Sample of field aligned currents
(see ΔB_ϕ on view graph)

Ionosphere Currents

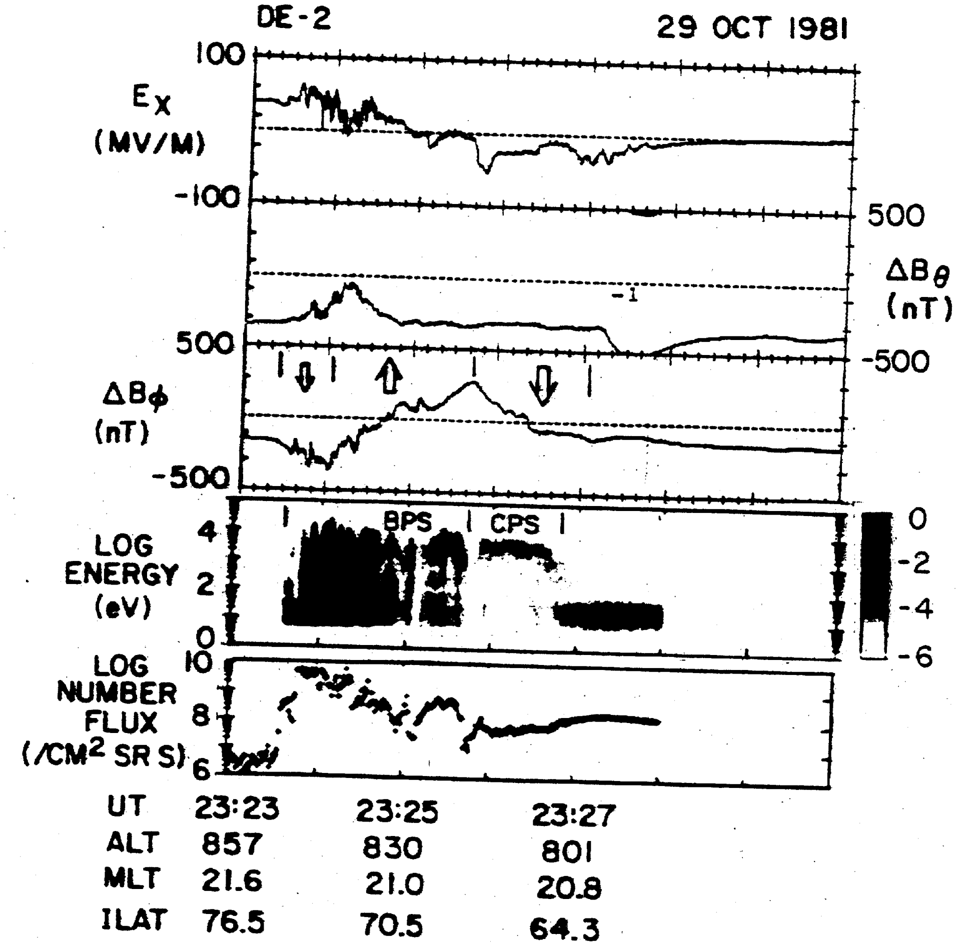
Now $\sigma \neq \infty$ in ionosphere $\rightarrow$ so what is $\overleftrightarrow{\sigma}$?

below ~ 85 km σ is scalar
from 85 $\rightarrow$ 300 km $\overleftrightarrow{\sigma}$ is tensor
with important components ~~ot~~ $\perp B$
above ~ 300 km $\overleftrightarrow{\sigma} = \sigma_0 \hat{B}\hat{B}$ only has
a component along $\vec{B}$

We want a relationship between
Driving Electric field and Current:

$$\vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E}$$

calculate $\overleftrightarrow{\sigma}$ in these 3 region



The components of the electric and magnetic fields and the electron spectrogram and number ... Fig. 2 caption) for an evening pass on October 29, 1981.

...onent of the electric field, the dipole ... and east-west components of the ...eld, and the electron energy-time ...at zero degree pitch angle and the ...mber flux obtained from LAPI, for a ...ide pass near magnetic local time ...urs on October 20, 1981. Electrons ...e in the energy range 5 eV to 32 keV. ... mode of operation a 32 point energy ... obtained every second. The electric ... field data are 1/2 second averages. ... indicate that the upward field-...rent region extends approximately from ...0758:20, and that a downward current ... from 0758:20 to about 0759:00. The ...rections are schematically indicated by ...he figure. The x component of the ...eld in Figure 2 (and also in Figure 3 ...outhward. Therefore the coefficient ...tion between E_x and ΔB_ϕ has an opposite ... case shown in Figure 1. The termi-...nningham et al. (1975) has been found ...etermining the relationships between the characteristics of electrons and field-aligned currents. According to Winningham et al. (1975), the electron flux precipitating from the central plasma sheet (CPS) is relatively stable with respect to 'substorm time' and spatially uniform, and its variation, if any, is a uniform increase or decrease in intensity. The boundary plasma sheet (BPS) precipitation is characterized by highly variable plasma precipitation poleward of the CPS region. It is in the BPS region that structures such as the 'inverted V' are observed, as seen in the figure. As to the field-aligned currents, it is more convenient for the present purpose to categorize the field-aligned current regions simply by upward and downward current regions rather than by regions 1 and 2 as is usually done following the nomenclature of Iijima and Potemra (1976).

In Figure 2 the upward field-aligned current region coincides with the inverted V's in the boundary plasma sheet (BPS) precipitation and the downward current region is inside the central plasma sheet (CPS). In this example there is a i

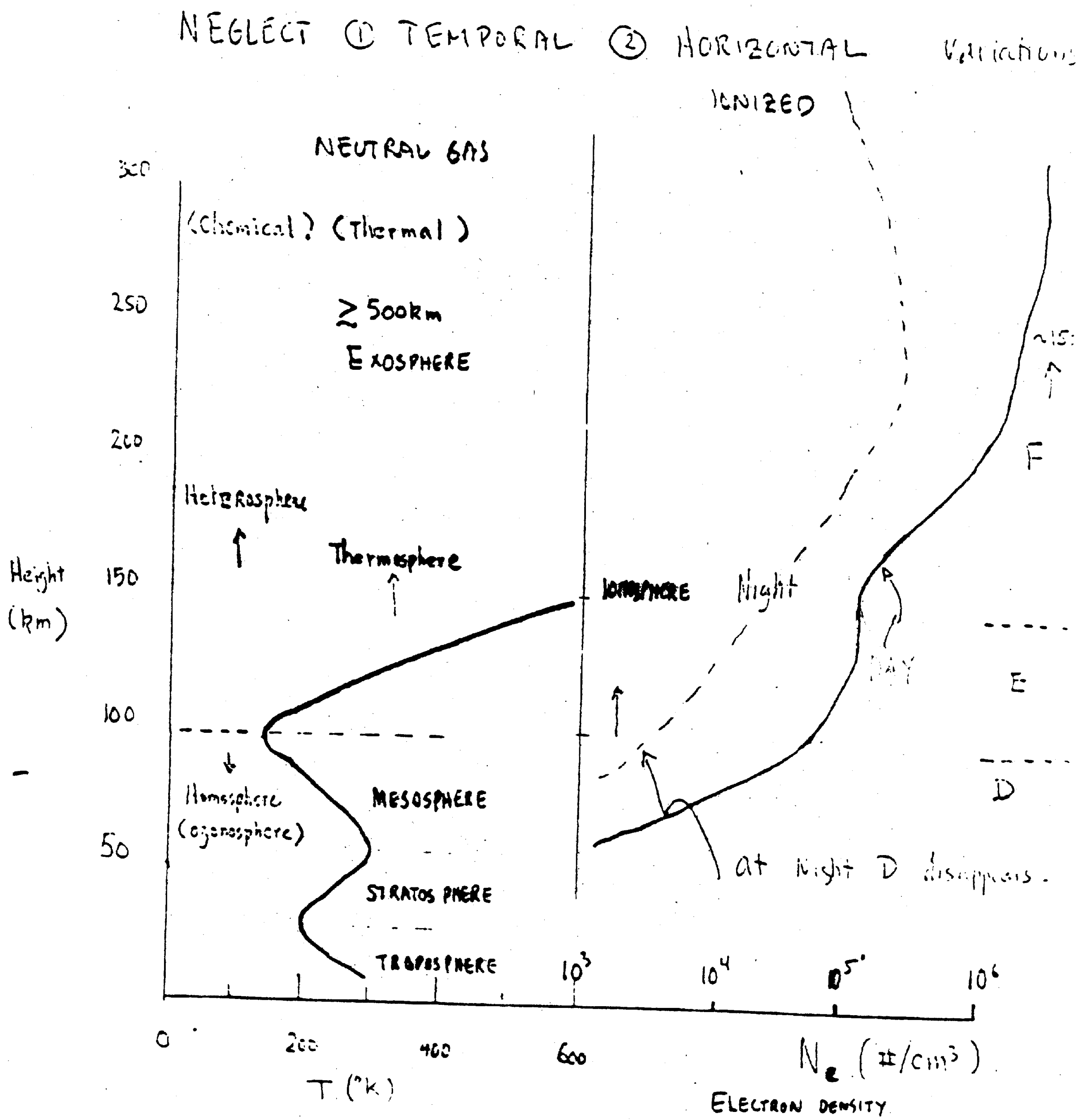


Figure 13 - Electron density as a function of height.

Fig 4.1

R. Germany

Laboratory 4

re rocket-borne ion mass
developments. Interest is
nts and related progress
omponent. Attention is
composition measure-
ction of neutral trace
tion mass spectrometry.
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e ion mass spectrometry in
erimental methods,
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tion not only on ions, but
lusters and, perhaps most
ral trace gases, which
measured ion composition.
chemical ionization mass
lty being due to the high
rom the long-range charge-
rable cases, PACIMS may
as per cm^3. Various
MS in the middle
derstanding of trace gcs
A most striking example is
here by PACIMS (ARNOLD and
e gas gives rise to the
at least temporarily influ-
an impact on climate.
ion of meteoric metal atoms
t al., 1971) which catalyt-

were originally used in the
e the gas pressure is
mass spectrometer to be
into the denser atmospheric
eters yielded the first ion
..sphere.

detection at very low total ion concentrations, with 100-10,000 cm^{-3} being typical of most parts of the middle atmosphere.

The first ion mass spectrometer equipped with a compact high speed cryopump was built by the group of Narcisi at the AFGL (Air Force Geophysics Laboratory; formerly Air Force Cambridge Research Laboratory) and successfully flown on a rocket on October 31, 1963 (NARCISI et al., 1965). This pioneering experiment opened a new area of atmospheric research. In the meantime, various research groups including those at NASA Goddard Space Flight Center, Greenbelt, Maryland (NASA), at the Max-Planck-Institut for Kernphysik, Heidelberg (MPIK), and at the University of Bern (UB) joined the AFGL group in this difficult field of research and contributed to make rocket-borne ion mass spectrometry a vivid and productive area of research up to the present time.

More recently, sampling of middle atmospheric ions was greatly extended by balloon (ARNOLD et al., 1978; ARIJS et al., 1979), aircraft (HEITMANN and ARNOLD, 1983), and most recently also by parachute-borne drop-sonde ion mass spectrometry (PFEILSTICKER and ARNOLD, 1984). Thus, atmospheric ion mass spectrometry now covers the entire range of the middle atmosphere (10-100 km) and even major parts of the troposphere (Figure 1). These recent extensions have revealed new aspects and possibilities of atmospheric ion research, some of them also stimulating new interest in the upper parts of the middle atmosphere, which can be probed only by using rocket-borne ion mass spectrometers. A striking manifestation of this renewed interest is the development of a novel parachute-borne drop-sonde mass spectrometer payload which is carried by a single-stage rocket to 60-70 km. Recently, this "dropmas" payload was flown for the first time by the MPIK group (PFEILSTICKER and ARNOLD, 1984) with great success.

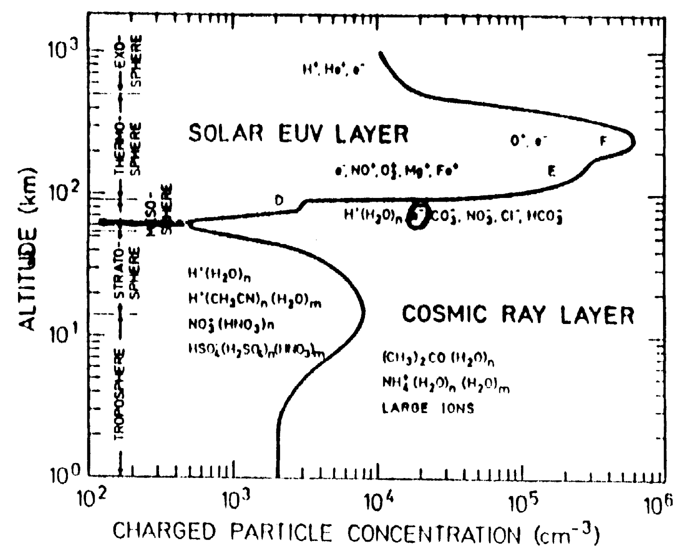

Figure 1. Schematic representation of the atmospheric ionized component.

Arnold + Viggiaro, 1986

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What is $\overleftrightarrow{\sigma}$?

σ_1 (atmosphere) - is scalar up to 85 km. For a single atmospheric ion species at dc:

$$\sigma = \frac{ne^2}{m\nu} \text{ (Spitzer Conductivity)}$$

ν is due to ion-neutral collisions and comes from Boltzman Equation:

$$\frac{\partial f}{\partial t} + \vec{V}\cdot\frac{\partial f}{\partial \vec{r}} + \frac{q}{m}(\vec{E} + \vec{V}\times\vec{B})\frac{\partial f}{\partial \vec{V}} = \left.\frac{\partial f}{\partial t}\right|_c \text{ (= 0 in fluid theory)}$$

let $f = f_0 + f_1$ and $f_1 \ll f_0$

$$\left.\frac{\partial f}{\partial t}\right|_c = \frac{f(\vec{r},t) - f_o}{\underbrace{\tau(V)}_{\text{Velocity Dependent}}} \simeq \frac{f(\vec{r},t) - f_o}{\underbrace{\tau}_{\text{mean collision time}}}$$

relaxes to f_0 after long tim

set $\nu \equiv \dfrac{1}{\tau}$ to get: $\sigma = \dfrac{ne^2}{m\nu}$ for each species

To get n integrate Boltzman eqtn. over $\vec{V}$:

$$\frac{dn}{dt} = \frac{\partial n}{\partial t} + \nabla\cdot(n\vec{V}) = 0 = \text{Source} - \text{Sink}$$

(steady state non convecting)

$$= \underbrace{\Pi}_{\text{pair production}} - \underbrace{\alpha n^2}_{\text{recombination}} - \underbrace{\beta n_A n}_{\text{Aerosol Attachment}}$$

What is σ_1 ? (Low Atmosphere)

$$m\frac{d\vec{V}}{dt} + m\nu\vec{V} = e\vec{E} \quad \text{(force eqtn.)}$$

To solve: assume plane wave superposition in steady state:

$$\vec{V} = \frac{e}{m(\nu - i\omega)}\vec{E}_0 e^{-i\omega t}$$

From which we can get σ by using

$$\vec{J} = \sum_s n_s e_s \vec{V}_s = \sigma\vec{E} \quad \text{(Ohms Law)}$$

for a single species at dc:

$$\sigma = \frac{ne^2}{m\nu} \quad \text{(Spitzer Conductivity)}$$

What is $\overleftrightarrow{\sigma}_2$

Now that we understand better where ν (collision frequency) comes from, we can go back to simple equations again. Look at the Force equation on a particle

$$m\frac{d\bar{V}}{dt} + \nu m\bar{V} = e(\bar{E} + \bar{V}\times\bar{B}) \quad \left(\begin{smallmatrix}\text{Lorentz}\\ \text{force}\end{smallmatrix}\right)$$

"ad hoc" resistance term - ultimately from $\left.\frac{\partial f}{\partial t}\right|_{collision}$ term of Boltzman

take Steady state $\left(\frac{\partial}{\partial t} = 0\right)$

and incorporate the $\bar{V}\times\bar{B}$ term into $\overleftrightarrow{\sigma}$

That is $\quad \nu_s m_s \bar{V}_s - e_s \bar{V}_s\times\bar{B} = e_s\bar{E}$ ← same type equation for each species

3 equations and 3 unknowns (V_x, V_y, V_z)

we want $\quad \vec{J} = ne\vec{V} = \overleftrightarrow{\sigma}\cdot\vec{E}$

so write out component equations

$$\nu m V_x - eV_yB_z + eV_z\cancel{B_y} = e\bar{E}$$

0 $\quad \vec{B} \parallel \hat{z}$

$\vdots$

Same for x, y, z

Sum over species to get

What is $\overleftrightarrow{\sigma}_2$? (ionosphere)

$$\overleftrightarrow{\sigma} = \begin{pmatrix} \sigma_P & \sigma_H & 0 \\ -\sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_o \end{pmatrix} \qquad \text{where using } \omega_s = \frac{e_s B}{m_s}$$

$$\sigma_P = \sum_s \frac{n_s e_s^2 \nu_s}{m_s(\omega_s^2 + \nu_s^2)} = ne^2\left(\frac{\nu_-}{(\omega_-^2 + \nu_-^2)m_-} + \frac{\nu_+}{(\omega_+^2 + \nu_+^2)m_+}\right)$$

$$\sigma_H = \sum_s \frac{n_s e_s^2 B}{m_s^2(\omega_s^2 + \nu_s^2)} = ne^2\left(\frac{\omega_-}{(\omega_-^2 + \nu_-^2)m_-} - \frac{\omega_+}{(\omega_+^2 + \nu_+^2)m_+}\right)$$

NOTES:

1. $\sigma_P \rightarrow \sigma_o = \dfrac{ne^2}{m\nu}$ for $B = 0$

2. For $B \rightarrow 0$, $\sigma_H \rightarrow 0$

3. In E-region ionosphere $\omega_- \gg \nu_-$ (electrons) but $\omega_+ \ll \nu_+$ (ions)

$$\text{so } \sigma_H \approx \frac{ne^2}{m\omega_-}$$

What is σ_3?

σ_3 is similar to σ_2 except that in this region $\sigma_o \to \infty$

So σ_P and $\sigma_H \ll \sigma_o$

Thus we treat the $\vec{B}$ field lines as highly conducting wires for $\lambda > 300$ km and $\tau > 10^2$ sec.

So $\overleftrightarrow{\sigma}_3 = \sigma_o \hat{B}\hat{B}$

Now look at example.

Note that at some altitude we have that $\Omega = \frac{eB}{m}$ becomes smaller than collision frequency ν

That is below some altitude $\Omega_s << \nu_s$ if this altitude is different for species then can have one species $\bar{E}\times\bar{B}$ drifting because they are still "magnetized" while the other species is colliding too frequently with neutrals to make a gyro orbit.

since $\Omega \propto \frac{1}{m}$ >> for electrons than ions

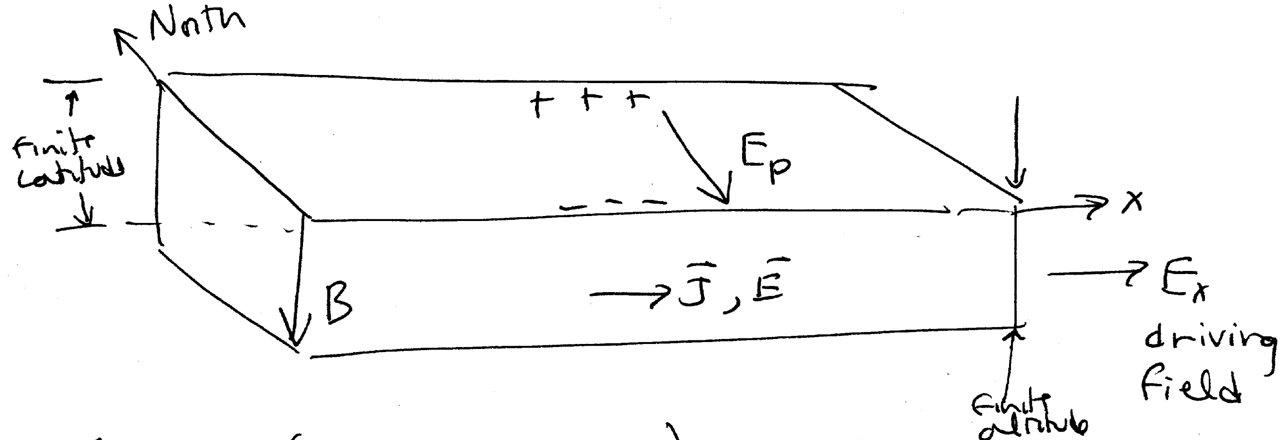
we have a region between ~ 85 and 120 km where

$$\Omega_e >> \nu_e \quad \text{but}$$
$$\Omega_i << \nu_i$$

so electrons $\bar{E}\times\bar{B}$ drift but ions do not

$\therefore$ The Hall term NOW gives a current! (because only one sign of charge is drifting)

Case 1
SLAB of Northern hemisphere Ionosphere



$$\overleftarrow{\sigma} = \begin{pmatrix} \sigma_P & \sigma_H & 0 \\ -\sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_0 \end{pmatrix} \qquad \overline{E} = \begin{pmatrix} E_x \\ E_p \\ 0 \end{pmatrix}$$

$$\vec{J} = \overleftrightarrow{\sigma} \cdot \vec{E} \Rightarrow \begin{array}{l} \sigma_P E_x + \sigma_H E_p = J_x \\ -\sigma_H E_x + \sigma_P E_p = J_y = 0 \end{array}$$

(assumes $J_{\parallel} = 0$)

bounded in latitude

so $E_p = \dfrac{\sigma_H}{\sigma_P} E_x$

and $J_x = \sigma_P E_x + \dfrac{\sigma_H^2}{\sigma_P} E_x$

assume $\sigma_H >> \sigma_P$ (as is the case for E region ionosphere)

~~$J_x \approx \sigma_P E$~~

$J_x = \sigma_H E_y$ and $J_y = -\sigma_H E_x$

driving fields

Note, in reality E_p is less than $\left[\dfrac{\sigma_H}{\sigma_P} E_x\right]$ because field aligned currents bleed off the charge.

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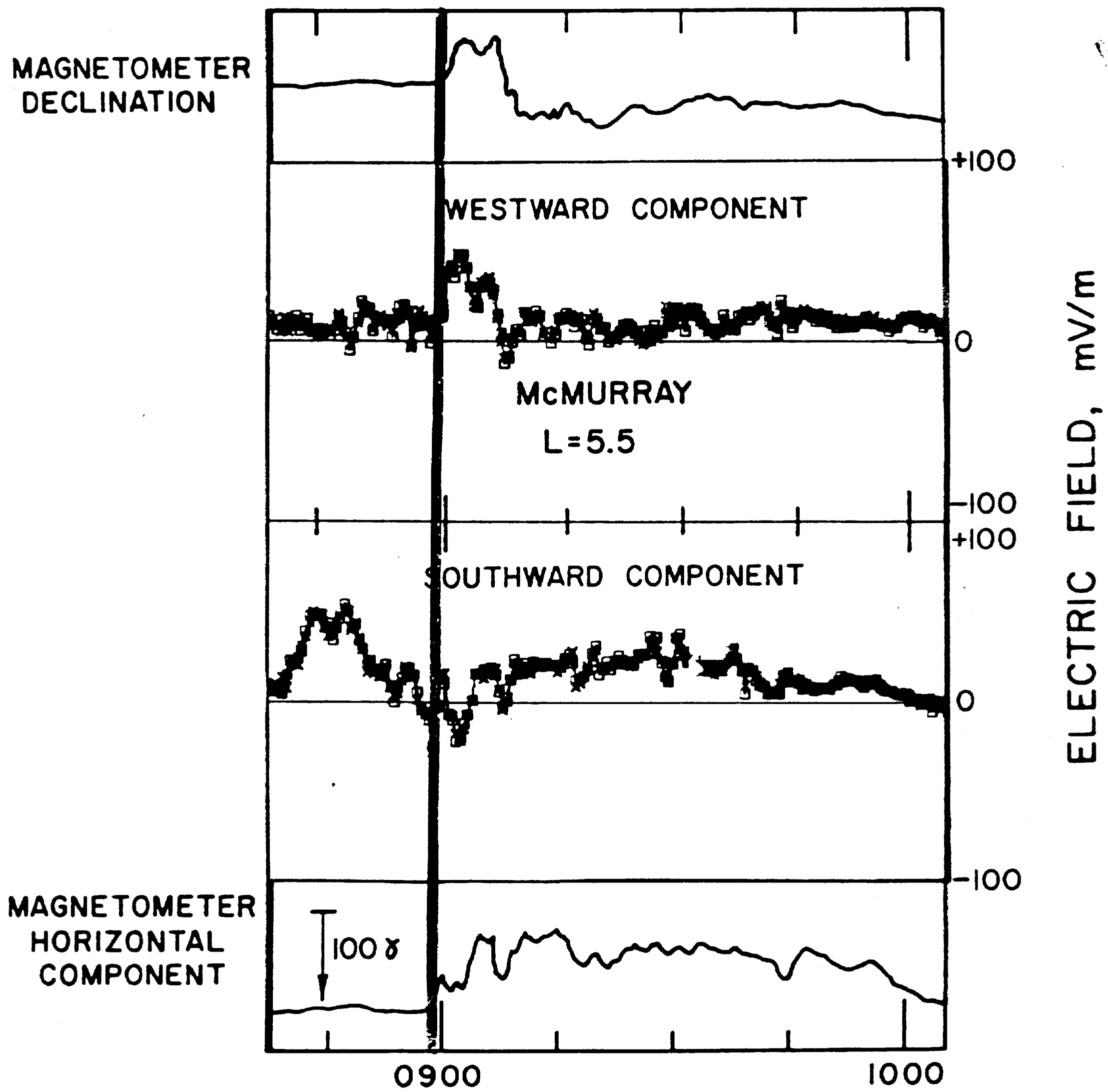
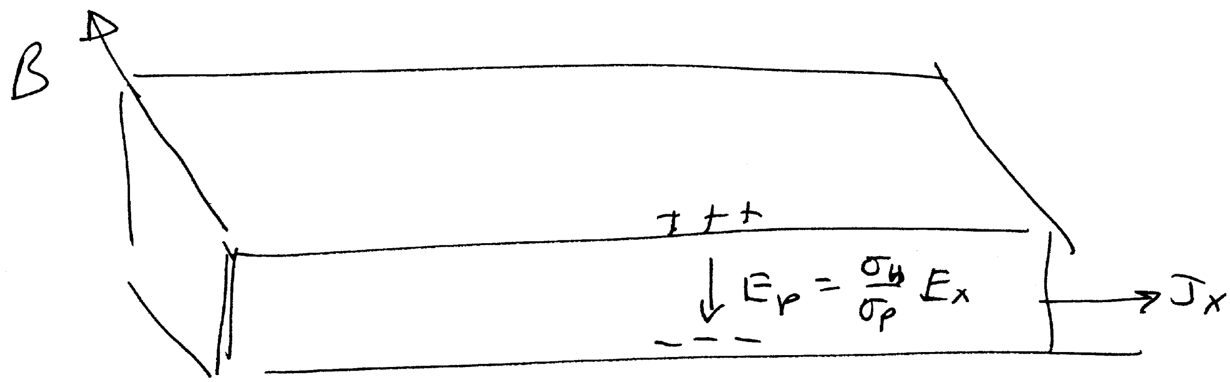
Case 1 example



UNIVERSAL TIME ON AUGUST 3, 1969

Case II

Equator Slab of ionosphere



Equatorial Electrojet

$$J_x = \underbrace{\left(\sigma_p + \frac{\sigma_H^2}{\sigma_p}\right)}_{\text{cowling conductivity}} E_x$$

eg: if $\sigma_H = 2\sigma_p$ then $J_x = 5\sigma_p E_x$
great enhancement
over simple $\sigma_p E_x$