GEOFISICA INTERNACIONAL

REVISTA DE LA UNION GEOFISICA MEXICANA. AUSPICIADA POR EL INSTITUTO DE GEOFISICA DE LA UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

Vol. 18 México, D. F., a 1o. de abril de 1979 Núm. 2

pp. 91-111

PLASMASPHERIC ELECTRON CONTENT

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(Received Nov. 7, 1979)

RESUMEN

A pesar del abundante trabajo realizado sobre el problema del contenido electrónico plasmasférico y sobre flujos relevantes de plasmas fríos, existen solamente pocas determinaciones experimentales directas de estos conceptos.

1. Sondeos ionosféricos (ionosondas terrestres y a bordo de satélites, mediciones de radar en experimentos de dispersión coherente e incoherente).
2. Mediciones de silbido ionosférico.
3. Instrumentos a bordo de satélites y cohetes.
4. Experimentos con señales enviadas desde satélites.

En este trabajo se hace énfaseis especial sobre la última técnica mencionada, pero no se discuten aspectos de su aplicación. Se demuestra que el contenido electrónico total N_T derivado de las mediciones del retraso diferencial de grupo da una buena estimación del contenido electrónico desviado (hasta la altura del satélite) para todas latitudes y en todos los casos siempre y cuando no ocurran fuertes cintilaciones.

En regiones de alta latitud la cantidad N_T se hace cada vez más importante, especialmente como información suplementaria para experimentos de dispersión incoherente y experimentos de "calentamiento". Se puede además demostrar que a medianas latitudes la cantidad $Np = N_T - N_F$ da una buena medida del contenido electrónico (residual) entre los 2 000 Km y 36 000 Km de altura aproximadamente. Debido a esta definición y a las definiciones existentes de plasmósfera surge la pregunta de si debemos continuar usando los términos de contenido electrónico plasmasférico, protonosférico y exosférico para la cantidad Np o si debemos cambiarla a contenido electrónico residual (CER). Es muy probable que la cantidad N_p sea la única cantidad

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obtenida en observaciones de percepción remota que permita el monitoreo continuo de los flujos electrónicos entre L = 1 y L = 2. Se presentan además algunos de los más importantes resultados deducidos de esta nueva cantidad N_p. Tales resultados muestran que N_p es una cantidad geofísica muy útil, y que puede ser fácilmente monitoreada en forma continua y a bajo costo desde muchas estaciones terrestres utilizando satélites equipados con instrumentación de señales de radio a tierra.

El estado de las investigaciones experimentales sobre técnicas de señales de radio dirigidas desde satélites, es actualmente muy avanzado. Es necesario que pronto se tomen decisiones sobre su aplicación y sobre la conveniencia de planificar experimentos operacionales basados en estas técnicas.

ABSTRACT

Despite substantial work on the problem of the plasmaspheric electron content and of relevant fluxes of cold plasma, there are only few direct experimental determinations, which do not replace but supplement each other.

1. Ionospheric sounding (ground-based and satellite-borne ionosondes, radar measurements like coherent and incoherent scatter)
2. Whistler measurements
3. Satellite –and rocket– borne instruments (in situ measurements)
4. Satellite Radio Beacon Experiments (RBE)

Here special emphasis is given to the latter. Application aspects are disregarded here. It is shown, that the total electron content N_T as derived from differential group delay measurements gives a good measure of the slant electron content (up to the altitude of the satellite) for all latitudes, in all cases, when no too strong scintillation occur. Especially in high-latitude regions N_T becomes more and more important, especially as supplementary information for incoherent scatter and so called "heating" experiments. It could be further shown that in midlatitudes the new quantity $N_p = N_T - N_F$ is a good measure of the (residual) electron content between about 2 000 km and 36000 km altitude. Due to this definition and to earlier definitions of the plasmasphere the question arises whether we should further use the terms plasmaspheric, protonospheric or exospheric electron content for N_p or whether we should change it into Residual Electron Content (REC). It is very likely that N_p is the only remote sensing measurement that allows a continuous monitoring of electron fluxes between L = 1 and L = 2. Some of the most important findings deduced from this new quantity N_p are presented. They show, that N_p is a very useful geophysical quantity, that could be relatively easy and inexpensive continuously monitored from many ground stations, provided satellites with Radio Beacon Experiments are available. We are close to the end of the experimental phase of the radio beacom experiments. Fairly soon decisions have to be made by the "application side" as well as by scientists in basic research whether and which, operational radio beacon experiments should be planned.

I. THE PLASMASPHERE

In recent years, the importance of the plasmasphere (Chappel *et al.*, 1971 a, b) and plasmapause (Foster *et al.*, 1978; Lemaire and Scherer, 1974; Titheridge, 1976) in the overall magnetospheric particle environment has become increasingly apparent. Interest in plasmasphere morphology and dynamics has grown because of three major fields:

a) magnetospheric convection

b) wave particle interaction

c) ionization interchange between the ionosphere and plasmasphere. The plasmasphere is defined as the collision-dominated ionized region of the upper atmosphere, which is separated from the collisionless ion-exosphere by the so called ion-exobase which coincides with the plasmapause in the low-latitude region (Lemaire and Scherer, 1974). At the geomagnetic equator the plasmasphere may reach for example up to an altitude of about five earth radii, while at the geomagnetic pole it only may reach up to an altitude of about 1000 km above the surface of the earth (~ 1.2 earth radii). Inside the plasmasphere and below the ion-exobase both hydrostatic models and hydrodynamics models are appropriate as a consequence of the large colision rate.

In the collisionless region beyond the plasmapause and above the exobase, a kinetic theory based on Liouville's equation is more appropriate than the classical hydrodynamic theory (Lemaire and Scherer, 1974). The previous example clearly shows why it is so different whether we deal with the plasmasphere in low –and mid– latitude regions or with the plasmasphere in the hig-latitude region. Furthermore we encounter a specific problem because the transition region between the two latitude regions changes its location as a function of time and geomagnetic activity. For example when viewed in context with the auroral oval it is evident, that stations between approximately 65° and 72° corrected geomagnetic (CG) latitude are, in the daytime, mid-latitude stations, while at night they are under the nighttime sector of the auroral oval. Stations between approximately 75° and 80° CG latitude are, by day, under the day sector of the oval, while at night they are typical polar cap stations. Stations between 72° and 75° CG latitude experience all three conditions (mid-latitude, oval and polar cap) at different times (Hartmann, 1975).

Main emphasis will be given here to the problems of the plasmasphere in low and mid-latitude regions, since the most relevant satellite radio beacon data belong to this region. However the very interesting transition region and the high-latitude region has been studied with radio beacon data in the context with the IMS program 0231 (Leitinger *et al.*, 1978).

All these definitions were considered here in more detail to show that the term plasmasphere and ionosphere mean the same in many cases, i.e. overlap, and that this type of splitting the subject into separate subjects is bound to the arbitrary, but has to be attempted from a methodological point of view.

A comprehensive treatment of magnetospheric convection can be found in a review by Axford (1969). In general, the convection model assumes the presence of a large-escale electric field directed from dawn to dusk across the magnetosphere. It was recently shown by Degenhardt *et al.* (1977) that radio beacon measurements of the protonospheric electron content might contribute to refinements of this model under disturbed conditions.

The application of wave particle processes as explanations for many magnetospheric phenomena has produced an increased interest in the thermal particle distribution (Banks and Doupnik, 1974) within the plasmasphere (see also review by Hartmann [1975]). Such phenomena as the distribution of energetic particles within the radiation belts, the precipitation of relativistic electrons during magnetic storms, the asymmetric shape of the ring current and its subsequent decay, and the occurrence of SAR (stable auroral red arcs) at the L values of the plasmapause can be explained in terms of wave-particle interactions. Relativistic electrons cannot be remotely sensed by radio frequencies close or below the critical frequency of the F2 layer of the ionosphere. This is no longer true for the much higher frequencies now used for radio beacon experiments (RBE). Nonetheless, as long as the ratio of the relativistic to non-relativistic electrons in the upper atmosphere is small, they can make no significant contribution to RBE electron content measurements. In contrast RBE scintillation measurements become more important in this context because relativistic electrons can produce ionospheric irregularities.

In recent years there has been considerable interest in the interaction between the ionosphere and magnetosphere, and the exchange of cool plasma between the two along magnetic flux tubes. This interaction has been discussed in connection with the maintenance of the nighttime ionosphere (Ebel *et al.*, 1976; Evans, 1975 b; Hargreaves, 1978; Jain and Williams, 1974; Kersley *et al.*, 1978 a; Kohl and Rishbeth, 1976; Park, 1970; Tyagi, 1974), the possibility of transport of ionization between conjugate ionospheres, the replenishment of the ionization in the magnetospheric flux tubes at high latitudes following its removal during magnetic storms (Park, 1970; Chappell, 1971 b; 1972), and the exchange of ionization induced by substorm electric field (Banks and Doupink, 1974; Degenhardt *et al.*, 1977; Kersley *et al.*, 1978 b; Lanzerotti and Webb, 1977; Mendillo *et al.*, 1972, 1974; Poletti-Liuzzi *et al.*, 1977 Soicher, 1976).

It has been shown by Park (1970) and Evans (1975 a, 1975 b) that substantial flux of ionization can be exchanged between the ionosphere and the protonosphere (see also chapter III). The exact degree to which this exchanges takes place is not well known, but its consequences on F-region phenomena are important (Mendillo and Klobuchar, 1978).

In a recent review by Foster *et al.* (1978) on plasmapause signatures in the ionosphere and magnetosphere the following conclusions were suggested:

1. The low-altitude total density and light ion troughs begin significantly equatorward of the equatorial plasmapause field line.
2. The ionospheric troughs are associated with flux tubes on which the equatorial density is below its equilibrium value and which are thus refilling from below. The troughs are not clear plasmapause signatures.
3. Plasma sheet electrons, with mirror heights as low as 1400 km, are observed on flux tubes outside the equatorial plasmapause at both dawn and dusk. Their low-latitude extent at this altitude can be used as a signature of plasmapause position.

II. THE IONOSPHERE

The ionosphere (Rawer and Suchy, 1967) occupies a key position in solar terrestrial physics because it impinges on both the magnetosphere and on the domain of meteorology. Qualitative understanding of the ionosphere certainly exists, and the ionization and energy balances are probably known quantitatively to within a factor of 2 (Kohl and Rishbeth, 1976). Better precision is attainable in some "case studies", but any attempt to achieve greater accuracy everywhere is hampered by the fact that the ionosphere, and particularly the F2 layer, shows marked spatial and temporal variability: place to place, hour to hour, day to day. Some features are repeatable, some attributable to magnetic disturbance, some apparently random. This variability has often been studied and commented upon, but never satisfactorily explained. Is it just "noise" resulting from random fluctuations of the many parameters that influence the ionosphere, in which case it is of limited scientific interest? Or does it conceal unrecognized physical processes or linkages between the sun, the magnetosphere, the upper atmosphere, the lower atmosphere and weather, terrestrial and oceanic phenomena?

Hence many topical questions still need to be solved (Kohl and Rishbeth, 1976). A few will be mentioned here to which the measurements of the plasmaspheric electron content might contribute some further informations.

1. Maintenance of the ionosphere at night, especially the F2 layer.
2. Nighttime ionization maxima.
3. The strong day to day variability of the F-region.
4. Effects of magnetic storms.
5. Differences between the North and South Hemispheres.
6. Seasonal anomalies.

III. THE FLUX OF ELECTRONS BETWEEN THE IONOSPHERE AND THE PROTONOSPHERE

In studying ionosphere – protonosphere coupling, the base of the protonosphere is defined as the O^+ to H^+ transition height at which the densities of O^+ and H^+ ions are equal. Because information on the location of the transition height is not readily available, however, the base of the protonosphere was often defined at a fixed altitude of 1000 km (Park, 1970). A flux of ionization (Amayenc and Vasseur, 1972; Bailey *et al.*, 1977; Carpenter and Park, 1973; Chappell, 1972; Evans, 1975 a, b; Geisler, 1967; Hagen and Hsu, 1974; Murphy *et al.*, 1976; Prölss and V. Zahn, 1974) across the 1000 km level may consist of two components

a) a flux of protons and electrons diffusing through the diffusive barrier
b) a flux of protons, electrons and O^+ due to changes in the height of the diffusive barrier.

It is only the first kind of flux that is relevant to the problem of interchange of ionization between the ionosphere and the protonosphere, and thus relevant to this review. The assumption of a completely effective diffusive barrier seems invalid at least for latitudes above 50°. However the flux due to the height variation of the barrier could contribute significantly to the maintenance of the nighttime ionosphere at geomagnetic latitudes of 25° – 45°. The magnitude of upward fluxes –at an altitude of about 1000 km– has been reported with a maximum value of 5×10^8 el/cm^2 sec (Soicher, 1976).

Park (1970), with whistler observations in the range $3.5 < L < 5$ under quiet conditions, observed upward fluxes of about 3×10^8 el/cm^2 sec –Kersley *et al.* (1978), calculated values from RBE measurements that are only slightly smaller– and fluxes of 1.5×10^8 el/cm^2 sec downward. Evans (1975 a) found for Millstone –with incoherent scatter measurements– fluxes smaller than 10^8 el/cm^2 sec from the ionosphere to the protonosphere. This is close to the so called limiting flux, which was given by Geisler (1967), he showed that a maximum of 1.5×10^7 protons/ cm^2 sec can diffuse into the protonosphere from the daytime ionosphere. Till now we have to deal rather with case studies than with any continuos measurement of fluxes.

IV. METHODS OF MEASURING THE PLASMASPHERIC CONTENT

Despite substantial work on the plasmasphere and the gradual acceptance of the view that significant amounts of ionization can be exchanged between the ionosphere and magnetosphere (Carpenter *et al.*, 1973) (with consequent important changes to one or both regions), there are few direct experimental determinations of field aligned fluxes of cold plasma. Fluxes have been deduced by four different methods, supplementing each other and measuring changes in the electron density (content):

1. Ionospheric sounding [by ground-based ionosondes, satellite-borne ionosondes (Rawer and Suchy, 1967), and incoherent scatter (Amayenc and Vasseur, 1972; Evans, 1975 a, b)].
2. Whistler meassurements (Park, 1970, 1973, 1974).
3. Satellite – and rocket-borne instruments for "in situ" measurments (Chappell *et al.*, 1971 a; Maier and Hoffman, 1974).
4. Satellite Radio Beacon Experiments (Almeida, 1973; Al'pert, 1975; Davies *et al.*, 1974; Davies *et al.*, 1975; Davies *et al.*, 1977 a; Davies, 1979; Rawer and Suchy, 1967).

Possibly the most direct method of observing vertical ionization fluxes is the use of incoherent scatter radar to measure simultaneously the density and vertical velocity of the plasma at high altitudes. The incoherent scatter technique provides the most complete information up to about 1000 km altitude. Ground-based ionosondes give data up to the maximum of the F2 layer, while topside sounders provide information from the F2 peak up to the altitude of the satellite. However, incoherent scatter is the most expensive method and all facilities are only intermittently operated. The ionospheric or plasmaspheric electron content up to a limiting altitude, which is determined by the technical characteristics of the equipment, is obtained by integrating the profiles. To date no large collection of vertical flux results gathered by incoherent scatter and/or topside sounding has been studied with the purpose of determining variations in the protonospheric flux.

Parks' (1970, 1973, 1974) whistler observations of "tube content" –electron content of a flux tube above 1000 km with a cross section of 1 cm^2 at 1000 km– appear to stand alone on the experimental side, i.e. there is no continuous monitoring of the protonospheric electron content and its variations by whistler methods. The plasma flux can be determined from the rate of change of the electron content.

All measurements of group 1 and 2 belong to the category of "*remote sensing*" experiments. While those from group 1 are also called *active* measurements, those from group 2 are also called passive measurements.

Satellite-borne instruments that carry out measurements at the location of the satellite belong to the category of "in situ" measurements.

In general they provide a "snaphot" of the electron density profile which when integrated yields the electron content.

A continuous monitoring of larger parts of the upper atmosphere –with sufficient temporal and spatial resolution– by using experiments aboard geostationary and/or "low polar orbiting" satellites is possible only if the same experiment can be simultaneously flown aboard several low orbiting and geostationary satellites. This could be shown for example by combining radio beacon data from the geostationary satellite ATS-6 and the six orbiting US NNSS satellites (Davies *et al.*, 1977 a, b; Leitinger *et al.*, 1975).

Satellite Radio Beacon Experiments (RBE) provide a fairly new tool for measuring the columnar electron content of the ionosphere and/or the plasmasphere. The belong to the category of active remote sensing methods. These measurements entered their most advanced phase with the launch of the geostationary satellite ATS-6, in May 1974, and the successful operation (to June 1979) of the Radio Beacon Experiment (Davies *et al.*, 1975; Fritz, 1976; Davies *et al.*, 1976; Davies *et al.*, 1977 b; Davies *et al.*, 1978 a, b). They yield, for the first time, measurements of the total columnar electron content N_T –over long time periods– up to geostationary altitudes 36000 km. Radio Beacon Experiments of this type are relatively inexpensive, easy to handle and are well suited for "Intermediate Technology" (Schumacher, 1973), they maybe also be examples in which the latest technical progress is included (Grubb, 1978; Hicks, 1978).

V. RESIDUAL ELECTRON CONTENT N_p AS DEDUCED FROM THE ATS-6 RBE

Two aspects of the ATS-6 RBE are of particular interest to us.

1. The *Faraday rotation* experiments, which consists of measuring the rotation of the plane of polarization of a linearly polarized radio wave that has travelled through the ionosphere. Since this effect is linearly dependent on the earth's magnetic field, the strength of which decreases approximately with the cube of the distance from the center of the earth, it is rather insensitive to the electrons encountered in the upper parts of the ray path. Consequently, it gives a measure of the electron content of that part of the ionosphere, where most of

the ionization is known to occur. We call this quantity the Faraday content N_F. Due to the fact that we have to account for the weighting effect of the earth's magnetic field this quantity N_F can only be derived *indirectly* from the measurement. The vast majority of the existing data on electron content often also denoted as Total Electron Content (TEC) is obtained by the use of Faraday rotation experiments (Hibberd, 1978; Poletti-Liuzzi *et al.*, 1977; Titheridge, 1972).

2. The *differential group delay* experiment

It measures the difference in transit times of two (modulated, coherent) radio waves across the ionosphere. The measurement is equally sensitive to all electrons, regardless of their position along the ray path. The total electron content N_T integrated along the entire ray path can be directly computed from this observation (Davies *et al.*, 1975).

The difference between the total electron content N_T – up to the altitude of the geostationary satellite– and the Faraday content N_F gives the quantity $N_P = N_T - N_F$.

For discussions on the accuracy with which Np can be determined, i.e. on its physical meaning see (Davies *et al.*, 1977 b; Poletti-Liuzzi *et al.*, 1977; Kersley, 1978 a).

It should be noted that with increasing amplitude – and/or phase scintillation strength the accuracy is reduced with which N_T and N_F can be determined. During very strong scintillation events neither N_T nor N_F can be determined. However, apart from these cases, which are rare in mid-latitudes, for the high radio frequences under consideration, Np can be continuously monitored provided the Radio Beacon Experiment is continuously operated.

It has been shown (Davies, 1979; Davies *et al.*, 1978; Kersley *et al.*, 1978 a; Poletti-Liuzzi *et al.*, 1977) that in mid-latitudes Np gives a good measure of the integrated electron content between about 2000 km and 36000 km. Its absolute accuracy varies there between 10% and 50% depending whether we deal with nighttime or daytime conditions. The relative accuracy is much better.

Problems related with rapid magnetic activity changes – e.g. the accuracy with which Np can be determined during these fairly short periods – are discussed by Mendillo and Klobuchar (1978).

In low latitudes (<10° geomagnetic) Np is even less accurate since errors of more than 50% can occur, because of diffculties with the definition of the Faraday content N_F (Davies *et al.*, 1978 b). However, Donnelly *et al.*, (1978) showed that even then the measurement of the Faraday rotation –without converting into N_F – is a useful quantity for studying the dynamics of the ionosphere. Klobuchar *et al.* (1978) showed that Np measurements might be the only remote sensing measurements that give information about electron fluxes in the upper atmosphere between L shell 1 and L shell 2. The usefulness of the Np data could be increased by a chain of receivers along a meridian. A combination of ATS-6 RBE differential gruoup delay data with differential doppler data from the 6 low orbiting US NNSS satellites (Davies *et al.*, 1977 a; Leitinger *et al.*, 1975) can give a fairly accurate electron content between about 1100 km and 36000 km altitude, however with poorer temporal resolution than for Np, derived only from ATS-6 RBE measurements.

However N_T is a quantity that can be measured in all three regions with the same good accuracy provided there are no strong scintillations.

Due to the earlier given definition of the plasmasphere and our definition of Np the question arises whether we should stick to the term plasmaspheric electron content or whether we should use the term Residual Electron Content (REC). We note that earlier attempts to measure this quantity were hampered by satellite spin and phase calibration problems. These difficulties have been overcome in the ATS-6 RBE.

The continuous monitoring of Np has been hampered by two facts:

1. Many RBE outages –due to power sharing aboard ATS-6– have led to loss of data, even longer than the off-periods, due to phase lock losses and recalibration problems (Davies *et al.*, 1975; Davies *et al.*, 1977 b).
2. NASA abandoned ATS-G which was planned as a successor of ATS-6 (former ATS-F) and which was to have an identical Radio Beacon Experiment to ATS-6.

ELECTRON FLUXES DERIVED FROM Np

One can use the time rate of change of Np to indirectly estimate the plasma flux in the ionosphere at an altitude of about 2000 km. The technique is indirect because the actual plasma flows along magnetic field lines whereas Np changes refer to the linear ray path between satellite and receiver. Since the ray path intersects a wide range of L tubes (up to about L = 4) the electron flux, thus estimated, is a parameter integrated over these tubes.

As some of the recent results will show this seems to be nonetheless an important and useful quantity, which could be further improved by using a chain of stations along a meridian rather than a single station.

VI. SOME RECENT RESULTS DEDUCED FROM Np AND N_T

Only problems related to basic physics will be considered here. The very important application aspects, like those for radio navigation and radio communication systems are disregarded here and are mentioned among others in (Davies *et al.*, 1977 a, 1978 a; Dieminger and Hartmann, 1978; Hartmann, 1975; Hibberd, 1978).

1. A depression of the residual electron content Np, following enhanced geomagnetic activity, has been observed, i.e. Np decreases with an increase of geomagnetic activity (Degenhardt *et al.*, 1977; Kersley *et al.*, 1978 b; Lanzerotti and Webb, 1977; Poletti-Liuzzi *et al.*, 1977).
2. There is a very slow refilling of the protonosphere after a storm. In some cases Np increases for 10 or 20 days (Davies, 1979; Davies *et al.*, 1978 a; Degenhardt *et al.*, 1977; Kersley *et al.*, 1978 b). Poletti-Liuzzi *et al.*, (1977) gave a value of 1.4×10^5 el/cm^2 for the rate at which the plasmasphere is replenished from the ionosphere.
3. Np may be a more sensitive indicator of solar terrestrial disturbance than is the Ap-index (Davies *et al.*, 1978 a).
4. The assumption of a magnetospheric electric field directed exactly dawn to dusk is certainly questionable under disturbed conditions. A rotation of the electric field vector by about 10^0 would give much better agreement between drift reversal and the start of the observed decrease in Np (Degenhardt *et al.*, 1977).
5. There is good agreement between the Np variations at widely separated stations (Davies *et al.*, 1978 a).
6. During the winter months Np over the USA reaches a maximum in

the middle of the night (~ 0.3 LT) whereas in Europe the maximum (if one is present) occurs near noon (Davies *et al.*, 1978 a). Kersley *et al.*, (1978 c) have suggested that this phase difference is related to ionospheric conditions near the feet of magnetic field lines in the conjugate (southern) hemisphere.

7. The average integrated fluxes deduced from Np by Kersley *et al.*, (1978 a) for Aberystwyth show that to within the accuracy of the estimates the upwards flux by day in magnitude and duration is broadly compensated by the downwards flux at night. Park (1970) has estimated average flux magnitudes generally greater than the levels given by Kersley, with the average daytime upwards flux exceeding the downwards nighttime flux by a factor of 2. While Kersley's studies are based on monthly median "protonospheric" data the values in Park's case study refer to a poststorm period during which the protonosphere is being replenished with daytime refilling exceeding nighttime draining. It can be concluded from Kersley's findings that both local and conjugate ionospheres play important parts in filling and depletion of the "protonospheric" flux tubes. This result is also supported by recent theoretical work (Bailey *et al.*, 1976; Murphy *et al.*, 1976).
8. Lanzerotti and Webb (1977) used measurement of the slant "plasmaspheric" electron content Np from an 11 months period for Boulder (Fritz, 1976) to calculate the plasmapause position after geomagnetic storm activity has caused this boundary to move closer to the earth. The recovery of the plasmasphere after six geomagnetic storm periods is examined. The deduced filling rate is found to be comparable to the total flux tube filling rates reported by Park (1973) from whistler studies. The rate of the equatorial "plasmasphere" filling and the rate of decay of the ring current intensity appear to be related, at least for the six events examined.
9. N_T and N_F are of importance in measuring so called "holes of ionization" in the ionosphere (Davies, 1977 a). This might be of interest in connection with Spacelab experiments which produce artifical "holes".
10. Winter nighttime enhancements in electron content were reported by several authors (Anderson *et al.*, 1978; Davies *et al.*, 1977 b; Ebel *et al.*, 1976; Tyagi, 1974). Ebel *et al.* (1976) mentioned down-

ward fluxes at night of 2×10^8 el/cm^2/sec at mid-latitude regions, but also simultaneous horizontal fluxes. Present studies seem to nourish the hope, that Np data will make an essential contribution to the physical explanation of this phenomena.

VII. CONCLUSION

If we denote as plasmasphere the collision dominated ionized region of the upper atmosphere then its upper boundary reaches to about five earth radii at the geomagnetic equator and up to only 1.2 earth radii at the geomagnetic pole. Despite substantial work on the problem of the plasmaspheric electron content and of relevant fluxes of cold plasma, there are few direct experimental determinations which do not replace but supplement each other.

1. Ionospheric sounding (ground-based and satellite-borne ionosondes, radar measurements like coherent and incoherent scatter – electron density profiles up to 2000 km)
2. Whistler measurements (flux tube electron content above 1000 km)
3. Satellite – and rocket-borne instruments (in situ measurements of electron density profiles)
4. Satellite Radio Beacon Experiments (Electron content up to the altitude of the satellite).

Each method has its advantages and disadvantages and due to equipment characteristics measures up to different altitudes in the plasmasphere.

Main emphasis has been given here to the Radio Beacon Experiments. The ATS-6 Radio Beacon Experiment for the first time enabled long time series measurements of the total electron content by means of differential group delay measurements, up to an altitude of 36000 km where the geostationary satellite is located. It also allowed the measurement of the so called Faraday content N_F, from which the vast majority of the RBE data stem. It has been shown that the new quantity $Np = N_T - N_F$ is in mid-latitude-regions, a good measure of the (Residual) Electron Content (REC) or plasmaspheric electron content between about 2000 km and 36000 km. The total electron content N_T, as derived by differential group delay, is a good measure of the electron content up to the altitude of the satellite for low–, mid-latitude– and high-latitude-regions, except when strong scintillations occur. Some of the most important findings deduced from the new quantity Np have been mentioned. They show that Np is a useful geophysical quantity that is a relatively easy and inexpensive continuously monitor from many ground stations, provided satellites with radio beacons are available. N_T data reduced from RBE measurements with the 6 US NNSS satellites as well as RBE scintillation and Radio holography studies (Schmidt and Tauriainen, 1978) will likely be of substantial interest and a fairly inexpensive contribution to the studies of the high latitude ionosphere by means of EISCAT (European Incoherent Scatter) and of the "Heating" experiment presently being designed by the Max-Planck-Institut für Aeronomie. It is likely that Np measurements will be the only remotely sensed measurements that can give information about electron fluxes in the upper atmosphere between L shell 1 and L shell 2. New concepts for radio beacon experiments (Grubb 1978; Hicks, 1978), supplemented by some old ones could provide a fairly inexpensive world-wide future monitoring of N_T, Np and scintillations. However, it became quite clear during the COSPAR Symposium on Beacon Satellite Measurements of Plasmaspheric Properties (May 22 - 25, 1978; Firenze, Italy) that we are close to the end of the experimental phase of the radio beacon experiments. Soon decisions need to be made by the "application side" as well as by scientists in basic research whether and which operational radio beacons should be planned.

In summary: The studies indicate that the measurement of the residual electron content Np are useful in studying the dynamics of the plasmasphere. This include filling and loss rates, effects of convection processes, and movements of the plasmasphere boundary. Up to the present a lot of published work, however, has been descriptive, which is the usual state of affairs when a new technique is introduced. It is hoped that this review will help to stimulate more attempts at interpretating these data in terms of recent theories on the upper atmosphere.

ACKNOWLEDGMENTS

The author thanks the following colleagues –in alphabetical order– for substantial discussions, suggestions, etc., most of it during the COSPAR Symposium on Beacon Satellite Measurements of Plasmaspheric and Ionospheric Properties, May 22–25, 1978; Firenze, Italy.

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