Arctic Cyclones and Sea Ice in HadGEM3
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1. Introduction
Several recent studies using observational data have identified relationships between Arctic cyclone activity and September minimum sea ice area and extent. For example:

- Years with a large reduction in sea ice area in summer tend also to have a large reduction in cyclone numbers at high latitudes between May and July (Screen et al., 2011).
- Stronger cyclones in August and September generally lead to a reduced annual minimum sea ice extent (Simmonds & Kaye, 2009).
- Ice rotation in the Beaufort Gyre is strongly related to local cyclone activity; ice rotation in turn has an impact on ice transport across the Arctic and thus on total sea ice area (Asplin et al., 2009).

The aim of this study is to identify whether such correlation between cyclone activity and sea ice area and extent exists in the output from a present-day control simulation of the Met Office coupled climate model, HadGEM3. It is hoped that this study will help to inform future model enhancements, resulting in a more accurate representation of cyclone-sea-ice interactions in the future.

2. Data and methods

HadGEM3 Output
- Present-day (fixed year-2000 emissions) coupled equilibrium simulation of HadGEM3 at N216 resolution.
- Atmospheric resolution: T63 lateral and T519 vertical.
- Sea ice resolution: CICE 4.4.
- Preceding HadGEM3 output from the Los Alamos Sea Ice Model (CICE).

Cyclone Tracking – TRACK Algorithm
- Cyclone tracking performed on 6-hourly MSLP and 850 hPa U & V wind fields using TRACK algorithm (Hoskins & Hodges, 2001).
- Cyclone centres identified in filtered 850 hPa relative vorticity fields and linked together to form trajectories (tracks) subject to intensity and longevity thresholds.
- Algorithm outputs cyclone tracks (latitude and longitude of maximum 850 hPa relative vorticity) and intensities (calculated as differences in both MSLP and 850 hPa relative vorticity).

3. TRACK output and HadGEM3 sea ice

Example HadGEM3 N216 Northern Hemisphere sea ice concentrations and cyclone tracks for one model year. Cyclone centre points are determined by relative vorticity anomaly.

4. Beaufort Sea cyclones and Beaufort Gyre region MSLP

- Weak negative correlation between monthly count ($r = -0.3$) and mean intensity ($r = -0.45$) of cyclones entering Beaufort Sea and monthly mean MSLP over Beaufort Gyre region between May and September.

5. Beaufort Gyre region MSLP and ice vorticity

- Strong negative correlation ($r = -0.57$ in MJJAS, $-0.72$ in JJA) between monthly mean MSLP and mean ice vorticity (curl of ice velocity) in Beaufort Gyre.
- Similarly, there is a strong positive correlation between cyclone count and intensity and Beaufort Gyre vorticity (not shown here).

6. Beaufort Gyre ice vorticity and Transpolar Drift Stream (TDS) ice fluxes

- Strong positive correlation ($r = 0.55$) between Beaufort Gyre mean ice vorticity and Western Transpolar Drift Stream (TDS) ice flux.
- Weak negative correlations in the Central ($r = -0.24$) and Eastern ($r = -0.45$) TDS.

7. TDS ice fluxes and sea ice area

- Mean TDS ice fluxes in June, July and August have only weak correlation ($r=0.4$) with annual minimum sea ice area (SIA).
- However, during years of large summer ice loss (Interglacial SIA change $>110$), there is a highly significant ($p > 0.99$) increase in the magnitude of the Fram Strait flux and decrease in the magnitude of the Western TDS flux.
- Similarly, during years of large summer ice gain (Interglacial SIA change $<110$), the opposite is true – there is a highly significant ($p > 0.99$) decrease in the Fram Strait flux and increase in the Western TDS flux.

8. Summary and conclusions

- In HadGEM3, cyclones do not appear to affect sea ice as seen in observations.
- Years with large summer ice loss tend to have a large increase in the magnitude of the western Transpolar Drift Stream and Fram Strait flux.
- These fluxes are correlated with the Beaufort Gyre ice vorticity, which itself is correlated with cyclone activity. However, direct correlation between cyclones and ice fluxes is weak.
- Impacts of cyclones on thermodynamic processes (basal, lateral and surface melt) affecting the sea ice area are insignificant in HadGEM3 (results not shown here), contrary to findings of observational studies.
- Further work is required to determine the reasons for this lack of agreement with observations (see next panel).

9. Further work

- Investigate effects of other processes (e.g., changes in cloud cover leading to changes in snowfall, leading in turn to surface albedo changes, warming of ocean mixed layer leading to increased basal melt).
- Study sensitivity to coupling timestep.
- Carry out analysis on higher resolution output.
- Study processes resulting from individual cyclones in hindcasts with the SSH-based seasonal forecasting system.
- Perform similar analysis on output from historical and/or climate change simulations (as opposed to the control run used here).

References