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SOLAR SITE TESTING

K. O. KIEPENHEUER.

1. **Introduction.** — While at night almost all optical effects of the atmosphere have to be investigated by using stellar images, the solar observer has at his disposal the solar disk of about half a degree in diameter, covered all over with low contrast details of about 1″, the granules, and confined to the sky by a sharp limb. This enables him to observe all effects occuring within the area of the Sun simultaneously, to follow even the propagation of certain atmospheric effects across the disk. On the other hand he has only the Sun and cannot — as night

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astronomers might do — extend his observations to all directions in the sky.

At night exposure times of minutes and hours are needed. In solar work exposure times will almost never exceed a few seconds. For this reason rather short intervals of excellent image quality can be already of great value to the solar physicist. One has to distinguish clearly between two types of solar sites: The site which gives images of extreme quality during short intervals and the site which gives less excellent but still very good images during much longer intervals.

The physical conditions in the surroundings of an astronomical observatory are very different at day and at night: During the day the surface of the Earth, heated by the Sun's radiation, changes the temperature-distribution of the atmosphere completely up to several thousand meters by convective heating. Mountains, so well suited for night observations and for a short period after sunrise, are transformed at day time into efficient sources of turbulent convection, which spoils the atmosphere optically up to altitudes probably well above the mountain peaks. The ascending air currents produce clouds above the mountains, while the bordering plain might remain unclouded. We will see later that the characteristic motions of air around mountains can be also of great value for the astronomer. Also the exchange of air between land and sea is changing direction from night to day. The sea breeze at day time can be of great help to the solar observer.

Very few astronomers have been giving systematic attention to such possibilities. Altogether the choice of a site for solar work is certainly not easier than for night observation. Fortunately the atmosphere above 2 000 to 3 000 m altitude is — at least over a plain — the same at day and at night.

The terms which have been introduced to describe and to classify the quality of the image of stars (Rösch, Minnaert, 1961) can be applied with little modification also to the Sun. It has been decided to combine all the effects influencing the image quality in the term " Image Deterioration ". The following terms will be used to describe in detail the image quality:

Image motion	Agitation de l'image	Bildunruhe
Scintillation (1)	Scintillation	Szintillation
Distortion	Distorsion	Distorsion
Blurring	Altération	Verwaschung
Contrast	Contraste	Kontrast

To investigate the different modes of disturbances occurring in the solar image, observation by eye-piece and Colzi prism is the most effi-

(1) In general without importance for solar work.

cient procedure. The magnification should be such that the diameter of the field is not more than half of the Sun's disk. Projection should be used only in well shaded rooms, the disk's diameter should be at least 250 mm. A refractor is by far better than a reflector. The latter has to be handled very carefully in order to avoid deformation of the mirror and inhomogeneous heating of the tube and the air inside the tube. The focal heat should be taken out of the instrument, similar to the technique used in coronographs. In reflectors the 45° mirror should be replaced by a Herschel prism, which sends back most of the light. This is convenient for visual observation. The results obtained will depend strongly upon the aperture of the telescope. We believe that the best diagnoses of the various atmospheric disturbances at action can be given with an instrument of about 15 cm aperture only. Such a small aperture will separate very clearly image motion and blurring and therefore enable the observer to integrate these effects in time or over a larger telescopic aperture as he wishes.

In order to recognize the optical effects of the various layers of our atmosphere it is further indispensable to eliminate the optical turbulence arising close to the ground by using e.g. free standing observing towers (*see* § 3 *b*). The use of a dome will make the diagnosis much more difficult or even impossible! With these precautions taken the following variety of defects in the solar image can be stated (for more details, *see* also J. Rösch, 1961) :

A. Sharp solar limb, saw-toothed with rather a short " wavelength "; granulation well visible. Limb structures and image distorsions move (in direction and speed) with scraps of clouds. The focus is very well defined all over the image. Cause : Turbulence in the cumulus layer or below.

When the Sun very low above horizon (often observed from mountain observatories) : Sharpness of limb and disk, excellent, limb slowly ondulating easily to be followed visually. Cause : Stratification of atmosphere in some kilometres distance.

B. Scalloped solar limb, only partially sharp. " Wavelength " of structures greater than for A. On the disk, cushionlike patterns of blurred or distorted regions, which move faster than in A (phenomenon also called *réseau photospherique de Janssen* (*plate* XIII). Speed and direction is the same as motion of air in the vicinity of the telescope (as judged from high flying seeds). The disturbed regions on the disk can be refocussed occasionally. The described effects occur preferably during strong and variable ground wind in the first few hundred metres above the telescope.

C. The whole disk of the Sun jumps or boils, the limb sometimes appears double, amplitude $\lesssim 5''$, without showing wave structure. Sharpness mostly poorer than in B. Cause : Turbulence in the very vicinity of the instrument, ground heating, buildings, dome etc. (Can be avoided completely by putting the telescope in the open air, at least 20 m above ground.)

D. The whole disk of the Sun blurred, granulation hardly discernable. Sometimes no conspicuous image motion, sometimes also strong agitation. Cause: Turbulence in extended layers, reaching from the telescope to some kilometres distance along the line of sight, strongly related to the meteorologic situation (origine of air, vertical temperature distribution).

The following five step scale of classification of image quality for visual solar observation has been used by us for more than 20 years. It can be applied successfully without difficulty also by observers with little training and seems to be the appropriate scale for first site testing.

Quality of solar image.

Quietness.	Sharpness.
Quality 1	
No image motion visible, neither on limb nor on the disk.	Granulation very conspicuous, structure of penumbra recognizable.
Quality 2	
Image motion ($< 2''$) only on limb detectable, on the disk almost undiscernible.	Granulation well defined, penumbra well visible, but almost without fine structure.
Quality 3	
Image motion ($< 4''$) well visible on limb and on disk, solar limb ondulated or pulsating.	Only traces of granulation, but structure of solar surface still easily detectable when solar image is displaced. Umbra and penumbra still well separated, but no fine structure.
Quality 4	
Image motion ($> 5''$) almost prevents distinction of umbra and penumbra, solar limb strongly ondulated or pulsating.	Umbra and penumbra separable only for larger spots. No granulation structure detectable.
Quality 5	
Amplitude of motion reaches diameter of sunspot.	Even for larger spots umbra and penumbra undistinguishable.

2. **Measurement of the criteria and discussion of results.** — *a.* Amount of sunshine. — Even in Europe only very rough values of the number of sunshine hours per month are available. For the solar observer even more important is the *distribution* of sunny hours, whether sunshine occurs in sequences of days or whether it comes in unpredictable accidental bits of short periods. Further, every observer knows that there are hours with good and with poor seeing. The effective number of hours will be therefore considerably smaller than the sunshine hours as defined by meteorology.

A rough idea of the *relative* distribution of sunshine over Europe within a year can be obtained from the table I, which gives the monthly means of cloudiness in percentage of the hemisphere for 32 places in Europe and in the southern Mediterranean.

The amount of sunshine available north of the Alps can be considerable at least during the summermonths, but long lasting periods of sunshine are extremely rare. In most cases one has to wait for weeks to have a sequence of a few days. If one asks in addition for hours of good seeing, the number of effective hours will shrink terribly.

The situation is much better in the southern parts of the Alps. The number of sunhours per month there is roughly the same all over the year. The annual mean is even higher than for Milano, Roma, Madrid and Napoli (2). Only in southern Spain (Cartagena, Sevilla) and along the northafrican coast, which is always within the subtropic high pressure belt, one can be sure to have all the year round long sequences of days without clouds. We will see later what fraction of this sunshine is of value for solar research.

Continuous solar work, as it can be done in California or in Arizona is feasable in Europe only in its very southern parts, let us say south of the latitude of Rome.

b. Image motion. — The visual estimation of image motion of the Sun's limb does not offer any difficulties, while on the disk some auxiliary devices are needed. Photoelectric measurements of solar image motion have been obtained early by Siedentopf (1939). A handy solar seeing monitor has recently been described by Bray, Loughhead and Norton (1959), which is used in connection with a 5-inch photoheliograph. A 3.5-inch objective and a magnifying lens forms a solar image, 109 mm in diameter. Two narrow circular slits allow light from the east and west limbs to fall on two photocells. The two slits reach both into the Sun's disk by 0.5 mm. With a perfectly steady image the light falling on each cell would remain steady. When the image is agitated the intensity recorded by each cell fluctuates irregularly; the corresponding photocell

(2) The island of Capri, only 30 km west of Napoli, has a much smaller cloudiness.

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TABLE I.

Monthly and annual means of cloudiness in percent of hemisphere.

Years.	Place.	Lat.	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.
28.....	Cairo	30°	44	40	37	35	28	12	14	16	16	25	32	43
35.....	Tel Aviv	32	51	48	51	39	33	17	19	19	21	28	42	53
38.....	Casablanca	33	38	40	44	44	39	35	35	33	33	35	40	45
36.....	Haifa	33	52	46	47	37	30	25	26	25	21	26	42	51
40.....	Malta	36	55	52	48	45	39	25	12	16	31	47	52	56
30.....	Sevilla	37	36	38	41	39	33	20	08	09	23	36	40	39
46.....	Tunis	37	59	61	61	49	46	36	19	15	44	47	54	60
48.....	Syracusa	37	60	60	56	56	49	34	18	22	42	57	60	64
40.....	Athens	38	55	57	53	48	40	25	11	12	22	40	57	59
29.....	Cartagena	38	37	34	42	32	23	15	12	13	30	36	37	32
42.....	Lisboa	39	51	50	50	50	44	34	21	20	36	48	52	53
42.....	Madrid	40	48	46	46	49	47	37	21	22	39	47	51	52
48.....	Napoli	41	48	50	50	49	42	32	19	16	28	43	49	52
48.....	Barcelona	41	48	48	52	55	52	53	37	40	51	54	52	49
47.....	Roma	42	55	56	55	56	53	41	23	22	38	52	53	58
54.....	Pic du Midi	43	53	51	58	61	67	57	42	43	53	55	53	53
48.....	Firenze	44	55	53	56	55	52	43	29	25	36	53	57	66
45.....	Nice	44	44	38	48	55	60	47	32	31	37	57	41	48
57.....	Milano	46	64	55	56	58	58	52	43	44	49	63	71	66
43.....	Locarno	46	40	39	43	50	50	43	37	38	42	49	50	38
63.....	Zürich	47	77	67	62	59	57	56	52	51	53	67	78	80
63.....	Basel	47	70	67	65	61	60	58	54	52	53	67	75	72
59.....	Wien	48	74	68	58	67	56	56	49	43	45	56	71	76
64.....	München	48	71	68	63	63	62	61	59	56	56	65	74	76
64.....	Freiburg	48	71	67	64	61	60	58	52	57	67	76	76	76
60.....	Paris	49	70	65	58	57	57	55	52	49	51	59	69	76
64.....	Berlin	52	73	72	66	60	56	56	61	58	55	65	73	77
69.....	Hamburg	54	74	73	69	64	61	61	68	66	60	72	75	80

First column gives annual means. (After KÖPPEN-GEIGER, *Handbuch der Klimatologie*, III M.)

output then contains both a steady and an A. C. component, the latter being a measure for the agitation. The output is displayed on a cathode ray tube or can be read quantitatively on a volt-meter, averaged over a period given by the amplifier or the volt-meter. The advantage of adding the outputs of two cells is to minimize the effect of momentary guiding displacements or wind shake.

The instrument has not only been used as a meter for image motion, but also, according Giovanelli (1961), as a monitor to trigger a camera shutter during short periods of steady images. Many of the photo-electric guiding devices for solar telescopes (Plesse, 1961) which have come into use in recent years are based on the same principle and can be easily abused as agitation meter or seeing monitor.

It is obvious, however, that the human eye is much more capable than a seeing monitor to distinguish between the different types of image motion and deterioration. Even if a seeing monitor is available, visual observation should not be excluded completely therefore.

c. Sharpness of image. — Already with small telescopes, diameter of 10-15 cm, and with a clear sky, blurring and motion of the image can easily be distinguished. Quite reliable visual estimates can be made, corresponding to the visibility of granulation in the center of the disk or the fine structure of the penumbrae. The judgment of the sharpness, especially when there is an appreciable amount of scattered light, is however not as easy as for the image motion.

The photoelectric measurement of the sharpness of the solar image does not present great difficulties. What is being measured however is the contrast, which is the result of the combined action of blurring and atmospheric light scattering. The handy instrument, which is in use at the Fraunhofer Institute already a long time and which has been transistorized recently, is not larger than an exposure meter (Zindel, 1962), as can be seen in figure 47.

Through a pin hole of 0.1 mm a portion of a second of arc in diameter is cut out of a projected image of the Sun, 150 mm in diameter, and is

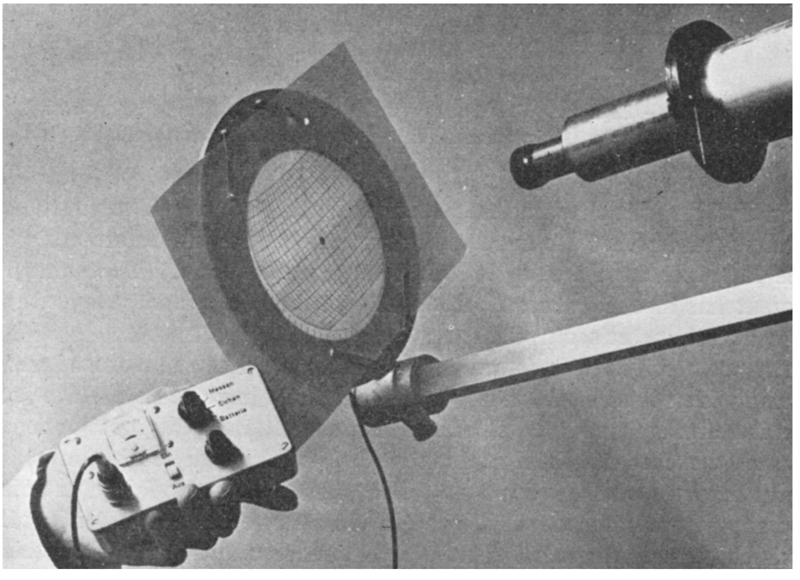

Fig. 47. — Contrast Meter used at Fraunhofer Institut.

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projected on a silicon photoelement. The output of this cell is amplified by a four stage A. C.-transistor amplifier — amplification 90 dB — and can be read on a micro-amperemeter. In the range 100-2 700 c/s the amplification is independant of frequency. Does one move the cell across the Sun's disk (an hour drive for the telescope is not needed !) the granules passing the pin hole produce an A. C. signal, which represents a measure for the contrast. The speed of moving the Sun's disk back and forth practically does not effect the result. The calibration of the instrument is made by 100 % modulation of the light reaching the cell, while reducing the amplification by a factor 20. With full amplification 5 % contrast will give then full scale output. This value has been reached quite often on top of our seeing towers.

Figure 48 gives a comparison between visual estimates of image sharpness (blue sky, refractor 110/1650 mm, observation through Colzi

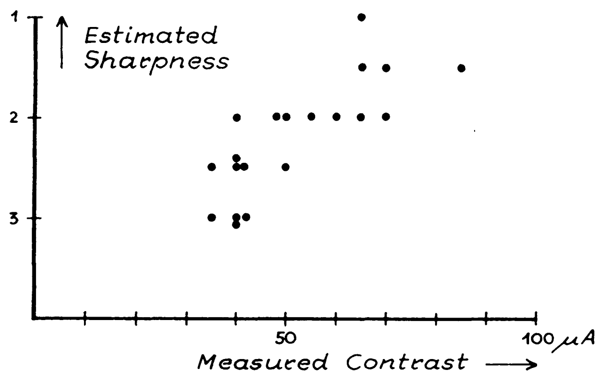

Fig. 48. — Comparison between visual estimates of image sharpness (refractor 110/1 650 mm, Colzi prism) and photoelectric measurement of contrast.

prism and eye-piece) with photoelectric measurements. The visual scale is that of table II. The uncertainty of the visual estimate amounts to a little less than ± 0.5 step in the 5 step visual scale. The same instrument has also been used successfully to focus a telescope by reading the contrast meter's output.

If a promising site is found by applying the described procedures or by using the visual scale, more refined methods have to be used to judge about the image quality. It is our impression, that the most economic way will be then to obtain as often as possible high resolution photographs of parts of the solar disk. This can be done by fairly untrained people. In order to get an idea about the image distorsion (or in other words about the integrated effect of image motion and blurring), specially on days with excellent images, white light or monochromatic pictures should be taken with exposure times of several seconds. In this case

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the white light intensity has to be cut down by a factor of the order of 1000. Such pictures will tell us then about the definition of a solar structure centered on the slit of a spectrograph during a few seconds. The telescopic aperture should also be here not more than 15 cm.

Such a test is very hard and can give even on days with seemingly excellent seeing very poor image quality. For many years we had the opportunity to take almost simultaneously pictures in integrated light (1/500 s) and H_α-filtergrams (2 s). Only a small fraction of these pairs show a comparable image resolution. It is quite clear, that even the best sites available on the ground will pass this test only for very short periods, while in the stratosphere, as Schwarzschild has shown with his *Stratoscope I* balloon-borne telescope (Schwarzschild, 1959) image distorsion is completely absent.

d. Effect of scattered light. — Diminution of contrast by scattered light and by blurring can be distinguished in principle. By measuring the sky brightness outside the disk as a function of distance from the Sun's limb, the intensity of scattered light to be expected on the disk of the Sun can easily be estimated (David, Elste, 1962).

The measurement of the sky brightness near the Sun's limb is no problem as long as the contribution of instrumental scattered light is included. In most cases a sensitive exposure meter (type Lunasix) equiped with a diaphragm will do it.

The visual estimation of atmospheric scattered light without special devices is not reliable. Often a seemingly blue sky gives more scattered light than a faint veil of cumulus clouds !

The instrumental contribution almost never can be neglected. The following orders of magnitude have to be expected for the sky brightness at 40″ distance from the Sun's limb in fractions of the Sun's brightness :

Coronagraph.	Refractor.	Coelostat or reflector.
10^{-5}–10^{-6}	10^{-3}–10^{-4}	$>10^{-2}$

The scattered light in these three instruments is varying by a factor of about 10 000 !

It is well known that in many cases a slight haze or a milky sky will improve steadiness and sharpness of the solar image, because of reducing the convection around the instrument. Under such circumstances one should not forget however, that the weakening of contrast by scattered light will reduce the telescopic resolving power as well. As long as the sky brightness close to the limb exceeds a few percent of that of the Sun, the resolution will be definitely reduced. It is to be recommended therefore, that not only coronal stations but also other solar observatories should check their sky brightness as well as the scattered light produced in their instruments as coelostats, telescopes, Lyot-filters, spectrographs etc.

3. **Local meteorological effects on the image quality.** — In this section the disturbing influences arising in the surrounding of the observatory up to distances of the order of 50 km will be discussed.

a. Surface of the Earth. — Decisive for the disturbing action of the ground is the temperature on the very surface reached by the absorption of the Sun's radiation. The measurement of this temperature is not quite easy, because very often vertical temperature gradients of more than 10°C/cm will occur. The equilibrium requires that the absorbed solar energy (solar plus sky radiation) + loss of energy to the atmosphere by convection + evaporation loss + loss of energy by infrared radiation + loss of energy by conduction downward = 0. The balance depends strongly upon the type of soil, of the cover, of the heat conduction, the content of water and the degree of roughness of the surface. A few figures might illustrate, how much the equilibrium temperature on a sunny day will vary with the material: Asphalt, 35.4°C; dry soil, 35.1°C; sand, 31.1°C; gravel, 42.6°C; under grass, 29.3°C; clayey soil, 24.6°C. The air temperature was 21.8°C (Geiger, 1960). The lowest temperatures are obtained with soils of great heat capacity, great heat conductivity and a sufficient supply of water for evaporation. The drying out of the surface layer must be avoided. Water also fills the pores, increases the specific heat as well as the heat conduction.

For night observation exactly the opposit is wanted: Small heat capacity poor heat conduction in order to facilitate cooling by convection.

In high mountains the amount of solar energy absorbed by the ground is mostly greater, while the air temperature is considerably lower than at sea level (Maurer, 1916). The resulting larger temperature-difference between ground and air leads to an increased convection producing stronger optical disturbances. The decrease of the refractive index of the air in the mountains, caused by the decrease of temperature and density is far from compensating this effect.

Very suited from a thermal point of view seems solid rock, which because of its great specific heat and its high conductivity warms up very slowly in the course of the day. The temperature can be further kept down by covering the rock with white paint.

Also a water surface can be recommended in spite of the fact, that about 90 % of the solar energy is being absorbed. But most of the absorption occurs in a depth of about 10 m. Therefore a large volume has to be heated. Any difference of temperature is smoothed out rapidly because of the efficient transport of energy by conduction and convection.

Not to be recommended is a grass lawn, which under the Sun's radiation can adopt very high temperatures, because of its insulation against the ground, except the lawn is kept all the time very wet to allow temperature control by evaporation.

As long as the subsoil water comes close to the surface, also a mixed forest of leaf and conifer trees can be of advantage in the plain. However in the later part of a day such a forest will release bodies of warm air, which might produce disturbances. In addition a forest might hinder the free circulation of air around the observatory and reduce in this way the effective height of the telescope above ground (*see* § 3 *b*). To all those who need information in this subject the book of R. Geiger, *Das Klima der bodennahen Luftschichten*, Braunschweig, 1960, is recommended.

b. Image quality and height above ground. — Already G. E. Hale has shown that the image quality improves very rapidly with distance from the ground. This effect is most striking, when observing horizontaly. Already the change from 50 to 100 cm will improve the image quality then enormously.

Several investigations about the variation of the optical properties of the atmosphere with height have been done by R. R. McMath and A. K. Pierce and by R. G. Giovanelli in the plane — measuring distance 170 m —. He Finds for the amount of image motion $1.5\, e^{-\frac{h}{3.5}}$ seconds of arc (height in metres). For the blurring effect he finds a similar law.

We came in Capri on a distance of 150 m to similar results (Kiepenheuer, 1961). With the aid of our seeing towers in the Rhine valley (height : 21 m) we could also show that the improvement of the image with height depends strongly on the air circulation, which on the other hand will affect the temperature gradient along the tower. Sometimes, if the instruments look just over the upper level of a complex of buildings or of trees, an increase in height by only 1 m might bring a large gain in image quality.

If there is no obstacle and the air can circulate freely, a height of the tower of more than about 30 m will probably not bring an essential improvement. Only in regions with very weak winds there might still be a gain. The most direct proof, whether the observing instrument is high enough above ground, is the absence of a diurnal variation of the quality of the solar image. This condition is best fulfilled for both of our towers in the plain of the Rhine valley, which is about 50 km wide. It must be mentioned however, that these towers are both mounted on small and isolated hills. The true heights of the towers above the plain are therefore about 55 resp. 90 m.

A comparison of image quality observed on our tower in the Rhine plain and on Schauinsland observatory is given in figure 49.

This result seems to be true also for deserts. The author had the opportunity to check the image quality in Iran, Israel and Egypt over very extended sandregions without any vegetation. Only in a few meters height above ground very steady and sharp images could be observed occasionally even at noon time. Our result is in good agreement with the knowledge about the distribution of temperature in the lower parts of the atmosphere. According to Brocks (1948) there is an unstable

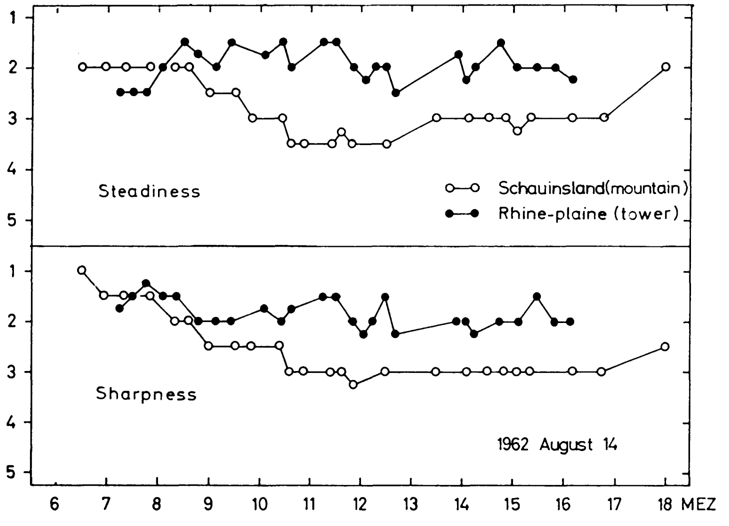

Fig. 49. — Comparison of daily variation of image quality (steadiness and sharpness of the image) for the moutain-observatory Schauinsland and the seeing tower in the Rhine plain.

layer of variable thickness — in summer up to 20 to 30 m — and in winter up to about 10 m — which shows quite clearly a logarithmic decrease of temperature and which builds up some time after sunrise. At the top of this layer the temperature gradient rather abruptly goes over to the adiabatic value. An example of this temperature distribution is given in figures 50 and 51 for the months February, May, July and November (after Brocks, *loc. cit.*). The layer builds up after sunrise, reaching a flat maximum around noon and disappears before sunset. Figure 52 gives an example for a summermonth (after Brocks, *loc. cit.*).

From the given results it follows, that — in order to be above this layer — the telescope should be at least 30 m above ground. It is our impression however, that the upper part of the mentioned superadiabatic layer-that is above about 15 or 20 m — is optically already rather unefficient.

A few words about the construction of our seeing towers might be appropriate here. They are screwed together of prefabricated steel tubes of 50 mm diameter and 2 m length, as they are used very often for scaffoldings. The towers have 20 m height and a cross-section

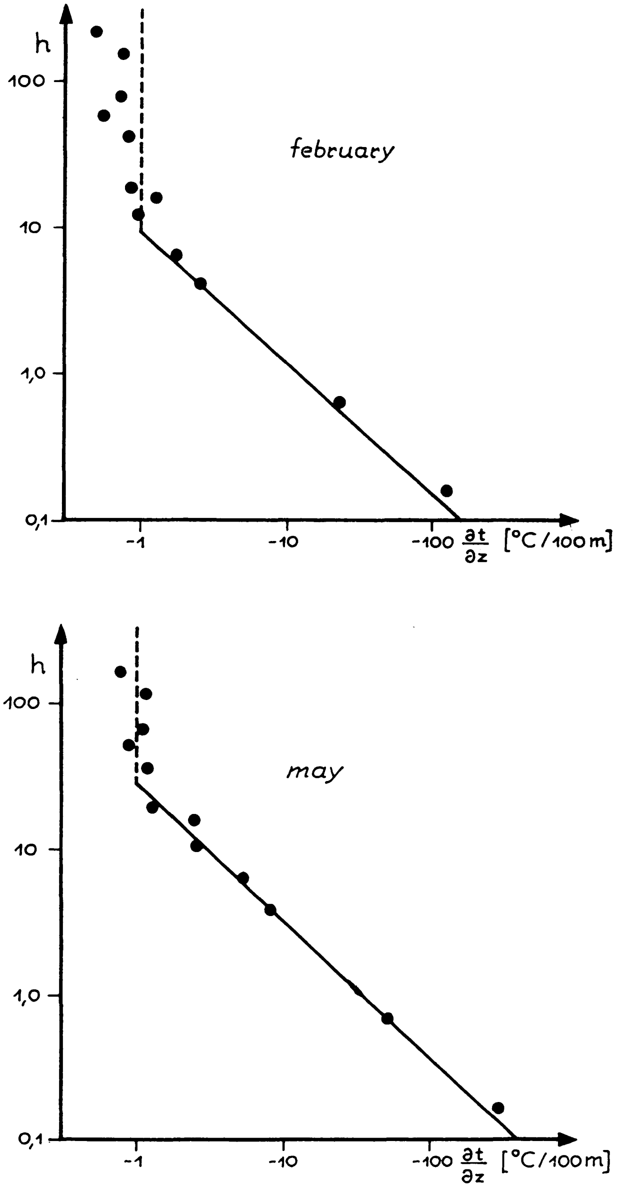

Fig. 50. — Vertical temperature distribution near the ground for the months February and May (after Brocks, *loc. cit.*).

of 2×2 m. An example is given in figure 53. They are rigid enough for visual solar observation even without ropes, as long as the wind is not too strong and too fluctuating. It was interesting to note for us, that the tower does not bend, when pushed by the wind, but moves

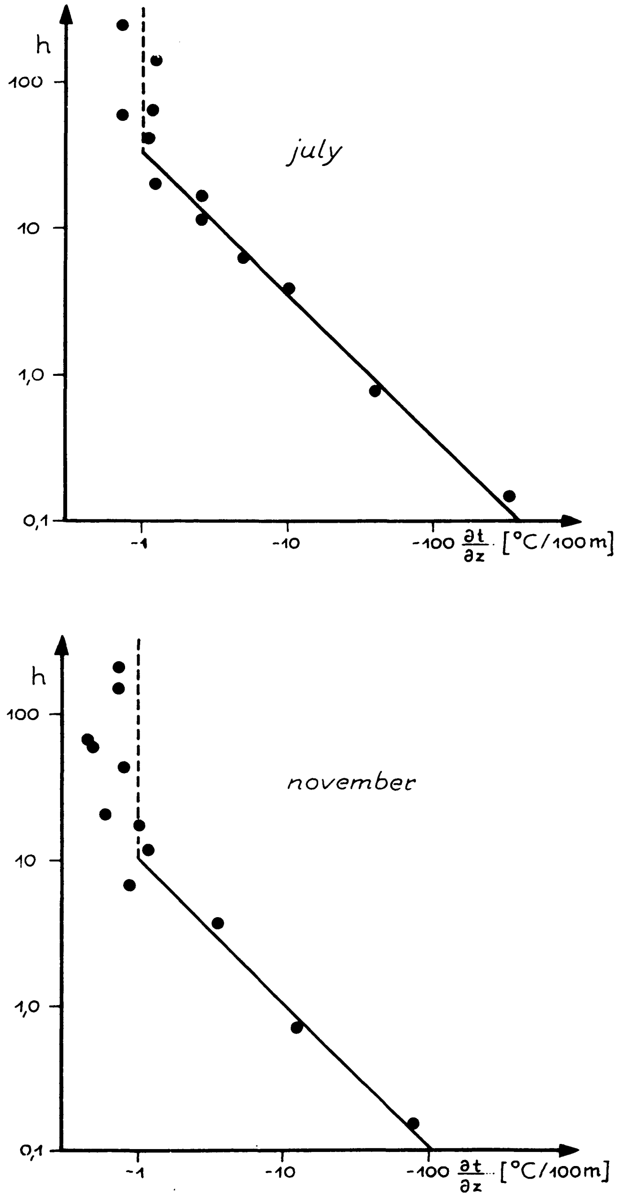

Fig. 51. — Vertical temperature distribution near the ground for the months July and November (after Brocks, *loc. cit.*).

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more like a parallelogram. This means that even on a moving tower a sunspot group will not get out of the eye-piece! In addition, the image displacements brought in by the motion of the tower can rather easily be distinguished from the atmospheric effects.

c. The subcloud regime. — Above this shallow superadiabatic layer of forced convection of only a few metres thickness follows the subcloud regime or the layer of free convection, extending upward to the cumulus niveau. Also this part of the atmosphere thermodynamically belongs to the ground. The convective elements rising in the subcloud

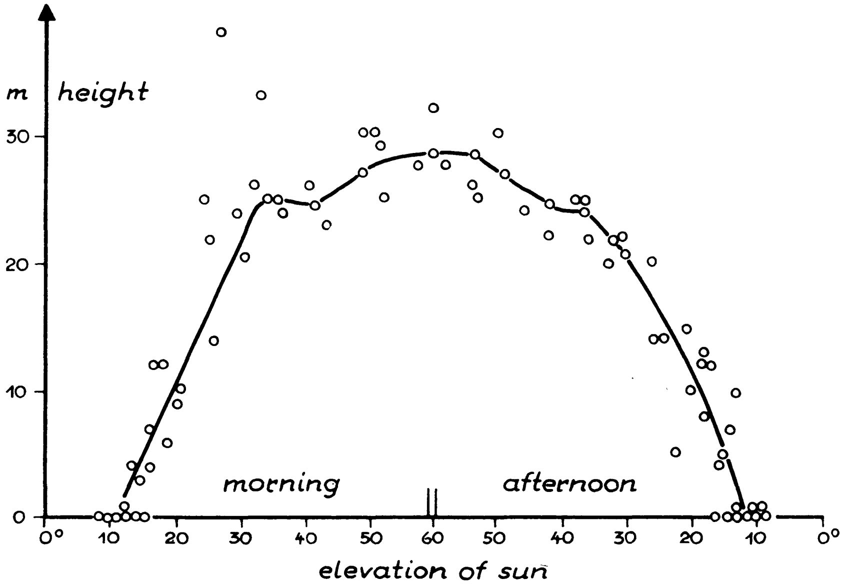

Fig. 52. — The height of the superadiabatic ground layer as a function of elevation of the sun (after Brocks, *loc. cit.*).

layer through neutral and undisturbed surroundings may assume numerous shapes. There seem to be two basic forms of the convective elements: the spherically shaped detached thermals and the columns or plumes still attached to the ground (Woodward, 1960).

It is interesting to note that these thermals, well known to the glider pilots under both forms, also on cloudy days affect the image quality only very little or not at all, as long as the cumulus cover is not too big. We could confirm this result quite often on our seeing towers in the Rhine valley, which gave us at least some guaranty to be above the layer of forced convection. Obviously the optical efficiency of these thermals — as long as they are not forming clouds — is steadily decreasing with their diameter, which might increase very roughly proportional to their height above ground.

d. Orographic influences. — The question, whether the ideal site of a solar observatory is on a mountain or in the plain cannot be answered in general terms. The answer will depend upon the specific goal of the observatory.

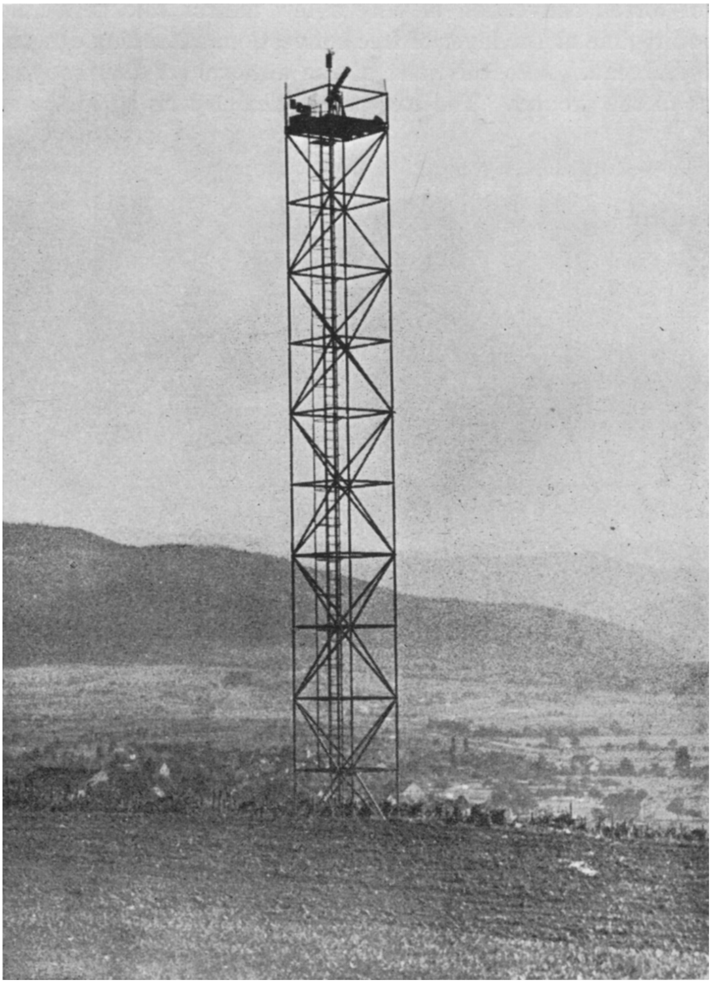

Fig. 53. — Free standing steel tower of 21 m height with 15 cm reflector for solar observation. Rhine plain near Freiburg (Fraunhofer Institut).

A mountain observatory ($h >$ 1000 m) on an isolated peak brings doubtless on the average a higher transparency, less scattered light and very sharp and steady images at night and also during a short period

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after sunrise. One of the consequences of the increased transparency is, that the sun can be observed very early in the morning, while the atmosphere is still in night condition. If winds are favorable, keeping away the turbulent air ascending along the mountain slopes from the line of sight the period of good seeing can last occasionally for several hours. For coronal observations, which require a very pure atmosphere with very little scattered light, a mountain observatory is even indispensable, in spite of the well known difficulties of its management.

We will discuss first the possible influences of mountains on the atmosphere in order to get a general idea about their positive and negative effects on solar observation.

Mountains, whether covered with vegetation or not, produce very soon after sunrise a system of upslope winds, which extend — as all glider pilots know — far above the summits and which reach easily speeds of several meters per second (Silverman, 1960). The optical effect of this wind system is much stronger than that of the free convection in the subcloud regime over a plain. Very little is known, at which height above a mountain the optical effect of these upwinds will cease. Preliminary observations made in the Black Forest mountains indicate that the situation is quite complex. For certain wind directions and meteorologic situations image quality will increase definitely by lifting the telescope to a height of 40 m above ground (e.g. Feldberg, 1550 m a. s. l.), in other cases no improvement of image quality with elevation above ground was observed on a mountain, while in the plain there was always a clear gain, already in 10 m height.

Both the 60-foot and the 150-foot tower of Mount Wilson Observatory show most of the time a definite diurnal variation of image quality, which to a small extent might be due to the heating of the dome and of the building. More systematic studies of optical effects above mountains are urgently needed.

The ascending air will produce also — especially during the summer — additional clouds, which might reduce in certain seasons the number of observing hours of a mountain observatory. This loss might be compensated somehow by the gain of hours during winter, when the cloud layer stops below the summit.

In the lee of mountains very often clouds are dissolved because of falling air, called Föhn. This sort of wind brings indeed a local additional sunshine and high transparency. But systematic seeing tests in Freiburg have shown that the Alpenföhn coming from the south across the Alps causes a strong deterioration of images, just as wind does which comes from the east and which has to cross the Black Forest mountains before reaching the Freiburg Observatory.

Also in the lee of very small hills we have observed a distinct decrease of image quality. We believe that in this case the very strong temperature variation close to the surface of the hill are brought to the top of our seeing tower in the lee of it, thus deteriorating the solar image even at 21 m height.

e. UTILIZATION OF THE MOUNTAIN-WIND-SYSTEM. — *Slope winds.* — As a consequence of the stronger heating of a slope, exposed to the Sun, a wind system is developing, which streams the slope upward in rather a thin layer. The supply of fresh air does not come from the bottom of the valley but — as shown in figure 54 — arrives from an almost horizontal direction and is supplied therefore from a reservoir of undisturbed air. The flow of (too) cool air toward the slope produces a strong vertical

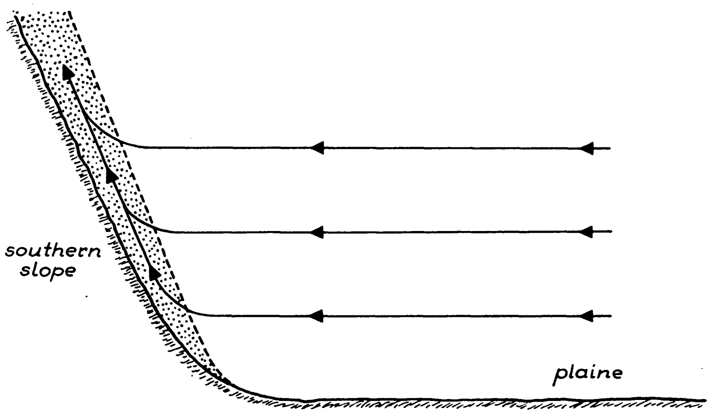

Fig. 54. — The system of mountain winds developing on southern slopes.

temperature gradient above the slope, which is maintained dynamically (Geiger, 1960). The volume containing mostly upwinds is widening in its higher parts, as indicated in figure 54 by the dotted line. Already a few metres above the slope the cool breeze from the plain can be felt on warm days.

As we could observe on different places, especially good on the wooded South-West-slope of the Schlossberg about 50 m above Freiburg (Kiepenheuer, 1961), this horizontal air stream is practically free of turbulence. The observations were made on a free terrace, which is situated about 10 m above the slope. Even on warm days the image quality was excellent still at noon time. Often after a flat maximum at noon a further improvement in the course of the afternoon was observed. Only 1 or 1.5 h before sunset the image began to deteriorate. Quite often however the solar image was even still perfect when the Sun was so low that the line of sight passed all across the heated town of Freiburg in a height of a few hundred metres only. Figure 55 gives an example of the variation of image quality during the day for the South-

West-slope and for the Schauinsland Observatory on 1200 m altitude, in the black forest. The difference between the two sites is quite striking.

Some simultaneous observations made on the same slope some 150 to 200 m higher gave good images only in the early morning, but around 10 or 11 h already poor quality. It must be said however that these latter observations could be made only at a point which did not stick out of the slope as much as the above mentioned terrace.

The numerous results which we obtained on the South-West-slope are not inferior at all to the findings on our two towers in the Rhine valley, which stand very much more freely.

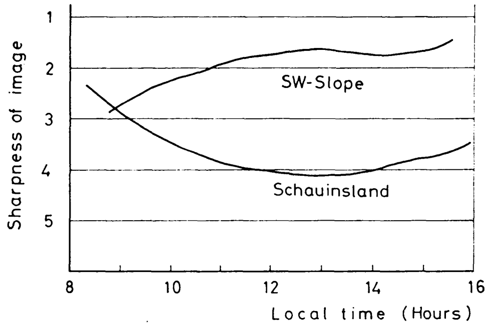

Fig. 55. — Diurnal variation of image sharpness on a South-West-slope (50 m above plain of the Rhine valley) and on Schauinsland (1200 m above sea level)

Still more pronounced is the wind system which develops during a sunny day along an ascending mountain valley. In addition to the slope winds on both sides of the valley which tend to form a closed stream system, there is a wind moving up the valley along its bottom. The resulting stream system leaves little hope for getting good image qualities on the slope or at the bottom of such an ascending valley. Corresponding tests in different high mountain valleys in southern Switzerland have confirmed this expectation.

Much more profitable is it to utilize the strong day time sucking effect of such a valley at its exit into the bordering plain as shown in figure 56 (7). The famous Höllental entering deeply into the Black Forest mountains sucks during the day a considerable volume of air from the Rhine valley. This air shows — at least before penetrating into the valley — quite a laminar flow when crossing Freiburg. This flow can serve as an efficient screen against turbulent convection from the ground, as long as the telescope is inbedded in this stream at a reasonable height. This mechanism — and the same is true for the mentioned

South-West-slope — will work even when there is no large scale wind. It has to be said that this type of sucking effect is much stronger than that of the slope winds.

There is little doubt, that there can be found quite a number of sites of this type all over the world. Preliminary measurements obtained at the southern rim of the Demavend mountain chain (mean alti-

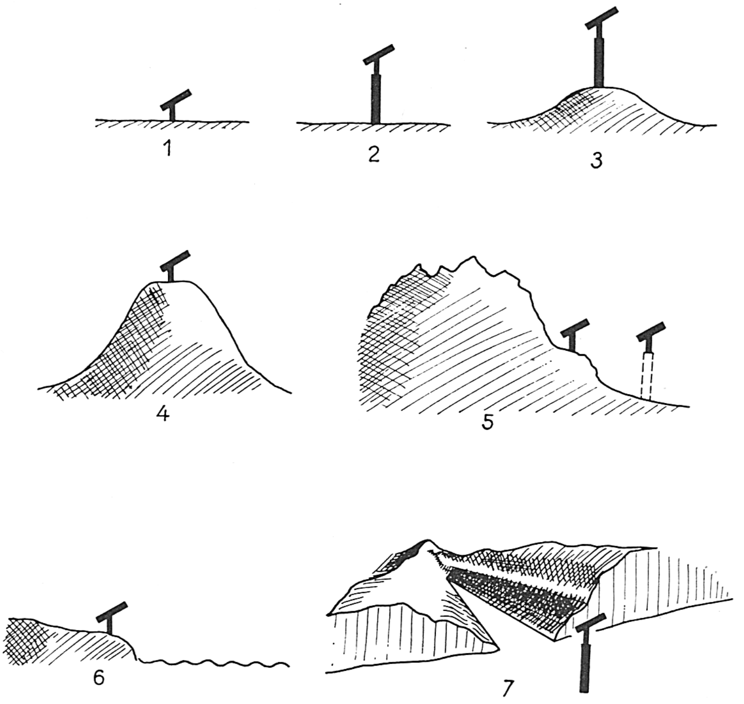

Fig. 56. — Sketch of the different types of solar observatory sites :

1. Telescope close to the ground (plain);
2. Telescope on a free standing tower of about 20 m height (plain);
3. Telescope on a tower which is put on a little hill of some 30 to 50 m height;
4. Mountain observatory on the peak of an isolated mountain (> 1 000 m);
5. Telescope on a southern slope of a mountainous region, some 50 m above the bordering plain, or on a tower of about 20 m in the plain;
6. Telescope a few metres above ground on a southern sea shore;
7. Telescope on a free standing tower in the plain before the entrance of a mountain valley.

tude > 3 000 m) north of Teheran, in Amirabad, about 100 m above the southern plain, also seem to confirm the stabilizing action of the named sucking effect.

An interesting example how under special conditions even within a deep mountain valley good image qualities can be obtained occasionally,

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has been demonstrated by the late ten Bruggencate at the Locarno station of the Göttingen observatory in southern Switzerland. The station is located above the north rim of the long Lago Maggiore, about 300 m above the level of the lake. Here it is the sucking effect of the heated Maggia valley and the Piano di Magadino (mouth of the river Ticino), which brings a stream of fresh air called Ora towards the southern observatory slope. The isothermal surface of the lake, horizontal over a distance of more than 50 km, contributes probably considerably to the laminar structure of this flow. Also at this station sharpness and steadiness of the solar image in general is improving in the course of the day. Deterioration sets in only shortly before sunset.

However, discussing all these positive effects of mountains we must not overlook that these sites are efficient only as long as the atmosphere above them is free of disturbing turbulence (*see* section 4) and also that a tower of 20 or 30 m height in a suitable wide plain if available might give even a better quality of images and more sunshine.

f. Influence of the sea and of lakes. — A similar pulsating wind system is formed across the coast of big lakes or of the sea, as a consequence of the difference of temperature between the surfaces of land and water. The sea breeze front as it develops during the day is in general only a few hundred metres wide, but extends very often to an altitude of more than 2 000 m. On islands like Capri, on days with feeble general wind, one can observe how the sea breeze is turning with the Sun's azimuth, especially during the middle of the day.

This air flow towards the coast seems optically to be quite " laminar ". Observations on the southern shore of Capri on an isolated rock (Marcellino) in the sea, about 50 m from the shore gave excellent images all over the day even in 2 m height above sea level. The air was always a few degrees warmer than the sea. It is obvious however that the installation of an observatory on such a rock presents many problems.

The situation becomes very favorable when the sea breeze and the general wind have the same direction. This happens at our Capri station in the summer. By means of a provisional tower of 14 m height, which was erected on the Damecuta, a small plateau about 150 m above the sea, we obviously reached already into this airflow. It was found that the image quality was excellent all over the day. There was practically no diurnal variation. During short intermission of the wind however the image quality immediately decreases and the striking difference between the image quality on top of the tower and on ground disappeared. Quite generally it is found in Capri, that winds coming from the open sea always bring the better images, except strong south wind (Scirocco), which is a very warm flow of air with violent turbulence.

Very promising results have been obtained this summer also in the Oasis Fayum in northern Egypt at the east coast of the Qarun lake (extension about 10×50 km). The observations are made at the end of a pier, leading about 300 m into the lake, close to the Auberge Fayum. In spite of the fact that the ground temperature around the lake rose to very high values, excellent images of the Sun were observed all over the day at only 2.50 m above the lake. The quality was definitely decreasing when the water temperature was higher than that of the air (early in the morning and in the later afternoon). The observations at this ideal site are beeing continued ([3]).

Also the good image quality obtained at the Roma Observatory (Monte Mario) all over the day (Rainone, Torelli, 1962) is probably caused by a very steady sea breeze (called ponente) which has to pass however the town of Roma before reaching the observatory. The solar tower (30 m height) is about 170 m above the town.

4. **The influence of large scale circulation.** — There can be no doubt, that also the large scale meteorologic situation has a definite influence on image quality. The observed effects are so predominant, that the synoptic meteorologic situation of a site might be more important than topographic or orographic factors. As it is well known, two different days with fair weather, same temperature of air and ground and same pressure can give completely different image qualities.

As a typical example for the situation in central Europe I will give here the outcome of an extensive seeing test carried out in Freiburg during a period of 17 months with 278 observing days. Among these 28 days with excellent images, 28 with very poor image quality (with special reference to the sharpness) have been selected and the associated meteorologic conditions studied. As we know from our colleagues elsewhere, the Freiburg results apply to many other observatories in moderate latitudes with their unstable and variable weather :

Throughout the best image qualities are observed during the invasion of maritime warm air from South-West or from West, unimportant wether this air flow is part of a cyclonic or an anticyclonic system. The improving effect of the body of warm air will be efficient down to very small altitudes above the ground, destroying the superadiabatic convective layer. It will also strongly reduce the upslope-winds in the mountains, thus improving the image quality strikingly even on a mountain peak close to the ground.

([3]) The observations are made in cooperation of Helwan Observatory and Fraunhofer Institute. I would like to express also here my best thanks to Dr. A. H. Samaha, Director of the Helwan Observatory, for his interest and efficient help.

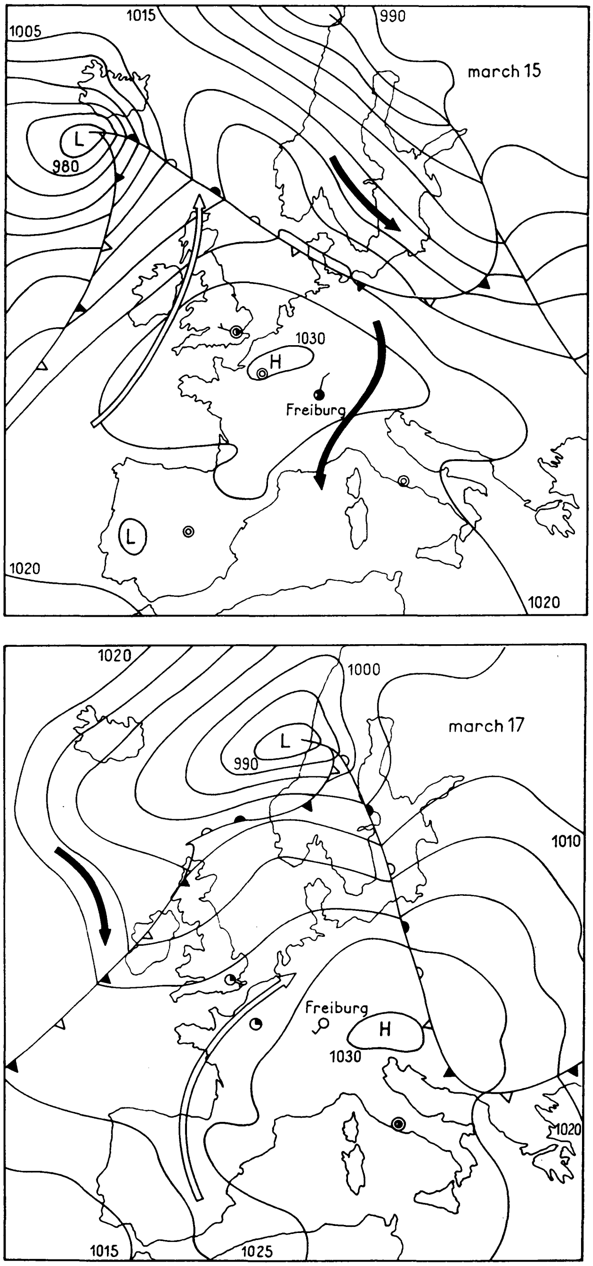

Fig. 57. — Meteorological charts of Europe of March 15, 1961
(very poor image quality in Freiburg) and March 17, 1961 (excellent image quality)

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The passage of cold air from the North or North-East on the contrary is always connected with a strong deterioration of the image. The same is true for the mistral in France and the tramontana in southern Italy. A typical example is represented in the two weather maps of figure 57. While on March 15th Freiburg lays within a cold stream of air, which brings very bad images, two days later on March 17th a stream of warm air from the South-West is passing over the observatory producing excellent images. In this case the eastward motion of the high pressure nucleus is responsible for the observed improvement of image quality.

A strong wind from the South — this means for Freiburg in the lee of the Alps a Föhn type wind — also brings poor image quality, but at the same time high transparency and low scattered light is observed.

From a meteorologic point of view these results are quite evident. Cold bodies of air have in general an unstable vertical distribution of temperature, which by the slightest orographic or thermal disturbance can be turned upside down up to the upper boundary of the troposphere. The degree of stability or the tendency of the troposphere to become turbulent can be got hold of best by the vertical temperature gradient between 850 and 350 mb (1.5 to 9.0 km altitude), which in cold air amounts to about 1°C per 100 m, while in warm air being much smaller and therefore more hindering upward convection and consequently the growing of turbulence.

The good optical properties of a body of warm air can be also observed on a mountain peak, and there even close to the ground. Obviously the disturbing upslope winds cannot develop on such days. This fact is well known to the glider pilots, which avoid flying in the warm front area.

In order to find and ideal place for a solar observatory one should look therefore for sites which show as much as possible all over the year a cloudless sky with the smallest vertical gradients of temperature. The latter especially applies to stable high pressure situations, but only to the dynamical type, in which the same body of air extends from the ground to the stratosphere. This situation occurs in central Europe only two or three times per year for rather short periodes. Usually these dynamical highs are domiciled in the horse latitudes, that is in the subtropical high pressure belt, which during the summer occasionally leaks over the Alps.

From our summer-experiences obtained in Capri (40° North) we must conclude that the large scale flow of air from the West is already quite laminar there. The observations carried out from a free standing tower of 14 m height (160 m a. s. l.) did not show hardly any diurnal variation of image quality, as long as the wind was strong enough. No systematic experiences of day time seeing are available yet for the central part of the horse latitudes.

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5. **Influence of stratospheric jet-streams.** — Unfortunately the subtropical belt of high pressure with its beautiful climate coincides more or less with the subtropical jet-stream. It seems even that the two phenomena are causal related. We known from aerologic measurements and still better from airplane results, that the jet-streams can become an efficient source of the socalled clear air turbulence (Reiter, 1960).

How much the jet-streams affect the image quality if the line of sight passes the stream is not quite clear yet. The relations between brightness, scintillation of stars and windspeeds in different altitudes between 5 and 12 km found by Mikesell (1960) favour such an effect. It still has to be shown whether steadiness and sharpness of the solar image also are affected. Some observations at our Capri station on the northern boundary of the subtropical jet-stream indicate that its effect on the image quality cannot be very striking. This agrees with the general belief, that the subtropical jet is much more stable and shows less turbulence than the polar jets.

The best suited region in Europe to study the subtropical jet-stream's influence on image quality seems to be southern Spain, e.g. San Fernando on the west coast and Cartagena on the east coast. The two places show very little cloudiness all over the year. Aerologic data would be available from the near Gibraltar.

6. **On the meteorology of atmospheric scattered light.** — Looking for a solar observatory site, the intensity of scattered light is generally not taken into account too much, except when projecting a coronal station. If the amount of available sunshine and the quality of images is satisfying, the scattered light is being accepted as an indispensable evil. In many cases this attitude is sensible, especially when a coelostat or a reflector is in use, which gives in general at least ten times as much scattered light as a refractor.

Unfortunately, days with high transparency and low scattered light, as for instance during and after an invasion of cold air, bring very unsteady images — on the other hand a stable high pressure situation as well as the arrival of warm air bring always more scattered light, but steady and sharp images. Also Föhn cleans up the atmosphere down to the deepest layers, but the image quality is very poor. Long lasting periods of small scattered light can be achieved only on mountain observatories and have to be payed by a certain loss of hours with steady and sharp images.

To observe the inner corona in monochromatic or in integrated light, the sky brightness in a distance of about 30″ to 40″ from the Sun's limb has to be below 250×10^{-6} of that of the Sun's disk. For the outer parts of the corona, it should be even below 10×10^{-6}. A sky brightness of this order is reached in central Europe in rather modest altitudes, as the coronal observing stations of Wendelstein (1840 m), Arosa Tschuggen (2 050 m) and Pic du Midi (2 861 m) have proved.

In Arosa during the period 1940-1948, 54 % of all observing days permitted coronal work (in the average 2.48 h per day), Wendelstein (1947-1951) resp. 40 % of the days (Waldmeier, 1949). With higher demands on scattered light this fraction will decrease very rapidly.

The three coronal stations in Europe do not give a gapless observation, because their climates are not independant of each other. Including U. S.-, U. S. S. R.- and japanese stations, practically there is left no day without observation. Sudden coronal events however, lasting only a few hours or less, still easily can escape observation.

Some meteorologic rules for the scattered light might be mentioned here (Waldmeier, 1949):

1. The sources of fair weather atmospheric scattered light are located mostly within the convective layer (subcloud regime), which extends to much greater altitudes in summer than in winter, in southern latitudes more than in polar regions. Mountain stations therefore will be better in winter than in summer. For the same reason the diurnal variation of scattered light will be stronger in summer than in winter. With decreasing latitude the altitude needed to reach a certain value of scattered light will increase. At Pulkovo (60° North) coronal observations have even been obtained at sea level.

2. Maritime bodies of air show less scattered light than continental ones. The latter can scatter so strongly, that even with unclouded sky coronal observation cannot be made.

3. Very strong decreases of scattered light occur during the passage of a cold front.

Coronal observatories of higher altitudes would still give less scattered light and possibly also more coronal observing days per year. But it has to be kept in mind also, that the living and working conditions — at least in our latitudes — become extremely difficult in greater altitudes. The running expenses will also increase in no reasonable proportion to the astronomical gain. Things might be a little different in other latitudes and continents.

As mentioned already the probability is quite small to detect an ideal site for an allpurpose observatory, which includes coronal work and which will supply a large number of hours with a high image resolution. There is some hope however to find such a site on high plains as they occur in South-America. For this reason it seems to me a very important task to study the nature of the daytime superadiabatic ground layer (*see* § 3 *b*) at high altitudes (> 3 000 m) as well as the sky brightness over such high plains.

7. **Conclusions**. — The most conspicuous difference between night and day condition — as far as the optical effects of the Earth' atmosphere are concerned — is the formation of a thin superadiabatic layer of forced convection, which reaches in the plain only a few meters above the ground and which optically is very efficient. In the mountains a system of upwinds develops shortly after sunrise, which produces disturbing optical effects on a mountain peak observatory and probably also at heights well above the peak.

If an especially small intensity of scattered light is not needed, but a large number of hours wanted with steady and sharp solar images, the plain is to be prefered to the mountain site, which is doubtless the better one at night and possibly in the early morning. This is true only as long as the ground convection is kept away from the line of sight. This can be accomplished by mounting the instrument at least 20 m above ground. But also — according to the geographic situation — mountain slope winds, valley winds and the sea breeze can be utilized to eliminate the influence of the ground-convection. The tower method will become less efficient if there is no wind, while the mountain wind system will not stop as long as the Sun is shining.

With these precautions taken the number of hours with good image quality will then depend only on the number of sunshine hours available and on the general meteorological situation. While in central Europe with its rapid succession of cyclons and anticyclons only rather a small fraction of the sunny hours (mostly during the passage of warm air) will supply images of excellent or good quality, in southern Europe within the subtropical high pressure belt this fraction will increase distinctly. This is probably true also for the horse latitudes all around the globe.

The probability to find a good site for an allpurpose observatory is small. A small and isolated mountain on a high altitude plain with a large extension might supply the only site which combines at day time an atmosphere of high transparency and low scattered light with freedom of optical turbulence in a manageable distance above ground.

The following three investigations seem to me of crucial value for further progress in finding ideal solar sites :

1. The study of the optical efficiency of atmospheric turbulence above mountains, by using high towers or balloons.

2. The study of the ground convection and the sky brightness above high plains, altitude $>$ 3 000 m.

3. The systematic study of distorsion in the Sun's image on days with very good image quality.

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