H.-B. de Saussure: The First Mountain Meteorologist

R. G. Barry
Institute of Arctic and Alpine Research
and Department of Geography
University of Colorado
Boulder, Colo. 80309

Abstract

The investigations of de Saussure on altitudinal effects on meteorological elements in the Alps during the 1780s are discussed. His ideas on the cause of cold in mountains and his attempts to determine evaporation and atmospheric transparency are especially notable and little known in comparison with the recognition of his contributions to developments in hygrometry.

1. Introduction

The name of Horace-Bénédict de Saussure is already widely recognized in the annals of meteorology because of his development in 1781 of the hair hygrograph (Middleton, 1969). In contrast, his extensive research on the physical environment of mountains is little known. Mill (1920) credited him with establishing the first (temporary) mountain meteorological station, but in a brief outline of de Saussure's observations, he did not make reference to some significant contributions. In view of our still limited knowledge of mountain climates, it is worthwhile "rediscovering" the work he was attempting to pursue 200 years ago.

De Saussure was born in 1740 in Geneva, where he lived until his death in 1799. Following his appointment as Professor of Philosophy in the Geneva Academy at the age of 22, he carried out research in physics and geology (Freshfield, 1920). Like his compatriot J. A. Deluc, another 18th century meteorological theorist, de Saussure was a keen mountaineer. After several attempts, he became the second person to climb Mt. Blanc in August 1787, and following from this mountaineering activity, he developed a strong scientific interest in meteorological and other natural phenomena of the Alps. The scope of his work is demonstrated by the massive collection of writings on geology, glaciology, magnetism, astronomy, and meteorology entitled *Voyages dans les Alpes*, published between 1779 and 1796, together with *Un Essai sur l'Histoire Naturelle des Environs de Geneve* (De Saussure, 1779–96).

His contributions to meteorological thought appear to have been substantial, but apart from his studies of hygrometry, they are largely unrecognized in histories of the development of meteorology (e.g., Frisinger, 1977). This paper highlights some of the fundamental problems that he was trying to elucidate and the types of inference that he was able to derive from his limited observations.

0003-0007/78/0702–0705$05.00

2. The cause of cold conditions in mountain areas

In the mid-18th century the reason for the observed decrease of temperature with height was under active debate. In particular, there were several conflicting arguments about the role of rising heat (*particules de feu*). The mathematician Jean-Henri Lambert, cited by de Saussure (1779–96, Vol. 2, chap. 35, §923), believed that heat particles were lighter than air and must rise at an accelerating rate, proportional to the air density. As translated from German by de Saussure from Lambert's (1779) book *Pyrometrie,* his argument was as follows:

> the ascent of heat depends on its great lightness, its speed in rising becoming continually greater. . . . Thus, it follows that the density of heat particles (*parties de feu*) and accordingly the warmth diminishes in the upper regions of the air.

From this viewpoint, and by assuming that the separation between the rising heat particles increased at a constant interval (1, 3, 5, 7, etc.), Lambert calculated expected temperatures in the free air over France and made comparisons with snow line elevations observed in Peru. De Saussure showed from temperature data on mountains in Europe that Lambert's table gave differences substantially greater than those that were observed between mountains and plains.

De Saussure recognized that the rise of heat was "not due to lightness inherent in the heat-fluid (*fluide igné*) itself" (De Saussure, 1779–96, Vol. 2, chap. 35, §925). Based on laboratory methods of Lambert, he demonstrated experimentally that "hidden" heat (*chaleur obscure*) from a heated iron ball could be reflected by concave mirrors 12 ft apart and concentrated at the focal point like light (*chaleur lumineuse*). He concluded from this experiment that

> the heat-fluid, the source of heat in the strict sense, easily crosses an air layer 12 feet thick, and consequently one may attribute to this fluid a sufficient ability to rise according to the air pressure or to become more dense by its own weight (De Saussure, 1779–96, Vol. 2, chap. 35, §926).

On the basis of his experiment, de Saussure criticized the concept of de Luc that heat was a fluid resembling air and suggested that

> what we call heat in substances depends on a certain perturbation of the heat fluid, enclosed in their pores, and this perturbation is transferred by oscillations that should be called *calorific*. Such oscillations are able to

be reflected, as are sound waves[1] (De Saussure, 1779–96, Vol. 2, chap. 35, §927).

This idea apparently anticipated later definitive experiments carried out individually by Count Rumford and Sir Humphrey Davey in 1799 that showed that heat was a vibratory motion of the corpuscles of heated bodies (Jeans, 1947, p. 264).

De Saussure also drew extensively on the ideas of Pierre Bouguer based on observations in Peru. He quoted from Bouguer (1749):

> The more diaphanous the medium, the less it must receive heat by the direct action of the sun. . . . Dense air is heated from below by contact, or by the proximity of more dense bodies which are near it and over which it rises; the heat can be transferred from one to another, up to a certain distance. The lower part of the atmosphere receives very considerable heat each day by this means. . . . But it is clearly not the same thing at 1½ or 2 leagues [6–8 km] above the earth's surface, even though light should be stronger when it enters there" (De Saussure, 1779–96, Vol. 2, chap. 35, §930).

Using a "heliothermometer" that he devised, de Saussure was the first to demonstrate the increase of solar radiation with altitude. The instrument consisted of a thermometer exposed in a wooden box that was lined with blackened cork and covered with three spaced sheets of glass. Measurements made in July 1774 showed that the heliothermometer registered 87.5°C after an hour's exposure on the summit of Cramont (on the Italian side of Mt. Blanc), but only 86.2°C after similar exposure under identical conditions on the following day at Courmayeur, 1515 m below. Air temperature readings made at the same times with an unshielded thermometer gave 24°C at Courmayeur but only 6°C on the summit. This and similar experiments convinced de Saussure that Bouguer's views were correct. He concluded:

> The principal reason for the prevailing cold on high and isolated summits, is that they are surrounded by and chilled by air which is constantly cold. This air is cold because it cannot be strongly heated, neither by the rays of the sun, due to its transparency, nor by the surface of the earth due to the distance separating them (De Saussure, 1779–96, Vol. 2, chap. 35, §932).

Comparison of the different heights of tree line in the Peruvian Cordillera (3100 m) and on Mt. Blanc (1950–2050 m) persuaded de Saussure also of the fact that low temperature and not low air density was the factor limiting vegetation growth in the high mountains (De Saussure, 1779–96, Vol. 4, §2022).

3. Observations on altitude effects in the Alps

During July 1788, de Saussure and his son spent two weeks camped on a rocky spur on the Col de Géant (3360 m) making meteorological observations (see Fig. 1). The Col is located on the massif of Mt. Blanc, some 6 km northeast of the summit. Pressure, temperature, and humidity were recorded every 2 h between 4 a.m. and midnight and compared with synchronous measurements at Chamonix (1050 m) and Geneva (375 m).[2] Some of the principal results are now summarized.

The decrease of pressure with increased altitude had been determined in the late 17th century by E. Mariotte and E. Halley (e.g., see Frisinger, 1977, p. 116). The barometric height determinations made by de Saussure on Mt. Blanc and elsewhere were, therefore, nothing new, although it is worth mentioning that the effect of various possible temperature corrections was discussed and the altitude given (4775 m compared with a modern estimate of 4807 m) was a mean of five such determinations (De Saussure, 1779–96, Vol. 4, §2003). More interesting is de Saussure's observation that at the Col du Géant, the diurnal pressure minimum occurred at 8 a.m. with a maximum at 2 p.m., whereas at Geneva the maximum occurred at 8 a.m. and the minimum at 4 p.m. He noted that this agreed with the findings of de Luc who had proposed that the air over the lowlands must rise in response to expansion due to daytime heating.

De Saussure calculated[3] a mean lapse rate of 0.64°C/100 from his observations and recognized from its diurnal variation (0.48°C/100 m at midnight and 0.80°C/100 m at noon, between Chamonix and the Col) that the rate would be less in winter. He estimated an annual mean value of 0.51°C/100 m, close to the figure obtained a century later by Julius von Hann. He also noted that the diurnal range decreased with altitude from 12.6°C at Geneva and at Chamonix to 5.3°C at the Col du Géant and inferred that there would be no diurnal variation at 12 000–14 000 m in the free atmosphere. In fact, Brunt (1934, p. 24) notes that the range is only ~0.5°C at 4 km.

Similar altitudinal comparisons were made using de Saussure's hair hygrometer, of which a description and illustration are given by Middleton (1969, pp. 101 ff.). The measurements were expressed in absolute units (grains per cubic feet) according to Middleton (1969, p. 84). It was noted that the absolute humidity was considerably less on the Col du Géant than at Chamonix or Geneva; this finding confirmed earlier observations on Mt. Blanc, where he found the absolute humidity to be 6 times less than that at Geneva (De Saussure, 1779–96 Vol. 4, §2007). He found that following a maximum soon after sunset the humidity tended to decrease during the night in fine weather. Another maximum occurred at ~0400–0500. Minimum values were observed at ~1600, as at lower elevations.

De Saussure was aware that sky color becomes a darker blue with altitude. In order to make comparative

---

[1] The concept of a "caloric," which permeated the pores of substances making them hotter or colder according to its quantity, was one of the so-called "imponderables" that were gradually eliminated from consideration by 18th–19th century science (see Jeans, 1947, pp. 256–64).

[2] The observations were published posthumously (De Saussure, 1891).

[3] The original temperature values are in degrees Réaumur (for differences, 1°R = 1.25°C) and heights are in toise (=1.949 m).

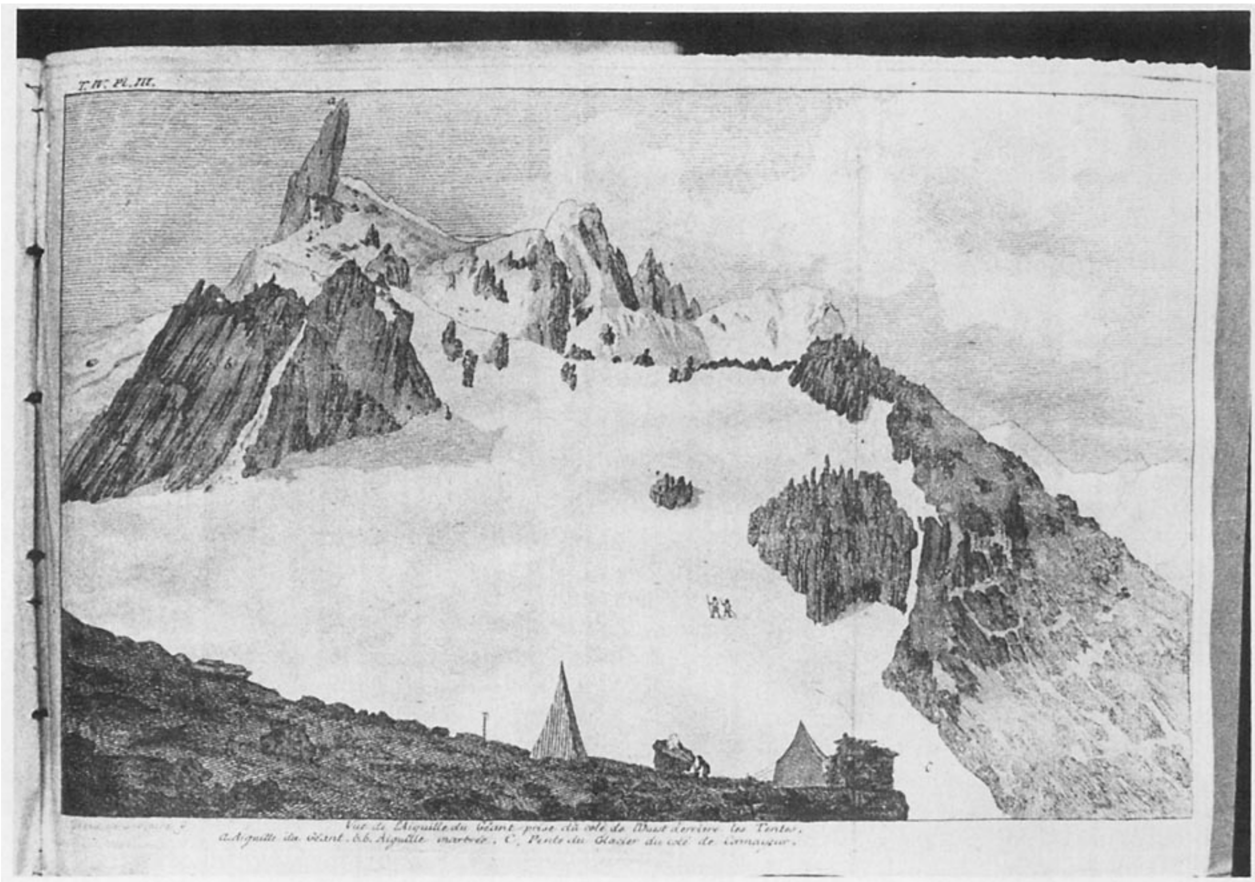

FIG. 1. A view of the Entreves glacier and the Aiguille de Géant (a) from the west by Theodor de Saussure, showing the two tents and stone shelter. The stake from which the thermometers and hygrometers were suspended is to the left of the tents (De Saussure, 1779–96, Vol. 4, Plate 3).

observations between Mt. Blanc, Chamonix, and Geneva in August 1787, he devised a "cyanometer" with paper strips painted in shades ranging from light blue (16) to dark Prussian blue (1) (De Saussure, 1779–96, Vol. 4, §2009). Subsequently, for the work at Col du Géant, an enlarged scale of 51 shades (beginning at almost white) was used.[4] Average zenith values at midday on this scale were 31 at Col du Géant, 19 at Chamonix, and 23 at Geneva (De Saussure, 1779–96, Vol. 4, §2084). The highest value was 37 at Col du Géant, compared with 39 on the same scale at Mt. Blanc. These measurements were also made at various times of day, and it was noted that the sky color increased much more rapidly in the early morning at Col du Géant (from 16 to 27 between 4 a.m. and 6 a.m.) than at Chamonix or Geneva, where it increased barely 1 shade. De Saussure was impressed by the fact that despite this contrast, the air over the mountains in the morning seems to contain almost as much moisture as that over the plains. He remarks also that since the sun produces only a small effect on air temperature in the mountains, the influence of heat on evaporation must therefore be much greater in the mountains than in the denser air over the plains. This idea appeared to confirm his direct observations of evaporation, which are discussed next.

4. Evaporation measurements

The stated goal of de Saussure in attempting to compare the rate of evaporation on the mountains with that on the plains was to distinguish the effectiveness of heat, dryness (defined as saturation deficit), air motion, and air density (De Saussure, 1779–96, Vol. 4, §2058). The apparatus that he used consisted of a fine rectangular cloth about a foot square attached to, but not touching, a light frame and suspended on a balance beam. The cloth was weighed dry and wet giving a range of 150 grains of moisture content.[5] A thermometer and hygrometer were suspended 6 inches from the cloth and a calibration was made between their readings and the weight of the cloth, after wetting, at 20 min intervals. The measurements on the Col du Géant and at Geneva were compared in terms of the actual evaporation, by weight, per degree Réaumur (heat) and per degree of

[4] A full description of this instrument was provided by de Saussure (1788–89); this has not been seen by the author.

[5] 1 grain $\simeq$ 0.05 g.

saturation deficit on the hygrometer.[6] De Saussure estimated that in calm conditions, on the mountains, 1°R of temperature change had an effect just over 3 times that of 1° of "dryness" (on the hygrometer), whereas on the plains, 1° of dryness was 50% more effective than 1°R of temperature change. He recognized that the latter relationship implied that dense air could contain more vapor than rarefied air. His overall conclusion, from three sets of measurements in each location, was that "other things being equal, a decrease of about one third in air density causes more than a doubling of the evaporation amount" (De Saussure, 1779–96, Vol. 4, §2062). However, from other experiments carried out with a sling psychrometer that de Saussure had designed, he showed that with air flow (equivalent to 12 m s^{-1}) the increase in evaporation with reduced air density was less pronounced than in calm conditions. Even now, there are so few good determinations of actual evaporation in mountain areas that it would be difficult, if not impossible, to give definitive assessments of such relationships.

De Saussure went on to consider the apparent effects of rarefied air on the body, particularly with regard to its apparently greater desiccating effect.

5. Carbon dioxide

The recognition that air is a mixture of gases did not come until the 1770s. According to Bolin (1972), C. W. Scheele noted the presence of carbonic acid (or carbon dioxide) in the atmosphere in 1773. It is interesting, therefore, to find that in 1787 de Saussure showed its occurrence on the summit of Mt. Blanc. He observed the formation of a blue purple film on an exposed mixture of distilled water and limewater (De Saussure, 1779–96, Vol. 4, §2010). He suggested that since at this altitude the atmosphere is still mixed with an appreciable quantity of carbonic acid, it must be transported from the lowlands by rising air currents. However, he also remarked that the process was not a purely mechanical one and considered that the different gases remain associated in given proportions.

6. Discussion

The inventiveness displayed by de Saussure is clearly apparent from the foregoing. The range of his experiments and observations was considerably greater than discussed here. They included measurements of the evaporation of ether, observations on clouds, atmospheric electricity, hail, eudiometric determinations including tests on air contained in snow, and calculations on the duration of twilight. He also measured water temperature in the depths of Lake Geneva. Apart from the technical ingenuity, there must also have been considerable logistical skill involved in transporting the equipment into the mountains. His writings indeed give a few glimpses of difficulties with guides and problems in traversing the crevassed glaciers.

To credit de Saussure with being "the first mountain meteorologist" seems fully justified, even if such recognition is long overdue. His studies of alpine glaciers were also extensive, but discussion of those observations belongs elsewhere.

[6] De Saussure refers to a calibration table (1783, §176) and notes that at 15°R (20°C) a hygrometer reading of 98 corresponded to saturation with a vapor content of 11.96 grains/ft^3 ($\simeq$21.1 g/m^3).

References

Bolin, B., 1972: Atmospheric chemistry and environmental pollution. *Meteorological Challenges: A History,* edited by D. P. McIntyre, Information Canada, Ottawa, pp. 237–266.

Bouguer, P., 1749: *La Figure de la Terre, Determinée par les Observations des Messieurs Bouguer et de la Condamine . . . Envoyés par Ordre du Roi au Perou . . . avec une Relation Abrégée de ces Voyages.* Académie des Sciences, Paris, 394 pp. (Cited by de Saussure (1796).)

Brunt, D., 1934: *Physical and Dynamical Meteorology.* MacMillan, New York, 411 pp.

De Saussure, H. B., 1779–96: *Voyages dans les Alpes, Précédés d'un Essai sur l'Histoire Naturelle des Environs de Geneve.* Vol. 1, 452 pp. (1779); Vol. 2, 568 pp. (1786); Vol. 3, 532 pp. (1796); Vol. 4, 596 pp. (1796); L. Fauche-Borel, Neuchâtel, Switzerland. (The following sections are especially referred to: *Tome Second, Continuation du Voyage Autour du Mont Blanc,* Chap. 35 and 53, and *Tome Quatrième, Cinquième Voyage—Col du Géant,* Chap. 5–9.)

——, 1783: *Essais sur l'Hygrométrie.* S. Fauche Père et Fils, Neuchâtel, Switzerland, 524 pp.

——, 1788–89: Description d'un cyanométre ou d'un appareil destiné à mesurer la transparence de l'air. *Mém. Acad. Roy. Turin,* **4**, 409–24.

——, 1891: Observations météorologiques faites au Col du Géant du 5 au 18 Juillet 1788 par Horace-Bénédict de Saussure. *Mem. Soc. Phys., Hist. Natur., Geneve,* Suppl. Vol. 1890, No. 9, 32 pp. (Available, Library of Congress.)

Freshfield, D. W., 1920: *The Life of Horace Benedict de Saussure.* E. Arnold, London, 479 pp.

Frisinger, H. H., 1977. *The History of Meteorology: To 1800.* Science History Publications, New York, and AMS, Boston, 147 pp.

Jeans, J., 1947: *The Growth of Physical Science.* Cambridge University Press, London, 364 pp.

Lambert, J. H., 1779: *Pyrometrie, oder von Maase des Feuers und der Wärme.* Bey, Haude und Spener, Berlin, 360 pp. (Cited by de Saussure (1796) and Middleton (1969).)

Middleton, W. E. K., 1969: *Invention of the Meteorological Instruments.* Johns Hopkins Press, Baltimore, 362 pp.

Mill, H. R., 1920: A note on the meteorological work and observations on deep temperatures of H. B. de Saussure, *The Life of Horace Benedict de Saussure,* by D. W. Freshfield, E. Arnold, London, pp. 457–65.