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A New Zealand perspective on centennial-scale Southern Hemisphere westerly wind shifts during the last two millennia

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ABSTRACT

The strength and latitudinal position of the Southern Hemisphere westerly winds control regional climate and influence the global carbon cycle by physically regulating Southern Ocean CO_2 exchange with the atmosphere. However, the mechanisms driving interannual to millennial variability of the westerlies remain poorly understood. Here, we present an 1800-yr record of westerly wind variability recorded in New Zealand fjord sediments. Located west of the Southern Alps, fjord basins receive large amounts of westerly-driven orographic precipitation (>6 m yr^{-1}) and strong winds lead to vigorous fjord mixing. Because of these links, reconstructing precipitation and fjord circulation provides information on westerly wind behavior over southwest New Zealand. Applying a multiproxy approach, we find several intervals of inferred regional wind variability. The intervals of 1450-1400, 825-775, 575-550, and 50-0 cal yr BP were anomalously wet, while 325-300 and 250-225 cal yr BP were anomalously dry. These interpreted intervals appear to be in phase with regional paleoclimate records. Two centennial-scale wet intervals align with a multi-centennial warm interval identified in the Pages2k Australasian temperature reconstruction, while the drier intervals generally occur during cooler times. The wet/dry intervals presented here are matched by opposite wind and/or precipitation trends reconstructed from the windfield core in Chile and the southern windfield margin in Antarctica. Such spatial patterns support the notion of centennial-scale latitudinal wind shifts or contraction/expansion of the core. Consistent with observations, all sites show wind strengthening from ~50 cal yr BP to present, indicating an overall intensification of winds that is observed in modern instrumental and reanalysis data sets.

1. Introduction

The Southern Hemisphere westerly winds (SHWW) are centered between 30° and 60°S and are almost completely uninterrupted by major landmasses. The lack of extensive continental regions, particularly south of 40°S, allows a strong circumpolar circulation pattern to develop. Because of their strength and latitudinal position, the SHWW influence Southern Ocean circulation and regulate air-sea CO_2 exchange, thereby exerting influence on mid-latitude climate, meridional overturning circulation, and the global carbon cycle (Anderson et al., 2009; Toggweiler et al., 2006).

Variability of the strength and latitudinal position of the SHWW has been identified on seasonal to glacial/interglacial timescales (e.g., Denton et al., 2010; Lovenduski et al., 2008; Nakamura and Shimpo, 2004; Toggweiler et al., 2006). Seasonal changes have been well documented in instrumental and reanalysis data sets, with the SHWW contracting poleward in the austral summer and expanding equatorward in the winter (Garreaud et al., 2013; Trenberth, 1991). On observational timescales (e.g., days to decades), there are links between changes in wind strength, precipitation patterns, and wind-driven ocean currents (e.g., Fogt et al., 2012; Thompson and Solomon, 2002; Ummenhofer and England, 2007; Ummenhofer and England, 2009). However, centennial-to millennial-scale variability is less clear. Informative reconstructions of SHWW variability on these timescales have

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emerged in the last few decades (e.g., Knudson et al., 2011; Moy et al., 2011; Koffman et al., 2014; Moreno and Videla, 2016; Hahn et al., 2016), yet there is still a need for well-dated, high-resolution records from: a) understudied regions within the SHWW belt; and b) mid-latitudes (40–45°S) near the northern margin of the modern wind field maximum, a latitudinal range sensitive to north/south wind shifts.

The South Island of New Zealand is one of the few landmasses that extend into the northern margin of the SHWW (Fig. 1), making it an ideal locale for reconstructing wind variability in the understudied SW Pacific Ocean. Yet to date, few records exist that utilize well calibrated proxies and provide sub-centennial-to-millennial-scale resolution of SHWW behavior in the region (Knudson et al., 2011; Lorrey et al., 2008; Shulmeister et al., 2004; Wilmshurst et al., 2002). One remaining question related to the overall appearance or configuration of the wind belt on these timescales: Does it behave the same at a single latitude across the hemisphere (symmetrical), or are there regional differences (asymmetrical)? As there is evidence for both symmetrical and asymmetrical SHWW behavior across the Pacific Ocean (Fletcher and Moreno, 2012, 2011; Knudson et al., 2011), more information is needed to understand the local and global driving mechanisms behind SHWW variability. In this study, we use a well-dated, high-resolution record to further investigate the potential symmetry of the SHWW across the Pacific Basin on multidecadal/centennial timescales. If regional asymmetry exists on these timescales, constraints on Southern Ocean upwelling (Wunsch, 1998), air-sea gas exchange (Takahashi et al., 2009), and hemispheric hydrologic trends (Garreaud, 2007) may need localized revision.

In Fiordland National Park, New Zealand (Fig. 1), there is a close link between the strength of the SHWW and regional precipitation (Fig. 2), which is amplified by intense orographic precipitation as the Southern Alps, east of Fiordland, intercept the SHWW (Salinger and Mullan, 2001). Stronger SHWW also lead to increased estuarine fjord circulation (Stanton and Pickard, 1981). Therefore, proxies for regional precipitation and fjord circulation should effectively reconstruct changes in local SHWW strength.

Previous modern process studies in Fiordland have established the sensitivity of the region to SHWW change and determined the proxies best suited for reconstructing past westerly wind change (Hinojosa et al., 2015, 2014; 2016). To track delivery of terrestrial organic carbon enhanced by precipitation/fluvial discharge, we utilize organic carbon-to-nitrogen ratios (C/N) and magnetic susceptibility. To track fjord circulation changes, we measure carbon accumulation rates (CAR) and the authigenic enrichment of redox-sensitive iron (Fe).

2. Study AREA and background

2.1. Fiordland/Doubtful Sound

Fiordland National Park is located along the southwest margin of the South Island of New Zealand spanning 44.5–46.5°S. During Quaternary glacial advances, plutonic granites and gneisses (Turnbull et al., 2010) were scoured to form deep (up to 450 mbsl), narrow (<5 km wide) fjord basins with shallowing entrance sills. To the east of the park lie the Southern Alps, a mountain range that sharply rises to >1000 m above sea level. The mountains intercept

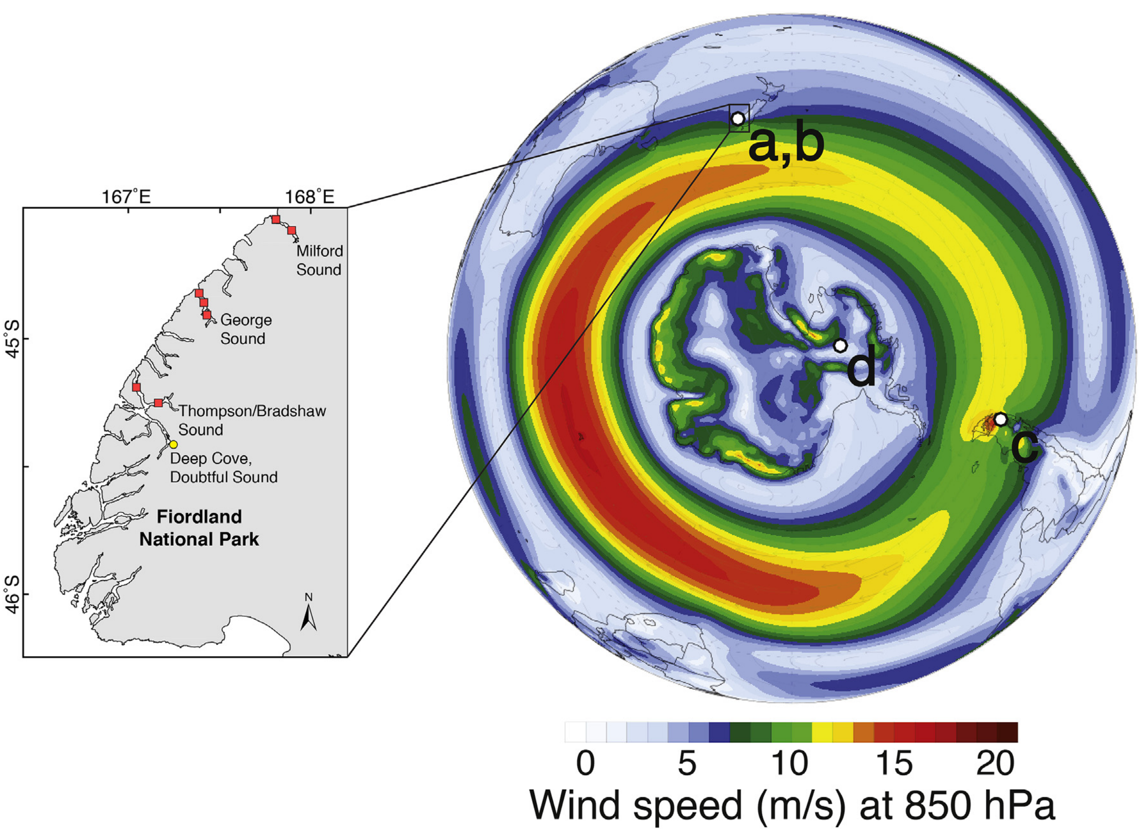

Fig. 1. ERA-Interim reanalysis data showing annual average wind speed at 850 hPa from 1979 to 2013. Wind speed map generated at cci-reanalyzer.org. Letters correspond to locations of records presented in Fig. 6. Inset map shows sampling location in Fiordland, New Zealand and sites of other records mentioned in the text. Yellow dot: sediment core from Deep Cove, Doubtful Sound (this study). Red squares: sediment cores from Knudson et al. (2011). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)