North Pacific climate change impacts as projected by a suite of CMIP5 model output

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Introduction

• Climate Model Intercomparison Project Phase Five – CMIP5 (pcmdi9.llnl.gov)

• Model selection criteria:
  – Historical and Future Projection RCP8.5
  – Monthly output
  – Phytoplankton and zooplankton carbon
  – First simulation (r1i1p1) only
  – Most recent version

• Resulted in 14 simulations output by 8 models
  – Regridded to a common 1° × 1° grid

Taylor et al. 2012
Model Suite

- Canadian Center for Climate Modeling and Analysis Earth system model (CanESM2)
- Community Earth System Model, version 1 - Biogeochemistry (CESM1)
- Geophysical Fluid Dynamics Laboratory Earth System Model
  - Modular Ocean Model 4 (GFDL-ESM2G)
  - Generalized ocean layer dynamics (GFDL-ESM2M)
- NASA Goddard Institute for Space Sciences ModelE2 Earth System Model
  - Carbon cycle coupled to the HYCOM ocean model (GISS-E2-H-CC)
  - Carbon cycle coupled to the Russell ocean model (GISS-E2-R-CC)
- HadGEM2 of the Met Office Unified Model
  - Coupled Carbon Cycle (HadGEM2-CC)
  - Full Earth System (HadGEM2-ES)
- Institut Pierre Simon Laplace
  - Low resolution CM5A (IPSL-CM5A-LR)
  - Medium resolution CM5A (IPSL-CM5A-MR)
  - Low resolution CM5B (IPSL-CM5B-LR)
- Max-Planck-Institute Earth System Model
  - Low resolution (MPI-LR)
  - Medium resolution (MPI-MR)
- Meteorological Research Institute Earth System Model Version 1 (MRI)

Representative Concentration Pathway (RCP) 8.5

- RCP8.5 simulates radiative forcing reaching 8.5 W m\(^{-2}\) by 2100
- “... a relatively conservative business as usual case with low income, high population and high energy demand due to only modest improvements in energy intensity.” Riahi et al. 2011
Projections from Previous Work

- Basin-wide warming
- Tropical easterlies weaken
- Westerlies and polar easterlies weaken and shift poleward
- Reduced wind-stress curl
- Weakened vertical velocities and increased stratification
- Nutrient redistribution

- Expansion of the oligotrophic North Pacific Subtropical Gyre
- Declines in large phytoplankton density, shift in size structure
- Decline in large fish biomass
- Spatial shifts in suitable habitat
- Conditions favorable for smaller body sizes

Focus of Talk

• Areas of greatest change in phytoplankton densities over the 21st century
• Ecosystem implications of bottom-up change

  – Why look at phytoplankton density rather than primary production or chlorophyll?
    • Lack of simple relationship between large phytoplankton biomass and chlorophyll or primary production
    • Small phytoplankton biomass may not be well represented by chlorophyll concentrations
    • Suggested relationship between phytoplankton biomass and large fish biomass
    • Models differ in exact geographic placement of features

Gnanadesikan et al. 2011, Morán et al. 2010, Woodworth-Jefcoats et al. 2013
Percent Change in Phytoplankton Density

Last 20 years for the 21st century (2081 – 2100) relative to Last 20 years of the historical run (1986 – 2005)
Mean phytoplankton density for 1986 – 2005

Declines of ≥ 25% over the 21st century outlined
Phytoplankton Density and Areas of Greatest Change

Mean phytoplankton density for 1986 – 2005

Declines of ≥ 25% over the 21st century outlined
Determining Plankton Spectra

Plankton output by the models span various size classes:

- **Zooplankton**
  - micro
  - meso

- **Phytoplankton**
  - small
  - nano
  - large

<table>
<thead>
<tr>
<th>Equivalent Spherical Diameter (μm)</th>
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<tr>
<td>0.2 2 20 200 500</td>
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</table>

Discretize biomass evenly across size class (0.1 log\(_{10}\) grams wet weight)
Divide biomass at size by cell volume to get abundance at size

Changing Plankton Spectra

\[ \log_{10} \text{Body Size} \]
\[ \log_{10} \text{Abundance} \]

Jennings and Brander 2010
Changing Plankton Spectra

Δ Slope
Composition

\[ \log_{10} \text{Body Size} \]

\[ \log_{10} \text{Abundance} \]

Jennings and Brander 2010
Changing Plankton Spectra

$\Delta$ Slope
Composition

$\Delta$ Intercept
Abundance
Composition

Jennings and Brander 2010
Change in Plankton Spectra Slopes

North of NPSG

Percent Change in Plankton Spectra Slope (relative to 1986 – 2005 mean)

NPSG

South of NPSG

GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H-CC
GISS-E2-R-CC
HadGEM2-CC
HadGEM2-ES
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MRI-ESM1
Change in Plankton Spectra Intercepts

North of NPSG

Percent Change in Plankton Spectra Intercept (relative to 1986 – 2005 mean)

NPSG

South of NPSG

GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H-CC
GISS-E2-R-CC
HadGEM2-CC
HadGEM2-ES
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MRI-ESM1
Changes to Plankton Spectra

• Declines in both slope and intercept
  – Slope: declines 0 – 6%
  – Intercept: declines 0 – 30%
• Greater declines in intercept than slope
  – Decline in abundance > change in size structure
  – Reduced biomass available to higher trophic levels
Annual Phytoplankton Biomass North of the NPSG

Phytoplankton declines of 15 – 60% projected

Phytoplankton Density (g C m\(^{-3}\))

- GFDL-ESM2G
- GFDL-ESM2M
- GISS-E2-H-CC
- GISS-E2-R-CC
- HadGEM2-CC
- HadGEM2-ES
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- IPSL-CM5B-LR
- MRI

1986 – 2005 Mean
2081 – 2100 Mean
Annual Phytoplankton Biomass South of the NPSG

Phytoplankton declines of 24 – 48% projected

Phytoplankton Density (g C m⁻³)

Month Month Month Month

GFDL-ESM2G GFDL-ESM2M

GISS-E2-H-CC GISS-E2-R-CC

HadGEM2-CC HadGEM2-ES

IPSL-CM5A-LR IPSL-CM5A-MR

IPSL-CM5B-LR MRI
Impacts of Projected Temperature Change

Block et al. 2011

Howell et al. 2008

Lehodey et al. 2008
Annual SST North of the NPSG

SST increases of 1.6 – 5.0°C projected

GFDL-ESM2G

GFDL-ESM2M

GISS-E2-H-CC

GISS-E2-R-CC

HadGEM2-CC

HadGEM2-ES

IPSL-CM5A-LR

IPSL-CM5A-MR

IPSL-CM5B-LR

MRI

**SST (°C)**

1986 – 2005 Mean

2081 – 2010 Mean
Annual SST South of the NPSG

SST increases of 2.1 – 4.3°C projected

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<thead>
<tr>
<th>Model</th>
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Conclusions and Next Steps

• Conclusions
  – Projected declines in phytoplankton biomass greatest in association with the boundaries of the North Pacific subtropical gyre
  – Change in plankton spectra suggest overall plankton biomass declines are greater than relative changes in size structure
  – Areas of greatest phytoplankton declines are of ecological significance for top predators
  – Declines in phytoplankton biomass are accompanied by increasing SST, potentially exacerbating ecosystem impacts
  – Areas to focus climate and ecosystem monitoring efforts

• Next steps
  – Closer examination of changes in size structure
  – Examine mechanisms behind model disparities
  – Incorporation into ecosystem and food web models