

# “Mieux comprendre le système climatique terrestre à travers l’observation spatiale à l’IPSL”

Journée Scientifique organisée par Le Pôle Observation de l’IPSL

Lundi 4 juillet 2016 (9h00– 18h)

Amphi Gérard Mégie,  
11 Bd d’Alembert, Guyancourt

## La fluorescence de la végétation : une nouvelle donnée spatiale pour le suivi du cycle du carbone

Goulas Y.<sup>(1)</sup>, Moya I.<sup>(1)</sup>, Ounis A.<sup>(1)</sup>, Lopez M.L.<sup>(1)</sup>, Maignan F.<sup>(2)</sup>, Bacour C.<sup>(3)</sup> et Soudani K.<sup>(4)</sup>

(1) LMD, Ecole polytechnique

(2) LSCE, Saclay

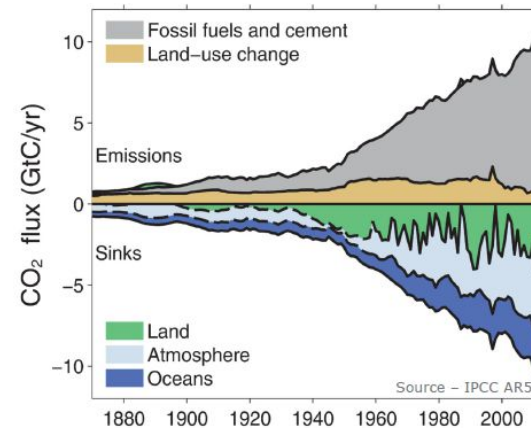
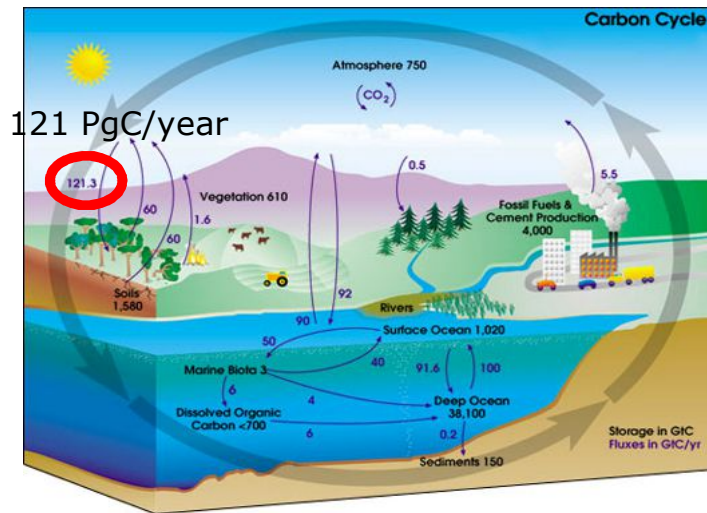
(3) NOVELTIS, Labège

(4) ESE, Orsay

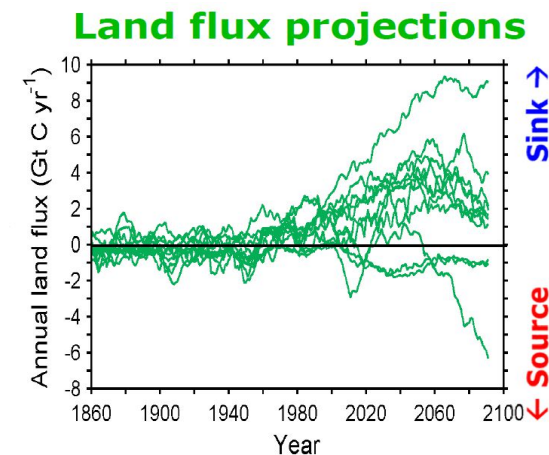


# Enjeux : 1) La composante photosynthétique du cycle du carbone

"Over at least the last 30 years, the net result of all these processes has been uptake of atmospheric CO<sub>2</sub> by terrestrial ecosystems. It is critical to understand the reasons for this uptake and its likely future course. Will uptake by the terrestrial biosphere grow or diminish with time, or even reverse so that the terrestrial biosphere becomes a net source of CO<sub>2</sub> to the atmosphere ? ", IPCC report, 2007



PgC.yr <sup>-1</sup>	1980s	1990s	2000-2005
Atmosphere increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.1
Emissions	5.4 ± 0.3	6.4 ± 0.4	7.2 ± 0.3
Ocean	-1.8 ± 0.8	-2.2 ± 0.4	-2.2 ± 0.5
Surface	<b>-0.3 ± 0.9</b>	<b>-1 ± 0.6</b>	<b>-0.9 ± 0.6</b>



Source P. Ciais, adapté de Friedlingstein (2014)

- Améliorer l'estimation et les prévisions de GPP (Gross Primary Production)

# Assessment of Gross Primary Production (GPP) from space

$$GPP = \varepsilon_g \times fAPAR_{canopy} \times PAR \quad (\text{Monteith, 1972})$$

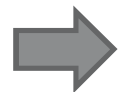


$$fAPAR_{canopy} = f(LAI) = f(NDVI)$$

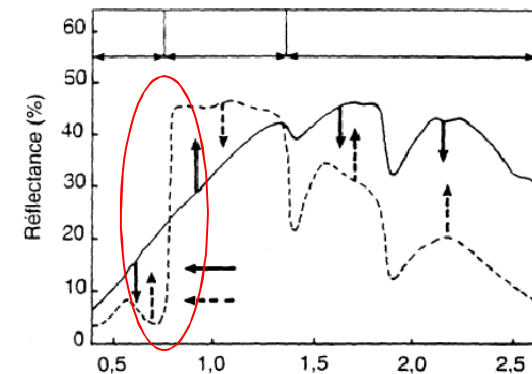
Light Use Efficiency (LUE) (gC/ mol PAR)

$$\varepsilon_g = \varepsilon_0(\text{constant})$$


or f(Air temp., Soil Moisture,  
Water vapour pressure deficit,  
Leaf Water content, etc)



Uncertainties!



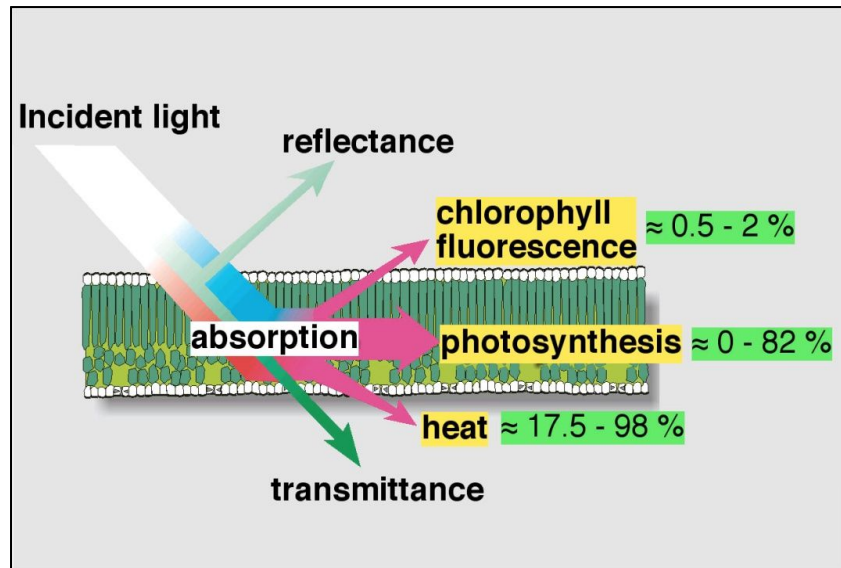
D'après Guyot, Signatures spectrales en télédétection



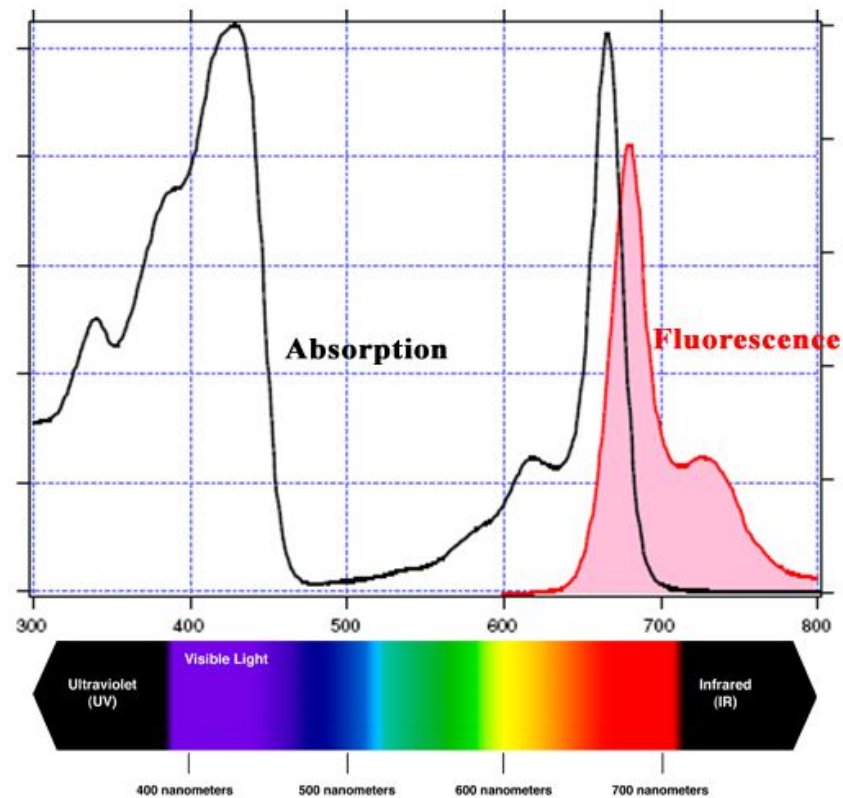
## La fluorescence de la chlorophylle comme indicateur de l'activité photosynthétique

# Chlorophyll fluorescence

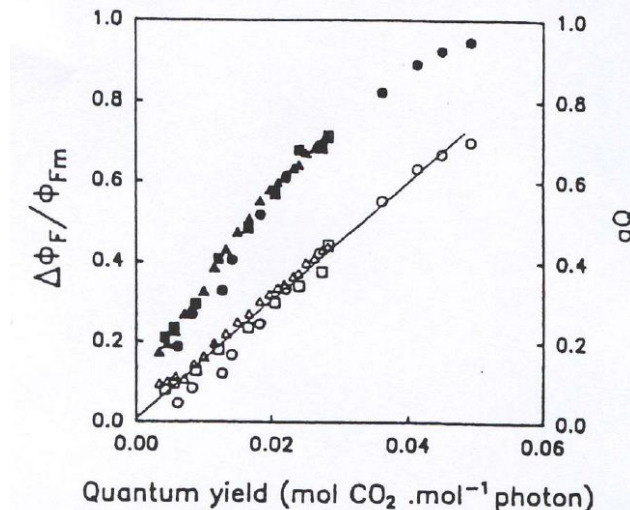
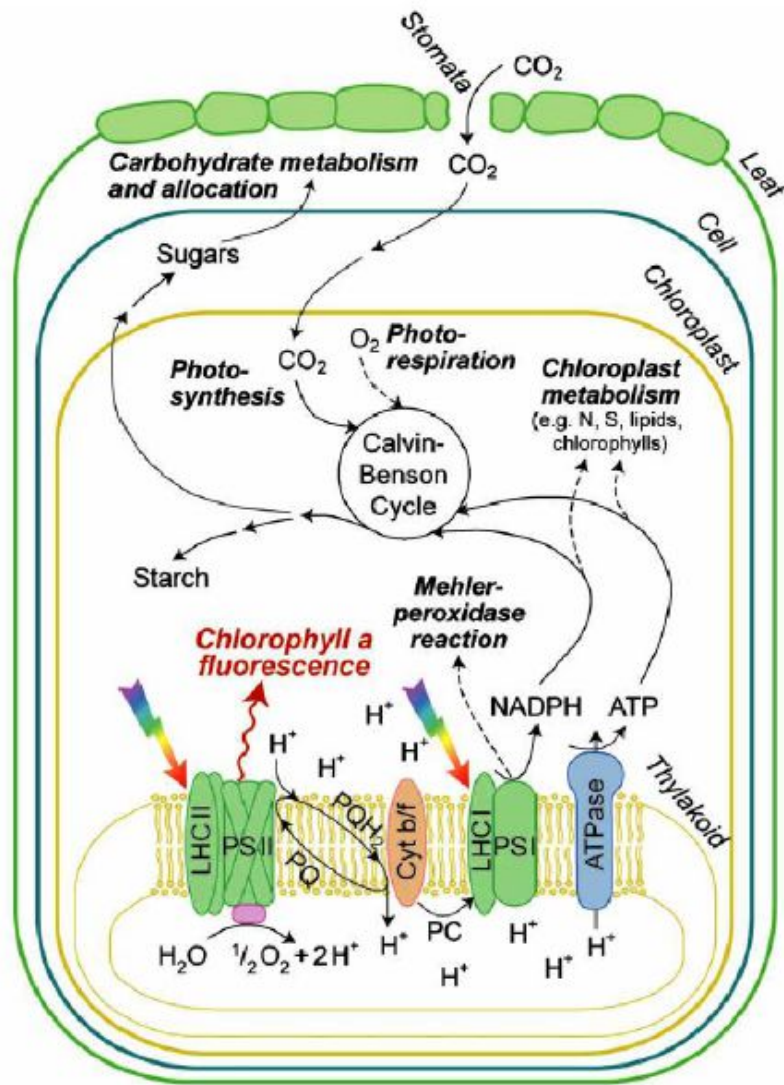
## Energy budget at the leaf level



## Chlorophyll fluorescence



# Lien entre fluorescence et photosynthèse



Genty B, et al., (1989). *Biochim. Biophys. Acta* 990: 87-92



PAM-2000  
Portable Chlorophyll  
Fluorometer

for investigating  
photosynthesis in the field,  
greenhouse and laboratory





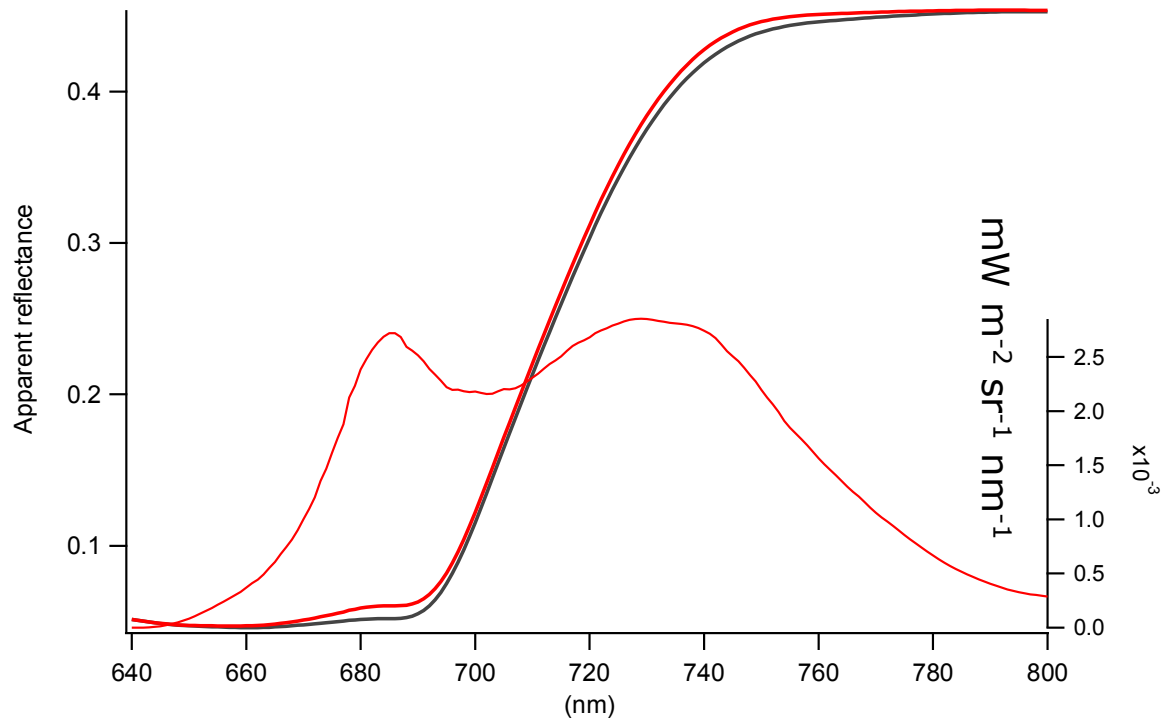
## Comment mesurer la fluorescence en télédétection ?

# Téledétection de la fluorescence des couverts végétaux

La fluorescence représente un très faible partie du signal réfléchi (<1%)

## Ordres de grandeurs

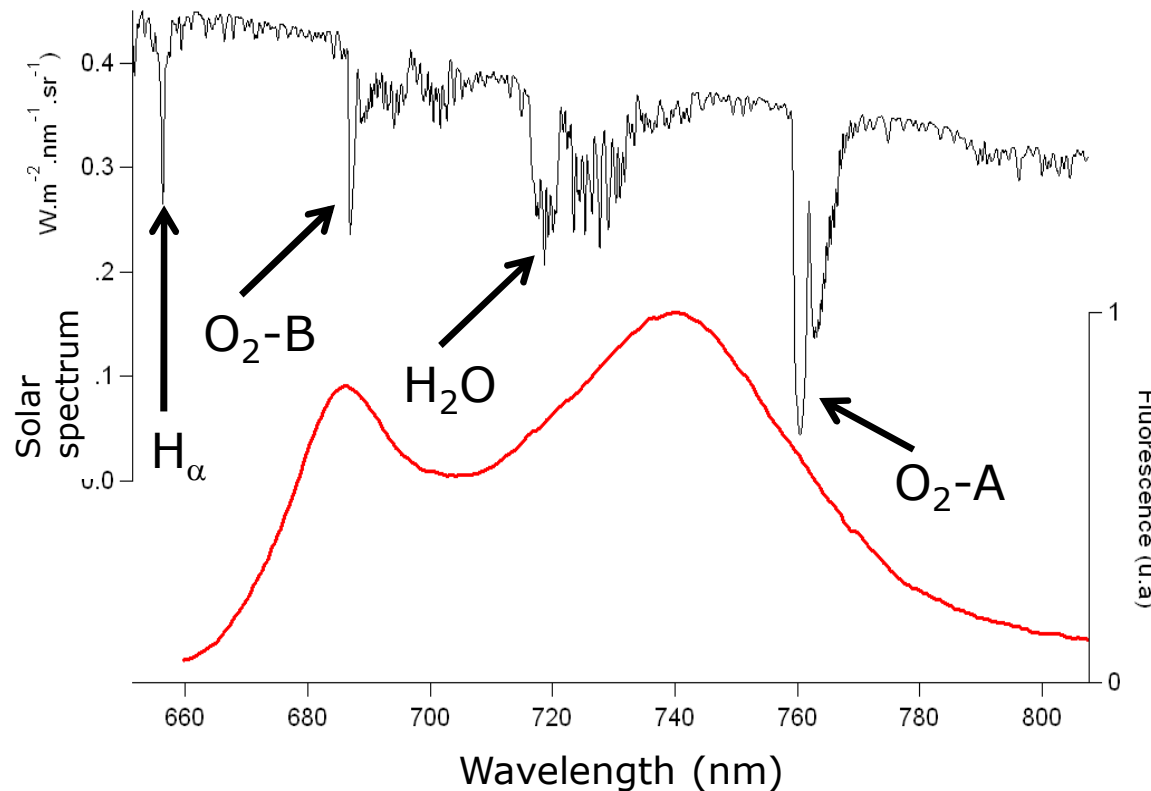
- ✓ Eclairement :  
 $\approx 1 \text{ W m}^{-2} \text{ nm}^{-1}$
- ✓ Luminance de la surface :  
 $\approx 0.1\text{-}0.3 \text{ W m}^{-2} \text{ nm}^{-1} \text{ sr}^{-1}$
- ✓ Fluorescence  
 $\approx 2 \text{ mW m}^{-2} \text{ nm}^{-1} \text{ sr}^{-1} \text{ max.}$





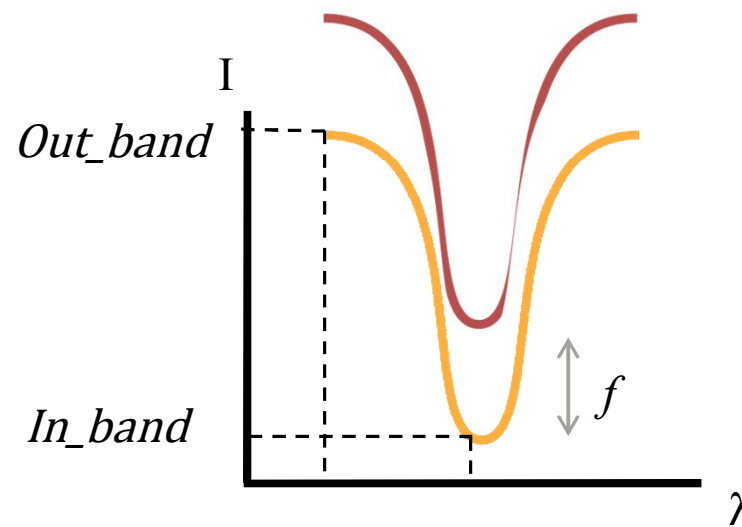
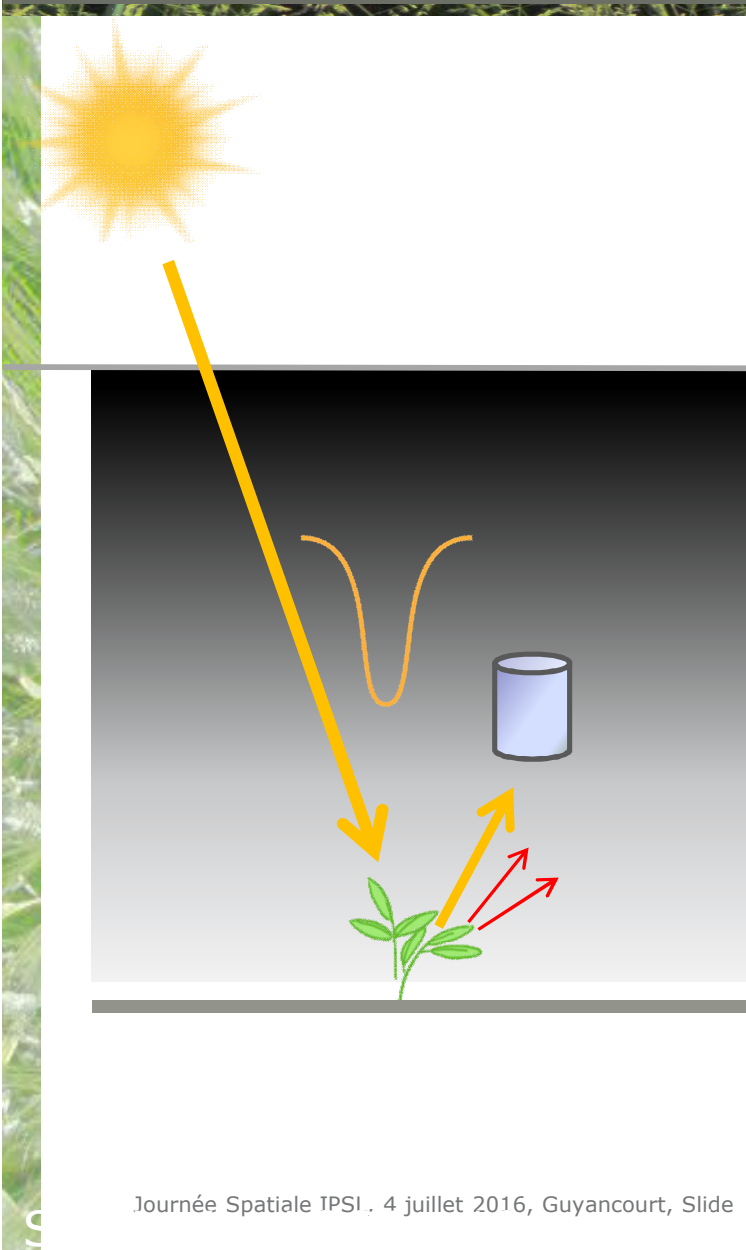
# Utilisation des bandes d'absorption pour la télédétection de la fluorescence

Les bandes d'absorption de l'oxygène ( $O_2$ -A et  $O_2$ -B) sont préférentiellement retenues pour la mesure passive de la fluorescence



- ✓ Position spectrale par rapport aux deux pics de fluorescence rouge et rouge lointain
- ✓ Largeur et profondeur (SNR)
- ✓  $O_2$  est un composant atmosphérique stable
- ↳ La profondeur varie avec l'état de l'atmosphère

# Principe de base de la mesure passive de la fluorescence induite par le soleil



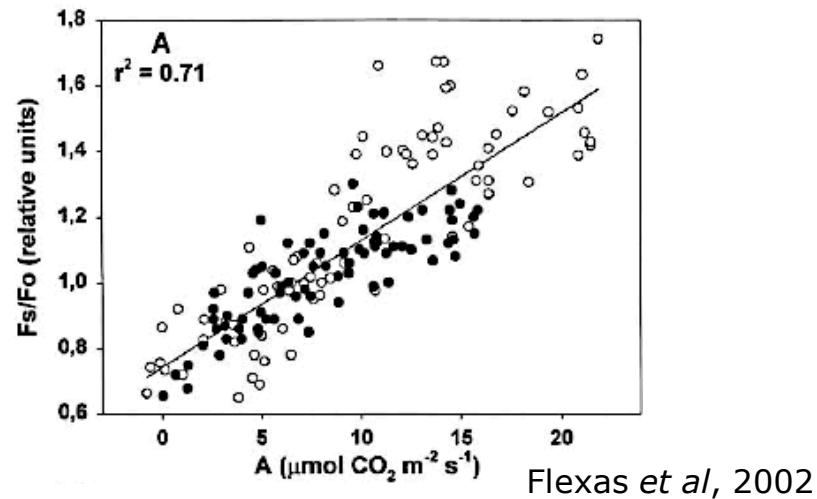
$$\text{Rapport Spectral} = \frac{\text{Out\_band}}{\text{In\_band}}$$

$$RS_{\text{végétation}} = \frac{\text{Out\_band} + f}{\text{In\_band} + f}$$

} Fluorescence flux

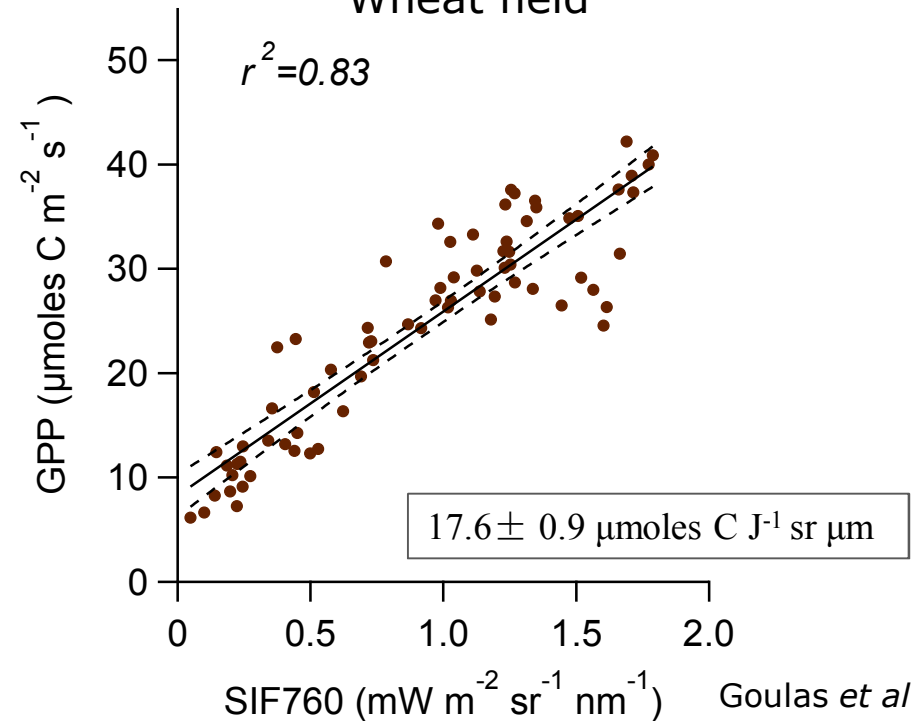
# Relation fluorescence-photosynthèse (mesures in-situ)

Leaf level  
under high light  
(field condition)



Carbon assimilation

Canopy level  
Wheat field

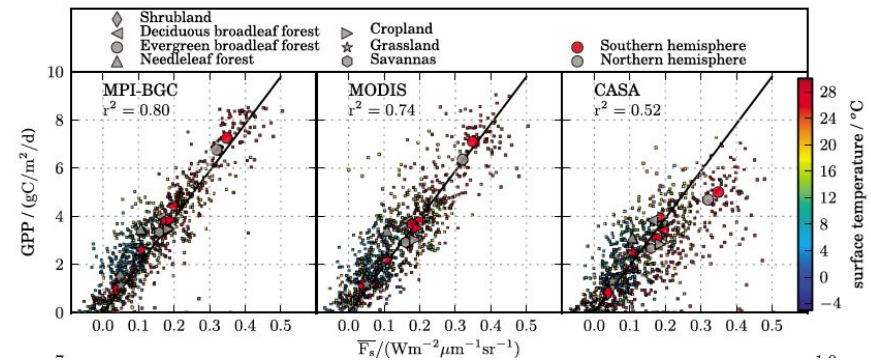
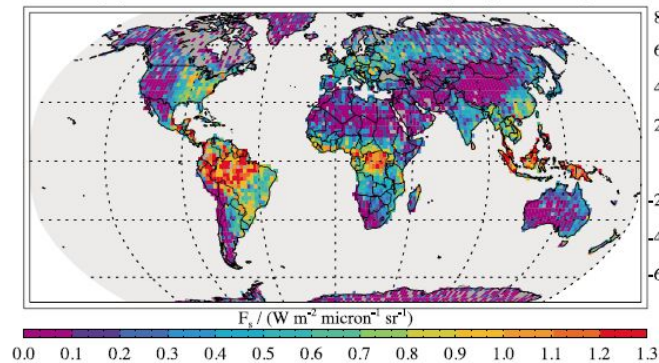


La relation SIF-GPP est robuste, par rapport à:

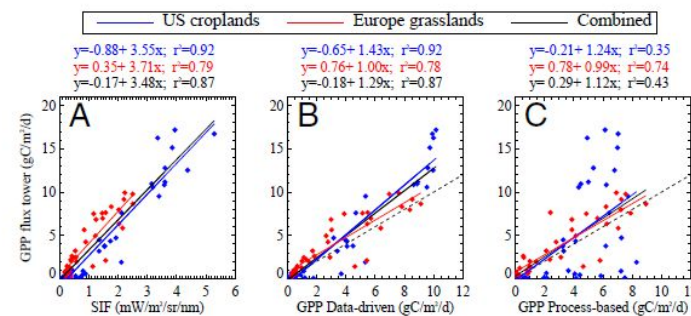
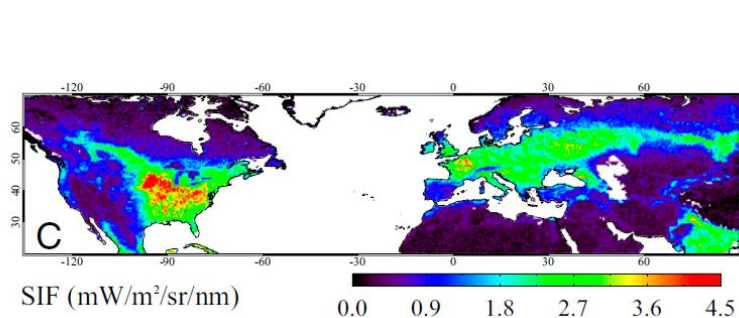
- ✓ échelle de temps (journée/mois-année)
- ✓ échelle spatiale ( $4 \text{ m}^2 / 40\text{-}400 \text{ km}^2$ )
- ✓ technique de mesure ( $\text{O}_2\text{-A}/\text{Fraunhofer}$ )
- ✓ distance de mesure ( $20 \text{ m} / 600\text{-}800 \text{ km}$ )

# Fluorescence and photosynthesis at global scale

A Chlorophyll a fluorescence at 755 nm, June 2009 through May 2010 average



**Greenhouse Gases Observing Satellite (GOSAT)** First global observations of vegetation fluorescence, (Joiner et al., 2010; Frankenberg et al. 2011)



**Global Ozone Monitoring Experiment-2 (GOME-2)**  
(Guanter et al. 2014)

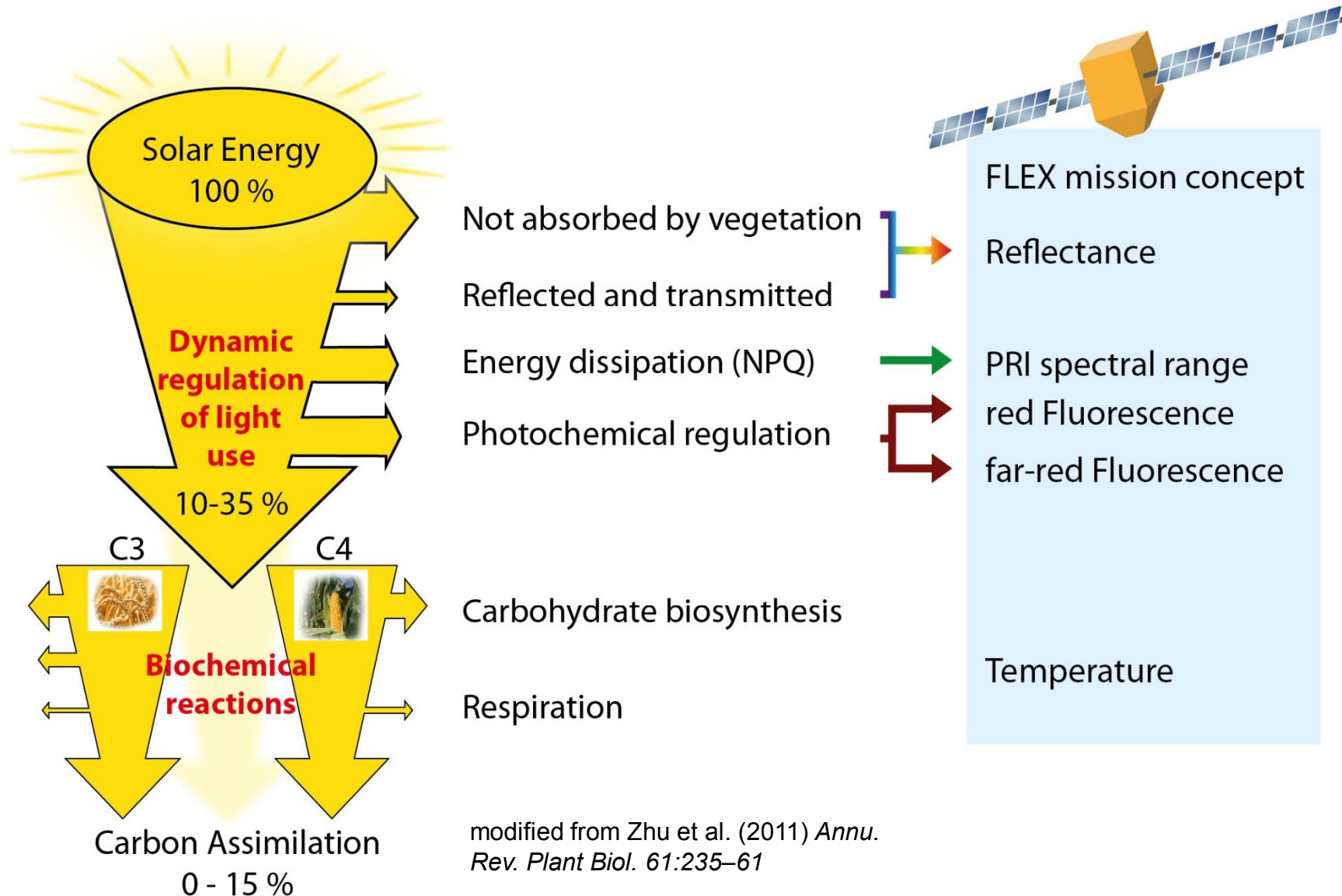
# FLEX: FLuorescence EXplorer

FLEX will quantify **actual photosynthetic activity** of terrestrial ecosystems

FLEX will provide **physiological indicators** for vegetation health status

by direct measurements of **vegetation fluorescence** at relevant spatial scales

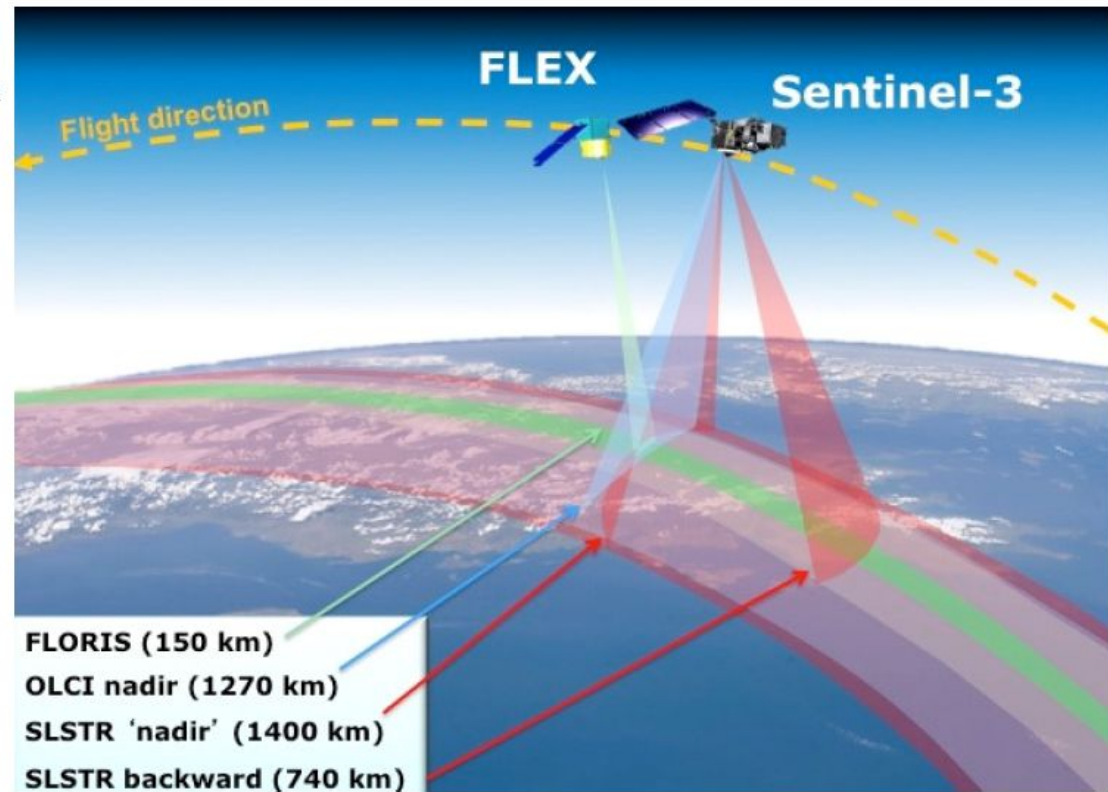
# Measurements needed to determine actual photosynthesis



modified from Zhu et al. (2011) *Annu. Rev. Plant Biol.* 61:235–61

# FLEX concept (1)

- Safe formation flying with Sentinel-3 (any unit)
- Observations temporally (6 to 15 s) and spatially co-registered with OLCI and SLSTR
  - ✓ FLEX swath within OLCI swath
- Single instrument: FLuORescence Imaging Spectrometer (FLORIS)
  - ✓ Pushbroom spectrometer
  - ✓ Swath of ~ 150 km
  - ✓ Pixel size of 0.3 x 0.3 km<sup>2</sup>



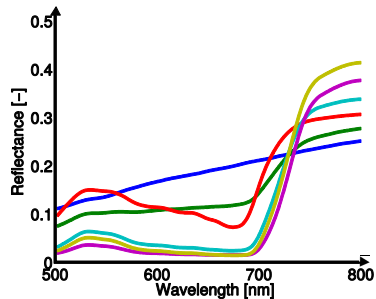
# Vers un schéma d'assimilation des données FLEX

- ✓ Données multi-paramétriques
  - ✓ Fluorescence
  - ✓ Réflectance visible et proche IR (res. spec. 0.6-3 nm) : paramètres biophysiques, LAI, Chl, fPAPAR
  - ✓ Réflectance dans le vert (PRI): cycle des xanthophylles, dissipation thermique dans les photosystèmes
  - ✓ IR thermique: température foliaire
- ✓ Modèles de fonctionnement des couverts couplant propriétés optiques et photosynthèse
  - ✓ SCOPE, ORCHIDEE, CASTANEA (forêts),...
- ✓ Observations pour la validation et la calibration
  - ✓ Echelles spatiales (up scaling: feuille-> couvert -> paysage )
  - ✓ Echelles temporelles (diurne -> saisonnière -> inter-saisons)

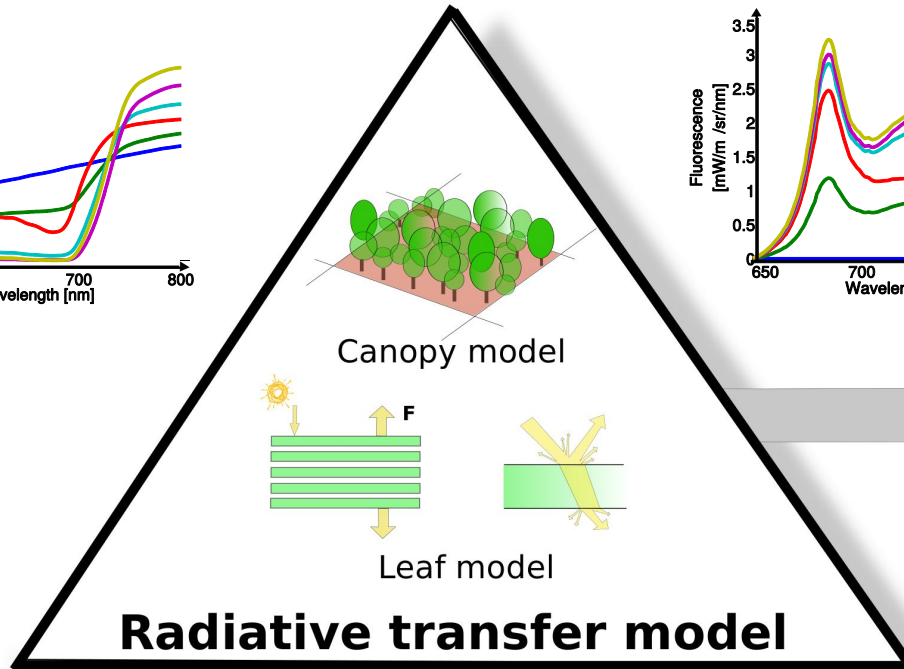
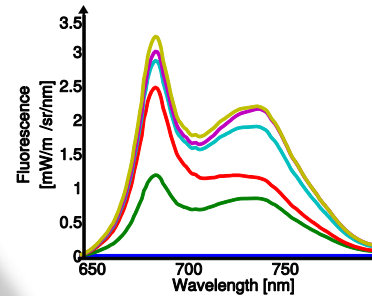


# Modelling fluorescence / photosynthesis relationship and dynamics

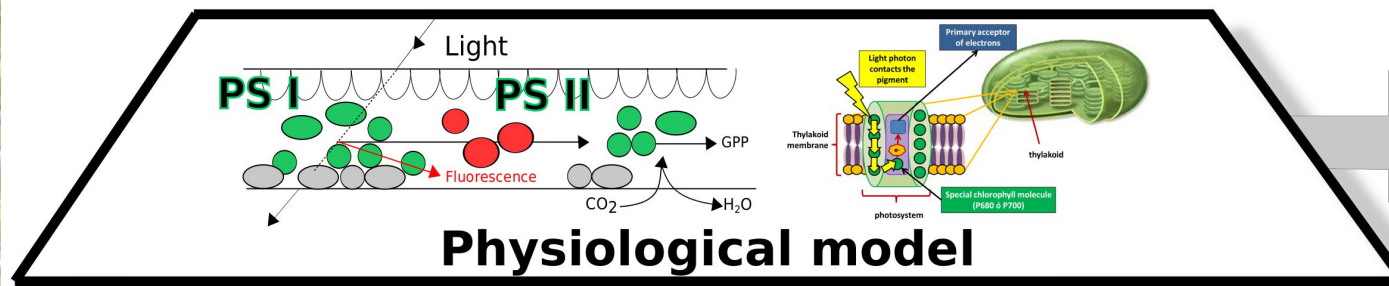
## Reflectance



## Fluorescence



SCOPE

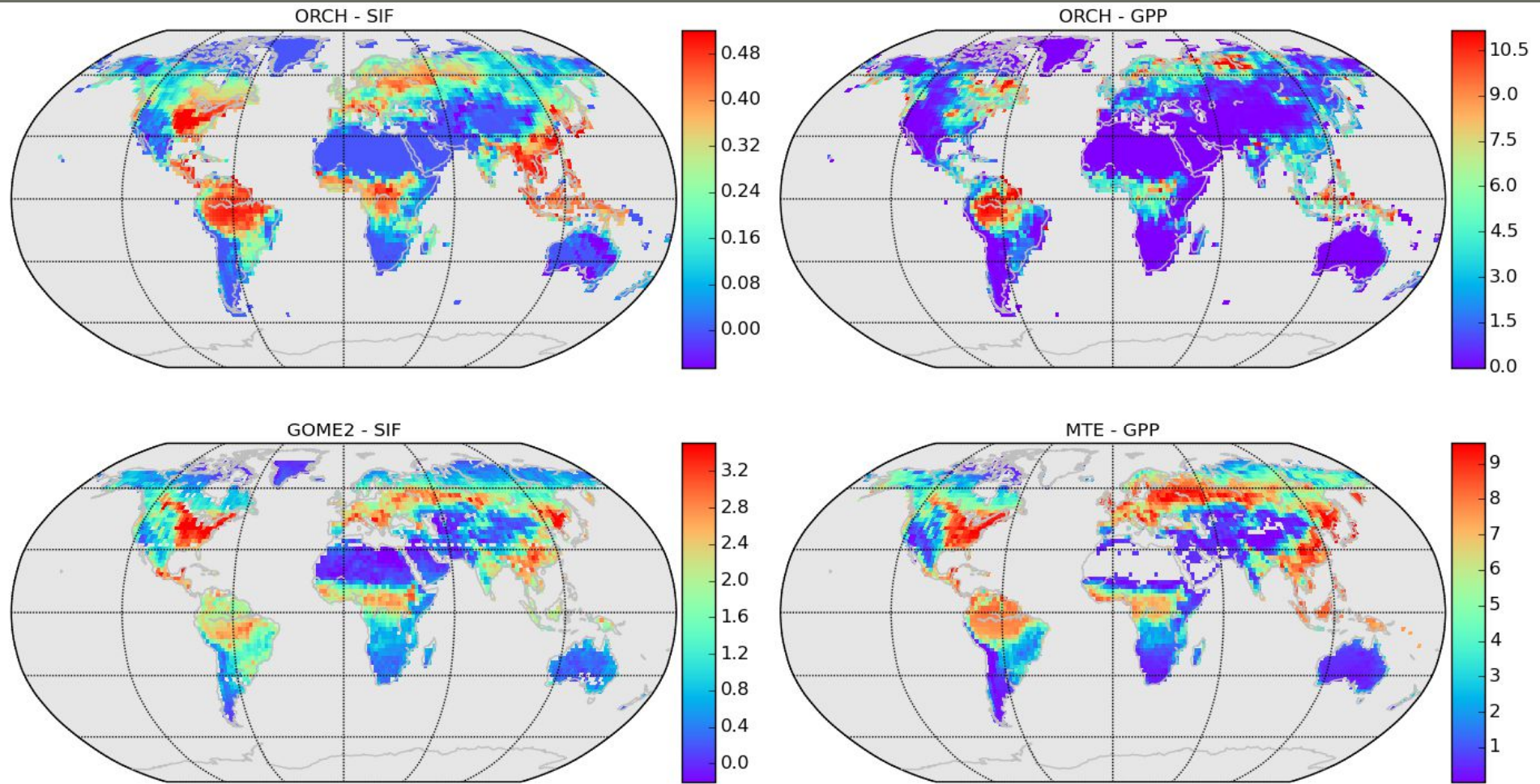


Retrievals

**DATA  
ASSIMILATION**

Signal  
understanding

# Implementation of fluorescence at leaf/canopy levels in the IPSL Land Surface Model ORCHIDEE (CNES/TOSCA funding)



July 2008

Comparison with GOME2  
**fluorescence** product

Comparison with global FLUXNET-derived  
**Gross Primary Production (GPP)** product

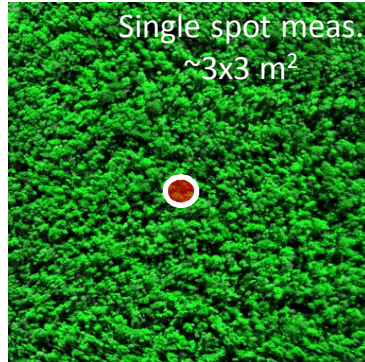
**Objective and next step:** Assimilation of fluorescence observations to optimise photosynthesis and GPP



# Mesures à l'échelle du champ



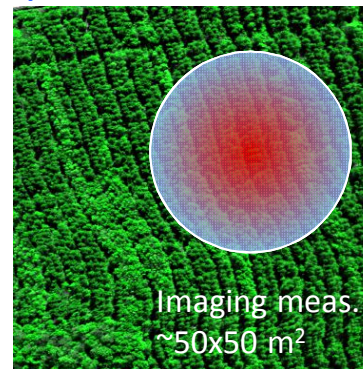
Spot spectroradiometer



Fluorescence at O<sub>2</sub>-A and O<sub>2</sub>-B  
Fully autonomous  
Single spot, localized  
High temporal sampling (seconds)



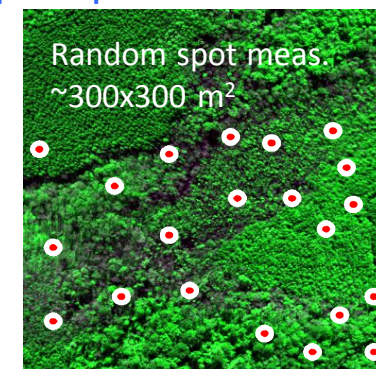
Robotized imaging spectroradiometer



Fluorescence at O<sub>2</sub>-A  
Fully autonomous  
Imaging, localized  
Mid temporal sampling (hours)



UAV mounted spot spectroradiometer



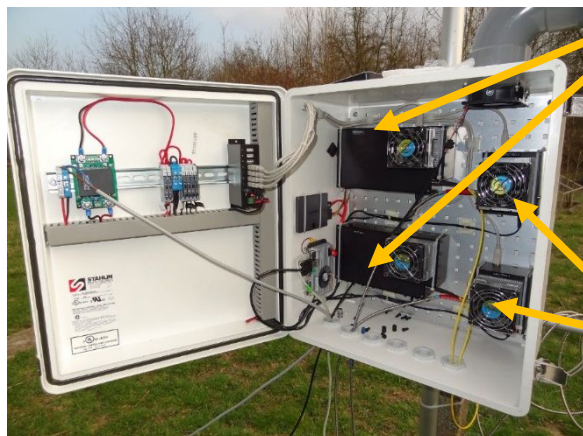
Fluorescence from RT modelling  
Partially autonomous  
Multiple spots, delocalized  
Low temporal sampling (days)

# Mesures de télédétection in-situ

- ❑ LMD, Palaiseau, instrumentation active et passive
- ❑ ESE, Orsay, mesures passives de fluorescence, bilan carboné des forêts, site ICOS de Barbeau
- ❑ ECOSYS/INRA, bilan carboné des cultures, site ICOS de Grignon



Barbeau, Fontainebleau oak, hornbeam

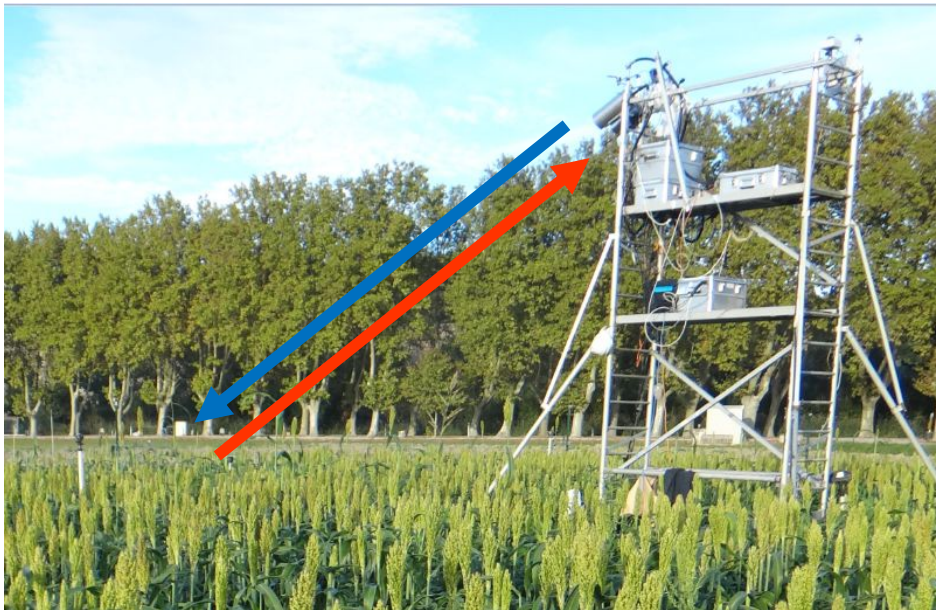


x2  
600-800 nm  
0.2 nm resolution  
Thermo-cooled  
O<sub>2</sub>-A and O<sub>2</sub>-B  
fluorescence

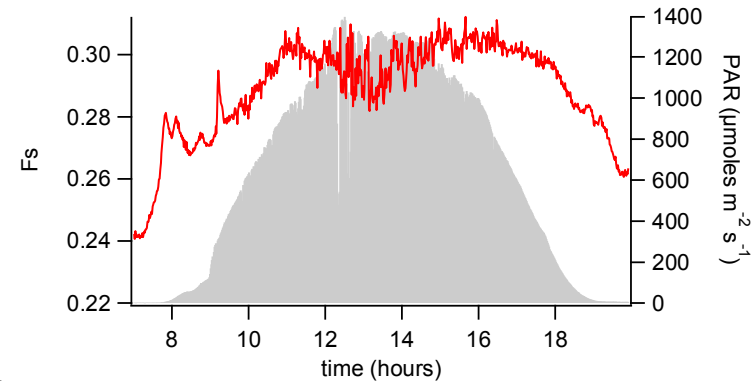
x2  
400-800 nm  
0.3 nm resolution  
Reflectance  
(NDVI, PRI,...)



# Active instruments for remote sensing of fluorescence



- ✓ Blue electroluminescent diodes (LEDs) as excitation source
- ✓ Measuring distance up to 10 m
- ✓ Up to 100 Hz sampling rate
- ✓ Assessment of fluorescence yield on canopy
- ✓ Analysis of  $F_s=f(\text{PAR})$  at different time scales



PIs-contact:

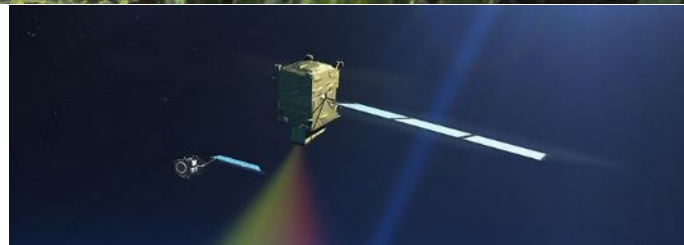
A. Ounis: [ounis@lmd.polytechnique.fr](mailto:ounis@lmd.polytechnique.fr)

I. Moya: [ismael.moya@lmd.polytechnique.fr](mailto:ismael.moya@lmd.polytechnique.fr)

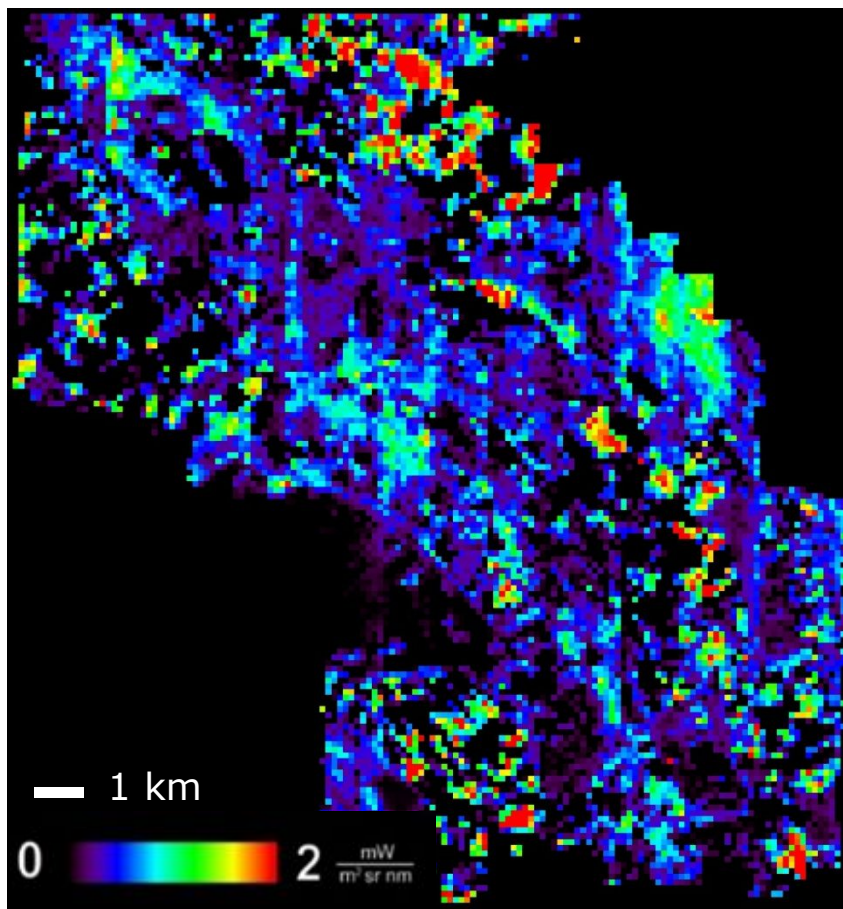
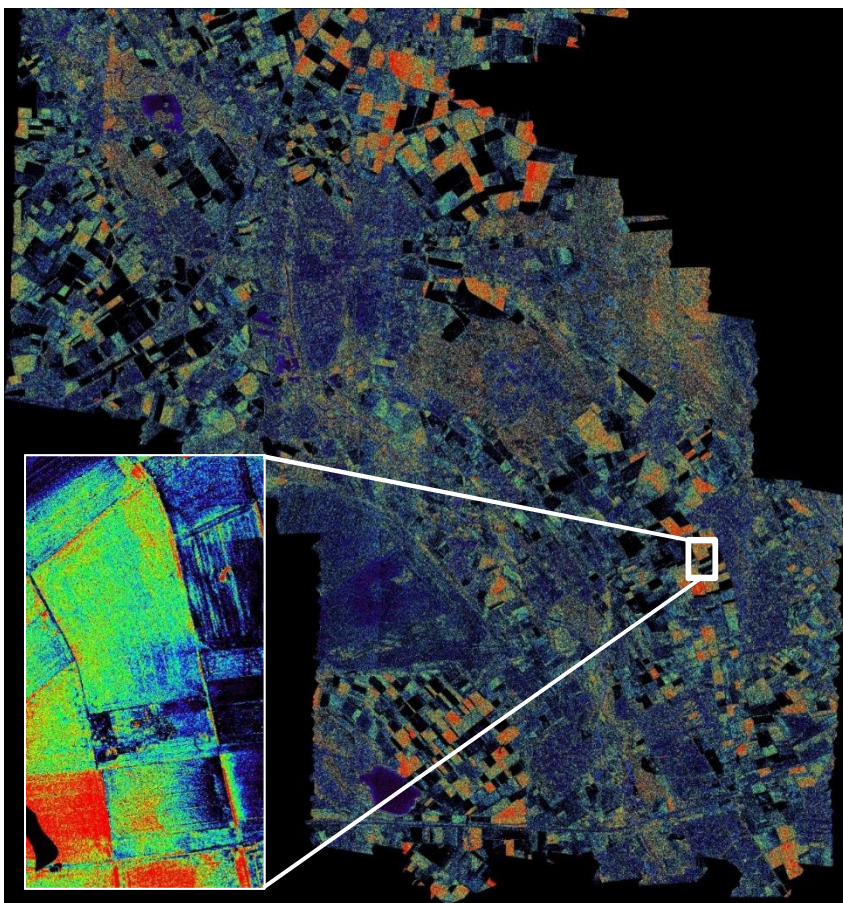
# Mesures aéroportées (upscaling)



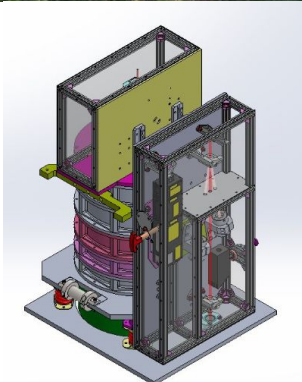
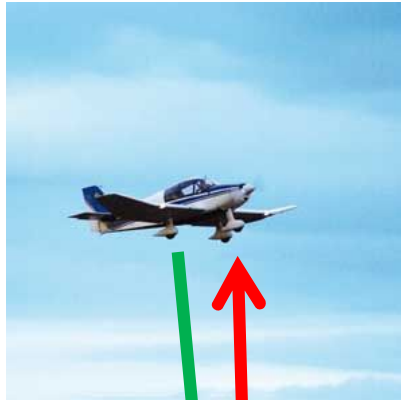
- AIRFLEX
- HYPLANT
- LASVEG



- FLEX
- GOME2
- OCO2
- MicroCarb



# Upscaling of fluorescence signals with airborne F-lidar (LMD)



## ❑ Ecosystems monitoring

The CALSIF sensor will give access to key variables of **ecosystems functioning and carbon cycle analysis**

Sensor	Observable	Variable
Active FLidar	Fluorescence yield	Photosynthesis efficiency (Flexas 2002)
Passive spectroradiometer	Sun Induced Fluorescence (SIF)	GPP (Frankenberg 2011)
Waveform Lidar	Canopy vertical profile	Above ground carbon stocks (Asner 2012)

❑ **Upscaling of eddy covariance measurements** using fluorescence remote sensing

# Conclusions et perspectives

- ✓ La fluorescence de la chlorophylle est une observable spatiale liée à la photosynthèse
- ✓ La mission FLEX de l'ESA (2022) fournira un jeu de paramètres étendu (dont la fluorescence) pour évaluer le fonctionnement des couverts végétaux
- ✓ Assimilation des données de fluorescence
  - Mise en place de réseaux de mesures multi-échelles (temporelle, spatiale): mesures in-situ, avionnées, passives, actives
  - Prise en compte des dynamiques temporelles (diurne, saisonnière) dans les modèles et schémas d'assimilation
- ✓ Collaborations et points de prospective scientifique à l'IPSL
  - Développement de modèles et schémas d'assimilation (LSCE, LMD + ESE, ECOSYS)
  - Développement des réseaux de mesures (LMD, ESE, ECOSYS)
  - Modèles d'absorption dans les bandes de l'oxygène (LMD, J.M. Hartmann, H. Tran, A. Perrin)