Global monitoring of terrestrial sun-induced chlorophyll fluorescence from space

L. Guanter\textsuperscript{1}, C. Frankenberg\textsuperscript{2}, J. Joiner\textsuperscript{3}, J. A. Berry\textsuperscript{4}, M. Jung\textsuperscript{5}, Y. Zhang\textsuperscript{1}, M. Voigt\textsuperscript{1}, P. Köhler\textsuperscript{1}

(1). Free University Berlin, Germany
(2). NASA Goddard Space Flight Center, USA
(3). JPL, California Institute of Technology, USA
(4). Carnegie Institution of Washington, USA
(5). Max Planck Institute for Biogeochemistry, Germany
Sun-induced chlorophyll fluorescence (SIF)

Pathways of solar energy after absorption by chlorophyll:
- Part of the energy is used for photochemical processes and photosynthesis resulting in ecosystem gross primary production (GPP).
- Part of the energy is dissipated as heat.
- A remaining fraction is re-emitted as fluorescence.

Under natural conditions, fluorescence and photosynthesis are positively correlated → a measurement of fluorescence can be related to photosynthetic activity.

SIF & Photosynthesis

Conceptual model (Joe Berry)

\[
\text{GPP} = \text{PAR} \times \text{FAPAR} \times \text{LUE}
\]

\[
\text{SIF} = \text{PAR} \times \text{FAPAR} \times \text{Fs}_{\text{yield}} \times F_{RT}
\]

\[
F_{\text{biochem}} = \text{Fs}_{\text{yield}} / \text{LUE}
\]

\[\rightarrow \text{GPP} = \text{SIF} \times F_{\text{biochem}} \times F_{RT}^{-1}\]

(top-of-canopy, midday, clear-sky GPP)
First SIF global maps produced in 2011 by Joiner et al. & Frankenberg et al.

Researchers have created a global map of the fluorescence emitted by land-based plants during photosynthesis. This subtle glow at certain wavelengths could serve as an early warning system for plant stress and help scientists better understand Earth's carbon cycle.
SIF retrieval from space: in-filling of solar Fraunhofer lines

Measurements by the GOSAT Fourier Transform Spectrometer (FTS)

- Fractional depth of absorption features decreases ("in-filling") because of SIF.
- High spectral resolution measurements in 650-800 nm needed.
- Atmospheric chemistry sensors:
  - Sufficient spectral resolution & SNR (+)
  - Low spatial resolution (-)

Alonso et al
Global SIF Data Sets

**GOSAT/TANSO-FTS**
- 6/2009-today
- Acquisition time ~13:00 LT
- Circular FOVs, 10 km diam.
- Sparse spatial sampling, 2° grid

**MetOp-A/GOME-2**
- Joiner et al (2013)
- 1/2007-today
- Acquisition time ~9:30 LT
- Rectangular pixels, 40x80 km²
- Global coverage, 0.5° grid
Global SIF Data Sets

GOSAT
SIF at 757 nm

GOME-2
SIF at 737 nm

SIF (mW/m²/sr/nm)

July 2009

0.0 0.4 0.7 1.1 1.4 1.8

0.0 0.7 1.4 2.1 2.8 3.5
Annual Average
Jun09-May10

Guanter et al, RSE, 2012

SIF vs GPP, annual average
SIF-GPP per biome
(each point is a monthly average)

High linear relationship, but
GPP/SIF varies with biome:
Canopy structure? Temporal
sampling? Biochemistry?

\[ \text{GPP} = \text{SIF} \times F_{RT} \times F_{\text{biochem}} \]
(top-of-canopy, midday, clear-sky GPP)

GPP from M. Jung – MPI-BGC
Mostly <20% signal loss even for AOD 1-6

→ Very low sensitivity to clouds & aerosols

→ High potential for the monitoring of tropical rainforest areas

Frankenberg, O’Dell, Guanter and McDuffie, AMT (2012)
Chlorophyll fluorescence remote sensing from space in scattering atmospheres: Implications for its retrieval and interferences with atmospheric CO₂ retrievals.
Amazonian productivity vs water stress

2010 drought

Upcoming missions with potential for SIF retrieval

1. **OCO-2** (NASA-JPL):
   - Launch ~Jul 2014
   - Improved spatial resolution (~1km$^2$) and coverage (~100x more measurements than GOSAT)

2. **Sentinel-5 Precursor TROPOMI** (ESA/KNMI/SRON):
   - Launch ~Jan 2015
   - Global coverage with improved spatial resolution (~7x7 km$^2$)

3. **Sentinel-5** (ESA/Copernicus): ~2019, similar to TROPOMI

4. **Sentinel-4** (ESA/Copernicus): ~2020, Geostationary orbit

5. **ESA Earth Explorer 8$^{th}$: FLEX or CarbonSat** - selection for implementation to be made ~ 2015, launch >2019
Summary

- **Sun Induced Chlorophyll Fluorescence**: a new data stream to look into the terrestrial carbon cycle from space.

- **Potential of space-based SIF to monitor vegetation functioning**:
  - Better correlation to GPP than greenness-driven indices.
  - Intrinsic link to green APAR $\rightarrow$ Good indicator of phenology.
  - Good proxy for crop photosynthesis.
  - Low sensitivity to atmospheric contamination: high potential for the monitoring of tropical areas.

- **Challenge**: to estimate absolute GPP from Fs observations $\rightarrow$ **Process Modeling required**: canopy structure, temporal sampling & biochemistry (non-photochemical quenching).

- **Exciting short- and mid-term observation perspectives**.
Thank you for your attention!

…and also:

- **Data:** JAXA/NIES/MOE, NASA, ESA & Eumetsat
- **Funding:** German Research Foundation, Emmy Noether Programme, GlobFluo project