Are the tropics expanding faster than models indicate?

An updated comparison of model trends with observations

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US CLIVAR

Workshop on Confronting Earth System Model Trends with Observations

INTRODUCTION

Fifteen years ago, a number of studies came to the conclusion that Earth's tropical belt, the sinking branches of the Hadley circulation, and the associated subtropical dry zones were expanding rapidly poleward over the satellite era (1979–present), potentially much faster than projected by climate models (e.g., Seidel et al. 2008; Johanson and Fu 2009). At the time, it was suggested that the observed atmospheric circulation may be more sensitive to anthropogenic forcing than models indicate.

Through a series of synthesis studies by the US CLIVAR Working Group on the Changing Width of the Tropical Belt, the differences between the observed and modeled trends were largely reconciled (Waugh et al. 2018; Grise et al. 2019; Staten et al. 2020). First, a careful selection of metrics for the tropical edge was necessary, which minimized sources of error in reanalysis trends. Second, a careful accounting of internal variability was required for model trends to be directly compared with those from observations.

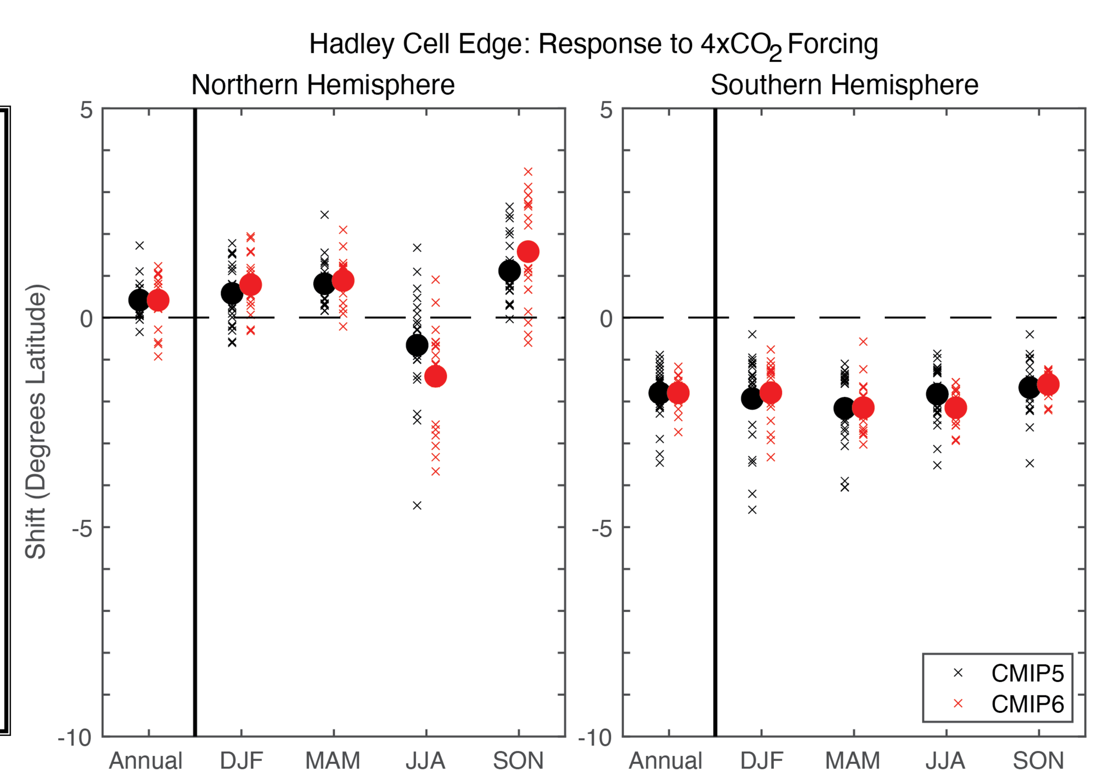
In this poster, we revisit the comparison between modeled and observed circulation trends, now that the satellite-era reanalysis record has extended to 45 years in length (1979-2023).

BACKGROUND

Circulation response to increasing greenhouse gases in climate models (see also Watt-Meyer et al. 2019):

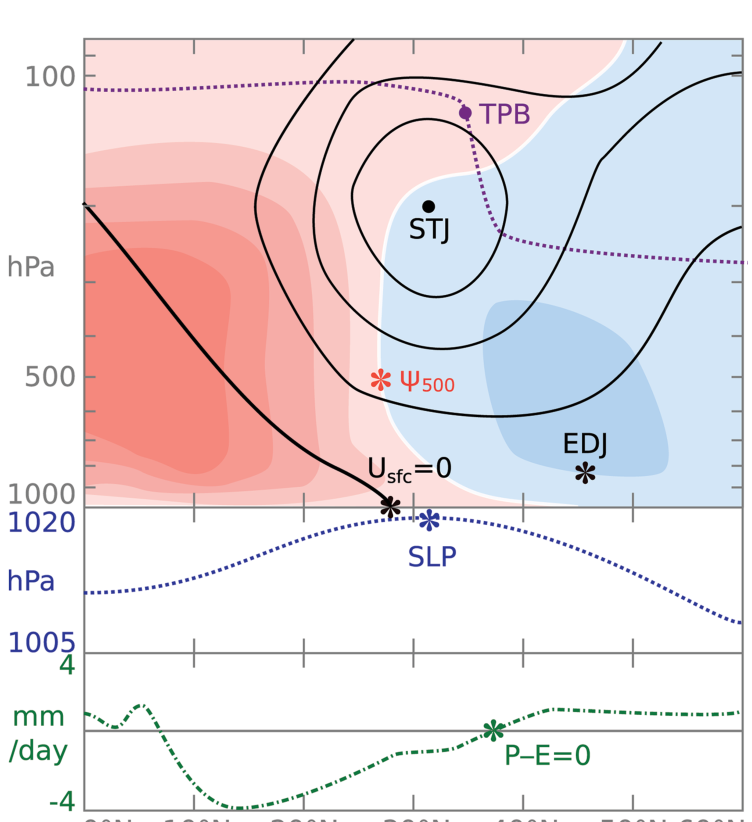
- **Larger poleward expansion in Southern Hemisphere**
- **Little seasonality to expansion in Southern Hemisphere**
- **Poleward expansion in Northern Hemisphere fall (SON) similar to that in Southern Hemisphere**

If anthropogenic forcing is dominating observed trends, we should see similar signals in observations.



Grise and Davis (2020) (based on U_{sfc} metric, 4xCO$_2$ – piControl)

METHODS



Staten et al. (2020)

Four metrics for tropical expansion:

SLP	**Latitude of zonal-mean sea level pressure (SLP) maximum in subtropics**
Ψ_{500} (PSI)	**Latitude where 500 hPa mean meridional streamfunction changes sign in subtropics**
U_{sfc}	**Latitude where zonal-mean surface easterlies transition to surface westerlies**
EDJ	**Latitude of zonal-mean zonal wind maximum at 850 hPa (eddy-driven jet)**

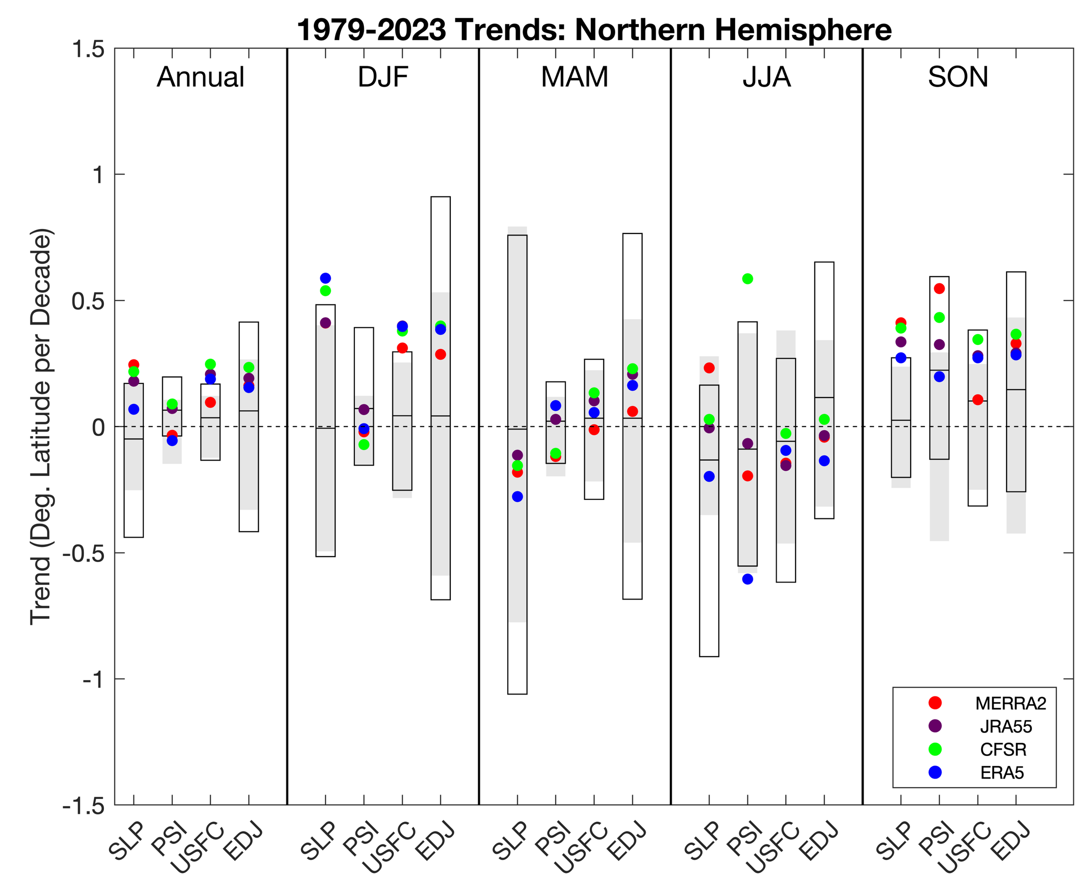
Interannual variability in these metrics are highly correlated with one another, suggesting that they measure similar dynamical variations (Waugh et al. 2018).

Metrics are calculated using a standard open-source code package (TropD; Adam et al. 2018).

BEST PRACTICES FOR COMPARISON

1. **Use multiple circulation metrics, which are calculated using different quantities but co-vary strongly on an interannual basis. For reanalysis data, focus on metrics that are tightly constrained by assimilated data.**
2. **Use multiple observational or reanalysis data sets to characterize observed trends, which can vary substantially across data sets.**
3. **Apply identical methods to calculate circulation metrics in observations and models, ideally with shared open-source software and documentation so that studies by different authors can calculate metrics consistently.**
4. **Consider individual model ensemble members (not just the multi-model mean) when comparing to observed trends. Also, consider the uncertainty in, and spread of, observed trends.**
5. **If available, examine both fully-coupled and prescribed sea surface temperature (SST) model runs, in case that observed coupled atmosphere-ocean variability is not replicated in the internal variability of the fully-coupled model runs.**

TRENDS IN CIRCULATION METRICS



Annual, DJF: Observed trends in SLP and U_{sfc} metrics greater than CMIP models' historical runs

MAM, JJA: Observed trends do not exceed models' control variability.

SON: Observed poleward shift in all four metrics; magnitudes more likely in presence of historical forcing
Seasonality consistent with greenhouse gas forcing!

Observed Trends from Reanalysis:

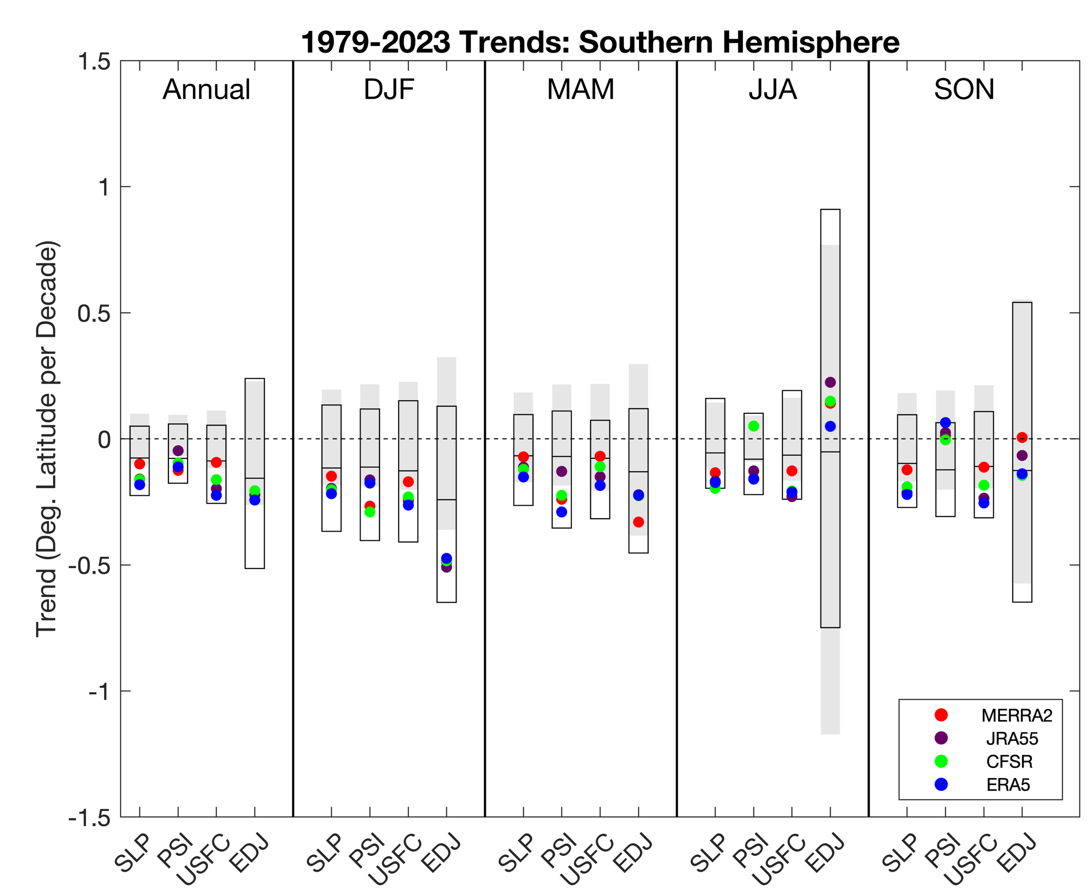
- **NASA MERRA version 2 (MERRA2) (1980–2023 period for MERRA2)**
- **Japanese 55-year reanalysis (JRA55)**
- **NOAA Climate Forecast System (CFSR)**
- **ECMWF reanalysis version 5 (ERA5)**

Multi-Model Mean

Range of 45-year CMIP pre-industrial control trends

Range of CMIP 1979-2023 trends: Historical + RCP8.5/SSP5-8.5

24 CMIP5 models, 20 CMIP6 models (see Grise and Davis 2020)



Observed poleward shift in all four metrics during DJF and MAM; SLP and U_{sfc} metrics shift poleward during all seasons.

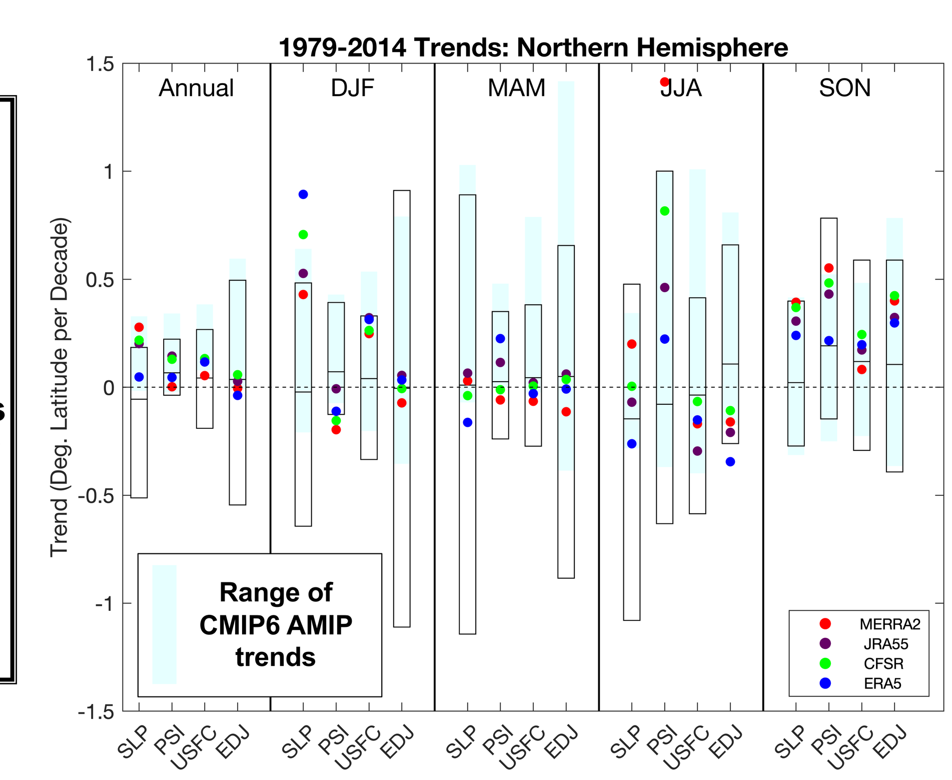
DJF: Season of largest observed poleward circulation shift; magnitudes more likely in presence of historical forcing
Seasonality consistent with stratospheric ozone depletion!
(e.g., Waugh et al. 2015)

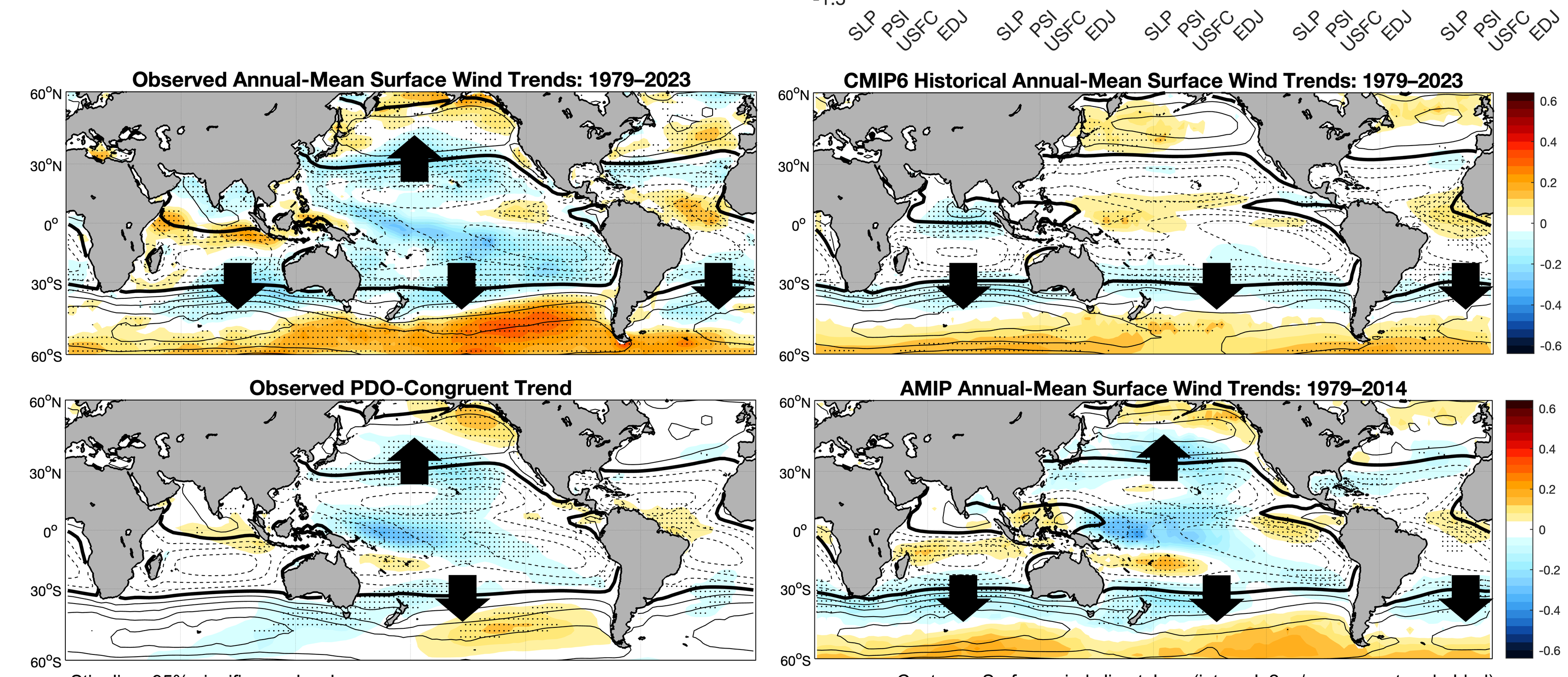
ROLE OF RECENT SST TRENDS

Trends over 1979–2014 period are similar in character to those over 1979–2023 period.

Model runs with SSTs prescribed to observations (AMIP) show slightly greater poleward circulation shifts in the Northern Hemisphere, suggesting that any current discrepancy between observed and fully-coupled (CMIP) model circulation trends can be explained by the coupled models' inability to replicate recent SST trends.

New CERESMIP experiments (Schmidt et al. 2023) will extend AMIP runs to present-day, allowing for better evaluation of current trends.





Stippling: 95% significance level

Contours: Surface wind climatology (interval: 2 m/s; zero contour bolded)

Observed circulation trends in the Northern Hemisphere resemble those driven by recent SST trends, particularly the trend toward the negative phase of the Pacific Decadal Oscillation (PDO).

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