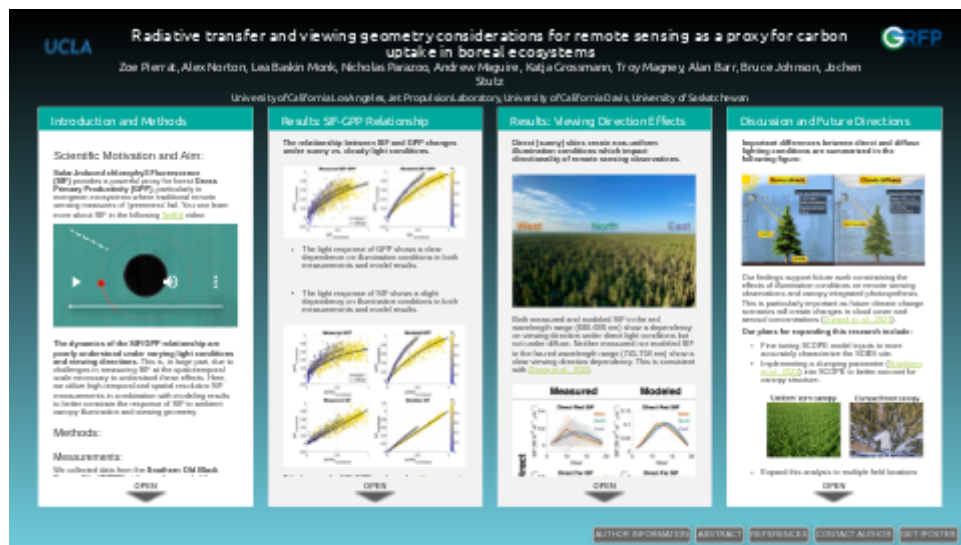


Radiative transfer and viewing geometry considerations for remote sensing as a proxy for carbon uptake in boreal ecosystems

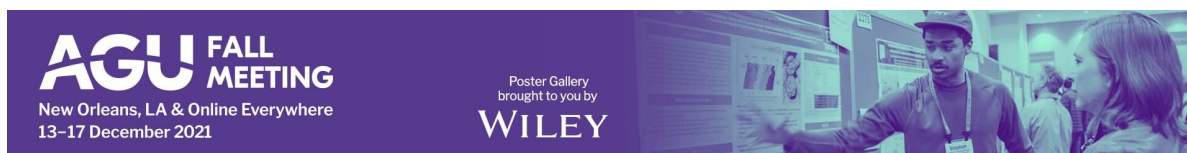


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University of California Los Angeles, Jet Propulsion Laboratory, University of California Davis, University of Saskatchewan



PRESENTED AT:



INTRODUCTION AND METHODS

Scientific Motivation and Aim:

Solar-Induced chlorophyll Fluorescence (SIF) provides a powerful proxy for forest **Gross Primary Productivity (GPP)**, particularly in evergreen ecosystems where traditional remote sensing measures of 'greenness' fail. You can learn more about SIF in the following TedEd (<https://www.youtube.com/watch?v=3jpy8UZUEOw&t=158s&fs=1&modestbranding=1&rel=0&showinfo=0>) video:

v=3jpy8UZUEOw&t=158s&fs=1&modestbranding=1&rel=0&showinfo=0) video:

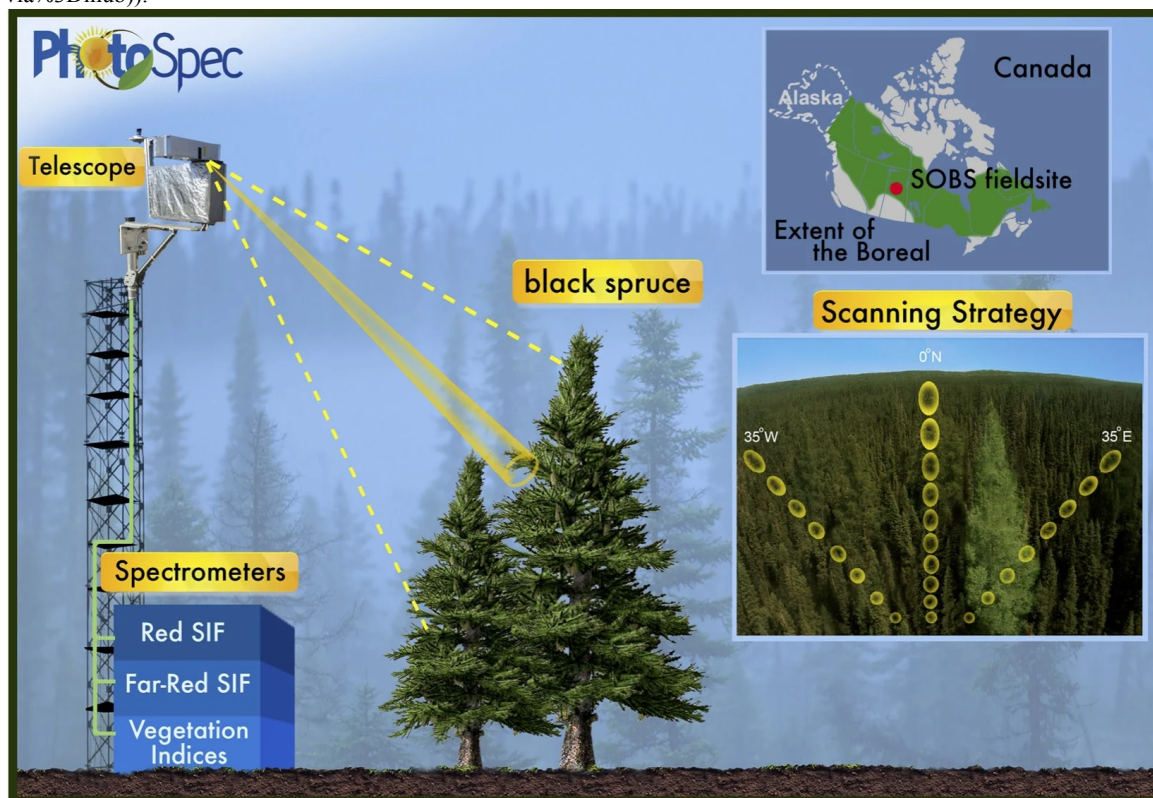
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The dynamics of the SIF/GPP relationship are poorly understood under varying light conditions and viewing directions. This is, in large part, due to challenges in measuring SIF at the spatiotemporal scale necessary to understand these effects. Here, we utilize high-temporal and spatial resolution SIF measurements in combination with modeling results to better constrain the response of SIF to ambient canopy illumination and viewing geometry.

Methods:

Measurements:

We collected data from the **Southern Old Black Spruce Site (SOBS)** at the southern end of the Canadian boreal forest in the summer of 2019. SIF data were collected using PhotoSpec (Grossmann et al., 2018 (<https://www.sciencedirect.com/science/article/pii/S0034425718303298?via%3Dihub>)) and GPP data were derived from flux-tower measurements (Barr et al., 2004 (<https://www.sciencedirect.com/science/article/pii/S0168192304001686?via%3Dihub>)).



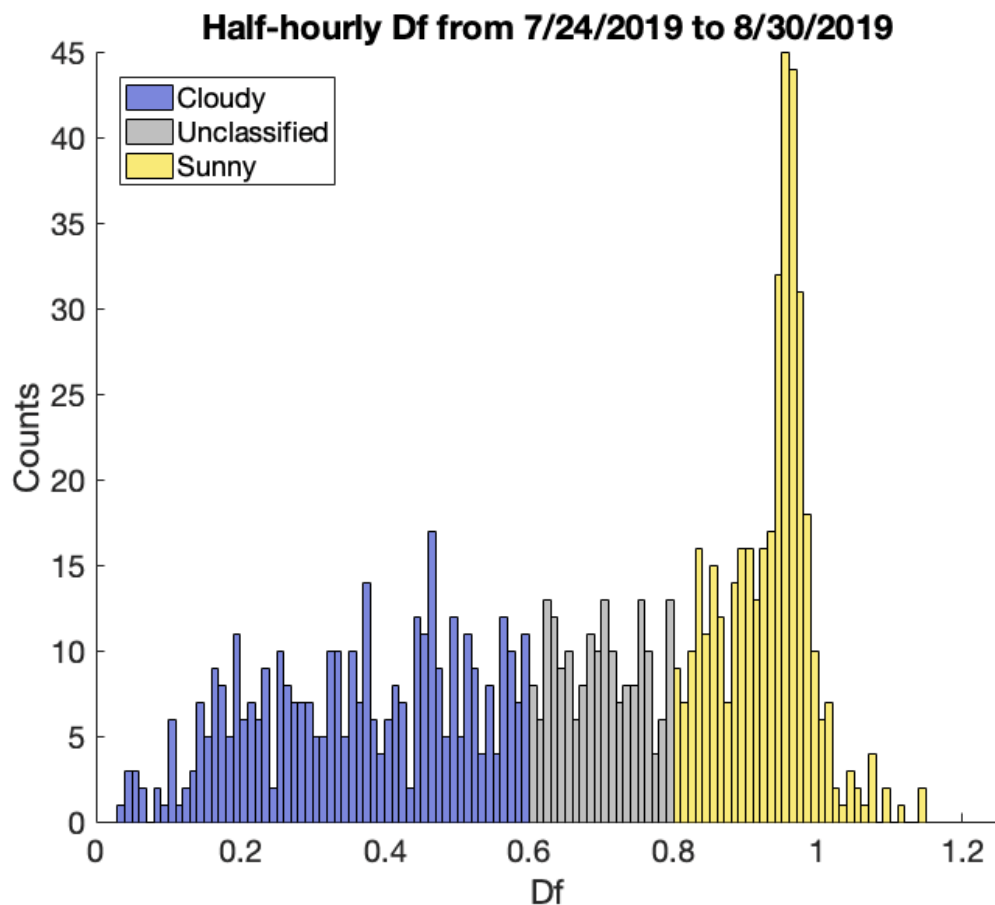
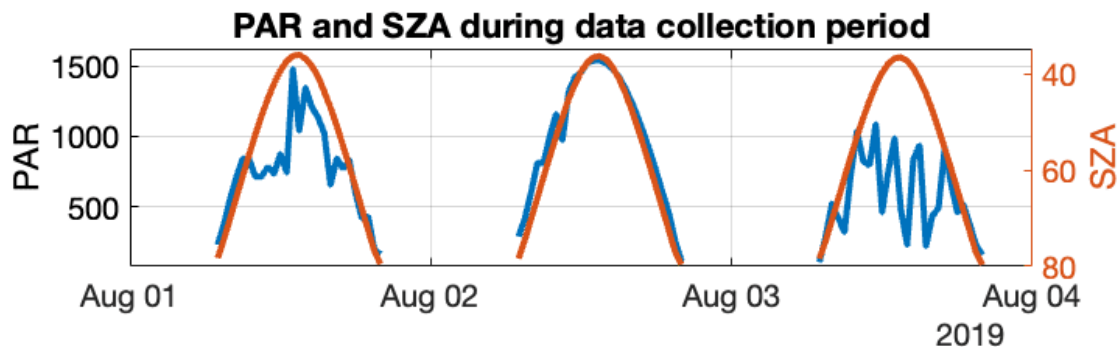
Modeling:

We compared our measurements to model results from the **Soil Canopy Observation Photochemistry and Energy fluxes model (SCOPE)** (van der Tol et al., 2009 (<https://bg.copernicus.org/articles/6/3109/2009/bg-6-3109-2009.html>)).

- We drove the model using input parameters measured from the SOBS field site
- We modified the model to **mimic PhotoSpec's viewing strategy**.
- **We simulated the effects of direct vs. diffuse illumination** by applying two top-of-canopy incoming spectra with differing diffuse fractions (55% and 15%). This simplified approach represents two somewhat extreme cases, useful for sensitivity analysis, but does not represent the full temporal variability of diffuse radiation observed at the site.

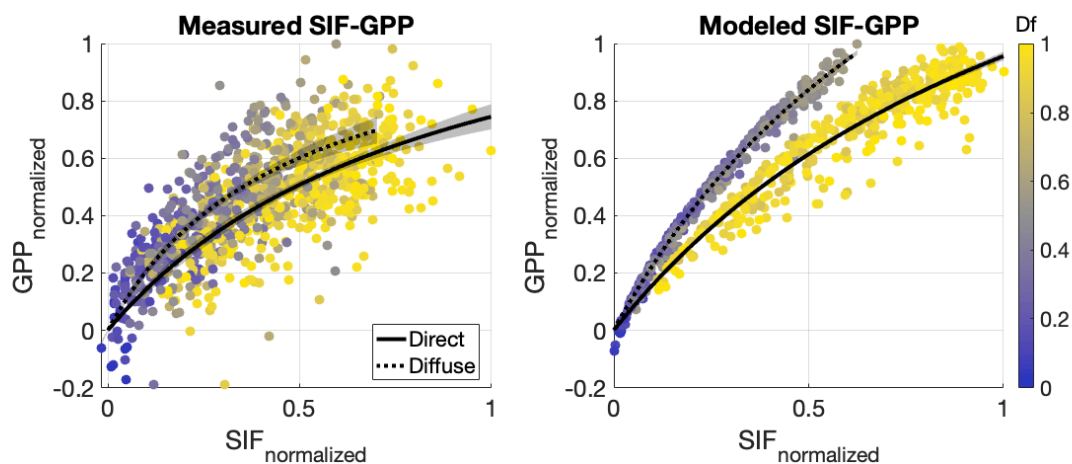
Defining Illumination Conditions:

We separated sunny (direct) from cloudy (diffuse) illumination conditions by defining a clear sky comparison metric, D_f . D_f reflects the deviation of PAR at a given solar zenith angle from the expected PAR during a clear sky reference day so that $D_f=1$ is clear sky conditions.

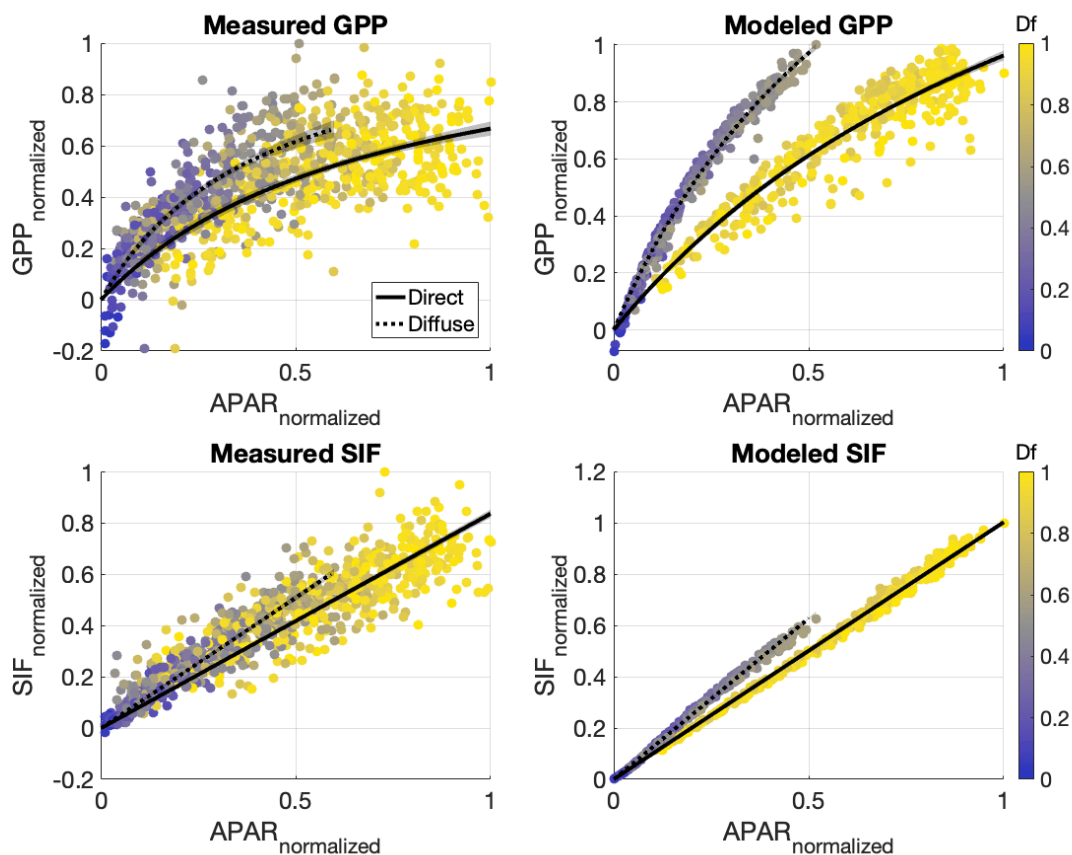


RESULTS: SIF-GPP RELATIONSHIP

The relationship between SIF and GPP changes under sunny vs. cloudy light conditions.



- The light response of GPP shows a clear dependence on illumination conditions in both measurements and model results.
- The light response of SIF shows a slight dependency on illumination conditions in both measurements and model results.



Fitted curves for SIF-GPP are based on Damm et al., 2015 (<https://doi.org/10.1016/j.rse.2015.06.004>) as:

$$GPP = \frac{a * SIF}{b + SIF}.$$

Fitted curves for the light responses of SIF and GPP are based on the light-use efficiency model (LUE) where:

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

and

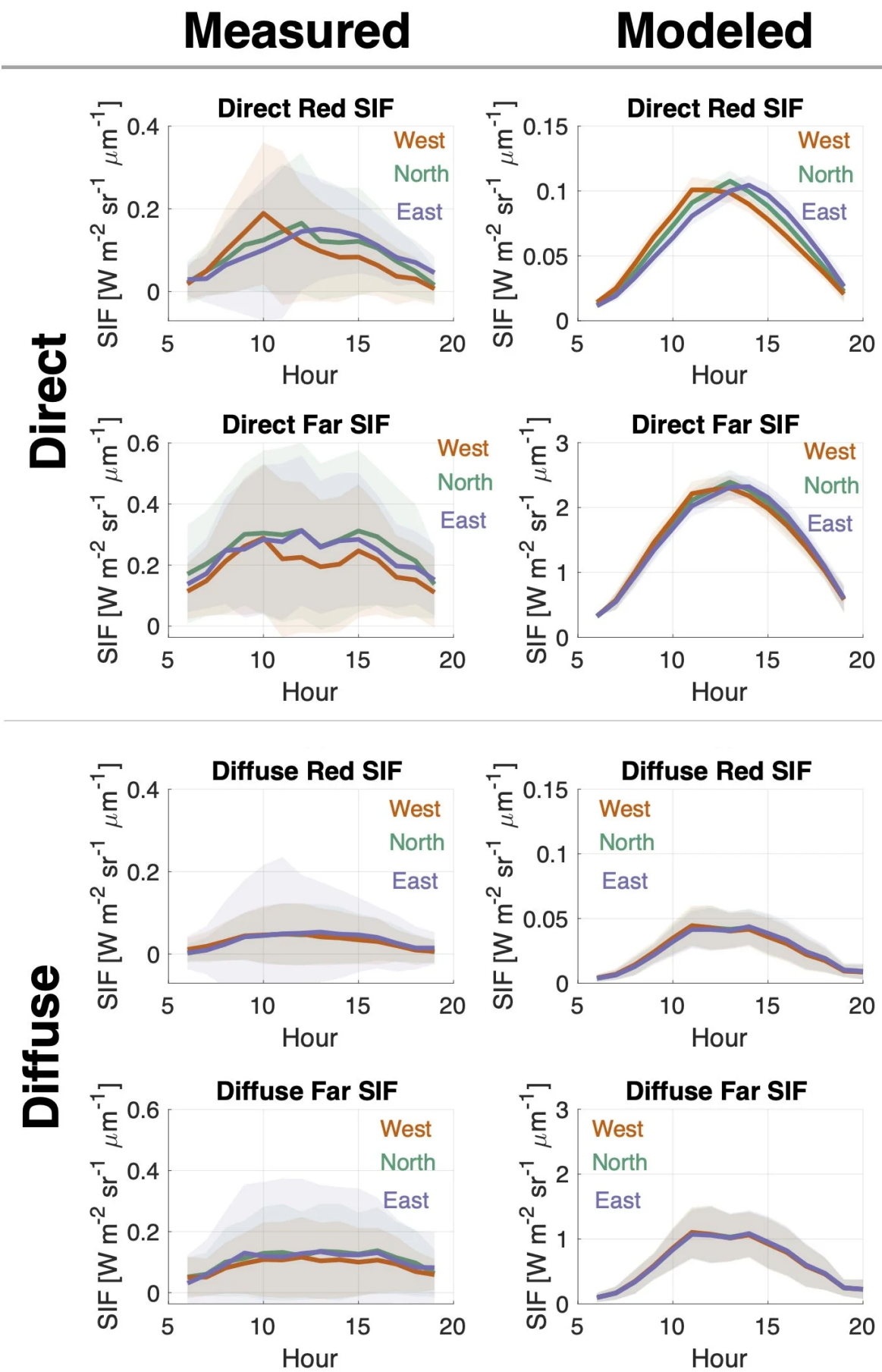
$$GPP = LUE_P * APAR = \frac{GPP_{max} * APAR}{c + APAR}$$

RESULTS: VIEWING DIRECTION EFFECTS

Direct (sunny) skies create non-uniform illumination conditions which impact directionality of remote sensing observations.

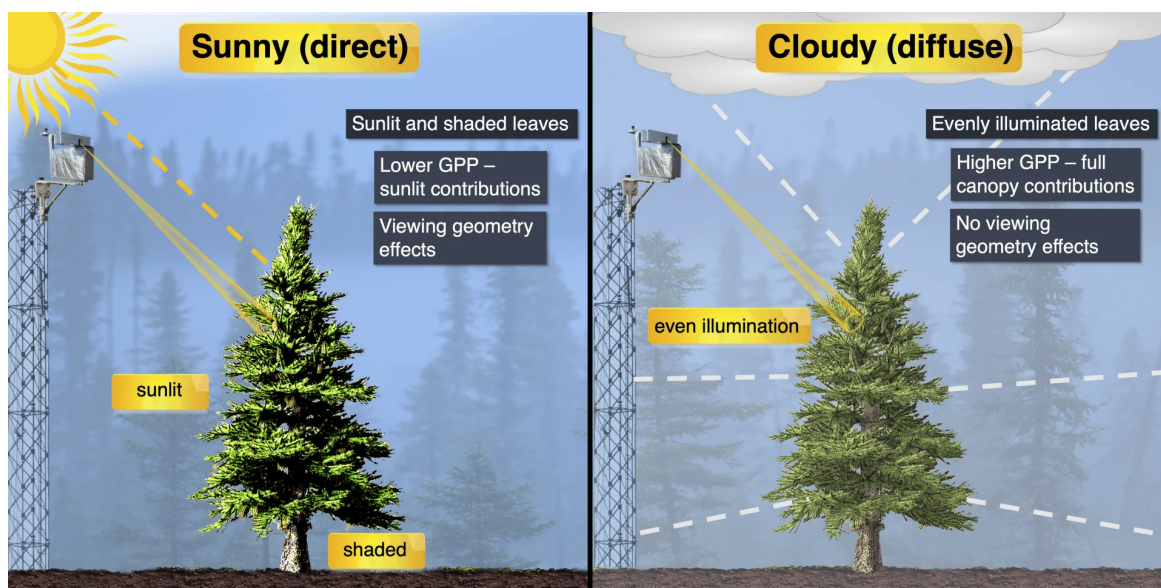


Both measured and modeled SIF in the red wavelength range (680-686 nm) show a dependency on viewing direction under direct light conditions but not under diffuse. Neither measured nor modeled SIF in the far-red wavelength range (745-758 nm) show a clear viewing direction dependency. This is consistent with Zhang et al., 2020 (<https://www.sciencedirect.com/science/article/pii/S0168192320302495?via%3Dihub>).



DISCUSSION AND FUTURE DIRECTIONS

Important differences between direct and diffuse lighting conditions are summarized in the following figure:



Our findings support future work constraining the effects of illumination conditions on remote sensing observations and canopy integrated photosynthesis. This is particularly important as future climate change scenarios will create changes in cloud cover and aerosol concentrations (Durand et. al., 2021 (<https://www.sciencedirect.com/science/article/pii/S0168192321003701?via%3Dihub#fig0007>)).

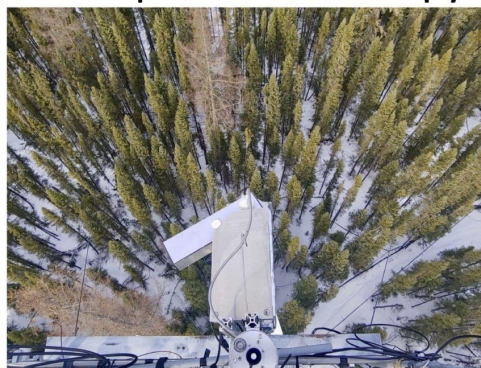
Our plans for expanding this research include:

- Fine tuning SCOPE model inputs to more accurately characterize the SOBS site.
- Implementing a clumping parameter (Braghiere et al., 2021 (<https://www.sciencedirect.com/science/article/pii/S0034425721002157?via%3Dihub>)) into SCOPE to better account for canopy structure.

‘Uniform’ corn canopy



Clumped forest canopy



- Expand this analysis to multiple field locations (Delta Junction, Alaska)
- Provide recommendations for observations at the satellite level to account for illumination conditions on the relationship between SIF and GPP.

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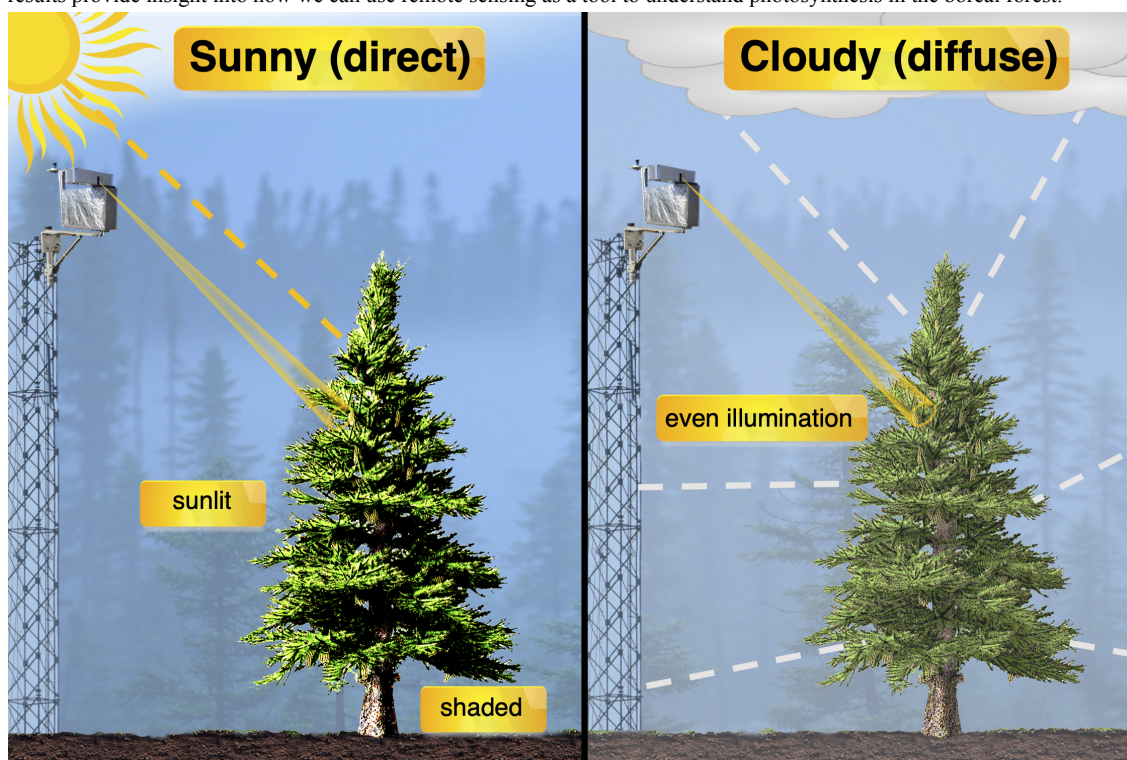
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ABSTRACT

The boreal forest plays an important role in the global carbon cycle but has remained a significant source of uncertainty. Remote sensing can help us better understand the boreal forest's role in the global carbon cycle. A faint light signal emitted by plant's photosynthetic machinery, known as solar-induced chlorophyll fluorescence (SIF), is a promising remotely sensed proxy for carbon uptake, also known as gross primary productivity (GPP), due to its connection to photosynthesis and its strong relationship with GPP when observed by satellite. However, SIF and GPP are fundamentally different quantities that describe distinct, but related, physiological processes. The relationship between SIF and GPP is therefore complicated by both physical and ecophysiological controls. In particular, the dynamics of the SIF/GPP relationship are poorly understood under varying viewing directions and light conditions. This is further complicated in evergreen systems where canopy clumping and the presence of needles create a unique radiative environment. We use a combination of tower-based SIF and GPP measurements from a boreal forest field site compared with a coupled biochemical-radiative transfer model to understand illumination effects on the SIF/GPP relationship. We find that GPP is amplified under cloudy sky conditions in both measurements and model results. SIF on the other hand, shows no significant difference between sunny or cloudy sky conditions in modeled results, but does show a difference in measurements. We suggest that these differences may be due to viewing geometry effects that are important for SIF under sunny sky conditions or the presence of clumping. Accounting for the differences in the SIF/GPP relationship therefore is critical for the utility of SIF as a proxy for GPP. In summation, our results provide insight into how we can use remote sensing as a tool to understand photosynthesis in the boreal forest.



(https://agu.confex.com/data/abstract/agu/fm21/4/6/Paper_835064_abstract_783618_0.jpg)

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