Arctic Sea Ice Decline: Faster than Forecast?

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Introduction

Climate models are in near universal agreement that Arctic sea ice extent will decline through the 21st century in response to atmospheric greenhouse gas (GHG) loading. From 1953-2006, Arctic sea ice extent at the end of the summer melt season in September has declined at a rate of -7.8%/decade (see Figure 1). Over the period of modern satellite observations (1979-2006) the trend is even larger (-9.1% per decade). Trends for March (the climatological maximum ice extent), while much smaller, are also downward, at -1.8% and -2.9%/ decade over these two time periods.

Although it is tempting to attribute these trends to GHG loading, the observed sea ice record has strong imprints of natural variability. However, a role of GHG loading finds support in Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) model simulations that indicate downward trends in the annual mean ice cover over the observational period.

Data and Observations

❖Observational Record
- ❖Arctic: blended aircraft, ship reports and satellite record based on Had1SST and modified as described in Meier et al. [2007] (1953-2006).
- ❖Antarctic: ESMR/SMMR/SSM/I record described in …. (1973-2006).

❖IPCC AR4 simulations
- ❖21st century forcings based on SRES A1B "business as usual" scenario, scenario, where CO_2 is projected to reach 720 ppm by 2100 (compared to approximately 370 ppm in 2000).
- ❖Only use models with mean ice extent within 20% of observations from 1953-1995 for Arctic and 1975-1995 for Antarctic
  - -This screening resulted in 13 and 18 models for the September and March Arctic comparisons, respectively.
  - -Some models have more than one ensemble member which are used to generate the ensemble mean for that particular model.
  - -A multi-model ensemble mean and its inter-model standard deviation are computed.

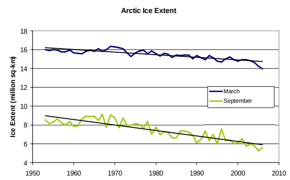

Figure 1. Time-series of March and September sea ice extent from 1953-2006.

Arctic Ice Extent Comparisons

September Observed and Modeled Ice Extent

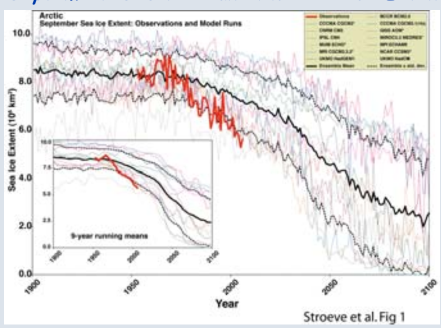

Figure 2. September sea ice extent ($\times 10^6$ km²) from observations and the 15 screened IPCC AR4 models.

March Observed and Modeled Ice Extent

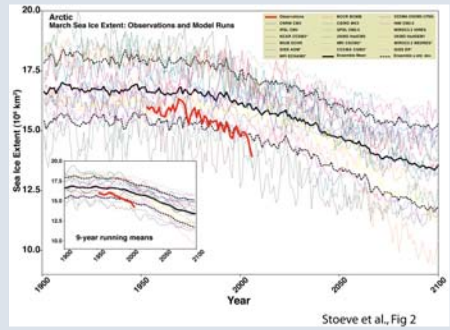

Figure 4. March sea ice extent ($\times 10^6$ km²) from observations and 18 IPCC AR4 models.

Results for September, and to a lesser extent March, indicate decay of the ice cover is proceeding more rapidly than expected based on the model simulations.

September: 1953-2006
- ❖Observed trend is -7.8 $\pm$ 0.6 %/decade.
- ❖Multi-model mean trend is -2.5 $\pm$ 0.2%/decade.

  None of the models or their individual ensemble members have trends as large as observed for this period.

September: 1979-2006
- ❖Observed trend is -9.1 $\pm$ 1.5%/decade.
- ❖Multi-model mean trend is -4.3 $\pm$ 0.3%/decade.

  Again a strong mismatch, and trends from only 5 of 29 individual ensemble runs (from only two models: NCAR CCSM3, UKMO HadGEM1) are comparable to observations.

March: 1953-2006
- ❖Observed trend is -1.8 $\pm$ 0.1%/decade.
- ❖Multi-model mean trend is -0.6 $\pm$ 0.1%/decade.

  Only 2 simulations (CCCMA GCM3, UKMO HadGEM1) have trends within 20% of observations. Note however, none of the model trends are significant at 95% confidence.

March: 1979-2006
- ❖Observed trend is -2.9 $\pm$ 0.3%/decade
- ❖Multi-model mean trend is -1.2 $\pm$ 0.2%/decade.

  Trends from 5 models are within 20% of observations.

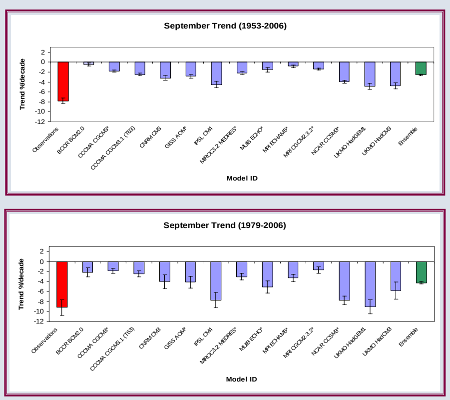

Figure 3(a)-(b). Trends in September ice extent (%/decade) for two different time periods: 1953-2006 (a), 1979-2006 (b). Trends statistically significant at 95% confidence are in solid color. Observations are shown in red, ensemble mean in green.

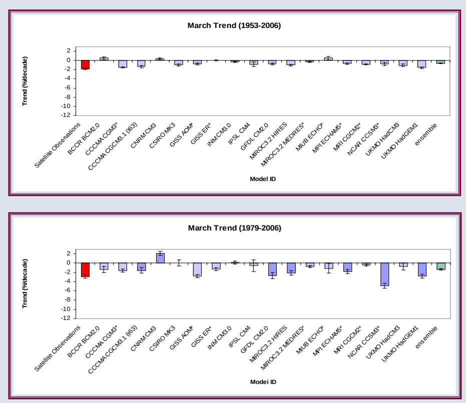

Figure 5(a)-(b). Trends in March ice extent (%/decade) for two different time periods: 1953-2006 (a), 1979-2006 (b). Trends statistically significant at 95% confidence are in solid color. Observations are shown in red, ensemble mean in green.

Natural vs. Forced

If we assume the September time series from the multi-model ensemble mean over the period 1953-2006 allows for a correct depiction of the externally forced trend, we can estimate the forced component of the observed trend.

- ❖As one estimate, we divide the multi-model mean trend by the observed trend.
- ❖As another, we compute anomalies of the multi-model mean time-series for each year with respect to 1953, subtract these from the observed time series (see Figure 6), and then re-compute the trend from the adjusted observations.

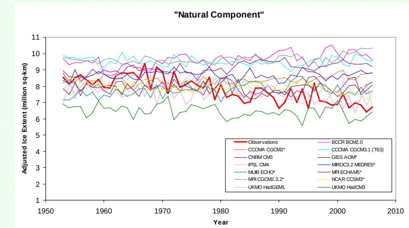

Figure 6. Time-series of September ice extent after subtracting multi-model mean anomalies with respect to 1953.

These calculations indicate:
September: 33%-38% (1953-2006) and 47-57% (1979-2006) of the observed trend is externally forced.
March: 34 to 39% (1953-2006) and 45 to 52% (1979-2006) of the trend is externally forced.

However, if the models as a group under-represent the GHG response the forced components must be larger.

The residual time series for individual simulations after removing the multi model-mean trend include a combination of each simulation's natural variability and departures in GHG sensitivity with respect to the multi-model mean. The larger downward residual trends will tend to include those simulations especially sensitive to GHG loading that (by chance) are paired with a downward trend associated with natural variability. Since none of the negative residual trends from 1953-2006 are comparable to that from the observations after removing the forced component, this implies natural variability in the models is underestimated. However, this again assumes that the multi-model ensemble mean time series correctly represents the GHG response.

Summary

❖All models participating in the IPCC AR4 show declining Arctic ice cover from 1953-2006. However, depending on the time window for analysis, none or very few individual model simulations show trends comparable to observations.

❖If the multi-model ensemble mean time series provides a true representation of forced change by GHG loading, 33-38% of the observed September trend from 1953-2006 is externally forced, growing to 47-57% from 1979-2006.

❖Given evidence that as a group, the IPCC models underestimate the GHG response, the externally forced component may be larger.