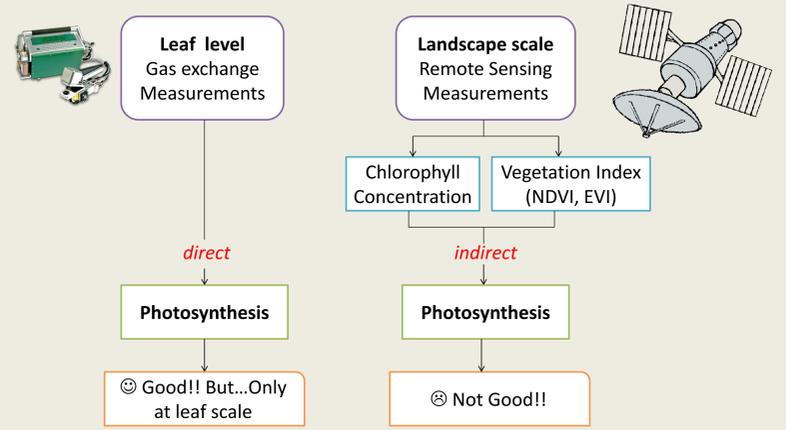


1. Introduction

Crop yield decreases when photosynthesis is limited by drought conditions. Yet farmers do not monitor crop photosynthesis because it is difficult to measure at the field level in real time. Chlorophyll fluorescence (*ChF*) can be used at the field level as an indirect measure of photosynthetic activity in both healthy and physiologically-perturbed vegetation. *ChF* can be measured by satellite-based sensors on a regular basis over large agricultural regions.



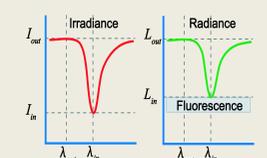
We need a good estimate of photosynthesis at field level !!

We think that answer lies in: **CHLOROPHYLL FLUORESCENCE**, which we can measure using **Pulse-amplitude modulated** instruments (PAM, i.e., active technique) and we will be able to measure by **satellite** (i.e., passive technique). The **Fluorescence EXplorer (FLEX)** is the first mission proposing to launch a satellite for the global monitoring of Sun induced fluorescence (*SIF*) in terrestrial vegetation.

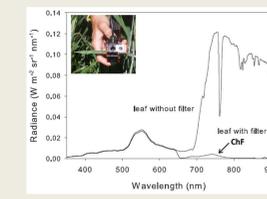
2. Methods: Passive and Active Techniques

	Active technique	Passive technique
Approach	PAM (Licor 6400)	FLD (3FLD and iFLD) Filtered illumination (Fluowat)
Nomenclature	$F_{s700-715}$	3FLD ₇₆₃ iFLD ₇₆₃ F_{w687} $F_{w700-715}$
Measuring light	red LEDs	Sun light
<i>ChF</i> spectrum measurement wavelength	700 - 715 nm	689 nm (O ₂ -B band) 763 nm (O ₂ -A band)
<i>ChF</i> measured mainly re-emitted by	PSII & PSI	PSI
Target distance	cm	cm/ground/airborne/satellite observation

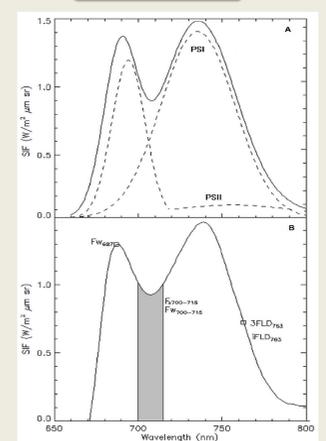
Passive techniques - Fraunhofer Line Discrimination (FLD)



Passive techniques - Fluowat



Summary



3. Research Question

★ **Is it possible to extrapolate the knowledge acquired about *ChF* using active techniques at leaf level to passive measurements of *SIF*?**



4. Experiment

- Orita* wheat cultivar were grown **outdoors** field at University of Arizona's Maricopa Agricultural Center (MAC).
- After 2 months of plant growth, *ChF* measurements were taken once a week from February 24th to April 27th 2012, 9 days in total.
- Treatment:**
 - 3 nitrogen treatments were applied.
 - n = 243 (3N treatments x 3replicates x 3 leaves x 9 days).
- Measurements:**
 - Active and passive techniques were used to measure *ChF*.
 - Photosynthetic active radiation (PAR)

Complementary analysis:

- PAR was measured to computed *ChF* yield (normalized data).
- Coefficient of variance (*cv*=standard deviation/mean) of the main factors affecting *ChF* measurements was computed per each day:
 - leaf area
 - leaf heterogeneity (CO₂ assimilation and stomata conductance to water vapor)
 - measurements inputs (PAR, reference and vegetation target spectrums).
- The *cv* for active and passive *ChF* measurements was computed.
- The *cv* for leaf heterogeneity, active and passive *ChF* measurements for a one day experiment in **cotton** leaves growing in a **growth chamber** under different water treatments (n = 28) was also computed.

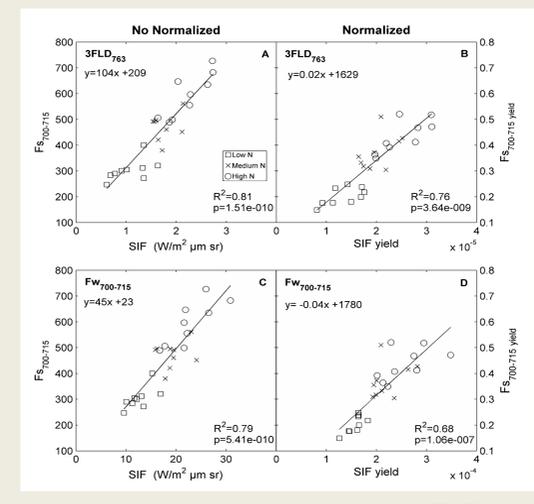


5. Field Scale

5.1 Seasonal

- Strong and significant positive linear relationship between active and passive techniques in both normalized and not normalized date set.
- Constant bias between techniques was observed; no zero intercept was found.
- Due to different:
 - Measuring wavelength.
 - ChF* excitation light.

✓ **Best results:**
 → 3FLD₇₆₃ and $F_{w700-715}$
 → No normalized



Note difference in scale at A-B and C-D because $F_{w700-715}$ represents the area between 700 to 715 nm

5.2 Daily

✓ 3FLD₇₆₃ and $F_{w700-715}$ showed a better agreement with $F_{s700-715}$.
 ✓ 3FLD₇₆₃ better results than iFLD₇₆₃.

- Later in to the season the **variability in leaf heterogeneity decrease** (days 83, 90, 97, 111, and 118) → where $F_{s700-715}$, 3FLD₇₆₃ and $F_{w700-715}$ showed the **same response for the nitrogen treatments**.
- In contrast the **days with higher variability for leaf heterogeneity** (days 55, 62, 69, and 104) **no match was found** between techniques.

Technique	N	Days								
		55	62	69	83	90	97	104	111	118
$F_{s700-715}$	L	321 ^a	312 ^a	272 ^a	400 ^a	300 ^a	290 ^a	305 ^a	283 ^a	247 ^a
	M	380 ^a	497 ^b	451 ^b	495 ^a	489 ^b	460 ^b	561 ^b	421 ^b	491 ^b
	H	597 ^b	555 ^b	682 ^c	499 ^a	492 ^b	506 ^b	727 ^c	635 ^c	647 ^b
3FLD ₇₆₃	L	1.63 ^a	1.32 ^a	1.35 ^a	1.35 ^a	0.91 ^a	0.77 ^a	1.01 ^a	0.68 ^a	0.61 ^a
	M	1.71 ^a	1.60 ^{a-b}	2.11 ^{a-b}	1.58 ^a	1.53 ^b	1.63 ^b	2.13 ^a	1.64 ^b	1.57 ^b
	H	2.28 ^a	2.26 ^b	2.73 ^b	1.92 ^a	1.85 ^b	1.80 ^b	2.72 ^a	2.62 ^c	2.03 ^b
iFLD ₇₆₃	L	1.36 ^a	1.14 ^a	1.14 ^a	0.91 ^a	0.65 ^a	0.51 ^a	0.72 ^a	0.59 ^a	0.54 ^a
	M	1.49 ^a	1.31 ^a	1.85 ^{a-b}	1.21 ^a	1.06 ^{a-b}	1.21 ^a	1.64 ^a	1.12 ^a	1.23 ^b
	H	1.92 ^a	1.95 ^a	2.30 ^b	1.53 ^a	1.46 ^b	1.31 ^a	2.16 ^a	2.13 ^b	1.49 ^b
F_{w687}	L	1.54 ^a	1.26 ^a	1.40 ^a	1.28 ^a	1.08 ^a	0.93 ^a	1.04 ^a	1.18 ^a	1.00 ^a
	M	1.71 ^a	1.42 ^{a-b}	2.25 ^{a-b}	1.61 ^a	1.26 ^a	1.50 ^a	1.99 ^a	1.49 ^a	1.70 ^b
	H	1.83 ^a	1.97 ^b	2.79 ^b	1.86 ^a	1.40 ^a	1.62 ^a	2.22 ^a	2.27 ^b	1.81 ^b
$F_{w700-715}$	L	16.9 ^a	13.1 ^a	13.5 ^a	15.2 ^a	12.2 ^a	10.1 ^a	11.7 ^a	11.3 ^a	9.61 ^a
	M	17.8 ^a	16.1 ^{a-b}	24.1 ^{a-b}	18.8 ^{a-b}	15.9 ^{a-b}	17.8 ^b	23.1 ^a	18.8 ^b	19.5 ^b
	H	21.6 ^a	22.2 ^b	30.8 ^b	21.6 ^b	16.7 ^b	19.5 ^b	25.9 ^a	26.5 ^c	21.8 ^b



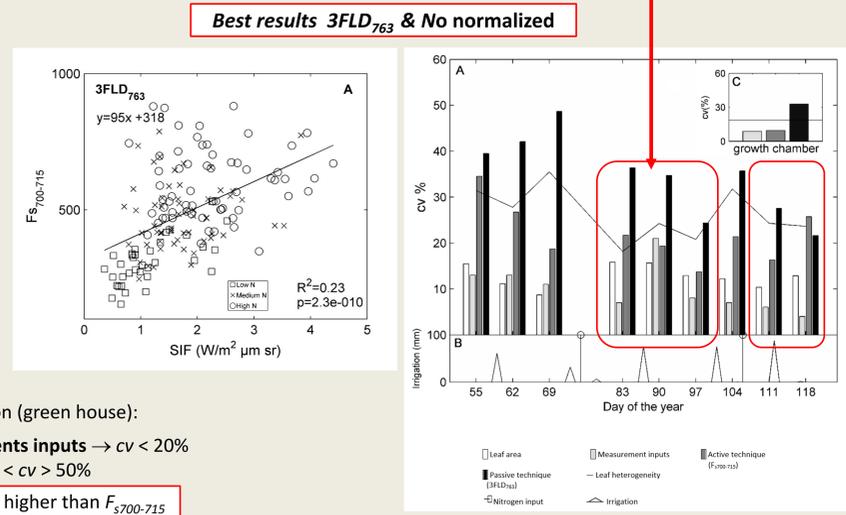
6. Leaf Scale

6.1 Seasonal

✓ **Weak but significant** relationship was observed between active and passive techniques across treatments at leaf level.

- Large **scattering** was found when we analyzed leaf to leaf correlation between techniques.

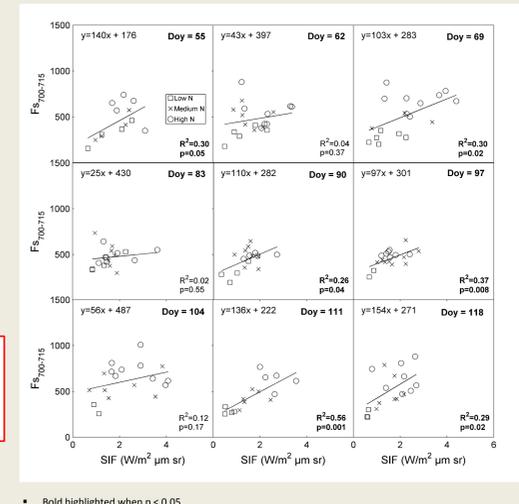
- Why?
 ⇒ Both wheat (outdoors) & cotton (green house):
- No** → leaf area or measurements inputs → *cv* < 20%
 - Yes** → leaf heterogeneity 20% < *cv* > 50%
- ✓ *cv* for 3FLD₇₆₃ was consistently higher than $F_{s700-715}$



6.2 Daily

- Weak but significant** relationship was observed between active and passive techniques for **most of the days** (*p* ≤ 0.05, days 55, 69, 83, 90, 97, 111, 118).
- No significant difference between slopes for day 55 and 111, day 55 and 118, day 69 and 90, and day 69 and 97 (*p* < 0.05)

✓ **At leaf level and daily scale it was not possible to define a unique equation to estimate *SIF* from active *ChF* measurements.**



7. Take Home Message

- Passive and active measurements:
- Field scale – seasonal → Strong and significant correlation - 3FLD₇₆₃ and $F_{w700-715}$ best results.
 - Field scale – daily → 3FLD₇₆₃ and $F_{w700-715}$ presented the better agreement with $F_{s700-715}$.
 - Leaf scale – seasonal → Weak but significant correlation.
 - Leaf scale – daily → Weak and not always significant.

★ It is possible to compare **active and passive *ChF* measurements at leaf level** to improve our understanding of the **seasonal behavior *SIF***, and this in turn, can be used to **better design satellite missions to globally monitor *SIF* in terrestrial vegetation.**

Acknowledgements

This research was supported in part by the NASA Soil Moisture Active Passive (SMAP) Science Definition Team (08-SMAPSDT08-0042) and is a result of a fellowship funded by the USDA OECD Co-operative Research Programme. Thanks Bhaskar Mitra, Dpahne Szutu, Ami Kidder, Daniel Alan, and Zack Guido for their good advice.

