Examining the Role of Dispersion Relation and Collision Frequency Formulations on Estimation of Shortwave–Fadeout

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Abstract

Over–the–Horizon (OTH) communication is strongly dependent on the state of the ionosphere, which is susceptible to solar flares. Trans–ionospheric high frequency (HF) signals experience a strong attenuation following a solar flare, commonly referred to as Short–Wave Fadeout (SWF). In this study, we examine the role of dispersion relation–collision frequency formulations on the estimation of flare–driven HF absorption seen in Riometer observation using a data assimilation framework. Specifically, the framework first uses modified solar irradiance models (such as EUVAC, FISM), which incorporate high–resolution solar flux data from GOES satellite X-ray sensors, to compute the enhanced ionization produced during the flare events. The framework then uses different dispersion relation–collision frequency formulations to estimate enhanced HF absorption. Finally, the modeled HF absorption is compared against the data to determine which combination of dispersion relation–collision frequency formulation best reproduces the Riometer observations. From the modeling work, we find that the Appleton–Hartree dispersion relation in combination with Schunk–Nagy collision frequency profile produces the best agreement with Riometer data.

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Overview

- High frequency (3-30 MHz, HF) communication is strongly dependent on the state of the ionosphere, which is fragile to solar X-ray flares (Davies 1990).
- HF systems observe a sudden enhancement in signal attenuation following a solar flare, commonly known as Short-Wave Fadeout or SWF. For example riometers record a sudden enhancement in cosmic noise absorption (Fiori et al. 2018).
- Previous studies described sudden enhancement in D–region electron density as the primary driver of enhanced HF absorption [Benson, (1964); Davies, (1990)] and neglected importance of collision frequency, electron temperature [Zawdie et al., (2017); Kero et al., (2004)].
- Existing models [DRAP2 – Sauer, (2008); Levine, (2019)] only incorporate
  1. impact due to increase in solar soft X-ray irradiance
  2. impact on a narrow band of HF signal.
- This study proposes a physics–based model that
  1. incorporates flare time dynamics from EUV and X-ray data.
  2. examine the role of collision frequency on HF absorption.

Open Question

- Can we accurately account for the characteristics of SWF in terms of ionospheric processes using physics–based modelling?

Significance

- Insights to the ionospheric properties and their variability during solar flares. Better predict the HF blackout phase following a solar flare.

Event Study

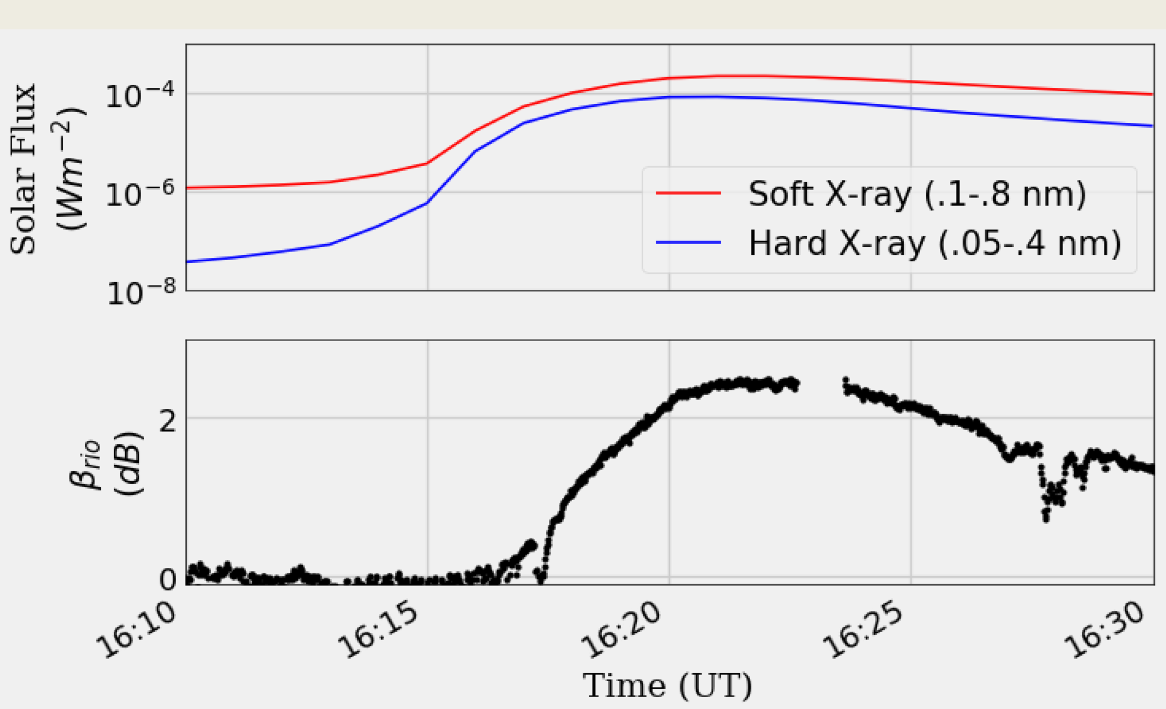


Figure 1: Typical solar flare event and its impacts on various HF systems: (a) GOES-15 X-ray sensor data, (b) riomerer (Ottowa station) response (HF absorption) to the solar flare.

HF Absorption Theory

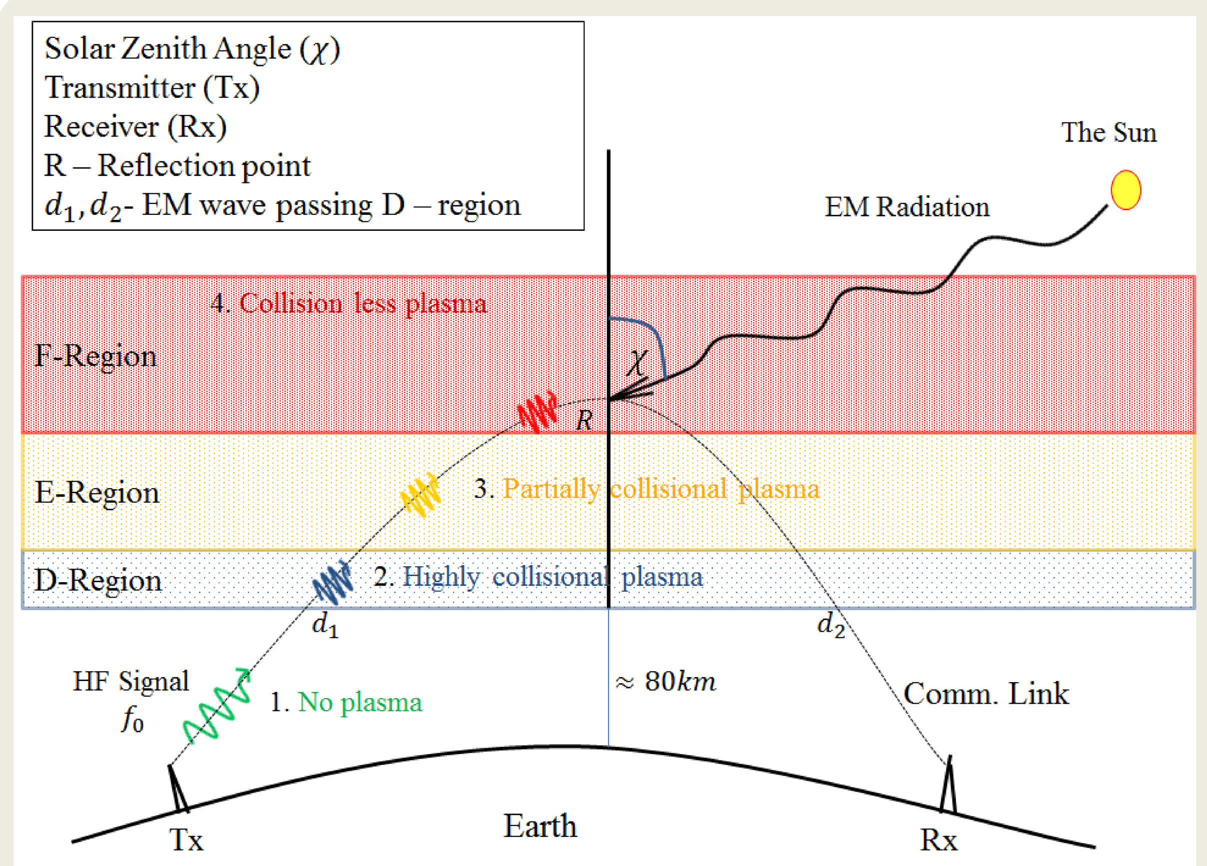
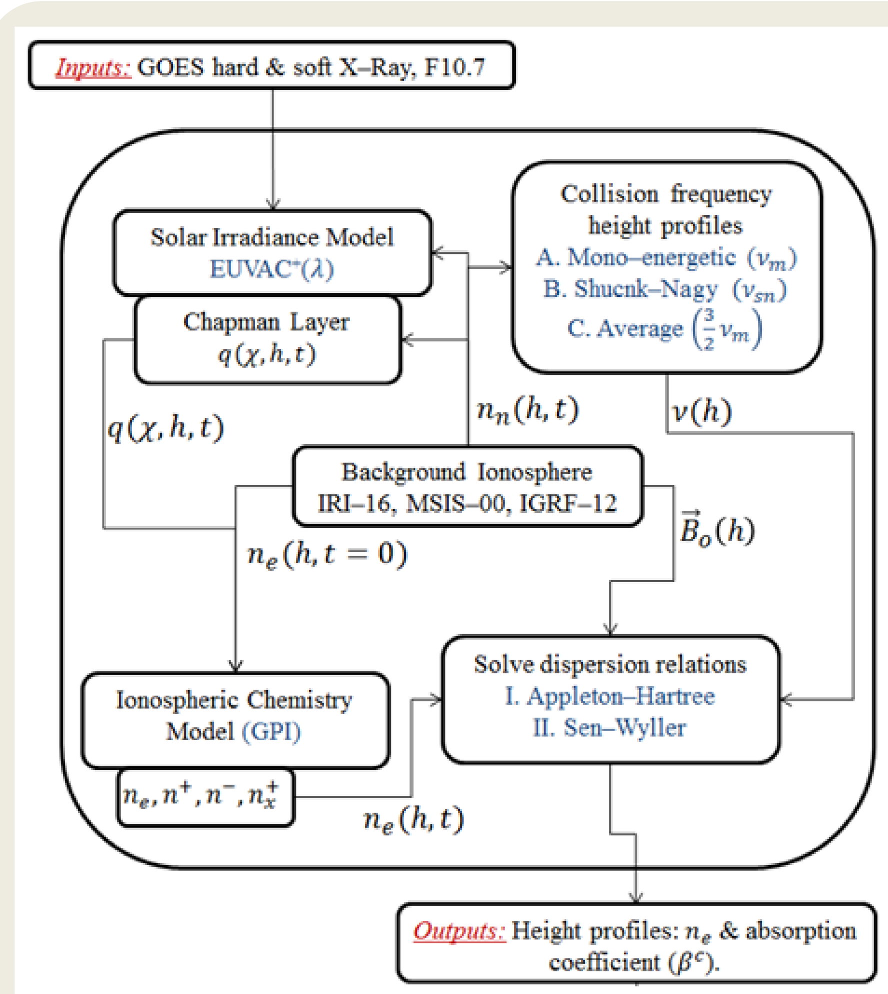


Figure 2: Schematic diagram showing the cause of HF absorption. HF absorption caused due to the collision between electrons and neutrals in the D and E layer ionosphere that *converts EM energy into heat energy* (*Davies, 1990*).

	Plasma	Collision
Neutral	No	No
D - Region	Yes	High
E - Region	Yes	Partially
F - Region	Yes	Collision less

Model Architecture



Combinations
I – A
I – B
I – C
I I– A

Figure 3: We modified EUVAC model by introducing GOES soft and hard X-ray data.

Appleton – Hartree	Sen – Wyller
Collision frequency ν is independent of electron energy	Collision frequency ν is dependent on electron energy
Uses averaged collision freq.	Uses distribution of collision freq.

Model Output

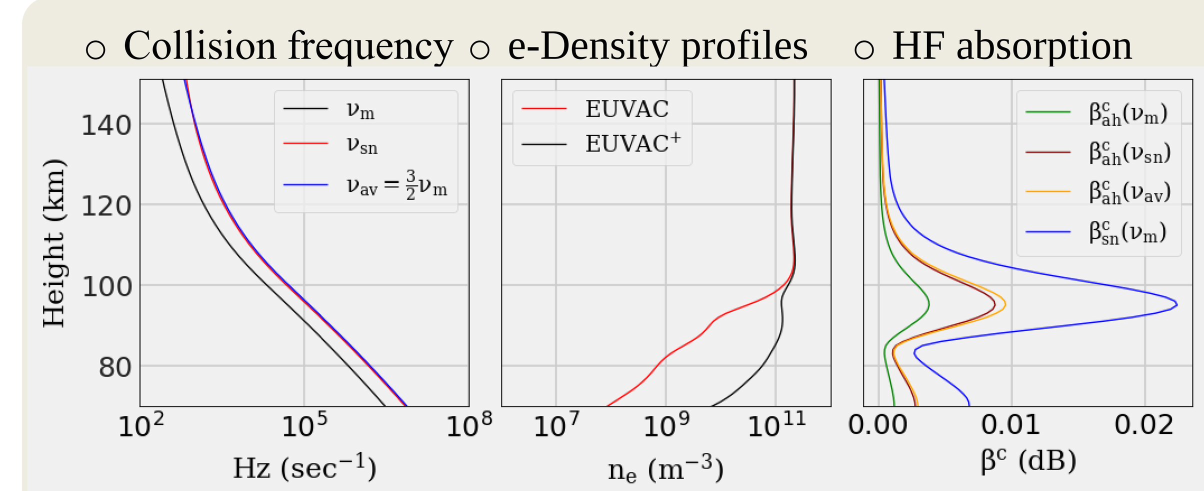


Figure 3: Introduction of GOES hard and soft X-ray flux data changes flare time lower ionospheric e-density profile.

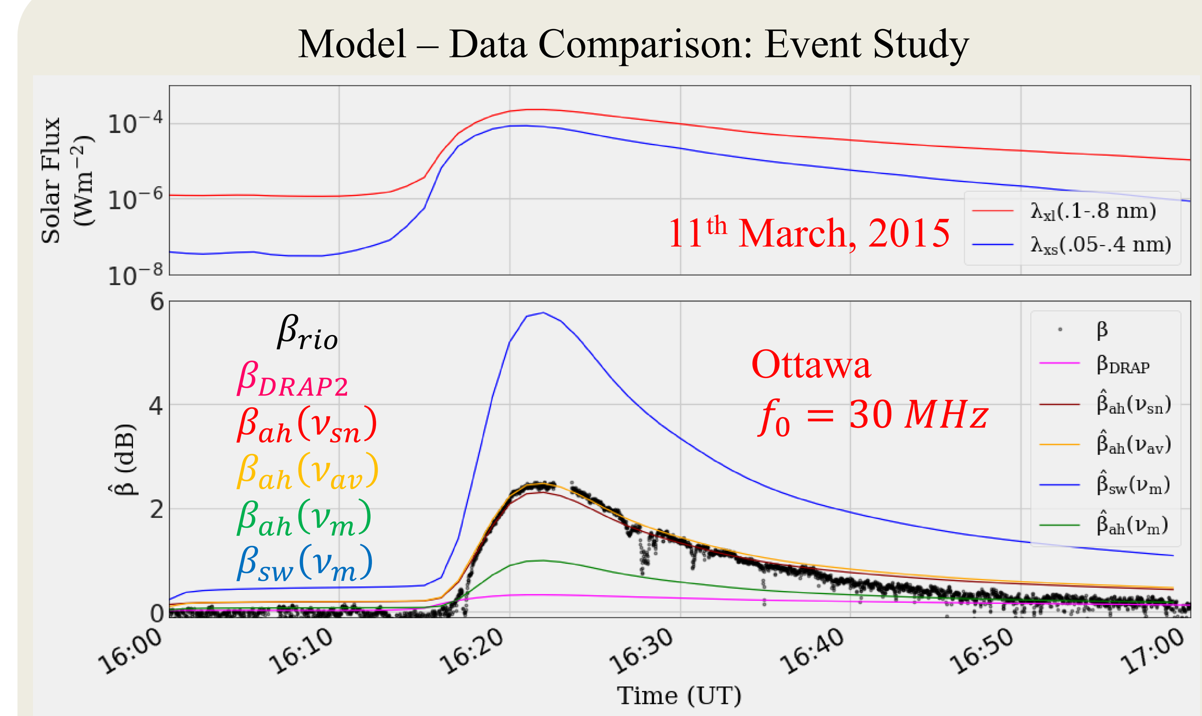
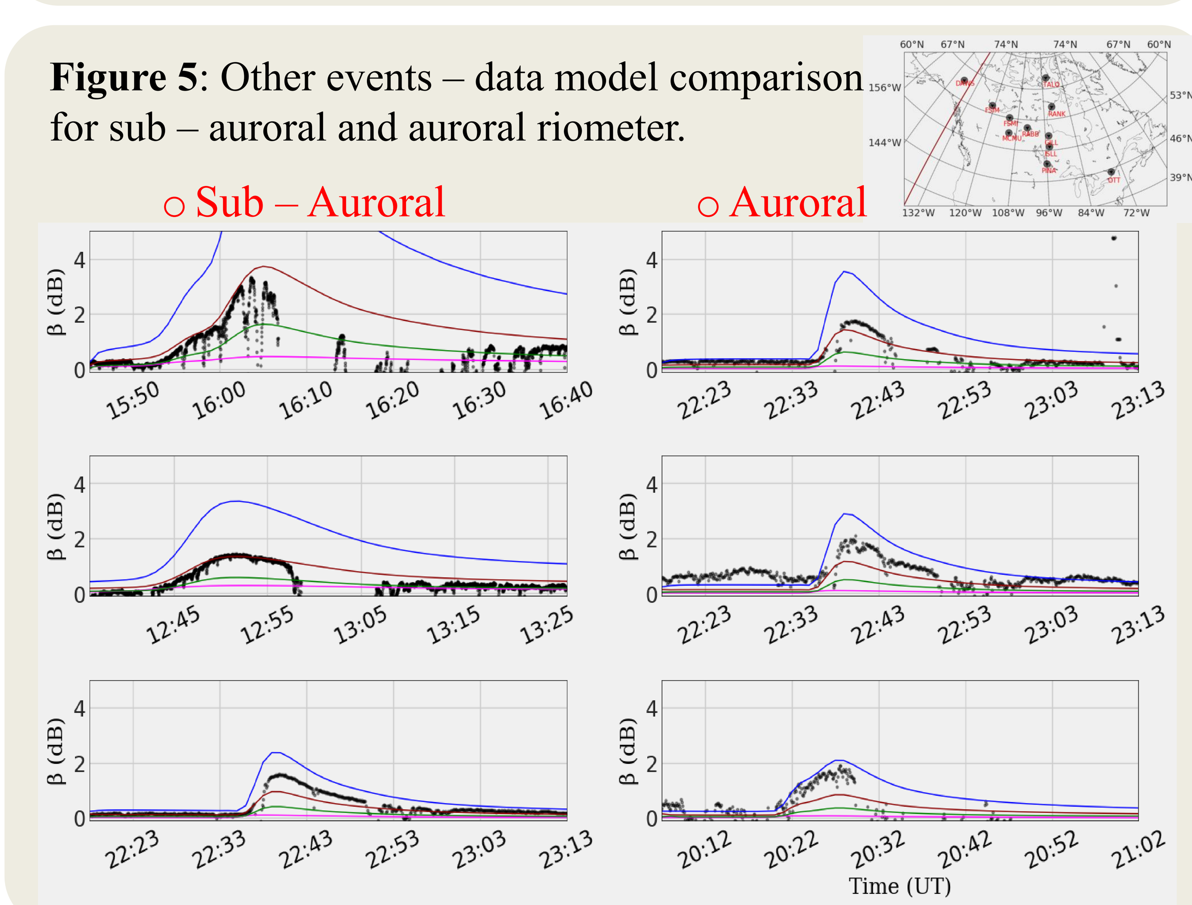


Figure 4: Appleton-Hartree dispersion relation with Schunk-Nagy and average collision frequency combinations best reproduce riometer observation.

Figure 5: Other events – data model comparison for sub – auroral and auroral riometer.



- Appleton-Hartree dispersion relation with Schunk-Nagy and averaged collision frequency model (red) best fit for sub-auroral riometer observation.
- For higher latitudes Sen-Wyller with mono energetic collision frequency formulation (the blue line) seems to be better fit.

Model Output

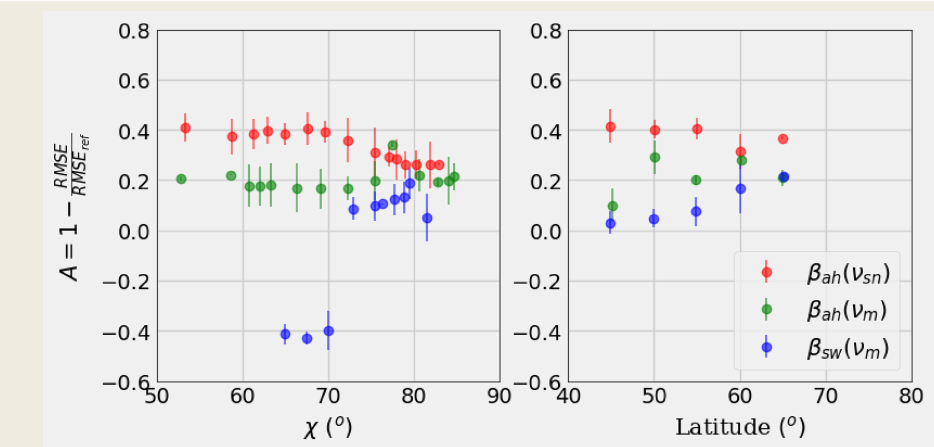


Figure 6: Model skills versus solar zenith angle (χ) and latitude. Statistically, with increasing χ and latitudes the Sen-Wyller with mono energetic collision (the blue line) seems to be better fit. Statistics drawn from 75 X class flare events. Model skill is the relative metric that shows how good model is performing w.r.t existing model DRAP. $A = 1 - \frac{RMSE_M}{RMSE_{DRAP}}; A \in (-\infty, 1)$

Summary & Conclusions

- Soft X-ray is a good estimator for sub-auroral SWF [*Sauer, (2008), Levine, (2019)*]. We find introduction of hard X-ray can improve the SWF estimation.
- *Heino et al., (2019)* showed Sen-Wyller can better estimate SEP-driven PCA, and with increase in geomagnetic (geodetic) latitudes error decreases. We find Sen-Wyller better estimates flare driven auroral ionospheric HF absorption.

	Collision Frequency
Sub-auroral	NOT a function of electron energy
Auroral	Function of electron energy

- We find, Appleton-Hartree dispersion relation Schunk-Nagy and average collision frequency profiles produce the best agreement with sub-auroral riometer observation.
- There is no significant change in sub-auroral electron temperature, that contributes to change in collision frequency.

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