DATA COVERAGE FOR *D*-REGION MODELLING

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ABSTRACT

Data from the lower ionosphere are not available from satellites and therefore scant by nature and do not exist on a global basis. A survey of the data is given showing various sources and the geophysical conditions covered by the measurements. From the high latitudes the largest data sets are available, due to the large variability, however, not all situations are adequately covered. The sensitivity of models to the inclusion or omission of single electron density profiles is demonstrated.

DATA SOURCES

The *D*-and *E*-regions are characterised by a relatively large neutral background which makes many methods that are popular and successful at higher altitudes unreliable below, say 100 km. The undisputed best method to establish electron densities is to use a rocket borne wave propagation experiment, combined with an *in-situ* measurement by a probe aboard the same payload [1]. Since the advent of sounding rockets 276 such experiments were flown under most diverse geophysical conditions. Many more research rockets carried probes which are inherently uncertain in their absolute values because of payload charging and/or aerodynamic effects. However for comparative studies data obtained from identical instruments, preferably with identical rocket motors, can be used, although a systematic bias can not be ruled out. One such data base is a series of more than 400 electrostatic probe measurements made at Kapustin Yar (Volgograd) in southern Russia with M100B rockets. Incoherent radars have thresholds which make them attractive for measurements in the *E*- rather than the *D*-region, except when the latter is disturbed. The resolution is rather poor, but can be assumed to have no bias. The largest such installation is at Arecibo, but due to the variety of scientific objectives pursued with the installation, it has produced fewer electron density profiles than EISCAT since its beginning in 1984.

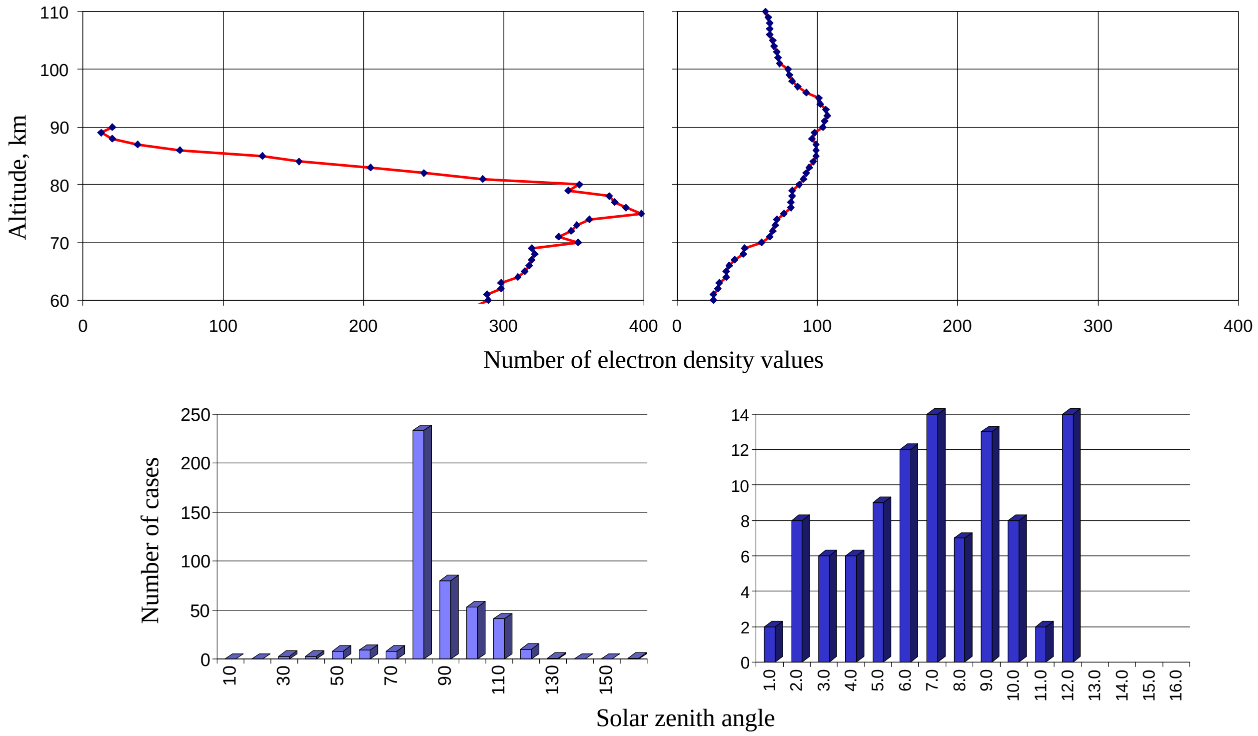

Fig. 1 Height coverage of rocket borne probe measurements from Kapustin Yar (left panel) and of data from wave propagation instruments (right panel). Note that despite the much larger number of probe data, the zenith angle coverage is largely restricted to twilight measurements (*cf*. lower panels).

Most other incoherent scatter radars are better suited for *E*- and *F*-region studies (EISCAT Svalbard, Jicamarca, Millstone Hill, Søndre Strømfjord). Fig. 1 shows the height and solar zenith angle coverage of non-auroral probe and wave propagation measurements.

NON-AURORAL

The lower ionosphere is characterised by (*a*) the relatively short lifetime of the free ions and electrons, and (*b*) by a rather complex chemistry governing the recombination. Whereas the former justifies the use of a steady-state approach, the latter requires to also involve the composition of the neutral atmosphere. Solar radiation provides the major contribution to the ionisation, only below, say 65 km cosmic rays can dominate the ion-pair production. We can thus *a-priori* assume that the electron densities will positively correlate with solar activity and inversely with the solar zenith angle. Only the fluxes of cosmic rays are inversely related to solar activity and hence also the electron densities at the lowest heights. The impact of season and latitude is largely due to the insolation, *i.e.* the amount of solar flux deposited in the atmosphere. On the ground this is manifested in the seasonal and latitudinal variation of temperature, at higher altitudes it leads to changes in the composition of minor species. Outside the immediate equatorial region a seasonal trend can certainly reasonably be assimilated by a sinusoidal variation peaking at solstice; the latitudinal variation in the neutral atmosphere is not so obvious, but a linear trend is always a good first approximation. One approach to find cases better or insufficiently covered by measurements is to bin the data according to the various parameters listed and combinations thereof. We will use a more illustrative method. The ionised part of the mesosphere (the *D*-region) strongly depends on the composition of minor species and the temperature. The concentration of relevant trace constituents (O, NO) is largely controlled by the amount of solar radiation. One may therefore characterise the neutral atmosphere by the amount of radiation received in a day. For this purpose we form the integral of the cosine of the solar zenith angle from sunrise to sunset, a parameter that lumps both season and latitude. Fig. 2 shows the variation of this quantity (normalised to the hypothetical situation of overhead Sun for 24 hours in a day) as a function of geographic latitude and season. One can clearly see that the largest seasonal variation of this Daily Integrated Insolation occurs at high latitudes, and that at the equator there are two seasonal peaks in the insolation (at the equinoxes). In this figure rocket launches (with wave propagation instruments) are indicated as full dots for non-auroral situation, as circles for auroral conditions and as X's for conditions whose data can not be used for climatological modelling (*i.e.* eclipse, post-storm, or winter anomaly). It is evident that the overwhelming majority of the data were taken in the northern hemisphere and at certain permanent rocket ranges; most prominent are the launches from Thumba, Wallops Island, Kapustin Yar, South Uist, Kiruna and Andøya at 8, 38, 49, 57, 68 and 69°N, respectively. If we now surmise that the effective length of the day has a decisive influence on the neutral atmosphere, and in consequence the *D*-region, we can extract a more general picture from Fig. 2 in

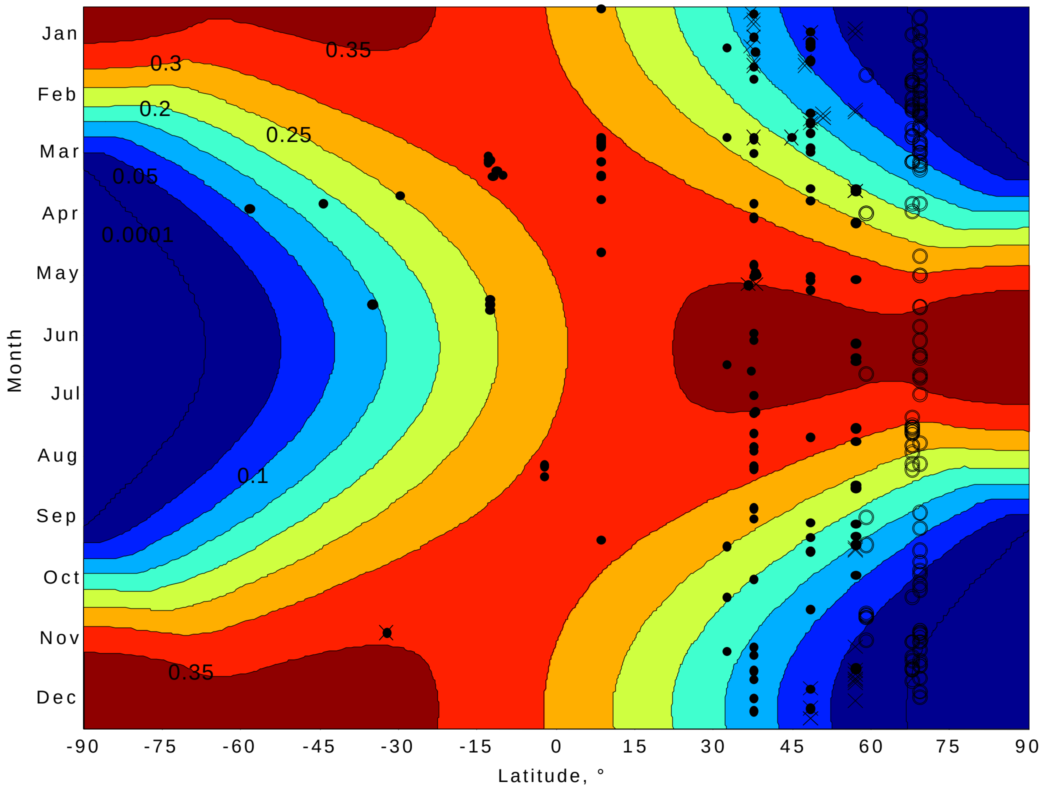

Fig. 2 Lines of constant daily integrated insolation. Rocket flights carrying wave propagation instruments are indicated as circles for auroral conditions, as full dots usable for non-auroral climatological modelling, and X for special cases.

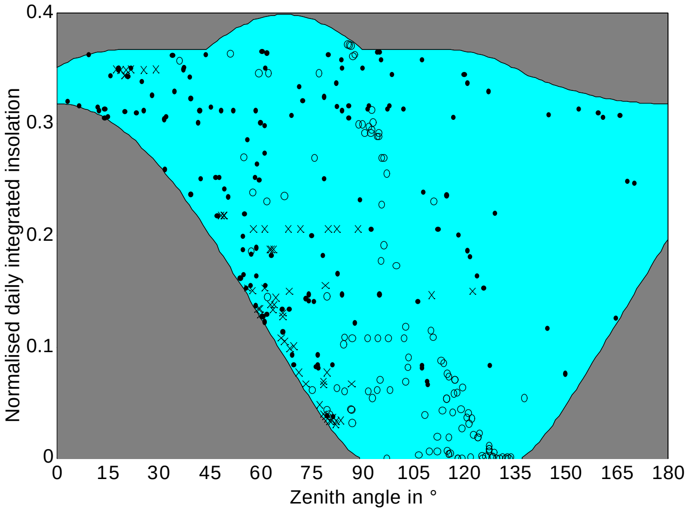

Fig. 3 Rocket flights and their relation to solar zenith angle and Daily Integrated Insolation. Note that not all combinations are possible.

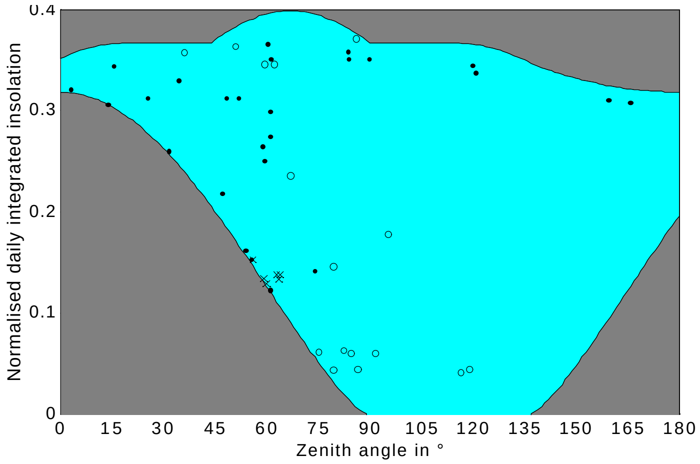

Fig. 4 Same as Fig. 3, but for 60 km only.

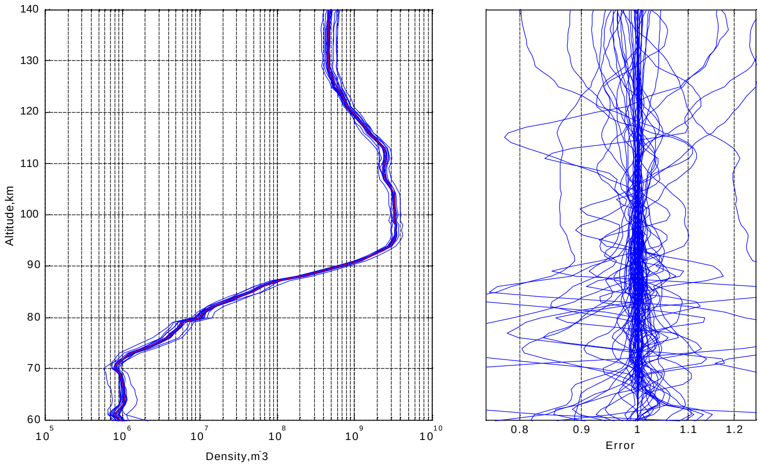

Fig. 5 A night-time electron density profile according to the model FIRI. The various solutions obtained by omitting individual profiles are also indicated, together with the factor to the "correct" profile (right panel)

order to illustrate the coverage by rocket soundings for different atmospheric conditions. Fig. 3 shows Daily Integrated Insolation *vs.* solar zenith angle and again the rocket launches with their different symbols. The "allowed" area appears reasonably evenly covered by measurements; this is however not the case at all altitudes. Fig. 4 shows the situation at 60 km and clearly displays a lack of data for night-time conditions when electron densities are below the threshold of the wave propagation experiment and only calibrated probes aboard the same payloads can provide the data.

We have thus established that despite half a century of rocketry, there evidently still is a need for more measurements and hence it is interesting to test to what extent an empirical model depends on an individual input value. In the semi-empirical model FIRI a simple theoretical ionospheric model is corrected by *n* (= 120) electron density profiles due to rocket borne wave propagation experiments [1]. The empirical correction is an analytical function fitted to the individual deviations between theoretical model and the individual measurements. In Fig. 5 only *n*-1 electron density profiles are used and one thus obtains *n* solutions if one electron density profile at a time is left out. Shown is a case of a full night situation (which is poorly covered by data), in the right panel of the figure the ratio between the "full" solution (*i.e.* using all data) and the various solutions when leaving out one profile each, is displayed. There are obviously "crucial" profile necessary to describe the electron densities for the desired conditions, whereas the omission of most of the others only leads to marginally different results.

HIGH LATITUDES

At high latitudes most of the time the ionisation is dominated by energetic charged particles (electrons or protons). Only rarely is the ionosphere "quiet", *i.e.* it varies with solar zenith angle and solar activity. Fig. 6 gives an overview over more than a solar cycle of operation of the European Incoherent Scatter Radar EISCAT [3]. This huge amount of data becomes less impressive when one plots the electron densities at certain pressure surfaces (altitudes) *vs.* the riometer absorption prevailing at the time of the measurement. Whereas the situation in the left panel of Fig. 7 shows an unquestionable dominance of

EISCAT data, lower down any modelling effort must rely on the few rocket data. Since the high latitude ionosphere is more variable than elsewhere, it is necessary to introduce an additional "disturbance" parameter in addition to the usual descriptors such as zenith angle, solar activity or season. The global index K_p is easily accessible, but not very relevant at high latitudes and say 100 km. A local magnetic index, as *e.g.* available for Tromsø, is much better suited, but still is a 3-hour index of a variation of the geomagnetic field caused by currents in the *E*-region. By contrast locally measured riometer absorption correlates well with *D*-region electron densities, but is not available everywhere; even the EISCAT data in Fig. 6 only have corresponding riometer values in about 60 % of the cases.

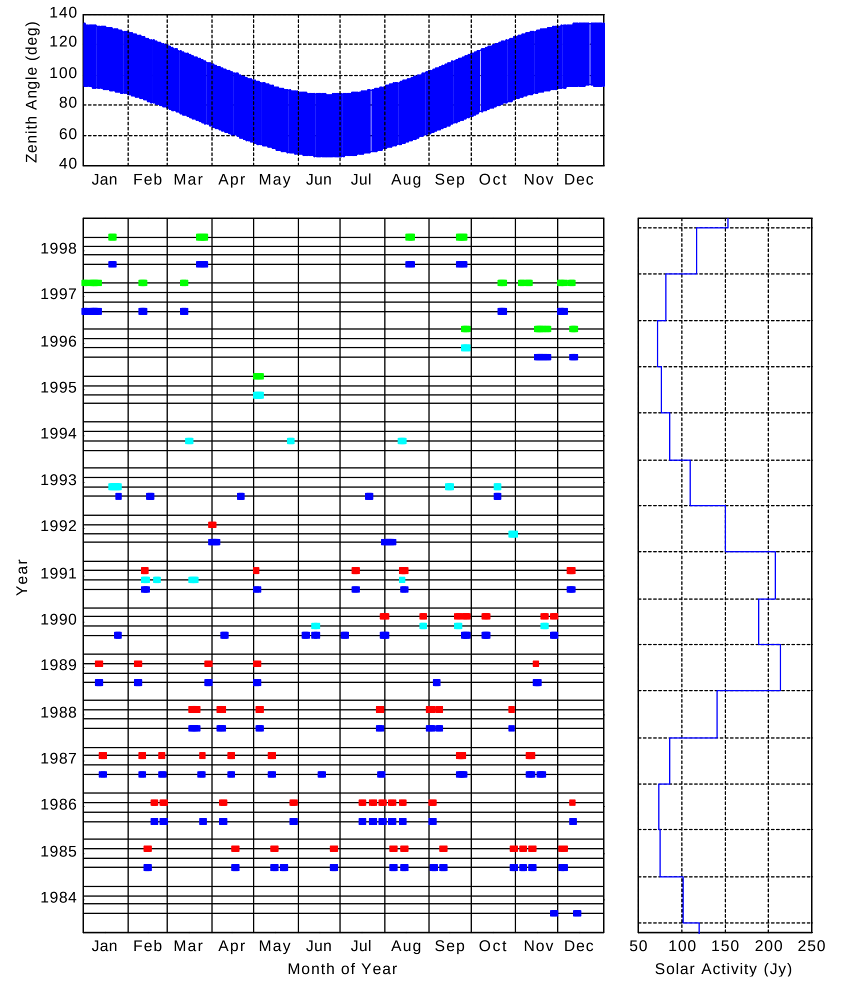

Fig. 6 Coverage by EISCAT measurements. For details see text.

For the situation inside the polar cap the new EISCAT Svalbard radar yields data since 1996, but again mainly from the *E*-region, and only under disturbed conditions also from lower altitudes. The only rocket data to complement these measurements are so far from the (uncalibrated) probe data from the Russian Heiss Island.

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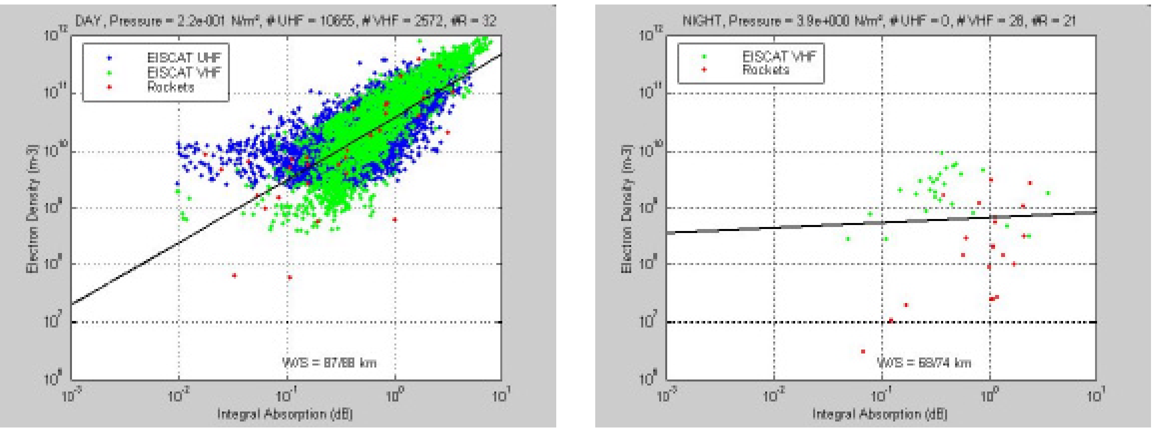

Fig. 7 Electron densities at two pressure levels (*ca.* 87 km [left] and 71 km [right]). The data are plotted *vs.* integral absorption, *i.e.* riometer absorption plus a small contribution by the quiet ionosphere. Note that at lower altitudes only the rocket data are left, whereas the few EISCAT dots are probably erroneous results.