Arctic System Science:
The Arctic and Climate Change

SENIORS’ ALUMNI
LEARNING FOR LIFE PROGRAM

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Canada Research Chair in Arctic System Science
Associate Dean, Research, Faculty of Environment
University of Manitoba.
Outline

• Some context.
• What can history tell us?
• What can the Arctic tell us?
• How we do our work.
• There are surprises.
• Why should you care?
Intergovernmental Panel on Climate Change

**CO₂ concentrations**

**Temperature**

**Past and future CO₂ atmospheric concentrations**

- Ice core data
- Direct measurements
- Projections

<table>
<thead>
<tr>
<th>Scenarios</th>
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<tbody>
<tr>
<td>A1B</td>
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<td>A1T</td>
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<td>A1F1</td>
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<td>A2</td>
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<td>B1</td>
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<td>B2</td>
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<td>IS92a</td>
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</table>

400 ppm
Observations - Five year running average (corrected)

NASA, 2012
What can history tell us?
### Oxygen Revolution (2.2 bya)

- **Earliest known eukaryotes (1.5 bya)**
  - Javaux et al., 2001, Nature

### Dinosaurs stopped by and roared hello (230–65 mya)
- **Homo erectus** (1.8 mya)
- **Homo sapiens** (0.2 mya)
- **Out of Africa** (70 ka)
- **Reaching N.A.** (30 ka)
- **Agriculture** (10 ka)
- **Julius Caesar**
- **Industrial revolution**
Finding a historical analog

The Cenozoic Era

End of Cretaceous (65 My BP)  Present Day

Global Climate Forcings
External (solar irradiance): +1 W/m²
Surface (continent locations): ~1 W/m²
Atmosphere (CO₂ changes): > 10 W/m²
PETM
Warm and wet
Cenozoic Era (65 Million Years)

Deep Ocean Temperature (°C)

Paleocene-Eocene Thermal Maximum

Antarctic Ice Sheet

N. Hemisphere Ice Sheets

My BP

PETM – Ellesmere Island

Today – Ellesmere Island
- Continents stabilize close to present position
- CO₂ rapidly drops
- <450ppm Antarctic icesheet forms
Summary: Cenozoic Era

1. Dominant Forcing: Natural $\Delta$CO$_2$
   - Rate $\sim$100 ppm/My (0.0001 ppm/year)
   - Human-made rate today: $\sim$2 ppm/year

Humans Overwhelm Slow Geologic Changes

2. Climate Sensitivity High
   - Antarctic ice forms if CO$_2$ < $\sim$450 ppm
   - Ice sheet formation reversible

Humans Could Produce “A Different Planet”
What about the recent past?

400ppm
General Circulation Models

Validation
- Paleoclimates
- contemporary
- hindcasting
- ensemble runs
- intercomparisons

Hah – they can’t even predict the weather tomorrow
But they can predict:

- Current teleconnection patterns (e.g., ENSO)
- Past climates (back 65 My BP years)
- Recent past climates (1000’s y BP)
- Current Global warming trends
- Current Arctic trends

Model are actually conservative on most predictions relative to observations
Sea ice minimum (Observed) relative to IPCC model estimates (CMIP3)
What can the Arctic tell us?
Sea Ice and Climate Change
Reduction in the Sea Ice summer minimum - winter?

\[ f(x) = -0.0041411 \times y^2 + 16.43 \times y - 16295 \]

\[ R^2 = 0.78 \]
Trend in Open Water by Month (1979 – 2010)

September

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

October

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

November

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

December

α = 0.001
Trend in Open Water by Month (1979 – 2010)

January

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

February

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

March

OW Area

Year

\( \alpha = 0.001 \)
Trend in Open Water by Month (1979 – 2010)

April

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

May

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

June

OW Area

Year

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

July

\[ \alpha = 0.001 \]
Trend in Open Water by Month (1979 – 2010)

August

OW Area

\( \alpha = 0.001 \)

Year
Trends in Percent change in SIC
\[ \alpha \leq 0.05 \]

August

Barber et al. 2015
So how significant is this change?

The Medieval Warm Period
So how significant is this change?

Kinnard et al. 2011
Glacial freshwater fluxes
Inevitable collapse of the West Antarctic Ice Shelves (Joughin et al 2014; and Rignot et al. 2014)
Glacial freshwater fluxes

Zachariae Isstrom (NE Greenland) glacier enters period of rapid retreat contributing 0.5M of sea level rise equivalent

Melt water lubrication
Glacial freshwater fluxes

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.

Source: Roger Braithwaite, University of Manchester (UK)
How we do our work
Arctic Marine Research in Prairie Canada
<table>
<thead>
<tr>
<th>Tenure Track Faculty (18)</th>
<th>Research Faculty (9)</th>
<th>Adjunct Faculty (8)</th>
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<tbody>
<tr>
<td>Barber, David <em>(CRC)</em></td>
<td>Dmitrenko, Igor</td>
<td>MacDonald, Robbie</td>
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<tr>
<td>Rysgaard, Soeren <em>(CERC)</em></td>
<td>Galley, Ryan</td>
<td>Michel, Christine</td>
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<td>Wang, Feiyue <em>(CRC)</em></td>
<td>Lui, George</td>
<td>Ferguson, Steve</td>
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<td>Stern, Gary</td>
<td>Lukovich, Jennifer</td>
<td>Prinsenberg, Simon</td>
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<tr>
<td>Lot Shafi <em>(CRC)</em></td>
<td>McCullough, Greg</td>
<td>Loseto, Lisa</td>
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<tr>
<td>Puyan Majobi</td>
<td>Raddatz, Rick</td>
<td>Miller, Lisa</td>
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<tr>
<td>Mundy, C.J.</td>
<td>Hubert, Casey</td>
<td>Hammill, Mike</td>
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<tr>
<td>Kuzyk Zou. Zou.</td>
<td>Ogi, Masayo</td>
<td>Gosselin, Michel</td>
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<tr>
<td>Ehn, Jens. E.</td>
<td>Puko, Monika</td>
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<td>Hanesiak, John</td>
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<td>Papakyriakou, Tim</td>
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<td>Halden, Norman</td>
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<td>Iacozza, John</td>
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<td>Hansen, Mark</td>
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<tr>
<td>Stewart, Ron</td>
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<tr>
<td><em>3 new faculty</em></td>
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</tbody>
</table>

35 MSc, 30 PhD, 17 PDF, 28 Tech/admin = 135 staff
CERC Program

>350 people

Totally Integrated Academic and Research Programs!
First ASP planning meeting in Gimli - Canada
One of 21 Networks of Centres of Excellence (NCE) jointly funded by the 3 Research Councils of Canada.

Funded for 7 years (2004-2011) with possibility of 14 years (2004-2018) $CDN 6.4 Million from NCE per year

$CDN 9.2M from NCE per year (2011-2018)
A pan-Canadian distributed Arctic Institute

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**Nodes**

- CCGS Amundsen
- CCGS Diefenbaker
- Nunanut CHARS
- Nunavut
- Newfoundland and Labrador
  - Memorial University
- Québec
  - Université Laval (INQ)
  - National HQ
- Ontario
  - University of Toronto
- Manitoba
  - University of Manitoba
- Alberta
  - University of Calgary
  - University of Alberta
- British Columbia
  - University of British Columbia
  - University of Victoria
- Nunavut

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**Partners**

- CCGS
- Nunanut
- CHARs
• Sea Ice physics
• Meteorology
• Climate Change
• Paleo science
• Biogeochemistry
• Carbon fluxes
• Ecosystems
• Shelf-ice
• Land-ice
• Techniques
Opening of the Arctic
Work with Industry
Work with Industry

$14.7M
Work with Industry

- KGS Group
- Golder Associates
- Stantec
- MDA
- ASL Environmental Sciences
- C-CORE
The Churchill Marine Observatory (CMO)

Science and Technology
In support of Arctic Sustainable Development

$31.8M capital and $18M operating
The Churchill Marine Observatory (CMO)

1. Oil in Sea Ice Mesocosm (OSIM)
   - labs
2. Environmental Observatory (EO)
   - Atmosphere
   - Ocean
   - Ecosystem
   - Contaminants
   - Freshwater
3. Marina/Wharf
   - Garage

Winnipeg Free Press

David Barber
Oil in Sea Ice Mesocosm - OSIM

- A concept to allow controlled testing of the ocean, sea ice system response to oil, LNG, and contaminants.

- Science would concentrate on
  - **Detection** (of oil in sea ice)
  - **Impacts** (of oil spills on marine ecosystems)
  - **Mitigation** (of oil spills in sea ice using both genomics-enhanced bioremediation technologies and conventional techniques)
Environmental Observatories (EOs)

- Estuary
- Ocean
- Atmosphere
The Churchill Marine Observatory (CMO)

A *national centre with an international mandate.*

OSIM process studies  Scaling Arctic wide through EO system, CHARS, ARF, and international field programs

- 170 researchers
- 6 CDN universities
- 10 gov. departments
- 10 private sector
- 4 NGO, co-management
- 50 HQP
Unexpected Discoveries

Seven Surprises
CO₂ exchange  Bromine – Ozone  Mercury Exchange

Thinner and Saltier Ice Surfaces
Snow on sea ice
Polar Bear and Seal Habitat
The appearance of a ‘new’ type of summer sea ice (rotten ice).
Increasing Ice Hazards?

Winds  Faster Motion  Glacial Ice  Thick MY

Increasing Ice Hazards?
Warm ocean cold continent hypothesis

Polar Vortex
Traps cold air in the Arctic

Polar Vortex breaks down
Increases cold outflows and persistence

Overland et al., 2014
In summary

1. A saltier ice surface increases exchange with atmosphere
2. Snow on sea ice causes decrease in MYI does not affect FYI
3. Polar bear habitat increasing in some areas decreasing in others
4. Whole ecosystem (virus – whales) affected (invasive species have arrived)
In summary

5. Rotten sea ice is now common in the high Arctic – northern sea routes are opening

6. Paradoxically - Ice hazards are increasing

7. Polar Vortex appears to play a large role in cold air outbreaks and persistence of climate at lower latitudes
Motivation
Motivation
Motivation
Motivation

- 7000yrs – first billion;
- 130 yrs – second billion;
- 12-14yrs – third and onwards
Motivation