North-south asymmetry in the thermosphere and ionosphere

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Abstract

North-south asymmetry has been found in the total neutral density of the upper atmosphere already in second half of the XXth century. This asymmetry has been described in upper atmosphere models, but in spite of inclusion of new data there remained north-south asymmetry in the models (e.g. CIRA 86). This asymmetry means that the total neutral density is larger in the northern, than in the southern hemisphere. This may be due to the lower mean temperature of the northern hemisphere than that of the southern hemisphere. The temperature depends on energy input into the upper atmosphere. Less energy can get to the northern hemisphere, which can occur, if the place of main energy input, the auroral zone extends to higher latitudes by night in the northern hemisphere, than in the southern hemisphere. This situation may be induced by the geomagnetic field, since axis of the dipole field differs from axis of rotation of the Earth. Asymmetry has been found also in the ionosphere hinting at a larger electron density in winter months in northern hemisphere, than in the southern hemisphere. If the mean temperature of the northerm hemisphere is lower, than that of the southern hemisphere, this temperature difference may explain asymmetry of the electron density. It decreases the linear recombination coefficient in the northern hemisphere in winter as compared with the southern hemisphere, not only by increasing the [O/N_2] ratio in the F region, but also by the reduced rate coefficient of ion-molecule interchange reaction in β type recombination

1. Introduction

North-south asymmetry of the total neutral density in the upper atmosphere has been revealed determining neutral density by the drag of satellites. In order to have larger latitudinal extension than that enabled by satellites having an accelerometer enabling greater spatial and temporal resolution on board, optically determined satellite drag data were used in this study. Several million positions have been determined between 1957 and 1977 using optical observations of satellites in Eastern European countries and in the Soviet Union, as well as in some Western European countries. On the basis of these measurements of orbital data, period changes were deduced and density data were obtained from optical observations of 59 satellites. In order to obtain data as accurate as possible, satellites have been used in our investigations, eccentricity of which was large enough (e>0.02). These conditions enable a reasonably exact determination of position to which the density refers.

Annual variation (north-south asymmetry) in the F region has also been studied (Yonezawa, 1971; Yonezawa and Arima, 1959; Rishbeth et al., 2000a).

2. Method and data

According to the King Hele method (King Hele, 1964) related to orbital decay of satellites, density refers to an altitude larger by ½ H than height of the perigee, - where H is the density scale height – if the orbital eccentricity of satellites changes between 0.02 < e 0.2. Thus, 20 satellites from 59 fulfilled this criterion. These satellites had inclinations between 5° and 96°. Data refer to the height region from 175 to 420 km, that is to the thermosphere.

For study of the north-south asymmetry differences between measured and total neutral density values obtained from models of the upper atmosphere devided by the latter values ($\rho^{obs} - \rho^{model}$)/ ρ^{model} were applied (Illés-Almár and Almár, 2……..).

Concerning that part of the ionosphere, which coincides with the thermosphere, it is the F region. Physical processes in this region are especially affected by the neutral atmosphere. There are two parameters, composition and temperature of the neutral atmosphere, which result in change of the electron density in this height range. Electron density in the F region is determined on the one hand by the ratio [O/N_2] because of the linear or β type recombination process, on the other hand by molecular diffusion. However, in case of β type recombination reaction coefficient of the ion-molecule interchange depends on both ion and neutral temperatures (St. Maurice and Torr, 1978). Further, α type recombination NO^+ + e in the second step of β type recombination is also temperature dependent, but in this case on electron temperature.

For investigation of a north-south asymmetry in F region of the ionosphere, ionospheric stations were selected, which are located nearly at the same geographical or geomagnetic latitude and longitude in the northern and southern hemisphere, respectively. As such geographically or geomagnetically conjugated stations can only be found, if as many conjugated ionospheric station pairs may be selected as possible, foF2N-foF2S data of stations operated during the International Geophysical Year 1957-58 were used (Annals of the IGY). Six station pairs Narsarsuak (61°11'N, 314°35'E) - Decepcion (62°58'S, 299°17'E), Wakkanai (45°24'N, 141°41'E) – Hobart (42°55'S, 147°10'E), Ottawa (45°24'N, 284°06'E) – Port Stanley (51°42'S, 302°09'E), Alma Ata (43°12'N, 76° 55'E) – Kerguelen (49°18'S, 70°30'E), Puerto Rico (18°20'N, 292° 50'E) – La Pauz (16°29'S, 291°54'E), Panama Canal (9°24'N, 280°06'E) – Chimbote (9° 04'S, 281° 25'E) having nearly the same geographical coordinates have been found and three station pairs with similar geomagnetic coordinates. As it was probable that north-south asymmetry is related to neutral temperature, it seemed reasonable to select conjugated station pairs on the basis of geographical coordinates. Though only three geomagnetically conjugated station pairs could be found because of the selection rules, it seemed useful to compare results referring to geographically conjugated station pairs with results of geomagnetically conjugated station pairs.

At the same time using data obtained during the International Geophysical Year, data related to maximum solar activity could be applied. This circumstance was favourable from the point of view of the study, since former investigations have shown that annual anomaly in the F region representing the north-south asymmetry is more definite in years of solar activity maximum (Zou et el., 2000).

Monthly mean values of hourly foF2 data were used for obtaining average values referring to the given month in case of both northern and southern hemisphere stations of station pairs. Study of north-south asymmetry is based on differences foF2N-foF2S of foF2 monthly average values between the northern and southern hemisphere stations of station pairs. Interval included into the investigation is the period between 09 1957 and 06 1958.

3. Results

In Fig. 1 latitudinal variation of ($\rho^{obs} - \rho^{model}$)/ ρ^{model} using the same observed data but different models are shown. Fig. 1 indicates that north-south asymmetry appears in the total neutral density, which decreases from CIRA72 to NRLMSIS-00 as atmosphere models are corrected by inclusion of new data and introduction of new construction methods. However, north-south asymmetry appears still in the latest models. In Fig. 2 north-south asymmetry of the total neutral density is demonstrated by latitudinal variation of the total neutral density in different altitudes using for its presentation different satellites. It may be seen that north-south asymmetry can be revealed in the whole height region from 260 km to 435 km (Illés-Almár and Almár,……..; Berger and Barlier, 1981; Paetzold and Zschörner, 1961).

These latitudinal variations of the total neutral density are compared to the latitudinal variation of electron density indicated by foF2. In Fig. 3 differences of foF2 monthly mean values between the northern and southern hemisphere stations of station pairs foF2N-foF2S in winter months of the corresponding hemisphere are plotted as a function of latitude for 12 1957 – 6 1958 and 01 1958 – 07 1958. Figures concerning two various months, which differ which differ by six months at station pairs are constructed by mirroring curves referring to the equator. In Fig. 3 the well known December anomaly can be seen. However, examining further similar illustrations of the north-south asymmetry, it may be established that – at least in winter 1957-58 and in case of these station pairs – the December anomaly, or the north-south asymmetry was more developed in the first northern winter months of 1958 (February and March) (Fig. 4), than in December. Another peculiarity of the results is this asymmetry being limited to low mid-latitudes (20°-45°N) in April, May, June and July, as well as September and November (Figs. 5, 6 and 7). Depressions appear in the southern hemisphere at places of maxima in the northern hemisphere, this means that they are places, where differences – (foF2N-foF2S) are largest due to processes (change of [O/N_2] ratio, meridional wind), which increase foF2 in the northern hemisphere, but decrease it in the southern hemisphere. Furthermore, these extreme values - –hough indicated several times only by one station – may be regarded significant as they appear systematically from month to month. In the period 11 1957 – 04 1958 two maxima appear in the curves, a low latitude maximum at about 10°N and a high mid-latitude maximum at about 50°N. The low latitude maximum may correspond to the place of the equatorial anomaly in the F region. The high mid-latitude maximum might be related to the SAR (Sub Auroral Red Arc), where increased temperature has been observed due to precipitating particles from the inner radiation belt (Wagner et al., 1986). One might assume that in May, June and September, the two maxima merge into one maximum at low mid-latitudes.

4. Discussion and conclusions

From north-south asymmetry of total neutral density data deduced from satellite drag, the conclusion may be drawn that the neutral temperature is larger in the southern-hemisphere than in the northern hemisphere. Density data enable determination of the temperature difference, if model values are used as reference data, data from models of the upper atmosphere, which do not indicate the north - south asymmetry (CIRA 1965, Jacchia, 1970, Jacchia, 1977). Using this idea, it has been found that north-south asymmetry of the total neutral density amounts to about 20 % [$6 \cdot 10^{-13}$(kg m^{-3})]corresponding apprximately to a north-south temperature asymmetry of 170 K. It is to be noted that magnitude of north-south asymmetry of the total neutral density agrees with measure of the north-south asymmetry in the F region, that is with amplitude of the annual anomaly (Zou et al., 2000). As the total neutral density may be considered to be equal to density of atomic oxygen in height range of the F region, north-south asymmetry in the thermosphere may be regarded as north-south asymmetry of atomic oxygen density. As it is known, number density of 0 is higher in winter months than in summer months due to transport of atomic oxygen from the summer to the winter hemisphere (Johnson and Gottlieb, 1973; Alcayde et al., 1974). However, the temperature decrease in the northern hemisphere as compared with the southern hemisphere involves also increase of the $[O/N_2]$ ratio at a given height in the northern hemisphere, which controls the recombination process in the F region. An enhancement of the $[O/N_2]$ ratio would decrease recombination reducing the rate of β type recombination through the ion-molecule interachange reaction $O^+ + N_2 \rightarrow NO^+ + N$. Really, excessive enhancement of electron density, that is that of foF2 is observed in the northern hemisphere.

Temperature affects, however, not only the $[O/N_2]$ ratio, but also rate coefficient of the ion-molecule interchange reaction $O^+ + N_2$.

The rate coefficient of the ion-molecule interchange reaction is also proportional to temperature. Thus, it must be cleared, in which degree the two effects participate in development of the north-south asymmetry. Ratio of the relative density change $\Delta\rho/\rho$ to relative change of the rate coefficient $\Delta k_{N_2}/k_{N_2}$ might be considered for settling this question. $\Delta\rho/\rho$ is determined by $(\rho^{obs}-\rho^{model})/\ \rho^{model}$ data and $\Delta k_{N_2}/k_{N_2}$ may be calculated by the equation

$$k_{N_2} = 1.533\cdot10^{-18} - 5.92\cdot10^{-19}\left(T_f/300\right) + 8.6^{-20}\left(T_f/300\right)^2 \qquad (1)$$

where

$$T_f=(7T_i+4T_n)/11 \qquad (2)$$

is the effective temperature (St.Maurice and Torr, 1978). In case of $T_f>1250$

$$K_{N_2} = \frac{k_{N_2}\left(T_f - 1000\right)}{250} \qquad (3)$$

in which vibrationally excited state of N_2 has also been taken into account (Richards and Torr, 1986).

Concerning north-south asymmetry in the thermosphere, it is $\Delta\rho/\rho$~0.2 as it has already been mentioned.. Substituting into Eq. (2) once the neutral temperature T_n obtained from north-south asymmetry of the total neutral density and ion temperature T_i corresponding to T_n from ionospheric models (IRI 90), then T_n belonging to ρ^{model} used in calculation of $\Delta\rho/\rho$,we get for $\Delta k_{N_2}/k_{N_2}$~-0.08; that is efficiency of β type recombination is reduced by decrease of rate of the ion-molecule interchange reaction amounting to 8 % and contributing to extreme increase of the electron density and foF2 in the nothern hemisphere, known as December anomaly.

Concerning geomagnetically conjugated station pairs, unfortunatelly all station pairs are located at high mid-latitudes. These station pairs are Providenie Bay (+59.7°, 235.6°)-Maquarie Island (-61.6°, 243.1°), Leiningrad (+56.2°, 117.3°) – Kerguelen (-57.2°, 128.0°), Fort Monmouth (+51.7°, 353.9°) – Port Lockroy (-53.4°, 3.9°) (Annals of the IGY). Though, latitudinal variation can not be studied by these station pairs, but they may be compared with geographycally conjugated station pairs, e.g. in case of Fort Monmouth–Port Lockroy with Ottawa-Port Stanley. In Fig. 8, monthly mean values of foF2N-foF2S are compared with monthly mean values of foF2 (+) – foF2 (-). As according to geomagnetic latitude the geomagnetically conjugated station pairs Leningrad-Kerguelen and Forth Monmouth-Port Lockroy are not far from each other, small scale changes can also investigated. Fig. 8. indicates that in case of the geomagnetically station pair north-south asymmetry lats longer than shown by the geographically conjugated station pair, at least in case of the station pairs compared in this Figure.

At the beginnig of this paragrph, it has been mentioned that north-south asymmetry may be due to temperature increase in the southern hemisphere as compared with the northern hemisphere. Zou et al. (2000) and Rishbeth et al. (2000) analysed extensively annual and semiannual variations of foF2. For investigations of the north-south asymmetry their conclusions referring to the annual variation are interesting. According to Zou et al. (2000) observed variations at midlatitudes not successfully explained are annual anomaly, i.e greatest worldwide electron density in December beyond the 6% effect due to varying Sun-Earth distance, further other phenomena that need further study include eastwest longitude differences. Regions of large [O/N_2] at high sub-auroral latitudes might be explained by asymmetry of the eccentric magnetic dipole used in this study for the approximation of the geomagnetic field. Concerning Rishbeth et al. (2000) remarks, explanations of annual variations of NmF2 include composition changes due to large scale dynamical processes (Rishbeth, 1998).

Asymmetry of the geomagnetic field is due to deviation of the magnetic poles from the geographical poles. Thus, the auroral oval extends to lower subauroral latitudes in the southern hemisphere from dusk to dawn during the most active period of auroral activity, than in the northern hemisphere as demonstrated by the schematic and exaggerated representation in Fig. 9. This displacement of the auroral oval by night to lower latitudes independent of geomagnetic activity may increase energy input at high midlatitudes and cause enhanced heating in the southern hemisphere. As a result of this heating, increased temperature would reduce [O/N_2] ratio in southern and aigment it in the northern hemisphere.

In this way, not only the annual variations of foF2, or December anomaly due to enhanced [O/N_2] ration, increasing electron density in the northern hemisphere as compared with the southern hemisphere may develop, but it would also contribute to development of regions of high [O/N_2] ratio at high sub-auroral latitudes. East-west longitude differences may also be related to structure of the geomagnetic field indicating longitudinal variations well recognizable in map of the total intensity B (.................). Thermospheric circulation initiated by upwelling at southern high latitudes and directed to the northern hemisphere due to enhanced temperature in the southern hemisphere as compared with the northern hemisphere, would cause regional lowering of the [O/N_2] ratio in the southern hemisphere F region and decrease electron density (Rishbeth, 1968). In northern high latitudes, thermospheric circulation is characterized by regional downwelling, which would create regional increase of the [O/N_2] ratio in the F region and augment electron density.

Between southern and northern high latitudes – still in the southern hemisphere – behaviour of electron density is affected by both decrease of the [O/N_2] ratio due to excessive heating and vertical movement of the F region plasma produced by the meridional wind directed equatorwards. The former causes electron density decrease, the latter contributes to increase of electron density raising the F region into an environment of larger [O/N_2] ratio. However, as the effect of vertical movement depends on change of the [O/N_2] ratio, electron density will be reduced. Moving equatorward from high southern latitudes, change of the [O/N_2] ratio will be decreased because of decreasing heating. Vertical movement of the F region plasma is also diminished, since directions of meridional wind and geomagnetic field approach each other and thus, vertical component of the driving force ceases. As a result this two processes determining electron density decrease looe their effect. In the northern hemisphere the opposite change of electron density takes place. Advancing poleward from the equator, the [O/N_2] ratio increases due to further temperature decrease as compared with temperature of the corresponding place in the southern hemisphere. Concerning vertical movement produced by thermospheric meridional wind, it is directed downward. Thus, enhanced electron density may be observed, this tendency increasing with latitude.

It may be concluded that in development of the north-south asymmetry, or annual variation in the F region consideration of structure of the geomagnetic field may contribute to explanation of phenomena, which are not successfully explained, or need further study. It is also to be noted that a common consideration of variations hinting at a north-south asymmetry in the neutral upper atmosphere and the ionosphere make easier to find the right explanation of observed phenomena (Bencze, 1991).

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