Evolution of the three-dimensional structure of atmospheric carbon dioxide during the 21st century

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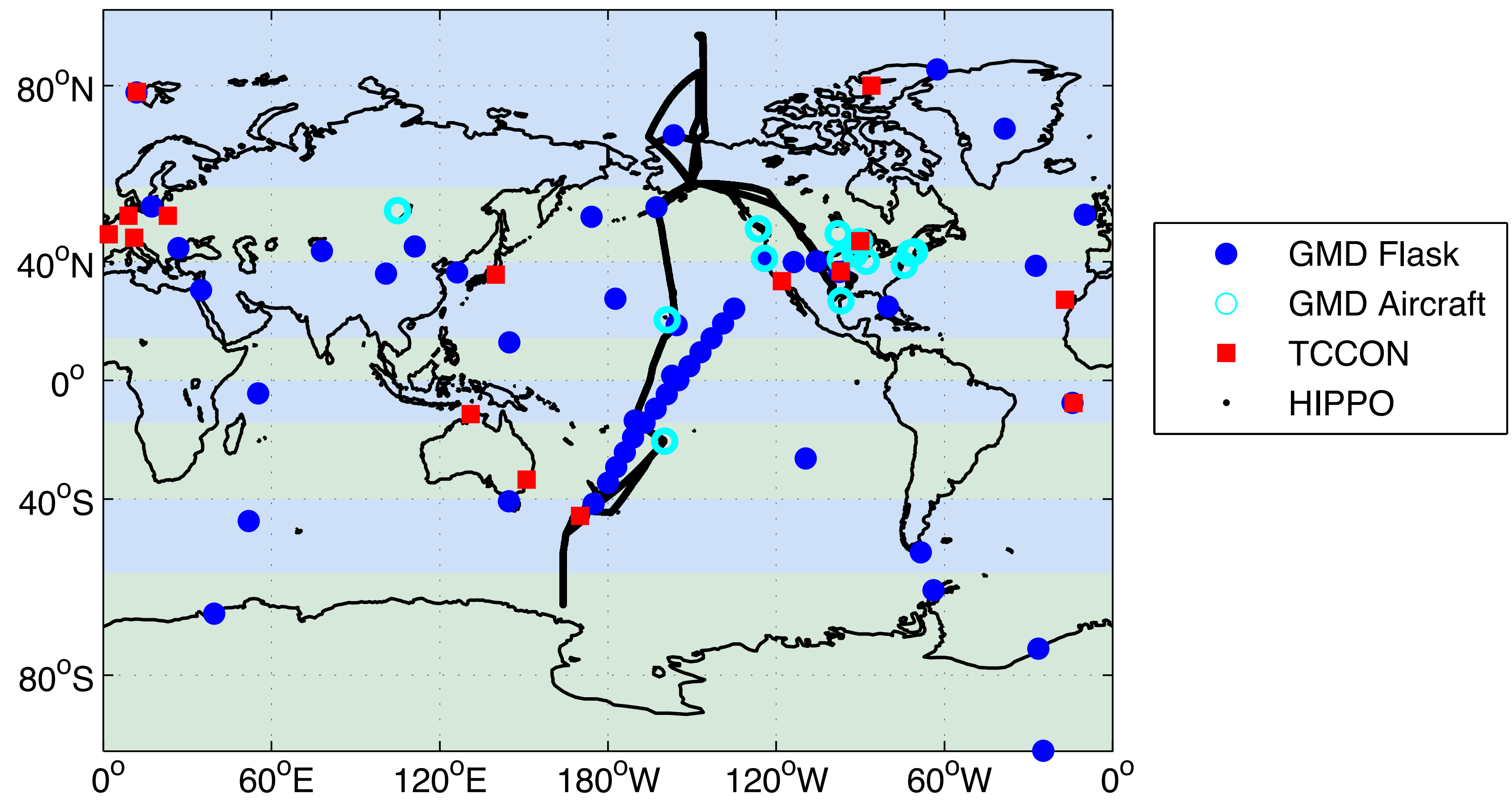
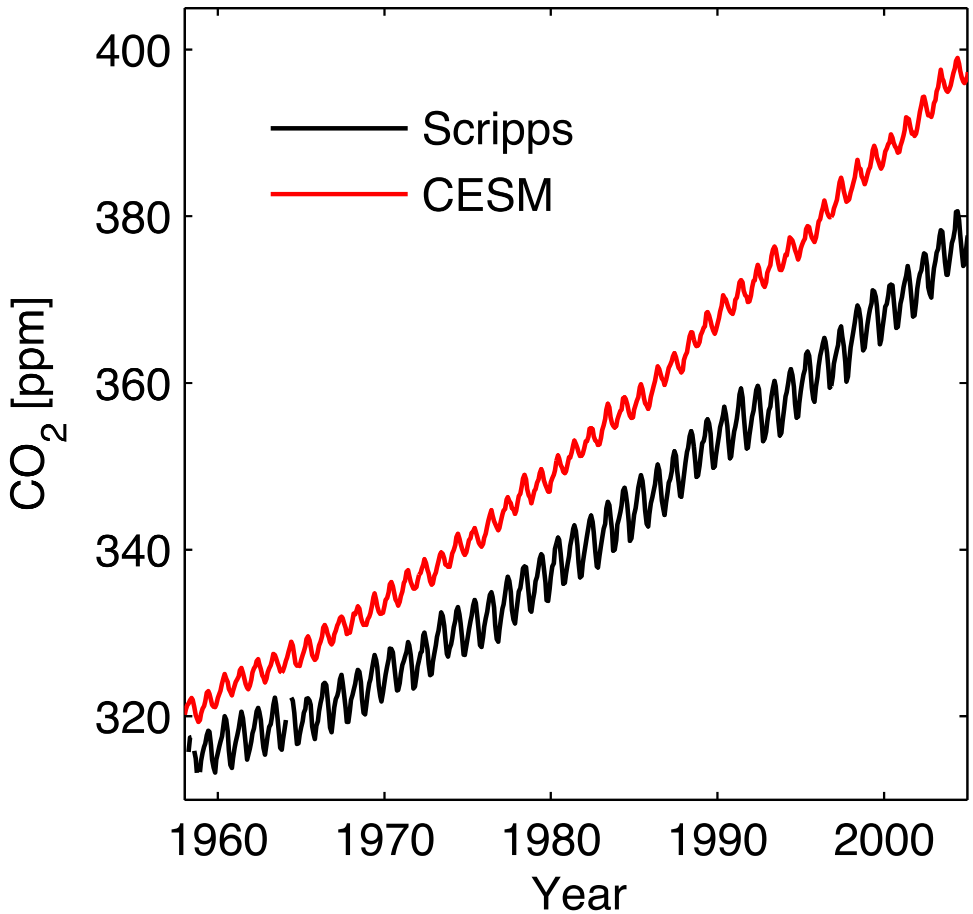
Atmospheric CO_2 Observations



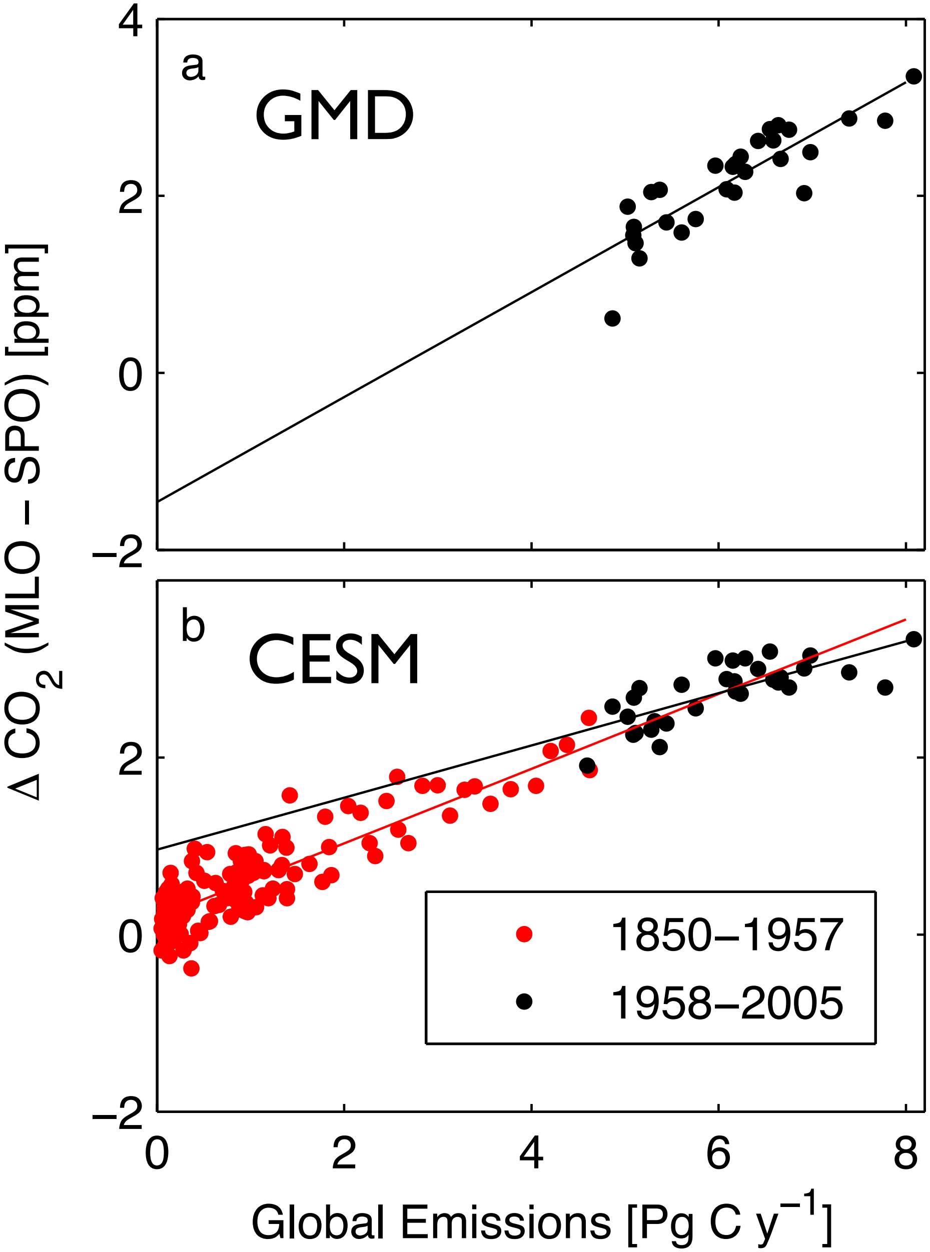
Observations that characterize vertical CO_2 are crucial for evaluating CO_2 in a model.

Growth rate in atmospheric CO_2



CESM airborne fraction of anthropogenic CO_2 is 25% high.

Interhemispheric CO_2 difference

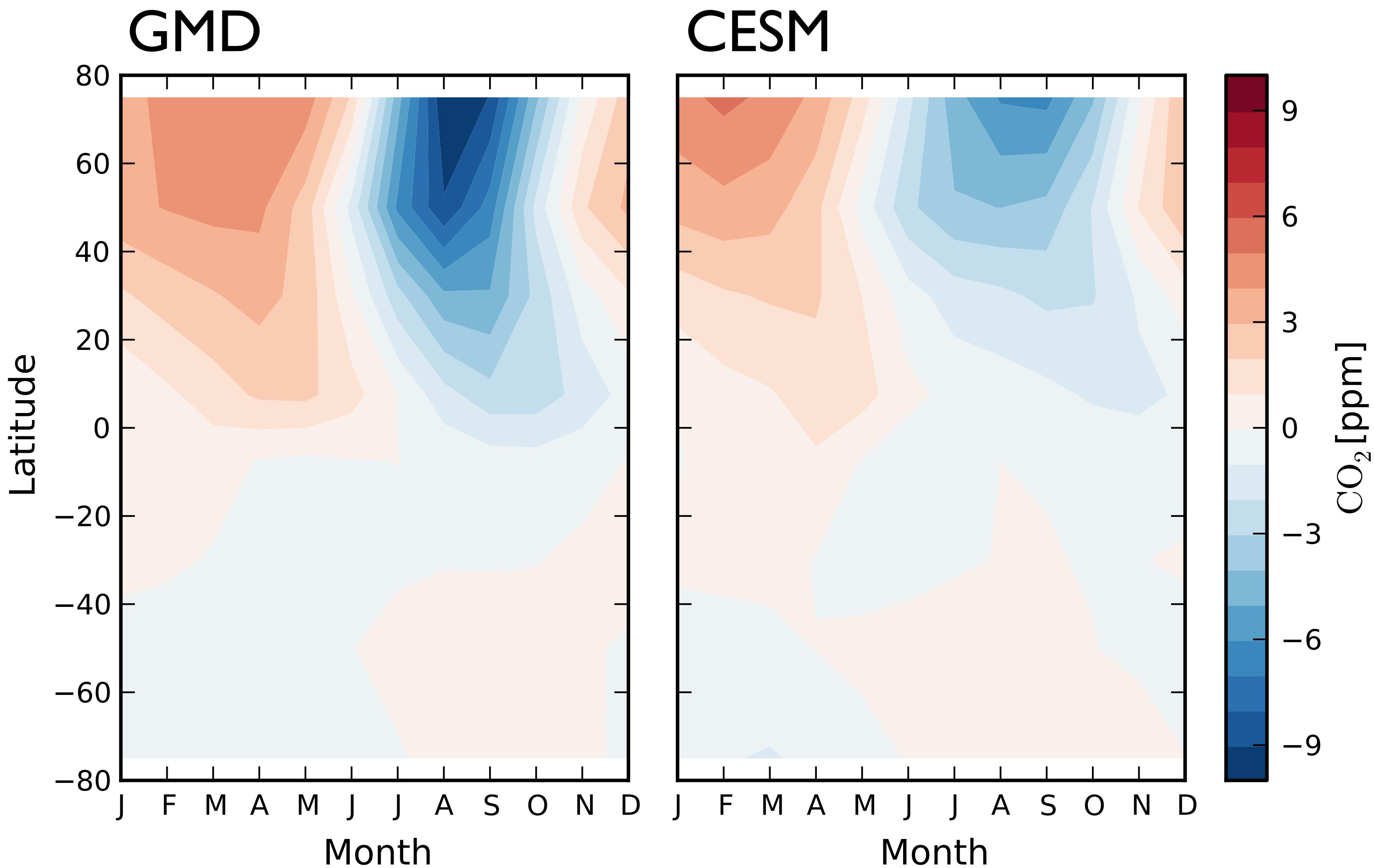


Slope: 0.6 ppm Pg^{-1}
Intercept: -1.5 ppm

Slope: 0.3 ppm Pg^{-1}
Intercept: +1.0 ppm

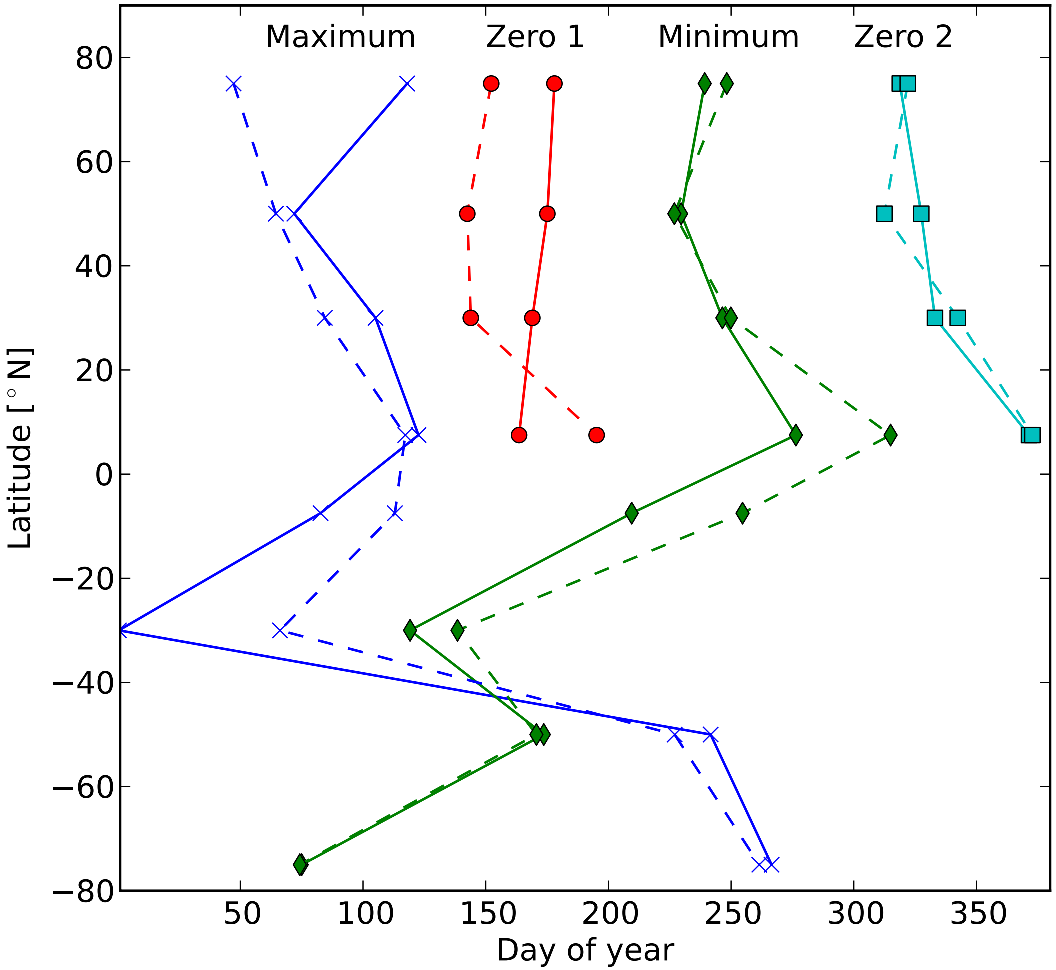
Difference between observed CO_2 at MLO and SPO suggests relatively higher southern hemisphere CO_2, whereas CESM has higher northern hemisphere background CO_2.

Seasonal patterns in CO_2

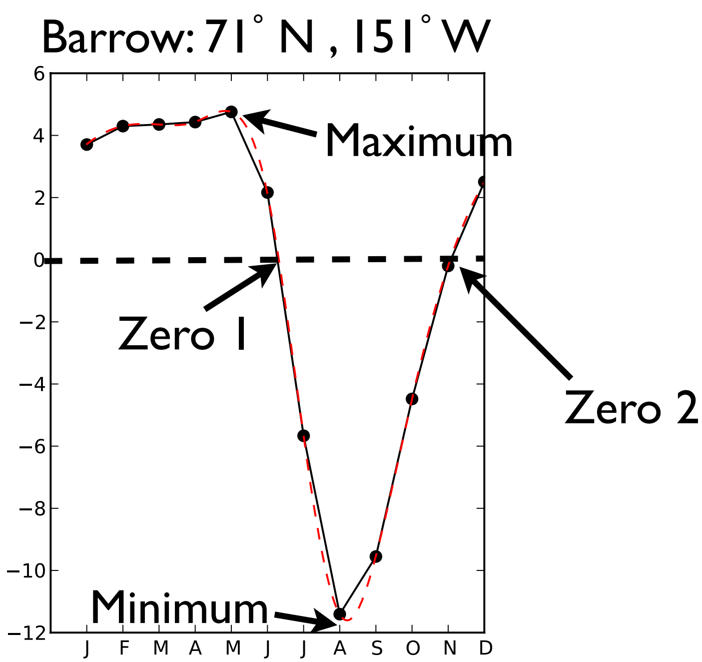


Seasonal and spatial patterns in CO_2 are underestimated in CESM.

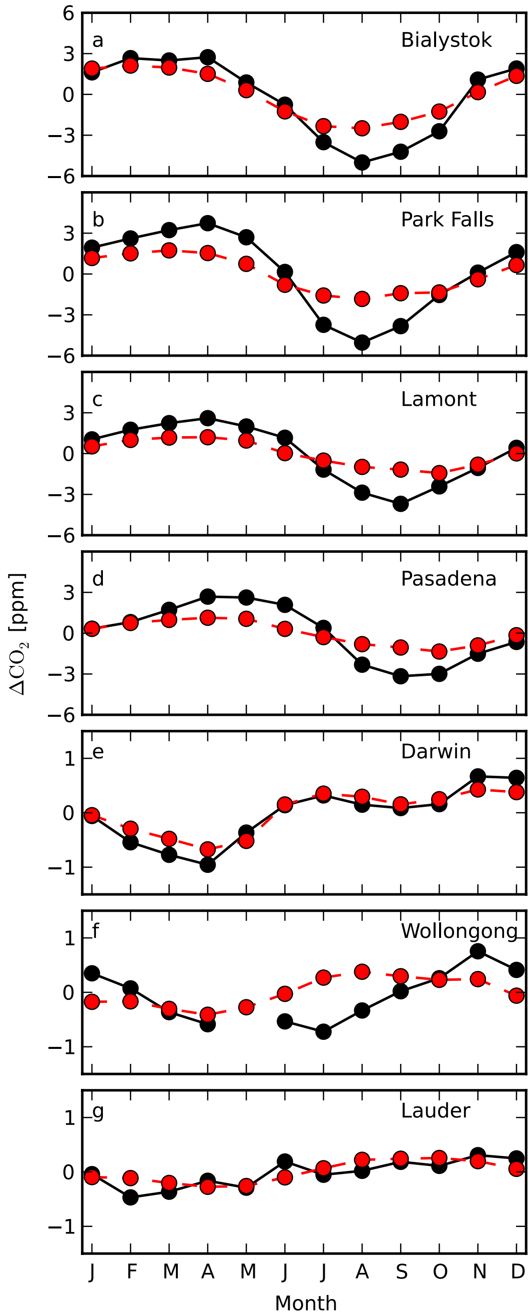
Phasing of the seasonal cycle

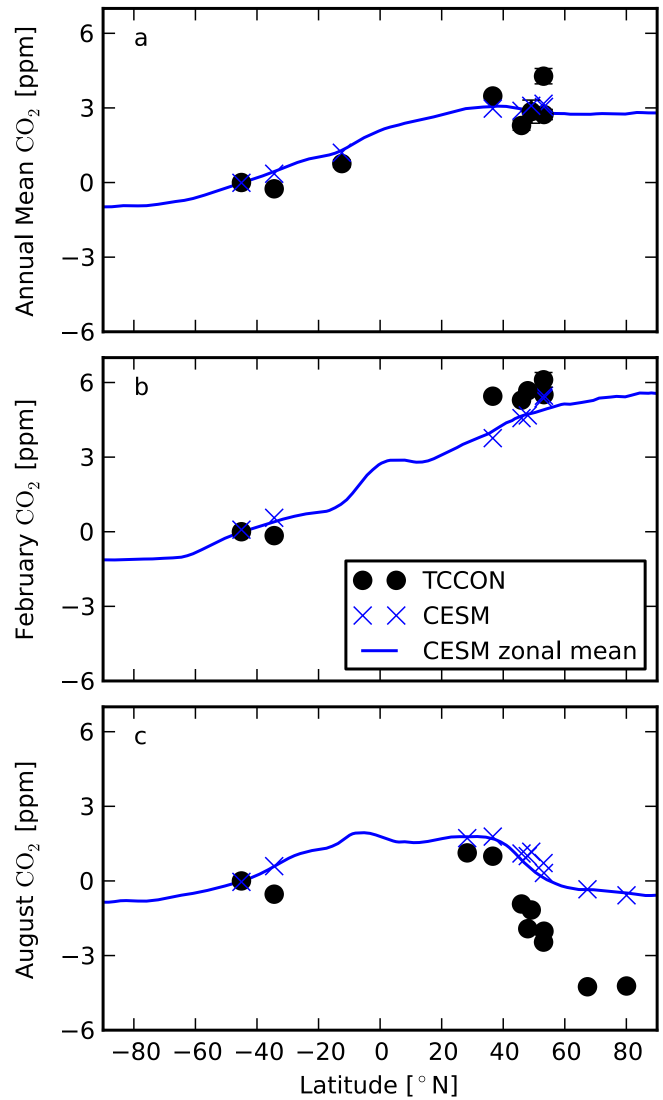


The onset of the growing season occurs too early in CESM.



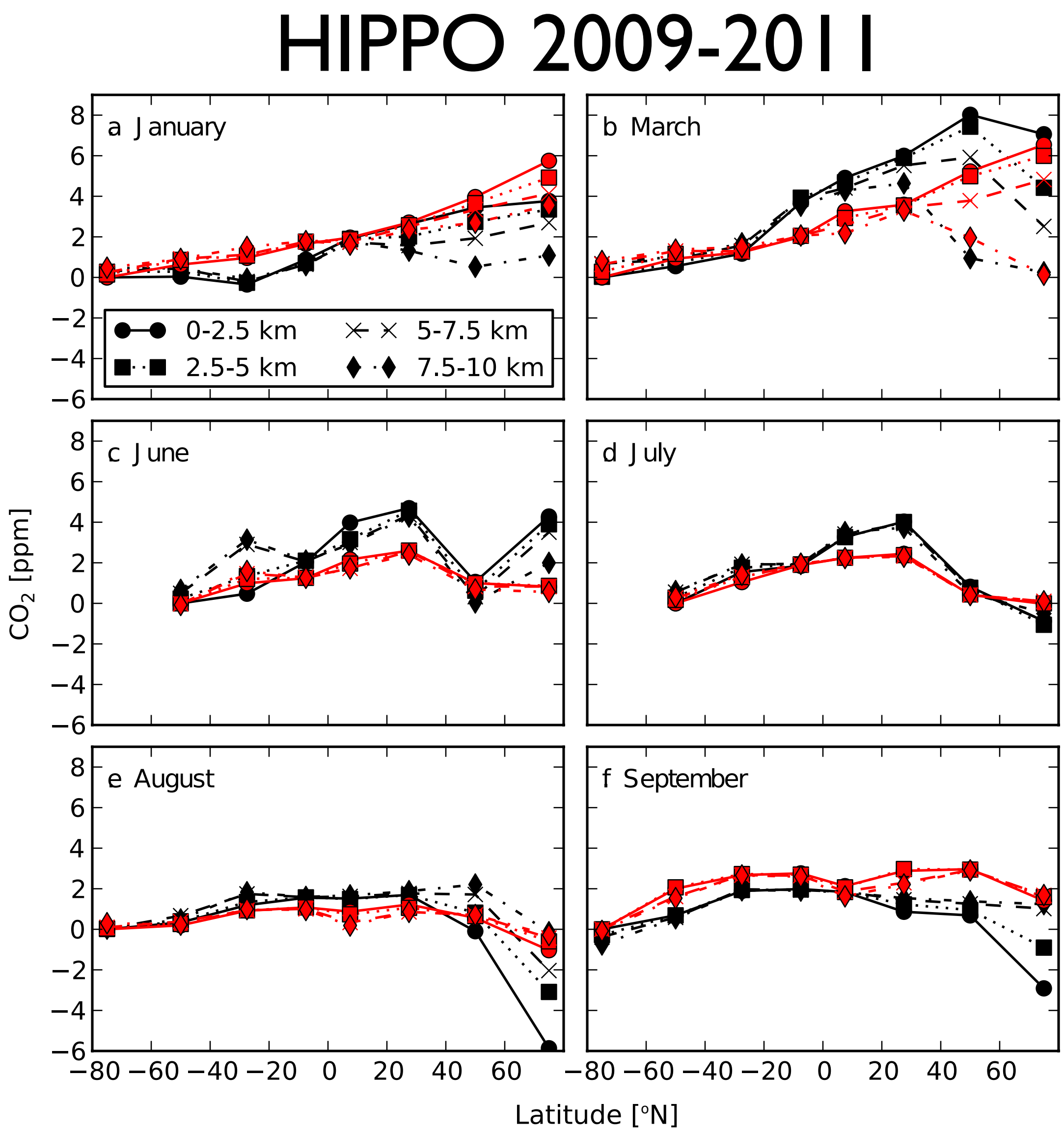
Variations in Column CO_2





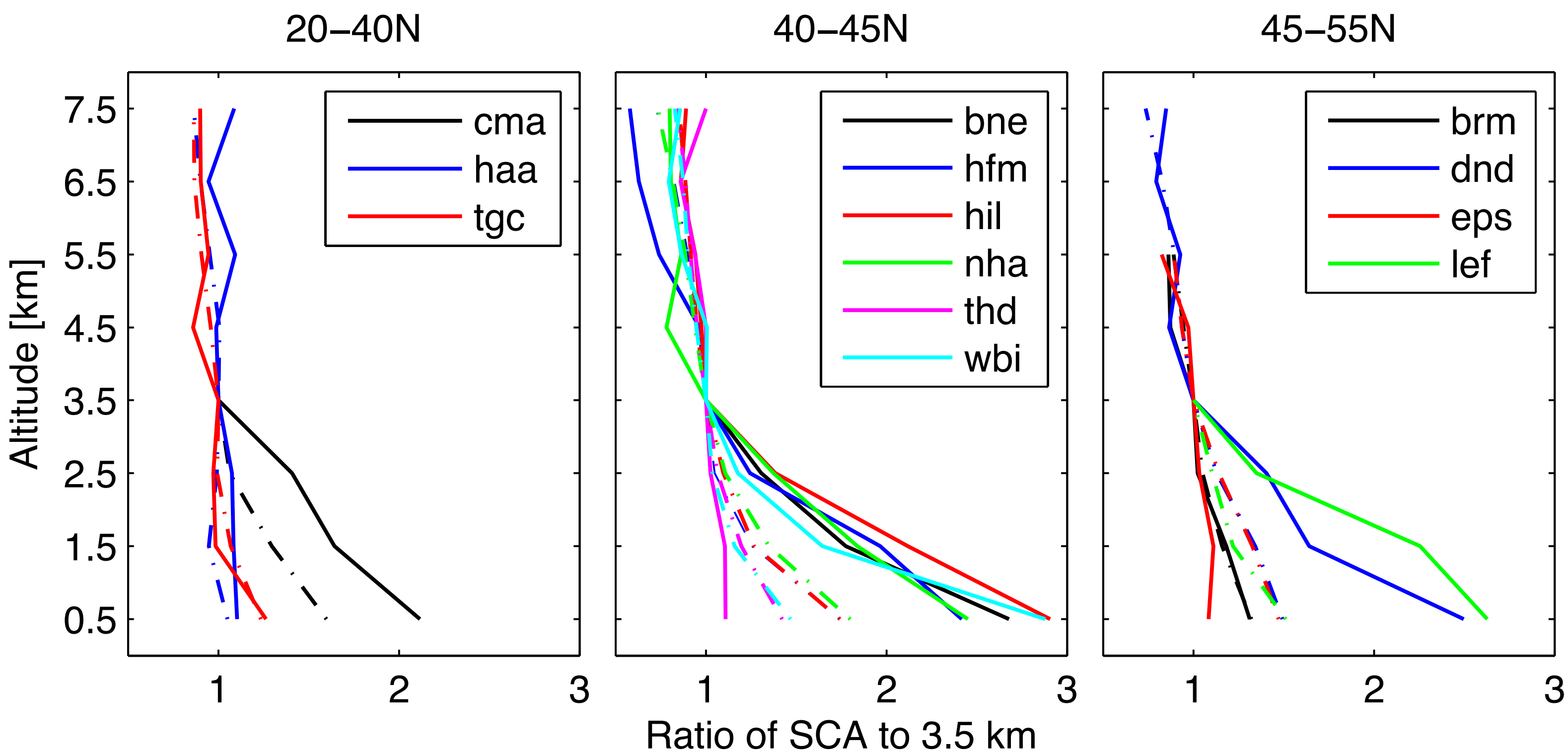
Total column CO_2 likewise suggests that CESM northern hemisphere NEP is small during the growing season.

Gradients in the free troposphere



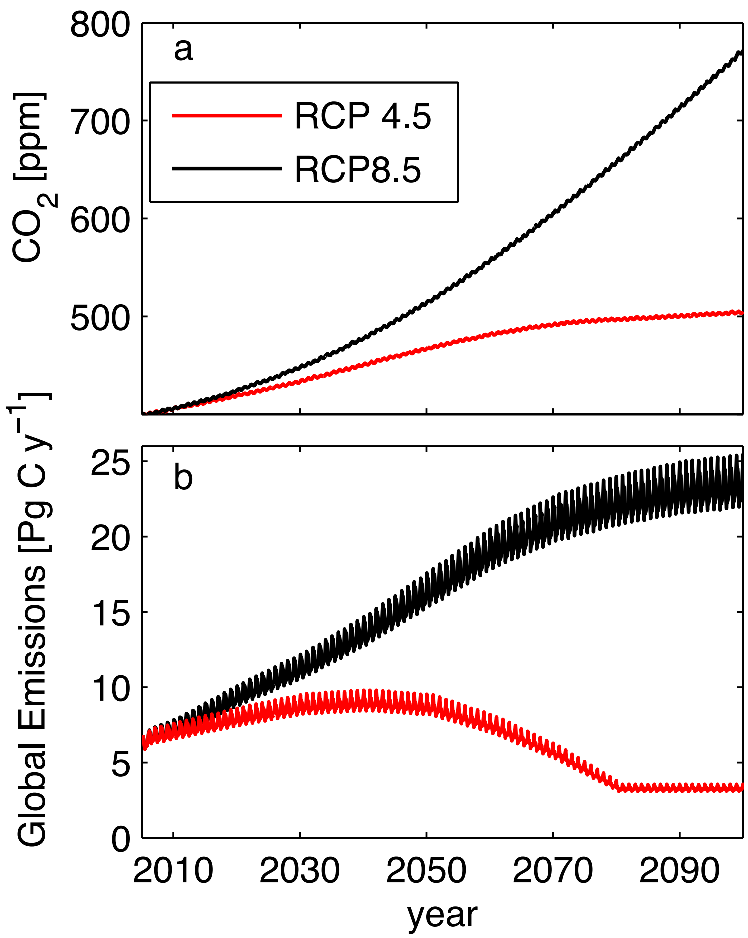
HIPPO data show larger north-south gradients during the growing season and more vertical stratification than CESM.

Vertical propagation of the seasonal cycle



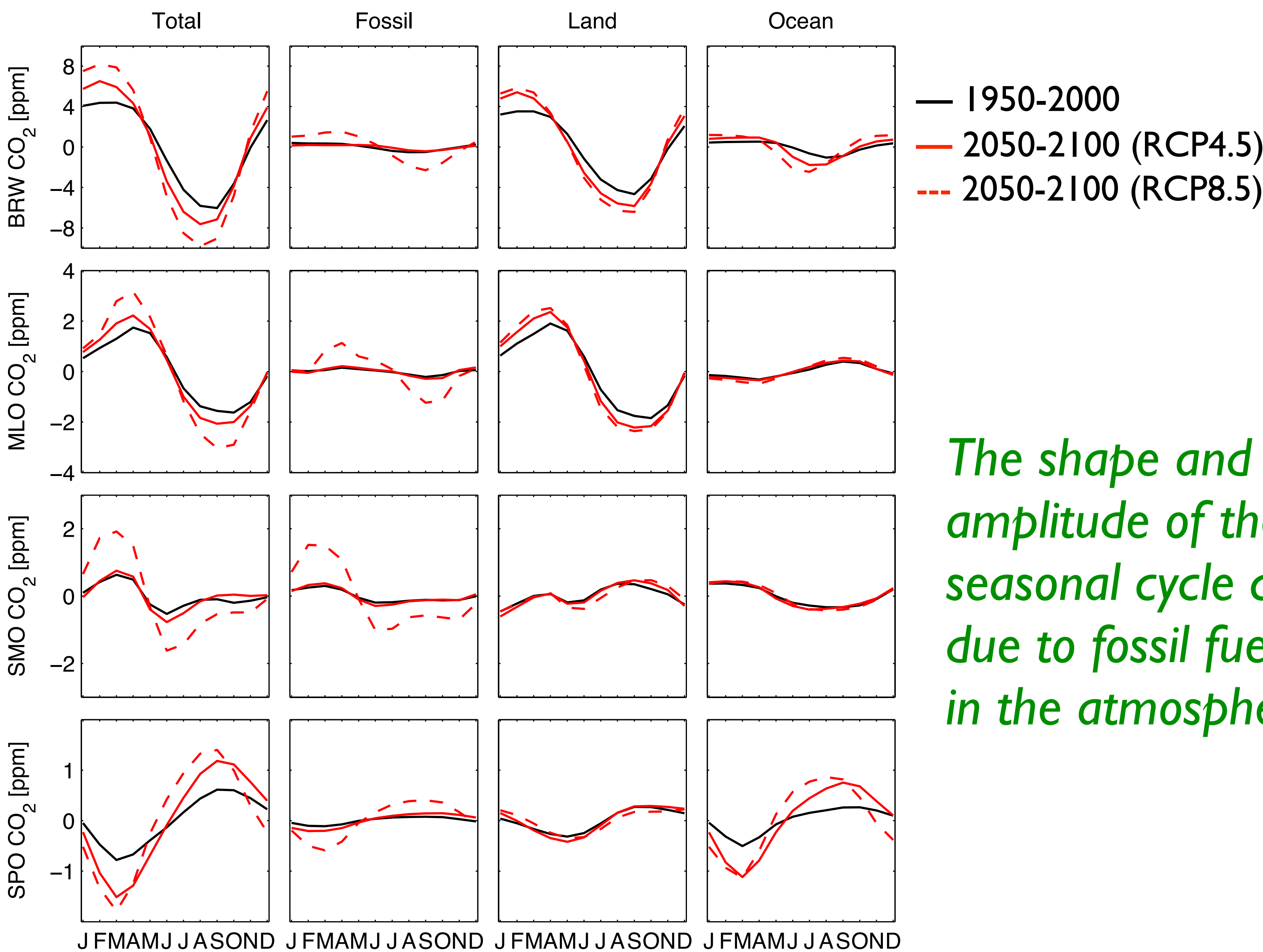
Seasonal cycle amplitudes are similar at the surface and aloft in CESM, whereas observations show a larger decrease in amplitude with altitude.

Evolution of CO_2 in RCPs



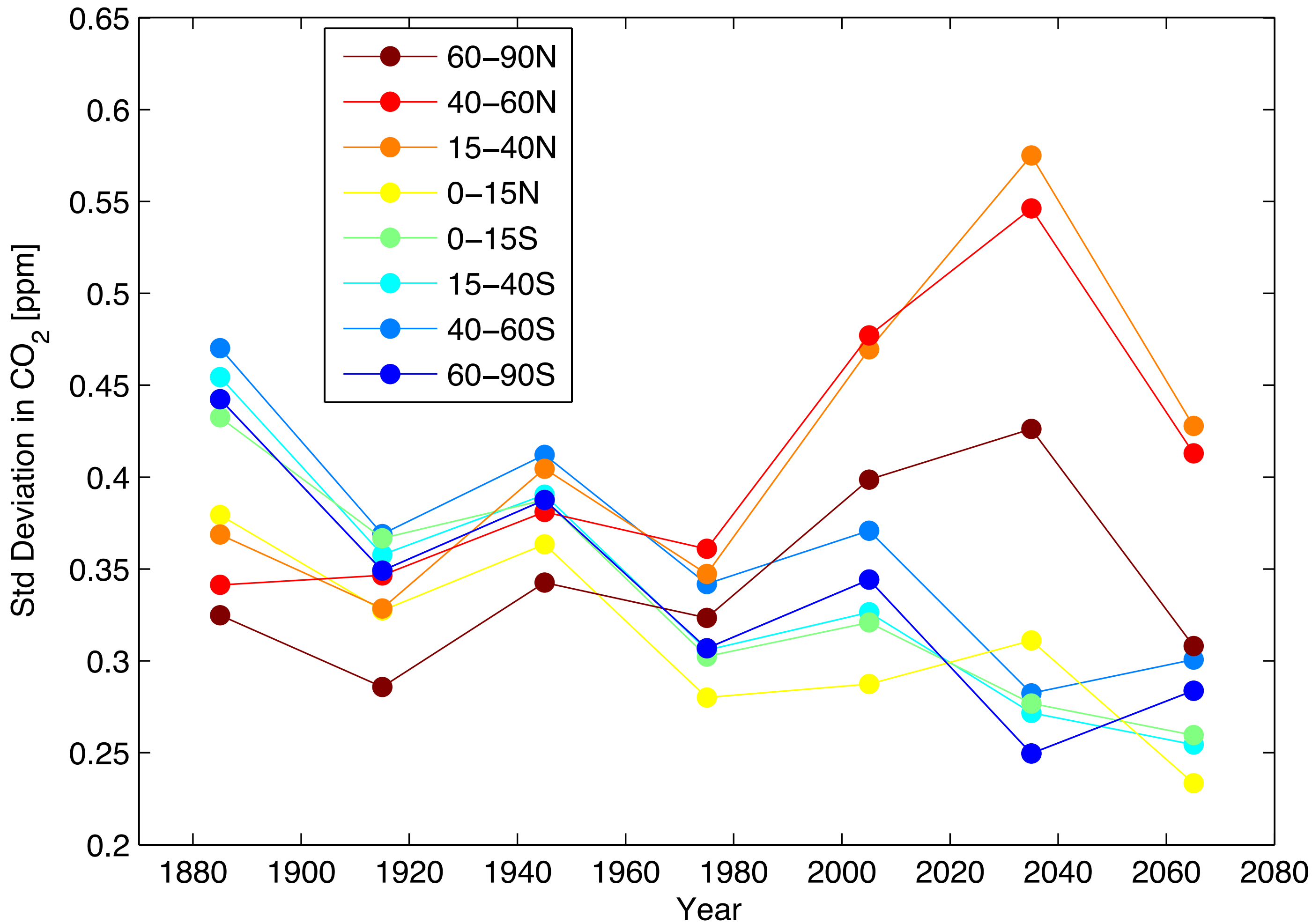
Trajectory of fossil fuel emissions in RCP4.5 and RCP8.5 scenarios leads to large differences in atmospheric CO_2.

21st century changes in seasonality



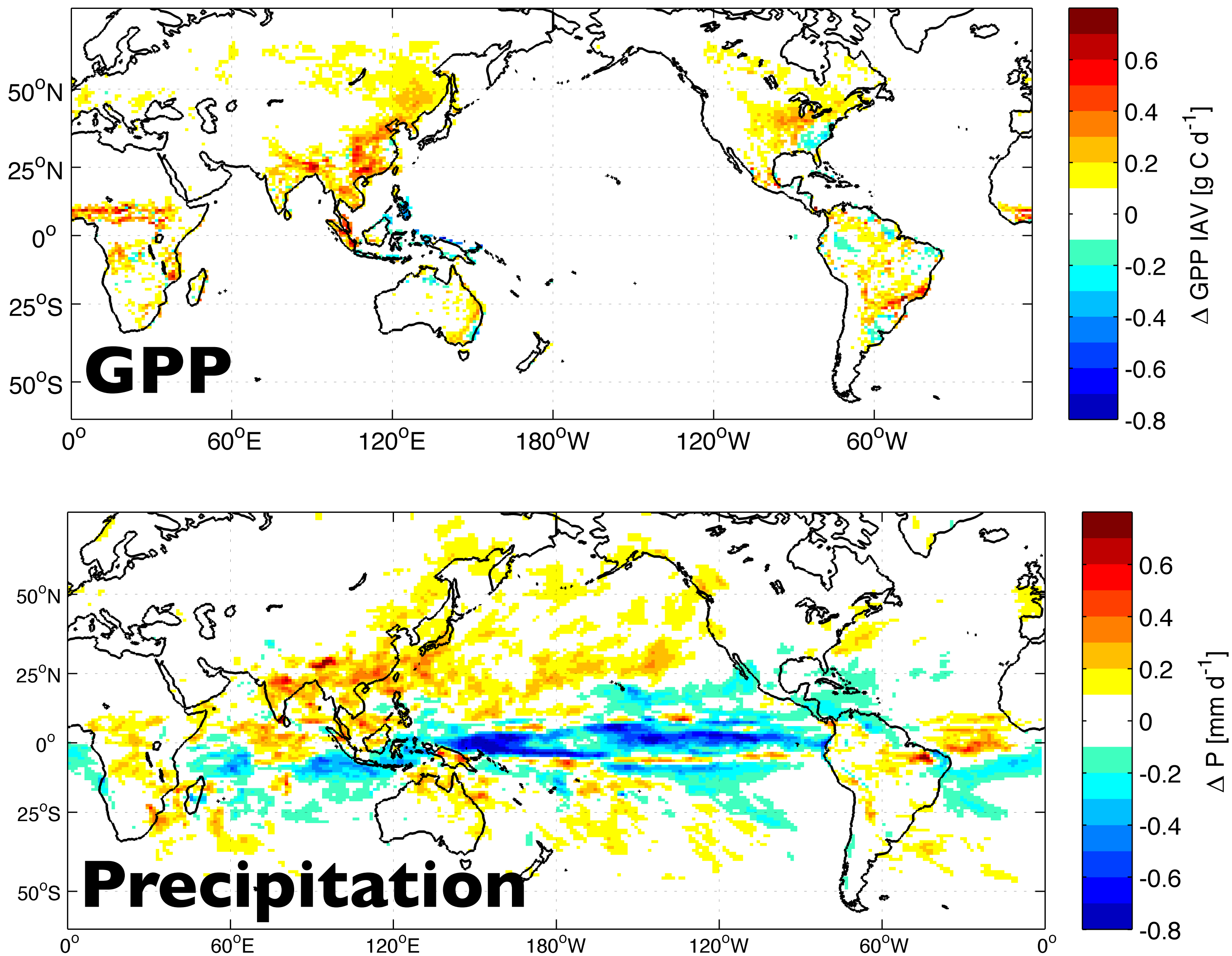
The shape and amplitude of the CO_2 seasonal cycle changes due to fossil fuel CO_2 in the atmosphere.

Interannual variations in CO_2



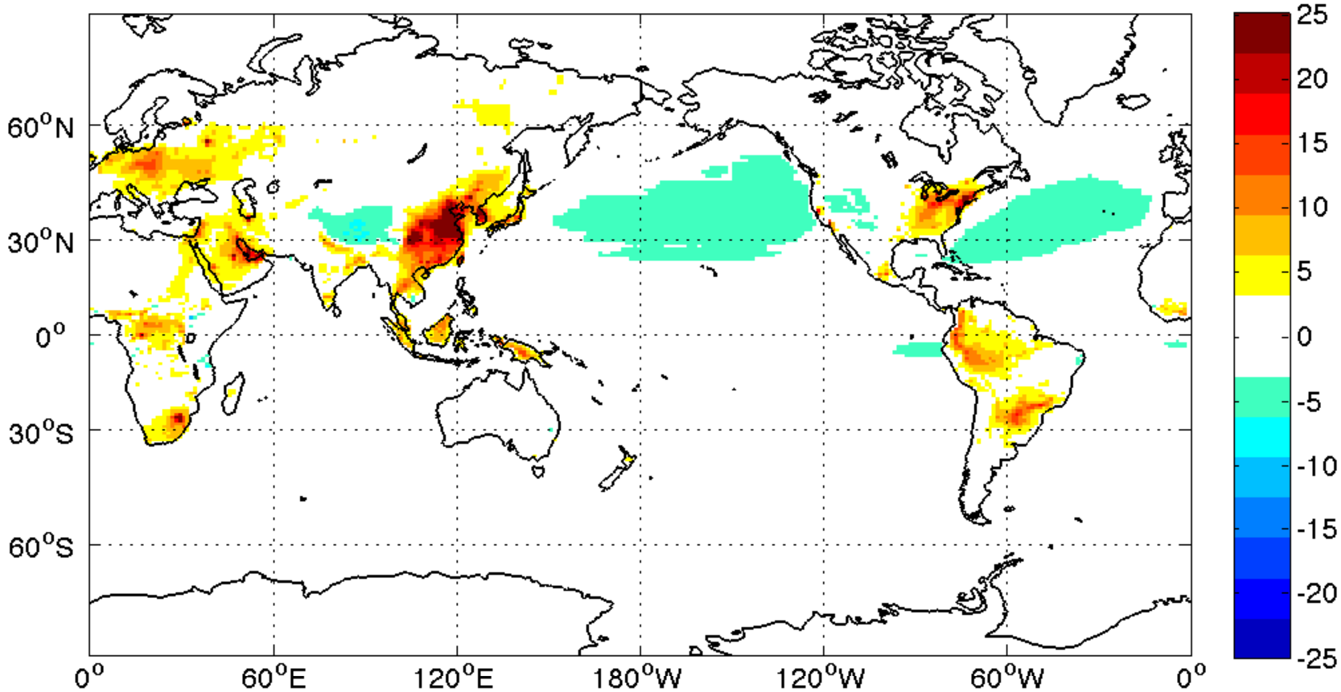
Variations in CO_2 at periods between 2-10 years increase in the northern hemisphere midlatitudes.

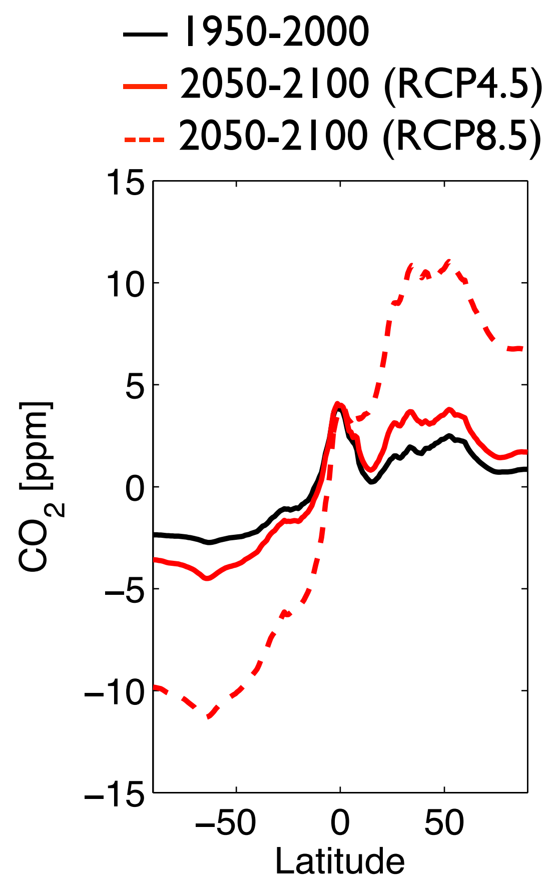
Interannual Variability in CO_2 drivers



Zonal anomalies for 2050-2100

RCP 8.5 - RCP4.5

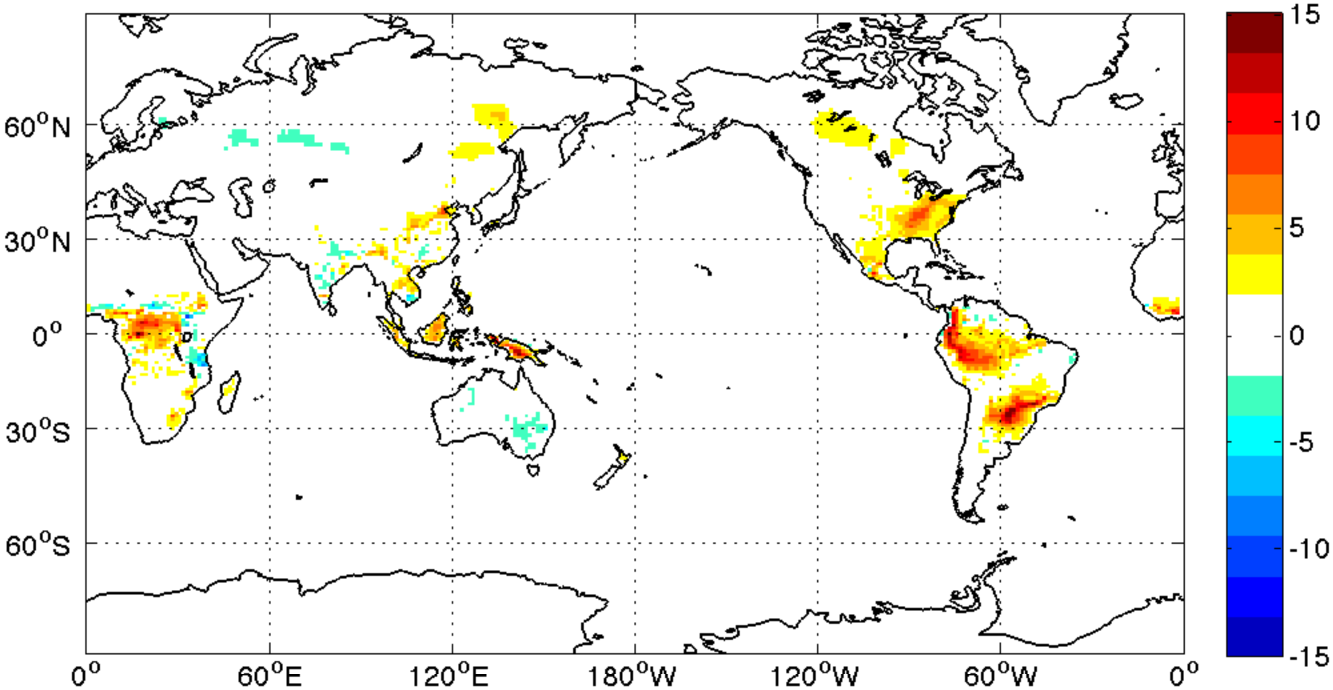


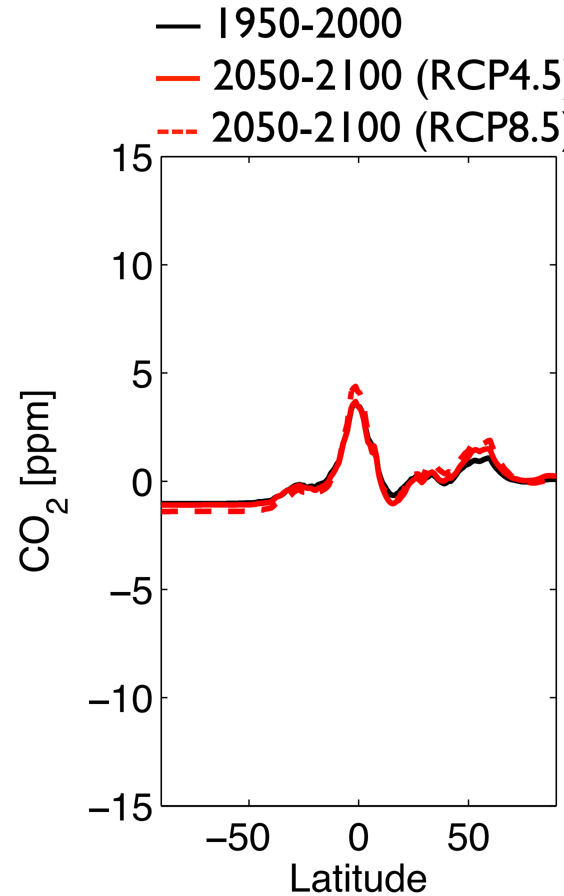


Regional patterns emerge to separate RCP8.5 from RCP4.5 scenario.

Zonal anomalies from land fluxes

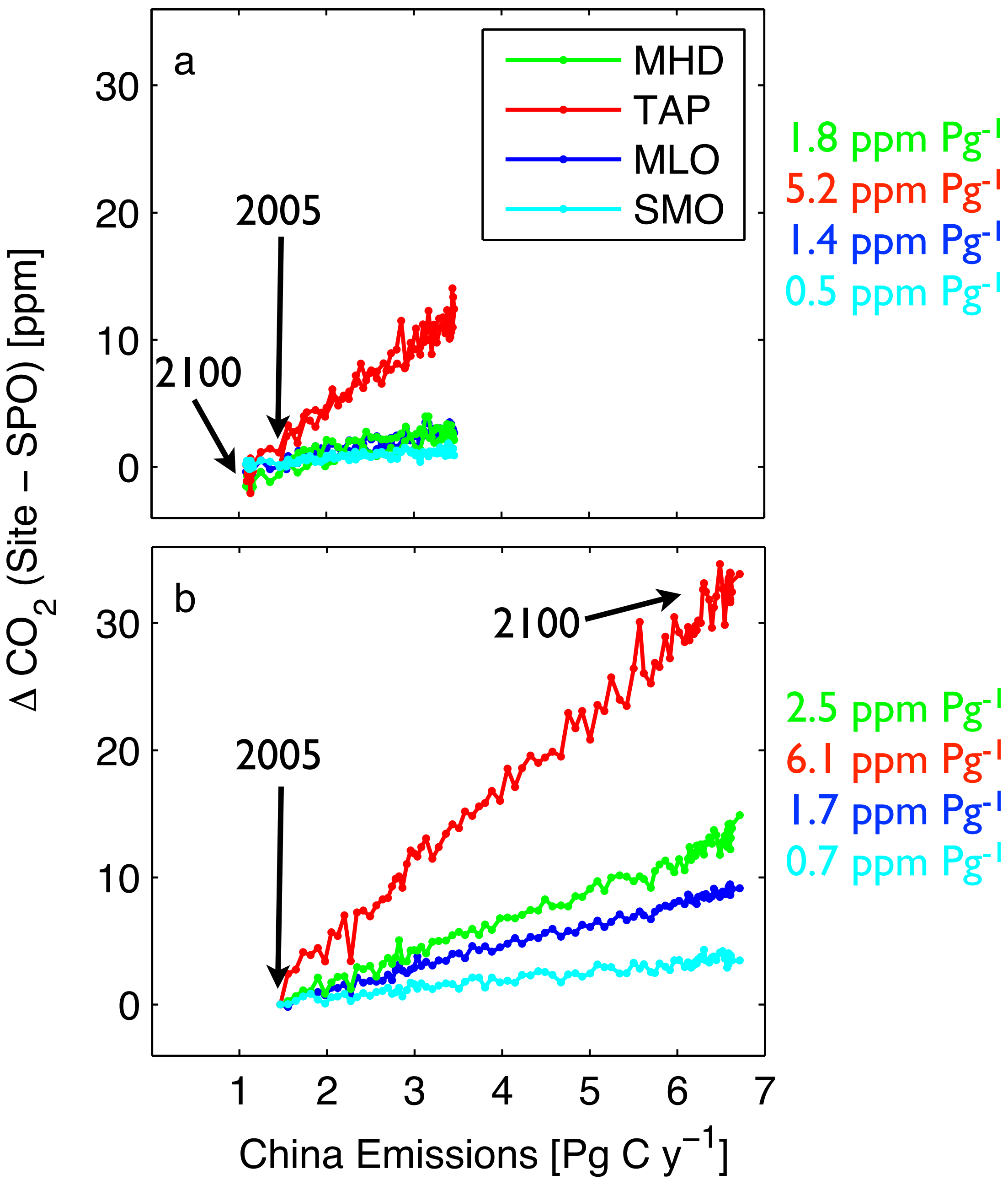
RCP 8.5 - RCP4.5





Land and ocean fluxes will generate regional anomalies, in addition to fossil fuel emissions.

Evolution of gradients in CO_2



Korean surface station shows faster increase in CO_2 relative to SPO than do other northern hemisphere stations.

Conclusions and future work

Terrestrial exchange is underestimated during northern hemisphere summer by CLM

Atmospheric CO_2 may allow us to understand CAM physics better

Export of carbon from terrestrial uptake to oceans may improve the north-south gradient in background CO_2

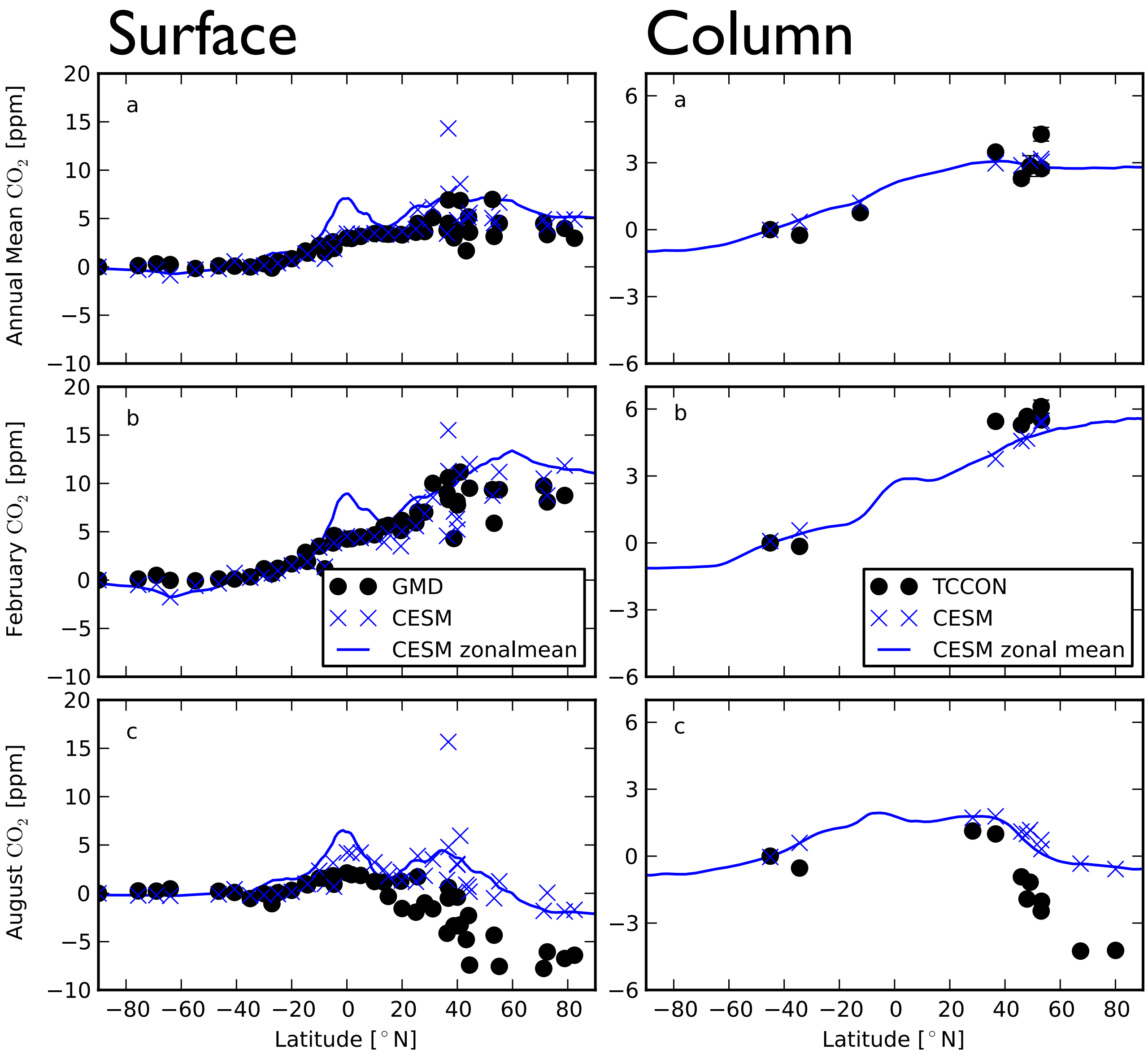
Large differences emerge in the 21st century as fossil fuel emissions follow different trajectories

CESM: trends in E-W surface gradient

Trend [ppm yr^{-1}]

Site	Data	CESM	CESM(FFF)
tap	0.17	0.19	0.19
mhd	0.06	0.02	0.07
mlo	0.06	0.02	0.06
smo	0.03	-0.04	0.01

Meridional gradient in CO_2



The north-south gradient at the surface and the column is underestimated in summer.