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14. Abstract/Notes

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A SIMPLIFIED UPPER ATMOSPHERE MODEL TO EXPLAIN SEASONAL PHENOMENA

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ABSTRACT

The upper atmosphere can be modeled using a system of fluid equations for each particle species. The amount of processing for this approach is extremely large, and not always required in its whole length to explain some experimental results. A bidimensional differential model is suggested, in this paper, as an alternative approach to deal with energy unbalancing dependent phenomena. The method consists of assuming a steady dynamical equilibrium of energy, along the vertical, and particle transport as relaxation mechanism, to restore the balance. With these simplifications only the equation of motion needs to be considered for most of the cases. A qualitative discussion, based on the proposed approach, is presented to explain some seasonal peculiarities of middle and high latitudes. The method can be considered satisfactory to the light of evidences.

INTRODUCTION

The added number of seasonal interdependent upper atmosphere phenomena (F region winter anomaly, seasonal variations in the lower thermosphere composition, TID's, etc.) is a clear evidence that one may develop a unified theory for all of them. To explore this idea a bidimensional differential model is proposed, in this work, to describe the upper atmosphere reaction when perturbed by energy input variations.

A fluid type approach is assumed to hold for the upper atmosphere. The grounds for this modeling may be found for instance in Rishbeth and Garriott (1969), CIRA (1972), etc. For each particle species the three basic vector equations express the conservation of mass, energy and momentum. A satisfactory solution of these equations involves a considerable amount of processing, part of which can be estimated from the work of Banks (1969). The simplifications used are described in CIRA (1972). For our purposes here an oversimplified approach will be taken. A bidimensional differential model will be assumed based on the equation of motion and on the maintenance of vertical dynamical equilibrium.

The proposed model considers the diffusive equilibrium as a valid approximation along the vertical above a given location. Energy perturbation is assumed to drive transport mechanisms to restore the internal equilibrium (relaxation). Only a few perturbations of interest to the matter will be analysed. Emphasis is put on the qualitative use of the model to explain each considered phenomenum.

Following a procedure similar to that of Gridchin et al (1980) only meridional energy differences will be taken into account. Meridional circulation of plasma along the magnetic field lines is taken as an equilibrium restoring mechanism to balance the energy differences. This is one step further in complexity as compared with neutral atmosphere modeling for circulation (Dickinson et al, 1975, 1977).

In order to neglect the continuity equation of particles, it is necessary to assume that the production-loss, background mechanism, has a much larger effect than the transport term, due to perturbations. This is a valid assumption when the time variation of the densities for all particle species is usually much smaller than the densities themselves.

The heat transfer equation will not be considered based on the assumption that the incremental heating is not large enough to significantly alter the equilibrium temperature. Stated otherwise, the entropy variation is small enough to be neglected.

Whenever the complete system of hydrodynamic equations is required a note on its expected result is made. This is particularly important at high latitudes, where the vertical dynamical equilibrium is often broken.

THE UPPER ATMOSPHERE SYSTEM UNDER VERTICAL DIFFUSIVE EQUILIBRIUM

Detailed description of the upper atmosphere system has been reported by many authors (e.g. Rishbeth and Garriott, 1969, Whitten and Poppoff, 1971). A brief outline of its behavior, concerning the distribution and transport of energy, will be considered here. Our purpose is to establish the mechanism which accounts for energetic differences between hemispheres and analyse some possible consequences of these differences.

The upper atmosphere can be thought of as a system composed of particles and fields. The solar radiation will be considered as a natural "excitation" acting on this system. The "responses" to this excitation are mainly particle transformations (photoionization, photodissociation, etc.). Man-made excitation, like nuclear explosions, may perturb the system giving rise to responses, such as, for instance, gravity waves (Francis, 1975). The response of the system depends on the form of the incident energy. Electromagnetic waves, for instance, may drive particle transformations, according to the frequency of oscillation (Rishbeth and Garriott, 1969), whereas thermal sources are quite likely to produce field depending responses as transport of particles, for example.

For the purpose of a global energy balance we will split the upper atmosphere in three regions:

a) Lower atmosphere - including the troposphere, stratosphere, mesosphere and the lower thermosphere.

b) Upper atmosphere - the thermosphere comprising the bulk of available ionization (most of the F layer).

c) Exosphere where light ions predominate (see Rishbeth and Garriott, 1969).

This division is slightly different than that of Volland (1969) as far as the limit between the lower atmosphere and thermosphere is concerned. In our model this limit coincides with the transition between molecular to atomic ions of the ionosphere.

The regular source of energy input for the upper atmosphere is the sun. The solar radiation is mostly used for particle transformation (photodissociation) by the system. It contributes with an energy density of 30 mwm^{-2} (Rishbeth and Garriott, 1969) in the range 1026-1750 Å. Most of this energy is distributed in the lower atmosphere. A smaller contribution, whose density amounts to 3 mwm^{-2}, comes from the solar ultraviolet radiation shorter than 1026 Å, (Hinteregger, 1965). This goes to the production of ionization on the E and F layers, in the thermosphere; and also in smaller quantity on the top F layer, in the exosphere.

The ionized particles transfer their energy, in part, to the neutral atmosphere through collisions since in the lower atmosphere mechanical collision dominates, whereas for the upper regions charge transfer chemical reactions are more effective. The energy transferred by ion-neutral collisions increases the neutral atmosphere temperature.

If energy equilibrium is broken above the lower atmosphere, by excessive heating of the neutral particles, a redistribution process takes place. This redistribution consists of the thermal transport of energy from the hotter to the cooler regions of the neutral atmosphere. Considering only the solar radiation the lengthscale for horizontal variation (of density, temperature, etc.) is of the order of the earth's radius. The vertical scale height, for the neutral atmosphere, is essentially smaller than this value. As a consequence horizontal gradients can be negleted for analysing transformations performed on the solar radiation energy.

The neutral atmosphere presents a monotonically increasing temperature with height in the lower thermosphere and above it. Therefore a downward heat flux, given by:

$$\phi = -AT^{1/2} \quad \partial T/\partial h, \tag{1}$$

may be expected (Rishbeth and Garriott, 1969) towards the bottom into the lower atmosphere region. Values for the constant A were determined by Nicolet (1961) for the most important constituents of the thermosphere.

In the thermosphere, O^+ ions predominate, whereas in the exosphere there is a characteristic predominance of H^+ ions. The internal equilibrium of energy between the thermosphere and exosphere is maintained by the chemical reactions (charge transfer collisions):

$$H^+ + O \rightleftarrows O^+ + H \tag{2}$$

and the rates for the forward and reverse directions may be found for instance in Fehsenfeld and Fergunson (1972). When an excessive heating of the neutral atmosphere occurs in the thermosphere, a downward flow of H^+ ions with an upward flow of O^+ ions is established to redistribute the exceeding energy. The reverse flow is expected when the excessive heating is in the exosphere.

The chemical diffusion, between the lower atmosphere and the bottom of the lower thermosphere, can be assumed to be negligible, since no ion fluxe due to this process occur in the boundary of these two regions. The thermal diffusion between the thermosphere and exosphere can also be neglected because the temperature gradient where the transition occurs is very small.

Within the thermosphere itself lies one important transition for the energy balance. It is the transition between molecular and atomic ions in the ionosphere. This roughly occurs at the bottom of the F_2 layer. At these heights the temperature gradient is negligible and chemical diffusion, between the lower and upper thermosphere, is the process to be considered in the energy balance. The chemical reactions, that are responsible for the energy transfer at the transition molecular to atomic ions, are the loss mechanism for O^+ ions:

$$O^+ + O_2 \rightarrow O_2^+ + O \qquad (3)$$

$$O^+ + N_2 \rightarrow NO^+ + N \qquad (4)$$

and only a downward flow may be expected. Excess energy present in the lower thermosphere will be easily removed by downward thermal diffusion. Because of the importance of this transition it was chosen as the limit between the two lower regions of our model.

It is interesting to compare the effectiveness of reactions (3) and (4) relative to reaction (2) as a way by which the excess energy in the upper thermosphere can be removed. Consider the neutral atmosphere model of Jacchia (1970), with exospheric temperature of 1000°K, average O^+ concentration of the order of 10^6 ions/cm^3, and thermal equilibrium between neutral and ionized species. Under these conditions, the ion production rates from equations (3), (4) and (2) are respectively:

$$q(O_2^+) \cong 10^3 \text{ ions cm}^{-3} \text{ s}^{-1} , \tag{5}$$

$$q(NO^+) \cong 10^3 \text{ ions cm}^{-3} \text{ s}^{-1} , \tag{6}$$

$$q(H^+) \cong 10^3 \text{ ions cm}^{3} \text{ s}^{-1} , \tag{7}$$

where $q(\cdot)$ denotes the ion production rate of each reaction. The reaction rate to obtain $q(O_2^+)$ came from Dunkin et al. (1968); to get $q(NO^+)$ from Lindinger et al. (1974); and to estimate $q(H^+)$ from Fehsenfeld and Fergunson (1972). It can be observed that the time interval to remove an additional ionization, of the same order of the average O^+ concentration, can be as large as half an hour. Moreover the excess energy, in the upper thermosphere, can be removed at nearly the same rate downwards and upwards off this region.

The production rate of ionization by solar radiation, can be as large as 750 ions cm^{-3} s^{-1} in the upper thermosphere. Therefore chemical diffusion can take care of any excess energy brought by this energy source, at these heights.

In addition to the energy from solar radiation, which produces ionization, those from solar corpuscular bombardment and gravity waves must also be considered in the energy balance. Solar corpuscular bombardment constitutes a nonregular energy input to our system. It contributes eventually by as much as 0.6 mwm^{-2} (Volland and Mayr, 1972a) of energy flux. This energy is controlled by the earth's magnetic field and goes mainly to high latitudes where it penetrates in a downward flux (Rishbeth and Garriott, 1969). Gravity waves dissipation also contributes for the energy balance. Like the heat flux expressed by (1) this energy can be classified as an internal reaction to restoring the equilibrium broken in the lower atmosphere region of our model. An upward flow of energy may be expected from the lower atmosphere due to gravity waves propagation. Hines (1965) estimated an approximate upward flux of 0.7 mwm due to gravity waves dissipation and a comparable input from tidal oscillations. Vidal-Madjar (1979), performing the numerical computation of the heat input resulting from gravity wave dissipation, found that, during summer, this energy is deposited between 120 and 200 km of altitude. Moreover he compared the determined energy input to 10% of that to solar radiation in the same range. Vidal-Madjar (1979) results are in agreement with the estimates of Hines (1965).

When no other energy source but the solar radiation affects the upper atmosphere (quiet days) and a perfect symmetry is reached between hemispheres (roughly true during equinoxes) we may assume to have a dynamical equilibrium condition. Under these circumstances a simple unidimensional model or incomplete bidimensional model, like that of Volland (1969), is enough to describe the behavior of the upper atmosphere. In a unidimensional model just vertical variations need to be taken into account, then thermal and chemical diffusion are the only important balancing mechanisms. A detailed modeling of the dynamical vertical equilibrium (equinoctial condition) is a lengthy task (see for instance Banks, 1969). An ion thermal energy balance equation (Salah and Evans, 1973) is used to describe the vertical equilibrium in quantitative terms for each altitude considered. If however equilibrium is broken (seasonal differences, particles bombardment, nuclear explosion etc.) more complete models are necessary to account for the actual distribution of energy. For these models, the horizontal transport of energy is required to complete the energy balance. This matter will be discussed in the next section.

A DIFFERENTIAL MODEL FOR THE CIRCULATION IN THE LOW AND MIDDLE LATITUDES

It has been pointed out, in the last section, that when an energy enhancement appears, in one of the three regions of our model, thermal and chemical diffusion may redistribute the extra energy. This is true if the energy is pumped at a rate compatible with the speed of the vertical diffusion. There are, however, situations when the whole upper atmosphere, above a given location, has its energy enhanced relative to other location connected to it by a geomagnetic field line (summer winter opposition). Other exception occurs when some energy is released so quickly that diffusion processes are unable to redistribute it, whithout a severe break of the equilibrium (particles bombardment, nuclear explosions, etc.). Horizontal transport must then be considered to complete the energy balance.

If particles are not homogeneously distributed then a gradient in its concentration exists. This gradient imposes a pressure which affects the equilibrium of forces. Assuming a new steady state condition can be reached we will have:

$$\nabla W = \sum_{j} F_j, \tag{8}$$

where W is the energy density distribution and F_j, for varying j, are the forces involved in the system. Thermal disequilibrium may also contribute to have an inhomogeneous W and its effect should be added in the computations of W for (8).

In the last section we assumed a vertical distribution of particles to be already known and (8) to be satisfied in our model. To some extent this is possible for equinoctial quiet days, by using average upper atmosphere models. If an energy enhancement occurs, the upper thermosphere, as discussed in the last section, is unable to store its excess energy, which is transferred upwards, to the exosphere, and downwards, to the lower thermosphere. When a reasonable amount of excess energy exists the equilibrium will be broken in both the exosphere and lower atmosphere. Assuming a vertical dynamical equilibrium is reached we may consider separately the effects of excess energy in these two regions.

In the exosphere charged particles may be assumed to rotate in nearly circular orbits occasionally perturbed by a charge transfer collision with neutral particles. The order of magnitude of the production rate of 0^+ from equation (2) is:

$$q(0^+) = 6.0 \times 10^{-3} \text{ cm}^{-3} \text{ s}^{-1},$$

where the reaction rate came from Fehsenfeld an Fergunson (1972), average ion concentration from Whitten and Poppoff (1971), and neutral atmosphere characteristics from Jacchia model (1970), for exospheric temperature of 1000^{o} K. The cyclotron frequency is of the order of 300 Hz of ions and 8×10^5 Hz for electrons. Therefore the assumption of motion around the magnetic field lines holds well for charged particles.

From the considerations above a model accounting for vertical and magnetic field aligned variations of particle density and temperature is enough to represent the behavior of the exosphere. Equation (8) can be then rewritten as:

$$\frac{\partial W}{\partial s} = \sum_j F_j, \tag{9}$$

where assumption has been made of a quasiequilibrium in the vertical direction. Here s stands for the length along the magnetic field line and F_j are the necessary forces in the s direction to restore equilibrium. We can consider further that equilibrium in (9) is reached if the net balance of forces yields a plasma flow along the magnetic field line. Under these circumstances an average diffusion velocity may be taken as:

$$v_d = \left(\frac{2}{mN_s} \Delta W\right)^{1/2}, \tag{10}$$

where m is the particle mass N_s, an average value for the particles concentration along s, and ΔW the excess energy density between the magnetic conjugated points located in different hemispheres. The sign in (10) depends on the location of the starting point for integration along s. If this point is located in the energy enhanced hemisphere v_d is positive, it will be negative otherwise.

The product $N_s v_d$ gives an idea of the particle flow between hemispheres. The actual flow can only be determined if we integrate (9) along the exospheric portion of a magnetic s field line. To do this we have:

$$W = N(s, h, t)\ KT(s,t), \tag{11}$$

where isothermal behavior was assumed for the same particle species in the exosphere. Here h stands for the height and t for the time. The hypothesis of quasi-equilibrium allows us to write:

$$N(s, h, t) = N(s,t) \exp(-h/H), \tag{12}$$

where diffusive equilibrium was considered to hold in the vertical direction, and H is the scale height for the considered particle species. Moreover one has:

$$\frac{dh}{ds} = -\sin I,$$

where I is the dip angle at the given location. For a given location the integration starting time t_0 is considered as the time when energy disequilibrium appears between hemispheres at exospheric heights. Energy differences start at early morning if seasonal differences are responsible for the energy unbalance. Since we consider only meridional circulation, the difference $t - t_0$ cannot be too large. A set of steady state stages has to be considered when the time interval increases. For a nuclear explosion, during equinoxes, t_0 will be the time when additional ionization starts appearing at the considered exospheric altitude. The forces to be considered in the right hand side of (9) are essentially due to gravity, electric fields, geomagnetic field and gradients in both concentration and temperature.

The consideration of all elements involved in (9) is extremely complicated. Simplified approaches may be found in Rishbeth and Garriott (1969), Chapman and Cowling (1952), etc. Here we consider the Macleod (1966) treatment as valid with the collisional force replaced by the gradient force. It is obvious that no steady state is reached before the diffusion velocity vanishes. Since we are interested in the transient, following Macleod (1966) we may write the vector equation:

$$\frac{d\underline{v}}{dt} = \frac{1}{mN} \frac{\partial}{\partial s} (\delta W)\underline{s} + \frac{\ell}{m} (\underline{v} \times \underline{B}), \tag{14}$$

which refers to positive ions. Here δ stands for the forward finite difference between the considered point and a chosen reference point. Moreover since the electrons are tied down to the ions they will be simply dragged along (Francey, 1963). The component parallel to $\underline{B}$ yields the diffusion velocity given by:

$$v_d = \frac{1}{m} \int_{t_0}^{t} \frac{1}{N} \frac{\partial}{\partial s} (\delta W) \, d\tau, \tag{15}$$

where δW is the excess energy between the starting point and the location where v_d is being computed. Equations (11), (12) and (13) must be considered for a more realistic result to be obtained from (15). If we consider in (15) the density and energy averages along s, we essentially recover (10). One gets this assuming ΔW, the energy density difference between hemispheres, to be uniformely distributed along s. Then expression (15) may be rewritten as:

$$1 = \frac{1}{mN_s} \int_{t_0}^{t} \frac{\delta W(\tau)}{v_d(\tau)} \frac{d\tau}{\delta s(\tau)} \cong \frac{1}{mN_s} \int_{t_0}^{t} \frac{\delta W(\tau)}{v_d(\tau)} \, d\left[\frac{1}{v_d(\tau)}\right],$$

whose result along the distance between the two magnetic conjugated points, at exospheric hights, yields v_d given by (10).

After the plasma flow is established between hemispheres in the exosphere, the vertical equilibrium is broken in both magnetic conjugated locations. Energetic particles, as well as energy in other forms, will then be redistributed. This process can thus be considered as a natural relaxation of the upper atmosphere to restore its internal balance.

At this point a question arises about the possibility of diffusion, along magnetic field lines, to be important in the thermosphere region. For moderate energy difference (< 30%) between hemispheres, the vertical gradient of ionization, in the region where O^+ ions dominate, is much larger than the gradient along the magnetic field line. This is the case of seasonal differences, for instance. Under these conditions magnetic field aligned diffusion can be neglected.

We now turn down to the lower atmosphere region, which ranges downward, starting in the transition between molecular to atomic ions of the ionosphere. Energy transport at these heights is mostly accomplished by vertical heat flux, according to expression (1). In the absence of a large energetic ionized flux a quasi-equilibrium condition holds. This is the case of seasonal differences, but not of a nuclear explosion.

Under the quasi-equilibrium condition, the excess energy above a given location is removed by horizontal diffusion transport to its neighborhood. Equation (8) takes then the vectorial form:

$$\frac{d\underline{v}}{dt} = \frac{1}{mN}\left[\frac{\partial}{\partial x}(\delta W)\underline{\underline{i}} + \frac{\partial}{\partial y}(\delta W)\ \underline{j}\right], \tag{16}$$

where x and y stand for horizontal coordinates. When, however, the equilibrium is severely broken equation (8) above is not enough to describe the system behavior. One also need to consider the continuity equation:

$$\frac{d(Nm)}{dt} = \Delta(Nm), \tag{17}$$

where $\Delta(Nm)$ is the rate of production of mass per unit volume, and the heat transfer equation:

$$NmT\,\frac{dS}{dt} = Q, \tag{18}$$

where S is the entropy per unity mass and Q is the rate of change of heating per unit volume. The system of equations composed with (8), (17) and (18) yields to gravity wave oscillations (Yeh and Liu, 1974). The larger the perturbation on the dynamical equilibrium the larger will be the effect of equation (18) and consequently larger will be the amplitude of oscillations. This is what one should except from the fact that entropy measures the disorder of the system and from the effect of equation (18) on the dispersion relation (see derivation in Yeh and Liu, 1974). During nuclear explosions the complete system of equations needs to be considered and the effect of equation (18) is considerable (large entropy variation during relatively short time intervals).

Horizontal diffusion and gravity waves can thus be considered as natural relaxation reactions in the lower atmosphere. The presence of either diffusion or gravity waves will break the vertical equilibrium and a vertical redistribution of energy takes place to restore the broken balance.

When gravity waves propagate, most often horizontally, they force the ionized part of the lower atmosphere to oscillate. This behavior is the result of the mechanical collision interaction between neutral and ionized species in the lower thermosphere. Also the production rates, of O_2^+ and NO^+, due to loss mechanisms of O^+ (equations 3 and 4) will present an oscillatory behavior. As a result the lower atmosphere perturbation will affect the O^+ content in the upper thermosphere, being thus transferred upwards. This is the relaxation mechanism to remove excess energy from the lower atmosphere to the above regions.

QUALITATIVE COMPARISION WITH EXPERIMENTAL RESULTS FOR LOW AND MIDDLE LATITUDES

A discussion is presented next on some experimental results that seem to confirm the validity of the mechanisms presented in sections 2 and 3.

Before considering actual experimental results, one must take into account the characteristics of earch?s orbit around the sun, that matter to our approach. The axis of revolution of the earth is tilted with respect to the normal to the orbital plane. This tilting is partially responsible for the seasonal differences. As a matter of fact, the receiving cross section of the summer hemisphere, for the energy input from the sun, can be larger than that of the winter hemisphere by as much as 27%. This excess heating, as pointed but before, should be redistributed in a global scale. Another 10% difference exists between the Southern Hemisphere summer (winter) and the Nouthern Hemisphere summer (winter). This difference results from the eccentricity of the earth's orbit around the sun, and must be taken into account in a quantitative model. North-south asymmetry of the neutral exosphere was discussed by Keating et al (1973) based on meridional circulation mechanism. It was realized that the heat input for the Southern Hemisphere should be greater than that of the Nouthern Hemisphere, considered the local summer at each hemisphere. This is a strong evidence of the effect of the eccentricity of the earth's orbit around the sun.

The so called winter anomaly, in the noon N_mF_2, can be qualitatively explained by our model. In fact, excess energy in the summer hemisphere will be removed along the magnetic field lines to the winter, energy depleted, hemisphere. The energetic particles entering in the protonosphere will increase the H^+ density. A consequent downward diffusion of O^+ ions will follow, resulting from an increase in the reaction rate of:

$$H^+ + O \rightarrow O^+ + H$$

which depends on the square root of the ion temperature (Fehsenfeld and Fergunson, 1972). This temperature is enhanced by the incoming hotter ions coming from the opposite hemisphere. These ions heat the local ions by the chemical reations (2). Since electrons are constrained by electrostatic forces to follow the ion motion, the diffusion of O^+ ions implies an electron flow into the F_2 region. The downward electron motion tends to bring down the F_2 peak, with a decrease in N_mF_2 (Rishbeth and Garriott, 1969), when no additional electron source is present. The extra electrons, brought from the opposite hemisphere, will increase N_mF_2 at this new h_mF_2. The net effect is a lower h_mF_2 with increased N_mF_2 in good agreement with experimental observation. This proposed mechanism is quite similar to that used by Evans (1965) and Carlson (1966) to explain the presunrise phenomena of the F_2 layer and follows the indication of Whitten and Poppoff (1971).

The qualitative description of a possible mechanism based on our model to explain a seasonal anomaly needs further test in order to be accepted. Actually the plasma flow will undergo a transformation on its ion composition in the transition between the thermosphere and exosphere. It continues its downward motion increasing the O^+ content in the thermosphere. The excess energy of the thermosphere yields a downward flow of atomic oxigen, according to reaction (3). The consequences of the complete process can be inferred as:

a) There is a net energy enhancement in the whole vertical above the location where energy incides (increase in the N k T product of all species).

b) All the products of chemical reactions should be observed as enhanced during winter.

Seasonal variations, which can be attributed to planetary waves (with probably annual period), have been observed in the lower thermosphere parameters (see Champion, 1967; Waldteufel, 1970; Zamlutti, 1973). For this type of wave only the latitudinal difference matters (Volland and Mayr, 1972b). Surplus incoming energy, which can be distinguished by an increase in the neutral temperature, was consistent in summer for the whole set of data referred above. Differences were observed in the ion neutral collision frequencies, which for the lowest latitudes (Zamlutti, 1973) follow the same behavior as neutral temperature, whereas for middle latitudes (Champion, 1967; Waldteufel, 1970) have an opposite characteristic, being larger in winter. The N k T product, from Waldteufel (1970) data, is at least 35% larger in winter than in summer for the neutral particles in the range 100-120 km. The middle latitude results of Waldteufel (1970) have been confirmed latter by Alcayde et al (1974) and Salah et al (1974). More recently, Alcayde et al (1979) and Marcos and Champion (1980) tried to include a linear temperature dependence on $\bar{F}_{10.7}$ solar flux index (Jacchia, 1970; Jacchia and Slowey, 1973) and obtained different results from middle latitude data. This last outcome is somehow questionable since the index itself includes a seasonal dependence. The linearity between temperature and solar flux may be a reasonable assumption for the regions where photoionization is followed by charge exchange reactions. In the lower thermosphere, where dissociative recombination is the loss mechanism, the linear relation is questionable. The thermospheric models themselves do not imply a linear correspondence between temperature and solar flux, in the lower thermosphere range (Jacchia, 1970). A more convincing account for the effect of the solar flux variations seems to be that of Salah and Evans (1973) which also include the $\bar{F}_{10.7}$ index seasonal variations. We therefore stay with the earlier results concerned middle latitude behavior (Waldteufel, 1970; Alcayde et al, 1974; Salah et al, 1974).

As far as the low latitude data (Zamlutti, 1973) are concerned, the interpretation is quite simple since the N k T product, for all particles species, follwos the seasonal behavior, i.e., it is larger in summer and therefore controlled exclusively by the local incident solar radiation, Then, no field aligned transport will disturb the energy equilibrium along the vertical above the given location. The energetic behavior will depend only on the incident solar radiation being larger during the summer. This manifests in the lower thermosphere with an increase in both temperature and collision frequency.

The middle latitude seasonal dependence can be analised in good agreement with our model. In fact, during summer, the energetic behavior is enhanced as observed in the temperature characteristics. The peculiar increase observed in the collision frequency, during winter, is certainly a result of the atomic oxigen flow predicted in our model. The possibility of an atomic oxygen enhancement to explain the collision frequency results was explored by Waldteufel (1970). Moreover it was also verified a relative increase of O^+ ions at and above the transition region betweem atomic to molecular ions. This outcome is consistent with the predictions based on the proposed model. to complement these evidences of the validity of the present approach to explain the winter anomaly, Waldteufel (1970) analysis has also shown that the observed composition changes could not be the result of just a thermal expansion; transport mechanism should be taken into account as we did in this work.

An interesting aspect of the proposed mechanism is that the lower thermospheric atomic oxygen concentration, for middle latitudes results, has large values during winter because of the increase in its production by chemical reaction (3), used to remove the excess energy from the upper thermosphere.

One last comment concerning the middle latitude results delected in this work (Alcayde et al, 1979) is that their semiannual density variation has no consistent support from other related data. In fact, the molecular nitrogen concentration is only affected by temperature variations (Johnson and Bauer, 1973), which presents an anual period (e.g. Salah and Evans, 1973). If a semiannual density variation was actually existing it would be also observed at lower latitudes, a result not confirmed by Zamlutti (1973) data. The invariance in the low latitude neutral molecular mass during solstices observed by Zamlutti (1973) and an expected decrease in the mean molecular mass, for middle latitudes during winter predicted in our model, are in agreement with the empirical OGO-6 model of Hedin et al (1974).

THE UPPER ATMOSPHERE BEHAVIOR AT HIGH LATITUDES

The magnetic field lines become closer to the vertical with increasing the geomagnetic latitude. A vertical quasi-static equilibrium cannot therefore hold at these locations during the day, except, may be, during quiet equinoctial days. This is what one should expect, as an extrapolation of the above proposed model, valid for lower and middle latitudes. This extension of our model is discussed in Blum and Schuchardt (1980) for explaining the observed seasonal latitudinal density variations of the minor thermospheric constituents. Moreover any energy disequilibrium occuring at atmospheric heights will disturb the auroral upper atmosphere. This sensitiveness to small energy variations also manifests in the auroral lower atmosphere region. This is to a certain extent predictable, since the shielding action performed by the upper regions at middle and low latitudes is drastically reduced by the vertical magnetic field transport mechanism. As a consequence, the entropy in equation (18) will vary in time scales shorter than the tidal periods characteristics of solar radiation excitation in the lower atmosphere region for high latitudes.

To increase the dynamical behavior complexity of the lower atmosphere at auroral latitudes, an additional energy input comes from particles precipitation. The net result is that the auroral region becomes a potential source of atmospheric waves for a wide range of frequencies. The generation of gravity waves is particularly important for high latitudes and can be interpreted as the natural relaxation behavior at these locations.

When low energy particles penetrates the upper atmosphere, above a given high latitude location, we still may assume that the chemistry mechanism of the two upper regions of our model will balance with transport. A quasi-equilibrium condition is then taken as a first order representation of the phenomena. Lower altitudes will be reached by downward chemical diffusion, with no other consequences than a horizontal diffusion, in the lower atmosphere. The above referred shielding action is still felt at low altitudes.

The incidence of high energy particles has a different reaction from the upper atmosphere system. These particles penetrate down to the lower atmosphere where most of their energy is released. The upper regions effects from these particles incidence are not as important as the lower altitudes perturbation. An increase of ionized particles provokes a gradient disequilibrium and a net horizontal flow of ionized particles is then possible, thus originating E-region currents. The particular current distribution in the polar ionosphere (Heelis, 1982), with current flowing from dayside to nightside region, is consistent with a winter downward ion flow, as proposed in our model. If the precipitation velocity is larger than the diffusion velocity, the diffusion mechanism is unable to explain the resulting phenomena. Under these circunstances the system of equations composed with (8), (17) and (18) is required to properly describe the behavior of the lower atmosphere. Electric fields are then invoked to account for the transport of charged particles (Banks et al, 1974; Rino et al 1977; Kamide and Brekke 1977; Brekke and Rino, 1978). The electric fields may be considered as a manifestation of the interaction of the stream of precipitating particles with the upper atmosphere system.

If one assumes a large downward ion velocity one gets, as a consequence of equation (8) a steady flow and, as a result, a negligible component of the electric field parallel to the magnetic field (Cole, 1971). Moreover no upper regions effect is felt to modify the ion velocity, which is only changed by mechanical collisions in the lower atmosphere. A careful balance of the effectiveness of the dissipation mechanisms, for the energy of precipitating particles, may be found in Cole (1975). The effect of an energy increase of the neutral particles may be removed either by an horizontal eddy diffusion (Johnson and Gottlieb, 1970) or by a meridional circulation with reverse sense to that of the ions flow (Richmond, 1979). An increase in neutral particles energy, as pointes out before, may also produce gravity waves.

Of particular interest is the fact that there is almost a steady state flow of particles in the upper atmosphere at auroral zones. The combined results of the last two considerations, on low and high energy particles, are therefore quite common. The net consequence is that low energy particles affect the lower atmosphere maintaining a background variation in the entropy. A small high energy particles flux may then be enough to increase the entropy to unstable levels with a consequent generation of gravity waves. The importance of the joule heating to this particular may be inferred from the works of Brekke and Rino (1978) and Maeda (1982). The interesting aspect of our model, as extended to high latitudes, is that the winter auroral zone, being energy depleted, must receive most of the energy from precipitation particles. This outcome is a straightforward consequence of equation (8) for the energy balance at exospheric heights.

QUALITATIVE COMPARISION WITH EXPERIMENTAL RESULTS RELATED TO HIGH LATITUDE BEHAVIOR

The bulk of available data, concerning the parameters we are interested in, is from the incoherent scatter radar at Chatanika (65,1°N, 147.5°W). A review on the matter was presented by Banks and Doupnik (1975).

The behavior of ionization can be summarized as follows:

a) Small enhancement of whole ionosphere in both opposition seasons (summer and winter), relative to the average equinoctial value, during daytime, for nonparticle precipitating condition.

b) Large enhancement of the lower ionosphere (mostly the E region) during particles precipitation condition.

The N-S component of the plasma drift was verified to be largest in the magnetic field line direction. The E-W component of plasma drift presented small amplitudes during quiet periods and was enhanced during particles precipitation periods.

The results from the Chatanika radar agree well with the predictions based in our model extension. The daytime redistribution of energy incident at only one hemisphere is clear from the first result of the ionization behavior a above. The dominance of the N-S component of the plasma drift for quiet days is an evidence of the effectiveness of the transport mechanism along the magnetic field lines in the exosphere. Moreover, it is easy to verify, from geometrical conditions, that the auroral receiving cross-section for the solar radiation is larger than twice, during summer, than that during equinox. Therefore after redistribution of ionization we may expect to have slightly more ionization at each hemisphere in the summer-winter opposition than during equinoxes.

The result b above, together with the increase of the E-W component of plasma drift, seems to confirm our predictions that horizontal transport should increase in the lower atmosphere, during particle precipitation periods. Moreover, this result shows that for high energetic particles the shielding effect of the above regions is very poor as predicted by our approach.

The winter hemisphere, being energy depleted, attracts particles precipitation and may therefore be more likely the locus source of TID's. This consequence of our model is consistent with experimental results (see review by Francis, 1975) and with the suggestion made by Georges (1968). The apparent controversy between the form of propagation (free or ducted waves) discussed in Francis (1975) is, to some extent, reduced in our model by the presence of a background triangular shape excitation due to seasonal differences between hemispheres. This particular shape is favorable to an energy growth with distance that compensates its atenuation (Francis, 1975). This may be a clue to the solution of the problem of explaning medium scale TID's in terms of gravity waves.

ADDITIONAL COMMENTS ON THE MODEL

The presented model can be considered satisfactory as far as a qualitative agreement with observed results are concerned. One can therefore suggest that it will be worthwhile to carry on simultaneous experiments at magnetic conjugated points, with enough time coverage, so that a quantitative test be possible.

In summary one can say that the approach based on energy differences is able to account for seasonal phenomena. Other classes of events, like localized releases of energy, may eventually be also explained with our model.

The shortcoming of the undertaken method is that the meridional transport mechanisms, for both exosphere and lower atmosphere, involve time scales incompatible with the consideration of instantaneous energetic differences. In fact, the diffusion velocity computed with expression (10), for a 30% energy density difference and exosphere temperature of 2.000ºK, is of the order of 2km/sec. This yields a diffusion time around 2 hr for the shell $L = 2$ and about 6 hr for the shell $L = 4$. The alternative is then to use average energetic difference for the involved time periods. Nevertheless the time restrictions, the 2 hr delay, between energy enhancement in one hemisphere and its effects in the opposite hemisphere, is consistent with the observed retardation in the daily maximum, of $N_m F_2$ in the winter, for mid-latitudes (Rishbeth and Garriott, 1969).

The alternative of using convenient time averaged values for the energy may be considered as a first order approximation for a tridimensional model. This extension is the one to be actually considered in a quantitative application of our method. To the moment, except for the consistency presented in last paragraph, not much can be added in favor of the quantitative reliability of the proposed approach.

CONCLUSIONS

A bidimensional differential model was suggested as a tool for studying seasonal phenomena comprised within a same context. The model was used in a qualitative way and the expected effects of it checked with experimental results. The comparisons were satisfatory to the light of evidences.

A quantitative test of the model is not straighforward since the basic assumption of nonrotating earth does not hold when seasonal disequilibrium occurs. The reason is that the involved transport mechanisms to restore the broken equilibrium imply in time scales of the order of a few hours, incompatible with any static assumption. Nevertheless this restriction, the proposed approach seems still consistent with experimental results. A longitudinal average of the energy was suggested to account for the earth's rotation. This can be considered as a first order approximation to a tridimensional extension of the model. Experimental data for a more effective quantitative test of our suggestion are still missing in a global scale.

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