Climate Change & Marine Biogeochemical Modeling from Local to Global Scales
Scott Doney (WHOI & Palmer LTER)
NSF Science Council Meeting (May 2011)

Outline
- Climate change trends on West Antarctic Peninsula (WAP)
- Local & regional food-web impacts
- Global primary production & plankton community structure trends

Climate Trends along Western Antarctic Peninsula
- Rapid warming along WAP ~6x global average
- Reduced sea-ice cover & expanding seasonal ice free conditions

Decadal Change in Surface Chlorophyll
Montes et al. Science (2009)

Ecological Responses to Retreating Sea-Ice
Penguin Populations near Palmer Station
Adélies declining, Gentoo and Chinstrap invading and increasing

Inverse Model of WAP Food Web
- Linear herbivorous food-chain - strong transfer to higher trophic levels & export

Penguin
Fish
Krill
Large phytoplankton

Microzooplankton
Large phytoplankton
Small phytoplankton
- Reduced transfer to higher trophic levels & export

Inverse Model of WAP Food Web
Inverse Model of WAP Food Web

**Small phytoplankton**

**Large phytoplankton**

**DOC**

**Microzooplankton**

**Krill**

**Fish**

**Bacteria**

**Detritus**

**Penguin**

**Microbial loop**
- high recycling &
  almost no export

**Salps**

**High sinking export &
low transfer to higher trophic levels**

**Legend**

- gpS: primary production small,
  phS: phytoplankton small,
  gpL: primary production large,
  phL: phytoplankton large,
  mic: microzooplankton,
  kri: krill, sal: salp, pg: fish
  (a.k.a. krill sp.), pen: penguin (Adelie sp.),
  ext: export, det: detritus, bac: bacteria

**Primary production, input**

**Constrained compartment**

**Constrained through other compartment**

**Model estimated flows, export & respiration**

**Observed Trends**

*Primary Production (mmolC m⁻² d⁻¹)*

*Phytoplankton structure (% large cells)*

**Model Estimates**

*Export Ratio* (Herbivorous food web)

*Transfer from compartment as % primary production at North station*

**Ocean-Ice Hindcast Simulation (CESM1)**

- Global NCAR CESM1 forced with NCEP Reanalysis & Satellite data

**North**
- No fish in penguin diet
- Decreased penguin population
- More salps
- Influenced earlier by warming

**South**
- Increased primary production
- Fish as part of penguin diet
- Probably in the state the north was 10-20 years ago
Biogeochemical Impacts of Ice Retreat

- Chlorophyll
- Diatom fraction
- Photosynthesis
- CO₂ flux (positive into ocean)


21st Century Change in zonal integrated primary production

Spatial patterns from multi-model ensemble (stippled regions of large contemporary errors)


Phytoplankton Community Structure

Changes in temperature, nutrients, light & transport => shifts in relative abundance of diatoms to small phytoplankton

Marinov et al. Biogeosciences (2010); Marinov Global Biogeo Chem. submitted

Ocean Acidification

- Rising CO₂; declining pH & CaCO₃ saturation state
- Polar waters undersaturated for aragonite by mid-century

Dore et al. PNAS 2009; Steinacher et al. Biogeosciences 2009

Conclusions & Future Directions

- Rapid regional warming along Antarctic Peninsula driven by interactions with winds & ACC (upwelling)
- Marine & terrestrial ecosystems responding at all trophic levels
- Impacts on key biogeochemical process: productivity, plankton composition, export & air-sea CO₂ flux
- Lessons applicable to regional & global questions

Murphy et al. Prog. Oceanogr. Submitted ICED Southern Ocean Food Web Modeling Workshop

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Sea-Air pCO2 Trends

- Rising atmospheric anthropogenic CO2
- Stronger westerly wind stress & upwelling
- Positive sea-air pCO2 \(\Rightarrow\) weaker CO2 uptake


Le Quere et al. Nature Geosciences (2009) Figure 3 | Trends in the observed partial pressure of CO2 for ocean mixed air, for 1985-2007. The observed trends are calculated by fitting a

Inverse Model of WAP Food-Web

Topological food web
- "who eats who"
- Primary food sources
- Export pathways

Physiological constraints
- Maximum rates
- Growth & assimilation efficiency

Site-specific data
- Palmer survey grid
- Biomass & flow data
- Respiration rates

Internally consistent food-web
- Match available data
- Mass conservative
- Steady-state

Constraints on other stocks & flows
- Unmeasured parts of the ecosystem
- Minimization criteria
- Monte-Carlo methods to give error bounds

Daniels, Richardson & Ducklow, Deep-Sea Res. II (2006)
Soetaert and Von Oevelen, Oceanography (2009)

Coupled Ocean-Atmosphere Model: CCSM-3 21st Century Projections

- SST (°C)
- Ice fraction (%)
- Nitrate (mmol N/m²)
- Total primary prod (Pg/Clyr)

Marinov et al. (Global Biogeochem. Cycles, submitted)

Phytoplankton Community Structure

Changes in temperature, nutrients, light & transport \(\Rightarrow\) shifts in relative abundance of diatoms to small phytoplankton (critical nutrient hypothesis)

Marinov et al. Biogeosciences (2014), Marinov Unpub. ms Geochim. submitted