THE STUDY OF ATMOSPHERIC CUR-RENTS BY THE AID OF LARGE TEL-ESCOPES, AND THE EFFECT OF SUCH CURRENTS ON THE QUALITY OF THE SEEING.

BY A. E. DOUGLASS.

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THE writer's observations on this subject began at the Harvard College Observatory, in Arequipa, Peru, during the summer of 1892. That observatory is situated close to a river valley, down which, on clear nights, a swift stream of cold air descends. In the latter part of the night this frequently attains such a volume as to flow over the observatory grounds. During the summer mentioned, the thirteen-inch Clark refractor was devoted to observations on Mars, and it was noted that when this cold air reached the objective the seeing was immediately ruined. Frequently, an interval of some minutes could be perceived between its first entrance into the dome and its attaining the height of the objective. When the seeing on Mars thus became extremely bad, if the eye-piece was removed, and the eye placed in the focus, fine parallel lines could be seen to move swiftly across the illuminated lens in the direction of the wind, the lines themselves always being parallel to their motion. When this current once became established, no more good seeing could be expected for the remainder of the night.

After leaving Arequipa the subject was practically left in abeyance until the summer just passed, but in the preceding February some experiments were witnessed at the Clark manufactory which have a bearing on the present subject. The Yerkes forty-inch lens was at that time placed in position for the Foucault test. Mr. Lundine, Mr. Clark's head-workman, courteously explained the methods of using the apparatus, and

obligingly performed a few experiments to show how exquisitely delicate it is in detecting small differences in temperature. For instance, he placed a lighted lamp in front of the lens, and a dense vertical column of heated air could be seen rising from the chimney. A lighted match produced a violent commotion. Even the bare hand held in view was seen surrounded by dark lines, indicating higher temperature, and frequently small masses of air would get sufficiently warmed and ascend. The warming effect of a person standing some four feet from the optical axis could be observed without difficulty. At my suggestion he placed the lamp beneath the optical axis, and close to the eye-piece. This caused the lens to appear to move bodily. Finally, he waved rapidly to and fro a piece of light board to try the effect of motion in the air. It was with greatest diffi-culty that any increased pressure could be seen. As the board (seen edgewise from the focus) passed, for example, downwards, a very faint line curved upwards and away from its end, similar to the wave produced at the tip of an oar.* The idea of measuring cloud-heights by the change in position of the eye-piece to bring them into focus was broached, but received only discouragement from him.

The similarity between atmospheric currents, and the effects of temperature in the Foucault experiment was at once appar-ent. The fine parallel lines or waves, by which a current is detected, are unquestionably caused by variations in density of the air. This in turn may be due to rapid motion of the air, or to the contact of two bodies of air at unequal temperature, or to inequalities of temperature throughout the mass. The term "wave" as used in this paper refers to the system of (usually) straight parallel lines, placed at substantially equal intervals and of approximately equal densities, which is seen through an objective of sufficient size. We may define it more generally as the resultant of all unequal densities in a body of air, whether upon the upper or under surface of that body or extending throughout its mass. Whatever may be the actual form of this resultant, its motion past the objective is so rapid that it cus-tomarily appears as a series of parallel lines, moving longitudi-

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* The writer deeply regrets that lack of time prevented the systematic pursuit of these experiments. They are described from memory.

nally as described.   The analogy to waves on water is shown in the resemblance between shadow bands in a total eclipse, and the light markings on the bottom beneath water disturbed by the wind.

These experiments tended to show that inequalities of density in the air are more likely due directly to its temperature changes than to its rapid " gust" motion.   But this was stated provisionally because no quantitative experiments were made, and it still remains in uncertainty.

Again, when the lamp was placed near the focus, the air waves became very large in comparison with the bundle of rays which eventually entered the eye.   Instead of producing so much confusion over portions of the lens, the entire lens moved bodily.   This suggested the possibility that bad seeing might sometimes be improved by stopping down the lens, thus making it more nearly the same size as the air waves, and producing a large bodily motion in place of a complete confusion of fine planetary detail.   The loss in light and contrast is the serious objection to this procedure, but the matter deserves further experiment by means of large telescopes and under different grades of seeing.*

One other inference was drawn at the time from these experiments, namely : that the slightest change of temperature in the dome or in the telescope tube, would be harmful.   However, even in this comparatively steady air the effect of lanterns near the telescope cannot be perceived at all.   It will be an easy matter to try heating the dome, or some part of it, and by simply looking through the objective at some planet to tell at once if harm is being done.   On some extremely good nights the

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* Prof. W. H. Pickering has devised a scale of seeing which is simple and accurate, though it varies for different apertures.   It is as follows : —

With sufficient power (100 to 150 to the inch) the star image consists of a large central disk and a series of rings.

Seeing 10.   Disk well defined, rings motionless.

Seeing 8.   Disk well defined, rings complete but moving.

Seeing 6.   Disk well defined, rings broken into dots and lines, but still traceable.

Seeing 4.   Disk well defined, no evidence of rings.

Seeing 2.   Disk and rings in one confused mass, constant motion, no increase in size.

Seeing 0.   Disk and rings in one confused mass, violent motion, image greatly enlarged (for example to twice the diameter of outer ring).

effect might be bad, while on poor nights it might give the observer comfort without altering the seeing in the slightest. A slight examination of the ordinary atmosphere through a good lens will convince the observer that the Foucault test is immensely more severe than any test on a star ; that usually our lenses are much too good for their atmospheres.

After this introduction we may take up the remainder of the subject under special headings.

I. *Time and Development of Recent Observation.*

The first observation made at this observatory was on Sept. 28. By placing the eye in the focus of the eighteen-inch Brashear telescope when turned on Mars, a swift north-east and a slow north or north-west current were found. The direction of the currents was obtained by considering the waves to be arcs of great circles whose intersection with the horizon gave the required azimuth. This same method is yet used, but while it answers for present purposes, more accurate determinations should be made. On the following night the size of the wave was described by stating a rough estimate of the number of waves, side by side, within the diameter of the objective. Yet this estimate was so very rough that it has often seemed sufficient for the most part to merely state that they were fine, medium, or coarse. During the following week the changeableness of each wave system, and its conspicuousness, began to be noted, though the importance of each separate item for completing the observation was not at once recognized. Readings of the thermometer were taken with fair regularity as bearing on the subject. Omissions have been supplied from the daily readings of the minimum thermometer.

Shortly after the middle of November, attempts were made to estimate the swiftness of the currents, but it was not until Dec. 2 that a direct effort was made to measure their height. This at once disclosed another vitally important feature, namely, their relative heights, for, in viewing them through the objective alone, they are projected one upon the other, and in nearly every case it is impossible to tell which is lowest.

Special observations have been made at various times. The effect of using different celestial sources of light was tried on November 20. The effect of different sized telescopes had
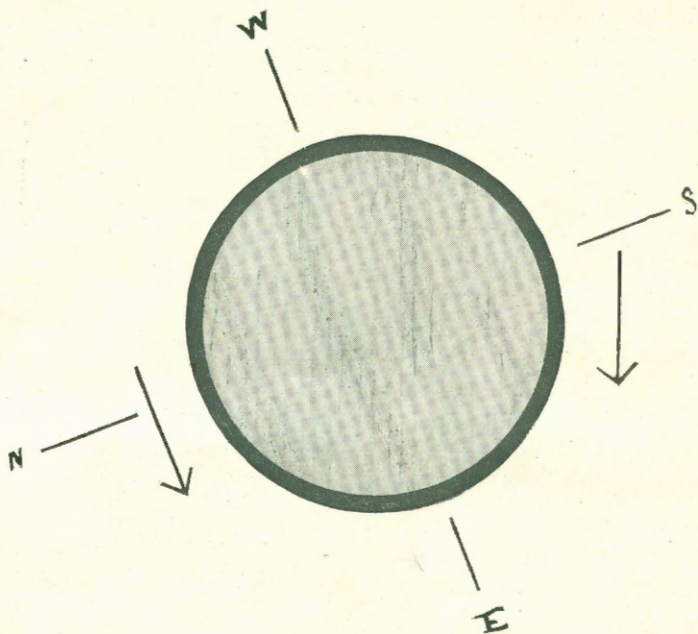
ATMOSPHERIC CURRENTS SEEN THROUGH AN 18-in. LENS,
DEC. 24, 1894, AT FLAGSTAFF, ARIZONA. SCALE, $\frac{1}{10}$.

The fine lines belong to the higher current, whose lower surface was observed to vary in the course of observation from 3,400 to 5,400 feet above the ground, (10,600 to 12,600 feet above sea-level.) The waves were on the average 0.8 inches wide, and moved with a velocity estimated at 17 miles per hour. The coarse lines belong to a lower current which was felt as a strong west wind. The waves had a mean width of 6.0 inches, and moved with a speed estimated at 8 miles per hour.

been tested a week or two before that date. The effect of pass-
ing clouds was noticed at various times, especially on November
27 and 30 and December 16. On many other dates some record
was made of the general weather.

II. *Different Forms of Waves and Method of Observing and Describing Them.*

While all wave systems are sufficiently alike to be recognized
as essentially the same thing, there are three forms that present
individual features.

The first form, recognized from the very start, consists of the
straight, equal parallel lines, equally separated, moving longitu-
dinally. This is the typical form. They are not always of
precisely equal density, nor are they invariably separated by
equal intervals. The second form, though noticed before, was
not regularly recorded until early in November. The lines in it
are extremely fine and occasionally parallel, but all twisted and
bent, and move slowly or float in any direction. A slight predom-
inance of movement in the direction of some wave system indicates
that they are not currents inside the telescope tube or within
the dome. They were, from an early date, supposed to form
the stratum lying next the earth, and observation with the eye-
piece has confirmed this view.

The third form is not yet understood. It partakes of the
character of each of the others. The lines are usually very fine,
parallel, and straight, and the longitudinal motion very rapid,
yet they appear irregularly, and over very limited areas, pro-
ducing the appearance of bands or ribbons crossing the objec-
tive. This may be called the ribbon form, as the preceding has
been named the floating or syrup form. The actual elevation
of the ribbon form has not yet been noted; in fact, it is of rare
occurrence and was first separately recorded on December 17.

A certain combination of currents of the first form produces
such a perplexing appearance that it deserves a word in expla-
nation. It has been termed a "vibrating" appearance. The
objective appears strewn with large regular spots which pulsate.
No movement can be assigned because no current is visible.
The probable explanation is that two wave systems of equal
size are crossing each other at such relative velocities and direc-
tion as to produce the "obstruction" figures noticed when one

looks through two pieces of wire gauze, whose wires lie in the same plane but differ in direction. The vibrating effect might be called "twinkling" from its appearance, and it is possible that to the unaided eye it increases, or perhaps is the chief cause of, that effect on stars. Sometimes a single current will have a " fluttering" appearance, somewhat similar to the " vibration " and probably produced by a second current much fainter than, but quite similar to, the first.

Enough has been said to suggest the method of observing and describing atmospheric currents ; but a brief review will bring it into a more compact form.

The definition obtained without the eye-piece is far superior to that with it ; the observer begins, therefore, by placing the eye in the focus of the objective, and noting down the direction, steadiness, fineness, swiftness, and conspicuousness of each current, distinguishing them by letters of the alphabet, and making a special note if they belong to the second or third class. The eye-piece is then replaced, and brought to a focus on the micrometer threads. A scale on the side of the draw-tube reads zero when the planet (Mars has been used almost exclusively for this work) is in focus on these threads. Then the eye-piece is slowly turned out. Scale-readings are made as fast as currents appear or change from one to another, and at each reading estimates of the velocity of the current in view are made. After the eye-piece is carried out as far as the draw-tube allows, the process is reversed and check-readings taken on turning it in. Recent observations have included the altitude of the star or planet, and the amount of motion (due to the atmosphere) it exhibits when examined in the focus.

III. *Effect of Using Different Sources of Light.*

This may be very briefly stated. The larger the source of light, the less is the contrast between the waves and the valleys, if they may be so named. The twinkling of a sufficiently small source of light appears to be due to the concentration or scattering by these waves of the pencil of light, which enters the eye ; the farther apart the waves, the larger may be the source of the twinkling light. In a large telescope a star does not twinkle, because the objective includes several waves and valleys. Stars that show no variation in brightness in a six-

inch telescope may twinkle decidedly in a two-inch finder. Yet, this is not the whole explanation, because stars sometimes twinkle when the atmospheric waves are very inconspicuous. It may be due to a wave so coarse that the telescope does not show it.

IV. Effect of Different Apertures on Currents and Seeing.

At the present writing, the original observations on this subject are not at hand, but theory and observation agree. The size of the waves does not vary with different apertures, nor, in fact, do they differ in any respect save that with a small glass, it is more difficult to study them.

The effect on seeing is what we should expect. In the smaller instrument, where the width of the wave is nearly as large as the diameter of the objective, there is more bodily motion, and in the larger, a steady limb with confusion of detail. In fact, we have, in work on Mars, frequently expressed the quality of the seeing by two figures, — one referring to the amount of detail visible, and the other to the steadiness of the planet.

The present topic leads us to the question as to whether stopping down the lens can ever improve the seeing. Let us suppose that the maximum refraction produced on each slope of a wave amounts to $\frac{1}{2}''$. There the total vibratory effect on each point of the disk of the planet will amount to $1''$ and if the objective includes several waves, we shall have a steady but ill-defined limb. The air waves vary more or less from one-fourth inch to six inches in distance between crests, with a customary distance of one and one-half inches. Suppose, for example, that the waves are four inches apart. It is evident that if we stop the lens down to two inches, we shall see the entire planet vibrate through $1''$, at a rate depending chiefly on the speed of the current, but there will be no confusion of detail, unless the current be travelling too fast for the eye to follow this motion (which I am inclined to consider unusual). The loss of light, however, will be enormous. If we use a four-inch stop, the planet will alternately show confusion of detail and misplacement.* Six inches will still give us mis-

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* Sometimes I have seen Mars rapidly change its outline from a circle to ellipses of varying directions and eccentricities, due probably to this relation of air wave and lens.

placement, but the loss of detail will be more pronounced ; and the more we add to the aperture, the more certain is the loss of all detail, smaller than 1″, and the steadier appears the ill-defined limb.   Experience declares that a steady ill-defined limb is better for micrometer work than a moving limb of perfect outline ; for such work, therefore, a full aperture evidently is preferable.   But confusion in planetary detail is lessened by greatly diminishing the aperture, and if the loss of light be not too great, advantage may result.   Two influences in practice interfere with these conclusions, namely, cross currents of different sizes, and the changeableness of the very current we may be trying to improve.

V. *Effect of Different Currents or Their Combinations on Seeing.*

Since a perfect lens is one which, in the Foucault test, shows no irregularities of illumination, it is evident that bad seeing, if not the worst, must exist where the greatest atmospheric disturbance is revealed by the objective.   This is rarely caused by a single current.   Even a conspicuous current, if alone, may give seeing four on the scale mentioned.   The addition of a second current nearly always reduces it to 1 or 2.   If the added current be of the second form, seeing 0 to 1 results; the effect of the third form has not been observed.

Almost invariably, two currents of the first form are visible, and curiously enough, they nearly always form an angle of 45° or less with each other.   When it is more than 45°, the waves are likely to differ greatly in size.   Usually, one of these is continuous and the other variable, changing its direction occasionally and frequently ceasing altogether for a time.   This is the cause of the variation in seeing from moment to moment. Frequently, one or two currents of form I exist with seeing from 2 to 5.   Subsequently, if the syrup form appears rather conspicuously, the seeing drops to 0.   This can be explained by assuming that the refractive power of the syrup form is greater than that of the others.   That may be a result of its lower elevation.   If the waves exist only at the surfaces of contact between bodies of air, their refractive or "confusing" power must depend largely, if not wholly, on the difference of density between such bodies.   But atmospheric refraction depends on the same thing.   It may be that some quantitative

connection will be discovered between the two, though at present this involves an assumption which we are by no means prepared to maintain.

Two currents do not necessarily mean bad seeing. If they are very faint the seeing may reach 6 or 8, but even then the best moments are when one current disappears and but a single faint one remains.

VI. *Effect of Clouds on Currents and Seeing and the Cause of Coarse and Fine Currents.*

It has been stated that detail may sometimes be improved and the limb made less steady by diminishing the aperture. The same result may be obtained from increase in the coarseness of the air waves. This is one reason why the seeing sometimes is very good amidst clouds. When clouds are passing the waves of the most conspicuous current are very apt to change rapidly in size. They are usually fine before the cloud comes on, they may be fine or coarse while it is passing, and are more likely to be coarse immediately after it has gone. The effect on the planet is what we should expect, — steady and ill defined before the clouds come on (detail 3, limb 7), usually steady and very badly defined amidst them (detail 2, limb 10), and well defined but in considerable motion after they pass (detail 7, limb 4).* This observation has been repeated several times on clouds moving past the telescope, but always, it so happpens, on that kind of cloud, which, by its tendency to dissipate and reappear, shows the air to be full of moisture.

This fact, that air waves change their size in the presence of clouds, suggests that temperature influences their size, and that they grow coarser with its increase. But we get little more than the suggestion, for evidently the higher currents must be the colder and yet they have been coarser in at least three cases out of five. Density may have something to do with it, but rapidity of motion does not, apparently, because they do not change their velocity in the vicinity of clouds, nor in general do the coarse currents differ conspicuously in speed from the fine

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* These figures represent, on a scale of 10, the perfection of the detail and steadiness or freedom from bodily motion of planet in one of the observations above mentioned. They are made to agree as far as possible with the stellar standard of seeing.

ones. Direction has no influence. A more plausible hypothesis is that their size depends on freedom from moisture. This accounts for the upper ones being usually coarser and is not incompatible with the observed effect of condensation. Condensation of moisture produces a slight temporary warming and consequently drying of the surrounding air. The cold and relatively moist air that descended the river valley at Arequipa was (if correctly remembered) composed of very fine waves, and certainly the syrup form of current almost universally presents an exceedingly fine structure.

VII. Direction of Upper Currents.

The majority of records show a general westerly current, but up to the present writing so few observations on relative heights have been made, that no generalization can be formed. Out of eight actual observations the highest current came from between S. W. and W. N. W. five times. Once it came from the north, once from the south, and once from the east. In two cases of westerly upper wind, no lower current was visible; of the remaining six, three times the lower wind differed from the upper by two points of the compass, — once by four points, once by six points, and once by a quadrant.

VIII. Height of Currents and Clouds.

The means of getting the height has already been mentioned. With the focal length of the telescope, F, and the extension, e, of this focus, in order to bring an object into best definition, the distance D of that object is thus found: $D = \frac{F(e+F)}{e}$ It is easy to construct a curve which will give D for different values of e. The height of the object equals D into the cosine of the zenith distance. It is evident that the longer focus and larger aperture a telescope has, the more accurately will it give these distances. Not the least puzzling part of it is why these currents should come into focus at certain given positions of the eye-piece. The rays of light from a star, for instance, being parallel, it is easy to see how interposed air waves become visible in unchanged dimensions when the eye is placed in the focus of the lens. Similarly it would seem more probable that they should show equally good definition through a great range

of movement of the eye-piece, but such is certainly not the case. The explanation seems to be that they diffuse much more light than we expect. It is not impossible that while the heights obtained represent something definite, they may have been influenced by the refractive power of individual waves.

Much yet remains to be learned in regard to the heights of atmospheric currents, but one point of some interest was brought out very clearly. On Dec. 23 and 24, during a rather strong west wind, it appeared that below a certain level the movement of the wind became intermittent, that is, it moved in gusts. When the telescope was focused on some part of this disputed region, for a time currents would appear precisely similar to the steady stream above. Then an interval followed in which nothing but the syrup form showed itself, moving in any direction, only to be effaced by a second gust. The altitude of the lower surface of the steady flow of air was found to be about 3,400 feet on the first night, and between 2,900 and 3,500 on the second (altitude of observatory 7,250).

This conception of gusts reaching down here and there from an overhead current is not new. In Winslow, Arizona, early in May last, I assumed this to be the explanation of the sand-storms for which that place is famous. Standing in a slightly elevated position west of the town a broad expanse of desert was presented to view. As many as fifteen sand-whirls were seen at one time.* The sand-storm proper was caused by an extremely local wind. Judging the wind by the dust it raised, the average storm (or gust) of that day covered an area half a mile long by one quarter of a mile wide, and might move, in all, two miles with a rate estimated at ten miles an hour. They were scarce, there being, at a guess, one in ten square miles. The velocity of wind in the storm seemed to be much greater than the speed of the storm. While the storm was yet at a distance, the air was perfectly quiet; as it passed near by the motion of the surrounding air towards it could be perceived. All the while clouds were moving regularly by overhead.

The trouble with this method of determining distances is the difficulty of getting a good focus. Even the principal focus

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* One of them deserves mention. It was a cylinder about two hundred feet in diameter. After travelling a quarter of a mile, it broke up into six small whirls which kept on an equal distance.

seems to vary with the character of the object. This needs to be studied. It was thought that cloud-heights might be easily observed, but in a trial on some cirrus cloud no satisfactory focus could be found. Cumulus clouds against a clear sky might give better results; and recently a trial on rather low clouds passing in front of the moon seemed to give sufficiently definite figures which agreed with estimates derived from the position of the cloud on a neighboring mountain. That the method can be successful if given sufficient contrast and definition is shown by the result obtained on measuring a known distance of nine and one quarter miles. The mean of six settings gave eight and one half miles (using the principal focus given by a star). This discrepancy is not surprising, when one considers that the maximum base-line used was only eighteen inches.

IX.   *Velocity of Currents and Clouds.*

Velocities may be estimated with or without the eye-piece. There is no great choice between the two methods. Theoretically, using the eye-piece on a planet of large diameter should give the best results, for thus the movement may be followed through a greater arc. The difficulty with each method is the great speed of the current in comparison with the size of the field.

Without the eye-piece, we are evidently watching the unchanged motion of the air through a distance equal to the diameter of the objective. Sometimes the motion is slow enough to enable the observer to estimate the fraction of a second required in passing the objective, but usually it is so rapid that this method gives but the roughest possible approximation. A better plan, still exceedingly rough, is to give to the eye a movement equal to that of the current, and lasting one second or one-half second. This, repeated many times, will give at least an estimate of the number of diameters traversed in a given time.

With the eye-piece, the size of the field has to be computed from the position of the eye-piece and the diameter of the source of light. With a star, it remains constantly the same size as the objective, but with a planet this must be increased by the apparent diameter of the planet at the distance which happens to be in focus. The number of fields traversed by the stream of air

in a given time may be estimated in the same manner as before.

As to the actual velocities estimated in currents of Form I., they range usually between five and twenty miles an hour, and sometimes reach higher. This seems less than expected, and may partly be attributed to the uncertainty of the method, and partly to the fact that high velocities of surface winds are almost unknown in Arizona. The average hourly wind-velocity for the year is between six and seven miles.*

X. *Effect of Currents on Local Winds and Weather.*

This subject has received very little attention, but is included because it is deemed well worth a careful study. In two cases a verbal prediction was made as to the probable wind on the following day, and each was verified. As a rule, it seems a matter of chance whether the upper currents change their direction at night or day; if at night, the local winds will probably do the same on the succeeding day.

Nothing new has been learned in regard to the effect of currents on the formation of storms. We knew long since that summer storms came on southeast and winter storms on southwest winds. If it is true that fine-air waves indicate high relative humidity, combining that with the height and direction of currents may give us valuable assistance in predicting weather.

XI. *Instruments for observing Atmospheric Currents.*

For direction and size, two parallel wires may pass in front of the object glass or mirror, as the case may be. By rotating these from the eye-end and reading off a scale, the direction may be obtained. It could easily be arranged so that the direction could be read directly from a compass. One of these wires should be movable, and, by a scale showing its position, the size of the waves is given directly. For velocities, the largest possible aperture (at least in the direction of the current) is needed. From the focus, this should appear large enough to allow the eye to appreciate the rate of the current,

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* See letter from the Secretary of War, on Irrigation and Water Storage, 1891. These observations, however, are all at lower elevations than Flagstaff.

and yet so small that the eye does not have to move through too great an arc in the given interval of time. If a long scale, on which to measure this motion, could be rendered visible by a prism close to the eye, it would greatly help. In this observation good definition is superfluous. In measuring heights, the larger the aperture, the better; obviously, because the aperture gives the base-line. The focal length probably makes little difference. Better definition is required here than for velocities; but it is quite probable that a large lens, cast and roughly ground — possibly a single glass — would answer the purpose for both these observations. Serious imperfections in the glass would not affect velocities, and in observing heights they could be covered with patches. If it was found easier in manufacture, a narrow section of a lens might be cast, giving full diameter in one direction only. Placed in the direction of currents, it would give their speed and direction, and placed transversely it would give size and height.

The remarks on this subject are merely suggestions. Doubtless if it is desirable to make extensive observations some suitable apparatus will be prepared.

XII. List of Observations from Sept. 28 to Dec. 31, 1894.

The time given in the following table is that of the 105th meridian. The observations are of such diverse character that the following abbreviations are necessary. Each current is, in the complete observation, followed by four characters describing it. The first of these refers to the continuousness of the current, and has one of four letters : *s* means steady ; *i*, intermittent ; *r*, rare ; and *c*, changeable in direction. For the second letter, describing size, *f*, means fine ; *m*, medium ; and *c*, coarse. When the size of the wave is estimated, it is given in inches and tenths. The third letter gives the speed : *f* means fast or swift ; *m*, medium ; and *s*, slow. If the speed was observed it is given in miles per hour. The fourth letter indicates intensity or conspicuousness of the current : *f* means faint; *m*, medium ; and *c*, conspicuous. Between two currents a space is left for the observed height of the division. A column is reserved for the third current which usually is of the floating form, so that Fl in that place signifies this form, and R, the ribbon form ; small *r* means rare, and *f*, faint. The next column

gives the "confusion" or movement which the air currents cause in a body under scrutiny. This is really an attempt to give quantitative seeing. It is expressed in tenths of one second of arc, the first number referring to confusion of detail and the second to extent of bodily motion. The wind unfortunately was rarely recorded, but a column is reserved for it. In the same column, *h* means haze, and *c*, clouds. The temperature at the time of observation is given for the most part, but when failures were made to note it down, its place is supplied by the reading of the minimum thermometer for that night, preceded by the letter *m*. The final column gives the seeing at the time of observation. The figures average quite low, since these observations were chiefly made when it had become too poor for anything else. They also include an almost continuous month of bad weather, December, due, presumably, to the temperate zone circulation reaching down and including us in its moist currents.

Only the most complete observation for each evening is given.

SEPTEMBER.		I.	Ht.	II.	Ht.	III.	CONF.	WIND.	TEMP.	SEEING.
d.	h.									
28.	12.8	NE. —. —. f. —	....	NNW. —. —. s. —	....	....	....	NW.	33.7°	0 to 1
29.	14.0	S. —. 1·5. f. —	....	....	....	....	....		44.5	1
30.	14.1	W. — 0·4. f. —	....	....	....	....	....		32.8	0 to 1
October.										
1.	11.0		....	....					39.5	2 to 5
2.	11.1	ENE. —. 1·0. f. —	....	N. —. 3·6. m. —	....	....	....		46.5	1
3.	14.3	E. s. 0·9. —. —.	....	NE. c. 0·9. —. —.	....	....	....		49.8	1 to 2
4.	14.9	NE. —. 0·9. f. f.	....	....	....	....	....		54.6	5 to 9
5.	15.0	SW. — 0·6. f. f.	....	....	....	....	....		m46.0	3
6.	—		....	....					m44.9	2 to 8
7.	14.6	NW. —. 0·9. f. m.	....	SW. i. 3·0. s. —	....	....	....		m46.3	3
8.	10.4	....	....	....					54.2	3 to 5
9–10.		No observations.								
11.	14.5	NE. —. c. s. f.	....	....	....				m47.	3 to 4
12.	14.2	NE. s. f. f. —	....	ESE. s. f. f. —	....	SW. or Fl.	....		m46.5	3 to 4
13–14.		No observations.								
15.	12.0	NE. — f. f. m.	....	....	....				m45.8	2
16.		No observations.								
17.	14.6	SW. — c. f. c.	....	WSW. —. f. f. c.	....			W.S.W.	m47.0	4
18.		No observations.								
19.	15.7	WSW. — f. f. c.	....	....	....			W.	36.9	3
20–22.		No observations.								
23.	14.6	SW. —. c. f. c.	....	NW. —. f. m. m.	....			W.	m45.8	2 or 3
24–30.		No observations.								
31.	13.3	WNW. —. f. f. c.	....	....	....			....	m38.1	0
November.										
1.	10.4[1]	NE.[1] —. c. f. c	....	....	....	Fl.		W.	m32.5	0
2.	13.9	W. —. f. m. m.	....	....	....	....		N.W.	m32.4	{ 8 to 10 for limb { 2 for detail.
3.	12.5	S. s. m. m. c.	....	E. i. m. m. c.	....	....			m40.9	{ 8 to 2 for limb. { 2 for detail.
4.	3.4	E. by N. — c. s. c.	....	....	....	....			m40.8	2
5.	12.5	N. —. c. s. f.	....	E. —. f. m. f.	....	....		......	m39.8	1 to 3
6.	13.6	NNE. —. m. f. c.	....	....	....	Fl.	....	W. by S.	m39.4	{ 4 for limb. { 2 for detail.

The column I. sub-headers (vertical): (Steadiness.) (Size.) (Velocity.) (Conspicuousness for Density.)

7.	12.9	N by E. —. m. f. c.	....	N to NW. c. f. —. c.	....	Fl.[2]	....	N.	44.0	1
8.		No observations.								
9.	14.2	NE. s. —. s. c.	....	E. i. —. s. c.	....	....	....	....	m38.5	1
10.	12.0	E. s. m. m. c.	....	NE. to SE. i. m. m. c.	....	Fl.	....	....	m38.5	1
11.	9.5[3]	W. —. —. f. —	....	....	....	Fl. r.	....	....	m39.2	1 to 2
12.		No observations.	....	....	....					
13.	12.8	E. —. —. f. c.	....	II. is finer than I. and makes an angle of 5° with it.	....	....	....	....	m36.6	2 to 4
14.	13.4	W. by N. — f. f. f.	....	....	....	....	....	....	m41.6	4 to 7
15.	12.8[4]	SW. s. c. —. —.	....	W. i. f. —. —.	....	....	....	SW.	m37.0	4
16.		No observations.								
17.	16.8[5]	NW. —. —. s. —	....	....	....	Fl.	....	....	m34.2	0
18.	12.4[6]	E. by S. s. f. f. c.	....	NE. i. c. m. c.	....	....	....	....	34.0	1
19.	11.7	NW. s. f. f. c.	....	....	....	Fl.	....	h. W.	38.0	2 to 4
20.	11.4	N. s. c. 10. m.	....	WNW. c. f. 10. m.	....	Fl.	....	....	m37.6	2
21.	11.0	SW. s. m. f. m.	....	W. r. f. f. f.	....	Fl.	....	....	39.5	3 to 4
22.	13.0	SW. s. c. m. c.	....	WNW. i. m. m. c.	....	Fl.	....	....	33.2	3
23.	11.9	SW. s. c. —. m.	....	NW. r. f. —. m.	....	Fl.	....	....	37.4	4 to 7
24.	12.6	ENE. s. f. f. c.	....	NE to ESE. i. f. f. c.	....	Fl. r.	....	E.	43.0	1 to 5
25.	8.2	S. by W. s. c. f. m.	....	W. i. f. f. m.	....	Fl. r.	....	....	m39.2	3
26.		....	....	....	....	....	....	....	m39.1	5
27.	7.0	SW. s. f. f. m.	....	W. i. f. f. f.	....	....	....	....	46.0	3
28.	6.9	WSW. s. f. f. m.	....	SSW. r. m. f. f.	....	Fl. r.	....	....	m36.0	4
29.		....	....	....	....	....	....	....	m30.3	0
30.	7.8	SW. s. f. to c. f. c.	....	W. i. f. f. m.	....	....	....	c. WSW.	39.0	1 to 2
December.										
1.	9.8	E. by S. s. 1·8. m. m.	....	NE. s. f. m. —	....	Fl.	....	E.	29.8	2
2.	7.9	S. s. 1·2.m. c.	3,600 feet.	E. s. 1·2. m. c.	....	....	....	E.	33.0	1 to 2
3.		....	....	....	....	R. and Fl.	....	....	36.0	7
4 to 9.		Cloudy.								
10.	7.4	N. by W. s. 6·0. 19[2]. c.	4,000 feet.	NE. by N. s. f. 19[2]. c.	3,000 feet.	Fl. r.	....	....	23.5	0 to 1
11.	7.2	SW. —. —. —. m.	....	W. —. —. —. m.	....	Fl.	....	{ H 3500 V 8³ }	27.5	3
12.	7.6	S. by E. i. 2·6. 12[4]. m.	8,400 feet.[5]	ESE. i. f. 49.[6] c.	4,100 feet.	E.[7] s.f.f.c.	....	E.	30.8	0 to 4
13 to 15.		Cloudy.								
16.	8.2	W. by S. s. 1·5. f. m.	variable.	N. by W. i. 1·0. f. m.	2,100 feet.	Fl. r. f.	....	W. by N.[8]	29.5	1 to 2
17.	10.6	SW. r. f. 15. m.	18,000 feet.[9]	SSW. s. 0·6. f. c.	7,700 feet.	R.[5]	....	....	32.0	2 to 6
18 and 19.		Cloudy.								

DECEMBER.	I.	H. T.	II.	H. T.	III.	CONF.	WIND.	TEMP.	SEEING.
d. h.									
20. 6.6	SW. s. 2·2. 8.[10] c.	3,800 feet.	....	....	Fl.[11]	....	h. c.	37.0	2
21 and 22.	Cloudy.								
23. 7.4	WSW. s. 2·2. 21.[12] c.	3,600 feet.	WSW. gusts to earth.	....	Fl. r. f.	2.6	h. c.	35.0	0 to 1
24. 8.5	WNW.[13] i. 0·8.14. c.	4,400 feet.[14]	W. s. 6·0. 7. c.	....	....	4.9	W.	29.0	0 to 2
25 to 31.	Cloudy.								

NOTES.   Nov.

[1] Two observations were made that night: 10.4h.   I. N. by E. — Lowell, observer and 18.7h   I. E.   III. Fl.   Pickering, observer.   This is the first recognition of the floating form.   It undoubtedly had existed many times before.

[2] This Fl. was recorded at 17.4 h. by Prof. W. H. Pickering; he observed a NE. current in place of the N. by E. given.

[3] Observed by Mr. Lowell.

[4] A less complete but similar observation was made by Mr. Lowell at 7.3 h.

[5] Observed by Prof. Pickering.   This NW. current showed a "vibrating" effect.

[6] Observations verified in 6 in. and 12 in. telescopes.

NOTES.   Dec.

[1] Observed by Prof. Pickering.

[2] ± 8.

[3] Height and movement of clouds.

[4] ± 4.

[5] Reading 20 m. later gave 18,200.   Velocities taken at second reading.

[6] ± 33.   Too swift to estimate well.

[7] May be same as Current II.

[8] Currents I. and II. were very variable; sometimes together and sometimes one alone seemed to occupy the entire atmosphere.   Clouds followed.

[9] At 9.0 h. this division was about 4,700 feet.   Current III. was then of the syrup form.

[10] Taken with eye-piece.   Without it a velocity of 14 was estimated.

[11] Average speed 2m. an hour from S.

[12] An estimate in which clouds interfered gave 14.

[13] This observation on Aldebaran.   Previous observations on Mars showed more than usual variability in currents as to height, direction, and size.

[14] ± 1,000 feet.   Varied between settings.

In conclusion we should be reminded that the preceding observations are distinctly local, and that they cover a very brief portion of the year. Situated, as this observatory is, near the meteorological line which separates the temperate from the torrid zone, it belongs to neither one, pure and simple, but partakes of both; and perhaps especially complex is the mixture at this season of the year when winter is coming on and the southern limit of the temperate zone is moving equator-ward. But we may reasonably hope that future observations will render our knowledge more general, both as regards time and place.

LOWELL OBSERVATORY,
FLAGSTAFF, ARIZONA, JAN. 1, 1895.

Photography
begun about 1900
Amateur Telescope Making
Seeing +c

Photograph of Shadow Bands
1925 Jan
Zodiacal Light
1915 +