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

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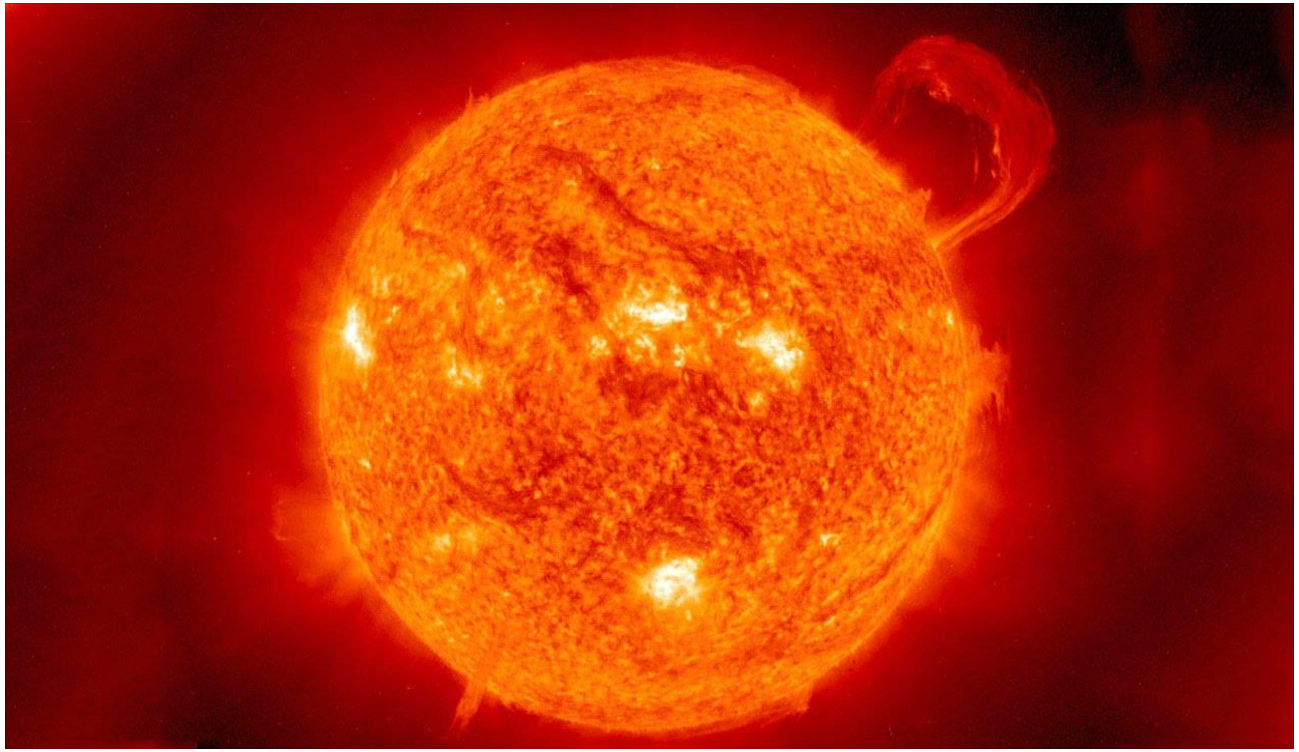
The Sun – the heart of our solar system



Credit: SOHO, NASA

- The Sun emits electromagnetic radiations in X–ray and EUV spectrum.
- Often Sun shoots out the sudden localized intensification of EM radiation, commonly known as *solar flare*.
- In this study we are going to focus on the *solar flare* impact on the Earth’s ionosphere.

Outline

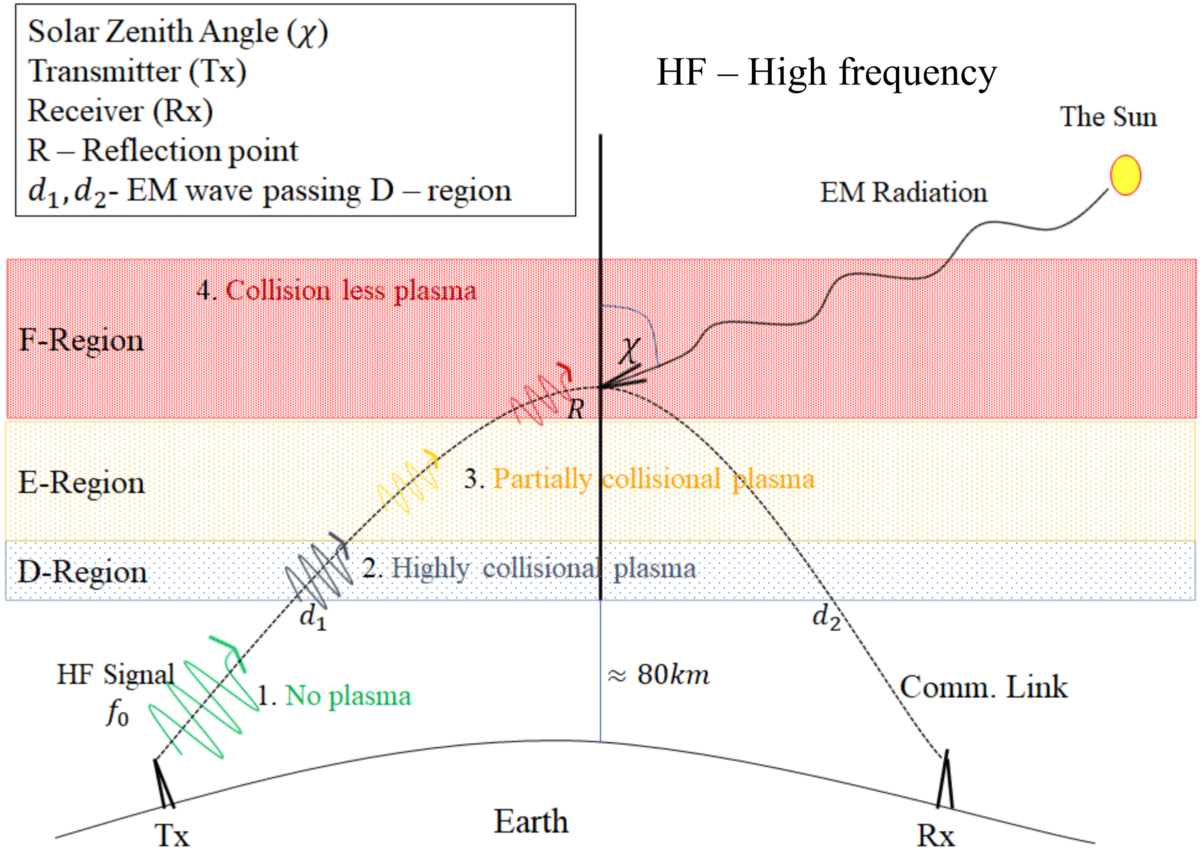
1. **Introduction**
   - ➢ The Sun and Ionosphere
   - ➢ Impact of Solar Flares in the traveling Radio Wave
   - ➢ Instrument: SuperDARN

2. **Solar Flare Effects on SuperDARN Observations**
   - ➢ Event Study: 5th May 2015
   - ➢ Timing Analysis and Phase Identification

3. **Using SuperDARN as a Solar Flare Monitor**

4. **Summary**

Earth's Atmosphere – Ionosphere



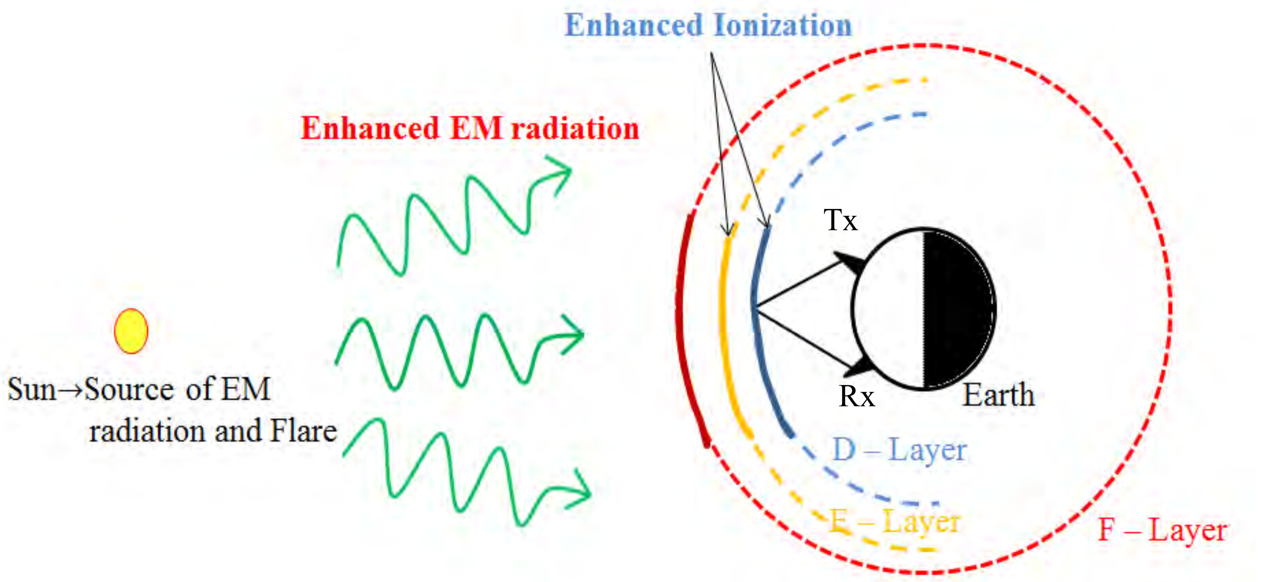
- <u>Ionosphere</u>: Ionized part of the upper atmosphere, are consists of different layers (D, E, and F).
- Ionosphere plays an important role in radio wave propagation, that is directly related to ***Amateur Radio***.
- Ionosphere is highly variable and is dependent on solar activities [*Knipp et al., 2016; Frissell et al., 2014*].
- *In this study we primarily focus on impact of <u>solar flares</u> in the ionosphere.*

Effects of Flare: SID, SWF, and SFD

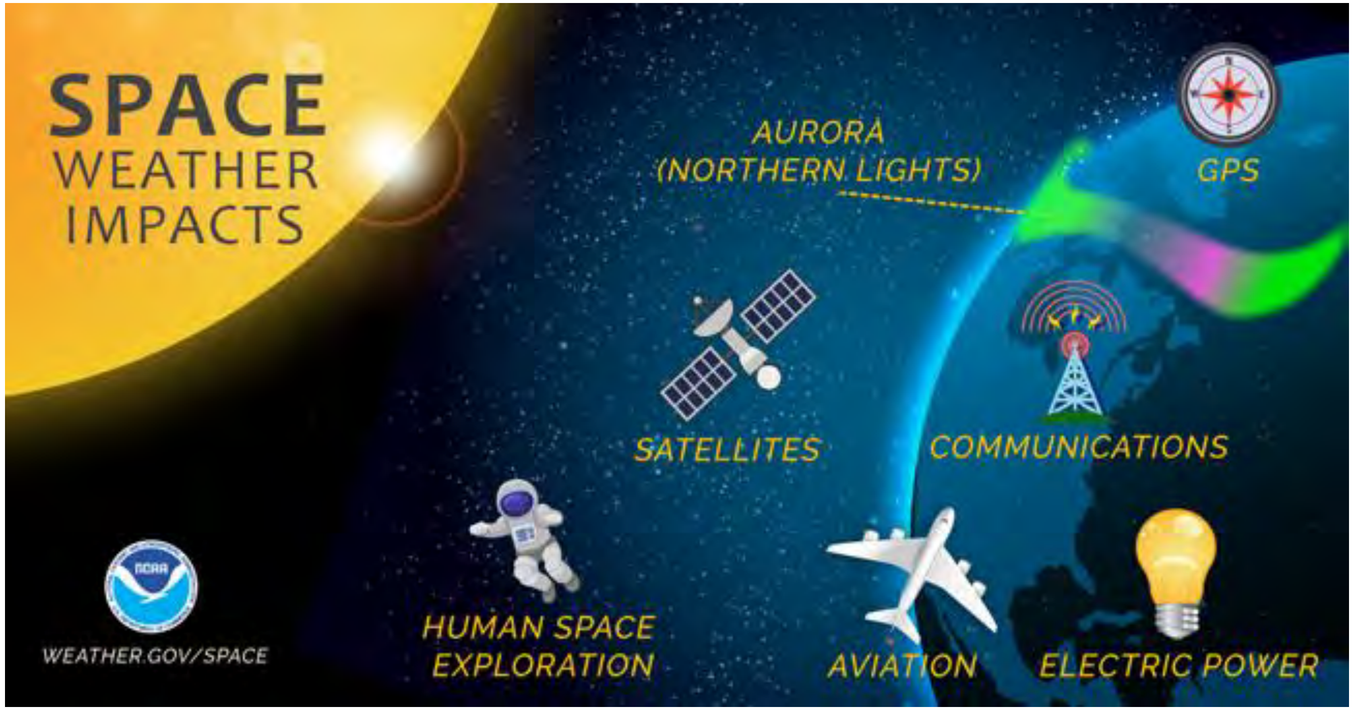
- <u>Sudden Ionospheric Disturbance (SID)</u>: sudden enhancement of *plasma density* in the *dayside* D and lower E-regions of the ionosphere (*Davies, 1990*).

- <u>Shortwave Fadeout (SWF)</u>: sudden increase in *radio-wave absorption* in high frequency (HF) ranges (3-30 MHz) (*Davies, 1990*).

- <u>Sudden Frequency Deviation (SFD)</u>: sudden change in *radio-wave frequency* that alters the phase path length of the traveling wave (*Davies, 1990*).



Why do We Study Solar Flare Effects?



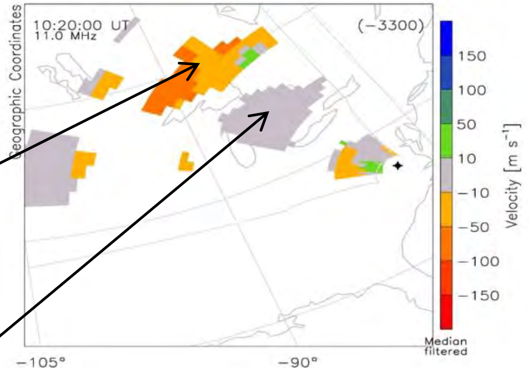
- <u>Space Weather</u>: Mitigate the impact of SWF and SFD on ***amateur radio***, HF communication, used in aviation, emergency management, defense, etc [*Frissell et al., 2019; Redmon et al., 2018*].

- <u>Space Science</u>: Improve our understanding of fundamental ionospheric processes, such as:
  1. HF absorption – SWF
  2. Frequency Anomaly – SFD

- Solar Flare induced SIDs and its impacts on traveling radio waves are the fastest Space Weather phenomena seen on Earth, as solar flare takes only ~8 min to reach Earth.

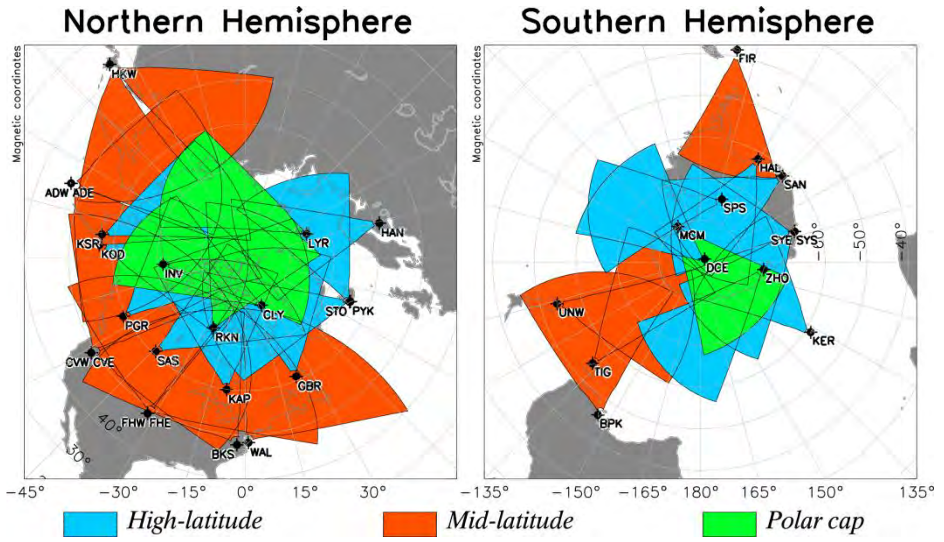
Instruments: SuperDARN HF Radar

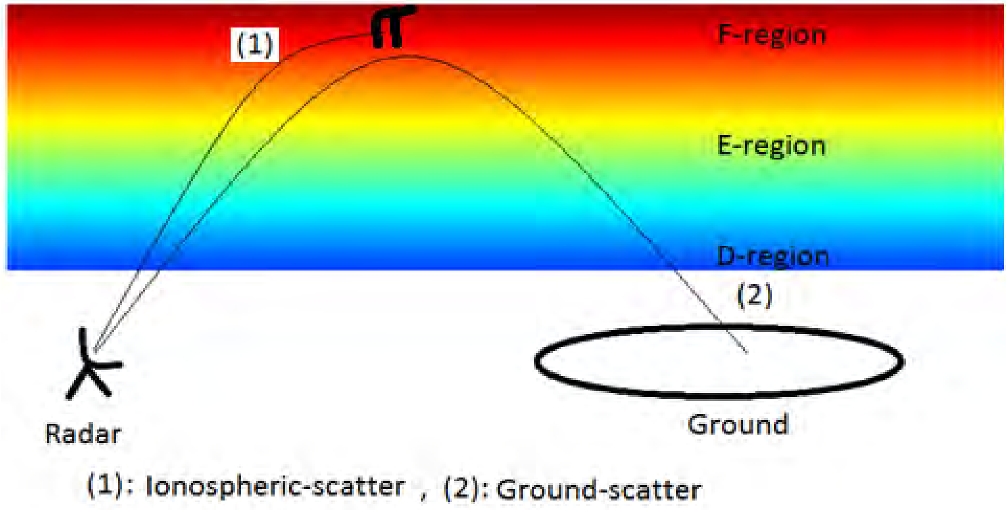
- SuperDARN: An international HF radar network that probes the Earth's upper atmosphere and ionosphere.
- HF propagation depends on refraction due to ionospheric electron density gradients.
- There are two primary backscatter targets:
  1. Ionospheric scatter: Backscatter from ionospheric irregularity structures.
  2. Ground Scatter: Backscatter from the Earth's surface.



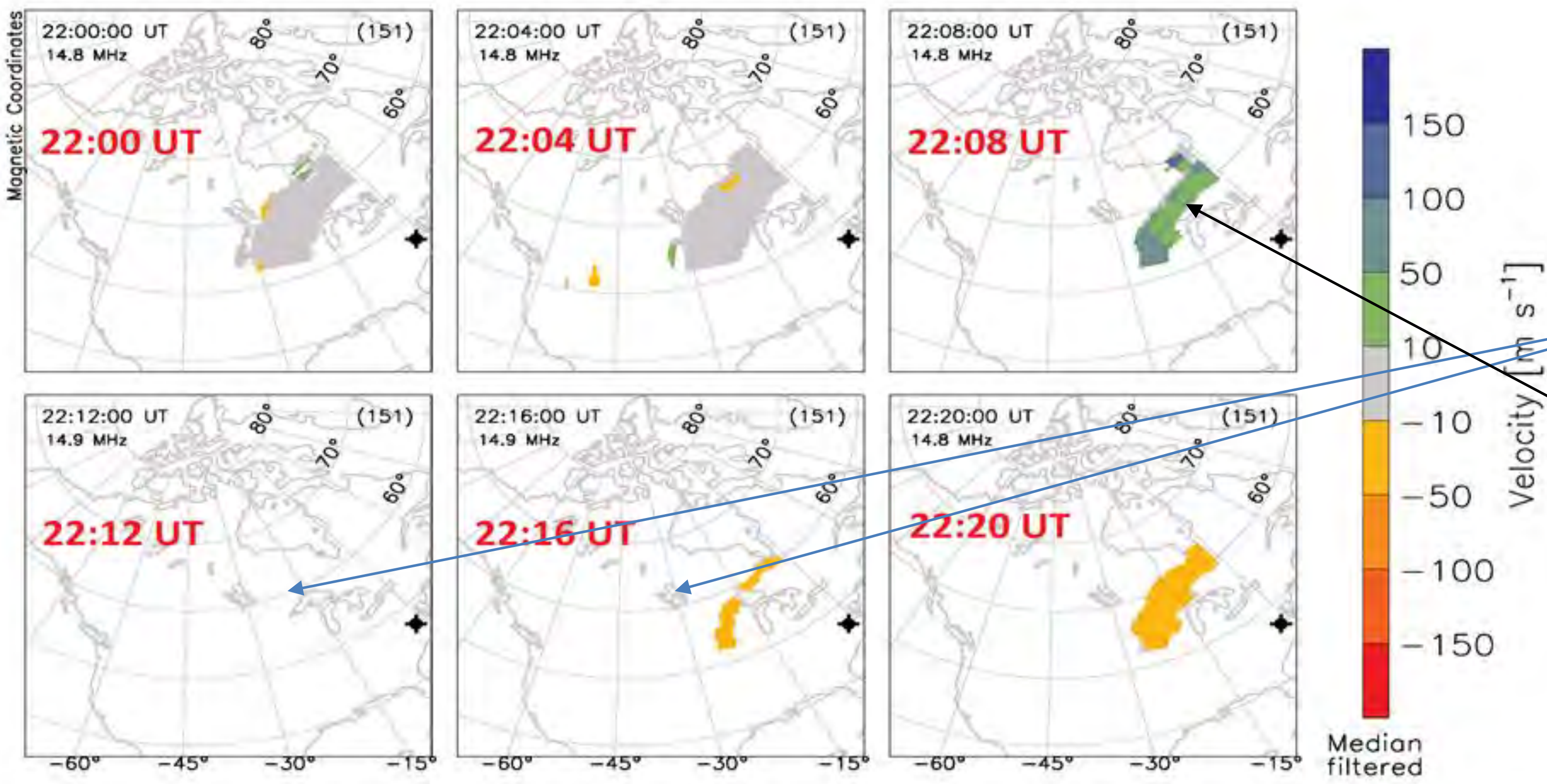
Radar Scan

- Ground scatter replicates a ground-to-ground communication link just like an ***amateur radio*** link does.
- Here, ground scatter data is used to study the ionospheric response to solar flares.





Flare impact on Radar (Event Study: 5th May 2015)

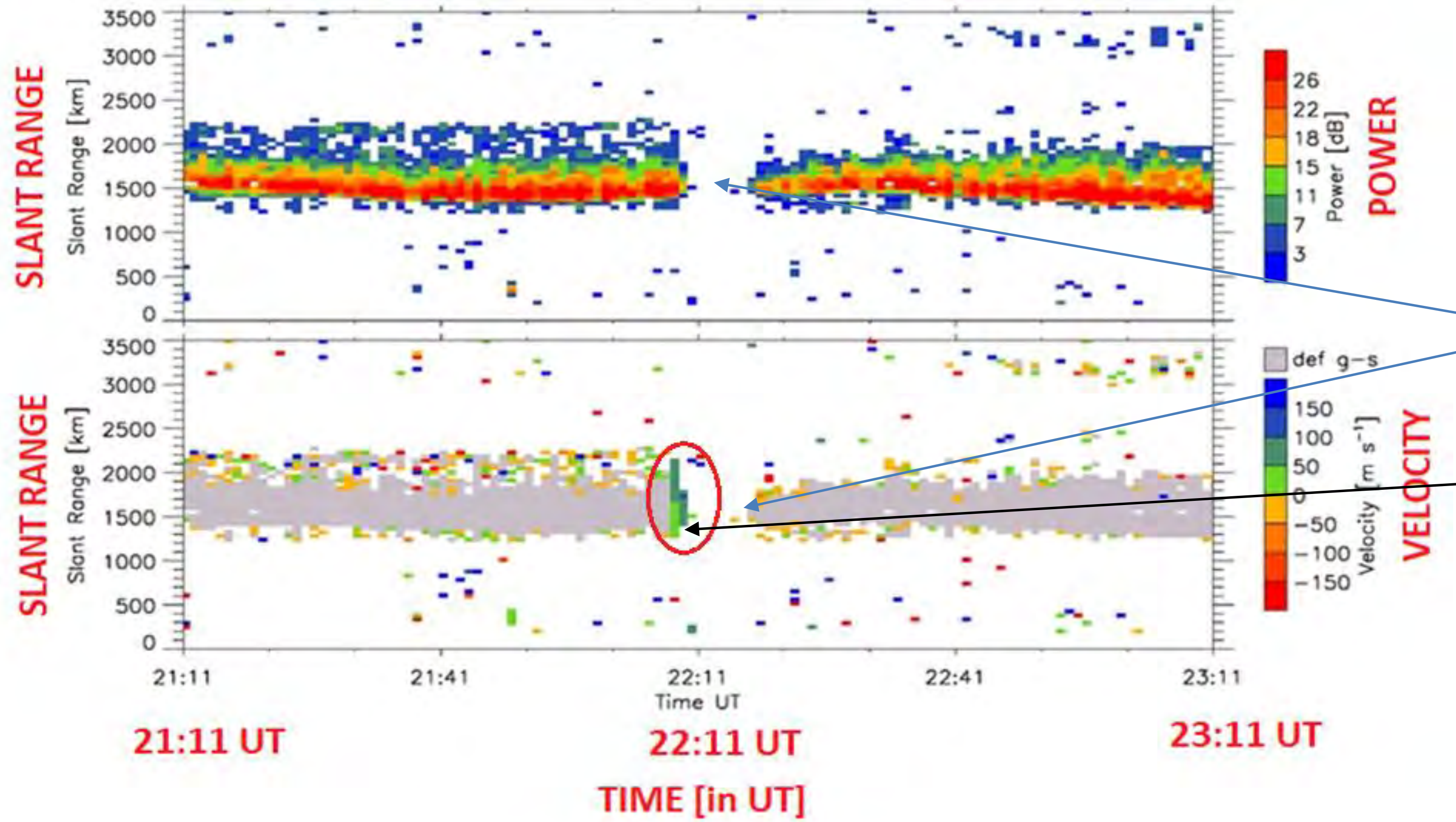


Radar station – Blackstone

Sudden Ionospheric Disturbances: SIDs

1. Absorption Effect – SWF
2. Sudden Frequency Deviation – SFD
   Doppler Flash

Flare impact on Radar (Event Study: 5th May 2015)



Radar station – Blackstone

Sudden Ionospheric Disturbances: SIDs

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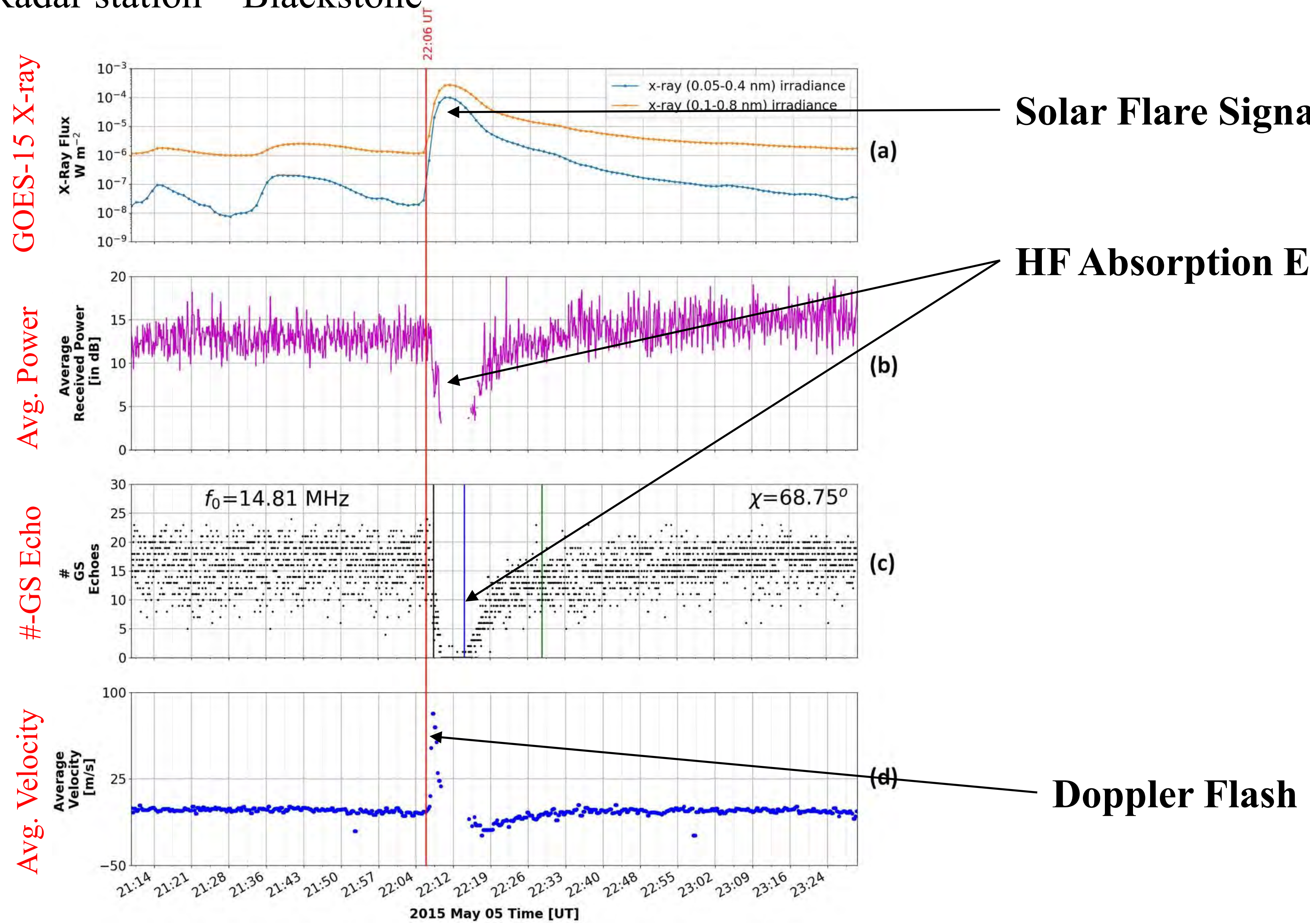
Timing Analysis

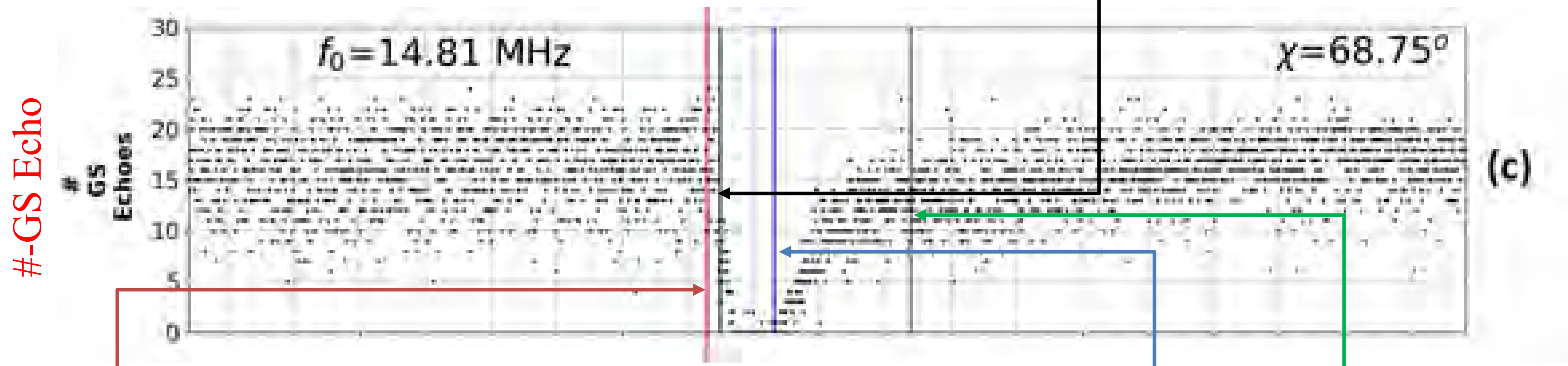
Radar station – Blackstone



Timing Analysis

Radar station – Blackstone

Radio Blackout Start - Start of the HF absorption



Recovery Onset - Start of recovery

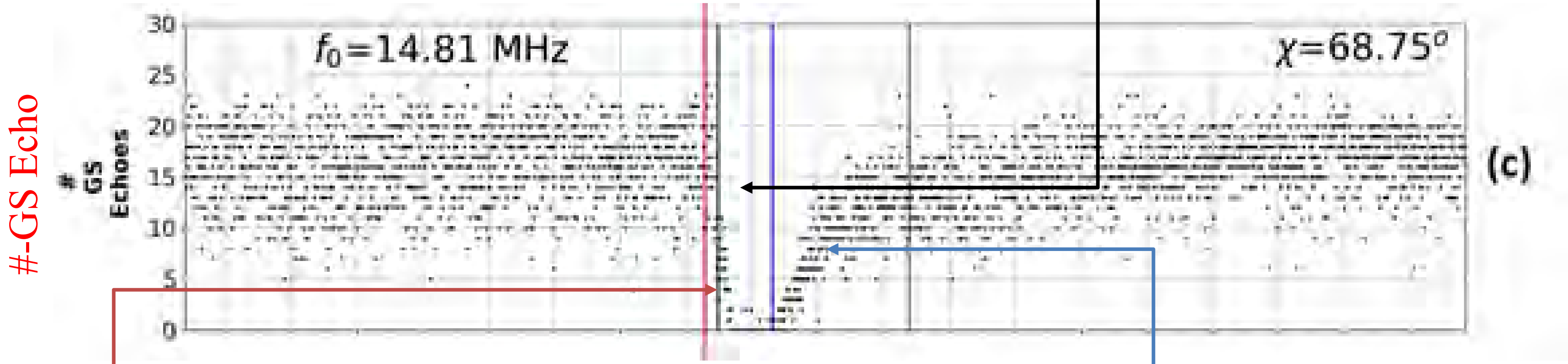
Onset - Onset of the HF absorption

Recovery - GS recovered

Timing Analysis: Phases

Radar station – Blackstone

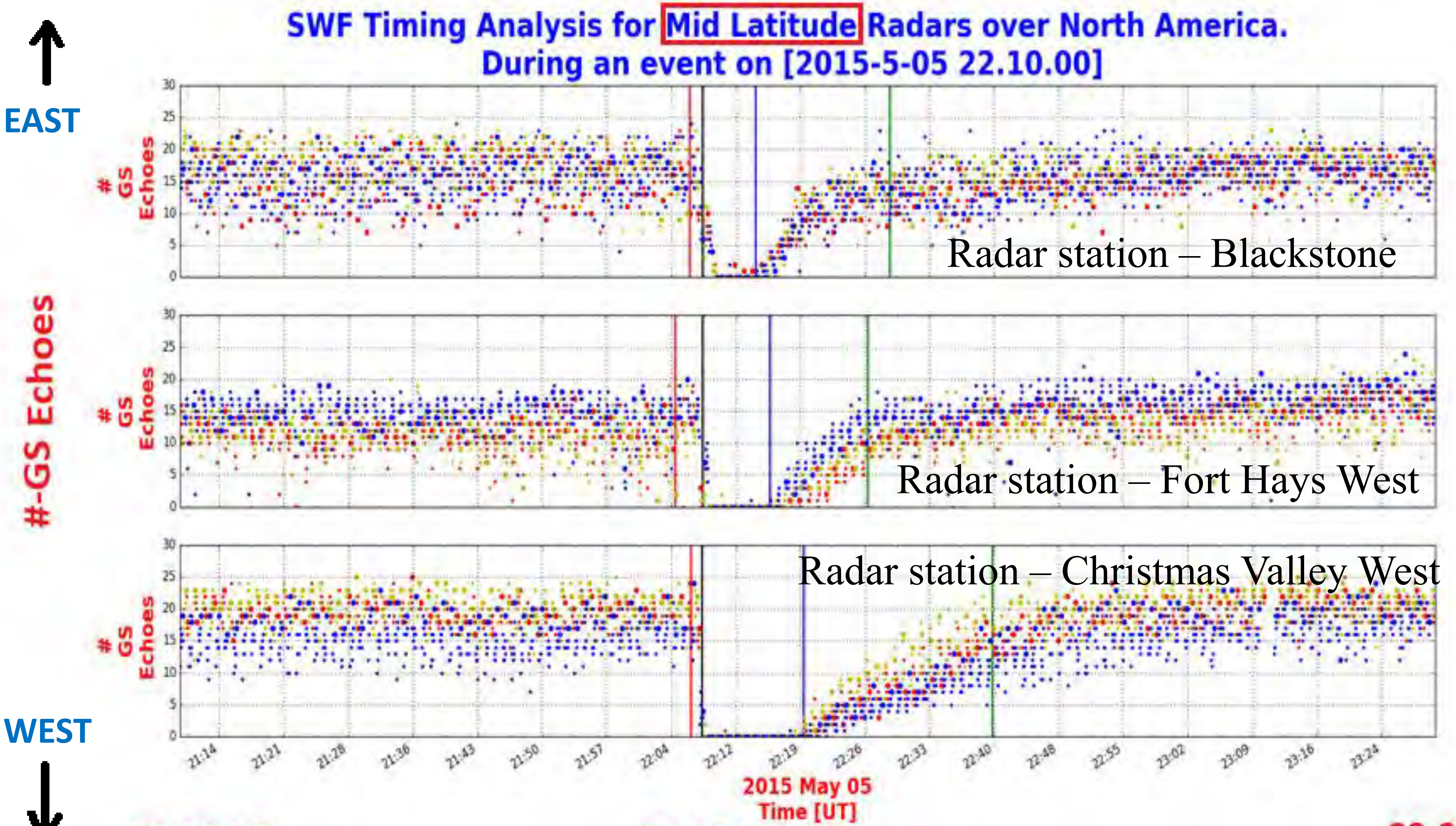
Radio Blackout – Peak of signal loss



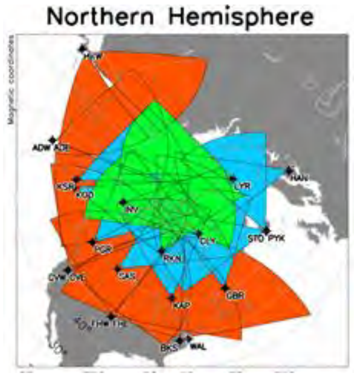
Gradual Recovery – Signal strength restore back to preflare condition

Onset – Precursor of absorption

Timing Analysis: Solar Zenith Angle (SZA)

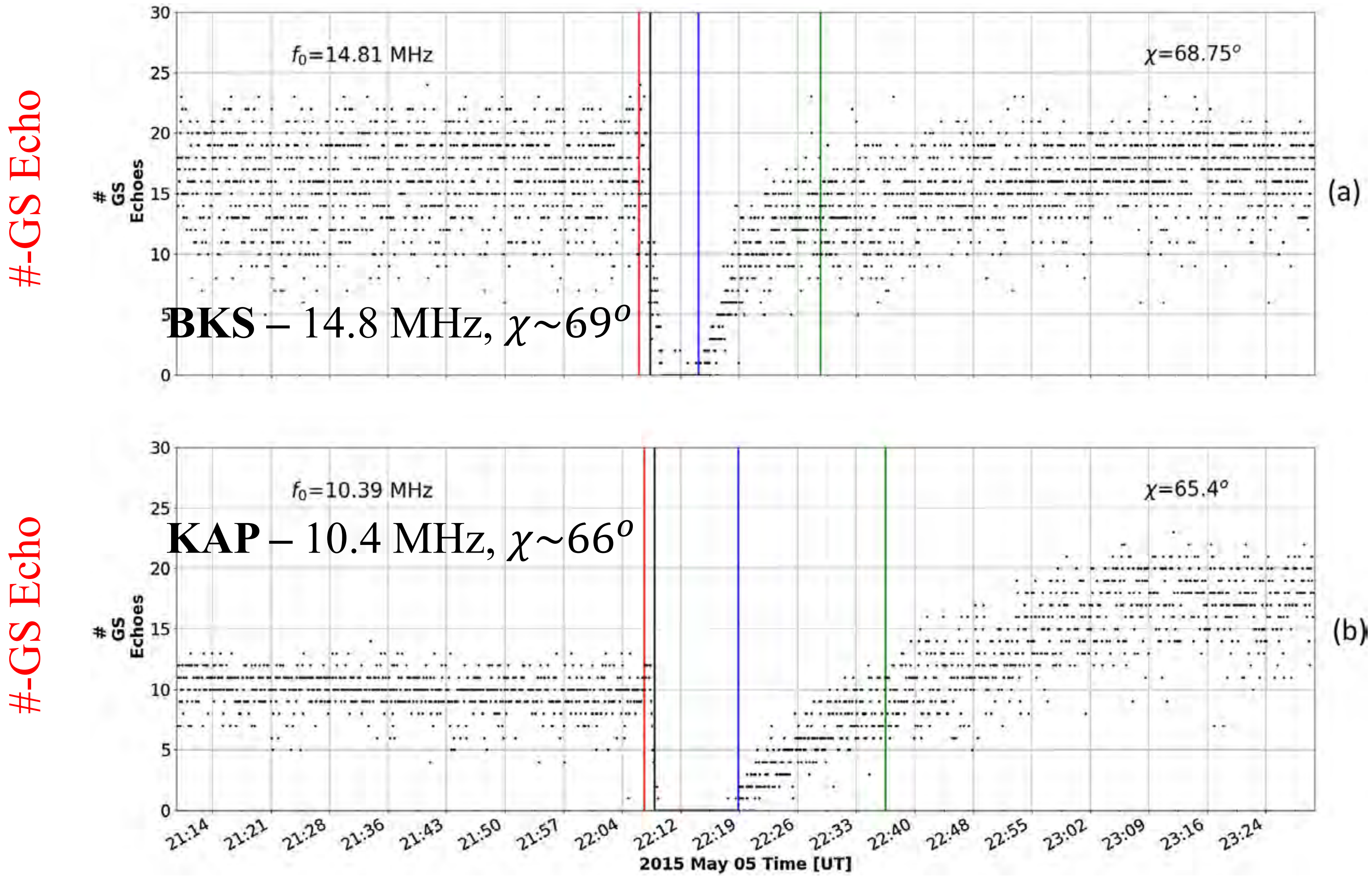


21:10 UT 22:10 UT 23:30 UT



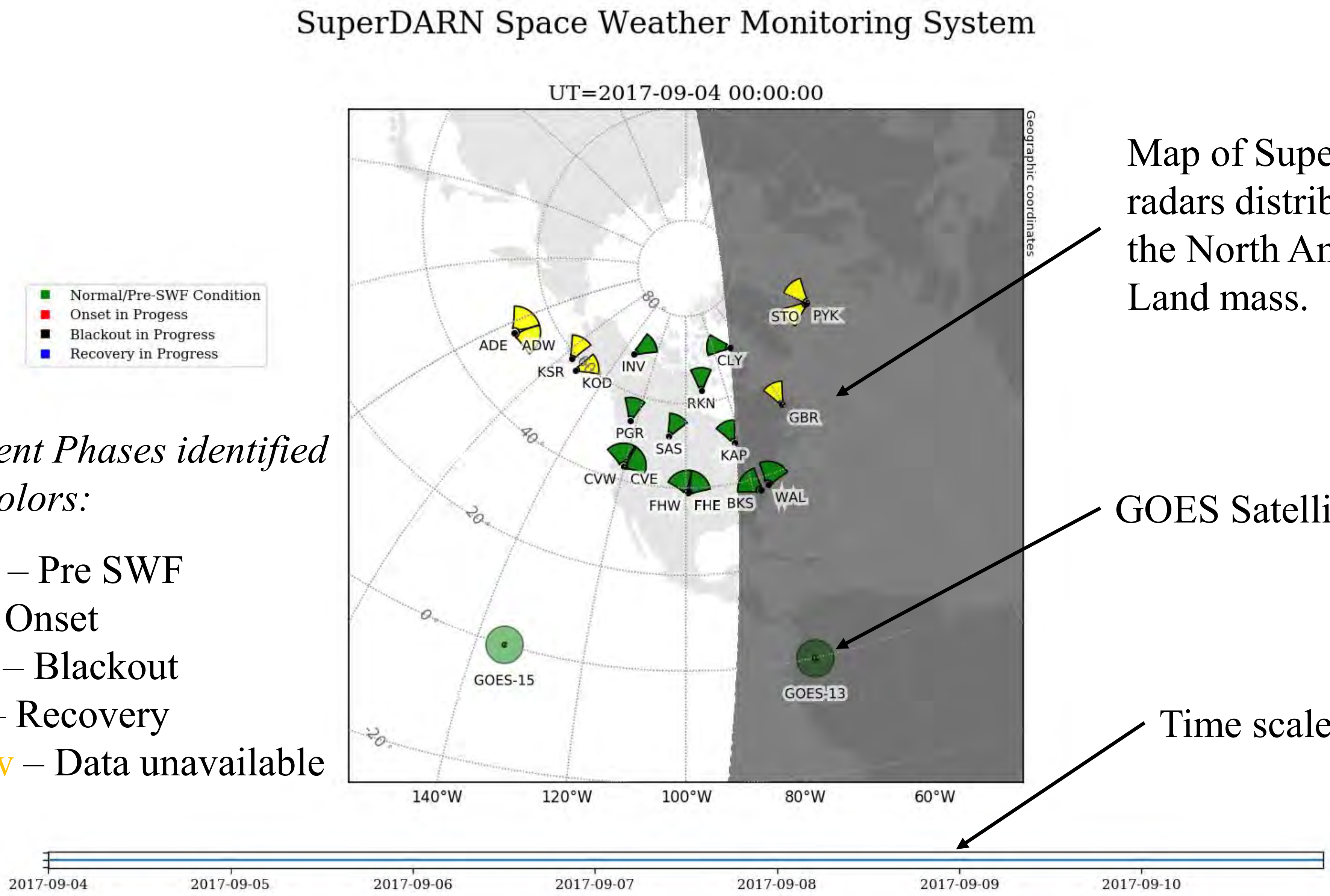
- Backscatter signals of the radars located near to subsolar point are affected more severely than radars located at larger solar zenith angles.

Timing Analysis: Signal Frequency



- Backscatter signals of the radars operating at relatively lower frequencies are affected more severely than radars operating at higher frequencies.

SuperDARN HF Radars distributed across North American Land Mass



Map of SuperDARN radars distributed across the North American Land mass.

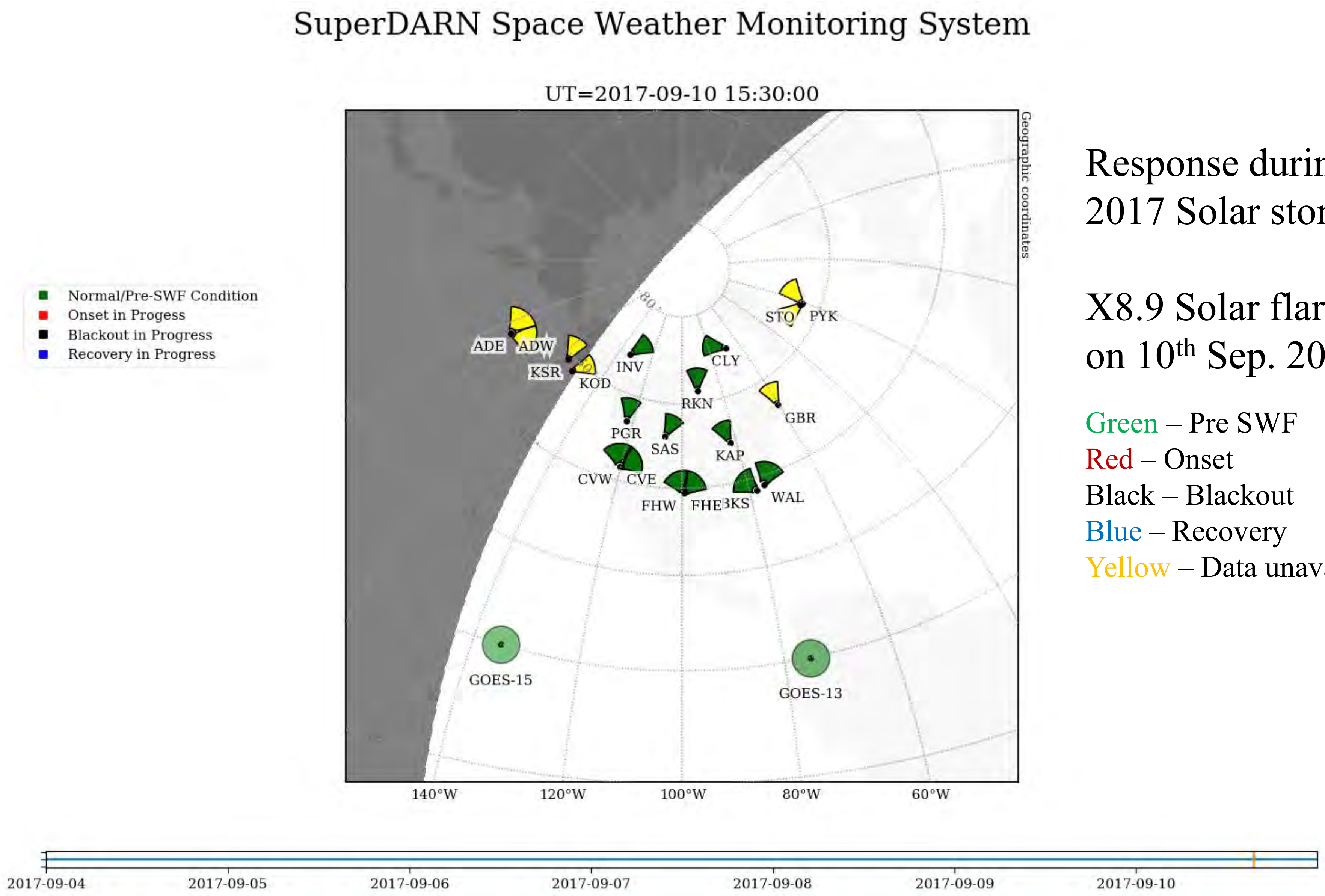
GOES Satellites

Time scale

Different Phases identified by 4 colors:

Green – Pre SWF
Red – Onset
Black – Blackout
Blue – Recovery
Yellow – Data unavailable

SuperDARN HF Radars distributed across North American Land Mass



Response during September 2017 Solar storm.

X8.9 Solar flare at ~15:30 UT on 10th Sep. 2017

Green – Pre SWF
Red – Onset
Black – Blackout
Blue – Recovery
Yellow – Data unavailable

Summary

- Daytime SuperDARN ground-scatter replicates ground-to-ground communication link (just like the ***amateur radio***) which is susceptible to solar flares.

- Clearly, we can see a progression of different phase timings along longitude and Solar Zenith Angle.
  - Impacts are mitigated as we move away from the solar noon position. It can also be interpreted as local time effect.

- Timings are also constrained by the transmitted frequency of the radar. Radars with low operating frequency affected much more by the event.

- **A subnetwork of SuperDARN HF Radars can be used to monitor solar flare driven HF absorption across North American Sector.**

Thank you!

Questions?

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Supplementary Materials of this Presentation

- **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

- 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