IAR frequency scale calculation using IRI-2012 model at medium and high latitudes

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The paper addresses a problem of ionosphere-magnetosphere interaction through Alfvén wave propagation. A new approach to analysis of emission of ionospheric Alfvén resonator (IAR) is proposed. We apply the IRI-2012 version of International Reference Ionosphere model to calculate difference between frequencies of adjacent harmonics (frequency scale) of IAR emission. The calculated values are compared with the frequency scale data obtained from search-coil magnetometer observations. For measurements made at medium latitudes, it appears that to reach satisfactory results it is necessary to modify IRI-2012 model replacing the vertical profile of ionospheric parameters adopted in the standard model with the profile elongated along the magnetic field lines. For polar latitudes, where the field lines deviate from the vertical insignificantly, such a procedure is not necessary. Subsequent improvement was obtained by the model correction with using local f_0F_2 measurements. Finally, our results showed strong correlation between the estimated and measured values of the frequency scale. Calculated Δf_{calc} versus measured Δf_{meas} values of the IAR frequency scale are shown in Figure as a result of computation based on the modified IRI-2012 model. Dashed line is the regression line running through the origin of coordinates; gray line is the line of the perfect match $\Delta f_{calc} = \Delta f_{meas}$. The relative mean-square error of the model estimates is approximately 15%.

Ionospheric Alfvén resonator (IAR) is the plasma structure formed between the bottom and top of ionosphere that is capable to catch Alfvén waves within the upper part of ULF frequency range (0.5 to 10 Hz), see [Polyakov, Rapoport, 1981] – theory, and [Belyaev et al., 1987] – first experimental detection. We observed IAR emissions at Mondy magnetic observatory with search-coil magnetometer. Dynamic spectrum of the oscillations looks like a series of fan-shaped bands (Figure 1). Frequency scale Δf of IAR emission is frequency difference between adjacent spectral bands of emission. It is clear that Δf depends on properties of the local ionosphere in the moment of observation. To reveal quantitative relation between Δf and the ionosphere characteristics we compared observed values of frequency scale Δf_{meas} with calculated Δf_{calc} predicted by the simplest model of the emission frequency based on formula

$$\Delta f = 1/T_0 = \left(\int_{l_{bottom}}^{l_{top}} dl/A(l) \right)^{-1},$$

here T_0 is the Alfvén travel time between the resonator walls; l_{bottom} and l_{top} are positions of the lower and upper walls of the resonator, respectively; $A(l)$ is the Alfvén speed. (Details see in [Potapov et al., 2014].) To compute Alfvén speed, we use ready-made models DGRF/IGRF for the magnetic field and the International Reference Ionosphere IRI-2012 for the ionospheric plasma. Because IRI-2012 is limited in altitude by $l_* = 2000$ km, we supplemented this model by extrapolation formulae for number density profiles of different sorts of ions. In total, for 13 selected days of observations, we have performed 99 runs of the frequency scale Δf_{calc} tied to the corresponding hours of observations, and compared the results with the measured values Δf_{meas}. We took $l_{bottom} = 50$ km; l_{top} was taken equal to altitude of the Alfvén speed maximum, and step in altitude was $\Delta h = \Delta l = 50$ km. The result of comparison is presented in Figure 2. Systematic error is evident.

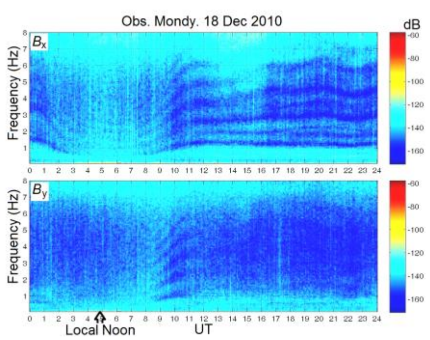

Figure 1. An example of the IAR emission daily spectra. Shown are spectrograms of the magnetic field *X*- and *Y*-components from the measurements by LEMI-30 induction magnetometer.

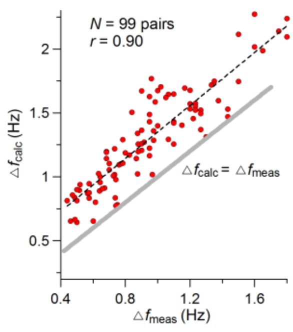

Figure 2. Calculated Δf_{calc} versus measured Δf_{meas} values of the IAR frequency scale. Used the standard IRI-2012 model with vertical profile. Dashed line is the linear regression; gray line is the line of perfect match $\Delta f_{calc} = \Delta f_{meas}$.

Next our step was calculating frequency scale from the model based on the inclined profile. To do this, we used multiple computations of IRI-2012 results for a chain of ground sites along the Mondy meridian. The procedure was as follows. First we calculated the required parameters of ionospheric plasma for 100 km altitude above Mondy observatory (the 1st point of profile). Then we moved along the field line that is magnetically conjugated with the 1st point. The 2nd point position is at the crossing of this field line with the 150 km altitude level. Coordinates of the corresponding on-ground site under the 2nd point we found from the magnetic field DGRF/IGRF model. Using coordinates found we find plasma parameters in the 2nd point from the IRI-2012 model. The 3rd point of profile is at the crossing of the field line with the 200 km altitude level, and so on, until we reach 2000 km level. To obtain plasma parameters at higher levels we again used the extrapolation, this time not along height, but along field line. The results are shown in Figure 3. This time, as we have expected, the regression line running through the origin of coordinates almost coincide with the line of perfect match $\Delta f_{calc} = \Delta f_{meas}$.

The scatter of the points on the plot in Figure 3 is quite large. Unlike the Figure 2, error is random, not systematic. We supposed the reason of the error to be an inaccurateness of IRI-2012 estimation of critical frequency F_0f_2. To exclude this source of error, we compared F_0f_2 predicted by IRI-2012 with F_0f_2 measured by Irkutsk Digisonde DPS-4, see Figure 4a, and used the results to correct results of the previous step. Our final result is shown in Figure 4*b*. We see that the correlation coefficient increased up to $r = 0.99$. The mean-square error of Δf estimate is 0.14 Hz, reducing by half as compared to non-corrected value. Taking into account mean value of $\Delta f_{meas} \approx 0.95$ we obtain the relative mean-square error of 0.147.

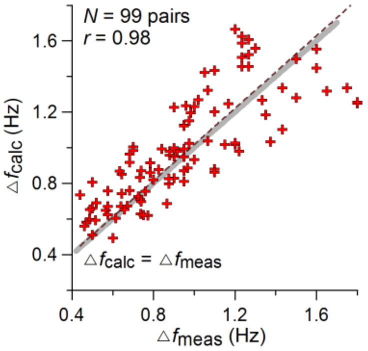

Figure 3. Calculated Δf_{calc} versus measured Δf_{meas} values of the IAR frequency scale as a result of calculations based on the modified IRI-2012 model with inclined profile elongated along the local geomagnetic field line.

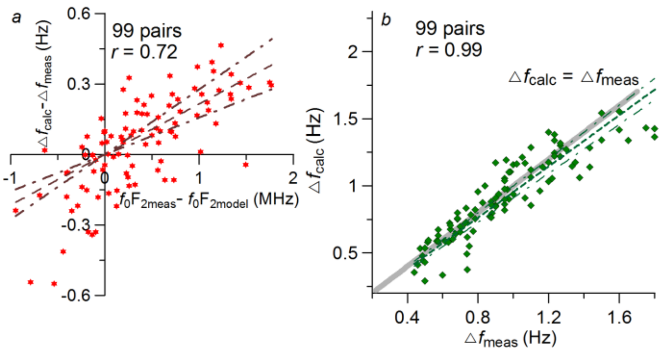

Figure 4. Correction of results by taking into account difference between predicted and measured f_0F_2: (*a*) Deviation of Δf_{calc} from Δf_{meas} versus difference between F_2 layer critical frequency f_0F_2 estimated by IRI-2012 model and that measured by DPS-4 Digisonde®; (*b*) the same as in Figure 3, but with correction taking into account dependence of $\Delta f_{calc} - \Delta f_{meas}$ difference on inaccurateness of IRI-2012 model in f_0F_2 estimates.

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