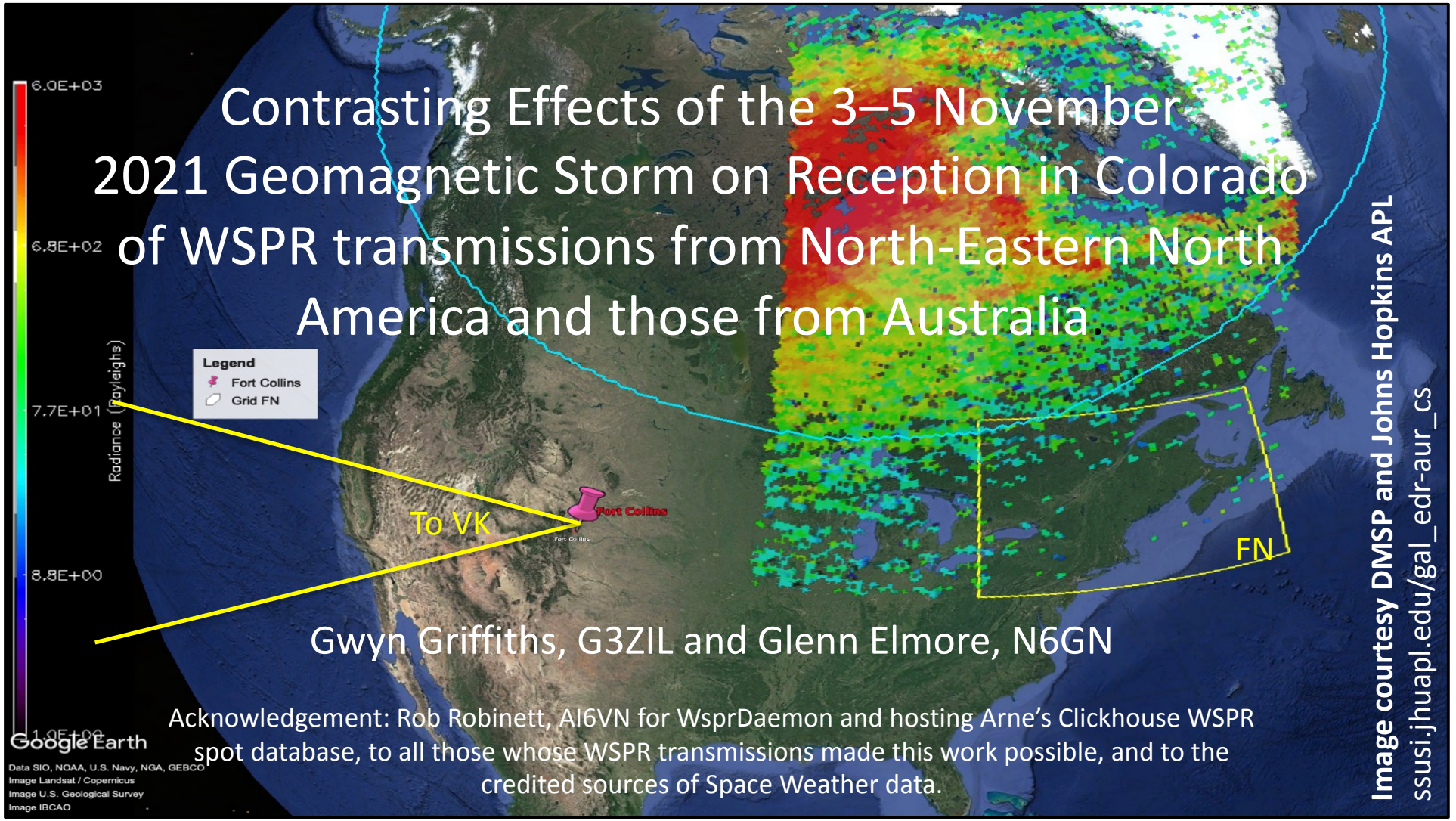


Contrasting Effects of the 3–5 November 2021 Geomagnetic Storm on Reception in Colorado of WSPR transmissions from North-Eastern North America and those from Australia.

Gwyn Griffiths, G3ZIL and Glenn Elmore, N6GN

Acknowledgement: Rob Robinett, AI6VN for WsprDaemon and hosting Arne's Clickhouse WSPR spot database, to all those whose WSPR transmissions made this work possible, and to the credited sources of Space Weather data.

N6GN/K, quiet remote site, 7500’ ASL ~13 miles NW of Fort Collins.

Kiwi SDRs with microwave data link to Glenn at Fort Collins.

Spot reporting and noise level estimation using WsprDaemon.

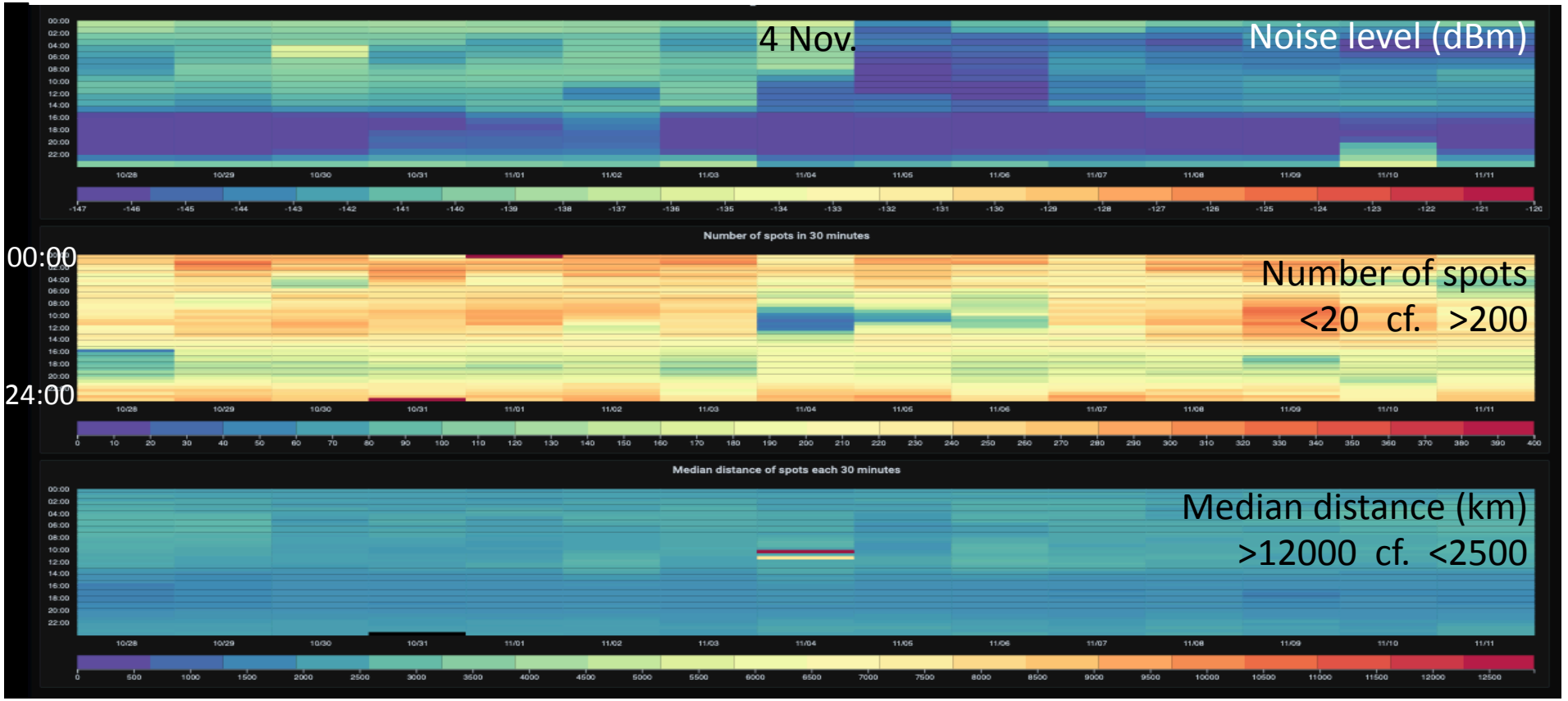
Synopsis

- Unusual collapse of WSPR spot count and increase in median distance on 7 MHz on 4 Nov. 2021 at N6GN/K, Colorado.
- Was there a Space Weather connection? We’ll look at:
  - WSPR spots data
  - Spaceweather.com narrative
  - D region excess absorption
  - Geomagnetic disturbance: Kp, Boulder Magnetometer, Auroral Electrojet
  - Auroral Glow
  - Ionosondes: Ionograms and Drift Analysis

Unusual pattern: WSPR Spots on 7 MHz at N6GN/K, Colorado

Noise level, # spots & median distance in 30 min intervals (rows)

28 October – 11 November 2021 (Column for each day)



Narrative: Geomagnetic Storm of 3-5 November 2021

Daily summary abstracted from spaceweather.com and spaceweatherlive.com

2 November: M1.7 SOLAR FLARE peaking at 03:01 UTC. X-ray flux remained above M 1.0 for an hour. Preceding flares were of M1.5 at 01:45 UTC 1 November and M1.6 on 2 November at 02:51 UTC.

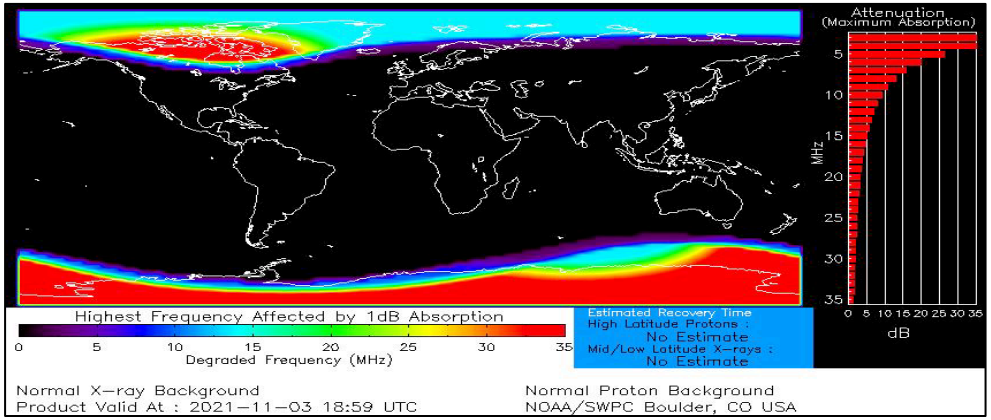
3 November: CME IMPACT SPARKS GEOMAGNETIC STORM: A cannibal Coronal Mass Ejection (CME) hit Earth's magnetic field on Nov. 3rd at about 19:30 UTC. Solar wind data from DSCOVR spacecraft shows stair-step structure - two or more CMEs pressed together. A moderately strong **G2** storm is underway; could escalate to **G3** in coming hours.

4 November: THE STORM IS SUBSIDING: Earth's magnetic field is reverberating from yesterday's CME impact, but the storm is subsiding. The planetary K-index has dropped to 4, technically below the threshold of geomagnetic storms.

5 November: THE STORM IS OVER: Earth's magnetic field is calming as our planet exits the wake of the Cannibal CME. Almost 20 hours of strong geomagnetic storms followed the CME's impact. During the apex of the G3 event, auroras were sighted as far south as **California**, **New Mexico** and **Colorado**.

D Region Excess Absorption

3 Nov. 19:00 – 23:59 UTC



3 November

As the CME hits the Earth's magnetic field

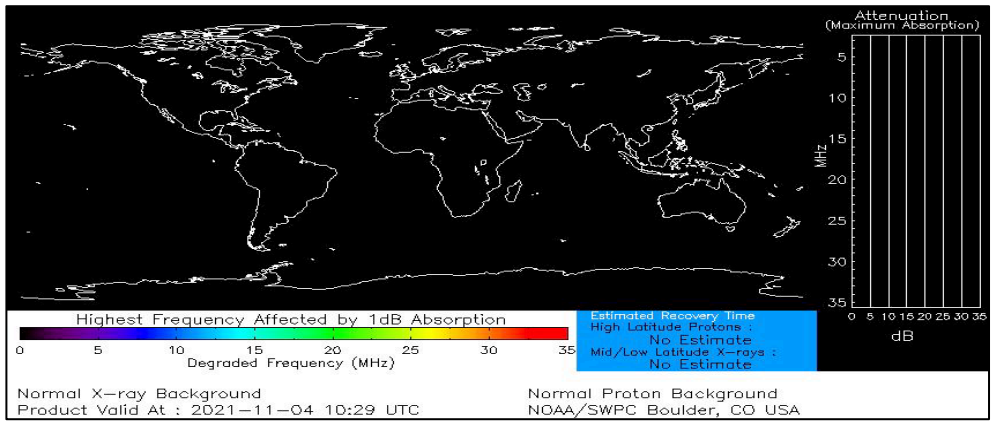
Images courtesy US National Geoscience Data Center, NOAA at https://www.ngdc.noaa.gov/stp/drap/data/2021/11/

AVI animation created using FIJI

4 Nov 10:30–12:00 UTC

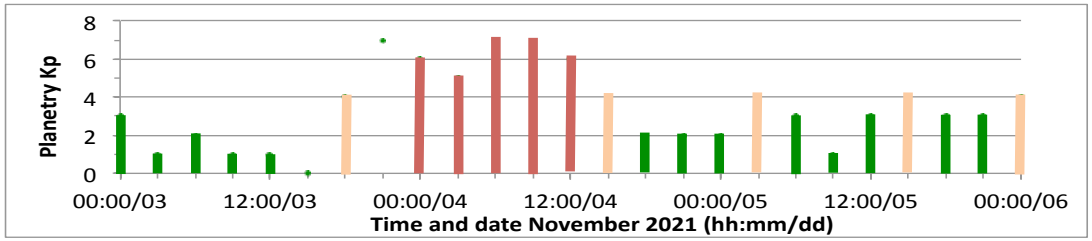
4 November

During the time of the 95% drop in 7 MHz WSPR spots at N6GN/K



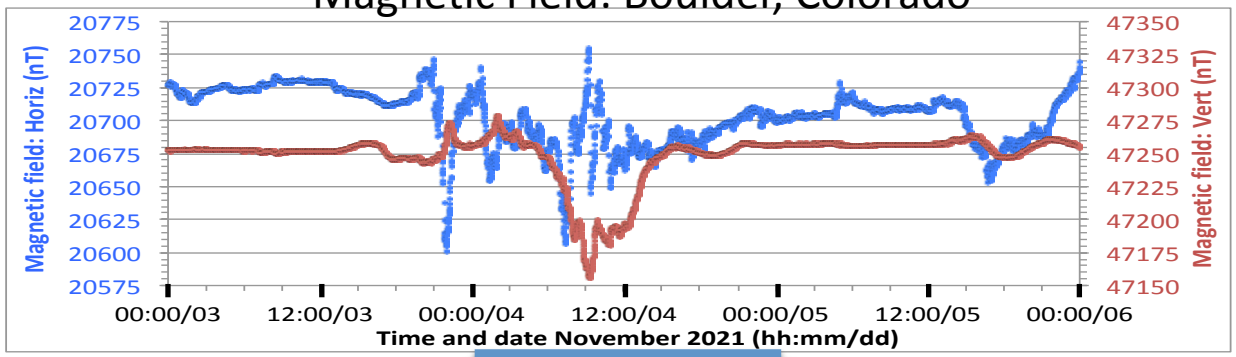
Geomagnetic Disturbance: 3 – 6 November 2021

Planetary Geomagnetic Disturbance Index Kp



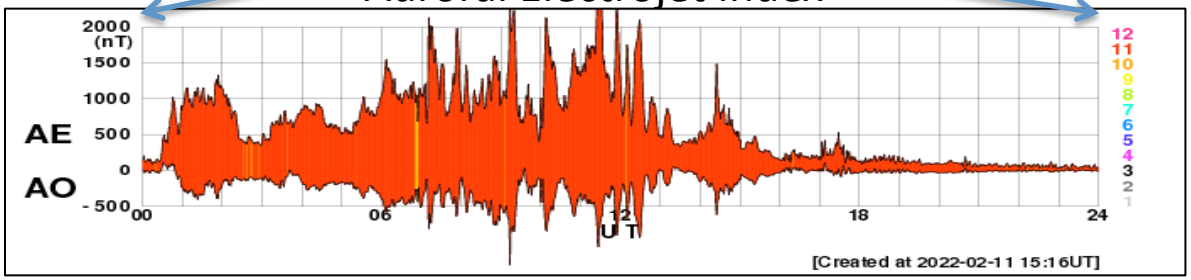
Data courtesy NOAA SWPC

Magnetic Field: Boulder, Colorado



Data courtesy USGS and Intermagnet

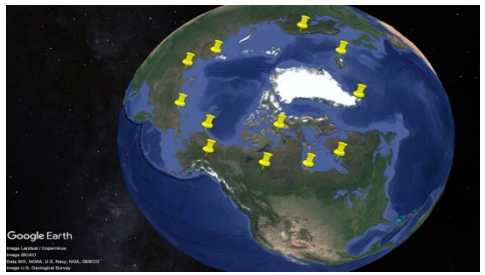
Auroral Electrojet Index



Auroral Electrojet Index

AE index of overall activity.

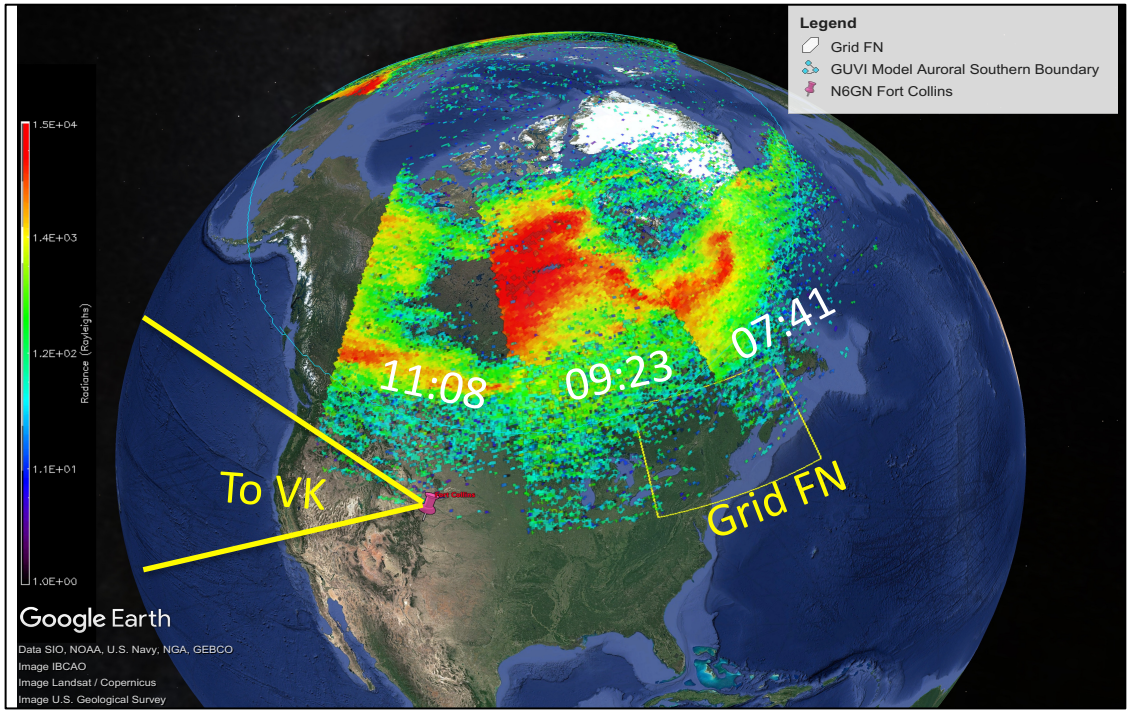
AO a measure of equivalent zonal current



Data courtesy World Data Centre for Geomagnetism at Kyoto University.

'Real-time' data, no QC, via wdc.kugi.kyoto-u.ac.jp/ae_realtime

Auroral Glow 0741–1108 UTC 4 November 2021



Orbit times from celestrak.com

N Greenland -> Newfoundland

62131 07:43–07:45 UTC

N Greenland -> Nova Scotia

62132 09:18–09:28 UTC

NW Greenland -> Great Lakes

62133 11:02–11:11

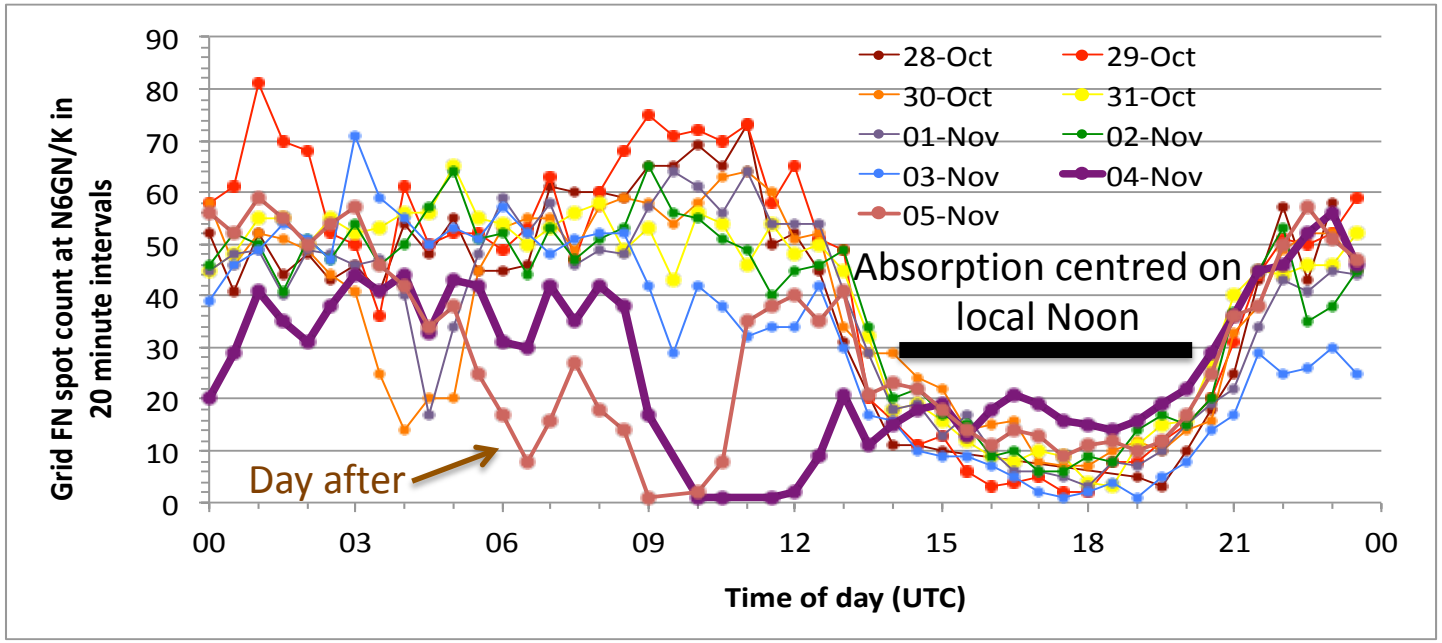
Auroral glow changes substantially over the 101 minutes between orbit passes.

Composite of Lyman-Birge-Hopfield short ultraviolet (140 nm – 160 nm) and atomic oxygen (135.6 nm) Auroral Glow Emission from the Special Sensor Ultraviolet Spectrometer on US Defense Meteorological Satellite Program satellite F18 (Norad 35951) on Orbits 62131–3, 4 November 2021.

Data from selector at ssusi.jhuapl.edu/gal_edr-aur_cs

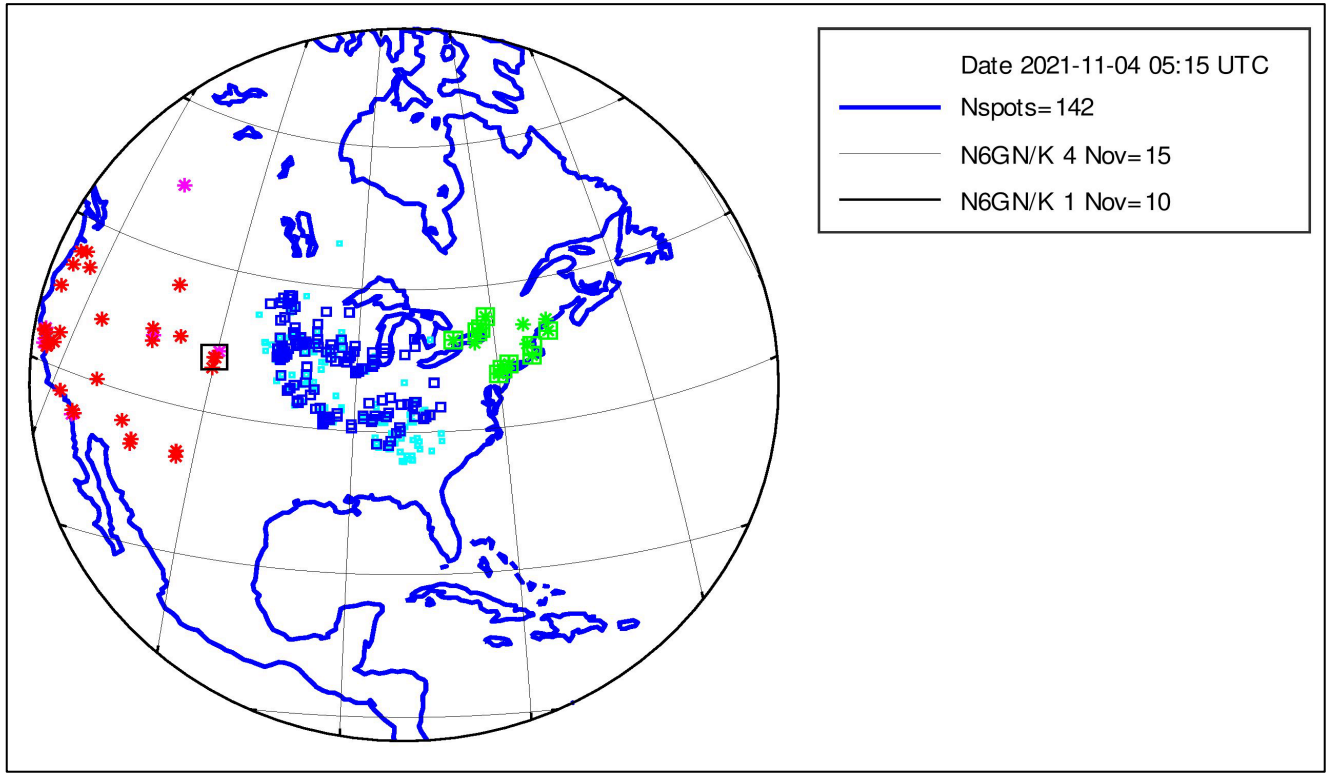
7 MHz N.E. North America (Grid FN) to N6GN/K

WSPR spot counts in 20 minute intervals 28 Oct – 5 Nov '21



- Quantitative daily time series shows (main points):
  - Underlying daily pattern, with variability, on 'undisturbed' days 28 Oct-3 Nov
  - Dramatic reduction from 08:40 UTC on 4 Nov.
  - Disturbed conditions persist for some 24 hours.

A Wider WSPR View: Grid FN to Western N. America



Key

Green Square: Tx

Star, heard 4 Nov by N6GN/K

Magneta: Rx 1 Nov

Red: Rx on 4 Nov

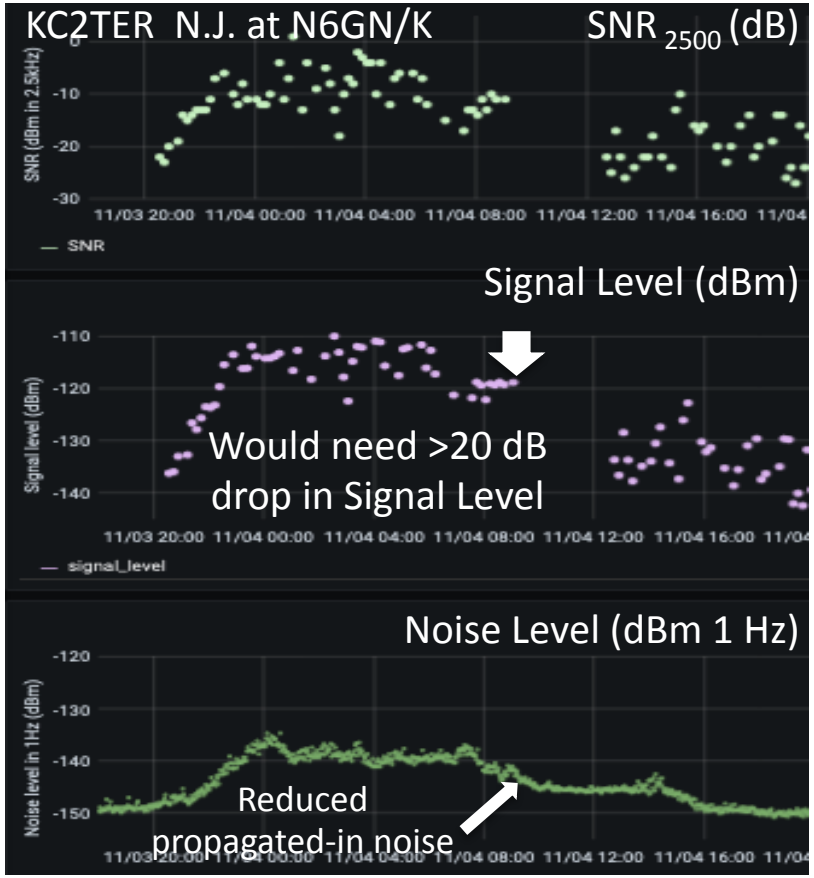
Cyan: Mid-points 1 Nov

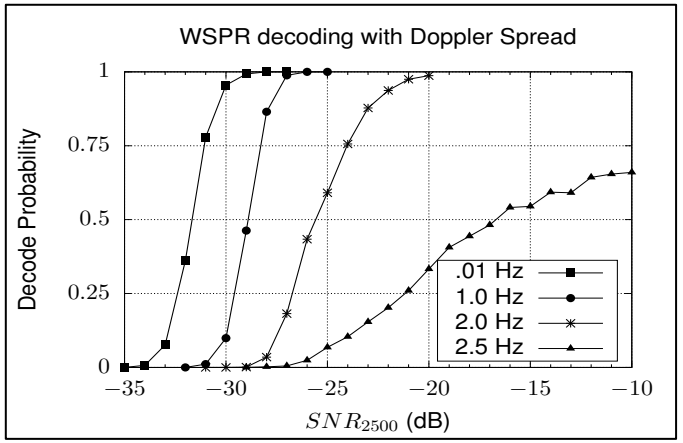
Blue: Mid-points 4 Nov

Each frame has data over 10 minutes. Box gives time in UTC, spots in each interval, and numbers received at N6GN/K on 1 and 4 November 2021. This is on 7 MHz.

Data from WsprDaemon WSPR spots database using Octave and m_map. Animation using FIJI.

Reduced SNR or Doppler Spread or Both?



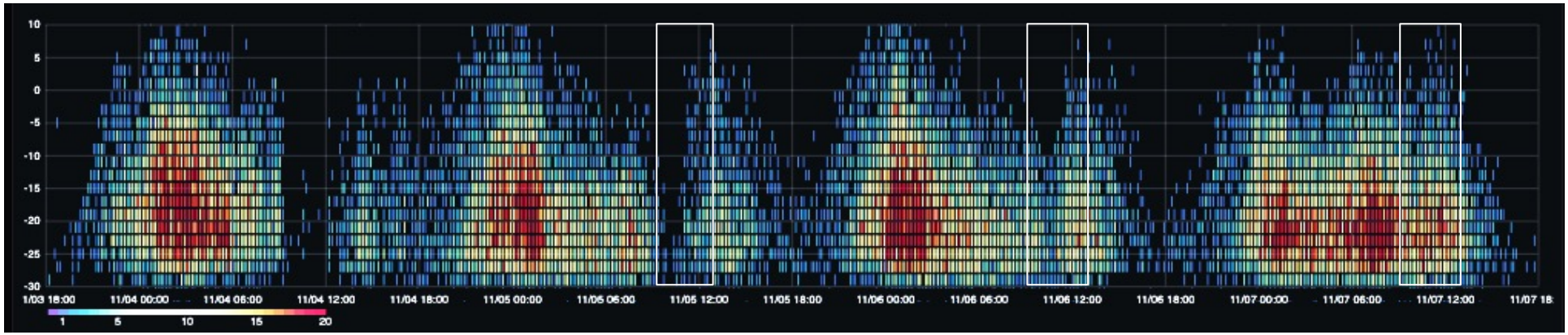


- ❑ Assumes transmit callsign seen before.
- ❑ Assumes no delay and Gaussian spreading.
- ❑ Outcomes:
  - ‘Graceful degradation’ of decode probability out to Doppler spread of 2 Hz.
  - 50% probability decode at -17 dB SNR at 2.5 Hz
  - No 50% probability of decode at <u>any</u> SNR at 3 Hz.

Doppler graph and modelling courtesy Steve Franke, K9AN. Based on, “Testing of HF Modems … Using Ionospheric Channel Simulators”, Recommendation ITU-R F.1487, ITU, 2000.

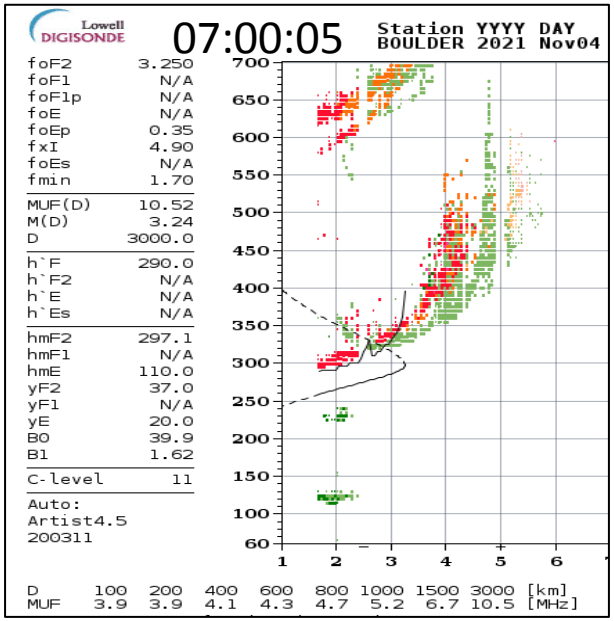
A Wider View: SNR Heatmap Grid FN to Western N. America

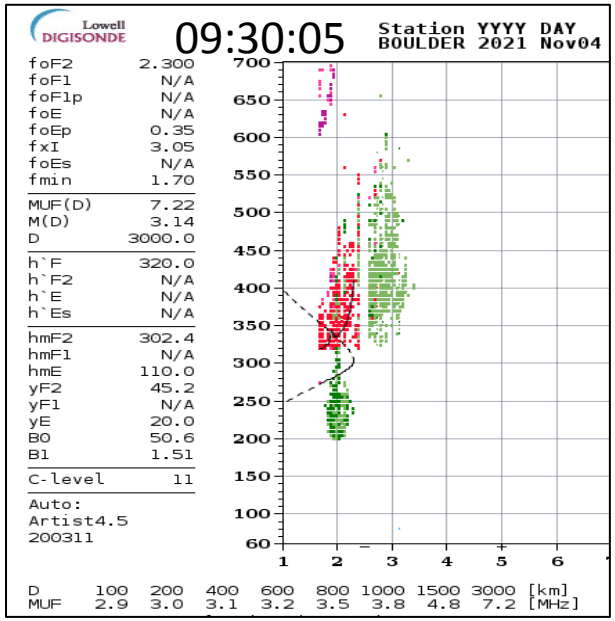
10 minute and 2 dB bins

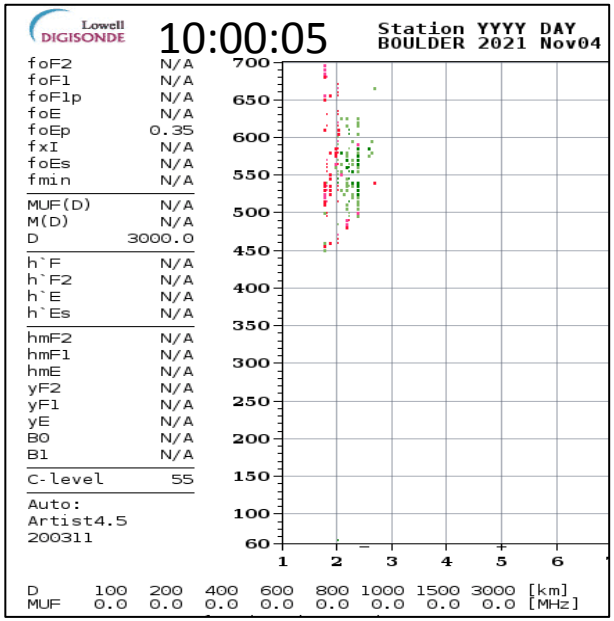


- Key 4 Nov feature remains the ‘switch-like’ cessation of spot reporting whether prior SNR -30 dB or 0 dB, not like gradual fall and rise from diurnal D layer absorption.
- Perhaps, some indication of fewer low SNR (<-25 dB) spots prior to the cessation, perhaps because of increased Doppler.
- Recovery of spot counts and SNR in this 4 hour interval took 3 days.

4 Nov. 2021: Ionograms from NGDC Boulder, Colorado





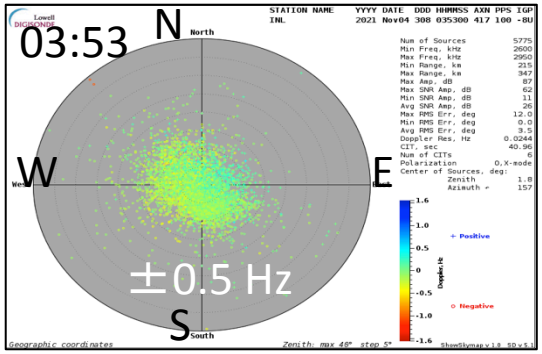


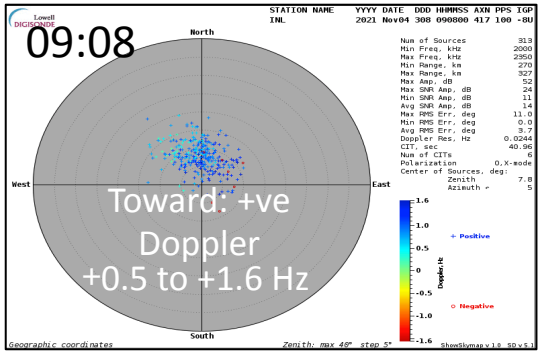
- At the western end of the propagation path MUF [1500 km] dropped from 6.7 MHz to 4.8 MHz between 07:00 and 09:30. Electron count dropped.
- By 10:00 the Automatic Scaler (ARTIST 4.5) could not output a critical F2 frequency or MUF list, and no electron count estimate.

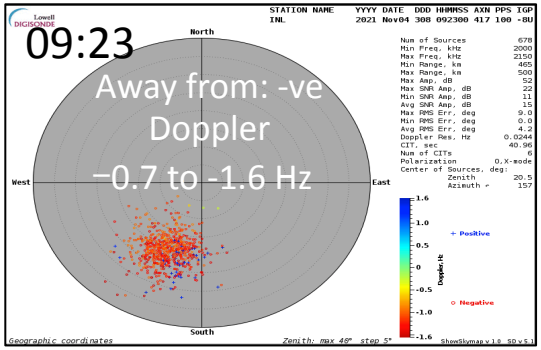
Digital Ionograms courtesy Lowell GIRO Data Center (LGDC) at U. Mass. Lowell via the portal at https://giro.uml.edu/didbase/ and National Geophysical Data Center, NOAA for data.

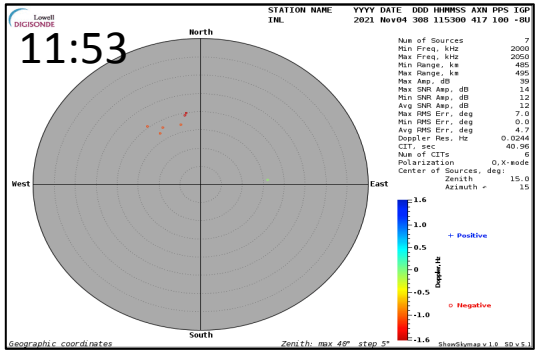
4 Nov. 2021: Digisonde Drift Analysis−Plasma Velocity

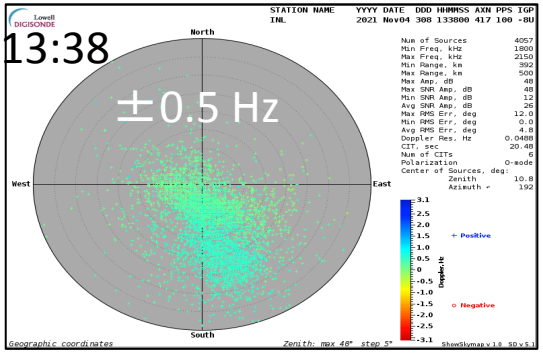
- Multi-element antenna interferometry determines source location of ionospheric echoes. Fourier analysis estimates Doppler shift. Centre overhead, edge 40˚, frequency 2–3 MHz.
- **Idaho:** No Boulder data or Millstone Hill, Ma.
- Much variability over 15 min gap
- Max range 300–500 km
- Real risk of selection bias.
- 1.6 Hz Doppler at 3 MHz is 3.7 Hz at 7 MHz.





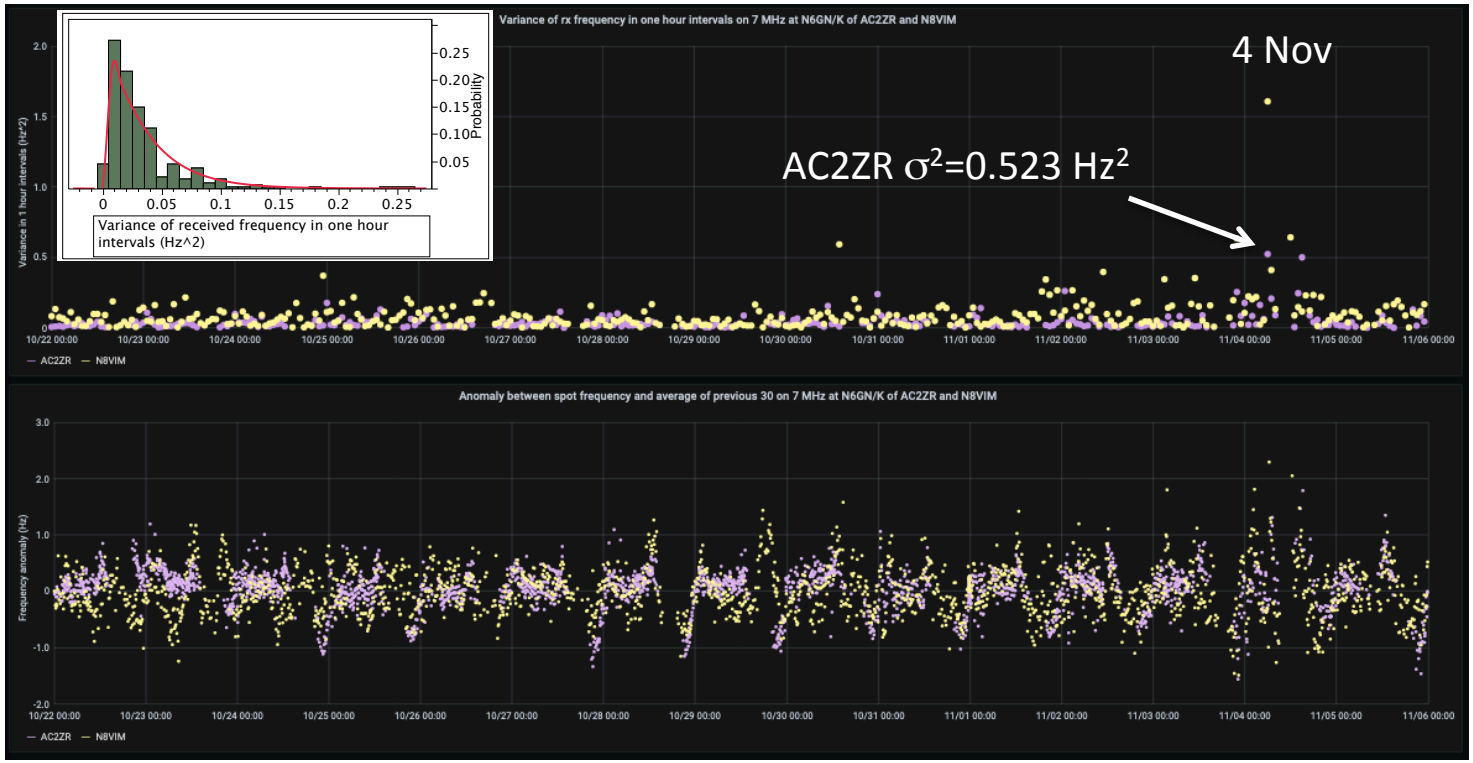






Digital Drift Images courtesy DriftBase, Lowell GIRO Data Center (LGDC) at U. Mass. Lowell via the portal at https://giro.uml.edu/driftbase/ and Idaho National Lab. for data.

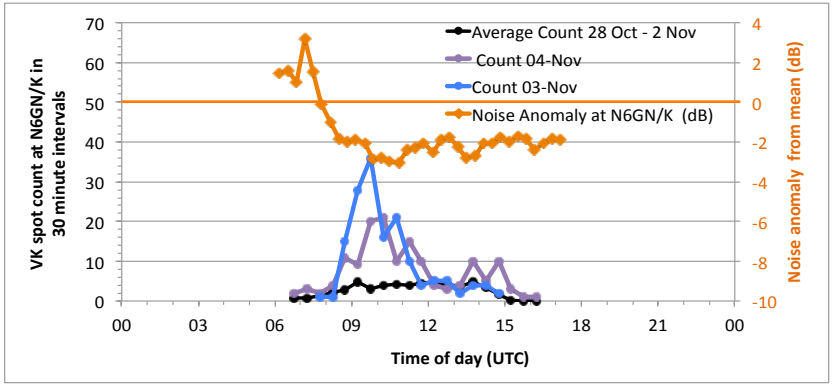
Frequency variance and Doppler shift of WSPR signals

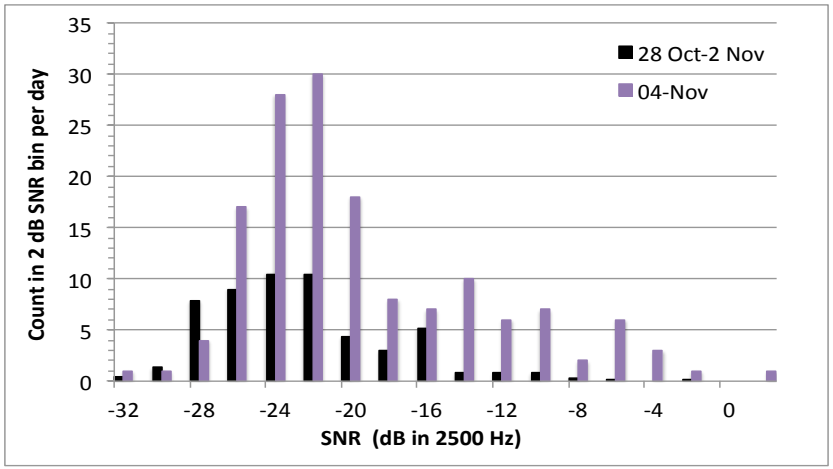


- WsprDaemon extended spots tables store frequency with 0.1 Hz resolution.
- N6GN/K KiwiSDR uses external GPSDO as do some transmitters.
- Top: Frequency variance in 1 hour intervals.
- Bottom: Frequency anomaly, spot frequency from mean of previous 30.

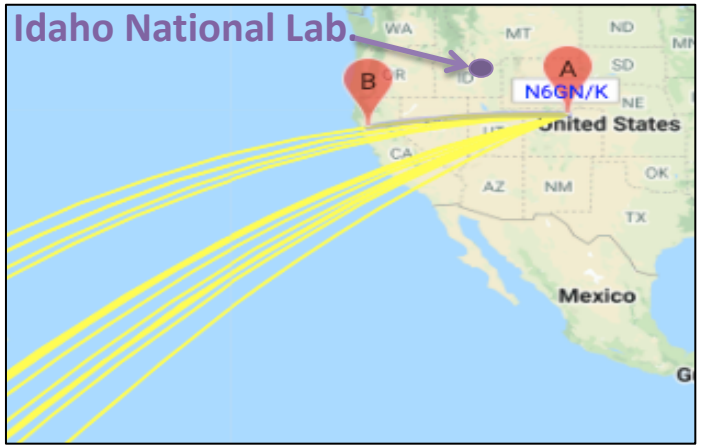
- If statistics do not change, variance of the frequency should show a Chi-squared distribution. Here a Gamma distribution is fitted for the data from 22 Oct to 6 Nov *except* for 4 Nov for AC2ZR (purple).
- Probability that the variance of 0.523 seen at 06:00 on 4 Nov is from this distribution is $1.5 \times 10^{-5}\%$

7 MHz Australia to N6GN





- 150 spots on 4 Nov from 31 TX. Average 55 a day 28 Oct−2 Nov from 22 TX.
- Did the high X-ray flux on 2 Nov improve propagation on this path?
- Ionisation high enough, and Doppler low enough, at last encounter of these signals with the Ionosphere to not cause spot count collapse.
- 2 dB lower noise at N6GN/K secondary factor to improved propagation, far more spots with SNR >-16 dB.



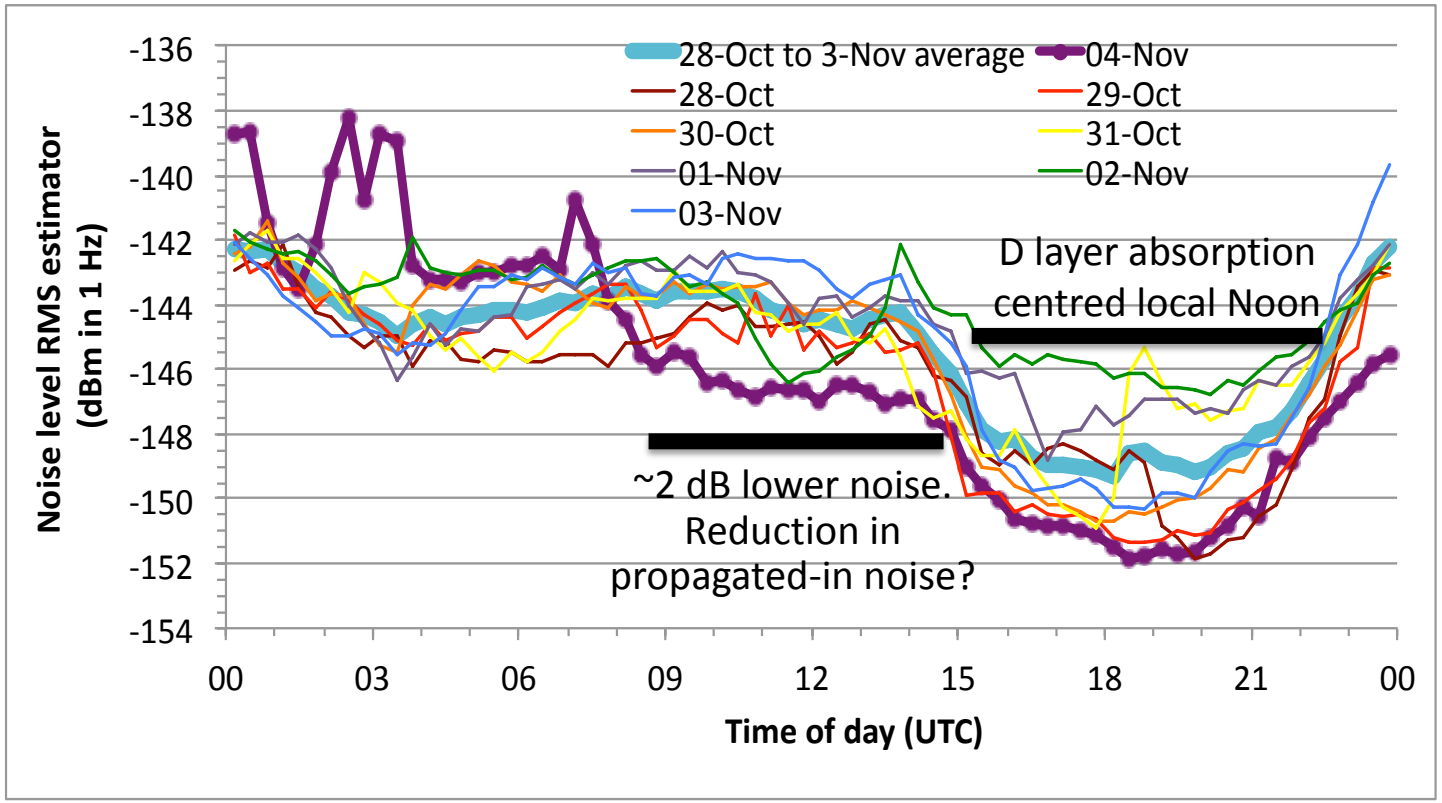
Paths of 91 WSPR VK to N6GN/K transmissions 0900–1300 UTC 4 Nov 2021.

Conclusions

- Clear WSPR spots anomaly: Sudden, precipitous drop of 95% in 7 MHz spots at Fort Collins, Co., during which spots from Australia dominated.
- We asked, “Was there a Space Weather connection?”
  - The anomaly was during a 3-day space weather event (CME & storm).
  - It was probably **not** due to excess D region absorption (NGDC DRAP).
  - Timing coincided with highest Kp index (7), deepest dip in vertical magnetic field at Boulder (-75 nT) and highest values of Auroral Electrojet Index.
  - Satellite far-UV sensor observed Auroral Glow between E. North America and Colorado at the time of the WSPR spot count collapse.
  - Boulder, Co. Ionosonde showed reduction in electron count and in MUF.
    Idaho Ionosonde showed periods of Doppler shift > 3Hz at 7MHz.
    Either, alone or combined, could have caused WSPR spot count collapse.
  - Path between Australia and Colorado likely sufficiently far south not to be affected. Perhaps higher prior X-ray flux enhanced propagation, with lower propagated-in noise a secondary factor.

Noise level (RMS estimator) at N6GN/K

28 Oct – 4 Nov ‘21



7 MHz VK6KOZ W. Australia to N6GN/K