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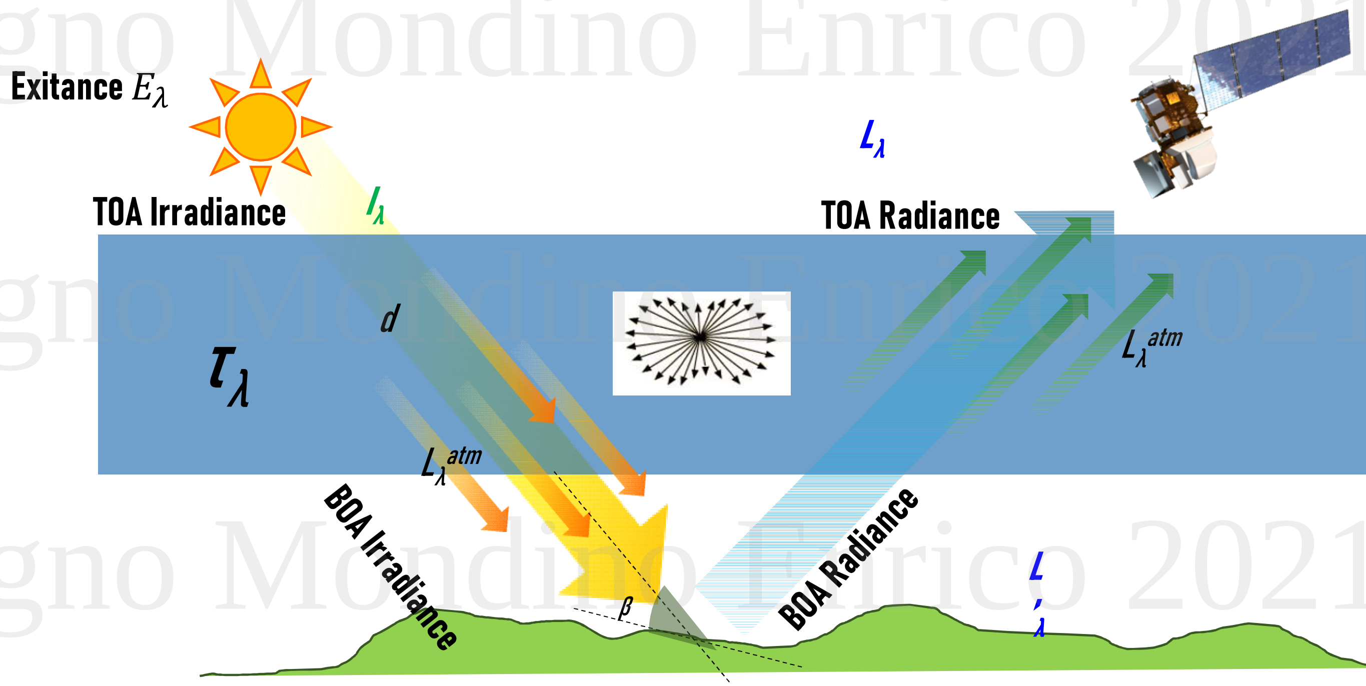
IMAGE CALIBRATION

From DN to BOA (Bottom of the Atmosphere) REFLECTANCE

THE ROLE OF THE ATMOSPHERE

The atmosphere is an important player in remote sensing. It plays a double role depending on its transmittance and scattering properties. **A)** Sun light is attenuated both while reaching (irradiance) and leaving (radiance) the ground. Atmosphere transmits differently the different wavelengths of light; **B)** atmosphere scatters light in all directions, included towards the sensor and down to the ground.

BOA = Bottom of the atmosphere
TOA = Top of the atmosphere



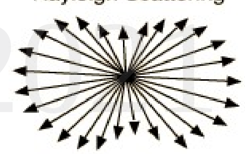
ATMOSPHERIC SCATTERING

Scattering can be somehow considered the reflecting behaviour of the atmosphere

3 TYPES of SCATTERING

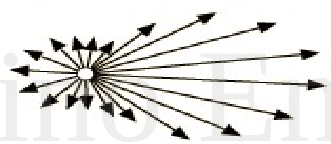
SELECTIVE SCATTERING (RAYLEIGH) – Natural in clear sky conditions

Particles with dimensions « λ (wavelength in the range we are interested in [400-2500 nm] (atmospheric gases)



MIE SCATTERING – Man related activities

Particles with dimensions near to λ (dust and smoke in the low atmosphere)

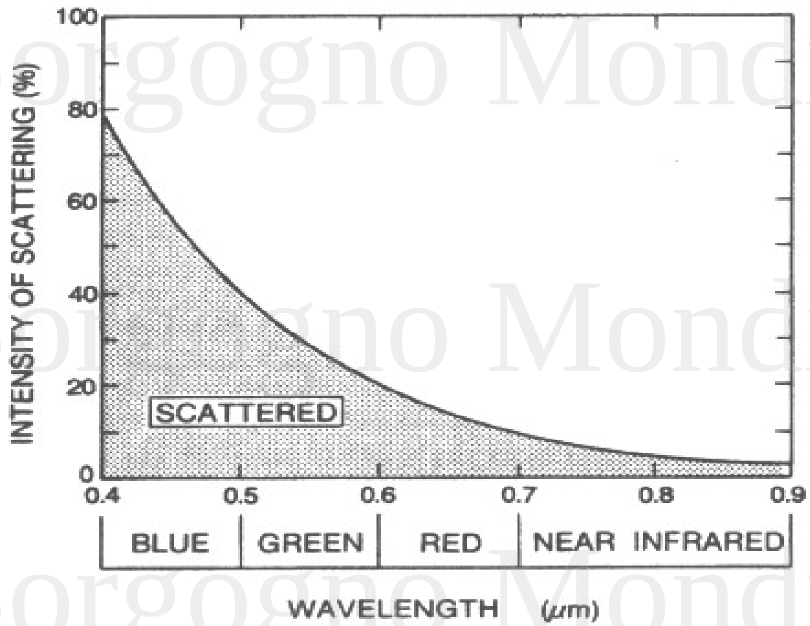


NOT-SELECTIVE SCATTERING – Natural in cloudy conditions

Particles with dimensions » λ (condensed water, clouds)

ATMOSPHERIC SCATTERING

RAYLEIGH's SELECTIVE SCATTERING: bands are scattered differently by the atmosphere. Scattering is active in the visible region of the spectrum, and turns to be negigible in the medium infrared region.



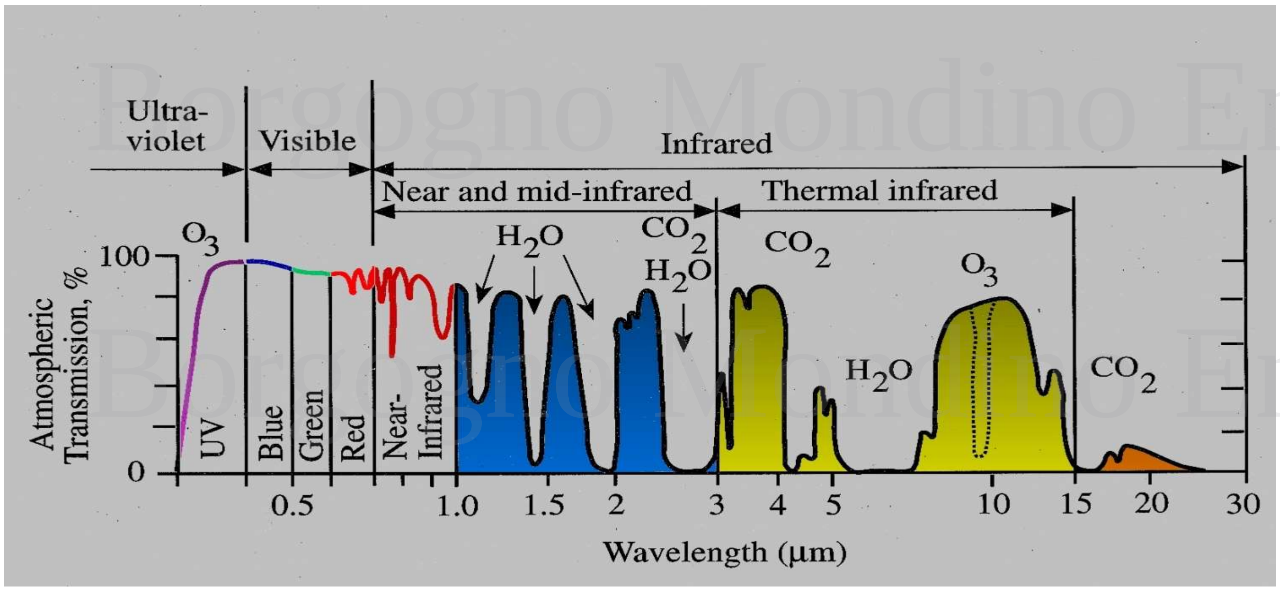
Effects

1) **Sky colour** → it depends on the optical path of the signal, therefore on the hour of the day

2) **Back-Scattering** towards the sensor. It records both the atmospheric contribution and the surfaces contribution to the signal

ATMOSPHERIC TRANSMITTANCE

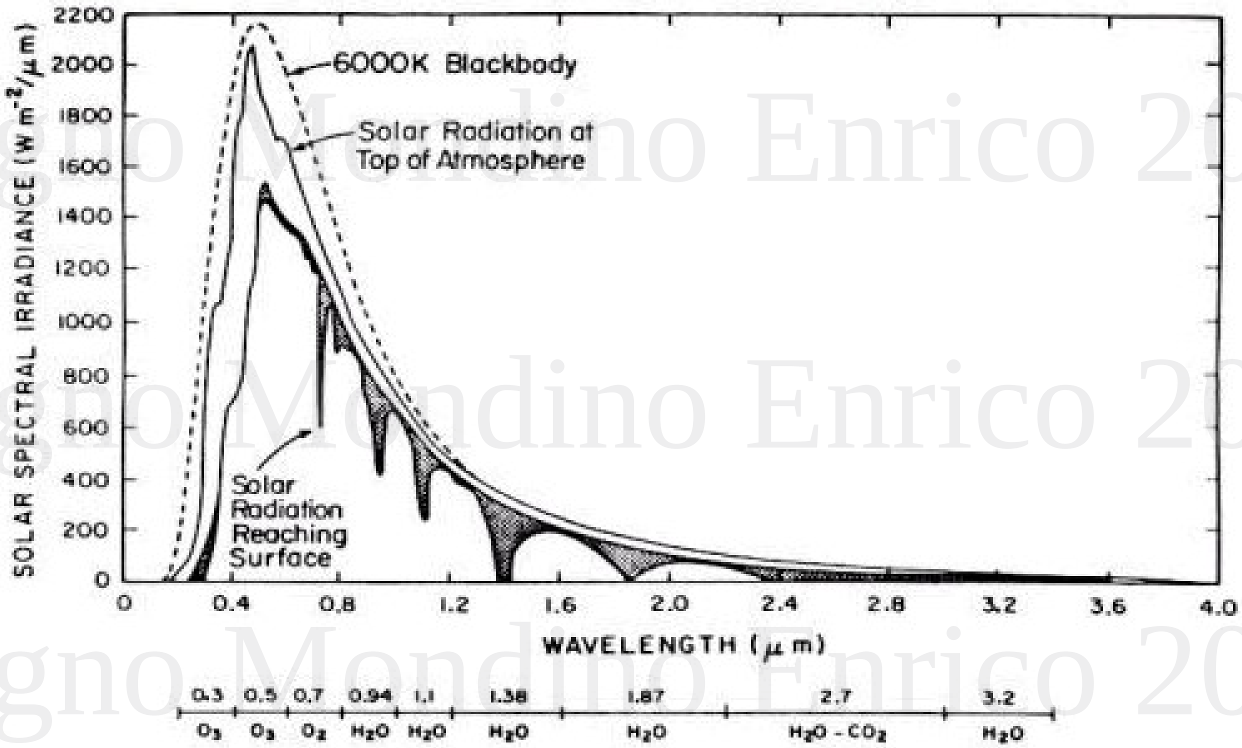
Atmosphere is selective respect to signal wavelengths → it lowers signal intensity differently for the different bands. Those REGIONS of spectrum where atmosphere is transparent (transmittance near to 1) are called **ATMOSPHERIC WINDOWS**.



Satellite sensors must necessarily operate in the atmospheric windows.

ATMOSPHERIC TRANSMITTANCE

Atmospheric windows modify Sun irradiance availability at the ground.

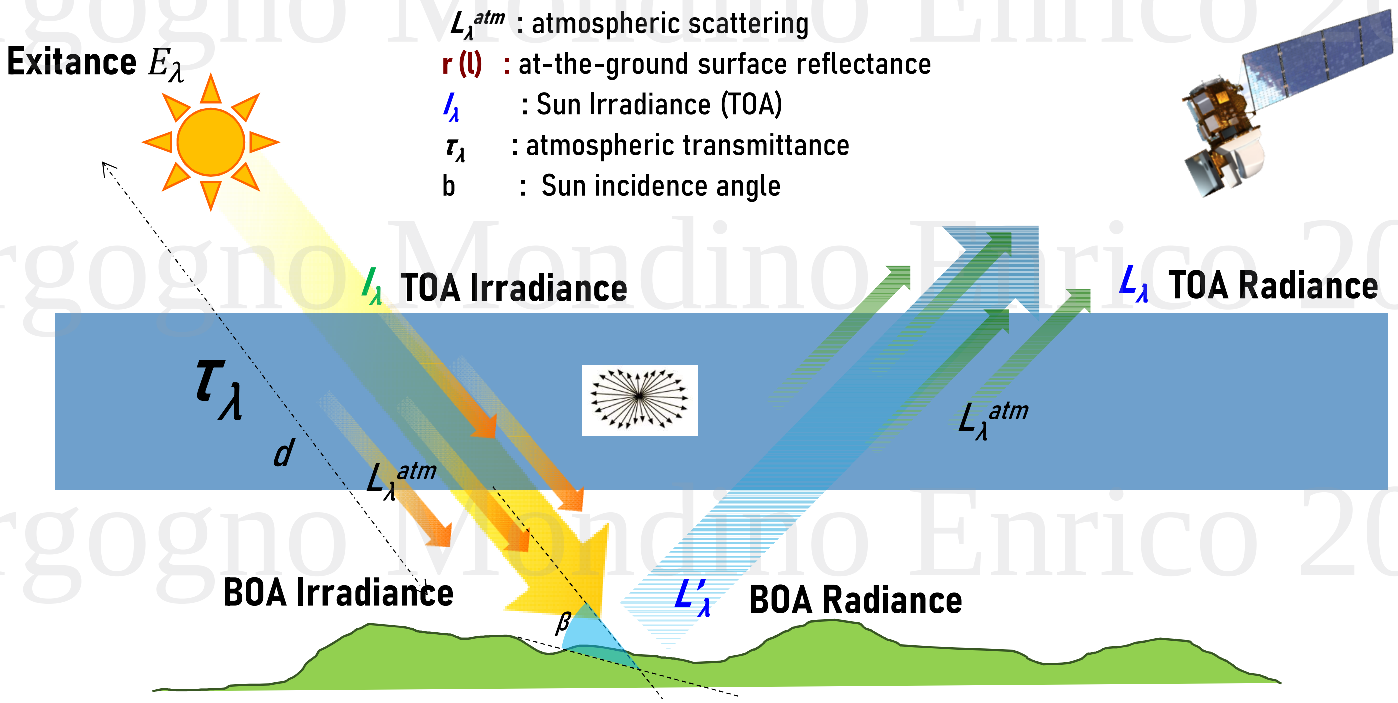


WORKING WITH XS IMAGERY: RECOVERING REFLECTANCE FROM RAW DATA

Premises

a) Raw images code Radiance, NOT Reflectance
b) At-the sensor recorded radiance is made of ground surface contribution + atmospheric scattering (noise)
c) Atmosphere weakens both incoming and outgoing radiation (transmittance)

→ Raw multispectral images cannot be interpreted as a collection of spectral signatures



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WORKING WITH XS IMAGERY: RECOVERING REFLECTANCE FROM RAW DATA

The function relating surface reflectance to lighting conditions and at-the-sensor recorded radiance (L_λ) is called **RADIATIVE TRANSFER MODEL (RTM).**

π takes into account the Lambertian behaviour of the surface. The incoming radiation, when reflected is diluited over an emisphere (= p steradiants)

k is the Earth-Sun distance factor in charge of tuning the reference Sun Irradiance (equinox) in respect of the date of acquisition

$\hat{L}_\lambda^{atm}$ is the scattering contribution of the atmosphere that has to be taken into consideration at the sensor (noise to be minimized) and at the ground (scattered light increases energy availability at the ground)

τ_λ is the estimated transmittance at the moment of the acquisition (band dependent)

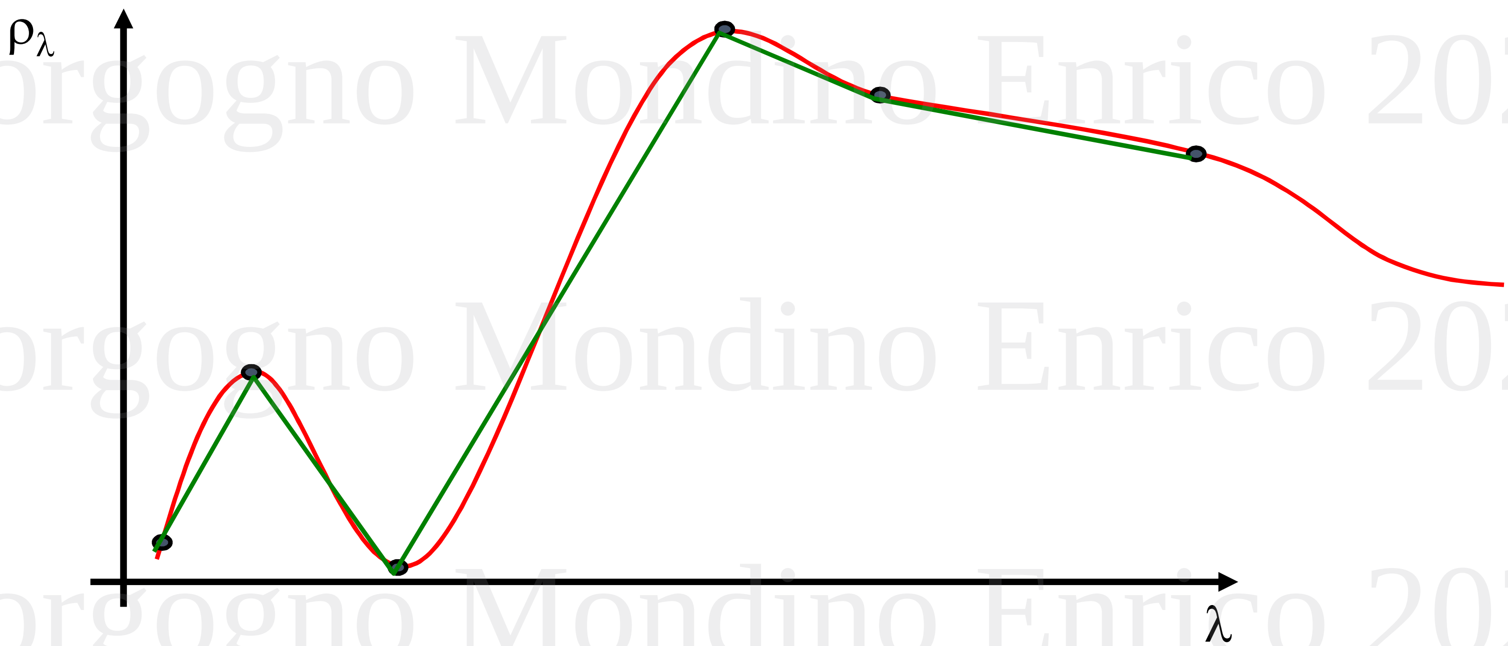
$$\rho_\lambda(x,y) = \frac{\pi \cdot \left[L_\lambda(x,y) - \hat{L}_\lambda^{atm}\right]}{\tau_{\lambda out} \cdot \left[\tau_{\lambda in} \cdot k \cdot \sin[\beta(x,y)] \cdot E_\lambda + \hat{L}_\lambda^{atm} \cdot \pi\right]}$$

While dealing with public open data this problem can be easily overcome by selecting the proper Processing LEVEL for data (LEVEL 2 in general) that means AT-THE GROUND REFLECTANCE CALIBRATED DATA and ORTHOPROJECTED (in general in WGS 84 Geographic Coordinates, or WGS84 UTM Projected coordinates)

Borgogno Mondino Enrico 2021

WORKING WITH XS IMAGERY:
RECOVERING REFLECTANCE FROM RAW DATA

Sampled spectral signatures (as recorded by sensors) are discrete approximations of the real ones. Higher is the spectral resolution of images, higher is the consistency between real and observed spectral signatures.

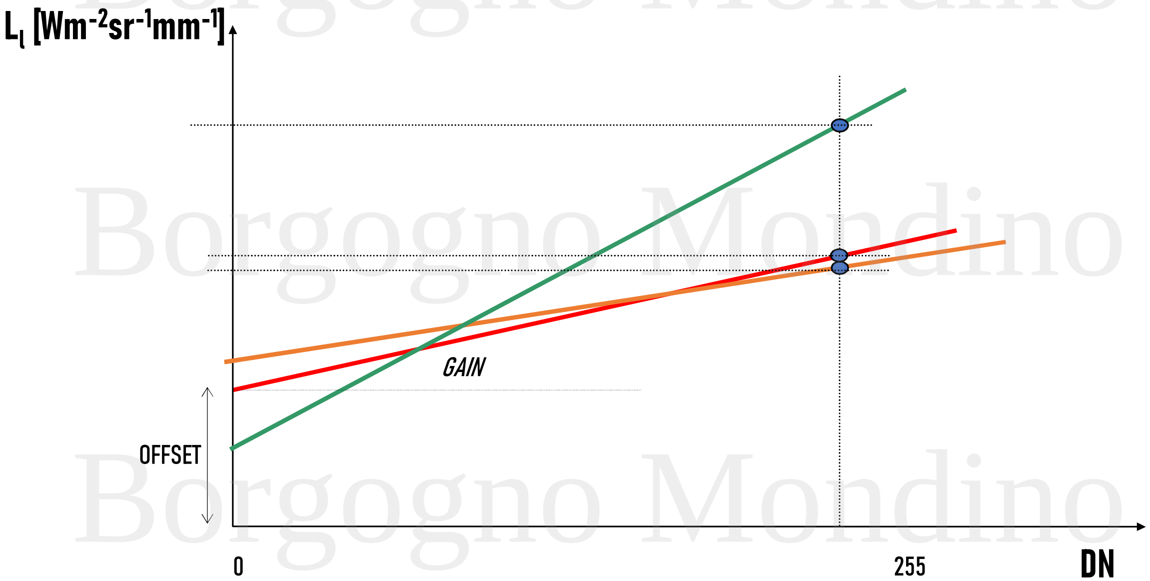


But we don't start from reflectance, but from DN. **How to do?**

IMAGE CALIBRATION: FROM DN to RADIANCE

The first step is to convert DN into correspondent radiance values is Image Calibration. DN are related to correspondent radiance value by a CALIBRATION FUNCTION.

- Each detector has a specific calibration function.
- The calibration function defines the relationship between DNs and correspondent Radiance values
- Each band refers to different detectors, therefore bands have different calibration functions.



RADIANCE measurment units

[W m^{-2}sr $^{-1}$µm $^{-1}$]

$$L_\lambda = OFFSET_\lambda + GAIN_\lambda \cdot DN_\lambda$$

$$OFFSET = L_{\min}$$

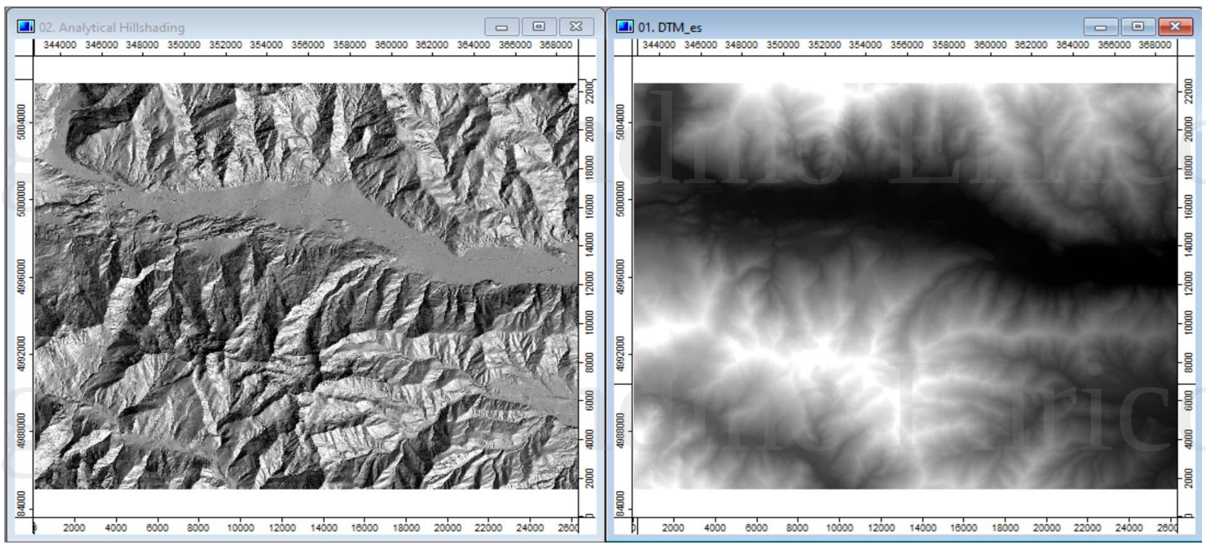
$$GAIN = \left(\frac{L_{\max} - L_{\min}}{255}\right)$$

L_{max} and L_{min} are respectively the high and low limits of the recordable radiances

CALIBRATING IMAGES
Topographic correction (Incidence Angle, β, map)

Ordinary GIS tools can be used, once known time and date of the acquisition, of mapping the Sun Incidence Angle.

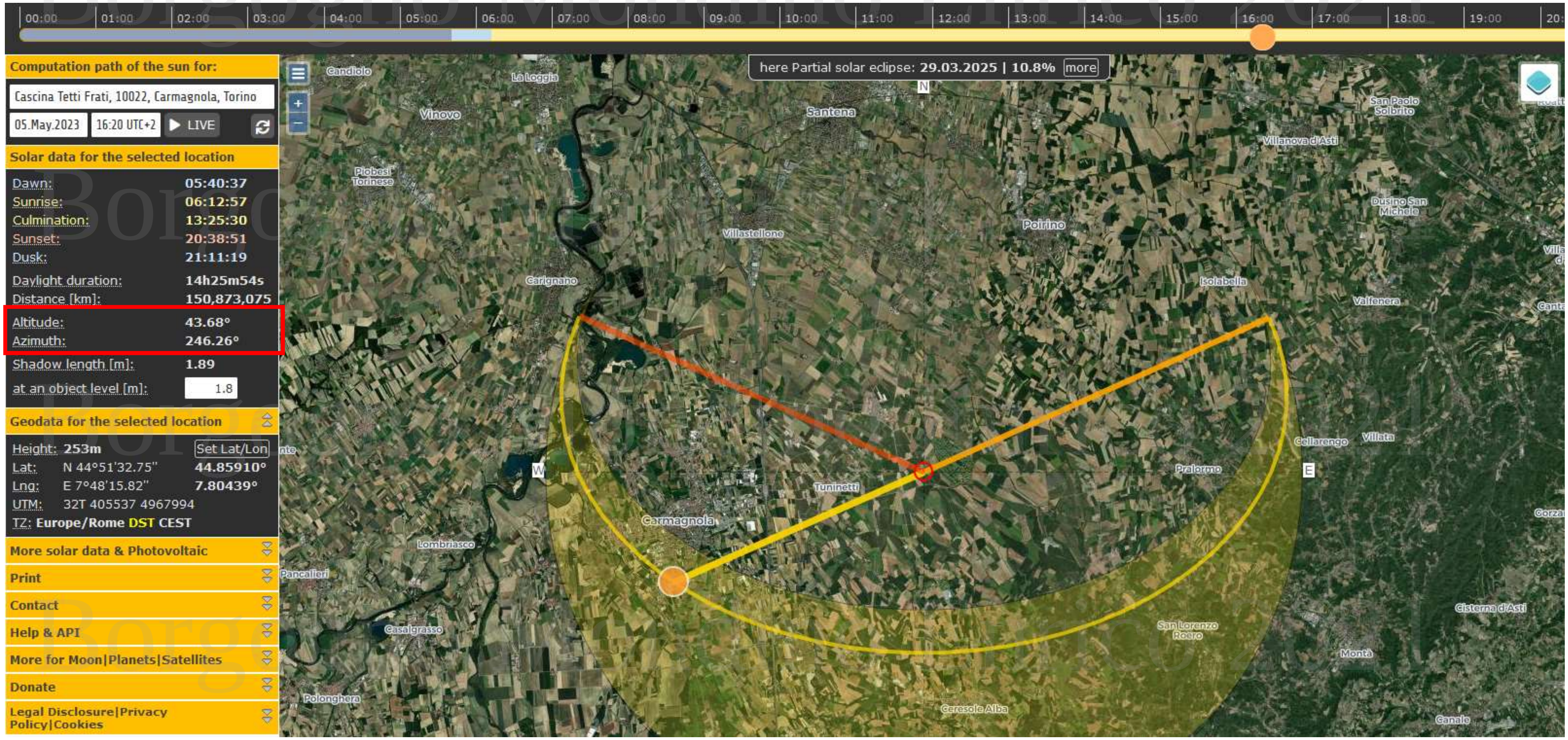
INCIDENCE ANGLE MAP ← **DTM (Digital Terrain Model)**



The Sun position at the moment of the acquisition can be obatined through astronomic calculators. One of them can be accessed through https://www.suncalc.org/

CALIBRATING IMAGES

Topographic correction (Incidence Angle, β, map)



Trasmittance (τ) and Scattering ($\hat{L}_{\lambda}^{atm}$)

Transmittance and Scattering can be estimated :

a) By rigorous physically-based approaches, where atmosphere is modelled, as it was at the acquisition time; well known models operating in this way are ATCOR3/4, FLAASH, MODTRAN.

b) By empirical approaches based on strong simplifications, but effective enough for the most of applications (NOT for studies concerning water or snow analysis). In general, this approach adopts: a) some reference values for transmittance from literature (basically suggested for different latitudes and landscapes); b) simplified strategies for scattering estimation, in general operating in **DOS (dark object subtraction)** mode.

Trasmittance (τ) and Scattering ($\hat{L}_\lambda^{atm}$)

Transmittance (τ)

Reference transmittance values are reported for summer mid-latitude areas with clear sky (Landsat 8 OLI bands).

Often these reference values are locally tuned in respect of pixel geograhic position (both planimetric and altimetric), since transmittance effect strictly depends on light rays optical path (thickness of atmosphere that radiation goes through).

Bande L8 OLI	t
1	0.50
2	0.60
3	0.65
4	0.65
5	0.80
6	0.89
7	0.92

Scattering ($\hat{L}_\lambda^{atm}$): DOS approach

Intensity of scattering (depending on band) is performed according to the following hypotheses :

a) Shadow areas should not reflect other than scattered component of light;
b) Shadow areas can be found where radiance is minimum;
c) Scattered radiance is the same for the whole scene to calibrate (true only for limited and flat areas)

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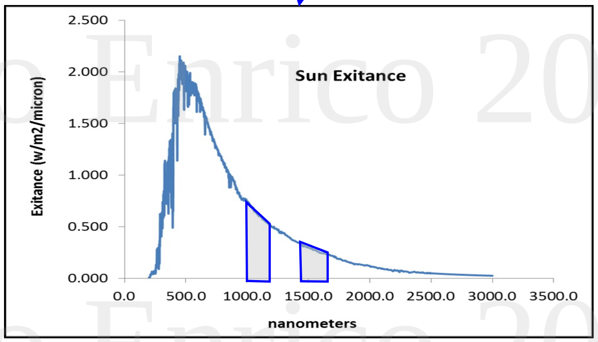
Sun Irradiance (I_λ) and Earth-Sun distance factor (k)

IRRADIANCE VALUES at the top of the atmosphere can be estimated once known Sun EXITANCE (from **Planck's Law**) and a seasonal coefficient (SF, k or d) able to tune up this value according to the istantaneous distance between Sun and Earth. Since bands, that sensors can record, correspond to ranges of wavelegths the EXITANCE curve from Planck's Law has to be integrated within these ranges. An example is given for Landsat 8 OLI and Sentinel 2 MSI sensors.



band	Transmittance	IRR [W/m2]	Band center (micron)	band name
1	0.5	1913.57	0.443	Aerosol
2	0.6	1941.63	0.4905	Blue
3	0.63	1822.61	0.5605	Green
4	0.62	1512.79	0.665	red
5	0.8	1425.56	0.7055	NIR Red Edge 1
6	0.8	1288.32	0.7405	NIR Red Edge 2
7	0.8	1163.19	0.783	NIR Red Edge 3
8	0.8	1036.39	0.8425	NIR wide
8a	0.8	955.19	0.865	NIR Red Edge 4
9	0.4	813.04	0.945	Water/Vapour
10	0.35	367.15	1.375	Cirrus
11	0.89	245.59	1.61	MIR1
12	0.92	85.25	2.19	MIR2

Sentinel 2 MSI

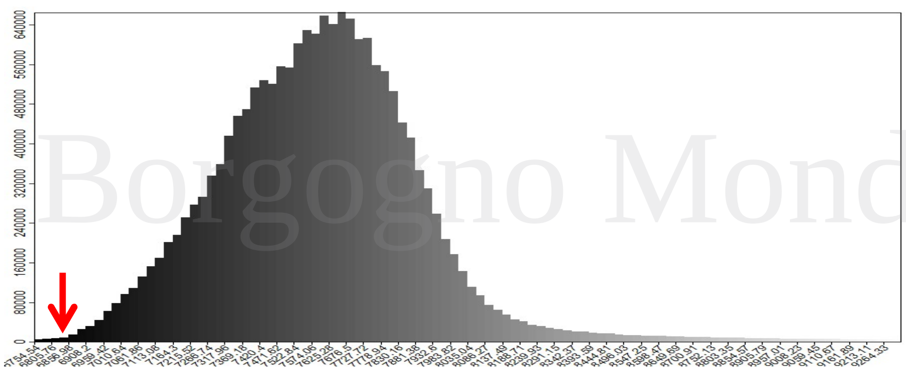
band	Transmittance	IRR [W/m2]	Band center (micron)	band name
1	0.5000	1955.31	0.443	Aerosol
2	0.6000	1989.08	0.482	Blue
3	0.6300	1864.87	0.5615	Green
4	0.6200	1593.92	0.6545	red
5	0.8014	987.38	0.865	NIR
6	0.8951	247.56	1.6085	MIR1
7	0.9161	76.75	2.2005	MIR2

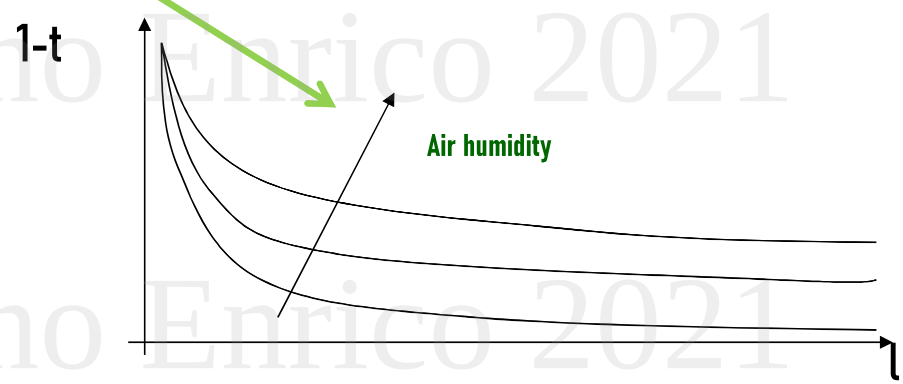
Landsat 8 OLI

Trasmittance (τ) and Scattering ($\hat{L}_\lambda{}^{atm}$)

Scattering ($\hat{L}_\lambda{}^{atm}$) : DOS approach

The intensity of the atmosphere scattered light is expected to be different for each band and possibly decreasing while wavelengths increase (according to Rayleigh's law). Its estimation can be achieved in different ways. Here, the proposed DOS approach is based on the band (radiance calibrated) histogram analysis. We assume as an estimate of scattering intensity the radiance value (X axis) preceding the steep left slope trait of the histogram (red arrow).





Sun Irradiance (I_λ) and Earth-Sun distance factor (k)

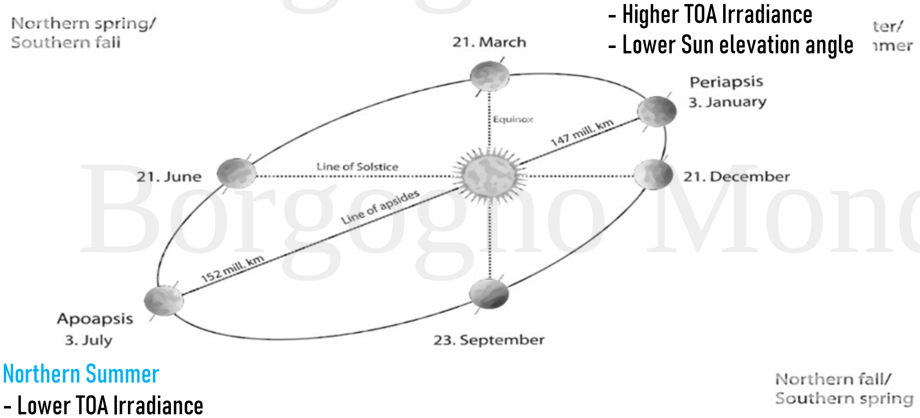
SF can be obtained through formulas related to the astronomical model relating Earth and Sun movements.
SF can be known as k or d depending on the applied formula. k is higher when d is lower and vice versa. SF value changes date by date and can be suppplied within images METADATA (for official data) or computed by empirical formulas as the ones reported below.

$$d = 1 - 0.01672 \cdot \cos[0.9856 \cdot (Julian\ Day - 4)]$$

$$k = \frac{1}{d^2} = \left\{1 + 0.0167 * \cos\left[\frac{2\pi(DOY - 3)}{365}\right]\right\}^2$$

DOY = Day of the Year (counter of days from 1° January)

Northern winter
- Higher TOA Irradiance
- Lower Sun elevation angle



Northern Summer
- Lower TOA Irradiance
- Higher Sun elevation angle

© https://upload.wikimedia.org/wikipedia/commons/thumb/f/f0/Seasons1.svg/600px-Seasons1.svg.png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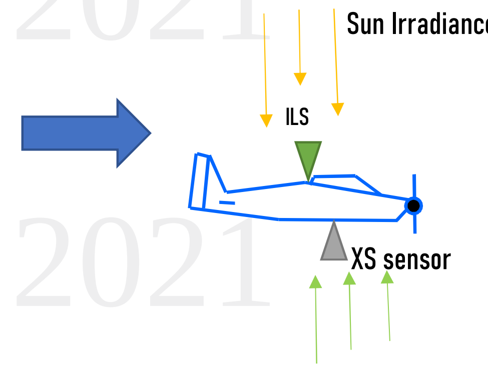
Draft subset of METADATA from Landsat Images

RADIOMETRIC IMAGE CALIBRATION

RAW DATA from sensors record RADIANCE (Power flux) and NOT REFLECTANCE. Consequently they cannot be used as they come. A radiometric calibration of multispectral images is required. **HOW? → Different Approaches are possible**



1. DIRECT MEASUREMENT OF SUN IRRADIANCE by dedicated SENSORS (ILS – Incidence Light Sensor) or by calibrated PANELS placed at the ground during image acquisition.

2. EMPIRICAL LINE (an empirical regressive model must be calibrated with refrence to some spectral measures from ground campaigns). The assumption is that the Radiative Transfer model can be reduced to a linear relationship linking calibrated ground measures with Digital numbers

$$\rho_\lambda = \alpha_{x,y}^{\lambda} \cdot DN_\lambda + \beta_{x,y}^{\lambda}$$

3. An opportune RADIATIVE TRANSFER MODEL can be applied. Many auxiliary infos are required concerning: sensor technical features, atmosphere properties, scene lightning geometry

$$\rho_\lambda = \frac{\pi(R_\lambda - R_\lambda^{atm})}{\tau_\lambda^{out} \cdot [\tau_\lambda^{in} \cdot k \cdot \sin(i) \cdot I_\lambda^{d} + I_\lambda^{bs}]}$$

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RADIOMETRIC IMAGE CALIBRATION: EMPIRICAL LINE

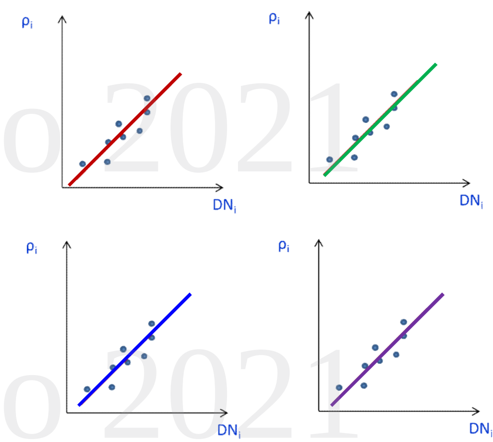
The RADIATIVE TRANSFER MODEL can be somehow reduced (with some simplifications) to a linear model possibly directly relating BOA REFLECTANCE to DN. This model is known as EMPIRICAL LINE.

$$\rho_\lambda = \frac{\pi(R_\lambda - R^{atm}_{\lambda})}{\tau_{out}[\tau_\lambda \cdot k \cdot \sin(i) \cdot I^d_\lambda + I^{bs}_\lambda]} = \frac{\pi R_\lambda}{\tau_{out}[\tau_\lambda \cdot k \cdot \sin(i) \cdot I^d_\lambda + I^{bs}_\lambda]} + \frac{-\pi R^{atm}_{\lambda}}{\tau_{out}[\tau_\lambda \cdot k \cdot \sin(i) \cdot I^d_\lambda + I^{bs}_\lambda]} = \alpha^\lambda_{x,y} \cdot R_\lambda + \beta^\lambda_{x,y}$$

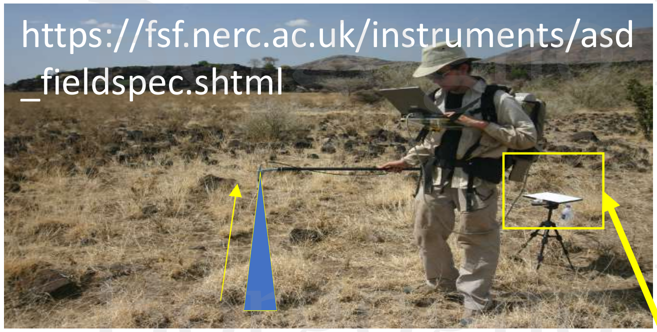
Model coefficients change depending on atmosphere conditions, therefore acquisition by acquisition. The linear model has therefore to be calibrated with reference to spectral measures obtained by ground campaign operated by SPECTRORADIOMETER. The latter is a handheld instrument able to record spectral signatures of surfaces with a very high spectral resolution

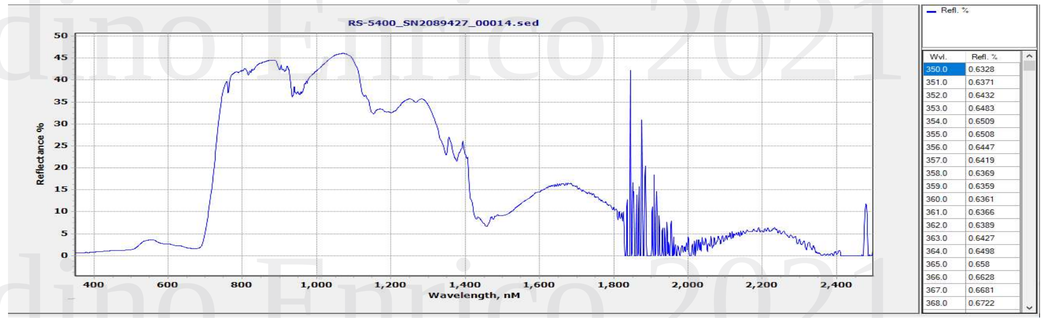
These spectral ground measures have to be integrated (similarily to Sun Irradiance) within the ranges of wavelength correspoding to the sensor bands

Georeferenced ground spectral measures have to be compared with the correspondent DN values from uncalibrated images (raw data) by scatterplot; the correspondent linear relationships defined by an Ordinary Least Squares approach. <u>Each band define a different relationship, therefore different coefficients</u>.



EMPIRICAL APPROACHES TO CALIBRATION





Calibrated panel: it is assumed having a REFLECTANCE equal to 1 for all the bands.

Spectroradiometer-based measures are double:

1. One concerning local and istantaneous BOA IRRADIANCE (including both scattered and direct contributions) → calibrated white panel

2. One concerning the radiance reflected by the observed surface (L_l)

Measures, needed for EMPIRICAL LINE calibration, should refer to surfaces, within the scene, having different spectral signatures guaranteeing a complete coverage of the ranges of reflectance values in all the bands.

Ground measures have to be georeferenced to be correctly positioned within the image to be calibrated.

RESULTS ARE DIFFERENT since CALIBRATION COEFFICIENTS, BACKSCATTERING AND ATMOSPHERE TRANSMISSIVITY TERMS depends on BAND and ACQUISITION DATE/TIME.

Spectral signatures of the same pixel from calibrated (red) an not calibrated Landsat image

Spectral indices, built as normalized RATIOS, can reduce difference. Nevertheless, some test done on satellite imagery proved that:

1. NDVI values from NOT CALIBRATED data is often UNDERESTIMATED (- 0.2, 0.3 NDVI points)
2. Correlation (Pearson's r) between NDVI temporal profiles from calibrated and not calibrated images varies between 0.5 and 0.95 depending on the pixel.
3. Temporal comparisons from not calibrated data are not reliable at all.