Optical Sensing of Ecosystem Carbon Fluxes: Tower-mounted Spectrometers

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FUSION is an automated tower-mounted instrument package to provide optical measurements of vegetation

- Sense hyperspectral reflectance and fluorescence
- Describe diurnal and seasonal dynamics
- Describe bidirectional reflectance/emission
- Provide measurements that could scale satellite observations
- Make measurements with spatial and resolution that can be linked to carbon fluxes measured by flux towers
FUSION 1 Instrumentation

An automated sensor system collecting observations of incoming and reflected radiation:
- A pan-tilt unit points fiber optics of the downward viewing sensors
- Cosine corrected hemispheric viewing for upward viewing sensors

Instruments are housed in an insulated thermoelectric temperature control for instruments:

Instruments:
1) upward and downward viewing Ocean Optics Spectrometers (345-1040 nm with resolution FWHM);
2) upward and downward viewing Ocean Optics Spectrometers (650-840 nm at a resolution FWHM sampled at 0.06 nm);
3) CFmicro SF15 infrared sensor (8 to 14 μm)
FUSION Operations

FUSION is mounted atop a 10 m tall tower and:
- Makes 350° azimuth angle scans
- At six zenith angles (15°, 25°, 35°, 45°, 55°)
- Takes about 25 minutes for a full set
FUSION Operations

FUSION is mounted atop a 10 m tall tower:
- Makes 350° azimuth angle scans
- At six zenith angles (15°, 25°, 35°, 45°, 55°, 65°)
- Takes about 25 minutes for a full set
FUSION and Satellite Cal/Val

FUSION collects a large number of samples within an area of satellite pixels.
Provides a description of bidirectional reflectance patterns for use in interpreting view angle effects.
Spectral data can be convolved to any satellite band.
Continuously collect measurements to examine effects of different overpass times.
Describes seasonal change.
An important challenge is deciding on the tradeoffs of the measurement strategy. Collect full set of measurements as quickly as possible:
- Avoid cloud contamination in BRDF determination
- Capture short-term transients if possible
- Match with flux tower data

Balanced against:
- Number of different view angles observed
  (more angles are better)
- Observation integration time
  (longer times provide better signal-to-noise ratio)
Combining Optical and Flux Data

Flux tower ~105 m from FUSION tower
Seasonal/Diurnal Observations

Simultaneous measurements of incident and reflected radiance allow data collections under cloudy conditions.

\[
PRI = \frac{(R531 - R570)}{(R531 + R570)}
\]

\[
NDVI = \frac{(R800 - R670)}{(R800 + R670)}
\]

Single view angle: 25° VZA, 330° VAZ
SeASONAL/DIURNAL OBSERVATIONS

Solid points - clear sky observations near AM overpass
Open points - clear sky observations near PM overpass

\[
\text{PRI} = \frac{R_{531} - R_{570}}{R_{531} + R_{570}}
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Seasonal/Diurnal Observations

Solar Induced Fluorescence at O$_2$A (760 nm) from 3FLD algorithm. All observations

Single view angle: 25° VZA, 330° VAZ
Seasonal/Diurnal Observations

Solar Induced Fluorescence at $O_2A$ (760 nm) from 3FLD algorithm

Red points - clear sky observations near GOME-2 overpass
Blue points - clear sky observations near OCO-2 overpass

Single view angle: 25° VZA, 330° VAZ
Seasonal/Diurnal Observations

Solar Induced Fluorescence at O$_2$A (760 nm) from 3FLD algorithm

![Graphs showing seasonal and diurnal observations of gross ecosystem production over two years, 2014 and 2015. The x-axis represents dates from June 10 to November 7, 2014, and from July 15 to November 3, 2015. The y-axis represents gross ecosystem production from 0.0 to 3.0. The graphs show a decrease in gross ecosystem production from early summer to late fall.]

Single view angle: 25° VZA, 330° VAZ
Seasonal/Diurnal Observations

Variations in Yield at different times in the growing season

3FLD O2A Average over all View Azimuths, VZA=35°
Bidirectional Observations -

Morning and afternoon bidirectional patterns of Photochemical Reflectance Index (PRI = (R531-R570)/(R531+R570))
August 14, 2014, SZA ~ 50° at both times

Morning
10:00 AM

Afternoon
4:30 PM

From Neuburger et al., 2015
Bidirectional Observations -

Morning and afternoon bidirectional patterns of Far-red Solar Fluorescence (SIF) in the O$_2$A absorption band (760 nm) on August 14, 2014, SZA ~ 50° at both times.

Morning
10:00 AM

Afternoon
4:30 PM

From Neumayer Station
Diurnal/seasonal patterns of PRI and Far-Red SIF from four distinct viewing geometries:
- in the direction of the hot spot (backscattering)
- in the direction of the cold spot (forward scattering)
- perpendicular to the solar principle plane (cross plane)
- in a fixed direction (due north)
- all with 45° view zenith angles
- all observations under clear conditions
Clear observations from 2
Half-hourly GEP from flux
GEP and Far-Red SIF

View angle, time of day, and period in growing season affect results.

Hot Spot Region

Cold Spot Region

Cross

SIF

EARLY

MIDDLE

LATE

Morning

Afternoon

GEP
PRI and Photosynthetic Light Use Efficiency

Canopy Types:
- Hot Spot
- Cold Spot
- Cross Plane
- Due North

Parameters:
- Hot Spot: \( R^2 = 0.66, SE = 0.016 \)
- Cold Spot: \( R^2 = 0.76, SE = 0.015 \)
- Cross Plane: \( R^2 = 0.71, SE = 0.019 \)
- Due North: \( R^2 = 0.78, SE = 0.015 \)
Estimating GEP from FUSION Optical

O2A SIF vs. PRI, where the colors of the points indicate GEP values.

Single view angle: 25° VZA, 330° VAZ
Data covers entire 2014 season, clear and cloudy conditions
Estimating GEP from FUSION Optical

Half-hourly GEP modeled using an analytic model with NDVI, PRI, describing 79% of the variance in GEP compared to 63% using NDVI alone.

Single view angle: 25° VZA, 330° VAZ
Data covers entire 2014 season, clear and cloudy conditions
Estimating GEP from FUSION Optical

Light Use Efficiency model using NDVI and PAR with a variable LUE regression tree model using PRI and SIF at O₂A and O₂B

Single view angle: 25° VZA, 330° VAZ
Data covers entire 2014 season, clear and cloudy conditions
Estimating GEP from FUSION Optical

GEP determined from Partial Least Squares Regression using spectral reflectance sampled at 5 nm train
random selection of 250 points

Single view angle: 25° VZA, 330° VAZ
Data covers entire 2014 season, clear and cloudy conditions
Estimating GEP from FUSION Optical

Red points - clear sky observations near AM overpass
Blue points - clear sky observations near PM overpass

Single view angle: 25° VZA, 330° VAZ
Data covers entire 2014 season, clear and cloudy conditions
Conclusions

• FUSION provides optical measurements supporting scientific studies, algorithm development, and satellite/aircraft production.

• In our cornfield studies with FUSION we were able to:
  – Observe significant bidirectional effects in spectral vegetation indices and SIF related to sun and geometry
  – Observe new aspects of seasonal phenology and optical indices
  – Develop optically-based algorithms to describe and seasonal patterns of Gross Ecosystem Production
Future

OLD
FUSION 1
Paired OOPs HRs viewing upward and downward
Bidirectional, no Nadir View

NOW
FUSION 2
Paired OOPs QEs viewing upward and downward
Bidirectional with Nadir View

NE
FUSION
Single OOP
switching upward and viewing
Bidirectional Nadir