Future interannual variability of Arctic sea ice and its implications for marine navigation

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Data

• 40 independent realizations from CESM-LE
  • Past forcing, 1920-2005: observed radiative
  • Future forcing, 2006-2100: RCP8.5 emissions scenario
  • Monthly ice variables; all seasons

• 33 ensemble members from 12 CMIP5 models
Monthly Sea Ice Area Projections

Ensemble mean of 5-year running mean ice area
Ice Area Standard Deviation and Rate of Loss

- 10-year running standard deviation applied to running mean of ice area
- 1-year difference in ice area (running mean)
Ice Extent Standard Deviation and Rate of Loss – CMIP5

- 10-year running standard deviation applied to running mean of ice area
- 1-year difference in ice area (running mean)
## Ice Volume and Standard Deviation of Ice Area

<table>
<thead>
<tr>
<th>Month</th>
<th>Year of Peak Std. Deviation</th>
<th>Year When Volume &lt; 0.5 x 10^{17} km^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>2099</td>
<td>2052</td>
</tr>
<tr>
<td>February</td>
<td>2099</td>
<td>2069</td>
</tr>
<tr>
<td>March</td>
<td>2099</td>
<td>2081</td>
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<tr>
<td>April</td>
<td>2099</td>
<td>2088</td>
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<td>May</td>
<td>2099</td>
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<td>June</td>
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<td>July</td>
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<td>2013</td>
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<td>October</td>
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<td>November</td>
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<td>2022</td>
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<tr>
<td>December</td>
<td>2076</td>
<td>2023</td>
</tr>
</tbody>
</table>
Standard Deviation of Ice Area in Year when it Peaks

White contour indicates mean 0.25 m thickness
Ice Area Variability – Self Organizing Maps

- Artificial neural network used to separate distinct patterns in the underlying spatial data
- Monthly sea ice area 10-year running standard deviation
- Input is 12 months x 18 decades (spatial)
Mean Ice Thickness Mapped to SOM Nodes

September, 2050’s
August, 2060’s
November, 2080’s
Mean Ice Thickness Mapped to SOM Nodes
November
1920 - 2000

Ice fraction
November
2050’s

Ice fraction
November
2080’s

Ice fraction
Ice Numeral

- $IN = C_1*IM_1 + C_2*IM_2 + \ldots C_n*IM_N$)

- $C_x$ is ice concentration of type $x$
- $IM_x$ is the ice multiplier of ice type $x$ (ranging from -4 to +2)
- 8 ice types ranging from open water to the oldest, thickest ice
- $IN < 0$ is a significant hazard to ships

- $IN$ calculated for “Type C” vessels – moderately ice-strengthened
- Ensemble-averaged $IN$ calculated for each decade (September only)
Ice Numeral – September Ensemble Mean

Northern Sea Route becomes navigable on average by 2020’s in September

Dashed contour indicates >75% ensemble members agree IN > 0
Ice Numeral – 1 Ensemble, September 2020’s

NSR navigability varies by year, despite the downward trend and mean IN < 0
Conclusions

• Arctic sea ice is expected to become more variable in coverage as it diminishes
  • Consistent across seasons and robust among ensembles and CMIP5 models
• Highest magnitude of ice area standard deviation peak occurs Nov-Jan, twice that of spring.
• Relatively consistent spatial pattern of variability that follows the thinning of the ice pack
• Increasingly navigable Arctic is tempered by increased variability