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# The sources of variability and uncertainty in global cirrus clouds

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Although recent research has focused on more accurately representing heterogeneous ice nucleation in climate models, significant uncertainties are still associated with these nucleation spectra. Here we present adjoint techniques as a new, computationally efficient means of helping to minimize these uncertainites. Automatic differentiation tools are used to construct the adjoint model of the 2009 Barahona and Nenes ice nucleation parameterization (ABN13), run in both the Community Atmosphere Model version 5 and the Goddard Earth Observing System Model version 5 at pressure levels relevant to both cirrus and mixed-phase clouds. Ice crystal number sensitivities to dynamic and aerosol inputs are calculated using two empirical spectra (Phillips et al. 2008 and Phillips et al. 2013) and one spectrum based on classical nucleation theory (Barahona and Nenes 2009). At cirrus-relevant altitudes, the sensitivity can be used to classify freezing regime; we see large regions of homogeneous freezing in the tropics but predominantly heterogeneous freezing elsewhere. The more recent empirical spectrum indicates the importance of accumulation mode dust number; of appropriately representating vertical motions; and of accurate threshold supersaturations in determining in-cloud crystal number on a global scale. Glassy aerosol has a small, seasonally-dependent contribution at high altitudes, while the global contribution of black carbon to ice number becomes negligible. Attribution analyses also allows us to pinpoint which variables and regions generate the most variability in ice crystal number, and whether this variability comes from inherent parameterization biases or from input fluctuations.