Supplement of

Large Uncertainty in Observed Meridional Stream Function Tropical Expansion

Daniel Baldassare[1], Thomas Reichler[1], Piret Plink-Björklund[2], and Jacob Slawson[2]

- [1]Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT 84112, USA
- [2]Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80401, USA

Correspondence: Daniel Baldassare (daniel.baldassare@utah.edu)

Table S1: Intermember Trend STD

Intermember Trend STD

		MAM	JJA	SON	DJF	ANN
NH	SF	0.011	0.004	0.006	0.011	0.004
	STJ	0.003	0.002	0.003	0.011	0.002
	EDJ	0.005	0.009	0.006	0.002	0.002
	P-E	0.011	0.027	0.017	0.018	0.009
	UAS	0.002	0.003	0.002	0.002	0.002
	PSL	0.002	0.001	0.001	0.001	0.001
SH	SF	0.010	0.118	0.009	0.005	0.005
	STJ	0.005	0.001	0.002	0.002	0.004
	EDJ	0.004	0.005	0.004	0.004	0.003
	P-E	0.030	0.263	0.015	0.017	0.019
	UAS	0.002	0.003	0.003	0.002	0.001
	PSL	0.003	0.002	0.003	0.004	0.001

Table S1: HC trend intermember standard deviation (degrees per decade) in each hemisphere, for all seasons and the annual mean, of all six metrics across the nine ensemble members. Results are qualitatively similar to the kernel density estimates (Fig. 1, Fig. 2) but instead provide a single uncertainty value rather than a range of probable values.

Text S1: Meridional and zonal wind errors

The normalized error in meridional wind was found to be much larger than zonal wind, as shown in Fig. S1. The larger normalized differences between ensemble members in meridional wind compared to zonal wind indicate that the greater uncertainty in SF compared to STJ, EDJ or UAS may be the result of larger relative errors in the underlying data. The non-normalized intermember STD for meridional wind was found to be of similar magnitude to zonal wind (not shown), with the low absolute values and subsequent smaller time variation resulting in larger normalized errors.

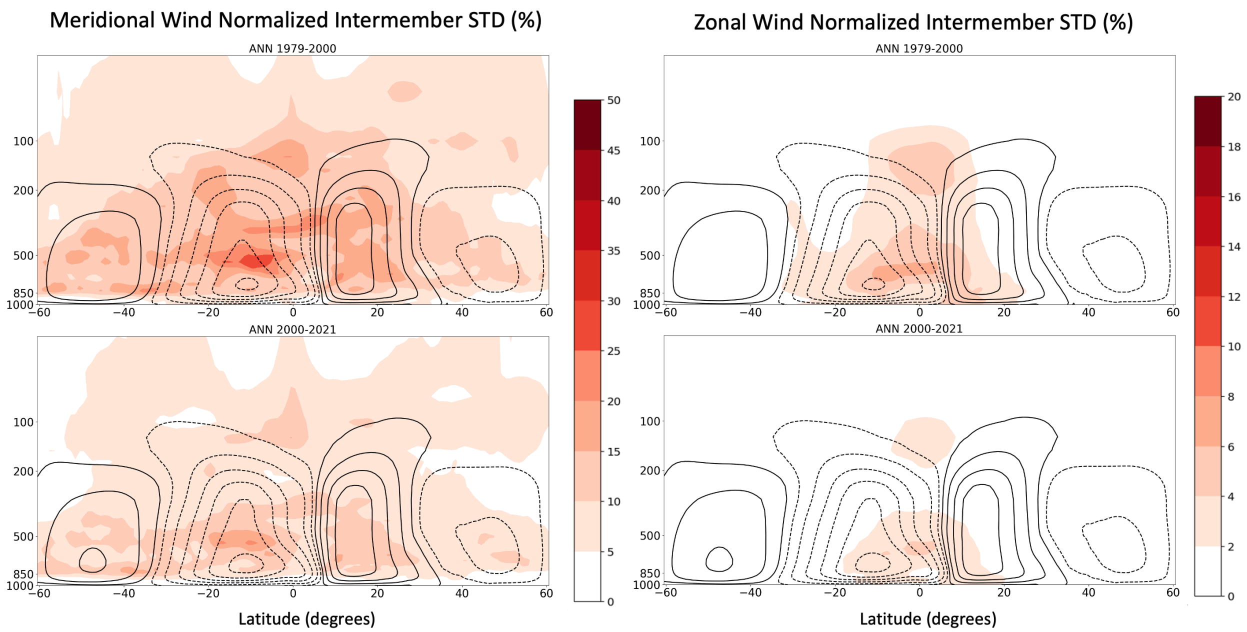

Fig. S1: Annual mean meridional wind (left) and zonal wind (right) normalized intermember STD (%) from 1979-2000 (top) and 2001-2021 (bottom). Note the different scales for meridional and zonal wind due to the much larger errors in meridional wind.

Text S2: Unenclosed stream function northern hemisphere summer 2019 and 2020

The NH JJA HC in 2019 and 2020 was found to be unenclosed in some ensemble members, with no positive circulation near 500 hPa and 20 degrees North. In 2019 a majority of ensemble members showed these features, while in 2020 only one member did not have a single enclosed cell in the NH. These were the only two years where this behavior occurs. A variety of climatic oscillations were checked in the attempt to find an explanation for why this only occurs in these two years, but no satisfactory explanation was found. Examples of the unenclosed circulation are shown in Fig. S2. The SF metric is not able to calculate a HC extent in this situation, leading to imperfect estimates of SF uncertainty.

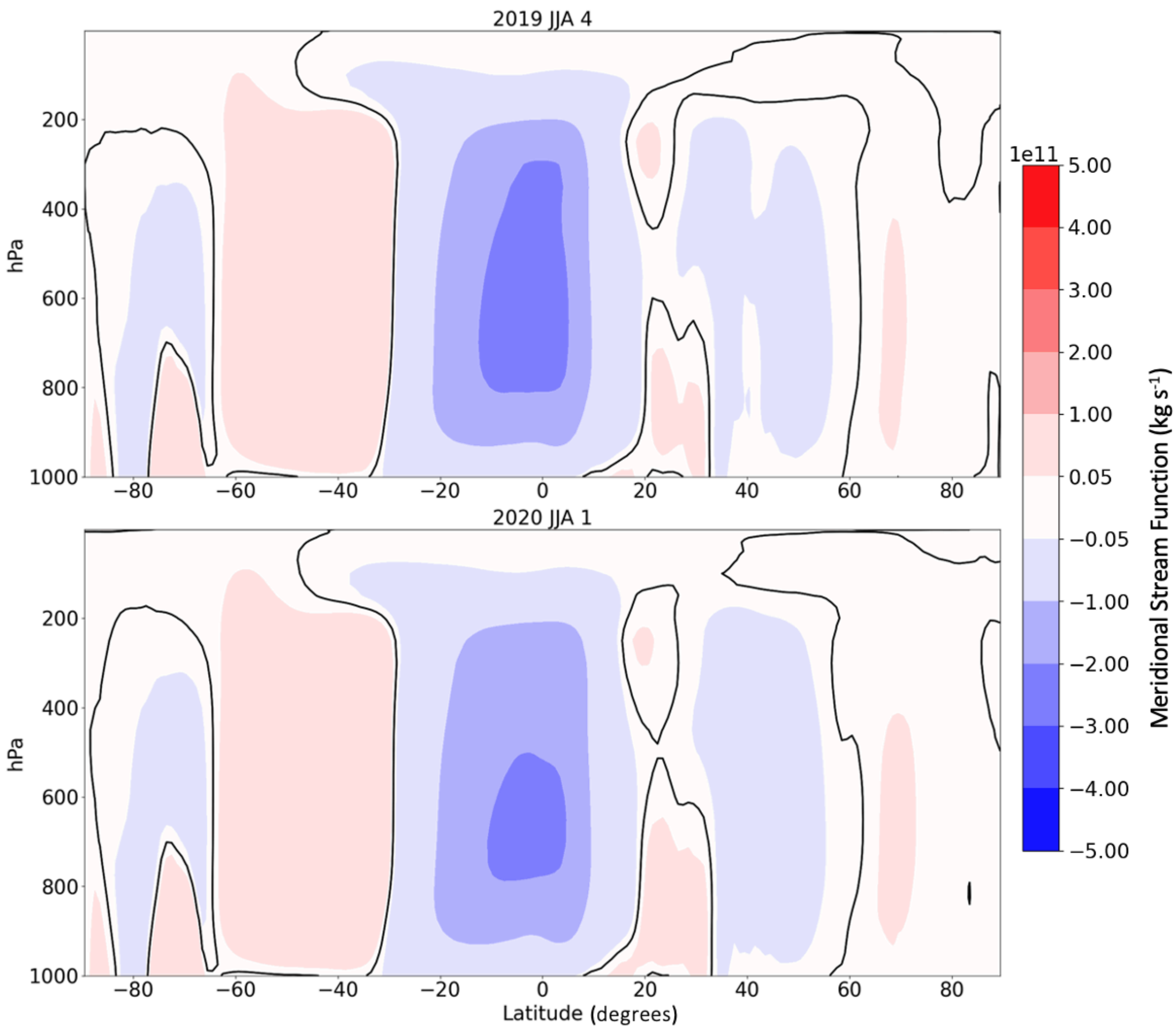

Fig. S2: SF values (kg s^{-1}) for ensemble member 4 in JJA 2019, and ensemble member 1 in JJA 2020, showing an unenclosed NH HC. The black contours indicate the zero-crossing, while shading signifies SF intensity. Note the region near 500 hPa and 20 degrees in both years where there is no positive circulation.

Text S3: Poor correlation between climatological mean SF uncertainty and SF extent

The climatological mean SF uncertainty and climatological mean SF extent were not found to be well correlated in this analysis, leading to the interpretation that climatological mean SF uncertainty is best explained by Δ. The scatter plot of these two variables is shown in Fig. S3. The SF uncertainty near the tropical edge at 500 hPa does not vary noticeably by season or hemisphere, while the extent STD does.

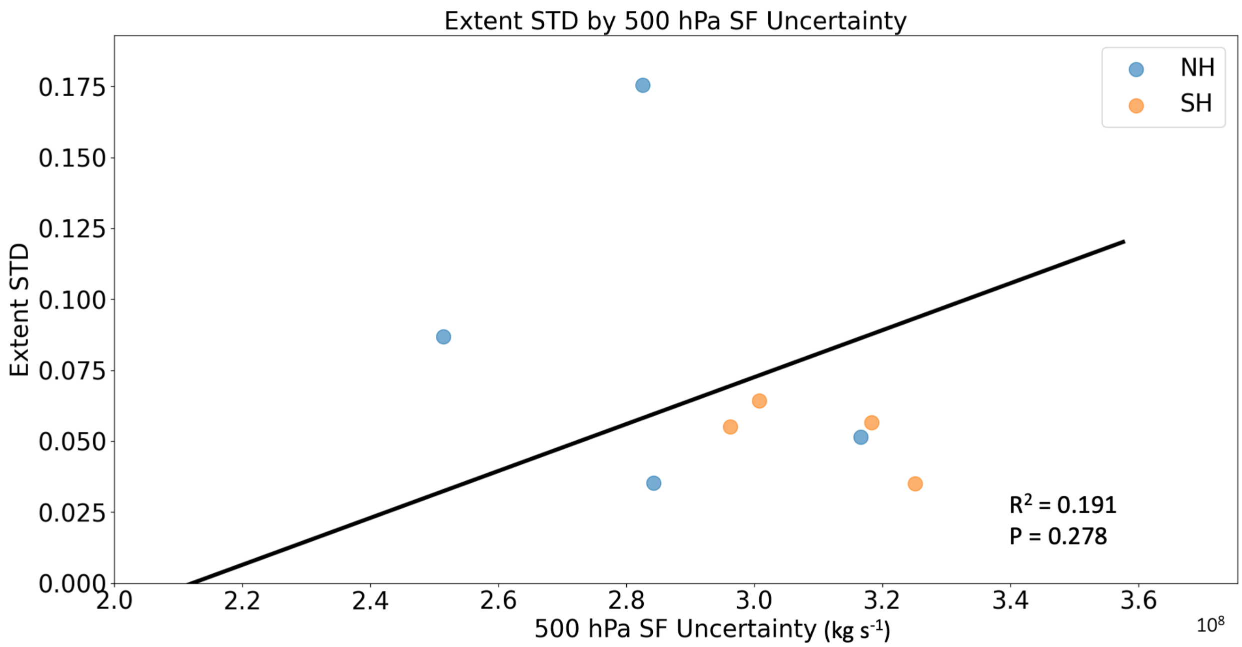

Fig. S3: Climatological mean SF extent STD (degrees latitude) by 500 hPa SF uncertainty (kg s^{-1}) near the tropical edge, showing no significant relationship.

Text S4: Annual mean SF extent STD and Δ

When analyzing the annual mean SF uncertainty over individual years, Δ is a poor predictor. The relationship between these two variables is shown in Fig. S4. The width of Δ does not change noticeably during the time period of this study, while the extent STD decreases. Further, Δ is most noticeable in the difference between seasons and hemispheres, and is less important in the annual mean.

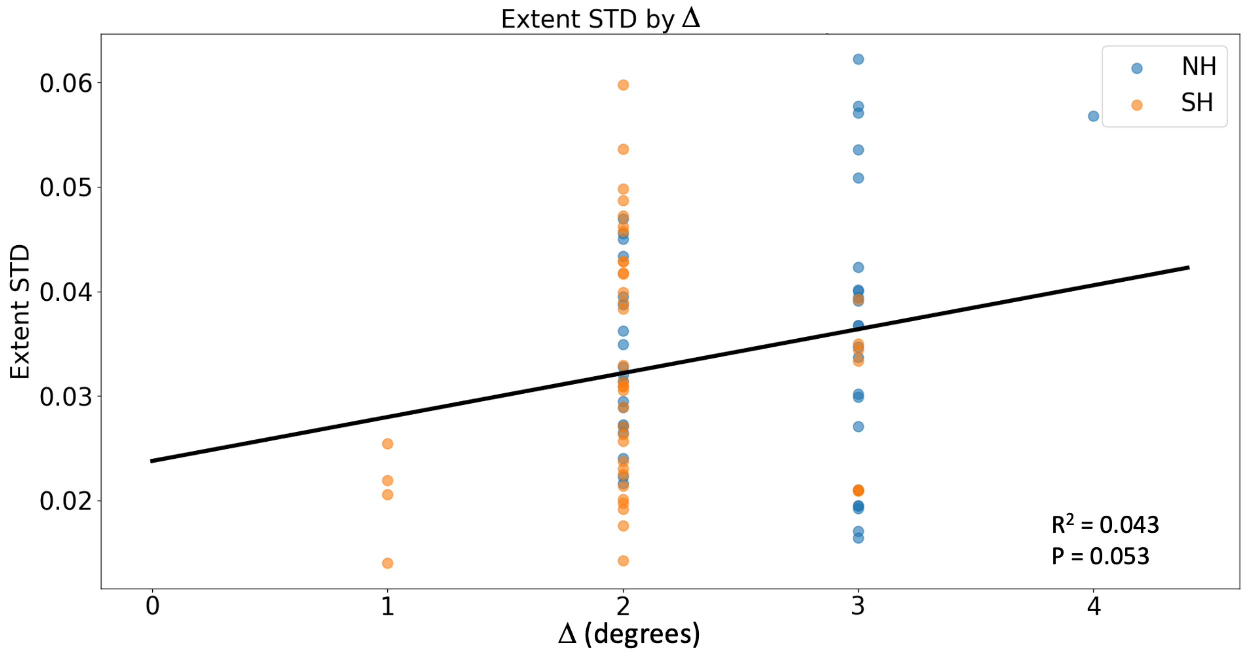

Fig. S4: Annual mean extent STD (degrees latitude) by Δ (degrees latitude), demonstrating that Δ is not a useful predictor of SF extent STD in the annual mean.

Text S5: SF trend STD by 500 hPa SF uncertainty

Similar to the climatological mean SF extent STD, no relationship was found between the SF trend STD and the 500 hPa SF uncertainty. The trend uncertainty differences between seasons are not well-described by the SF error differences, indicating that the particularly poor performance of SF in NH JJA is unrelated to data error.

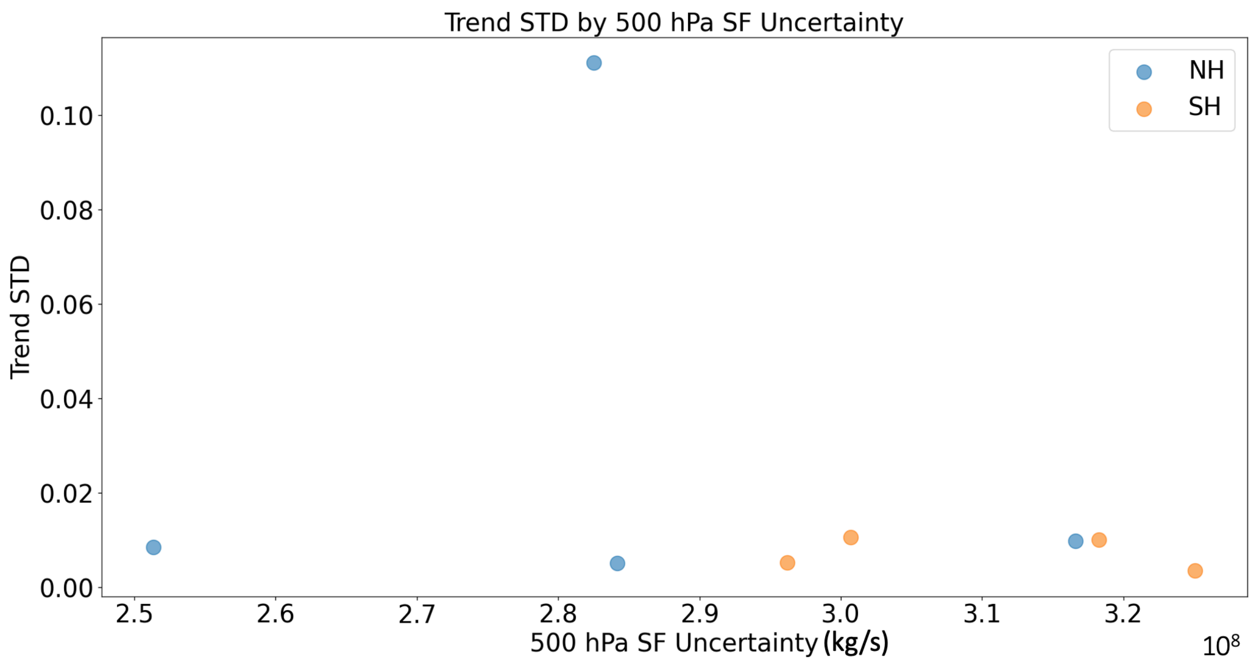

Fig. S5: SF trend STD (degrees per decade) by 500 hPa SF uncertainty (kg s^{-1}) for all four seasons in both hemispheres.

Text S6: SF trend STD by Δ

Aside from NH JJA, which features both large trend STD and large Δ, the relationship between trend STD and Δ among seasons is unclear. However, it is shown here that the large trend STD in NH JJA is caused by the large Δ values during this season as the small perturbations in reanalysis data are able to cause large differences in trend. Here we can see once again the Δ functioning as a sensitivity to data error.

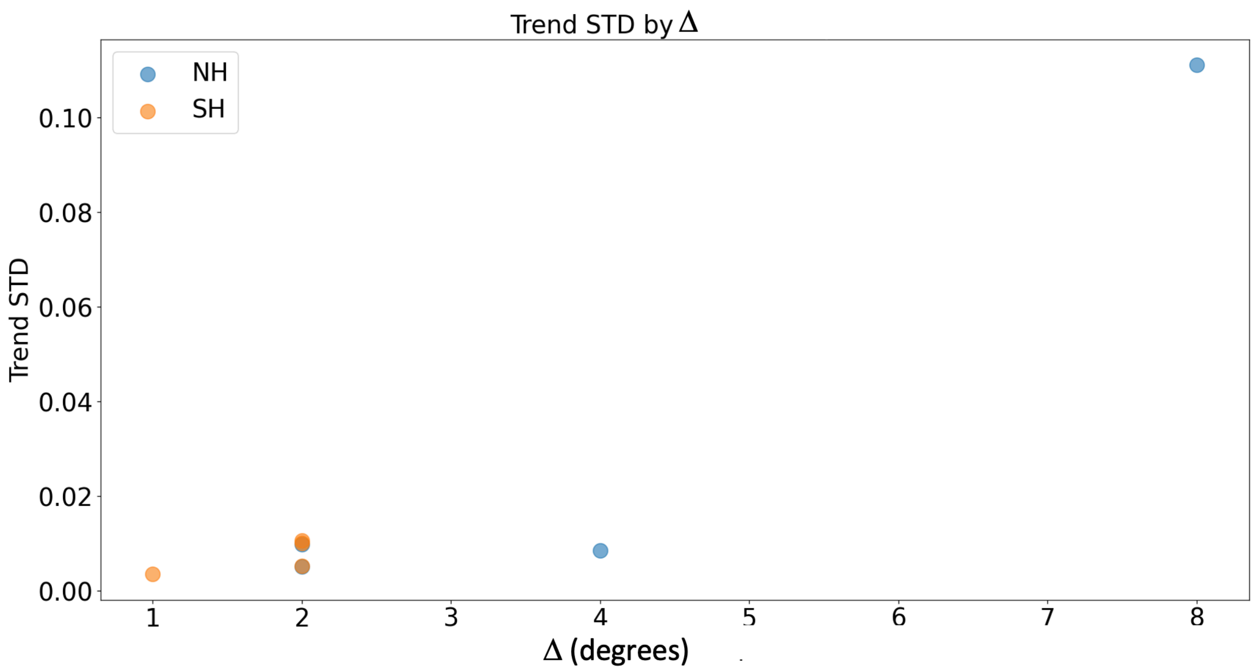

Fig. S6: SF trend STD (degrees per decade) by Δ (degrees) for all four seasons in both hemispheres.

Table S2: Improvements in HC extent uncertainty

As shown in Fig. 3, the HC extent uncertainty improves from 1979-2022 for almost all metrics in every season and the annual mean. This coincides with increasing quantity and quality of observations. Here, we quantify the improvement in the annual mean uncertainty by applying a linear best fit to the time series of intermember extent STD for each metric in the NH and SH. This results in larger improvements for the least certain metrics, P-E and SF, though improvements are substantial for all metrics in both hemispheres.

ANN Extent Intermember STD Change (degrees per decade)

	SF	STJ	EDJ	P-E	UAS	PSL
NH	-0.0042	-0.0033	-0.0011	-0.0065	-0.0010	-0.0014
SH	-0.0074	-0.0037	-0.0041	-0.0021	-0.0020	-0.0012

Table S2: Annual mean HC extent intermember STD change (degrees per decade) for all six metrics in both hemispheres.