Physical and ecophysiological controls on the relationship between solar-induced chlorophyll fluorescence and gross primary productivity across diurnal and seasonal scales in the boreal forest

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Abstract

Solar-Induced Chlorophyll Fluorescence (SIF) is a powerful proxy for gross primary productivity (GPP) in Boreal ecosystems. However, SIF and GPP are fundamentally different quantities that describe distinct, but related, physiological processes. Recent work has highlighted non-linearities between SIF and GPP at finer spatial (leaf- to canopy- level) and temporal (half-hourly) scales. Therefore, questions have arisen about when, where, and why SIF is a good proxy for GPP and what the potential sources for divergence between the two are. The goal of this study is to answer two specific questions: 1) At what temporal scale is SIF a good proxy for GPP and 2) What are the predominant physical and ecophysiological drivers of nonlinearity between SIF and GPP in boreal ecosystems? We collected tower-based measurements of SIF (and other common vegetation indices) with PhotoSpec (a custom spectrometer system) and eddy-covariance GPP data at a 30-minute resolution at the Southern Old Black Spruce Site (SOBS) in Saskatchewan, CA. We applied a combination of statistical and machine learning approaches to disentangle the influence of structural/illumination effects and ecophysiological variations on the SIF signal. Our results show that at a high temporal resolution (half-hourly), SIF and GPP are predominantly dependent on photosynthetically active radiation (PAR). Therefore, the non-linear light response of GPP drives non-linearity between SIF and GPP. Additionally, canopy structure and illumination effects become important to the SIF signal at high temporal resolutions. At the seasonal timescale, SIF and GPP exhibit co-varying responses to PAR, even when accounting for changes in canopy structure. We attribute changes in the light responses of SIF and GPP to sustained photoprotection over winter which co-varies with changes in temperature. Finally, we show that the relationship between SIF and GPP has a seasonal dependence caused by small differences between the light use efficiencies of fluorescence and photosynthesis. Accounting for this seasonally variable relationship will improve the use of SIF as a proxy for GPP.

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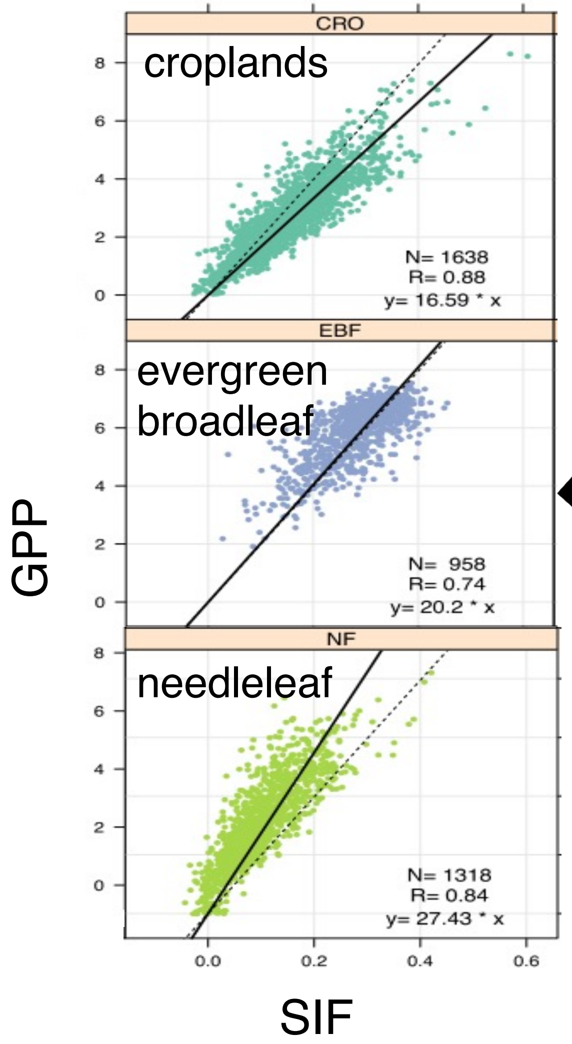
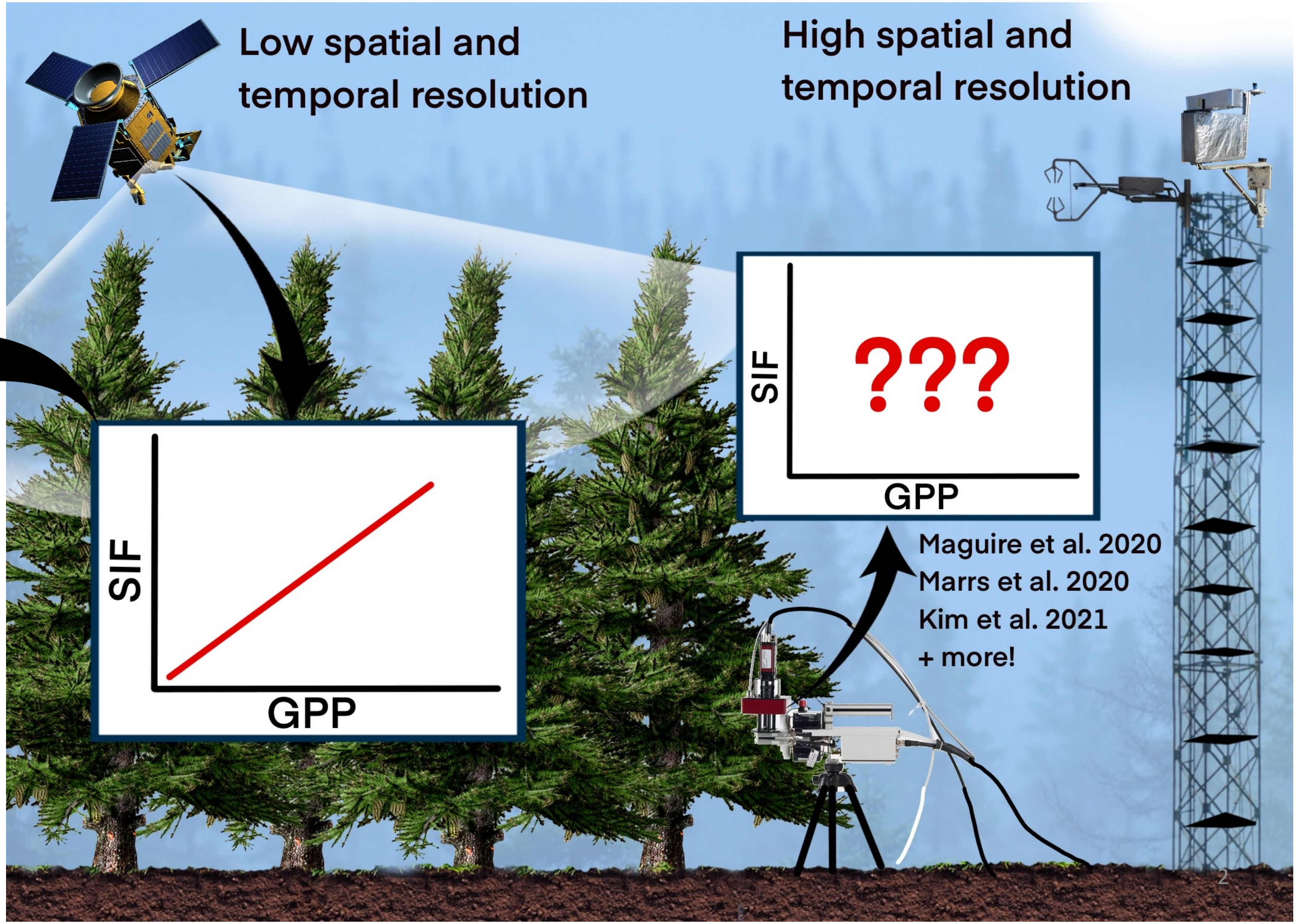
ABoVE ARCTIC – BOREAL VULNERABILITY EXPERIMENT

SIF is a powerful proxy for GPP, however, smaller scale studies have highlighted nuance to the relationship between SIF and GPP



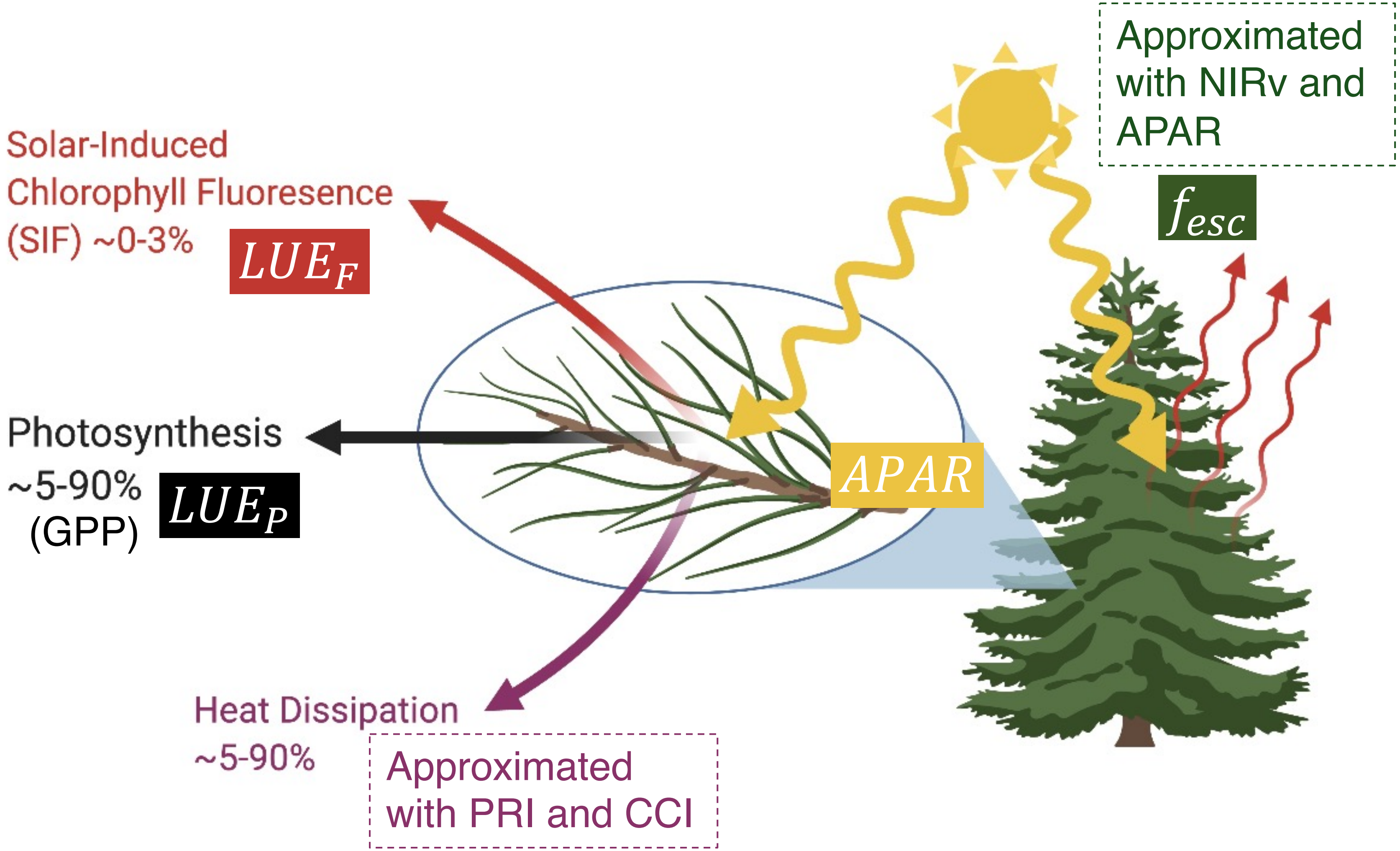
Sun et al., 2018



A SIF emission is one of three potential pathways an absorbed photon can take. We can use this information to relate SIF and GPP

$$GPP = APAR * LUE_P$$
$$SIF = APAR * LUE_F * f_{esc}$$

$$GPP = SIF * \boxed{\frac{LUE_P}{LUE_F * f_{esc}}}$$



Photon plant interactions over complex canopy structures (*physical*) create significant challenges for interpreting SIF and connecting it to plant productivity (*ecophysiological*)

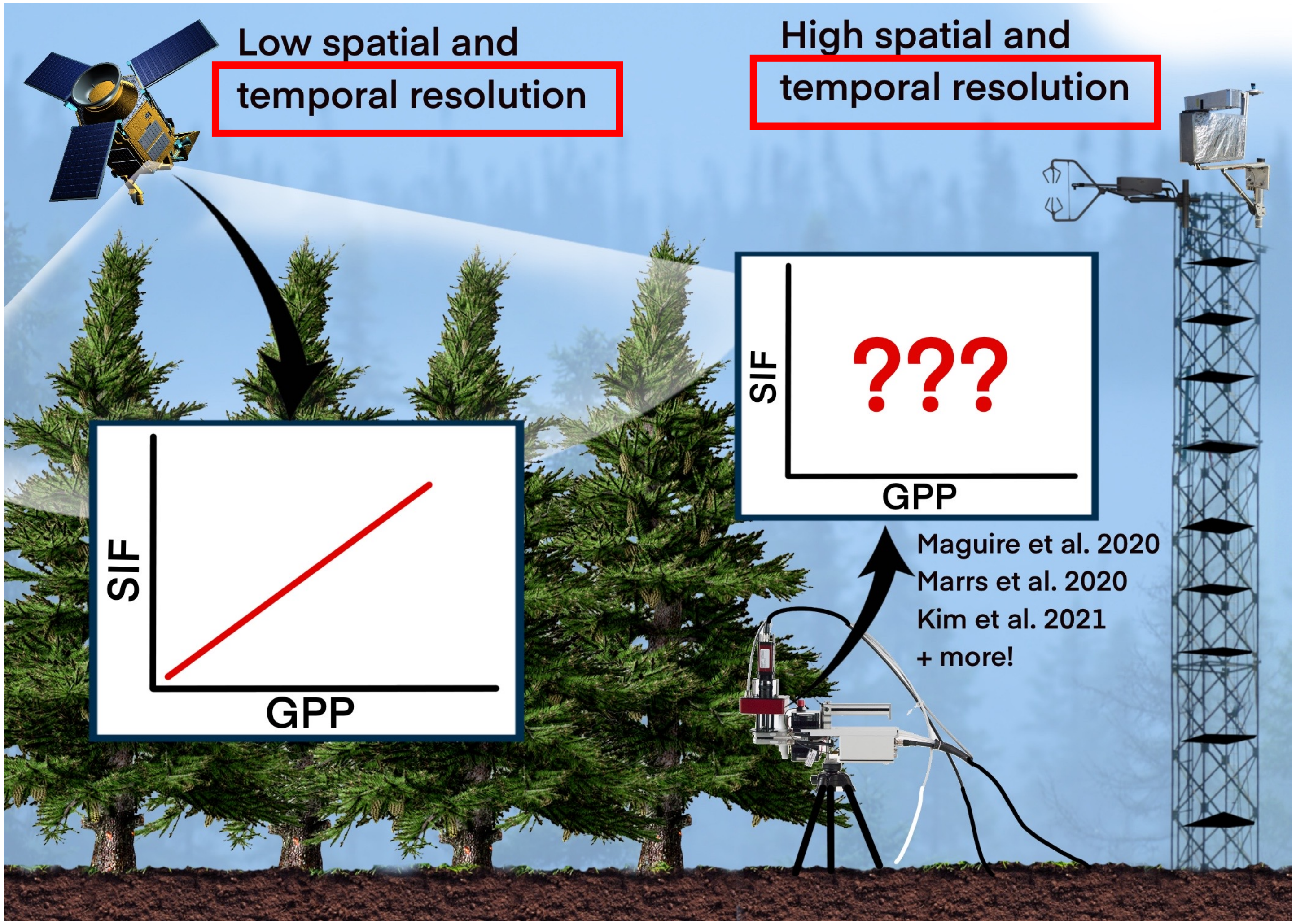
The goals of this study:

$$GPP = SIF * \frac{LUE_P}{LUE_F * f_{esc}}$$

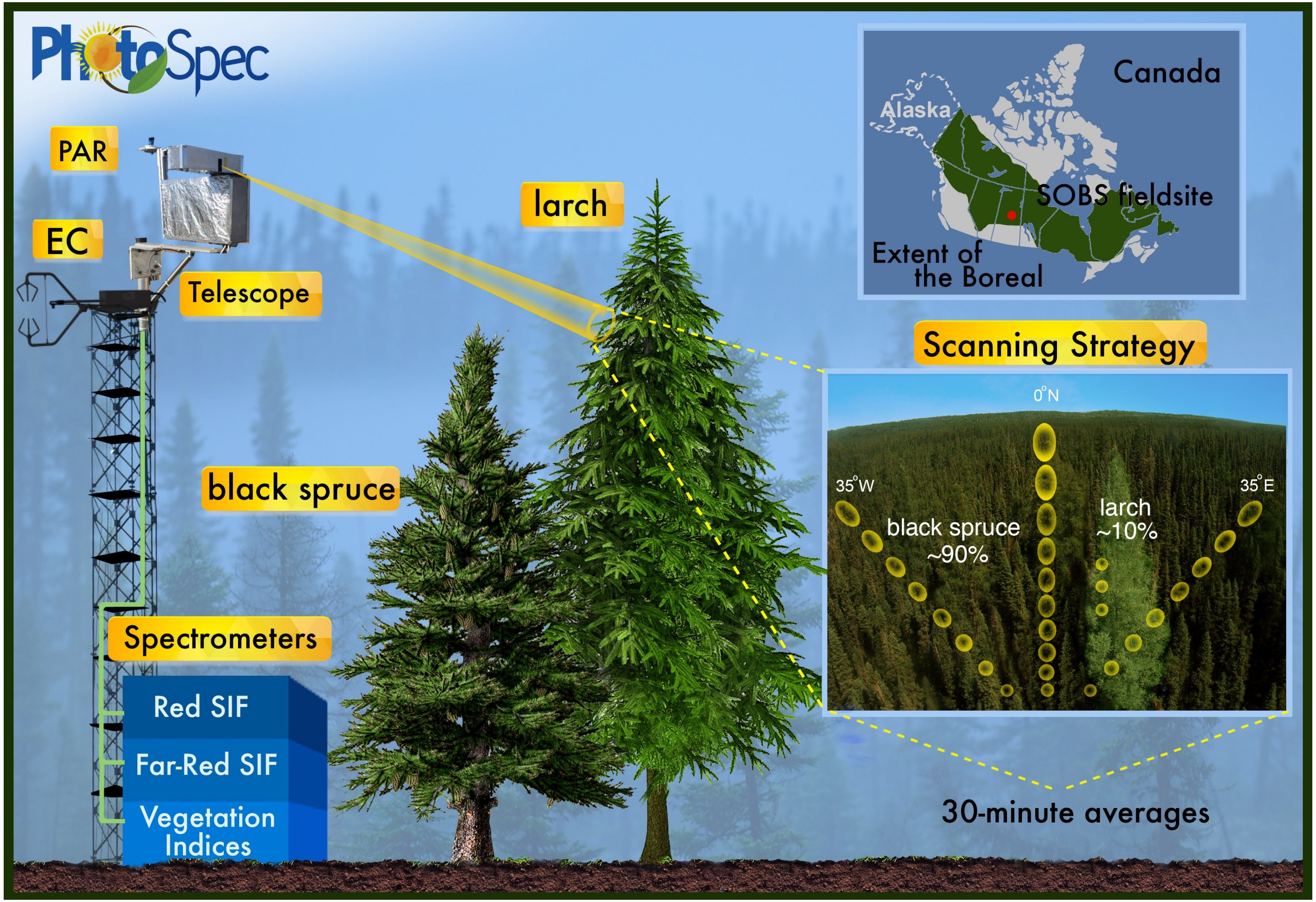
1. What are the relationships among SIF, VIs, and GPP?

2. How do the dynamics of LUE_P, LUE_F, and f_{esc} impact the relationship between SIF and GPP at varying temporal scales?

*in the boreal forest

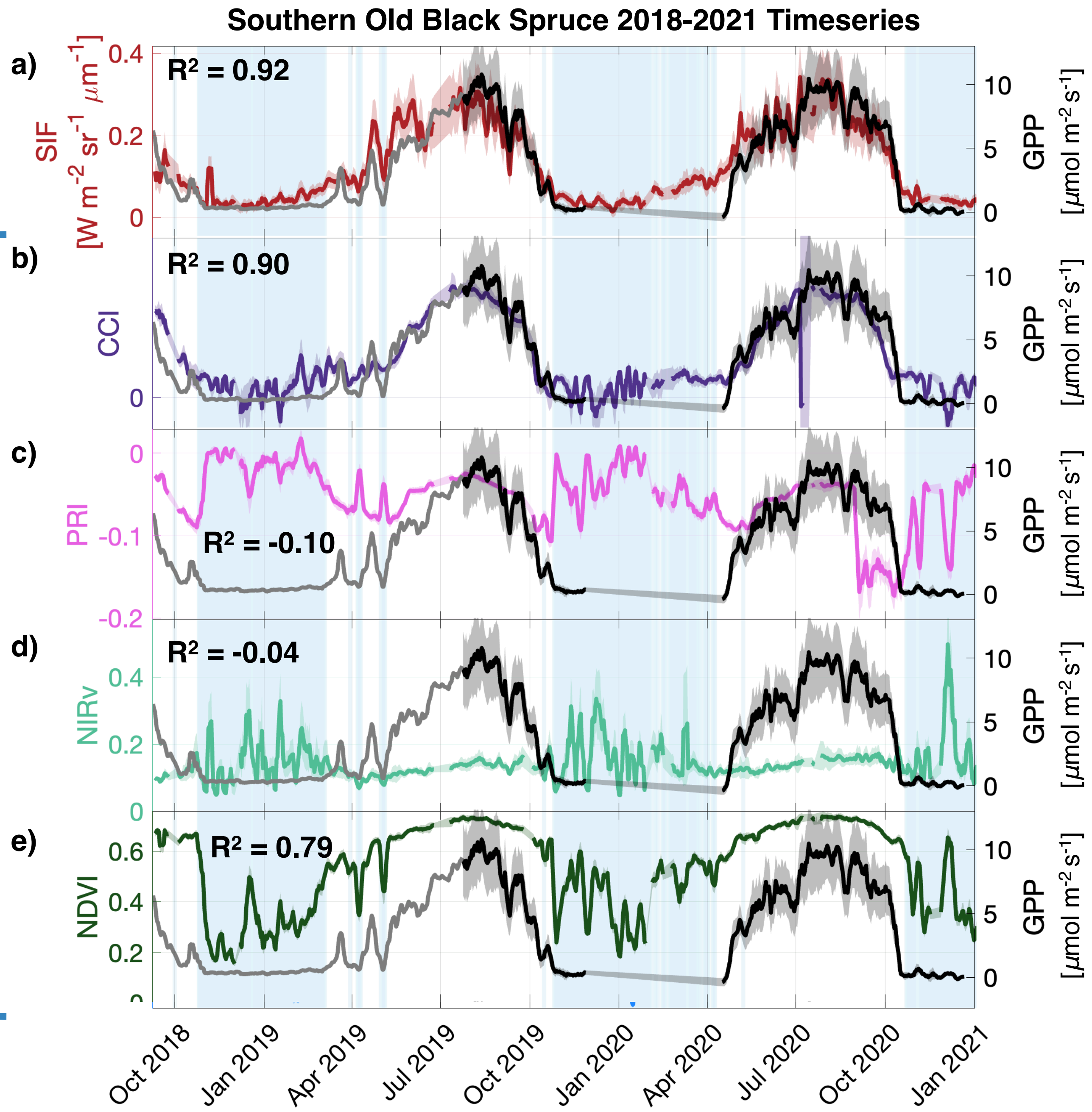


We collected data from PhotoSpec in a boreal mixed-species needleleaf forest



Pierrat et al., 2021
Pierrat et al., in revision
Grossmann et al., 2018

SIF and vegetation indices as a proxy for GPP



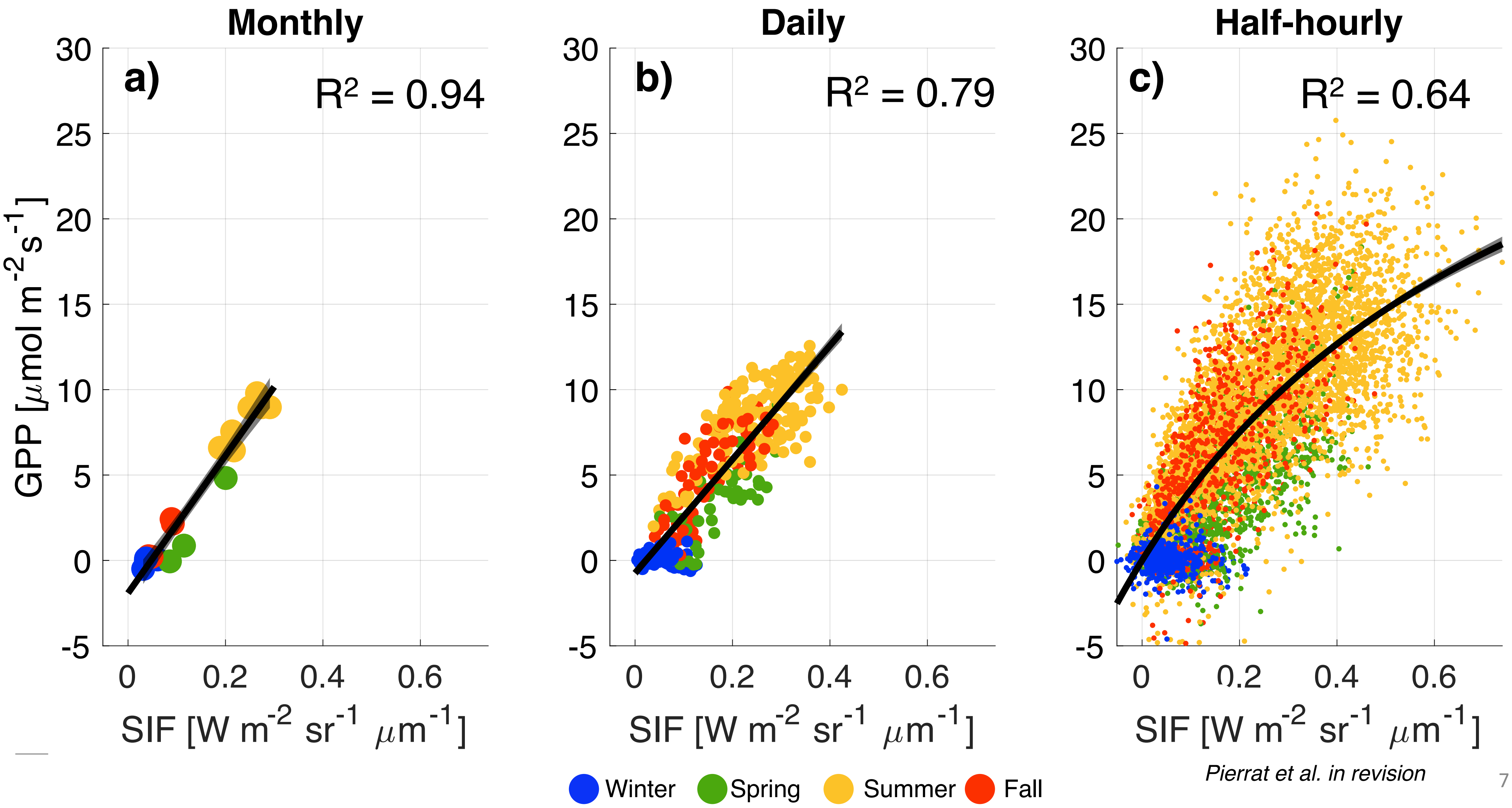
Snow impacts all VIs

Physiologically sensitive metrics (SIF, CCI, PRI*) show seasonal correlations with GPP

Structurally sensitive indices (NDVI and NIRv) show little seasonal variation

Pierrat et al. in revision

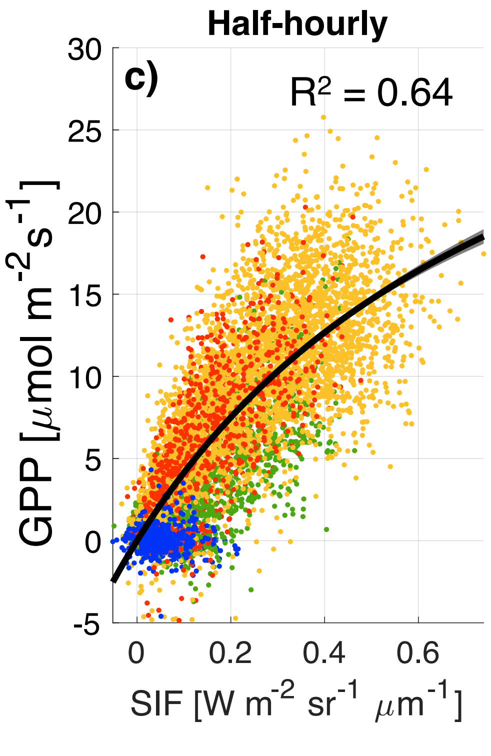
The SIF-GPP relationship becomes **increasingly non-linear** at high temporal resolutions

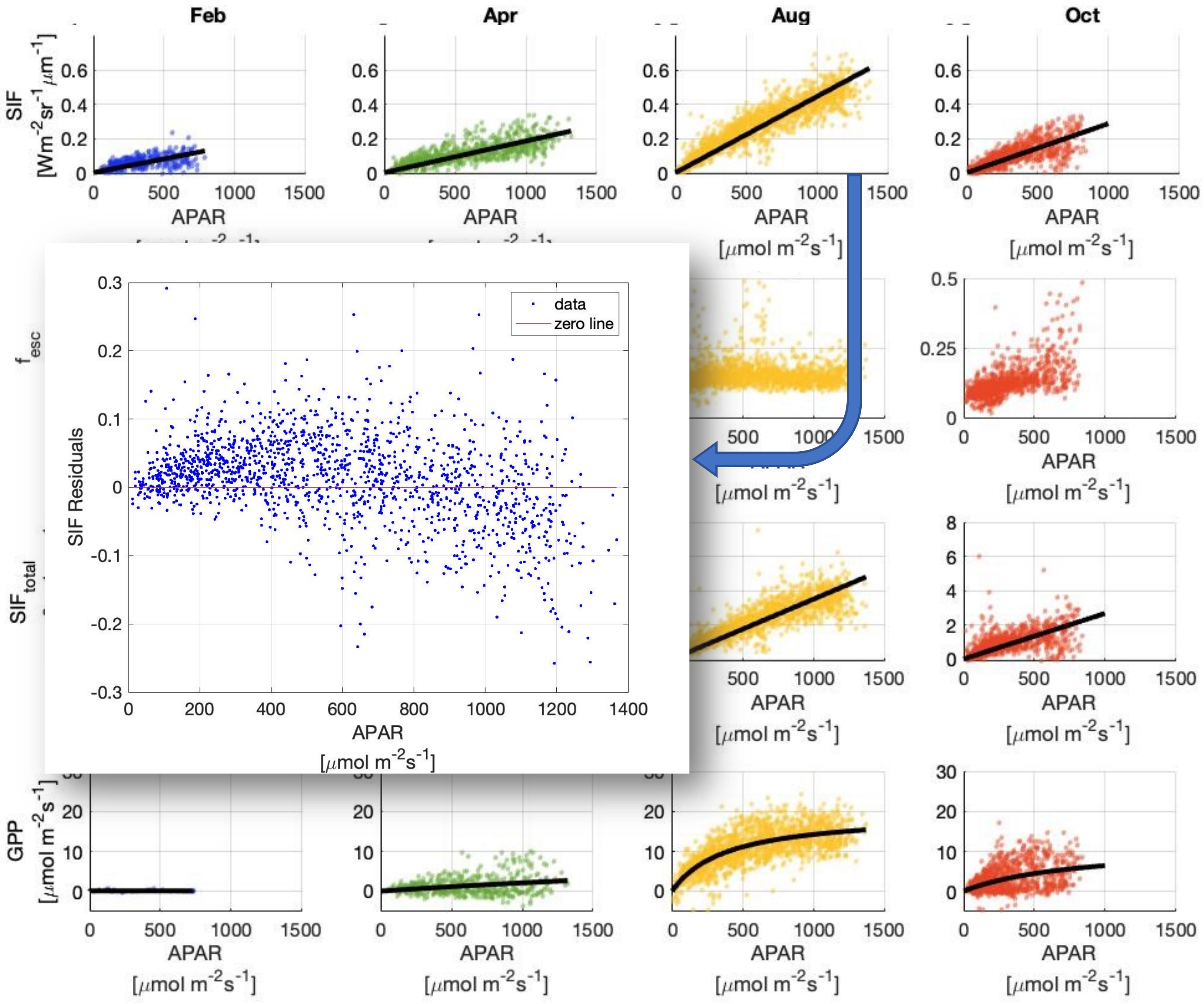


Pierrat et al. in revision

Light saturation of GPP is the primary driver of the non-linear SIF/GPP relationship at a half-hourly resolution

$$GPP = SIF * \frac{LUE_P}{LUE_F * f_{esc}}$$





$$SIF = APAR * \boxed{LUE_F * f_{esc}}$$

$$f_{esc} = \frac{NIRv}{fPAR}$$

Zeng et al., 2019

$$\frac{SIF}{f_{esc}} = SIF_{total} = APAR * LUE_F$$

$$GPP = APAR * LUE_P$$

$$LUE_P = \frac{GPP_{max} * APAR}{c + APAR}$$

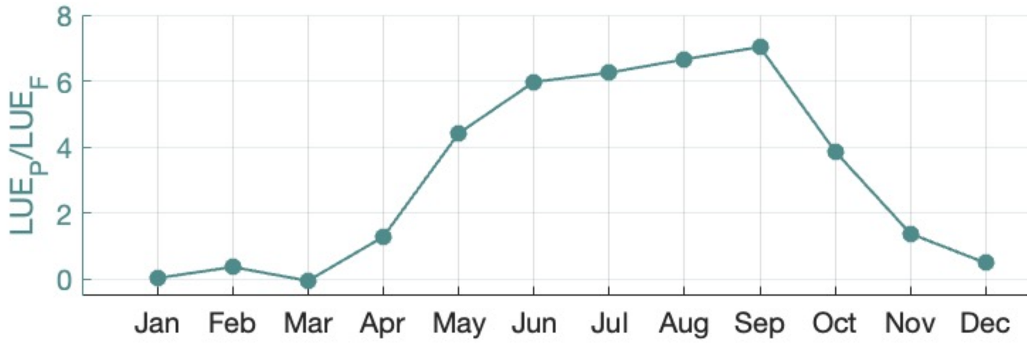
Co-variation between LUE_F and LUE_P drives the seasonal convergence of SIF and GPP, but there is a seasonal dependence

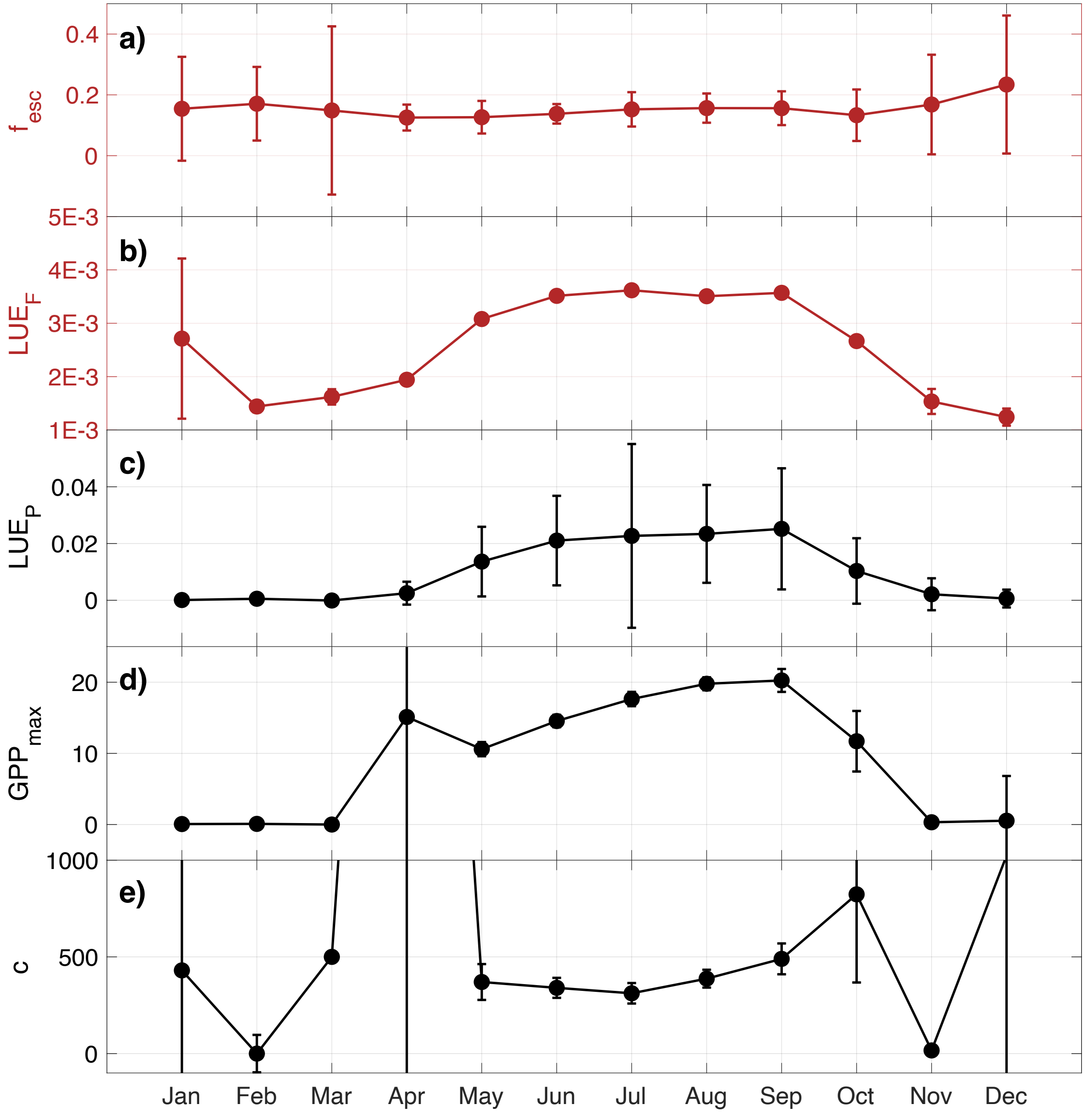
$$GPP = SIF * \frac{LUE_P}{LUE_F * f_{esc}}$$

$$SIF = APAR * LUE_F * f_{esc}$$

$$GPP = APAR * LUE_P$$

$$LUE_P = \frac{GPP_{max} * APAR}{c + APAR}$$





Calculated using NIRv following *Zeng et al., 2019*

Calculated from light response curves of SIF_{total}

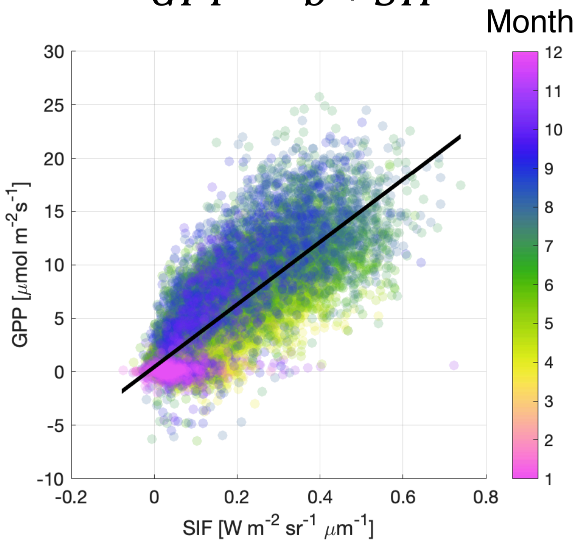
Calculated as GPP/APAR

Calculated from light response curves of GPP

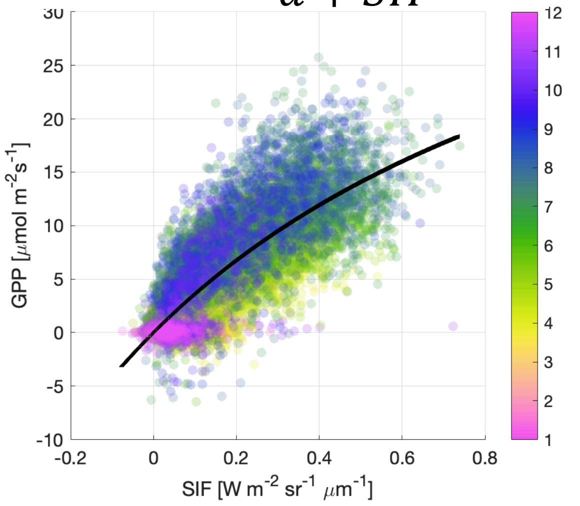
Pierrat et al. in revision

A seasonally variable SIF-GPP relationship can help account for nuances in the seasonal variability of f_{esc}, LUE_F, and LUE_P

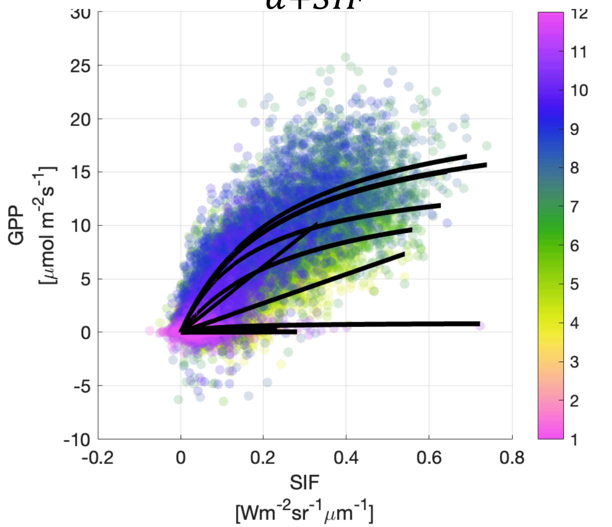
$$GPP = b * SIF$$



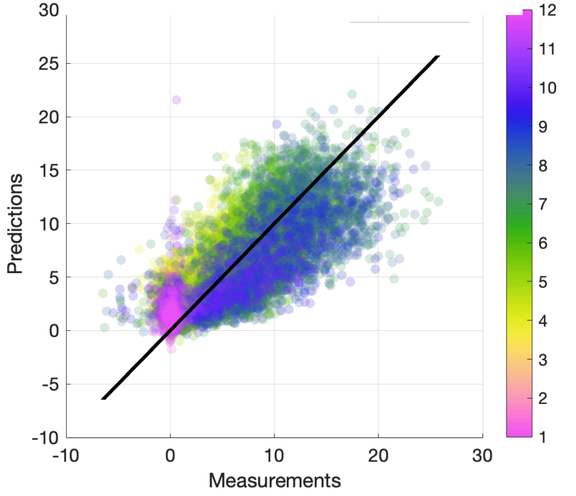
$$GPP = \frac{SIF * GPP_{max}}{a + SIF}$$



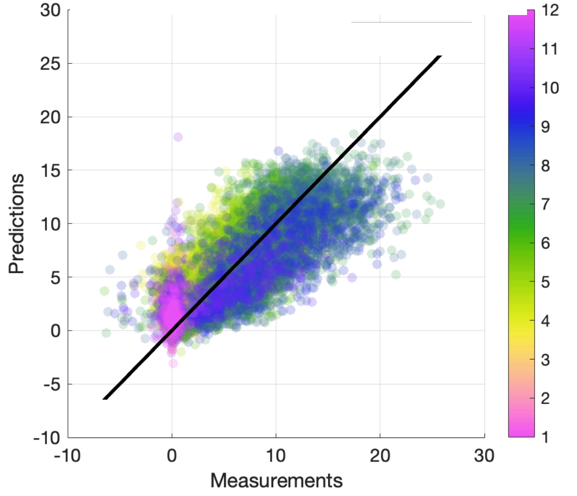
$GPP = \frac{SIF * GPP_{max}}{a + SIF}$, variable



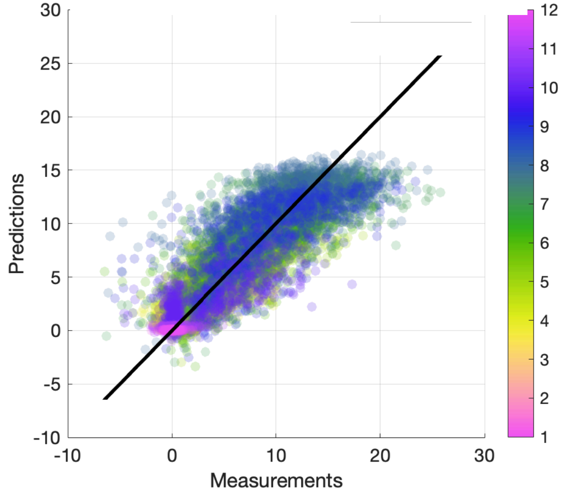
Predictions, $R^2 = 0.61$



Predictions, $R^2 = 0.62$

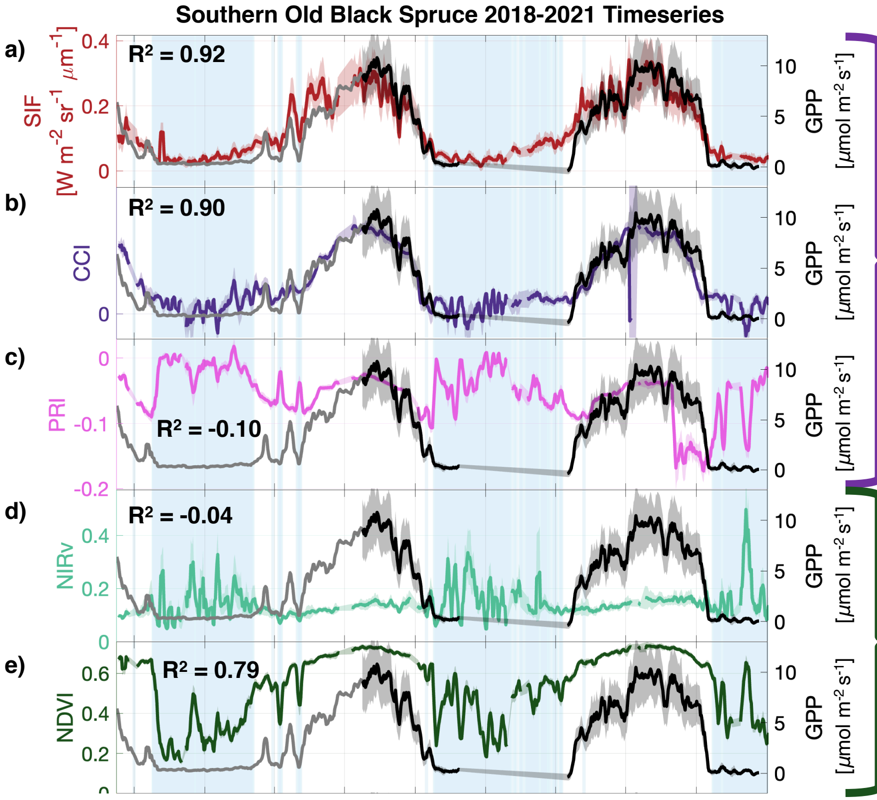


Predictions, $R^2 = 0.79$



Conclusions:

1. What are the relationships among SIF, VIs, and GPP across varying temporal scales?

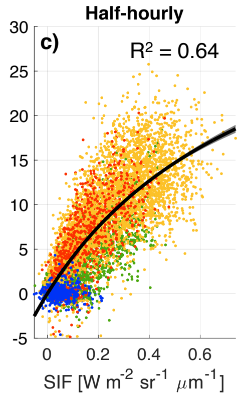


Physiologically sensitive metrics (SIF, CCI, PRI) show seasonal correlations with GPP

Structurally sensitive indices (NDVI and NIRv) show little seasonal variation

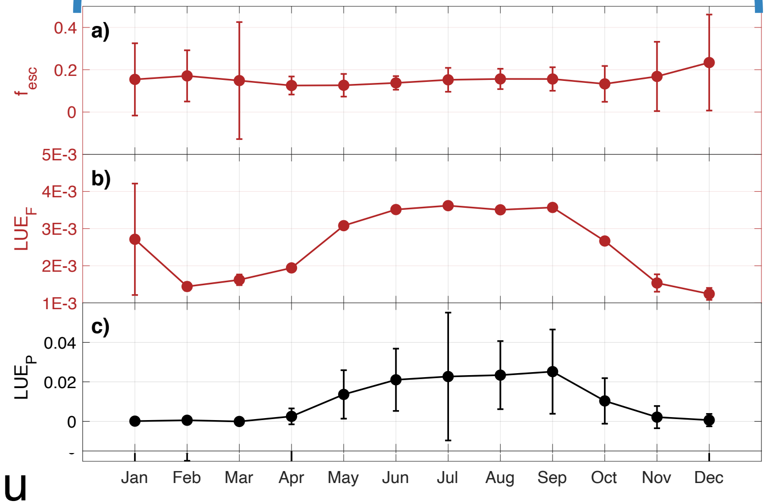
Snow needs to be considered!

2. How do the dynamics of LUE_P, LUE_F, and f_{esc} impact the relationship between SIF and GPP at varying temporal scales?



Diurnal nonlinearity due to light saturation of GPP/LUE_P

Co-variation between LUE_F and LUE_P drives seasonal convergence



A seasonally variable SIF-GPP relationship will help account for additional nuances to the SIF-GPP relationship

Questions?

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