I-6. Summary of the Disturbances in the Ionospheric Region

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-6-P1. Density and Energy in the Upper Atmosphere

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Various aspects of the variability of density in the upper atmosphere are discussed with special emphasis on the effect on the upper ionosphere. Various questions raised by this discussion, particularly with respect to heating during magnetic storms, are presented.

1. In order to determine conditions for which an external effect can play a rôle in the upper atmosphere, it is interesting to consider a parameter such as the kinetic energy of a vertical column.

At 100 km, the total kinetic energy cannot be less than 3×10^5 erg cm^{-2} whilst it is only of the order of 10^4 erg cm^{-2} at 200 km. If an energy of the order of 1 erg cm^{-2} sec^{-1} is introduced in the atmosphere at 100 km, the thermosphere will not be subject to great changes below 100 km. But above that altitude, it is clear that the thermosphere will receive a total energy in one day corresponding to the kinetic energy of the vertical column. The result is a gradient of temperature which leads to a heat transport by conduction. The energy (E erg cm^{-2} sec^{-1}) of heat transport is given by the following expression, $400\leq T\leq1600°$K,

$$\left(\frac{dT}{dz}\right)_{\text{km}}=(20\pm3)E$$

for an undissociated atmosphere. The normal distribution of the temperature in the thermosphere shows that a heat source by ultraviolet radiation corresponds to a flux density of heat not less than 1 erg cm^{-2} sec^{-1}.

The satellite data show that a diurnal variation of density is the principal variation which increases with the altitude of the perigee. Such a result is explained by the diurnal variation of the atmospheric heating from a sunlit atmosphere to night conditions. The temperature is lower during the night than during the day since the time of conduction is short enough at high altitude to lead to different conditions.

2. If we compare energies which are involved in the airglow with the energy transported by conduction, it is clear that the airglow emissions may play a rôle in the heat budget. However, photometric measurements of the airglow show that the total intensity corresponding to about 3 erg cm^{-2} sec^{-1} is due to OH. Since the OH emission occurs below 100 km, the atmosphere is not affected even it is a process of heat loss. The line at 62 μ due to the transition between two levels of the ground ^3P term leads to another emission which dissipates a small energy above 100 km. The emission of the green and red lines of atomic oxygen are without importance as far as the energy is concerned. However, these observations of these two lines lead to interesting conclusions concerning the structure of the ionosphere. For example, the observation of the tropical arc above 240 km shows that the red line at 6300 A comes from the ion interchange process

$$O^+ + O_2 \rightarrow O_2^+ + O\ ;\ O_2^+ + e \rightarrow O + O(^1D)$$

and that the additional emission of the green line at 5577 A comes from the same process

$$O^+ + O_2 \rightarrow O_2^+ + O\ ;\ O_2^+ + e \rightarrow O + O(^1S).$$

However, the stable arc which has been observed at 400 km without any effect on the green line cannot be explained by electrons if they have energies greater than 4 eV. The cross-section for the excitation of the metastable level ^1D is less than 10 times the cross-section for ^1S.

If, in the aurora, energies up to 400 erg cm^{-2} sec^{-1} can be involved, a certain fraction is dissipated as heat in the atmosphere. It does not seem unreasonable to assume that there is a special heating in the auroral zone during a magnetic storm. In fact, measurement of rotational temperature of N_2^+ bands in sunlit auroras shows that temperatures of the order of 2000°K are observed. The

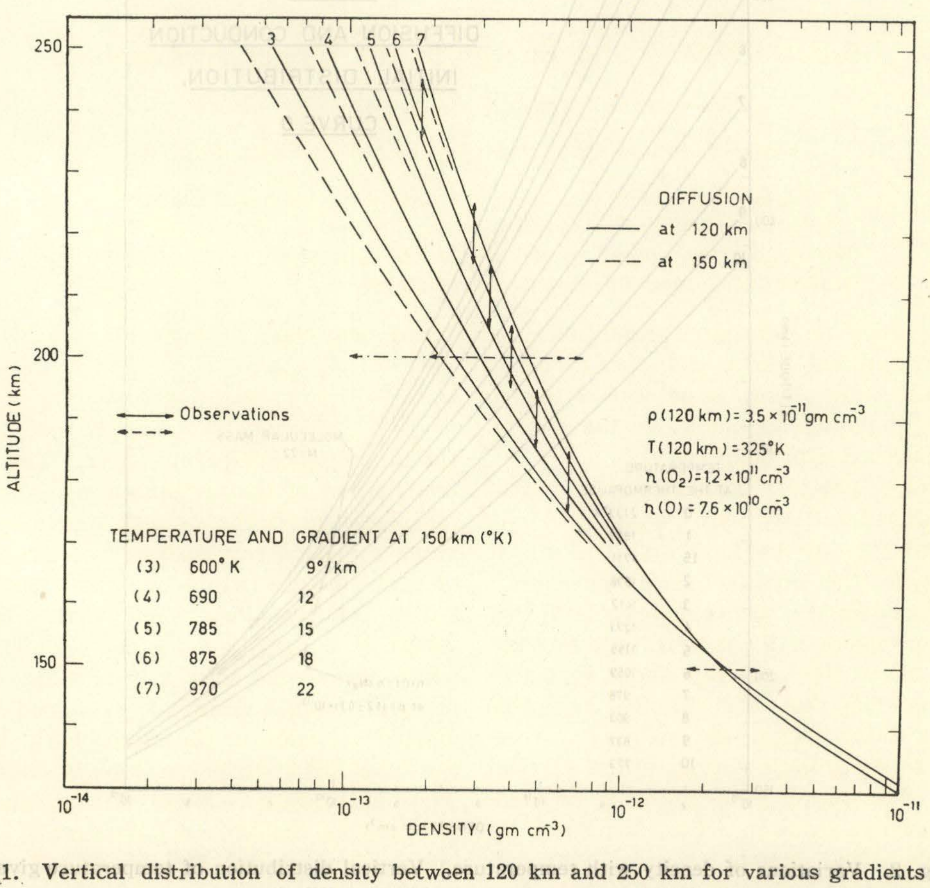

Fig. 1. Vertical distribution of density between 120 km and 250 km for various gradients of temperature.

measured rotational temperature is equal to the kinetic temperature not only of the auroral ray but also of the atmosphere. Up to the greatest heights the vibrational temperature corresponds to the rotational temperature, and there is reason to suppose that the essential reaction is the symmetrical resonance charge transfer process,

$$(N_2^+)_a + (N_2)_b \rightarrow (N_2)_a + (N_2^+)_b \,.$$

Such a reaction which leads to the equality of the vibrational temperature and kinetic temperature shows that the atmosphere reaches temperature of the order of 2000°K. But, the source of heating cannot be only a direct corpuscular heating since heating occurs at very low latitude during geomagnetic storms. The atmospheric-drag perturbations which are observed during magnetic storms must be included in the same atmosphere which leads to day-to-day variations depending on solar activity. It is clear also that there is an increase of the amplitude of the acceleration with the altitude of the perigee from 200 km to 700 km during magnetic storms at all latitudes. Therefore, the results of Jacchia cannot be explained by a direct corpuscular heating but by the hydromagnetic heating as suggested by DESSLER. Of particular importance is the heating by ultraviolet radiation in a sunlit atmosphere and by hydromagnetic waves during magnetic storm so that the heating has always a worldwide effect. It must be pointed out that a general heating by fast particles (certainly necessary outside of the auroral zone) cannot be invoked since their collisions would lead to associated ionization and excitation.

Sources of heating other than electro-

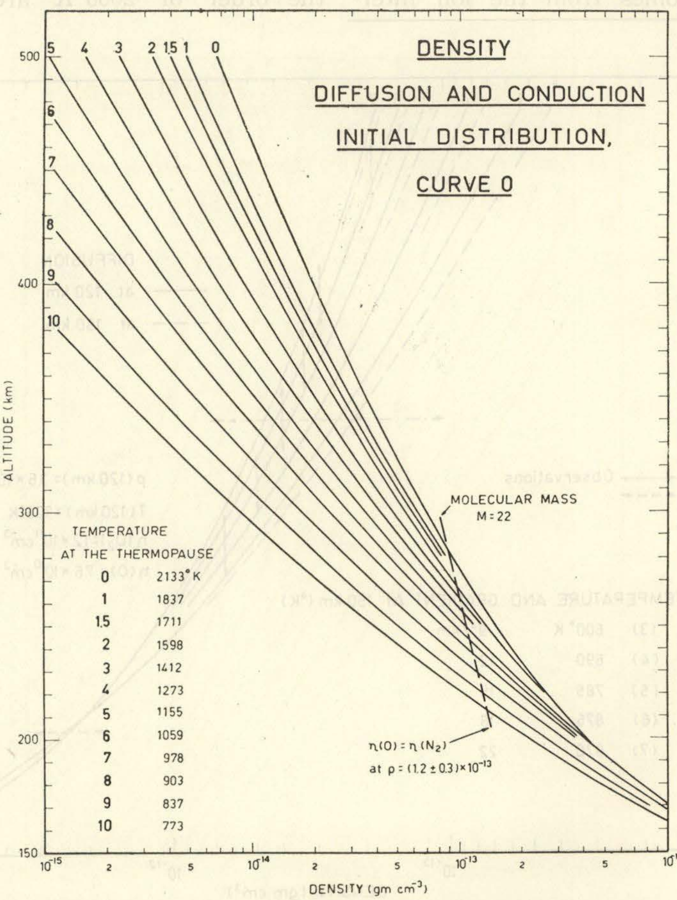

Fig. 2. Variations of density with temperature. Vertical distribution of temperature given by conduction and distribution of constituents subject to diffusion.

magnetic radiation depend on the energy which is available. The use of the energy of the radiation belt in one form or another is limited by the total energy which is less than 10^{23} ergs whilst the energy which is involved in a magnetic storm is of the order of 10^{22} ergs. The maximum energy available for the earth's atmosphere cannot be more than 10^4 erg cm^{-2} during normal conditions. An energy supplied to the atmosphere of the order of 1 erg cm^{-2} sec^{-1}, which would be given by electrons of the order of 10 keV, will lead to the total energy of the radiation belt in about 3 hours. In fact, diffuse auroras are observed when an electron flux of the order of 3×10^7 cm^{-2} sec^{-1} is assumed. However, special conditions corresponding to geomagnetic storms with energy available of the order of 10^{22} ergs may lead to appreciable transient heating since it corresponds to 0.5 erg cm^{-2} sec^{-1} for the entire earth during one hour. The hydromagnetic heating, therefore, must be kept as the only process which has been proposed to explain the atmospheric heating at very low latitudes during geomagnetic storms. Furthermore, it must be kept among the hypotheses needed to explain the earth's storms.

3. Since heat conduction leads at sufficiently high altitudes to practically isothermal conditions, the vertical distribution of the density becomes a function of a constant temperature and of a varying molecular mass. If there is a gradient of temperature, the gradient cannot increase with height and any atmospheric model involving an increasing gradient of temperature does not represent real physical conditions. It must be realized that any vertical distribution of density based on any law of absorption of the ultraviolet energy leads at high altitudes to a distribution of temperature depending on the heat transport. The redistribution of the temperature after heating depends on a time

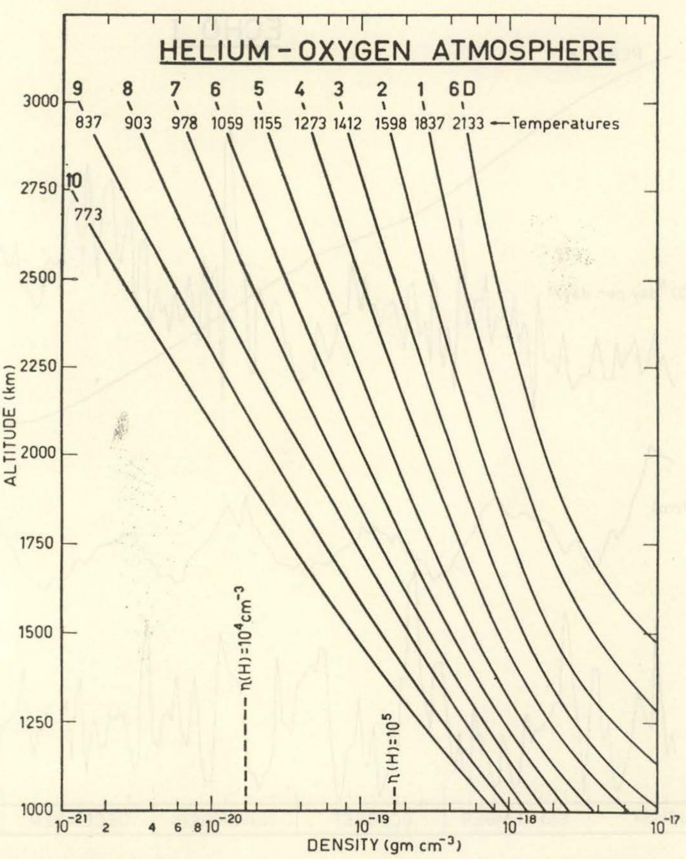

Fig. 3. Density in the exosphere in a helium-oxygen atmosphere without the effect of atomic hydrogen.

interval which is proportional to the concentration and the square of the distance. Therefore, the temperature of the isothermal layer is the essential parameter at high altitudes when boundary conditions are assumed at levels where diffusion begins. For example, the conditions in the region between 100 km and 150 km depend on several parameters: temperature and its gradient, ratio of atomic oxygen and molecular nitrogen concentrations, and beginning of diffusion. But at high altitudes, the conditions correspond to a change of the temperature. The acceleration of Vanguard I (1958 $\beta 2$) which varied from about 7.5×10^{-7} days per day in October 1958 to less than 5×10^{-8} days per day in October 1960 shows that the density varied by a factor of the order of ten. In other words, such a variation represents a difference of about 1000°K in the temperature of the thermopause, i. e. a temperature of the order of 2000°K in October 1958 (sunlit atmosphere and high solar activity) and of the order of 1000°K (night atmosphere in 1960). In such circumstances, the concentration of atomic oxygen at 700 km decreases by a factor of 10 while the concentration of molecular nitrogen decreases by a factor of 100. It is clear that such variations due to the variation of the temperature will occur also during a magnetic storm.

When attention is confined to heights above 700 km, evidence becomes available from higher satellites that the constitution of the atmosphere changes. The transition cannot be from atomic oxygen to atomic hydrogen since there is not enough hydrogen to explain the density at 1500 km deduced from the variation of the period of the Echo I satellite. Diffusion of helium in the thermo-

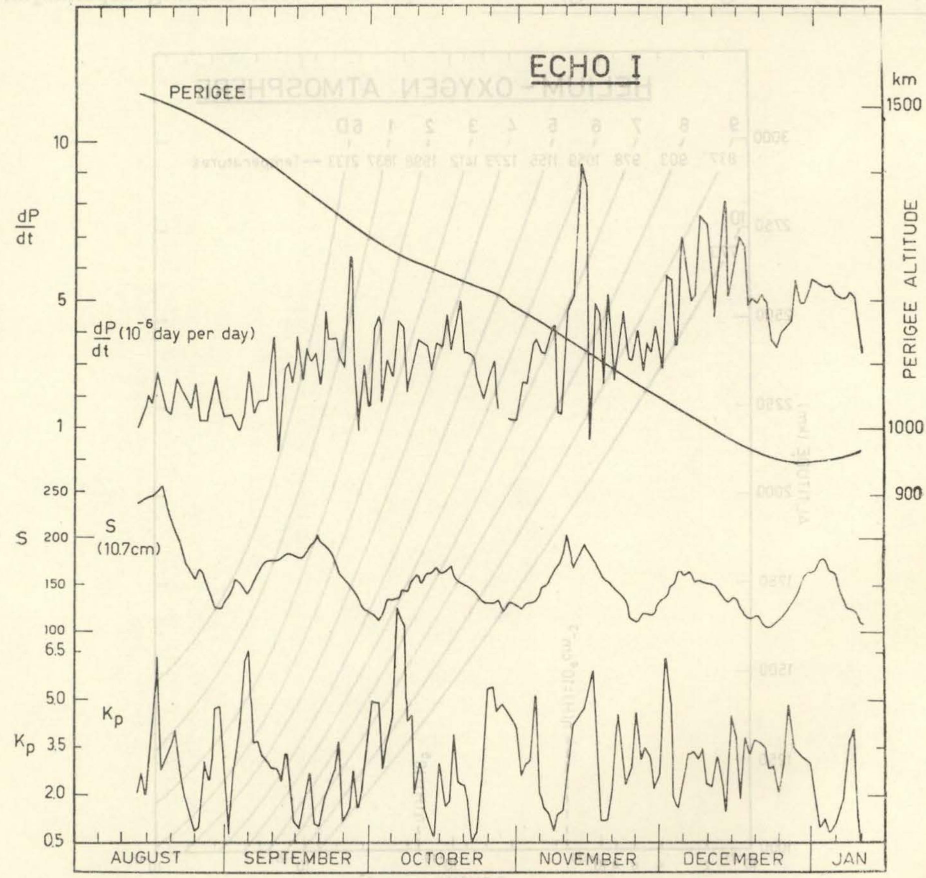

Fig. 4. Rate of change of the period of ECHO I between August 1960 and January 1961 due to air drag between 1500 km and 950 km. From Zadunaisky, Shapiro and Jones, Research in Space Science, Smiths. Inst. No. 61, 1961.

sphere shows that it is an important constituent. When the diffusion is assumed at 105 km the concentration $n(\mathrm{He})=(1.8\pm0.5)\times10^6$ cm^{-3} at 500 km for temperatures between 800°K and 2000°K. If the diffusion starts above 105 km, the values at 500 km can be corrected by decreasing by a factor of 2 for each step of 5 km. The decrease of $n(\mathrm{He})$ with height is as follows for $T=1600°\mathrm{K}$.

1000 km	1500	2000	3000
6.7×10^5 cm^{-3}	2.4×10^5	9.6×10^4	2.1×10^4

With the preceding concentrations, the density of neutral helium reaches that of atomic oxygen near 1250 km for $T=1600°\mathrm{K}$ and near 1000 km for $T=1250°\mathrm{K}$.

Since the ionization rate coefficient of He is of the order of 10 per cent of that of atomic oxygen, the total production of He^+ above 500 km reaches values of the order of 10^6 ions cm^{-2} sec^{-1}. Furthermore, the vertical distribution of helium ions will be subject to the law of the vertical distribution of ions

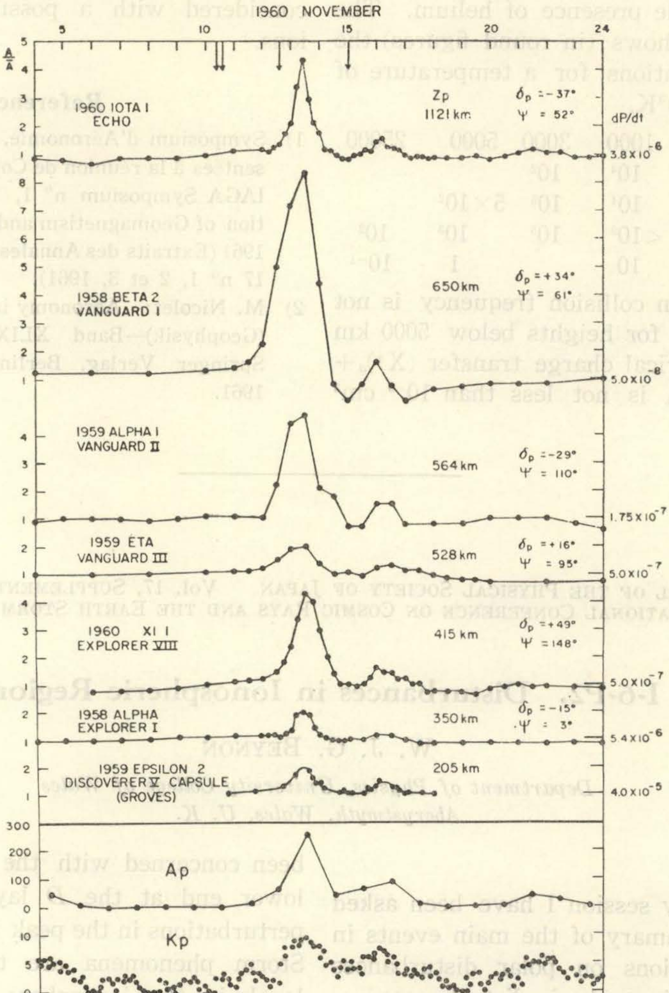

Fig. 5. Atmospheric-drag perturbations during the November 1960 events of satellites with perigee heights between 200 km and 1120 km deduced from accurate accelerations by L. Jacchia (2nd COSPAR Symposium, Florence, 10-14 April 1961).

in electrostatic distribution deduced by Mange and there is a layer of helium ions between the layer of atomic oxygen ions and the layer of atomic hydrogen ions. In other words, neutral and ionized helium play a leading rôle between 100 km and 3000 km.

The vertical distribution of the electron concentration above the F_2 peak must be interpreted as indicating that helium ions predominate after atomic oxygen ions and before protons. A consideration of the effects of magnetic storms on the ionosphere should include the presence of helium. The following table shows (in round figures) the various concentrations for a temperature of the order of 1600°K.

	500 km	1000	3000	5000	25000
O^+	10^5 cm^{-3}	10^4	10^2		
He^+	10^3	10^4	10^3	5×10^2	
H^+	10^1-10^2	$<10^3$	10^3	10^3	10^2
ν_e	100 sec^{-1}	10		1	10^{-1}

Since the electron collision frequency is not less than 1 sec^{-1} for heights below 5000 km and the symmetrical charge transfer $(X^+)_a+(X)_b \rightarrow (X^+)_b+(X)_a$ is not less than 10^{-9} cm^3 sec^{-1}, the vertical distribution of ions in the earth's magnetic field should be based on conditions in which collisions play a rôle. Thus, during magnetic storm conditions, the nature of the ions should be considered when the electron concentration varies. An increase of the temperature in the lower F_2 region increases the number of neutral molecules which leads to an increase of the recombination coefficient since the ion interchange rate coefficient must increase. In the exosphere, a decrease of the electron content should be considered with a possibility of escape of ions.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-6-P2. Disturbances in Ionospheric Regions

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Introduction

At this plenary session I have been asked to present a summary of the main events in the earlier sessions on polar disturbances and in those on ionospheric disturbances.

Nearly all discussions of the ionospheric disturbances in this conference have been concerned with the results of ground based radio studies, and consequently they refer to that part of the ionosphere below the peak of the $F2$ layer. None of the discussions have dealt with the upper side of the ionosphere, and indeed most of the papers have been concerned with the phenomena at the lower end at the D layer heights or with perturbations in the peak $F2$ electron density. Storm phenomena are to be found at all levels in the ionosphere, but they are most obvious in the D and $F2$ layers. It is however worth noting that the study of small but significant perturbations in the middle and lower part of the ionosphere, especially at the upper part of the region E, may well be profitable, since these levels are now believed to be those where the important dynamo currents flow.