Cross-Calibration over Desert sites : Description, Methodology and Operational Implementation

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The need for cross-calibration of space sensors

Cross-calibration of space-based Earth observing systems is the way to guarantee consistency between 2 time series from 2 different sensors in order to build long-term time series of observations, which is essential in the frame of global analysis and climate change monitoring.

- combining measurements from different sensors → improve spatial coverage or compute geophysical products
- analyzing differences between products obtained from measurements of different sensors: (MODIS & PARASOL in the A-train context)
- combination of data from AM and PM sensors (MODIS instruments on-board TERRA and AQUA satellites)
- meteorological applications: guarantee consistency between observations from LEO and GEO satellites. Part of GSICS mission: cross-calibrate geostationary weather satellites (GOES and MSG), but also characterize them w.r.t. low orbit sensors (MODIS)

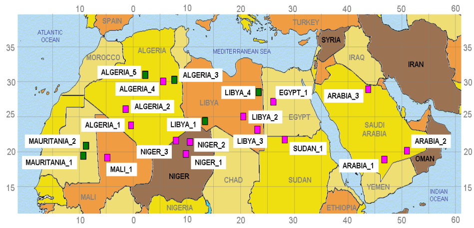
Calibration over desert sites can be used:

- *to provide a cross-calibration between two sensors*
- *to provide powerful information for multi-temporal monitoring or trending*

This poster focuses on the cross-calibration rather than the monitoring, but both aspects can be linked through specific optimizations that can be made for temporal monitoring (select a specific geometry, select the best reference sensor, …)
The approach can be extended to SWIR bands (1.6 or 2.2 µm) → the results presented here are limited to spectral range from VIS to NIR

The desert sites

- Based on Meteosat-4 data
- 100x100km2 areas were identified
- Spatial uniformity less than 3%
- 30 to 60% of non cloudy days
- Variation of BRDF: less than 15%
- Redefined and fixed to 0.45° in latitude and longitude



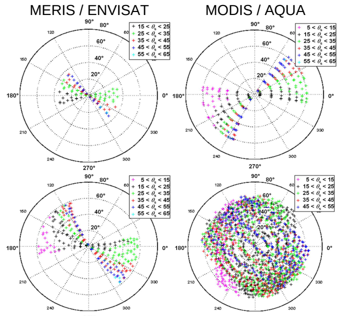
- 20 desert sites selected in 1996
- Among them, 6 sites (in green) selected by IVOS (Infrared and Visible Optical Sensors) working group of CEOS to become international calibration sites

Site	Central Latitude (°)	Central Longitude (°)
Algeria 1	23.80	-00.40
Algeria 2	26.09	-01.38
Algeria 3 (*)	30.32	07.66
Algeria 4	30.04	05.59
Algeria 5 (*)	31.02	02.23
Arabia 1	18.88	46.76
Arabia 2	20.13	50.96
Arabia 3	28.92	43.73
Egypte 1	27.12	26.10
Libya 1 (*)	24.42	13.35
Libya 2	25.05	20.48
Libya 3	23.15	23.10
Libya 4 (*)	28.55	23.39
Mali 1	19.12	-04.85
Mauritania 1 (*)	19.40	-09.30
Mauritania 2 (*)	20.85	-08.78
Niger 1	19.67	09.81
Niger 2	21.37	10.59
Niger 3	21.57	07.96
Sudan 1	21.74	28.22

(*) site selected by IVOS

Geometrical sampling

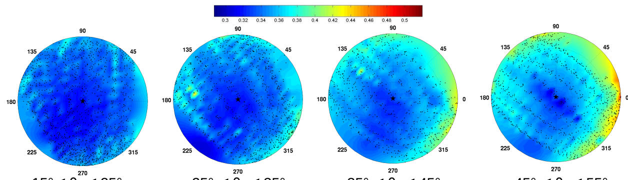
Typical geometrical sampling of selected acquisitions
- one year of acquisitions over Libya-1
- θ_v from 0 to 80°
- $\Delta\varphi_v$ from 0 (on the right) to 360° (counterclockwise)



MERIS / ENVISAT — MODIS / AQUA — VEGETATION / SPOT5 — POLDER / PARASOL

BRDF

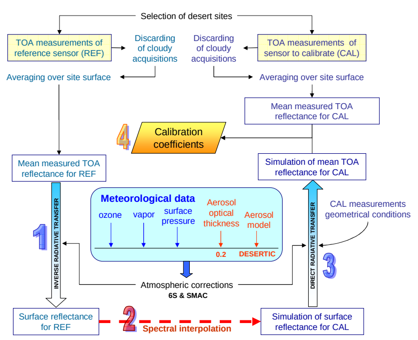
Bidirectional reflectance illustration for Libya-1 at 565 nm for 4 Sun zenith angle (θs) ranges.
- ground reflectances derived from PARASOL measurements 2005-2008 (black dots)
- other values interpolated for this representation
- BRDF plotted in polar coordinates



15° ≤ θs ≤ 25° — 25° ≤ θs ≤ 35° — 35° ≤ θs ≤ 45° — 45° ≤ θs ≤ 55°

The process of selecting the best desert sites suitable for cross-calibration includes an extensive evaluation of the radiometric characteristics of all desert sites, performed over the years:
- morphology
- brightness
- spectral profile
- spatial homogeneity
- altimetry
- bidirectional effects
- seasonal variations
- long-term stability

Cross-calibration method



← Synoptic view illustrating how measurements from the reference sensor (REF) are used to compute reflectances to be compared to measurements from the sensor to calibrate (CAL).

Construction of the reference reflectance

The loop is performed for each pair of measurements → modelling the reflectance that the reference sensor (REF) would have measured in the same geometrical conditions and same spectral bands than the sensor to calibrate (CAL):

1 **Atmospheric contribution (inverse radiative transfer)**
TOA reflectance from REF is corrected from the atmosphere → surface reflectance in REF spectral bands
SMAC (Simplified Method for Atmospheric Corrections) using:
- sensors spectral responses
- meteo data (water vapor, pressure from NCEP)
- ozone data (TOMS)
- aerosols optical thickness assumed to be 0.2 at 550nm
- desertic aerosol model

2 **Spectral interpolation**
→ Surface reflectance in CAL spectral bands
Use of a Spline function. May introduce a bias if high descrepancy between spectral bands of the 2 instruments to inter-calibrate

3 **Atmospheric contribution (direct radiative transfer)**
→ TOA reflectance in CAL spectral bands

4 **Computation of inter-calibration coefficients**
Ratio between the reflectance computed with REF and the one actually measured by CAL → calibration coefficient for the considered geometrical configuration

Geometrical coupling
- uses matched measurements from 2 sensors for which simultaneity is not required
- Same geometrical and solar conditions → limit the impact of bidirectional behaviour of the site and of atmospheric contribution
- Definition of a geometrical window
- Reciprocity principle ($\theta_s \leftrightarrow \theta_v$)

→ increase number of matchups

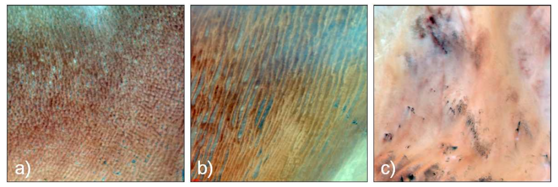
Standard definition of geometrical window for coupling:

$$\left|\theta_S^{(CAL)} - \theta_S^{(REF)}\right| < 2\ \mathrm{deg}$$
$$\& \quad \left|\theta_V^{(CAL)} - \theta_V^{(REF)}\right| < 2\ \mathrm{deg}$$
$$\& \quad \left|\,\left|\varphi_S^{(CAL)} - \varphi_V^{(CAL)}\right| - \left|\varphi_S^{(REF)} - \varphi_V^{(REF)}\right|\,\right| < 5\ \mathrm{deg}$$

θ_s : Sun zenithal angle
φ_s : Sun azimuthal angle
θ_v : Sensor zenithal angle
φ_v : Sensor azimuthal angle

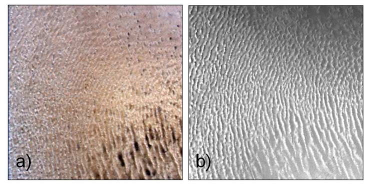
Views of desert sites

Typical VISNIR MODIS views over 3 desert sites



a) **Algeria-5** Small dunes — b) **Algeria-2** Long and oriented dunes — c) **Libya-3** Sand and rocks

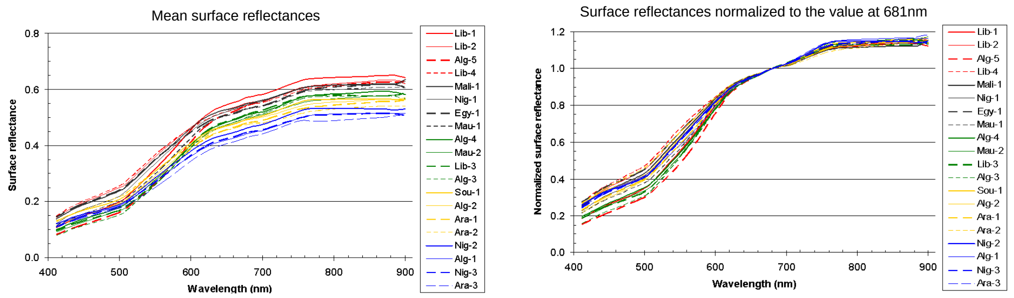
The **Libya-4** desert site



a) Typical VISNIR aspect (color composite from a MODIS view) — b) Digital elevation model from SRTM measurements (altitude 225 to 380m)

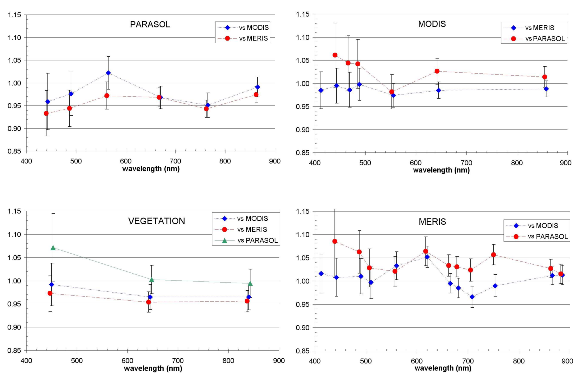
Surface reflectance

Mean surface reflectance for the 20 desert sites derived from a set of MERIS acquisitions in various geometrical conditions (mean over a 4-year archive). Sites are listed from the brighter site for 865nm (Libya-1), to the darker site (Arabia-3).

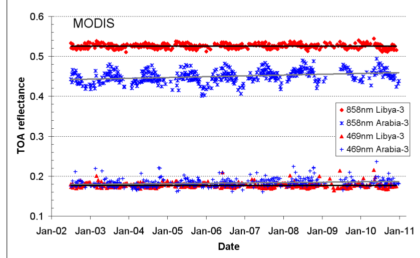


Cross-calibration results: PARASOL, MODIS, VEGETATION, MERIS

Cross-calibration results for PARASOL, MODIS, *VEGETATION*, and MERIS using various sensor as reference for the 400-900nm spectral range. When required, spectral bands are shifted by +/- 3nm for clarity. Error bars report the standard deviation.



MODIS time series



Time series of MODIS top-of-atmosphere reflectance:
- Libya-3 (red)
- Arabia-3 (blue)
- blue band (469nm)
- near infrared band (858nm)

- extracted from SADE (*) database
  (*) Data Repository for Calibration Measurements (French acronym)
- time period: 2002-2011
- criteria: $\theta_v \leq 40°$ & $\Delta\varphi_v \geq 90°$

Except seasonal variations and assuming that MODIS radiometric trending is perfectly corrected, Libya-3 shows a very long-term stability while Arabia-3 evidences a long-term increase of TOA reflectance for both wavelengths.

And now ? Work in progress…

- BRDF consideration for the geometrical coupling step (dynamic window size depending on geometrical conditions): the geometrical window used for coupling could be enlarged → more matchups, reduction of errors due to bidirectional effects
- A priori on surface spectrum for spectral interpolation (combining on-ground measurements when available with satellite-based measurements) → reduce spectral interpolation error by a few tenth of percent.
- Extension of the spectral domain to SWIR: surface reflectance of desert sites up to 0.7, limited atmospheric contribution out of absorption bands
- Cross-calibration GEO-LEO: method fully applicable (necessary to optimize the geometrical coupling step)

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