Arctic Climate and Weather Extremes: Polynya Events in the Last Ice Area (Wandel Sea)

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Last Ice Area (WWF)
Wandel Sea
Two Polynyas: Feb 2018, Aug 2020

Wandel Sea

Feb 25 2018

Aug 15 2020

AMSR-2 Artist Ice Concentration [%]
MOSAiC route to reposition to the North Pole in August 2020

...via the Wandel Sea!

August, 2020

Sea Ice Concentration [%]

AMSR-2 (ARTIST Sea Ice, U of Bremen)
Wandel Sea Polynya Events: Summary of two papers, plus some new results

See also:

V. Ludwig et al. (The Cryos., 2019): 2018 event (hi res sat, NAOSIM model)
Y. Lee et al. (The Cryos. Discussion, in review): Winter Polynyas (RASM model)
Moore et al. 2021 (GRL) Spring 2020 Polynya north of Ellesmere Island
Science Questions:

• Historical context. How special where they?
• What caused these events? Mechanisms
• What’s the role of climate change (attribution)?
• What is likely to happen in the future?
The Winter Wandel Polynya: Feb 2018

February Ice Concentration [%]

PIOMAS CNTRL: Ice-Ocean model forced with NCEP/NCAR, no Data Assimilation after January 1, 2018

Moore et al. (GRL, 2018)
Winter Minimum (Dec-March) Ice Concentration

Data: NSIDC CDR
The long view: 1901-2020

PIOMAS-20C: model-based reconstruction using ERA-20C atmosphere data to force ice-ocean model (HadISST 2 daily ice concentrations assimilated)
(see Schweiger et al. 2019 Journal of Climate)

PIOMAS: Standard PIOMAS model
2018 February Event was caused by very strong southerly winds.

Meridional Wind Speed at Station Nord (Moore et al. 2018). Dashed/dotted lines are one and two sigma of 1961-2017 climatology.

The strong wind anomaly that created the Polynya was associated with a strong Stratospheric Warming Event in Early February.

Hypothesis: Thin Ice made sea ice more susceptible to deformation and allowed Polynya formation

PIOMAS MODEL (SI1979) with:
- 1979 initial conditions (ice thickness/concentrations)
- 1979 thermal forcing (radiation/temperature)
- 2018 Wind Forcing

CNTRL: (Historical Forcing/no DA)  Thick and Cold but 2018 Winds

Result: Polynya would have occurred without thinning ice or warming (but size might have been a bit smaller)

Note: Lee et al. (TCD). Finds similar results with RASM (coupled) model
Summer 2020

Summery Event: August 2020

AMSR-2 (ARTIST Sea Ice, U of Bremen)

But the ice was thick in the spring of 2020?

Especially puzzling, given relatively thick springtime ice!
August 2020 Polynya: 41 year context

Polynya

2020 was lowest
...but other years were also low!

Aug. min. sea ice conc. (%)

Minimum Ice Concentration for each year

SMMR/SSMI/SSMIS (NOAA/NASA CDR, NSIDC)

Feb 2018
Why was August 2020 so low: Examining Ice Mass Budget

Dynamics vs Thermodynamics

Modeled ice thickness $\Delta$ partitioned as:

$$\frac{\Delta h_{\text{ice}}}{\Delta t} = F_{\text{adv}(\text{ection})} + F_{\text{prod}(\text{uction})}$$

$F_{\text{adv}} = $ thickness flux convergence
($>0$ means thickening)

$F_{\text{prod}} = $ net growth – melt
($>0$ means thickening)
Summer (JJA) Advection and Production Anomalies

Dynamics vs Thermodynamics

Data from PIOMAS model

Summer 2020:
• Large divergence
• Large net melt

Strong Advection events earlier: 2020 both went downL
**Advection**

Dynamics vs Thermodynamics

\[ \frac{\Delta h_{\text{ice}}}{\Delta t} = F_{\text{adv}} + F_{\text{prod}} \]

Big, strong high pressure cell → “giant Beaufort High”

*Mallett et al. (Nature Comm. Earth & Environ, 2021)*
*Moore et al. (Nature Comm. Earth & Environ., 2021)*

Lots of divergence out of the Wandel Sea

Summer 2020 PIOMAS ice motion
Dynamics vs Thermodynamics

\[ \frac{\Delta h_{\text{ice}}}{\Delta t} = F_{\text{adv}} + F_{\text{prod}} \]

More thin ice in recent years

Stored ocean heat is mixed upward

Bottom melt

High surface stress events

F_{\text{ocean-ice}}
Ocean Heat Melts Ice

Stored ocean heat is mixed upward

Decrease in subsurface ocean heat (NSTM = Near-Surface Temp. Max.)

high surface stress event

F_{ocean-ice}
Advection has the stronger impact on Ice Thickness
Q: What would have happened if Summer 2020 started with ice-ocean conditions

*From another year...*

Testing the contribution “long-term ice thinning”:
The role of June 1, 2020 ice-ocean conditions (climate change)

INIT Experiment:
- June 1 ice-ocean conditions from June 1, 1979, 1980, … 2019
- 2020 Atmospheric Forcings

Historical Simulation
(2020 initial, 2020 Forcing)

- low SIC from the start
- not much change (relative to ensemble) over the summer
The role of summer 2020 atmos. Forcing (weather)

Q: What if 2020 had different “weather”?

Experiment (Atmos)
- Atmos. forcing from summer 1979, 1980, etc.
- June 1, 2020 ice-ocean conditions

Assumption: This is the weather/internal contribution

SIC moves outside ensemble spread in late summer
June 1 conditions vs. summer atmos. forcing

SIC at low end of ensemble starting in *Early* Summer

SIC Moves to low end of ensemble in *Late* Summer

Climate Change Contribution

~20%

Weather Contribution

~80%
June 1 conditions vs. summer atmos. forcing

20% June 1 vs. 80% atmos. → 2020 SIC min. (mid-August)

climate change signal (i.e., ice thinning)

~ NYC flooding from Swain et al. (One Earth, 2020)

Superstorm Sandy October, 2012
Wandel Sea Ice Concentration: Replication with a fully coupled Global Model.

Satellite Observed Ice Conc.
NCAR CESM Model in “replay mode” nudged with reanalysis (ERA-5) winds north of 60N
(Ding et al. Journal of Climate in review)

Note: Monthly Data. Y-axis compressed!
What will happen in the future: winter

How do we generate daily ice information at suitable resolution:
- **GFDL-ESM4** IPCC AR6 historical + ssp585 atmosphere forcing for PIOMAS-like model
- **CNRM-CM6-1-HR** IPCC AR6 historical + ssp585 atmosphere forcing for PIOMAS-like model
- Some calibration of forcing to ERA-5 reanalysis
- Model tuning

Result: Winter event (Feb 2018) was a really “out of the park” event. Not likely to be seen before 2070 (model caveats apply)
What will happen in the future: summer

Result:
- Likelihood of 2020-like summer events will increase over the next 50 years but will remain rare through 2050
- Model differences/calibration over historical period make interpretation difficult
Summary

• Both Polynya events were primarily wind driven
• 2018 winter event was an extreme stochastic event with climate change playing no clear role
• Climate change, via thinning sea ice, is responsible for about 20% of the 2020 summer event. Weather accounts for about 80%.
• Winter events like 2018 will remain unlikely through 2070
• Summer events –like 2020- will remain rare but will become more likely over the next 30 years or so.
• Sea ice thickness distribution is important (mean thickness alone doesn’t tell the story)

Future work/Recommendations/Thoughts:
- Need more, better calibrated climate model simulations for future (daily output, more scenarios, not just ssp585). Nudged (replay simulations)
- 42-year observed record is still relatively short for extreme events. Improved long term 150+ year reconstructions would be helpful. Resolution, algorithms relevant for smaller scale events.
- Attribution likely model sensitive. Replication is needed.
Thank You
$\Delta h_{\text{ice}} / \Delta t = F_{\text{adv}} + F_{\text{prod}}$

Dynamics vs Thermodynamics

More thin ice in recent years

Stored ocean heat is mixed upward
C6H : 4.3, GFLD-ESM4: 2.7