Is the Loss of Perennial Arctic Sea Ice Reversible?

Marika Holland and David Bailey, National Center for Atmospheric Research
Projected loss of perennial sea ice

Arctic Ocean

September Sea Ice Extent: Observations (red) versus Models and Model Mean (averaged model data and s.d. in black)

(Updated from Stroeve et al. 2007)
Projected loss of perennial sea ice

September Arctic Sea Ice Extent

Arctic Ocean
September Ice Extent
CCSM3 – 8 Ensemble Members

Range across Ensemble Members

Observations

Range in model 2007 extent from natural variability
~ 4.8 to 7 million km²

(Holland et al., 2006)
Possibility of a Tipping Point?
Could ice loss be irreversible?

(Courtesy of Don Perovich)
Observations and models suggest the loss of perennial sea ice may be unavoidable

• Would this change be irreversible?
• If global forcing change is removed (CO2 levels decrease) would the perennial Arctic ice recover?
• If so, what mechanisms would influence this recovery?
• Performed highly idealized experiments using CCSM3
• Runs initialized with 2100 CCSM3 conditions (seasonally ice free Arctic state)
• Reductions in CO$_2$ concentrations applied
The graphs illustrate the changes in September extent and March thickness of Arctic ice over time and in response to CO2 levels. The September extent (as function of time) shows a decrease over time, with fluctuations, starting around 1950 and continuing to 2200. Similarly, the March thickness (as function of time) also decreases over time, with significant fluctuations starting around 1950 and continuing to 2200. Both graphs indicate a significant reduction in ice extent and thickness in response to increased CO2 levels, especially after 2000. The graphs also show that the impact of CO2 on ice conditions is more pronounced in March than in September.
Relationship to global surface air temperature

- Linear relationship of annual NH ice extent and global SAT
- Relationship with September extent and ice thickness not linear
- Relationship nearly identical for the ice loss and ice recovery simulations

-2.4 million km²/K
What allows sea ice recovery?

Ice Loss - Run with increasing GHG

Ice Recovery - decreasing GHG
Arctic amplification

Arctic amplification has similar characteristics for the loss and recovery of perennial sea ice.

In CCSM3, the Arctic surface air temperature change is about 3Xs that of the global change.
Conclusions

• Climate simulations were initialized from seasonally ice free (2100) state with applied reductions in CO2 (from 2100 A1B levels)

• Arctic recovers a perennial ice pack with some time lag

• Relationship of sea ice conditions (state, mass budget) to global air temperature is nearly identical for the loss and recover of perennial sea ice

• Suggests that loss of perennial sea ice is reversible
Questions?
Mass budget

Characteristics as a function of ice state are similar during the ice loss and ice recovery simulations.

Hints of a difference with ice divergence response (more obvious in other run), but not clear how robust/significant.
Diagnosing Ice Loss

Multi-model Sea Ice Mass Budget Change

- Initial increases in melt
- Gives way to reductions in ice growth
- Partially compensated by reduced loss via ice transport
- By 2100, considerable ice volume loss of about 1.5m on annual avg

(Holland et al., 2010)
Diagnosing Ice Loss

**CCSM3 Sea Ice Mass Budget Change**

- Initial increases in melt (and increases in ice growth)
- Gives way to reductions in ice growth
- Partially compensated by reduced loss via ice transport
- Results in ~2m of thinning

(Holland et al., 2010)
Translating ice volume change to ice extent loss

For thick ice: small extent loss per meter of ice thickness loss

For 1-2m ice, large ice extent loss per ice volume change; variable across models; related to spatial distribution of ice within the Arctic

In general, models with more realistic ice, lose Sept extent earlier

(Holland et al., 2010)