Relationships between the Hadley Cell and Subtropical Jet

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Introduction

Recent interest in tropical expansion predicted to occur under a warmer global climate has led to a handful of studies comparing the various metrics used to define the edge of the tropics[◇]. A surprising result from these studies reveal that the location of the subtropical jet (STJ) does not co-vary with the Hadley Cell (HC), as theorized by previous work[‡]. In this research, we perform further analysis of the HC and STJ using data from IPCC's CMIP5 to better understand the relationship between the two atmospheric features in their natural variability and in response to an instantaneous quadrupling of atmospheric CO_2.

References

◇Waugh, Darryn W., et al. "Revisiting the relationship among metrics of tropical expansion." *Journal of Climate* 31.18 (2018): 7565-7581.

‡Held, Isaac M., and Arthur Y. Hou. "Nonlinear axially symmetric circulations in a nearly inviscid atmosphere." *Journal of the Atmospheric Sciences* 37.3 (1980): 515-533.

*Chemke, R., and L. M. Polvani. "Exploiting the abrupt 4xCO2 scenario to elucidate tropical expansion mechanisms." *Journal of Climate* (2018), in press.

§Lu, Jian, Gang Chen, and Dargan MW Frierson. "Response of the zonal mean atmospheric circulation to El Niño versus global warming." *Journal of Climate* 21.22 (2008): 5835-5851.

Conclusion 1: *The HC edge and STJ location are not correlated.*

Conclusion 2: *The STJ strength shows weak correlation with HC, but that relationship differs between natural variability and response to forcing scenarios.*

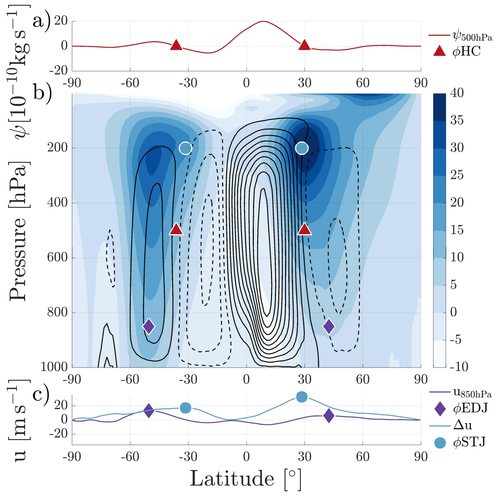

Figure 1. (a) Mean meridional circulation at 500 hPa, (b) zonal-mean zonal wind (blue contours) and mean meridional circulation (black contours, solid and dashed lines denote positive and negative values, respectively), and (c) zonal-mean zonal wind at 850 hPa (purple) and the change in wind between the upper troposphere and 850 hPa (blue) for ERA-interim. Locations of the HC edge, EDJ, and STJ are denoted by the red triangle, purple diamond, and blue circle respectively.

Definition of Metrics

Hadley Cell

$$\varphi HC = \varphi(\psi_{500\,hPa} = 0)$$
$$maxHC = max(\psi_{500\,hPa})$$

Subtropical Jet

$$\varphi STJ = \varphi(\max(\Delta u))$$
$$maxSTJ = \Delta u(\varphi STJ)$$
$$\Delta u = u_{100-400\,hPa} - u_{850\,hPa}$$

Eddy Driven Jet

$$\varphi EDJ = \varphi(\max(u_{850\,hPa}))$$

Analysis

Natural Variability

The HC and EDJ move together but there is little to no correlation between the HC and STJ location.

Poleward, weaker HC → Weaker STJ

	Southern Hemisphere DJF	MAM	JJA	SON	Northern Hemisphere DJF	MAM	JJA	SON
ϕHC ϕEDJ	**0.723** (0.184)	**0.462** (0.471)	**0.245** (1.188)	**0.403** (0.709)	**0.473** (1.023)	**0.484** (0.976)	**0.398** (0.466)	**0.452** (0.375)
ϕHC ϕSTJ	**-0.103** (1.449)	**0.102** (0.538)	**0.118** (0.155)	**-0.029** (0.341)	**0.016** (0.144)	**0.287** (0.27)	**0.2** (0.292)	**-0.08** (0.321)
ϕHC maxSTJ	**-0.337** (0.338)	**-0.143** (0.22)	**-0.25** (0.409)	**-0.105** (0.235)	**-0.304** (0.319)	**-0.521** (0.537)	**-0.286** (0.113)	**-0.154** (0.124)
maxHC maxSTJ	**0.057** (0.091)	**0.259** (0.226)	**0.179** (0.179)	**0.222** (0.178)	**0.206** (0.304)	**0.395** (0.306)	**-0.012** (0.043)	**0.118** (0.127)
maxHC ϕSTJ	**0.006** (0.232)	**-0.107** (0.226)	**-0.042** (0.101)	**-0.079** (0.185)	**0.057** (0.099)	**-0.078** (0.213)	**-0.011** (0.235)	**-0.031** (0.659)
ϕSTJ maxSTJ	**-0.075** (0.079)	**-0.208** (0.223)	**-0.333** (0.371)	**-0.269** (0.234)	**-0.22** (0.374)	**-0.391** (0.37)	**0.007** (0.084)	**-0.034** (0.054)
ϕHC maxHC	**-0.005** (0.169)	**-0.305** (0.186)	**-0.234** (0.273)	**-0.355** (0.194)	**-0.255** (0.193)	**-0.345** (0.379)	**0.026** (0.087)	**-0.068** (0.1)

Figure 2. Model-mean correlations in time (bold, colored) and standard deviations (in parentheses) of model spread for various metric relationships. Correlations were calculated with piControl data.

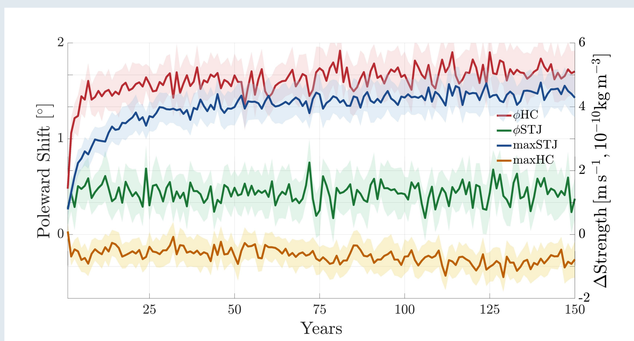

Figure 3. Time series of response to quadrupling atmospheric CO_2 for the HC edge (red), strength (orange) and the STJ location (green) and strength (blue). Response is taken as the difference between abrupt4xCO_2 and the piControl climatology.

Response to 4xCO_2

The HC shifts poleward ~1.6° and weakens slightly while the STJ strengthens by about 10% and shifts poleward ~0.4°.

Poleward, weaker HC → Stronger STJ

Mechanisms

Time Series of Response

Conclusion 3: *The HC poleward shift follows the shift of maximum eddy momentum fluxes[*] and the STJ strengthening follows the evolution of max meridional temperature gradient, accounting for the difference in evolution.*

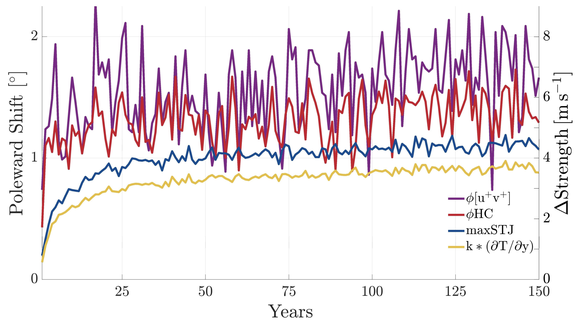

Figure 4. Time series of response to a quadrupling of atmospheric CO_2 for the HC edge (red), location of max eddy momentum flux[*] (purple), STJ strength (blue) and max meridional temperature gradient (yellow). Response is taken as the difference between abrupt4xCO_2 an piControl climatology. The max meridional temperature gradient is converted to a thermal wind according to:

$$u = -\log\frac{p_r}{p}\left(\frac{R}{f}\right)\frac{\partial T}{\partial y}$$

Natural Variability vs Global Warming

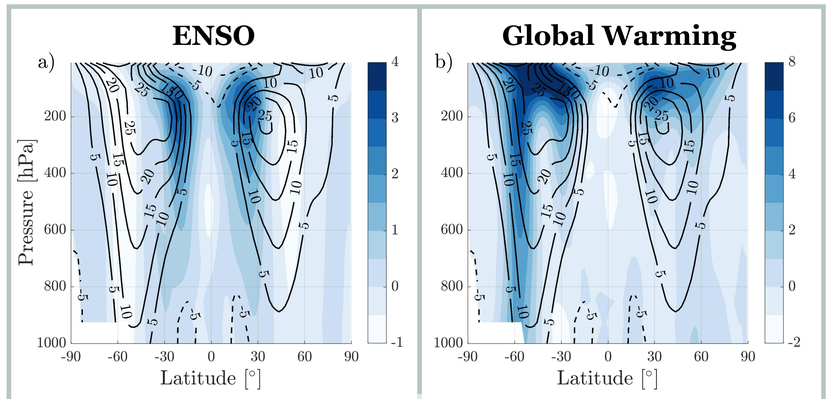

Figure 5. Zonal-mean climatological zonal wind (black contours) and zonal-mean change in zonal wind (blue shading) for (a) ENSO forcing (El Nino minus La Nina) and (b) abrupt quadrupling of atmospheric CO_2 (abrupt4xCO_2 minus piControl climatology) for GFDL-ESM2G. (c.f. Lu et al. 2008[§])

Narrow Warming	Broad Warming
HC, EDJ Contracts	HC, EDJ Expands
STJ strengthens	

Conclusion 4: *The HC and STJ relationship differs between natural variability and global warming due to different responses to narrow vs broader warming[§].*