Using CryoSat-2 estimates to analyse sub-grid scale sea ice thickness distribution in HadGEM3 simulations for CMIP6

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Motivation

- A sub-grid scale sea ice thickness distribution (ITD) is a key parameterization to enable a large-scale sea ice model to simulate winter ice growth and sea ice ridging processes realistically.
- Recent sophisticated developments, e.g. a melt pond model, a form drag parameterization, a floe-size distribution model, fundamentally depend on the ITD.
- In spite of its importance, knowledge is poor about the accuracy of the simulated ITD.
Here, we derive the ITD from individual Arctic sea ice thickness estimates available from the CryoSat-2 (CS2) radar altimetry mission during ice growth seasons since 2010. We bin the CS2 data into 5 ice thickness categories:

- Cat1 [0-0.6] m
- Cat2 [0.6-1.4] m
- Cat3 [1.4-2.4] m
- Cat4 [2.4-3.6] m
- Cat5 [>3.6] m

Ice Fraction in category (Jan 2012)
Comparison of ice volume

- Cryosat-2: 2011-2014
- HadGEM3-GC3.1-LL-SSP5: 2015-2019
- HadGEM3-GC3.1-LL-SSP5: 2020-2024
- HadGEM3-GC3.1-LL-SSP5: 2025-2029

Ice volume / grid cell in m

Mean annual cycle

Nov, Jan, Mar, May, July, Sep, Nov

Volume flow year-to-year and seasonal variability dominates FW transport variations (e.g., Jahn et al., 2012); model of 2.1 ± 1.4 Sv; obs. of 2.1 ± 1.5 Sv

Decrease in the model volume export 2000-2015: opposite trends in the Fram & Davis straits (e.g., Aksenov et al., 2010 & 2016 & Wang 2018)

Observations (pink) (Data Courtesy Craig Lee, APL-UW)

Model mean and variability of FW transport is consistent with observations (pink)
Comparison of ice volume

- Mean values over red region (Central Arctic, Cryosat-2 data most reliable)
- 4 ensemble member from historical run (blue lines) represent annual cycle of mean ice volume (2011 to 2014) realistically.
- Strong decrease in climate projection with mean September sea ice thickness down to 10cm in September in the period 2025 to 2029.
The model mean and variability of FW transport is consistent with observations (pink) (Data Courtesy Craig Lee, APL-UW).

No clear model FW trend.

Variability increases after 2000.

Decrease in the model volume export 2000-2015: opposite trends in the Fram & Davis straits (e.g., Aksenov et al., 2010 & 2016 & Wang 2018).

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Comparison of thick ice area fraction (h>3.6m)
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- Strong annual cycle according to CS-2: 2% in October vs 22% in April
- Weak annual cycle in all HadGEM3 simulations
- 3 of 4 members from historical simulation show values around 10%, but one member around 25%
- Decrease of thick ice fraction in climate projections, but some thick ice (1-2%) survives summer melt even in 2025-2029 period under nearly “ice-free” conditions.
- **Should we care about the mismatch given mean ice volume seems to be realistic?**
Comparison of ice area fraction

Sea ice fraction in %

- SSM/I Bootstrap
- HadGEM3-GC3.1-LL-SSP5: 2015-2019
- HadGEM3-GC3.1-LL-SSP5: 2020-2024
- HadGEM3-GC3.1-LL-SSP5: 2025-2029

Mean annual cycle
Comparison of ice area fraction

- HadGEM3 underestimates summer sea ice area fraction.
- While thick ice melts too slowly, thin ice melts too fasts.
- Strong decrease of summer sea ice are fraction in projections realistic?
Thick ice area fraction (h>3.6m) in forced NEMO-CICE simulations

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- Model mean and variability of FW transport is consistent with observations (pink)
- No clear model FW trend
- Variability increases after 2000
- Decrease in the model volume export 2000-2015: opposite trends in the Fram & Davis straits (e.g., Aksenov et al., 2010 & 2016 & Wang 2018)
- Volume flow year-to-year and seasonal variability dominates FW transport variations (e.g., Jahn et al., 2012); model of 2.1 ± 1.4 Sv; obs. of 2.1 ± 1.5 Sv
Thick ice area fraction (h>3.6m) in forced NEMO-CICE simulations

- NEMO is the ocean model and CICE the sea ice model used in HadGEM3.
- Forced NEMO-CICE simulations and stand-alone CICE simulations (not shown) reveal same behaviour as HadGEM3: very weak annual cycle of thick ice area fraction.
- The amount of thick ice can be increased by modifying the ice strength (here reduced Cf parameter for weaker ice), but not the magnitude of the annual cycle.
Summary

- Sea ice volume simulated realistically in historical HadGEM3-GC3.1-LL runs.
- Cyrosat-2 estimates indicate pronounced annual cycle of thick ice fraction (h>3.6m) in each grid cell: Nearly no thick ice in October, but more than 20% in April.
- HadGEM3 simulations do not represent this neither in historical run nor in future projections, nor do forced ocean-ice or stand-alone simulations with the same sea ice component CICE
- **Missing physical process regarding the decay of sea ice ridges in CICE**