SAND2019-14982C

Sandia National Laboratories

Arctic Sea Ice Internal Variability and Trends in E3SM

Kara Peterson, Amy Powell and Erika Roesler

Background

- Arctic sea ice extent has been declining over the past four decades with the most significant loss in summer months.
- The decline caused by anthropogenic global warming is superimposed over large interannual and decadal oscillations caused in part by internal variability in the coupled Earth system.
- Estimates of timing for a seasonally ice-free Arctic depend on a better understanding of the dynamics and variation of this strongly coupled system.

Data and Approach

Ice concentration, thickness, surface air temperature and sea surface temperature were obtained from 1-degree global coupled simulations of the Energy Exascale Earth System Model (E3SM) [1,2].

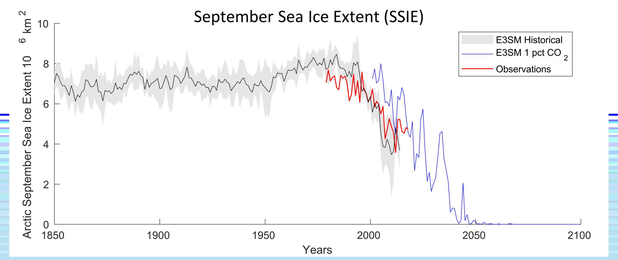
- **Pre-Industrial Control**, 500 years, 1850 level CO_2
- **Historical**, 1850-2014, 5 ensemble members
- **1pctCO2**, 150 years – prescribed 1 percent per year CO_2 increase

Observational data and reanalysis products are used for comparison.

- **NOAA/NSIDC,** passive microwave sea ice extent, 1979-2018 [3]
- **NCEP Reanalysis 2,** surface air temperature 1979-2018 [4]
- **ERSSTv2,** sea surface temperature 1979-2018 [5]
- **PIOMAS,** Arctic sea ice volume 1979-2018 [6]

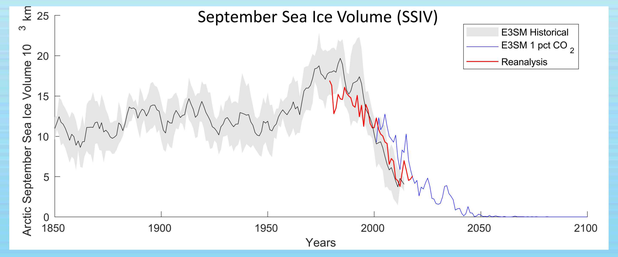
We evaluate variability and trends of September average sea ice extent and volume with respect to average annual global surface temperature and annual polar sea surface temperature. Linear fits and trends are computed in all cases using least squares.

Historical and 1 pct CO_2 Simulation Results



SSIE Trends (10^6 km^2 /decade)

NSIDC	-0.82
Historical 1	-1.72
Historical 2	-1.08
Historical 3	-1.37
Historical 4	-1.35
Historical 5	-1.64
1 pct CO_2	-1.57



SSIV Trends (10^3 km^3 /decade)

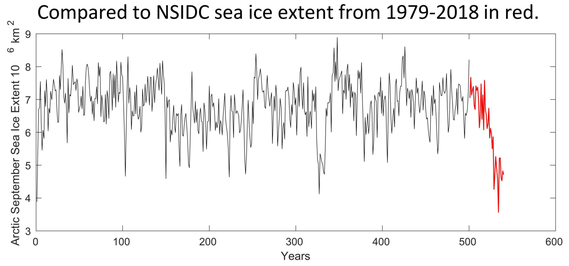
PIOMAS	-3.22
Historical 1	-6.01
Historical 2	-2.79
Historical 3	-4.59
Historical 4	-5.54
Historical 5	-4.77
1 pct CO_2	-2.86

Trends computed for years 1979-2014 in historical ensemble and for first 40 years of 1 pct CO_2 simulation.

Pre-Industrial Control Simulation Results

E3SM Pre-industrial Control September Sea Ice Extent

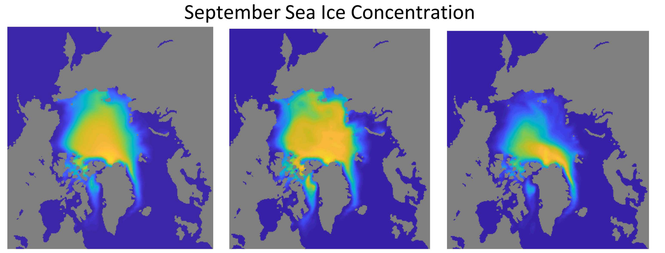
Compared to NSIDC sea ice extent from 1979-2018 in red.



Statistics (10^6 km^2)

Average	6.831
Std. Dev.	0.752
Minimum	4.126
Maximum	8.900

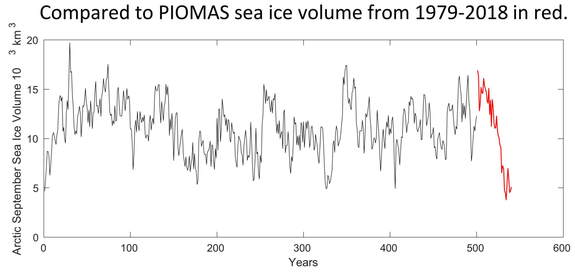
September Sea Ice Concentration



Average over 500 years (left). Average over 10 years with largest sea ice extent (middle). Average over 10 years with smallest sea ice extent (right).

E3SM Pre-industrial Control September Sea Ice Volume

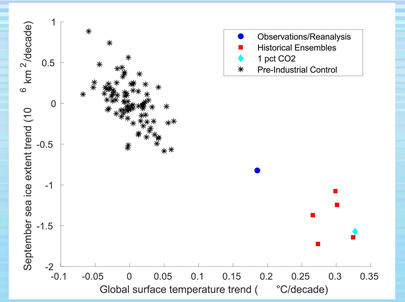
Compared to PIOMAS sea ice volume from 1979-2018 in red.

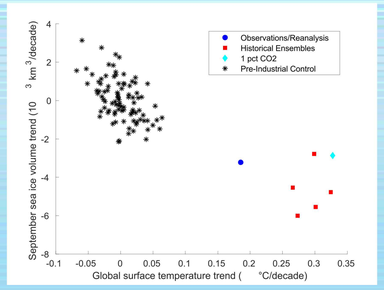


Statistics (10^3 km^3)

Average	11.10
Std. Dev.	2.55
Minimum	4.66
Maximum	19.69

Arctic Sea Ice Decadal Trends



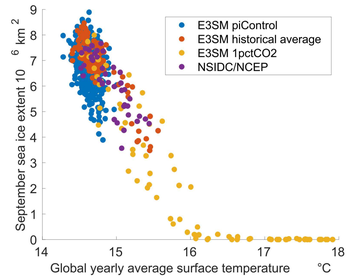


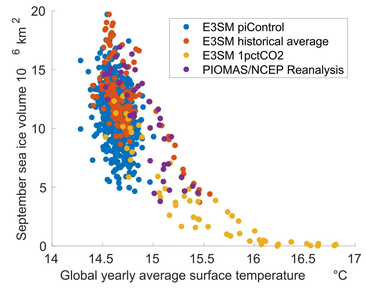
Global surface temperature versus sea ice extent (left) and sea ice volume (right) trends. Historical ensemble trends are computed for the years 1979-2014 and overlapping 35-year pseudo-ensembles are created from the pre-industrial control simulation for the computed trends.

Arctic Sea Ice Sensitivity

We compute sensitivity as the linear least squares fit of September sea ice extent or volume and yearly global average surface temperature or polar sea surface temperature [7].

Sea Ice Extent Data	SSIE vs Surface Temp		SSIE vs Polar SST	
	Slope 10^6 km/ K	R^2	Slope 10^6 km/ K	R^2
NSIDC	-3.54	0.644	-3.60	0.790
Historical 1	-5.65	0.810	-4.86	0.798
Historical 2	-3.77	0.656	-3.97	0.877
Historical 3	-4.94	0.728	-4.64	0.739
Historical 4	-4.02	0.705	-4.46	0.828
Historical 5	-4.73	0.805	-4.75	0.852
piControl	-2.65	0.135	-3.00	0.275
1 % CO_2	-4.39	0.758	-4.47	0.571





Sea Ice Volume Data	SSIV vs Surface Temp		SSIV vs Polar SST	
	Slope 10^6 km/ K	R^2	Slope 10^6 km/ K	R^2
PIOMAS	-13.7	0.712	-13.9	0.879
Historical 1	-18.3	0.788	-15.7	0.755
Historical 2	-10.6	0.449	-11.4	0.792
Historical 3	-17.1	0.695	-14.2	0.672
Historical 4	-17.2	0.766	-17.3	0.824
Historical 5	-12.4	0.690	-11.8	0.724
piControl	-8.42	0.121	-7.24	0.142
1 % CO_2	-6.92	0.791	-8.50	0.550

Discussion

- We provide a preliminary evaluation of September sea ice extent and volume trends in E3SM.
- Trends for the E3SM historical ensembles are generally faster than observational and reanalysis trends and 35-year pseudo-ensembles of the 500-year pre-industrial control simulation exhibit trends that are significantly slower than either the forced simulations or observations.
- Results are consistent with other analyses that have predicted September ice free conditions at 1.5 C above pre-industrial levels [8].
- Future work will investigate drivers of sea ice extent and volume variability in the coupled model.

References

[1] Golaz *et al.*, The DOE E3SM Coupled Model Version 1: Overview and Evaluation at Standard Resolution, *JAMES,* 2019.
[2] Petersen *et al.*, An Evaluation of the Ocean and Sea Ice Climate of E3SM Using MPAS and Interannual CORE-II Forcing, *JAMES,* 11, 1438-1458, 2019.
[3] Meier, W., F. Fetterer, M. Savoie, S. Mallory, R. Duerr, and J. Stroeve. 2017. NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration, Version 3. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.7265/N59P2ZTG. [Date Accessed: December 13 2018].
[4] M. Kanamitsu, W. Ebisuzaki, J. Woollen, S-K Yang, J.J. Hnilo, M. Fiorino, and G. L. Potter. NCEP-DOE AMIP-II Reanalysis (R-2). 1631-1643, Bulletin of the American Meteorological Society Nov 2002.
[5] Huang, B. *et al.,* Extended Reconstructed Sea Surface Temperature version 4 (ERSST.v4), Part I. Upgrades and Intercomparisons, J. Climate, 2014.
[6] Schweiger, A., R. Lindsay, J. Zhang, M. Steele, H. Stern, Uncertainty in modeled arctic sea ice volume, J. Geophys. Res., doi:10.1029/2011JC007084, 2011.
[7] Winton, M, Do Climate Models Underestimate the Sensitivity of Northern Hemisphere Sea Ice Cover? J. Climate, Vol. 24, 3924-3934, 2011.
[8] Notz, D., and J. Stroeve, The Trajectory Towards a Seasonally Ice-Free Arctic Ocean,, J. Curr Clim Change Rep (2018) 4: 407, 2018.

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology &Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. _____

Sandia National Laboratories