Attribution of Extreme Events in Arctic Sea Ice Extent

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To what extent has the magnitude of recent extreme events in Arctic sea ice extent been influenced by anthropogenic forcings?

Ensembles of ALL and NAT Forcing

Simulate Arctic sea ice extent (SIE) under anthropogenic + natural forcings (ALL) and only natural forcings (NAT) and compare the probabilities of occurrence of a particular extreme event under each forcing.



Internal Variability Comparison

How does model internal variability compare to observations?

Compare standard deviation of each annual SIE time series with observed (black line).

ALL NAT PIC

A linear trend has been removed from ALL and OBS before the standard deviation is computed.



- Most models show more variability than observations
- Generally good agreement between forcing scenarios
- CESM1 underestimates variability in Sep.

Detection/Attribution Results

How much of the observed temporal pattern in SIE can be explained by the ALL and NAT responses?



ALL and ANT forcing signals detected with almost all models for both annual and Sep. and are generally consistent in magnitude with observations

Det./Att. Results – March Max.



- Also decreasing trend in March maximum extent
- Record minimum in 2015 (2016 was close)
- ALL forcing signal detected with both models though CanESM2 needs to be scaled down and CESM1 scaled up
- 2-signal ANT detected and consistent with 1 while NAT not detected



Defining SIE Extreme Events



Event Attribution Methods

- (1) Pool data from all ensemble members for each decade
- (2) Fit density curves
- (3) Integrate to determine probability of an event more extreme than each anomaly threshold
- (4) Compare probability of event under ALL forcing with the probability of the same event under NAT forcing



Event Attribution Metrics

 p_1 = probability of event with ALL forcing

Fraction of Attributable Risk (FAR)

• Fraction of risk of event occurrence additionally contributed by ALL forcing

Probability of Necessary Causality (PN)

- Probability that ALL forcing is needed for the event to occur
- If PN = 1, ALL forcing required for event

Probability of Sufficient Causality (PS)

- Probability that inclusion of ALL is enough to cause the event
- If PS = 1, ALL forcing guarantees event

Risk Ratio (RR)

Stc

 Times more likely event occurrence is under ALL than under NAT

$$FAR = 1 - \frac{p_0}{p_1}$$

 p_0 = probability with NAT forcing

$$PS = 1 - \frac{1 - p_1}{1 - p_0}$$

$$RR = \frac{p_1}{p_0}$$

Event Attribution Results – Sep.



All models indicate an event of a magnitude equal to or more extreme than the 2012 record minimum would be *exceptionally unlikely* to occur under natural forcing alone. ALL forcing is a necessary, but not sufficient cause.

Event Attribution Results – Mar.



Both models indicate ALL forcing is a necessary condition for the 2015 event. In CanESM2 it is almost a sufficient condition as well.

Event Attribution Results



All models indicate an event of a magnitude equal to or more extreme than the current record minimum would be *exceptionally unlikely* to occur under natural forcing alone.

Conclusions

- An anthropogenic signal is detected in Arctic SIE with all ensembles for the annual time series and also for September and March separately
- ALL forcing is necessary for the occurrence of SIE events more extreme than the current record minima (2012 for Sep., 2015 for Mar.), but not yet sufficient
 - If the current trends continue, ALL forcing will become sufficient for the occurrence of such events
- Arctic SIE presents a counterexample to the statement that individual extreme events cannot be attributed to human influence

Questions?



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