Changing Arctic: climate, environment, metocean conditions, with a special focus on sea ice

(IPCC AR4, WG II, Ch.15)

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Global Map of Impacts on the Ocean: Cumulative Impact Scores

(vulnerability-weighted sum across all stressors and ecosystems for each 1km² pixel but without taking into account changes in sea ice)

41% of the ocean subject to medium to very high impact

Less than 4% subject to very low impact

(B. Halpern et al., Science, 2008)

- Very Low Impact (<1.4)
- Medium Impact (4.95–8.47)
- Low Impact (1.4–4.95)
- Medium High Impact (8.47–12)
- High Impact (12–15.52)
- Very High Impact (>15.52)
Industrial Development

Sources: United States Geological Survey (USGS); AMAP 1997, 1998 and 2002; CAPP, 2007; UNEP World Conservation Monitoring Centre (WCMC); United States Energy Information Administration (EIA); International Energy Agency (IEA); Barents Euro-Arctic Council (BEAC); Comité professionnel du pétrole (CPP), Paris; Institut français du pétrole (IFP), Paris; National Oceanic and Atmospheric Administration (NOAA); The World Bank; Alaska Department of Environmental Conservation; Division of Oil, Prevention and Response; United States Coast Guard (USCG).

Shipping

Observed sea ice September 2002
Projected 2060-2080
Projected winter surface temperature increase around 2050 (°C)

7 - 12
4
0 - 3
Navigational routes

(UNEP)
(Kevin Kallaugher, “The Economist” August 2008)
IPCC Projections

(IPCC AR4, WG I, Ch.10)
Detected temperature increases

Increases in mean annual temperatures for 2001-2005 relative to 1951–1980

*(Hansen et al., 2006)*
How much do we know about the Arctic and from what?

(Toward an Integrated Arctic Observing Network, NAS 2008)

J. Stroeve

V. Ryabinin
Major Relevant Assessments

- Arctic Climate Impact Assessment
- IPCC AR4
- Global Outlook by UNEP
- WWF Update since ACIA
- Millennium Ecosystem Assessment
- Arctic Human Development Report
- Global International Waters Assessment
- Arctic Marine Shipping Assessment 2008 (?)
10 Main Messages from ACIA

1. Arctic climate is warming rapidly and much larger changes are projected.
2. Arctic warming and its consequences have worldwide implications.
3. Arctic vegetation zones are projected to shift, bringing wide-ranging impacts.
4. Animal species' diversity, ranges, and distribution will change.
5. Many coastal communities and facilities face increasing exposure to storms.
6. Reduced sea ice is very likely to increase marine transport and access to resources.
7. Thawing ground will disrupt transportation, buildings, and other infrastructure.
8. Indigenous communities are facing major economic and cultural impacts.
9. Elevated UV radiation levels will affect people, plants, and animals.
10. Multiple influences interact to cause impacts to people and ecosystems.
Examples of observed changes

Melt Area

mln km²

(Huff and Steffen)

Snow Area, million km²

IPCC AR4, SfPM, WG1

Annual Arctic Sea Ice Extent

Year

Extent (million sq km)

Petersen et al., 2002

Arctic River Run-off

Over to Julienne!
Poster Child of Climate Change: Arctic Sea Ice

September Sea Ice Extent

Rate of decline: -10%/decade

50% reduction

pre-satellite satellite 27% drop
Ice Loss in 2007 Extended Further Into Central Arctic
2007 also saw the Opening of the NWP

2005 Median September Ice Extent
1979-2000 Median September Ice Extent
1953-2000 Median September Ice Extent
Transition Towards Younger Ice

• Ice age tracking algorithm from C. Fowler and J. Maslanik show ice 5 years or older now only makes up 10% of the perennial ice pack.

Spring 1986  Spring 1990  Spring 2007

Maslanik et al., 2007
Younger Ice is Thinner Ice

- Comparison between ice age and ice thickness from 4 years of spring ICESat GLAS-derived thickness fields from J. Zwally and D. Yi.
- Results suggest a decrease in mean thickness of 2.6 m in March 1987 to 2.0 m in March 2007

Maslanik et al., 2007
What about 2008?

• Given the dramatic ice loss in summer 2007
  – Did the sea ice recover this winter?
  – How likely is another record in summer 2008?
**Conditions for 2008: Ice Extent/Concentration**

- Some recovery in winter extent, but still well-below normal
First-year ice now covers 72% of the Arctic Basin, whereas in 2007 it covered 59%.

Data from C. Fowler and J. Maslanik
Conditions for 2008: Freeboard

Comparison between 2007 and 2008 suggests the seasonal ice cover is 5-10 cm thinner and covers more area in 2008
Thinner Ice Already Showing Weakness

Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)

Extent (millions of square kilometers)

Feb  Mar  Apr  May  Jun

2008
2007
1979–2000 Average

National Snow and Ice Data Center, Boulder CO

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Survival of Winter Formed First Year Ice

Survival of Winter FYI

- FYI week 11 (70-90N)
- FYI remaining at end of Summer Melt Season

Year

FYI Fraction (%)
Estimated 2008 Minimum Sea Ice Extent

Estimated end-of-summer minimum sea ice extent for 2008
based on previous years’ melt data

2007 Record minimum extent: 4.13 mil. sq-km
Average estimate: 3.48 mil. sq-km
Climate Model Projections

- GCMs suggest decreasing Arctic ice cover will continue.
- 50% of the IPCC AR4 climate models reach seasonally ice free conditions by 2100.
- Observations suggest it may happen much sooner.

*Updated from Stroeve et al. (2007)*
Abrupt Sea Ice Loss

- Climate models suggest that once the ice thins sufficiently, it becomes vulnerable to natural variability such that abrupt ice losses may occur (Holland et al., 2006).

![September Sea Ice Extent graph](image)

- Model drop: 1.8 million sq km, 2024–2025
- Observed drop: 1.6 million sq km, 2006–2007

*NCAR CCSM3 model simulation*
*Observations*
The Set up Looks Right

- Mean thickness (70-90N) in CCSM3 before abrupt change: 1.71 m
- Mean thickness (70-90N) from ICESat in Spring 2007: 1.75 m (data from J. Zwally)
Natural Variability Remains Important!

NCAR CCSM3 Mean Ice Thickness vs. Std. Dev. Ice Extent

- Natural variability increases with a thinning ice pack until the ice is gone
Thus, Sea Ice May Recover this Summer

- If we have a strong cyclonic pattern with attendant cold temperatures as in 1996, we may not set a new record in summer 2008.
Does the Thin Ice Imply a Tipping Point?

- If the simulated abrupt transitions are the manifestation of a “tipping point”, then it is likely they would be preceded by a similar critical state.

<table>
<thead>
<tr>
<th>Run 1: Year 2024</th>
<th>Run 2: Year 2025</th>
<th>Run 3: Year 2030</th>
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<td><img src="image2" alt="Map" /></td>
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<td>Run 4: Year 2027</td>
<td>Run 5: Year 2029</td>
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<td><img src="image4" alt="Map" /></td>
<td><img src="image5" alt="Map" /></td>
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Over to Vladimir!

From M. Holland
Changes in the Atmosphere - new warming/circulation pattern

1977 - 1988
North Pacific Pattern

1989 - 1995
Arctic Oscillation

2000 - 2005
Arctic Warm

(J.E. Overland)

(J.E. Overland)
Atmospheric Circulation Does Not Appear to Explain Recent Warming over the Arctic

From C. Deser and J. Stroeve
Complexity of feedbacks

(Chapin III et al., 2005)
In the result, are we capable to predict the expected changes in the Arctic atmosphere?

**DJF sea-level pressure response to 2xCO₂**

So far, there has been no adequate large-scale forcing available for regional climate models in the Arctic!
Changes in the Ocean

State of the Arctic Ocean in 2007: “warmth spreading poleward along the boundary”

(I. Polyakov)

(P. Holliday)
Changes in the ocean, from freshening to more saline waters

(Dickson et al., 2002) 

(P. Holliday, 2008)
Simulated changes of pH & $[\text{CO}_3^{2-}]$ in two Polar Oceans:

(J. Orr et al., pers. comm.)
Resilience of ecosystems is related to ability of species to migrate, accommodate the change, or evolve. It strongly depends on the rate of change and combination of stressors: e.g. acidification and pollution weaken resilience to temperature change.

Migration to colder regions is not an option in the Arctic: nowhere to go!

Sea ice is a very valuable but vulnerable habitat for the Arctic ecosystem.
Other changes (1)

- **Changing marine cryosphere (beyond sea-ice):**
  - iceberg calving,
  - ice phases shifting,
  - changes in fast ice,
  - probable changes in pressure ridge properties,
  - etc.
Other changes (2)

- Where once was sea ice, one now has to predict waves!

- Changes in (long-return) wind waves due to
  - changes in fetch and
  - storminess.

- Changes in storm surges due to
  - changes in fetch,
  - storminess,
  - tides,
  - mean sea-level rise,
  - and evolution of coasts.

(V. Dymov)

(D. Atkinson)

(D. Atkinson)
Other changes (3)

- Accelerated coastal erosion due to likely higher wave impact, exposure of the coast to action of wind waves and ice, thawing of coastal permafrost.

- Elevated risk of “ice storms” (wave + ice action): an event, which is highly dangerous for shipping and destructive for coasts.
Implications of the changes for Arctic metocean interests

1. A host of changes in the Arctic may occur faster than anticipated in ACIA, IPCC AR4 and other assessments.
   • Dramatic ice loss as in 2007 does not occur until mid-century in climate models.
   • There will likely be some changes (“surprises”) in the Arctic that have not been observed in the past.
   • Changes may happen abruptly without crossing a threshold (or tipping point), affecting our ability to predict events.

2. Past observations in the Arctic may be not representative for the future because of climate change and decadal variability.

3. This may affect the validity of conclusions made in various previous EIAs for Arctic projects and in the design considerations (“previous” meaning made on past data records without taking into account the projected changes).
Proposal for consideration

One meaningful way forward for development of required offshore metocean applications in the Arctic would be to

a) run ensembles of updated global climate models with best sea-ice modules (and some other enhancements), (validation on the pan-Arctic domain using past observations)
b) undertake regional downscaling of the projections, (validation in regional domains on the past record)
c) use regionally downscaled projections for development of industrial applications.

Consider how to take into account decadal variability: WCRP’s intensive work on predicting it is ongoing.

Need to focus now on hemispheric impact assessments of the loss of Arctic sea ice.

This could potentially form a joint project between climate change and offshore industry communities.