ACTIVATE
Aerosol Cloud Meteorology Interactions Over the Western Atlantic Experiment

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

# BNL Update: 2003–2020 long term trends of aerosols, low clouds, and meteorology

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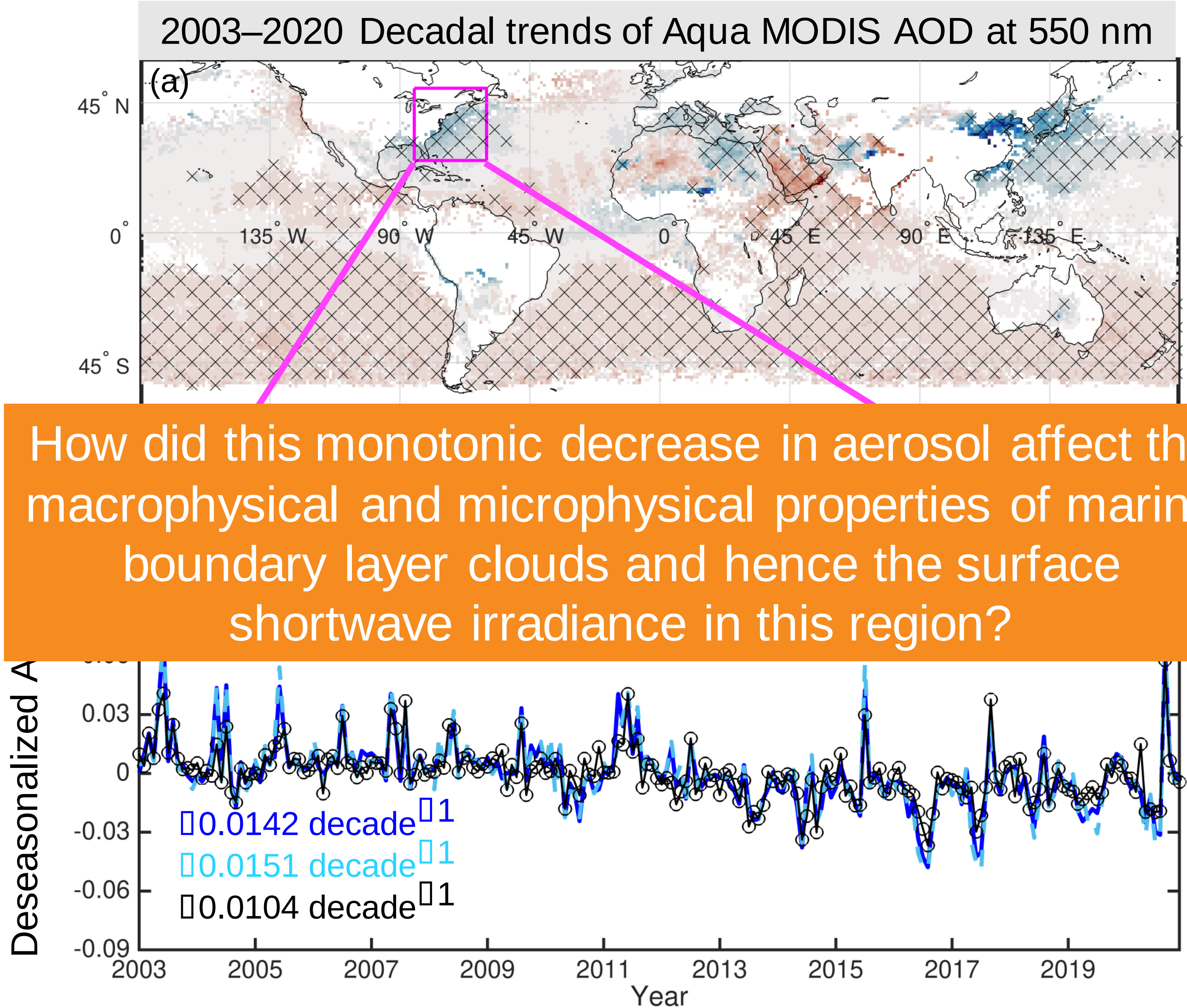
November 7, 2022

# A continuous & robust decrease in aerosol optical depth




How did this monotonic decrease in aerosol affect the macrophysical and microphysical properties of marine boundary layer clouds and hence the surface shortwave irradiance in this region?

# Approach

## Approach

- Decadal trend analysis of 18-year (2003–2020) monthly data
- Mann-Kendall test for statistically significant trends

## Dataset and variables

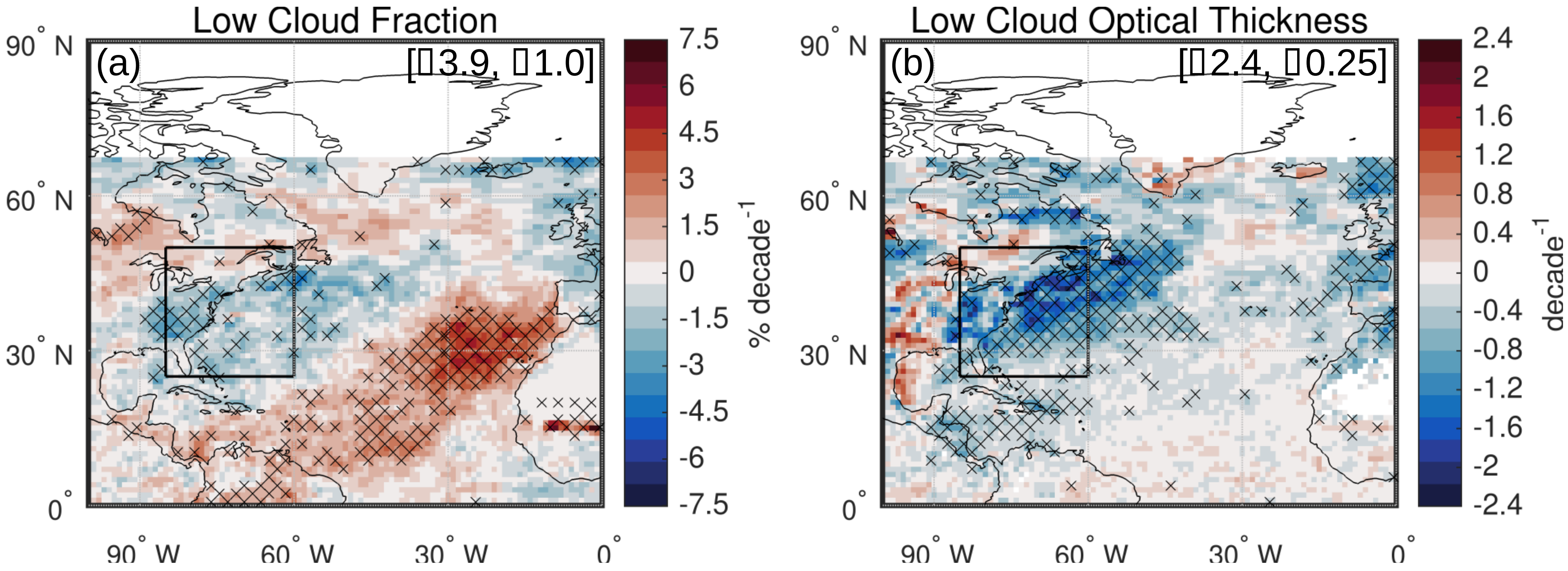
### Aerosol, clouds, and radiation

- CERES EBAF Ed4.1 surface shortwave radiation flux
- Aqua MODIS aerosol optical depth at 550 nm
- CERES MODIS SSF Level 3 low cloud (heights below 700 hPa) properties

### Meteorology

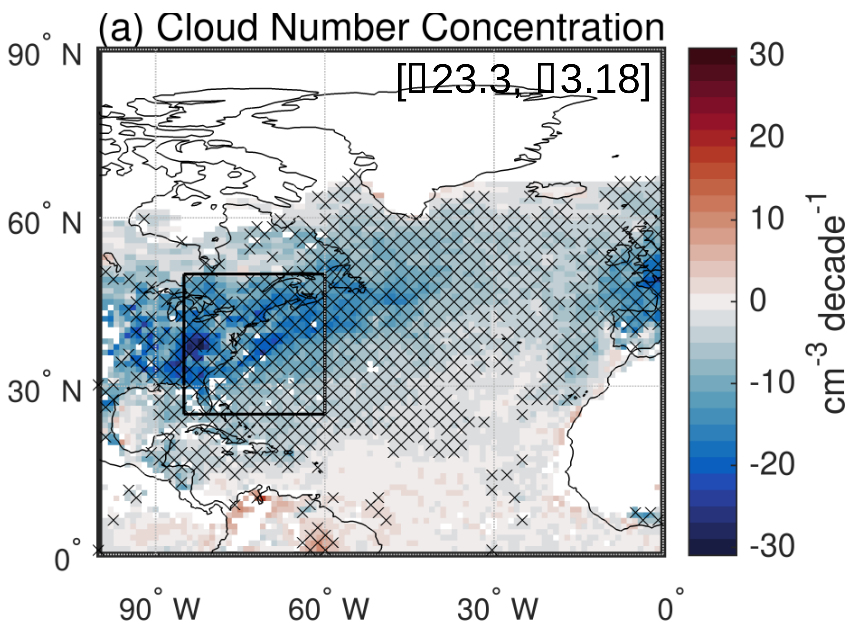
- OISST v2 sea surface temperature
- RSS total precipitable water
- ERA-5 mean sea level pressure, 500-hPa geopotential height, and 10-m wind
- NOAA CPC North Atlantic Oscillation index

# Changes in low cloud macrophysical properties

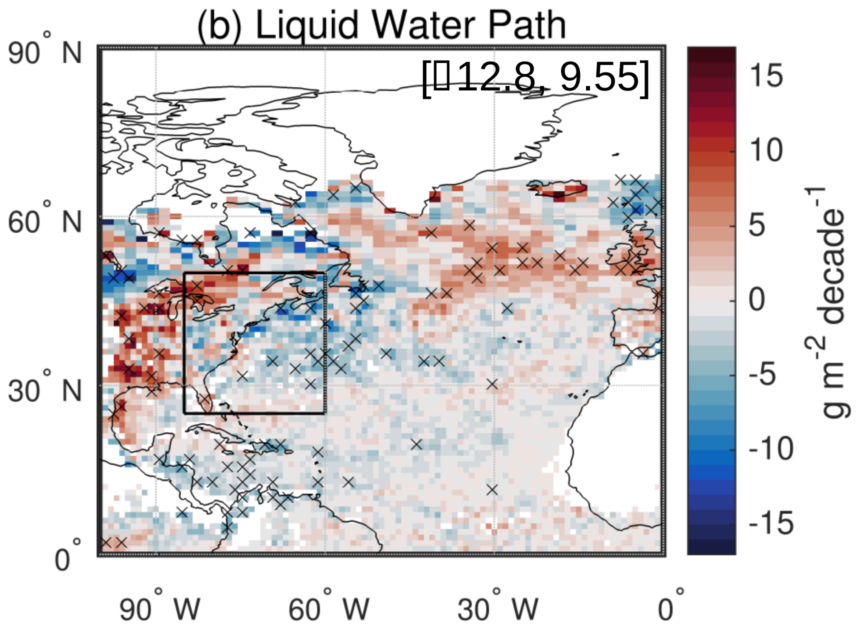


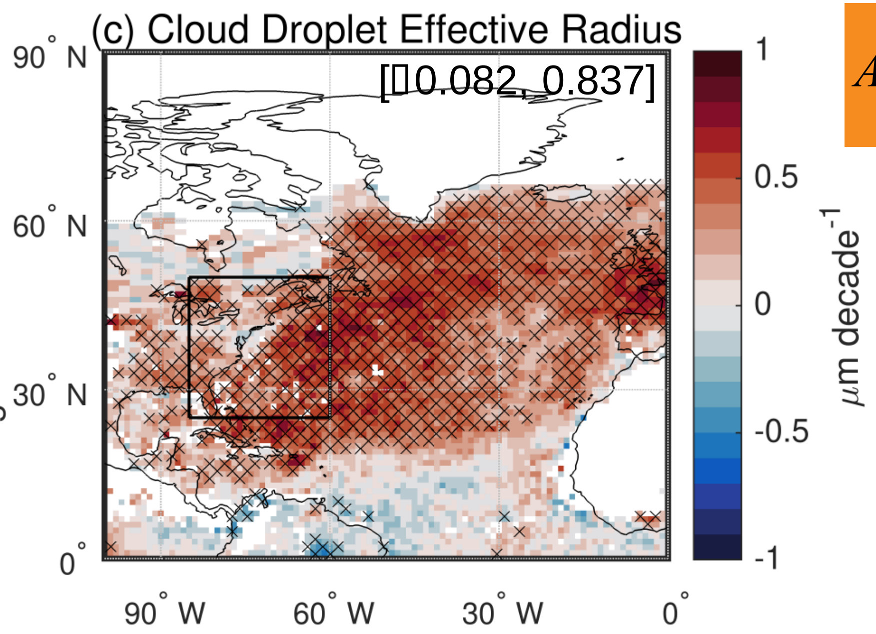

Cloud fraction and optical thickness are primary drivers of the cloud radiative effect

# Changes in low cloud microphysical properties



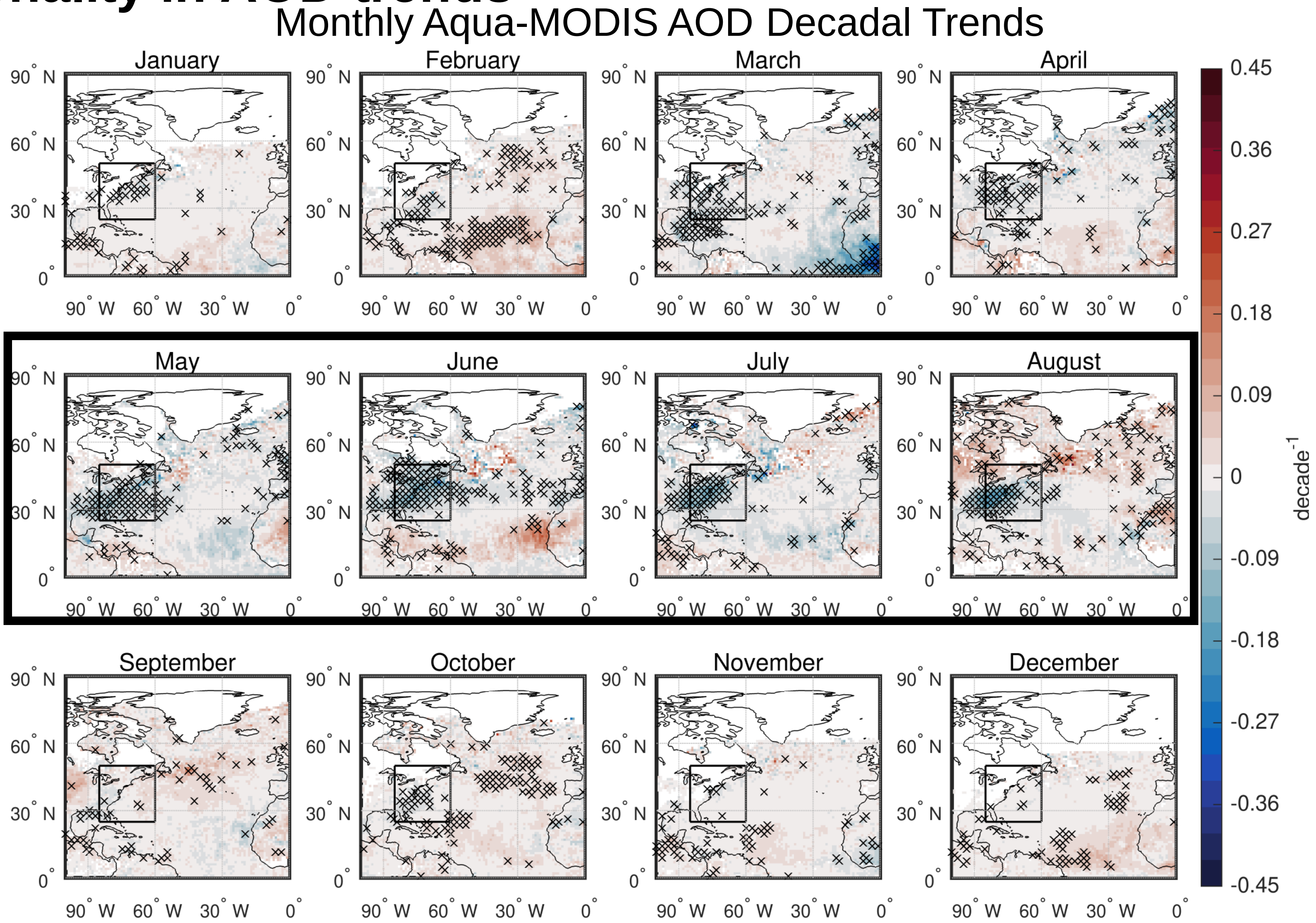

- Pervasive trends in droplet effective radius and number concentration with limited changes in liquid water path
- Significant changes in cloud microphysics:
  - *absent* from May–August when the magnitude of decreasing trends in aerosol optical depth is greatest
  - *present* from October–March when limited significant trends in aerosol optical depth is observed



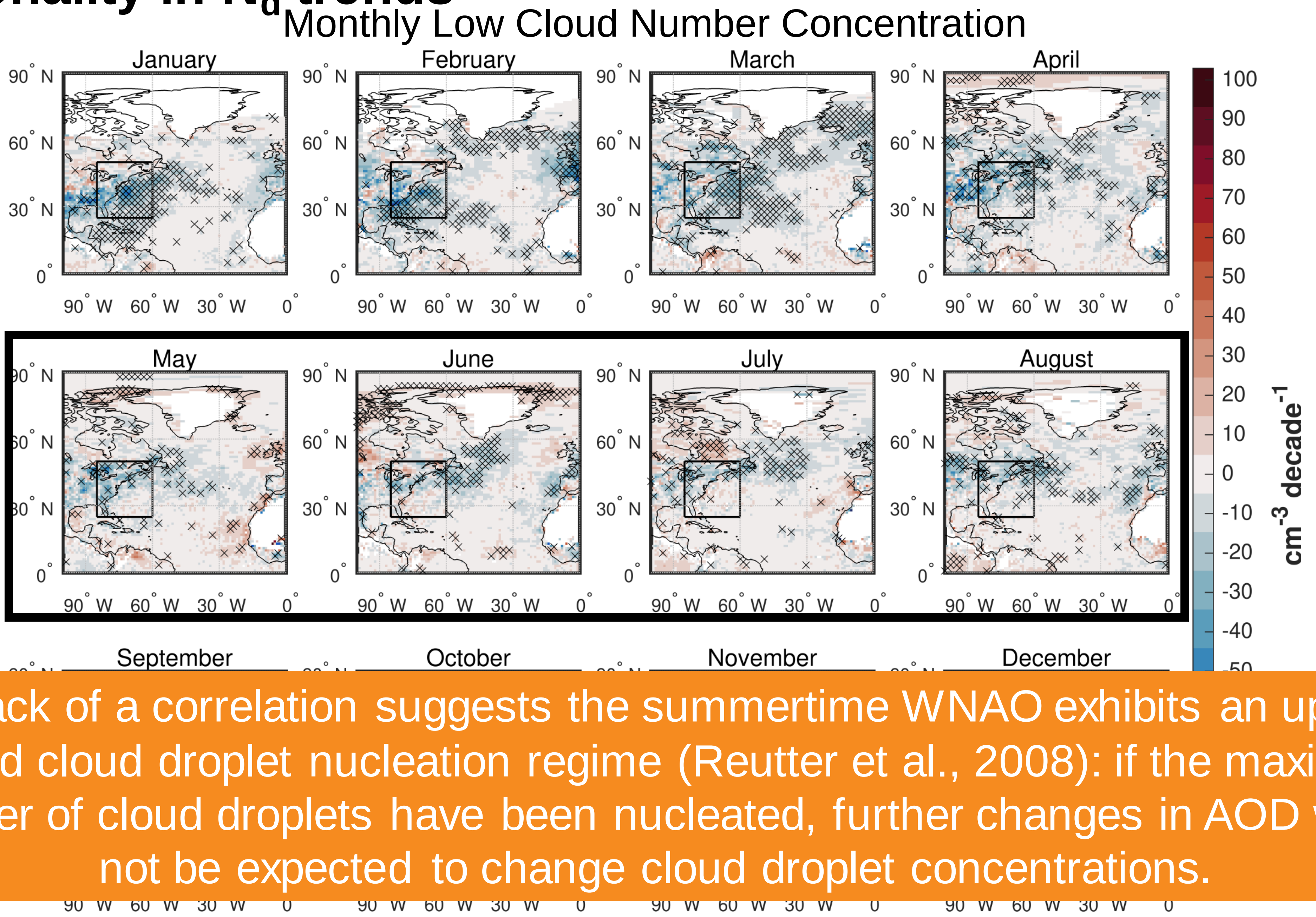




$$ACI = \left.\frac{\partial \ln \tau_c}{\partial \ln \alpha}\right|_L = -\left.\frac{\partial \ln r_e}{\partial \ln \alpha}\right|_L = \frac{1}{3}\frac{d \ln N_d}{d \ln \alpha}$$

# Seasonality in AOD trends

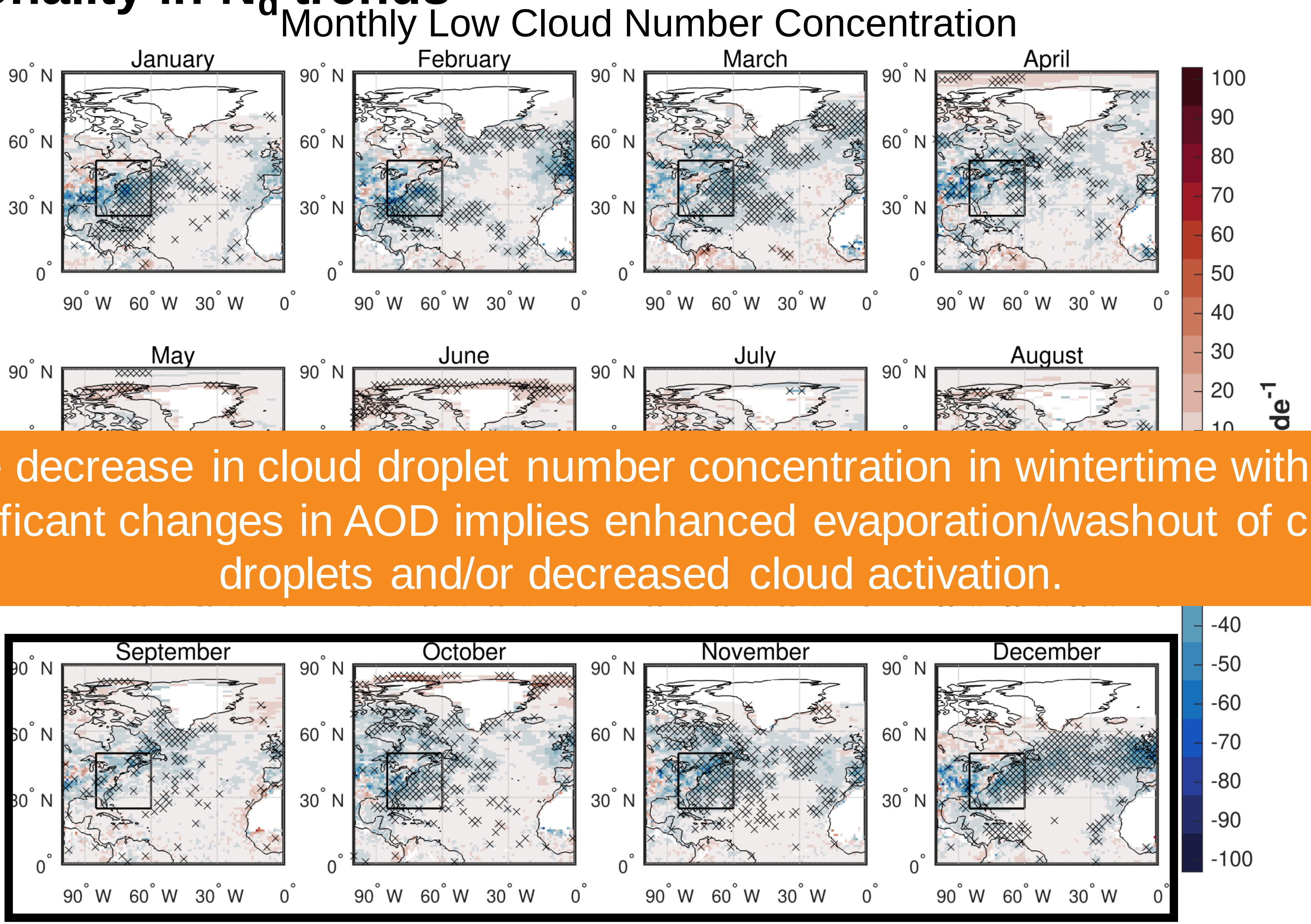


# Seasonality in $N_d$ trends



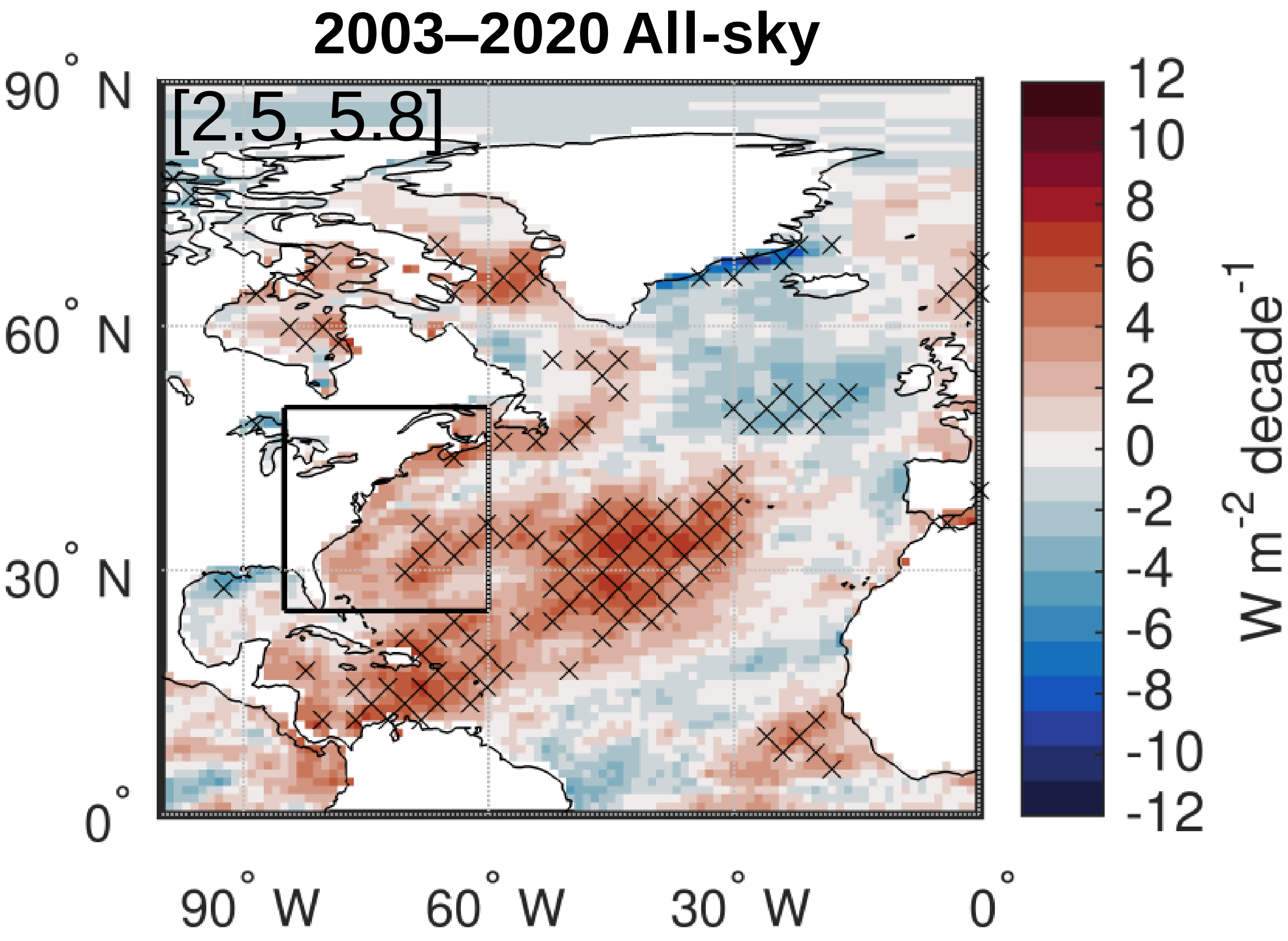

This lack of a correlation suggests the summertime WNAO exhibits an updraft-limited cloud droplet nucleation regime (Reutter et al., 2008): if the maximum number of cloud droplets have been nucleated, further changes in AOD would not be expected to change cloud droplet concentrations.

# Seasonality in $N_d$ trends




The decrease in cloud droplet number concentration in wintertime without significant changes in AOD implies enhanced evaporation/washout of cloud droplets and/or decreased cloud activation.

# Pervasive changes in cloud microphysics are not reflected in the downwelling surface solar irradiance

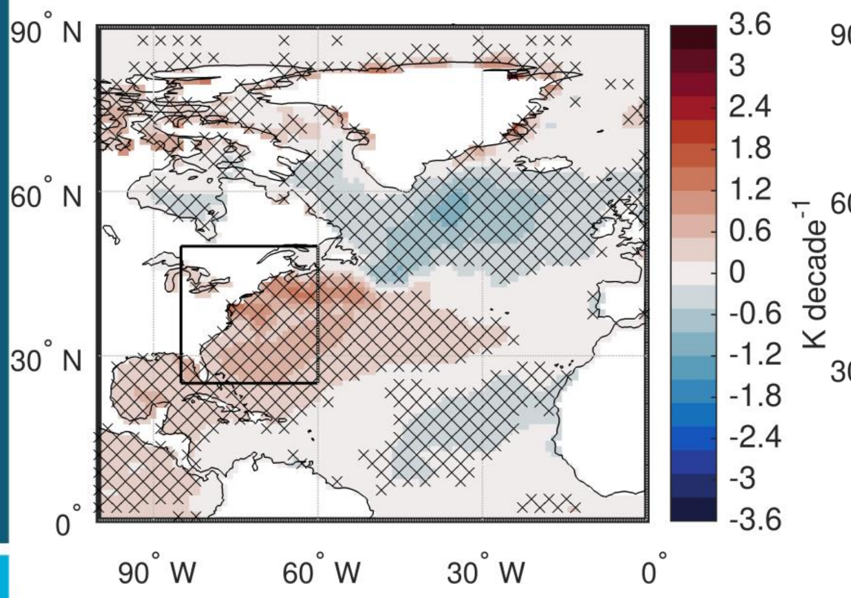



- Accounting for seasonality, this indication of negative Twomey effect is not reflected in the trends in surface shortwave irradiance due to many complex factors operating on the radiation balance in this region

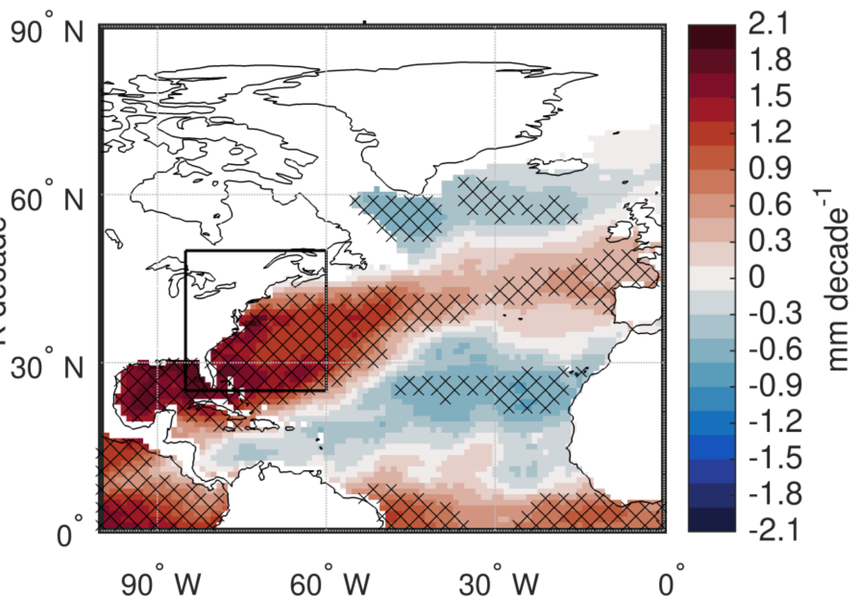
# Changes in meteorological fields

- Tripolar pattern
- Midlatitude SST warming, subtropical and subpolar cooling
- Corresponding increase and decrease in TPW
- Changes in the base state

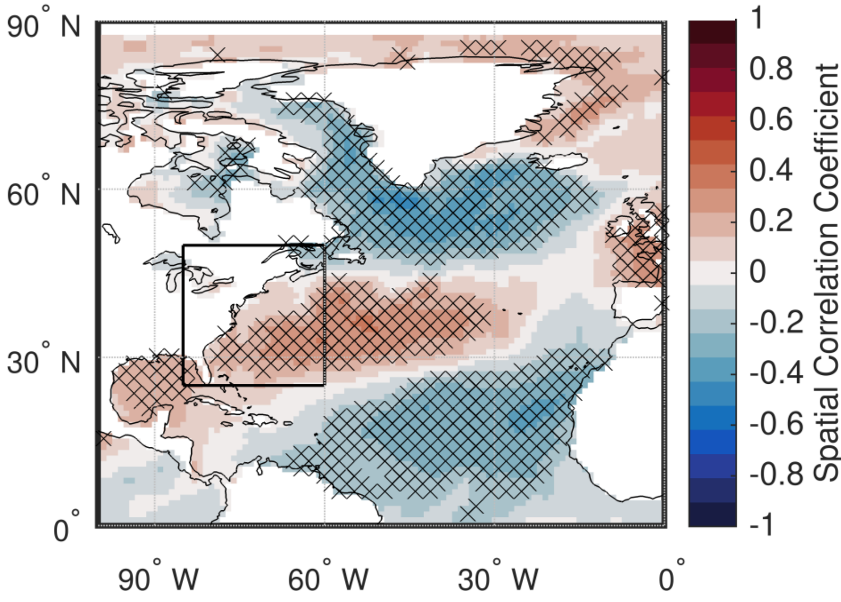
Trends in SST



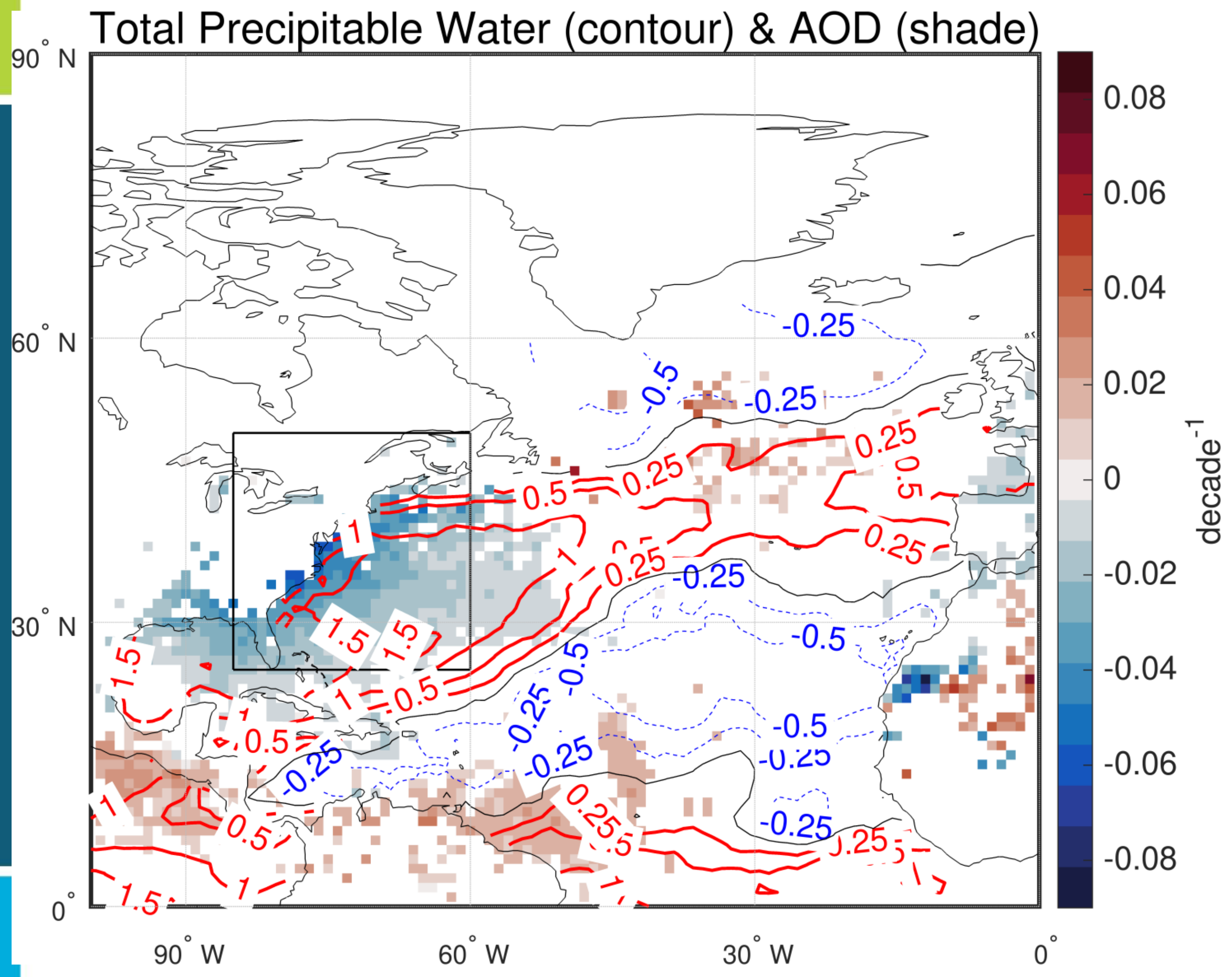

Trends in TPW

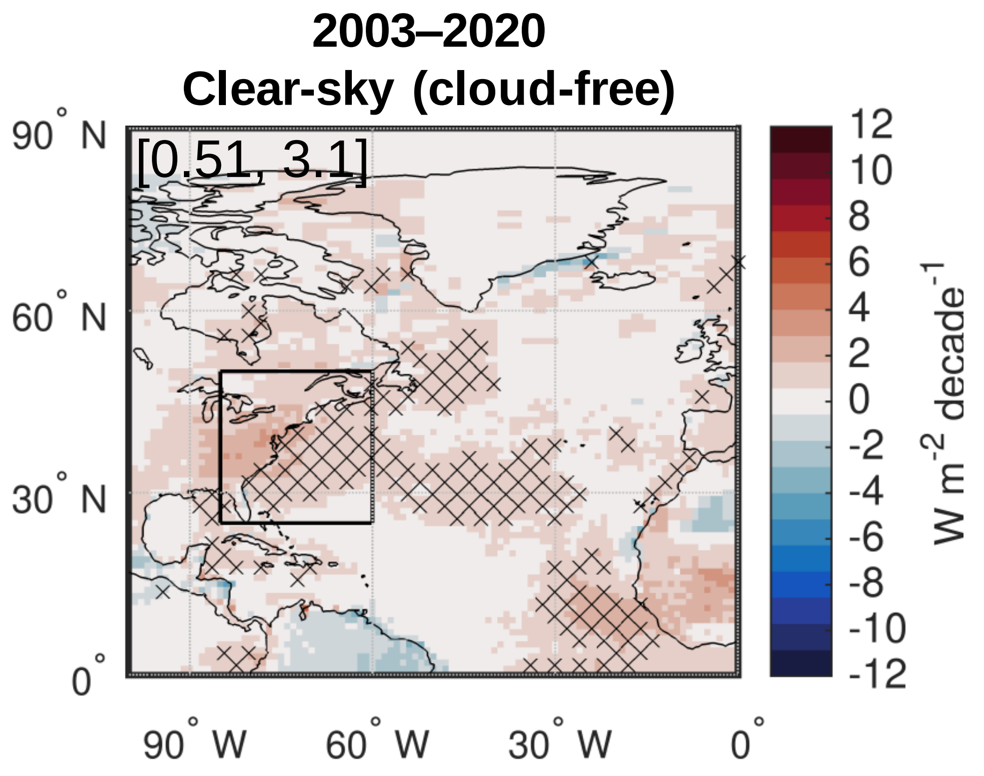



Correlation between NAO index & SST



# Opposite radiative effect between decreasing AOD & increasing total precipitable water in clear sky



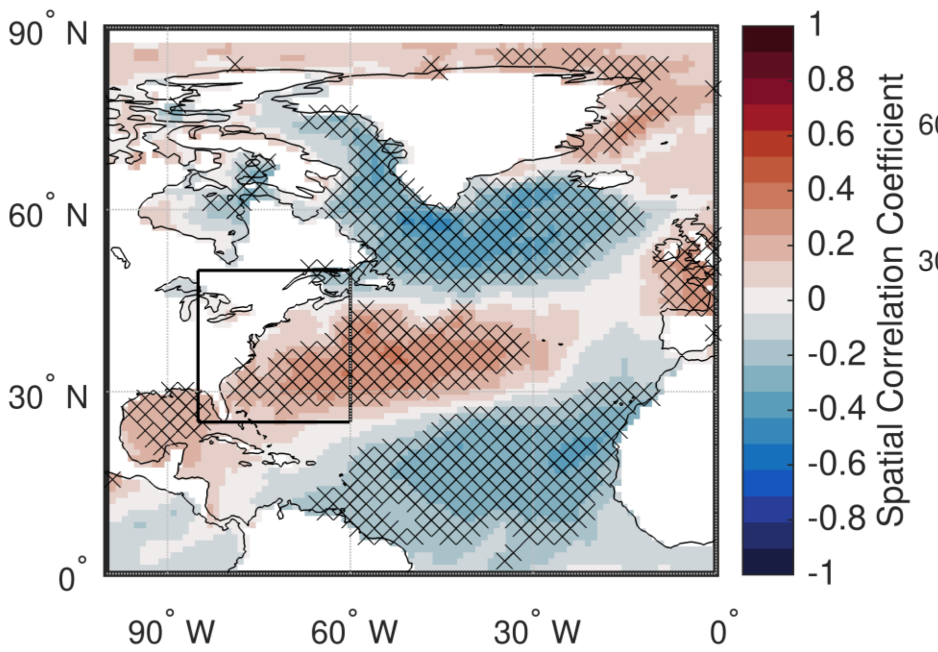



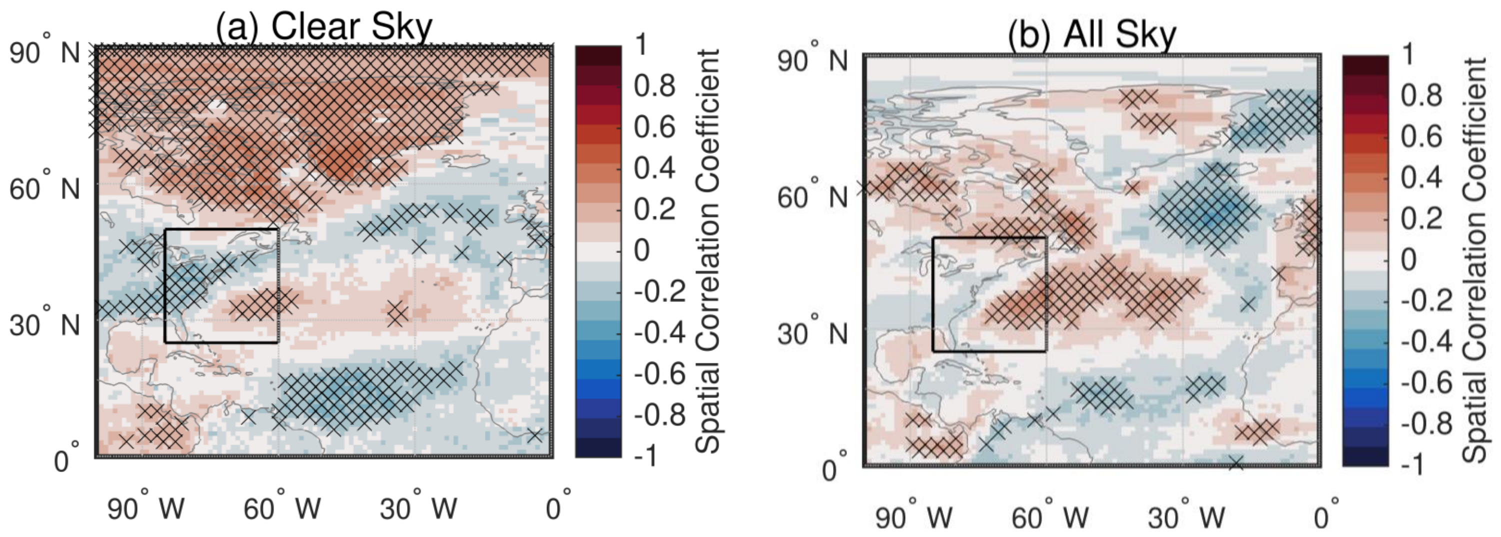

- Brightening from decreasing AOD
- Dimming from increasing TPW via shortwave absorption
- **Net brightening**

# Tripolar patterns in NAO-surface solar irradiance correlation

Correlation between NAO index & surface irradiance

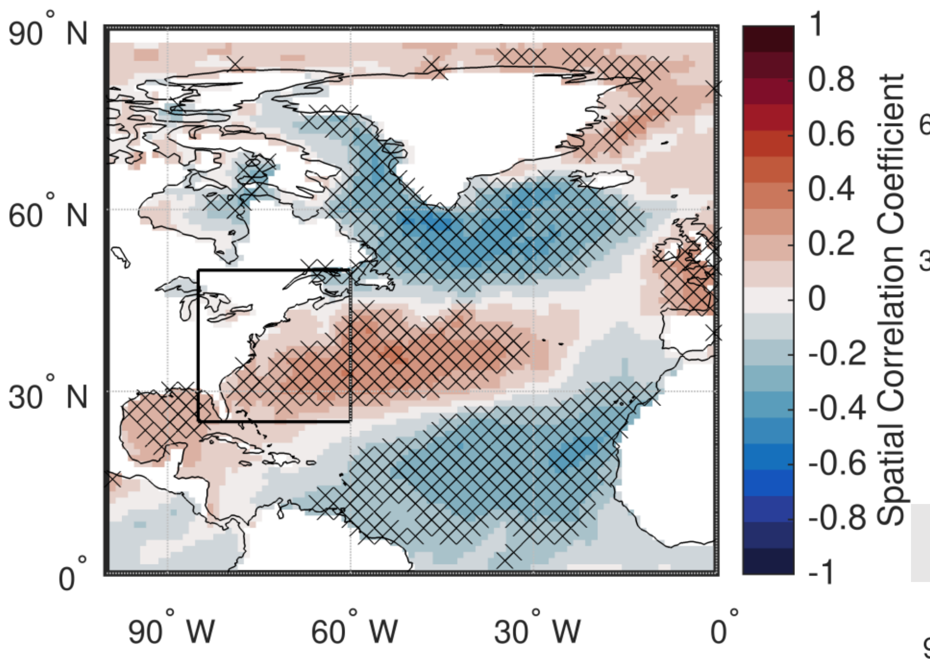
Correlation between NAO & SST



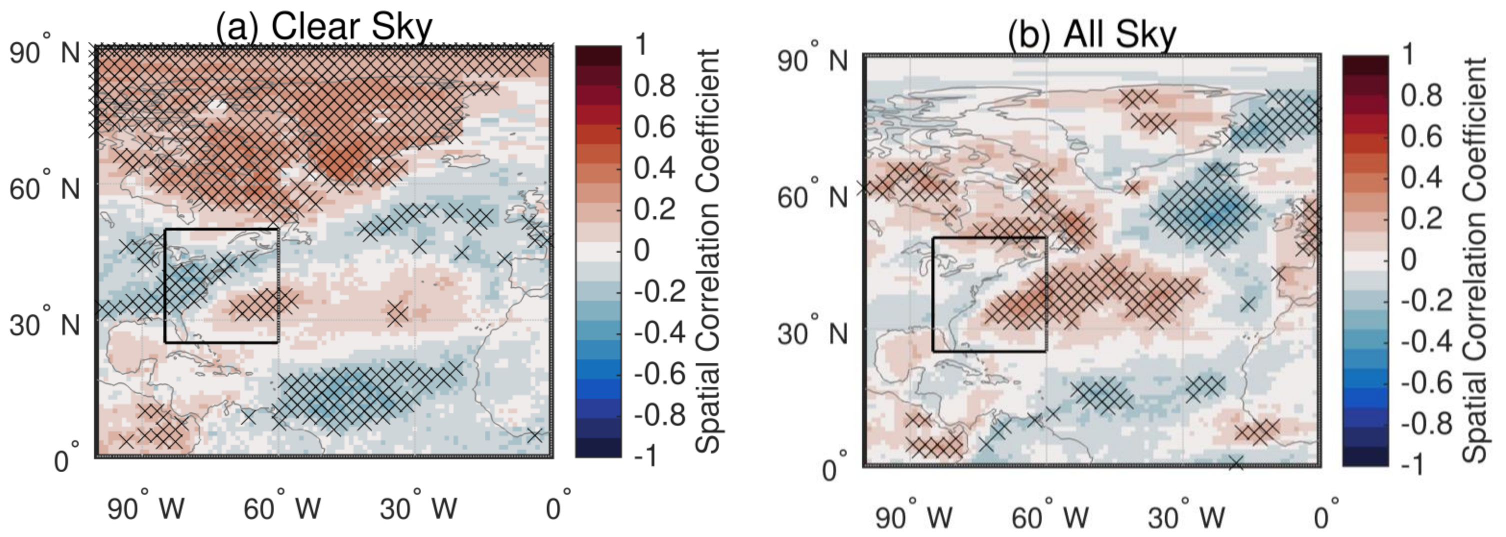



# Tripolar patterns in NAO-surface solar irradiance correlation

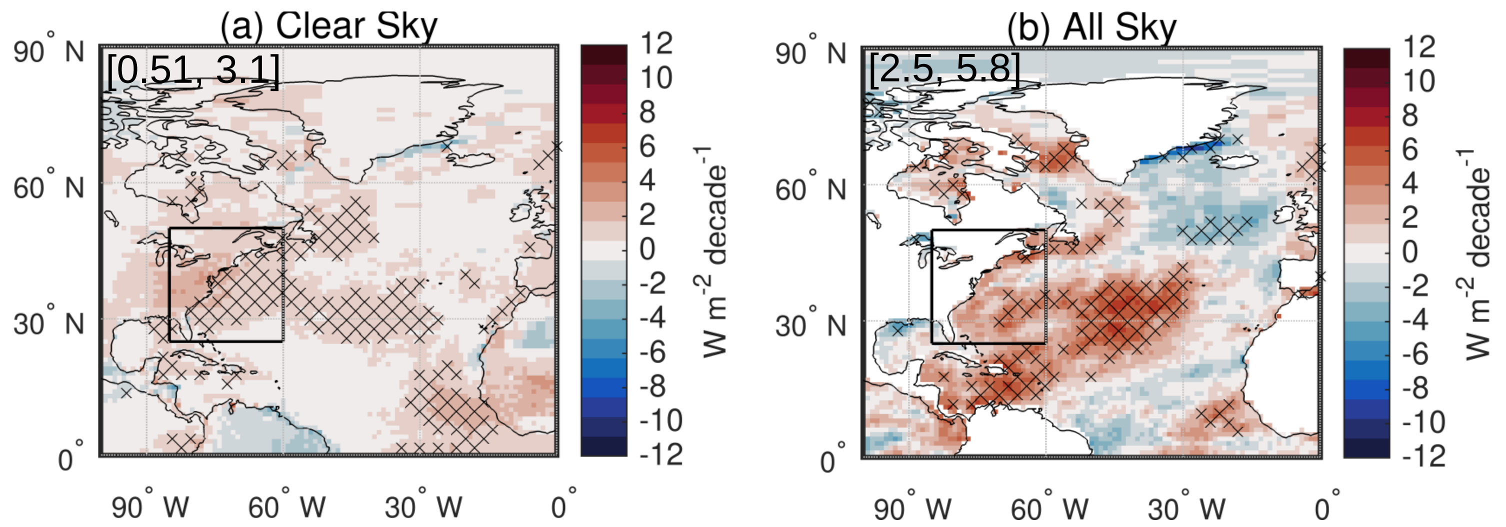
## Correlation between NAO & SST



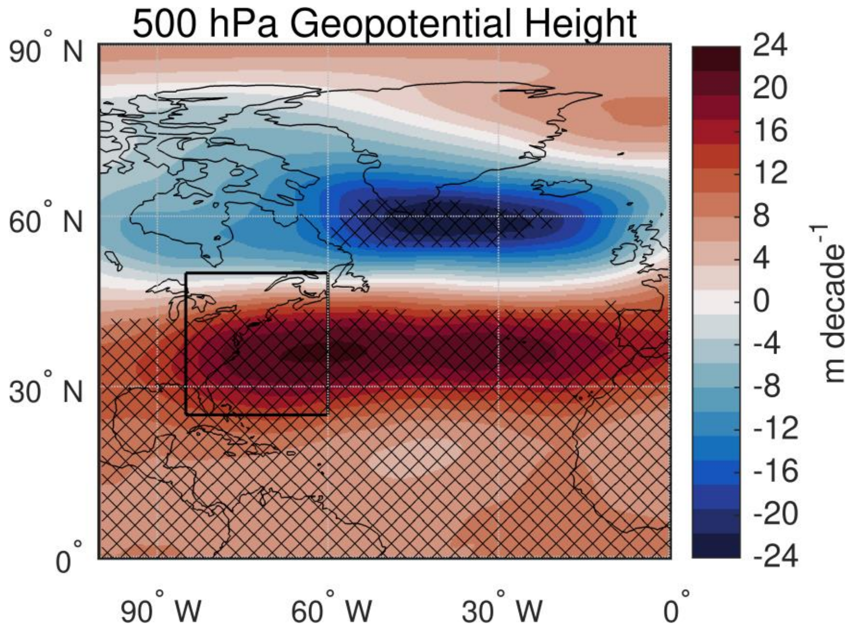

## Correlation between NAO index & surface irradiance

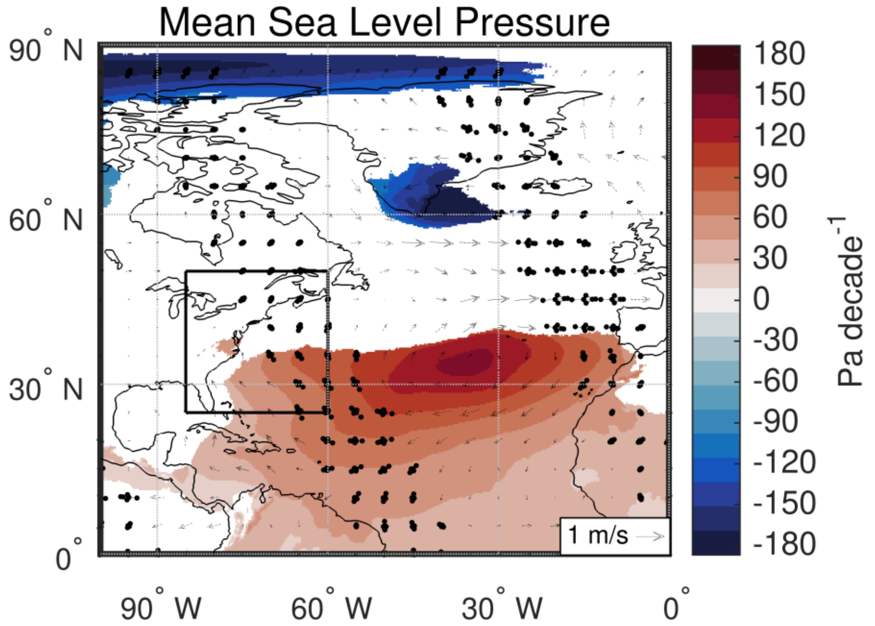


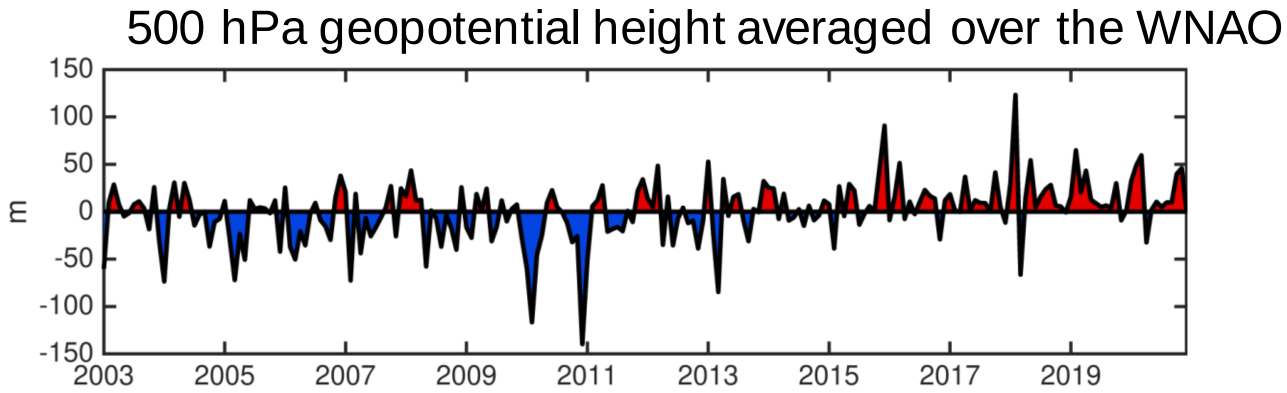

## Decadal trends of surface shortwave irradiance

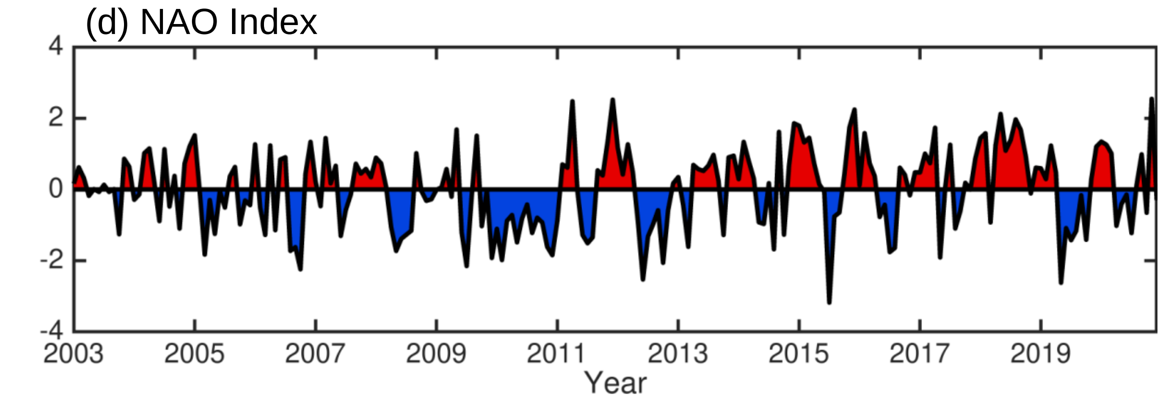


# Has the North Atlantic Oscillation changed?




- Stronger Bermuda-Azores high
- Stronger subpolar low
- Greater pressure gradient
- Implying changes in North Atlantic Oscillation
- Likely bounds the spatial extent of AOD trends

# Summary

1. How have aerosol-cloud interactions influenced the surface radiation budget in the Western North Atlantic over the 18-year satellite data record?
   - Despite a robust signal in cloud microphysical properties over the WNAO (increasing $\mathbf{r}_{\mathrm{eff}}$/decreasing $\mathbf{N}_{\mathbf{d}}$ with decreasing AOD), a corresponding increase in the surface shortwave radiation is not found.
   - Processes other than ACI, therefore, are likely responsible for controlling the surface shortwave radiation budget in this region.

2. Can we use the different spatiotemporal patterns in aerosol and meteorological variability to characterize the contributions of aerosol indirect effects and climate variability to changes in the radiation budget via the cloud radiative effect?
   - Changes in water vapor which are shown to impact the clear-sky surface shortwave radiation may also impact cloud radiative properties.
   - Changes in SST and water vapor exhibit a tripolar pattern that is positively correlated to the NAO and may impact cloud properties through natural variability.
   - While not shown here, statistically significant changes in mid- and high-level clouds were found that may compensate for aerosol-induced changes in low clouds.

# Next Step: Self-Organizing Map (SOM)

Input: 2003–2022 May and June 500 hPa geopotential height

- To distinguish synoptic regimes in relation to Bermuda high (location and intensity of the center)
- *If summertime WNAO is an updraft-limited cloud droplet nucleation regime, we can distinguish spatial patterns of the low cloud $N_d$ as a function of the Bermuda high hence associated vertical motions*