D-region HF Absorption Models Incorporating Real-time Riometer Measurements

Neil Rogers*[1] and Farideh Honary[1]

[1] Space Plasma Environment and Radio Science group (SPEARS),
Department of Physics, Lancaster University, Lancaster, U.K.
ncrogers@physics.org and f.honary@lancaster.ac.uk
Tel: +44 1524 510410

Abstract

Absorption of HF (3-30 MHz) radio waves is largely determined by the electron density in the ionospheric D region (50-90 km altitude). During solar proton events (SPE), when the flux of >10 MeV solar protons exceeds 10 $cm^{-2} s^{-1} sr^{-1}$, the D region ionization may be significantly enhanced at high latitudes where geomagnetic shielding is weaker. This results in polar cap absorption (PCA) events which can cause HF communications outages lasting several days.

Models of PCA events are being improved to provide accurate real-time and short-term forecast models of HF absorption for use by HF radio users such as aircraft operating on trans-polar routes. The models are based on the D-region Absorption Prediction model (D-RAP) from the US Space Weather Prediction Service [1, 2] which predicts absorption from real-time measurements of solar X-ray and integral proton flux at one of the Geostationary Operational Environmental Satellites (GOES). Protons with energy below a cut-off energy E_c at a given invariant latitude – a function of geomagnetic indices K_p and D_{st} [3] – lack the rigidity (momentum per unit charge) required to overcome geomagnetic shielding, whilst protons with energy less than thresholds E_{tn} and E_{td} for night and daytime ionospheres respectively, fail to penetrate down to the D-region.

Coefficients of the D-RAP model were based on physical modelling and absorption measurements from a single riometer in Thule, Greenland [3] which measures cosmic noise absorption at 30 MHz. The accuracy of the model was validated for 11 SPEs at Thule by Sauer and Wilkinson [2] and for five further riometers in Canada and Finland by Akmaev *et al.* [4] who suggested possible errors in the location of the rigidity cut-off at high geomagnetic latitudes. In this paper we extend validation of D-RAP to measurements from 13 riometers in the Canadian NORSTAR array and a riometer in Kilpisjärvi, Finland for 93 solar proton events (SPE) spanning the whole of solar cycle 23 (1996-2008). To improve model performance, coefficients are optimized using a non-linear least-squares fit to minimize the root-mean-squared error (RMSE) of the absorption estimate. Using optimized coefficients the RMSE reduces from 0.78 dB to 0.72 dB (using all 14 riometers) or from 0.82 dB to 0.53 dB taking only the single highest latitude riometer, Taloyoak (64.5°N, 93.6°W). By introducing linear terms characterizing the Magnetic Local Time (MLT) dependence, the RMSE may be further reduced to 0.66 dB (all riometers). The inclusion of further linear terms proportional to the hardness of the proton energy spectrum and on solar-zenith angle yielded no significant improvement to the RMSE. The benefits of two modifications to D-RAP suggested by Neal *et al.* [5] based on Polar Operational Environmental Satellite (POES) measurements – a 1-2° correction in the rigidity cut-off invariant latitude and a 3-hour time lag in the K_p index used in its determination – will also be presented.

A short-term forecast capability may be implemented by measuring proton flux at the Advanced Composition Explorer satellite (ACE) located at the L1 libration point which provides 25-70 minute forewarning of proton flux changes (depending on solar wind velocity). An optimized model using ACE integral proton flux measurements (time-shifted to Earth's location) instead of D-RAP reduces the RMSE from 0.57 dB to 0.47 dB (Taloyoak riometer) and from 0.69 dB to 0.64 dB (all riometers).

The nowcast accuracy of the PCA model may be improved by finding model parameters coefficients using a weighted least-squares fit, with higher weights assigned in the most recent 30-minute period of riometer measurements. An example of this technique is presented for the 6-day SPE following the particularly intense solar flare of 14 July 2000, known as the "Bastille-day event".

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

2. Acknowledgments

This work was supported by the UK Engineering and Physical Sciences Research Council, grant EP/K007971/1. Operational support for the CANOPUS / NORSTAR instrument array was provided by the Canadian Space Agency. We acknowledge the efforts of Don Wallis who was principally responsible for the scientific operation of the CANOPUS riometer array and the NORSTAR team for providing the riometer data used in this study.

3. References

1. R. Akmaev, "Global D-Region Absorption Prediction Documentation", available online: http://www.swpc.noaa.gov/drap/dregion_absorption_documentation.html, 23 June 2008.

2. H. H. Sauer and D. C. Wilkinson, "Global mapping of ionospheric HF/VHF radio wave absorption due to solar energetic protons", Space Weather, **6**, S12002, 2008.

3. B. Sellers, F. A. Hanser, M. A. Stroscio, and G. K. Yates, "The night and day relationships between polar cap riometer absorption and solar protons", Radio Sci., **12**, 1977, pp.779-789.

4. R. A. Akmaev, A. Newman, M. Codrescu, C. Schulz and E. Nerney, "D-RAP Model Validation: I. Scientific Report", available online: http://www.ngdc.noaa.gov/stp/drap/DRAP-V-Report1.pdf , 13 January 2010.

5. J. J. Neal, C. J. Rodger and J. C. Green, "Empirical determination of solar proton access to the atmosphere: Impact on polar flight paths", Space Weather, **11**, 2013, pp. 420–433.