Halo Identification Algorithm for Sky Images Produced in TSI Series

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Abstract

The goal of this project is to extract information about cloud composition, as well as about the spatial and temporal distribution of cirroform clouds based on ice halo observations. Cirrus optical scattering behavior is influenced by the types of ice particles, which may be present in many forms, including crystalline hexagonal habits in form of plates, pencils and prisms, hollow columns, bullets and bullet rosettes, and also as amorphous ice pellets, fragments, rimed crystals and others. If smooth hexagonal crystals are present, the optical scattering behavior of the cirrus cloud gives information about the cloud particle types in form of ice halos, most frequently appearing as a bright ring of 22° radius around sun or moon. An important question emerges: How can we use ice halos to improve our knowledge about the composition of cirroform clouds and the conditions in the upper troposphere? One of the first tasks is to establish frequency of halo appearances across seasons and years, as well as geographically. Sky images have been collected for decades at several research facilities. We are using series of images produced by Total Sky Imagers (TSI) at Atmospheric Radiation Measurement (ARM) Climate Research Facilities in order to assess the presence of ice halos on these sites. This study focuses on the Southern Great Plains (SGP) Central Facility[1]. The images have been produced and collected every 30 seconds over many years. We present an image-processing algorithm to automatically identify ice halos in TSI images. The radial brightness curve of four sky quadrants surrounding the sun are analyzed for all three color channels. The radial brightness decay, the presence of the bright band, and the general sky conditions inform a Sky Type Score (STS), and assigns an ice halo score (IHS). Data were obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Climate and Environmental Sciences Division.

Scored Image Properties

Sky Type Scores (STS)			
CS	PCL	CLD	CLR
Cirrostratus	Partly cloudy	Cloudy	Clear
Ice Halo Score (IHS)			

Basic Idea of the Algorithm

Define a set of N_p characteristic properties of the image

$$X = \{x_i\}_i^{N_p}$$

Position of target feature in space of properties at the mean values

$$M = \{\mu_i\}_{i=1}^{N_p} \text{ with } \mu_i = \frac{1}{N_{master}} \sum_{k=1}^{N_{master}} x_{ik}$$

With covariance matrix

$$\Sigma = \overline{(X-M)(X-M)^T} = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \dots \\ \sigma_{21} & \sigma_{22} & \dots \\ \dots & \dots & \dots \end{pmatrix}$$

To define

$$F_{image} = C_0 exp\left(-\frac{1}{2}\left(X_{image}-M\right)^T \Sigma^{-1}\left(X_{image}-M\right)\right)$$

Characteristic properties are continuously gathered and sorted in a master table, where means and inverse covariance table are computed.

Flow chart for program haloloop

Import
- List of images, calibration parameters, M and Σ^{-1} for STS and IHS

For each image
- Calibrate image for color, orientation, and distortion
- Identify sun position from geographical position and time
- Reposition and crop to generate sun-centered local sky map
- Compute and analyze radial intensity I(s)
- Compute the properties of I(s)
- Compute STS and IHS
- Running time average for IHS; output STS and IHS

Clean-up and close

Acknowledgement

Data were obtained from the Atmospheric Radiation Measurement (ARM) Program sponsored by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, Climate and Environmental Sciences Division. The work was supported by The Undergraduate Research Opportunities Program (UROP) at the University of Minnesota, as well as a grant to the University of Minnesota, Morris from the Howard Hughes Medical Institute through the Precollege and Undergraduate Science Education Program. SB wishes to thank the University of Minnesota-Morris for the generous one-semester release from teaching obligations, allowing the completion of this work.

References

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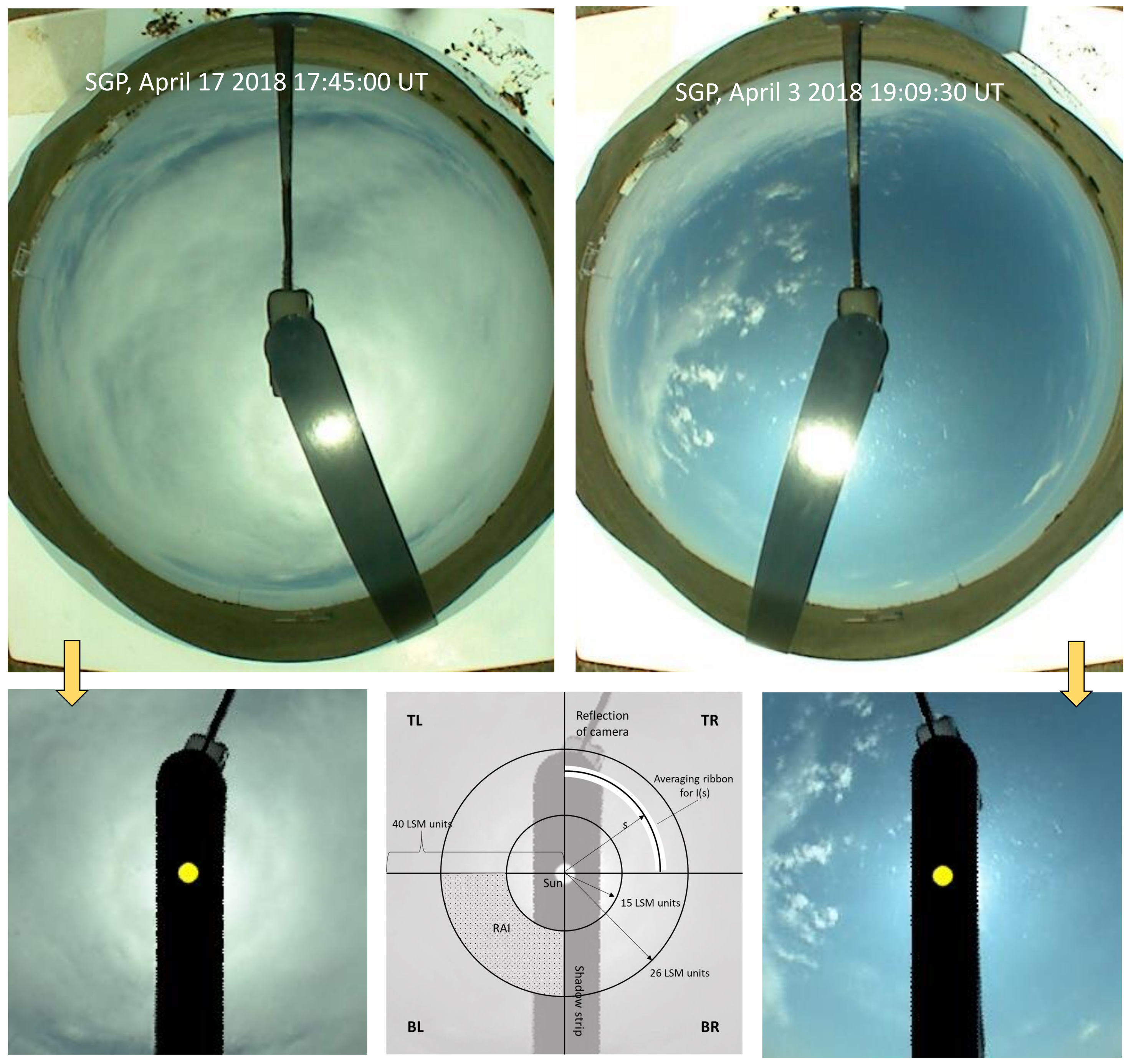
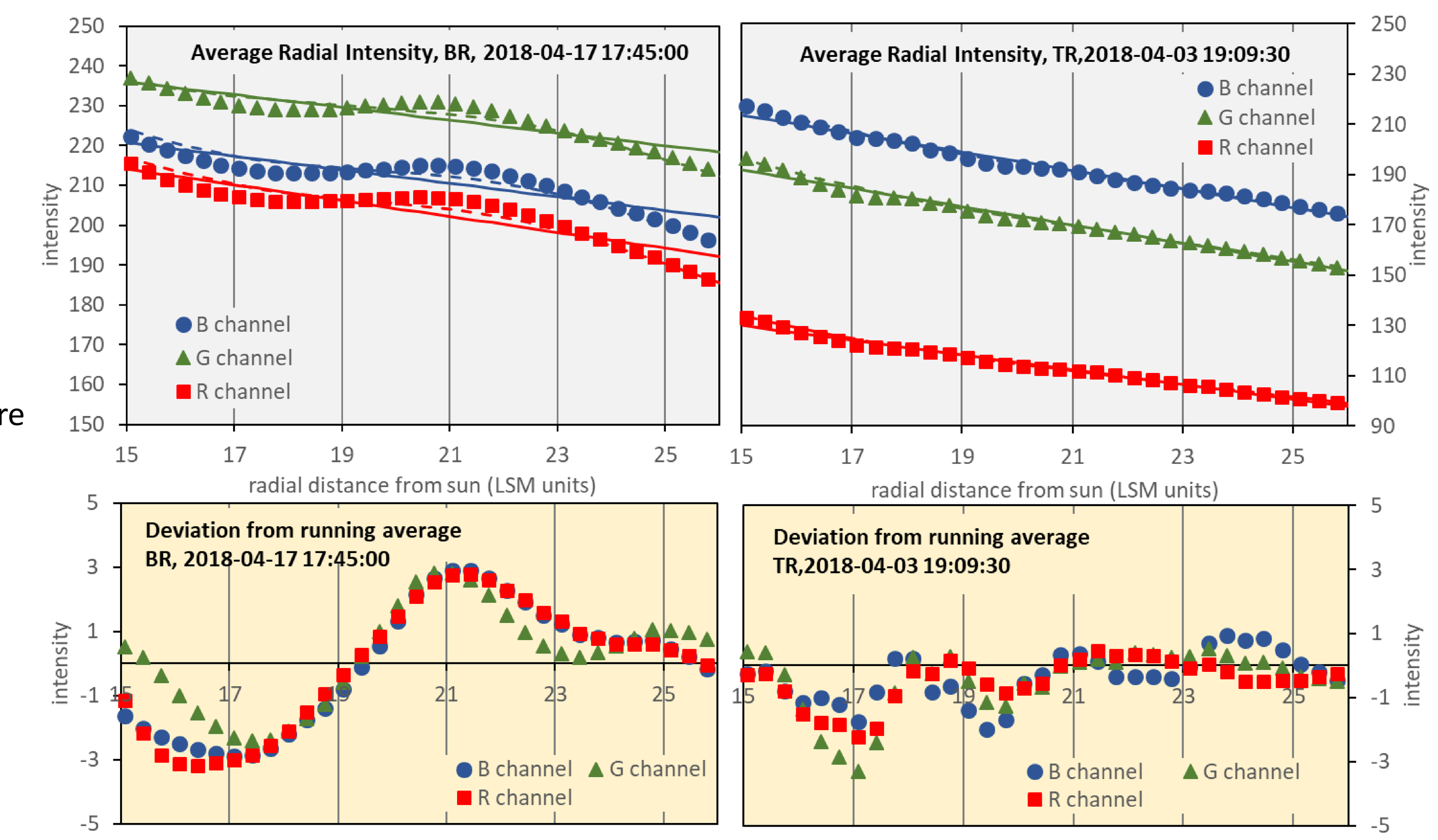
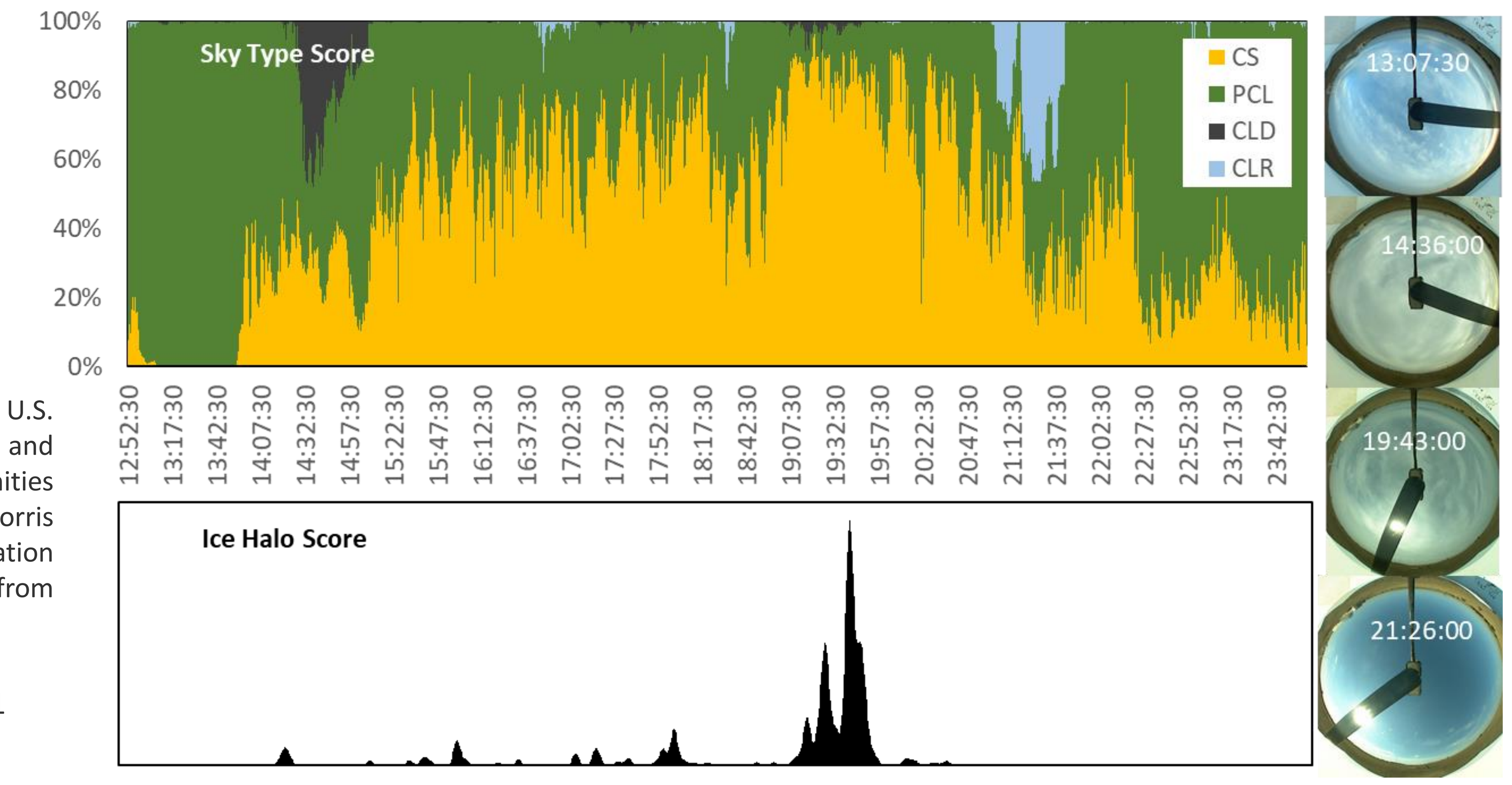
More details can be found in the extended abstract https://ams.confex.com/ams/2019Annual/meetingapp.cgi/Paper/351343

Characteristic Image Properties





A one-day example (SGP March 10 2018)



Performance Testing

results for SGP March 2018. Given are the percentages of images of visual type that have been assigned an algorithm type (%vis), and the percentages of the algorithm type that correspond to a visual type (%alg).

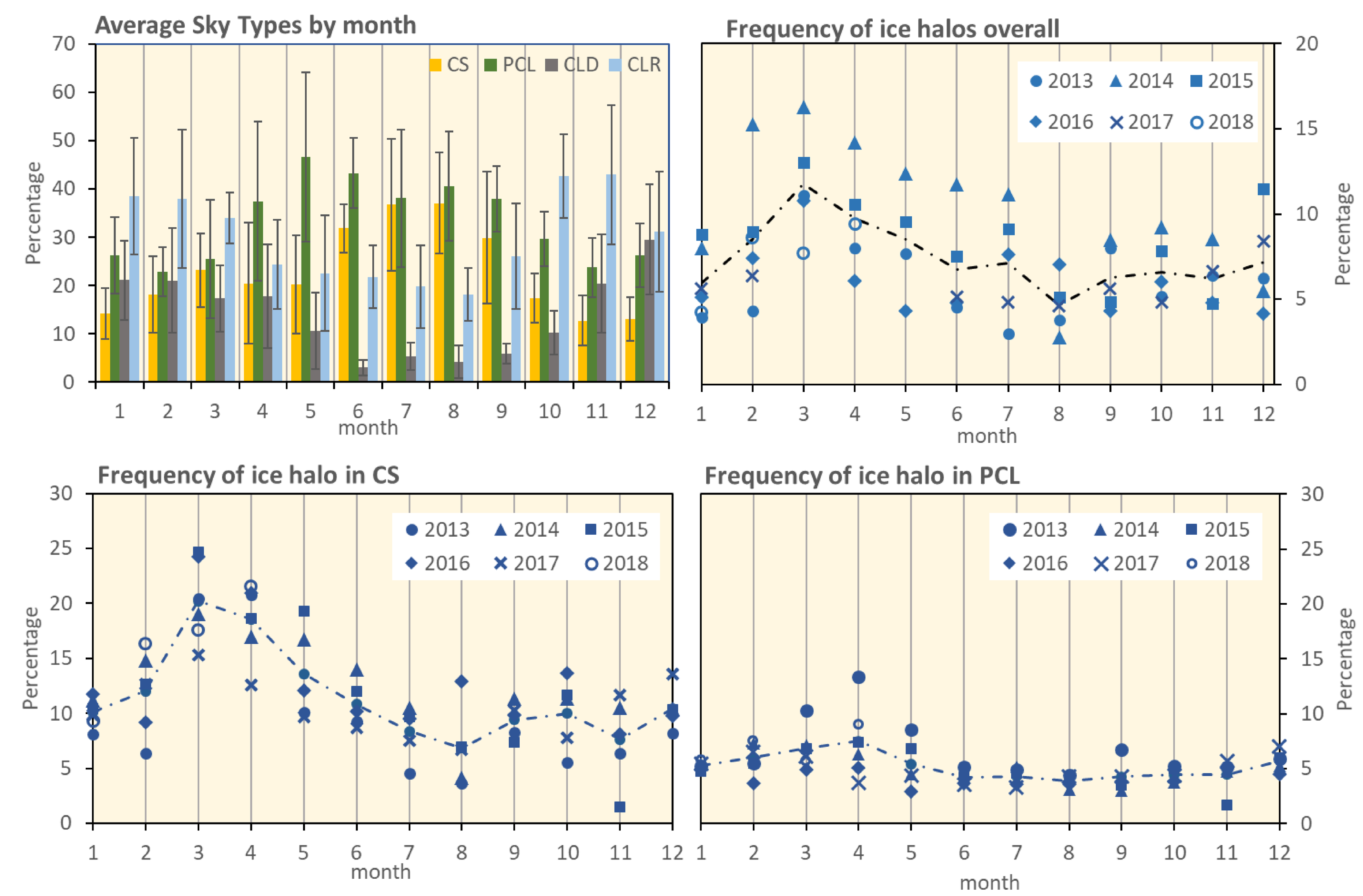
Algorithm assignment	Visual assignment							
Sky Type	CS		PCL		CLD		CLR	
	%vis	%alg	%vis	%alg	%vis	%alg	%vis	%alg
CS	**88**	**86**	11	9	1	0	4	5
PCL	2	3	**87**	**91**	3	3	2	3
CLD	1	1	1	1	**97**	**98**	0	0
CLR	8	6	2	1	0	0	**95**	**93**
N/A	12597 (40% of all images)							

Ice Halos	22° halo		No 22° halo	
	%vis	%alg	%vis	%alg
22° halo	**85**	**88**	1	12
No 22° halo	15	1	**99**	**99**

Long-term findings

The data represent the findings from the Southern Great Plains TSI record (SGP) from January 2013 to April 2018. During this time period, on average 49 incidences of ice halo have been observed per month.

Ice Halo Persistence Time		Frequency of partial ice halo appearances	
average time	21 min	only one quadrant	5 %
minimum detectable time	4 min	two quadrants	27 %
average monthly maximum time	140 min	three quadrants	35 %
maximum observed (Sep 12 2017)	412 min	all four quadrants	33 %



Conclusions and Outlook

An algorithm for the detection of ice halos in TSI images has been developed and applied to the recent several years of the TSI record collected at the SGP ARM site. This algorithm was tested and trained on a complete month's record, taken at the SGP site in March 2018. The algorithm is flexible and trainable, and can be expanded for other image features. Sky type and ice halo scores are assigned based on the behavior of the radial brightness gradient in the near-solar region of an image. Tests show that the scoring of sky type and halo presence is about 90% reliable. Data on the annual variation in sky type and annual distribution of ice halo appearances have been presented. In order for an ice halo to form, smooth crystal habit must be represented in the atmosphere. We find that this crystalline habit peaks during March and April for the SGP site.

Further work will address:

1. An analysis of the complete SGP record, as well as NSA, and ENA records. We will find insight into temporal and geographical distributions of ice halos and their relation to cirroform clouds.
2. Such an analysis will be significantly strengthened with the inclusion of ceilometer and Lidar data, depending on availability. The usefulness of other radiative measurements for the analysis will be explored.