



Measurement of Visibility Conditions with Traffic Cameras

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Measurement of Visibility Conditions with Traffic Cameras

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Résumé / Abstract A computer vision method was proposed in 2011 by Ifsttar to estimate the meteorological optical range with a roadside camera in daytime conditions. The method was developed thanks to a set of images collected with a basic CCTV camera installed on a weather observation site alongside with reference visibility and luminance meters, between February 27 and March 1st 2009. In order to validate the method, we are collecting images and weather data from different sites. Meanwhile, we have implemented the method in C, and tested it with images and data collected on the original observation site in March and April 2009. The first Section of this report recalls the visibility estimation method. The second Section describes the implementation of the method. The third Section focuses on the detection of Lambertian surfaces in the scene. The fourth Section shows some results for different low visibility episodes. These results are then discussed and the next steps toward deployment are listed. We found that the Lambertian map is not always successful at suppressing the influence of illumination in the scene. We also found that the calibration of the method is affected by the fact that visibility extracted from an image is instantaneous whereas visibility measured by a scatter meter is averaged over 1 minute or more. Finally, we confirmed that the range of the method is limited by the characteristics of the camera. For further tests, we will use the data which we are currently collecting from other sites. When possible, we will need to collect sequences of images instead of single frames every 10', to smooth out insignificant variations. We will also need to estimate the depth map of the scene, to explore the possibility of calibrating the method without reference meteorological optical range data. We intend to investigate alternative local contrast estimation methods and an alternative calibration method for the response curve.	
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	Jean-Philippe Tarel	24/03/2017	Comments on the entropy minimization method and the relevance of gradient as a proxy for contrast.
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Measurement of Meteorological Visibility Conditions with Traffic Cameras

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Introduction

A computer vision method was proposed in 2011 by Ifsttar to estimate the meteorological optical range with a roadside camera in daytime conditions. The method was developed thanks to a set of images collected with a basic CCTV camera installed on a weather observation site alongside with reference visibility and luminance meters, between February 27 and March 1st 2009.

In order to validate the method, we are collecting images and weather data from different sites. Meanwhile, we have implemented the method in C, and tested it with images and data collected on the original observation site in March and April 2009.

The first Section of this report recalls the visibility estimation method. The second Section describes the implementation of the method. The third Section focuses on the detection of Lambertian surfaces in the scene. The fourth Section shows some results for different low visibility episodes. These results are then discussed and the next steps toward deployment are listed.

Atmospheric visibility from image contrast

In daytime, airborne particles interact with light, causing the attenuation of the luminance of surfaces and the addition of a veiling luminance, both as an exponential function of distance. These effects of haze and fog on the luminance of the surfaces in a scene illuminated by skylight are described by the famous Koschmieder law:

$$L(d) = L(0) e^{-kd} + (1 - e^{-kd}) L(\infty) \quad (1)$$

where $L(d)$ is the luminance of a surface observed from a distance d , $L(0)$ is the luminance of the same surface observed at close range, $L(\infty)$ is the luminance of the far away horizon, and k is the extinction coefficient of the atmosphere. The latter is related to the meteorological optical range V :

$$V \approx 3 / k \quad (2)$$

The merging of the luminance of distant surfaces with that of the sky at the horizon, also known as atmospheric perspective, results in an extinction of contrast as a function of distance. Consider an object with an intrinsic contrast $C(0)$ resulting from a difference in luminance dL in its texture. Its contrast as seen from a distance d will then be:

$$C(d) = dL e^{-kd} / L(\infty) = e^{-kd} C(0) \quad (3)$$

We see here that the lower the meteorological visibility, i.e. the higher the atmospheric extinction coefficient, the lower the contrast at a given distance. Hence the idea to use contrast as a proxy for visibility (see for instance Xie et al, 2008, or Taylor and Moogan, 2010).

Babari et al (2011) investigated that idea for the purpose of using traffic surveillance cameras to monitor atmospheric visibility along road networks. They looked into the mean of contrast over the entire image grabbed by a given camera. They used the Sobel gradient operator to approximate local luminance differences, and simply used the maximum pixel intensity ($I_{\max} = 2^8 - 1 = 255$ for an 8-bit digital camera) as a reference to compute the contrast at every pixel:

$$C_{ij} = G_{ij} / I_{\max} = (G_x^2 + G_y^2)^{1/2} / I_{\max} \quad (4)$$

with G_x the Sobel gradient in the horizontal direction and G_y the Sobel gradient in the vertical direction at any given pixel of coordinates (i, j) . Note that the Sobel operator is normalized to ensure that $C_{ij} \leq 1$.

The major difficulty is that contrast varies not only with visibility, but also with illumination. So the authors introduced a weighting factor w based on the correlation between pixel intensity and sky luminance in high visibility conditions, in an attempt to focus on regions in the image where contrast is independent of lighting conditions. Hence the final expression of the weighted mean of contrast:

$$C = \sum w G / I_{\max} \quad (5)$$

with $\sum w = 1$. They called the weight map a Lambertian map, as it provides an indication of the diffuse character of the surfaces in the scene.

As can be seen in Figure 1, they obtained satisfactory results with that approach when they tested it on the 3-day dataset collected between February 27 and March 1st 2009 on a weather observation site in Trappes (France).

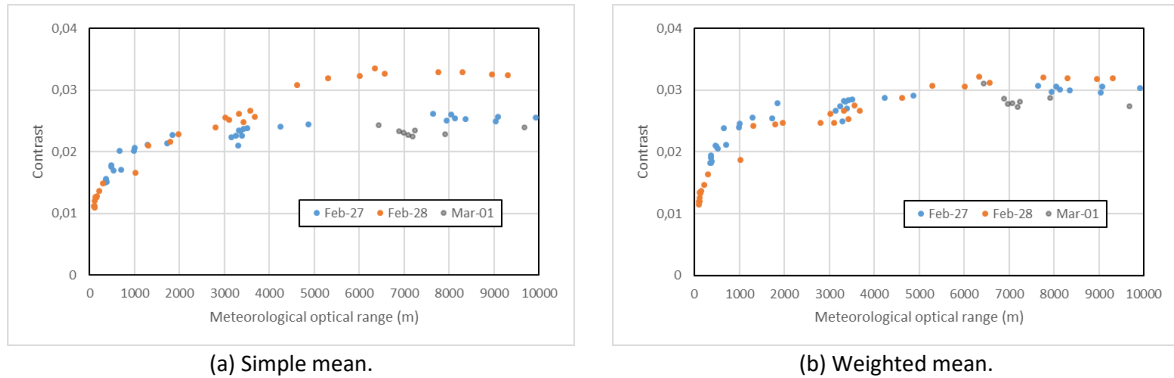


Figure 1. Mean of contrast in a digital image versus atmospheric visibility, (a) without and (b) with Lambertian map.

Then they studied the theoretical relation between contrast C and visibility V based on the distribution of distance in the field of view of the camera. Hypothesizing an exponential distribution function, they found an analytic model for the response function of the camera as a visibility meter:

$$C(V) = a / (1 + b / V) + c \quad (6)$$

where $C(0) = c$ is the contrast caused by image noise only, $C(\infty) = a + c$ is the theoretical contrast when the scene is imaged in ideal visibility conditions (asymptote of the model when V is large), and $V_{\max} = 3b$ indicates the visibility beyond which the model is expected to produce prohibitively large errors.

Setting the noise term to $c = 2/255$, and using the Levenberg-Marquardt algorithm (LMA) to fit the model to the data, this method provides acceptable estimations of the atmospheric visibility. The authors obtained even better results, as can be seen in Table 1, by introducing the uncertainty of visibility measurements into the fit (using the multiplicative inverse of the reference visibility as a

weight), and by using only low visibility data ($V < 1000$ m) to fit the model. Table 2 presents the 90th centile of the relative error for the different fitting methods. The models are confronted with the data in Figure 2.

Table 1. Model parameters and resulting average relative errors between estimated and reference atmospheric visibility, for different fitting methods and for different classes of visibility.

	a	b	< 400 m	< 1 km	< 2 km	< 5 km	< 10 km
allV	0,0234525	497,126	12%	16%	20%	23%	> 100%
allV weighted	0,0240172	490,171	9%	12%	17%	25%	> 100%
lowV	0,0256141	516,038	9%	11%	16%	30%	37%
lowV weighted	0,0283758	612,260	8%	10%	18%	35%	47%

Table 2. 90th centile of the relative errors between estimated and reference atmospheric visibility, for different fitting methods and for different classes of visibility.

	< 400 m	< 1 km	< 2 km	< 5 km	< 10 km
allV	25%	35%	58%	58%	> 100%
allV weighted	20%	27%	42%	59%	> 100%
lowV	16%	20%	47%	63%	68%
lowV weighted	15%	21%	52%	67%	77%

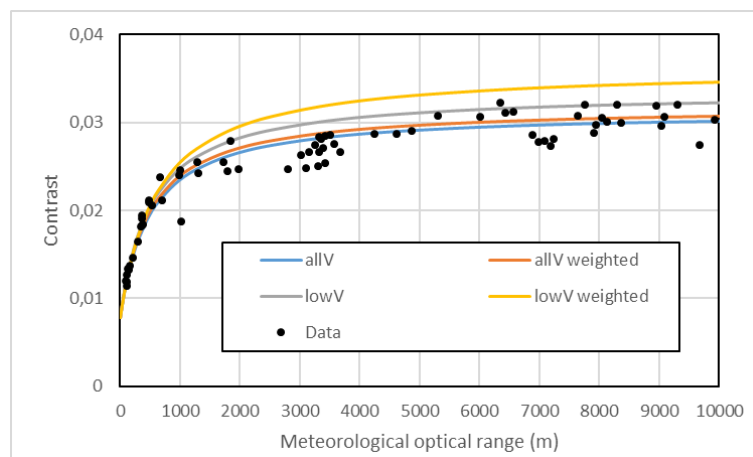


Figure 2. Model fitted to the all data without weight (allV), to all data with weight (allV weighted), to low visibility data without weight (lowV) and to low visibility data with weight (lowV weighted).

Implementation in C language

The method to estimate atmospheric visibility from the mean of weighted contrast was programmed in C language. It consists of 4 command-line programs: dosel, domap, docal and dotst.

The first program produces a list of data which can then be processed by the three other programs. It allows selecting data between two dates, for a given interval of time each day, for a given interval of luminance and for a given interval of visibility. These criteria are provided by means of an ASCII parameter file.

The second program computes a Lambertian map based on a selection of images and associated luminance. The solar angle can be used as a proxy for luminance. Several possibilities are available to compute the values in the map (using positive, negative or all Pearson coefficient values). The resulting weight map is saved in the portable float map file format.

The third program fits the model relating contrast to visibility, using Levenberg-Marquardt algorithm. It works on a selection of data generated with the first program. The data must contain low visibility episodes. The program computes the mean of the contrast in every images, weighted by a specified Lambertian map. The parameters of the fitted model are saved into an ASCII file.

The last program evaluates the mean and the 90th centile of the relative error between the visibility estimated with the model and the reference visibility for a selection of data generated with the first program. The parameters of the model and the selection of data are specified by means of an ASCII parameter file. The results are given for several classes of visibility.

In order to convert the images of the dataset to the portable grey map file format, the programs make system calls to a widely used, free, portable and open-source third party program called ImageMagick®; the path to that program must be specified in the input parameter files. The calibration program docal uses the Levenberg-Marquardt algorithm as implemented by Joachim Wuttke.

Influence of the Lambertian map

The so-called Matilda dataset selected by Babari et al (2011) to develop their method contains data collected between February 27 and March 1, 2009. This period was chosen because it offered a wide variety of visibility (with fog in the morning of February 27 and 28) and sky conditions (sunny, cloudy and overcast). The Lambertian map presented by the authors was computed using the data from the afternoon of March 1, with $L > 500 \text{ cd/m}^2$ and $V > 5 \text{ km}$.

We tried building the Lambertian map with data from before the fog episodes of the Matilda dataset. We tried with data from February 25, which was a sunny day, and with data from February 26, which was an overcast day (as observed from the shadows cast by vertical objects in the scene). We can see in Figure 3 that the Lambertian map built with data from the sunny day fails to improve the tightness of the data along the response curve, contrary to the weight map from the overcast day. The estimation errors are presented in Table 3.

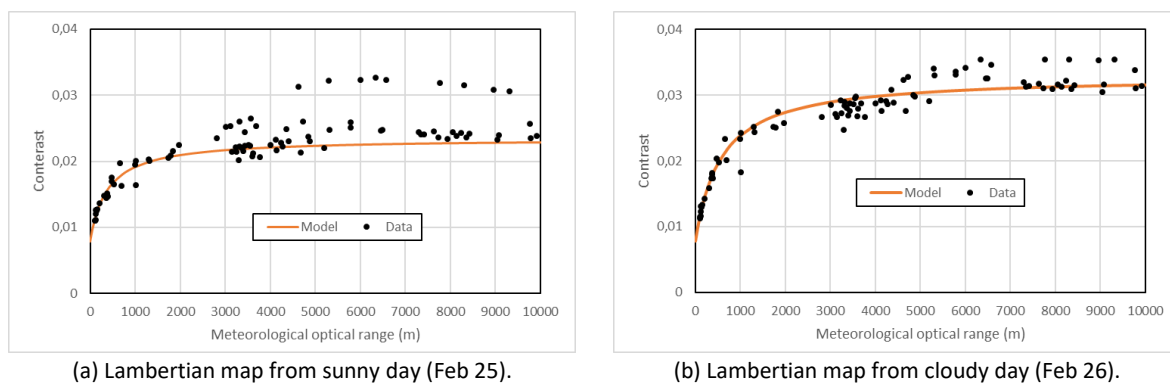


Figure 3. Influence of the Lambertian map on the response function of the camera-based visibility estimation system.

Table 3. 90th centile of the relative errors between estimated and reference atmospheric visibility, depending on the data which served to build the Lambertian map.

	a	b	< 400 m	< 1 km	< 2 km	< 5 km	< 10 km
Feb 25 (sunny)	0,0156364	385,327	24%	39%	54%	> 100%	> 100%
Feb 26 (overcast)	0,0251376	566,246	32%	46%	62%	76%	79%

The Lambertian maps are presented in Figure 4. We see that the map from February 25 (sunny) is not really selective, especially in low contrast areas (the lawn), contrary to the map from February 26

(overcast). There are large differences between the map from February 26 and that of March 1, which is also an overcast day.

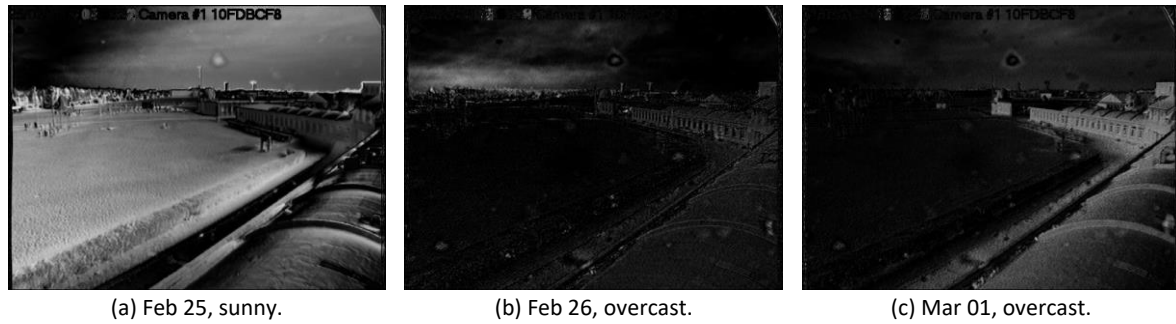


Figure 4. Lambertian maps built with data from days with different sky conditions ((a) sunny and (b) overcast), compared with the original map (c).

Evaluation on different low visibility episodes

Although the Matilda dataset only contains data collected between February 27 and March 1, the data collection actually started on February 5 and lasted until April 10. There were 7 low visibility episodes during that period, always around sunrise: February 7, February 21, February 27, February 28, March 5, March 23 and April 4. Having used the data from the episodes of February 27 & 28 to calibrate the meteorological visibility estimation system, we focused on the last 3 episodes, and then on the whole period, to evaluate the method. We used the model obtained by fitting low visibility data without weight (parameters are given in line 3 of Table 1). The data for the last episode and for the whole period is plotted versus the model in Figure 5.

Table 4. Mean and 90th centile of the relative errors between estimated and reference atmospheric visibility, for different periods with low visibility episodes (italicized when computed with less than 10 data).

	< 400 m		< 1 km		< 2 km		< 5 km		< 10 km	
Mar 03-05	11%	29%	11%	25%	15%	33%	16%	33%	53%	94%
Mar 21-23	37%	37%	25%	37%	22%	37%	29%	78%	54%	80%
Apr 01-03	23%	65%	26%	66%	29%	67%	51%	91%	88%	> 100%
Mar 02 - Apr 10	16%	33%	17%	33%	20%	55%	42%	86%	74%	91%

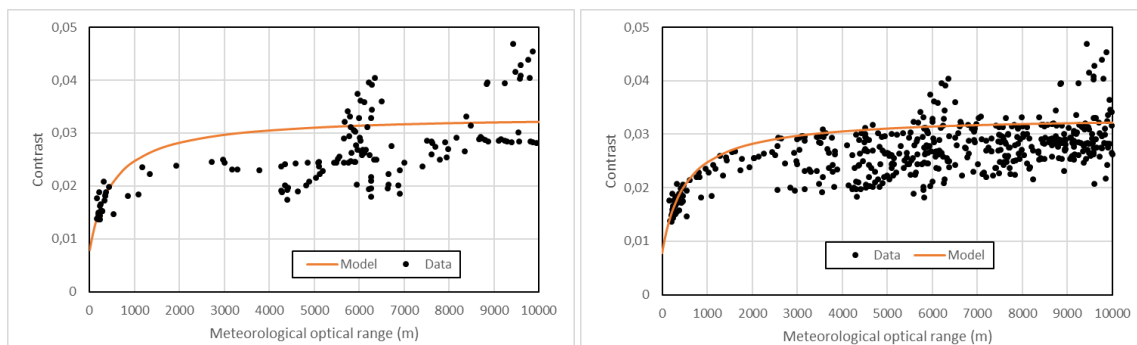


Figure 5. Data of April 1-3, computed with the Lambertian map and the model computed from the Matilda dataset.

Discussion

Babari et al (2011) found that their physically-based method could estimate atmospheric visibility with reasonable accuracy (under 20% relative error in more than 90% of the cases) for meteorological optical range up to more than 2 km. Two limitations prevent a generalization of this result, however. The first limitation is that they tested their method on the same data that was used

to calibrate it. The second limitation is that they applied the Lambertian map backwards in time. When we apply the calibrated model to estimate visibility from data collected on the same site with the same camera but at different times (Table 4), or even when we use a Lambertian map computed from data collected before the data used for the test (Table 3), the results are less accurate, even when we focus on very low visibility. The shape of the model does however seem to fit the data, only not as accurately as expected.

We can draw a parallel between the hyperbolic increase of the deviation between estimated and measured atmospheric visibility and the hyperbolic relation between the distance in the scene and the line number in the image. With the flat world hypothesis, this relation is:

$$d = \lambda / (v - v_h) \quad (7)$$

where d is the distance from the camera to the ground at line v in the image, and v_h is the horizon line:

$$v_h = v_0 - \tan \beta_0 \quad (8)$$

where v_0 is the vertical position of the optical center in the image, and β_0 is the pitch angle of the camera; λ depends on various characteristics of the camera:

$$\lambda = H f / (\mu \cos^2 \beta_0) \quad (9)$$

where H is the mounting height, f is the focal length and μ is the pixel size. For the particular camera installed in Trappes, with $H = 8.3$ m, $\beta_0 = 9.8^\circ$, $f = 4$ mm, $\mu = 9$ μ m and $v_0 = 240$, we have $\lambda = 3799$ and $v_h = 163$. Furthermore, we can estimate the distance δ spanned by one line at distance d :

$$\delta(d) = \lambda / (E(v_h + \lambda / d) - v_h) - \lambda / (E(v_h + \lambda / d) + 1 - v_h) \quad (10)$$

where $E(x)$ is the integer part of x . These equations are taken from Hautière et al (2006) and the parameter values are taken from Hautière et al (2013). We can thus compute the distance beyond which $\delta(d)$ is more than 20% of d , and we find 640 m, which corresponds to the line number 169.

Hypothesizing that it is impossible to get any accuracy from pixels pointing at surfaces beyond that distance, we tried to compute the unweighted mean of contrast over the lower part of the image, below line number 169. After calibrating the model proposed by Babari et al (2011) and inverting it to estimate the visibility from the contrast, we got the results in the graph on the left in Figure 6, with the 90th centile of the relative error at 18% for $V < 400$ m and 34% for $V < 1$ km. The parameters of the model are $a = 0.0225176$ and $b = 418.636$. We find that the results are similar to what was obtained on the same dataset (the so-called Matilda dataset) by Caraffa and Tarel (2014) using their entropy minimization method, as can be seen in the graph on the right in Figure 6.

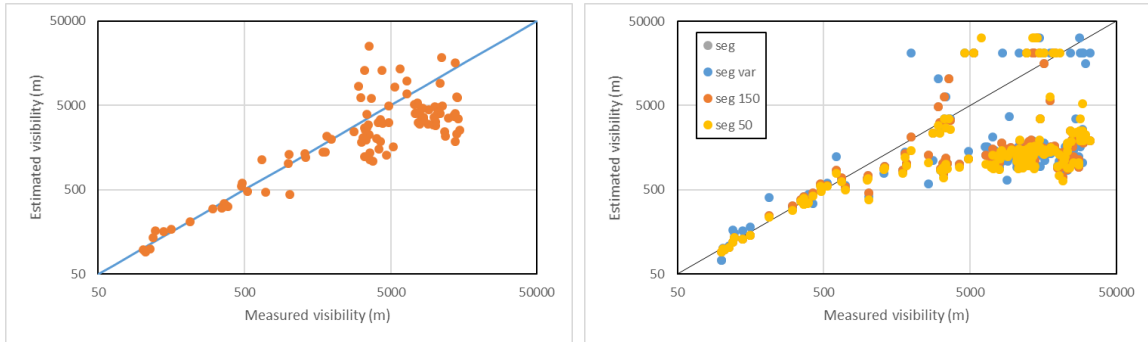


Figure 6. Visibility estimated from the mean of contrast in the lower part of the image (left), and visibility estimated by entropy minimization as proposed by Caraffa and Tarel (2014) (right), using the Matilda dataset.

Measurement of Visibility Conditions with Traffic Cameras

We then tested the model calibrated from the Matilda dataset (i.e. February 27 to March 1st) on data from the low visibility episode of April 1-3. We found the 90th centile of the relative error to be higher than 20% even for $V < 400$ m. We also tried calibrating the model with the data from the April 1-3 episode, but surprisingly, the results were worst (see Figure 7).

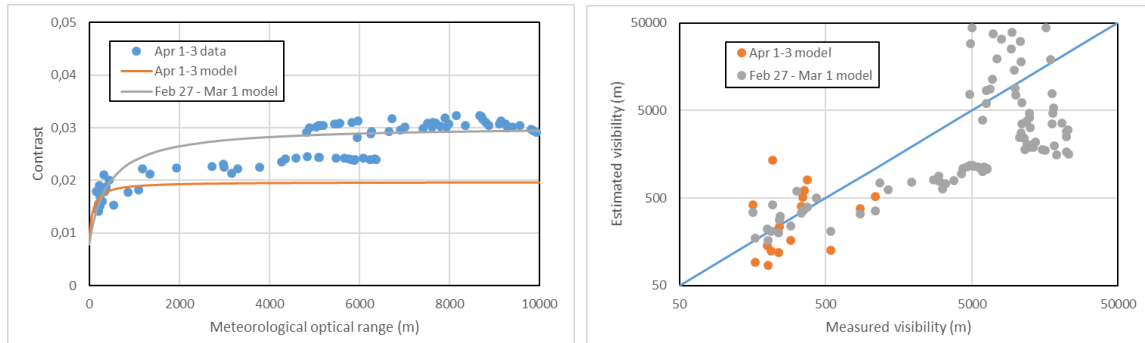


Figure 7. Left: average contrast in the lower part of the image as a function of MOR for the April 1-3 episode, with models calibrated from different datasets. Right: visibility estimated with two models versus measured visibility.

The poor quality of the last results led us to question the quality of the reference data. We see in Figure 8 that the MOR, as measured with a scatter meter, varies literally by the minute, although the measurements are actually averaged over 6 minutes to smooth out non-significant instantaneous variations. The visibility estimated with the camera, on the other hand, is an instantaneous value. Therefore, we should also test averaging the results extracted from several images. Unfortunately, only 1 image every 10 minutes were collected in Trappes, so we need new data to pursue this line of investigation.

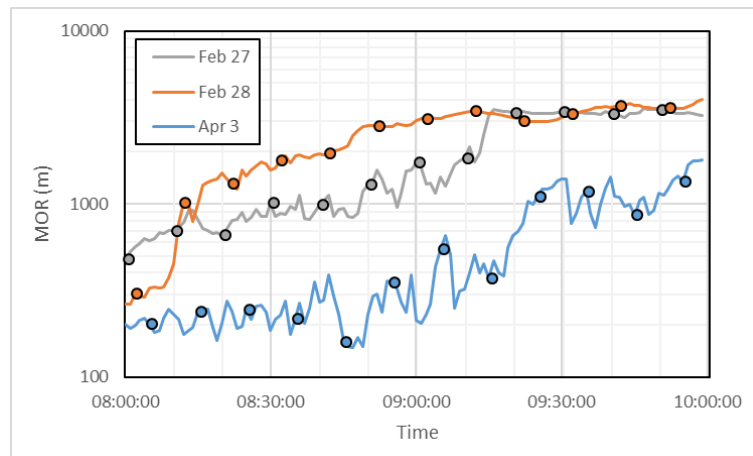


Figure 8. Variations of MOR between 08:00 and 10:00 in the morning of 3 low visibility episodes (the dots correspond to the values that are associated with images).

Meanwhile, we tried using the median value of the MOR over 10-minute periods around the time each image was captured. The results were noticeably improved, as can be seen in Figure 9, although the 90th centile of the relative error is still 58% for $V < 400$ m and 65% for $V < 2$ km (there is no data for V between 400 m and 1 km). The parameters of the model are $a = 0.0223199$ and $b = 357.314$, which is quite close to the model obtained earlier with the data from the Matilda dataset using the contrast in the lower part of the image. This raises our hopes that the model calibrated using a low visibility episode might remain valid for later episodes.

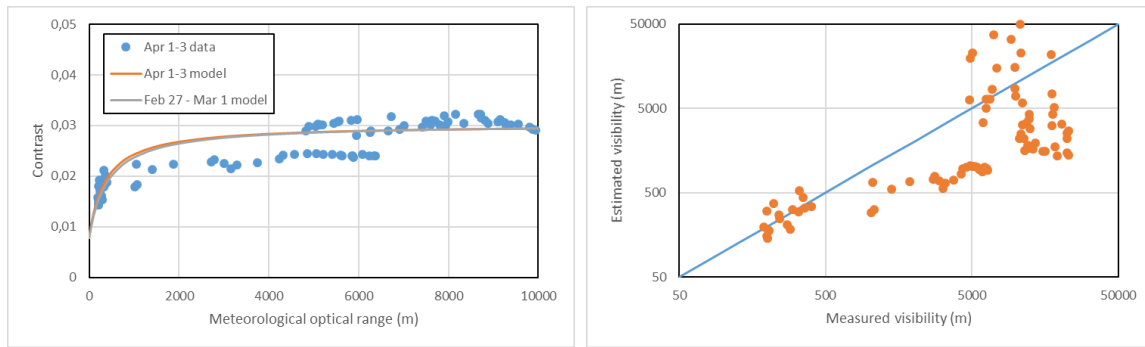


Figure 9. Left: data and model for the April 1-3 episode using the median value of the MOR over 10' periods, along with the model from the Matilda dataset. Right: visibility estimated by inverting the model, versus measured visibility.

Conclusions and future work

We have implemented the physically based method proposed by Babari et al (2011) to estimate atmospheric visibility from the weighted mean of contrast in the image of a scene captured by a CCTV camera. We found that the so-called Lambertian weight map does not successfully suppress the influence of illumination in the scene outside the time frame originally tested by the authors. Simply using the mean of contrast below a certain line in the image seems to provide results with similar accuracy. We also found that calibrating the model outside the timeframe originally tested by the authors does not always produce an acceptable model (one that can be inverted to estimate visibility from contrast with reasonable accuracy). However, it does not necessarily follow that the method is invalid: imprecision in the results may come from the instantaneous nature of the computed contrast, compared to the reference data where visibility is averaged over a period of several minutes. The same remark holds for the more recent method proposed by Caraffa and Tarel (2014). Whatever the method, it seems impossible to obtain reasonably accurate results beyond a certain visibility value which depends on the intrinsic and extrinsic characteristics of the camera (basically its resolution, mounting height and pitch angle).

We have started collecting data from other sites to complete the evaluation of the camera based visibility estimation method(s). When possible, we will collect sequences of images (e.g. 10 images at 1 Hz) instead of single frames every 10 minutes, in order to smooth out non-significant variations. We will also need to estimate the depth map of the scene when possible (e.g. using a stereo vision system), in order to explore the possibility of building the model relating contrast and visibility without need for the reference visibility data required for calibration as proposed in Babari's PhD thesis (2012).

There are several things that we want to investigate in future work. First, we want to look into the definition of the local contrast that we extract in the images. Up to this point, we have implemented a contrast which is actually a gradient (as can be seen in Equation 5). Other possibilities are listed in Hautiere's early work (2005) which might be more relevant for computing contrast maps. We will also consider visibility level as an alternative to contrast (Tarel et al, 2015). Secondly, we want to look into the two-steps calibration method of calibrating the response curve of the camera proposed in Babari's PhD thesis (2012): 1. implement a calibration-free meteorological visibility estimation method which gives reasonably accurate results for very low visibility conditions, such as the inflection point method (Hautiere, 2005) or the entropy minimization method (Caraffa and Tarel, 2014), to learn the slope of the lower part of the response curve, i.e. a/b from Equation (6); 2. Use images acquired in the best visibility conditions to learn the asymptotic value of the response curve, i.e. $a+c$ from Equation (6).

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This project was initiated by Ifsttar in 2008 with Raouf Babari's PhD, co-funded by Meteo-France and co-supervised by IGN. A grant from Institut Carnot VITRES made it possible in 2013 to recruit Abderraouf Zermane to program the visibility estimation method in C language. The work has been pursued in the framework of Ifsttar's COMET research project.

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Appendix 1: program codes

dosel.c (page 2)

Object: selects images acquired in a given period (based on their timestamp) in given weather conditions (based on weather data, specially visibility and luminance).

Syntax: `.\dosel sel_in.txt > sel_out.txt`

Input: arguments are provided by means of an ASCII file (sel_in.txt); the parameters are documented in the comments of that file.

Output: the matching images are listed with the weather data in an ASCII file (sel_out.txt) which can then serve to compute the Lambertian surface map, to calibrate the camera-based visibility meter or to test the results.

domap.c (page 9)

Object: computes the time correlation between pixel intensity and a given weather parameter (normally luminance, or sun elevation) as an indicator of the Lambertian character of surfaces, from data selected using DOSEL.

Syntax: `.\domap map_in.txt`

Input: arguments are provided by means of an ASCII file (map_in.txt). The parameters are documented in the comments of that file.

Output: the map of Lambertian surfaces is stored into a PFM file, the name of which is specified in the input file.

docal.c (page 14)

Object: computes the parameters of the response function of the camera-based visibility meter, from data selected using DOSEL.

Syntax: `.\docal cal_in.txt > cal_out.txt`

Input: arguments are provided by means of an ASCII file (cal_in.txt). The parameters are documented in the comments of that file.

Output: the weighted mean of gradient in each image is given (to plot the response) are stored into an ASCII file, at the end of which and the values of the model parameters are given.

dotst.c (page 20)

Object: computes the error between estimated and reference visibility with data selected using DOSEL.

Syntax: `.\dotst tst_in.txt > tst_out.txt`

Input: arguments are provided by means of an ASCII file (tst_in.txt). The parameters are documented in the comments of that file.

Output: the mean and the 90th-centile of the relative error are tabulated for several classes of visibility.

```

/*
CAM2 toolbox: DOSEL
=====
Object: selects images acquired in a given period (based on their timestamp) in given weather
conditions (based on weather data, specially visibility and luminance).
Syntax: .\dysel sel_in.txt > sel_out.txt
Input: arguments are provided by means of an ASCII file (sel_in.txt); the parameters are
documented in the comments of that file.
Output: the matching images are listed with the weather data in an ASCII file (sel_out.txt)
which can then serve to compute the Lambertian surface map, to calibrate the camera-based
visibility meter or to test the results.
*/

#include <stdio.h>
#include <string.h>
#include <time.h>
#include <sys/stat.h>
#include <math.h>

#define BUFSIZE 1024
#define PI 3.14159265358979323846
#define RAD (PI/180)
#define TWOPI (2*PI)
#define EMR 6371.01 // earth mean radius in km
#define AU 149597890 // astronomical unit in km

typedef struct struct_data
{
    int valid; // 1 for valid data, 0 for invalid data
    int hour;
    int min;
    int sec;
    float vi;
    float bl;
} type_data;
#define sizeof_data sizeof(type_data)
typedef unsigned char uchar;

const char * codestr[] = { "Date\0", "Time\0", "VI\0", "BL\0" };

typedef enum
{
    codeDate = 0,
    codeTime = 1,
    codeVI = 2,
    codeBL = 3
} type_code;

#define Oops(m) {fprintf(stderr, "\n\nOops! %s\n\n", m); exit(-1);}
#define warn(m) {fprintf(stderr, "\n\nHum... %s\n\n", m);}

// from http://www.psa.es/sdg/sunpos.htm
float SunPos(float longitude, float latitude,
    int year, int mon, int mday, int hour, int min, int sec)
{
    // Main variables
    double dElapsedJulianDays;
    double dDecimalHours;
    double dEclipticLongitude;
    double dEclipticObliquity;
    double dRightAscension;
    double dDeclination;
    double dZenithAngle;
    double dAzimuth;

    // Auxiliary variables
    double dy;
    double dx;

    // Calculate difference in days between the current Julian Day
    // and JD 2451545.0, which is noon 1 January 2000 Universal Time
    {
        double dJulianDate;
        long int liAux1;
        long int liAux2;
        // Calculate time of the day in UT decimal hours
        dDecimalHours = hour + (min + sec / 60.0) / 60.0;
        // Calculate current Julian Day
        liAux1 = (mon-14)/12;
        liAux2 = (1461*(year + 4800 + liAux1))/4
            + (367*(mon-2-12*liAux1))/12
            - (3*((year + 4900 + liAux1)/100))/4
            + mday-32075;
        dJulianDate = (double)(liAux2)-0.5+dDecimalHours/24.0;
        // Calculate difference between current Julian Day and JD 2451545.0
        dElapsedJulianDays = dJulianDate-2451545.0;
    }
}

```

```

// Calculate ecliptic coordinates (ecliptic longitude and obliquity of the
// ecliptic in radians but without limiting the angle to be less than 2*Pi
// (i.e., the result may be greater than 2*Pi)
{
    double dMeanLongitude;
    double dMeanAnomaly;
    double dOmega;
    dOmega = 2.1429-0.0010394594*dElapsedJulianDays;
    dMeanLongitude = 4.8950630+ 0.017202791698*dElapsedJulianDays; // Radians
    dMeanAnomaly = 6.2400600+ 0.0172019699*dElapsedJulianDays;
    dEclipticLongitude = dMeanLongitude + 0.03341607*sin( dMeanAnomaly )
        + 0.00034894*sin( 2*dMeanAnomaly )-0.0001134
        -0.0000203*sin(dOmega);
    dEclipticObliquity = 0.4090928 - 6.2140e-9*dElapsedJulianDays
        +0.0000396*cos(dOmega);
}

// Calculate celestial coordinates ( right ascension and declination ) in radians
// but without limiting the angle to be less than 2*Pi (i.e., the result may be
// greater than 2*Pi)
{
    double dSin_EclipticLongitude;
    dSin_EclipticLongitude = sin( dEclipticLongitude );
    dY = cos( dEclipticObliquity ) * dSin_EclipticLongitude;
    dX = cos( dEclipticLongitude );
    dRightAscension = atan2( dY,dX );
    if( dRightAscension < 0.0 ) dRightAscension = dRightAscension + TWOPI;
    dDeclination = asin( sin( dEclipticObliquity )*dSin_EclipticLongitude );
}

// Calculate local coordinates ( azimuth and zenith angle ) in degrees
{
    double dGreenwichMeanSiderealTime;
    double dLocalMeanSiderealTime;
    double dLatitudeInRadians;
    double dHourAngle;
    double dCos_Latitude;
    double dSin_Latitude;
    double dCos_HourAngle;
    double dParallax;
    dGreenwichMeanSiderealTime = 6.6974243242 +
        0.0657098283*dElapsedJulianDays
        + dDecimalHours;
    dLocalMeanSiderealTime = (dGreenwichMeanSiderealTime*15 + longitude)*RAD;
    dHourAngle = dLocalMeanSiderealTime - dRightAscension;
    dLatitudeInRadians = latitude*RAD;
    dCos_Latitude = cos( dLatitudeInRadians );
    dSin_Latitude = sin( dLatitudeInRadians );
    dCos_HourAngle = cos( dHourAngle );
    dZenithAngle = (acos( dCos_Latitude*dCos_HourAngle
        *cos(dDeclination) + sin( dDeclination )*dSin_Latitude));
    dY = -sin( dHourAngle );
    dX = tan( dDeclination )*dCos_Latitude - dSin_Latitude*dCos_HourAngle;
    dAzimuth = atan2( dY, dX );
    if ( dAzimuth < 0.0 )
        dAzimuth = dAzimuth + TWOPI;
    dAzimuth = dAzimuth/RAD;
    // Parallax Correction
    dParallax = (EMR/AU) * sin(dZenithAngle);
    dZenithAngle = (dZenithAngle + dParallax)/RAD;
}

return 90.0-dZenithAngle; // solar elevation
}

time_t settime(int year, int month, int day, int hour, int minute, int second)
{
    /*=====*/
    struct tm *timeinfo;
    time_t rawtime;
    int week;
    char buf[4];
    /*=====*/

    time ( &rawtime );
    timeinfo = gmtime ( &rawtime );
    timeinfo->tm_year = year-1900; // year since 1900
    timeinfo->tm_mon = month-01; // month since January
    timeinfo->tm_mday = day;
    timeinfo->tm_hour = hour;
    timeinfo->tm_min = minute;
    timeinfo->tm_sec = second;
    rawtime = mktime(timeinfo); // make sure all fields of the tm struct are ok

    return rawtime;
}

```



```

int getweek(int year, int month, int day)
{
    /*=====*/
    struct tm *timeinfo;
    time_t rawtime;
    int week;
    char buf[4];
    /*=====*/

    time (&rawtime);
    timeinfo = gmtime (&rawtime);
    timeinfo->tm_year = year-1900; // year since 1900
    timeinfo->tm_mon = month-01; // month since January
    timeinfo->tm_mday = day;
    rawtime = mktime(timeinfo); // make sure all fields of the tm struct are ok
    timeinfo = gmtime (&rawtime);
    strftime(buf, 4, "%w", timeinfo);
    sscanf(buf, "%d", &week);
    //printf("\n%s => week nb %d", asctime(timeinfo), week+1);

    return week+1;
}

int readweatherData(char *filename, type_data *data, int *indexVI, int *indexBL)
{
    /*=====*/
    FILE *f;
    char buf[BUFSIZE];
    char *ptr, str[5];
    int nbparam, p, nbdata, i;
    type_code *codeparam;
    float value;
    int year, mon, mday, hour, min, sec, t;
    /*=====*/

    // open file
    f = fopen(filename, "rt");
    if (!f) return 0; // no (*data) file by that name

    // read the head line
    if (!fgets(buf, BUFSIZE, f))
    {
        fclose(f);
        return 0; // empty (*data) file
    }

    // count parameters in the head line
    // knowing they are separated by tabs
    // (Date and Time are the first 2)
    nbparam = 1;
    ptr = strchr(buf, '\t');
    while (ptr)
    {
        nbparam++;
        ptr = strchr(ptr+1, '\t');
    }
    // printf("\n %s contains %d parameters.", strchr(filename, '\\')+1, nbparam-2);
    codeparam = (type_code*)malloc(nbparam*sizeof(int));
    if (!codeparam) Oops("Not enough memory.");

    // identify the parameters from their code
    *indexVI = *indexBL = -1;
    ptr = buf;
    for (p=0; p<nbparam; p++)
    {
        sscanf(ptr, "%s", str);
        if (!strcmp(str, "Date"))
            codeparam[p] = codeDate;
        else if (!strcmp(str, "Time"))
            codeparam[p] = codeTime;
        else if (!strcmp(str, "VI"))
        {
            codeparam[p] = codeVI;
            *indexVI = p;
        }
        else if (!strcmp(str, "BL"))
        {
            codeparam[p] = codeBL;
            *indexBL = p;
        }
        else
            Oops("Unknown paramater.");
        // printf("\n %d: %s", p, codestr[p]);
        ptr = strchr(ptr+1, '\t');
    }
    // if ((*indexVI)>0) printf(" VI%d", *indexVI);

```

```

// if ((*indexBL)>0) printf(" BL@%d", *indexBL);
if (((*indexVI)<0) || ((*indexBL)<0))
{
    fclose(f);
    free(codeparam);
    warn("No visibility (VI) or luminance (BL) in (*data) file.");
    return 0; // neither visibility nor luminance
}

// count the lines, i.e. (*data) points
// to allocate memory
nbdata = 0;
while (fgets(buf, BUFSIZE, f))
    nbdata++;
if (nbdata<1) return 0; // No (*data)
// printf("\n There are %d items.", nbdata);

// initialize data array
for (hour=0; hour<24; hour++)
    for (min=0; min<60; min++)
        data[hour*60+min].valid = 0;

// rewind, and read the (*data)
rewind(f);
fgets(buf, BUFSIZE, f); // skip head line
for (i=0; i<nbdata; i++)
{
    if (fscanf(f, "%d/%d/%d %d:%d:%d",
                &year, &mon, &mday, &hour, &min, &sec)<6)
        Oops("Data format error (yyyy/mm/dd hh:mm:ss).");
    t = hour*60+min;
    data[t].hour = hour;
    data[t].min = min;
    data[t].sec = sec;
    for (p=2; p<nbparam; p++)
    {
        if (fscanf(f, "%F", &value)<1)
            Oops("Data format error (numerical values).");
        if (p==(*indexVI)) data[t].vi = value;
        else if (p==(*indexBL)) data[t].bl = value;
    }
    data[t].valid = 1;
}
fclose(f);

// clean memory
free(codeparam);

return nbdata;
}

int searchweatherData(type_data *data, int i_hour, int i_min, int i_sec, int *w_timer)
{
    /*=====*/
    int dt1, dt2;
    int t, t1, t2;
    /*=====*/

    // image timer
    t = *w_timer = i_hour*60+i_min;

    // check for exact match
    if (data[t].valid) return 1;

    // go back 6 mins
    dt1 = 1;
    while ((dt1<6) && (t1-dt1>=0) && !(data[t-dt1].valid))
        dt1++;
    // go forth 6 mins
    dt2 = 1;
    while ((dt2<6) && (t+dt2<1440) && !(data[t+dt2].valid))
        dt2++;
    // choose the closest in time
    if (dt1<dt2)
        *w_timer = t-dt1;
    else if (dt2<dt1)
        *w_timer = t+dt2;
    else return 0; // no matching timestamp with 12 min

    return 1;
}

float getvisibilityIndicator(char *filename, int wmin, int hmin, int wmax, int hmax)
{
    /*=====*/
    FILE *f;
    char buf[BUFSIZE];

```

```

int width, height;
int w, h, x, y;
uchar **image, imax;
float dLx, dLy, g, m;
// use Sobel operator to approximate first derivative
float Kx[3][3] = {{+0.25, 0.0, -0.25}, {+0.5, 0.0, -0.5}, {+0.25, 0.0, -0.25}};
float Ky[3][3] = {{+0.25, +0.5, +0.25}, {0.0, 0.0, 0.0}, {-0.25, -0.5, -0.25}};
/*=====*/

// check window
if ((wmin<=0) || (wmax>=width) || (hmin<=0) || (hmax>=height))

// convert image to pgm file format
if (!system(NULL)) Oops("Cannot execute command.");
sprintf(buf, "C:\\prgm\\ImageMagick-6.8.8-7\\convert.exe %s tmp.pgm", filename);
system(buf);

// read image
f = fopen("tmp.pgm", "rb");
if (!f) Oops("Image conversion failed.");
if (!fgets(buf, BUFSIZE, f)) Oops("Empty PGM file.");
if (strcmp(buf, "P5", 2)) Oops("Not a binary PGM file (P5).");
if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of PGM file.");
if (sscanf(buf, "%d %d", &width, &height)<2) Oops("PGM header error (size).");
if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of PGM file.");
if (sscanf(buf, "%u", &imax)<1) Oops("PGM header error (max value).");
image = (uchar**)malloc(height*sizeof(uchar*));
if (!image) Oops("Not enough memory for image.");
for (h=0; h<height; h++)
{
    image[h] = (uchar*)malloc(width*sizeof(uchar));
    if (!image[h]) Oops("Not enough memory for image line.");
    if (fread(image[h], width*sizeof(uchar), 1, f)<1)
        Oops("Failed to read image from file.");
}
fclose(f);

// compute mean gradient module
m = 0.0;
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
    {
        dLx = 0;
        dLy = 0;
        for (y=-1; y<=1; y++)
            for (x=-1; x<=1; x++)
            {
                dLx += Kx[1+y][1+x] * (float)image[h+y][w+x];
                dLy += Ky[1+y][1+x] * (float)image[h+y][w+x];
            }
        m += sqrt(dLx*dLx+dLy*dLy);
    }

// clean memory
for (h=0; h<height; h++)
    free(image[h]);
free(image);

return m/(float)(wmax-wmin+1)/(float)(hmax-hmin+1)/(float)imax;
}

int main(int argc, char **argv)
{
    /*=====*/
    FILE *f;
    struct stat fileinfo;
    char buf[BUFSIZE], path[BUFSIZE], ifile[BUFSIZE], dfile[BUFSIZE];
    int nbDays;
    type_code *codeparam;
    type_data wdata[1440]; // allocate for 1day=24h*60min max of measurements
    int nbdata, indexVI, indexBL;
    float longitude, latitude;
    float S; // sun position (sun elevation)
    float L, Lmin=-1, Lmax = -1; // luminance
    float V, Vmin=-1, Vmax = -1; // visibility
    int yy, mm, ww, dd, yy1, mm1, ww1, dd1=-1, yy2, mm2, ww2, dd2=-1;
    int d, h, h1, h2, m, m1, m2, s, i, t;
    int wh, wm;
    int set_Date, set_Time, set_VI, set_BL, set_Path, set_Pos;
    time_t tt, tt1, tt2;
    struct tm *ti;
    /*=====*/

    if (argc<2) Oops("Syntax: ./dosel select.txt");

    /*
    // read input parameters from file (argv[1])

```

```

*/
f = fopen(argv[1], "rt");
if (!f) Oops("Input file not found.");
set_Date = set_Time = set_VI = set_BL = set_Path = 0;
path[0] = '\0';
while (fgets(buf, BUFSIZE, f))
{
    if (buf[0] != '#')
    {
        if (strstr(buf, "Date"))
        {
            if (sscanf(buf, "Date from %d/%d/%d to %d/%d/%d",
                &yy1, &mm1, &dd1, &yy2, &mm2, &dd2)<6)
                Oops("Error at date.");
            set_Date = 1;
            // printf("\n d1 = %d/%d/%d", yy1, mm1, dd1);
            // printf("\n d2 = %d/%d/%d", yy2, mm2, dd2);
        }
        else if (strstr(buf, "Time"))
        {
            if (sscanf(buf, "Time between %d:%d and %d:%d",
                &h1, &m1, &h2, &m2)<4)
                Oops("Error at time (wrong format).");
            if ( (h1<0) || (h2<0) || (h1>23) || (h2>23)
                || (m1<0) || (m2<0) || (m1>59) || (m2>59))
                Oops("Error at time (out of range).");
            set_Time = 1;
            // printf("\n t1 = %d:%d", h1, m1);
            // printf("\n t2 = %d:%d", h2, m2);
        }
        else if (strstr(buf, "Luminance"))
        {
            if (sscanf(buf, "Luminance from %f to %f", &Lmin, &Lmax)<2)
                Oops("Error at Lmin.");
            set_BL = 1;
            // printf("\n %g <= L < %g", Lmin, Lmax);
        }
        else if (strstr(buf, "Visibility"))
        {
            if (sscanf(buf, "Visibility from %f to %f", &Vmin, &Vmax)<2)
                Oops("Error at Vmin.");
            set_VI = 1;
            // printf("\n %g <= V < %g", Vmin, Vmax);
        }
        else if (strstr(buf, "Path"))
        {
            strcpy(path, strchr(buf, ' ')+1);
            if ((strlen(path)<2) || (strlen(path)>BUFSIZE-2))
                Oops("Error at path.");
            path[strlen(path)-1] = '\0';
            // printf("\n path = %s !", path);
            if (stat(path, &fileinfo)<0) Oops("Invalid path.");
            set_Path = 1;
        }
        else Oops("Unknown parameter in input file.");
    }
}
fclose(f);
if ((!set_Date) || (!set_Time) || (!set_BL) || (!set_VI) || (!set_Path))
    Oops("Missing parameter(s).");

/*
// find weather station description in path/
*/
sprintf(buf, "%s\\%s.txt", path, strrchr(path, '\\')+1);
f = fopen(buf, "rt");
if (!f) Oops("Description of weather station not found.");
while (fgets(buf, BUFSIZE, f))
{
    if (buf[0] != '#')
    {
        if (strstr(buf, "Position"))
        {
            if (sscanf(buf, "Position %f %f", &latitude, &longitude)<2)
                Oops("Error at position in station description file.");
            set_Pos = 1;
            // printf("\n position = %g, %g", latitude, longitude);
        }
    }
}
fclose(f);
if (!set_Pos)
    Oops("Missing parameter(s).");

// output header
printf("# Selection parameters:\n");
printf("# Path = %s \n", path);

```

```

printf("# Location: %c %f , %c %f \n",
    (latitude<0)?'S':'N', latitude,
    (longitude<0)?'W':'E', longitude);
printf("# Time period: %4d/%02d/%02d (%02d)",
    yy1, mm1, dd1, ww1 = getweek(yy1, mm1, dd1));
printf(" to %4d/%02d/%02d (%02d) \n", yy2, mm2, dd2, ww2 = getweek(yy2, mm2, dd2));
printf("# %02d:%02d <= T <= %02d:%02d \n", h1, m1, h2, m2);
printf("# %g <= L (cd/m2) < %g \n", Lmin, Lmax);
printf("# %g <= V (m) < %g \n", Vmin, Vmax);
printf("Image\\tDate\\tTime\\tSE\\tBL\\tVI\\n");

/*
// find image and (*data) files in path/yyyy/ww/
*/
tt1 = settime(yy1, mm1, dd1, 0, 0, 0);
tt2 = settime(yy2, mm2, dd2, 23, 59, 59);
nbDays = ((int)difftime(tt2, tt1)+1)/(24*60*60);
// printf("\n %d => %d (%d days)", tt1, tt2, nbDays);
tt = tt1;
nbdata = 0;
for (d=0; d<nbDays; d++)
{
    ti = gmtime(&tt); // printf(" %d ", tt);
    yy = ti->tm_year+1900;
    mm = ti->tm_mon+1;
    dd = ti->tm_mday;
    ww = getweek(yy, mm, dd); // warning: getweek resets ti (!?)
    sprintf(dfile, "%s\\%4d\\%02d\\%4d%02d%02d.txt",
        path, yy, ww,
        yy, mm, dd);
    // if (*data) file exists and actually contains (*data), then look for images
    if (readweatherData(dfile, wdata, &indexVI, &indexBL))
    {
        for (h=0; h<24; h++) for (m=0; m<60; m++) for (s=0; s<60; s++)
            if ((h*60+m>=h1*60+m1)&&(h*60+m<=h2*60+m2))
            {
                sprintf(ifile, "%s\\%4d\\%02d\\%4d%02d%02d%02d.jpg",
                    path, yy, ww,
                    yy, mm, dd,
                    h, m, s);
                // if (f=fopen(ifile, "r")) { fclose(f); printf("\n %s", ifile);}
                if (!stat(ifile, &fileinfo)) // image file found
                {
                    // printf("\n %s => %s", strrchr(dfile, '\\')+1, strrchr(ifile, '\\')+1);
                    // look for data with similar timestamp
                    if ((searchweatherData(wdata, h, m, s, &tt)))
                    {
                        L = wdata[t].bl;
                        V = wdata[t].vi;
                        S = SunPos(longitude, latitude, yy, mm, dd, h, m, s);
                        // fprintf(stderr, "%s\\t%g\\t%g\\n", strrchr(ifile, '\\')+1, V, L);
                        if ( (V >= Vmin) && (V < Vmax)
                            && (L >= Lmin) && (L < Lmax))
                        {
                            printf("%s\\t%4d/%02d/%02d\\t%02d:%02d:%02d\\t%g\\t%g\\t%g\\n",
                                ifile, yy, mm, dd, h, m, s, S, L, V);
                            // getvisibilityIndicator(ifile, 16, 32, 616, 472);
                            nbdata++;
                        }
                    }
                }
                // else printf(" => no data within 12 min");
            }
        }
    // go to next day
    tt += 24*60*60;
}
if (nbdata) fprintf(stderr, "\n %d matching data found.", nbdata);
else fprintf(stderr, "\n No match.");

fprintf(stderr, "\n\n No problemo. \n\n");
return 0;
}

```

```

/*
CAM2 toolbox: DOMAP
=====
Object: computes the time correlation between pixel intensity and a given weather parameter
(normally luminance, or sun elevation) as an indicator of the Lambertian character of
surfaces, from data selected using DOSEL.
Syntax: .\domap map_in.txt
Input: arguments are provided by means of an ASCII file (map_in.txt). The parameters are
documented in the comments of that file.
Output: the map of Lambertian surfaces is stored into a PGM file, the name of which is
specified in the input file.
*/

#include <stdio.h>
#include <string.h>
#include <time.h>
#include <sys/stat.h>
#include <math.h>

#define BUFSIZE 2048

typedef unsigned char uchar;
typedef enum IndEnum
{
    NONE=0, // weight = 1
    CORR=1, // weight = squared correlation with luminance (or other parameter)
    PCOR=2, // weight = squared positive correlation
    NCOR=3, // weight = squared negative correlation
    ASDV=4, // weight = std-deviation of contrast
    RSDV=5 // weight = relative std-deviation of contrast
} indType;

#define Oops(m) {fprintf(stderr, "\n\nOops! %s\n\n", m); exit(-1);}
#define warn(m) {fprintf(stderr, "\n\nHum... %s\n\n", m);}

void readPGM(char *name, uchar ***data, int *width, int *height)
{
    /*-----*/
    FILE *f;
    int h, w;
    char buf[256];
    /*-----*/

    f = fopen(name, "rb");
    if (!f) Oops("File not found.");
    fgets(buf, 256, f);
    if (!strstr(buf, "P5")) Oops("Not a PGM file.");
    while ((fgets(buf, 256, f)) && (buf[0] != '#'));
    sscanf(buf, "%d %d", width, height);
    fgets(buf, 256, f);
    (*data) = (uchar**) malloc((*height)*sizeof(uchar*));
    if (!(*data)) Oops("Not enough memory.");
    for (h=0; h<*height; h++)
    {
        (*data)[h] = (uchar*) malloc((*width)*sizeof(uchar));
        if (!((*data)[h])) Oops("Not enough memory.");
        if (fread((*data)[h], (*width)*sizeof(uchar), 1, f)<1)
            Oops("Read error.");
    }
    fclose(f);
}

void writePFM(char *pfm, float **data, int width, int height, char *str, float total)
{
    /*-----*/
    FILE *f;
    int h, w;
    int doflip = 0;
    float s;
    /*-----*/

    f = fopen(pfm, "wb");
    fprintf(f, "PF\n# Created using dolamb\n");
    fprintf(f, "# Indicator: %s\n", str);
    if (total<0)
    {
        s = 0.0;
        for (h=0; h<height; h++)
            for (w=0; w<width; w++)
                s += data[h][w];
    }
    else s = total;
    fprintf(f, "# Total: %g\n", s);
    fprintf(f, "%d %d\n-1\n", width, height);
    if (doflip)
        for (h=height-1; h>=0; h--) fwrite(data[h], width*sizeof(float), 1, f);
}

```

```

    else
        for (h=0; h<height; h++) fwrite(data[h], width*sizeof(float), 1, f);
    fclose(f);
}

int main(int argc, char **argv)
{
    /*=====*/
    char * parcodestr[] = { "Image\0", "Date\0", "Time\0", "SE\0", "BL\0", "VI\0" };
    char * indcodestr[] = { "none\0", "corr\0", "pcor\0", "ncor\0", "asdv\0", "rsdv\0" };
    FILE *f;
    fpos_t marker;
    char buf[BUFSIZE], filename[BUFSIZE], infile[BUFSIZE], outfile[BUFSIZE], cmdstr[BUFSIZE];
    int set_In=0, set_Win=0, set_Par=0, set_Out=0, set_Cmd=0;
    indType set_Ind=0;
    char *ptr, date[11], time[9];
    int nbIma, n, p;
    int w, width, h, height;
    int wmin=16, hmin=32, wmax=616, hmax=472; // values for the Trappes database
    uchar ***ima;
    float **map;
    float *lum;
    float m1, s11, x, totalweight;
    float **mi, **sii, **sil;
    /*=====*/

    if (argc<2) Oops("Syntax: .\domap.exe domap.txt");

    /*
    // read input parameters from file (argv[1])
    */
    f = fopen(argv[1], "rt");
    if (!f) Oops("Input file not found.");
    set_In = set_Win = set_Par = set_Out = 0;
    set_Ind = NONE;
    while (fgets(buf, BUFSIZE, f))
    {
        if (buf[0] != '#')
        {
            if (strstr(buf, "selection"))
            {
                strcpy(infile, strrchr(buf, ' ') + 1);
                if ((strlen(infile)<2) || (strlen(infile)>BUFSIZE-2))
                    Oops("Error at selection filename.");
                infile[strlen(infile)-1] = '\0';
                printf("\n list = %s", infile);
                set_In = 1;
            }
            else if (strstr(buf, "window"))
            {
                if (sscanf(buf, "window: %d %d %d %d", &wmin, &wmax, &hmin, &hmax)<4)
                    Oops("Error at window coordinates.");
                set_Win = 1;
                printf("\n window = (%d,%d)->(%d,%d)", wmin, hmin, wmax, hmax);
            }
            else if (strstr(buf, "Indicator"))
            {
                if (strstr(buf, "none")) set_Ind = NONE;
                else if (strstr(buf, "correlation")) set_Ind = CORR;
                else if (strstr(buf, "positive")) set_Ind = PCOR;
                else if (strstr(buf, "negative")) set_Ind = NCOR;
                else if (strstr(buf, "absolute")) set_Ind = ASDV;
                else if (strstr(buf, "relative")) set_Ind = RSDV;
                else Oops("Unknown Lambertian indicator.");
                printf("\n indicator = %s", indcodestr[set_Ind]);
            }
            else if (strstr(buf, "Parameter"))
            {
                if (sscanf(buf, "Parameter index: %d", &set_Par)<1)
                    Oops("Error at parameter index.");
                set_Par -= 1;
                printf("\n parameter = %s", parcodestr[set_Par]);
            }
            else if (strstr(buf, "Save map"))
            {
                strcpy(outfile, strrchr(buf, ' ') + 1);
                if ((strlen(outfile)<2) || (strlen(outfile)>BUFSIZE-2))
                    Oops("Error at output filename.");
                outfile[strlen(outfile)-1] = '\0';
                printf("\n output = %s", outfile);
                set_Out = 1;
            }
            else if (strstr(buf, "Conversion"))
            {
                strcpy(cmdstr, strrchr(buf, ' ') + 1);
                if ((strlen(cmdstr)<2) || (strlen(cmdstr)>BUFSIZE-2))
                    Oops("Error at image converter path.");
            }
        }
    }
}

```

```

        cmdstr[strlen(cmdstr)-1] = '\0';
        printf("\n cmd = %s", cmdstr);
        set_Cmd = 1;
    }
    else Oops("Unknown parameter in input file.");
}
}
fclose(f);
if ((!set_In) || (!set_Win) || ((set_Ind==CORR) && (!set_Par))
    || (!set_Out) || (!set_Cmd))
    Oops("Missing parameter(s).");
if (set_Ind>NCOR) Oops("The contrast-based indicators are not implemented.");

/*
// look at selected images and associated data to build weight map
*/
// read selection
f = fopen(infile, "rt");
if (!f) Oops("List file not found.");
// skip header
buf[0] = '#';
while (buf[0]=='#')
    if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of file.");
// TODO: check presence of parameter
// count items
fgetpos(f, &marker); // set marker
nbIma = 0;
while (fgets(buf, BUFSIZE, f)) nbIma++;
if (!nbIma) Oops("Empty list.");
fsetpos(f, &marker); // rewind to marker
// printf("\n %d items\n", nbIma);
// read images
ima = (uchar***)malloc(nbIma*sizeof(uchar**));
if (!ima) Oops("Not enough memory for images.");
lum = (float*)malloc(nbIma*sizeof(float));
if (!lum) Oops("Not enough memory for lum data.");
for (n=0; n<nbIma; n++)
{
    if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of file.");
    // read filename (1st column) and parameter to correlate
    strcpy(filename, buf); *(strchr(filename, '\t')) = '\0';
    // printf("\n %s", strrchr(filename, '\\')+1);
    ptr = strchr(buf, '\t');
    for (p=1; p<set_Par; p++)
        ptr = strchr(ptr+1, '\t');
    // printf(" %d", p);
    if ((!ptr) || (sscanf(ptr, "%f\t", &(lum[n]))<1))
        Oops("could not find parameter.");
    // printf(" %g", lum[n]);
    // convert image to pgm file format
    if (!system(NULL)) Oops("Cannot execute command.");
    sprintf(buf, "%s %s tmp.pgm", cmdstr, filename);
    system(buf);
    // read image
    readPGM("tmp.pgm", &(ima[n]), &w, &h);
    if (n==0)
    {
        width = w;
        height = h;
        /*
        // "Empty" map => weight=1 inside the processed window, 0 elsewhere
        */
        if (!set_Ind)
        {
            map = (float**)malloc(height*sizeof(float*));
            if (!map) Oops("Not enough memory for lamb map based on luminance.");
            for (h=0; h<height; h++)
            {
                map[h] = (float*)malloc(width*sizeof(float));
                if (!map[h]) Oops("Not enough memory for lamb map.");
                for (w=0; w<width; w++)
                {
                    if ((w>=wmin)&&(w<=wmax)&&(h>=hmin)&&(h<=hmax))
                        map[h][w] = 1.0;
                    else map[h][w] = 0.0;
                }
            }
            writePFM(outfile, map, width, height, indcodestr[set_Ind],
                (wmax-wmin+1)*(hmax-hmin+1));
            for (h=0; h<height; h++) free(map[h]);
            free(map); free(ima); free(lum);
            fclose(f);
            fprintf(stderr, "\n\n No problemo. \n\n");
            return 0;
            // Bye bye
        }
    }
}
}

```



```

        else if ((w!=width) || (h!=height))
            Oops("Images with different sizes.");
    }
fclose(f);

// compute means of intensity, gradient and luminance
mi = (float**)malloc(height*sizeof(float*));
if (!mi) Oops("Not enough memory for pixel mean.");
for (h=0; h<height; h++)
{
    mi[h] = (float*)malloc(width*sizeof(float));
    if (!mi[h]) Oops("Not enough memory for pixel mean.");
}
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
    {
        mi[h][w] = 0.0;
        for (n=0; n<nbIma; n++)
            mi[h][w] += (float)(ima[n][h][w]);
        mi[h][w] /= (float)nbIma;
    }
m1 = 0.0;
for (n=0; n<nbIma; n++)
    m1 += lum[n];
m1 /= (float)nbIma;
// compute std-deviations and cross-correlation
sii = (float**)malloc(height*sizeof(float*));
if (!sii) Oops("Not enough memory for pixel std-dev.");
sil[h] = (float**)malloc(height*sizeof(float*));
if (!sil) Oops("Not enough memory for pixel std-dev.");
for (h=0; h<height; h++)
{
    sii[h] = (float*)malloc(width*sizeof(float));
    if (!sii[h]) Oops("Not enough memory for pixel std-dev.");
    sil[h] = (float*)malloc(width*sizeof(float));
    if (!sil[h]) Oops("Not enough memory for pixel std-dev.");
}
s11 = 0.0;
for (n=0; n<nbIma; n++)
    s11 += (lum[n]-m1)*(lum[n]-m1);
if (s11 == 0.0) Oops("Constant luminance...");
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
    {
        sii[h][w] = sil[h][w] = 0.0;
        for (n=0; n<nbIma; n++)
        {
            sii[h][w] += ((float)(ima[n][h][w])-mi[h][w])*
                        ((float)(ima[n][h][w])-mi[h][w]);
            sil[h][w] += ((float)(ima[n][h][w])-mi[h][w])*(lum[n]-m1);
        }
        if (sii[h][w] == 0.0)
            sil[h][w] = 0.0;
        else
            sil[h][w] /= sqrt( sii[h][w] * s11 ); // Pearson coefficient
    }

// Save weight map
map = (float**)malloc(height*sizeof(float*));
if (!map) Oops("Not enough memory for lamb map based on luminance.");
totalweight = 0.0;
for (h=0; h<height; h++)
{
    map[h] = (float*)malloc(width*sizeof(float));
    if (!map[h]) Oops("Not enough memory for lamb map.");
    for (w=0; w<width; w++)
    {
        if ((w<wmin) || (w>wmax) || (h<hmin) || (h>hmax))
            map[h][w] = 0.0;
        else
        {
            x = sil[h][w];
            switch(set_Ind)
            {
                case PCOR:
                    // map[h][w] = 1.0 + x;
                    // map[h][w] = (x<0.0)?0.0:x;
                    map[h][w] = (x<0.0)?0.0:x*x;
                    break;
                case NCOR:
                    map[h][w] = (x>0.0)?0.0:-x;
                    // map[h][w] = (x>0.0)?0.0:x*x;
                    break;
                default:
                    // map[h][w] = (x<0)?-x:x;
                    map[h][w] = x*x;
            }
        }
    }
}

```

```

        totalweight += map[h][w];
    }
}
writePFM(outfile, map, width, height, indcodestr[set_Ind], totalweight);
// clean memory
for (n=0; n<nbIma; n++)
{
    for (h=0; h<height; h++)
        free(ima[n][h]);
    free(ima[n]);
}
free(ima);
free(lum);
for (h=0; h<height; h++)
{
    free(mi[h]);
    free(sii[h]);
    free(sil[h]);
    free(map[h]);
}
free(mi);
free(sii);
free(sil);
free(map);

fprintf(stderr, "\n\n No problemo. \n\n");
return 0;
}

```



```

void readPFM(char *name, float ***data, int *width, int *height, float *Smap)
{
    /*-----*/
    FILE *f;
    int h, w;
    char buf[256];
    int gotTotal = 0;
    /*-----*/

    f = fopen(name, "rb");
    if (!f) Oops("File not found.");
    fgets(buf, 256, f);
    if (!strstr(buf, "Pf")) Oops("Not a PFM file.");
    while ((fgets(buf, 256, f)) && (buf[0] != '#'))
    {
        if (strstr(buf, "Total"))
        {
            if (sscanf(buf, "# Total: %f", Smap) < 1) Oops("Lambertian map header error.");
            gotTotal = 1;
        }
    }
    // if (!gotTotal) Oops("Lambertian map does not contain its total value.");
    sscanf(buf, "%d %d", width, height);
    fgets(buf, 256, f);
    (*data) = (float**) malloc((*height) * sizeof(float*));
    if (!(*data)) Oops("Not enough memory.");
    for (h=0; h<height; h++)
    {
        (*data)[h] = (float*) malloc((*width) * sizeof(float));
        if (!((*data)[h])) Oops("Not enough memory.");
        if (fread((*data)[h], (*width) * sizeof(float), 1, f) < 1)
            Oops("Read error.");
    }
    fclose(f);
}

void writePGM(char *pgm, uchar **data, int width, int height, int doflip)
{
    /*-----*/
    FILE *f;
    int h, w;
    /*-----*/

    f = fopen(pgm, "wb");
    fprintf(f, "P5\n# Created using docal\n");
    fprintf(f, "%d %d\n255\n", width, height);
    if (doflip)
        for (h=height-1; h>=0; h--) fwrite(data[h], width, 1, f);
    else
        for (h=0; h<height; h++) fwrite(data[h], width, 1, f);
    fclose(f);
}

float getVisibilityIndicator(char *filename, char *cmdstr,
    int wmin, int hmin, int wmax, int hmax, float **map)
{
    /*=====*/
    FILE *f;
    char buf[BUFSIZE];
    int width, height;
    int w, h, x, y, imax;
    uchar **image;
    float **sob, dLx, dLy, m, weight, s;
    // use Sobel operator to approximate first derivative
    float Kx[3][3] = {{+0.25, 0.0, -0.25}, {+0.5, 0.0, -0.5}, {+0.25, 0.0, -0.25}};
    float Ky[3][3] = {{+0.25, +0.5, +0.25}, {0.0, 0.0, 0.0}, {-0.25, -0.5, -0.25}};
    float invnorm;
    /*=====*/

    // convert image to pgm file format
    if (!system(NULL)) Oops("Cannot execute command.");
    sprintf(buf, "%s %s tmp.pgm", cmdstr, filename);
    system(buf);

    // read image
    f = fopen("tmp.pgm", "rb");
    if (!f) Oops("Image conversion failed.");
    if (!fgets(buf, BUFSIZE, f)) Oops("Empty PGM file.");
    if (strncmp(buf, "P5", 2)) Oops("Not a binary PGM file (P5).");
    // skip comments
    buf[0] = '#';
    while (buf[0] == '#')
        if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of PGM file.");
    if (sscanf(buf, "%d %d", &width, &height) < 2) Oops("PGM header error (size).");
    if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of PGM file.");
    if (sscanf(buf, "%d", &imax) < 1) Oops("PGM header error (max value).");
    image = (uchar**) malloc(height * sizeof(uchar*));

```

```

if (!image) Oops("Not enough memory for image.");
for (h=0; h<height; h++)
{
    image[h] = (uchar*)malloc(width*sizeof(uchar));
    if (!image[h]) Oops("Not enough memory for image line.");
    if (fread(image[h], width*sizeof(uchar), 1, f)<1)
        Oops("Failed to read image from file.");
}
fclose(f);

// check window
if ((wmin<=0) || (wmax>=width) || (hmin<=0) || (hmax>=height))
    Oops("window should provide 1-pixel border at least.");

// allocate for contrast map
sob = (float**)malloc(height*sizeof(float*));
if (!sob) Oops("Not enough memory for gradient image.");
for (h=0; h<height; h++)
{
    sob[h] = (float*)malloc(width*sizeof(float));
    if (!sob[h]) Oops("Not enough memory for gradient image line.");
    memset(sob[h], 0, width*sizeof(float));
}

// compute contrast (i.e. gradient module / 255 ) map
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
    {
        dLx = 0;
        dLy = 0;
        for (y=-1; y<=1; y++)
            for (x=-1; x<=1; x++)
            {
                dLx += Kx[1+y][1+x] * (float)image[h+y][w+x];
                dLy += Ky[1+y][1+x] * (float)image[h+y][w+x];
            }
        sob[h][w] = sqrt(dLx*dLx+dLy*dLy)/255.;
    }

// locate over- and under-exposed pixels
// to avoid false contrast
/*
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
        for (y=-1; y<=1; y++)
            for (x=-1; x<=1; x++)
                if ((image[h+y][w+x]<5) || (image[h+y][w+x]>250))
                    sob[h][w] = 0;
*/

// Compute weighted mean contrast
m = 0.0; s = 0.0;
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
        //if (sob[h][w]>0.0)
        {
            // use Lambertian surface map to ponder the contribution of the pixel
            if (!map) weight = 1.0;
            else weight = map[h][w];
            s += weight;
            m += sob[h][w] * weight;
        }
if (s == 0.0) Oops("Zero weight map.");
m /= s;

// clean memory
for (h=0; h<height; h++)
{
    free(image[h]);
    free(sob[h]);
}
free(image);
free(sob);

// normalize so that the total sum of the weight is 1.0 => /Smap
return m;
}

/* model function */
double fct( double x, const double *p )
{
    return p[0] / ( 1.01 + p[1] / x ) + 2.01/255.01 ;
    //return p[0] / (2.01*p[1]) * (1.01-exp(-p[1]/x)) + 2.01/255.01;
}

/* inverse model function */
double invfct( double y, const double *p )

```

```

{
    return p[1] / ( p[0] / ( y - 2.01/255.01 ) - 1.01 ) ;
    //double c = 2.01 / 255.01;
    //return p[1] / ( Lambertw( p[0]*exp(p[0]/(c-y))/(c-y) ) - p[0]/(c-y) );
}

/* determination of weighted residues */
void evalw( const double *par, int m_dat, const void *data,
            double *fvec, int *info )
{
    /* for readability, explicit type conversion */
    data_struct *D;
    D = (data_struct*)data;

    int i;
    for ( i = 0; i < m_dat; i++ )
    {
        fvec[i] = D->y[i] - D->f( D->x[i], par );
        /* weight with measurement uncertainty */
        fvec[i] /= 0.2*D->x[i];
    }
}

/* determination of residues */
void eval( const double *par, int m_dat, const void *data,
           double *fvec, int *info )
{
    /* for readability, explicit type conversion */
    data_struct *D;
    D = (data_struct*)data;

    int i;
    for ( i = 0; i < m_dat; i++ )
    {
        fvec[i] = D->y[i] - D->f( D->x[i], par );
    }
}

int main(int argc, char **argv)
{
    /*=====*/
    const char * codestr[] = { "Image\0", "Date\0", "Time\0", "SE\0", "BL\0", "VI\0" };
    FILE *f;
    fpos_t marker;
    char buf[BUFSIZE], line1[BUFSIZE];
    char filename[BUFSIZE], infile[BUFSIZE], mapfile[BUFSIZE], cmdstr[BUFSIZE];
    int set_In=0, set_Win=0, set_Par=0, set_Map=0, set_Cmd=0, set_Wei=0, set_Lim=0, set_Ini=0;
    int doweight = 1;
    float vmax = 1000.0;
    char *ptr, date[11], time[9];
    int nbIma, n, p;
    int w, width, h, height;
    int wmin=16, hmin=32, wmax=616, hmax=472;
    float **map;
    float *sob, *mor, smap;
    double *Y, *X, W;
    double par[2] = { 0.011, 1001 }; // guesses for the values of model parameters
    /*=====*/

    if (argc<2) Oops("Syntax: .\docal.exe cal_in.txt");

    /* test Lambertw */
    W = Lambertw(1.01);
    printf("\n w(%lg) = %lg (%lg)", 1.0, w, (w-0.5671432904097838730)/w);
    W = Lambertw(2.01);
    printf("\n w(%lg) = %lg (%lg)", 2.0, w, (w-0.8526055020137254914)/w);
    W = Lambertw(20.01);
    printf("\n w(%lg) = %lg (%lg)", 20.0, w, (w-2.2050032780240599705)/w);
    **/

    /*
    // read input parameters from file (argv[1])
    */
    f = fopen(argv[1], "rt");
    if (!f) Oops("Input file not found.");
    set_In = set_Win = set_Par = 0;
    while (fgets(buf, BUFSIZE, f))
    {
        if (buf[0] != '#')
        {
            if (strstr(buf, "Selection"))
            {
                strcpy(infile, strchr(buf, ' ') + 1);
                if ((strlen(infile)<2) || (strlen(infile)>BUFSIZE-2))
                    Oops("Error at selection filename.");
                infile[strlen(infile)-1] = '\0';
                fprintf(stderr, "\n list = %s", infile);
            }
        }
    }
}

```

```

        set_In = 1;
    }
    else if (strstr(buf, "window"))
    {
        if (sscanf(buf, "window: %d %d %d %d", &wmin, &wmax, &hmin, &hmax)<4)
            Oops("Error at window coordinates.");
        set_Win = 1;
        fprintf(stderr, "\n window = (%d,%d)->(%d,%d)", wmin, hmin, wmax, hmax);
    }
    else if (strstr(buf, "index"))
    {
        if (sscanf(buf, "visibility index: %d", &set_Par)<1)
            Oops("Error at visibility index.");
        set_Par -= 1;
        fprintf(stderr, "\n parameter = %s", codestr[set_Par]);
    }
    else if (strstr(buf, "Lambertian map"))
    {
        strcpy(mapfile, strchr(buf, ' ')+1);
        if (strstr(mapfile, "none"))
        {
            map = (float**)NULL;
            Smap = 1.0;
            fprintf(stderr, "\n Lambertian map: none");
        }
        else
        {
            if ((strlen(mapfile)<2) || (strlen(mapfile)>BUFSIZE-2))
                Oops("Error at Lambertian map filename.");
            mapfile[strlen(mapfile)-1] = '\0';
            fprintf(stderr, "\n Lambertian map = %s", mapfile);
            readPFM(mapfile, &map, &w, &h, &Smap);
        }
        set_Map = 1;
    }
    else if (strstr(buf, "Conversion"))
    {
        strcpy(cmdstr, strchr(buf, ' ')+1);
        if ((strlen(cmdstr)<2) || (strlen(cmdstr)>BUFSIZE-2))
            Oops("Error at image converter path.");
        cmdstr[strlen(cmdstr)-1] = '\0';
        fprintf(stderr, "\n cmd = %s", cmdstr);
        set_Cmd = 1;
    }
    else if (strstr(buf, "weighted"))
    {
        if (strstr(buf, "yes")) doweight = 1;
        else if (strstr(buf, "no")) doweight = 0;
        else Oops("Error at weighted fit.");
        fprintf(stderr, "\n weighted fit = %s", doweight?"yes":"no");
        set_Wei = 1;
    }
    else if (strstr(buf, "Maximum"))
    {
        if (sscanf(buf, "Maximum visibility: %f", &Vmax)<1)
            Oops("Error at visibility limit.");
        fprintf(stderr, "\n limit = %g m", Vmax);
        set_Lim = 1;
    }
    else if (strstr(buf, "Initialization"))
    {
        if (sscanf(buf, "Initialization: %lf %lf", &(par[0]), &(par[1]))<2)
            Oops("Error at initialization.");
        fprintf(stderr, "\n initialization = (%lg,%lg)", par[0], par[1]);
        set_Ini = 1;
    }
    }
}
fclose(f);
if ( (!set_In) || (!set_Win) || (!set_Par) || (!set_Map)
    || (!set_Cmd) || (!set_Wei) || (!set_Lim) || (!set_Ini))
    Oops("Missing parameter(s).");

/*
// go through the provided list of data (infile)
*/
f = fopen(infile, "rt");
if (!f) Oops("List file not found.");
// skip header
line1[0] = '#';
while (line1[0]!='#')
    if (!fgets(line1, BUFSIZE, f)) Oops("Unexpected end of file.");
// TODO: check presence of parameter
// count items
fgetpos(f, &marker); // set marker
nbIma = 0;
while (fgets(buf, BUFSIZE, f)) nbIma++;

```

```

if (!nbIma) Oops("Empty list.");
fsetpos(f, &marker); // rewind to marker
// printf("\n %d items\n", nbIma);
mor = (float*)malloc(nbIma*sizeof(float));
if (!mor) Oops("Not enough memory for weather data.");
sob = (float*)malloc(nbIma*sizeof(float));
if (!sob) Oops("Not enough memory for sobel data.");
line1[strlen(line1)-1] = '\0';
printf("%s\t<C>\n", line1); // verbose
for (n=0; n<nbIma; n++)
{
    if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of file.");
    // read filename (1st column) and MOR
    strcpy(filename, buf); *(strchr(filename, '\t')) = '\0';
    // printf("\n %s", strrchr(filename, '\\')+1); //debug
    ptr = strchr(buf, '\t');
    for (p=1; p<set_Par; p++)
        ptr = strchr(ptr+1, '\t');
    // printf(" %d", p); //debug
    if ((!ptr) || (sscanf(ptr, "%f\t", &(mor[n]))<1))
        Oops("Could not find parameter.");
    // printf(" %g", mor[n]); //debug
    sob[n] = getVisibilityIndicator(filename, cmdstr, wmin, hmin, wmax, hmax, map);
    buf[strlen(buf)-1] = '\0';
    printf("%s\t%g\n", buf, sob[n]); // verbose
}
fclose(f);

/*
// fit model to data with 'lmfit'
*/
lm_control_struct control = lm_control_double;
lm_status_struct status;
control.verbosity = 0;
X = (double*)malloc(nbIma*sizeof(double));
if (!X) Oops("Not enough memory for weather data.");
Y = (double*)malloc(nbIma*sizeof(double));
if (!Y) Oops("Not enough memory for sobel data.");
p = 0;
for (n=0; n<nbIma; n++)
    if ((vmax==0.0) || (mor[n]<vmax))
    {
        X[p] = (double)mor[n];
        Y[p] = (double)sob[n];
        p++;
    }
/* simple fit
lmcurve( 2, par, p, X, Y, fct, &control, &status );
printf("\n\n C = 2/255 + %lg / ( 1 + %lg / v ) ", par[0], par[1]);
lmcurve( 2, par, p, Y, X, invfct, &control, &status );
printf("\n\n V = %lg / ( %lg / ( C - 2/255 ) - 1 ) ", par[1], par[0]);
*/
// direct fit
data_struct data = { X, Y, fct };
if (doweight)
    lmmin( 2, par, p, (const void*) &data, evalw, &control, &status );
else
    lmmin( 2, par, p, (const void*) &data, eval, &control, &status );
printf("\n\n%swighted fit ", doweight?"yes":"no");
if (!vmax) printf("for all data.");
else printf("for visibility < %g m.", vmax);
printf("Fit status: %s\n", lm_infmsg[status.outcome]);
printf("Nb of iterations: %d\n", status.nfev);
printf("Fitted model: C = 2/255 + A / ( 1 + B / v )\n");
printf("Model parameters: \tA=%g\tB=%g\n", par[0], par[1]);
/*
// inverse fit
data.x = Y; data.y = X; data.f = invfct;
lmmin( 2, par, p, (const void*) &data, eval, &control, &status );
printf("\n\nInverse fit\n %s (%d) \n V = %lg / ( %lg / ( C - 2/255 ) - 1 ) ",
    lm_infmsg[status.outcome], status.nfev, par[1], par[0]);
// inverse weighted fit
lmmin( 2, par, p, (const void*) &data, evalw, &control, &status );
printf("\n\nInverse weighted fit\n %s (%d) \n V = %lg / ( %lg / ( C - 2/255 ) - 1 ) ",
    lm_infmsg[status.outcome], status.nfev, par[1], par[0]);
*/

// clean memory
for (h=0; h<height; h++)
    free(map[h]);
free(map);
free(mor); free(sob); free(X); free(Y);

fprintf(stderr, "\n\n No problemo. \n\n");
return 0;
}

```



```

/*
CAM2 toolbox: DOTST
=====
Object: computes the error between estimated and reference visibility with data selected using
DOSEL.
Syntax: .\dotst tst_in.txt > tst_out.txt
Input: arguments are provided by means of an ASCII file (tst_in.txt). The parameters are
documented in the comments of that file.
Output: the mean and the 90th-centile of the relative error are tabulated for several classes
of visibility.
*/

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <time.h>
#include <sys/stat.h>
#include <math.h>

#define BUFSIZE 2048

/* type for pixel intensity values */
typedef unsigned char uchar;

#define Oops(m) {fprintf(stderr, "\n\nOops! %s\n\n", m); exit(-1);}
#define warn(m) {fprintf(stderr, "\n\nHum... %s\n\n", m);}

void readPFM(char *name, float ***data, int *width, int *height, float *Smap)
{
    /*-----*/
    FILE *f;
    int h, w;
    char buf[256];
    int gotTotal = 0;
    /*-----*/

    f = fopen(name, "rb");
    if (!f) Oops("File not found.");
    fgets(buf, 256, f);
    if (!strstr(buf, "Pf")) Oops("Not a PFM file.");
    while ((fgets(buf, 256, f)) && (buf[0] != '#'))
    {
        if (strstr(buf, "Total"))
        {
            if (sscanf(buf, "# Total: %f", Smap) < 1) Oops("Lambertian map header error.");
            gotTotal = 1;
        }
    }
    // if (!gotTotal) Oops("Lambertian map does not contain its total value.");
    sscanf(buf, "%d %d", width, height);
    fgets(buf, 256, f);
    (*data) = (float**) malloc((*height) * sizeof(float*));
    if (!(*data)) Oops("Not enough memory.");
    for (h=0; h<*height; h++)
    {
        (*data)[h] = (float*) malloc((*width) * sizeof(float));
        if (!((*data)[h])) Oops("Not enough memory.");
        if (fread((*data)[h], (*width) * sizeof(float), 1, f) < 1)
            Oops("Read error.");
    }
    fclose(f);
}

float getVisibilityIndicator(char *filename, char *cmdstr,
    int wmin, int hmin, int wmax, int hmax, float **map)
{
    /*=====*/
    FILE *f;
    char buf[BUFSIZE];
    int width, height;
    int w, h, x, y, imax;
    uchar **image;
    float **sob, dLx, dLy, m, weight, s;
    // use Sobel operator to approximate first derivative
    float Kx[3][3] = {{+0.25, 0.0, -0.25}, {+0.5, 0.0, -0.5}, {+0.25, 0.0, -0.25}};
    float Ky[3][3] = {{+0.25, +0.5, +0.25}, {0.0, 0.0, 0.0}, {-0.25, -0.5, -0.25}};
    float invnorm;
    /*=====*/

    // convert image to pgm file format
    if (!system(NULL)) Oops("Cannot execute command.");
    sprintf(buf, "%s %s tmp.pgm", cmdstr, filename);
    system(buf);

    // read image
    f = fopen("tmp.pgm", "rb");
    if (!f) Oops("Image conversion failed.");
}

```

```

if (!fgets(buf, BUFSIZE, f)) Oops("Empty PGM file.");
if (strcmp(buf, "P5", 2)) Oops("Not a binary PGM file (P5).");
// skip comments
buf[0] = '#';
while (buf[0] == '#')
    if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of PGM file.");
if (sscanf(buf, "%d %d", &width, &height)<2) Oops("PGM header error (size).");
if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of PGM file.");
if (sscanf(buf, "%d", &imax)<1) Oops("PGM header error (max value).");
image = (uchar**)malloc(height*sizeof(uchar*));
if (!image) Oops("Not enough memory for image.");
for (h=0; h<height; h++)
{
    image[h] = (uchar*)malloc(width*sizeof(uchar));
    if (!image[h]) Oops("Not enough memory for image line.");
    if (fread(image[h], width*sizeof(uchar), 1, f)<1)
        Oops("Failed to read image from file.");
}
fclose(f);

// check window
if ((wmin<=0) || (wmax>=width) || (hmin<=0) || (hmax>=height))
    Oops("window should provide 1-pixel border at least.");

// allocate for contrast map
sob = (float**)malloc(height*sizeof(float*));
if (!sob) Oops("Not enough memory for gradient image.");
for (h=0; h<height; h++)
{
    sob[h] = (float*)malloc(width*sizeof(float));
    if (!sob[h]) Oops("Not enough memory for gradient image line.");
    memset(sob[h], 0, width*sizeof(float));
}

// compute contrast (i.e. gradient module / 255 ) map
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
    {
        dLx = 0;
        dLy = 0;
        for (y=-1; y<=1; y++)
            for (x=-1; x<=1; x++)
            {
                dLx += Kx[1+y][1+x] * (float)image[h+y][w+x];
                dLy += Ky[1+y][1+x] * (float)image[h+y][w+x];
            }
        sob[h][w] = sqrt(dLx*dLx+dLy*dLy)/255.;
    }

// locate over- and under-exposed pixels
// to avoid false contrast
/*
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
        for (y=-1; y<=1; y++)
            for (x=-1; x<=1; x++)
                if ((image[h+y][w+x]<5) || (image[h+y][w+x]>250))
                    sob[h][w] = 0;
*/

// Compute weighted mean contrast
m = 0.0; s = 0.0;
for (h=hmin; h<=hmax; h++)
    for (w=wmin; w<=wmax; w++)
        //if (sob[h][w]>0.0)
        {
            // use Lambertian surface map to ponder the contribution of the pixel
            if (!map) weight = 1.0;
            else weight = map[h][w];
            s += weight;
            m += sob[h][w] * weight;
        }
if (s == 0.0) Oops("Zero weight map.");
m /= s;

// clean memory
for (h=0; h<height; h++)
{
    free(image[h]);
    free(sob[h]);
}
free(image);
free(sob);

// normalize so that the total sum of the weight is 1.0 => /Smap
return m;
}

```

```

void sortdata(float **data, int size)
{
    /*=====*/
    int i, j, done = 0;
    float tmp[3];
    /*=====*/

    for (i = 0; (i < size) && !done; ++i)
    {
        done = 1;
        for (j = 1; j < (size - i); ++j)
        {
            if (data[j-1][2] > data[j][2])
            {
                tmp[0] = data[j-1][0]; tmp[1] = data[j-1][1]; tmp[2] = data[j-1][2];
                data[j-1][0] = data[j][0]; data[j-1][1] = data[j][1];
                data[j-1][2] = data[j][2];
                data[j][0] = tmp[0]; data[j][1] = tmp[1]; data[j][2] = tmp[2];
                done = 0;
            }
        }
    }
}

int main(int argc, char **argv)
{
    /*=====*/
    const char * codestr[] = { "Image\0", "Date\0", "Time\0", "SE\0", "BL\0", "VI\0" };
    FILE *f;
    fpos_t marker;
    char buf[BUFSIZE], line1[BUFSIZE];
    char filename[BUFSIZE], infile[BUFSIZE], mapfile[BUFSIZE], cmdstr[BUFSIZE];
    int set_In=0, set_Win=0, set_Par=0, set_Map=0, set_Cmd=0, set_Fct=0;
    char *ptr, date[11], time[9];
    int nbIma, n, p, i, nbV;
    int w, width, h, height;
    int wmin=16, hmin=32, wmax=616, hmax=472;
    float **map;
    float *sob, *mor, *vis, *relerr, **data;
    float Smap, A, B, C;
    float vmax[5] = { 400.0 , 1000.0, 2000.0, 5000.0, 10000.0 };
    float meanerr;
    /*=====*/

    if (argc<2) Oops("Syntax: .\dotst.exe tst_in.txt");

    /*
    // read input parameters from file (argv[1])
    */
    f = fopen(argv[1], "rt");
    if (!f) Oops("Input file not found.");
    set_In = set_Win = set_Par = 0;
    while (fgets(buf, BUFSIZE, f))
    {
        if (buf[0] != '#')
        {
            if (strstr(buf, "selection"))
            {
                strcpy(infile, strrchr(buf, ' ') + 1);
                if ((strlen(infile)<2) || (strlen(infile)>BUFSIZE-2))
                    Oops("Error at selection filename.");
                infile[strlen(infile)-1] = '\0';
                fprintf(stderr, "\n list = %s", infile);
                set_In = 1;
            }
            else if (strstr(buf, "window"))
            {
                if (sscanf(buf, "window: %d %d %d %d", &wmin, &wmax, &hmin, &hmax)<4)
                    Oops("Error at window coordinates.");
                set_Win = 1;
                fprintf(stderr, "\n window = (%d,%d)->(%d,%d)", wmin, hmin, wmax, hmax);
            }
            else if (strstr(buf, "index"))
            {
                if (sscanf(buf, "visibility index: %d", &set_Par)<1)
                    Oops("Error at visibility index.");
                set_Par -= 1;
                fprintf(stderr, "\n parameter = %s", codestr[set_Par]);
            }
            else if (strstr(buf, "Lambertian map"))
            {
                strcpy(mapfile, strrchr(buf, ' ') + 1);
                if (strstr(mapfile, "none"))
                {
                    map = (float**)NULL;
                    Smap = 1.0;
                }
            }
        }
    }
}

```

```

        fprintf(stderr, "\n Lambertian map: none");
    }
    else
    {
        if ((strlen(mapfile)<2) || (strlen(mapfile)>BUFSIZE-2))
            Oops("Error at Lambertian map filename.");
        mapfile[strlen(mapfile)-1] = '\0';
        fprintf(stderr, "\n Lambertian map = %s", mapfile);
        readPFM(mapfile, &map, &w, &h, &Smap);
    }
    set_Map = 1;
}
else if (strstr(buf, "Conversion"))
{
    strcpy(cmdstr, strchr(buf, ' ') + 1);
    if ((strlen(cmdstr)<2) || (strlen(cmdstr)>BUFSIZE-2))
        Oops("Error at image converter path.");
    cmdstr[strlen(cmdstr)-1] = '\0';
    fprintf(stderr, "\n cmd = %s", cmdstr);
    set_Cmd = 1;
}
else if (strstr(buf, "Model"))
{
    if (sscanf(buf, "Model parameters: A=%f B=%f", &A, &B)<2)
        Oops("Error at model parameters.");
    C = 2.0/255.0;
    fprintf(stderr, "\n model: C = %g / ( 1 + %g / V ) + %g", A, B, C);
    set_Fct = 1;
}
}
}
fclose(f);
if ( (!set_In) || (!set_Win) || (!set_Par) || (!set_Map)
    || (!set_Cmd) || (!set_Fct))
    Oops("Missing parameter(s).");

/*
// go through the provided list of data (infile)
*/
f = fopen(infile, "rt");
if (!f) Oops("List file not found.");
// skip header
line1[0] = '#';
while (line1[0]!='#')
    if (!fgets(line1, BUFSIZE, f)) Oops("Unexpected end of file.");
// TODO: check presence of parameter
// count items
fgetpos(f, &marker); // set marker
nbIma = 0;
while (fgets(buf, BUFSIZE, f)) nbIma++;
if (!nbIma) Oops("Empty list.");
fsetpos(f, &marker); // rewind to marker
printf("\n %d items", nbIma); // verbose
printf("\n C = %g / ( 1 + %g / V ) + %g", A, B, C); // verbose
mor = (float*)malloc(nbIma*sizeof(float));
if (!mor) Oops("Not enough memory for weather data.");
sob = (float*)malloc(nbIma*sizeof(float));
if (!sob) Oops("Not enough memory for sobel data.");
vis = (float*)malloc(nbIma*sizeof(float));
if (!vis) Oops("Not enough memory for estimations.");
relerr = (float*)malloc(nbIma*sizeof(float));
if (!relerr) Oops("Not enough memory for estimations.");
line1[strlen(line1)-1] = '\0';
// printf("%s\tC\tV\n", line1); // verbose
for (n=0; n<nbIma; n++)
{
    if (!fgets(buf, BUFSIZE, f)) Oops("Unexpected end of file.");
    // read filename (1st column) and MOR
    strcpy(filename, buf); *(strchr(filename, '\t')) = '\0';
    // printf("\n %s", strchr(filename, '\\')+1); //debug
    ptr = strchr(buf, '\t');
    for (p=1; p<set_Par; p++)
        ptr = strchr(ptr+1, '\t');
    // printf(" %d", p); //debug
    if (!ptr || (sscanf(ptr, "%f\t", &(mor[n]))<1))
        Oops("Could not find parameter.");
    // printf(" %g", mor[n]); //debug
    sob[n] = getVisibilityIndicator(filename, cmdstr, wmin, hmin, wmax, hmax, map);
    // estimate visibility from contrast
    vis[n] = B / ( A / (sob[n]-C) - 1.0 );
    // calculate relative error
    relerr[n] = (vis[n]-mor[n])/mor[n];
    if (relerr[n] < 0.0) relerr[n] = - relerr[n];
    buf[strlen(buf)-1] = '\0';
    // printf("%s\tg\tg\n", buf, sob[n], vis[n]); // verbose
}
fclose(f);

```

```

// Analyze the errors for different classes of visibility
for (i=0; i<5; i++)
{
    // determine the size of the class
    nbv = 0;
    for (n=0; n<nbIma; n++)
        if (mor[n] < vmax[i]) nbv++;
    if (nbv)
    {
        printf("\n<%gm\t%d\t", vmax[i], nbv);
        // initialize data
        data = (float**)malloc(nbv*sizeof(float*));
        if (!data) Oops("Not enough memory for data analysis.");
        for (n=0; n<nbv; n++)
        {
            data[n] = (float*)malloc(3*sizeof(float));
            if (!data[n]) Oops("Not enough memory for data analysis.");
        }
        nbv = 0; meanerr = 0.0;
        for (n=0; n<nbIma; n++)
            if (mor[n] < vmax[i])
            {
                data[nbv][0] = mor[n];
                data[nbv][1] = vis[n];
                data[nbv][2] = relerr[n];
                nbv++;
                meanerr += relerr[n];
            }
        meanerr /= (float) nbv;
        sortdata(data, nbv);
        // for (n=0; n<nbv; n++) printf("%g\t%g\t%g\n",
            data[n][0], data[n][1], data[n][2]);
        printf("%g\t%g", meanerr, data[(int)(0.9*(float)nbv)][2]);
        for (n=0; n<nbv; n++) free(data[n]);
        free(data);
    }
}

// clean memory
for (h=0; h<height; h++)
    free(map[h]);
free(map);
free(mor);
free(sob);
free(vis);
free(relerr);

fprintf(stderr, "\n\n No problemo. \n\n");
return 0;
}

```

Appendix 2: input files

sel_in.txt

```
# Selection of images for computation of Lambertian map
#
# Path
Path ..\..\Data\Trappes
# Time period (yyyy/mm/dd & hh:mm)
Date from 2009/02/27 to 2009/03/01
Time between 00:00 and 23:59
# Range of background luminance (cd/m^2)
Luminance from 50 to 10000
# Range of visibility (m)
Visibility from 5000 to 15000
```

map_in.txt

```
# Input arguments for 'dolamb'
# which computes a Lambertian surface map
# from a list of images and their associated weather data
#
# Data selection (from 'dose1')
Selection: sel_out_map.txt
# Path for image converter
Conversion command: C:\prgm\ImageMagick-6.8.8-7\convert.exe
# Window to process: wmin, wmax, hmin and hmax
Window: 1 638 1 478
# Lambertian indicator: <none>;
# <positive>, <negative> or both <correlation> with parameter;
# <relative> or <absolute> std-dev of contrast
Indicator: correlation
# Correlation parameter: index in the head line of the list (starting at 1)
Parameter index: 5
# Output filename
Save map to: map.pfm
```

cal_in.txt

```
# Calibration of a camera for meteo optical range estimation
#
# Data selection (from 'dose1')
Selection: sel_out_cal.txt
# Path for image converter
Conversion command: C:\prgm\ImageMagick-6.8.8-7\convert.exe
# Window to process: wmin, wmax, hmin and hmax
Window: 16 616 32 472
# Index of VI (visibility) in the head line of the list (starting at 1)
Visibility index: 6
# Lambertian surface map (or "none")
Lambertian map: map.pfm
```

tst_in.txt

```
# Evaluation of image-based visibility estimation
#
# Data selection (from 'dose1')
Selection: sel_out_cal.txt
# Path for image converter
Conversion command: C:\prgm\ImageMagick-6.9.2-Q16\convert.exe
# Window to process: wmin, wmax, hmin and hmax
Window: 16 616 32 472
# Index of VI (visibility) in the head line of the list (starting at 1)
Visibility index: 6
# Lambertian surface map (or "none")
Lambertian map: map.pfm
# Model:  $C = A / (1 + B / V)$  + 2/255
Model parameters: A=0.028 B=600
```


Appendix 3: output files

sel_out.txt

```
# Selection parameters:
# Path = ..\..\..\Trappes
# Location: N 48.773586 , E 2.009236
# Time period: 2009/02/25 (09) to 2009/02/25 (09)
# 10:00 <= T <= 23:59
# 500 <= L (cd/m2) < 19999
# 5000 <= V (m) < 59999
Image                               Date       Time       SE        BL        VI
..\..\..\Trappes\2009\09\20090225100032.jpg 2009/02/25 10:00:32 26.1081 5496 17810
..\..\..\Trappes\2009\09\20090225101032.jpg 2009/02/25 10:10:32 27.0167 5250 17700
..\..\..\Trappes\2009\09\20090225102032.jpg 2009/02/25 10:20:32 27.8621 5628 16780
[...]
..\..\..\Trappes\2009\09\20090225165033.jpg 2009/02/25 16:50:33 5.2689 1377 11750
..\..\..\Trappes\2009\09\20090225170033.jpg 2009/02/25 17:00:33 3.71216 918 12330
..\..\..\Trappes\2009\09\20090225171033.jpg 2009/02/25 17:10:33 2.13842 535 14400
```

cal_out.txt

```
¶
Fit status: converged (the relative error in the sum of squares is at most tol)
Nb of iterations: 22
Fitted model:  $C = 2/255 + A / (1 + B / V)$ 
Model parameters: 0.024186 655.347
```

tst_out.txt

```
¶
127 items
¶
<400m      14      0.117213    0.222361
¶
<1000m     20      0.164149    0.429698
¶
<2000m     28      0.168166    0.429698
¶
<5000m     60      0.435414    0.587996
¶
<10000m    90      0.694271    1.77147
```