THE EFFECT OF ATMOSPHERIC ANOMALIES ON GEODETIC MEASUREMENTS

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In scientific and practical surveying the strive to a greater accuracy stresses the study of the atmosphere. In our century, especially in the recent decades, surveying instrumentation and measuring methods underwent a great development. Theoretical and technical conditions of a greater accuracy are given but our knowledge of the atmosphere has been based on more or less realistic assumptions. The change of atmospheric parameters alters the refraction coefficient of the atmosphere and the visibility, and the change of both factors greatly affects surveying measurements.

Relation between lapse rate and refraction coefficient

From the characteristic of atmosphere causing refraction in the range of visible light, the change of temperature described by lapse rate is the most important one.

In meteorology, lapse rate is understood as the change of temperature along the height. Strictly speaking, the temperature to height difference ratio $\Delta t/\Delta z$ gives only an approximation of the first derivative of temperature vs. height dt/dz. Neglecting the difference between the two ratios does not affect the accuracy required for our measurements.

In international practice the vertical lapse rate is expressed in °C/100 m.

Lapse rate involves some characteristic values of importance for surveying, the most important one being adiabatic lapse rate (without heat exchange):

$$\gamma_{\mathrm{ad}} = -0{,}974\ {}^\circ\mathrm{C}/100\ \mathrm{m}. \tag{1}$$

In practice, the adiabatic lapse rate is taken as -1 °C/100 m. The actual value of lapse rate determines the stability conditions of the atmosphere:

a) $\gamma = \gamma_{\mathrm{ad}}$: indifferent

b) $\gamma > \gamma_{\mathrm{ad}}$: stable

c) $\gamma < \gamma_{\mathrm{ad}}$: unstable.

The sign of lapse rate — in conformity with the marking in surveying — is understood as follows:

if the temperature decreases as a function of height, the sign is negative;

if the temperature increases as a function of height, the sign is positive.

Negative lapse rate is expected on hot days where unstable stratification develops due to the intensive radiation on the surface.

Positive lapse rate is expected during the night — from one or two hours before sunset to one or two hours after dawn — when the stratification of the atmosphere is stable.

Nearly all the year round, the sign of the lapse rate changes twice a day and so do the stability conditions of the atmosphere.

A straight sighting line results from a uniform density of the air ($k = 0$) considered optically homogeneous.

This condition is, however, pertinent—rather than to zero lapse rate —to the case where the effect of decrease of temperature is compensated by depression i. e. at a gradient $\gamma = -3{,}42$ °C/100 m. Exceeding this value in the negative sense the refraction coefficient will have a negative sign and the curve of refraction will be *concave from above.*

From the point of view of surveying measurements the lapse rate of $\gamma = -1{,}7$ °C/100 m is of importance where the sighting line has a constant radius of curvature resulting in a *circular arch.*

For $\gamma = -1{,}4$ °C/100 m the curvature of the sighting line is a *linear function of height.*

In case of isothermy in the morning and afternoon hours when $\gamma = 0$ °C/100 m the density of air vs. height decreases with pressure so the refraction coefficient is positive and the refraction curve is *convex from above.*

Exceeding the adiabatic gradient in the negative sense an unstable air stratum develops near the ground. The period of the development of this layer and the astronomically possible sunshine duration are strictly correlated. The most important factors determining sunshine duration are, besides the astronomical factor of the lengths of daily arch, the relief and the meteorological factor of cloud cover. In summer the development of the unstable layer lasts nearly 12 hours, 80 per cent of the astronomically possible sunshine duration, and the depth of the layer is more than 20 m in the case of 10 hours. In winter the layer generally less than 10 m deep develops in 4 to 5 hours, 60 per cent of the possible sunshine duration. The yearly and daily variations of the lapse rate near the ground and of the depth of the unstable lower air layer are shown in Figs 1 and 2, respectively.

The unstable lower layer starts to develop — as a yearly average — from 1 ½ to 1 ¾ hours after dawn, and 10 minutes more are required for the depth of 2 m — of importance for levelling — to develop. Subsequently, the depth is rather fast to grow, in summer the depth is about stabilized

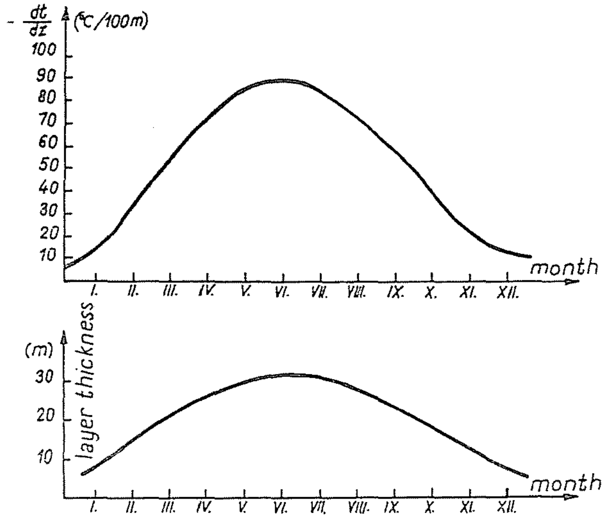

Fig. 1

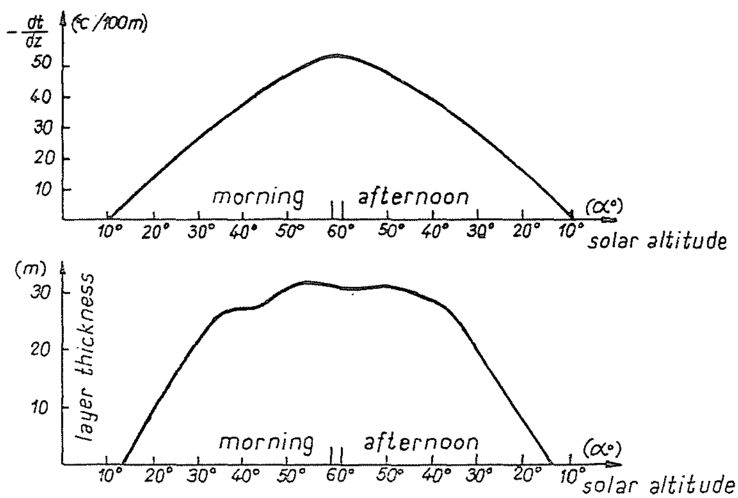

Fig. 2

around 10 o'clock while the negative gradient increases to maximum around noon or a bit later. After a peak the lapse rate immediately begins to decrease while the depth of the layer only some hours later. Before sunset isothermy develops above the ground due to the prevalence of ground radiation when the unstable layer is still more than 2 m deep with a strong tendency to decrease. If energy supply is off the depth of the layer drops then disappears. The 2,5 to 30 cm layer above the ground exhibits a yearly average gradient of $+140\,°C/100$ m at sunset corresponding to a refraction coefficient $k = +6{,}66$.

The range of the negative refraction coefficient and the concave from above refraction curve extends to mid-height of the unstable layer, then it becomes asymptotic when the effect of cooling is compensated by depression. After this, the refraction curve becomes a line then convex from above passing through an inflection point (Fig. 3) characterized by the positive refraction coefficient.

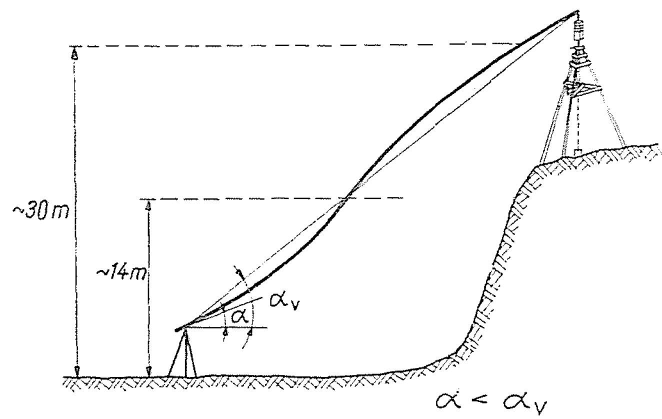

Fig. 3

The examination of the lapse rate above the unstable layer is needed for the determination of refraction coefficients in trigonometrical height measurement. Part of this layer has a less than adiabatic gradient while the whole layer has an adiabatic lapse rate of expansion. The adiabatic upper layer develops only with the stagnation of the unstable lower one. At this stage the greater the convection with the upper layer, the deeper is the adiabatic upper layer, and the more the lower part of the upper layer tends to have a less than adiabatic gradient. In Hungary the adiabatic upper layer extends to 200 m as an average at noon, in early spring and autumn to 150 m. The less than adiabatic lapse rates range from $-1{,}0$ to $-1{,}2\,°C/100$ m causing a refraction coefficient of $k = +0{,}107$; that in the adiabatic upper layer from $-0{,}8$ to $-1{,}1\,°C/100$ m with a refraction coefficient $k = +0{,}114$.

The refraction coefficient can be determined from the lapse rate by means of the Brocks formula with the required accuracy:

$$k = 5{,}03\,\frac{p}{T^2}\,(3{,}42 - \gamma)\,. \tag{2}$$

In the factor 5,03 the radius of the Earth (in hectometers) and the normal value of refractive index of the air referred to the D-line of sodium are expressed; p is pressure in Torr; T is temperature in °K, $T = 273° + t$ °C; $\gamma = -dt/dz$ the vertical lapse rate (with negative sign) in °C/100 m.

The mean values of refraction coefficients delivered from average lapse rates by the BROCKS formula have been compiled in Tables I and II. Table I is compiled from several years' measurements in Hungary (Erdőhát), Table II of measurements on the German plain.

Table I

June	Height range (cm)	Mean from all days	Mean from bright days	Mean from dull days
7^h	10— 50	—3,42	— 4,75	—1,76
	50—100	—0,65	— 1,87	—0,54
	100—200	—0,28	— 0,88	—0,16
10^h	10— 50	—5,36	— 8,75	—4,53
	50—100	—1,90	— 2,48	—1,02
	100—200	—1,14	— 1,36	—0,54
11^h	10— 50	—8,24	—10,92	—4,61
	50—100	—1,99	— 3,00	—1,40
	100—200	—1,13	— 1,51	—0,74
12^h	10— 50	—7,80	—11,47	—3,68
	50—100	—2,56	— 3,17	—1,41
	100—200	—1,41	— 1,94	—0,93

Table II

Height	6^h	12^h
0 — 1,2 m	$k = +0,70$	$k = -1,30$
1,2— 20 m	+0,33	—0,18
20 —100 m	+0,24	+0,15
100 —200 m	+0,22	+0,16
200 —500 m	+0,21	+0,16
1,5—250 m (mean value)	+0,25	+0,14

The effect of visibility on surveying measurements

Visibility determines both range and accuracy of traditional surveying — mainly horizontal and vertical angular measurements — and greatly affects max. range of electro-optical distance measurements.

Before examining the question, let us set out the concept of visibility.

Meteorological visibility is the greatest horizontal distance — by day — from where a suitably big black object or target of definite characteristics on the horizon can be seen and identified.

Optical visibility means the greatest distance from where a given object is seen and perceived true to geometry under given illumination and atmospheric conditions.

Geometrical visibility is the greatest distance for a light beam from an object to reach the observer without extinction.

In theoretically determining the visibility, KOSCHMIEDER assumed the black object viewed against a sky of given brightness to emit no radiation, the atmosphere to be homogeneous — along the sighting line —, illumination being by sunshine, and sky brightness to be uniform.

He found the following relationship for the relative contrast value:

$$K_R = K_0 e^{-\sigma_0 s} \tag{3}$$

where K_0 = absolute contrast value; σ_0 = dispersion coefficient of air; and s = the sensing distance.

Visibility can be expressed from Eq. (3) by substituting the contrast treshold for the human eye $K_R = \varepsilon$ for the relative contrast value. Taking the generally agreed 2% as the contrast threshold sensitivity of the relaxed eye, and solving the equation for visibility s:

$$s = 3{,}912 \cdot \frac{1}{\sigma_0} . \tag{4}$$

The dispersion coefficient σ expresses the fading of light while passing the tested layer.

In geodesy, slant range of visibility is needed. DUNTLEY defined slant range as equivalent in a homogeneous atmosphere to the horizontal distance where the dispersion coefficient σ equals the real dispersion coefficient over the real (slant) distance d.

About half a million laboratory tests were done by BLACKWELL in order to define the value of contrast limit. Envelope curves for round objects of various sizes observed against different background lights are seen in Fig. 4. Straight sections of the diagrams correspond to constant surface area by illumination products. In these ranges the sign can be taken as a point light source. Subsequently, Blackwell found the laboratory test results to be valid also in field conditions.

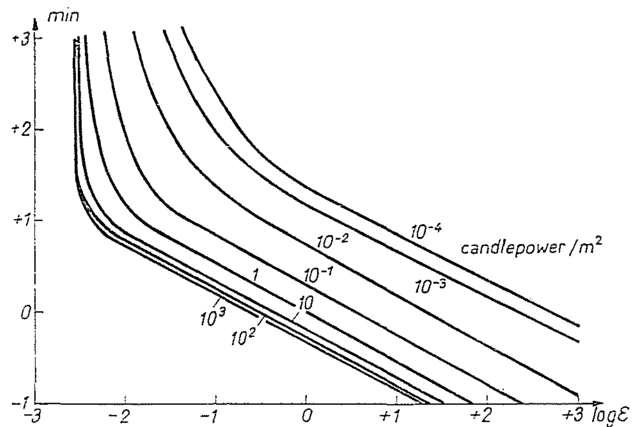

Fig. 4

For surveying measurements, the similarity of observations through a telescope is of interest, taking reduction of contrast by the optical system into consideration. In field conditions, determinations are also affected by finding and recognizing dot marks as a function of visibility and other psychological factors.

According to BRICHAMBAUT, the contrast threshold may range from $\varepsilon = 0{,}02$ for an experienced observer, to

$\varepsilon = 0{,}06$ under poor visibility conditions,
$\varepsilon = 0{,}03$ being a generally agreed mean value.

As to the contrast threshold, however, it should be noted that in surveying measurements it depends on the actual physiological condition of the observer, hence a visibility range determined from contrast threshold averages is only a representative value. Besides, the contrast threshold value of the eye depends on whether an adaptation condition to darkness or to brightness is considered, the transition between both being about 2×10^{-3} m^{-2} of candlepower. Remind the restriction of colour sensing to brightness adaptation condition.

The dispersion coefficient depends on the atmospheric concentration of absorbed gas molecules such as colloids and aerosols. These are likely to weaken the light arriving from the atmosphere:

- either by diffusion on the particles if their ratio is less than or equal to the light wavelength, or
- by reflection on particles of radii longer that the light wavelength.

Timely and spatial distribution of a visibility range less than 1000 m are decisively affected by the wind, the atmospheric pollution, temperature distribution (vertical and horizontal lapse rate) and atmospheric humidity.

A slight wind may contribute to the development of flow — advection — mists. On the other hand, wind speeds over 8 m/sec are likely to dissipate fog.

In no-wind conditions, air pollution — due primarily to conventional energy carriers — is rather high. The free energy of vapour depends on the relative atmospheric humidity.

This free energy defines the interaction between moisture, hygroscopical, soluble and insoluble particles. Smoke particles form condensation nuclei, increasing the stability of fog drops. Cities are prone to quickly develop lasting fogs with less than 100 m visibility. Examinations done in different regions and seasons have shown that visibility values at meteorological stations near cities allow to conclude on long-term air pollution trends, of high value for environmental protection, too.

Until recently, visibility has been assessed visually and this is still the case in some weather-stations. The difficulties and inaccuracy of visual determination made it imperative to develop automatic measuring instruments and recorders. The instruments used nowadays are of two types:

1) Transmittance meters for the optical penetrability of air. These are fit for continuous indication of visibility.
2) Instruments measuring the dispersion coefficient i. e. the losses of the beam after passing the atmosphere.

With modern electro-optical distance measuring instruments the most important requirement is to get good vision between the instrument and the reflecting surface. Knowledge of the interaction between the range of the instrument, the visibility, and of the expected meteorological visibility are decisive in planning and achieving the measurement program.

The following graph due to Richter presents range values vs. visibility. Accordingly, the range is about one-third, and one-fifth of the visibility up to 3 km, and 7 km, respectively. The decrease of visibility affects both accuracy and economy, depending in turn on the selection of measuring times. To improve the efficiency of electro-optical telemeters in greater surveying programs, it is advisable to determine the exact light loss value by means of an instrument for determining the dispersion coefficient. This permits exacter planning of the range of electro-optical telemeters and of measurement accuracy.

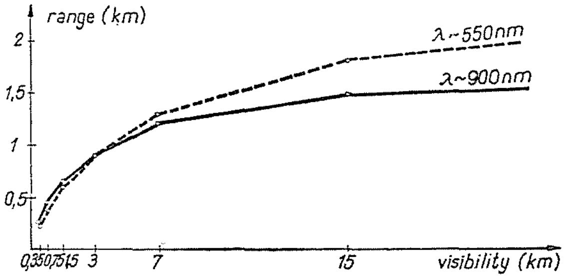

Fig. 5

Summary

Rather than to consider refraction a problem of geometry alone, physical-meteorological research leads to an ever more accurate determination of the refraction coefficient by way of a comprehensive study of the physical components of atmosphere.

Measurements are mostly done in unstable lower layers developing in daytime, hence from geodesy aspects, knowledge of the expected layer thickness and of its short-time and long-time variation are of importance. The mean lapse rate yields the refraction coefficient; tables show atmospheric anomalies to result in abnormal (irregular) coefficients.

Visibility affects surveying measurements, its decrease restricts accuracy and efficiency of conventional surveying.

Development and utilization of up-to-date electro-optical telemeters urges to a better knowledge of the range of visibility. Namely, a reduced visibility much shortens the telemeter range and hampers or even inhibits the surveying program.

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