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ART. VIII.—*Astronomical Observations on the Atmosphere of the Rocky Mountains, made at elevations of from 4,500 to 11,000 feet, in Utah and Wyoming Territories and Colorado*; by HENRY DRAPER, M.D., Professor of Analytical Chemistry and Physiology in the University of New York.

ANYONE who observes with a large telescope soon becomes aware of the great obstacle atmospheric undulation offers to the pursuit of astronomy, particularly in the application of photography and the spectroscope. During two years when I photographed the Moon on every moonlight night at my observatory* there were only three occasions on which the air was still enough to give good results, and even then there was unsteadiness. Out of 1,500 lunar negatives only one or two were really fine pictures. A letter which the late Mr. Bond wrote to me states that in seventeen years he had never met with a perfectly faultless night at the Cambridge Observatory.

Such facts naturally cause astronomers to consider whether it is not possible to diminish atmospheric disturbances, and have led to the celebrated expeditions of Professor Piazzi Smyth to the Peak of Teneriffe and Mr. Lassell to Malta. Theoretically, it would seem that the only complete solution is to ascend high mountain ranges or isolated peaks, and leave as much as possible of the air below the telescope.

Having had occasion during the months of August and September, 1876, to go on a hunting trip with two distinguished officers of the United States Army into the Rocky Mountains

* Professor Henry Draper's Observatory is at Hastings-on-Hudson, near New York; latitude $40^{\circ} 59' 25''$; longitude $73^{\circ} 52' 25''$; elevation above the sea, 225 feet.

and Wahsatch range, I thought it desirable to carry a telescope with a view of ascertaining whether there would be sufficient inducement to return with my twelve-inch achromatic or twenty-eight-inch reflector and make a prolonged stay. The experience which Professor Young had had at Sherman station, on the Union Pacific Railroad, left the question open, for he suffered from an unusually cloudy season, and, while he obtained very gratifying results, he seems on the whole to have been disappointed with the character of the atmosphere.

As the region into which the party proposed to go was difficult of access and entirely without roads and much of the traveling was to be on horseback, through fallen timber and up precipitous places, it was not feasible to take an instrument of any great size. I therefore contented myself with a small achromatic of unusual excellence. Though of only one and one-quarter inches aperture, it bears a power of upwards of sixty completely, and I think would carry one hundred. It was provided with a short brass tripod, holding an altitude and azimuth movement, giving both steadiness and smoothness of action. The eye-piece was capable of adjustment by a rack and pinion, and the object-glass was so arranged in its cell as to be free from injurious compression. This little lens stands the severe tests invented by Foucault, and in spite of its size is capable of doing good work.

In such observations on the atmosphere as those proposed during this trip, it is obvious that there are mainly two points to be considered: first, freedom from tremor, and second, transparency. A station which combines both is most desirable, but a marked predominance of steadiness gives special advantages for celestial photography while increase of transparency even if accompanied by unsteadiness is of value in eye observations. I had been led to suppose, from conversations with Government officers and persons connected with the geological and geographical surveys of the Territories, that the Wahsatch range, which is intermediate between the Sierra Nevada on the west and the true Rocky Mountains on the east, would offer the greatest advantages. This supposition turned out to be altogether incorrect, though it might have been argued that a high range flanked at a distance on either side by other higher ranges should have given the maximum chance for cloudless and still skies.

We first went to Salt Lake City, which, according to the Casella aneroid I carried, is at an elevation of 4,650 feet above the sea. It lies at the foot of the Wahsatch range. At eleven o'clock on the evening of arrival, August 25th, I took some observations from the hotel, after carefully centering the object-glass. Saturn looked about the same as on an ordinary

night at my observatory. Capella, which was just clear of the house-tops across the street, twinkled as badly both to the naked eye and in the telescope as I have ever seen it at the sea-level. Lieutenant Warren, of Camp Douglas (a military post near the city) said there had been a heavy rain the week previous and the air was more moist than usual. I had noticed that the sun set among just such a bank of clouds as we are accustomed to see in New York. I was somewhat prepared for a tremulous condition in these high regions, because, the preceding night having stopped for a few minutes at Fort Steele, on the Union Pacific Railroad, I perceived that Antares twinkled very much though we were nearly 7,000 feet above the sea.

However, in order to make a thorough trial it seemed best to ascend one of the high peaks of the Wahsatch, and accordingly the Red Butte was selected. The officers at Camp Douglas facilitated the trip in every way, furnishing horses and a guide, and the surgeon of the Post, Dr. Smart, who is an able and scientific man, accompanied me. The peak proved to be 7,350 feet high. Though it was quite clear when we started, clouds gathered in every direction as the sun went down, and at night-fall the sky was entirely overcast. Moreover, the wind blew so strongly that it was necessary to retire over the brow of the mountain, and eventually we returned to Camp Douglas. At this point, 5,250 feet above the sea and about 600 feet higher than Salt Lake City, the telescope was set up to take advantage of some breaks in the clouds, through which the Moon, Antares, ζ Ursæ Majoris and Jupiter appeared. With a power of only twenty the twinkling was surprisingly great; I do not remember ever to have seen it worse with my large instruments.

These results led to an examination into the meteorology of Salt Lake City, so as to find out the rainfall and its distribution and the percentage of cloudy days. Dr. Smart had the following copy of the post records made for me:

TABLE I.—*Rainfall and other Cloudy Days at Salt Lake City.*

	JANUARY.		FEBRUARY.		MARCH.		APRIL.		MAY.		JUNE.	
	Rain fall & melted Snow.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.
1872	1·30	--	2·60	19	1·20	--	2·04	--	2·34	16	·58	11
1873	2·18	23	1·89	19	·90	11	2·00	10	4·10	16	·24	5
1874	1·28	18	1·03	17	2·87	21	·77	16	2·89	16	·72	13
1875	2·21	31	·80	28	2·37	31	1·05	23	3·29	4	1·10	7
1876	1·22	27	·90	23	4·00	28	1·79	17	4·04	19	·14	7

TABLE I—continued.

	JULY.		AUGUST.		SEPTEMBER.		OCTOBER.		NOVEMBER.		DECEMBER.	
	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.	Rain fall.	Cl'dy days.
1872	·02	10	·72	16	·94	9	1·44	13	·66	16	2·26	15
1873	·12	7	·94	14	·42	6	·84	13	·38	10	1·20	24
1874	2·12	10	2·11	9	·30	6	1·89	27	2·26	26	1·06	27
1875	·64	14	0	6	1·15	13	1·48	18	4·54	30	2·78	31
1876	1·08	6										

From Table I, it appears that the average annual rainfall for the past five years is $18\frac{4}{5}\frac{0}{5}$ inches, distributed as shown in Table II. There is no perfectly dry month, the nearest approach being during the summer. The cloudy days are 194 per annum, the disposition being similar to the rainfall.

TABLE II.

January,	1·64 inches of rain.	25 cloudy days.
February,	1·44 “	21 “
March,	2·27 “	23 “
April,	1·53 “	16 “
May,	3·33 “	14 “
June,	·56 “	9 “
July,	·80 “	9 “
August,	·94 “	11 “
September,	·70 “	8 “
October,	1·41 “	18 “
November,	1·96 “	20 “
December,	1·82 “	24 “

A former pupil of mine, and graduate of the University, Dr. Benedict, informed me that the Mormons believed the rainfall had much increased since their community had settled in Utah, and this seems to be borne out by the statement that whereas formerly three gallons of Salt Lake water produced on evaporation one gallon of salt it now takes four gallons to produce the same quantity.

On the whole it is doubtful whether there would be enough advantage in bringing a large telescope to this region to make it worth while to encounter the labor and expense.

On August 30th, having taken an escort we moved south from Fort Steele, latitude $41^{\circ} 48'$, longitude $107^{\circ} 09'$, along the north fork of the Platte River into the main range of the Rocky Mountains. During the fifteen days' expedition there were only two nights on which we saw clouds enough to prevent astronomical working, and only one thunder storm of any moment took place in our immediate vicinity; about one-quarter of an inch of rain fell. The sky was rarely perfectly

free from clouds and many local thunder storms occurred about the higher peaks, but they seldom extended to the plateaus below.

September 1st and 2d our camp was 8900 feet above the sea in the vicinity of mountains rising 10,000 and 11,000 feet. These peaks seemed to be nearer than they really were, for the transparency of the air causes estimates of distance to be deceptive. From the top of one I subsequently saw the Seminole mountain which was 150 miles distant; it did not appear to be 50 miles away. The night of Sept. 1st was quite clear, with very little cloud, and the atmosphere remarkably tranquil. Antares, when near setting, hardly twinkled at all, and Arcturus in the telescope exhibited four diffraction rings unbroken by flickering. The central disc was as hard and sharply defined as the pinhole in the lamp screen I am accustomed to use in testing specula and lenses. I looked for the companion of Polaris, but partly on account of the nearly full Moon, and partly from the thickness of the diffraction rings, I could not be sure of it. The Moon was perfectly steady; with a power of 60 there was no trace of twinkling at the terminator. I tried to see Titan, the largest satellite of Saturn, but did not succeed. At the time it was not certain whether this failure was due to the position of Titan with relation to Saturn, or whether it arose from the blinding effulgence of the Moon. Capella was perfectly steady though there was a slow change of color from bluish to reddish occupying about a second.

The succeeding night at nine o'clock, though the sky was mostly covered with cumulus clouds in motion southward, I was surprised to find the terminator of the Moon absolutely free from twinkling, and Arcturus down among the tops of the dead aspen trees as steady as possible. The four diffraction rings round the central disc were not perfectly circular, but that was the fault of the lens. Every defect of centering or of surface, and any vein in the glass comes out even more clearly than in the workshop examinations, because while the air is as steady the light is far more intense.

I am certain if a large telescope could be brought here and maintained against the furious winds great results might be attained if there is much of this weather. But this particular place is difficult of access and possibly no better than other situations on the line of the railroad. The sky is not as black as I had expected; it is rather of a light blue, though the full Moon makes much difference.

On several other nights in both lower and higher places I made observations but never saw the combination of steadiness and transparency again. On the plateaus at the foot of the mountains and away from the groves of aspen trees and pines

the sun sends down scorching rays all day long on the alkali plains where only sage plants are sparsely scattered, and even on horseback one can see the heated waves rising from the ground. The air is far from being moist for the lips are apt to crack and bleed, and the mucous membrane of the nose is parched. When the sun sets the ground radiates rapidly, and we frequently had by morning one-quarter of an inch of ice in our vessels of water standing outside the tents. These plateaus are on an average about 7250 feet above the sea. The mere fact of broken ground and wooded surroundings does not however suffice to produce, even at this season, a tranquil air, for when we rode over the Rocky Mountains along the margin of perpetual snow to the headwaters of Snake River, and camped at Trout Lake nearly 10,000 feet high, though the air was exceedingly transparent it was very unsteady. I rose at four A. M. to see Venus, and her splendor was so great that it led to a most delusive estimate of her apparent size. Occasionally during clear frosty weather in midwinter a night of similar characteristics is seen at my observatory. On such an occasion I obtained at the principal focus of the 15 $\frac{1}{2}$ -inch reflector a photograph of the Moon near her third quarter in less than a second.

The officers of Fort Steele and the guides say it would be impossible to do any astronomical work in this region from the middle of October till the middle of May, that is, for seven months. The fierce winds, heavy falls of snow and intense cold would be unbearable. Even in the beginning of September we needed large camp fires in the morning and evening. Our camp at Trout Lake could only be reached for six weeks in summer on account of the depth of snow in the fallen timber.

On the whole it may be remarked of this mountain region that the astronomical condition, particularly for photographic researches, is unpromising. In only one place were steadiness and transparency combined, and only two nights out of fifteen at the best season of the year were exceptionally fine. The transparency was almost always much more marked than at the sea level, but the tremulousness was as great or even greater than near New York. It is certain that during more than half the year no work of a delicate character could be done. At the end of August in sheltered positions, and in good tents, we slept under half a dozen thicknesses of blanket and only partially undressed. Such a degree of cold distracts the mind and numbs the body. Apparently, therefore, judging from present information, it would not be judicious to move a large telescope and physical observatory into these mountains with the hope of doing continuous work under the most favorable circumstances.