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Use of a remote sensing data repository for in-flight calibration of optical sensors over terrestrial targets.

François Cabot[1], Olivier Hagolle, Caroline Ruffel and Patrice Henry
CNES/QTIS/GC, 18, Av. Edouard Belin,
31401 TOULOUSE CEDEX 4, FRANCE

ABSTRACT

The present study is part of an investigation aimed at optimizing the use of desertic sites for absolute or relative calibration of satellite visible sensors. This effort includes characterization of the surface, gathering of climatology or atmospheric data sets, ground- and air-based measurements as well as results of calibration of various sensors over these sites. All these measurements and estimates are stored in a repository and made available to various methods for calibration.

Post-launch degradation and relative sensitivity of various sensors have been estimated using north african desertic sites as radiometrically stable targets. The selected areas have first been characterize in terms of bidirectional and spectral reflectances by making use of POLDER capabilities, then to cross-calibrate SeaWifs, VEGETATION onboard SPOT4 and AVHRR onboard NOAA-14 by reference to POLDER. Results are compared with absolute and relative calibration issued from other sources.

Extensive period of time are spanned to assess the ability of this method to monitor long term trends in sensor evolutions. Results of this cross calibration will be presented. The method developed for this study will be presented as well, in order to make it applicable to other sensors (e.g. optical sensors onboard EOS-AM1, ENVISAT)

A sensitivity study has also been realized, considering synthetic data, allowing to evaluate the main contributions to the error budget. The need for aerosol optical thickness is then evidenced, and will lead to the set up of a sun photometer on one of the selected sites in 1999.

1. INTRODUCTION

In the very next years, the number of scientific Earth observing systems will increase. With the launch of SPOT4, NOAA-K, EOS-AM1, Landsat7, ENVISAT and commercially owned systems, a considerable amount of data should become available to scientific communities by the end of the century. Still, the use of these newly acquired data sets will rely heavily on the use of existing archives. Availability of long term series (more than 10 years) allows analysis of major trends regarding terrestrial environment or climate change. Inter calibration of past, present and future sensors is therefore a major issue for the use of these archives as well as forthcoming measurements.

One way to address this issue is to rely on the stability and the monitoring of satellite-borne instruments by means of onboard calibrating devices. But, even when available, onboard calibrating devices are not sufficient to ensure consistent intercalibration due to the wide diversity of crossing times, spectral responses, sampling techniques and period of life. To account for all these differences, one has to apply techniques known as vicarious calibrations to the intercalibration problem. Making this techniques easy to apply on a routine basis, it has been found necessary to build a repository able to include large time series of measurements from various sensors, over selected targets, along with ancillary information. The basic description of this repository and all the data types it has to contain can be found in Cabot, 1997.

1.Tel: (33) 5 61 27 33 04 - Fax: (33) 5 61 27 31 67 - e-mail: francois.cabot@cnes.fr

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After a brief description of the data sets used in this study, we will present the developed method, results obtained, and will discuss the potential application to a wider range of sensors.

2. DATA SETS

The selected data sets included in this repository span almost three years, starting from the beginning of life of POLDER onboard ADEOS in early November 1996. Since then, we have been gathering measurements from AVHRR over the whole period, SeaWiFS and VEGETATION as Orbview-2 and SPOT4 were launched. Beside these data sets, ancillary data such as water vapor content from ECMWF or NCEP and ozone content from TOMS (onboard ADEOS then onboard Earth Probe) are also acquired routinely. Figure 1 shows period of time covered by each data set.

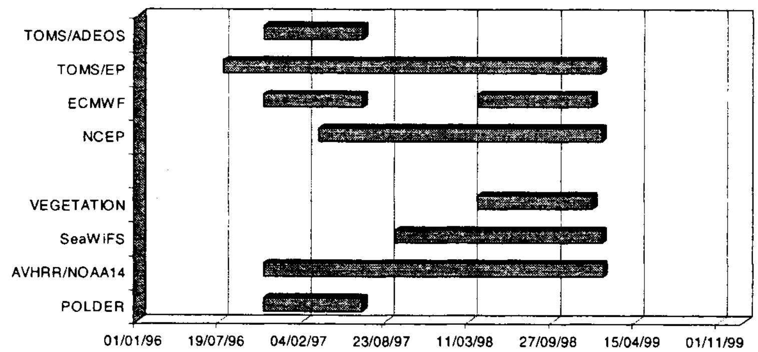

Figure 1. Periods covered by the different data sets

2.1. Desertic sites

When concerned with relative calibration, one has to look for a common target, known as a reference. Several effects will modify the behavior of this reference: i) acquisition and lighting geometry, ii) state of the atmosphere, and iii) geolocation accuracy. Desertic sites must present the following properties, allowing to minimize the impact of these effects:

•large extent with good homogeneity to minimize misregistration and various field-of-view impact.

•temporal stability of the surface, and low variability of overlying atmosphere, including low cloudiness.

•faint directional effects.

Based on these requirements, an extensive search for such desertic sites took place before the launch of ADEOS (Cosnefroy et al., 1996) and ended with a selection of 20 areas, each larger than 100x100km² in North Africa and Saudi Arabia. Figure 2

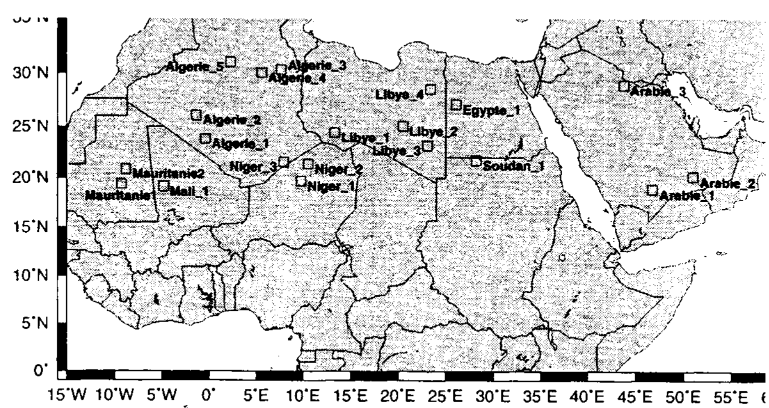

Figure 2. Geographic position of the 20 sites selected as reference targets.

shows the geographic position of the selected sites.
These sites are accessible to measurement almost once a day for all the sensors involved in this study, allowing for the constitution of an extensive archive. Geomorphological data, when available, have been included in the repository, and ground measurements, available for 3 sites in Algeria are also included.

2.2. POLDER

The POLDER data used in this study are extracted from level 1 standard products. Calibration has been applied according to Hagolle *et al.* 1998.
A 15x15 subimage including each site is extracted and average radiometry, standard deviation, minimum and maximum are computed for each spectral band. Filtering for clouds and high aerosol contents is also conducted at this step. Absolute thresholds are applied to top of atmospher reflectances and spectral indices are used to identify cloudy pixels. At last a statistical analysis is conducted on the time series to remove anomalous variations in the contrast of the scene, supposed to be due to broken cloud fields or aerosol events.
Thanks to POLDER capability the sampling of the bidirectional reflectance is nearly complete as can be seen on figure 3. This figure shows for all the sensors the available sampling of the BRDF, during the whole period, over site Libya 1 as an example. It has to be underlined for POLDER that, for solar zenith angles between 10° and 50°, a quasi complete coverage of the hemisphere is available. It can be compared to the other sensors, acquiring each in specific plane.

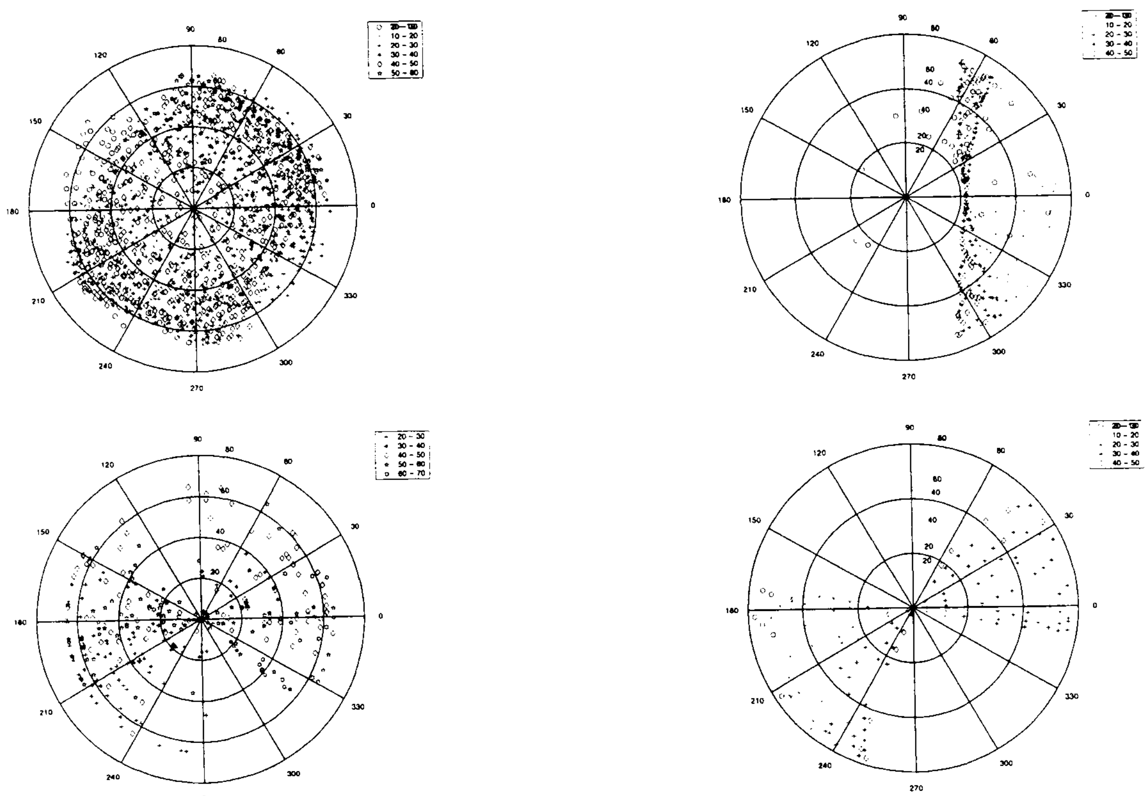

Figure 3. Geometrical sampling of the BRDF available over site Libya 1, for each sensor: top left POLDER, top right SeaWiFS, bottom left AVHRR, bottom right VGT. Different symbols indicate different solar zenith angle classes.

2.3. SeaWiFS

SeaWiFS data used in this work are extracted from level 1A GAC products. Extraction and filtering were conducted in the same way as what was done for POLDER. The calibration is applied as recommended by SeaWiFS project but using only the pre launch calibration table. Average values of the TOA reflectance are computed over the extent of each site for each date of acquisition.

2.4. AVHRR

AVHRR data sets have been extracted from level 1b GAC archive, calibration is applied according to Rao and Chen, 1996. Filtering is done with respect to the thermal infrared channels to eliminate cloud contamination.

2.5. VEGETATION

VGT data are extracted from the archive after conversion into TOA reflectances. As for SeaWiFS, only pre launch calibration coefficients are considered. Extraction and filtering is conducted in a similar way to POLDER except for the use of the SWIR band.

2.6. Meteorological data

As can be seen on figure 1, extensive archives of meteorological data are included in the repository. This allows us to get day to day estimates of water vapor content, ozone content and surface pressure over all the sites. At this point, no reliable source of information has been identified for aerosol optical depth and this appears to be a problem to address if we want to improve the accuracy of the method, as will be shown. We can only assess the fact that filtering as is applied allows to minimize the impact of high aerosol optical depth, on the other side very tight filtering gives access to only a limited number of data points.

3. METHODS FOR CALIBRATION

The basic principle of the comparison conducted here is to consider POLDER as a transfer radiometer. That is, making use of its spectral and directional capability, we compute reference reflectance for the other sensors and compare these reference to the measured reflectance from the other sensor. The basic principle of the method is sketched on figure 4: the POLDER TOA measurements are first corrected for atmospheric effects to obtain surface level reflectances, then a spectral empirical model is fitted against these reflectances to obtain a continuous spectrum for the surface reflectance. This spectrum is then integrated in the other sensor spectral bands to obtain reference surface reflectances. At last, these reflectances are used to simulate TOA reference reflectances to compare to original measurements from the other sensor, giving access to estimate of calibration coefficient with reference to POLDER. This comparison can be conducted in two ways to account for directional effects.

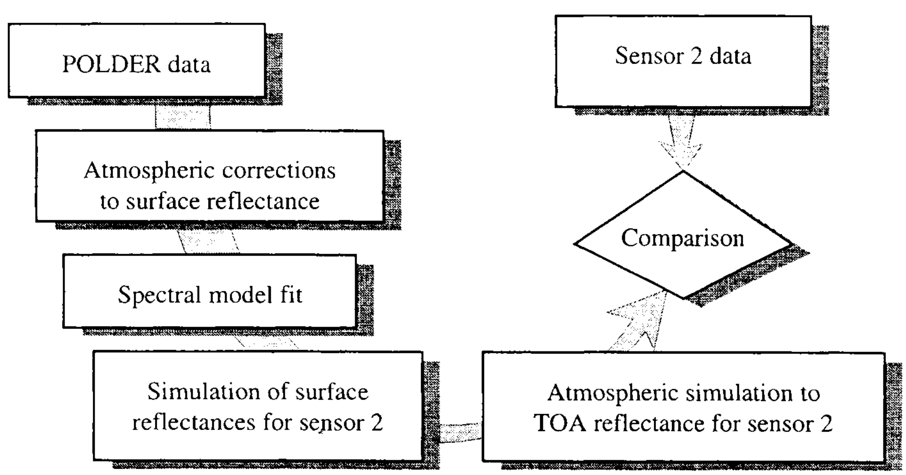

Figure 4. Basic principle for the method, for estimating reference reflectance from POLDER data

3.1. Atmospheric corrections

In order to remove as much variability as possible from the measurements and to ensure a smooth variation of the reflectance with wavelength, atmospheric corrections are applied to POLDER data to obtain surface level reflectances. The spectral impact is depicted on figure 5. The selected algorithm for atmospheric corrections is the SMAC method (Rahman and Dedieu, 1994, Berthelot and Dedieu, 1996) allowing to use the same algorithm for downward and upward simulations. Corrections are applied considering water vapor and ozone content and surface pressure from meteorological data, and a constant aerosol optical thickness of 0.2, the selected aerosol model is desertic. This value is expected to be representative of the average condition, once removed very high values coincident with aerosol events.

For the upward simulation, depending on the method of comparison, as explained below, the state of the atmosphere can be described at POLDER acquisition time, thus assuming that the state of the atmosphere is stable as is the surface, or at the real time of the other sensor acquisition, thus accounting for variations in the state of the atmosphere between the two periods.

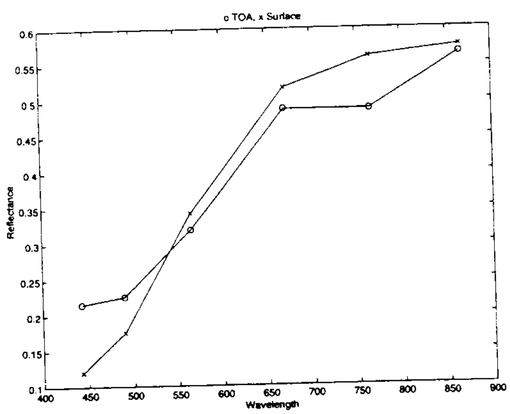

Figure 5. Spectral impact of atmospheric corrections as applied to POLDER data. o TOA, x Surface (example for site Libya 1)

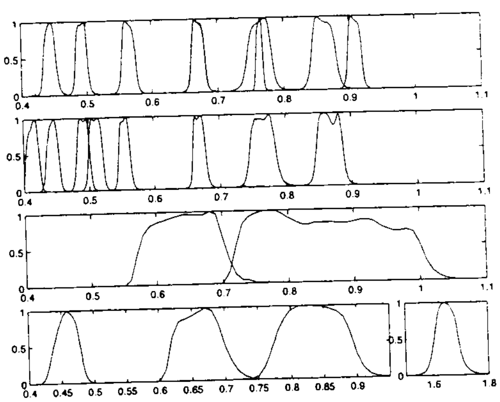

Figure 6. Spectral responses for the various sensors. From top to bottom: POLDER, SeaWiFS, AVHRR and VGT.

3.2. Spectral interpolation

Accounting for differences in spectral responses (figure 6) has been addressed, as mentioned, by fitting an empirical spectral model to surface reflectances estimated from POLDER.

The selected model can be written as:

$$\rho(\lambda) = a\,\mathrm{atan}((\alpha\lambda + \beta) + b) \qquad \text{Eq. 1}$$

Where ρ is the calculated reflectance at wavelength λ, and α, β, a and b are fitted parameters.

It is obvious on figure 6 that the expected accuracy of the model will decrease rapidly below 443 nm and above 865 nm (due to its high sensitivity to water vapor content, the 910 nm band is not used in the fitting procedure). Consequently, results for the SWIR band of VGT, and even for channel 2 of AVHRR have limited interest so far, until we can complement our knowledge of surface BRDF in these spectral bands.

3.3. Geometric effects

The minimization of the impact of different acquisition geometry can be addressed by two different methods:

3.3.1. Polynomial fit (PF)

For each sensor to compare to POLDER, acquisitions are selected in the specific acquisition plane. These planes, as can be seen on figure 3 vary with the sensor, the season, and therefore with solar zenith. Fortunately, for each period considered (with minor exceptions) POLDER data is available, in this specific plane, with the same range of solar zenith angles. Extraction of data acquired in the same geometry, with the same lighting geometry is therefore almost always possible. From these extraction the comparison can be done by fitting against each data set (original measurements and reference built from POLDER) a second degree polynomial, function of view zenith angle. The estimate of the calibration coefficient is then derived as the average of the ratio of these polynomials over the available range of view zenith angles.

3.3.2. Closest geometry

Instead of selecting a common plane of acquisition, this method searches, for each acquisition of the sensor to compare to POLDER, a POLDER-built reference in the same geometry. This limits the number of data points to be used but ensure no bias is introduced by the use of a model.

4. ACCURACY ISSUES

4.1. Sensitivity study

A sensitivity study has been conducted on the method itself. It has basically consisted in generating artificial data sets representative of the real data sets for all the sensors, and apply the same method for comparison. Atmospheric effects have been simulated and meteorological data used for the simulation have been added noise for the comparison. In a same way, randomly generated aerosol optical thickness has been used, but the constant value of 0.2 has been used for the comparison. The resulting calibration coefficients from this experiment are representative of the sensitivity of the method to atmospheric perturbation, including aerosol, and to bidirectional sampling effects (possibility to retrieve coincident geometry, possible bias introduced by solar zenith variations...). The overall accuracy estimated from this experiment ranges from 2% to 3.2% depending on the method of comparison and wavelength considered. The VGT blue band appears to be the most sensitive for the PF method and the less sensitive for the CG method, probably due to the very different accounting for atmospheric effects. An estimate of the accuracy expected on the trends of the calibration coefficients is also computed to be always less than 0.15%/month.

It is obvious that this sensitivity analysis does not take any account of the spectral model deficiencies, expected to give uncontrolled biases for bands outside the spectral domain accessible to POLDER.

4.2. Reciprocity principle

A last accuracy indicator has been estimated: the verification of the reciprocity principle on TOA reflectances estimated from POLDER.This can be done by searching, for each POLDER acquisition, a reciprocal acquisition in the POLDER data set. That is pairing data points for which $\theta_{s1}=\theta_{v2}$ and $\theta_{v1}=\theta_{s2}$ with the same relative azimuth. This test is aimed at verifying the stability of the test site during POLDER life, the stability of POLDER sensor itself and the impact of the atmosphere. It is impossible from the results of this test to separate the contributions of all these effects but it gives a good estimate of the upper bound of the sensitivity of the various bands to these effects. As can be seen on figure 7, this impact ranges from 3.79% for blue bands to 1.84% for near infrared, with the exception of the 910 nm most affected by water vapor.

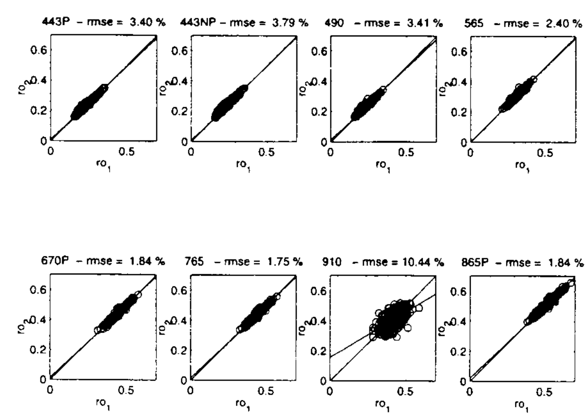

Figure 7. Reciprocity principle applied to POLDER estimated TOA reflectances

5. RESULTS

From each comparison of a data point to the corresponding reference reflectance, we can estimate a calibration coefficient. And from all these estimates, we compute the average and standard deviation. These results are reported in table 1 as average and standard deviations of the reflectances ratios: $\rho_{sensor}/\rho_{POLDER}$. These results are representative of the comparisons of the data sets as a whole, that is with no consideration given to temporal trends, except for the AVHRR data set that was separated in year 1997 and 1998. First thing to underline is the consistency between the two methods for comparison, confirming the robustness of the methods to atmospheric effects. Beside, standard deviations are generally low and this confirms again the level of accuracy expected from the method.

Table 1 : Overall intercalibration results - Italic figures indicate standard deviation of results.

	SeaWiFS/POLDER							
	412 nm	443 nm	490 nm	510 nm	555 nm	670 nm	765 nm	865 nm
PF	0.968	1.065	1.042	1.024	1.006	0.996	1.001	0.971
	0.017	*0.013*	*0.016*	*0.015*	*0.008*	*0.015*	*0.009*	*0.007*
CG	0.973	1.065	1.047	1.029	1.007	1.004	1.003	0.969
	0.045	*0.056*	*0.053*	*0.044*	*0.031*	*0.025*	*0.030*	*0.028*
	VGT/POLDER							
	B0	B2	B3	SWIR				
PF	1.003	0.932	0.978	1.184				
	0.023	*0.011*	*0.010*	*0.044*				
CG	0.994	0.921	0.972	1.156				
	0.035	*0.016*	*0.014*	*0.029*				
	AVHRR 98/POLDER			AVHRR 97/POLDER			AVHRR 98/AVHRR 97	
	C1	C2		C1	C2		C1	C2
PF	1.061	1.153		1.028	1.074		0.970	0.933
	0.016	*0.014*		*0.013*	*0.008*		*0.012*	*0.010*
CG	1.072	1.182		1.051	1.107		0.974	0.935
	0.038	*0.044*		*0.060*	*0.070*		*0.055*	*0.058*

5.1. SeaWiFS

At first, one can observe a very good accordance between the two sensors. Difference in sensitivity are always less than 6.5% overall and less than 1% for wavelengths between 555 and 765 nm. Results at shorter wavelengths show larger standard deviation, especially for the CG method, because of larger atmospheric contribution. Result at 865 nm is representative of the evolution of the SeaWiFS band discussed in Barnes et al, 1998. At last, result at 412 nm should be considered with caution since no POLDER band is available below 443 nm.

All these results can be further analyzed by paying attention to the temporal trends that can be observed by both methods.

5.1.1. Polynomial fit method

To account for temporal trends this method needs to be applied to a shorter periods in the data sets. The POLDER data set is always considered entirely, but the other sensor is considered month by month. Thus, for each month of acquisition, we can estimate a calibration coefficient. An example of comparison is plotted on figure 8, for the month of April 1998, over Sudan 1 site. The estimated calibration coefficient is the average of the ratio of the plotted polynomials in the range of view zenith angles accessible to SeaWiFS. These coefficients are plotted on figure 9 as a function of the number of days since the first image. On the same figure, the dashed lines represent the evolution of the calibration coefficients as provided by SeaWiFS project. One can see that the temporal evolution of the 865 nm band is estimated in a very similar way. On the other hand a trend is found for 443 nm, although the expected accuracy and the scattering of the points does not allow to be affirmative.

The seasonal behavior that appears for bands up to 555 nm still need to be investigated.

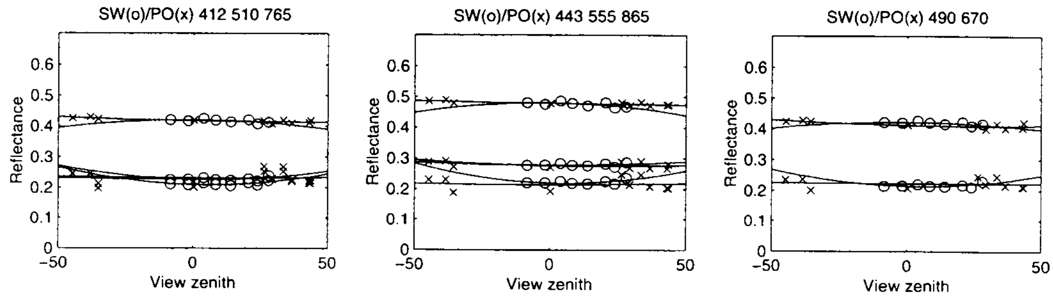

Figure 8. Result for the PF method over Sudan 1 site, for April 1998.

5.1.2. Closest geometry

Since this method compares data points to data points, it is straightforward to analyze temporal trends. To estimate the consistency of the trend estimates, the calibration coefficient are averaged over one month periods. Again, the evolution of the 865 nm band is correctly estimated. On the other hand, the behavior of the 443 nm band is still in disagreement with the calibration as given by SeaWiFS by about 6%. At last the seasonal behavior for shortwave bands is also present.

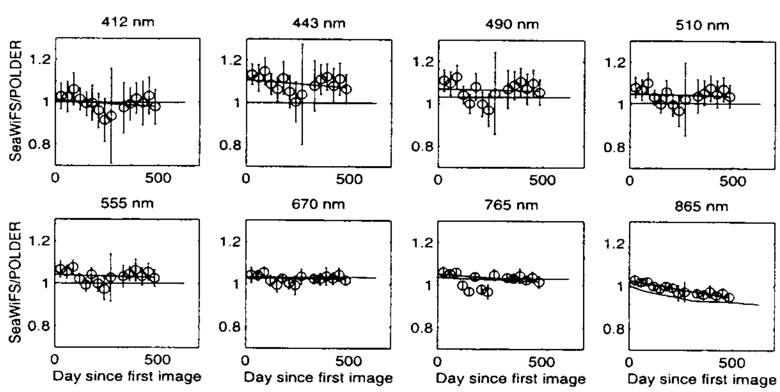

Figure 9. Temporal evolution of SeaWiFS calibration coefficient, as estimated from POLDER using PF method.

5.2. VEGETATION

At first, one can note the discrepancies between the two sensors that can reach 7 or 8% for red band (apart from SWIR band, that is clearly outside the spectral domain accessible to POLDER) very low standard deviations always lower than 4.4% for all bands and as low as 1.6% for red and near infrared bands. Again, results for SWIR band should be considered only like preliminary. The agreement between the two methods is slightly lower than for SeaWiFS, which is probably an effect of the wider spectral bands.

5.2.1. Polynomial fit

The temporal results for this method are shown on figure 10. As can be seen, the temporal evolutions are in good agreement with the calibration coefficient from VGT project, plotted with dashed line. Only the absolute level of the coefficients needs to be further investigated.

5.2.2. Closest geometry

For this method, and despite lower standard deviations, the temporal evolution for red and near infrared bands do not appear as clearly. A very small positive slope is even found.

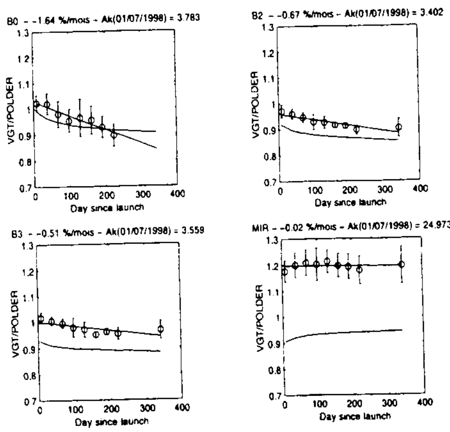

Figure 10. Temporal evolution of VGT calibration coefficients as estimated from POLDER using PF method.

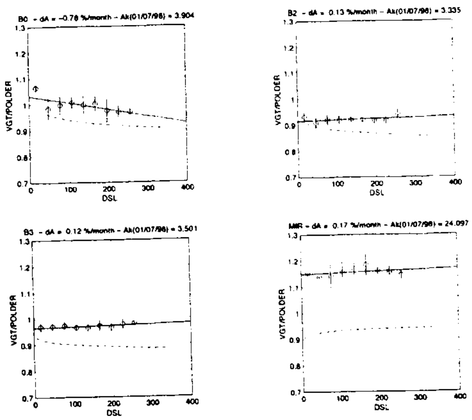

Figure 11. Temporal evolution of VGT calibration coefficients as estimated from POLDER using CG method.

5.3. AVHRR

Results for AVHRR are only given to allow an additional check of the consistency of our results over long period of time. For this instrument, we were able to compare it to POLDER as for the others and to compare it to itself one year apart. Results of the comparison between 1997 and 1998 are very comparable when estimated from POLDER or by direct comparison, even for channel 2, for which we little expectation regarding the absolute level, because of its spectral width. Discrepancies are as small than 0.6% overall. This gives us additional confidence in the stability of the sites and robustness of the method to different atmospheres.

6. CONCLUSION - PERSPECTIVES

An extensive archive from various sensors has been collected, over desertic sites spanning almost three years. Ancillary data have also been collected to allow accounting for as man atmospheric effects as possible. Methods for comparison of these data sets have been developed and applied, essentially based upon the capability of POLDER to serve as a transfer radiometer. Results appear promising even if they are very sensitive to aerosol optical thickness, highly variable through time and space. To reduce this sensitivity, we need additional information regarding these aerosols. The deployment of sun photometer on one of the sites will help to document aerosols events and to validate satellite based methods for the estimation of aerosol optical thickness over desertic areas.

The gathering of data over these sites will continue and inclusion of additional sensors, operating such as ATSR2, or shortly available like MODIS, MISR onboard EOS Terra and MERIS onboard ENVISAT are planned through investigations for which the authors have been selected by NASA and ESA.

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