Reexamining the Characteristics of Flare-Driven Doppler Flash using Multipoint HF Observations

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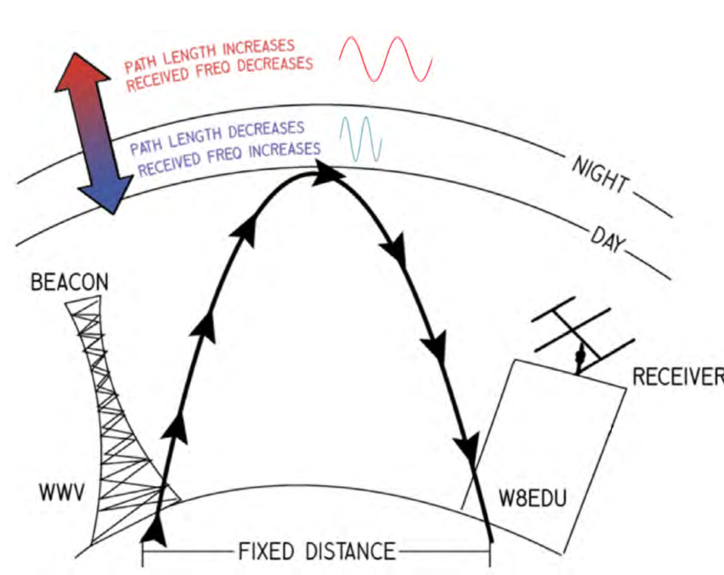
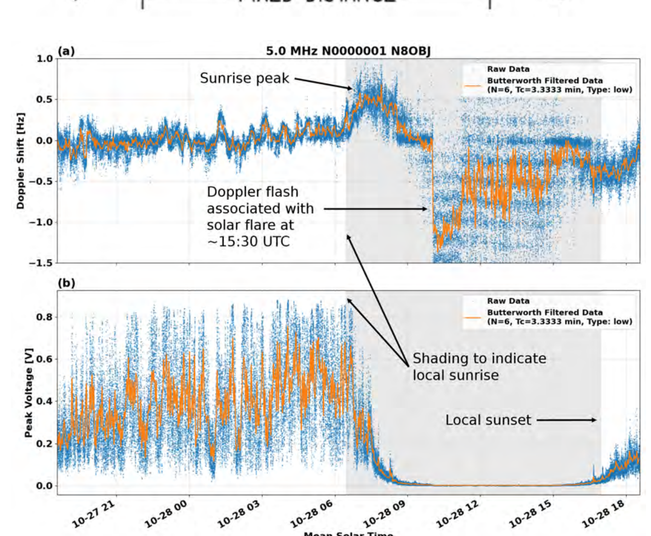
Background and Motivation

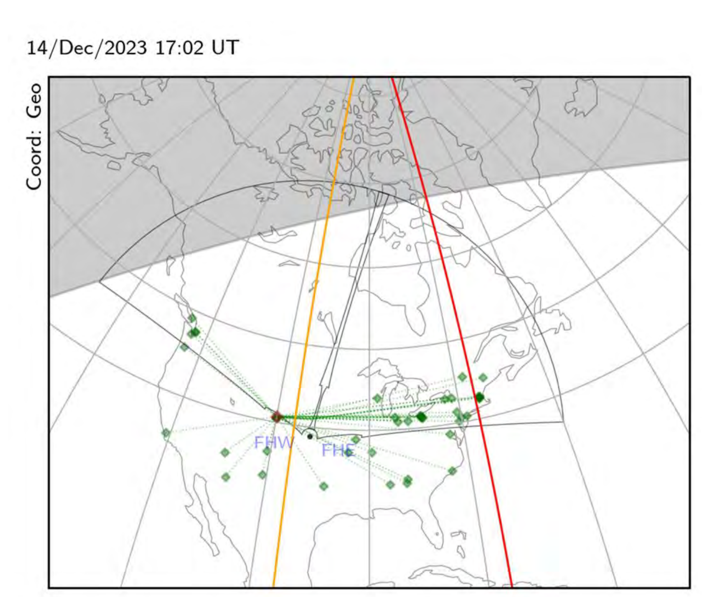
A solar flare is a space weather event that causes a transient in the ionospheric system, commonly known as the solar flare effect (SFE). Sudden enhancement in high-frequency (HF) absorption is a well-known impact of solar flare-driven Short-Wave Fadeout (SWF). Less understood is a perturbation of the radio wave frequency as it traverses the lower ionosphere in the early stages of SWF, also known as the Doppler flash, typically observed via the SuperDARN radar network. Previous investigations have suggested that the change in the F-region refcative index is the primary driver of the Doppler flash. Recent development showed that distributed Doppler observations of time standard stations, such as those collected by citizen science participants in the HamSCI Personal Space Weather Station project, can provide insight into the physics behind changes in phase path length of the trans ionospheric radio signals. In this study, we demonstrate how these observations may be used to infer flare-driven changes in ionospheric properties. We present the Doppler flash observation as a function of flare strength and location on the Earth, and compare these findings with previous studies that used SuperDARN observations.

Instrumentation

The HamSCI Personal Space Weather Station (the “Grape”) measures Doppler shift in the carrier signals of time standard stations, primarily WWV in Colorado, WWVH in Hawaii, and CHU in Ottawa. The systems are open source and over 50 stations are maintained by radio amateurs, primarily in North America. Data and processing code are available in FAIR-compliant form and updated frequently.



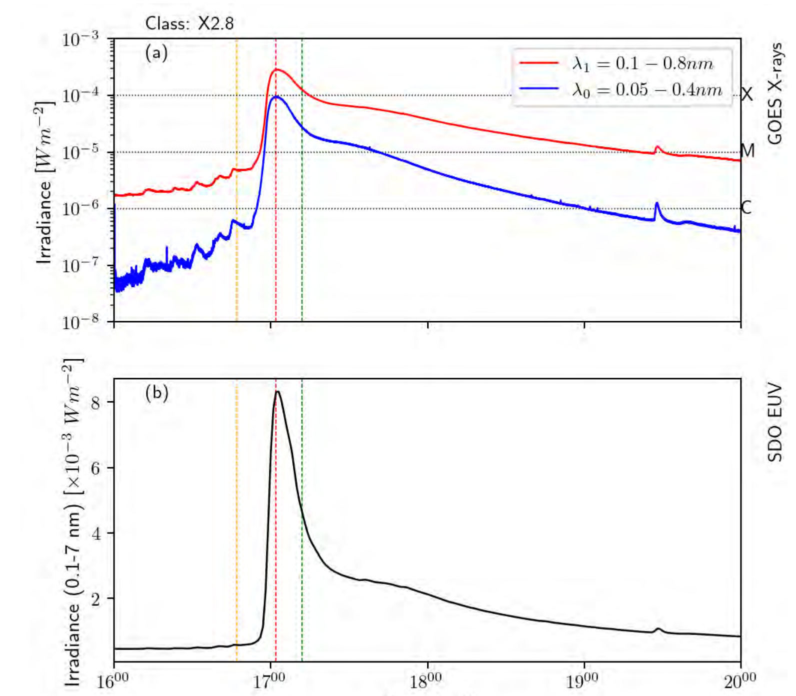




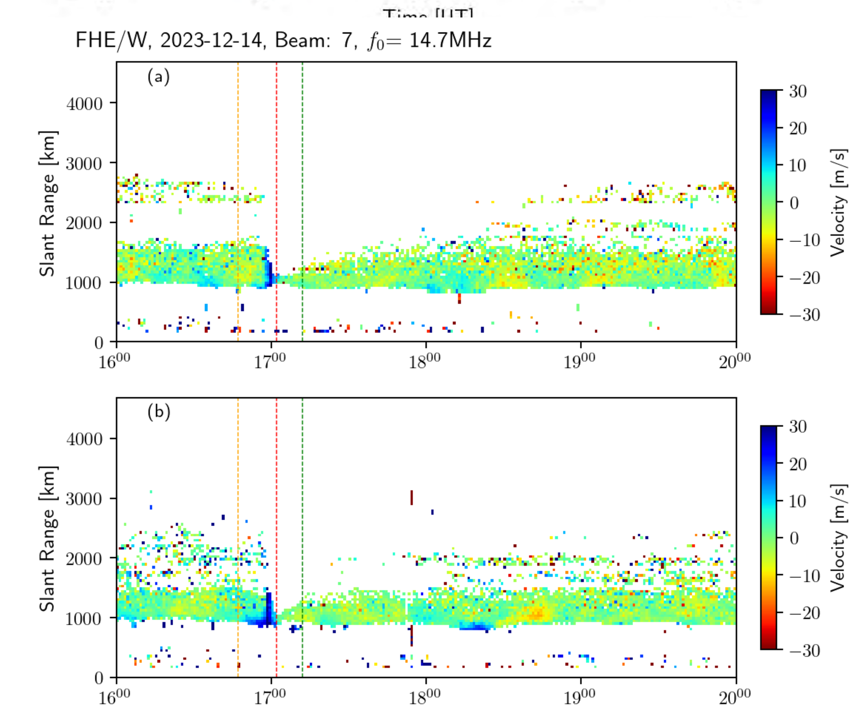
Above: *Map showing fields-of-views (FoVs) of the SuperDARN HF radars, HamSCI PSWS (in green diamond), and WWV station located at Boulder CO (in red diamond), across the North American sector in a geographic coordinate system. Code names of the radars and PSWS are mentioned in blue and green text, respectively. Gray shading indicates the dark ionosphere (nightside) determined at 17:02 UT on 14 December 2023. The red and orange line at -72.2° and -102° longitude indicate the longitudinal locations of the GOES 16 and SDO satellites, respectively.*

Case Study

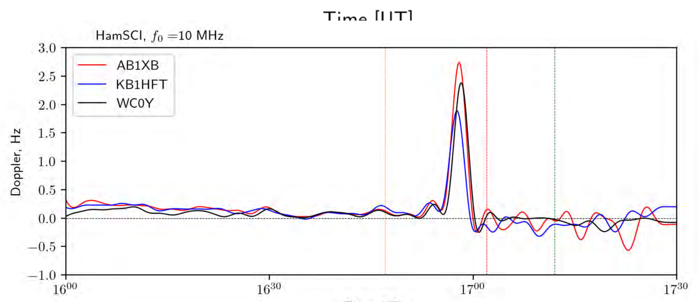
Doppler flash associated with solar flares during Cycle 25 was measurable by SuperDARN and PSWS.



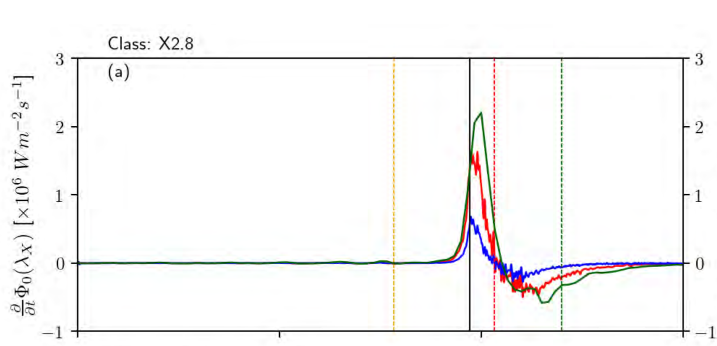
Solar X-rays and EUV (0.1-7 nm waveband) fluxes measured by the (a) GOES 16 X-ray and (b) SDO EVE sensors, on 14 March 2023. Red and blue curves in panel (a) present X-ray flux from 0.1-0.8 nm and 0.05-0.4 nm wavebands. The vertical orange, red, and green lines drawn in both panels present flare start, peak, and end of the X2.8 flare (provided by NOAA). Horizontal black lines indicate thresholds for C, M, and X class flares.



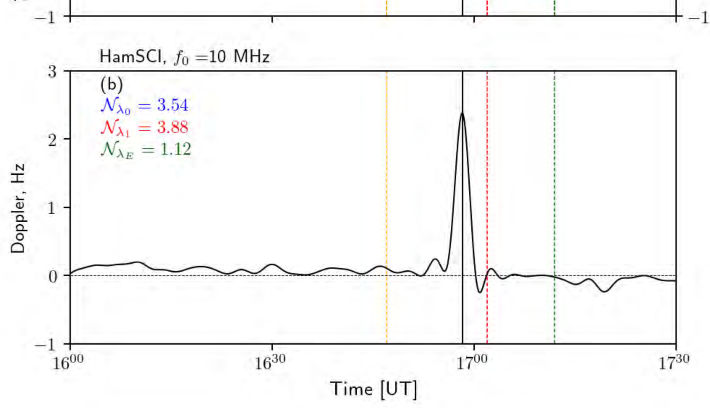
Range-Time Intensity (RTI) plots showing Doppler velocity of the backscatter signal from beam 7 of (a) Fort Hays East (FHE), and (b) Fort Hays West (FHW) SuperDARN radars, respectively, during the X2.8 class flare on 14 December 2023. The vertical orange, red, and green lines drawn in both panels present flare start, peak, and end of the X2.8 flare (provided by NOAA).



Doppler observations from HamSCI PSWS operating at 10 MHz. The callsigns are listed in the figure legend. The vertical orange, red, and green lines drawn in both panels present flare start, peak, and end of the X2.8 flare (provided by NOAA).



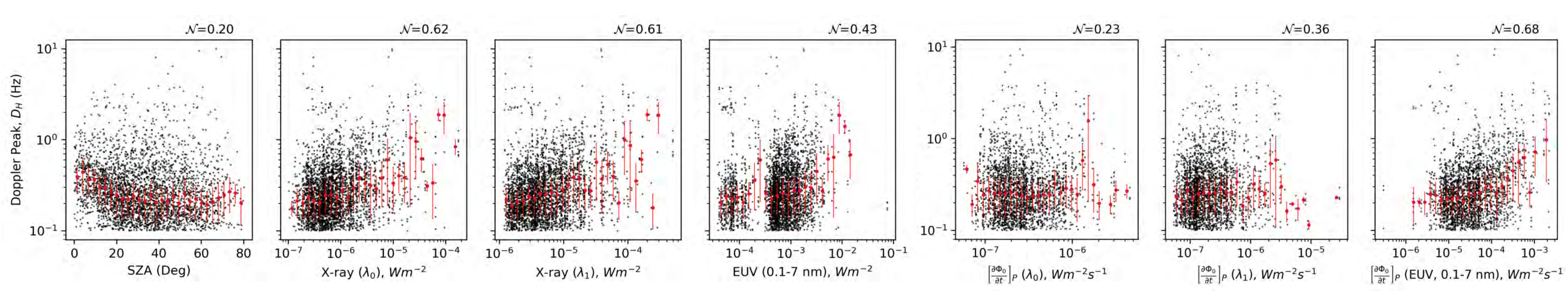
Time series depicting rate of change in incoming solar flux from the two wavebands of GOES 16 X-ray (in red and blue) and SDO EUV (in green) sensors.



Time series showing HamSCI Doppler measurements from WC0Y during the X2.8 class flare event on December 14, 2023. The normalized mutual information (NMI) between three different wavebands and the Doppler measurement is listed (N_λ).

Analysis

- To characterize statistical behavior of DS and DH signatures in SuperDARN and HamSCI PSWS datasets, we choose events from latest solar cycle, start of 2021 to end of 2023.
- We use mutual information-based analysis to show the relative comparison between the degree of dependence between two geophysical drivers of Doppler flash. This analysis suggests that typically Doppler Flash (DH) peaks when flare peaks and rate of change in EUV flux is highest.



MI-based analysis between Doppler Flash (DH) and (a) SZA, (b) peak in GOES X-ray λ_0, (c) peak in GOES X-ray λ_1, (d) peak in SDO EUV (0.1-7 nm) wavebands, and peak in peak of first order time derivative of (f) GOES X-ray λ_0, (g) GOES X-ray λ_1, and (h) SDO EUV (0.1-7 nm) wavebands, respectively. Black dots represent the observed values of each station event. Red dots represent the binned median values and associated the red vertical lines represent the median absolute deviation of DH at that bin. The NMI between the parameters is listed on the top right corner of each panel.

Summary & Conclusion

- Key advantages of Personal Space Weather Station Doppler instruments: density, cadence, dynamic range (bistatic radar rather than monostatic), low cost, amateur engagement
- EUV has stronger correlation than X-ray — consistent with impact in E, F1 layers, rather than D region.
- Derivative of the X-ray and EUVs have even higher correlation — shows rate of change in irradiance is a better proxy of flare-driven SIDs.

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