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July 5, 99

Compliments of the Author.

The Effect of Mountains on the Quality of the Atmosphere.

A. E. DOUGLASS.

Reprint from POPULAR ASTRONOMY, No. 67.

THE EFFECT OF MOUNTAINS ON THE QUALITY OF THE ATMOSPHERE.

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For Popular Astronomy.

The great Colorado Plateau which occupies the northeastern portion of Arizona varies in elevation by gradual slopes from 5,000 feet in the valley of the Little Colorado up to something over 7,000 feet at distances of 50 miles on either side of that river. The Little Colorado River is central in this plateau and its course is in general from southeast to northwest. The higher part of the plateau to the west of this, culminates in the group of mountains called the San Fancisco Peaks, whose highest point is 12,800 feet above the sea. Westerly from these peaks stretches within 40 miles a line of mountains rising to 9,000 or 10,000 feet, Sitgreave's, Kendrick's and Bill William's. If one travels 30 or 40 miles southwest of this group of great peaks, he reaches what is called the Rim, that is the edge of this plateau, which, running in a northwest and southeast direction, forms its southwestern boundary. Beyond that the land drops away very rapidly to the south and west.

The San Francisco mountains which form the highest part of this plateau consist of a close group of elevated points, forming, perhaps, the ring of an ancient crater. Their sides fall away in all directions to the general level of the plateau, save on the southeast, where Elden Mountain or "Mesa" stretches eight miles away from the main summit at a constant elevation of over 2,000 feet above the level of the plain. In the same general direction as Elden Mountain, smaller lava flows extend to the southeast and south from the main peak and between two of these in a valley 300 feet below the tops of these lava streams,

is situated Flagstaff at a distance of 9 miles from the peaks. The Observatory is situated on the lava stream to the west of the town 350 feet above it and a mile distant from its centre. Seen from the Observatory the mountains, therefore, occupy a conspicuous place above the northern horizon. The main peaks reach from NNW to NNE, rising to an altitude of about 8 degrees, distant 9 miles; and Elden Mountain extends from NNE to ENE, rising to an altitude of 6 degrees and distant 4 to 8 miles. It is evident, therefore, that when winds blow from the north and northeast over this plateau that they must pass over these mountains before reaching the Observatory.

Knowing the location of these mountains with reference to the Observatory, it became evident during the early investigations of atmospheric currents in 1894 5 that there was some alteration in the direction of local winds produced by these great elevations. It was found that a telescopic current from the north at great elevation was frequently accompanied by one from the easterly direction or by a local easterly wind, evidently an eddy produced by these mountains in the great stream of air. Another more serious effect was suspected, namely, that the mountains had an effect upon the winds passing over them, causing very bad seeing.

During the present winter, we have had many nights in which fine currents came from the north and produced seeing that rendered work wholly useless. A series of tests on these currents, or air-waves, showed that they were not necessarily near the dome nor did they seem to come from the surrounding forest. Thinking then, that they came from the mountain, the final method of testing the truth of that assumption evidently was to compare at the same moment the currents at Flagstaff with those at some point so far removed that the mountain could have no possible effect. This comparison was effected in an advantageous manner by means of a concave mirror, 12 in. in diameter, 7 ft. 6 in. in focus, which was recently purchased from the firm of Alvan Clark & Sons. Supplied with a leather case and carried from point to point by the writer on a freight train, it has served as a means of examining the atmospheric currents at points widely separated in distance but within short intervals of time.

On Feb. 18th, the writer, taking the mirror, left town at 8 P. M. (7.34 Local Time) on an East bound freight train and at 8.50 made an observation 11 miles east of town. At 9.40, an observation was made 21 miles east of town. From 10.30 to

17.20 he observed at Winslow, 58 miles east (by rail) and then returned to a point 32 miles distant and made an observation at dawn. Observations were begun at that same point as the first stars appeared on the following evening. Special tests were made of the currents passing down a Cañon 250 feet deep (Cañon Diablo) and at midnight, after further observations near the railroad station, the trip west was begun. An examination of the atmosphere was made at points 21 and 15 miles east of Flagstaff and at Flagstaff itself. On each of these nights Mr. S. L. Boothroyd made continuous observations at proper intervals in the 24-inch telescope of the Observatory.

As this is the first investigation of precisely this kind and the results are so definite and conclusive the entire observations are given in full below including the comparison observations through the telescope at Flagstaff. Those who have followed the writer's work on this subject will recognize the various data. In the top line is placed the hour and locality. Then follows a note giving such data regarding the locality as affect the appearance of the atmospheric currents; namely, the elevation above the sea, the direction and distance of the mountain peaks and the character or contour of the immediate surroundings. Then follows in a line by itself the star observed, and below that the currents observed, each in a single line beginning with the highest and most general current. Remarks about the twinkling, cloudiness or wind follow the list of currents. Notes and remarks in parentheses call attention to significant points.

While glancing these over, it should be remembered that conspicuous currents are more harmful than faint in any kind of telescopic work, that fine currents are far more harmful than coarse ones in planetary work and that the form called sheets does more serious harm to the seeing than any other form yet observed overhead at night

The direction and size of currents are each variable in themselves and also difficult to estimate from the lack of comparison marks on the mirror or objective. As variations of 10° or even 20° in direction or 15 to 30 per cent in size must be considered of little importance.

During the two days included in these observations and, of course, for much time before, the San Francisco Peaks were partly covered with snow. It was very deep on the north side and on Elden mountain but had largely melted on the southern slopes although a fair amount lingered down to as low an elevation as that of Flagstaff.

Comparison Observations

of atmospheric currents at Flagstaff and points as far as sixty miles east.

Abbreviations.

The direction of the current is always followed by its size in inches; then its conspicuousness, etc:—v. = very, c. = conspicuous, m. = medium, f. = faint; cst. = constant or unchangeable, oc. = occasional; sw. = swift in motion; ord. = ordinary form of wave as seen in high and general currents; fl. = floating form, low and local; eels. = a variation of floating in which the "streaks" are fewer and more conspicuous; sh. = sheets produced by floating form in rapid motion; wr. = wrinkled produced by great thickness of floating form, with or without motion; mot. = mottled, only positively identified as characterizing a "pool" of quiet cold air such as settles in valleys at night; tw. = twinkling of stars on an arbitrary scale in which 0 = no twinkling and 10 = maximum twinkling.

February 18, 1899.

Observations in 24 inch at Observatory in Flagstaff, at an elevation of 7,250 feet.

S. L. Boothroyd, oberver.

7^h (= 14^h G. M. T. = 6^h 34^m local T.)

Betelgeuse, z. d. 30° ±

NxE (?)3.0-4.0 c. cst. sw.
NW susp. 2.4 (f) cst. sw.
NxE 0.8 v.c. cst. sw.

Seeing 0, much diffused light about star and much internal motion (boiling) of image.

Small wisps of cloud, but generally quite clear.

9^h 20^m

1st Mag. star. z.d. 25° ±

NxE 0.8 v.c. cst. sw.
Exs 0.8 v.c. cst. sw.

Seeing 0, very poor. Star nebulous, much diffused light. Seeing worse

Observations in 12 inch mirror at various points.

A. E. D. observer.

7^h 33^m Flagstaff.

In town, one mile east of Observatory. Elevation 6,900 ft. In an open valley sloping S.

On Capella.

NExN 0.7–1.2 c. cst.
Mot. same direction (?) Fl.

(The coarse currents seen at the Observatory were not noticed in the mirror being obscured by the mot. This current. about 1 in. in size is the one due to the mountain and which disappears in the subsequent observations in this column.)

8^h 50^m Cosnino.

At 11 miles east of Flagstaff, by rail, elevation 6,300 feet. San Francisco Peaks lie from WNW to NW, distant 9 to 14 miles and one isolated peak of 9,000 feet, 14 miles NNW. In a hollow, sloping E.

On Capella.

NNE 2.0-2.4 m-c cst.
W fl.

On Sirius.

Pulsating blotches, 3 in. across.

On Mars.

Fl. only.

9..07 Pollux tw. 2
Sirius tw. 8

than at 7h but the boiling image is not so noticeable.

Small wisps of cloud here and there. Very marked halo around Moon.

(The easterly current is probably caused by an eddy from the mountain.)

9h 39m Angell.

At 21 miles east of Flagstaff, elevation 5,800 feet. The Peaks lie WxN to NWxW, distant 24 miles. On an open plain, slight slope to S.

NNE 2.4 m. cst.
NNW susp. 3.4 f. cst.
E and W fl. very abundant, probably from engine or lanterns.

Cirro strattus clouds in streamers from N horizon to zeneith.

Twinkling of α Ursæ Maj. 4, altitude 45°, train in motion.

10h 48m Winslow

At 58 miles east of Flagstaff by rail. Elevation 4,900 feet. The Peaks lie WNW to NWxW, distant 60 miles. The town lies in an open plain with a very slight slope to NE.

On Pollux.

NNE 2.4 f-m. cst.
NNW susp. 3.0 f. cst.
fl. all directions, probably from torches in train yard.

No other fine currents or mot. visible.

11h 5m Observatory.

1½ Mag. star. z.d. 30° ±

NxE	0.8	v.c.	cst.	sw.
NxE	2.0	v.c.	cst.	sw.
E	0.8	c.	cst.	sw.

Seeing about the same as at 9h 20m.

Halo around the Moon.

(This NxE or NNE, 2 0-3.0, evidently existed over all the region including Flagstaff and Winslow.)

11h 0m Winslow, ctd.

South of town.

NNE 2.0 m-c. cst.
NNW susp. occasionally.
fl.
eels. from E.

12h 20m Winslow, ctd.

On mound 25 feet high in E centre of town.

On Regulus, near meridian.

NNE 3.0 f. cst.
NW susp. 6.0 f. cst.
fl. very little, possibly from S.
eels. from W.

A 2 mile breeze from S. Star clear but in W haze rises to 60° altitude and in E up to 45°. Regulus tw. 1, Sirius, 9.

14h 5m Observatory.

1½ Mag. Star. z.d. 15°
2nd Mag. star. z.d. 30°

NxE	2.4-3.0	v.c.	cst.	m.
NxE	0.8	f.	cst.	sw.
ENE	0.8	c.	cst.	sw.

14h 25m Winslow, ctd.

On 40 foot mound, W of town.

On Arcturus, z.d. 30° ±.

NNE 2.4 m. cst.
W susp. 6 f. cst.
fl. a little from S.

Seeing about the same as at 9^h 20^m. Wind springing up from a little E of N. Sky more or less hazy all over; cloudy in N and NW and slightly in SE.

Currents faint but whole mirror seems to twinkle.

Very slight S breeze if any. Moon in thin clouds to W. Sky overhead very slightly hazy.

14^h 30^m.

At NW foot of mound.

Currents same as on top of mound except, in addition eels from SSW, coming around edge of mound.

14^h 55^m Winslow, ctd.

N of town on street level.
On Arcturus and Regulus.

NNE 2.0 m-f. cst.
Fl. more than at mound.

Stars tw. 0-2. Sky seems clear overhead. (These observations at different parts of the town were for the purpose of getting effect of adjacent town on seeing. The town is fairly circular in form and about two-thirds of a mile across. The houses are nearly all of wood, and at this hour there were no fires of any kind in it except in the R. R. engine house, freight yard and restaurant, lying along its S edge. There seemed to be very little bad effect from the proximity of the town and most of what there was, came from the railway houses, engines, etc.)

15^h 6^m Winslow, ctd.

On mound 25 feet high in E center of town, three blocks N of engine house. On Arcturus.

NNW 6.0 v.f. cst.
NNE 2.0 3-0 f. cst.
Fl. fairly numerous, from S, visible only with eye piece.
Currents faint, and slight general vibration.

Arcturus tw. 0, Regulus tw. 0-1.

15^h 20^m Winslow, ctd.

S. of town. On Arcturus.

NNE 2.0–2.4 f. cst.
fl. less than N. of town but not much different. No eels. Slight vibration or twinkling of whole of mirror.

Stars tw. very slightly; Arcturus 0, Antares 7.

17^h 15m Winslow, ctd.

In freight yard. On Arcturus.

NNW 2.4–3.0 m. cst.

fl. a good average, no increase with lateness of hour.

Arcturus tw. 1.

17^h 30^m left Winslow. 17^h 40^m dawn begins.

18^h 0^m Observatory.

2d Mag. star z.d. 30° ±

NNE 2.4–3.0 v.c. cst. m.

ENE 0.8 c. cst. s.w.

Very doubtful traces of NxE, fine.

fl. abundant.

Seeing very bad, about the same as before. Sky clear. Light breeze from NNE.

18^h 55^m Cañon Diablo.

At 32 miles east of Flagstaff, by rail; elevation 5,200 feet. The Peaks lie WxN to NWxW, distant 36 miles. On an open even plain with a slight slope to E.

On Jupiter; Venus and Jupiter, alone, visible.

"Sheets" from W. fine, c. cst.

Air, cold, from W. clear as crystal. (These "sheets" may have been from engine which was W of observer. Coarse currents rarely show on a planet.)

19^h 6^m Sun half above horizon.

February 19, 1899.

Notes About Canyon Diablo.

They had much fog here from middle of December, 1898, to early February, 1899, and at one time two feet of snow. This morning (Feb. 19, 1899,) the wind was W at sunrise, flowing directly down hill from Elden Mountain towards the Little Colorado. Now, at 3 to 4 P. M., the breeze is from N, in the general up-hill direction of the Little Colorado, and also about the same as the currents seen at Winslow last night. Very slight hazy clouds now visible.

Cañon Diablo, from which the station takes its name, lies one-third mile west of the station; it is 500 feet wide and its bottom is 250 feet below the surrounding plain. It lies in a north-east and south-west direction with a drainage toward the north-east.

(The tests made in the Cañon for characteristic currents occur in the following paragraphs.)

Note.

On this date the agreement between the two columns is not so exact but this is easily explained by the fact that all the stations occupied were in the lee of mountains which produced slight eddies in the streams of air.

6^h 30^m Cañon Diablo.

At bottom of Cañon. Cold air in lowest 20 feet of depth. Occasional flow of cold air down Cañon (sunset a few minutes after 6^h).

6^h 35^m.

On Mars; bottom of Cañon.

There seems to have been a general flow of air from NNW-WNW. From the Observatory this appeared to be of size 1 2 to 2.0 inches and was usually accompanied by a slightly finer current from about N. probably an eddy about the mountain. East of Flagstaff, this stream had waves of size 2.0-3.0 inches as seen from Winona, 17 miles south-east of the mountains, 2.4 inches at Angell, 24 miles east-south-east of the mountains, and 2.4-4.0 inches at Canyon Diablo, 36 miles east-south-east of the mountains. The finer currents were not visible from any of the places. When thus summarized the increase of size of wave with increase of distance from the mountain is noticeable.

$7^h\ 10^m$ Observatory.

On Alcyone, z.d. 20° ±

NW 2.0 c. cst. m.
N 1.0 v.v.c. cst. sw.
NNE 1.2 m. oc.

Seeing 0, stars nebulous and showing much motion, much as at $9^h\ 20^m$ last night.

N ± 0.9-1.2 c. cst.
Fl. c. down Cañon.
(Size always uncertain on a planet.)

$6^h\ 40^m$.

On Capella, from bottom of Cañon.

NWxw 6.0 c. cst.
W 2.0 c. cst.
fl. and eels. c. from near side of Cañon (evidently the cold air floating down toward the bottom).
(Few minutes later:—)
NNW 1.3-1.5 c. cst.
W 3.0 c. cst.
(Few minutes later:—)
Star 2nd to 3d Mag. in west, setting behind edge of Cañon, z.d. 45° ±
fl. very abundant; wr. and twinkling of whole of mirror.
Zeneith stars tw. 2.

$7^h\ 10^m$.

On star between ties of high bridge over Cañon.

fl. very abundant (and other currents).

$7^h\ 22^m$.

On Capella, from bottom of Cañon. At this moment is felt the first distinct breeze down Cañon. It was preceded by

SW sh. down Cañon. 0.4 f. oc.
Very faint at first. It is now:—
NNW 4.0 m-f. cst.
WNW 2.4 m-f. cst.
SW sh. 0.4 m-c. cst. down Cañon.

$7^h\ 27^m$
Other currents and
SW sh. 0.4 c-v.c. down Cañon.
Vibrating or twinkling effect in coarse currents.
Feel constant gentle breeze down Cañon.

$7^h\ 35^m$

On Mizar, at low altitude but close above N edge of Cañon, looking through great thickness of down-flowing cool air, which is felt as a breeze from SW.

"Terribly" wrinkled appearance with conspicuous and great pulsations.

(The former, the wr. has been found to come chiefly from great thickness of fine currents and the latter, the pulsations, from great thickness of coarse currents.)

$7^h\ 40^m$.

Down-Cañon breeze has grown more conspicuous.

$7^h\ 53^m$ On edge of Cañyon; breeze SxW.

$8^h\ 6^m$

On plain, near edge of Cañon; on Capella.

WxN } 2.4
to NW } to 4.0 m. cst.
fl. susp. f. oc. mostly from S.
S susp. 1.2 f. oc. doubtful.

And on Mizar:—
S or N, prob. S coarse c. cst. colored.
W 0.8 ± wr.

Currents not nearly as bad as at the bottom of Cañon and lacking the SW sh. down Cañon.

$9^h\ 0^m$ Observatory.

1.5 Mag. star, z.d. 15° ±

NW	2.0	c.	cst.	m.
NNW	1.2	c.	cst.	m.
N	1.0	v.c.	cst.	m.

Seeing 0 but possible a trifle better than at $7^h\ 10^m$.

$10^h\ 0^m$ Observatory.

On Betelgeuse, z.d. 35° ±

NNW	2.0	v.c.	cst.	sw.
N	1.0	v.v.c.	cst.	sw.

Seeing 0, or about as at $7^h\ 10^m$.

$11^h\ 35^m$ Cañon Diablo.

At depot, on Pollux.

WNW
to NNW 2.4-4.0 f. cst.
No fl.
Vibrating or twinkling effect.

Breeze SW, light.

$12^h\ 45^m$ Observatory.

1.5 Mag. Star, z.d. 30° ±

NW	1.5	v.c.	cst.	v.sw.

N susp. — v.f. oc. m.
fl. abundant.

Seeing 0-1; better than for several days but yet very poor. Motion of image very great and very rapid nearly all the time.

$12^h\ 50^m$ Angell.

At 21 miles east of Flagstaff by rail; elevation 5,800 feet. The Peaks lie WxN to NWxW, distant 24 miles. On an open plain, slight slope to S.

NW	2.4	m-c.	cst.
WxN	1.0	m-f.	cst.

No fl.
(WxN also shows on Mars.)

$13^h\ 0^m$ Angell, ctd.

On Regulus.

NNW	2.0	m.c.	cst.
WNW	3.0	m.c.	cst.

(No WxN—or other was wrong direction—and no fl. or sh.)

Breeze W and oc. Stars tw. 1.

$13^h\ 40^m$ Winona.

At 15 miles east of Flagstaff; elevation 6,300 feet. The Peaks lie WNW to NW, distant 17 miles. An isolated peak of 9,000 feet elevation, lies 14 miles NNW. In an open, shallow valley sloping N. On Arcturus.

NNW 2.0 f. cst.
WNW 3.0 f. cst.
WNW } from
fl. abundant, c. cst. } engine.

Arcturus tw. 1.

$13^h\ 50^m$ Winona, ctd.

On Regulus.

NNW and WNW 2.0 c. cst.
(No fl. or other fine currents.)

$15^h\ 15^m$ Observatory.

1st Mag. star, z.d. 25° ±

NW 1.2-1.5 m-c. cst. v.v.sw.
fl. abundant.
(No trace of N current.)

Seeing 0, not quite so good as at $12^h\ 45^m$ and motion of image more rapid and violent. Star has long fringes in rapid motion and the central image is much blurred.

$15^h\ 25^m$ Flagstaff.

At a point 1 mile east of Observatory, in open valley with gentle slope to S; on Arcturus.

NW susp. 3.0 v.f. cst.
Mot. NW and mot. NNE, and eels, all v.c.

Stars tw. 0-1.

Upon examining the observations of the first date, the effect of the mountains is at once apparent. The fine northerly and very harmful current seen at Flagstaff disappeared at a point eleven miles east of town. Probably the coarse current observed by Mr. Boothroyd was a genuine one and displayed the average size of wave pervading the great stream of air moving to the south but the contact of this air with the mountain peaks, covered with snow, or by rocks chilled by excessive radiation, resulted in the production of the fine conspicuous current. The change between Flagstaff and the observations made at Cosnino were so marked that at the time it seemed as if the character of the night had changed and I entertained misgivings with regard to the value of the observations but the records made in the 24-inch telescope at the Observatory show that the night not only did not change for the better but actually grew worse during the early evening and the results therefore, became very conclusive that high mountains have the most harmful effect upon winds passing over them.

The observations on the second night were not so conclusive as those on the first but yet are suggestive with regard to the de-

pendence of size of the waves upon their age. The two northwesterly currents or the single variable WNW—NNW current, observed from the stations along the railroad, indicated a stream of air from the general direction of the mountains and during the trip back to Flagstaff, the mountains, certainly an important source of these currents, were gradually approached and it will be observed that the currents become somewhat smaller and more conspicuous.

This decrease in size upon approaching the source of the waves or upon seeing them when their age is less, is what we would expect from theoretical considerations. Even in 1894, it was suggested that the coarse currents were high up in the atmosphere and, since then, that has been found to be the case in occasional observations upon clouds, and the theory has been formed that when the waves are first produced, that is when the air is first filled with irregularities in temperature and density, these irregularities are apt to be numerous and strongly marked but by the diffusion of the air and the equalization of temperature and density the separation of irregularities must become less marked and the irregularities themselves less numerous. Such a mass of air under observation must, therefore, present at first fine and conspicuous waves and at the end coarse waves which gradually become more diffuse and finally disappear, as do the streaks in a mixture of glycerine or syrup and water. The size, therefore, is a function of the age of the wave.

Besides depending upon the age, it is quite possible that the size at commencement of the waves is dependent upon the intensity with which they are produced, that is upon the difference of temperature between the air and the solid particles with which it comes in contact and from which it obtains heat or to which it gives heat. Very likely also the size is dependent upon the speed of the wind which passes over the heated or cooled surface; but in any case, these variations in size at starting are comparatively small, varying probably between one quarter of an inch and an inch from crest to crest. Mr. Boothroyd has occasionally observed the northerly current to grow finer as the night advanced, a change which may therefore be due the growing chilliness of the mountain peaks or to increased velocity of the wind in the later hours of the night.

One other investigation is found in this collection of observations, namely the effect of being in a narrow valley which forms a drainage channel for the settled cold night air. Cañon Diablo is 250 feet deep and 500 feet wide at the top. In the earliest ob-

servations from the bottom of the Cañon only local floating forms of waves appear, indicating that the chilled air was seeking the lowest point but an hour and a half after sunset and following a few preliminary indications a characteristic fine current appeared flowing down the Cañon, which was not visible from the plain above. This identified, (as has been done at other times) the source of that characteristic fine current.

The results now discussed regarding the effect of mountains on currents, the effect of age on size of waves, and the characteristics of valley currents show that this method of investigation with a mirror can be made a fruitful source of estimating the astronomical characteristics and qualities of any given region and it may be that in astronomical exploration, this cheap and portable apparatus will prove of the greatest use.

LOWELL OBSERVATORY, Flagstaff, Arizona.

July 5, 1899.