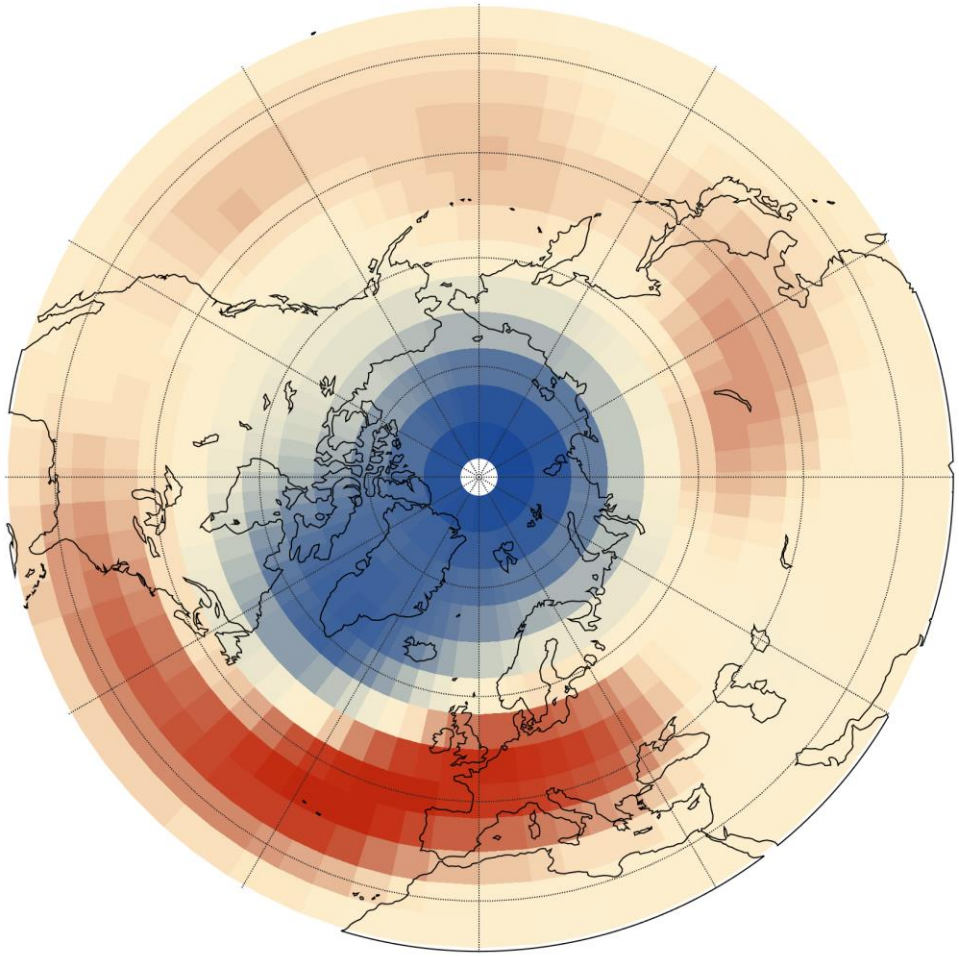
Observed and Modeled Cloud Responses to the Annular Modes

Andrew Geiss and Roger Marchand

Climate and Dynamics Seminar, Nov. 7th, 2018

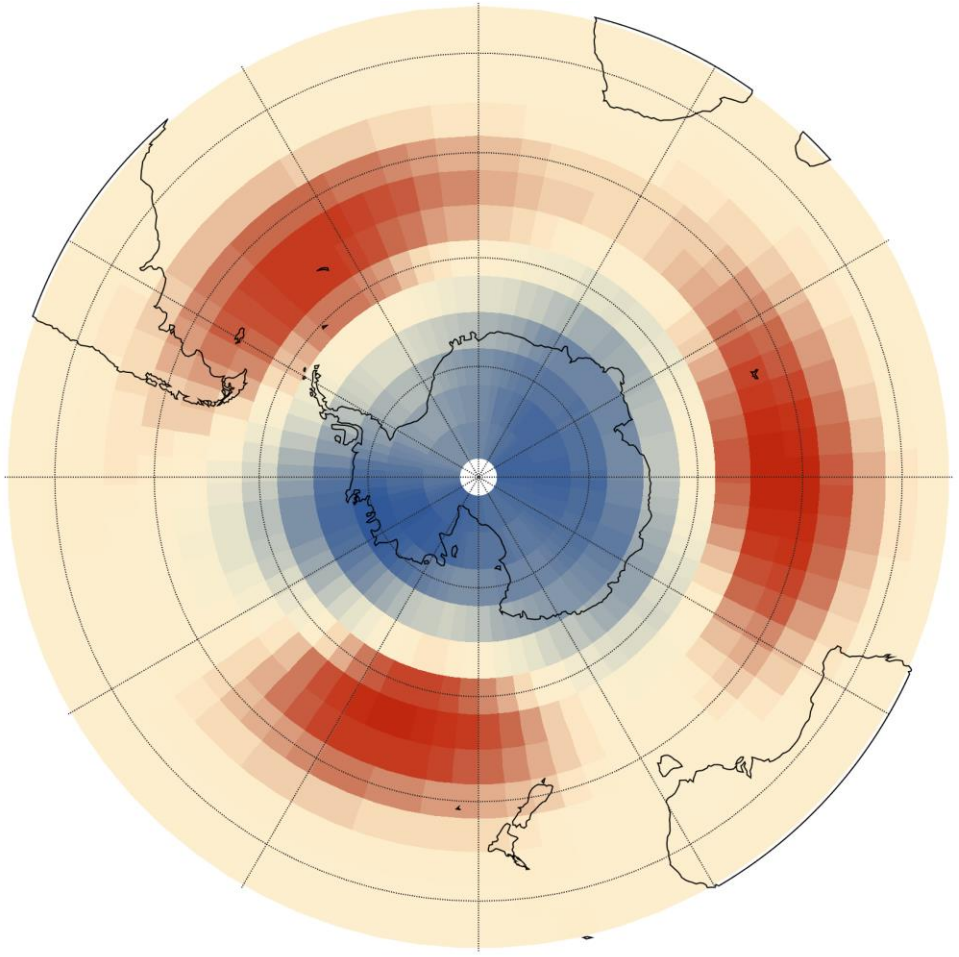
Background: Annular Modes



ERA-Interim NAO (10%)

700hPa Height Anomaly ($m\sigma^{-1}$)

-50 -40 -30 -20 -10 0 10 20



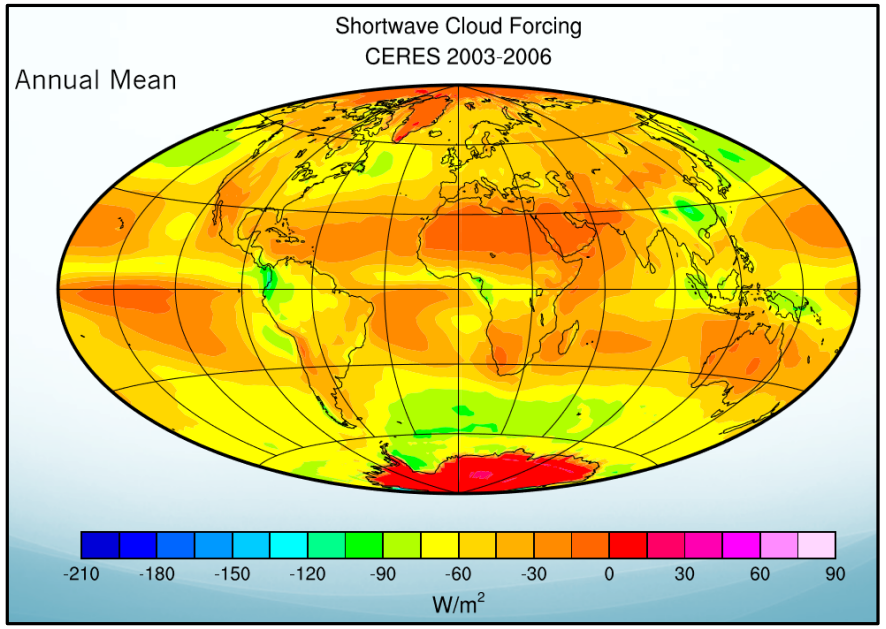
ERA-Interim AAO (12%)

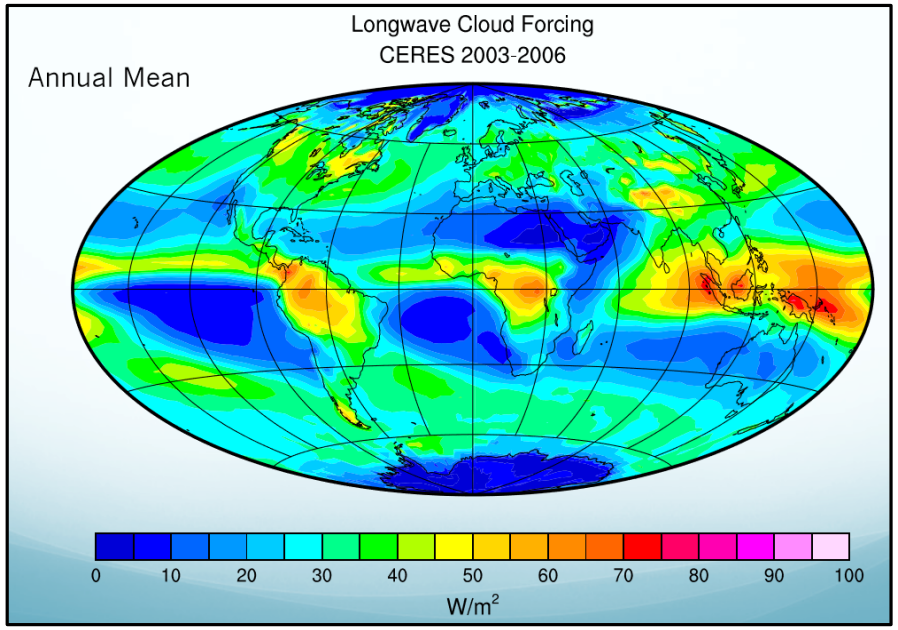
700hPa Height Anomaly ($m\sigma^{-1}$)

-60 -40 -20 0 20

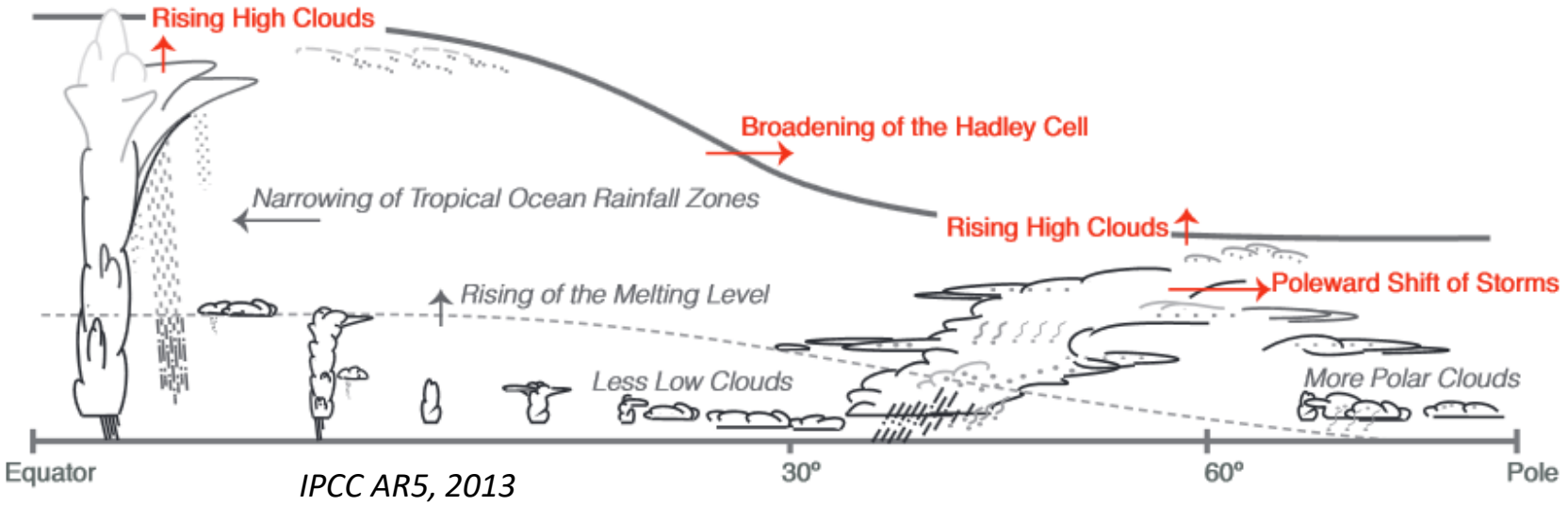
Background: Motivation

Clouds have a substantial impact on the Earth's radiative budget





Hartmann, 2014

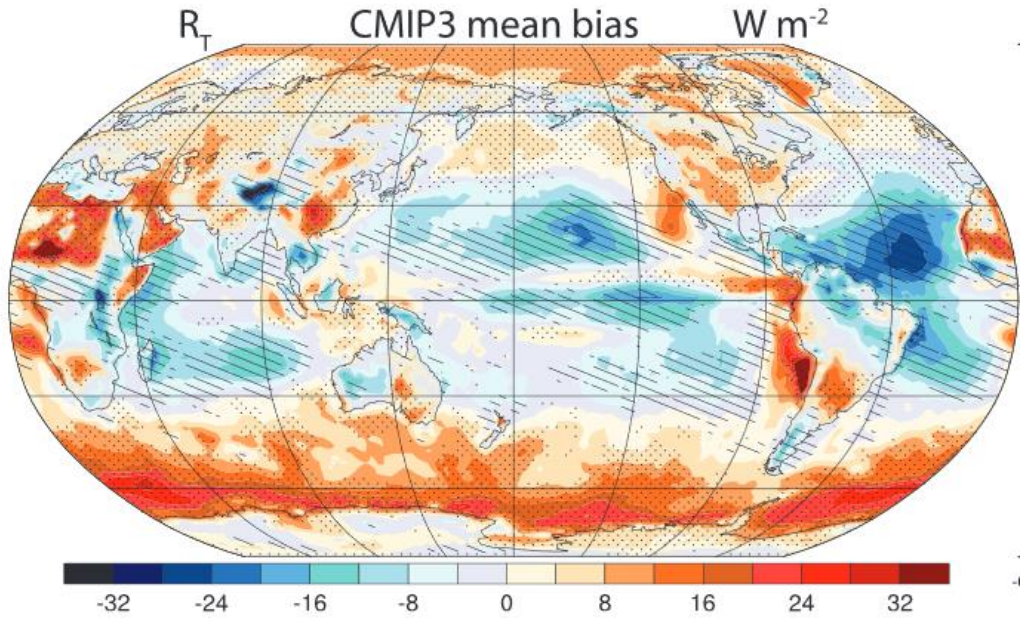


IPCC AR5, 2013

There are a several expected cloud responses to climate change

Some are more certain than others

Background: Extratropical Cloud



Trenberth and Fassulo 2010

Models struggle to reproduce clouds (particularly low cloud) in this region

Radiative forcing biases can lead to changes in circulation in the model *(Hwang and Frierson, 2013)*

Southern Ocean cloud is radiatively very important

Bodas-Salcedo 2013

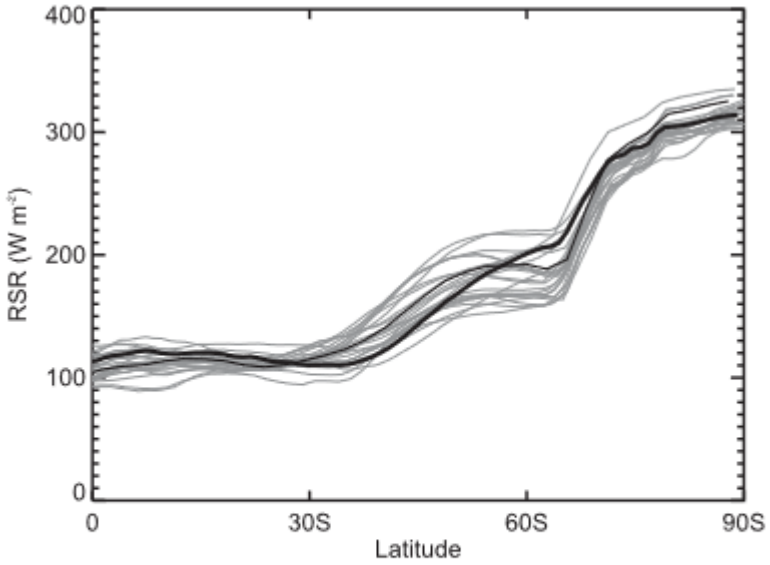


FIG. 2. Zonal mean of the Southern Hemisphere DJF climatology of TOA upwelling shortwave radiation. CERES is the thick black line, ISCCP is the thin black line, and the models are the thin gray lines.

Goals

How do the annular modes influence extratropical cloudiness?

What are the underlying changes in the meteorology?

What are the resulting changes in TOA radiative fluxes?

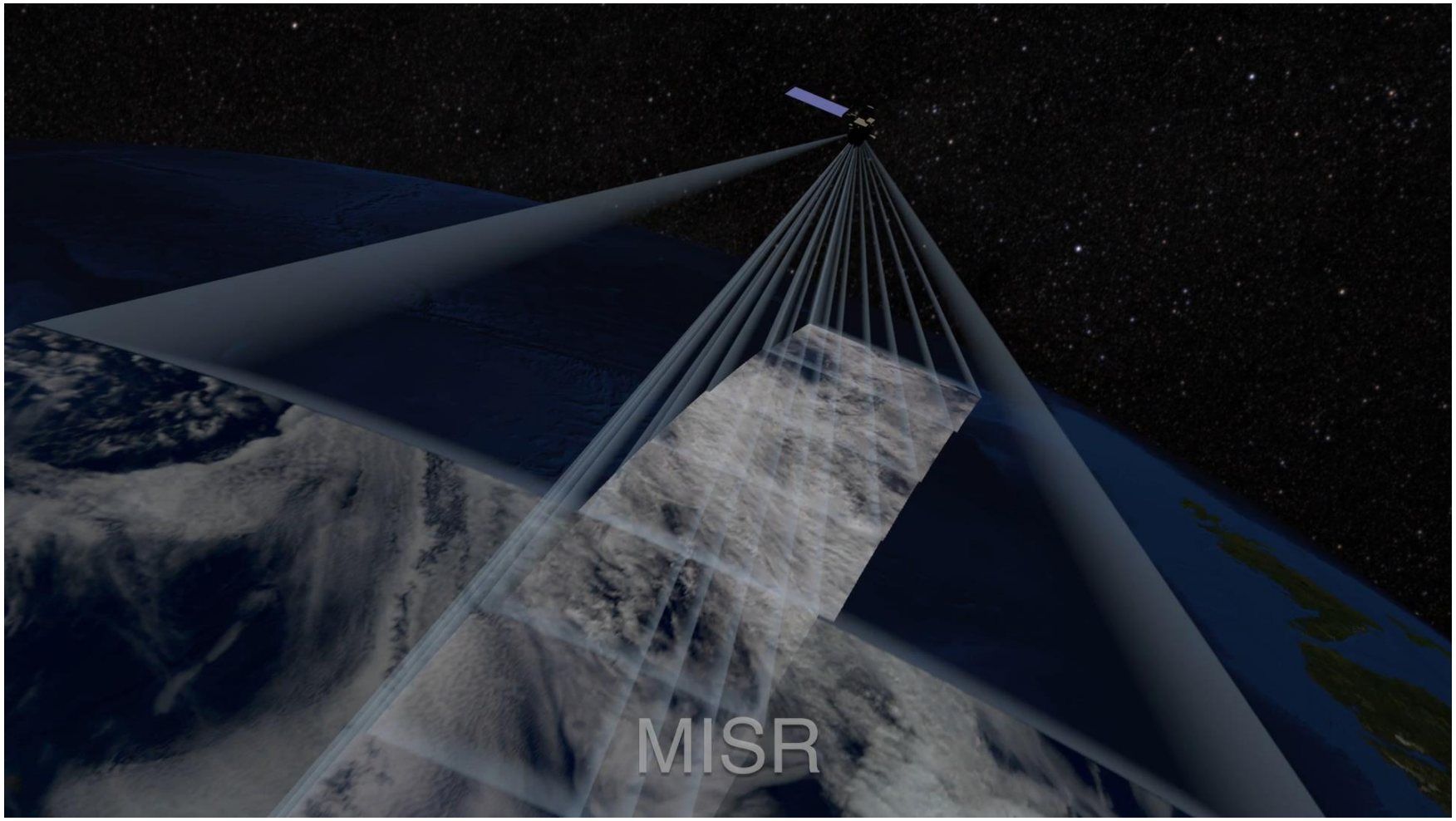
Are these changes captured in models?

Data: MISR Cloud Occurrence

MISR = Multi-angle Imaging Spectro-Radiometer

Onboard EOS Terra (2000-Present)

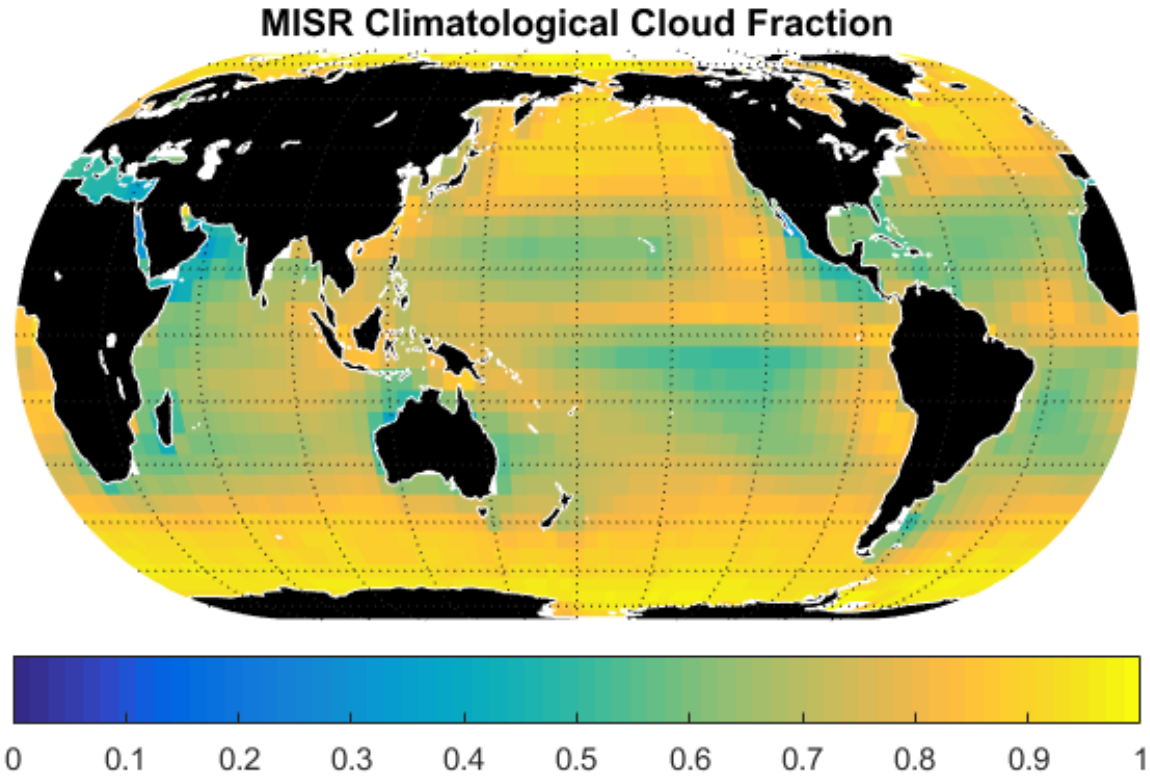
Uses multi-view geometry to measure cloud top heights (instead of IR)

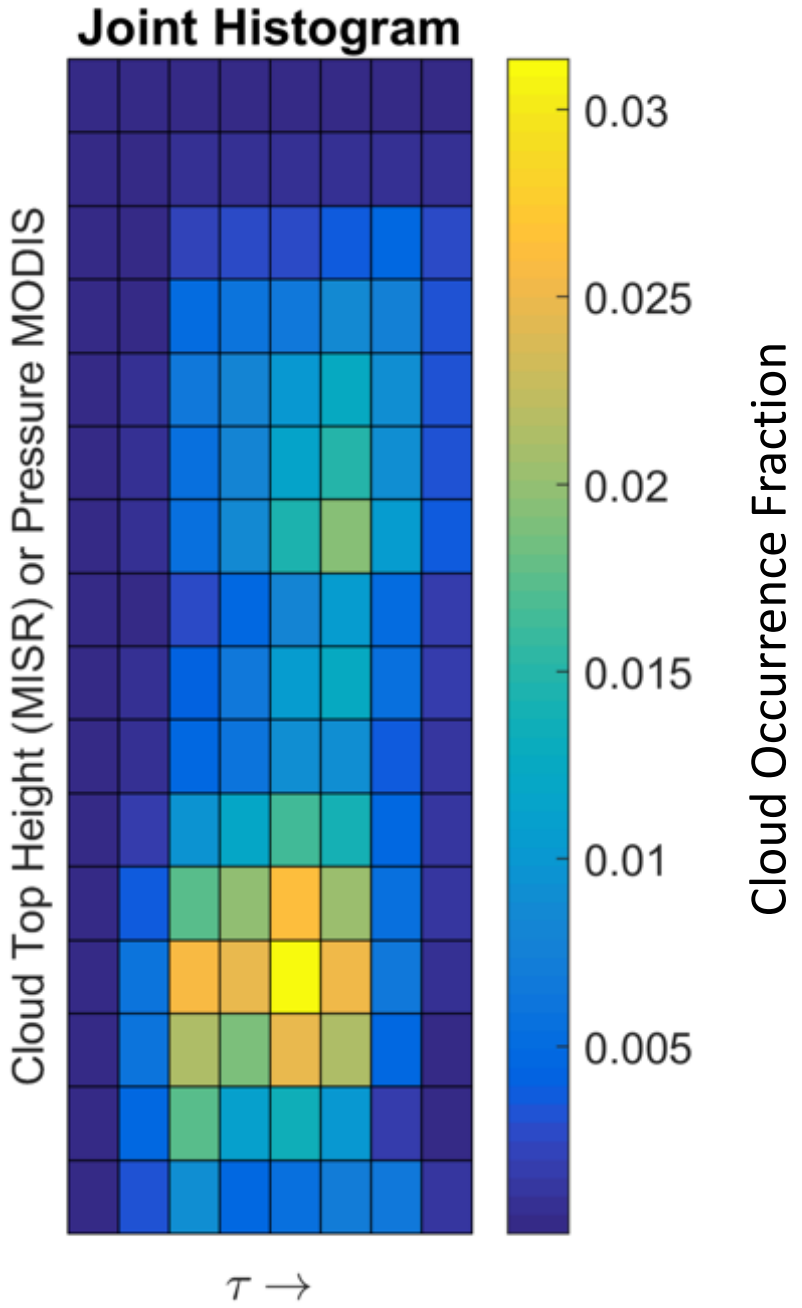


(Di Girolamo, UIUC)

Data: MISR Cloud Occurrence

5-Degree gridded monthly CTH-OD joint histograms



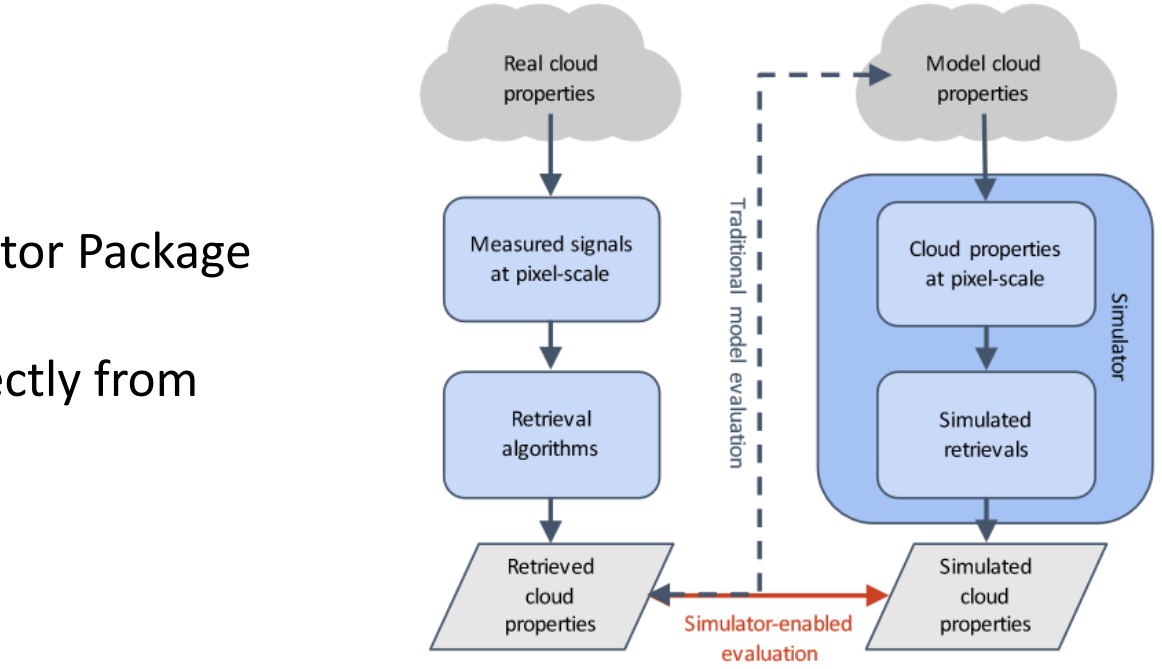


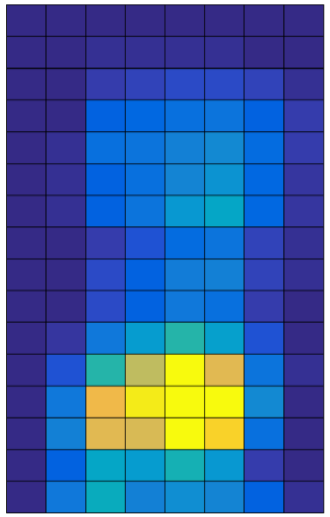
Data: COSP

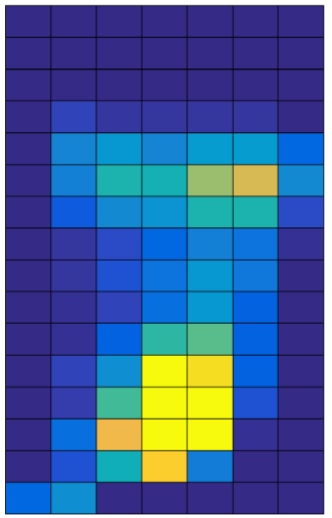
HadGEM COSP MISR Simulator:

COSP -- CFMIP Observational Simulator Package

Emulates MISR CTH-OD product directly from model cloud fields







Data: Reanalysis/Model

ECMWF ERA-Interim Reanalysis

Interpolated to MISR cloud top height Levels,

Interpolated to 5-Degree grid,

Monthly Data 2000-2015,

HadGEM2 CFMIP3 Experiment

Interpolated to MISR cloud top height Levels,

Interpolated to 5-Degree grid,

Monthly 1979-2008 historical run (prescribed SST)

Model Variables: Temperature, Pressure, Humidity, Absolute Vorticity, Divergence, Vertical Velocity

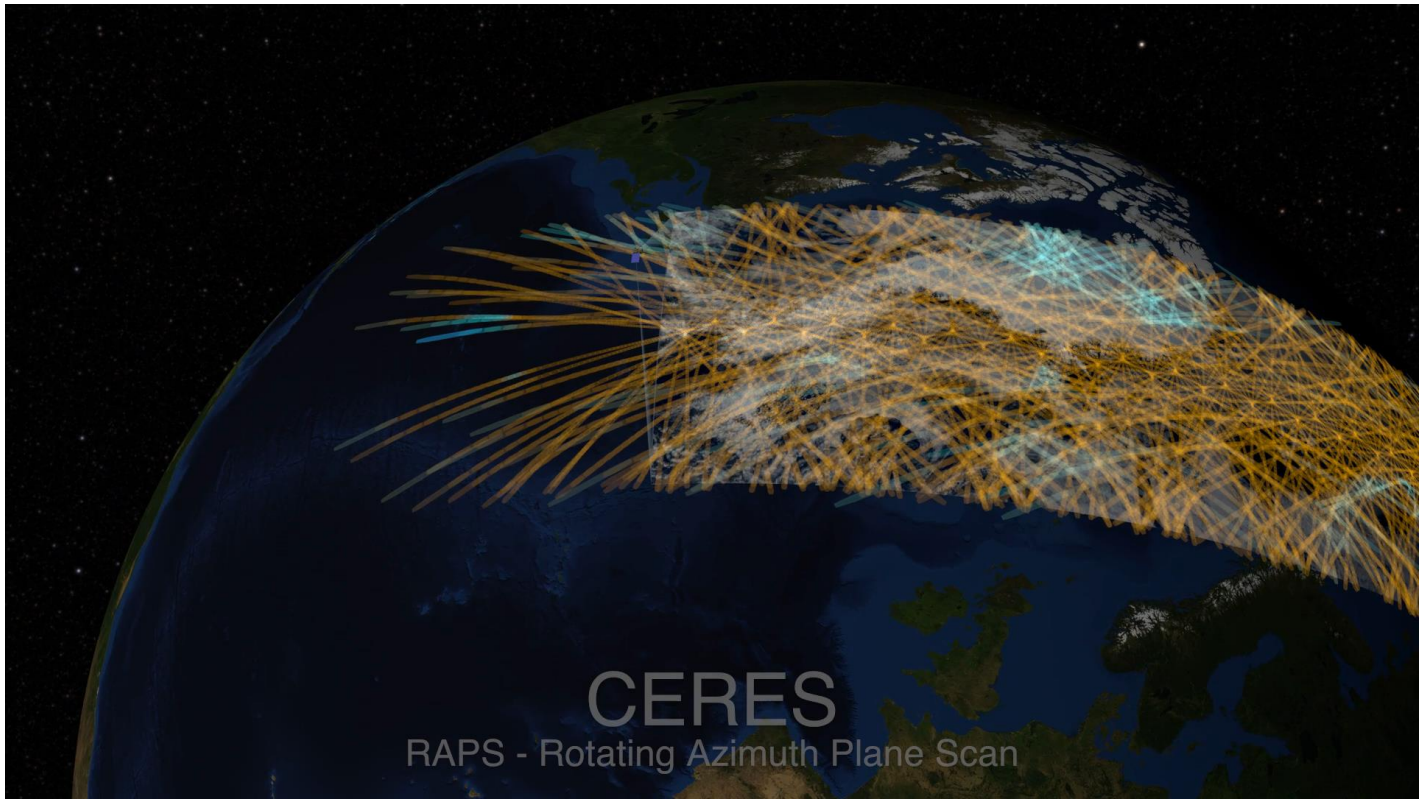
Data: CERES Terra TOA Fluxes

Two broadband scanning radiometers:

- Long-Wave up (8-12 µm)
- Short-Wave up (0.3-5 µm)

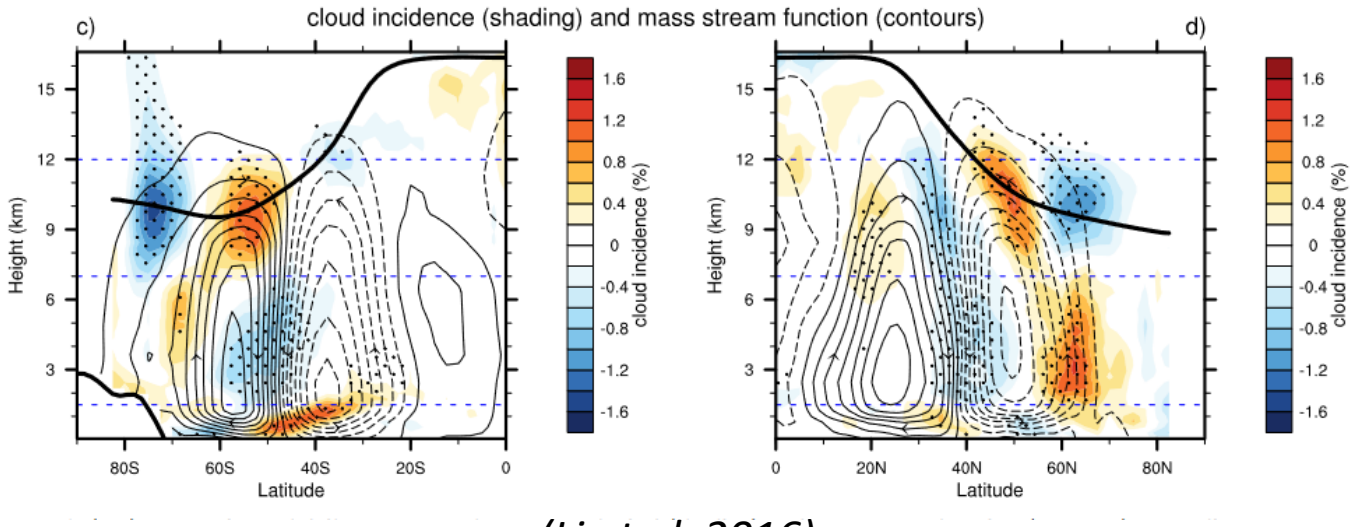
Also onboard EOS Terra

Can compare to HadGEM TOA Fluxes



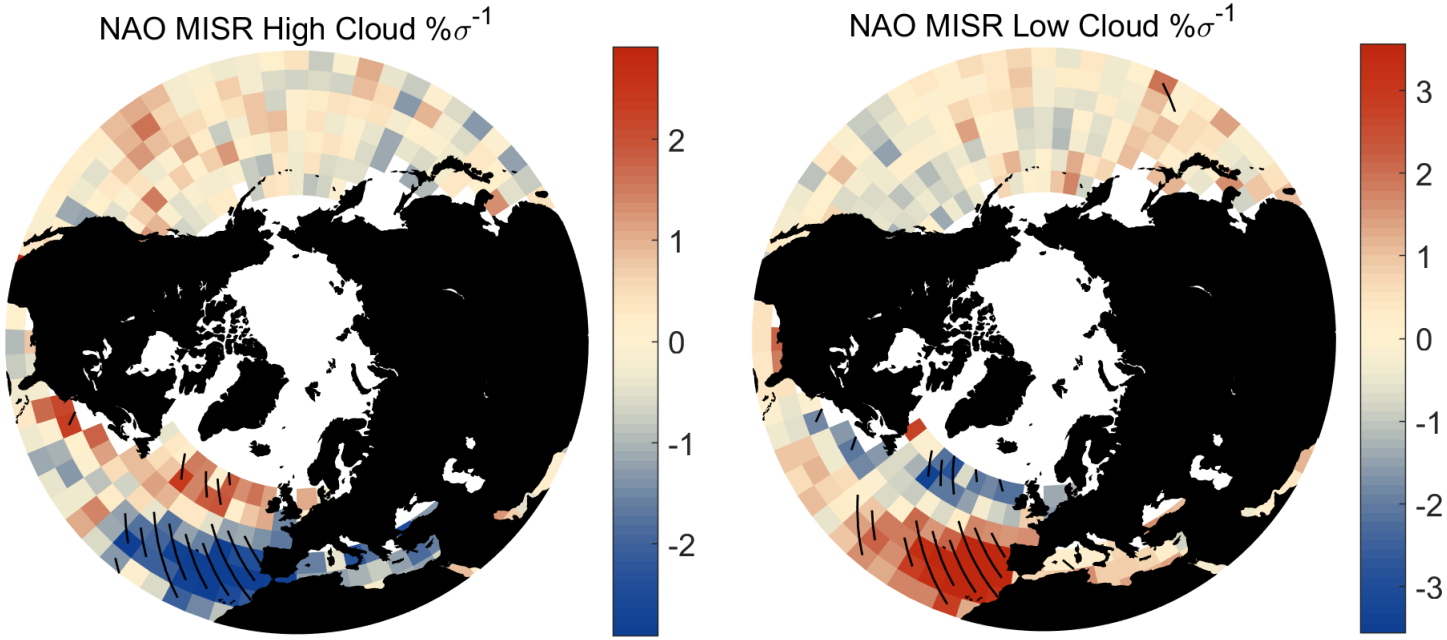
(Di Girolamo, UIUC)

Method: Regression



(Li et al. 2016)

Linear regression between de-seasonalized, detrended, variable anomalies and AAO and NAO principal components



Method: Clustering

K-means algorithm:

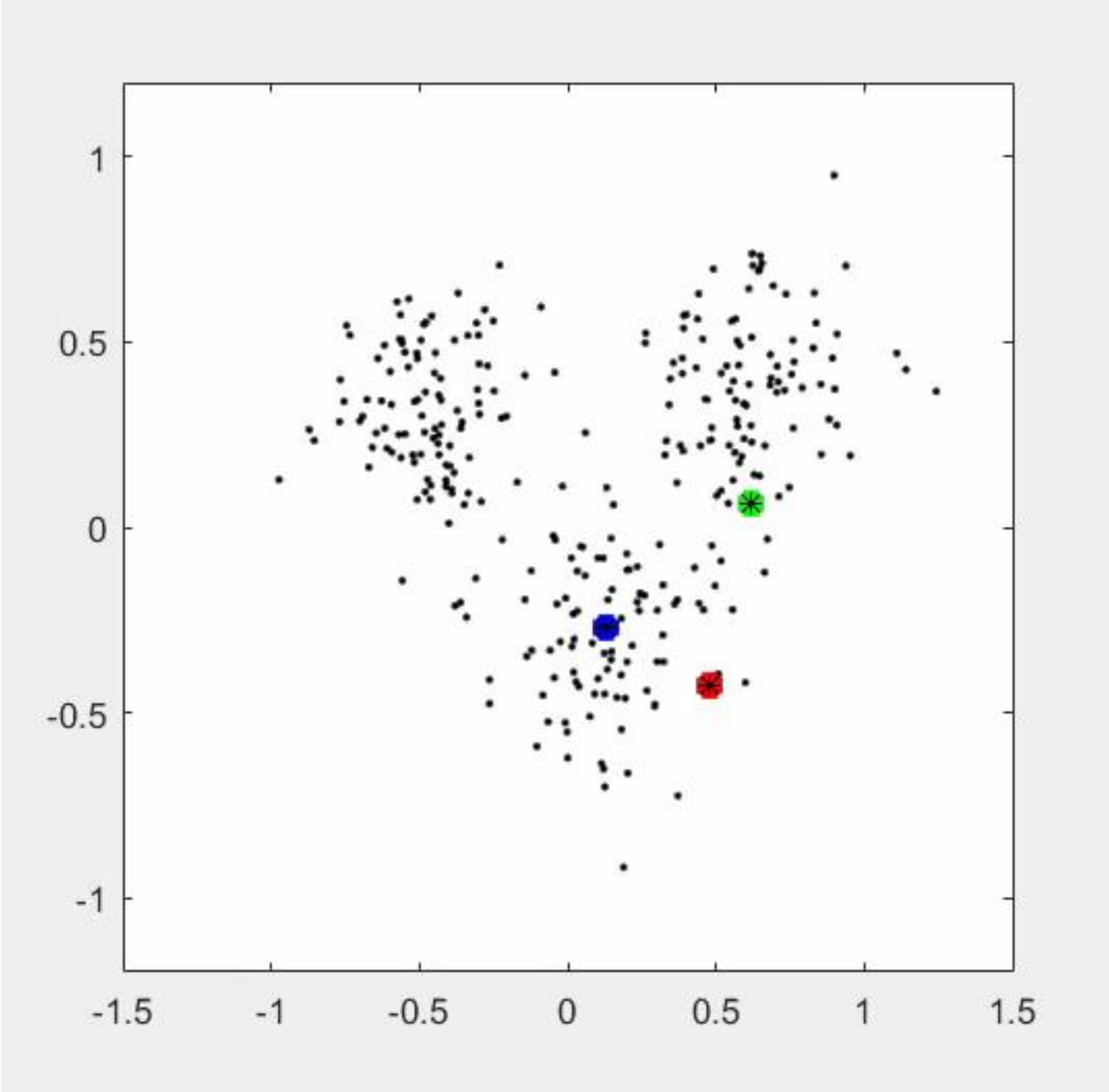
Choose K

Random cluster centers

Assign points to clusters

Update cluster centers

Stop when no points change clusters

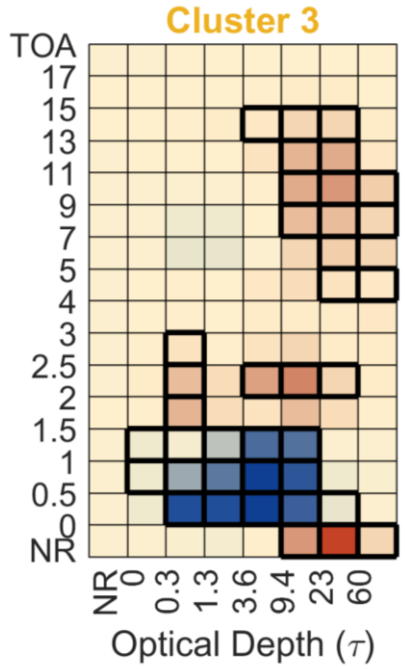


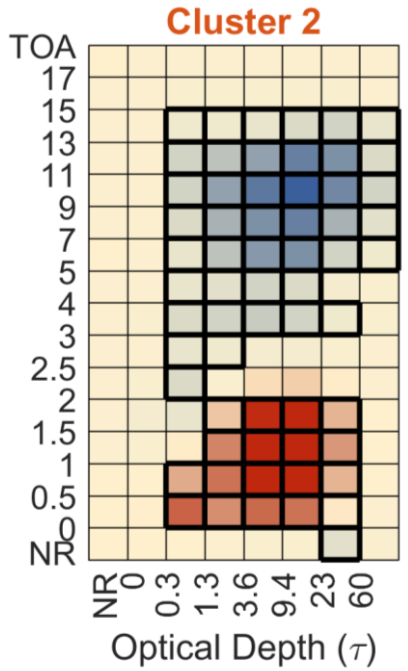
Method: Clustering

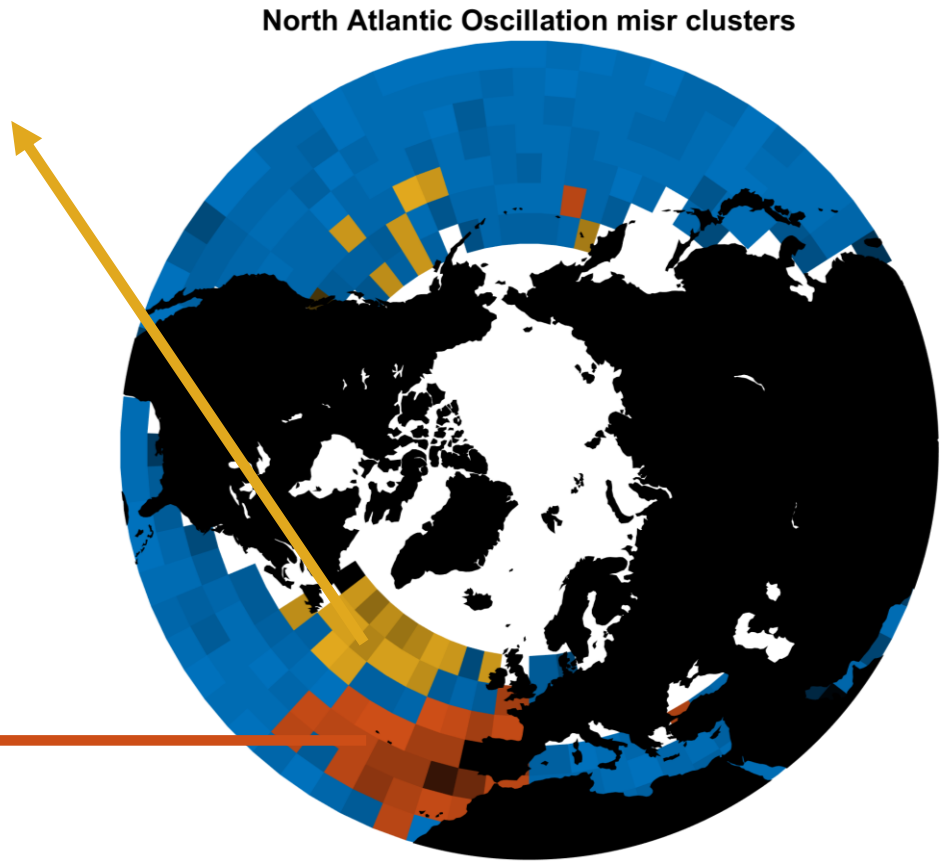
-Cloud occurrence histograms provide detailed information about cloud type

-Can produce a regression coefficient for every cloud category at every grid point

-Then group regions with similar cloud responses

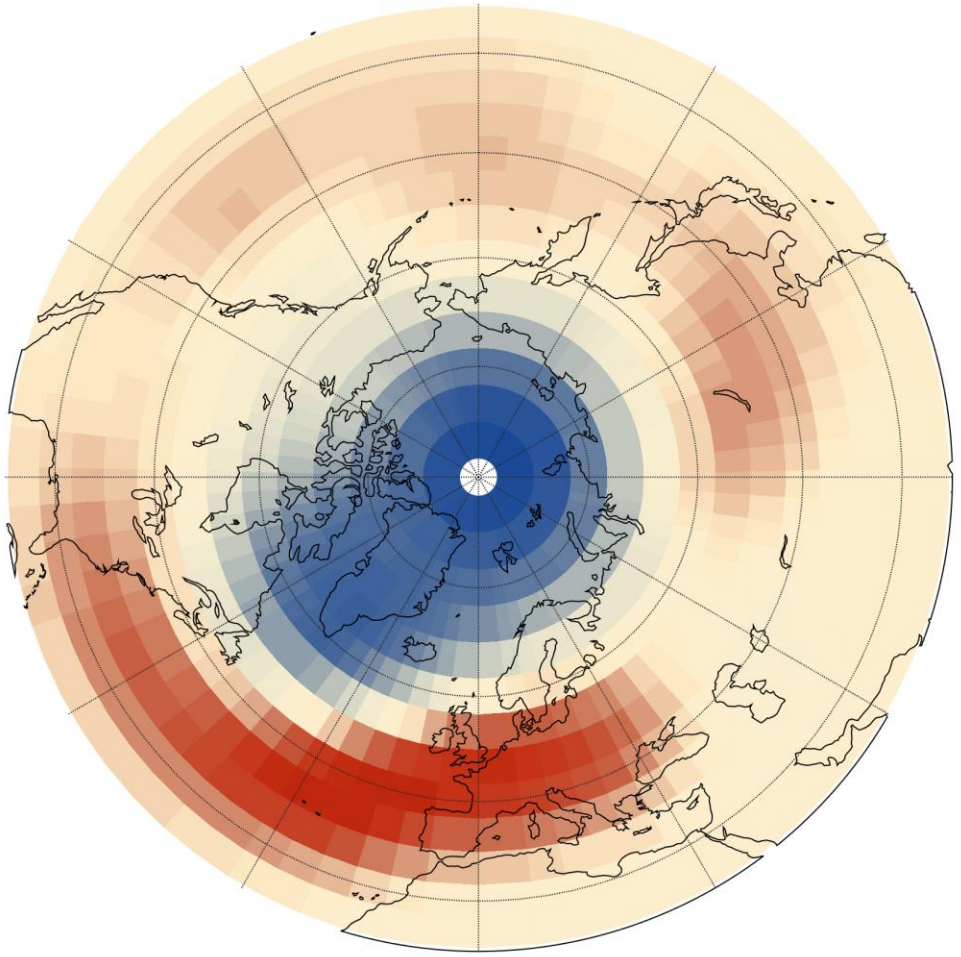






The North Atlantic Oscillation

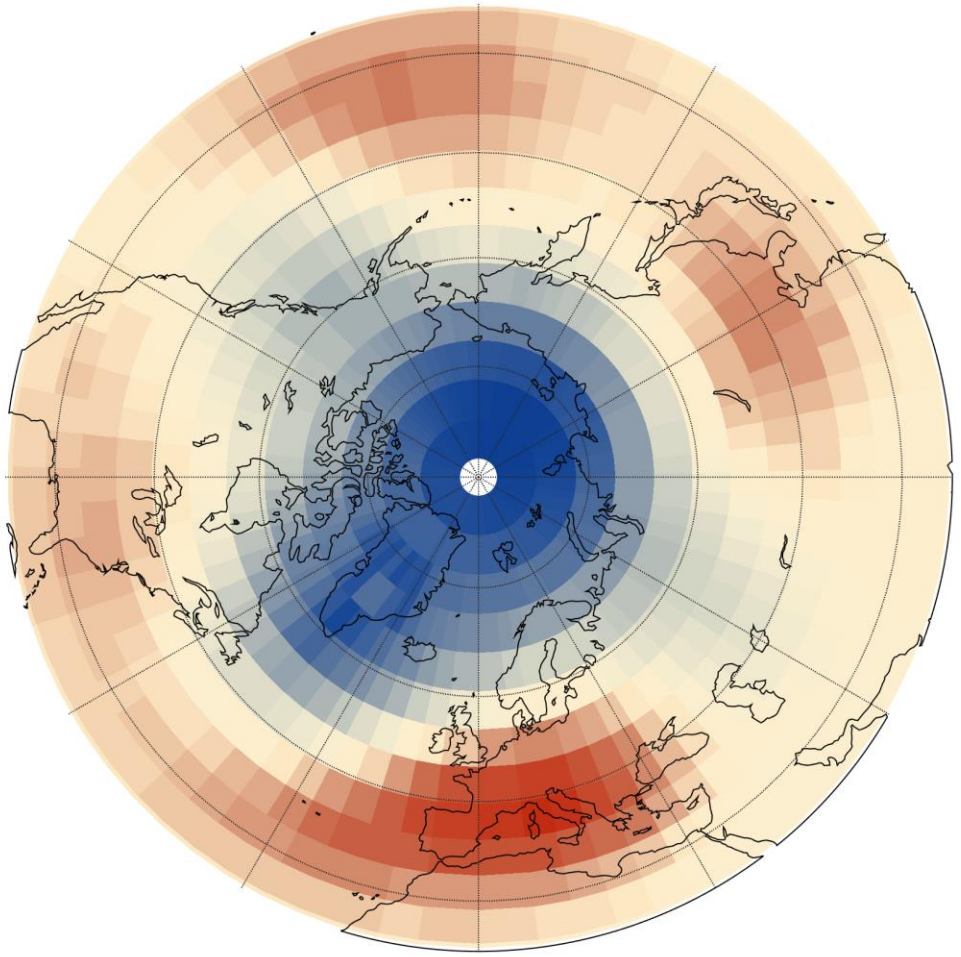
NAO: Loading Patterns



ERA-Interim NAO (10%)

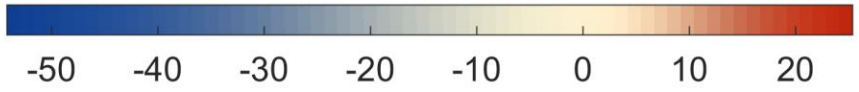
700hPa Height Anomaly ($m\sigma^{-1}$)

ρ = 0.97

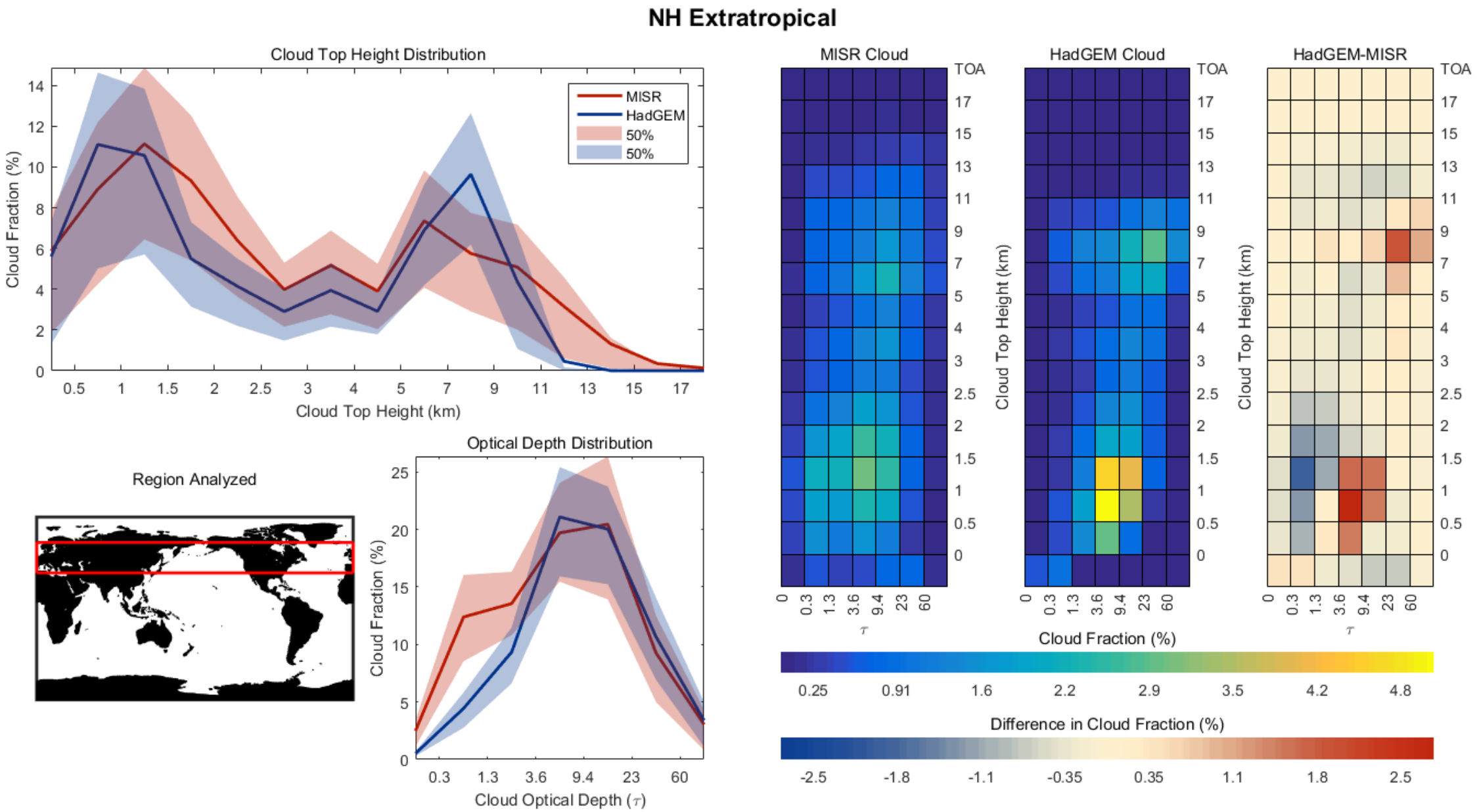


HadGEM NAO (9%)

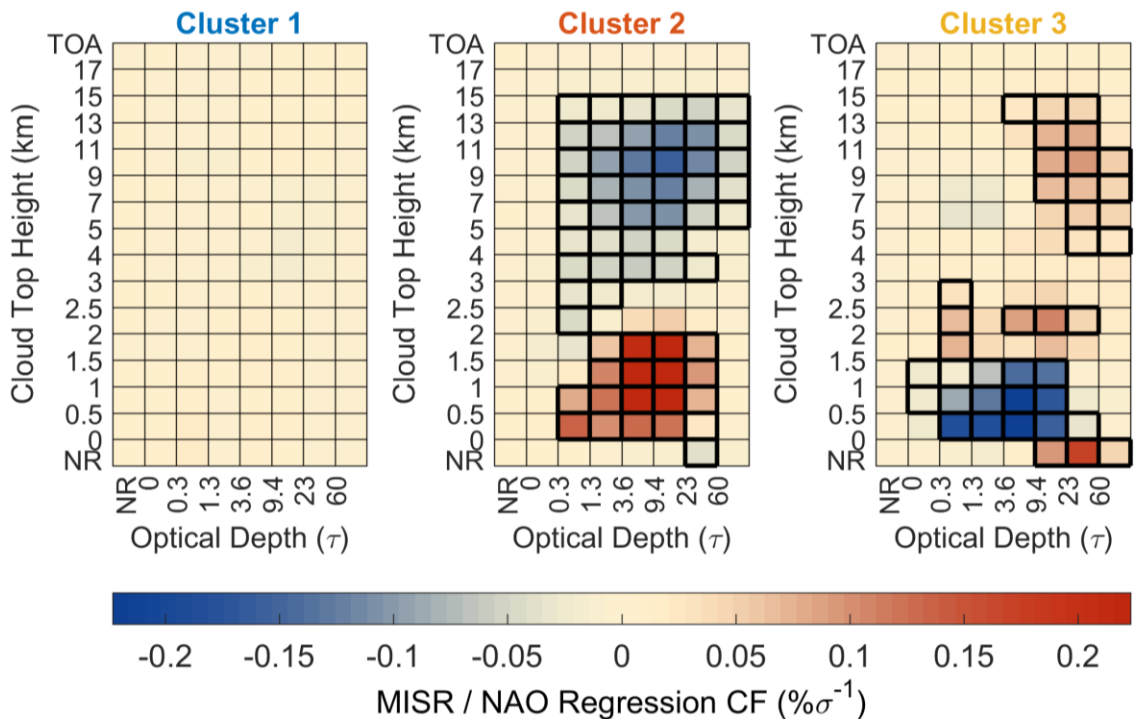
700hPa Height Anomaly ($m\sigma^{-1}$)

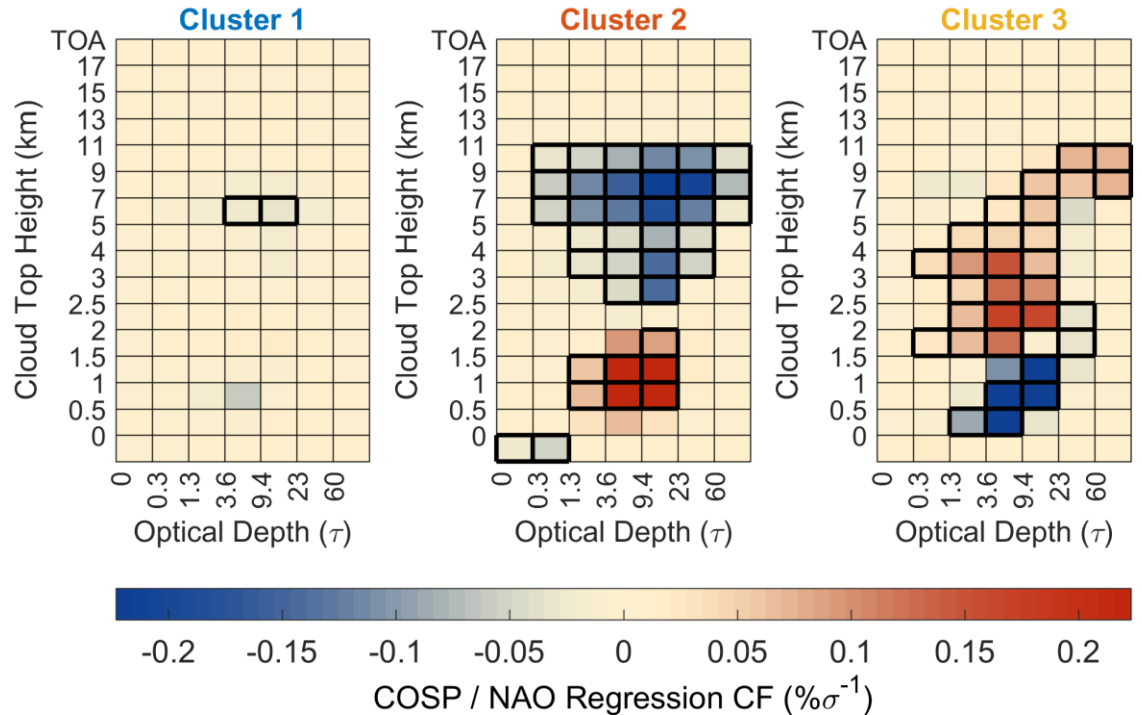


NAO: Modeled Cloud

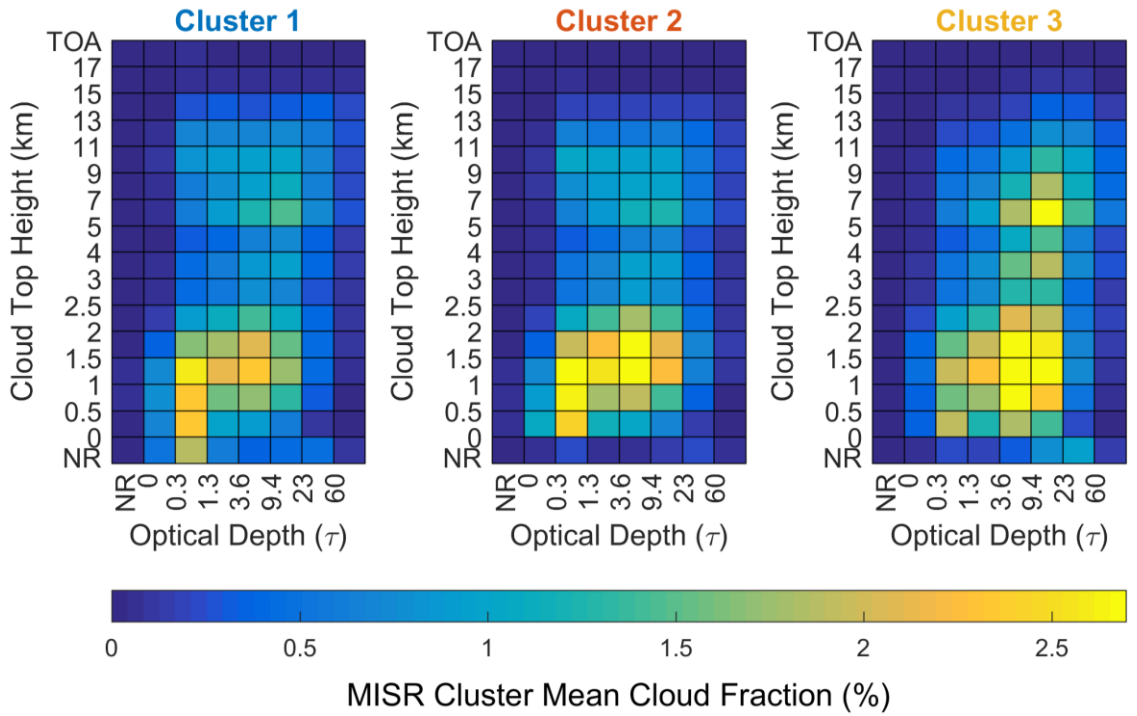


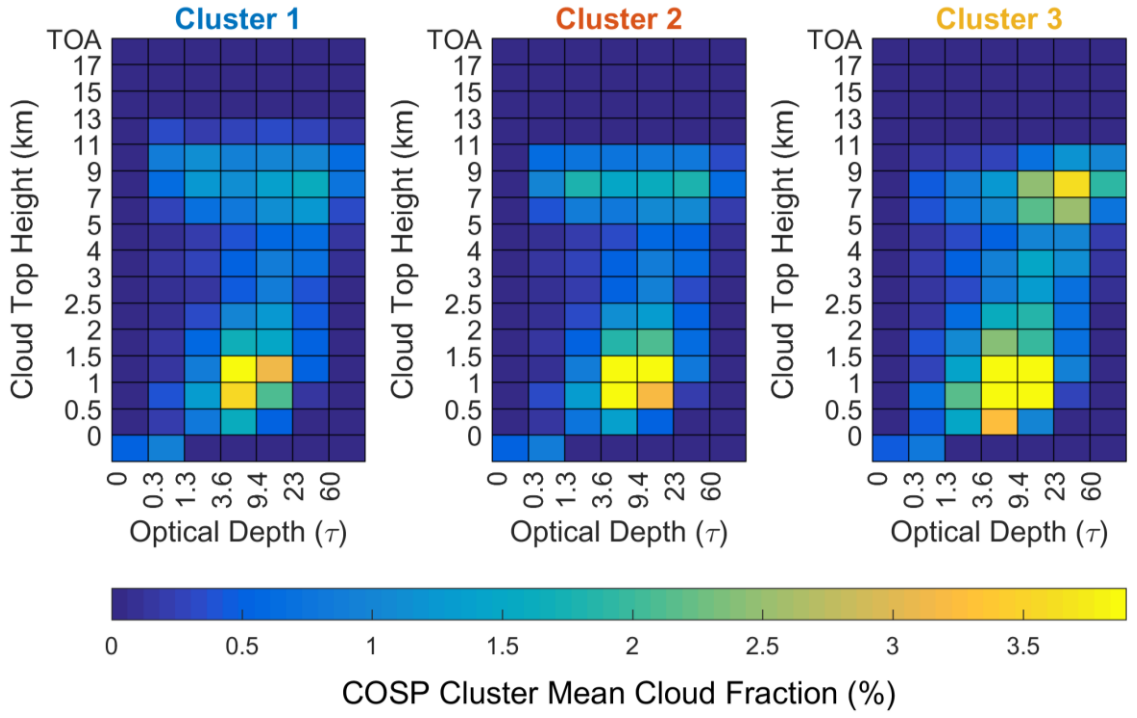
NAO: Cloud Variability



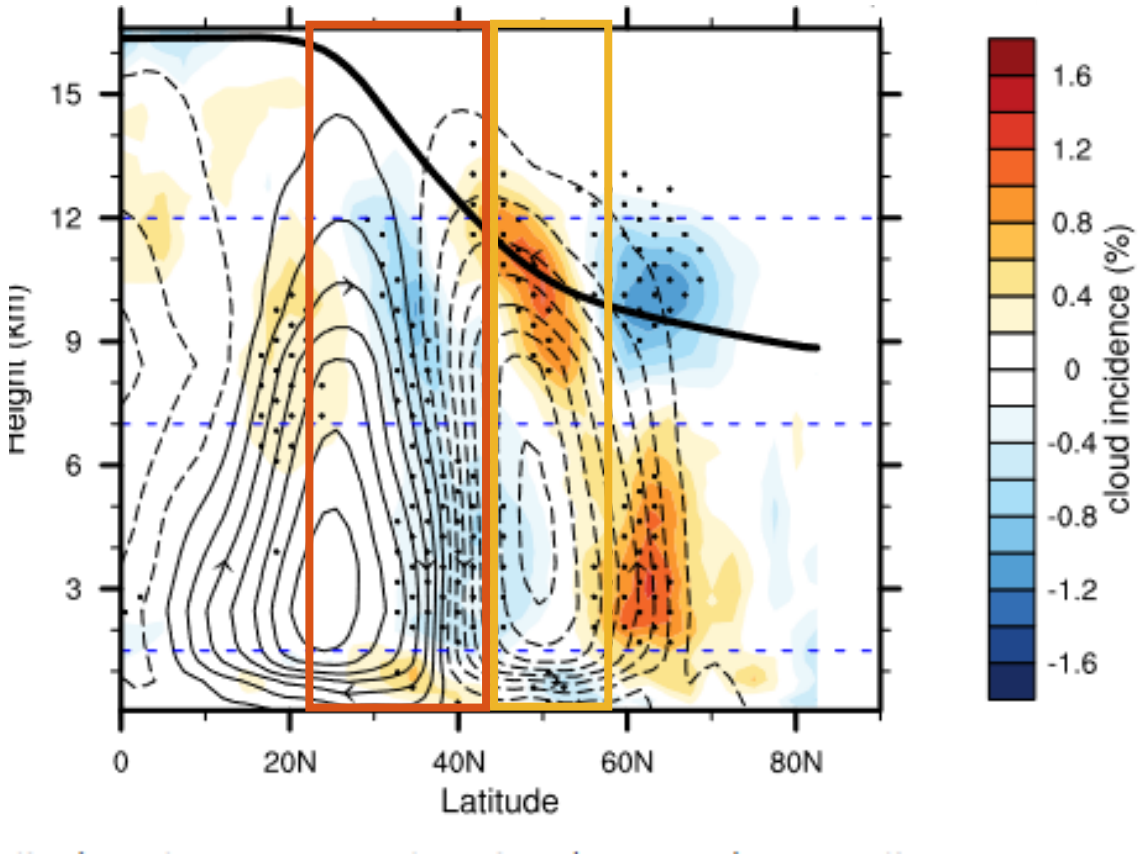


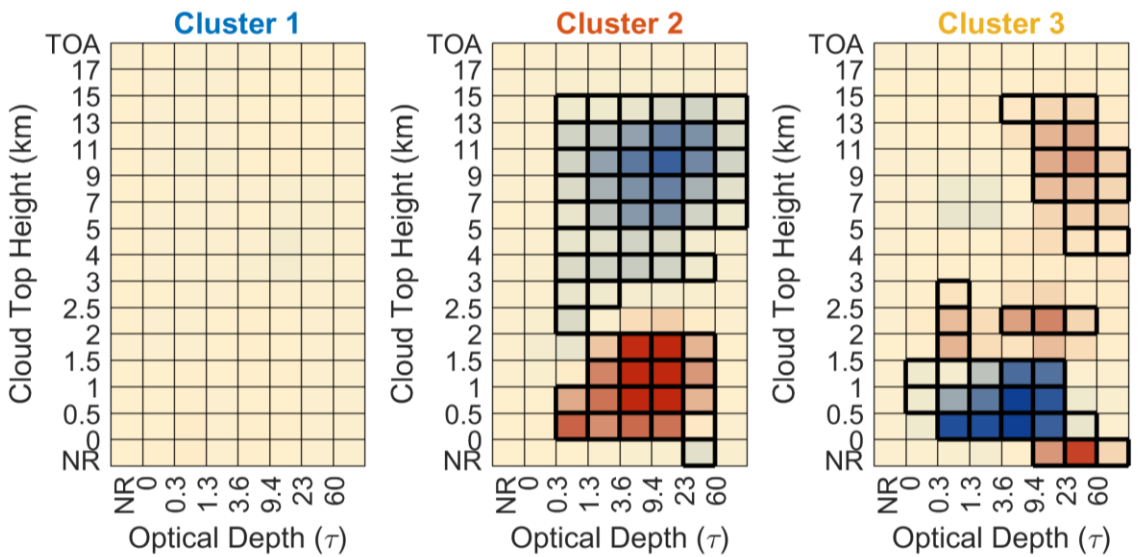
NAO: Cloud Variability

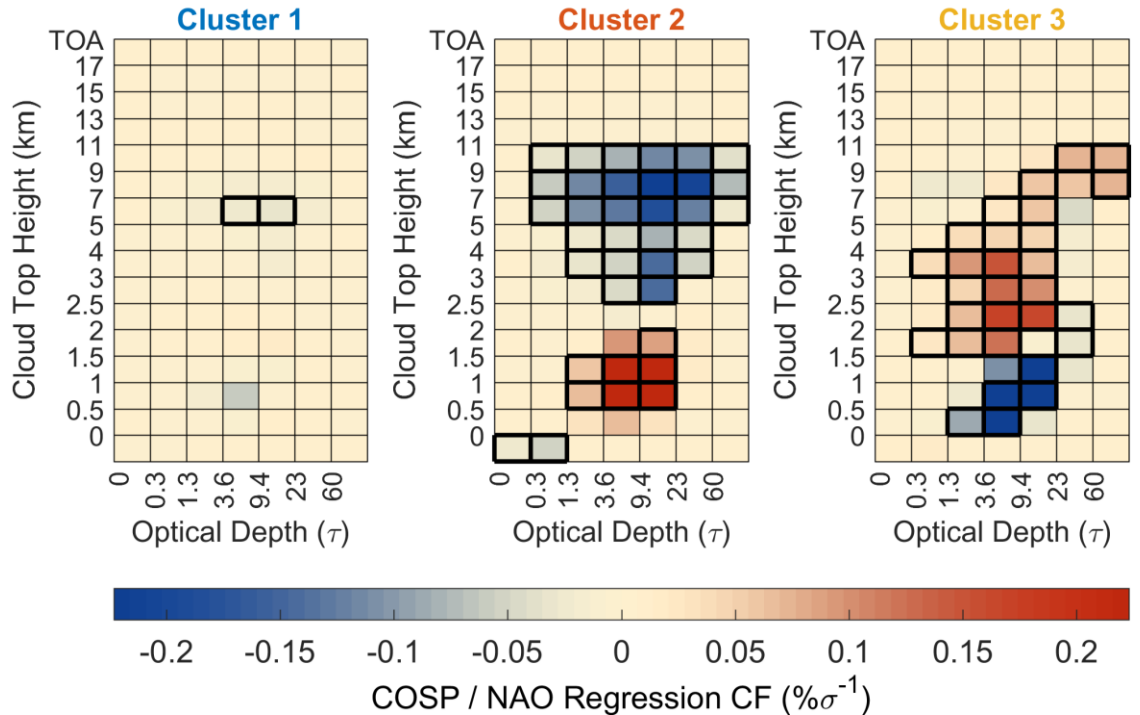


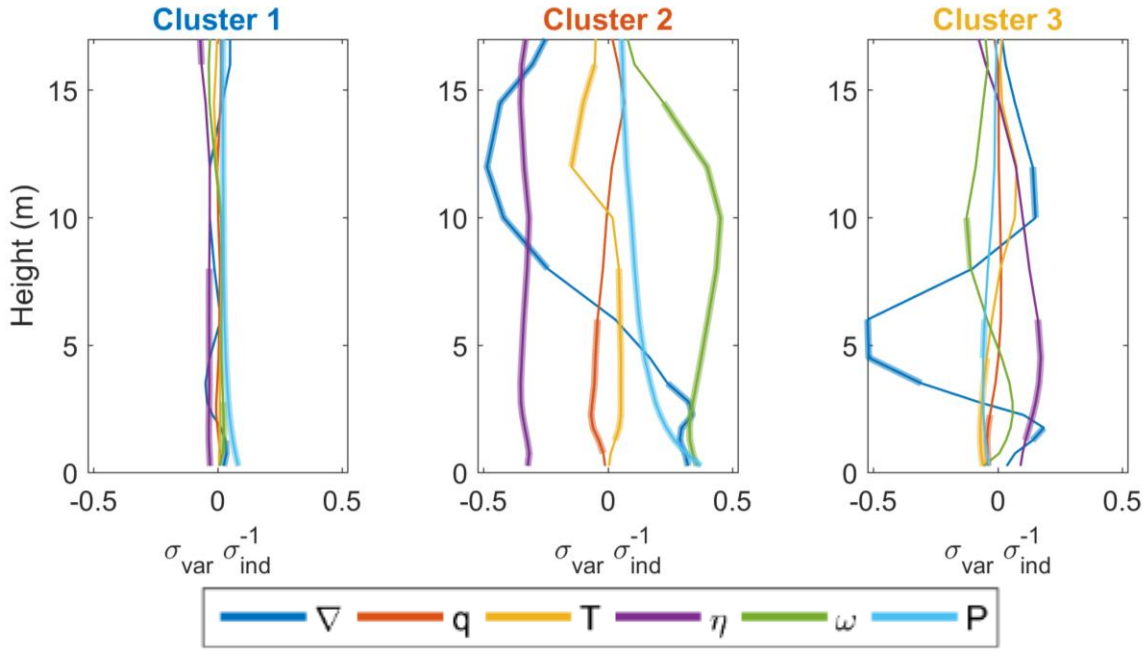


NAO: Cloud Variability

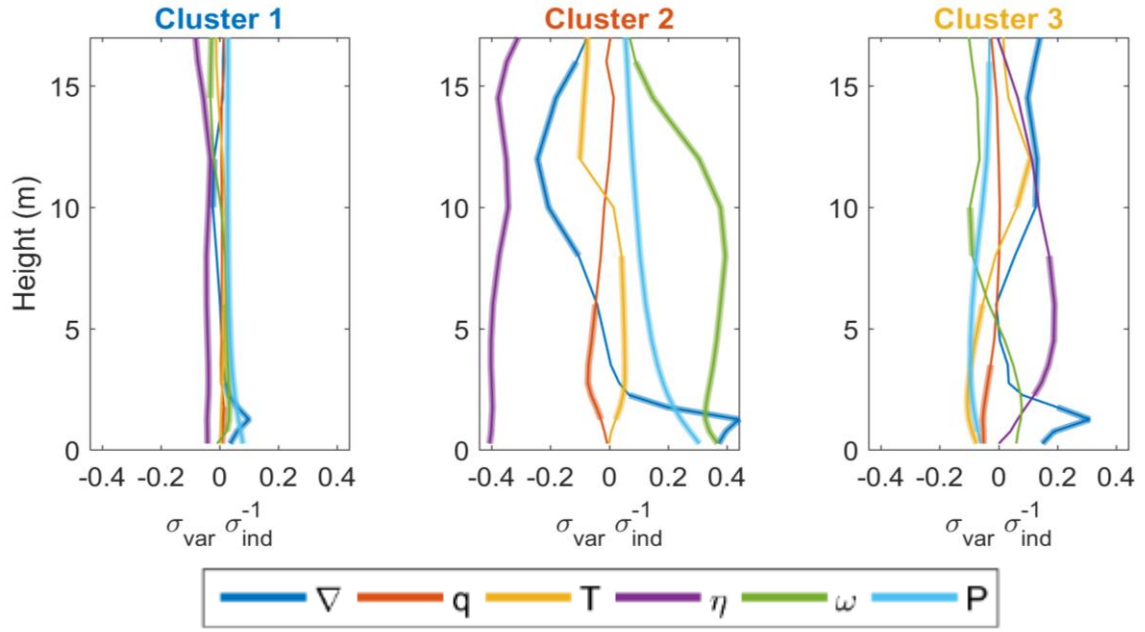




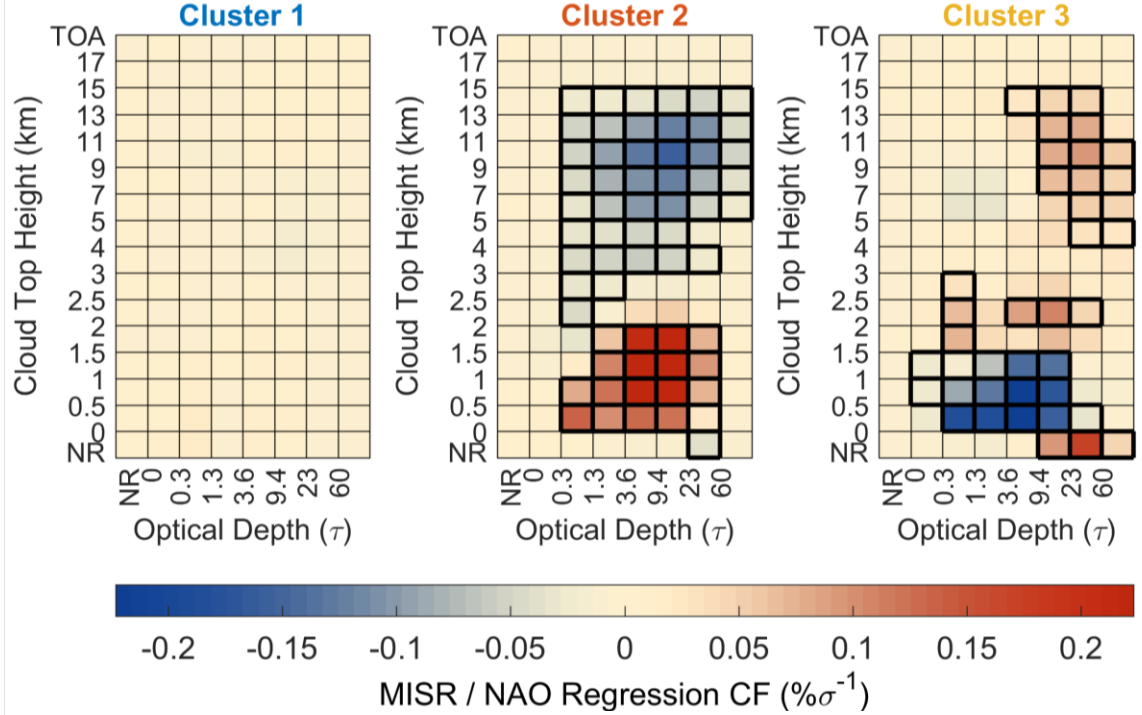


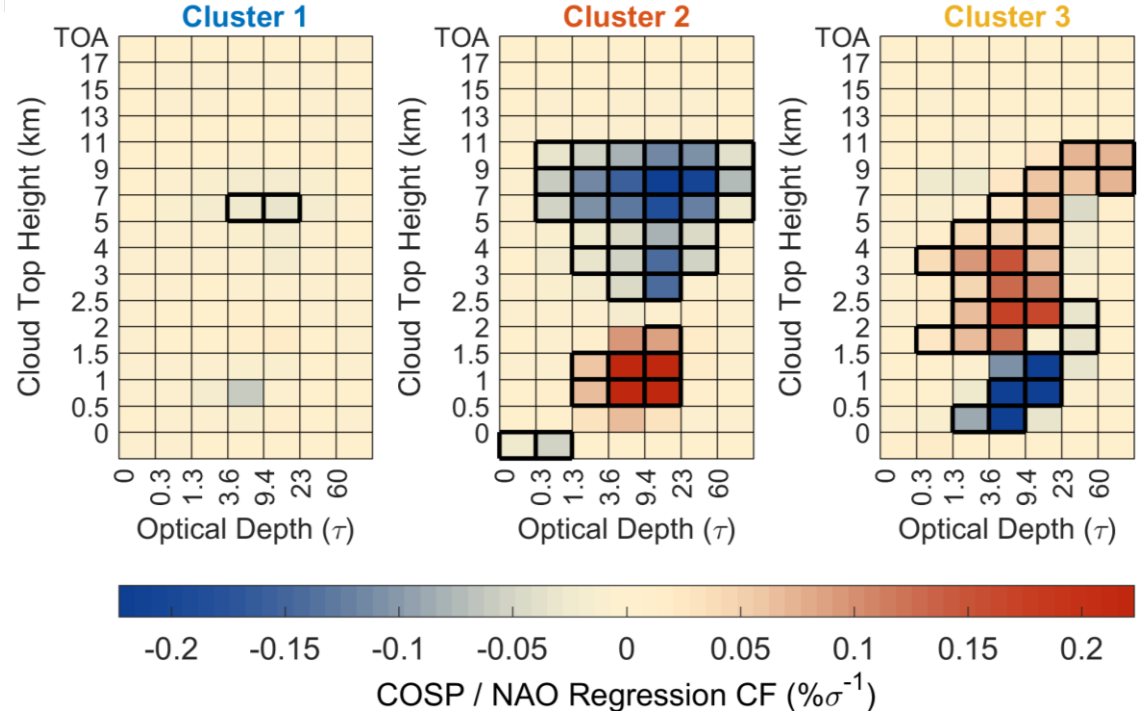


ERA-Interim / NAO Regression Coefficients

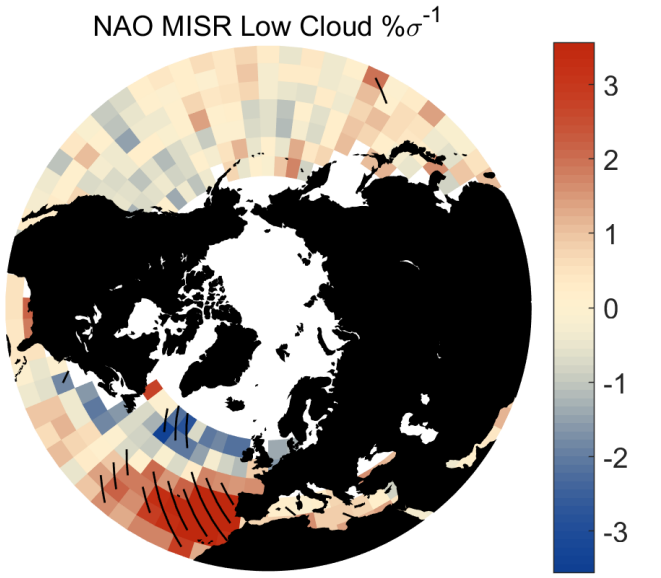


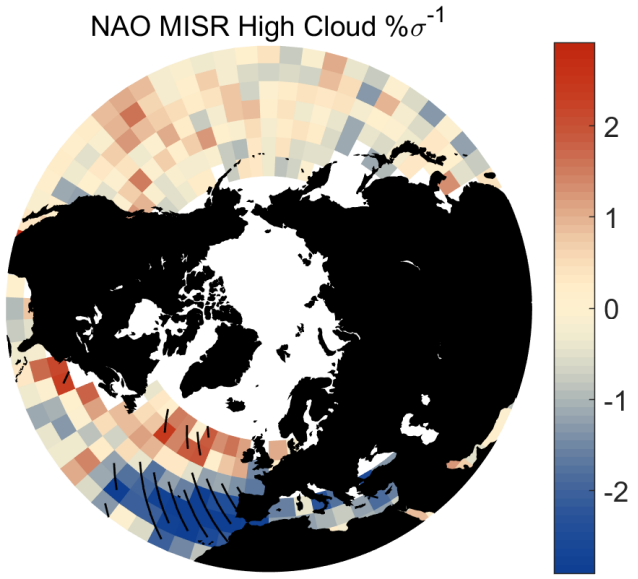
HadGEM / NAO Regression Coefficients

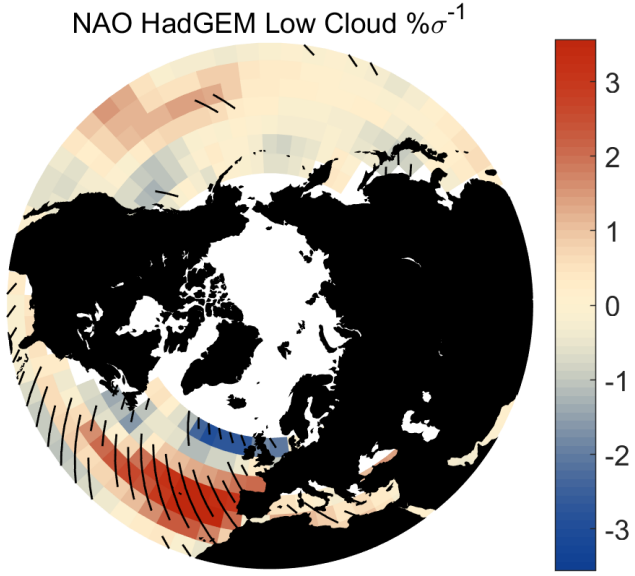


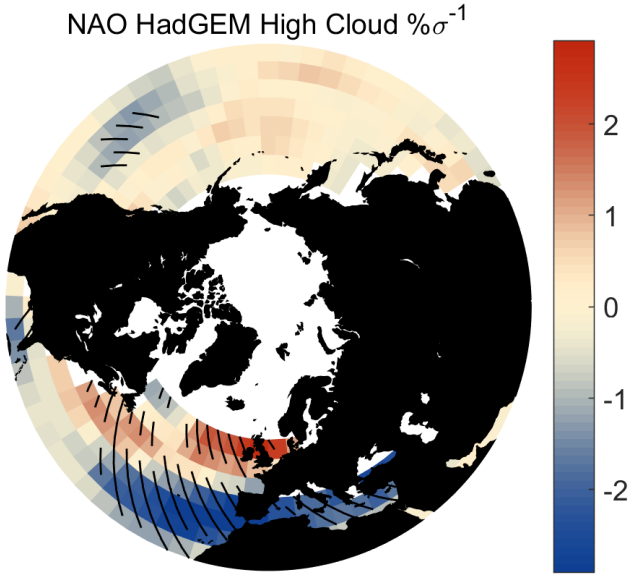


NAO: Radiative Fluxes

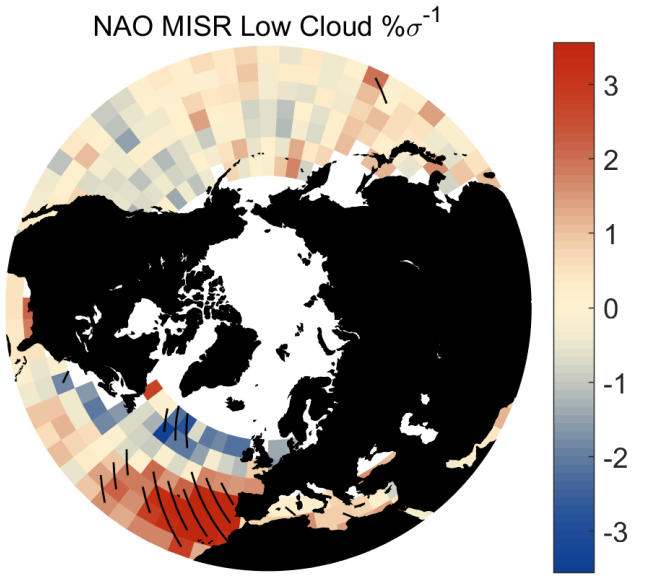


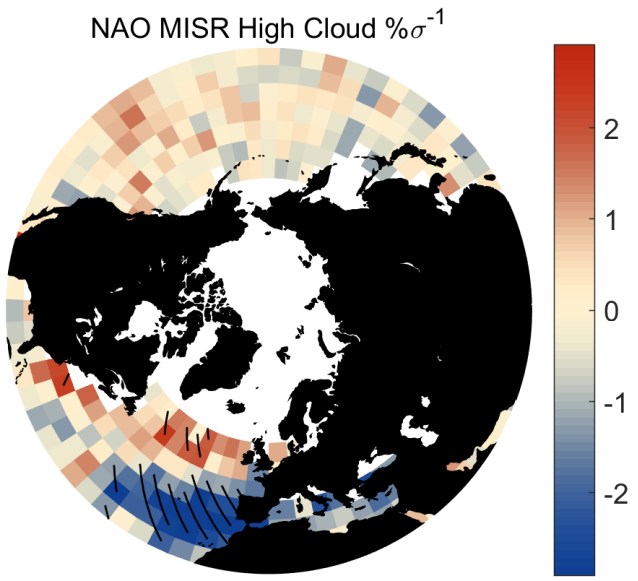


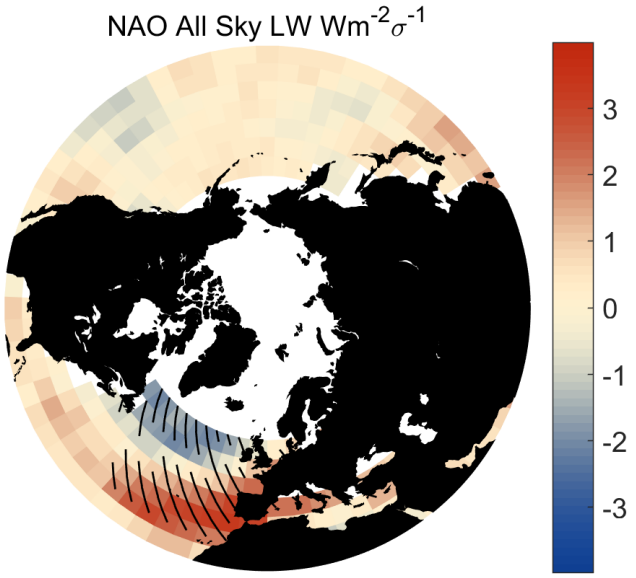


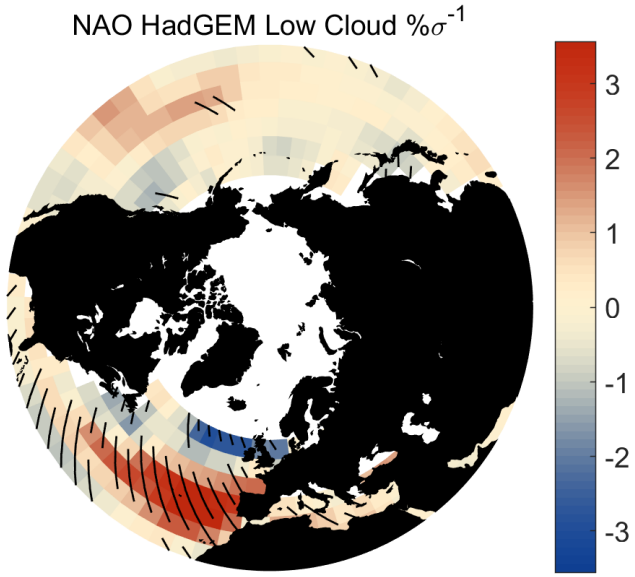


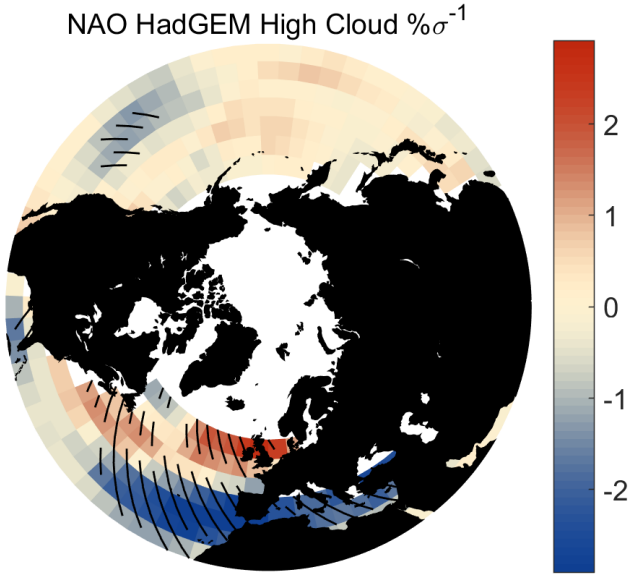
NAO: Radiative Fluxes

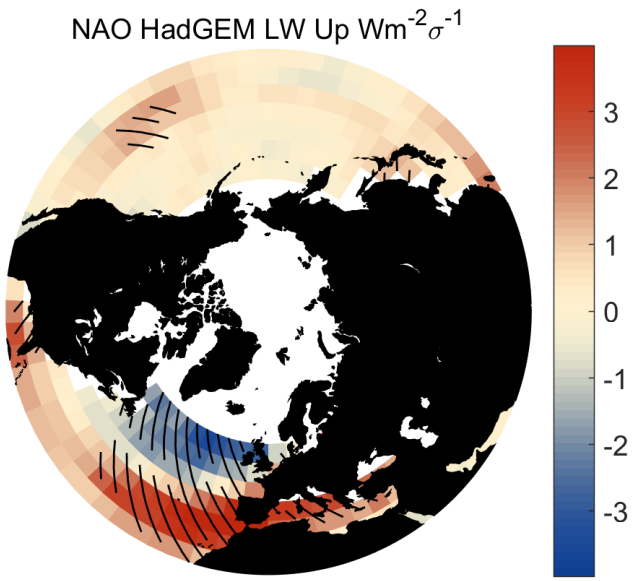




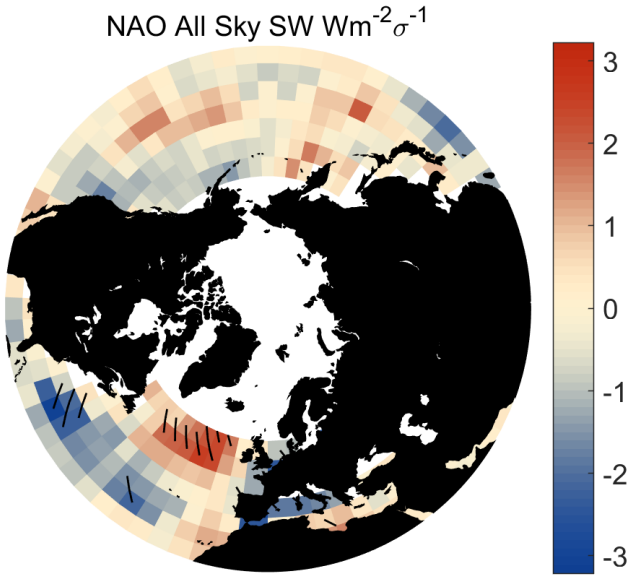


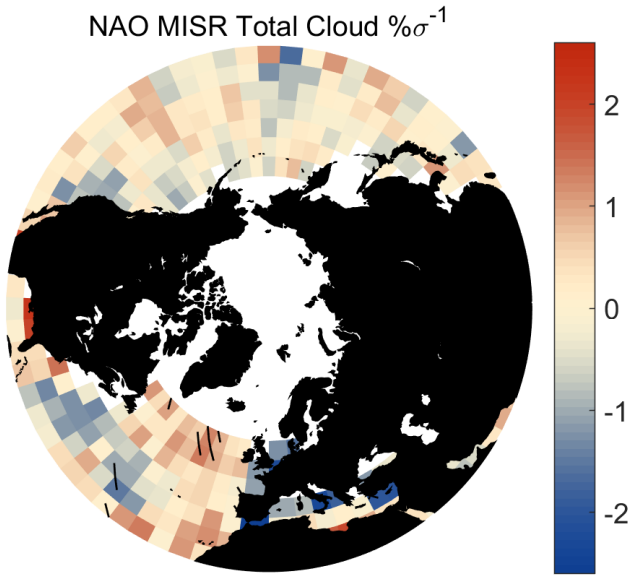


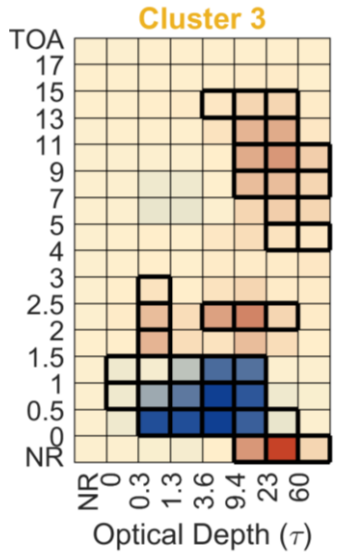


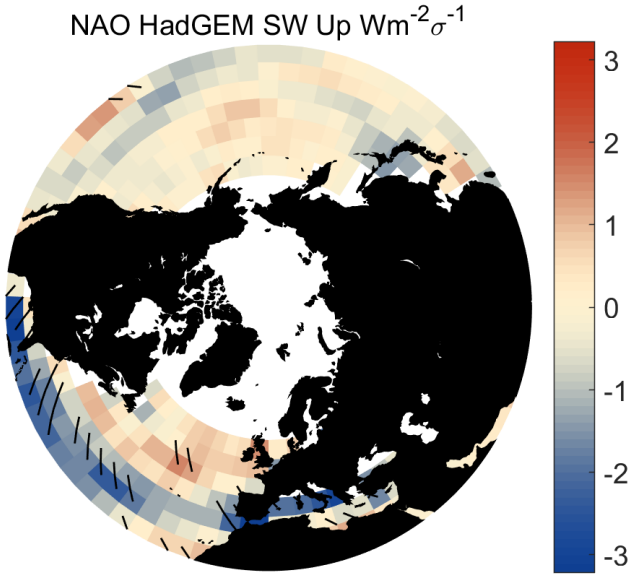


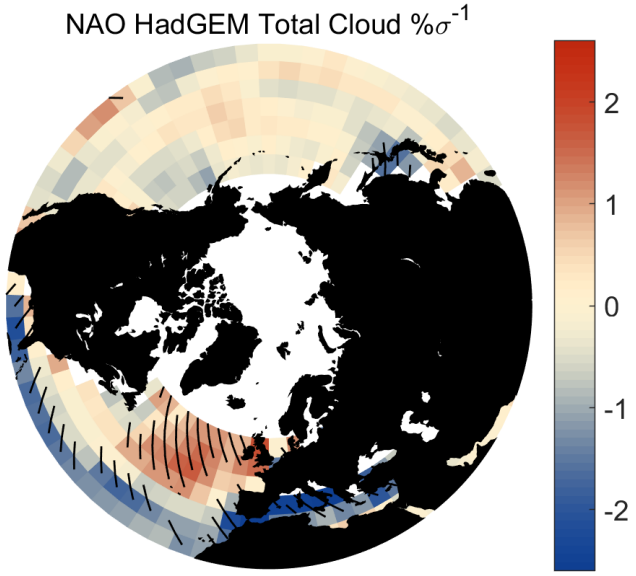
NAO: Radiative Fluxes

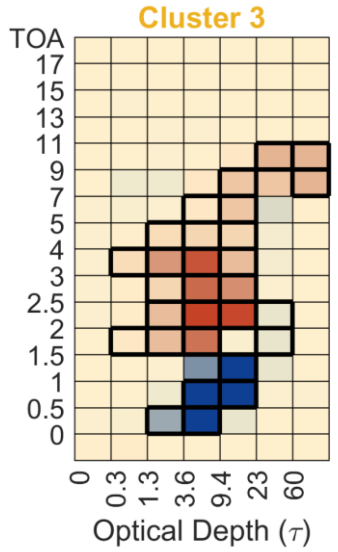






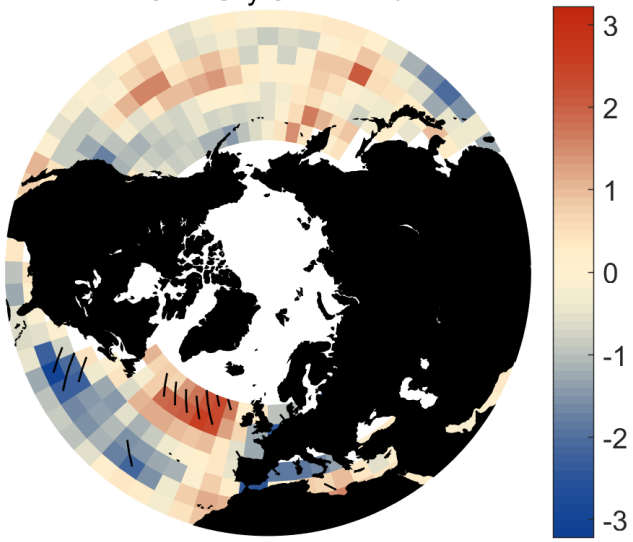




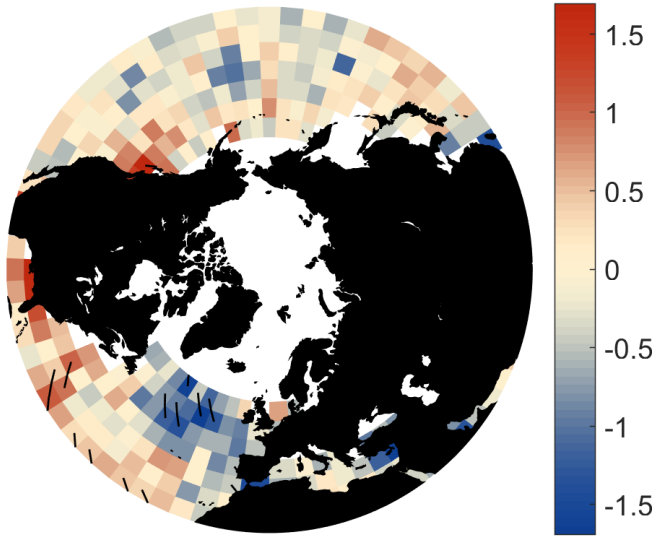


NAO: Radiative Fluxes

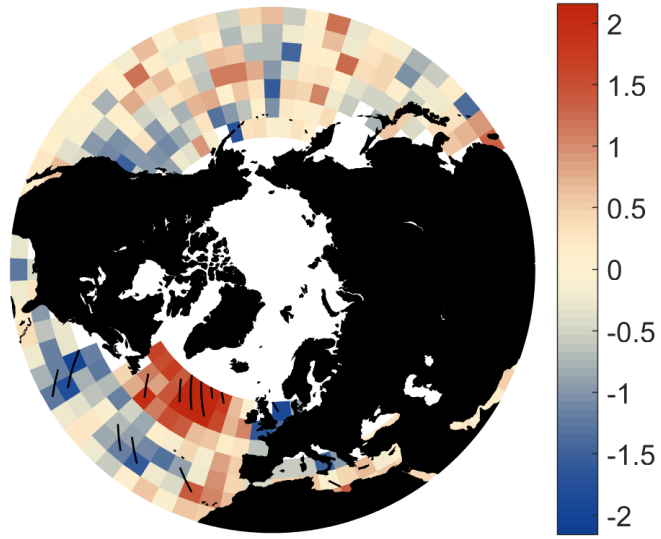
NAO All Sky SW $Wm^{-2}\sigma^{-1}$



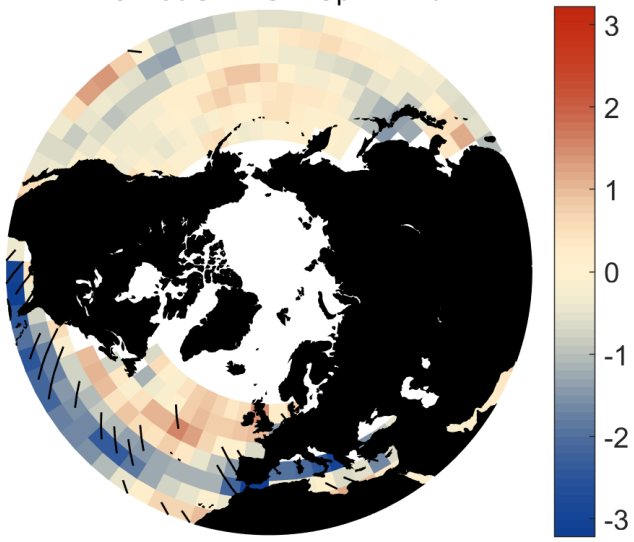
NAO MISR Thin Cloud $\%\sigma^{-1}$



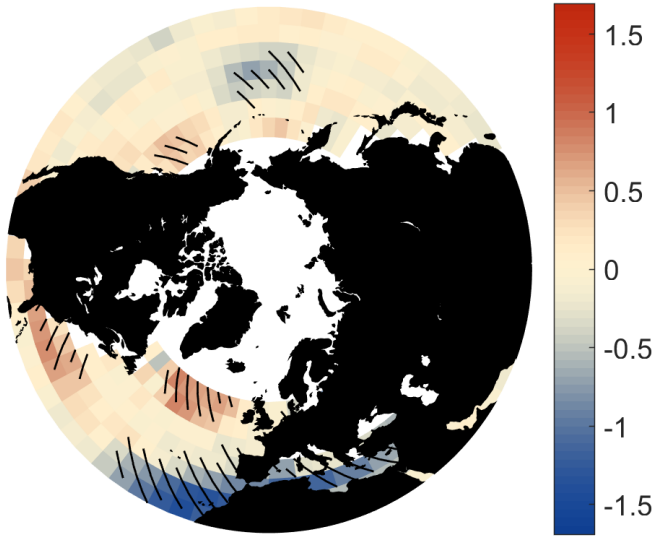
NAO MISR Thick Cloud $\%\sigma^{-1}$



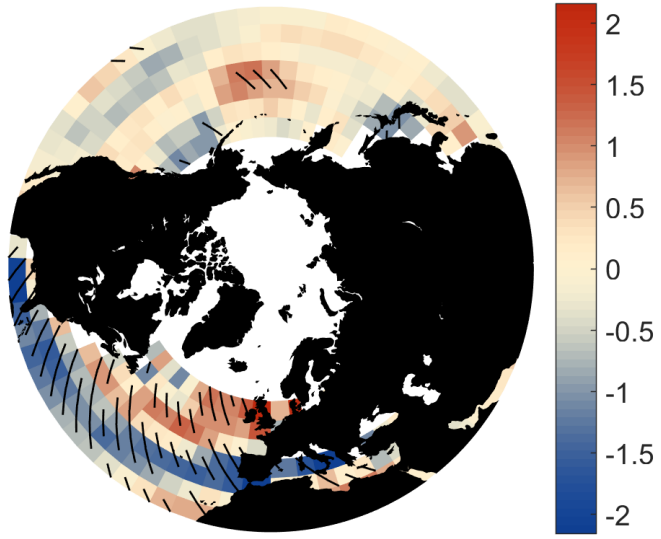
NAO HadGEM SW Up $Wm^{-2}\sigma^{-1}$



NAO HadGEM Thin Cloud $\%\sigma^{-1}$



NAO HadGEM Thick Cloud $\%\sigma^{-1}$



NAO: Summary

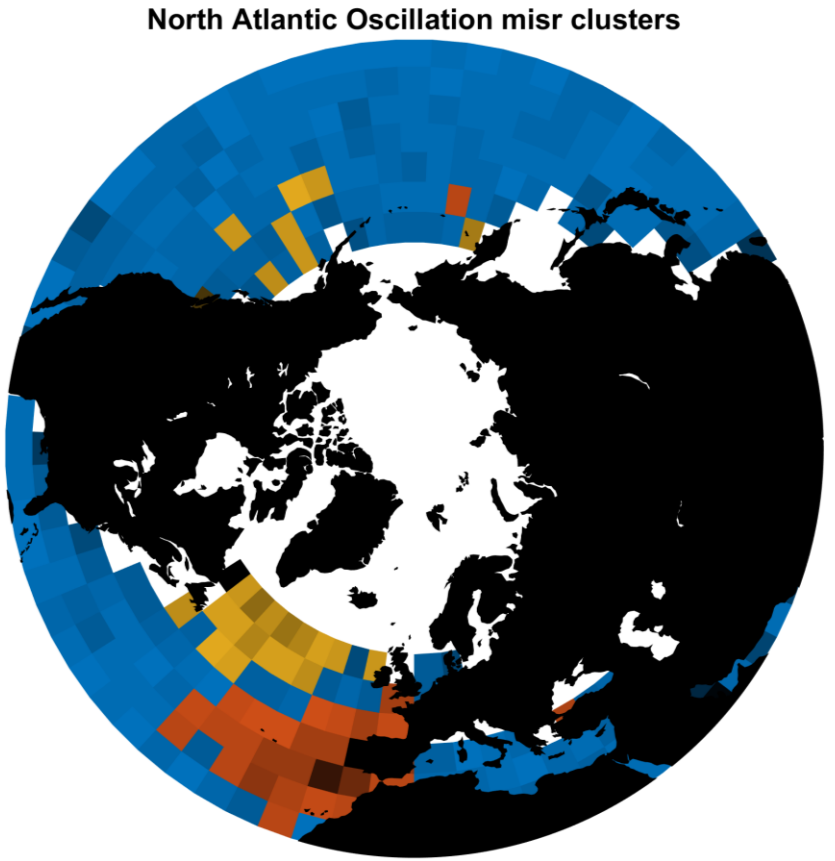
Cluster 2

Increased low cloud & decreased high cloud

Causes increased outgoing LW

Caused by increased tropospheric descent, anti-cyclonicity, surface divergence

HadGEM Reproduces all of this well



NAO: Summary

Cluster 3

Increased high-thick cloud, decreased low cloud of moderate thickness

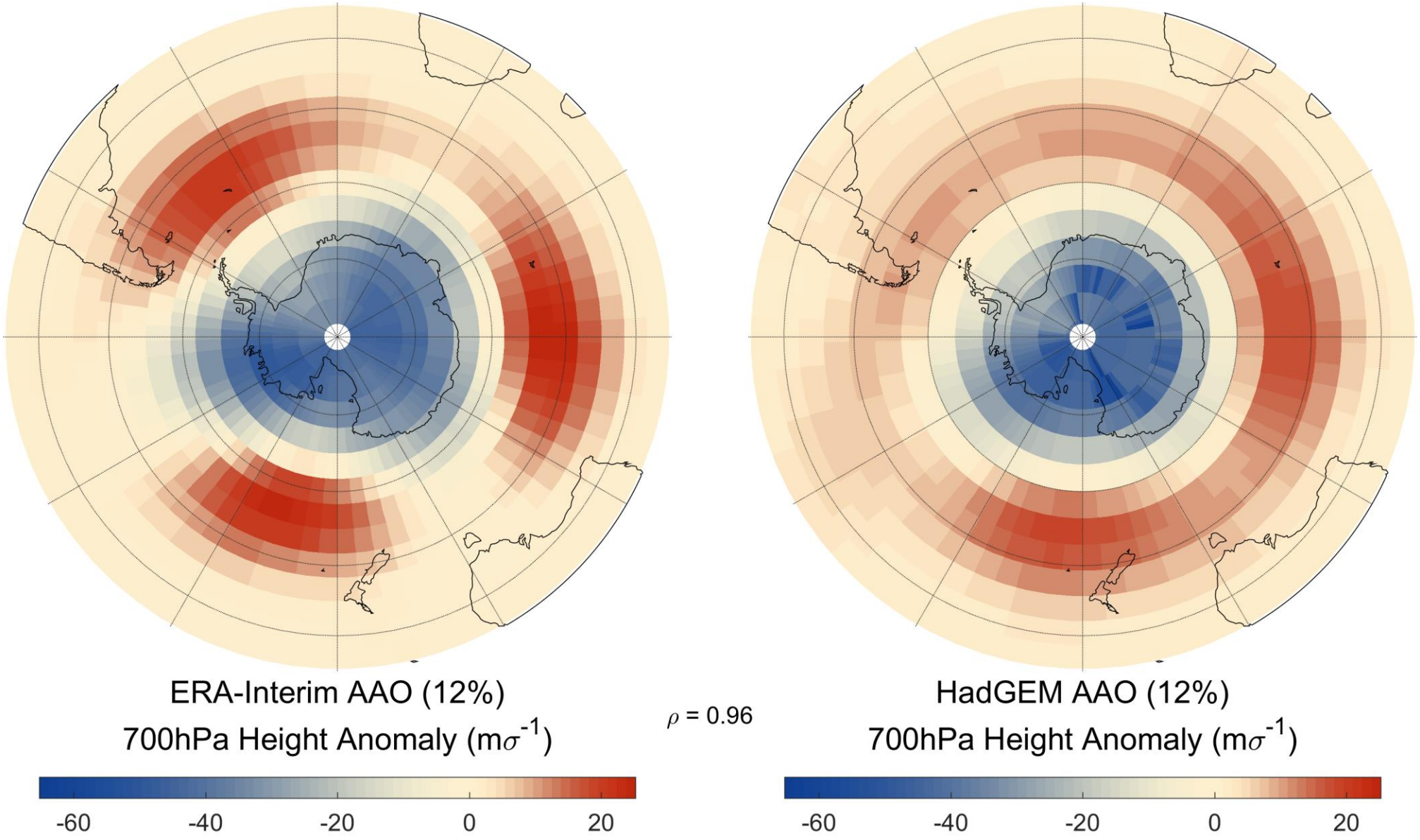
Reduces outgoing LW, increases outgoing SW

Associated with increased cyclonicity (northward movement of storm tracks?)

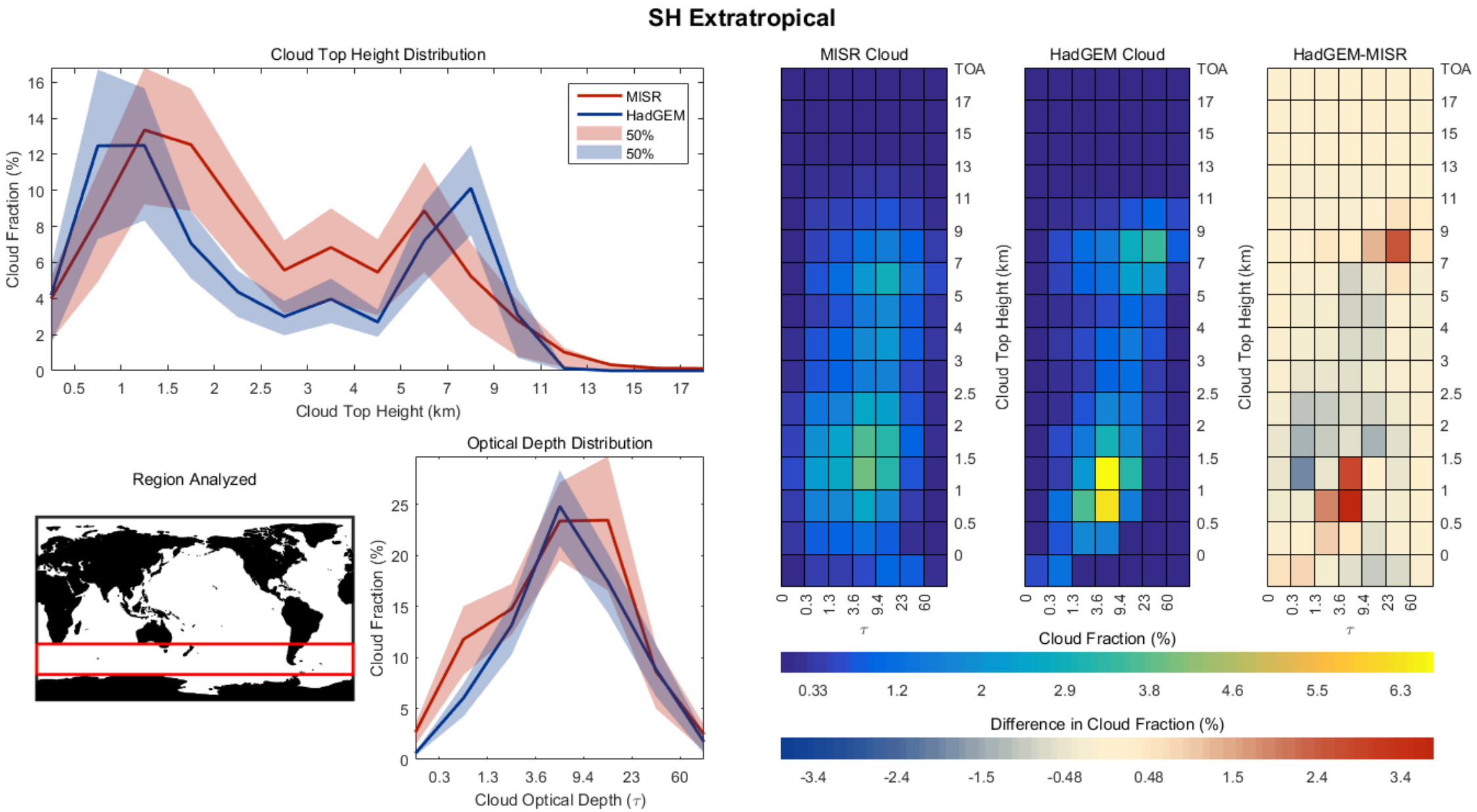
HadGEM reproduces everything but optical depth reduction. TOA SW doesn't match cloud changes.

The Southern Annular Mode

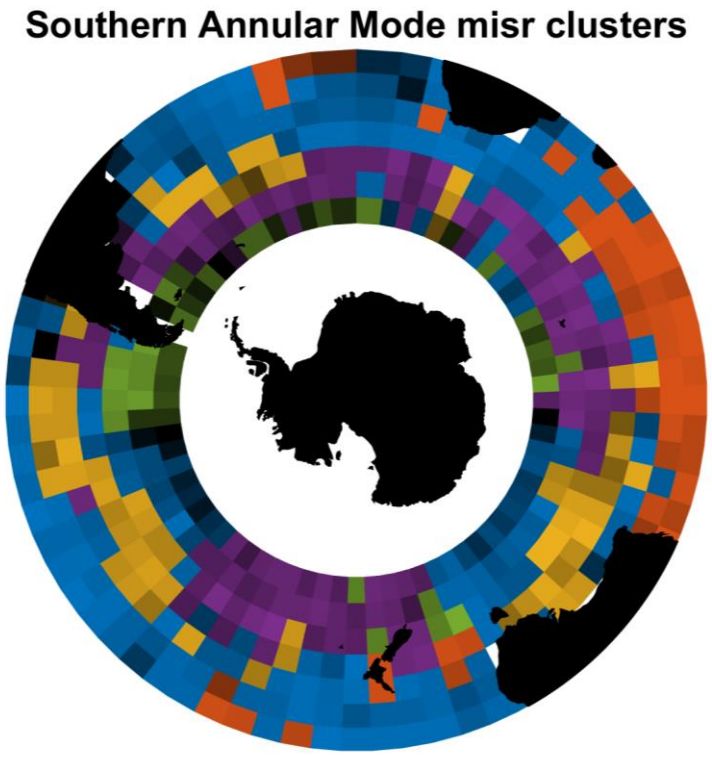
HadGEM: Antarctic Oscillation

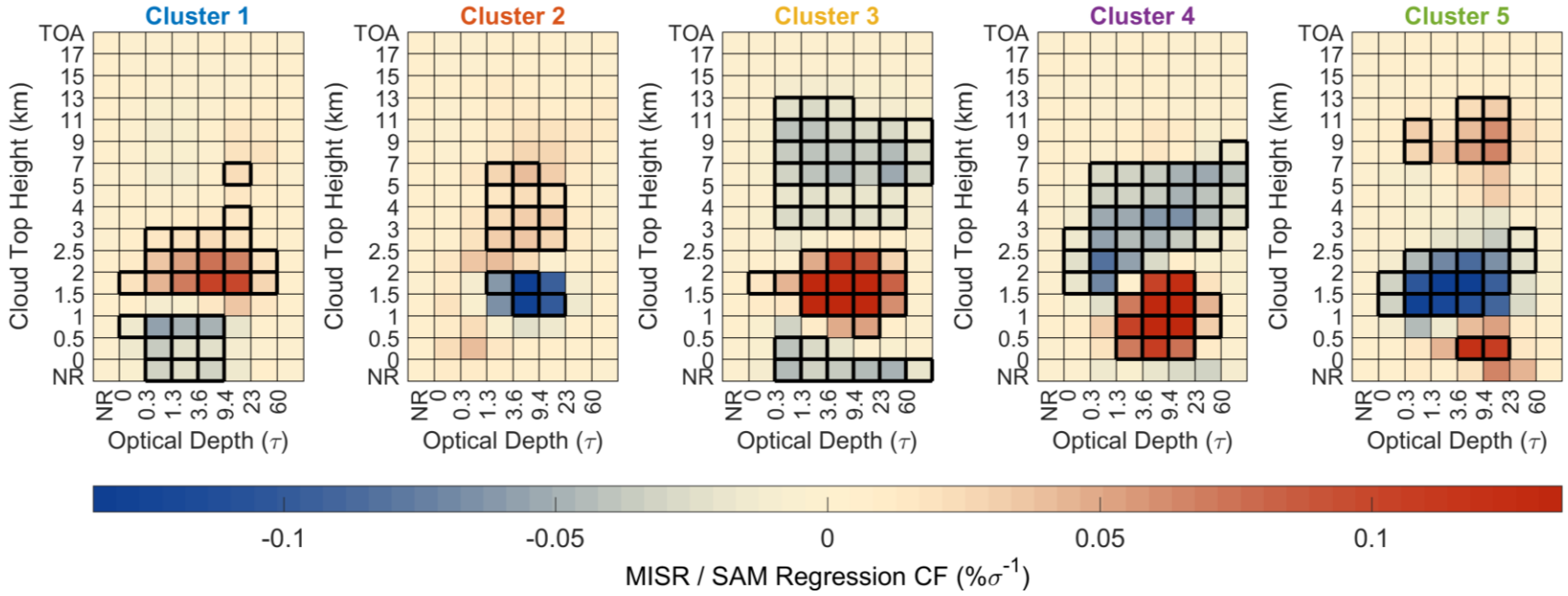


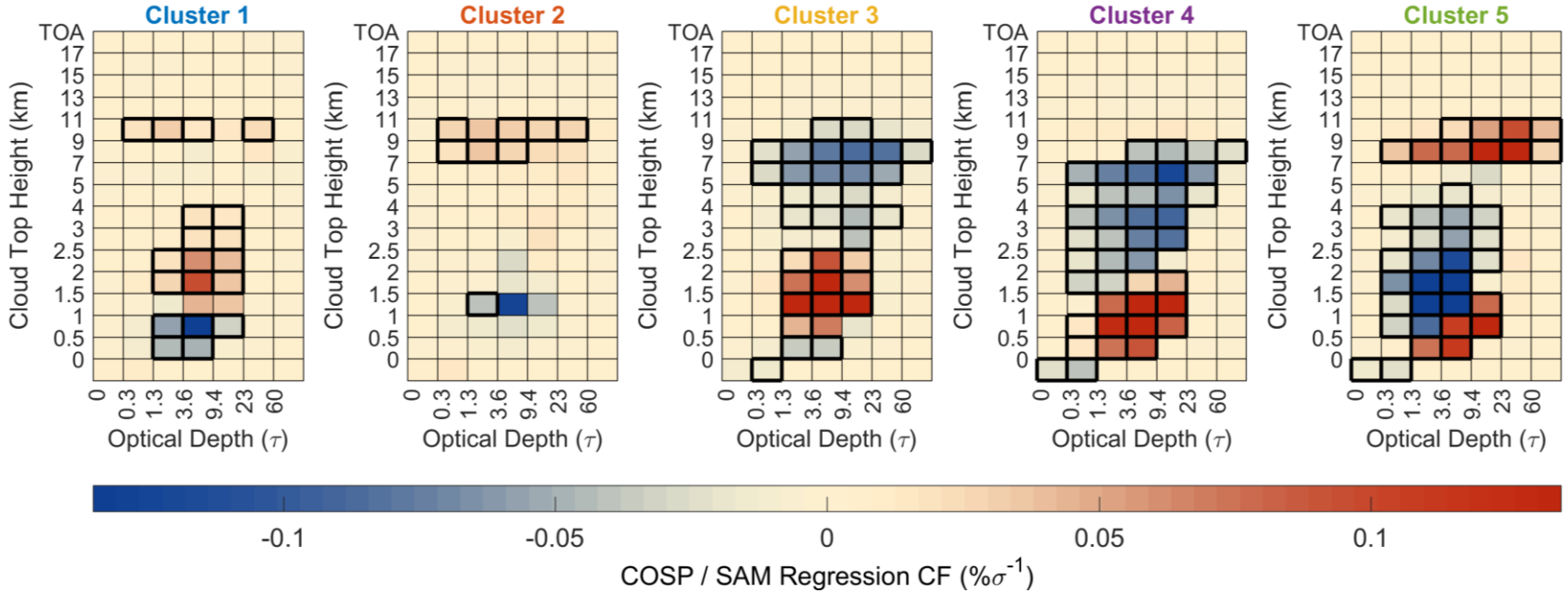
HadGEM Mean Cloud Fields



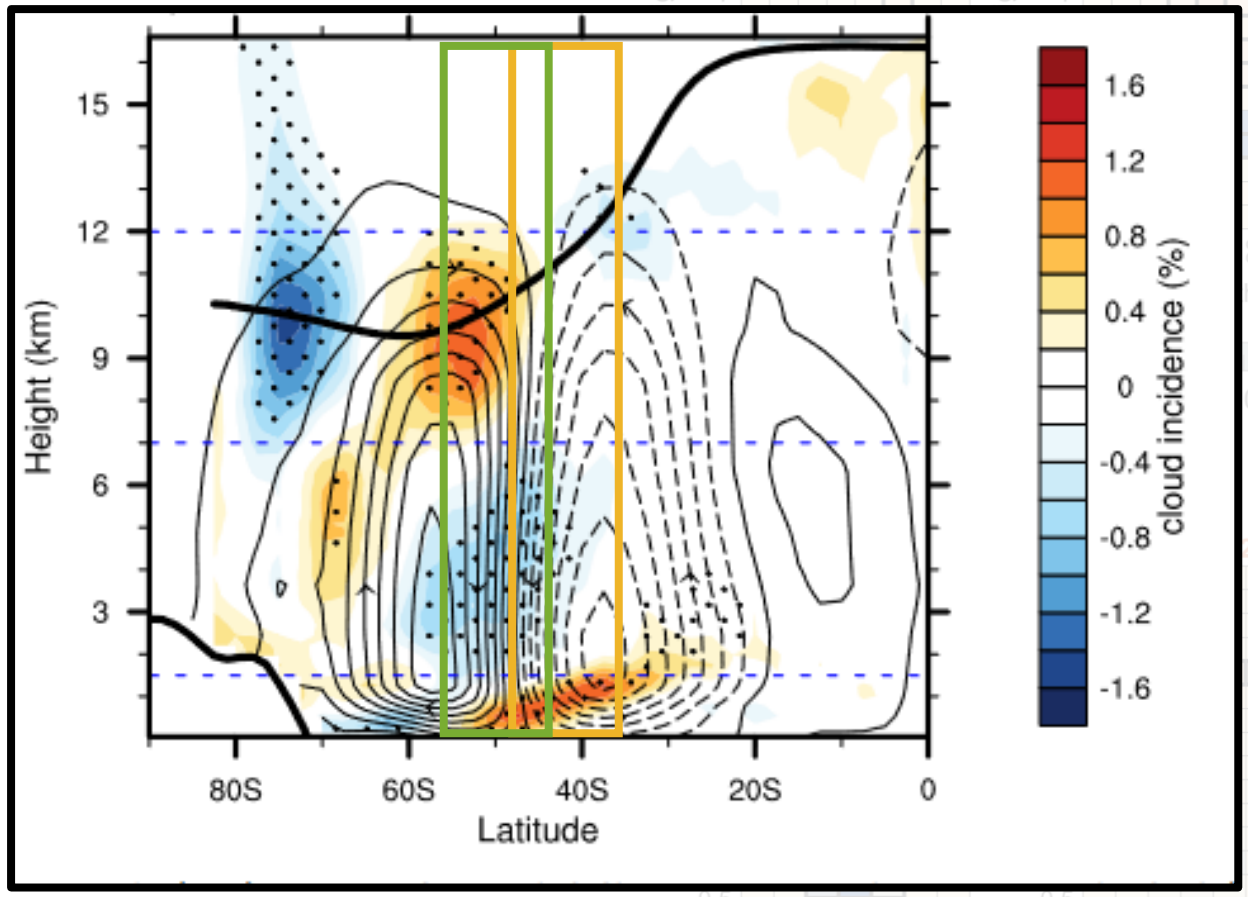
SAM: Clouds

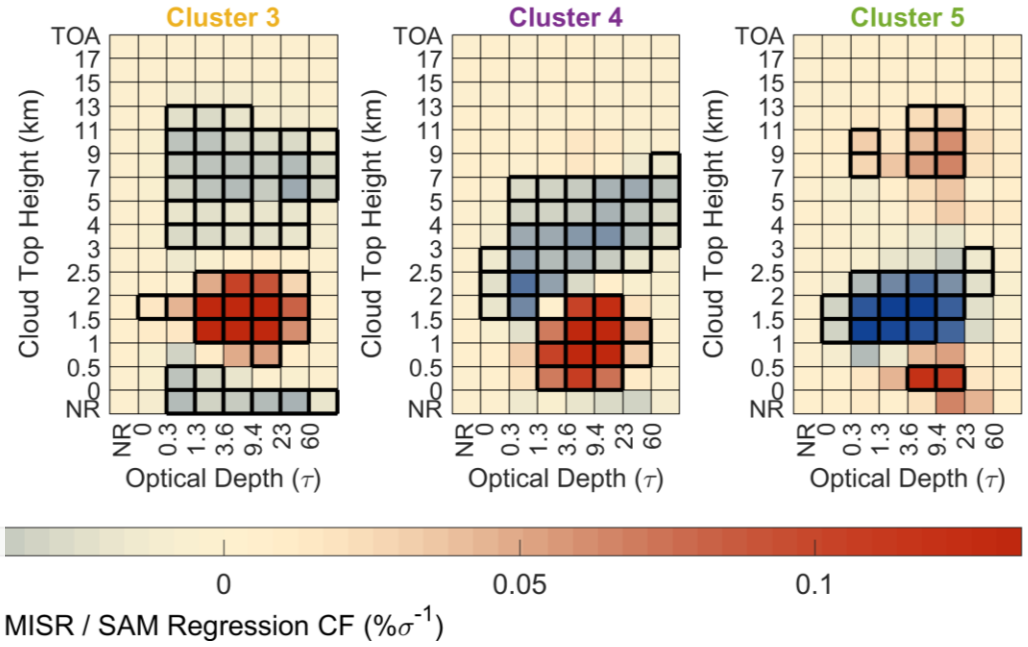

Southern Annular Mode misr clusters

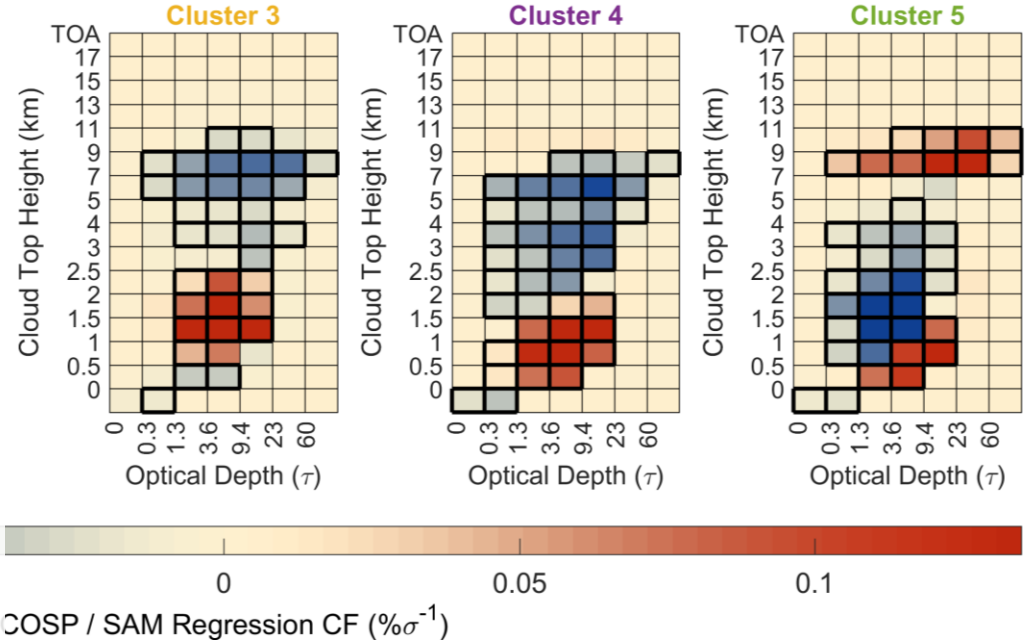

Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cloud Top Height (km)
TOA
17
15
13
11
9
7
5
4
3
2.5
2
1.5
1
0.5
0
NR
0
0.3
1.3
3.6
9.4
23
60
Optical Depth (τ)
-0.1
-0.05
0
0.05
0.1
MISR / SAM Regression CF (%σ-1)


Cluster 1
Cluster 2
Cluster 3
Cluster 4
Cluster 5
Cloud Top Height (km)
TOA
17
15
13
11
9
7
5
4
3
2.5
2
1.5
1
0.5
0
0
0.3
1.3
3.6
9.4
23
60
Optical Depth (τ)
-0.1
-0.05
0
0.05
0.1
COSP / SAM Regression CF (%σ-1)

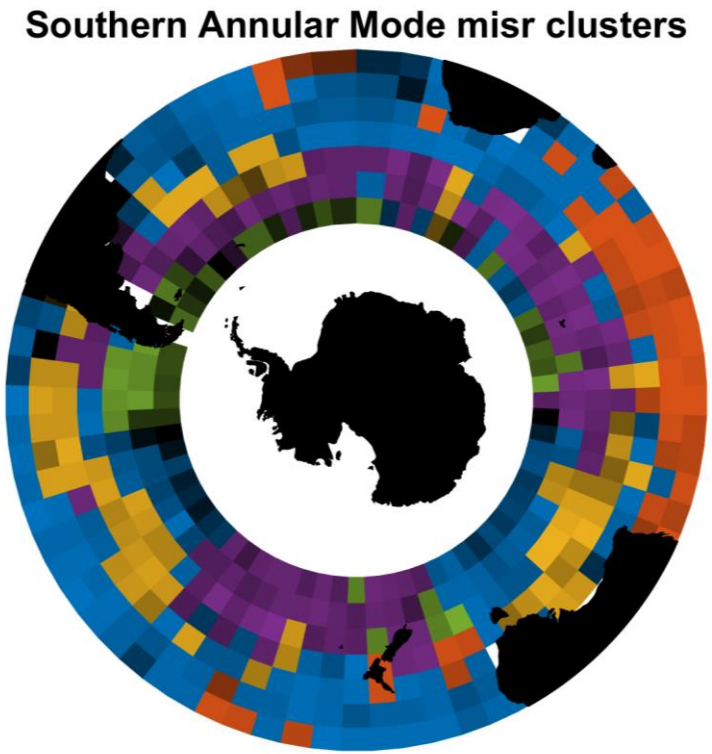
SAM: Clouds

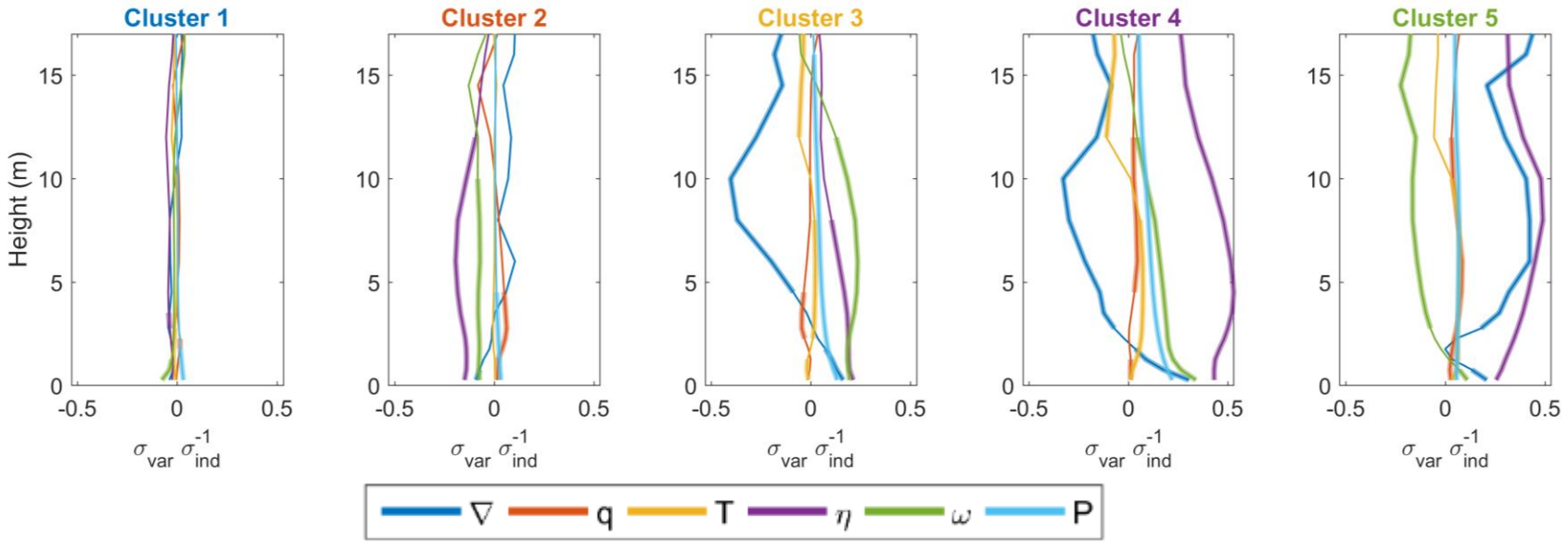

Height (km)
15
12
9
6
3
80S
60S
40S
20S
0
Latitude
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
cloud incidence (%)


Cluster 3
Cluster 4
Cluster 5
TOA
Cloud Top Height (km)
Optical Depth (τ)
NR
0
0.3
1.3
3.6
9.4
23
60
0
0.05
0.1
MISR / SAM Regression CF (%σ-1)

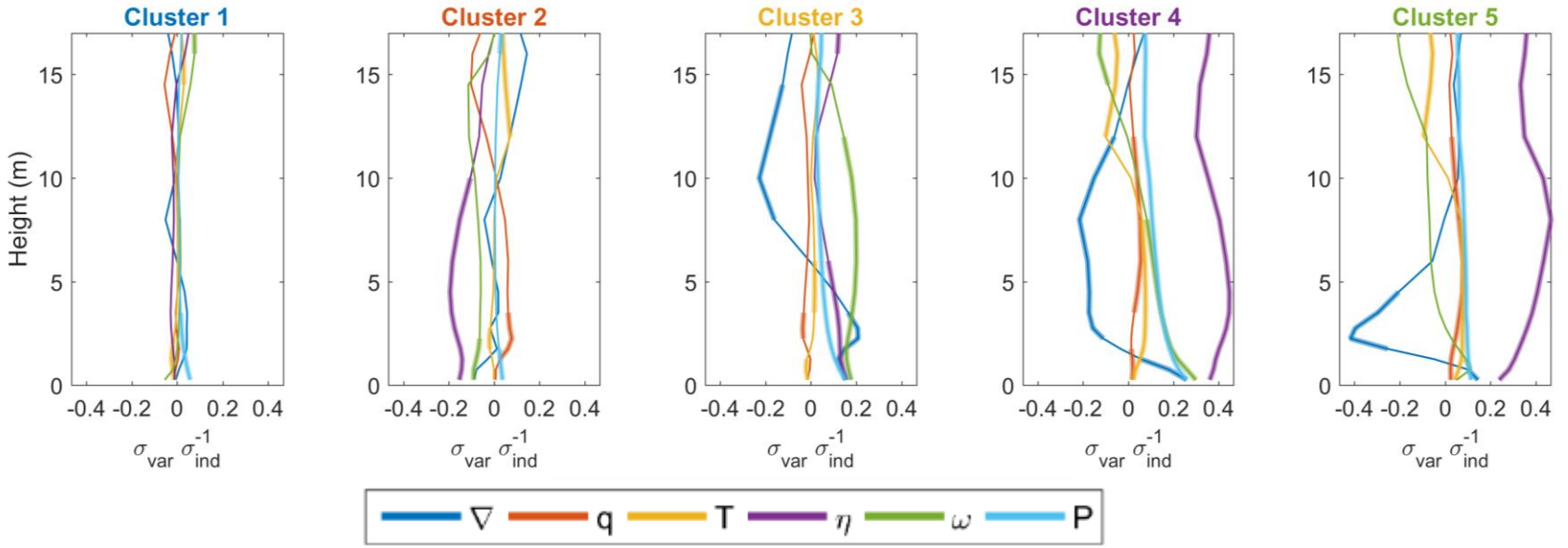

Cluster 3
Cluster 4
Cluster 5
TOA
Cloud Top Height (km)
Optical Depth (τ)
0
0.05
0.1
COSP / SAM Regression CF (%σ-1)

SAM: Meteorology



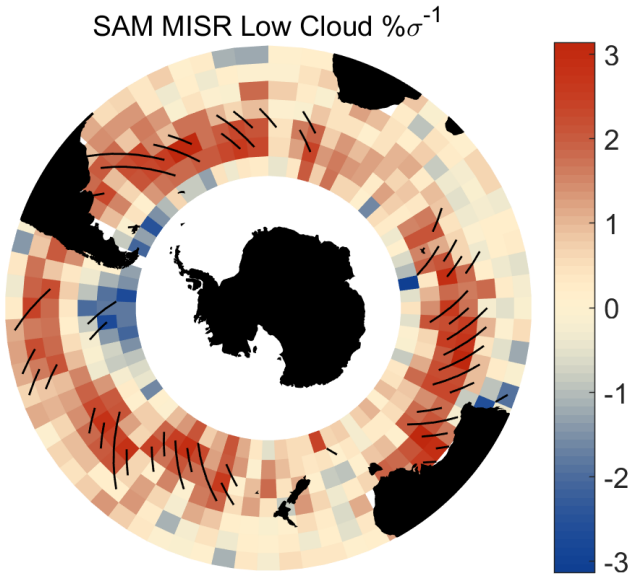


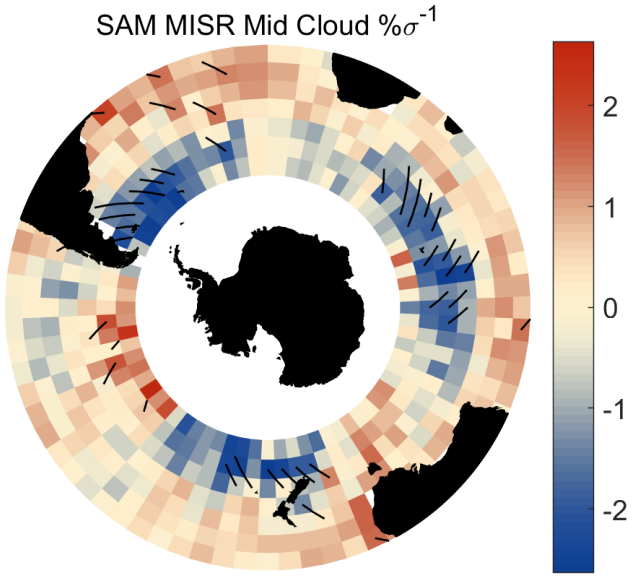
HadGEM / SAM Regression Coefficients

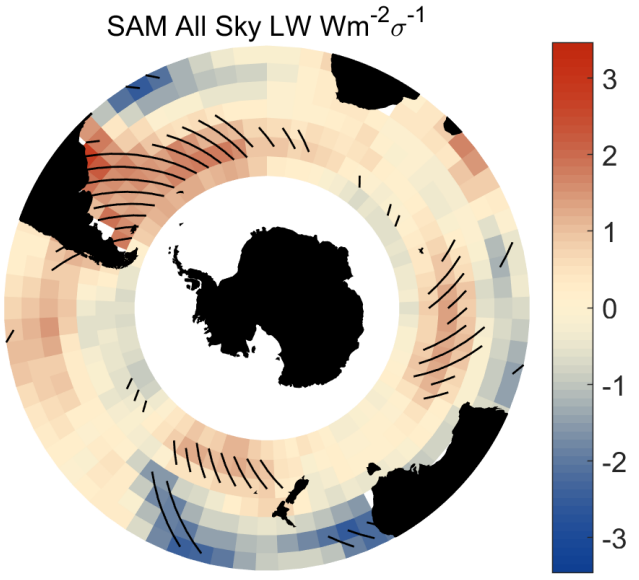


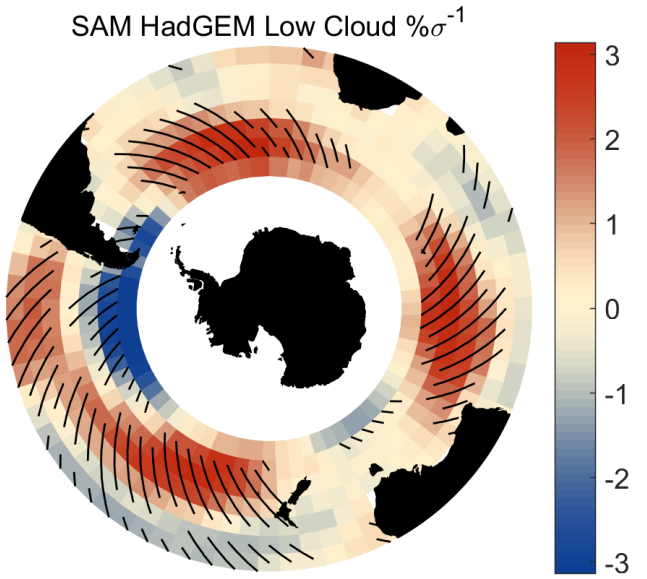
ERA-Interim / SAM Regression Coefficients

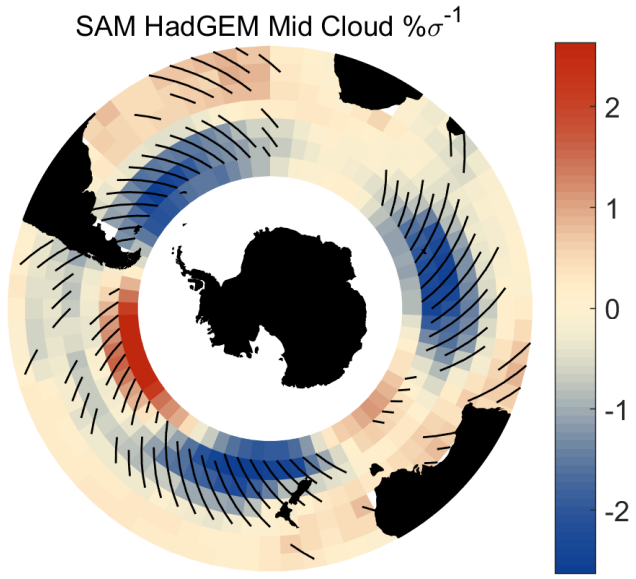
SAM: TOA Radiation

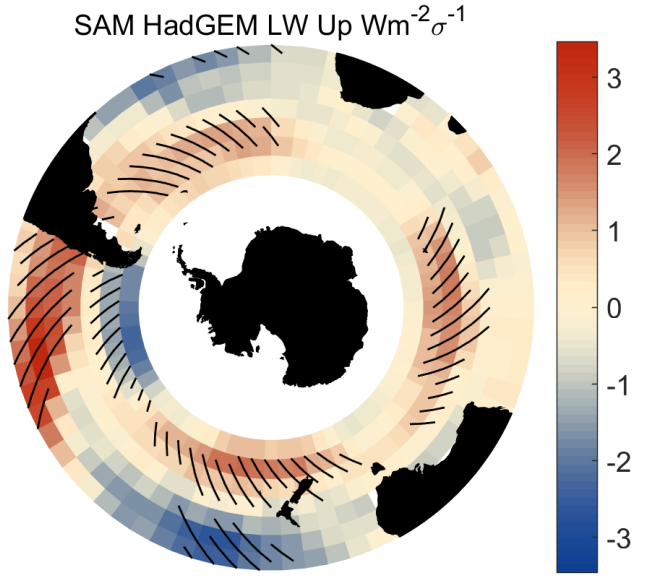




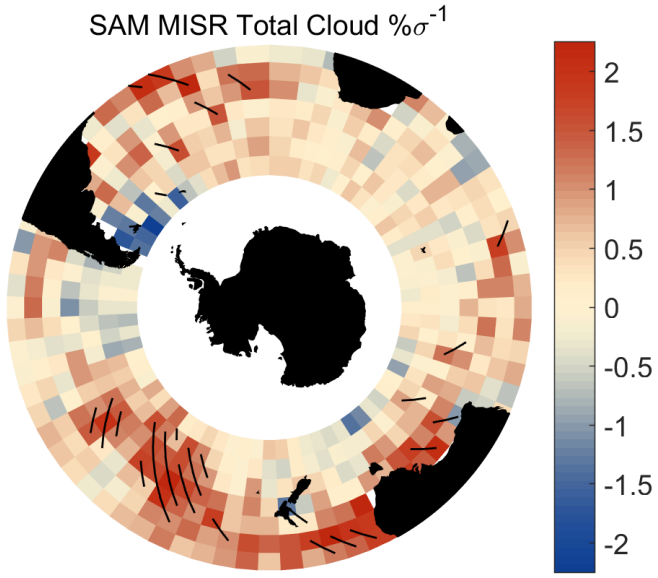


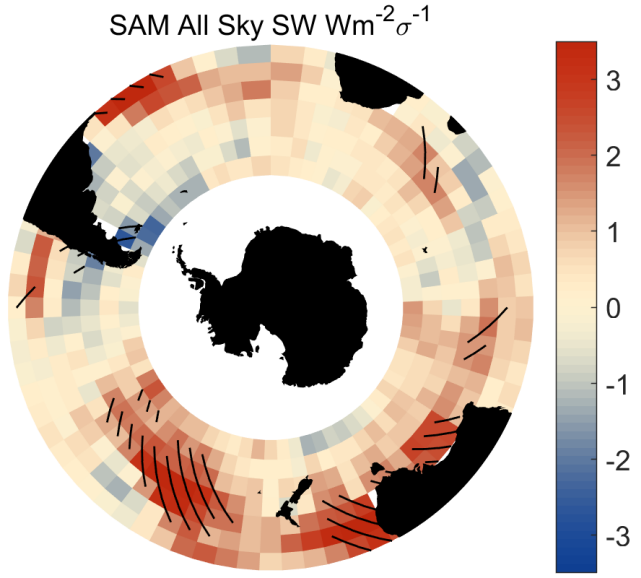


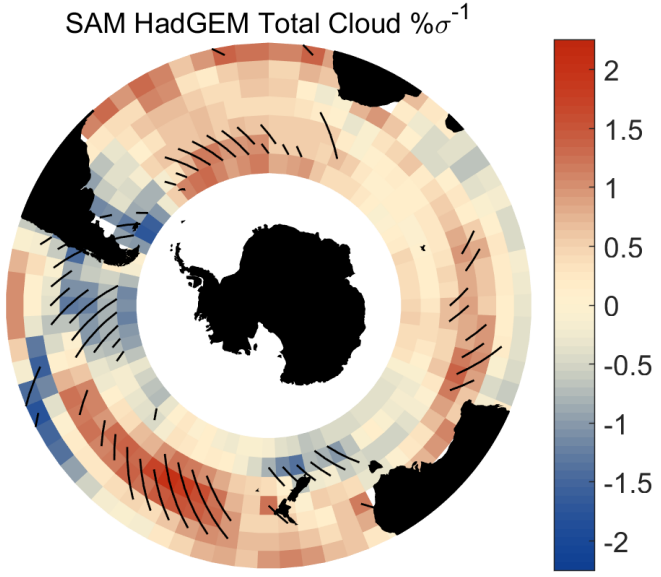


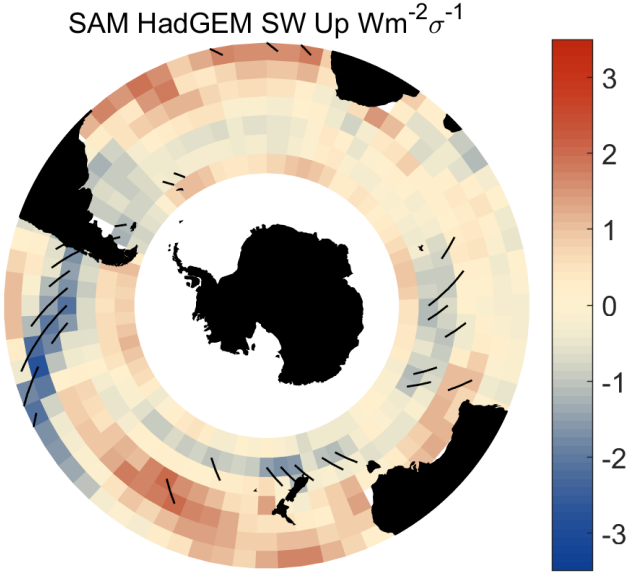


SAM: TOA Radiation









SAM: Summary

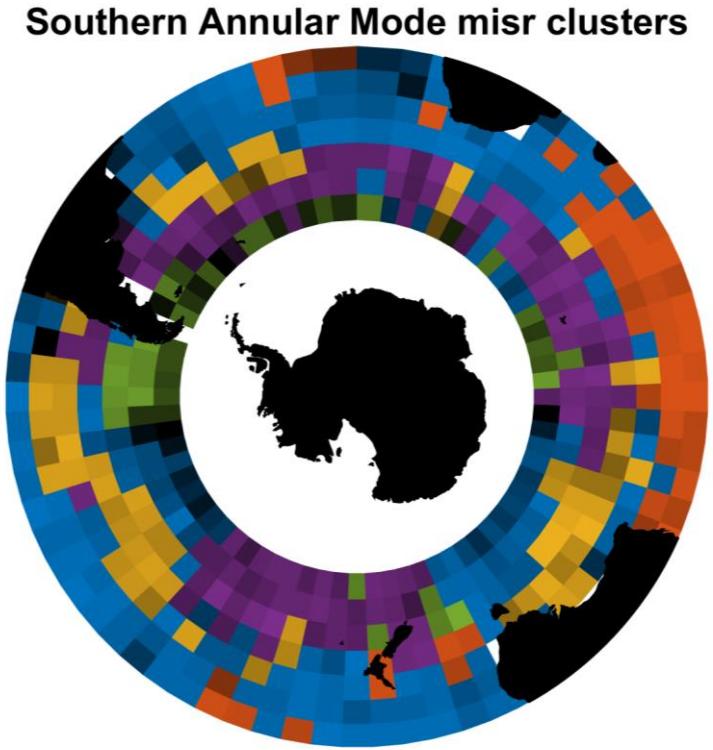
Cluster 1 & Cluster 2

Mostly subtropical

Almost no changes in meteorology

Weak changes in cloudiness (advection?)

Well represented in model, except in subtropical pacific



SAM: Summary

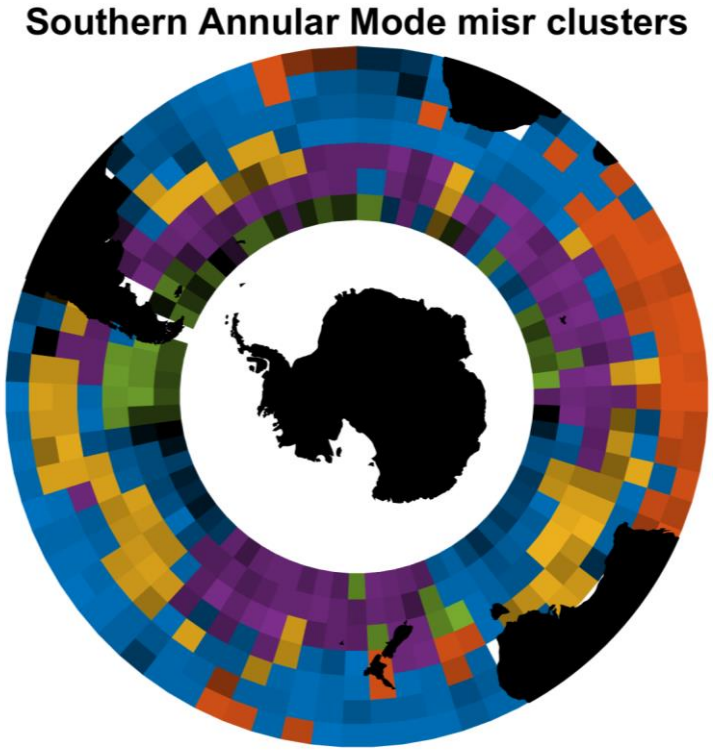
Cluster 4

-SAM High Pressure centers

-Reduced mid-level cloud increased low cloud

-Causes increased upwelling longwave

-HadGEM reproduces this



Cluster 3

-Similar to cluster 4 but weaker changes in meteorology

SUMMARY

-Primary cloud response to annular modes is increased low cloud and reduced high (NAO) or mid-level (SAM) cloud at high pressure centers

-Associated with increased anticyclonicity, pressure, subsidence, etc.

-Causes increased upwelling longwave

-HadGEM2 captures all of this well, but struggles with upwelling shortwave changes due to cloud optical thickness or total cloud amount changes