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ISOTOPIC COMPOSITION AND TEMPERATURE OF FORMATION OF ANTARCTIC SNOWS

By E. PICCIOTTO

Université de Bruxelles (Expédition Antarctique Belge, 1958)

X. DE MAERE

Service Météorologique de la Force Aérienne de Belgique (Expédition Antarctique Belge, 1958)

AND

I. FRIEDMAN

U.S. Geological Survey, Washington

IN an earlier communication[1], variations in the isotopic composition of the oxygen in falls of snow collected during 1958 at the Belgian Antarctic Base (King Baudouin Base, 70° 26′ S., 24° 19′ E.) were shown.

We intend, here, to present the variations in the isotopic composition of the hydrogen contained in the same samples.

The analysis of the aerological radio soundings carried out at the King Baudouin Base in the course of the International Geophysical Year[2] has enabled us to estimate the temperature range in the cloud corresponding to each snow-fall. This is, to the best of our knowledge, the first attempt carried out with the view of establishing a direct correlation between the isotopic composition of a snow-fall and its temperature of formation. The interesting results obtained in this field up to the present[4,5] originate from average samples representing accumulations over several months, or even years.

Variations of the Deuterium : Hydrogen Ratio

The ratio deuterium : hydrogen has been measured at the U.S. Geological Survey, Washington. The mass-spectrometric methods used have already been described[6].

Fig. 1 shows the variations of the deuterium : hydrogen ratio in the course of 1958. Each point represents an individual sample. The composition of the hydrogen is expressed as percentage variation of the deuterium : hydrogen ratio with respect to a conventional standard (standard mean ocean water). The variations of the deuterium : hydrogen ratio

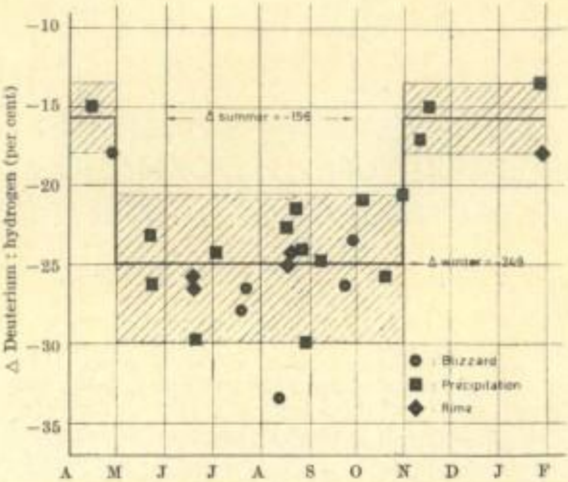

Fig. 1. Variations of deuterium : hydrogen ratio in snow samples during the course of the year (1958)

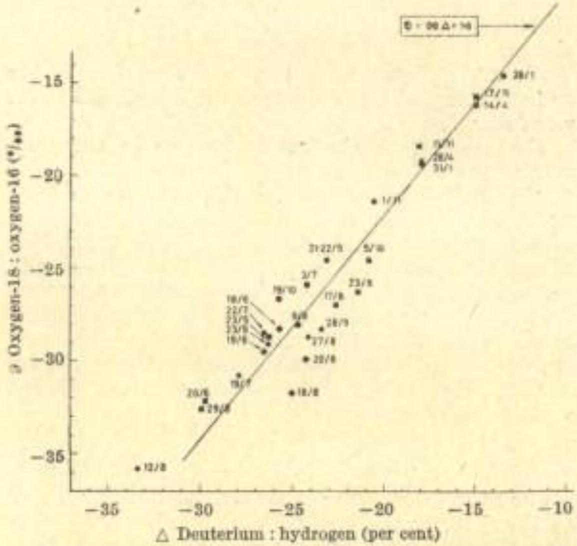

Fig. 2. Deuterium : hydrogen ratio compared with oxygen-18 : oxygen-16 ratio in the same sample. Same symbols as in Fig. 1. The date of collection is given for each sample. Oxygen isotopes data from Gonfiantini *et al.* (ref. 1)

present the same characteristics as those of the oxygen-18 : oxygen-16 ratio previously discussed[1]; but their amplitude is 10 times larger[3]. Thus, summer

Table 1

Sample No.	Date	Ground temperature (°C.)	Temperature in the cloud		∂ Oxygen-18 (‰)*	△ D/H (per cent)	Type and mean height of cloud
			Min.	Max.			
P 1	14/4	− 7	− 7	−14	−16·2	−14·9	st. 800 m.
P 2	21/5	− 9	−11	−19	−24·6	−23·1	sc. 1,400 m.
P 3	23/5	− 8	−19	?	−28·7	−26·2	as. 3,000 m.
R 4	18/6	−24	−24	−24	−28·3	−25·7	(rime) 0
R 5	19/6	−23	−25	−27	−29·5	−26·5	(rime) 0
P 6	20/6	−17	−22	−29	−32·2	−29·7	sc. 1,750 m.
P 7	3/7	−10	−15	−29	−25·9	−24·2	as. 2,800 m.
S 7	19/7	−18	−19	−30	−30·8	−27·9	ns. 2,300 m.
P 8	17/8	−21	−22	−22	−27·0	−22·6	sc. 1,300 m.
R 9	18/8	−28	−28	−28	−31·7	−25·0	(rime) 0
R 10	20/8	−27	−25	−30	−29·9	−24·2	(rime) 0
P 11	23/8	−24	−23	−28	−26·3	−21·4	sc. 1,100 m.
P 12	29/8	−31	−35	−37	−32·6	−29·9	ac. 2,550 m.
P 13	8/9	−17	−15	−27	−28·1	−24·7	sc. 1,800 m.
P 14	5/10	−12	−12	−20	−24·6	−20·8	st. 1,000 m.
P 15	19/10	− 6	−16	−27	−26·7	−25·7	ac. 3,700 m.
P 16	1/11	− 7	−16	?	−21·4	−20·5	ac. 2,100 m.
P 17	11/11	−10	−13	−16	−18·4	−17·3	st. 1,200 m.
P 18	17/11	− 5	− 6	−16	−15·7	−15·7	sc. 1,200 m.
P 19	28/1	− 3	−11	?	−14·6	−13·4	
R 20	31/1	−13	−13	−16	−19·3	−17·9	(rime) 0

* Oxygen isotopes from Gonfiantini (ref. 1).

snows are, in the average, 10 per cent richer in deuterium than winter snows. The maximum relative variation in the deuterium content is 20 per cent.

Fig. 2 shows the variations of ∂ (oxygen-18 : oxygen-16 $^{0}/_{00}$) with respect to Δ (deuterium : hydrogen per cent). As a first approximation, all the points are grouped about a straight line of equation : $\partial = 0{\cdot}8\ \Delta + 1{\cdot}8$. It appears that some points corresponding to August and September, that is, the end of winter, form a separate group.

Isotopic Composition and Temperature of Formation

In order to estimate the range of the temperature of formation of every fall of snow, we have noted from the radiosonde data the temperature at the base and at the top of the cloud at the moment of precipitation. This temperature is well defined in the fortunately frequent case of thin stratiform clouds with no higher cloud sheets. In the case of rime deposits, the temperature at a height of 1 metre above ground was taken. Drift-snow samples were excluded.

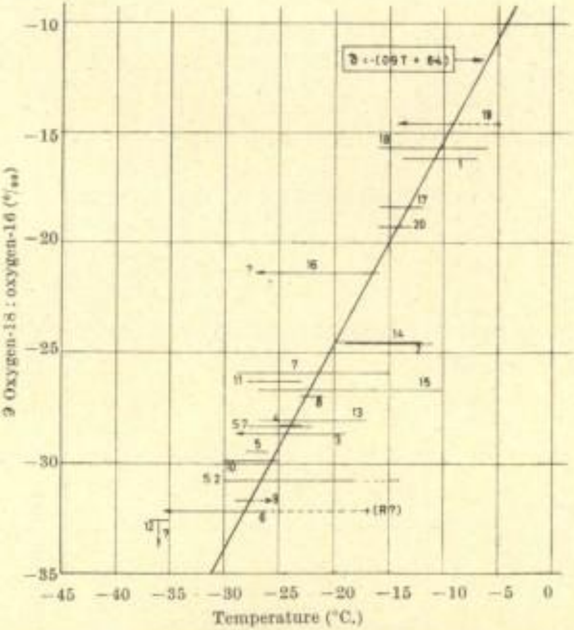

Fig. 3. Isotopic composition of oxygen in snow falls with respect to the temperature in the corresponding cloud sheet. Sample numbers refer to Table 1

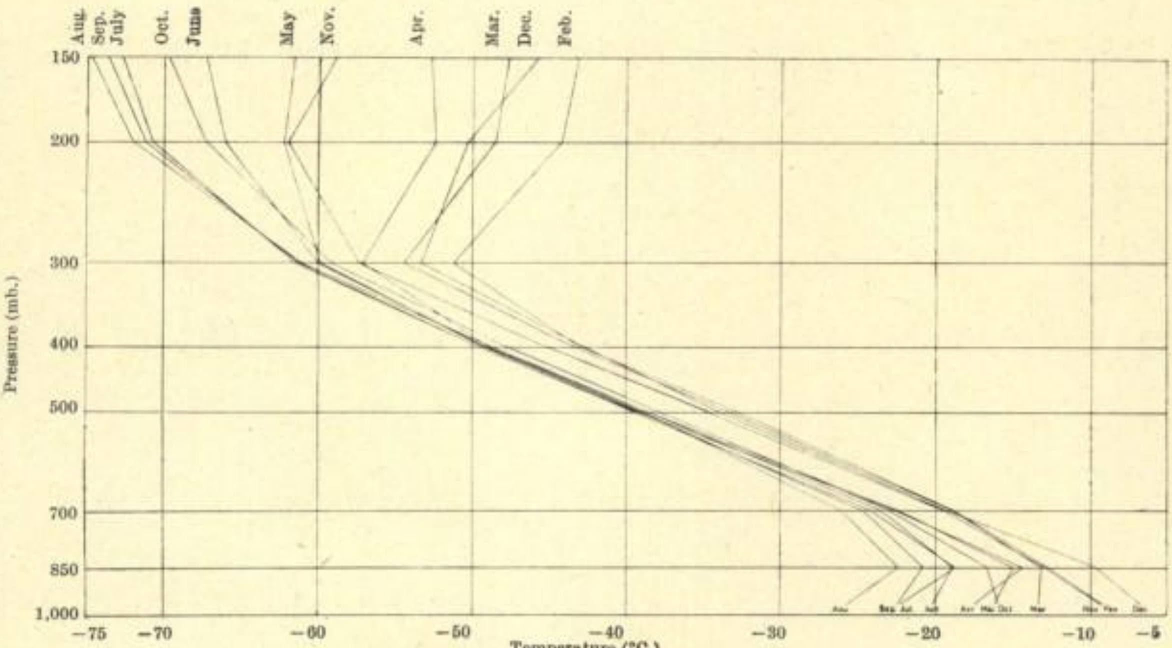

Fig. 4. Monthly mean temperatures from upper-air soundings at King Baudouin Base—1958

Table 1 shows the information obtained from the aerological soundings.

Fig. 3 shows the isotopic composition of the oxygen in each fall, with respect to the temperature-range in the corresponding cloud sheet. The straight line corresponding to the mean temperature of the cloud has been traced. There is seen to be a remarkable correlation between ∂ oxygen-18 and the temperature of formation of the precipitation, T.

The equation connecting ∂ and T is :

$$\partial(\text{oxygen-18}) = -(0{\cdot}9T + 6{\cdot}4)$$

An equally precise correlation has been found to exist between Δ (deuterium) and T, and is represented by the equation :

$$\Delta\ (\text{deuterium}) = -(0{\cdot}8T + 8)$$

The isotopic compositions ∂ and Δ essentially depend on the temperature of formation, and appear, at first sight, to be independent of any other condition such as the cloud height or the type of precipitation.

The very marked seasonal effect, and the very rapid transition from the 'isotopic winter' to the 'isotopic summer' (Fig. 1), may be clearly interpreted by referring to Fig. 4, which presents the mean monthly temperature of the air with respect to its height, in the atmosphere above King Baudouin Base. The known polar climatic characteristics very clearly discussed in a recent article by Wexler[7] are found here. It is clear that the temperatures of the middle troposphere in which the precipitating clouds form are closely grouped about two mean values, and that these temperatures pass from the mean summer to the mean winter values in two abrupt jumps—between March and April, and between October and November. These two periods correspond very well to the abrupt variations in the isotopic composition of the precipitation (Fig. 1). As this behaviour of the tropospheric temperature is characteristic of the antarctic climate[7], it is to be hoped that the type of isotopic variations observed in 1958 follows a rule which will apply to other years.

On Fig. 4 is to be noted the wide dispersion of the ground temperatures, due mainly to the winter ground-inversion. This shows that ground temperature is not the best parameter to be used in work of this type.

In conclusion, the ratios oxygen-18 : oxygen-16 and deuterium : hydrogen in the snow-falls are seen to vary in a very similar pattern. These two parameters represent a veritable thermometer of the temperature of the middle troposphere, where the clouds causing the precipitation are formed. A variation of 1 deg. C. corresponds to a relative variation of about 1 ‰ in the ratio oxygen-18 : oxygen-16, and 0·8 per cent in the ratio deuterium : hydrogen—both values are well above the experimental errors of measurement.

The recent work of Dansgaard *et al.*[5] carried out on Greenland ice of known ages confirms that the isotopic composition of snow is conserved for at least several hundreds of years, even through compaction and transformation into ice. A very important application of these results would be a study of the recent climatic variations of the antarctic continent.

A full account of this work will be published elsewhere.

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