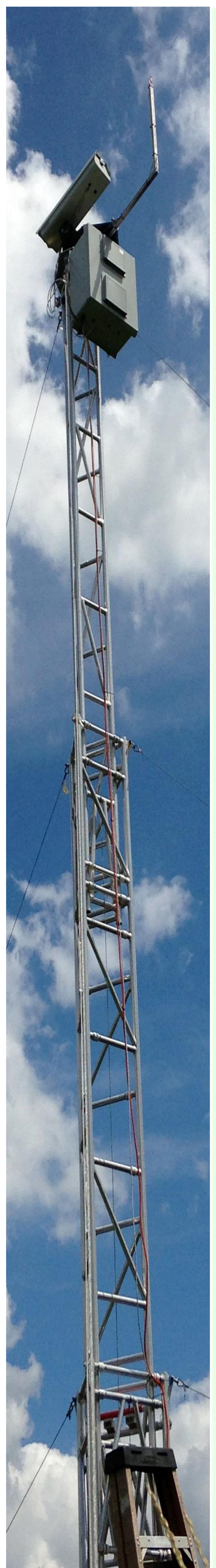
Automated optical sensing of the dynamics in vegetation fluorescence, reflectance and temperature, indicative of ecosystem function and carbon assimilation

P. Campbell[a, b], E. Middleton[b], F. Huemmrich[a, b], L. Corp[b], Qingyan Zhang[b], Sergio Bernardes[b], *David Landis*[b], Julie Leifeld[c] and Milton Hom[b]

[a]University of Maryland at Baltimore County, Catonsville, MD, US; [b] NASA/Goddard Space Flight Center, Greenbelt, MD, US; [c] University of Minnesota, Minneapolis, US



BACKGROUND

Chlorophyll fluorescence has strong potential to assess plant photosynthesis over large areas using Earth observation technology. However, more work needs to be done to determine the impact of the diurnal and seasonal dynamics in vegetation illumination and canopy structure in the remote estimation of plant photosynthesis.

The goals of this study are to better understand the dynamic relationships between vegetation photosynthetic function and its spectral fluorescence and reflectance properties, at different light levels and at both leaf and canopy level.

METHODS

During the summer of 2014 we collected complimentary leaf and canopy measurements of corn (*Zea mays*, L.), growing under four nitrogen treatments, ranging from deficiency (N 0 and 50 %), optimal (N 100%), to excess (N 150%). Leaf measurements included: photosynthetic pigments, chemical constituents, fluorescence emissions (Fluorolog 3, Horiba Jobin Yvon inc.), photosynthesis (Amax) and the associated fluorescence kinetic and steady state parameters (LI6400, Lincoln, NE, US). The dependences of the corn leaf photosynthetic parameters on light and CO2 levels were measured using LI6400 in the summer of 2013, for mature corn crop under the complete range of nitrogen treatments.

FUSION measured diurnal changes in canopy reflectance and solar induced fluorescence (SIF) throughout the growing season for corn growing in optimal nitrogen treatment (N 100%). FUSION consists of 2 dual channel sensors (upward and downward looking spectrometers), which simultaneously collect high spectral resolution radiance measurements (W m^{-2} nm^{-1} sr^{-1}). The first pair of upwelling/downwelling spectrometers covers the VIS-NIR range from 350-1100 nm with an optical resolution of 1.5 nm FWHM (Ocean Optics USB 4000, Dunedin, Fl, USA), while the second set of high resolution spectrometers covers the NIR range from 650-800 nm at an optical resolution of 0.2 nm FWHM (Ocean Optics HR4000, Dunedin, Fl, USA). A computer controlled motorized pan tilt unit enables simultaneous whisk-broom data collection of the instruments downward hemispherical FOV with a contiguous 5° sampling resolution. FUSION solar induced canopy chlorophyll fluorescence (SIF) is retrieved using the Fraunhofer Line Depth (FLD) method. The specifications of the FUSION sensors and the system are available at ftp://fusionftp.gsfc.nasa.gov/FUSION/.

For this study we analyzed FUSION data (**Figure 1**) from three days representative of the corn vegetative, reproductive and senescent growth stages - August 4, August 15 and September 23, 2014. The normalized difference vegetation index (NDVI) was calculated as a normalized reflectance ratio using 800 and 670 nm wavelengths (**Fig. 2**). The photochemical reflectance index (PRI) was calculated as a normalized reflectance ratio using 531 and 570 nm wavelengths (**Fig. 3**). Fluorescence (SIF) was calculated applying the 3 FLD approach, a depth ratio between spectral features from the reference panel and the vegetation, at the atmospheric absorption features centered at 688nm and 760nm (**Fig. 4**). Their SIF R/FR was also calculated. To investigate the diurnal and seasonal changes in the calculated PRI, SIF685 (R), SIF760 (FR), SIFR/FR and NDVI, as a function of view angle and illumination condition, we plotted the parameters by interpolating the view angles of the pan tilt unit at the time of the measurements (**Figs. 2--7**). The position of the sun is indicated with red circle and the Solar Principle Plane (SPP) is outlined with a grey line. Means and Coefficient of Variation (CV=SD/mean) within the SPP of the calculated FUSION reflectance and SIF parameters are presented in **Table 1**.

The optical measurements were compared with the Light Use Efficiency (ε) derived from flux tower measurements,

$$\varepsilon = GEP/(fAPAR\ Qin) = GEP/Qa,$$

where GEP is gross ecosystem productivity, Qin is incident Photosynthetically Active Radiation (PAR), fAPAR is the fraction of absorbed PAR estimated from NDVI, and Qa is the absorbed PAR (**Figs. 8** and **9**).

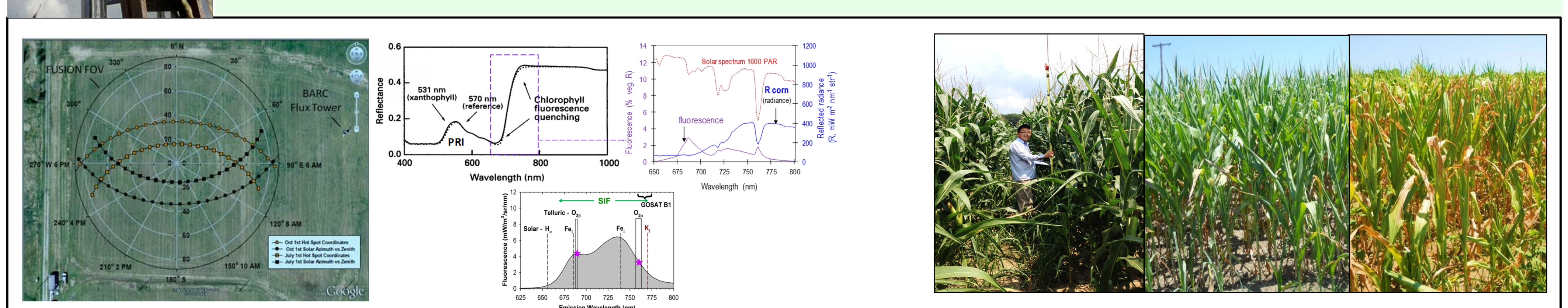


Figure 1. The FUSION automated system (NASA/GSFC) simultaneously collects high resolution VNIR reflectance and fluorescence measurements for monitoring the diurnal and seasonal dynamics in vegetation function.

FUSION AUTOMATED PRODUCTS and RESULTS

FUSION produces seasonal and diurnal profiles of spatially resolved, high spectral resolution calibrated VNIR radiance (W m^{-2} nm^{-1} sr^{-1}) measurements, which are ideal for the study of vegetation function in relation to its reflectance and SIF bi-directional properties. Comparing morning to afternoon NDVI we did not observe significant differences (**Fig. 2**). From August 4, 2015 to September 23, 2014 NDVI declined from 0.95 to 0.89. Changes in PRI were clearly seen throughout the day, which were strongly associated with viewing geometry (Fig. 3). Higher PRI were measured in the morning from the cold spot (within the solar principle plain, SPP). This trend was more pronounced earlier in the season (August 4th), when PRI was higher. During the season PRI declined from 0.04 (August 4 - maximum) to -0.1 (September 23 - minimum) and with the advancement of senescence, the variation within the data declined (see CV, **Tab. 1**).

FUSION NDVI, OPE3, 2014

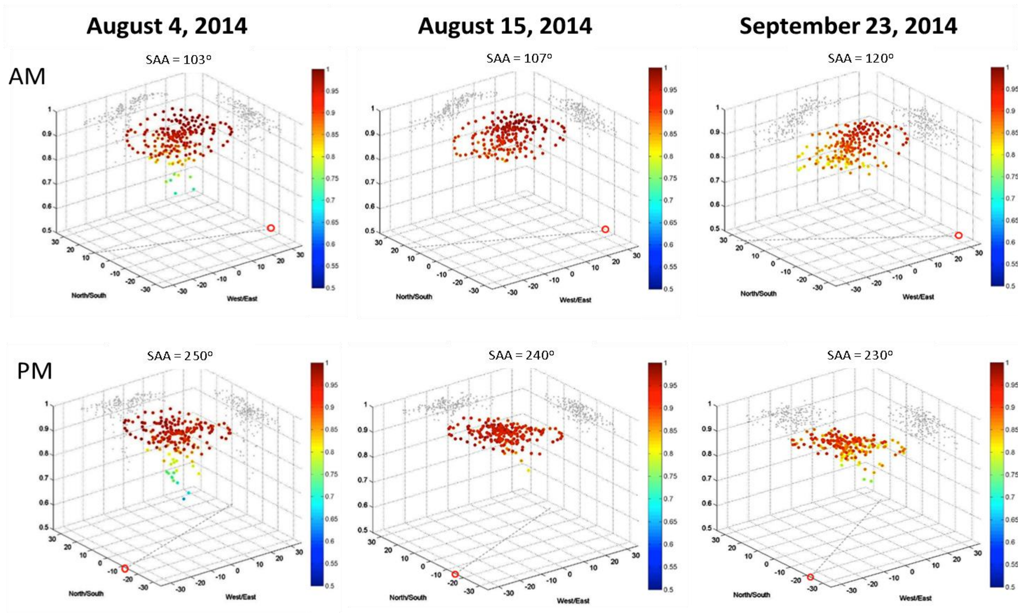


Figure 2. Diurnal and seasonal differences in FUSION NDVI, as function of viewing and illumination geometry. The sun position is indicated with red circle and the Solar Principle Plane is outlined with a grey line.

FUSION PRI, OPE3, 2014

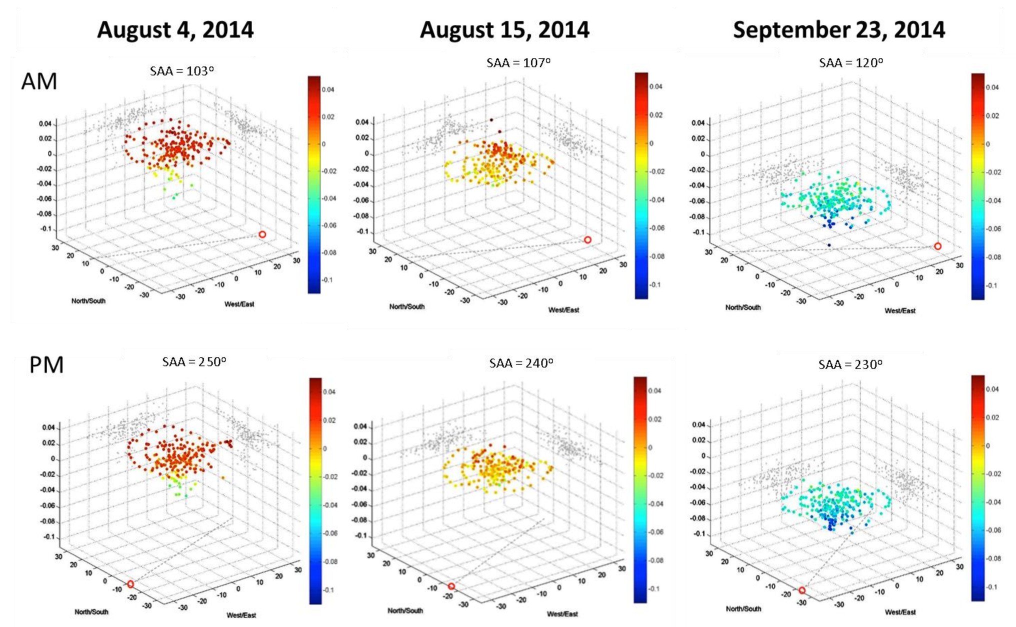


Figure 3. Diurnal and seasonal differences in FUSION PRI, as function of viewing and illumination geometry. The sun position is indicated with red circle and the SPP is outlined with a grey line.

We observed diurnal and seasonal changes in both SIF685 (**Fig. 4**) and SIF760 (**Fig. 5**), and differences associated with viewing illumination and geometry, which were more pronounced earlier in the season. The SIF685 measurements were always lower as compared SIF 760. SIF increased from cold to hot spot, within the SPP (**Fig. 6**). This trend was more pronounced for SIF685. Both SIF685 and SIF760 declined during the season. The CV for both SIF parameters was higher in the morning (as compared to PM) and increased throughout the season. The SIF688/760 ratio increased during the season, indicating a change in the proportion of SIF red and far-red emissions.

FUSION : SIF for OPE3 Cornfield (100%N, non-watered)

SIF685 (FLD B, W m^{-2} nm^{-1} sr^{-1})

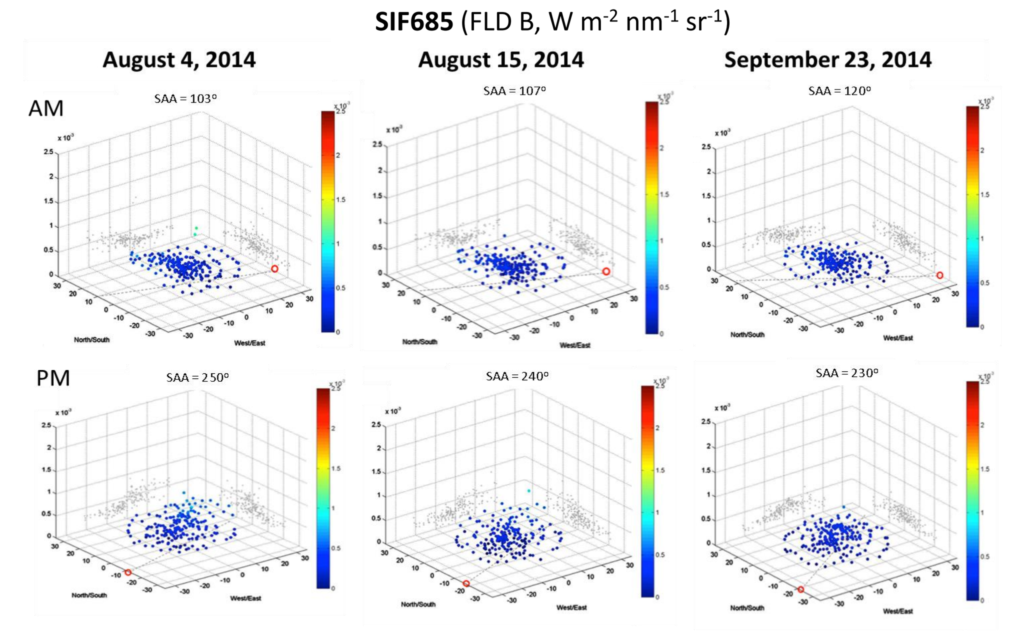


Figure 4. Diurnal and seasonal differences in FUSION SIF685, as function of viewing and illumination geometry.

FUSION : SIF for OPE3 Cornfield (100%N, non-watered)

SIF760 (FLD A, W m^{-2} nm^{-1} sr^{-1})

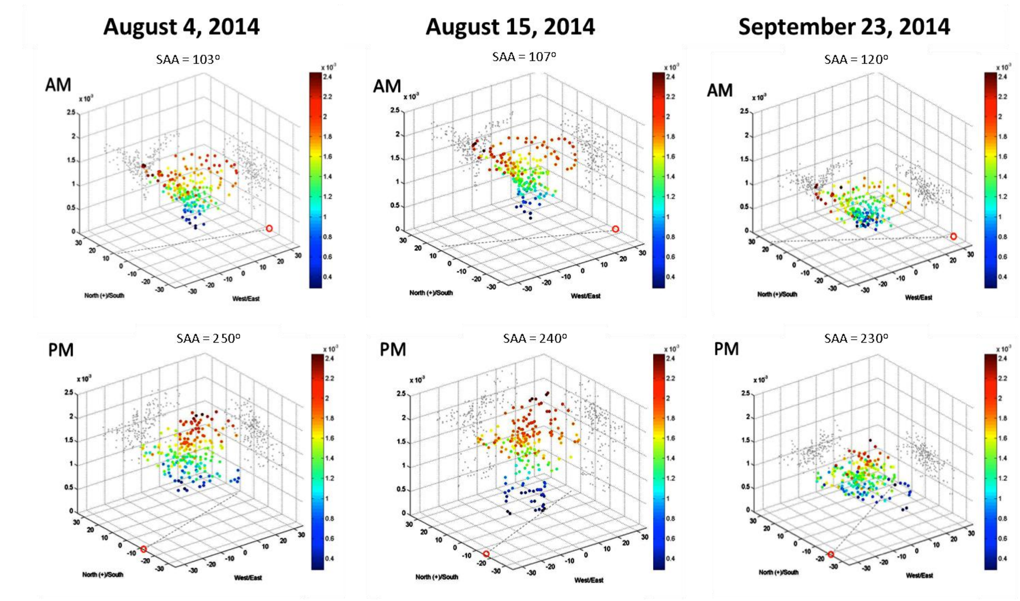


Figure 5. Diurnal and seasonal differences in FUSION SIF685, as function of viewing and illumination geometry.

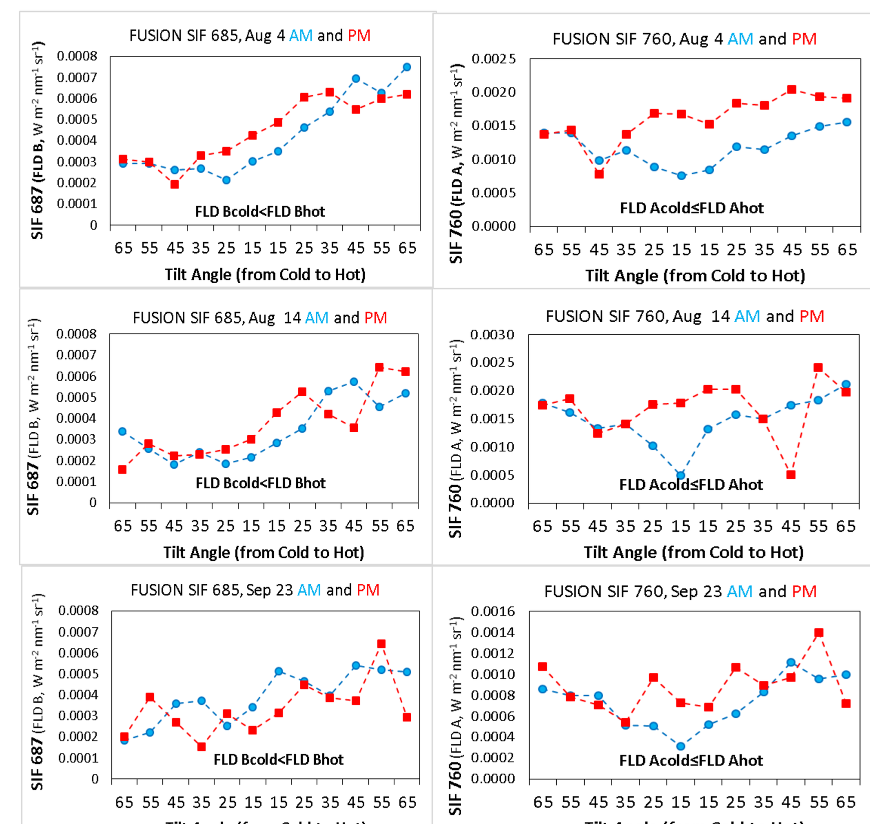


Figure 6. Differences in corn SIF685 and SIF760 within the SPP, for the vegetative, reproductive and senescence corn stages.

FUSION SIF Red/Far-Red Ratio, OPE3, 2014

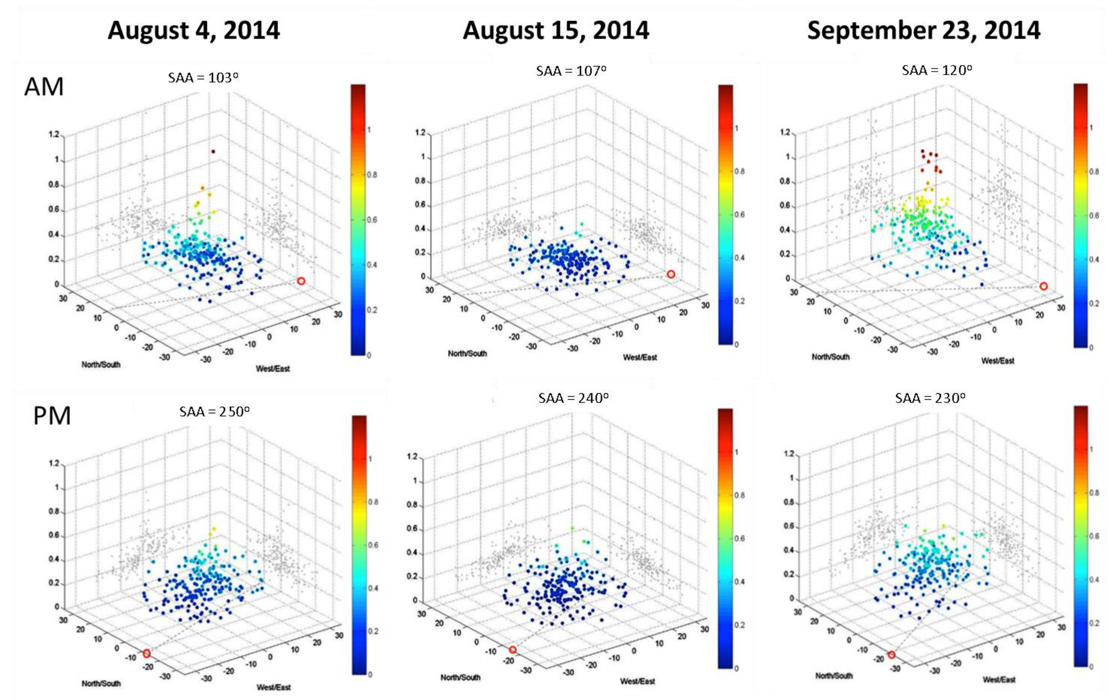


Figure 7. Diurnal and seasonal differences in FUSION SIF R/FR, as function of viewing and illumination geometry.

Table 1. Evaluation of FUSION reflectance and solar induced fluorescence (SIF) parameters within the solar principle plane (SPP). Means and Coefficient of Variation (CV= Standard Deviation/Mean) were calculated to describe the variation in the data associated with view angle and solar illumination.

FUSION	8/4/2014		8/15/2014		9/23/2014	
	AM	PM	AM	PM	AM	PM
Mean						
SIF 685	0.00042	0.00045	0.00034	0.00037	0.00039	0.00033
SIF 760	0.0012	0.0016	0.0015	0.0017	0.0007	0.0009
SIF R/FR	0.35	0.27	0.23	0.20	0.58	0.38
PRI	0.017	0.011	-0.004	-0.009	-0.057	-0.052
NDVI	0.92	0.90	0.92	0.92	0.86	0.86
Coefficient of Variation (CV = STDeviation/Mean)						
SIF 685	0.44	0.34	0.41	0.43	0.32	0.39
SIF 760	0.23	0.21	0.29	0.29	0.33	0.26
SIF R/FR	0.32	0.18	0.30	0.32	0.45	0.23
PRI	0.65	0.43	-1.81	-0.68	-0.32	-0.15
NDVI	0.03	0.04	0.03	0.02	0.06	0.04

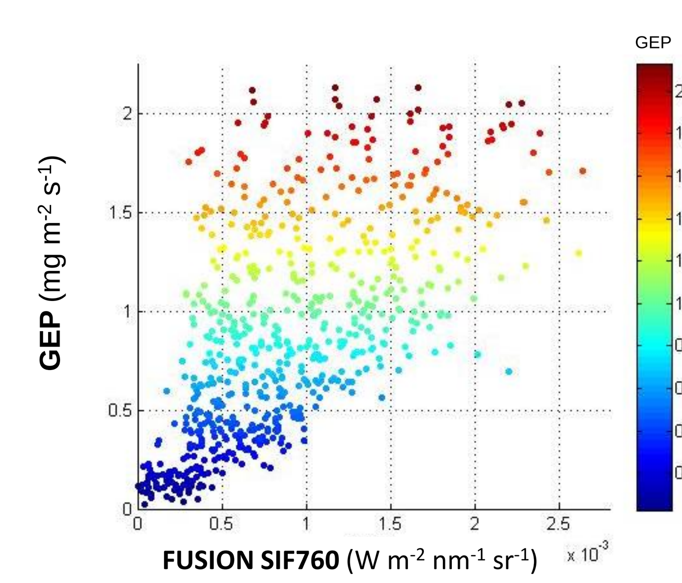


Figure 8. Comparison of GEP from OPE3 eddy covariance flux tower and FUSION SIF760 (at a constant view zenith angle of 25° and view azimuth of 330° from north). The comparison includes 632 measurements, collected in the period from August 1 to October 15, 2014. Included are half-hourly observations throughout the day when Solar Zenith Angle < 60°.

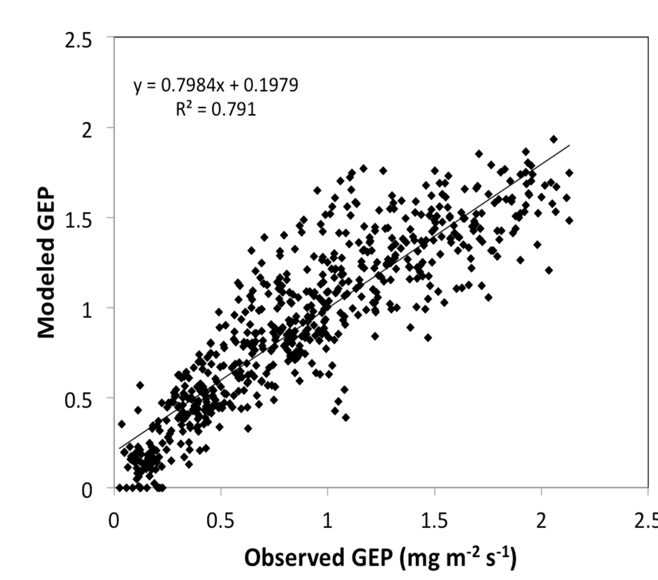


Figure 9. Comparison of observed vs FUSION modeled GPP. The FUSION model calculation of GEP uses a combination of NDVI, PRI, SIF760, and Incident PAR for single view angle from FUSION.

CONCLUSSIONS and FUTURE DIRECTIONS

FUSION successfully collected multi-angular, high spectral resolution reflectance and solar induced fluorescence (SIF685 and SIF 760) measurements, which are useful for characterizing the bi-directional properties, diurnal and seasonal differences in PRI, SIF685 and SIF 760. During the summer of 2014 we simultaneously observed the seasonal and diurnal changes in corn Gross Ecosystem Production (GEP) from eddy covariance, the associated canopy SIF685, SIF760, and spectral reflectance PRI and NDVI from FUSION. FUSION parameters were useful in characterizing the dynamics in vegetation productivity, and strongly associated with short term canopy CO_2 fluxes. The different diurnal and seasonal trends in PRI, SIF685, SIF760 and SIF685/760 indicate that they provide different information for the vegetation canopy, and that a combination of these measurements would likely provide an improved capability for monitoring vegetation function, than any of the parameters alone. In future research we will combine the leaf and canopy measurements within the SCOPE modeling to simulate leaf and canopy level photosynthetic function and the associated reflectance and fluorescence properties. This study will be expanded to corn under nitrogen and water deficiency/excess.

petya.campbell@nasa.gov