VERTICAL MIXING IN THE MARS POLAR ATMOSPHERE.

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Introduction

We have published (1) a brief report of the observation of an enhancement of the argon mixing ratio in the southern winter polar region as the CO_2 condenses out of the atmosphere to the polar cap. Not explicitly mentioned was the fact that we assumed the Ar to be uniformly mixed in the vertical, even though the source is concentrated near the surface. The deduced abundance does depend slightly on the vertical distribution, because some of the 1294-keV gamma rays by which the argon is detected are absorbed by the overlying atmosphere, and the flux of the neutrons that generate the gamma rays is slightly dependent on altitude.. Below we summarize the reasoning that supports our assumption of a vertically uniform mixing ratio.

Vertical mixing is treated through the mechanism of eddy diffusion, which operates on scales too small to be resolved by a General Circulation Model (GCM). Eddy diffusion coefficients are normally obtained by analysis of "tracers", minor consstituents whose vertical distribution can be measured (2, 3). We lack any such tracer for the winter polar regions of Mars, and must therefore proceed by suggesting a source for the fluctuating vertical motions and scaling from what we know from study of the Earth's atmosphere.

Mechanisms

A mechanism for producing vertical mixing was suggested in 1971 by Lindzen (4). Wave motions alone do not cause mixing; they move parcels of air up and down but do not mix them with other parcels. But a wave that dies out after a non-integral number of cycles will leave its parcels in a place different from where they started. At altitudes around 80 km and greater, another, more predictable mechanism becomes inportant: dissipation of wave motions whose pressure amplitude begins to be comparable with the mean pressure (5).

Another process is proposed here: strong horizontal winds are known to exist in the atmospheres of both Mars and Earth. Such winds do not move in a strictly straight line; their direction fluctuates in a manner that appears to be random. We are conscious of the fluctuations in the horizontal, but they must exist in the vertical also. We estimate their magnitude by a simple scaling argument and then "calibrate" the results, as suggested above, by comparing them with known values for the Earth.

The vertical eddy diffusion coefficient K_z may be estimated by the mixing-length approximation (6) as the product of a typical velocity and a mixing length. We begin with a typical wind speed of $v_h \simeq 10^3$ cm/s. To estimate the fluctuating vertical speed v_z we scale by H/R, the ratio of the scale height to the planetary radius: $v_z \simeq 10^3 H/R$ cm/s. Below we discuss how this speed may be reduced by the static stability of a height region. The vertical mixing length is equal to H, but near the surface it is limited to the altitude; we shall take H/2. Then

$$K_z \simeq 500 H^2/R \; cm^2/sec. \tag{1}$$

Rough values of H and R for the Earth are 6 km and 6000 km; the corresponding value of K_z is therefore 2×10^5 cm^2/sec.

Comparison with observed values

The static stability at a level in an atmosphere is defined as

$$S = dT/dz + \Gamma, \tag{2}$$

where Γ is the adiabatic lapse rate, 9.8 K/km for Earth and 6.6 K/km for Mars. If S is negative the region is unstable against convection, which will transfer heat in such a way as to reduce the absolute value of S to nearly zero. With a positive value the region resists vertical mixing, and K_z is likely to be reduced from the value estimated above. We proceed to estimate this reduction by use of known values for the Earth. A convenient compilation appears in (3); more recent work has resulted in minor changes and extensions, but they do not affect the argument here. We shall focus on the region 0 – 50 km, the results for which are derived in (2), which uses the height distribution of methane to deduce the corresponding distribution of K_z. Table 1 summarizes the results for the troposphere and the lower and upper stratosphere; the last column shows the factor of reduction from the 2×10^5 cm^2/sec derived above. The temperature gradients (given, like Γ above, in K/km), are from the 1976 U. S. Standard Atmosphere, quoted in (6).

Height, km	dT/dz	S	K_z, cm^2/sec	factor
0–10	-6.5	3.3	2×10^5	1
20	1.0	10.8	1×10^4	20
50	0	9.8	1×10^5	2

Table 1. Static stability and eddy coefficients for Earth.

Apparently the effect of static stability is modest until it exceeds almost 10 K/km.

Mars

At this planet the scale height in the troposphere is 10 km, the radius is 3400 km, and wind speeds are similar to those on Earth. Substitution in (1) gives $K_z \simeq 1.5 \times 10^6$ cm^2/sec, substantially greater than for Earth. This agrees with values derived from Phobos 2 solar occultations (7). But the region inside the winter polar vortex could be different. The static stability in the lowest couple of scale heights (8) is a couple of K/km. This does not exceed the threshold of 10 K/km obtained above for a large factor of diminution, and a factor of 3 seems like a generous estimate. We therefore suggest that the polar-night K_z should be 5×10^5 cm^2/sec.

The mixing time over a height range Δz is $(\Delta z)^2/K_z$. The first two scale heights contain all but 26% of the atmospheric mass , and the mixing time over this range is 8×10^6 sec or 93 Earth days. For one scale height it is 23 days. The time scale for the observed argon enhancement is around 100 days. Thus, although the vertical mixing may not be quite complete, a mixed atmosphere is a much better approximation than one with the argon confined near the surface.

References

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