Rapid Arctic Sea Ice Loss

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Outline

1. Observed Arctic sea ice change
   - Factors influencing change

2. Projected change in future Arctic ice cover
   - Possibility of abrupt transitions
   - Mechanisms driving change
   - Possible “Tipping Point” behavior?
   - How climate models differ

3. Conclusions
Sept Ice Extent 1979-2008

2007: 23% less than previous minimum

Source: NSIDC

Arctic summer sea ice

Source: Cryosphere Today, U. Illinois
Loss of the summer ice cover in context

From 1980 to 2005: ice loss equal to 24 states; most of the US east of the Mississippi

To 2007: 5 additional states
Transition Towards Younger, Thinner Ice

- Ice age tracking algorithm from C. Fowler and J. Maslanik
- By 2007 ice >5 years is only 10% of the perennial ice pack.
- Younger ice is generally thinner ice
- Consistent with ULS data; hindcast model experiments

Spring 1986

Spring 1990

Spring 2007

Maslanik et al., 2007
Factors driving observed thinning and retreat

- Dynamic forcing
  - prolonged increase in NAO from 1960s to mid-1990s
  - increased ice transport from the Arctic into the North Atlantic (Rigor et al., 2002; Kwok and Rothrock, 1999)

Winter NAO Index; 1864-2003
Factors driving observed thinning and retreat

- Thermodynamic forcing
  - warmer air temperatures and enhanced ice melt (Rothrock and Zhang, 2005); increased down LW (Francis and Hunter, 2006)
  - increased ocean heat transport to the Arctic with possible effects on ice melt/growth

Arctic Ocean change

Polyakov et al., 2005

Natural variability or anthropogenic change? Both likely...
Arctic change: The poster child for global climate change

'Arctic is screaming,' say scientists seeing new data; worry over 'tipping point'

WASHINGTON: An already relentless melting of the Arctic greatly accelerated during the Northern Hemisphere's hot summer months, a warning sign that some scientists worry could mean global warming has passed an ominous tipping point. One is even speculating that summer sea ice would be gone in five years.

Greenland's ice sheet melted nearly 19 billion tons (17.26 metric tons) more than the previous high mark, and the volume of Arctic sea ice at summer's end was half what it was just four years earlier, according to new NASA satellite data obtained by The Associated Press.

Arctic ice hits 'tipping point'

By Roger Highfield, Science Editor

Dwindling Arctic sea ice may have reached a 'tipping point' that could make British winters even wetter, according to researchers.

Arctic sea ice levels naturally ebb and flow throughout the year and are always lowest in September. But September 2005 marked their lowest level in 50 years and satellite data show average September sea ice extent down by 8.6 per cent per decade and accelerating.

Some computer models even predict an ice-free Arctic Ocean in September by 2050.
Peering into the future...
### 20th century runs
- branched from 1870 control run
- include variations in sulfates, solar input, volcanoes, ozone, GHGs ($CO_2$, $CH_4$, $N_2O$), Halocarbons (CFCs), black carbon

### 21st century runs
- A1B scenario: rapid economic growth; global population that peaks mid-century; rapid introduction of new and more efficient technologies; balance across fossil/non-fossil energy sources.
Future climate scenarios

- Relatively gradual forcing.
- Relatively gradual response in global air temperature
Air Temperature: Typical “business as usual” scenario by 2100

Global mean warming of ~2.8°C (or ~5°F);
Much of land area warms by ~3.5°C (or ~6.3°F)
Arctic warms by ~7°C (or ~12.6°F)

IPCC-AR4
Simulated change over historical record

Satellite Observations

Range in model 2007 extent from natural variability
~ 4.8 to 7 million km$^2$

Simulated trend generally consistent with observed loss
CCSM3 does not obtain 2007-like conditions until 2013
Simulated natural variability is considerable and comparable to obs
Abrupt reductions in the September sea ice cover

Holland et al., 2006

1990–1999 Avg SEPT ice

2040–2049 Avg SEPT ice

September sea ice extent

Ice Extent (10^6 km^2)

SSMI observed
CCSM3
CCSM3 – smoothed

9 events across 8-member CCSM3 A1B ensemble

Holland et al., 2006
Forcing of the Abrupt Change

- Change is driven thermodynamically
- Dynamics plays a small stabilizing role

Ice melt rates directly modify ice thickness
- Ice thickness shows large drop associated with event
- This change is similar to earlier reductions in 20th century that had little ice extent change.
Processes contributing to abrupt change

Increased efficiency of OW production for a given ice melt rate
- As ice thins, vertical melting more efficiently produces open water
- Relationship with ice thickness is non-linear
Processes contributing to abrupt change

**Albedo Feedback**

- Increases in absorbed solar radiation as the ice recedes.
- Contributes to increased basal melting.

**Increases in ocean heat transport**

- Over abrupt transition.
- Contributes to increased basal melting and provides a possible “trigger” for the event.
Both trend and shorter-timescale variations in OHT appear important. OHT “natural” variations lead changes in ice cover and are correlated to an NAO-type pattern in SLP. (Holland et al, in press)
A possible role for cloud feedbacks?

Cloud cover before event

Cloud cover after event

Cloud Cover difference

2000 2060
A possible role for cloud feedbacks?

- LWCF
- SWCF
- Cloud Cover
- Cloud cover difference
Mechanisms Driving Abrupt Transition

1. Transition of ice to a more vulnerable state
   - thinning of the ice

2. A Trigger - (Natural?) rapid increases in OHT.
   - Other natural variations could potentially play the same "triggering" role

3. Positive feedbacks that accelerate the retreat
   - Surface albedo feedback
   - OHT feedbacks? Mechanisms not fully understood.
   - Possible cloud feedbacks under investigation

Similar mechanisms at work for abrupt events in other ensemble members
Relative importance of various factors differs among events
Conditions implicated in 2007 ice loss

1. Thinning of ice to a more vulnerable state
2. A Trigger - anomalous high pressure over Beaufort Sea
   - Other associated variations possibly played a role
3. Positive feedbacks that could accelerate future retreat
   - Surface albedo feedback

Ice Thickness

SLP, Summer 2007

SST Anomaly

(Stroeve et al., 2008)

NCEP Reanalysis

(Steele et al., 2008)
Is simulated Rapid Ice Loss a consequence of “Tipping Point” behavior?

Where, Tipping Point = an intrinsic threshold such that sea ice decline will become rapid and irreversible once the threshold is crossed
Role of forced versus natural change

As ice thins, the “natural” variability in extent increases

A combination of large “forced” change and large intrinsic variability necessary

(Holland et al., in press)
Searching for a “critical” ice threshold

- Ice lost over events varies in thickness, location, distribution
- Interaction of forced change & natural variations make events difficult to predict based on ice state
If fix CO2, does ice continue to retreat?

Model results suggest

• that sea ice may not go seasonally ice-free if no continued increases in CO2
• Strongly suggests this is not Tipping Point behavior

(Bitz et al., in prep)
Do other models have abrupt transitions? 

Some do…

From an analysis of 15 additional IPCC-AR4 models, we find that 50% of them simulate abrupt reductions for some future forcing scenario. Rapid ice loss is more likely in simulations with higher anthropogenic forcing.

Data from IPCC AR4 Archive at PCMDI
IPCC-AR4 climate model projections

September Ice Extent

Large range in simulated ice extent and extent loss

Models generally conservative compared to observations

Stroeve et al., 2007
Is it possible to identify why various models exhibit differences in their possible future abrupt ice retreat?
Simulated late 20th century ice conditions

Ann avg 1980-1999 ice thickness

IPCC AR4
Dash=March extent
White=Obs Extent
Feedback Strength and Model Parameterizations

For example, studies suggest that including a subgridscale ice thickness distribution enhances the albedo feedback

(Holland et al., 2006)
Increases in Ocean Heat Transport to the Arctic

Change in poleward ocean heat transport at 2XCO2 conditions in CMIP2 models

OHT increases to the Arctic are common in climate models but vary considerably in their magnitude

(From Holland and Bitz, 2003)
Conclusions

• Rapid summer ice loss has occurred since 1979 and climate models project that this could accelerate in the future

• In most extreme case, conditions go from near-present day to near-ice free Septembers in ~10 yrs

• The transitions result from:
  – A vulnerable, thin ice state: Increased OW per melt rate
  – A trigger: Increased OHT (natural variability?)
  – Accelerating feedbacks: Albedo change/OHT?/Clouds?

• Rapid ice loss results from interaction of natural variability and anthropogenic change

• Little indication that these are a “tipping point” response

• Models differ on simulation of abrupt summer ice loss
Questions?