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A NEW MECHANISM FOR THE MAINTENANCE OF FAIR WEATHER ELECTRIC FIELD AND CLOUD ELECTRIFICATION

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1. INTRODUCTION

Wilson's hypothesis of the global air-electric circuit with the thunderstorms as generators has not been proven up to now. The exact physical mechanism responsible for the generation of fair weather electric field is not clearly understood. Some of the recent remarkable observations showed evidence for the horizontal fields in the magnetosphere and ionosphere which penetrate at least into the stratosphere and perhaps into the troposphere (Kelly, 1983). In the present paper a gravity wave feed back mechanism for the coupling of the troposphere and the ionosphere has been discussed. The physical mechanism proposed can offer an alternate explanation for the atmospheric electrical phenomena during fair and disturbed weather.

2. A NEW PHYSICAL MECHANISM FOR THE TROPOSPHERE-IONOSPHERE COUPLING

A simple conceptual model for the coupling between the lower atmosphere and the ionosphere has been developed. The model considers certain physical processes in the atmospheric boundary layer (ABL) and the vertical mass exchange takes place through a gravity wave feedback mechanism. The vertical mass exchange couples the troposphere to the ionosphere leading to variations in the global magnetic field. It is shown in another paper of this Conference (Poonam Sikka et al., 1984) that there is a two way interaction between the ionospheric S_q current system and the weather systems in the troposphere. A geomagnetic storm in association with a solar flare enhances the vertical mass exchange resulting in the intensification of the weather systems in the troposphere.

The vertical chain of convective scale eddies is visualised to extend from the lower troposphere up to ionospheric S_q current system level. Turbulent eddies of surface frictional origin ride up on the envelopes of these convective scale eddies (Fig.1). It is shown that the microscale-fractional-condensation which takes place in the turbulent eddies provides a continuous supply of buoyant energy for the maintenance and growth of the large eddies in the vertical (Mary Selvam et al., 1983 a,b). The turbulent eddies perform vertical mixing of the large eddy volume with overlying environmental air. This results in vertical mass exchange in the atmospheric column extending from the surface to the ionospheric levels. This vertical mass exchange gives rise to upward transport of positively charged aerosols from the surface layers. An aerosol current thus flows in the vertical and extends up to ionospheric levels. This aerosol current is responsible for variations in the H component of the geomagnetic field. The aerosol current is a measure of the convective scale activity and thus the geomagnetic field variations are closely associated with weather systems in the troposphere. Any perturbation in troposphere would be transmitted to ionosphere and vice versa. A global perturbation in ionosphere as the one caused by solar variability, is transmitted to the troposphere influencing weather systems on global scale.

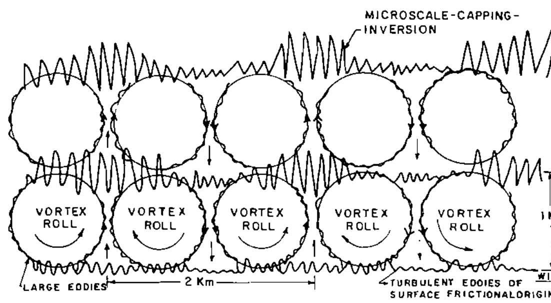

Fig.1 : Eddies in the atmospheric boundary layer.

The observational evidence for the vertical mass exchange and for the existance of vertical chain of eddies has been discussed (Poonam Sikka et al., 1984). The new physical mechanism proposed in the paper is useful for explaining certain atmospheric electrical phenomena which are discussed below.

3. DISCREPANCY IN AIR-EARTH CONDUCTION CURRENT DENSITY OBTAINED FROM DIRECT AND INDIRECT METHODS

In the indirect method the air-earth conduction current density (i_p) is estimated by taking the product of the atmospheric electric field (F) and the atmospheric electrical conductivity (λ).

$$i_p = F(\lambda_+ + \lambda_-) = F\lambda_{total}$$

In the direct method the total conductivity is estimated from the electrical relaxation time t of the atmosphere i.e., the time taken for an insulated charged conductor to attain 1/e of its initial charge as a result of charge leakage in the atmosphere. The total conductivity is equal to the inverse of the electrical relaxation time of the atmosphere.

The air-earth conduction current (i_d) by the direct method of measurement is given as

$$i_d = F \lambda_{direct}$$

Observations show consistently that $i_d = \frac{1}{2} i_p$ at all levels in the atmosphere (Chalmers, 1967, Rosen et al., 1982). The discrepancy between i_d and i_p can be explained as follows.

Turbulent eddy fluctuations transport air from lower to higher levels and vice versa inside the turbulent eddy volume. Thus excess positive space charges from lower hemisphere of the turbulent eddy are carried up and excess negative charges from upper hemisphere are brought down. Thus there is an aerosol current i_t inside the turbulent eddy volume which is given by

$$i_t = \frac{0.5V}{t}(N_+\uparrow + n_+\uparrow + N_-\downarrow + n_-\downarrow)$$

where V = Volume of the turbulent eddy$=\frac{4}{3}\pi r^3$

t = Turbulence time period$= \frac{2\pi r}{w}$

N and n represent respectively the large and small ion concentrations in the atmosphere. The arrows indicate the direction of motion.

Thus at any time, half the number concentration of ions in any volume of atmosphere are taking part in the turbulent aerosol vertical current i_t. This dynamical charge separation process occurs at the turbulent eddy circulation speed of about $1ms^{-1}$ which is two orders of magnitude larger than the small ion mobilities. Thus a charged insulated conductor at any point in the atmosphere loses charge by leakage due to static small ion mobilities of half the number concentration of total ions present in the atmosphere. Hence the atmospheric electrical conductivity λ_d determined by the direct method will be equal to half the conductivity due to the total ion concentration of the atmosphere.

Thus $\lambda_d = \frac{1}{2} \lambda_{total}$

Therefore $i_p = 2 i_d$

The observed discrepancy in the air-earth conduction current density determined by the direct and indirect method is due to the dynamical vertical charge separation process taking place in the atmosphere by turbulent eddy fluctuations.

4. UNIVERSAL DIURNAL VARIATION OF POTENTIAL GRADIENT

The universal diurnal variation of potential gradient shows a maximum at about 1900 GMT. This observation has been attributed to the global thunderstorm activity which has a peak at about 1900 GMT in the tropical regions. The conventional theory for the maintenance of the fair weather electric field postulates that thunderstorms are the main generators of global atmospheric electric field i.e.the thunderstorms transfer negative electric charge to earth by lightning and provide the return path of the positive air-earth currents in fair weather regions of the globe. The vertical mass exchange mechanism offers an alternate explanation which is discussed below.

The lower troposphere is coupled to the ionosphere by the vertical eddy chain as described earlier. In the regions of thunderstorm activity the ionosphere is perturbed. These perturbations cause travelling ionospheric disturbances (TID) which propagate to all regions of the globe with supersonic speeds. Thus maximum ionospheric perturbation in the form of enhanced turbulent eddies occurs around 1900 GMT throughout the globe. This global ionospheric turbulent eddy enhancement is transmitted to lower tropospheric levels by the vertical eddy chain. Hence the vertical mass exchange processes are enhanced in the lower troposphere which result in the enhanced aerosol current and gives rise to larger surface atmospheric electric fields. Thus the universal diurnal variation of the surface atmospheric electric field is a response of the vertical mass exchange processes to the global ionospheric turbulent eddy energisation due to global thunderstorm activity.

5. VERTICAL PROFILE OF ATMOSPHERIC ELECTRICAL CONDUCTIVITY

The atmospheric electrical conductivity is found to increase with height exponentially. This observed profile can be derived from the new theory of vertical mass exchange as follows:

Vertical mass exchange occurs in the atmospheric column extending from the surface to ionospheric levels. At a height z from the surface, a fraction f of surface air will be transported. Similarly starting from the ionosphere as the origin, a fraction f of ionospheric airmass will be transported down to a height z from the ionosphere. Thus small ions from the ionosphere are transported downwards while at the same time large ions (charged aerosols) are transported upward from the surface. The increase in small ion concentration with height can be computed as follows starting from the surface concentration of small ions.

As surface air rises up its volume gets reduced to a fraction f due to dilution by vertical mixing i.e., by influx of air from higher levels. The rate of influx of air from higher level at any level $z = (1/f - 1)$. Thus if n_* is the small ion concentration at the surface, the small ion concentration n at environment of the microscale-capping-inversion and charge separation results in a positive dipole layer. When this positive dipole layer reaches sufficient intensity the positive surface atmospheric electric field starts decreasing and reaches a minimum about the noon time. Maximum positive dipole strength results from the maximum turbulence intensity in the capping-inversion layer. Also, the positive dipole layer is at a maximum height of 1 km above the surface during the noon time. During the afternoon the positive dipole aerosol layer becomes weaker due to decrease in turbulence intensity and the surface atmospheric electric field starts increasing. The noon time minimum in surface electric field over urban areas can thus be explained by the formation of positive dipole charged aerosol layer in the rising inversion of the daytime ABL. Over the oceanic and rural areas the noon time minimum in the surface electric field is absent. Instead there is a single maximum in the surface electric field at the noon time. This is due to lower particulate concentration and turbulence intensity in the rising inversion of the day time ABL over the rural areas than over urban areas. The positively charged dipole layer overhead is weak and will not result in the reduction of the positive surface electric field. Thus turbulence intensity plays a major role in the formation of the overhead aerosol layer and the charge separation in it.

9. SUNRISE EFFECT

Observations of the surface electric field over the globe during the past century have shown that the electric field starts increasing from a minimum well before the ground sunrise. Various theories have been put forth to explain the observed 'sunrise effect'. However none of them have proved totally satisfactory.

In the following an alternate theory has been invoked to explain the observed sunrise effect. Gravity waves are generated in the ABL (Mary Selvam et al., 1983a) due to the microscale-fractional-condensation process which gives rise to migrating eddies with semi-diurnal periodicity and stationary with respect to local time. This is the semi-diurnal tidal oscillation which gives rise to the semi-diurnal pressure variation. The low pressure at pre-sunrise hours gives rise to convergence and upward mass flux. The upward mean flux gives rise to the aerosol current which results in the increase in the surface atmospheric electric field. Thus the 'sunrise effect' of the surface atmospheric electric field is due to the early morning minimum in surface pressure and the resultant upward aerosol current.

10. TROPOSPHERE-MAGNETOSPHERE COUPLING

The turbulent eddies of surface frictional origin ride up on the envelopes of large eddies and get transported to ionospheric and magnetospheric levels. It is postulated that the presence of these turbulent and large eddies at ionospheric and magnetospheric levels give rise to the non-thermal radio continuum emissions, field aligned currents and allied phenomena, which have been observed by satellites (Barbosa, 1982, Saflekos et al.,1982).

11. EXTRA-TERRESTRIAL EFFECTS

The turbulence scale interaction of eddy systems described earlier, with the solar wind at the magnetopause give rise to energy/mass exchange between the solar wind and the magnetosphere/troposphere through the vertical eddy chain system. Thus the solar wind leaves the fine structure signature on the earth's atmosphere and in turn carries the fine structure signature of the earth's atmosphere.

Thus it is possible that there is mutual energy/mass exchange between the solar and planetary atmospheres in the solar systems. This concept may be extended to stellar atmosphere also i.e., there is mutual energy/mass exchange between galaxies in the universe. The above physical mechanism may explain the ionospheric effects of x-rays from discrete galactic sources reported by some investigators (e.g., Ananthakrishnan et al.,1970).

It has been found from satellite observations that the inter-planetary magnetic field carries the signatures of the Earth, Jovian and Saturnian magnetospheres and also that there is mutual interaction between Jovian and Saturnian magnetospheres (Intriligator et al., 1979). Thus the energy/mass exchange by turbulent eddies between planetary atmospheres and the solar atmosphere (heliosphere) may lead to a feedback effect of the planetary magnetospheres on the solar activity. It is thus postulated that the solar activity may be controlled by a feedback effect from the planetary magnetospheres interacting with the solar heliosphere, the energy/mass exchange between the solar and planetary atmospheres taking place basically by the turbulent eddy mixing process analogous to that occuring in the earth's atmosphere. The above physical mechanism may also explain the statistical relationship between the solar cycle and planetary motion reported by some investigators (e.g., Morth and Schlamminger,1979)

12. CLOUD ELECTRIFICATION

Extensive aircraft observations of cloud liquid water content, corona discharge current cloud drop charges and vertical velocities in-warm monsoon clouds indicates that turbulent eddies are mainly responsible for charge separation mechanism in clouds with the cloud drops acting as charge carriers (Mary Selvam et al., 1982). Naturally occuring negative space charges from higher levels are brought down by turbulent downdrafts. These negative space charges get attached to condensing water droplets in the updraft. The updrafts from subcloud layer carry a net positive space charge which get attached to larger cloud drops near cloud top regions. Downdrafts in precipitating clouds thus bring down positively charged droplets. This is basically the convective type of charge separation mechanism originally proposed by Vonnegut (1955). The turbulent eddies have circulation speeds several times larger than the large eddy (cloud) and thus the charge separation takes place faster than the

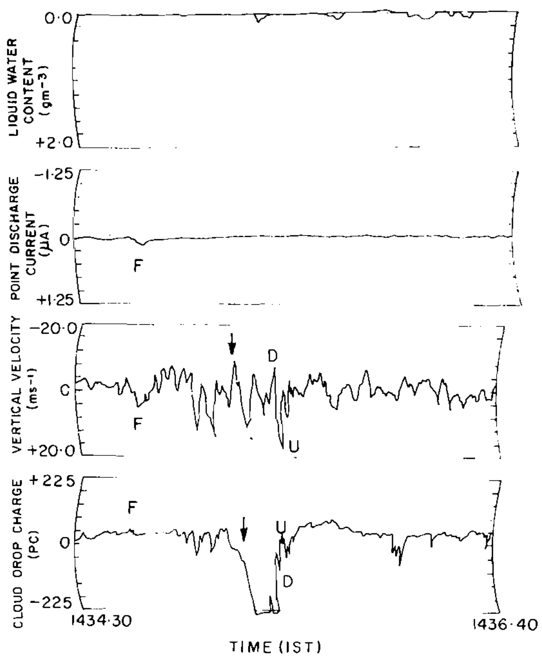

Fig.4 : Recording of cloud drop charge, vertical velocity, point discharge current and liquid water content obtained during aircraft panetration into small growing cloud of depth 600 m on 12 August 1982. Regions of updrafts/downdrafts are closely associated with positive/negative space charges in the clear air region. Arrow indicates location of the downdraft region associated with negative space charges which are transported upwards into the growing cloud from adjacent updraft region. F indicates the clear air updraft region with small positive electric field showing the presence of positive space charges.

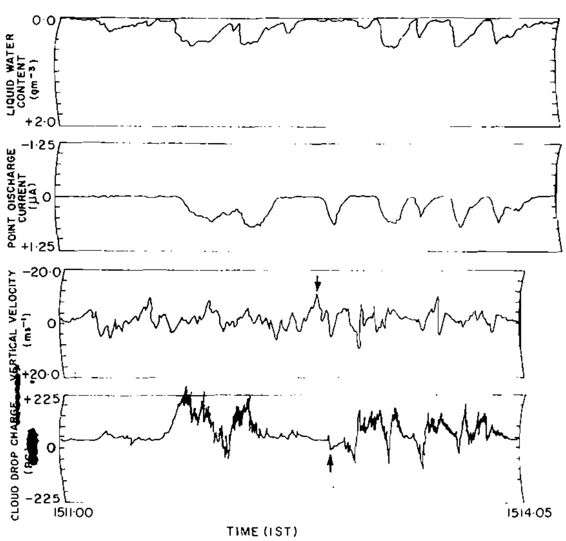

Fig.5: Same as Fig.4. For a growing cloud of depth 1500 m. Arrow indicates regions of downdraft and associated negative charges in clear air. These negative charges are transported in the adjacent updraft regions which are associated with higher liquid water content and electric fields. When the width of the downdraft region is larger positively charged cloud drops originating from cloud-top regions are noticed.

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