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South Pacific Split Jet, ITCZ shifts, and atmospheric North–South linkages during abrupt climate changes of the last glacial period

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A B S T R A C T

A number of key paleoclimate records in the Southern Hemisphere midlatitudes exhibit climate changes synchronous with abrupt climate changes in the North Atlantic. We advance a hypothesis – argued from consideration of model evidence, observational climate diagnostics, and atmospheric dynamics – that attributes said climate changes in the Southern Hemisphere to a modulation in the strength of the South Pacific Split Jet, a pronounced zonally asymmetric feature of the wintertime Southern Hemisphere westerlies. North Atlantic cooling is associated with a weaker Split Jet, characterized by weaker South Pacific subtropical and subpolar jets and a strengthened midlatitude jet. It leads to climate impacts over the South Pacific sector that coincides with regions with observed paleoclimate changes timed to the North Atlantic. These circulation changes are envisioned to operate in addition to the climate impacts resulting from the oceanic bipolar seesaw.

A proposed global atmospheric teleconnection links North Atlantic cooling to the weakening of the Split Jet. North Atlantic cooling induces a southward shift of the marine Intertropical Convergence Zone and weakening of the Asian monsoon. The resulting Hadley circulation change weakens the wintertime South Pacific subtropical jet, and which in turn leads to a weaker South Pacific Split Jet. A weaker Split Jet leads to a southward shift of the zero wind-stress curl line, implying a shift in the same sense for the South Pacific subtropical front. Over land, it leads to winter warming over New Zealand, winter cooling over subtropical South America, drying over Western Patagonia, and winter warming and wetting of southernmost Patagonia. Our hypothesis also predicts reduced storminess over West Antarctica. Similar changes but of opposite sign occur in the Northern Hemisphere, where a stronger wintertime North Pacific subtropical jet increases precipitation over the Western United States.

1. Introduction

The transition from the Last Glacial Maximum (LGM) to the Holocene was punctuated by abrupt climate changes over the high latitude North Atlantic, namely the Heinrich Stadial 1 cold, Bølling–Allerød (B/A) warm and Younger Dryas (YD) cold events. They have been tied to global climate changes, most prominently the Intertropical Convergence Zone (ITCZ) (Peterson et al., 2000; Wang et al., 2004), Asian monsoon (Wang et al., 2001), and midlatitude climates in both hemispheres (Broecker et al., 2009; Kaplan et al., 2010; Moreno et al., 2001).

Interpretations of Southern Hemisphere midlatitude paleoclimate changes typically invoke a wholesale meridional shift of the westerlies (Toggweiler, 2009), paralleling recent developments in dynamical meteorology examining poleward shifts of the westerlies under global warming (Yin, 2005), and the Annular Mode-type interannual variations in the midlatitudes (Thompson and Wallace, 2000). Variations to the interpretation include (i) intensification of the westerlies (Moreno et al., 2010; Lee et al., 2011); and (ii) meridional contraction/expansion of the westerly belt (Lamy et al., 2010).

Our paper advances an alternative hypothesis for these changes, namely the modulation of the South Pacific Split Jet during austral winter. The Southern Hemisphere westerlies are largely perceived

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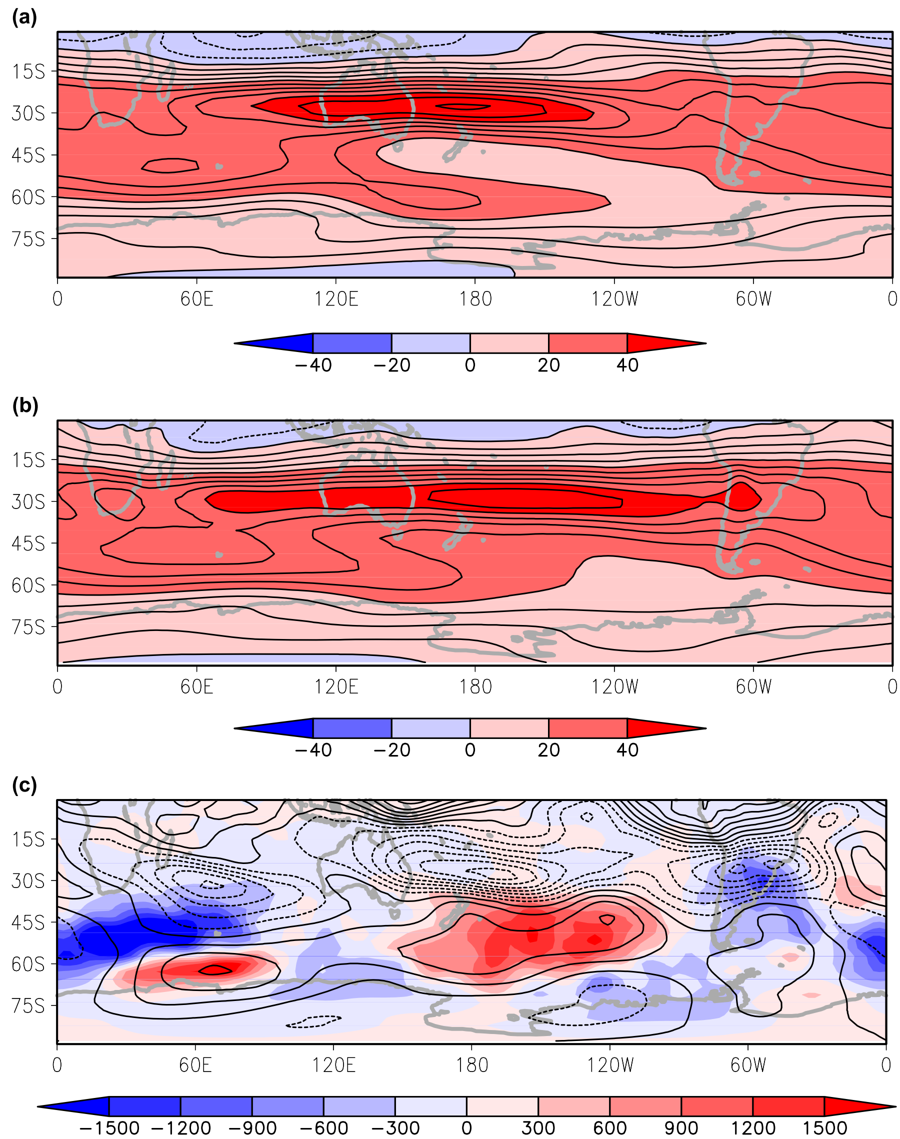

Fig. 1. (a) June–August (JJA) 250 mb zonal wind climatology from NCEP reanalyses (Kalnay et al., 1996) averaged over 1979–2009, showing the presence of the Split Jet in the South Pacific. Contour interval is 5 m/s. Negative values are stippled. (b) Simulation of 250 mb climatological JJA zonal wind (contour interval 5 m/s). (c) JJA 250 mb zonal wind anomalies (contour interval 2 m/s) and anomalies in the JJA 2–8 day bandpassed variance in 500 mb geopotential height, a measure of transient eddy activity (shading; units are m^2) in response to North Atlantic cooling. In (b) and (c) the climatology is the BASE simulation in Lee et al. (2011), and the anomaly the difference between the HE and BASE simulations respectively. The anomaly shows the weakening of the South Pacific Split Jet in response to North Atlantic cooling. The strengthening zonal wind in the midlatitude South Pacific is associated with a strengthening of transient eddy activity.

to be zonally symmetric, but in fact exhibit a pronounced zonal asymmetry in the austral winter where the core of the upper-level westerlies splits into a subtropical and subpolar branch just south of Australia (Fig. 1a). This ‘Split Jet’ is a well-documented feature in the dynamical meteorology literature (e.g. Inatsu and Hoskins, 2004; Nakamura and Shimpo, 2004), and exhibits strong interannual variability (e.g. Bals-Elsholz et al., 2001). While the Southern Annular Mode is thought to be the leading mode of atmospheric variations in the Southern Hemisphere extratropics, this is strictly true only for the austral summer; in the other seasons, variations to the Southern Hemisphere westerlies exhibit strong zonal asymmetries (Ding et al., 2012).

We advance the hypothesis that the South Pacific Split Jet *weakens* during North Atlantic stadials. Initial motivation for this hypothesis comes from our previous modeling study (Lee et al., 2011) that showed a Southern Hemisphere westerly intensification to imposed North Atlantic cooling, in particular over the South Pacific sector. Since then, we have more specifically identified these changes as a South Pacific Split Jet response.

We briefly clarify the meaning of North Atlantic ‘stadials/interstadials’ (or ‘cold/warm’ phases) used here. Virtually all paleoproxy evidence cited for Southern Hemisphere climate changes (excluding Antarctica) tied to the North Atlantic occurs during the deglacial Heinrich Stadial 1 – Bølling–Allerød – Younger Dryas sequence. There is yet no convincing evidence for changes coincident with Dansgaard–Oeschger (D/O) cold/warm phases, although this may reflect a lack of long-term high-resolution records rather than an absence of signal. On the other hand, the modeling evidence used in this paper mimics North Atlantic cooling as occurring during a slowdown scenario of the Atlantic Meridional Overturning circulation (AMOC). While AMOC variations are thought to play a central role in D/O variations (e.g. see Alley, 2007), this view is not universal (for example, see a recent hypothesis by Dokken et al., 2013). Our hypothesis only cares that the North Atlantic cools or warms; as such, we simply pose our