ON LOOMING DURING ALPINE FOEHN

(Research Note)

KLAUS P. HOINKA

DLR, Institute for Atmospheric Physics, D-8031 Oberpfaffenhofen, Germany

(Received in final form 22 May, 1991)

Abstract. The note deals with looming during foehn north of the Alps. The results show that there is a weak effect in stretching optically the orography. However, the increase in view angle is probably not detectable by human observers looking south from Munich towards the Alps. The impression that the orography seems to be stretched during a foehn is also due to psychological effects which might be a factor of greater importance.

1. Introduction

It is claimed by weather observers north of the Alps that during a foehn the Alps appear to be stretched to considerably greater than normal heights. This stretching may be due to a looming which is a mirage effect produced by greater than normal refraction in the lower atmosphere (Huschke, 1959). Greater than normal refraction occurs as soon as the air density decreases more rapidly with height than usual and this is generally the case during a foehn when a shallow surface layer of cold air is surmounted by warmer air advected by the foehn (Figure 1). Similar features are reported for regions just to the east of the Rocky Mountains preceding the chinook (Glenn, 1961). Events with strong looming leading to a superior mirage occur (Wegener, 1926) but these are exceptional.

In most cases of an Alpine foehn, there is a shallow layer of cold air located to the north of the Alps over which the foehn glides up (Hoinka and Rösler, 1987). Close to the mountains, the foehn erodes the underlying cold air and reaches the ground whereas at a distance of 80 km near Munich, the foehn is unable to replace the cold surface air. Thus the foehn is not observed at that distance from the Alps. Vertical temperature differences of up to 15 K have been observed over 100 m across the inversion between the surface-based cold air and the foehn air (Nater *et al.*, 1979). A very strong change was observed during a chinook event in South Dakota (USA) with horizontal differences of up to 27 K (Hamann, 1943). These horizontal differences were measured at the beginning and the end of foehn pauses, and indicate the upper limit of the vertical temperature differences between both layers.

The refraction depends on stratification; it is modified strongly as soon as the vertical stratification deviates from the conditions described by the standard atmosphere, leading to large errors in the determination of exact heights. However, there are a number of geophysical problems where the exact determination of heights is of importance. For these purposes, the so-called "geometric nivelle-

Boundary-Layer Meteorology **57**: 289–294, 1991.

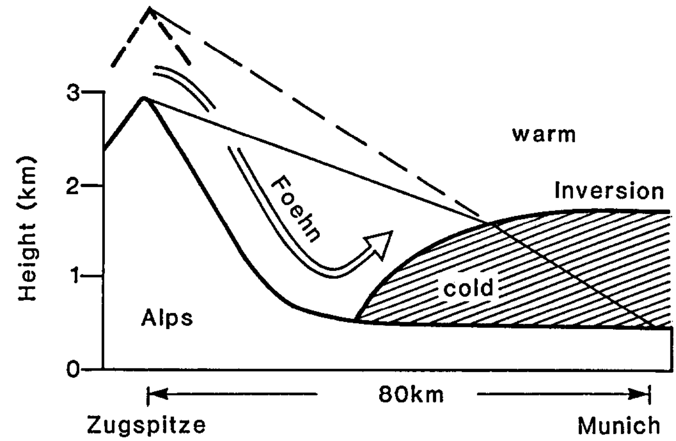

Fig. 1. Diagram showing the distortion of a light ray due to refraction at an inversion during a foehn downwind of the Alps.

ment" is applied, which is characterized by using very short horizontal distances between 30 and 50 m where the variation of the refractive index is negligible. However, in difficult terrain this method cannot be applied and the less exact method of trigonometric height measurement must be used (Brocks, 1950). Due to strong variances in the refractive indices along a light path, this less expensive method might result in less exact heights; the present accuracy is of the order of 10 cm, which is valid for horizontal distances of the order of 2 km. For geodetic measurements, the refraction is considered to be characterized by a refraction coefficient of 0.13. However, during extreme conditions, like the foehn, measurements are not performed because the strong stratification generates unacceptable inaccuracies.

The looming during a foehn or chinook has been known qualitatively for a long time (Perntner and Exner, 1922); however, a quantitative estimation has not yet been made. In this note, the looming during a foehn associated with an observed stratification is examined, in order to determine if the effect is visible.

2. Method

In our calculations, we consider the geographical situation north of the Alps where the summit of the Zugspitz mountain (≈3000 m) is seen by an observer at a distance of 80 km in Munich (altitude ≈500 m). This peak is selected because of its prominent shape in the northern Alps. At this distance, the footline of the Alps is about 500 m below the geographical horizon due to the curvature of the earth. This value is reduced, however, according to the refraction due to the vertical stratification in the troposphere. For simplicity, it is assumed in the following calculations that the earth has no curvature, which is reasonable in the present case because the results do not depend on this factor. Secondly, we consider only

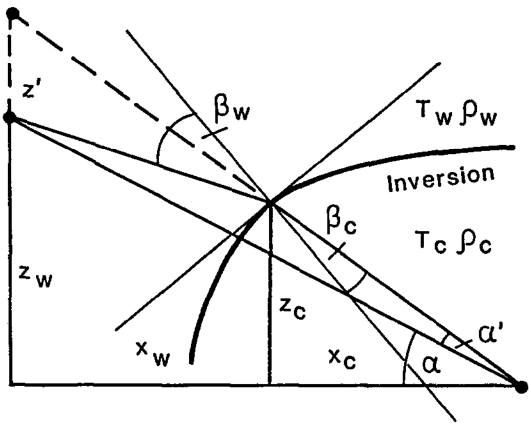

Fig. 2. Schematic diagram of the refraction at an inversion.

the deviation in refraction associated with the foehn, so that only the deviation in the refraction that would occur in a standard atmosphere is considered. Finally we assume that the surface-based cold air and the overlying warm foehn air are both isothermal. Thus the entire refraction occurs at the boundary between air masses and this is assumed to result in the same looming of the Alps as that obtained with a gradually decreasing temperature within both layers.

Figure 2 shows the situation schematically. The straight line between the observer to the right and the peak to the left indicates the geometric path of a light ray between the observer and the object. In the real atmosphere, this light path would be a curved line due to refraction. The indices 'w' and 'c' define parameters in the warm and cold air, respectively. The temperature difference $T_w - T_c$ between the two air masses is defined by ΔT. For an observer at a distance of $(x_w + x_c)$, the obstacle of real height z_w appears to be stretched in the vertical by z'. The parameter x_w indicates at what distance from the obstacle the refraction occurs and in turn indicates the extension of the cold pool towards the orography. The value x_c then gives approximately the total extension of the cold air from the location of the observer towards the mountains. The thickness of the cold layer at the point where the refraction occurs is denoted by z_c. The distance between the observer and the point on the inversion where the light ray leaves the cold air increases with increasing thickness of the cold layer: $x_c \approx 15$ km ($z_c = 500$ m), ≈ 30 km (1000 m) and ≈ 45 km (1500 m). The observer sees the peak at an angle of α, which is increased by α' due to refraction.

In a first approach, the optical deviation z' is calculated assuming that it depends on $(x_c + x_w)$, z_w, z_c and the difference angle $\beta_w - \beta_c$. This is done using simple trigonometrical relations derived from Figure 2. With this approach, however, it is only possible to obtain the difference of both angles. In order to evaluate the angles themselves, we use a different approach, making use of the refraction coefficient n_i of air with density ρ_i (against a vacuum), which is evaluated by

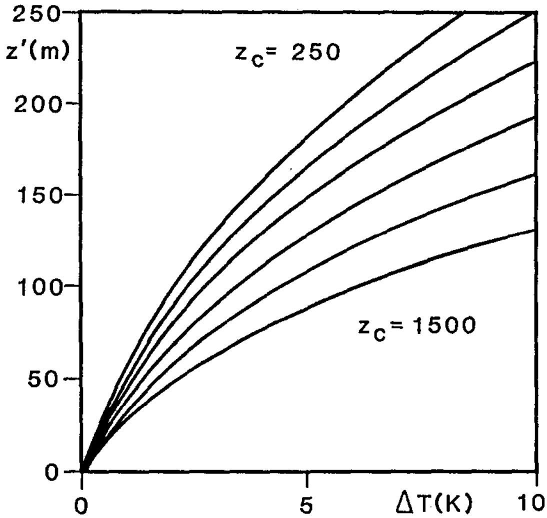

Fig. 3. The optical deviation z' as a function of the temperature difference ΔT between warm and cold air and as a function of the thickness of the surface-based cold air.

$$n_i = 1 + (n_0 - 1) \cdot \frac{\rho_i}{\rho_0}, \tag{1}$$

where n_0 is the refraction coefficient of air with density $\rho_0 = 1.293\,\mathrm{kg\,m^{-3}}$. The refraction law of Snellius is given by

$$n_w \cdot \sin \beta_w = n_c \cdot \sin \beta_c, \tag{2}$$

where n_w and n_c are the refraction coefficients of the warm and the cold air against a vacuum, respectively. Applying this, the ratio of the refraction angles β_w/β_c is determined from ΔT; in turn, the corresponding value of z' is obtained.

3. Results

In Figure 3 the deviation z' due to refraction is given depending on the ΔT and on the thickness of the cold layer z_c. It is obvious that only with strong temperature differences is significant looming observable. With a foehn at the northern rim of the Alps, the observed difference ΔT between the cold and warm air is as much as 10 K in extreme cases (Hoinka and Rößler, 1987), whilst the thickness of the surface-based cold air is observed to be around 500 m. With these values, an optical deviation of 250 m is obtained. However, a temperature difference of 10 K is a very large value. Using a more frequent value of around 5 K, the optical surmount becomes 150 m, which corresponds to an increase of the angle of $\alpha' = 3'13''$ at which the Zugspitz mountain is seen from Munich.

In order to obtain the results shown in Figure 3, it was assumed that the upper surface limiting the cold air is horizontal or inclined towards the south. It is known that at the interface between the cold and the warm air, Kelvin-Helmholtz waves may occur, generated by the shear across the interface. Thus it may happen that the interface inclines towards the north. In this case, the refraction is a maximum as soon as the light ray leaving the cold air is directed about parallel to the interface. This maximum value of the refraction angle is evaluated by Equation (2) where sin β_w equals one. With a ΔT of 5 K, the angle $(90 - \beta_c)$ is about 10′ and for a ΔT of 10 K this angle increases to about 14′.

The value of the optical surmount due to this maximum refraction experienced by the observer depends on the location where the refraction occurs, with respect to the object – the Zugspitz mountain – and the observer at Munich. There is no surmount if the refraction occurs close to the object and the maximum value is obtained for a refraction occurring close to the observer. In the latter case, the maximum surmount is about 215 m for a ΔT of 5 K and about 315 m for a ΔT of 10 K.

4. Discussion

The anatomic limit of the chromatic resolution power of the human eye depends on the diameter of a single cone in the eye which is about 1.5 mμ (Schober, 1954). This diameter allows resolution of two distinct points at a visible angle greater than 20″. However, Schober claims that during normal (less optimal) conditions, the differentiation between two points is seldom smaller than 90″. This allows us easily to see, for instance, the moon with an optical angle of about 30′ and even parts of the moon during its cycle. From the above mentioned limit, it should be possible to recognize the above obtained optical surmount ($\alpha' = 3'13''$). However, because the above derived value for looming during a foehn is only a surmount value of weak magnitude, it cannot explain the subjective experience of observing a significant optical surmount of the Alps during a foehn.

Of great importance is that during a foehn, very dry clean air is located in the lower troposphere north of the Alps so that the Alpine massive is seen more clearly than usual on the southern horizon from Munich. Also during synoptic situations with westerly flows, very clean air advected from the Atlantic Ocean allows a similar good view towards the Alps. Usually the Alps cannot be seen from Munich, which means that we have no ‘standard’ magnitude or optical measure corresponding to atmospheric conditions without any additional refraction due to a foehn. Thus weak variations in the observed magnitude of the Zugspitz mountain during various foehn situations are not perceptible. Only if there are significantly strong inversions of more than 10 K, might it be possible to distinguish between cases.

It should be mentioned that a psychological effect also exists in perceiving the optical environment. Usually the Alps cannot be seen from Munich. During a foehn or in westerly flow situations, the Alps are clearly visible from a considerable distance to the north. Because we are used to associating the distance between us and an object with its magnitude, it seems reasonable to assume that the normally 'invisible' Alps are far away whereas the 'visible' Alps during a foehn are close to the observer. Additionally the extension and the relative scale of strongly structured parts of an object are overestimated whereas weakly structured parts of the object are underestimated (Schober, 1954).

All the above mentioned effects are further fortified due to the contrast intensification which occurs during a foehn where the Alps are illuminated from their southern side by the sun. Observers report that in the morning and in the late afternoon, the Alps seem to be higher than at noon of the same day with a foehn; this might be due to the fact that in the first case, the sun illuminates the Alps from the side – from the southeast in the morning and from the southwest in the late afternoon – which leads to a stronger contrast than at noon where the sun illuminates the barrier directly from the south.*

Acknowledgements

Dr. Gerhard Ruppersberg (DLR) and Prof. Heinrich Quenzel (University of Munich) are thanked for their comments on an earlier version of the manuscript. Thanks also go to Dr. Andrew Robertson (University of Munich) for improving the readability of the manuscript.

References

Brocks, K.: 1950, 'Meteorologische Hilfsmittel für die geodätische Höhenmessung', *Zeitschr. f. Vermessungswesen*, Jahrgang 1950, Heft 3–5, 1–19.

Glenn, Ch. L.: 1961, 'The Chinook', *Weatherwise* **14**, 175–182.

Hamann, R. R.: 1943, 'The Remarkable Temperature Fluctuations in the Black Hills region, January 1943', *Mon. Wea. Rev.* **71**, 29–32.

Hoinka, K. P. and F. Rösler: 1987, 'The Surface Layer on the Leeside of the Alps during Foehn', *Meteorol. Atmos. Phys.* **37**, 245–258.

Huschke, R. E.: 1959, *Glossary of Meteorology*, American Meteorological Society, Boston, pp. 638.

Nater, W., Richner, H. and P. D. Philips: 1979, 'Shear Instabilities and their Characteristics during Foehn', *Geophys. Astrophys. Fluid Dynamics* **13**, 215–223.

Pertner, J. M. und F. M. Exner: 1922, *Meteorologische Optik*, Wien und Leipzig, Universitätsbuchhandlung, pp. 907.

Schober, H.: 1954, *Das Sehen*, Band I und II, VEB Fachbuchverlag Leipzig.

Wegener, A.: 1926, 'Photographien von Luftspiegelungen an der Alpenkette', *Meteorologische Zeitschrift* 1926, 207–209.

* A reviewer mentioned that a mountain (or anything else) which appears closer than it really is, also appears smaller.