

# Trends and Variability in Stratospheric $\text{NO}_x$ from Merged SAGE II and OSIRIS Satellite Observations

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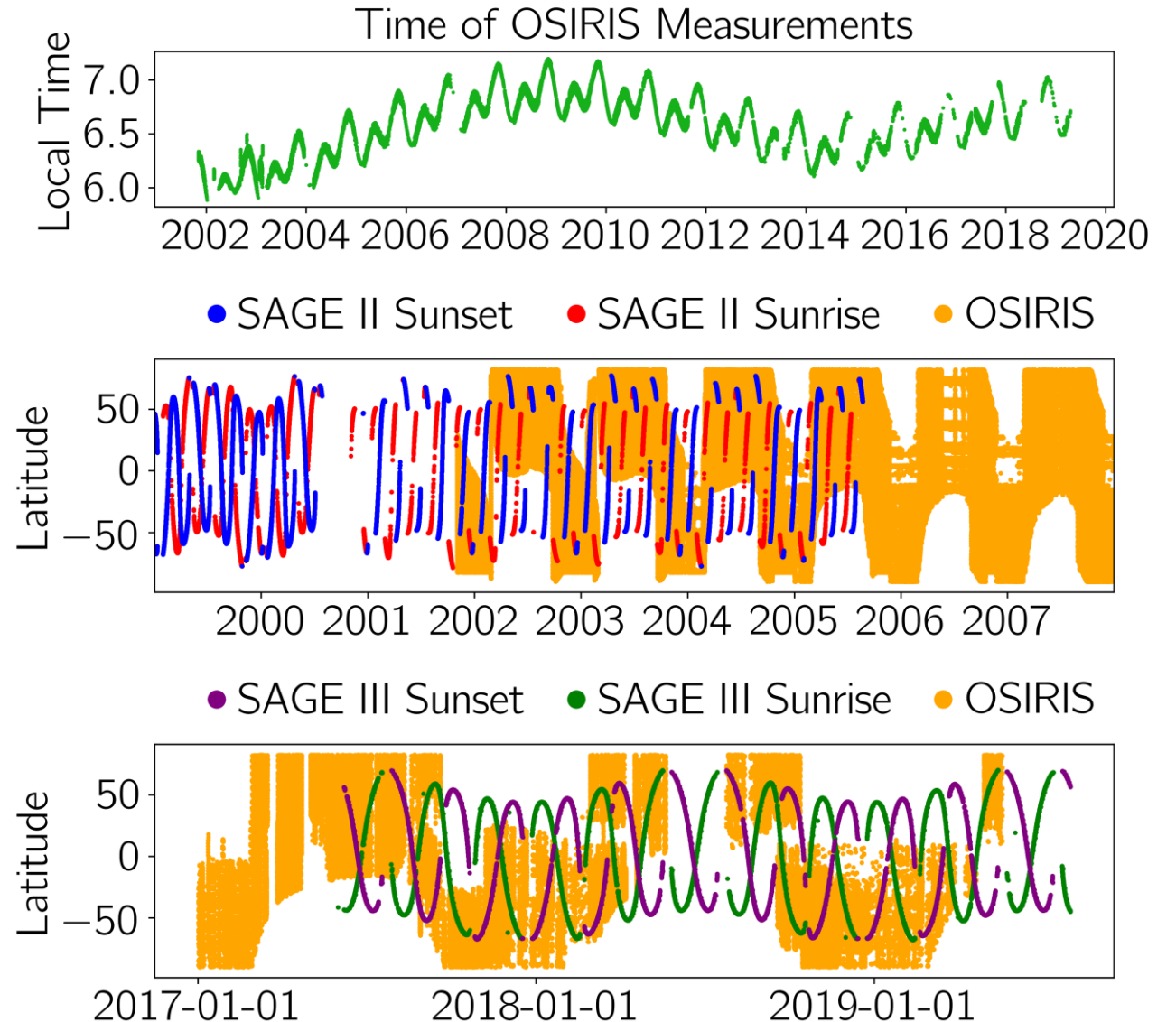
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# Outline

- Instruments
- Merging
  - Photochemical Correction
  - Results
- Linear Regression
  - Aerosol Effect
  - Trends
- Conclusions

# Instruments

- OSIRIS
  - October 2001 - Present
- SAGE II
  - October 1984 – August 2005
- SAGE III/ISS
  - June 2017 - Present

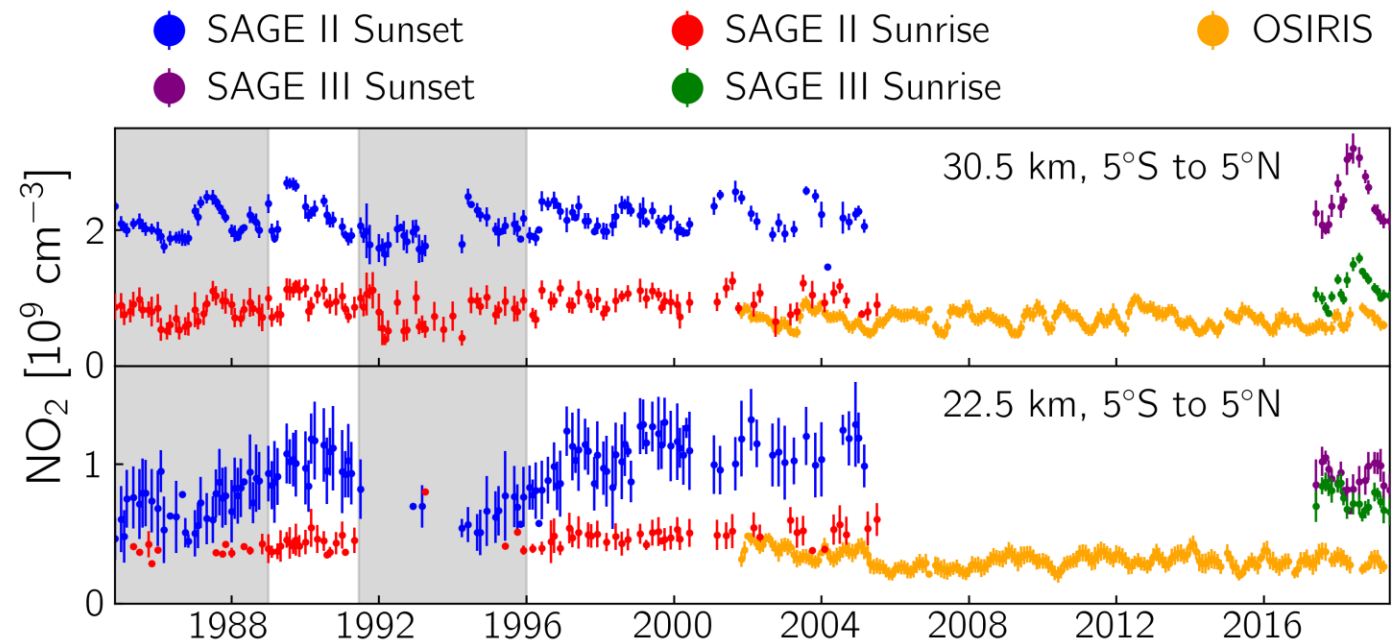
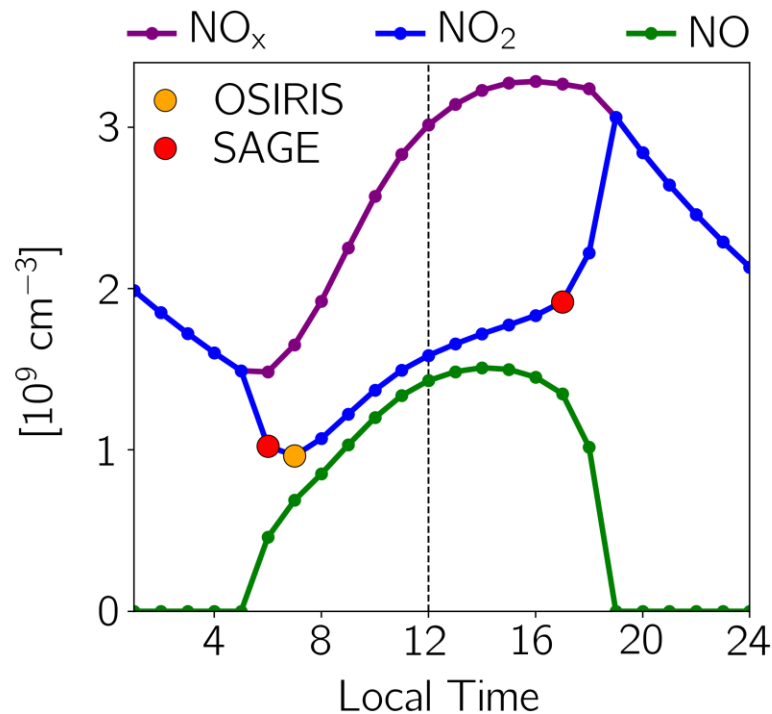


# Merging Idea

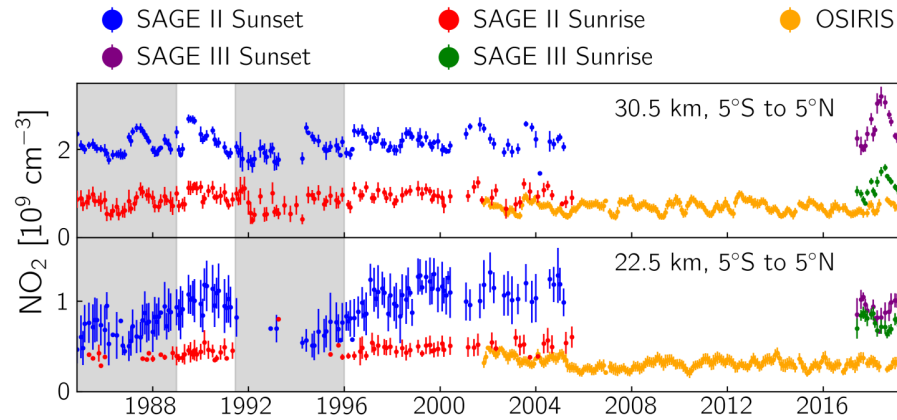
- Together SAGE II and OSIRIS provide over 34 years of data
- Use 4-year overlap to combine NO<sub>2</sub> into single data set
- Ozone and aerosol measurements from OSIRIS and SAGE II have already been merged (eg. Bourassa et al. 2014)
- Can also combine OSIRIS with SAGE III using the same method

# Difficulty with Merging $\text{NO}_2$

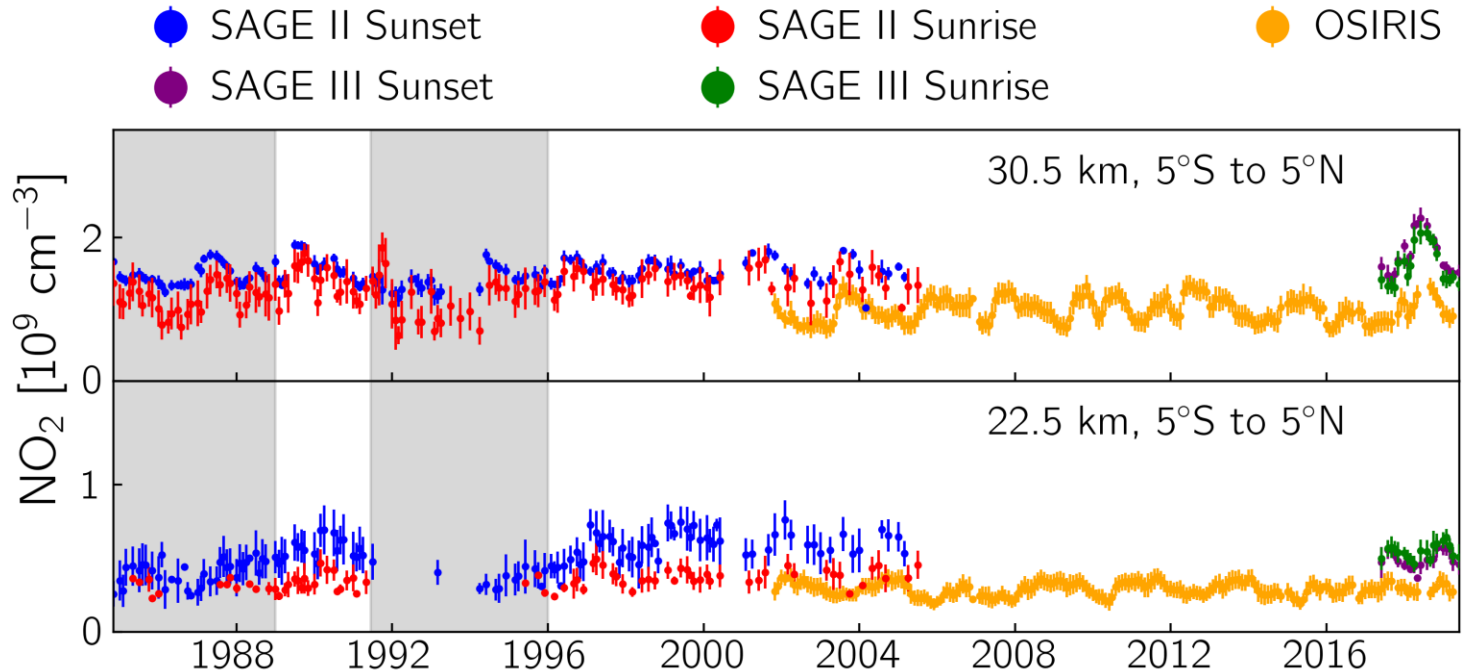
- $\text{NO}_2$  has a diurnal cycle: need to consider measurement time of day
  - OSIRIS measures limb-scattered sunlight near 6:30 am local time
  - SAGE II takes occultation measurements at local sunrise and sunset



# Photochemical Correction

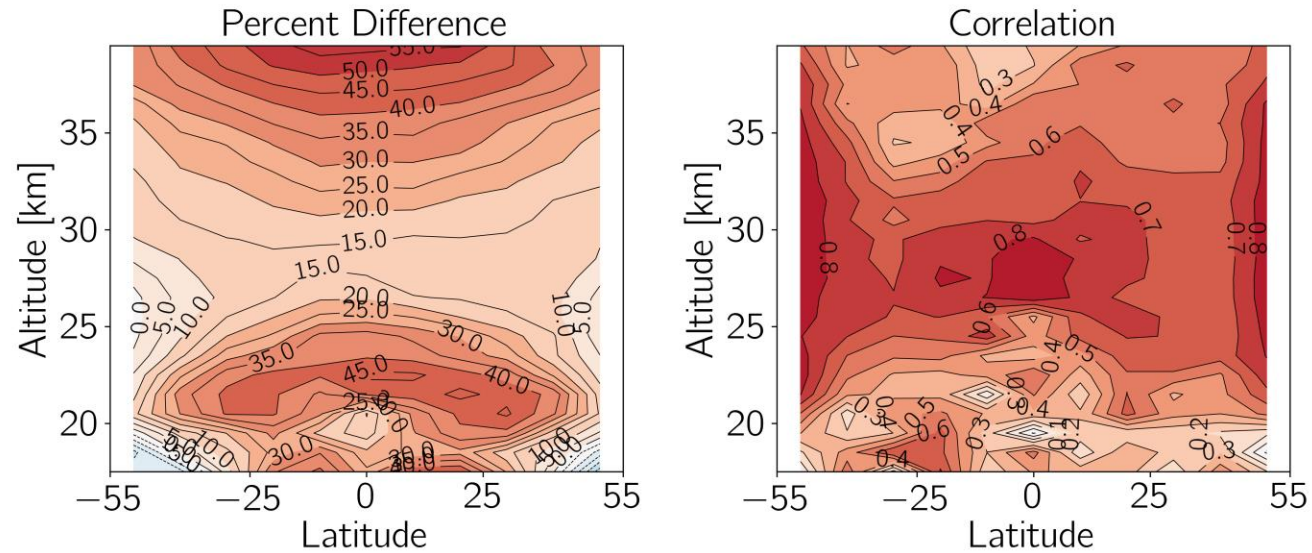


$$[\text{NO}_2]_{12:00}^{meas.} = [\text{NO}_2]_{lst}^{meas.} \frac{[\text{NO}_2]_{12:00}^{model}}{[\text{NO}_2]_{lst}^{model}}$$

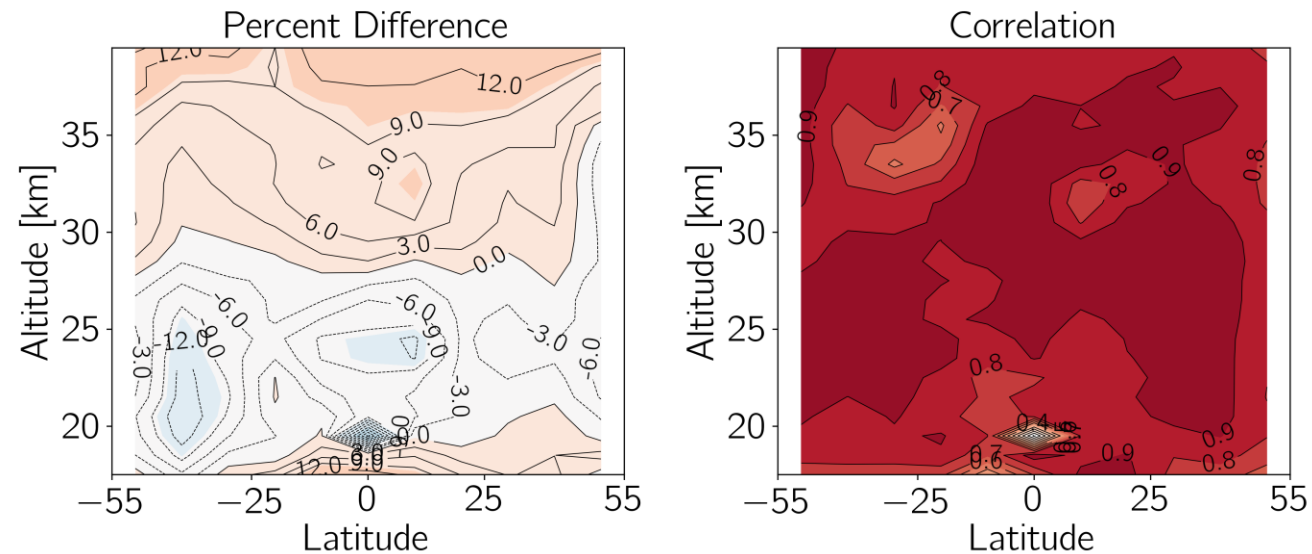


# Sunrise –Sunset Bias & Correlation

- SAGE II

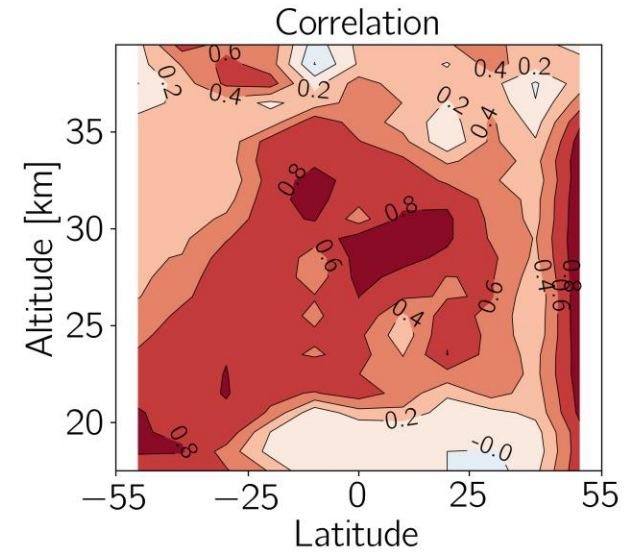
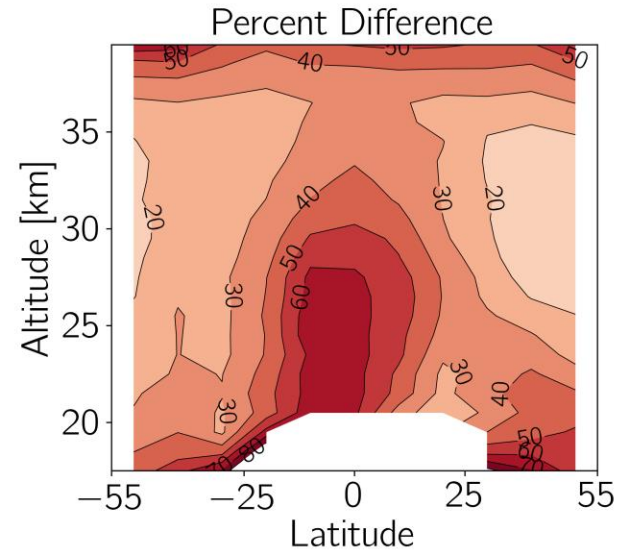


- SAGE III

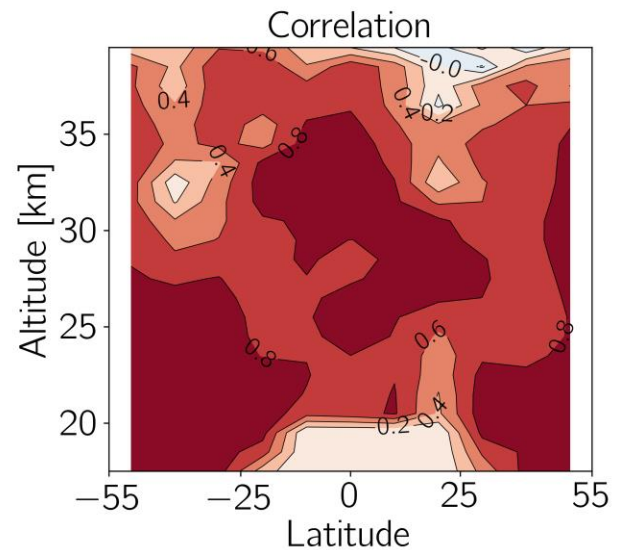
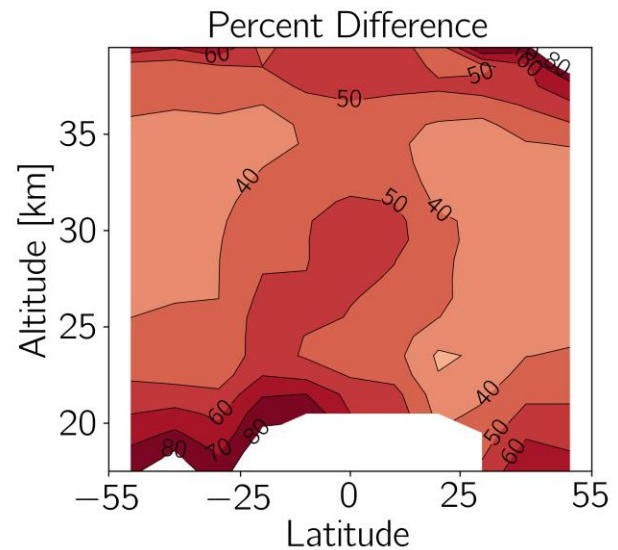


# SAGE Sunset – OSIRIS Bias & Correlation

- SAGE II

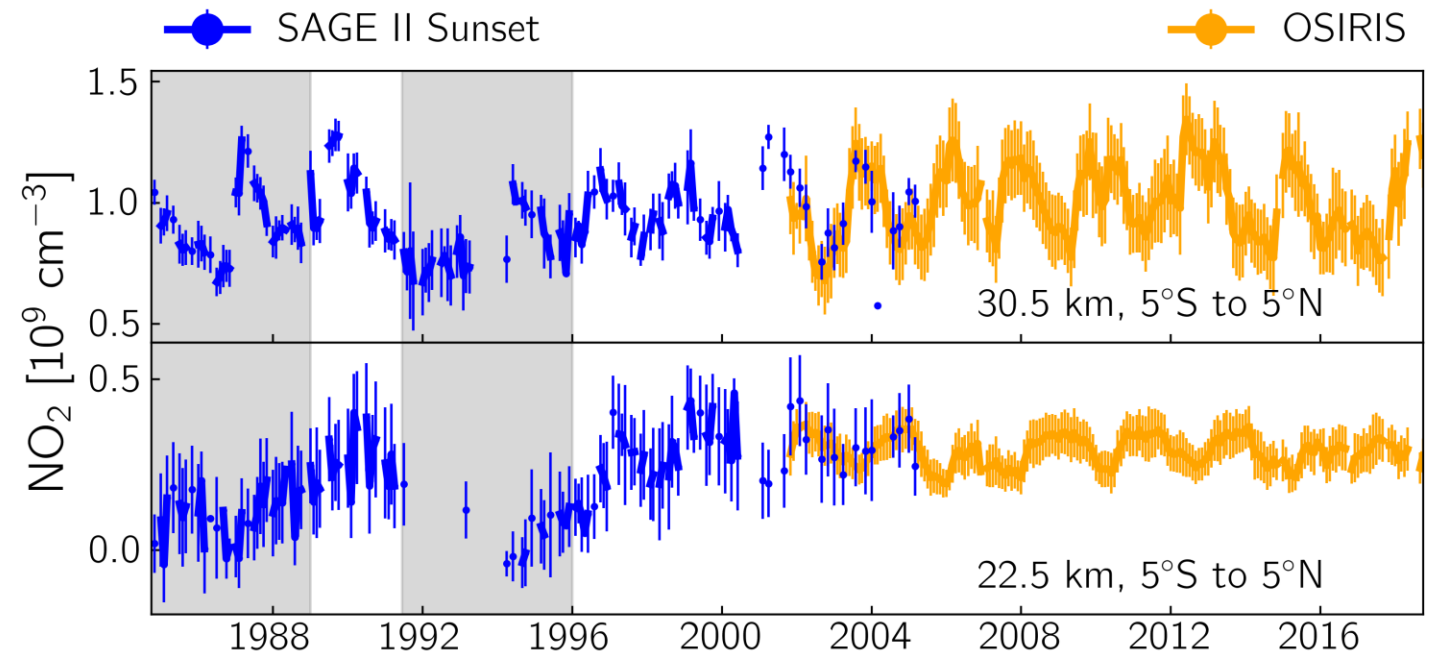


- SAGE III



# Merging

- Remaining results shown for just SAGE II Sunset-OSIRIS
- Subtract bias from SAGE II
- Deseasonalize individually
- Average together



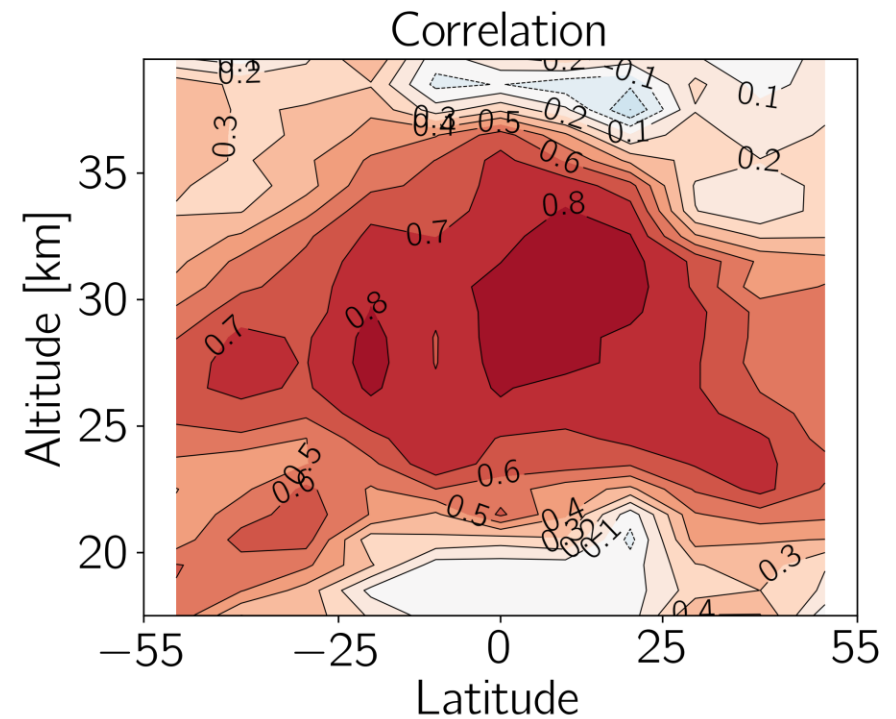
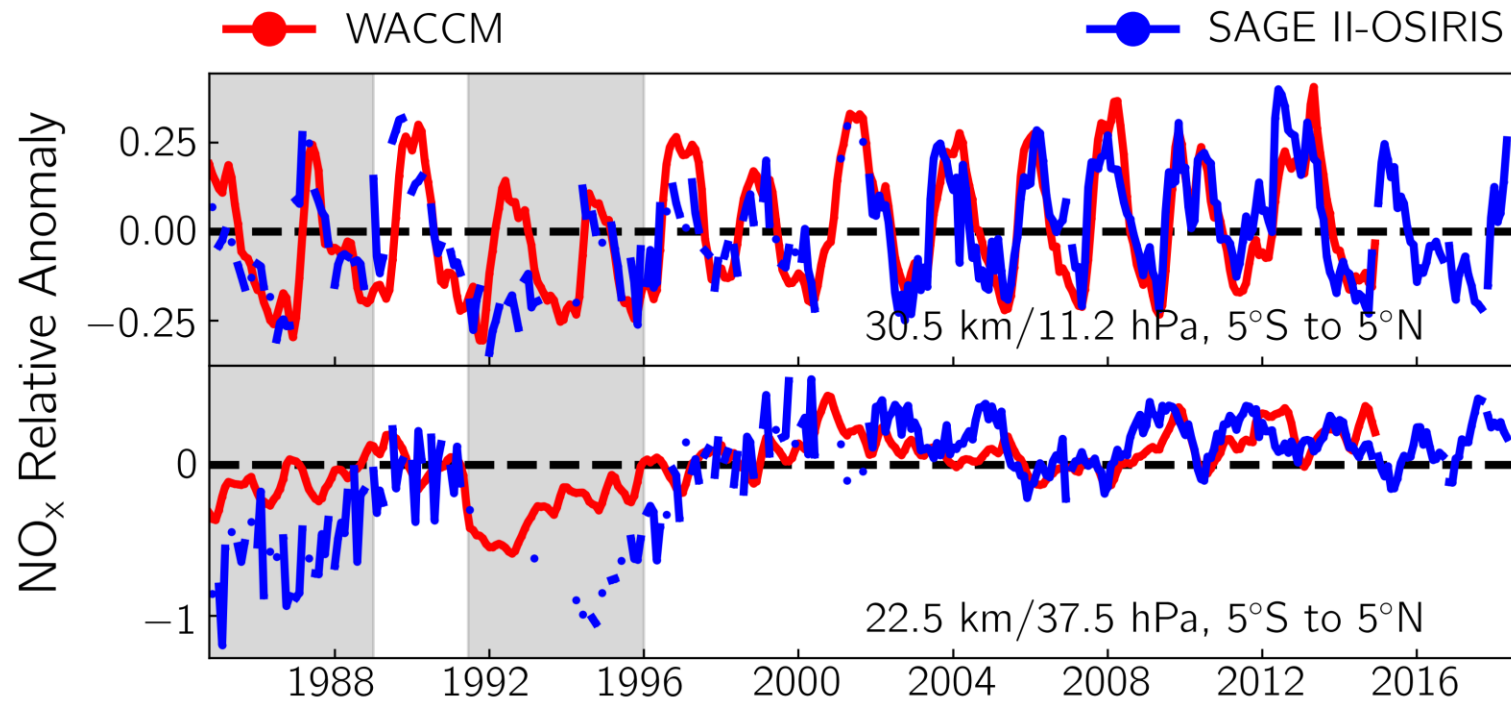
# NO<sub>x</sub> Anomaly

- NO<sub>2</sub> is converted to NO<sub>x</sub> with a factor from the photochemical model

$$[\text{NO}_x]^{meas.} = [\text{NO}_2]^{meas.} \frac{[\text{NO}_x]^{model}}{[\text{NO}_2]^{model}}$$

- Relative anomaly is calculated by subtracting the mean of each month from the data and dividing by the overall mean

# Comparison with WACCM



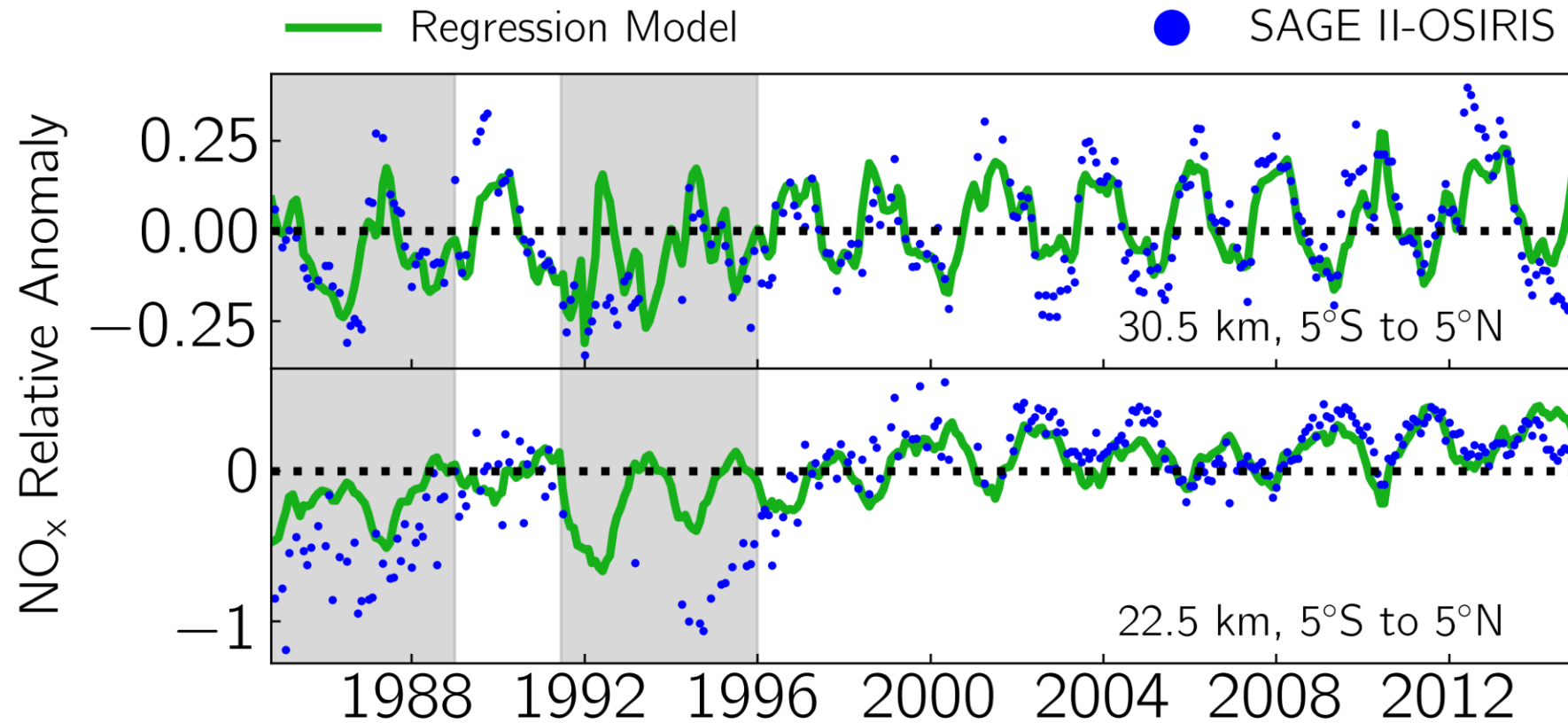
# Linear Regression

$$[\text{NO}_x] = \text{const}^{(2)} + \text{linear}(t) + \text{QBO}_a^{(2)}(t) + \text{QBO}_b^{(2)}(t) \\ + F10.7(t) + ENSO(t) + \text{GloSSAC}(t) + R(t)$$

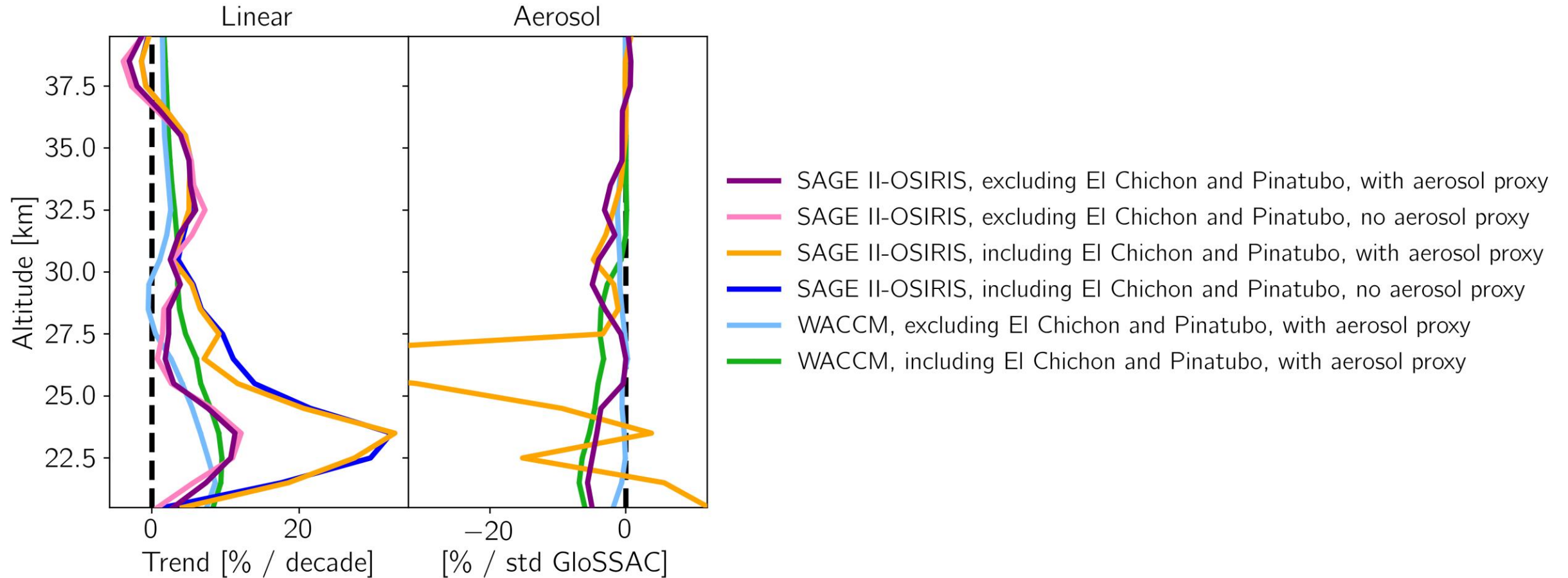
- $\text{QBO}_a^{(2)}(t)$  and  $\text{QBO}_b^{(2)}(t)$  are first two principal components of Singapore zonal winds
- $\text{GloSSAC}(t)$  is monthly mean aerosol extinction
- Superscripts are number of seasonal harmonics included for that term. Harmonics have form

$$1 + \sum_{i=1}^n \left( \sin \left( \frac{2\pi}{365.25} it \right) + \cos \left( \frac{2\pi}{365.25} it \right) \right)$$

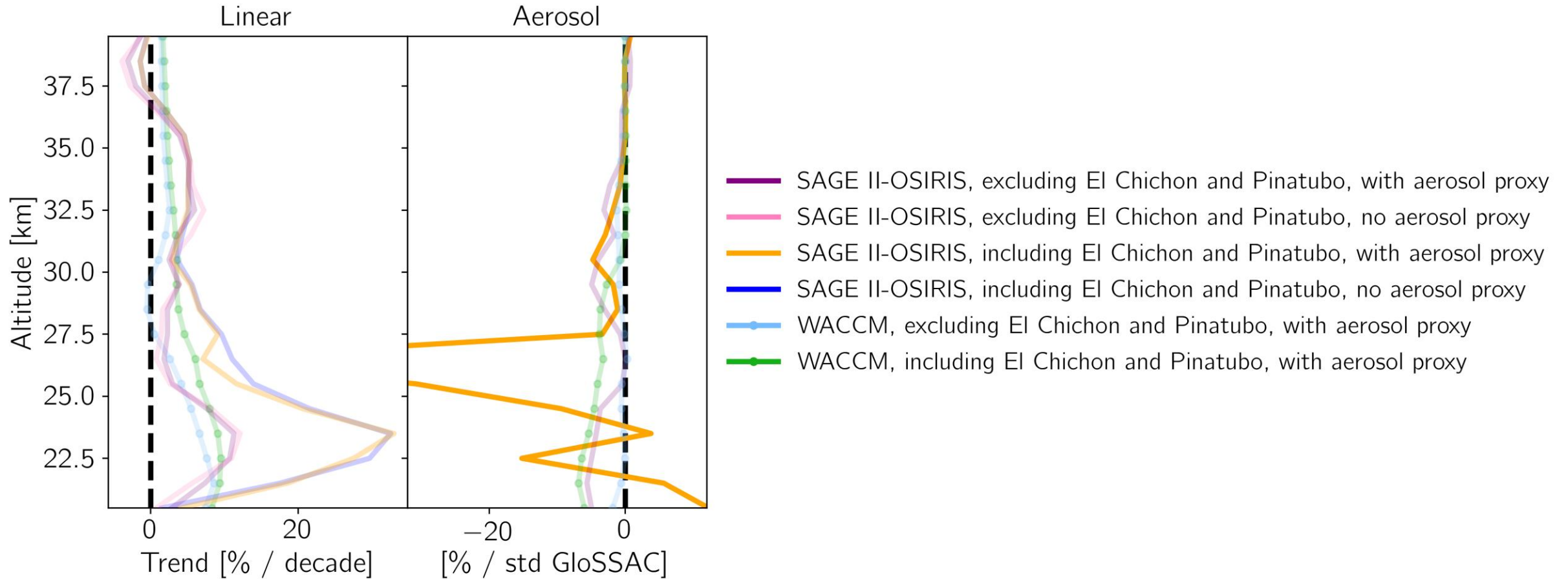
# Linear Regression



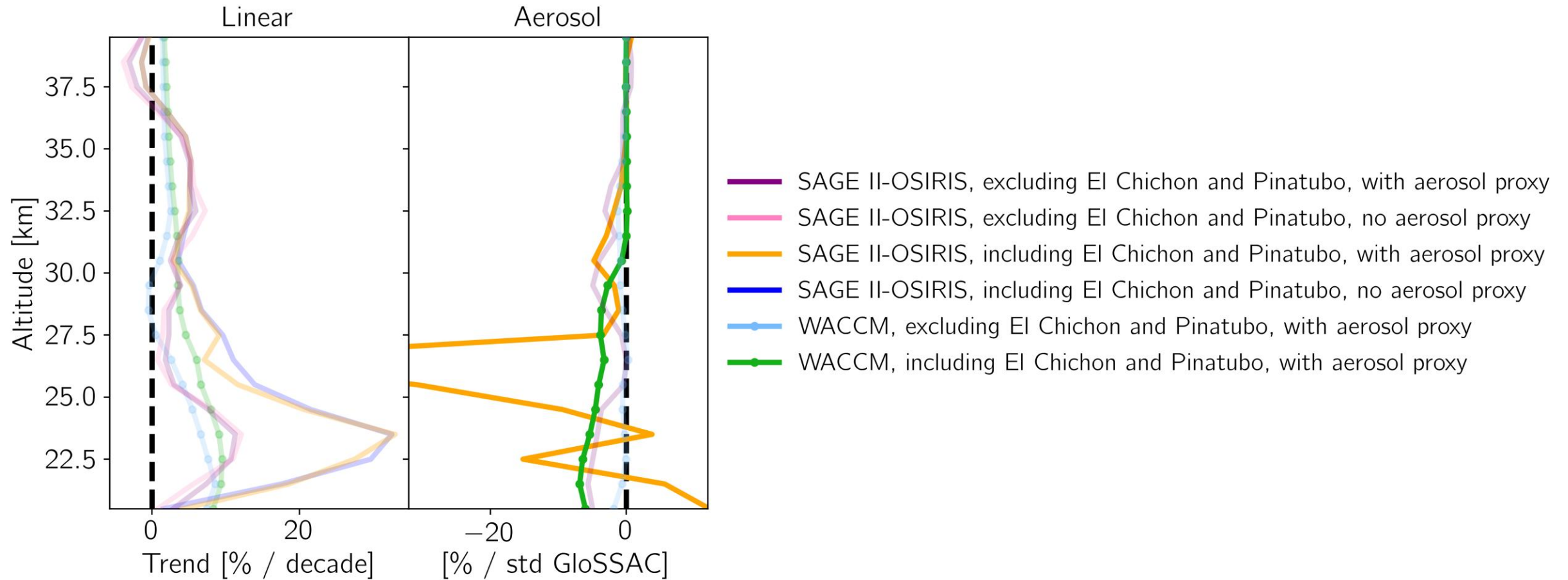
# Linear Regression



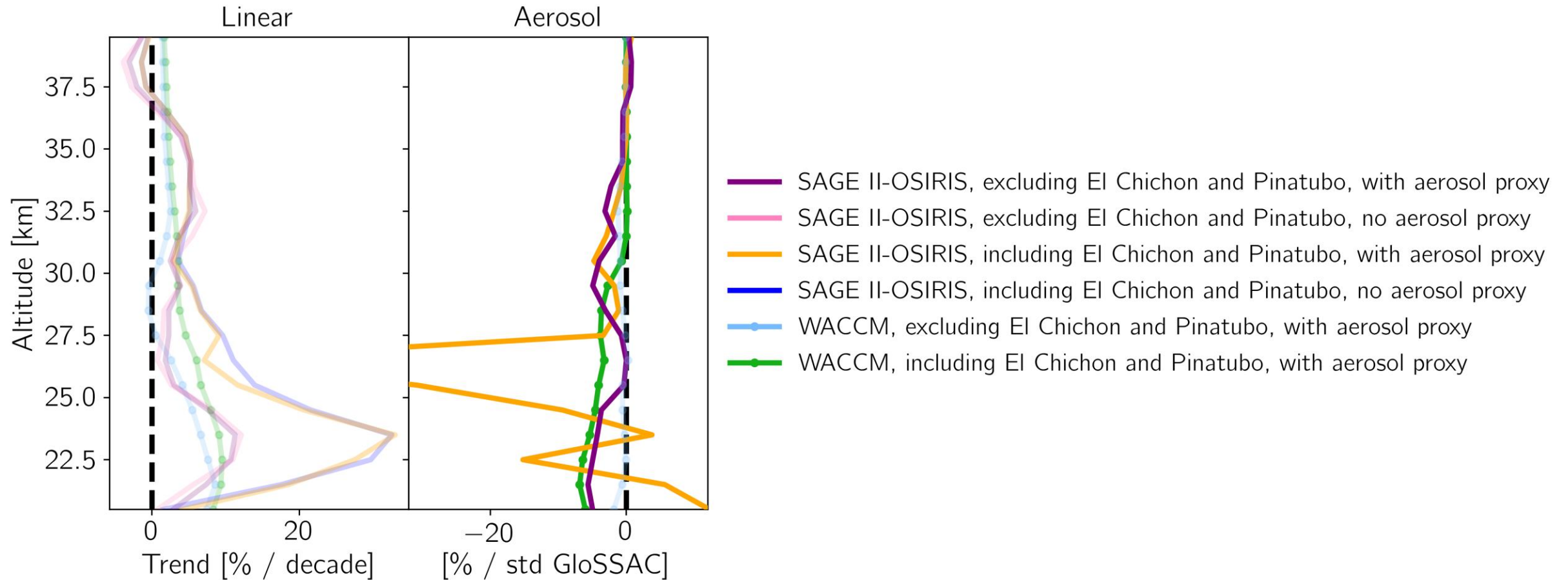
# Linear Regression



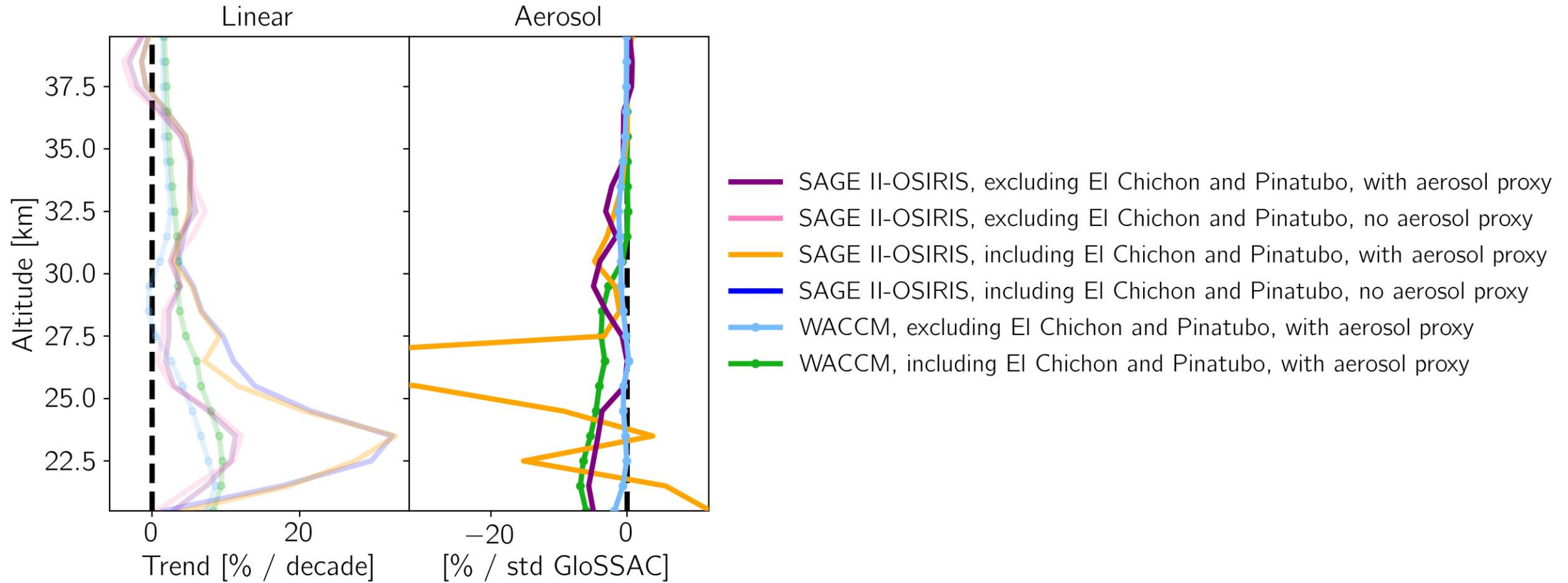
# Linear Regression



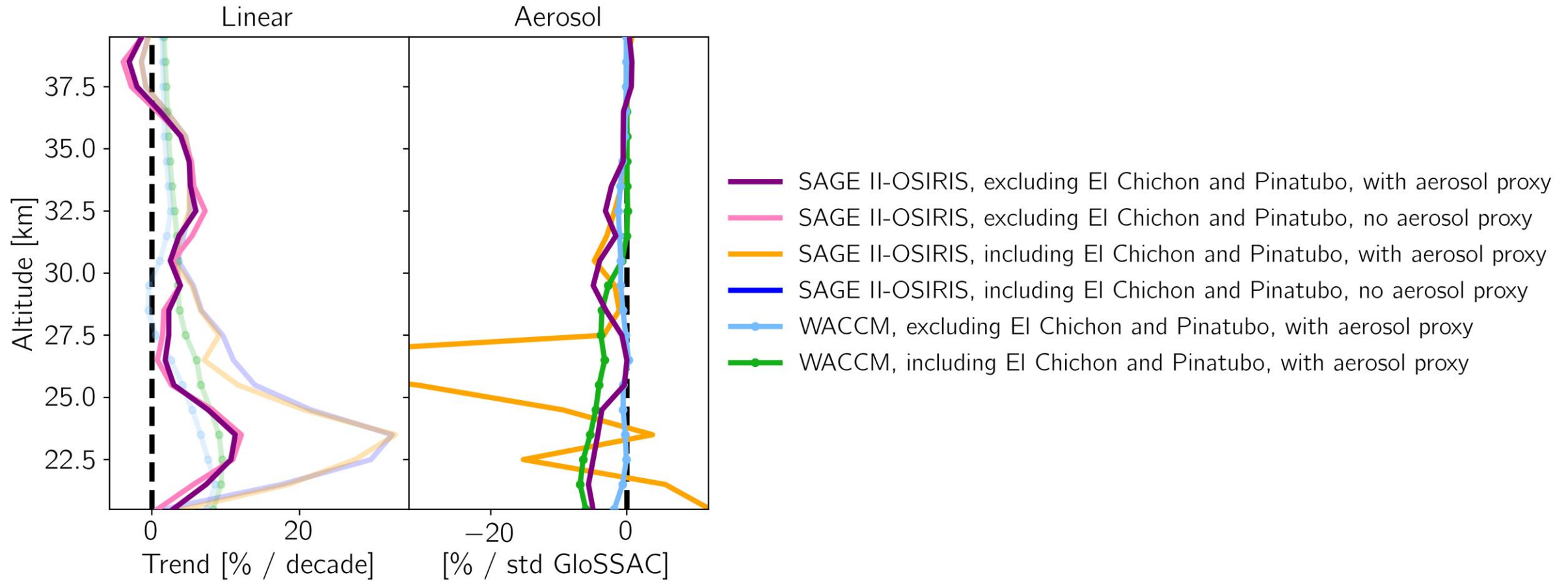
# Linear Regression



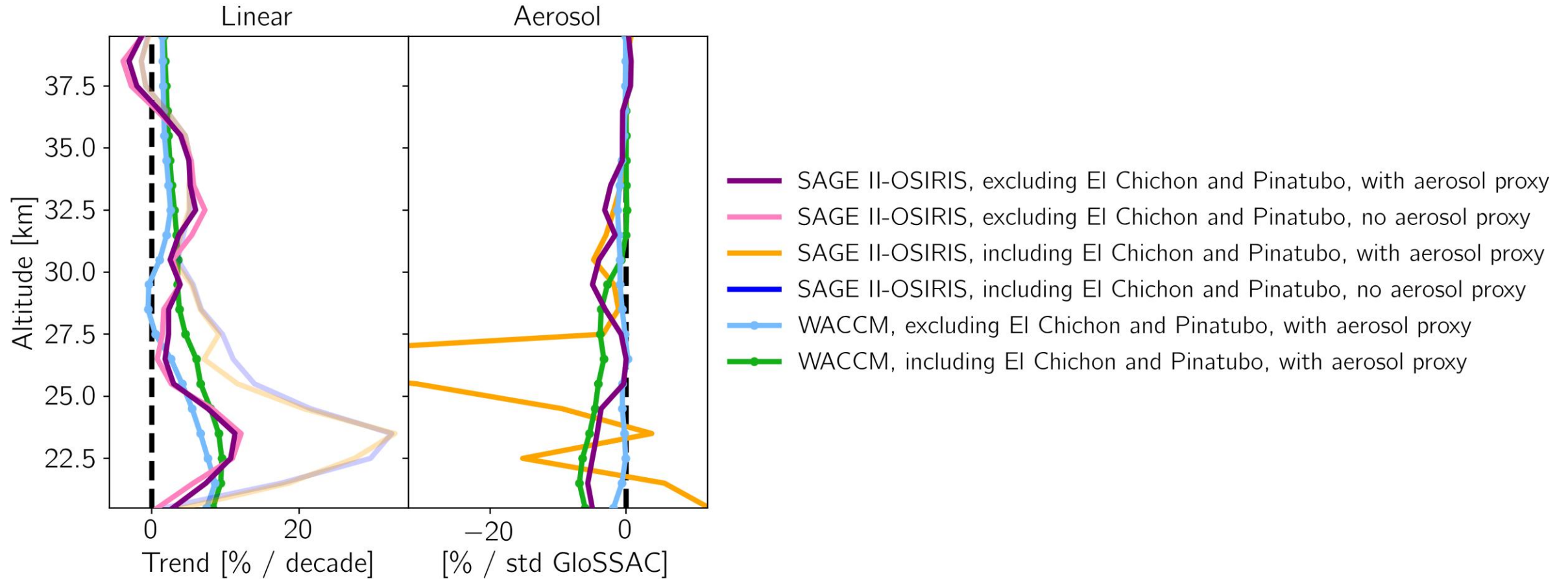
# Linear Regression



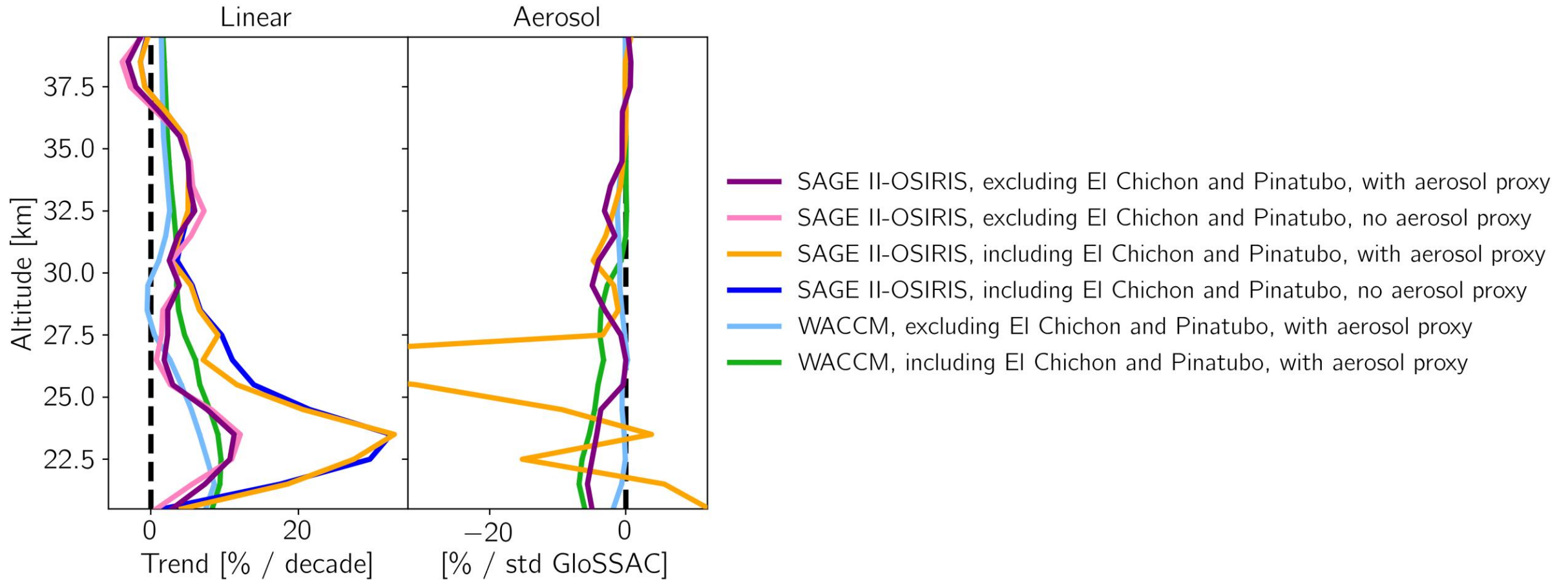
# Linear Regression



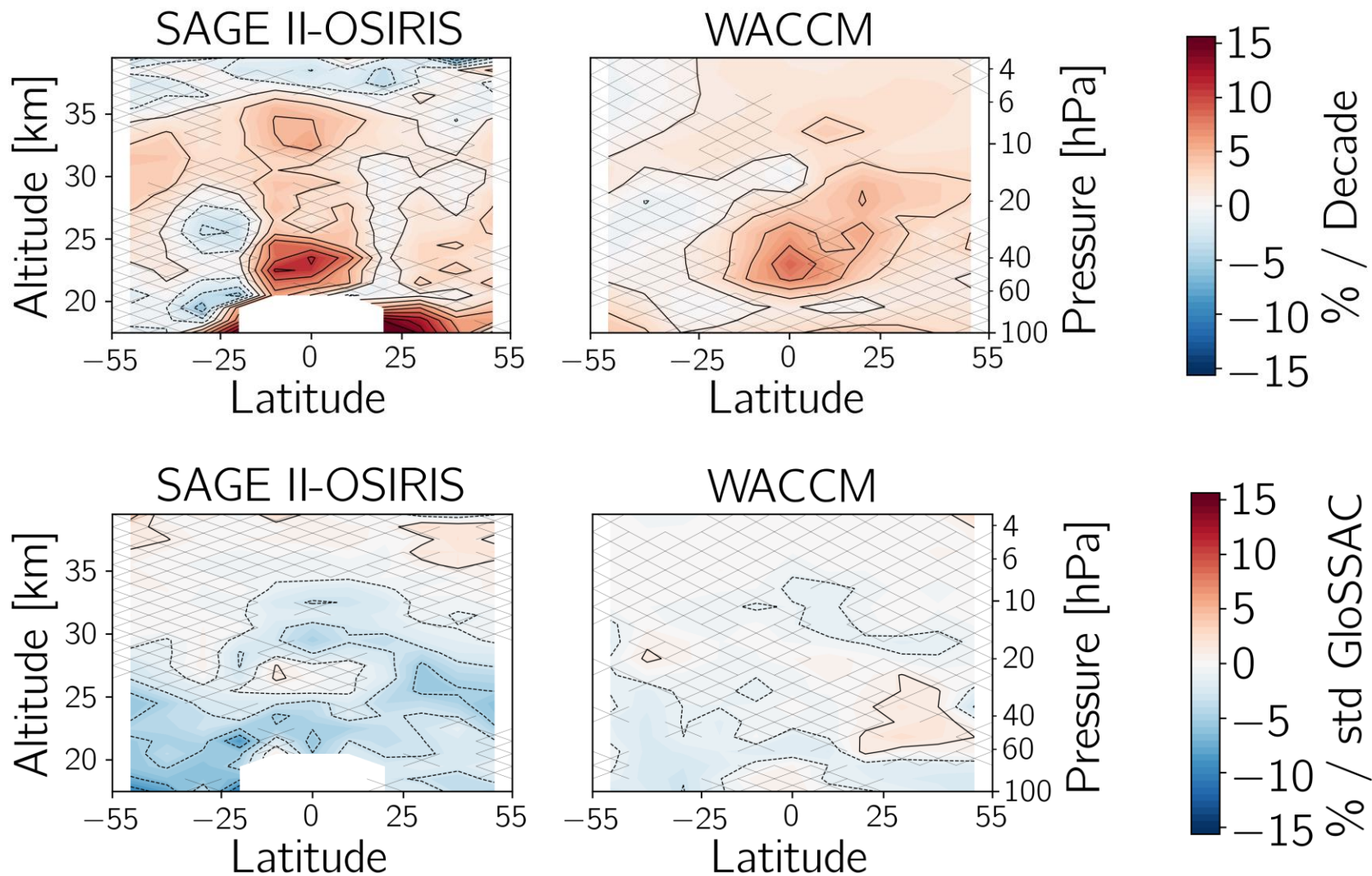
# Linear Regression



# Linear Regression



# Linear Regression



# Conclusion

- Merged  $\text{NO}_2$  (and  $\text{NO}_x$ ) from SAGE II and OSIRIS was created
- Resulting dataset shows very good agreement with WACCM
- Data has increasing linear trends of 8-10% per decade, WACCM 6-7% per decade
  - The trends in the data are influenced by aerosol from large volcanic eruptions
- Both WACCM and regression model underestimate the effect of aerosol on  $\text{NO}_x$
- Sunrise and sunset  $\text{NO}_2$  from SAGE III-ISS agree well with one another and with OSIRIS.
  - SAGE III  $\text{NO}_2$  can easily be added to the merged dataset