Modelling the impacts of climate change and variability on productivity and health of high-latitude marine ecosystems: the Beaufort Sea and Gulf of St. Lawrence case studies

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Climate change: Reduction in ice extent and volume

Sea ice extent trend for the Northern Hemisphere (from NSIDC)

Sea ice extent trend for the Canadian Arctic (dashed) and Gulf of St. Lawrence (bold)

http://www.arctic.noaa.gov/detect/ice-seaice.shtml

Courtesy of D. Bourgault (ISMER)
Changes in Freshwater runoff in the Arctic

Wu et al. (2005)
Changes in Freshwater runoff in the GSL

St. Lawrence River freshwater runoff at Québec City

Future trend?

Angel and Kunkel (2009): Positive or negative trend in Great Lakes water level depending on climate change scenario
**Two downscaling methods**

**Downscaling:** method for obtaining high-resolution climate or climate change information from relatively coarse-resolution global climate models (GCMs).

**Statistical downscaling:**
- use statistical relationships between observed small-scale variables and larger scale GCM variables
- requires low human, financial and computing resources

**Dynamical downscaling:**
- use a regional climate model driven by boundary conditions from a GCM model
- requires high human, financial and computing resources
The Beaufort Sea case

• PP on most shelves is nutrient limited due to the strong stratification

• Considering the increasing freshwater flux, will nutrient supply to the mixed layer increase, and will that increase be enough to sustain a large increase in PP (e.g. Arrigo et al. 2008)?

Panarctic distribution of total primary production

Carmack et al. (2006)
The coupled model

h = snow/ice thickness
T = temperature
F and Q = heat fluxes

Mellor and Kantha (1989)

Lavoie et al. (2005, 2009)
Historical data and CGCM2 projections

CGCM2 model results:

- 2041-2060 → 2041-2059
- 2081-2100 → 2081-2099

Using the **A2** IPCC emission scenario

**Tuktoyaktuk Airport Data (1972-1994):**

- surface air temperature
- wind speed
- cloud amount
- relative humidity
- snow thickness
Changes in forcing between each period

Surface air temperature:

\[ X_F(t) = X_P(t) + \left( \overline{C_F} - \overline{C_P} \right) \]

All other meteorological variables:

\[ X_F(t) = X_P(t) \times \left( \frac{\overline{C_F}}{\overline{C_P}} \right) \]

\( P \): present

\( F \): future
Freshwater flux

Using shape of Mackenzie River runoff

Applied 9% + 2% increases for future periods (Wu et al. 2005, and P-E in CGCM2)

\[ F_S = (W_O - W_{RO})(S_I - S_0) + S_0 R \]

(similar to Holland et al. 1997)
Future scenarios

(a) Ice and snow

(b) Salinity

(c) Mixed layer depth

(d) Nitrogen

Future scenarios

Ice and snow

- 1983
- 2050
- 2090

Salinity 0-40 m

Mixed layer depth

Nitrogen 0-40 m
Future scenarios

Primary production

(a) 1983 (23.4 g C m\(^{-2}\) yr\(^{-1}\))
2050 (24.8 g C m\(^{-2}\) yr\(^{-1}\))
2090 (25.5 g C m\(^{-2}\) yr\(^{-1}\))

Increase of 6% and 9%

Secondary production

(b) 1983 (5.2 g C m\(^{-2}\) yr\(^{-1}\))
2050 (5.6 g C m\(^{-2}\) yr\(^{-1}\))
2090 (6.2 g C m\(^{-2}\) yr\(^{-1}\))

Increase of 8% and 19%

Detrital flux

(c) 1983 (10.1 g C m\(^{-2}\) yr\(^{-1}\))
2050 (11.2 g C m\(^{-2}\) yr\(^{-1}\))
2090 (11.7 g C m\(^{-2}\) yr\(^{-1}\))

Increase of 11% and 16%
Results of 1D modelling study suggest that:

- Relative importance of the spring bloom decreases while the importance of the subsurface bloom increases.
- The increase in in situ primary and export production in the Beaufort Sea, and potentially in other areas as well, will be moderate due to the strong stratification.

See Lavoie et al. (2010)
The Gulf of St. Lawrence case
Horizontal circulation

Depth-averaged monthly mean currents (0 - 30 m) (cm/s)

August
Horizontal circulation

From Koutitonsky and Bugden (1991)
Nutrient pump

Annual mean depth-averaged (0-50 m) nitrate concentration
Light attenuation function of freshwater

Annual mean depth-averaged (0-10m) total diffuse attenuation coefficient

Le Fouest et al. (2010)
Simulated Chl a and ice concentration

Depth-integrated (0-50 m) primary production (gC/m²)
The coupled model (GSBM-GSS4): NPZD, $O_2$, and pH modules

- **Atmospheric forcing** (Winds, light, precipitation, $CO_2, O_2$)
- **Hydrologic forcing** (River runoff)

**O$_2$ and CO$_2$ Atm./ocean gas exchange**

**Net biologically induced consumption /release**

- **Oxygen:**
  - Production
  - Consumption

- **CO$_2$:**
  - Consumption
  - Production

**Coupling**

- **Entrainment** + **Mixing**
- **Sinking**

**Oceanic model**

**Sea ice model**

**PON**

**MEZ**

**MIZ**

**LP**

**SP**

**NO$_3$**

**NH$_4$**

**DON**

**SSS**

**Alkalinity**

**pH**

**TCO$_2$**
GSS4 and NEMO domain

Depth Averaged Velocity

Maritime Canada Domain

6 km by 6 km

D. Brickman, A. Drozdowski and J. Chassé (DFO)
DFO - Climate Change Science Initiative (CCSI)

A regional atmosphere-ocean climate downscaling system for the Gulf of St. Lawrence, Scotian Shelf and Gulf of Maine

CCSI Thematic area: Predictions and Scenarios
DFO regions: Maritimes, Gulf and Quebec
Institutions: BIO, GFC and IML
Participants: J. Chassé (GFC), W. Perrie (BIO), Z. Long (BIO), D. Brickman (BIO), L. Guo (BIO), A. Drozdowski, J. Loder (BIO), Cody Sipkema (BIO), D. Lavoie (IML), M. Starr (IML)
How will PP change in the St. Lawrence system?

• We don’t know yet …

• Effect of an increase in FW:
  • Decreases pumping at the head of the channel
  • Increases estuarine circulation and entrainment
    • Less nutrients but carried further away where light is available
  • Shift towards flagellates?

• and vice versa
Effect of river regulation

Regulated minus natural

PP - May 2000
More answers, or questions, coming this year ...