

# **Challenges and opportunities in operating a high altitude site**

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## **ABSTRACT**

Observing stations at elevations in excess of 4,000 meters are rare. This report discusses the efforts to sustain and preserve one such site in the Rocky Mountains of Colorado, in North America. The long-term value of such sites can be measured in terms of their optical and infrared characteristics, as well as their ability to inspire astronomers and students to study the universe. The sustainability of this site is yet to be determined.

## **INTRODUCTION**

Historically, the placement of telescopes atop hills and mountains improved the access to as much sky as possible. Since the days of George Hale, advantages of higher sites for reasons beyond panoramic views have emerged, including seeing and transparency, especially at near- and non-optical wavelengths.

Colorado, in North America, is blessed with numerous peaks in excess of 4,000 meters elevation. Hale himself site tested Pikes Peak in 1894, but unfortunately sampled the site during the height of a spring blizzard, and never returned to these longitudes [Hale, 1894].

### *Rationale for this high altitude site*

Mt. Evans, Colorado is located 35 miles [53km] west of Denver, at altitude 14,148 ft (4305m) above sea level, at Latitude 39d 35m 13s N, Longitude 105d 38' 25" W. The measured local acceleration of gravity is reduced to  $g = 9.79006 \text{ m/sec}^2$  at this relatively extreme altitude. Between 1972 and 1999, it was consistently listed as highest observatory in the world in the USNO Astronomical Almanac, eclipsed only recently by newer facilities in India [Hanle, 4467m] and proposed facilities in the Atacama desert in Chile at elevations in excess of 5,000 m. The combination of good seeing due to treeless tundra and unobstructed airflows, low water vapor columns on average in terms of infrared transparency, and favorable cloud statistics all result in excellent site advantages for astronomy from the Mt.Evans summit. Road access to the site promotes relative ease in training and instrumentation, and the site should be preserved for future scientific use.

To appreciate the opportunities afforded by the Mt. Evans site, a review of local astronomy history is appropriate. In 1880, Herbert A. Howe arrived from the Cincinnati Observatory as a new professor of mathematics and astronomy at the University of Denver. By the end of that decade, a patron enabled Howe to design and build Chamberlin Observatory featuring an 0.5 meter aperture Clark-Saegmueller refractor. Site selection seemed to involve finding a level parcel of land near the young university, then located well outside Denver city. The south Denver parcel featured dark skies, good airflow and access convenience. Howe soon reported completion of the observatory, telescope and first light [Howe, 1894].

When did high altitude sites begin to be used? Early high altitude installations include Mt. Hamilton (Lick Observatory) in 1888, and earlier, Pic du Midi, 1873. During the 19<sup>th</sup> century, science was expanding with global expeditions of discovery regarding the atmosphere and the spectrum of sunlight. This set the stage for an early proponent of high altitude observatories, the Astronomer Royal of Scotland, Charles Piazzi Smythe, who in 1856 climbed Mount Teide on Tenerife and detected infrared radiation coming from the Moon. Bruck [2002] states that, despite his discovery, Smythe was not able to persuade the British government to finance a mountain station in that era.

#### *Site history and development*

According to Colorado historical sources, in 1888, the Cascade and Pikes Peak Toll Road Company completed a 16-mile road up the north side of Pikes Peak. This became a major attraction, drawing tourists away from Denver area. Not to be outdone, Denver's Mayor Speer proposed that a road be constructed to the top of Mt. Evans. In 1917, he was able to procure state funds to build the road that was completed in 1927. Soon thereafter, Arthur Compton of Chicago University arrived to study cosmic rays at altitude [Rossi, 1990]. Bruno Rossi himself demonstrated the time dilation effects on mu mesons from atop Mt. Evans in 1939.

In the post-World War II era, an international collaboration of researchers sponsored by the University of Denver flocked to Mt. Evans and its Echo Lake facilities. This activity flourished into the 1960s when accelerators elsewhere began to eclipse the direct observation of cosmic rays from high mountain sites. During this time, the "Space Race" and increasing interest in air pollution monitoring inspired the Denver Research Institute to propose a telescope for the Mt. Evans site, in collaboration with local universities. The first telescope was an 0.6 meter Ritchey-Chretien telescope by Ealing-Beck completed in 1972. Funding for operations limited its use to studies of comets Kohoutek [1972] and Halley [1986]. The site was nearly abandoned when a bequest to the University of Denver appeared in 1990 that included funds for a new mountaintop telescope and observatory. This author was hired in 1992 to fulfill this bequest by William Herschel Womble. Denver University teamed with Eric Meyer, who provided a unique dual 0.7 meter telescope for the site, and the Meyer-Womble Observatory atop Mt. Evans was completed in summer 1996, with first light summer 1997, following proposal and environmental impact studies with US Forest Service who manage the district. Usage is largely limited to summer season when access is easiest. Consistent summer observing

programs, guest observers and classes have been held each year since 1997, and observing proposals welcomed via the website, <http://www.du.edu/~rstencil/MtEvans>

## OPPORTUNITIES

What is the research potential of a high, dry site like Mt. Evans? First, there is the human need to see as far as possible, the “vision thing”. Imagine a great observatory. It is most likely to be located on a high mountain site, for reasons including excellent seeing, low water vapor for infrared and sub-millimeter wavelength work, and favorable cloud statistics. Easy access encourages student training and instrument testing. Because few sites of this quality are available, we support the IAU efforts to preserve and protect astronomical sites. However, though Denver city can be seen from the summit, the observatory itself is remote and challenging. To sum it up, “everything up here is an experiment”.

The University of Denver has continuously operated a modest weather station atop Mount Evans since January of 1991. This station has been outfitted with sensors to measure temperature, barometric pressure, relative humidity, wind speed and direction, and battery voltage maintained by solar panels. The station's data logger has been programmed to poll the sensors every minute and report hourly averages, as well as minimum/maximum values and standard deviations for that hour. The bulk of the data presented in this section has been acquired from this station. Partial gaps in the data sets are due to occasional sensor malfunctions during these periods. A pyranometer was added to the sensor package in June of 1996. Although battery voltages, despite a voltage limiter in the circuit, can indicate the fraction of sunny hours, the pyranometer provided more direct sunshine statistics.

The daily average, minimum, and maximum temperatures as a function of the day of the year were examined for each of the years between January 1991 and the present. The temperature profile is remarkably constant from year to year with diurnal variations being on the order of 10 degrees Fahrenheit. Also of special note is the infrequency of days below zero degrees Fahrenheit, although minima of  $-40^{\circ}\text{C}/\text{F}$  and  $-28^{\circ}\text{C}$  were noted. These results are significant because the hourly temperature gradient is small, which minimizes thermal distortions, and operationally, one may not require engineering for super-cold, arctic conditions (i.e. significantly below  $-40^{\circ}\text{F}/\text{C}$ ).

Wind data has been examined and reveals average and maximum hourly wind speeds for the four seasonal periods December- February, March-May, June-August, and September-November, where median and mean wind speeds average 25 to 30 knots, with sigma about 10 knots. Maximum winds measured to date have not exceeded 107 knots, although it would be prudent to plan for higher speeds.

The hourly averaged wind direction versus its corresponding speed clearly demonstrate that when the wind speeds are greater than 15 knots, the winds are tightly constrained to a direction out of the west-south-west (Azimuth =  $255^{\circ}$ ). Below this value, the

direction is more random but still generally out of this west south-west direction. This result is important for several reasons. First, the average wind speed is comfortably below dome closure requirements of 40 knots. Second, the wind direction is the most favorable for inducing laminar flow over the observatory parcel, i.e. from the steep western side of the ridge, cresting above the observatory and descending to the east. This latter behavior accounts for the seeing stability noted toward the west side of the sky (see image motion monitoring, below).

Relative humidity, barometric pressure, and temperature data can be used to calculate the partial pressure of water vapor at the site (see Allen, Astrophysical Quantities, 3rd ed., p.120). For the latitude of Mount Evans, the partial pressure of water in millibars, nearly equates to the vertical column of water in precipitable millimeters. A water column less than 2 millimeters (<2mb) corresponds to excellent infrared transparency. The daily averages, as well as the minimum and maximum for the partial pressure of water as a function of day for a given year range between 1.1 mm in winter and 3-4 mm during summer monsoon. Data gaps are primarily due to failures in the relative humidity sensor during those periods. The data show excellent conditions for infrared observations during the fall and winter months. If the ground humidity is elevated due to surface evaporation, these results represent upper limits to the dryness of the Mt. Evans site. A one hundred page report "Water Vapor as a Factor in the Selection of Solar Observation Sites" by N.Medrud, NCAR/High Altitude Observatory, March 1970 is available from this author on request, which includes Rocky Mountain sites.

Cloud cover is certainly a very important parameter in determining the quality of any astronomical site. This information, however, is somewhat difficult to obtain as one is generally interested in night time conditions wherein cloud cover data is not readily available. For the Mt. Evans site, we believe that conditions at sunrise can serve as a reliable proxy to conditions of the previous evening, at least for the several hours prior to sunrise. In addition, morning daylight hours are often prime time for infrared observations. From the observations to date, we conclude that conditions atop Mt. Evans are Suitable For Astronomy (SFA) 60+% of the time with roughly one half of those nights (33% of the time) being of photometric quality. This is based on analysis of satellite data, weather bureau data, line of sight observations and climatology studies. A more recent analysis of cloud cover statistics, available from this author, is "A Satellite survey of Water Vapor and Cloud Cover at Selected Existing and Potential Infrared Telescope Sites in the Southwestern U.S.A." by Andre Erasmus [Dec.2000], which reaches similar conclusions: sub-mm water vapor columns in winter, 54% photometric nights, 69% useable [spectroscopic or better].

Daily records of snowfall have not been measured directly at the summit, but such data has been acquired at our Echo Lake Lab base camp, located approximately 15 miles to the north at an elevation of 10,600 feet, during the past several decades. This location should represent an adequate proxy to the summit for measuring snowfall. The monthly snowfall amounts for six years for the Echo Lake locale indicate that December and January are very dry months, as also indicated from water vapor data. November and March are the snowiest months with year to year variability being quite large. This is

consistent with experience of Colorado skiers, that there are fresh autumnal and spring snows, separated by a sometimes long, mid-winter dry spell.

Studies of seeing conditions have been made at Mt. Evans observatory. As reported by Stencel et al. (1995 BAAS 26:1321), vertical acoustic sounding measurements were made at the Mt.Evans site during September 1994. Primary conclusions include that (a) refractive and turbulent parameters are comparable to those reported at Mauna Kea by Forbes and others; (b) the measured values imply the atmospheric contribution to the seeing disk due to turbulence in the 100 or so meters above the site is no more than 0.1 arcsec; (c) the deduced Fried parameter based on these measurements can be as large as one or more meters.  $C(n)^2$  values were found to be comparable to Mauna Kea, Hawaii reported testing, circa  $1E-17 \text{ m}^{-2/3}$ .

CCD images were acquired at the summit for selected double stars. Double stars were used to accurately determine the plate scale of the images. Seeing was ascertained by measuring the full width half maximum of the individual stars. Visual inspection of the images at the telescope suggest the camera did not ideally record the true seeing quality, due to residual aberrations in the 10 and 24 inch telescopes used. None of these data have been deconvolved with the telescope diffraction limits (0.25 and 0.15 arcsec), nor enhanced by any active optics. Despite these problems with CCD frames, it seems reasonable to conclude based on these measurements that at least "arcsecond" quality seeing (0.68 arcsec formally) is routine on Mt. Evans. Hartmann mask differential image motion monitoring offers the potential to directly observe the seeing cell sizes and their fluctuations (cf. Get al. 1995). We conducted a series of these measurements during summer 1995. Fried parameters were found to occur between 5 and 24 cm, and these appear to correlate with azimuth of the star observed, being larger toward the west (windward) side of the sky. Analysis is ongoing, and preliminary results show a range of  $r_0$  values from 5-10 cm on the leeward side of the observing site, to 10-35 cm on the windward (upwind) side, as might be expected for air flowing over the ridge. These values include unmitigated dome seeing effects.

Mt. Evans experiences excellent seeing, due to its isolated location and elevation. The site is situated some 3,000 feet above tree line and the routine west-southwest winds come from a direction that is unobstructed for several miles. The only local obstruction to the telescope site is the true summit situated to the north. Airflow is highly laminar as it crosses the observatory parcel.

Preliminary measurements of sky brightness were conducted during September 1994, resulting in an estimated 21.5 mag/sq.arcsec, V band, zenith. This compares favorably with estimates by Garstang (1989) of sky brightness at Mt.Evans. Natural background of 22 mag/sq.arcsec is almost achieved, and factors involving solar activity and regional forest fire smoke could be factors in the results to date. A series of VRI observations of cluster NGC7006 has been carried out since 1998 with the Meyer Binocular Telescope to monitor increasing sky brightness. The city lights of Denver fortunately do not affect more than about 5 to 10 degrees of the eastern sky due to relatively low altitude scattering and a semi-stable inversion layer over the city, although population increases are a factor.

In summary, Mt. Evans offers an attractive continental infrared site with conditions comparable, at times, to the best astronomical IR sites. The combination of extreme high altitude, existing special use permits, nearby base camp, access to supplies and transportation make Mt. Evans an appropriate site for a significant astronomical facility.

An unusual dual-aperture 28.5-inch, f/21 Ritchey-Chretien telescope has been completed and installed in the high altitude observatory facility, with first light August 1997. It was designed by Eric T. Meyer to optimize high spatial resolution imaging. This Meyer Binocular Telescope incorporates active thermal management of the telescope structure. The secondary mirror support elements are fabricated from INVAR and permit active tip-tilt and focusing capability. The optics were fabricated from Zerodur by Contraves USA, and each system has a measured total wavefront error  $<0.050$  at 633nm. All optical surfaces are coated with a multi-layer dielectric enhanced silver, providing high reflectance from below 350nm to beyond 26 microns. The telescope control system has been designed to allow initial operation from an insulated control room. Long-term plans call for totally remote operation from the University of Denver campus – 53 km line of sight distance - via direct microwave radio link.

## CHALLENGES

### *Access*

The observatory is situated at the end of a 14 mile [20 km] state highway that is paved to the 14,115 ft [4,302 meters] level, with the last few hundred yards [meters] unpaved, to the building base at 14,125 ft [4,305 m]. Conditions along the route vary even in the best weather, including rockfalls and frost heaving of the surface near Summit Lake [elev 12,500 ft, mile 9.5]. The latter road damage creates undulations that grow vertically a few cm per year in contrast on a scale of a meter or two in horizontal terms. With tight budgets, this situation is not expected to be repaired soon. Despite all this, with state highway assistance, routine access by vehicle has been possible between early May and mid-October annually. With effort and preparation, virtually all months can allow access.

### *Weather*

Mid-latitude, mountain weather can be variable and fierce at times. During the 1990s, a weather station was operated and data collected reflecting hourly averages and extremes. John Starkey both designed and installed this solar PV and battery powered modem-accessible device. Extremes include temperatures ranging from highs of 65F [23.6C] to lows of -40F/C. Wind speeds have been recorded up to 107 knots, although rime icing has taken a toll on simple anemometers, so maxima could be higher. However, the monitoring shows a wind rose with average speeds under 20 knots and strongly from the WSW direction. Observing experience confirms this tendency.

### *USFS rules and fees*

In the United States, most interesting astronomical sites tend to be under the jurisdiction of the USDA Forest Service. The Forest Service operates under a plethora of rules and regulations, driven by the 1967 National Environmental Protection Act [NEPA]. As such, Mt. Evans observatory operates under a Special Use permit, which has been renewed regularly since the 1970s, now valid until 2015. The 1994 proposal to modernize the observatory triggered an expensive Environmental Assessment study during 1995 and eventually a construction permit for 1996. The study considered a variety of impact factors, such as water, air, flora and fauna and visual effects of the proposed project. Although the established use patterns of the site helped demonstrate that there would be no additional impact on biological factors, the “visual impact” of the new building resulted in design constraints that tripled the eventual cost of the structure [rounded, rock-faced, tan coloration of the dome]. Following the approval for the new building, the Forest Service has been relatively unobtrusive about managing activities at the site – other than relentless increases in permit fees – but this may be due to staffing and budget cuts on a national scale, rather than willingness to micromanage their dominion. Should we wish to charge for access to the telescopes, the Forest Service expects a hefty share of the proceeds, making this cost ineffective.

### *Power*

A key factor for remote sites is the provision of electrical power and communications. The Mt. Evans summit is 15 miles [20+ km] from the nearest land lines for either. For power, we have traditionally relied on diesel generators to produce the local 220/110VAC, but this involves importation of fuels. Natural energy supplies in the form of sun and wind are abundant but challenging to harvest. We did get cooperation and some grant funding to place solar photoelectric panels atop adjacent buildings near the observatory, capable of providing 1500 watts under peak sun, and partial support for the addition of another 1200W of panels on the observatory itself. However, these are allowed only during winter season, due to ‘visual impact’. Wind power is an excellent option for the site, but the Forest Service will not permit free-standing towers or additional major structures. In addition, storage of captured energy is non-trivial. Fuel cells represent an interesting option, but the wait for low maintenance, affordable units continues.

### *Communications*

As mentioned, the nearest land lines are over 20 km distant, requiring us to solve communication problems with wireless means. An acceptable solution for internet access has been achieved with a low power, spread-spectrum 900MHz link with the University of Denver campus, 53 km distant, providing a workable internet for observers. Cell phones and their reception territory have evolved nicely since the mid-1990s. Today, an observer can take mobile calls, at the telescope, atop the mountain, whereas ten years ago, a weighty, high power analog portable phone unit was required for intermittent

communications. This is one benefit of the line of sight from the summit to Denver city below, despite the price paid in increased sky glow from poorly designed urban lighting.

### *Staffing and guest observers*

The major resource shortage of the observatory since its founding in the 1970s has been staffing – rarely more than 2 FTE during summer season, excluding construction periods. Comparison with published UKIRT budgets, suggests we should have a minimum of 4 FTE: one for electro-optical maintenance, one for computer support and two FTE for observer support. In part, this shortfall has been overcome in part with guest observers who volunteer time during summers in exchange to telescope access. Guest observers from academic institutions and astronomy clubs have participated since 1998.

### *Tourist site*

Because the Mt. Evans summit can be accessed by paved road, the highway is maintained by the state of Colorado (largely for tourism purposes). This brings a mixed blessing for the research site. On one hand, the maintenance allows for easy travel during the summer season. On the other hand, there is a persistent public demand for access to the telescopes during the limited number of clear and dry summer nights needed for research and training. Balancing those is challenging, although the benefits of some tourist accommodation are recognized, and scheduled programs have been offered in recent years. With additional staffing, more astronomy outreach during the day could be done.

## FURTHER OPPORTUNITIES

### *NIMBY & NOMBY*

In the USA we have a catch-phrase, NIMBY, regarding where development is to be sited. NIMBY refers to opposition of neighbors: “Not In My Back Yard”. Understandably, no one wants a toxic waste dump to open next to their home. However, with the disappearance of environmentally unspoiled wilderness, pressures increase to protect remaining areas from all human encroachment. Only the historical use pattern of research at Mt. Evans, and the ability to mobilize interested local amateur and professional astronomers to weigh in with the Forest Service and balance the de rigeur pro-conservation petitions that almost any proposed action in wilderness can be expected to generate, allowed the project to move forward. However, with the proliferation of 10 and 30 meter class telescopes at world class sites in Hawaii and Chile, mid-latitude sites may disappear due to lack of professional interest. Similarly, as there are advantages of site convenience and control, one sees a NOMBY response from astronomical peers – Not Other than My Back Yard – in terms of resistance to pooling resources among possibly redundant small-scale efforts.



## *Space Station Mt. Evans*

One of the strongest scenarios for the future of the Mt. Evans observatories involves the effort toward complete automation and remote control. The severity of conditions drives a need for highly redundant safing systems, which themselves require reliable power. However, the advantages in terms of productivity would be substantial if a fully remote system could be realized. Only funding separates us from that end. Human participation, on site or over the net would continue under that arrangement as appropriate. For continued on-site participation, it is imperative to modernize the base camp facilities at DU's High Altitude Research Station, a.k.a. Echo Lake Lab

## QUO VADIS?

By 2015, the special use permit for the observatory to occupy its lofty perch comes up for renewal. According to permit rules, facilities added to the land must be removed when the permit is no longer in force. If the University of Denver does not augment staffing for astronomy, and/or external interest in the research and educational potential of the site does not materialize, it is possible that the site will be lost to the astronomical community. During the present golden era of 10 and 30 meter ground based telescopes, and multi-wavelength telescopes in space, perhaps a small facility is not justified. However, once lost, this site may prove difficult to reclaim.

There are many people to acknowledge in a project like the development and continuance of the Mt. Evans Observatory, in addition to my very tolerant wife Susan and daughter Claire. I thank William Herschel Womble for provision of a bequest to the University of Denver in support of mountaintop astronomy and the pursuit of educational research in astronomy and astrophysics. Patrick Meyer and his team of heroic builders made the construction possible during limited summer seasons. Eric Meyer provided the initial telescope system. John Starkey, deceased, pioneered the communications and power infrastructure that makes work at the summit feasible, along with Joe Burdick and Ken Thames. Russ Mellon and colleagues help improve on many telescopic features, and Mike Silva provided vital air transport to sustain systems. A generation of cosmic ray scientists, as well as atmospheric and astronomical researchers helped secure the site through the 20<sup>th</sup> century, for its current 21<sup>st</sup> century uses. Student interest sustains me, even if outside professional interest is limited.

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Illustrations:



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