3. *On determining the Heights and Distances of Clouds by their reflexions in a low pool of water, and in a mercurial horizon.* By FRANCIS GALTON, *M.A., F.R.S.*

The calm surface of a sheet of water may be made to serve the purpose of a huge mirror in a gigantic vertical range-finder, whereby a sufficiently large parallax may be obtained for the effective measurement of clouds. The observation of the heights and thicknesses of the different strata of clouds, and of their rates of movement, is at the present time perhaps the most promising, as it is the least explored branch of meteorology. As there are comparatively few places in England where the two conditions are found of a pool of water well screened from wind, and of a station situated many feet in height above it, the author hopes by the publication of this memoir to induce some qualified persons who have access to favourable stations, to interest themselves in the subject, and to make observations.

The necessary angles may be obtained with a sextant and mercurial horizon, but it is convenient, for reasons shortly to be explained, to have in addition a tripod stand, with a bar of wood across its top to support the mercurial trough, and some simple instrument for the rapid and rough measurement of altitudes. I have used the little pocket instrument sold by Casella, of Holborn Bars, London, called a 'pocket alt-azimuth,' and have employed Captain George's mercurial horizon on account of its steadiness and ease in manipulation.

The observer has to determine :—

1. The difference of level in feet between the mercury and the pool of water (call it d).

2. The angle between the reflexions of a part of a cloud in the mercury and in the pool (call it p). This should be carefully measured.

3. The angle between the portion of the cloud and its reflexion in the *mercury* (call it $2a$). This may be roughly measured; its altitude a may most conveniently be taken at once by the pocket alt-azimuth or other instrument. The subjoined tables will then give the required result with great ease.

If p be not greater than 3°, and if n be the number of minutes of a degree in p, the error occasioned by writing $n \sin 1'$ for $\sin n'$, will never exceed six inches in a thousand feet, and may be disregarded. Other errors of similar unimportance, due to the eye not being close to the mercury, may also be ignored. Under these conditions, since log. sin. $1' = 6{\cdot}46373$, it can be easily shown that

$$\text{distance of cloud} = \frac{d}{n} \times 6875{\cdot}5 \cos (a + p).$$

$$\text{vertical height of cloud} = \text{distance} \times \sin a.$$

The following table has been calculated for these values when $\frac{d}{n} = 1$. To use it, multiply the tabular numbers by d (the difference in feet between the level of the mercury and that of the pool) and divide by n (the number of minutes of a degree in the angle between the reflexion in the mercury and that in the pool). The result will be the distance, or height, as required in feet.

TABLE for calculating distances and height of clouds by their reflexions from a mercurial horizon, and from a pool of water at a lower level.

a = Altitude of cloud, (being half the sextant angle between the cloud and its reflexion as seen in the *mercury*, not pool).

p = Angle between the reflexion of the cloud in the mercury and that in the pool.

d = Vertical height of mercury above pool.

n = Number of minutes of a degree in the angle p.

Then the distances and heights of clouds = tabular numbers $\times \frac{d}{n}$

$a+p$	Distance from Observer	Vertical Height of Cloud above Observer			
		$n=0$ (or $p=0°$)	$n=60$ (or $p=1°$)	$n=120$ (or $p=2°$)	$n=180$ (or $p=3°$)
10°	6771	1176	1059	942	825
15°	6641	1719	1607	1494	1381
20°	6461	2210	2103	1997	1889
25°	6231	2633	2534	2435	2334
30°	5954	2977	2886	2795	2703
35°	5632	3230	3149	3067	2985
40°	5267	3386	3314	3243	3170
45°	4862	3438	3377	3316	3253
50°	4419	3386	3335	3284	3232
55°	3944	3230	3198	3150	3108
60°	3438	2977	2947	2915	2883
65°	2906	2633	2612	2597	2566
70°	2352	2210	2195	2180	2165

The observation of the angle between the two reflexions is perfectly easy with a full-sized sextant, if the trough of mercury be so propped up that the reflexion from the pool can be viewed *underneath* the trough. For this purpose I use a tripod stand with a bar of rough wood, say 18 inches long, 3 wide, and 2 thick, secured horizontally across its top. I lay the mercurial horizon on one of its projecting ends and between a few studs that have been driven in to prevent its accidentally slipping off. The edge of the bar is bevelled, and its thickness is reduced at the place where the mercury trough is set. Then the observation is taken, just as any other sextant observation would be. The reflexion from the mercury falls upon the index-glass, and that from the pool is viewed directly through the object-glass below the trough and its supporting bar.

Unless the sextant be a full-sized one, this operation cannot be effected, because the index-glass will not stand high enough above the line of sight to catch the reflexion from the mercury. It will simply reflect the side of the trough.

If there be no tripod stand, and it becomes necessary to lay the trough on the ground, an observation can still be made, but in an inconvenient fashion. The sextant will have to be held topsy-turvy, that the brighter reflexion of the cloud from the mercury, and not the feebler one from the pool, should fall on its index-glass. The angle read will be negative; it will be what is commonly called an 'off' angle. A small sextant may be used in this method, because the rim of the trough is narrow that intervenes between the further edge of the mercury and the objects seen beyond and over it.

The most convenient method of measuring the rate of movement of clouds, after the height of the cloud plane has been once determined, is to watch the movements of a patch nearly overhead, and passing away from the zenith, as seen reflected in the mercury, and measuring its angle of depression (=its altitude) with some simple and suitable instrument, such as the pocket alt-azimuth already mentioned. Two measurements, a_1 and a_2 are taken, as well as the intervening time, t seconds, whence we obtain rate of movement = height of cloud × (cotan a_2 − cotan a_1) in t seconds.

When the water is almost wholly calm, I find that 2′ of error is the utmost that need be feared. If wholly calm 1′ would be ample to make allowance for in a set of three or four observations. Now suppose we wish that our determination shall never be more than, say, 10 per cent. in error, we can easily find from the tables what the minimum height of the station must be in any given case, to secure this result. In the first instance we should require a parallax of 10′ and in the second of 20′. This is obtained by an elevation of 10 or 20 feet as the case may be, when the height of the clouds in feet corresponds to the tabular numbers; that is, when it is between 2000 and 3000 feet. At 100 or 200 feet elevation, clouds of ten times that height could be observed with equal accuracy. Numerous stations exist whence mountain tarns can be seen lying at a much lower level than this, and where even the highest cirrus could be measured with satisfactory precision.

Useful regular work might be done by a meteorologist whose station was at a height of even 50 feet above a pool, supposing it to be so well sheltered from the wind as to frequently afford perfectly good reflexions with, say, 1′ maximum error. Very shallow water is much stiller than deep water, as waves cannot be propagated over it; thus we may often see wonderfully good reflexions in road-side splashes and puddles, in the intervals between puffs of wind. The most stagnant air is in the middle of a high and broad plantation, where there is also plenty of dense underwood. Detached puddles of water in broad ruts would be a good equivalent for a pool. As regards the size of the pool, if we let fall a perpendicular k from the mercury trough to the level of the water, the utmost portion of the surface of the pool that can be used with effect extends between the distances of about $\frac{1}{2}k$ and $4k$ from the base of the perpendicular. The angles of depression would be then from 64° to 14° about, or say, a range of 50°. The usual limits would be from k to $3k$, or between 45° and 18°, being a range of 27°.

Improved Heliograph or Sun Signal. By TEMPEST ANDERSON, *M.D., B.S.c*

The author claims to have contrived a heliograph, or sun-telegraph, by which the rays of the sun can be directed on any given point with greater ease and certainty than by those at present in use.

When the sun's rays are reflected at a small plane surface considered as a point, the reflected rays form a cone, whose vertex is at the reflector and whose vertical angle is equal to that subtended by the sun. Adding to the size of the mirror adds other cones of light, whose bounding rays are parallel with those proceeding from other points of the mirror, and only distant from them the same distance as the points on the mirror from which they are reflected. Hence increasing the size of the mirror only adds to the field to which the sun's rays are reflected a diameter equal to the diameter of the mirror, and this at any distance at which the sun-signal would be used is quite inappreciable. Adding to the size of the mirror adds to the number of rays sent to each point, and hence to the brightness of the visible flash, but not to the area over which it is visible.

By the author's plan, an ordinary field-glass is used to find the position of the object to be signalled to, and to it is attached, in the position of the ordinary sun-shade, a small and light apparatus, so arranged that when the mirror is turned to direct the cone of rays to any object within the field of view of the glass, an image of the sun appears in the field, at the same time as the image of the distant object, and magnified to the same degree, and the part of the field covered by this image is exactly that part to which the rays are reflected, and at which some part of the sun's disc is visible in the mirror.

A perfectly plane silvered mirror, A, takes up the rays of the sun, and when in proper position reflects them parallel with the axis of D, which is one barrel of an ordinary field-glass. The greater part of the light passes away to the distant object, but some is taken up by the small silvered mirror E, which is placed at an angle of 45° to the axis of D, and reflected at a right angle through the unsilvered plane mirror, F, and the convex lens, K, by which it is brought to a focus on the white screen, H, which is placed in the principal focus of K. The rays from this image diverge in all directions, and some are taken up by the lens K and restored to parallelism; some of these are reflected by the unsilvered mirror, F, down to the field-glass, D, and if this is focussed for parallel rays, as is the case in looking at distant objects, an image of the sun is seen projected on the same field of view as that of the distant object. As the mirrors E and F are adjusted strictly parallel, the rays proceeding from F into the field-glass are parallel and in the opposite direction to those going from the mirror A to E, which form part of the same pencil as those going to the distant object. Hence the image of the sun seen in the field exactly covers the object to which the sun-flash is visible, and in whatever