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Positive feedbacks: using simple systems diagrams, the Himalayas, and ice core oxygen isotope data to introduce first-year college students to the complexities of Earth's climate system

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Students are introduced to the concept of system science through a combined lecture and lab module in three parts in the context of Earth's climate system. The first part of the module is an introduction to systems terms and concepts such as components, reservoirs, residence time, couplings, and feedbacks, etc. in lecture, which is then developed and reinforced in Systems Lab #1. Students brainstorm in groups about common CO2 couplings and feedbacks in the Earth system, and construct simple systems diagrams to illustrate those relationships.

The second part of the module builds on the first, and leads students to discover the limitations of simple systems diagrams in the context of the Earth system through time. The rapid exhumation of the syntaxes of the Himalayan orogenic zone is presented in lecture as an example of a geosphere-climate feedback, and the concepts of orographic precipitation, weathering and erosion, and isostatic response are introduced. Systems Lab #2 reinforces these concepts by asking the student to explicitly identify the components of the geosphere-climate feedback loop, their signs, and possible perturbations and/or forcings to the system. Students are asked to consider stability in the system, and hypothesize about how a feedback could change from positive to negative, given time. Experience has shown that introductory-level earth system science students are surprisingly capable of demonstrating an understanding of the role that geologic time and fast-versus-slow geologic processes play in system stability, even though their knowledge base is still fairly limited at this point. The rate of successful completion of Systems Lab #2 is high, and students gain confidence in their ability to grasp complex concepts.

In part three of the module, students process and graph oxygen isotope data from the NOAA National Climate Data Center's Ice Core Gateway website using a spreadsheet program. Background content on oxygen isotope fractionation and preservation in ice cores is presented in lecture prior to the lab. Students plot yearly 18O/16O ratios, decadal averages, and 20 & 30-year averages against time, and are asked to identify periods of relative warming and cooling over the past $\sim$7000 years, and comment on the data processing. The procedure is repeated for several ice cores from around the world, and students are asked to find similarities and/or differences between the oxygen isotope records, and hypothesize about possible reasons for the differences. The abrupt warming beginning in the 19th and 20th centuries is apparent in some data sets, and most students are able to identify the trend and connect it to the CO2 feedbacks that they diagramed in the first lab. This final exercise in the module serves several purposes: it forces students to make decisions about data processing and presentation that geoscientists must make, it reinforces lecture material, and it asks students to recall and attempt to apply what they have already learned about the climate system and feedbacks to explain the recent climate record in different parts of the world.
This three-part climate system module employs simple laboratory exercises to compliment and reinforce lecture material, drawing upon examples of climate system feedbacks through geologic time, as well as real ice core oxygen isotope data, to lead introductory earth systems students to a basic understanding of systems science in the context of Earth's climate system.