The Role of Atmospheric Dynamics Shifts in Determining Cloud Radiative Effect Variability

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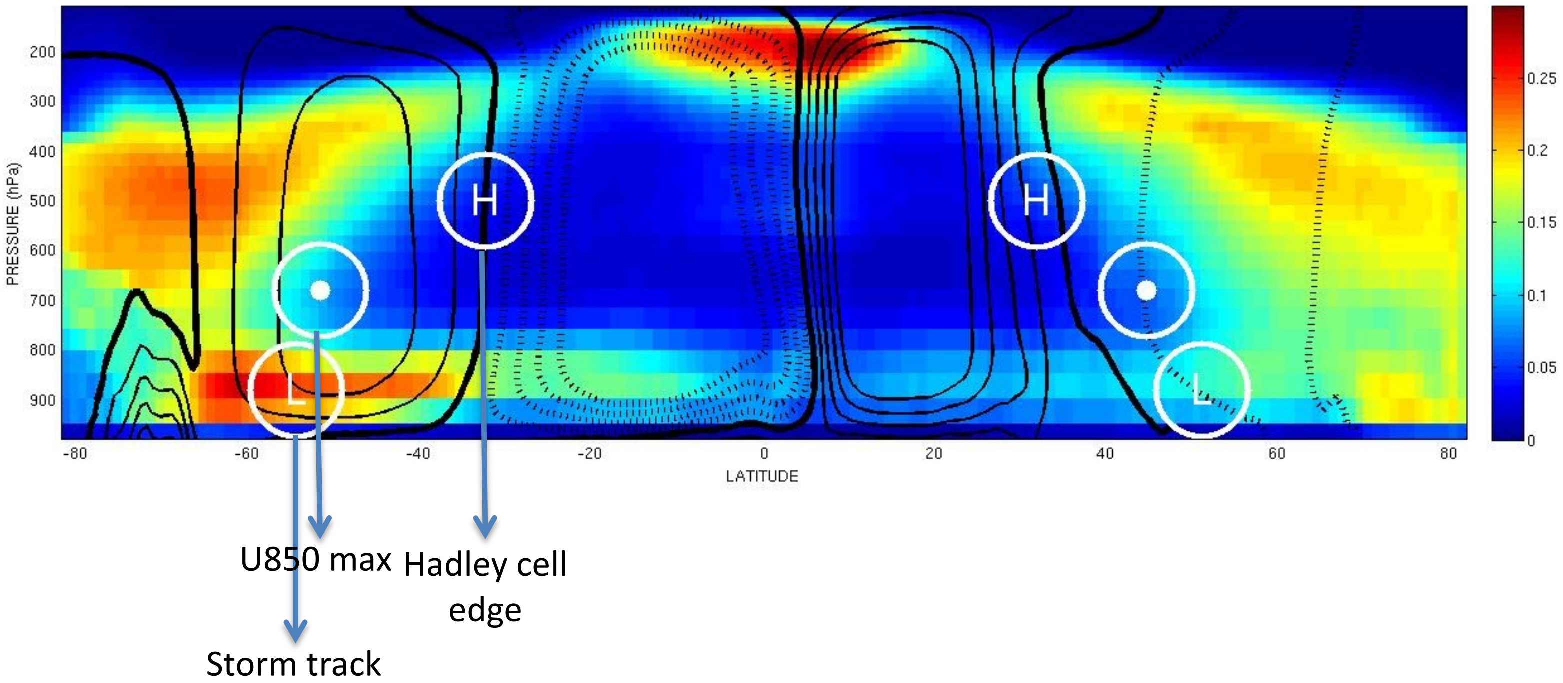
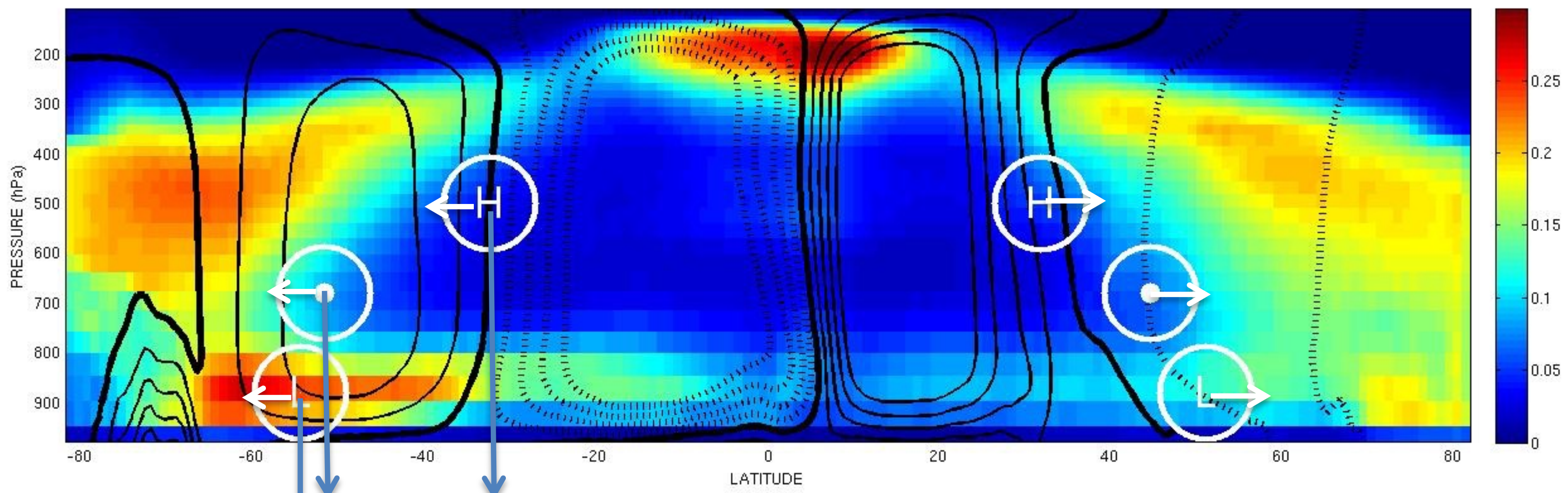
- How shifts in the main features of the atmospheric zonal mean circulation affect the components of the cloud radiative effect?
- How well do models simulate this cloud/circulation coupling and what are the effects of model simulation deficiencies on climate sensitivity?



What are the cloud/radiation effects of circulation shifts?

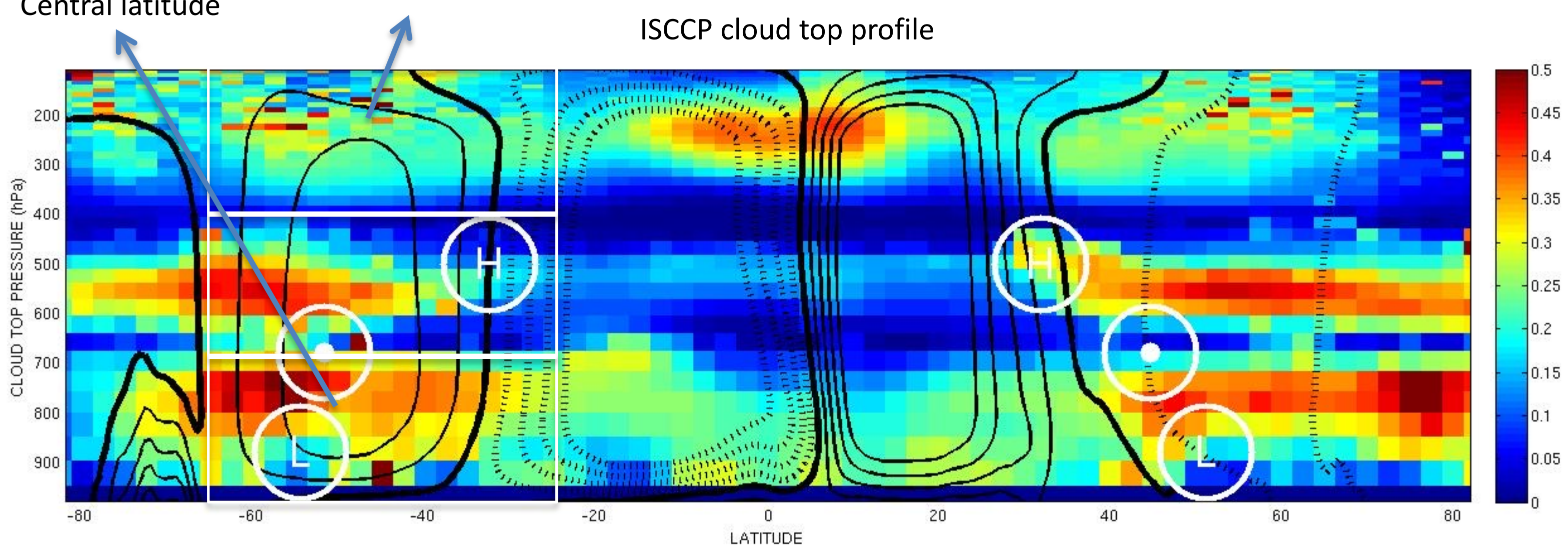
CloudSat/CALIPSO cloud vertical profile



We regressed midlatitude total/high/low-cloud central latitude and mean SWCRE/LWCRE on all major circulation features

Tselioudis, Lipat, Grise, Polvani, 2016

ISCCP cloud top profile



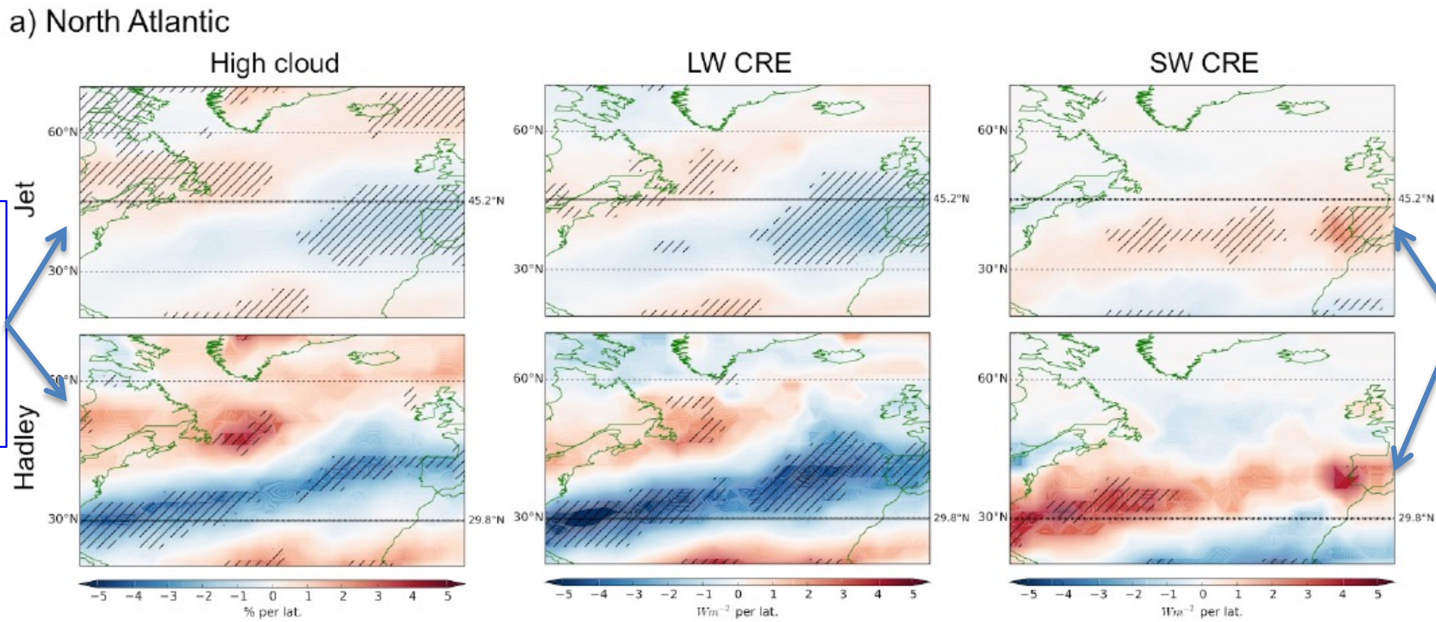
Regressions between Hadley/Jet shifts and cloud and CRE properties

		SH				N. Atl.				N. Pac.			
DJF		Hadley (°)		**m=0.54 R=0.58** Jet (°)		Hadley (°)		**m=0.15 R=0.57** Jet (°)		Hadley (°)		m=0.10 R=-0.29 Jet (°)	
		m	R	m	R	m	R	m	R	m	R	m	R
	Total (°)	0.506	0.292	2.320	0.060	0.820	0.367	**0.149**	**0.518**	25.64	0.007	-0.191	-0.346
	High (°)	**1.206**	**0.466**	2.370	0.224	**1.553**	**0.646**	**0.464**	**0.555**	8.475	0.100	-3.745	-0.081
	Low (°)	**-0.756**	**-0.441**	-1.284	-0.245	-1.292	-0.364	-0.385	-0.313	-3.571	-0.116	-0.632	-0.236
	SW CRE (Wm^{-2})	**-6.024**	**-0.429**	**-6.024**	**-0.404**	**3.610**	**0.391**	**0.622**	**0.583**	-14.09	-0.104	-4.785	-0.111
	LW CRE (Wm^{-2})	2.494	0.359	4.202	0.201	**-3.247**	**-0.536**	**-0.898**	**-0.498**	6.369	0.212	14.93	0.032
JJA		Hadley (°)		m=0.15 R=0.17 Jet (°)		Hadley (°)		m=0.37 R=0.31 Jet (°)		Hadley (°)		m=0.33 R=0.39 Jet (°)	
		m	R	m	R	m	R	m	R	m	R	m	R
	Total (°)	1.148	0.239	-1.745	-0.098	0.545	0.289	-2.494	-0.074	0.259	0.339	0.340	0.224
	High (°)	**1.938**	**0.490**	9.804	0.061	**0.450**	**0.522**	2.110	0.131	**0.591**	**0.395**	0.793	0.254
	Low (°)	**-1.140**	**-0.630**	-1.672	-0.268	-2.273	-0.103	-1.852	-0.149	0.549	0.283	0.902	0.149
	SW CRE (Wm^{-2})	**-2.857**	**-0.405**	-3.195	-0.226	-41.70	-0.021	3.205	0.311	-11.49	-0.117	3.279	0.353
	LW CRE (Wm^{-2})	8.000	0.187	5.747	0.162	-6.623	-0.052	-1.230	-0.329	3.378	0.137	-1.076	-0.371

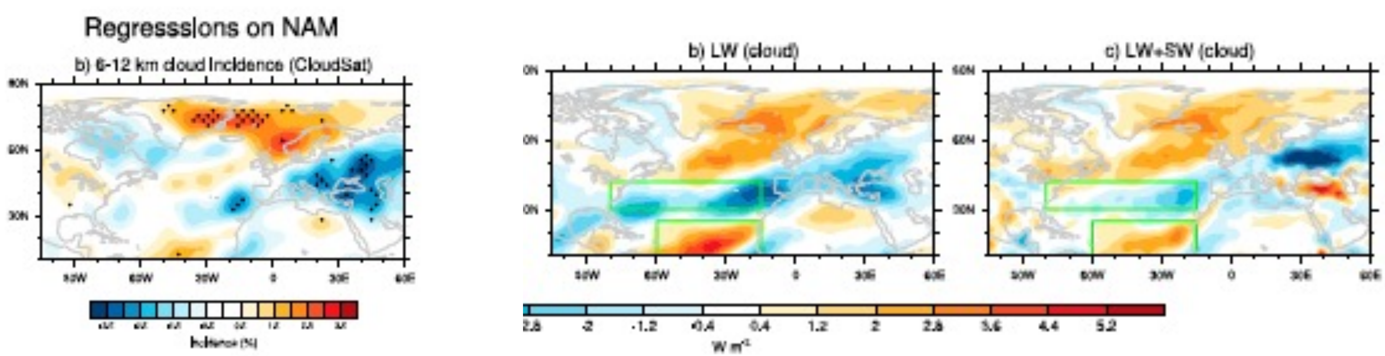
- Only Dynamics-Clouds pair coherently shifting in (almost) all basins/seasons is Hadley-High Cloud
- Jet shifts coherently with High Cloud only in N. Atlantic - DJF
- High Cloud-Jet/Hadley poleward shifts in N. Atlantic – DJF produce SW warming, while High Cloud-Hadley poleward shifts in S. Ocean DJF/JJA produce SW cooling

Cloud/radiation changes with poleward Hadley/jet shifts

The pulling of the high-cloud curtain….



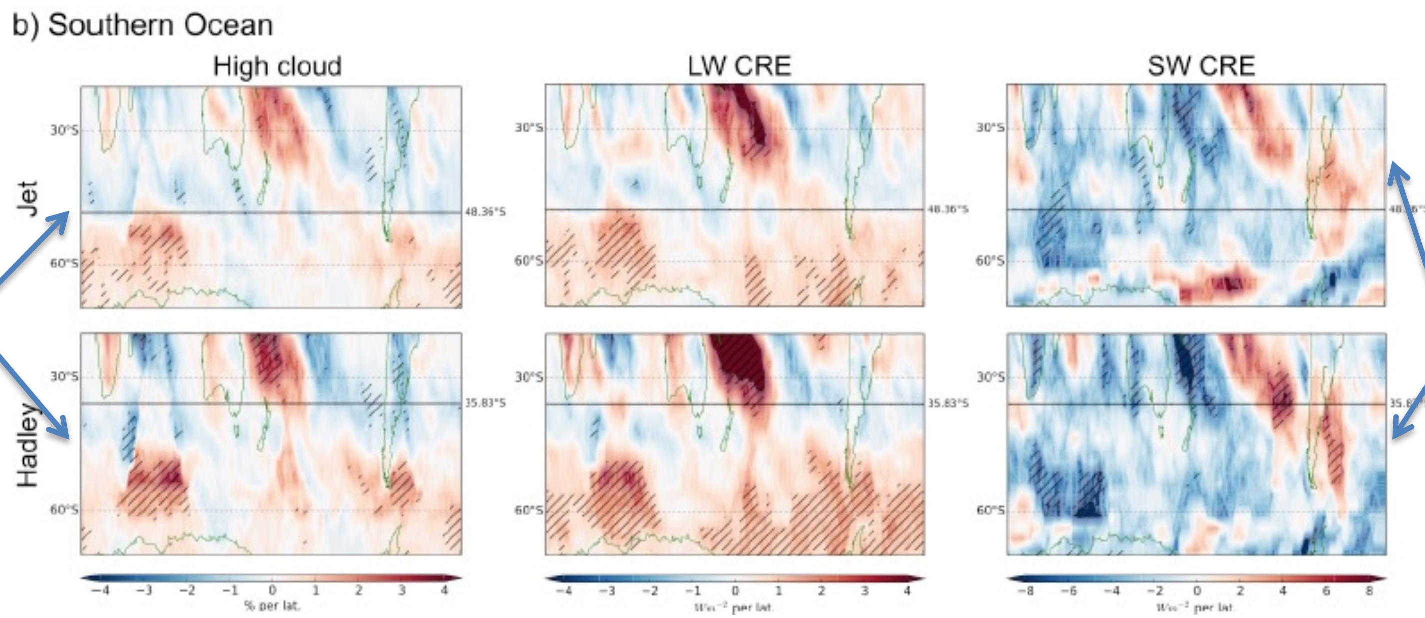
….lets more solar flux in the lower midlatitude surface



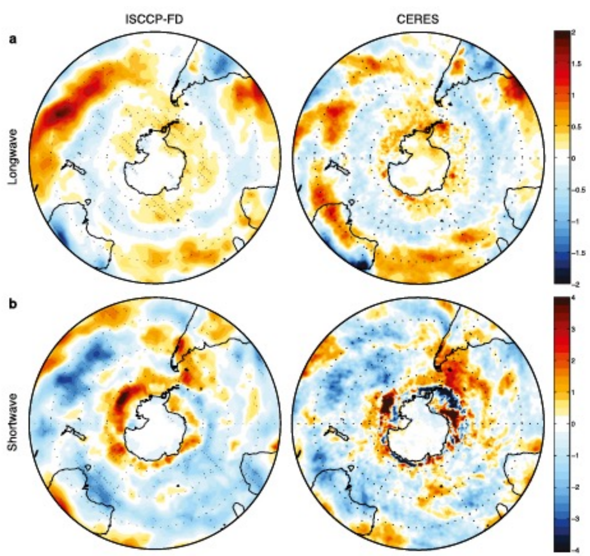
Li, Thompson, Huang, Zhang, 2014

Cloud/radiation changes with poleward Hadley/jet shifts

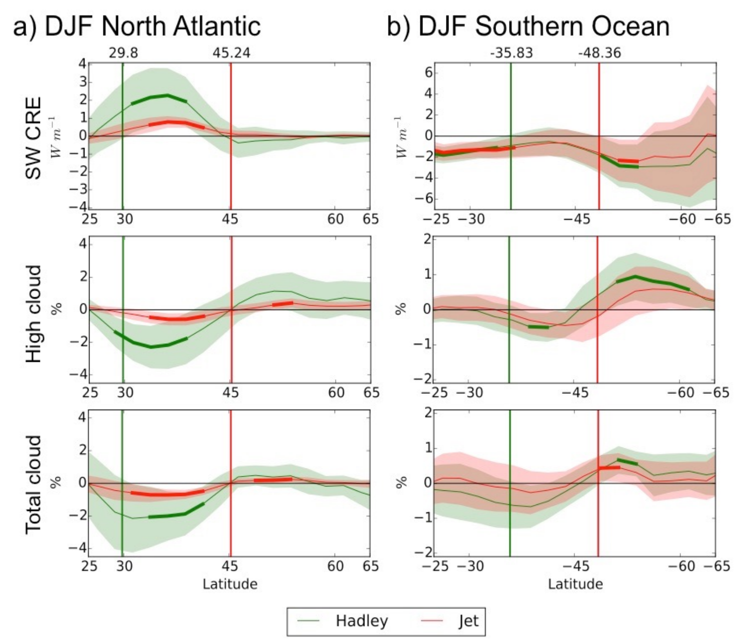
The high-cloud curtain is still pulled….



….but the lower midlatitude surface solar flux does not increase



High cloud shift
– Total cloud decrease
– SW warming



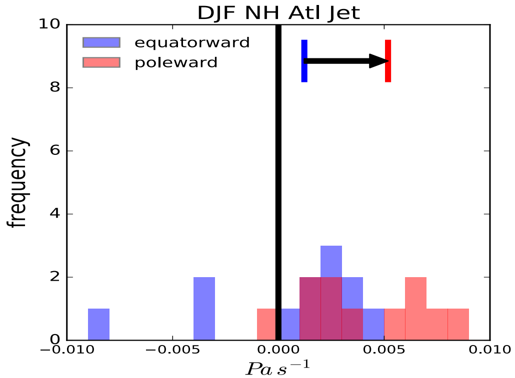
High cloud shift
– No Total cloud change
– weak SW cooling

Grise and Polvani, 2014

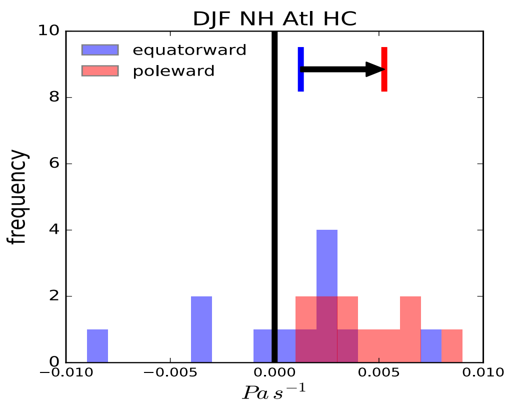
Omega changes with Jet and Hadley shifts

N. Atl. 30-45N DJF

Jet

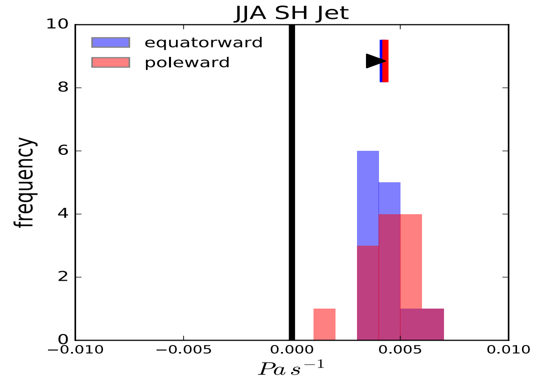


Hadley

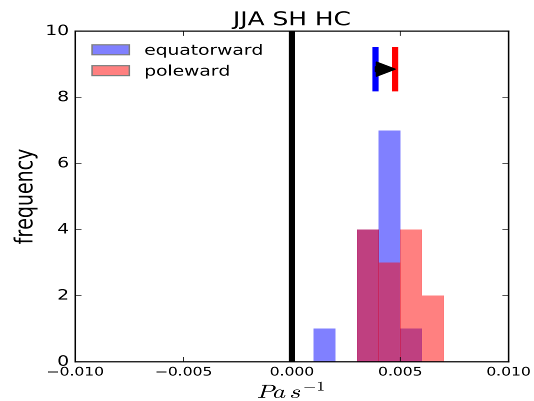


S. Ocean 30-45S JJA

Jet



Hadley

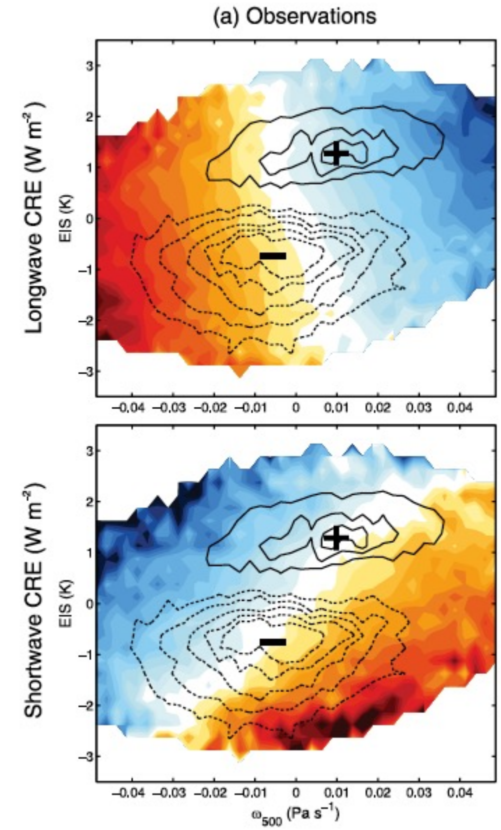


In the N. Atlantic winter, Jet and Hadley shifts correspond to large omega changes, while in the Southern Ocean winter the omega changes from such shifts are small

CRE changes with omega/EIS

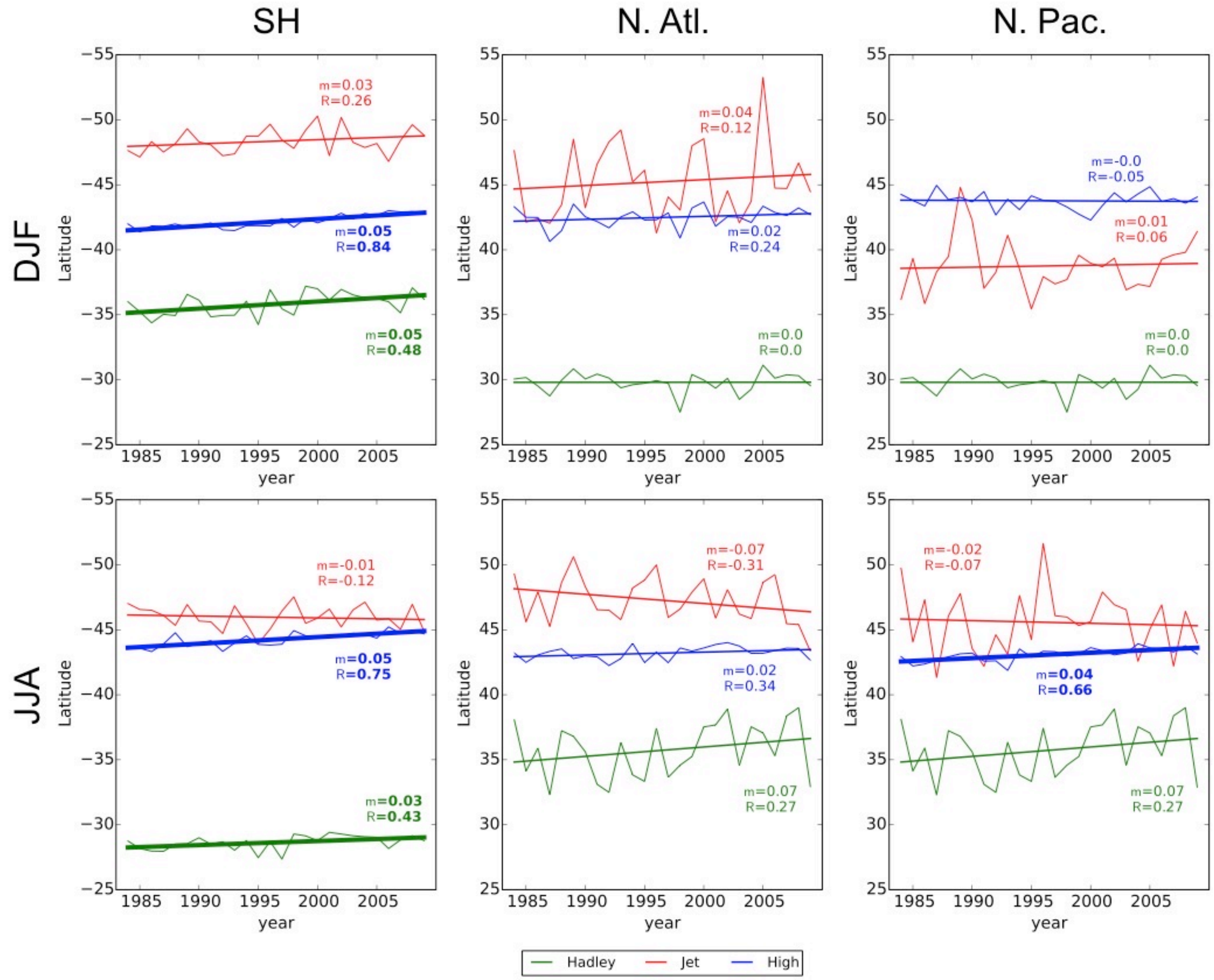
Grise and Madeiros 2016

S. Ocean 40-50S



LWCRE varies primarily with omega, while SWCRE variability is dependent on both omega and EIS

High cloud, Hadley, and Jet shifts in the 1983-2009 period



- Hadley cell and high clouds have been shifting consistently poleward at rates of 0.3-0.5 degrees/decade in the Southern Hemisphere

- Hadley cell expansion would be the primary culprit for the observed cloud poleward shifts

Discussion

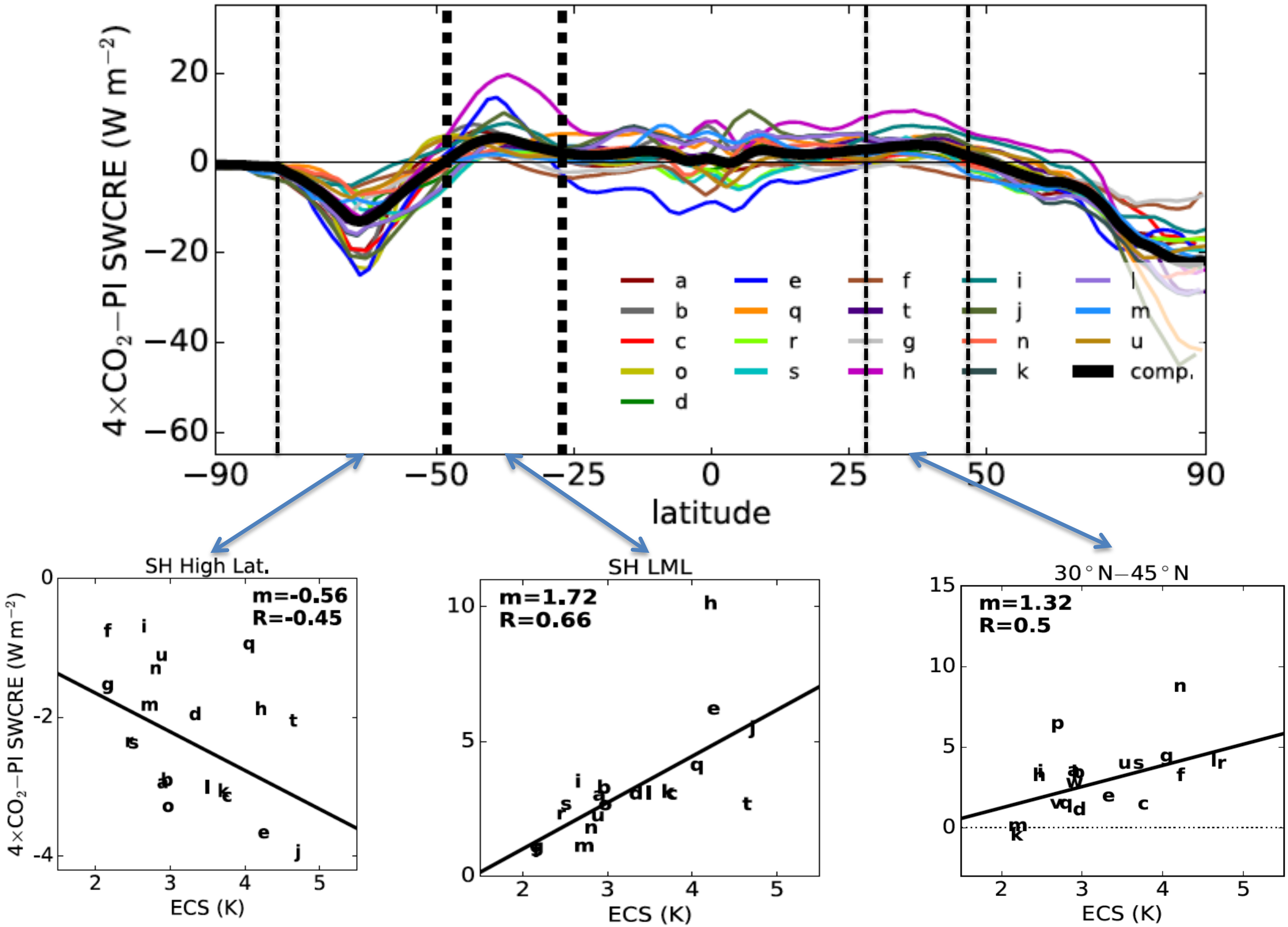
- Hadley cell extent correlates strongly with high cloud shifts in almost all basins and seasons. Storm track or eddy jet location show weaker correlations with high cloud, mostly in the winter seasons.

- Radiative effects of cloud shifts are complex and vary with latitude and season. LW CRE shows expected warming/cooling dipole with poleward high cloud shifts. SW CRE shows subtropical warming with Hadley/jet shifts in the N. Atl. but cooling almost everywhere in the Southern Ocean. Lack of S. Ocean warming with the high cloud shifts may be due to weak vertical velocity response and/or large cloud amount of the background low and middle cloud field.

- The high cloud poleward shift observed in ISCCP in the 83-09 period can be attributed to Hadley cell expansion rather than jet poleward shift.

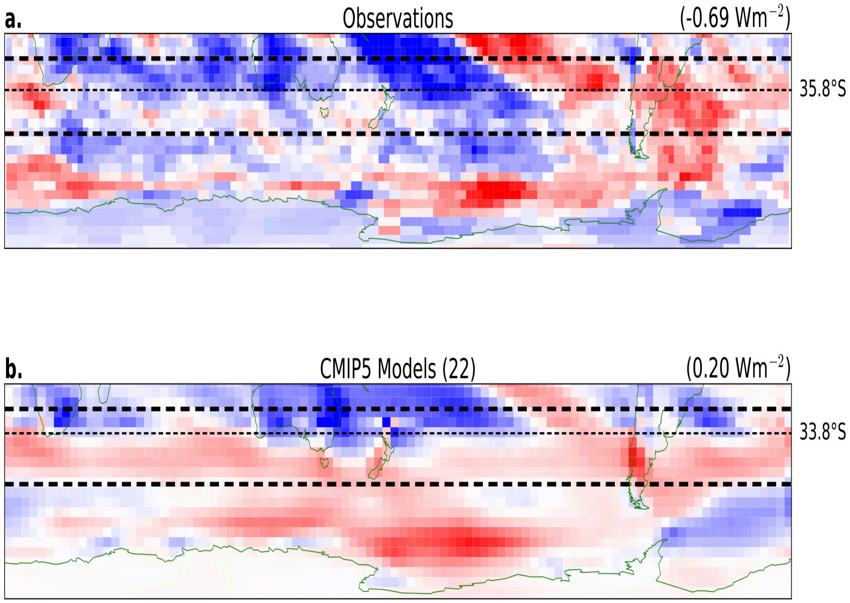
- **Question now is, how do models simulate those coherent dynamics-clouds-radiation shifts, and do those shifts matter to model climate sensitivity**

Annual 4xCO2 SWCRE changes in CMIP5 models and their relation to climate sensitivity

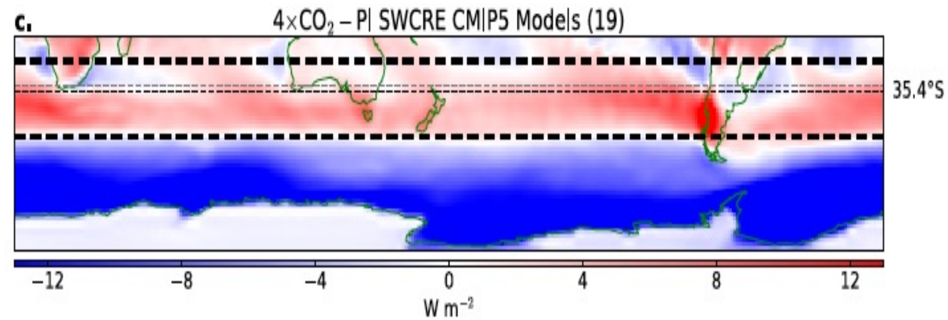


Lipat, Tselioudis, Grise, Polvani, GRL, 2017

Observational and model control run SWCRE response to 1-degree poleward HC shift



CMIP5 model SWCRE change in 4xCO2 experiments

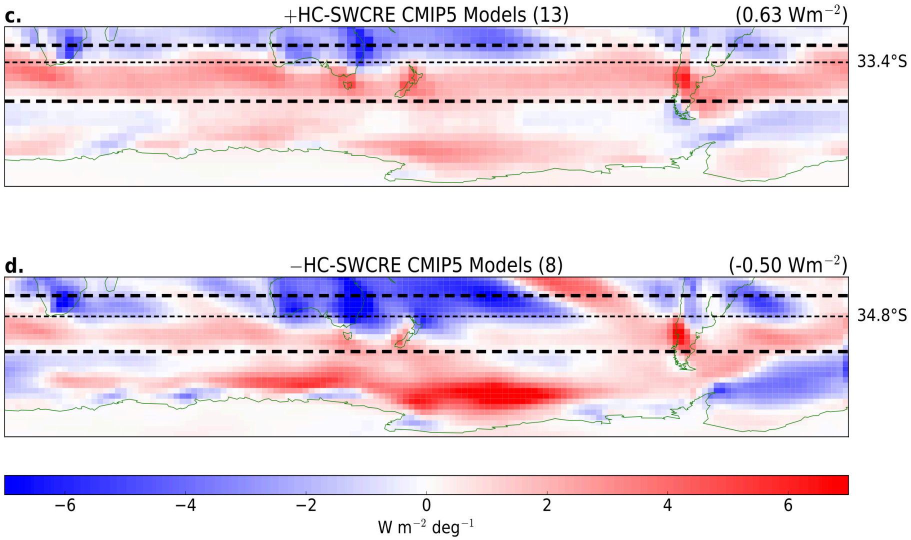


Unlike the observations, model control runs show a zone of SWCRE warming in the SH LML region when HC edge shifts poleward.

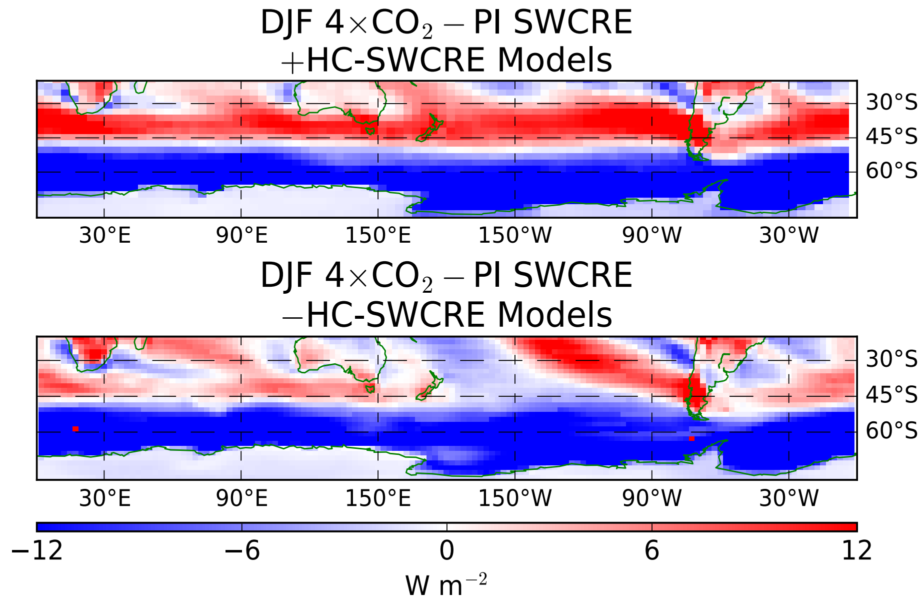
Zone of 4xCO2 SW warming in the Lower Midlatitudes, with patterns similar to the warming from poleward HC shift in the control runs

Lipat, Tselioudis, Grise, Polvani, GRL, 2017

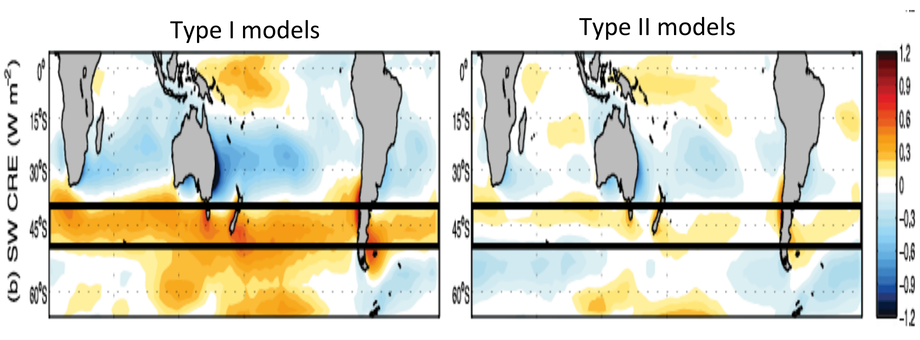
Models that in control runs warm strongly the LML region with poleward HC shifts....

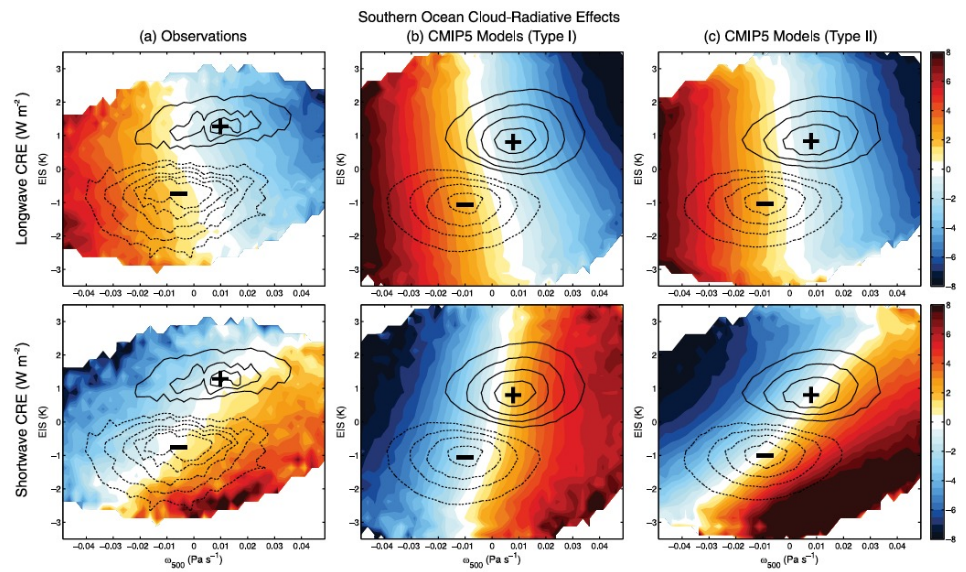


...are the models that warm strongly the LML region in 4xCO2 simulations......



....but also the models with the more narrow climatological Hadley cells

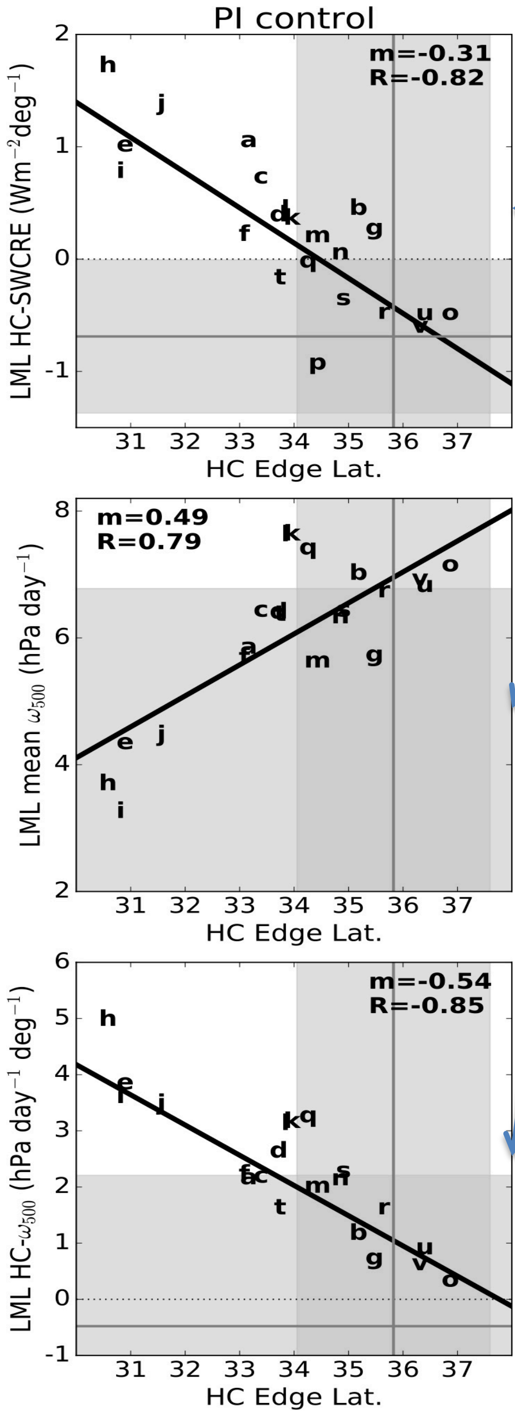




Similar separation of Type I-II models based on SWCRE warming with poleward jet shifts

Attributed to differences in the dependence of SWCRE on omega and EIS

Grise and Madeiros 2016

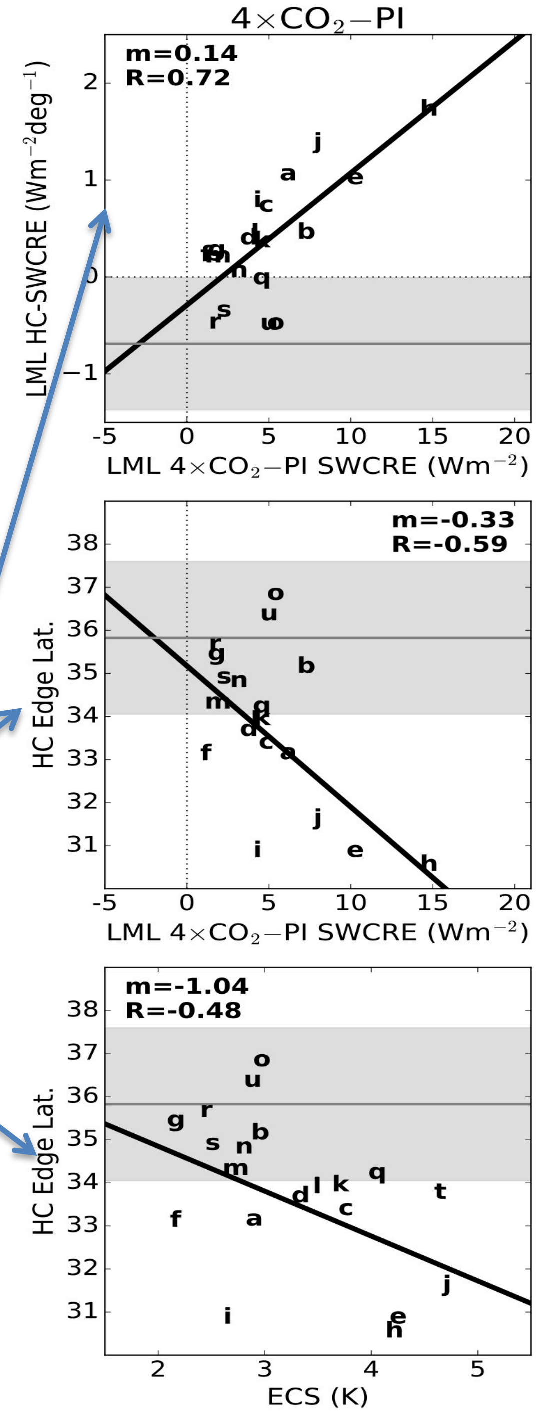


In Pre-Industrial control runs:

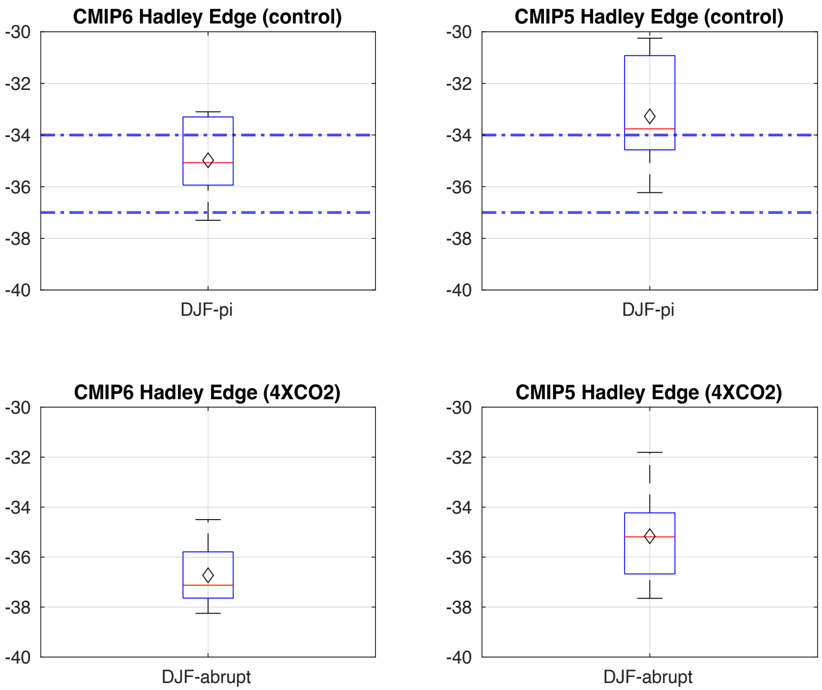
- Changes in LML SWCRE with poleward Hadley cell shift correlate strongly with HC edge climatological position
- This is because LML mean subsidence is weaker in models with more narrow HC, and their subsidence change is larger when the HC edge shifts poleward

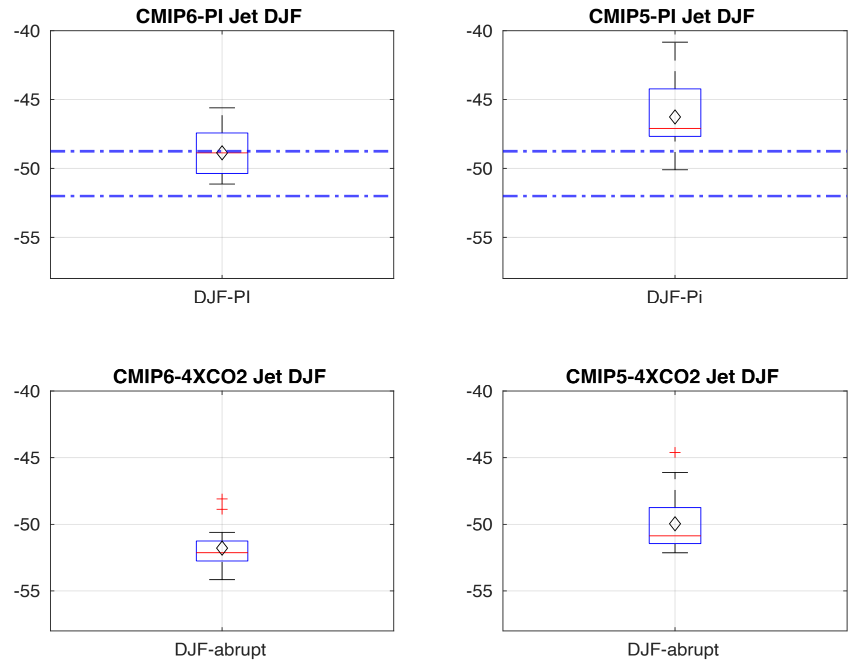
In 4xCO2 runs:

- LML SWCRE warming is significantly predicted by control SWCRE change with poleward HC shift and, thus, by climatological HC edge position
- ***Therefore, ECS is significantly constrained by the climatological HC edge position, and models with more realistic HC edge positions tend to have lower ECS values***



CMIP6 models: How well do they simulate HC edge and jet position?

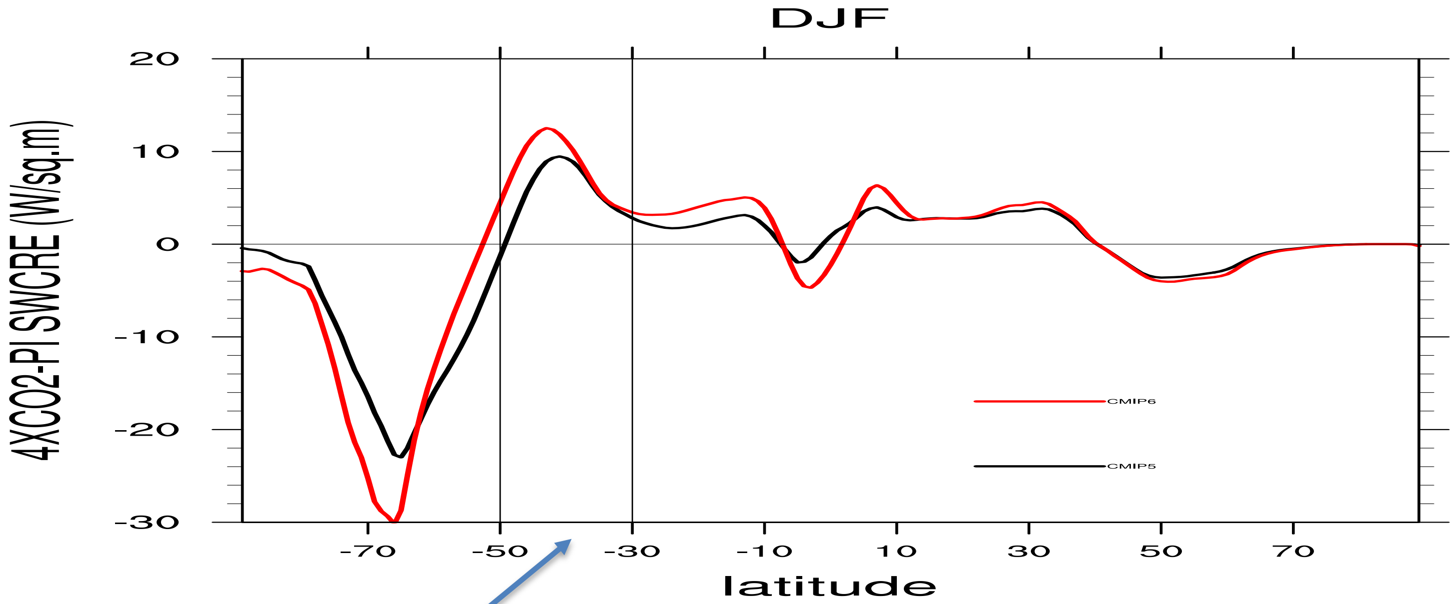


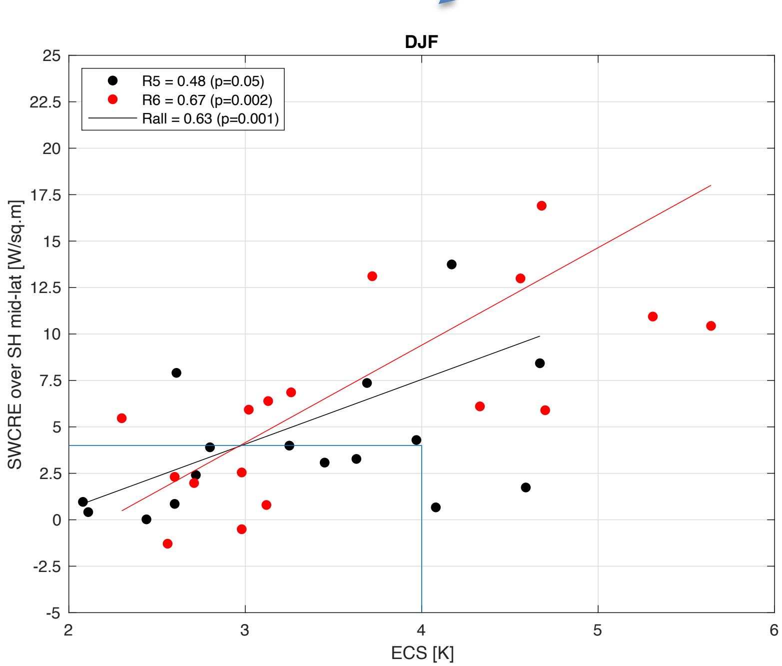


CMIP6 models simulate wider, more realistic Hadley Cells in their control runs, and 4xCO2 poleward HC shifts similar to the CMIP5 models

CMIP6 models simulate more poleward jets in their control runs, and 4xCO2 poleward jet shifts smaller than the CMIP5 models

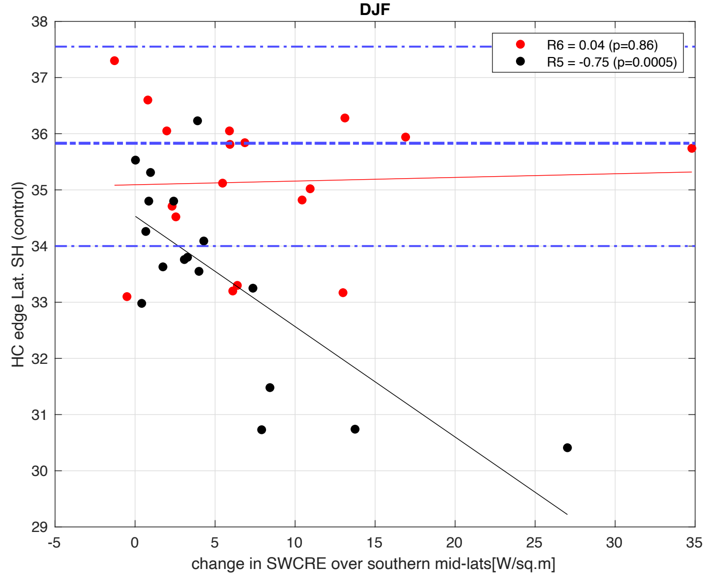
However, as is widely known, CMIP6 models have generally higher ECS values.....



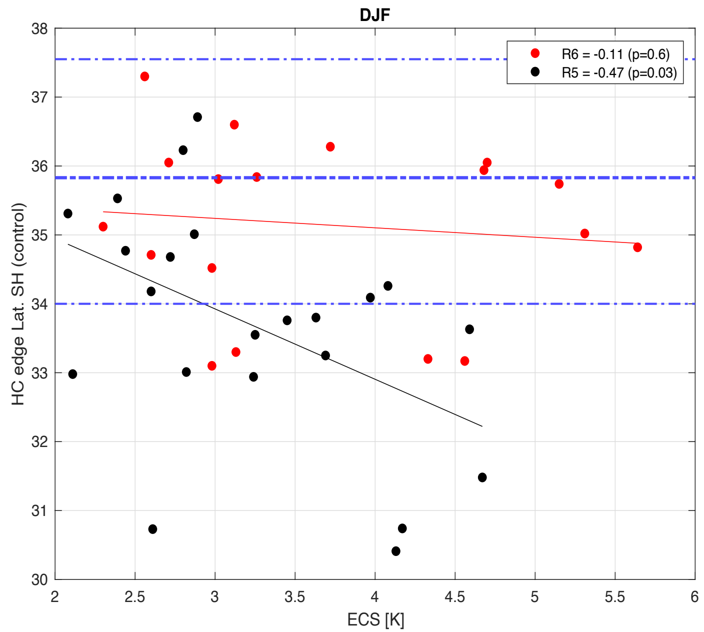


...driven primarily by stronger SH lower midlatitude SWCRE warming

In CMIP6 models, the SH LML SWCRE warming is not related to the position of the HC edge in the control run…..



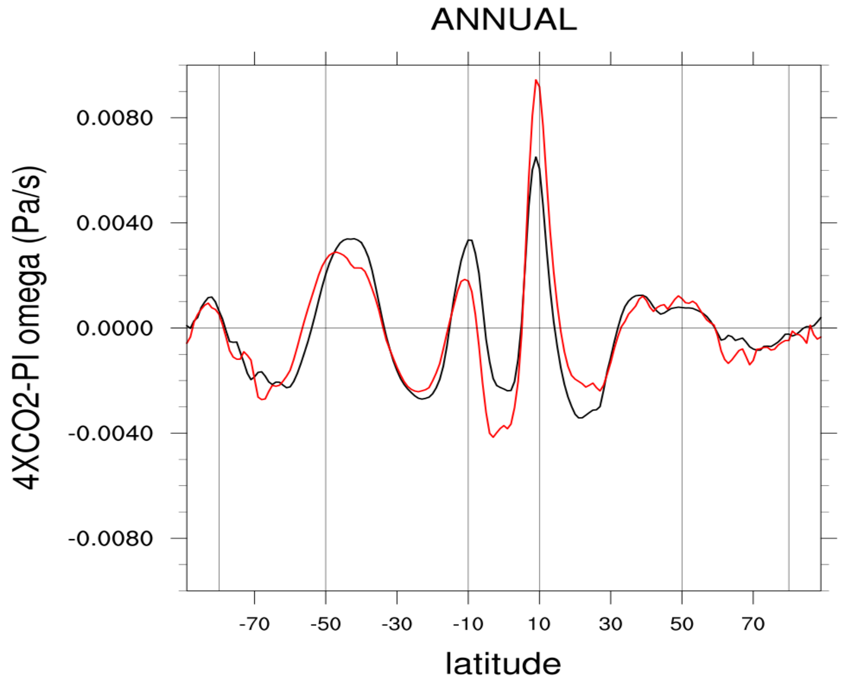
….and, therefore, the ECS is not constrained by the climatological HC width



Discussion

Lower midlatitude SWCRE warming in CMIP5 models shows dependence on climatological HC circulation, but such dependence is not present in CMIP6 simulations

Potential explanation is that, in CMIP6 models, SWCRE is not as strongly dependent on vertical velocity (more Type II models), and therefore still produce SH LML SWCRE warming, despite the fact that they produce smaller subsidence increases due to HC poleward expansion



This implies that the strong SH LML SWCRE warming is a result of changes in cloud microphysical (e.g. water phase transition) or thermodynamic (e.g boundary layer stability), or other dynamic (e.g. temperature advection) processes