AN EVALUATION OF SAO SITES FOR LASER OPERATIONS

Technical Report
RTOP 161-01-03

Grant NGR 09-015-002
Supplement No. 57

J. M. Thorp, M. A. Bush, and M. R. Pearlman

October 1974

Prepared for
National Aeronautics and Space Administration
Washington, D.C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

The Smithsonian Astrophysical Observatory
and the Harvard College Observatory
are members of the
Center for Astrophysics

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ABSTRACT

The purpose of this document is to provide operational criteria for the selection of laser tracking sites for the Earth and Ocean Physics Applications Program sponsored by the National Aeronautics and Space Administration.

The report contains a compilation of data concerning the effect of weather conditions on laser and Baker-Nunn camera operations. These data have been gathered from the Smithsonian Astrophysical Observing station sites occupied since the inception of the Satellite-Tracking Program. Also given is a brief description of each site, including its characteristic weather conditions, comments on communications and logistics, and a summary of the terms of agreement under which the station is or was operated.

AN EVALUATION OF SAO SITES FOR LASER OPERATIONS

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1. INTRODUCTION

The selection of laser tracking sites for the Earth and Ocean Physics Applications Program must be governed by operational considerations as well as by geophysical and geodetic requirements. The sites must be chosen to ensure adequate data volume, accessibility, communications, and logistics. In addition, locations should be selected where political and environmental considerations are conducive to long-term site operation.

In this document, we have compiled data on most of the Smithsonian Astrophysical Observatory (SAO) sites that have been occupied during the Satellite-Tracking Program, which began in 1957. The information contains a general description of the area and its weather conditions, details on communications and logistics, and a statement on the agreements under which the station is or was operated. We have also included station-operations statistics, where available, and observer-recorded cloud-cover conditions. The quantities used to characterize the operation at each site, where appropriate, are as follows: 1) percentage of Baker-Nunn passes not attempted nor found owing to weather, 2) percentage of laser passes not attempted owing to weather, and 3) percentage of laser passes not attempted owing to weather plus those not found (for any reason). The second and third quantities place approximate upper and lower bounds on the influence weather will have on laser operations. It should be pointed out that the Baker-Nunn statistics characterize cloud cover at night, whereas in most cases, laser statistics are indicative of both daytime and nighttime conditions. For some stations, this may introduce some bias in the interpretation of the data; however, we feel that the general conclusions are valid. A successful laser pass has been defined as any

This work was supported in part by Grant NGR 09-015-002 from the National Aeronautics and Space Administration.

satellite pass for which data have been validated. This includes passes with anywhere from a few returns up to 70 or 80 points, with averages in the neighborhood of 20 to 25 points per pass. A successful Baker-Nunn pass is one in which a satellite was photographed and the resulting film successfully measured.

Correlations between laser and Baker-Nunn camera statistics have been examined to develop criteria for site evaluation regarding weather. Data from the SAO stations in Arizona, Peru, South Africa, and Brazil show that laser and camera operations are both degraded to about the same degree as a result of cloud cover and that, on the average, no station was able to obtain camera or laser tracking data when cloud cover was much greater than 50%.

2. SAO LASER STATIONS

2.1 Arizona (Mt. Hopkins)

The Mt. Hopkins Astrophysical Observing Station is part of the SAO Mt. Hopkins Observatory, whose scientific facilities also include a 10-m optical (gamma-ray) reflector and a 1.5-m reflecting telescope. It is located 29 km east of Amado, Arizona, at a height of approximately 2310 m in the Santa Rita Mountain Range of the Coronado National Forest. Amado is approximately 64 km south of Tucson, Arizona, and 48 km north of Nogales, Mexico, on U.S. Route 89. The station, originally established in Las Cruces, New Mexico, in 1957, was moved to Mt. Hopkins in 1968, when that facility was completed.

The weather on the mountain is usually sunny and cool, with seasonal variations. From mid-March to June, spring is characterized by clear skies and low precipitation, with temperatures ranging from March lows averaging -1°C to June highs averaging 20°C and winds at a fairly steady 16 to 24 kph. The summer season, from July through mid-September, is dominated by cloudy, stormy weather with large amounts of precipitation. Temperatures range from 10° to 20°C, and winds average 8 to 16 kph. The fall, from mid-September through November, is marked by clear skies and low precipitation; temperatures range from an average in September of 18°C to a typical low in November of 0°C, and winds are generally 8 to 16 kph. Winter may bring occasional severe snows to the site, and winter skies are frequently cloudy. Temperatures average between -1 and 10°C, with extremes from below -12° to about 20°C. Winds blow rather steadily at 16 to 24 kph. Detailed information on meteorological conditions and astronomical viewing quality at the Mt. Hopkins Observatory is provided in SAO Special Report Nos. 345 and 357 (Pearlman et al., 1972, 1974).

Geologically, the Mt. Hopkins area is underlain by several different Late Cretaceous intrusive igneous rocks. The most widespread types are Josephine Canyon diorite, a dark, fine-grained, dense rock, and Josephine Canyon quartz monzonite, a softer, buff-colored rock.

Tucson, Arizona, is served by major airlines, and the station site is about 2 hours from Tucson by automobile. Both commercial and Federal Telecommunications Service (FTS) telephone and telegraph communications are available to the site.

The laser, camera, and cloud-cover statistics for Mt. Hopkins for the period April 1973 to March 1974 are shown in Figure 1. A strong correlation is found among the percentages of laser passes not attempted owing to weather, of camera passes not attempted and not found as a result of weather, and of the time the cloud cover exceeded 50%. The largest differences occur in August, when operations were closed down for half the month. Because of this strong correlation between Baker-Nunn and laser statistics, we expect to be able to use Baker-Nunn and cloud-cover data to project the influence weather will have on laser operations.

Baker-Nunn camera statistics averaged over a 6-year period for Mt. Hopkins are given in Figure 2. Only during July and August are more than 50% of the passes lost to weather, on the average. For 8 months of the year, the loss is less than 40%. The strong correlation between laser and camera data (Figure 1) indicates that we expect this to be a good laser site for most months of the year. Operating experience has borne this out.

2.2 Peru (Arequipa)

The Smithsonian Astrophysical Observing Station near Arequipa, Peru, was established in 1958 under cooperative agreements with the Instituto Geofisico del Peru (IGP) and the Universidad Nacional de San Agustin (UNSA). The station site, 5 km outside Arequipa in the village of Characato, is provided under an agreement with the UNSA, which operates a seismic station nearby. The SAO observing site is run in cooperation with these two organizations.

An agreement with the IGP was concluded August 2, 1961, and is considered to have come into effect as of July 1, 1959; it extends for an indefinite period, until such time as either party gives 90-day written notice to terminate. An agreement with the UNSA, originally made before June 30, 1959, has been extended through October 5, 1975.

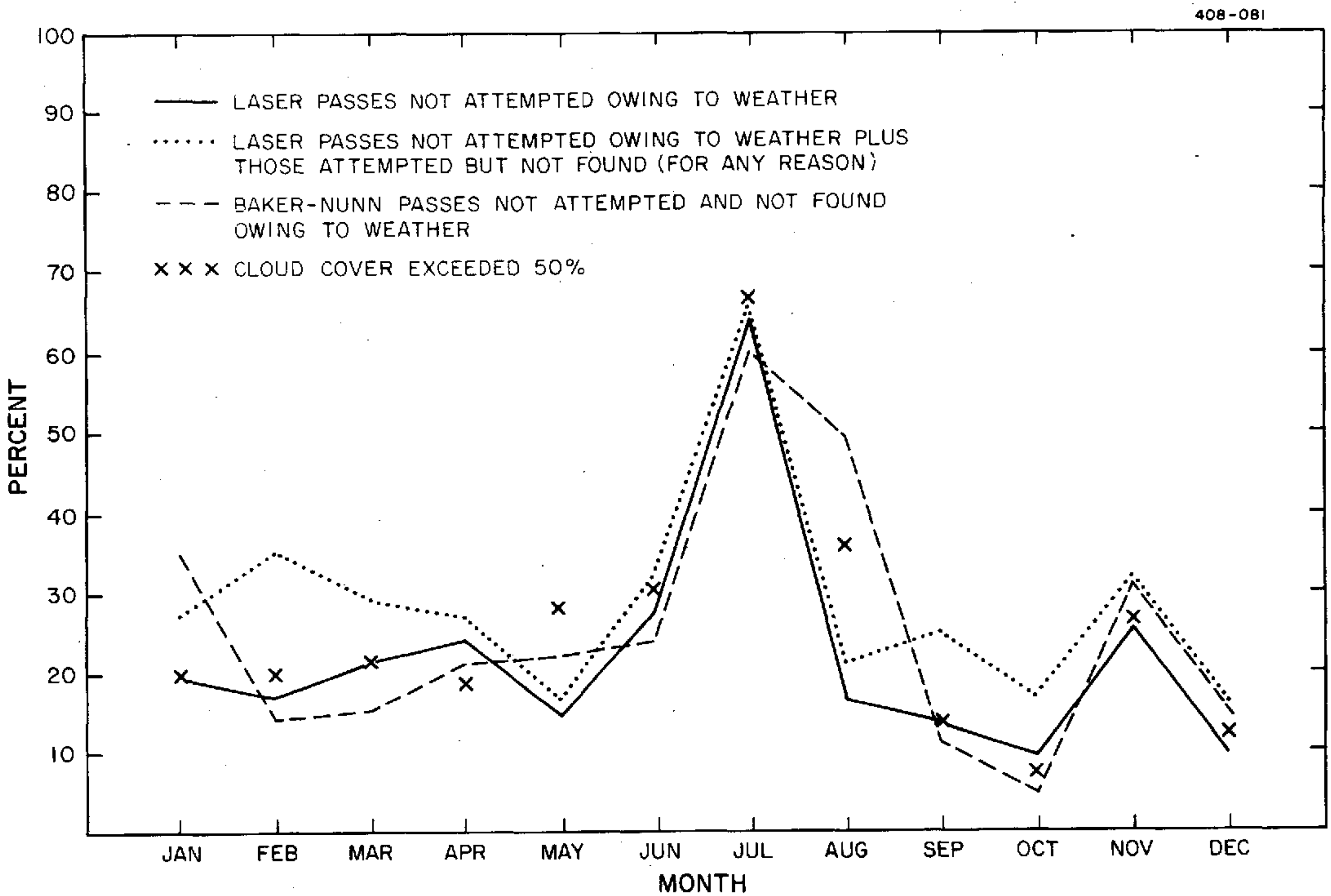

Figure 1. Weather and cloud-cover statistics for laser and camera sites at Mt. Hopkins, April 1973 to March 1974.

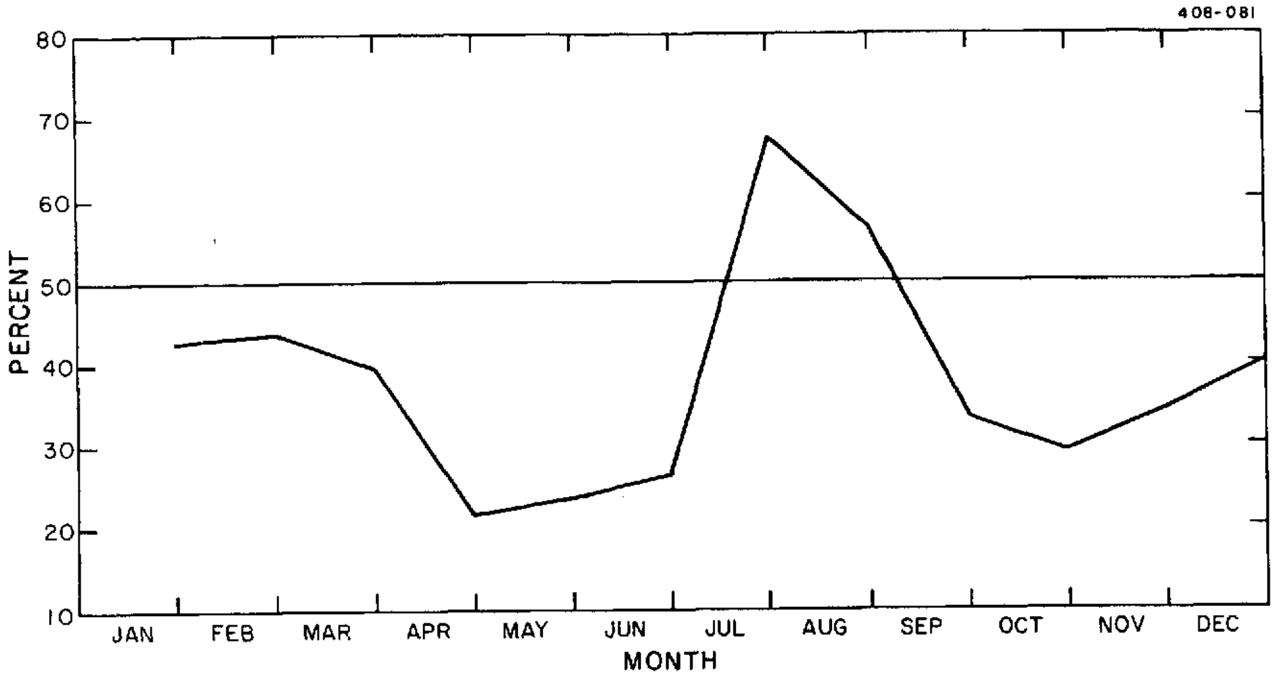

Figure 2. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Mt. Hopkins averaged from 1968 to 1973.

Arequipa and the village where the station is located are in an elevated valley about 2400 m above sea level in mountainous country near the Altiplano, or high-plateau, region of the Andes Mountains. The city is surrounded by spectacular snow-capped mountain peaks, some reaching a height of more than 6000 m. Arequipa is in the valley of the Rio Chile, about 80 km inland and 1000 km south of Lima; it is Peru's second largest city, with a population of about 95,000.*

The climate is mild and sunny during the daytime and very cool at night. This diurnal change is a function of the elevation. The only usual precipitation occurs during the summer cloudy season, November to April. Although precipitation is rare, the skies are often cloudy. The area is also subject to violent earthquakes.

*Population information circa 1968 (Hayes, 1968).

Arequipa is well serviced by air and by sea via Lima (Callao). Air freight normally arrives within 2 weeks. A consular certificate must be obtained from the Peruvian Consul for each shipment. Currently, SAO enjoys duty-free privileges through an agreement between the IGP and the National Aeronautics and Space Administration (NASA); however, some discussion is under way concerning the continuing validity of these privileges, with the result that a new or modified agreement may have to be arranged.

Rapid communications are maintained between Arequipa and SAO by radio link.

Laser, camera, and cloud-cover data for Arequipa for the period April 1973 to March 1974 are shown in Figure 3. The correlation between laser data lost to weather and cloud cover greater than 50% is quite strong, although cloud cover greater than 50% appears to give a pessimistic view for all months.

Operationally, however, a significant number of passes are attempted during adverse conditions and are probably unsuccessful owing to weather. The curve for cloud cover greater than 50% falls about midway between passes not attempted owing to weather and those attempted but unsuccessful for any reason; this curve is a reasonable estimate of the percentage of passes lost to weather in total. Baker-Nunn data lost as a result of weather follow the laser and cloud-cover statistics fairly well; but in summer months, differences are large. We believe the differences reflect overall poor daylight weather conditions.

Baker-Nunn statistics averaged over a 7-year period for Arequipa are given in Figure 4. During 6 months of the year, less than 40% of the passes are lost to weather. Camera operations during the local summer season are poor. However, from the correlation between laser and camera data (Figure 3), it appears that the nighttime-only camera statistics are a weak indication of combined day and night laser operations during summer and that we could expect 24-hour laser operation to be about 20% better than the Baker-Nunn statistics show. Arequipa should be an excellent site for all but 3 or 4 months of the year. Our experience with laser operations there for the past 3 years has verified this.

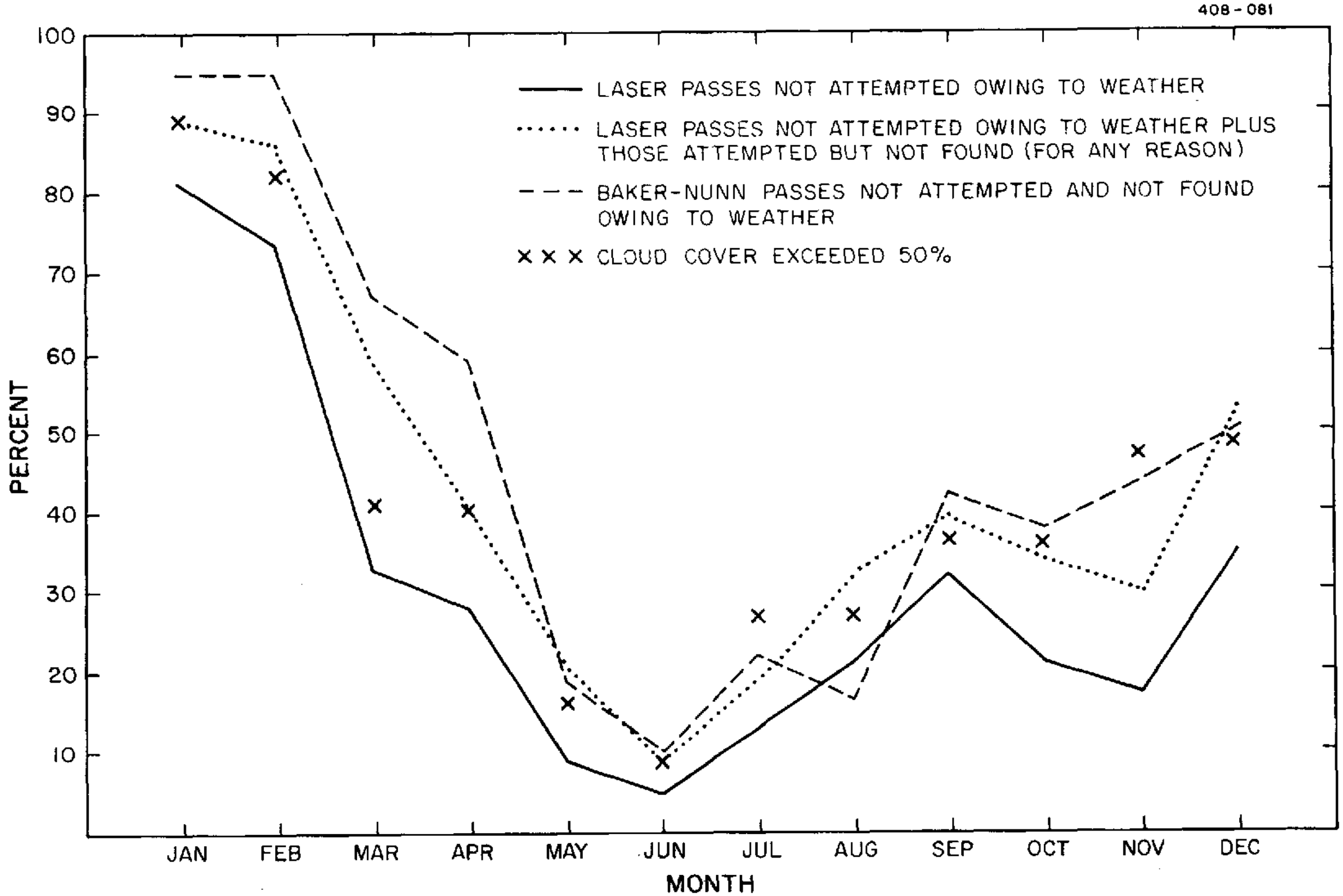

Figure 3. Weather and cloud-cover statistics for laser and camera sites at Arequipa, April 1973 to March 1974.

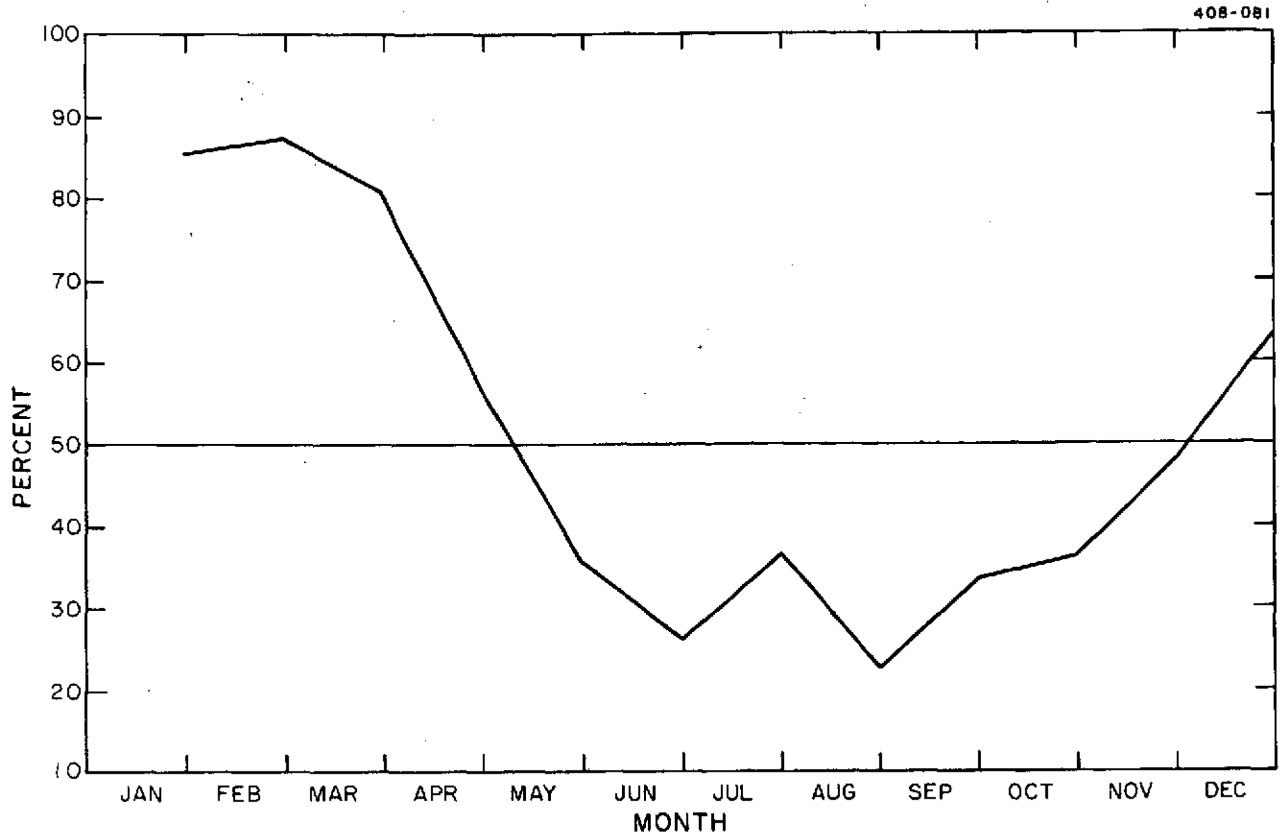

Figure 4. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Arequipa averaged from 1967 to 1973.

2.3 South Africa (Olifantsfontein)

The Astrophysical Observing Station in South Africa was established in February 1958 under an arrangement between the United States and the South African National Committee for the International Geophysical Year (IGY). On September 13, 1960, a country-to-country agreement was signed between the governments of the United States and South Africa naming NASA and the Council for Scientific and Industrial Research (CSIR) as cooperating agencies and specifying the SAO installation as one of the facilities in the cooperative program. This agreement will remain in force until September 13, 1975. There are no current plans to extend it.

The station at Olifantsfontein (elephant's drinking pool) is 40 km from Johannesburg, halfway between Johannesburg and Pretoria, on a bleak veldt plateau broken by occasional scrub and timber. Approximately 1600 km from Cape Town and 720 km from Durban, Johannesburg lies on a high plateau about 1800 m above sea level. The

Magaliesburg Mountain Range is about 48 km to the north, and the Drakensburg Range, about 320 km to the east. The Transvaal, the area in which the station is located, is subject to recurring droughts and floods. The average annual temperature is about 15°C; and the average normal rainfall, about 76 cm, all of which falls during the warmer months, October to March. A steady, drizzling rain is not uncommon in Johannesburg. The maximum summer temperature seldom rises above 32°C, and the nights are relatively cool. During the hottest months, December to February, sudden thunder storms are often accompanied by hail.

Johannesburg enjoys practically uninterrupted sunshine during the colder months of May to September. Although the average winter temperature is about 10°C, the daily range is often from 0° at night to 25°C during the day. Winters are dry and clear.

A few windy days occur during August and September, when the air is filled with dust from the numerous mine dumps. The humidity is relatively low, ranging from 52 to 60% in the interior. Annual rainfall is about 80 cm per year.

Johannesburg is connected with major sea ports by an extensive and generally good system of railroads, highways, and airways. This city is also the South African port of entry for the several international airlines serving the country. All shipments for the station (sea and air) are sent to the CSIR National Institute for Telecommunications Research, where they are routinely serviced and processed through customs. Although careful documentation is required, no problems have been encountered.

Communications are currently maintained via NASA link to their nearby installation, from which messages are transmitted by direct link to the station. Although NASA does not plan to retain this link, commercial telegraph will be available at an average of from 21 to 34¢* per word after September 1975.

The laser, camera, and cloud-cover statistics for Olifantsfontein for the period April 1973 to March 1974 are shown in Figure 5. The correlation between laser passes

*Price information is current except where otherwise indicated.

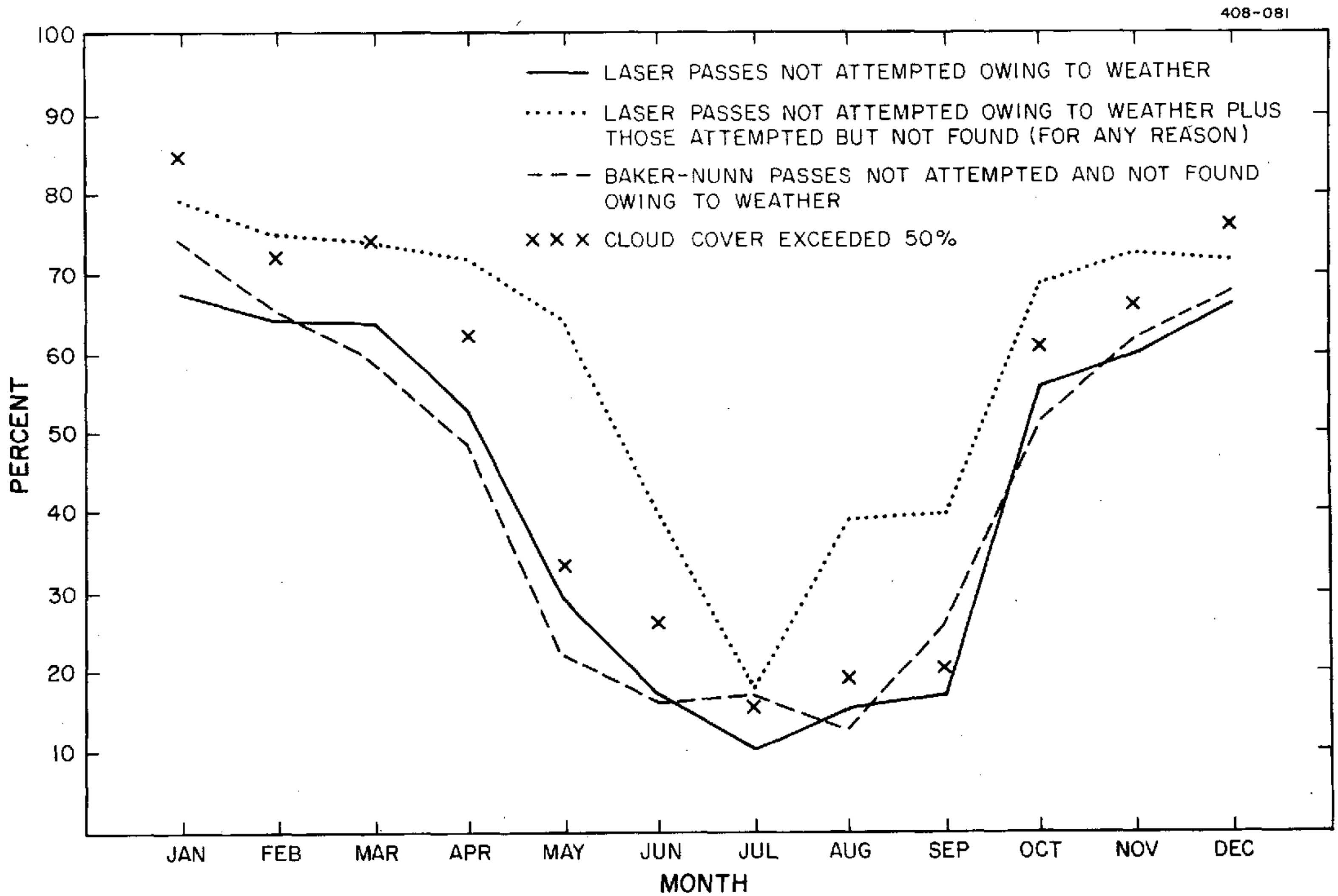

Figure 5. Weather and cloud-cover statistics for laser and camera sites at Olifantsfontein, April 1973 to March 1974.

lost to weather and cloud cover greater than 50% is again very strong, with cloud cover giving a slightly pessimistic view. Here again, this is probably a reflection of unsuccessful passes attempted during adverse conditions. Baker-Nunn data lost to weather agree very well with the laser statistics and appear to give a good indication of the influence of weather on laser operations.

Baker-Nunn camera statistics averaged over a 6-year period for Olifantsfontein are shown in Figure 6. During the local winter months (June, July, and August), only about 20% of the satellite passes are lost to cloud cover; and from midfall to midspring, generally 50% or less of the passes are lost. Conditions during summer, however, are poor. From the correlation with laser statistics (Figure 5), these results indicate that we would lose half the laser passes during 6 or 7 months of the year, but for the rest of the year, conditions would be excellent. This has been borne out by our laser operations for the past 3 years at this site.

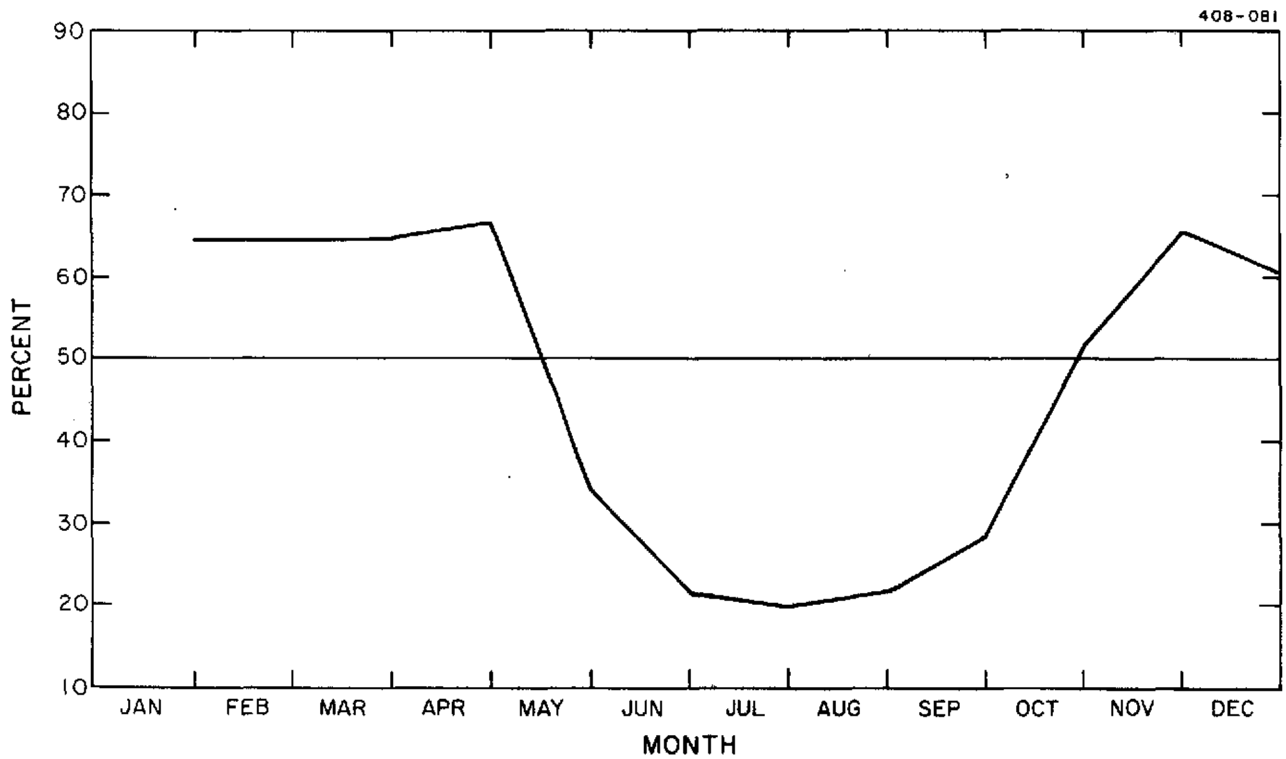

Figure 6. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Olifantsfontein averaged from 1967 to 1969 and 1971 to 1973.

2.4 Brazil (Natal)

An Astrophysical Observing Station was established in Brazil in September 1966, after having been moved from its former location in Curaçao, Netherlands, Antilles. The station is run in cooperation with the Instituto de Pesquisas Espaciais (INPE), formerly the Comissao Nacional de Atividades Espaciais, under the terms of an agreement dated March 29, 1966. This agreement remains in force indefinitely (until 90-day written notice of intent to terminate is provided by either party) and is contingent on the availability of funds. Local station personnel are employees of the INPE, in accordance with a Brazilian law that prevents Brazilian citizens from receiving money from foreign organizations. SAO reimburses the INPE for these services monthly.

The station itself is on the grounds of a research complex, in an area known as the Barreira do Inferno. The complex, about 17 km southeast of Natal, also includes other United States and Brazilian scientific installations and a rocket-launching facility. The research complex is operated under the auspices of INPE, and the launch facility is administered by the Brazilian Air Force.

Natal, with a population 160, 000,* is the capital of the state of Rio Grande do Norte. The city is located on a hilly point of land between the Atlantic Ocean and the broad estuary of a minor river, the Rio Potengi, at longitude 35°12'W, latitude 5°17'S, on the northeast hump of Brazil. The surrounding countryside is well watered, rather flat, and fairly fertile, but not far inland, the coastal plain ends and the arid mountainous interior begins.

Thanks to the moderating influence of the southeast trade winds, which blow continually at 8 to 24 kph, temperature extremes are not experienced in Natal. The mean daily maximum temperature in summer is 30°C, and in midwinter, 28°C. The respective mean daily minima are 23 and 20°C. The highest temperature recorded in the 10 years from 1954 through 1963 was 32°C, and the lowest, 17°C. The relative humidity

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*Population information circa 1965 (SAO internal communication).

is usually about 70%. Mean annual precipitation is about 1 m, mostly in the form of brief, local showers. A distinguishable rainy season lasts from March through July, when the monthly rainfall is about four times greater than it is during the rest of the year; however, it does rain every month of the year.

Natal is serviced by air, overland, and sea. Parcel-post and sea-freight shipments are easily made through the United States Consulate General in Recife, about 240 km south of Natal. Air freight is used very little because of difficulties in transshipment from Rio de Janeiro. Air mail takes 7 to 14 days.

Rapid communications are maintained between Natal and SAO by radio link. Commercial cable is also available, with an estimated 7- to 8-hour delivery time.

Laser, camera, and cloud-cover data for Natal for the period April 1973 to March 1974 are shown in Figure 7. The correlation between laser passes lost to cloud cover and cloud cover greater than 50% is apparent; however, the cloud-cover data give a very pessimistic view. Even if we accept cloud cover of 60%, or even 70% or greater, we still get a poor prediction for laser operations. The problem with this analysis in Natal in particular is that the weather there is very cloudy in general, and ranging is often attempted during severely adverse conditions when success is unlikely. A better indication of laser passes lost to weather is to use percentage of passes not attempted owing to weather <u>plus</u> those attempted but not successful (for any reason). (The latter quantity really reflects weather conditions because, according to the station staff, weather is a dominant reason for the loss of attempted satellite passes.) This combined quantity fairly closely follows the 60% or greater cloud-cover data; however, such a high percentage of cloud cover still gives a slightly pessimistic forecast for laser operations. We attribute the fact that Brazil has had apparent success in combatting weather problems in its laser operations to the operating techniques the staff has developed for such poor weather conditions. The observers place very high priority on even the shortest of satellite passes that must be shot through holes in the clouds. This is borne out by their 15 points-per-pass average, which is about 5 points per pass less than that at other stations.

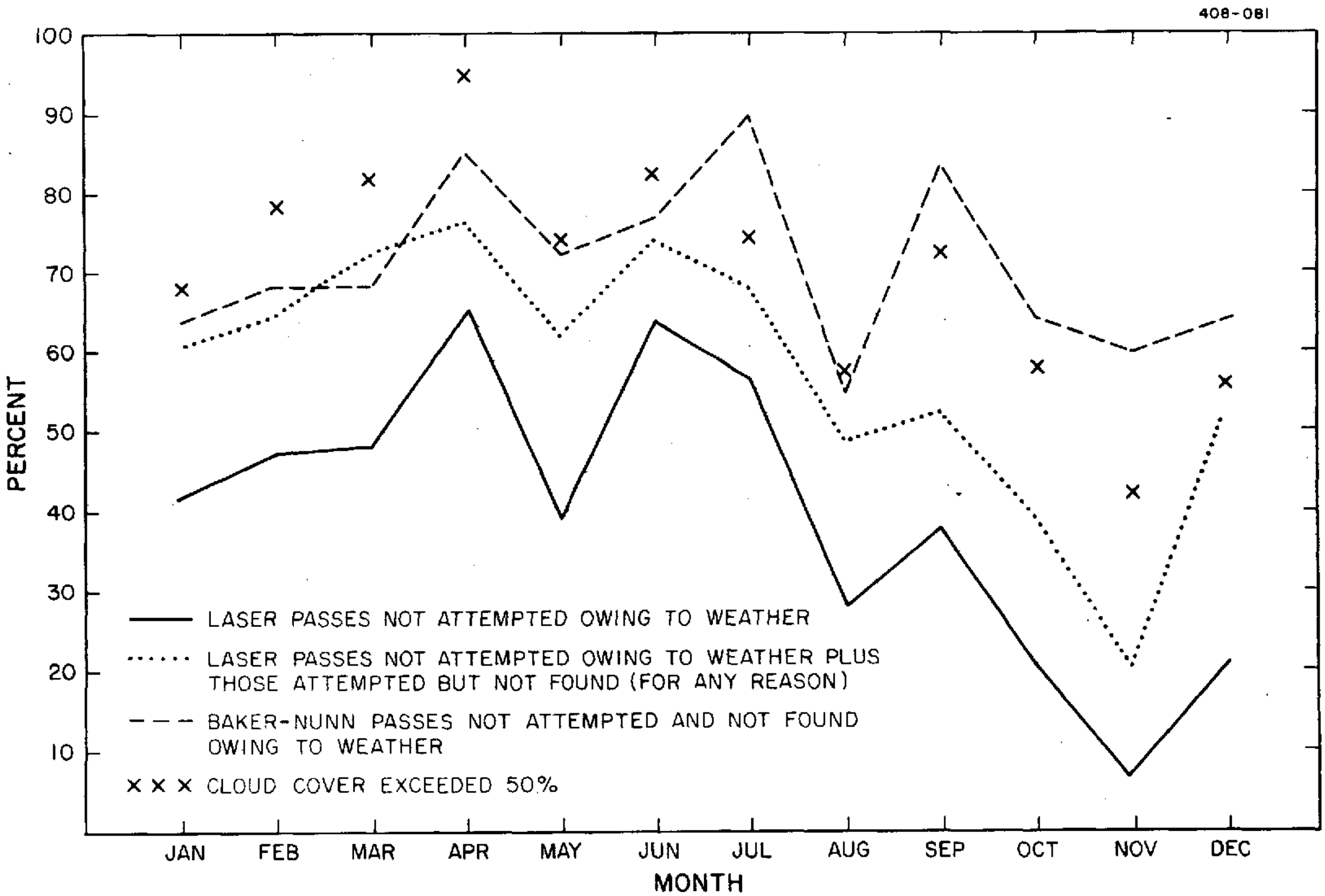

Figure 7. Weather and cloud-cover statistics for laser and camera sites at Natal, April 1973 to March 1974.

Baker-Nunn data lost to weather follow fairly well the greater-than-50% cloud-cover data. Again, there is some correlation between the Baker-Nunn statistics and the percentage of passes not attempted as a result of weather plus those attempted but not successful; however, the camera statistics give a slightly pessimistic view of laser operating conditions. As with Peru, this may be a reflection of better overall daytime conditions, since the laser data are taken during both day and night, while the camera can operate only at night.

Baker-Nunn camera statistics averaged over a 7-year period are shown in Figure 8. The loss due to weather averages about 65%. From the correlation data, we can expect this estimate of how well the laser would do to be slightly weak (by maybe 10%). During most months of the year, we would probably lose more than half the laser passes to weather. This, indeed, has been our experience with our laser operation in Natal for the past 3 years.

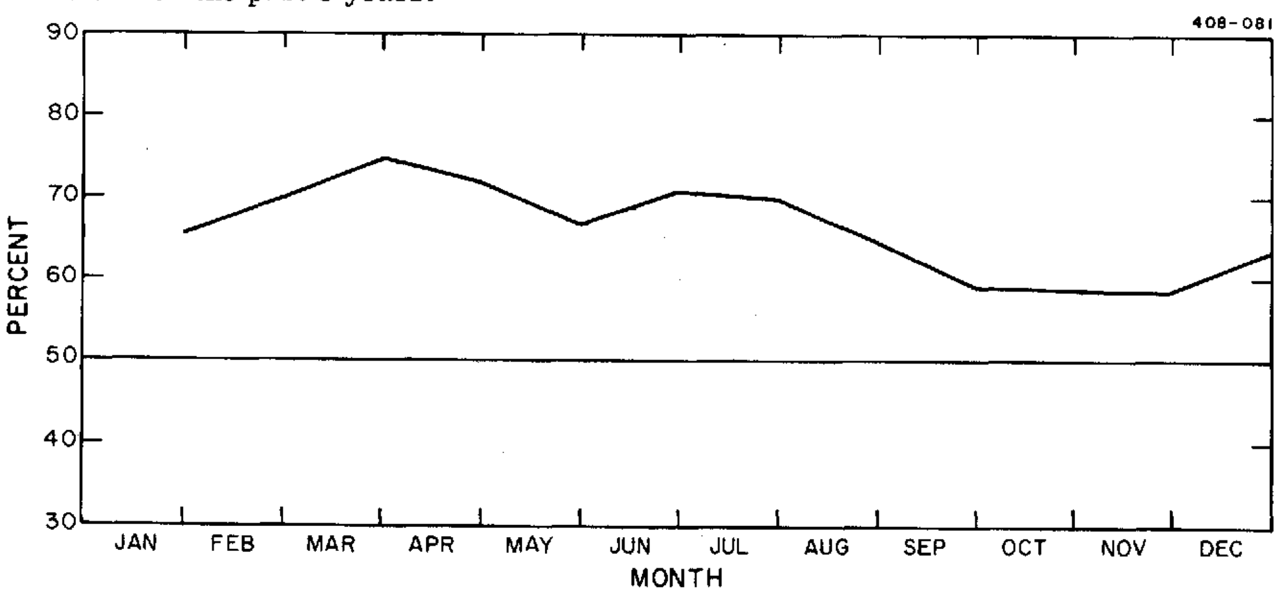

Figure 8. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Brazil averaged from 1967 to 1973.

3. SAO BAKER-NUNN CAMERA STATIONS

3.1 Ethiopia (Debre Zeit)

The observing station in Ethiopia was established in August 1966 in cooperation with the Haile Selassie I University (HSIU) under the terms of an exchange of letters dated October 8, 1965, and a subsequent implementing agreement dated May 4, 1966. This agreement remains in force indefinitely (until 90-day written notice of intent to terminate is given by either party), contingent on the availability of funds and the scientific needs of the SAO program. The station was formerly located in Shiraz, Iran.

The station is situated in Debre Zeit (Mount of Olives), about 40 km southeast of Addis Ababa, near the edge of a crater lake on the African Rift. Addis Ababa, the capital and major city of Ethiopia, is in the midst of mountains at an altitude of about 2500 m.

There are two basic seasons, dry and rainy, with the latter being divided into the "small rains" and the "big rains." The dry season extends from mid-October to February or March, with a seemingly endless procession of bright, sunny days and moderate temperatures. The small rains are generally intermittent showers occurring during February, March, and April, while the big rains usually start about mid-June and continue to the end of September. Although it rains practically every day during this time, these days are interspersed with periods of sunshine. The average rainfall of Addis Ababa is 1.25 m. Temperatures are comparatively constant throughout the year, with an average mean temperature of 17°C; daytime temperatures rarely reach 27°C. The temperature drops sharply after sunset, with nighttime temperatures sometimes (but not often) as low as 3°C in October and November. Frost is rare. According to a local report, the weather is "sunnier" in Debre Zeit than in Addis Ababa.

Addis Ababa is serviced by air from major European capitals and by sea via Djibouti. It normally takes from 3 to 4 months for surface shipments to arrive and 2 to 3 weeks for air freight. Customs procedures are difficult, as our cooperating agency no longer enjoys customs-free status.

Commercial telegraph and Telex are available. Air mail takes approximately 5 to 7 days to reach the United States.

Statistics on Baker-Nunn data lost to weather for Debre Zeit averaged over 7 years appear in Figure 9. In general, about half the passes are lost, with the worst conditions occurring during the summer. In the fall and early winter, the weather is quite favorable. We consider these data to give a fairly good indication of the influence weather will have on laser operations at the site. If anything, these data may be 5 to 10% pessimistic.

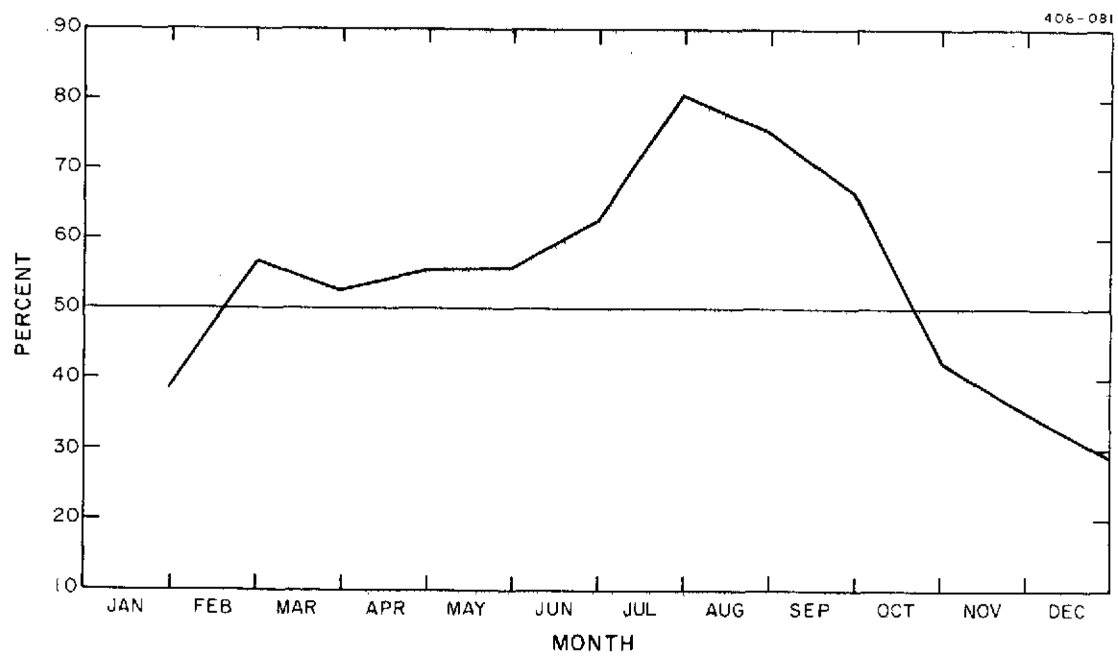

Figure 9. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Debre Zeit averaged from 1967 to 1973.

3.2 Greece (Dionysos)

In November 1967, a Baker-Nunn camera was moved from Jupiter, Florida, to Dionysos, Greece. It is operated in cooperation with the National Technical University (NTU) of Athens under terms of an agreement dated October 3, 1966. This agreement, contingent on the availability of funds, remains in force until either party furnishes written notice to terminate. The Dionysos station is staffed and supported jointly by the two organizations.

Approximately 40 km northwest of Athens, Dionysos is in a fairly mountainous scrub pine forest overlooking the Plain of Marathon and the Aegean Sea. The climate is typically Mediterranean, with moderately cold winters and warm summers.

Athens is situated 90 m above sea level on the Attica Plain, which is bordered on the south by the Aegean Sea and by Mts. Parnes, Penteli, and Hymettus on the other sides. The plains are agriculturally fairly rich, but they are surrounded by semiarid hills and mountains, characteristic of much of Greece.

In Athens proper, the winter (December through March) temperature averages 4°C. From June through September, the daytime average temperature is slightly less than 32°C, although the temperature frequently reaches 38°C; humidity rarely exceeds 60%, averaging about 40%. Fresh breezes from the sea and mountains temper the climate. Rainfall in Athens occurs chiefly in the winter months. Summer months are usually rainless and consequently very dusty. Cold northerly winds blow in winter, and snow occasionally flurries in the suburbs; the surrounding mountains are lightly blanketed by snow.

Logistics arrangements for the Greece station are excellent. SAO enjoys United States Embassy privileges at no cost. Communications are provided via the Autodin link to the nearby United States Naval Base at Nea Makri, from where they are brought to Dionysos by station personnel.

Statistics on Baker-Nunn data lost to weather in Athens averaged over 7 years are shown in Figure 10. From midspring to late fall, conditions are fairly good, falling to only 25% loss during the summer. Operations during the winter months are poor. This pattern corresponds roughly with the availability of data from the NTU laser system, operated jointly by NTU and SAO. We consider these data to be a good indication of the influence of weather on laser operations at this site.

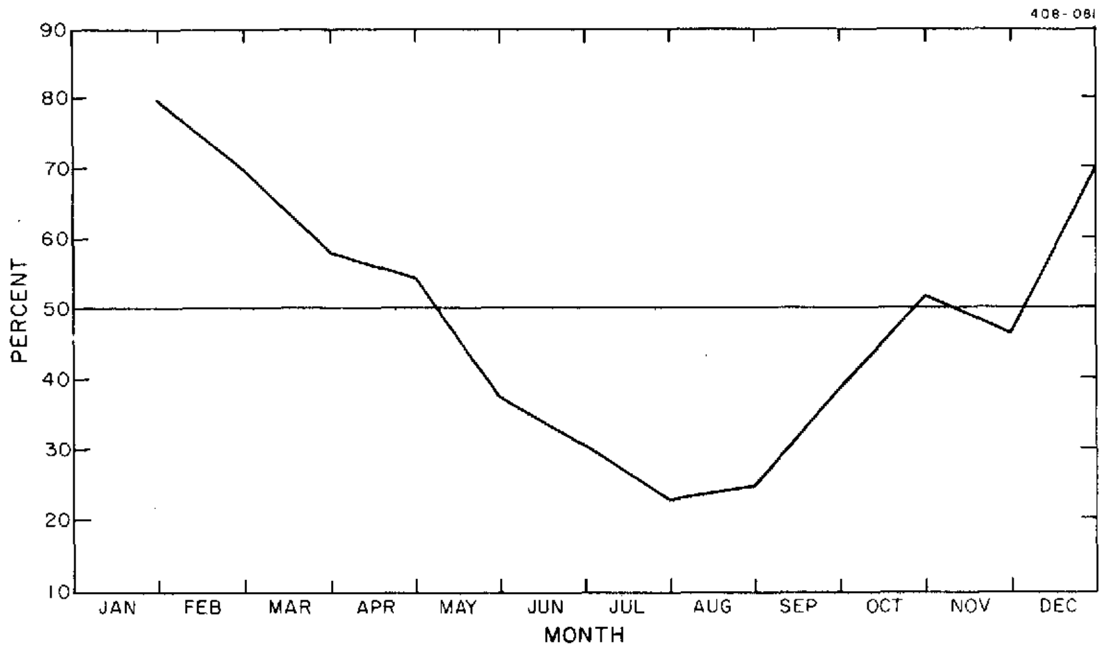

Figure 10. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Dionysos averaged from 1967 to 1973.

3.3 Hawaii (Maui)

The Maui, Hawaii, Astrophysical Observing Station was established in June 1958 through the cooperation of Dr. C. E. Kenneth Mees, retired Vice President and Director of Research, Eastman Kodak Co., and the University of Hawaii (UH). The University provided the station site and contributed $11, 000 toward building the facilities. The original agreement between SAO and UH was concluded on April 3, 1962, and expired June 30, 1970; a new agreement was signed on July 24, 1970, for a 10-year period ending June 30, 1980. Under the terms of these agreements, the physical facility at the Maui station site shall become the property of the University of Hawaii should SAO leave the site. Cooperating groups at the University are the Institute of Geophysics and the more recently created Institute for Astronomy. Since

February 1970, the station has been funded by AVCo, under subcontract to the Advanced Research Projects Agency.

The Maui station is located within 450 m of the top of Mt. Haleakala (House of the Sun), the largest dormant volcanic crater in the world. The observing station is one of several installations on the mountain top, which is nicknamed "Science City."

From the farming cênters and cane towns of Maui, a 35-km, extremely winding road leads up the mountain to the station. Almost every kind of climate is found on Maui. One side of the mountain is completely arid, while the other is a tropical rain forest. The station is about 3000 m in altitude, above almost all clouds; if there are clouds, they are seen as fog. Cinder dust in a strong wind is a problem, although not a serious one. Occasional snow storms blanket the mountain top.

The Haleakala station is served by air from Honolulu, Oahu, to Kahului, Maui, near the foot of the mountain, and by sea via barge from Honolulu. Communications are currently provided by Autodin link to Pearl Harbor and by leased line directly to the station.

Figure 11 presents 6-year averaged statistics on the Baker-Nunn data lost to weather in Maui. On the average, about 45% of the passes are lost. Conditions improve a little from midspring to midfall. We view this as a good indication of the influence weather will have on laser operations.

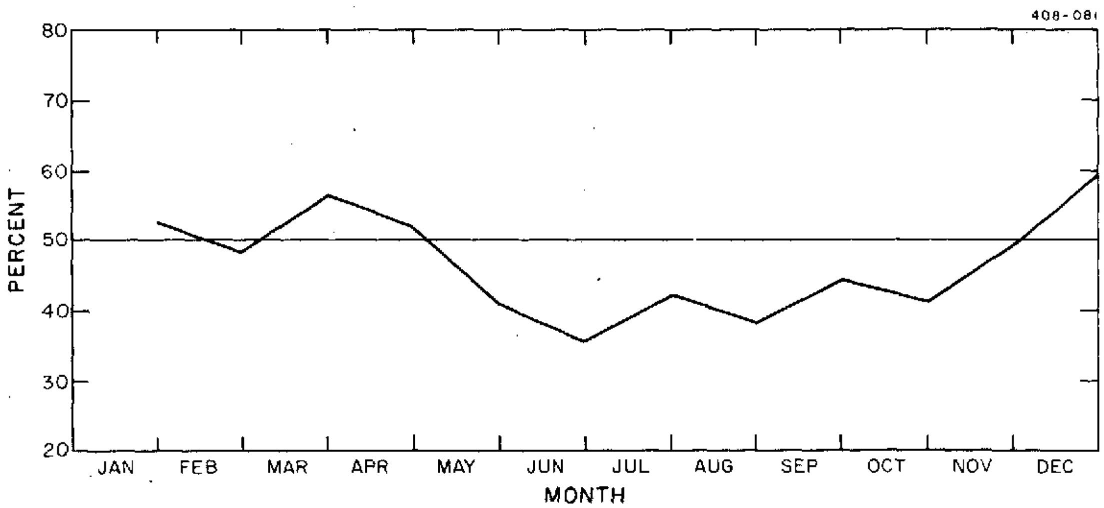

Figure 11. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Maui averaged from 1967 to 1969 and 1971 to 1973 (some months are missing).

3.4 India (Naini Tal)

In 1958, an Astrophysical Observing Station was established in Naini Tal, India, in cooperation with the Uttar Pradesh State Observatory (UPSO), counseled by the Indian National Committee for the IGY. Under terms of a cooperative agreement dated December 6, 1963, UPSO maintains, staffs, and operates the station and SAO provides the necessary equipment and supplies, including the Baker-Nunn camera, which was provided at the onset of the program. This agreement remains in force, subject to the availability of funds, until 6 months after either party gives written notice of an intent to terminate.

UPSO is the only observatory in India that is a state institution; its director, Dr. S. D. Sinvhal, is responsible to the Department of Cultural Affairs and Scientific Research, Government of Uttar Pradesh, and the Observatory receives most of its support from the state government. It has several scientific instruments, including a recently constructed 1-m reflecting telescope.

The India station is approximately 240 km north of New Delhi and 12 km from Naini Tal, a town of 12,000 people.* Naini Tal is in an open valley 1930 m above sea level and is surrounded on three sides by hills, the tallest of which, Chiena Peak, rises in the north at 2600 m. The camera, on Manora Peak, was the first instrument to be installed at UPSO. As an historical note, Naini Tal was the first of the hill stations of India, where European administrators in the days of British rule used to escape from the extreme summer conditions on the plains of India.

In Naini Tal, the average maximum daytime temperature is 18°C in winter and 29°C in summer. The average rainfall is 2.5 m, much of which occurs during the monsoon season, from June to October.

There is no airport close to Naini Tal; the area is serviced overland by road or rail from New Delhi. Shipping and customs procedures are complex and time consuming, even though our cooperating agency is an institution of the Indian State Government. All shipments valued over $21.00 (cost including freight) must go through the Director General of Supplies and Disposals in Bombay, despite their being designated as "gifts

*Population information circa 1968 (Hayes, 1968).

for scientific use." This procedure involves their being transshipped to Bombay from New Delhi or Calcutta (a distance of at least 800 km) by local airlines and then returned to New Delhi for final shipment to Naini Tal. The large amount of paperwork required must be in perfect order, and even then, delays of up to several months are experienced. Duty is paid on all supply items (including Baker-Nunn film); duty is also charged on "duty-free" items (equipment) if papers and shipments are not in order.

Commercial telegraphic communications are available at approximately 40¢ per word. Average transmission time is under 10 hours. Through special arrangement, same-day messenger service for communications to Naini Tal is available to SAO one day per week at minimal cost, via the American Embassy in New Delhi and the driver of the overnight bus to Naini Tal. Return messages are sent through regular commercial channels.

Figure 12 shows statistics on Baker-Nunn data lost to weather in Naini Tal averaged over 7 years. During most of the year, less than 50% of the passes are lost, while in summer months, cloud cover nearly closes down operations. We think these data indicate fairly well the influence weather will have on laser operations at this site.

3.5 Spain (San Fernando)

The Spain station was established in February 1958 in cooperation with the Instituto y Observatorio de Marina (IOM), which has played a distinguished role in European astronomy. It was one of the 14 observatories that undertook the "Carte du Ciel" at the turn of this century. The original agreement between SAO and the IOM was dated August 14, 1959; a new agreement between the two parties, concluded September 18, 1972, updates the original one and extends the active cooperation of the IOM in the pursuit of space research. New provisions include the appointment of a Spanish Naval Officer, salaried by the IOM, as Station Chief. This agreement remains in force until 90-day written notice of intent to terminate is received by either party; the agreement can be modified on demand by either party.

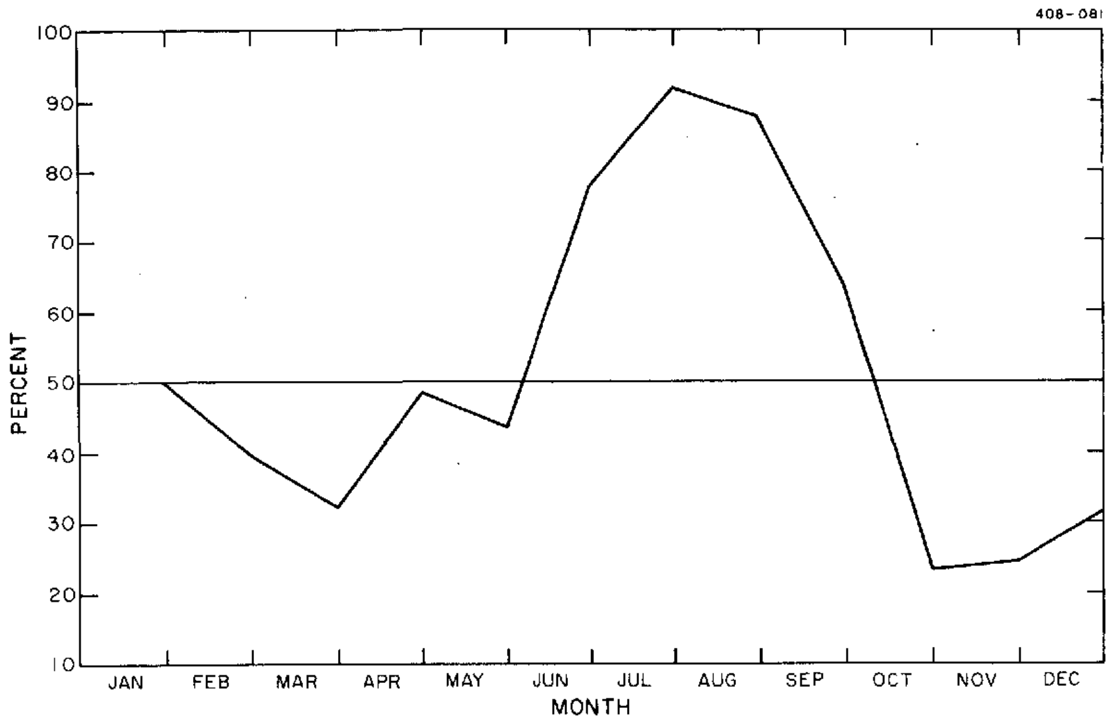

Figure 12. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Naini Tal averaged from 1967 to 1973 (some months are missing).

The station is near the Observatorio de Marina in the town of San Fernando, about 80 km northwest of Gibraltar. Cadiz, the nearest city, is about 8 km away; it is situated on a narrow peninsula between the Atlantic Ocean and the Bay of Cadiz. Its population numbers about 40,000.*

Most of the country in the Cadiz area is dry; it receives considerable rainfall during the winter but little between mid-April and mid-November. The climate is very agreeable, the temperature normally ranging from 7 to 10°C in winter and 29 to 32°C in summer.

*Population information circa 1968 (Hayes, 1968).

Most of the vineyards and olive groves of the country are found in this area, and the region is also the home of the Spanish wine-making industry. About 25 km from Cadiz, huge tracts of cork trees are also seen.

Cadiz is serviced overland and by rail from Seville and Madrid. Air parcel-post shipments are sent to the nearby Rota Navy Base; they arrive in about 1 week, and no problems have been encountered. Air freight is not used, because of difficulties in clearing customs in and transshipment from Madrid. Sea freight is sent to the United States Army dock in Cadiz. For the past several years, a low volume of materials was shipped to Spain. No United States personnel are currently assigned to the site, and no provision exists for private ownership of United States vehicles should United States personnel be assigned there in the future.

Communications are sent on the Autodin circuit to the Rota Navy Base, where messages are transmitted by teletype over land line to the station.

Figure 13 shows statistics on Baker-Nunn data lost to weather in San Fernando averaged over 7 years. Data losses are less than 50% except for late winter, and even at this time, they do not exceed 50% at night. During the summer months, data losses are less than 30%. We view these data as a very good indication of the influence of weather on laser operations at this site.

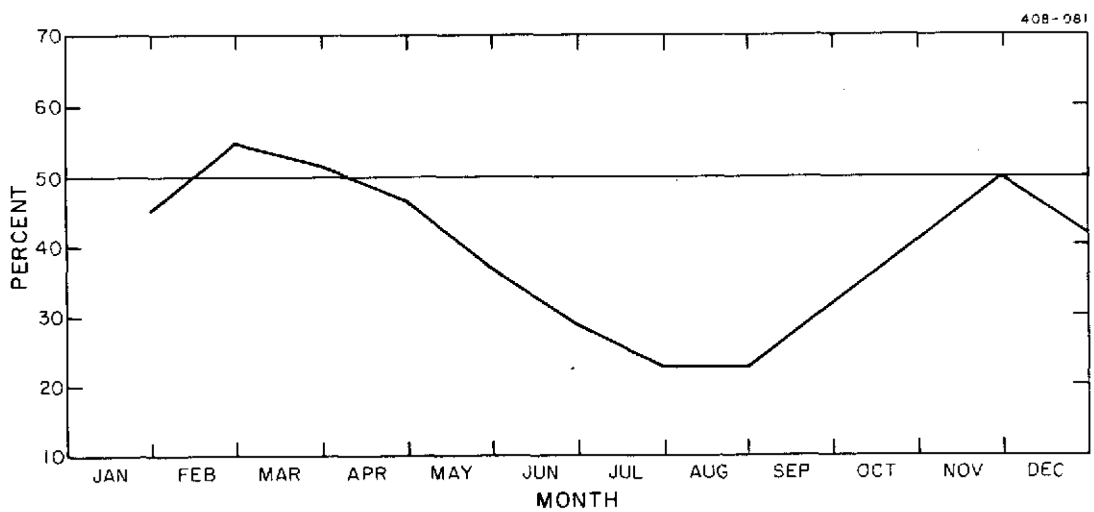

Figure 13. Statistics of Baker-Nunn passes not attempted and not found owing to weather for San Fernando averaged over 1967 to 1968 and 1970 to 1973.

3.6 Australia (Orroral Valley)

The SAO Baker-Nunn station in Australia is operated under terms of an agreement signed February 18, 1966, between NASA, as cooperating agency for the Government of the United States, and the Department of Supply (DOS), for the Government of Australia. Under the terms of this agreement, which is pursuant to an agreement effected by an exchange of notes between the two governments, NASA exercises its responsibilities and obligations through Smithsonian Institution (SI), which is also party to the agreement, and bears all costs in connection with relocation, management, operation, maintenance, support, modification, and termination of the station, except such sums as agreed on with the DOS. The station is staffed and operated independently by the DOS, in close cooperation with SAO. Until 1969, when funds were no longer available, an SAO "representative" was assigned to Australia as a regular observing crew member.

This agreement continues in force indefinitely until reasonable notice is given by one of the signatories to the other two; it is, of course, contingent on the continuation of the government-to-government agreement referenced above.

The station in Australia, established in February 1958, was initially located at Range "G" and subsequently at Island Lagoon, Woomera, where it operated until early 1973. The equipment is now awaiting installation in its new location, at the NASA station in Orroral Valley.

Orroral Valley is in New South Wales, Australia, 64 km southwest of Canberra, the capital of Australia. Canberra is 300 km from Sydney, at latitude 35°37'S and longitude 148°57'E. The Orroral Valley/NASA station complex, in an area of approximately 16 hectares and at a height of about 920 m, was completed in July 1965; it includes a Minitrack facility and a 25-m dish, along with several administration and operations buildings.

According to climatological data taken for the period 1912 to 1939 in Canberra, Australia, and reported in "STDN Station Plant Facilities Development and Station Description, Orroral, Australia" (National Aeronautics and Space Administration, 1972), temperatures vary from a high of 36°C in January (local summer) to a low of -5°C in June and July (local winter). Average daily maxima and minima vary from 28°C in January to -5°C in July, for a yearly average of 20 and 7°C, respectively. Absolute maxima and minima for the same months are 43 and -10°C. Relative humidity varies from 85% in June and July to 35% in January. Yearly precipitation averages 58 cm; no month averages higher than 5.5 cm or lower than 4 cm.

NASA maintains teletype communications with the site; the station mail address is in Canberra City, which is accessible from all parts of the world by air and sea, via Sydney. In the past, air and sea-freight shipments were made c/o DOS, and presumably no customs problems have been encountered. Under terms of the NASA/DOS agreement, DOS is responsible for arranging transportation of all SAO-furnished equipment within Australia.

Since the station in Orroral Valley is not yet operational, we do not have Baker-Nunn camera data. However, we do have cloud-cover data for Canberra furnished by the Bureau of Meteorology in Australia. Statistics on cloud cover, averaged over a period of 34 years, are presented in Figure 14, from which we see that cloud-cover conditions remain fairly constant throughout the year, with cover greater than 50% occurring about 45 to 50% of the time. This is probably a fairly good indication of the influence of cloud cover on a laser operation in this area. From the correlations examined in Section 2, however, it may be slightly pessimistic.

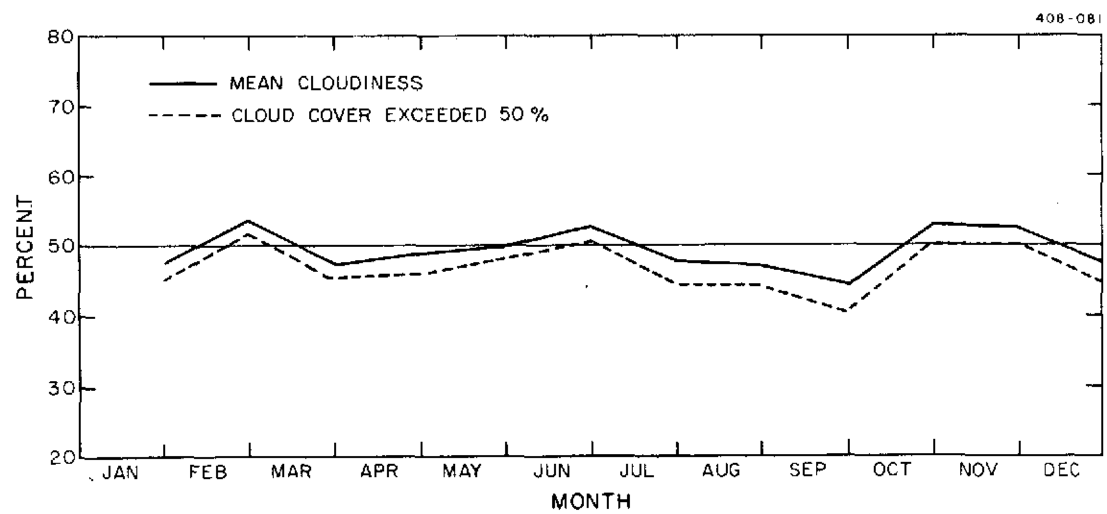

Figure 14. Statistics on cloud cover in Orroral Valley averaged over 34 years.

4. PREVIOUS SAO BAKER-NUNN CAMERA STATIONS

4.1 Argentina

The Astrophysical Observing Station in Argentina was first established in Villa Dolores in 1958 under a cooperative agreement with the Astronomical Observatory of the University of Cordoba. In March 1962, a country-to-country agreement between the governments of Argentina and the United States was signed, naming the Comisión Nacional de Investigaciones Espaciales and SI as cooperating agencies for the continued operation of the research facility. Under the terms of this agreement, an implementing agreement was executed by the two parties in February 1966, before the station was moved to Comodoro Rivadavia, Argentina, that November. This agreement was allowed to lapse after the station in Comodoro Rivadavia was closed in late 1969; however, in anticipation of possible future cooperative programs, the government-to-government agreement remains in force until written intent to terminate is received by either party.

4.1.1 Villa Dolores

The station site at Villa Dolores is in the province of Cordoba on the west side of the Sierras Grandes de Cordoba, a mountain range that forms a natural boundary between the fertile plains to the east and the semiarid lands to the west. The station is about 800 km inland from Buenos Aires and 10 km outside Villa Dolores, a large rural town with a population of about 30, 000.*

Villa Dolores has a warm, temperate, moderately humid climate, quite similar to that of central Texas. In winter, June through August, temperatures may drop well

*Population information circa 1968 (Hayes, 1968).

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below freezing at night but usually rise during the day. Winters are dry, with infrequent precipitation, although there are brief periods of cloudy, chilly, damp weather. Very occasional snow flurries occur, but the snow rarely lasts more than a few hours, or overnight on the mountains, and melts as soon as it falls in Villa Dolores.

During summer, December through February, temperatures usually range from 10 to 15°C at night through 20 to 26°C during the day, with some hot spells near 40°C. Rain occurs about one-third of the summer days, but generally in the form of short thunderstorms, which may be quite heavy and may be accompanied by hail and wind.

The country around the station consists of rolling foothills, covered with thick native thorn and wiry brush. It is a ranching and small-farm area with citrus and olive groves, fruit orchards, and tobacco, corn, and vegetable patches. Most of the farms and orchards are irrigated. The surrounding pueblos and Villa Dolores have a variety of trees, flowering shrubs, and flowers.

The site is logistically remote. The closest air service is from Buenos Aires to Cordoba about 160 km away, from which the Villa Dolores area is serviced overland, over a range of mountains, by bus and truck. Customs procedures in Buenos Aires are difficult and time consuming. Good communications were previously maintained between Villa Dolores and SAO by radio. Commercial cable is also available at an estimated 14 to 33 hours for delivery. Airmail takes from 7 to 10 days.

The only statistics available for the Baker-Nunn camera in Villa Dolores are percentage of passes not attempted owing to weather; shown in Figure 15, these data probably present an understatement of the influence of cloud cover by about 5%. Less than 50% of the passes are lost during almost all months of the year. The month-to-month variations are small, but the best results are obtained during the local winter months. These data are probably a fair indication of the influence weather would have on a laser operation at this site.

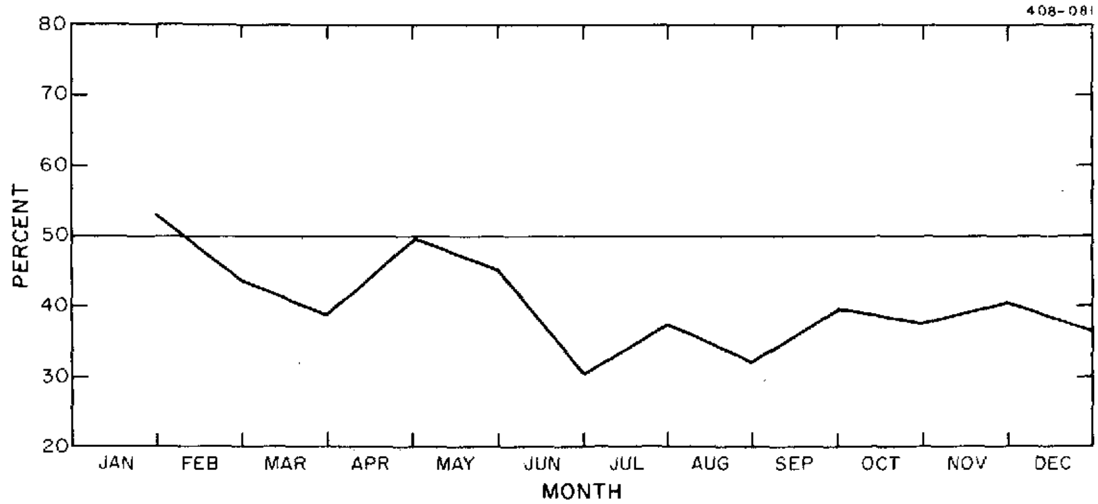

Figure 15. Statistics of Baker-Nunn passes not attempted owing to weather for Villa Dolores averaged from 1962 to 1963.

4.1.2 Comodoro Rivadavia

The Comodoro Rivadavia station is located in Patagonia, about 12 km south of Comodoro Rivadavia and approximately 1400 km south of Buenos Aires, on a high (200 m) rolling pampa between two ranges of hills running east and west from the Pampa del Castillo to the Atlantic Ocean. The surrounding land is scrub brush, thorn bush, and wiry grass. Visibility is excellent in all directions.

The dry, maritime climate is characterized by moderate temperatures in midsummer and relatively mild winters. The mean daily maximum temperature in midsummer is 26°C, and in midwinter, 10°C; near the station, four or five snowfalls of about 5 to 10 cm can be expected each winter. Normal annual rainfall is near 20 cm. The wind is usually cool and dry from the west and averages 32 kph both day and night.

The soil is composed of fossilized mollusk shells in a dense mud-like sediment overlain with a thick, fine dust. In dry weather, dust storms are common.

According to an SAO site survey conducted in August 1965, faulting and earthquakes are unknown in the area. Appendices A through D gives details of weather observations, wind velocity, and percentage of cloud cover for selected periods.

Although Comodoro Rivadavia is on the sea, all materials destined there must enter the country at Buenos Aires and be transshipped. Exports also move via Buenos Aires. Comodoro Rivadavia is serviced overland and by air from Buenos Aires. Customs procedures can be time consuming and difficult.

Good communications were previously maintained between Comodoro Rivadavia and SAO by radio link, and commercial communications are available. Cables to New York cost about 30¢ per word in 1965 and took 8 hours for delivery. First class airmail takes about 1 week.

Figure 16 shows statistics on Baker-Nunn data lost to weather in Comodoro Rivadavia averaged over 2 to 3 years. On the average, approximately 45 to 50% of the passes are lost. The best results are obtained in the spring, when only about 35% are lost. We think this is a fair indication of the influence weather would have on a laser operation at this site.

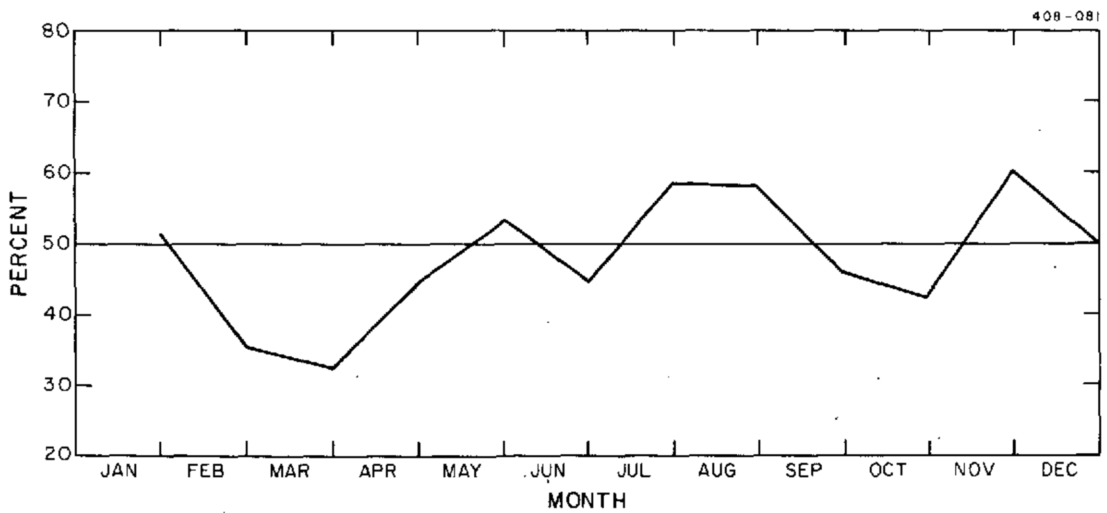

Figure 16. Statistics of Baker-Nunn passes not attempted and not found owing to weather for Comodoro Rivadavia from February 1967 to October 1969.

4.2 Florida (Jupiter)

The observing station in Florida was established in May 1958, in Jonathan Dickinson State Park in Jupiter, Florida, and was moved to Greece in November 1967. The site was provided under lease between the Florida Board of Parks and Historic Memorials and the United States at an annual fee of $1.00. In 1968, after the station had been moved to Greece, SI assigned this lease to the United States Air Force, who operated a Baker-Nunn tracking station there until July 1970. The site has been vacant since that time (except for a United States Civil Defense installation in the underground storage tank); however, the lease remains in force should we or some other group wish to occupy it.

Johnathan Dickinson State Park is 25 km north of West Palm Beach at an elevation of about 13 m, with a typical subtropical climate. Cumulo-stratus clouds move in from the ocean in early evening and usually do not clear off until morning. The humidity is high, and rust and corrosion result. Salt spray and haze are also common. In the summer months, July through September, afternoon thunder showers are frequent. Typically, summer temperatures are 35°C during the day and 24 to 27°C at night, with 95% humidity. Winters are more temperate, with warm days and cool nights. Insects can be a problem.

There is a jet airport at West Palm Beach. Communications can be sent by teletype or commercial cable, taking from 3 to 45 min to reach SAO. FTS communications may be available.

For the station at Jupiter, the only Baker-Nunn statistics we have are percentage of passes not attempted owing to weather. These data appear in Figure 17. Again, these figures most likely underestimate the influence of weather by about 5%. In general, the data lost are about 50% and remain pretty constant throughout the year. From these data, we probably have a fair estimate of the influence of weather on a laser operation at this site.

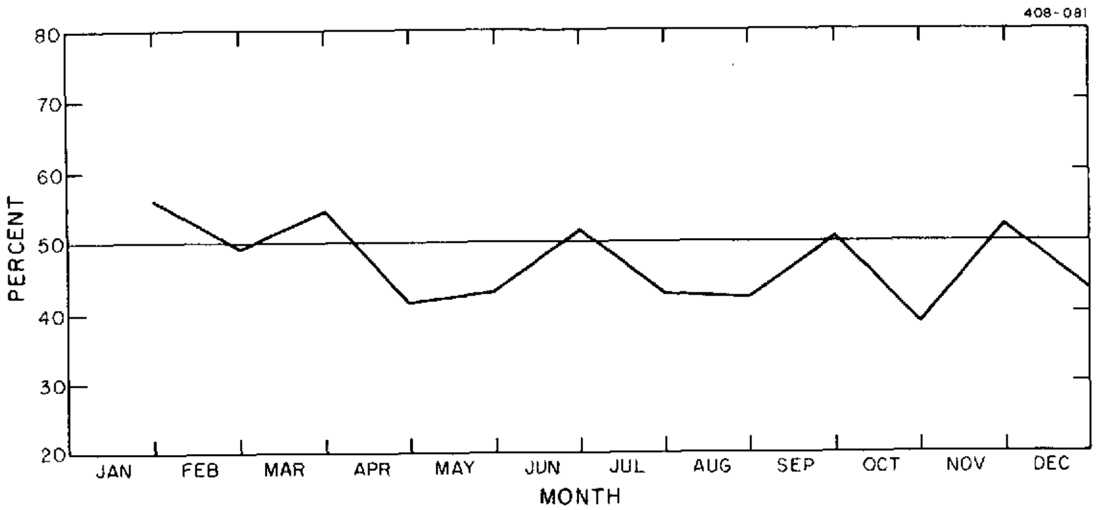

Figure 17. Percentage of Baker-Nunn passes not attempted owing to weather for Jupiter averaged from 1962 to 1963.

4.3 Iran (Shiraz)

The Smithsonian Astrophysical Observing Station formerly located in Shiraz, Iran, was moved to Ethiopia in August 1966. The Shiraz station was established in 1958 through arrangements with the University of Teheran. The Universities of Teheran and Shiraz assumed the construction costs of the buildings and arranged for lease of the land. According to SAO records, no formal agreement was ever concluded between the two parties or governments of the respective countries, although several were drafted. A letter dated November 1, 1957, from Karl G. Henize of SAO to Hossein Kashy Afshar of the Geophysical Institute of the University of Teheran, served as the basis of understanding for the operation of the station. SAO and the University of Teheran were considered cooperating agencies, and an agreement for the use of some property and equipment belonging to SAO at the former Shiraz site is currently in force between the two organizations. This agreement will remain in force until 6-month written notice of intent to terminate is received by either party.

The terrain of Iran consists chiefly of arid valleys, steep rocky mountains, and unexplored, uninhabitable deserts. The station site is in Shiraz, about 640 km from Teheran, in an arid region of the country. In southwest Iran, Shiraz has a population of about 130,000.* The city itself is in a flat, fairly green valley at an elevation of about 1600 m between two arid mountain ranges about 2400 m high, which are generally snow-capped in winter. The station is in the foothills of the mountains on the property of the Nemazec Hospital, about 6 km outside the city. Although in an arid region, the city is irrigated; with its abundance of fine trees, Shiraz is sometimes called the "City of Roses."

Shiraz is on the edge of the monsoon belt, which has an adverse effect on observing conditions, as do the dust and haze. In summers, the weather is bright and hot in the day and often very cool at night. Daytime temperatures may reach 38°C. August is the warmest month. The rainy, cool weather commences in November, and although winter temperatures are not extreme, winter is quite cool and damp.

Transportation to Shiraz is by air; goods must be transshipped from Teheran, and air freight takes from 4 to 5 weeks to reach Shiraz from the United States. Although Shiraz can be reached by sea through Khorramshahr on the Persian Gulf, even heavy equipment has been sent by air, as sea shipment is not convenient, presumably because few cargo ships go from the United States to the Persian Gulf. During SAO operations in Iran, customs clearance and communications services were provided through the United States Embassy under an agreement for shared administrative support.

The only information we have for Baker-Nunn camera operation in Shiraz is the percentage of passes not attempted owing to weather. These data, averaged over 2 years, are presented in Figure 18. We estimate that these statistics underestimate the actual data lost as a result of weather by no more than 5%. In general, the results show this to be an excellent site with regard to weather. Losses are 25% or less for 7 months of the year and reach 50% only in April. We consider these data to be a good indication of the influence of weather on a laser operation at this site.

*Population information circa 1968 (Hayes, 1968).

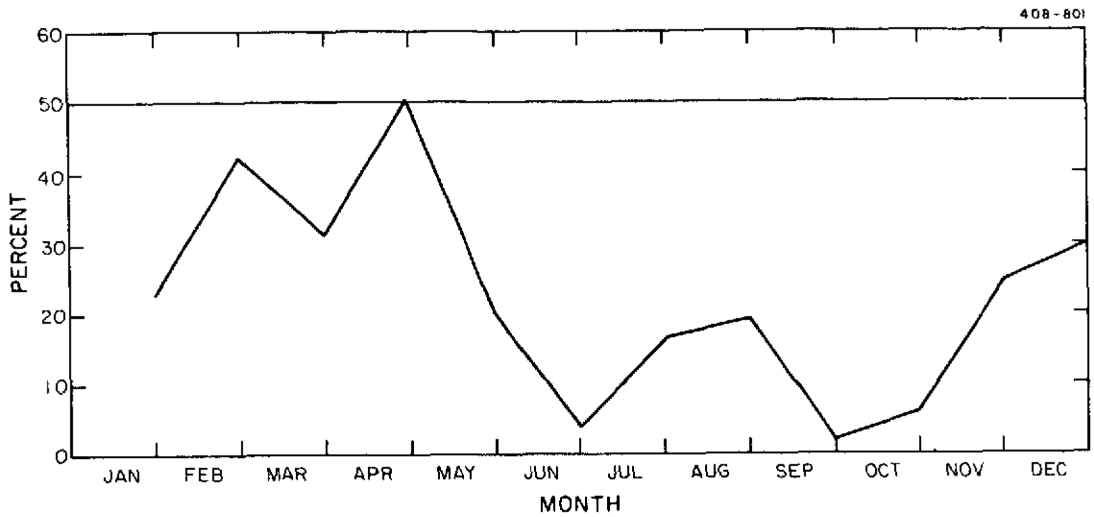

Figure 18. Percentage of Baker-Nunn passes not attempted owing to weather for Shiraz averaged from 1962 to 1963.

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APPENDIX A

WEATHER OBSERVATIONS

This table presents a resume, by months, of weather observations at the Comodoro Rivadavia airport (latitude 45°47'S, longitude 67°30'W, elevation 61 m) for the 10 years from 1951 through 1960.

Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Mean or Absolute
Mean barometric pressure (mbar)	998.7	1000.9	1001.3	1003.4	1002.1	1004.7	1002.7	1002.3	1004.2	1003.8	1000.9	1000.1	1002.1
Average temperature (°F)	66.2	65.3	61.2	53.6	48.6	43.2	43.8	46.6	48.7	54.8	61.2	64.0	54.8
Mean maximum temperature (°F)	77.9	76.8	72.4	63.5	56.8	50.4	51.3	55.2	58.4	65.6	72.5	75.3	64.8
Mean minimum temperature (°F)	56.1	54.7	52.0	45.9	42.1	36.7	37.6	39.6	40.5	45.9	51.3	54.0	46.2
Absolute maximum temperature (°F)	99.5	97.7	95.0	82.0	78.3	66.8	69.2	74.0	82.0	86.7	92.4	95.7	99.5
Absolute minimum temperature (°F)	41.4	41.4	34.0	36.7	29.1	22.6	22.6	22.3	28.0	30.4	36.7	36.1	22.3
Mean relative humidity (%)	41	42	46	53	58	63	57	53	50	44	40	42	49
Mean cloudiness (%)	58.8	52.5	48.8	53.7	56.3	56.3	52.5	55.0	52.5	53.8	56.3	61.3	55.0
Mean wind velocity (mph)	22	19	19	17	18	17	21	21	19	21	24	22	20
Maximum instantaneous wind (mph)	67	78	75	115	87	68	76	76	93	137	124	93	137
Mean precipitation (in.)	0.75	0.28	0.83	0.87	1.38	0.71	0.59	0.43	0.51	0.24	0.39	0.47	7.45
Deviation from normal precipitation (in.)	+0.31	-0.31	+0.12	+0.20	+0.16	-0.32	-0.31	-0.28	-0.08	-0.16	-0.16	0	-0.83
Mean frequency, days with precipitation	6	4	4	6	7	6	5	6	5	3	4	4	60
Mean frequency, days with frost	0	0	0	0.5	1	8	6	4	2	0.1	0	0	21.6
Mean clear days (cloudiness <25%)	3	4	7	5	5	6	7	6	6	6	4	2	61
Mean overcast days (cloudiness >75%)	8	6	5	7	10	10	9	9	8	8	8	9	97
Mean frequency, days with fog	0.2	0	0.1	0.8	0.6	0.5	0.3	0.2	0.4	0.2	0.4	0.2	3.9
Mean frequency, days with electrical storms	0	0.2	0.4	0	0.1	0	0.1	0	0.1	0.1	0.8	0.5	2.3
Mean frequency, days with hail	0.2	0.3	0.1	0.3	0.4	0.2	0.2	0.3	0.6	0.3	0	0.7	3.6

APPENDIX B

WIND DATA

We give below the frequency of wind direction and the mean velocity of the wind by direction in each month of the year, as measured at the airport of Comodoro Rivadavia from 1951 to 1960. Each entry is of the form n/V, where n is the number of instances per thousand and V is the mean velocity in miles per hour.

Direction	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Mean
North	55/12	64/12	40/11	31/12	47/14	35/10	35/14	44/12	42/6	37/11	50/12	50/14	44/12
Northeast	84/16	92/14	44/13	36/13	25/10	17/9	24/12	31/11	52/14	71/16	101/17	131/16	59/14
East	52/11	52/10	50/12	28/11	18/9	5/9	6/7	18/11	32/11	42/11	41/11	60/13	34/11
Southeast	42/12	33/14	30/12	33/11	27/12	27/11	20/14	21/9	28/11	34/14	24/12	40/11	30/12
South	49/17	50/17	37/16	48/17	43/15	74/17	57/17	35/17	32/16	38/14	39/17	55/19	46/16
Southwest	188/27	149/23	123/22	153/17	152/17	195/19	166/19	148/21	168/22	138/22	168/26	183/29	161/22
West	422/30	408/27	483/25	447/22	456/23	418/21	434/24	471/27	443/25	470/26	438/33	357/30	437/26
Northwest	48/24	59/21	81/20	81/21	132/21	112/21	166/25	127/22	91/22	69/22	57/26	40/22	89/22
Calm	60/0	93/0	112/0	143/0	100/0	117/0	92/0	105/0	112/0	101/0	82/0	84/0	100/0

APPENDIX C

WIND-VELOCITY DATA

This table shows average hourly wind velocities at Comodoro Rivadavia for the years 1936 through 1943. The mean value, 16 mph, is significantly lower than the value shown in Appendix A because the meteorological station was located in the city, which is sheltered by hills, in 1936 to 1943, and at the airport in 1951 to 1960. Differences between town and airport annual average wind readings tend to be large in Patagonia, ranging up to 162% at Esquél.

Local Hour	Mean Velocity (mph)	Mean Velocity (kph)	Local Hour	Mean Velocity (mph)	Mean Velocity (kph)
0100	15	24	1300	17	27
0200	16	25	1400	18	29
0300	15	24	1500	18	29
0400	15	24	1600	17	28
0500	15	24	1700	17	27
0600	14	23	1800	15	24
0700	15	24	1900	14	23
0800	16	25	2000	14	22
0900	16	26	2100	14	22
1000	17	27	2200	14	23
1100	17	28	2300	14	23
1200	17	27	2400	14	23

APPENDIX D

CLOUD-COVER DATA

The following table gives the percentage of cloud cover at Comodoro Rivadavia at selected hours by month for the years 1952 through 1961. Figures are mean totals by hour for all days of each month in all years. Hours are given in local time.

Month	0200	0800	1400	2000	Daily Mean
January	42.3	60.0	68.1	64.6	58.9
February	35.6	53.6	65.0	56.4	52.7
March	35.8	55.5	57.5	45.6	48.8
April	40.0	57.0	64.6	48.0	52.4
May	47.6	65.8	65.9	44.2	56.1
June	47.9	59.6	63.9	47.0	54.8
July	46.5	58.9	63.3	49.3	54.5
August	44.0	60.6	63.5	47.8	54.0
September	39.5	56.5	66.0	49.1	52.8
October	37.6	56.5	65.2	51.0	52.8
November	39.6	57.6	67.7	60.4	56.2
December	40.2	61.7	70.9	65.0	59.6
Averages:	41.4	58.5	65.1	52.4	54.5