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ABSTRACT: The primary goal of Earth System Models (ESMs) is to improve understanding and projection of future global change. In order to do this they must accurately represent the huge carbon fluxes associated with the terrestrial carbon cycle. Photosynthetic CO₂ uptake is the largest of these fluxes and is well described by the Farquhar, von Caemmerer and Berry (FvCB) model of photosynthesis. Most ESMs use a derivation of the FvCB model to calculate gross primary productivity (GPP). One of the key parameters required by the FvCB model is an estimate of the maximum rate of carboxylation by the enzyme Rubisco (Vc,max). In ESMs the parameter Vc,max is usually fixed for a given plant functional type (PFT) and often estimated from leaf N content.

An investigation of the source of Vc,max values used in ESMs revealed that despite representing the same PFTs, models were parameterized with a wide range of Vc,max values (-46 to +77% of the PFT mean). Examination of models that linked leaf N content mechanistically to Vc,max identified errors that would collectively decrease Vc,max by 31% in C₃ plants. Only four ESMs currently have an Arctic PFT and the data used to derive Vc,max for the Arctic PFT in these four models relied on small data sets and unjustified assumptions.

As part of a multidisciplinary project to improve the representation of the Arctic in ESMs (Next Generation Ecosystem Experiments - Arctic) we measured leaf N content and the response of photosynthesis (A) to internal CO₂ concentration (cᵢ) in order to determine Vc,max for two sedges (Carex aquatilis, Eriophorum angustifolium), a grass (Dupontia fisheri), a forb (Petasites frigidus) and a shrub (Salix pulchra) growing on the Barrow Environmental Observatory, Barrow, AK. The values of Vc,max currently used to represent Arctic PFTs in ESMs are 67% lower the values we measured in these species. Separate measurements of A made at ambient conditions in Salix pulchra and Petasites frigidus were compared with A modeled using the Vc,max values we measured in Barrow, and those used by the ESMs. The A modeled with the Vc,max values used by the ESMs was 77% lower than the observed A. When our measured Vc,max values were used, modeled A was within 5% of observed A. Examination of the derivation of Vc,max in CLM identified that cause of the relatively low Vc,max value in CLM was the result of underestimating both the leaf N content and the investment of that N in Rubisco.

Here we have identified significant problems with the derivation of Vc,max in ESMs that is relevant in all biomes, and provided new physiological characterization of Arctic species that is mechanistically consistent with observed CO₂ uptake. This new data can be used in future model projections to improve representation of the Arctic landscape in ESMs.