Impacts of Shifting Subtropical Highs on Precipitation in North America

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Background

- Hadley cell expansion has been studied as a potential driver of 21st century precipitation change (e.g. Lu et al, 2007; Scheff & Frierson, 2012; Lau & Kim, 2015).
- However, on regional scales, and especially during the warm season, the descending air at subtropical latitudes is not well-described by the zonal-mean Hadley cell.
- Instead, descent is driven by a combination of the Hadley circulation and (more importantly for the warm season) regional monsoon circulations (Rodwell & Hoskins, 2001).
- The resulting descent is separated into subtropical highs centered over the ocean basins, and these may be more useful for understanding warm-season precipitation trends (cf. Li et al, 2012).

Methods

- We consider the longitude, latitude, and strength of the North Pacific and North Atlantic Subtropical Highs (NPSH and NASH, respectively).
- We define the longitude and latitude of each high in terms of the centroid of the $P > 1018\ hPa$ region within the rectangle 100°W—180°W, 0—60°N (NPSH) or 0°—100°W, 0—60°N (NASH).
- We define the strength of each high as the mean sea level pressure (SLP) over a 10°x10° box centered at the centroid (cf. Song et al, 2018).

Data Sources

- We use monthly-mean data from the CESM Large Ensemble (CESM-LENS), and from the CMIP5 models.
- For comparison, we also use monthly-mean data from observations and reanalyses. For SLP, we use ERA-Interim, CFSR, JRA-55, MERRA-2, NCEP-DOE, and HadSLP2r. For precipitation, we use the GPCP and CMAP datasets. We truncate all these datasets to the period 1980 to 2016 for consistency.

Short-Term Sensitivity

- Figure 1 shows the SLP and precipitation anomalies associated with changes in the subtropical high indices in the CESM uncoupled control run. Note that changes in longitude, latitude, and strength have comparable impacts, so all three need to be considered.
- Much of this variability would not be captured by the width and strength of the zonal-mean Hadley cell—which have weaker impacts (Fig. 2).

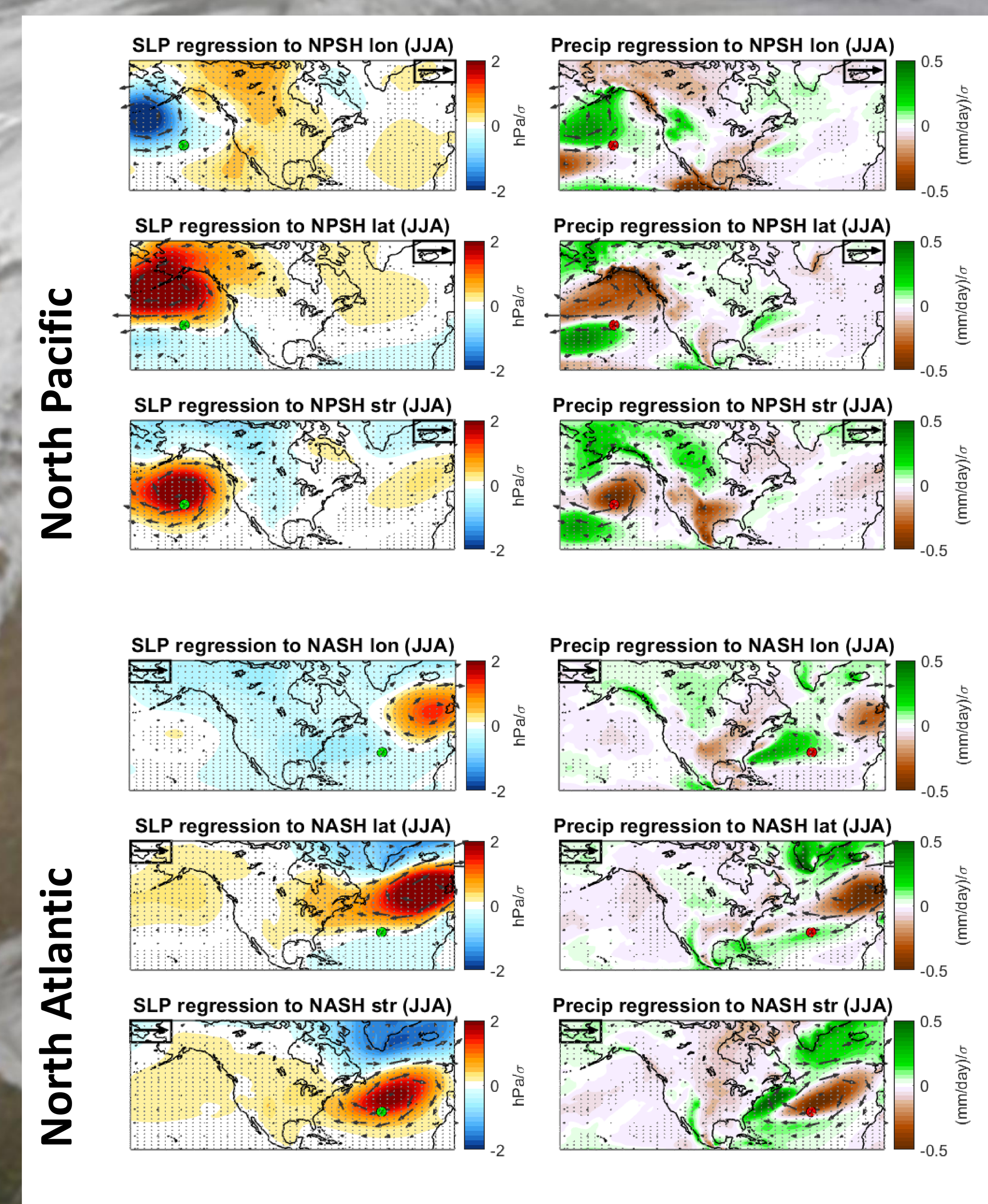

Figure 1. Regressions of local SLP **(left columns)** and precipitation **(right columns)** to the NPSH indices **(top)** or the NASH indices **(bottom)** in the JJA season, using data from the CESM uncoupled control run. Patterns correspond to a 1 standard deviation (sigma) change in the respective subtropical high indices. Stippling indicates that the SLP or precipitation regressions are statistically significant at the $p < 0.01$ level. Gray arrows indicate regressions of 936 hPa wind to the NPSH or NASH indices, with the bold black arrow in the upper right representing 2.5 (m/s)/sigma for scale. The green or red dot represents the climatological position of the high for the JJA season.

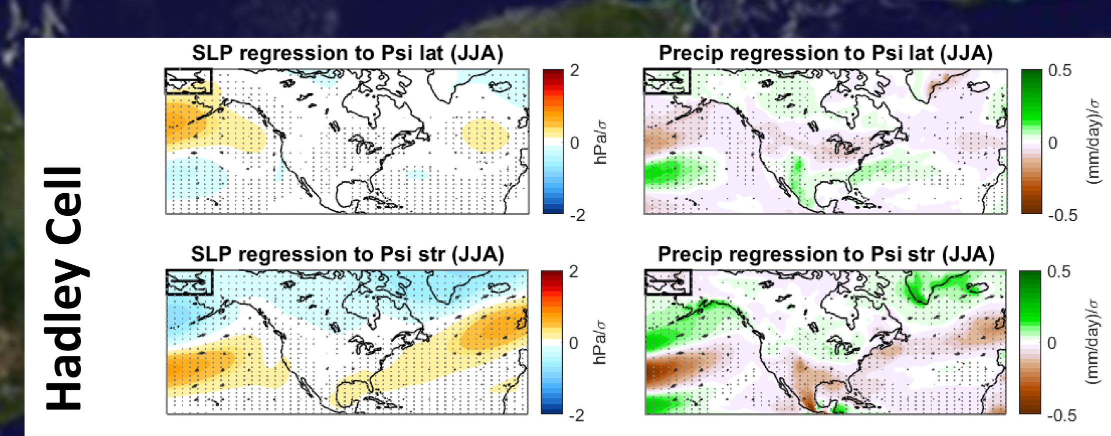

Figure 2. As in Fig. 1, but for the width and strength of the Northern Hemisphere Hadley cell in the JJA season.

Short-Term Sensitivity

- Repeating this analysis for the observations and reanalyses gives similar results (not show).
- Note that Figs. 1 & 2 are based on short-term (month-to-month) variability in the subtropical highs. We now turn to the question of long-term (21st century) trends.

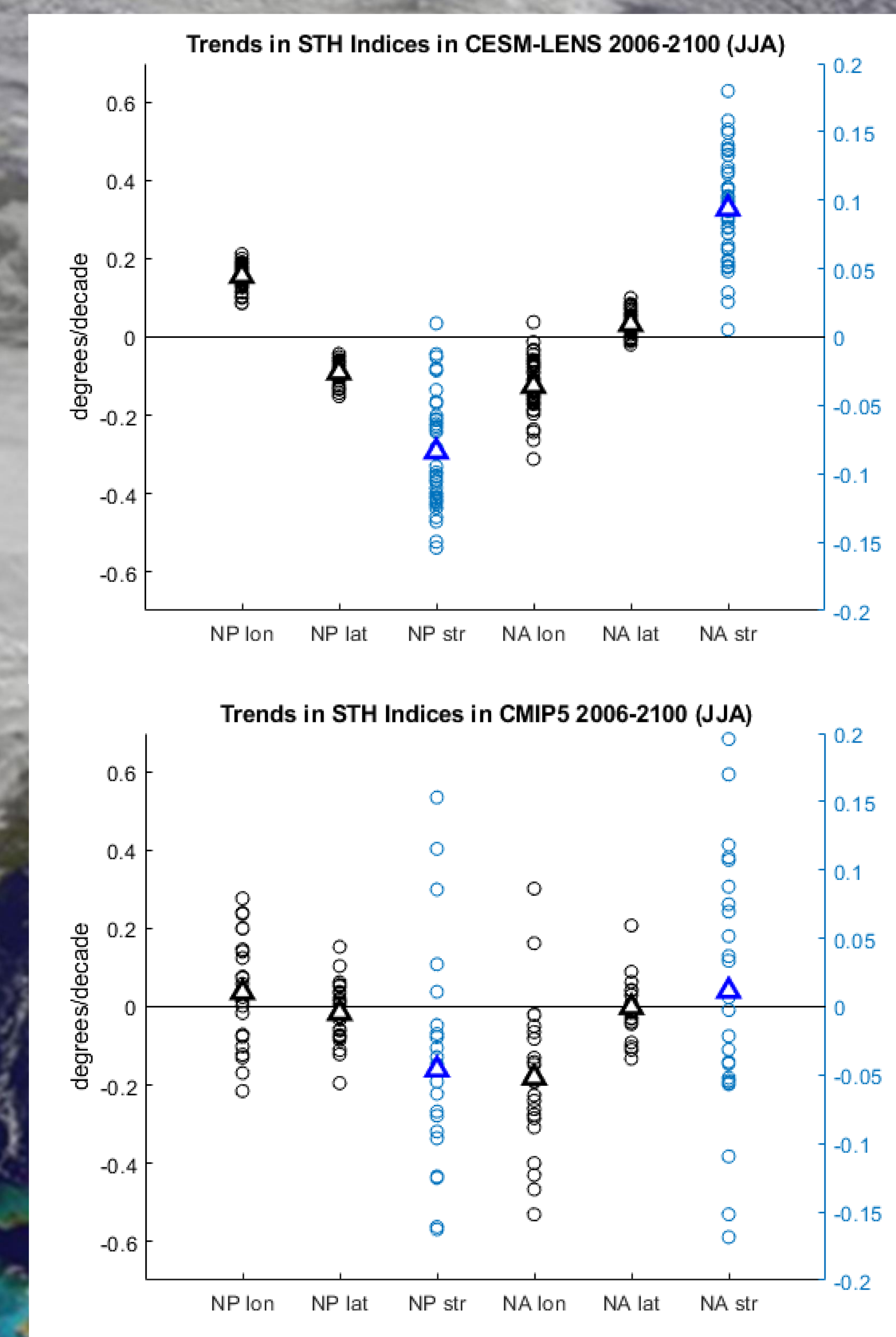

Figure 3. Trends in subtropical high indices according to **(top)** the 2006-2100 RCP 8.5 runs of the CESM Large Ensemble and **(bottom)** the 2006-2100 RCP 8.5 runs of CMIP5. Trends are calculated from JJA seasonal-mean data. Triangles indicate (top) the ensemble mean and (bottom) the multi-model mean.

Trends in Subtropical Highs

- During the 2006-2100 period in the RCP 8.5 scenario, the NASH strengthens and shifts westward (cf. Li et al, 2012) and the NPSH weakens and shifts southeast, according to CESM-LENS (Fig. 3: top).
- CMIP5 results mirror this (Fig. 3: bottom), though the inter-model spread is quite large.

Resulting Trends in Precipitation

- To estimate the precipitation trends associated with each subtropical high index, we multiply the regression of precipitation to the index (Fig. 1) by the trend in the index (Fig. 3).
- The resulting congruent trends are shown in Figure 4.

Resulting Trends in Precipitation

- Note that the longitudes are the most important drivers of precipitation change.
- Also, the trends shown here are much stronger than the analogous precipitation trends congruent to Hadley cell width and strength (not shown).
- Finally, the trends shown here account for 30% or more of the full precipitation trend in some regions.

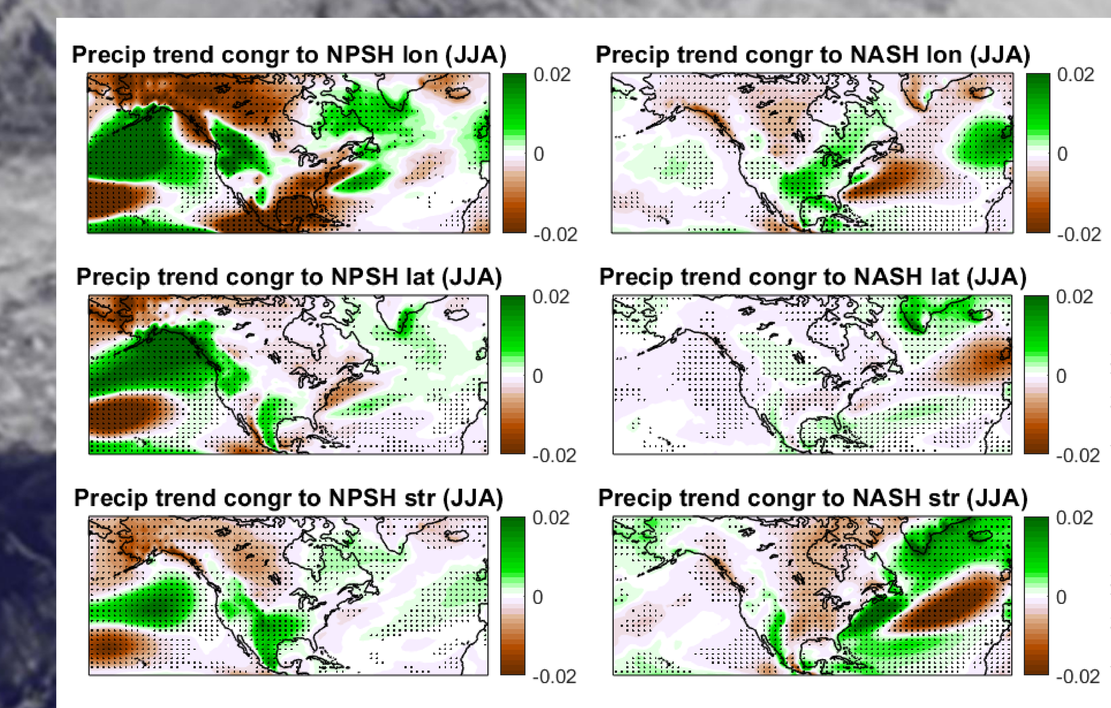

Figure 4. Trends in local precipitation congruent with trends in the various NPSH indices (left panels) and NASH indices (right panels). These are calculated as the product of (1) the regression of local precipitation to each index in the CESM uncoupled control run, and (2) the ensemble-mean trend in the index in CESM-LENS, using years 2006-2100 only. Stippling indicates statistical significance of the regression at the $p < 0.01$ level.

Summary

- Subtropical highs are key drivers of 21st century precipitation trends over North America.
- Subtropical highs have a stronger impact on JJA-season precipitation trends than the Northern Hemisphere Hadley cell.

References

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