Stratospheric role for tropospheric circulation change

A high-top low-top comparison study with the GFDL climate model

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1. Introduction

In this modeling study, we explore the response of the atmospheric general circulation to anthropogenic climate change. We use the **uncoupled** GFDL AM2/3 climate model to understand how sensitive the response is to forcings such as ozone depletion, greenhouse gas increase, and warming SSTs.

2. Experimental Setup

We prescribe climatological mean SSTs from the coupled GFDL model. Each experiment is at least 40 years long and is conducted twice with the low- (L24) and high-top (L48) version of the model to understand the influence of stratospheric resolution for the simulation of climate. The following experiments are conducted:

Simulations

Name	Length	SSTs	GHGs	Ozone	Aerosols
SST_{19}	500	P	P	P	V
O_3 SST_{19}	200	P	P	I	V
½CO_2 SST_{19}	80	P	½	P	V
CO_2 SST_{19}	“	P	I	P	V
2xCO_2 SST_{19}	200	P	x2	P	V
4xCO_2 SST_{19}	40	P	x4	P	V
CO_2 O_3 SST_{19}	80	P	I	P	V
SST_{20}	“	I	P	P	V
O_3 SST_{20}	“	I	P	I	V
CO_2 SST_{20}	“	I	I	P	V
CO_2 O_3 SST_{20}	“	I	I	I	V
SST_{21}	“	A1B	P	P	V
2xCO_2 SST_{21}	“	A1B	x2	P	V
SST_{23}	“	A1B	P	P	V
2xCO_2 SST_{23}	“	A1B	x2	P	V
nV SST_{19}	40	P	P	P	B

Control

Present-day

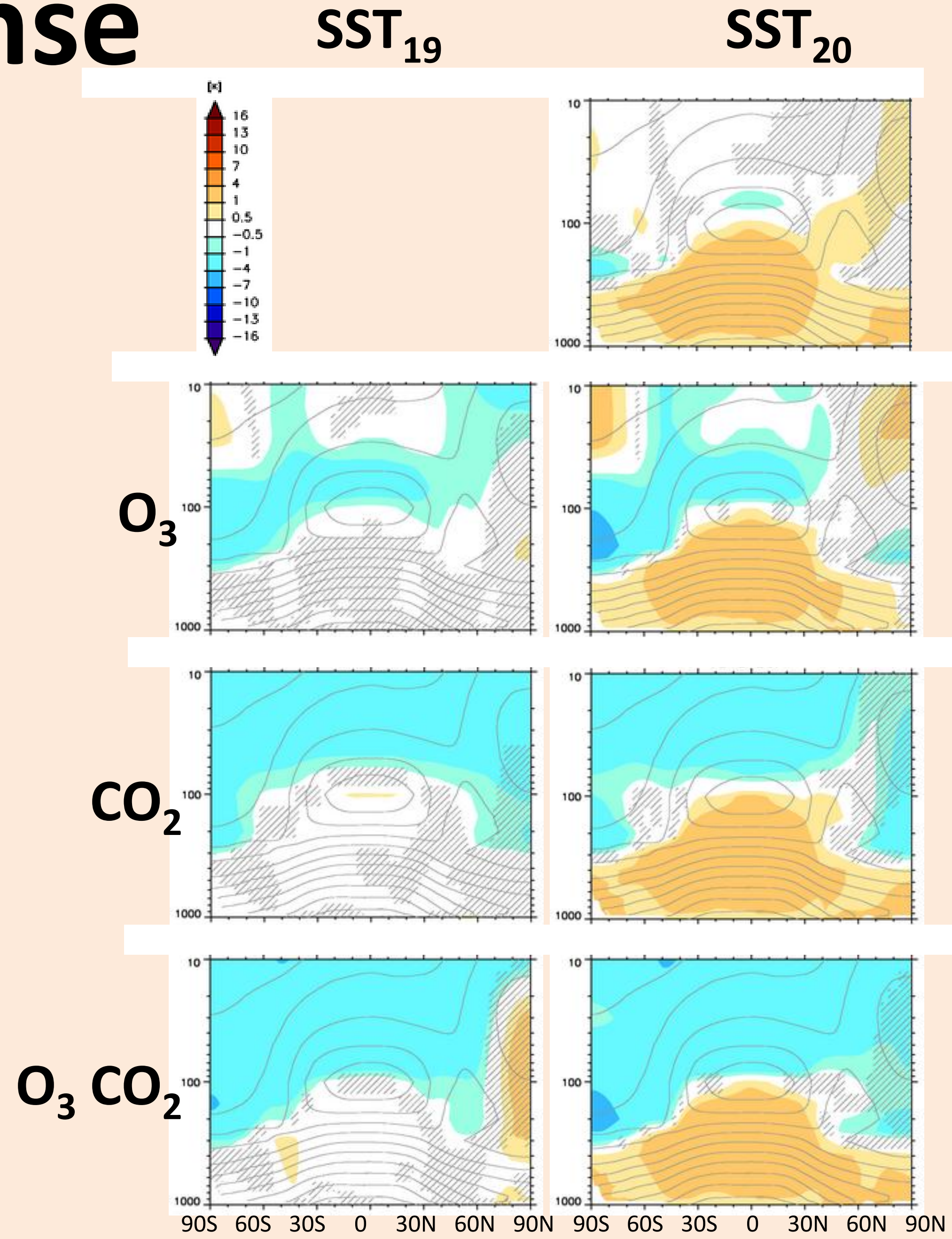
P: Pre-industrial **I**: Industrial **V**: Variable **B**: Background

SSTs were derived from corresponding runs with the coupled version of the model (CM2.1).

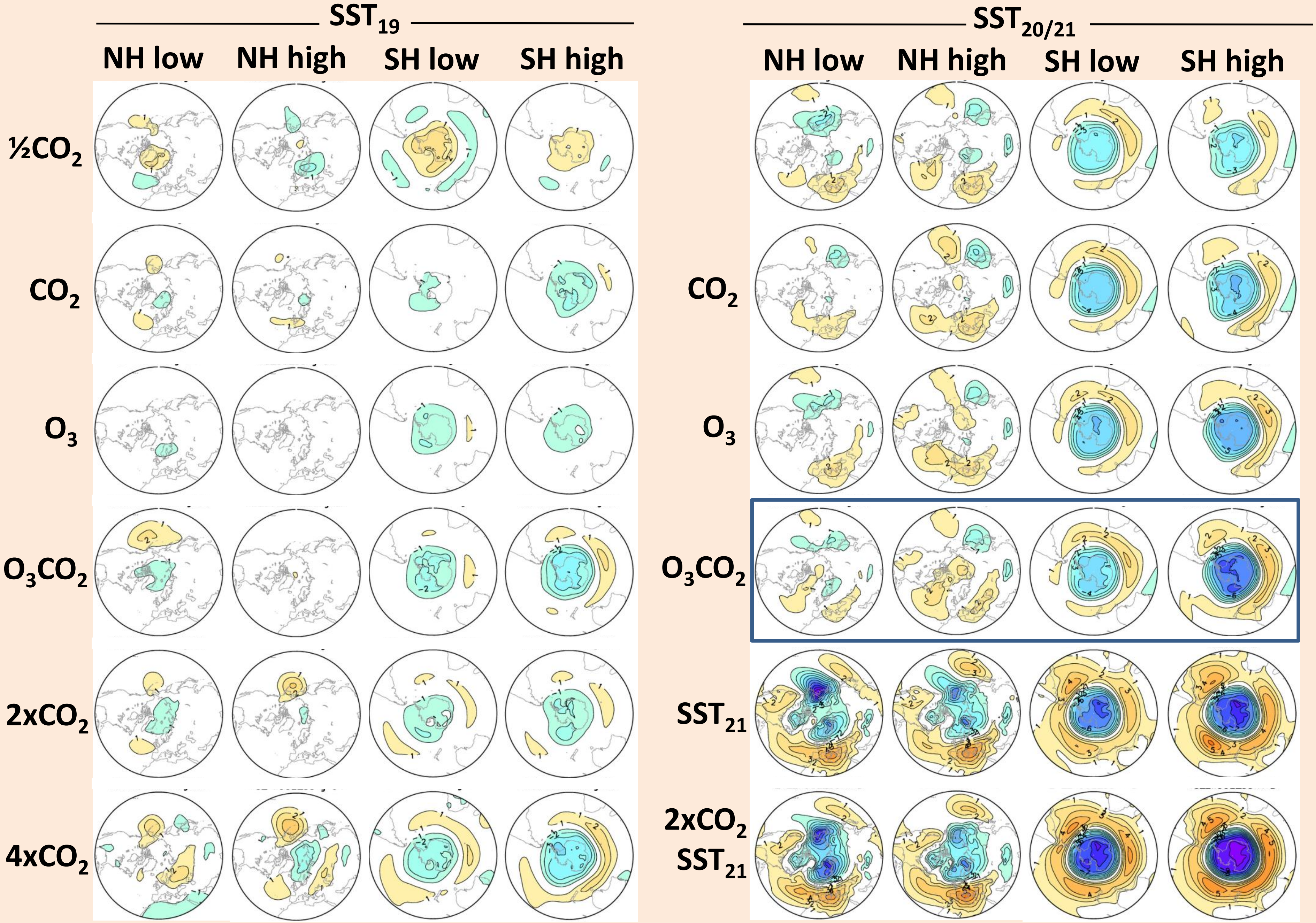
3. Basic Response

T (DJF)

- Tropospheric warming - stratospheric cooling
- SSTs control tropospheric temperatures
- O_3 and CO_2 largely control stratospheric temperatures
- Strong O_3 related cooling (-5 K) over South Pole

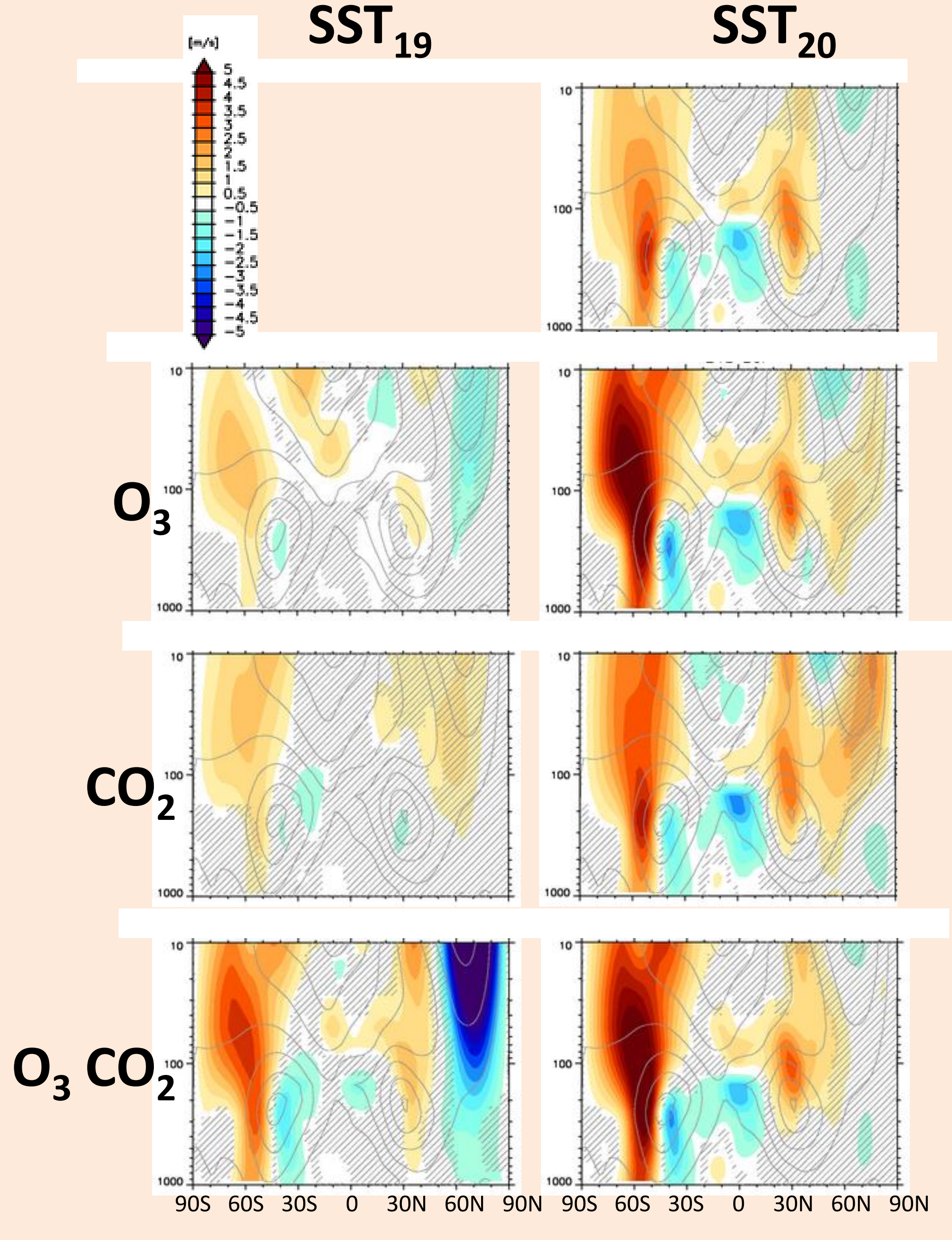


SLP DJF

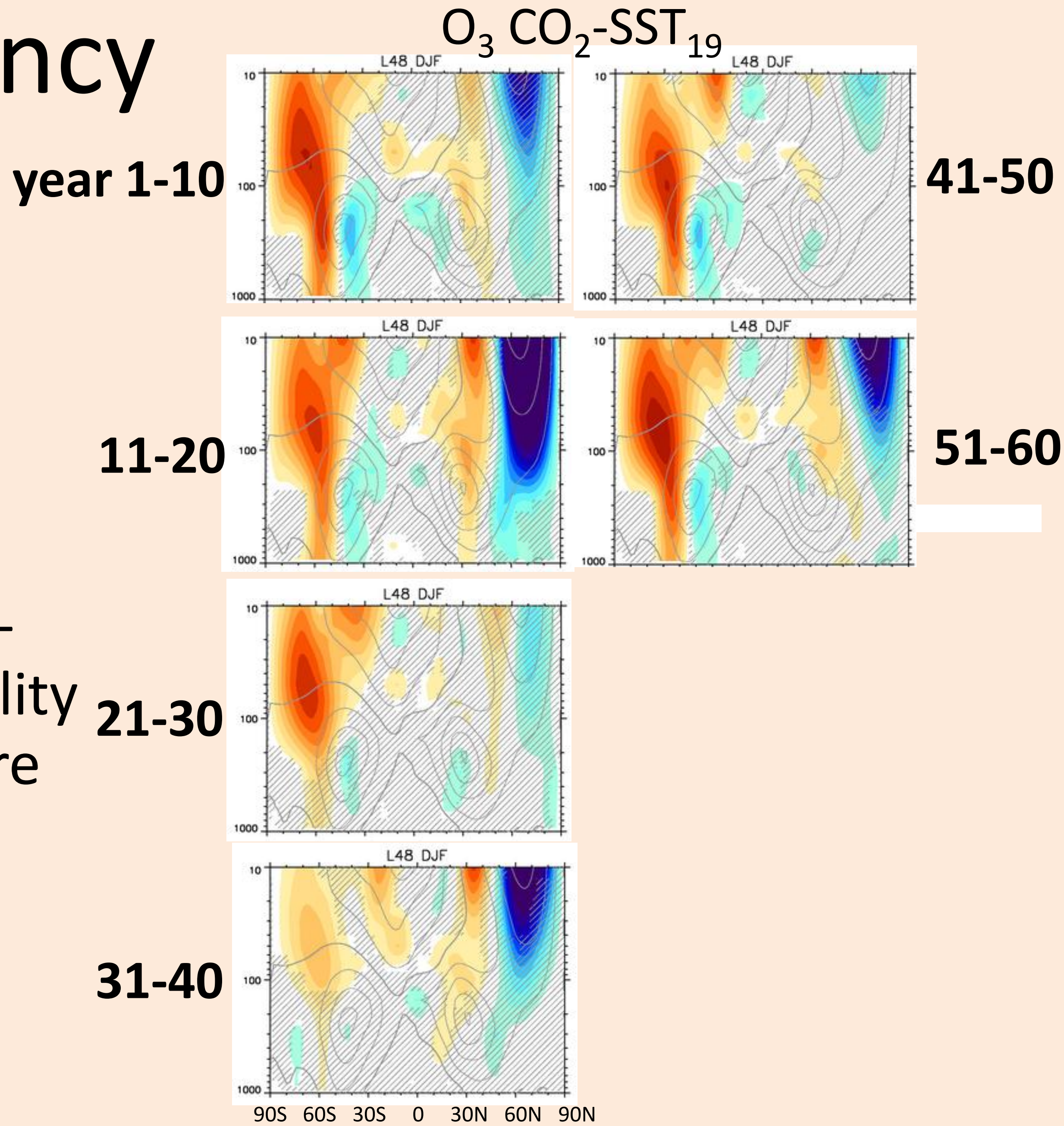

SST19
SST20/21
NH low
NH high
SH low
SH high
NH low
NH high
SH low
SH high
½CO2
CO2
O3
O3CO2
2xCO2
4xCO2
CO2
O3
O3CO2
SST21
2xCO2
SST21

u (DJF)

- In all cases intensified and poleward shifted polar vortex
- Clear tropospheric response (SAM+), even if only stratosphere is perturbed (downward influence)



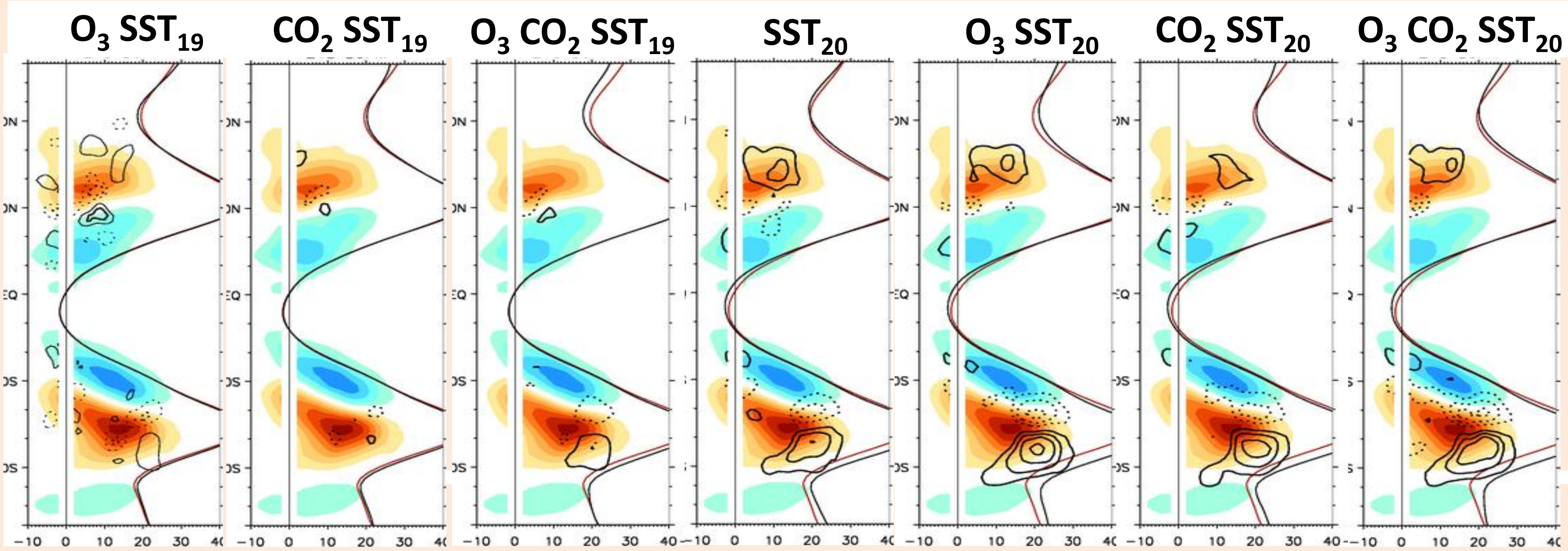
Low frequency variability u (DJF)



- Considerable low-frequency variability in the stratosphere
- Frequency of stratospheric sudden warming events?

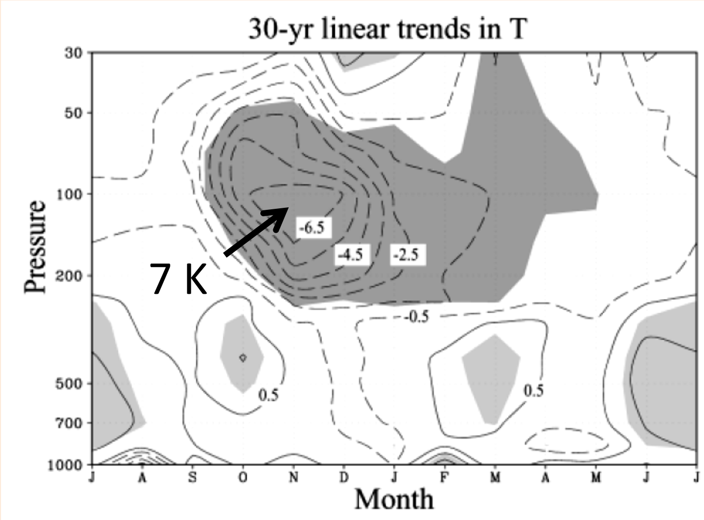
Phase Speed Spectra

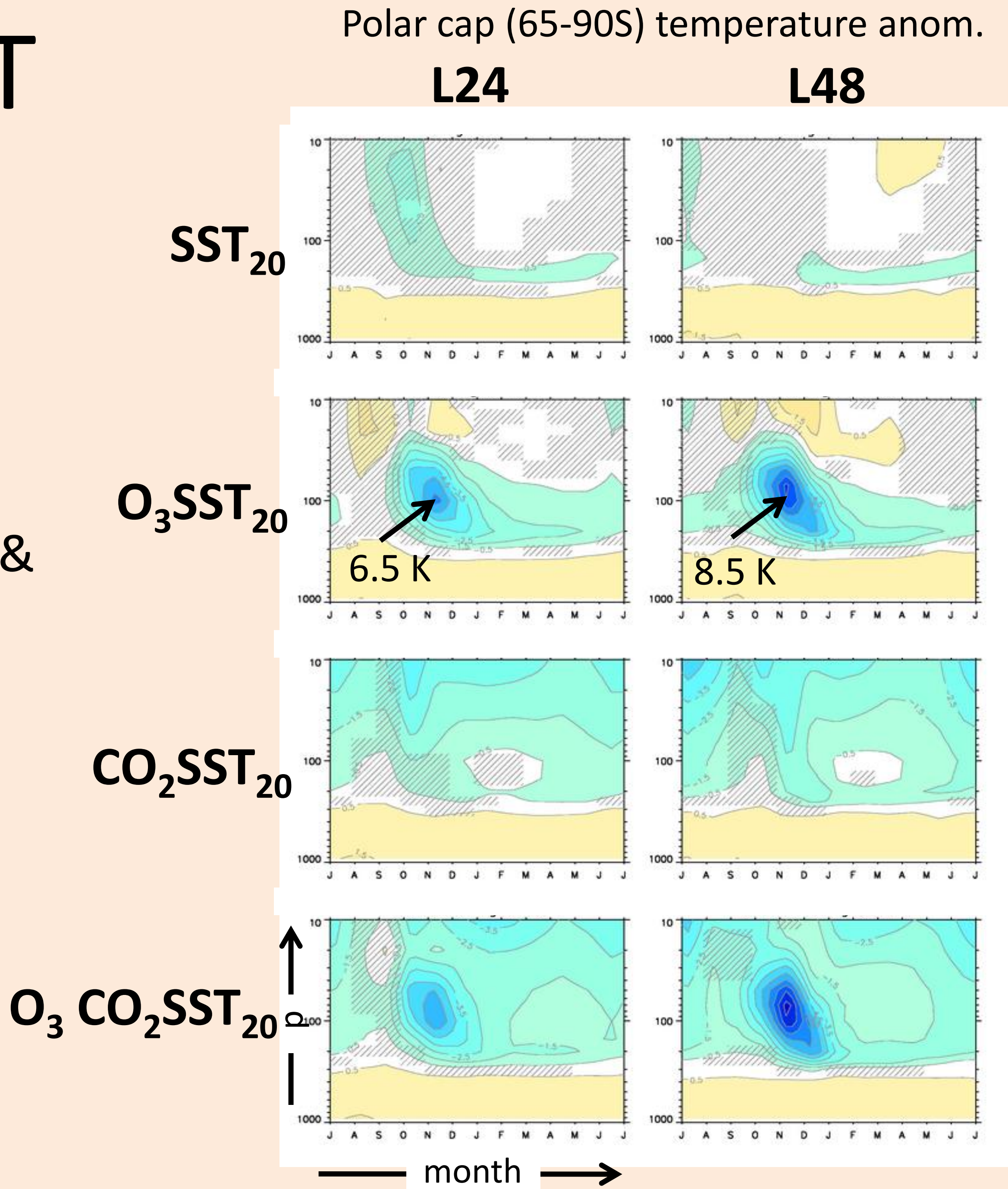
DJFM



South Pole: T Seasonality

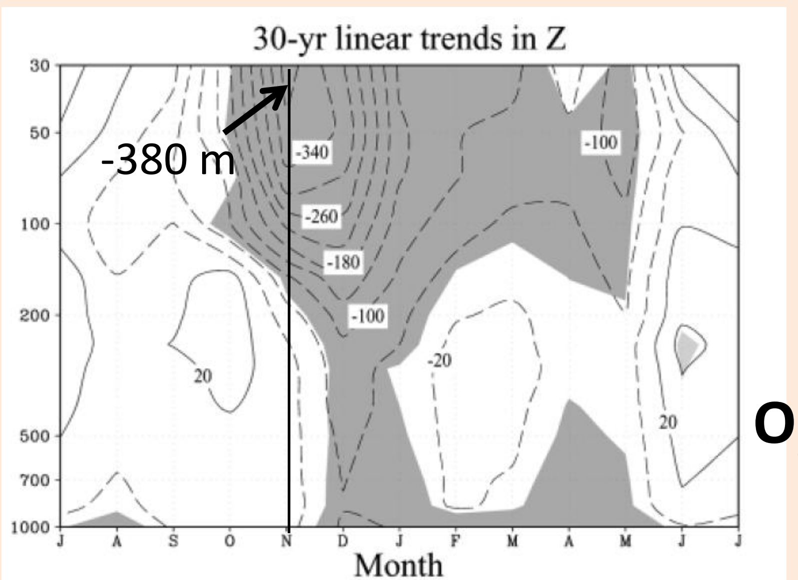
- Amplified O_3 cooling in L48
- Similar to observations reported by Thompson & Solomon (2002):

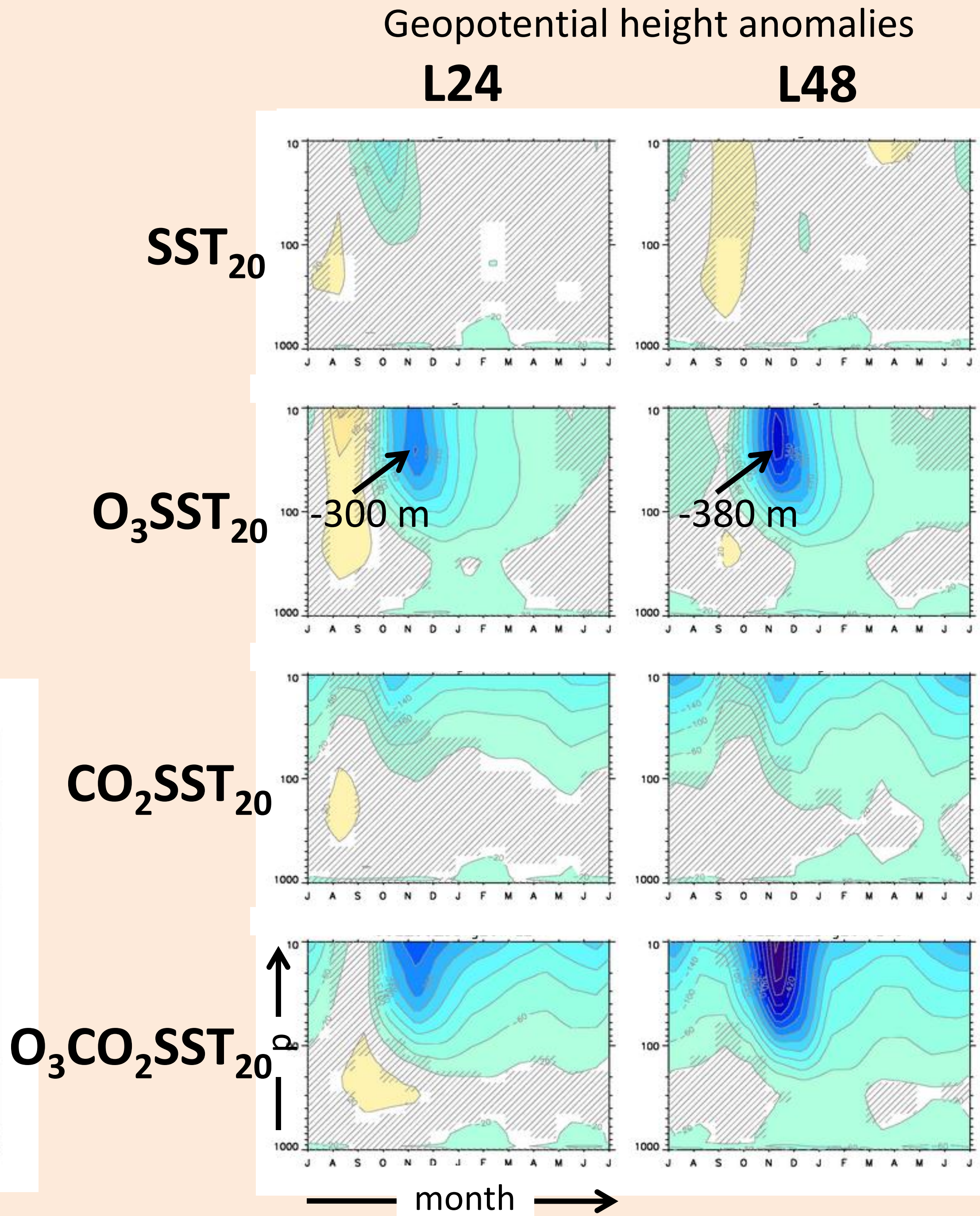




South Pole: Z Seasonality

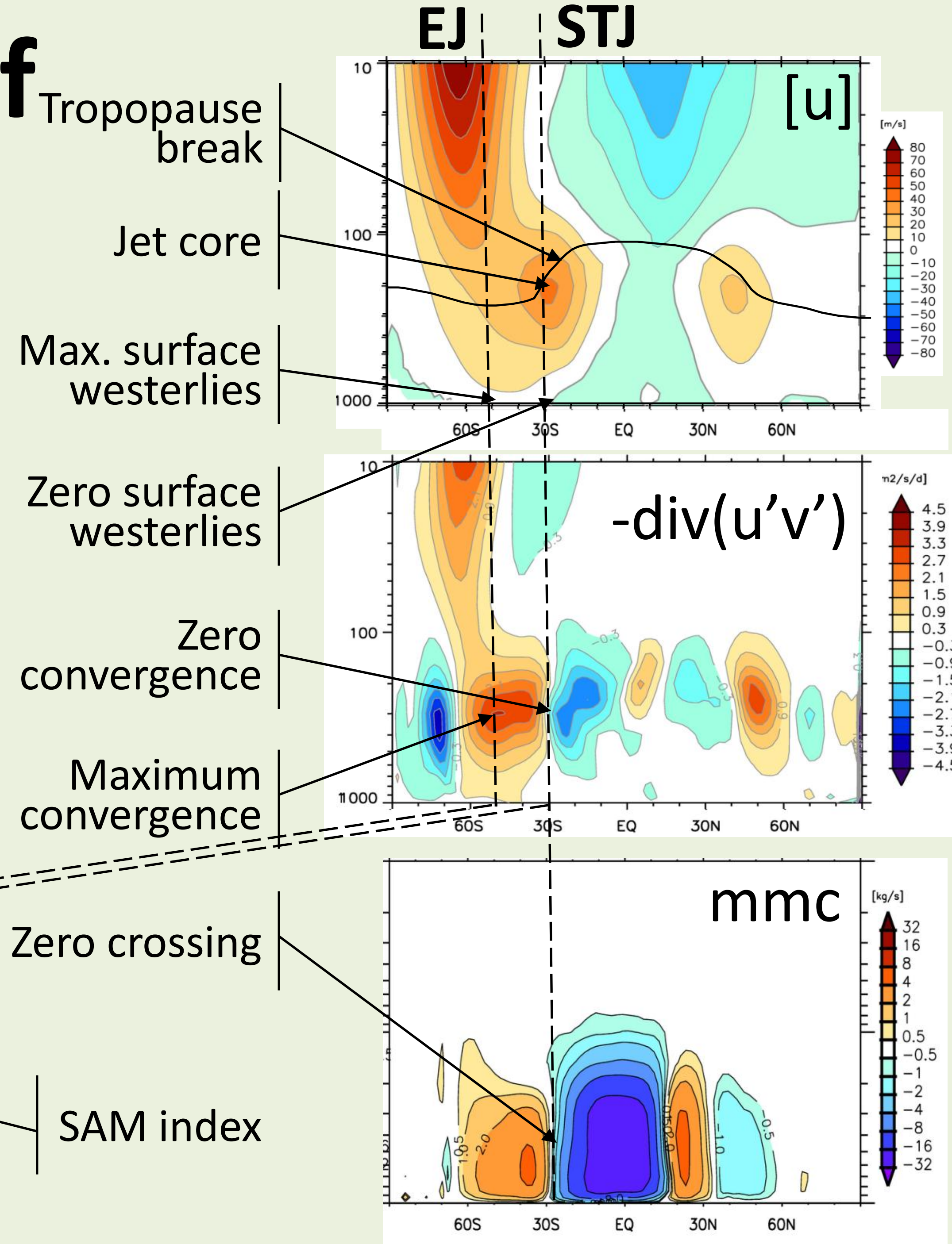
- Amplified tropospheric SAM+ response in L48
- Again, very similar to Thompson & Solomon (2002):

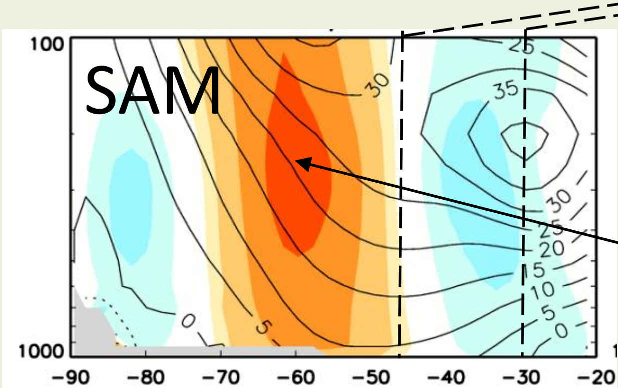




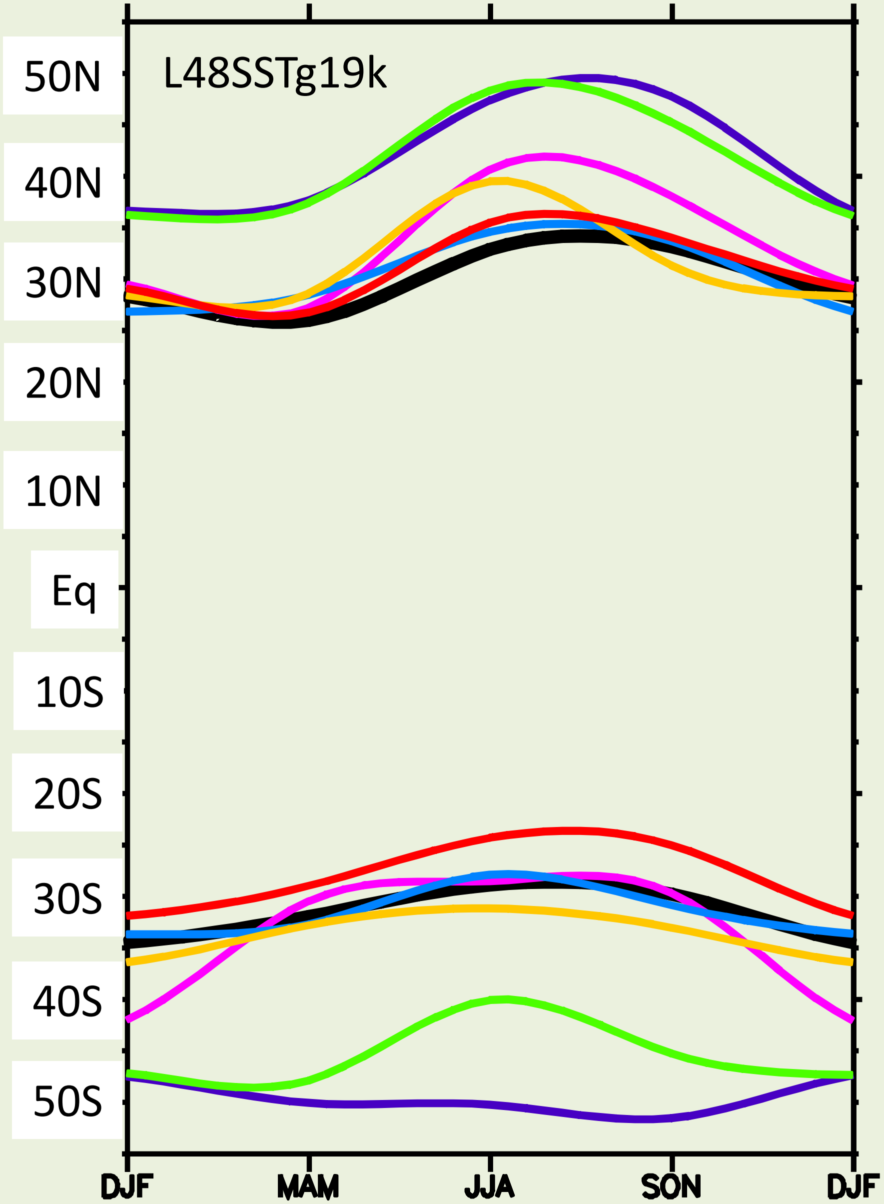
4. Widening of the General Circulation

Zonal mean circulation during JJA





Annual Cycle Relationships



HC • **mmc**

• **tropopause** ✓✓

• **u_{sfc}= 0** ✓✓

• **–div(uv) = 0** ✓

STJ • **u_{250} = max**

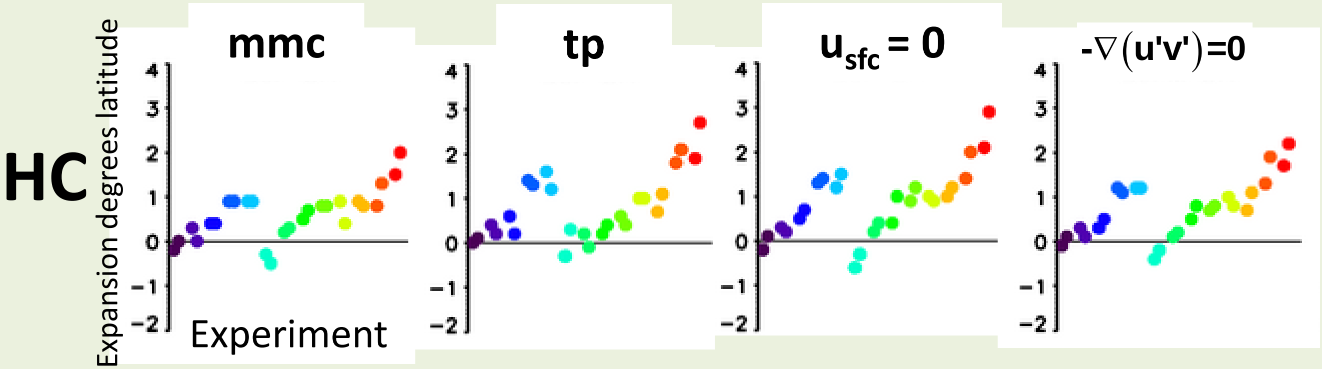
HC equatorward during summer
else joined

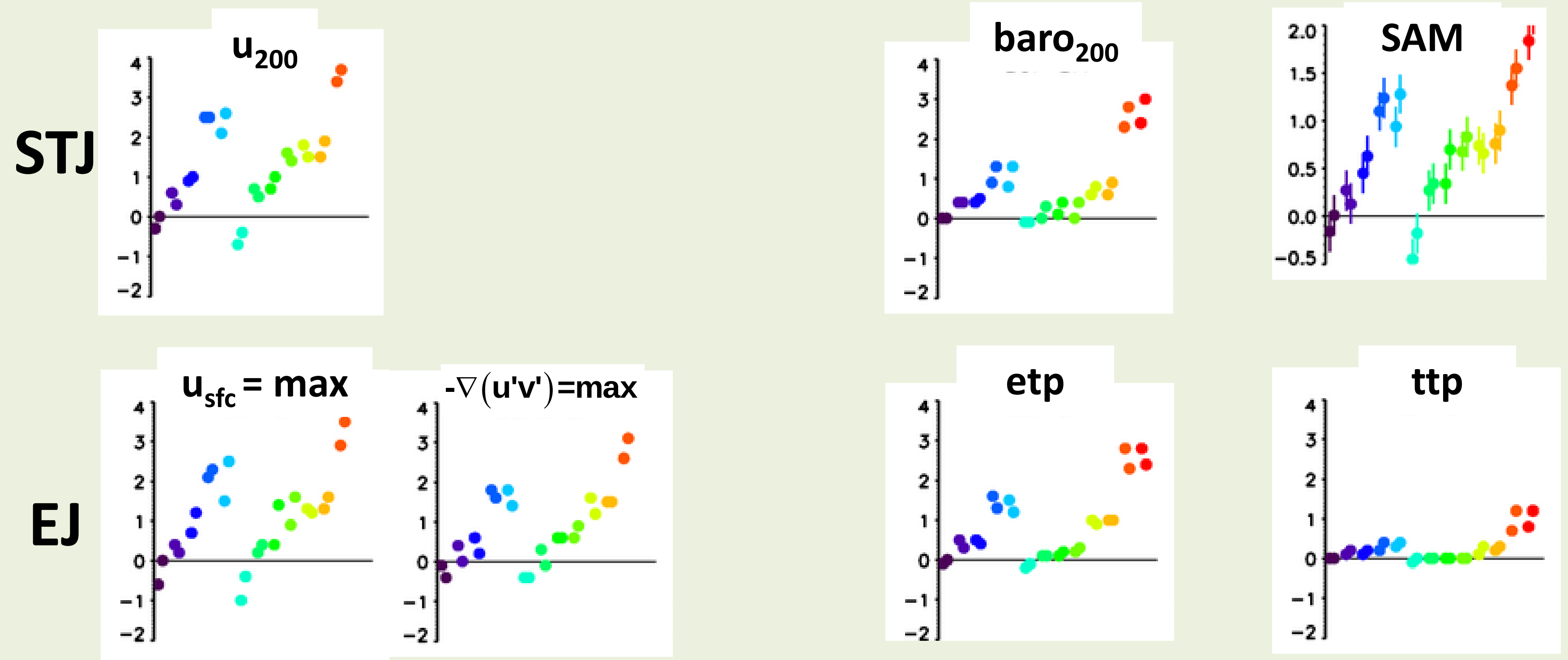
EJ always poleward
separated during SH winter
else close (ca. 7°)

EJ • **u_{sfc} = max** ✓

• **-div(uv) = max** ✓

Widening: SH-DJF

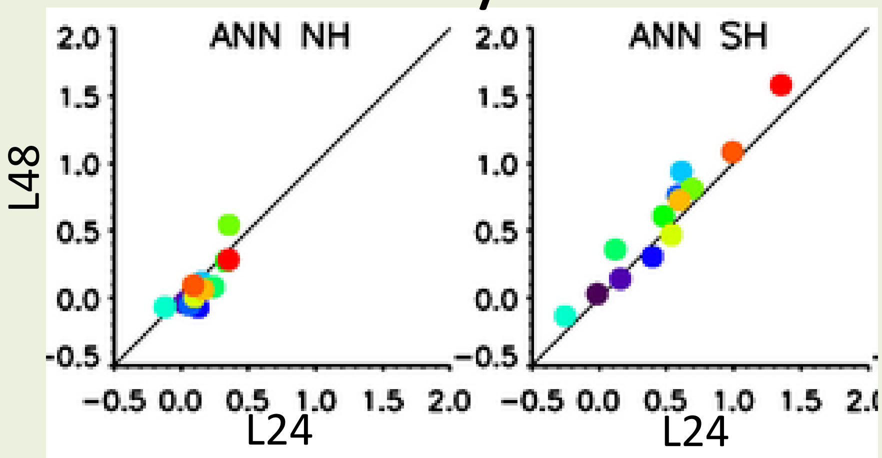




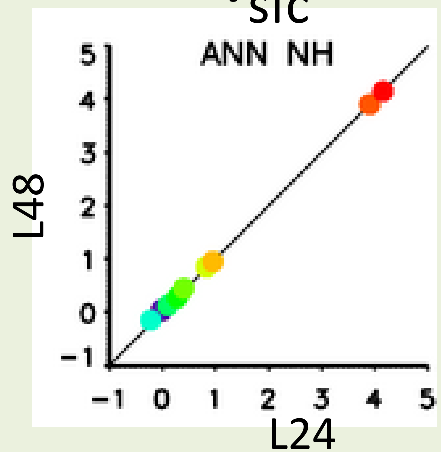
Low/high-top differences

Total annual mean change

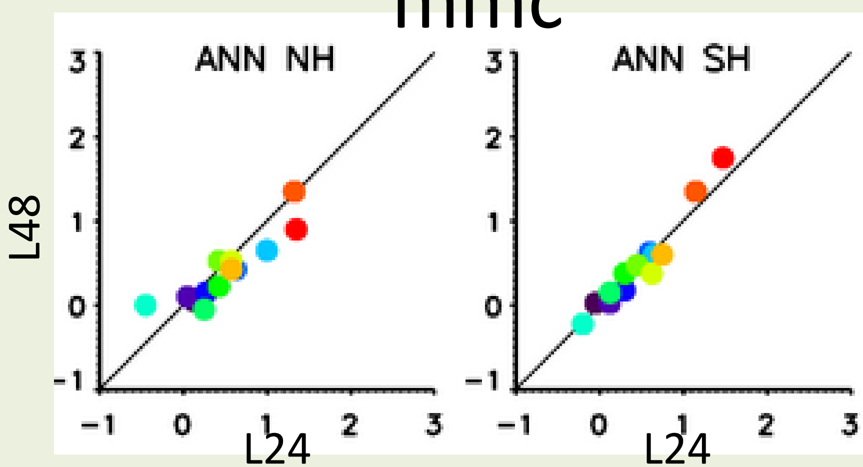
NAM/SAM



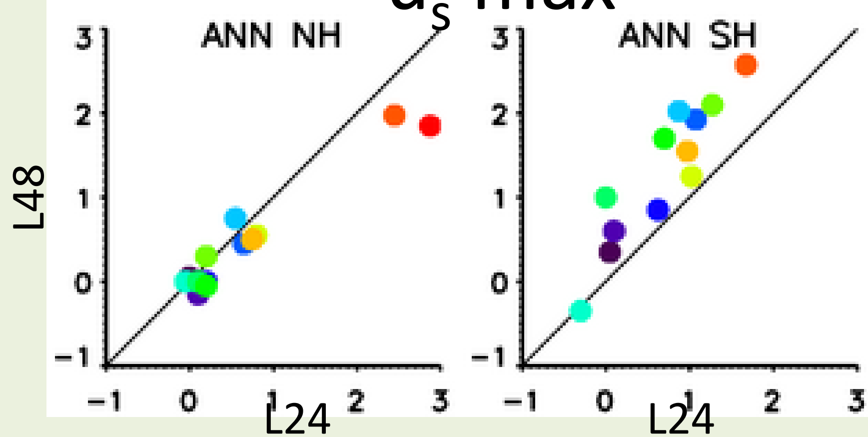
T_{sfc}



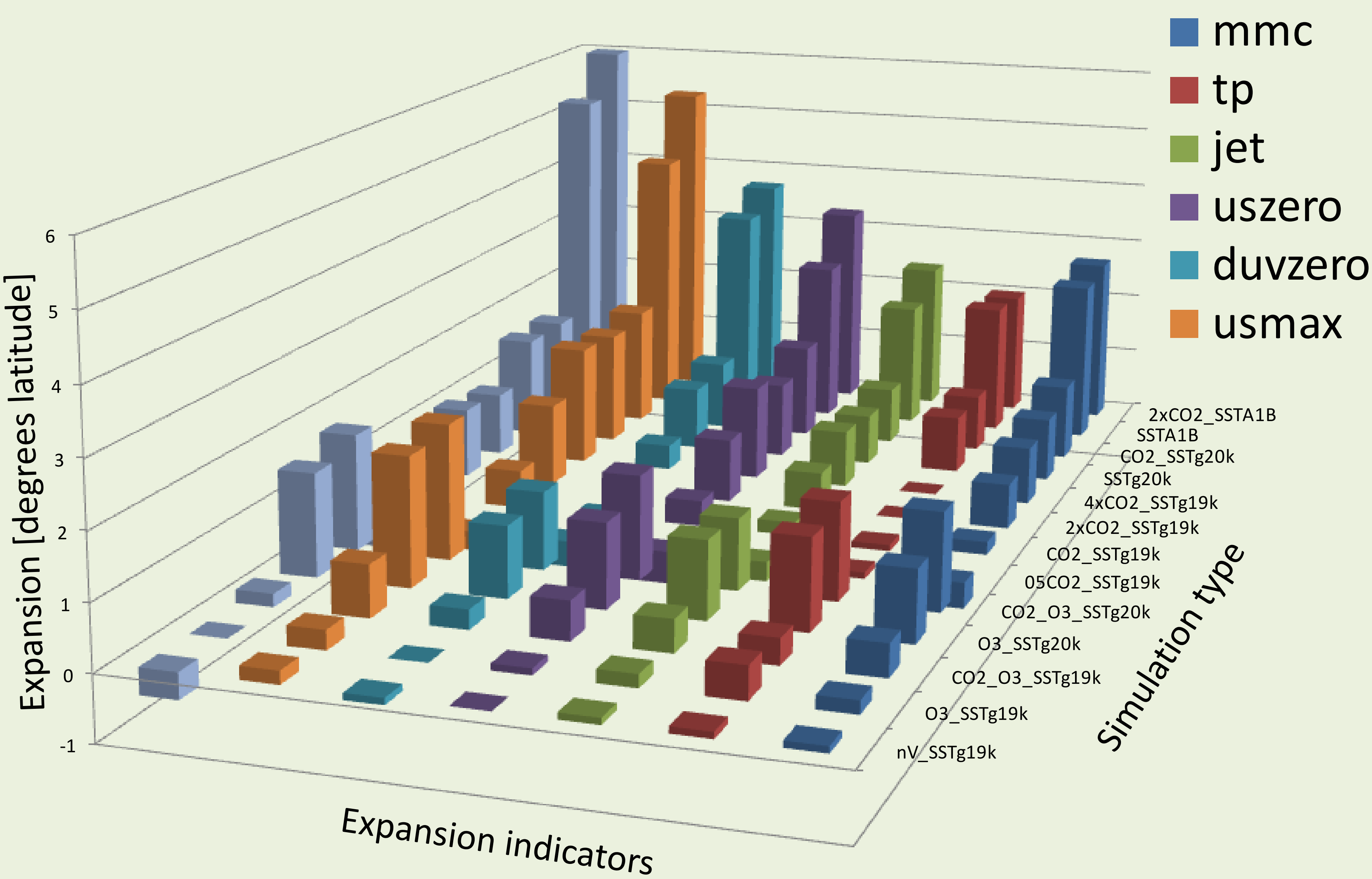
mmc



u_s max



Annual Mean Total Expansion



5. Tropical Expansion

Averaged over 5 measures (jet, mmc, tp, u_{sfc}=0, d(uv)=0), the model simulates the following annual mean tropical expansion:

Annual mean expansion with respect to pre-industrial control in degrees latitude

	NH	SH	total	range
2000	0.6	0.8	**1.4**	1.1-1.6
2100 (A1B)	1.3	1.6	**2.8**	2.0-3.7

Factors for Tropical Expansion

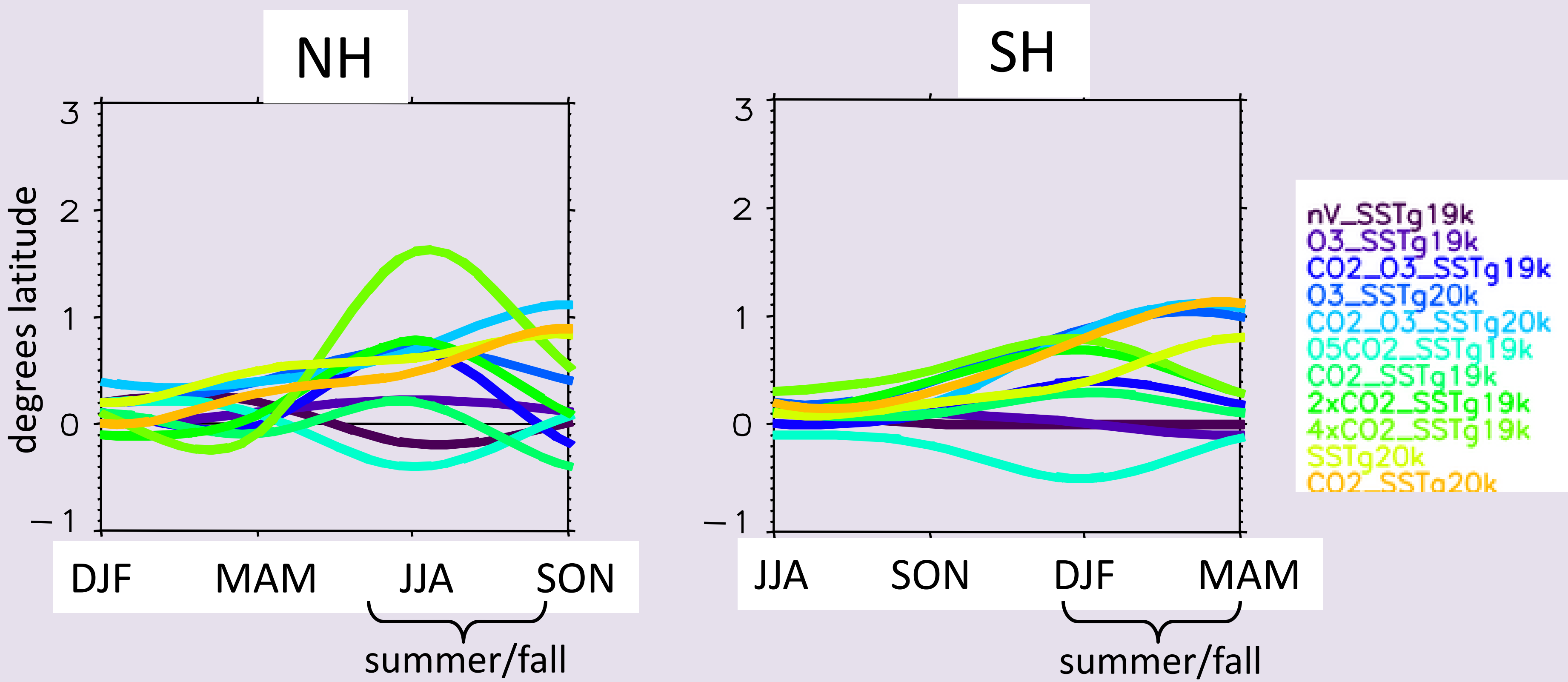
Annual mean total tropical expansion average over five measures
with respect to pre-industrial control in degrees latitude

	SST_{19}	SST_{20}
	-	1.0
O_3	0.2	1.2
CO_2	0.1	1.1
$O_3 + CO_2$	0.5	1.4

- Note the individual effects are almost linearly additive
- SSTs are important, i.e., tropospheric control
- Some effect from stratosphere: O_3 and CO_2

Seasonality of Widening

mmc expansion by experiment and season



- As in observations, strongest expansion during summer and fall in each hemisphere (weak HC)

6. Conclusion

- Model simulated widening:
  - 1.4° by today
  - 2.8° by 2100
- Widening is not restricted to Tropics; many elements of the general circulation shift poleward
- Widening strongest during summer and over SH
- SSTs are most important contributor
- Tropospheric response of low-top model is very similar to that of high-top model