Clouds and the general circulation: Midlatitude cloud shifts and the role of the Hadley cell and the baroclinic storm track

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- Observational and modeling evidence for systematic circulation shifts with climate warming, namely storm track poleward shifts and Hadley cell expansion (tropical widening)

- Observational analysis finds poleward cloud shifts in satellite retrievals over the last 30 years (Bender et al. 2008)

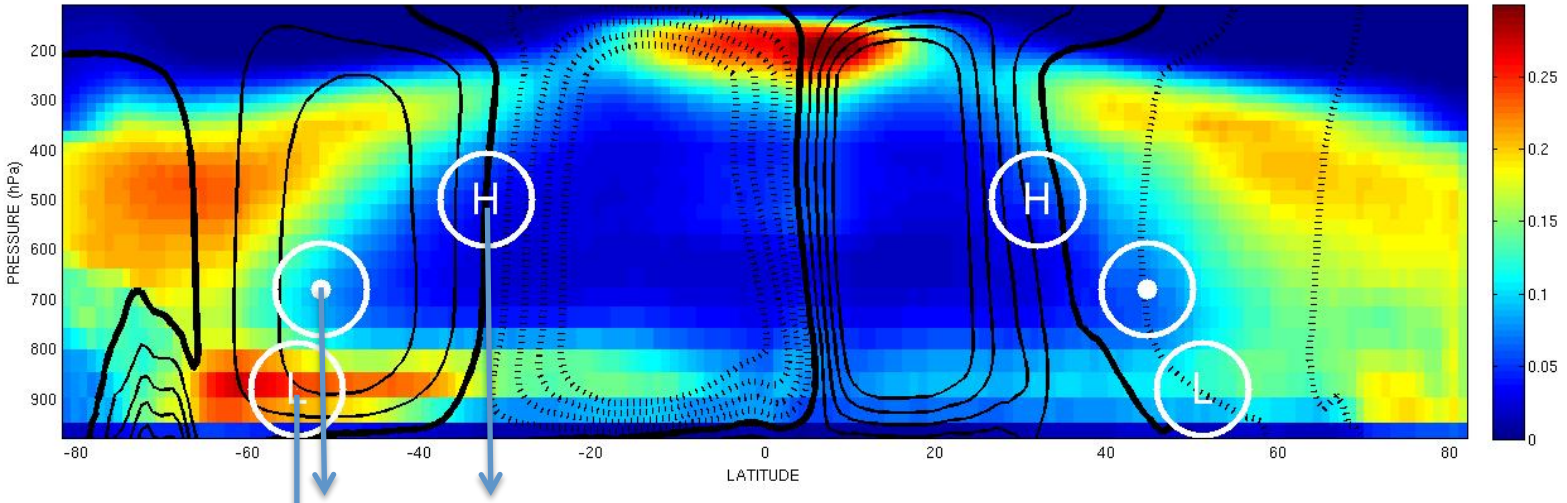
- What is the radiative effect/feedback of the dynamically driven cloud shifts? Theoretical argument calls for cloud radiative warming due to a cloud shift to a regime of lower solar insolation

- Modeling results show differing relationships between poleward storm and cloud shifts and radiation changes

- All this makes it crucial to understand and quantify relationships between dynamics and cloud latitudinal shifts, and their radiative effects

Cloud field and dynamic indices

CloudSat/CALIPSO cloud vertical profile



U850 max

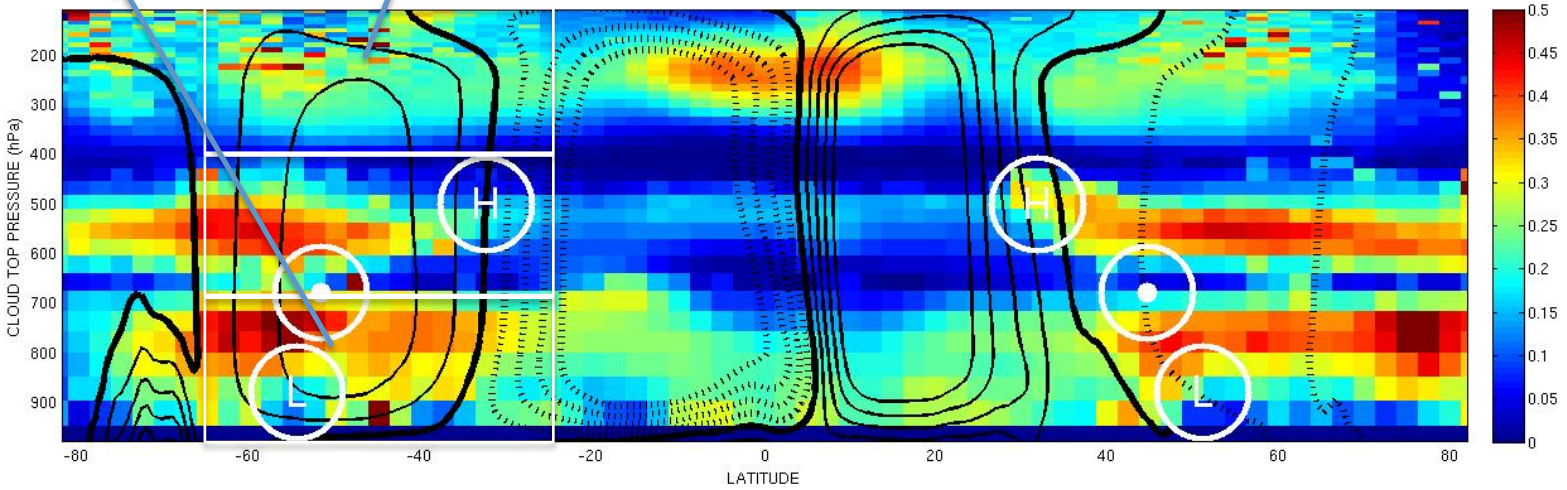
Hadley cell edge

Storm track

Low cloud
Central latitude

High cloud
Central latitude

ISCCP cloud top profile



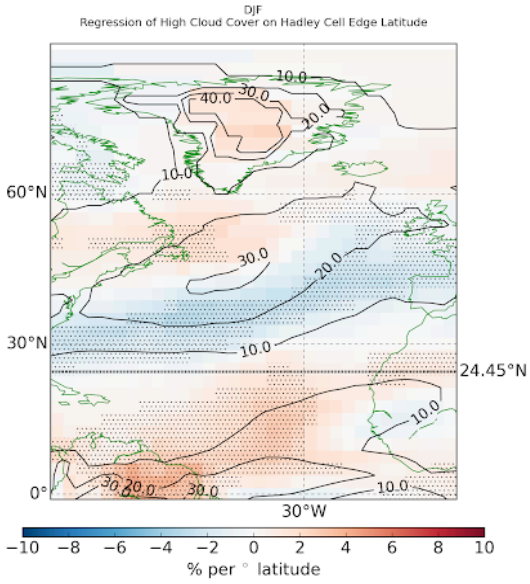
N. Atl. DJF

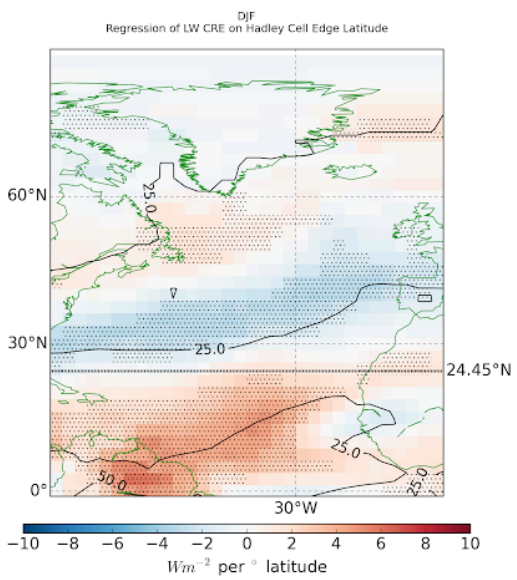
High Cloud

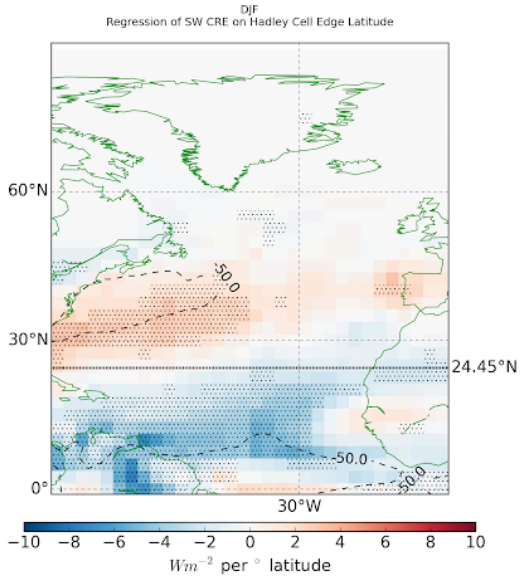
LW CRE

SW CRE

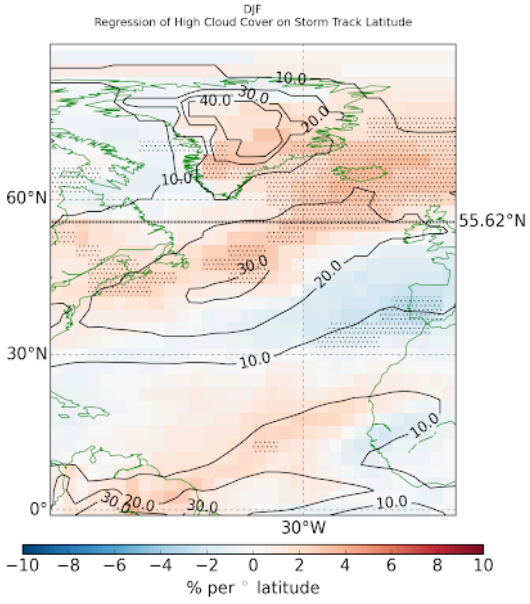
Hadley Cell

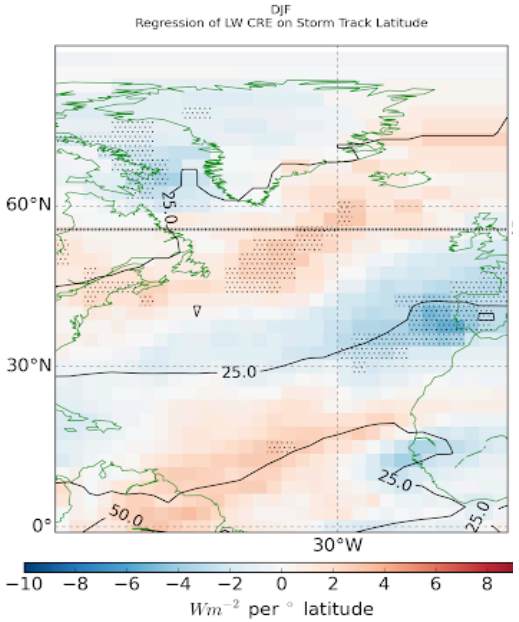


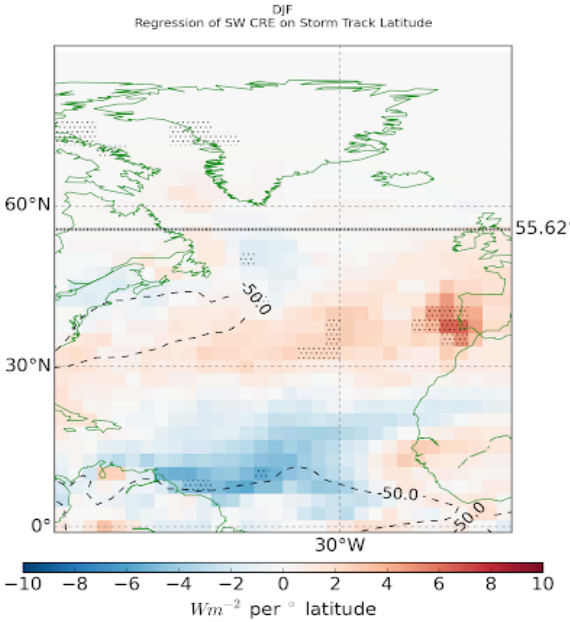




Storm Track







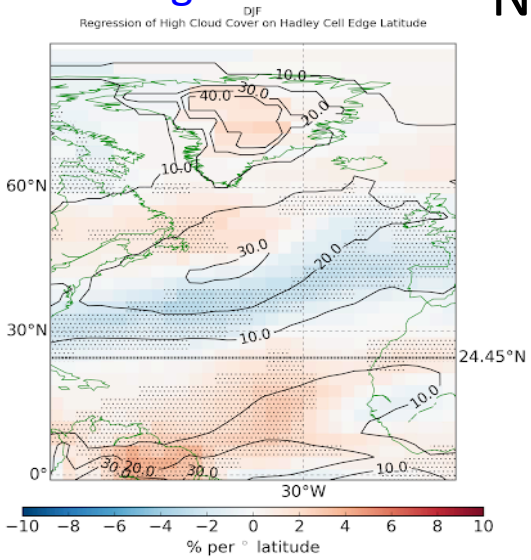
N. Atl. DJF

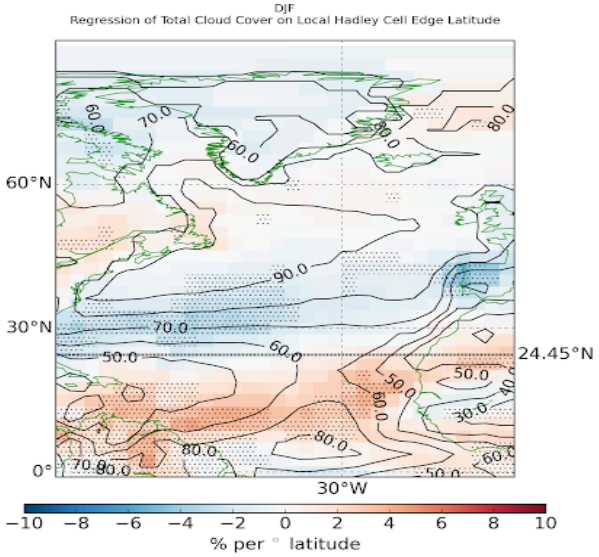
High Cloud

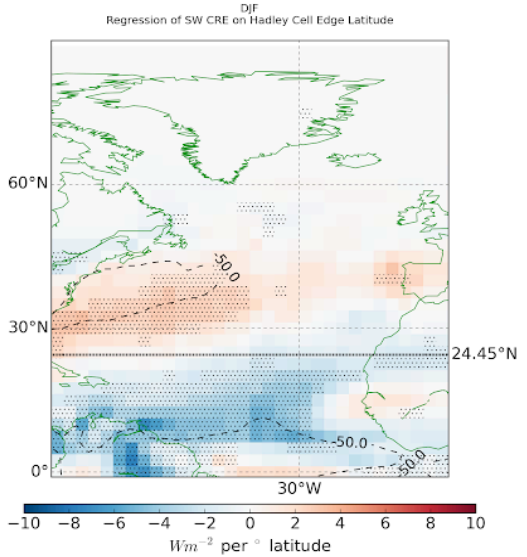
Total Cloud

SW CRE

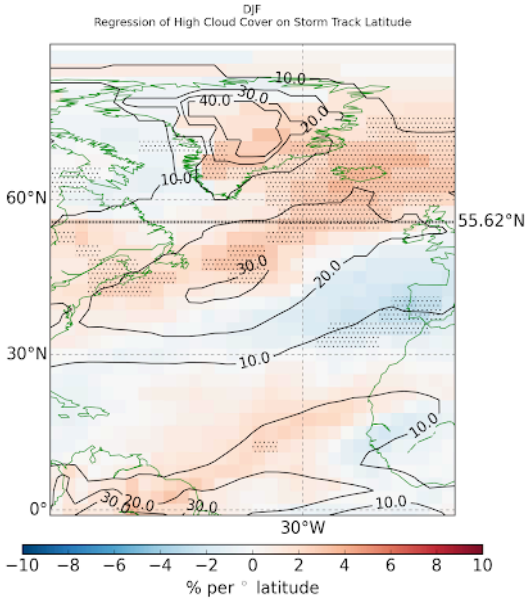
Hadley Cell

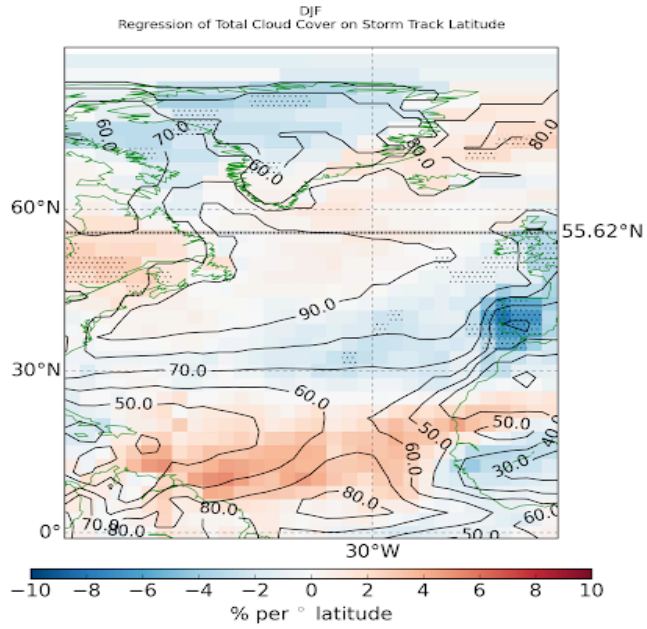


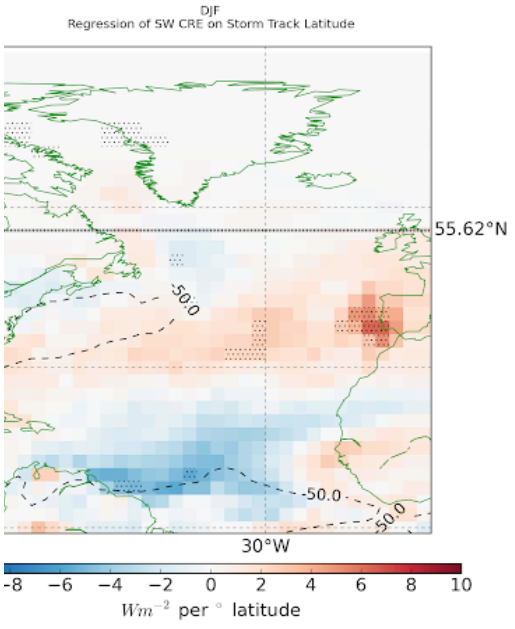




Storm Track

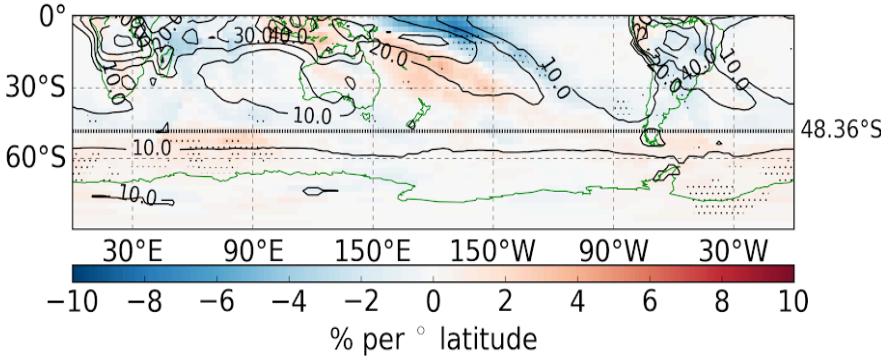




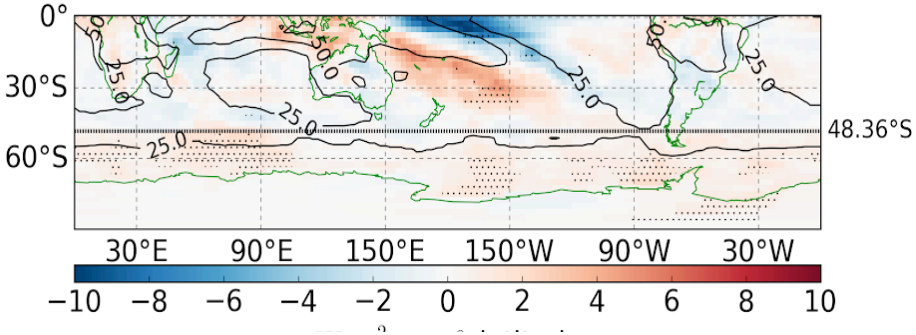


Regressions to Eddy driven Jet
DJF S. Oc.

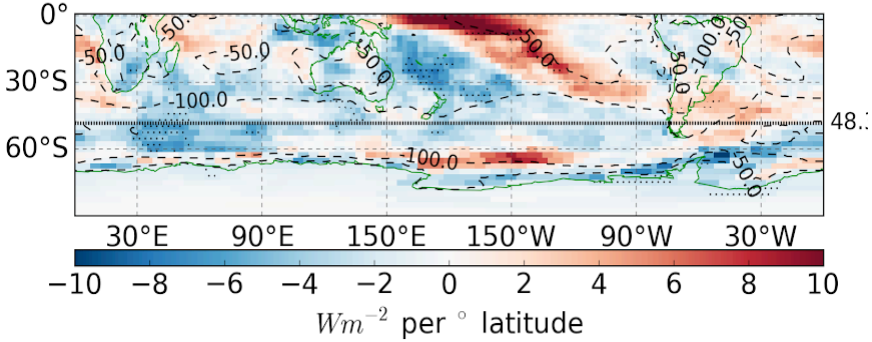
High Cloud



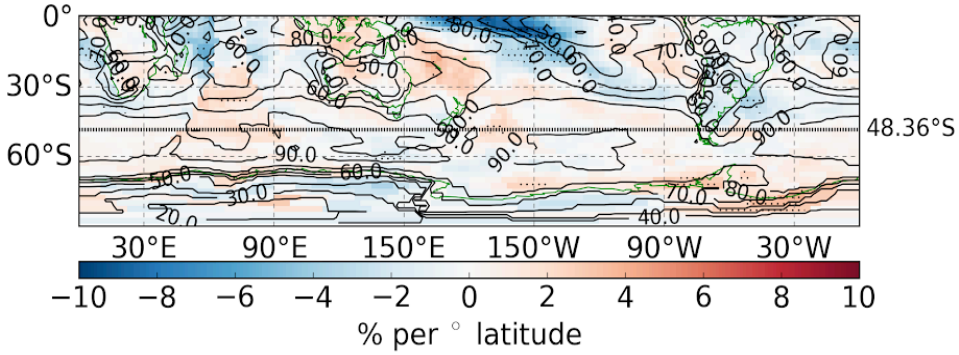
LW CRE



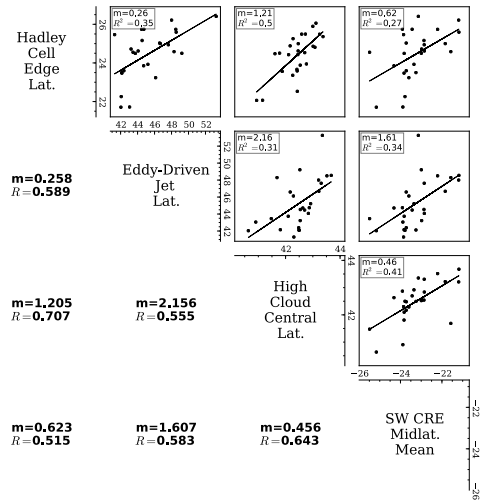
SW CRE



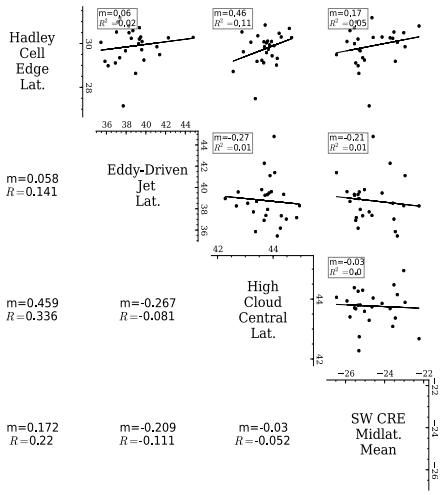
Total Cloud



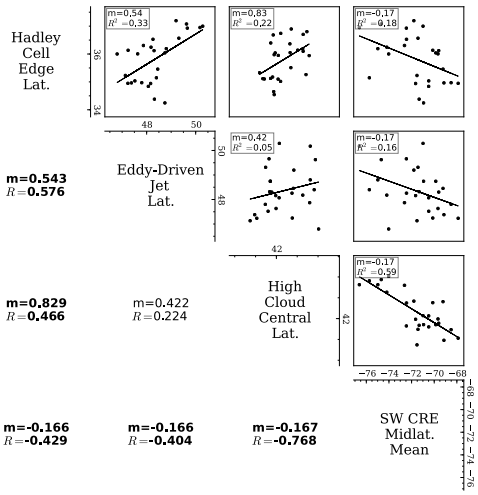
N. Atl.



N. Pac.

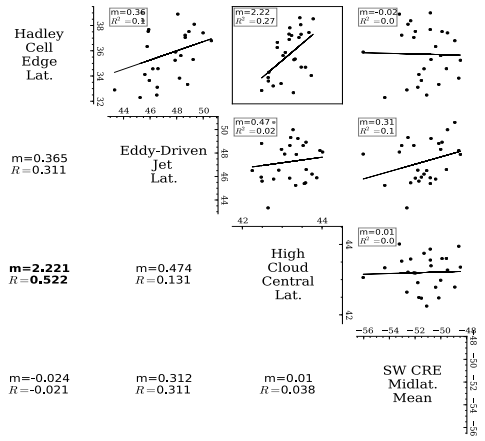


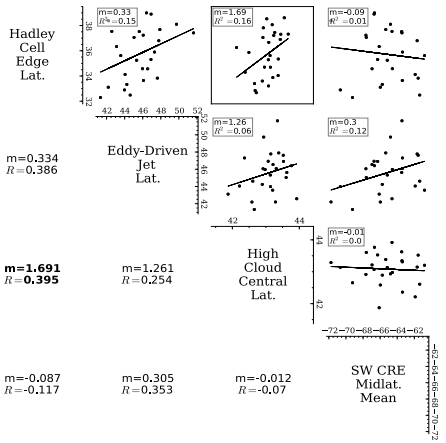
S. Oc.

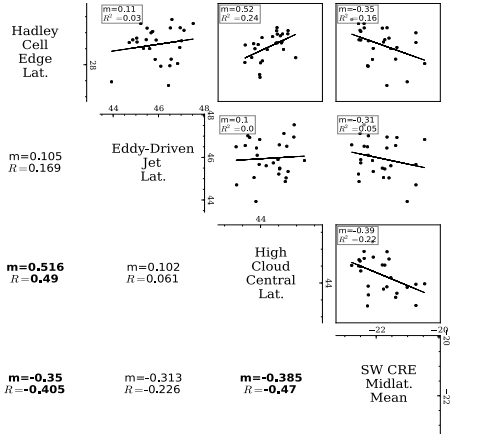


DJF

JJA



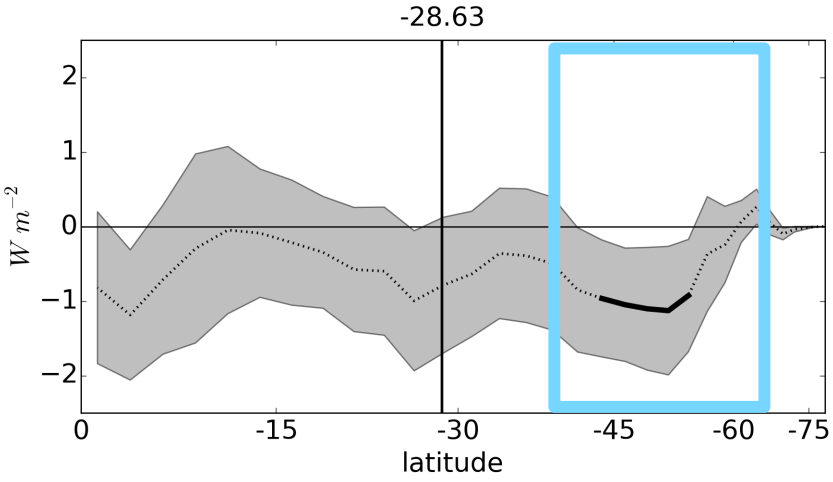




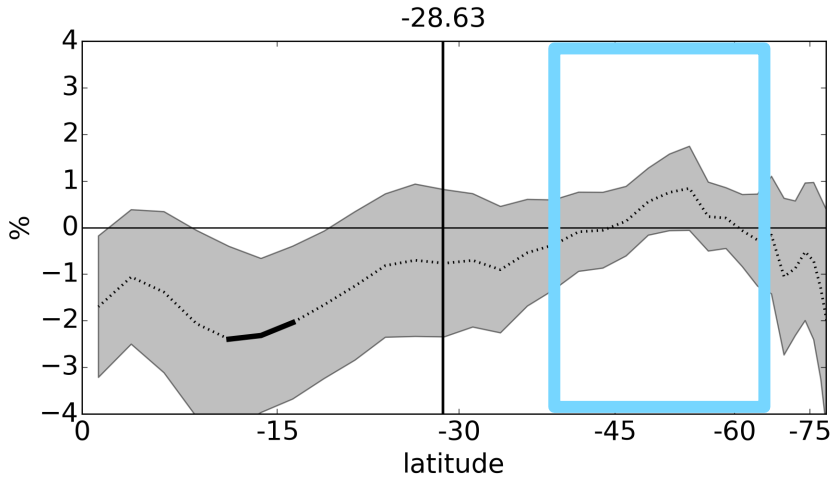
- Hadley cell shifts correlate with high cloud changes in almost all basins/seasons
- Radiative signature of poleward cloud shifts is complex and different in different basins

Regression on Hadley cell in JJA

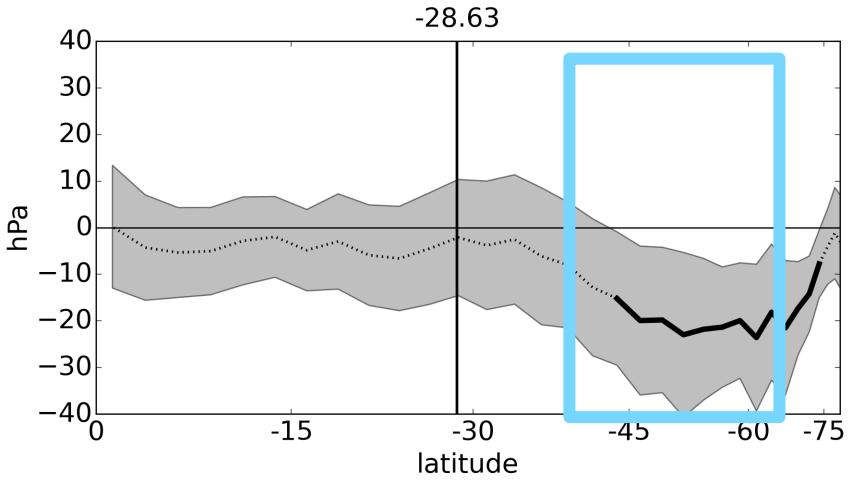
SW CRE



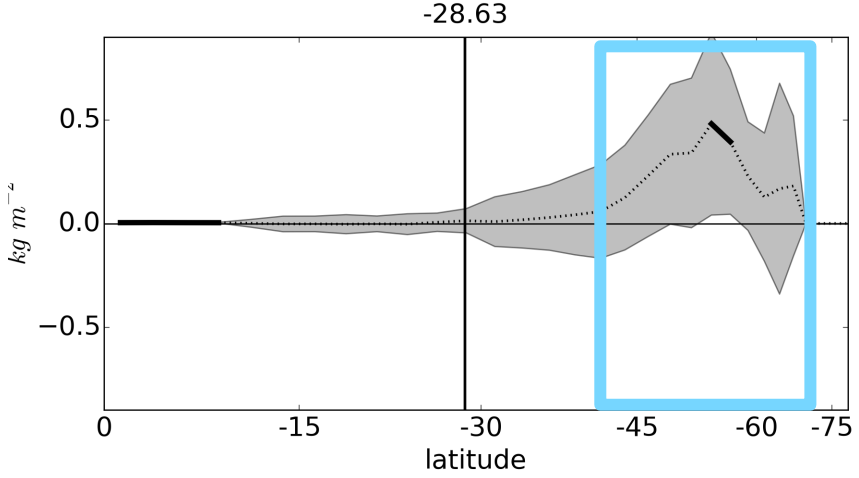
Total cloud cover



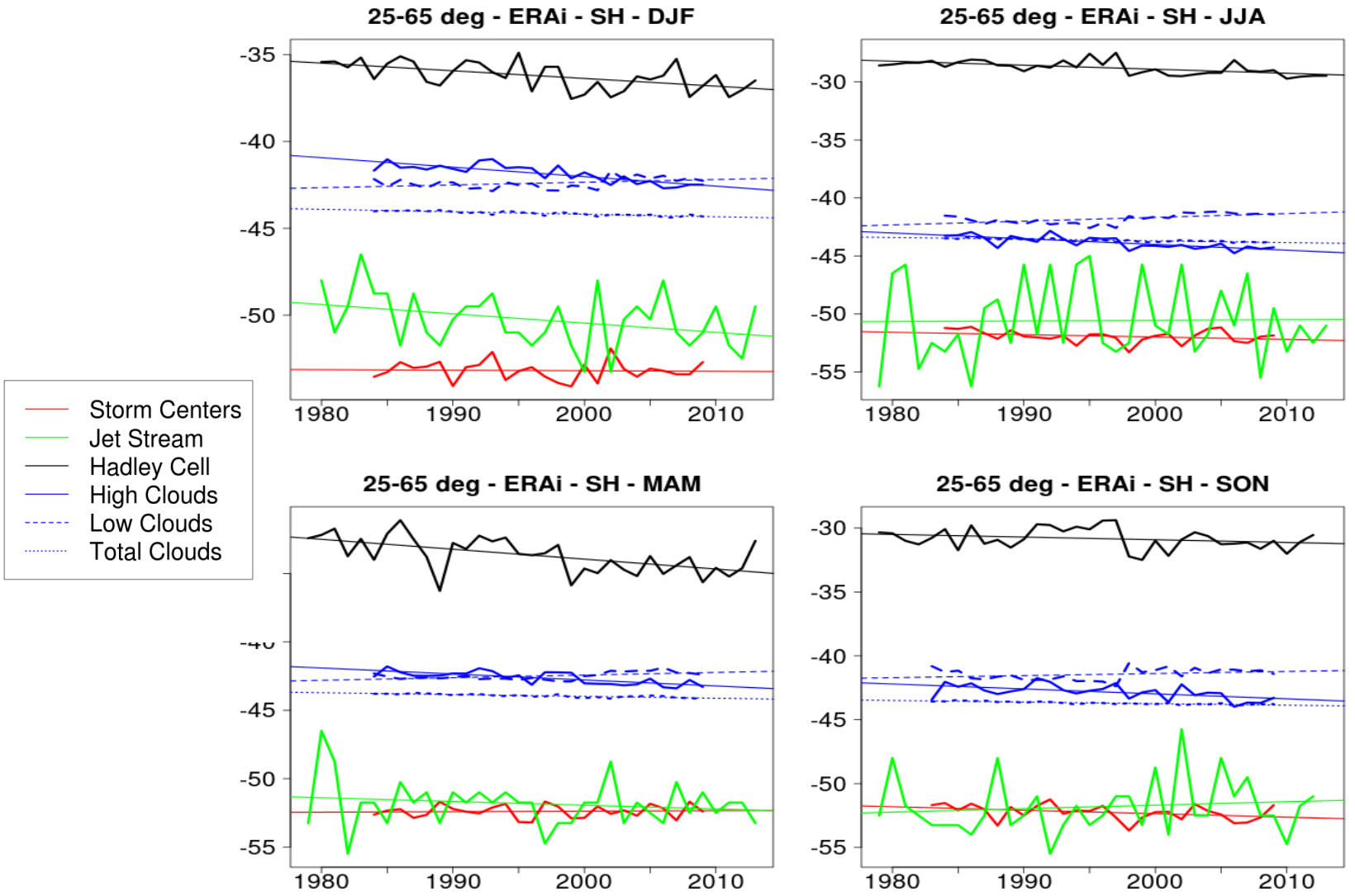
Mean cloud top pressure



Cloud water path



Trends in cloud and dynamics central latitudes in the last 29 years



- Hadley cell and high clouds have been shifting consistently poleward at rates of 0.35-0.72 degrees/ decade or about 1.5 degrees in the last 30 years

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

Discussion

- Hadley cell extent correlates with high cloud shifts in almost all basins and seasons. Storm track or eddy jet location shows 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 warming with Hadley/jet shifts in the N. Atl. Winter but cooling in the Southern ocean. Increase in high latitude LWP may be the reason for the SW cooling.

- The high and total cloud poleward shift observed in ISCCP in the last 30 years can be attributed to Hadley cell expansion.

- More work is needed to incorporate effects of changes in the strength of the dynamical circulations.

Summary of relationships between cloud and dynamics shifts

DJF – S.Hem. – 25-65°

	Storm Centers	Jet Stream	Hadley Cell
High Clouds	0.101	0.188	0.386
Low Clouds	0.194	-0.256	-0.339
Total Cloud	-0.032	-0.049	0.208

JJA – S.Hem. – 25-65°

	Storm Centers	Jet Stream	Hadley Cell
High Clouds	**0.511**	-0.024	**0.516**
Low Clouds	-0.002	-0.177	**-0.669**
Total Cloud	0.350	-0.144	0.204

MAM – S.Hem. – 25-65°

	Storm Centers	Jet Stream	Hadley Cell
High Clouds	0.215	-0.240	**0.599**
Low Clouds	0.051	0.147	-0.360
Total Cloud	0.045	-0.156	**0.503**

SON – S.Hem. – 25-65°

	Storm Centers	Jet Stream	Hadley Cell
High Clouds	0.463	-0.059	**0.583**
Low Clouds	-0.246	0.063	**-0.699**
Total Cloud	0.464	-0.453	0.078

- High clouds correlate with Hadley cell extent in all seasons and with storm centers in winter and spring
- Low clouds correlate with Hadley cell extent in all seasons
- Total cloud correlates with storm centers in the winter and spring, with Jet stream in the spring, and with Hadley cell extent in the fall

Summary of trends in cloud and dynamics central latitudes in the last 29 years

	S.Hem.			
Deg. / decade	**DJF**	**MAM**	**JJA**	**SON**
Storm Centers	-0.030	0.037	-0.208	-0.273
Jet Stream	-0.533	-0.273	0.055	0.269
Hadley Cell	**-0.442**	**-0.724**	**-0.347**	-0.210
High Clouds	**-0.546**	**-0.438**	**-0.496**	**-0.388**
Low Clouds	0.156	**0.192**	**0.325**	0.162
Total Cloud	**-0.143**	**-0.134**	**-0.146**	**-0.123**

- Hadley cell and high clouds have been shifting consistently poleward at rates of 0.35-0.72 degrees/ decade or about 1.5 degrees in the last 30 years

- Total cloud has been shifting poleward at rates of 0.12-0.15 degrees/decade or about 0.4 degrees in the last 30 years