Hydroclimatic Variability in the Panama Bight Region During Termination 1 and the Holocene

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Abstract A transect of sediment cores from high-sedimentation rate locations from the Panama Bight (eastern tropical Pacific) in combination with climate model experiments provides an opportunity to improve our understanding of the role of the tropical hydrologic cycle as a potential driver of global climate change during the Holocene and Termination 1. The reconstruction of regional sea-surface salinity patterns suggests the development of an anomalous precipitation dipole in the tropical eastern Pacific during Heinrich Stadial 1 (H1) with reduced rainfall over the western Panama Basin and off Costa Rica, and wetter conditions along the Colombian coast. Freshwater hosing experiments with the climate model CCSM3, mimicking the climatic reorganizations during H1, capture this precipitation dipole, while showing no change in the Atlantic-to-Pacific water vapor flux in response to a slowdown of the Atlantic meridional overturning circulation (AMOC). We conclude that the cross-isthmus vapor flux feedback on AMOC variations is negligible.

Keywords Termination 1 · Heinrich stadial 1 · Holocene · Moisture transport · Atlantic meridional overturning circulation · Panama bight · Sea-surface salinity · Global climate modeling

1 Introduction

Today, a significant portion of rainfall in the eastern tropical Pacific is attributed to the atmospheric transport of water vapor from tropical Atlantic/Caribbean sources via the northeasterly trade winds that cross Central America (e.g., Benway and Mix

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2004). This net export of freshwater helps to maintain relatively high salinities within the Atlantic and has been argued to exert a strong influence on the strength and stability of the Atlantic meridional overturning circulation (AMOC) (e.g., Zaucker et al. 1994; Romanova et al. 2004). So far, only three paleoceanographic studies were devoted to past changes in the cross-isthmus vapor transport during the Late Quaternary (Benway et al. 2006; Leduc et al. 2007; Pahnke et al. 2007). In these studies sea-surface salinity (SSS) reconstructions from the eastern tropical Pacific were used to infer changes in the Atlantic-to-Pacific moisture flux. Reconstructed local salinity increases (decreases) were basically interpreted as decreased (increased) cross-isthmus moisture transport, which however led to seemingly contradictory results, in particular during Heinrich Stadial 1 (H1). Increasing eastern Pacific SSS off Costa Rica (Benway et al. 2006; Leduc et al. 2007) and decreasing SSS in the Panama Bight (Pahnke et al. 2007) were later reconciled by postulating the development of an anomalous precipitation dipole in the eastern tropical Pacific during H1, similar to a modern La Niña situation (Prange et al. 2010). This analog would be associated with reduced Atlantic-to-Pacific vapor export (Schmittner et al. 2000) and hence a positive feedback on the H1 AMOC slowdown due to anomalous Atlantic Ocean freshening. In the framework of our study, a transect of sediment cores along the Colombian and Panamanian margins in combination with climate model studies provides an opportunity to improve our understanding of the role of the tropical hydrological cycle as a potential driving force for global climate change through Termination 1 and the Holocene.

2 Materials and Methods

In order to reconstruct past variations of the hydroclimate in the Panama Bight region, we use high-deposition rate sediment cores retrieved during R/V Knorr cruise 176-2 in 2004 (Fig. 1a; www.marine.whoi.edu/kn_synop.nsf). Located along the rim of the basin, these cores allow for the reconstruction of temporal changes in spatial hydroclimatic patterns by means of well-established geochemical methods. Coring sites from the Colombian margin are ideally located to sensitively monitor changes in continental river runoff. Using stable-isotope analyses on planktonic foraminifera (*Globigerina ruber*, *Neogloboquadrina dutertrei*) in combination with alkenone sea-surface temperatures (SSTs; Mg/Ca SST reconstructions were not possible due to the sparsity of *G. ruber* in most samples), a history of SSS changes and thermocline depth in the Panama Bight is developed for Termination 1 and the Holocene.

The proxy studies are accompanied by simulations of Holocene and deglacial (H1) climate states, using the atmosphere-ocean general circulation model CCSM3 (Collins et al. 2006). A reliable simulation of the regional climatic features in the eastern tropical Pacific with correct position of the Choco Jet—a low-level westerly wind jet centered at 5°N which transports Pacific moisture towards Colombia—requires the use of a relatively high spatial resolution of the atmospheric component. We therefore employed the T85 (1.4° transform grid) version of the model.

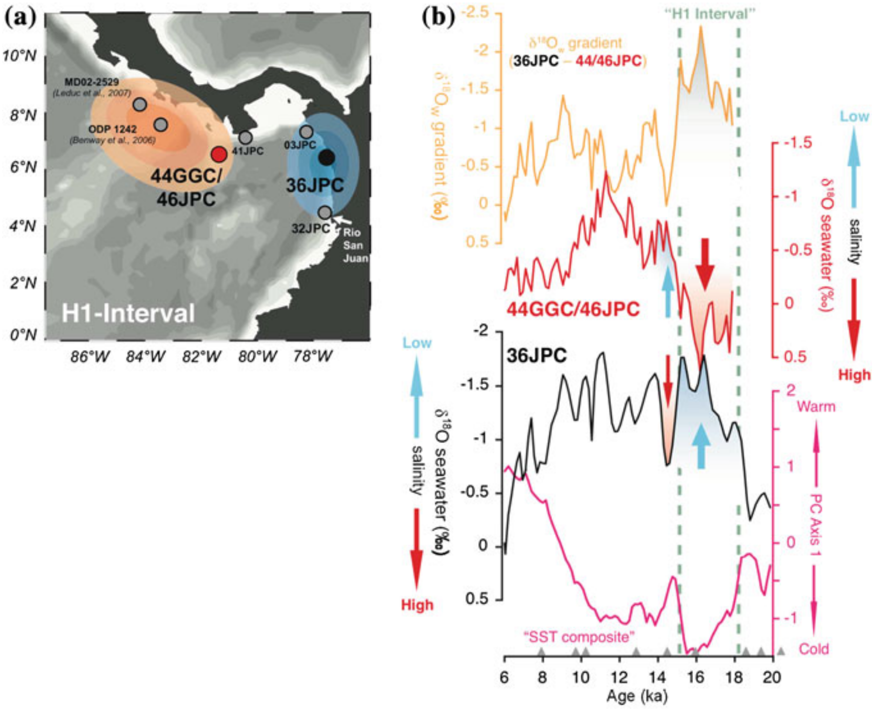

Fig. 1 **a** Locations of sediment cores collected during Knorr Cruise KNR176-2, which were analyzed. Cores used in previous studies (Benway et al. 2006; Leduc et al. 2007) are also shown. The location of the Rio San Juan delta is marked by an *arrow*. The H1 anomalous SSS or rainfall dipole is schematically illustrated by *blue* (wet) and *red* (dry) shading. **b** From *bottom* to *top*: leading principal component of 44GGC/46JPC, 36JPC, and 32JPC alkenone SST records; sea-level corrected $\delta^{18}O_{seawater}$ records of 36JPC and 44GGC/46JPC; difference between the two $\delta^{18}O_{seawater}$ records. *Grey triangles* mark AMS ^{14}C dates for core 32JPC, calibrated using Calib5.0.1-Marine04 without local offset

A modern control run shows that the model is able to successfully simulate the annual cycle of the regional wind pattern including strong northeast trades in late winter and early spring, and a large transport of water vapor from the Pacific to western Colombia with the Choco Jet during summer (not shown).

Freshwater hosing experiments under different background climatic conditions (pre-industrial, 8.5 thousand years (ka) before present (BP) early Holocene, and Last Glacial Maximum) were carried out to identify possible feedbacks between AMOC strength and tropical atmospheric vapor transports, with a particular eye towards the "8.2 ka BP event" (early Holocene experiment) and H1 (glacial experiment). In these hosing experiments, freshwater at a rate of 0.2 Sv is injected into the northern North Atlantic for 400 years leading to substantial weakening of the AMOC.

3 Key Findings

Three high-resolution alkenone SST records covering the entire Holocene and Termination 1 have been completed (44GGC/46JPC, 36JPC, 32JPC). These records are very similar in both absolute values and variability. So far, AMS ^{14}C dating has been carried out only for core KNR176-2 32JPC, but almost identical temperature evolutions allow for a straightforward correlation of the records. The leading principal component of the SST records reveals a pronounced cooling of the eastern tropical Pacific during H1 (Fig. 1b) in the order of 1–2 °C. Moreover, the alkenone records suggest a delayed deglacial warming in the region (starting at ~11 ka BP and possibly related to changes in local winter insolation) and two Holocene cold events.

The oxygen isotope records from the three cores all reveal a deglacial decrease in $\delta^{18}O$ of *G. ruber*, but with different timing. The sea-level corrected $\delta^{18}O_{seawater}$ record (indicative of local SSS changes) from 32JPC, which is located close to the river mouth of Rio San Juan, indicates higher SSS during the glacial period and a freshening trend during H1 (not shown). At the same time, the $\delta^{18}O$ difference between the thermocline dweller *N. dutertrei* and the shallow dweller *G. ruber* increases (not shown), consistent with enhanced upper-ocean stratification due to freshening of the surface layer (cf. Steph et al. 2009). The results agree with earlier findings by Pahnke et al. (2007) based on δD in alkenones from the same core. Moreover, the comparison of the sea-level corrected $\delta^{18}O_{seawater}$ records from different sites indicates a pronounced "salinity dipole" in the tropical eastern Pacific during H1, with enhanced SSS (and weaker upper-ocean stratification) in the western Panama Basin (core 44GGC/46JPC) and reduced SSS (and stronger stratification) near the Colombian coast (core 36JPC; Fig. 1b). These results corroborate the precipitation dipole previously hypothesized for that region (Prange et al. 2010).

The CCSM3 model results help interpret the proxy records and set them into a large-scale dynamical context. Independent of the background climatic state, all hosing experiments capture a precipitation-anomaly dipole in the Panama Bight region in response to a weakening of the AMOC, with enhanced rainfall over western Colombia and reduced rainfall over the Gulf of Panama and west of Costa Rica (significant at the 0.05 level according to a t-test). The simulation of this hydroclimatic "fingerprint" lends confidence to the model. As an example, Fig. 2a shows the net precipitation response to a substantial AMOC weakening under preindustrial conditions.

The annual mean net moisture transports from the Atlantic to the Pacific were computed along the 6 °N–14 °N segment for all experiments based on daily model output. Compared to the pre-industrial simulation, the moisture transport at the Last Glacial Maximum decreases by 16 % (from 0.31 to 0.26 Sv). An increase of northeasterly trades is overcompensated by a lower atmospheric moisture content. The net vapor transport in the early Holocene run is very similar to the pre-industrial value (0.28 Sv). The net moisture transports across Central America for

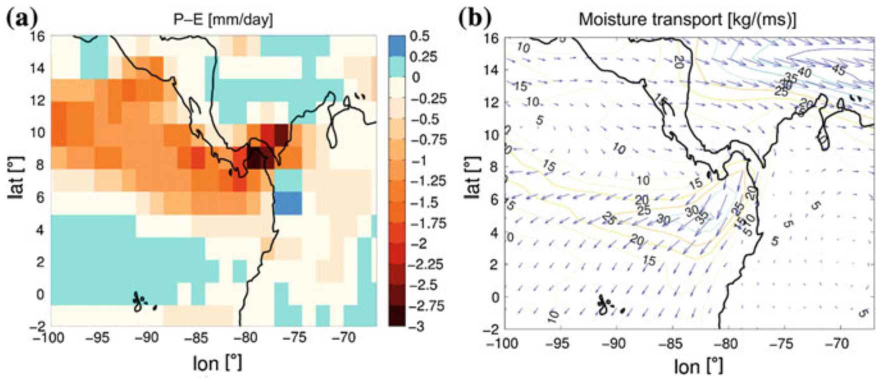

Fig. 2 **a** Annual mean P–E (precipitation minus evaporation; mm d^{-1}) response to a ~50 % AMOC slowdown under preindustrial boundary conditions. **b** Corresponding changes in annual mean vertically integrated moisture transport (contour *lines* indicate the magnitude of transport; kg m^{-1} s^{-1})

the pre-industrial, early Holocene and glacial basic states show no differences (<0.01 Sv) compared to their freshwater hosing counterparts. As shown in Fig. 2b, slightly enhanced vapor fluxes across Panama are compensated by eastward flux anomalies further north. We therefore conclude that the cross-isthmus vapor flux feedback on AMOC variations is negligible. Moreover, our results suggest that changes in the rainfall and SSS patterns in the eastern tropical Pacific provide no straightforward information on changes in Atlantic-to-Pacific moisture transport across Central America.

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