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The topside sounder database – Data screening and systematic biases

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Abstract

The ionospheric topside sounder measurement database developed at the US National Space Science Data Center (NSSDC) is a valuable source of information when investigating the composition and complex dynamics of the upper ionosphere. The database is increasingly used by many scientists around the world for both research and development of empirical models. However, there is always a danger of indiscriminately using the data without properly assessing the data quality and applicability for a given purpose. This paper is concerned with the issue of data screening and pre-processing of the Alouette/ISIS topside sounder database. An overview of the original database availability and formatting is given and the use of solar and geomagnetic indices is discussed. Data screening procedures, concerning detection and handling of erroneous profiles, are also presented. Special attention is drawn to the systematic biases observed in the database and the possibilities for their removal.

Keywords: Ionosphere; Topside sounding; Data screening

1. Introduction

The Alouette and ISIS satellites flew from 1962 until 1995 and carried, among other instruments, an ionosonde used to take soundings of the topside ionosphere. Part of the data obtained from these soundings has been converted to a digital format (Jackson, 1969, 1980, 1986, 1988). Each topside sounder measurement is a virtual signal depth profile as a function of plasma frequency which is then used for converting to electron density height profile. Selected datasets are now available from the National Space Science Data Center (NSSDC) and can be used for different research purposes, for which no other data of this kind is available. The space-borne radio sounding databases contain valuable data that can be used to investigate the topside ionospheric variations (Benson, 1996, 2010; Benson and Osherovich, 2004) over several solar cycles. Since the beginning of the topside sounder data restoration project (Bilitza et al., 2003), several studies have been carried out making good use of these databases (e.g. Benson and Grebowsky, 2001; Marinov et al., 2004; Webb et al., 2006a,b; Coisson et al., 2006; Kutiev and Marinov, 2007). The Alouette/ISIS topside sounder data was also used to substantially improve the topside profile specification in the International Reference Ionosphere (IRI) model (Bilitza, 1990, 2001, 2004; Bilitza et al., 2006; Bilitza and Reinisch, 2008).

However, when using this database, a special care should be taken to do an appropriate data screening/cleaning. While analysing these databases, many profiles have been encountered that contain physically impossible characteristics or are incomplete. Also, several systematic biases, stemming from the non-uniformity of the distribution of the data in both time and space, should be taken into account. This paper deals with several issues of data cleaning and bias removal that are relevant to our on-going work with topside sounder data. Even though the paper mainly concerns the issues encountered in the latter these are general concerns regarding the databases themselves and might also be useful for other research.

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2. Database overview – data availability and geophysical indices

2.1. Original data availability and formatting

The databases containing the topside sounder data are available for download from the ftp site of the National Space Science Data Center (ftp://nssdcftp.gsfc.nasa.gov). There are three datasets containing data from the Alouette-1 spacecraft and one set each for Alouette-2 and ISIS-1 and -2. In total, there are 176,662 measured profiles available. An overview of the number of data available in each database, as well as the time period covered, is given in Table 1.

NSSDC provides the topside sounder database together with a description of the data format (see Appendix). Each profile comes with a header containing the date and universal time of the measurement, geographical coordinates, magnetic inclination, L-value, the solar zenith angle at 100 km, sunspot and IG indices and several parameters predicted by the IRI. Also included are a spacecraft identifier and a quality index. However, the spacecraft identifiers are not used as described (see Appendix) and the exact definition of the quality index is not quite clear. In this work we do not explicitly consider the quality index. Instead, for each profile we try assessing for what research project it could possibly be used, in terms of the parts of the ionosphere that are covered by the profile. This is a consideration complementary to the intrinsic quality of the profile. To assure the quality of the research results this index should be considered in conjunction with the points discussed in the present paper.

2.2. Solar and geomagnetic indices

Since the ionospheric variability depends on the level of solar and geomagnetic activity, it is important that the most representative indices are used in the analysis. The NSSDC database does include the 12 month running mean of sunspot number and the IG index as measures of solar activity at the time of the measurements. For our study however, these indices are not as useful as the solar flux index, $F10.7$. Also, even though the magnetic inclination and the L-value are included, no indices for geomagnetic activity are given. Therefore, for our purposes, the NSSDC database has been supplemented with $F10.7$, K_p and D_{st} indices (for each density profile and corresponding to time of measurement) via the NOAA Space Physics Interactive Data Resource, SPIDR (http://spidr.ngdc.noaa.gov/spidr).

3. Erroneous and incomplete profiles

3.1. Physically impossible data

The topside sounder, ideally, measures the electron density down to the ionospheric F_2-layer peak density height, h_mF_2, which is in all cases above 100 km. In the database however, there are instances when the profile goes down to very low altitudes (Fig. 1). While the shape of the electron density profile looks “normal”, the lowest point at which the density was apparently measured is at a height of 17 km. This would mean that the F_2 peak is at or below 17 km above the surface. This is physically not possible and using such profiles can negatively affect studies focused on vertical plasma distribution and dynamics, radio wave propagation, etc. (e.g. Webb et al., 2006a; James, 2006). Fig. 2 shows the distribution of the lowest points of the profiles for each of the four satellites. Only for Alouette-1 do some of the profiles go down below 100 km. However, that does not guarantee the validity of the lowest reaching profiles measured by the other satellites.

It is unclear what causes this type of erroneous profiles. There must have been something wrong either with the measurement itself or with the analogue-to-digital conversion. A possible explanation might be the influence of a trace from an oblique sounding on the conversion procedure. There is no obvious way to filter them out from the database. The only available ways to remove these profiles from the database is through visual inspection (not practical) or by the use of a cut-off height. Originally, a cut-off value using a fixed minimum peak-height of 100 km was used. This is still very low and might not remove all faulty profiles. However, it still assures that no eligible profiles will be removed. In the subsequent analyses it was decided that removing all faulty profiles was a higher priority than preventing the removal of correct profiles. Therefore, a cut-off height was introduced, a height relative to the F_2 peak height predicted by the IRI. These cutoffs are implemented together with the control of completeness of the profile, as discussed below.

Table 1
Overview of the different datasets and satellite orbit characteristics.

Database	Number of profiles	Period (yyddd)	Satellite orbit altitude (Km)	Inclination (°)
Alouette 1 a	15,706	62273–63082	1000	80
Alouette 1 b	43,614	62272–66089	1000	80
Alouette 1 c	26,452	62323–71350	1000	80
Alouette 2	9301	65349–72192	500–3000	80
ISIS 1	38,953	69030–80151	500–3500	88
ISIS 2	42,596	71088–79239	1400	88