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THE PENNSYLVANIA STATE UNIVERSITY

# IONOSPHERIC RESEARCH

## Scientific Report 439

# CALCULATION OF CONDUCTIVITIES AND CURRENTS IN THE IONOSPHERE

by

Volker W. J. H. Kirchhoff and Lynn A. Carpenter

November 28, 1975

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IONOSPHERE RESEARCH LABORATORY

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13. ABSTRACT

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## ABSTRACT

Formulas and procedures to calculate ionospheric conductivities are summarized. Ionospheric currents are calculated using a semi-diurnal E-region neutral wind model and electric fields from measurements at Millstone Hill. The results agree well with ground based magnetogram records for magnetic quiet days.

# 1. INTRODUCTION

Ionospheric conductivities have been studied for many years and presently the theory on conductivities and currents is covered in most textbooks on aeronomy. The earlier calculations however, had to use rather crude models for the neutral and ion densities (Maeda, 1953, 1956) while more recent treatments (Rishbeth and Garriott, 1969; Boström, 1974) present only a few particular cases.

One of the objectives of this work is therefore to provide additional information on conductivities by calculating numerical values as a function of height and local standard time (L.T.) for a midlatitude location (Millstone Hill, 42.6N, 71.5W).

The other objective of this work is to test recently deduced models of neutral winds and electric fields by using them in the calculation of currents and comparing the results with magnetogram records. To this end the basic formulas are briefly reviewed. The E-region neutral wind dominant at Millstone Hill has been identified as the (2,4) tidal mode by Salah et al (1975). This mode is used for the calculation of currents averaged in height. The electric field (i.e. drift velocity) model for Millstone Hill has been described in detail by Kirchhoff (1975).

## 2. Conductivities

### 2.1 Review of formulas

The collision frequencies for ions ($\nu_i$) and electrons ($\nu_e$) are given by Rishbeth and Garriott (1969) as

$$\nu_i = 7.5 \times 10^{-16} \times \rho$$

$$\nu_e = 5.4 \times 10^{-16} \times (T_N)^{1/2} \times \rho$$
$$+ (59 + 4.18 \times \log_{10} (T_N{}^3/N)) \times 10^{-6} \times T_N{}^{-3/2} \times N$$

where $\rho$ is number density of neutrals ($m^{-3}$)

$T_N$ is neutral temperature ($^oK$)

N is electron number density ($m^{-3}$)

The collision frequencies are calculated as a function of height up to 700 km and for two local standard times (L. T.) in Fig. 1. Also shown in Fig. 1 are the gyrofrequencies for ions ($\omega_i$) and electrons ($\omega_e$) where $\omega$ is given by

$$\omega = Bq/m$$

where q is the electronic charge and m the mass of ion or electron. B is the magnitude of the magnetic field, here assumed to be dipolar and thus given by

$$B = \frac{3.1 \times 10^{-5} \sqrt{1 + 3 \sin^2 \lambda}}{(1 + h/R_E)^3} \quad (T)$$

where $\lambda$ is latitude, h is height above the earth, $R_E$ is the earth radius. Numerical values used are

$$q = 1.6 \times 10^{-19} C$$
$$m_i = 2.66 \times 10^{-26} \text{ (oxygen ion mass) kg}$$
$$m_e = 9.11 \times 10^{-31} \text{ kg}$$
$$R_E = 6356.76 \times 10^3 \text{ m}$$

It can be seen from Figure 1 that $(\nu_e / \omega_e)^2 << 1$ and $\omega_i/\nu_i < \omega_e/\nu_e$ at all heights. The expressions for the conductivities in mho/m, can therefore be simplified to

$$\sigma_o = \frac{Nq^2}{m_e \nu_e}$$

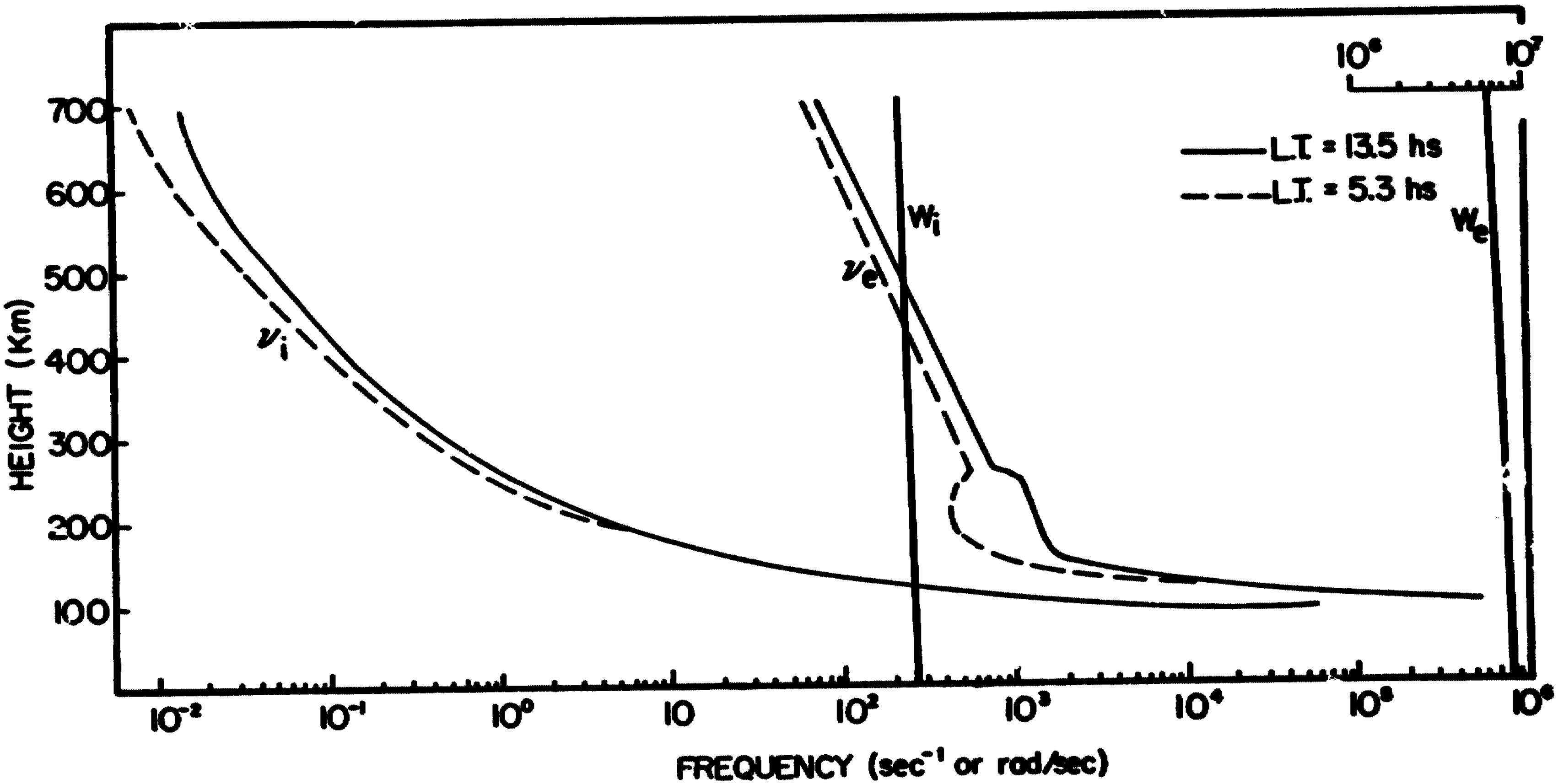


Figure 1. Collision Frequencies and Gyro-frequencies for Electrons and Ions as a Function of Height

$$\sigma_P = \frac{Nq}{B} \left[ \frac{\omega_i}{\omega_i^2 + \nu_i^2} \nu_i + \frac{\omega_e}{\omega_e^2 + \nu_e^2} \nu_e \right] \quad (2.1)$$

$$\sigma_H = \frac{Nq}{B} \frac{1}{1 + (\omega_i/\nu_i)^2}$$

## 2.2 Results

Using equation 2.1 the conductivities are calculated for several local times and shown in tables 1-13. Up to 250 km, the electron densities are calculated using the Ching and Chiu (1973) model. Above that height incoherent scatter measurements of electron density for Millstone Hill are used. Collision frequencies are calculated using the CIRA (1972) neutral model. The calculations are for 18 July 73 for which input parameters, needed to initialize the model calculations are as follows:

day number D = 199
$\Sigma K_p = 12$
F10.7 = 80.9
$\bar{F}10.7 = 86.1$
Sunspot number S = 43.3
Geographic latitude 42.6N
Geomagnetic latitude 54.1N

The tables are each divided in two parts. The first part gives the height, electron densities, the Pedersen and the Hall conductivities as a function of height (90 - 700 km) with height intervals that vary according to the availability of measurements. The second part gives and E-region detail listing of the conductivities from equation 2.1 as a function of height. Height integrated conductivities are shown in the bottom line of each table where SIGE1, SIGE2, SIGF1 and SIGF2 stand

TIME IS 0.45

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.783E 09 | 0.190E-06 | 0.274E-05 |
| 0.115E 06 | 0.736E 10 | 0.788E-05 | 0.234E-04 |
| 0.140E 06 | 0.711E 10 | 0.574E-05 | 0.137E-05 |
| 0.165E 06 | 0.212E 11 | 0.457E-05 | 0.274E-06 |
| 0.190E 06 | 0.716E 11 | 0.575E-05 | 0.126E-06 |
| 0.215E 06 | 0.146E 12 | 0.513E-05 | 0.483E-07 |
| 0.240E 06 | 0.208E 12 | 0.356E-05 | 0.157E-07 |
| 0.266E 06 | 0.125E 12 | 0.109E-05 | 0.241E-08 |
| 0.304E 06 | 0.201E 12 | 0.976E-06 | 0.109E-08 |
| 0.341E 06 | 0.196E 12 | 0.548E-06 | 0.317E-09 |
| 0.379E 06 | 0.148E 12 | 0.242E-06 | 0.747E-10 |
| 0.420E 06 | 0.109E 12 | 0.108E-06 | 0.181E-10 |
| 0.470E 06 | 0.855E 11 | 0.535E-07 | 0.492E-11 |
| 0.520E 06 | 0.679E 11 | 0.282E-07 | 0.144E-11 |
| 0.570E 06 | 0.546E 11 | 0.157E-07 | 0.462E-12 |
| 0.650E 06 | 0.396E 11 | 0.821E-08 | 0.152E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.425E-04 | 0.190E-06 | 0.274E-05 |
| 0.950E 05 | 0.347E-03 | 0.352E-06 | 0.902E-05 |
| 0.100E 06 | 0.160E-02 | 0.738E-06 | 0.171E-04 |
| 0.105E 06 | 0.487E-02 | 0.187E-05 | 0.230E-04 |
| 0.110E 06 | 0.111E-01 | 0.425E-05 | 0.252E-04 |
| 0.115E 06 | 0.209E-01 | 0.788E-05 | 0.234E-04 |
| 0.120E 06 | 0.345E-01 | 0.113E-04 | 0.180E-04 |
| 0.125E 06 | 0.593E-01 | 0.119E-04 | 0.103E-04 |
| 0.130E 06 | 0.891E-01 | 0.973E-05 | 0.517E-05 |
| 0.135E 06 | 0.131E 00 | 0.738E-05 | 0.256E-05 |
| 0.140E 06 | 0.194E 00 | 0.574E-05 | 0.137E-05 |
| 0.145E 06 | 0.292E 00 | 0.480E-05 | 0.822E-06 |
| 0.150E 06 | 0.450E 00 | 0.434E-05 | 0.553E-06 |
| 0.155E 06 | 0.707E 00 | 0.423E-05 | 0.411E-06 |
| 0.160E 06 | 0.111E 01 | 0.433E-05 | 0.328E-06 |

SIGE1,SIGE2,SIGF1,SIGF2 0.34 0.69 0.59 0.01

Table 1. Calculated Conductivities as a Function of Height at 0.45 Local Time for 18 July 1973

TIME IS 2.10

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.899E 09 | 0.218E-06 | 0.314E-05 |
| 0.115E 06 | 0.847E 10 | 0.907E-05 | 0.269E-04 |
| 0.140E 06 | 0.771E 10 | 0.622E-05 | 0.148E-05 |
| 0.165E 06 | 0.141E 11 | 0.303E-05 | 0.181E-06 |
| 0.190E 06 | 0.439E 11 | 0.350E-05 | 0.762E-07 |
| 0.215E 06 | 0.987E 11 | 0.344E-05 | 0.322E-07 |
| 0.240E 06 | 0.153E 12 | 0.258E-05 | 0.113E-07 |
| 0.266E 06 | 0.160E 12 | 0.138E-05 | 0.299E-08 |
| 0.304E 06 | 0.173E 12 | 0.819E-06 | 0.906E-09 |
| 0.341E 06 | 0.136E 12 | 0.361E-06 | 0.210E-09 |
| 0.379E 06 | 0.103E 12 | 0.158E-06 | 0.495E-10 |
| 0.430E 06 | 0.582E 11 | 0.524E-07 | 0.930E-11 |
| 0.480E 06 | 0.384E 11 | 0.209E-07 | 0.213E-11 |
| 0.530E 06 | 0.264E 11 | 0.904E-08 | 0.540E-12 |
| 0.580E 06 | 0.191E 11 | 0.427E-08 | 0.155E-12 |
| 0.675E 06 | 0.116E 11 | 0.179E-08 | 0.436E-13 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.487E-04 | 0.218E-06 | 0.314E-05 |
| 0.950E 05 | 0.398E-03 | 0.404E-06 | 0.104E-04 |
| 0.100E 06 | 0.184E-02 | 0.847E-06 | 0.196E-04 |
| 0.105E 06 | 0.559E-02 | 0.214E-05 | 0.264E-04 |
| 0.110E 06 | 0.128E-01 | 0.489E-05 | 0.289E-04 |
| 0.115E 06 | 0.240E-01 | 0.907E-05 | 0.269E-04 |
| 0.120E 06 | 0.398E-01 | 0.130E-04 | 0.208E-04 |
| 0.125E 06 | 0.684E-01 | 0.137E-04 | 0.119E-04 |
| 0.130E 06 | 0.102E 00 | 0.112E-04 | 0.593E-05 |
| 0.135E 06 | 0.148E 00 | 0.832E-05 | 0.288E-05 |
| 0.140E 06 | 0.210E 00 | 0.622E-05 | 0.148E-05 |
| 0.145E 06 | 0.295E 00 | 0.483E-05 | 0.826E-06 |
| 0.150E 06 | 0.415E 00 | 0.396E-05 | 0.502E-06 |
| 0.155E 06 | 0.589E 00 | 0.343E-05 | 0.332E-06 |
| 0.160E 06 | 0.844E 00 | 0.314E-05 | 0.237E-06 |

SIGE1,SIGE2,SIGF1,SIGF2 0.38 0.79 0.42 0.01

Table 2. Calculated Conductivities as a Function of Height at 2.10 Local Time for 18 July 1973

TIME IS 3.90

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.141E 10 | 0.343E-06 | 0.494E-05 |
| 0.115E 06 | 0.134E 11 | 0.144E-04 | 0.427E-04 |
| 0.140E 06 | 0.126E 11 | 0.102E-04 | 0.243E-05 |
| 0.165E 06 | 0.175E 11 | 0.377E-05 | 0.225E-06 |
| 0.190E 06 | 0.378E 11 | 0.302E-05 | 0.657E-07 |
| 0.215E 06 | 0.806E 11 | 0.281E-05 | 0.263E-07 |
| 0.240E 06 | 0.128E 12 | 0.215E-05 | 0.944E-08 |
| 0.266E 06 | 0.287E 12 | 0.253E-05 | 0.538E-08 |
| 0.304E 06 | 0.256E 12 | 0.124E-05 | 0.135E-08 |
| 0.350E 06 | 0.249E 12 | 0.707E-06 | 0.392E-09 |
| 0.400E 06 | 0.144E 12 | 0.235E-06 | 0.716E-10 |
| 0.450E 06 | 0.107E 12 | 0.106E-06 | 0.175E-10 |
| 0.500E 06 | 0.805E 11 | 0.502E-07 | 0.460E-11 |
| 0.550E 06 | 0.617E 11 | 0.252E-07 | 0.130E-11 |
| 0.600E 06 | 0.481E 11 | 0.135E-07 | 0.403E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.766E-04 | 0.343E-06 | 0.494E-05 |
| 0.950E 05 | 0.625E-03 | 0.634E-06 | 0.163E-04 |
| 0.100E 06 | 0.288E-02 | 0.133E-05 | 0.308E-04 |
| 0.105E 06 | 0.878E-02 | 0.337E-05 | 0.416E-04 |
| 0.110E 06 | 0.201E-01 | 0.771E-05 | 0.457E-04 |
| 0.115E 06 | 0.379E-01 | 0.144E-04 | 0.427E-04 |
| 0.120E 06 | 0.631E-01 | 0.208E-04 | 0.332E-04 |
| 0.125E 06 | 0.109E 00 | 0.221E-04 | 0.192E-04 |
| 0.130E 06 | 0.164E 00 | 0.182E-04 | 0.965E-05 |
| 0.135E 06 | 0.238E 00 | 0.136E-04 | 0.472E-05 |
| 0.140E 06 | 0.337E 00 | 0.102E-04 | 0.243E-05 |
| 0.145E 06 | 0.465E 00 | 0.783E-05 | 0.134E-05 |
| 0.150E 06 | 0.629E 00 | 0.621E-05 | 0.788E-06 |
| 0.155E 06 | 0.839E 00 | 0.508E-05 | 0.492E-06 |
| 0.160E 06 | 0.111E 01 | 0.430E-05 | 0.324E-06 |

SIGE1,SIGE2,SIGF1,SIGF2 0.62 1.25 0.50 0.01

Table 3. Calculated Conductivities as a Function of Height at 3.90 Local Time for 18 July 1973

TIME IS 5.35

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.555E 10 | 0.135E-05 | 0.194E-04 |
| 0.115E 06 | 0.542E 11 | 0.580E-04 | 0.172E-03 |
| 0.140E 06 | 0.574E 11 | 0.464E-04 | 0.111E-04 |
| 0.165E 06 | 0.734E 11 | 0.159E-04 | 0.951E-06 |
| 0.190E 06 | 0.937E 11 | 0.755E-05 | 0.166E-06 |
| 0.215E 06 | 0.129E 12 | 0.456E-05 | 0.431E-07 |
| 0.240E 06 | 0.168E 12 | 0.287E-05 | 0.128E-07 |
| 0.266E 06 | 0.207E 12 | 0.184E-05 | 0.403E-08 |
| 0.304E 06 | 0.166E 12 | 0.799E-06 | 0.908E-09 |
| 0.360E 06 | 0.113E 12 | 0.310E-06 | 0.190E-09 |
| 0.410E 06 | 0.910E 11 | 0.146E-06 | 0.485E-10 |
| 0.460E 06 | 0.726E 11 | 0.706E-07 | 0.129E-10 |
| 0.510E 06 | 0.578E 11 | 0.351E-07 | 0.357E-11 |
| 0.560E 06 | 0.457E 11 | 0.180E-07 | 0.104E-11 |
| 0.625E 06 | 0.335E 11 | 0.890E-08 | 0.309E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.301E-03 | 0.135E-05 | 0.194E-04 |
| 0.950E 05 | 0.244E-02 | 0.249E-05 | 0.636E-04 |
| 0.100E 06 | 0.113E-01 | 0.523E-05 | 0.121E-03 |
| 0.105E 06 | 0.342E-01 | 0.133E-04 | 0.164E-03 |
| 0.110E 06 | 0.781E-01 | 0.307E-04 | 0.181E-03 |
| 0.115E 06 | 0.147E 00 | 0.580E-04 | 0.172E-03 |
| 0.120E 06 | 0.247E 00 | 0.856E-04 | 0.136E-03 |
| 0.125E 06 | 0.422E 00 | 0.934E-04 | 0.813E-04 |
| 0.130E 06 | 0.636E 00 | 0.789E-04 | 0.419E-04 |
| 0.135E 06 | 0.918E 00 | 0.608E-04 | 0.211E-04 |
| 0.140E 06 | 0.127E 01 | 0.464E-04 | 0.111E-04 |
| 0.145E 06 | 0.170E 01 | 0.362E-04 | 0.620E-05 |
| 0.150E 06 | 0.219E 01 | 0.288E-04 | 0.366E-05 |
| 0.155E 06 | 0.273E 01 | 0.233E-04 | 0.226E-05 |
| 0.160E 06 | 0.331E 01 | 0.191E-04 | 0.145E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 2.63 5.06 0.99 0.04

Table 4. Calculated Conductivities as a Function of Height at 5.35 Local Time for 18 July 1973

TIME IS 7.35

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.105E 11 | 0.255E-05 | 0.367E-04 |
| 0.115E 06 | 0.104E 12 | 0.111E-03 | 0.331E-03 |
| 0.140E 06 | 0.118E 12 | 0.965E-04 | 0.233E-04 |
| 0.165E 06 | 0.155E 12 | 0.344E-04 | 0.212E-05 |
| 0.190E 06 | 0.190E 12 | 0.159E-04 | 0.364E-06 |
| 0.215E 06 | 0.233E 12 | 0.874E-05 | 0.870E-07 |
| 0.240E 06 | 0.273E 12 | 0.503E-05 | 0.238E-07 |
| 0.266E 06 | 0.350E 12 | 0.343E-05 | 0.808E-08 |
| 0.304E 06 | 0.274E 12 | 0.149E-05 | 0.183E-08 |
| 0.360E 06 | 0.206E 12 | 0.654E-06 | 0.436E-09 |
| 0.410E 06 | 0.153E 12 | 0.290E-06 | 0.106E-09 |
| 0.460E 06 | 0.115E 12 | 0.134E-06 | 0.271E-10 |
| 0.510E 06 | 0.879E 11 | 0.645E-07 | 0.735E-11 |
| 0.560E 06 | 0.678E 11 | 0.325E-07 | 0.212E-11 |
| 0.625E 06 | 0.493E 11 | 0.160E-07 | 0.624E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.569E-03 | 0.255E-05 | 0.367E-04 |
| 0.950E 05 | 0.460E-02 | 0.469E-05 | 0.120E-03 |
| 0.100E 06 | 0.211E-01 | 0.988E-05 | 0.228E-03 |
| 0.105E 06 | 0.638E-01 | 0.252E-04 | 0.311E-03 |
| 0.110E 06 | 0.145E 00 | 0.584E-04 | 0.346E-03 |
| 0.115E 06 | 0.271E 00 | 0.111E-03 | 0.331E-03 |
| 0.120E 06 | 0.454E 00 | 0.166E-03 | 0.265E-03 |
| 0.125E 06 | 0.753E 00 | 0.184E-03 | 0.161E-03 |
| 0.130E 06 | 0.112E 01 | 0.159E-03 | 0.850E-04 |
| 0.135E 06 | 0.158E 01 | 0.124E-03 | 0.436E-04 |
| 0.140E 06 | 0.214E 01 | 0.965E-04 | 0.233E-04 |
| 0.145E 06 | 0.278E 01 | 0.761E-04 | 0.133E-04 |
| 0.150E 06 | 0.346E 01 | 0.612E-04 | 0.793E-05 |
| 0.155E 06 | 0.416E 01 | 0.499E-04 | 0.495E-05 |
| 0.160E 06 | 0.485E 01 | 0.413E-04 | 0.319E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 5.24 9.75 2.05 0.10

Table 5. Calculated Conductivities as a Function of Height at 7.35 Local Time for 18 July 1973

TIME IS 9.43

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.150E 11 | 0.363E-05 | 0.523E-04 |
| 0.115E 06 | 0.150E 12 | 0.160E-03 | 0.476E-03 |
| 0.140E 06 | 0.177E 12 | 0.148E-03 | 0.367E-04 |
| 0.165E 06 | 0.248E 12 | 0.578E-04 | 0.372E-05 |
| 0.190E 06 | 0.325E 12 | 0.293E-04 | 0.718E-06 |
| 0.215E 06 | 0.397E 12 | 0.165E-04 | 0.180E-06 |
| 0.240E 06 | 0.443E 12 | 0.930E-05 | 0.496E-07 |
| 0.266E 06 | 0.458E 12 | 0.523E-05 | 0.143E-07 |
| 0.304E 06 | 0.428E 12 | 0.281E-05 | 0.410E-08 |
| 0.350E 06 | 0.329E 12 | 0.129E-05 | 0.103E-08 |
| 0.400E 06 | 0.261E 12 | 0.633E-06 | 0.283E-09 |
| 0.450E 06 | 0.207E 12 | 0.318E-06 | 0.799E-10 |
| 0.500E 06 | 0.162E 12 | 0.163E-06 | 0.232E-10 |
| 0.550E 06 | 0.127E 12 | 0.857E-07 | 0.699E-11 |
| 0.600E 06 | 0.984E 11 | 0.459E-07 | 0.218E-11 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.810E-03 | 0.363E-05 | 0.523E-04 |
| 0.950E 05 | 0.654E-02 | 0.668E-05 | 0.171E-03 |
| 0.100E 06 | 0.299E-01 | 0.141E-04 | 0.324E-03 |
| 0.105E 06 | 0.899E-01 | 0.360E-04 | 0.443E-03 |
| 0.110E 06 | 0.202E 00 | 0.836E-04 | 0.494E-03 |
| 0.115E 06 | 0.376E 00 | 0.160E-03 | 0.476E-03 |
| 0.120E 06 | 0.626E 00 | 0.241E-03 | 0.384E-03 |
| 0.125E 06 | 0.101E 01 | 0.270E-03 | 0.238E-03 |
| 0.130E 06 | 0.148E 01 | 0.236E-03 | 0.128E-03 |
| 0.135E 06 | 0.207E 01 | 0.188E-03 | 0.672E-04 |
| 0.140E 06 | 0.275E 01 | 0.148E-03 | 0.367E-04 |
| 0.145E 06 | 0.351E 01 | 0.119E-03 | 0.212E-04 |
| 0.150E 06 | 0.431E 01 | 0.969E-04 | 0.130E-04 |
| 0.155E 06 | 0.511E 01 | 0.805E-04 | 0.828E-05 |
| 0.160E 06 | 0.588E 01 | 0.678E-04 | 0.547E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 7.77 14.08 3.54 0.17

Table 6. Calculated Conductivities as a Function of Height at 9.43 Local Time for 18 July 1973

TIME IS 11.45

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.173E 11 | 0.419E-05 | 0.604E-04 |
| 0.115E 06 | 0.174E 12 | 0.186E-03 | 0.553E-03 |
| 0.140E 06 | 0.215E 12 | 0.183E-03 | 0.463E-04 |
| 0.165E 06 | 0.331E 12 | 0.804E-04 | 0.540E-05 |
| 0.190E 06 | 0.454E 12 | 0.439E-04 | 0.115E-05 |
| 0.215E 06 | 0.540E 12 | 0.245E-04 | 0.293E-06 |
| 0.240E 06 | 0.571E 12 | 0.135E-04 | 0.805E-07 |
| 0.266E 06 | 0.307E 12 | 0.390E-05 | 0.125E-07 |
| 0.304E 06 | 0.245E 12 | 0.183E-05 | 0.327E-08 |
| 0.350E 06 | 0.195E 12 | 0.874E-06 | 0.896E-09 |
| 0.400E 06 | 0.151E 12 | 0.418E-06 | 0.251E-09 |
| 0.450E 06 | 0.116E 12 | 0.204E-06 | 0.724E-10 |
| 0.500E 06 | 0.897E 11 | 0.101E-06 | 0.216E-10 |
| 0.550E 06 | 0.689E 11 | 0.509E-07 | 0.660E-11 |
| 0.600E 06 | 0.526E 11 | 0.260E-07 | 0.208E-11 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.936E-03 | 0.419E-05 | 0.604E-04 |
| 0.950E 05 | 0.755E-02 | 0.772E-05 | 0.197E-03 |
| 0.100E 06 | 0.345E-01 | 0.163E-04 | 0.375E-03 |
| 0.105E 06 | 0.103E 00 | 0.416E-04 | 0.512E-03 |
| 0.110E 06 | 0.231E 00 | 0.968E-04 | 0.573E-03 |
| 0.115E 06 | 0.429E 00 | 0.186E-03 | 0.553E-03 |
| 0.120E 06 | 0.711E 00 | 0.281E-03 | 0.448E-03 |
| 0.125E 06 | 0.113E 01 | 0.317E-03 | 0.282E-03 |
| 0.130E 06 | 0.165E 01 | 0.281E-03 | 0.155E-03 |
| 0.135E 06 | 0.230E 01 | 0.228E-03 | 0.829E-04 |
| 0.140E 06 | 0.307E 01 | 0.183E-03 | 0.463E-04 |
| 0.145E 06 | 0.392E 01 | 0.150E-03 | 0.275E-04 |
| 0.150E 06 | 0.481E 01 | 0.125E-03 | 0.173E-04 |
| 0.155E 06 | 0.570E 01 | 0.107E-03 | 0.113E-04 |
| 0.160E 06 | 0.656E 01 | 0.921E-04 | 0.772E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 9.26 16.45 4.72 0.24

Table 7. Calculated Conductivities as a Function of Height at 11.45 Local Time for 18 July 1973

TIME IS 13.47

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.166E 11 | 0.402E-05 | 0.579E-04 |
| 0.115E 06 | 0.167E 12 | 0.179E-03 | 0.531E-03 |
| 0.140E 06 | 0.217E 12 | 0.187E-03 | 0.479E-04 |
| 0.165E 06 | 0.357E 12 | 0.885E-04 | 0.607E-05 |
| 0.190E 06 | 0.482E 12 | 0.481E-04 | 0.130E-05 |
| 0.215E 06 | 0.541E 12 | 0.257E-04 | 0.322E-06 |
| 0.240E 06 | 0.542E 12 | 0.135E-04 | 0.857E-07 |
| 0.266E 06 | 0.323E 12 | 0.444E-05 | 0.153E-07 |
| 0.304E 06 | 0.290E 12 | 0.235E-05 | 0.456E-08 |
| 0.341E 06 | 0.227E 12 | 0.111E-05 | 0.125E-08 |
| 0.390E 06 | 0.177E 12 | 0.542E-06 | 0.360E-09 |
| 0.440E 06 | 0.136E 12 | 0.267E-06 | 0.107E-09 |
| 0.490E 06 | 0.105E 12 | 0.133E-06 | 0.324E-10 |
| 0.540E 06 | 0.807E 11 | 0.679E-07 | 0.101E-10 |
| 0.590E 06 | 0.619E 11 | 0.352E-07 | 0.326E-11 |
| 0.700E 06 | 0.344E 11 | 0.135E-07 | 0.853E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.897E-03 | 0.402E-05 | 0.579E-04 |
| 0.950E 05 | 0.724E-02 | 0.740E-05 | 0.189E-03 |
| 0.100E 06 | 0.331E-01 | 0.156E-04 | 0.359E-03 |
| 0.105E 06 | 0.992E-01 | 0.399E-04 | 0.491E-03 |
| 0.110E 06 | 0.223E 00 | 0.928E-04 | 0.549E-03 |
| 0.115E 06 | 0.414E 00 | 0.179E-03 | 0.531E-03 |
| 0.120E 06 | 0.690E 00 | 0.271E-03 | 0.432E-03 |
| 0.125E 06 | 0.110E 01 | 0.307E-03 | 0.275E-03 |
| 0.130E 06 | 0.162E 01 | 0.277E-03 | 0.154E-03 |
| 0.135E 06 | 0.229E 01 | 0.228E-03 | 0.839E-04 |
| 0.140E 06 | 0.308E 01 | 0.187E-03 | 0.479E-04 |
| 0.145E 06 | 0.398E 01 | 0.156E-03 | 0.291E-04 |
| 0.150E 06 | 0.492E 01 | 0.133E-03 | 0.186E-04 |
| 0.155E 06 | 0.587E 01 | 0.115E-03 | 0.125E-04 |
| 0.160E 06 | 0.678E 01 | 0.101E-03 | 0.859E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 9.14 15.89 5.13 0.27

Table 8. Calculated Conductivities as a Function of Height at 13.47 Local Time for 18 July 1973

TIME IS 15.78

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.125E 11 | 0.303E-05 | 0.437E-04 |
| 0.115E 06 | 0.126E 12 | 0.135E-03 | 0.401E-03 |
| 0.140E 06 | 0.172E 12 | 0.148E-03 | 0.377E-04 |
| 0.165E 06 | 0.293E 12 | 0.722E-04 | 0.492E-05 |
| 0.190E 06 | 0.392E 12 | 0.386E-04 | 0.103E-05 |
| 0.215E 06 | 0.429E 12 | 0.200E-04 | 0.247E-06 |
| 0.240E 06 | 0.420E 12 | 0.102E-04 | 0.638E-07 |
| 0.266E 06 | 0.369E 12 | 0.498E-05 | 0.167E-07 |
| 0.304E 06 | 0.318E 12 | 0.251E-05 | 0.471E-08 |
| 0.341E 06 | 0.274E 12 | 0.131E-05 | 0.141E-08 |
| 0.390E 06 | 0.200E 12 | 0.595E-06 | 0.377E-09 |
| 0.440E 06 | 0.145E 12 | 0.274E-06 | 0.104E-09 |
| 0.490E 06 | 0.105E 12 | 0.129E-06 | 0.297E-10 |
| 0.540E 06 | 0.771E 11 | 0.619E-07 | 0.876E-11 |
| 0.590E 06 | 0.566E 11 | 0.304E-07 | 0.268E-11 |
| 0.700E 06 | 0.292E 11 | 0.107E-07 | 0.649E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.678E-03 | 0.303E-05 | 0.437E-04 |
| 0.950E 05 | 0.548E-02 | 0.559E-05 | 0.143E-03 |
| 0.100E 06 | 0.251E-01 | 0.118E-04 | 0.272E-03 |
| 0.105E 06 | 0.758E-01 | 0.301E-04 | 0.371E-03 |
| 0.110E 06 | 0.172E 00 | 0.701E-04 | 0.415E-03 |
| 0.115E 06 | 0.323E 00 | 0.135E-03 | 0.401E-03 |
| 0.120E 06 | 0.545E 00 | 0.205E-03 | 0.327E-03 |
| 0.125E 06 | 0.891E 00 | 0.234E-03 | 0.210E-03 |
| 0.130E 06 | 0.134E 01 | 0.213E-03 | 0.118E-03 |
| 0.135E 06 | 0.194E 01 | 0.178E-03 | 0.651E-04 |
| 0.140E 06 | 0.268E 01 | 0.148E-03 | 0.377E-04 |
| 0.145E 06 | 0.353E 01 | 0.125E-03 | 0.231E-04 |
| 0.150E 06 | 0.445E 01 | 0.107E-03 | 0.149E-04 |
| 0.155E 06 | 0.539E 01 | 0.932E-04 | 0.100E-04 |
| 0.160E 06 | 0.630E 01 | 0.819E-04 | 0.695E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 7.05 12.06 4.21 0.21

Table 9. Calculated Conductivities as a Function of Height at 15.78 Local Time for 18 July 1973

TIME IS 17.75

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.783E 10 | 0.190E-05 | 0.274E-04 |
| 0.115E 06 | 0.785E 11 | 0.840E-04 | 0.249E-03 |
| 0.140E 06 | 0.111E 12 | 0.938E-04 | 0.236E-04 |
| 0.165E 06 | 0.208E 12 | 0.498E-04 | 0.330E-05 |
| 0.190E 06 | 0.299E 12 | 0.283E-04 | 0.724E-06 |
| 0.215E 06 | 0.345E 12 | 0.152E-04 | 0.177E-06 |
| 0.240E 06 | 0.349E 12 | 0.787E-05 | 0.457E-07 |
| 0.266E 06 | 0.383E 12 | 0.474E-05 | 0.144E-07 |
| 0.304E 06 | 0.409E 12 | 0.297E-05 | 0.490E-08 |
| 0.341E 06 | 0.316E 12 | 0.137E-05 | 0.127E-08 |
| 0.379E 06 | 0.276E 12 | 0.745E-06 | 0.388E-09 |
| 0.430E 06 | 0.213E 12 | 0.367E-06 | 0.111E-09 |
| 0.480E 06 | 0.164E 12 | 0.185E-06 | 0.324E-10 |
| 0.530E 06 | 0.126E 12 | 0.946E-07 | 0.981E-11 |
| 0.580E 06 | 0.962E 11 | 0.494E-07 | 0.306E-11 |
| 0.675E 06 | 0.570E 11 | 0.199E-07 | 0.824E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.425E-03 | 0.190E-05 | 0.274E-04 |
| 0.950E 05 | 0.344E-02 | 0.350E-05 | 0.897E-04 |
| 0.100E 06 | 0.158E-01 | 0.733E-05 | 0.170E-03 |
| 0.105E 06 | 0.481E-01 | 0.188E-04 | 0.232E-03 |
| 0.110E 06 | 0.110E 00 | 0.437E-04 | 0.259E-03 |
| 0.115E 06 | 0.209E 00 | 0.840E-04 | 0.249E-03 |
| 0.120E 06 | 0.357E 00 | 0.127E-03 | 0.203E-03 |
| 0.125E 06 | 0.604E 00 | 0.146E-03 | 0.129E-03 |
| 0.130E 06 | 0.937E 00 | 0.133E-03 | 0.728E-04 |
| 0.135E 06 | 0.140E 01 | 0.112E-03 | 0.404E-04 |
| 0.140E 06 | 0.201E 01 | 0.938E-04 | 0.236E-04 |
| 0.145E 06 | 0.275E 01 | 0.805E-04 | 0.147E-04 |
| 0.150E 06 | 0.361E 01 | 0.703E-04 | 0.962E-05 |
| 0.155E 06 | 0.451E 01 | 0.623E-04 | 0.657E-05 |
| 0.160E 06 | 0.542E 01 | 0.556E-04 | 0.461E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 4.43 7.51 3.12 0.14

Table 10. Calculated Conductivities as a Function of Height at 17.75 Local Time for 18 July 1973

TIME IS 19.85

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.159E 10 | 0.386E-06 | 0.557E-05 |
| 0.115E 06 | 0.157E 11 | 0.168E-04 | 0.500E-04 |
| 0.140E 06 | 0.307E 11 | 0.255E-04 | 0.629E-05 |
| 0.165E 06 | 0.990E 11 | 0.228E-04 | 0.145E-05 |
| 0.190E 06 | 0.194E 12 | 0.172E-04 | 0.416E-06 |
| 0.215E 06 | 0.267E 12 | 0.108E-04 | 0.116E-06 |
| 0.240E 06 | 0.301E 12 | 0.609E-05 | 0.318E-07 |
| 0.266E 06 | 0.404E 12 | 0.443E-05 | 0.117E-07 |
| 0.304E 06 | 0.446E 12 | 0.283E-05 | 0.392E-08 |
| 0.341E 06 | 0.366E 12 | 0.138E-05 | 0.103E-08 |
| 0.379E 06 | 0.292E 12 | 0.677E-06 | 0.276E-09 |
| 0.430E 06 | 0.187E 12 | 0.266E-06 | 0.625E-10 |
| 0.480E 06 | 0.133E 12 | 0.120E-06 | 0.163E-10 |
| 0.530E 06 | 0.968E 11 | 0.574E-07 | 0.452E-11 |
| 0.580E 06 | 0.716E 11 | 0.286E-07 | 0.134E-11 |
| 0.675E 06 | 0.428E 11 | 0.116E-07 | 0.361E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.864E-04 | 0.386E-06 | 0.557E-05 |
| 0.950E 05 | 0.705E-03 | 0.715E-06 | 0.183E-04 |
| 0.100E 06 | 0.325E-02 | 0.150E-05 | 0.348E-04 |
| 0.105E 06 | 0.994E-02 | 0.382E-05 | 0.471E-04 |
| 0.110E 06 | 0.229E-01 | 0.881E-05 | 0.522E-04 |
| 0.115E 06 | 0.442E-01 | 0.168E-04 | 0.500E-04 |
| 0.120E 06 | 0.775E-01 | 0.256E-04 | 0.409E-04 |
| 0.125E 06 | 0.143E 00 | 0.302E-04 | 0.266E-04 |
| 0.130E 06 | 0.247E 00 | 0.293E-04 | 0.159E-04 |
| 0.135E 06 | 0.428E 00 | 0.271E-04 | 0.963E-05 |
| 0.140E 06 | 0.726E 00 | 0.255E-04 | 0.629E-05 |
| 0.145E 06 | 0.118E 01 | 0.247E-04 | 0.439E-05 |
| 0.150E 06 | 0.182E 01 | 0.242E-04 | 0.322E-05 |
| 0.155E 06 | 0.262E 01 | 0.238E-04 | 0.243E-05 |
| 0.160E 06 | 0.355E 01 | 0.234E-04 | 0.187E-05 |

SIGE1,SIGE2,SIGF1,SIGF2 1.03 1.55 1.83 0.06

Table 11. Calculated Conductivities as a Function of Height at 19.85 Local Time for 18 July 1973

TIME IS 22.25

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.859E 09 | 0.208E-06 | 0.300E-05 |
| 0.115E 06 | 0.813E 10 | 0.869E-05 | 0.258E-04 |
| 0.140E 06 | 0.116E 11 | 0.947E-05 | 0.228E-05 |
| 0.165E 06 | 0.501E 11 | 0.111E-04 | 0.676E-06 |
| 0.190E 06 | 0.134E 12 | 0.112E-04 | 0.252E-06 |
| 0.215E 06 | 0.222E 12 | 0.822E-05 | 0.808E-07 |
| 0.240E 06 | 0.279E 12 | 0.507E-05 | 0.236E-07 |
| 0.266E 06 | 0.201E 12 | 0.190E-05 | 0.446E-08 |
| 0.304E 06 | 0.260E 12 | 0.138E-05 | 0.166E-08 |
| 0.341E 06 | 0.239E 12 | 0.737E-06 | 0.466E-09 |
| 0.379E 06 | 0.200E 12 | 0.371E-06 | 0.125E-09 |
| 0.420E 06 | 0.130E 12 | 0.145E-06 | 0.272E-10 |
| 0.470E 06 | 0.998E 11 | 0.706E-07 | 0.737E-11 |
| 0.520E 06 | 0.773E 11 | 0.361E-07 | 0.213E-11 |
| 0.570E 06 | 0.605E 11 | 0.194E-07 | 0.662E-12 |
| 0.650E 06 | 0.418E 11 | 0.941E-08 | 0.204E-12 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.466E-04 | 0.208E-06 | 0.300E-05 |
| 0.950E 05 | 0.380E-03 | 0.336E-06 | 0.989E-05 |
| 0.100E 06 | 0.176E-02 | 0.810E-06 | 0.187E-04 |
| 0.105E 06 | 0.534E-02 | 0.205E-05 | 0.253E-04 |
| 0.110E 06 | 0.122E-01 | 0.467E-05 | 0.277E-04 |
| 0.115E 06 | 0.230E-01 | 0.869E-05 | 0.258E-04 |
| 0.120E 06 | 0.386E-01 | 0.126E-04 | 0.201E-04 |
| 0.125E 06 | 0.679E-01 | 0.138E-04 | 0.120E-04 |
| 0.130E 06 | 0.109E 00 | 0.122E-04 | 0.650E-05 |
| 0.135E 06 | 0.179E 00 | 0.104E-04 | 0.364E-05 |
| 0.140E 06 | 0.305E 00 | 0.947E-05 | 0.228E-05 |
| 0.145E 06 | 0.525E 00 | 0.927E-05 | 0.161E-05 |
| 0.150E 06 | 0.889E 00 | 0.952E-05 | 0.123E-05 |
| 0.155E 06 | 0.144E 01 | 0.100E-04 | 0.988E-06 |
| 0.160E 06 | 0.218E 01 | 0.106E-04 | 0.814E-06 |

SIGE1,SIGE2,SIGF1,SIGF2 0.45 0.78 1.07 0.03

Table 12. Calculated Conductivities as a Function of Height at 22.25 Local Time for 18 July 1973

TIME IS 23.58

| HEIGHT | EL.DENS. | SIG.PED. | SIG.HAL |
|---|---|---|---|
| 0.900E 05 | 0.783E 09 | 0.190E-06 | 0.273E-05 |
| 0.115E 06 | 0.736E 10 | 0.788E-05 | 0.234E-04 |
| 0.140E 06 | 0.792E 10 | 0.642E-05 | 0.154E-05 |
| 0.165E 06 | 0.298E 11 | 0.647E-05 | 0.389E-06 |
| 0.190E 06 | 0.943E 11 | 0.766E-05 | 0.169E-06 |
| 0.215E 06 | 0.177E 12 | 0.634E-05 | 0.604E-07 |
| 0.240E 06 | 0.240E 12 | 0.419E-05 | 0.187E-07 |
| 0.266E 06 | 0.175E 12 | 0.157E-05 | 0.351E-08 |
| 0.304E 06 | 0.187E 12 | 0.921E-06 | 0.106E-08 |
| 0.341E 06 | 0.155E 12 | 0.434E-06 | 0.264E-09 |
| 0.379E 06 | 0.117E 12 | 0.191E-06 | 0.627E-10 |
| 0.430E 06 | 0.703E 11 | 0.678E-07 | 0.126E-10 |
| 0.480E 06 | 0.455E 11 | 0.266E-07 | 0.285E-11 |
| 0.530E 06 | 0.305E 11 | 0.112E-07 | 0.707E-12 |
| 0.580E 06 | 0.212E 11 | 0.506E-08 | 0.195E-12 |
| 0.675E 06 | 0.117E 11 | 0.189E-08 | 0.494E-13 |

E REGION DETAIL

| HEIGHT | SIG.PAR. | SIG.PED. | SIG.HAL. |
|---|---|---|---|
| 0.900E 05 | 0.424E-04 | 0.190E-06 | 0.273E-05 |
| 0.950E 05 | 0.347E-03 | 0.352E-06 | 0.902E-05 |
| 0.100E 06 | 0.160E-02 | 0.738E-06 | 0.171E-04 |
| 0.105E 06 | 0.487E-02 | 0.187E-05 | 0.230E-04 |
| 0.110E 06 | 0.111E-01 | 0.425E-05 | 0.252E-04 |
| 0.115E 06 | 0.208E-01 | 0.788E-05 | 0.234E-04 |
| 0.120E 06 | 0.346E-01 | 0.113E-04 | 0.180E-04 |
| 0.125E 06 | 0.596E-01 | 0.120E-04 | 0.104E-04 |
| 0.130E 06 | 0.908E-01 | 0.997E-05 | 0.530E-05 |
| 0.135E 06 | 0.138E 00 | 0.781E-05 | 0.271E-05 |
| 0.140E 06 | 0.214E 00 | 0.642E-05 | 0.154E-05 |
| 0.145E 06 | 0.343E 00 | 0.574E-05 | 0.987E-06 |
| 0.150E 06 | 0.561E 00 | 0.557E-05 | 0.712E-06 |
| 0.155E 06 | 0.916E 00 | 0.572E-05 | 0.558E-06 |
| 0.160E 06 | 0.145E 01 | 0.606E-05 | 0.460E-06 |

SIGE1,SIGE2,SIGF1,SIGF2 0.36 0.69 0.74 0.02

Table 13. Calculated Conductivities as a Function of Height at 23.58 Local Time for 18 July 1973

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for Pedersen E-region, Hall E-region, Pedersen F-region and Hall F-region, respectively.

The information on the Pedersen and Hall conductivities as a function of height is repeated in Figs. 2-14 for convenience of analysis.

Figure 15 shows the local time variation of the height integrated Pedersen and Hall conductivities of the E-region (90-150 Km) as well as their ratio. Nighttime values are of the order of 0.1 mhos while the ratio Hall/Pedersen remains close to two throughout the 24 hr. period.

## 3. Current calculations

### 3.1 Review on formulas

Given an electric field perpendicular to the magnetic field lines ($\vec{E}_{\perp}$), the current component perpendicular to the magnetic field lines is given by (i.e. Rishbeth and Garriot, 1969)

$$\vec{J}_{\perp} = \sigma_p \vec{E}_{\perp} + \sigma_H (\vec{b} \times \vec{E}_{\perp}) \qquad (3.1)$$

where

$\vec{J}_{\perp}$ is current density ($A/m^2$)

$\sigma_p$, $\sigma_H$ are Pedersen and Hall conductivities $(\Omega m)^{-1}$

$\vec{E}_{\perp}$ is the total electric field (V/m)

$\vec{b}$ is a unit vector in the direction of the magnetic field

In equation 3.1 both conductivities are positive quantities. Some authors, however, take $\sigma_H$ as a negative quantity and the second term in equation 3.1 is then written $\sigma_H (\vec{E} \times \vec{b})$ (e.g. Brekke et al, 1974).

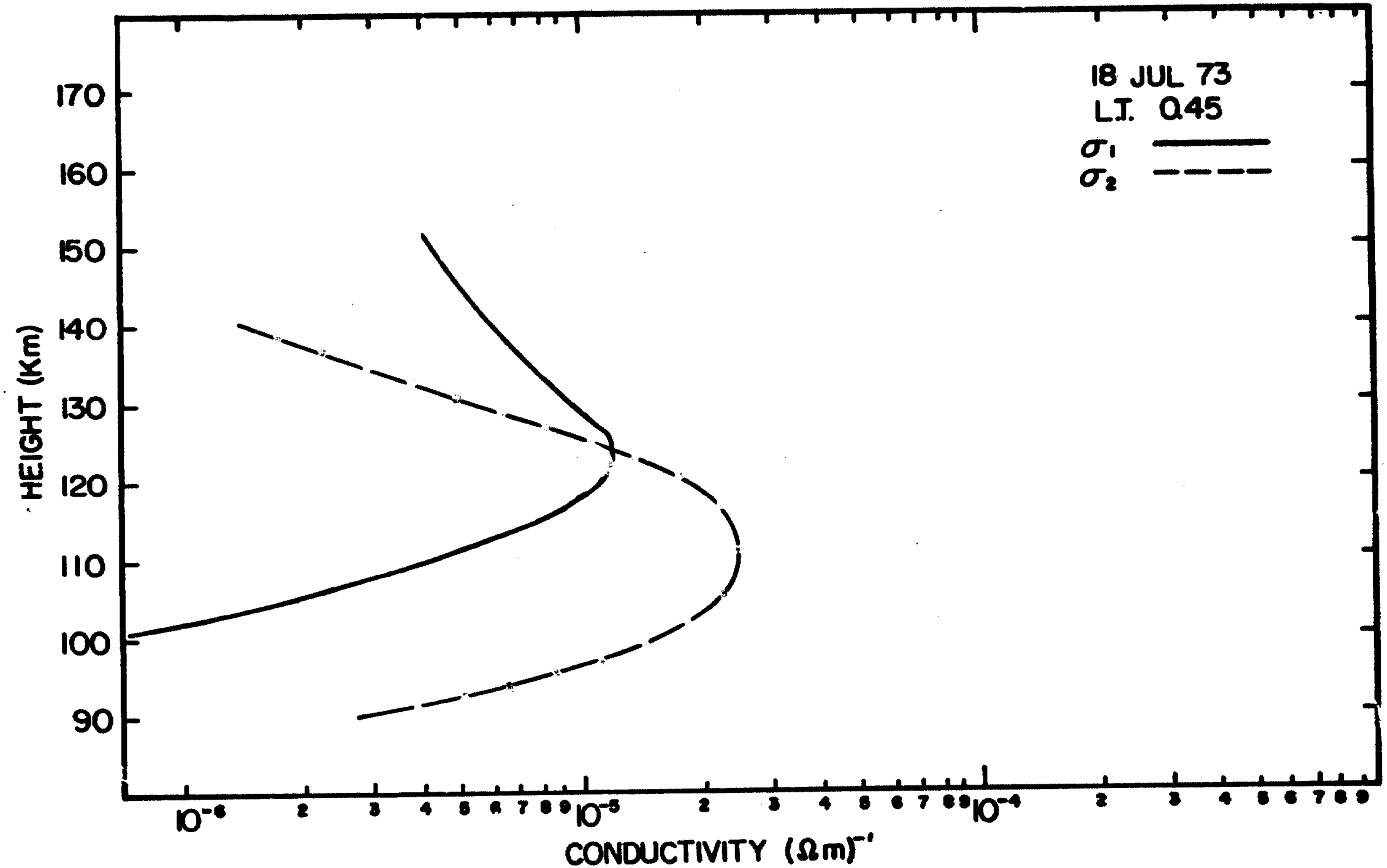


Figure 2. E-region Pedersen and Hall Conductivities as a Function of Height at 0.45 Local Time

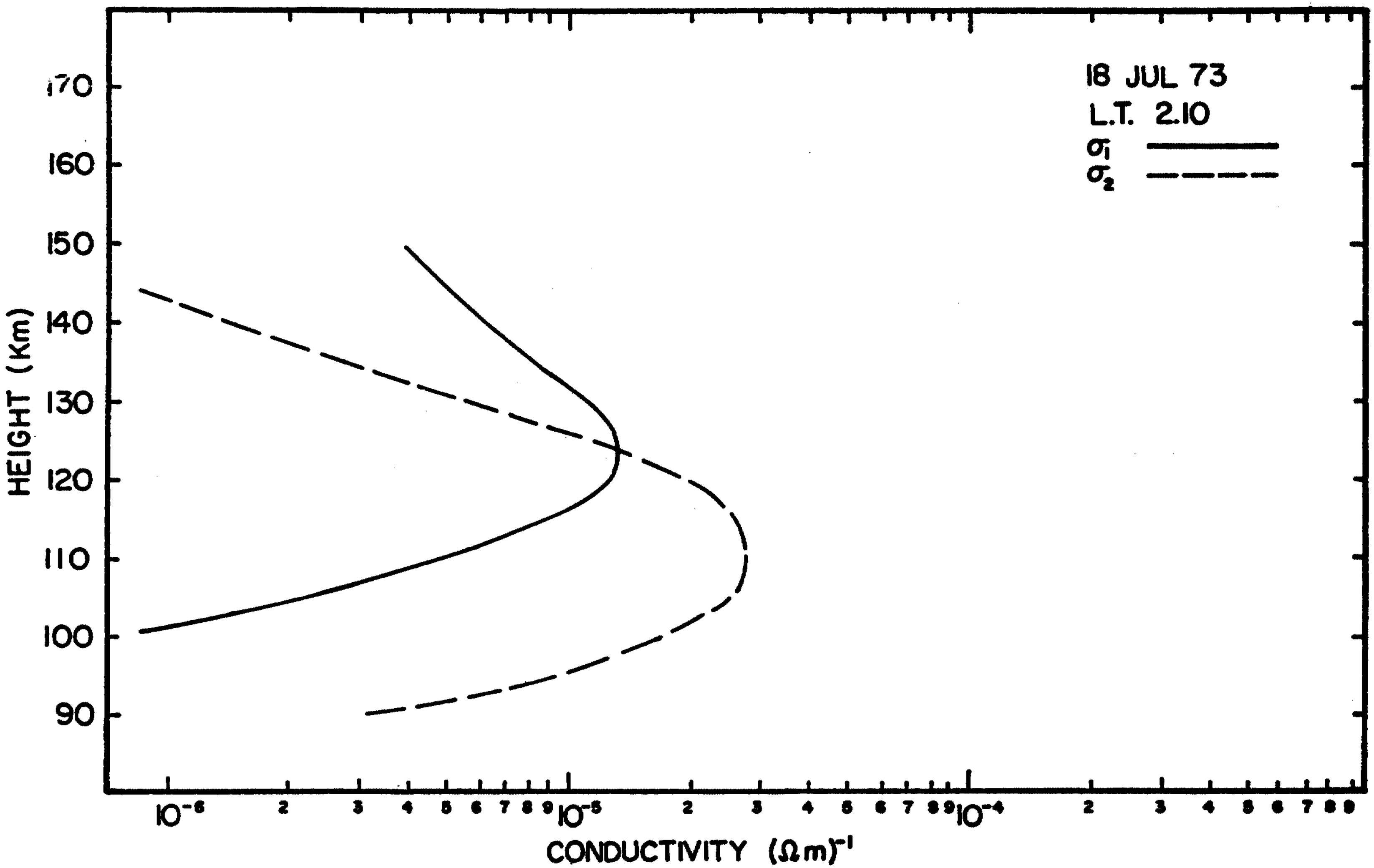


Figure 3. E-region Pedersen and Hall Conductivities as a Function of Height at 2. 10 Local Time

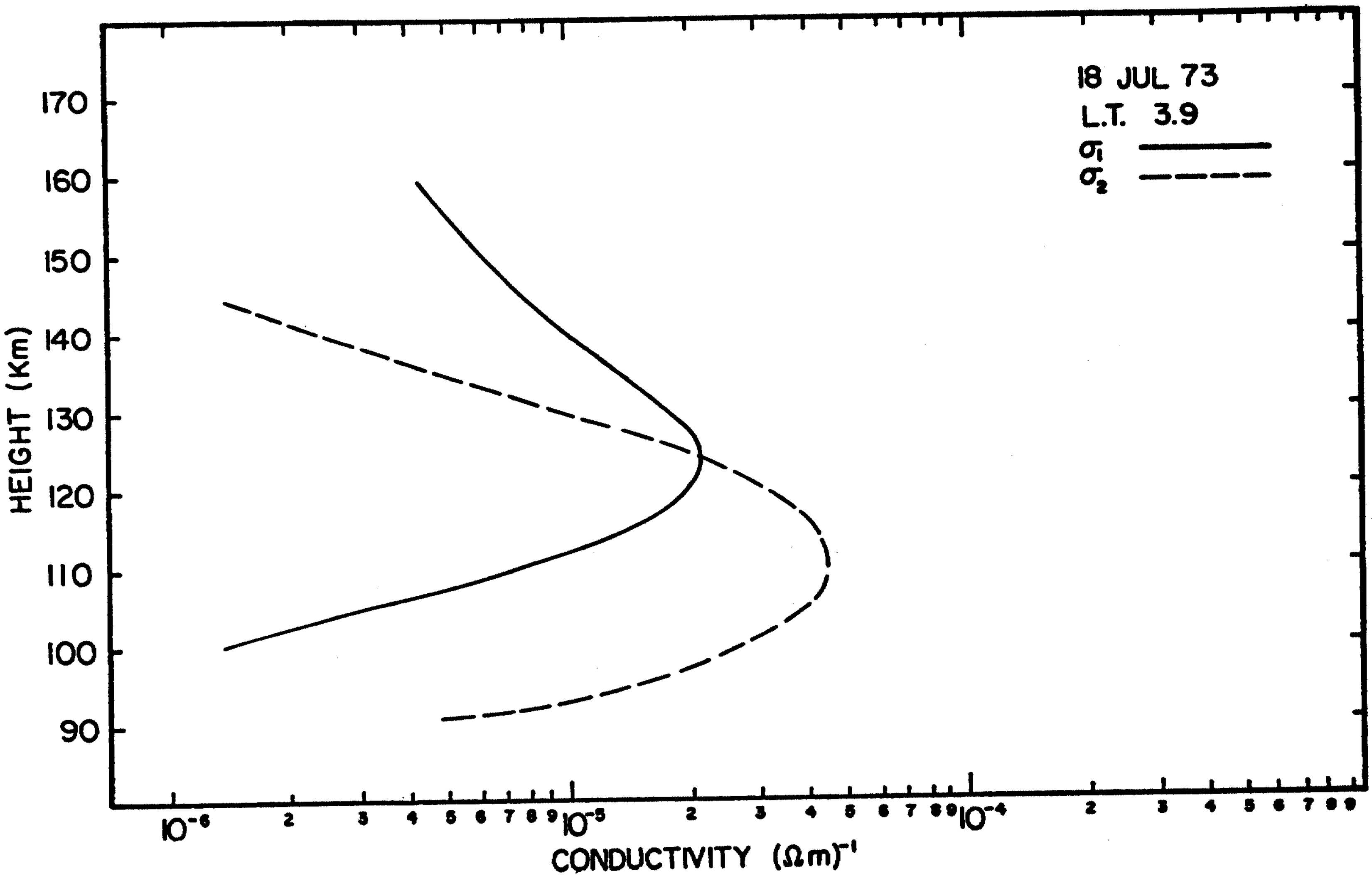


Figure 4. E-region Pedersen and Hall Conductivities as a Function of Height at 3.9 Local Time

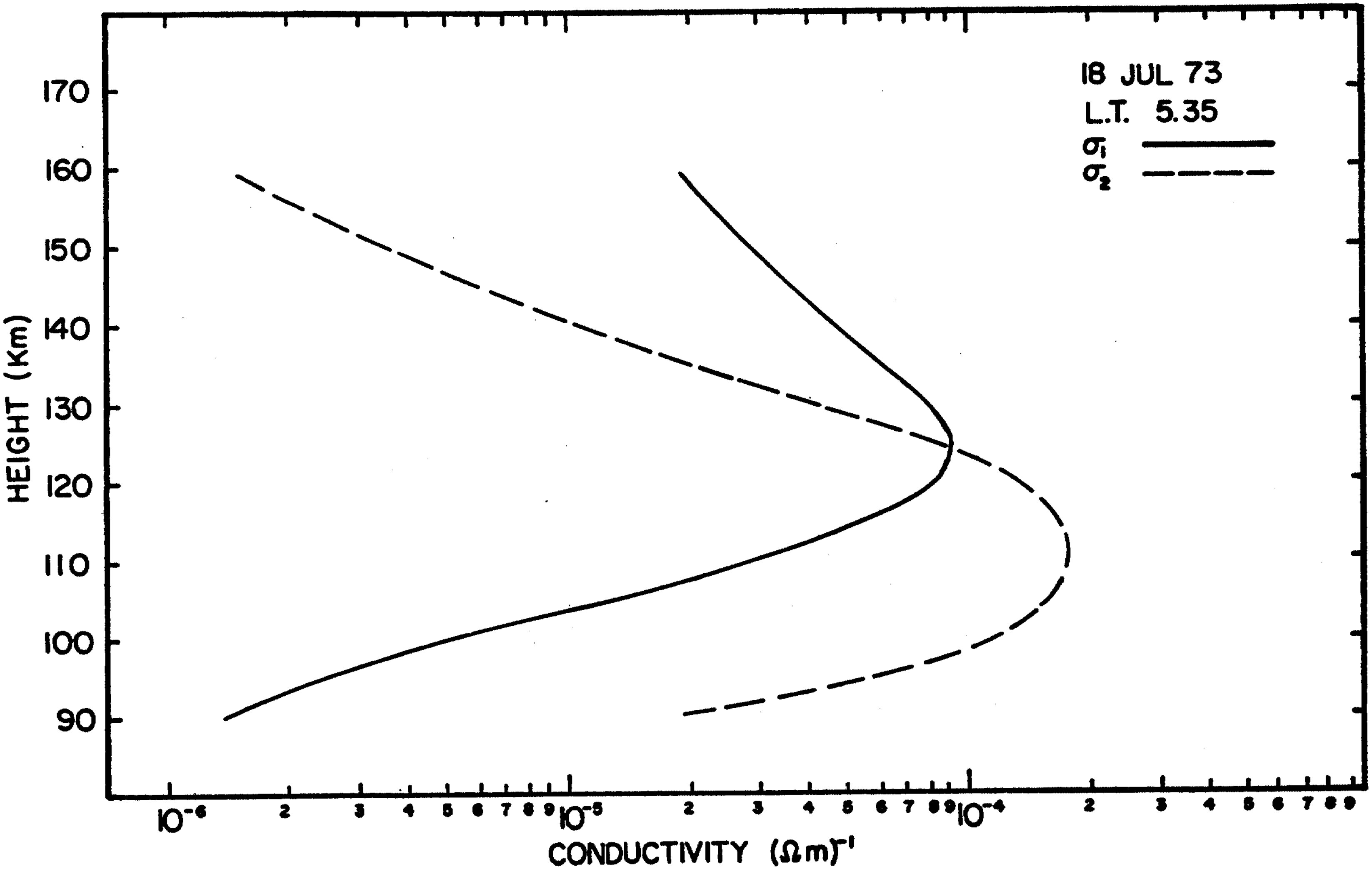


Figure 5. E-region Pedersen and Hall Conductivities as a Function of Height at 5.35 Local Time

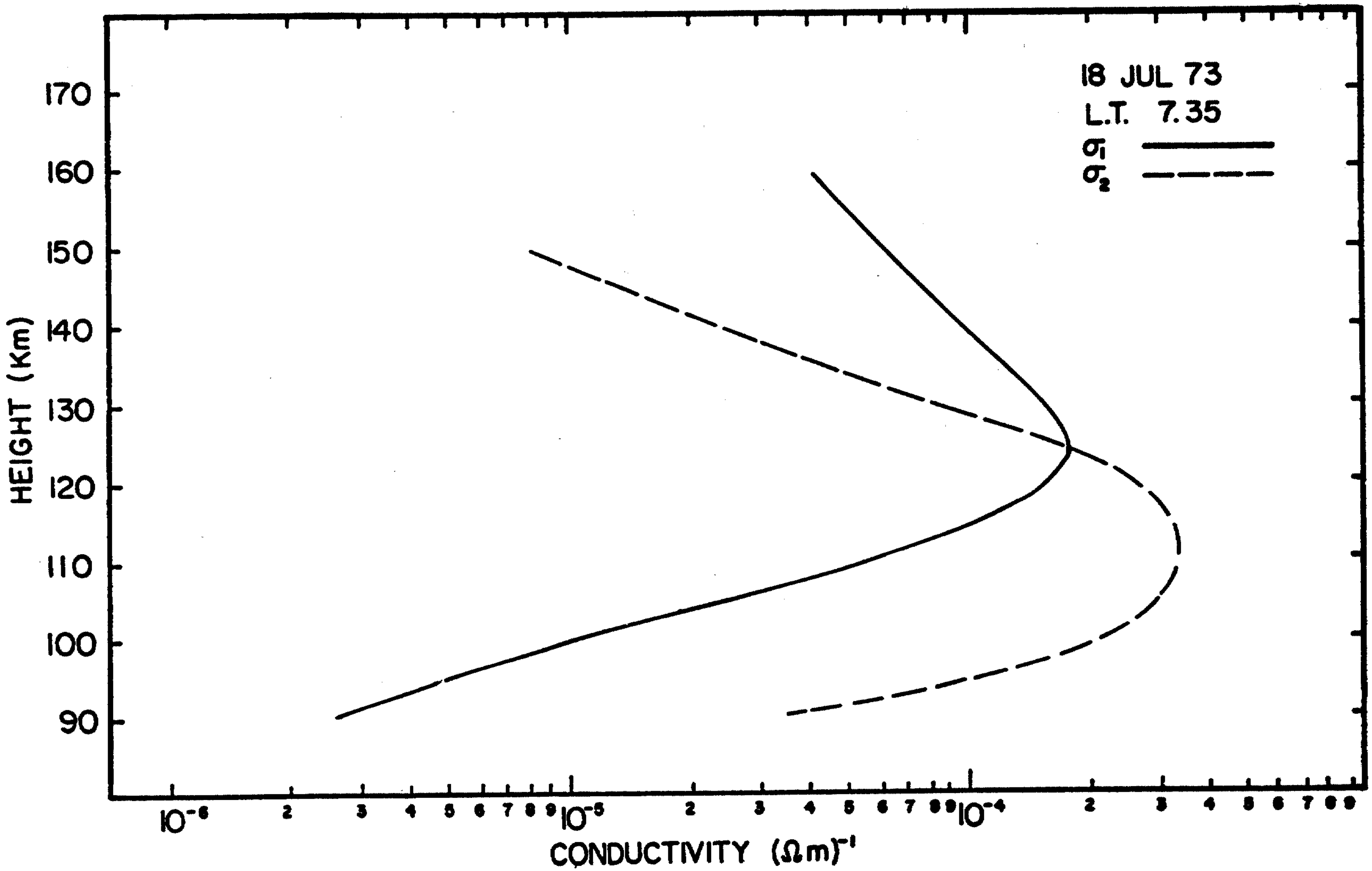


Figure 6. E-region Pedersen and Hall Conductivities as a Function of Height at 7.35 Local Time

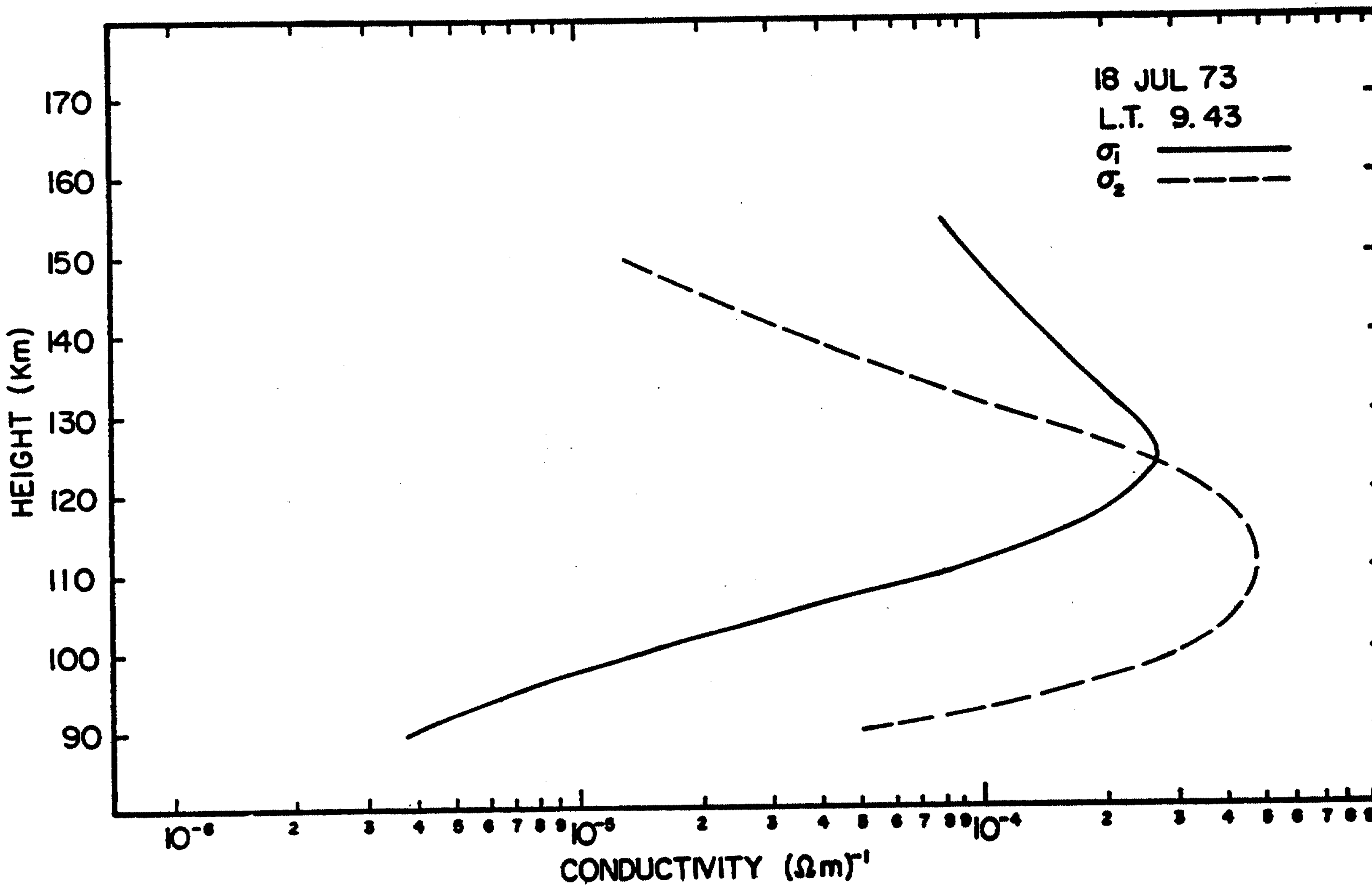


Figure 7. E-region Pedersen and Hall Conductivities as a Function of Height at 9.43 Local Time

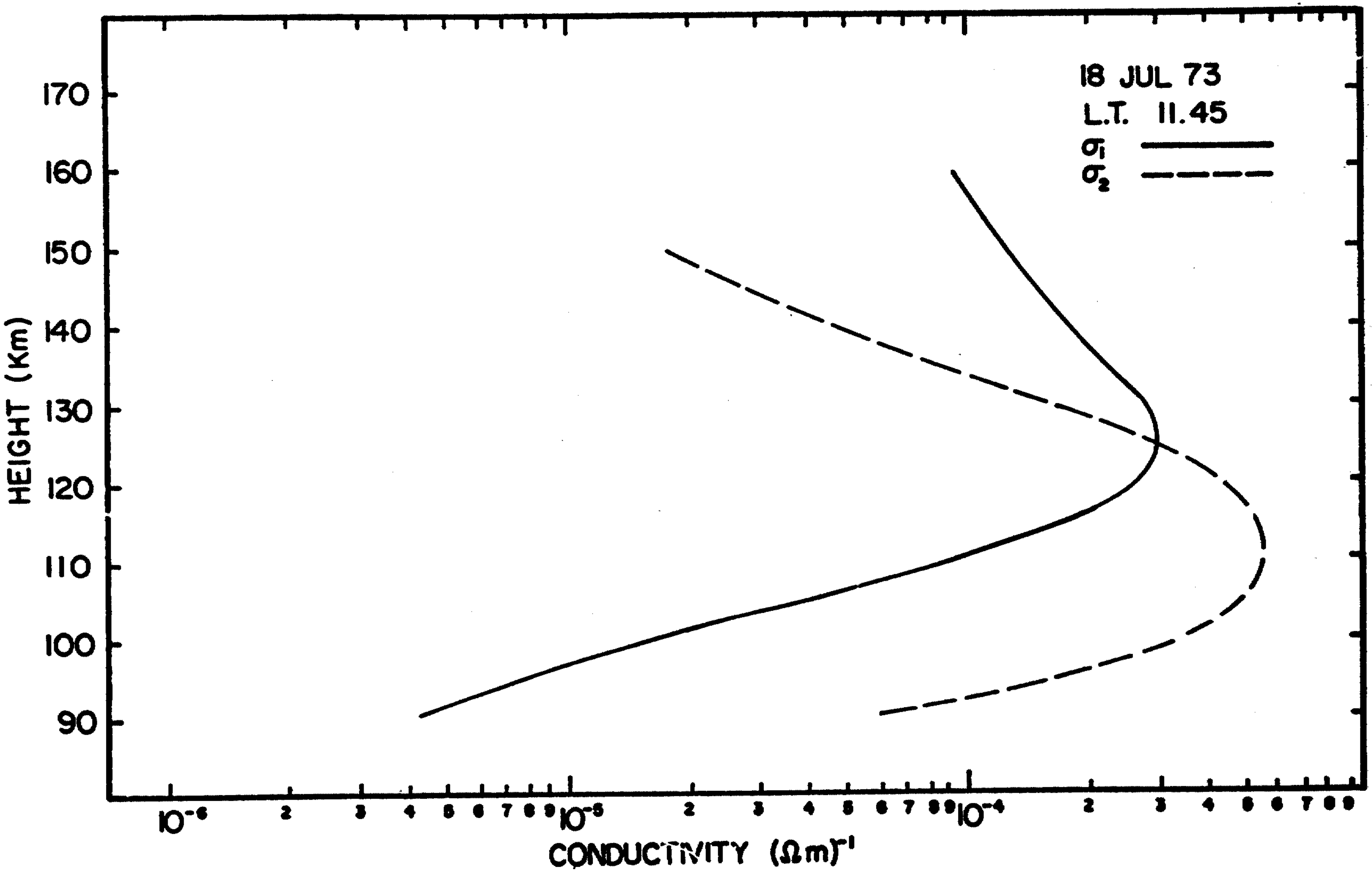


Figure 8. E-region Pedersen and Hall Conductivities as a Function of Height at 11.45 Local Time

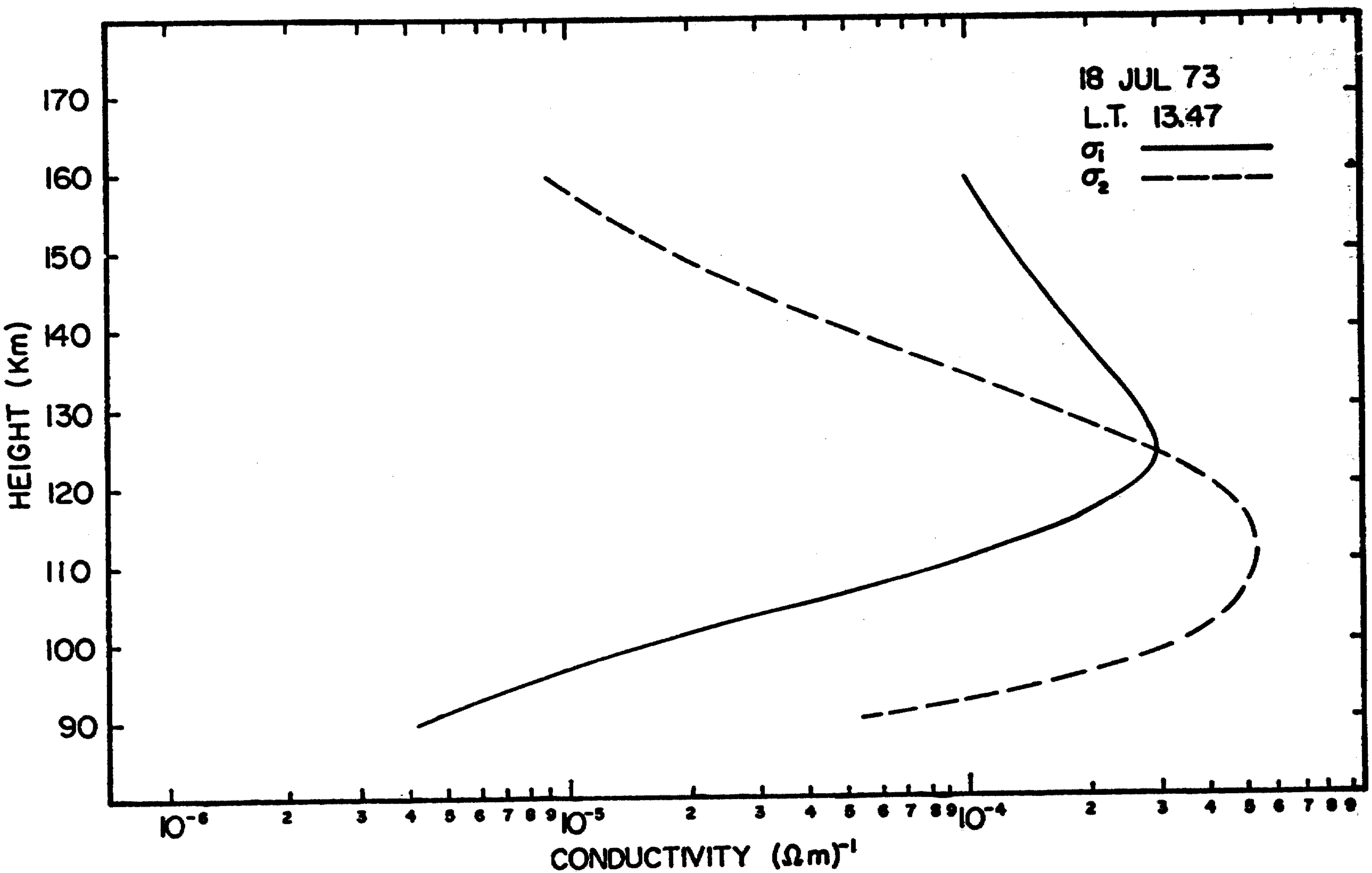


Figure 9. E-region Pedersen and Hall Conductivities as a Function of Height at 13.47 Local Time

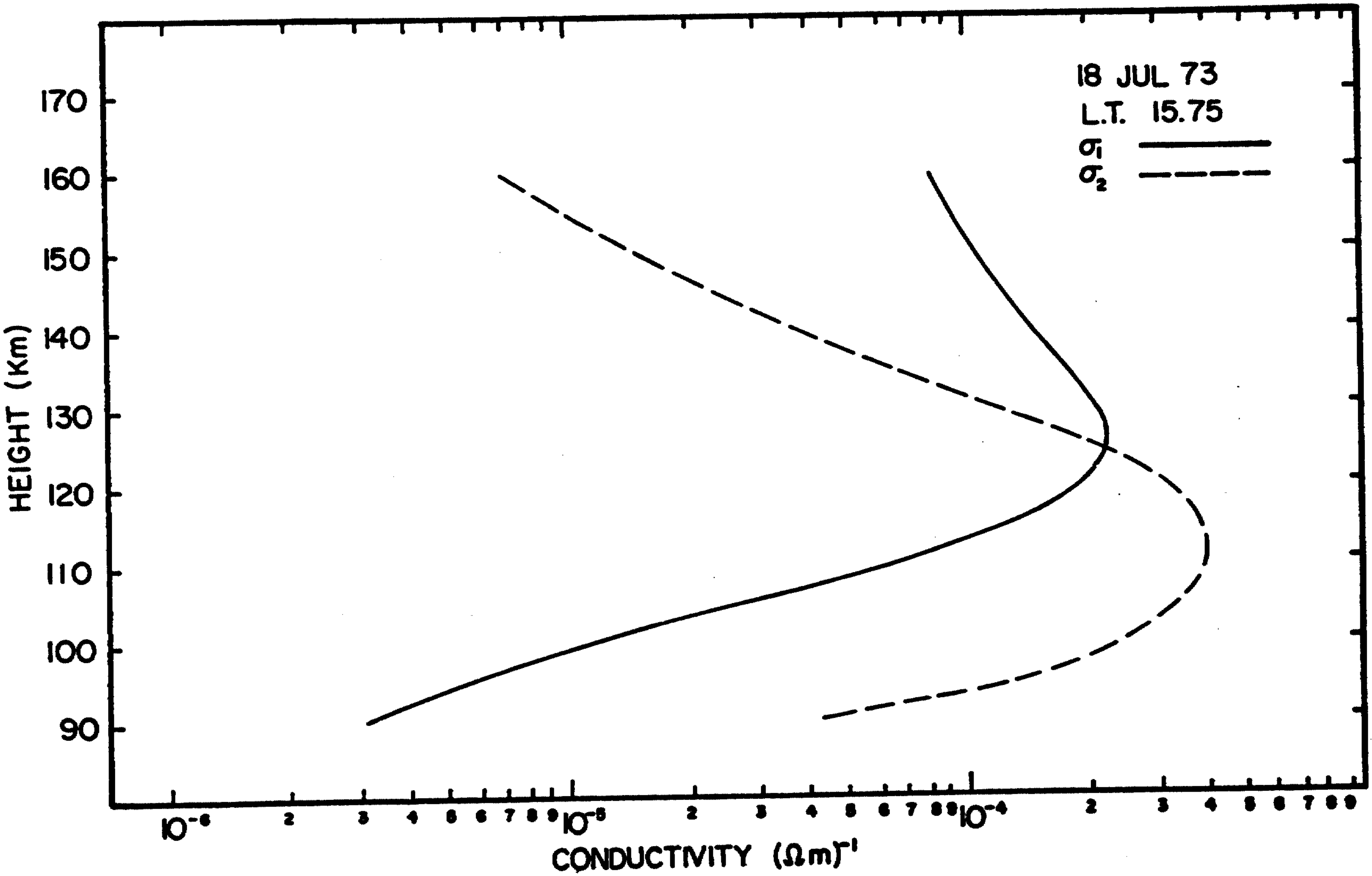


Figure 10. E-region Pedersen and Hall Conductivities as a Function of Height at 15.75 Local Time

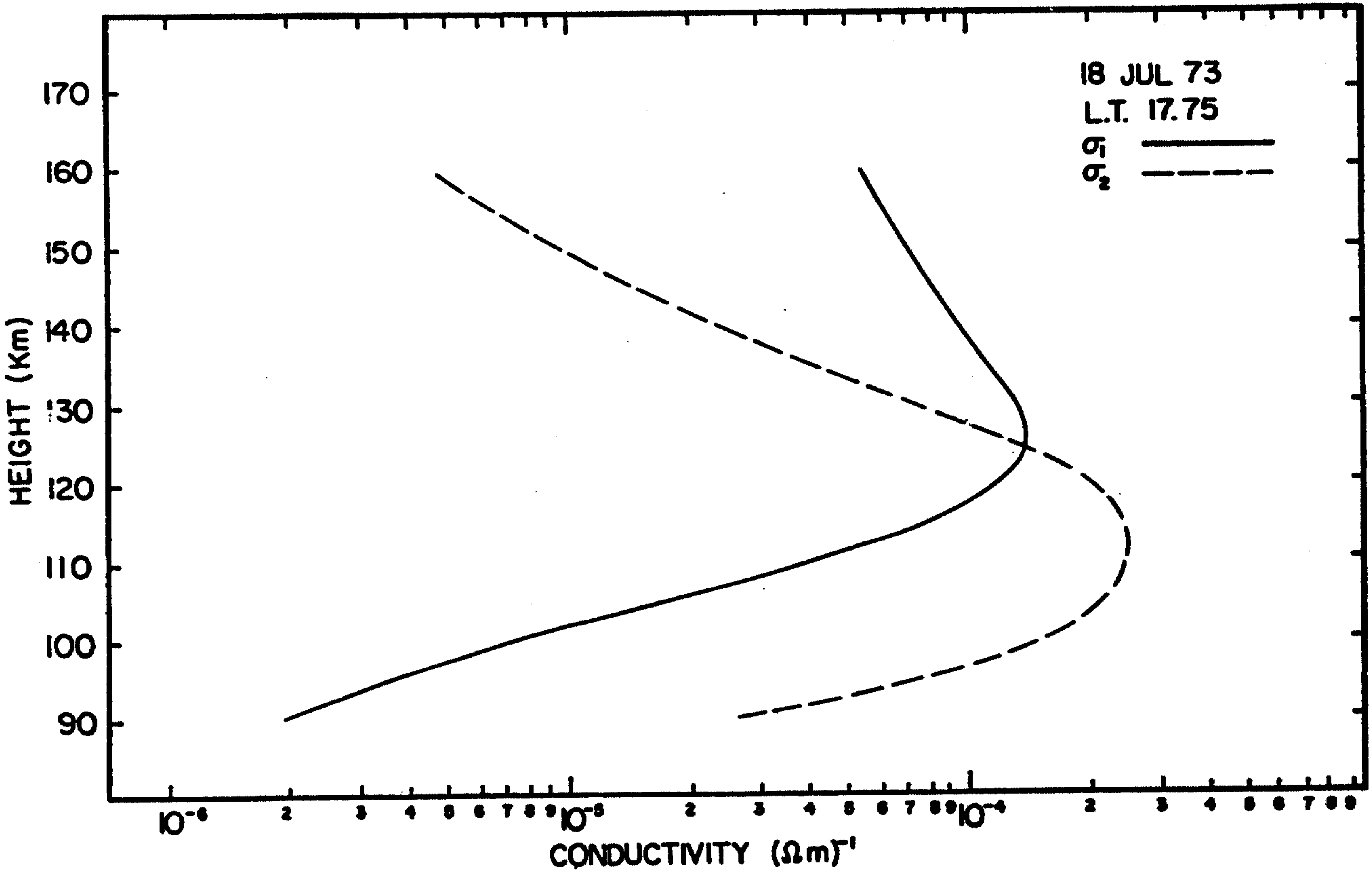


Figure 11. E-region Pedersen and Hall Conductivities as a Function of Height at 17.75 Local Time

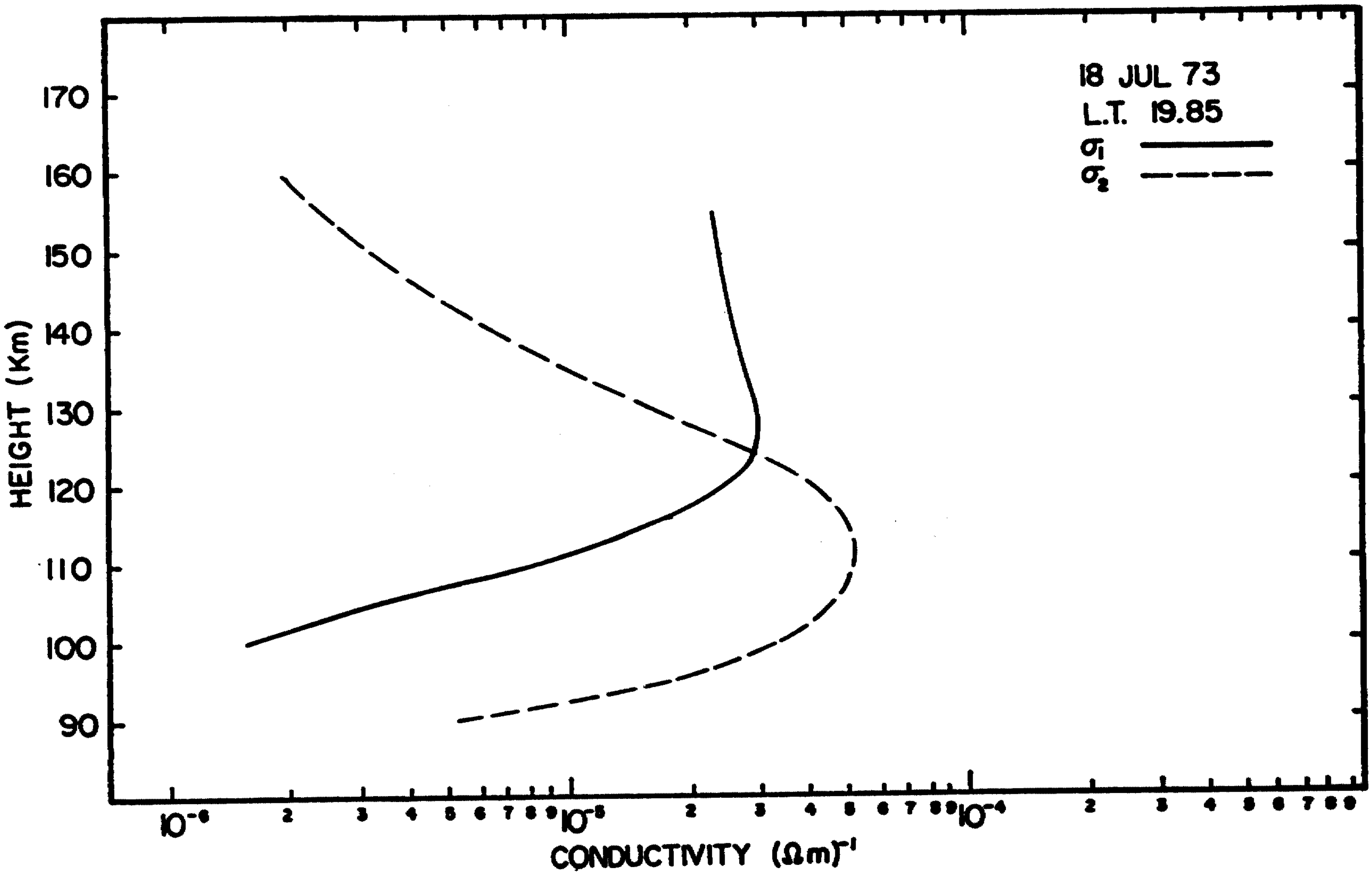


Figure 12. E-region Pedersen and Hall Conductivities as a Function of Height at 19.85 Local Time

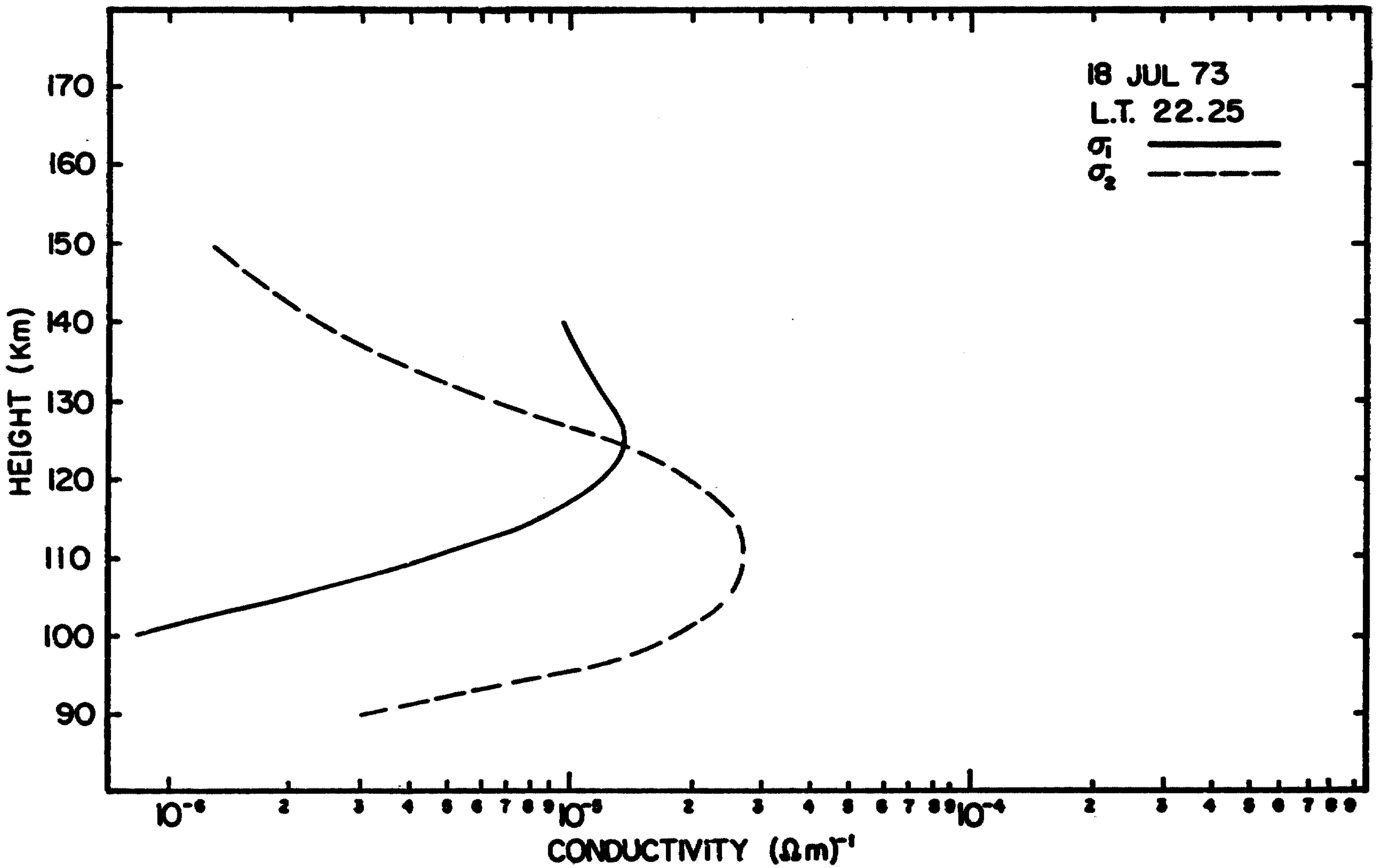


Figure 13. E-region Pedersen and Hall Conductivities as a Function of Height at 22.25 Local Time

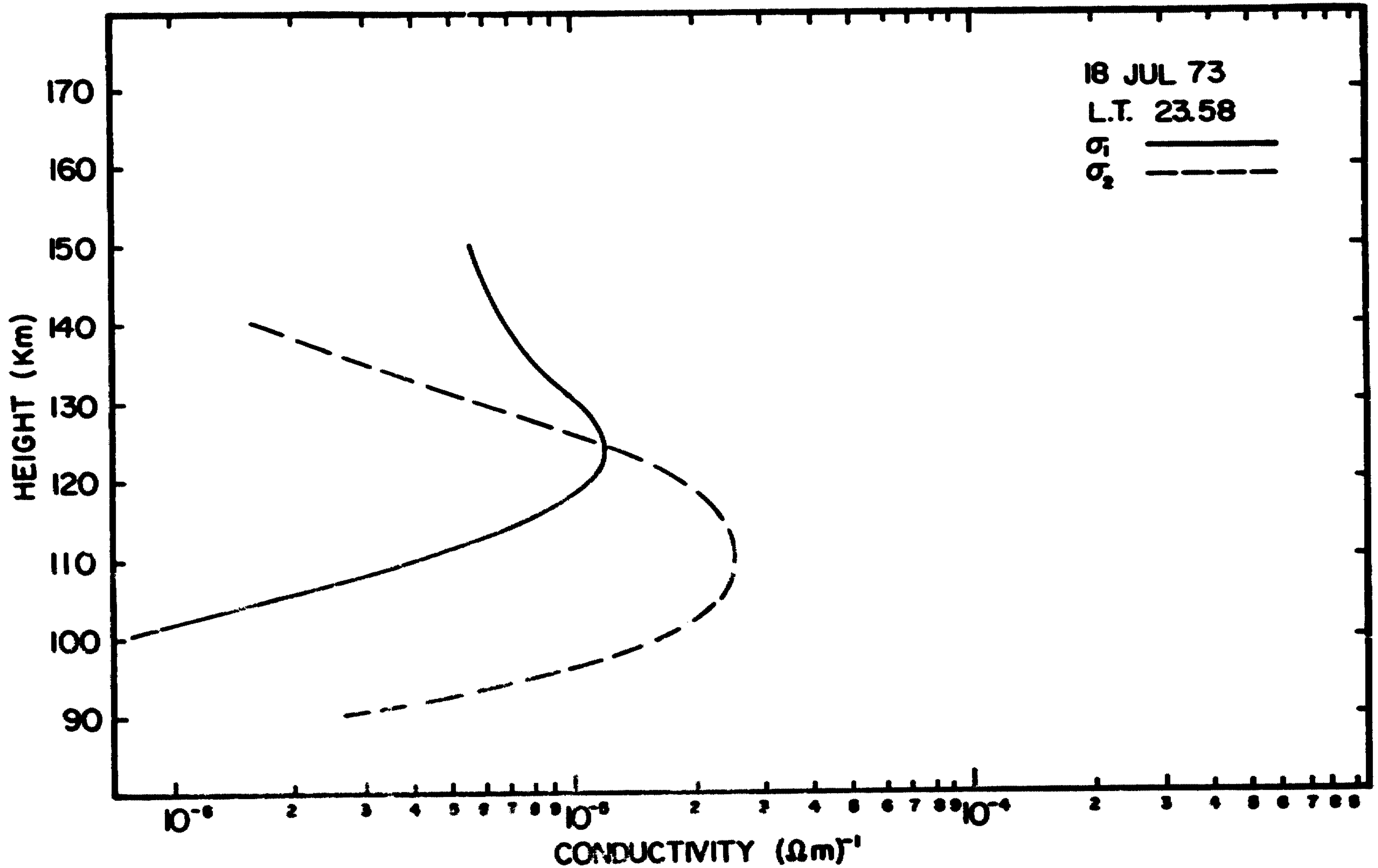


Figure 14. E-region Pedersen and Hall Conductivities as a Function of Height at 23.58 Local Time

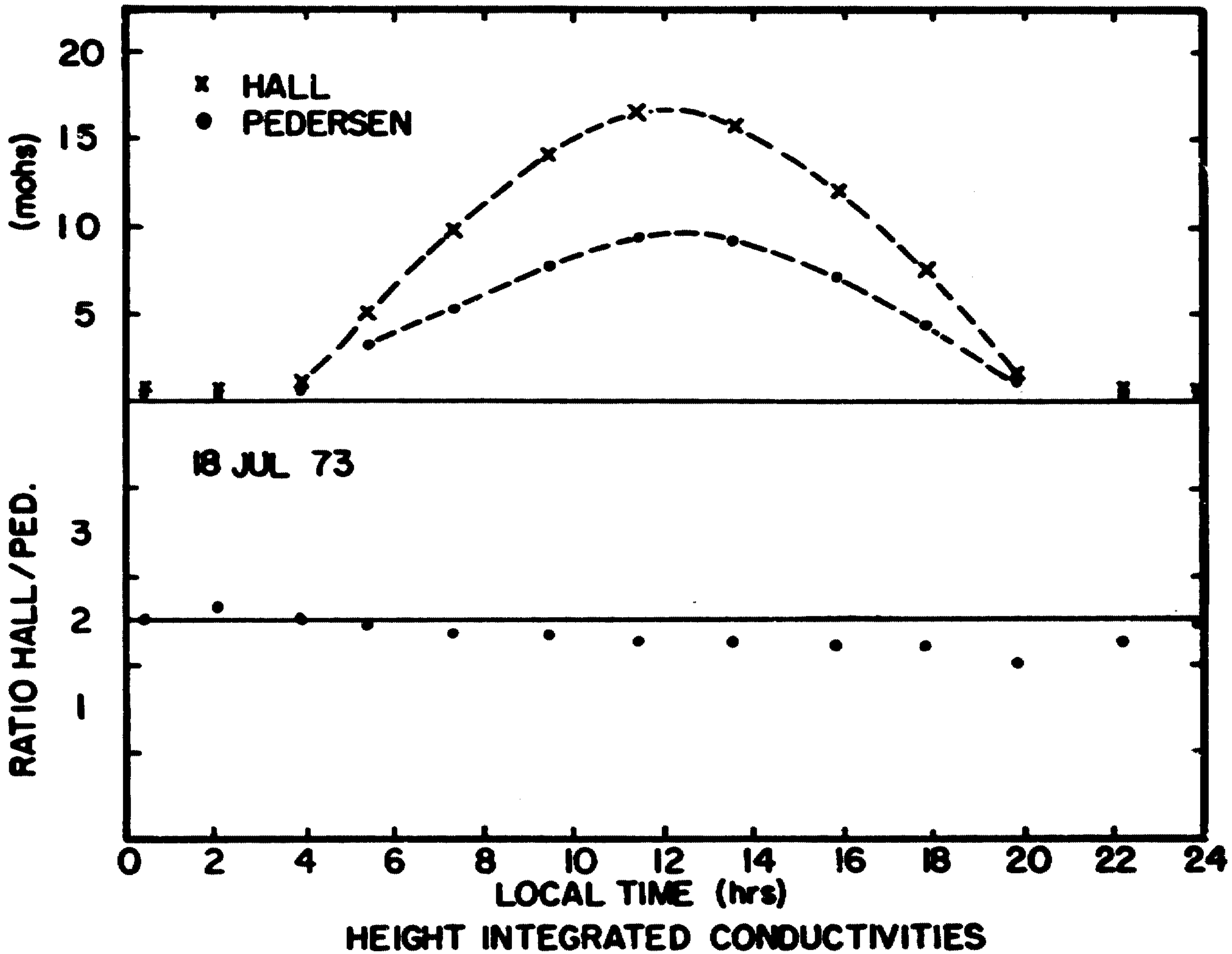


Figure 15. Height Integrated Pedersen and Hall Conductivities of the E-region and their Ratio as a Function of Local Time

Separating Eq. 3.1 into horizontal east and northward (magnetic) current components, and using height integrated quantities gives

$$I_E = \Sigma_p^1 (E_E + (U_S \times B)) + \Sigma_H^1 (E_N + (U_E \times B))$$
$$I_N = -\Sigma_H^1 (E_E + (U_S \times B)) + \Sigma_p^1 (E_N + (U_E \times B)) \quad (3.2)$$

where

$I_E$, $I_N$ are now height integrated E-region currents (A/m), E for eastward, N for northward

$\Sigma^1$ is the height integrated layer conductivity $(\Omega)^{-1}$

E is the polarization field (V/m)

$U_S$, $U_E$ are the average E-region neutral wind components (m/sec), S for southward, E for eastward

These currents should be highly correlated with ground based magnetic field variations; $I_E$ with positive H trace, $I_N$ with westward D trace. Equation 3.2 is valid in both hemispheres, but, in the southern, $\Sigma_H^1$ is negative.

Substituting the polarization electric fields in Eq. 3.2 by the correspondent F-region drift velocities, the currents will be

$$I_E = \left[(\Sigma_p/\sin^2 I)(V_N + U_S \sin I) + (\Sigma_H/\sin I)(V_W + U_E)\right] \times B$$
$$I_N = \left[(-\Sigma_H/\sin I)(V_N + U_S \sin I) + \Sigma_p (V_W + U_E)\right] \times B \quad (3.3)$$

where the $\Sigma$ are now the height integrated conductivities, $V_N$ is northward drift velocity and $V_W$ is westward drift velocity. I is the inclination angle, positive in the northern hemisphere ($I = 72^o$ for Millstone Hill) and B is the magnitude of the magnetic field at the average E-region height (130 km) and for Millstone Hill is $5 \times 10^{-5}$ Weber/$m^2$ (T).

### 3.2 Results

Using Eq. 3.3 the currents are calculated for a magnetically quiet day, 18 JUL 73 with $\Sigma K_p = 12$ and for a magnetically active day, 27 FEB 73 with $\Sigma K_p = 37^+$. Five different combinations of E-region neutral winds and electric fields are used according to Table 14. The Salah 75 E-region neutral wind is given by

$$U_N = 25 \cos (30\,t - 0) \text{ m/sec}$$

$$U_E = 25 \cos (30\,t - 270) \text{ m/sec}$$

where $U_N$, $U_E$ are geographic north and eastward components and

t is local standard time

The Salah 74 electric fields are those given by Salah et al (1974), and in terms of drifts may be expressed by

$$V_N = 47 \cos (30\,t - 306) \text{ m/sec}$$

$$V_W = 36 \cos (30\,t - 306) \text{ m/sec}$$

The electric fields Kirchhoff 75 are those described by Kirchhoff (1975).

For case V a diurnal component has been added to the winds. Since the dominant component is semidiurnal according to Salah et al (1975), the diurnal component should be smaller than 25m/sec. We assumed an amplitude for this component of 10m/sec. and the wind components are then, in m/sec.

$$U_N = 10 \cos (15\,t - 180) + 25 \cos (30\,t - 0)$$

$$U_E = -10 \cos (15\,t - 90) - 25 \cos (30\,t - 270)$$

The winds and drifts are all transformed to the geomagnetic horizontal coordinate system, using for Millstone Hill a declination angle of $15^\circ$W.

Table 14. Combinations of Electric Fields and Neutral Winds for the Calculation of Ionospheric Currents

| Case | E-region Neutral Wind | Electric fields |
|---|---|---|
| I | Salah 75 | zero |
| II | zero | Kirchhoff 75 |
| III | Salah 75 | Salah 74 |
| IV | Salah 75 | Kirchhoff 75 |
| V | Salah 75 + diurnal | Kirchhoff 75 |

The results for the five cases are shown in Figures 16 and 17. Also shown are magnetograms for Ottawa (45.4N, 75.5W) and Fredericksburg (38.2N, 77.4W). The three characteristics that will be compared between calculations and magnetograms are indicated by vertical dashed lines and the zero level in the magnetograms by a short section of horizontal line.

## 3.3 Discussion and conclusions

Case I. In this calculation the electric field contribution has been neglected. The east and northward peaks as well as the zero level are not well reproduced by the calculations.

Case II. The neutral wind contribution has been neglected in this case and the resulting currents do not follow the magnetogram traces as expected.

Case III. Neither the peaks nor the zero level could be reproduced in the currents from this combination.

Case IV. This combination shows excellent agreement in the peaks of the currents and the zero level, as compared to the magnetogram traces. The combination used is the semidiurnal neutral wind of Salah et al (1975) and the drifts of Kirchhoff (1975).

Case V. This is the case where a diurnal component of 10m/sec has been added to the neutral wind. Again the peaks are well reproduced but the zero level not so well, particularly for the northward component.

The good agreement between calculated currents and the magnetogram traces is remarkable considering all the averaging processes that are involved in both wind and electric field models. Furthermore, although the electric field model represents summer season, the winds do not represent any particular season. Seasonal

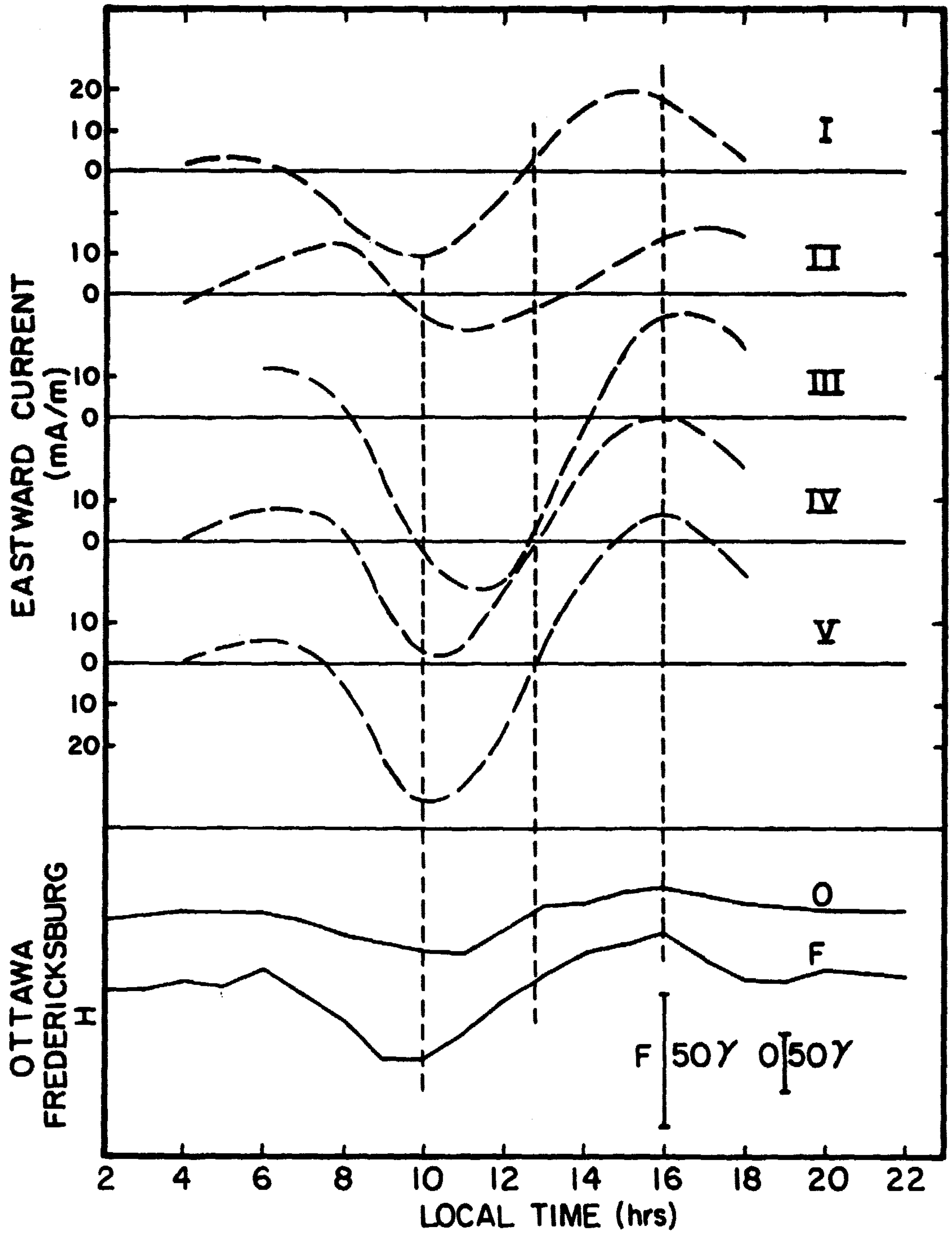


Figure 16. Eastward Height Integrated Currents as a Function of Local Time Calculated from Different Models, and Magnetogram Traces

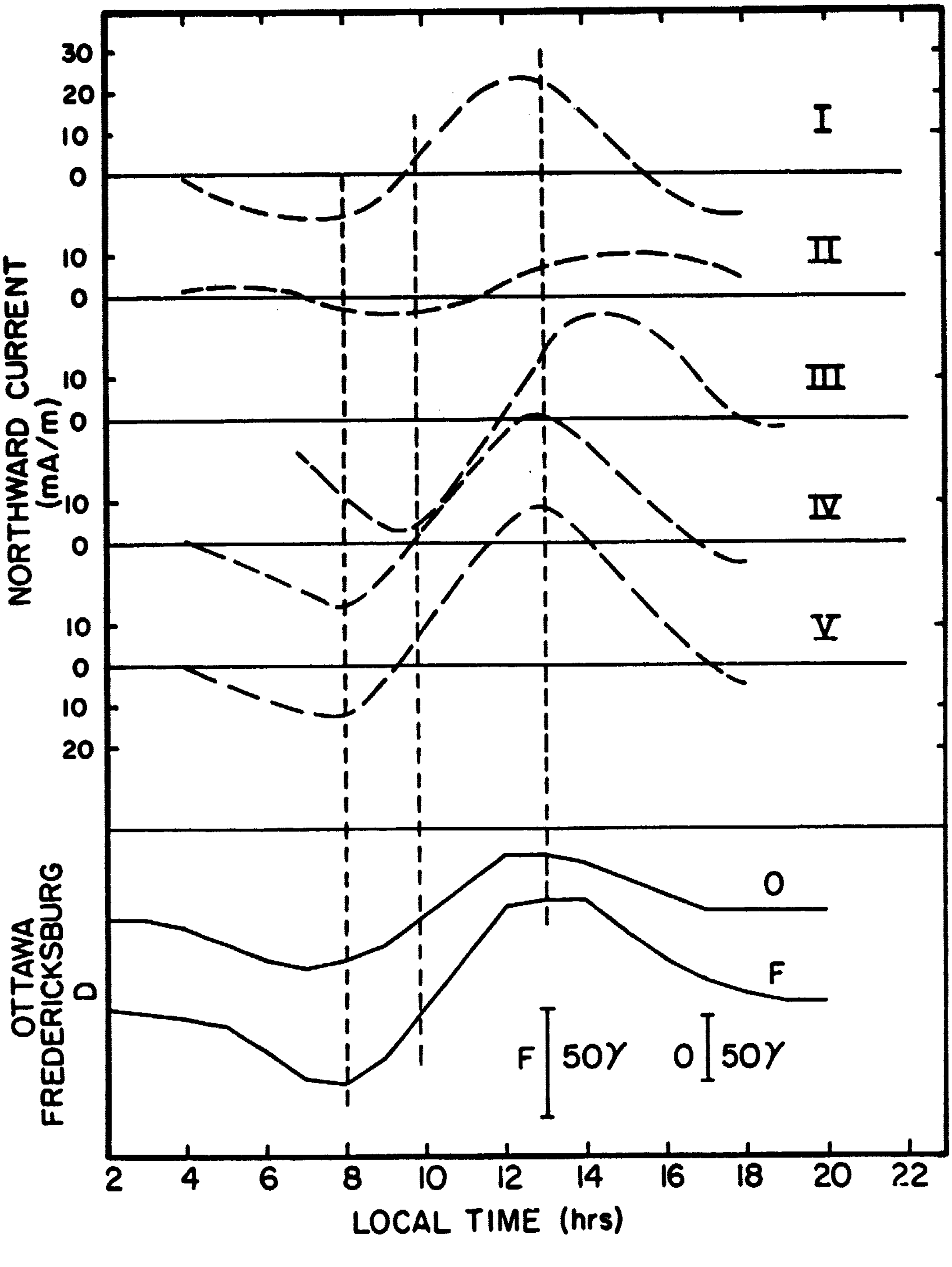


Figure 17. Northward Height Integrated Currents as a Function of Local Time Calculated from Different Models, and Magnetogram Traces

variations seem to be responsible for the secondary eastward peak at about 6 L. T. An analysis of magnetograms from Weston Observatory for the year 1968 shows that this feature is present during summer and equinox but not winter. Since the wind model at this stage does not include seasonal characteristics only the consistent features indicated by the vertical dashed lines are compared.

The currents calculated for the magnetic perturbed day are shown in Figures 18 and 19. Measured values of electric fields and Salah 75 were used. The complete lack of agreement between calculated currents and magnetograms is apparent and is probably due to the fact that neutral E-region winds, like the electric fields, suffer drastic changes during periods of high magnetic activity.

The comparison of the magnitudes of the currents, calculated and deduced from the magnetograms, is not so good. The magnetic variations on the ground and the currents in the ionosphere (infinite sheet currents) are related by

$$\Delta B = \mu_o I/ 2f$$

where

$\Delta B$ is the magnetic variation ($\Delta H$ or $\Delta D$)

$\mu_o$ is the permeability $4 \pi 10^{-7}$ (H/m)

I is the current density (A/m)

f accounts for induction within the earth and most often is given the numerical value of 0.6.

Inverting the relation above with $\Delta B$ in games and I in (mA/m), we have

$$I(mA/m) = .955 \times \Delta B (\gamma) \qquad (3.4)$$

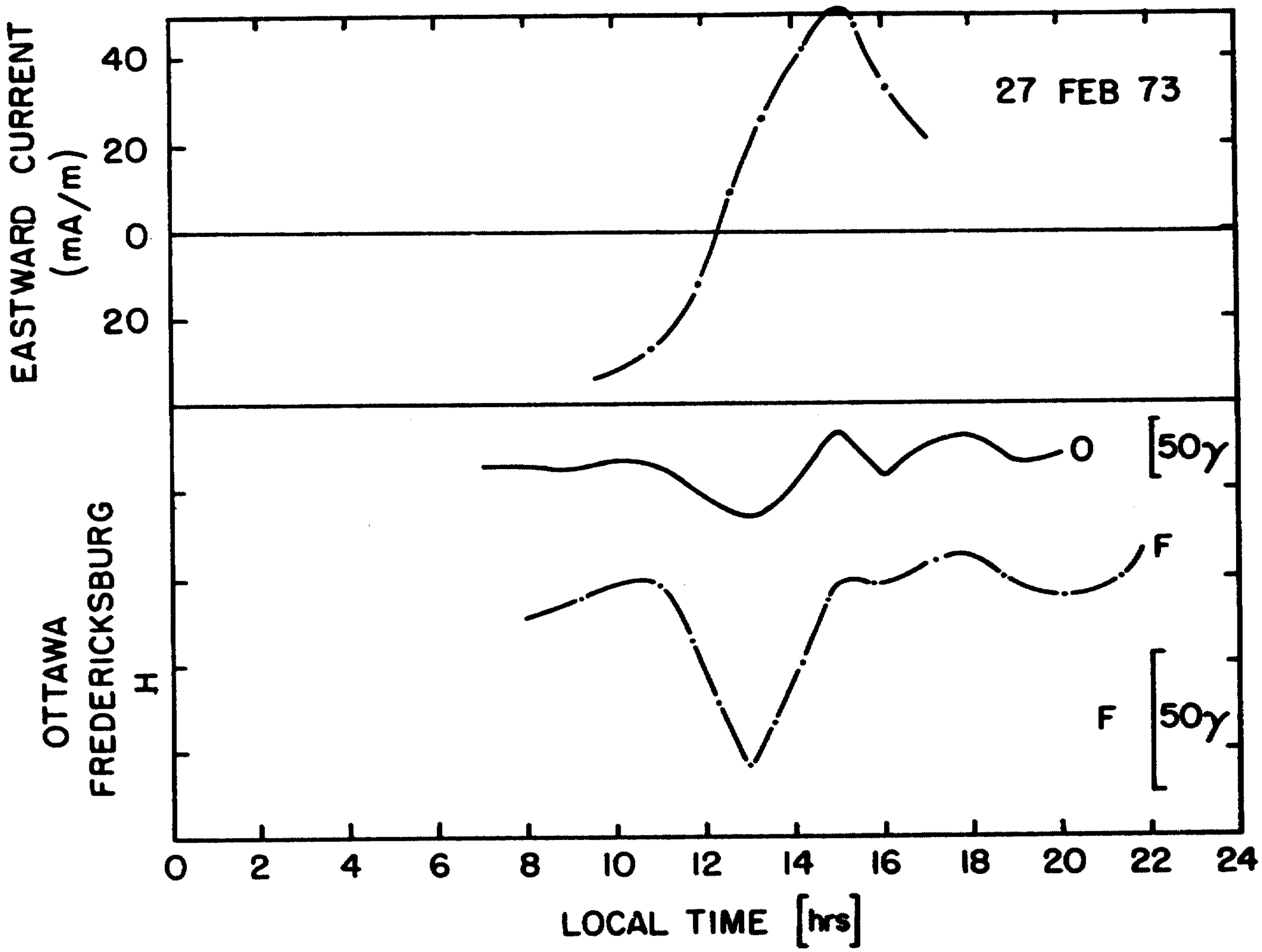


Figure 18. Eastward Current for a Magnetic Active Day Compared to Magnetogram H and D Traces

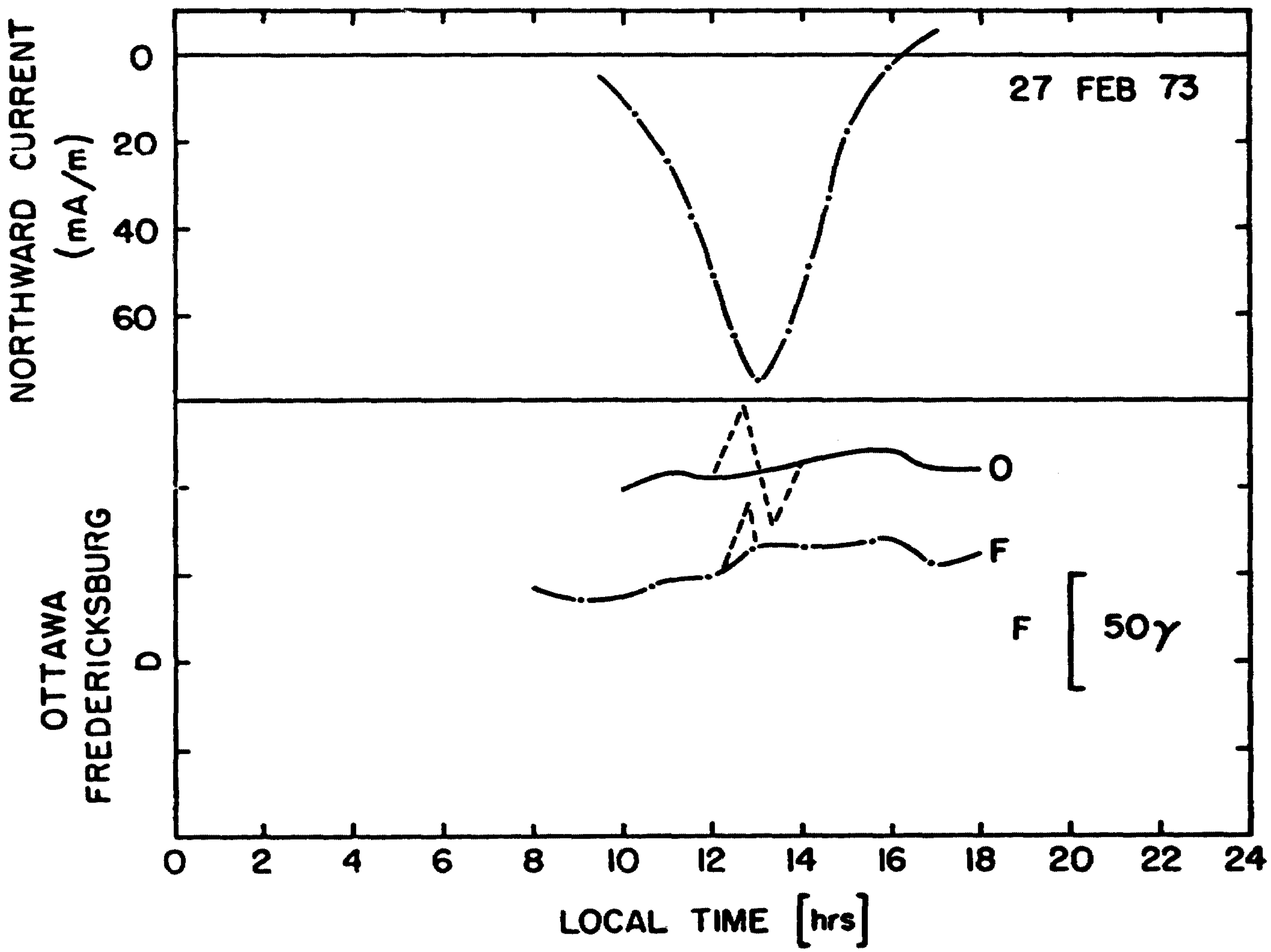


Figure 19. Northward Current for a Magnetic Active Day
Compared to Magnetogram H and D Traces

For Fredericksburg (see Table 15) the westward peak is about 30 mA/m while Case IV gives 28 mA/m but for the eastward peak the H trace gives only 16 mA/m while Case IV gives 31 mA/m.

For the southward component the currents from the magnetograms are larger than the calculated values. The southward peak in $\Delta D$ is 33 mA/m while Case IV only gives 15 mA/m and the northward peak is 46 mA/m from $\Delta D$ and 30 mA/m from Case IV.

Table 15. Peak Value Comparison of Currents from Equations 3.3 and 3.4 for 18 July 73

| ΔB(γ) Fredericksburg | $I_E$ (mA/m) Eq. 3.4 | $I_N$ (mA/m) Eq. 3.4 | $I_E$ (mA/m Eq. 3.3 | $I_N$ (mA/m) Eq. 3.3 |
|---|---|---|---|---|
| 31.0 | -30 | | -28 | |
| 16.7 | 16 | | 31 | |
| 35 | | -33 | | -15 |
| 48 | | 46 | | 30 |

## Appendix A - Note on the E-region shorting effect

The E-region current that can be driven by the dynamo F-region electric field is

$$I_E = (\Sigma_p)_E\,(U \times B)$$

and the F-region current by

$$\vec{J} = Nq\,\vec{V} = Nq\,U\,\frac{\nu}{\omega}\quad(\vec{U} \times \vec{B})\,/\,UB$$

$$= Nq/B\,\frac{\nu}{\omega}\quad BU$$

or

$$I_F = (\Sigma_p)_F\quad UB$$

where $\Sigma_p$ is the height integrated Pedersen conductivity

U is the neutral wind

V is the drift velocity

N is electron number density

$\nu$ is collision frequency

$\omega$ is gyro frequency

B is the magnetic field

According to Rishbeth (1971) the E-region can short-circuit any F-region polarization field if

$$I_E \geqslant I_F$$

or substituting the currents, if

$$(\Sigma_p)_E \geqslant (\Sigma_p)_F$$

From section 2 we have that this is true for most of the daytime period for which we have approximately $(\Sigma_p)_E/(\Sigma_p)_F \cong 2$ and for the nighttime period $(\Sigma_p)_E/(\Sigma_p)_F \cong 0.5$. This indicates that the nighttime F-region electric fields created by the action of the thermospheric wind system (as opposed to the tidal E-region neutral wind, responsible for the E-region dynamo) are effective current drivers, as previously concluded by Rishbeth. The implication is that at night the F-region dynamo makes a substantial contribution to the total ionospheric polarization electric field, but not during the day. This is substantiated by recent model calculations (Kirchhoff, 1975) which indicate that nighttime drifts resulting from the action of thermospheric winds may be as large as 100 m/sec.

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