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Water Vapour and Ozone in the Atmosphere and Stratospheric Circulation*

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1. Water vapour in the stratosphere

Most of what we know about water vapour in the stratosphere has come from the development of the frost-point hygrometer by Dobson, Brewer and Cwilong (1946) and its regular use in the Meteorological Research Flights of the U.K. Meteorological Service. Additional information is available for the study of mother-of-pearl clouds in Scandinavia and Russia, some measurements made in U.S.A. with balloon-borne frost-point hygrometer, and a few aircraft measurements of infra-red absorption by water vapour in U.K. and U.S.A.

The existing knowledge is summarised in the following two diagrams—

Fig. 1. A histogram of frost-points measured at 48,000 ft over U.K. Taken from a paper on "Further observations of humidity up to 50,000 ft made from an aircraft" by N. C. Helliwell *et al.* in *Quart J. R. met. Soc.*, **83**, 1957, p. 257.

Fig. 2. A diagram showing temperatures and frost-points at 34,000 ft and 46,000 ft in July 1956 obtained by Meteorological Research Flights extending from 40° to 65°N at about the longitude of U.K. (*Weather*, Sep. 1958).

Reference may also be made to a paper on "Humidity in the Stratosphere at 27 km" by F.R. Barclay *et al.* in the *Quart. J. R. met. Soc.*, **86**, 1960 where they found a frost-point of —76°C.

The Meteorological Research Flights of U.K. have established that while the frost-point *at the tropopause* is variable over the U.K. from —50° to —78°C, it decreases rapidly with height above the tropopause, and becomes practically constant at about —83°C at a level of 15 km (Mixing ratio 2×10^{-3} gm/kgm). They have also shown that at the same height (15 km) over Idris in Morocco, a similar value of the frost-point is observed. The special meridional flights undertaken by them have shown that while at low stratospheric levels, the frost-point depends on the synoptic weather situation, at 15 km, the latitudinal variation of humidity becomes small, although there are marked discontinuities of frost-point on crossing fronts with lower frost-points towards the north.

The infra-red observations made by Houghton over U.K. show an average mixing ratio of 3×10^{-3} gm of H_2O/kgm of air above 13·5 km. This is in reasonable agreement with the frost-point hygrometer findings.

On the other hand, a few American soundings made in 1949-50 and the indirect evidence of mother-of-pearl clouds over Norway indicate higher frost-points at 23-27 km. The question is : Is the very low frost-point of 190°K confined to a restricted depth in the lower stratosphere or can it be considered to extend throughout the stratosphere?

The conclusion drawn by Brewer and Dobson (1946) from the persistent extreme

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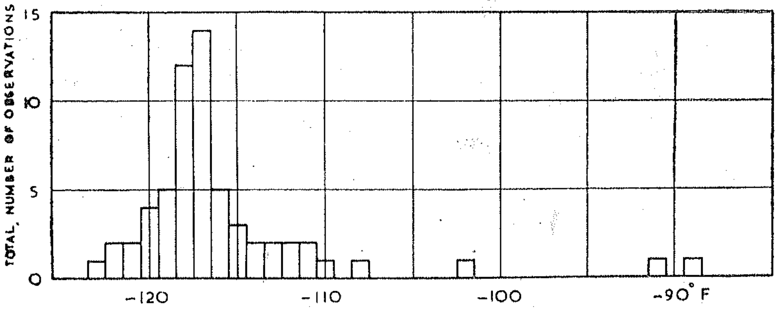

FIG. 1. HISTOGRAM: FROST POINTS AT 48,000 FT OVER U.K

(HELLIWELL & OTHERS)

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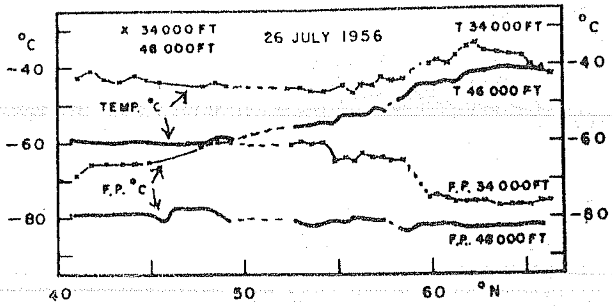

TEMPERATURES AND FROST POINTS AT 34000 AND 46000 FT. ON

26 JUL. 1956, ROUGHLY ALONG U.K. MERIDIAN

FIG. 2 (a)

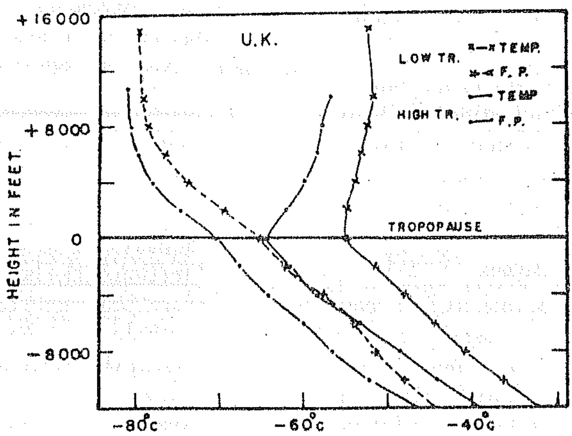

FIG.2(b).TEMPERATURES AND FROST POINTS IN LOWER

STRATOSPHERE OVER U.K. (AFTER HELLIWELL)

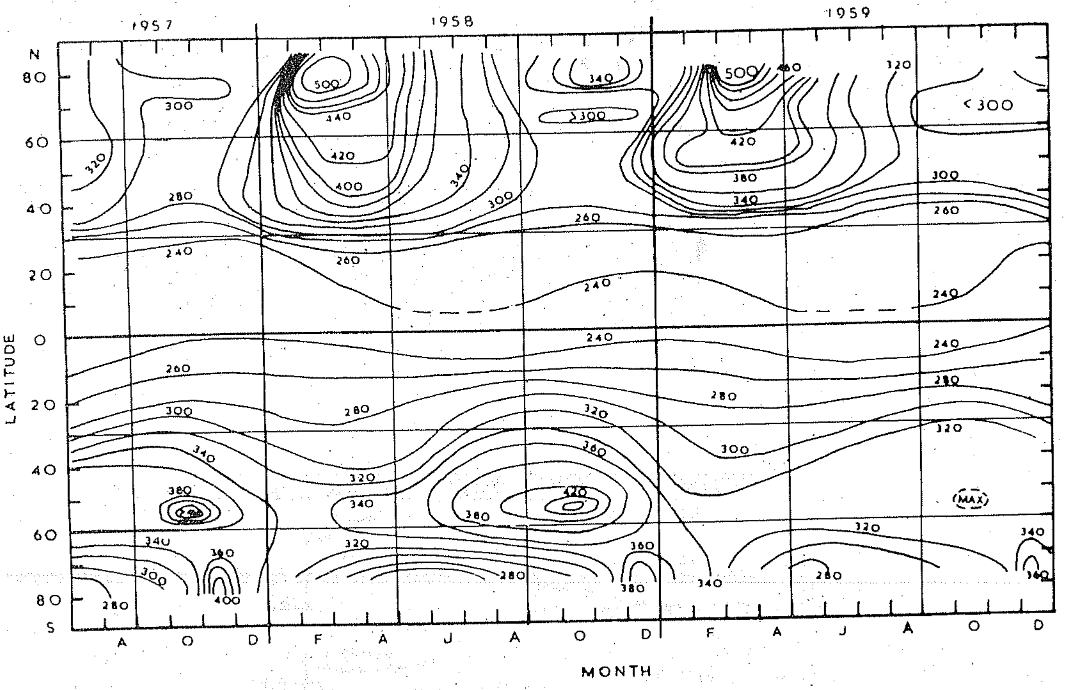

FIG. 3. OZONE DISTRIBUTION IN DIFFERENT MONTHS FROM 1957 TO 1959

dryness of air at 15 km over U.K. is well-known, namely, it provides evidence of a meridional circulation involving ascent of air over equatorial latitudes across the tropopause and slow sinking of the dried air in the lower levels of the stratosphere over middle and polar latitudes.

Umkehr studies and recent ozone observations made by Brewer and Milford (1960) over Malta, Arosa, Liverpool and Tromso in summer provide supporting evidence for the transport of stratospheric air in the indicated direction.

2. Atmospheric Ozone and its variations

Before the IGY 55 ozone stations had been has been able to get the provisional daily ozone data of about 36 stations. Umkehr observations are also available from a few stations.

Diagrams illustrating some important points about the distribution of ozone and its variations are given below—

(1) Latitudinal variations of total ozone (1957—1959) in different months (Fig. 3).

It may be noted that the mean monthy ozone amount is not a function of the latitude only, but that there are regional differences. For

modern science and technology into our culture, to an extent comparable to the integration of philosophy and religion in our average lives.

The integration of philosophy and religion in our culture keeps India politically stable, and free from blood-shed in spite of the grinding poverty of the masses. There is a school of thought which feels that it is this philosophical Indian culture (Hindus, Muslims and Christians alike) which has opiated the poor. Therefore, the first step for the development of any poor country, this school feels is the *removal* of the philosophical culture and its *replacement* by a culture of science and technology.

Men enjoying all the advantages of a highly developed society, still find that a sense of true fulfilment escapes them. Man needs an emotional culture provided by some kind of religion or faith or ethical code, besides his material comforts, to derive happiness or satisfaction. Otherwise, his contentment appears to be as limited as that of a lap dog. Again, if men are possessed only by greed and worship of power, a knowledge of science and technology will lead to several forms of violence inflicted by them on fellow-men. To avoid this, a culture of *Ahimsa,* an ability to make an ethical and moral choice, (the creed practised and advocated by Mahatma Gandhi), should be present along with the knowledge of science or technology. Common human weal depends on the coexistence of scientific knowledge based on a rigorous experimental logic, and ahimsa based on faith. The need for a culture based on faith also is now quite important for the so-called developed nations.

I would not suggest the replacement of the philosophical culture of our people. It is necessary, however to integrate a large measure of modern science and technology into our culture along with the philosophical or emotion-based culture, inherited through millenia of Indian civilisation, and the joint living of Hindus, Muslims and Christians. Absorption of modern technology and science into our culture would have occurred by itself during the last three decades of political freedom and the active science policy of the Government of India, but for inherent difficulties. Therefore, if vigorous steps for its integration are not taken it will be a long time before the bulk of our people obtain the minimum benefits available from modern science and technology.

Graduates in science and technology necessarily acquire a scientific background, even though for most of them it is only a means of livelihood. It is estimated that in another fifteen years we will have about four million graduates in science, engineering, agriculture and medicine. These professionals will form only a small fraction of our total population.

primary requirements provided by an income well above the poverty line.

Schools run between 10 a.m. and 5 p.m. is not the ideal method to spread education among our poor rural people, or even the poor sections of cities. Children have to attend to family chores or earn something. If classes are conducted between 7 a.m. and 9 a.m. or between 5 p.m. and 7 p.m., pupils can do remunerative work at other times. Attendance will improve and drop-outs decrease substantially.

The spread of the culture of science and technology has to be achieved by each village having a workshop with modern tools for carpentry, metal work and masonry, open from 6 a.m. to 10 p.m. It should be accessible to children from the age of seven or eight and also to adults. Attached to these should be laboratories where inexpensive experiments with materials available in the neighbourhood can be conducted to inculcate a spirit of learning through inquiry. This is more or less what Gandhiji advocated through his Basic Education. A boy or girl can learn about a simple pendulum or a "Danish Steel Yard" or about microbes at the age of eight, and need not wait till his fourteenth year as I had to do.

A good scientific culture can be imparted by the age of ten or twelve. At this age a boy can wind an electric motor, make a good pulley, weave cloth, engage in carpentry, apart from helping his elders in farming. Village carpenters should be encouraged to make cuckoo clocks for us in the villages. Making such clocks can impart a good scientific culture. Every household that sends children to school should have a few tools for carpentry and other handyman's work. Middle class homes should also have a small laboratory. The plea that they cannot afford it is not valid, as most of the homes do have gold ornaments. With an investment much smaller than in ornaments one can purchase a handyman's box and other physical equipment, which in reality are scientific toys.

How has philosophical culture been imbibed by Indians, urban and rural? It is not through school and college education. It has been through folk songs, readings from the epics or the Bible or the Koran and through literature and drama. The common places of worship — temples, mosques and churches — have played a significant role. A small fraction of the waking hours are regularly devoted to common worship in many households, rich and poor. A large amount of the so-called classical knowledge — the sastras — found place in poetry and drama, in Sanskrit as well as local languages. In addition, most of the homes also have a small room where pictures of the Hindu Gods or of Christ, or the Sacred book Koran or the Grantha Sahib is kept. And the people in the house, particularly the mothers do something every day to remind us that there is some power beyond what is obvious, and that moral and ethical values are important.

It is suggested that we adopt a similar methodology for imparting a scientific and technological culture among the masses, and even among the elite. We should have poems written about scientific principles, scientists and their achievements. There should be dramas and other theatrical arts where the principal characters are not villains or good people but well known scientists, engaged in their work, and making contributions to science or engineering. Such dramas should be educative and entertaining. It is noteworthy that the works on Ayurveda by Charka and Sushruta are composed in Sanskrit poetry, which as Sanskrit literature can compete with the literature of Kalidas or Harsha. For example, here is an Ayurvedic recipe for keeping one-self healthy.

नित्यं मिताहार विहारसेवी
समीक्ष्यकारी विषयेष्वसक्त :
दाता सम : सत्यपर : क्षमावान्
आप्तोपसेवी च भवत्यरोग :

One becomes free from illness, when his daily intake of food is limited, takes a limited amount of daily exercise, has equanimity of mind, is indifferent to sense-objects, is a giver, is not perturbed by praise or abuse, is truthful, has patience and keeps company of good people.

Corresponding to temples and other places of common worship we should have *workshops and science museums.* These should be open from morning till evening. Facilities available in the mornings and evenings are accepted as indigenous and such timings makes it possible for many householders to participate. These science museums must be developed like the Smithsonian Institution of Washington, the science museum of London, the Exhibition of Moscow, or better still, like the Science Museum of Munich. Similar to the other Museums, the last one contains exhibits showing developments in science and technology and in addition has a large workshop. In this workshop, anybody would be permitted to handle any equipment. A guide will provide the necessary guidance. The visitor can make anything he is capable of, making use of the equipment available in the museum's workshop. He has to bring his own raw materials but can take home the final product. It is suggested that smaller versions of such museums with workshops be established all over rural India.

The introduction of science and technology into our culture, along with, but without replacing our philosophical culture, will increase the benefits of science and technology and will geographically extend them to the villages where most of India's people live.

Such a system of humanised science and technology will avoid for us the pitfalls which the advanced countries of the West and East are now facing through excessive use of natural resources and the upsetting of eco-systems. And in the long run, after India's economy improves considerably, our methodology may be adopted by several nations of the world.

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APPENDIX

The series for arc tan X-Z as we know it today is due to Leibritz (1673). This series for a value of $X = 1$, that is for $\pi/4$ was anticipated by Madhava (1350-1410 A. D.), while enunciating a rule for determining the circumference of a circle. That rule is given in the following verse.

व्यासे वरिधि निहतें रुपहृते व्यास सागरामिहते

त्रि–शरादि विषमसंख्या भक्तं ऋणं स्वं पृथक् क्रमात् कुर्यात्

(Quoted from Madhava's Commentary KRIYAMAKARI on Bhaskara's LILAVATI.)

Multiply the diameter by four. Substract from it and add to it alternately the quotients obtained by dividing four times the diameter by the odd integers 3, 5 etc.

For the circumference C of a circle of diameter D, this gives the formulae,

$$C\ (\text{or } \pi\ D) = 4D - \frac{4D}{3} + \frac{4D}{5} - \frac{4D}{7} + \ldots\ldots$$

$$\text{or } \frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \ldots\ldots$$