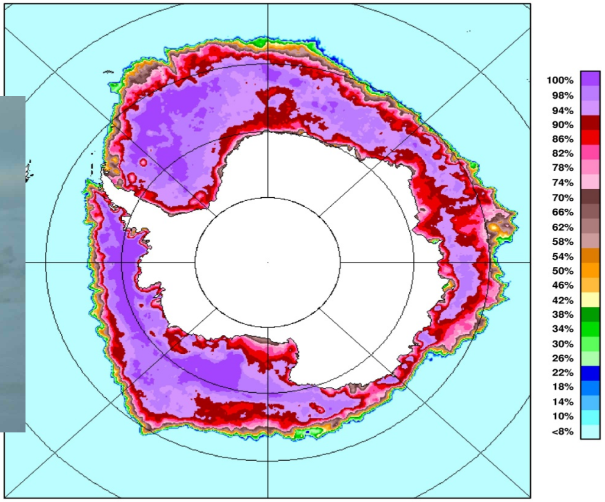

SeaWiFS climatology (1997–2004) of chlorophyll a concentrations for January 1-14

**Marrari, Daly, & Hu (2008)**

*Documented Changes in the Antarctic*

- In the past 30 years in the northern west Antarctic Peninsula, populations of ice-dependent Adélie penguins have declined by 90%,

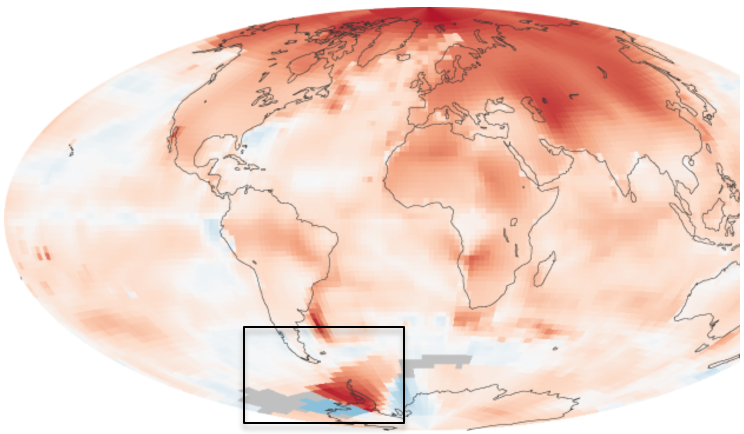
- Populations of ice-intolerant Chinstrap and Gentoo penguins have risen in the northern and mid-Peninsula region (Ducklow et al. 2007).



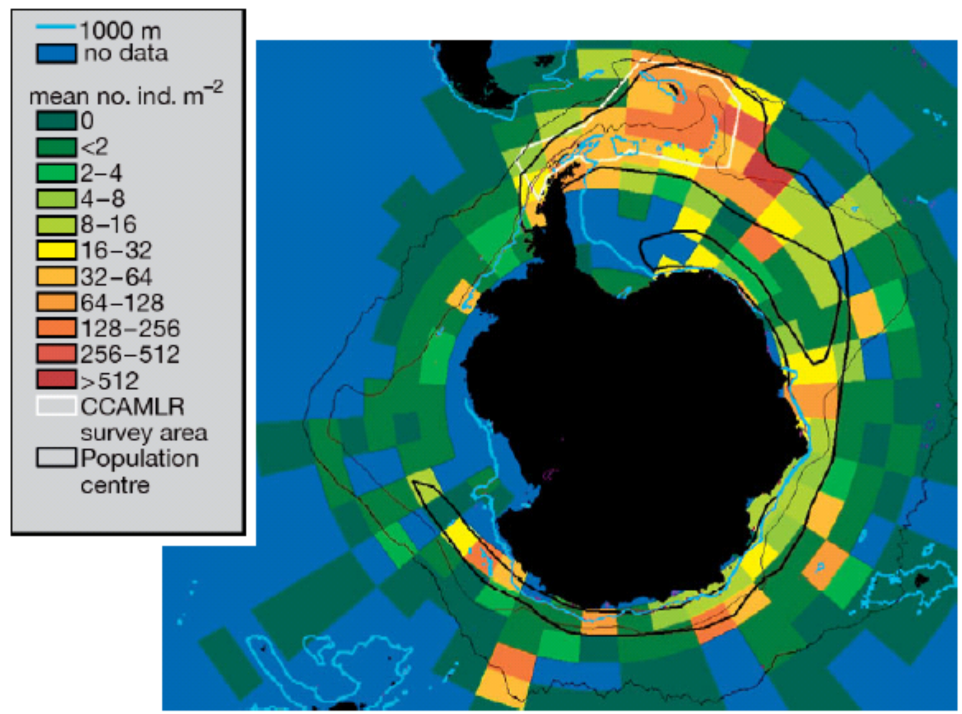

Maximum extent of sea ice 2001

## *Documented Changes in the Antarctic*

The Antarctic krill, *Euphausia superba*, has a heterogeneous circumpolar distribution, with about 50% of its population in the SW Atlantic sector, coincident with region of warming.



*E. superba*, up to 65 mm in length

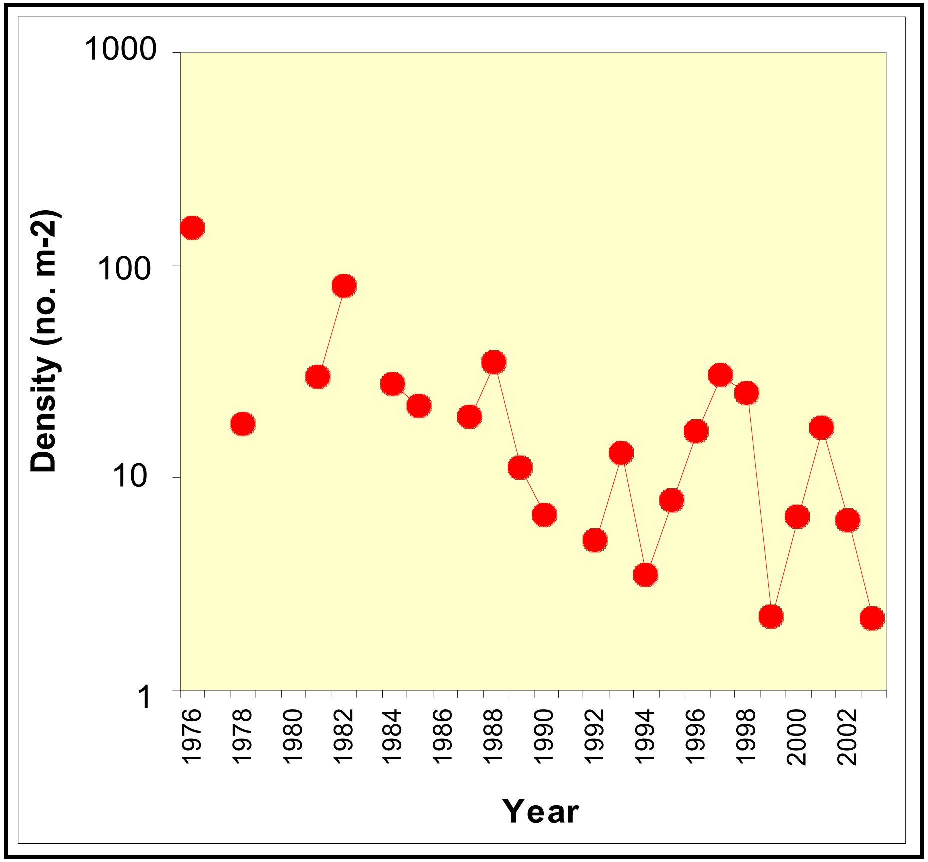



**Atkinson et al. (2008) MEPS 362**

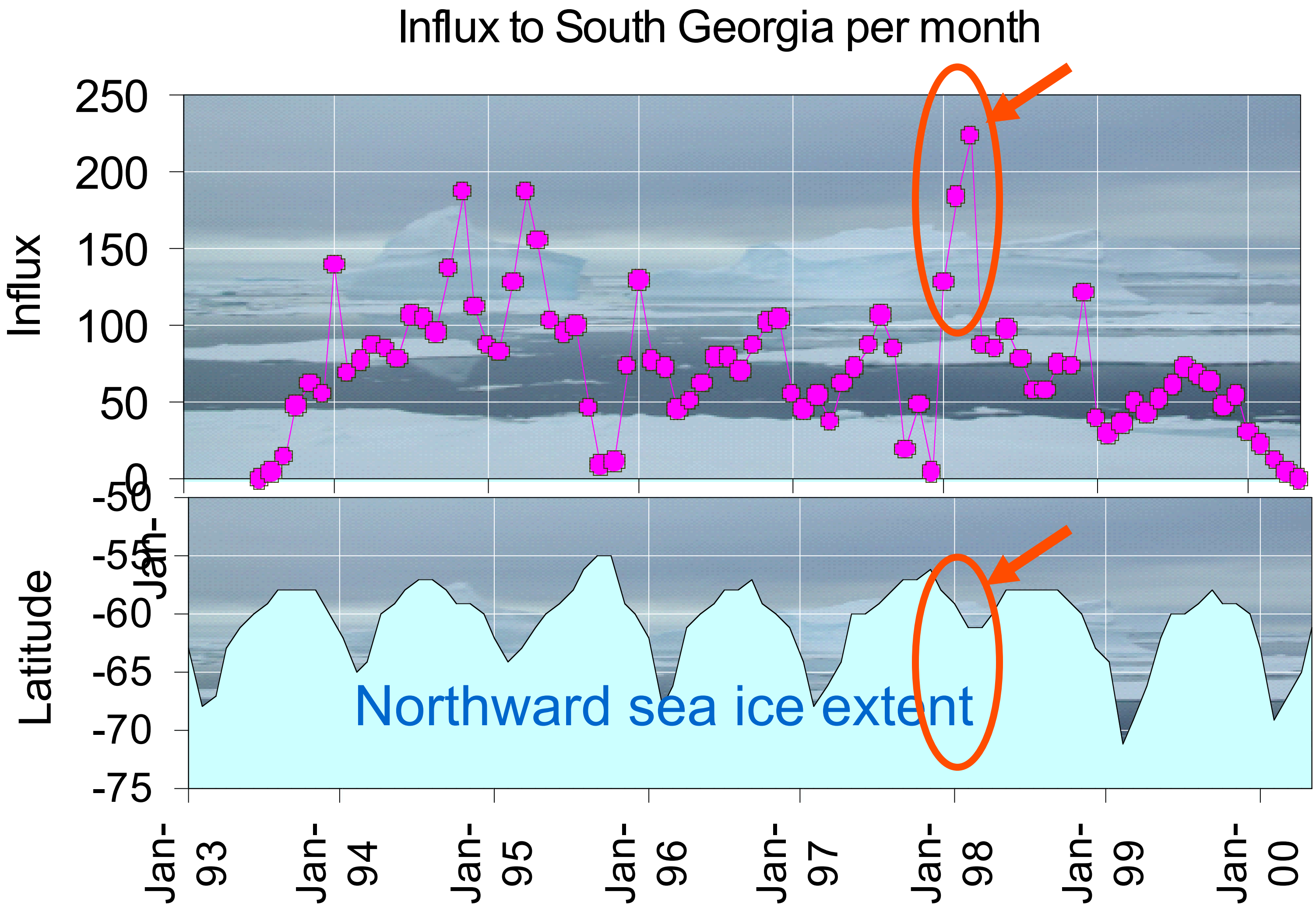
## *Documented Changes in the Antarctic*

Long-term decline in krill stock and increase in salps in the Southern Atlantic sector of the Southern Ocean (Atkinson et al. 2004 Nature 432)

- Decline in Antarctic krill during last 30 years.
- Spatially, summer krill density positively correlated with chlorophyll concentrations.
- Decreasing winter ice in the major spawning and nursery areas (the Antarctic Peninsula and Southern Scotia Arc) affects krill density across the Atlantic basin.



- Variability in transport and connectivity of krill populations between the Bellingshausen Sea and South Georgia related to northern sea ice extent.

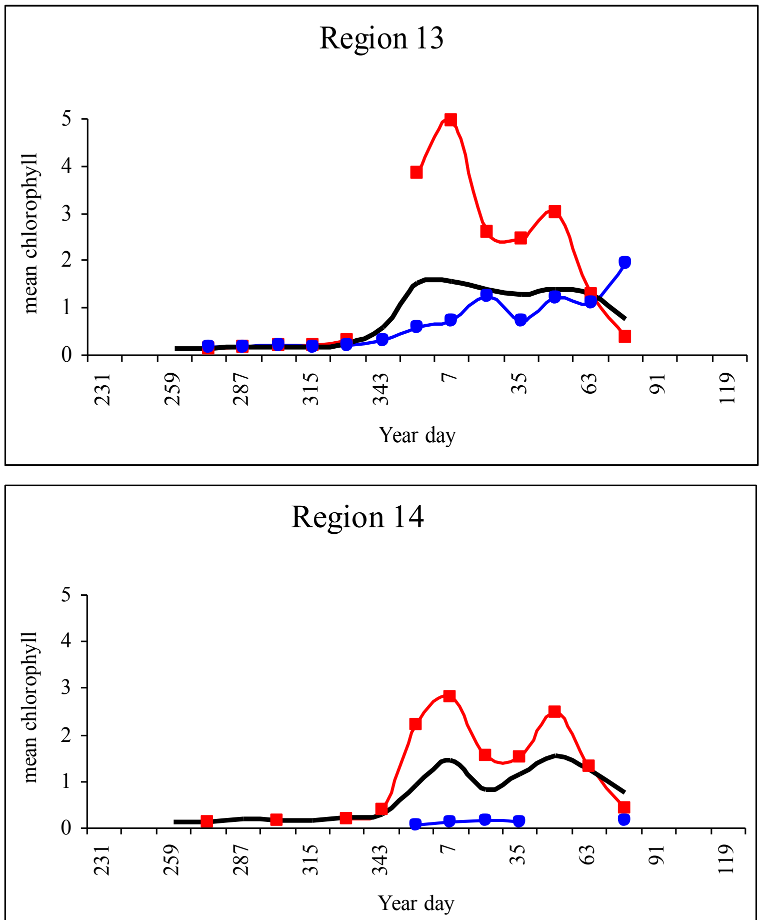


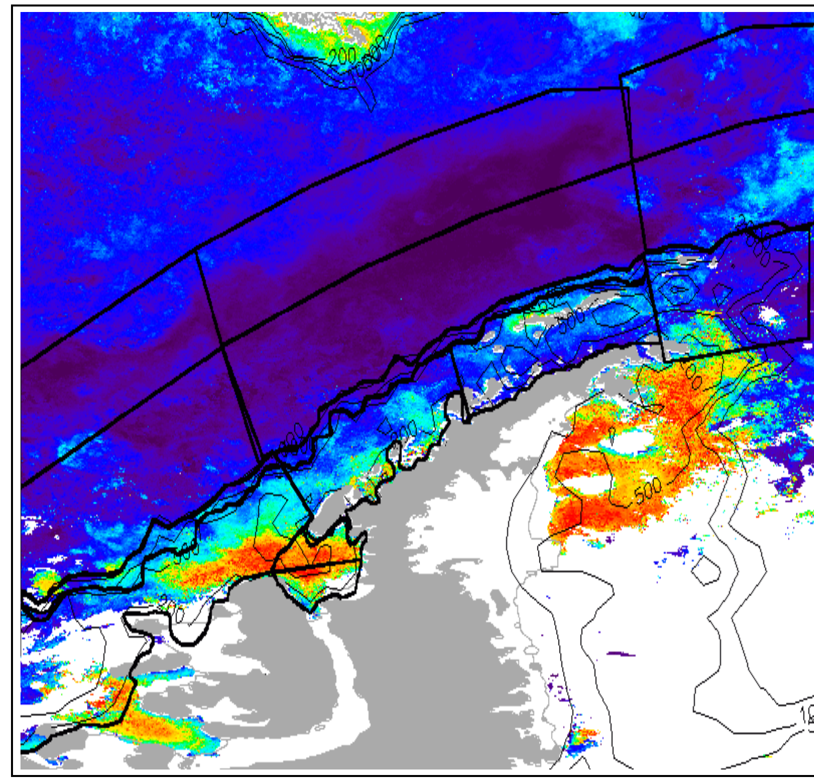

Thorpe et al. (2007)

*Antarctic scenario testing: Combined field observations and models*

How will zooplankton respond to changing sea ice and phytoplankton?

- ❖ 2001 Marguerite Bay phytoplankton significantly above climatology



2000-2001
2001-2002

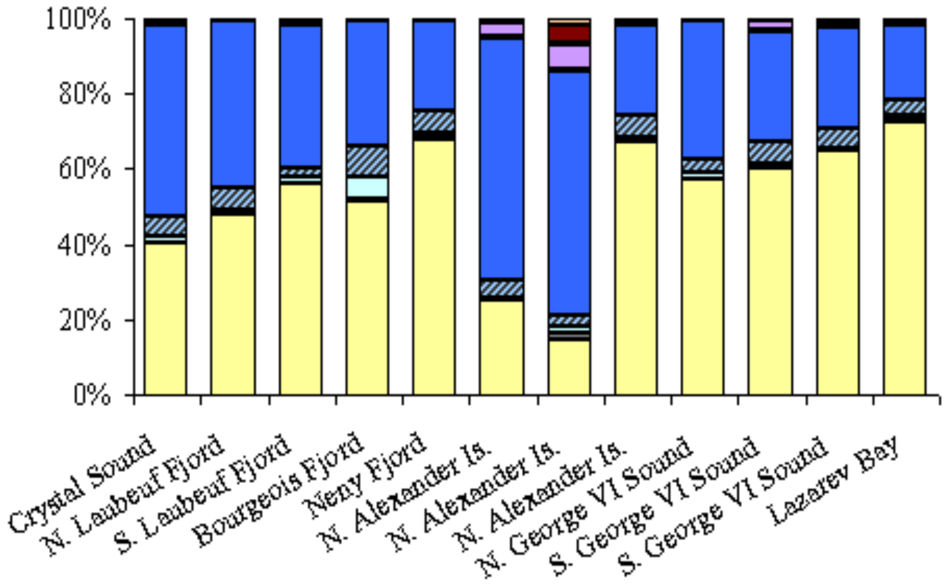
**Marrari et al. (2008)**

*Antarctic scenario testing: Combined field observations and models*

2001 Marguerite Bay summer phytoplankton significantly above climatology, whereas winter sea ice extent was typical for region

<u>Zooplankton community response</u>

- ❖ Chlorophyll ↑
- ❖ All euphausiids species reproductive success and recruitment ↑
- ❖ Herbivorous copepod populations (*Calanoides acutus* & *Metridia*) ↑

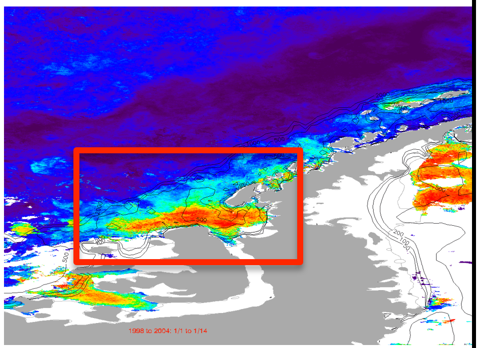


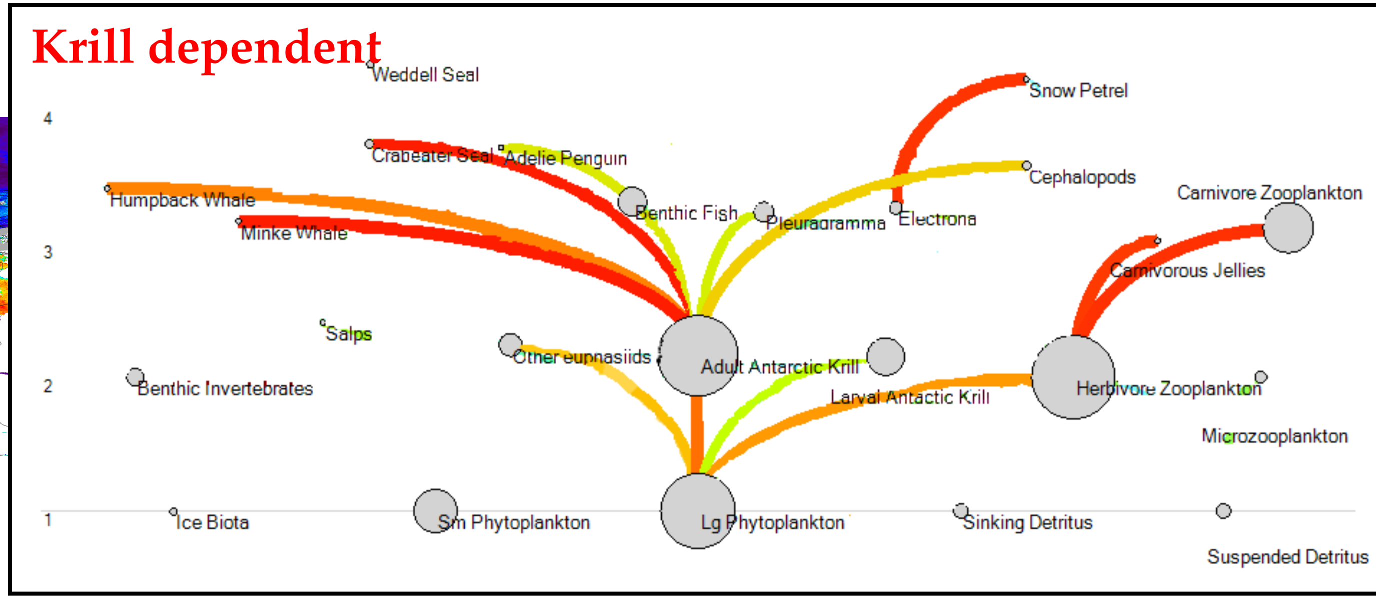

<u>% of copepod community</u>
*C. acutus* = 52% (yellow)
*M. gerlachei* = 38% (blue)

**Marrari et al. (2011) DSR II**

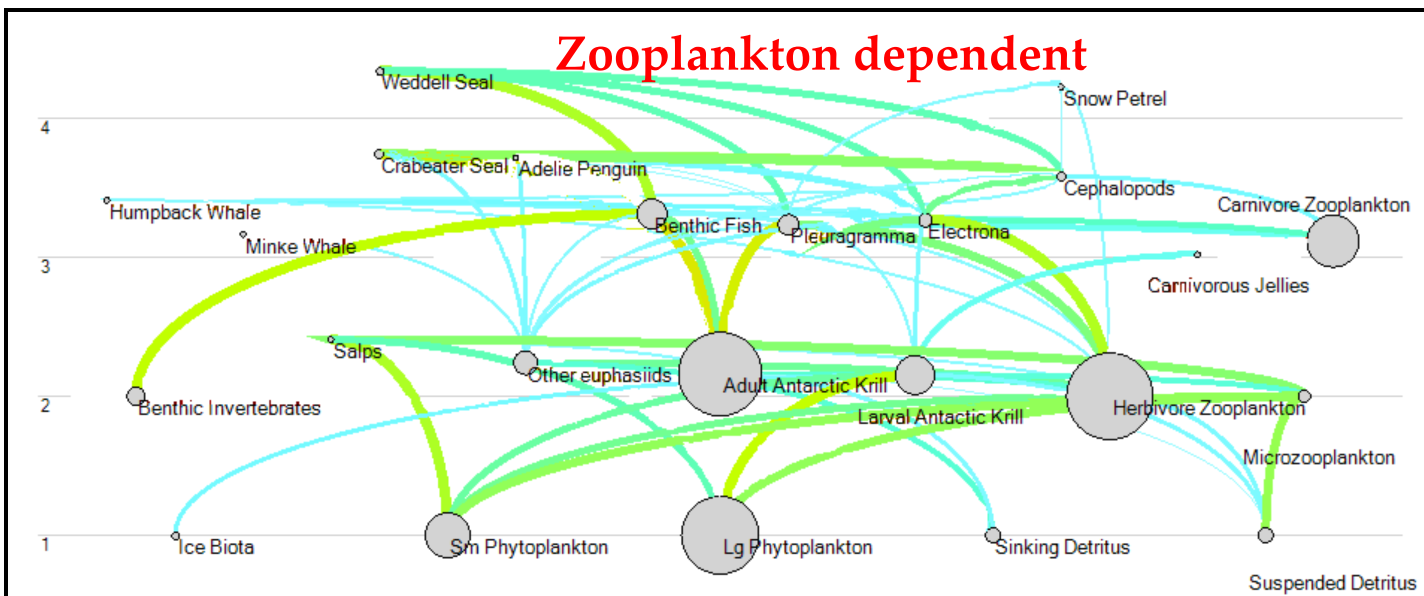
# *Antarctic scenario testing: Combined field observations and models*

End-to-end food web model for Marguerite Bay (Ballerini, Hofmann, Daly, Marrari, et al.)





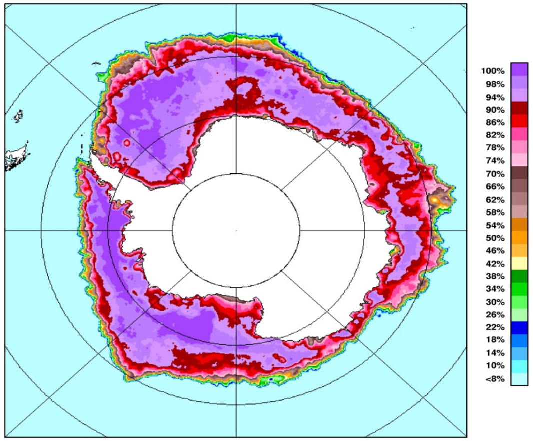

Trophic efficiency varies depending on alternative pathways based on diet structure

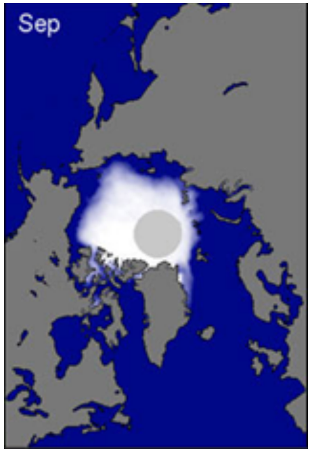



Investigate impacts of climate & fishing

# Path forward: Assessing climate impacts on ecosystems

- Food webs are not the same everywhere in the Arctic Ocean or Southern Ocean
- Considerable heterogeneity in forcing and habitat structure
- Regional differences in ecosystem responses
- Baseline data and understanding of underlying processes are lacking



# Path Forward: Assessing Climate Impact on Ecosystems

- Continue existing time series and start new time series in strategic locations
- Obtain better seasonal coverage
- Deploy observing platforms and sensors for continuous observations
- Continue satellite remote sensing observations
- Develop new tools (e.g., molecular techniques, models) to detect climate impacts and assess different climate scenarios