Hadley Cell Edge Modulates the Role of Ekman Heat Flux in a Future Climate

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1. Background

- Hadley cells, featuring rising air near the tropics and sinking near the subtropics, are projected to expand poleward due to climate change [1].

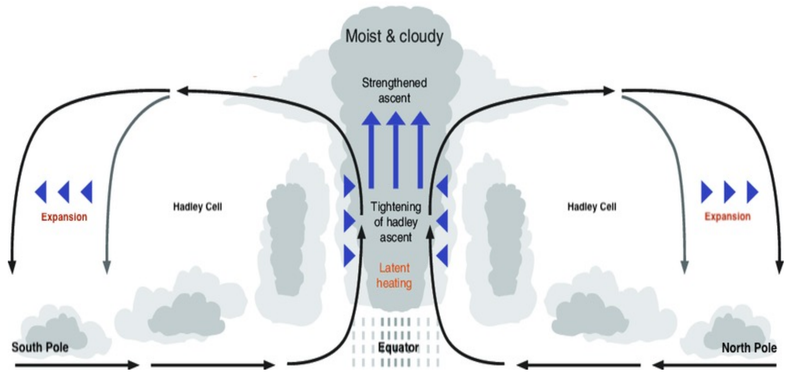

Figure 1. Schematic of the poleward expansion of the Hadley cells [2]

- Easterly surface winds associated with the Hadley cells are also projected to expand poleward [3].

2. Motivation

- Two important drivers of global sea surface temperature (SST) variability are strongly related to the prevailing surface winds [4].
  - Turbulent (latent + sensible) heat fluxes through wind speed
  - Wind-driven Ekman heat flux through wind stress
- Changes in the prevailing surface wind pattern can change the SST variability by modulating turbulent and Ekman heat flux relationships.

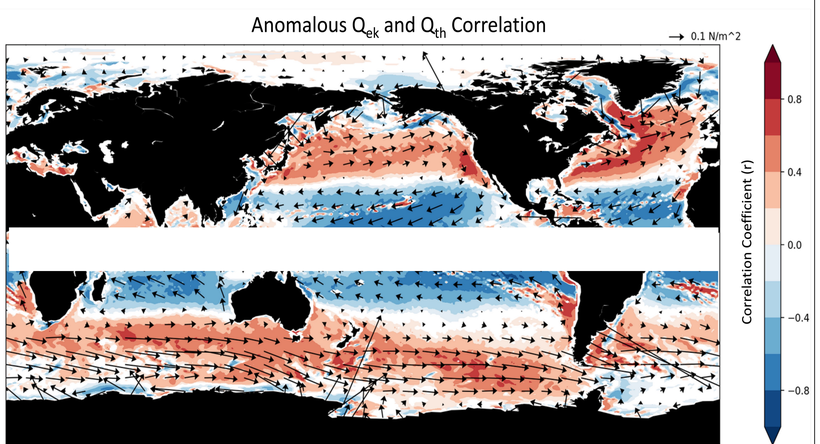

Figure 2. Shadings represent a 95% statistically significant correlation between anomalous Q_{th} and Q_{ek} from the ERA5 dataset. Arrows represent the climatological surface wind-stress

Subtropics: Easterly prevailing wind, **Q_{ek} anomaly opposes Q_{th} anomaly**

Midlatitudes: Westerly prevailing wind, **Q_{ek} anomaly reinforces Q_{th} anomaly**

3. Science Question

Can the projected poleward shift of the Hadley cell boundary correspondingly shift the latitudes where the Ekman heat flux changes its role to turbulent heat flux anomaly?

4. Datasets & Definitions

- Reanalysis Datasets: ERA5, JRA55, NCEP/NCAR (1979-2014)
- Model Datasets: 8 Climate Model Intercomparison Project version 6 (CMIP6) model outputs
  - Period: 1979-2014 (Historical), 2015-2100 (Future Projection)
- **Hadley Cell (HC) Boundary:** Latitude where zonal-mean surface wind stress changes from easterlies (subtropics) to westerlies (midlatitudes)
- **Ekman Transition (ET) Boundary:** Latitude where zonal-mean correlation between Q_{ek} and Q_{th} anomalies changes sign from negative (subtropics) to positive (midlatitudes)

5. Results

Time Evolution of HC and ET Boundaries

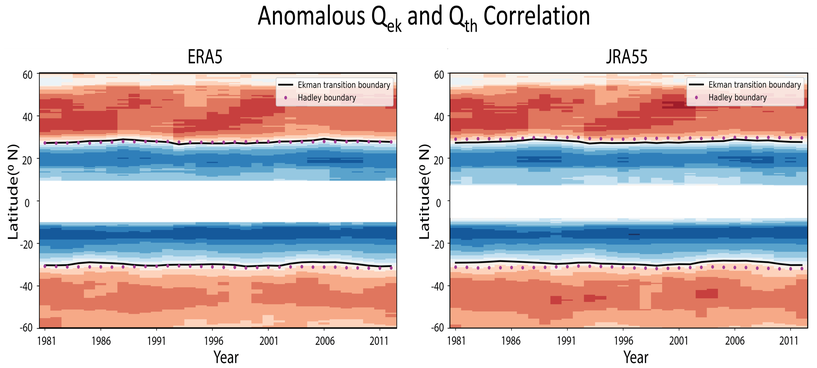

Figure 3. Time-latitude plot of the zonal-mean Q_{th} and Q_{ek} anomaly correlation. Hadley and Ekman Transition boundaries are depicted by dotted and solid lines

- Consistent Q_{ek} and Q_{th} anomaly correlation in the subtropics and mid-latitudes over the historical period.
- Ekman Transition boundary closely follows the Hadley cell boundary.

References

(1) Lu et al., (2008). J. of Clim.
(2) Su et al. (2019). Nat. Commun.
(3) Grise et al., (2019). J. of Clim.
(4) Larson et al., (2018). J. of Clim.

Acknowledgment

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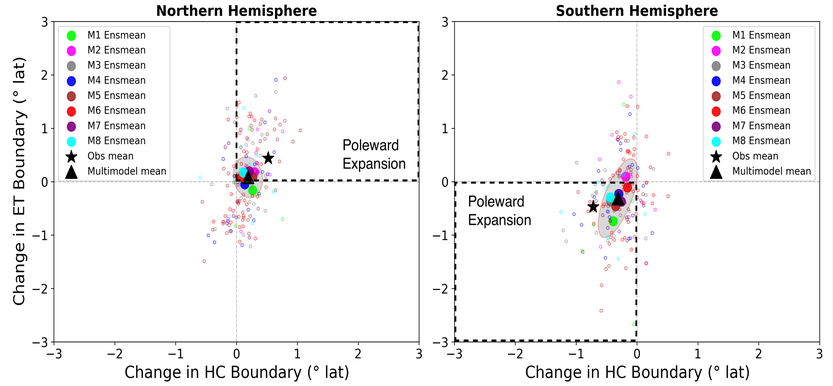
5. Results Continued

Historical Trends



Future Trends

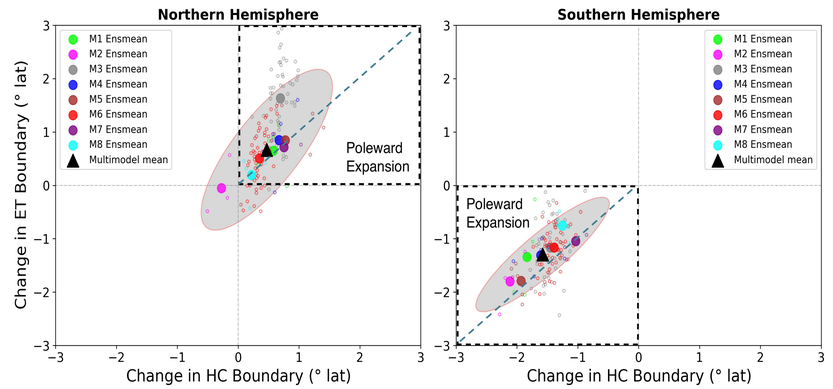


Figure 4. Scatter plot of the trend in the latitudinal position of the Ekman Transition (ET) boundary vs. Hadley Cell (HC) boundary over historical and future climate

- A linear one-to-one relationship between the boundaries.
- Anthropogenic forced response only emerges in future climate.

6. Conclusions

- The Ekman Transition (ET) boundary is generally modulated by the Hadley cell (HC) boundary.
- The anthropogenic trends of both boundaries are small over the historical period.
- The anthropogenic trends emerge in future climate.
  - Potential implications to subtropical SST variability in future climate

7. Future Directions

Quantify the change in the SST variability in the latitudes where the role of Ekman heat flux is projected to change in future climate.