The influence of initial conditions and climate forcing on Arctic predictability

SESSION C5 - M183A

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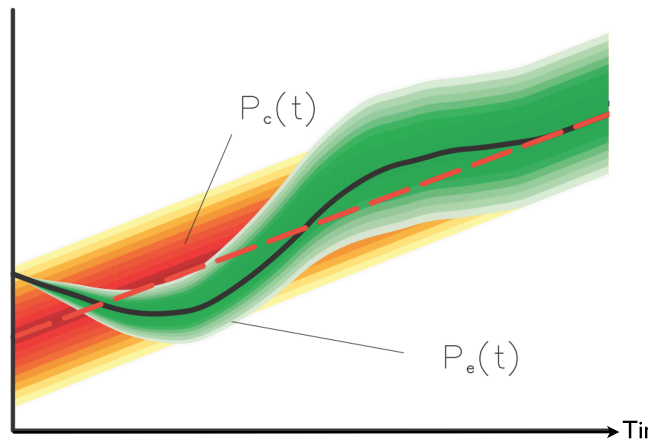
Introduction

•The recent sharp decline in Arctic sea ice, particularly during summer months, has brought with it an increase in the interest of Arctic sea ice predictability, not least driven by the potential of significant human industrial activity in the region that would benefit from such predictability.

•We set out to quantify how long Arctic sea ice predictability is dominated by dependence on its initial conditions ('predictability of the first kind', [Lorenz 1975]) versus dependence on its secular decline in a state-of-the-art global circulation model (GCM) under a 'perfect model' assumption ('predictability of the second kind', [Lorenz 1975]).

• This predictability from changing boundary conditions, such as results from anthropogenic climate forcing, could be very important for a system whose mean state is rapidly changing, as is the case for Arctic sea ice. This 'forced' predictability results in a transient in the ensemble mean of an ensemble forecast distribution. A question of interest is how long initial-value predictability dominates over forced predictability in sea ice, or is there a gap when there is no predictability.



Schematic diagram of time-evolving distributions under changing external forcing. The yellow–red shading represents the climatological distribution, Pc(t). It is independent of any particular initial state. Pe(t) is an ensemble of predicted states evolving from a specific tight cluster of initial conditions. Eventually, Pe(t) converges to Pc(t) as the influence of the particular initial conditions is lost. A comparison of Pe(t) to Pc(t) represents "**initial-value predictability**,", whereas a comparison of Pc(t) to Pc(0) corresponds to "**forced predictability**". Used with permission from G. Branstator.

Experiment Design

•We investigate predictability of pan-Arctic sea ice area and volume in perfect model studies with the Community Climate System Model version 4 (CCSM4) [Gent et al., 2011] at 1° resolution in all components. We conduct an ensemble of prediction experiments (EPEs) for each start time composed of 60 runs with initial conditions drawn from six different 20th Century integrations as shown below.

•We refer to runs with initial conditions from the same start time and 20th century integration as a set. Each set has either 8 or 20 members of 2 or 5 years in length (as noted in Table 1), and all members of the set have the same sea ice, land, and ocean initial conditions. The set members are unique in their atmospheric initial conditions, which are drawn from consecutive days centered on 1 January or September.

•For the control, or 'reference' distribution, we use years 1996–2005 of the six 20th century integrations to construct statistics of a 'reference' distribution:

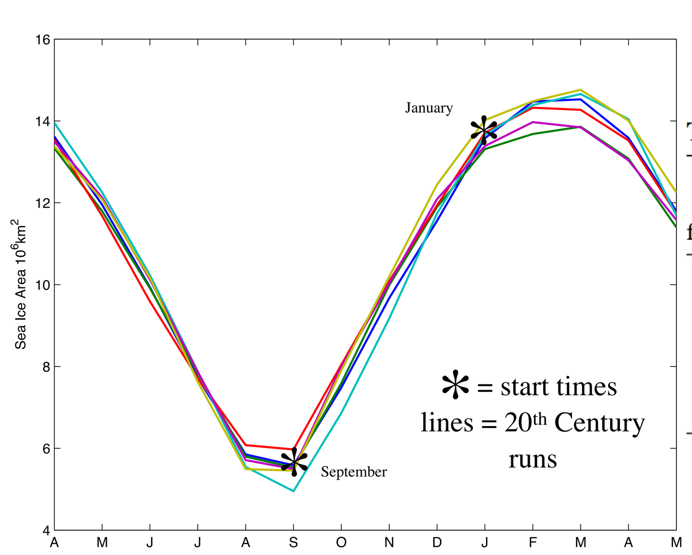


Table 1. Description of Ensembles of Prediction Experiments

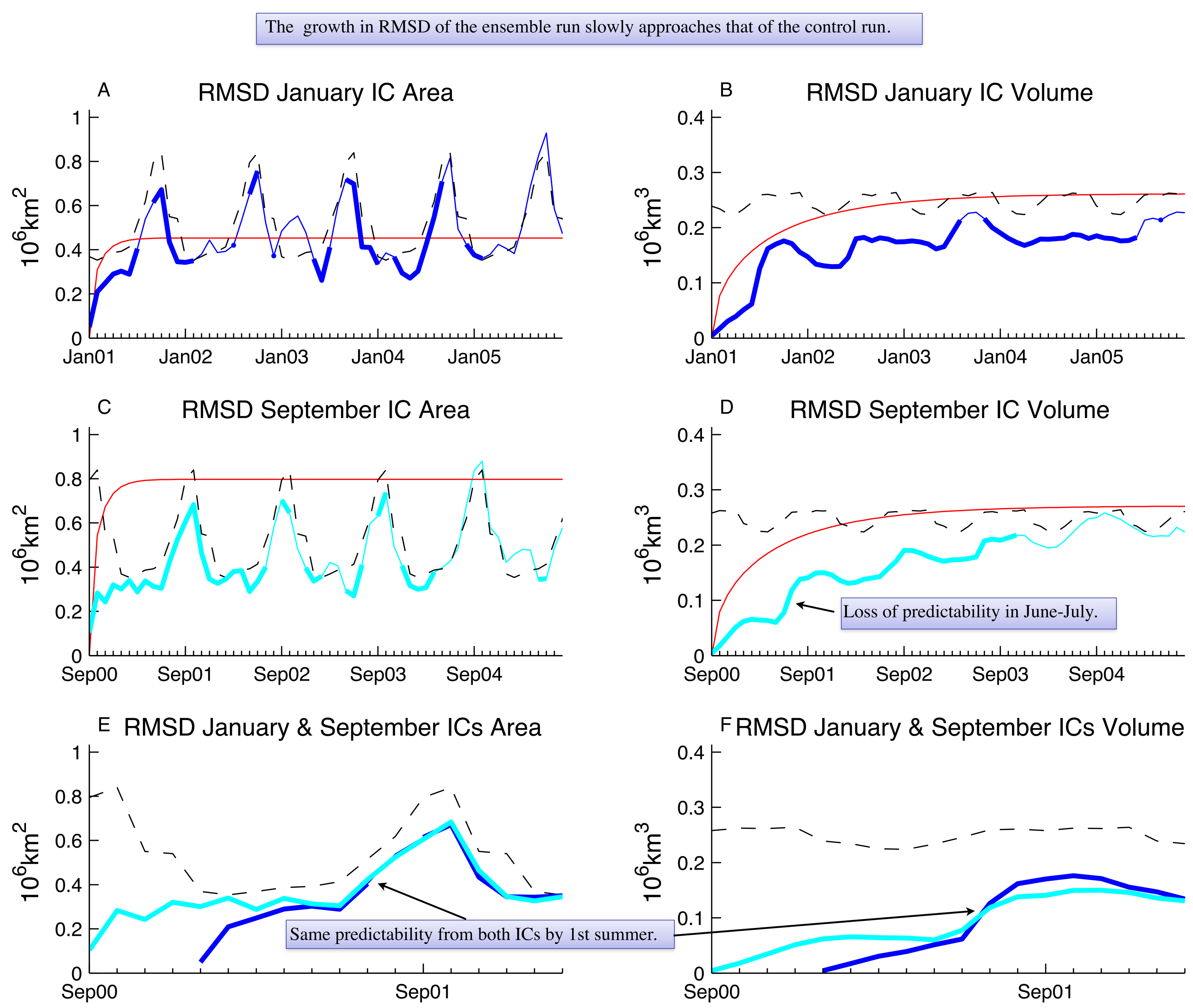
20th Century Run Used for Initialization	Starting Times	Length of Runs	Number of Members
1	Sep 2000, Jan 2001	2 years	20
2	Sep 2000, Jan 2001	5 years	8
3	Sep 2000, Jan 2001	5 years	8
4	Sep 2000, Jan 2001	5 years	8
5	Sep 2000, Jan 2001	5 years	8
6	Sep 2000, Jan 2001	5 years	8

Methods and Results

We use 2 metrics to asses the predictability in the model: The Root Mean Square Deviation (RMSD) and relative entropy. The RMSD assesses the 'spread' component of initial value predictability. An RMSD of zero indicates perfect predictability, and the reference RMSD is the limit above which there is no predictability. (eg Pohlmann et al 2004).

$$RMSD = \sqrt{\frac{1}{N}\sum_{j=1}^{6}\sum_{i=1}^{8,20}\sum_{k\neq 1}(x_{kj}-x_{ij})^2}$$

where x_{ij} is either sea ice area or volume and the indexes j indicates the set, i,k indicates ensemble member, and N the total number of variables in the summation minus 1

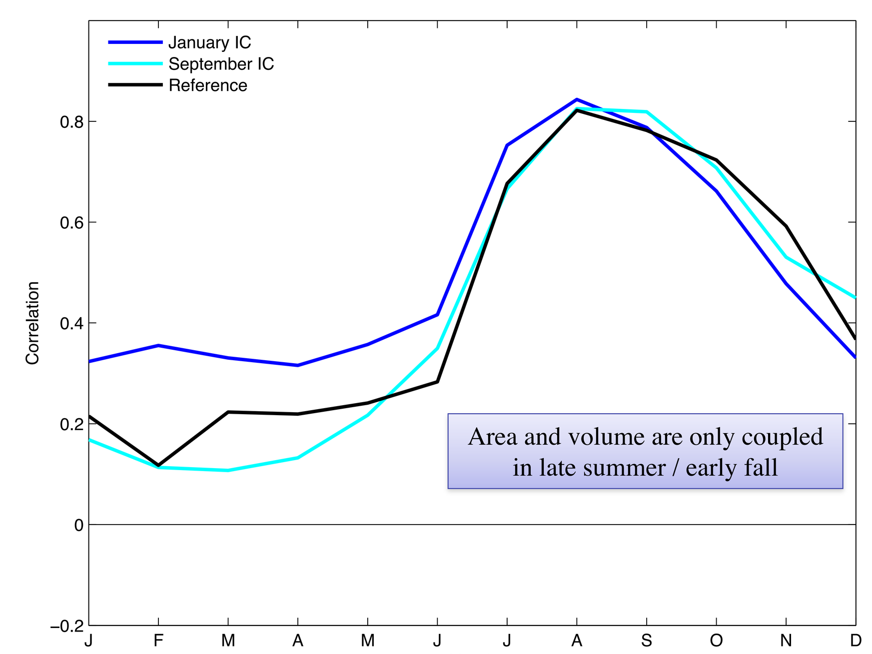


RMSD of Arctic sea ice volume and area for the (a, b) January (dark blue), (c, d) September (light blue), (e, f) January and September EPEs. and reference integration (black dashed). The blue lines are heavy when the RMSD of the ensemble is significantly below the reference RMSD. The red lines are the RMSD of an AR1 model, which provide a measure of the RMSD expected from persistence alone.

•Initial value predictability is lower for area than for volume. Beyond 2 years the RMSD for area is significant only intermittently, with a tendency for significance to recur in some months, notably May–July and September–October of years 3 and 4. After 4 years all initial-value predictability of area is lost. For sea ice volume, the initial-value predictability of each EPE is significant continuously for 3–4 years (Figures 1b and 1d).

•Negligible area predictability in spring followed by reemergence of area predictability in summer- fall (e.g., see Figures 1a and 1c in 2002 and 2003) is a result of coupling between the slowly-varying volume and the generally faster-varying area.

•Rapid loss of predictability of volume in June-July driven by strong positive albedo feedbacks at time of snow cover melt.



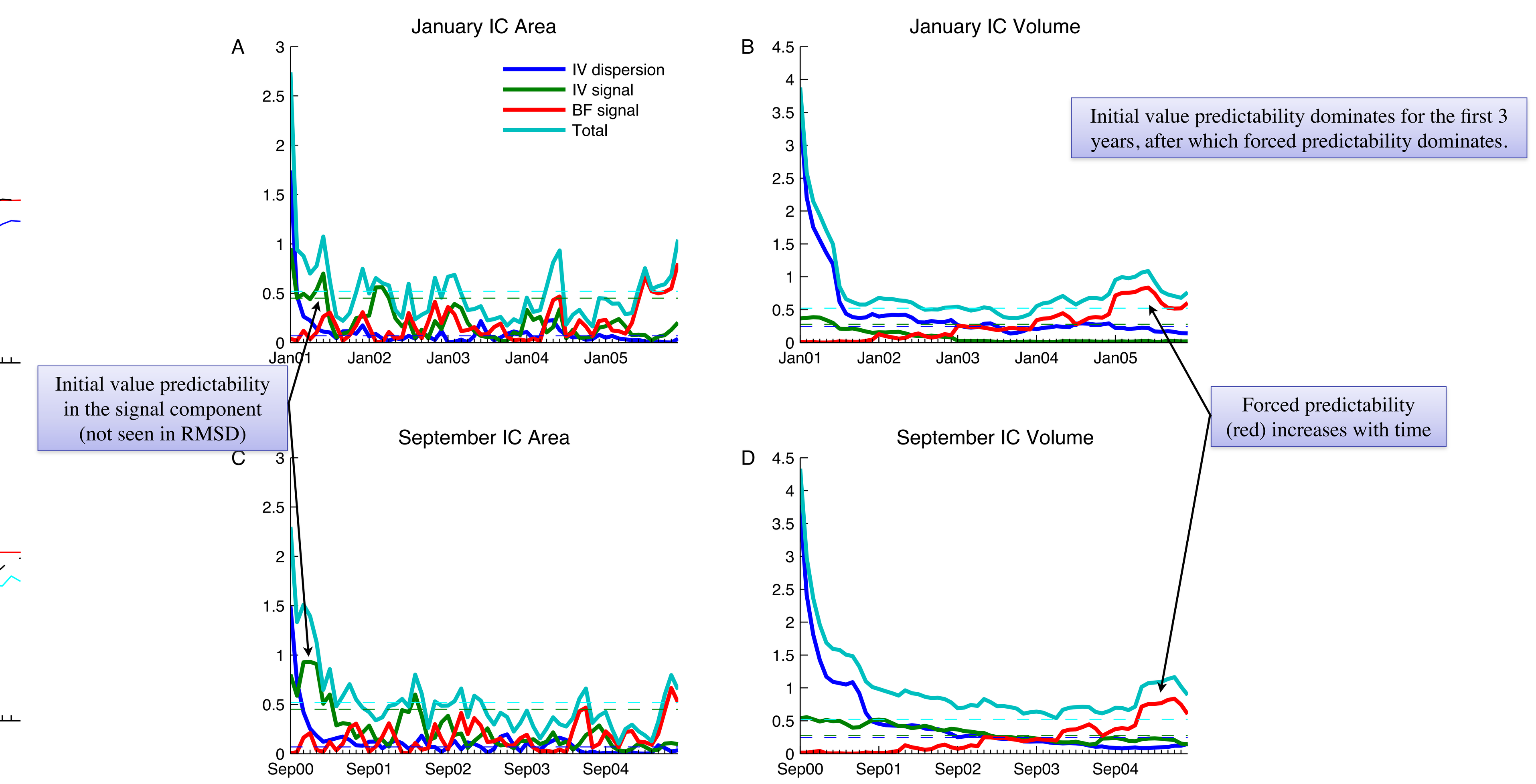
Correlation between area and volume anomalies. Monthly r values for January and September IC EPEs and reference run.

Relative entropy is arguably a more comprehensive measure of predictability, since it takes into account not only how the spread of the predictor compares to the climatological spread, but also how the mean of the predictor compares to the climatological mean (see Kleeman, 2002, and Abramov, Majda, Kleeman, 2005). Relative entropy can assess initial value predictability and forced predictability.

$$RE = \frac{1}{2}\left[\ln\left(\frac{\sigma_c^2}{\sigma_e^2}\right)+\frac{\sigma_e^2}{\sigma_c^2}+\frac{(\mu_e-\mu_c)^2}{\sigma_c^2}-1\right]$$

"Dispersion" "Signal"

where σ_c and σ_e are standard deviations of the reference and experiment, and μ_c and μ_e is the mean of the reference and experiment respectively.



Relative entropy (unit less) of sea ice volume and area for (a, b) January and (c, d) September IC EPEs. The dashed lines represent the 95% null hypothesis rejection levels for dispersion (blue), signal (green) and total (cyan).

Summary

•Initial value predictability in sea ice area is continuous for 1-2 years, considerably longer than the persistence timescale of sea ice area in the Arctic (~2-5 months, Blanchard-Wrigglesworth et al 2010). Prognostic predictability is an improvement over that offered from damped persistence alone.

•While there is longer predictability in total volume owing to its longer timescale, area and volume anomalies are only coupled in late summer/early fall. This makes summer sea ice area predictions from forcing thickness anomalies possible (e.g. see SEARCH Outlook 2011). This coupling is however subsequent to the marked loss in predictability in volume in June/July.

•Beyond the spring of the first year, model predictions are equally good whether initialized in September or January, implying that in practice forecasts of summer sea ice may be made as early as the fall without loss of accuracy compared to winter forecast initialization.

•Using relative entropy, predictability in volume is gained after two years from the forced response. This is due to the strong secular trend. The near agreement between the model and observations (where possible) supports the finding from our model results that at present predictability of the Arctic sea ice system beyond about 3–5 years is principally a boundary-forcing problem. In contrast, predictability for less than 3–5 years is an initial-value problem.

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