Weather trends at the Magdalena Ridge Observatory

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ABSTRACT

There have been astronomical observatories on Magdalena Ridge in south-central New Mexico since the late 1960s. Magdalena Ridge is relatively flat, at an average elevation of 10,560 feet (3220 meters) with a north-south length of 3/4 of a mile. In 2000 the Magdalena Ridge Observatory began site testing for two new facilities: a 2.4-meter optical telescope and a 10-element optical interferometer. As part of that testing, meteorological instrumentation was deployed at several locations across the mountain. As a result, we have an 18 year history of regular experience with the environment, including weather and cloud cover data for much of this time period. We present trends in the basic meteorological parameters: temperature, humidity, barometric pressure, wind speeds and directions, and cloud cover. Diurnal temperatures ranges vary from 15 C° in the spring when it is largest to 10 C° in the summer months when it is smallest. Barometric pressure varies more in the spring and fall than in the summer. Annual rain fall levels vary greatly with an average of about 10 inches of rain per year. The snow amounts have traditionally been very hard to measure as the area is partly above the tree line and wind-blown snow can leave parts of the region barren while other parts have a foot or more of snow. Winds speeds are typically 10 to 20 miles per hour. Wind speeds have been measured above 100 mph (45 m/s), with wind gusts as high as 125 mph (56 m/s), though this is primarily a spring phenomenon. The wind direction is predominately out of the Southwest. Wind speeds at the 2.4-meter telescope location are frequently 2 times as high wind speeds at the optical interferometer site due to the differences in terrain to the West of the two sites. An optical allsky camera has been in operation on the Ridge from 2003 to 2012 with nightly sequences of images obtained on most nights when the winds were less than 15 m/s and the humidity below 90%. Analysis of this imagery shows that a majority of the nights would be useable for astronomical observations. We present an overview of statistics of the site and discuss how these statistics will be used for defining appropriate operational windows for the Magdalena Ridge Observatory Interferometer.

Keywords: Weather conditions, allsky imagery,

1. INTRODUCTION

The area known as Magdalena Ridge at an elevation of 10,560 feet (3220 meters) was first operated as a thunderstorm research station in 1963 and a lightning research station in 1964[1]. It was named after Nobel Laureate Dr. Irving Langmuir. In 1970 an area 8 by 9 kilometers was set aside as a restricted air space so the atmospheric scientists could conduct rocket launches up into thunderstorms to study electric fields and other parameters of thunderstorms during the summer monsoon seasons. In the late 1960s a supernova search telescope[2] was installed as the first astronomical observatory. In 1973 a small observatory consisting of 14-inch photographic Schmidt telescope and a 16-inch f/35 planetary telescope, obtained from NASA Goddard Space Flight Center, was constructed to photograph comets to determine the nature of interplanetary magnetic fields. It was known as the Joint Observatory for Cometary Research, JOCR[3] and it was in operation until 1992. In 1985 some 35,000 acres around the top of Magdalena Ridge in Cibola National forest were set aside for astrometric and astronomical research by Congress. This law allows continued access to the clear dark skies at a high elevation where one can see for 150 miles in every direction except up (where with the unaided eye one can see at least 2.5 million light years). In 2000 the Magdalena Ridge Observatory, MRO, began studying the meteorological and environmental data of the site in a concentrated way. This paper will present results from that study covering a period of 18 years from June 2000 through the present day.

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2. METEOROLOGICAL STATIONS

During the last 18 years, meteorological stations have been located at various locations on Magdalena Ridge. Figure 1 shows these locations. The approximate locations of 6 weather stations are indicated. Table 1 gives the station name, data logger brand and model number and the period of operation for each station. As with any outdoor measuring system the coverage is not complete due to various conditions like power or equipment failure, hoar frost, etc. All stations except NCDC record at a minimum: temperature, pressure, relative humidity, wind speed and direction. The NCDC station only provided temperature and precipitation.

Figure 1. An artist impression of the completed MROI array showing the locations of the meteorological stations and other facilities on the Ridge.

Table 1. Magdalena Ridge weather stations

Magdalena Ridge weather stations																				
Location	data logger	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
2.4-meter (1)	Vaisala WXT510 + Thies Anemometer								■	■	■	■	■	■	■	■	■	■	■	■
MROST (2)	Campbell Scientific CR10x + sensors				■	■	■	■	■	■										
NCDC (3)	N/A											■	■	■	■	■				
MROI center (4)	Campbell Scientific CR10x + sensors						■	■	■	■										
MROI tower (5)	Campbell Scientific CR1000 + sensors										■	■	■	■	■	■	■	■	■	■
Microphone Hill (6)	Davis Instruments + sensors	■	■	■	■	■	■	■												

3. TEMPERATURE RANGES

Figure 2 shows the minimum and maximum temperatures for each year from all of the weather stations. When there is more than one symbol for a given year this implies that we were getting data from more than one weather station. The maximum daytime temperature never got about 30° C (86°F). The minimum nighttime temperature never got below -20°C (-4°F). The minimum values below -30°C (-22F) are a result of faulty readings from the weather stations. The various weather station data loggers would set an obvious error value when that happens.

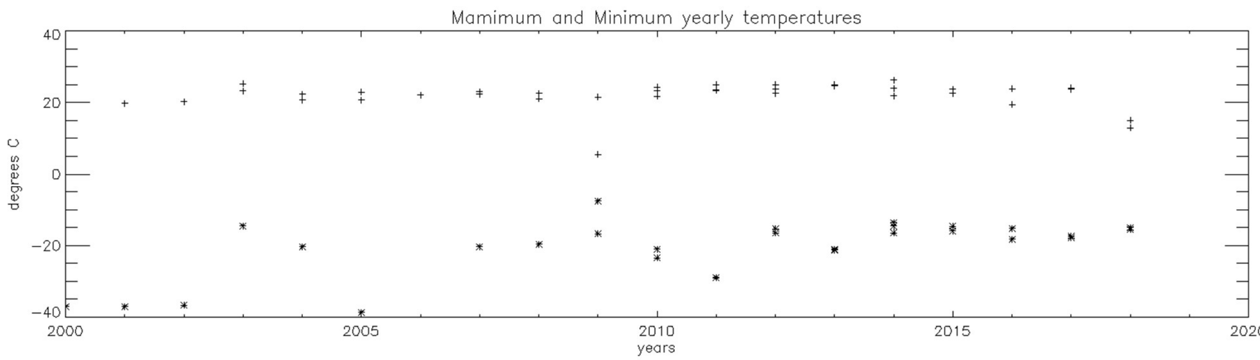

Figure 2. Minimum and maximum temperatures from all weather station for the years 2000 through 2018.

Figure 3 shows the combined diurnal temperature range for all of the weather stations. While there is a great deal of scatter, there clearly is a trend that the diurnal range is larger during the late spring months, (days 80 – 160), compared to winter months (days 320 – 80). This is probably due to the dry atmosphere in the late spring, which favors strong radiative cooling to space at the surface[4].

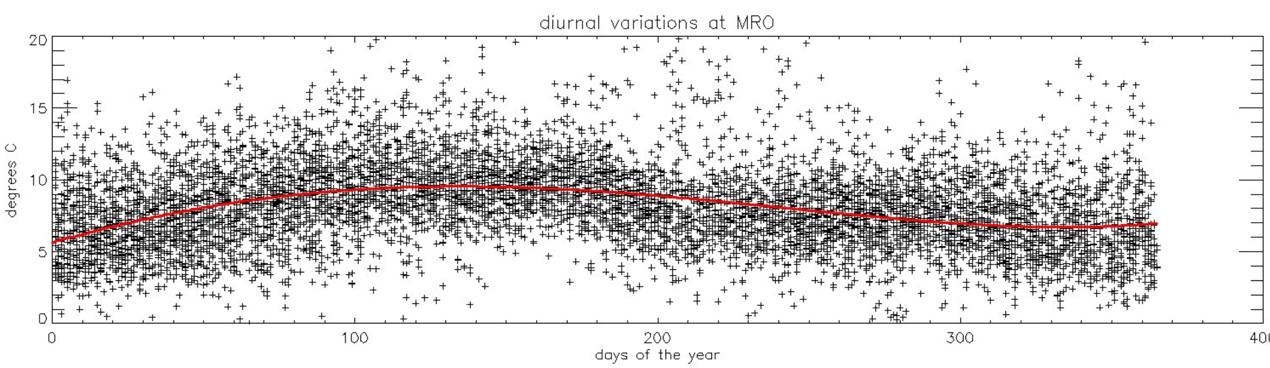

Figure 3. Diurnal temperature variations for all of the weather stations on Magdalena Ridge.

4. BAROMETRIC PRESSURE

Five of the 6 weather stations recorded barometric pressure once per hour. There is a variation of elevation on the order 45 meters between the various barometers. Pressure drops 1.1 mbars for every 10 meters in increased elevation. Nevertheless, our barometers were within a few mbars of each other over course of the 18 years that we have been recording meteorological parameters. There is no long term trend in the barometric pressure at our observatory. There is annual range variation in the daily pressure values as shown in figure 4 which the pressure results from the 2.4-weather station. It is easy to pick the low pressure systems that passed over the observatory. Interestingly enough the diurnal pressure variation during the summer months is about 1/3 to 1/4 variation during the rest of the year. There are generally fewer mid-latitude storm systems at our latitude due to fact that the storm track has moved well to the north and weakened[4].

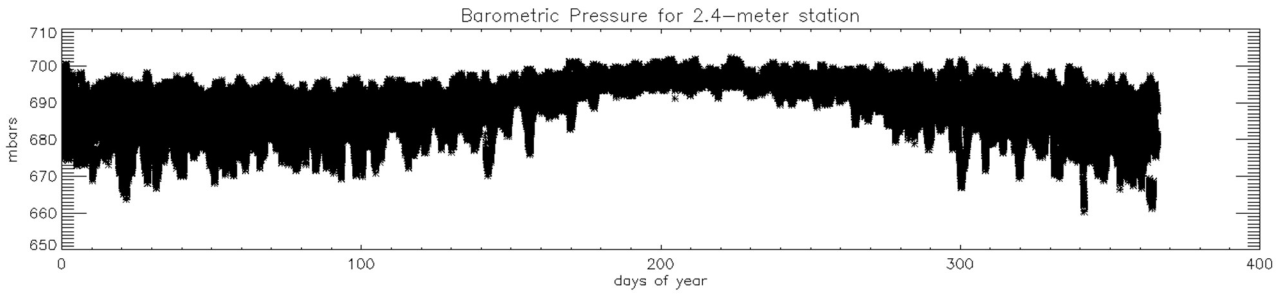

Figure 4. Barometric pressure from the 2.4-meter weather station for the years 2007 - 2018.

5. WINDS

Five of the 6 weather stations have anemometers. Microphone hill, MROST and MROI Center used cup anemometers. MROI tower uses a propeller type anemometer. The 2.4-meter weather station uses a Thies anemometer with no moving parts. During the 18 years we have measured winds speeds of over 45 meters/second. The wind rose shown in Figure 5 is a 3-D histogram presenting both wind speeds and wind direction. The circles are wind speeds in meters/second. The cardinal points represent wind direction. North is 0° azimuth, East is 90°, South is 180° and West is 270°. The values in the histogram are the number of times that we recorded a wind speed at a given azimuth. The period covered was from 2003 through 2008 from the MROST weather station. The color coding is such that the outer black points are the fewest counts and the inner pink points are the largest counts. The spike pointed to North is a caused by the fact that the anemometer used at the MROST site had a dead band from 355° through 360°. This result for MROST is our most complete data that we have. The MROST weather station has had the highest average wind speeds probably because it is at the highest elevation on the Magdalena ridge. Also the mountain drops off steeply to the west. The interferometer array has at least a half mile of relatively flat terrain to the west which tends to slow down the wind coming from the west.

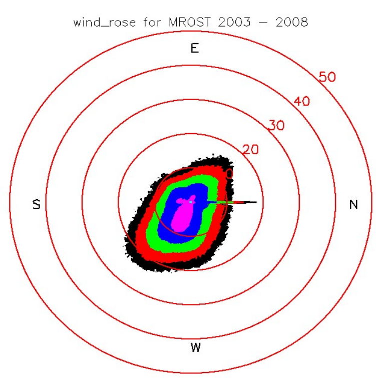

Figure 5. Wind Rose for the MROST anemometer that was in operation from 2003 through 2008.

6. DEW POINT AND RELATIVE HUMIDITY

One of the major concerns at an astronomical observatory that has lots of optical surfaces open to the night air is moisture (dew and/or frost) forming on the optical surfaces. The extent to which one operates close to the dew point really depends on the chance one is willing to take to get that last bit of data before the optical surfaces become wet. In other words, how close to the dew point is one willing to operate? Most all modern weather station systems can calculate the dew point given the air temperature and relative humidity. The plot in figure 6 shows the difference between air temperature and dew point as a function of relative humidity for the 2.4-meter weather station.

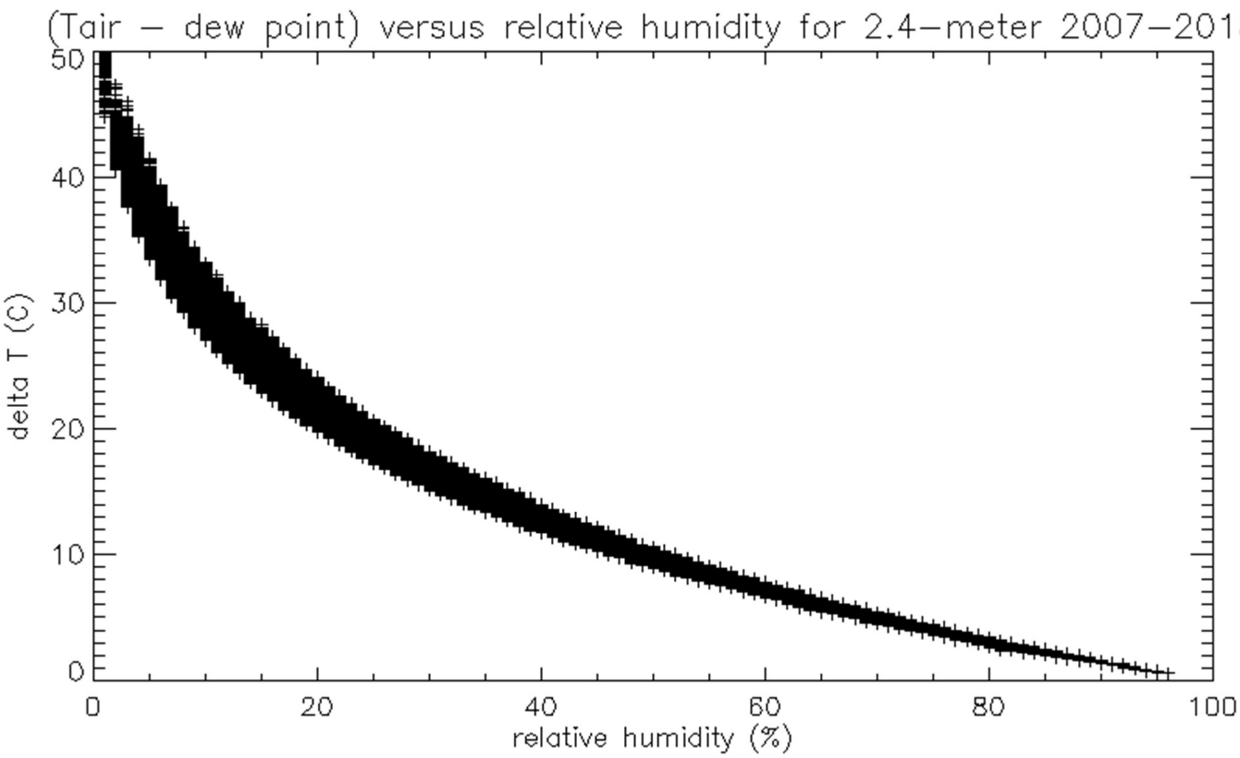

Figure 6. Difference between T_{air} and dew point versus relative humidity for 2.4 met

7. LONG-TERM TRENDS

While the previous sections show variations during the year, nothing stands out as a long-term change in the meteorological parameters. However, there is an observation that does show a long-term change. We have recorded the first and last frost for each season from 2000 through the end of the winter of 2017. The results are shown in figure 7. The vertical axis is the day of the year and the horizontal axis is the year. The blue points are the last frost for a given year and the orange points are the first frost for the previous year. There is more than one point per year because we had multiple weathers functioning at the same time as shown in table 1. The dotted lines are least squares fit with a linear function to the two sets of data. In 2000 there were 138 days that had no freezing and in 2017 there were 150 days that had no freezing. It appears that it has been warmer more often in 2017 than in 2000.

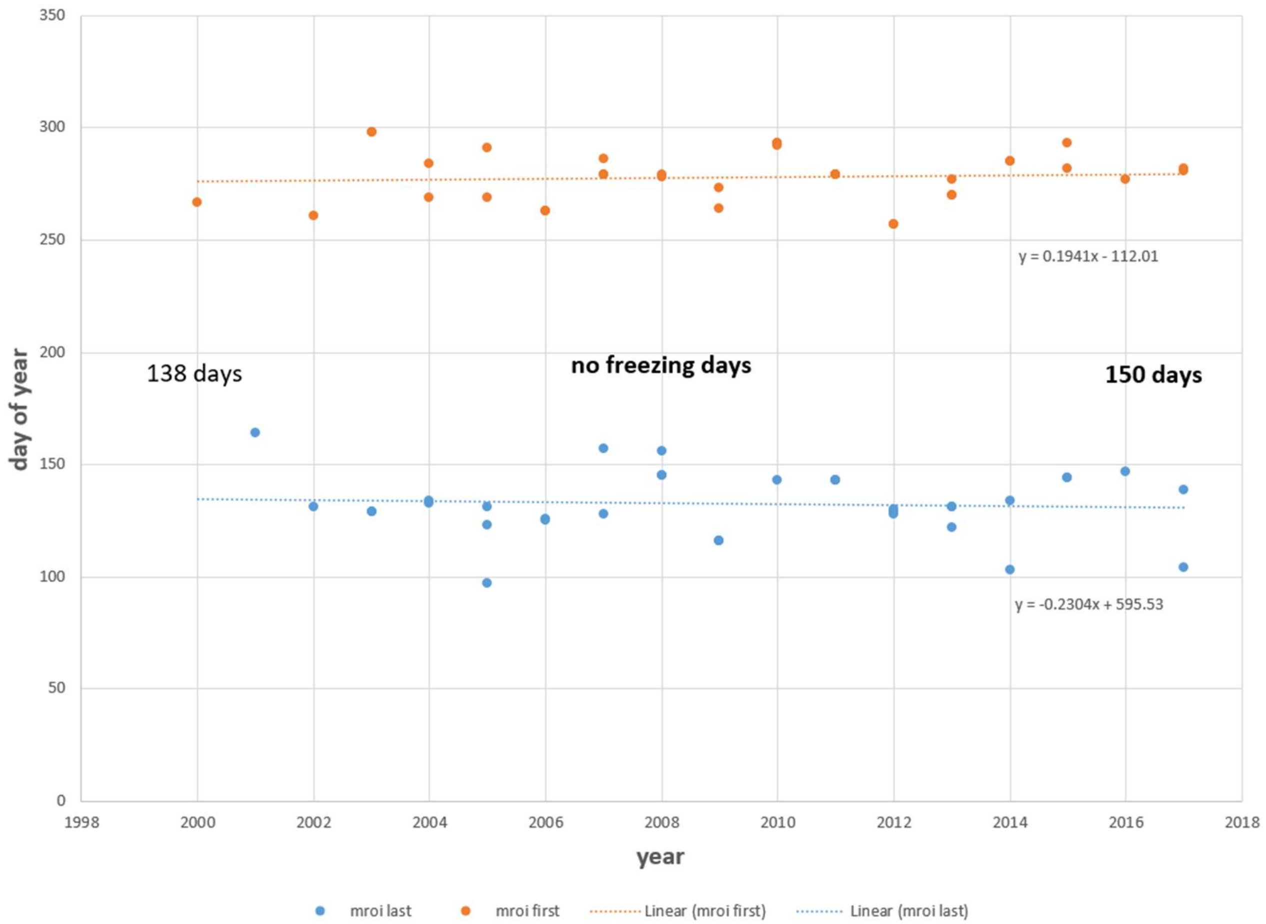

Figure 7. Long-term trends in the number of frost free days.

8. ALLSKY IMAGERY

8.1 Introduction

In order to make the best use of sky conditions once we are operational, we will make use of real-time weather predications and an allsky camera that allows the array operator see the actual visible cloud cover. During the course of the 18 years of study we have had two different versions of the Santa Barbara Instrument Group, SBIG, allsky cameras. We currently are using the black and white SBIG-340 system[5]. The system generates a 640 x 480 pixel image. The pixel size is 7.4 microns. The camera lens is a Fujinon FE185C046HA-1 f/1.4 with a focal length of 1.4 mm. We normally take a 15 second exposure every 5 minutes from the end of astronomical evening twilight to the beginning of astronomical twilight the following morning.

We are attempting to determine sky conditions automatically by continuing the work of Ben Webb and Hugh Emerson in their master's projects at Cambridge under the direction of David Buscher from Cambridge University. To do this we have divided the allsky imagery into two parts, images with bright moon and images with little to no moon and processed them separately. The reason for the separation of the images into two parts is that the bright moon saturated a large part of our images, skewing the averages, medians and standard deviations. For the no-moon imagery we use four categories: dark/clear, dark/cloudy, clouds present and/or moon, and stars present/clear. For the moon imagery we use three categories: clear, clouds present and/or moon and full moon.

8.2 Analysis procedure

A dark image is taken at the beginning of the night after the CDD had been cooled down to a stable temperature. It is then subtracted from the raw allsky images taken during the night to minimize electronic noise. From the dark subtracted images we compute the average level, the median level and the standard deviation of the each image. Table 2 shows Standard Deviation Range that was used to determine which condition was selected. We used the median value of the image instead of the Standard Deviation.

Table 2. Criteria for determining sky conditions for MROI allsky imagery.

Condition	STD range		Notes
no-moon imagery			
	lower	upper	
dark/cloudy	0	350	
dark/clear	350	800	
clear/stars	800	1400	
clouds and/or some moon	1400	4000	
moon imagery			
clear/stars	0	2300	
clouds and/or moon	2300	3600	
full moon	0	500	using median rather than STD

After running the computer analysis all of the images were visually inspected and an independent judgement of the image quality was made. Table 3 shows the agreement between the two analyses. For the no-moon imagery we obtained much better agreement between the two. For the moon imagery the agreement was not as good due wide variation in conditions when the moon was bright. Table 3 has 5 columns: image year, numbers processed, number of images that agreed, number that did not agree and percent of agreement. Clearly the no-moon imagery was easier to classify. We will be proceeding with more techniques to break the image into segments that should allow taking into account both the overexposed areas.

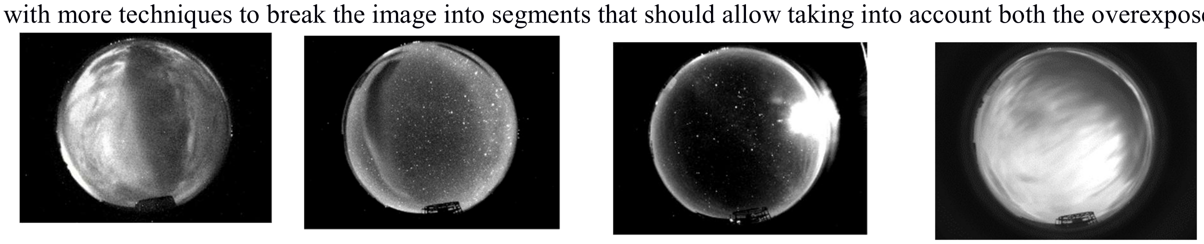

Figure 8. typical images from the no-moon set. Left to right: dark/cloudy (STD 9 – 350), dark/clear (STD 350 – 800), clear/stars (STD 800 – 1400), clouds and/or moon (STD 1400 – 4000)

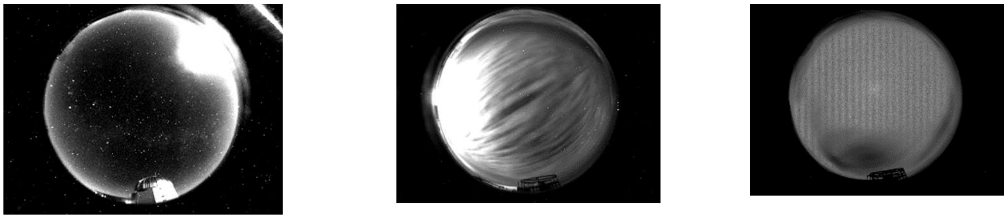

Figure 9. Typical images from the moon set. Left to right: clear/stars (STD 0 – 2300), clouds and/or moon (STD 2300 – 3600), full moon (median 0 – 500)

Table 3. Agreement between computer analysis and visual estimations for the allsky images

Figures 8 and 9 show typical images for the various conditions that we selected. There is a lot of variation in the images for any one criteria. We will be refining that classification scheme in the future.

9. CONCLUSIONS

Agreement between computer and visual analysis				
year	# images	# agree	# disagree	% agree
2003 moon	42	31	11	74
2004 moon	142	124	5	87
2005 moon	142	91	51	64
2006 moon	348	193	155	55
2007 moon	378	193	185	51
2008 moon	383	252	131	66
2003 noomoon	139	124	5	89
2004 noomoon	307	270	33	88
2005 noomoon	179	152	23	85
2006 noomoon	455	405	50	89
2007 noomoon	569	520	49	91
2008 noomoon	684	646	38	94

While there are several annual trends in our meteorological data. There is only one long-term trend and that is the fact that we see an increase in the number of days per year that are warmer. From photographic records, and as implied by first and last frost dates, it is clear that there is less snow now in winter of 2017-2018 than there was 10 or 20 years ago.

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