DECam Note
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Useful Observation Time at CTIO for the Dark Energy Camera Survey

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Abstract

We estimate the "useful" observation time for the Dark Energy Camera Survey. The airmass through which images are taken, the ephemeris of the moon, and weather statistics at CTIO are used to estimate useful observation time for the Dark Energy Camera project. In the five year period between 2008-2013, we estimate the number of dark hours to be 1749 $\pm$ 114 hrs. The number of additional hours of grey time is estimated to be 1665 $\pm$ 155 hrs. The number of "useful" hours will be reduced when considerations of the survey area at high airmass or even below the horizon are taken into account.

1 Introduction

The Dark Energy Camera (DECam) project seeks to perform a wide field astronomical survey with precise photometry in four, *griz*, filter bands. The total area of the survey is determined by the number of available "useful" hours for observing at Cerro Tololo Inter-American Observatory (CTIO) and the time between exposures in each of the four filter bands. By "useful," one requires the survey area to be at low airmass, dark skies, and good weather conditions. For the *gr* filter bands, dark skies are moonless hours between astronomical twilight. For the *iz* filter bands, useful observing can be performed during times when the moon is above the horizon provided it is not too close to the area towards which the telescope is pointed. Also, some cloud cover is allowed in observing the *iz* filter bands.

We use an astronomical planetarium program [1] to simulate the time during which the survey area is at low airmass. In order to estimate the expected number of useful hours available for the survey, one needs to determine the location of the moon during the night. The same planetarium program also calculates the ephemeris of the moon. One also needs to estimate the expected impact by weather effects such as cloud cover. Information on cloud cover is provided by NOAO in a historical form nightly for years 1975-2003 where each quarter of the night is evaluated [2]. We perform analysis on this historical cloud cover data to estimate the weather impact on the usefulness of observation.

2 Survey area

We make the following assumptions regarding the survey area, which is not yet finalized. The assummed survey area is shown in Fig. 1. In this note, we consider the survey area to be between declinations of 30° and 75° in celestial south latitude in order to be at least 30° above the horizon at the south pole and 45° above the horizon at CTIO. We define low airmass to be at least 45° above the horizon. We are interested in surveying right ascension (RA) between 21^{h} and 6^{h} such that the south galactic pole, through which there is a minimal amount of galactic dust, is near zenith at midnight close to the middle of our survey period. The survey area is slightly shifted towards RA 6^{h} in order have extend viewing into January when the seeing is improved at CTIO [3]. The effect on "useful" seeing of the boundaries of the survey area not being observable through low airmass will be discussed near the end of this document.

3 Hours of darkness

Hours of darkness can be calcuated as the time between evening and morning twilight. Astronomical twilight is usually defined as beginning and ending when the center of the refracted sun is 18° below the horizon. Similarly, civil and nautical twilights are defined when the sun is 6° and 12° below the horizon respectively. For this note, we assume only hours between astronomical twilight can be considered as dark time or of photometric quality. Time outside of this period but between nautical twilight may be used for calibrations or for other observations besides the main wide field survey.

Figure 2 shows the hours of darkness using civil, nautical, and astronomical twilight as a function of day of the year. The months of June and July have the longest nights on average; however, as will be discussed, the months during December and January offer better seeing and have better weather in terms of less cloud cover. It is fortuitous that these months also present at high altitude the region near the south galactic pole that is the target for the DECam survey.

4 Ephemeris of the moon

When the moon is above the horizon, seeing is degraded especially at the shorter wavelengths covered by the *gr* filters [4]. The moon limits photometric nights for these wavelengths. In order to understand the impact of the presense of the moon, the dark hours are calculated for the five year period 2008-2013 (year 2013-2014 is also included). Figure 3 shows the hours of darkness as a function of day taking into account the presence of the moon above the horizon. As an initial proposal, it is suggested that the DECam survey cover five lunar cycles that end in the month of January. Table 1 provides the dates of the survey according to this initial proposal.

We can also compute the total number of possible photometric hours for each of the planned survey years. Since each survey year starts on a different date and the nights are shorter near the year boundary, we expect differences between the survey years. Table 2 also shows the maximum number of photomentric hours for the different survey years. Note that surveys beginning in 2008 and 2011 are within four days of starting; yet, the difference in the maximum number of possible photometric hours is 41.2 hours (a 7% effect).

	Survey start		Survey end	
Year	Date	Day of the year	Date	Day of the year
2008 - 2009	Aug 18	231	Jan 8	8
2009 - 2010	Sept 6	249	Jan 27	27
2010 - 2011	Aug 26	238	Jan 16	16
2011 - 2012	Aug 15	227	Jan 6	6
2012 - 2013	Sept 2	246	Jan 23	23
2013 - 2014	Aug 22	234	Jan 12	12

Table 1: Initial proposal of the dates of observing. Dates are chosen to finish before the end of January and to cover five lunar cycles beginning with nights when the moon is below the horizon.

5 Cloud cover at CTIO

The presence of clouds generally obscures good photometric viewing. Historical data on cloud cover at CTIO is provided by estimating the fraction to the nearest $1/8^{\mathrm{th}}$ of the sky covered by clouds over four quarters of each night beginning in 1975. Figure 4 shows the average fraction of cloudless nights as a function of the day of the year and as a function of season for the yearly data. As a function of day of year, the advantages of the months Oct. through Mar. show an average of 62.6% cloudless, while the months Apr. through Sept. are cloudless an average of 32.4% of the time. If one considers quarters of the night with $3/8^{\mathrm{ths}}$ cloud cover or less, the average fraction of these nights rises considerably by a factor of 1.3-1.4. The yearly variation, however, is considerable. As a function of year, Fig. 4 shows considerable scatter about the averages depending upon the year. Vertical lines show rough periods of strong El Niño [5] years when the fraction of cloudless nights for the Oct. through Mar. nights is less than 50%.

6 Dark time and Grey time

For the expected survey years beginning in 2008-2009 through 2012-2013, we can compute the expected dark hours when both the presence of the moon and the average weather is taken into account. Figure 5 displays this information by showing the average effect of weather (based upon the 1975-2003 weather statistics) overlayed with the number of moonless hours. The fraction of time expected to be not affected by clouds is also displayed graphically. From this calculation, one can derive both the total possible dark hours (no weather effects) and the expected number of dark hours with weather included. These derivations are tabulated in Tab. 2. Note that yearly correlations exist so that the expectation of a five year survey would not necessarily be the sum of averages.

We can derive the number of grey hours that are defined for this note as those hours useful for observation in the *iz* bands. Figure 6 shows a calucation based upon Sloan Digital Sky Survey Data on the impact of seeing in the different filter bands as a function of the angular distance to the moon. Thus, grey time include hours when the moon is up provided the telescope not pointed towards the moon within $30°$. Because the moon is within $5.5°$ of the ecliptic plane and because the ecliptic plane is always at least $66.5°$ of the south galactic pole, the moon is never closer to our observing area than $60°$. Thus, the moon should never affect photometric observations in the z band. In the i band, the moon can have an effect; however, the fraction of the time the moon can effect the i band is small such that careful scheduling between the i and z bands should allows for fully efficient use of time when the moon is above the horizon. Figure 7 shows the amount of grey time (not dark time) available for the different survey years requiring cloudless nights. Note that these hours peak out of phase with the dark hours shown in Fig. 5. The derivation of the number of grey hours for the different survey years is tabulated in Tab. 2.

We can also derrive the number of grey hours available if one also allows for cloud cover of $3/8^{\text{ths}}$ or less. Table 2 includes this calculation. If the clouds do not obscure the actual image field, then there are potentially more hours available for grey time imaging. It is suggested that these additional hours not be included in calculations that estimate the number of "useful" hours; rather, they be considered as some contingency.

	Dark	Dark with	Min	Max	Grey	Grey with	Grey with
Year	hrs.	weather hrs.	hrs.	hrs.	time hrs.	weather	$3/8^{\text{ths}}$ clouds
2008-2009	621.2	368.5	260.6	460.4	544.2	320.6	559.9
2009-2010	586.9	377.5	289.7	492.8	526.9	337.3	554.1
2010-2011	576.2	352.9	269.8	429.7	567.1	349.5	578.6
2011-2012	580.0	342.3	236.1	444.5	605.9	361.3	605.8
2012-2013	557.8	349.0	267.1	464.1	562.7	357.2	575.5
2013-2014	589.3	352.4	262.3	430.2	566.4	344.6	578.7

Table 2: For the survey years indicated, the number of hours with no moon between astronomical twilights is shown along with the average number of expected hours based upon weather statistics. The minimum and maximum hours correspond to the overlay of the worst and best weather from 1975-2003 upon the survey year. Grey time is the total and expected amount time available for viewing in the iz filters.

The expected number of dark and grey hours during the entire five year survey must include some averaging of the effects of weather. As seen in Fig. 4 and tabulated in Tab. 2, the minimum or maximum number of hours available in an given year can vary considerably. Thus, to calculate the expected number of "useful" hours available, we consider a mapping of the dates of our planned survey years (Tab. 1) onto rolling five year periods of weather statistics beginning with 1975-1979 through 1998-2002. Figure 8 shows the sum of the expected dark time and additional grey time for the different five year periods. Note that there are correlations between adjacent point and next-to-adjacent points since the points share common years. It is thus difficult to quantify the variation observed from these data. We simply use 1/2 the range (i.e. the max minus min) of hours. From Fig. 8, the expected (mean) number of dark hours available for the survey is 1749 ± 114 hrs. The expected number of additional grey hours is 1665 ± 155 hrs. As a contingency, the grey time available allowing for up to $3/8^{\text{ths}}$ cloud cover is 2791 hrs.

7 Survey area at high airmass

We still have to estimate the reduction in useful hours due to the fact that part of the survey area is at high airmass or below the horizon at the edges of the survey time. We can use only partial nights in Aug.-Sept. and Dec.-Jan.

8 Determination of “useful” observing at CTIO

9 Conclusions

References

[1] The program Skymap Pro 9, www.skymap.com, is used to calculate hours of darkness, twilight, and ephemeris of the moon for latitude (30° 9’ 57”.8 S), longitude (70° 48’ 54”.36), and elevation (2210m) of CTIO. The geographic data comes from the following: http://www.ctio.noao.edu/facil/s1/sec1.html Local mean time includes an adjustment for daylight savings time.

[2] Cloud cover can be found at the following URL for sky conditions at CTIO: http://www.ctio.noao.edu/site/phot/sky_conditions.html

[3] Seeing information can be found at the following URL: http://www.ctio.noao.edu/telescopes/opteng/optics.html

[4] H. Lin, private communication based upon study of Sloan Digital Sky Survey data by D. Tucker.

[5] A concensus of El Niño years can be found at: http://ggweather.com/enso/years.htm

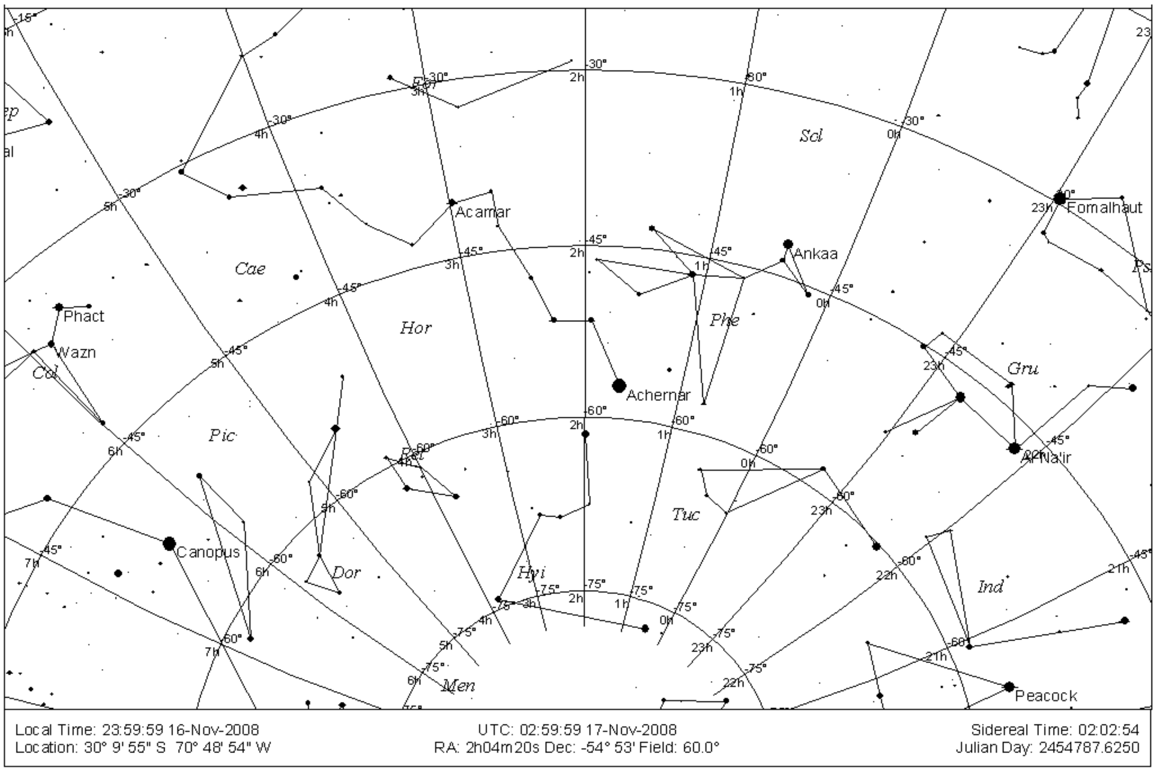

Figure 1: The assummed area for the Dark Energy Camera survey is shown. The area is the view looking south from CTIO at midnight on Nov 16. The declination and right ascension coordinates are shown where the axes converge onto the south celestial pole.

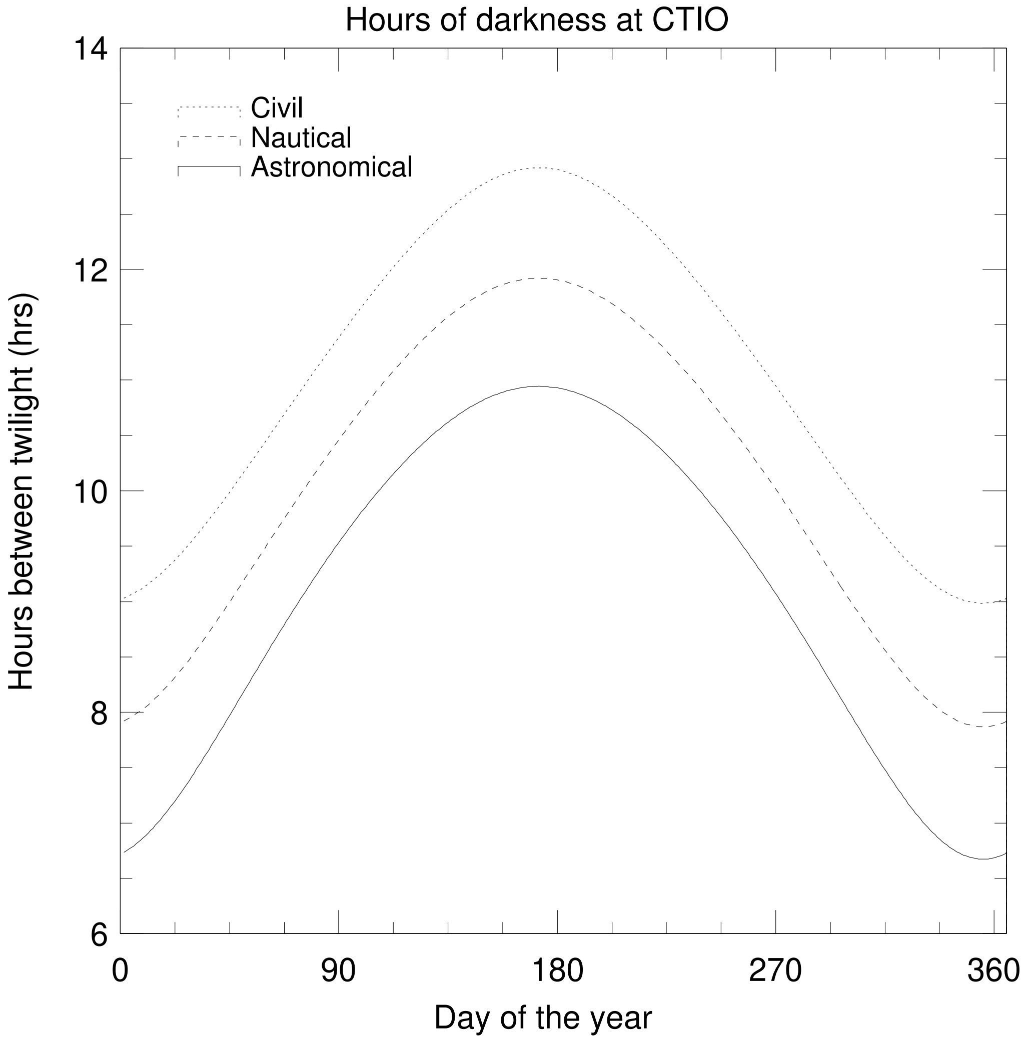

Figure 2: As a function of day for year 2008, the number of hours of darkness is shown for the time period between astronomical (solid), nautical (dashed), and civil (dots) twilight.

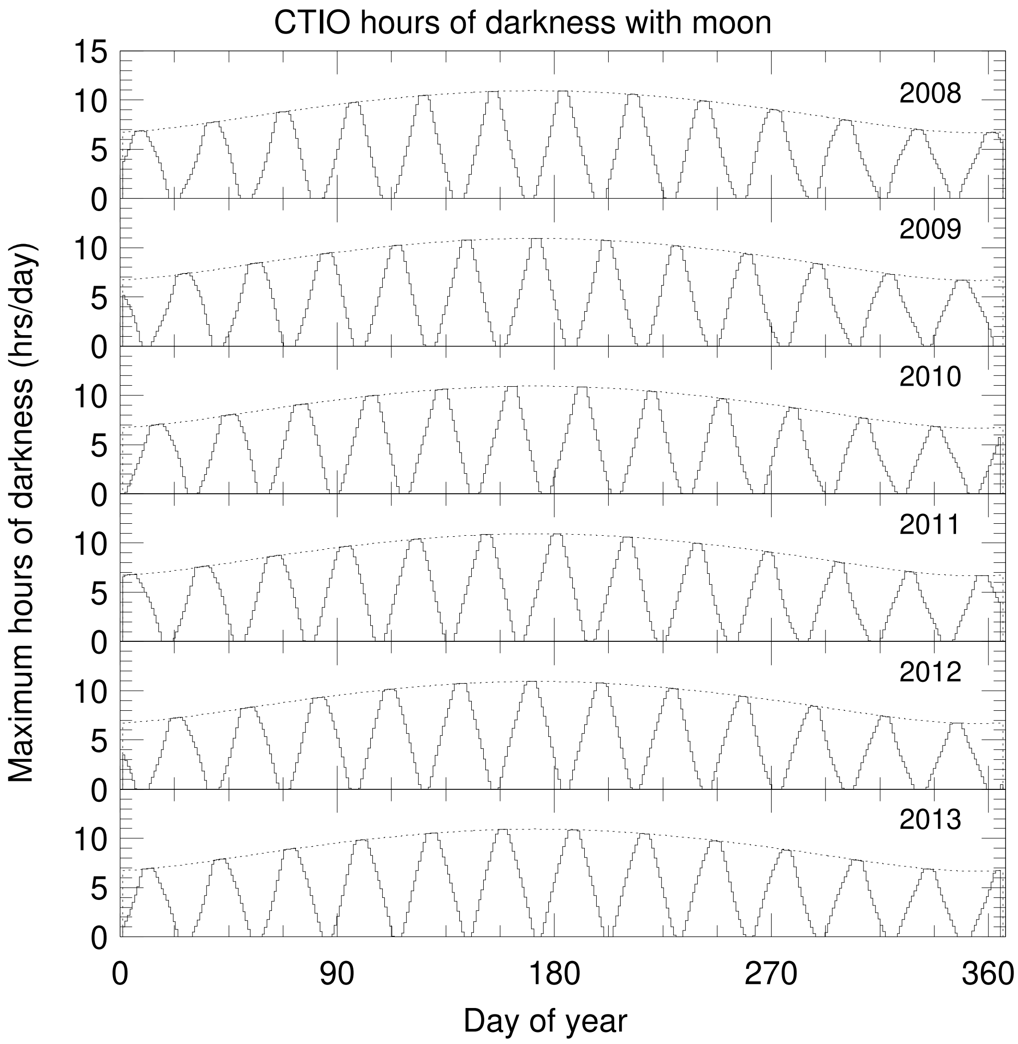

Figure 3: As a function of day for years 2008-2013, the number of hours of darkness. The solid curves show the hours of darkness when the moon is below the horizon and the dots show the duration between astronomical twilight.

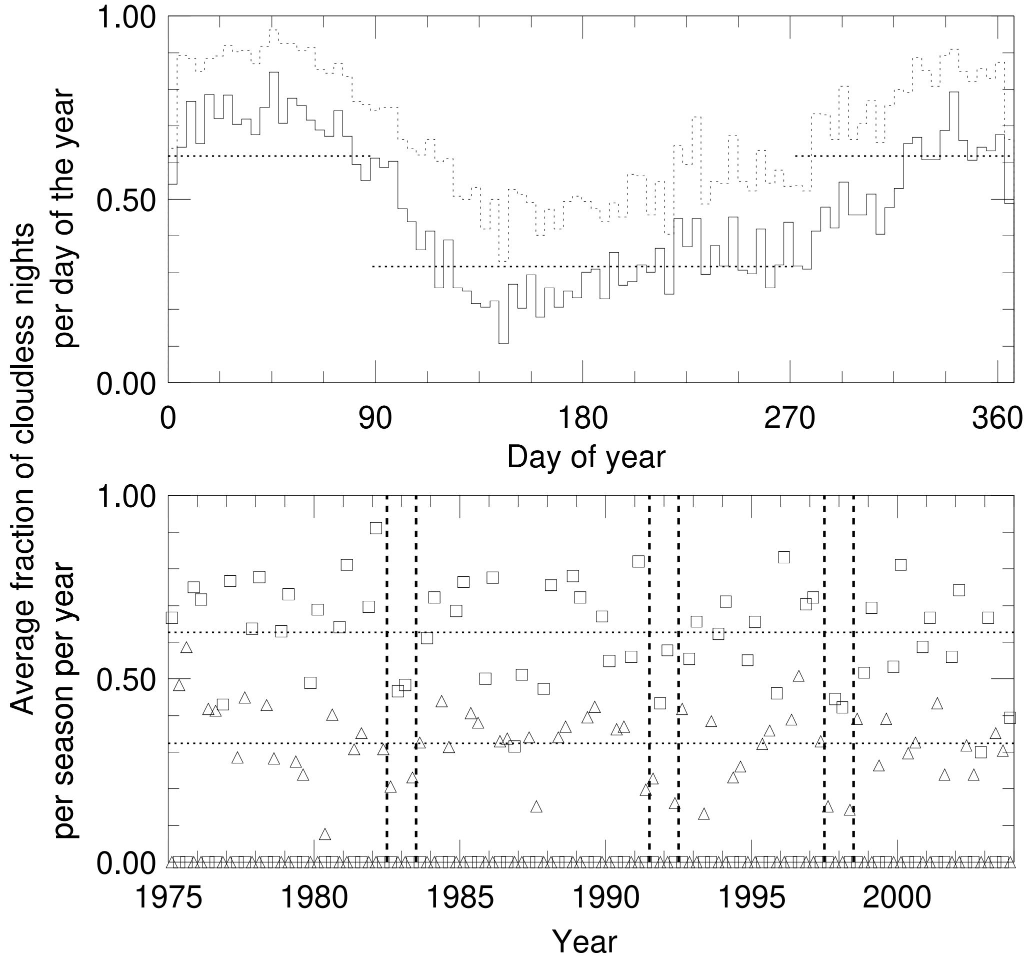

Figure 4: Average fraction of cloudless nights as a function of day of the year (top plot, solid line). The average is shown separately by the horizontal lines for the days indicated. The dotted line shows the average fraction if quarters of night with up to $3/8^{\text{ths}}$ cloudy is used in the calcuation. The fraction of cloudless nights is shown as a function of year and of season (bottom). Open squares are the averages for Jan.-Mar. and Oct.- Dec. while open triangles correspond to Apr.-Jun. and Jul.-Sept. The vertical lines indicate approximate dates of three strong El Niño periods.

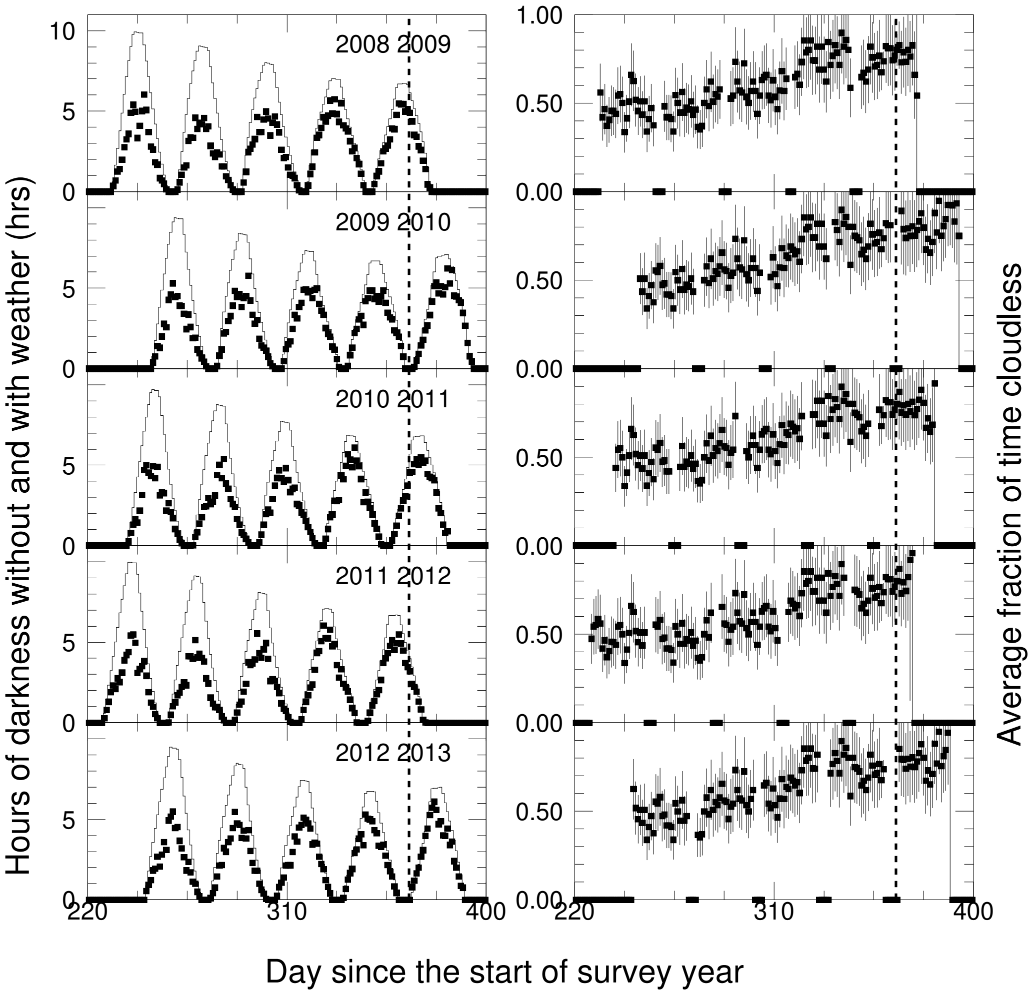

Figure 5: As a function of day for years 2008-2013, the number of hours of darkness without and with weather effects. The solid curves show the hours of darkness when the moon is below the horizon and the points show the reduction in hours due to the average amount of time with some cloud cover. The fraction of the time expected to be lost due to cloud cover is also shown as a function of the day of the survey.

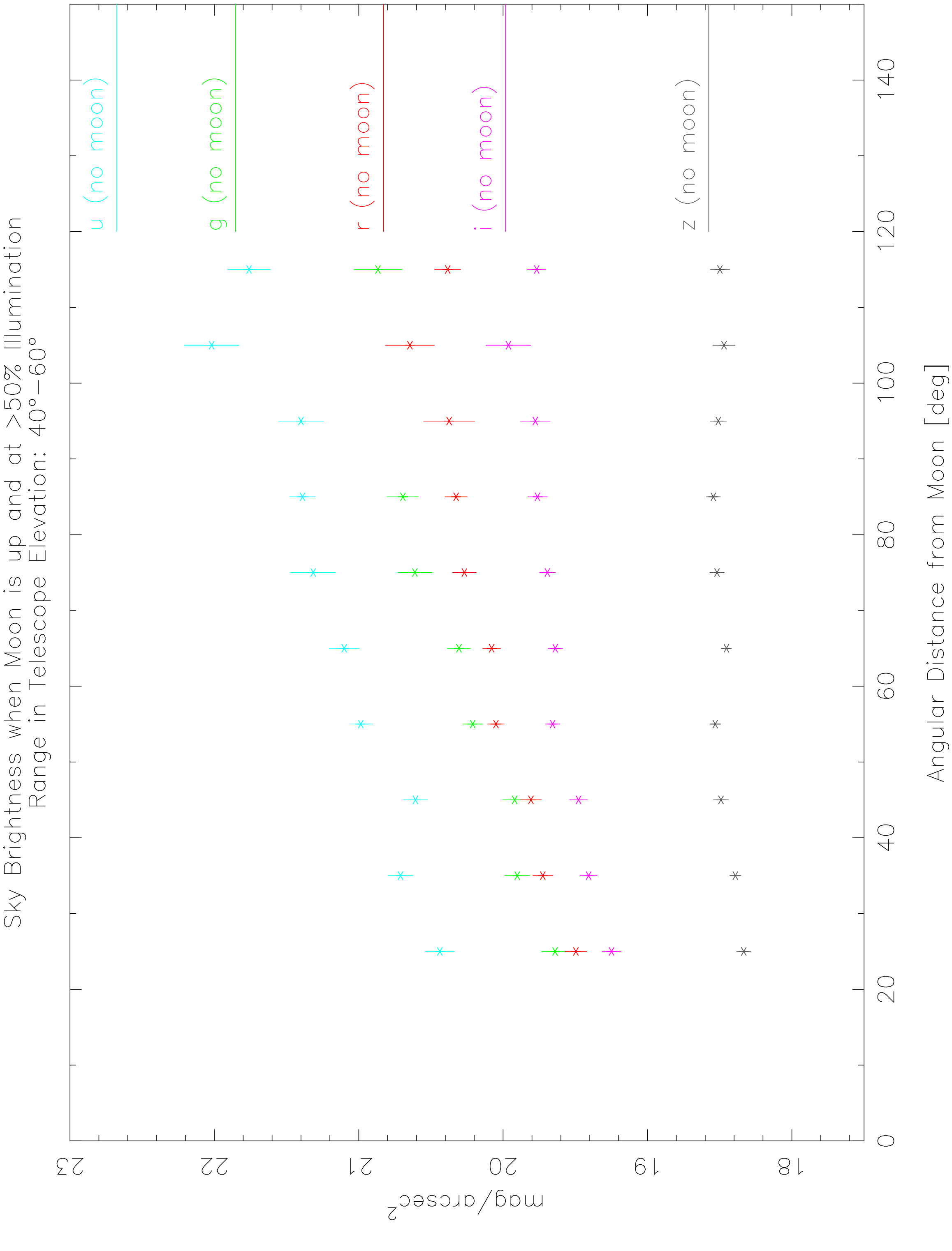

Figure 6: The effect on seeing in the four filters bands *griz* is shown as a function of the angular separation with respect to the moon.

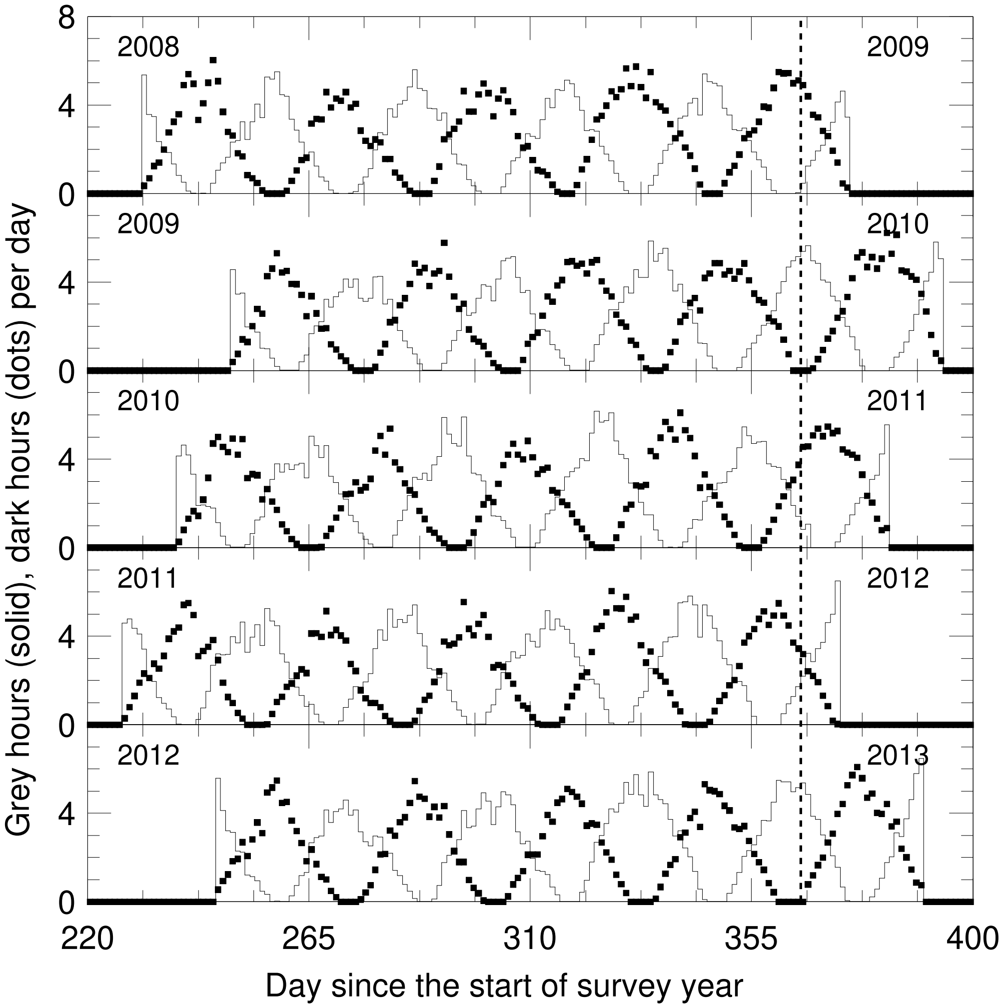

Figure 7: As a function of day for years 2008-2013, the number of grey hours is shown (solid) including weather effects. Also shown are the number of dark hours (dots).

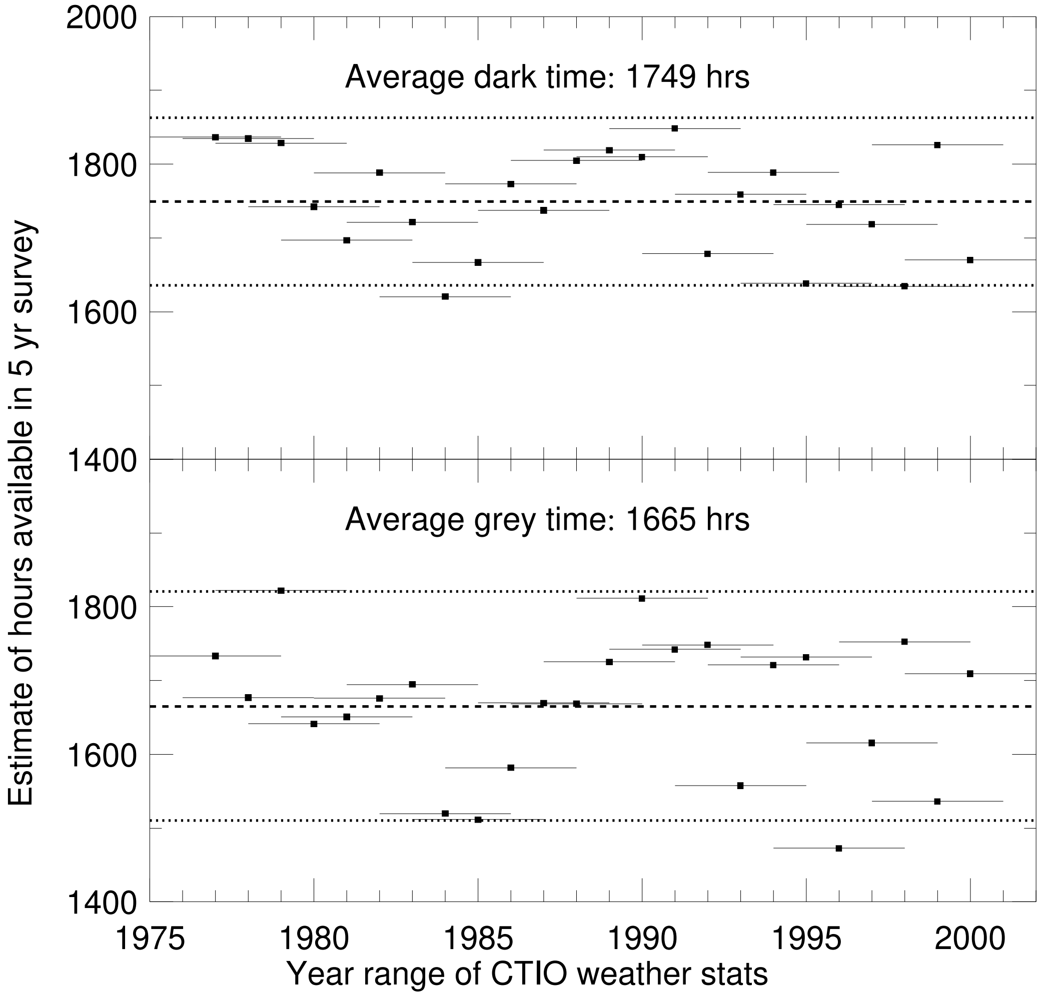

Figure 8: The expected number of dark hours (top) and grey hours (bottom) for the survey years 2008-2013 as a function of the weather for five-year rolling periods based on historical CTIO weather statistics for the dates shown.