Is One Ensemble Enough? Model Climates in 14 50-member CCSM4 IC Ensembles

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Research Questions

- Climate is usually defined i.t.o temporal statistics (or probability distributions; Werndl, 2015); are these equivalent to ensemble statistics (Conradie, 2015)?
- Are there differences in ensemble statistics depending on ensemble ICs used (cf. "macroscopic" IC uncertainty (ICU); Stainforth et al., 2007)?

Methods

- Run CCSM4 (Gent et al., 2011) super-ensemble (cf., Hawkins et al., 2016)
- Analyse distributions across ensemble & over time for individual members using robust Theil-Sen trends (Sen, 1968) and bootstrapped CIs for ECDFs.

Experimental Design & Model Set-Up

- CCSM4 lowest resolution: atmosphere: $\approx 4 \times 5^\circ$ fv; ocean & sea-ice: $\sim 3^\circ$
- 11 60-year ensembles run with 2000AD forcing; 3 with RCP8.5
- 2 controls (1 at NERSC, 1 at CHPC)
- Some ensembles branched from controls, some from a previous ensembles

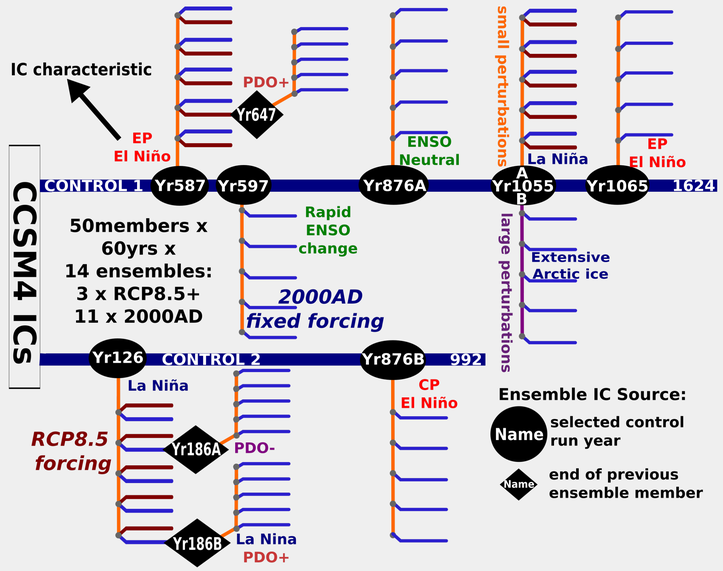

Figure 1:Schematic of control runs performed, ensembles produced and characteristics of their ICs

Results: RCP8.5 sea ice loss

- Regional total sea ice volume expressed as % of 2000AD multi-ensemble mean.
- RCP8.5 trends computed for 2005-2064 (figure 2) & for years 11-60 (2015-2064) only (figure 3), after IC predictability $\rightarrow\sim 0$.

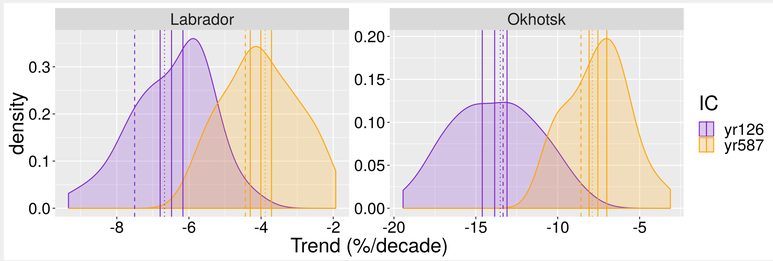

Figure 2:Distribution of ensemble member trend in sea ice volume over 6 decades of 2 RCP8.5 ensembles. Solid vertical lines are mean trend over members with approximate (t-test) 95% CI; dashed lines the trend in ensemble mean & dotted lines the trend for full ensemble

Labrador Sea trend differences between ensembles are significant ($p < 0.0005$) even after correcting for trends in corresponding 2000AD ensembles.

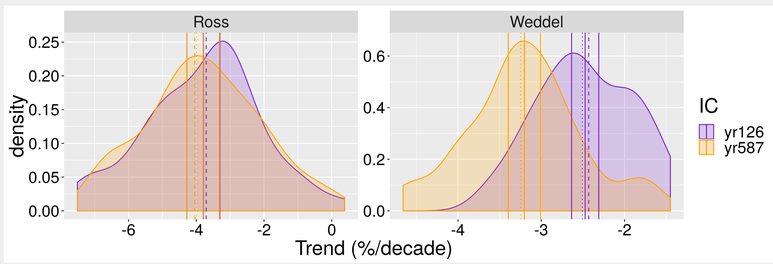

Figure 3:As in Fig. 2 for 4 SH domains, for years 11-60 only

Results: Ensemble vs temporal distributions

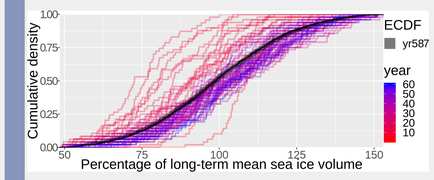

Figure 4:Okhotsk Sea ensemble ECDFs for yr587

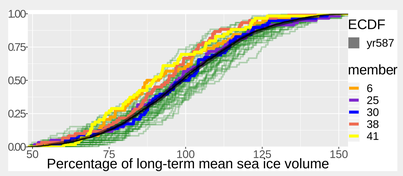

Figure 5:As in Fig. 4, for temporal distributions

Results: Intra-ensemble differences

- "Almost intransitivity" (Lorenz, 1968) causes frequent significant differences between full ensemble and member distributions in some regions (e.g. Fig. 5)
  - $>$ 40% of members for Southern Ocean SST in ensembles with weak IC forcing (e.g. Yr876A)
  - no members for Tropical SST with strong IC forcing (e.g. Yr1065).

Results: Inter-ensemble comparisons

- 2 factors can shift multi-decadal quasi-steady regional climate away from background state (not all regions or variables):
  1. large ($\sim O(10K)$) perturbation in atmospheric temperature IC – yr1055B
  2. forcing history – yr647 – RCP8.5 $\times$ 60 yrs $\Rightarrow$ 2000AD
- Regional sea ice volume ECDFs with 99% bootstrapped CIs for illustration:

Factor 1 & 2: Distinct summer climate clusters

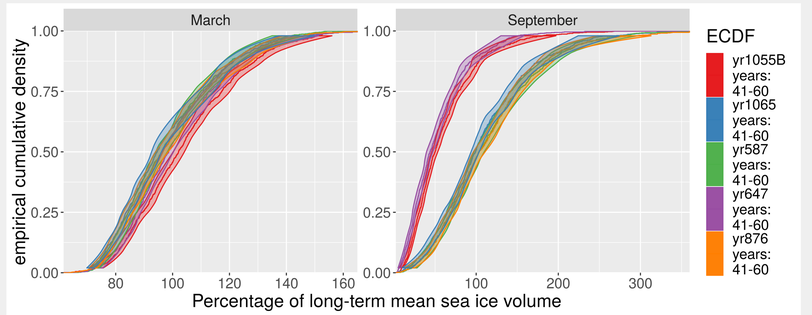

Figure 6:March & September Labrador Sea sea ice volume ECDFs

Factor 2: Relaxes to prior state, then rebounds to warmer state in Okhotsk Sea

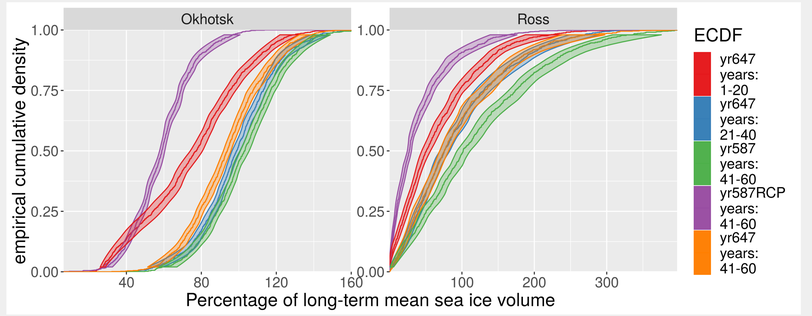

Figure 7:March NW Pacific & Ross Sea sea ice volume ECDFs

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Conclusion

Micro-scale (irreducible) ICU:

- Ensemble distributions tend to better capture regional model climates than temporal equivalents in this simple (unrealistic) model set-up

Macro-scale ICU:

- Distinct seasonal, regional climate states observed under fixed forcing through system IC changes
- ICs appear to have influence on climate change response beyond model IC predictability horizon

- **Employing IC super-ensembles may allow for better quantification of model climates, ICU & consequently near-term climate change projections (cf. Hawkins et al., 2016)**

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