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

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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

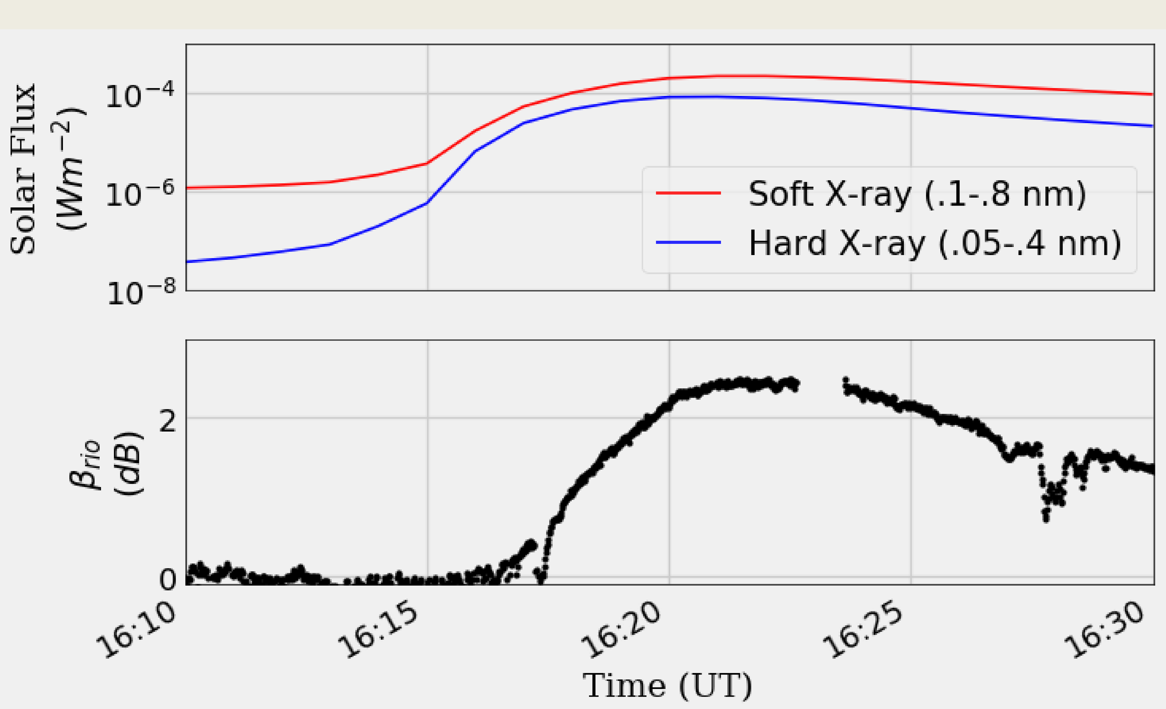


Figure 1: Typical solar flare event and its impacts on various HF systems: (a) GOES-15 X-ray sensor data, (b) riomerer (Ottowa station) response (HF absorption) to the solar flare.

HF Absorption Theory

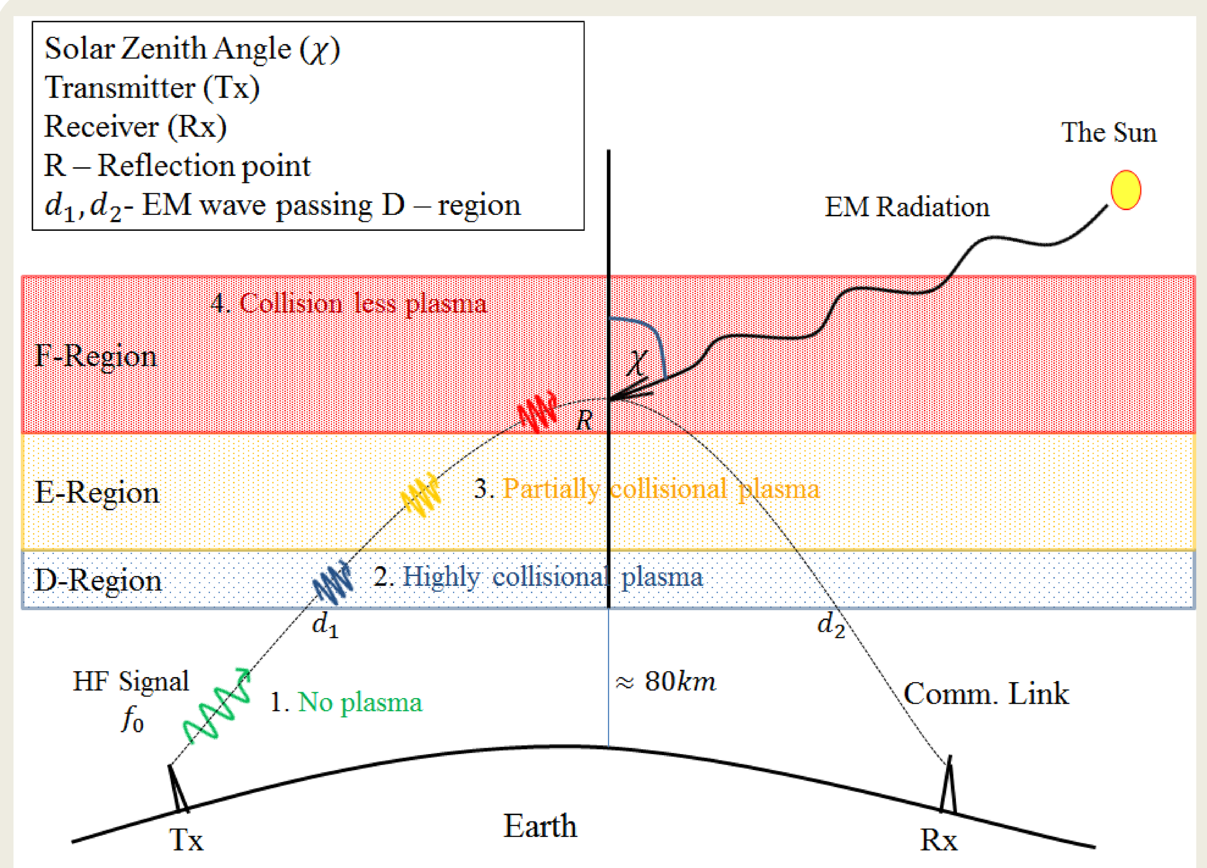
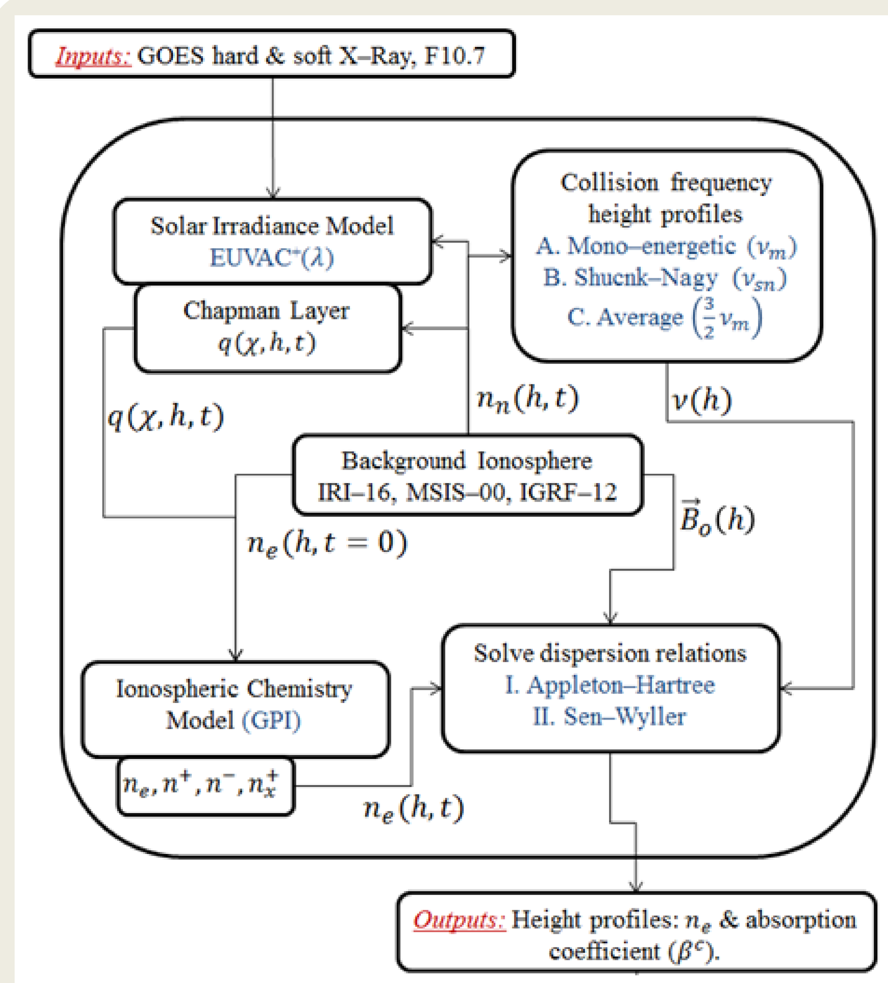


Figure 2: Schematic diagram showing the cause of HF absorption. HF absorption caused due to the collision between electrons and neutrals in the D and E layer ionosphere that *converts EM energy into heat energy* (*Davies, 1990*).

	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

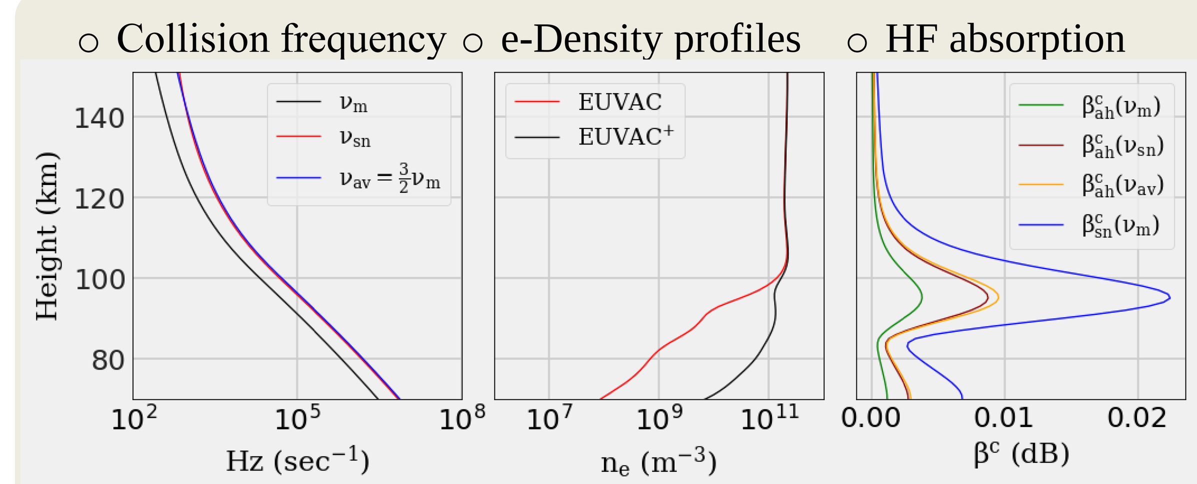


Figure 3: Introduction of GOES hard and soft X-ray flux data changes flare time lower ionospheric e-density profile.

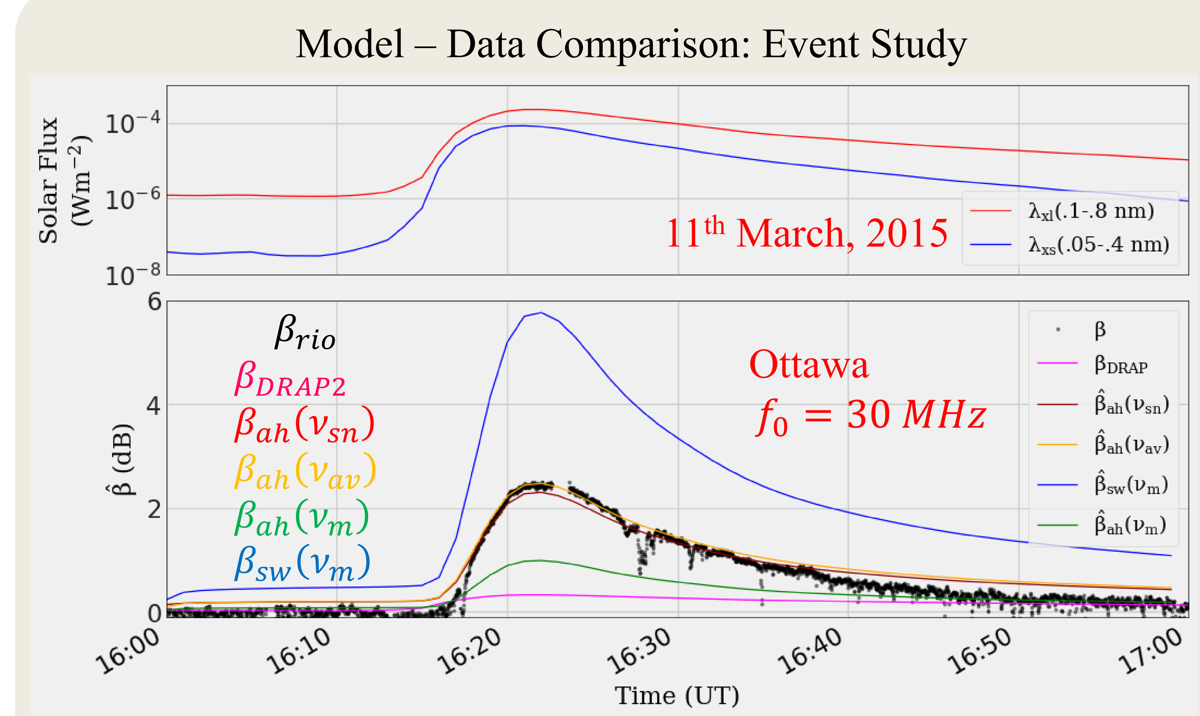
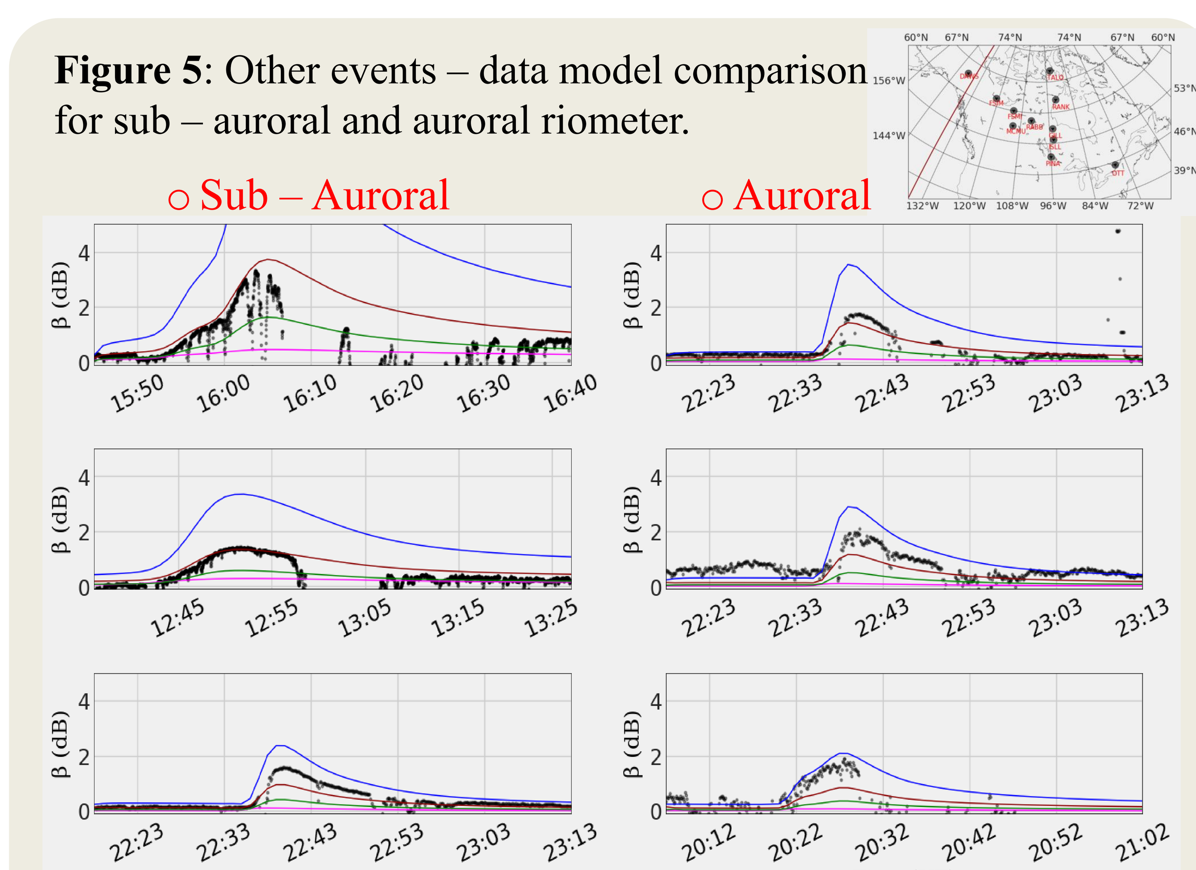


Figure 4: Appleton-Hartree dispersion relation with Schunk-Nagy and average collision frequency combinations best reproduce riometer observation.

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

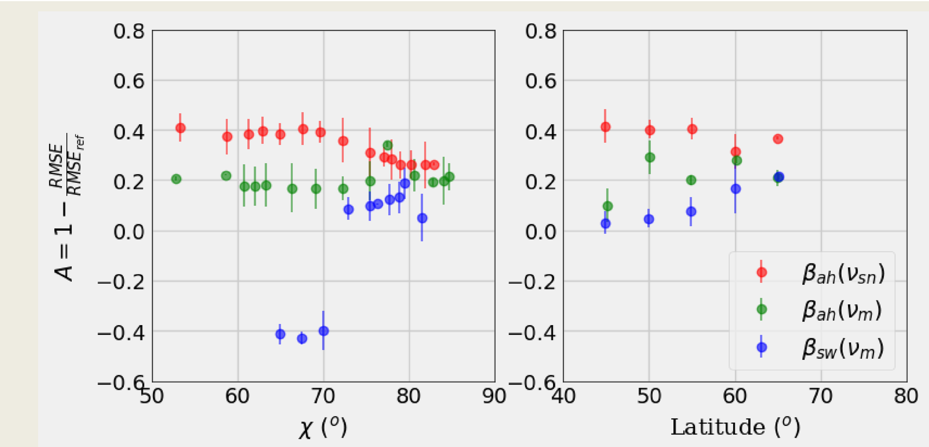


Figure 6: Model skills versus solar zenith angle (χ) and latitude. Statistically, with increasing χ and latitudes the Sen-Wyller with mono energetic collision (the blue line) seems to be better fit. Statistics drawn from 75 X class flare events. Model skill is the relative metric that shows how good 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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