Separating climate variability and climate change: How many ensemble members are needed?

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It represents a critical challenge in climate science to separate observed temperature changes into contributions from anthropogenic climate change and atmosphere-ocean internal variability. Traditional approaches rely on computing the average climate response over an ensemble of climate models, but the answer depends on the model(s) used. Here, we use the CESM large ensemble to investigate how many ensemble members are needed to separate the ensemble-mean climate response from modes of atmosphere-ocean internal variability. In particular, we test two statistical methods – low-frequency component analysis (LFCA) and a linear inverse model optimal perturbation filter (LIMopt), which identify the slowest changing components of the climate system – for isolating the surface temperature response to external forcing from sub-ensembles, individual ensemble members, or observations. We find that these statistical methods need only 1-3 ensemble members to identify the ensemble-mean pattern of global warming (depending on the degree of accuracy required). The Pacific Decadal Oscillation (PDO), a predominant pattern of atmosphere-ocean internal variability, can likewise be identified from 1-3 ensemble members. However, higher-order patterns of forced response (e.g., the temperature responses to anthropogenic aerosol forcing and volcanic eruptions) and other patterns of multi-decadal internal variability (e.g. the Atlantic multi-decadal oscillation), can only be accurately separated and identified when 10 or more ensemble members are used. By comparing the statistical estimates of the forced response from individual ensemble members to the true answer, diagnosed from the ensemble mean, we can characterize the uncertainty that would remain when applying this approach to identify the forced component of observed temperature changes. Our results suggest that the predominant pattern of global warming can be identified from individual ensemble members or observations, but they also identify questions for which a large ensemble of climate models is required.