Viability of nowcasting solar flare-driven radio-blackouts using SuperDARN HF radars

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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.
- 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 [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.

Objectives

- Can SuperDARN be used to monitor solar flare driven HF absorption across North American Sector?
- Can we accurately account for the characteristics of SWF in terms of ionospheric processes using physics–based modelling?

Flare Impact on SuperDARN and Riometer

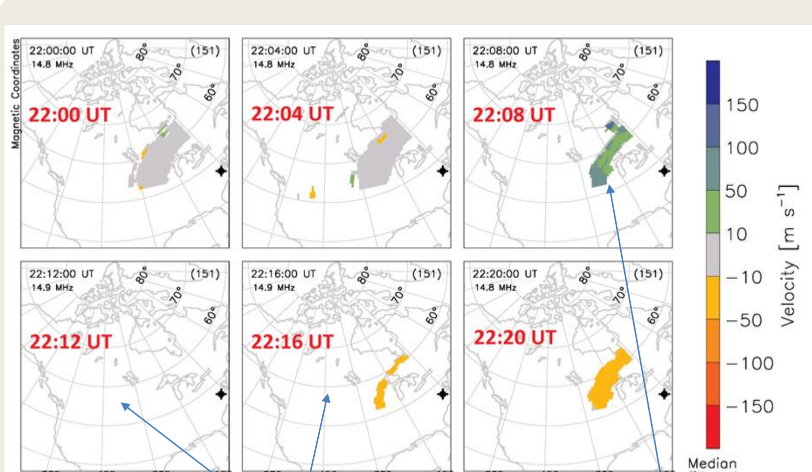

Figure 1: Series of SuperDARN radar's field-of-view plot showing Doppler velocity color coded by the colorbar on right. Solar flare impacts on SuperDARN BKS radar on 5th May 2015.

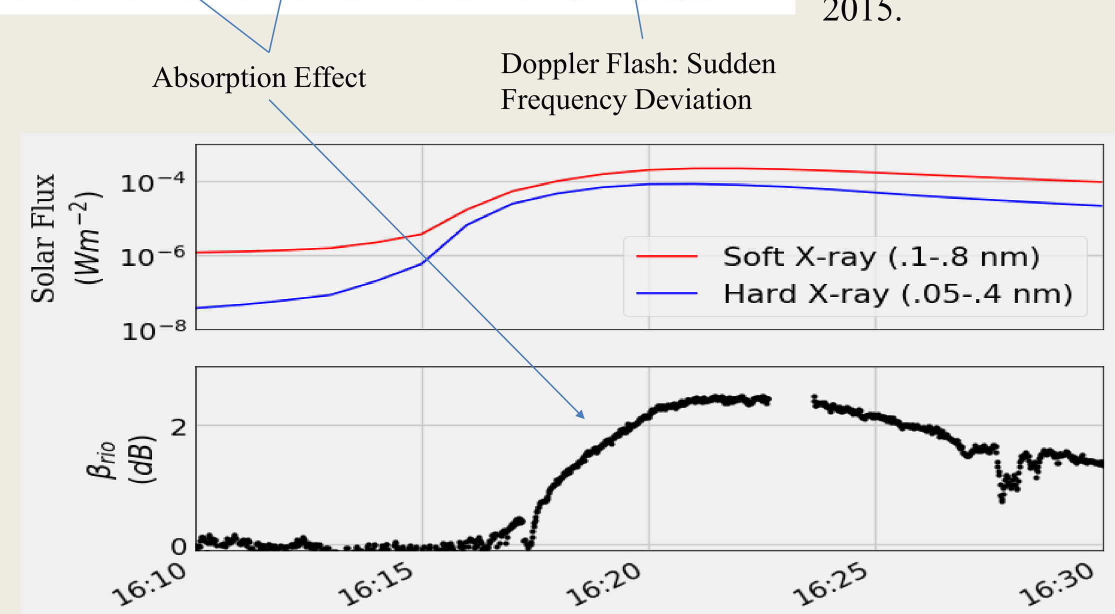

Figure 2: Solar flare event and its impacts on Ottawa riometer on 11th March 2015: (a) GOES-15 X-ray sensor data, (b) riomerer (Ottowa station) response (HF absorption) to the solar flare.

Timing Analysis

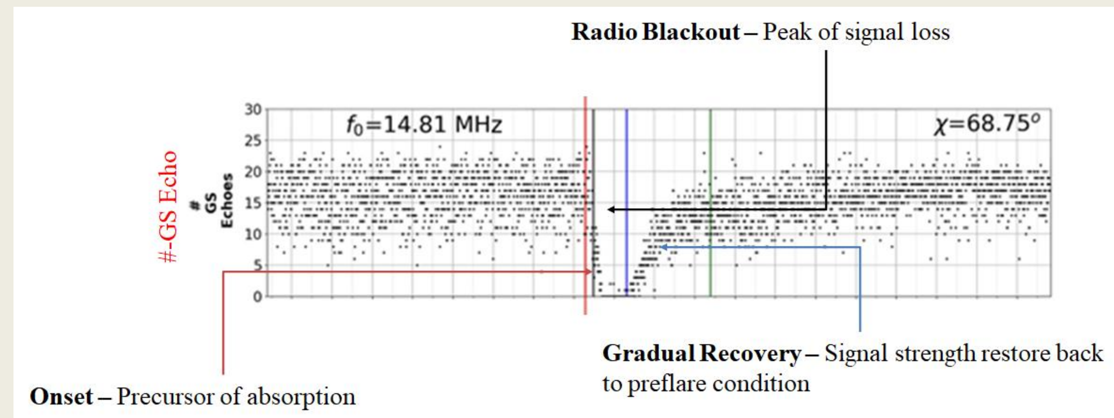

Figure 3: Timing analysis of number of SuperDARN Blackstone radar's ground scatter echoes. Three phases of the solar flare driven SWF is identified in the figure with four vertical lines. (Chakraborty et al. 2018)

1. Backscatter signals of the radars located near to subsolar point are affected more severely than radars located at larger solar zenith angles.
2. Backscatter signals of the radars operating at relatively lower frequencies are affected more severely than radars operating at higher frequencies.

Solar Flare Monitor

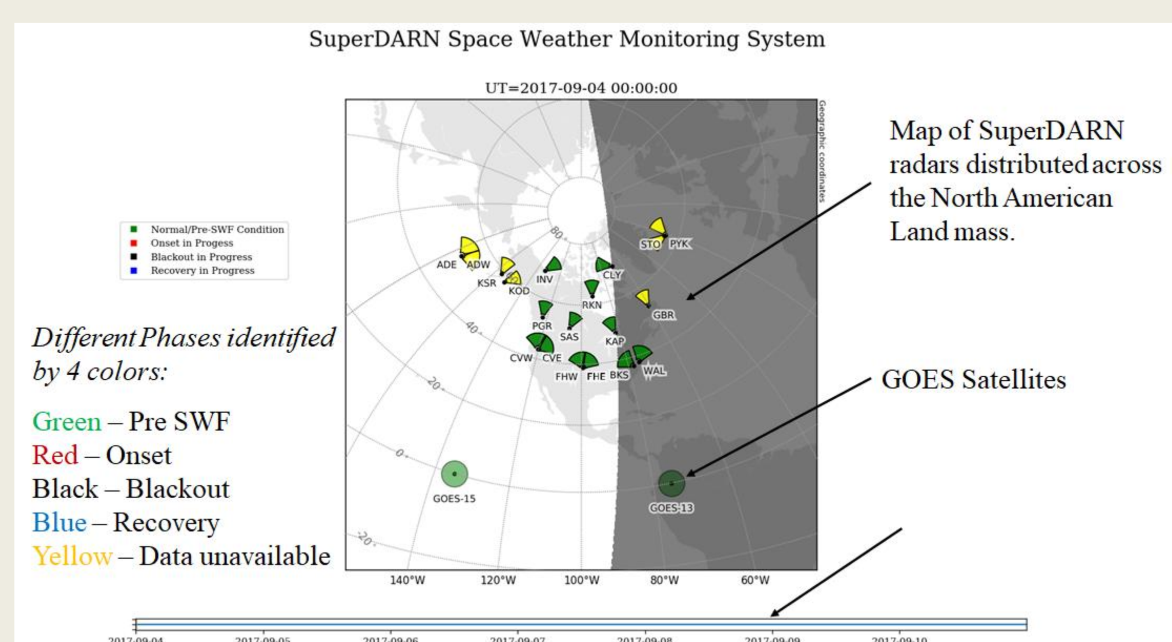

Figure 4: Solar flare monitoring system. SuperDARN HF radars distributed across North American land mass.

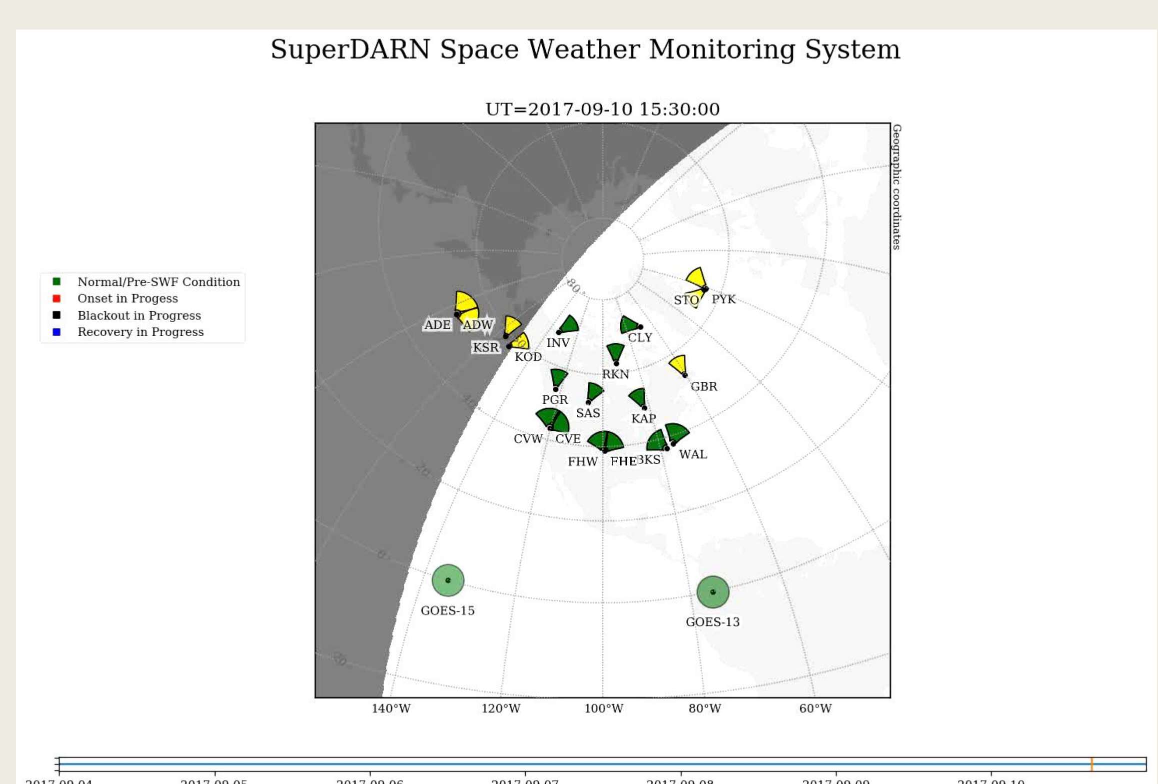

Figure 5: Response during September 2017 Solar storm. X8.9 Solar flare at ~15:30 UT on 10th Sep 2017.

HF Absorption Model

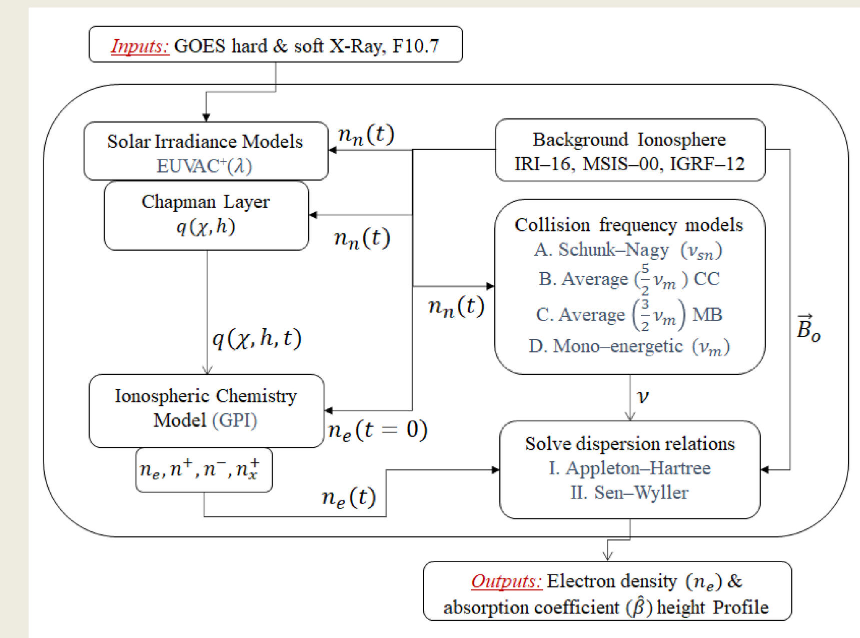

Figure 6: Model architecture for calculating electron density and HF absorption height profiles showing the component modules (borrowed, modified, and developed) and their interconnection. (Chakraborty et al. 2021)

Irradiance model	Dispersion Relation	Collision Frequency
EUVAC⁺	Appleton – Hartree	Schunk – Nagy (ν_{sn}) Average: Chapman – Cowling Integral (ν_{av}^{cc}) Average: Maxwellian – Boltzmann Integral (ν_{av}^{mb}) Monoenergetic (ν_{me})
	Sen – Wyler	Monoenergetic (ν_{me})

Table 1: The four combinations of dispersion relation-collision frequency formulations used in the new model.

Model – Data Comparison: Event Study

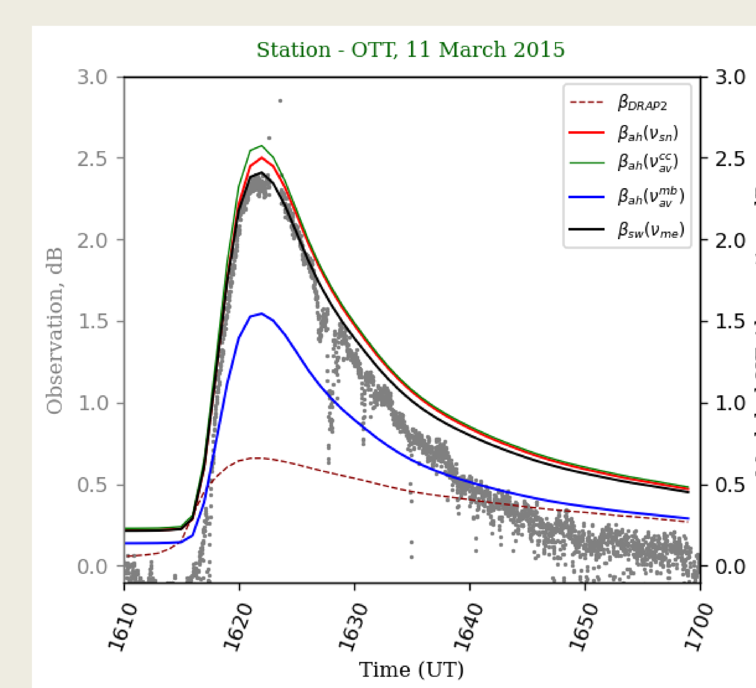

Figure 7: Comparison of HF absorption modeled using different dispersion relation and collision frequency combinations and Ottawa riometer data in response to a solar flare on 11th March 2015. (Chakraborty et al. 2021)

1. Event study shows the [S-W] dispersion relation with monoenergetic collision frequency (black) best reproduces riometer observation.
2. The [A-H] dispersion relation with Schunk-Nagy and average collision (Chapman-Cowling Integral) frequency combinations (red & green) best reproduces riometer observation.

Summary & Conclusions

- Impacts are mitigated as we move away from the solar noon position. This can also be interpreted as local time effect.
- Timings are constrained by the transmitted frequency of the radar. Radars with low operating frequency are affected much more by SWF.
- A subnetwork of SuperDARN HF Radars can be used to monitor solar flare driven HF absorption across the North American sector.
- Modeling in an event study indicates that the [S-W] dispersion relation with monoenergetic collision frequency (black) best reproduces riometer observation, however, a statistical study is required to confirm the findings from this event study.

Future Work

- The future extension of this work is to develop an early warning system to identify, monitor, and forecast radio blackouts using HF radars currently deployed to support space science research.
- A statistical study is required to confirm the findings from the modeling event study.

References

- Daiki Watanabe, N. Nishitani, Study of ionospheric disturbances during solar flare events using the SuperDARN Hokkaido radar, 2013.
- Chakraborty, S., Ruohoniemi, J. M., Baker, J. B. H., & Nishitani, N. (2018). Characterization of short-wave fadeout seen in daytime SuperDARN ground scatter observations. Radio Science, 53, 472–484. https://doi.org/10.1002/2017RS006488
- Chakraborty, S., Baker, J. B. H., Fiori, R. A. D., Ruohoniemi, J. M., & Zawdie, K. A. (2021). A Framework to Estimate Ionospheric HF Absorption in Response to a Solar Flare. Radio Science, Under Review.
- Fiori, R. A. D., Koustov, A. V., Chakraborty, S., Ruohoniemi, J. M., Danskin, D. W., Boteler, D. H., & Shepherd, S. G. (2018). Examining the Potential of the Super Dual Auroral Radar Network for Monitoring the Space Weather Impact of Solar X-Ray Flares. Space Weather, 16, 1348– 1362. https://doi.org/10.1029/2018SW001905
- Zawdie, K. A., D. P. Drob, D. E. Siskind, and C. Coker (2017), Calculating the absorption of HF radio waves in the ionosphere, Radio Sci., 52, 767–783, doi:10.1002/2017RS006256.
- NOAA, Global D-Region Absorption Prediction Documentation, 2015.
- Davies, Ionospheric Radio 1990.
- Schunk & Nagy, Ionospheres, 2009.

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