Improving HF Communications Availability Forecasts for Aircraft on Trans-Polar Routes

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1: Introduction

An increasing number of aircraft operate on polar routes for which radio communications via VHF or geosynchronous satellite relays are unavailable. Airlines and air traffic control (ATC) authorities nonetheless require reliable HF communications with high availability and the ability to predict outages several hours in advance of a flight departure. However, ionisation of the D-region polar cap and auroral ionosphere due to solar flares and energetic particle precipitation increases the absorption of HF radio waves in this region.

A new UK/Canada research collaboration aims to develop a nowcasting and forecasting model of HF radio absorption in high northern latitudes that incorporates measurements from a Global Riometer Array (GLORIA). Riometer locations are shown in Fig. 1a with model auroral oval and mid-latitude trough locations also shown for K_p=5. Real-time satellite measurements of the solar wind, interplanetary magnetic field, solar X-ray flux and energetic particle precipitation will improve the model's forecast capability.

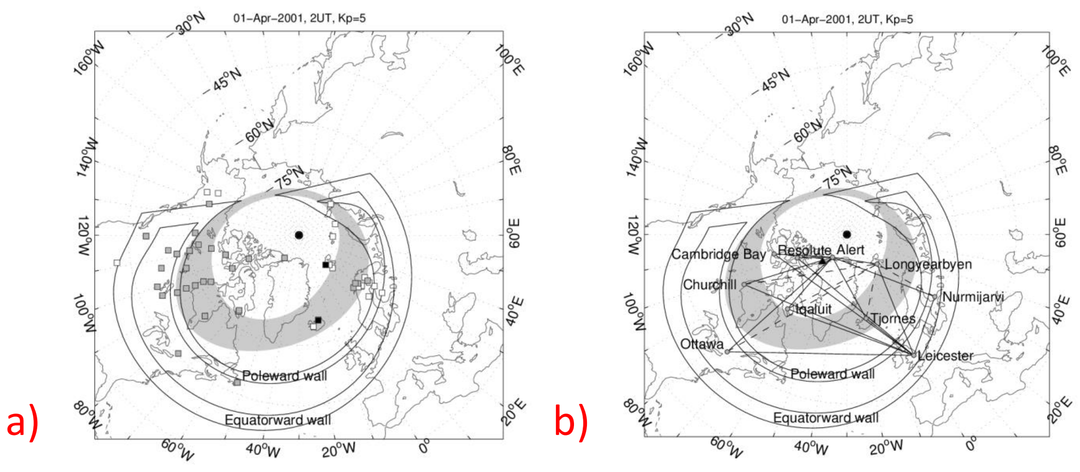

Fig. 1: a) The Global Riometer Array, b) HF sounders and direction finding receivers.

Maps of absorption will be combined with the Leicester University three-dimensional HF ray tracing model. As part of this project, the HF propagation model will use data from a network of HF transmitters (collocated with ATC stations) and direction-finding receivers at high northern latitudes (Fig. 1b). Measurements on these paths will further improve and validate the HF predictions by ensuring that non-great-circle propagation paths are adequately modelled. The main product of the research programme will be an online HF communications planning and forecasting tool designed for the particular needs of civilian airlines.

This poster presents initial research at Lancaster University. Two methods are described in which riometer measurements of cosmic noise absorption may be assimilated into a model of polar cap absorption resulting from solar proton events.

2: The Relation Between Precipitating Proton Flux and 30 MHz Cosmic Noise Absorption (CNA)

Previous studies [1,2] have established that CNA (dB) is proportional to the square-root of the proton flux , *J*, above an energy threshold E_t. In particular,

- Daytime absorption: $A_d = m_d\sqrt{J(>E_{t,d})}$ (dB) Eqn. 1
- Night-time absorption: $A_n = m_n\sqrt{J(>E_{t,n})}$ (dB) Eqn. 2

Based on 30 MHz riometer measurements at Thule, Greenland, [3] determined that m_d = 0.115, $E_{t,d}$ = 5.2 MeV and m_n = 0.020, $E_{t,n}$= 2.2 MeV, and these form the basis of NOAA's D-Region Absorption Prediction (DRAP) model [4]. Energy thresholds are increased to a rigidity cut-off energy, E_c, at lower invariant latitudes depending on geomagnetic activity indices, K_p and D_{st} [4].

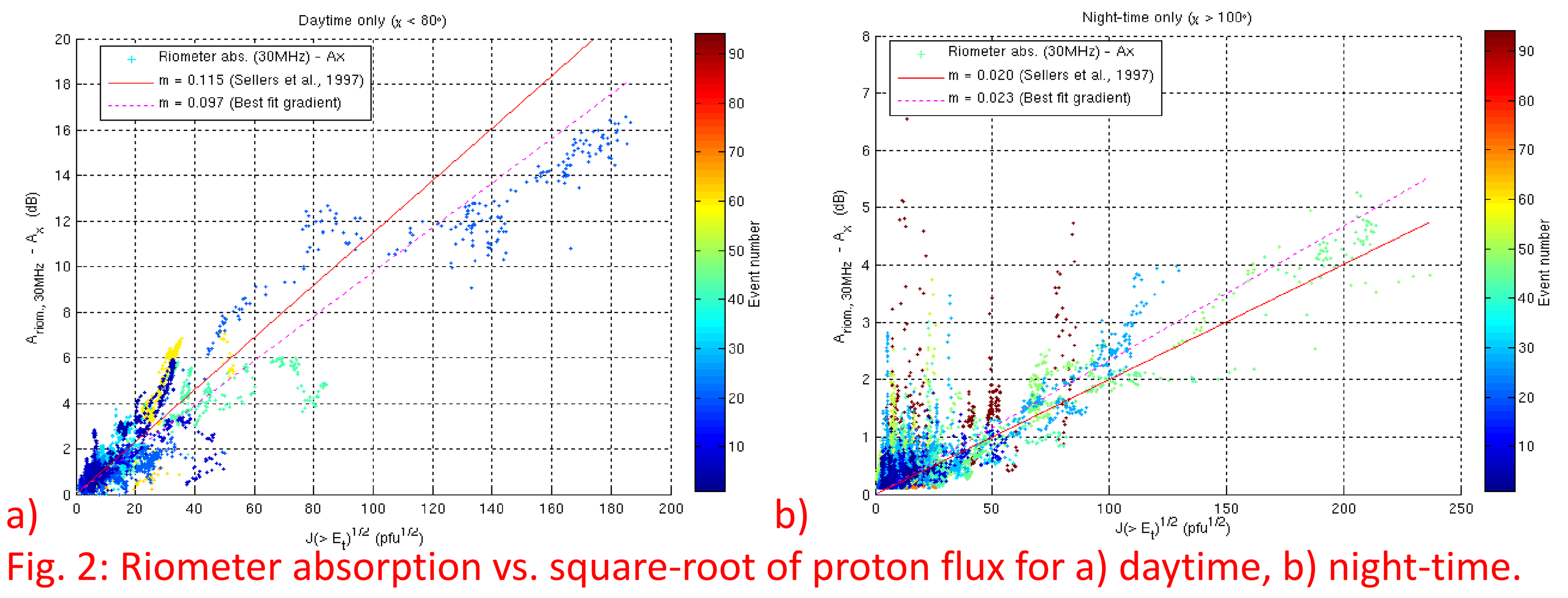

Fig. 2: Riometer absorption vs. square-root of proton flux for a) daytime, b) night-time.

Fig. 2 presents a comparison of 38 MHz absorption (5-min. averages) at the IRIS Kilpisjärvi riometer (69.1° N, 20.8° E) (scaled to 30 MHz using a $f^{-1.5}$ power law) against $\sqrt{J(>E_c)}$ for (a) daytime (solar-zenith angle, χ < 80°), (b) night-time (χ > 100°). All solar proton events (periods for which J(>10 MeV) > 10 cm^{-2} s^{-1} sr^{-1}) for the 1996-2006 period are shown and coloured separately. DRAP predictions of absorption due to X-ray ionisation are subtracted. The solid lines represent the gradients used in DRAP [3,4], whilst the dashed line is a linear regression to the Kilpisjärvi measurements.

- **Measurements at Kilpisjärvi indicate that the DRAP model over-predicts absorption during the day** (reducing m_d from 0.115 to 0.097 provides a better fit) **and under-predicts absorption during the night** (m_n should increase from 0.020 to 0.023).

3: Assimilation of Riometer Measurements into a Background Polar Cap Absorption Model

The DRAP absorption model assumes a linear transition between day and night given by

$$A = A_d Z + (1-Z)A_n \quad \text{where} \quad Z = \begin{cases} 1 & \chi < 80^\circ \\ (\chi - 80^\circ)/20^\circ & 80^\circ < \chi < 100^\circ. \\ 0 & \chi > 100^\circ \end{cases} \qquad \text{Eqn. 3}$$

This linear system permits m_d and m_n (Eqn. 1 and 2) to be found simultaneously by linear regression (a classic data inversion problem [5]). Applying this model to all Kilpisjärvi riometer measurements associated with Solar Proton Events (SPE) in the period 1996-2006 yields best-fit values of m_d = 0.103 and m_n = 0.023.

Linear regression to absorption measurements from multiple riometers may be used to optimise values of m_d and m_n in real time. Fig. 3 presents the best-fit values for the large SPE of July 2000 using multiple riometers from the GLORIA network for periods up to 30 minutes prior to the times shown.

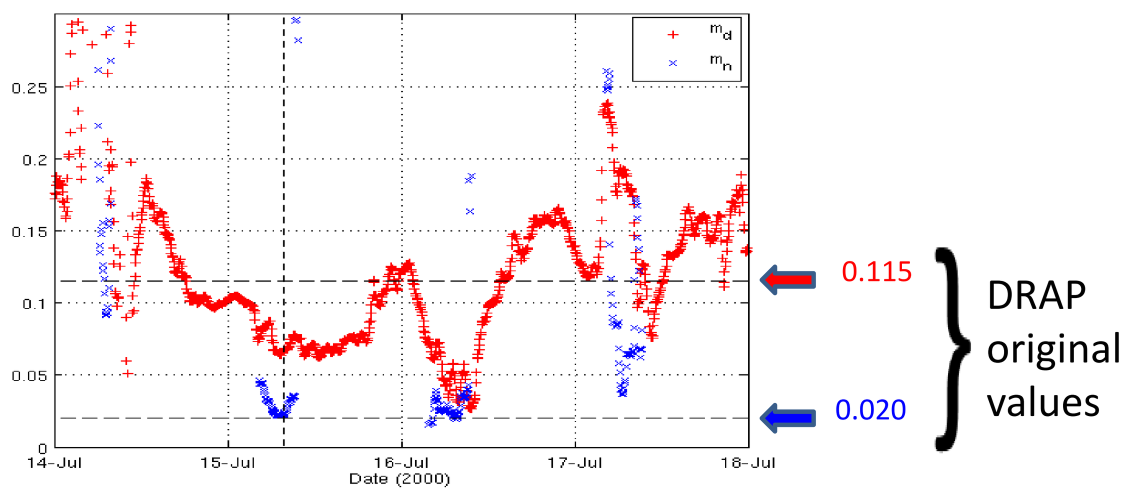

Fig. 3: DRAP model parameters m_d and m_n providing a best fit to measurements from the Global Riometer Array.

The absorption map shown in Fig. 4a presents DRAP outputs for 08:00UT on 15 July 2000, with the original DRAP values of m_d and m_n. Measured absorption values at riometer locations (coloured circles) are over-predicted by the model. Fig 4b presents the modified output using best-fit values of m_d and m_n to illustrate the technique.

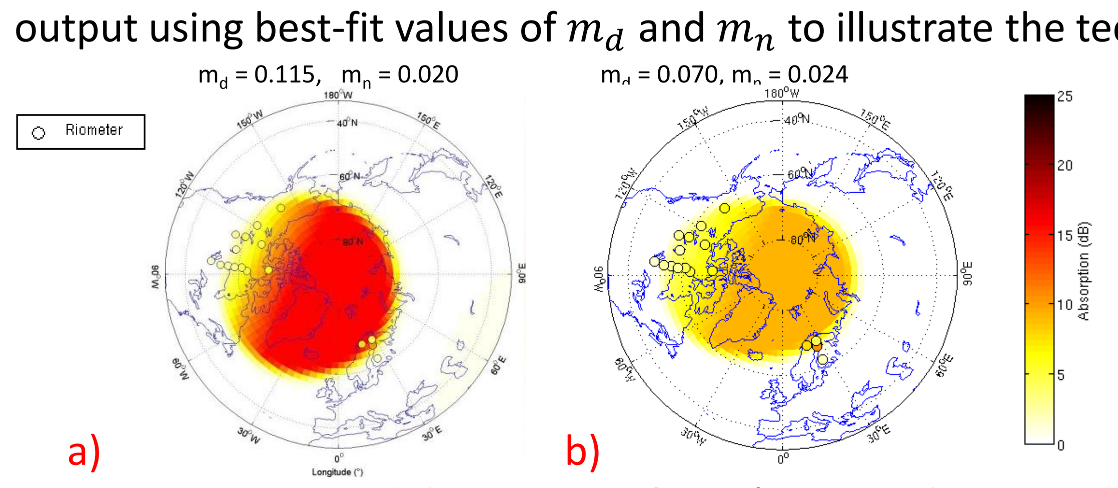

Fig. 4: DRAP model outputs for a) original DRAP parameters, and b) modified parameters m_d = 0.07 and m_n = 0.024 providing best fit to riometer measurements.

An alternative approach to assimilating riometer measurements into the background model is to fit an interpolating function to both measurements and model predictions given by a truncated series of spherical harmonic basis functions,

$$\Phi(\theta,\varphi) = \sum_{l=0}^{L_{max}} \sum_{m=-l}^{l} A_{lm} P_l^m(\cos\theta)\, e^{im\varphi} \qquad \text{Eqn. 4}$$

where P_l^m are associated Legendre polynomials, θ = colatitude (which are scaled to cover only the high-latitude region) and φ = longitude. The coefficients A_{lm} are found by a weighted linear regression, which allows higher weights to be assigned to the riometer measurements. An example of this fitting method is presented in Fig. 5 for L_{max}= 6 (in Eqn. 4) and with a) original DRAP parameters and b) modified values of m_d and m_n. This method allows a better fit to the measurements although the shape of the absorption map is not preserved and may be physically unrealistic.

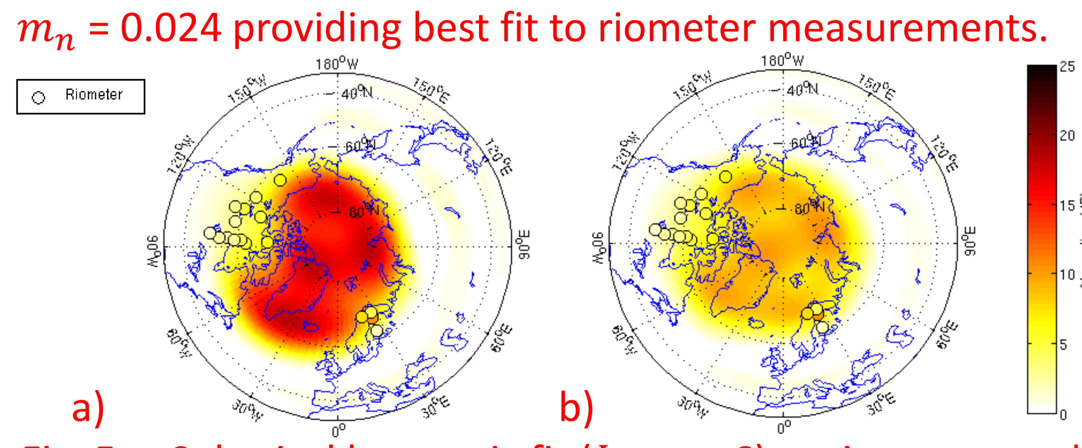

Fig. 5: Spherical harmonic fit (L_{max} = 6) to riometers and DRAP model data for a) original DRAP parameters, and b) modified (best-fit) parameters m_d = 0.07 and m_n = 0.024.

4: Summary and Conclusions

- A new UK/Canada research collaboration aims to provide real-time and forecast predictions of HF radio absorption at high latitudes using an extensive network of riometers and HF sounders.
- Comparison of the DRAP polar cap absorption model predictions against measurements from the IRIS Kilpisjärvi riometer (1996-2006) indicate that DRAP over-predicts absorption on the dayside by 12-19% and under-predicts on the nightside by 15%.
- Riometer measurements may be used to linearly scale the absorption model parameters in real-time and so produce an optimised map of polar cap absorption
- Alternatively a spherical harmonic function may be fit to the riometer data by weighted linear regression, with extra points provided by a model.

References

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