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Association between recent U.S. northeast precipitation trends and Greenland blocking

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Abstract
Since the early 2000s, the northeastern region of the United States (USNE) has received increased total annual precipitation along with more frequent extreme precipitation events. Although previous work has discussed the contribution to increased extreme precipitation from tropical cyclones, the large-scale driver(s) of summer precipitation increases in the extratropics has received little attention. Here, we show that the summer-season rainfall surpluses across the USNE are related to the increased frequency of atmospheric blocking over Greenland and the negative phase of the North Atlantic Oscillation. The occurrence of these patterns in summer has been previously connected with southward shifted storm tracks and wet conditions across the eastern North Atlantic. Over the USNE, the circulation shifts are also related to enhanced rainfall due to southerly wind anomalies and increased moisture transport into and vertical motion over the region. It is important to note that the current generation of climate models used for future projections is unable to reproduce the observed tendency towards increased atmospheric blocking over Greenland. Thus, clarifying the association between Greenland blocking and recent precipitation changes across the USNE may help inform future climate projections of summer season rainfall for the region.

KEYWORDS
extratropical cyclones, fronts, Greenland blocking, summer precipitation

1 | INTRODUCTION

A growing body of literature identifies a trend of increasing annual precipitation over the past 100 years across the northeastern United States (USNE; Griffiths and Bradley, 2007; Brown *et al.*, 2010; Kunkel *et al.*, 2013a; Frei *et al.*, 2015; Easterling *et al.*, 2017; Huang *et al.*, 2017). The most pronounced increase has occurred over the past 20 years, with the rise in total annual precipitation driven in large part by significant seasonal increases in summer and fall (Huang *et al.*, 2017). Extreme events, typically defined as the heaviest 1% of wet days, have also become more frequent and intense across the USNE (Frei *et al.*, 2015; Collow *et al.*, 2016; Hoerling *et al.*, 2016; Huang *et al.*, 2017; 2018; Howarth *et al.*, 2019), where extreme precipitation has increased at a higher rate than any other region in the United States (Kunkel *et al.*, 2013b; Easterling *et al.*, 2017).

It is generally thought that the recent increase in extreme precipitation is related to increased hurricane activity associated with the mid-1990s abrupt shift to positive sea surface temperature anomalies across the North

Atlantic (Landsea *et al*., 1999; Enfield *et al*., 2001; Goldenberg *et al*., 2001; Huang *et al*., 2021). Rainfall events associated with tropical moisture sources, and land-falling hurricanes and tropical storms, account for 48% of the increase in annual extreme precipitation since 1996 (Huang *et al*., 2018). Tropical cyclones are responsible for many of the heaviest precipitation events (Barlow, 2011; Howarth *et al*., 2019); however, only 19% of extreme events from 1979 to 2008 were associated with tropical cyclones (Agel *et al*., 2015).

The most frequent cause of extreme precipitation annually in the USNE is extratropical cyclone activity and its associated fronts (Dowdy and Catto, 2017). In the past quarter century, substantial increases in these precipitation events have occurred in early summer and late winter, with 25% of the post-1996 extreme precipitation increase attributed to frontal activity in June and July (Huang *et al*., 2018). Although a causal mechanism for the upsurge in early summer extreme precipitation was not specified, the authors noted an associated increase in southerly upper-level winds over the USNE region and northerly winds in the Midwest during this period, consistent with the concomitant weakening of zonal winds and the increased jet stream "waviness" (i.e., higher amplitude tropospheric wave patterns) indicated in other studies (Francis and Vavrus, 2012; 2015; Vavrus *et al*., 2017). In summer, low-level and mid-level southerly or southwesterly flow promotes greater moisture flux from the Gulf of Mexico and the Atlantic, resulting in heavy rainfall in the USNE (Girardin *et al*., 2006; Thibeault and Seth, 2014; Collow *et al*., 2016; Agel *et al*., 2018; 2019). In contrast, abnormally dry summers are associated with either a more northward-displaced polar jet stream (Klein, 1952) or northerly surface flow accompanying ridging to the west (Namias, 1966; 1983; Leathers *et al*., 2000; Seager *et al*., 2012), resulting in a reduction in the flow of moisture from the Gulf of Mexico and Atlantic into the USNE.

Although not previously discussed in the literature for the USNE, there are indications that broader circulation changes in the North Atlantic could be related to recent precipitation increases. Previous work has shown that since the 1990s there has been an increasing summertime trend in the Greenland Blocking Index (GBI), a measure of the frequency of high-latitude atmospheric blocking over the North Atlantic basin (Hanna *et al*., 2015; 2016; 2018a; 2018b). This upward GBI trend appears to be linked to slower zonal flow and greater meridionality of the North Atlantic jet stream (Francis and Vavrus, 2012; 2015; Overland *et al*., 2012; 2015; 2021). As in other instances of high-latitude blocking, Greenland blocking events are more likely to divert the prevailing westerly flow equatorward rather than completely block it (Woollings *et al*., 2008). The resulting southward diversion of the North Atlantic polar jet tends to accompany the negative phase of the North Atlantic Oscillation (NAO) index (Woollings *et al*., 2010; Overland *et al*., 2012; Hanna *et al*., 2015). The NAO represents fluctuations in the strength of the surface westerlies across the North Atlantic in response to pressure anomalies across the basin; specifically, the Azores High and Icelandic Low. Previous studies have linked a series of wet summers from 2007 to 2012 in the British Isles and northern Europe to the equatorward shift of storm tracks over the North Atlantic associated with a positive GBI and negative NAO (Blackburn *et al*., 2008; Folland *et al*., 2009; Hanna *et al*., 2015; 2016). Additionally, enhanced surface melting on the Greenland Ice Sheet is associated with high GBI index events, where increased southerly flow associated with blocking results in greater transport of subtropical air masses into the region and high-pressure anomalies over Greenland promote sunny and dry conditions (Hanna *et al*., 2013; 2014; Rowley *et al*., 2020; Tedesco and Fettweis, 2020).

Identifying mechanisms that contribute to the USNE summertime precipitation surplus will help to clarify the deficiencies of climate projections for the USNE. At present, climate models are unable to skilfully replicate the seasonal cycle and observed historical trends in precipitation across the USNE (Rawlins *et al*., 2012; Thibeault and Seth, 2014; 2015; Lynch *et al*., 2016). Current climate projections reflect a continuation of modelled historical precipitation trends—positive trends in winter and spring, conflicting with the observed positive trends for the fall and annual average—as well as a phase shift in the seasonal distribution of precipitation, with more annual rainfall occurring during the cold season (November–April) and less during the warm season (May–October) (Lynch *et al*., 2016). The summer-season contribution to the future annual precipitation signal remains unclear due to differences in the representation of the North Atlantic subtropical anticyclone and associated large-scale circulation patterns in the current generation of climate models (Lynch *et al*., 2016; Easterling *et al*., 2017; Karmalkar *et al*., 2019).

This study is motivated by two fundamental research questions: (a) what changes in the large-scale circulation are associated with the recent increase in summer rainfall across the USNE and (b) to what extent are these identified changes associated with an increased frequency of Greenland blocking? In our analysis (described in section 2), we highlight upper-tropospheric regional and large-scale atmospheric circulation features, as well as low-level and mid-level moisture transport, associated with enhanced summertime precipitation in the USNE. To examine the association of these anomalous circulations with Greenland blocking, we also compare circulation features present in recent years and during summers with high GBI values (section 3.1). We discuss the mechanisms for increased summer precipitation associated with high-pressure blocking over Greenland, how those mechanisms may differ across the North Atlantic basin (section 3.2) and the implications of the results of this study (section 4).

2 | DATA AND METHODOLOGY

2.1 | Datasets

This study utilizes reanalysis and observational datasets, each covering the period 1950–2020 for the months of June, July, and August (JJA). Seasonal average precipitation data for the USNE (defined here as the states of Connecticut, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont) are from the U.S. Climate Divisional Database (CDD; Vose *et al.*, 2014) and obtained from NOAA Climate at a Glance (NOAA, 2021). The CDD is a 5 km gridded dataset based on station data from the Global Historical Climatological Network-Daily dataset (GHCN-D) and other supplemental data sources to improve coverage in western states (Remote Automatic Weather Station [RAWS] and Snow Telemetry [SNOTEL] networks) and along international boarders (Environment Canada [EC] and Mexico's Servicio Meteorologico Nacional [SMN] networks). Precipitation anomalies are defined using the 1950–2020 average as a baseline. Reanalysis fields of sea-level pressure (SLP), 500 hPa geopotential height (GPH), *u*- and *v*-wind components (850, 500, and 250 hPa), 500 hPa vertical velocity (omega), total column water vapour (precipitable water), specific humidity, and precipitation are from the ECMWF Reanalysis version 5 (ERA5; Hersbach *et al.*, 2020), which were obtained from the Copernicus Climate Change Service (Copernicus Climate Change Service, 2017). ERA5 is a fifth-generation global reanalysis product with a horizontal grid cell resolution of $0.25 \times 0.25°$ ($\sim 31 \times 31$ km) and 137 vertical levels from the surface to a height of 80 km. The ERA5 data are used to compute the GBI, defined as the mean 500 hPa geopotential height averaged for the sector 60°–80°N, 20°–80°W (Fang, 2004; Woollings *et al.*, 2010; Hanna *et al.*, 2013; 2014; 2015). Low-level (850 hPa) and mid-level (500 hPa) moisture transport is calculated using the formula:

$$\vec{Q} = q\vec{V}_h,$$

where q is specific humidity and V is the horizontal wind vector. Seasonal values of the NAO index, defined as the leading empirical orthogonal function (EOF) of sea-level pressure anomalies over 20°–80°N, 90°–40°E and calculated from the NCAR Sea Level Pressure dataset (Hurrell *et al.*, 2020), are obtained via the NCAR Climate Data Guide (NCAR, 2021).

2.2 | Methodological approach

Our analysis compares regional precipitation and large-scale circulation over the period 1950–2020, focusing on circulation changes following the USNE summer precipitation changepoint in 2002 identified by Huang *et al.* (2017) and during a noted wet period in the region (e.g., Fernandez *et al.*, 2015; 2020; Birkel and Mayewski, 2018). In this study, two analysis techniques are utilized. First, a linear trend analysis of the USNE precipitation anomaly, GBI, and NAO for the full period of study (1950–2020) and separately the periods prior to and following the 2002 changepoint. Second, an analysis of changes in atmospheric circulation between 1950–2002 and 2003–2020 by subtracting the composites of atmospheric variables for the two time periods. The composite difference maps shown here were generated using the University of Maine Climate Change Institute's Climate Reanalyzer (https://climatereanalyzer.org/). Statistical significance of the difference in composite mean values is assessed at the 95% level using a 2-tailed Student's t test.

3 | RESULTS AND DISCUSSION

3.1 | Key findings

A comparison of the JJA USNE precipitation anomaly, GBI, and NAO index for the period 1950–2020 is shown in Figure 1. For the full period, there is a statistically significant ($p < .05$) positive trend for USNE precipitation and the GBI, and a negative but not statistically significant trend in the NAO. However, there is not a statistically significant correlation between USNE precipitation and either the GBI or NAO indexes ($r = .01$ and $r = .02$, respectively) for the full period. In addition, for the period 1950–2002, no statistically significant trends are identified in either USNE precipitation or the GBI, indicating the influence of recent changes on the statistically significant trends shown in Figure 1 for the full analysis period. There is a period of especially wet summers and fewer, less intense dry spells in the USNE corresponding to a prolonged period of notably higher GBI years and lower NAO values, which are particularly pronounced from 2007 to 2013. Similarly, our results show that the

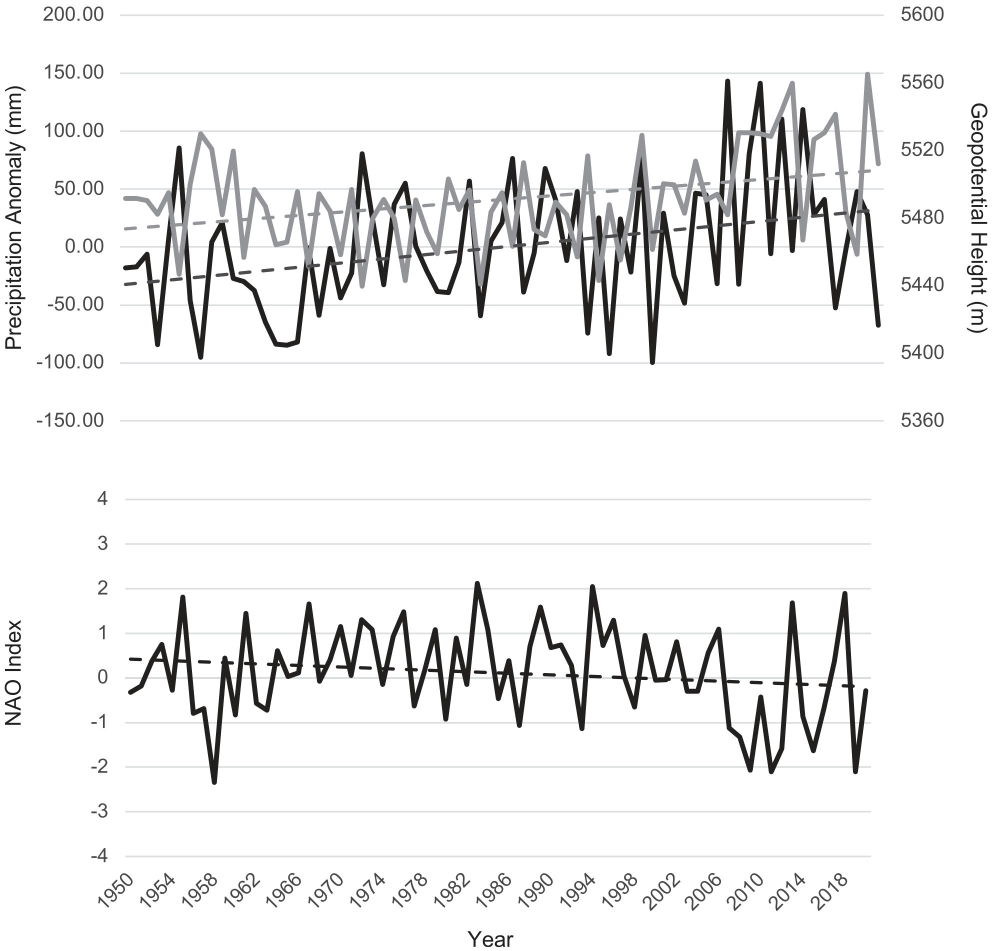

FIGURE 1 Precipitation anomaly (based on 1950–2020 mean, in millimetres) for the USNE (top, black), GBI values in meters (top, in grey), and NAO principal component index (bottom) for JJA. Linear trends are indicated by the dashed lines. The precipitation and GBI trends for the period 1950–2020 are statistically significant ($p < .05$), the NAO trend is not statistically significant, and the correlation between the GBI and NAO is −0.88

NAO index was only below −1.25 once between 1950 and 2002, but six times (2008, 2009, 2011, 2012, 2015, 2019) since 2003. During these 6 years, the JJA GBI was above the 1950–2020 mean (i.e., positive anomaly) and the USNE summer precipitation anomaly was positive, except in 2012.

To investigate the circulation patterns associated with the recent wet summers of 2003–2020 in the USNE, Figure 2 shows the difference in composite fields of several meteorological variables from the ECMWF ERA5 reanalysis between the recent wet period of 2003–2020 and the preceding period 1950–2002. In Figure 2a, a low–high–low SLP difference pattern appears over the North Atlantic, with relative low-pressure centres over the eastern United States and United Kingdom and high pressure over Greenland. This pattern corresponds with statistically significant 500 hPa height differences over Greenland and northeastern Canada (Figure 2b). At 250 hPa, there are statistically significant negative zonal wind differences across the North Atlantic to south of Iceland, with negative values also seen across eastern Canada and the USNE (Figure 2c). Statistically significant, positive zonal wind differences at 250 hPa (i.e., enhanced jet stream) are seen in a broad region extending from the central to the eastern North Atlantic, with positive differences (although not significant) to the south of the USNE. A tripole pattern in 250 hPa meridional wind differences is observed across the North Atlantic (Figure 2d), featuring positive values over the USNE and western Europe and negative values extending into southern Greenland. Figure 2e,f show differences in horizontal moisture transport (vector magnitude) at 850 and 500 hPa, which are similar to the differences in 250 hPa zonal winds. Statistically significant increases in moisture transport at 850 and 500 hPa are indicated in a band that extends across the North Atlantic. Over the USNE, there are statistically significant areas of increasing and decreasing moisture transport at 850 hPa and increasing moisture transport at 500 hPa. Increased precipitation over the eastern North Atlantic (Figure 2g) is associated with increased moisture transport (Figure 2e,f) corresponding with positive zonal and meridional wind differences over the region, while increased precipitation over the western North Atlantic and USNE accompanies increased moisture transport associated mainly with positive meridional wind differences.

To explore the disparity in low- and mid-level moisture transport between the eastern and western North

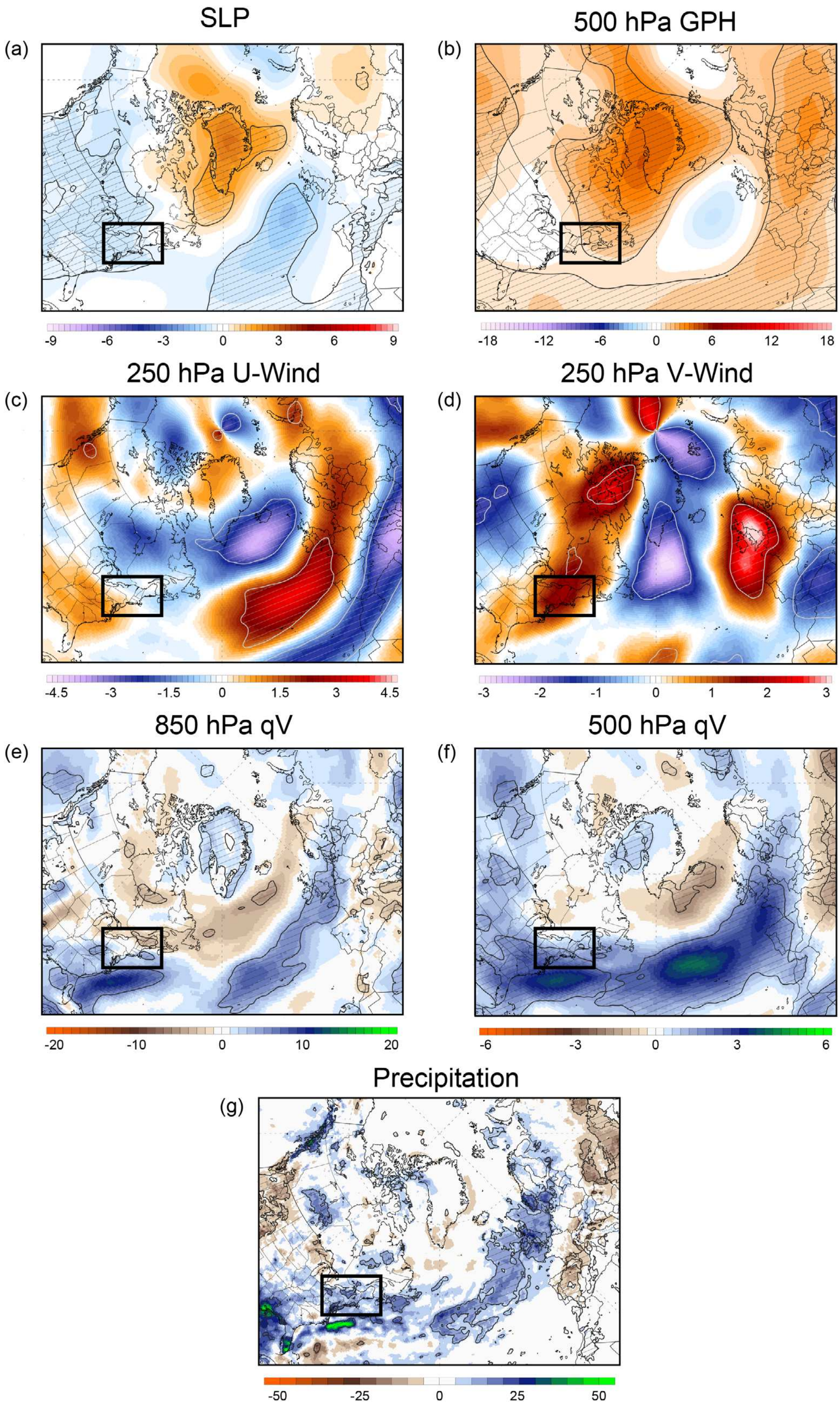

FIGURE 2 Reanalysis composite difference fields (2003–2020 mean minus 1950–2002 mean) of (a) mean SLP (hPa), (b) 500 hPa GPH (m), (c) 250 hPa *u*-winds ($m \cdot s^{-1}$) and (d) 250 hPa *v*-winds ($m \cdot s^{-1}$), (e) 850 hPa moisture transport (vector magnitude, $kg \cdot m \cdot s^{-1}$) and (f) 500 hPa moisture transport (vector magnitude, $kg \cdot m \cdot s^{-1}$), and (g) precipitation (% change) for JJA. The USNE region is outlined in black and hatching indicates statistically significant anomalies at the 95% level. Maps generated using the Climate Reanalyzer and the ECMWF ERA5 reanalysis (Hersbach *et al*., 2020)

Atlantic, we considered differences in the zonal and meridional components of moisture transport, as well as the importance of dynamical factors, notably the 500-hPa vertical motion (omega). The decreases in moisture transport at 850 hPa over parts of the USNE are associated with corresponding decreases in zonal moisture transport

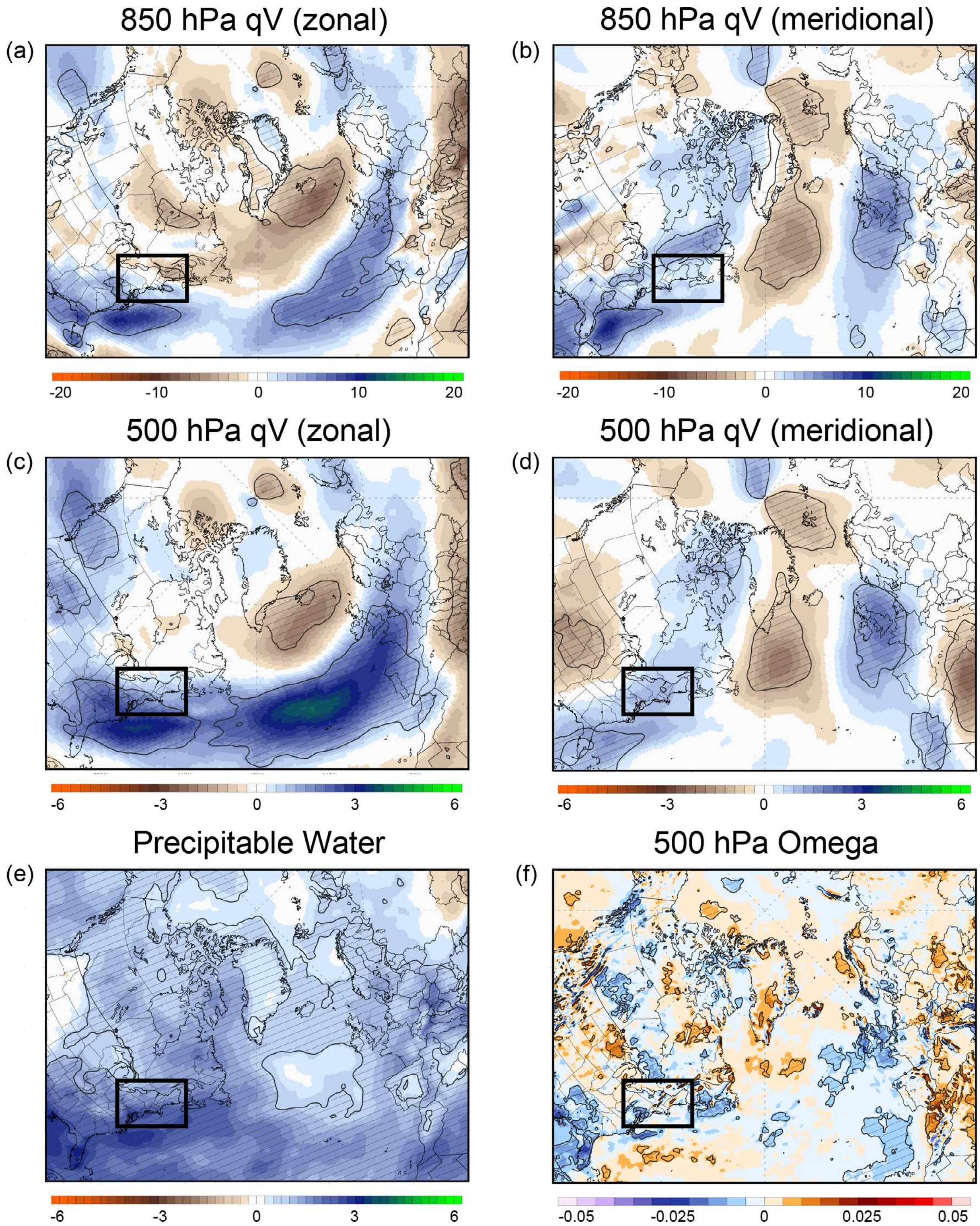

FIGURE 3 Reanalysis composite difference fields as in Figure 2 of (a) 850 hPa moisture transport (u-component magnitude, kg·m·s^{-1}), (b) 850 hPa moisture transport (v-component magnitude, kg·m·s^{-1}), (c) 500 hPa moisture transport (u-component magnitude, kg·m·s^{-1}), (d) 850 hPa moisture transport (v-component magnitude, kg·m·s^{-1}), (e) total column water vapour (kg·m^{-2}), and (f) 500 hPa vertical velocity (Pa·s^{-1})

(Figure 3a) despite increases in meridional moisture transport (Figure 3b), while both components are positive over the eastern North Atlantic. At 500 hPa, the zonal and meridional components of moisture transport are positive over the eastern and western North Atlantic (Figure 3c,d). Statistically significant increases in precipitable water over much of the domain (Figure 3e), including the USNE and western North Atlantic, indicate greater moisture availability likely a result of increasing temperatures among other possible factors. Additionally, Figure 3f shows generally increased upward vertical motion (negative values) in the recent period over much of the USNE as well as the eastern North Atlantic. Reduced low-level convergence and accompanying vertical motion over the USNE than over the opposite side of the North Atlantic, even with plentiful moisture available, would result in lesser precipitation increases when compared to increased convergence (implied by the positive differences for both u- and v-wind components) over the eastern North Atlantic.

Figure 4 shows the difference in composite fields for atmospheric variables during summers with high GBI values (2007–2012, 2014–2016, 2019). The precipitation increases during the high GBI summers (Figure 4a),

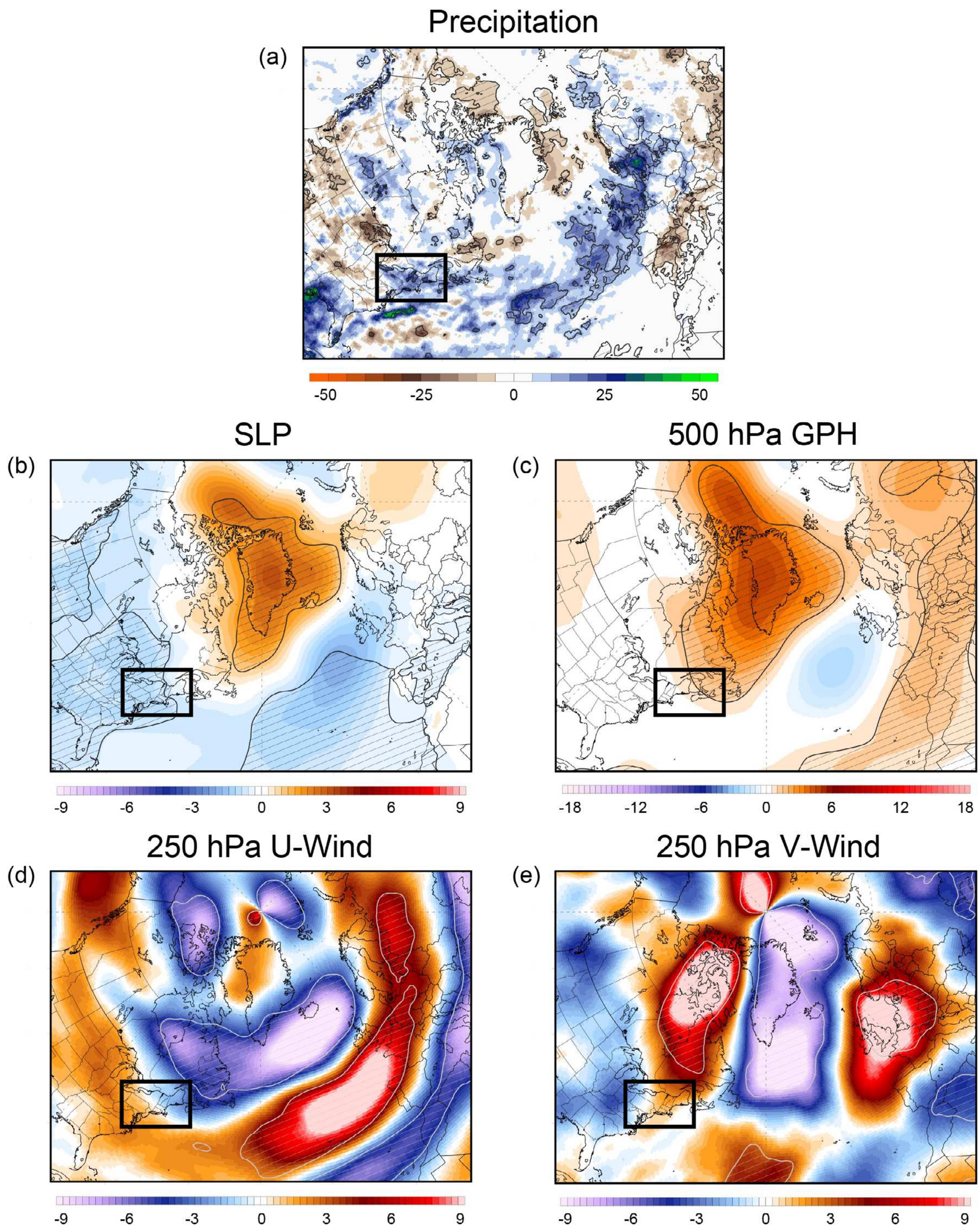

FIGURE 4 Reanalysis composite difference fields (mean of high GBI years [2007–2012, 2014–2016, 2019] minus 1950–2002 mean) of (a) precipitation (% change), (b) mean SLP (hPa), (c) 500 hPa GPH (m), (d) 250 hPa *u*-winds ($m{\cdot}s^{-1}$), and (e) 250 hPa *v*-winds ($m{\cdot}s^{-1}$) for JJA. The USNE region is outlined in black and stippling indicates statistically significant anomalies at the 95% level

including across the USNE, is a substantial part of what is driving the increases shown during the recent wet period as a whole (Figure 2g). The changes in circulation during these years imply that the reduced zonal moisture transport over the northern section of the domain (Figure 3a) is likely the result of anomalous easterly moisture flux off the North Atlantic, while climatologically the moisture flux (not shown) is westerly. The north–south gradient in SLP differences, with significant decreases to the east of the USNE and increases to the north (Figure 4b), gives rise to easterly flow at low levels. Additionally, the circulation features present during the high GBI summers are markedly similar to those for the recent period, notably the positive 500 hPa GPH differences over Greenland (Figures 2b and 4c), the negative and positive zonal wind differences south of Iceland (Figures 2c and 4d), and the tripole pattern of positive and negative meridional wind differences (Figures 2d and 4e). Overall, the composites indicate that the circulation shifts for the recent period shown in Figure 2 are largely driven by changes during summers with more frequent and intense Greenland blocking events (i.e., high GBI).

3.2 | USNE impacts from Greenland blocking and Arctic warming

Our results suggest the mechanisms for recent increases in summer precipitation across the North Atlantic basin. As noted by other studies, Greenland blocking and the circulations associated with the strength of basin wide SLP patterns (represented by the NAO) have exerted substantial influence over the summer precipitation patterns for northern Europe and the United Kingdom over the full study period. The recent positive precipitation differences over the eastern North Atlantic result from an equatorward shift in summer extratropical storm tracks, which typically occurs during summers when the GBI is positive and the NAO is negative (e.g., Blackburn *et al.*, 2008; Folland *et al.*, 2009). In contrast, summer precipitation in the USNE is not directly correlated with the GBI over the full study period. However, the enhanced meridional wave pattern linked to more frequent and persistent blocking over Greenland in recent years promotes southerly flow over the USNE, which supports the transport of oceanic moisture into the region, and thus increased precipitation.

Although our results do not show a direct correlation between precipitation in the USNE and Greenland blocking, there is evidence to support the hypothesis that recent circulation patterns linked to Greenland blocking have had an impact on summer precipitation in the USNE. Summertime precipitation extremes in the USNE, in contrast to the eastern North Atlantic, are more closely attributed to increased moisture availability than shifting storm tracks. Agel *et al.* (2018, 2019) found that large-scale meteorological patterns associated with extreme precipitation events in the USNE are most often associated with weak synoptic systems and trailing cold fronts from remote cyclones, resulting in widespread light precipitation with localized extremes. One of the key components distinguishing extreme events from nonextreme events is enhanced moisture transport. Multiple studies have also associated recent increases in extreme precipitation in the USNE with the same circulation patterns reported here. For example, increased summer extreme precipitation in the USNE over the period 1980–2014 has previously been associated with decreased SLP and lowered 500 hPa geopotential heights over the USNE, as well as increased 500 hPa geopotential heights to the northeast of the region (Collow *et al.*, 2016; 2017), which are consistent with the circulation patterns shown in Figure 2a and Figure 2b. Additionally, the North Atlantic high–low pressure difference configuration (Figure 2a) was previously linked to the unusually wet interval 2005–2014 over the U.S. state of Maine (Birkel and Mayewski, 2018). During this wet period, long-term daily precipitation records for Farmington, Maine show a 30% increase in precipitation largely due to more 25 and 50 mm precipitation events (Fernandez *et al.*, 2020). Likewise, nine out of the 11 stations analysed registered the highest frequency of extreme events (precipitation events >50.8 mm in 24 hr) for this 10-year period than for any other decade on record (Fernandez *et al.*, 2015). The upper-level u and v-component wind pattern shown in Figure 2c,d is often cited as one promoting strong vertical ascent of air as well as moisture flux into the USNE from the Gulf of Mexico and the Atlantic (Leathers *et al.*, 2000; Thibeault and Seth, 2014; Collow *et al.*, 2016), and was proposed by Huang *et al.* (2018) as a contributing factor to the increase in early summer extreme precipitation attributed to frontal processes.

The hypothesized association between USNE regional precipitation and large-scale circulation changes has two main implications. First, it highlights the influence of high-latitude circulation patterns on middle-latitude weather. Although it is unclear what mechanisms produced the recent positive GBI trend, it has been suggested that the increased occurrence of summer Greenland blocking events is associated with a number of atmospheric and cryospheric climatic factors. These factors include a slower zonal flow and weaker polar jet stream in response to extensive warming and sea-ice loss in the Arctic (Francis and Vavrus, 2012; 2015; Overland *et al.*, 2012; 2015; Stroeve *et al.*, 2012a; 2012b; Cohen *et al.*, 2020), Rossby wave-train activity accompanying variations in tropical Pacific sea surface temperatures (Ding *et al.*, 2014), the characteristics of the underlying landmass and topography of Greenland (Scorer, 1988), and the role of positive sea surface temperature anomalies in the North Atlantic accompanying the positive phase of the Atlantic Multidecadal Oscillation (AMO) in forcing a more negative summer NAO (Folland *et al.*, 2009; Sutton and Dong, 2012). However, it is unclear the extent to which each of these factors has contributed to the Greenland blocking trend, as the potential mechanisms examined here result in similar effects on the upper-tropospheric circulation of the extratropical North Atlantic. Second, an association between USNE regional precipitation and large-scale circulation changes extending over Greenland also highlights the limitations of current climate projections, which rely on climate model simulations. At present, the literature shows that state-of-the-art climate models do not correctly depict seasonal patterns or trends in precipitation for the USNE (Lynch *et al.*, 2016; Karmalkar *et al.*, 2019), nor do they adequately represent key properties of the North Atlantic polar jet stream (e.g., wave amplitude, wind speed), as well as trends and patterns of blocking over Greenland (Davini and Cagnazzo, 2014; Davini and D'Andrea, 2016; Hanna *et al.*, 2018a; Delhasse *et al.*, 2021). Furthermore, the underestimation of blocking in the North Atlantic has persisted in climate models of the last 20 years with little improvement (Davini and D'Andrea, 2016). If the positive GBI trend continues into the future, then climate models could potentially be underestimating an important contribution to summer rainfall in the USNE.

4 | CONCLUSIONS

This study examines recent changes in summer precipitation in the USNE to large-scale atmospheric circulation shifts associated with Greenland blocking. We show that the recent increase in summer precipitation occurs in conjunction with more frequent blocking over Greenland (increased GBI), which is associated with a negative NAO. Although most previous work has focused on the association of these recent climate trends with an equatorward shift in the summer extratropical storm track over the eastern North Atlantic, the accompanying higher amplitude upper-level flow over the eastern United States is also linked to rising precipitation through increasing both the southerly moisture transport into and upward vertical motion over the USNE. The results of this study highlight the impact of changes in large-scale circulation patterns, which are influenced by changing conditions in the Arctic and tropics, on regional precipitation in the mid-latitudes. Although the details of the association between Greenland blocking and precipitation in the USNE need to be explored further, this association could have implications for the confidence in future climate prediction of precipitation across the western North Atlantic region. Therefore, it would be beneficial for future studies to closely examine Greenland blocking and precipitation teleconnections as more simulations from the latest generation of climate models become available.

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AUTHOR CONTRIBUTIONS

Julia M. Simonson: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; validation; visualization; writing – original draft; writing – review and editing. **Sean D. Birkel:** Conceptualization; data curation; investigation; methodology; project administration; resources; software; supervision; visualization; writing – review and editing. **Kirk A. Maasch:** Conceptualization; methodology; project administration; supervision; writing – review and editing. **Paul A. Mayewski:** Conceptualization; project administration; supervision; writing – review and editing. **Bradfield Lyon:** Conceptualization; methodology; project administration; supervision; writing – review and editing. **Andrew M. Carleton:** Conceptualization; methodology; project administration; supervision; writing – review and editing.

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