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Key Points:
- Most moisture exported to the Pacific from the Atlantic originates between 10°N and 20°N
- With warming, all of the net increased evaporation from the Atlantic precipitates over the Pacific
- In a warmer world, Atlantic-to-Pacific moisture export increases due to greater transport distances

Supporting Information:
- Supporting Information S1

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Greater aerial moisture transport distances with warming amplify interbasin salinity contrasts

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Abstract The distance atmospheric moisture travels is fundamental to Earth's hydrologic cycle, governing how much evaporation is exported versus precipitated locally. The present-day tropical Atlantic is one region that exports much locally evaporated moisture away, leading to more saline surface waters in the Atlantic compared to the Indo-Pacific at similar latitudes. Here we use a state-of-the-art global climate model equipped with numerical water tracers to show that over half of the atmospheric freshwater exported from the Atlantic originates as evaporation in the northern Atlantic subtropics, primarily between 10°N and 20°N, and is transported across Central America via prevailing easterlies into the equatorial Pacific. We find enhanced moisture export from the Atlantic to Pacific with warming is due to greater distances between moisture source and sink regions, which increases moisture export from the Atlantic at the expense of local precipitation. Distance traveled increases due to longer moisture residence times, not simply Clausius-Clapeyron scaling.

1. Introduction

The salinity of the Atlantic exceeds that of the Pacific by at least 1.0 practical salinity unit on average between 30°S and 65°N above 500 m [*Peixoto and Oort*, 1992; *Levitus et al.*, 2013; *Boyer et al.*, 2013] (Figure 1a). As a result, surface waters in the Atlantic are more dense than surface waters at comparable latitudes in the Pacific; in general, Atlantic waters have a density equal to Pacific waters that are between 3° and 10°C colder. In the Atlantic, high salinity subtropical waters flow northward into the Labrador and Greenland-Iceland-Norwegian Seas, thereby conditioning these surface waters to sink to great depths with surface heat loss and enabling a vigorous meridional overturning circulation [*Rahmstorf*, 1996; *Weaver et al.*, 1999; *Thorpe et al.*, 2001; *Vellinga and Wu*, 2004; *Haupt and Seidov*, 2007]. In contrast, in the Pacific, incoming waters from lower latitudes are too fresh, and surface waters in the North Pacific cannot densify sufficiently to sink to great depths and drive a basin-wide circulation.

The Atlantic is a net evaporative basin [*Bryan and Oort*, 1984] (Figure 1c), and aerial freshwater export has long been implicated in its high salinity [*Weyl*, 1968; *Broecker et al.*, 1990; *Broecker*, 1991]. In general, the steady state salinity of ocean surface waters result from a balance between the precipitation minus evaporation ($P-E$, the net surface freshwater flux due to atmospheric moisture transport), river runoff, and a collection of advective, diffusive, and turbulent oceanic salinity fluxes that balance this atmospheric input [*Schmitt*, 2008].

Today, surface waters in the Pacific are freshening while those of the tropical Atlantic, particularly the subtropical mode waters, are becoming more salty [*Curry et al.*, 2003; *Boyer et al.*, 2005; *Grodsky et al.*, 2006]. These salinity changes have profound impacts on ocean circulation and global climate [*Seager et al.*, 2002; *Sutton and Hodson*, 2003, 2005]. Indeed, many studies have proposed that changes in basin-scale moisture export and runoff from ice melt, which instigate basin-wide changes in salinity and ocean circulation, may have instigated abrupt climate change events evident in the paleoclimate record [*Lohmann*, 2003; *Leduc et al.*, 2007; *Prange et al.*, 2010]. Here we describe the role of the atmosphere in maintaining the high salinity of the tropical Atlantic basin, and we show how robust changes in the aerial hydrologic cycle with warming, particularly the increase in the distance between moisture source and sink regions evident from global climate model (GCM) experiments with numerical water tracers (WTs), amplify the Atlantic-Pacific interbasin salinity contrast.

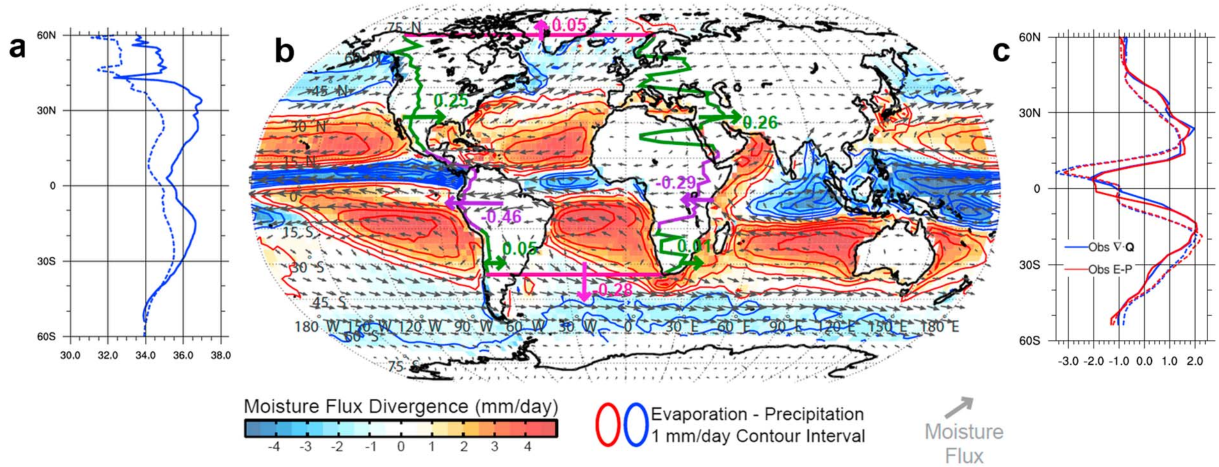

Figure 1. Sea surface salinity (SSS), evaporation minus precipitation ($E - P$), and moisture flux divergence ($\nabla \cdot Q$). (a) SSS in the Atlantic basin (solid lines) and over the rest of the world ocean (dotted lines), from the World Ocean Database. (b) Vertically integrated moisture flux divergence climatology from ERA-I (colors) and evaporation minus precipitation (contours at intervals of 1 mm d^{-1}). The gray vectors show the moisture flux vectors; the colored arrows with accompanying moisture fluxes in Sv (1 Sv = 10^9 kg s^{-1}) give the moisture fluxes across the boundaries of the Atlantic drainage basin, with green arrows and numbers corresponding to extratropics, purple for the tropics, and pink for the northern and southern boundaries. (c) Same as Figure 1a but for observed $E - P$ (orange) and $\nabla \cdot Q$ (blue), an inferred $E - P$ from aerial moisture flux ERA-I reanalysis.

2. Methods

2.1. Designation of the Atlantic Drainage Basin

The surface freshwater input into an ocean basin is equal to $P - E$ over the basin plus river runoff; in steady state, the latter is equal to $P - E$ integrated over the drainage basin. Thus, $P - E$ integrated over the combined ocean and drainage basin defines the freshwater input to the ocean basin, and interbasin freshwater transport results from atmospheric moisture fluxes across continental divides. Therefore, we adopt a drainage basin perspective to further understand the Pacific-Atlantic contrast in freshwater input. For all computations, the Atlantic drainage basin is designated as follows: the northern edge is at 70°N; the western edge is the longitude of maximum topography over either North or South America at each latitude from 70°N to 35°S; the southern edge is at 35°S; and the eastern edge is defined as the maximum topography between the prime meridian and 30°E. Also see Figure 1.

2.2. Observations and Reanalyses

Observed vertically integrated moisture fluxes into and out of the Atlantic drainage basin are computed from the ERA-interim atmospheric reanalyses using velocity and specific humidity fields for each month between 1979 and 2009 [*Dee et al.*, 2011]. The divergence of the vertically integrated moisture fluxes calculated from the reanalyses is compared to independent estimates of $E - P$. Precipitation data are from the National Oceanographic and Atmospheric Administration's Climate Prediction Center's (NOAA CPC) merged analysis [*Xie and Arkin*, 1996], and evaporation is taken from the ERA-interim reanalysis latent heat flux. Further details can be found in the supporting information (SI).

2.3. CMIP5 Models

To understand the role of CO_2-induced warming on perturbations in sea surface salinity (SSS) and $E - P$, the final 50 years of the abrupt CO_2-quadrupling simulation (Ab4XCO2-CMIP5) in 13 Coupled Model Intercomparison Project Phase 5 (CMIP5) models are compared to each of their corresponding preindustrial control (piC-CMIP5) simulations. See SI for further details.

2.4. Simulations With Water Tracers

We use the Community Earth System Model version 1.1 (CESM 1.1) [*Hurrell et al.*, 2013] with the Community Atmosphere Model version 5 (CAM5) [*Neale et al.*, 2012] at 1° spatial resolution in all components. Water tracing capability was incorporated into CAM5, with water entering the atmosphere tagged at its region of evaporation (or sublimation) and followed in a bulk sense during its transit through the atmosphere (as vapor, liquid, or ice); tags are reinitialized when water precipitates and is absorbed by the land or ocean model components. Water was tagged in 10° latitude bands in each of the major ocean basins (Atlantic, Pacific, and Indian); continents have one tag each, with the exception of Eurasia and North America, which have two tags each. There are 48 tags in total. Two 30 year experiments were performed with numerical water tracers (WTs): the first branched from an equilibrated preindustrial control experiment (piC) and the second branched from year 270 of a doubled-CO_2 experiment in which all other constituents and parameters were set at preindustrial conditions (Eqm2XCO_2). The latter run is at quasi-equilibrium with the net top-of-atmosphere flux not exceeding 0.1 W/m^2 in magnitude. Results are presented as annual mean climatologies of these final 30 year segments. See SI for further details.

3. Results

3.1. The Atlantic-Pacific Interbasin Salinity Contrast

There is disagreement regarding how freshwater is exported from the Atlantic, particularly whether this exported moisture evaporates (and hence "originates") from the tropics [*Broecker et al.*, 1990; *Broecker*, 1991] or the midlatitudes [*Ferreira et al.*, 2010]. Observational estimates of $P-E$ and atmospheric moisture fluxes (see section 2) support the former interpretation (Figure 1b): the atmospheric export of moisture across Central America (0.46 sverdrup (Sv); 1 Sv = 10^6 m^3 s^{-1} = 32,500 Gt yr^{-1}) greatly exceeds the import across Africa (0.29 Sv) between 20°N and 15°S, due to the relatively low orography and narrow extent of Central America compared to eastern Africa. The East African (Somali) Jet also presents a dynamic barrier to moisture transport across the continent [*Bannon*, 1979]. In contrast, the difference between import into and export out of the Atlantic basin in the extratropical latitudes only leads to a modest net import of moisture into the extratropical Atlantic: westerly import across North America (0.25 Sv) is nearly identical to export across Europe (0.26 Sv) over 20°N to 70°N, while moisture import across South America (0.05 Sv) slightly exceeds export across Africa (0.01 Sv) over 20°S to 35°S. Similar calculations performed with vertically integrated moisture fluxes from the National Centers for Environmental Prediction (NCEP) reanalysis agree with these findings [*Trenberth and Stepaniak*, 2004]. Therefore, there is strong observational evidence of atmospheric moisture export out of the Atlantic basin by easterly advection in the tropics. Nevertheless, this budget approach for quantifying net freshwater export from the Atlantic drainage basin is not conclusive in that it cannot properly account for moisture transport pathways, source regions, or path length.

Therefore, we employ a GCM configured with WTs to facilitate analysis of moisture transport pathways and source region provenance. WTs allow atmospheric moisture to be followed from its point of evaporation, transpiration, or sublimation from a land or ocean surface, through atmospheric transport and phase changes, to its point of precipitation. Our preindustrial control experiment (piC) (see section 2) confirms that moisture originating from the Atlantic basin precipitates not only within the Atlantic drainage basin but also over the equatorial Pacific (Figure 2a), particularly over the eastern Pacific around 5°N. Indeed, one quarter of the moisture sourced from the Atlantic basin precipitates outside its drainage basin. On the other hand, substantially less moisture evaporating elsewhere precipitates in the Atlantic drainage basin (Figure 2b). Integrating these two quantities, we find that 1.4 Sv of moisture evaporated from the Atlantic basin precipitates outside the Atlantic drainage (the gross freshwater export, equal to approximately 25% of the total moisture evaporated from the Atlantic drainage basin), while only 0.4 Sv of moisture evaporated from outside the Atlantic drainage basin falls within the Atlantic drainage basin (the gross freshwater import). As a result, the Atlantic drainage basin has a net freshwater deficit of 1.0 Sv in our model run, which agrees reasonably with the moisture flux divergence calculations of *Broecker* [1991] as well as with the two independent present-day estimates (0.45 Sv and 0.51 Sv; Figure 1c).

In piC, most of this moisture exported from the Atlantic to the Pacific originates in the subtropical North Atlantic, varies little seasonally, and peaks between 10°N and 20°N (Figure 2c). Indeed, nearly 0.4 Sv of freshwater precipitating in the eastern Pacific intertropical convergence zone (ITCZ) in piC originally evaporated between the equator and 30°N in the Atlantic basin. Figure 2c also reveals a smaller, seasonally variable aerial moisture export from the subtropical south Atlantic, though this contribution is smaller in magnitude (but not in magnitude per unit area) than the contribution from the rest-of-globe SH subtropics to the Atlantic drainage basin. Overall, these results agree with our interpretation of moisture fluxes in the ERA-interim (Figure 1c), where precipitable water from the subtropical North Atlantic follows a northeasterly route over the Isthmus of Panama and over other low-lying regions of Central America to the equatorial Pacific and is preferentially precipitated in the east Pacific ITCZ near 5°N.

3.2. A Robust Increase in the Atlantic-Pacific Interbasin Salinity Contrast With Warming

We now turn to the question of Atlantic salinity perturbations that result from hydrologic cycle changes associated with CO_2-induced warming. Enhanced Atlantic-to-Pacific moisture transport with increased atmospheric

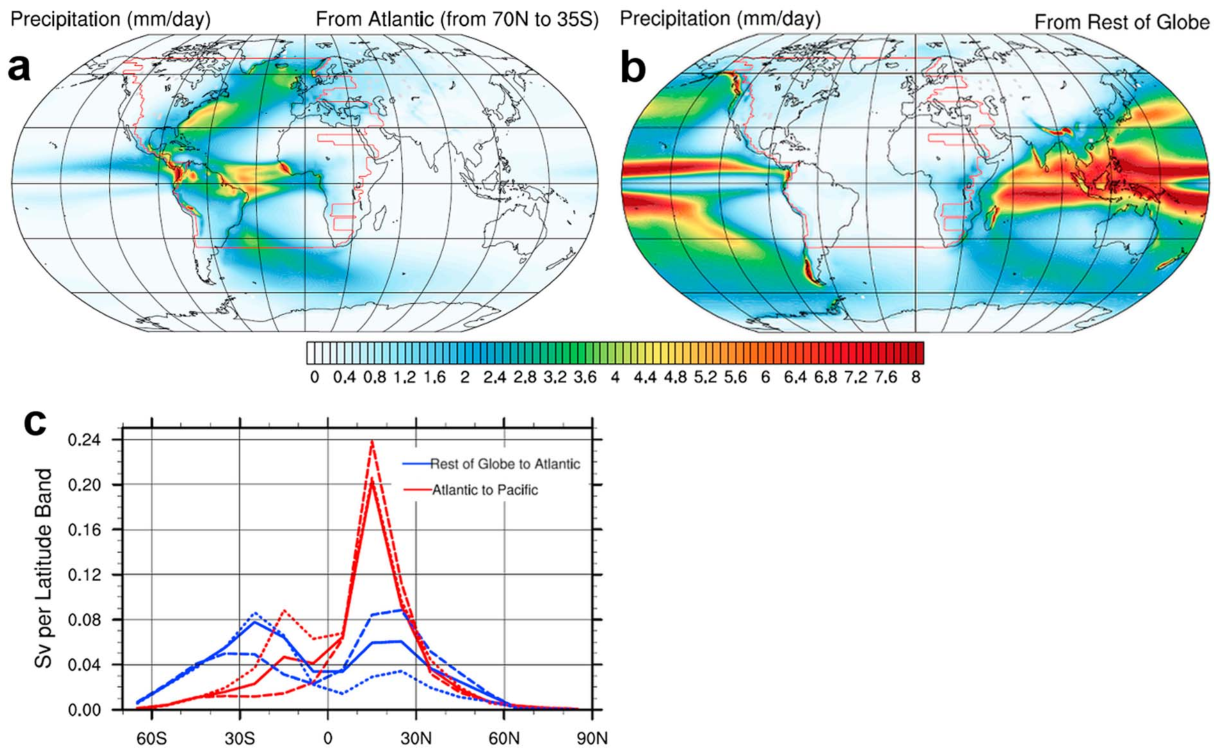

Figure 2. Precipitation sourced from Atlantic and rest of globe. (a–b) Annually averaged precipitation (in mm d^{-1}) in piC (Figure 2a) originating from the Atlantic basin and (Figure 2b) originating from the rest of the globe; the Atlantic drainage basin is demarcated (red line). (c) Annual (solid), June–August (JJA) (dashed), and December–February (DJF) (dotted) interbasin moisture contribution (in Sv) in piC from the Atlantic to Pacific (red) and from the rest of the globe to Atlantic (blue) per 10° latitude band.

CO_2 has been demonstrated in a coarse-resolution GCM [*Zaucker and Broecker*, 1992]. Furthermore, CMIP5 models (see section 2) display a robust Atlantic sea surface salinity (SSS) increase with abruptly quadrupling CO_2 (Ab4 $\times$ CO_2-CMIP5) relative to the preindustrial control experiment (piC-CMIP5), particularly between 30°S and 40°N, while SSS decreases in the Indo-Pacific [*Levang and Schmitt*, 2015] (also see SI). The striking intermodel agreement in the SSS response suggests that the mechanism driving this increase is robust across models and, therefore, captures fundamental changes in model dynamics with warming.

In fact, $E - P$ increases over much of the Atlantic drainage basin in Ab4 $\times$ CO_2-CMIP5; over the rest of the globe, all models have an equatorial minima in the $E - P$ response, a feature notably absent over the Atlantic alone in most models [*Levang and Schmitt*, 2015] (also see SI). The integrated change in $E - P$ in Sv for the Atlantic drainage basin is positive for all models, with a multimodel mean of 0.11 Sv. Indeed, the intermodel correlation between the $E - P$ response over the Atlantic drainage basin for a given model and the Atlantic SSS response is $r = 0.83$ (both reckoned between 20°N and 20°S; see SI). Using SSS to calculate $E - P$ over the world's oceans is one strategy for evaluating the hydrological cycle [*Bryan and Oort*, 1984; *Schmitt*, 2008] and perturbations to its climatology [*Terray et al.*, 2012]. To first order, SSS does not affect the aerial hydrological cycle; therefore, perturbations in SSS are mostly responses to $E - P$ perturbations.

Using WTs, we assess changes in net freshwater loss from the subtropical Atlantic with quasi-equilibrium CO_2-doubling (Eqm2 $\times$ CO_2, see section 2). Comparing Eqm2 $\times$ CO_2 to piC, moisture originating in the Atlantic and precipitating over the Pacific increases by 0.2 Sv, which is also equal to the evaporation increase over the Atlantic drainage basin; on the other hand, moisture originating from the rest of the globe and precipitating over the Atlantic increases by only 0.1 Sv. This leaves the Atlantic drainage basin with an increased freshwater deficit of 0.1 Sv. Indeed, P arising from moisture originating within the Atlantic basin decreases over much of the Atlantic drainage basin itself but increases significantly over the eastern Pacific ITCZ (Figure 3a). Meanwhile, P arising from moisture evaporated from the rest of the globe does not appreciably increase over the Atlantic drainage basin (Figure 3b), indicating insufficient compensating freshwater gain.

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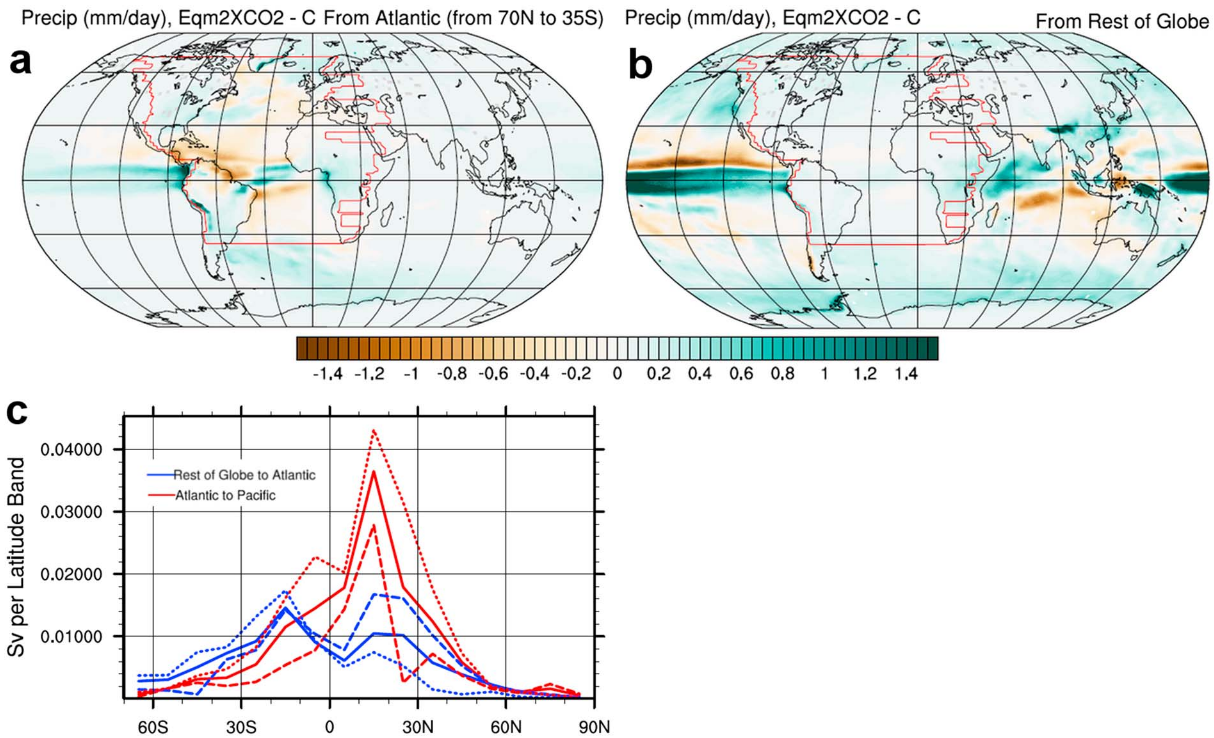

Figure 3. Change in precipitation sourced from Atlantic and rest of globe with CO_2-doubling. (a–b) Annually averaged difference in precipitation (in mm d^{-1}) between Eqm2 × CO_2 and piC (Figure 3a) originating from the Atlantic basin and (Figure 3b) originating from the rest of the globe; the Atlantic drainage basin is demarcated (red line). (c) Annual (solid), JJA (dashed), and DJF (dotted) interbasin moisture contribution change (in Sv) in Eqm2 × CO_2 relative to piC from the Atlantic to Pacific (red) and from the rest of the globe to Atlantic (blue) per 10° latitude band.

Increased Atlantic-to-Pacific moisture export in Eqm2 × CO_2 arises mostly from evaporation in the subtropical North Atlantic (Figure 3c), with a substantial peak in the 10°N to 20°N latitude band amounting to a 20% increase of the mean state Atlantic-to-Pacific moisture export. There is also a substantial increase in Atlantic-to-Pacific moisture transport originating in the subtropical south Atlantic; this increased contribution amounts to 35% of the mean state Atlantic-to-Pacific export from that region. These peaks in the subtropics where most of the increased Atlantic-to-Pacific moisture export originates also coincide well with the subtropical peaks in SSS increase in the Atlantic in the Ab4 × CO_2-CMIP5 multimodel mean (see SI and Figure 3a). This supports our claim that increased SSS in the subtropical Atlantic is due to a robust increase in moisture exported from the Atlantic subtropics to the equatorial Pacific.

From a Lagrangian perspective, the increase in Atlantic-to-Pacific moisture export in Eqm2 × CO_2 may be attributed to either of two mechanisms: (1) the Atlantic-to-Pacific moisture export scales with increased evaporation over the Atlantic basin, which is exported from the Atlantic by the climatological moisture transport (the increased evaporation hypothesis), or (2) the length and/or direction that water parcels originating within the Atlantic travel changes with warming, independent of the increase in evaporation (the altered transport hypothesis). To distinguish between these hypotheses, we decompose the precipitation perturbation $\Delta\vec{P}$ as

$$\Delta\vec{P} \approx \mathbf{M}(\Delta\vec{E}) + (\Delta\mathbf{M})\vec{E}\,, \qquad (1)$$

where $\mathbf{M}$ is the transport operator, $\vec{E}$ is the evaporation vector, and Δ is used to denote the difference between Eqm2 × CO_2 and piC (see SI). If the evaporation hypothesis is correct, most of the increase in Atlantic-to-Pacific moisture export will be contained in the first term, which is the portion of $\Delta\vec{P}$ due to the change in evaporation alone. On the other hand, if changes in transport are responsible for the increase in Atlantic-to-Pacific moisture export, the latter term (which encompasses the portion of $\Delta\vec{P}$ due to changes in the transport operator) will dominate the sum.

We find that the substantial increase in Atlantic-to-Pacific moisture export is better explained by the transport hypothesis than the evaporation hypothesis. Increased evaporation over the Atlantic with constant transport,

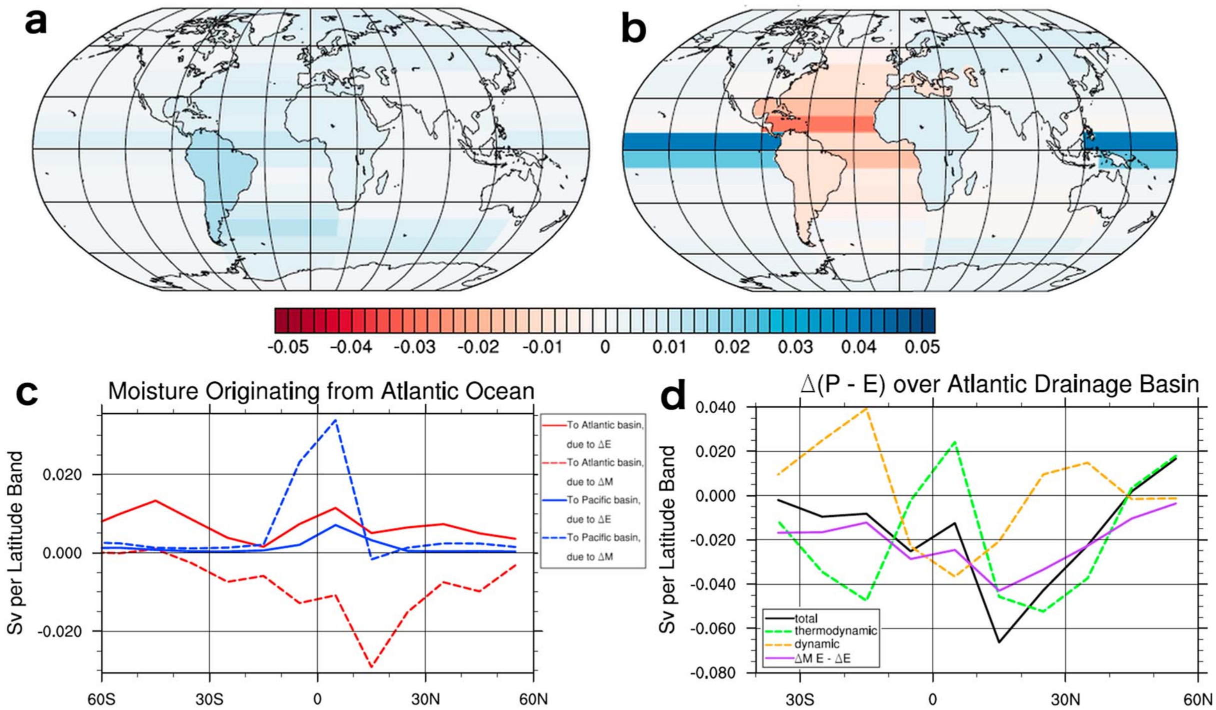

Figure 4. Decomposition of precipitation perturbation in Eqm2 $\times$ CO_2. (a–b) Change in precipitation originating from moisture evaporated from the Atlantic basin, (Figure 4a) due to changes in evaporation $\vec{E}$ and (Figure 4b) due to changes in the transport operator **M**. (c) Change in precipitation originating from the Atlantic and falling on the Atlantic (red lines) and falling on the Pacific (blue lines), where dashed lines denote changes due to differences in the transport operator **M**, and solid lines denote changes due to differences in evaporation $\vec{E}$. (d) Change in $P - E$ over the Atlantic basin (black line) decomposed into the change due to thermodynamics (green line) and the change due to dynamics (yellow line); the perturbation $\Delta\mathbf{M}\vec{E} - \Delta\vec{E}$ (see text) is also shown (purple line).

which increases Atlantic-sourced atmospheric moisture (i.e., the $\mathbf{M}\Delta\vec{E}$ term), only increases precipitation slightly over the Atlantic basin and over the neighboring equatorial Pacific (Figure 4a). Because evaporation increases nearly everywhere, this term is always positive and cannot account for regions of declining precipitation over the Atlantic. On the other hand, changing transport with evaporation held constant (i.e., the $\Delta\mathbf{M}\vec{E}$ term) decreases precipitation over the Atlantic basin and increases it dramatically over the equatorial Pacific between 10°N and 10°S (Figure 4b). In fact, in an integrated sense, all of the increased Atlantic-sourced precipitation in Eqm2 $\times$ CO_2 (0.2 Sv) falls outside its drainage basin, compared to only a quarter (reckoned to be a 0.05 Sv increase, given climatological transport) in the mean state. Only the change in the transport operator **M** can account for a decrease in Atlantic-sourced precipitation over the Atlantic basin and an increase in Atlantic-sourced precipitation over the equatorial Pacific, which together salinize the Atlantic and freshen the Pacific. Quantifying these terms, we find that increased evaporation over the Atlantic basin accounts for <10% of the total increase in Atlantic-sourced precipitation over the Pacific; the remaining >90% is due to changes in the transport operator (Figure 4c). Surprisingly, one quarter of the precipitation increase over the tropical eastern Pacific in Eqm2 $\times$ CO_2 originates as moisture evaporated from the Atlantic basin.

We now place these changes in aerial freshwater export with CO_2-induced warming in the context of the "wet get wetter, dry get drier" paradigm put forward by *Held and Soden* [2006] (hereafter HS06), whereby changes in $P - E$ scale as the climatological $P - E$ multiplied by the fractional change in moisture content, assuming that the circulation remains unchanged:

$$\Delta(P-E)_{\text{thermo}} = \frac{\Delta T}{Q}\frac{\partial Q}{\partial T}(P-E)_0. \tag{2}$$

Changes in $P - E$ from these thermodynamic considerations alone suggest that the tropical Atlantic (between 5°S and 10°N)—where $P_0 > E_0$ and there is net climatological moisture flux convergence—should freshen, which disagrees with the robust tendency toward decreasing $P - E$ and higher salinities seen in our model simulation (Figure 4d) and in the CMIP5 models. Furthermore, the HS06 thermodynamic paradigm also predicts an equal magnitude drying of the NH and SH Atlantic subtropics, which is also not evident in $\Delta(P - E)$

(cf. the dashed green line and black line in Figure 4d). Overall, these results suggest that while HS06 may explain the broad global features of the zonal mean changes in $P - E$, it is poorly suited for making quantitative predictions of ocean basin scale $\Delta(P - E)$, as suggested previously by *Seager et al.* [2010] and *Wills et al.* [2016]. On the other hand, the change in precipitation over the Atlantic basin due to changes in the transport operator, $\Delta\mathbf{M}\vec{E}$ (Figure 4c), closely matches the shape of the $\Delta(P - E)$ curve (Figure 4d); furthermore, the sum $\Delta\mathbf{M}\vec{E} - \Delta\vec{E}$ matches both the shape and the magnitude of $\Delta(P - E)$ (Figure 4d). In other words, both greater evaporation over the Atlantic basin and changes in precipitation solely due to changes in how moisture is partitioned between source and sink regions are responsible for the strong drying of the Atlantic basin and, by extension, the moistening of the Pacific.

4. Discussion

An important question that remains is how altered transport increases Atlantic-to-Pacific moisture export in Eqm2 $\times$ CO_2. As noted earlier, there is remarkable agreement among CMIP5 models that salinity in the tropical Atlantic increases in Ab4 $\times$ CO_2, suggesting a common and simple mechanism. Furthermore, analyses of the CMIP3 models indicate that increased CO_2 tends to decrease the strength of the atmospheric circulation in the tropics [*Vecchi and Soden*, 2007], suggesting that enhanced interbasin transport cannot be explained by more vigorous easterly winds.

We propose that increased Atlantic-to-Pacific moisture export is due to an increase in the advective moisture transport length scale with warming [*Held and Soden*, 2006], which is a result of a decrease in the large-scale precipitation efficiency γ, the ratio of the precipitation P to the atmospheric specific humidity Q:

$$\gamma = \frac{P}{Q}. \tag{3}$$

Given that

$$\delta\gamma = \left(\frac{\delta P}{P} - \frac{\delta Q}{Q}\right)\frac{P}{Q}, \tag{4}$$

it is clear that γ must decrease in a warming world where Q increases more rapidly with temperature than either E or P [*Trenberth*, 1998; *Allen and Ingram*, 2002]. A simple heuristic model can be used to show that decreasing precipitation efficiency, which is evident in all state-of-the-art GCMs, corresponds to increased moisture residence times [*Bosilovich et al.*, 2005] and, therefore, increased advective length scales (see SI). In *Singh et al.* [2016], we use WTs to demonstrate that this increased advective length scale is evident in the global hydrologic cycle, not only in Atlantic-to-Pacific moisture export; decreased precipitation efficiency alters moisture transport globally, shifting it toward longer distances between moisture source and sink regions. Consequently, long-range moisture transport increases, including Atlantic-to-Pacific moisture export, at the expense of short-range transport, including intrabasin moisture convergence within the Atlantic itself. This net moisture export from the Atlantic remains uncompensated by moisture import from the Indo-Pacific due to the (unchanged) orographic and dynamic barriers presented by the African continent. We emphasize that such Lagrangian changes in moisture transport should not be interpreted as equivalent to Eulerian changes due to dynamics (versus thermodynamics) but rather as a complementary framework for understanding the hydrologic cycle's perturbation response to CO_2-induced warming [*Singh et al.*, 2016].

Our results show that increased salinity in the subtropical Atlantic is a robust outcome in GCM experiments with increased CO_2 because the hydrologic cycle response it arises from is consistent across models. By itself, such a salinity increase would lead to an increase in salinity of water transported to the northern North Atlantic and, thereby, to increase the strength of the meridional circulation. GCM experiments, however, also project an increase in $P - E$ in the middle and high latitudes that offsets this salinity increase at low latitudes. Taken together, these two effects (decreased $P - E$ at low latitudes, increased $P - E$ at high latitudes) result in less vigorous sinking in the North Atlantic in most GCMs [*Cheng et al.*, 2013]. Nevertheless, if SSS did not increase at low latitudes, sinking in the North Atlantic would be expected to weaken even more. Thus, considering the salinity of the Atlantic subtropics, and changes therein, is necessary, though not sufficient, for understanding the strength of the overturning circulation in the Atlantic, and how it may respond to future climate perturbations.

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