SEASONAL ASTRONOMICAL OBSERVATIONS

Prepared for

English 1033

By

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ABSTRACT

This report describes three experiments used to calculate the average seasonal visibility on clear nights. The data for these experiments came from selected observations made during the last six years. In addition, the results of these experiments are also contained in this report.

SUMMARY

The three experiments described in this report have all led to the conclusion that winter is by far the clearest season of the year. In other words, the aerosol levels within the atmosphere are lowest during winter. It was also found that the seasonal order of atmospheric visibility decreases in the following order: winter, fall, spring, and summer. Since winter is the season with the best visibility, any astronomical experiments should be planned during the winter season if possible.

GLOSSARY

aerosol. . . . . a colloidal system in which a gas, frequently air, is the continuous medium, and particles of solids or liquids are dispersed in it.

color temperature. . . . . . . the apparent color of an object caused by the location of the peak wavelength within the continuous spectrum of that object.

film density . . . . the amount of light-stopping material on an exposed piece of film.

focal ratio. . . . . the ratio of focal length to the effective aperature diameter in a lens or lens system.

magnitude. . . . . the brightness of any astronomical object where the bright stars are of first magnitude and stars just visible to the unaided eye are of the sixth magnitude.

potential exposure . . . . . . the total exposure used to make a photograph and it is inversely proportional to the light intensity needed to make a correctly exposed photograph.

resolution . . . . the angular size of the smallest object which can be seen through an optical instrument.

INTRODUCTION

Three types of aerosol measurement experiments are occasionally conducted. First, long-term aerosol measurements are conducted in order to predict increases or decreases in air pollution. Second, seasonal aerosol measurements are conducted to predict the average visibility for each season. Third, daily aerosol measurements are made to compute the average visibility as a function of the time of day.[1]

The purpose of this report is to find out which season has the best astronomical observing conditions by using data from six years of selected astronomical observations. This answer can then be used as a guide to plan experiments that must be done during the period of highest atmospheric visibility.

Three experiments were employed to compute the season of highest visibility; they are described in this report. First, seasonal stellar observations near the horizon are described. Second, color temperatures of the sunrises are described; third, photographic exposures of some sunrises are also described.

STELLAR OBSERVATIONS NEAR THE HORIZON

Experiment Description

The first experiment employed to compute the visibility for each season was making seasonal comparisons between stellar observations near the horizon. The data for making these comparisons came from my fall 1981, spring 1980, and summer 1979 log books of astronomical observations.

The first step of this experiment consisted of plotting some observed telescopic objects on a graph. These objects were observed near the horizon during the summer of 1979. I then let the ordinate of this graph equal the objects' true magnitude[2] and the abscissa equal the objects' angle from the horizon. I then drew a line connecting the faintest (highest magnitude) objects on the graph. This limiting magnitude line was then transferred to figure 1.

In addition, figure 1 shows three limiting magnitude curves and a resolution curve. First, the limiting magnitude curve for my telescope is plotted on the graph. This curve was found by the method described above. Second, the limiting magnitude curve for my finderscope is plotted. This curve was found simply by subtracting 3.75 magnitudes from the telescope curve. Third, the limiting magnitude curve for the human eye is plotted; this curve was found by subtracting 7.80 magnitudes from the telescope curve. Finally, a resolution curve is also plotted on the graph. This curve shows that the atmosphere not only absorbs more light near the horizon than overhead, but it also blurs the light that is not absorbed by the atmosphere.

By looking at figure 1, it is immediately apparent that objects at the horizon must be very bright (low magnitude) in order to be seen. For example,

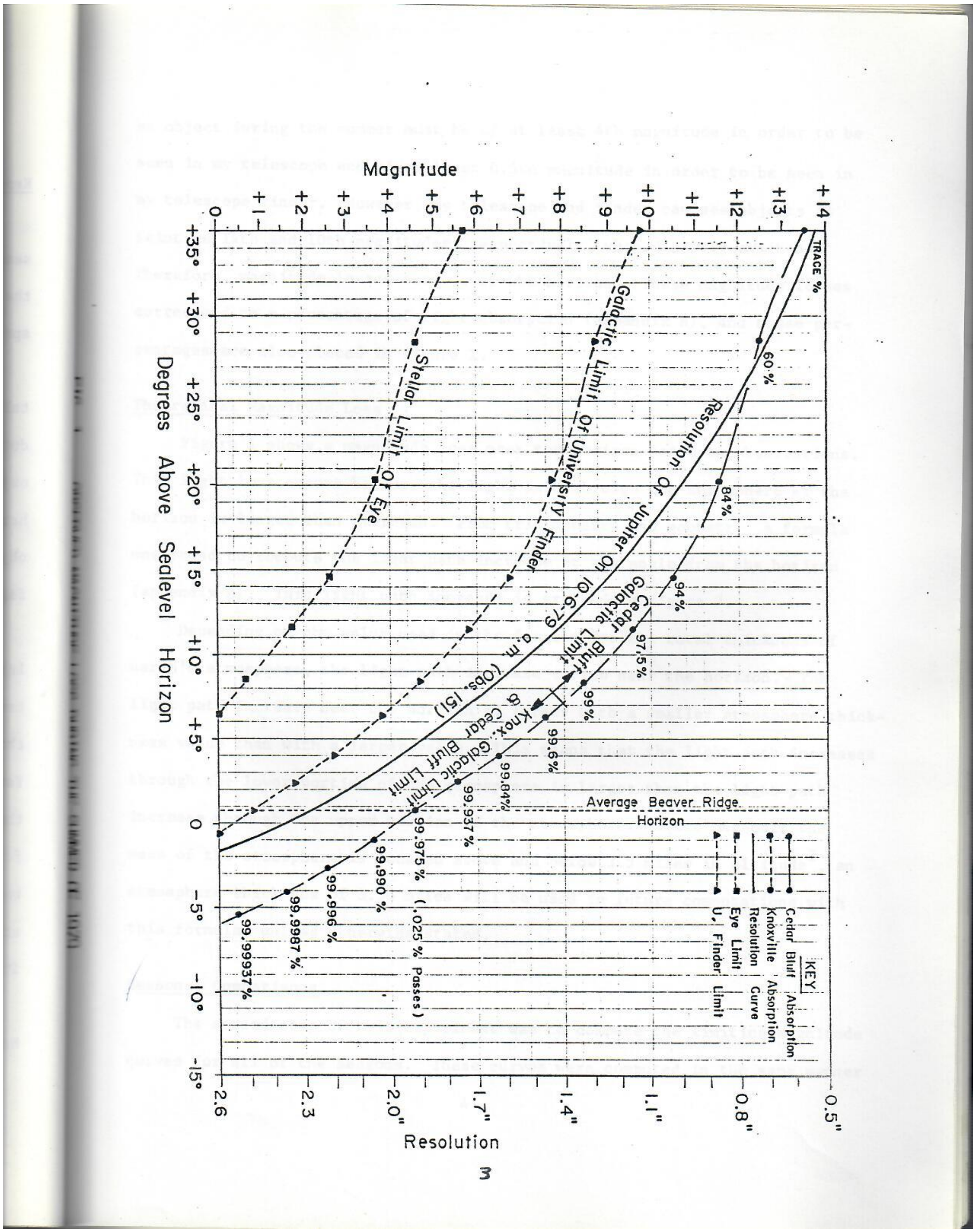

FIG. 1. OBSERVED MAGNITUDE LOSS DURING THE SUMMER OF 1979

an object during the summer must be of at least 4th magnitude in order to be seen in my telescope and of at least 0.5th magnitude in order to be seen in my telescope finder. However, my telescope and finder can see objects as faint as 14th and 10th magnitudes, respectively, when directly overhead. Therefore, magnitude losses occur near the horizon. These magnitude losses correspond to a percentage of light absorption (appendix B), and these percentages are also placed in figure 1.

Theoretical Magnitude Loss

Figure 1 shows a magnitude loss near the horizon based on observations. This light loss occurs because the light path through the atmosphere at the horizon is longer than overhead. From trigonometry and geometry, a formula was found to compute the light path increase at any angle from the horizon (appendix A). This light path increase is graphed in figure 2.

Depending on the value used in the formula for the total thickness of earth's atmosphere, the light path increase varies near the horizon. The light path increase near the horizon is larger with a smaller atmosphere thickness value than with a larger value. This means that the light path increases through the lower portion of the atmosphere is larger than the light path increase through the upper portion of the atmosphere. Since one-half the mass of the atmosphere is located above and below 3.5 miles in altitude[3], an atmosphere thickness of 3.50 miles will be used in future computations with this formula, unless otherwise stated.

Seasonal Comparisons

The second step of this experiment was to compute the limiting magnitude curves for all of the seasons. These curves were computed in the same manner

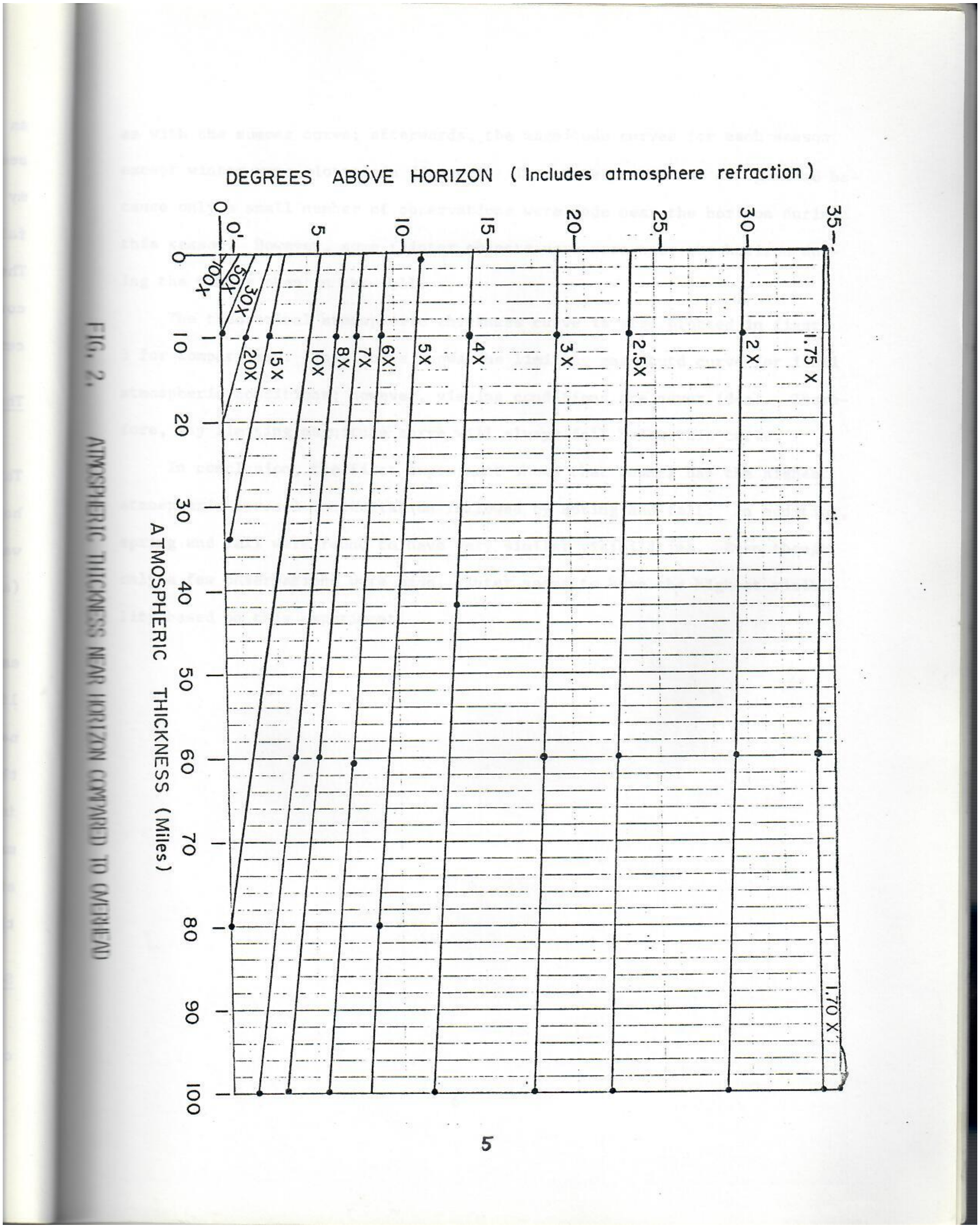

FIG. 2. ATMOSPHERIC THICKNESS NEAR HORIZON COMPARED TO OVERHEAD

as with the summer curve; afterwards, the magnitude curves for each season except winter were plotted in figure 3. The winter curve was not plotted because only a small number of observations were made near the horizon during this season. However, some fainter objects were seen near the horizon during the winter than in the fall.

The theoretical atmospheric thickness curve is also plotted in figure 3 for comparisons. This curve shows the limiting magnitutd curve for ideal atmospheric conditions; however, viewing conditions are never ideal. Therefore, any limiting magnitude curve will always fall below this curve.

In conclusion, the first experiment shows that summer has the highest atmospheric aerosol concentration followed by spring and fall. In addition, spring and fall were found to have very similar visibilities. Even though only a few observations were made, winter seems to have the highest visibility based on this experiment.

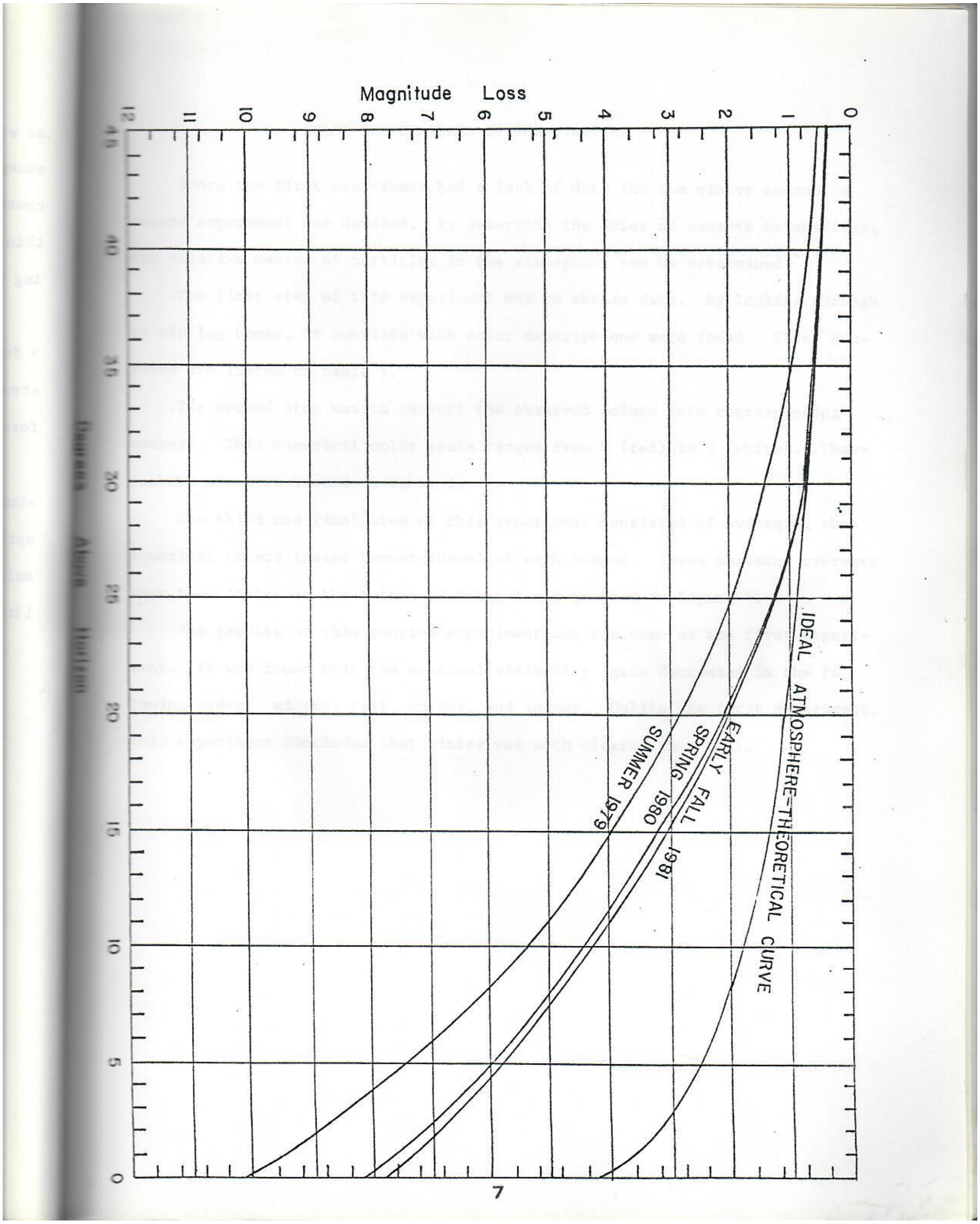

FIG. 3. OBSERVED SEASONAL MAGNITUDE LOSS

COLOR TEMPERATURES OF THE SUNRISES

Since the first experiment had a lack of data for the winter season, a second experiment was devised. By observing the color of sunsets or sunrises, the relative masses of particles in the atmosphere can be determined.[4]

The first step of this experiment was to obtain data. By looking through my old log books, 16 sunrises with color descriptions were found. These sunrises are listed in table I.

The second step was to convert the observed colors into corresponding numbers. This numerical color scale ranges from 8 (red) to 0 (white). These numbers are also listed in table I.

The third and final step of this experiment consisted of averaging the numerical colors (color temperatures) of each season. These seasonal averages were then listed at the bottom of table I and graphed in figure 4.

The results of this sunrise experiment are the same as the first experiment. It was found that the seasonal visibility again decreased in the following order: winter, fall, spring, and summer. Unlike the first experiment, this experiment concluded that winter was much clearer than fall.

TABLE I

SUNRISE COLOR TEMPERATURES *

OBSERVATION	DATE	WEATHER	SOLAR DISK COLOR TEMP.*	SEASON
Jason 163A	10-22-1977	Clear	8	Fall
54	09-04-1978	P/C	6	Summer
56	09-09-1978	Foggy	6	Summer
57	09-10-1978	Foggy	7	Summer
78	12-17-1978	Clear	5	Fall
89	02-10-1979	Clear	6	Winter
100	04-08-1979	Clear	8	Spring
126A	06-27-1979	Clear	8	Summer
129	07-02-1979	Clear	8	Summer
134	08-01-1979	Clear	7	Summer
157	10-20-1979	Clear	8	Fall
167	10-27-1979	Clear	6	Fall
Plate 25	12-07-1980	Clear	4	Fall
Plate 57	01-18-1981	Clear	4	Winter
Plates 78-9	03-24-1981	Clear	5	Spring
Plates 121-2	09-11-1981	Foggy	5	Summer

SEASONAL AVERAGES

SEASON	AVERAGE COLOR TEMP.	NUMBER OF OBSERVATIONS
Fall	6.20	5
Winter	5.00	2
Spring	6.50	2
Summer	6.71	7

* Color Temperature Scale: 8 — 6 — 4 — 2 — 0

8	6	4	2	0
Red	Orange	Yellow	White	

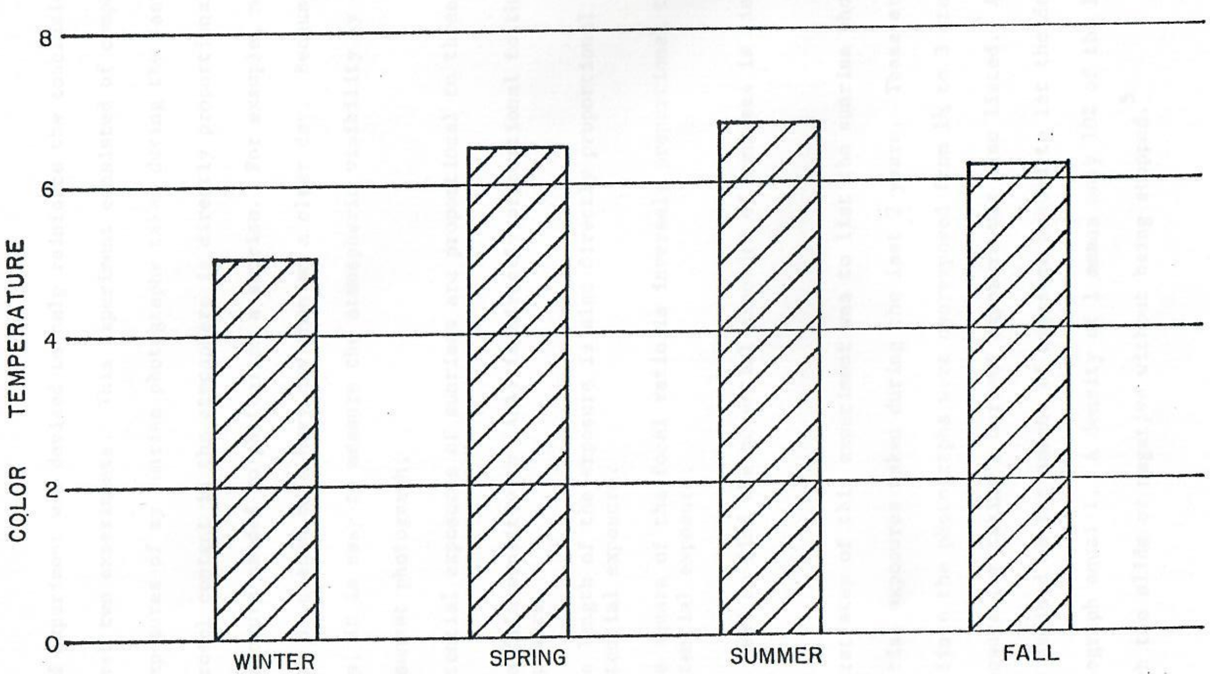

FIG. 4. AVERAGE SEASONAL AEROSOL LEVELS BASED ON SUNRISE COLORS

PHOTOGRAPHIC EXPOSURES OF SUNRISES

A third experiment was devised to help reinforce the conclusions drawn from the first two experiments. This experiment consisted of comparing the potential exposures of my sunrise photographs taken during the last 2 years.

The aerosol content in the atmosphere is directly proportional to the potential exposure needed to photograph a sunrise. For example, more potential exposure is needed on a hazy day than on a clear day. Because of this relationship, it is easy to measure the atmospheric visibility by taking a sunrise or sunset photograph.

The potential exposures of sunrises are proportional to three factors:

1. The film sensitivity (ASA) is directly proportional to the potential exposure.
2. The length of the exposure is also directly proportional to the potential exposure.
3. The square of the focal ratio is inversely proportional to the potential exposure.

The formula used to find the potential exposure of sunrises is listed in appendix C.

The first step of this experiment was to list the sunrise photographs and their potential exposures taken during the last 2 years. These are listed in table II. Since the photographs were overexposed from 1¼ to 3 stops, the potential exposure for taking a correct exposure was also listed. A correct exposure is defined as the amount of exposure needed to let the density (D) of the photograph equal 1. A density of 1 means only 10% of the light can pass through the slide or negative without being stopped.[5]

TABLE II

EXPOSURES USED TO TAKE SUNRISE PHOTOGRAPHS DURING 1980-81

PLATE	DATE	SEASON	PE USED	# EXPOSURE FROM NORMAL	PE NEEDED TO LET SUN'S D=1.0	REMARKS
25	12-07-1980	Fall	0.0020	+1¼	0.0008	Kodacolor Print
57	11-18-1981	Winter	0.0039	+3½	0.0003	Ektachrome
78	03-24-1981	Spring	0.0049	+1½	0.0017	Infrared* Emulsion
78	03-24-1981	Spring	0.0025	+2	0.0006	Infrared* Emulsion
121	09-11-1981	Summer	0.9800	+3	0.1225	Foggy, Ektachrome
122	09-11-1981	Summer	0.9800	+3	0.1225	Foggy. Ektachrome

TABLE II (continued)

PLAGE	APPROX. DEGREES ABOVE HOROZON	PE TO LET SUN D=0 ÷ THEOR. ATMOS. THICKNESS	@ PROPORTIONAL AEROSOL LEVELS
25	1.00	0.000031	2.10
57	1.42	0.000015	1.00
78	1.6	0.000053	3.60
79	1.75	0.000053	3.60
121	1.5	0.005489	372
122	1.7	0.005489	372

PE formula in Appendix

* Used an ASA of 125 in computations

@ Used a value of A = 6.0 miles in formula

The second stop of this experiment was to compensate for the angle the sun was above the horizon. For instance, the closer the sun is to the horizon, the higher the potential exposure needs to be in order to obtain a correctly exposed photograph. This is true because more light is absorbed near the horizon than overhead. In order to compensate for the sun's angle above the horizon, I divided the potential exposure needed to give a correct exposure (D = 1) by the theoretical atmosphere thickness increase and listed it in table II. This formula was also used in the first experiment and is listed in appendix A.

After these compensations were made, I adjusted the final numbers by letting the smallest one equal 1. This allows the relationship between each of them to be more easily seen.

This experiment also shows the same results of the first two experiments. The winter season again is shown to have the highest visibility followed by fall, spring, and finally summer.

CONCLUSION

The winter season is by far the clearest season of the year followed by fall, spring, and summer. Experiment 1 showed that the summer is very hazy, and it also showed that the spring and fall visibilities are very similar. However, the visibility during winter was not proven until the second experiment was conducted. Finally, the third experiment reinforced the conclusion of the first and second experiments.

NOTES

[1]University of Florida, Aerosol Measurement Workshop (Gainesville, Florida: University Presses of Florida, 1976), pp. xi-xvii.

[2]Robert S. Dixon and George Sonneborn, A Master List of Nonstellar Optical Astronomical Objects (Ohio: Ohio State University Press, 1980), pp. 51-828.

[3]E. J. McCartney, Optics of the Atmosphere: Scattering by Molecules and Particles (New York: Wiley, 1976), p. 85.

[4]R. D. Cadle, The Measurement of Airborne Particles (New York: Wiley, 1975), p. 268.

[5]Bruce Ferguson, ed., Kodak Color Films for Professional Use, 8th ed. (Rochester, New York: Eastman Kodak Company, 1980), p. 26.

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APPENDIX A

Theoretical Atmospheric Thickness Formula:

$$T = \frac{(R + A)\ \mathrm{SIN}\left\{180 - \left[\mathrm{Sin}^{-1}\left(\frac{\mathrm{Sin}\ (\Theta_1 + 90)\ \ R}{R + A}\right) + (\Theta_1 + 90)\right]\right\}}{\mathrm{SIN}\ (\Theta_1 + 90)},$$

where Θ_1 = Degrees above horizon,

~~Θ = $(\Theta_1 + 90)$,~~

R = 3959 miles (Earth's radius), and

T = Distance through atmosphere.

MATHEMATICAL DERIVATION FOR ATMOSPHERIC THICKNESS

From Figure A-I:

- R = Radius of earth
- A = Thickness of atmosphere
- T = Distance through atmosphere
- θ = 90^{o} + altitude above horizon.

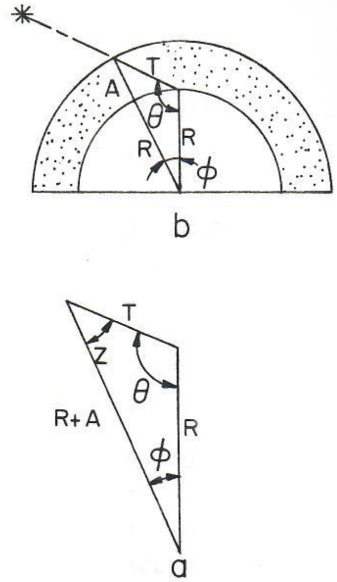

Figure A-I

Compute, T, where θ, R, and A are given:

From the law of sines,

$$\frac{\sin\theta}{R + A} = \frac{\sin Z}{R}\text{, and} \qquad (1)$$

$$\frac{T}{\sin\phi} = \frac{R + A}{\sin\theta}\text{; therefore,} \qquad (2)$$

$$Z = \sin^{-1}\frac{R\sin\theta}{R + A}\text{, and} \qquad (3)$$

$$T = \frac{(R + A)\sin\phi}{\sin\theta}. \qquad (4)$$

From plane geometry,

$$\phi = 180^{o} - (Z + \theta)\text{, and} \qquad (5)$$

$$\theta = \theta_1 + 90^{o} \quad \text{where} \qquad (6)$$

θ_1 = Degress above the horizon.

Substituting (3), (5), and (6) into (4) yields

$$T = \frac{(R + A)\sin\left\{180 - \left[\sin^{-1}\left(\frac{R\sin(\theta_1 + 90)}{R + A}\right) + (\theta_1 + 90)\right]\right\}}{\sin(\theta_1 + 90)}.$$

HP-67 PROGRAM FOR

SOLUTION OF ATMOSPHERIC THICKNESS

STEP	FUNCTION	STEP	FUNCTION
001	f LBL A	020	RCL 3
002	STO 0	021	÷
003	h R↓	022	g $\sin^{-1}$
004	9	023	RCL 1
005	0	024	+
006	+	025	1
007	STO 1	026	8
008	3	027	0
009	9	028	h $x \rightleftarrows y$
010	5	028	−
011	9	030	f sin
012	STO 2	031	RCL 3
013	RCL 0	032	X
014	+	033	RCL 1
015	STO 3	034	f sin
016	RCL 1	035	÷
017	f sin	036	RCL 0
018	RCL 2	037	÷
019	X	038	h RTN

INSTRUCTIONS: ENTER Θ_1

ENTER A

PRESS LBL A

APPENDIX B

MAGNITUDE EQUIVALENCE

Magnitude Loss	X Fainter	% Absorbed	Penetration
0	1	0	100.
1	2.51	60	40
2	6.31	84	16
3	15.85	94	6
4	39.81	97.5	2.5
5	100.00	99	1
6	251.19	99.6	.4
7	630.96	99.84	.16
8	1584.9	99.937	.063
9	3981.1	99.975	.025
10	10,000.0	99.990	.010
11	25,118.8	99.996	.004
12	63,095.6	99.9984	.0016
13	158,489	99.99937	.00063
14	398,106	99.99975	.00025
14.5	≈ 631,000	-	-
15	1,000,000	-	-
41.2*	30×10^{15}	-	-

*Sun's Magnitude

APPENDIX C

Sunrise Exposure Formula:

$$PE = 1.96 \frac{AE}{F^2},$$

where PE = potential exposure,

A = film ASA,

E = exposure in seconds, and

F = focal ratio.