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Site Comparison for Optical Visibility Statistics in Southern Arizona

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One of the best locations in the continental United States for astronomical telescopes is southern Arizona. The mountains surrounding Tucson have clear skies 80 percent of the year, with image quality generally better than 2″ on peaks. Two of the existing observatory sites in this area are being considered as locations for one of the three Atmospheric Visibility Monitoring (AVM) observatories. These sites are Mount Lemmon and Mount Hopkins. A comparison of the characteristics of each of the sites is made here to identify the more desirable of the two locations. It is recommended that Mount Lemmon be selected as the Arizona site for this project.

I. Introduction

The Atmospheric Visibility Monitoring (AVM) project is designed to create a model for cloud-cover correlation and atmospheric transmission in the southwestern United States for deep-space optical communications stations. By setting up three automatic telescopes to detect and measure light from selected stars, these atmospheric effects can be determined. A preliminary model has predicted a 94-percent probability of joint visibility from three sites located at least a few hundred kilometers apart in areas with at least 60 percent annual clear skies [1]. The mountains surrounding Tucson have clear skies 80 percent of the year, with image quality generally better than 2″ on peaks [2]. This article describes the process for choosing a site in southern Arizona.

II. Site Characteristics

Five major site characteristics were considered, each with a weighting for its importance to AVM. These characteristics are the probability of clear skies (weighted at 30 percent), low particle scattering (20 percent), suitability for a future large optical-reception station (20 percent), availability of security and maintenance (15 percent), and low turbulence (15 percent) [3]. Each site was rated on a 1-to-10 basis for each characteristic. The ratings were then weighted and summed to give an overall rating for each site. This process is described below and was used to discriminate between Mount Lemmon and Mount Hopkins for the southern Arizona AVM site.

A. Probability of Clear Skies

Mount Lemmon lies to the north of Tucson and Mount Hopkins to the south; they are within 130 km of each other. Satellite and ground statistics do not indicate a difference in the probability of clear skies for the two. Because Mount Lemmon is 0.5 km higher than Mount Hopkins, it is possible that Mount Lemmon may experience more clouds "clinging" to its peak at a higher altitude. However, it may also be above fog that can exist at the lower elevation of

Mount Hopkins. Local astronomers relate no appreciable difference in the number of cloudy or clear days between the two sites. Since they are both located in the area of the continental United States with the highest percentage of clear skies, both are rated as 9. A higher rating is not given because places such as Hawaii receive a higher annual percentage of clear skies.

B. Low Particle Scattering

Low particle scattering is typically exhibited in areas with appreciable vegetation, which keeps dust down, and areas with little precipitable water vapor. Research at Mount Lemmon has shown precipitable water vapor to be very low (1.4 mm) [4]. Records of precipitable water vapor measurements at Mount Hopkins are not available. Vegetation is adequate at both locations for minimizing dust particles in the atmosphere. Winds from the southwest (the direction of Tucson) blow particles and smog toward Mount Lemmon. However, the peak of Mount Lemmon at 2.791 km [4] is protected by an inversion layer at 2 km, which confines valley haze and smog. This elevation also helps decrease particle scattering, since the atmosphere is less dense and there is less of it to look through. Mount Lemmon's higher elevation and reputation as a good infrared site make it rate slightly better (9) for scattering than Mount Hopkins (8).

C. Suitability for a Future Large Optical Reception Station

Locating future 10-m receiving stations at AVM sites is also an important consideration in site selection. The AVM project will provide data on conditions that will be useful for such stations. Relations with the site management will be developed, and a working knowledge of the facilities and operations specific to a site will be gained. The management of Mount Lemmon is very receptive to the addition of a larger optical station, and there are several large areas where one could be located. There is a plateau at the peak, whereas Mount Hopkins has a ridge; Mount Lemmon thus has more space available. Mount Hopkins has a limited amount of space for large structures and, at this time, the management of Mount Hopkins would not approve the addition of a large telescope for communications. It is reserving the remaining sites for projects in astronomy. Five years from now the management might change its position, but there are no predictions.[1] Mount Hopkins is therefore rated very low for future suitability (2); Mount Lemmon is rated high (10).

[1] From a conversation with John Huchra, Center for Astrophysics, Cambridge, Massachusetts, November 14, 1989.

D. Availability of Security and Maintenance

The availability of security and maintenance at a site is also a consideration in order to make frequent visits by JPL personnel feasible. Security is necessary to protect the observatories from vandalism and prevent accidents caused by hikers who might get in the way of a moving telescope or roof. Both Mount Hopkins and Mount Lemmon are surrounded by gates and do not experience a large number of visitors. An additional fence around the AVM enclosure may be necessary at any site.

Necessary minimal maintenance would include snow removal and checks for weather damage and mechanical failure. It would also be useful to have someone at the site to receive calls from JPL personnel and respond appropriately to problems detected. The frequency of required periodic checks has not been determined.

Mount Lemmon has personnel available for daily checks on all the buildings on the peak. While these people are willing to make minor adjustments, they prefer not to be responsible for solving large problems. Mount Hopkins, however, has limited human resources. Support personnel are on the mountain from 9 a.m. to 4 p.m. weekdays. Two people are usually there, although additional people are available if snow needs to be plowed. However, the management of Mount Hopkins is hesitant to add to the duties of the support people.[2] On clear nights, only observers are on the mountain, and no one is on the mountain on cloudy nights. For the months of July and August, the observatories are closed for the rainy season.

Lou Boyd of Fairborn Observatory is in charge of maintaining the automatic telescopes for the Automatic Photoelectric Telescope Service on Mount Hopkins. He has offered to make routine checks of those AVM observatories located near Fairborn on Mount Hopkins. He is on the mountain only two or three days a week, but he is very familiar with automatic telescopes. He could fix any problem with the hardware, but he prefers not to have to change any software. This should not be a problem.

Mr. Boyd gets $15,000 a year from Vanderbilt University for his services, and would consider a similar arrangement with JPL. He would not be available in the case of an emergency; in fact, no one at Mount Hopkins would be available for such a response.

Since both sites have about the same degree of security, and maintenance would be available at all times on Mount

[2] ibid.

Lemmon, Mount Hopkins was rated lower (5) than Mount Lemmon (7).

E. Turbulence

Turbulence causes blurring of an image. Sites with low turbulence usually have a steep slope that rises from a valley in the direction of the wind source. Also, for low turbulence, there should be no peaks in that direction higher than 1 km for at least 30 km.

In Tucson, the winds come from the west and southwest for most of the year. Mount Lemmon is the highest peak in the Santa Catalina Mountains and has a medium slope up from lower parts of the range; the top of Mount Lemmon is a plateau. Mount Hopkins has a ridge geometry, which produces lower turbulence.

Turbulence is often measured by rms image motion. An average measurement of about 2″ is considered excellent for optical communications. The rms image motion averages 2.1″ on Mount Lemmon [5]. Typical rms image motion measurements are 0.6″ at Mount Hopkins [6]. (Mauna Kea exhibits rms image motion $\leq 1''$ only 33 percent of the nights [7].) Mount Hopkins is therefore rated higher (10) for low turbulence than Mount Lemmon (8).

III. Rating

The ratings for Mount Lemmon and Mount Hopkins in each characteristic are given in Table 1.

There is also a cost consideration. The Steward Observatory, University of Arizona, which runs Mount Lemmon, has given a cost estimate for services as shown in Table 2.

The total fee includes daily site security checks, winter snow removal, general (light) maintenance, and limited use of the machine shop and dormitory facilities. Not included are electricity, telephone, or installation charges. The Steward Observatory explained that this is a fair share of the costs necessary to keep the mountain operating and includes road and power-line maintenance.

Mount Hopkins would not charge for site rental, but would not provide much in the way of service. Maintenance at Mount Hopkins performed by Lou Boyd would cost $15,000 annually.

IV. Conclusions

Both Mount Lemmon and Mount Hopkins are high-quality astronomical sites. Based on this comparison study, it was recommended that Mount Lemmon be selected for the Arizona AVM site. The cost of operating at Mount Lemmon is a drawback, but it will cost less than $6,000 a year more than at Mount Hopkins, and the benefits outweigh this cost. The minimum amounts of maintenance provided will be adequate since the observatories are autonomous. Contract negotiations with Mount Lemmon have begun.

References

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[2] *Climatic Atlas of the United States,* U.S. Department of Commerce, Washington, D.C., 1968.

[3] K. Cowles, "Site Selection Criteria for the Optical Atmospheric Visibility Monitoring Telescopes," *TDA Progress Report 42-97,* vol. January–March 1989, Jet Propulsion Laboratory, Pasadena, California, pp. 235–239, May 15, 1989.

[4] G. P. Kuiper, "High Altitude Sites and IR Astronomy, II," *Lunar and Planetary Laboratory Communications* No. 156, U. of Arizona, Tucson, pp. 337–382, 1970.

[5] G. V. Coyne, "Preliminary Report on Optical Seeing Tests at Mount Lemmon, March–June 1971," *Lunar and Planetary Laboratory Communications* No. 170, U. of Arizona, Tucson, pp. 185–189, 1971.

[6] M. R. Pearlman, et al., "SAO/NASA Joint Investigation of Astronomical Viewing Quality at Mount Hopkins Observatory: 1969-1971," *SAO Special Report 357,* Cambridge, Massachusetts: Smithsonian Astrophysical Observatory, January 1, 1974.

[7] H. M. Dyck, and R. R. Howell, "Seeing Measurements at Mauna Kea from Infrared Speckle Interferometry," *Pub. Astr. Soc. Pac.,* vol. 95, pp. 786–791, October 1983.

Table 1. Ratings

Characteristic, weight	Mount Lemmon	Mount Hopkins
Clear skies (30 percent)	9	9
Low scattering (20 percent)	9	8
Future suitability (20 percent)	10	2
Security and maintenance (15 percent)	7	5
Turbulence (15 percent)	8	10
Rating	8.75	6.95

Table 2. Annual expenditures at Mount Lemmon

Item	Fee
10 percent resident engineer salary	$4,039
10 percent forest service lease	$6,500
10 percent site maintenance costs	$9,800
Total	$20,339