Large-Scale Transport Responses to Tropospheric Circulation Changes Using GEOS-5

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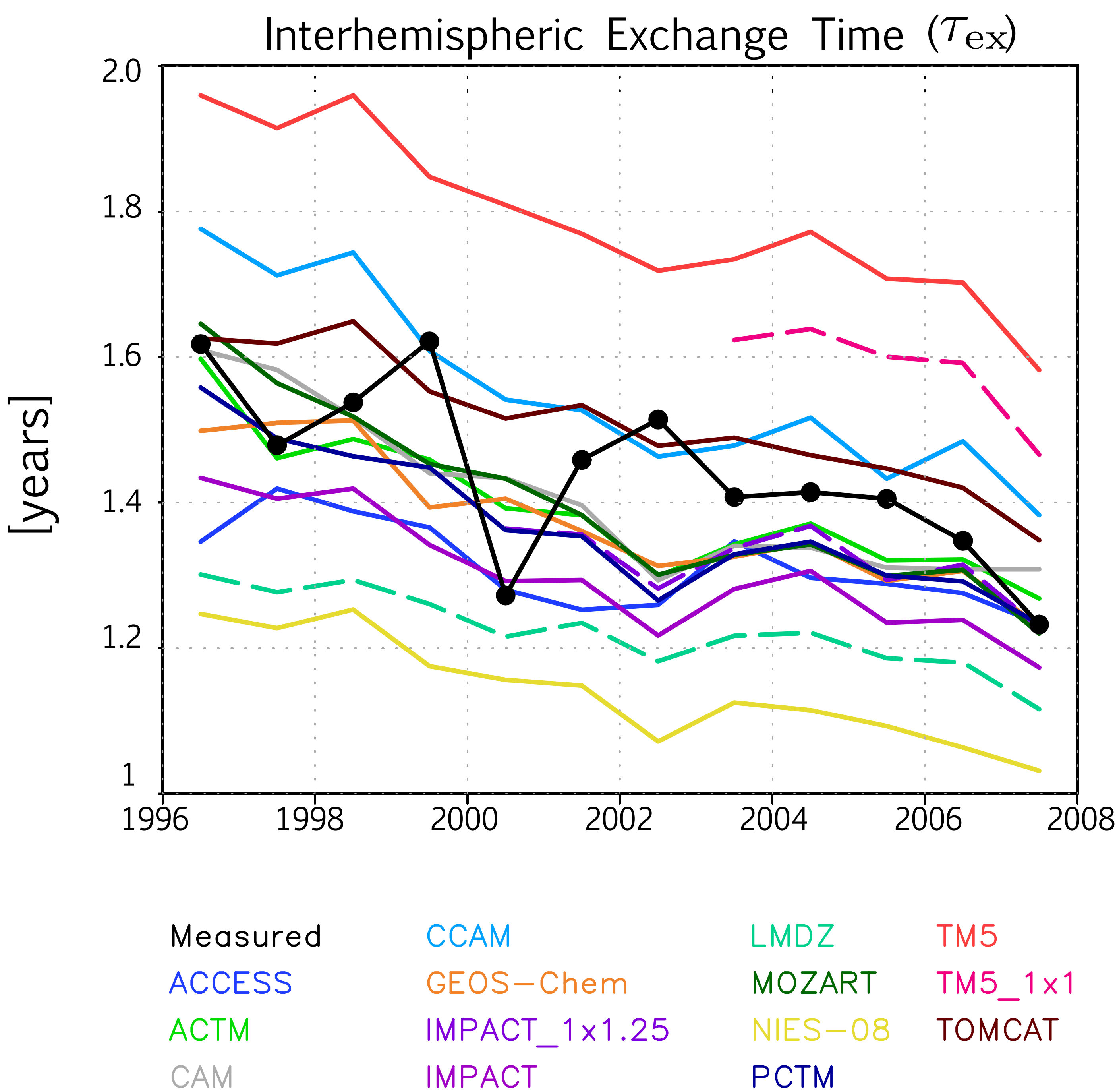
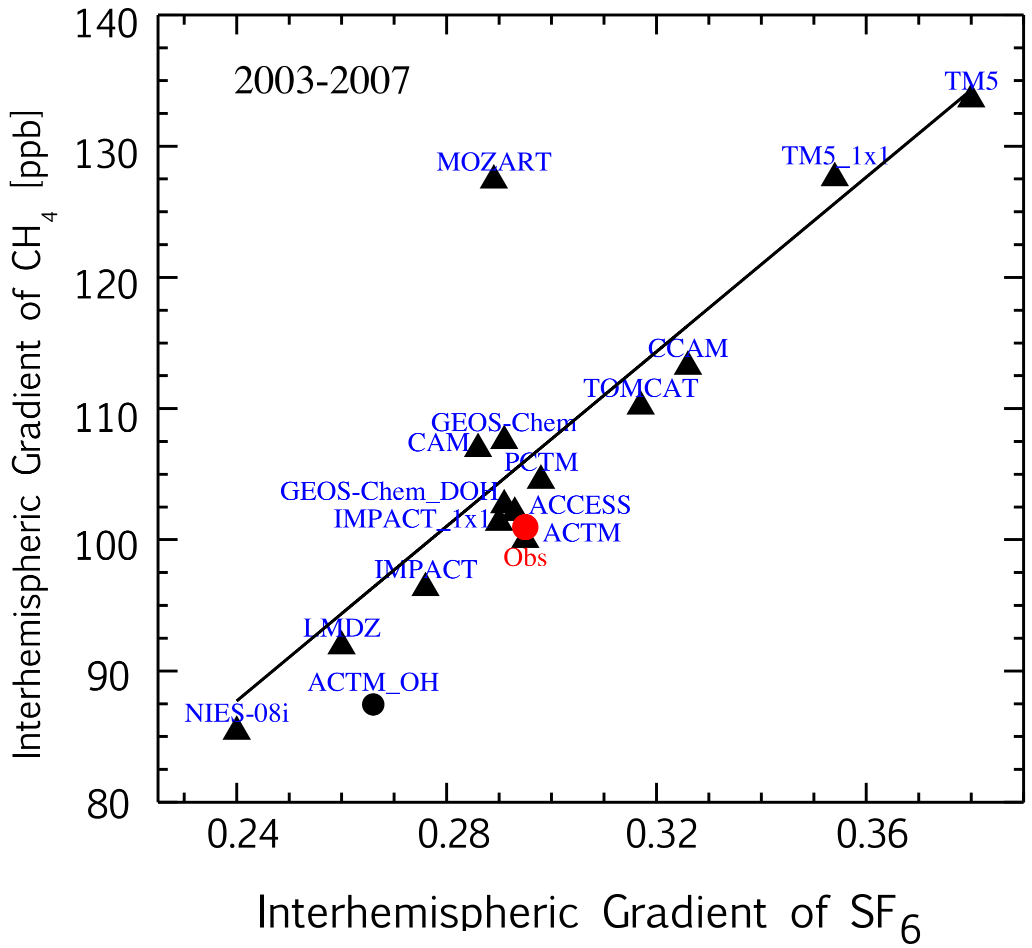
Motivation

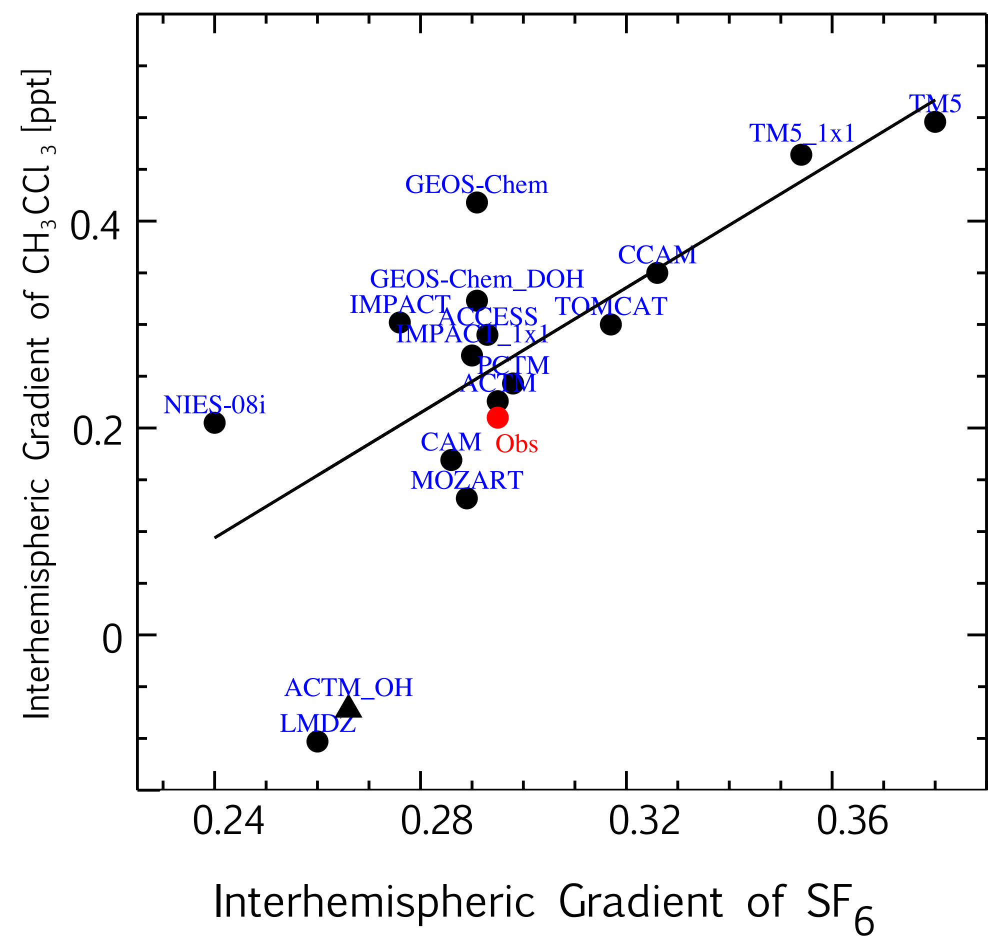
- Previous studies show that there are large interhemispheric transport differences among models (*Patra et al. (2011)*).



Background

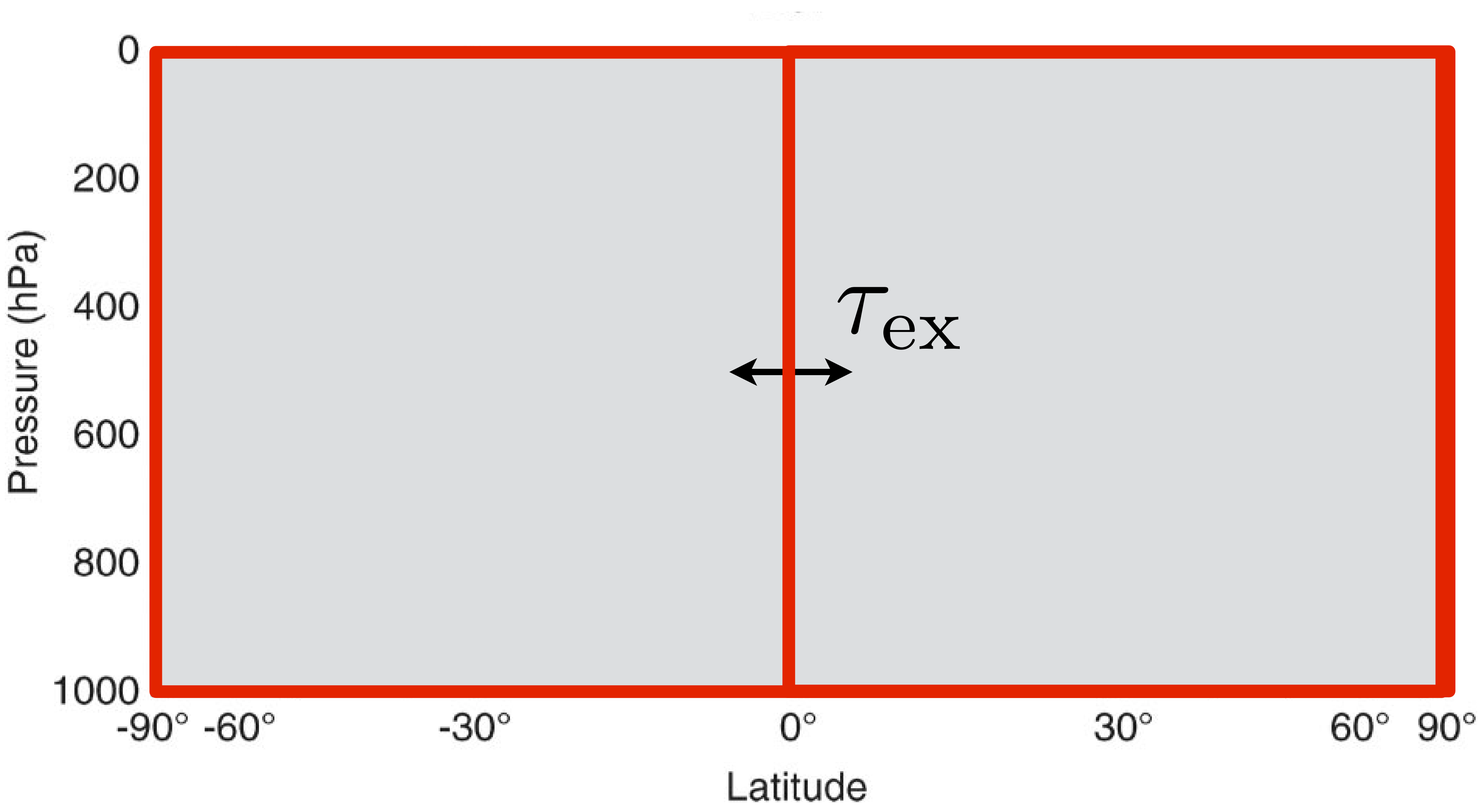
- Large interhemispheric transport differences have been linked to large differences in composition among models (*Patra et al. (2011)*).





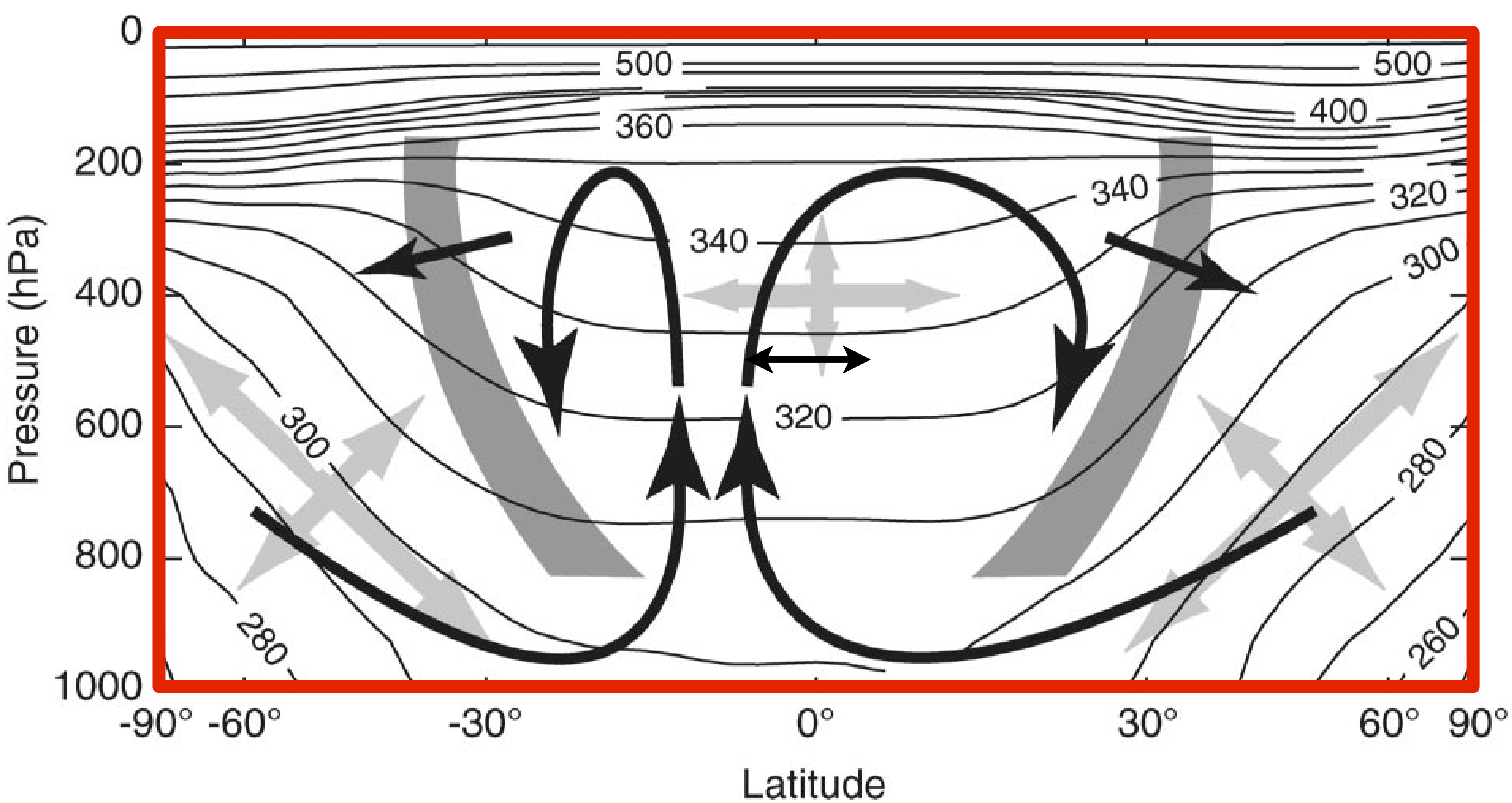
Background

- Interhemispheric transport differences among models are poorly understood.
- This is partly due to the use of gross hemispherically integrated transport diagnostics like the interhemispheric exchange time ($\tau_{\rm ex}$), which treat the transport circulation like two well-mixed boxes.



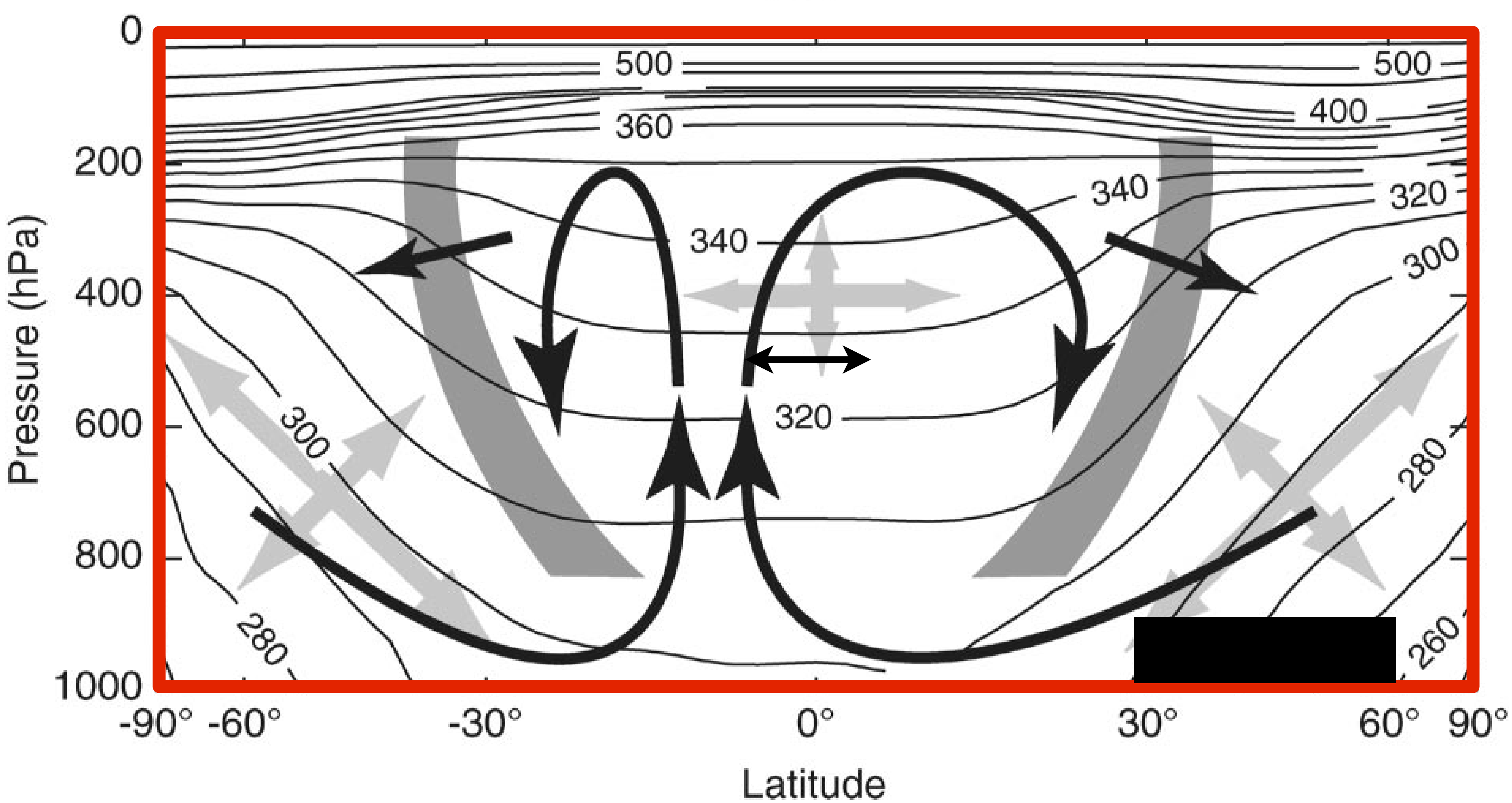
Background

- We know, however, that the large-scale transport circulation reflects transport both *within the deep tropics* and transport *across tropical-extratropical mixing barriers.*



Background

- Moreover, most anthropogenic emissions of greenhouse gases and ozone-depleting substances are located in the NH underworld, where they encounter a transport barrier en route to the tropics.



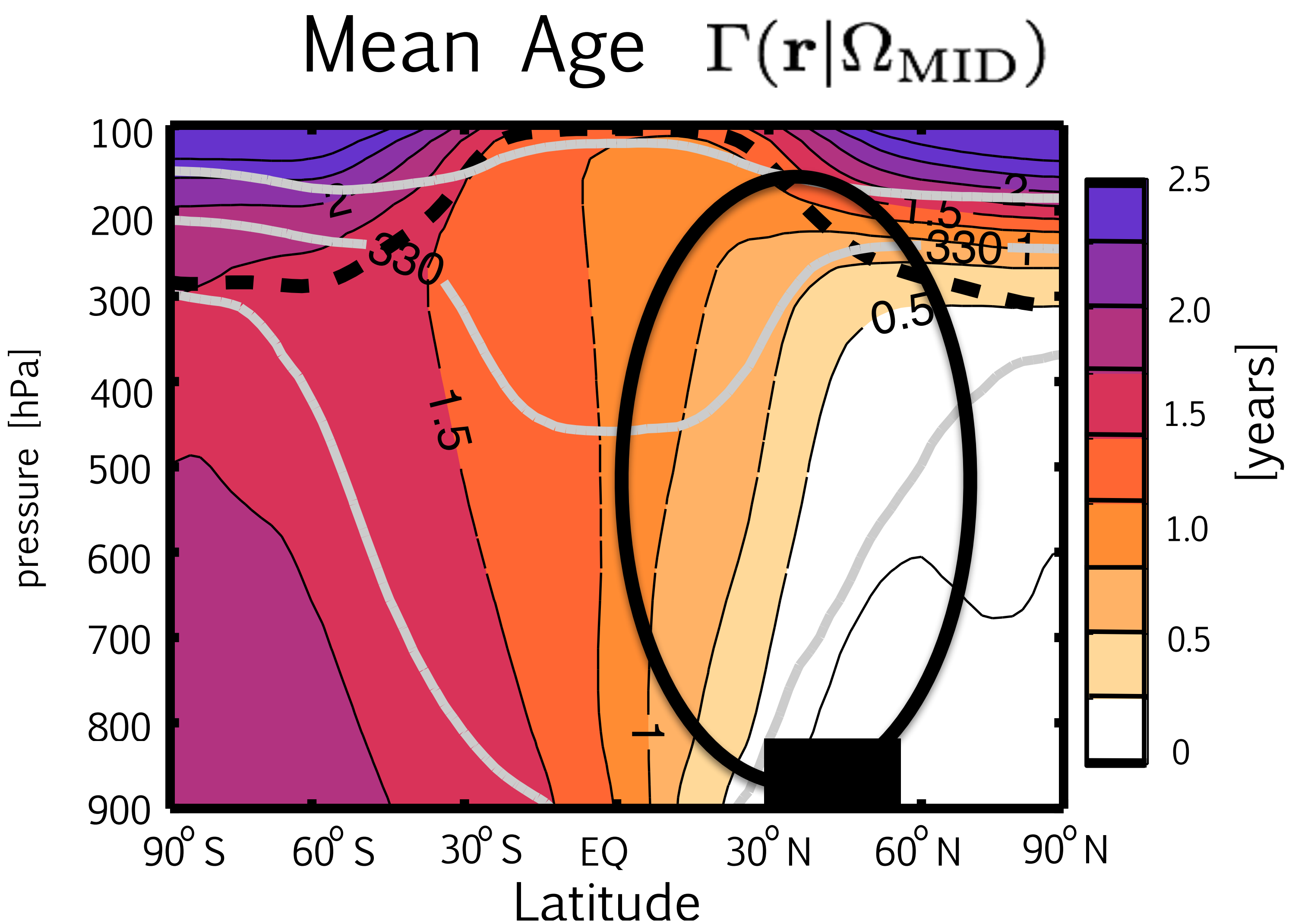
adapted from *Bowman and Erukhimova (2004)*

Background

- *Waugh et al. (2013)* diagnose interhemispheric transport in terms of the NH tropospheric mean age since air was last at the midlatitude surface. As such the “NH midlatitude mean age” is the mean of the Green’s function of the transport operator, often called the “transit time distribution” (TTD) or “age spectrum” (*Hall and Plumb (1994), Holzer and Hall (2000)*).

Background

- Simulations of the mean age in GCMs reveal strong gradients in the northern subtropics and extratropics, supporting the existence of a tropical-extratropical transport barrier (*Orbe et al. (2016)*).



Objective

- Similar to *Waugh et al. (2013)* we focus on interhemispheric transport between the northern and southern midlatitudes with a focus on *how that transport is affected by circulation changes in the tropics.*
- We perform numerical experiments using the Goddard Earth Observing System, Version 5 GCM (*Suarez et al. (2008)*), wherein the strength of the tropical circulation is changed by altering one parameter in the (deep) convective parameterization.
- The large-scale transport response to tropical circulation changes is measured using passive tracers with both subtropical and midlatitude surface sources.

Experiments

Experiment	Perturbation Region	Integration Length
+3K South Tropics	10°S - EQ	10 years
+3K North Tropics	EQ - 10°N	10 years
+3K Northern Subtropics	10°N - 30°N	10 years

- Tropical circulation anomalies are induced by perturbing one parameter in the model's deep convective parameterization.
- Three perturbations are applied over different tropical and subtropical bands. The perturbation amplitude is within the range of uncertainty in the convective parameterization.
- Significance of the response is assessed relative to internal variability within each ten-year-long simulation.

Large-Scale Transport Diagnostics

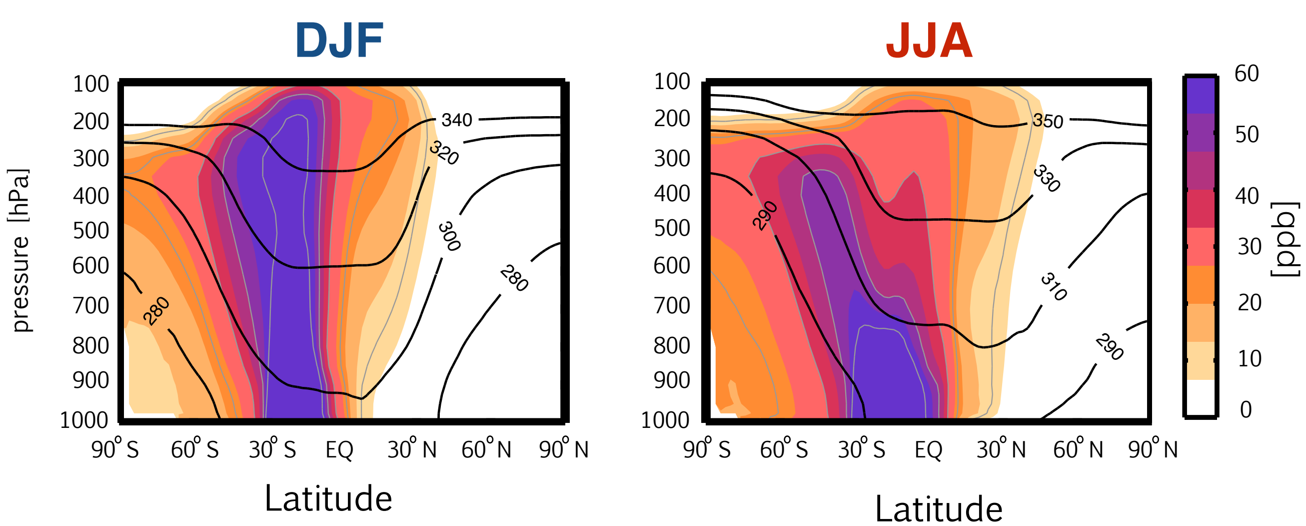
- We focus on idealized exponential loss and mean age tracers emitted over NH midlatitudes (30°N-50°N) and the subtropics (10°S/N-30°S/N). These are similar to (part of) the tracer suite integrated in the Chemistry Climate Modeling Initiative (CCMI) (*Eyring et al. (2013)*, *Orbe et al. (2017)*).

Tracer (χ)	Notation	Boundary Condition	Source (S)
NH Mean Age*	Γ_{MID}	0	1 year/year
NH Midlatitude 50-day Exponential Loss	$\chi_{\mathrm{NH},50}$	100 ppb	$-\chi/\tau_c$
NH Subtropical 50-day Exponential Loss	$\chi_{\mathrm{NTR},50}$	100 ppb	$-\chi/\tau_c$
SH Subtropical 50-day Exponential Loss	$\chi_{\mathrm{STR},50}$	100 ppb	$-\chi/\tau_c$

Large-Scale Transport Diagnostics

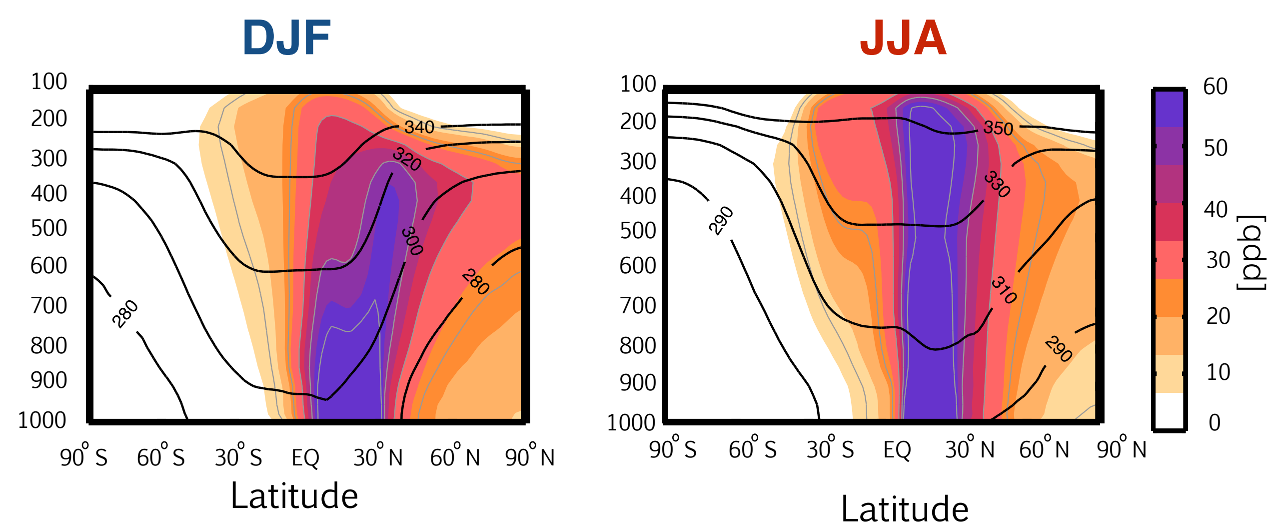
Southern Subtropical Loss Tracer

$\chi_{\mathrm{STR},50}$



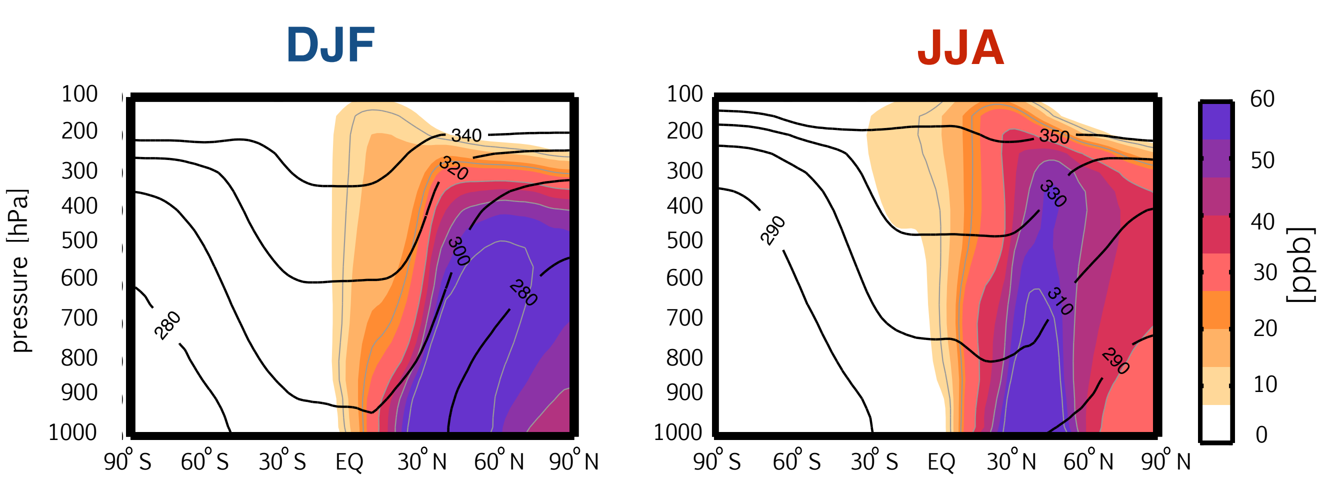
Northern Subtropical Loss Tracer

$\chi_{\mathrm{NTR},50}$



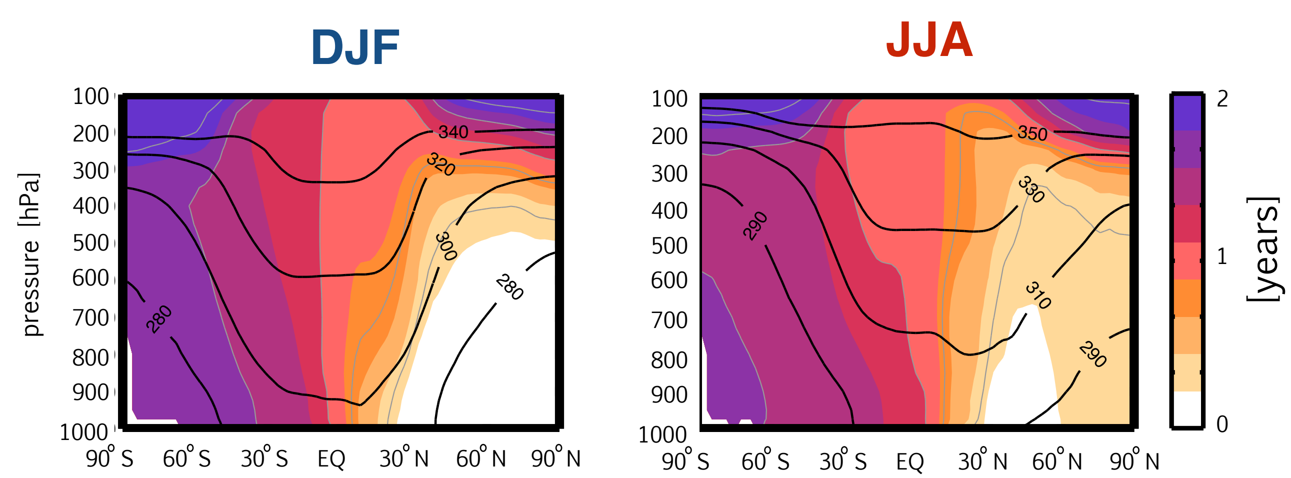
Northern Midlatitude Tracer

$\chi_{\mathrm{NH},50}$



Northern Midlatitude Mean Age

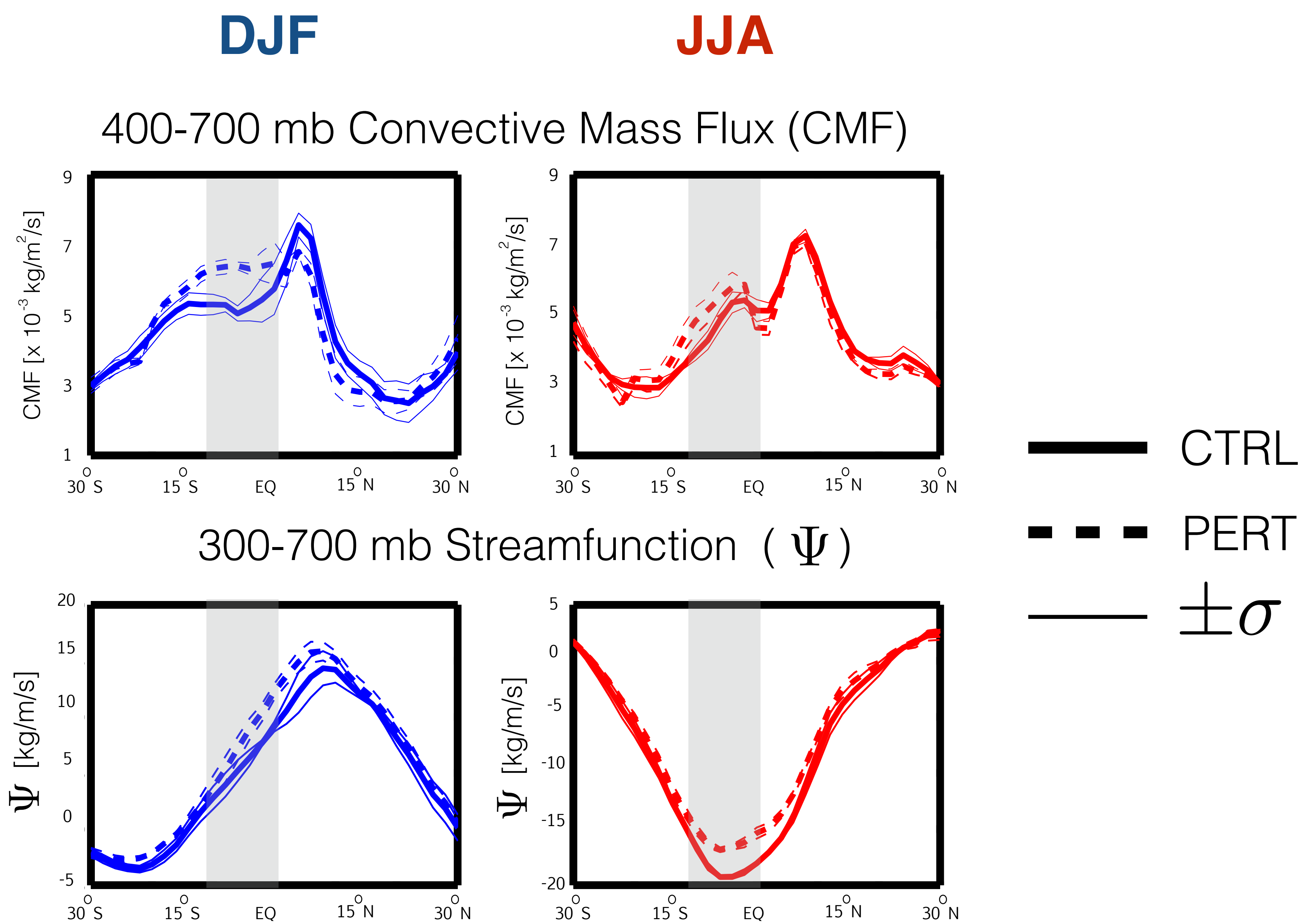
Γ_{MID}



Large-Scale Flow and Convection Changes

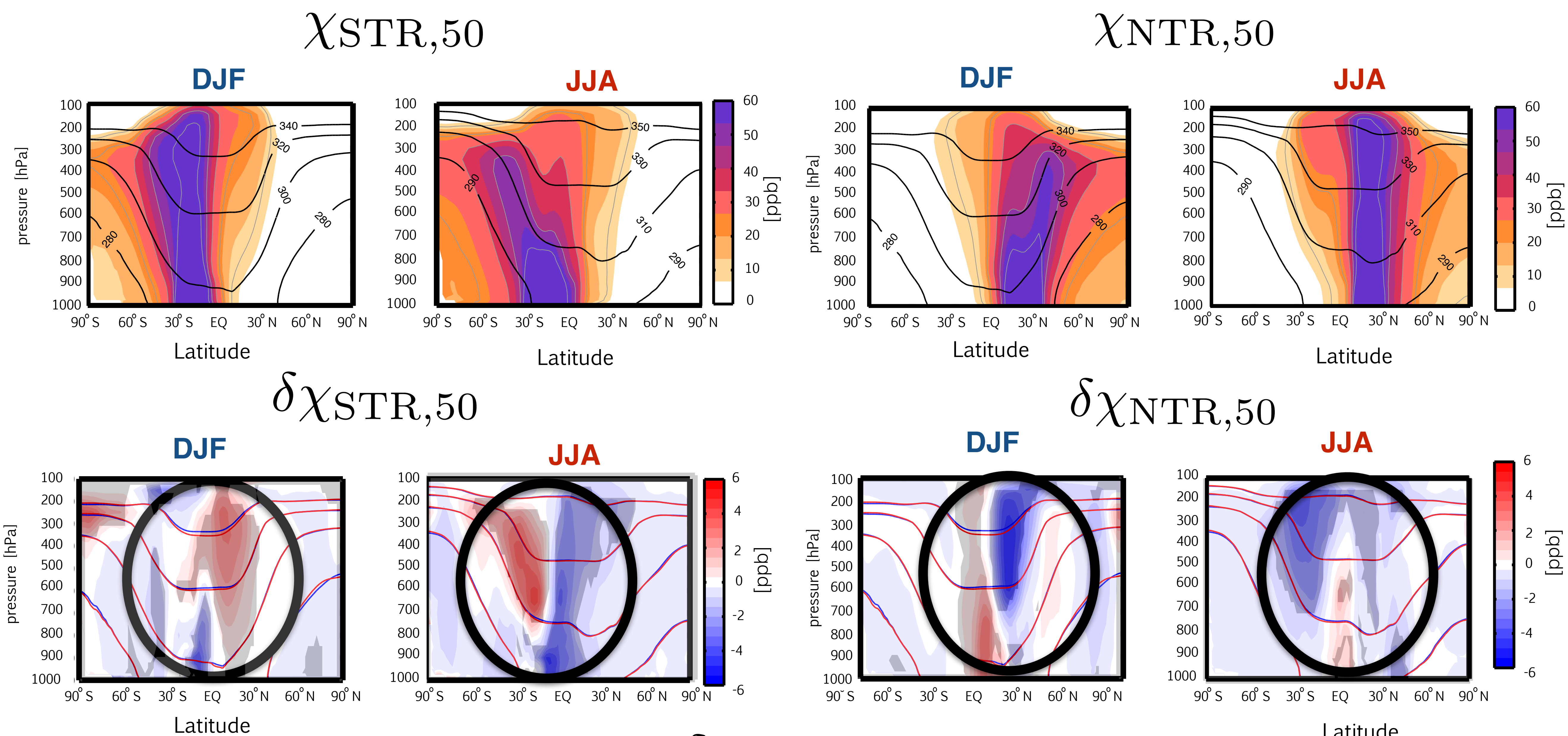
Perturbed tropical circulation in Experiment 1 features an an **enhanced winter Hadley Cell** and a **suppressed summer Hadley Cell.**

Experiment 1: +3K South Tropics



Subtropical Transport Response: Exp #1

Responses of subtropical tracers are consistent with an **enhanced winter Hadley Cell** and a **suppressed summer Hadley Cell**. Only responses in the tropics and subtropics are significant relative to internal variability (shading).

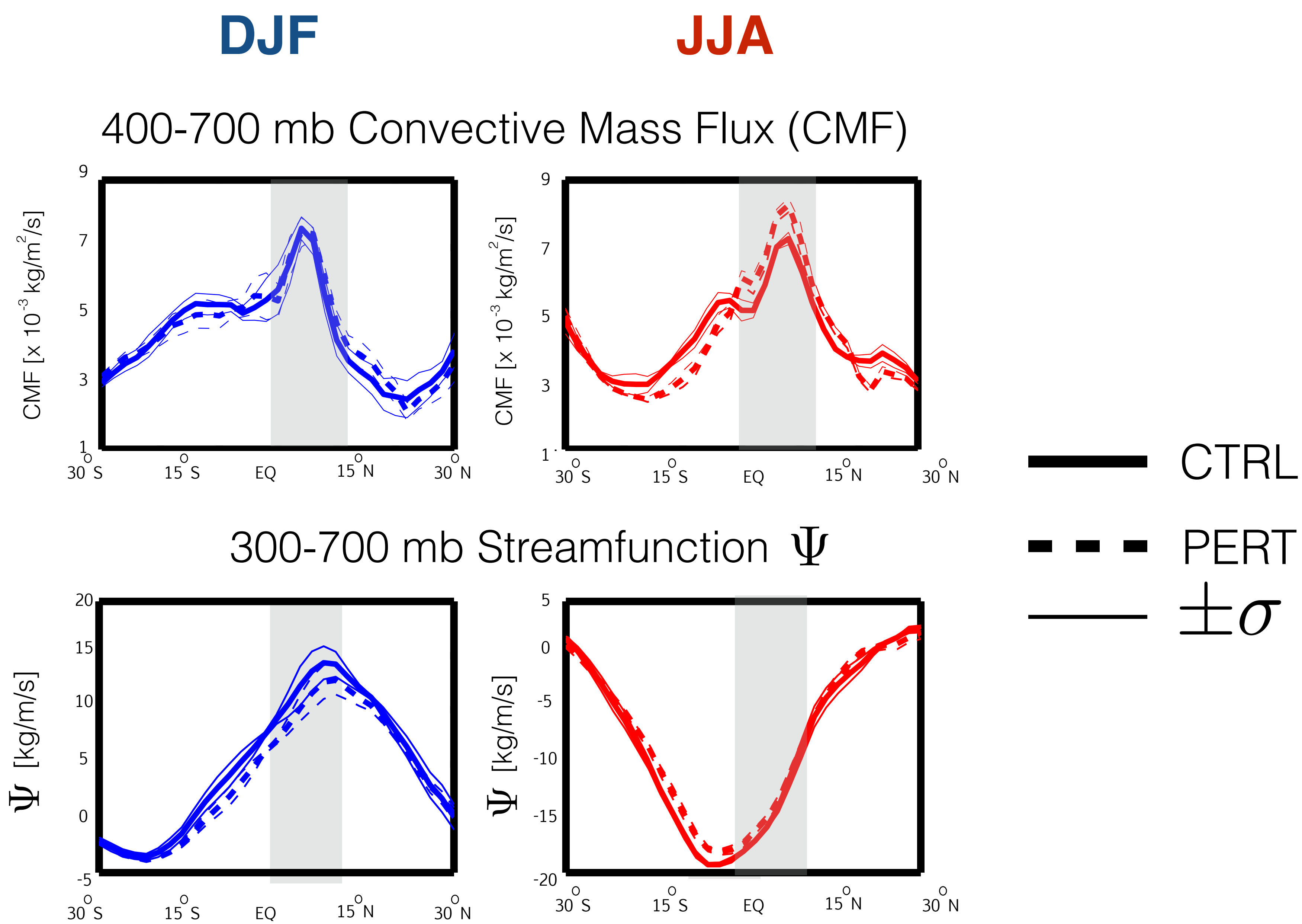


where $\delta \equiv$ PERT-CTRL

Large-Scale Flow and Convection Changes

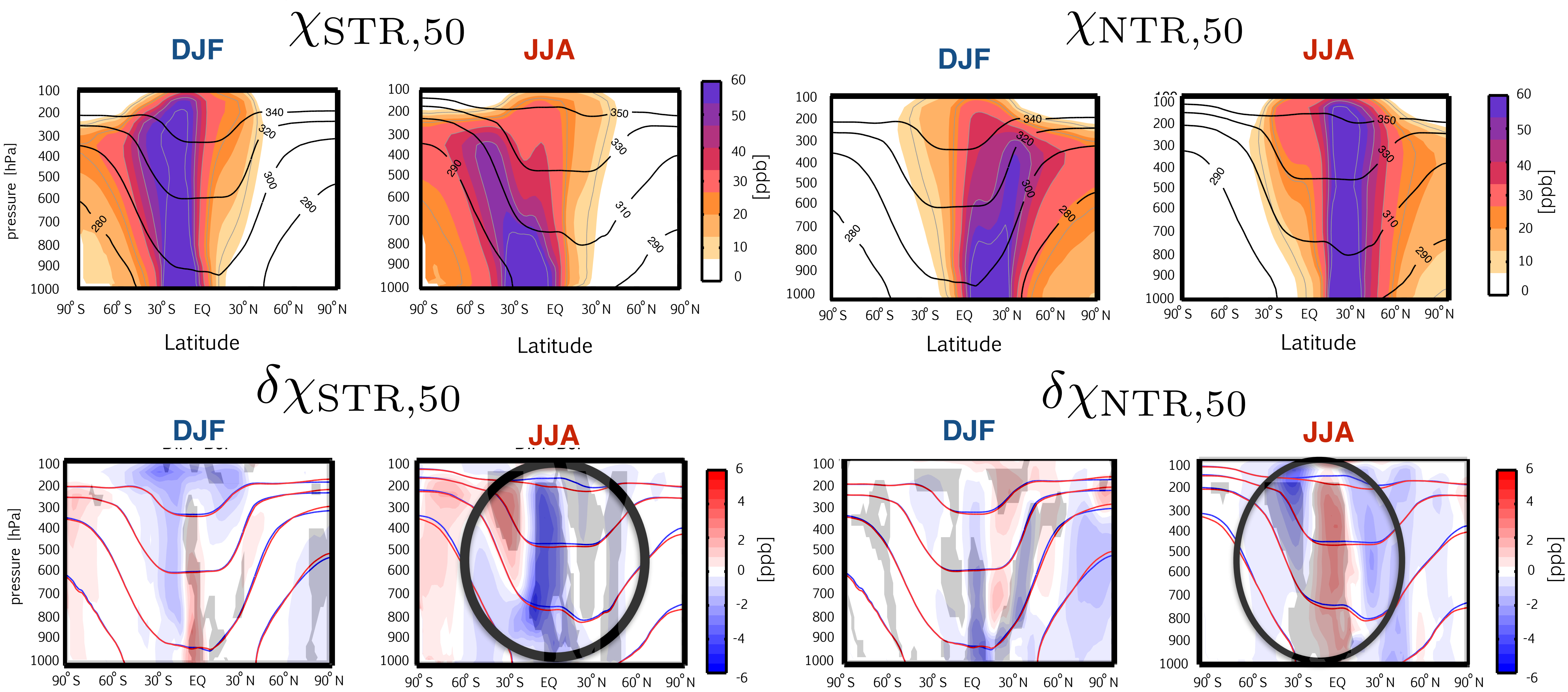
Perturbed tropical circulation in Experiment 2 features negligible changes in **winter Hadley Cell** and a **slightly suppressed summer Hadley Cell**.

Experiment 2: +3K North Tropics



Subtropical Transport Response: Exp #2

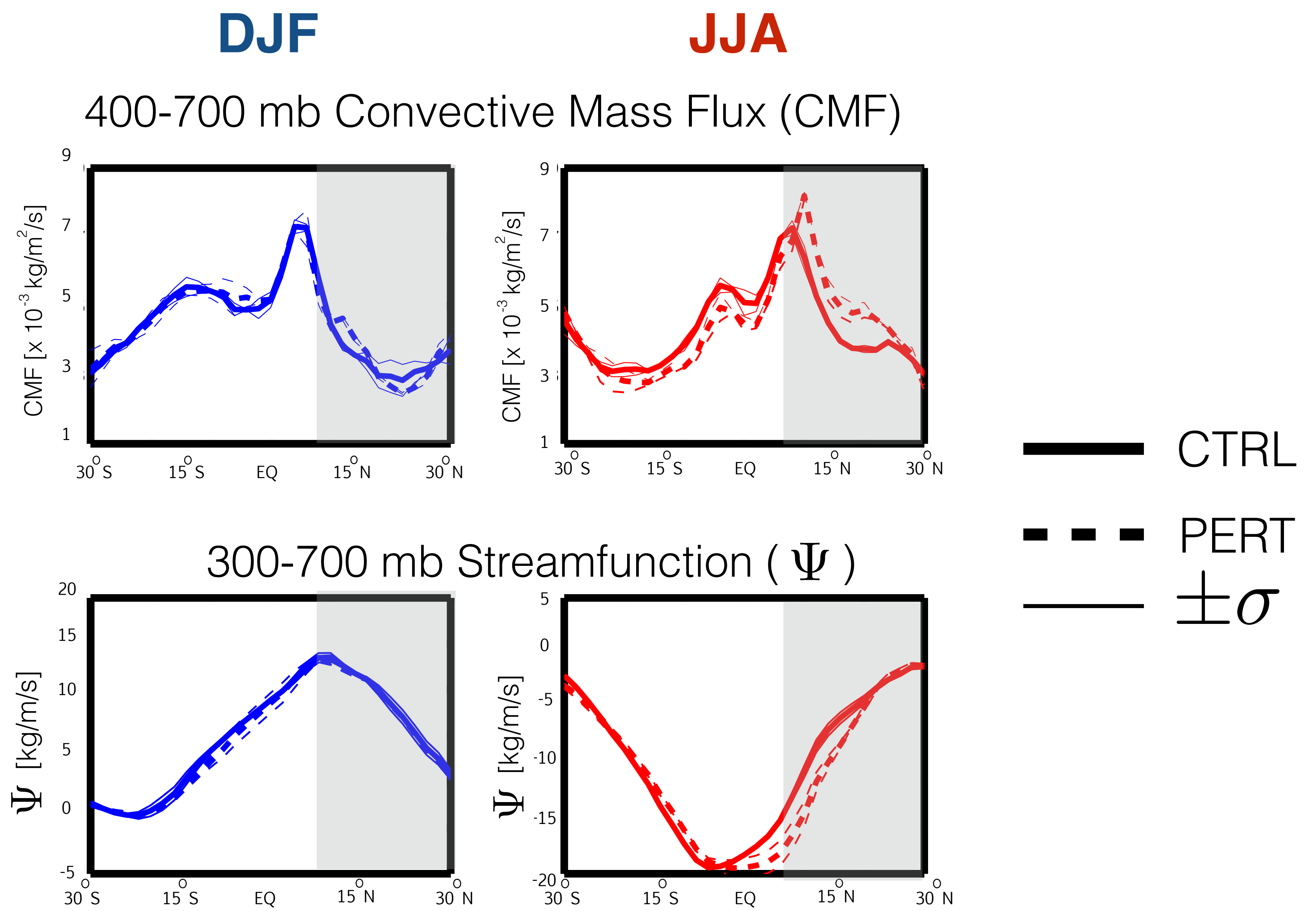
Response of subtropical tracers are consistent with a weaker perturbation to the boreal winter Hadley circulation and a **suppressed summer Hadley Cell** (albeit weaker).



Large-Scale Flow and Convection Changes

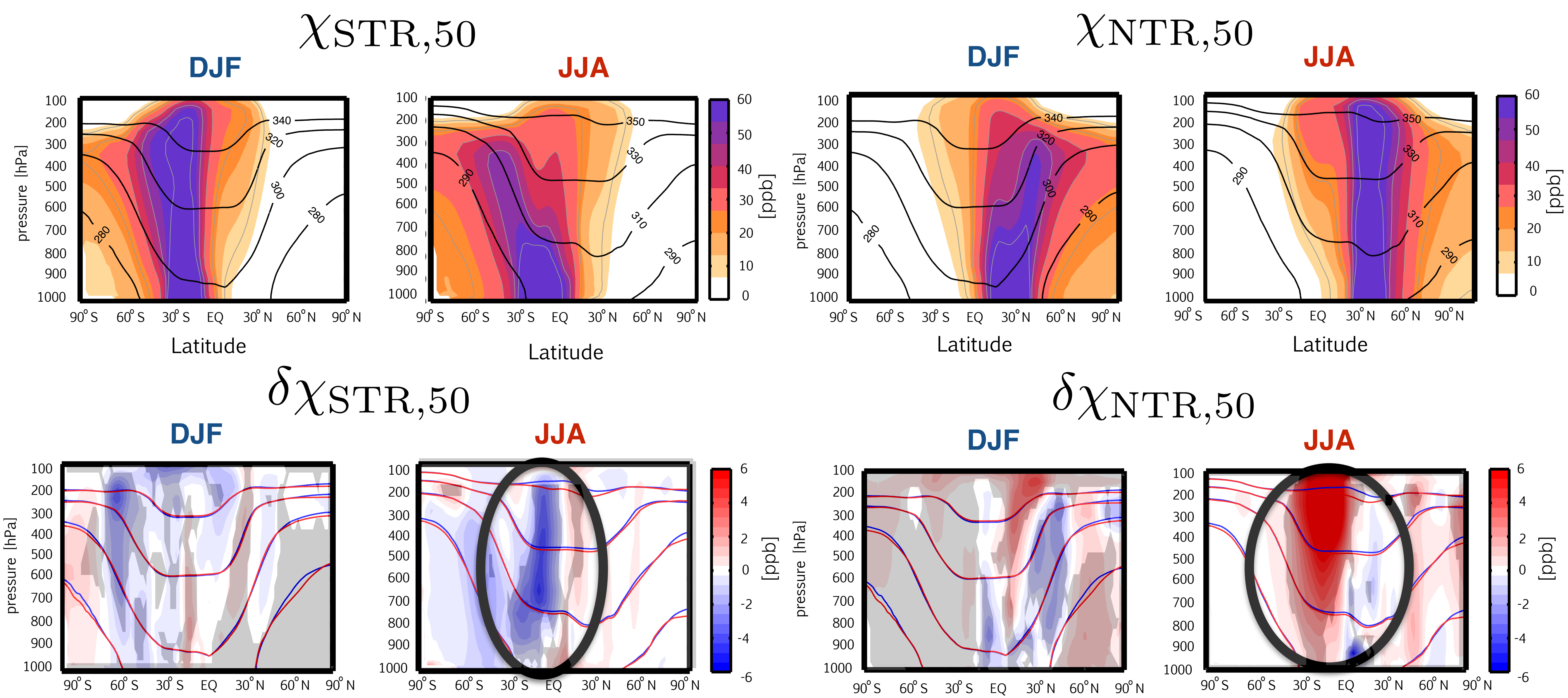
Perturbed tropical circulation in Experiment 3 produces negligible changes in **winter Hadley Cell** but a much **stronger summer Hadley Cell**.

Experiment 3: +3K Northern Subtropics



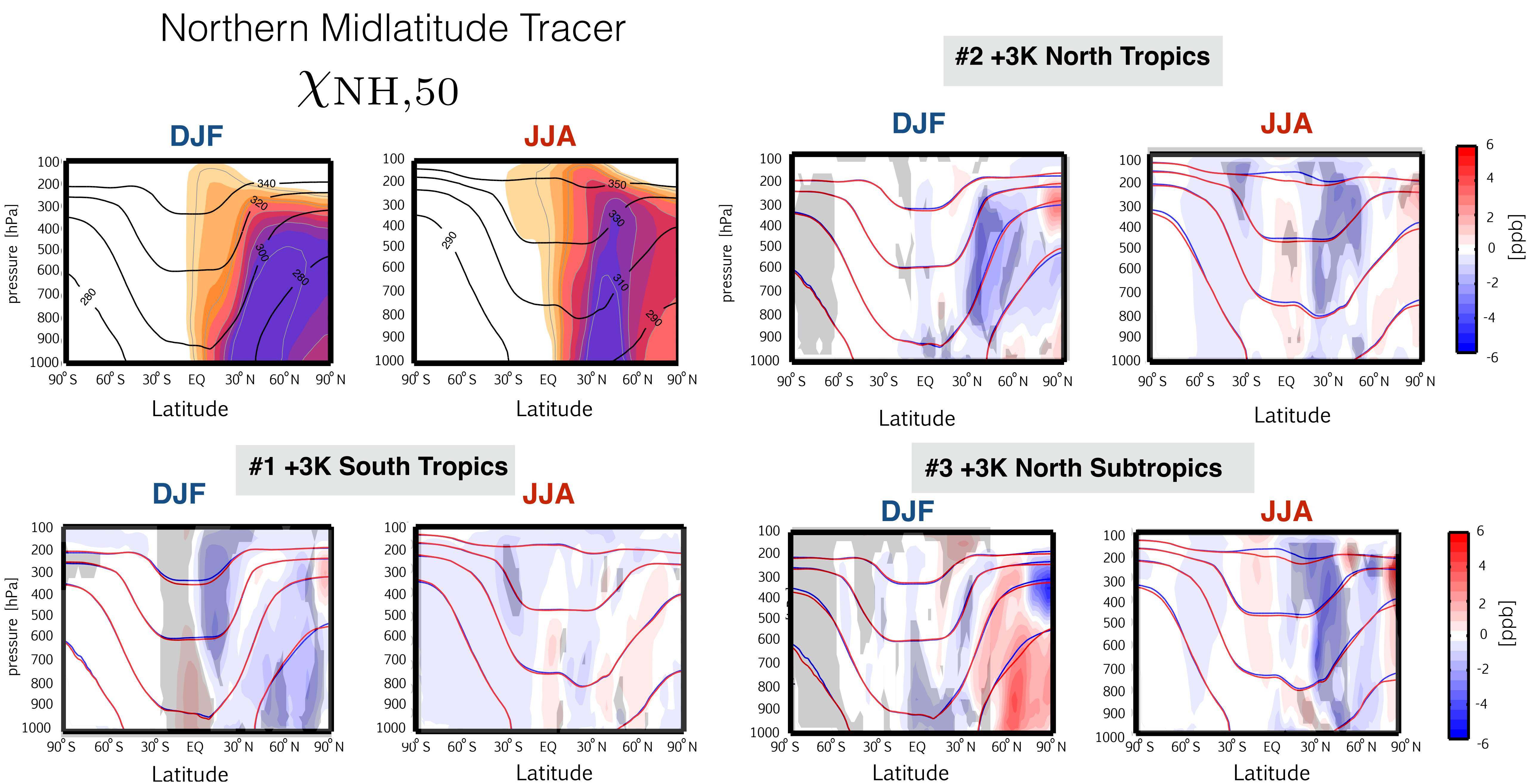
Subtropical Transport Response: Exp #3

Transport response of subtropical tracers are consistent with a significantly **enhanced summer Hadley Cell**.



Midlatitude Transport Responses

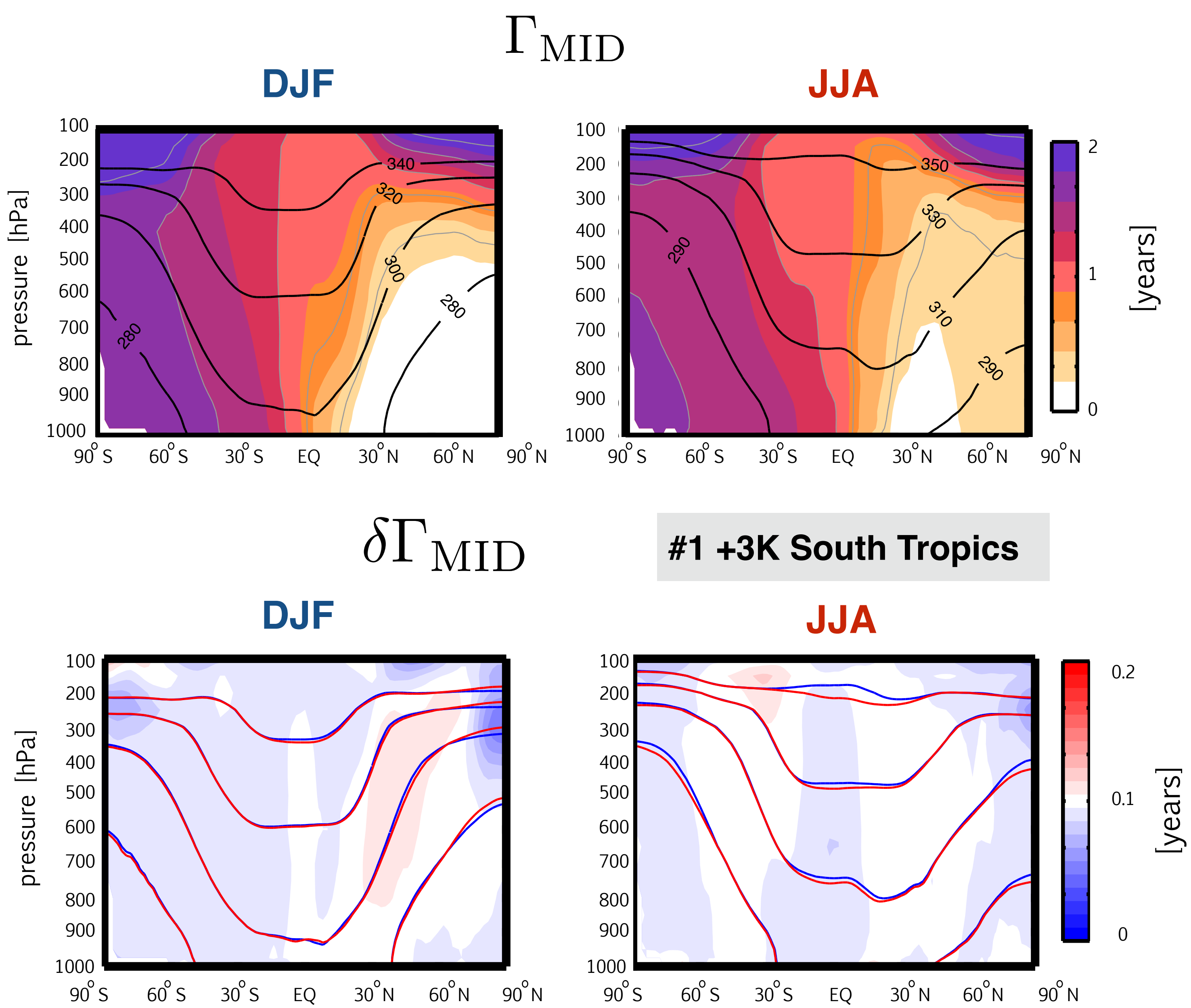
By comparison, the transport responses in the midlatitude source tracers are much weaker and rarely significant, relative to internal variability. This is true for all perturbation regions (Experiments 1-3).



Midlatitude Transport Responses

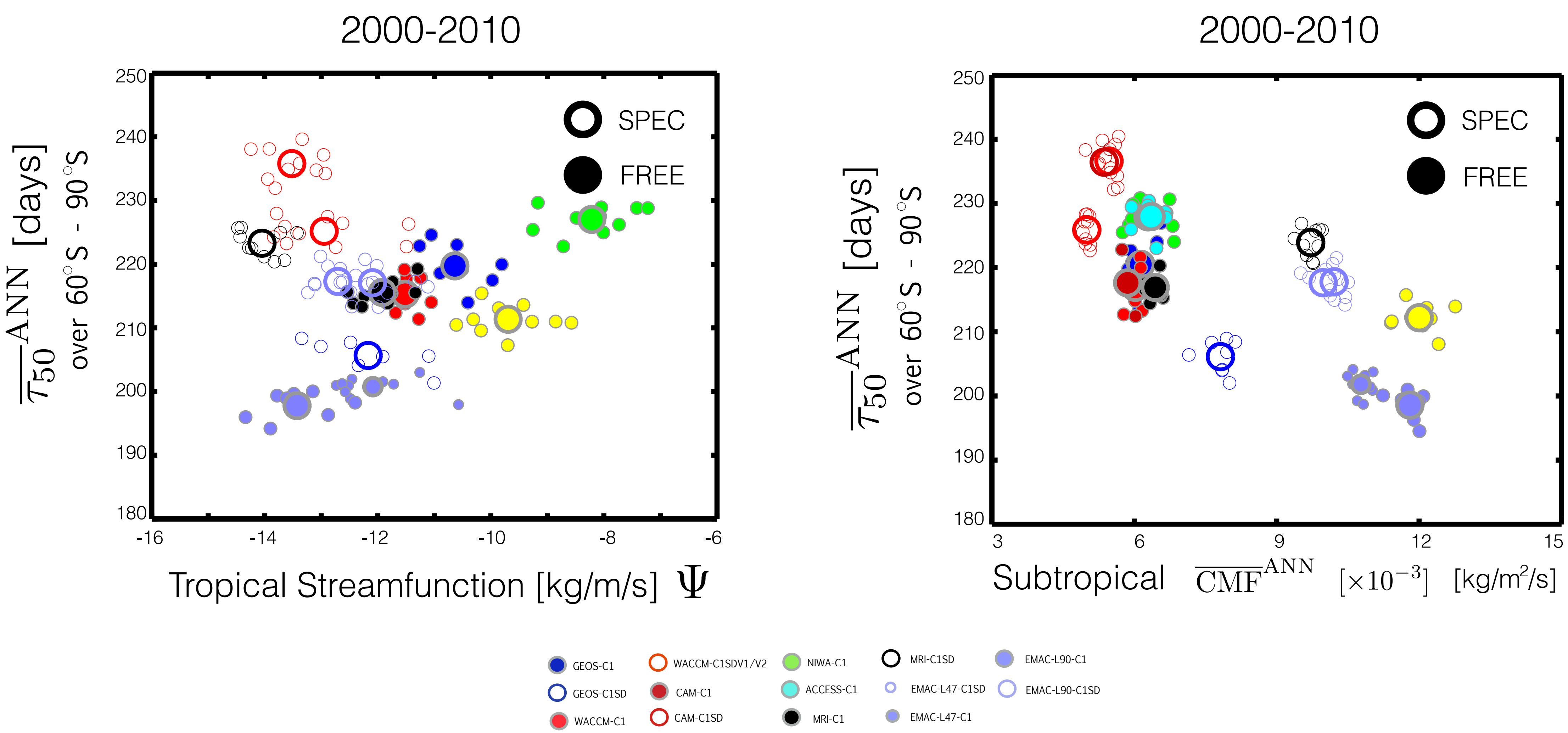
Similarly, the mean age since air was last in contact with the NH midlatitude surface is relatively unchanged (invariant to where the perturbation is applied).

Northern Midlatitude Mean Age



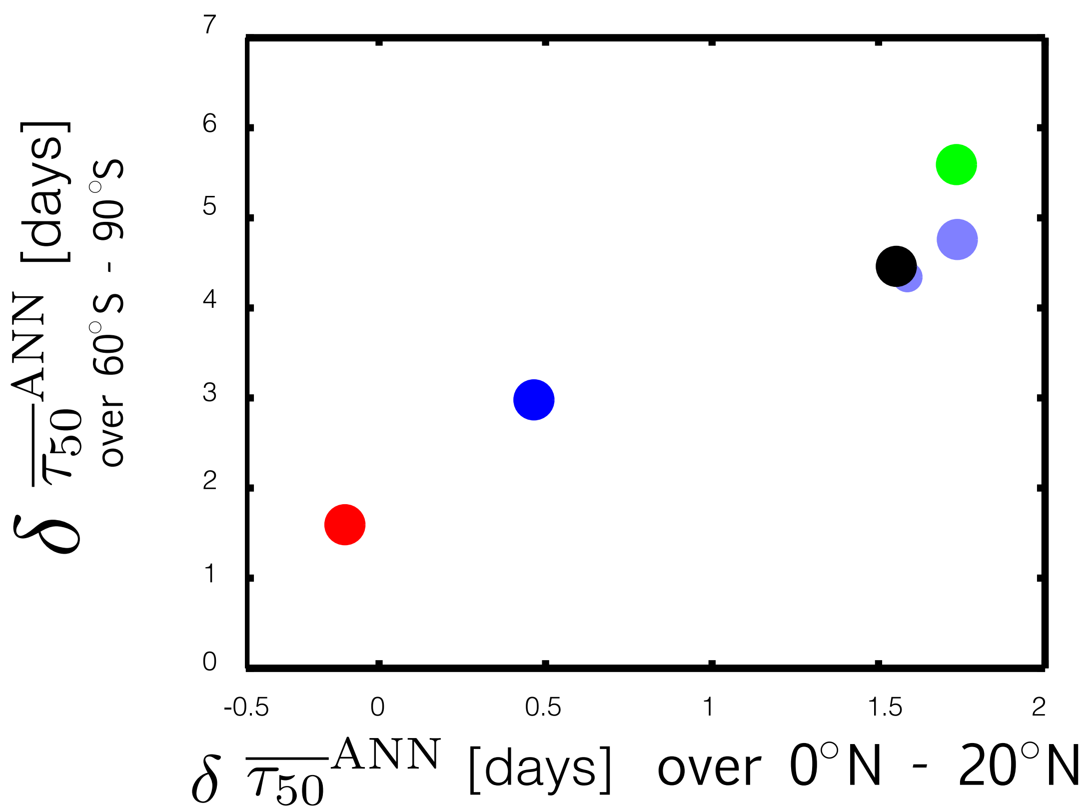
NH Midlatitude Age Differences Among CCMI Models

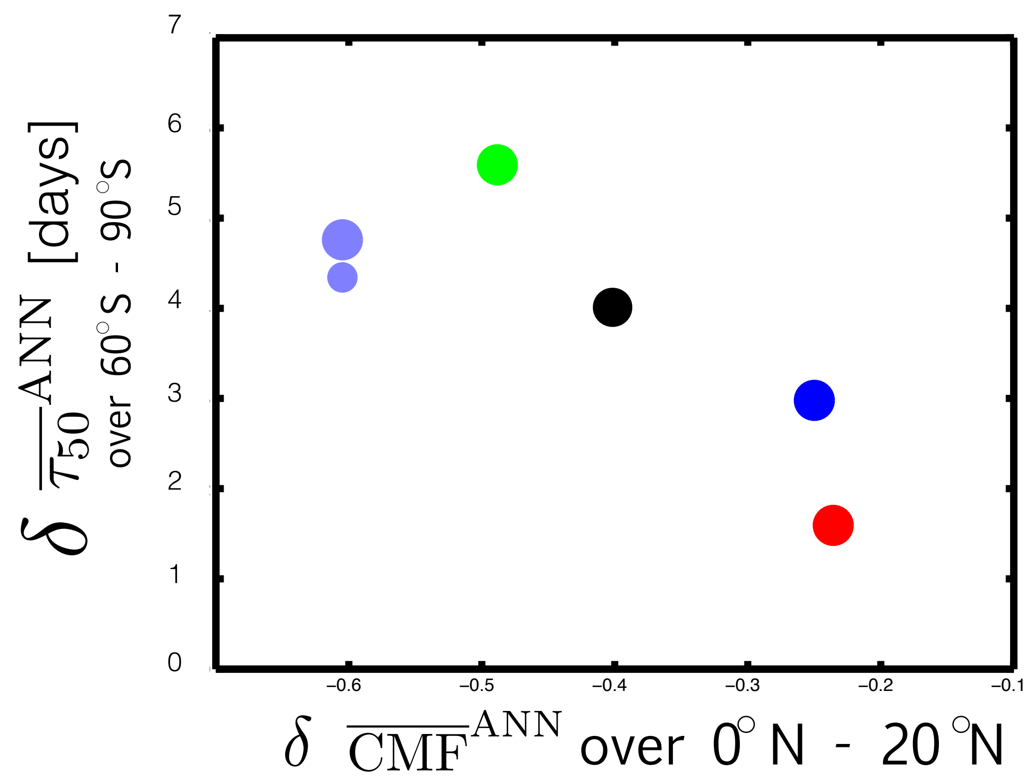
The spread in tracer ages among the CCMI Hindcast “free-running” (●) and “specified-dynamics” (○) simulations are correlated best with differences in northern subtropical lower tropospheric convection, not the mean strength of the Hadley Cell (*Orbe et al. 2017, Submitted*)

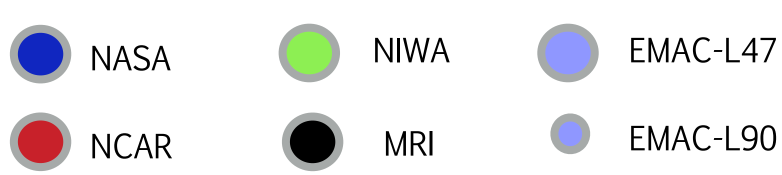


Projected Changes in NH Midlatitude Ages Among CCMI Models

Furthermore, projected 21st century changes in tracer ages among the CCMI simulations are correlated best with changes in northern subtropical lower tropospheric convection, not the mean strength of the Hadley Cell (*Orbe et al. 2017, In Prep.*).







where $\delta \equiv$ FTR-REF

Conclusions

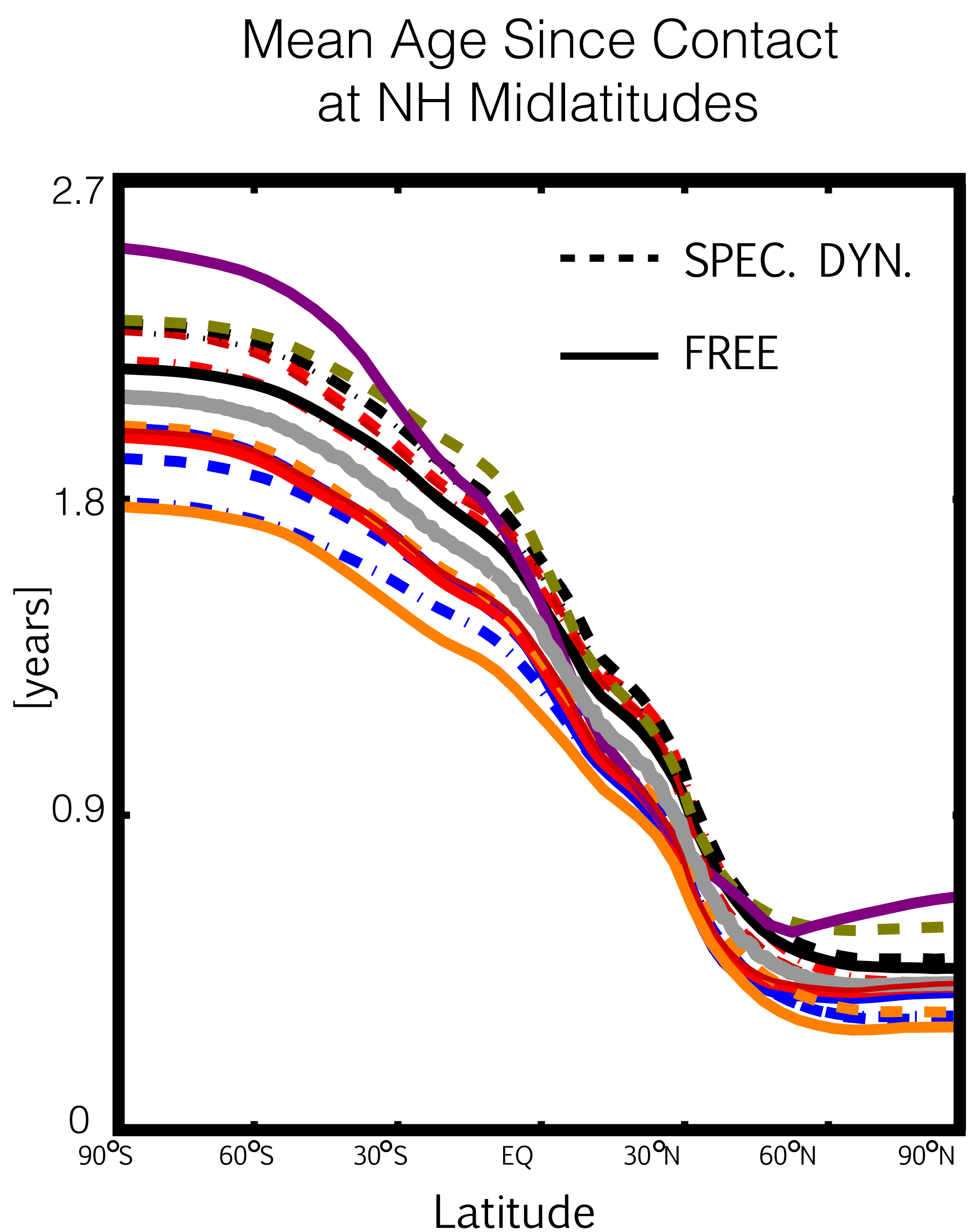
#1 GEOS-5 “perturbed convection” simulations reveal that subtropical sourced tracers are very sensitive measures of the tropical mean circulation.

#2 By comparison, tracers emitted over northern midlatitudes are much more sensitive to transport between the northern extratropics and tropics. Most atmospheric chemistry inversions and diagnostics of interhemispheric transport ignore this distinction.

#3 The strength of the tropical-extratropical transport barrier seems to be related to subtropical convection. Convection differences may be related to the spread among the CCMI models and projected trends in intermispheric transport.

Extra

Large-Scale Transport in CCMI Models



(Orbe et al., 2017; Submitted)

- Comparisons of idealized loss and age tracers reveal large (~30-40%) differences in transport to NH high latitudes and interhemispheric transport.
- The differences among "specified-dynamics" simulations are as large as differences among "free-running" simulations.

CMF [kg/m^2/s]

CMF [x 10^{-3} kg/m^2/s]

δ

Ψ [kg/m/s]

Southern Pole

$\overline{\tau_{50}}^{\mathrm{ANN}}$ [days]