Coupled spectrometers using optical shutters offer insight into plant stress, SIF, reflectance and quality of measurements under changing sky conditions

Arthur Zygielbaum[1], Timothy Arkebauer[2], and Elizabeth Walter-Shea[1]

[1]University of Nebraska Lincoln
[2]Univ Nebraska Lincoln

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Abstract

Light absorption in the photosynthetically active (400 – 700 nm) spectral region is necessary for plant CO2 fixation via photosynthesis. Light absorption in excess of that which can be used for photosynthesis may result in photoinhibition and/or other processes detrimental to normal plant function. Plants have evolved several photoprotective mechanisms to reduce light absorption under stressful conditions. For example, leaf-level reflectance and transmittance increased as a result of chloroplast movement within leaf cells in response to water stress in greenhouse-grown maize and soybean. This has implications for detecting (as a signal and noise) diurnal and stress-related changes in canopy reflectance in field-grown crops. These changes were recently investigated in the field using newly developed instrumentation systems and software. Two hyperspectral spectrometers, an Ocean Optics QE Pro (0.3 nm resolution in the 650 - 813 nm range) and a Flame (2.0 nm resolution in the 340 - 1028 nm range) are coupled through optical shutters to a downward looking fiber (25° field of view) and an upward looking fiber with cosine corrector. The spectrometers can be configured to see sky or surface targets concurrently or separately. This new configuration offers concurrent measures of derived solar induced fluorescence (SIF), and visible and near infrared reflectance on a mobile platform, acquiring spatially averaged responses. Our goal is to use SIF as an indicator of the level of photosynthetic activity in comparison to reflectance-derived indication of photoprotective response. In conducting data acquisition, several technical issues arose. Different spectrometer integration times, due to differing radiometric sensitivities and changing sky conditions, causes differences in measured reflectance between the two spectrometers. Also the approach highlighted the difficulty of obtaining reliable system calibration under varying sky conditions when using near-Lambertian reference panels. While results are promising in detecting SIF along with more conventional remote sensing spectral resolution, further research is needed to refine data acquisition to ensure quality reflectance measurements. We report on technical issues and on our success in tying photoprotection to changes in photosythentic activity.

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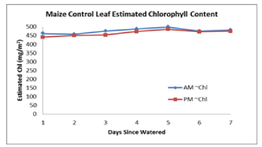
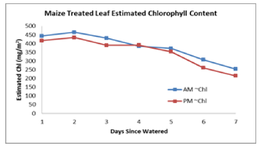
Arthur I. Zygielbaum[1], Timothy J. Arkebauer[2], Elizabeth A. Walter-Shea[1]
[1]School of Natural Resources, [2]Department of Agronomy and Horticulture, University of Nebraska-Lincoln, NE USA

Background

- AM/PM differences in PAR albedo and estimated chlorophyll observed in stressed greenhouse corn vs unstressed corn (see graph below)
- Exposing leaves to red versus white light showed that the effect is likely due to a photoprotective effect: Chloroplast Avoidance Movement
- In field, leaf level ASD measurements showed similar results
- Canopy level results are equivocal
- Why the greenhouse/field differences?
- Developed new instrument system and software, raised questions about calibration procedures





Goal

To use SIF as an indicator of the level of photosynthetic activity in comparison to reflectance derived indication of photoprotective response.

References

Gitelson, A.A., Y. Gritz, & M.N. Merzlyak. 2003. Journal of Plant Physiology 160: 271-282.

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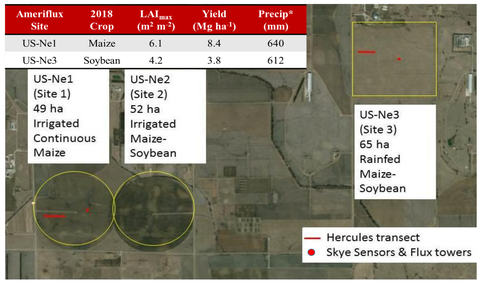
Acknowledgements

The US-Ne1 and US-Ne3 sites are supported by the Lawrence Berkeley National Lab AmeriFlux Data Management Program and by the Carbon Sequestration Program, University of Nebraska-Lincoln Agricultural Research Division. This work is supported by the USDA National Institute of Food and Agriculture Hatch project No. 1002649. Prior support includes the DOE Office of Science (BER; DE-FG03-00ER 62996, DE-FG02-03ER63639, and DE-EE0003149), DOE-EPS-CoR (DE-FG02-00ER45827), and NASA NACP (NNX08AI75G). We also acknowledge the support of program technicians, students, and postdocs.

Materials and Methods

Ameriflux Site	2018 Crop	LAI_{max} (m^2 m^{-2})	Yield (Mg ha^{-1})	Precip* (mm)
US-Ne1	Maize	6.1	8.4	640
US-Ne3	Soybean	4.2	3.8	612



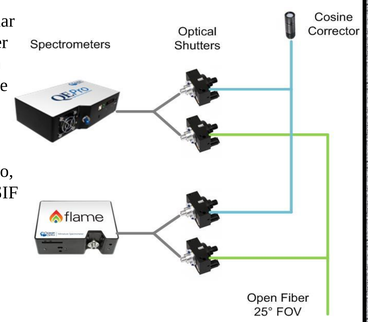
- Skye upwelling/downwelling

Model	λ_{green}	λ_{red}	$\lambda_{red\text{-}edge}$	λ_{NIR}
SKR 1850A	536-561 nm	664-675 nm	704-715 nm	862-874 nm

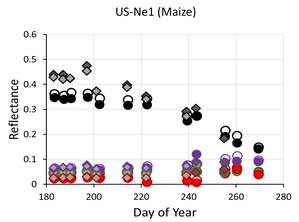
- Average canopy reflectance (ρ_λ) at 1 minute periods throughout the growing season

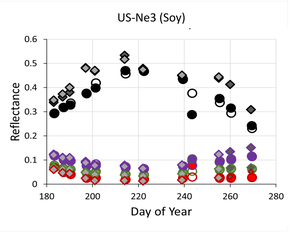
- Hercules Mobile Remote Sensing Platform
  - Two hyperspectral spectrometers coupled through optical shutters to a downward looking fiber (25° field of view) and an upward looking fiber with cosine corrector, and can be configured to see sky or surface targets concurrently or separately:
    - Ocean Optics QE Pro (0.4 nm resolution in the 650 - 813 nm range)
    - Flame (1.4 nm resolution in the 340 - 1028 nm range)
  - Four reflectances:
    - Serial: Up/Dn on each spectrometer
    - Parallel: QEPro Dn/Flame Up, Flame Up/QEPro Dn.
  - Configuration offers concurrent measures of derived solar induced fluorescence (SIF), and visible and near infrared reflectance on a mobile platform, acquiring spatially averaged responses.

- Data taken am & pm at similar solar angles/once or twice per week during growing season
- Transect is approx. 35 sample positions
- 30-40 minutes per transect
- Data reduced to PAR, NIR albedo, emulated Skye albedo, Chl RE Index, PRI, NDVI, SIF retrieval
- Calibration performed with 99% Spectralon panel
- Calibration data compared daily



Results – Stress Observations

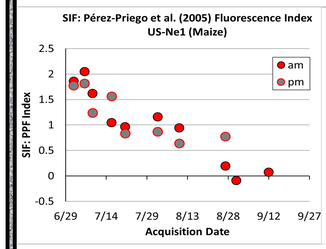


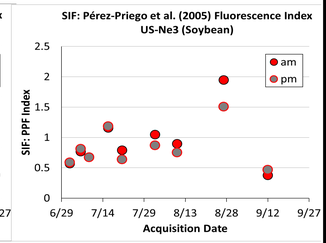


Hercules
Simulated Skye Reflectance
vs
Skye Reflectance

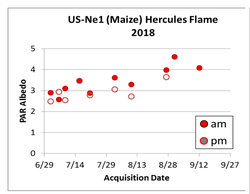
Skye green am
Skye green pm
Skye red am
Skye red pm
Skye red edge am
Skye red edge pm
Skye NIR am
Skye NIR pm
Hercules green am
Hercules green pm
Hercules red am
Hercules red pm
Hercules red edge am
Hercules red edge pm
Hercules NIR am
Hercules NIR pm

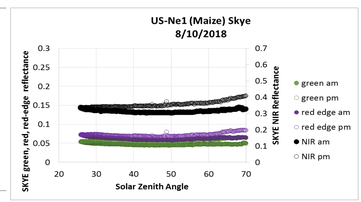
Hercules SIF Retrieval





AM/PM PAR Reflectance Differences





July wind damage

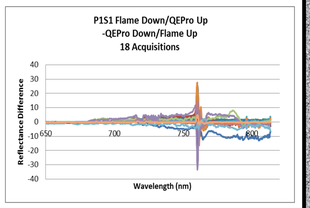
Hercules Transect Damaged and Undamaged Samples

Skye Target

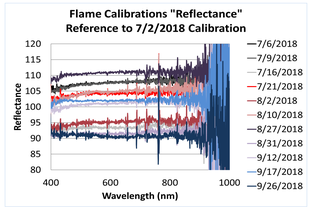
Results – Observation Challenges

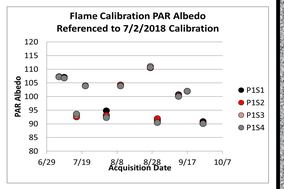
Hercules
Flame and QEPro
Reflectances Differ

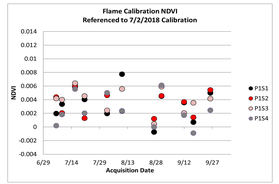
- Instrument differences: QEPro integration times approx. 10 times Flame integration times.
- i.e. QEPro 300 ms, Flame 20 ms

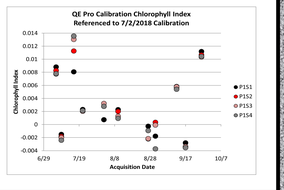


Spectralon Panel Calibrations Varied Significantly Day to Day









Conclusions

- Data from two different instrumentation systems, Skye and Hercules, showed largely comparable reflectances demonstrating the integrity of these types of measurements.
  - Observed AM & PM reflectance differences at US-Ne1 (Maize) likely due windstorm damage in early July. Up to 60% of plants in the Hercules transect were damaged. None damaged in Skye target.
- Under constant sky conditions, spectrometers with two different sensitivities and, therefore, different optimized integration times made essentially identical reflectance measurements.
- Rapidly varying sky conditions and differing integration times causes each spectrometer to sample a different light signature during its integration time. This can cause significant difference in calculated reflectance.
- Trying to calibrate out differences in the upwelling and downwelling optical paths and instrument radiometric sensitivity by using a white reference panel is common practice. However the light observed by the downwelling cosine corrector and that reflected from the panel are strongly and differentially affected by sky conditions. This caused up to a 20 % change in the calibration from day to day.
- Hence day to day albedo comparisons were not reliable.
- However, since changing sky conditions made essentially “DC” shifts across the reflectance spectrum, vegetation indices are minimally affected.
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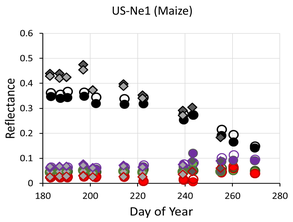

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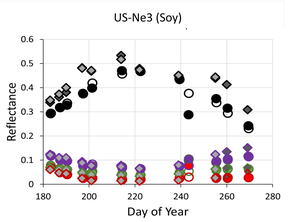
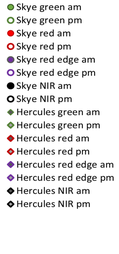
Simulated Skye Reflectance
vs
Skye Reflectance





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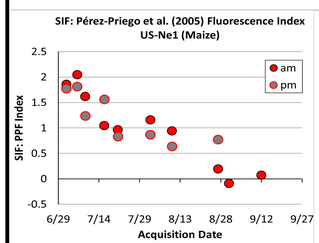

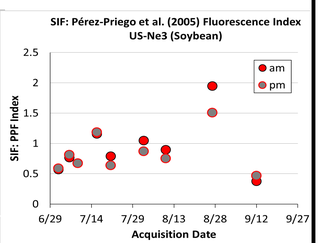

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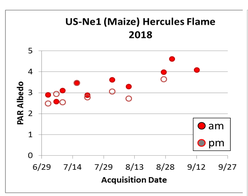

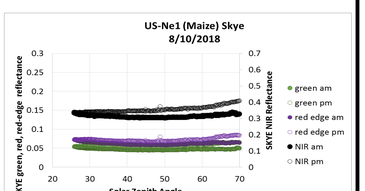

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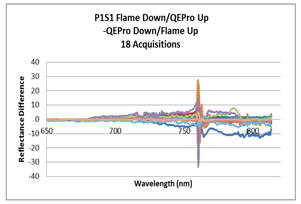

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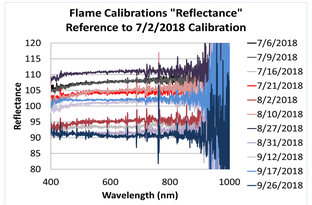
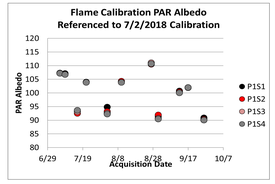
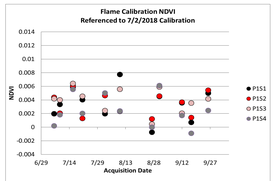
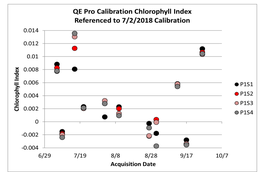
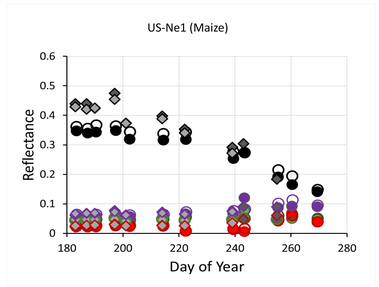
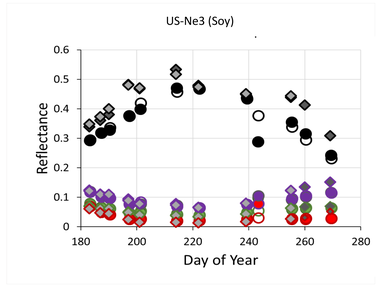


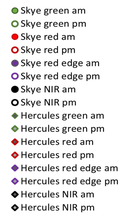


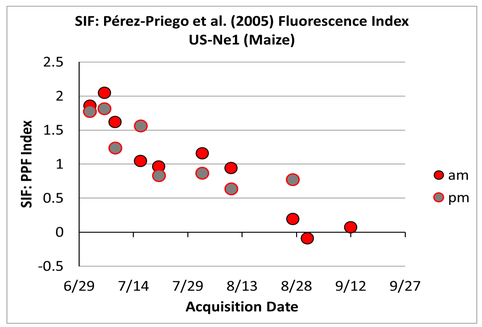


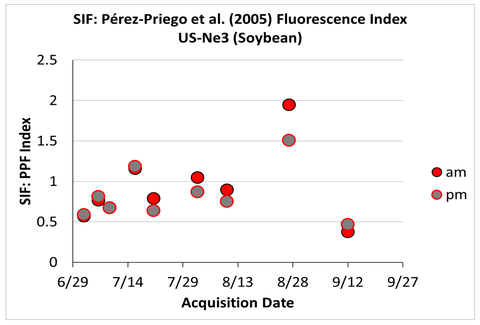



US-Ne1 (Maize)
Reflectance
Day of Year
0
0.1
0.2
0.3
0.4
0.5
0.6
180
200
220
240
260
280


US-Ne3 (Soy)
Reflectance
Day of Year
0
0.1
0.2
0.3
0.4
0.5
0.6
180
200
220
240
260
280


Skye green am
Skye green pm
Skye red am
Skye red pm
Skye red edge am
Skye red edge pm
Skye NIR am
Skye NIR pm
Hercules green am
Hercules green pm
Hercules red am
Hercules red pm
Hercules red edge am
Hercules red edge pm
Hercules NIR am
Hercules NIR pm


SIF: Pérez-Priego et al. (2005) Fluorescence Index
US-Ne1 (Maize)
SIF: PPF Index
Acquisition Date
-0.5
0
0.5
1
1.5
2
2.5
6/29
7/14
7/29
8/13
8/28
9/12
9/27
am
pm


SIF: Pérez-Priego et al. (2005) Fluorescence Index
US-Ne3 (Soybean)
SIF: PPF Index
Acquisition Date
0
0.5
1
1.5
2
2.5
6/29
7/14
7/29
8/13
8/28
9/12
9/27
am
pm

July wind damage

Hercules Transect Damaged
and Undamaged Samples

Skye Target

Hercules 7/21/2018
Location 20 155357

Location 38 161051

Radiation Mast
7/21/2018 @ 945

Conclusions

- Data from two different instrumentation systems, Skye and Hercules, showed largely comparable reflectances demonstrating the integrity of these types of measurements.
  - Observed AM & PM reflectance differences at US-Ne1 (Maize) likely due windstorm damage in early July. Up to 60% of plants in the Hercules transect were damaged. None damaged in Skye target.
- Under constant sky conditions, spectrometers with two different sensitivities and, therefore, different optimized integration times made essentially identical reflectance measurements.
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Zygielbaum, A.I, T.J. Arkebauer, E.A. Walter-Shea, & D.L. Scoby. 2012. Israel Journal of Plant Science 60: 37-47.

- Skye and Hercules reflectances mostly comparable.
- Observed AM & PM reflectance differences at US-Ne1 (Maize) likely due to plant physical condition following two windstorms in early July. 40-60% of plants in the Hercules transect were broken whereas none of the plants in the Skye field of view were damaged.
- Spectrometer Up/Dn configuration affected reflectances due to differing integration times with respect to changing sky conditions.
- Sky conditions affect calibration of canopy sensors making temporal comparisons of albedo difficult. Daily calibrations may not be necessary. Vegetation indices may be less affected by changing sky conditions.