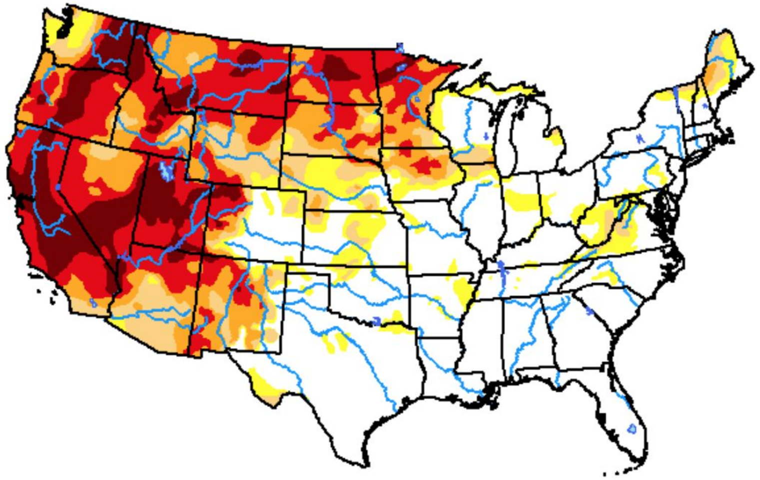
# Advancing Understanding of Plant Drought Responses in North American Ecosystems using Carbon Isotopic Discrimination in the Simple Biosphere Model



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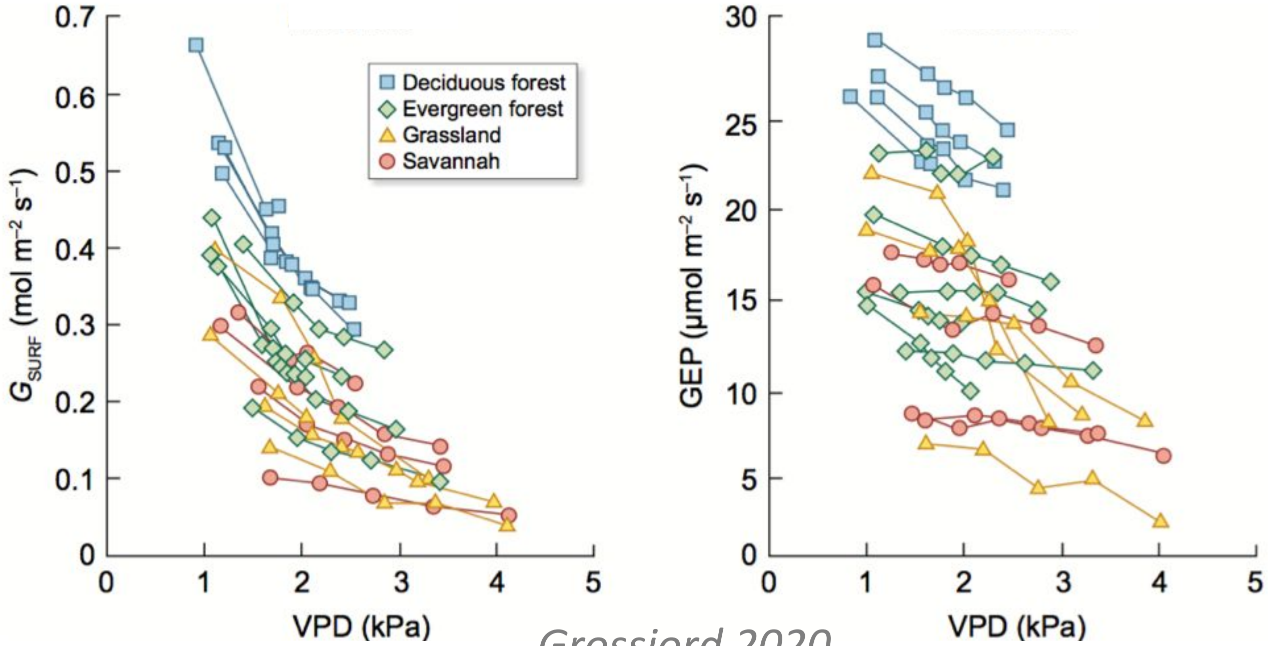
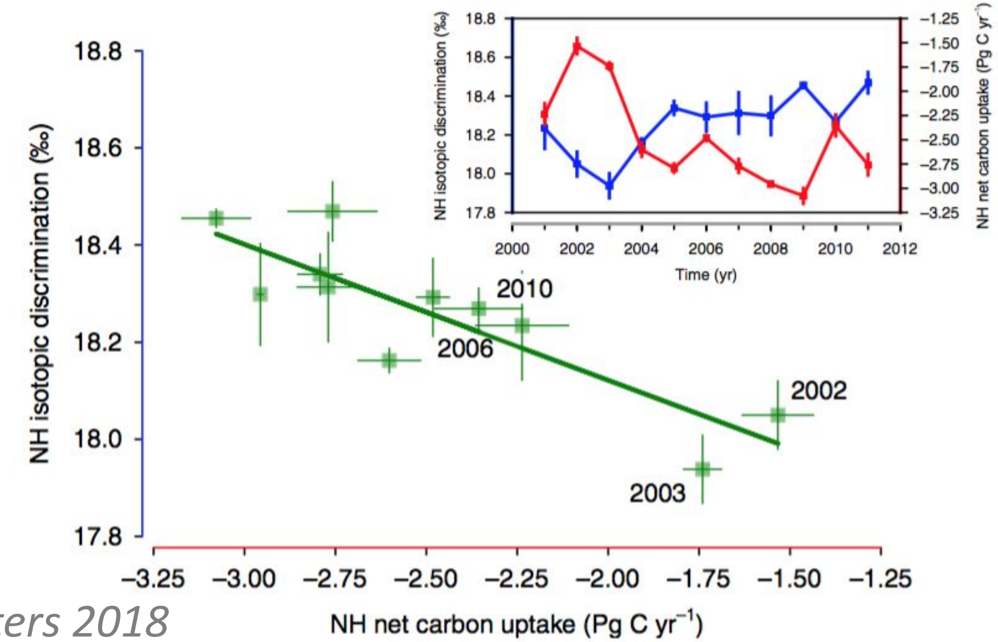
# Motivation

- Plant-drought interactions mediate ecosystem drought response
  - Plants close stomates to reduce water loss
  - Growth can be maintained, especially with higher atmospheric $CO_2$ levels



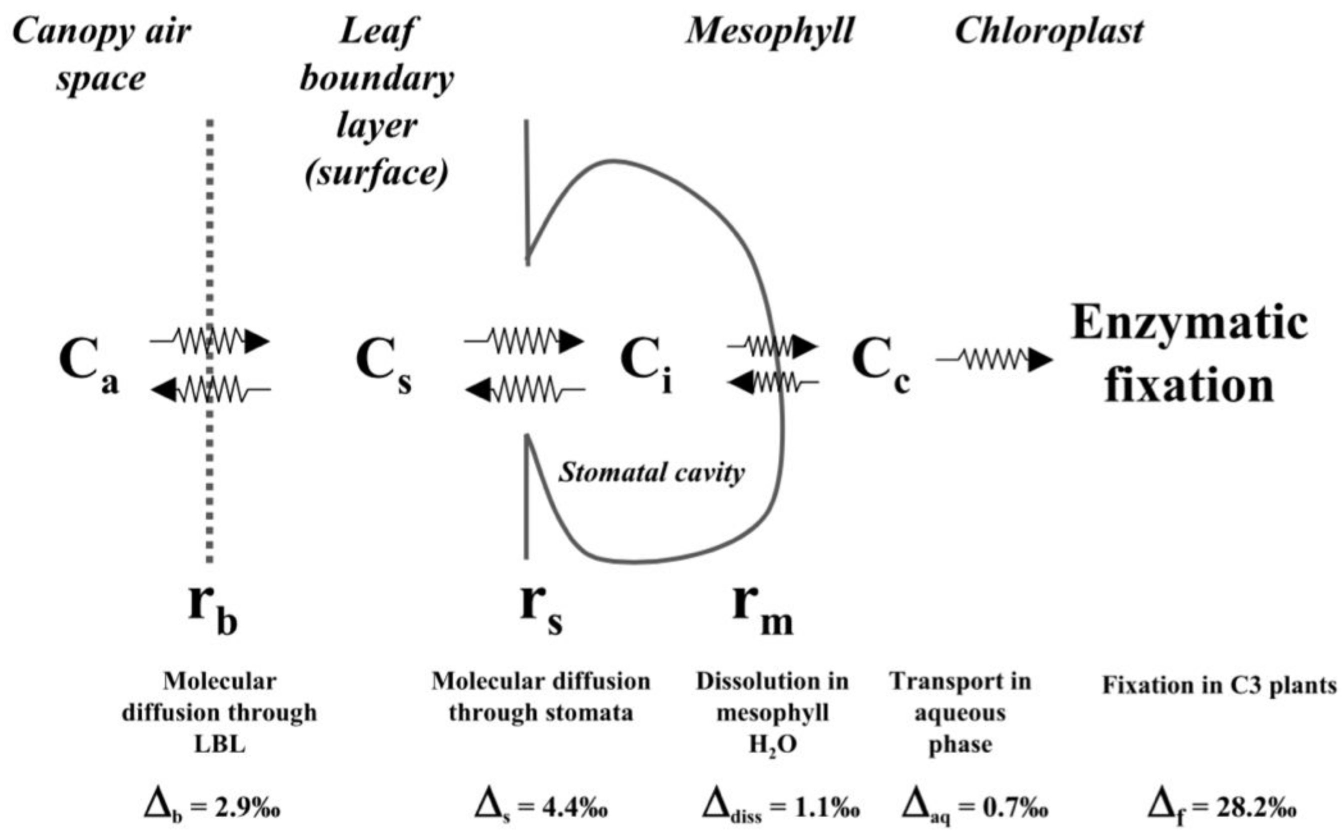

*Grossiord 2020*




*Peters 2018*

- Atmospheric $\delta^{13}$C traces drought stress
  - Plants prefer carbon-12 for photosynthesis
  - Stress leads to less discrimination, which is correlated with lower carbon uptake

# Isotopic fractionation during photosynthesis traces plant water stress




$$\Delta PS_{C_3} = \Delta_b\left(\frac{C_a - C_s}{C_a}\right) + \Delta_s\left(\frac{C_s - C_i}{C_a}\right) + (\Delta_{\text{diss}} + \Delta_{\text{aq}})\left(\frac{C_i - C_c}{C_a}\right) + (\Delta_f)\frac{C_c}{C_a}$$

*Suits 2005*

$$C_s = C_a - r_b A_n \times p,$$

$$C_i = C_s - r_s A_n \times p,$$

$$C_c = C_i - r_m A_n \times p.$$

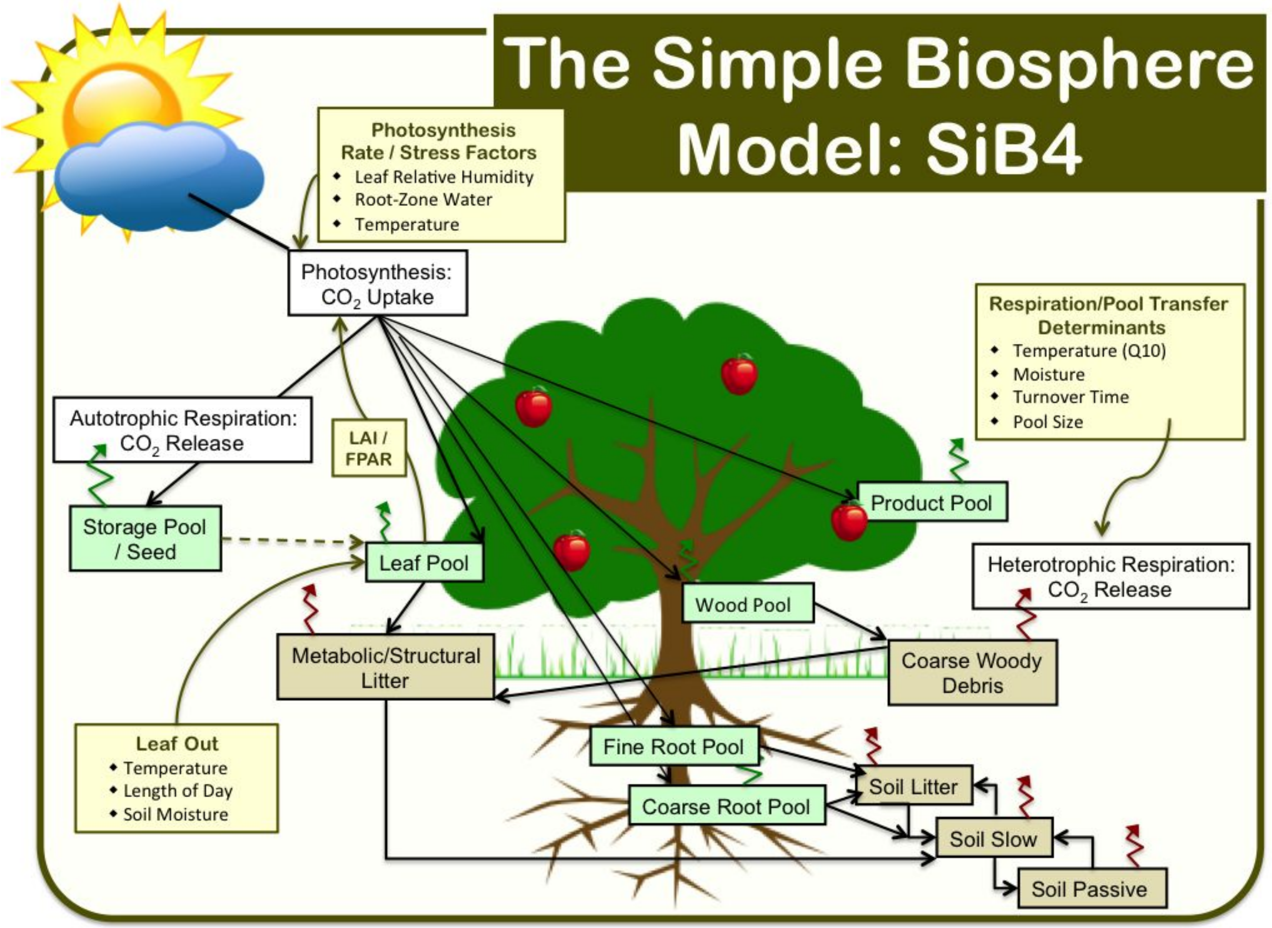
$$g_s = m\frac{(A_n h_s)}{C_s} \times p + b,$$

Ball-Berry equation

✔ We also added isotopic discrimination due to photorespiration based on Farquhar 1982

# Modeling $\delta^{13}C$-$CO_2$ with SiB4

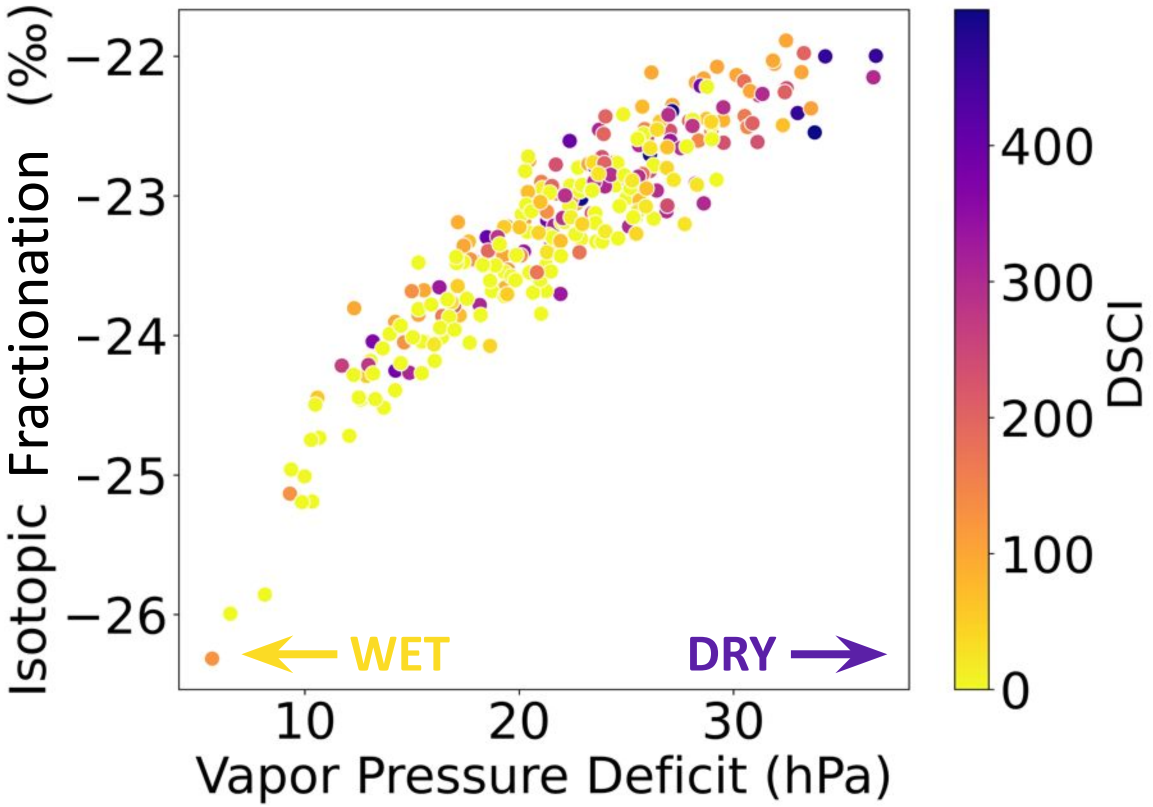
- Fractionation during photosynthesis, with photorespiration added
  *Suits, 2005; Farquhar 1982*
- Parallel pool structure for C-13 pools
- Spinup 1850-1874, run 1850-2021
- Input atmospheric $\delta^{13}C$ for 1850-2020 *Graven 2017, CU INSTAAR*
- Vary input $CO_2$ mixed layer concentration over time *NOAA GML*




*Haynes 2019a,b*

# SiB4 simulates more enriched isotopes for drier soils, higher VPD and more severe drought conditions

**GLEES site, Wyoming, ENF, Jun-Aug 2000-2020**

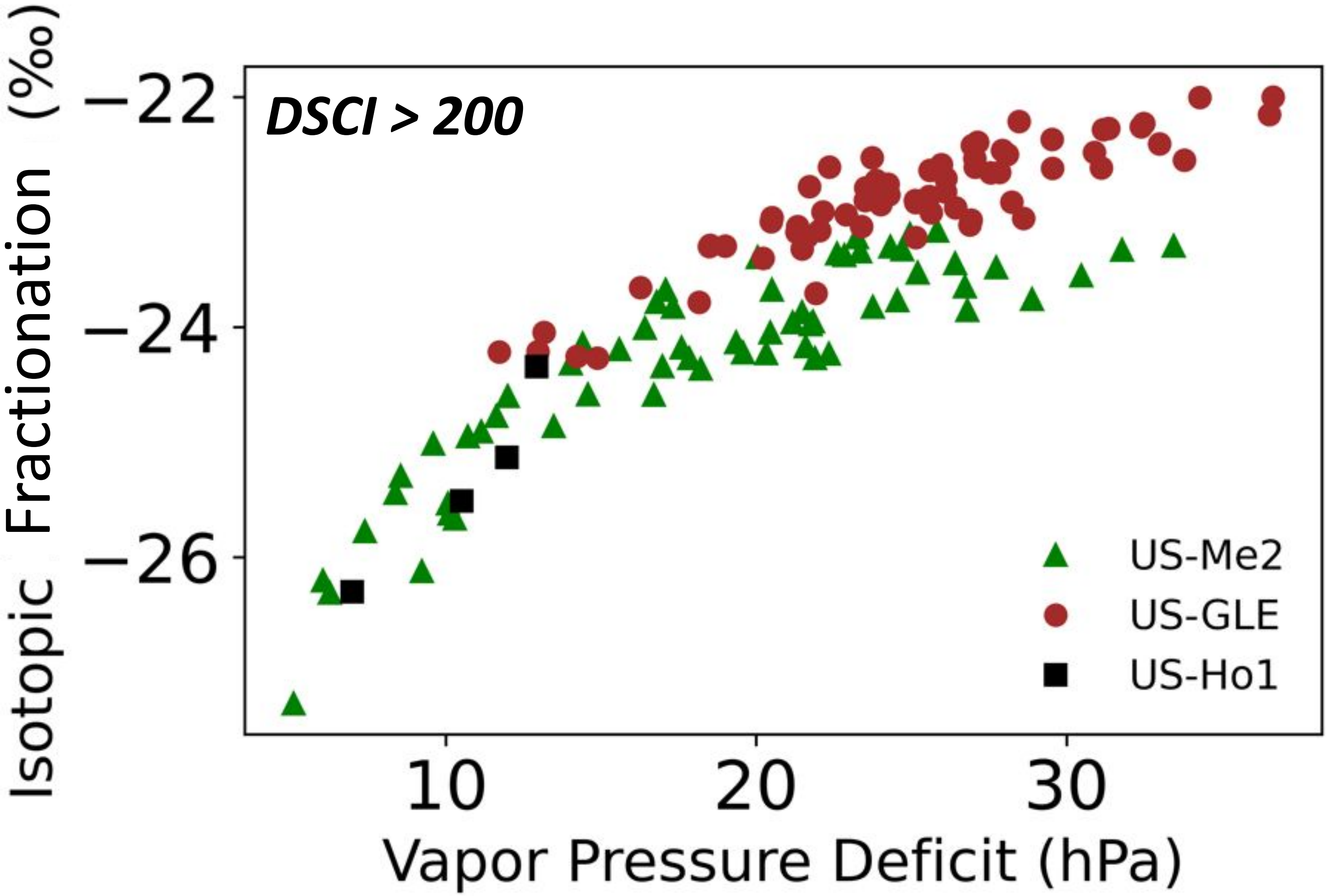



More enriched (less negative)
= more stress

$$\delta^{13}C = \left(\frac{R_{spl}}{R_{std}} - 1\right) x\,1000 \quad ; \quad R = \frac{^{13}C}{^{12}C}$$

Less enriched (more negative)
= less stress

# SiB4 dynamic range & magnitude of summertime isotope enrichment differs between climate regions for the same PFT




More enriched (less negative) = more stress

Less enriched (more negative) = less stress

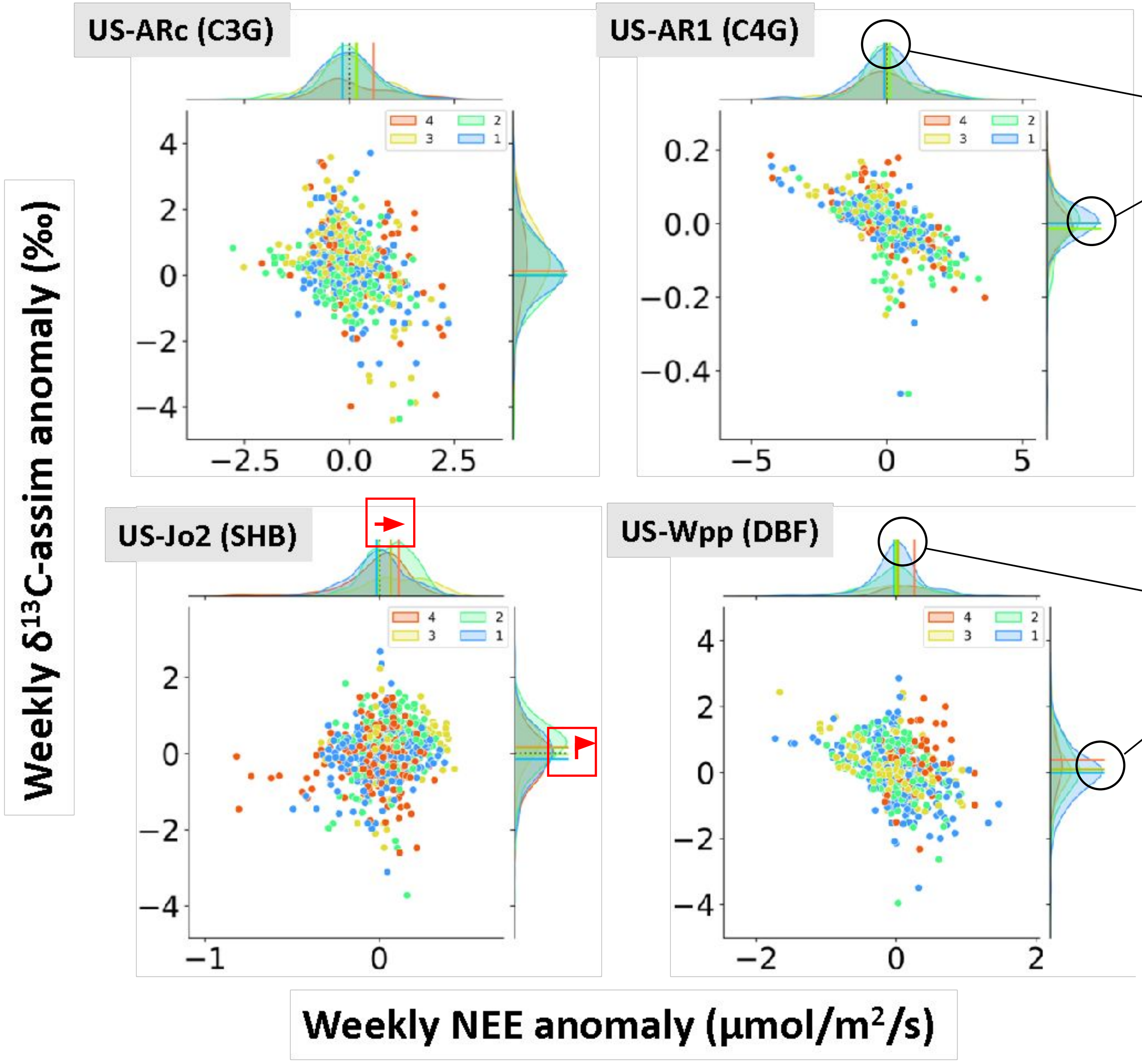
# Photosynthesis-$\delta^{13}$C variability traces drought stress

1 0 < DSCI < 100

2 100 ≤ DSCI < 200

3 200 ≤ DSCI < 300

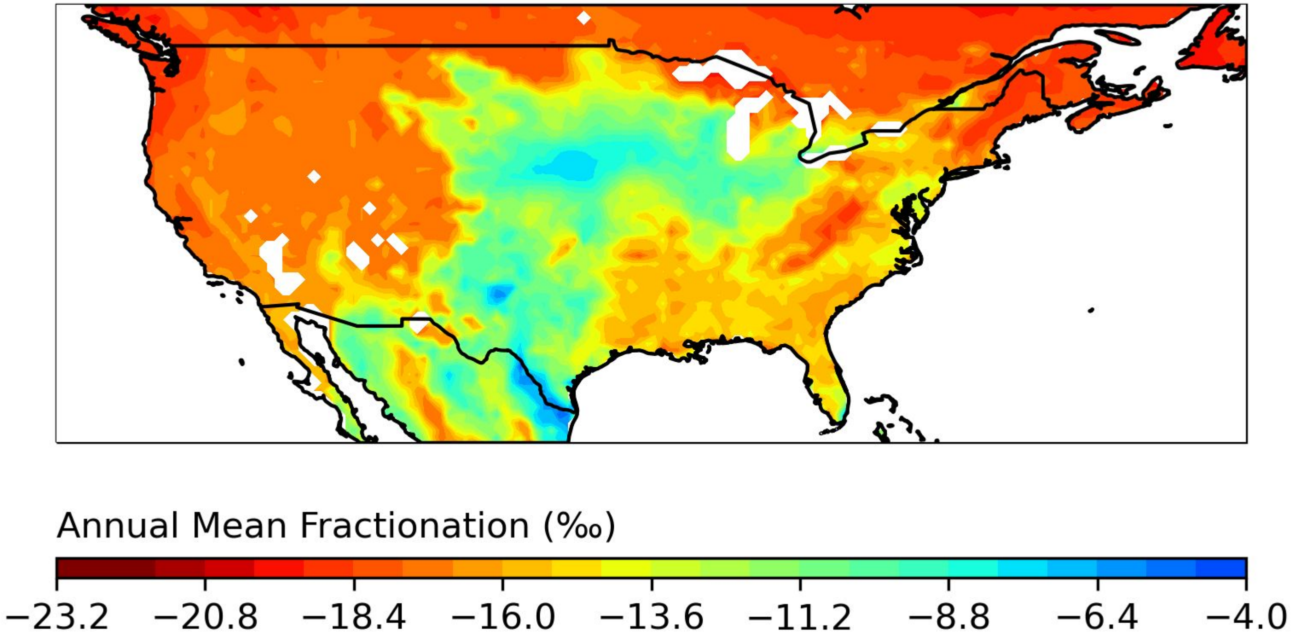
4 300 ≤ DSCI



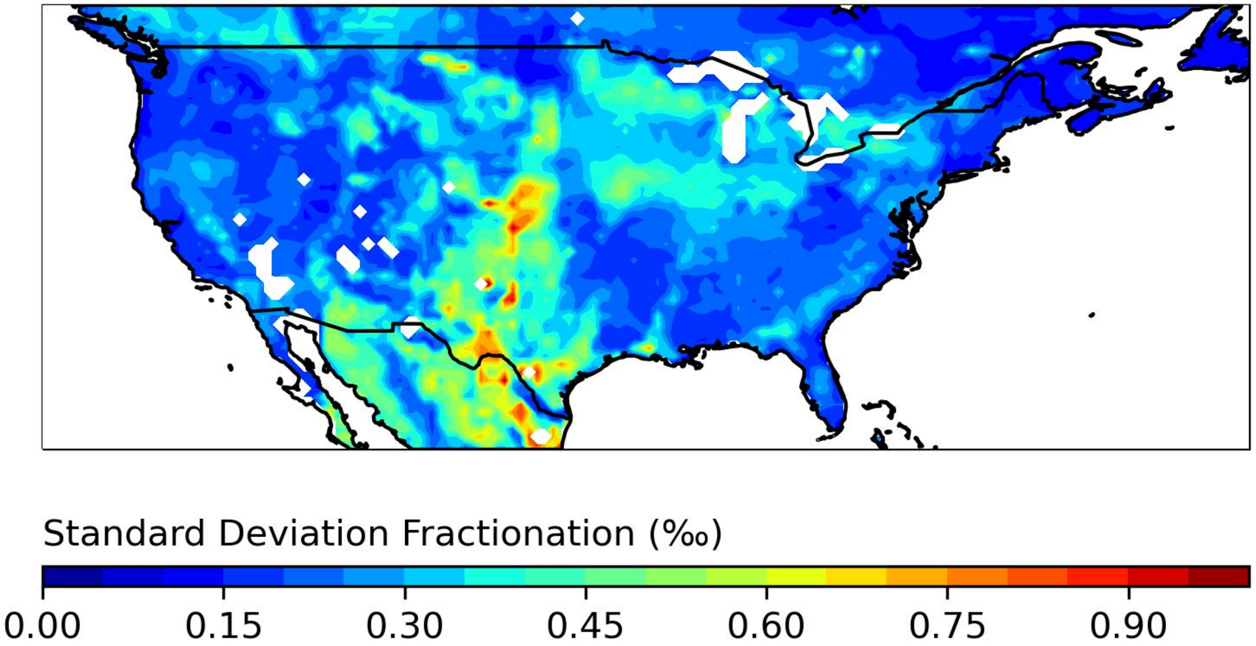

C4 grasslands show the least amount of change ('hot adapted')

Forests show some resilience to lower levels of drought

More severe drought = positive NEE & $\delta^{13}$C anomalies

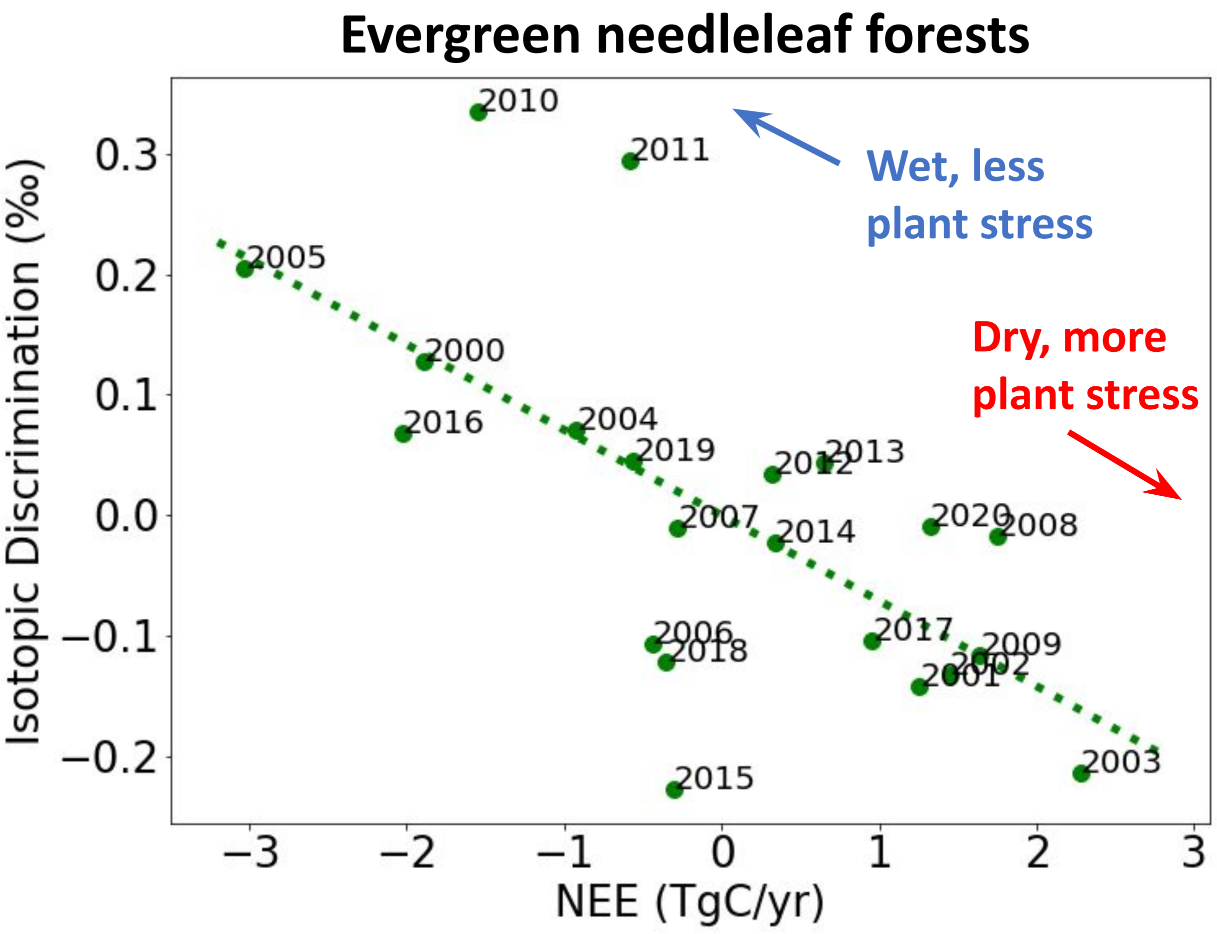


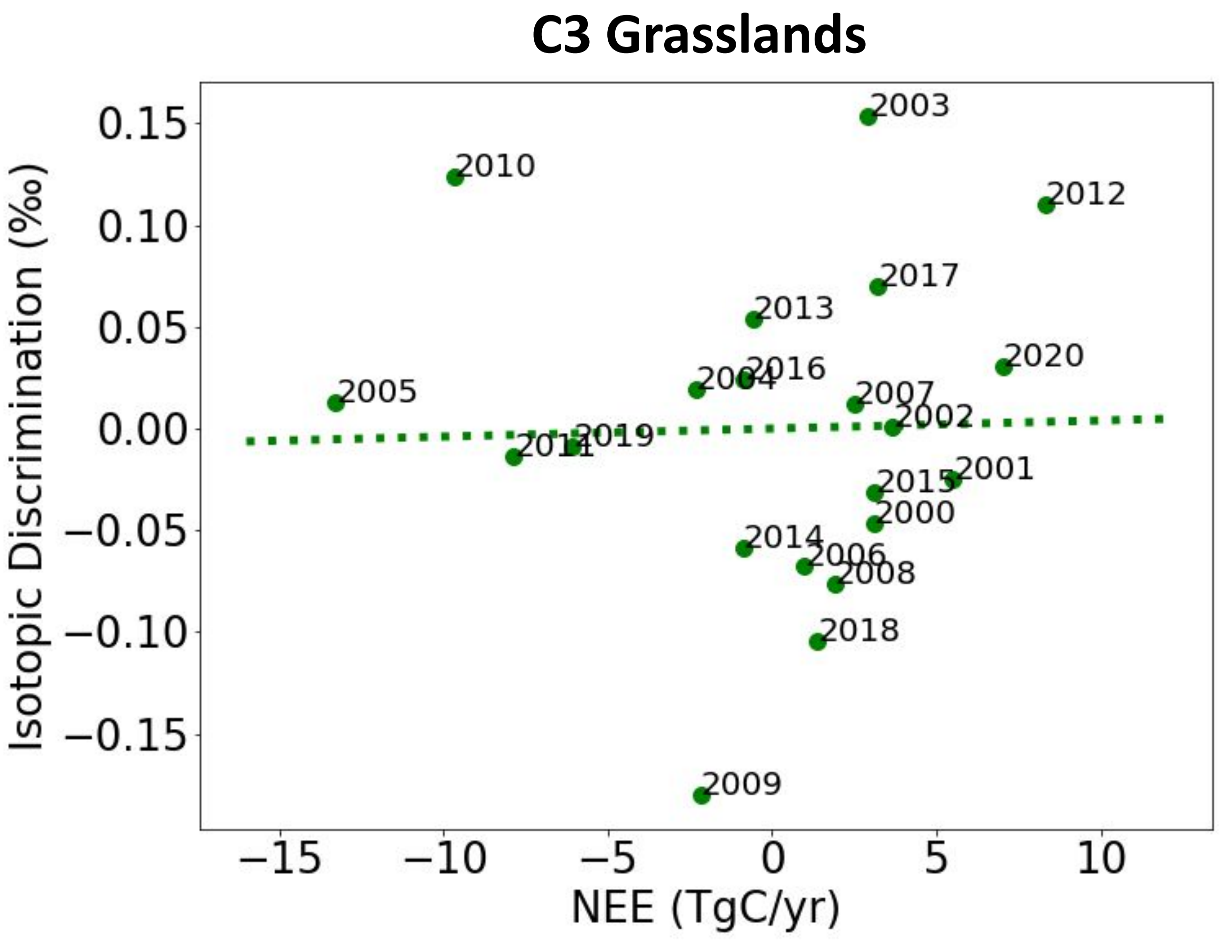

- Spatial distribution is driven by proportion of C3 vs C4 plants, as well as plant responses to climate




- High standard deviation (interannual variability) is likely driven by climate, and occurs more in mixed C3-C4 grid cells

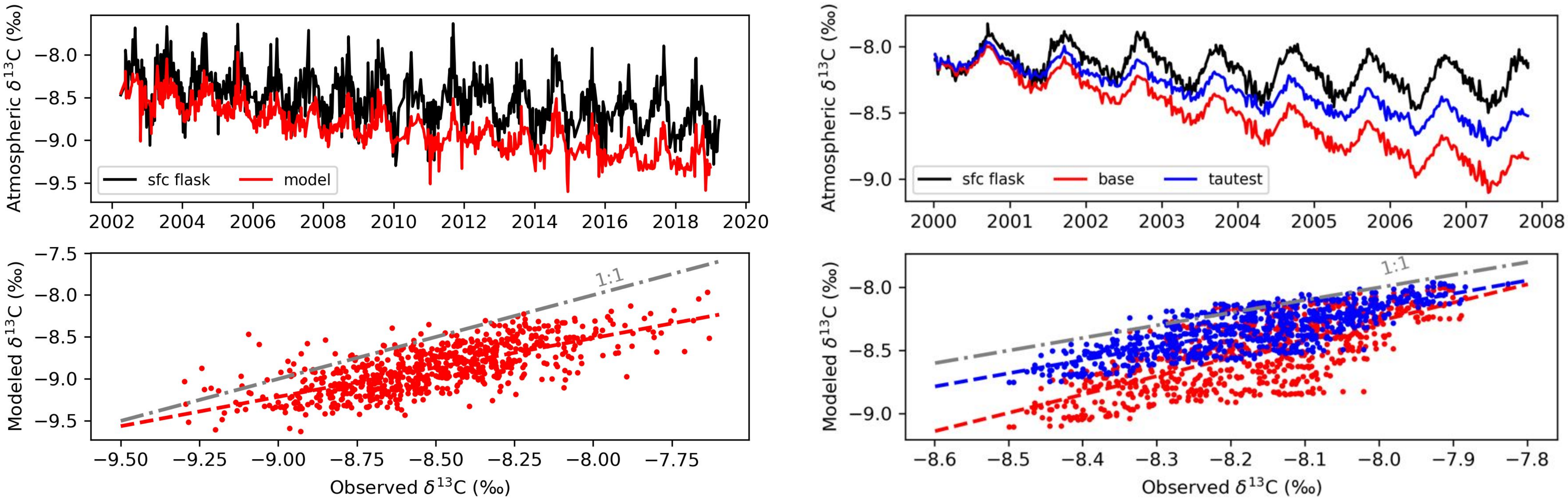
# Growing season discrimination-NEE correlation stronger in forests vs grasslands



# Using atmospheric data to diagnose model shortcomings

Atmospheric $\delta^{13}C$ signal ≈ Fossil + Net land + Land diseq. + Fire + Net ocean + Ocean diseq.




- Lack of $\delta^{13}C$ trend match is likely due to disequilibrium processes
- Adjusting modeled carbon residence times based on observations impacts disequilibrium and reduces the trend mismatch

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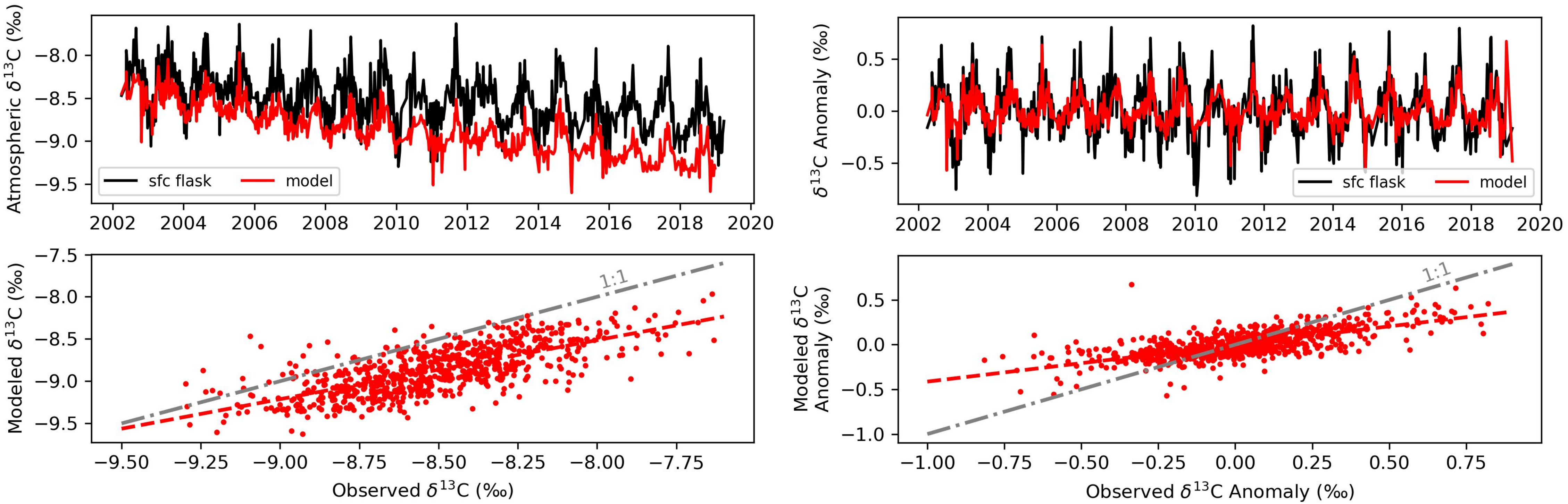


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- Model doesn’t capture the dynamic range seen in obs seasonality

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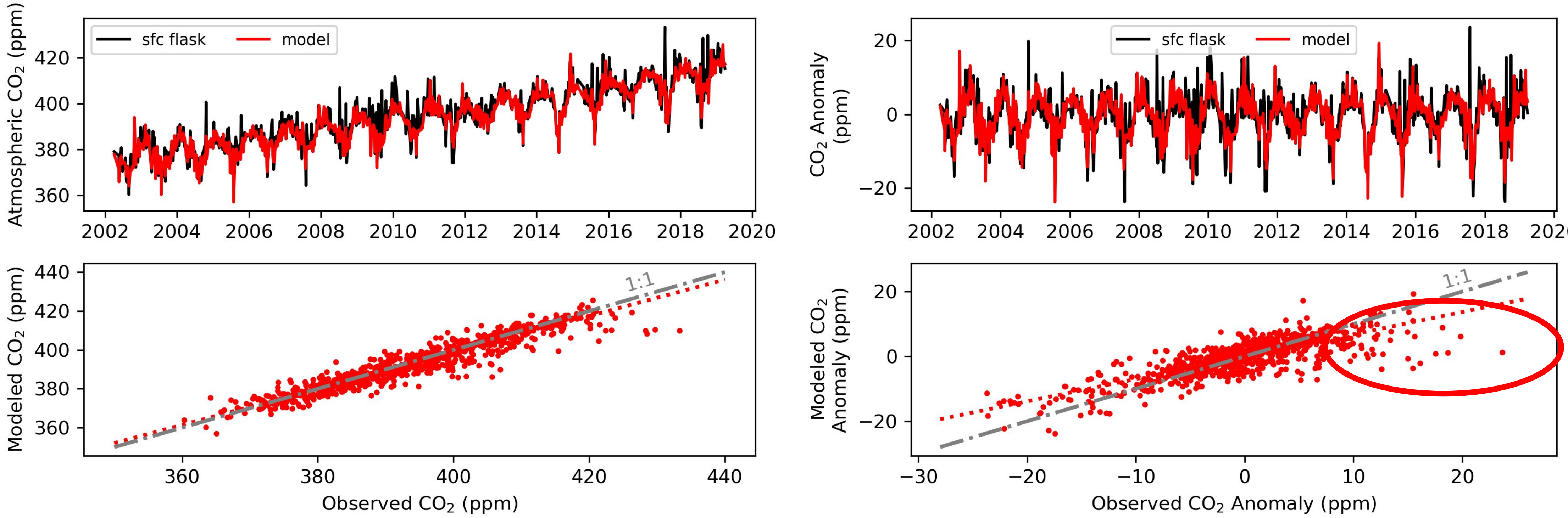


- Lack of $\delta^{13}C$ trend match is likely due to disequilibrium processes
- Model doesn't capture the dynamic range seen in obs seasonality
- Modeled $CO_2$ seasonal amplitudes miss more high $CO_2$ values

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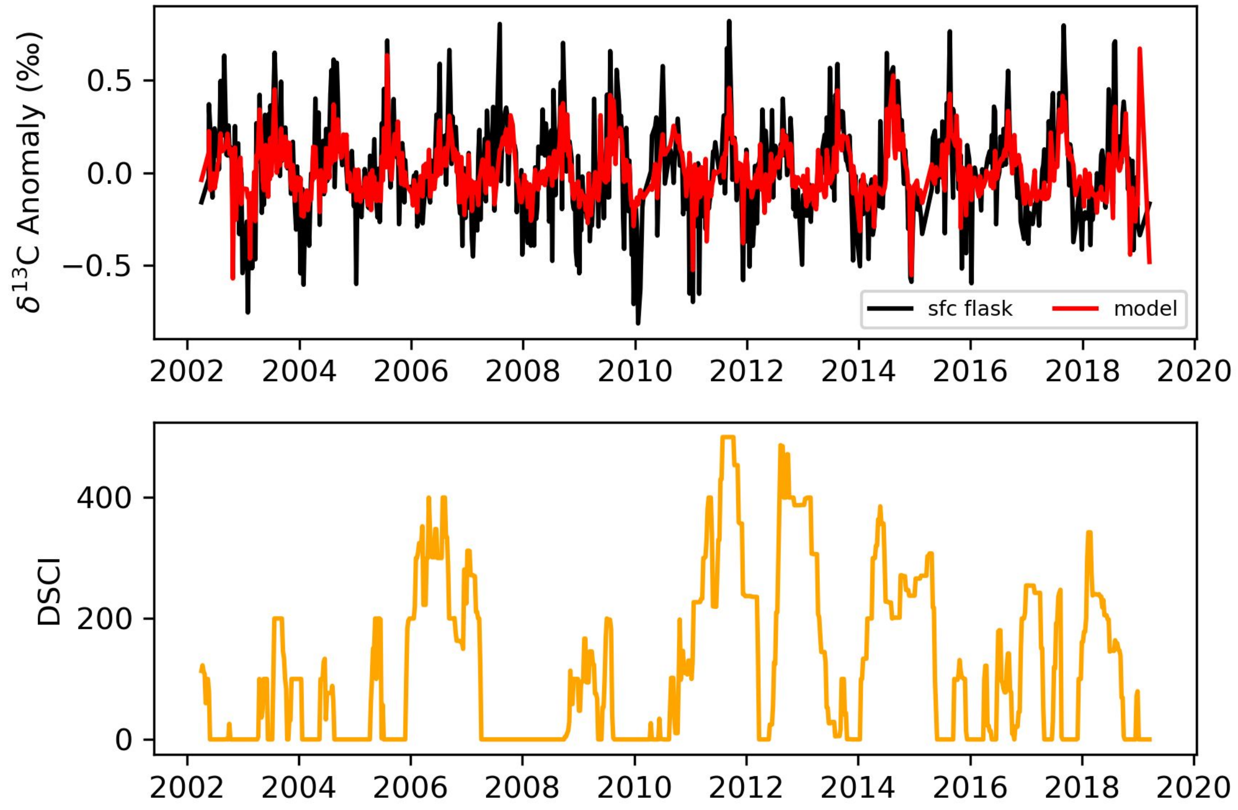
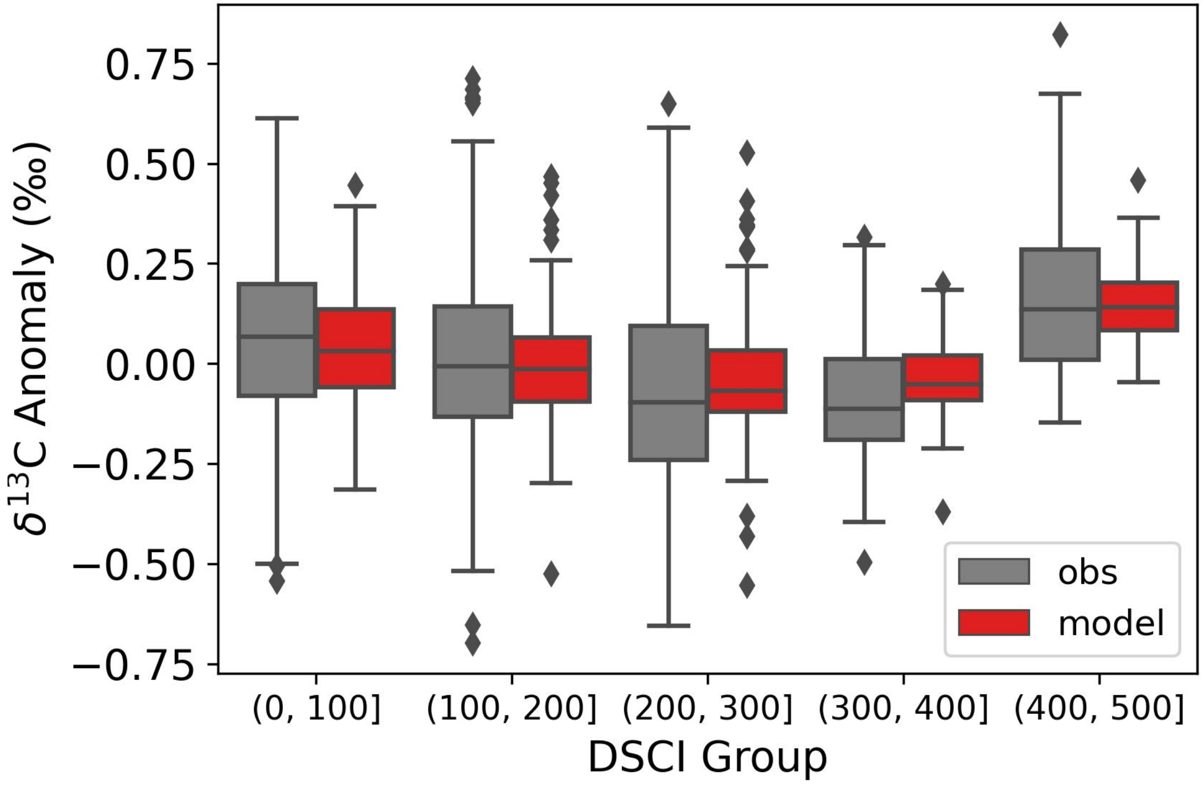
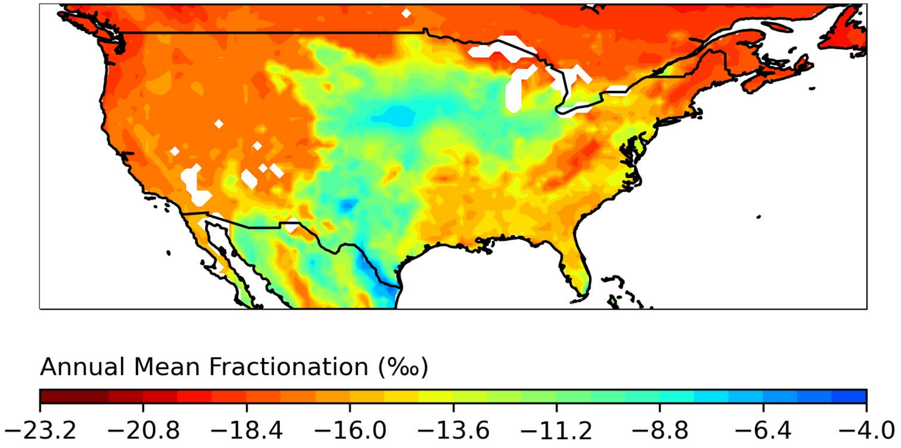


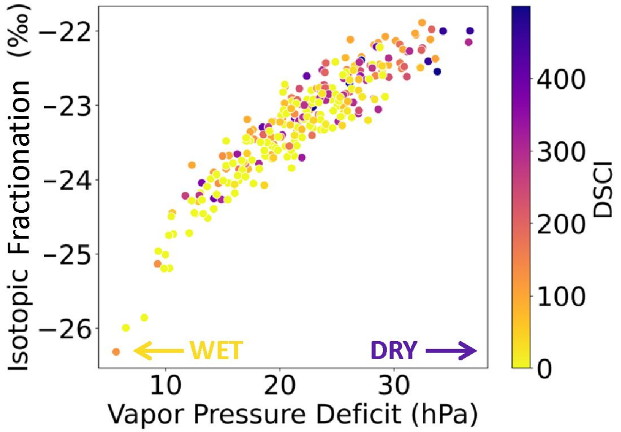



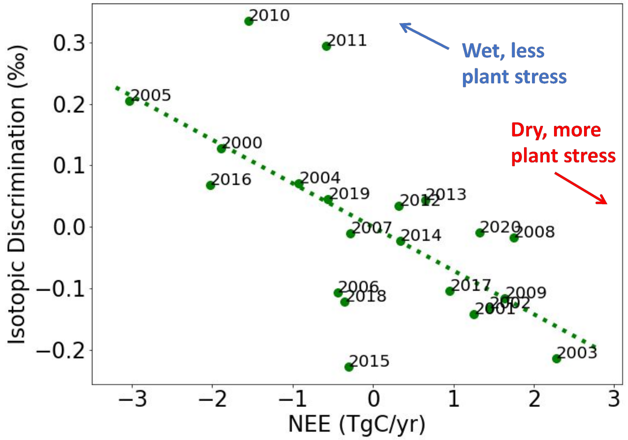

- Model misses dynamic range across all DSCI group classes
- Obs and model $\delta^{13}C$ anomaly highest for most severe drought category

# Conclusions

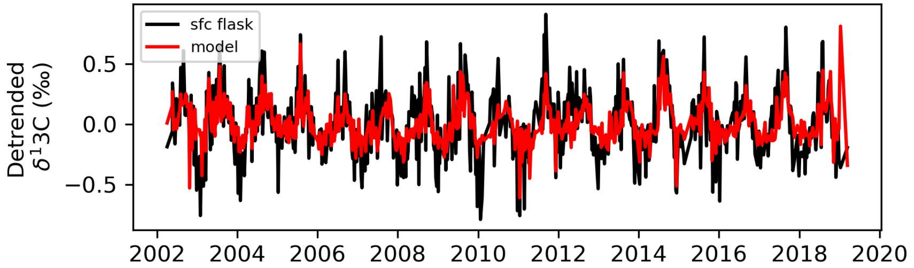
- $\delta^{13}C$-$CO_2$ can be used at regional scales as an indicator of drought stress

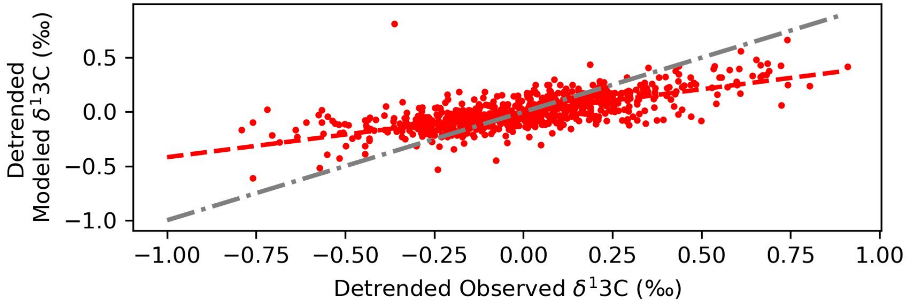



- SiB4 underestimates $\delta^{13}C$ seasonal amplitudes implying modeled drought stress response is not strong enough




*Thanks for listening! Contact me with additional questions:* ***aleya.kaushik@noaa.gov***