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Climate, volcanism and human impact on Iceland's landscape during the last two millennia.

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Biogeochemical proxy records from Icelandic lake sediment reflect large-scale shifts in North Atlantic Holocene climate and highlight the impact that North Atlantic Ocean- and atmospheric circulation has on Iceland's local climate. Following Early Holocene warmth, millennial-scale cooling has been modulated by centennial-scale climate change, culminating in the transition to the Little Ice Age (ca. 1300-1900 CE). Although the long-term cooling trend is presumably driven by variations in Earth's orbit and the concomitant decline in Northern Hemisphere summer insolation, the centennial-scale variability has been linked to variations in solar irradiance, the strength of the Atlantic Meridional Overturning Circulation, volcanism coupled with sea ice/ocean related feedbacks and internal modes of atmospheric variability. One manifestation of these regional climate changes on Iceland is the intensification of soil erosion, resulting in the degradation of its eco-systems and landscape. In recent millennia, persistent and severe soil erosion has also been linked to human impact on the environment following the settlement ~874 CE, rapid population growth and the poorly consolidated nature of tephra dominated soils. However, against the argument that the onset of severe soil erosion coincided with human settlement are composite landscape stability proxies extracted from the high-resolution, precisely-dated lake sediment cores. These data suggest event-dominated landscape instability and soil erosion began in the Middle to Late Holocene with an intensification of landscape instability around ~500 CE, several centuries before the acknowledged settlement of Iceland, after which soil erosion continue to increase. In order to statistically identify abrupt and persistent changes within our landscape stability proxy records, we performed an analysis that targets mean regime shifts in individual time series. The first clear regime shift occurred around ~500 CE, with a second large shift ~1200 CE. In order to provide a causal explanation for these regime shifts, we looked to a new 2 ka fully coupled climate transient simulation using CESM1, with forcing data from PMIP4, including insolation, volcanic aerosols, land-cover, and GHG. The CESM results show a ~0.5°C reduction in summer temperature in the first millennium CE, consistent with increased landscape instability and soil erosion in Iceland. A second phase of persistent summer cooling in the model occurs after 1150 CE, with stronger cooling after 1450 CE, reaching a minimum shortly after 1850 CE, ~1°C lower than at the start of the experiment. Orbitally driven declines in summer insolation

appear to be the dominant forcing early in the first millennium CE, with volcanism and solar irradiance reductions increasingly important after 500 CE and in the second millennium CE, but positive feedbacks from sea ice and the overturning circulation are necessary to explain the magnitude of peak LIA cooling when soil erosion is at its greatest in Iceland. Collectively, our initial results suggest that natural variations in regional climate and volcanism are likely responsible for soil erosion prior to human impact, with intensification of these processes following settlement particularly during the cooling associated with the Little Ice Age.