Remote Sensing of Geomagnetic Field and Applications to Climate Prediction

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Abstract
Observations show that geomagnetic field lines follow closely the atmospheric circulation patterns (Gribbins, *New Scientist* 5 Feb., 350-353, 1981). and that geomagnetic field variations are precursors to climate change (Courtillot *et al.*, *Nature* 297, 386-387, 1982). Therefore close monitoring of the local and global geomagnetic field variations by satellite systems will assist prediction of hurricane tracks, intensification and also long-term weather trends. The exact mechanism for the observed close relationship between global geomagnetic field and the tropospheric weather patterns is not clear. In this paper a universal theory of atmospheric eddy dynamics is presented which shows that the global geomagnetic field, atmospheric electric field and weather systems are manifestations of a semi permanent scale invariant hierarchical atmospheric eddy continuum. The scale invariant energy structure for the atmospheric eddy continuum has been documented and discussed (Lovejoy and Schertzer, *Bull. Amer. Meteorol. Soc.* 67, 21-32, 1986). In summary, quantitative equations are derived to show that the full continuum of atmospheric eddies exist as a unified whole and originate from buoyant energy supply from frictional turbulence at the planetary surface (Mary Selvam *et al.*, *Proc. VII Int'l. Conf. Atmos. Elec.* June 3-8, 1984, Albany, N.Y., 154-159). Large eddy growth occurs from turbulence scale by the universal period doubling route to chaos (Fairbairn, *Phys. Bull.* 37, 300-302, 1986). The turbulent eddies are carried upwards on the large eddy envelopes and vertical mixing occurs by the turbulent eddy fluctuations resulting in downward transport of negative space charges from from higher levels and simultaneous upward transport of positive space charges from surface levels. The eddy circulations therefore generate a large scale vertical aerosol current which is of the correct sign and magnitude to generate the horizontal component of the geomagnetic field. Therefore, atmospheric circulation patterns leave signature on the geomagnetic field lines whose global variations can be easily monitored by satellite borne sensors and thus assist in weather and climate prediction.

Introduction
Numerous studies indicate correlation between geomagnetic field variations and tropospheric weather activity (Herman and Goldberg, 1978; Gribbins, 1981; Courtillot *et al.*, 1982; Kalinin and Rozanova, 1984; Taylor, 1986). However, the exact physical mechanism for the observed coupling between meteorological and geomagnetic phenomena is not yet identified. In this paper a gravity wave feedback mechanism for the troposphere-ionosphere coupling is proposed.

Physical Mechanism
Vertical mass exchange in the troposphere-ionosphere-magnetosphere takes place by means of an eddy continuum. Any perturbation in the troposphere would be transmitted to ionosphere and vice versa. A global perturbation in the ionosphere, as the one caused by solar variability, is transmitted to troposphere influencing weather systems/geomagnetic/atmospheric electrification processes (Mary Selvam *et al.*, 1984; Poonam Sikka *et al.*, 1984). The atmospheric boundary layer (Mary Selvam and Murty, 1985; Mary Selvam and Murty, 1987; Mary Selvam, 1987). The circulation speed of the large eddy is related to that of the turbulent eddy
according to the following relation (Townsend, 1956). 

\[ W = w_\ast \]

where \( W \) and \( w_\ast \) are respectively the root mean square (r.m.s.) circulation speeds of the large and turbulent eddies and \( R \) and \( r \) their respective radii. The production of buoyant energy (turbulent scale) is maximum at the crest of the large eddy system. The turbulent eddies at the crest of the large eddies are identifiable by a micro scale capping inversion \( i_i \) which rises upwards with the convective growth of the large eddy in the course of the day. This is seen as the rising inversion of the day time \( i_i \) planetary boundary layer \( i_i \) in echosonde records. A conceptual model of the large and turbulent eddies in the \( i_i \) atmospheric boundary layer \( i_i \) is shown in Figure 1.

The turbulent eddy fluctuations mix overlying environmental air into the growing large eddy volume and the fractional volume dilution rate \( k \) of the total large eddy volume across unit cross section on its envelope is equal to

\[ k = \frac{w_\ast}{dW} \]

where \( w_\ast \) is the unidirectional turbulent eddy acceleration and \( dW \) the corresponding acceleration of the large eddy circulation (Mary Selvam and Murty, 1985) during the large eddy incremental length step growth \( \frac{dR}{i_i} \) equal to \( \frac{dR}{r} \). The variable \( \frac{dR}{i_i} \) is greater than \( \frac{dR}{r} \) for \( i_i \) less than \( \frac{dR}{r} \). Therefore organized large eddy growth can occur for scale ratio \( \frac{dR}{r} \) greater than or equal to \( \frac{dR}{r} \). Therefore a hierarchical scale invariant self similar eddy continuum with semi permanent dominant eddies at successive decadic scale range intervals is generated by the self-organised period doubling route to chaos growth process. The large eddy circulation speed is obtained by integrating Eq. 2 for large eddy growth from the turbulence scale energy pump at the planetary surface and is given as

\[ W = w_\ast f_0 \]

The steady state fractional upward mass flux of surface air is dependent only on the dominant turbulent eddy radius \( i_i \).

\[ Eddy Energy Spectral Slope\]

The eddy energy power spectrum is conventionally plotted as \( W_{i_i} \) versus \( f_0 \) and \( f_0 \) as a function of frequency. The steady state fractional upward mass flux of surface air is dependent only on the dominant turbulent eddy radius \( i_i \).

\[ E = f_0 \]

The spectral slope \( \frac{dR}{i_i} \) of the scale invariant eddy energy continuum is given as

\[ S = \ln \frac{E_0}{E} \]

The rising large eddy gets progressively diluted by vertical mixing due to the turbulent eddy fluctuations and a fraction \( f_0 \) of surface air which reaches the normalized height \( i_i \) is given by (Mary Selvam and Murty, 1985)
Therefore the universal period doubling route to chaos eddy growth mechanism gives rise to an eddy energy continuum spectral slope equal to $-2$. The universal scale invariant power spectrum for eddy energy has been observed in the atmospheric boundary layer turbulence (Van Zandt, 1982).

### Quantum Mechanical Nature of the Eddy Energy Structure

The kinetic energy $KE_i$ per unit mass of an eddy of frequency $n_i$ in the hierarchical eddy continuum is shown to be equal to $H n_i$, where $H$ is the spin angular momentum of unit mass of the largest eddy in the hierarchy. The circulation speed $W_{pl}$ of the largest eddy in the continuum is equal to the integrated mean of all the inherent turbulent eddy circulations. Let $W_{pl} = 2R$, the mean circulation speed or the zero level about which all the smaller frequency fluctuations occur.

### Normal Distribution Characteristics of the Eddy Energy Perturbation Field

Natural phenomena possesses energy/geometrical structure which is found to follow statistical normal distribution characteristics. The eddy continuum energy spectral slope is derived from the cumulative normal distribution curve as follows: $r = (dR/R) = 1/2$. The standard deviation $s_i$ with a cumulative probability of occurrence equal to $dR/(R+dR) = 0.35$. The cumulative normal probability distribution also gives $s_i/dR = 0.32$ probability at one standard deviation in close agreement with the statistical parameters generated by the period doubling sequence. Further, the slope of the log-log plot of the cumulative normal probability distribution at one standard deviation is equal to $-1.8$ for the eddy energy spectra.

The statistical distribution characteristics of natural phenomena commonly follow normal distribution associated conventionally with random chance. The normal distribution is characterized by the $\mu_i$ moment coefficient of skewness equal to $\mu_i$, signify-
ing $i/i_{symmetry}$. The $i/i_{moment coefficient of kurtosis}$ is equal to $\partial_{i/i} \cdot 3/i_{i}/i_{b_i}$ and represents the $i/i_{intermittency of turbulence}$. In the following it is shown that the universal period doubling route to chaos growth phenomena in nature gives rise to the observed statistical normal distribution parameters as a natural consequence. The period doubling route to growth is initiated and sustained by the turbulent (fine scale) eddy acceleration $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$; which then propagates by the inherent property of inertia of the medium. Therefore, the statistical parameters $i_{i_{mean}}/i_i$, $i_{i_{variance}}/i_i$, $i_{i_{skewness}}/i_i$ and $i_{i_{kurtosis}}/i_i$ of the perturbation field in the medium is given by $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$; $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$ respectively. By analogy, the perturbation speed $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$ (motion) for each second of the medium sustained by its inertia represents the mass, $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$ the momentum (or potential energy) and $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$ the spin angular momentum since an eddy motion has an inherent curvature to its trajectory. Because the eddy motion is inherently symmetric with bi-directional energy flow, the $i_{i_{skewness}}/i_i$ factor $b_{i/i} \cdot w_{sub}^{+}/i_{sub}^{+}/i_{i}/i_{b_i}$ is equal to zero for one complete eddy circulation thereby satisfying the law of conservation of momentum. The $i_{i_{moment coefficient of kurtosis}}$ which represents the intermittency of turbulence is shown in the following to be equal to $b_{i/i} \cdot 3/i_{i}/i_{b_i}$; as a natural consequence of the growth phenomenon by period doubling route to chaos.

From Eq.3/$i_{center}/i_{img}$ SRC=“Dweq.gif” height=55 width=158 $i_{center}/i_{img}$ SRC=“Kurteq.gif” height=61 width=248 $i_{center}/i_{img}$ SRC=“Kurval.gif” height=73 width=195 $i_{center}/i_{img}$ SRC=“Keq.gif” height=61 width=301

The above non-linear model represents the population values of the parameter $b_{i/i} \cdot X_{i}/sub_{i}/sub_{i}/sub_{i}$ at different time periods of $b_{i/i} \cdot X_{i}/i_{b_i}$; for small $i$/sub_{i}/sub_{i}/sub_{i}$ X_{i}/i_{i}/i_{b_i}$; and $i_{Feigenbaum’s (1980) research showed that the two universal constants $b_{i/i} \cdot a = -2.5029/i_{i}/i_{b_i}$ and $b_{i/i} \cdot d = 4.6692/i_{i}/i_{b_i}$ are independent of the details of the non-linear equation for the period doubling sequences where $b_{i/i} \cdot a_{i}/i_{i}/i_{b_i}$; and $b_{i/i} \cdot d_{i}/i_{i}/i_{b_i}$ denote the successive spacing ratios of $b_{i/i} \cdot X_{i}/i_{i}/i_{b_i}$ and $b_{i/i} \cdot L_i/i_{i}/i_{b_i}$ respectively for adjoining period doublings.$i_{font_i}$ $i_{br_i}$ $i_{font_i}$ face=“Arial,Helvetica”$i_{center_i}$ $i_{ip_i}_img$ SRC=“A2eq.gif” height=61 width=4
From Eq. (3) where \( b_{ij}^1 k_{ij}/b_{ij}^2 \) is the Von Karman's constant representing the non-dimensional steady state fractional volume dilution rate of large eddy by turbulent eddy fluctuations across unit cross-section on the large eddy envelope. Therefore \( b_{ij}^1 a_{ij}/b_{ij}^2 \) represents the non-dimensional total fractional mass dispersion rate and

\[
b_{ij}^1 a_{ij}/b_{ij}^2 \text{ represents the fractional energy flux into the environment.}
\]

Let \( b_{ij}^1 d_{ij}/b_{ij}^2 \) represent the ratio of the spin angular momentum for the total mass of the large and turbulent eddies. Let \( a \) represents the non-dimensional total fractional mass dispersion rate and \( a^2 \) represents the fractional energy flux into the environment. Therefore \( 2a^2 = 3d \) from Eqs. (8) and (9). The variable \( b_{ij}^1 2a_{sup}^2 i_{sup}/i_{ij}/b_{ij}^2 \) represents the total eddy energy flux into the environment in the bi-directional eddy energy flow and \( b_{ij}^1 3d_{ij}/i_{ij}/b_{ij}^2 \) represents the threefold increase in spin angular momentum generation in the large eddy during the period doubling sequence growth. In an earlier section it was shown that the period doubling sequence is associated with a three-fold increase in the spin angular momentum of the resulting large eddy and accounts for the \( a \) moment coefficient of kurtosis of the normal distribution. Therefore the above equation relating the universal constants is a statement of the law of conservation of energy, that is, the period doubling growth process generates a three fold increase in the spin angular momentum of the resulting large eddy and propagates outward as the total large eddy energy flow in the medium. The property of inertia enables propagation of turbulence scale perturbation in the medium by release of the latent energy potential of the medium. An illustrative example is the buoyant energy generation by water vapour condensation in the updraft regions in the atmospheric boundary layer.

\[
\text{Model for Atmospheric Electric and Geomagnetic Field}
\]

\[
h = \text{f_{ij}/b_{ij}^2}
\]

The atmospheric electric field \( F \) at any level can be expressed in terms of the surface concentration \( s_{ij} \) as:

\[
F = 4 \text{f_{ij}/b_{ij}^2}
\]

The computed vertical profile of electric field is shown at Figure 2 and is in agreement with observations (Imyanitov and Chubarina, 1967). The aerosol current at

\[
f_{ij}/b_{ij}^2
\]

The aerosol current at
any level \( i_{b_{a}}i_{\tilde{z}}i_{\tilde{b}_{a}}/b_{a} \) is given as \( i_{a} = (i_{f}/z_{*}f) x (w_{z_{*}f}/i_{b_{a}}) \) producing by the vertical mass exchange generates the observed atmospheric electric field. The conventional air earth conduction current (Chalmers, 1967) cannot discharge the atmospheric electric field thus produced since the dynamic charge transport by the vertical mass exchange process is faster than the ion mobilities by more than one order of magnitude. The convective scale aerosol current can be computed from Eq.(12) and shown to be \( j_{b_{a}}i_{\tilde{b}_{a}}1000i_{\tilde{b}_{a}}/b_{a} \) times larger and in opposite direction to the convective air-earth conduction current. The vertical aerosol currents are of the right order of magnitude and direction as those of the vertical current postulated to exist in the atmosphere by Bauer (1920) and Schmidt (1924) in their hypothesis for explaining the variations in the \( j_{b_{a}}i_{\tilde{b}_{a}}H_{b_{a}}i_{\tilde{b}_{a}}/b_{a} \) component of the geomagnetic field. The aerosol currents occur over convective scale, that is, one square kilometer and thus were not detected by conventional spot observations. The universal period doubling route to chaos growth process generates scale invariant atmospheric eddy continuum circulations extending from the planetary surface to the magnetospheric levels and above manifested in the geomagnetic field observations. Observational evidence for the tropospheric eddy continuum extension into the ionosphere is seen in satellite observations which indicate that increased currents at ionospheric levels are accompanied by a simultaneous increase in wind speed at lower levels. Measurements with \( j_{b_{a}}i_{\tilde{b}_{a}}Poker Flat/i_{\tilde{b}_{a}} \) radar and with \( j_{b_{a}}i_{\tilde{b}_{a}}NOAA/i_{\tilde{b}_{a}} \) radar at \( j_{b_{a}}i_{\tilde{b}_{a}}Fairbanks/i_{\tilde{b}_{a}} \) support this contention. The wind energy coupling in the terrestrial magnetosphere is indicated by the geomagnetic micropulsations and therefore also signal the continuous solar wind energy supply modulation of \( j_{b_{a}}i_{\tilde{b}_{a}}magnetosphere \) processes is well established and are therefore reflected in the tropospheric weather phenomena at the lower levels of the atmospheric eddy continuum which is a two-way energy flow channel between the lower and upper atmospheres. Therefore extra-terrestrial trigger of tropospheric weather changes can be forecast from the precursor signal from geomagnetic field variations. The scale invariant self-similar atmospheric eddy continuum generated by the universal period doubling route to chaos growth process exists as a unified whole, spanning the total planetary atmospheric boundary layer from the planetary surface to the outermost limits of the magnetosphere and is in constant two-way communication for energy flow from solar and other planetary/stellar atmospheres. The fine structure signal of the unified atmospheric eddy continuum is manifested as the luminescence phenomena of the auroral oval, where field-aligned currents in discreteauroral arcs indicated bi-directional eddy energy/charge flow. Field aligned currents in discrete auroral arcs are visible manifestations of atmospheric vertical mixing coupled to solar wind pumping of negative space charges downwards accompanied by simultaneous upward transport of terrestrial positive ions. Therefore, the aerosol currents originating from the planetary surface extend into the magnetosphere in the discrete auroral arcs and couple to the solar wind energy pump accounting for the observed close association between solar wind dynamic parameters, discrete auroras and geomagnetic micropulsations (Feldstein and Galperin, 1985). Therefore ground based monitoring of geomagnetic micropulsations will indicate the extra-terrestrial energy flow rate into the planetary atmosphere. The above theory proposed for \( j_{b_{a}}i_{\tilde{b}_{a}}magnetosphere \) - ionosphere - troposphere - energy coupling is consistent with satellite observations of the close association between magnetic field aligned currents, parallel electric fields, inverted \( j_{b_{a}}V_{i}/i_{b_{a}} \) structures and plasma pressure inhomogeneities in the magnetosphere and related geomagnetic micropulsations (Lundin and Evans, 1985; Chmyrev et al., 1985; Stasiewicz, 1985; Bosqued et al., 1986).