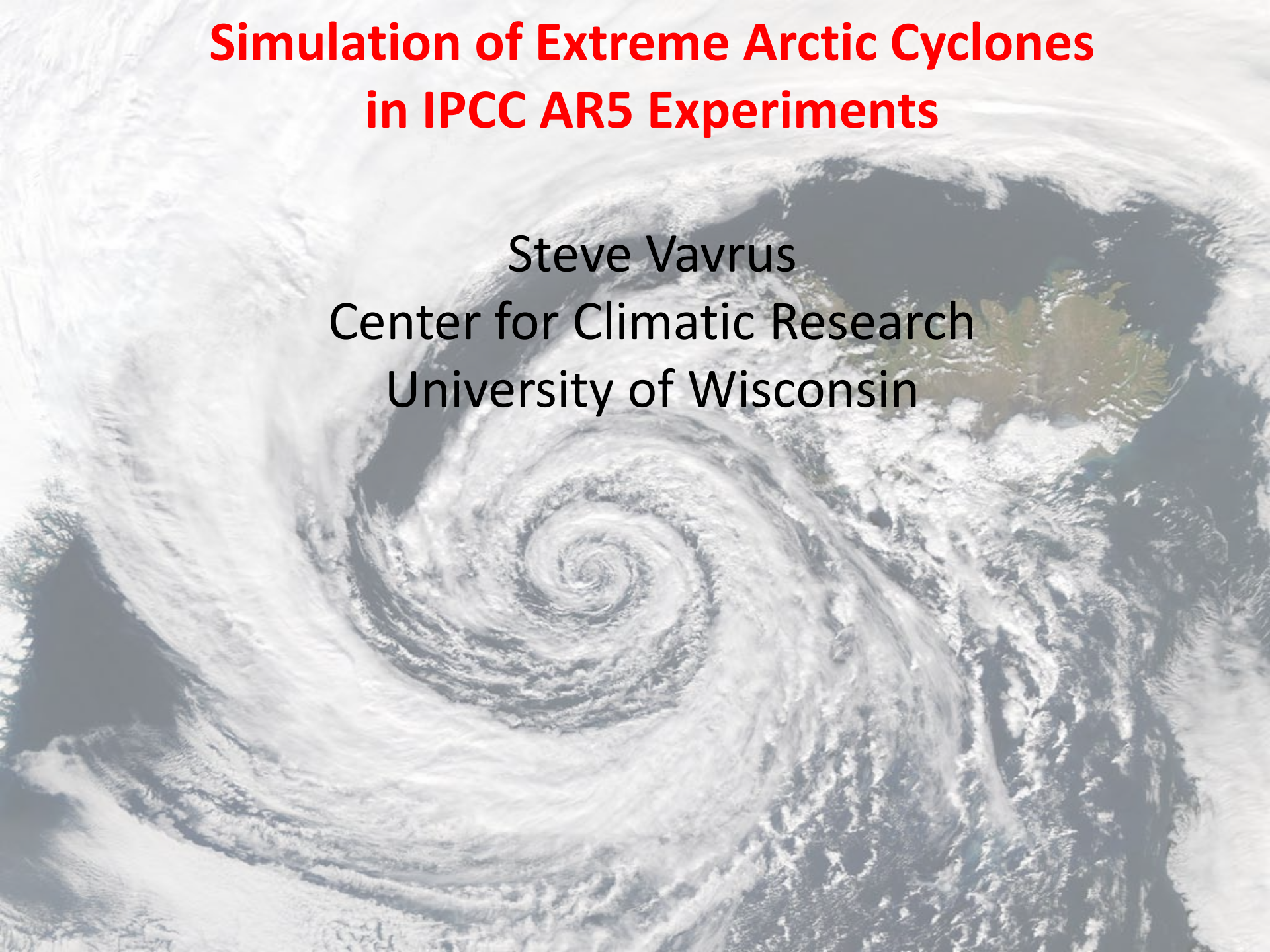
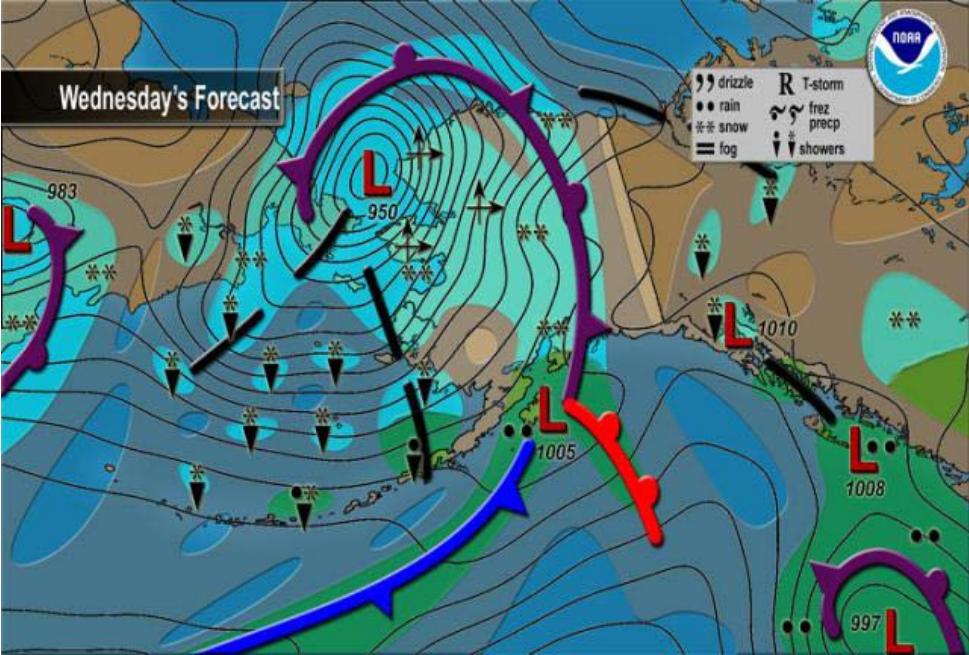


# Simulation of Extreme Arctic Cyclones in IPCC AR5 Experiments

Steve Vavrus  
Center for Climatic Research  
University of Wisconsin



# November 2011 Bering Sea Superstorm (943 hPa)



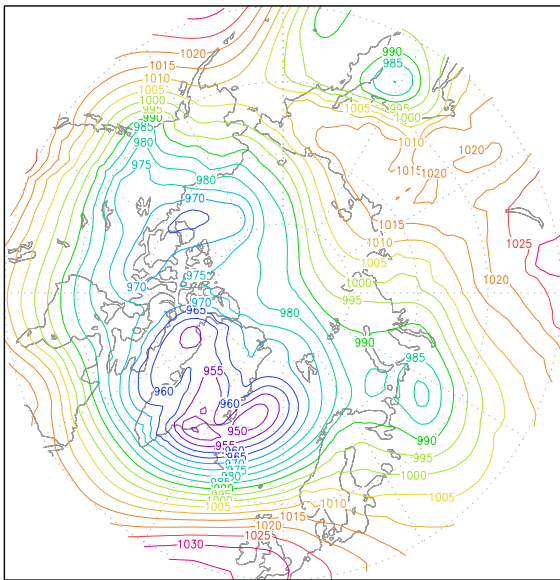


Sea ice loss + Coastline permafrost thaw + Strong storms =

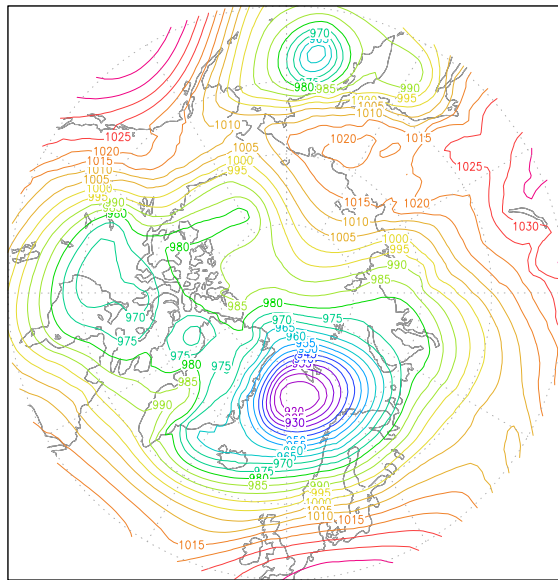
*Coastal Erosion*

# CCSM4 Simulation of an Arctic Megacyclone

Dec. 9, 2059

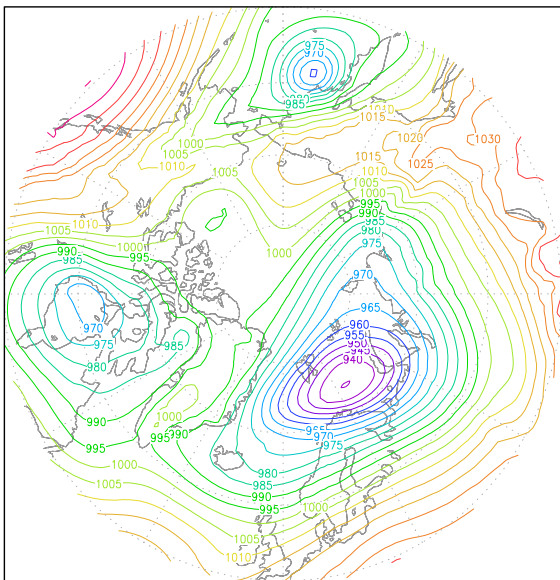


Dec. 10, 2059

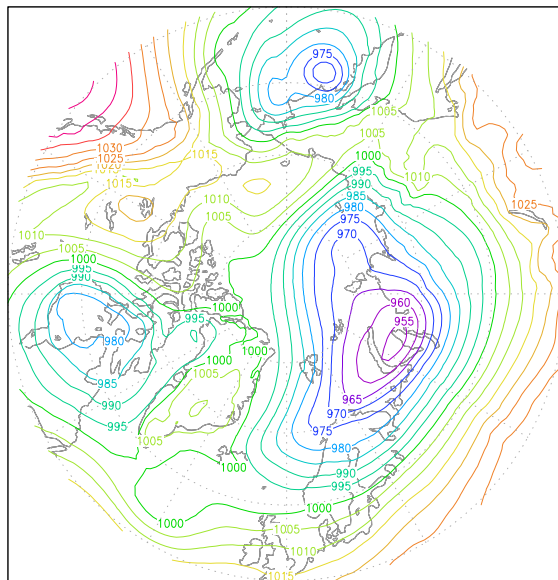


915 hPa  
minimum SLP

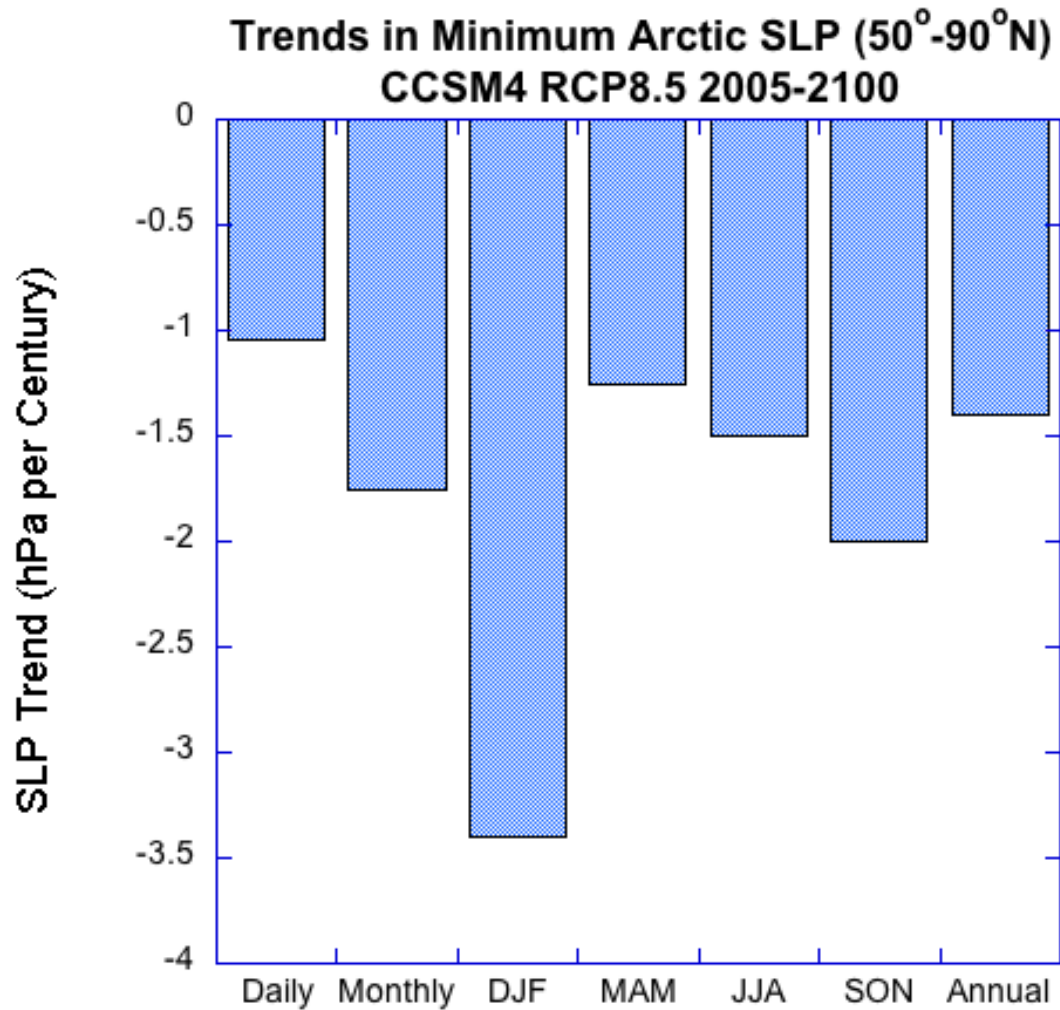
Dec. 11, 2059



Dec. 12, 2059



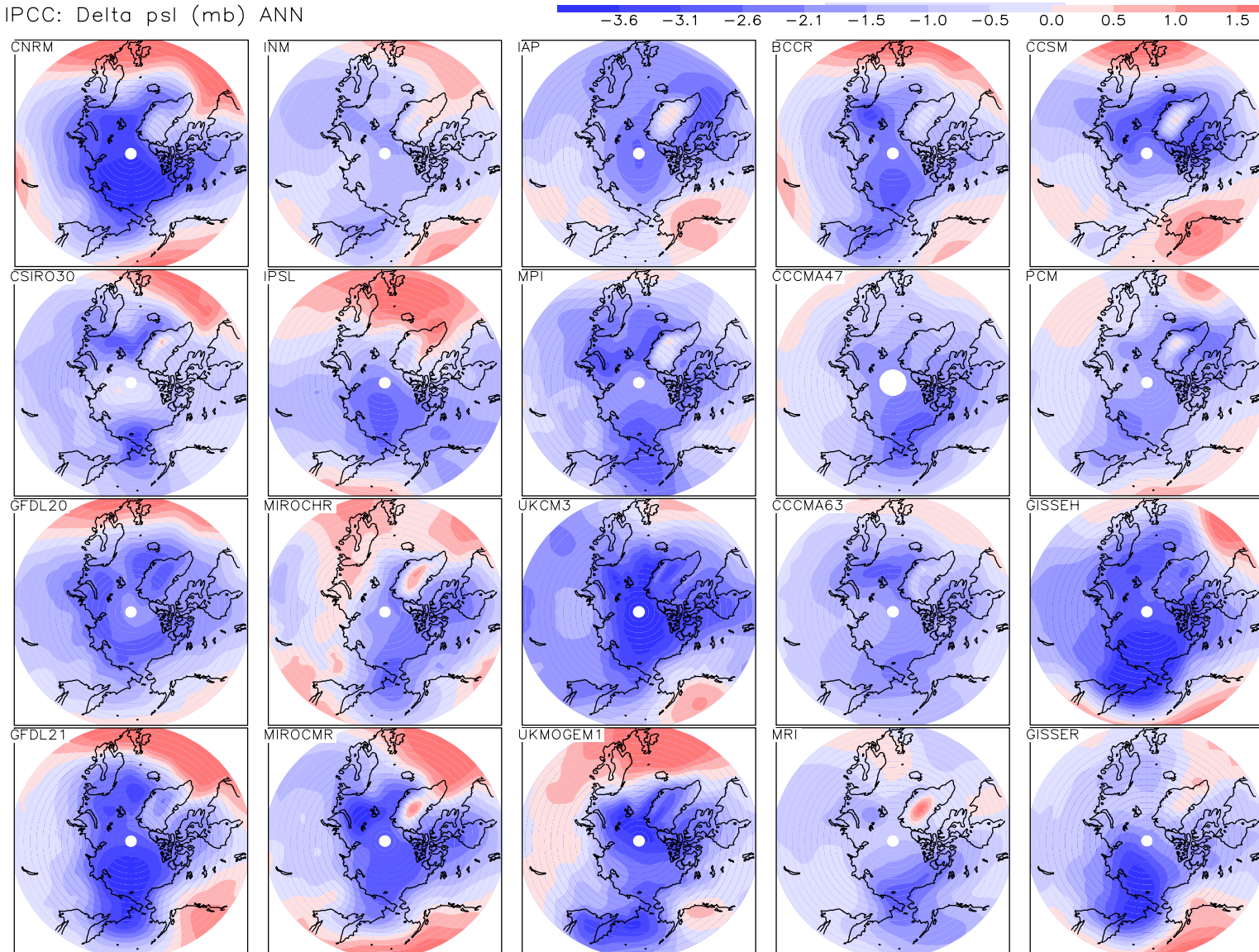
# Trends in Extreme Minimum SLP (CCSM4)

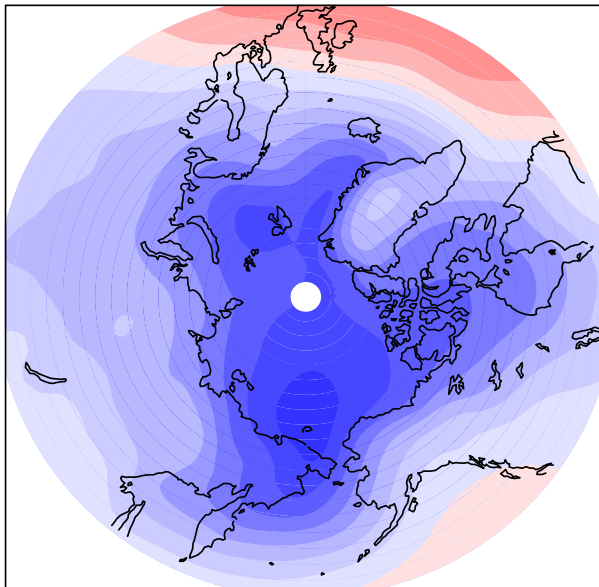


# CMIP3 Trend in Mean Annual SLP (hPa)

## Late 21<sup>st</sup> century – Late 20<sup>th</sup> century (A1B)

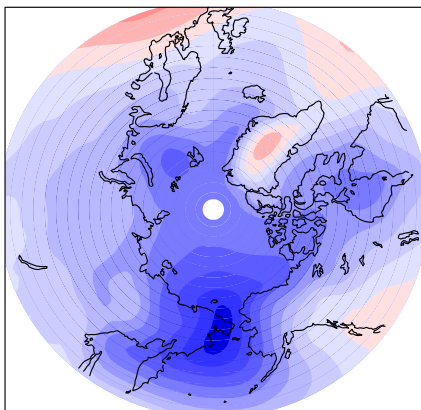
IPCC: Delta psl (mb) ANN





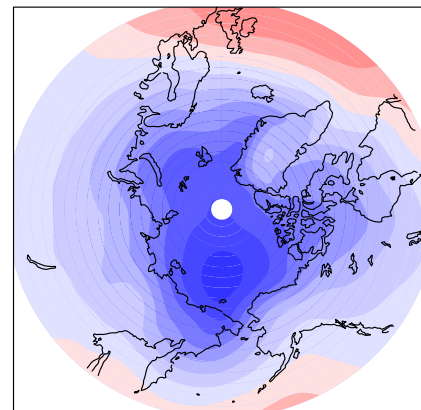
ANNUAL

DJF, 20 Model Mean -4.7 -4.1 -3.5 -2.9 -2.4 -1.8 -1.2 -0.6 0.0 0.6 1.2



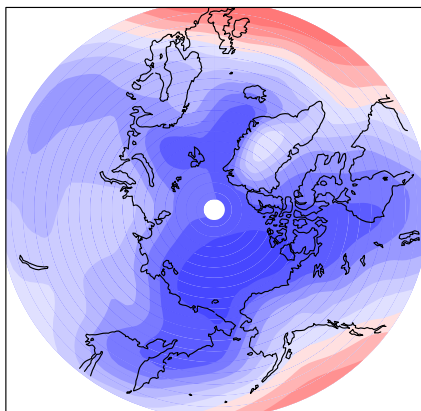
WINTER

SON, 20 Model Mean -4.2 -3.6 -3.0 -2.4 -1.8 -1.2 -0.6 0.0 0.6 1.2 1.8



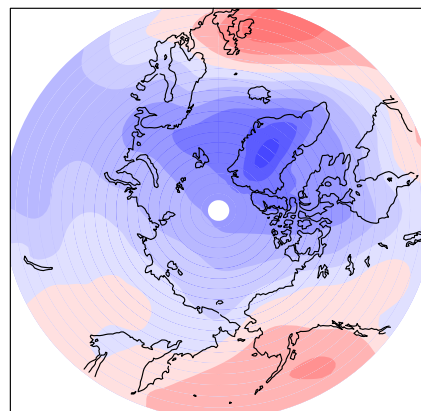
AUTUMN

MAM, 20 Model Mean -2.13 -1.82 -1.52 -1.22 -0.91 -0.61 -0.30 0.00 0.30 0.61 0.91



SPRING

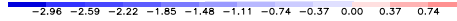
JJA, 20 Model Mean -2.18 -1.81 -1.45 -1.09 -0.73 -0.36 0.00 0.36 0.73 1.09 1.45



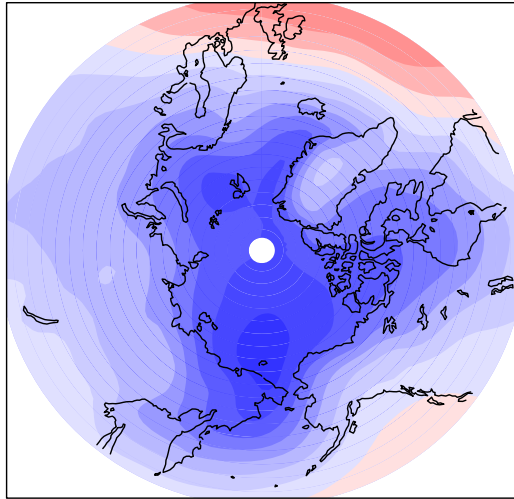
SUMMER

# CMIP3 20-Model Average Change (A1B) Late 21<sup>st</sup> Century – Late 20<sup>th</sup> Century

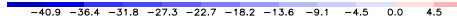
IPCC: Delta psl (mb) ANN, 20 Model Mean



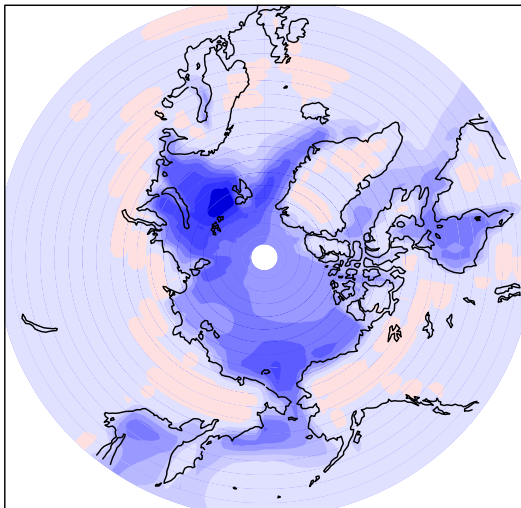
Annual SLP (hPa)



IPCC: Delta sic (%) ANN, 20 Model Mean



Annual sea ice cover (%)



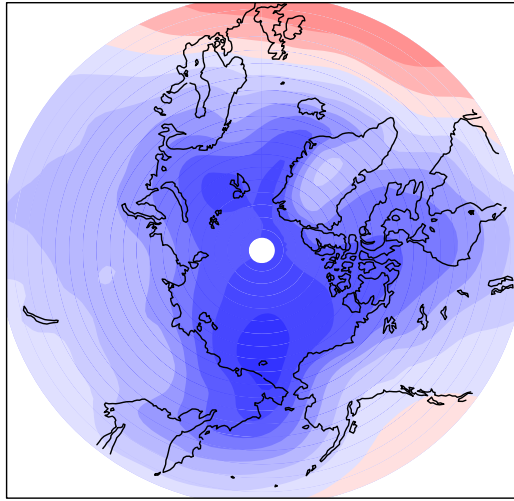


# CMIP3 20-Model Average Change (A1B) Late 21<sup>st</sup> Century – Late 20<sup>th</sup> Century

IPCC: Delta psl (mb) ANN, 20 Model Mean

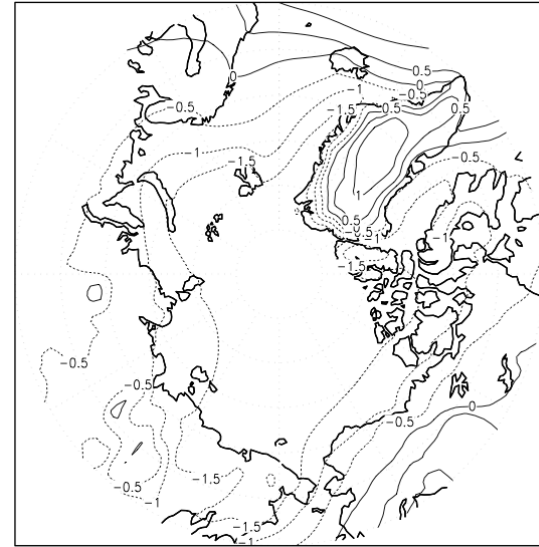
-2.96 -2.59 -2.22 -1.85 -1.48 -1.11 -0.74 -0.37 0.00 0.37 0.74

Annual SLP (hPa)



# CCSM4 Trend (RCP8.5) 2005– 2100

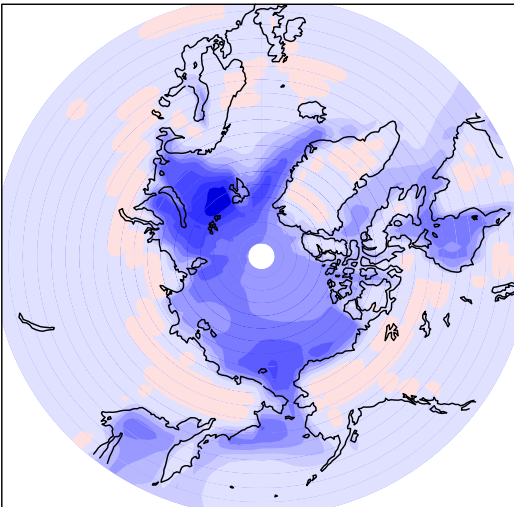
Annual SLP (hPa)



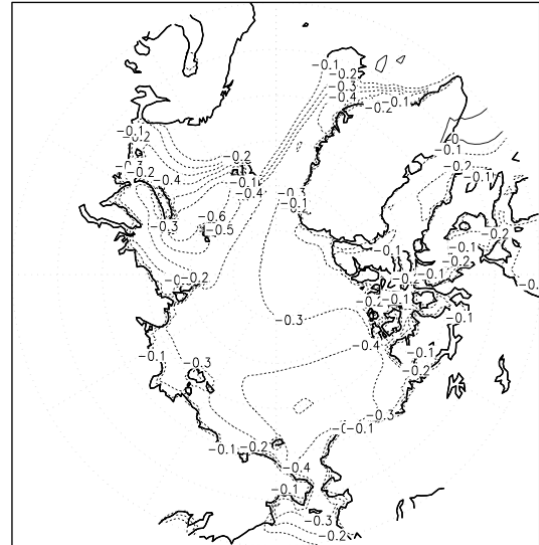
IPCC: Delta sic (%) ANN, 20 Model Mean

-40.9 -36.4 -31.8 -27.3 -22.7 -18.2 -13.6 -9.1 -4.5 0.0 4.5

Annual sea ice cover (%)



Annual sea ice fraction



**What are the spatial and seasonal characteristics of extreme Arctic cyclones?**

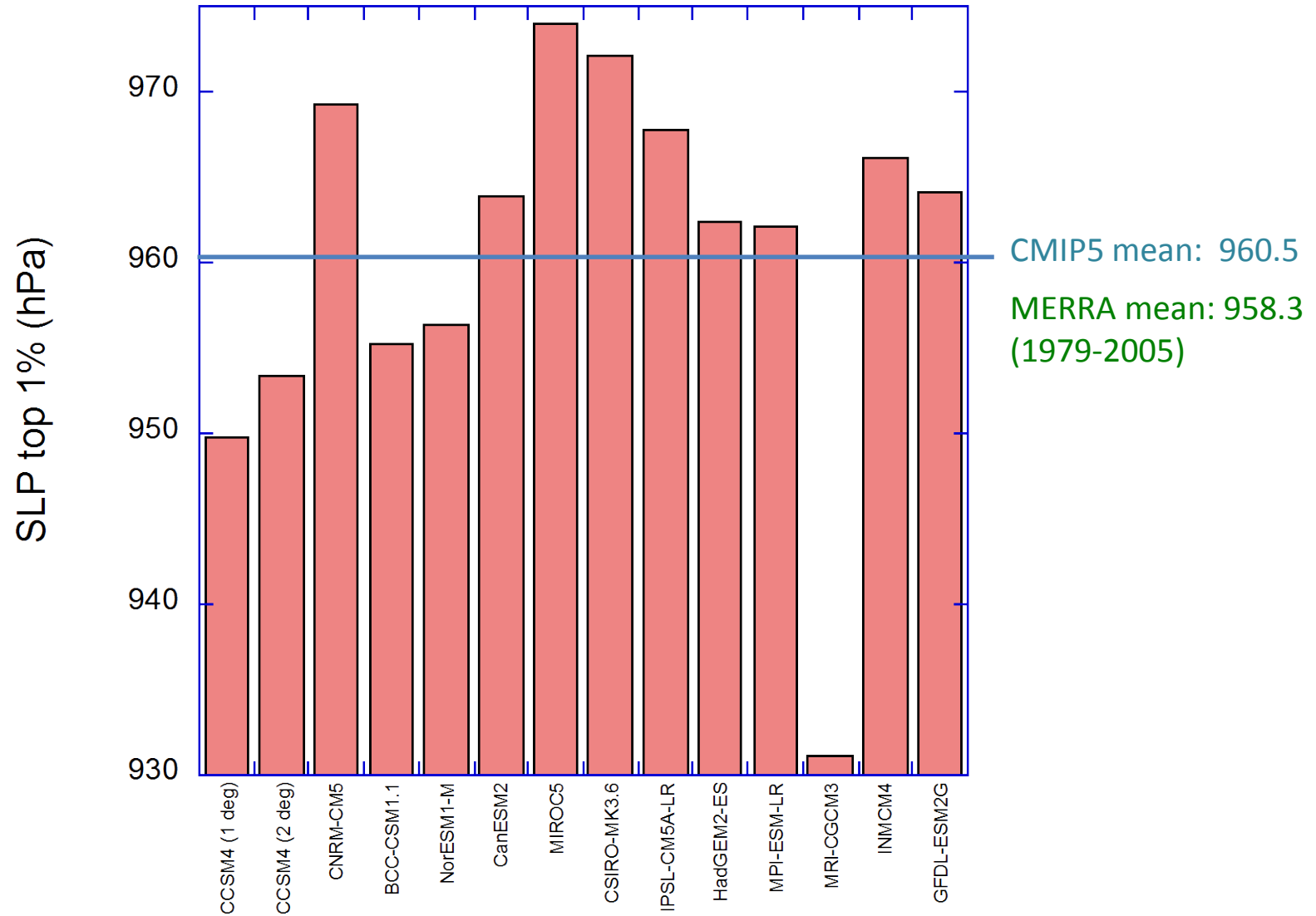
**How well do GCMs simulate them?**

**Are Arctic cyclones already showing the expected response in climate models?**

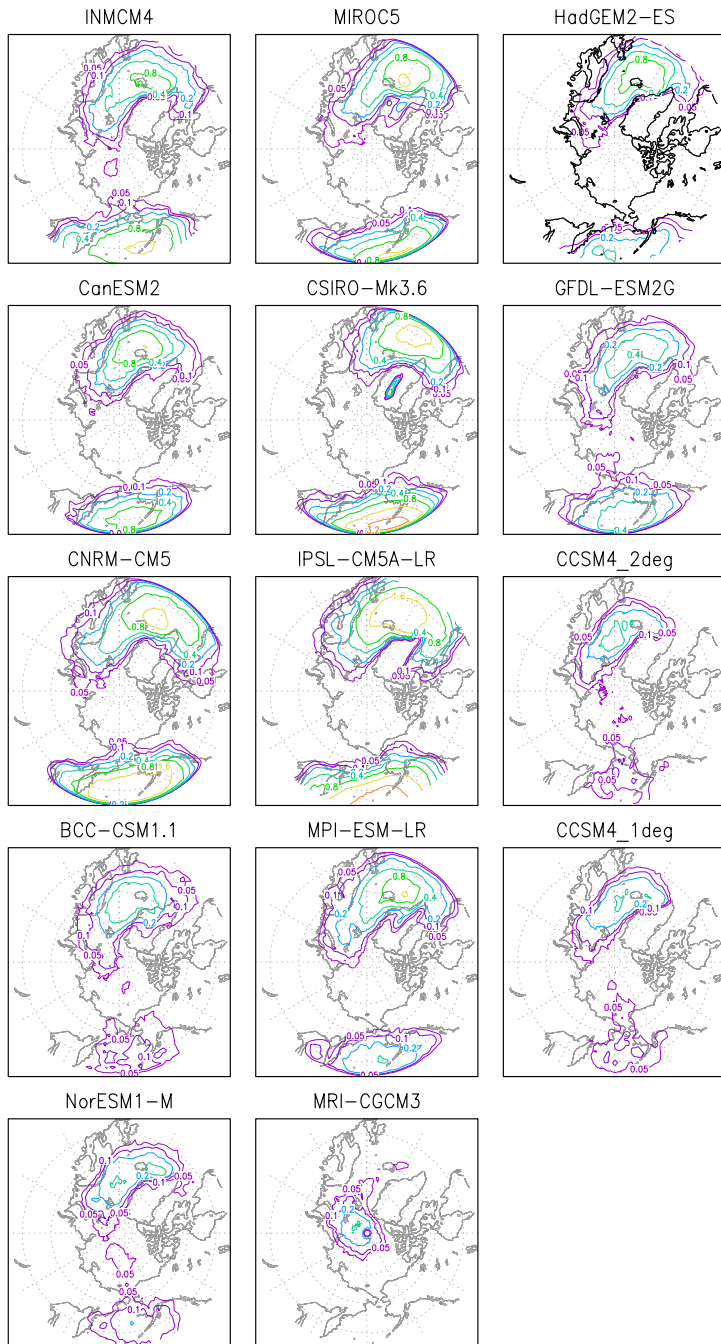
CMIP5 Historical Simulations (1850-2005):

- 14 GCMs (1 ensemble member)
- “Extreme cyclones”: lowest 1% of daily SLP *in each model* poleward of 70°N
- Comparison with MERRA Reanalysis (1979-2005)

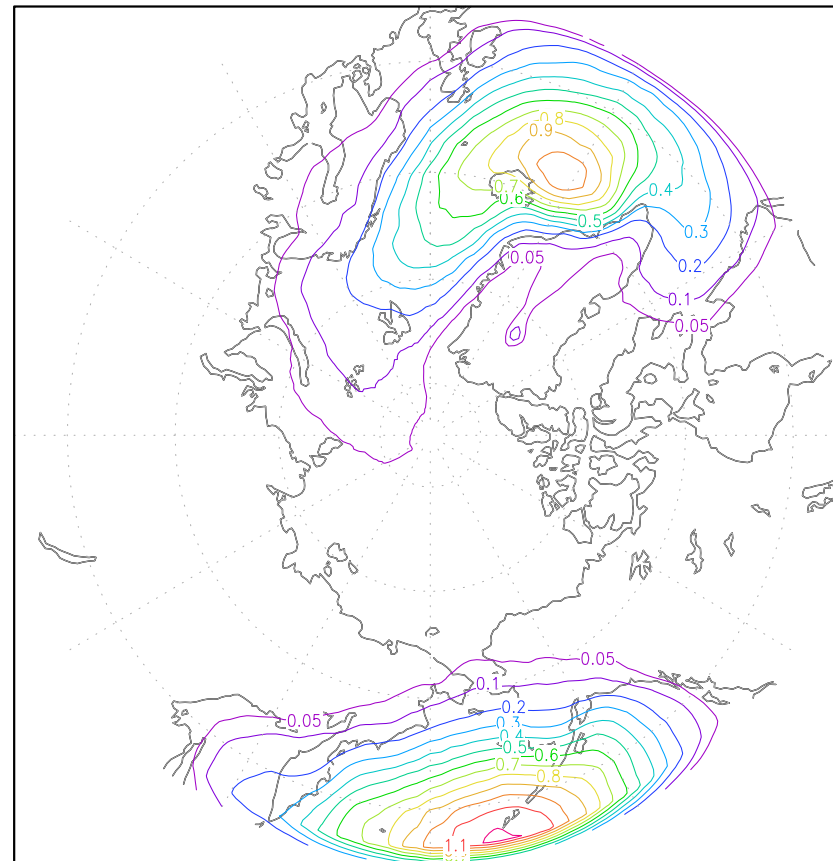
# Intensity of Strongest 1% of Arctic Cyclones (1850-2005)



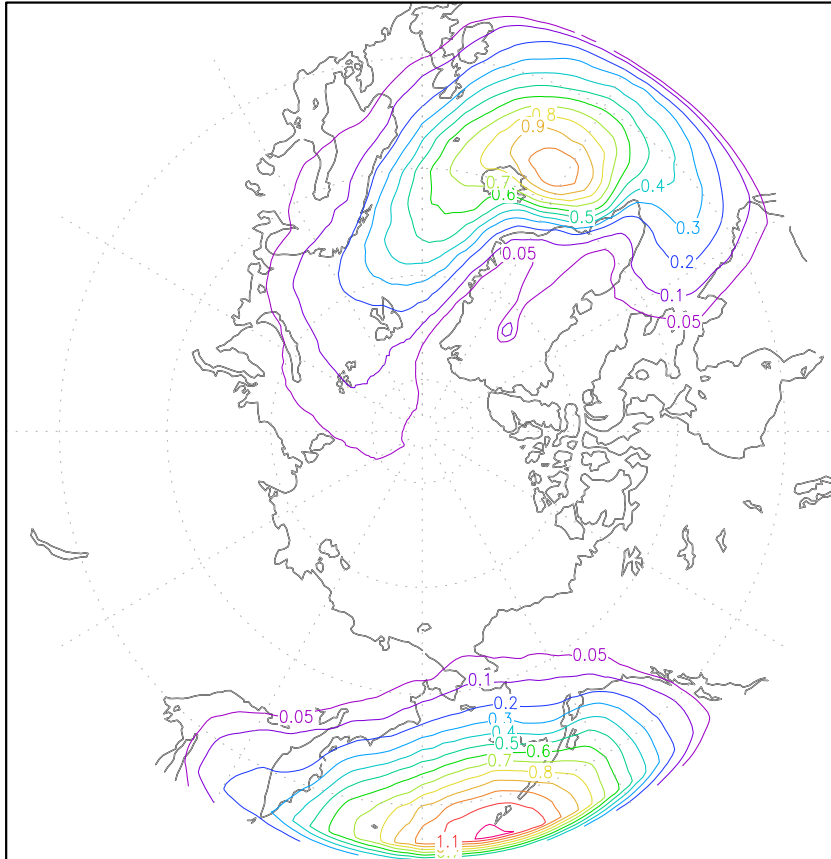
# CMIP5 Extreme Arctic Cyclone Climatology



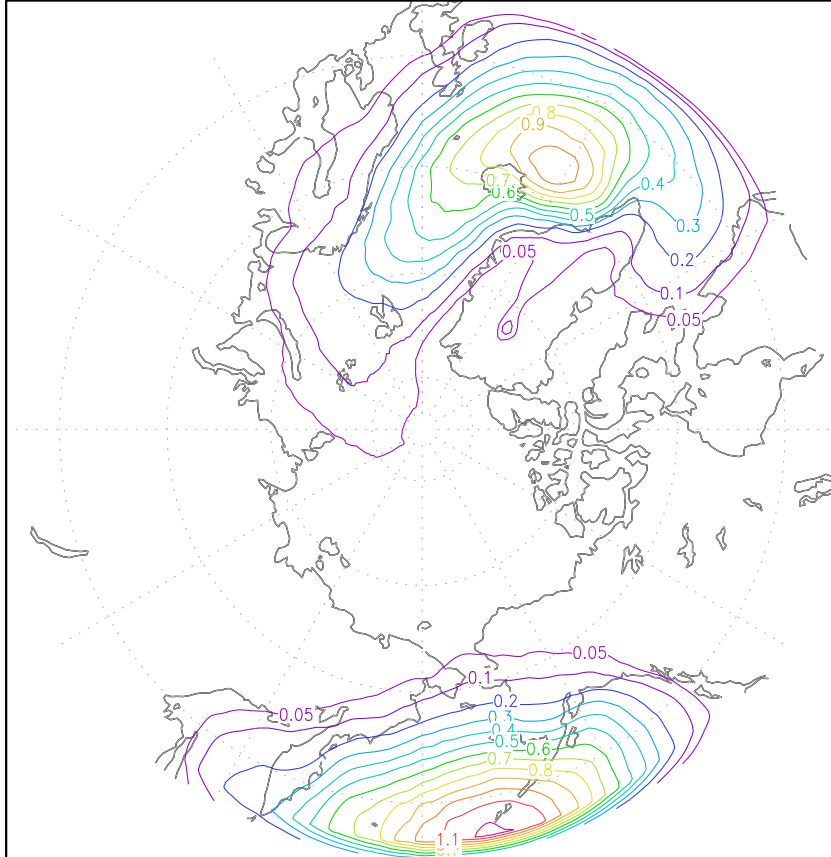
Model Average Extreme Cyclone Frequency  
Annual Means 1850–2005



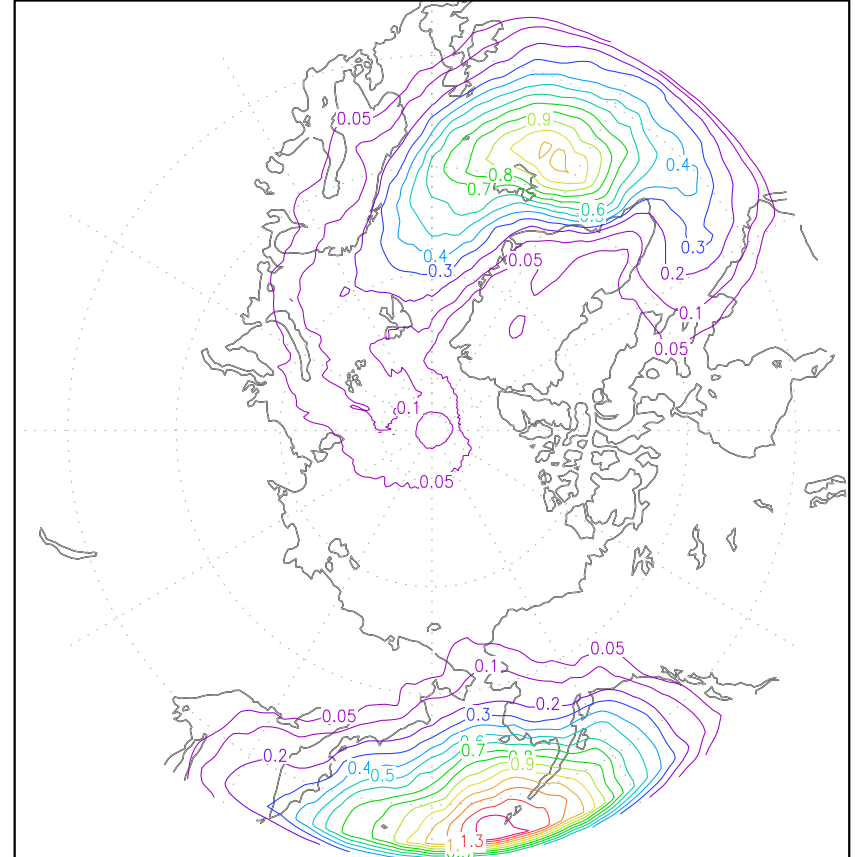
# Model Average Extreme Cyclone Frequency Annual Means 1850–2005



Model Average Extreme Cyclone Frequency  
Annual Means 1850–2005

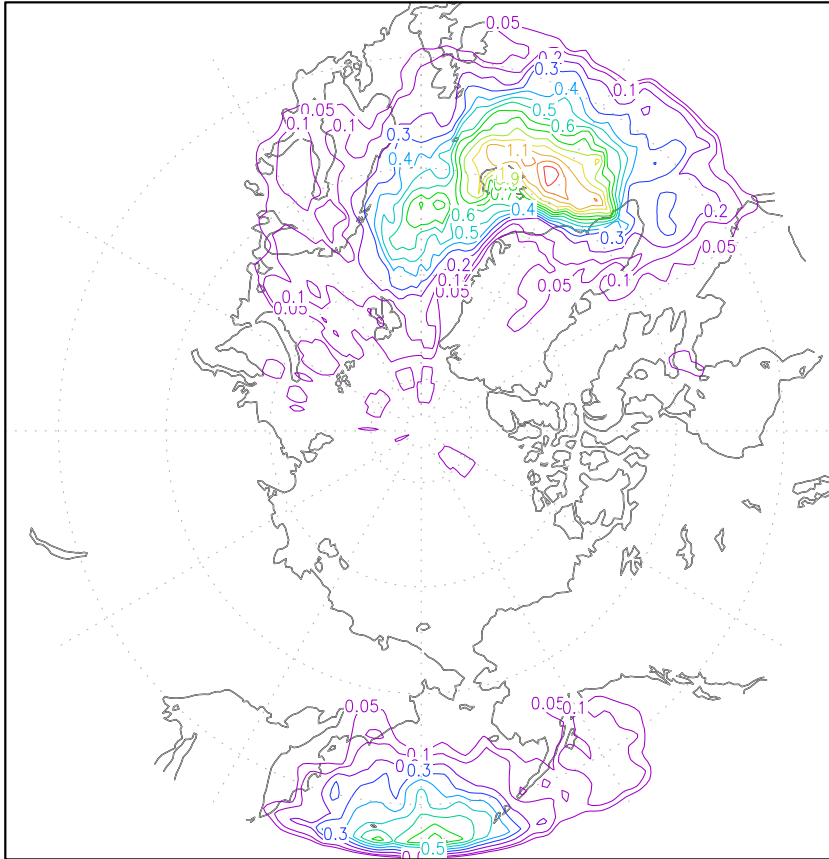


Model Average Extreme Cyclone Frequency  
Annual Means 1979–2005

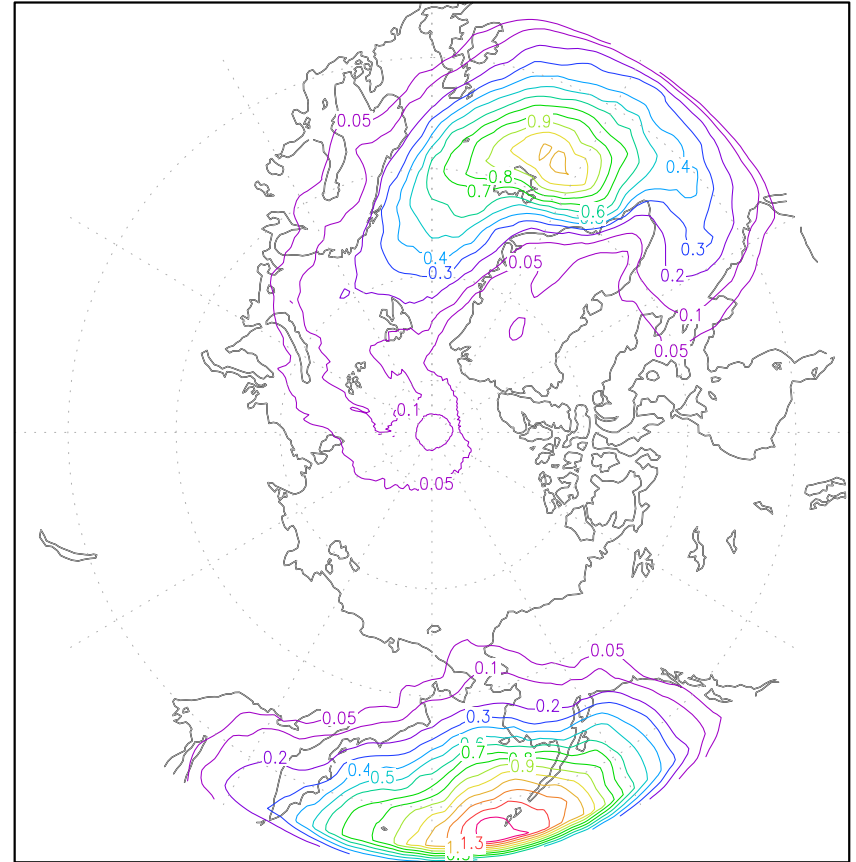


# MERRA Reanalysis

MERRA Average Extreme Cyclone Frequency  
Annual Means 1979–2005 (interpolated)

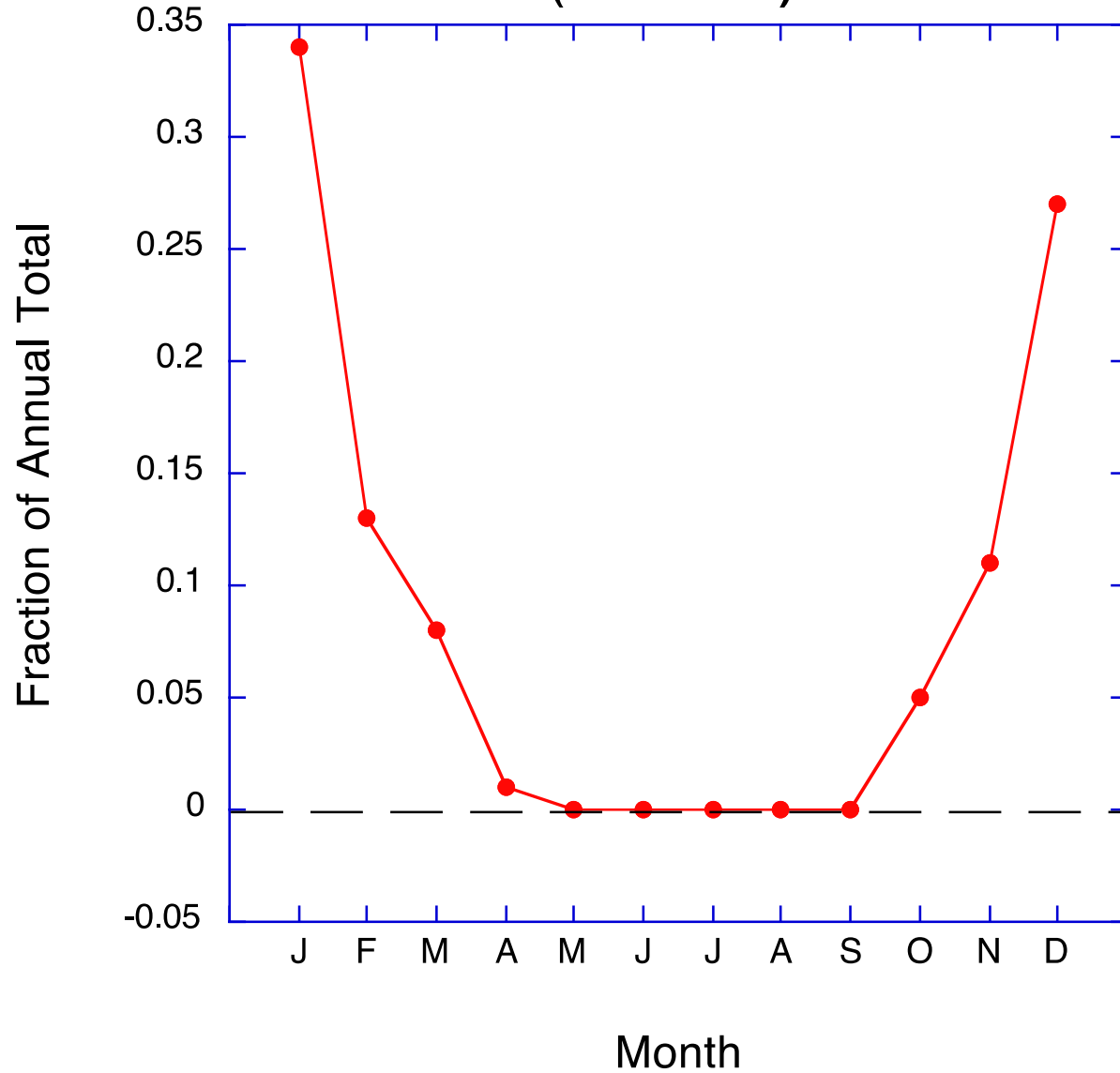


Model Average Extreme Cyclone Frequency  
Annual Means 1979–2005



MERRA

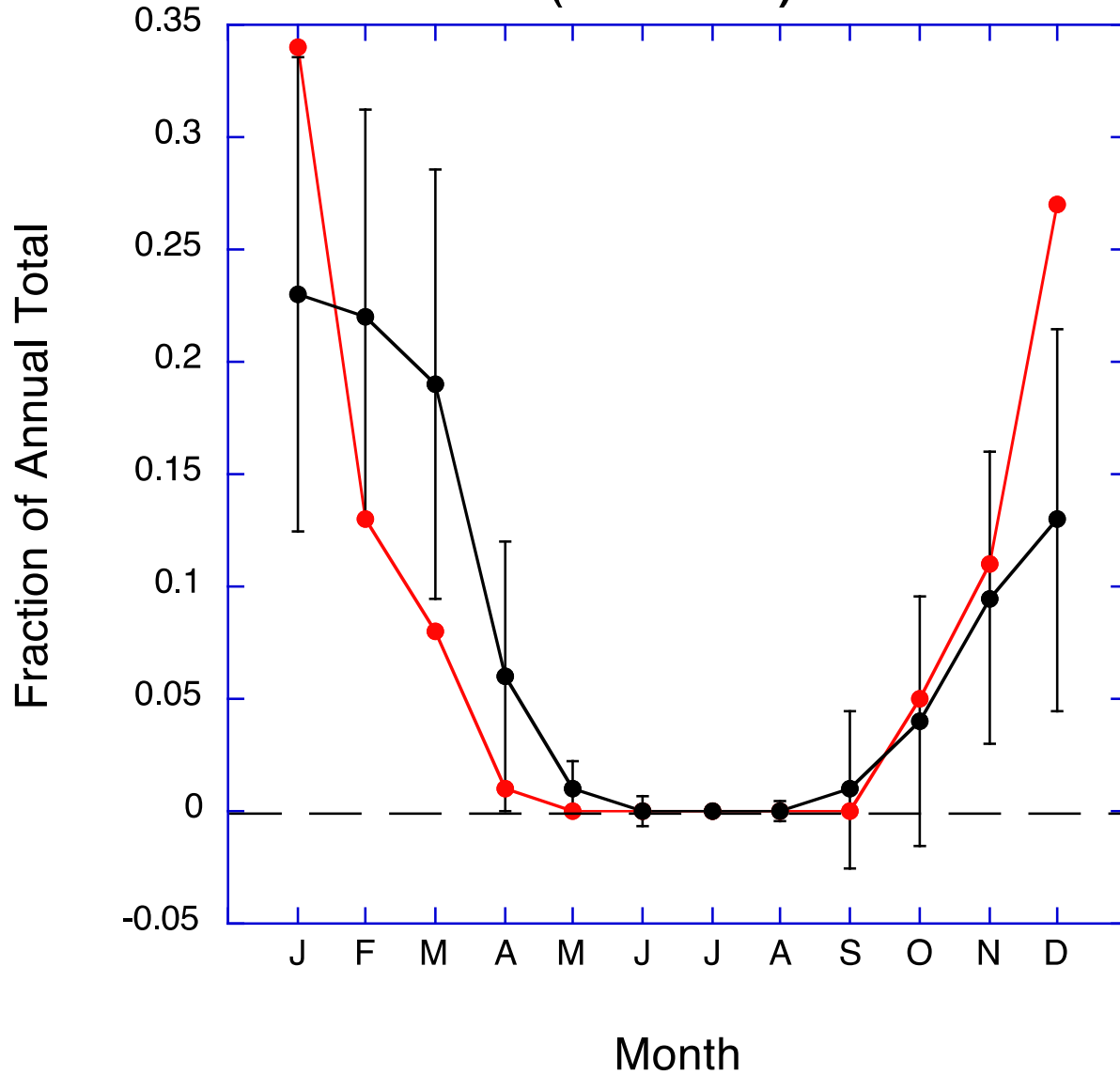
### Annual Cycle of Extreme Arctic Cyclones (1979-2005)





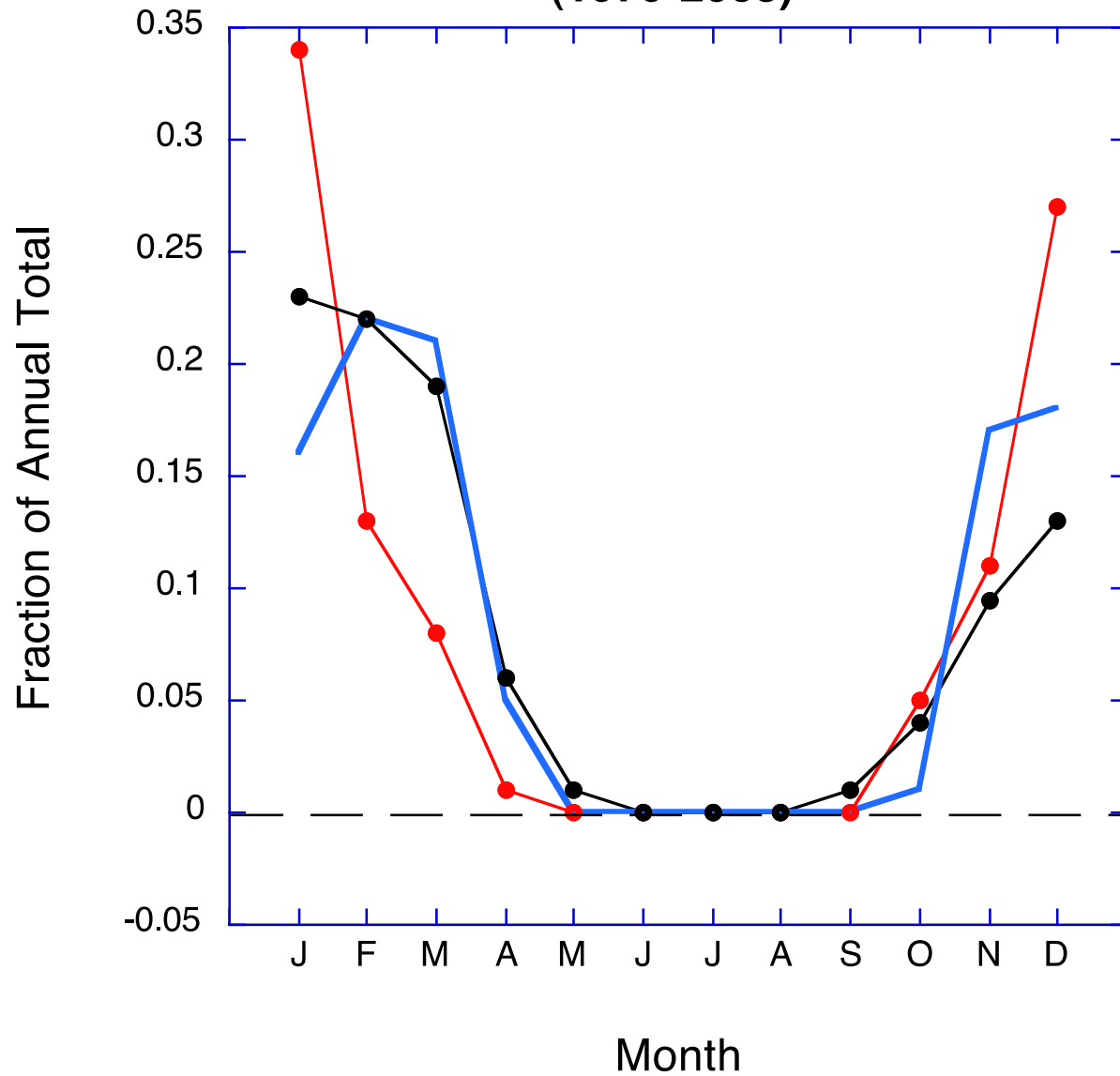


### Annual Cycle of Extreme Arctic Cyclones (1979-2005)

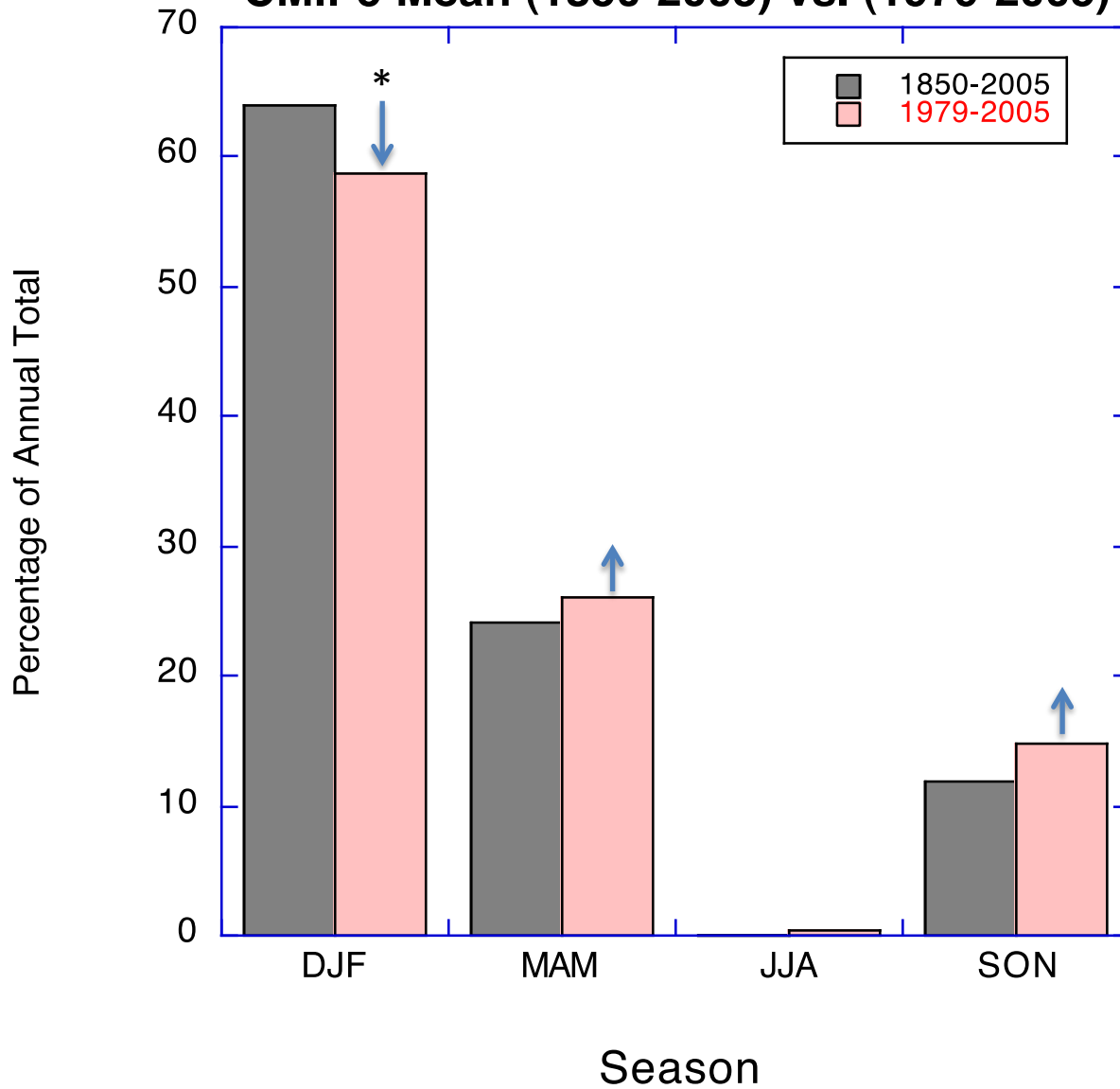




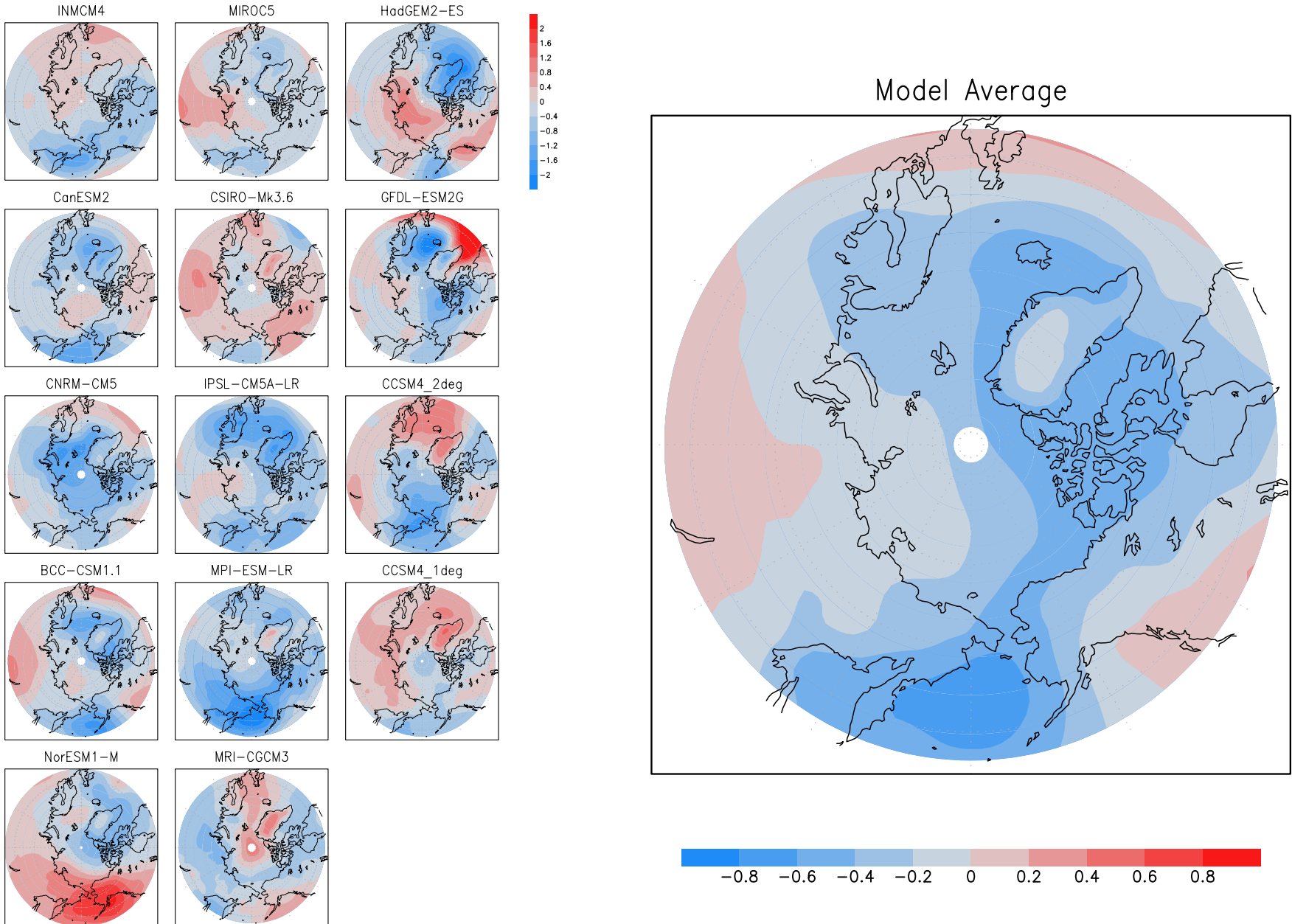
**Annual Cycle of Extreme Arctic Cyclones (1979-2005)**



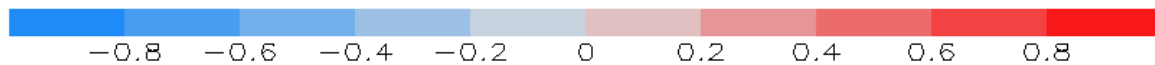
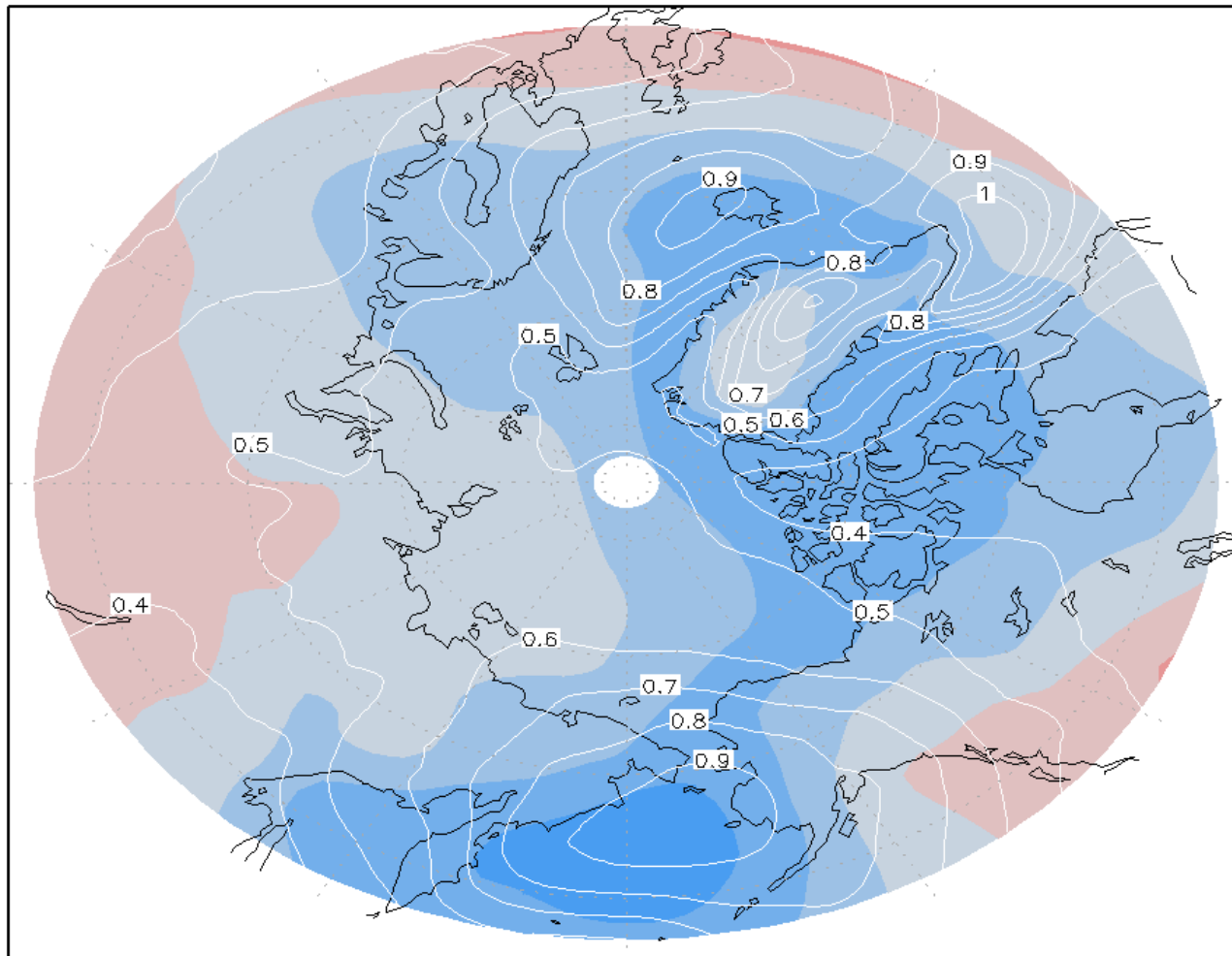
# Distribution of Extreme Arctic Cyclones CMIP5 Mean (1850-2005) vs. (1979-2005)



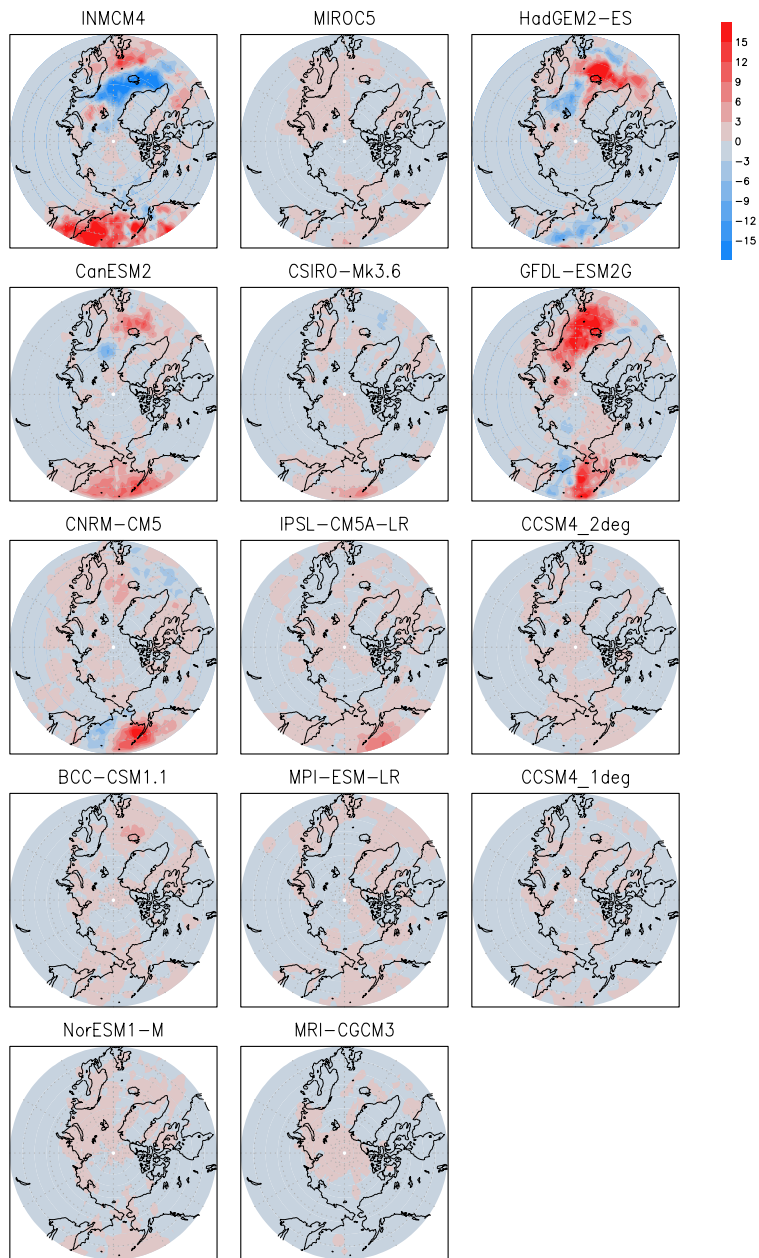
# CMIP5 Trend in Mean Annual SLP (hPa) from 1850 to 2005



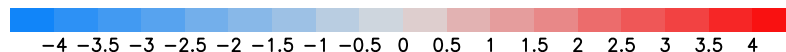
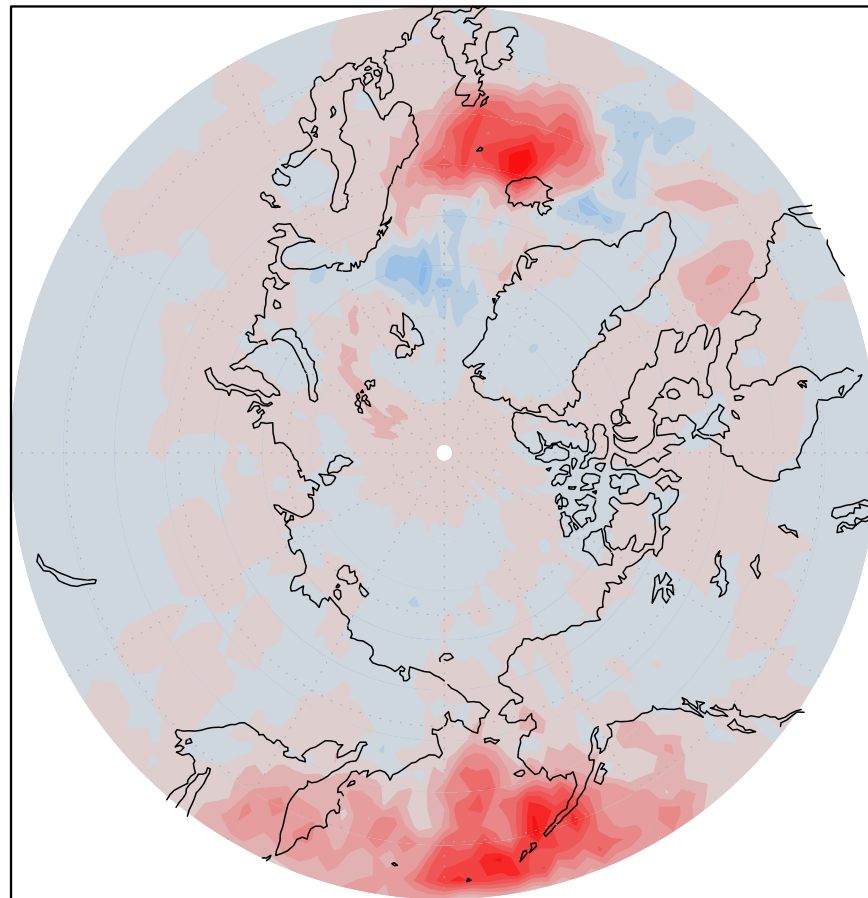
# Model Average, Intermodel Standard Deviation



# CMIP5 Trends in Extreme Arctic Cyclones (strongest 1%) 1850-2005



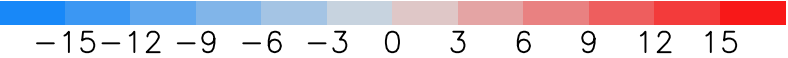
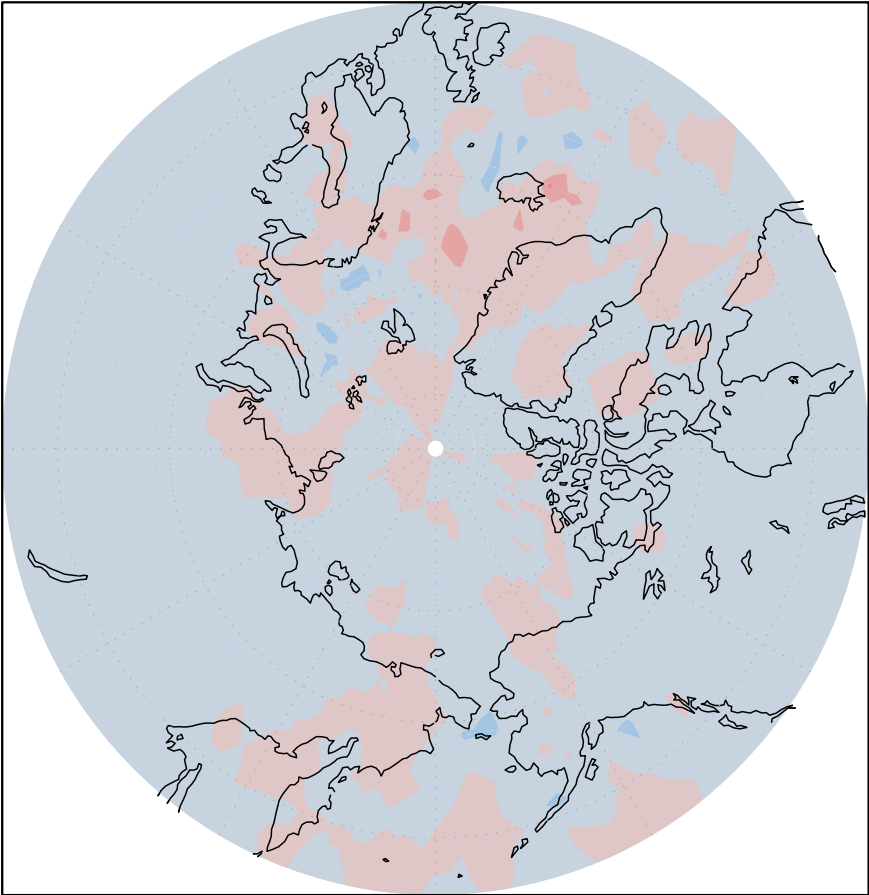
Model Average Trend in Extreme Cyclone Frequency ( $\times 10^4$ ) 1850-2005



# Trends in CCSM4 Extreme Arctic Cyclone Frequency (< 950 hPa)

PAST

CCSM4 Trend in Extreme Cyclone Frequency per century (x10E4) 1850-2005



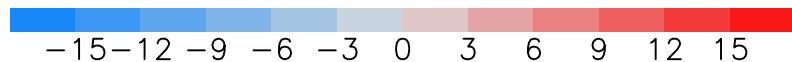
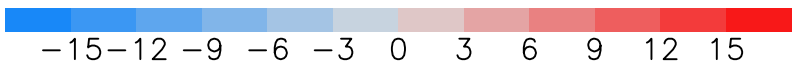
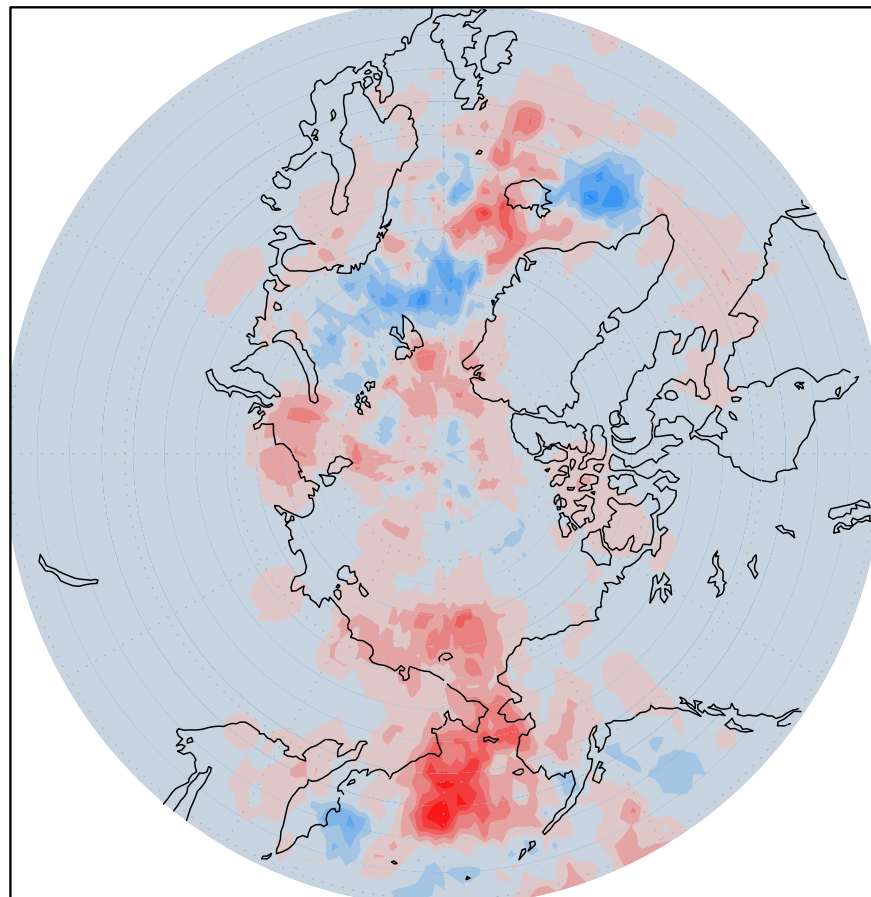
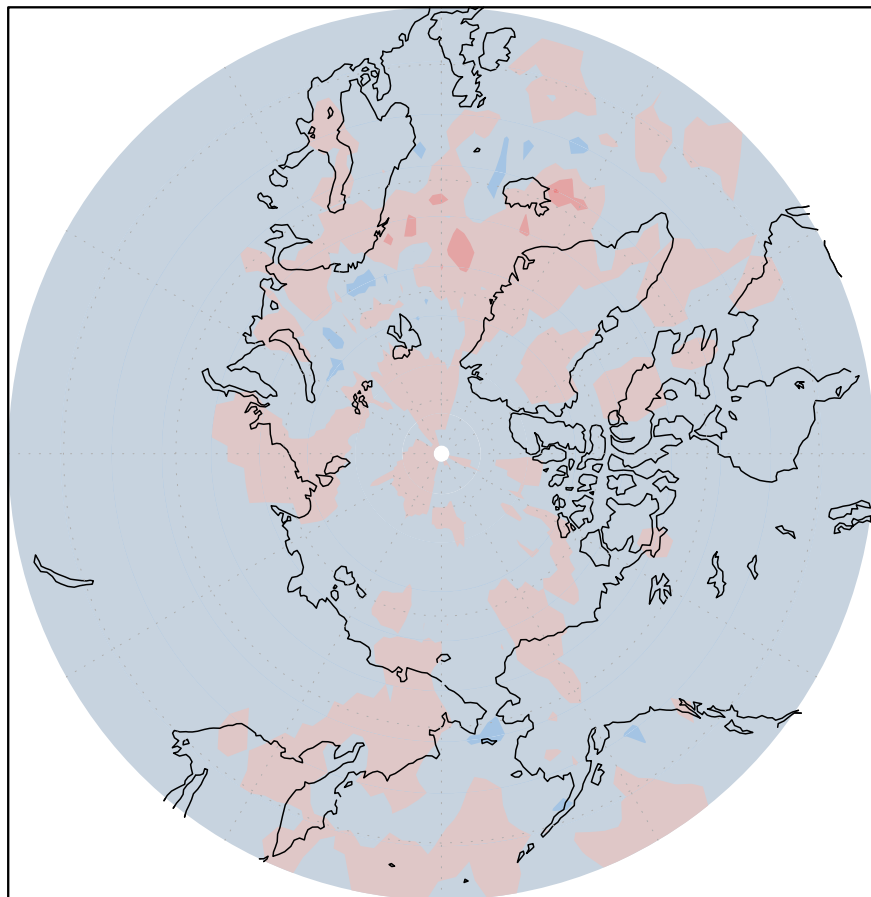
# Trends in CCSM4 Extreme Arctic Cyclone Frequency (< 950 hPa)

**PAST**

**FUTURE**

CCSM4 Trend in Extreme Cyclone Frequency per century (x10E4) 1850–2005

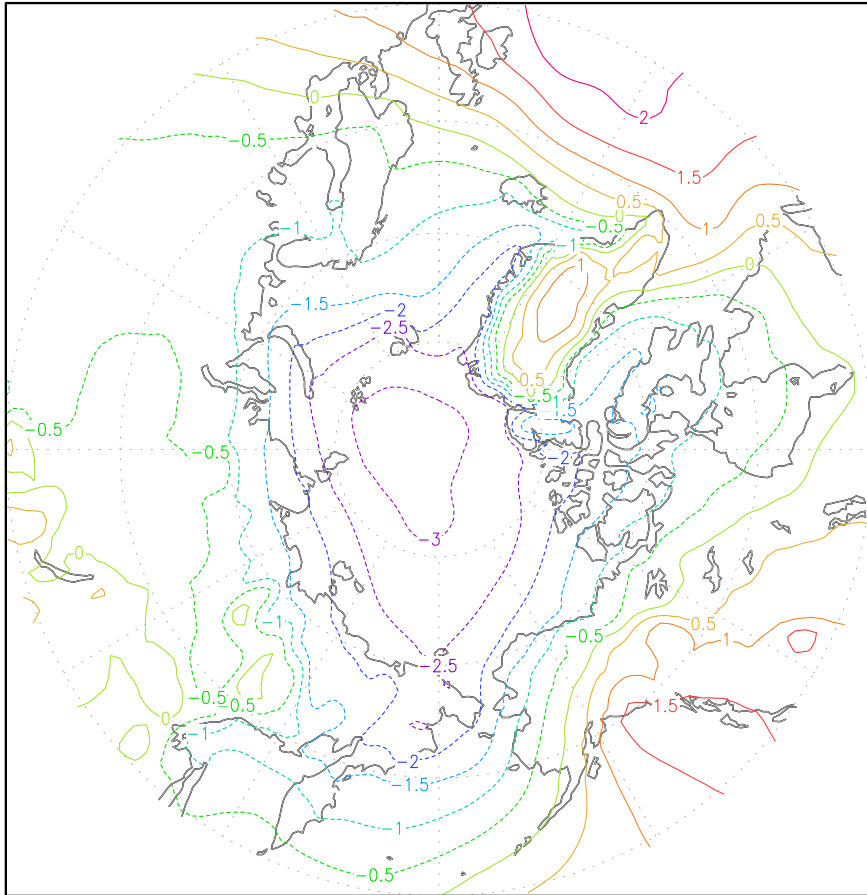
CCSM4 Trend in Extreme Cyclone Frequency per century (x10E4) 2005–2100 RCP8.5





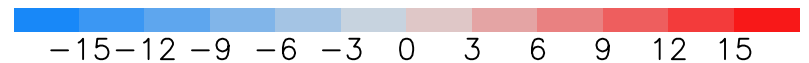
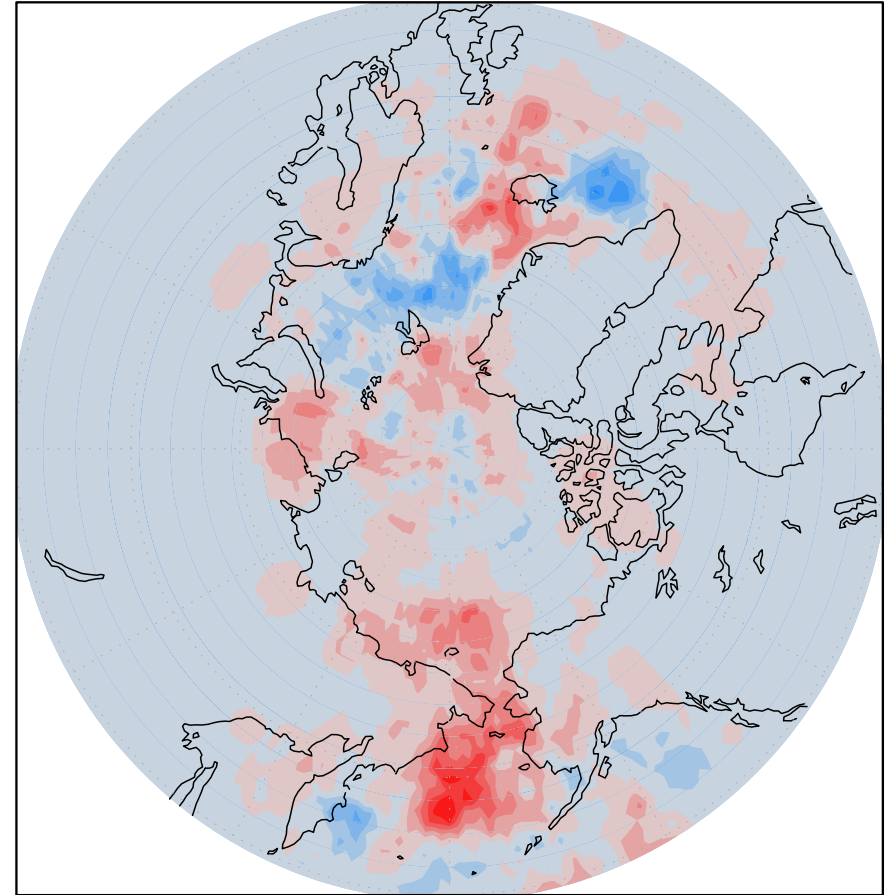
# FUTURE

CCSM4 Trend in Mean Annual SLP  
(ensemble member #1) 2005–2100 RCP8.5



# FUTURE

CCSM4 Trend in Extreme Cyclone Frequency  
per century (x10E4) 2005–2100 RCP8.5



# Conclusions

- GCMs are able to simulate extremely strong Arctic cyclones
- These storms are primarily a wintertime phenomenon
- Favored locations are within the climatological Aleutian and Icelandic Low regions
- Greenhouse warming is likely to cause lower Arctic SLP and more extreme cyclones, especially in the Arctic Ocean
- Equivocal signal of trends in mean and extreme Arctic cyclones since 1850 in models
- Recent pronounced retreat of Arctic sea ice since 2007 may initiate a stormier regime

*... find out at my updated presentation at the 55<sup>th</sup> CESM Workshop in June 2050*