6.2 MIDDLE ATMOSPHERE ELECTRICAL ENERGY COUPLING

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The middle atmosphere (MA) has long been known as an absorber of radio waves, and as a region of nonlinear interactions among waves. The region of highest transverse conductivity near the top of the MA provides a common "return" for global thunderstorm, auroral "Birkeland", and ionospheric dynamo currents, with possibilities for coupling among them. Their associated fields and other transverse fields "map" to lower altitudes depending on scale size. Evidence now exists for motion-driven "aerosol" generators, and for charge trapped at the "base" of magnetic field lines, both capable of producing large MA electric fields. Ionospheric "Maxwell" currents (curl H) parallel to the magnetic field appear to map to lower altitudes, with rapidly time-varying components appearing as displacement currents in the stratosphere. Lightning couples a (primarily ELF and ULF) current transient to the ionosphere and magnetosphere whose wave shape is largely dependent on the MA conductivity profile. Electrical energy is of direct significance mainly in the upper MA, but electrodynamic transport of minor constituents such as "smoke" particles or CN may be important at other altitudes.

Electrical Energy in M.A.

From Inside: "Big Fields" [Bragin/Hale; Tyutin/Maynard/Croskey]
Wind Driven Horizontal Aerosol [Curtis]
Gravity Driven Vertical Aerosol [Maynard and Aikin]

From Below: "Classical" G.C. [C. T. R. Wilson]
Lightning Radiation [J. R. Wait, Sentman]
"Charge Perturbation" [Hale and Baginski; Kelley and Siefring]

These due to removal
of "relaxation time"
restriction

From Above: Perpendicular E-Fields [Park and D.]
"Mapping" [Mozer Mafia; Hans Volland]
"Trapped Charge" [Hale]
Parallel J Maxwell [Hale]
(curl H) Mapping [?]

Knowledge before MAP summarized in:
N. C. Maynard (Ed) Middle Atmosphere Electrodynamics, NASA CP 2090
Subsequent reviews:
R. A. Goldberg, JATP 46, 1984, ESA SP-270, 1987
M. C. Kelley, Rev. Geophys. SP SCI. 21, 1983
L. C. Hale, Adv. Space Res., 4, 1984

Energy to Middle Atmosphere from Below
"D.C." output of T-storm ~10^8W but only ~ 1% above 20 km ~10^6W
~ 1000 storms = 10"W, 10^9W above 20 km
Locally ~ 10^{-6} W/m^3 at 20 km (10^{-3}W/kg) but decreasing exponentially with altitude.

Lightning radiation (mainly VLF) is ~ 1% of flash energy [Krider and Guo] of about 10^9 J/flash x 100 - 1000 FL/s mostly deposited in middle M.A. [Sentman], thus ~ 3 x 10^9W globally, 2 x 10^{-10}W/m^3 average, perhaps ~10^{-8} W/m$_3$ maximum at 60 km (10^{-2} W/kg).

However, in 1981 Penn State and Cornell (at NASA Wallops Facility) measured transients of orders of magnitude greater duration than predicted by conventional theory resulting in two Ph.D. theses: M. E. Baginski, Penn State, 1988 and C. L. Siefring, Cornell, 1988, and so far two accepted publication: L. C. Hale and M. E. Baginski, Nature, 329, 814, 1987 and M. E. Baginski, L. C. Hale, and J. J. Olivero, Geophys. Res. Lett., in press.
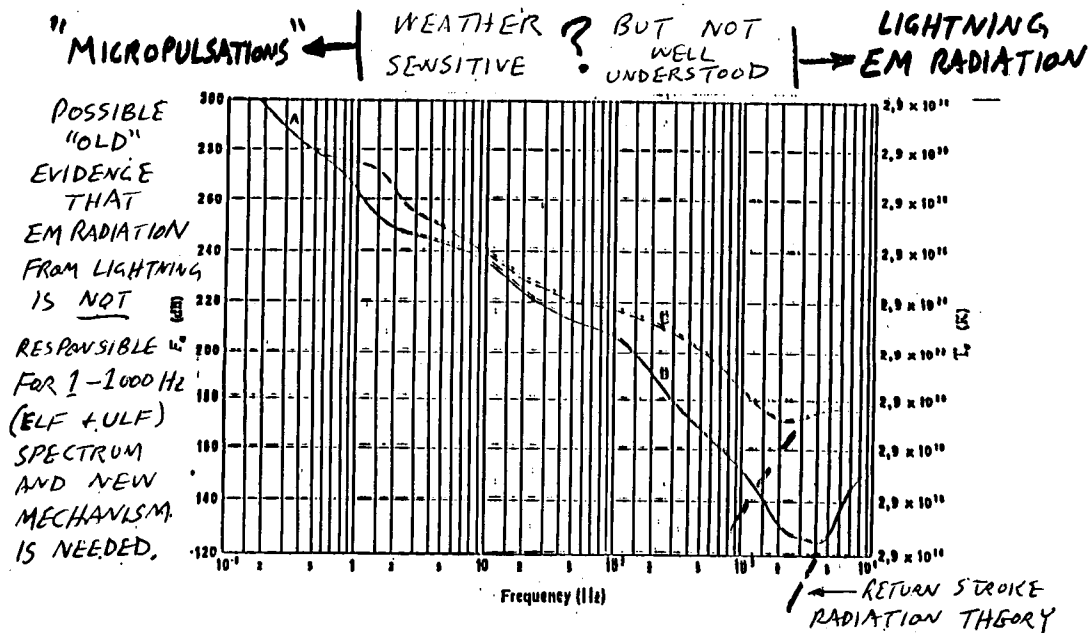

Figure 1. F minimum and maximum vs. frequency (0.1 to 10' Hz), A - micropulsations, B - minimum value expected of atmospheric noise, c - maximum value expected of atmospheric noise. Atmosphere noise spectrum after Spaulding in: *Handbook of Atmospherics*, H. Volland, Ed., CRC, Boca Raton, 1982.
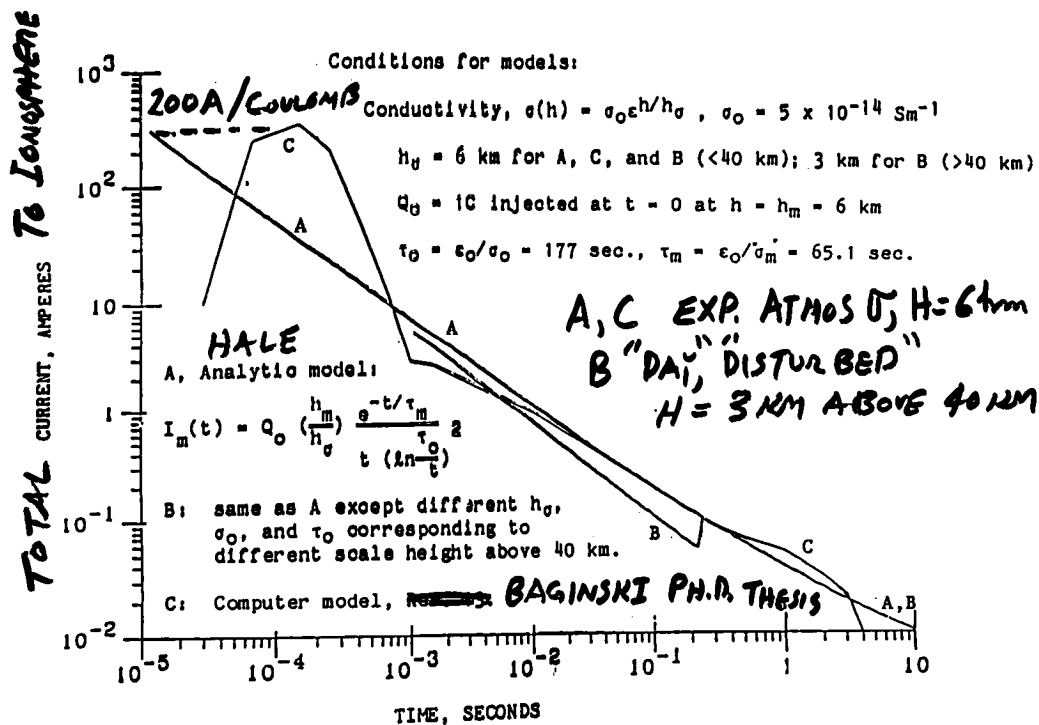
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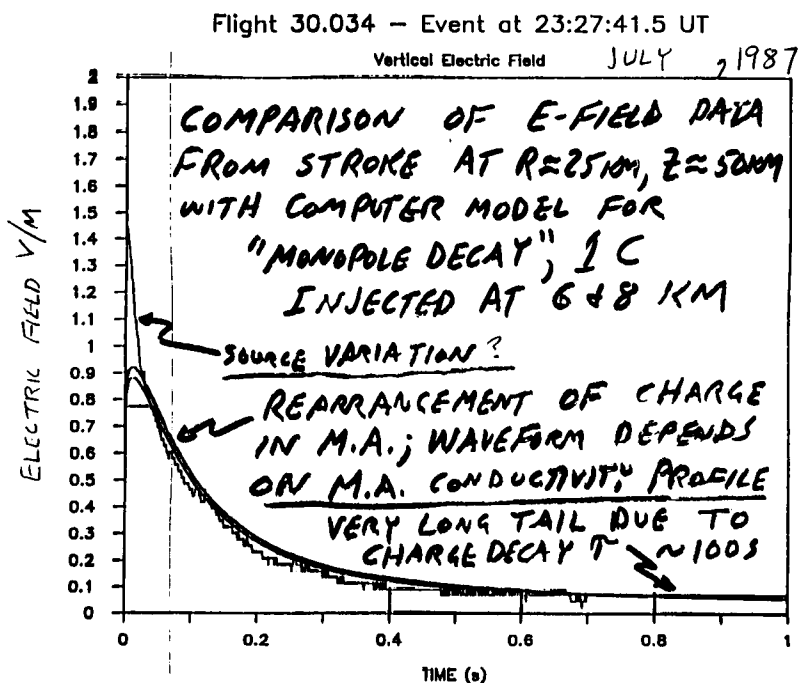Figure 2. Comparison of computer model with analytic model of 'monopole decay'.

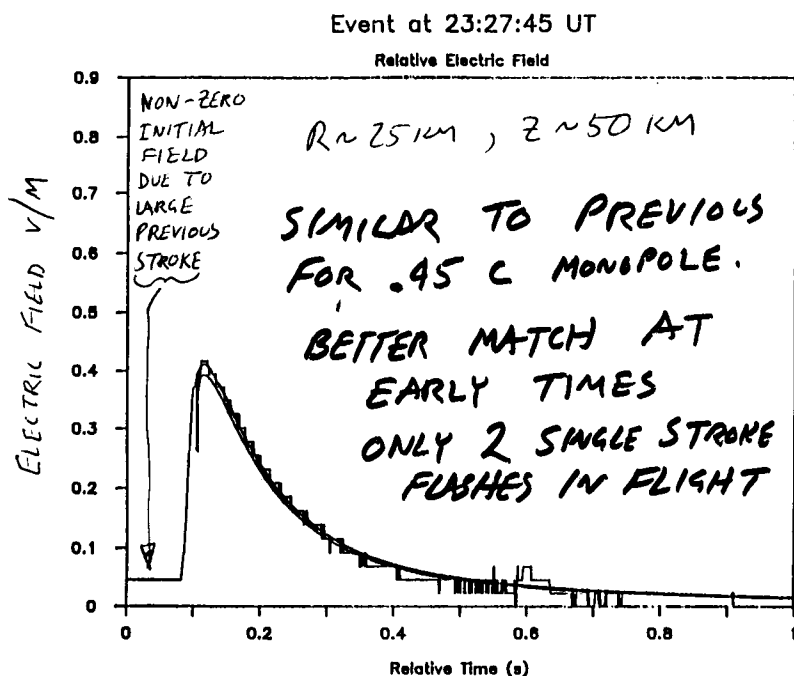Figure 3. Experimental verification of theory on rocket over thunderstorm.

Figure 4. Experimental verification of theory on rocket over thunderstorm.

LIGHTNING LAUNCED // CURRENTS
MOVE RIGHT UP FIELD LINES:

127.4s -10^{-6}

A m^{-2} O   #3

147KM $+10^{-6}$ LIGHTNING

                                    PRECIPITATED
                                    ELECTRONS ?
                                             ?
109.8s -10^{-6}

A m^{-2} O   # 2

120KM $+10^{-6}$

                                    MORE LIKELY
                                    LOW ENERGY
                                    "RELAXATION"

74s -10^{-6}

A m^{-2} O   # 1
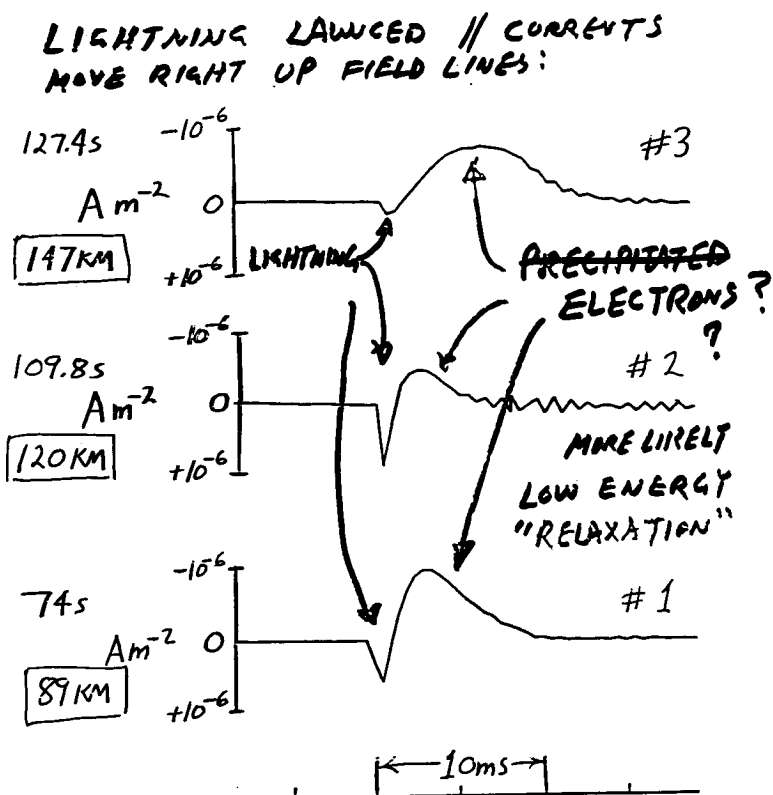
89KM $+10^{-6}$

|←— 10ms —→|

Figure 5. 33.052, 0155 UT, 15 July 1987: Three events related to Cornell E-field and "whistler" events. Not well correlated with lightning locator and initial direction indicates IC lightning or "positive" lightning.

Nongenerality of "Relaxation Time":
Maxwell's equations:

$$\nabla \cdot H = J + \frac{\partial D}{\partial t}, \; \nabla \cdot D = \rho$$

Assume **J** only conduction current and constant ε, $D = \varepsilon E$

Isotropic scalar σ, $\tau_{rel} = \varepsilon/\sigma$

Take divergence:

$$\nabla \cdot \nabla \times H = \nabla \cdot (\sigma E) + \nabla \cdot \frac{\partial D}{\partial t}$$

$$0 = E \cdot \nabla\sigma + \sigma\nabla\cdot E + (\partial/\partial t) \; \nabla\cdot D$$

$$0 = E \cdot \nabla\sigma + \sigma\nabla\cdot E + \varepsilon\frac{\partial E}{\partial t}$$

or $\quad 0 = \underline{E \cdot \nabla\sigma} + (\frac{\sigma}{\varepsilon})\rho + \frac{\partial \rho}{\partial t}$

if and only if
$\underline{\nabla\sigma \equiv 0}$

$$E = E_0 \varepsilon^{t/\sigma_{rel}}$$

$$\rho = \rho_0 \varepsilon^{t/\tau_{rel}}$$

singularity on boundary plays havoc with

Energy to Middle Atmosphere from Above

Fair weather return current $\sim 3 \times 10^{-12}$ A/M^2 - 10^{-11} W/M^3 at 20 km ($\sim 10^{-6}$ W/KG) decreasing exponentially with altitude.

"Tangential" E-fields "map" downwards depending on scale size [Park and D.; Mozer and students, Volland] could produce substantial heating in upper middle atmosphere ($\sim$80 km) in PCA [Banks].

Low latitude balloon measurements show $\sim$30 mV/M horiz field ($> 10 \times$ expec.) carried over 1000s of km could perturb D.C. global circuit [Holzworth].

"Parallel" "D.C." fields do not map well but J_{max} (curl H) at ELF couples capacitively so AC magnetospheric fields appear as displacement currents in middle atmosphere.

Relaxation of "Relaxation Time" restrictions $\rightarrow$ charge from REP electrons trapped at base of magnetic field lines -- could explain reversal of E-field during REP, lightning triggering [Hale, *Nature, 327*, p. 769].
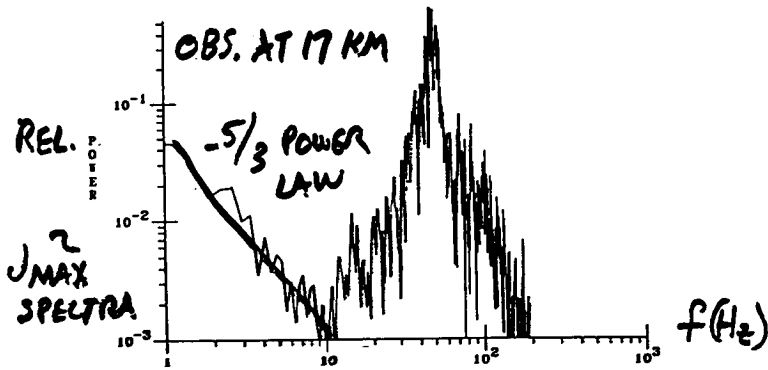
Figure 6. Conjuctive comparison with Viking satellite showed similar but featureless spectra [Lönnquist]. Now believe "feature" originates in magnetosphere, $J_{Maxwell}$ "maps" to middle atmosphere.
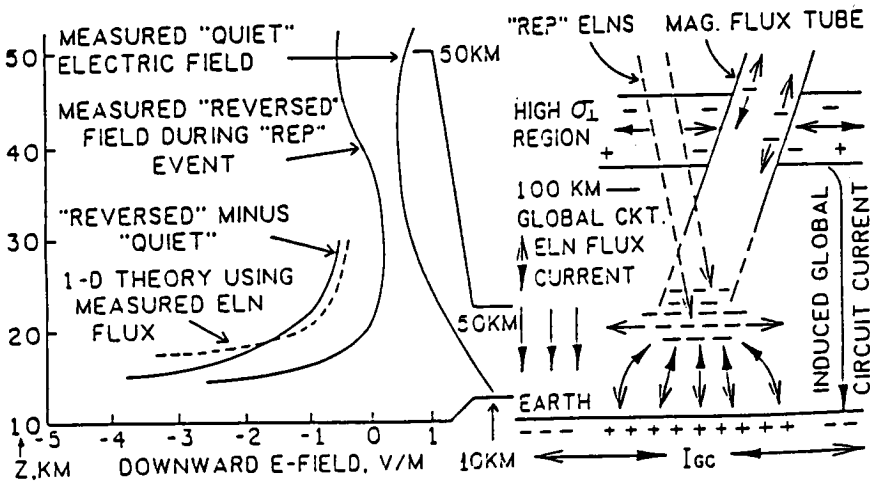

Figure 7. Removal of "relaxation time" restriction leads to possibility of excess charge due to high energy particles depositing at base of field lines and persisting for very long times, thus greatly enhancing coupling to lower altitudes.
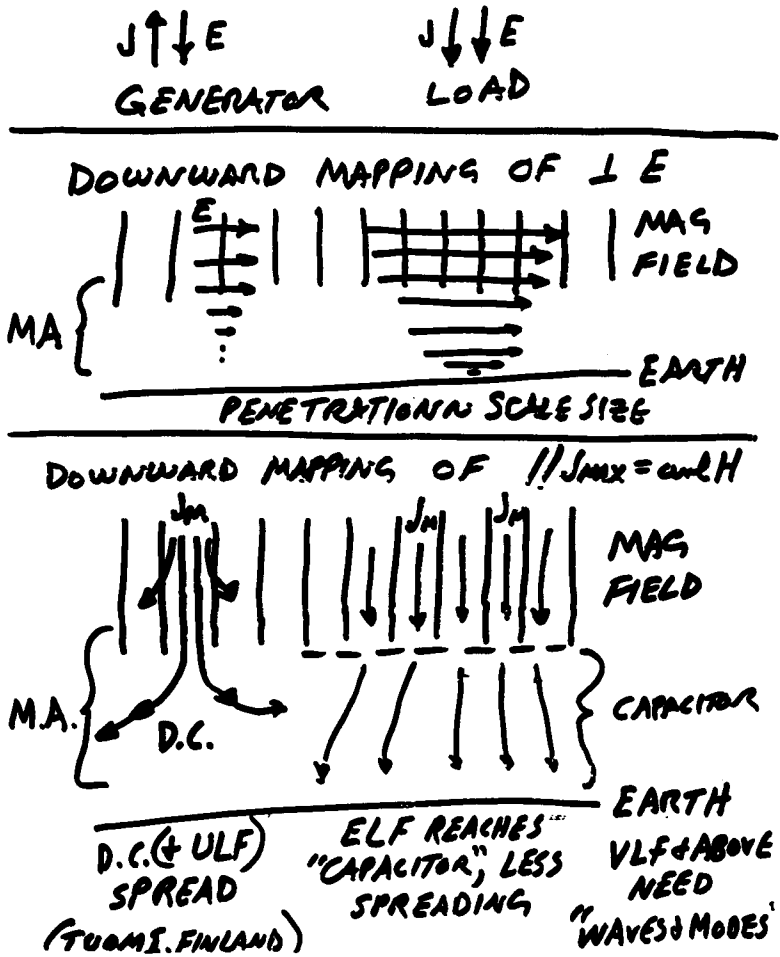
Figure 8.