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Quantifying Information Content of Flux and Remote Sensing Observations for Constraining Key Parameters in Process Based Modeling of Crops

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1. Introduction

1. Canopy structural and leaf photosynthesis parameters such as leaf area index (LAI), maximum carboxylation capacity (V_{cmax}), slope of the Ball-Berry stomatal conductance model (BB_{slope}) and leaf chlorophyll, carotenoid and dry matter content are crucial for modeling the canopy radiative transfer and plant physiological processes.

2. These key parameters have seasonal variability, are difficult to measure in-situ, and represent large sources of uncertainty for predictions of crop productivity and water fluxes in agricultural systems.

3. In this study we quantify the information content of eddy-covariance fluxes from tower based as well as remote sensing (RS) observations from ground-based PhotoSpec (Grossman et. Al, 2018) in an optimal estimation inversion framework using the Soil Canopy Observation Photochemistry and Energy fluxes (SCOPE) (Tol et. al, 2009) model towards estimation of the key parameters.

2. Objectives

1. Demonstrating the joint retrieval of key ecosystem parameters using flux (GPP, LE) and RS (spectrally resolved reflectance, outgoing LW radiation, Red and FarRed SIF) observations for Corn (C4) and Soy (C3) agricultural systems.

2. Analyzing the information contribution of Flux and RS observations across the growing season and possible attribution to forward model structure and its parameterization.

3. Moving Window Inversion Framework using SCOPE

SCOPE is an integrated 1-D vertical radiative transfer and energy balance model. SCOPE utilizes the spectrally resolved visible to thermal (0.4 to 50 μm) infrared irradiation at the canopy top to derive the fluxes of water, energy, carbon dioxide and vertical profiles of temperature as a function of canopy structure and weather variables. The detailed description of moving window inversion framework can be found in Dutta, et. al, 2019 and has been adapted to now incorporate the RS observations.

3. Flux and RS observations

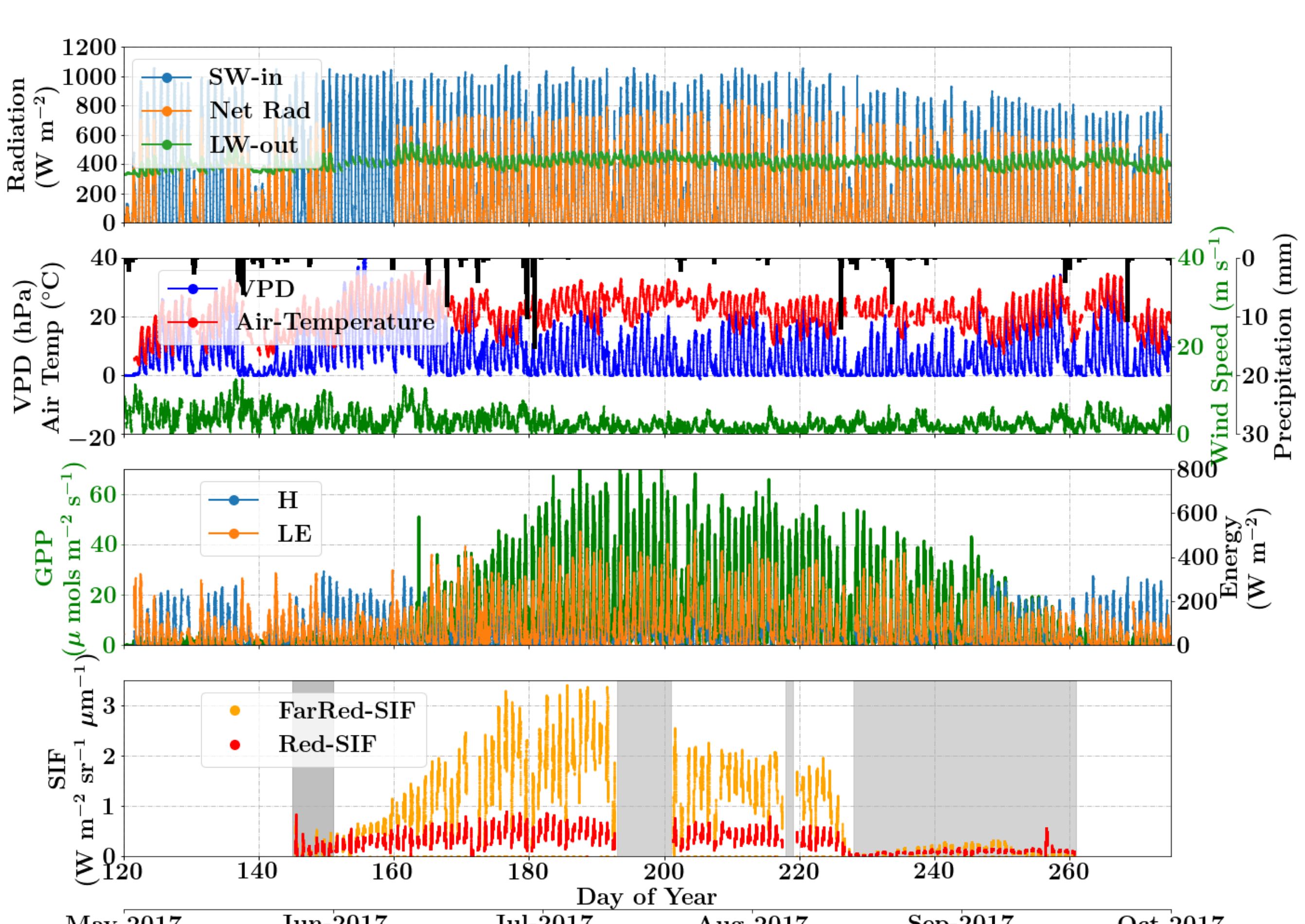
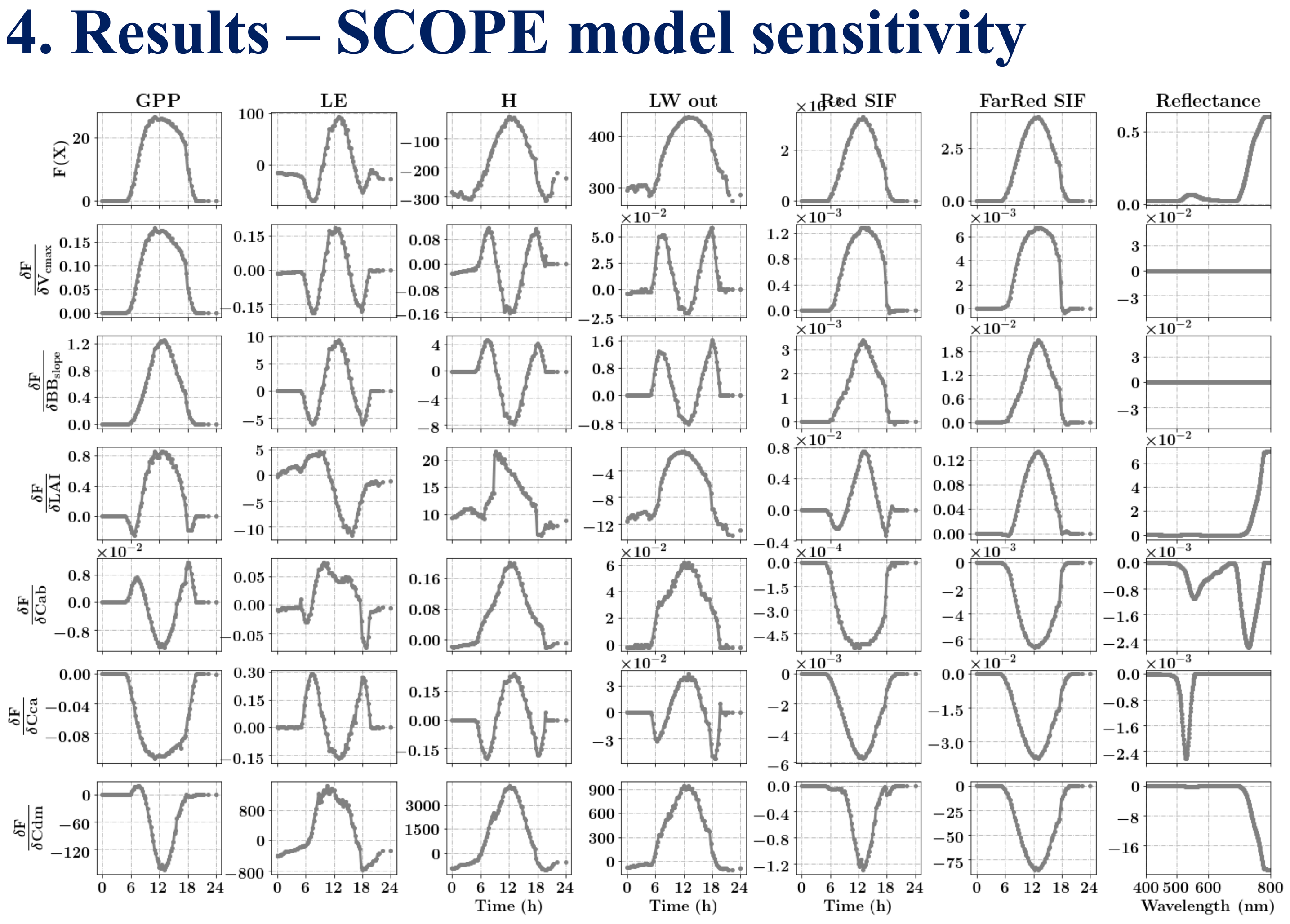


Fig. 1 Figure showing the seasonal and diurnal variability in important environmental and meteorological forcings used to drive the forward model and remote sensing and flux observations used for constraining the key parameters in the inversion framework. The Red, Far-Red and Reflectance data is derived from Photospec instrument. The data is for C4-Corn site in Iowa for the 2017 growing season.

4. Results – SCOPE model sensitivity



Units: GPP, V_{cmax}: [μ mols m^{-2} s^{-1}], LE, H, LW out: [W m^{-2}], SIF: [mW m^{-2} sr^{-1} nm^{-1}], LAI, BB_{slope}, Refl: [-], Cab, Cca [μg cm^{-2}], Cdm [g cm^{-2}]

Fig. 2 Figure showing the diurnal sensitivity of the SCOPE model parameter perturbations towards different observational constraints in the inversion. The figure represents the non-linear interactions of the variables used in the construction of the Jacobian matrix in the inversion. The data represents DOY 206 for C3-Soybean in Iowa.

5. Results – Parameter Estimations

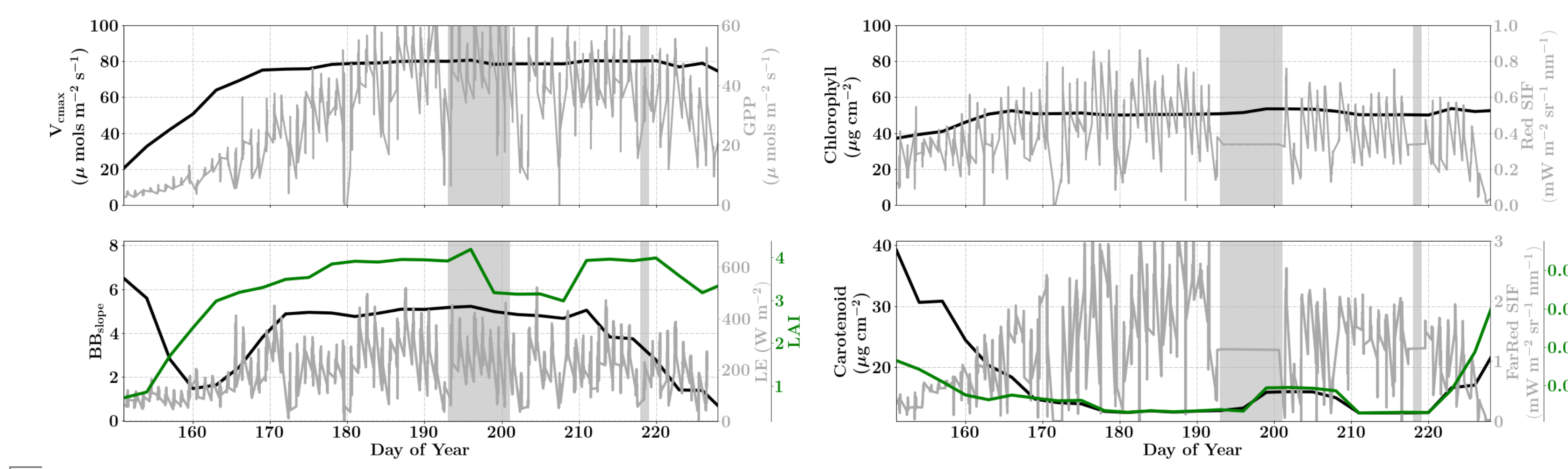


Fig. 3 Figure showing the seasonal variability in retrieved parameter values of V_{cmax}, BB_{slope}, LAI and Chlorophyll, Carotenoid and Dry Matter Content for the Iowa C4 Corn site using a 3-day moving window inversion approach for the year 2017. The actual points in the time series (grey lines) of the GPP and LE fluxes and Red and Far-Red SIF used as the target observations for the moving window inversion approach are shown in the background.

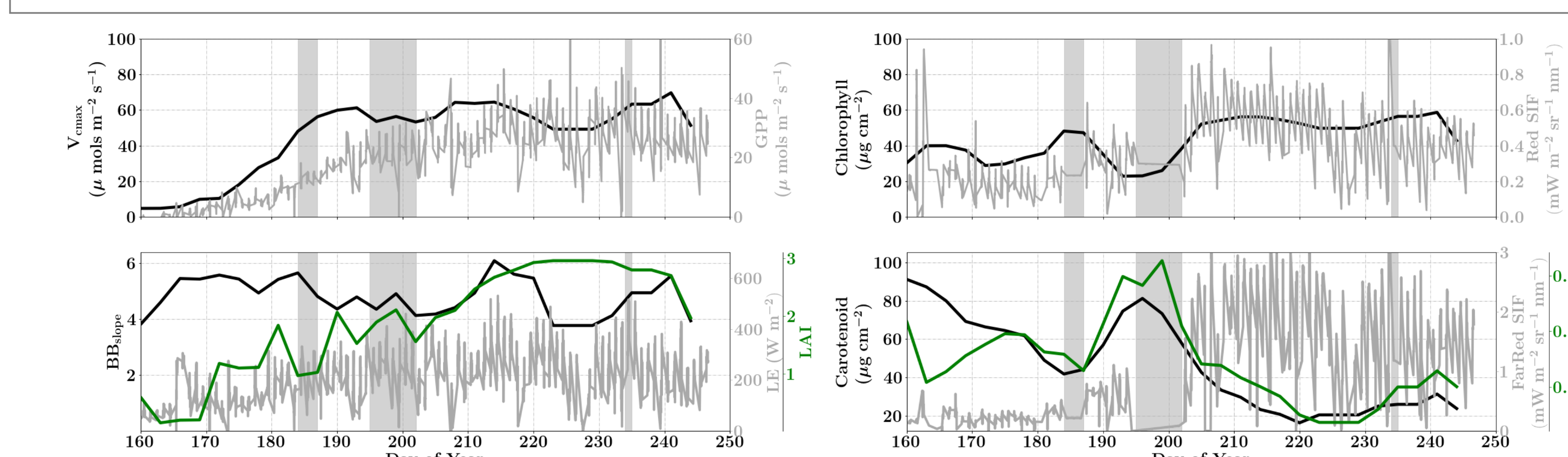


Fig. 4 Figure showing the seasonal variability in retrieved parameter values of V_{cmax}, BB_{slope}, LAI and Chlorophyll, Carotenoid and Dry Matter Content for the Iowa C3 Soy site using a 3-day moving window inversion approach for the year 2017. The actual points in the time series (grey lines) of the GPP and LE fluxes and Red and Far-Red SIF used as the target observations for the moving window inversion approach are shown in the background.

6. Results – Information Content Analysis

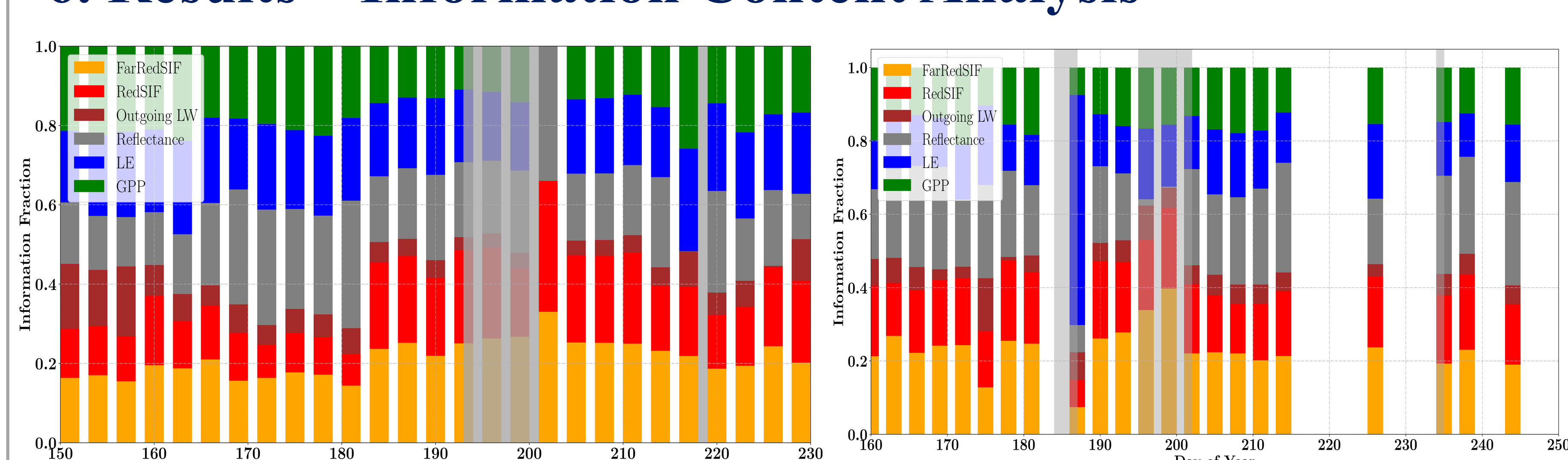


Fig. 5 Normalized Information Fraction for each of the individual observational streams towards the retrieval of all 6 parameters jointly for the C4 (left) and C3 (right) crops over the growing season. Each vertical bar represents a 3-day retrieval window. It is observed that for the system as a whole the contributions of the RS observations is larger compared to the flux observations.

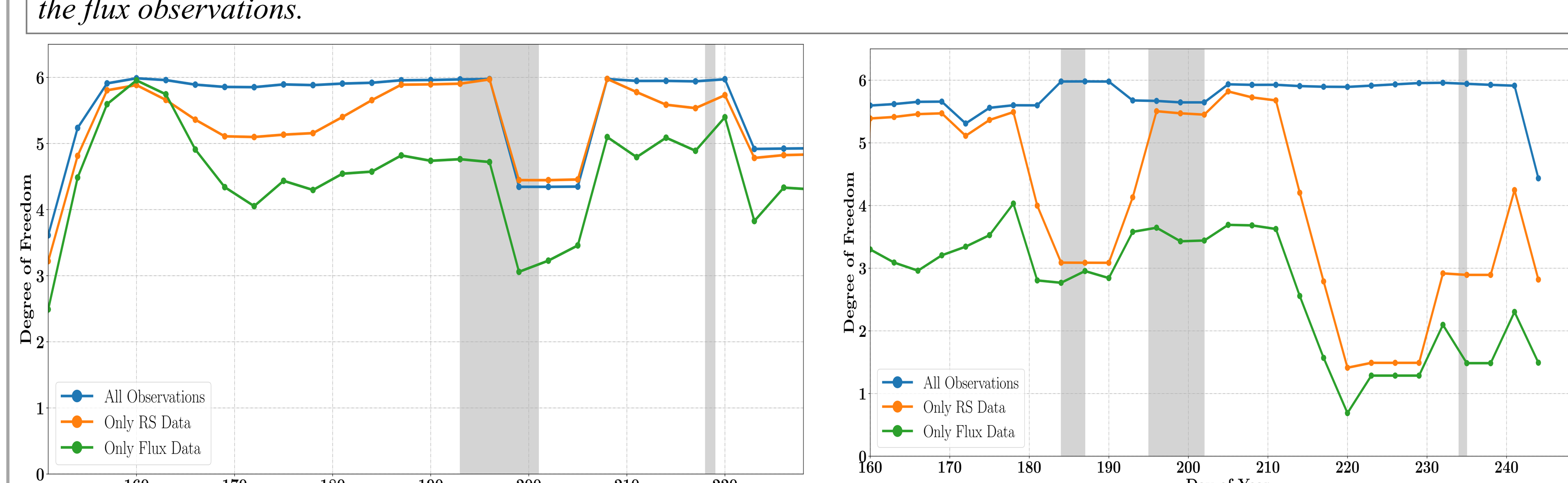


Fig. 6 Degree of Freedom (DOF-computed as the trace of the Averaging Kernel) for each of the Inversion windows for both C4 (left) and C3 (right) crops. Only RS or Flux data represents the computed DOF of the system for the scenarios when only the RS data or flux data has meaningful information towards retrievals and is obtained by appropriately choosing the prior observational error matrix.

7. Conclusions

1. Bayesian moving window inversion approach may be successfully applied to retrieve important parameters for agricultural ecosystems using constraining high temporal resolution flux, reflectance and fluorescence measurements from ground based instruments such as the PhotoSpec.

2. Our analysis further indicates that it may be possible to determine the seasonal variability in important ecosystem parameters utilizing only RS data (such as SIF and spectrally resolved reflectance) using newer models such as SCOPE which are equipped to utilize such high spectral resolution datasets. This has bigger implications for rapid and cost effective monitoring of global ecosystems using only space based observations.

8. References

1. Grossmann, K., Frankenberg, C., Magney, T. S., Hurlock, S. C., Seibt, U., & Stutz, J. (2018). PhotoSpec: A new instrument to measure spatially distributed red and far-red Solar-Induced Chlorophyll Fluorescence. *Remote sensing of environment*, *216*, 311-327.
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3. Tol, C., Verhoef, W., Timmermans, J., Verhoef, A., & Su, Z. (2009). An integrated model of soil-canopy spectral radiances, photosynthesis, fluorescence, temperature and energy balance. *Biogeosciences*, *6*(12), 3109-3129.

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