2-P04: Energy conserving and physically consistent method for isolating the impacts of sea-ice changes in a multi-model framework

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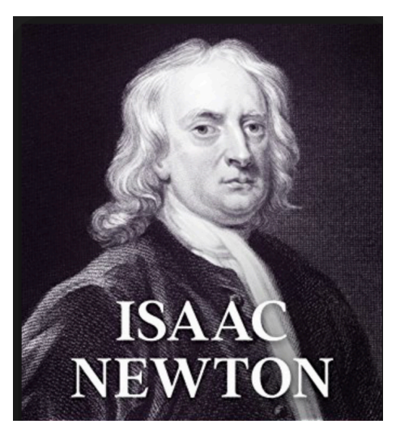
I Problem formulation

Most of the existing methods aimed at isolating the impacts of sea-ice loss on climate are either unphysical or non-energy conserving:

1. ‘painting the ice black’ or ‘turning the ocean white’

PROS: easy to implement, no artificial energy flux perturbations
CONS: fail to capture the full range of physical processes



2. imposing energy flux perturbations (nudging the SSTs, prescribing sea-ice cover)

PROS: wider range of physical processes captured compared to (1).
CONS: difficult to discern if the isolated climatic response is additionally altered by the imposed energy fluxes.

Here we illustrate a new approach that employs small perturbations to selected sea-ice physics parameter values that are imposed only within parameter’s respective expert defined ranges. We discuss its applicability based on simulations performed with CCSM4 and EC-Earth models, with the aim of setting a benchmark for other multi-model applications.

II Parameter selection and model configurations

Initial parameter selection is based on the uncertainty quantification study investigating the contributions from individual parameters and parameter interactions on the ensemble spread (Lucas et al. 2013, see Fig. 1). The 3 parameters: snow grain radius tuning parameter (R_snw), snow melt maximum radius (rsnw_melt_in) and thermal conductivity of snow (ksno) were found to account for most of the variability over the full seasonal cycle in CICE4 model.

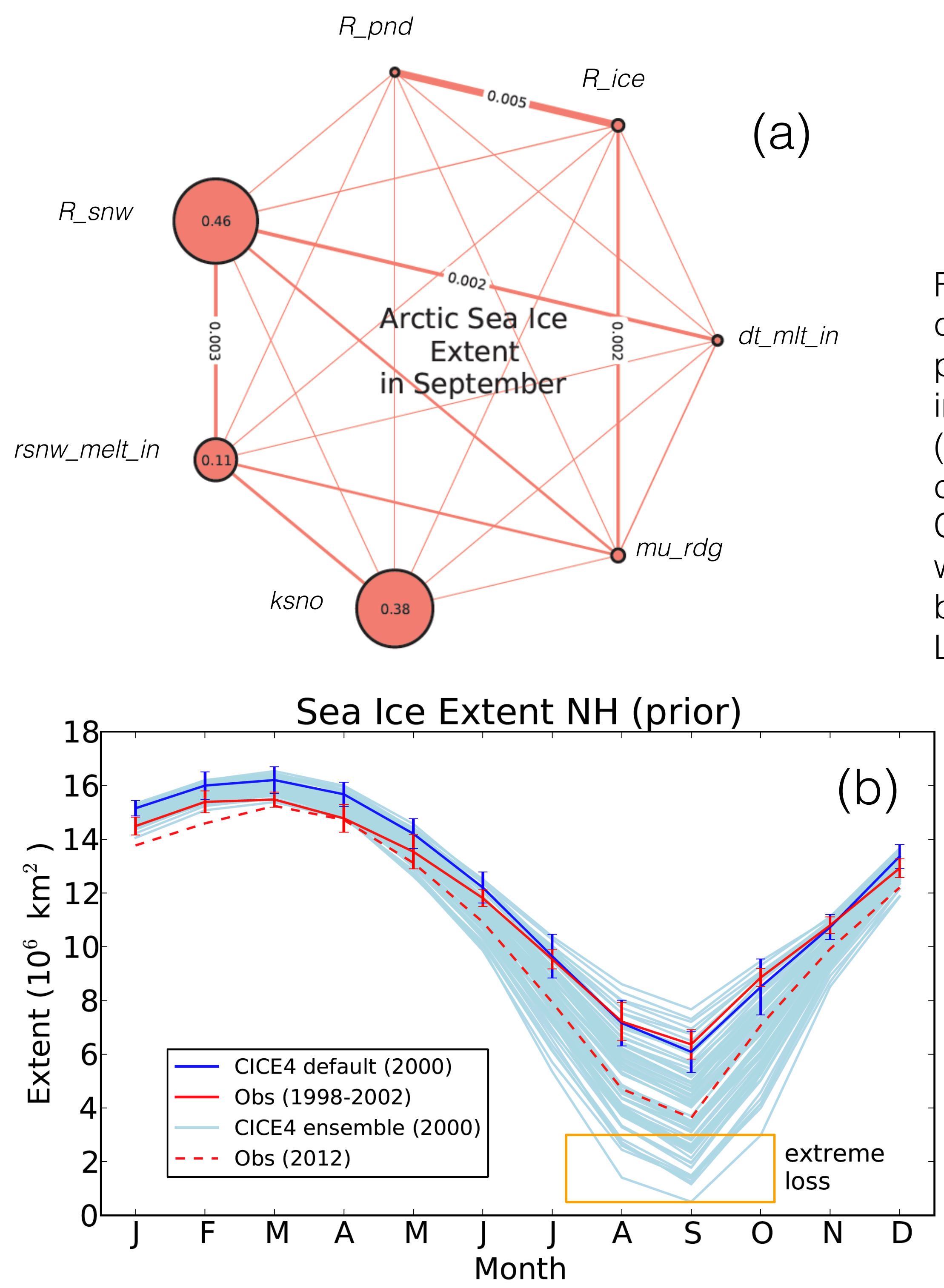


Fig. 1: (a) Ensemble variability decomposition: contributions from individual parameters (nodes) and parameter interactions (edges).
(b) Observed and simulated seasonal cycles of Arctic sea ice extent. The default CICE4 cycle (blue) in year 2000 agrees well with observations (solid red). Error bars show interannual variability. From Lucas et al. (2013)

CCSM4 (CICE4+CAM4+CLM4+slab ocean):

low Arctic ice “formula”

parameter	default value	expert defined range
snow grain radius tuning parameter	1.5	-1.9 - 1.9
snow melt maximum radius	1500	500 - 2000
thermal conductivity of snow	0.3	0.1 - 0.35

EC-Earth (NEMO3 + LIM3.6 + IFS) – testing set 1:

parameter	default value	expert defined range
dry snow albedo	0.85	0.85 – 0.87
melting snow albedo	0.75	0.72 – 0.82
thermal conductivity of snow	0.35	0.1 – 0.35
dry ice albedo	0.60	0.54 – 0.65
bare puddled ice albedo	0.50	0.49 – 0.58

IV Results

CCSM4 (year 2000 repeat)

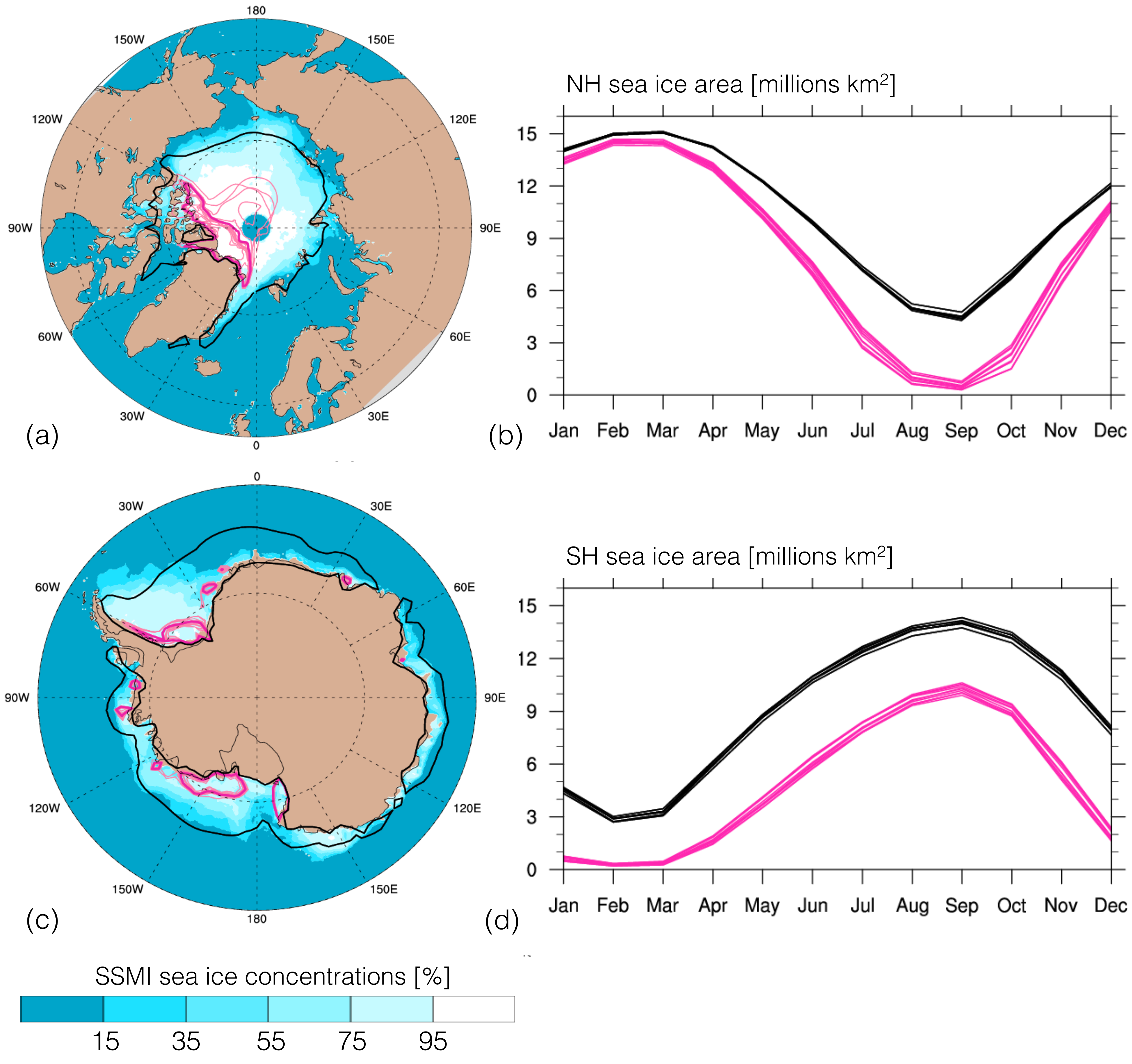


Fig. 2: September monthly-mean sea-ice concentrations (a) and Arctic monthly mean sea-ice areas in ‘low Arctic ice’ and control simulations. Areas contained within contour lines in (a) have sea-ice fractions larger than 15%. Thick black (purple) lines denote control (‘low ice’) ensemble means; thin purple lines show results for individual ‘low ice’ simulations. The colored shading indicates the average observed September sea-ice concentrations over the period 1992 to 2001 (from the Center for Satellite Exploitation and Research). Panels (c) and (d) show the same but over the Antarctic in ‘low Antarctic ice’ simulations.

EC-Earth (year 1950 repeat, testing set 1):

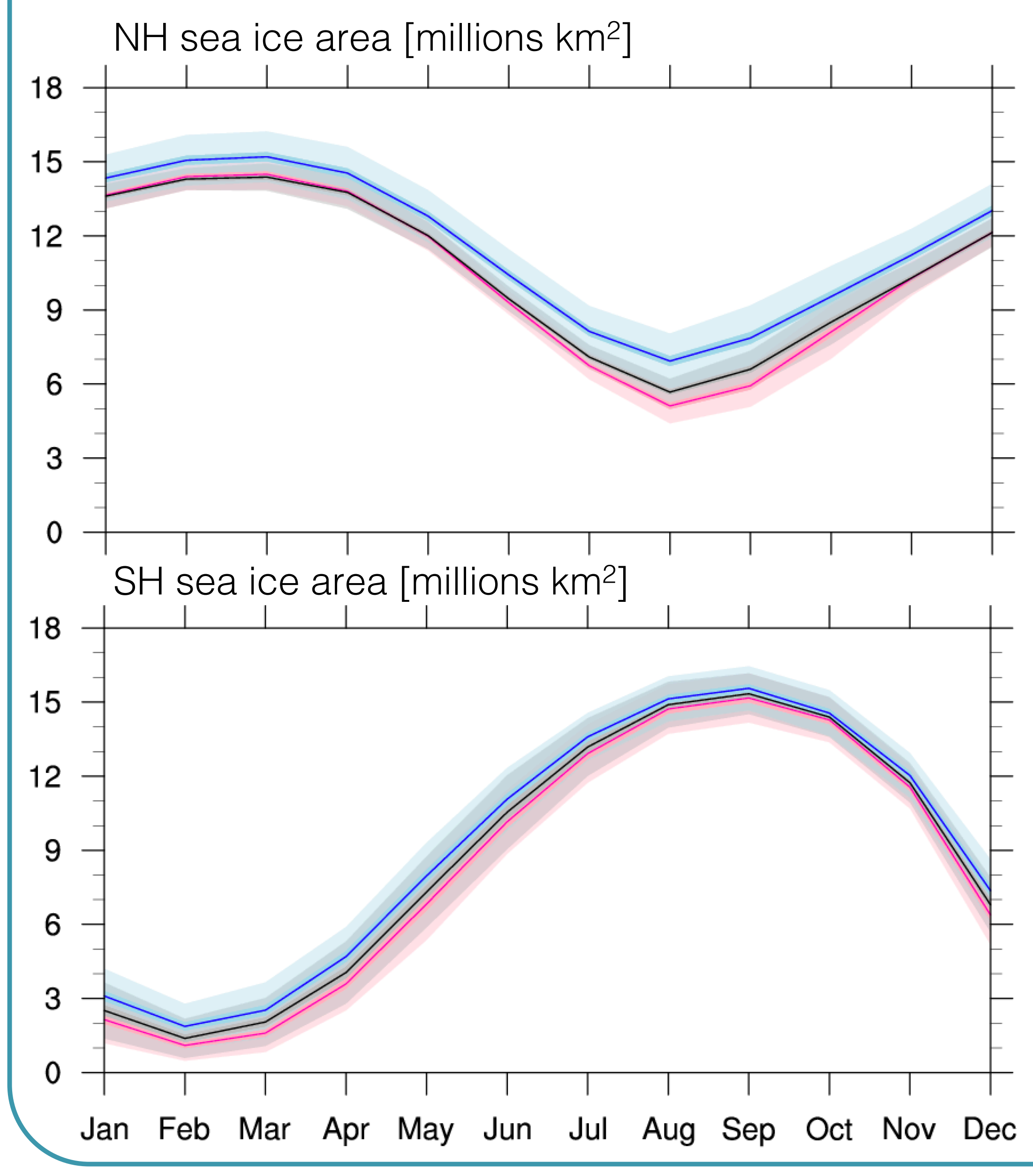


Fig. 3: Monthly mean sea-ice area in ‘control’ (black), ‘low’ (purple) and ‘high’ (blue) sea-ice simulations. The lighter (darker) colored shadings indicate two-standard deviations (standard error) from the mean over the first 30 years of simulations.

Further production:

Year 2000 repeat + testing set 1
testing set 2: set1 + P*
testing set 3: set 1 with different melt pond treatments

IV Conclusions

Sea-ice physics parameter perturbations present a promising new approach for isolating the impacts of sea-ice loss and sea-ice forcing on climate that is both physically realistic and energy conserving. As a side effect, they may also provide a new path for improvements in modeling of sea-ice changes.

References:
1. Lucas, D., et al. 2013: Quantifying uncertainties in the seasonal cycle of Arctic sea ice. 2013 AGU meetings abstracts: AGUFMGC31B1044L. 2. Cvijanovic, I., et al. 2017: Future loss of Arctic sea-ice cover could drive a substantial decrease in California’s rainfall, Nat. Comm. 1947,10.1038/s41467-017-01907-4.

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