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1 User Information

Thank you for purchasing the Cloud Base Height Software. Make sure to read this instruction manual thoroughly and to understand the contents before starting to operate the instrument. Keep this manual at safe and handy place for whenever it is needed.

For any questions, please contact us at the CMS office given below.

CMS reserve the right to make changes to specifications without prior notice.

1.1 Warranty

For warranty terms and conditions, contact CMS or your distributor for further details.

CMS guarantees that the product delivered to customer has been verified, checked and tested to ensure that the product meets the appropriate specifications. The product warranty is valid only if the product has been installed and used according to the directives provided in this instruction manual.

CMS shall in no event be liable for incidental or consequential damages arising from the faulty and incorrect use of the product.

In case of any manufacturing defect, the product will be repaired or replaced under warranty.

However, the warranty does not apply if:

Any modification or repair was done by any person or organization other than CMS service personnel.

The damage or defect is caused by not respecting the instructions of use as given on the product brochure or the instruction manual.

1.2 Contact Information

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2 Findclouds Software

The Findclouds software evaluates images of the sky and calculates the cloudiness. Especially it was designed for the Total Sky Camera J1006 using a fisheye lens for whole-sky images.

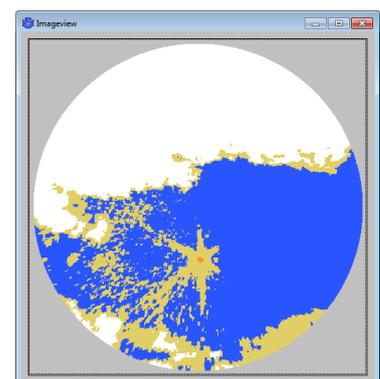
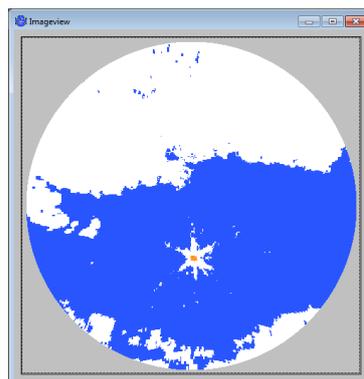
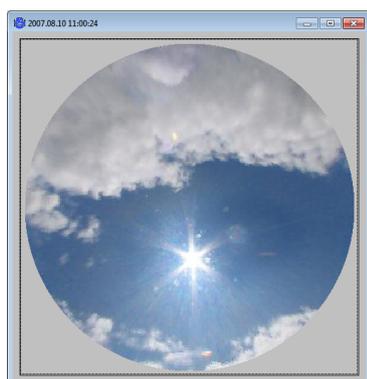
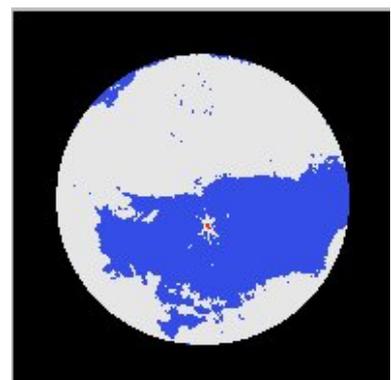
Evaluations of the total sky images by the analysis software may be done online on automatic mode or afterwards for campaign based data sets. This new software allows classifying the clear sky, the total hemispheric cloud cover, optically thick and thin clouds, the cloud cover of the free horizon or the cloud cover above an artificial horizon. In addition the presence of the direct sun is detected. If the natural horizon is not yet known, the software calculates it by drag-and-drop. All analysed data are stored as ASCII data including pictures for additional investigations.

The cloudiness tells, how much the sky is covered with clouds, using a number from 0.00 for cloudless sky to 1.00 for completely clouded sky. Normally the cloudiness is estimated by a meteorologist - the Findclouds software reduces the necessary individual manpower for analysis of the cloudiness.

The camera can operate in a high dynamic intensity range to be able to analyse the sky area near the sun.

Using a high dynamic intensity range out of the combination from a normal exposed and an underexposed image, the software is able to analyse the area near the sun and to tell, whether there was the sun visible or not. Nevertheless also when analysing a single image the software provides algorithms to tell about cloudiness and sun visibility.

In example these are pictures of normal and underexposed sky. The final evaluation with equalised range shows thin clouds, thick clouds and red marker on sun position.



2.1 System Requirements

2.1.1 Hardware Requirements

The software uses less than 10 MB hard disk space.

2.1.1.1 Operating-System-Requirements

MS-Windows-Version: Windows 2000, Windows XP, Windows Vista, Win7, Win8.

Linux-Version tested for current distributions of CentOS, Fedora, Debian, Ubuntu. Using other distributions, it might be necessary, to install missing libraries, or to start software using distributed libraries. There is no source code delivered, just the binary files.

Also there is no Linux installation software, only a Linux directory on install CD, including required Linux files and a "readme" file.

2.1.1.2 General Requirements

For view of PDF manual there must be a pdf-viewer installed and the file extension ".pdf" should be assigned to this viewer.

2.1.1.3 Program Files

"Program files" are permanent files, that won't be changed after installation, except of an update. So these files can be installed by the administrator in a protected read only directory.



The recommended name of the installation directory is "**findclouds**" and inside of this directory there is a subdirectory "**prg**" for program core files. This is a standard structure for CMS software and often beside from "prg" there are other directories.

Program core files are:

clouddir.sys - link file to the associated data directory, it contains simply the path

findclouds.exe - the executable software

Manual_findclouds.pdf - the manual

That's all, the software doesn't need additional dll-files and doesn't use the registry, all installation is done inside of "findclouds" directory and no windows system is affected.

2.1.1.4 Data Files

The program utilizes the images of the Total Sky Camera and managed by Cloudcam Control software.

The format of filenames is defined

"YYYYMMDDHHMMSS_ext.jpg". "YYYYMMDD" means date of photo (Year, Month, Day) and "HHMMSS" means time of photo (Hour, Minute, Second) specified in UTC time. "ext" is additional information about image type and the software only recognises and evaluates JPEG files with extension ".jpg".

The software works with a predefined directory structure:

The screenshot on right side shows a typical Cloudcam data directory. It contains directories for the Cloudcams, like "ccam_01051, ccam_01183,..." and the directory "system" for Cloudcam Control configuration, which now is also in use for Findclouds configuration

"findclouds.cfg".

Every Cloudcam directory contains directories for the days and again a "system" directory, containing log files of the Cloudcam and the Cloudcam configuration file (e.g. ccam_01000.cfg) created by software Findclouds.

Inside of the "days" directories the Findclouds software creates an additional directory "evaluations" for the processed images and the text file of evaluated cloudiness. The processed images take filename of original file, but there are additional extensions to specify kind of evaluation:

_BRBG is an evaluation using the blue/red and blue/green ratio of the image

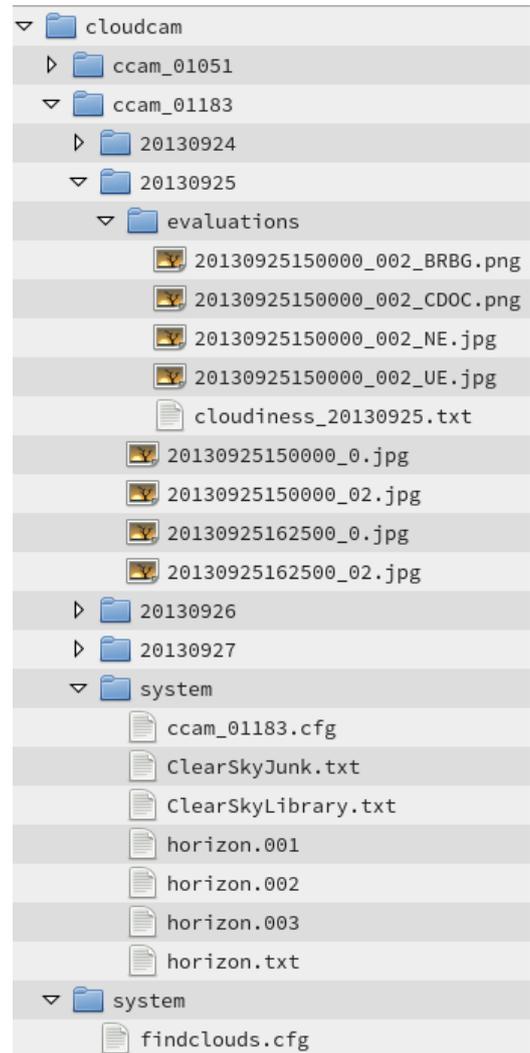
_CDOC is an evaluation using the cloud detection and opacity classification algorithm

_NE is the projection of the normal exposed image, first step of evaluations

_UE is the projection of the underexposed image

The path to the root directory "cloudcam" is defined by file "clouddir.sys" inside of the Findclouds program directory "findclouds/prg".

When there is no such directory structure provided, the software is able to use custom defined directories: When the software doesn't find "ccam" directories by using the "clouddir" root directory, it tries to find "days" directories and shows them. So when there is a customer specific named directory containing sky images, it is possible to start the software with this directory by entering it to "clouddir.sys". Anyway, when there is not a know directory structure, the configuration file won't be saved in an additional "system" directory, but inside of the given "days" root and it will be



named just "ccam.cfg", because there is no camera number known.

In addition to add several custom defined directories by use of main menu "Add Custom Image Folder". These directories won't be saved to "clouddir.sys", but the software saves them inside of the user-interface configuration "findclouds.cfg". The number of the custom directories is restricted by lowest number of Cloudcam, so normally it is possible to define up to 1000 custom directories.

2.1.1.5 Evaluation files

The table of evaluations, shown by the main window, also can be written as evaluation file. The title of these files is "cloudiness_" and the date of evaluation, e.g. "cloudiness_20150911.txt". The title doesn't contain the Cloudcam number, because it already is assigned to a Cloudcam by directory.

The columns are:

date the date of the evaluation. This column is not necessary, but results from the possibility, to show evaluations of several days in the main window table.

time the time the evaluated photos were shot.

Ext the merged extensions of the evaluated photos. When the evaluation results from one photo with extension "0" this results to "0", when the evaluation results from two photos with extension "0" and "02", this results to "002".

BRBG the total cloudiness evaluated with BRBG algorithm.

CDOC the total cloudiness evaluated with CDOC algorithm.

thick the cloudiness caused by thick clouds evaluated with CDOC algorithm.

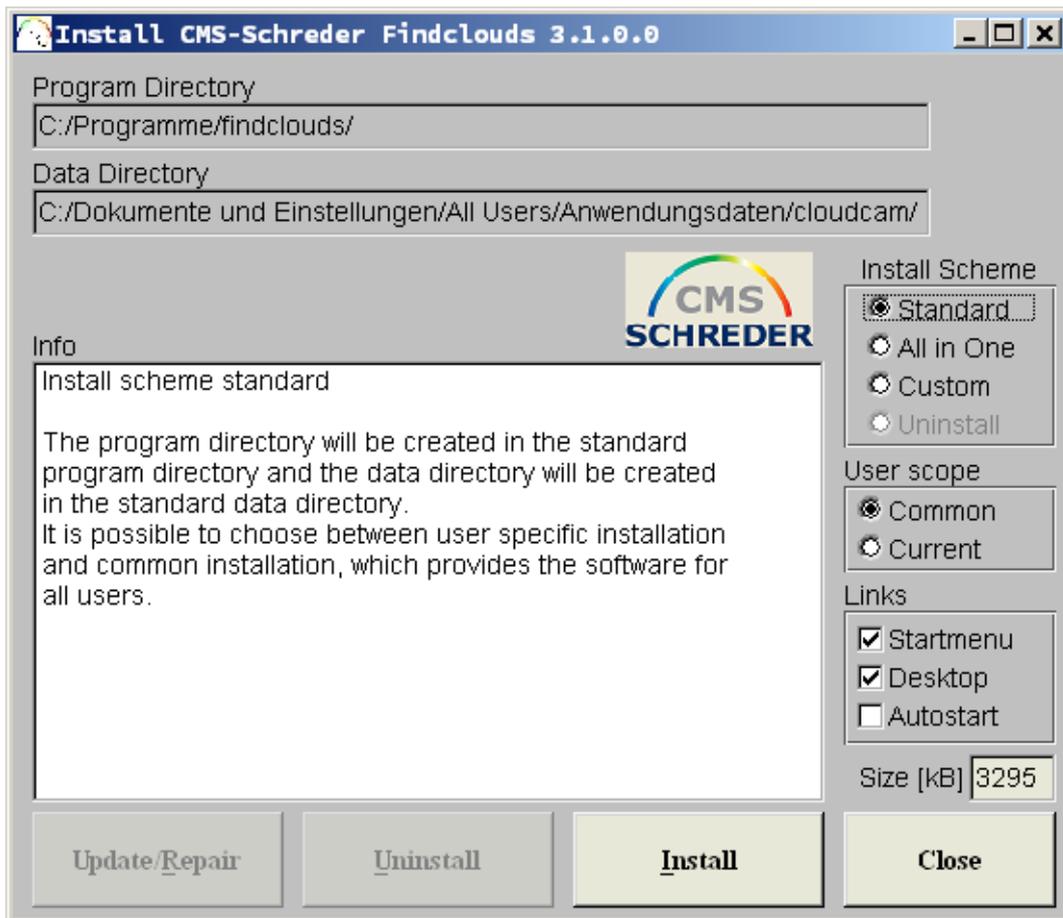
thin the cloudiness caused by thin clouds evaluated with CDOC algorithm.

sun is a number that shows visibility of the sun. These numbers are listed at the end of chapter "sunpixel evaluation"

%[yyyymmdd] [HHMMSS]		Relative Cloudiness					
%date	time	Ext	BRBG	CDOC	thick	thin	sun
20150911	085000	002	0.27	0.67	0.30	0.37	0
20150911	090000	002	0.48	0.71	0.58	0.13	0
20150911	091000	002	0.46	0.77	0.69	0.08	0
20150911	092000	002	0.75	0.92	0.92	0.00	0
20150911	093000	002	0.89	0.93	0.93	0.00	0
20150911	094000	002	0.73	0.82	0.77	0.05	0
20150911	095000	002	0.33	0.67	0.32	0.35	0
20150911	100000	002	0.10	0.62	0.03	0.59	0

20150911	101000	002	0.07	0.53	0.01	0.52	1
20150911	102000	002	0.08	0.79	0.00	0.79	0
20150911	103000	002	0.08	0.68	0.00	0.68	0
20150911	104000	002	0.07	0.69	0.00	0.69	1
20150911	105000	002	0.09	0.70	0.00	0.70	0

2.2 Software Installation



Installation software for installing the Findclouds Software to MS-Windows. This window appears, when you insert the install CD to your computer and press **[Install]**.

"Program Directory" shows the target of installation and **"Data Directory"** shows the directory, that will be used for configuration files and where existing Cloudcam images are saved.

"Info" list shows progress of installation and when it is finished, you can close this window and start Findclouds software by desktop link or start menu.

2.2.1 Install schemes

For customized installations, there are three basic installations schemes "Install Scheme":

2.2.1.1 Install scheme standard

The program directory will be created in the standard program directory and the data directory will be created in the standard data directory. It is possible to choose between user specific installation and common installation, which provides the software for all users. You can choose this also on right-hand side by "User scope".

The program directory and the data directory are placed in different locations and the administration of access rights is considered automatically. The user doesn't need to be administrator, because all of the files and directories, that will be changed or created new, are in scope of users access rights.

2.2.1.2 Install scheme all in one

The program directory and the data directories will be in a common installation directory "Findclouds". This is the most easy way to handle software and data e.g. for backups, but it is necessary to set user privileges for access of data directory or login as administrator. It is possible to choose another target directory than suggested, but the final installation directory is hard coded for "Findclouds". So it's a choice of basic directory, e.g. "c:\" for installation of "c:\Findclouds" or "d:\CMS" for installation of "d:\CMS\Findclouds".

2.2.1.3 Install scheme custom

The program directory and the data directory can be chosen before installation. The user must be administrator or access rights for users must be set by the administrator.

2.2.1.4 Links

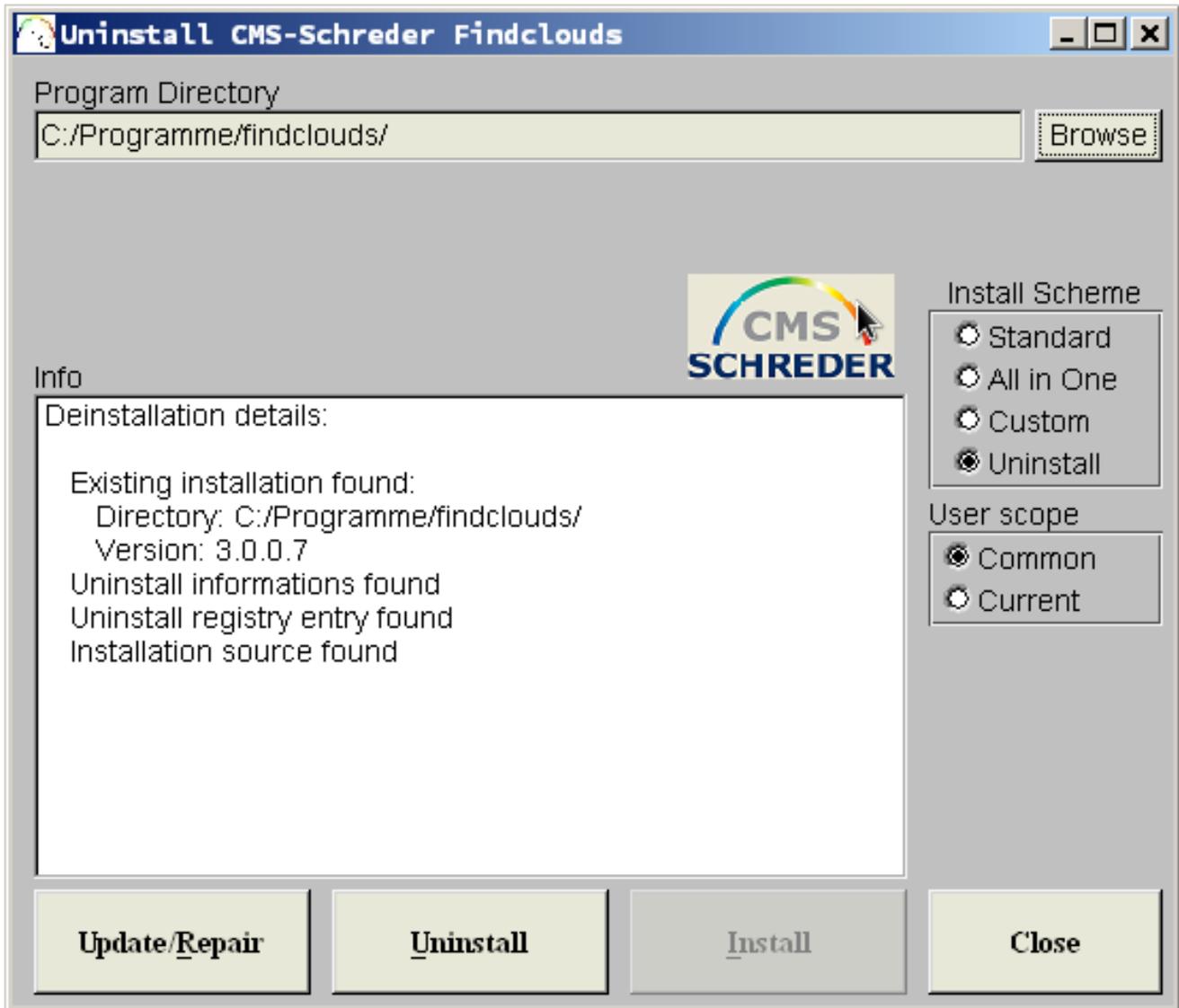
Before installation it is possible to configure the links to be created:

Default is to use the **Start menu** to create a new entry [Start] -> [Programme] -> [Findclouds] which contains links to the software and documentation.

Also there is a **Desktop** link default, for quick start of software by double click on Desktop icon.

The **Autostart** link can be activated to start the software automatically when the operation system starts.

The install software will appear like this, when there was an existing version of the software found. By using the buttons it is possible to [Update] the existing software, or to uninstall it. Also it is possible to set the Install Scheme from "Uninstall" to an installation scheme for installing the new version besides the existing version. But this is not recommended, because it can cause problems regarding to double links and uninstall information.



2.2.2 General functions

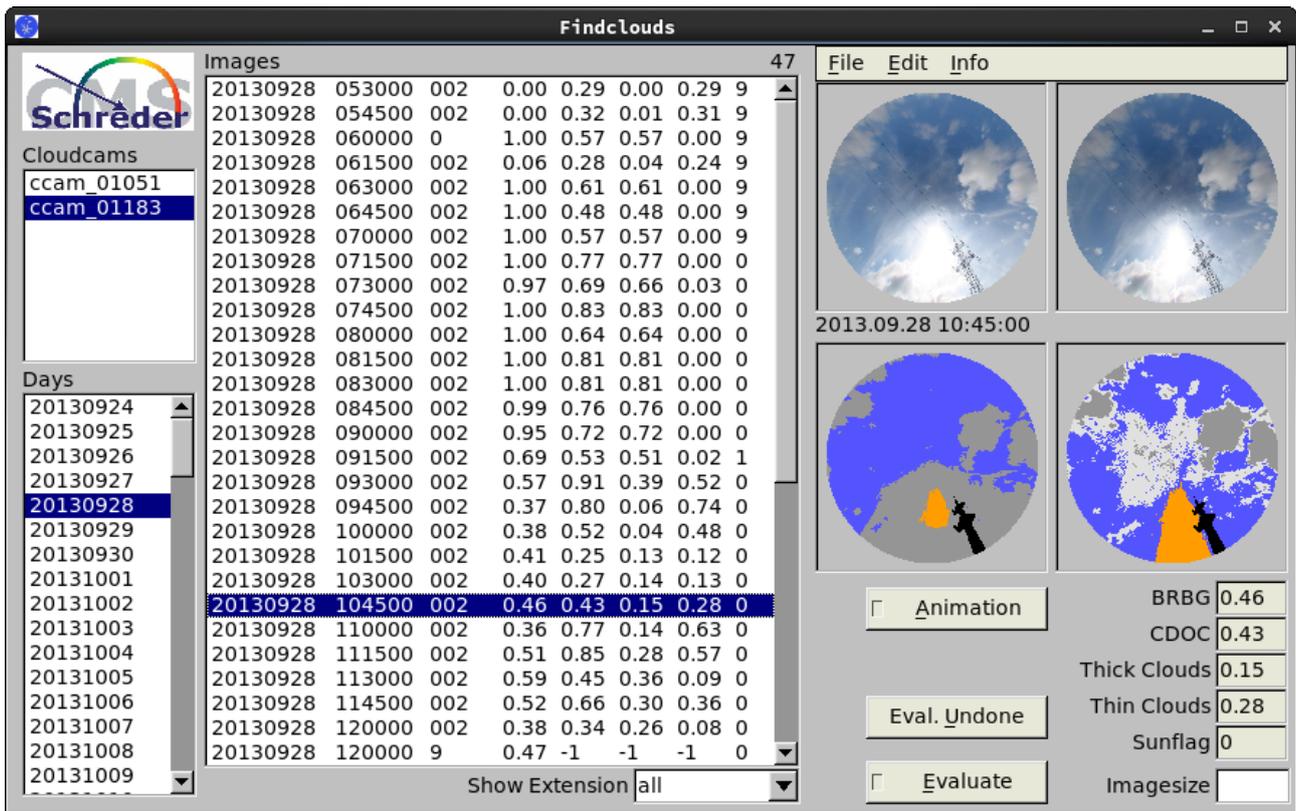
[Install] starts the installation to the shown target directories.

[Uninstall] uninstalls the software.

[Update/Repair] overwrites the existing installation by the current version.

[Close] terminates the installation software without processing anything else.

2.3 Main Window of Findclouds Software



Through the main window images can be selected for evaluation. Additionally it shows the results of evaluation in a table of values and the converted images.

In the top left, the browser "**Cloudcams**" is used to select a camera (it is possible to choose more than one). The software automatically reads in the list of "Days", provided inside of the camera directory. The selected camera also defines, which configuration file will be used. This file is named by the number of the camera, e.g. "ccam_01000.cfg" and will be saved into the "system" directory of the concerning camera.

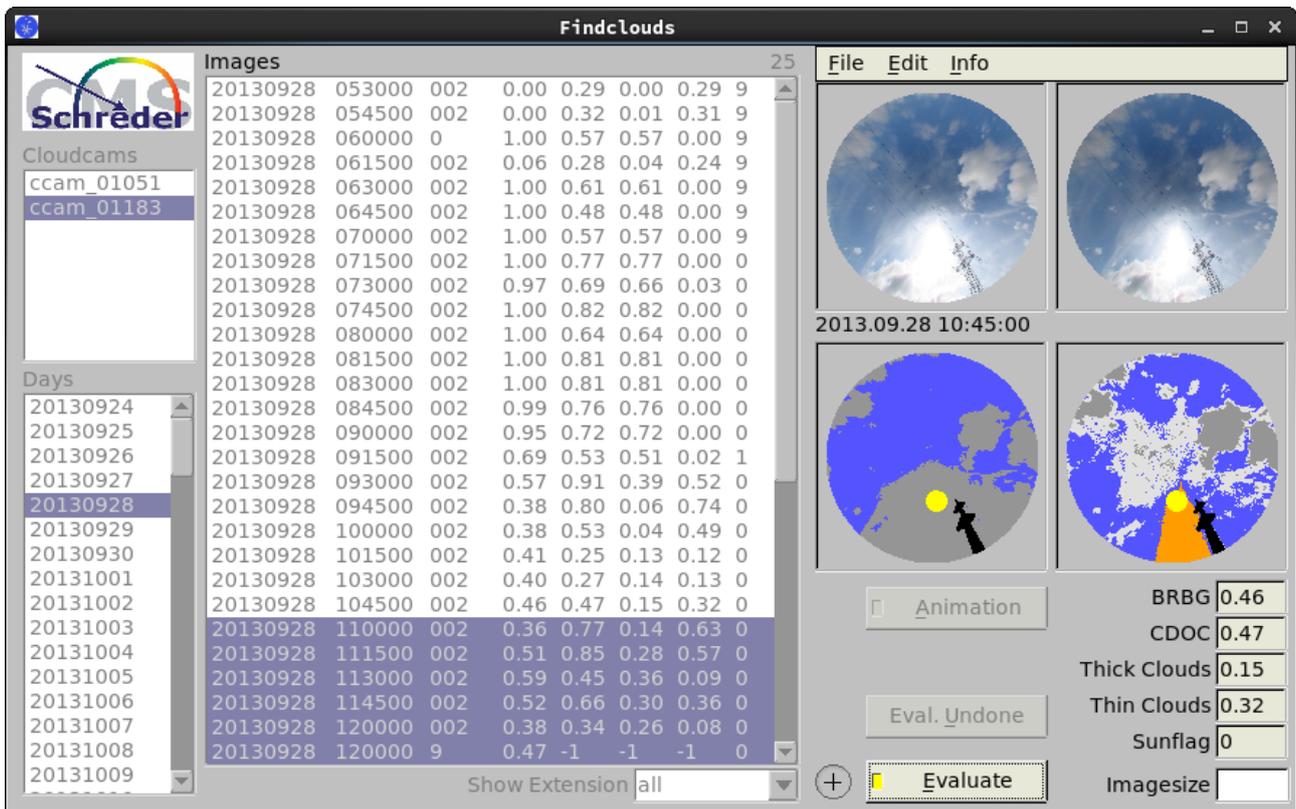
This is meant for the standard directory structure used by camera control software "CMS Cloudcam Control". When there is a different structure by customer, the software will use basic data directory for "custom" directory and show Days out of the basic data directory. Be aware that software only reads in directories in default format "YYYYMMDD" and will ignore other names.

The menu entry "File -> Add Custom Image Folder" is used to add more custom directories to "Cloudcams" browser. For evaluation of these directories, there is a configuration file necessary and the software doesn't use a default file, but saves the configuration to the current custom directory (no "system" directory is used!). This way the configuration file will be named "ccam.cfg" without a camera number - different custom configurations only differ in directory path.

Inside of the "**Days**" browser it is possible to select one or more days and the software will read out these directories and insert all ".jpg" files to browser "Images". You can select one directory by

clicking on its entry and add one or more directories by holding the "Ctrl" key. It is possible to add a block of directories by clicking to the first entry, holding the "Shift" key and clicking to the last entry. To add several different blocks, you must click to the first entry, hold the "Shift" key and click the last entry of first block, then release "Shift" key, hold "Ctrl" key and click to first entry of the second block, release the "Ctrl" key and hold the "Shift" key to click to last entry of second block, and so on.

The "**Images**" browser shows all ".jpg" files found in selected directories of days. The file names are splitted into date, time and level of exposure and the filename format of "YYYYMMDDHHMMSS_Ext.jpg" is mandatory given. When a pair of exposure levels is defined in configuration (e.g. "0" and "02") the software groups these files and shows them as one, but with grouped extensions. For evaluation the files can be selected the same way told above for "Days" browser, but additionally they all will be evaluated, when none is selected. The software doesn't care if a file was evaluated before, but evaluates all selected files.



When evaluation is started by button **[Evaluate]** the browsers and some buttons will be deactivated to prevent software from crashing by removing files being in evaluation. Anyway change of day/ Cloudcam will remove current evaluations from the image browser. While evaluating, the numeric results will appear in columns of "Images" browser.

The processed images will be shown on right side of the window - first the projected normal exposed and underexposed image, second the simplified images the cloudiness was calculated from.

It is also possible to save evaluations to hard disk and when there is a save option activated (see

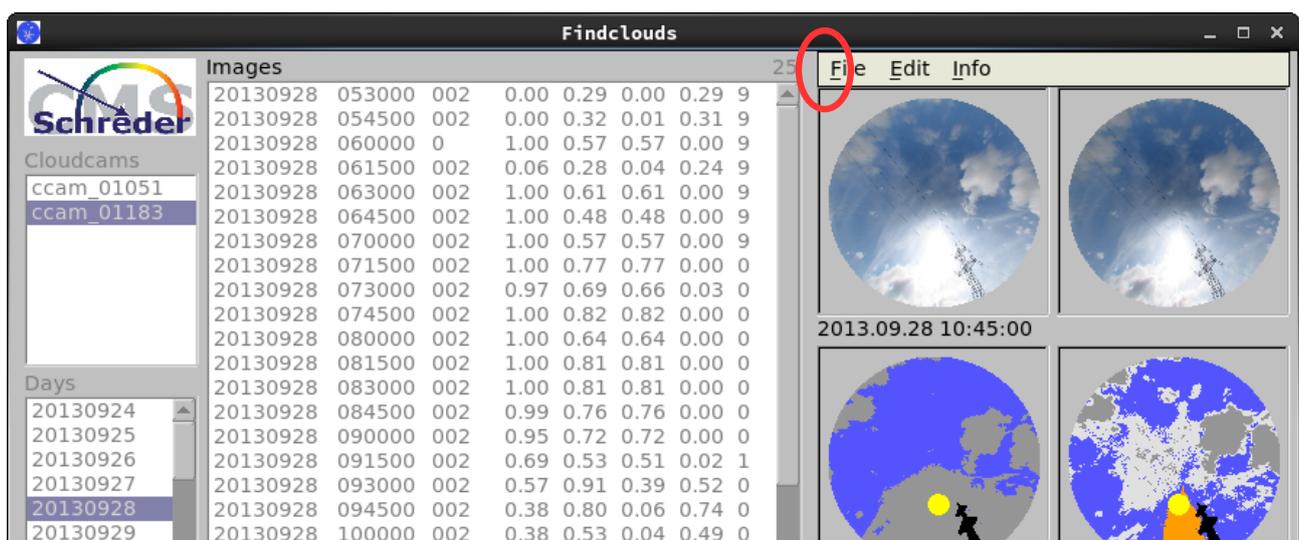
"User Interface") the software will create a new directory "evaluations" inside of each selected "days" directory.

[Animation] starts animation by going through all images preset by [Memorise Image], [Show Preview] or [Show Images] (see "User interface"). When active there appears a slider to control rate of animation. When using [Show Preview] or [Show Images], each image will be loaded just in time and will cause a lot of hard disk usage. It is not recommended to keep the software running in these modes for a long time.

[Eval. Undone] checks all cloudcam and days directories for images, that are not listed in the files of evaluated cloudiness and evaluates them. When there are a lot of directories, this function may last for some time.

[Imagesize] overwrites configuration value of desired image size for current evaluation. When this entry is empty, the value of the configuration will be used.

2.4 Overview of menu items



"File"

"Show Curves" opens graphical display of cloudiness evaluations for selected Cloudcam.

"Hide Curves" closes all graphical displays of cloudiness.

"Clear Evaluations" deletes the evaluation files of selected days.

"Clear Evaluation Images" deletes the evaluation images of selected days.

"Clear GUI Sizes" resets position and size of the windows to original values.

"Add Custom Image Folder" adds a directory that doesn't match to the Cloudcam directory scheme.

"Remove Custom Image Folder" removes the selected custom image folder from the list but not from the hard disk.

"Quit" closes all open Findclouds windows and quits the software.

"Edit"

"Configuration Userinterface" opens a dialogue to change user-interface settings.

"Configuration Cloudcam" opens a dialogue to change basic settings for selected Cloudcam.

"Configuration Evaluation" opens a dialogue to change evaluation settings for selected Cloudcam.

"Sky Library" opens a dialogue to administrate Clear Sky Images for selected Cloudcam.

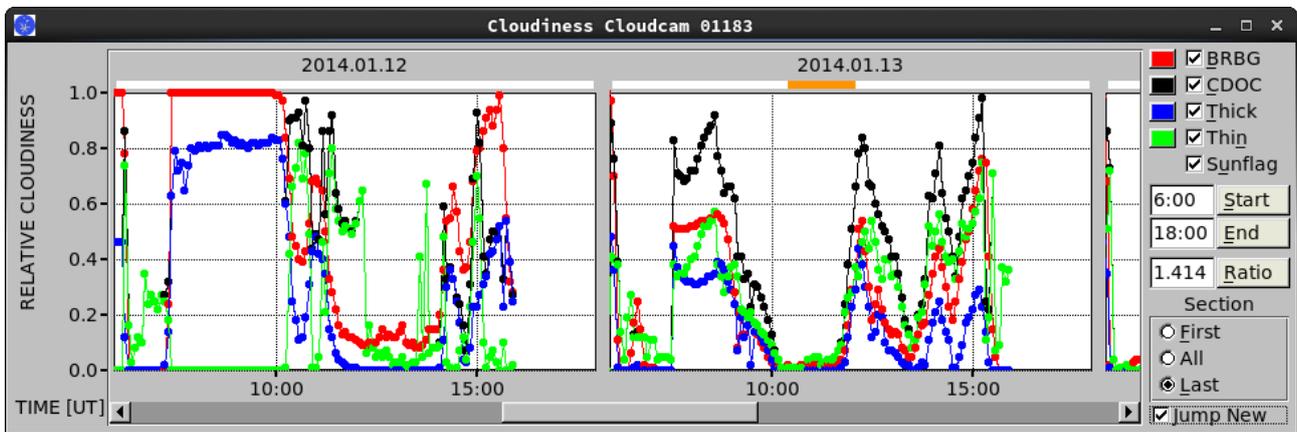
"Basic Image Folder" makes it possible to change the basic path to image folders.

"Info"

"Info" shows informations about the software.

"Help" calls this manual.

2.5 Show Curves – Display of Cloudiness



This dialog shows the daily evaluation files (e.g. "cloudiness_20140113.txt") as graphical line plot, to provide a better overview of cloudiness changes. This is much more demonstrative than viewing the table of cloudiness values.

As a matter of principle the display only shows selected days. Showing all days normally would take too much drawing time. When at least one display is opened ("Show Curves"), the software knows that selected days are desired to be shown and opens more displays, when days of another Cloudcam will be selected. Because this can cause a lot of open displays, in menu of main window there is an option to close them all at once ("Hide Curves").

As shown above each day gets an own drawing area and it is possible to scroll to the left or to the right for viewing single days. The example above doesn't show the original size of the window, but an enlargement to show more than one day at a time. Every display can be resized and positioned to match better to screen area and chosen range and will store its position and size.

On right-hand side of the display there are some options for configuration. They are the same for displays of different Cloudcams.

At first it is possible to activate or deactivate the plot of different types of cloudiness evaluation (BRBG, CDOC, Thick, Thin) and to set their colours. The "Sunflag" option shows or hides the white band on top of the drawing area, which shows visible sun in colour of sunpixel. This is the colour out of the user-interface configuration, to make the colours more consistent.

"Start / End" Next comes the input of the time range to show. It is possible to enter times in format "HH:MM" and to take them over by [enter] key or by pushing the button beside the input. When there is no time given, the software will take the time range out of the evaluation data. Also it is possible to enter just begin or end and the software will calculate the missing value of time range.

The **"Ratio"** input sets the aspect ratio of the drawing area the way, that width will be ratio * height. The example value of "1.414" is the DIN ratio of paper, larger values will stretch the drawing area, e.g. to show lots of values better.

"Section" deals with a special problem: When repeating evaluations the results will be appended at the end of the list (won't overwrite former evaluations). The software recognises these sections, because normally a time jump back shows beginning of a new line plot. When there are several plots inside of a daily evaluation, the "Section" offers a simple way of selection, by showing just the first, the last or all plots.

"Jump New" makes the plot follow an ongoing evaluation, when activated.

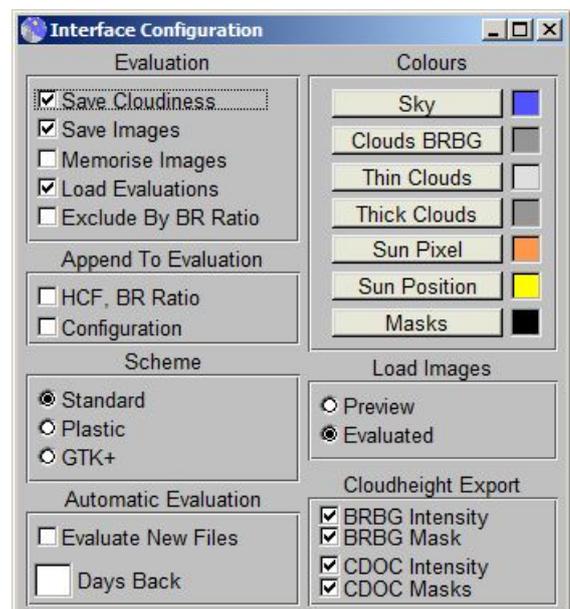
2.6 Configuration Userinterface

"Evaluation"

[Save Cloudiness] activates saving of numeric values to a text file. The text file will be named by the correspondent directory/date, e.g.

"cloudiness_20070810.txt" and will be saved into correspondent evaluations directory. It's an ACSII file and the columns are separated by tab character '\t'.

When opening the file using a spreadsheet program this will cause accurate tabulated columns. The software appends new evaluations to the existing file, so it is possible to add evaluations without losing existing values.



[Save Images] saves the processed images to the evaluations directory of correspondent date

when activated. The software will overwrite existing images when repeating the evaluation. The images will be named by date, time and the following extensions:

"NE" ... extension for normal exposed origin image.

YYMMDDhhmmss ... Year Month Day hour min sec

"UE" ... extension for underexposed origin image.

"BRBG" ... extension for simplified cloudiness evaluation using BRBG algorithm.

"CDOC" ... extension for simplified cloudiness evaluation using CDOC algorithm.

[Memorise Images] When activated the software keeps the images shown on top right side of the window in memory. This way you can click to evaluated lines and the correspondent images will be shown. When this option is not activated, the images will only be shown once and will vanish, when a new image was computed, or the line of evaluation was changed.

This option is meant to prevent the memory from being flooded by images, when a lot of files is evaluated. There is no relation to option [Save Images]. Be aware, that view options (see below) can override showing of memorised images.

[Load Evaluations] loads existing evaluations to the image list of main dialogue when activated. Otherwise this list will show only current evaluations.

[Exclude By Ratio] activates an analysis of the Blue/Red ratio before evaluation. When the minimal red blue ratio is equal to 1.0, probably it is not possible to evaluate this image and the software ignores it. Exclusion by colour ratio is shown as "-2" in the results of the evaluation of cloudiness.

"Append To Evaluation"

allows to append additional evaluation data to the line of cloudiness evaluation.

[HCF, BR Ratio] adds HCF value and the Ratios Blue/Red_{min}, Blue/Red_{mid} and Blue/Red_{max} to the line. A minimal BR ratio of 1.0 often is evidence that it is not possible to evaluate the image.

[Configuration] adds the current values of evaluation settings to the line. This is helpful to control the effect of altered settings.

"Scheme"

changes style of the software into another look. Changes of scheme need a restart of the software to take effect.

"Automatic Evaluation"

[Evaluate new files] causes the software to control the Cloudcam directories for newly created images and evaluate them.

[Days Back] With "days back" of zero it controls the directories of the current date. With a higher

number controls directories back for days of the specified number. E.g. if date is 04. and number of days back is "2" the software will recognise new images for dates 02., 03., 04.

"Load Images"

[Preview] if activated, the main dialog shows original images of selected image entries.

[Evaluated] will load processed images, when there are some. Otherwise also the original images will be shown.

"Cloudheight Export"

[BRBG Intensity] causes the software. to export the BRBG evaluation as a grayscaled intensity picture, where the sky parts are set to zero.

YYYYMMDDhhmmss_brbg_intens.png

[BRBG Mask] causes the software to export the mask that was used, to mask out the sky parts of the BRBG intensity picture.

YYYYMMDDhhmmss_brbg_mask.png

[CDOC Intensity] causes the software to export both CDOC evaluations (Thick, Thin) as a grayscaled intensity picture, where the sky parts are set to zero.

YYYYMMDDhhmmss_thik_intens.png

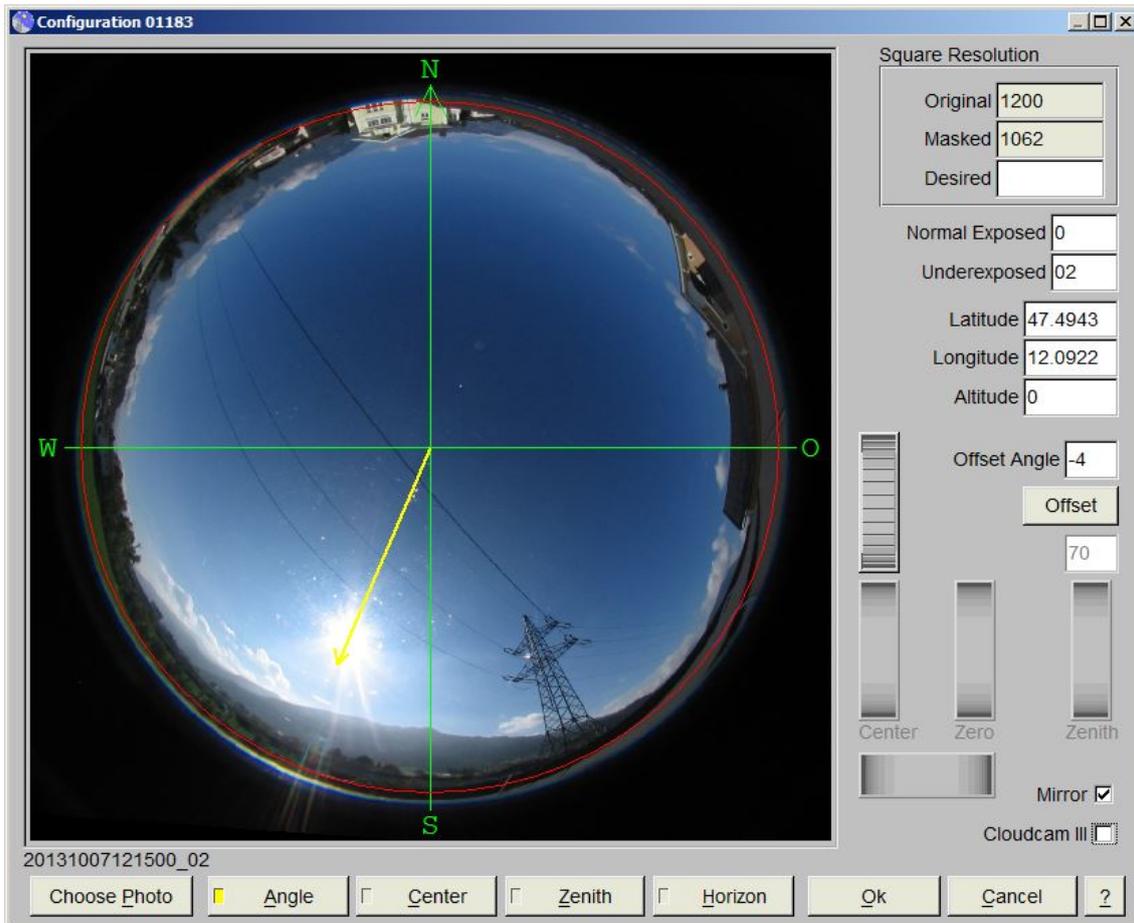
YYYYMMDDhhmmss_thin_intens.png

[CDOC Mask] causes the software to export the masks that were used, to mask out the sky parts of the CDOC intensity pictures.

YYYYMMDDhhmmss_thik_mask.png

YYYYMMDDhhmmss_thin_mask.png

2.7 Configuration Cloudcam



This is the start window of Cloudcam configuration dialog. For each Cloudcam in use there must be a configuration file for definition of the Cloudcam characteristics. There are some basic options, that can be changed at once by filling in values. Some options, that belong to the images made, are deactivated and for better control these options can only be changed, when a Cloudcam image was load. This way provides a direct verification of specified values, because they are applied to a real example.

Square Resolution

The Cloudcam uses a fisheye lens ("whole-sky lens") which takes a circular image near the middle of the rectangular photo. Because of that, both sides of the image are unused black areas, which can be cut off, resulting in a square image with same width as height. But also this image contains a lot of unused black areas. So configuration allows to define a "zero circle" that covers just the fisheye area and allows software to cut image into best detail.

"Original", "Masked" When there was an example image loaded, the "Original" resolution (original height) and the "Masked" resolution (the image is cut to) is shown.

"Desired" To speed up evaluation it is possible to reduce resolution one time more by setting a

"Desired" resolution. When the masked resolution exceeds the desired resolution, the software will scale the image down to desired resolution. Also when there are images with different resolutions this can be useful to get normalised images with the same size. When there is no desired size given (by empty input) the masked size will be used.

Normal Exposed/ Underexposed

The extensions to identify images that belong together for high dynamic evaluation by normal exposed and underexposed image. This way of evaluation causes a better evaluation of the area near the sun. Please be aware not to fill in the separative underscores - they don't belong to the extension.

Latitude / Longitude / Altitude

These values specify the position of the Sky Imager They are necessary to calculate the position of the sun, when evaluating the "near sun area" by underexposed images. When the position is not known, e.g. "Google Maps" could be used to find out, where the Cloudcam is placed.

[Mirror], when activated, the software mirrors the image when loading it. This changes the "upward looking" image to a "ground based image", as if the point of view is changed from ground to above the clouds. The new CMS All Sky Imager provides images, that are already mirrored, so this option must be deactivated, when "ground based images" are desired and ASI is in use.

[ASI] activates a non-linearity equalisation for the new CMS All Sky Imager. While the fisheye Images of the Cloudcam follow a strict linear ratio of angle to distance on image, there is a distortion on ASI images, that needs to be equalised.

[Choose Photo] loads an image made by the current Cloudcam. This image must be used for further adjustments and will activate buttons **[Center]** and **[Zenith]** when it was loaded successful.

[Angle] will switch to adjustment of the Cloudcams offset angle.

[Center] will switch back to adjustment of centering and calibration of fisheye area and deactivate accentuated contrast. It allows to centre up the image and adjust size of fisheye area.

[Zenith] will switch back to adjustment of offset angle and show not equalised image without field of view circle.

[Horizon] window for input of horizon.

[OK] saves changes and closes the window.

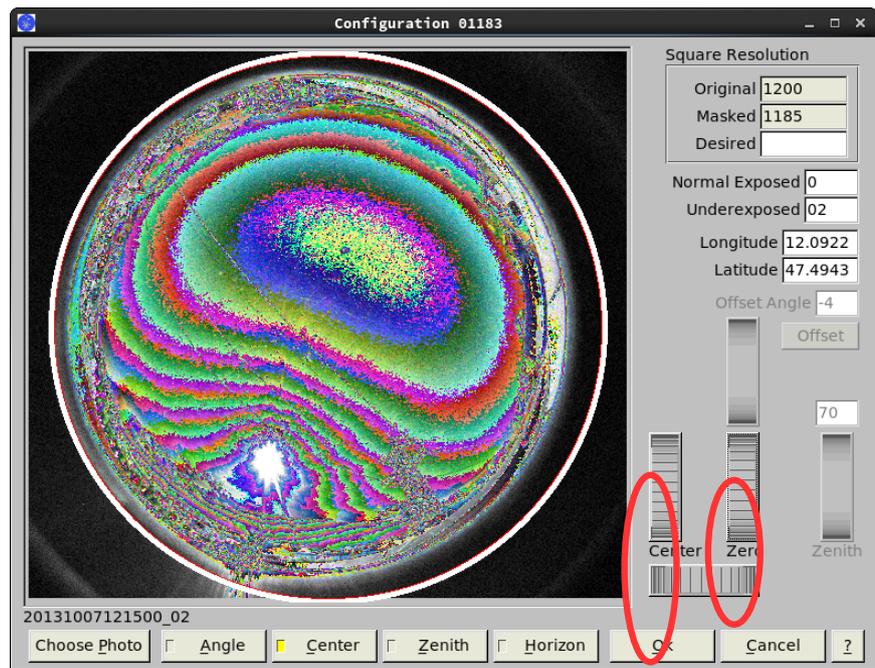
[Cancel] closes the window without saving changes, but asks for saving, when there are unsaved changes.

[?] calls the predefined internet browser to open this help file.

2.7.1 Centring and calibration of fisheye area

This screenshot shows mode for centring and adjusting size of fisheye area.

The image is shown with accentuated contrast, because normally the border of the fisheye area is dark and not easy to differentiate from unused black area. This way it is easy to see, where the real photo ends and a corona begins, which doesn't belong to the image.

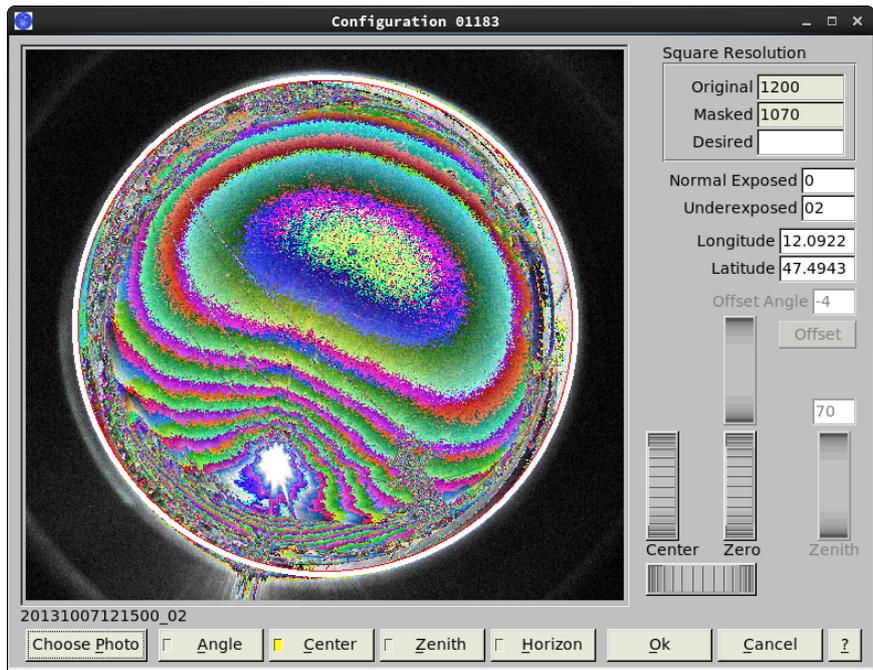


roller "Center":

The fisheye area is not centred. Using the vertical and horizontal "Center" roller, the image can be moved until exactly fitting to the center.

roller "Zero": The roller "Zero" allows adjustment of the border by changing size of white and red "zero circle". The white area of the circle is only meant to make it better visible. The inner red circle shows position of the border finally being used.

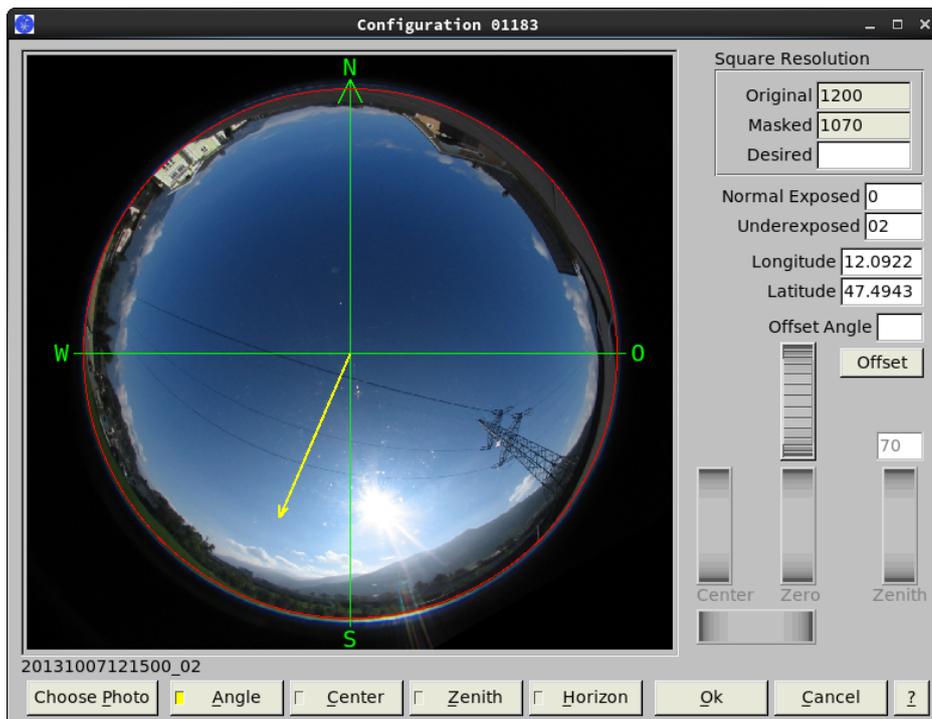
This screenshot shows the adjusted image. It's not perfect circular. There is a buckle on the bottom left side, caused by the rays of light from the sun on bottom left side. By comparison to an under-exposed image or another position of the sun one will find out, that the buckle will vanish or change position. Another possibility for better adjustment is enlarging the dialog by "maximise" button or pulling the edges.



[Center] will switch back to adjustment of offset angle and deactivate accentuated contrast. It allows to centre up the image and adjust size of fisheye area.

[Zenith] equalises the image and allows to adjust field of view.

2.7.2 Calibration of angle offset



This is the configuration window, when an image was loaded, and only the basic values had been changed. Now it is possible to change the offset angle of the Cloudcam and buttons for further

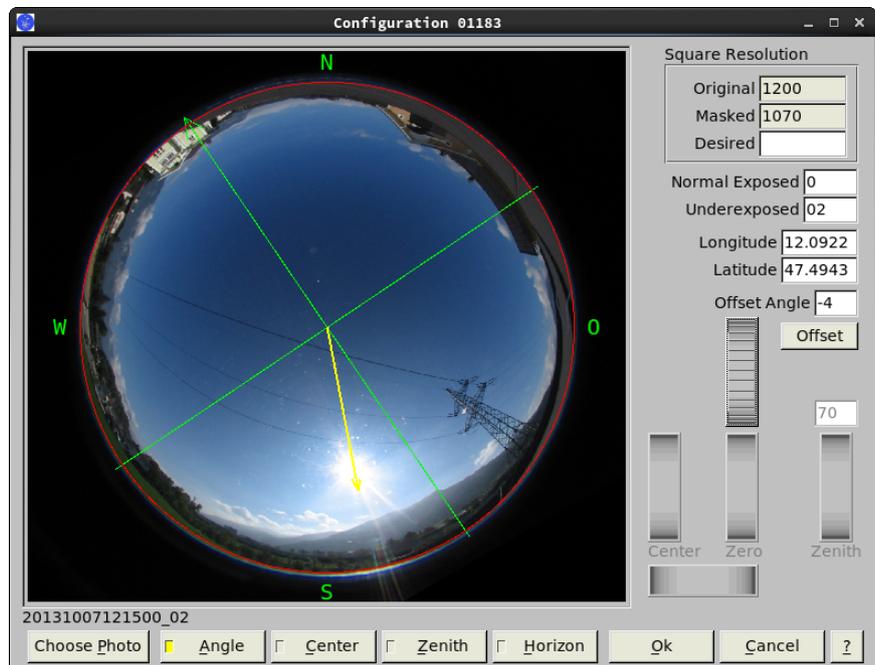
adjustments are activated now.

The screenshot shows current orientation of the image by a green wind rose and current size of fisheye area by a red circle. Also there is a little yellow arrow that points to direction of calculated sun position. For calculation of sun position the software uses Longitude/Latitude and the date and time of the filename (shown bottom left under the photo).

The images are desired to be in the same direction like a map, with direction to north on upper side (green arrow points to north) and also west and east side directed like a map. Because the photos are taken from the sky, but a map is orientated to the earth, the software swaps the sides of the image, when loading it. After that a cloud that is shown in the west in fact comes from the west and also the sun moves to the right direction.

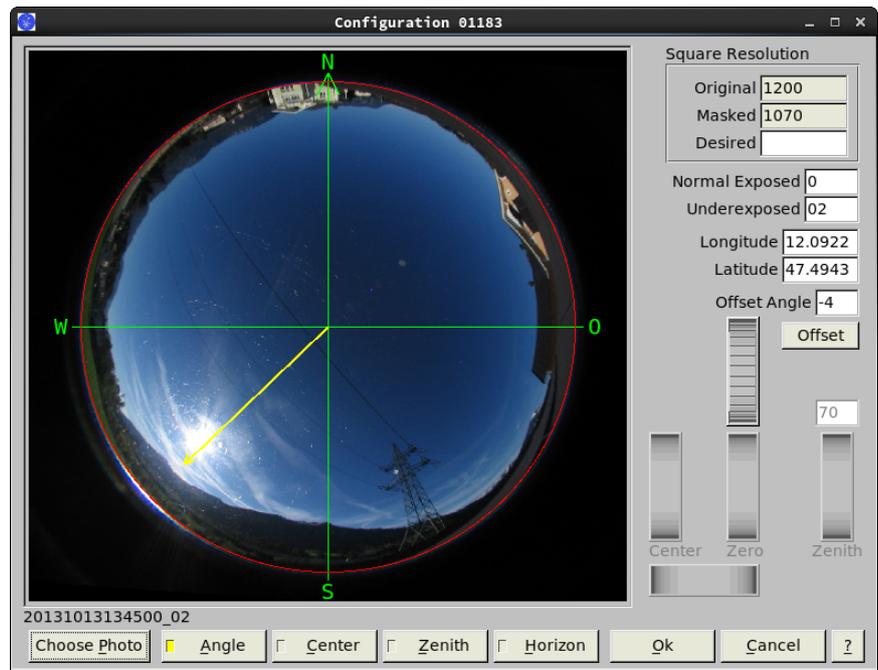
Looking at the screenshot above, it is easy to see by the sun pointer, that the Cloudcam is not placed in the right direction and an angle offset must be rectified. Also there is another problem to see - the fisheye area is not placed right to the middle, but there is an offset. So before rotating the image, it must be centred by using button [Center], because an excentric rotation will move the whole image to the wrong place.

This screenshot was made after centring the image and adjusting the size of fisheye area. It shows ongoing adjustment of the Cloudcams offset angle. Using the angle roller (the only one activated) the wind rose was rotated to the position it should have, if the photo would be a map. In the input field the value of rotation is shown as -4 degrees, so the photo must be rotated -4° in

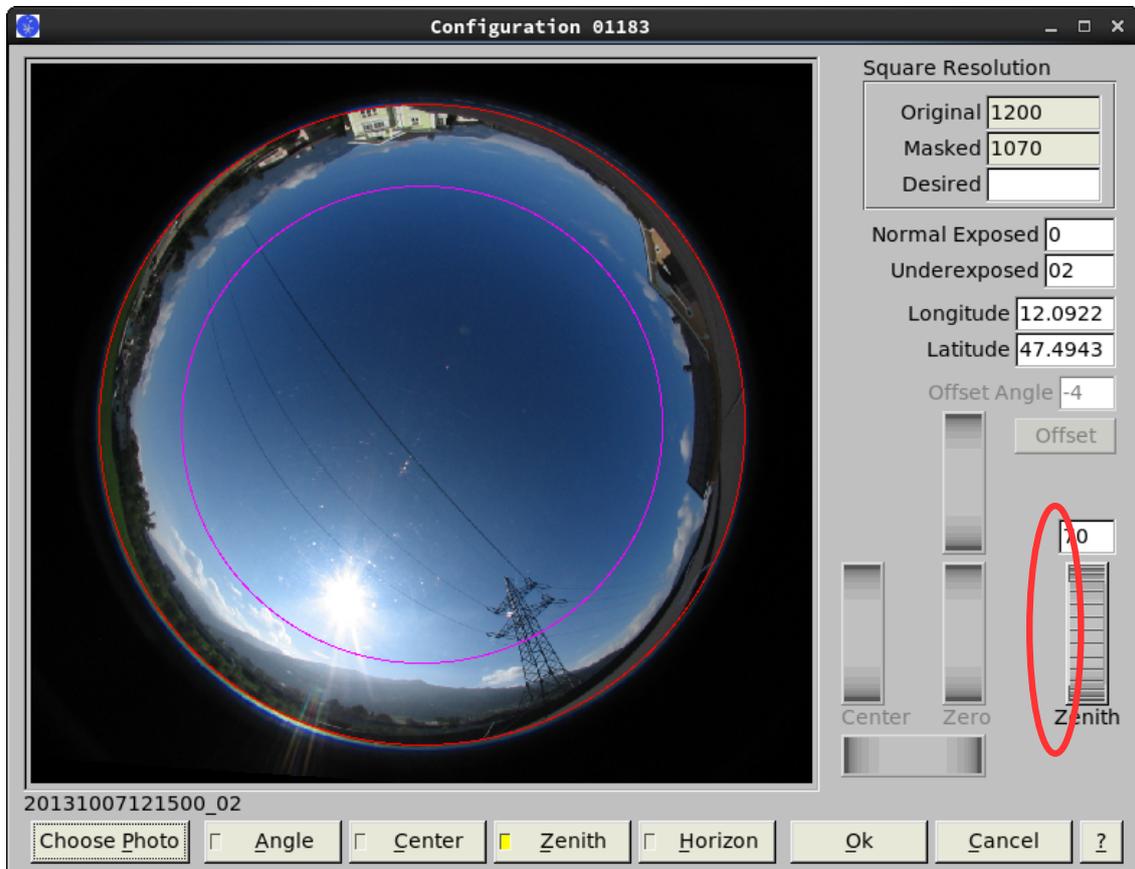


(mathematical) positive direction. By pushing button [Offset] or selecting input field "Offset Angle" and pushing enter key, this will be completed and the image will rotate.

The final screenshot shows another image that was loaded after adjusting and was rotated automatically by the given offset angle of -4° . It is easy to see, that all the values of Longitude, Latitude, Centring and Offset Angle most likely are accurate, because the sun pointer matches the position of moved sun. The arrowhead of sun pointer is not meant to point exact to the middle of the sun and also a little difference in angle won't be a problem, because area of sunmask is a good deal bigger than area of the sun.



2.7.3 Calibration of zenith angle



This is the configuration window for adjusting the field of view by zenith angle. It shows a image after being centred, north orientated and fitted into the window by borders of

fish-eye area.

The **zenith angle** starts with 0° at center and goes to 90° at red borderline, so a zenith angle of 90° would evaluate the whole image. But the zenith angle is restricted to 85° , because the plane projection of the image works with the mathematical tangent, so larger angles will approach infinity and prevent the image from being evaluable. For use of CDOC algorithm even a largest zenith angle of 70° is recommended for best evaluation.

roller "Center": The roller "Zenith" or the input field can be used to define a reduced zenith angle, shown by the pink circle. In the final calculation of cloudiness the software will only evaluate cloudiness inside of this circle.

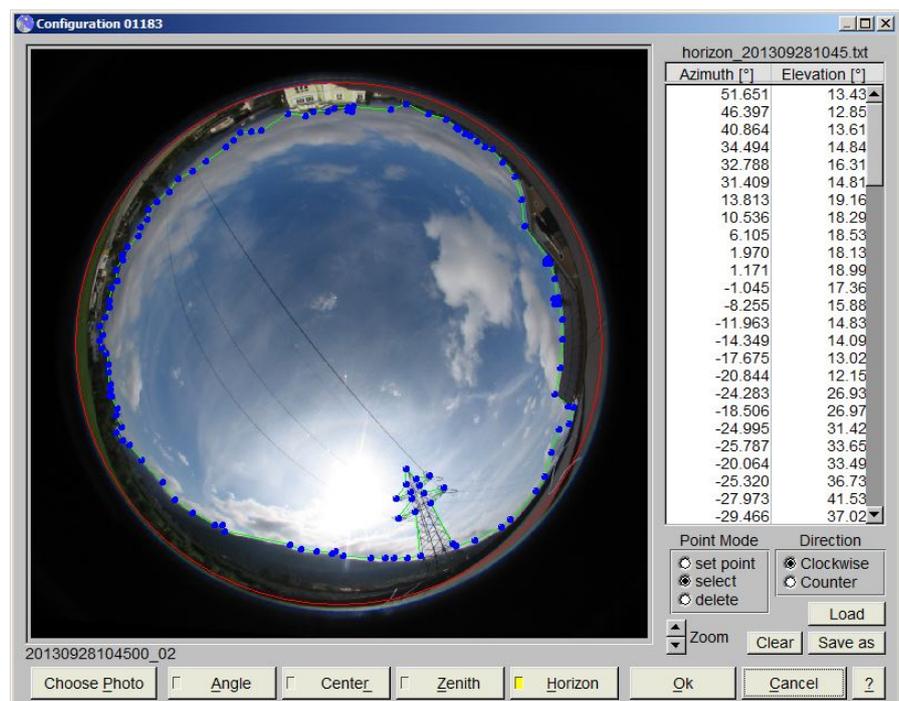
At this point all necessary adjustments are done and the dialog should be left by using [Ok] button for saving.

[Choose Photo] can be used to load another photo for comparison, e.g. to control match of sun position.

[Zenith] will switch back to adjustment of offset angle and show not equalised photo without field of view circle.

2.7.4 Input of Horizon

This is the configuration window for input of horizon, shown by the green line with supporting points. This view uses the projected image, to get a better match of input to real values of horizon line. Also this way the final mask used for evaluation will fit exactly to the projection of images. But the listed values of elevation most likely will differ from outdoor measured values, because graphical centring and equalisation are not high-precision.



We recommend to do horizon input, after all other calibrations had been done, because changing

these basic values will shift position of horizon to a wrong place.

The points of horizon line can be entered and edited by use of mouse and to be more exactly it is possible to zoom the window.

"Point Mode"

There are three operation modes, which can be switched circular by right mouse key:

"set point" sets a point on left mouse click.

"select" selects the point closest to left mouse click and allows to drag it by holding the left mouse button.

"delete" deletes the point closest to left mouse click.

"Direction"

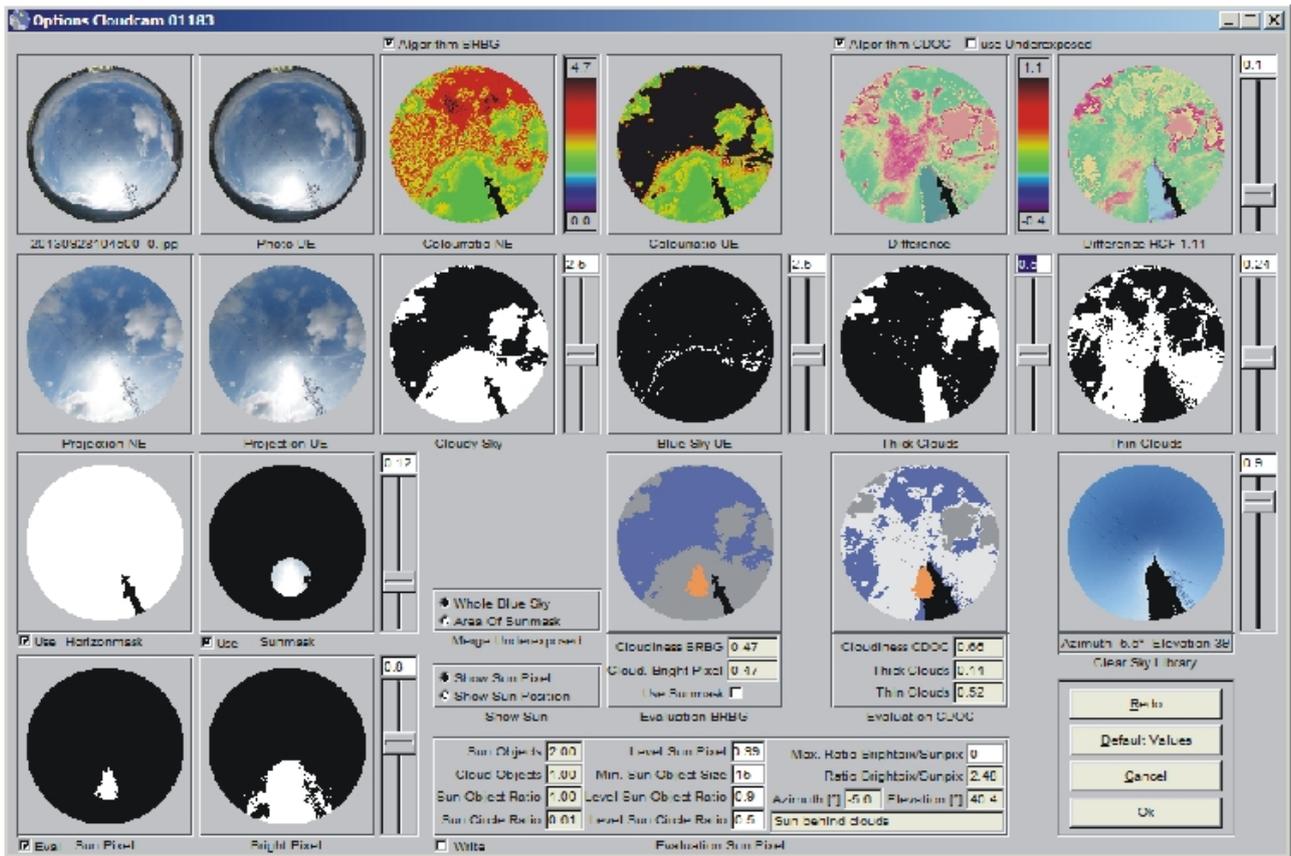
The "Direction" clockwise/counter (-clockwise) sets direction of "down the list". When there is "clockwise" activated, it is necessary to set consecutive horizon points in clockwise direction. Going into the wrong direction would switch inside and outside of the mask and would mask the inside of the horizon area and not the outside. It is possible to insert points by choosing a position inside of the list and go on with "set point".

[Load]: Loads a horizon file from inside the current Cloudcams configuration directory.

[Save as]: The horizon points are stored as "horizon_*.txt" inside of the current Cloudcams configuration directory, or the current chosen custom directory

[Clear] removes all points. This might be helpful, when centring of camera was changed and the horizon line doesn't fit any more.

2.8 Configuration of Evaluation

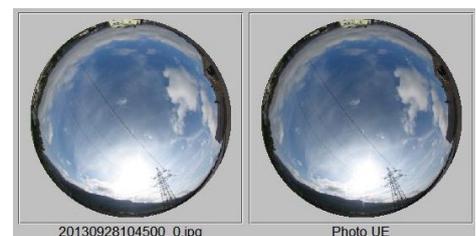


This is the dialog for configuration of evaluation. It shows all steps of evaluation and allows to configure the parameters and details of evaluation. So the results of evaluation are not "out of the blue", but can be retraced in detail and adjusted for better results. For maximum evaluation speed it is recommended to close this dialog. The options are part of the Cloudcam configuration, so it is possible to set different parameters to different Cloudcams.

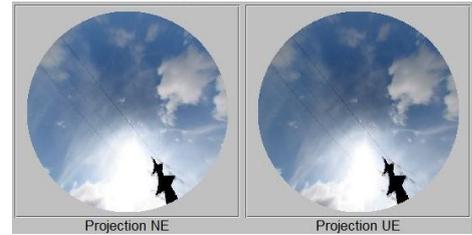
As a feature a more detailed image will be shown by clicking on one of the images. This is a copy and will stay when doing a new evaluation, so it can be used for comparison to evaluate parameter changes.

In general it is possible to change parameters by using the sliders, or by entering them to the white input fields and assign them by pressing enter key (e.g. "0.9<enter>" sets the new value 0.9).

The evaluation starts on top left showing the normal exposed image '20130928104500_0.jpg' and on right hand side of it there is the underexposed image 'Photo UE', which was associated by extension (Configuration of Cloudcam). When there is no underexposed image, this place and subsequent evaluations (Projection UE, Colourratio UE and Blue Sky UE) will be empty and gray.

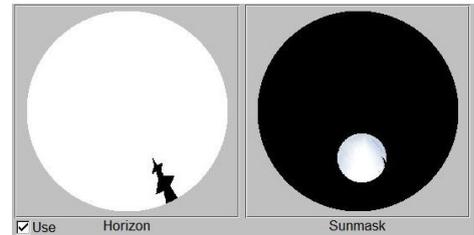


The first step of evaluation is equivalent map projection of the fisheye image to a plain image, which shows the area of zenith angle (The details of fisheye projection are explained in appendix). Now each pixel of the image covers the same size of sky area, so the cloudiness can be determined by count of pixel.



Next step is generation of horizonmask and sunmask.

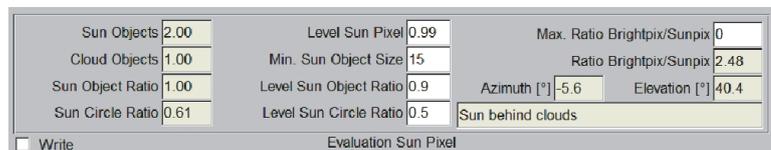
Horizonmask: The horizonmask excludes parts of the image from evaluation. Checkbox "Use" tells to use the mask. Anyway a circular mask will be used, to exclude the parts outside of the circular image.



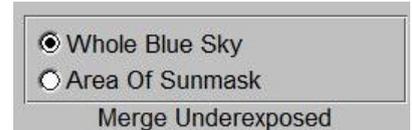
Sunmask: The sunmask masks an area around the sun position, which is determined by image name (containing date and time) and longitude/latitude (Configuration of Cloudcam). The slider on right hand side of sunmask sets the size of sunmask.

Three parts of evaluation are using the sunmask:

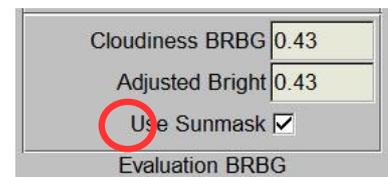
"Evaluation Sun Pixel" always uses the sunmask to restrict the sun pixel, but does not restrict the bright pixel.



"Merge Underexposed" can use the sunmask for adjusting only the part around the sun by underexposed image. It is possible to choose "Whole Blue Sky", without using the sunmask.

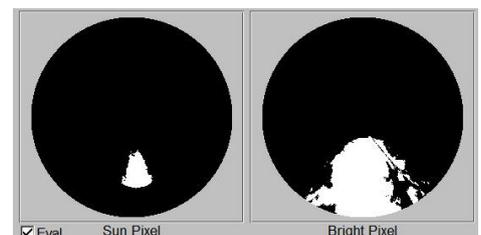


"Evaluation BRBG" For bright adjustment of BRBG evaluation the sunmask can be applied to Bright Pixels if the checkbox "Use Sunmask" is activated.



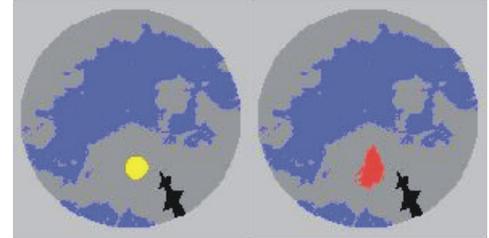
Information about visibility of sun:

"Sun Pixel" / "Bright Pixel" The evaluation of "Sun Pixel" and "Bright Pixel" is a separate evaluation to get informations about visibility of sun. It can be activated by checkbox "Eval". When active it produces several specific values (details in "Sunpixel Evaluation") to determine, whether the sun is on clear sky, partly cloud-covered or not visible.



Normally the software would recognise the white overexposed area near the sun as a cloud. Using the information from "Sun Pixel" the software can determine, whether the bright pixel area in "Bright Pixel" is blue sky or comes from clouds or atmospheric opacity. The checkbox **Use Sunmask** in "Evaluation BRBG" specifies to use only the sunmask area or the whole bright area for adjustment.

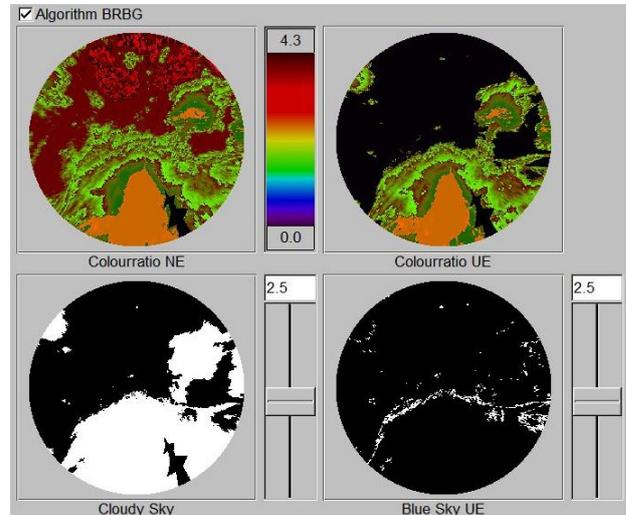
"Show Sun" can display the position of the sun as circle ('Show Sun Position') or as pixel area ('Show Sun Pixel') in the resulting pictures of the calculation of cloudiness.



Evaluation "Algorithm BRBG":

Next section of evaluation is "Algorithm BRBG" with images "Colourratio NE", "Colourratio UE", "Cloudy Sky", "Blue Sky UE" and the result "Evaluation BRBG".

For this analysis the checkbox "Algorithm BRBG" has to be activated.



The BRBG Algorithm calculates the ratio blue/red + blue/green out of the projected RGB image. It shows the result in "Colourratio NE" and "Colourratio UE". In reality the result of the three RGB values is a single "grayscale" value. The Colourratio images are coloured to make them more demonstrative. The colour bar between these images shows the range of values and scales the colours. It is valid for both images (NE and UE), so the same colour will show the same value and the images are directly comparable.

The **"Cloudy Sky"** shows pixel of "Colourratio NE" with values less than a defined value as cloud pixel. The slider on right hand side of the image allows to adjust the appropriate level and make the result visually match better to original sky image.

The **"Blue Sky UE"** shows additional blue sky pixel of the underexposed image. These pixel can be used to adjust the area around the sun ("Merge Underexposed": Area Of Sunmask), or to adjust the whole image ("Merge Underexposed": Whole Blue Sky).

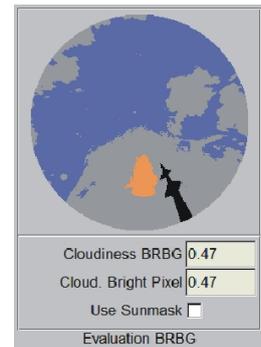
The "**Evaluation BRBG**" shows the final evaluation of the BRBG algorithm - the calculated cloudiness values. The cloudiness values are based on counting the pixels of this image.

The value "Cloudiness BRBG" is counted before adjustment of 'Bright Pixel'.

The value "Cloud Bright Pixel" is counted after adjustment of 'Bright Pixel'.

Now bright pixel caused by haze are not counted as cloud any more. This will cause a reduced cloudiness.

The check box "Use Sunmask" allows to reduce the 'bright pixel area' to the area of the sunmask. The picture on the right side shows this effect at the bottom of the sun pixel are, because there is a cut off looking like a semi circle.



Evaluation "Algorithm CDOC":

Next section of evaluation is "Algorithm CDOC" with images "Difference", "Difference HCF", "Thick Clouds", "Thin Clouds", "Clear Sky Library" and the result "Evaluation CDOC". For this analysis the checkbox "Algorithm CDOC" has to be activated.

This evaluation implements the algorithm which is described by "A method for Cloud Detection and Opacity Classification based on ground based sky imagery"^[3] (capitalisation shows our acronym CDOC). The algorithm uses images from a clear sky library (a collection of cloudless images). It determines clouds by creating the red/blue ratio of the current image and the best matching clear sky image and evaluating the difference of them. The simple "Difference" provides the thick clouds and the "Difference HCF" provides the thin clouds. For "Difference HCF" the mean values of blue sky pixel in current image and clear sky image will be calculated and the images will be adjusted for minimum difference of clear sky mean values. That way allows to determine small differences caused by thin clouds or haze.

The "**Difference**" and "**Difference HCF**" shows the differences of the red/blue ratio of the original image and the clear sky image. In reality these are grey scale values. They are colourised to make them more demonstrative. The colour bar between these images shows the range of values and scales the colours. It is valid for both images (Difference, Difference HCF), so the same colour will show the same value and the images are directly comparable.

The slider on right-hand side of "Difference HCF" adjusts the level of clear sky pixel. Pixel less than this value will be estimated as clear sky in HCF calculation.

The "**Clear Sky Library**" shows the image, that will be used to calculate the differences.

A problem of the CDOC method results out of the fact, that bright parts of the Clear Sky Image (the area near the sun) can not be evaluated, because there is no evaluable red/blue ratio left by overexposed pixel.

To handle this problem, there is the possibility to mask the bright parts of the Clear Sky Image. This reduces the area of evaluation, but ensures, that the remaining part will be evaluated in a correct way. Otherwise the evaluation will tell too less cloudiness, because the invalid area normally will be recognised as blue sky.

For adjustment of the "clear sky brightness mask" there is a slider on right-hand side of the image to adjust the level.

The examples at the right side show the unmasked evaluation (1) resulting in a cloudiness of 0.96 for a totally clouded image. This difference results out of the Clear Sky Image. By using the brightness mask (2), the calculated cloudiness results in 1.00. So there is a better result, although a smaller part of the image was evaluated. Anyway this difference will be reduced substantial by use of underexposed images, because underexposure reduces the overexposed area.

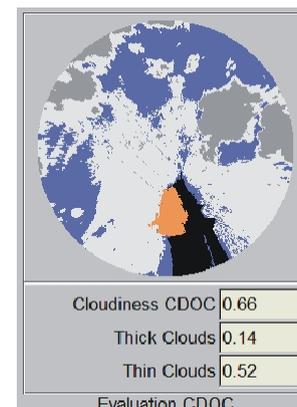
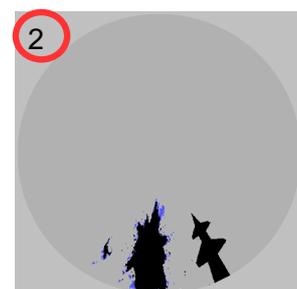
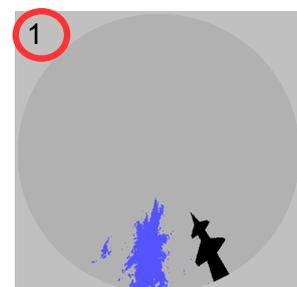
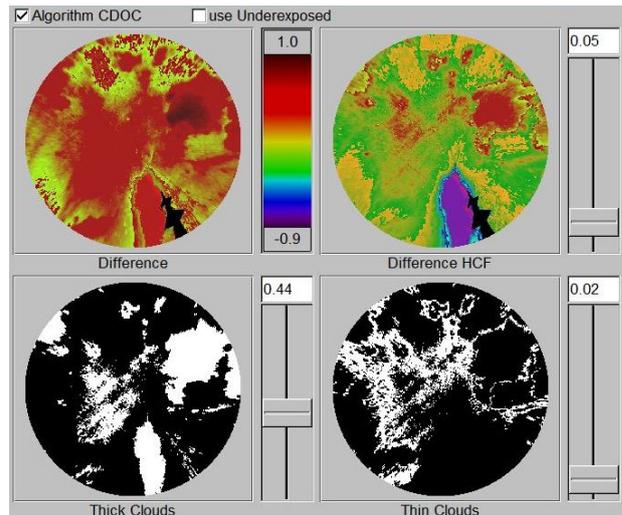
The "**Thick Clouds**" shows pixel of 'difference ratio' with values larger than "Level Thick Clouds" as thick cloud pixel. The slider on right hand side of the image allows to adjust the level of thick clouds and make the result visually match better to original sky image.

The "**Thin Clouds**" shows pixel of 'difference HCF ratio' with values larger than "Level Thin Clouds" as thin cloud pixel. The slider on right hand side of the image allows to adjust level of thin clouds and make the result visually match better to original sky image.

The "**Evaluation CDOC**" shows the final evaluation of the CDOC algorithm - the calculated cloudiness values. The cloudiness values are based on counting the pixels of this image.

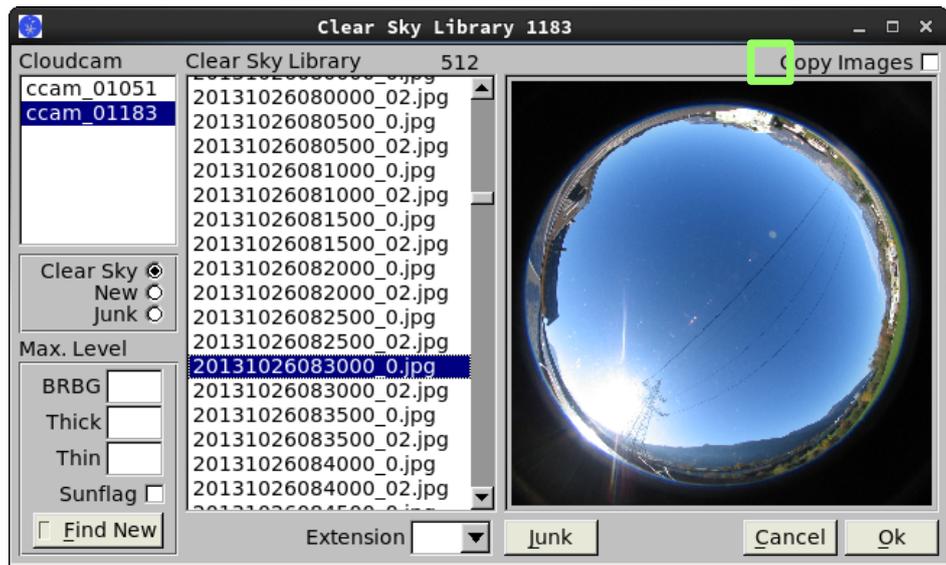
The analysis produces the values 'Thick Clouds' and 'Thin Clouds'.

The 'Cloudiness CDOC' is the sum of these two values to make a comparison to whole Cloudiness BRBG more easy.



2.9 Clear Sky Library

This is the dialogue to create and maintain the library of Clear Sky Images for the CDOC evaluation. Because the name is mistakable (it's a Clear-Sky Library and not for clearing Sky-Library) the menu for calling it, is named only "Sky Library".



The Clear Sky Images are separate for every Cloudcam and the list on left top side makes it possible to choose between the existing Cloudcams.

For each Cloudcam the Clear Sky Library administrates two files inside of the Cloudcams "system" directory. Both are necessary to exclude known files, when looking for new Clear Sky Images.

"ClearSkyLibrary.txt" ... contains the verified Clear Sky Images

"ClearSkyJunk.txt" ... contains rejected images, which are not usable for evaluations.

"Clear Sky", "New" and "Junk":

1) The choice "**Clear Sky**" shows the content of "ClearSkyLibrary.txt" inside of the list "Clear Sky Library". When an entry is selected (it is possible to select more than one), the dialog will show the appendant image on right-hand side of the list.



"Extension" The choice "Extension" makes it possible to select shown files by extension, e.g. "0", "02". The extension should represent an exposure time, so evaluation can group images and applicable Clear Sky Images by their extensions. It doesn't work well to use Images and Clear Sky Images with different exposure times.

[Junk] The button [Junk] moves entries from "ClearSkyLibrary.txt" to "ClearSkyJunk.txt". The button can be executed by left click of mouse, by pushing character 'j' or by pushing [Del] key.

2) The choice "**Junk**" shows the content of "ClearSkyJunk.txt" inside of the list "Junk Images" (the list of images will change it's name from "Clear Sky Library" to "Junk Images"). Now there are two buttons:



[Remove] The button removes entries from the list. When "Copy Images" is activated, the file will be deleted on [Ok] when closing the dialog. The button can be executed by left click of mouse, by pushing character 'r' or by pushing [Del] key.

[USE] The button moves entries from "ClearSkyJunk.txt" to "ClearSkyLibrary.txt". When the checkbox "Copy Images" is activated, the file will be copied on [Ok] when closing the dialog. The button can be executed by left click of mouse, by pushing character 'u' or by pushing [Ins] key.

3) The choice "**New**" at first shows nothing inside of list "New Clear Sky Images". To fill the list there is the group "Max. Level". By entering a Level (e.g. BRBG = 0.05) and pressing key **[Find New]** the software will search for images with evaluation less or equal of the particular level. To achieve this, existing evaluations are required.



[Junk] The button moves the selected images to the "ClearSkyJunk.txt".

[USE] The button moves the selected images to the "ClearSkyLibrary.txt".

[Select] The button selects the whole list.

So there are some steps necessary to establish a Clear Sky Library:

A BRBG evaluation of the existing images should be done.

Now the Sky Library dialogue can [Find New] Clear Sky Images by level BRBG.

By manually stepping through the list of "New Clear Sky Images" (Up-/Down-Cursor can be used) the images can be reviewed and e.g. bad (cloudy) images pushed to junk.

Remaining suitable images now can be selected (e.g. using button [Select]) and moved to "ClearSkyLibrary.txt".

Now there are Clear Sky Images defined and a CDOC evaluation can be done to find more Clear Sky Images.

The manual control of the automatically found images is highly recommended, because often there are unrecognised thin clouds or wrong evaluated images, that could muck up future evaluations. But by using the keyboard to step through the list, this work can be done very quickly, even when there are hundreds of images.

"Copy Images" The option establishes two kinds of image administration:

"Copy Images" deactivated When all the images are stored to a single data carrier and stay

accessible, the dialogue will only use a list of files and fetch the images from their original place. To achieve this, "Copy Images" must be deactivated.

"Copy Images" activated When older images will be deleted or moved to an archive data backup, the dialogue can copy Clear Sky Images to an individual directory "csi", to keep them accessible for evaluations. To achieve this, "Copy Images" must be activated.

The state of "Copy Images" depends on existing "csi" directory inside of the Cloudcam directory. It can be different for different Cloudcams. It is not possible to undo a new state "Copy Images" by using button [Cancel], these changes will be processed at once.

When activating "Copy Images", the software will create a "csi" directory for the particular Cloudcam and will copy all images of "ClearSkyLibrary.txt" to this directory. After that the software will fetch Clear Sky Images only out of this directory.

When deactivating "Copy Images", the "csi" directory will be deleted and included images will be lost. After that the software will fetch Clear Sky Images from their original position.

Furthermore the Findclouds software won't track manual changes of "csi" content. When there is no "ClearSkyLibrary.txt", but a "csi" directory, the software will rebuild the "ClearSkyLibrary.txt" using the content of "csi" directory.

[Cancel] / [OK] There are the common buttons [Ok] and [Cancel]. The button [Ok] will save changes of "ClearSkyLibrary.txt" and "ClearSkyJunk.txt" and the button [Cancel] will discard them.

2.10 Sunpixel Evaluation

Sun Objects	2	Level Sun Pixel	0.99	Level Ratio Brightpix/Sunpix	0		
Cloud Objects	1	Minimal Object Size	15	Ratio Brightpix/Sunpix	2.48		
Sun Object Ratio	1.00	Level Sun Object Ratio	0.9	Azimuth [°]	-5.6	Elevation [°]	40.4
Sun Circle Ratio	0.61	Level Sun Circle Ratio	0.5	Sun behind clouds			
<input type="checkbox"/> Write		Evaluation Sun Pixel					

One important information the software should provide, is visibility of the sun itself. To achieve this, the sky image will be changed into a gray scale intensity image. Using this image, it is easy to recognise overexposed pixel which are caused by the sun and its surrounding field.

The first version of this software checks for overexposed pixel and when there are some, it states sun as visible. But this caused a lot of false positives and stated sun as visible, even when there was just a bright spot in a completely clouded sky. This is caused especially by automatic choice of exposure, because a completely clouded sky will raise exposure time so much, that such a spot overexposes the same way as a directly visible sun. A simple and obvious solution of this problem would be a fixed exposure time, to set a defined level for recognition of sunpixel. But this often would cause an additional image and also won't recognise, when sun shines through a small gap

in cloudiness.

When thinking about these problems, it took our attention, that there are characteristic patterns of sunpixel, which change with amount of cloudiness or atmospheric opacity. Especially sunpixel of cloud-covered sun often contain gaps resulting out of covered parts of sun. So a simple pattern recognition was implemented to improve evaluation of sun.

"Sun Objects", "Cloud Objects": The algorithm analyses the sunpixel. It determines connected areas of sunpixel (called "Sun Objects") and of skypixel that are included by sunpixel (called "Cloud Objects"). Then it counts the number of pixel they consist of.

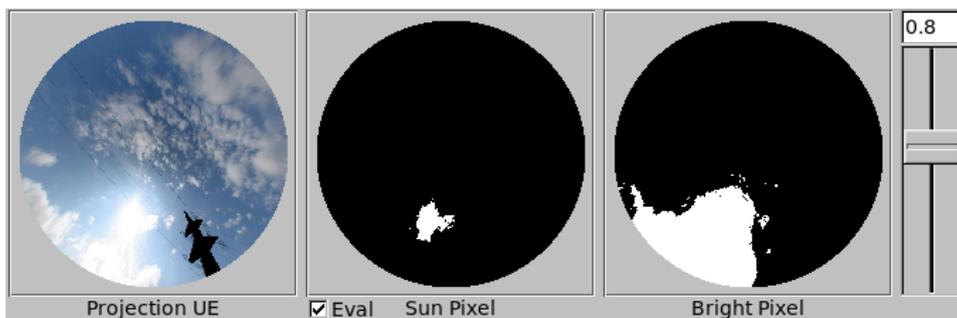
More than one Sun Objects is evidence of a cloud covered sun. Because of sparks, the number of Sun Objects often is not sufficient to make a reliable statement.

(Sun Object >1 → sun cloud covered)

(Cloud Object >2 → sun cloud covered)

Example:

20130928120000_0



This is an example of an image, which is difficult to analyse.

At first glance there seems to be a visible sun. When taking a closer look, a small cloud in front of the sun is detected. This highly enlightened cloud gets part of the sunpixel and changes the pattern like an unclouded sun would produce. Also the cloudiness results in a large area of brightness.

Sun Objects: 11749 98 28 9 9 8 6 6 5 5 5 3 3 3 2 2 2 2 1 1 1 1 1

The algorithm finds 23 Sun Objects, one of them containing most of the sunpixel and some "sparks".



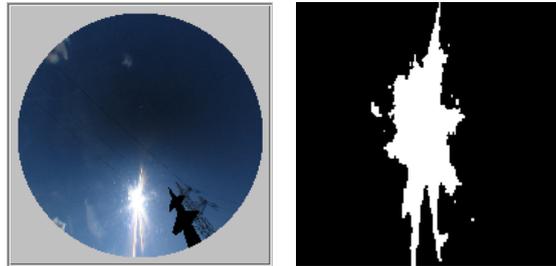
Cloud Objects: 50 19 11 5 1

The algorithm finds 5 Cloud Objects. At least two of them contain a considerable number of skypixel. This is strong evidence of a cloud covered sun.

"Sun Object Ratio": Is a characteristic value to determine the state of the sun. It is determined by dividing the pixel number of largest Sun Object through pixel number of all Sun Objects. Normally a Sun Object Ratio larger than 0.9 points to an uncovered sun. (>0.9 → SunOnClearSky)

Example: Sun Object Ratio = $11950/11749 = 0.983$

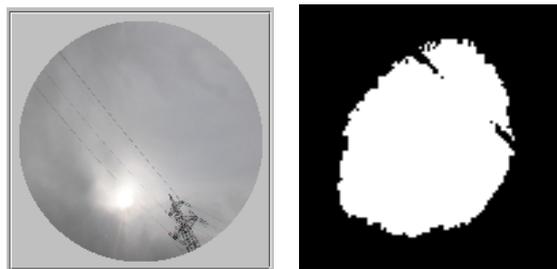
In the example the cloud coverage was only recognised by "Cloud Objects" and "Sun Circle Ratio"



"Sun Circle Ratio": Is another characteristic value to determine state of sun. It deals with the special problem to determine between sun on clear sky and sun behind continuous cloud coverage producing a spot.

($< \text{level} \rightarrow \text{SunOnClearSky}$)

A sun on clear sky causes rays by the optic and the sun object will appear jagged. A sun shining through clouds is smoothed and appears circular.



The "Sun Circle Ratio" tells, how good the sunpixel match to a circle. In the images on the right hand side it is obvious, that the sun is much more "circle like" than the jagged clear sky sun.

Ratio Brightpix/Sunpix: Tells about haze or thin clouds in front of the sun. On clear sky the ratio is less than 2 and rises with amount of haze or thin clouds.

($< 2 \rightarrow \text{SunOnClearSky}$)

Brief overview of level inputs:

"Level Sun Pixel": If the value of the pixel of the intensity image is higher than this level, it is classified as sun pixel. For badly underexposed images it might be necessary to reduce this value.

"Min. Object Size": "Sun Objects" & "Cloud Objects" that contain less number of pixel will be discarded.

"Level Sun Object Ratio": If "Sun Object Ratio" is $> \text{Level} \rightarrow \text{SunOnClearSky}$.

"Level Sun Circle Ratio": If "Sun Circle Ratio" is $< \text{Level} \rightarrow \text{SunOnClearSky}$.

"Level Ratio Brightpix/Sunpix": If "Ratio Brightpix / Sunpix" is $> \text{Level} \rightarrow \text{SunBehindClouds}$ (& value exists).

Remark:

This kind of evaluation is more sophisticated than the simple sun pixel evaluation.

Because of rays and sparks the pattern of 'Sun on clear sky' also can include Cloud Objects. In difference to real Cloud Objects they normally contain only a few pixel. By option "Min. Object Size" it is possible to exclude them and improve the evaluation. Also it is clear, that the evaluation depends on resolution of the image and the options must be adjusted, when images are calculated with less resolution.

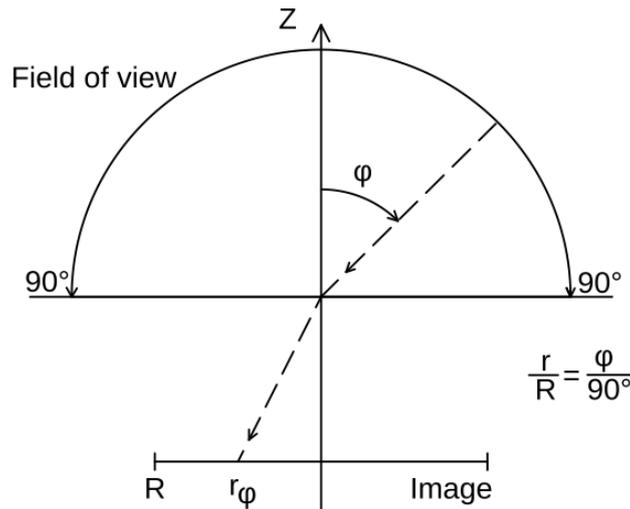
Table: sunflag numbers

New number	Old number	Description
0	0	Sun not visible
1	1	Sun on clear sky
3	0	Parts of sun cloud covered
5	0	Sun behind clouds, but a bright dot is visible
8	9	Sun outside view, either because of zenith angle, or sun is hidden by horizon
9	9	No Sunflag evaluation was made

3 Appendix

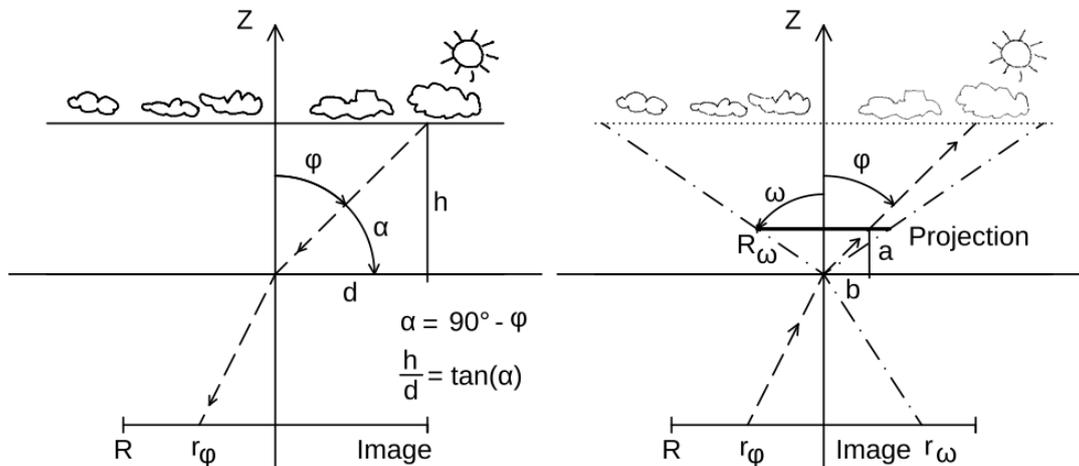
3.1 Geometry of fisheye projection

This text takes attention to a fisheye lens, which maps a hemispherical view field conformal to an image plane and produces a circular image. The radius of the image relates to the opening angle (zenith angle). The following image shows the path of rays inside of a fisheye lens.



For an ideal fisheye lens the image radius relates linear to the view angle and the whole field of view will be mapped to concentric circles. A real fisheye lens will produce some distortions, especially for larger angles. There will be aberrations from linear ratio of view angle and image radius. But for the moment we assume a linear, not distorted mapping.

A cloud cover can be seen like a two dimensional plane at a specific height in the sky, but when using a fisheye lens for cloud monitoring, it maps a hemispherical view field to the image and not the original plane.



The first part of the chart shows that for mapping of a plane in constant height h to an angular dependent fisheye lens image, the distance d depends on the tangent of viewing angle. For zenith

angles approaching 90° this distance will approach infinity. So the angular dependent concentric circles of the fisheye lens image for small angles φ maps the correspondent circle of the sky plane almost 1:1. For larger angles the mapped area will rise fast, until it even corresponds to infinity when approaching 90°.

The second part of the chart shows, how an existing fisheye lens image can be used to create a reproduction of the original sky plane by rear projection. Now the path of rays starts from the fisheye lens image and crosses an image plane in height a . The image plane covers the viewing angle ω . Dependent on ω and a , an image radius of R_ω results. The crossing point of image plane and angle φ results in height a and distance b and fulfils equations $h / d = a / b = \tan(\alpha)$. It is obvious to see, that path of rays produces a projected image ("Projection") that shows original sky plane true to scale.

In practice a constant viewing angle will be assigned to a constant image radius R_ω , whereby a constant distance a will result for all angles φ :

$$a / b = \tan(\alpha); \alpha = 90^\circ - \varphi \rightarrow a = b * \tan(90^\circ - \varphi)$$

By use of the specified values for ω and R_ω the constant a can be calculated:

$$a = R_\omega * \tan(90^\circ - \omega)$$

Using this it can be calculated, which distance b results out of a projection angle φ . So every radius of the fisheye lens image results in a radius of the plane image. R_ω sets the unit of measurement and it is most simple to use the unit "pixel". This way a pixel of the fisheye lens image can be moved to correspondent position on sky plane:

$$b = a / \tan(90^\circ - \varphi) = a / \tan(90^\circ - 90^\circ * r/R)$$

with r equal to current radius and R equal to whole radius of fisheye lens image.

By using $\tan(\alpha) = \cot(90^\circ - \alpha)$, $\cot(\alpha) = 1/\tan(\alpha)$ and keeping periodicity of tangent in mind it is possible to simplify the equation:

$$f(r) = a * \tan(90^\circ * r/R)$$

("forward calculation": Fisheye lens pixel to image plane)

This "forward calculation" doesn't include, that size of pixel raises in dependency from the angle, so projecting pixel one to one causes rising gaps between the pixel. A simple solution to avoid this problem is to calculate the pixel of the image plane backward to fisheye lens image and taking

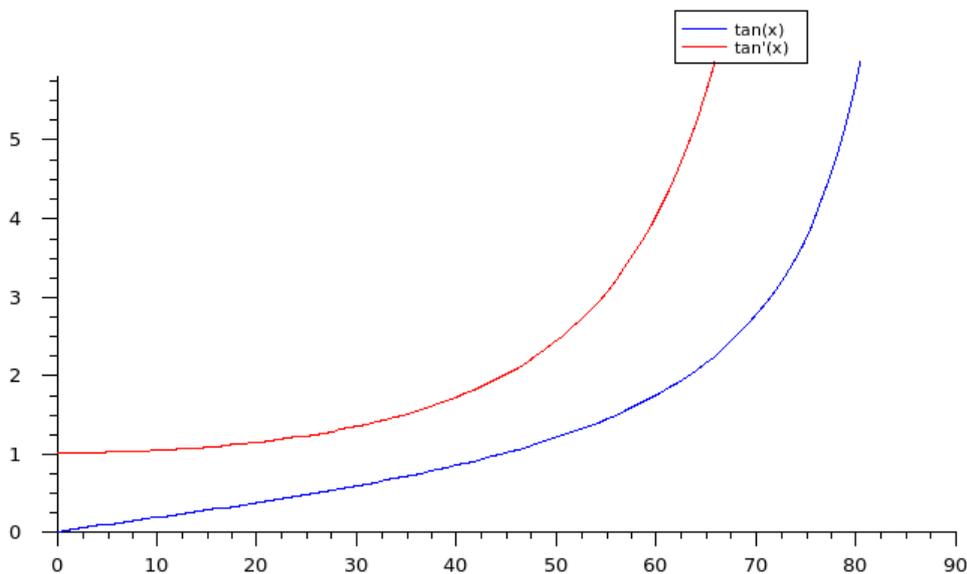
over one pixel for several times, when necessary:

$$f(r)^{-1} = R / 90^\circ * \text{atan}(b / a)$$

("backward calculation": plane image pixel with distance b to fisheye lens pixel with radius r)

This way a complete image will be created, but because of aliasing for large zenith angles there will result an aberration from the original sky plane. The pixel not only were enlarged, also a jitter appears, because the fisheye lens pixel won't match to an even number of plane image pixel. For plane pixel located on borderline of two fisheye lens pixel an interpolation should be used to reduce aberration.

3.2 Limits of useful graphical representation

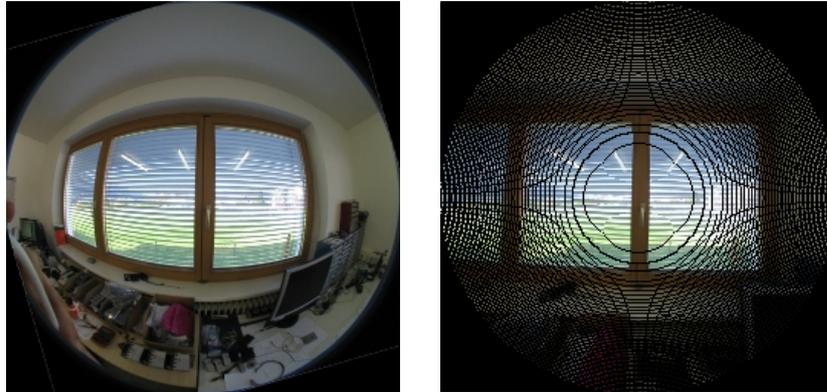


To appraise the effect of rising zenith angle and size of aberration it makes sense to look at the underlying tangent function. Especially the derivation of the tangent shows directly the difference between original fisheye lens pixel and resulting plane image pixel.

$f(r) = a * \tan(90^\circ * r/R)$ results in an angle range from 0° to 90° , because the ratio r/R covers the range from 0 to 1.

This plot shows the dependency of the plane image radius (y-axis) on zenith angle in degrees (x-axis). For angles less than 50° it is plain to see, that the radius rises almost linear with the angle, so the middle part of the image will project the original sky plane almost unaltered. In range from 50° to about 80° the projection will get more and more stretched until for angles larger than 80° the radius steeply rises to infinity. Also the derivation shows accordant factor of projection for range from 0° to 50° by 1:1 or 1:2 and fast rising for larger angles.

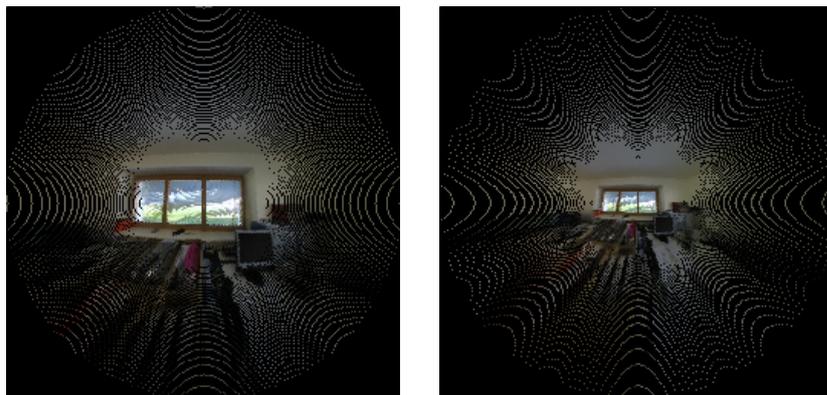
The following example shows some "forward projections" containing gaps to demonstrate effect of rising angles and loss of image content.



To make the images more demonstrative not a sky image was used, but an image of laboratory window.

First image is original fisheye lens image, second is projection of 60°, third of 80° and fourth of 85°.

These images demonstrate how the image content evolves with zenith angle.



For 60° projection there are only small gaps that need to be filled. For 80° it is clear to see that from half the image radius on, large areas must be interpolated from small pixel informations. For 85° angle the image content is restricted to a small region in the middle and most of the image must be interpolated.

In praxis the zenith angle should be restricted to values <80°. For opacity classification (CDOC algorithm) the scientists recommended not to exceed 70° of zenith angle (Field Of View < 140°).

3.3 References

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[3] M.S. Ghonima, B. Urquart, C.W. Chow, J.E. Shields, A. Cazorla, J. Kleissl: A method for cloud detection and opacity classification based on ground based sky imagery. Atmos. Meas. Tech., 5, 2881-2892, 2012.

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