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Research article

Post-1980 shifts in the sensitivity of boreal tree growth to North Atlantic Ocean dynamics and seasonal climate

Tree growth responses to North Atlantic Ocean dynamics

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ABSTRACT

The mid-20th century changes in North Atlantic Ocean dynamics, e.g. slow-down of the Atlantic meridional overturning thermohaline circulation (AMOC), have been considered as early signs of tipping points in the Earth climate system. We hypothesized that these changes have significantly altered boreal forest growth dynamics in northeastern North America (NA) and northern Europe (NE), two areas geographically adjacent to the North Atlantic Ocean. To test our hypothesis, we investigated tree growth responses to seasonal large-scale oceanic and atmospheric indices (the AMOC, North Atlantic Oscillation (NAO), and Arctic Oscillation (AO)) and climate (temperature and precipitation) from 1950 onwards, both at the regional and local levels. We developed a network of 6876 black spruce (NA) and 14437 Norway spruce (NE) tree-ring width series, extracted from forest inventory databases. Analyses revealed post-1980 shifts from insignificant to significant tree growth responses to summer oceanic and atmospheric dynamics both in NA (negative responses to NAO and AO indices) and NE (positive response to NAO and AMOC indices). The strength and sign of these responses varied, however, through space with stronger responses in western and central boreal Quebec and in central and northern boreal Sweden, and across scales with stronger responses at the regional level than at the local level. Emerging post-1980 associations with North Atlantic Ocean dynamics synchronized with stronger tree growth responses to local seasonal climate, particularly to winter temperatures. Our results suggest that ongoing and future anomalies in oceanic and atmospheric dynamics may impact forest growth and carbon sequestration to a greater extent than previously thought. Cross-scale differences in responses to North Atlantic Ocean dynamics highlight complex interplays in the effects of local climate and ocean-atmosphere dynamics on tree growth processes and advocate for the use of different spatial scales in climate-growth research to better understand factors controlling tree growth.

1. Introduction

Terrestrial biomes on both sides of the North Atlantic Ocean are strongly influenced by Arctic and Atlantic oceanic and atmospheric dynamics (D'Arrigo et al., 1993; Ottersen et al., 2001; Girardin et al., 2014). Some mid-20th century changes in the dynamics of the North Atlantic Ocean have been considered as early signs of tipping points in the Earth climate system (Lenton et al., 2008; Lenton, 2011). The Atlantic Meridional Overturning Circulation (AMOC) exhibited an exceptional slow-down in the 1970s (Rahmstorf et al., 2015). The cause of this slow-down is still under debate, but possible explanations include the weakening of the vertical structure of surface waters through the discharge of low-salinity fresh water into the North Atlantic Ocean, due to the disintegration of the Greenland ice sheet and the melting of Canadian Arctic glaciers. A further weakening of the AMOC may possibly lead to a wide-spread cooling and decrease in precipitation in the

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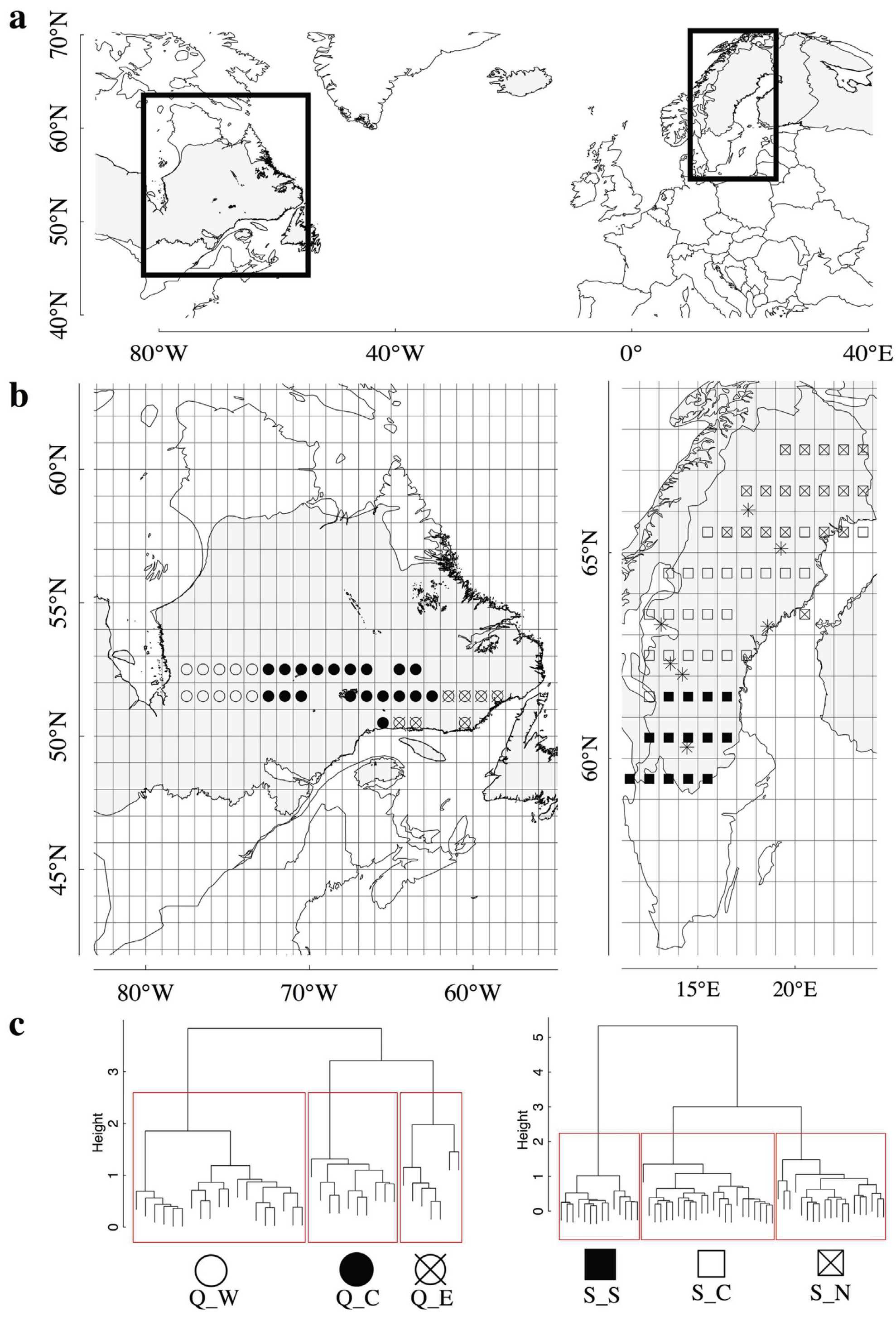

Fig. 1. a: Location of the two study areas (black frame); b & c: Clusters identified in each study area by ordination of 1° × 1° latitude-longitude grid cell chronologies. Ordination analyses were performed over the common period between grid cell chronologies in each study area using Euclidean dissimilarities matrices and Ward agglomeration methods. The common period was 1885–2006 for Quebec and 1936–1995 for Sweden. Ordinations included 36 and 56 grid cell chronologies in Quebec and Sweden, respectively. A western (Q_W), central (Q_C) and eastern (Q_E) cluster were identified in Quebec and a southern (S_S), central (S_C) and northern (S_N) cluster were identified in Sweden. Reference chronologies from the ITRDB used for the cross-dating of plot chronologies in Sweden are indicated with a ⋇ (swed011, swed012, swed013, swed014, swed015, swed017 and swed312). The grey shading indicates the boreal zone delimitation according to Brant et al., 2013

North Atlantic region (Sgubin et al., 2017), subsequently lowering the productivity of land vegetation both over northeastern North America and northern Europe (Zickfeld et al., 2008; Jackson et al., 2015). Despite increasing research efforts in monitoring climate-change impacts on ecosystems, effects of late 20th century changes in North Atlantic Ocean dynamics on mid- to high-latitude terrestrial ecosystems remain poorly understood.

The dynamics of North Atlantic oceanic and atmospheric circulation, as measured through the AMOC, North Atlantic Oscillation (NAO) and Arctic Oscillation (AO) indices, strongly influence climate variability in northeastern North America (NA) and northern Europe (NE) (Hurrell, 1995; Baldwin and Dunkerton, 1999; Wettstein and Mearns, 2002). NAO and AO indices integrate differences in sea-level pressure between the Iceland Low and the Azores High (Walker, 1924), with high indices representative of increased west-east air circulation over the North Atlantic. Variability in AMOC, NAO and AO indices affects climate dynamics, both in terms of temperatures and precipitation regimes. Periods of high winter NAO and AO indices are associated with below-average temperatures and more sea ice in NA and a warmer- and wetter-than-average climate in NE. Periods of low winter NAO and AO indices are, in turn, associated with above-average temperatures and less sea ice in NA and a colder- and dryer-than-average climate in NE (Wallace and Gutzler, 1981; Chen and Hellström, 1999). Low AMOC indices induce a wide-spread cooling and decrease of precipitation

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