

# SIF, STRESS, and GPP in Amazonia

Can we use SIF to constrain GPP in Amazonia?

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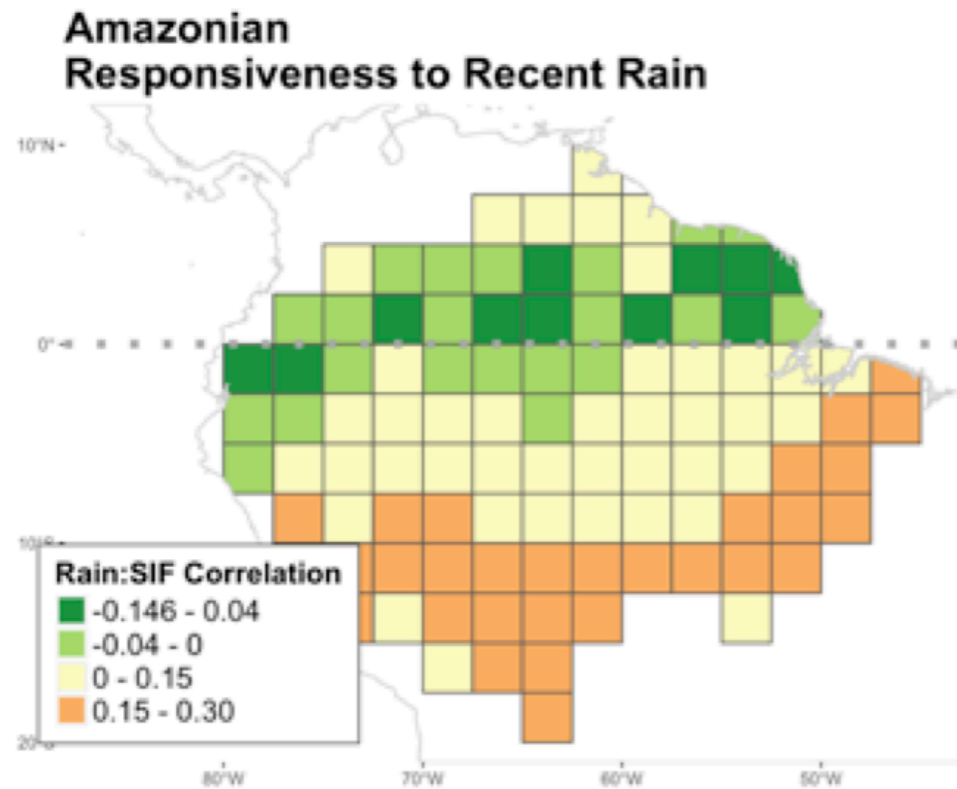
Colorado State University

Sarah's statistical analysis, using both OCO-2 and GOME-2, show some responsiveness to previous 30-day rain in drier regions of forest.

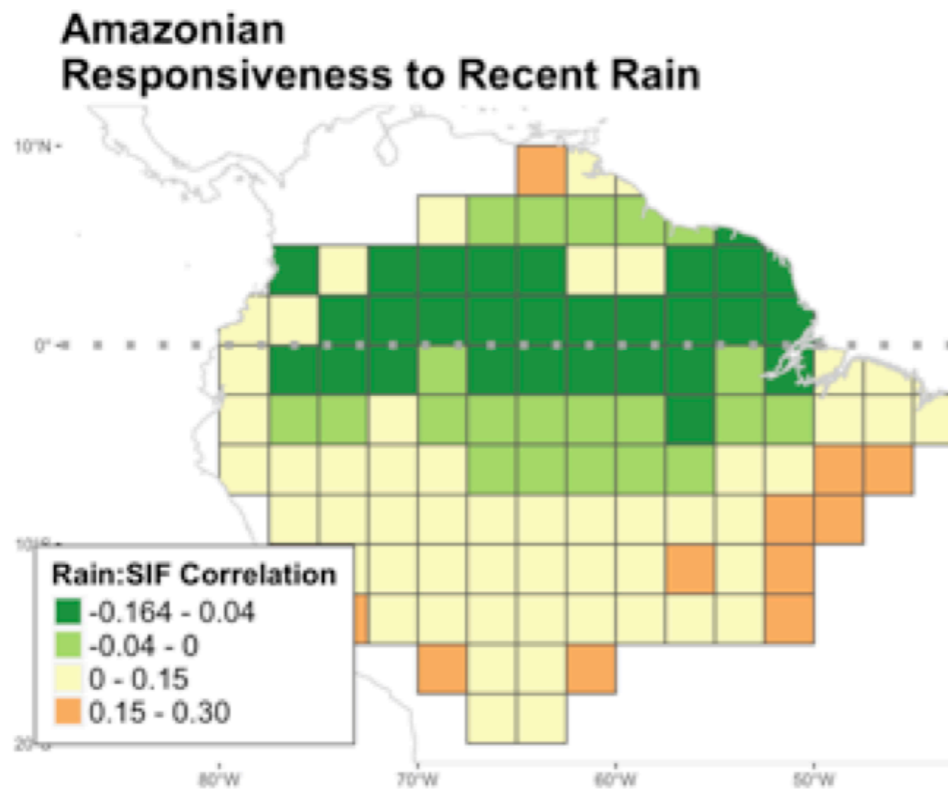
Negative or no response in wetter regions.

Simply put, these say that SIF increases in 'edge' forests following rain. In the interior this is not the case.

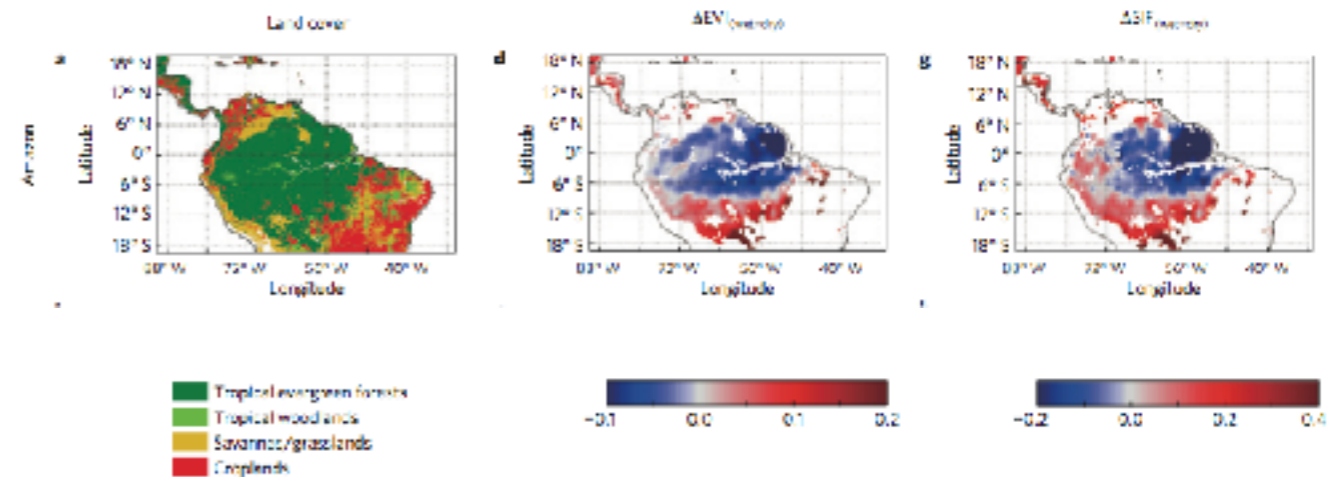
This result is consistent with Kaiyu Guan's 2015 paper.



**OCO-2**

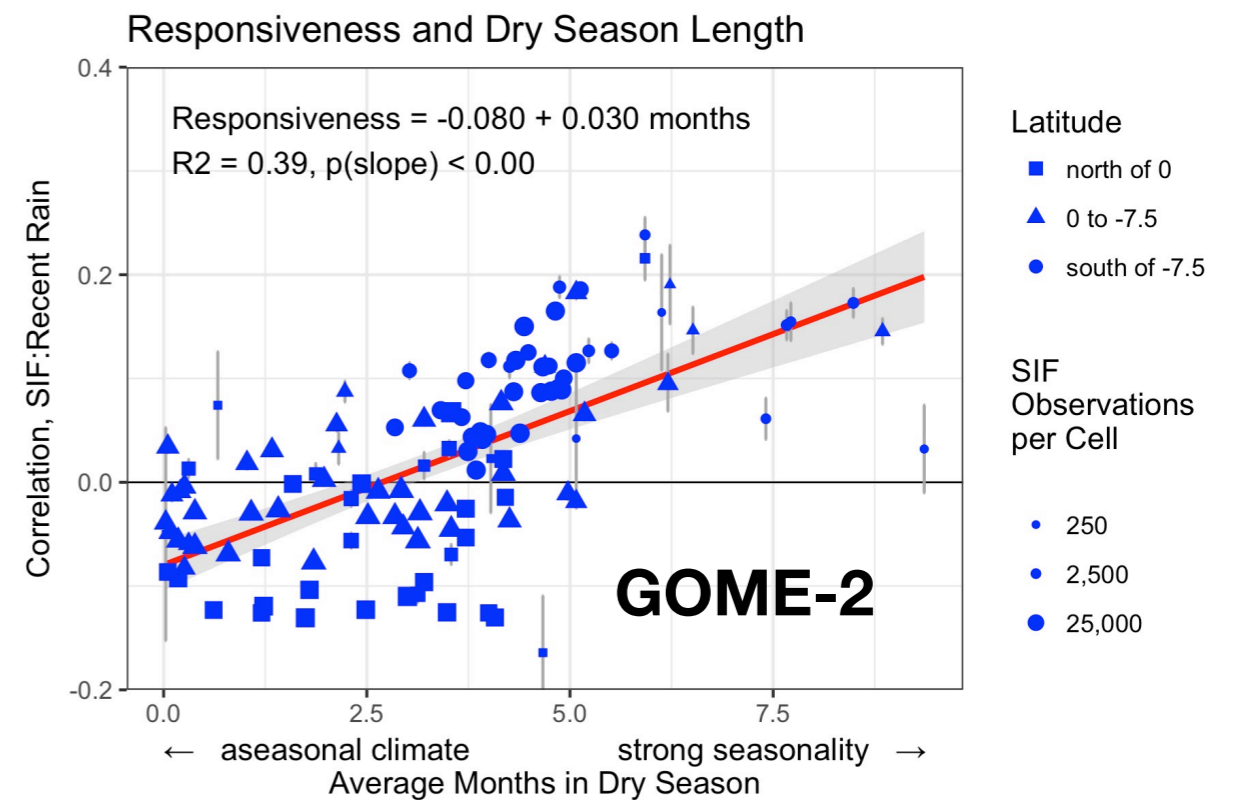
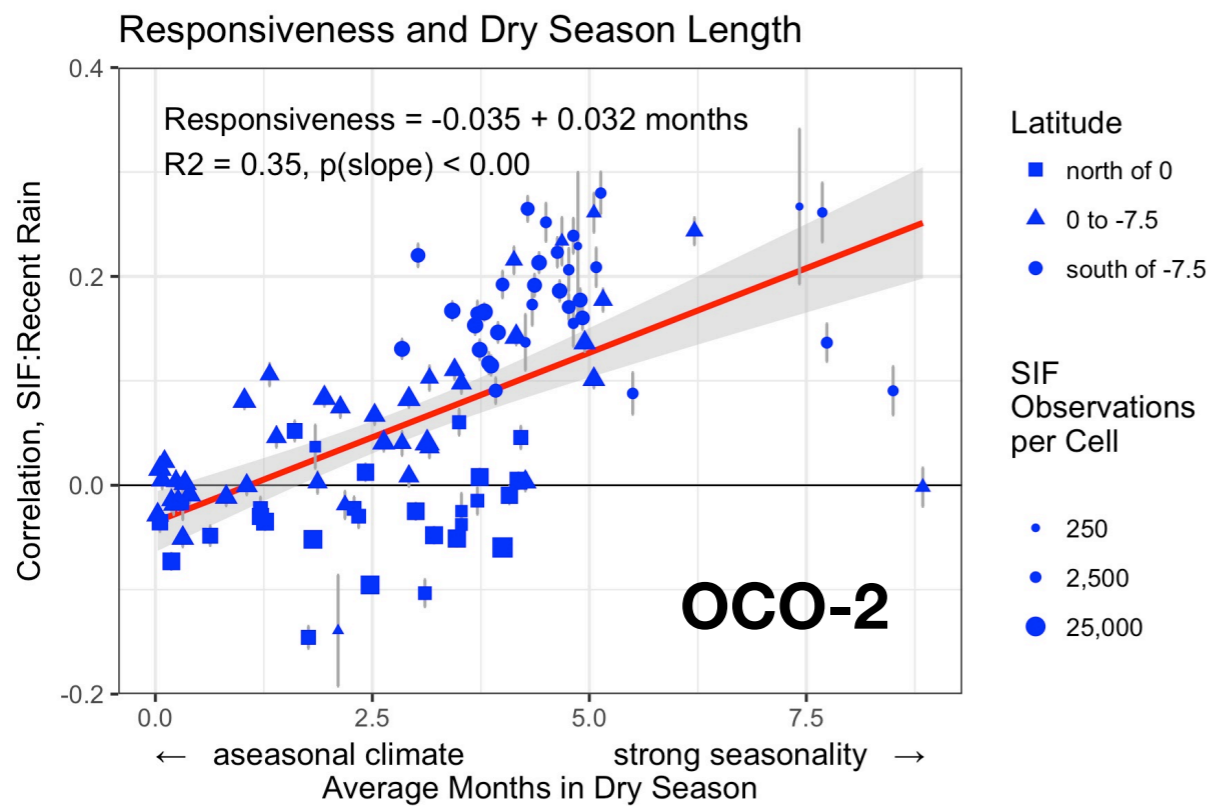


**GOME-2**



Guan et al., 2015

# Correlation strength and slope is similar for both OCO-2 and GOME-2

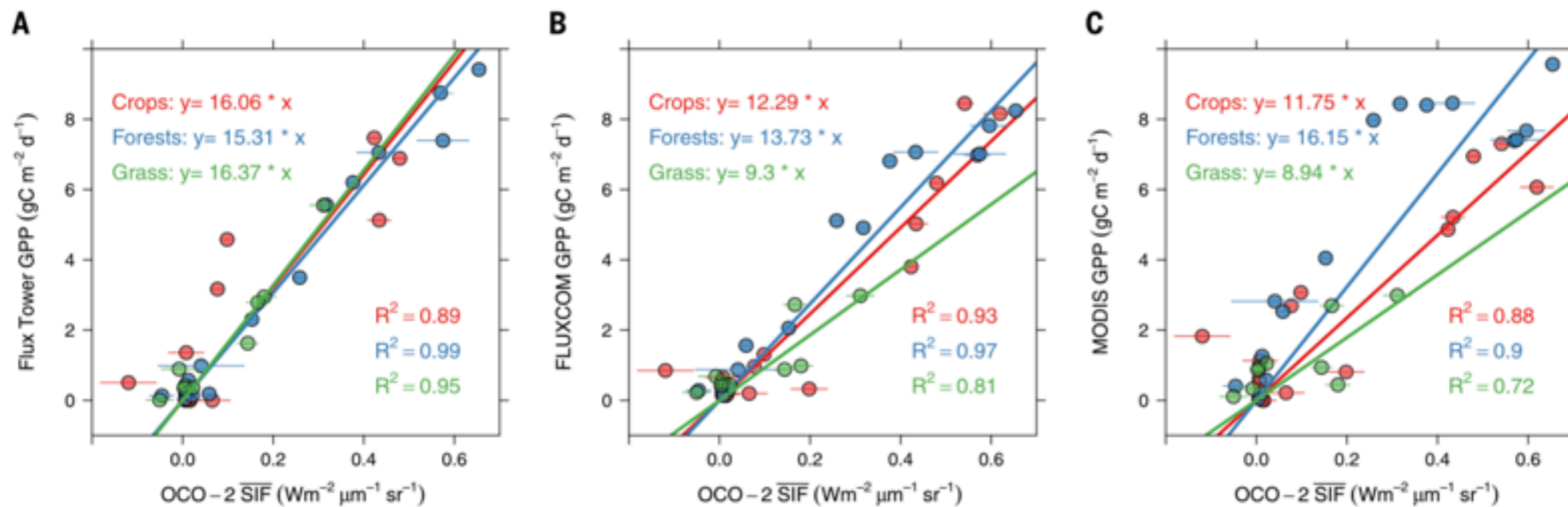


**Can we use these findings to say something about GPP? Might we expect the same relationships to apply?**

Ying Sun (and coauthors, 2017) says yes. Her results indicate that there is a relationship between SIF and GPP

$$\text{GPP} = \text{SIF} \times \sim 16.0 + (\text{some intercept})$$

Might this suggest that we now have some skill in predicting GPP response to drying/wetting in Amazonian forests?

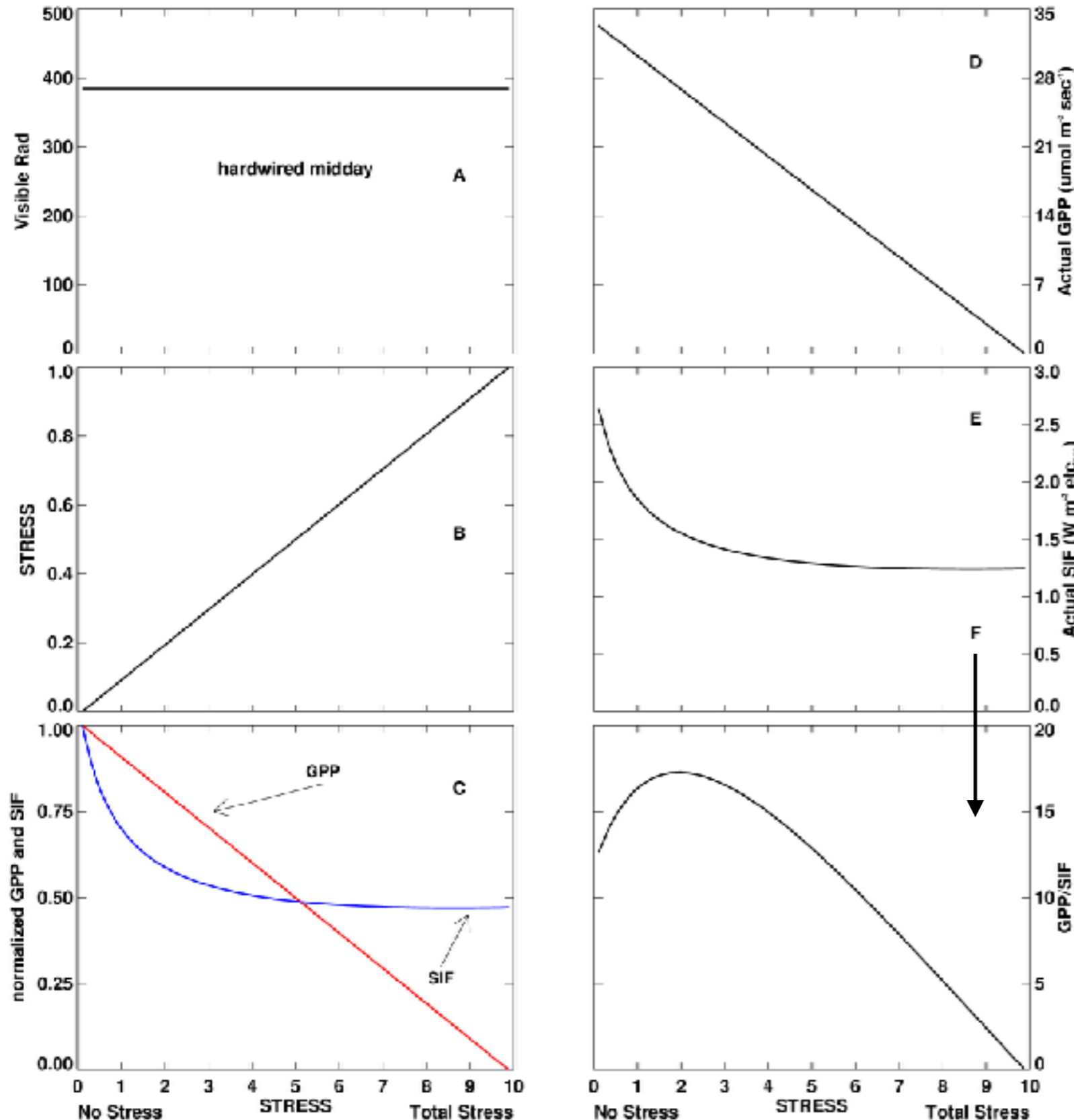


**Fig. 3. SIF-GPP relationships.** The relationship between GPP and OCO-2 SIF (daily mean value, denoted as  $\overline{\text{SIF}}$ , converted from instantaneous measurements) at three flux tower sites representative of three different biomes: crops (Minnesota Tall Tower KCMP) (30), grass (Stuart Plain in Australia) (31), and deciduous temperate forests [Missouri Ozark site (US\_MOz)]. The first two sites are selected because they are in the direct underpass of OCO-2 orbital tracks; for the US\_MOz site, OCO-2 SIF retrievals are obtained from representative forests in the vicinity of the tower. The KCMP footprint covers a mixture of corn, soybean, and grasses but is dominated by the two major crops. Error bars represent the SE of

the OCO-2 SIF retrieval. Daily GPP in the 2015 growing season is obtained during the OCO-2 overpasses from (A) eddy covariance measurements, (B) FLUXCOM products, and (C) MODIS products, sampled at these three flux sites. Both FLUXCOM and MODIS GPP are 8-day products and are linearly interpolated to the OCO-2 overpass dates. The site-specific FLUXCOM GPP value is extracted from the grid cell ( $0.083^\circ$  by  $0.083^\circ$ ) that corresponds to the latitude and longitude of the tower location. The site-specific MODIS (MOD17A2) GPP value is the average of nine adjacent pixels (1 km by 1 km) centered at the tower location. Both are roughly equivalent to  $\sim 9\text{-km}^2$  area.

**Important Caveat: Sun's results are from seasonal sites, not Tropical Forest!**

# MODELS OF SIF (not SCOPE, but based on van der Tol et al., 2014)



**UNIT TEST:** We simulate SIF using a single timestep from SiB. The only modification is to scale  $\text{GPP}/\text{GPP}_{\text{potential}}$  and see what happens

**X-AXIS: LOW STRESS on LEFT, HIGH STRESS on RIGHT**

**Panels:**

**A:** radiation. Held constant.

**B:** STRESS, or  $(1 - \text{GPP}/\text{GPP}_{\text{potential}})$ . No stress on LHS, total stress on the right.

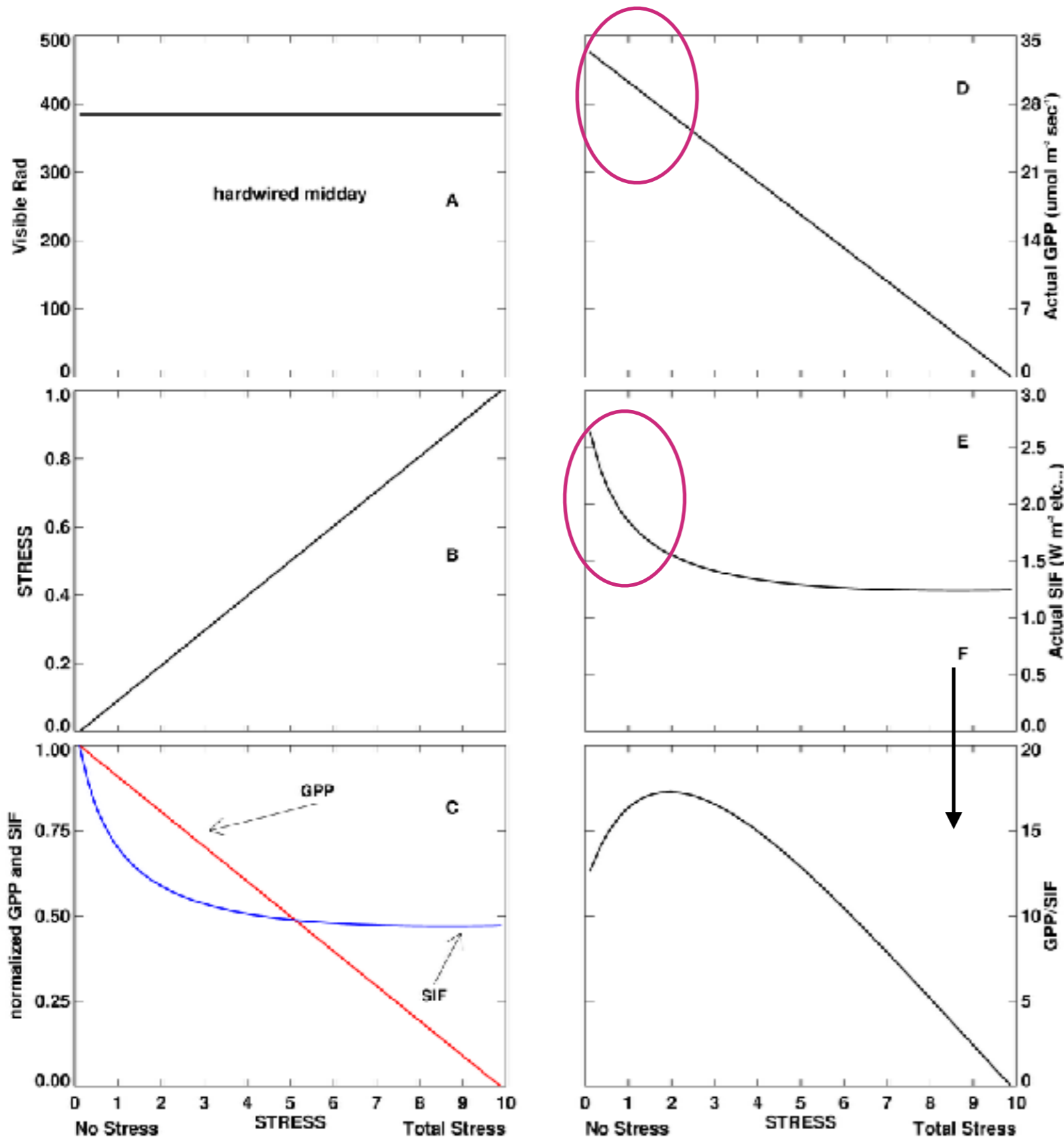
**C:** Normalized **GPP** and **SIF**. Can be thought of as a proxy for yields.

**D:** Actual GPP as calculated by SiB.

**E:** Actual SIF.

**F:** Ratio of GPP/SIF.

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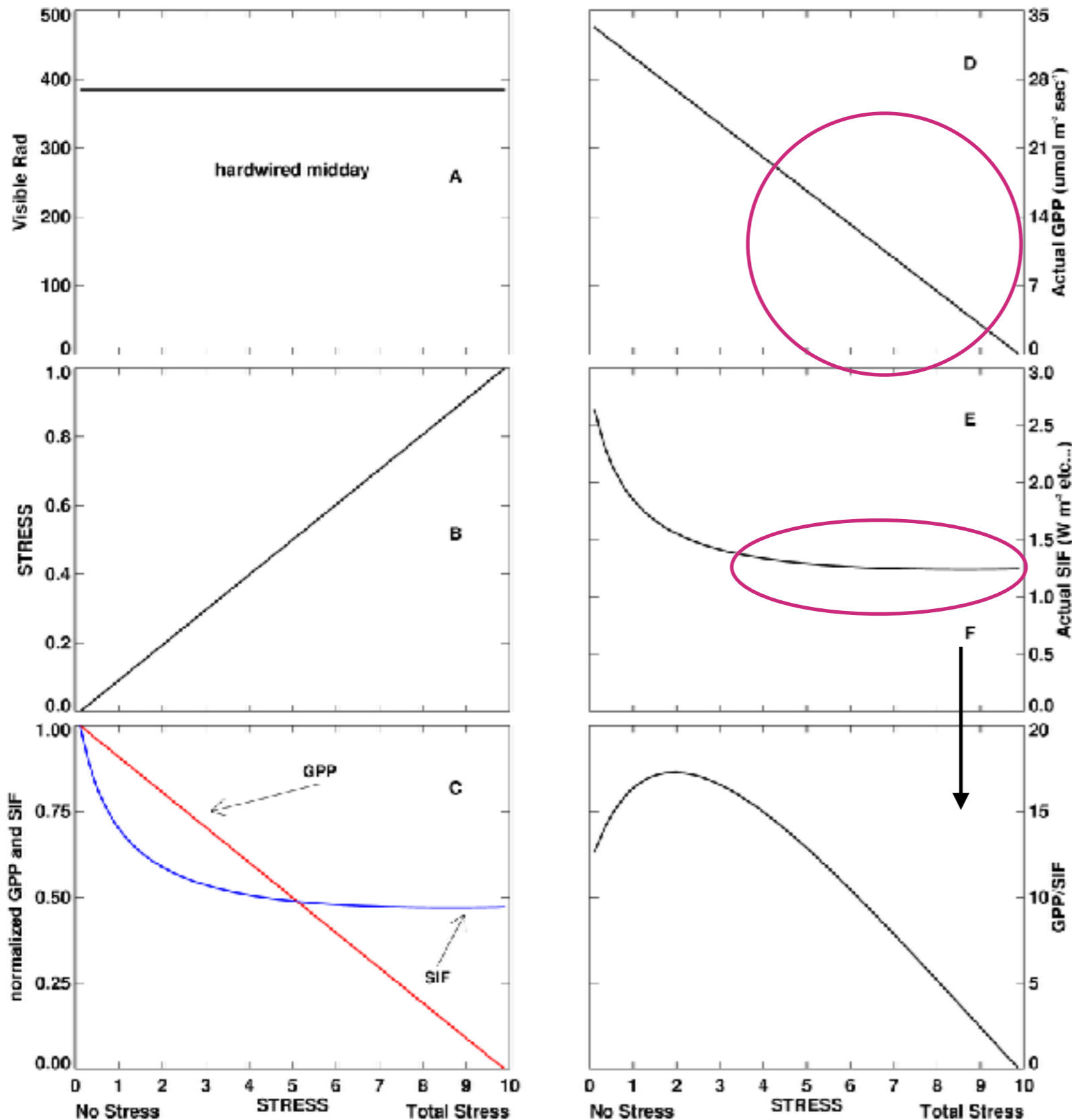
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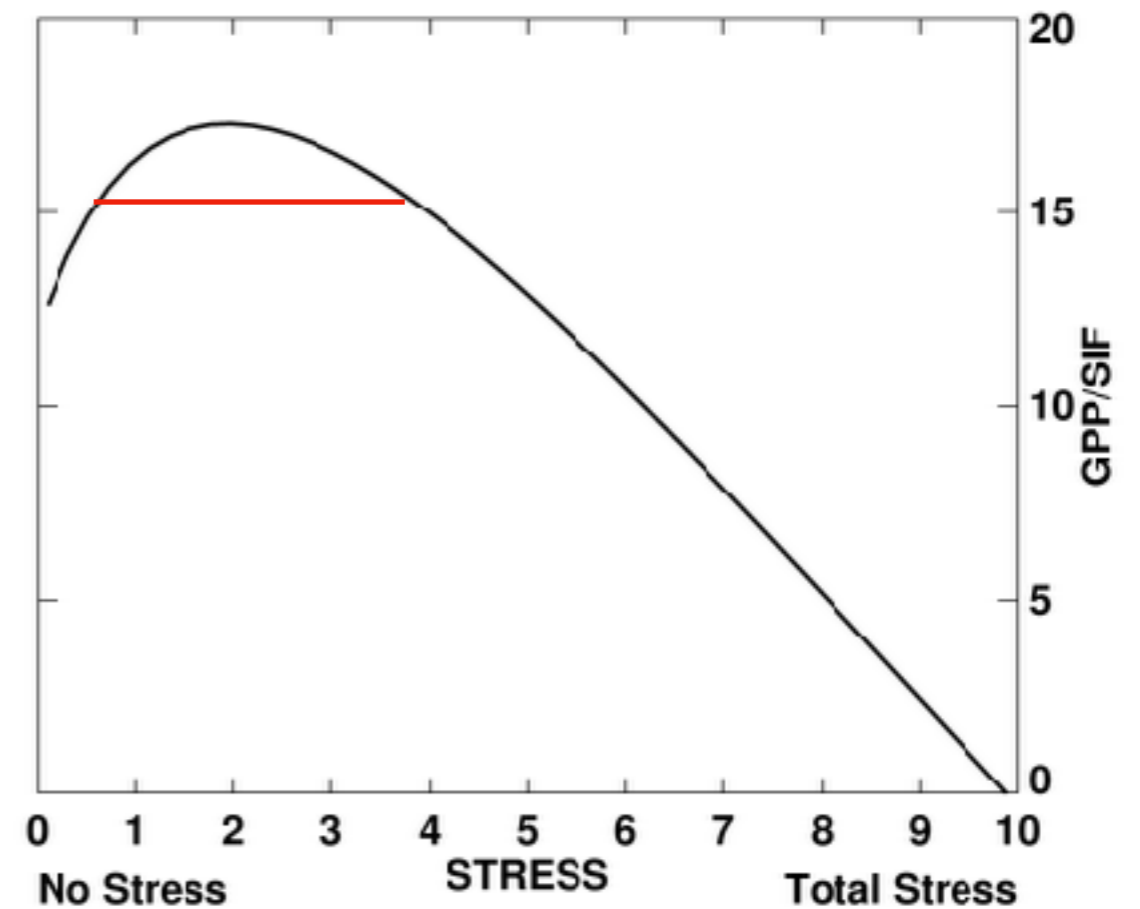
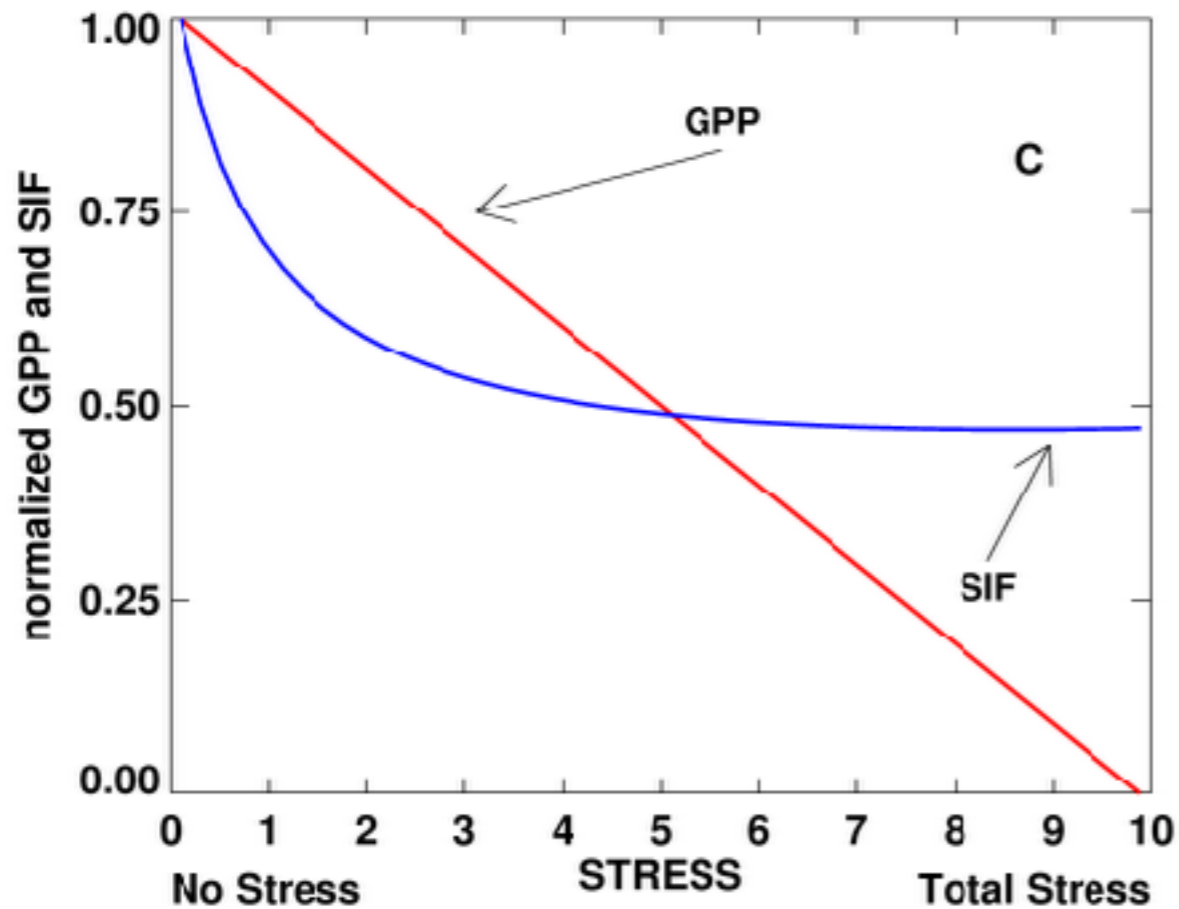
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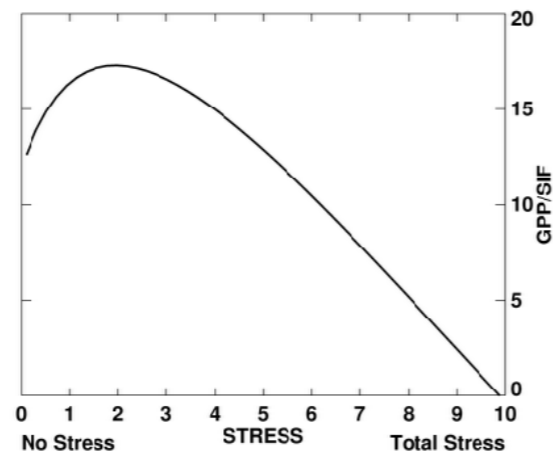
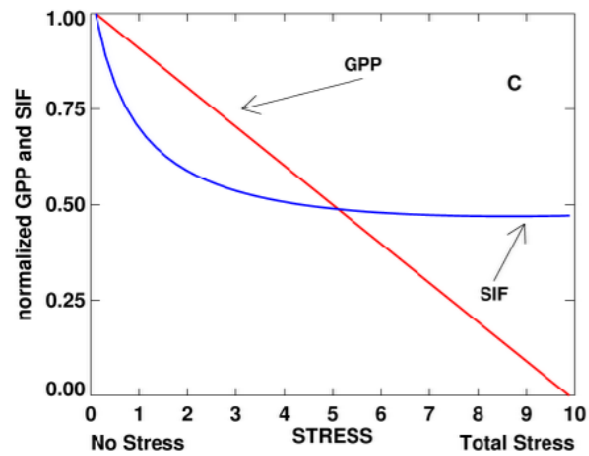


What these two panels indicate, from model results, is that GPP decreases continually with increasing stress, but SIF asymptotes out at a value of about 1/2 of the unstressed value.

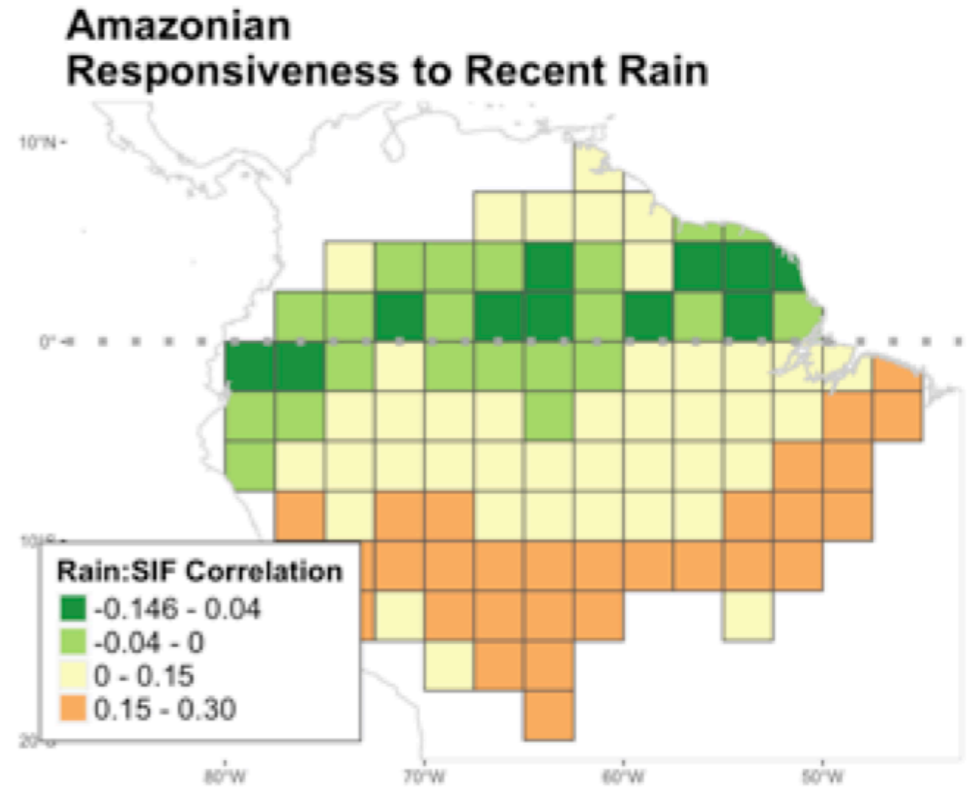
One *might* make the argument that the relationship between SIF and GPP is constant below ~35% stress (with a value of 16!), but that is kind of a stretch.

When stress is higher than 35%, the GPP/SIF ratio is constantly changing.





**Do Not Agree**



**WAIT A MINUTE!** The plot on the left says that SIF and GPP are disconnected at higher stress, and there is only the semblance of a relationship at low stress. ***THIS IS EXACTLY THE OPPOSITE OF WHAT SARAH FOUND IN THE OBSERVATIONS.***

So now we have a conflict between what we have inferred from observations and what our model predicts for SIF-GPP relationships with regard to stress.

**How can we explore this disconnect?**

**The unit test might not be the best use of the model. We took a single timestep, and ‘turned the knob’ on stress alone. As stress increases we could anticipate that non-linear relationships in the equations that describe our canopy processes would interact.**

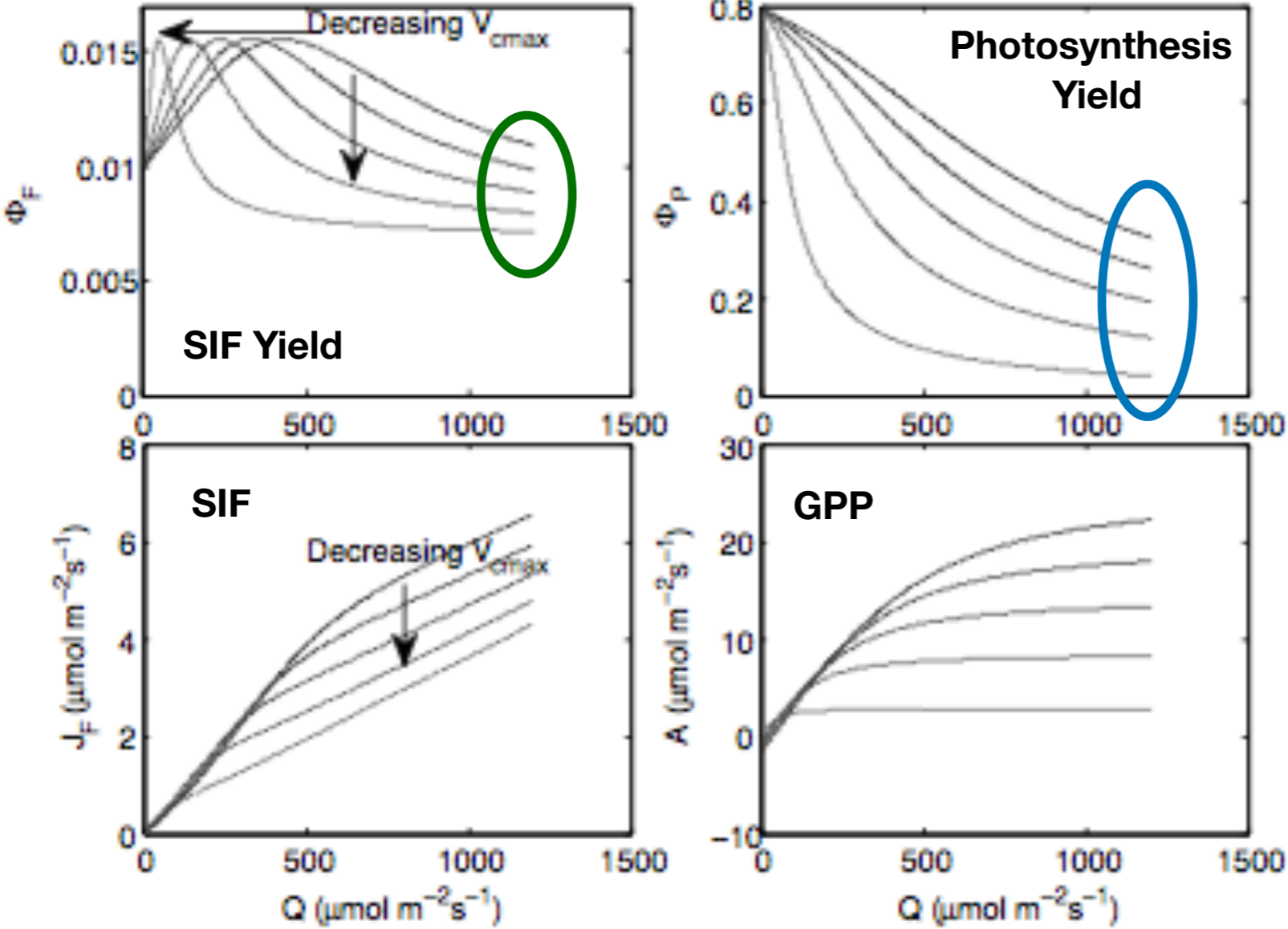
**So let’s look at it differently, in what I call a ‘drydown’ application. I initialize the model at 95% saturation of moisture in the soil, vegetation and isothermal soil initialized at the mean of the air temperature over the length of tower driver data.**

**I then take a single day of meteorological forcing (a day with few clouds and no rain) and run that day over and over (8 years) until I have ET-ed all the moisture out of the soil, down to total stress.**

**I’ve done this for sites K34, RJA (Reserva Jaru) and K83 in Brazil.**

**FIRST: How does Christiaan van der Tol (SCOPE) think things will behave?**

Note that at low light, high stress (low  $V_{cmax}$ ) can have higher SIF yield than low stress (high  $V_{cmax}$ )



As stress increases ( $V_{cmax}$  decreases) the SIF and GPP yields evolve in different ways.

The SIF yield asymptotes out around 1%.

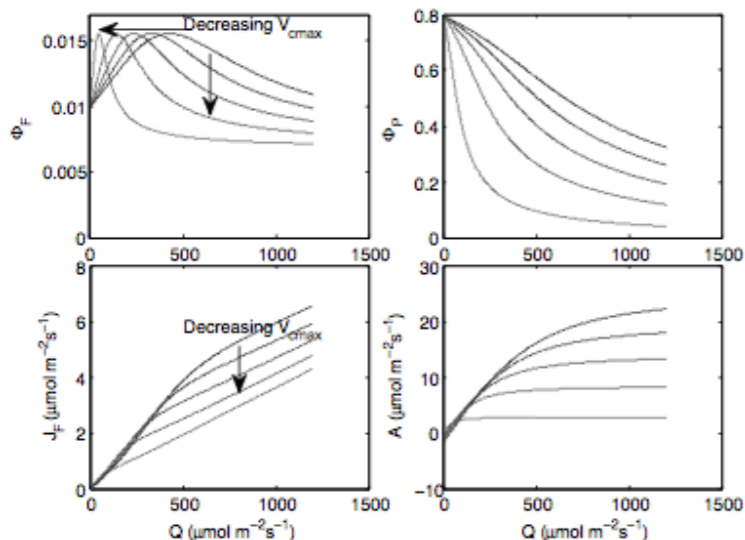
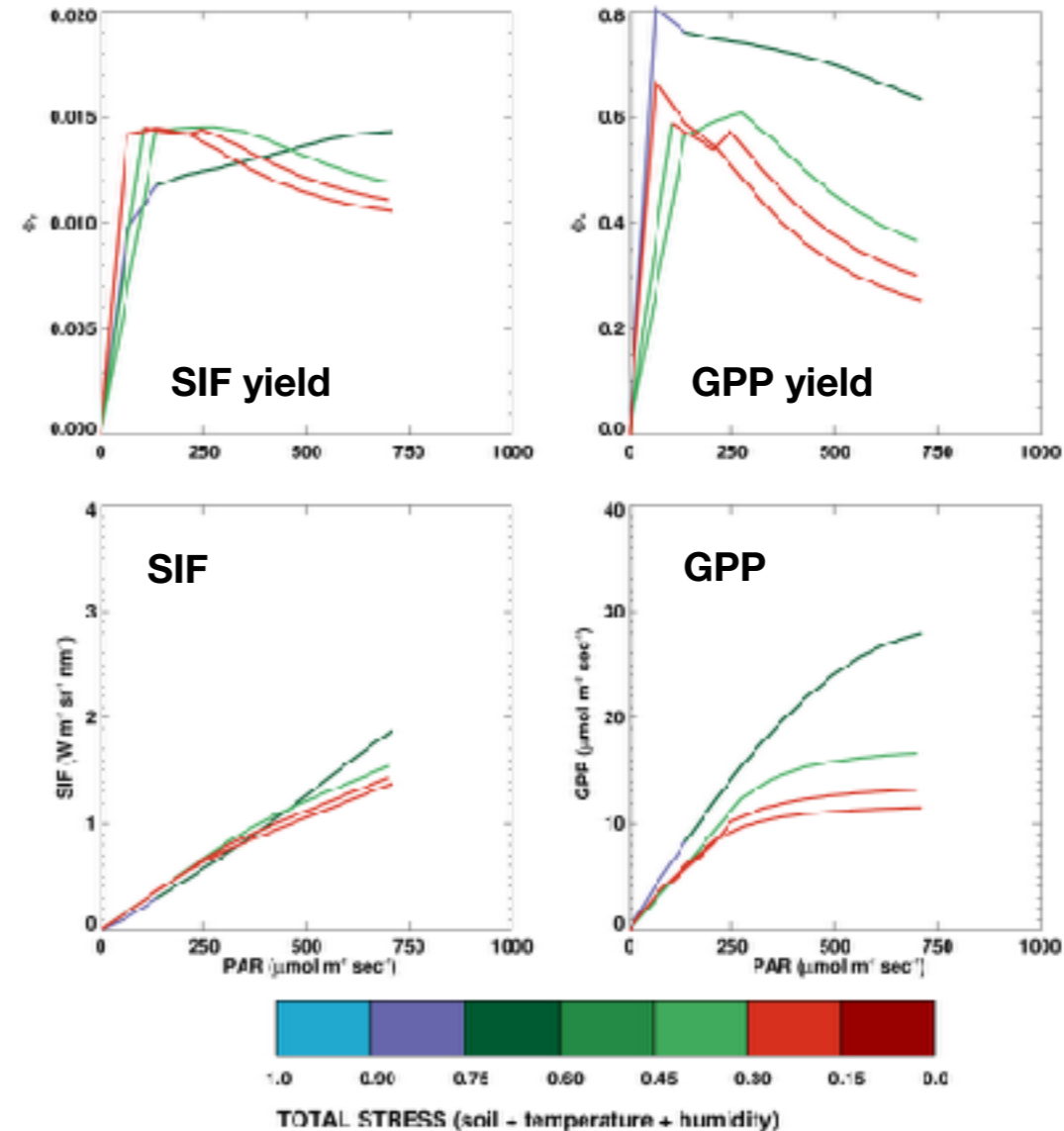
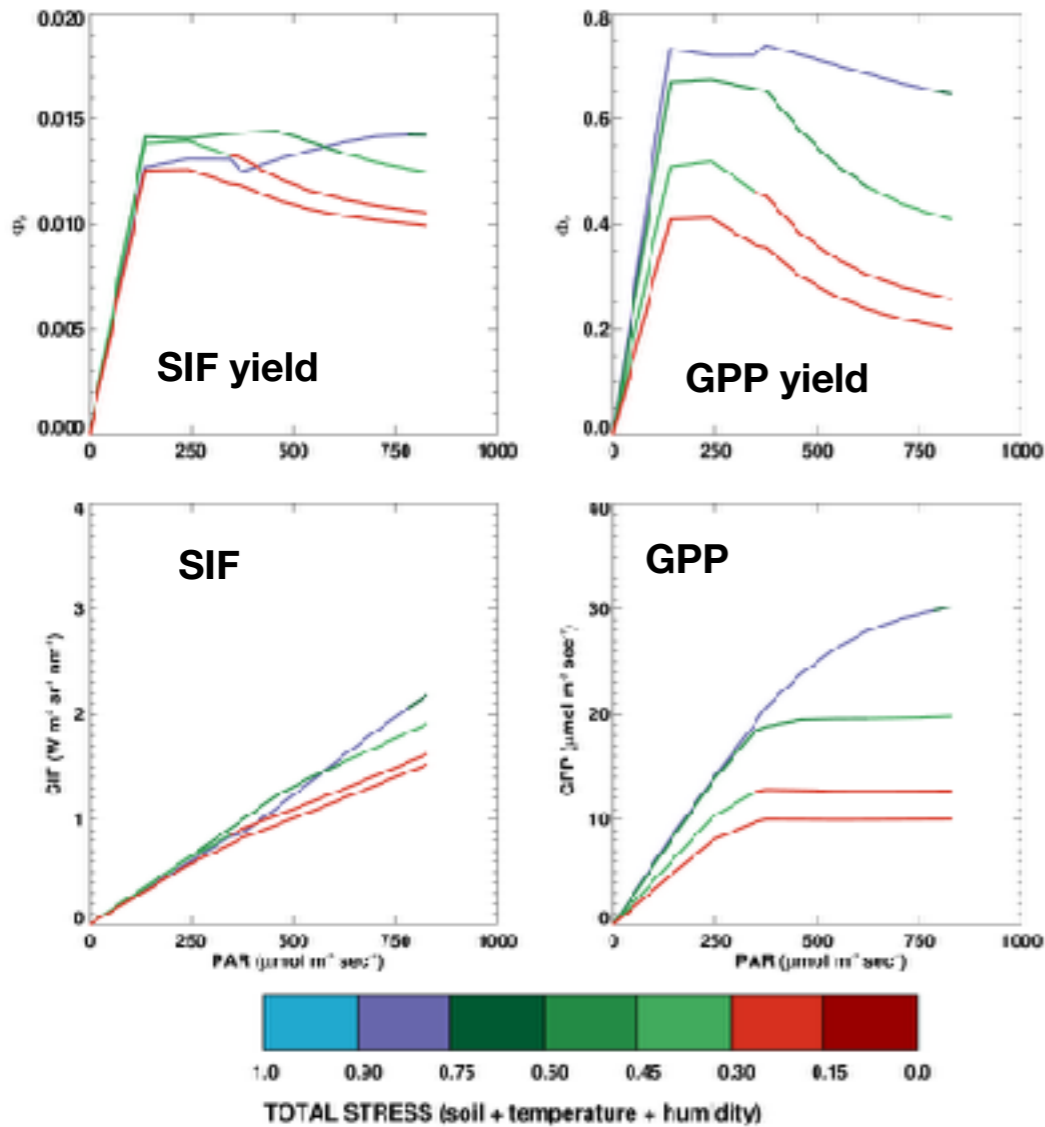
GPP yield drops continually.

The changes in SIF and GPP with stress reflect these differences

# Can our model reproduce this behavior?

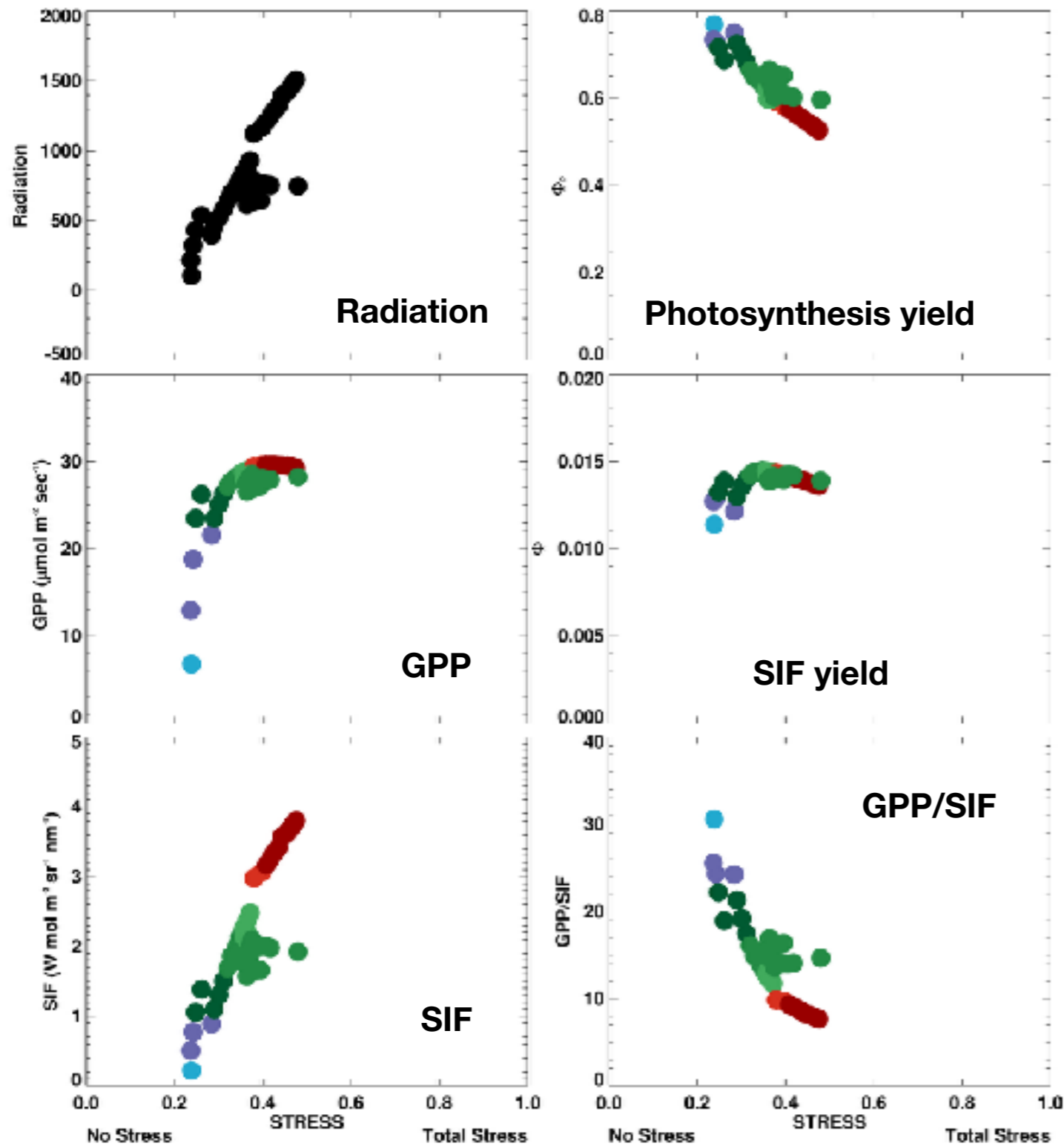
## RJA-Reserva Jaru

## K34-Manaus



I say yes, we can reproduce the results from van der Tol et al. (2014).

I don't worry about the GPP yield at low light. At 0 PAR our GPP is 0, so yield is 0 also. We don't get non-zero GPP until light gets high enough for assimilation to exceed dark respiration.



**What are we looking at here?**

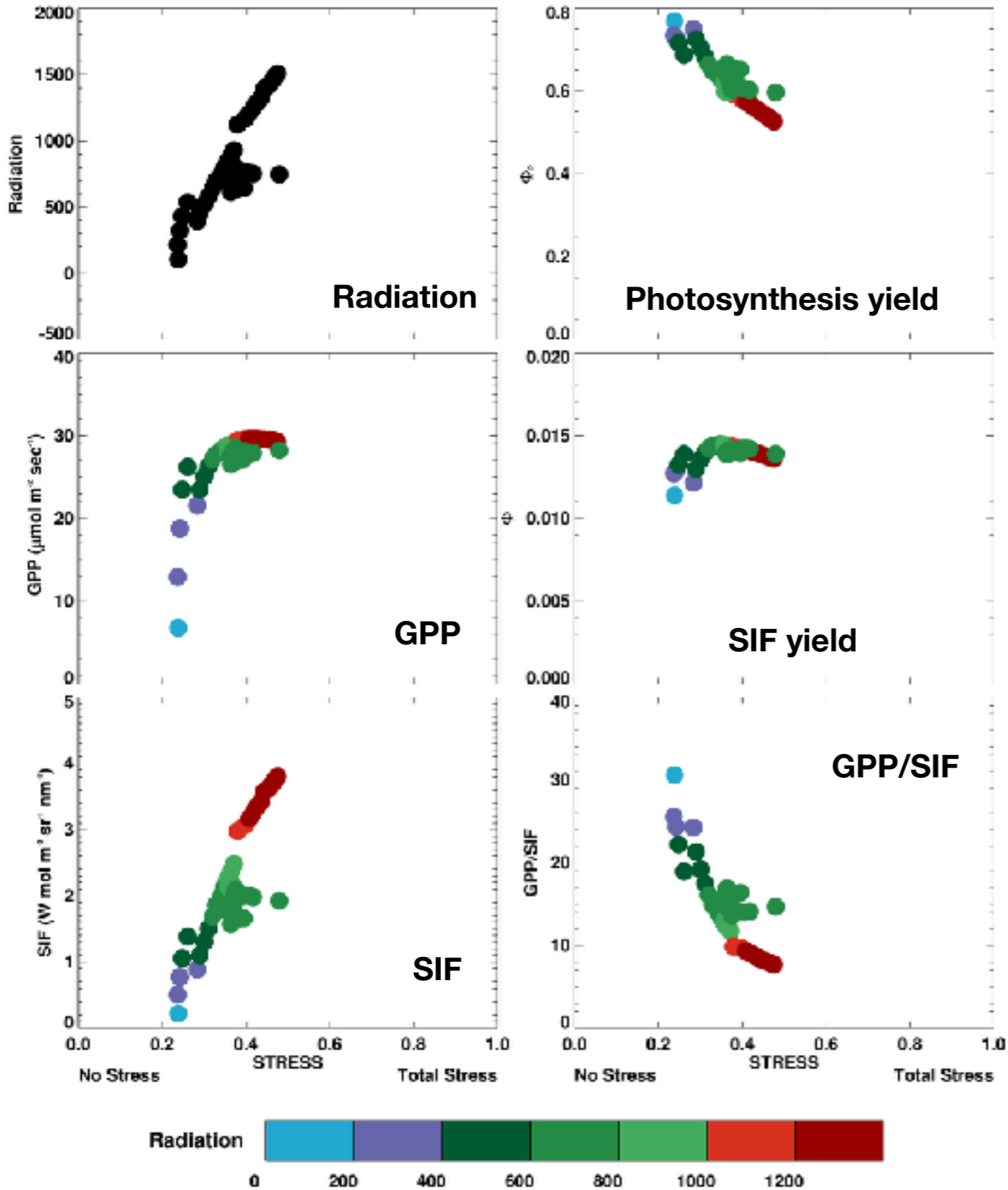
**This is ONE DAY, a dot for every timestep (10 minutes) where radiation is > 0.**

**TOTAL STRESS (temperature, humidity, soil moisture) IS ON THE X-AXIS (no stress on LEFT, high stress on the RIGHT).**

**Radiation amplitude is given by the color of the dot.**

**Upper-left panel shows radiation alone. Stress on the X-axis, radiation on the Y-axis. Radiation goes through a diurnal cycle, stress increases in the hottest/driest part of the day.**

# K83 January



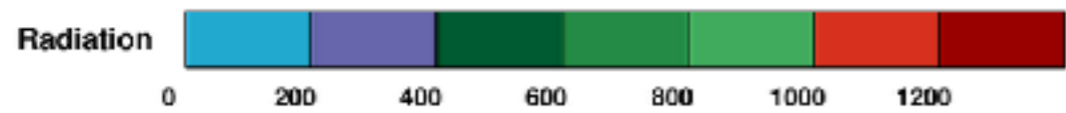
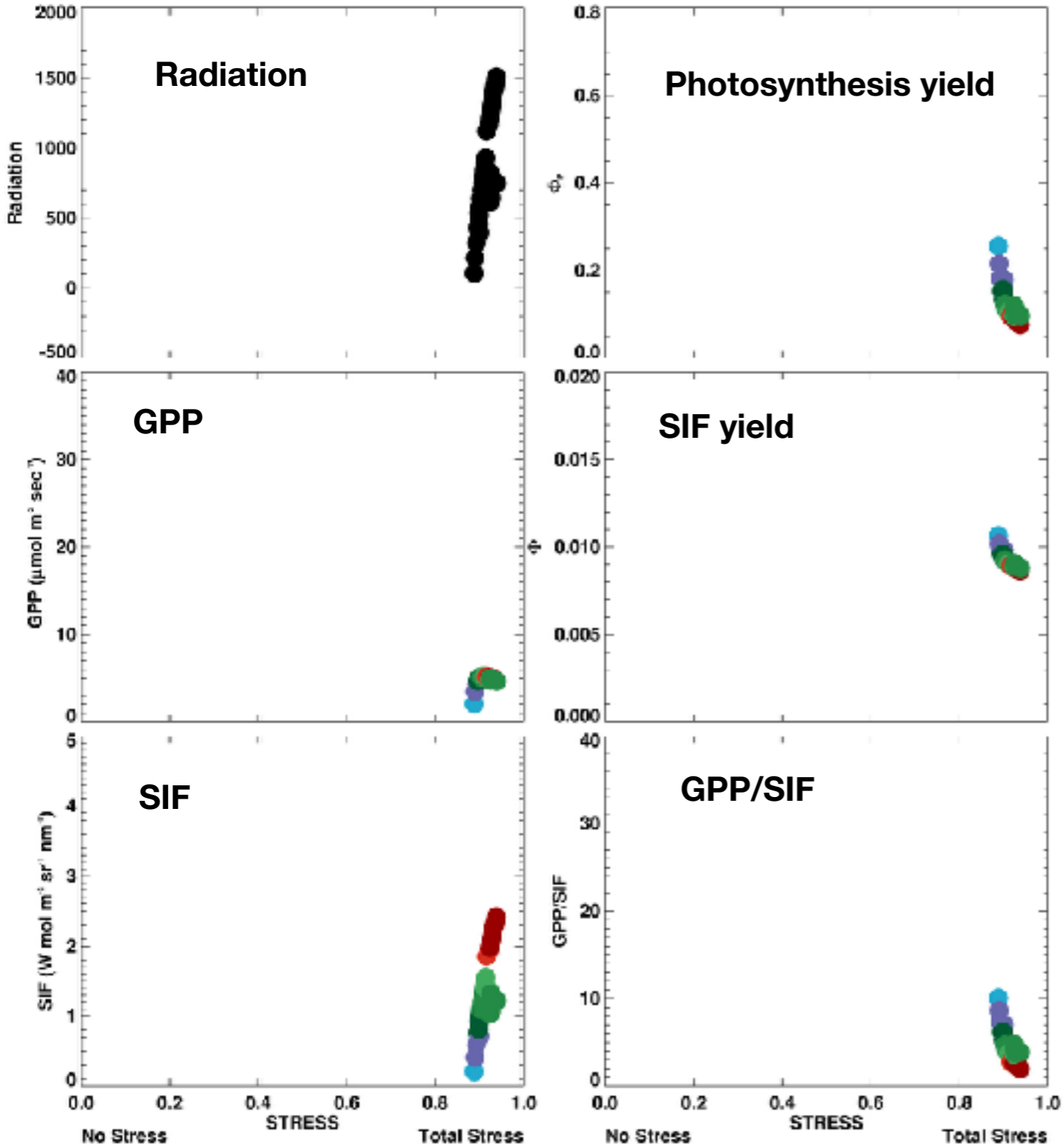
**What are we looking at here?**

**This day is fairly low-stress, from about 20% stress in the morning/evening up to ~50% stress at midday when temperature and VPD will be largest.**

**GPP looks like a light-response curve, yield drops with increasing light and stress.**

**SIF keeps increasing with increasing light, because the SIF yield is unchanging at around 1.4% even as stress increases.**

# K83 January



**This is a high-stress day from later in the drydown simulation.**

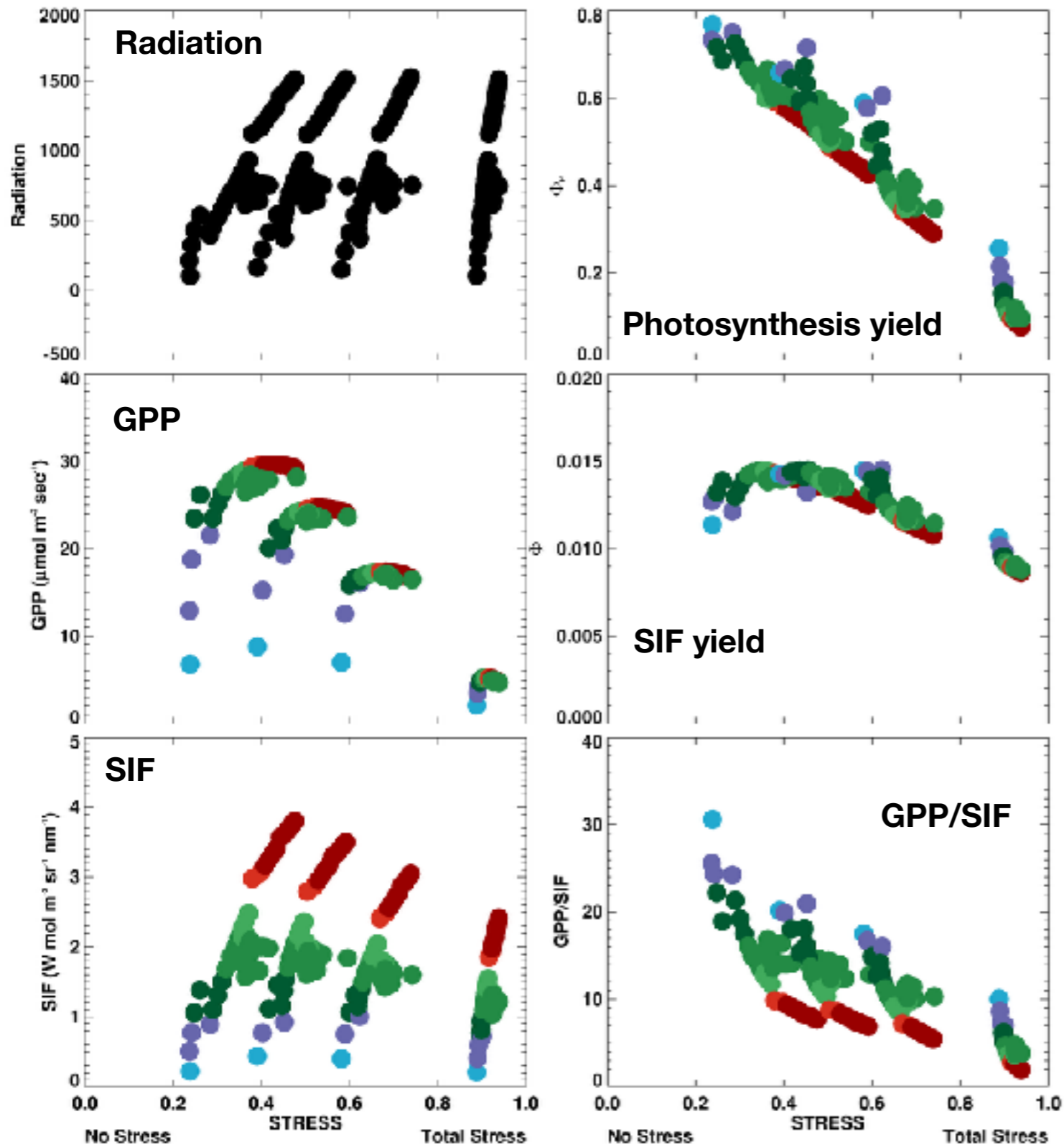
**Radiation goes through a diurnal cycle, but stress doesn't change much because it is so large to begin with (no water in soil).**

**GPP is almost nil.**

**SIF still has a pretty good diurnal range.**

**GPP/SIF ranges from 2 to 10.**

# K83 January



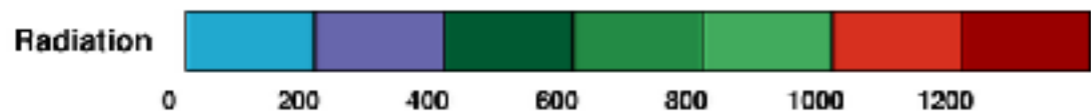
Here are 4 days selected from the drydown simulation as stress increases

Photosynthesis yield follows a nice line with increasing stress.

SIF yield behaves regularly, although non-linear.

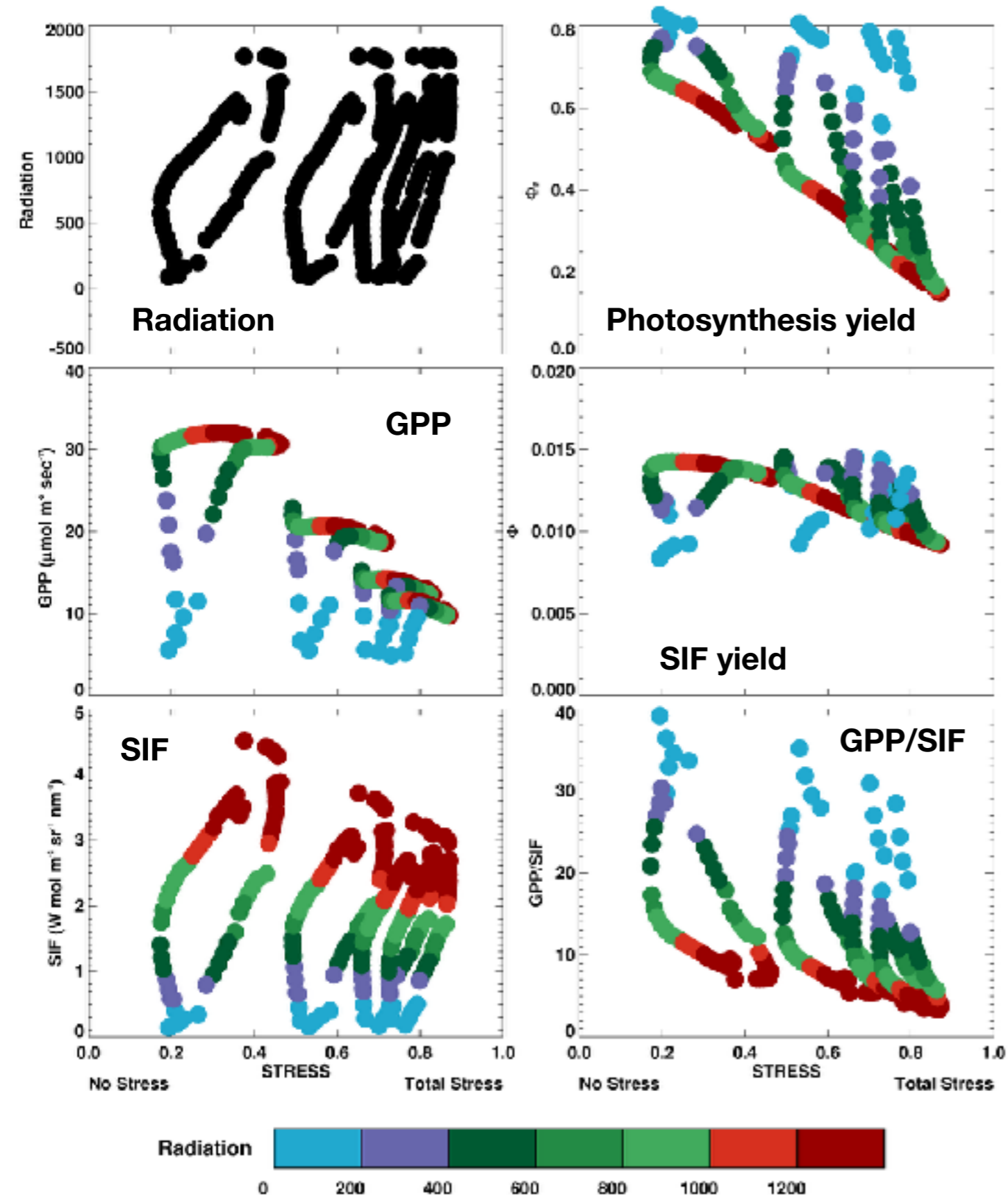
GPP/SIF changes diurnally by about a factor of 3.

Could we fit a line onto the GPP/SIF points?





# RJA January



Not every simulation behaves so nicely.

## **The models seem to say:**

- 1. There is a “quasi-linear” relationship between SIF and GPP at low stress.**
- 2. Once stress exceeds some (not very large) threshold, this relationship breaks down.**

## **While the observational data implies:**

- 1. There seems to be a relationship between SIF and GPP in regions that we would associate with having higher stress (less rainfall, longer dry season)**
- 2. Wetter (non stressed ) forest regions show little (or slightly negative) relationship between precipitation and SIF**
- 3. The strength of the relationship is weak**

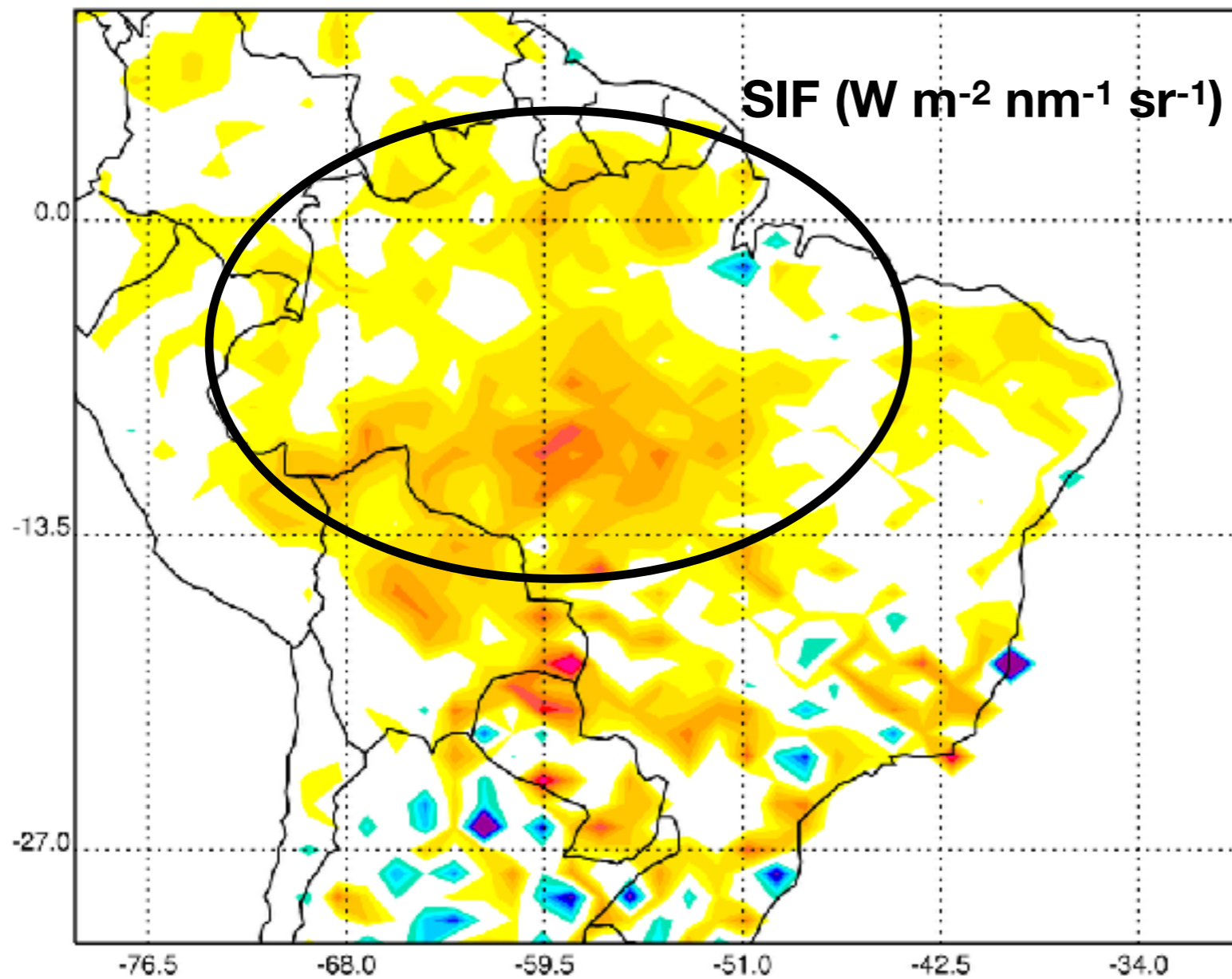
So the models and observations seem to contradict each other *in the Amazon*

What can we take from this?

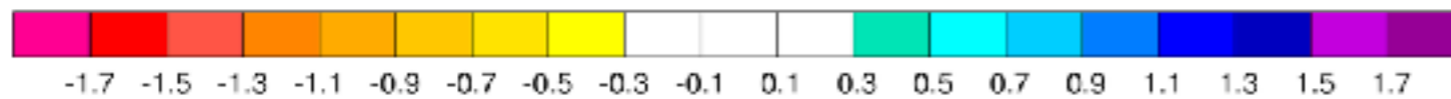
1. For both GPP and SIF, you need A) light, and B) leaves. In regions that are highly seasonal, we can expect a decent relationship between SIF and GPP.
2. In places like the Amazon, where there are always leaves and light, the relationship might be a little more complicated.

$$SIF = \phi_F \times PAR \times fPAR$$

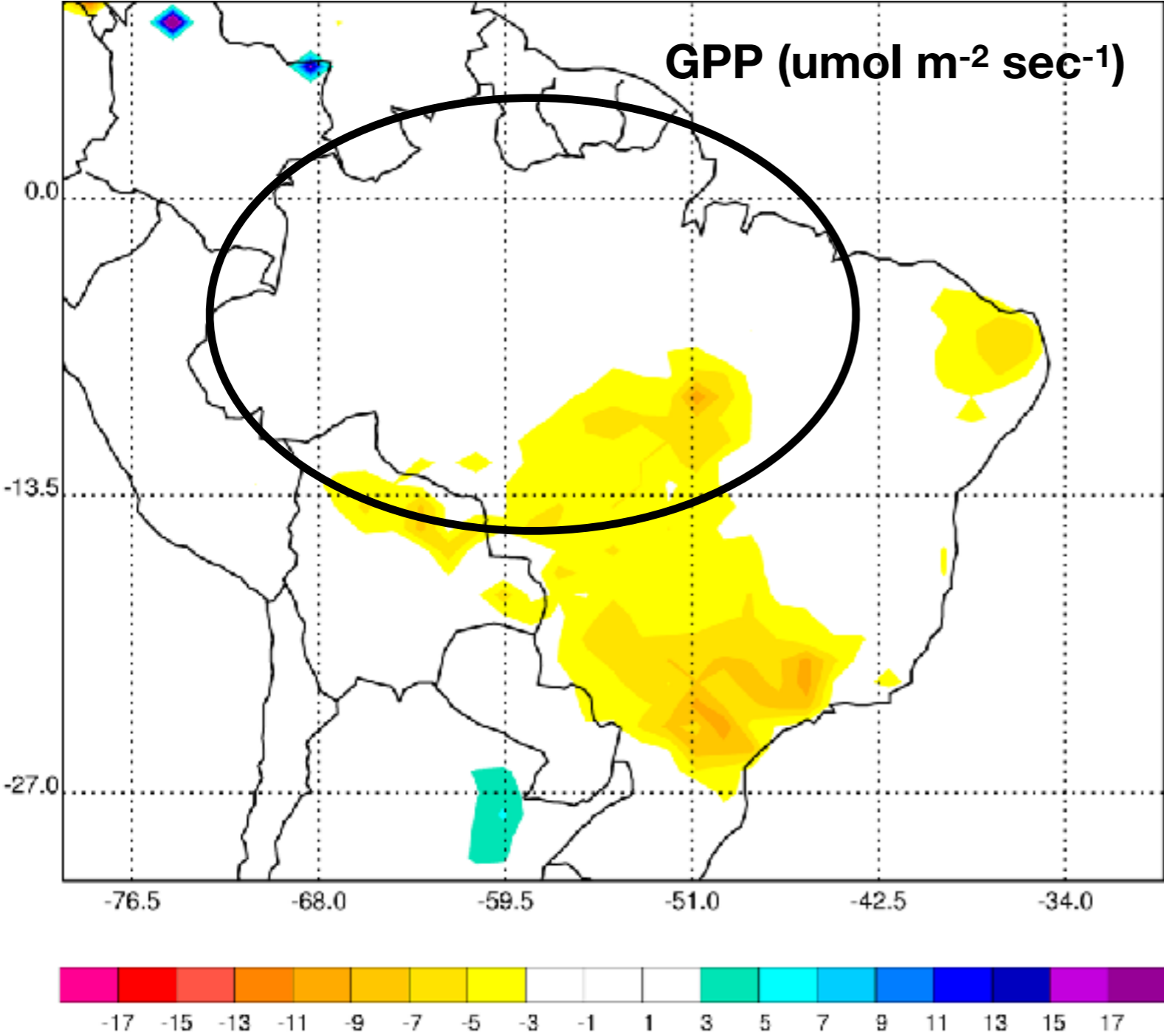
# GOME-2 SIF DIFFERENCE: September 2010 - September 2009



**We do see a difference in SIF in response to drought**

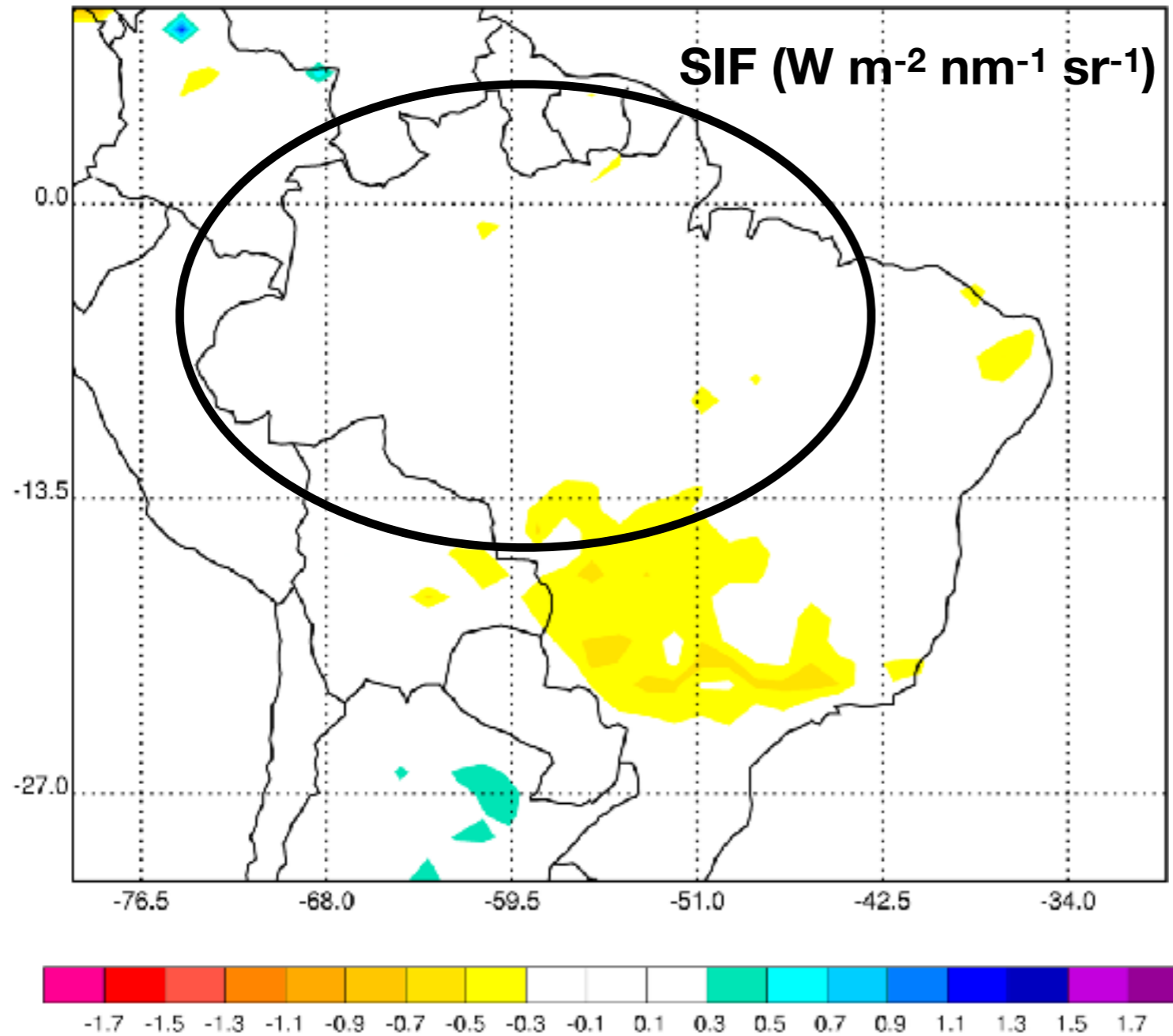


# SiB3 GPP DIFFERENCE: September 2010 - September 2009



**We also see a difference in model GPP in response to drought**

# SiB3 SIF DIFFERENCE: September 2010 - September 2009



But our model ***DOES NOT*** capture the drought signature in simulated SIF

***WE SPECULATE*** that we can reconcile the apparent disagreement between our model simulations and observations as follows:

- In tropical forests, response to stress may take the form of
  - Leaf curling
  - Leaf drop
  - Branch drop
  - Deciduous species in edge forests
- This has the effect of changing fPAR, which will modify SIF

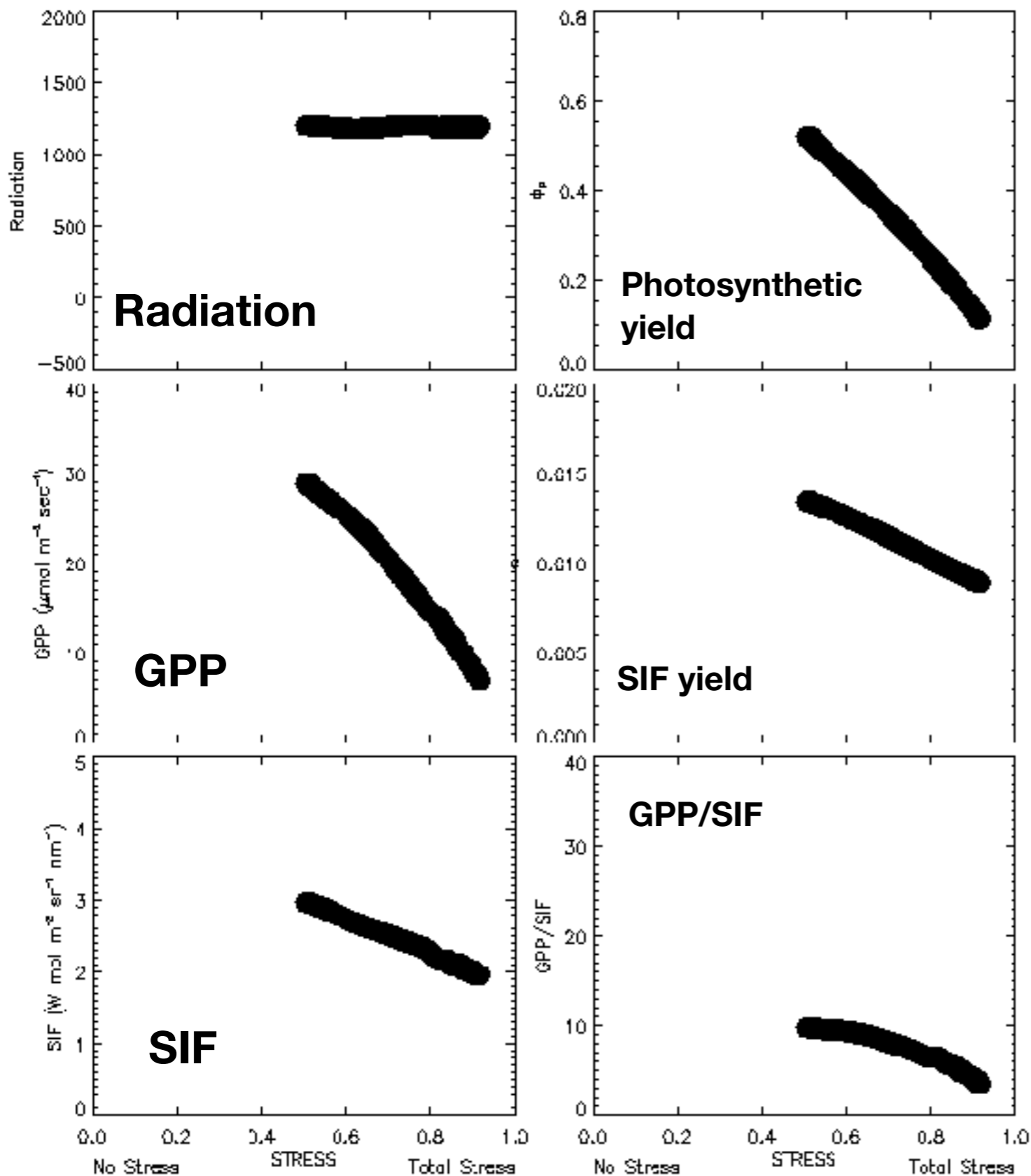
$$SIF = \phi_F \times PAR \times fPAR$$

**However, many of our models do not explicitly resolve these processes.**

**This serves as a caution to those who are trying to simulate SIF in tropical forests.**

**It also provides a reminder to those interpreting SIF observations as to what mechanisms may be involved to produce the signal that has been observed.**

# EXTRA Bonus Slide!



Drydown run sampled once per day during the drydown run, at time of OCO-2 overpass