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]

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
Energy to Middle Atmosphere from Below

"D.C." output of T-storm $\sim 10^8 W$ but only $\sim 1\%$ above 20 km $\sim 10^6 W$

$\sim 1000$ storms $= 10^7 W$, $10^9 W$ above 20 km

Locally $\sim 10^{-6} W/m^3$ at 20 km ($10^{-3} W/kg$) but decreasing exponentially with altitude.

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


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.
Figure 2. Comparison of computer model with analytic model of 'monopole decay'.

Conditions for models:

- Conductivity, \( \sigma(h) = \sigma_0 e^{h/h_0} \), \( \sigma_0 = 5 \times 10^{-14} \text{ S m}^{-1} \)
- \( h_d = 6 \text{ km} \) for A, C, and B (<40 km); 3 km for B (>40 km)
- \( Q_0 = 10 \) injected at \( t = 0 \) at \( h = h_m = 6 \text{ km} \)
- \( \tau_0 = \varepsilon_0/\varepsilon_0 = 177 \text{ sec.}, \tau_m = \varepsilon_0/\varepsilon_m = 65.1 \text{ sec.} \)

A, C: EXP. ATMOS 05, \( H = 6 \text{ km} \)
B "DAI, DISTURBED"
\( H = 3 \text{ km} \) ABOVE 40 km
Figure 3. Experimental verification of theory on rocket over thunderstorm.

Figure 4. Experimental verification of theory on rocket over thunderstorm.
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:
\[ \nabla \cdot H = J + \frac{\partial D}{\partial t}, \quad \nabla \cdot D = \rho \]
Assume \( J \) only conduction current and constant \( \varepsilon, D = \varepsilon E \)
Isotropic scalar \( \sigma, \tau_{rel} = \varepsilon/\sigma \)
Take divergence:
\[ \nabla \cdot \nabla \times H = \nabla \cdot (\sigma E) + \nabla \cdot \frac{\partial D}{\partial t} \]
\[ 0 = E \cdot \nabla \sigma + \sigma \nabla \cdot E + \nabla (\partial E/\partial t) \cdot \nabla D \]
\[ 0 = E \cdot \nabla \sigma + \sigma \nabla \cdot E + \frac{\partial E}{\partial t} \]
or
\[ 0 = E \cdot \nabla \sigma + \left( \frac{\sigma}{\varepsilon} \rho + \frac{\partial \rho}{\partial t} \right) \]
if and only if
\[ \nabla \sigma = 0 \]
\[ E = E_0 e^{\tau_{rel}} \]
\[ \rho = \rho_0 e^{t\tau_{rel}} \]
singularity on boundary plays havoc with

Energy to Middle Atmosphere from Above
Fair weather return current ~ 3 \times 10^{-12} \text{ A/M}^2 - 10^{-11} \text{ W/M}^3 at 20 km (~10^{-6} \text{ 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 (~80 km) in PCA [Banks].

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

"Parallel" "D.C." fields do not map well but \( J_{max} (\text{curl } H) \) 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, $J_{\text{Maxwell}}$ "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.