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Abrupt transitions to a cold North Atlantic in the late Holocene

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The Holocene provides a time interval with boundary conditions similar to present, except for greenhouse gas concentrations. Recent high-resolution Northern Hemisphere records show general cooling related to orbital terms through the late Holocene, but also highly non-linear abrupt departures of centennial scale summer cold periods. These abrupt departures are evident within the last two millennia (the transitions between the Roman Warm Period (RWP, ∼2,000 yr BP), the Dark Ages Cold Period (DACP, ∼500-900 years AD), the Medieval Warm Period (MWP, 1000-1200 years AD) and the Little Ice Age (LIA, ∼1300-1900 AD). A series of new, high-resolution and securely dated lake records from Iceland also show abrupt climate departures over the past 2 ka, characterized by shifts to persistent cold summers and an expanded cryosphere. Despite substantial differences in catchment-specific processes that dominate the lake records, the multi-proxy reconstructions are remarkably similar. After nearly a millennium with little evidence of significant climate shifts, the beginning of the first millennium AD is characterized by renewed summer cooling that leads to an expanding cryosphere. Slow summer cooling over the first five centuries is succeeded by widespread substantial cooling, with evidence for substantial expansion of glaciers and ice caps throughout our field areas between 530 and 900 AD, and an accompanying reduction in vegetation cover across much of Iceland that led to widespread landscape instability. These data suggest that the North Atlantic system began a transition into a new cold state early in the first millennium AD, which was amplified after 500 AD, until it was interrupted by warmer Medieval times between ∼1000 and 1250 AD. Although severe soil erosion in Iceland is frequently associated with human settlement dated to 871 ±2 AD our reconstructions indicate that soil erosion began several centuries before settlement, during the DACP, whereas for several centuries after settlement during the warmer Medieval times, there was little or no soil erosion. During the transition into the Little Ice Age (LIA), between 1250 and 1300 AD, soil erosion and landscape instability returned. A more severe drop in summer temperatures followed this initial LIA summer cooling, culminating between 1500 and 1900 AD. The Icelandic lake records compare favorably to paleo-environmental records from the North Atlantic such as the sea-ice reconstruction North of Iceland and ice-cap expansion dates based on a composite of Arctic Canada calibrated 14C dates on tundra plants emerging from beneath receding ice caps. Global modeling experiments suggest that changes in sea ice extent and duration provides one of the strongest feedbacks that may explain both the magnitude of the change and the abrupt nature of summer-cold departures over this time. An expansion of Arctic Ocean sea ice and its export into the North Atlantic subpolar gyre could have been a major amplifier of abrupt summertime cooling and a mechanism to explain persistent cold summers during the LIA in the northern North Atlantic.