Mapping Solar-Induced Fluorescence at High Spatial Resolution using Data from the Imaging Spectrometer DESIS on-board the International Space Station

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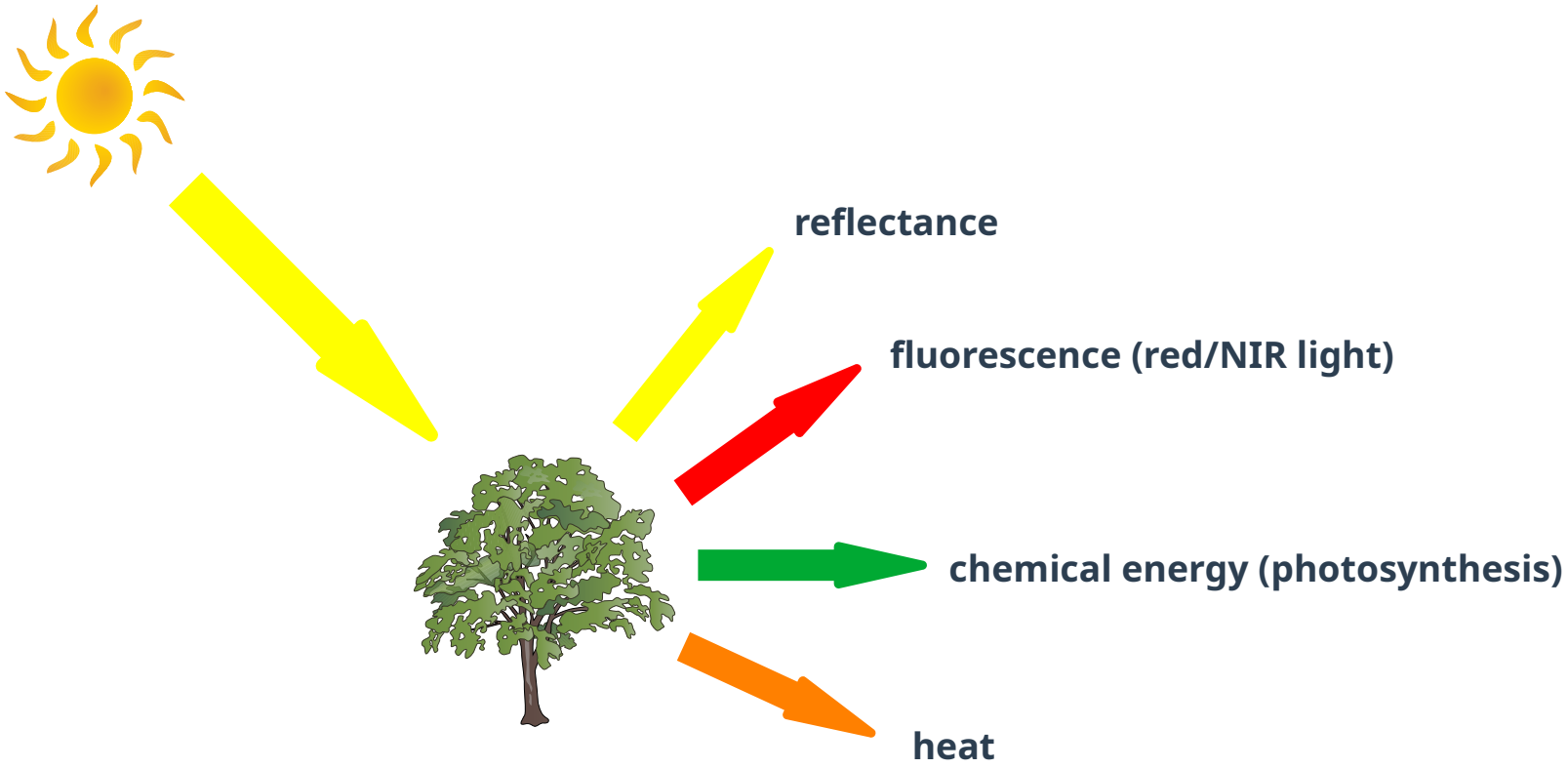
What is Solar Induced Fluorescence (SIF)?



sun and tree graphics from Jane Thomas and Tracey Saxby, Integration and Application Network (ian.umces.edu/media-library)

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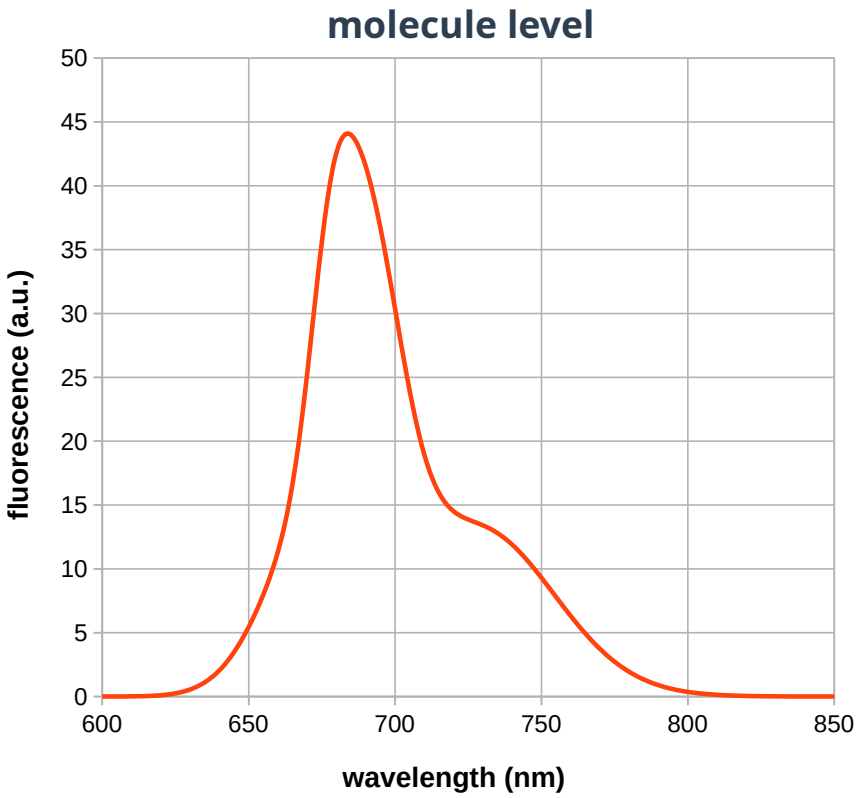
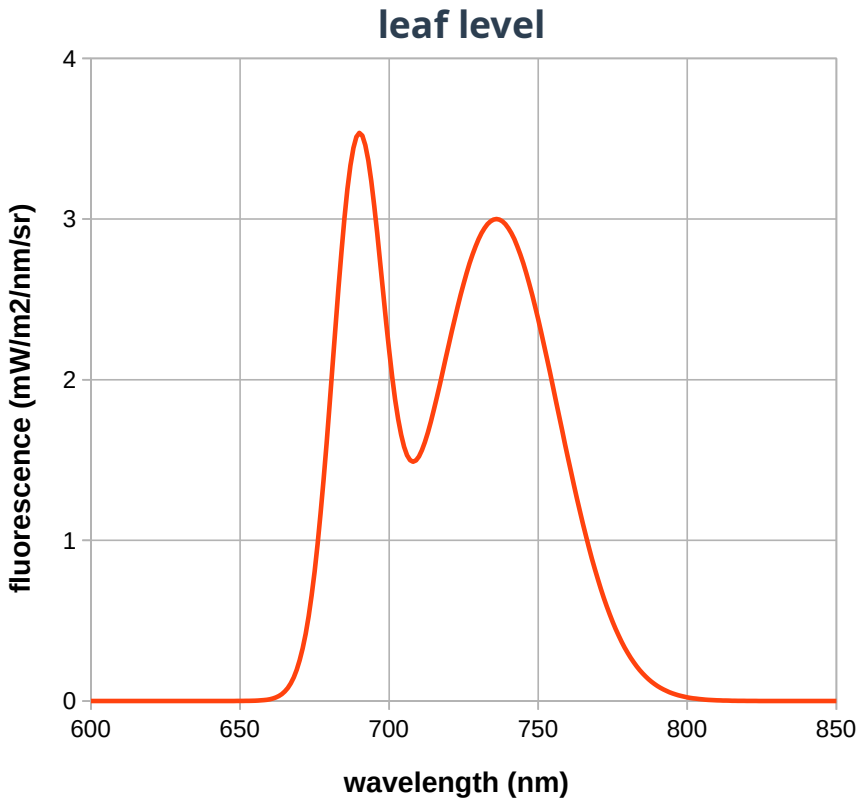
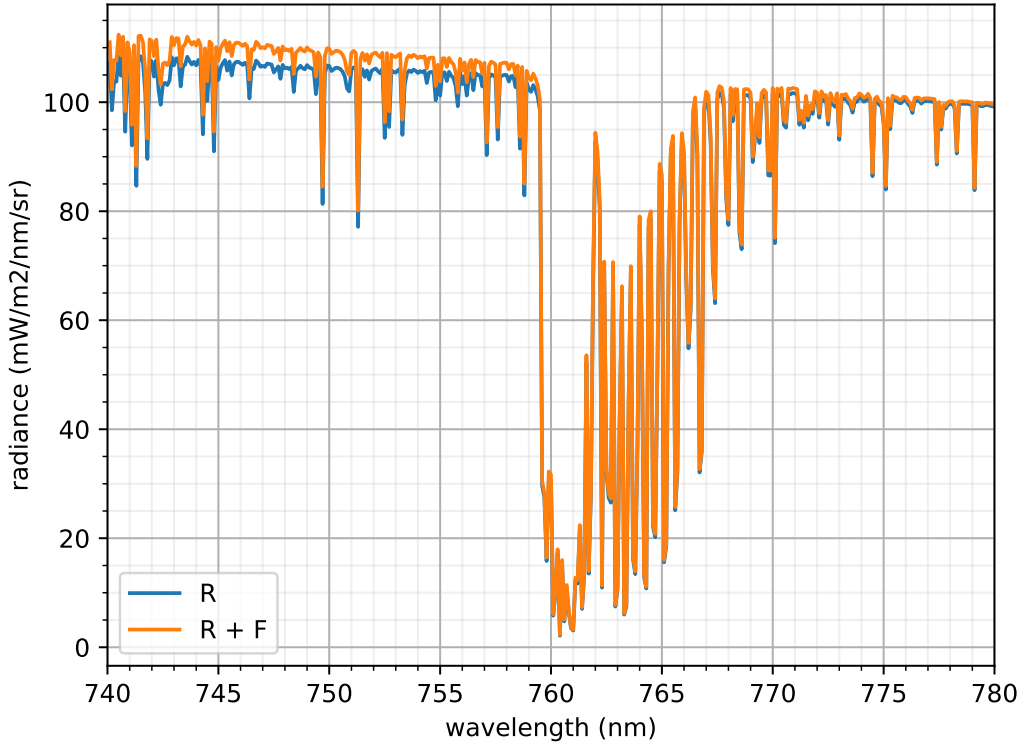


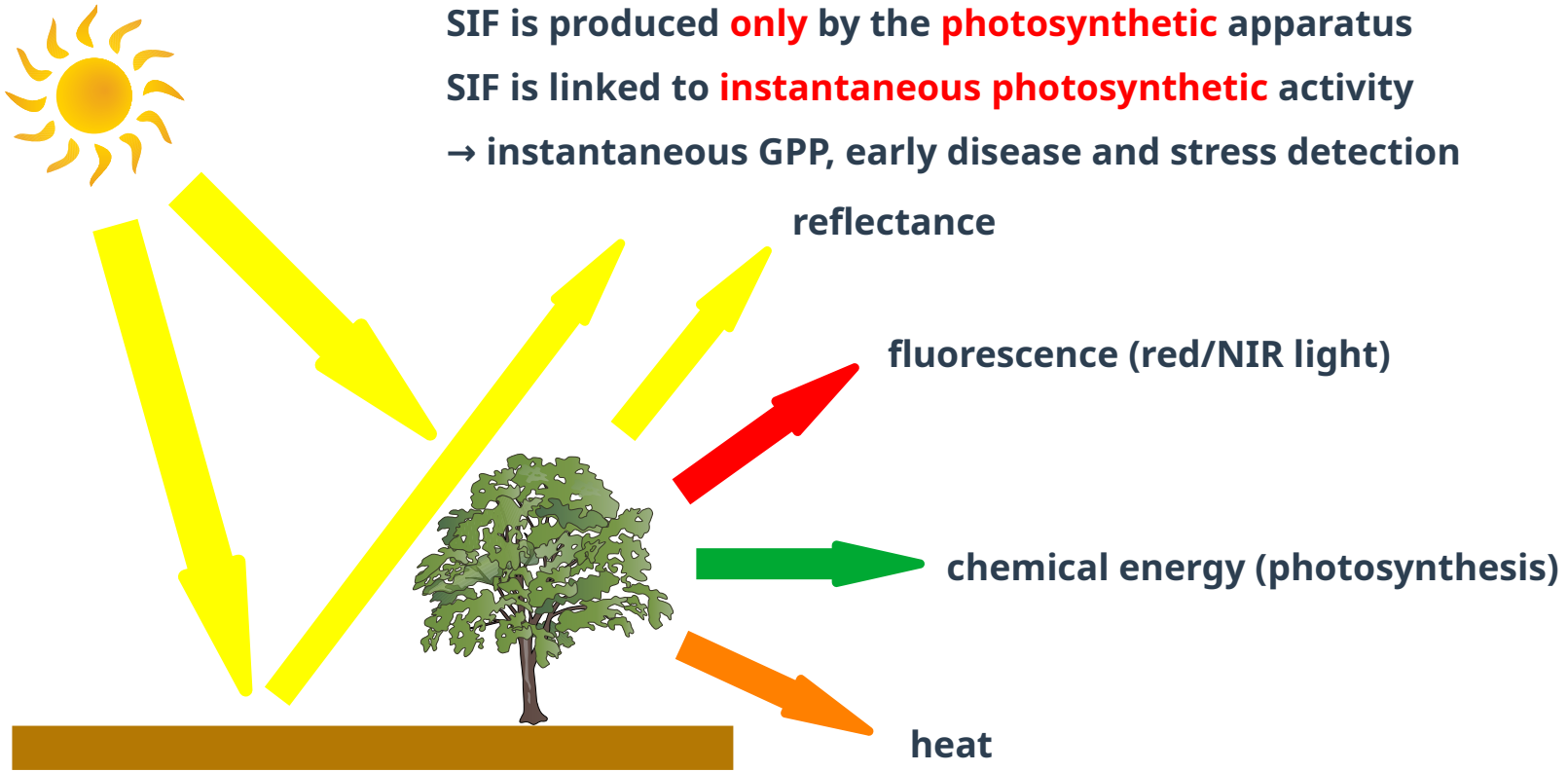


SIF Contribution to At-Sensor Radiance



space-borne sensor

What is SIF used for?



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SIF Retrieval - 3FLD Method

radiance at sensor (in small spectral range so R and $L_{fluorescence}$ are wavelength independent):

$$L_\lambda = \left(\frac{R\, E^0_\lambda}{\pi} + L_{fluorescence} \right) T_\lambda + L^{path}_\lambda$$

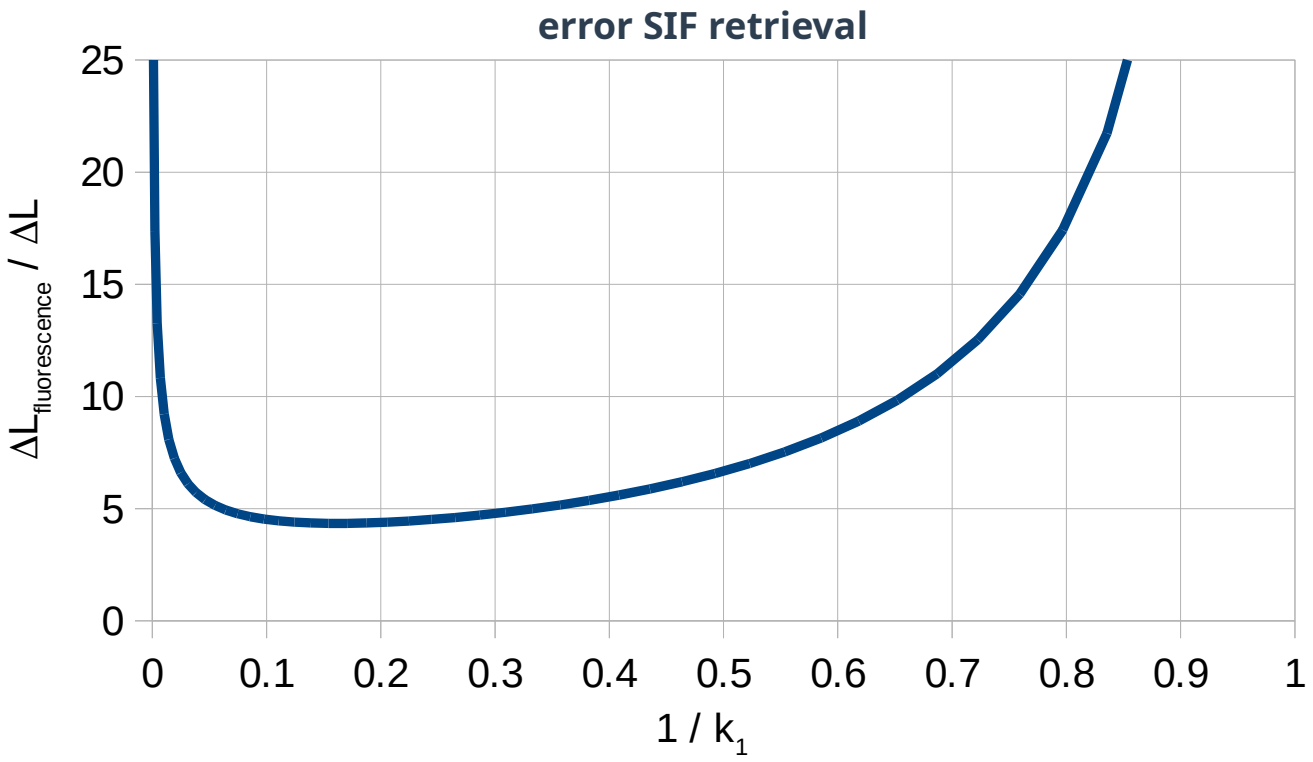
measure in two spectral bands (A, B):

$$L_{fluorescence} = \frac{1}{k_3} \left(L_A - k_1 L_B - k_2 \right) \qquad k_1 \equiv \frac{E^0_A T_A}{E^0_B T_B}; k_2 \equiv L^{path}_A - k_1 L^{path}_B; k_3 \equiv T_A - k_1 T_B$$

3FLD: A is a virtual band using sensor bands on both sides of B and centred on B

Maier, Günther & Stellmes 2003. Sun-induced fluorescence: a new tool for precision farming. In *Digital Imaging and Spectral Techniques: Applications to Precision Agriculture and Crop Physiology*, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, 209-222

3FLD Method - Retrieval Error



lowest error

$1/k_1$ ~ 0.16

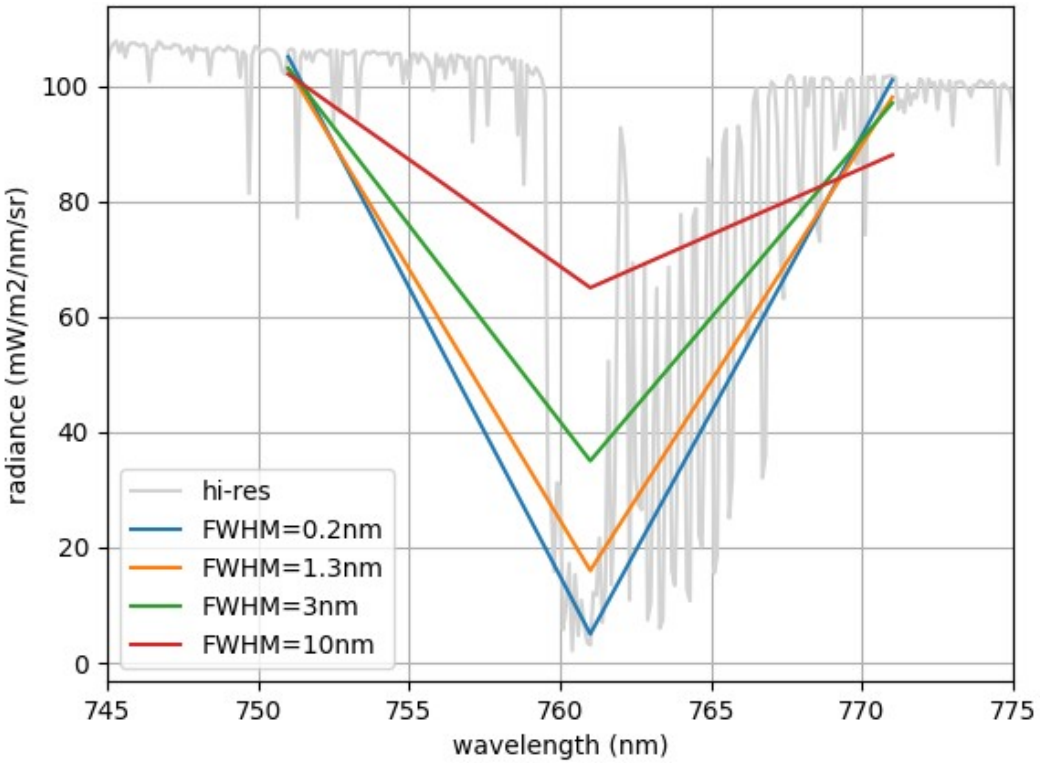
no atmospheric spectral features → $1/k_1$ = 1

Therefore:

B is in O_2A atmospheric absorption band

A is a virtual band using sensor bands on both sides of O_2A atmospheric absorption band

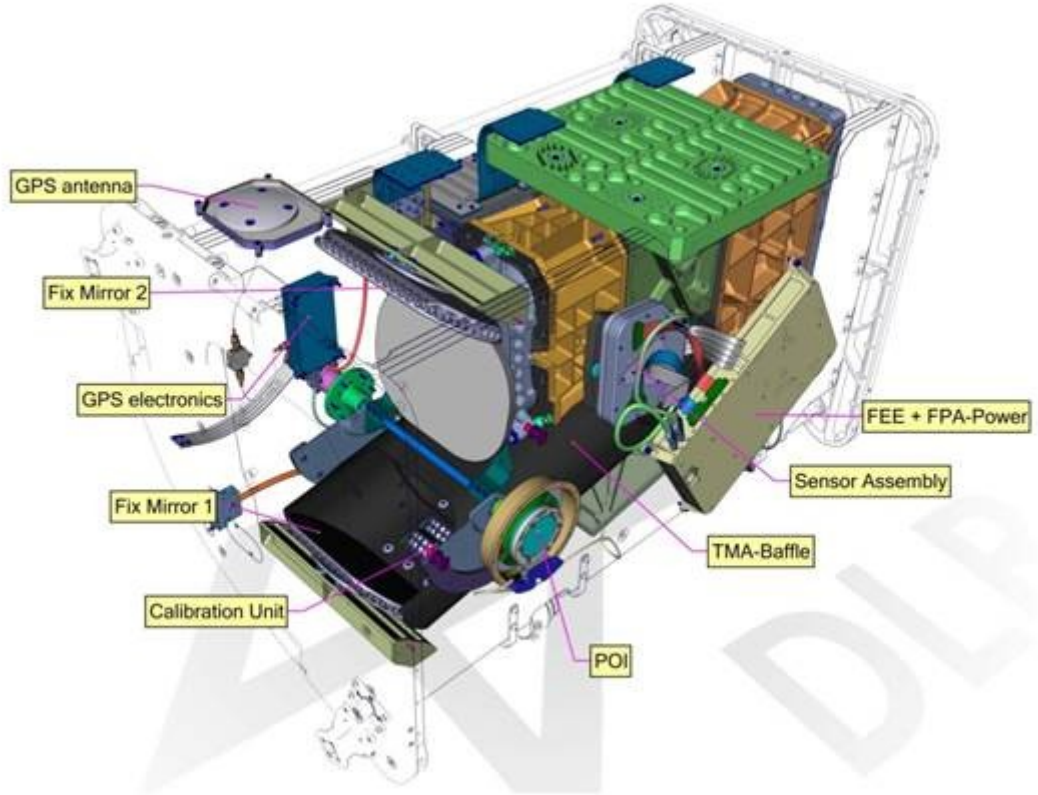
3FLD Method - Spectral Resolution



FWHM	$1/k_1$	$\Delta L_f / \Delta L$
0.2nm	~0.05	~5
1.3nm	~0.16	~4
3nm	~0.35	~5
10nm	~0.65	~10

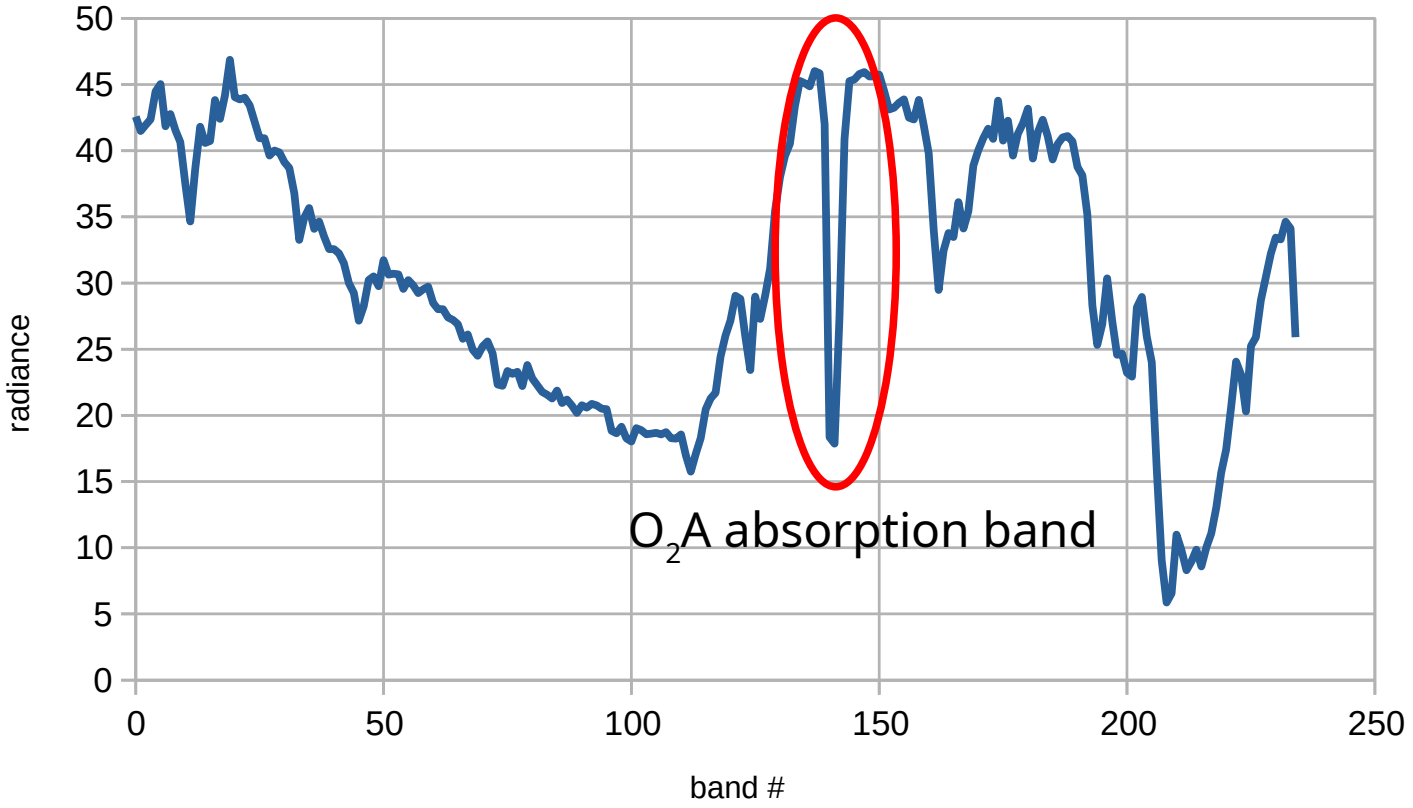
DESIS Overview

- imaging spectrometer (push-broom)
- platform: International Space Station
- no coverage of high latitudes
- frequent coverage of equatorial regions and mid-latitudes
- varying observation times
- 402 - 1000nm spectral range
- 235 spectral channels
- 2.55nm spectral sampling
- FWHM 3.5nm
- 30m spatial resolution
- 1024 spatial pixel
- 13bit + 1bit gain



source: DLR - Earth Observation Center - DESIS (http://www.dlr.de)

Is DESIS Suitable for 3FLD in O_2A Band?



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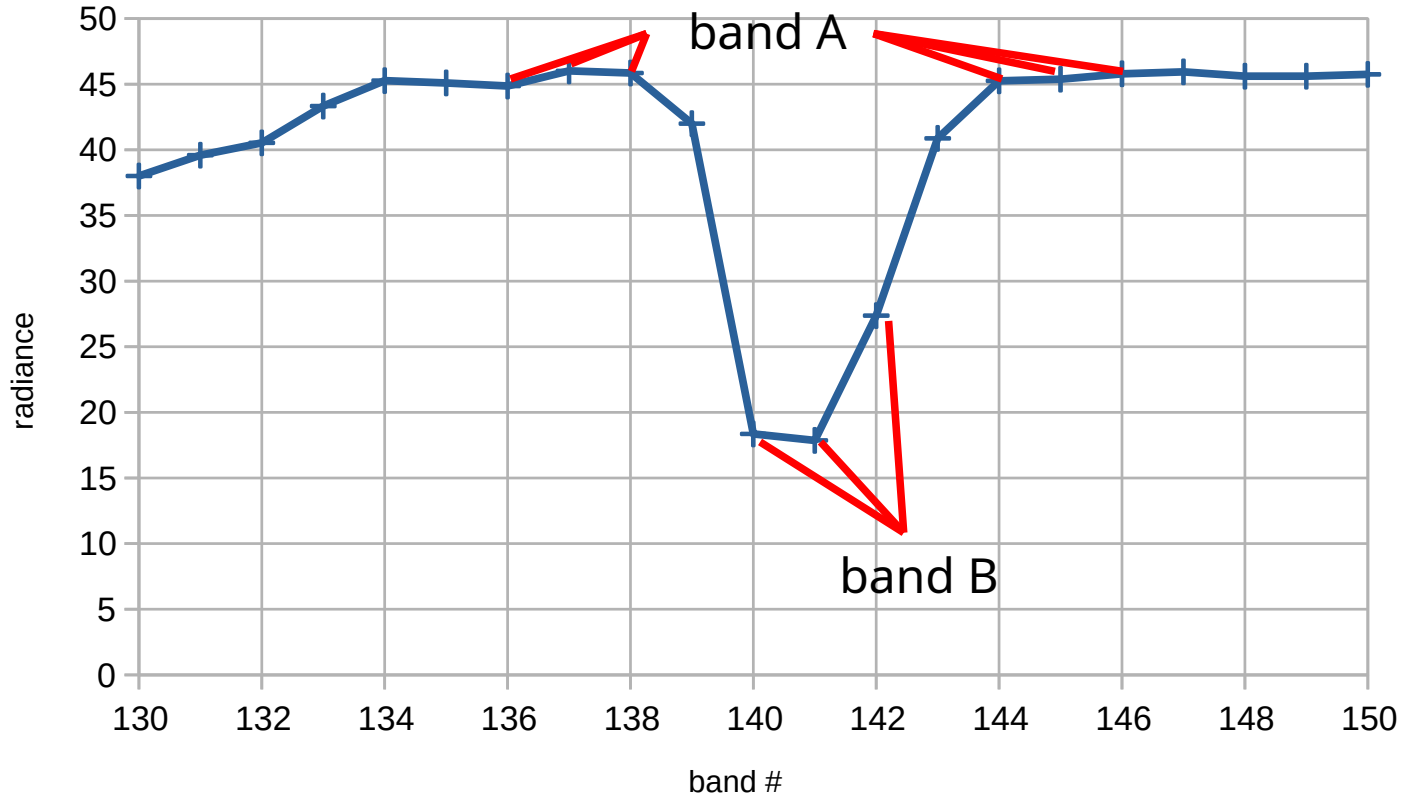


$1/k_1 \sim 0.45$

$\Delta L_f / \Delta L \sim 6$

3FLD Method - Determination of Constants

$$L_{fluorescence} = \frac{1}{k_3}\left(L_A - k_1 L_B - k_2\right) \qquad k_1 \equiv \frac{E_A^0 T_A}{E_B^0 T_B}; k_2 \equiv L_A^{path} - k_1 L_B^{path}; k_3 \equiv T_A - k_1 T_B$$

k_1, k_2 and k_3 depend on:

- **atmosphere**
- **observation geometry**
- **sensor spectral characteristics (band centre wavelength and FWHM)**

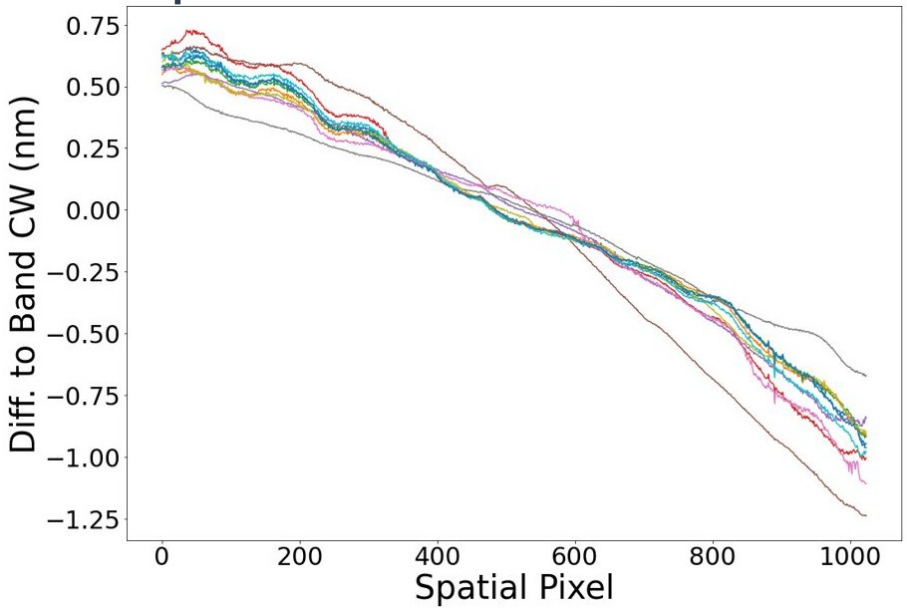
$L_{fluorescence}$ is very small. Requirement for very high radiometric accuracy, i.e. high demand on:

- **absolute radiometric calibration**
- **dark signal correction**
- **non-linearity correction**

Smile Effect DESIS

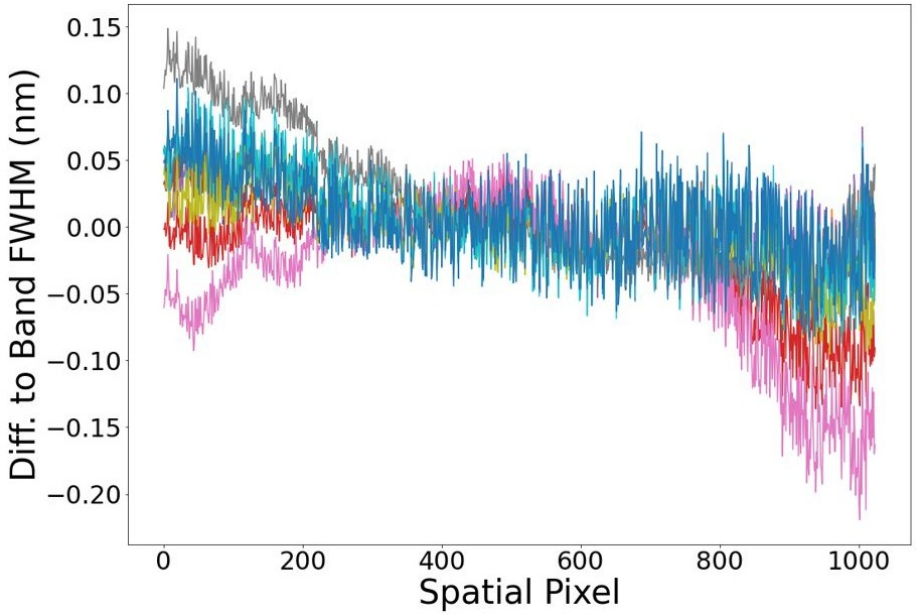
variation of band centre wavelength across-track (→ smile effect)

potentially variation of band centre wavelength with temperature / time



variation of spectral resolution across-track

potentially variation of spectral resolution with temperature / time



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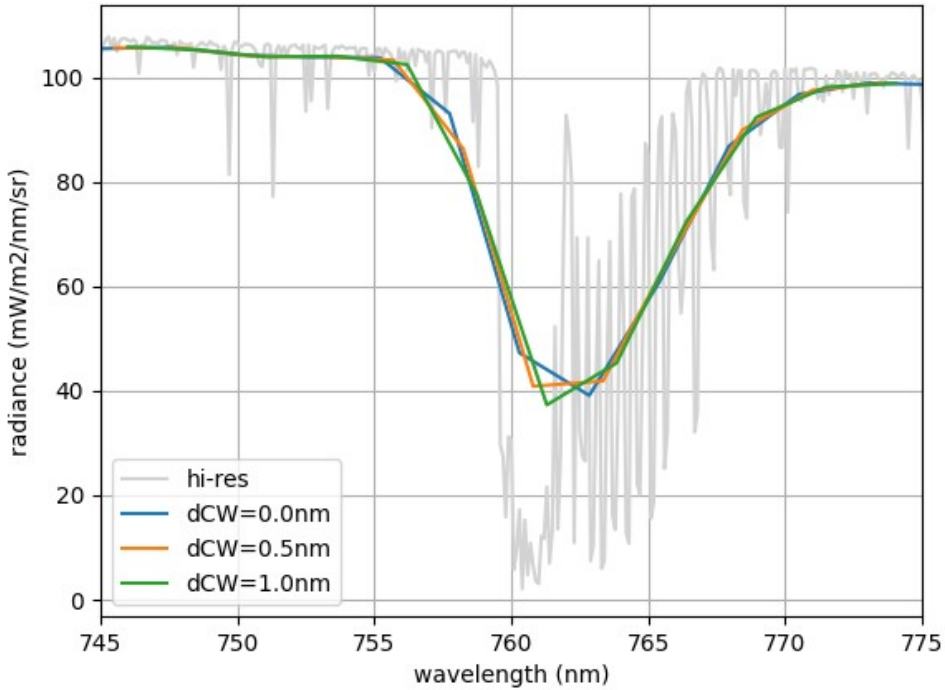
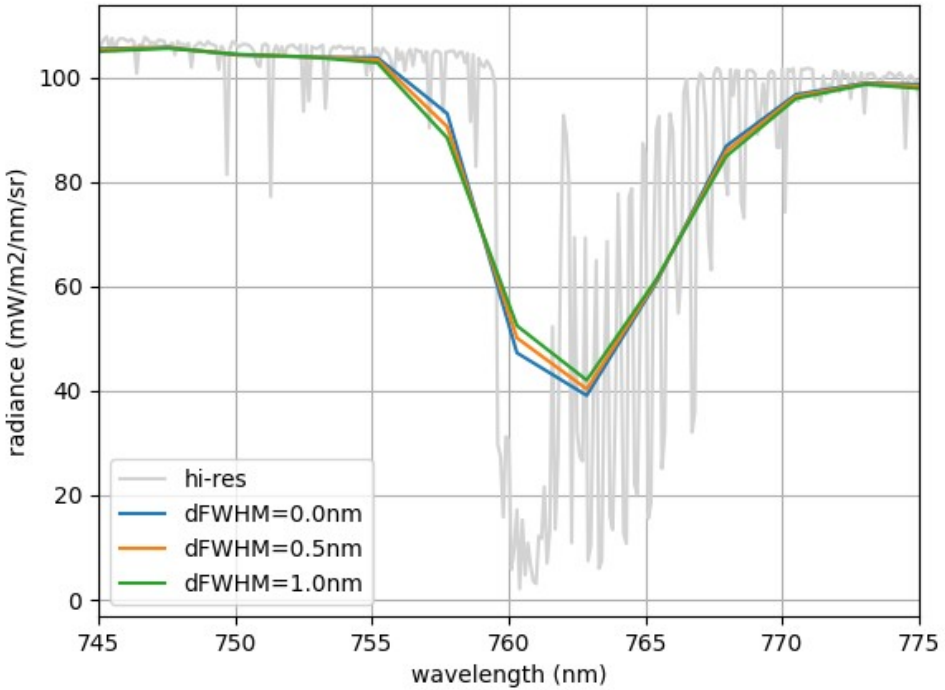
Impact of Varying Centre Wavelength and Spectral Resolution





In-Scene Instrument Calibration for 3FLD

3FLD equation:

$$L_{fluorescence} = \frac{1}{k_3}\left(L_A - k_1 L_B - k_2\right)$$

non-fluorescent targets:

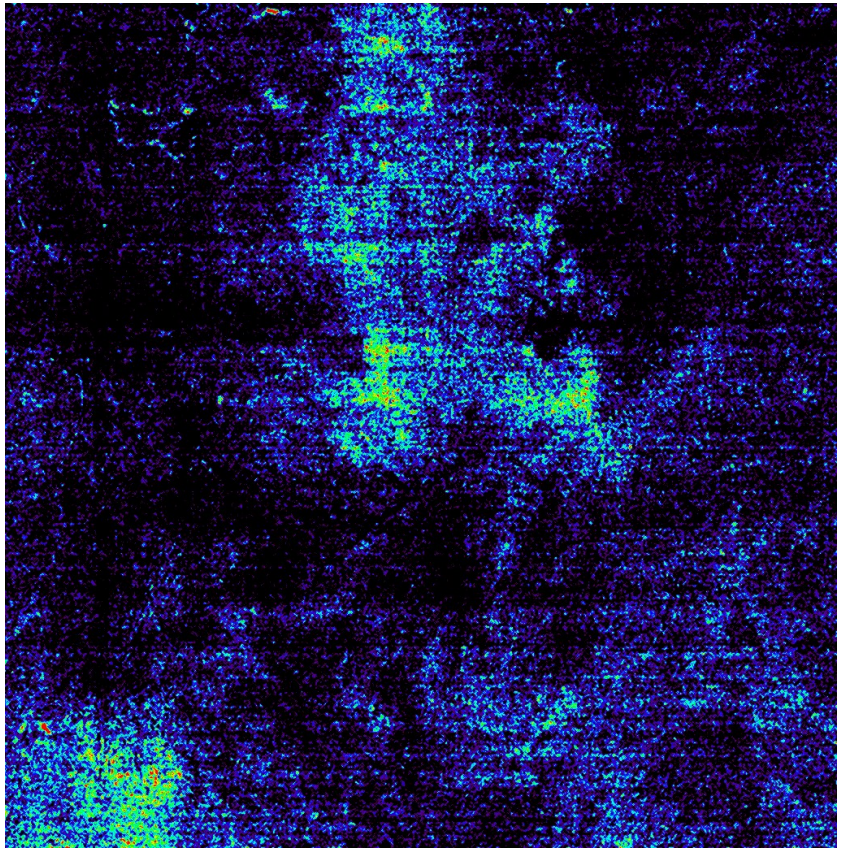
$$L_A = k_1 L_B + k_2$$

k_1 and k_2 can be determined from image scene by selecting non-fluorescent targets

sensor properties vary across track

→ k_1 and k_2 have to be determined for each across track pixel separately

Results (Litchfield Supersite / NASVF, Australia)



2019-07-11 01:00 UTC

10:30 local time

left: “truecolor”

right: SIF

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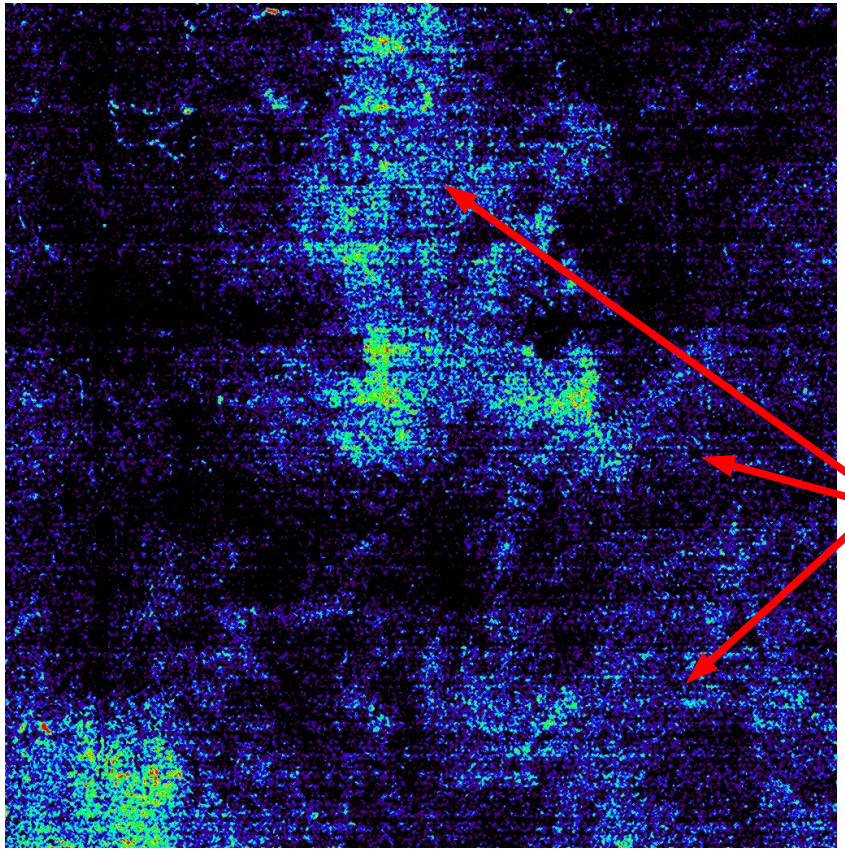

2019-07-11 01:00 UTC

10:30 local time

left: “truecolor”

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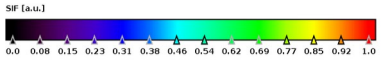
some across track striping

integration time jitter?

no significant striping along track despite column by column processing



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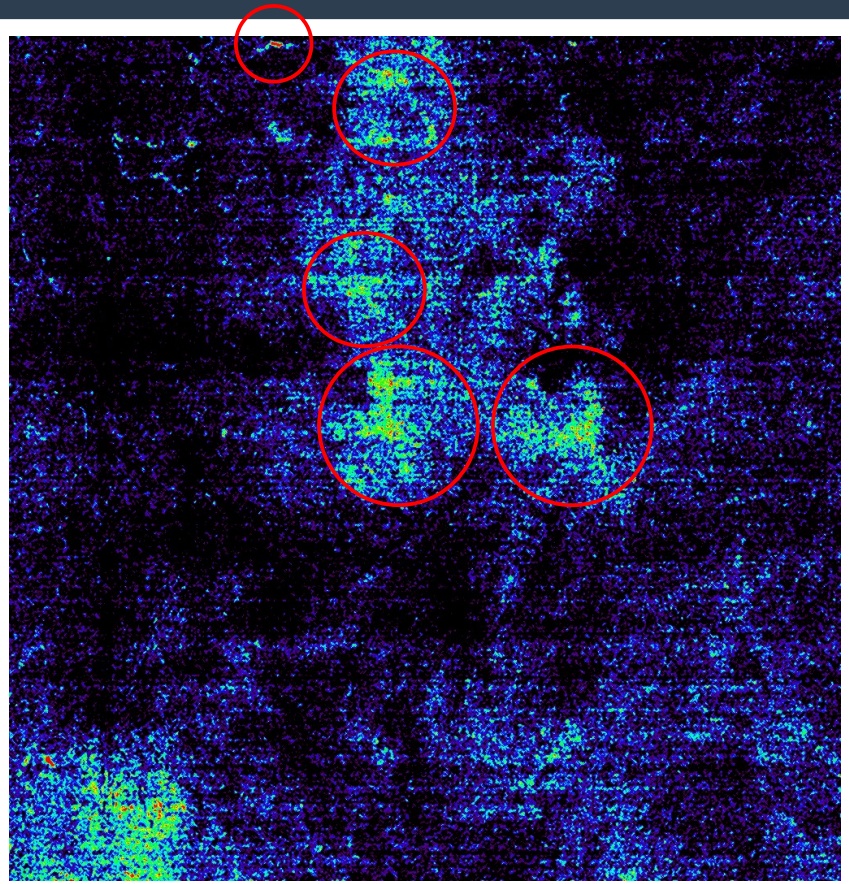

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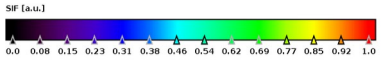
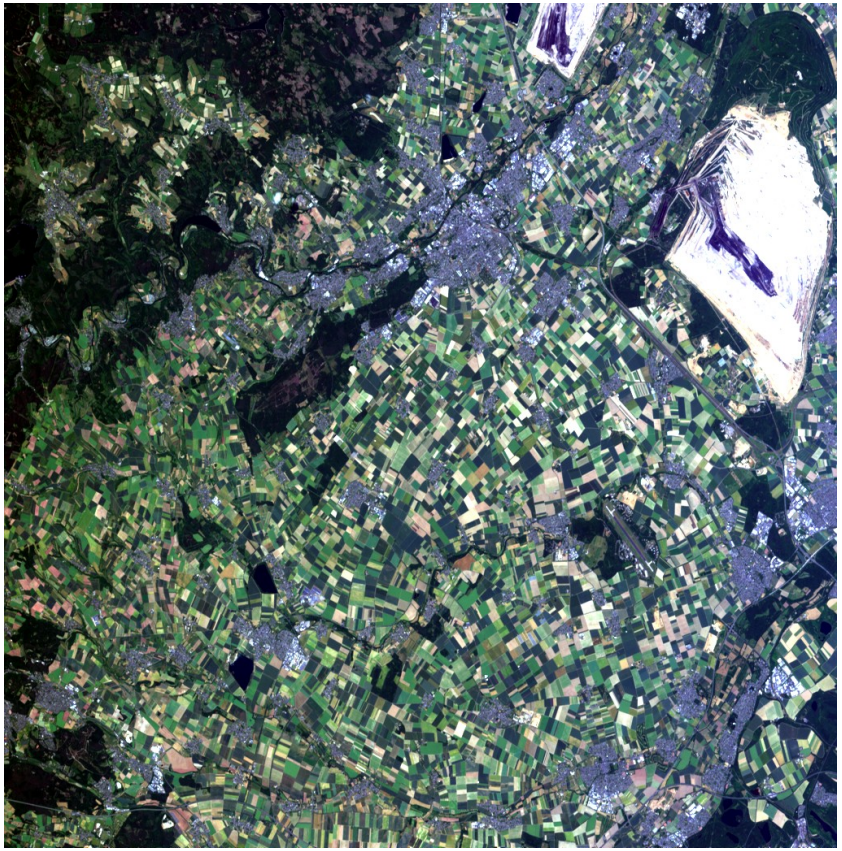
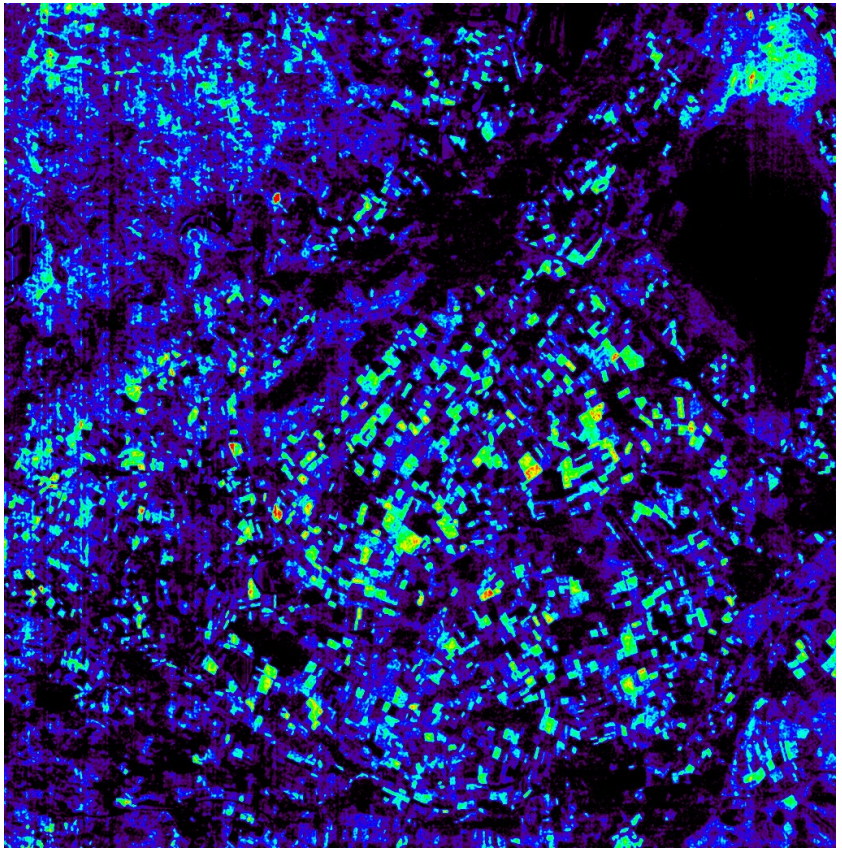
SIF hotspots

- riparian zones
- areas of different soils
- higher tree density



Results (Jülich, Germany)





2023-06-13 12:39 UTC

14:39 local time

left: “truecolor”

right: SIF

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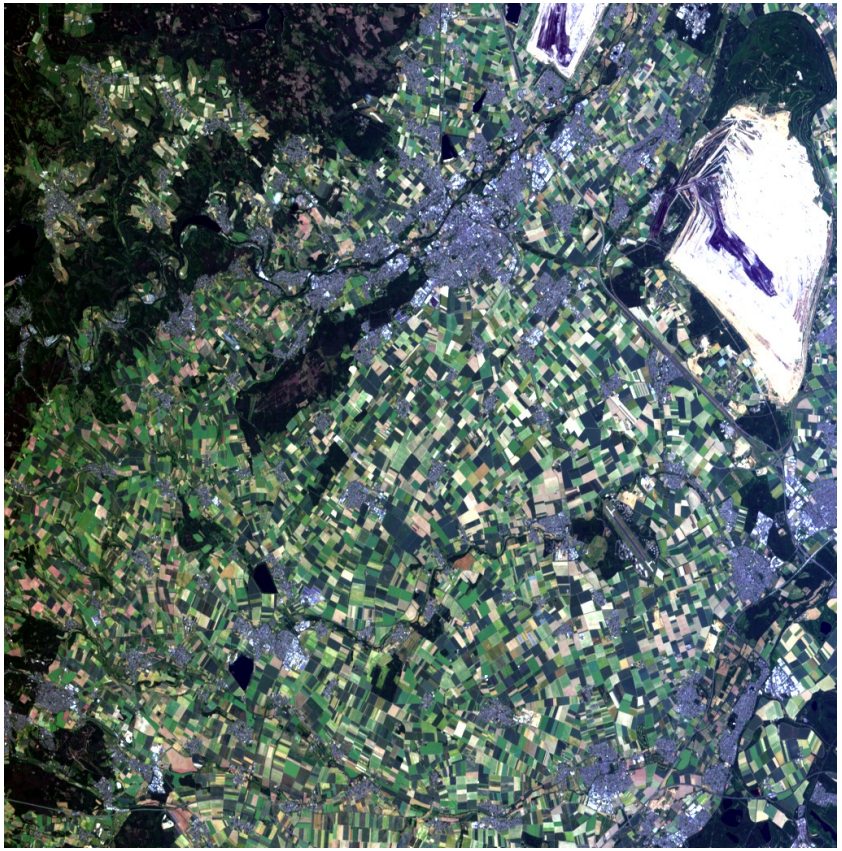

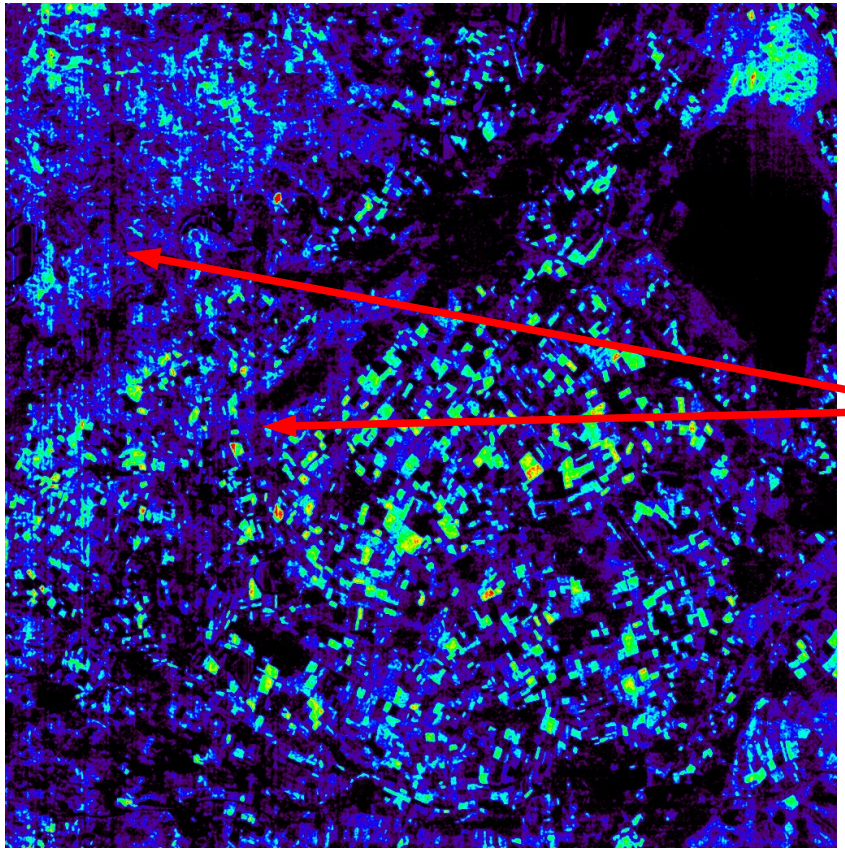

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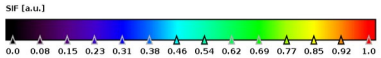
some along track striping



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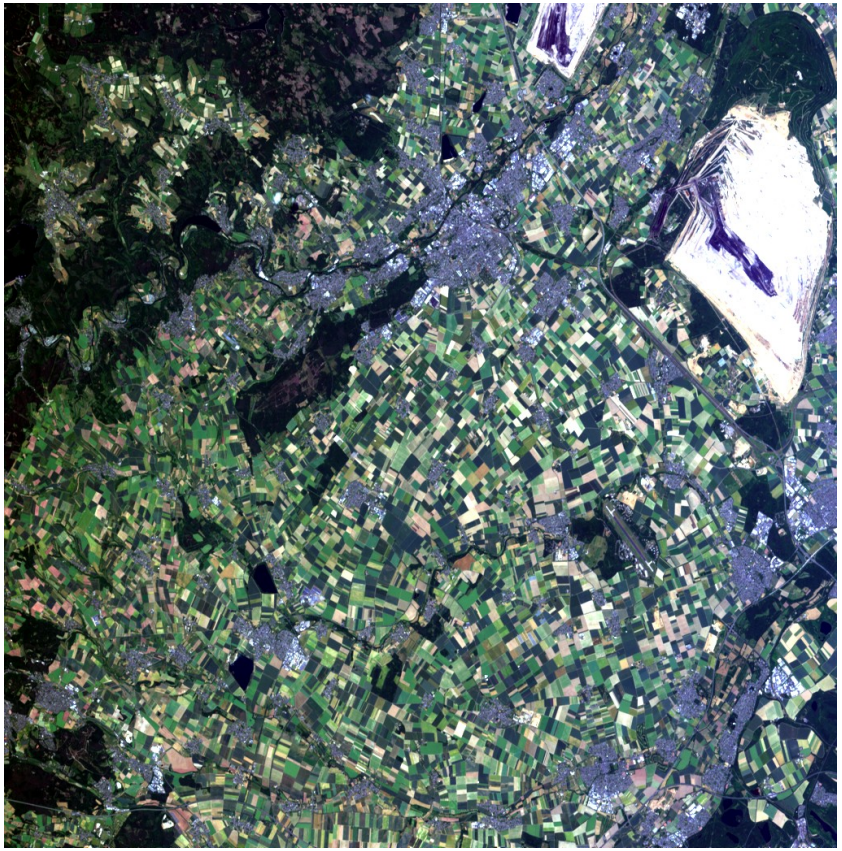

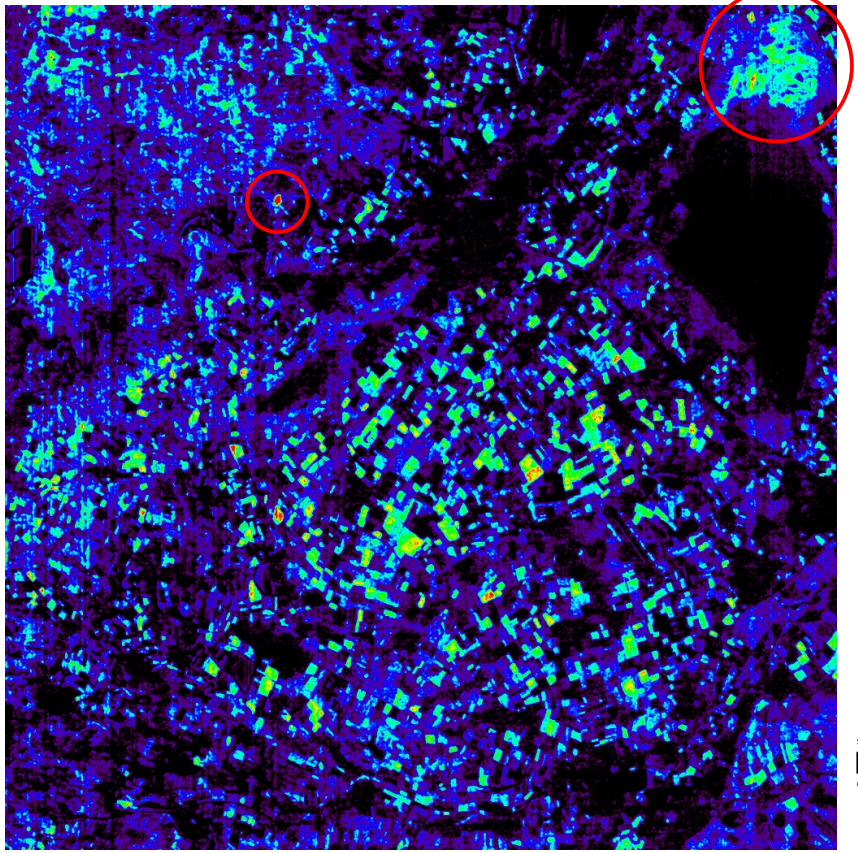

2023-06-13 12:39 UTC

14:39 local time

left: “truecolor”

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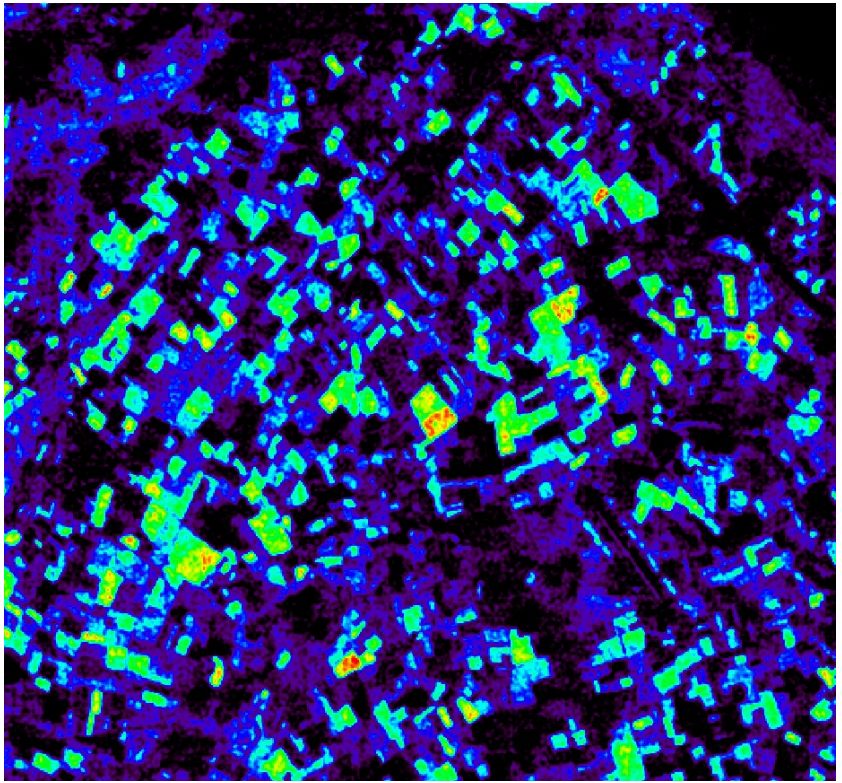
apparently high SIF

- hill up to 200m above surrounding area
- cloud

Results (Jülich, Germany)



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within field variability

Discussion

SIF can be retrieved from DESIS data

simultaneous sensor correction, atmosphere correction and SIF retrieval to achieve required accuracy and SNR (cannot be done using standard products)

SIF @30m resolution from space

fills important spatial and temporal scale gap

SIF retrieval possible despite very low / no understorey greenness

SIF retrieval possible despite canopy greenness at lowest level

SIF retrieval possible despite erectophile leaf angle distribution in canopy

orbit of International Space Station provides varying observation times

What’s Next?

comparison with radiative transfer modelling and neural network approach developed in FluoMap (DLR, FZJ, maitec)

comparison with simultaneous HyPlant SIF

implementation of operational processing chain for DESIS SIF retrieval

diurnal and seasonal studies (same area captured 2-3 times on same day)

compare differing dynamics of understorey and canopy of savanna vegetation

compare differing dynamics of savanna and riparian vegetation

development of detailed error model for DESIS and error analysis for 3FLD

Questions?

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