# Sustained Non-Photochemical Quenching Shapes the Seasonal Pattern of Solar-Induced Fluorescence at a High-Elevation Evergreen Forest


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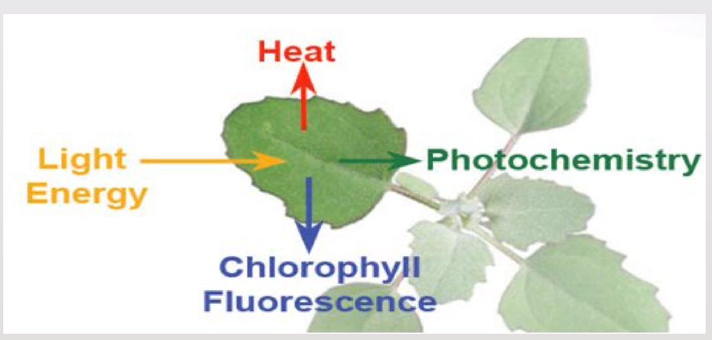
## MOTIVATION

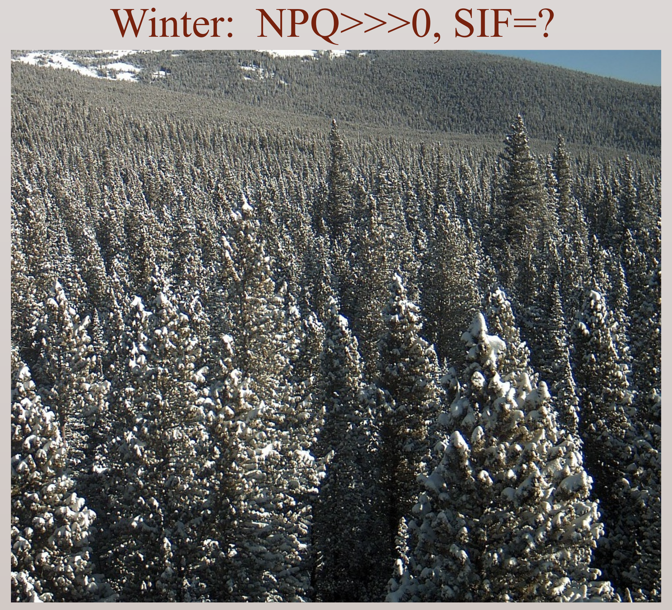
Solar-induced chlorophyll fluorescence (SIF) has emerged as a useful proxy for gross primary productivity (GPP) across a range of biomes. The growing network of remotely sensed SIF provides an opportunity to quantify and evaluate ecosystem function on a global scale. The SIF-GPP relationship is primarily empirical, however, and the mechanisms behind the generation of SIF are less well understood.




Absorbed light energy (APAR) is converted to photosynthesis, SIF or dissipated as heat (Non-Photochemical Quenching; NPQ). The division of energy depends upon the photosynthetic capacity of the leaf influenced by environmental conditions (light, temperature).

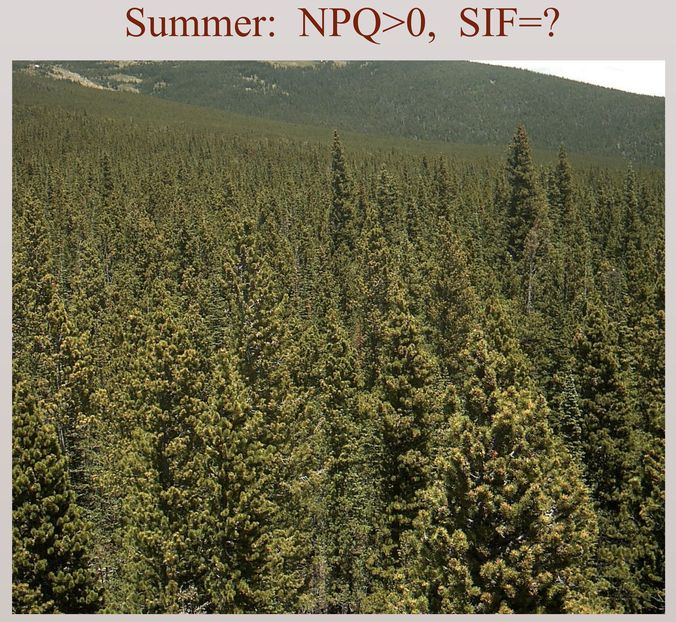
Cold climate conifer species maintain there leaf area during winter, yet photosynthesis ~ 0. NPQ increases significantly to dissipate the excess light energy. Does seasonal changes in NPQ impact SIF at a temperate conifer forest?

Winter: NPQ>>>0, SIF=?



Sub-alpine conifer forest located at Niwot Ridge, Colorado. (Phenocam, March 2018)

Summer: NPQ>0, SIF=?



Same as left, but in June 2018

**Objective:** Implement a fluorescence sub-model within CLM 4.5 to determine whether sustained NPQ improves the simulation of the seasonal pattern of SIF by comparing against tower- and satellite-based measurements

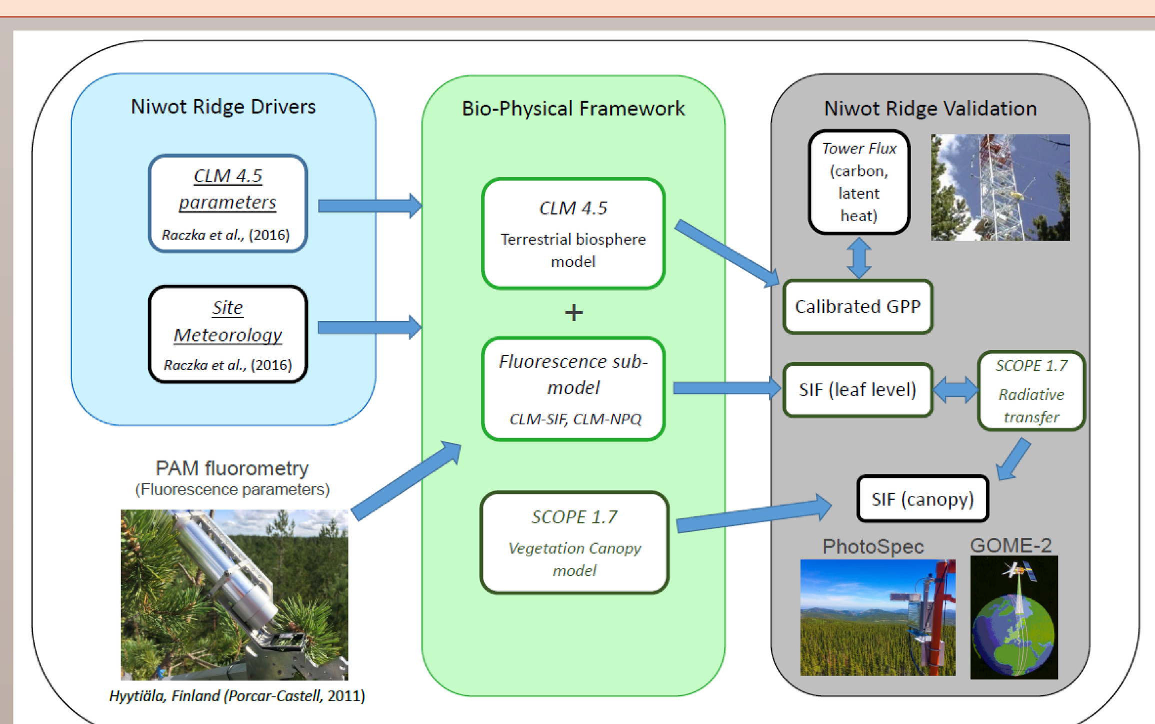



Figure 1. Overview of methodological workflow for model development, calibration and validation of canopy-level fluorescence at Niwot Ridge. PAM fluorometry measurements were made at Hyytiäla, Finland. Measurements from the tower-mounted PhotoSpec system (Grossmann et al., 2018) and GOME-2 satellite (Köhler et al., 2015) were compared against the CLM 4.5 and SCOPE SIF simulations

## Sustained ($k_S$) and reversible NPQ ($k_R$) should be represented when calculating fluorescence yield $\phi_F$

$k_N = k_R + k_S$; *expressed in rate coefficients* ($s^{-1}$)

$$\phi_F = \frac{k_F}{k_F + k_D + k_N}(1 - \phi_P);$$

*fluorescence efficiency* ($\phi_F$), *Photochemical efficiency* ($\phi_P$)

$$SIF = \phi_F \; APAR$$

Sustained NPQ ($k_S$) increases slowly, but dramatically during the winter months (Figure 2)

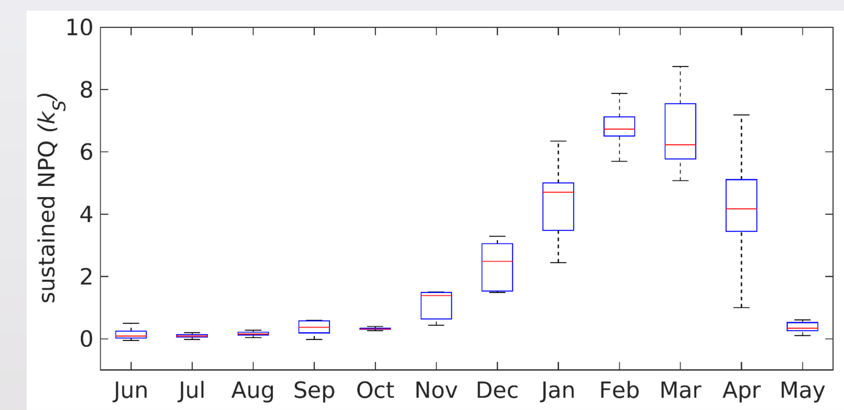


**Figure 2.** Seasonal pattern in sustained NPQ ($k_S$) measured in a Scots Pine Forest at Hyytiäla, Finland (2008-2009).

Reversible NPQ ($k_R$) responds quickly to the degree of light saturation influenced by diurnal changes in sunlight (APAR) (Figure 3)

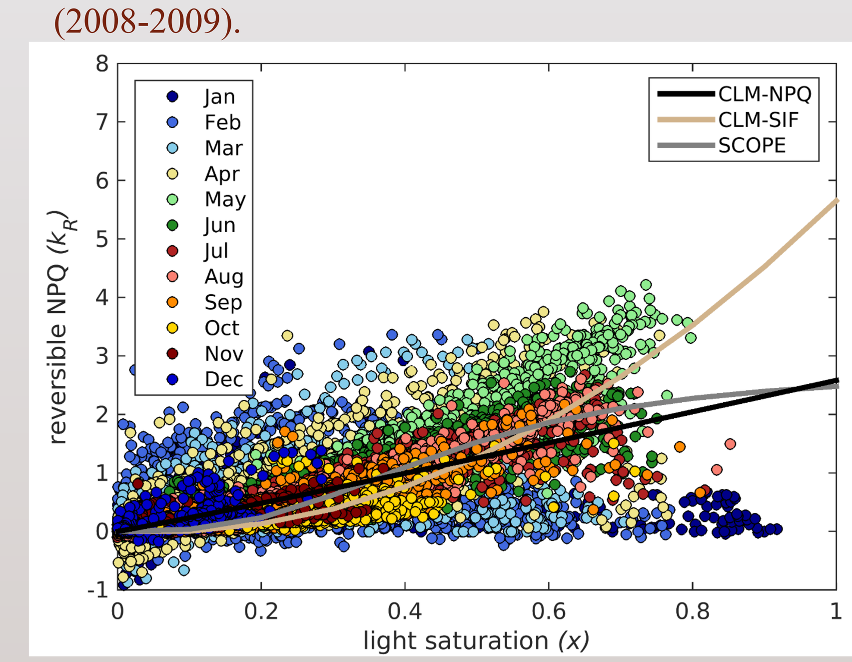


**Figure 3.** Reversible NPQ ($k_R$) as calculated from MONI-PAM fluorescence measurements (colored dots) at Hyytiäla (Porcar-Castell, 2011). A single fit for all the data for the Hyytiäla data was used for the *CLM-NPQ* simulation (Figure 4). *CLM-SIF* and *SCOPE* are fit to Flexas et al. (2002) data.

## Sustained NPQ increases the seasonal changes in simulated SIF

Sustained NPQ increased the seasonal changes in fluorescence efficiency and % change in seasonal SIF. This is more consistent with satellite and tower observations.

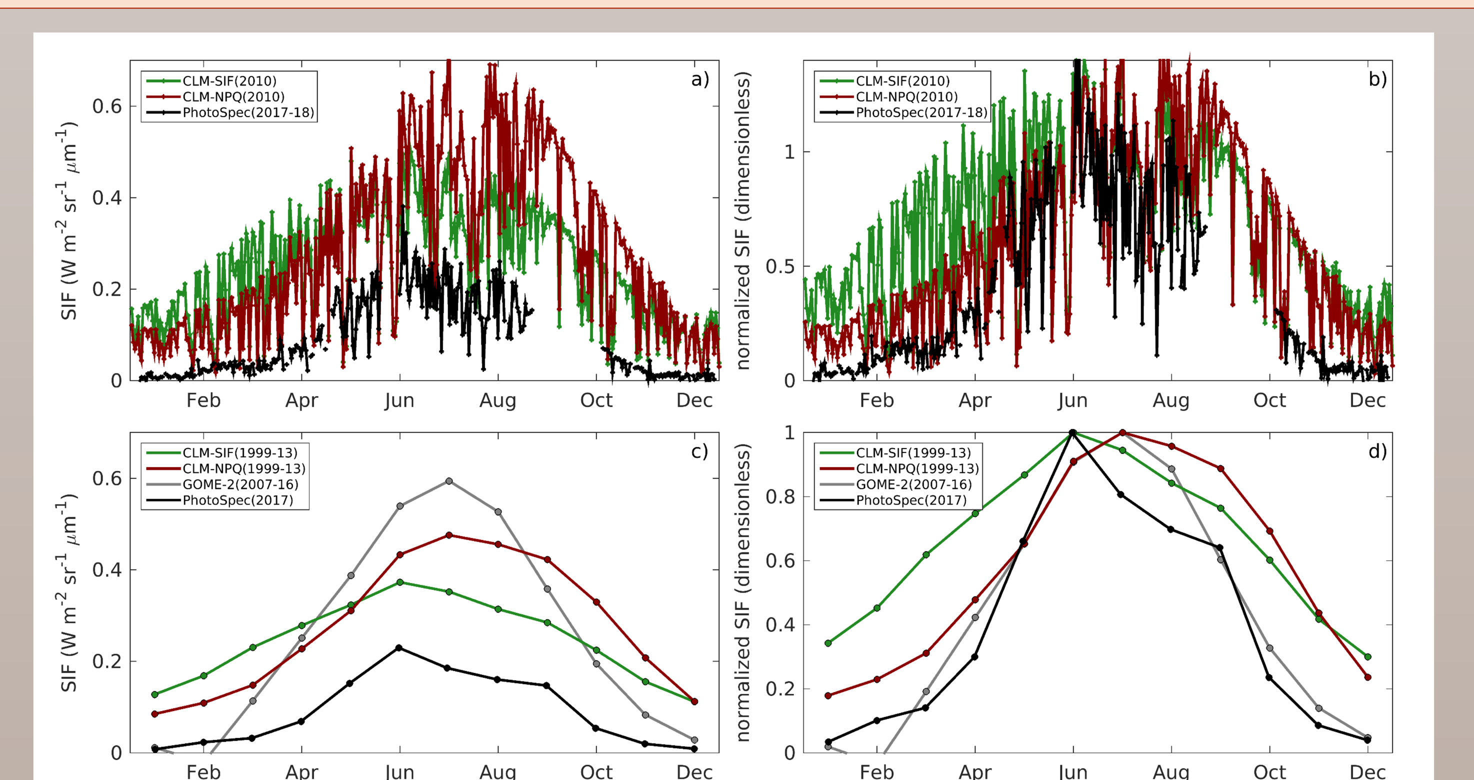


**Figure 4.** Simulated and observed seasonal patterns of canopy SIF (740 nm) for absolute SIF (panels a, c) and normalized canopy SIF (panels b, d). The single year simulations (panels a,b) are in daily resolution, the multi-year simulations (panels c,d) are monthly averages. The *CLM-SIF* simulation considers reversible NPQ ($k_R$) only, and the *CLM-NPQ* simulation considers both reversible ($k_R$) and sustained NPQ ($k_S$). Both a satellite SIF product (GOME-2, Köhler et al., 2015) and the PhotoSpec measurements (Grossmann et al., 2018) are included for comparison.

## Including time varying reversible NPQ weakens seasonal simulations, suggests missing mechanism

The weakened simulated SIF at Niwot Ridge suggests other mechanisms besides temperature influence NPQ such as light intensity or soil moisture stress.

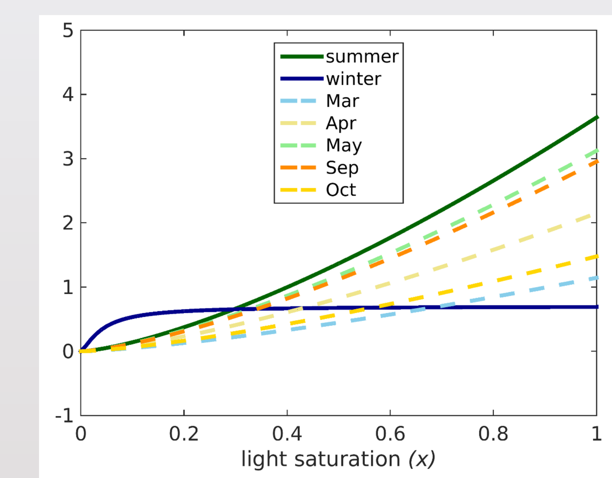


**Figure 5.** Fitted relationships of $\boldsymbol{k_R}$ versus light saturation (*x*) based on time of year. This seasonal varying $\boldsymbol{k_R}$ was inserted into *CLM-NPQ* (*CLM-NPQ+*$\boldsymbol{k_R}$ *(t)*) in Figure 6 (right).

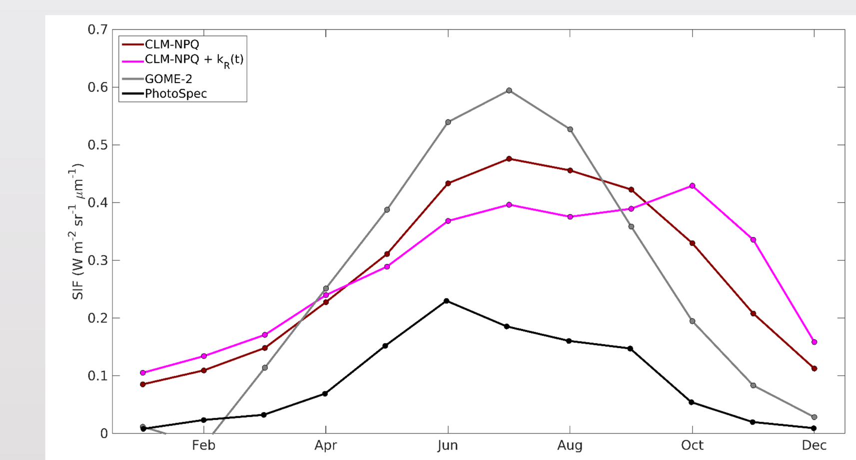


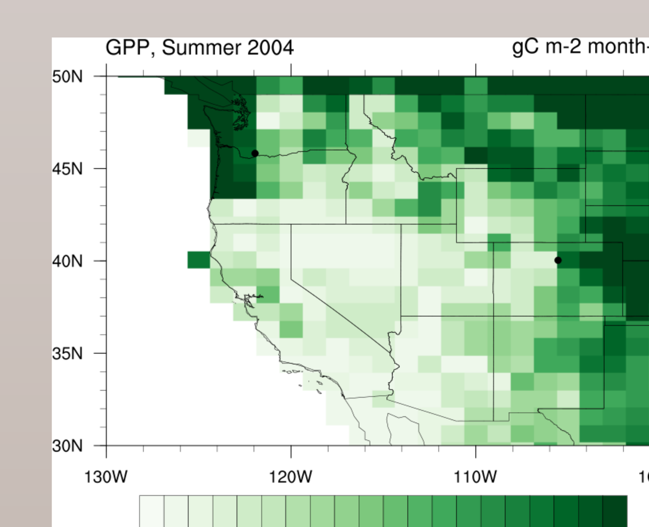
**Figure 6.** *CLM-NPQ* with time varying $k_R(t)$ as defined in Figure 5. SIF observations from the GOME-2 satellite (Köhler et al., 2015) and PhotoSpec (Grossmann et al, 2018).

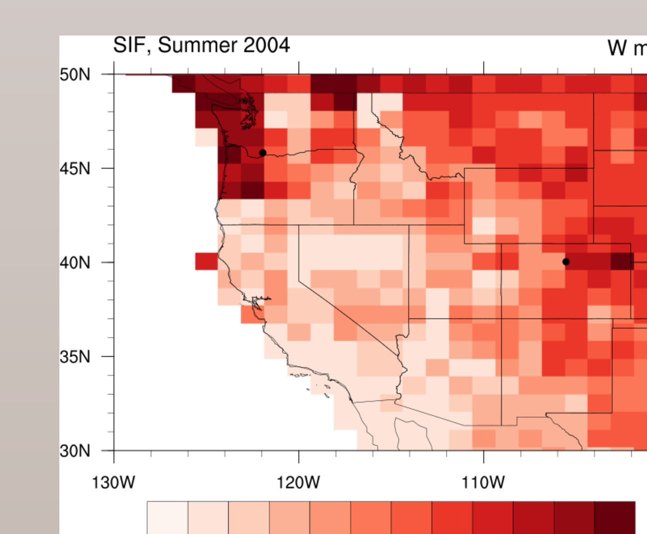
## CONCLUSIONS

- Land-surface models of solar-induced fluorescence in cold-climate evergreen biomes should include a representation of sustained non-photochemical quenching.
- Seasonal patterns of sustained non-photochemical quenching and air temperature are strongly correlated.

## FUTURE DIRECTIONS

We are currently upscaling our site-based implementation of the SIF model across the Western US with CLM. The goal is to use remotely-sensed SIF to constrain regional simulations of GPP.





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