Project acronym	IOPA
Project title	
Title	Retrieval of the aerosol phase function from CIMEL C138 measurements. D5: Report on AOP software, RAOP D7: Report on APFR software, RAPFR
Version	0.1
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Distribution	Internal

Introduction

The objective here is to describe the different steps required to process the CIMEL data in order to derive the aerosol phase function.

1. The CIMEL data from AERONET

This software package applies to any CIMEL C138 instruments. The AERONET network is an easy and popular provider of such data. Therefore, we know introduce the protocol to download CIMEL data from AERONET. AERONET is available at:

http://aeronet.gsfc.nasa.gov/

or you go directly to http://aeronet.gsfc.nasa.gov/data_menu.html

Then, in the data section, click "Download Tool"

DATAVersion 2 (Direct Sun Only)

+ Data Display

+ Download Tool

Version 1 (Direct Sun and Inversions)

+ Data Display

+ Download Tool

And select your CIMEL station (here Lille)

AERONET Data Download Tool

Select the AERONET site of interest:

Geographic Region	**Country/State**	**AERONET Site**
Europe	France	

Then, select a period of time and the type of data you want.

Select the start and end time of the data dow nload period:

START:

END:

Data Descriptions

Data Units

Update Log

Note: Data are not available if the data type is *italicized* Select the data type(s) w ith checkbox:

Aerosol Optical Thickness*:

1. Level 1.0 (Raw)

2. Level 1.5 (Cloud Screened)

3. Level 2.0 (Quality Assured)

Special. Single file w ith Instrument Information (Exact Wavelength) ****All Points Only** Merge w ith AOT file ****All Points Only**

*also Precipitable Water and Angstrom Parameter

Select All AOT

Important remark:

We selected here the level 2.0 AOT. These data are quality checked which in practical means that there are not produced in near real time. Level 2.0 data are most of the time consolidated every year. That means that level 2 are available up to December 31 the year before to date. For real time data, only level 1 are available.

You accept the data policy and after the request is processed and you get a WinZip file in which you have an AOT file and a PP file in this case.

```
Level 2.0. Quality Assured Data.<p>The following data are pre and post field calibrated,
automatically cloud cleared and manually inspected. Version 2 Direct Sun Algorithm
Location=Lille,long=3.142,lat=50.612,elev=60,Nmeas=22,PI=Philippe_Goloub,Email=Philippe.Gol
oub@loa.univ-lille1.fr AOT Level 2.0,All Points,UNITS can be found at,,,
http://aeronet.gsfc.nasa.gov/data_menu.html
Date(dd-mm-
yy),Time(hh:mm:ss),Julian_Day,AOT_1640,AOT_1020,AOT_870,AOT_675,AOT_667,AOT_555,AOT_551,AOT
_532,AOT_531,AOT_500,AOT_490,AOT_443,AOT_440,AOT_412,AOT_380,AOT_340,Water(cm),%TripletVar_
1640,%TripletVar_1020,%TripletVar_870,%TripletVar_675,%TripletVar_667,%TripletVar_555,%Trip
letVar_551,%TripletVar_532,%TripletVar_531,%TripletVar_500,%TripletVar_490,%TripletVar_443,
%TripletVar_440,%TripletVar_412,%TripletVar_380,%TripletVar_340,%WaterError,440-
```

In the AOT file, you have a full list of spectral bands which can be used. For a specific CIMEL instruments only some of them are available. Most of the time, we have the AOT at 1020 nm, 870 nm, 675 nm and 440 nm. The water vapour content is also available.

In the radiance file for the principal plane, we have a header

```
These data are raw data with calibration applied.
Location=Lille,long=3.142,lat=50.612,elev=60,Nmeas=28,PI=Philippe_Goloub,Em
ail=Philippe.Goloub@loa.univ-lille1.fr
Principal Planes,All Points,UNITS can be found at,,,
http://aeronet.gsfc.nasa.gov/data_menu.html
```

Then, for each line, we have:

```
Date(dd-mm-yyyy),Time(hh:mm:ss),Wavelength(um),SolarZenithAngle(degrees)
```

For the Lille CIMEL, we have successively 4 spectral bands: 1019 nm, 676 nm, 440 nm and 870 nm. The radiance (in W/m^2/ µm/sr) is measured at the following scattering angles:

```
-6,-5,-4,-3.5,-3,-2.5,-
2.,0,2,2.5,3.,3.5,4,5.,6,6,8,10,12,14,16,20,25,30,35,40,45,50,55,60,65,70,80,90,100,1
10,120,130,140,150.
```

The minus sign indicates scattering angles below the sun direction. The scanning protocol on the two sides of the solar direction is devoted to validate the good pointing. The gain changes at 6° and that the reason why the measurement at 6° is reported twice to validate the continuity of the signal. The maximum scattering angle to be considered is θ_s+90° ; above the CIMEL instrument views the ground.

For the almucantar measurements, the view geometry is given by the relative azimuth angle to the sun (negative is for azimuth north to the sun) with:

0.,-6,-5,-4,-3.5,-3.,-2.5,-
2,2,2.5,3,3.5,4,5,6,6,7,8,10,12,14,16,18,20,25,30,35,40,45,50,60,70,80,90,100,120,140,160,180,-
160,-140,-120,-100,-90,-80,-70,-60,-50,-45,-40,-35,-30,-25,-20,-18,-16,-14,-12,-10,-8,-7,-6,-6,-
5,-4,-3.5,-3,-2.5,-2,2,2.5,3,3.5,4,5,6

The file names are respectively 050101_051231_Lille.lev20, 050101_051231_Lille.ppl and 050101_051231_Lille.alm. Date start from January 1, 2005 to December 31, 2005 for the AOT at level 2, for the sky radiances in the principal plane and in the amulcantar. The 3 different files are stored in 3 different directories irregardless of the site.

2. *Input files for the phase function retrieval*

Generate new CIMEL file input files for the phase function algorithm

A site is first selected and for a given band (chosen among 870 nm, 670 nm and 440 nm) the following output file is generated for PP measurements:

```
Site        Date        Time TetaS   taua alphaNIR alphaVIS mes_-6 mes_-5 mes_-4
Anmyon 18-10-1999 05:30:01 55.191 0.3433 1.4782 1.2301 1.01256 1.08619 1.21521
```

The AOT is interpolated at the time of the sky radiance sequence and the dynamic Angstroem coefficient (actually -α) is provided between 670 nm/870 nm and 440 nm/670 nm.

No check on the proximity between the times of acquisition of radiances and irradiances are performed. It is recommended to check if the two irradiance sequences which bound the sky radiance measurements are within less than half an hour.

Then at the same scattering angle, the sky radiance L (w/m^2/µm/sr) is converted into normalized radiance with:

$$L^* = \frac{\pi \, . L_{1B}}{E_S^J} \qquad (1)$$

Where E_s^J is the solar irradiances corrected form the Earth-Sun distance (in UA) at the Julian day J and given by:

$$E_s^J = \frac{E_s}{(A - B\cos(2\pi\,(CJ - D)/E) - 0.00014\cos(4\pi\,(CJ - D)/E))^2} \qquad (2)$$

Where:

A=1.00014; B=0.01671; C=0.9856002831; D=3.4532868; E=360.0

The solar irradiances E_s are reported in table 1.

Then, the ozone absorption is corrected with:

$$L_{ng}^* = \frac{L^*}{T_{O3}} \qquad (3)$$

The ozone transmittance T_{O3} is given by:

$$T_{O3} = \exp(-U_{O3}\tau_{O3}/0.35/\cos(\theta_s)) \qquad (4)$$

The amount of ozone U_{O3} corresponds to monthly climatological values provided by latitude by steps of 10°. The solar zenith angle θ_s is in the data file. Table1 gives the ozone optical thicknesses τ_{O3} computed for a standard value of 0.35 cm-atm.

All the sky radiances in the principal plane for one site and for one band are stores in the same file. One line corresponds to one sequence.

λ (nm)	440	670	870
E_s (w/m²/μm/sr)	1928.267	1566.065	987.366
τ_{O3} (for 0.35cm.atm)	0.00400	0.04685	0.00485

Table 1: Solar irradiance and ozone optical thickness (for 0.35 cm.atm) in the 3 CIMEL bands.

The same approach applies for almulcantar measurements. Simply, one almulcantar sequence results in two different files on each side of the principal plane.

Validate the good pointing of the CIMEL instrument

3.2.1 Validate the zenith angle for the PPL protocol

The primary scattering regime dominates in the forward scattering. The normalized radiance is expressed as:

$$L^* = \frac{\exp(-\tau/\mu_s)\tau P(\Theta)}{4\mu_v} \qquad (5)$$

μ_v is the cosine of the view azimuth angle:

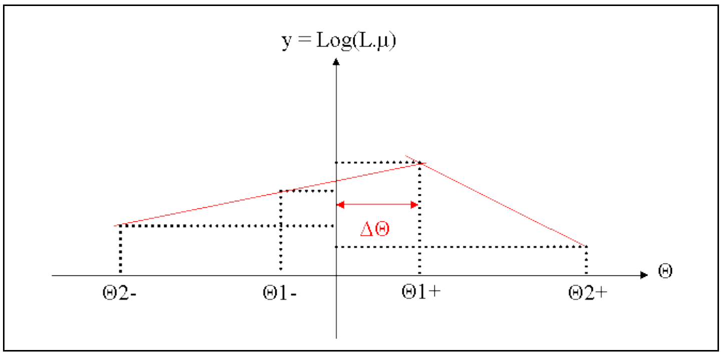
$$\theta_v = \theta_s - \Theta \qquad (6)$$

P is the phase function and τ the total optical thickness.

We have a set of symmetrical measurement at Θ_-=-6,-5,-4,-3.5,-3,-2.5,-2 and Θ_+ =6,5,4,3.5,3.,2.5,2. If the atmosphere is stable for a pair of symmetrical scattering angles and if the pointing is correct, then we have:

$$\mu_v^+ L^+ = \mu_v^- L^- \qquad (8)$$

Alternatively, it is possible to derive the pointing error Δθ in zenith. First, we take the log of $\mu_v L$. Then, we use simple linear equations to get the bias in zenith angle in the sun pointing.



$$\Delta\Theta = \frac{(y_1^+ - y_1^-) - \Theta_1^+(\alpha^- + \alpha^+)}{(\alpha^- - \alpha^+)}$$

$$\alpha^- = \frac{(y_1^- - y_2^-)}{\Theta_1^- - \Theta_2^-}$$

$$\alpha^+ = \frac{(y_2^+ - y_1^+)}{\Theta_2^+ - \Theta_1^+}$$

$$\Delta\Theta = \frac{\left(y_1^{+} - y_1^{-}\right) - \Theta_1^{+}\left(\alpha^{-} + \alpha^{+}\right)}{\left(\alpha^{-} - \alpha^{+}\right)}$$

Validation of the pointing is illustrated in the figure 1 below corresponding to sky radiance measurements collected on the site Anmyon at 440 nm using both level 1 (blue diamonds) and level 2 (red squares) Data. The results suggest than the pointing is correct.

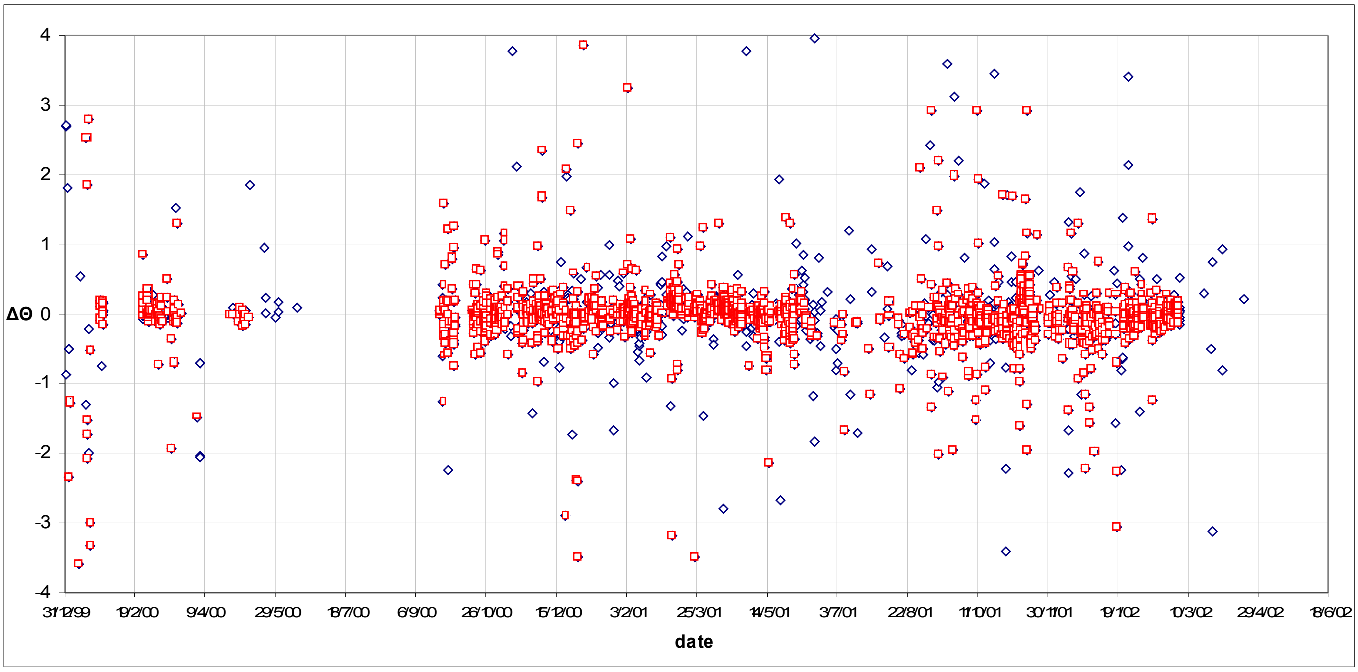


Figure 1: validation of the sun pointing in zenith angle.

3.2.2Validate the azimuth angle for the ALM protocol

We have a set of symmetrical measurement at ϕ_{-}=-6,-5,-4,-3.5,-3,-2.5,-2 and ϕ_{+}=6,5,4,3.5,3.,2.5,2. The same technique than above can be applied to determine the pointing error in azimuth $\Delta\phi$.

Data selection criteria

Three types of criteria are applied:

(i) On the measurements:

In order to study the spectral dependence of the phase function, we want to have a set of sky radiance measurements in the 3 bands quite simultaneously. The test implemented rejects series of sky radiances with an interval between measurements at 440 nm and 870 nm (and 670 nm) larger than 0.1 hour.

In order to have the full set of scattering angles between 2° and 150°, we process sequences at low solar elevations with:

$$65^\circ < \theta_s < 75^\circ \quad (13)$$

(ii) On the type of aerosols

The classification of the aerosol IOPs will be based on α. Over the ocean, the aerosol model is selected between the red and the near infra red. Therefore, we use α(670,870). Over the land, the aerosol model is selected between the blue and the red. Therefore, we use α(440,670). We bounded the two α in the interval:

$$-2.5 < \alpha < 0.5 \quad (14)$$

(iii) On the limitation of the phase function retrieval

We do not expect to accurately retrieve the aerosol phase function if the AOT is too small. The limit in the 3 bands is:

$$\tau_a > 0.02 \quad (15)$$

On the other extreme, the retrieval scheme does not work when combining to large solar angles and too large AOT. The following criteria are used:

At 440 nm: $$\tau_a / \mu_s < 1.5 \quad (16)$$

At 670 nm (or 870 nm): $$\tau_a / \mu_s < 2.5 \quad (17)$$

Generate auxiliary data

The meteorological data file

The first option was to use the meteorological information attached to the SeaWiFS instrument. The information to generate this auxiliary data file are also available at:

ftp://oceans.gsfc.nasa.gov/METOZ/

For each day, we have, at sea level, the following metrological parameters:

Pressure (hPA), zonal wind speed (m/s), meridional wind speed (m/s), relative humidity (percent) and the precipitable water content (kg/m^2). These pieces of information are in HDF files at 00, 06, 12, 18 solar time on a 1° by 1° lat-lon grid. SeaDas environment in IDL is used to read and process the HDF files in order to output at the CIMEL location and at the time of measurements the above meteorological parameters.

Accounting for the elevation of the site

The site elevation is known for each CIMEL station, and the barometric pressure is corrected from the elevation as:

$$P(z) = P(0)\exp(-z/8) \quad (18)$$

Accounting for the land surface albedo

We use here the MODIS albedo maps (monthly with 9 km x 9 km resolution) as available at:

http://modis-atmos.gsfc.nasa.gov/ALBEDO/browse.html.

HDF files are available but we simply use here the browse files to visually affect a surface albedo for each AERONET sites. We reported in figure the global albedo map at 470 nm, 665 nm and 858 nm in January and July 2001. Clearly, land surfaces, except on desert, are quite dark and stable with time in the blue and in the red. Therefore, one unique value characterizes a site in the two colours. In the NIR, 12 values are necessary per site because of the seasonal variability of the vegetation.

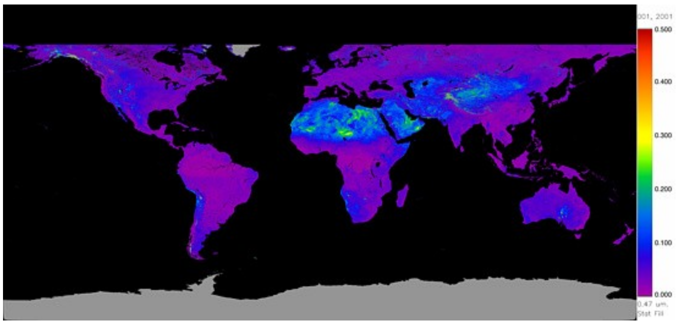
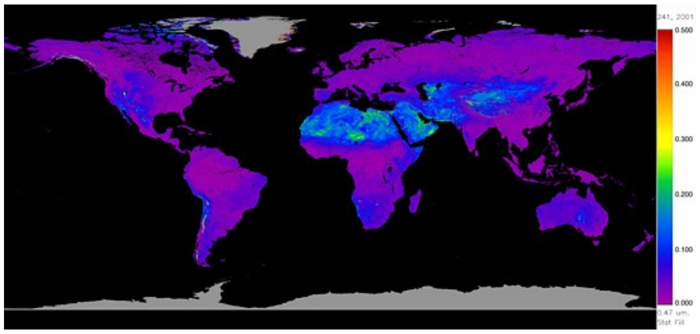
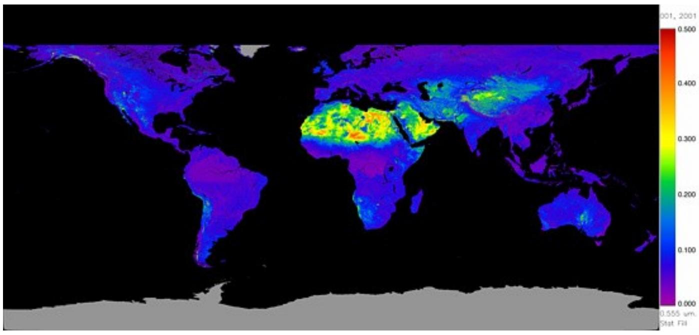
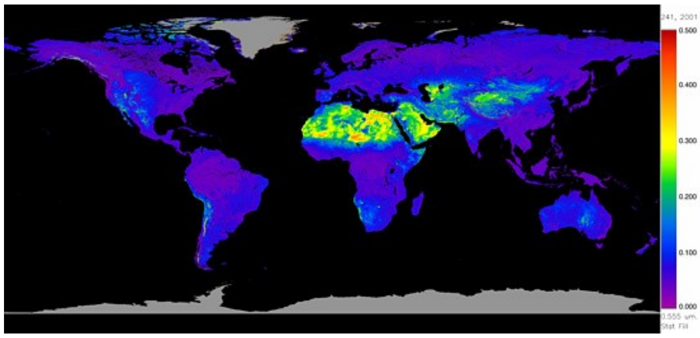
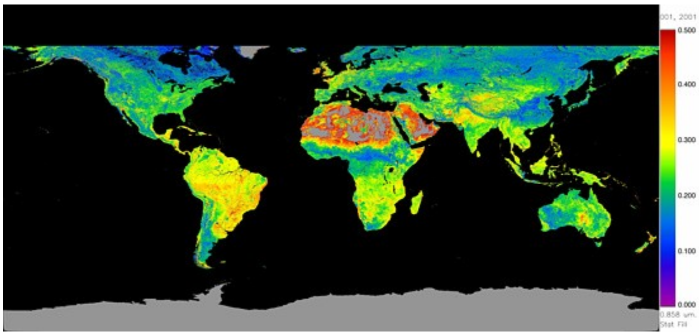
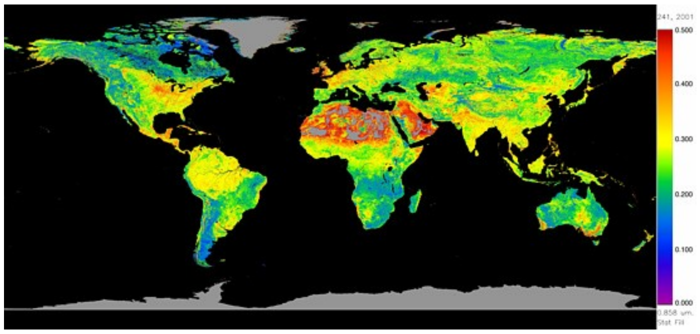
	
470 nm, January 2001	***470 nm, July 2001***
	
665 nm, January 2001	***665 nm, July 2001***
	
858 nm, January 2001	***858 nm, July 2001***

Figure 2: the MODIS level 3 land surface albedo maps

Generate input files for the phase function algorithm in the principal plane

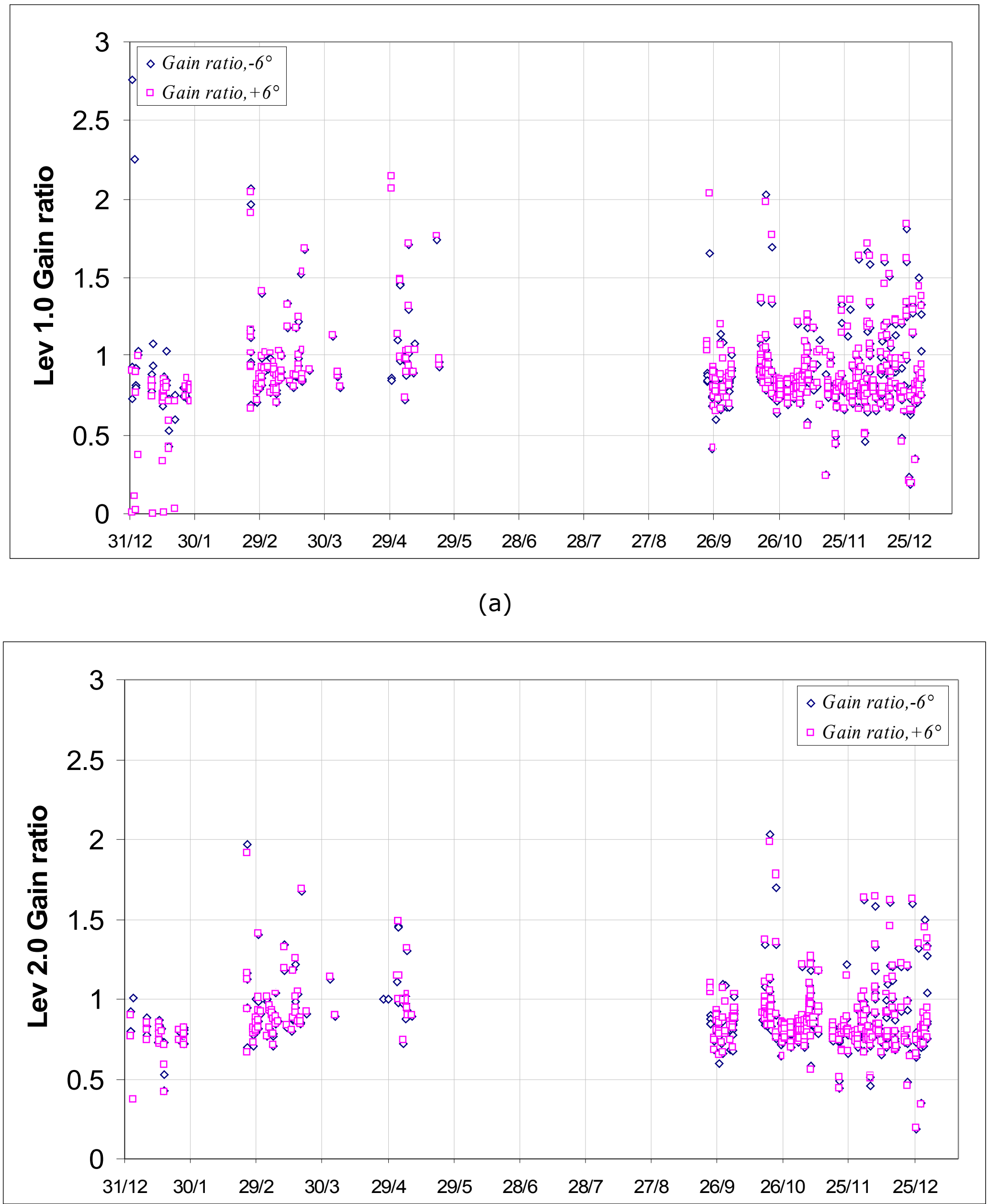
One example of the final CIMEL file from the Bermuda site is given below. The marine reflectance is set to zero because the contribution of the water body is negligible.

```
site      : Bermuda
date      : 16/03/1999
time      : 20:58:26
SZA ppl   : 72.2380
Ps        : 1010.56586
Alb-440   : 0.00000
Alb-675   : 0.00000
Alb-870   : 0.00000
AOT-440   : 0.28450
AOT-675   : 0.18050
AOT-870   : 0.14750
Gain440   : 0.86880
Gain675   : 0.91431
Gain870   : 1.32955
Ws zonal  : 8.90447
Ws merid  : -6.93156
RH        : 73.00954
dH2O      : 24.12071

Theta        Ldown-440       Ldown-670       Ldown-870
   0.0       0.00000         0.00000       0.00000
   2.0       7.02721        19.55893       1.21481
   2.5       4.14516        11.50078       0.47002
   3.0       3.30234         7.60823       0.31571
   3.5       2.84459         4.86569       0.26593
   4.0       2.50822         3.19582       0.21381
   5.0       2.02201         1.15673       0.17346
   6.0       1.38597         0.49094       0.18082
   8.0       0.54922         0.24029       0.15678
  10.0       0.51342         0.22023       0.12629
  12.0       0.37415         0.18776       0.11209
  14.0       0.19023         0.14743       0.10898
  16.0       0.16384         0.13114       0.10861
  20.0       0.13885         0.13854       0.10565
  25.0       0.18967         0.10197       0.09559
  30.0       0.16286         0.10277       0.10610
  35.0       0.12397         0.10015       0.18711
  40.0       0.11597         0.13216       0.20110
  45.0       0.12200         0.33964       0.14316
  50.0       0.14882         0.18731       0.10447
  55.0       0.14531         0.10619       0.13266
  60.0       0.11189         0.08819       0.19828
  65.0       0.10782         0.03384       0.32251
  70.0       0.07006         0.03145       0.17564
  80.0       0.06669         0.04888       0.12319
  90.0       0.06290         0.13695       0.11379
```

The value of L is set to zero for Θ=0°. The CIMEL field of view is nominally a little less than 1.5° to which we need to add the sun apparent diameter of 0.5°. The first possible measurement is therefore at Θ=2°. A limited statistical study indicated that for about 5% of the sequences L is set to zero at Θ=2° and 2.5°. We then only relies on measurements above Θ=3°. If zero (or negative) values appears for Θ>3°, we disregard the sequence

Two different gains are used for the same sky radiance measurement sequence: one for and below 6°, a second for and above 6°. At 6°, measurements of L are not the same at they should be. Three relative gains G are obtained at 6° scattering angle as the ratio of L(6°, forward)/L(6°, backward). They are plotted, in figure 3, both for Θ=6° and -6° for measurements at 440 nm collected at the Anmyon site both for level 1 and level 2 for year 2005.



(a)

(b)

Figure 4: relative gain at +/- 6° on the 440 nm sky radiance for level 1 and level 2 data in 2005 in Anmyon.

The forward peak for Θ<6° is adjusted to the radiance for Θ>6°. This decision is quite arbitrary but it ensures a good spectral continuity of the single scattering albedo.

Generate input files for the phase function algorithm in the almucantar

The header is identical than for the PPL. Two types of file are generated with $\phi>0$ and with $\phi<0$.

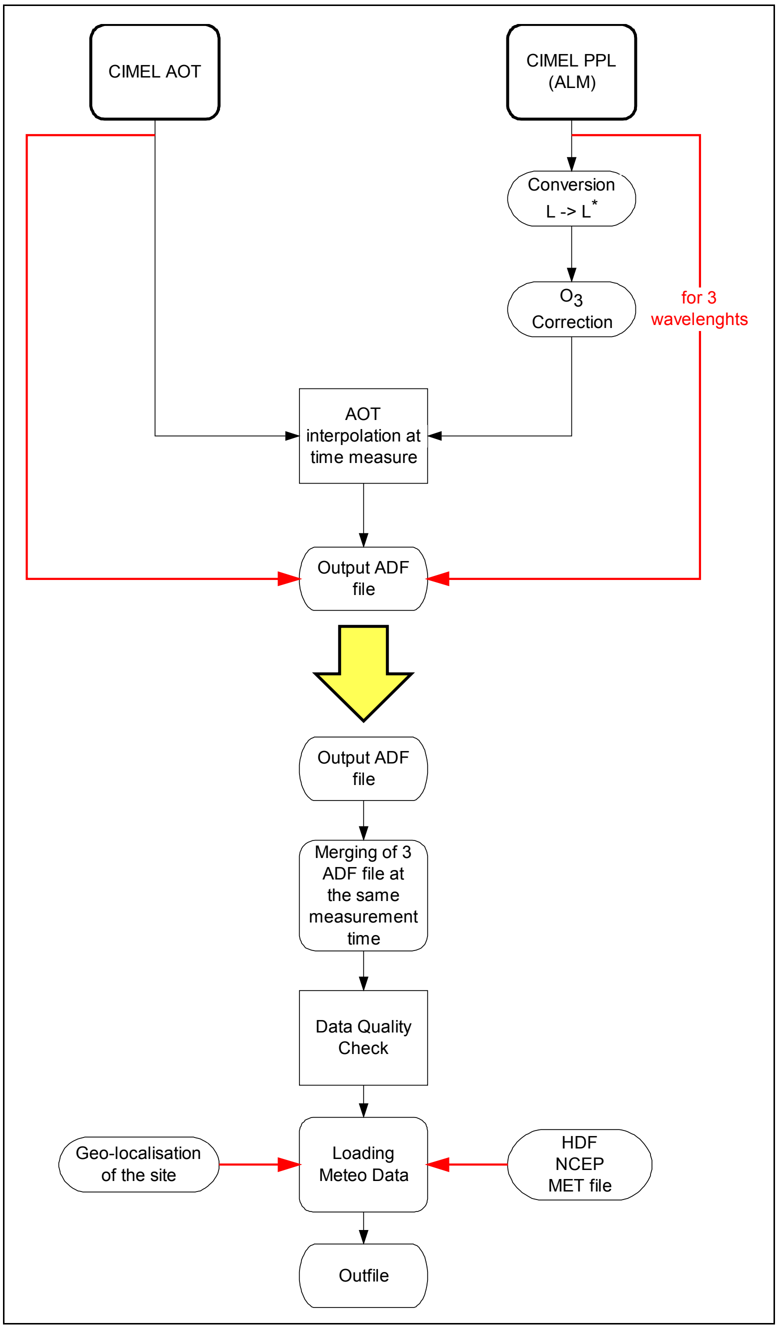
The same two gain problem occurs but for twin measurements at $\phi=+/-6°$ and we solve it similarly to the PPL measurements. For small ϕ, at first order, $\Theta=\phi$, and L values set to zero appear for $\phi=+/-$ 2° and 2.5°. The same approach than for PPL measurements applies.

```
site :      Lanai
date :      01:01:1998
site :      02:15:30
SZA ppl :   69.9970
Ps        : 1015.63605
Alb-440   : 0.00000
Alb-675   : 0.00000
Alb-870   : 0.00000
AOT-440   : 0.02130
AOT-675   : 0.02040
AOT-870   : 0.02300
Gain440   : 0.89288
Gain675   : 0.95677
Gain870   : 0.97004
Ws zonal  : -5.87631
Ws merid  : -0.44018
RH        : 82.02103
dH2O      : 34.08273

Phi         Ldown-440      Ldown-670       Ldown-870
   0.0        0.00000        0.00000        0.00000
   2.0        9.37572       20.83421        0.00000
   2.5        2.94192        4.96139        5.50639
   3.0        1.69674        2.56724        2.81500
   3.5        1.10947        1.35747        1.55578
   4.0        0.83170        0.80289        0.95082
   5.0        0.63569        0.46034        0.53004
   6.0        0.58092        0.39419        0.44888
   7.0        0.54474        0.34348        0.38991
   8.0        0.53262        0.31637        0.35834
  10.0        0.49083        0.27176        0.31855
  12.0        0.45688        0.22923        0.27471
  14.0        0.43576        0.19724        0.26989
  16.0        0.41597        0.17321        0.24410
  18.0        0.37837        0.15987        0.20937
  20.0        0.35351        0.14302        0.19192
  25.0        0.31269        0.12673        0.14879
  30.0        0.28462        0.11189        0.11067
  35.0        0.25317        0.08944        0.08661
  40.0        0.23989        0.07889        0.06504
  45.0        0.23321        0.06677        0.04336
  50.0        0.21512        0.05903        0.03371
  60.0        0.17216        0.04468        0.02418
  70.0        0.15167        0.03844        0.01882
  80.0        0.13901        0.03543        0.01763
  90.0        0.13322        0.03450        0.01710
 100.0        0.13233        0.03730        0.01924
 120.0        0.14187        0.05437        0.02895
 140.0        0.14231        0.12487        0.12908
 160.0        0.15577        0.15478        0.25565
 180.0        0.19212        0.19774        0.32034
```

4. Numerical considerations

4.1 General flow chart for the preparation module



4.2 Directory structure for automatic processing

This section describes the remote-directory where is located the software to create ADF files (Aeronet Data Format) and outfiles.

There are two steps as we can see on flow chart to provide outfile. For the first step (creation of ADF file) we use the following folders:

- DATA_ocean: Contains the CIMEL extinction measurements (AOT lev1.0) files for Ocean sites.
- DATA_terre: Contains the CIMEL extinction measurements (AOT lev1.0) files for Land sites.
- PPL_ocean: Contains the CIMEL radiance measurements (in the PPL) files for Ocean sites.
- PPL_terre: Contains the CIMEL radiance measurements (in the PPL) files for Land sites.
- ALM_ocean: Contains the CIMEL radiance measurements (in the ALM) files for Ocean sites.
- ALM_terre: Contains the CIMEL radiance measurements (in the ALM) files for Land sites.
- RES_ocean: Contains the created ADF files (per site) for Ocean sites.
- RES_terre: Contains the created ADF files (per site) for Ocean sites.

Note that the folder RES_...... contains the ADF files for both PPL (*.ADF) and ALM(*.ADF2)

For the second step (creation of outfile) we use the following folders:

- RES_ocean: Contains the created ADF files (per site) for Ocean sites.
- RES_terre: Contains the created ADF files (per site) for Land sites.
- OUTFILE_ocean: Contains the created outfiles for all Ocean sites.
- OUTFILE_terre: Contains the created outfiles for all Land sites.

Note that MET files are not in the same directory as the software. They are loaded from a specific directory.

4.3 Language and software

The philosophy's launchings of the treatment is as follows. For each type of treatment (ocean, land) there is initially a pre-treatment of formatting of the extinction and radiance data to merge them into one ADF file. For each pre-treatment and treatment, 4 files are necessary:

1 – An IDL routine named *.pro

2 – A BASH script named *.csh

3 – An input file named input.*

4 – A Batch file named batch_* of IDL commands

An example of input file: pre-treatment

```
-------------------------------------------------

#class model index

10

#wavelength number

3
```

#wavelength value

‘440’

‘675’

‘870’

#filename

/mnt/raid/CALVAL/foto/DATA_terre/xx.lev10

An example of Batch file: treatment

```
seadisp
.r MAC_BOMEM_78_LIB.pro
.r MAC_BOMEM_78_LIB.pro
.r extract_lum_met.pro
extract_MET
EXIT
```

An example of BACH script: treatment

```
# csh run_extract_lum_met.csh /mnt/raid/CALVAL/foto/VIDOT/RES_ocean
set c = "'"
set b = '"'
set rep = `ls $argv[1]`
echo $#rep

  @ cur_rep = 1
  while ( $cur_rep <= $#rep )
  echo $rep[$cur_rep]
     set file = $argv[1]/$rep[$cur_rep]
     set fic1 = `ls $file/*440_ADF`
     set fic2 = `ls $file/*675_ADF`
     set fic3 = `ls $file/*870_ADF`
     echo '# file name' > input.extract_lum
     echo $fic1 >> input.extract_lum
```

```
    echo $fic2 >> input.extract_lum
    echo $fic3 >> input.extract_lum
    echo 'seadisp' > batch_prog_for_met
    echo '.r MAC_BOMEM_78_LIB.pro' >> batch_prog_for_met
    echo '.r MAC_BOMEM_78_LIB.pro' >> batch_prog_for_met
    echo '.r extract_lum_met.pro' >> batch_prog_for_met
    echo 'extract_MET' >> batch_prog_for_met
    echo 'EXIT' >>  batch_prog_for_met
    /usr/local/seadas/etc/seadas batch_prog_for_met
@ cur_rep++
end
------------------------------------------------
```

Details of treatment:

- reading of input_format_aeronet file
- reading of *.lev10 file (AERONET aerosol measurements
- calculus of Angstrom coefficient in the solar (675/440) and in the PIR (870/675)
- reading of *.ppl file
- writing of a number of files which depend of the wavelength number containing: Site, date, hour, SZA, AOT, alphaPIR, alphaVIS, and for each CIMEL scattering angle, the normalized radiance

5 The hard inputs to the SOS code

Hard means here than these inputs are independent of the CIMEL data file.

5.1 The atmospheric parameter

The Rayleigh optical thickness at a standard pressure of 1013 hPa

The Rayleigh phase matrix is wavelength independent. The wavelength dependence is contained in the Rayleigh optical thickness. The SO computation is monochromatic but the filters which equipped the CIMEL instrument have a spectral response characterized in the figures ?. In order to stay with a monochromatic computation, we introduce the notion of effective optical thickness $\tau_{m,k}$ (and wavelength) for the Rayleigh in a given spectral band k characterized by it spectral response S:

$$\tau_{m,k} = \frac{\int_0^\infty E_s(\lambda)\, s_k(\lambda)\tau_m(\lambda)\, d\lambda}{\int_0^\infty E_s(\lambda) s_k(\lambda)\, d\lambda} \qquad (19)$$

E_s is the solar irradiance.

If we introduce now the spectral dependence of the Rayleigh in λ^{-4}, we can define an effective wavelength λ_ε :

$$\lambda_{e,k}^{-4} = \frac{\int_0^\infty E_s(\lambda)\, s_k(\lambda)\, \lambda^{-4} d\lambda}{\int_0^\infty E_s(\lambda) s_k(\lambda)\, d\lambda} \qquad (20)$$

Table below gives the nominal wavelength and the effective one for which the Rayleigh optical thickness should be computed.

Nominal (nm)	440	670	870
Equivalent (nm)	442	671	870

The vector mode

The SOS code includes the polarization. The polarization of the Rayleigh and of the Fresnel reflection is included while the aerosols are assumed to be not polarized.

The vertical distribution

The atmosphere is divided into 100 sub layers of equal optical thickness. Within each sub layer, the mixing ratio between the Rayleigh and the aerosol scattering is computed using a vertical distribution of the OAT:

$$\tau(z) = \tau(0)\exp(-z/H)$$

in which the scale height is fixed to 8 km for the molecules and TO 2 km for the aerosols.

The angular discretization

The angular integration is performed with 80 Gaussian angles. By consistency, the phase function is expanded in 80 Legendre polynomials and the Fourier series has also 80 terms.

5.2 The Fresnel reflection over the ocean

The Fresnel reflection is convoluted by the wave slope distribution probability of Cox and Munk. Two wind speeds can be considered: 3 and 7.2 m/s.

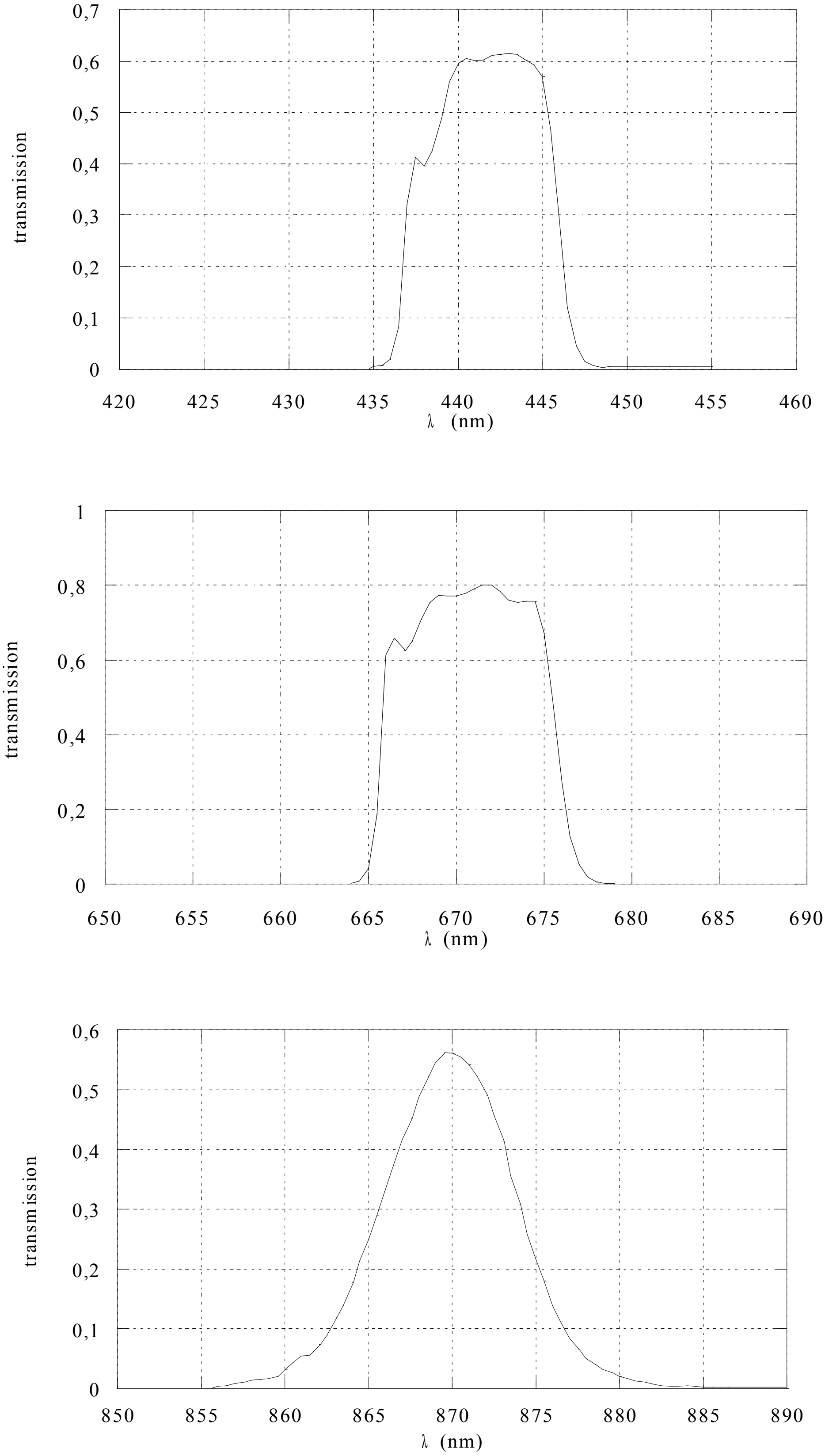


Figure 5: Transmittance of the filters

6 phase function retrieval

6.1 General scheme

Checking the CIMEL file

The program (READ_INPUT) just checks the CIMEL file

The preparation module

The program (CREATE_AUXFILE) uses as input the CIMEL file. It first return a file which provides the inputs to the SOS code (AOT, ROT and the aerosol scattering properties). Then, the CIMEL radiances are resampled to be fully consistent with the SOS code radiances.

The following steps are performed:

(i) For Θ=0°, the radiance is extrapolated on a log scale from the measured radiances at 2° and 2.5°.

(ii) The Angstroem coefficient is computed to select the associated Junge model. This model is used as a first guess in the iterative process and to extrapolate the phase function above Θ>150°. IOPs of the Junge model are read in auxiliary pre computed files.

(iii) The Rayleigh optical thickness is computed using the barometric pressure at surface.

(iv) In the SOS code, the phase function is needed for 80 Gaussian angles as scattering angles. The CIMEL radiances are interpolated to these Gaussian angles.

Inverting the aerosol phase function

The program (WOPAER) retrieves the aerosol phase function for a given spectral band as described in annex 1

The following steps are performed:

(i) Reading the SOS code hard inputs

(ii) Reading the new CIMEL file

(iii) Run the SOS

(iv) Derive the aerosol phase function

(v) Iterate n times step (iii)

(vi) Generate output file

The SOS code comprises two main parts:

(i) a computation of the radiance field for each Fourier series components: $L^s(\mu_v)$.

(ii) a specific computation of the radiance for the PPL or for ALM

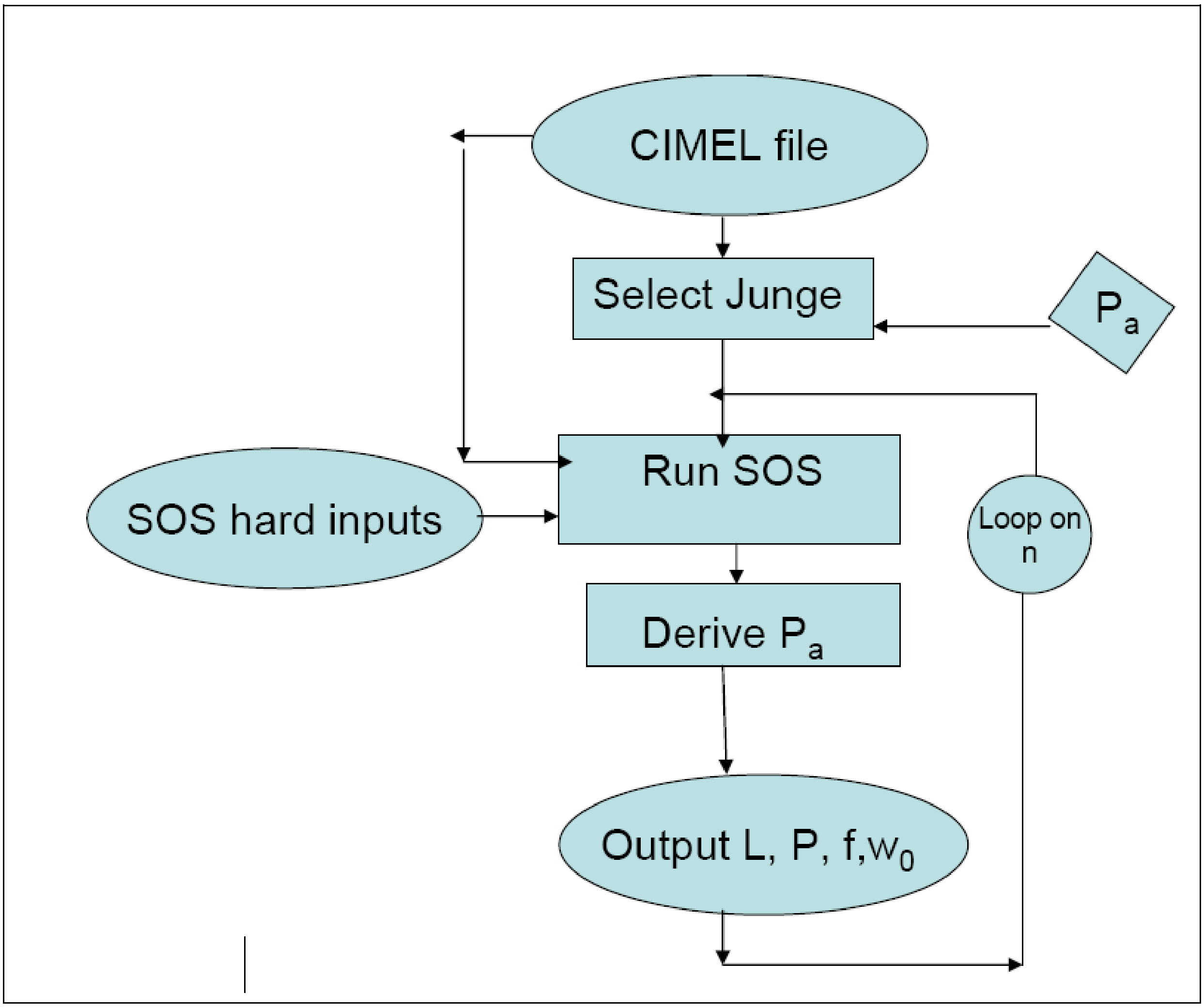
6.2 General flow chart

The CIMEL file is first read to select the Junge aerosol model characterized by α. The corresponding phase function is pre calculated from α=-2.5 to 0

The SOS hard inputs are read to start the iterative process.

At each step, we derive a new aerosol phase function and we save at order n, the computed radiances, the *f* ratio, the phase function and the single scattering albedo.

The iterative process is stopped at order n=5 at 865 nm and n=10 at 670 nm and 440 nm.


CIMEL file
Select Junge
Pa
Run SOS
SOS hard inputs
Loop on n
Derive Pa
Output L, P, f,w0

6.3 IO description

TBD by Zagolski

6.4 Extract outputs

TBD by Zagolski

7 The AERONET phase functions

7.1 The AERONET phase function product

One output (product) of AERONET is the aerosol phase function and the single scattering albedo These parameters are indirect outputs from the AERONET inversion scheme which aims to provide the aerosol size distribution and refractive index. Therefore the question is why we do not use this AERONET products? Different arguments can be used:

(i) the analysis of the CIMEL data is made using a RTC code in a scalar mode. The introduction of the polarization is a clear requisite to predict the total radiance.

(ii) The AERONET inversion scheme aims to retrieve at the best all the measurement data set. What we focus on is the retrieval of the aerosol phase function mostly in the back scattering region, in the geometry which closely corresponds in scattering angle to the MERIS one. Therefore, we believe than out technique is more accurate for our purpose.

7.2 Comparison between AERONET and our protocol

We now compare the AERONET outputs to the results of our inversion. The results are first inverted for 3 sites (Venice, lat=, lon=; Amyon, lat=, lon=; Shirahama, lat=, lon=) in oceanic conditions. The inversion was conducted at 870 nm, wavelength for which the aerosol contribution is emphasised. Figures ? is a comparison for Two scattering angles: 100° and 130°. The results of the comparison are quite similar to the comparison of the retrieved phase function with the MERIS phase functions computed for the MERIS standard aerosol model. The bias on Pa is 10% for Venice and 20 to 30% for the two other sites. The relative dispersion is around 20 to 30%.

Over land, we compare at 670 nm, because the land reflectance is quite dark and stable in this spectral band .The comparison, again conducted for 3 sites (Beijing, Nes Ziona, Fresno) gives important differences between the two sets of aerosol phase function and causes of such differences are under invstigations. One of them can be attributed to the larger contribution of the surface reflection which impacts on the AERONET results as a multi wavelength analysis.

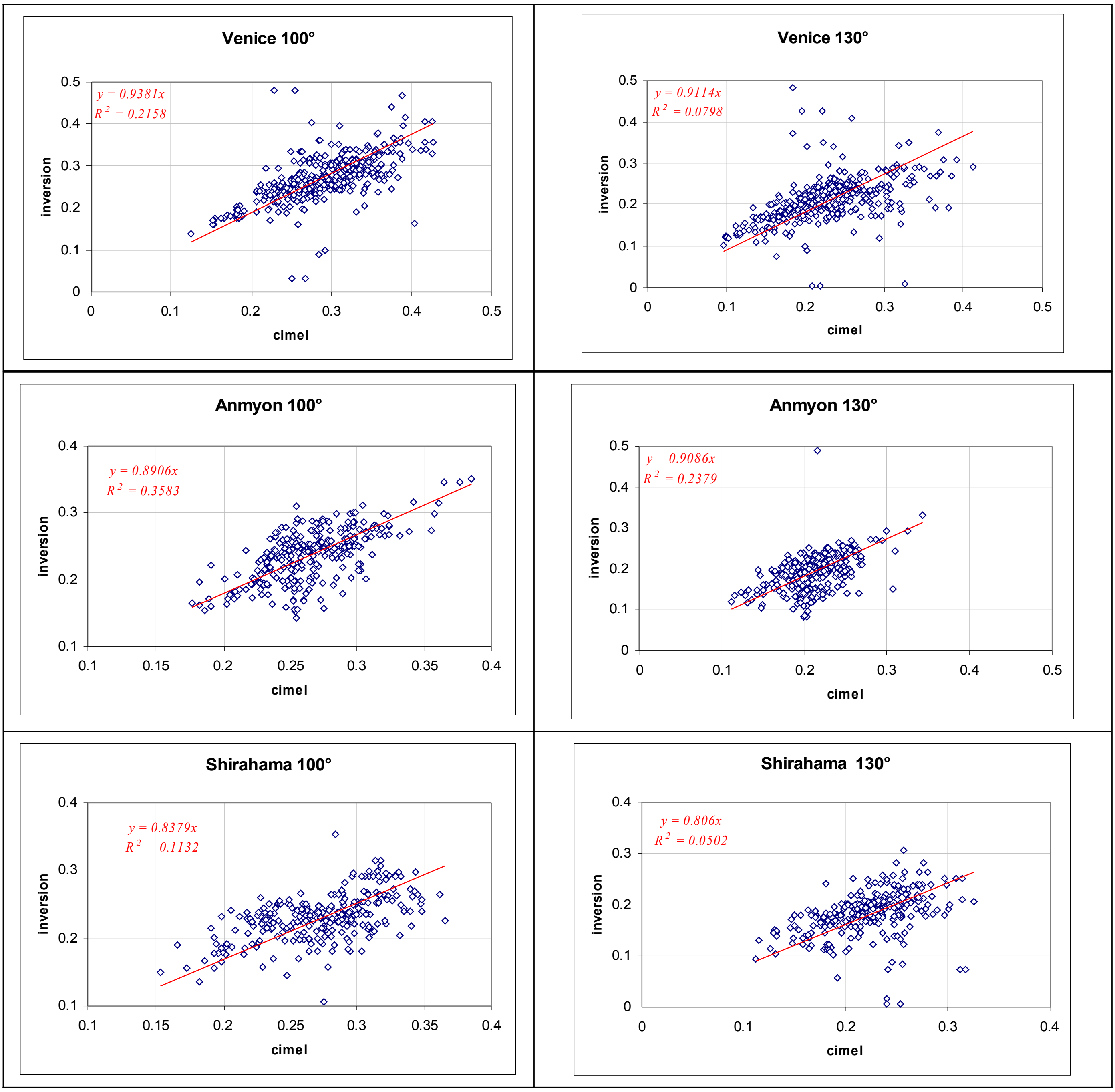


Figure 6: Aerosol phase function comparison at 870 nm between AERONET and our results. Oceanic sites

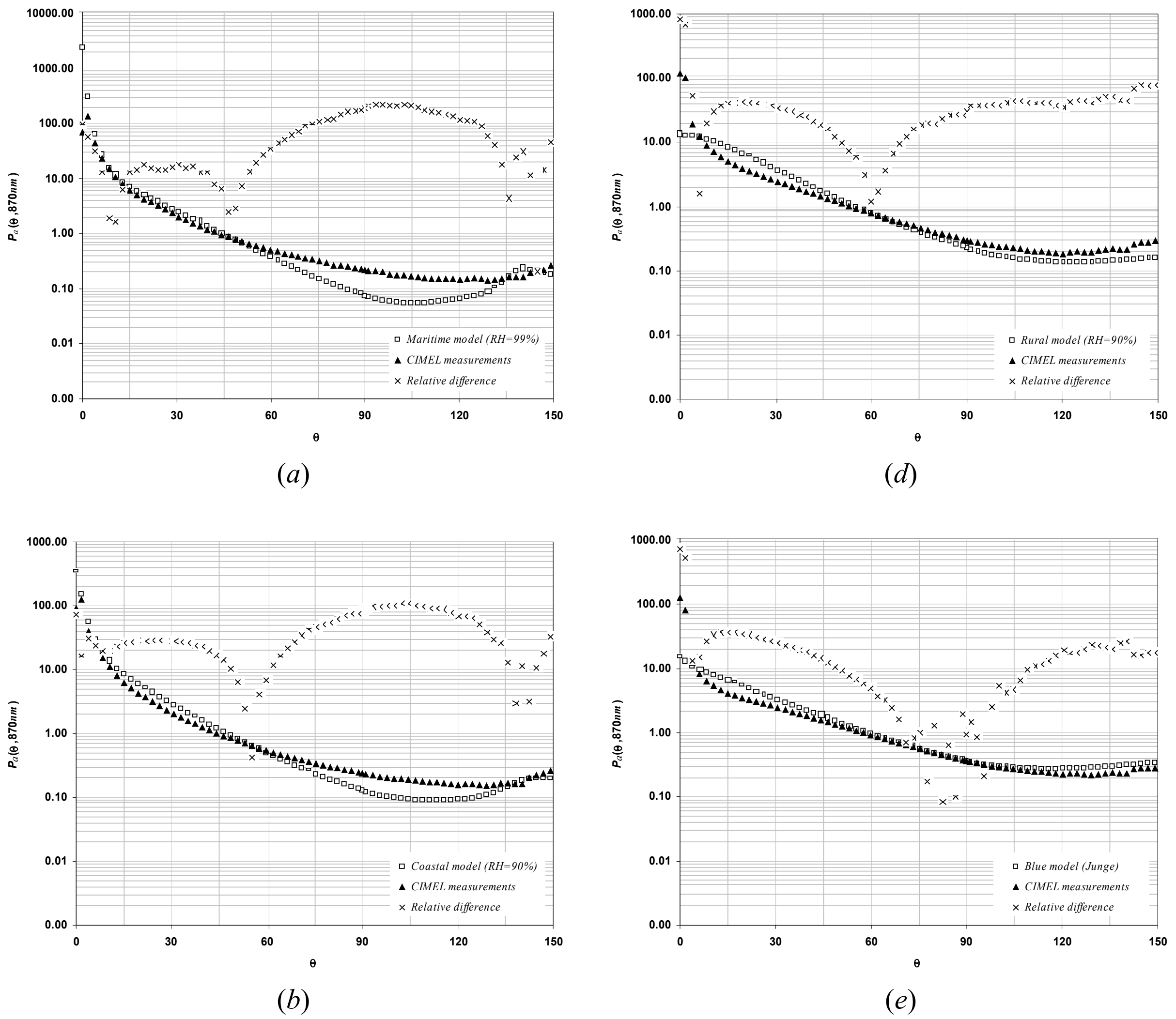


Figure 7: Comparison between aerosol phase functions $\omega_a.P_a(\Theta)$ at 870 nm derived from the CIMEL measurements and from the MERIS SAM's: (a) maritime model (RH=99%), (b) coastal model (RH=90%), (c) rural model (RH=90%), and (d) blue aerosol model (Junge). Relative differences, computed between CIMEL derived phase function and SAM, are plotted by the solid black line.

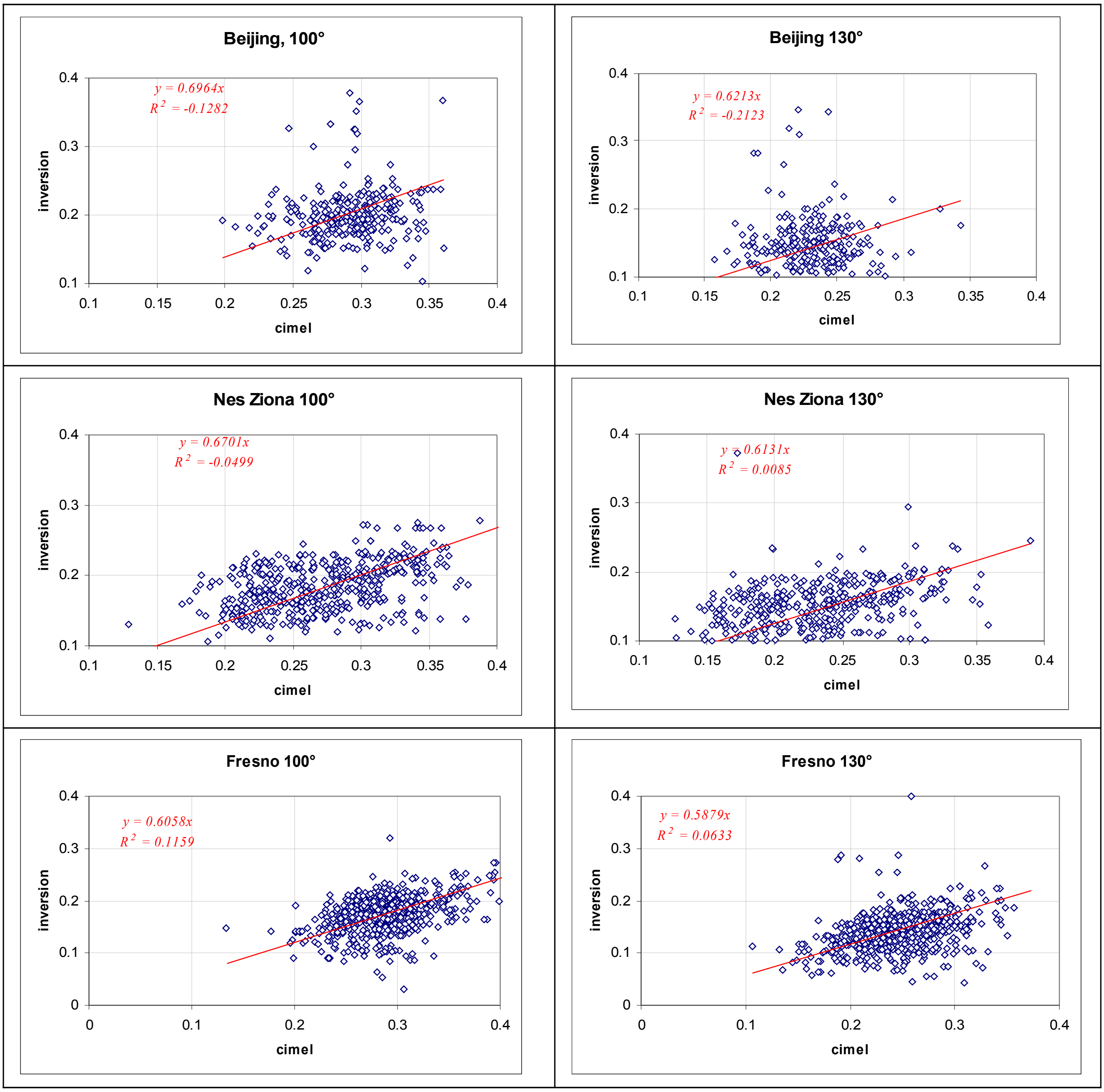


Figure 8: Aerosol phase function comparison at 670 nm between AERONET and our results. Land sites

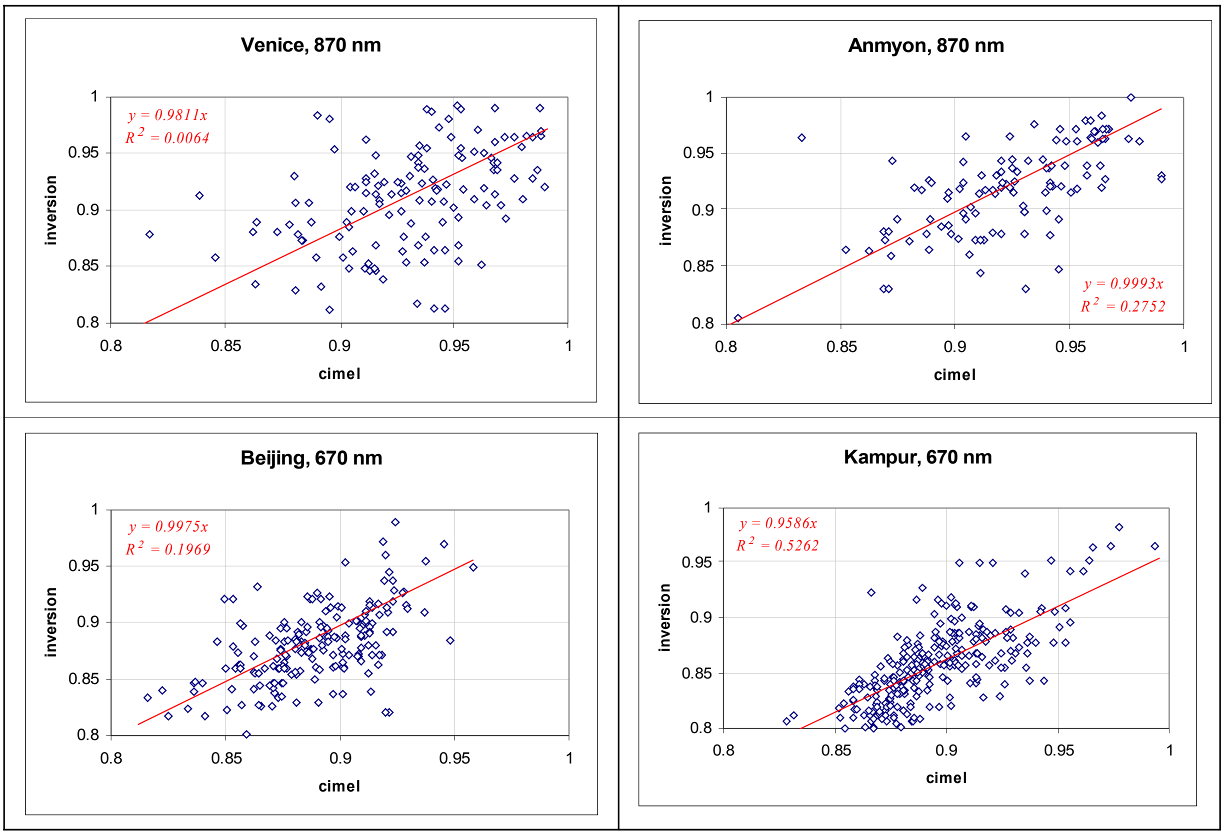


Figure 9: single scattering albedo comparison between AERONET and our results at 870 nm for oceanic sites and 670 nm for land sites.

8. References

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