Quentin Pochez
Traineeship Calitoo
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Calibration of the Calitoo photometer in laboratory

Introduction:

The aim of this document is to present the method to calibrate the sun photometer Calitoo in laboratory. Currently, we know how to calibrate that photometer by different methods but only with the sun. In it we will present the Calitoo and the different methods we know in order to finish by the method in laboratory.

I/ Presentation of the Calitoo and introduction of the subject

1) Presentation of the traineeship and the soft of calitoo
2) Calculation of the aerosol optical depth (AOD)
3) Comparison between AOD of Calitoo and AOD of aeronet

II/ Actual methods of calibration

1) Absolute calibration
2) Intercalibration with a Lille photometer
3) Intercalibration between two Calitoo

III/ New method in laboratory

1) Choice of this method and material used
2) Heating time
3) Principle of the method
4) Problems with the method
5) Presentation of the results and hopes for the future

I/ Introduction of the subject

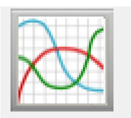
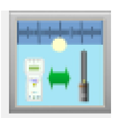
1) Presentation of the traineeship and the Calitoo

The Calitoo photometer is a manual photometer that we can take everywhere with you. Thanks to it, you can determinate the AOD. It uses 3 wavelengths (465nm, 540nm and 619nm) and it gives us some information like GPS position, time, pressure, the AOD and the Angström exponent. In order to calculate the AOD values, it uses some Cn which are some values which is proportional to the intensity of the source of light. These Cn go from 0 to 4096 and the precision announced by the web PHOTONS/LOA for the AOD is 0.02.

The current methods of calibration are the absolute calibration with Langley method or intercalibration with a photometer master of AERONET. These methods are a very long task and can’t be done at every moment because we need no cloud, so we try to found another method in laboratory to calibrate these photometers.

The society TENUM which produces the Calitoo develop also a soft for the Calitoo:

On this soft we can study the data of different Calitoo but also calibrate one of them. We can find on it different tools like intercalibration, the AOD calculator, data visualization, Langley calibration,… Here we will only use the data visualization and the intercalibration:

2) AOD calculation

Before knowing how to calculate the AOD, it is important to know what it is. The optical depth is a way to measure the transparency of the atmosphere. The aerosols can alter the transparency of this atmosphere and so the AOD describe how aerosol have an impact on the transparency for different wavelengths.

We know where we can see the values of the AOD with the Calitoo but it is important to understand how it works. From the Cn data, we can find again the AOD values. These calculations are done on an excel program which follows. In order to complete this folder, we need some coefficients like the R^2 and the Angstrom exponent (α). Their formula are:

$\mathbf{R} = \frac{(1-0.0167)^2}{1+0.0167\cos(2\pi(\frac{D}{365}))}$ where D is the number of the day and $\boldsymbol{\alpha} = -\frac{\ln(\frac{\delta_\lambda}{\delta\lambda 0})}{\ln(\frac{\lambda}{\lambda 0})}$. We need also the solar elevation and a coefficient m which is m=1/sin (solar elevation). After that the calculation of the AOD is $\mathbf{AOD} = -\frac{1}{m}.\ln(T_\lambda.R^2) - \tau_{r0\lambda}\left(\frac{p}{p0}\right) - \tau_{0\lambda}$ where m is the coefficient linked with the solar elevation, Tλ is the transmission, $\tau_{r0\lambda}$ is the ozone optical depth and $\tau_{0\lambda}$ the Rayleigh optical depth.

With all these equations, we are able to calculate directly the AOD by hand. In fact it is what is done by the soft of calitoo. So we can compare if we have the good equation comparing our calculated AOD and the one given by the soft. Doing that we find:

Date	Time	Elevation solaire	m	d : jour de l'a	R²	Pression	Raw 465	Raw540	Raw619	AOT 1 (465nm) Ca	AOT par le calcul	Erreur AOT 4	Erreur pourc
19/06/2017	08:48:02	0,802851456	1,39016359	170	1,03238754	1016	2332	2368	2013	0,1203	0,120274638	2,5362E-05	0,02108449
19/06/2017	08:49:15	0,802851456	1,39016359	170	1,03238754	1016	2317	2337	2004	0,125	0,124916554	8,3446E-05	0,06677882
19/06/2017	09:09:22	0,855211333	1,32501299	170	1,03238754	1016	2391	2405	2048	0,117	0,116940979	5,9021E-05	0,05045799
19/06/2017	09:09:48	0,855211333	1,32501299	170	1,03238754	1016	2396	2405	2054	0,1153	0,115316167	1,6167E-05	0,01402043

Data from Calitoo #45

Date	Time	Elevation solaire	m	d : jour de l'a	R²	Pression	Raw 465	Raw540	Raw619	AOT 1 (465nm) Ca	AOT par le calcul	Erreur AOT 4	Erreur pourc
19/06/2017	07:13:56	0,541052068	1,94160403	170	1,03238754	1016	1936	2191	1855	0,1366	0,136567671	3,2329E-05	0,02366969
19/06/2017	07:14:55	0,541052068	1,94160403	170	1,03238754	1016	1930	2179	1852	0,1382	0,138166342	3,3658E-05	0,02435754
19/06/2017	07:15:23	0,541052068	1,94160403	170	1,03238754	1016	1949	2199	1859	0,1333	0,133120814	0,00017919	0,13451358
19/06/2017	07:15:45	0,541052068	1,94160403	170	1,03238754	1016	1956	2208	1863	0,1312	0,131274325	7,4325E-05	0,0566338
19/06/2017	07:42:43	0,628318531	1,70130162	170	1,03238754	1016	2078	2305	1934	0,1419	0,141856379	4,3621E-05	0,0307451
19/06/2017	07:43:00	0,628318531	1,70130162	170	1,03238754	1016	2074	2293	1934	0,143	0,142988914	1,1086E-05	0,00775277
19/06/2017	07:43:10	0,628318531	1,70130162	170	1,03238754	1016	2083	2306	1932	0,14	0,140443773	0,00044377	0,31647912
19/06/2017	07:43:33	0,628318531	1,70130162	170	1,03238754	1016	2086	2311	1935	0,14	0,139597836	0,00040216	0,28767333

Data from Calitoo #62

Here are the results for the blue channel of the Calitoo, the error is only due to the rounded error done by the soft.

3) Comparison between AOD of Calitoo and AOD of aeronet

In order to know if our Calitoo are “good”, we can check if there values are similar to those of AERONET. To do that it is important to see that the wavelengths are not the same between aeronet and Calitoo. So we have to calculate the aeronet AOD to the wavelengths of Calitoo. To do that we use: $\boldsymbol{\tau}_{\boldsymbol{\lambda 0}} = \boldsymbol{\tau}_{\boldsymbol{\lambda}}(\frac{\boldsymbol{\lambda}}{\boldsymbol{\lambda 0}})^{\boldsymbol{\alpha}}$ where $\tau_{\lambda 0}$ is the value of the AOD to the wavelength we want, τ_{λ} the value of the AOD we know, λ and λ0 the linked wavelength and α, the Angstrom exponent.

We have another problem of interpolation which is the time. Sometimes, the values of aeronet and those of Calitoo are not taken in the same time. So we have to do a linear interpolation.

After that, we are able to compare the different values and see if the Calitoo is close to aeronet values. So we put that values in Excel and with a little program on it we can find:

AOT 1 (465nr	AOT aeronet	Erreur AOT 4	Erreur pourc	AOT 2 (540nr	AOT aeronet	Erreur AOT 5	Erreur pourc	AOT 3 (619nr	AOT aeronet	Erreur AOT 6	Erreur pourc
0,1203	0,11270985	0,00759015	6,51487869	0,091	0,08481262	0,00618738	7,03860221	0,0766	0,07268134	0,00391866	5,25003719
0,1173	0,11270985	0,00459015	3,99126774	0,0922	0,08481262	0,00738738	8,34672178	0,0711	0,07268134	0,00158134	2,19964172
0,1075	0,10677146	0,00072854	0,6800194	0,0806	0,0801736	0,0004264	0,53043347	0,0724	0,06978985	0,00261015	3,67135572
0,1063	0,10677146	0,00047146	0,44253347	0,0808	0,0801736	0,0006264	0,77826238	0,0704	0,06978985	0,00061015	0,87045906

Calitoo #45

Data from the 19/06/2017

AOT 1 (465nr	AOT aeronet	Erreur AOT 4	Erreur pourc	AOT 2 (540nr	AOT aeronet	Erreur AOT 5	Erreur pourc	AOT 3 (619nr	AOT aeronet	Erreur AOT 6	Erreur pourc
0,113	0,11586387	0,00286387	2,50268534	0,0959	0,0885793	0,0073207	7,93660323	0,0788	0,07315253	0,00564747	7,43319754
0,1142	0,11586387	0,00166387	1,44644291	0,0899	0,0885793	0,0013207	1,47994215	0,0705	0,07315253	0,00265253	3,69298601
0,1198	0,11586387	0,00393613	3,34046004	0,0856	0,0885793	0,0029793	3,42096298	0,079	0,07315253	0,00584747	7,6863209
0,1185	0,11586387	0,00263613	2,24960332	0,0839	0,0885793	0,0046793	5,42593185	0,0781	0,07315253	0,00494747	6,54199421
0,1133	0,11365964	0,00035964	0,31692104	0,0882	0,08662729	0,00157271	1,79916208	0,0751	0,07200054	0,00309946	4,21406943
0,1158	0,11365964	0,00214036	1,8655643	0,0816	0,08662729	0,00502729	5,97677935	0,0753	0,07200054	0,00329946	4,47990136
0,1135	0,11365964	0,00015964	0,14055439	0,0884	0,08662729	0,00177271	2,02564201	0,0701	0,07200054	0,00190054	2,67492373
0,1131	0,11365964	0,00055964	0,49359879	0,0875	0,08662729	0,00087271	1,00238526	0,0754	0,07200054	0,00339946	4,6125468

Calitoo #62

Data from the 19/06/2017

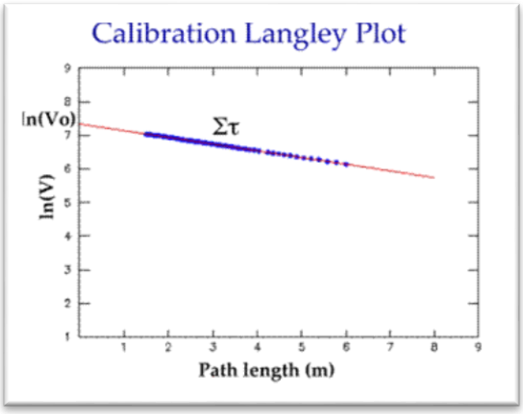
We can see here the errors between the AOD given by Calitoo and the one recalculated of AERONET. We can see that the values of the Calitoo are close to those of AERONET. So this Calitoo is considered as “good” but it’s possible to find other Calitoo which values could be far from that. The values given by AERONET are with a potential error of maximum 0.01 on the AOD and the one given by Calitoo 0.02. So if we take a look of the difference between the two AOD the maximum of difference must be under $\sqrt{0.01^2 + 0.02^2} \approx 0.022$. On these data, the maximum of error between AERONET and Calitoo is 0.007 so it is far under the 0.022 announced.

II/ Actual methods of calibration with the sun

1) Absolute calibration

The absolute calibration follows in fact the Langley calibration and doing that method, we have to take measures all the daylong in order to have a lot of measures in function of the air mass. We need to have a perfect sky and a constant AOD or zero. That is a difficulty of that method.

With all these measures and the equation of the AOD we can found the V0. In fact, we have the values of some V of the day and the equation: $\ln(V) = -mAOD + \ln(V0)$ so if the m value is 0, we can find the value of V0 and so calibrate the instrument. On this equation, the AOD is a constant that is the reason why we can do that, we have one less parameter. With all the values taken, we can draw a graph like the one which follows and we must find a straight line and the ordered at the origin gives us the value of the new V0.

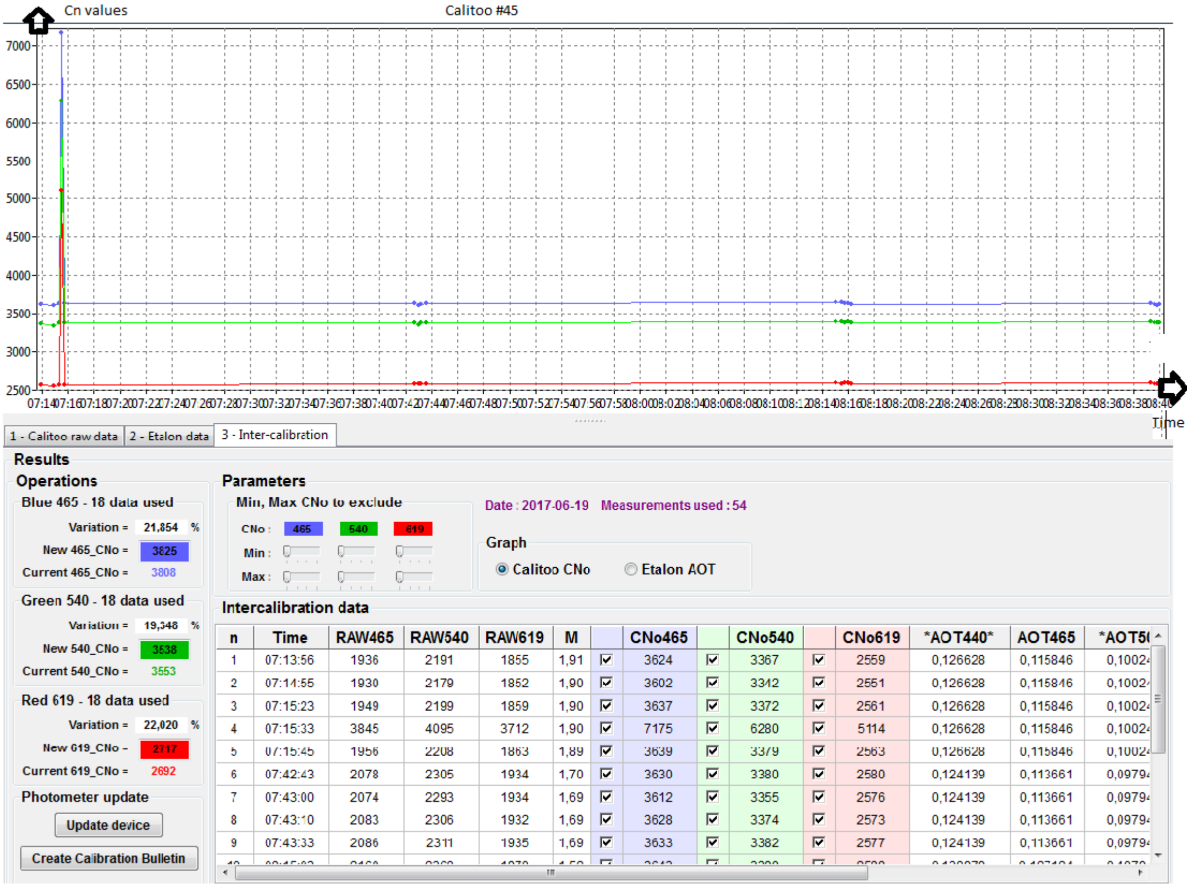


For the Calitoo this method is very repetitive because we have to take all measures by hand and by some perfect conditions. So this method was forget by the constructor and we can't do it here because it is complicated to put in place.

2) Intercalibration with a Lille photometer

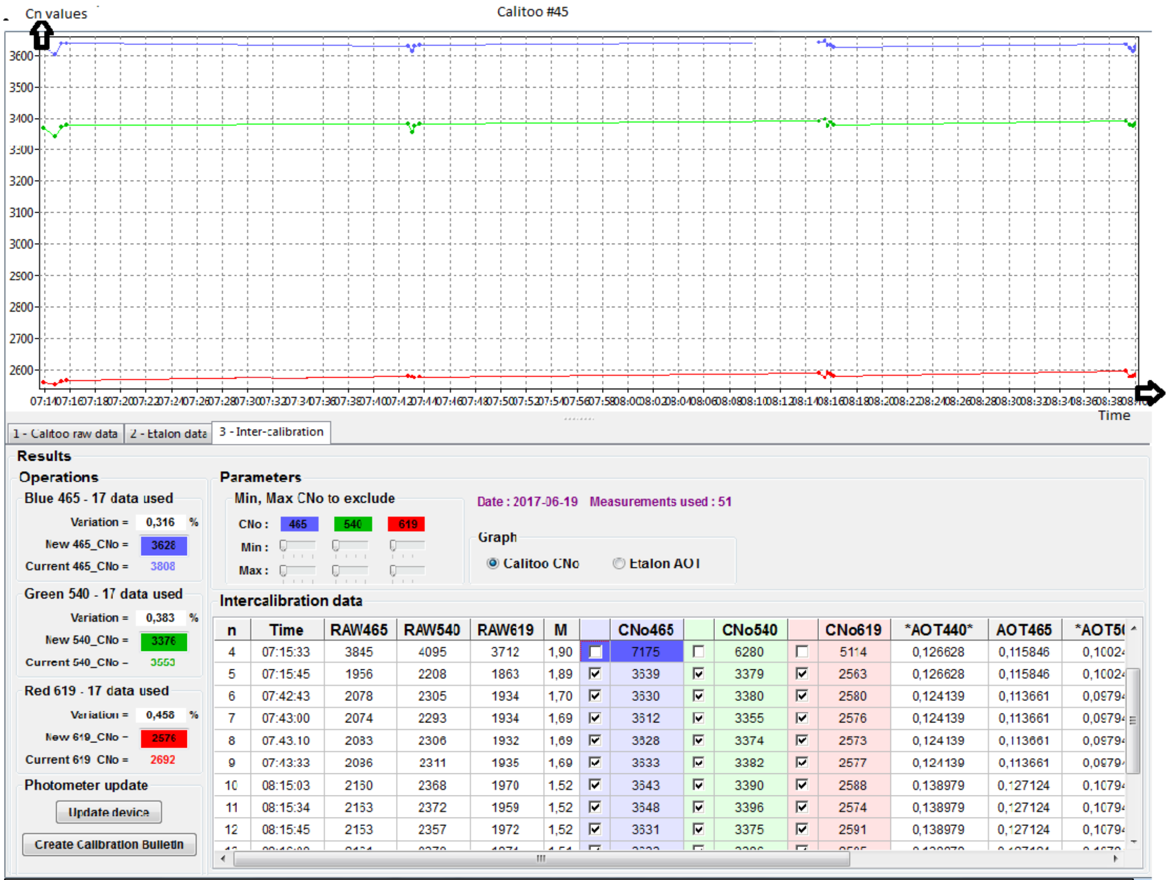
In order to calibrate our Calitoo we can use the method said as intercalibration and to begin we can intercalibrate a photometer on the roof of the PHOTONS network and a Calitoo. To put this method in place, we have to take some measures with our Calitoo on the roof near the AERONET photometer.

Our measures taken, we can analyze them. We have a tool on the soft of Calitoo which permit to intercalibrate the both. With that tool, we have only to connect the Calitoo, to choose the day when we have done the measures and to collect the AERONET data. After that the soft calculate automatically the new Cn0s and we can see the differences between the old and the new one or to select only the values we need.



Intercalibration of the Calitoo #45 on the 19/06/2017 without checking

For instance, on this picture we can see that the intercalibration is not very good because of one value so we can delete it to calibrate the calitoo.



Intercalibration of the Calitoo #45 on the 19/06/2017 without the bad data

Without the bad data we have a better calibration lose to old values of Cn0s so we can update the Calitoo and/or create a calibration bulletin like the one provided when you buy a Calitoo.

We can also do these calculations with a spreadsheet to understand better how it works. To be able to do that, we need also to do measures with the Calitoo but this time we will analyze them by hand. We need to know all the data of the Calitoo to calculate a coefficient which is the R^2. Its formula is: $\mathbf{R} = \frac{(1-0.0167)^2}{1+0.0167\cos(2\pi(\frac{D}{365}))}$ where D is the number of the day. We can also calculate the Angstrom exponent thanks to these data. This coefficient is:

$$\alpha = -\frac{\ln(\frac{\delta\lambda}{\delta\lambda 0})}{\ln(\frac{\lambda}{\lambda 0})}.$$

We can calculate the new Cn0 as done by the soft of Calitoo and compare both. The equation of the Cn0 is: $Cn0_\lambda = Cn_\lambda . R^2 . \exp(m. AOD_\lambda)$

V_465	V_465_Calitoo	V_540	V_540_Calitoo	V_619	V_619_Calitoo			
	5163,929933		4355,243446		3354,396779			
5063,339061		4198,733743		3214,301571				
V0_465	V0_465_Calitoo	Différence	V0_540	V0_540_Calitoo	Différence	V0_619	V0_619_Calitoo	Différence
	7611,528493			7620,374849			5239,114731	
7317,878871			7028,298177			4786,92912		
		293,6496226			592,0766723			452,1856113
		pourcentage de différence			Pourcentage de différence			Pourcentage de diférence
		3,93%			8,08%			9,02%

Values of different Cn0 calculated and differences between these Cn0

Here we calculate the difference between Cn0 calculated with AERONET data and Cn0 calculated with Calitoo data in order to have an idea of the calibration of the Calitoo. The details of the calculation are not written here but use the previous formulas. We can see that the percentage is high so if necessary we can produce some ratios and calculate the new Cn0 of the Calitoo but that is explained after.

3) Intercalibration between two Calitoo

Another method of calibration of the Calitoo is the intercomparison between two Calitoo. To use that method, we need a Calitoo which is good calibrated (data close to those of AERONET thing we can compare thanks to the program done previously). After that, we can do our measures respecting the protocol of beginning by the Calitoo reference, finishing with it and doing measures with him between the other Calitoo.

Once we have done these measures, we can produce some ratios between the values of the Cn of the reference and the Calitoo we want to calibrate. Thanks to these ratios, we can recalculate the value of the Cn0 for the Calitoo we have to calibrate.

Calitoo étalon													
Cn0_540_ref	Cn0_619_ref	Ray_465	Ray_540	Ray_619	Oz_540	Oz_619							
3322	2645	0,1949	0,10637	0,06119	0,0128	0,0154							
Calitoo à calibrer													
Cn0_540_1	Cn0_619_1	Ray_465	Ray_540	Ray_619	Oz_540	Oz_619							
3553	2692	0,1949	0,10637	0,06281	0,0128	0,0154							
étalon													
Date	Heure	Cn_465	Cn_540	Cn_619	AOD_465	AOD_540	AOD_619						
21/06/2017	11:23:33	1587	1692,66667	1512,33333	0,5222	0,45013333	0,39055833						
26/06/2017	09:25	2181,33333	2181	1857	0,19999933	0,184	0,1743						
26/06/2017	11:54:25	2412,3333	2412,333	2046	0,16463333	0,1362	0,1225						
05/07/2017	09:40:24	2567	2532,5	2143	0,07601667	0,06981667	0,06413333						
05/07/2017	11:36:07	2616,66667	2563,83333	2146	0,08976667	0,08035	0,0788						
à calibrer													
Date	Heure	Cn_465	Cn_540	Cn_619	AOD_465	AOD_540	AOD_619	V0_465_reca	V0_540_reca	V0_619_reca	AOD_465_re	AOD_540_re	AOD_619_recalcul
21/06/2017	11:23:33	1583,3333	1786	1540,333	0,56036667	0,47046667	0,40053333	3976,40823	3311,56488	2730,94721	0,5561008	0,44871936	0,403249219
26/06/2017	09:25:12	2220	2360,667	1917	0,2283	0,20183333	0,1885				0,21298312	0,18342202	0,179963743
26/06/2017	11:55:05	2286,66667	2426,66667	1985	0,2696333	0,23066667	0,20336667				0,17532119	0,13577217	0,126480542
05/07/2017	09:40:35	2029,99999	2191,11122	1814,111	0,13383333	0,11556667	0,1049	Erreurs_V0_4	Erreurs_V0_5	Erreurs_V0_6	Erreurs_AOD	Erreurs_AOD	Erreurs_AOD_619
05/07/2017	11:36:10	2564,83333	2663	2146,16667	0,15358333	0,13498333	0,12145	168,408226	-241,435124	38,9472135	-0,00426587	-0,02174731	0,002715889
								4,23518452	7,29066567	1,42614304	-0,01531688	-0,01841131	-0,008536257
			Rapports moyens				Ecart type				-0,09431211	-0,0948945	-0,076886125
540	619		465	540	619		465	540	619				
0,94774169	0,98182233		1,06491918	0,99685878	1,03249422		0,11471925	0,09242741	0,08637545				
0,92389143	0,9687011												
0,99409327	1,03073048												
1,15580623	1,18129486												
0,9627613	0,99992234												

Constants of master #71

Constants of field Calitoo #45

Data from master #71

Intercalibration between Calitoo master #71 and field Calitoo #45

Here we can see that we need some data from the calitoo to do that in particular the old Cn0s. After that, we put the data taken at the same time between the Calitoo and we produce our ratios (Cn_465_1stCalitoo/Cn_465_2ndCalitoo for instance) and so we are able to calculate the new value of the Cn0 for the second Calitoo. We can see that on the previous screen and the errors between the new and the old values for that manipulation. Here the difference could appear as big between those Cn0 but in percentage it is only few percent (between 1 and 7% of difference). We are also able to calculate by hand the values of the AOD with these ratios and the results are on the screen with the associated error. This error is also about few percent (maximum of 5% of difference between old and new Cn0).

Here the Calitoo number #71 is the master and it helps us to calibrate the #45, a field instrument. The results here show that if we use the new Cn0 and these ratios, the AOD value is closer to the one of a calibrated photometer.

To conclude we can compare these two methods. About the facility of the methods we can say that the absolute calibration is much more difficult to put in place than the intercalibration. Even if the absolute calibration is the more precise method, the results of the intercalibration show that this method is reliable. The results given by the intercalibration are used nowadays to calibrate the Calitoo. So the better method between both is the intercalibration because it needs less conditions to be put in place even if we need to have a clear sky and go to Izana it takes less time and it is an easier method. In order to complete that we try to find an alternative method in laboratory.

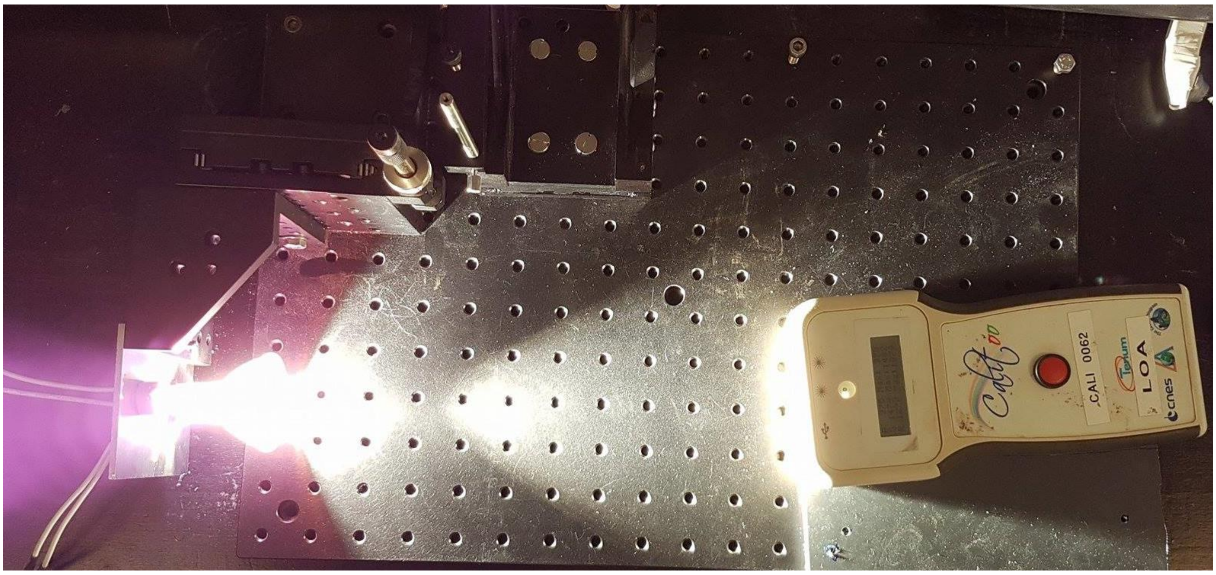
III/ New method of calibration

1) Choice of the method and material used

The calibration with the sun has some inconvenient that we would want to delete. In fact we can't do this calibration everywhere and every time and often, somebody has to go to the Izana (Canaries) in order to do the calibration. This is why we try to find a lab method of calibration easier to put in place. We need to calibrate the photometers regularly so it could be a gain of time and money if it is not necessary to go to Izana in order to calibrate the Calitoo.

To do that calibration, we place the calitoo in front of a lamp and we do measures. That calitoo is supposed to be calibrated and it will be our master. After that we place the other calitoo that we have to calibrate in front of the lamp and we also do measures. To finish we do again measures with the reference. All these data are analyzed after.

For the manipulation in laboratory, we need in addition to the calitoo, a powerful lamp in order to simulate the sun. This lamp is a 250W one with 12.5A and 24V. It is important to supply in consequence the lamp. Firstly, we used some batteries to know if the lamp was powerful enough for our Calitoo. After that we decided to buy a new supply which is more stable and less dangerous than the batteries. On this manipulation, we place the Calitoo in front of the lamp as we can see on the following photo:



Optical bench used for the calibration

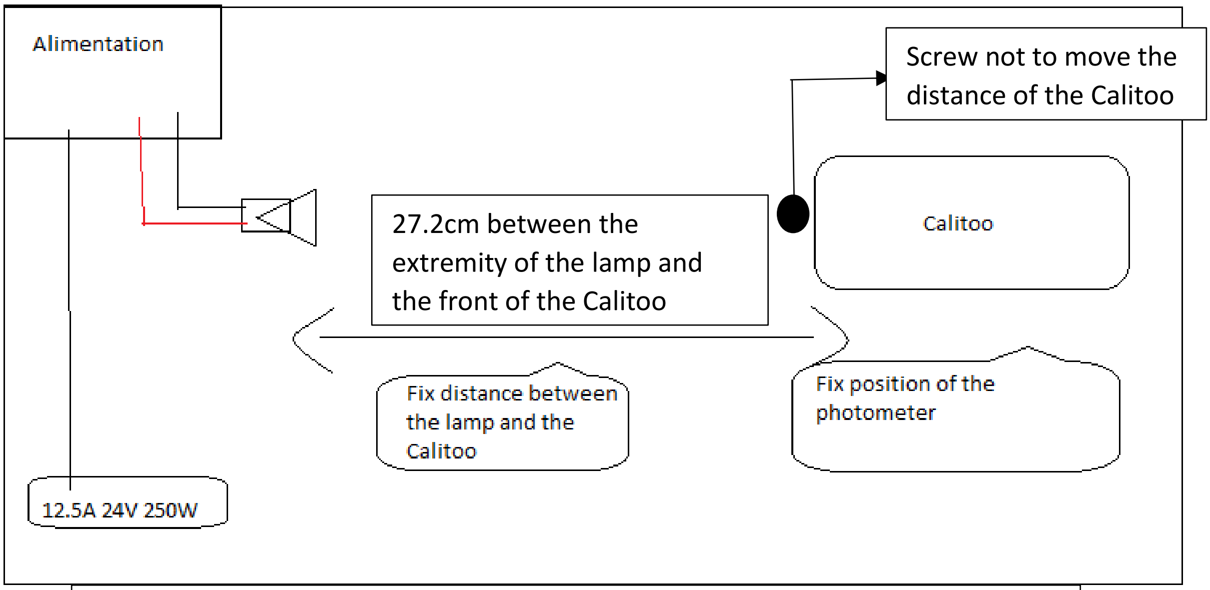
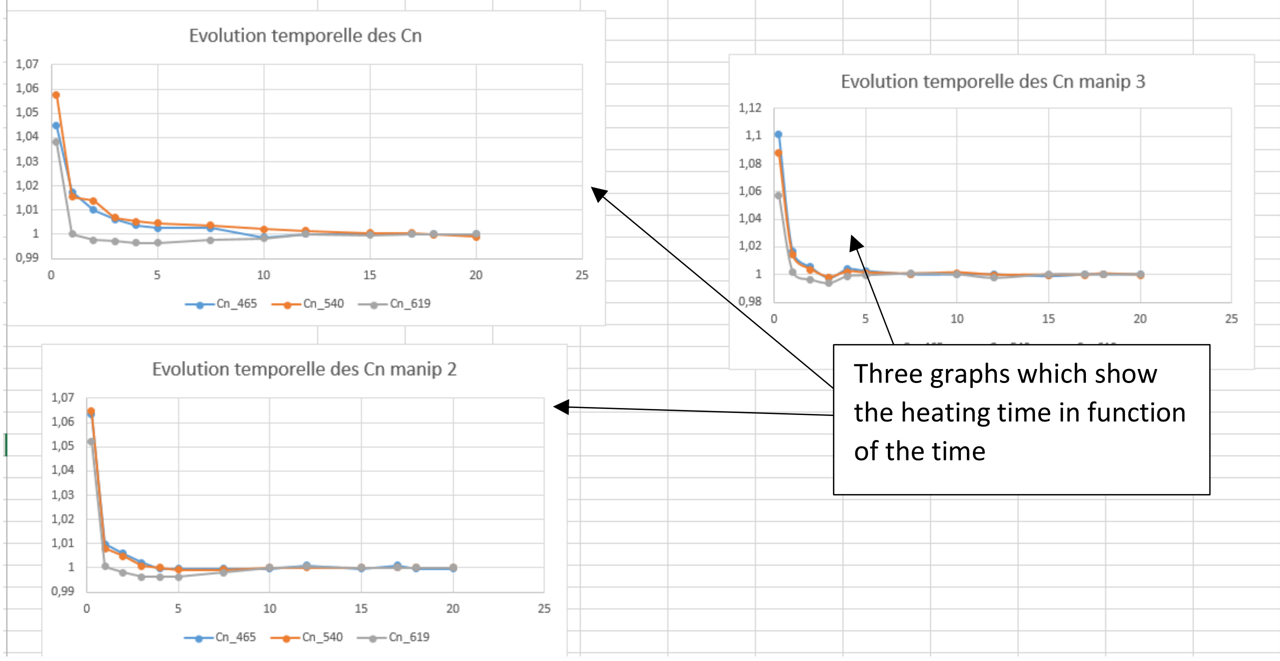


Diagram of the optical bench

2) Heating time

Before beginning the measures, we have to know the heating time of the lamp. Indeed, we can't do measures if the lamp is not stable. So in order to know it, we'll take measurements just after turning on the lamp. And we found the following results:

Temps après allumage de la lampe (minutes)	Cn_465	Cn_540	Cn_619	Temps après	Cn_465	Cn_540	Cn_619	Temps après	Cn_465	Cn_540	Cn_619
0,25	1,04477612	1,05769607	1,03809672	0,25	1,06349703	1,06466877	1,05229994	0,25	1,10110236	1,08774015	1,05726872
1	1,01741294	1,01545081	1,0001555	1	1,00969659	1,00788644	1,00063012	1	1,01669291	1,01406219	1,00188798
2	1,00995025	1,01388617	0,99766755	2	1,00594307	1,00473186	0,99810964	2	1,00535433	1,00376312	0,99622404
3	1,00621891	1,0068453	0,99704556	3	1,00218955	1,00078864	0,99621928	3	0,99779528	0,99821747	0,99370673
4	1,00373134	1,00528066	0,99642357	4	0,99968721	1	0,99621928	4	1,00409449	1,00217865	0,99874135
5	1,00248756	1,00449834	0,99642357	5	0,99968721	0,99921136	0,99621928	5	1,00283465	1,00138641	0,99937067
7,5	1,00248756	1,00371602	0,99766755	7,5	0,99968721	0,99921136	0,99810964	7,5	1,00031496	1,00059418	1,00062933
10	0,99875622	1,00215138	0,99828954	10	0,99968721	1	1	10	1,00031496	1,00138641	1
12	1	1,00136906	1,0001555	12	1,00093838	1	1,00063012	12	1,00031496	0,99980194	0,99748269
15	1	1,00058674	0,99953351	15	0,99968721	1	1	15	0,99905512	0,99980194	1
17	1	1,00058674	1,0001555	17	1,00093838	1	1	17	1,00031496	0,99980194	1
18	1	0,99980442	1,0001555	18	0,99968721	1	1	18	1,00031496	1,00059418	1
20	1	0,9990221	1,0001555	20	0,99968721	1	1	20	1,00031496	0,99980194	1



To determinate this time, we place the calitoo in front of the lamp, and after that, we turn on the lamp and we take some measures at different moments. The aim is to see from what moment the values of the Cn don't vary. For these graphs, we normalize it in order to be able to compare between the different wavelengths.

On these graph, we can determinate the heating time of this lamp. We can see that after 10 minutes the Cn don't vary more than 0.5% (which represent 1Cn for channel blue, 4 for the green and 3 for the red one). After 15 minutes the variation is only about 0.3% so we can say that the heating time of that lamp is about 15 minutes.

3) Flow of the method

Firstly we have to present how we will take our measures. So in order to be as precise as possible, we choose a master and take all the other Calitoo we want to calibrate. After that we do a set of measures (in general 10) with the master, then a set with the first we have to calibrate, the master again and that until the last photometer to calibrate and we finish with a set of measures with the master.

It is also important to know the value of the "black". To do that, we turn off the lamp and we take a measure. We see that the value is 0 and so the influence of other source of light has no impact on the values seen by the Calitoo during the calibration.

4) Problems we have with that method

-Position of the calitoo

So as to have the most precise measures as possible, we have to put the calitoo in the better place (where we have the maximum of intensity). So firstly, we found the distance between the calitoo and the lamp thanks to the Cn which are big enough to analyze but not too close to the lamp to avoid burning. With the sun, the values are close to 2000-2500 if the sky is clear and with the lamp these values are around 700-1600. To make the best measures as possible we have not to be under 1000 if it is possible. This value represent the value of measures on the sun/2. So we decided a place for the calitoo which is a good compromise. But distance is not the only parameter to take into account. We have to found also the high and the different angles to place the calitoo.

To be sure of the position of the Calitoo in order to repeat the method, we can put a stop where the Calitoo has to be (for now we use a screw). After that, we can move the directions of the Calitoo to find the maximum but the distance between the lamp and the Calitoo must be the same.

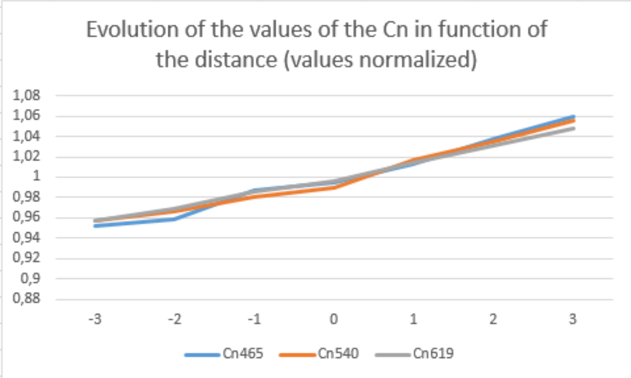
Where we place the Calitoo with the stop in order to fix the distance

We can also notice that the values of the Cn between the three wavelengths are not ion the same order with the sun and with the lamp. In fact with the sun the maximum is for the blue channel and the minimum for the red one and it is the opposite for the lamp. We can explain that with the spectrum of the sun and the lamp. The lamp has few power for the channel in UV in contrary to the sun. In fact it is quite impossible to have a lamp which deliver the same wavelengths as the sun because UV is dangerous for our skin and so constructors of the lamps block these UV.

We have here to found a maximum on the CN of the Calitoo but we noticed that that position is not the same between the different calitoo so we can’t find a ‘position of calibration’. So we have to found manually that position of maximum for every measure. We can change the different angles of the Calitoo but the distance never changes.

Some errors on the position can affect the values of the Cn like the angles or the high. So here is a recapitulation of the impacts of these parameters:

	709,285714	1265,14286	1471,14286
Distance	Cn465	Cn540	Cn619
-3	0,95204513	0,95731225	0,95717199
-2	0,95909732	0,96600791	0,96940857
-1	0,98730606	0,98023715	0,985724
0	0,99435825	0,98972332	0,99592114
1	1,01269394	1,01660079	1,01359619
2	1,03808181	1,03478261	1,03127124
3	1,05923836	1,05612648	1,04758668



The evaluation of the impacts of the angles is more difficult to put in place and we can find by hand the maximum possible at every measure. The error we can have due to the position of the Calitoo is about 4 Cn so 0.3%.

-Sensibility of the supply

We have also to be careful with the supply and not to change the value of the tension issued by the supply because the values of the Cn seen by the calitoo change with that tension. And so we can't compare some values if they are not done at the same tension.

-Choice of the reference

In order to do our calibration, we need a photometer reference or master. For the moment we use a calitoo which is supposed to be calibrated but we don't really know the precision of it instead is values are close to those of aeronet. The importance of that photometer is crucial because all the calibration depend on it. If it is possible we can also put another photometer like those in the roof of the laboratory in front of our lamp and do the same job but it is not for the moment.

-Position of all the elements

During a manipulation it is important not to move the different elements on the optical bench to be able to analyze our results.

5) <u>Presentation of the method</u>

Firstly, we have to know if our new method is stable and repeatable. In order to do that, we can take some measures with one Calitoo at different moments. Once we have these data, we can calculate the standard deviation of the Cn. We have done it for some data and find:

	CALITOO #1311-0071		**Master**
	Vo master		
	3734		
	3322		
	2645		
	Moyenne		
	791,6666667	1259	1583,58333
Ecart type	1,775250729	5,04524979	3,47610894
Pourcentage	0,22%	0,40%	0,22%

Data and constants from the master #71 (15 measures)

	CALITOO #1311-0062						
	3597						
	3155						
	2560						
	Moyenne				Rapports #62/master#71		
	793,2	1222,4	1593,2		1,00193684	0,97092931	1,00607273
Ecart type	0,447213595	0,54772256	0,83666003				
Pourcentage	0,06%	0,04%	0,05%				

Data and constants for the field Calitoo #62 (5 measures)

	CALITOO #1311-0045						
	3808						
	3553						
	2692						
	Moyenne				Rapports #45/maste#71		
	786,25	1320,5	1584		0,99315789	1,04884829	1,00026312
Ecart type	2,5	0,57735027	0,81649658				
Pourcentage	0,32%	0,04%	0,05%				

Data and constants for the field Calitoo #45 (5 measures)

We can see that the standard deviation in percentage is less than 0.5% for these three Calitoo. So the stability and repeatability of this method is not a problem for the following of the process.

With this method, we don’t need to do a temporal interpolation because after we get the stability of the lamp all the measures are done in the same conditions.

To validate this calibration method of Calitoo, we have to compare it to some other methods. We know how to calibrate the calitoo thanks to the sun and thanks to the soft of calitoo. If we compare the new Cn0 that we get with the soft and with the new method we have:

				465nm	540nm	619nm	
CALITOO #1311-0062			old V0	3597	3155	2560	
New V0 lab calibration		11/07/2017		V0 calculated by Calitoo			
3741,23217	3225,42716	2661,06236		3710	3146	2556	
Difference between old and new V0 (lab calibration)				Difference between old and new V0 by calitoo			
144,232168	70,4271644	101,062359		113	-9	-4	
Difference between these two new V0							
31,2321684	79,4271644	105,062359					
CALITOO #1311-0045			old V0	3808	3553	2692	
New V0 lab calibration		11/07/2017		V0 calculated by Calitoo			
3708,45158	3484,27403	2645,69594		3605	3361	2542	
Difference between old and new V0 (lab calibration)				Difference between old and new V0 by calitoo			
-99,5484211	-68,725973	-46,3040573		-203	-192	-150	
Difference between these two new V0							
103,451579	123,274027	103,695943					

The difference between the two different new Cn0 is important but we have always the one calculated in laboratory higher than the one given by the soft. If we take a look at the signs, we can see that there are always the same and that is a first good point for our method. But these values are not close enough to those of the soft Calitoo. So we have to investigate a little bit more in order to know where the problem is. In a first time, this method can be done with other Calitoo. We don't really know how good these ones are so we will check that with others just calibrated from Izana.

So we did the same experimentation with some other Calitoo taking for master a Calitoo calibrated from Izana. Here are some results:

CALITOO #1703-0236 Master

	Vo master		
	3481		
	3477		
	2580		
	Moyenne		
	706,2	1267,8	1467,9
Ecart type	2,043961296	4,39191176	1,59513148
Pourcentage	0,29%	0,35%	0,11%

CALITOO #1703-0237

	3298		
	3121		
	2528		
	Moyenne		
	668,3	1127,1	1430,2
Ecart type	3,713339318	6,52261025	7,85705628
Pourcentage	0,56%	0,58%	0,55%

Rapports #237/master#236		
0,94633248	0,88902035	0,97431705

CALITOO #1703-0237

New V0		
3294,18338	3091,12376	2513,73799
Difference between old and new V0		
-3,81662419	-29,8762423	-14,2620069
-0,12%	-0,97%	-0,57%

Percentage of difference

CALITOO #1703-0238

	3361		
	3155		
	2568		
	Moyenne		
	671,1	1126,7	1429,5
Ecart type	2,330951165	4,71522357	3,13581462
Pourcentage	0,35%	0,42%	0,22%

Rapports #238/master#236		
0,95029737	0,88870484	0,97384018

CALITOO #1703-0238

New V0		
3307,98513	3090,02674	2512,50766
Difference between old and new V0		
-53,0148683	-64,9732608	-55,492336
-1,60%	-2,10%	-2,21%

Data of the three Calitoo just calibrated from Izana 19/07/2017

The data for a first manipulation show that the standard deviation is correct for both of the field Calitoo. The percentage of difference between the old and the new V0 is also good (less than 1% of maximum for the #237). We can compare these measures with the same but in other days in order to know if it is repeatable.

So here are the results for the second day:

	CALITOO #1703-0236		**Master**								
	Vo master										
	3481										
	3477										
	2580										
	Moyenne										
	701,6666667	1256,86667	1458,6								
Ecart type	1,632993162	3,37779866	6,17367684								
Pourcentage	0,23%	0,27%	0,42%								
	CALITOO #1703-0237										
	3298										
	3121										
	2528								**CALITOO #1703-0237**		
	Moyenne				Rapports #237/master#236				New V0 lab calibration		
	668,2	1124,06667	1428,53333		0,95230404	0,89434042	0,97938663		3314,97036	3109,62165	2526,8175
Ecart type	3,687817783	6,29587923	3,41983013						Difference between old and new V0		
Pourcentage	0,55%	0,56%	0,24%						16,9703563	-11,3783483	-1,18250377
									0,51%	-0,37%	-0,05%
	CALITOO #1703-0238										
	3361										
	3155										
	2568								**CALITOO #1703-0238**		
	Moyenne				Rapports #238/maste#238				New V0 lab calibration		
	675	1129,33333	1440,93333		0,96199525	0,89853074	0,98788793		3348,70546	3124,19138	2548,75086
Ecart type	4,276179871	7,03731551	4,83243013						Difference between old and new V0		
Pourcentage	0,63%	0,62%	0,34%						-12,2945368	-30,8086246	-19,249143
									-0,37%	-0,99%	-0,76%

Percentage of difference

Data of the three Calitoo just calibrated from Izana 20/07/2017

For the second day, the values of the standard deviation are also correct as we can see the maximum is 0.63%. The percentage of difference between the old and the new Cn0 is less than 1% also here so we can say that it is a good point for the method but these Calitoo have just been calibrated from Izana so it may be thanks to that. In order to answer this problem, we can take a look at some other field Calitoo taking the same master.

Numéro	Cn_465 moy	Cn_540 moy	Cn_619 moy	Ecart type 46	Ecart type 54	Ecart type 61	ratio 465	ratio 540	ratio 619
CALITOO #1703-0236	701,666667	1256,86667	1458,6	0,00232731	0,00268748	0,0042326	Master	Master	Master
CALITOO #1703-0237	668,2	1124,06667	1428,53333	0,00551903	0,00560098	0,00239394	0,95230404	0,89434042	0,97938663
CALITOO #1703-0238	675	1129,33333	1440,93333	0,00633508	0,00623139	0,00335368	0,96199525	0,89853074	0,98788793
	V0 465	V0 540	V0 619	Anciens V0			Pourcentage de différence		
CALITOO #1703-0236	3298	3121	2528	3298	3121	2528			
CALITOO #1703-0237	3314,97036	3109,62165	2526,8175	3298	3121	2528	0,51%	-0,37%	-0,05%
CALITOO #1703-0238	3348,70546	3124,19138	2548,75086	3361	3155	2568	-0,37%	-0,99%	-0,76%

This is a recap of the previous data.

So we have done exactly the same protocol but with field Calitoo some new Calitoo that have never be used.

The first results are here:

	CALITOO #1703-0238	**Master**							
	Vo master								
	3361								
	3155								
	2568								
	Moyenne								
	671,1	1126,7	1429,5						
Ecart type	2,330951165	4,71522357	3,13581462						
Pourcentage	0,35%	0,42%	0,22%						
	CALITOO #1504-0188								
	3626								
	3182								
	2552						**CALITOO #1504-0188**		
	Moyenne			Rapports #188/master#236			New V0 lab calibration		
	705,6	1112,3	1417,4	1,05140814	0,98721931	0,9915355	3533,78274	3114,67693	2546,26317
Ecart type	5,719362824	8,1520277	3,20416396				Difference between old and new V0		
Pourcentage	0,81%	0,73%	0,23%				-92,2172553	-67,3230674	-5,73683106
							-2,61%	-2,16%	-0,23%
	CALITOO #1504-0184								
	3788								
	3369								
	2624						**CALITOO #1504-0184**		
	Moyenne			Rapports #184/master#236			New V0 lab calibration		
	745,8333333	1188,08333	1461	1,11135946	1,05448064	1,02203568	3735,27914	3326,88641	2624,58762
Ecart type	2,208797836	3,20392751	8,29019136				Difference between old and new V0		
Pourcentage	0,30%	0,27%	0,57%				-52,7208563	-42,1135913	0,58761805
							-1,41%	-1,27%	0,02%

Percentage of difference

Data taking as master one of the Calitoo from Izana and as fields some of Calitoo never used 20/07/2017

We can see here that the standard deviation is always less than 1% for every Calitoo. The difference between old and new Cn0 in percentage is not very high. We are under 3% so it could be acceptable for these Calitoo.

	CALITOO #1703-0236	**Master**	
	Vo master		
	3481		
	3477		
	2580		
	Moyenne		
	701,6666667	1256,86667	1458,6
Ecart type	1,632993162	3,37779866	6,17367684
Pourcentage	0,23%	0,27%	0,42%

	CALITOO #1504-0184									
	3788									
	3369									
	2624							**CALITOO #1504-0184**		
	Moyenne			Rapports #184/master#236				New V0 lab calibration		
	754	1198,6	1477,1	1,07458432	0,95364133	1,0126834		3740,62803	3315,81091	2612,72316
Ecart type	8	12,2764454	10,3650052					Difference between old and new V0		
Pourcentage	1,06%	1,02%	0,70%					-47,3719715	-53,1890946	-11,2768408
								-1,27%	-1,60%	-0,43%
	CALITOO #1504-0188									
	3626									
	3182									
	2552							**CALITOO #1504-0188**		
	Moyenne			Rapports #188/master#236				New V0 lab calibration		
	716,3333333	1123,66667	1428,44444	1,02090261	0,89402217	0,97932569		3553,762	3108,51509	2526,66027
Ecart type	3,16227766	4,52769257	4,69337595					Difference between old and new V0		
Pourcentage	0,44%	0,40%	0,33%					-72,2380048	-73,4849096	-25,3397322
								-2,03%	-2,36%	-1,00%

Percentage of difference

Data taking as master one of the Calitoo from Izana and as fields some of Calitoo never used 20/07/2017

We have done a second set of measures on the same Calitoo and we see always a few percantage of standard deviation (arround 1%). The difference between the Cn0 is more or less the same than the previous day so the method is also repeatable and as we are not so far from previous data, we can say that the method is also valuable.

Numéro	Cn_465 moy	Cn_540 moy	Cn_619 moy	Ecart type 46	Ecart type 54	Ecart type 61	ratio 465	ratio 540	ratio 619
CALITOO #1703-0236	701,666667	1256,86667	1458,6	0,00232731	0,00268748	0,0042326	Master	Master	Master
CALITOO #1504-0184	754	1198,6	1477,1	0,01061008	0,01024232	0,00701713	1,07458432	0,95364133	1,0126834
CALITOO #1504-0188	716,333333	1123,66667	1428,44444	0,00441453	0,00402939	0,00328566	1,02090261	0,89402217	0,97932569

	Lab intercalibration Master #236								
Numéro	V0 465	V0 540	V0 619	Anciens V0			Pourcentage de difference		
CALITOO #1703-0236	3788	3369	2624	3788	3369	2624			
CALITOO #1504-0184	3740,62803	3315,81091	2612,72316	3788	3369	2624	-1,27%	-1,60%	-0,43%
CALITOO #1504-0188	3553,762	3108,51509	2526,66027	3626	3182	2552	-2,03%	-2,36%	-1,00%

This is the recap of the different previous data.

To finish the validation of the method, we have to know if the method is also valuable for some Calitoo that have been used. Comparing with the new Cn0 calculated by the soft of Calitoo, we can know if we are close or not from these values and so know if we can applicate this method to every Calitoo.

So we have done the same protocol with the same master and with field instrument the #71 and the #45.

	CALITOO #1703-0236		**Master**				
	Vo master						
	3481						
	3477						
	2580						
	Moyenne						
	701,6666667	1256,86667	1458,6				
Ecart type	1,632993162	3,37779866	6,17367684				
Pourcentage	0,23%	0,27%	0,42%				
	CALITOO #1311-0071						
	3734						
	3322						
	2645						
	Moyenne				Rapports #71/master#2336		
	763,6363636	1206,18182	1525,63636		1,08831786	0,95967365	1,04595939
Ecart type	4,674884539	7,30504185	4,67488454				
Pourcentage	0,61%	0,61%	0,31%				
	CALITOO #1311-0062						
	3597						
	3155						
	2560						
	Moyenne				Rapports #62/master#236		
	775,6	1186,4	1551		1,10536817	0,94393465	1,06334842
Ecart type	1,429840706	3,40587727	3,19722102				
Pourcentage	0,18%	0,29%	0,21%				

Data taking as master a Calitoo from Izana and as fields two of Calitoo used previously 20/07/2017

So the standard deviation is under 0.6% for these two Calitoo as we can see here.

				465nm	540nm	619nm	
CALITOO #1311-0071			old V0	3734	3322	2645	
New V0				V0 calculated by Calitoo			
3788,43446	3336,78527	2698,57522		3796	3348	2686	
Difference between old and new V0				Difference between old and new V0 by calitoo			
54,4344634	14,7852717	53,5752216		62	26	41	
1,44%	0,44%	1,99%					
Difference between these two new V0							
-7,5655366	-11,2147283	12,5752216					
-0,20%	-0,34%	0,48%					
CALITOO #1311-0062			old V0	3597	3155	2560	
New V0				V0 calculated by Calitoo			
3847,7866	3282,06079	2743,43891		3790	3241	2713	
Difference between old and new V0				Difference between old and new V0 by calitoo			
250,786603	127,060786	183,438914		193	86	153	
6,52%	3,87%	6,69%					
Difference between these two new V0							
57,7866033	41,0607861	30,438914					
1,61%	1,30%	1,19%					

Data taking as master a Calitoo from Izana and as fields two of Calitoo used previously 20/07/2017

Here we can't study the difference between the old and the new Cn0 because these Calitoo are not calibrated. But thanks to the soft of Calitoo we can calculate a new Cn0 and so we can compare the two new Cn0 in order to know if the results of our method are similar to those of Calitoo.

We see a difference of less than 0.5% for the first Calitoo and less than 2% for the second one. So the values calculated by Calitoo and by our method are very close. In fact if we do the calibration with Calitoo or with our method we find more or less the same values of Cn0. This is good for the validation of the method.

Conclusion

To conclude we can say that the results we have seen previously show the future possibilities of that method. For the moment our results seem to validate the method because we have seen the repeatability and the stability of the method in addition to the prvious results. But we don't have enougth measures in order to know if we can do that for every Calitoo. Some parameters like the angles of the Calitoo or the precision of the lamp are not taken in count and if we want to validate all the method we have to understand what is the impact of these parameters.

We can recapitulate now the different errors which can affect our measures. Here is a list of these errors:

-stability of the lamp (1-2 Cn 0.1%)

-stability of the alimentation (1 Cn 0.1%)

-position of the Calitoo: angles, high,… (4 Cn 0.4%)

-precision of the Calitoo (0.02 on the AOD)

So we have an error of: $\sqrt{2^2+1^2+4^2+2^2}=\sqrt{25}=5$ on the Cn which represent less than 0.5% of error for each channel. This possible error on the Cn represent an error on the AOD of maximum 0.015.

Some atmospheric corrections (Rayleigh and Ozone) appear in the calculation of the AOD. These corrections are constant for each site but can introduce an error when the intercalibration or the Langley calibration is done. Doing the calibration in laboratory these correction don't come in count. This is one of the difference between the methods and advantage for the method in laboratory.

We have also to take in count the master because until now, we use a Calitoo as master but it will be better to use another photometer. A changement of the master could be considered in the future and two options can be considered: taking one of the CIMEL photometer or taking a MICROTOPS photometer.