Analysis of Ice Halo Appearances Using an All-Sky Camera

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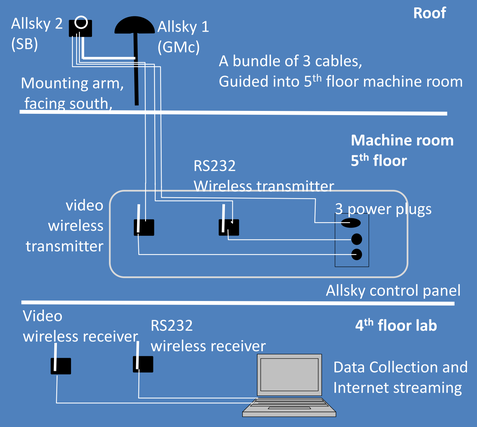
Abstract

Assessment of cirrus cloud coverage belongs to one of the more difficult problems in data collection. Spatial as well as temporal resolution is limited due to their optical properties, the restrictions of terrestrial observations and the evasiveness of cirrus in satellite images. Cirrus clouds often cause ice halos, in particular 22-degree halos. Other halo features, such as parhelia and various other subspecies of complex halo displays can be seen as well. Collecting data on these halos will, as a longitudinal set, allow assessment about the frequency, type and diurnal distribution of cirrus clouds. Data on complex halo features allow to make inferences about the types of ice crystals, which (in the future) may lead to an assessment of their growth conditions. We present our results on the observation of cirrus coverage over the first half of 2015, using an all-sky camera and our own image analysis software for the detection of ice halos. We record several thousand images per day. These images are then analyzed for the presence of ice halos, which allows us to compile statistics of their appearances, duration, intensity and correlation with other weather specifics. We present a halo detection algorithm, which was developed by iterative testing on large sets of images under varying sky conditions. Our goal is, to develop this combined all-sky camera/software system to a point at which it becomes portable to other locations, such as schools. This may allow a spatial resolution on the appearance of ice halos and their implications, in addition to the time resolution.

Camera details

- Orion Starshoot Allsky camera with auto iris
- On roof of science building since 7-21-2014
- Saves still frames every 30 s (chosen)
- Resolution 480 by 720
- Location
  Lat 45.589052
  Long -95.902858

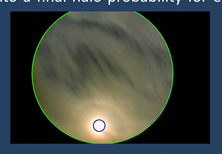


Halo identification program

Dubbed haloloop, the program must process large numbers of images in a reasonable amount of time, about 80 000 for each observation month. Images are saved and can be processed with varying goals. The current version of haloloop:

- Is written in C++, using openCV
- Removes image distortions due to fisheye projection
- Identifies the sun (or moon) position and radius
- Analyses the radial intensity distribution
- Several markers of the image are included and assigned probability factors as observed for halo images.
- The factors are combined into a final halo probability for each

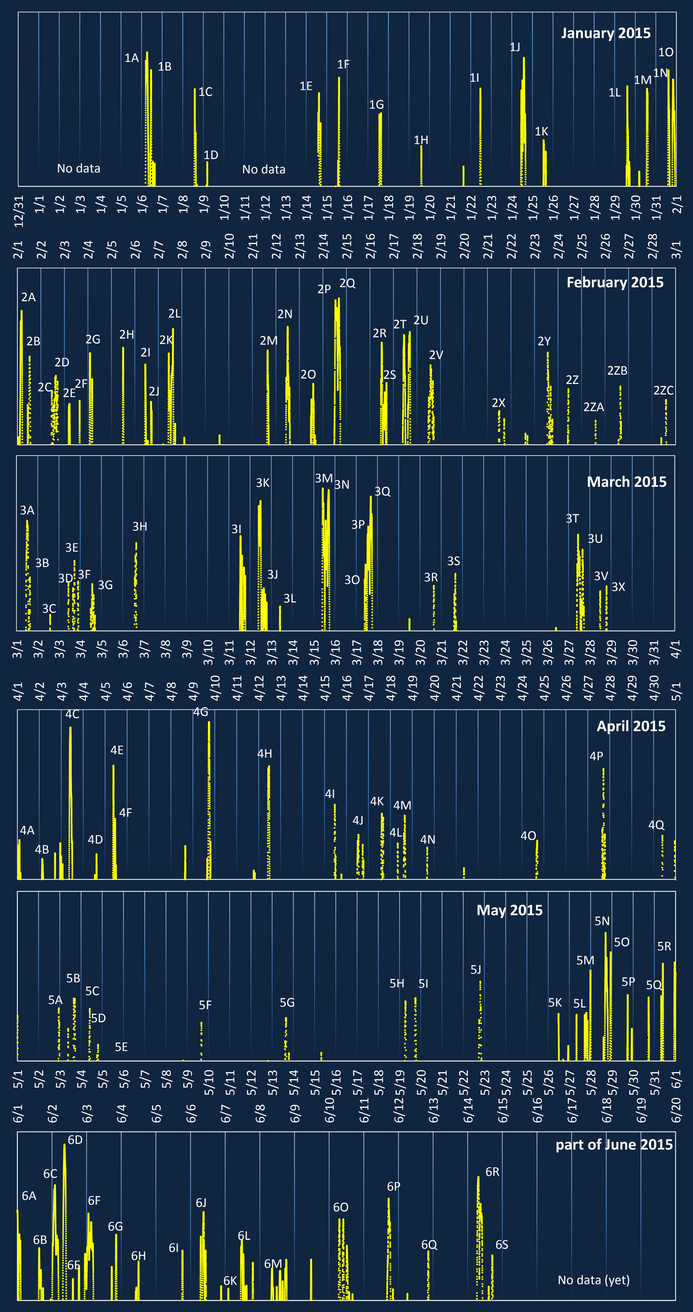
Original image



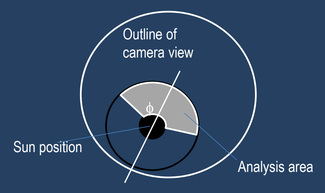
Distortion removed, mask applied and sun identified

Halo Observations

Shown is $\log(P_{halo})$ versus time for the first several months of 2015. The data have been Gaussian – broadened to enhance the influence of sequential halo signals.



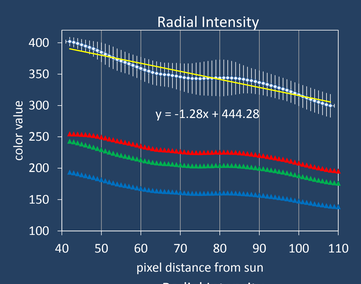
Radial intensity analysis

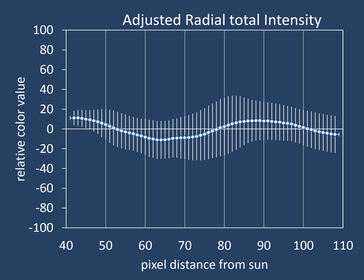


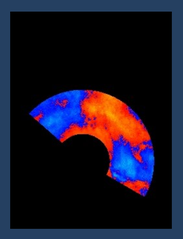
The radial color intensities and their standard deviations are analyzed within the gray area , see left. This area is also cleared of bias by subtracting an average plane before analysis. The total radial intensity is used as

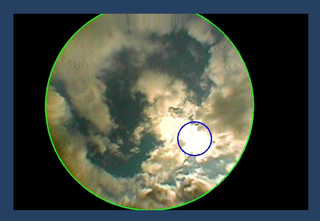
$$I_r = \sqrt{B_r^2 + G_r^2 + R_r^2}$$

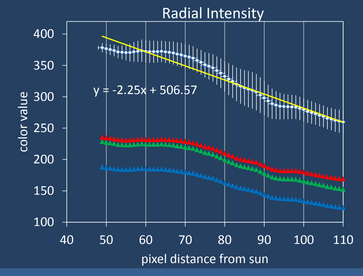
The adjusted radial total intensity is the result of subtracting the best fit line from the total radial intensity. This allows better contrast of the intensity fluctuations associated with a halo presence. The false-color images of the analysis area show the distribution of the adjusted intensity (red positive, blue negative).

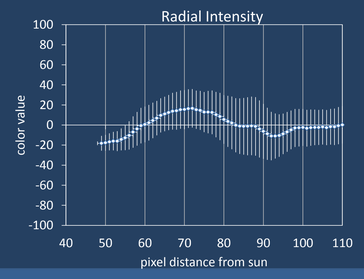


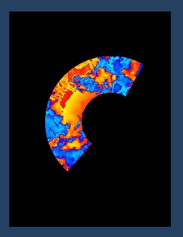












Halo Finding Algorithm

The halo probability of an image is a composite of probability factors which assess certain qualities of an image, based on the analysis area. There are seven such factors, comprised of three groups.

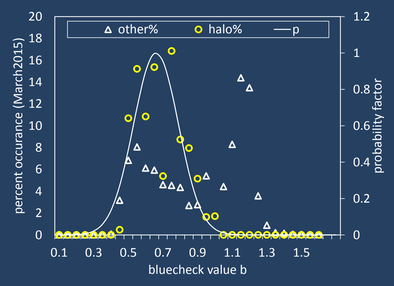
$$P_{Halo} = P_{blue}\, P_{MVA}\, P_{MVS}\, P_{slope}\, PR2\, P_{MPS}\, P_{MPC}\, P_{PMMP}$$

Color intensities (P_{blue}, P_{MVA}, P_{MVS})

P_{blue} is a Gaussian centered at 0.61 for

$$b = B^2/(RG)$$

This excludes clear-sky images.

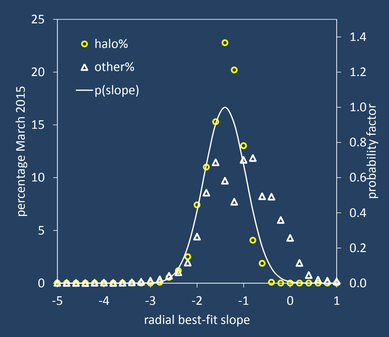


P_{MVA} and P_{MVS} assess variability of the radial total intensity (error bars in figures above) via its average (MVA) and standard deviation (MVS). This reduces fail signals from Ac and Sc skies.

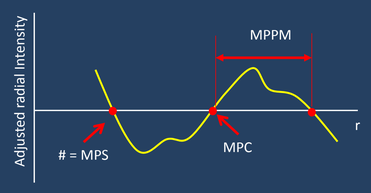
Line fit to the radial total intensity (P_{SLOPE}, P_{R2})

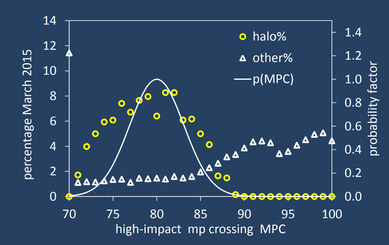
P_{slope} assesses the slope of the best-fit line. This reduces signals from overcast days (As, St) as well as very clear days.

P_{R2} is simply the R2 value of the fit. Low fit quality correlates with variable skies, such as Ac or Sc.



Markers for the adjusted radial intensity (P_{MPS}, P_{MPC}, P_{MPPM})





Solved Problems:

- Images from a commercial all-sky camera are being continuously recorded every 30 seconds.
- A program named *haloloop* has been developed to search for a halo signal in individual images. Currently, the focus is on the 22-degree ice halo.
- The program detects the sun, removes the lens distortion and any intensity bias in the analysis area.
- The halo algorithm has been iteratively tested on large numbers of images and refined to maximize fraction of recognized halos and minimize the false halo signals.
- The program was tested on the first several months of 2015.
- The tests demonstrate that halos are a frequent enough phenomenon to consider them as a factor in cirrus observations.

Unsolved Problems and challenges:

- There are still halo signals for some images that do not actually contain a halo. In particular, altocumulus skies are difficult, as well as the occasional cloud constellation that triggers a halo signal.
- There also are halo images that do not trigger a halo probability, in particular during transitions between Cs and As, while the cloud layer is thickening and the halo begins to fade.
- A good low-cloud subtraction mechanism needs to be implemented.
- Camera downtime due to water, computer storage problems, and focus drift need to be addressed.
- A higher-resolution camera, lower horizon and perhaps a conventional-camera array would be desirable.

Outlook and questions

- How frequent are halos, really?
- How can they be used to assess temporal and spatial cirrus coverage?
- Can halo observations be used to assess the characteristics of cirrus clouds?
- Will long-term observations allow to observe changes in cirrus coverage?
- With better camera arrangements, will it be feasible to assess detailed information on crystal distributions, optical thickness, time evolution?
- Can this information be used to make inferences about the growth conditions at cirrus altitude?

We are also working on a Lidar project to measure the clouds in the third dimension.

Acknowledgements

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