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Joint Research Centre

# Uncertainties FAPAR MERIS/OLCI

**Nadine Gobron**

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European Commission

# Sentinel-3 OLCI FAPAR

**Daily** OLCI (MERIS) FAPAR
Use information in blue, red and near-infrared (Gobron et al. 1999, Gobron, 2012).
Algorithm based on 1D-RT model simulations (semi-discrete + 6SV)

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Remote Sensing of Environment 112 (2008) 1871–1883
Remote Sensing of Environment
www.elsevier.com/locate/rse

Uncertainty estimates for the FAPAR operational products derived from MERIS — Impact of top-of-atmosphere radiance uncertainties and validation with field data

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as similar FAPAR products derived from other optical sensor data. The results indicate that the impact of top-of-atmosphere radiance uncertainties on the operational MERIS FAPAR products accuracy is expected to be at about 5–10% and the agreement with the ground-based estimates over different canopy types is achieved within ±0.1.

measurements acquired at the top-of-atmosphere, using a physically based approach. The products are operationally available at the reduced spatial resolution, i.e. 1.2 km, and can be computed at the full spatial resolution, i.e. at 300 m, from the top-of-atmosphere MERIS data by using the same algorithm. The quality assessment of the MERIS FAPAR products capitalizes on the availability of five years of data acquired globally. The actual validation exercise is performed in two steps including, first, an analysis of the accuracy of the FAPAR algorithm itself with respect to the spectral measurements uncertainties and, second, with a direct comparison of the FAPAR time series against ground-based estimations as well
as similar FAPAR products derived from other optical sensor data. The results indicate that the impact of top-of-atmosphere radiance uncertainties on the operational MERIS FAPAR products accuracy is expected to be at about 5–10% and the agreement with the ground-based estimates over different canopy types is achieved within ±0.1.


$$g_n[\tilde{\rho}(\lambda_i),\tilde{\rho}(\lambda_j)] = P(\lambda_i,\lambda_j)/Q(\lambda_i,\lambda_j)$$

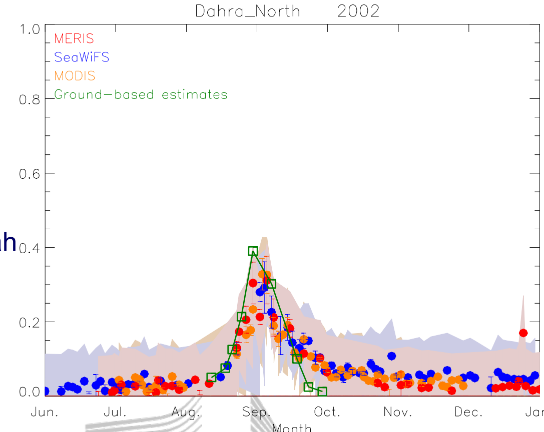
$$P(\lambda_i,\lambda_j) = l_{n1}(\tilde{\rho}(\lambda_i)+l_{n2})^2 + l_{n3}(\tilde{\rho}(\lambda_j)+l_{n4})^2 + l_{n5}\,\tilde{\rho}(\lambda_i)\,\tilde{\rho}(\lambda_j)$$

$$Q(\lambda_i,\lambda_j) = l_{n6}(\tilde{\rho}(\lambda_i)+l_{n7})^2 + l_{n8}(\tilde{\rho}(\lambda_j)+l_{n9})^2 + l_{n10}\,\tilde{\rho}(\lambda_i)\,\tilde{\rho}(\lambda_j) + l_{n11}$$

$$\mathrm{FAPAR} = g_0(\rho_{Rred},\rho_{Rnir}) = \frac{l_{01}\rho_{Rnir} - l_{02}\rho_{Rred} - l_{03}}{(l_{04}-\rho_{Rred})^2 + (l_{05}-\rho_{Rnir})^2 + l_{06}}$$


semi-arid grass savannah

Ref: Fensholt et al. 2004
FAPAR ≈ 1.-exp(-G(μ0)<LAI>/μ0)
<LAI> from PCA_LICOR

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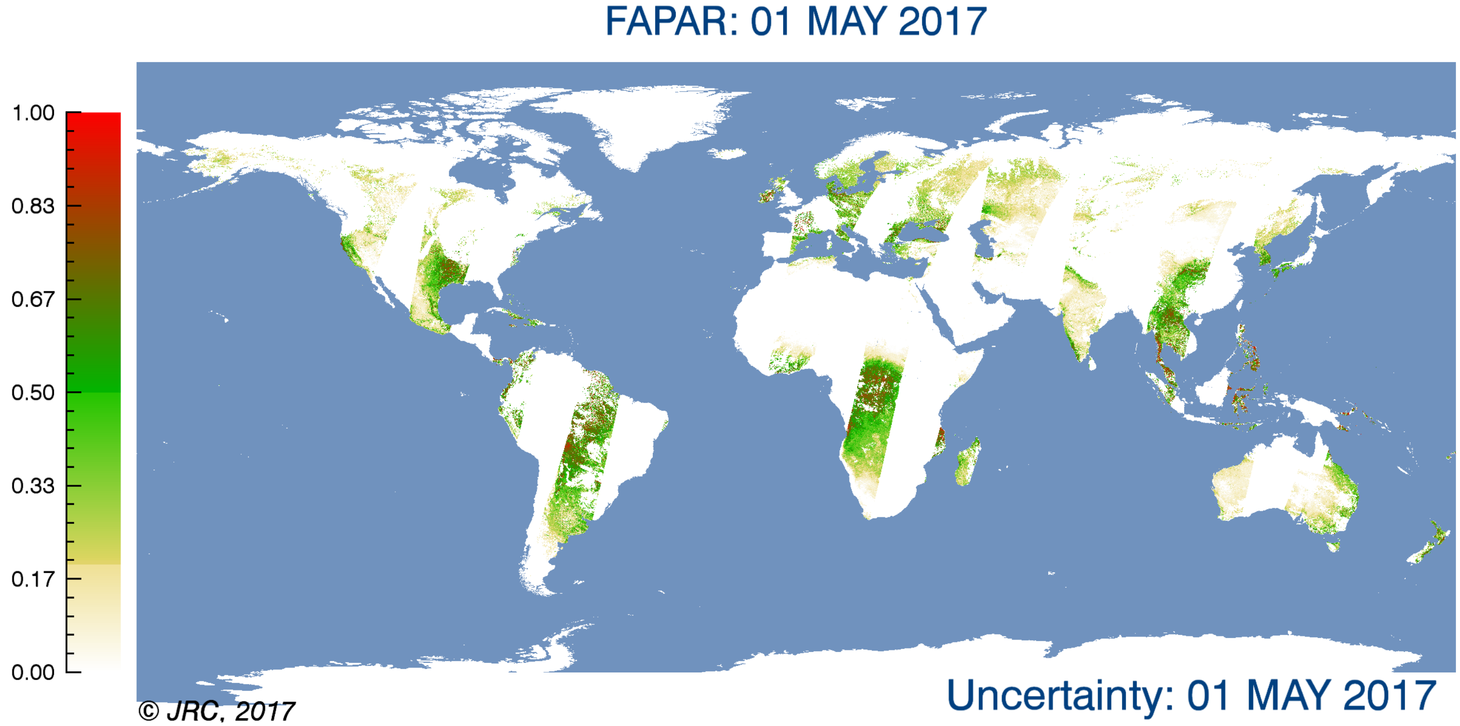
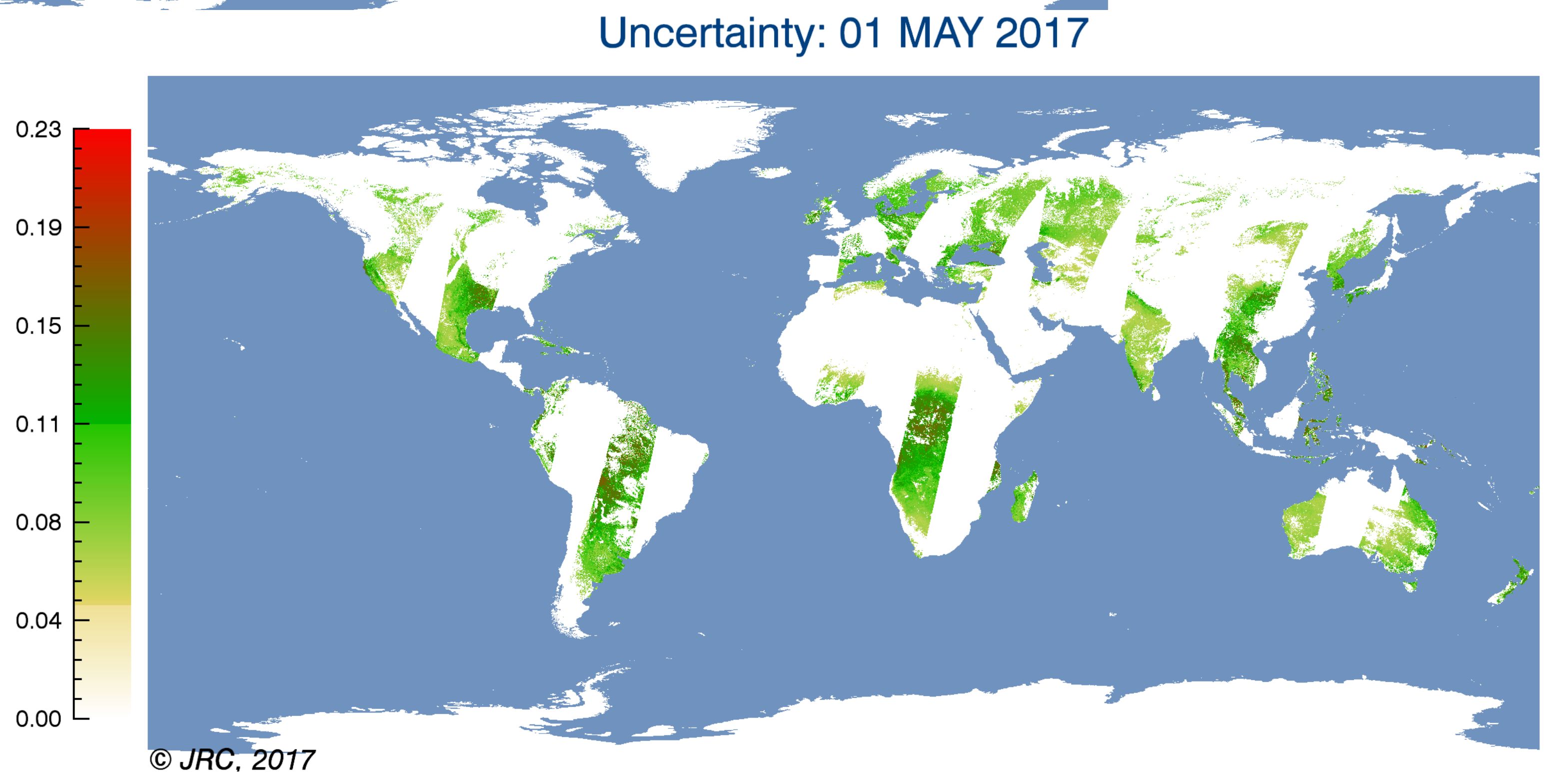
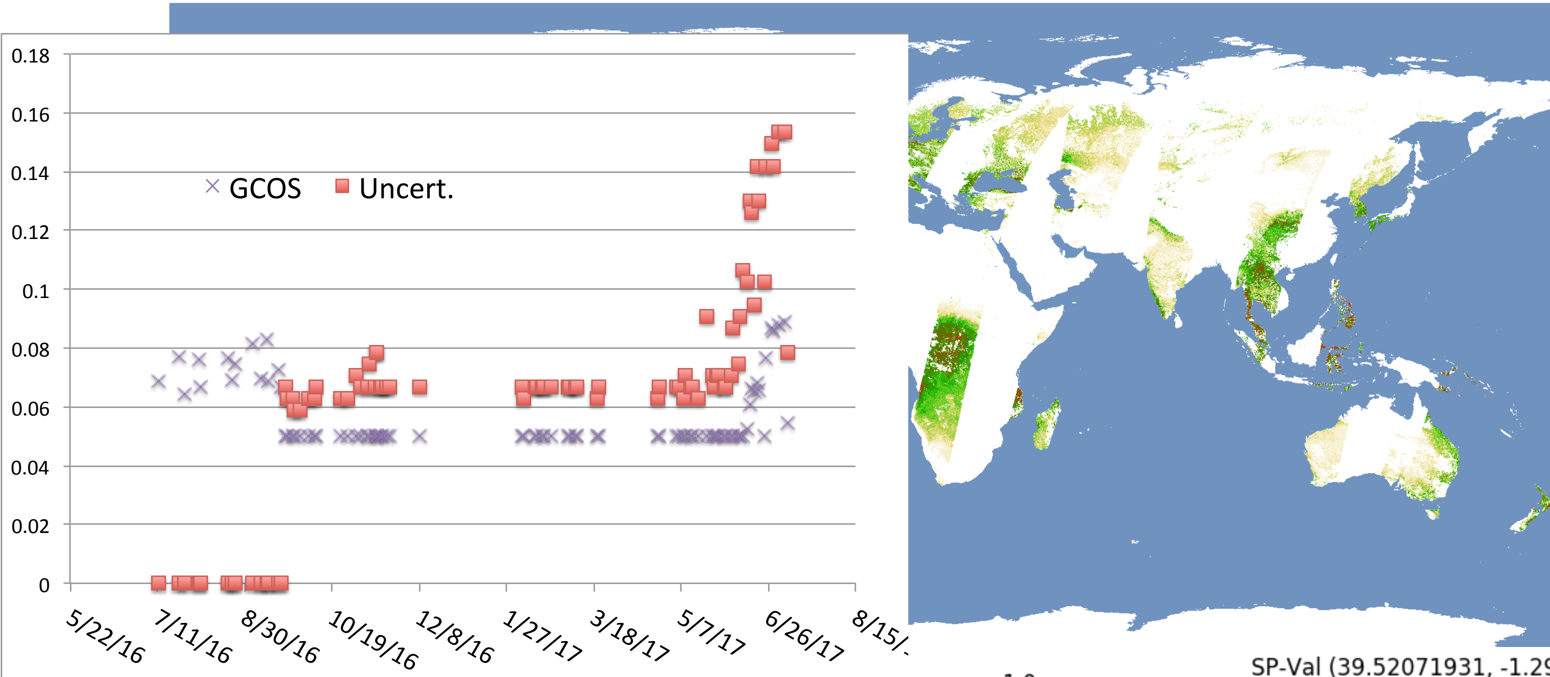
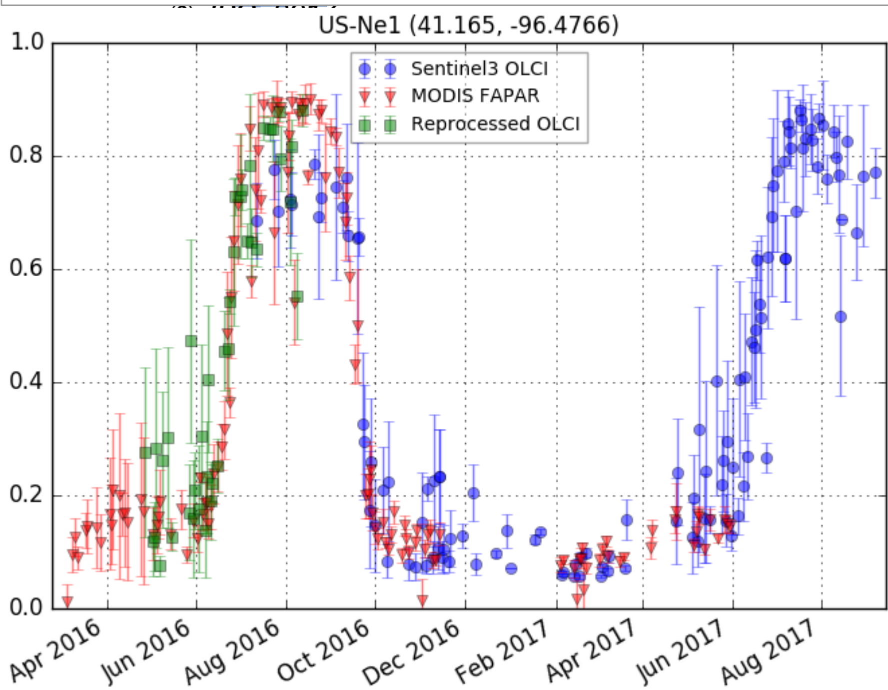


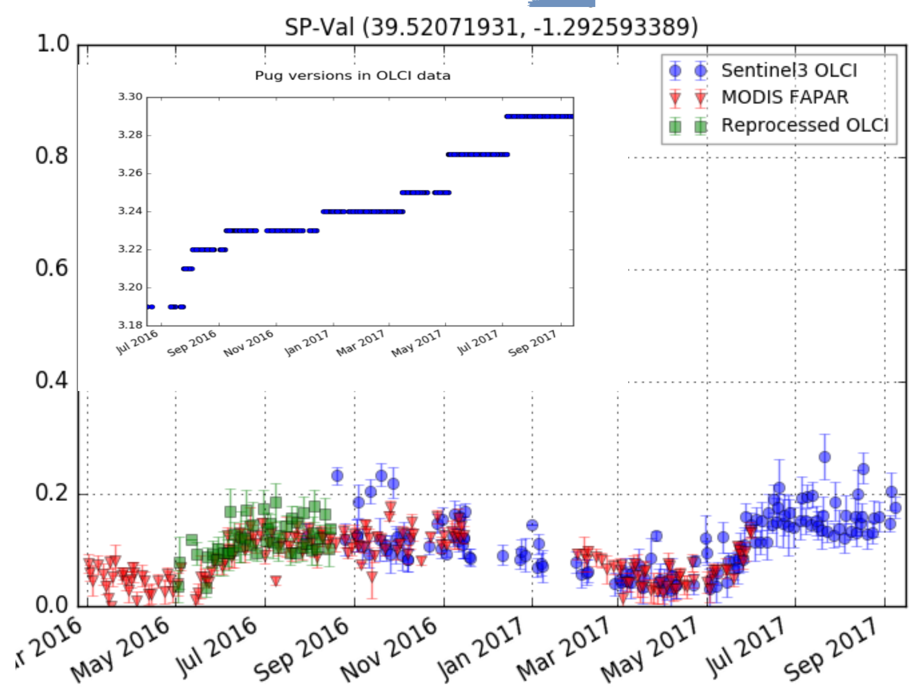

# Error propagation



# FAPAR: 01 MAY 2017



# Sentinel-3 OLCI FAPAR Uncertainties

The total uncertainties $\sigma^2_{Tot_{FAPAR}}$ take into account 1) the propagation uncertainties error from the retrieval algorithm $\sigma^2_{FAPAR}$ and 2) from assumptions coming from RT models and optimization $\sigma^2_{FOpt}$.

(14) $$\sigma^2_{Tot_{FAPAR}} = \sigma^2_{FAPAR} + \sigma^2_{FOpt}$$

The associated uncertainties $\sigma^2_{FAPAR}$ and $\sigma^2_{R\rho(\lambda)}$ are expressed as **standard deviation errors** using the following derivative equations:

(16) $$\boxed{\sigma^2_{FAPAR} = \left(\frac{\partial g_0}{\partial x}\right)^2 \sigma^2_x + \left(\frac{\partial g_0}{\partial y}\right)^2 \sigma^2_y + 2\frac{\partial g_0}{\partial x}\frac{\partial g_0}{\partial y}\sigma_{xy}}$$

where $\sigma^2_x$ and $\sigma^2_y$, *i.e.* $\sigma^2_{R\rho(\lambda)}$, are the standard deviation error of the rectified channels in red and near-infrared, $x$ and $y$, respectively.

We assume that $\sigma_{xy}$ is negligible, as the correlation between the uncertainties $\sigma_x$ and $\sigma_y$ should be independent.

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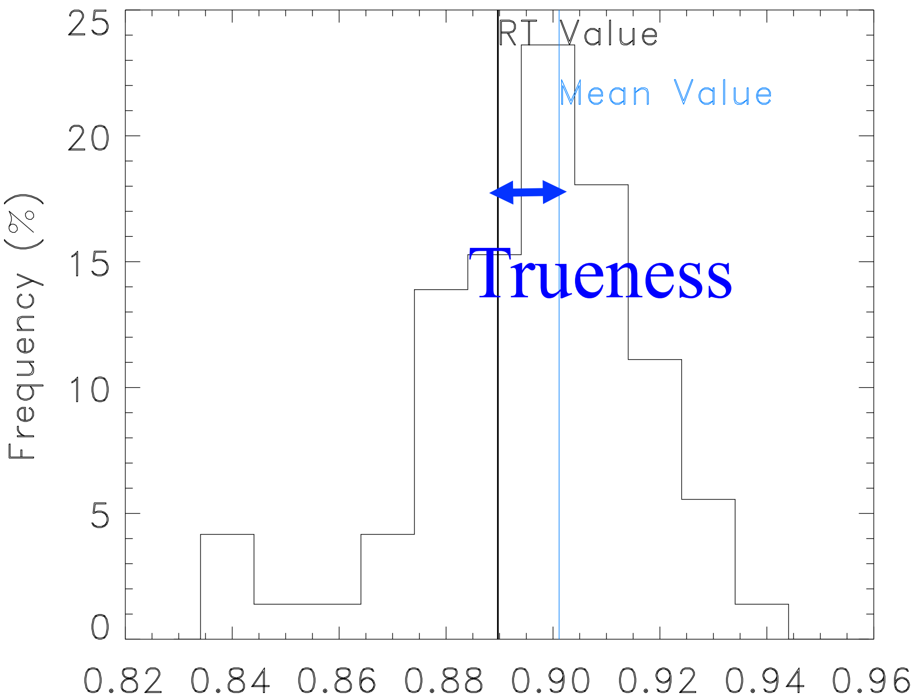
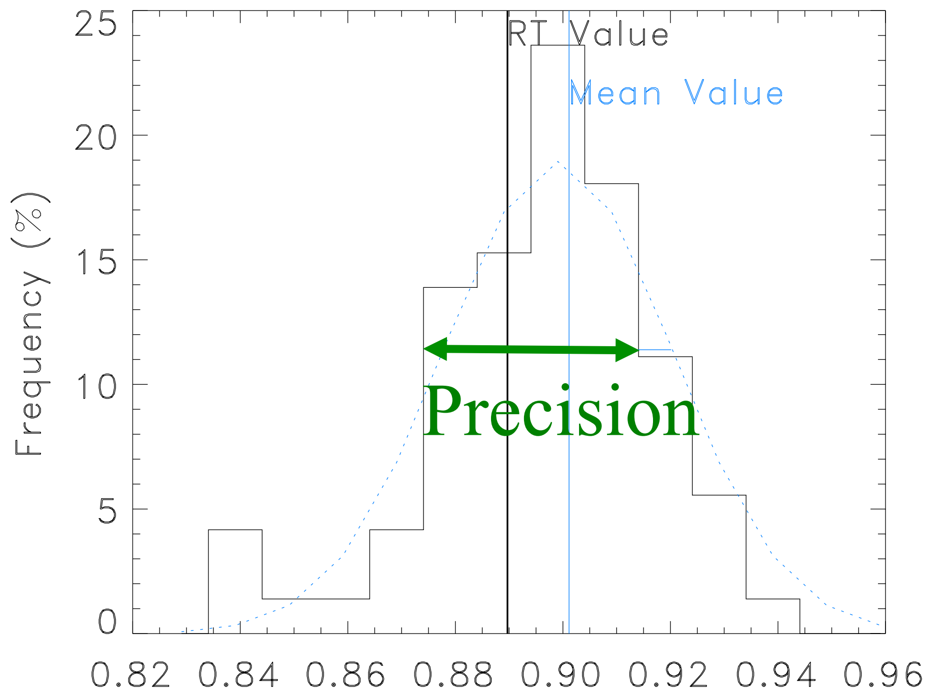
# FAPAR Uncertainties $\sigma_{Fopt}$

Using additional simulations, not used during the optimization, under different atmosphere properties and geometries of illumination and view values … some statistical results.



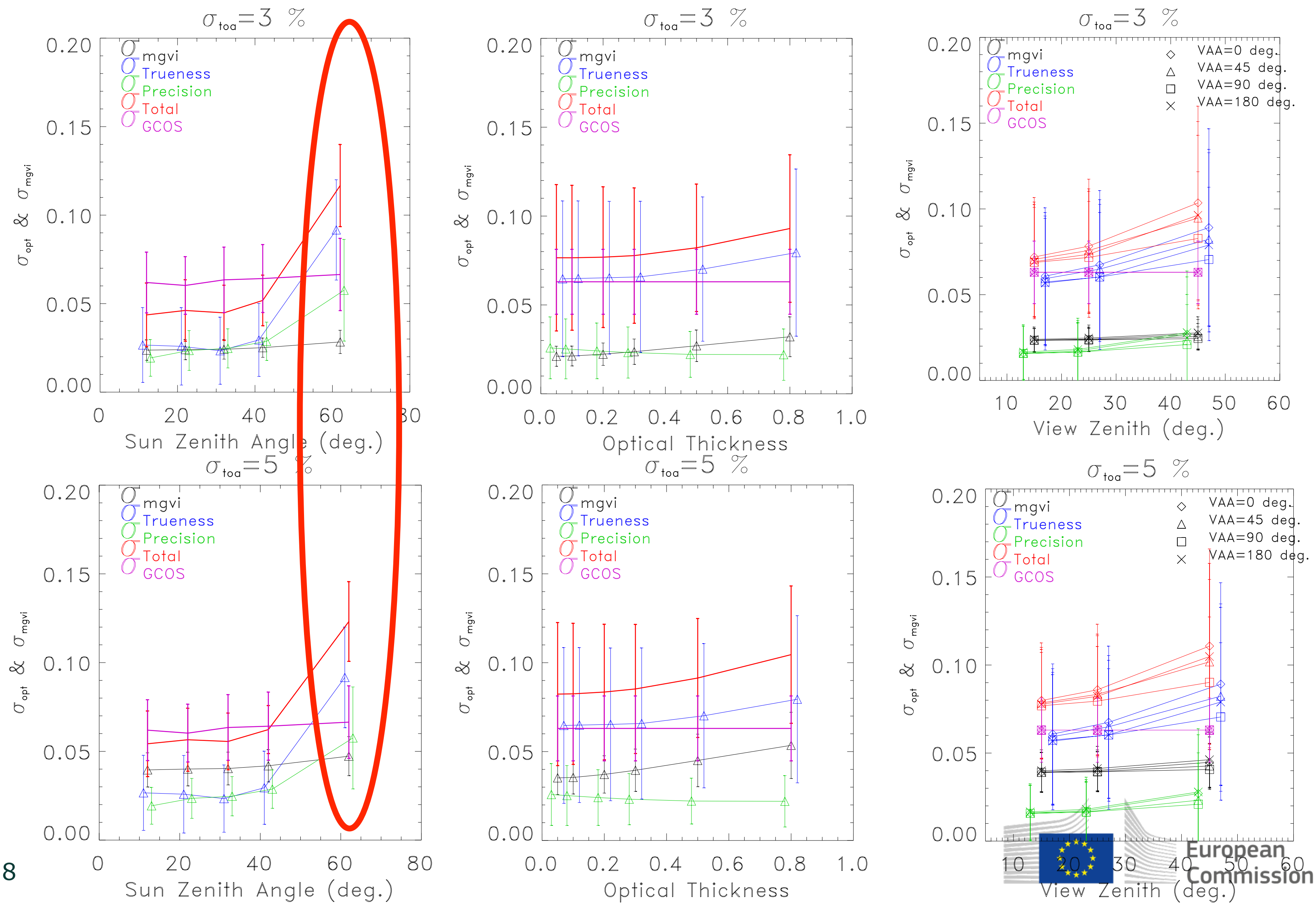

Estimation of optimization uncertainties $\boldsymbol{\sigma_{Fopt}}$**:**

$\sigma^2_{Fopt}=\sigma^2_{Trueness}+\sigma^2_{Precision}$

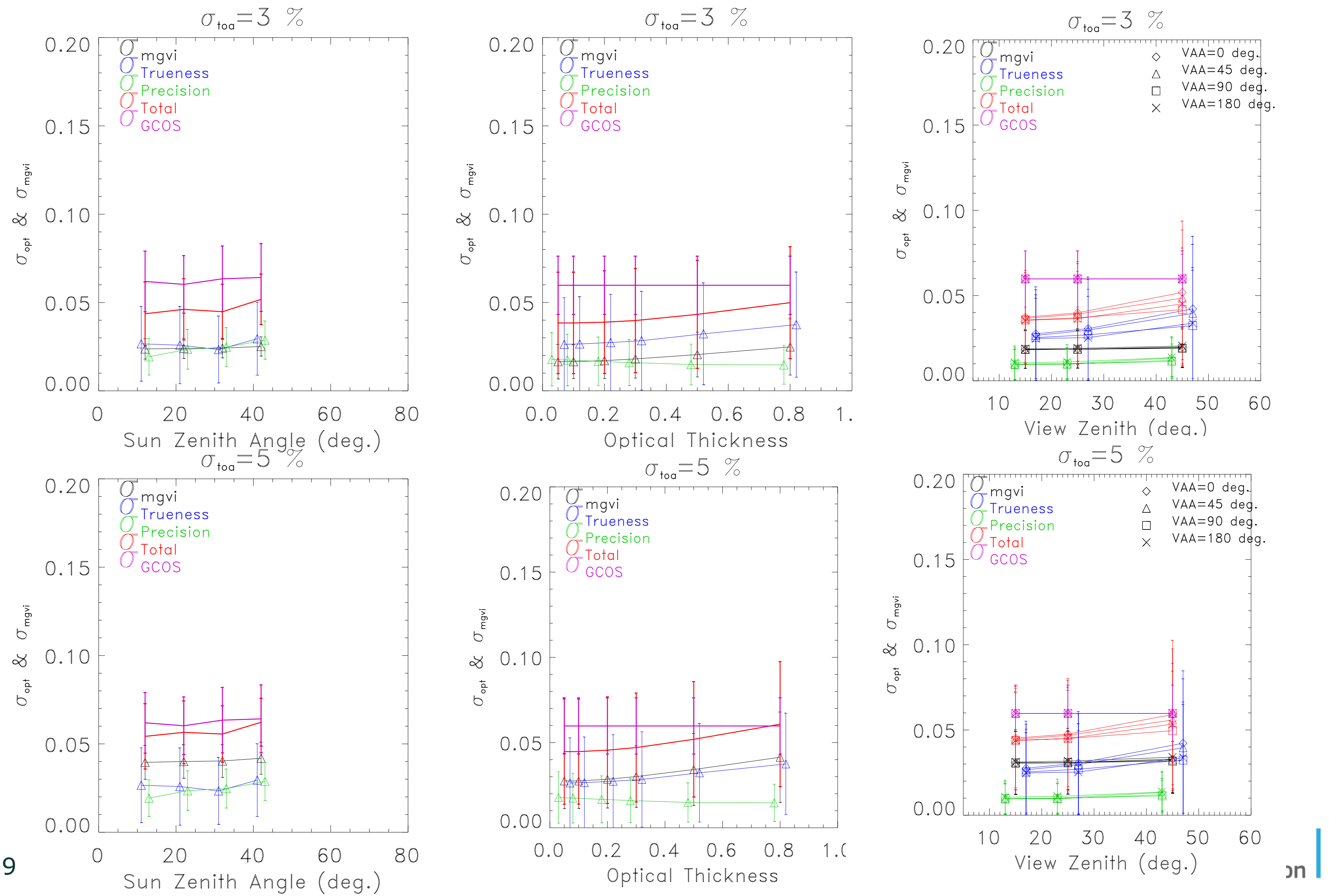
**$\sigma_{Trueness}$=Truth-<FAPAR>**

$\sigma_{Precision}$=SDEV(FAPAR(i)-<FAPAR>)

# Using 1D model RT simulations (1)



# Using 1D model RT simulations (2)



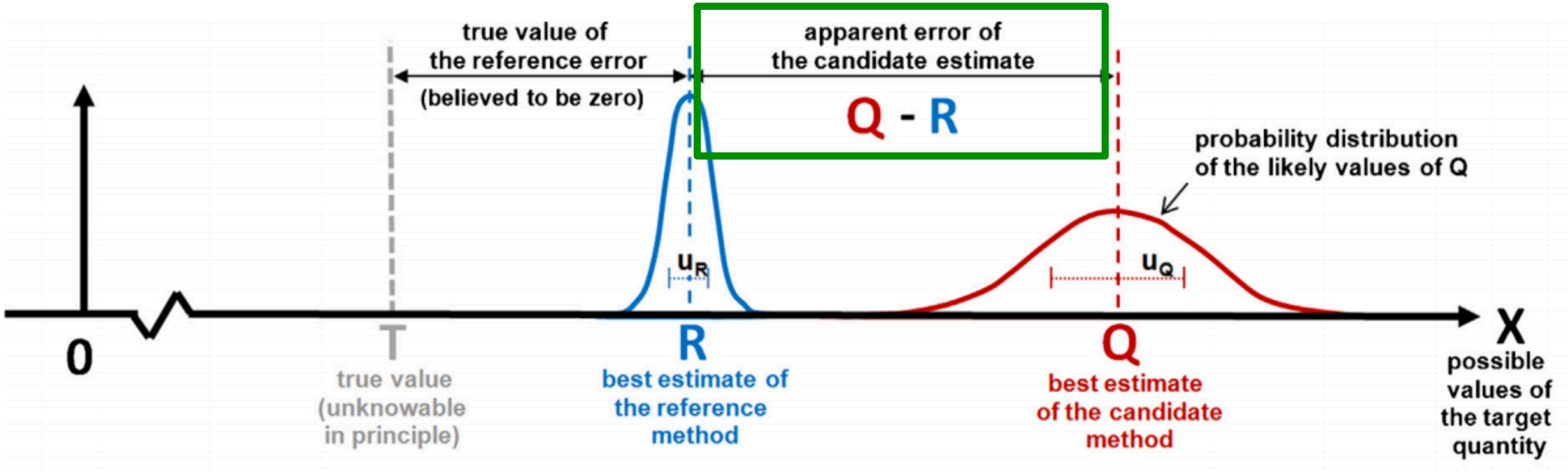
# Ground-based measurements for Land ECVs




http://www.kippzonen.com/, https://www.licor.com, http://www.decagon.com/, http://faculty.geog.utoronto.ca/

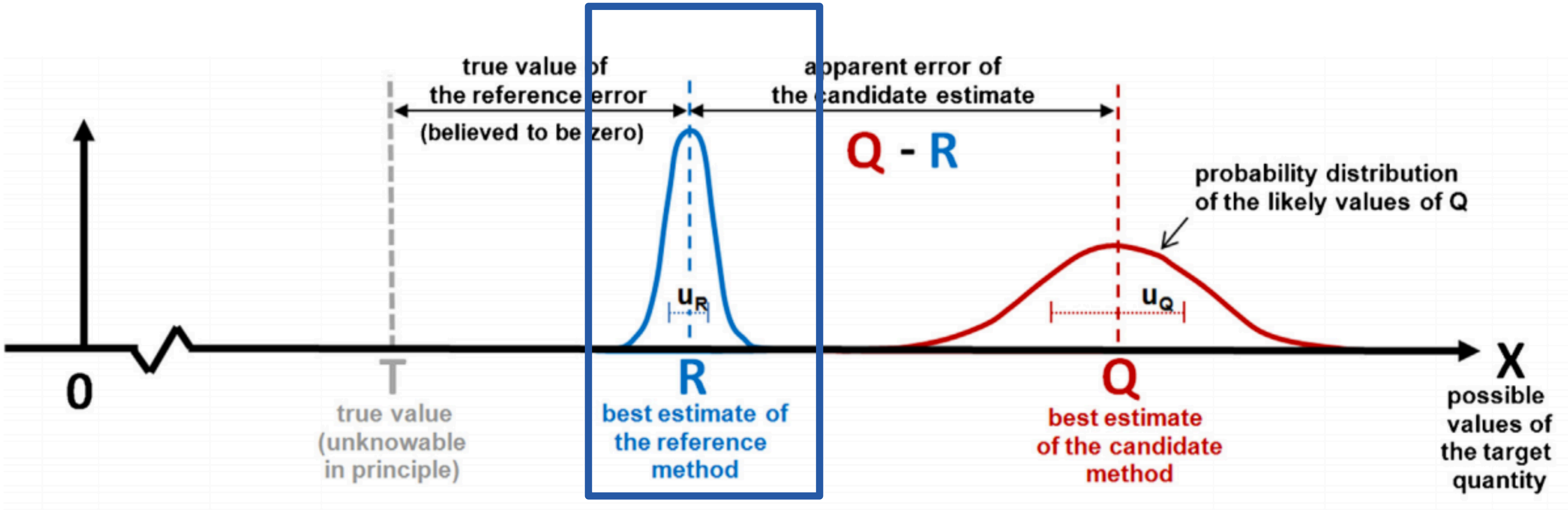
# Uncertainties EO products

***The apparent error between satellite-based and in-situ measurements are also a result of the uncertainty of both: but how can we quantify the contributions separately?***



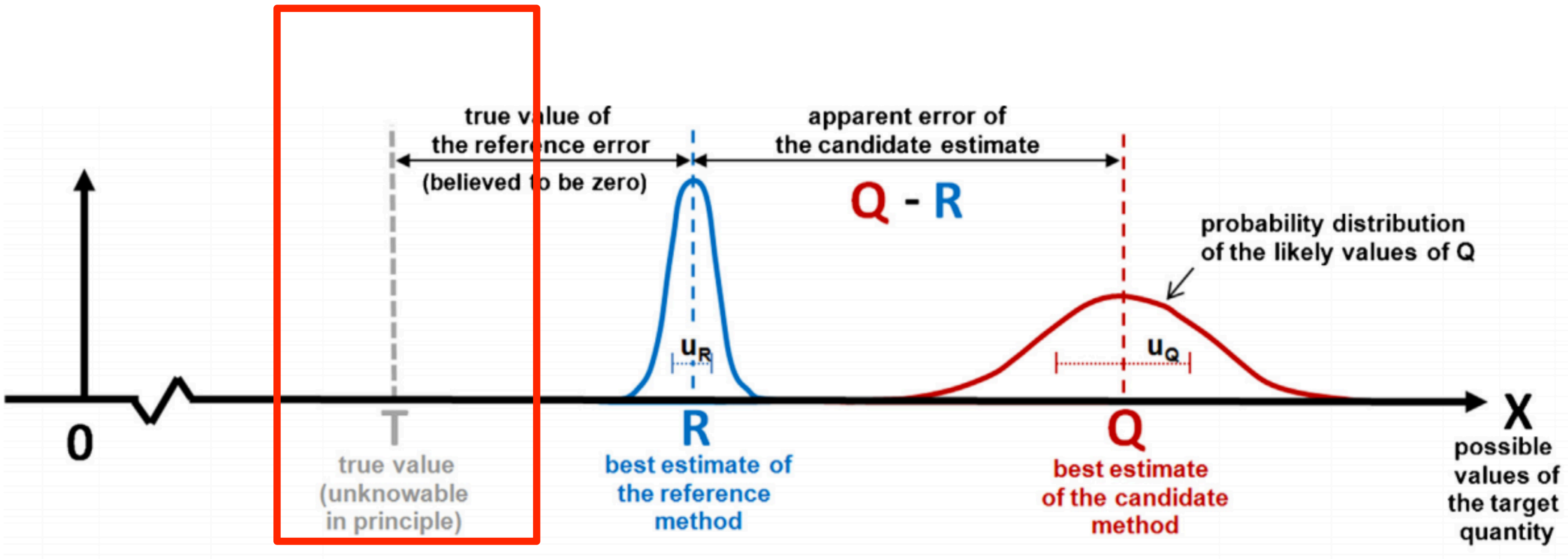
# Uncertainties EO products

***Field measurement uncertainty***



# Uncertainties EO products

***In-situ measurements may not measure to the true value of the target quantity per se, but rather, infer it's value***



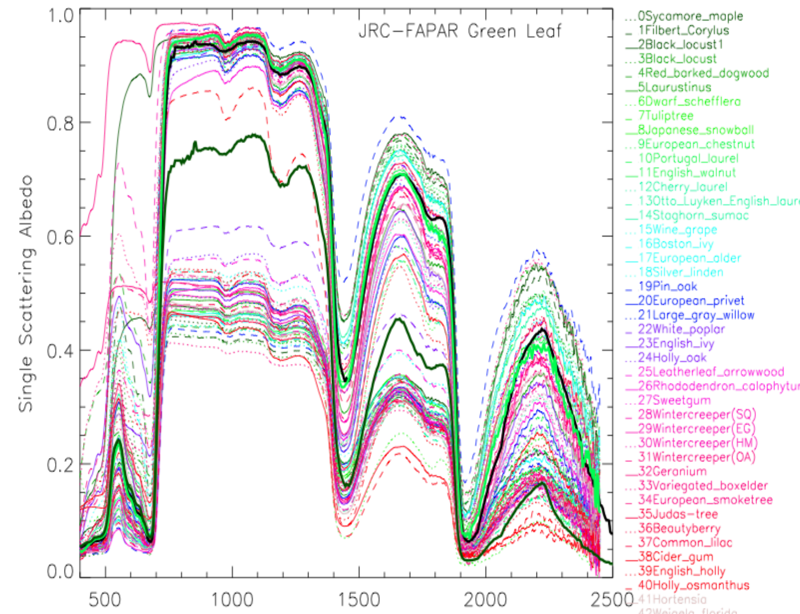
# FAPAR: definition

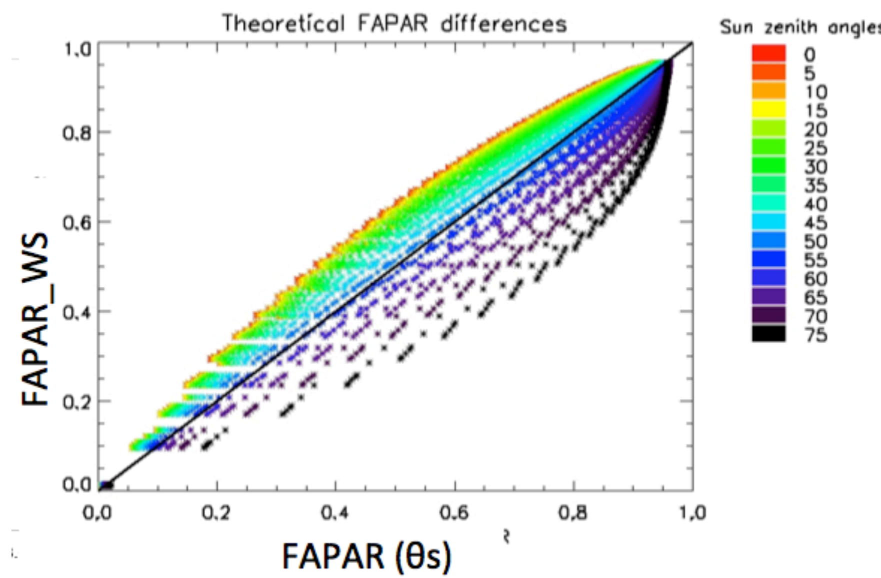
JRC retrieval method assumes that the leaves are alive and photosynthesizing, hence the name "**<u>green</u>**" FAPAR.

It also means that the single scattering albedo of leaves is "fixed" to only one value representing such 'green' leaves.

**JRC-FAPAR also refers to the <u>instantaneous and green value definition</u>.**

The theoretical FAPAR values are computed with RT model using the closure of the energy balance inside the plant canopy in the spectral range 400 to 700 nm.



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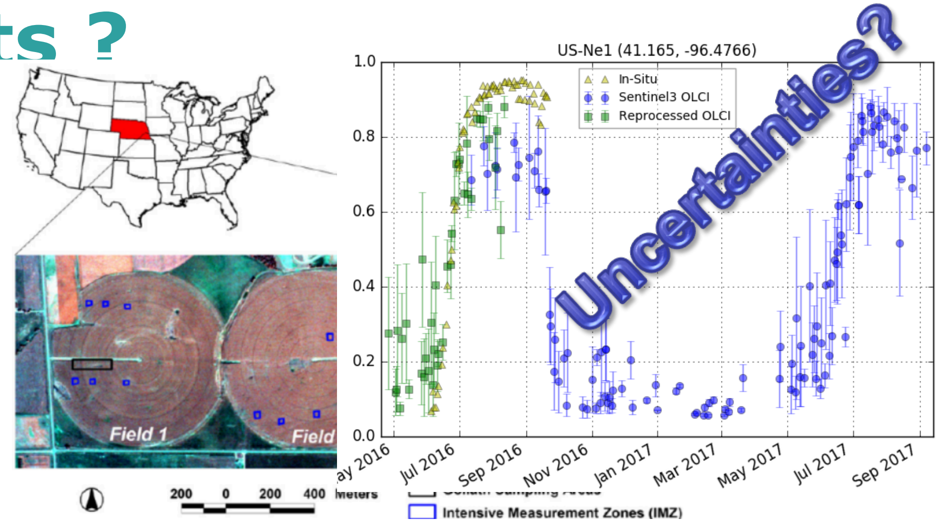
# Including the use of FIPAR ground-based measurements ?



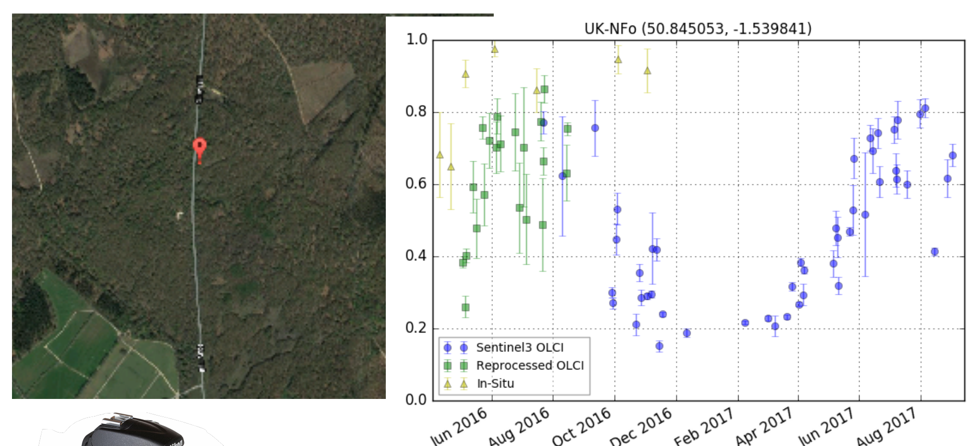

## Ground-based over US-NE1

Li-Cor quantum sensors (LI-COR Inc., Lincoln, Nebraska) were placed to collect hourly measurements of incoming PAR (PARin), PAR reflected by the canopy and soil (PARout), PAR transmitted through the canopy (PARtransm) and PAR reflected by the soil (PARsoil).

PI: Andrew Suyker (U. NEBRASKA LINCOLN)

## Ground-based over UK-Fo

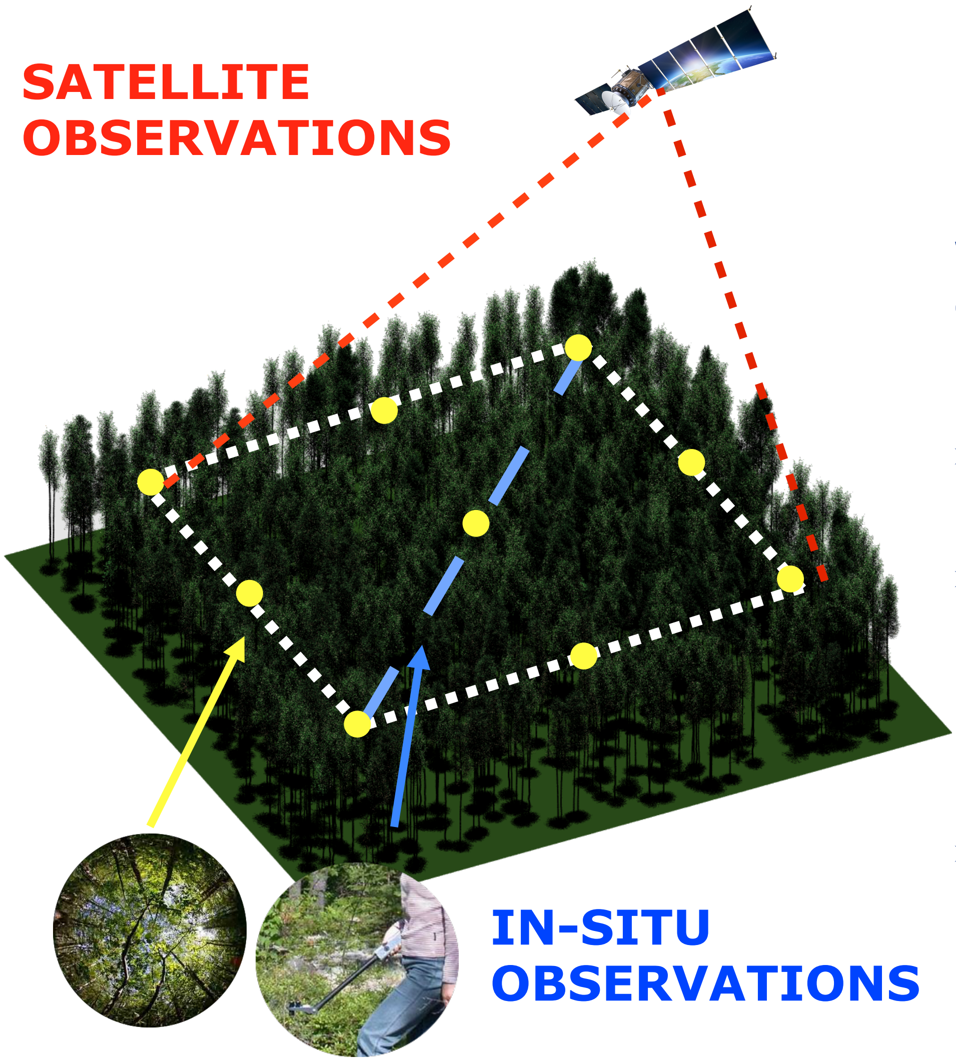
- DHP measurements in New Forest, UK at 8 dates during 2016
- 5 measurements in 9 ESUs covering 1km x 1km
- Images analysed by Can-Eye to extract FAPAR; instantaneous black-sky FAPAR (FAPAR_BS), daily integrated black-sky FAPAR and white-sky FAPAR (FAPAR_WS)




PI: Jadu Dash & Luke Brown (UoS)

# 3D Monte Carlo Radiative Transfer Modeling

- *Physically-based*
- *3D complexity*
- *Can place sensors above (satellites) or within (in-situ) the canopy*
- *Validated against in-situ measurements and other 3D MCRT models (RAMI, ROMC)*

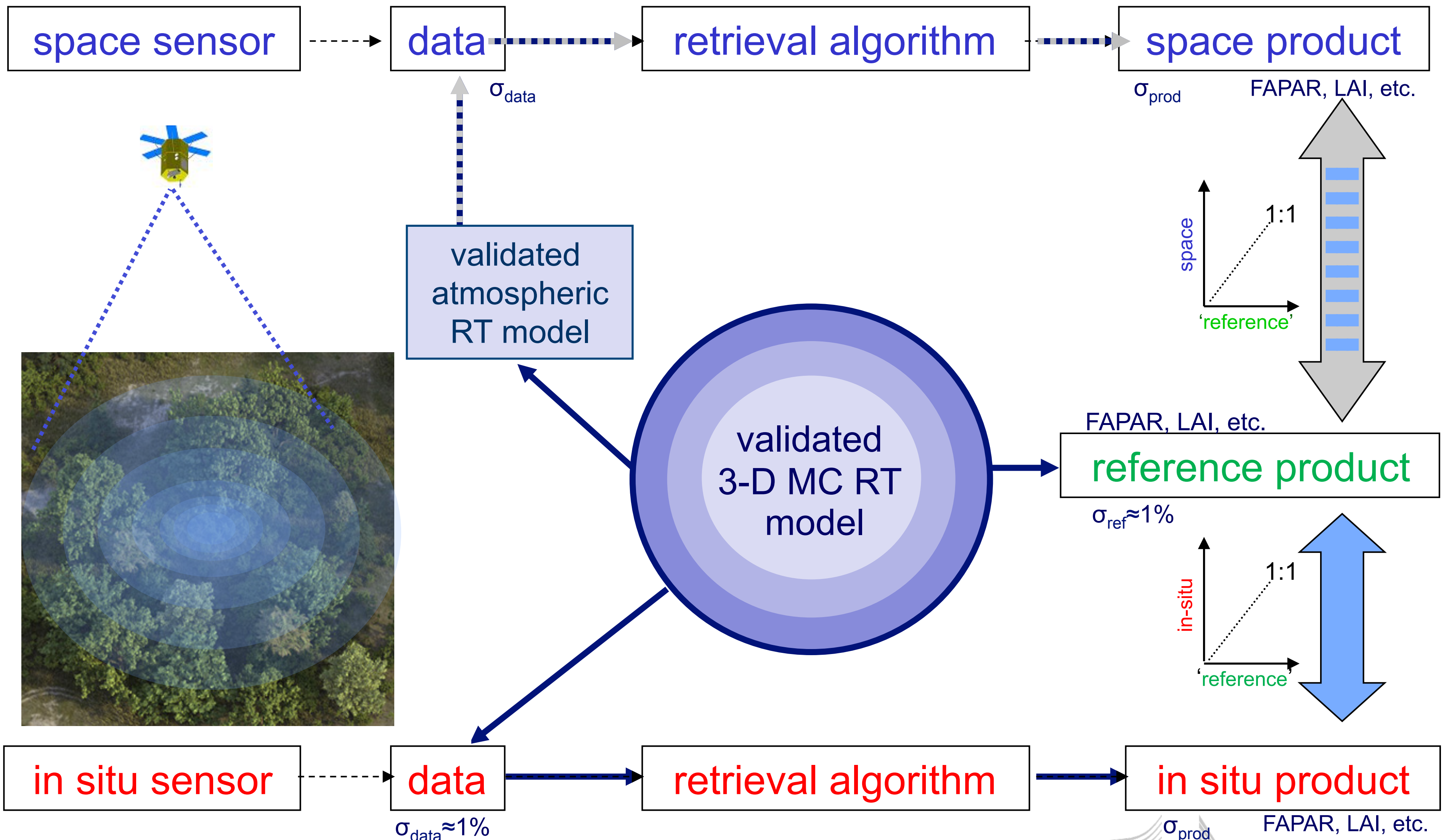



**IN 3D MODELLING WE KNOW OR CAN COMPUTE:**

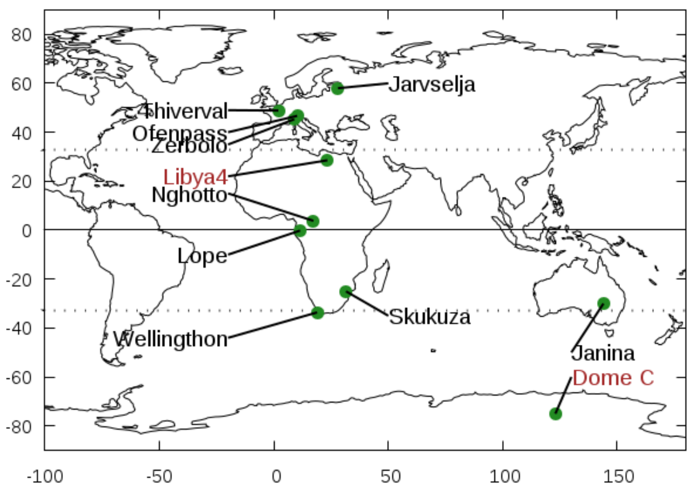
- The true values of LAI, FAPAR, Albedo
- The number, size, shape, orientation and reflectance properties of every scatterer
- Canopy architecture

RAMI: http://rami-benchmark.jrc.ec.europa.eu/

# 3D-RT Based for QA



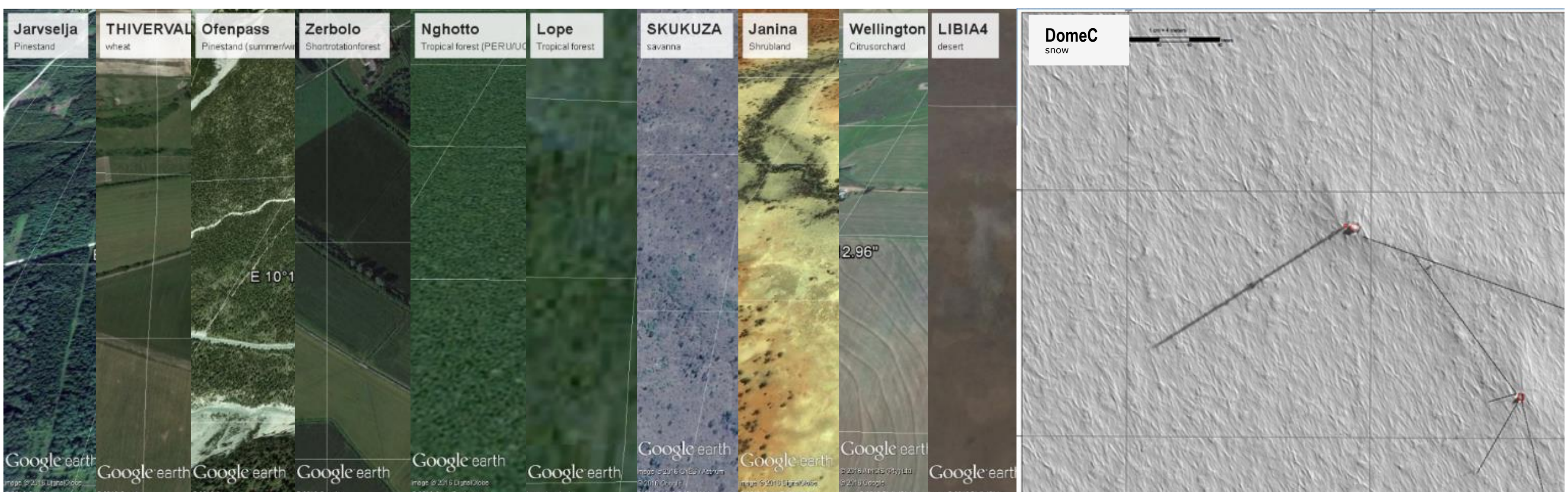
# QA4ECVs sites




| num | name | lat | long | alt | Scene | Land Cover Type |
|---|---|---|---|---|---|---|
| 1 | Jarvselja 1 | 58.313 | 27.297 | 43 | Birschstand Winter & Summer | Decideous Broadleaf |
| 2 | Jarvselja 2 | 58.277 | 27.342 | 43 | Pinestand Winter & Summer | Evergeen Needleleaf |
| 3 | Thiverval | 48.85 | 1.966 | 93 | Wheat | Crop |
| 4 | Ofenpass | 46.663 | 10.23 | 1890 | Pinestand Winter & Summer | Evergeen Needleleaf |
| 5 | Zerbolo | 45.295 | 8.877 | 101 | Short Rotation Forest | BroalLeaf |
| 6 | Libia4 | 28.55 | 23.39 | 117 | Dune | Bare Soil |
| 7 | Nghotto | 3.867 | 17.3 | 570 | Tropical (Gabon) | Tropical |
| 8 | Lope | -0.169 | 11.459 | 317 | Tropical (Peru) | Tropical |
| 9 | Skukuza | -25.0197 | 31.4969 | 393 | Savanna | Savanna |
| 10 | Janina | -30.077 | 144.136 | 347 | Shrubland | Shrubland |
| 11 | Wellington | -33.6 | 18.933 | 101 | Citrus orchard | Crop |
| 12 | DomeC | -75.1 | 123.3 | 3233 | Snow | Snow |

## Vegetation sites

## Vicarious Calibration






SEVENTH FRAMEWORK PROGRAMME

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# Simulation of DHP

- Simulate DHP as transmission probability from the DHP sensor (*x,y,z*) in a given direction (θ,Φ)
- Directional transmission probability normalised by π and defines values of 0 (no transmission, i.e. no gap) and 1/π (total transmission, i.e. gap)
- Directional transmission binned into solid patches is equivalent to the gap fraction probability
- Black and white image assumes a perfect image classification so uncertainties resulting solely from algorithms and field protocol investigated
- View directions: 2,500,000



Adams et al., 2017, in prep.

# DHP FAPAR algorithms & definitions

**FAPAR white-sky** (diffuse illumination); independent of SZA

$$FAPAR^{WS} = 2\int_0^{\pi/2} (1 - P_0(\theta))cos\theta sin\theta \mathrm{d}\theta$$

**FAPAR instantaneous black-sky** (direct illumination); dependent on SZA

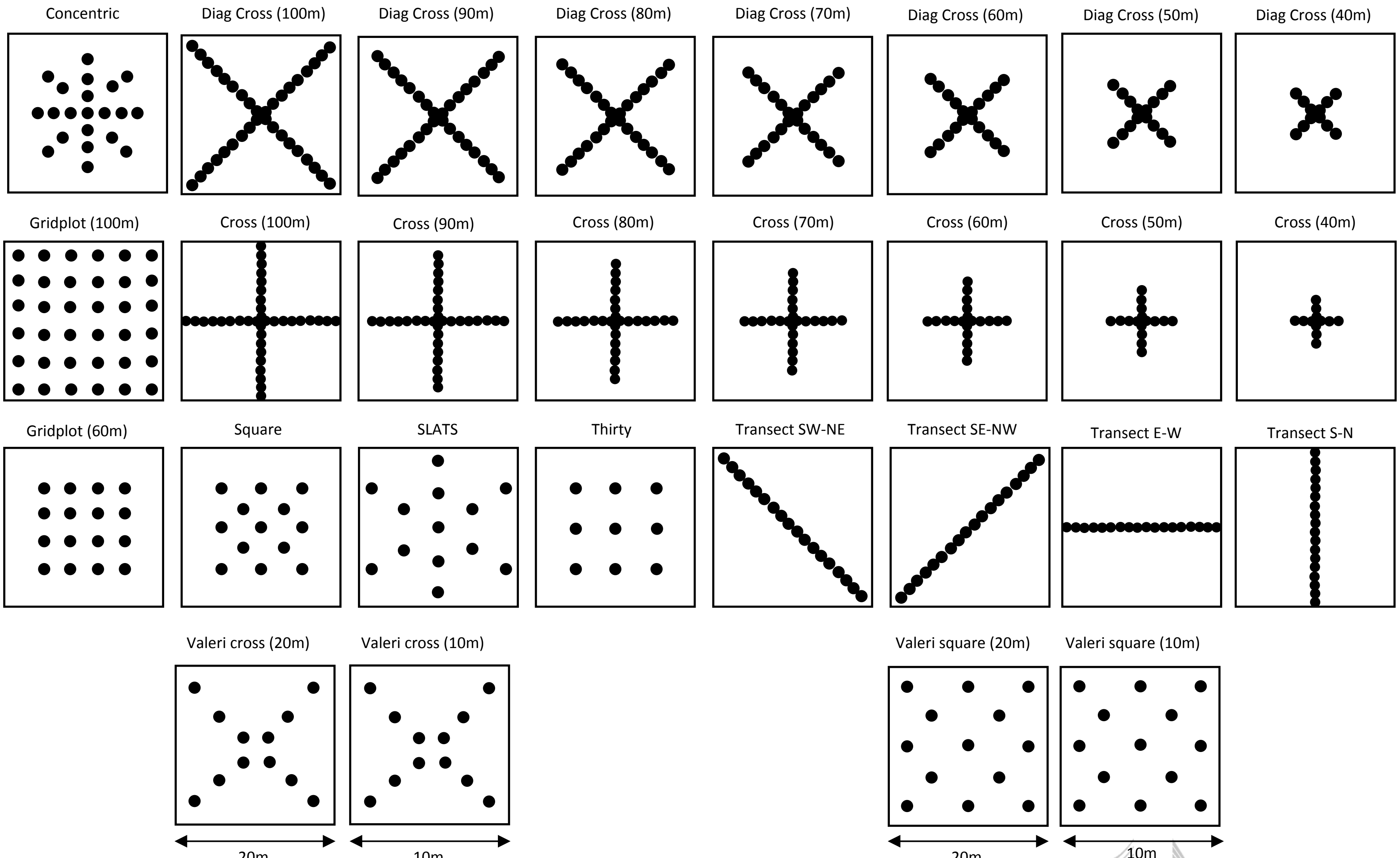
$$FAPAR^{BS}(\theta_s) = 1 - P_0(\theta_s)$$

**FAPAR daily black-sky** (direct illumination); integrated over SZA range

$$FAPAR^{BS}_{Day} = \frac{\int_{sunset}^{sunrise} cos(\theta)(1 - P_0(\theta))\mathrm{d}\theta}{\int_{sunset}^{sunrise} cos(\theta)\mathrm{d}\theta}$$

Adams et al., 2017, in prep.

# Sampling designs




Adams et al., 2017, in prep.

# Experimental Set-up

| Variable | Range of values | Increment of values |
|---|---|---|
| **Sampling design** | 28 | - |
| **ESU plot size** | 10-100 [m] | - |
| **Number of samples** | 9-36 | - |
| **Camera height** | 0.05 - 2.5 [m] | 0.25 m |
| **Minimum separation distance** | 0.0 - 2.0 [m] | 0.2 m |
| **Solar zenith angle (FAPAR black-sky)** | 0 - 90 [degrees] | 1 deg |

Adams et al., 2017, in prep.



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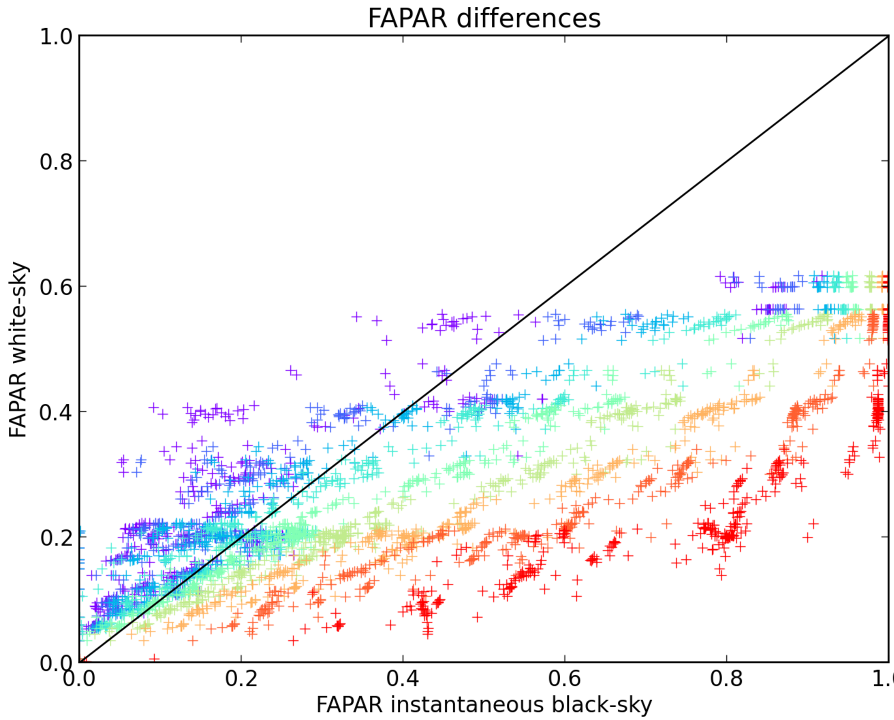
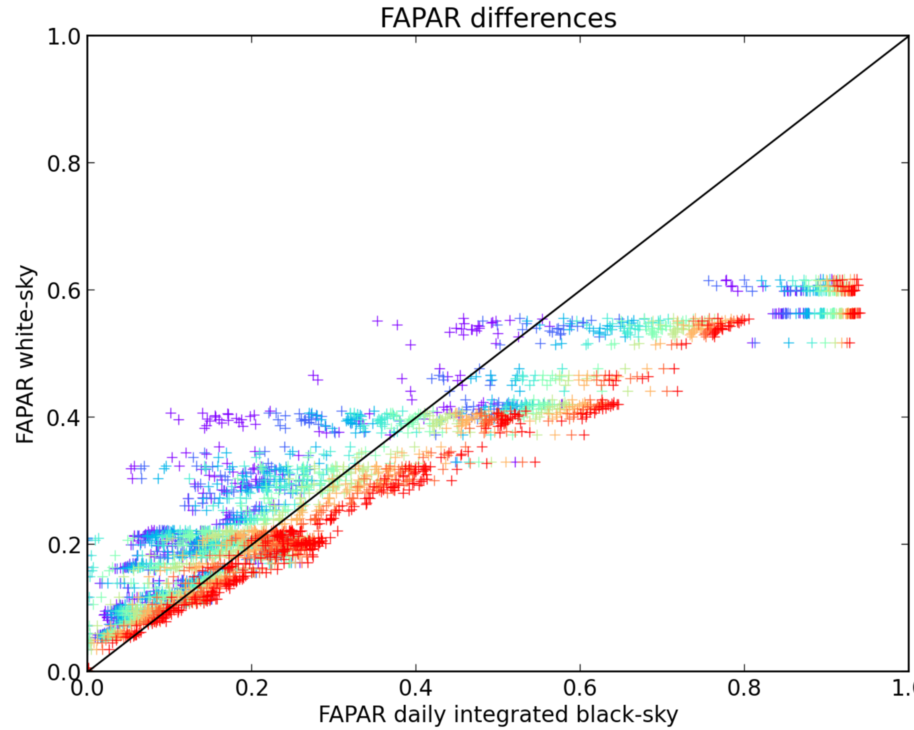
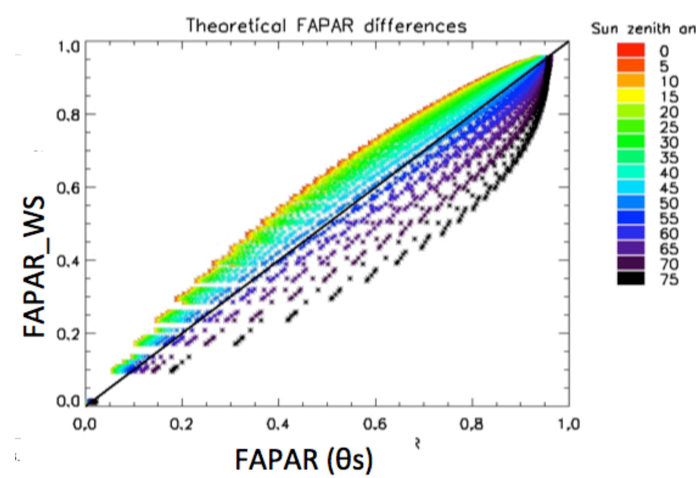
# Results: fapar definition




- Underestimation of white-sky compared to instantaneous black-sky
- Daily integrated black-sky FAPAR lies closer on the 1:1 line in comparison to instantaneous
- DHP recommendations of white-sky FAPAR (under isotropic light)
- Larger differences at extreme SZAs (0,80)



# Definition of “truth” and uncertainty analysis


**Truth = foliage**

**Truth = total (wood + foliage)**

## Transmittance in the PAR from defined elements in the 3D scene

**Absolute uncertainty**

$$\Delta = F_{true} - F$$

**Absolute value of absolute uncertainty**

$$|\Delta| = |F_{true} - F|$$

**Relative uncertainty**

$$\delta = \frac{F_{true} - F}{F_{true}}$$

**Absolute value of relative uncertainty**

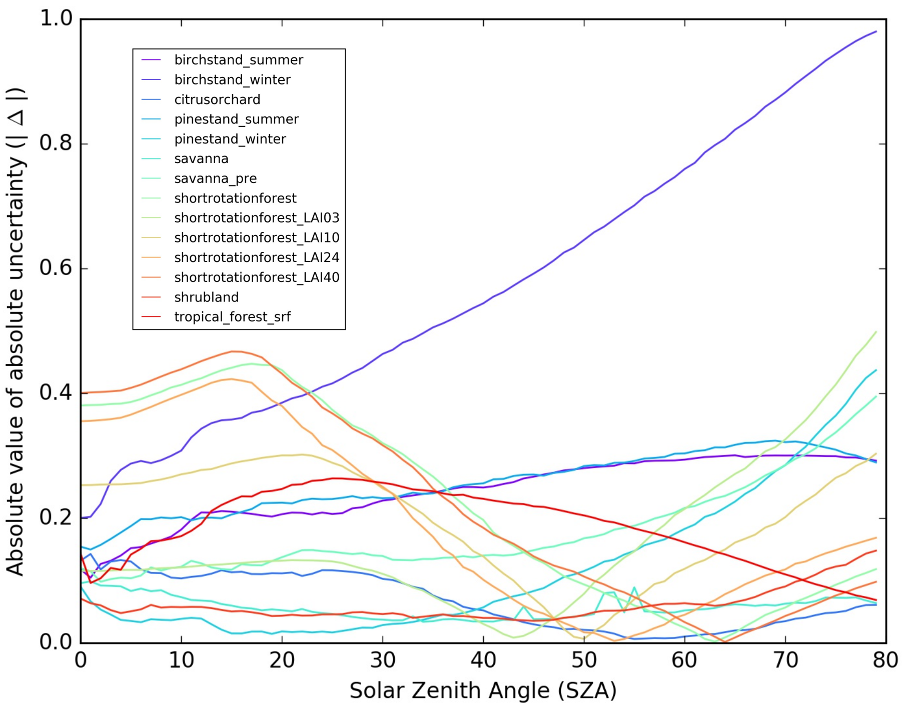
$$|\delta| = \frac{|F_{true} - F|}{F_{true}}$$

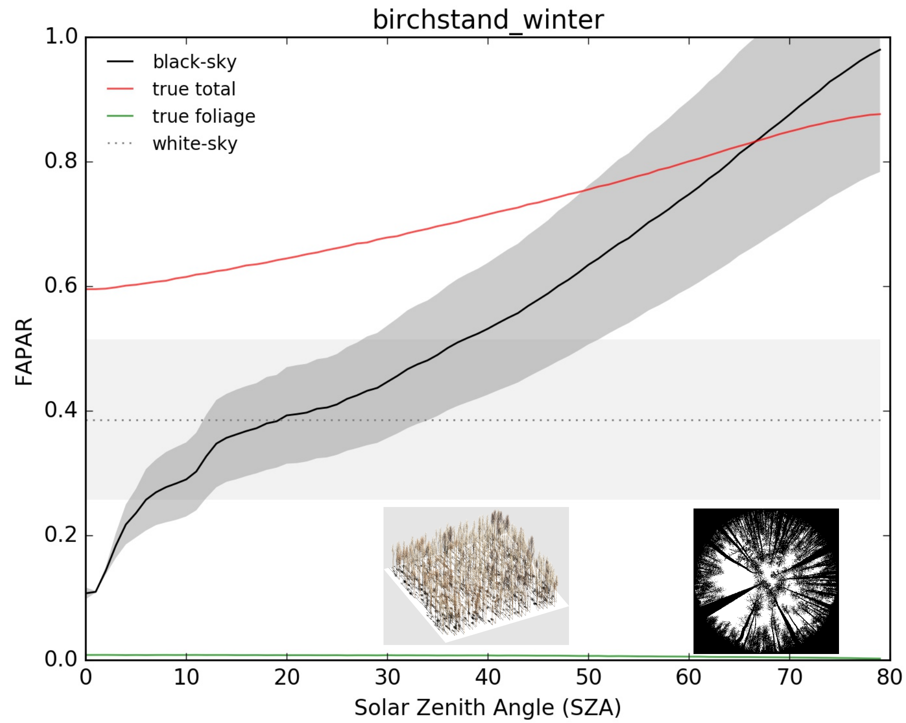


Adams et al., 2017, in prep.

# Results: definition of truth

True=foliage




- Uncertainties for foliage display larger uncertainties for most canopies, but for some, uncertainties are smaller when the truth is **foliage FAPAR**
- Winter/leaf-off canopies indicate how important choice of true FAPAR definition is…

Adams et al., 2017, in prep.

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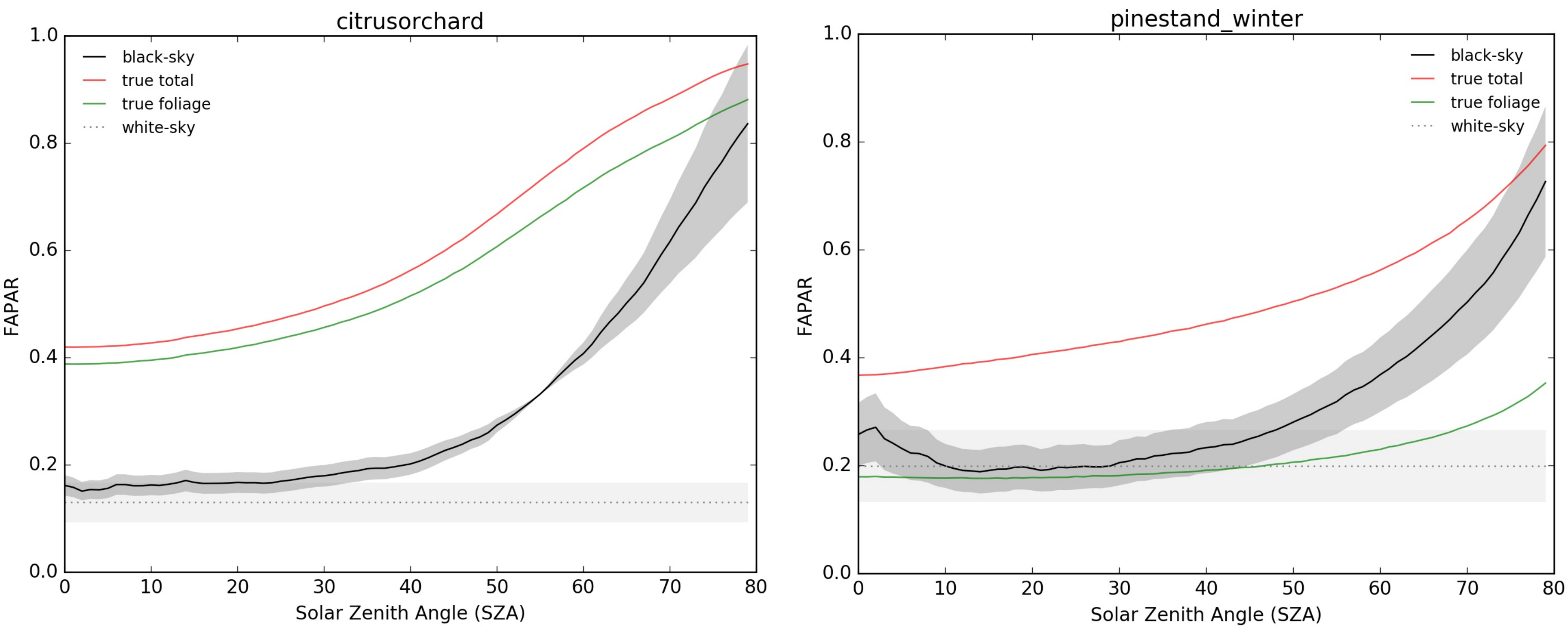
# Results: definition of truth



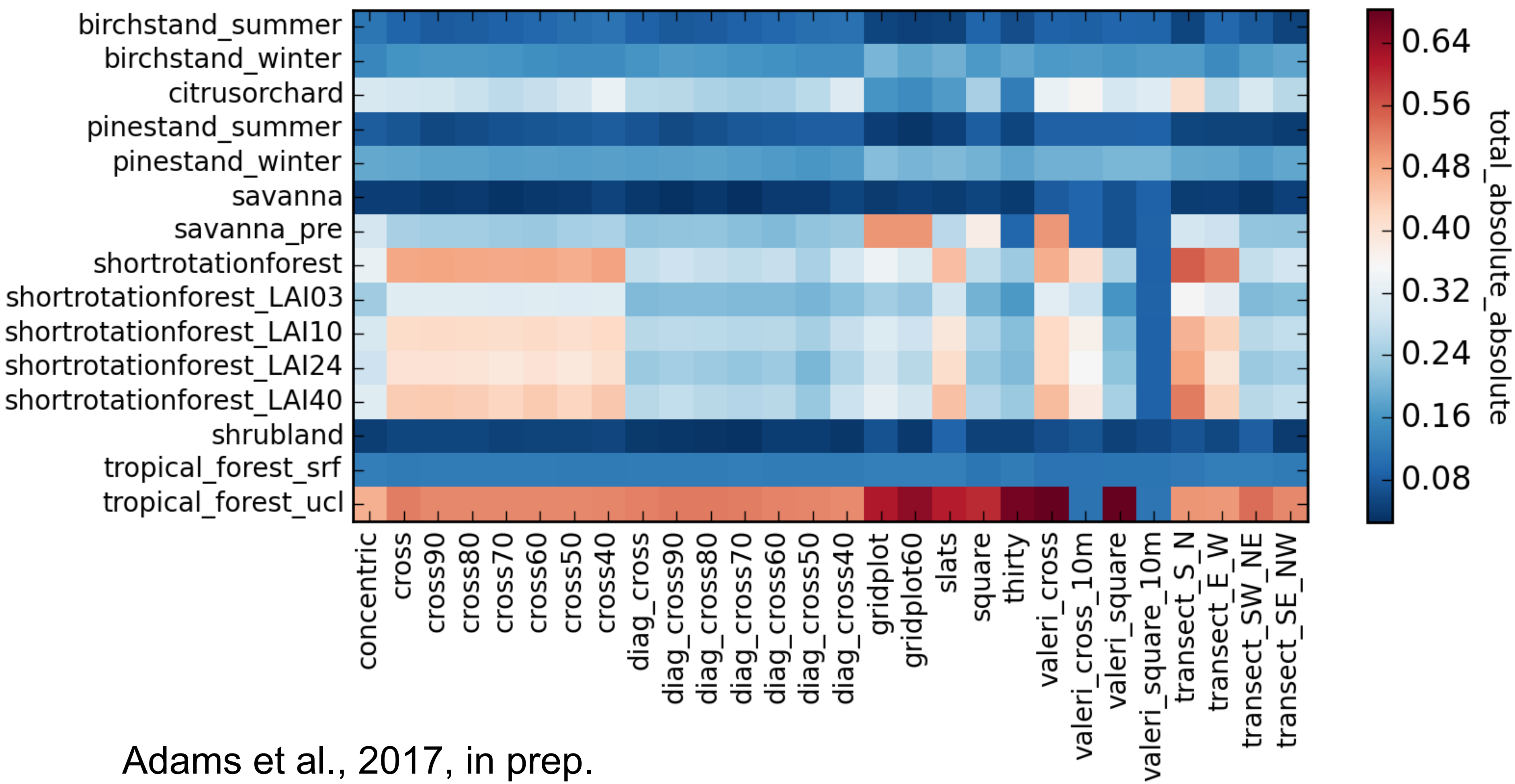

DHP measures **total FAPAR** (foliage + wood) rather than **foliage FAPAR**. Winter/leaf-off canopies indicate how different the two "truth" FAPAR definitions are, as well as row structured crops

Adams et al., 2017, in prep.

# Results: sampling

True=total

Abs value of absolute uncertainty for **FAPAR BS** across all SZAs, camera heights and minimum separation

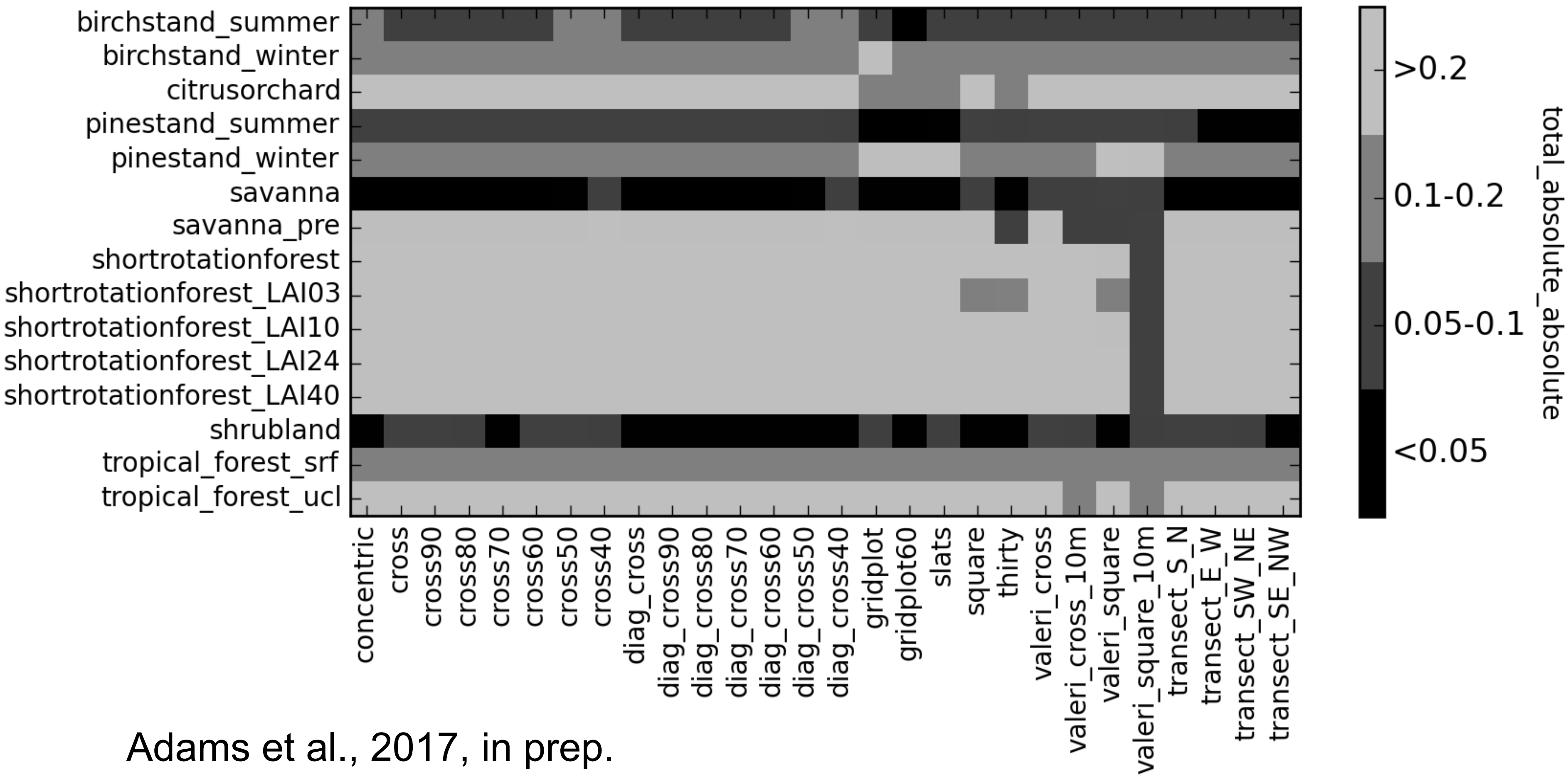



Adams et al., 2017, in prep.

# Results: sampling

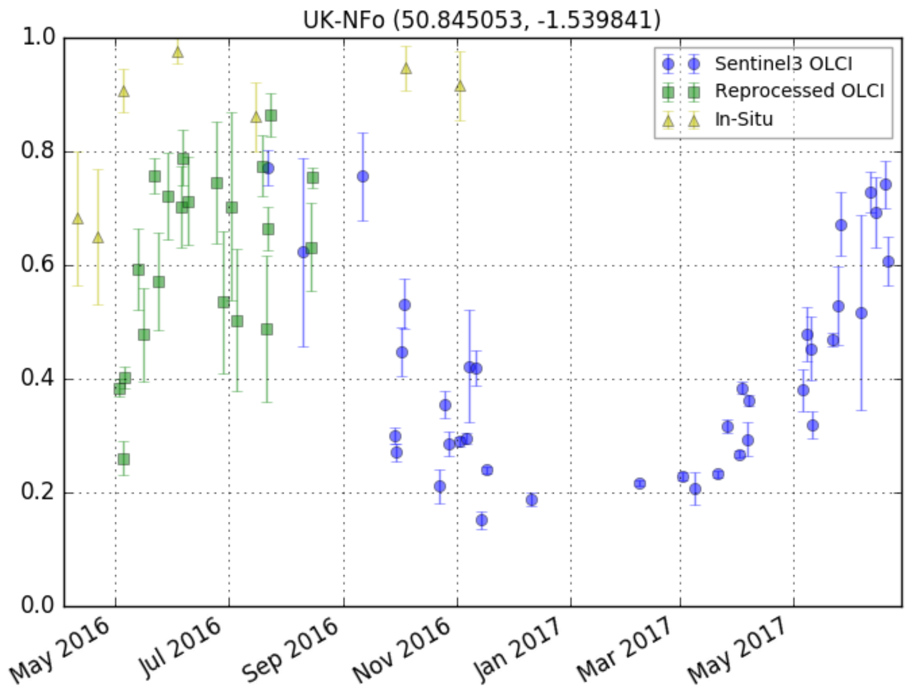
True=total

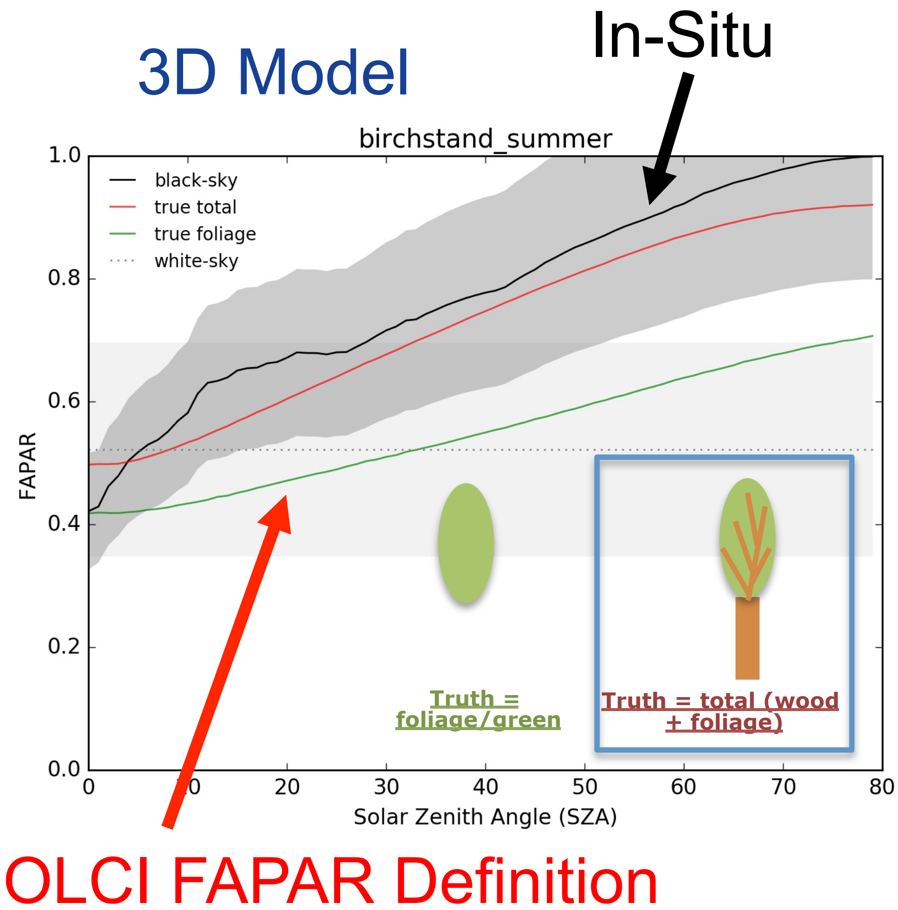
- Conformity to accuracy requirements; <0.05, 0.05-0.1, 0.1-0.2 and >0.2 (**FAPAR BS**)




Adams et al., 2017, in prep.

# Ground-based measurements: UK-Fo



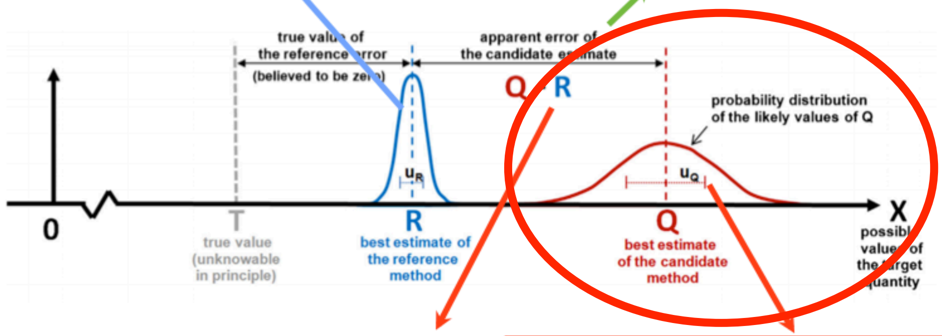




- In-situ measurements of FAPAR measure "**total**" FAPAR, whereas satellite-based FAPAR measures "**green**" FAPAR
- Comparison against S3 OLCI (black-sky ~10.50AM) indicates difference between the two definitions of FAPAR

Adams et al., 2017, in prep.

Field measurement uncertainty

The apparent error between satellite-based and in-situ measurements are also a result of the uncertainty of both: but how can we quantify the contributions separately?




Validate satellite-based products, space ECVs vs ground-based values

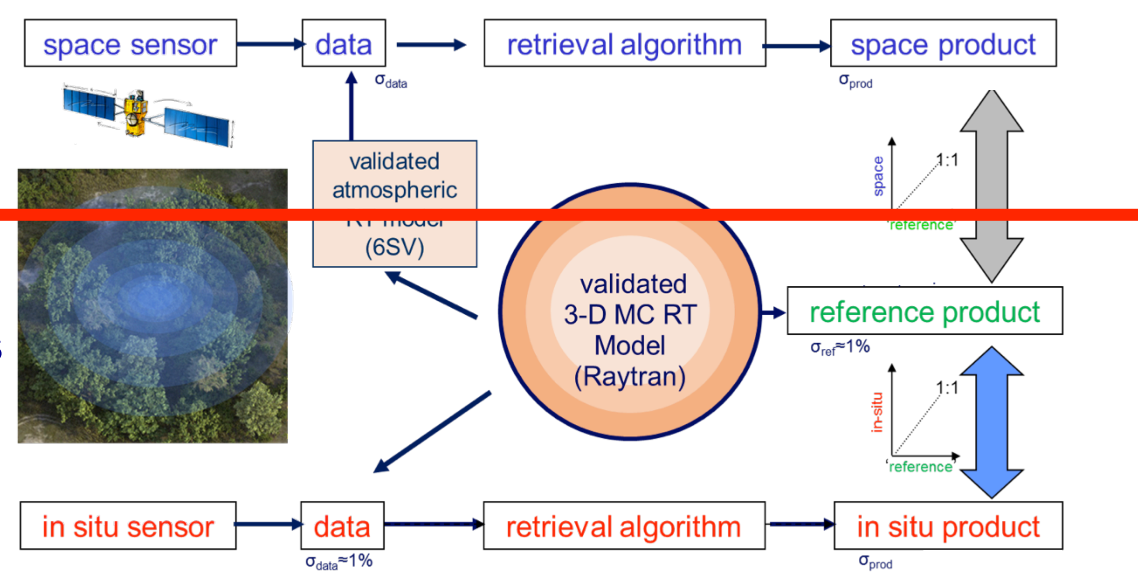
Test conformity with GCOS requirements

## Two Uncertainties Assessments:

1. Field measurements
2. **Retrieval Algorithm**

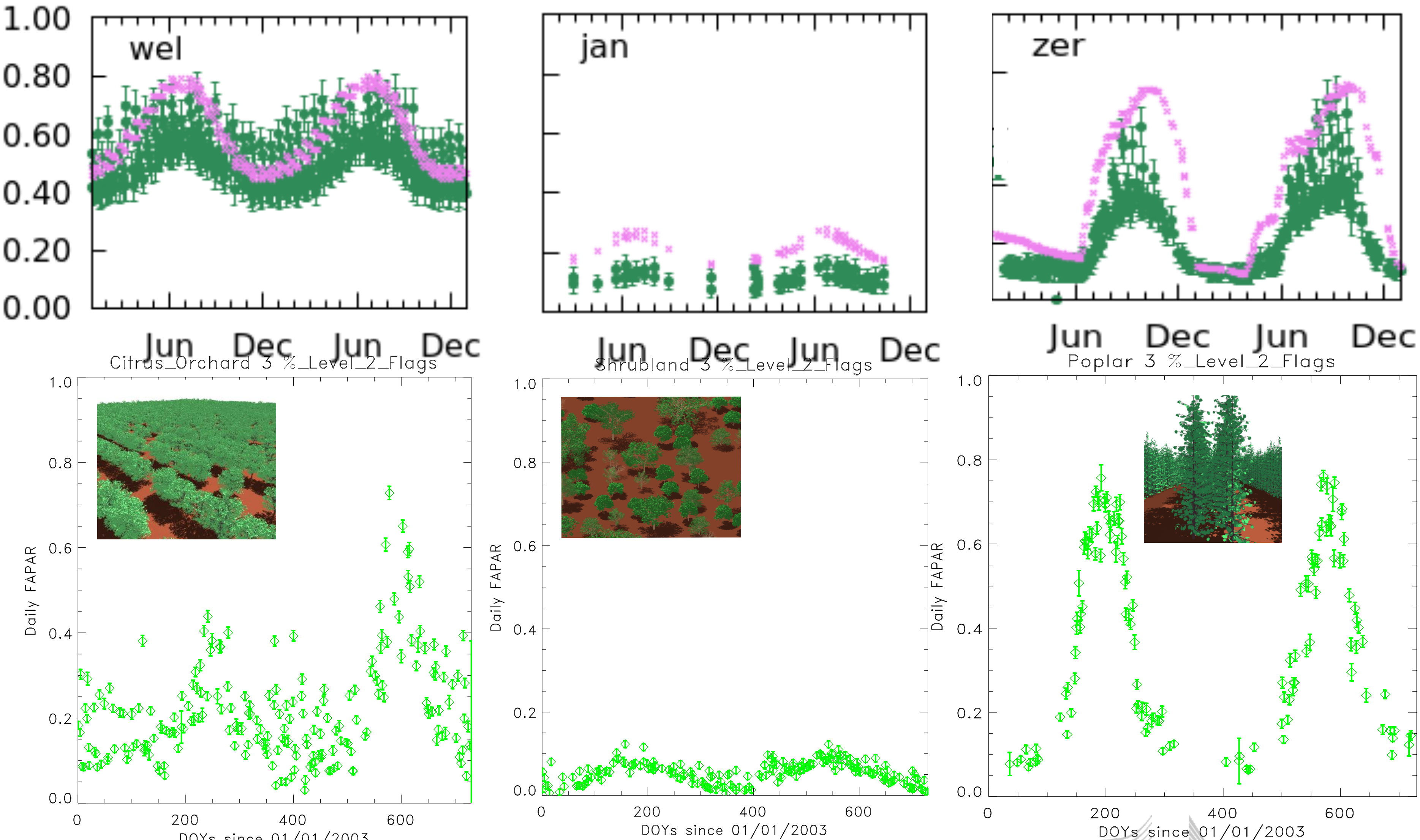
## Model-based approach

1. Space ECVs products
2. Ground-based measurements




Gobron et al., 2016

# Preliminary results




Lanconelli et al., 2017, in prep.

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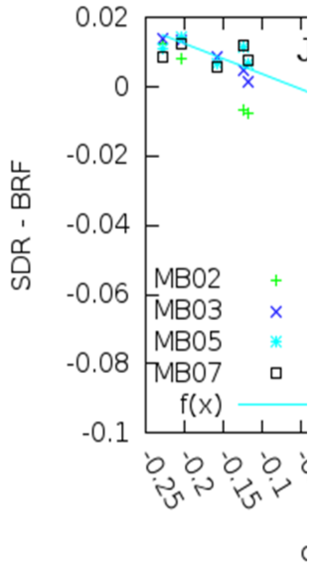
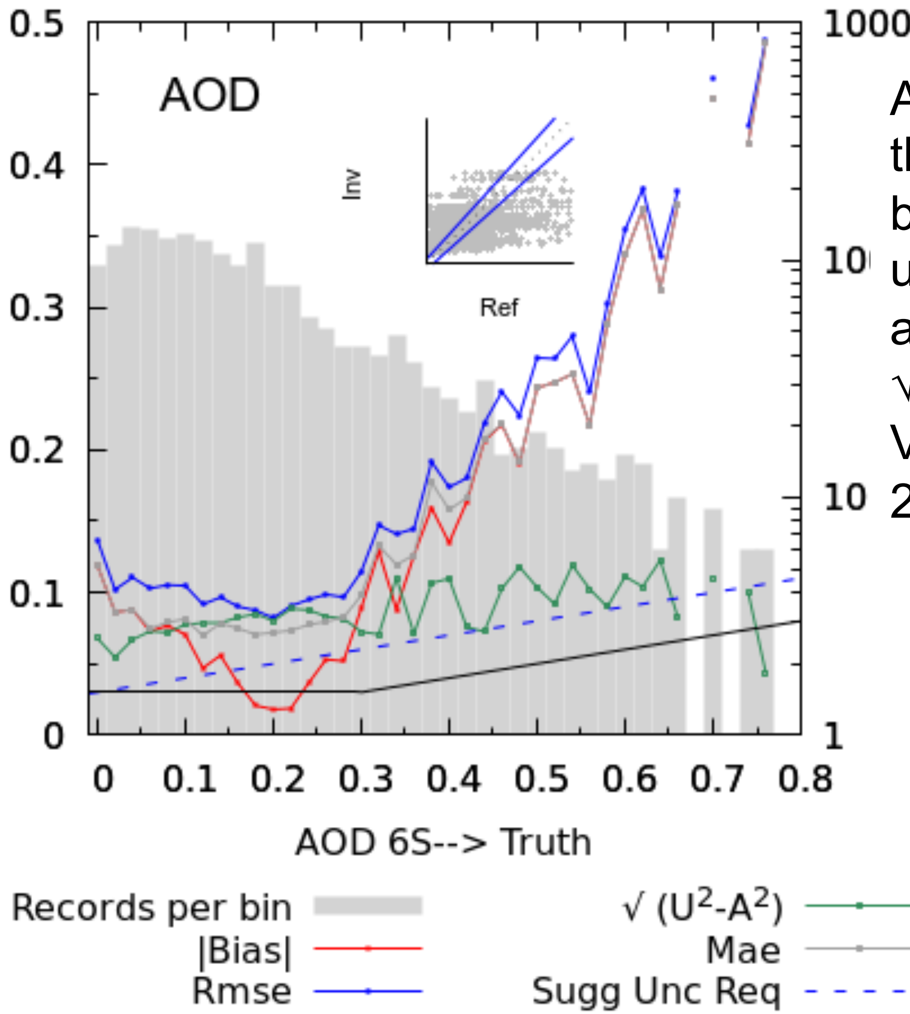
# Summary

- OLCI FAPAR pixel-based uncertainties in Level 2 are derived from error propagation.
- Optimization uncertainties are assessed through radiative transfer model.
- 3D RT model-based quality assurance infer the uncertainties of ground-based measurements against exact definition.

- This approach can be applied to any ECVs and infer the uncertainties budget in land retrieval algorithms.

# Effect of the aerosol uncertainty on MERIS TOC spectral directional reflectance




Accuracy: expressed through the absolute bias |BIAS|), the uncertainty U (~ RMSE), and the precision (P ~ $\sqrt{U^2-A^2}$) following Vermote & Kotchenova, 2008.

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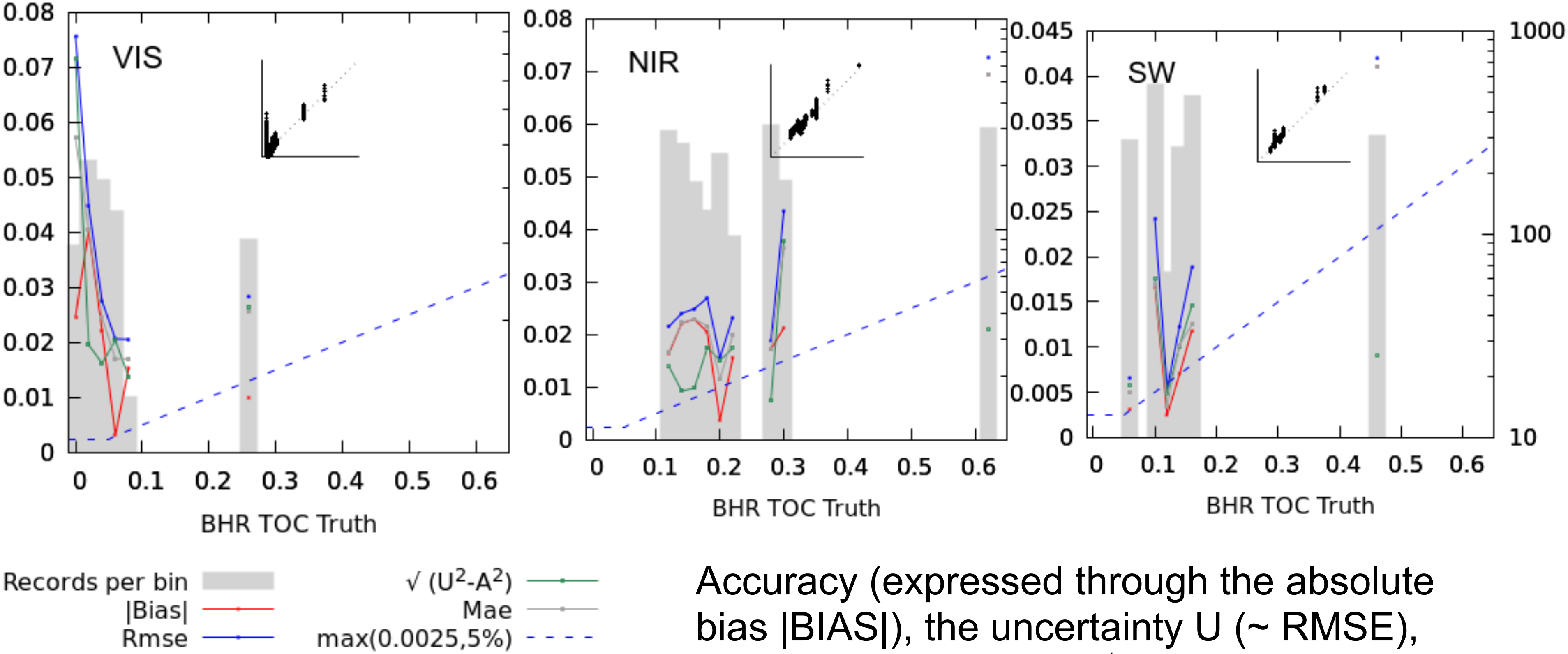
Lanconelli et al., 2017, in prep.

# BHR Results

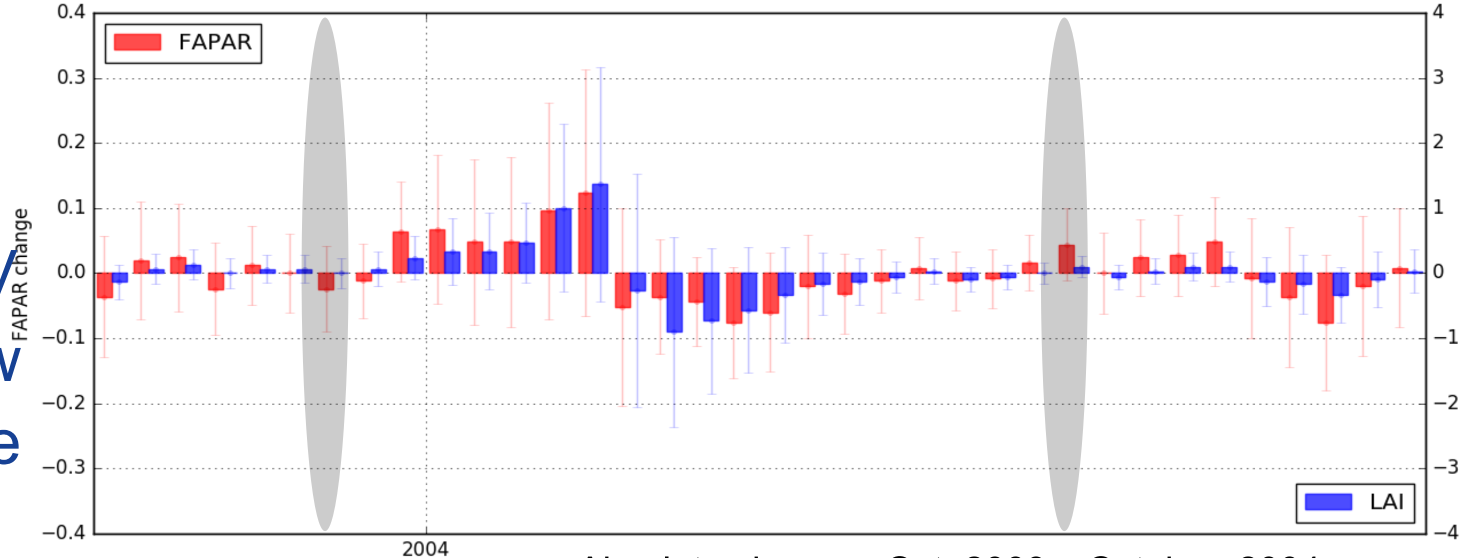



Accuracy (expressed through the absolute bias |BIAS|), the uncertainty U (~ RMSE), and the precision (P ~ $\sqrt{U^2-A^2}$) following Vermote & Kotchenova, 2008)

Lanconelli et al., 2017, in prep.

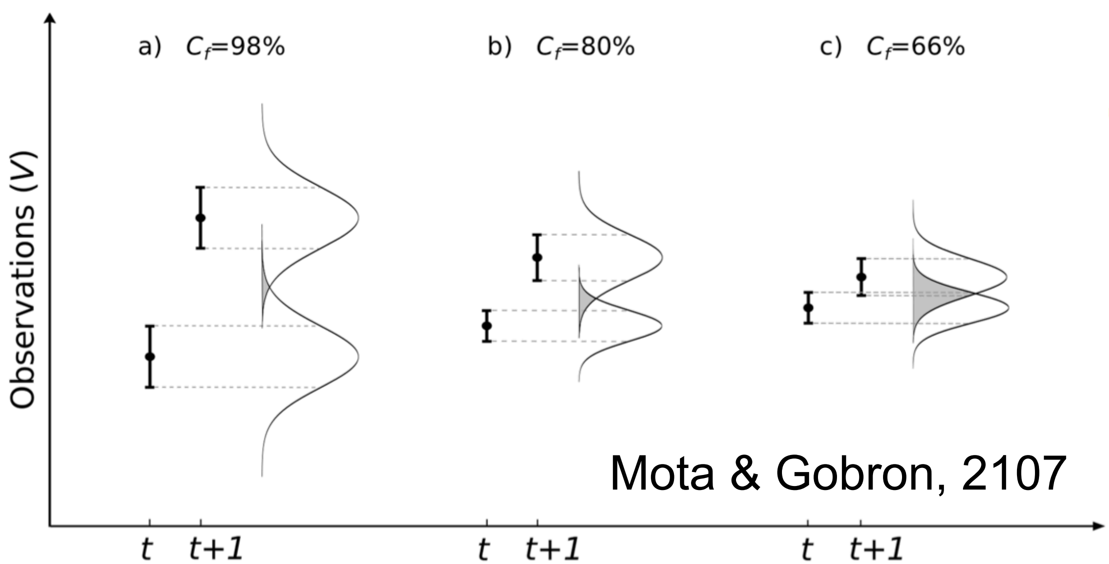
# Use of uncertainties in time series ECVs consistency …

If non-coherency between ECV changes, how significant are they?




Absolute changes Oct. 2003 – October. 2004

## How to determine the confidence of a change?




$$C_f\big|_t^{t+1} = \int_0^1 \frac{|p_t(x) - p_{t+1}(x)|}{p_t(x) + p_{t+1}(x)}\,dx$$

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$$

μ and σ are the observed and associated uncertainty values

Mota & Gobron, 2107

European Commission

# FAPAR: definition

"Total" FAPAR (absorbed component) is computed as the balance between sources and sinks, with positive inputs corresponding to:

- Incoming PAR at the top of the canopy (direct and/or diffuse);
- Incoming PAR from propagating horizontally (mostly important at very high spatial resolution) ;
- Light reflected by the underlying ground (soil and/or understory)

and losses corresponding to:

- Outgoing PAR reflected by the canopy (top and bottom)
- Outgoing PAR propagating horizontally

Leaves-only FAPAR refers to the fraction of PAR radiation absorbed by live leaves only, i.e., contributing to the photosynthetic activity within leaf cells.

This quantity is lower than "total" FAPAR because it does not include PAR absorption by the supporting woody material (in forest) or by dead leaves (in crops).