Atmospheric correction of very high spatial resolution images using multispectral satellite images

...the first six months of my PhD

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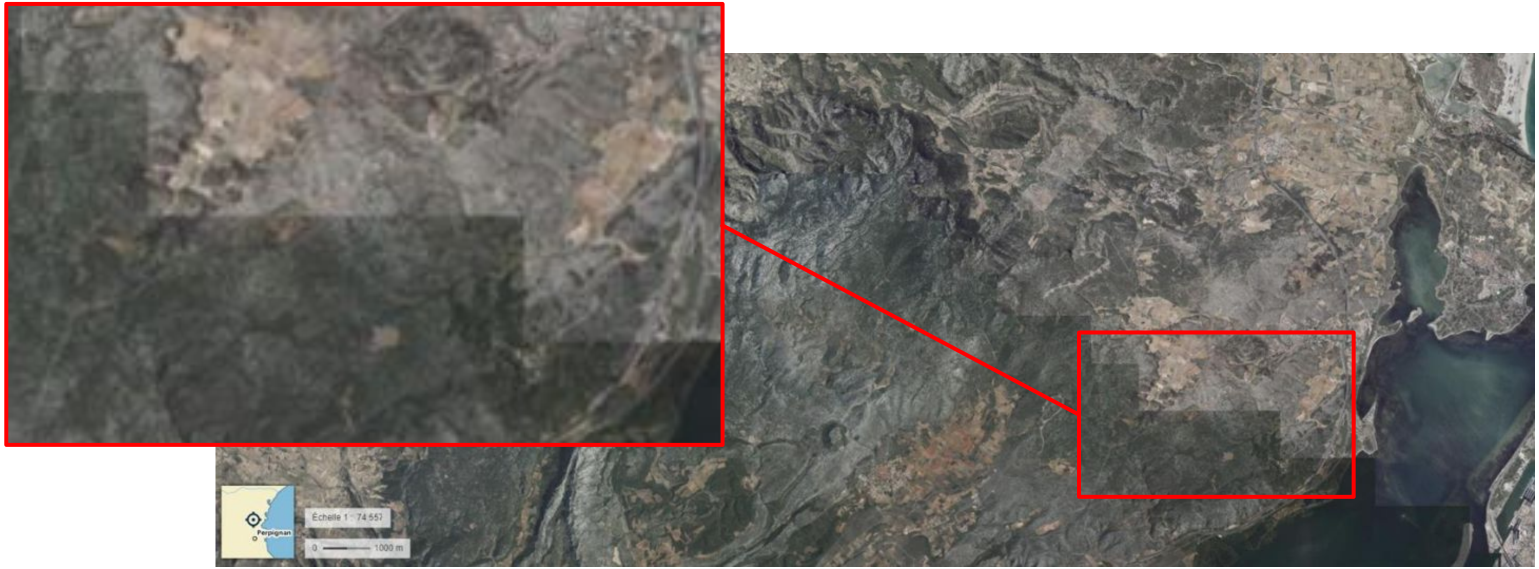
Summary

1. Context
2. Data presentation
3. Sensor calibration (first pipeline)
4. First result - to come

"Atmospheric correction of very high spatial resolution images using multispectral satellite images"

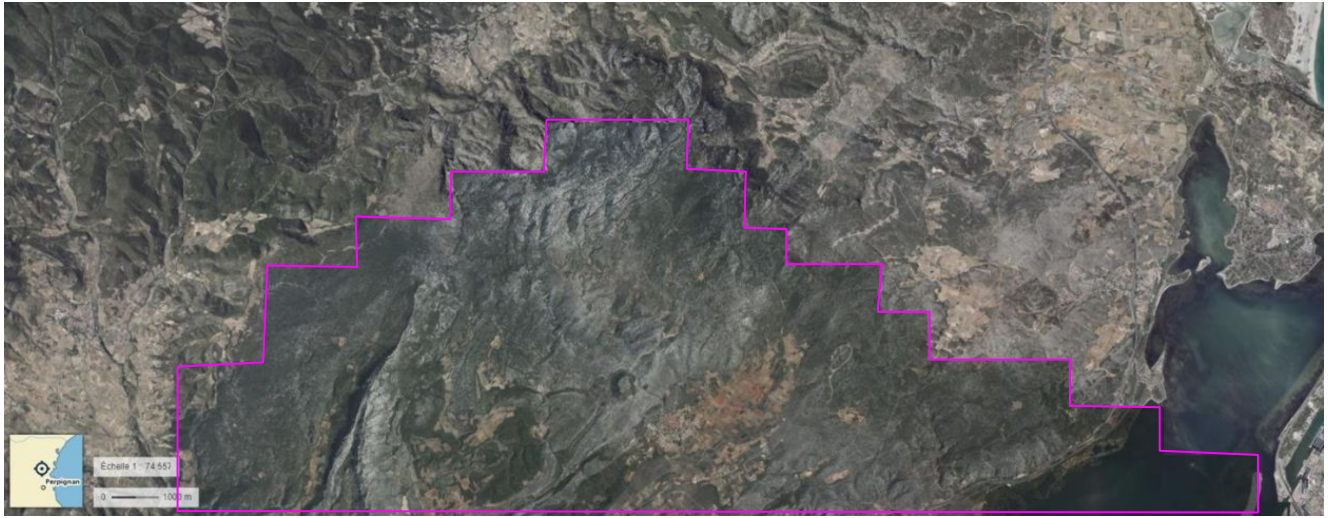
1. Context

"Atmospheric correction of very high spatial resolution using multispectral satellite images"



1. Context

“Atmospheric correction of very high spatial resolution using multispectral satellite images”



Several block of acquisition :

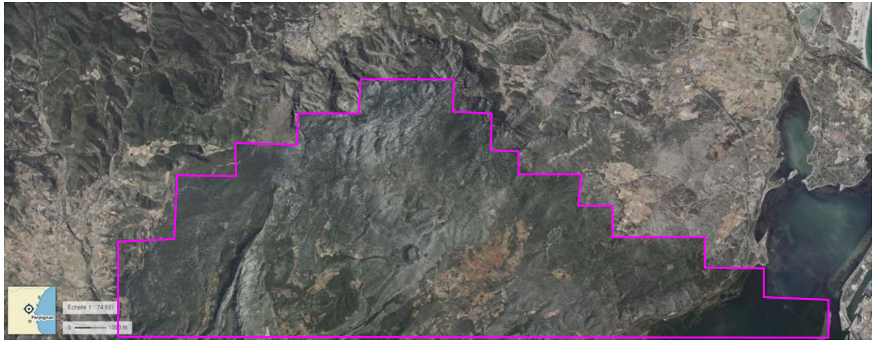
1. Context

"Atmospheric correction of very high spatial resolution using multispectral satellite images"

Several blocks of acquisition :

- Currently relatives radiometric equalizations (one per block)
- No absolute atmospheric corrections done

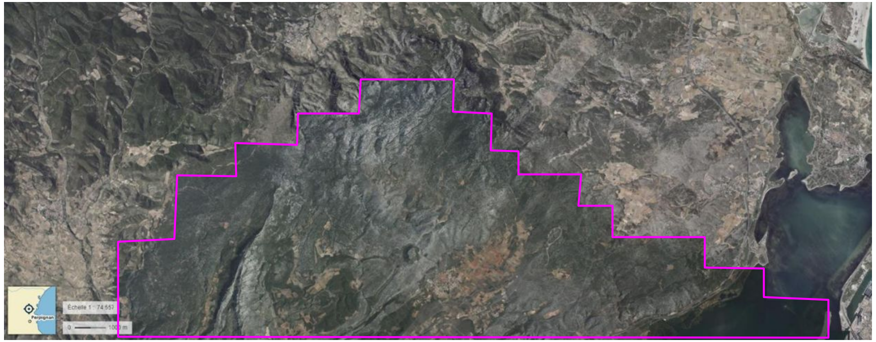
Pb : acquisition conditions changes (atmospheric conditions changes), sensor calibration is also relative to a block



1. Context

"Atmospheric correction of very high spatial resolution using multispectral satellite images"

Can we use ground reflectance images, in medium resolution, acquired before and after the aerial images, to estimate the ground reflectance of HR images, correcting atmospheric impacts and variations due to sensor calibration ?

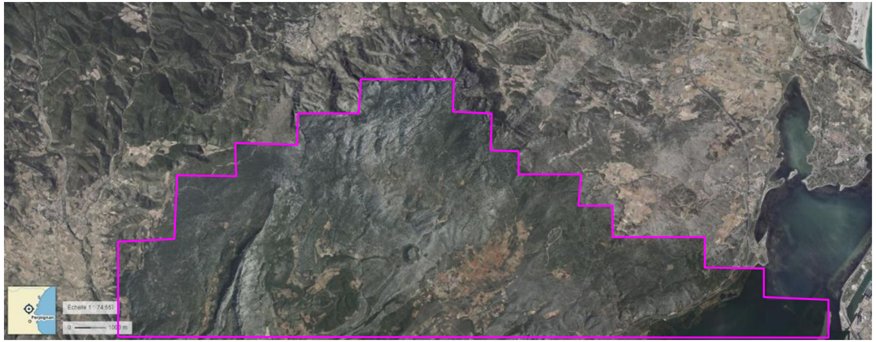


1. Context

"Atmospheric correction of very high spatial resolution using multispectral satellite images"

Can we use ground reflectance images, in medium resolution, acquired before and after the aerial images, to estimate the ground reflectance of HR images, correcting atmospheric impacts and variations due to sensor calibration ?

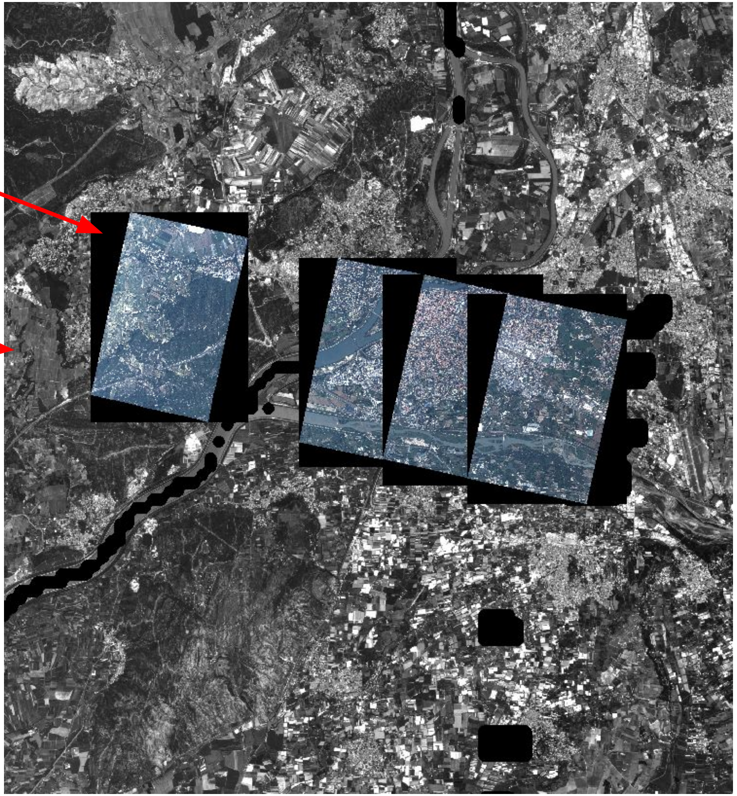
-> use satellite images as references to correct aerial images



2. Data presentation

UltraCam & Sentinel-2

- **High Resolution images (UltraCam)**
  - OPI (1 ortho / image)
  - RGB-PIR (60 cm) + panchro (20 cm)
- **Satellite images Sentinel-2**
  - 10m
  - B2 (490 nm) / B3 (560 nm) / B4 (665 nm) / B8 (842 nm)...



->make this data compatible

2. Data presentation

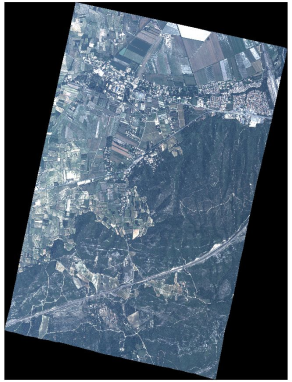
Aerial images - UltraCam (IGN)

G 60 cm

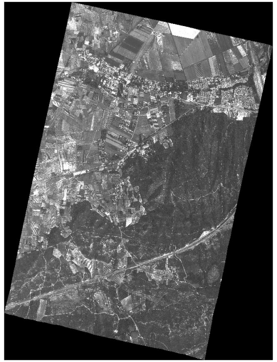
B 60 cm

R 60 cm

I 60 cm



P 20 cm



2. Data presentation

Sentinel-2 Images

B2 10 m

B3 10 m

B4 10 m

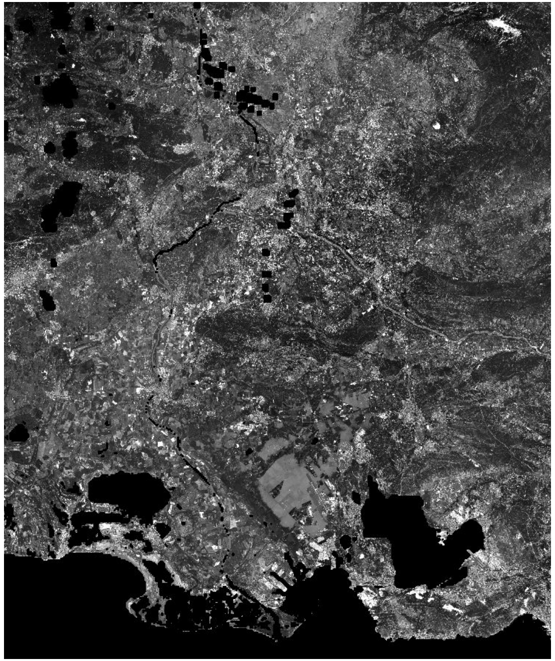
B5 20 m

B6 20 m

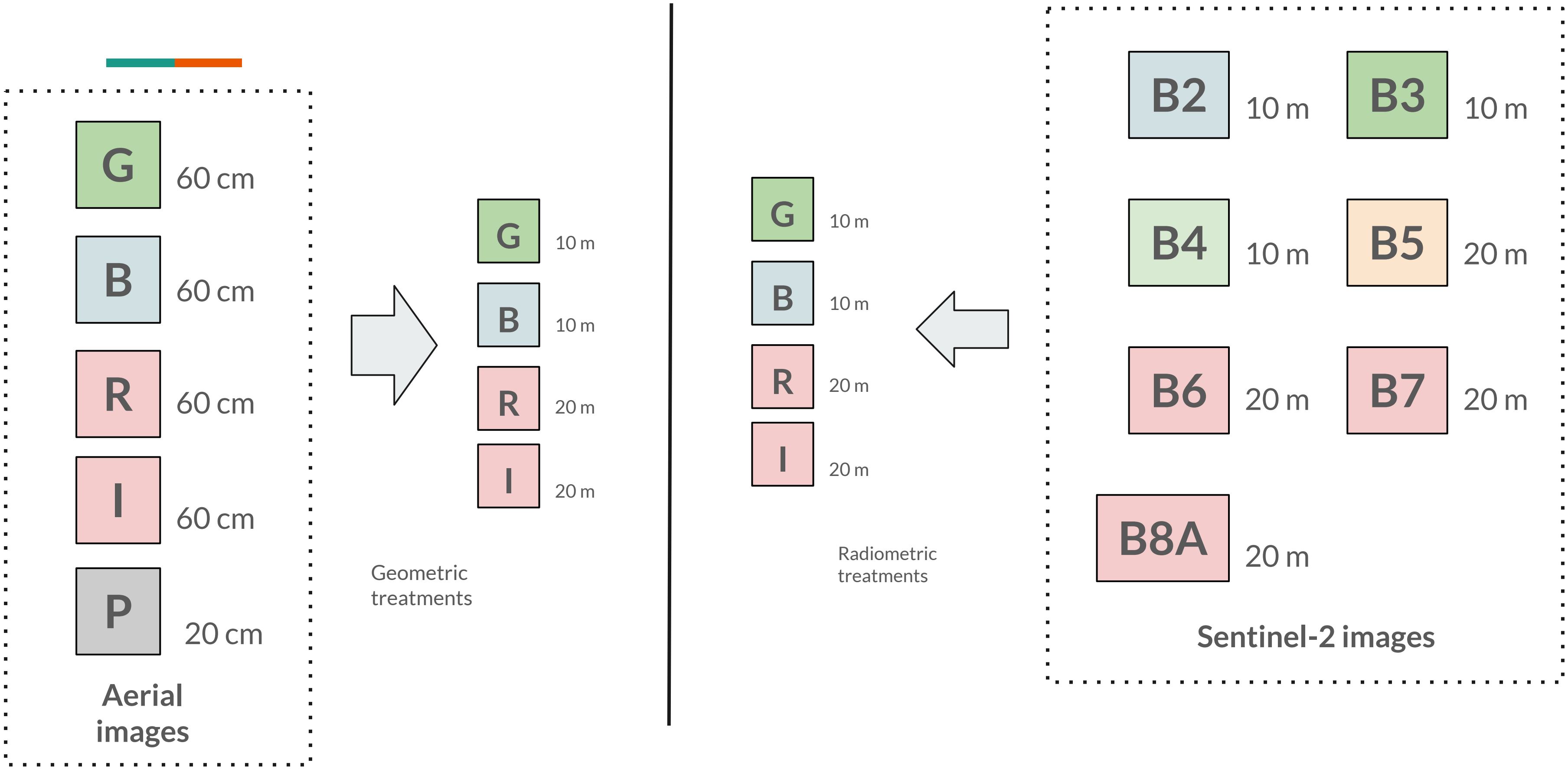
B7 20 m

B8A 20 m

Band	Band	Central wavelength (nm)	Bandwith (nm)	Spatial resolution (m)	Objective
B1		443	20	60	Aerosol Correction
B2		490	65	10	Aerosol Correction, Land Measurement Band
B3		560	35	10	Land Measurement Band
B4		665	30	10	Land Measurement Band
B5		705	15	20	Land Measurement Band
B6	VNIR	740	15	20	Land Measurement Band
B7		783	20	20	Land Measurement Band
B8		842	115	10	Water Vapor Correction, Land Measurement Band
B8a		865	20	20	Water Vapor Correction, Land Measurement Band
B9		945	20	60	Water Vapor Correction
B10		1380	20	60	Cirrus Detection
B11	SWIR	1610	90	20	Land Measurement Band
B12		2190	180	20	Aerosol Correction, Land Measurement Band



2. Data presentation - fitting together



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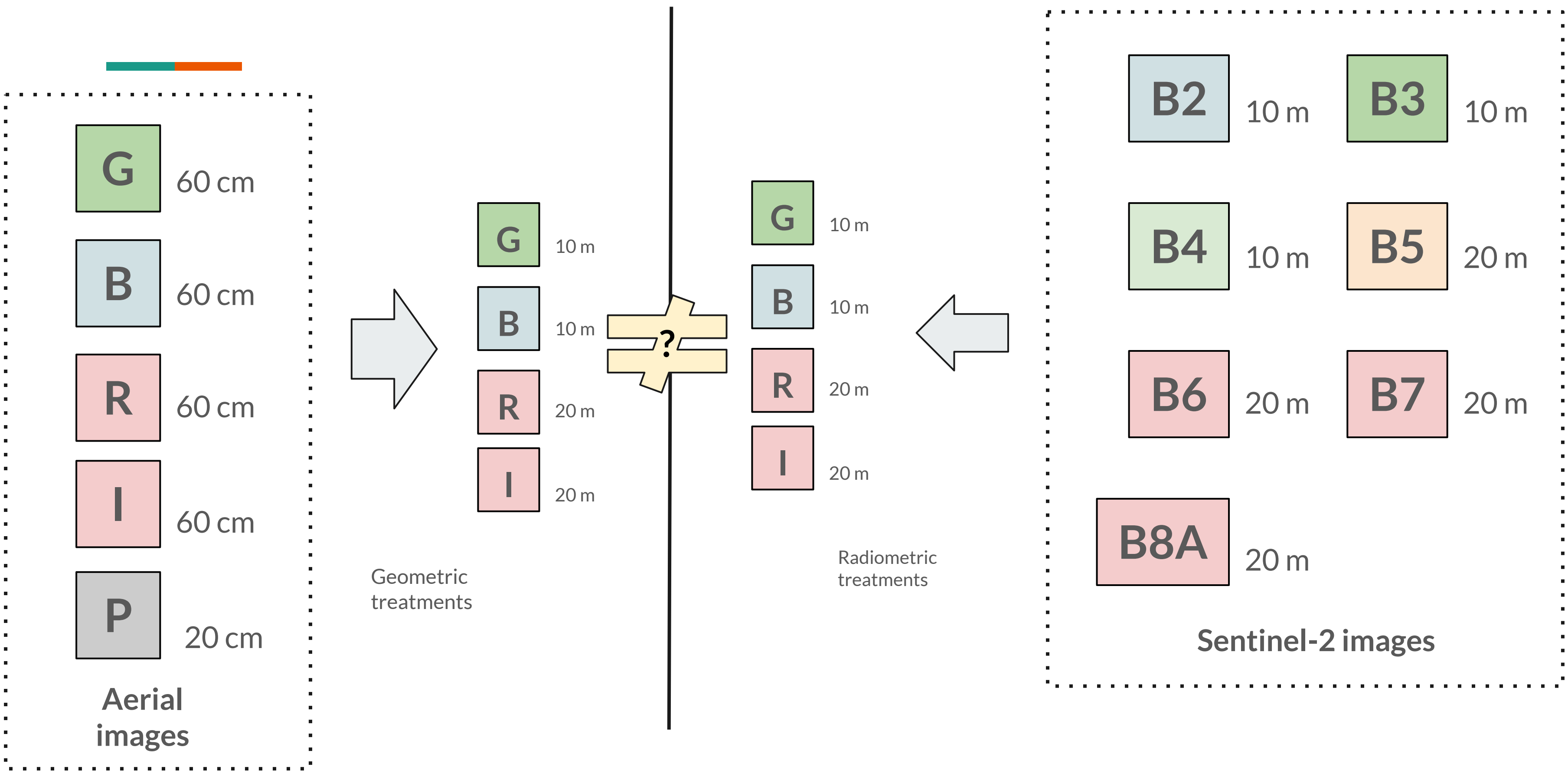
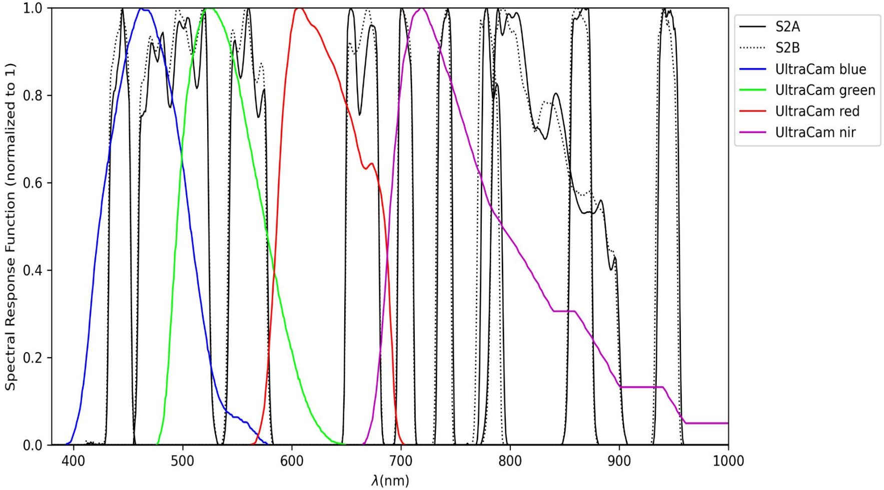


2. Data presentation - fitting together

Radiometric difference



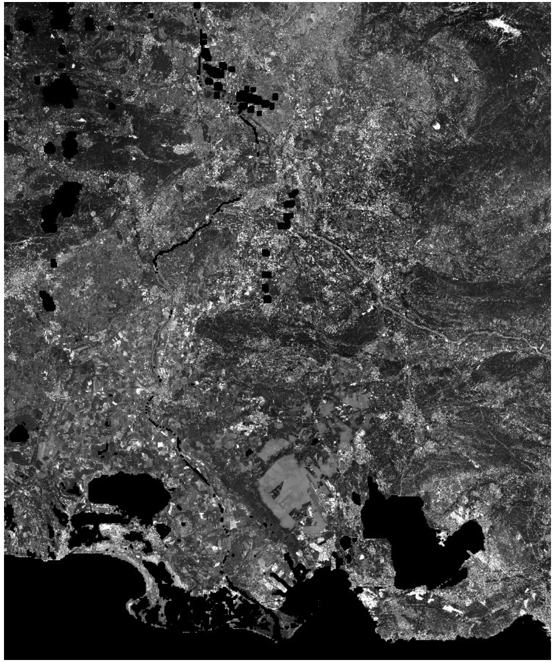
G 60 cm

B 60 cm

I 60 cm

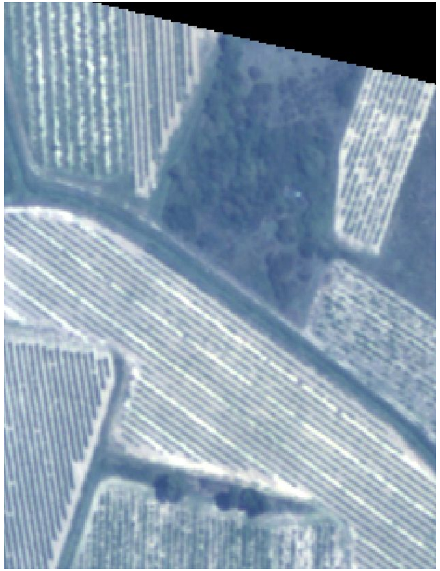
R 60 cm

P 20 cm

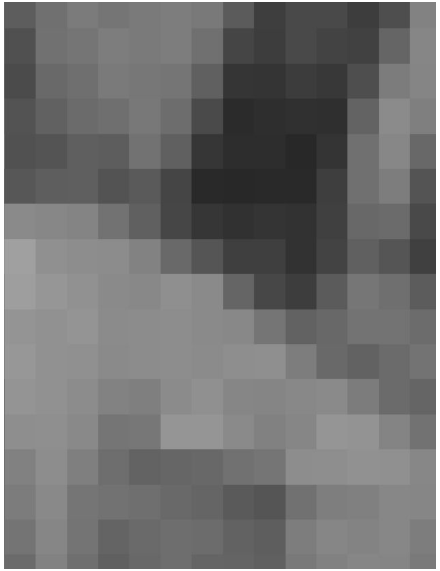


2. Data presentation - fitting together

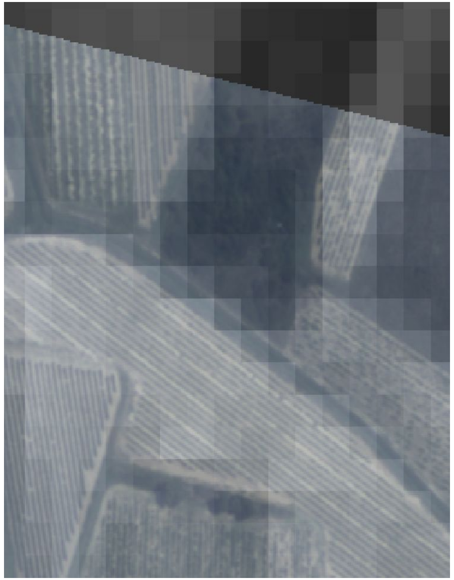
Geometric difference



aerial image (60 cm)

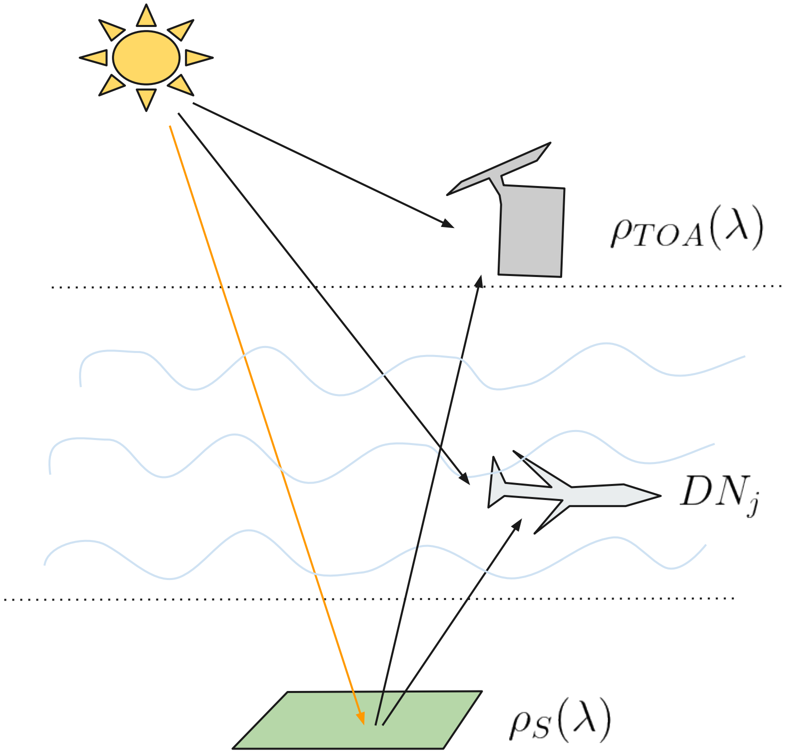


satellite image (10 m)



3. First pipeline - sensor calibration

What are we looking for ?



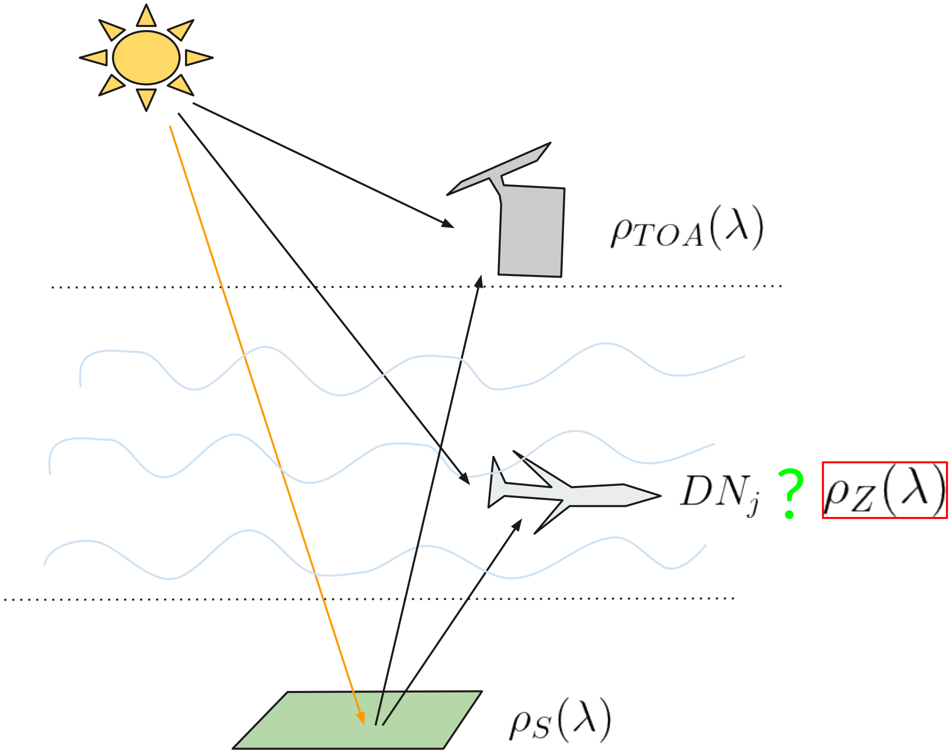
$\rho_{TOA}(\lambda)$: reflectance on Top Of Atmosphere

DN_j : Digital Numbers for RGB NIR bands

$\rho_S(\lambda)$: ground reflectance

3. First pipeline - sensor calibration

What are we looking for ?



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3. First pipeline - sensor calibration

What's the link between reflectance, equalization, satellite and aerial images ?!

(+) Airplane Images depends on the atmospheric conditions, ground reflectance, viewing conditions…

-> … *(-) but the atmosphere conditions changes each day*

(+) Satellite data provides us ground reflectance images and Top Of Atmosphere images

-> … *(-) but this ground reflectance is in a **very particular condition** (viewing angle, time, atmospheric conditions, solar radiance…)*

If we simulate this "very particular condition" for airplane images, we could compare the data !

3. First pipeline - sensor calibration

Hypothesis :

- the sensor is stable and his response is invariant within an acquisition mission
- atmospheric parameters are invariant within a day
- work only on a flat field first

3. First pipeline - sensor calibration

Notations :

Aerial images UltraCam ⇔ UC

Satellite images Sentinel-2 L2A ⇔ S2

3. First pipeline - sensor calibration

Pipeline summary

1. Finding aerial images at the same angular conditions than satellite images
2. Simulate aerial images at the satellite spatial resolution (60cm -> 10m)
3. For the entire satellite acquisition continuous spectrum, simulate atmospheric parameters
4. Simulate for every satellite acquisition bande the reflectance at the airplane sensor level
5. Convert the reflectance at the aerial spectral resolution (to RGB NIR)
6. Calibrate the sensor

3. First pipeline - sensor calibration

1. Finding aerial images

Satellite images acquired at the angular conditions (θ_v, ϕ_v) & (θ_s, ϕ_s)

We choose :

$$t_{UC} = t_{S2} \pm 10minutes$$

$$\theta_{v,UC} = \theta_{v,S2} \pm 5^\circ$$

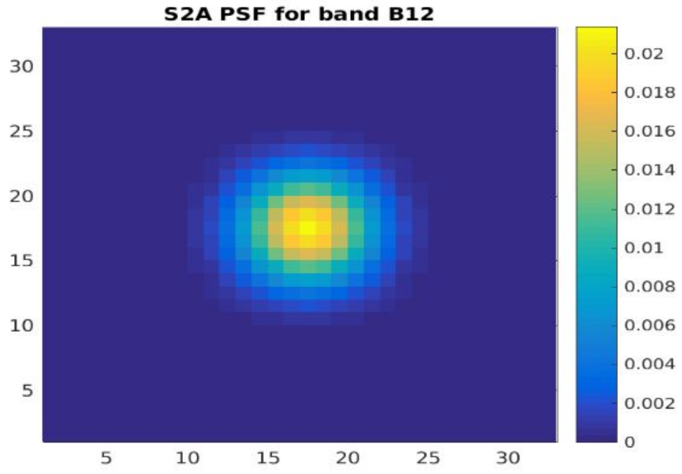
$$\phi_{v,UC} = \phi_{v,S2} \pm 5^\circ$$

3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution

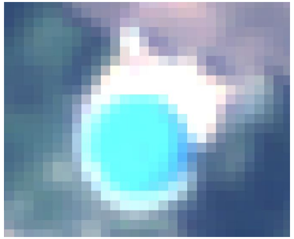
Conversion : ground pixel from 60cm -> 10m et 20m

- **Resample UC à 65cm**
- **for each UC pixels at the S2 resolution, apply PSF**

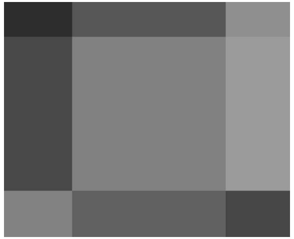


3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution

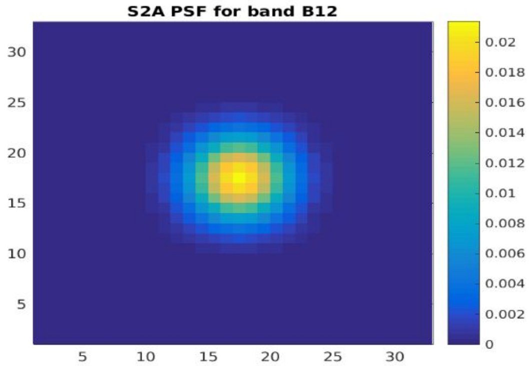


Aerial images (65 cm)



Sentinel-2 images 10 m (& 20 m)

use the Point Spread Function (PSF)



3. First pipeline - sensor calibration

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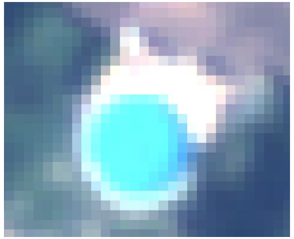

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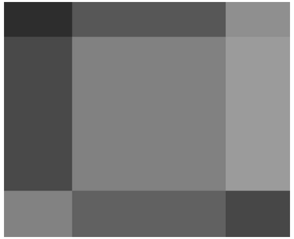

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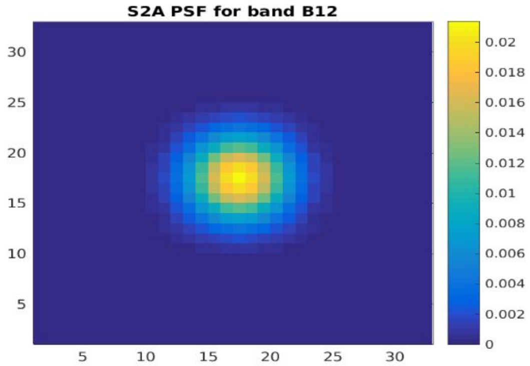
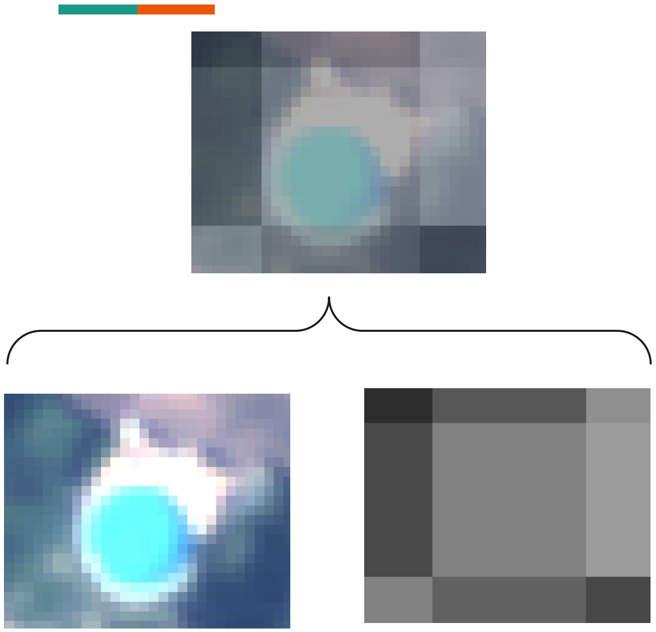


Simulate the PSF for the aerial spectral bands !

3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution



Aerial images (65 cm)

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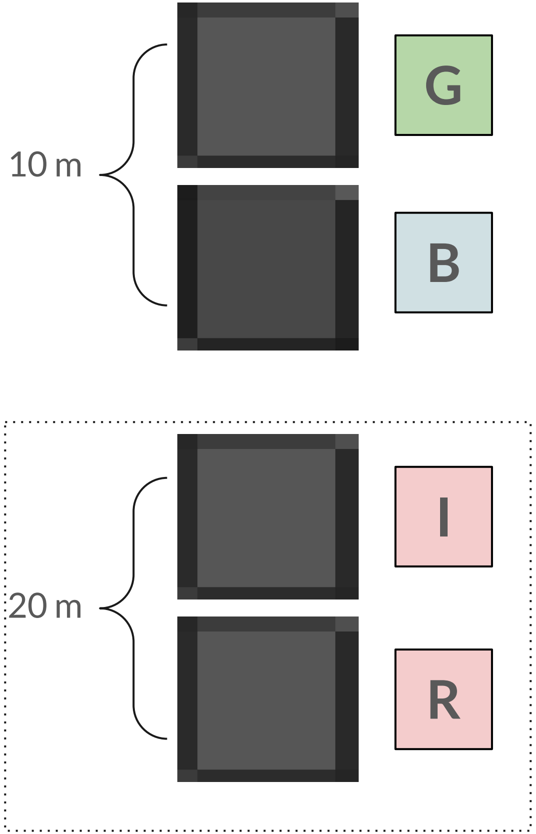
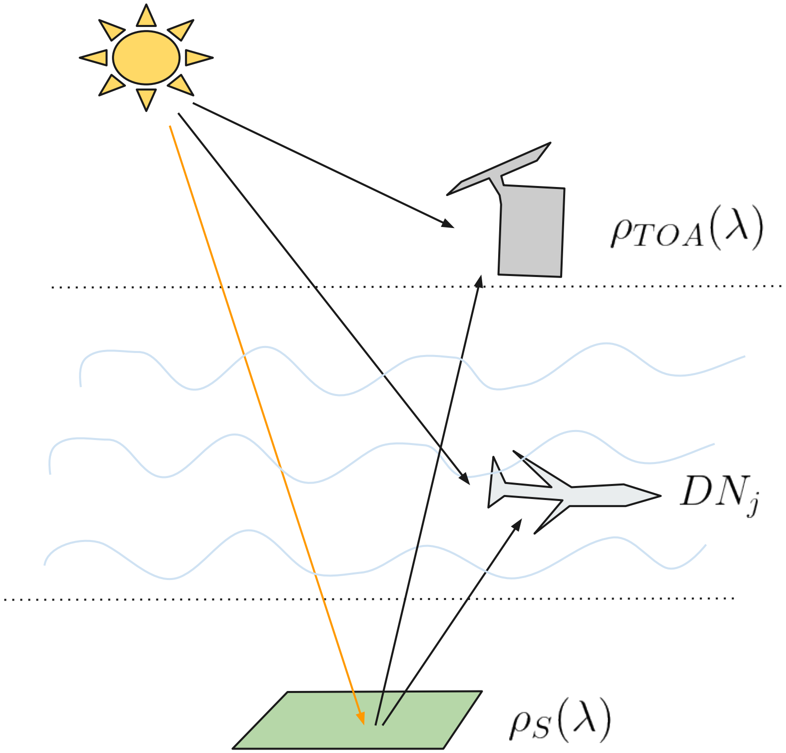


3. First pipeline - sensor calibration

What are we looking for ?



$\rho_{TOA}(\lambda)$: reflectance on Top Of Atmosphere

DN_j : Digital Numbers for RGB NIR bands

$\rho_S(\lambda)$: ground reflectance

3. First pipeline - sensor calibration

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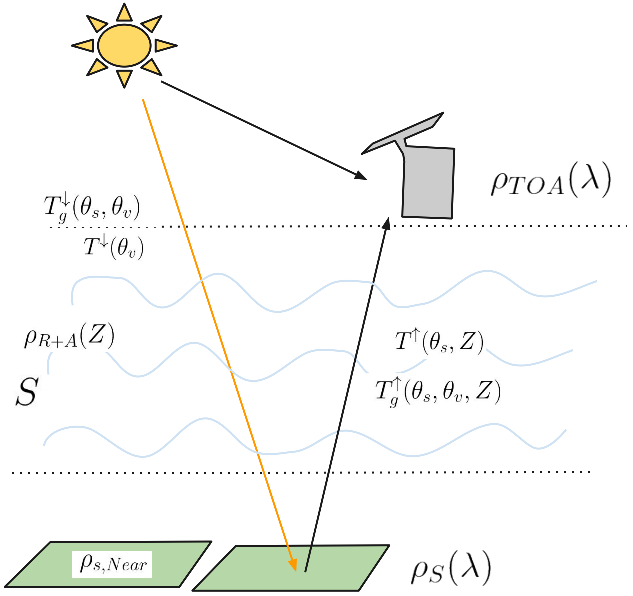


from Vermote et al. (1997)

$$\boxed{\rho_{TOA}(\theta_s, \theta_v, \phi_s - \phi_v) = T_g(\theta_s, \theta_v)[\rho_{R+A} + T^{\uparrow}(\theta_s)T^{\downarrow}(\theta_v)\frac{\rho_s}{1 - S\rho_s})]}$$

$\rho_{TOA}(\lambda)$: reflectance on Top Of Atmosphere

DN_j : Digital Numbers for RGB NIR bands

$\rho_S(\lambda)$: ground reflectance

$\rho_{R+A}(Z)$: intrinsic reflectance of molecular and aerosol layer

$T_g^{\uparrow}(\theta_s, \theta_v, Z)$: ascending gaseous transmission

$T_g^{\downarrow}(\theta_s, \theta_v)$: descending gaseous transmission

$T^{\uparrow}(\theta_s, Z)$: ascending atmospheric transmittance

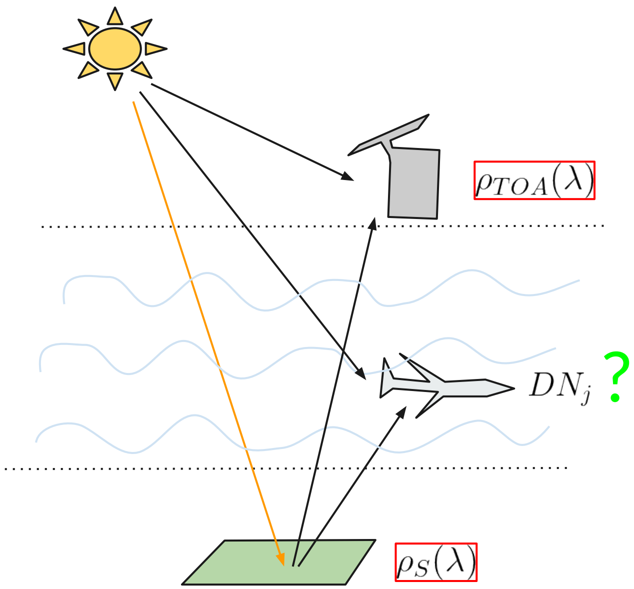
$T^{\downarrow}(\theta_v)$: descending atmospheric transmittance

S : total spherical atmospheric albedo

$\rho_{s,Near}$: neighbours reflectance contribution

3. First pipeline - sensor calibration

What are we looking for ?



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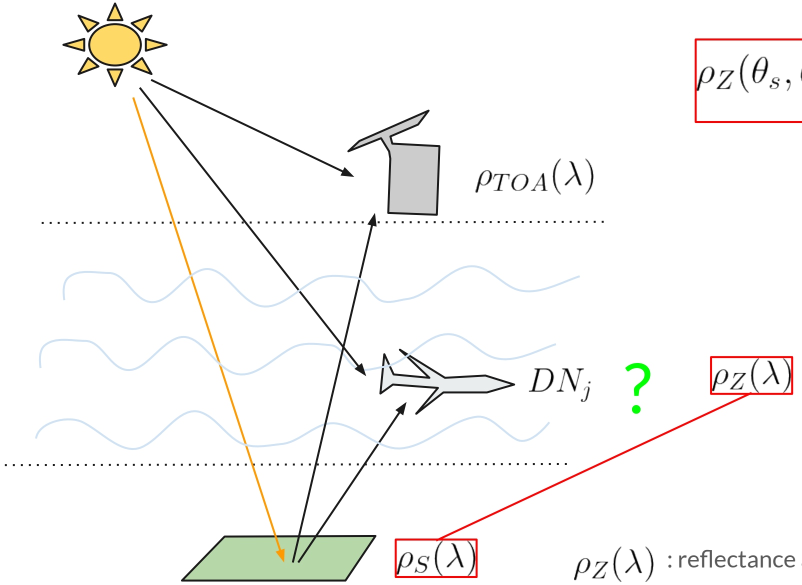

We work at the aerial altitude !

-> the ascending and descending light path are different, so the model becomes :

$$\boxed{\rho_Z(\theta_s, \theta_v, \phi_s - \phi_v) = T^{\uparrow}_{g,Z}(\theta_v) T^{\downarrow}_{g,Z}(\theta_s)[\rho_{R+A,Z} + T^{\uparrow}_Z(\theta_v) T^{\downarrow}_Z(\theta_s) \frac{\rho_s}{1 - S\rho_{s,Near}})]}$$

$\rho_Z(\lambda)$: reflectance at altitude Z

$\rho_{TOA}(\lambda)$: reflectance on Top Of Atmosphere

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from Vermote et al. (1997)

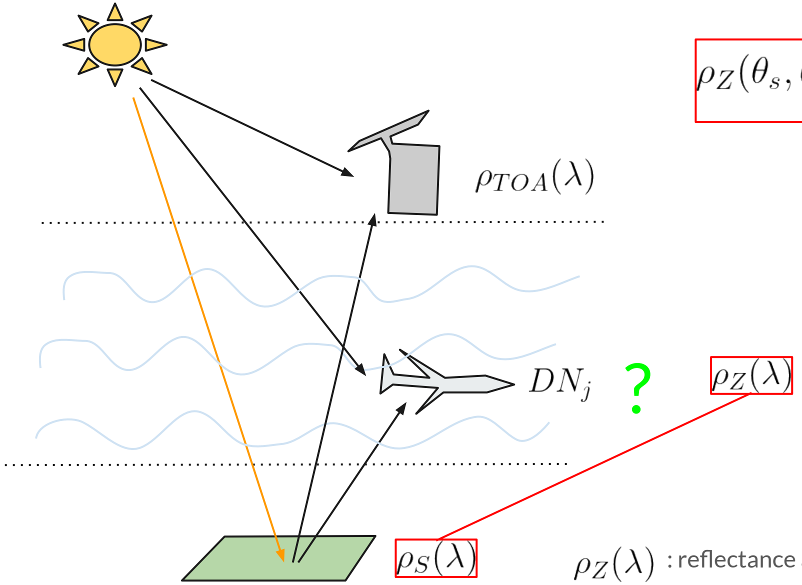
3. First pipeline - sensor calibration

4. Simulate Top Of Atmosphere reflectance for each S2 band

We work at the aerial altitude !

-> the ascending and descending light path are different, so the model becomes :

$$\boxed{\rho_Z(\theta_s,\theta_v,\phi_s-\phi_v) = T^{\uparrow}_{g,Z}(\theta_v)T^{\downarrow}_{g,Z}(\theta_s)[\rho_{R+A,Z}+T^{\uparrow}_{Z}(\theta_v)T^{\downarrow}_{Z}(\theta_s)\frac{\rho_s}{1-S\rho_{s,Near}})]}$$



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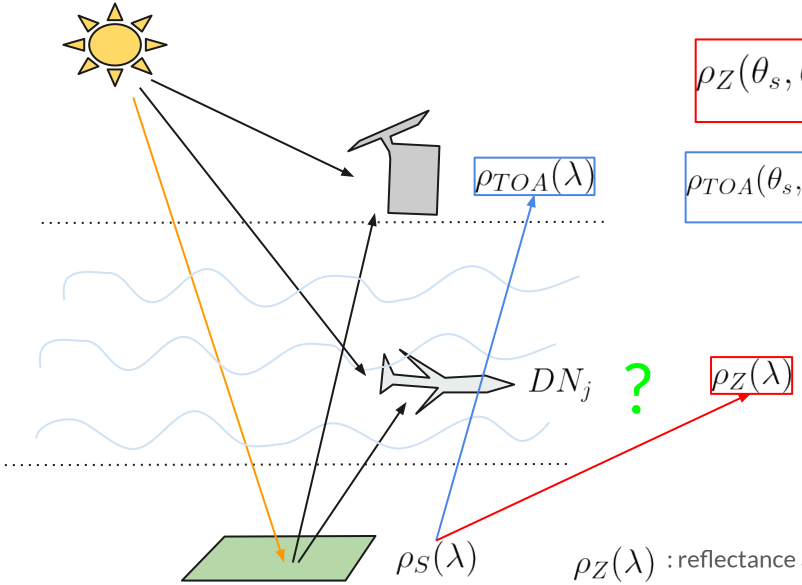

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What are we looking for ?

We work at the aerial altitude !

-> the ascending and descending light path are different, so the model becomes :

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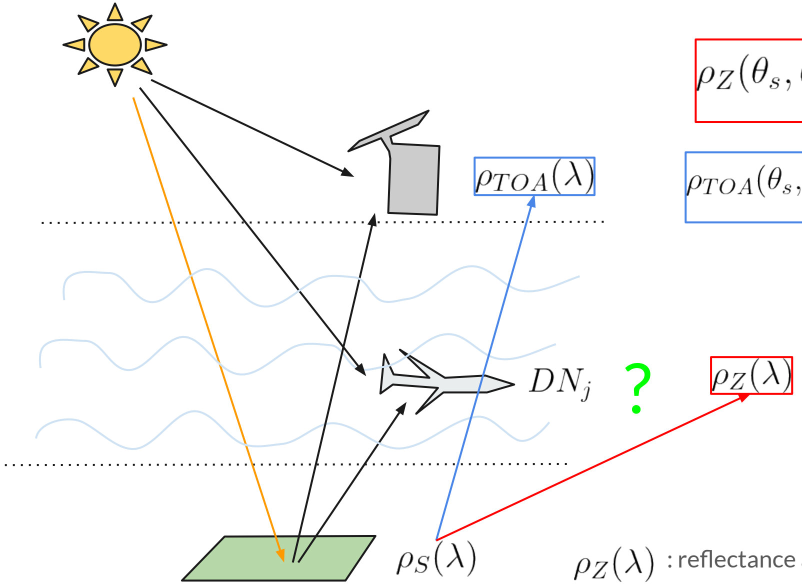

$\rho_S(\lambda)$

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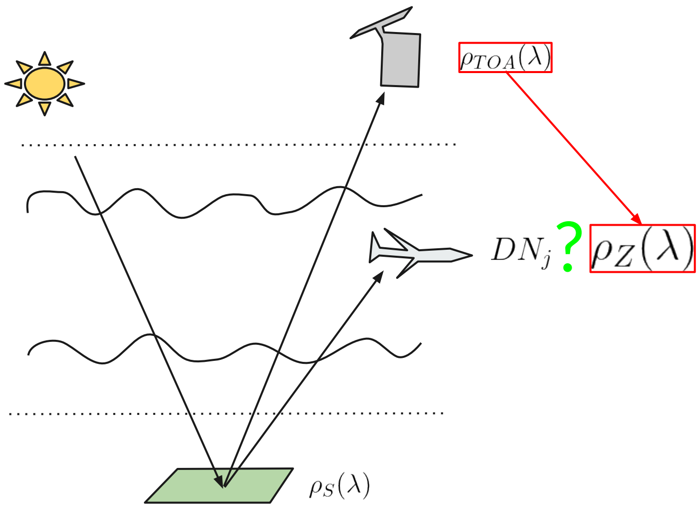
from Vermote et al. (1997)

3. First pipeline - sensor calibration

3. Simulate atmospheric parameters



We work at the aerial altitude !

-> the ascending and descending light path are different, so the model becomes :

$$\boxed{\rho_Z = T^{\uparrow}_{g,Z} T^{\downarrow}_{g,Z} \left(\rho_{R+A,Z} - \frac{T^{\uparrow}_{Z} T^{\downarrow}_{Z}}{T^{\uparrow}_{TOA} T^{\downarrow}_{TOA}} \rho_{R+A,Z}\right) + \frac{T^{\uparrow}_{g,Z} T^{\downarrow}_{g,Z} T^{\uparrow}_{Z} T^{\downarrow}_{Z}}{T^{\uparrow}_{g,TOA} T^{\downarrow}_{g,TOA} T^{\uparrow}_{TOA} T^{\downarrow}_{TOA}} \rho_{TOA}}$$

$$\sim$$

$$\boxed{\rho_Z = A * \rho_{TOA} + B}$$

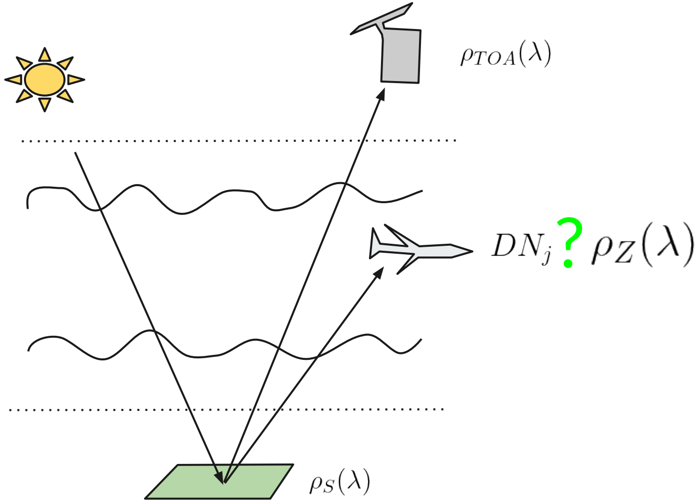
-> Simulate (with 6S tool) all the atmospheric parameters (Tz, Tg,z...) for Z=airplane altitude and Z=satellite altitude

-> now $\rho_Z(\lambda)$ must be simulated for the aerial spectral bands (RGB-NIR)

from Vermote et al. (1997)

3. First pipeline - sensor calibration

4. Simulate reflectance for each S2 band at the airplane altitude



Quick reminder :

We try to compare the DN from airplane with reflectance at the airplane altitude, to calibrate the sensor.

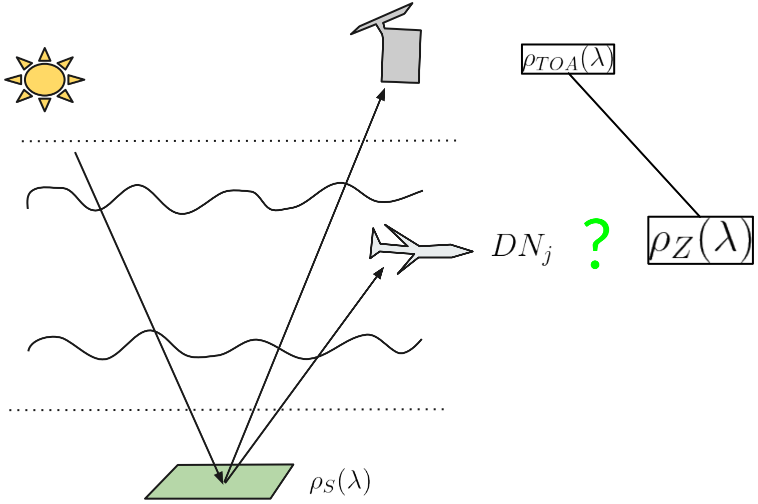
For every pixel, we want the DN to be equal to the reflectance (calibration).

But we have a reflectance for the continuous spectrum, impossible to compare with the DN number (4 spectral bands)

from Vermote et al. (1997)

3. First pipeline - sensor calibration

4. Simulate reflectance for each S2 band at the airplane altitude



$$\rho_{Z,j\in[RGBI]} = \int \rho_Z(\lambda) * f_j(\lambda) d\lambda$$

$$\rho_{Z,j\in[RGBI]}$$

$$\uparrow$$

$$\rho_Z(\lambda)$$

$$\uparrow$$

$$\rho_{TOA}(\lambda)$$

3. First pipeline - sensor calibration

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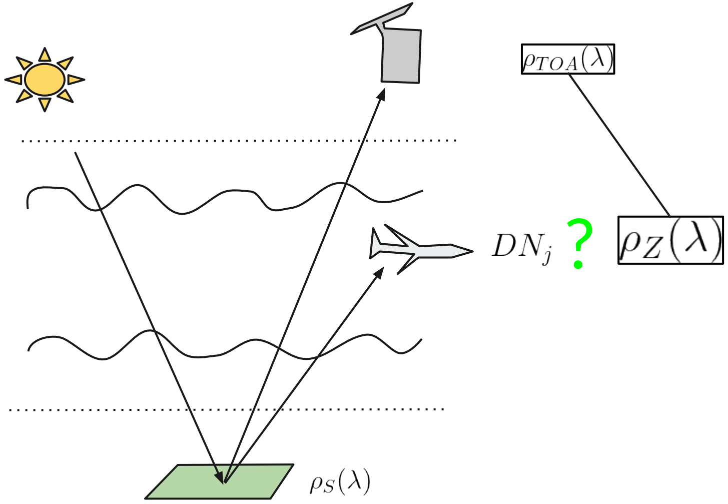


$$\cancel{\rho_{Z,j\in[RGBI]} = \int \rho_Z(\lambda) * f_j(\lambda) d\lambda}$$

$\rho_{Z,j\in[RGBI]}$

$f_j(\lambda)$

unknown !

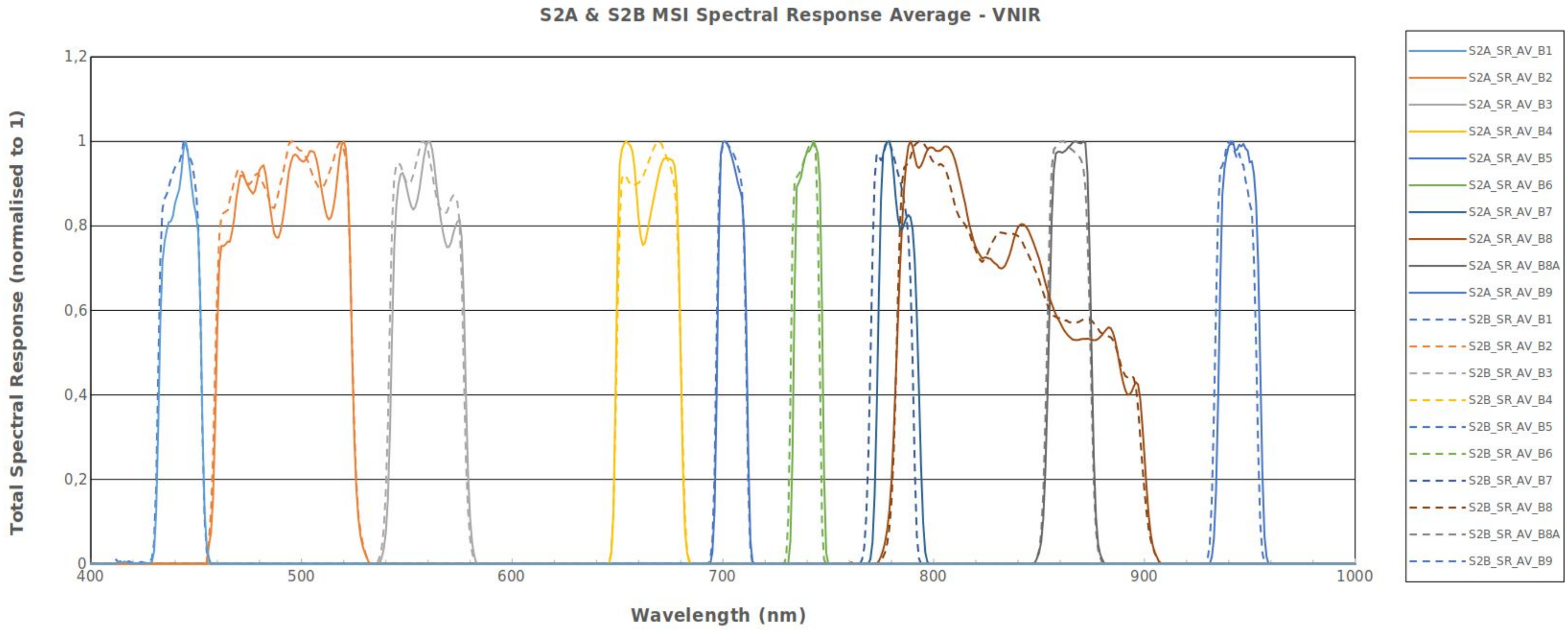
$\rho_Z(\lambda)$

$\rho_{TOA}(\lambda)$

3. First pipeline - sensor calibration

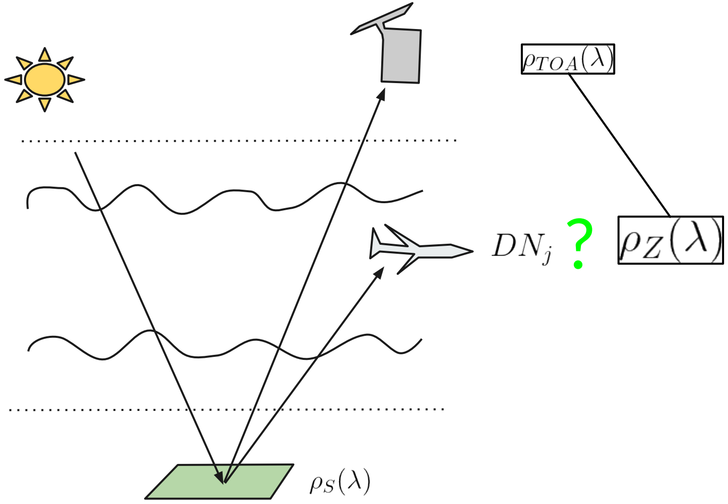
4. Simulate reflectance for each S2 band at the airplane altitude

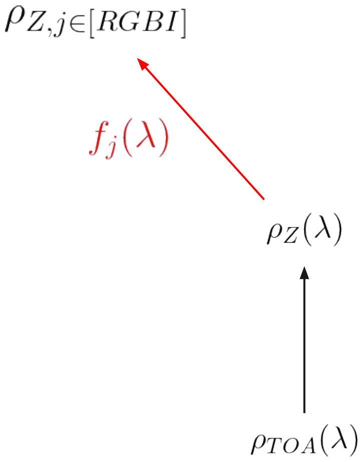
We can simulate 1 reflectance per Satellite band !



3. First pipeline - sensor calibration

4. Simulate reflectance for each S2 band at the airplane altitude





$M_{i\to j}$: pass matrix from S2 spectral bands to aerial bands

$\rho_{Z,j}$: reflectance at Z altitude for aerial spectral bands (RGB-NIR)

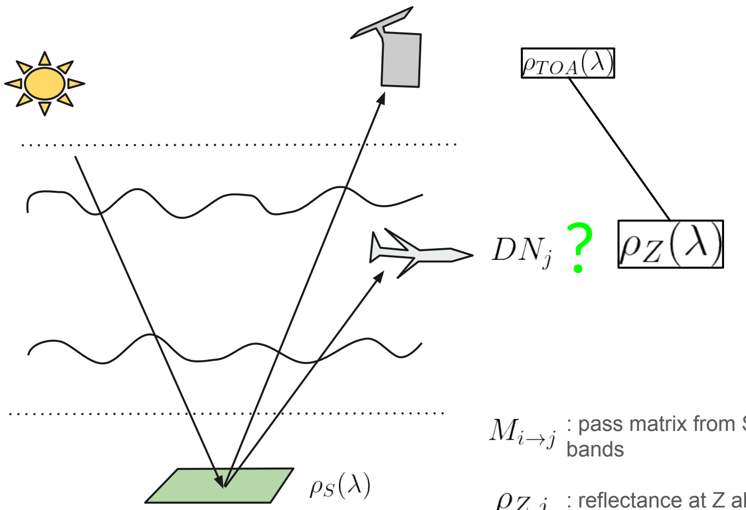
$\rho_{Z,i}$: reflectance at Z altitude for satellite spectral bands

$f_i(\lambda)$: spectral response function of the satellite sensors bands

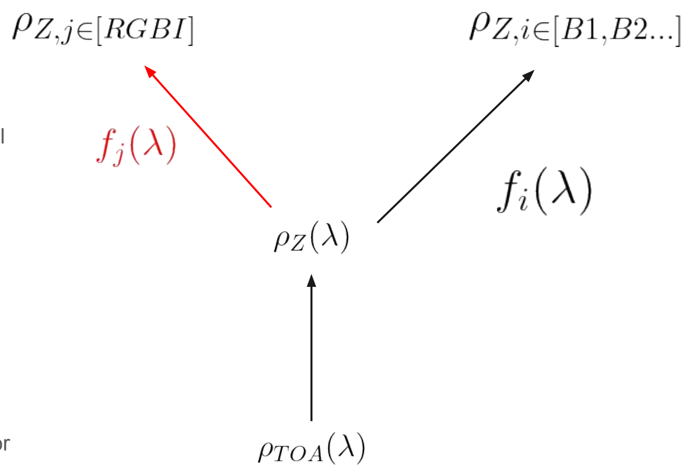
$f_j(\lambda)$: spectral response function of UC sensors for reflectance

3. First pipeline - sensor calibration

4. Simulate reflectance for each S2 band at the airplane altitude



$$\rho_{Z,i\in[B1,B2...]} = \int \rho_Z(\lambda) * f_i(\lambda) d\lambda$$



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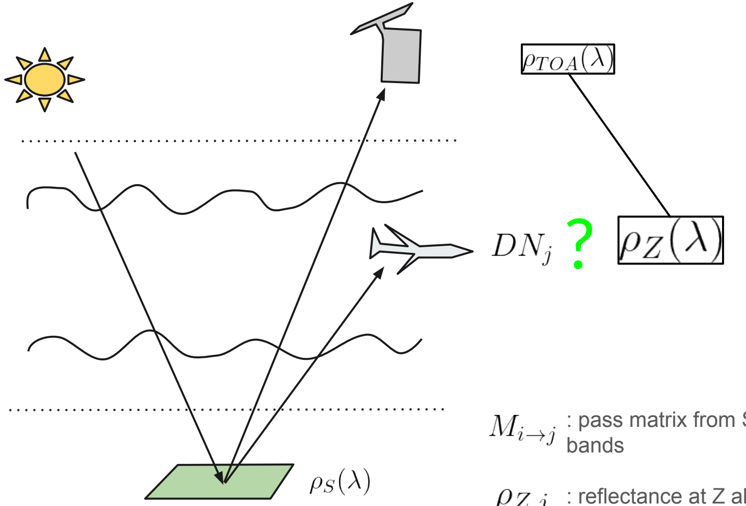
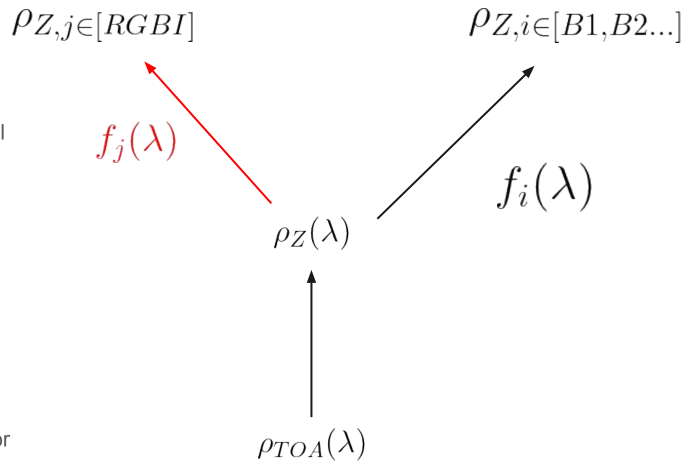
3. First pipeline - sensor calibration

4. Simulate reflectance for each S2 band at the airplane altitude



$$\rho_Z(\lambda_i) = \frac{\int_{\lambda_{i-1}}^{\lambda_{i+1}} \rho_Z(\lambda).f(\lambda)d\lambda}{\int_{\lambda_{i-1}}^{\lambda_{i+1}} f(\lambda)d\lambda} \sim \frac{\sum_{k=i}^{N} \rho_Z(\lambda_k) * f(\lambda_k)}{\sum_{k=i}^{N} f(\lambda_k)}$$



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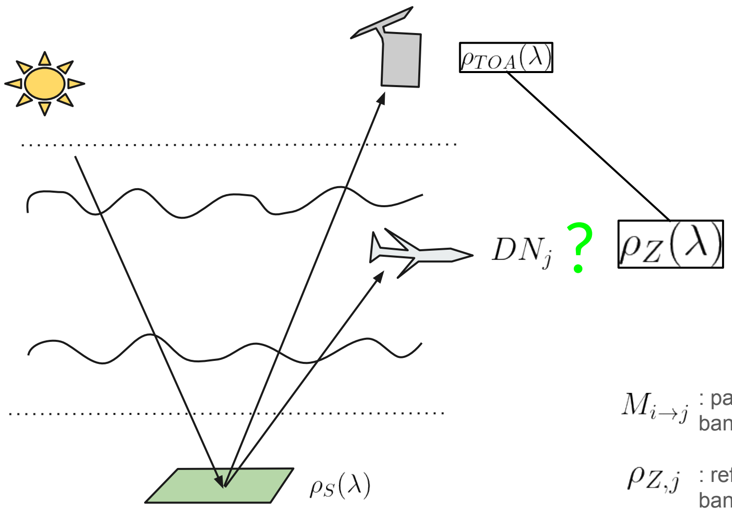
3. First pipeline - sensor calibration

5. Convert the reflectance at the airplane spectral resolution (to RGBI)



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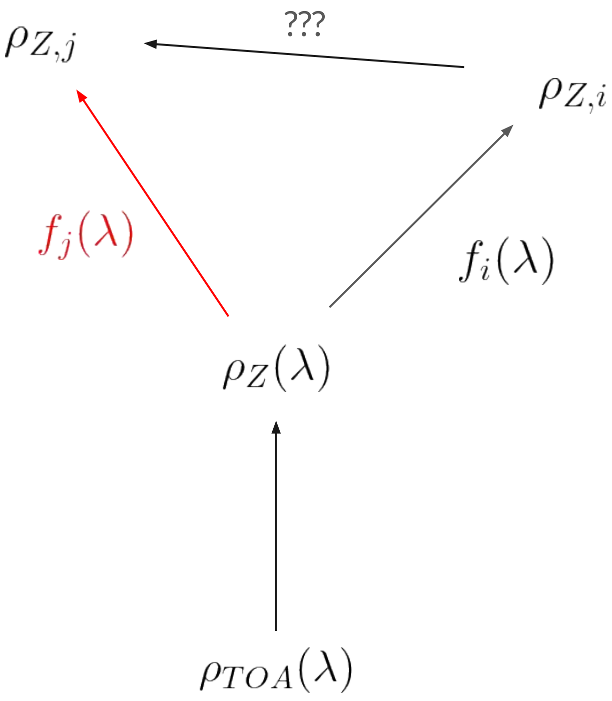

3. First pipeline - sensor calibration

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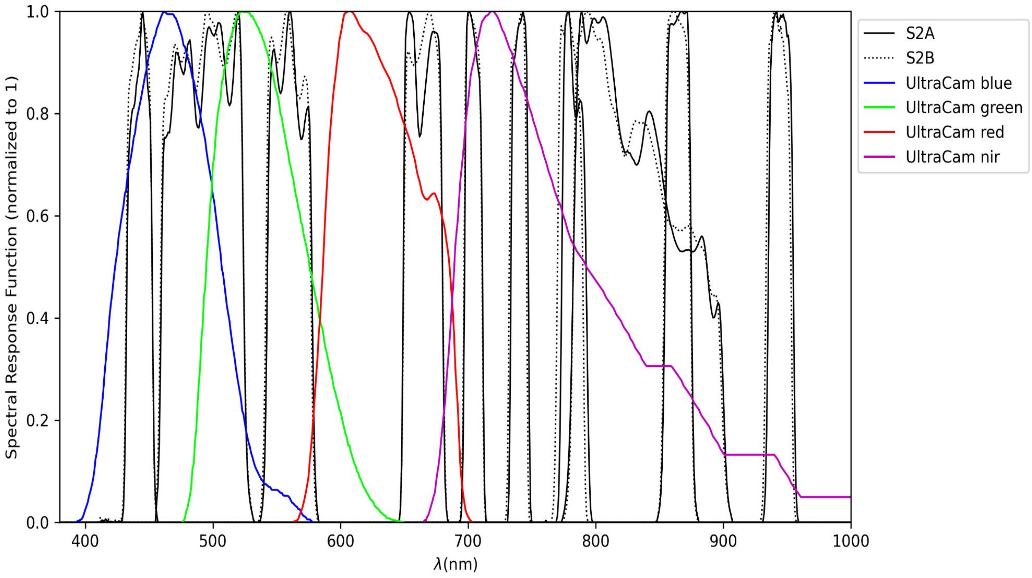

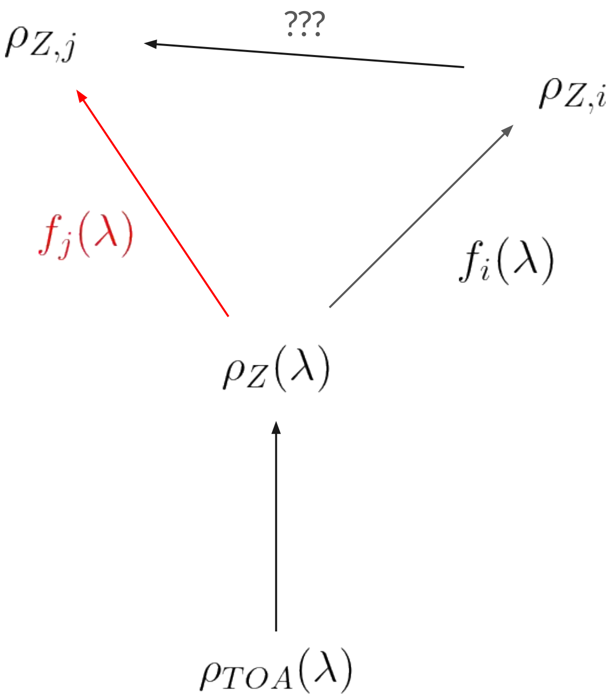

3. First pipeline - sensor calibration

5. Convert the reflectance at the airplane spectral resolution (to RGBI)

To calibrate the UC sensor, we need the S2 reflectance map to be at the same resolution :

-> We simulate the S2 reflectance at the 4 spectral bands resolution

$$\rho_{Z,BLUE} = \sum_{i}^{N} a_{BLUE,i} * \rho_{Z,B_i}$$

$$\rho_{Z,GREEN} = \sum_{i}^{N} a_{GREEN,i} * \rho_{Z,B_i}$$

$$\rho_{Z,RED} = \sum_{i}^{N} a_{RED,i} * \rho_{Z,B_i}$$

$$\rho_{Z,NIR} = \sum_{i}^{N} a_{NIR,i} * \rho_{Z,B_i}$$

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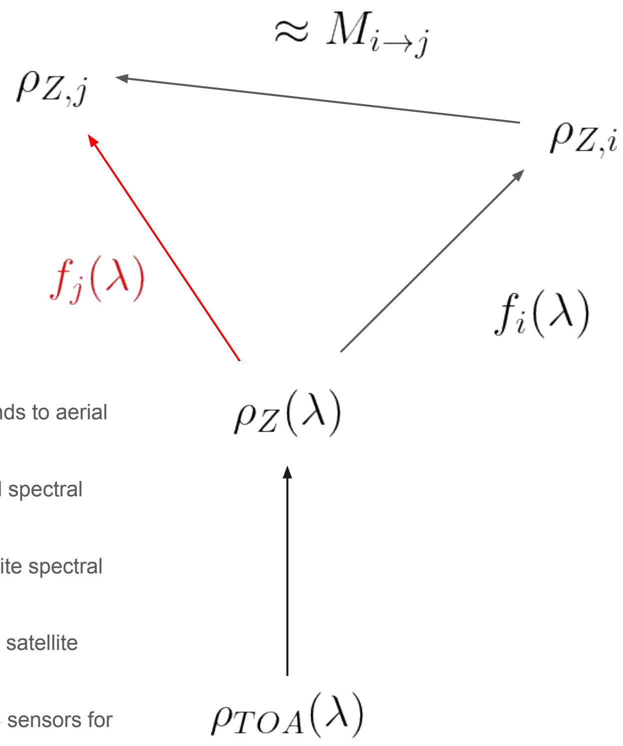

3. First pipeline - sensor calibration

6. Sensor calibration

We suppose

$$\forall \lambda \in [G, B, R, NIR], \exists (C_\lambda, B_\lambda, A_\lambda) \in \mathbb{R}^3$$

$$DN_\lambda = C_\lambda \cdot \rho_{TOA,\lambda} + B_\lambda$$

or

$$DN_\lambda = C_\lambda^2 \cdot \rho_{TOA,\lambda} + B_\lambda \cdot \rho_{TOA,\lambda} + A_\lambda$$

$$\begin{tikzcd}
DN_j \arrow[dr, leftrightarrow] & & & \\
& \rho_{Z,j} & & \rho_{Z,i} \arrow[ll, "\approx M_{i \to j}"'] \\
& & \rho_Z(\lambda) \arrow[ul, "f_j(\lambda)"] \arrow[ur, "f_i(\lambda)"'] & \\
& & \rho_{TOA}(\lambda) \arrow[u] &
\end{tikzcd}$$

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4. Results

TODO

thank you for listening :)