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

…the first six months of my PhD

Alexane Alice Nghien - Univ Gustave Eiffel, ENSG, IGN, LASTIG

supervised by Mathieu Brédif, Manchun Lei & Marc Pierrot-Deseilligny

Summary

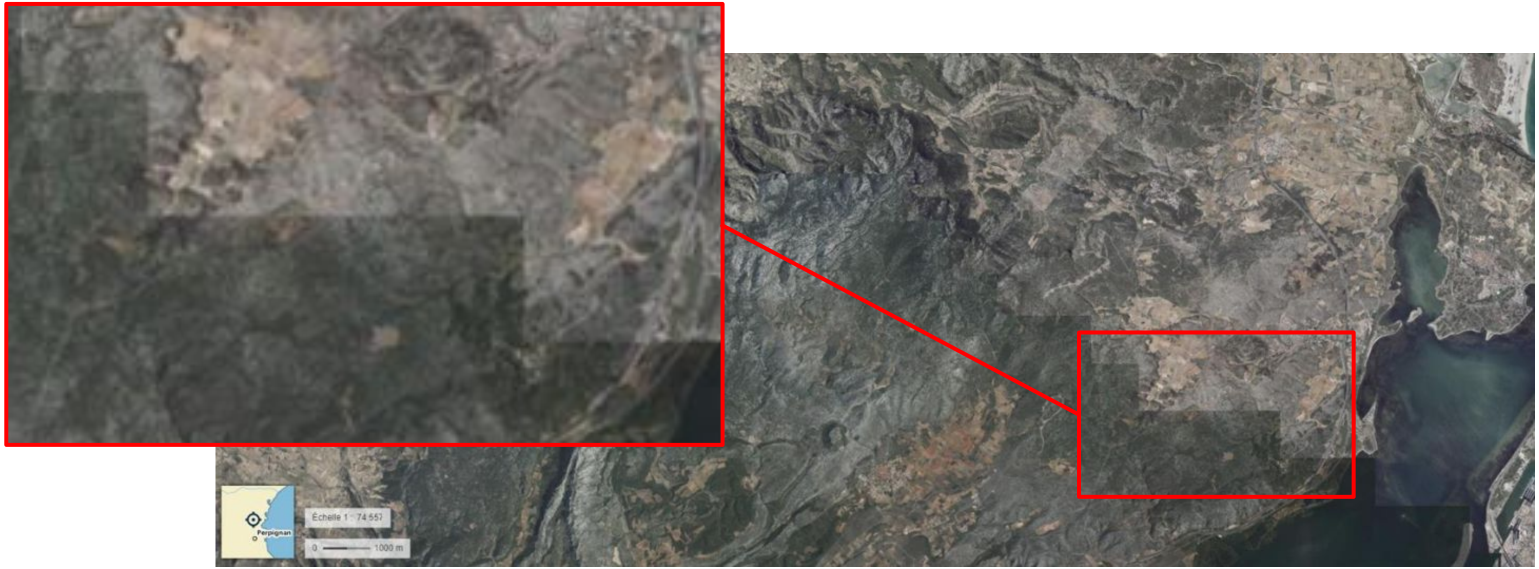
1. Context
2. Data presentation
3. First pipeline (sensor calibration)
4. First result - to come

1. Context

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

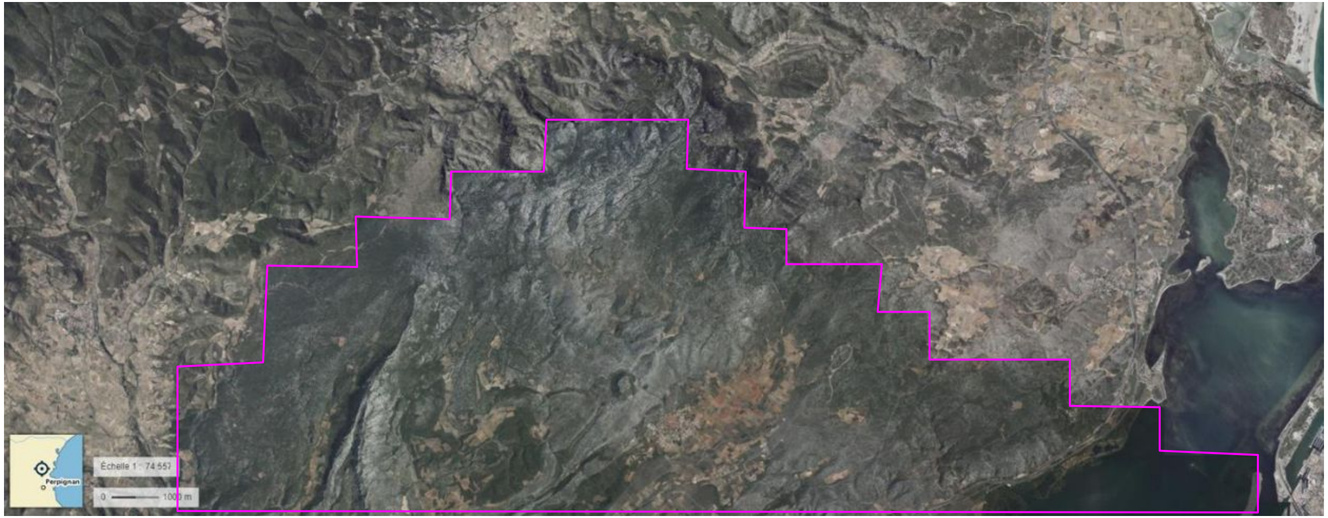
1. Context

"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 :

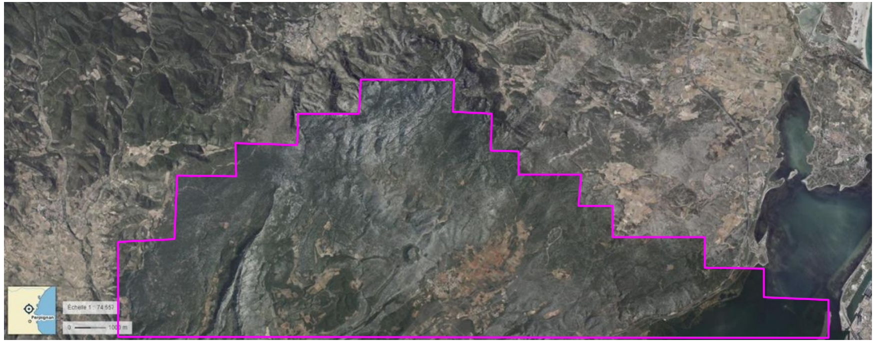
1. Context

“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

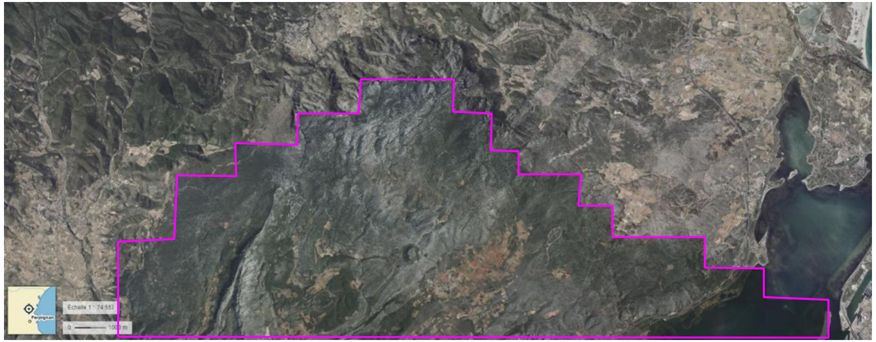
Pb : acquisition conditions changes (atmospheric conditions changes), sensor calibration is also relative to a block



1. Context

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

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

Ground reflectance

Aerial image

1. Context

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

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

-> physical approach

Ground reflectance

Aerial image

1. Context

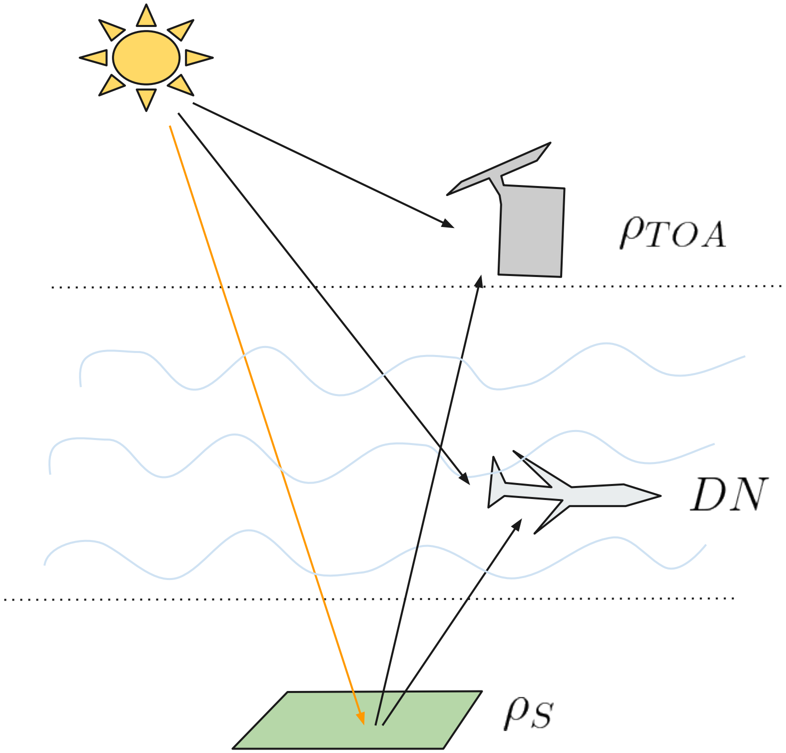
Notations :

Aerial images UltraCam ⇔ UC

Satellite images Sentinel-2 L2A ⇔ S2

1. Context

Physical approach



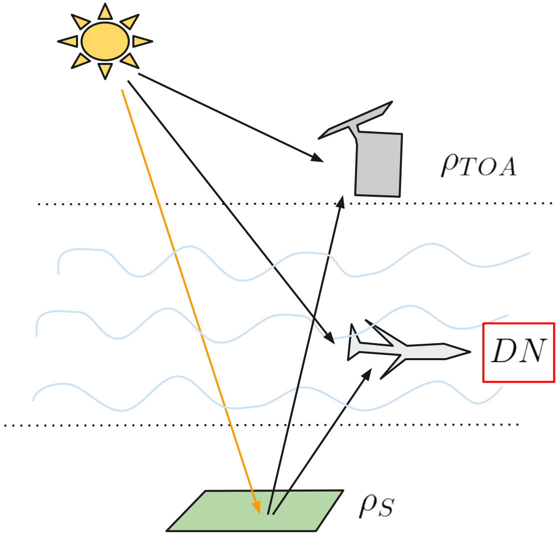
ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

2. Data presentation

Aerial images - UltraCam (IGN)

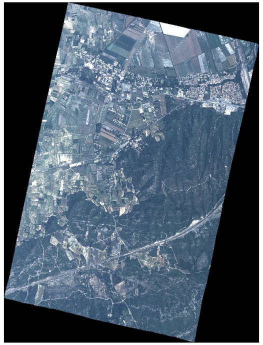


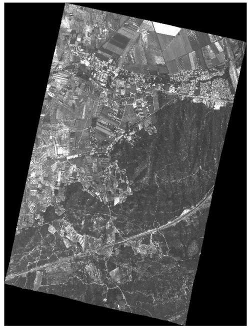
B 60 cm

G 60 cm

R 60 cm

I 60 cm



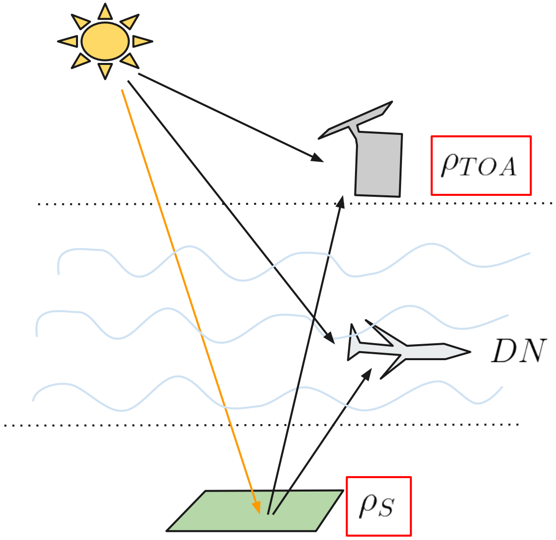


P 20 cm

2. Data presentation

Sentinel-2 Images

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



B2 10 m

B3 10 m

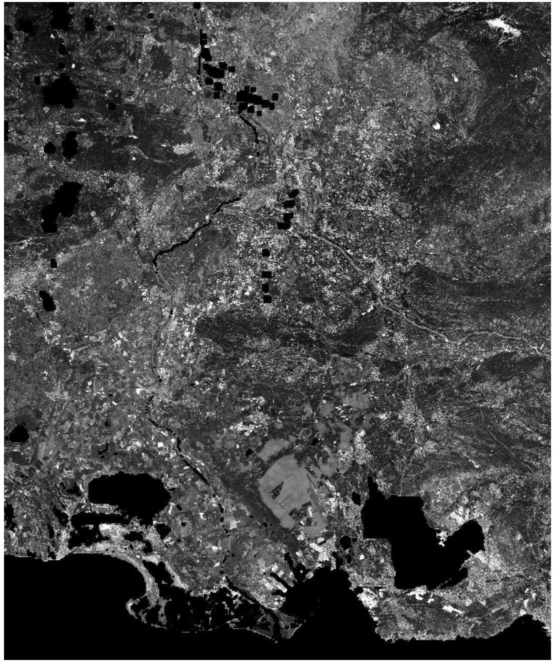
B4 10 m

B5 20 m

B6 20 m

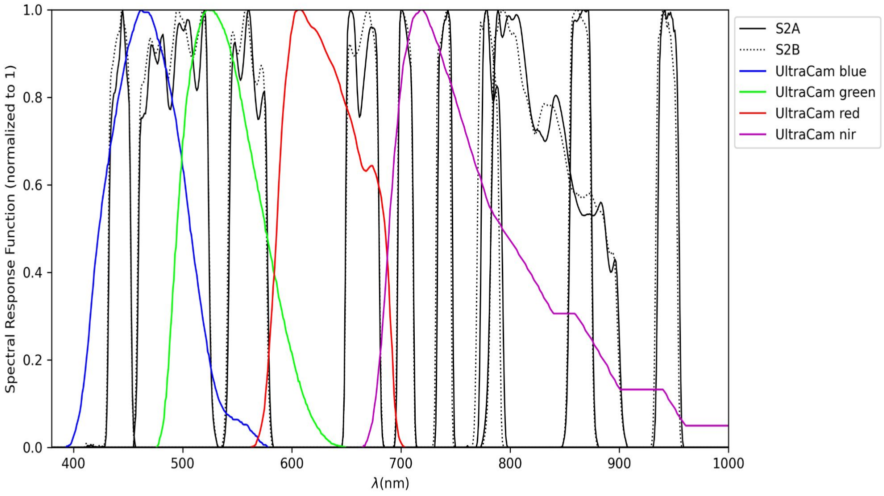
B7 20 m

B8A 20 m



2. Data presentation - differences

Radiometric difference

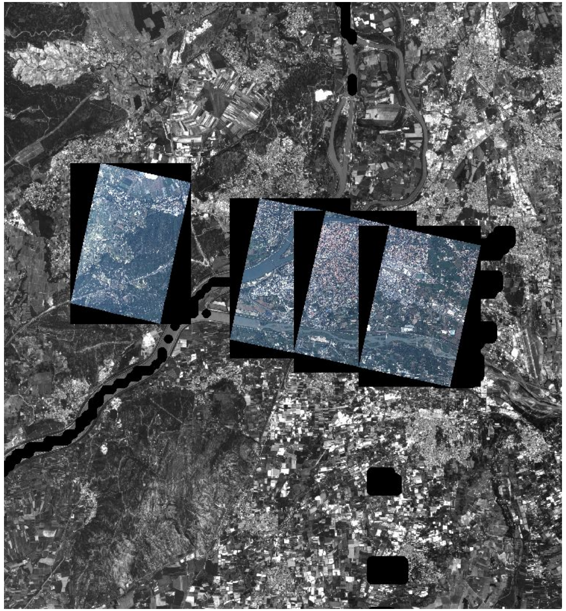


B 60 cm

G 60 cm

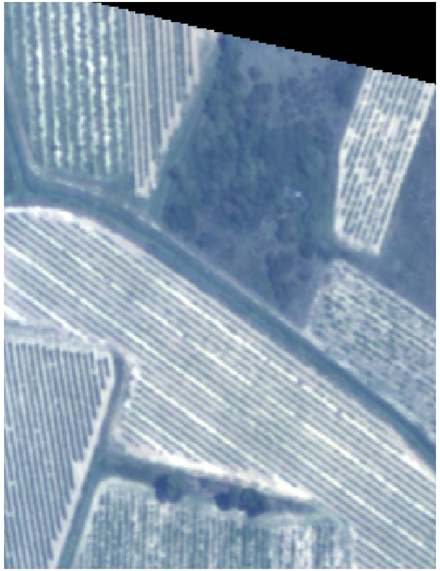
R 60 cm

I 60 cm

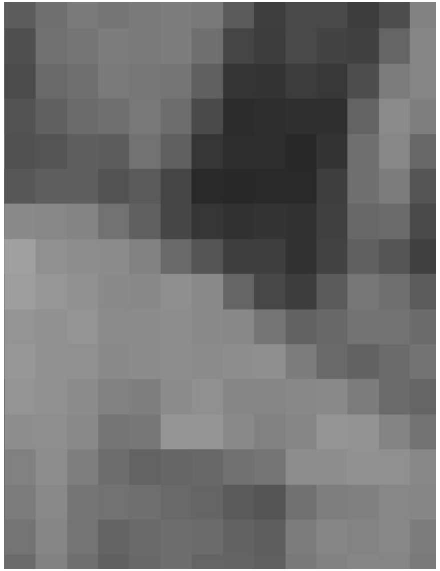


2. Data presentation - differences

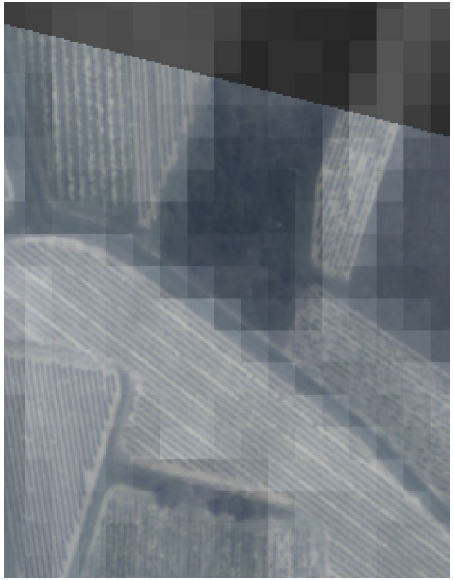
Geometric difference



aerial image (60 cm)

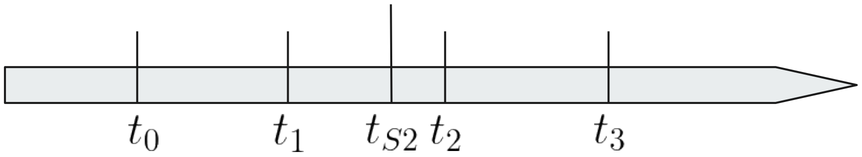


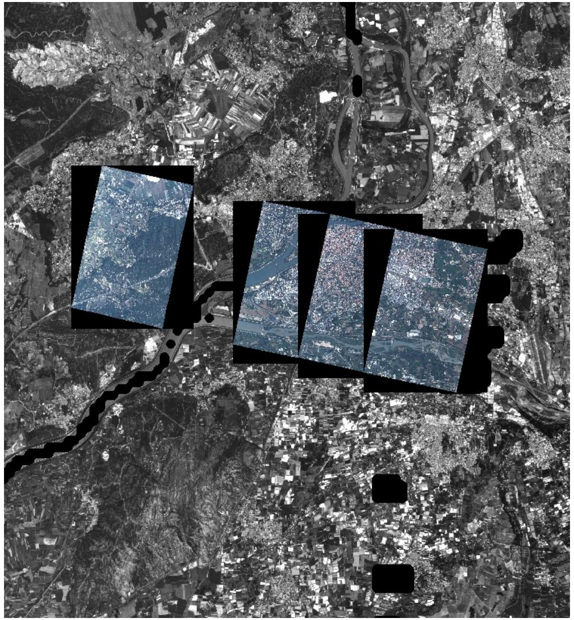
satellite image (10 m)



2. Data presentation - differences

Acquisition differences



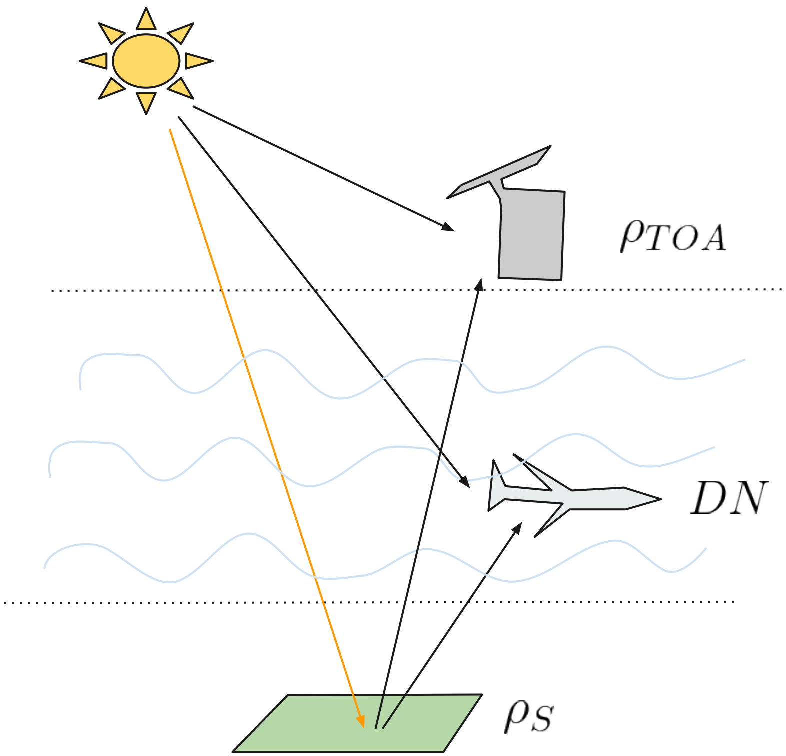


t_0 t_1 t_2 t_3 : time of acquisition of aerial images

t_{S2} : time of acquisition of satellite image

3. First pipeline - sensor calibration

What are we looking for ?



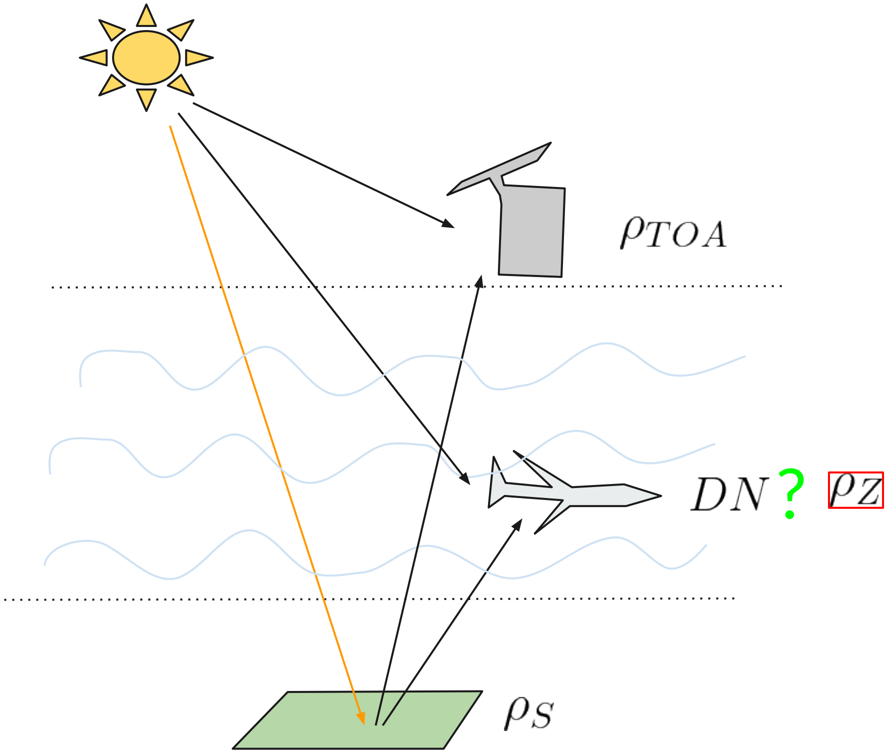
ρ_{TOA} : reflectance on Top Of Atmosphere

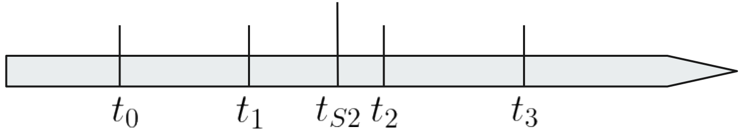
DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

3. First pipeline - sensor calibration

What are we looking for ?





t_0 t_1 t_2 t_3 : time of acquisition of aerial images

t_{S2} : time of acquisition of satellite image

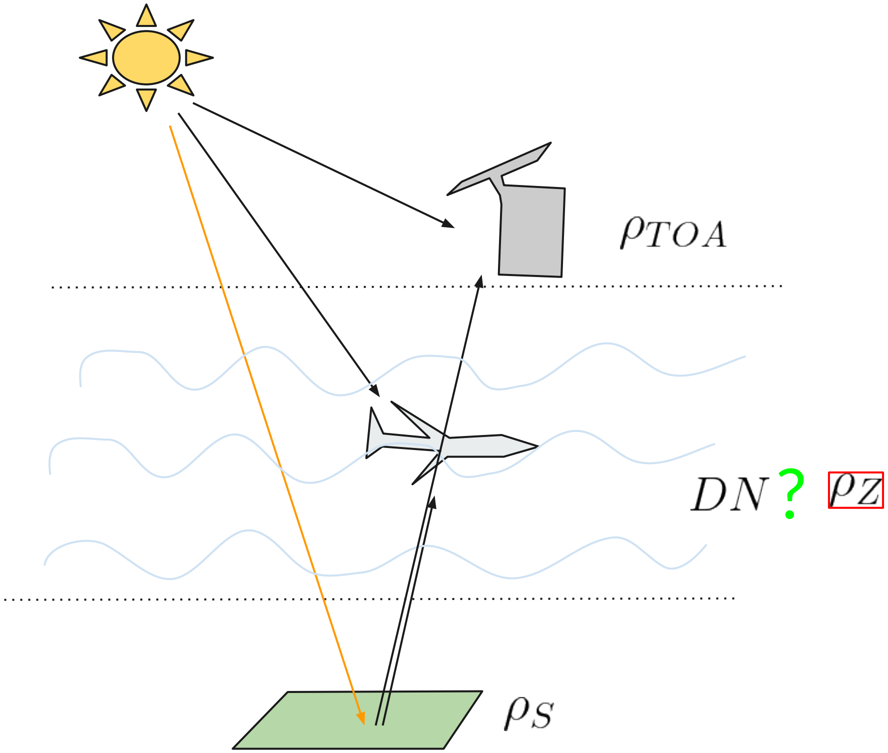
ρ_{TOA} : reflectance on Top Of Atmosphere

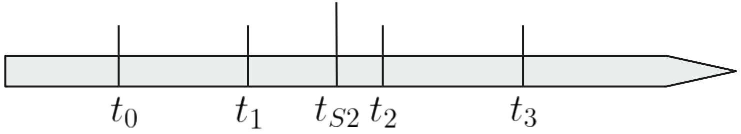
DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

3. First pipeline - sensor calibration

What are we looking for ?





$t_0 \;\; t_1 \;\; t_2 \, t_3$: time of acquisition of aerial images

t_{S2} : time of acquisition of satellite image

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

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 the reflectance at the airplane sensor level for every satellite acquisition bande
5. Convert the reflectance at the aerial spectral resolution (to RGB NIR)
6. Calibrate the sensor

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

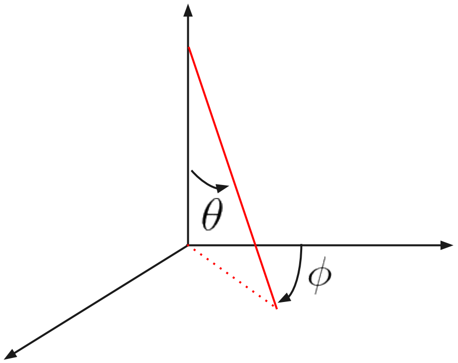
1. Finding aerial images

Satellite images acquired at the angular conditions (θ_{S2}, ϕ_{S2})

Aerial images acquired at the angular conditions (θ_{UC}, ϕ_{UC})

We choose :

$$t_{UC} = t_{S2} \pm 10minutes$$
$$\delta = cos^{-1}(cos(\theta_{S2})cos(\theta_{UC}) + sin(\theta_{S2})sin(\theta_{UC})cos(|\phi_{S2} - \phi_{UC}|))$$
$$\delta \leq 5^\circ$$

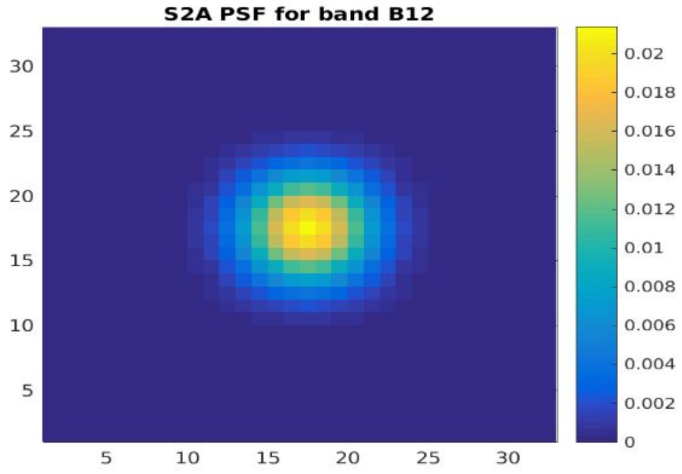


3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution

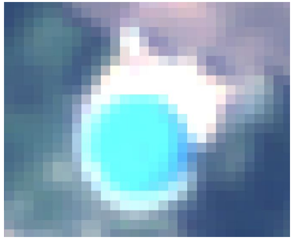
Conversion : ground pixel from 60cm -> 10m et 20m

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

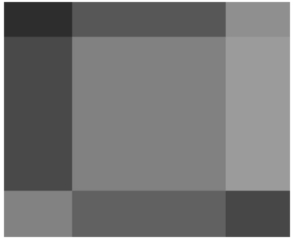


3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution

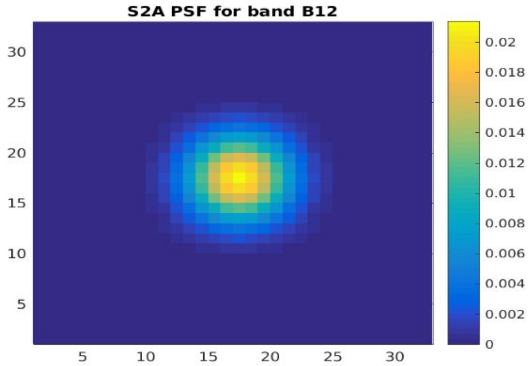


Aerial images (65 cm)



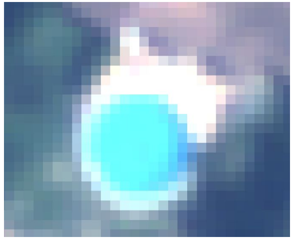
Sentinel-2 images
10 m (& 20 m)

use the Point Spread Function (PSF)

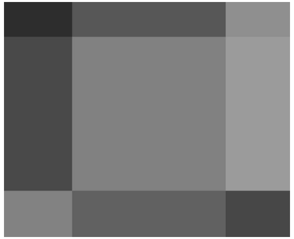


3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution

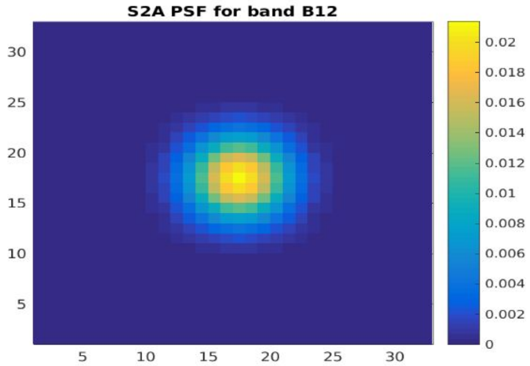


Aerial images (65 cm)



Sentinel-2 images 10 m (& 20 m)

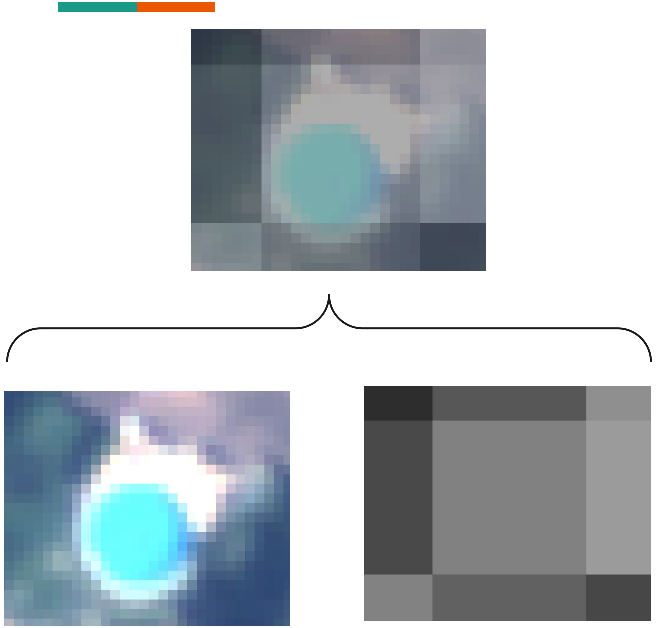
use the Point Spread Function (PSF)



Simulate the PSF for the aerial spectral bands !

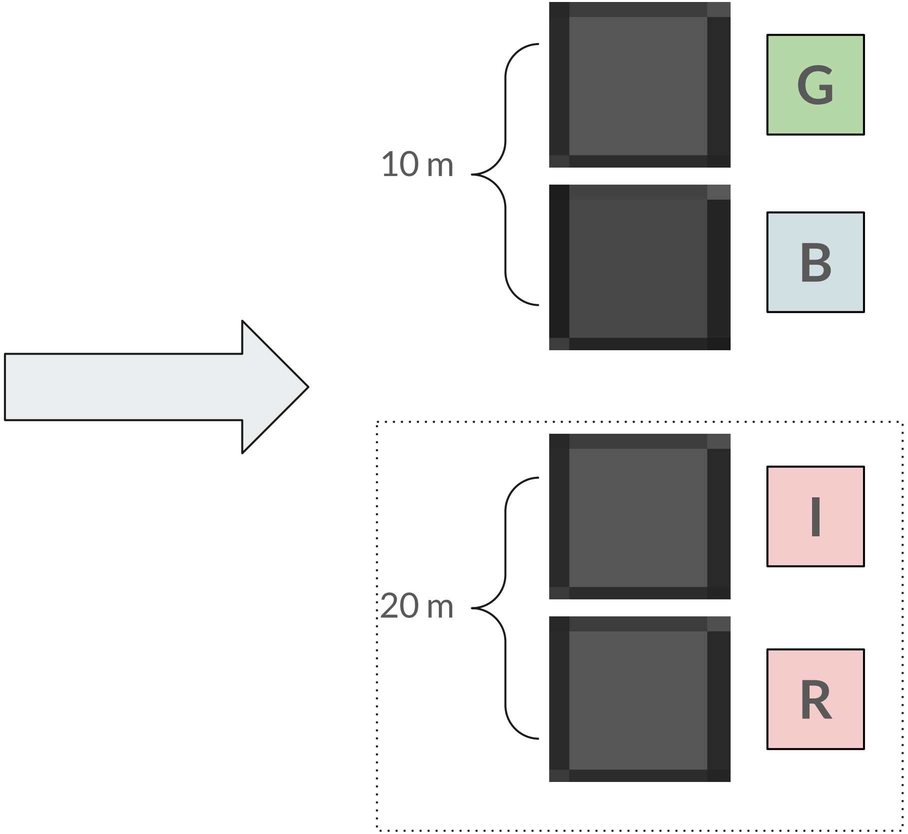
3. First pipeline - sensor calibration

2. Simulate UC images at the satellite spatial resolution



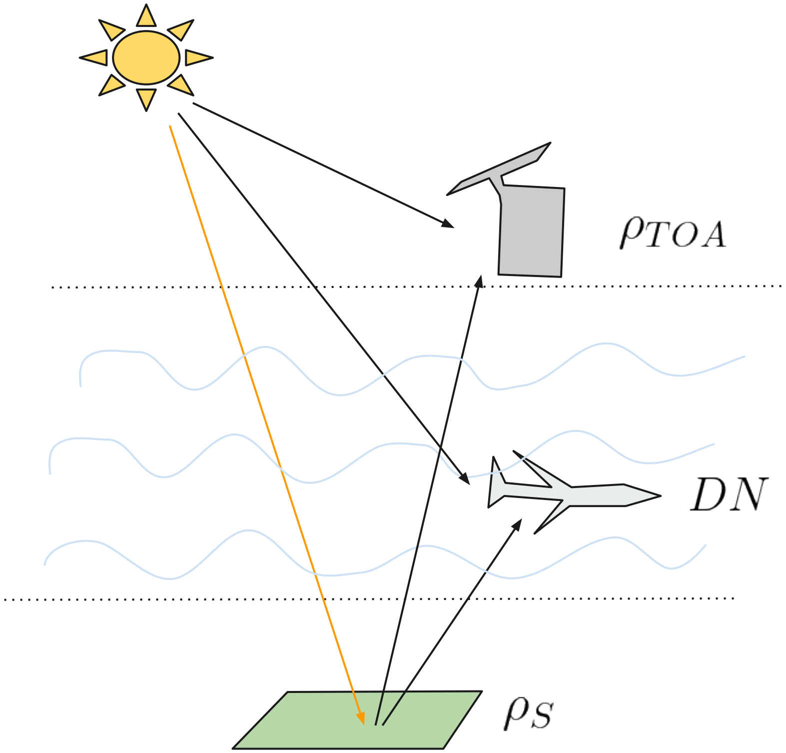
Aerial images (65 cm)

Sentinel-2 images 10 m (& 20 m)



3. First pipeline - sensor calibration

What are we looking for ?



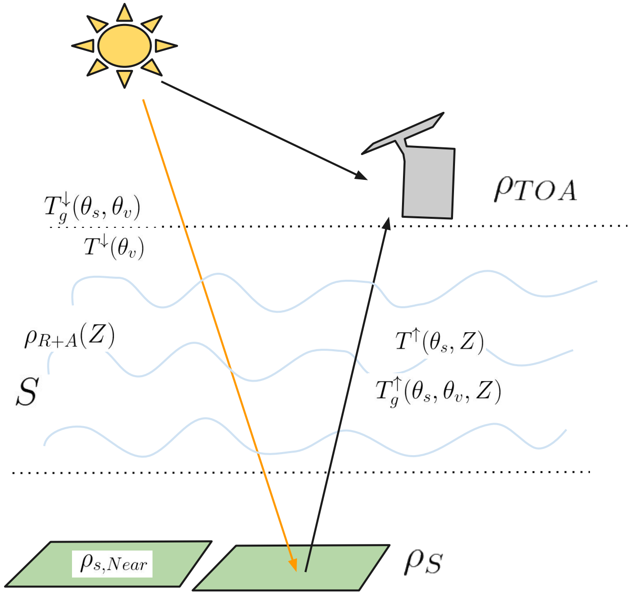
ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

3. First pipeline - sensor calibration

What are we looking for ?



from Vermote et al. (1997)

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

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : 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

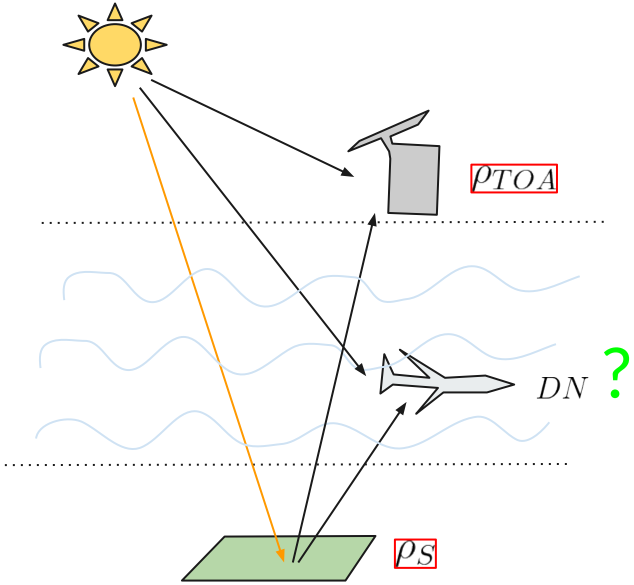
$T^{\uparrow}(\theta_s, Z)$: ascending atmospheric transmittance

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

S : total spherical atmospheric albedo

3. First pipeline - sensor calibration

What are we looking for ?



from Vermote et al. (1997)

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

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : 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

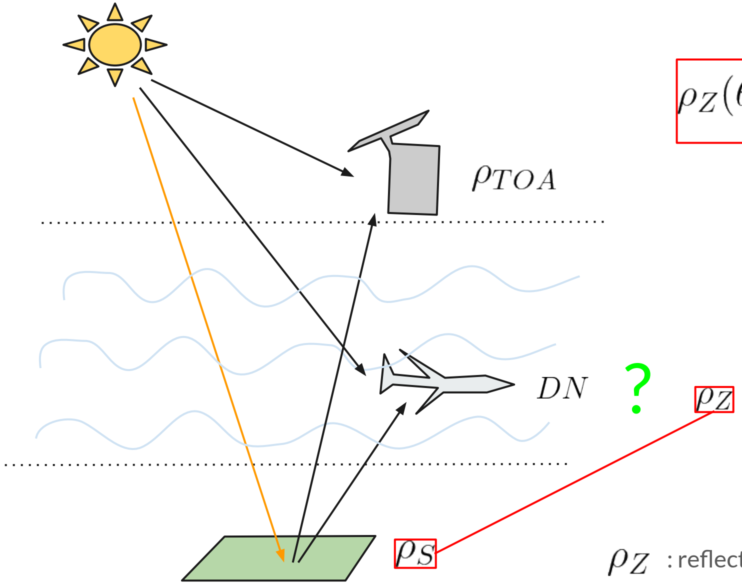
$T^{\uparrow}(\theta_s, Z)$: ascending atmospheric transmittance

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

S : total spherical atmospheric albedo

3. First pipeline - sensor calibration

What are we looking for ?



We work at the aerial altitude !

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

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

ρ_Z : reflectance at altitude Z

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : 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

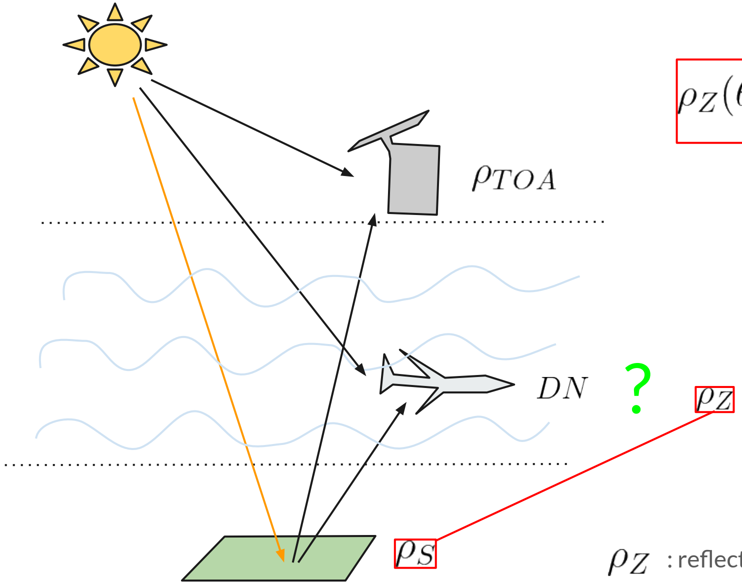
from Vermote et al. (1997)

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 :



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

ρ_Z : reflectance at altitude Z

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : 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

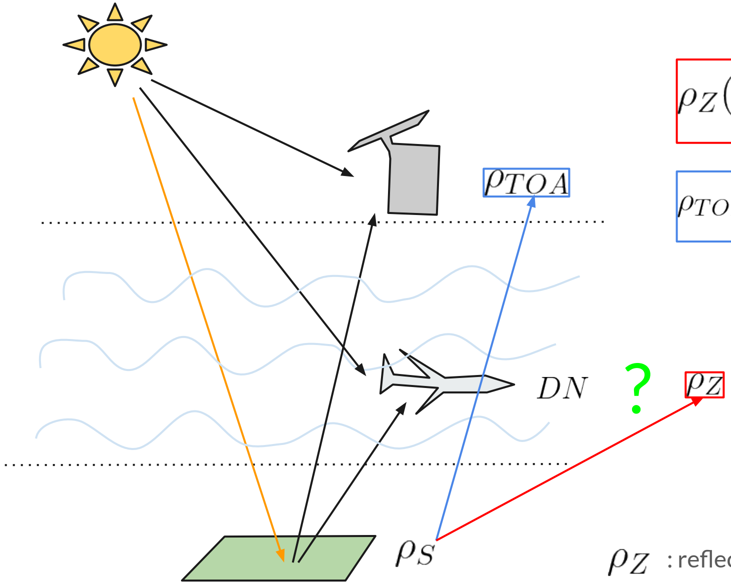
$T^{\downarrow}(\theta_v)$: descending atmospheric transmittance

$\boxed{S}$: total spherical atmospheric albedo

from Vermote et al. (1997)

3. First pipeline - sensor calibration

What are we looking for ?



We work at the aerial altitude !

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

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

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

ρ_Z : reflectance at altitude Z

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

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

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

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

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

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

S : total spherical atmospheric albedo

from Vermote et al. (1997)

3. First pipeline - sensor calibration

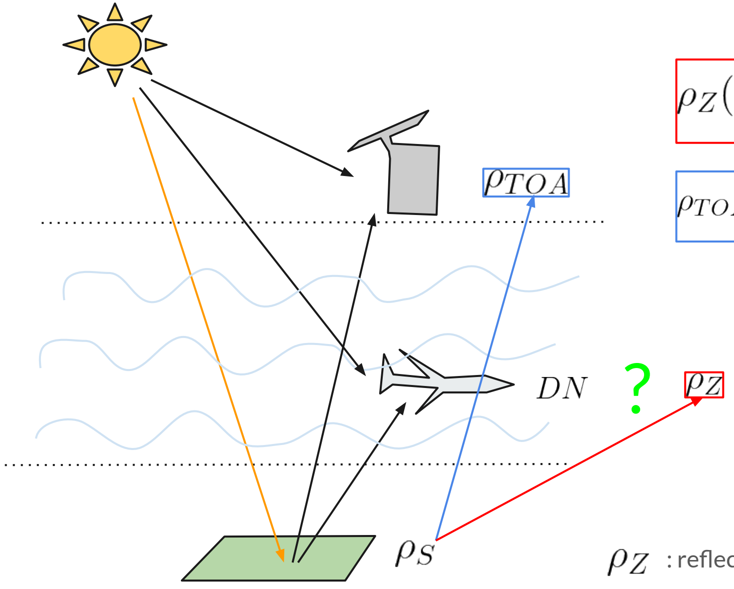
What are we looking for ?

We work at the aerial altitude !

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

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

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



ρ_Z : reflectance at altitude Z

ρ_{TOA} : reflectance on Top Of Atmosphere

DN : Digital Numbers for RGB NIR bands

ρ_S : ground reflectance

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

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

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

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

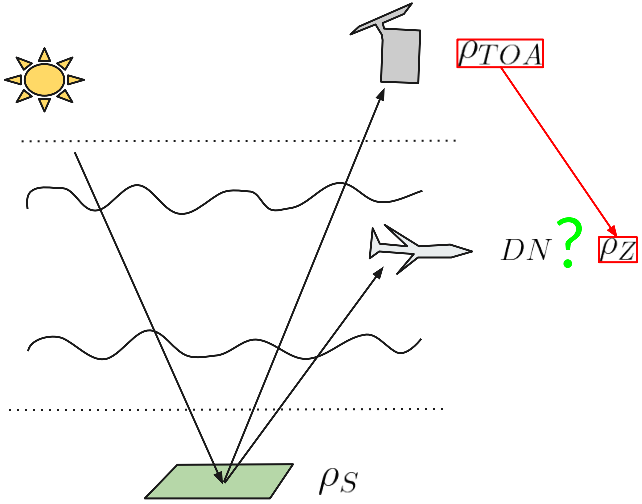
$T^{\downarrow}(\theta_v)$: descending atmospheric transmittance

S : total spherical atmospheric albedo

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 :

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

$$\sim$$

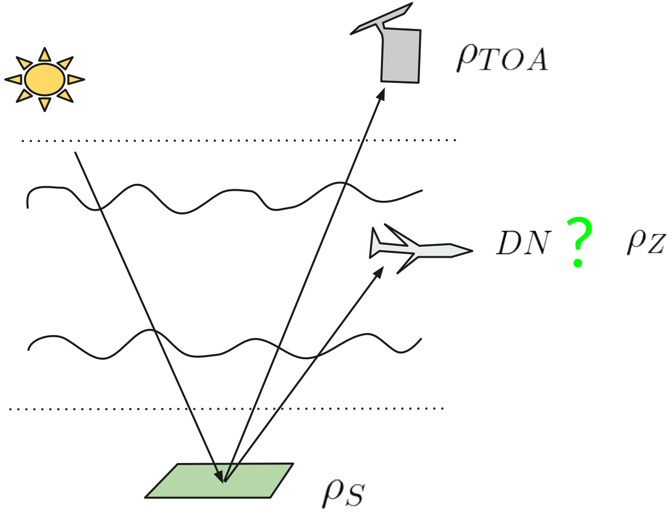
$$\rho_Z = \boxed{A} * \rho_{TOA} + \boxed{B}$$

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

from Vermote et al. (1997)

3. First pipeline - sensor calibration

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



Quick reminder :

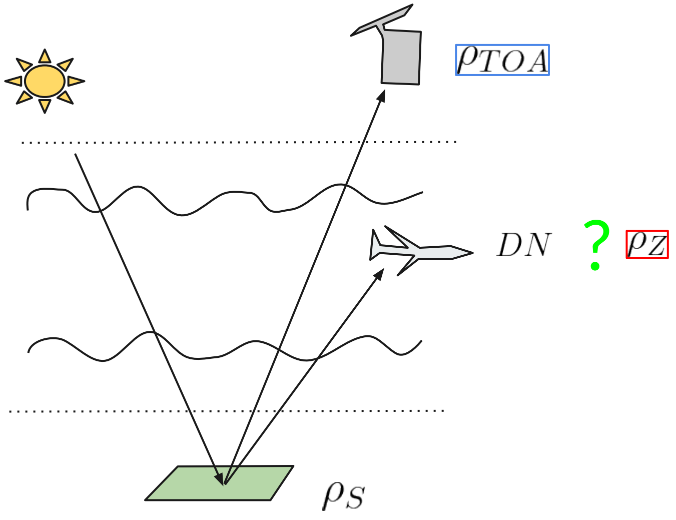
We try to compare the DN from airplane with reflectance at the airplane altitude, to calibrate the sensor.

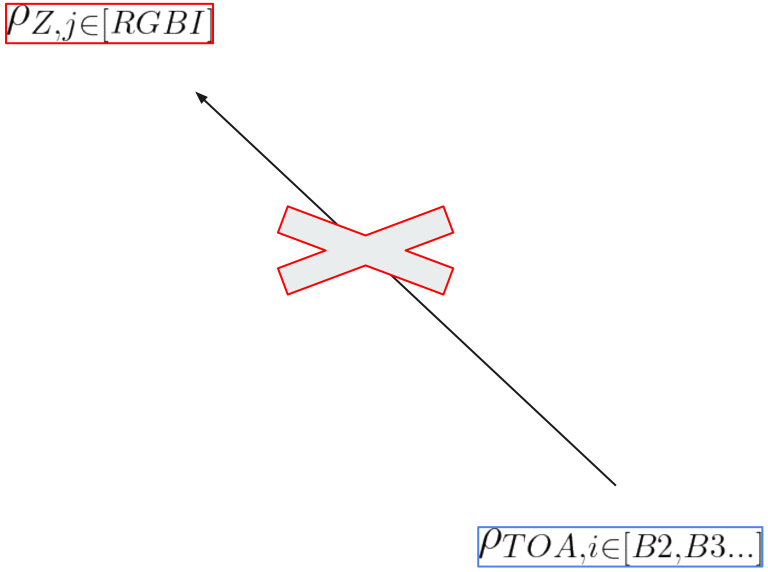
But we have a reflectance for the satellite spectral bands : impossible to compare with the DN number (4 spectral bands)

from Vermote et al. (1997)

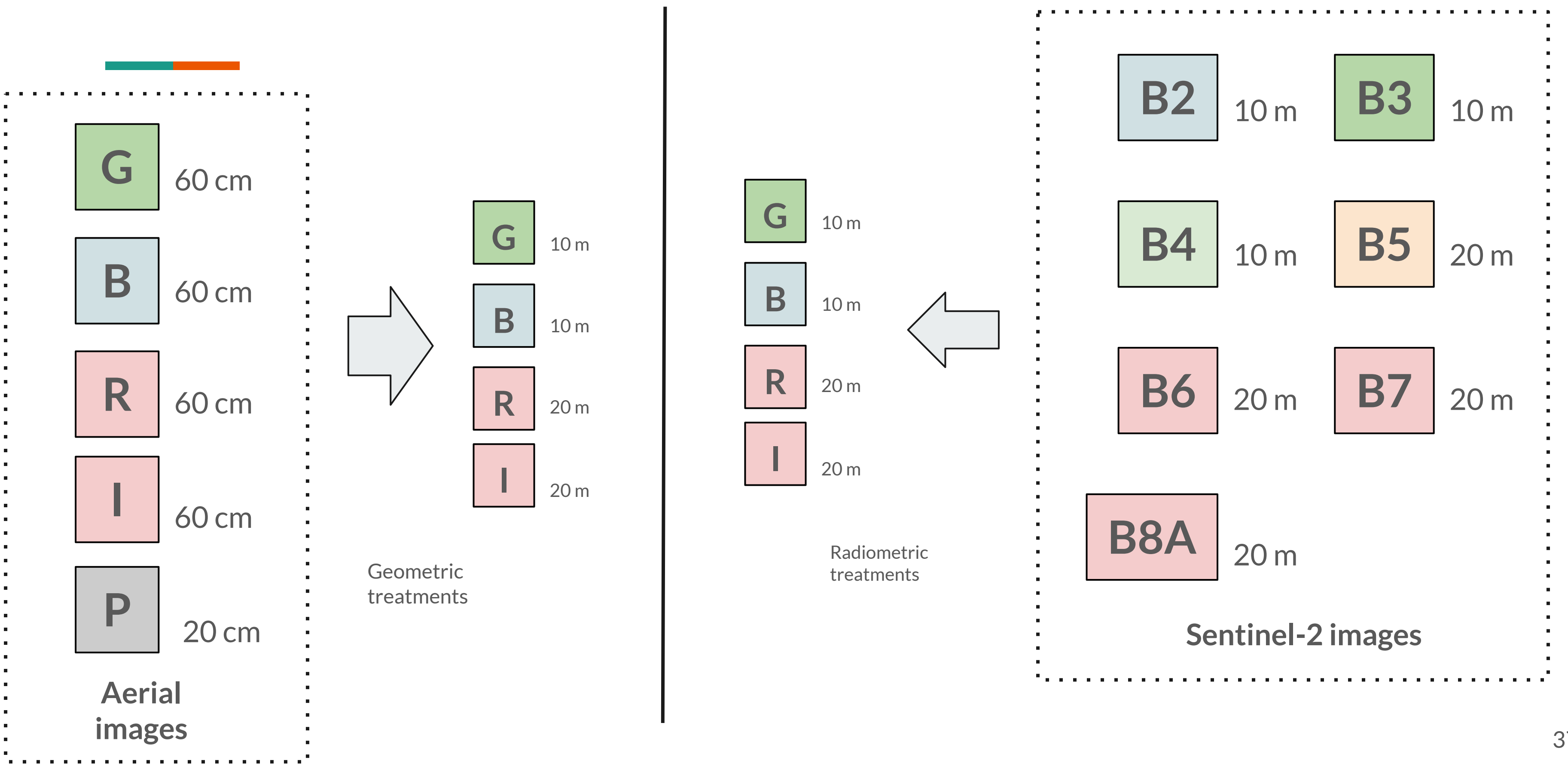
3. First pipeline - sensor calibration

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



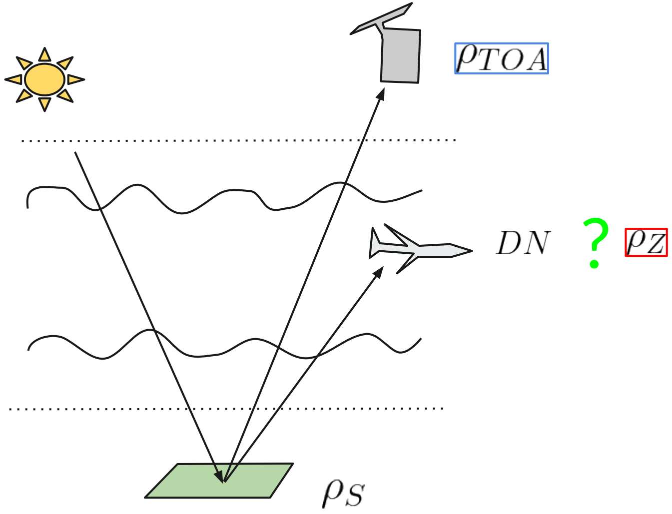


2. Data presentation - fitting together



3. First pipeline - sensor calibration

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

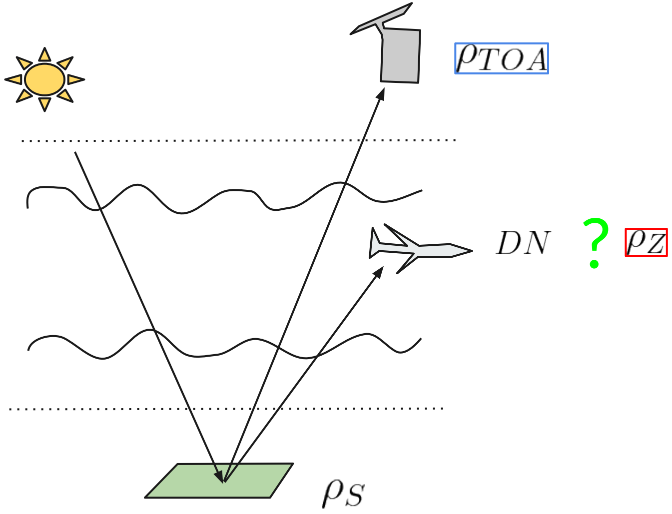


$$\boxed{\rho_{Z,j\in[RGBI]}}$$

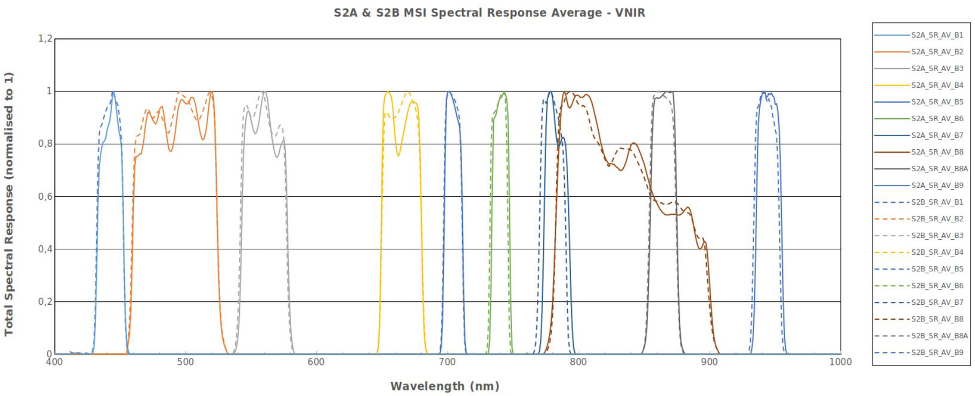
$$\rho_{TOA}(\lambda) \longrightarrow \boxed{\rho_{TOA,i\in[B2,B3...]}}$$

3. First pipeline - sensor calibration

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

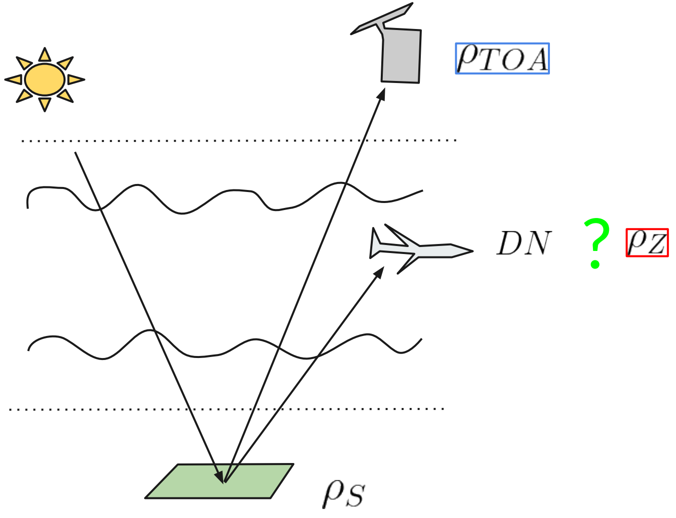


$\boxed{\rho_{Z,j\in[RGBI]}}$



$$\rho_{TOA}(\lambda) \longrightarrow \boxed{\rho_{TOA,i\in[B2,B3...]}}$$

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



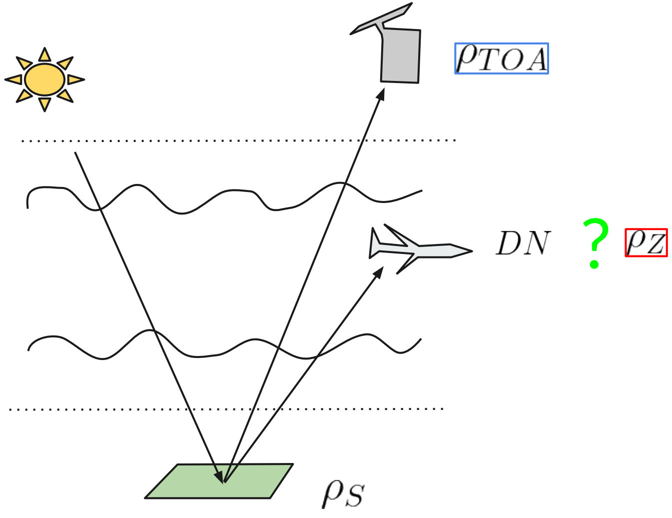
$\boxed{\rho_{Z,j\in[RGBI]}}$ $\qquad$ $\rho_{Z,i\in[B2,B3...]}$

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

$$\rho_{TOA}(\lambda) \longrightarrow \boxed{\rho_{TOA,i\in[B2,B3...]}}$$

3. First pipeline - sensor calibration

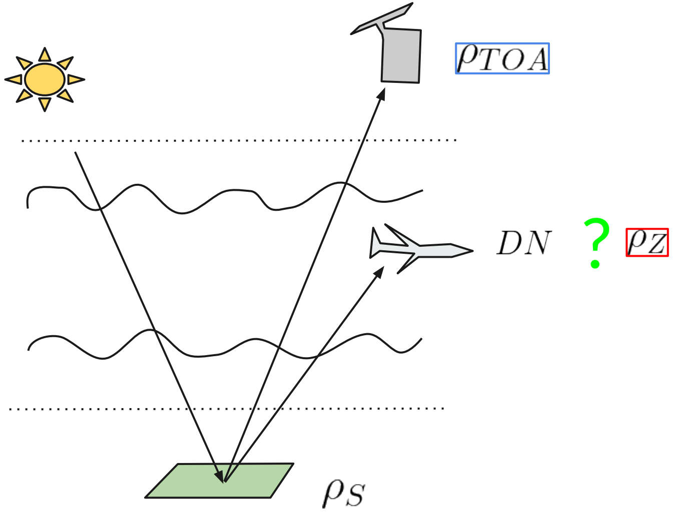
4. Simulate reflectance for each S2 band at the airplane altitude



$$
\begin{tikzcd}
\boxed{\rho_{Z,j\in[RGBI]}} & & \rho_{Z,i\in[B2,B3...]} \arrow[ll, "\text{spectral difference}"'] \\
\rho_{TOA}(\lambda) \arrow[rr] & & \boxed{\rho_{TOA,i\in[B2,B3...]}} \arrow[u]
\end{tikzcd}
$$

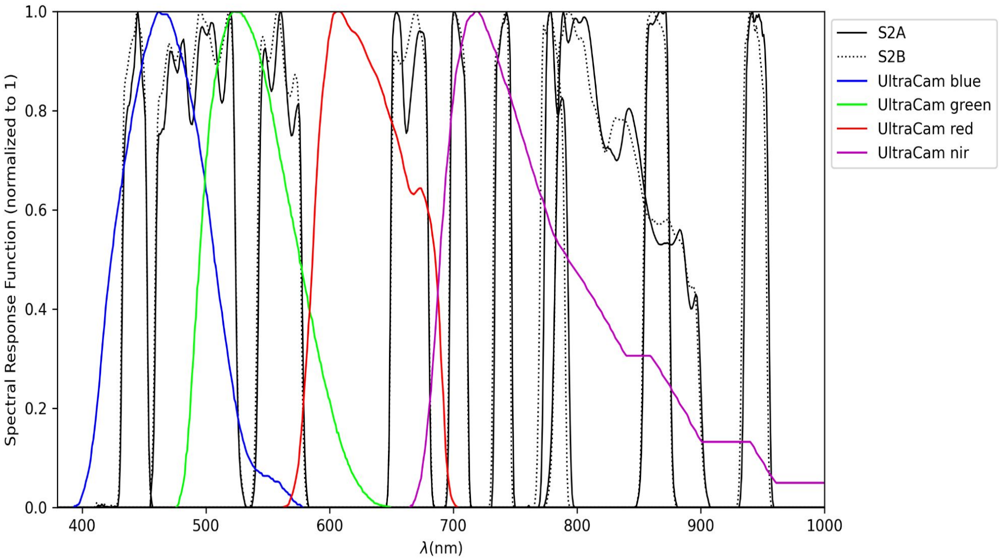
3. First pipeline - sensor calibration

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



spectral difference

$$\boxed{\rho_{Z,j\in[RGBI]}} \longleftarrow \rho_{Z,i\in[B2,B3...]}$$



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

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

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

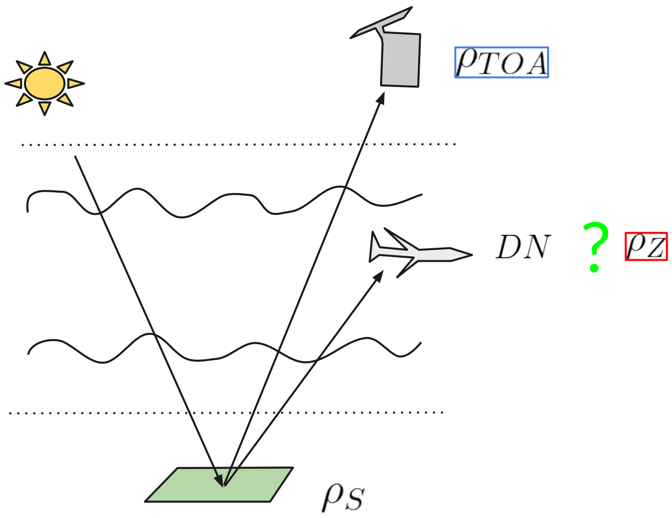
$$\rho_{Z,RED} = \sum_{i}^{N} a_{RED,i} * \rho_{Z,B_i}$$

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

$$\begin{tikzcd}
\boxed{\rho_{Z,j\in[RGBI]}} & \rho_{Z,i\in[B2,B3...]} \arrow[l, "\text{spectral difference}"'] \\
\rho_{TOA}(\lambda) \arrow[r] & \boxed{\rho_{TOA,i\in[B2,B3...]}} \arrow[u]
\end{tikzcd}$$

3. First pipeline - sensor calibration

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



$DN_{j\in[RGBI]}$

?

spectral difference

$\boxed{\rho_{Z,j\in[RGBI]}} \longleftarrow \rho_{Z,i\in[B2,B3...]}$

$\rho_{TOA}(\lambda) \longrightarrow \boxed{\rho_{TOA,i\in[B2,B3...]}}$

3. First pipeline - sensor calibration

6. Sensor calibration

We suppose

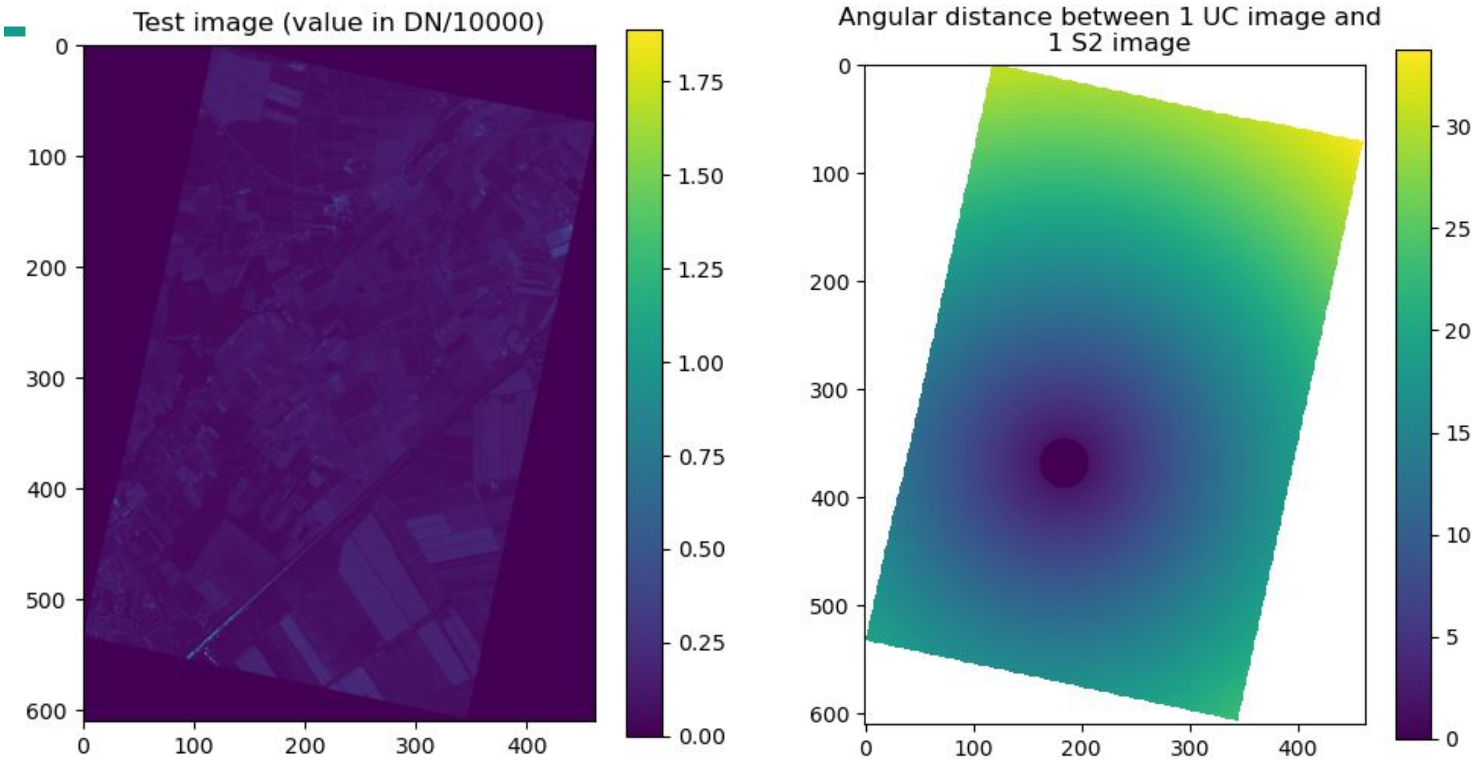
$$\forall j \in [B, G, R, I], \exists (C_j, B_j, A_j) \in \mathbb{R}$$

$$DN_j = C_j \cdot \rho_{Z,j} + B_j$$

$$DN_j = C_j \cdot \rho_{Z,j}^2 + B_j \cdot \rho_{Z,j} + A_j$$

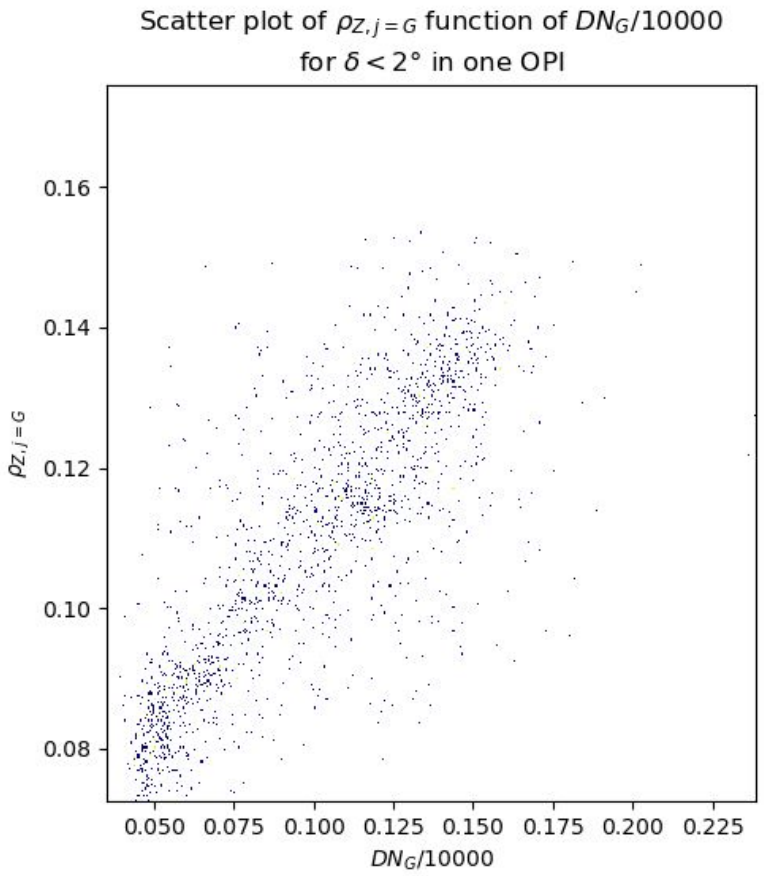
$$\begin{tikzcd}
DN_{j\in[RGBI]} \arrow[dr, leftrightarrow] & & \\
& \boxed{\rho_{Z,j\in[RGBI]}} & \rho_{Z,i\in[B2,B3...]} \arrow[l, "\text{spectral difference}"'] \\
& \rho_{TOA}(\lambda) \arrow[r] & \boxed{\rho_{TOA,i\in[B2,B3...]}} \arrow[u]
\end{tikzcd}$$

4. Results

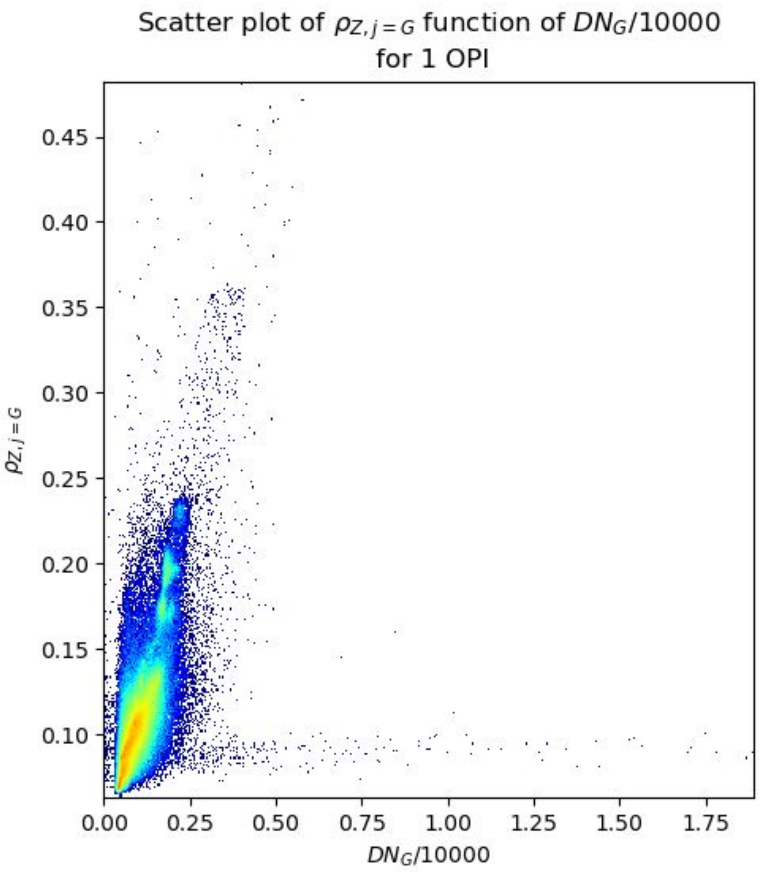


Test image (value in DN/10000)
0
100
200
300
400
500
600
0
100
200
300
400
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
Angular distance between 1 UC image and 1 S2 image
0
100
200
300
400
500
600
0
100
200
300
400
0
5
10
15
20
25
30

4. Results



Scatter plot of $\rho_{Z,j=G}$ function of $DN_G/10000$
for $\delta < 2°$ in one OPI
0.16
0.14
0.12
0.10
0.08
$\rho_{Z,j=G}$
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.225
$DN_G/10000$



Scatter plot of $\rho_{Z,j=G}$ function of $DN_G/10000$
for 1 OPI
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
$\rho_{Z,j=G}$
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
$DN_G/10000$

thank you for listening :)

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

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

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

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

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

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

$M_{i \to j}$: 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