IDENTIFYING 14 MHZ PROPAGATION MODES USING FST4W SNR AND SPECTRAL SPREAD

Gwyn Griffiths G3ZIL

HamSci Community, Southampton, UK

With thanks to Lynn Rhymes WB7ABP for precise frequency FST4W-120 transmissions

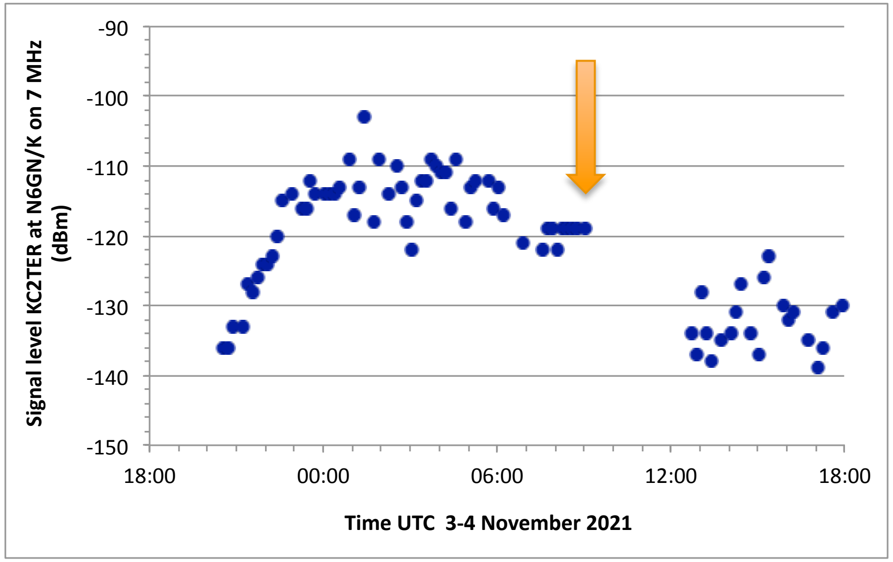
This study could not have been performed without the WsprDaemon software package from Rob Robinett, FST4W by the WSJT-X development team, PyLap from PharLap, HamSci and U. Scranton, and discussion and hardware from Glenn Elmore, N6GN.

Google Maps wspr.rocks for 13 Mar 2023

gwyn@autonomousanalytics.com

Motivation and Outline

HamSci 2022: Was the sudden absence of WSPR spots New Jersey to Colorado on 7 MHz during 4 Nov 2021 geo-magnetic storm reduced SNR or excessive Doppler or both?



- The FST4W mode in WSJT-X can measure spectral spread.
- How FST4W can be used to answer this and other propagation questions
- Results from:
  - December 2022 Experiment: California transmitter to ~3000 km East, North and West
  - February 2023 Experiment: UK transmitter to the Arctic and Missouri
- Learn to identify propagation modes and associated spectral spread

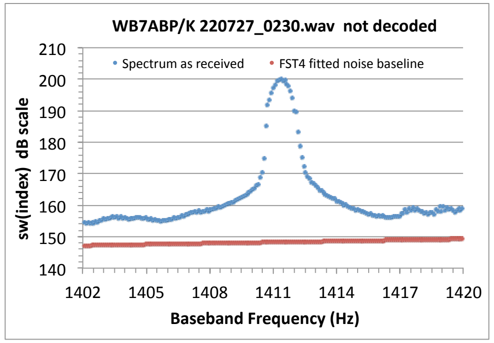
The FST4W mode in WSJT-X

- WSJT-X 2.3.0 added FST4 and FST4W, *"digital protocols designed particularly for LF & MF bands"*
- FST4W, a WSPR-like beacon mode, with advantages:
  - Option of 4 lengths: 120, 300, 900 and 1800 s
  - FST4W-120 has 1.4 dB lower decode threshold than WSPR (potentially)
  - Higher tolerance to spectral spread
- And some disadvantages:
  - No drift compensation
  - Tighter requirements on equipment spectral spread

Reference

Griffiths, G. et al. FST4W on the HF bands …. *ARRL/TAPR Digital Communications Conference*, Sept. 2022. At http://wsprdaemon.org/ewExternalFiles/FST4W_on_the_HF_bands_V1-4.pdf

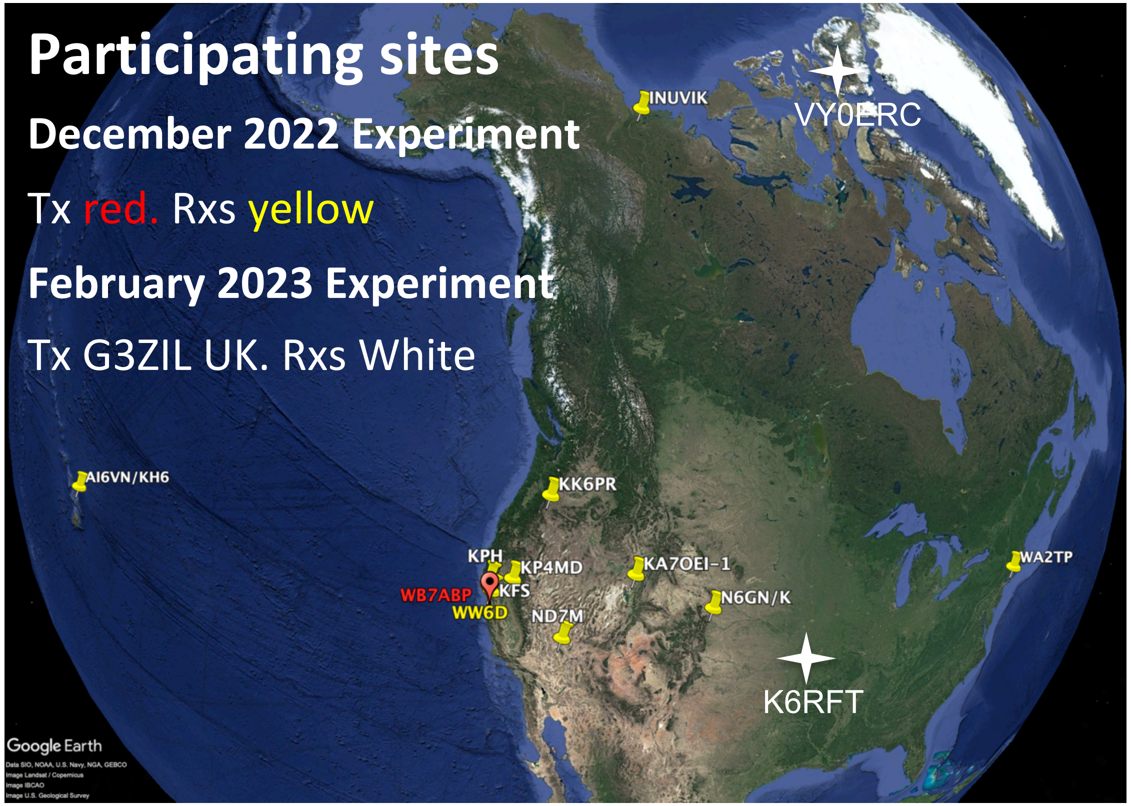
- FST4W measures spectral width if empty file *plotspec* present.
- Knowing spectral width:
  - Informs equipment needs, e.g. has already led to reduced jitter in KiwiSDR and QRP Labs QDX.
  - Can now say if spot decode failed from low SNR or excess spread.



FST4W-300 spot **not** decoded, excess spread. 14 MHz Santa Rosa to Maui.

gwyn@autonomousanalytics.com

Spectral spread and 14 MHz propagation modes



Thanks to the following for FST4W spots: Doug Bender (WW6D), the Maritime Radio Historical Society (KPH); Craig McCartney W6DRZ, Globe Wireless Radio Services and KFS Radio Club (KFS); Carol Milazzo (KP4MD), Dennis Benischek (ND7M), Rick Wahl (KK6PR), Clint Turner (KA7OEI), Glenn Elmore (N6GN), Rob Robinett (AI6VN), Bryan Klofas (KF6ZEO for Inuvik), Tom Paratore (WA2TP), Pete Freeman, K6RTF and Pierre Fogal for VY0ERC. Also, Chris Deacon G4IFX.

Not all data able to be shown. Visit http://wsprdaemon.org/fst4w.html

Methodology: FST4W = Weak Signal Propagation Analyzer

December 2022 Experiment

- **Frequency:** 14.097010 MHz
- **Mode**: FST4W-120 1 in 3 duty cycle
- **Tx:** Lynn Rhymes, WB7ABP. Santa Rosa, CM88ok. ANAN100-D GPSDO 5 W.
  KT-34XA 5-ele Yagi horizontal polarization directed northwest.
- **Path**: Terrain profile for <100 km, direction, over land, over water, across Auroral Oval …
- **Time series**: Signal level or SNR, spectral spread, sun elevation angle
- **Scatterplot:** Spectral spread *vs* signal level, with non-parametric density contours
- **Consulted:** 'The Literature' and much discussion with fellow amateurs
- **Ray tracing:** PyLap   **Propagation modeling**: Proppy ITU model

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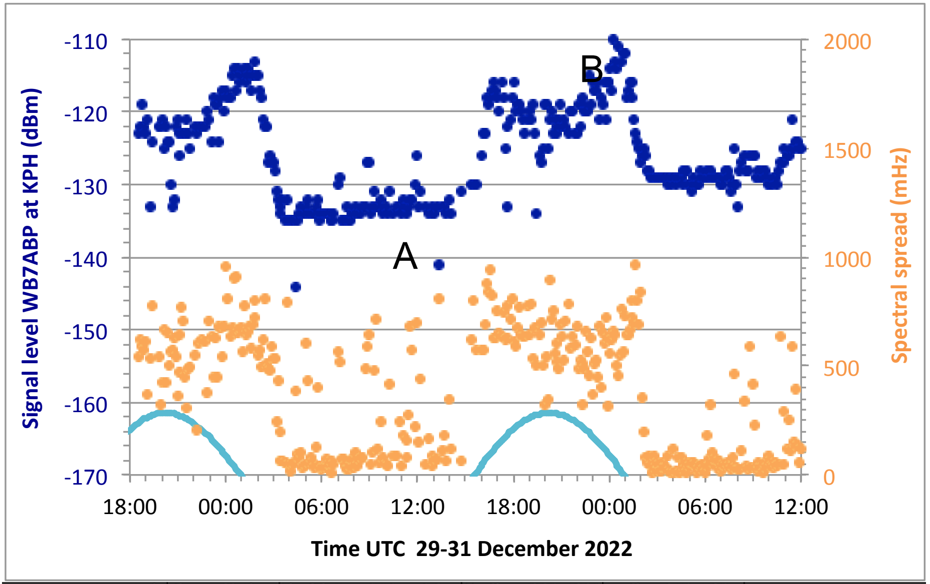
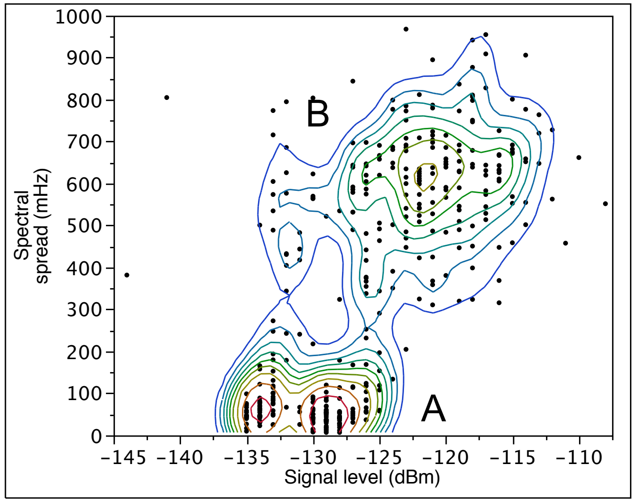
Results: The first puzzle, what are modes A and B?

Santa Rosa to KPH 40 km path on 14 MHz



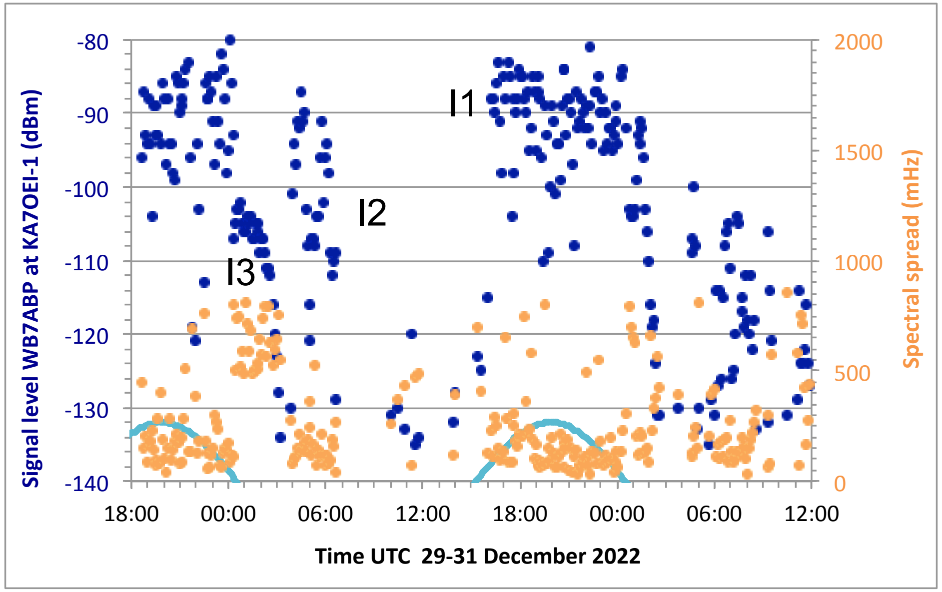


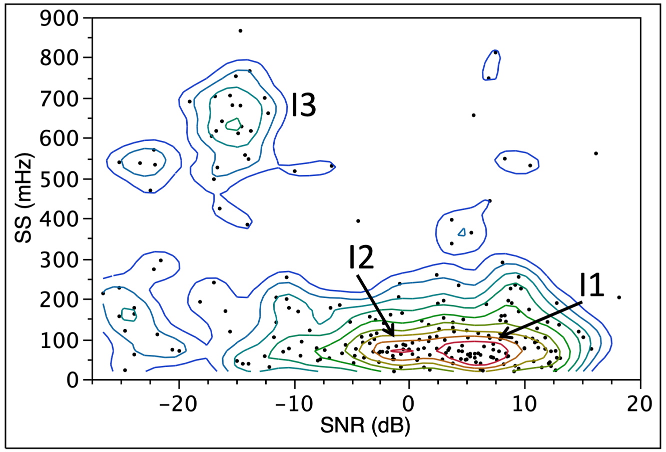
A: Low SL, much lower SS (factor 10 lower than **B**), mostly night time, most likely ground wave.

B: Higher SL, high SS and frequency variation, mostly daytime, starts just after sunrise and persists until just after sunset.

Results: Multiple modes on 960 km path

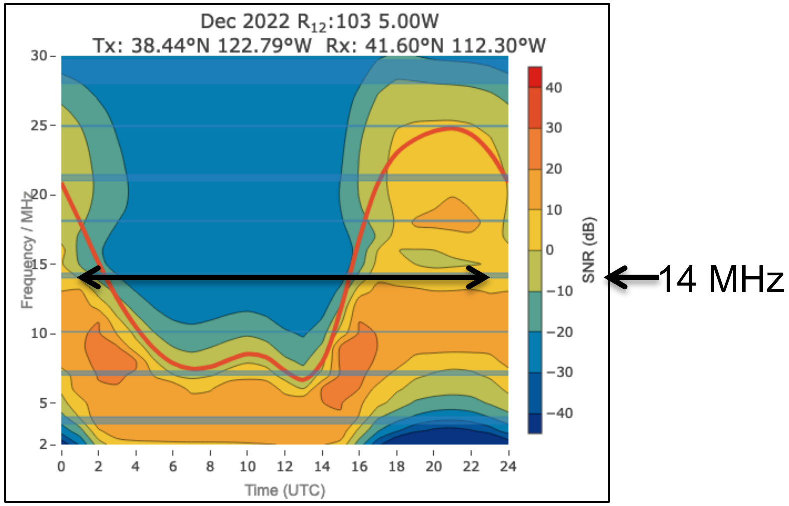
Santa Rosa to Northern Utah SDR

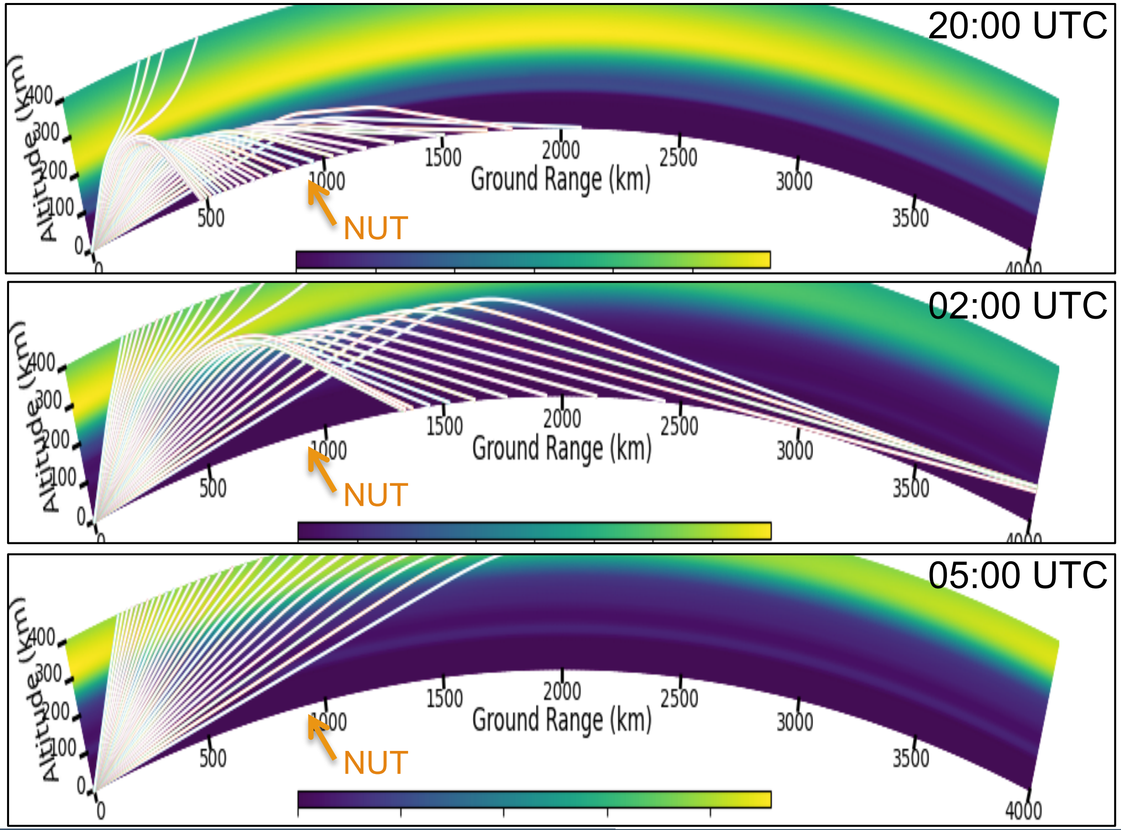




- **I1**: High SNR, but variable, with low SS, median 87 mHz, mostly daytime.
- **I2:** Lower SNR, but still with low SS, median 77 mHz, night time.
- **I3:** Lower SNR, but steady and decreasing with time, high SS, median 622 mHz, night time

960 km path: Propagation model and ray traces



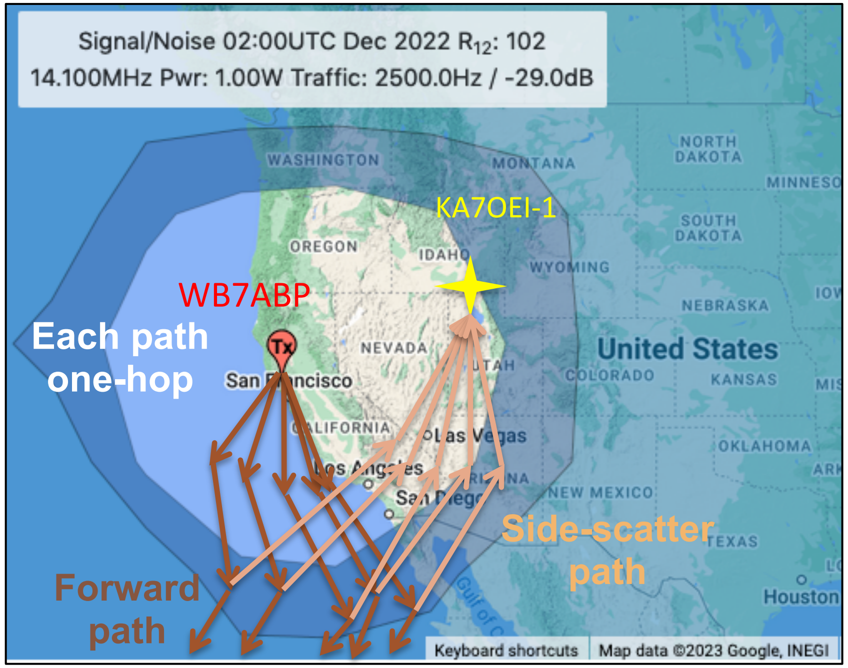


- ‘Proppy’ model (ITU-R P.533-14) shows daytime 14 MHz SNR peak.
- PyLap ray traces show single hop daytime, then within skip zone.
- **I1 is one hop F2 mode**

'Above the MUF' mode: Two-hop side scatter

- ARRL *Handbook: F-Layer backscatter and sidescatter, "Useful distances range from 100 km to normal one-hop"*
- ITU Recommendation ITU-R P.533 model for side scatter has a simple expression for excess loss depending on ratio of operating frequency *f* to basic MUF *fb*:

$$L_m = 36\left[\frac{f}{f_b} - 1\right]^{1/2}$$



https://soundbytes.asia/proppy/area

Multiple path-pairs possible. Is this what leads to high spectral spread and low SNR variation?

References

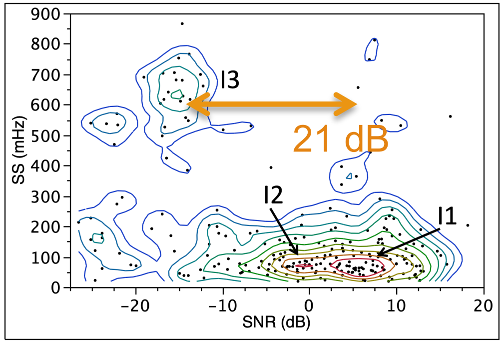
McNamara, L.F., et al., 2008. Night time above-the-MUF HF propagation on a mid latitude circuit. *Rad. Sci.*, *43*(2).

Hagg, E.L. and Rolfe, W., 1963. A study of transatlantic radio propagation modes at 41.5 Mc/s. *Can. J. Phys. 41*(2): 220-233.

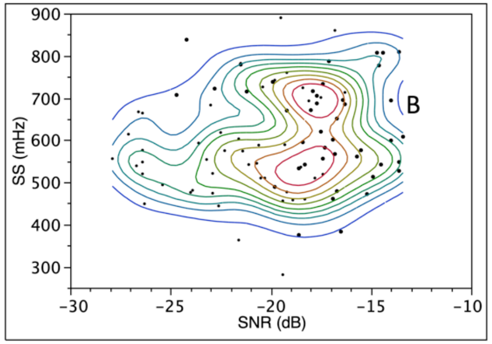
Silberstein, R. and Dickson, F., 1965. Great-circle and deviated-path observations on CW signals using a simple technique. *IEEE Trans. Ant. Prop.*, *13*(1): 52-63.

gwyn@autonomousanalytics.com

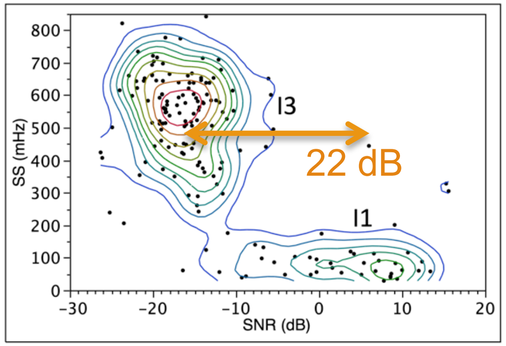
Side scatter each day 40 – 1000 km



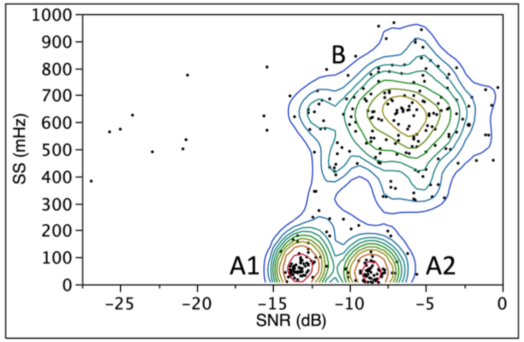
KA7OEI-1 960 km E. Utah



KP4MD 133 km NE. Citrus Hts.



KK6PR 679 km N. Oregon



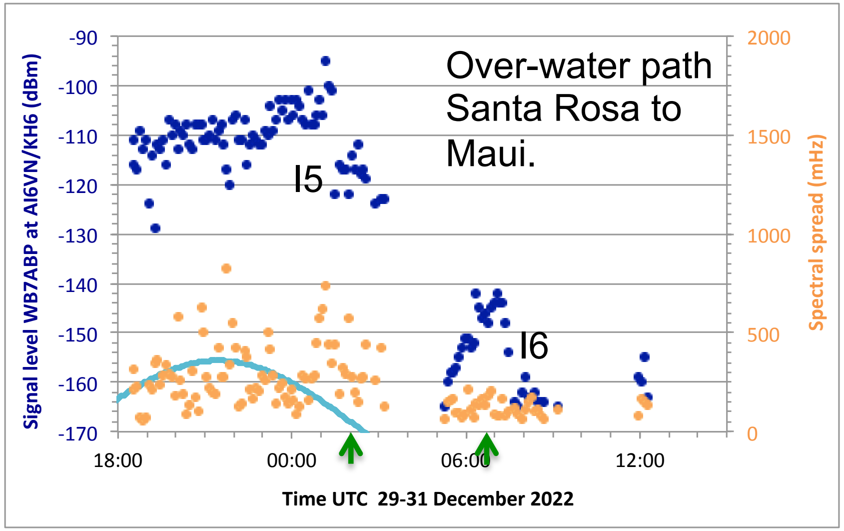
KPH 40 km SSW Point Reyes

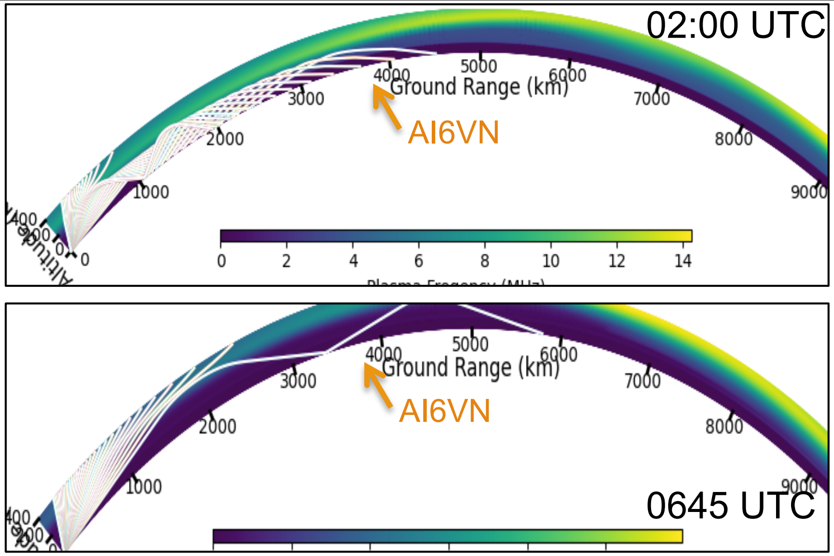
- Estimate basic MUF at cluster times from Digisonde at Idaho Nat. Lab.
- Fair agreement between model and measured excess loss.

Receiver	Path (km)	Med Lm model (dB)	Med Lm meas (dB)
KA7OEI-1	960	28	21
KK6PR	679	22	22

- **Clusters labeled I3 at KA7OEI-1 and KK6PR were two-hop F layer side scatter, as were clusters B at KP4MD and KPH.**
- No one-hop F layer propagation to KP4MD at 133 km this experiment.

Results: Two modes on 3762 km path, I5 and I6



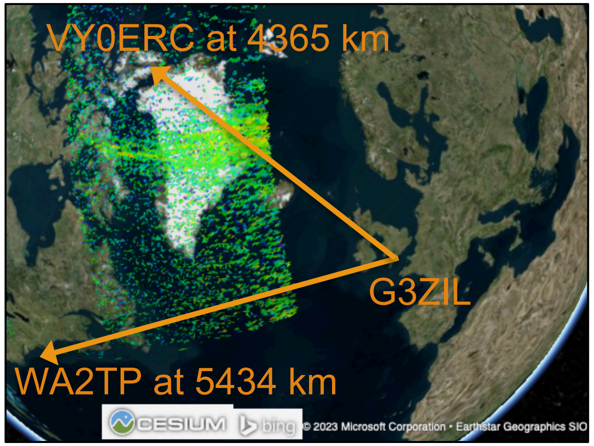


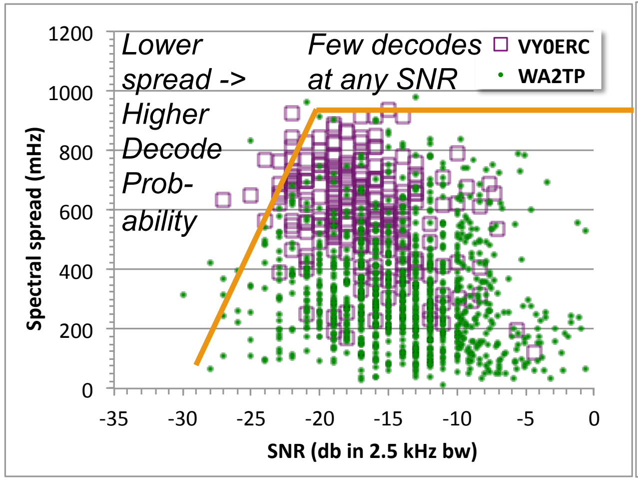
- **I5** most likely two-hop F2 layer propagation, median spectral spread 266 mHz. Not shown, but median spectral spread two-hop Santa Rosa to Long Island was 277 mHz
- **I6** most likely one-hop given median spectral spread 83 mHz, but is it refraction or, perhaps more likely, ionospheric scattering given it is ~45 dB below two-hop signal level?

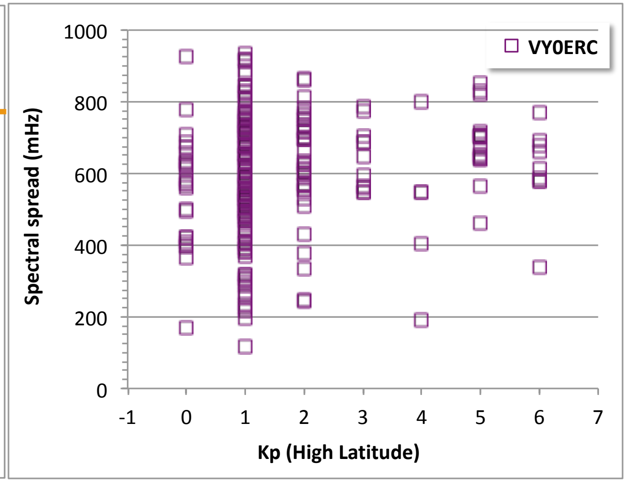
gwyn@autonomousanalytics.com

Results: Trans-Auroral Oval *vs.* Trans-Atlantic

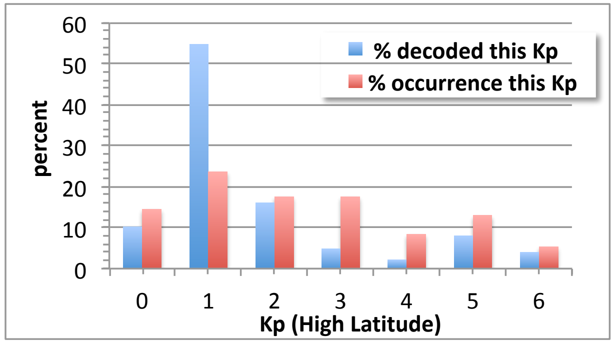
Satellite f18 Orbit 68720 13 Feb. 2023
https://ssusi.jhuapl.edu/gal_edr-aur_cs





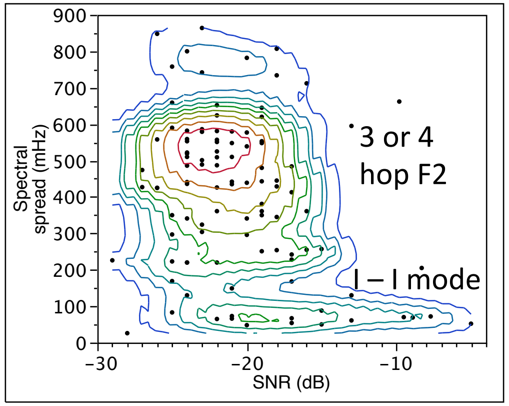


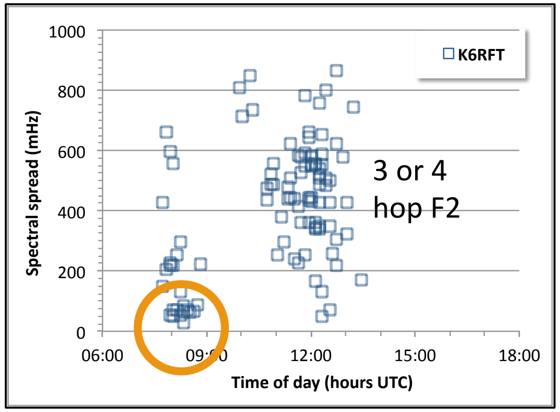
- Median spectral spread 4365 km path to VY0ERC (Eureka, Ellesmere Island) at 619 mHz double that on 5434 km path to WA2TP (Long Island) *and* fewer decodes 226 vs. 1032.
- Decodes at VY0ERC less likely if Kp > 2, decodes at Kp=1 greatly over-represented compared with Kp occurrence.

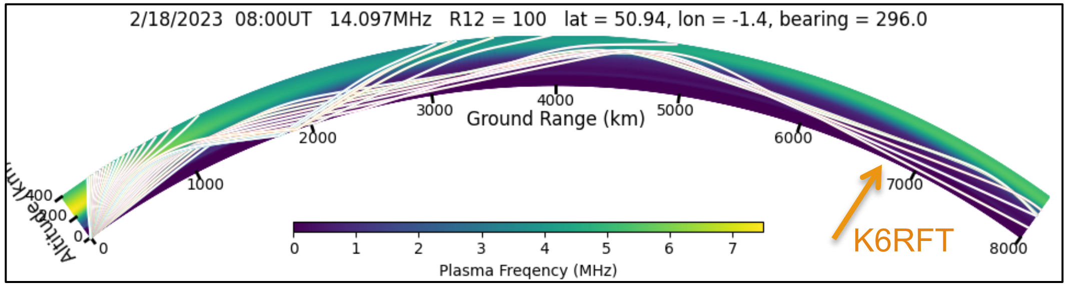


Results: Spread on Ionosphere–Ionosphere mode(s)

G3ZIL to K6RFT, Missouri
~0830 UTC mid-Feb 2023
6920 km







- Cluster of 9 spots <100 mHz spread on 18 Feb 0756-0850 UTC
- Fewer, sporadic, same time of day, on other days but ~ 200 mHz spread
- Low spread spots most likely Iono-sphere-Ionosphere mode(s)
- Py-Lap suggests this is possible from G3ZIL UK into the dark hemisphere to ~ 7000 km at ~0800 UTC

Can Spread vs SNR discriminate Chordal Hop *vs.* Ducting modes?
Ducting seen in PropLab Pro with URSI coefficients by Carl Luetzelschwab

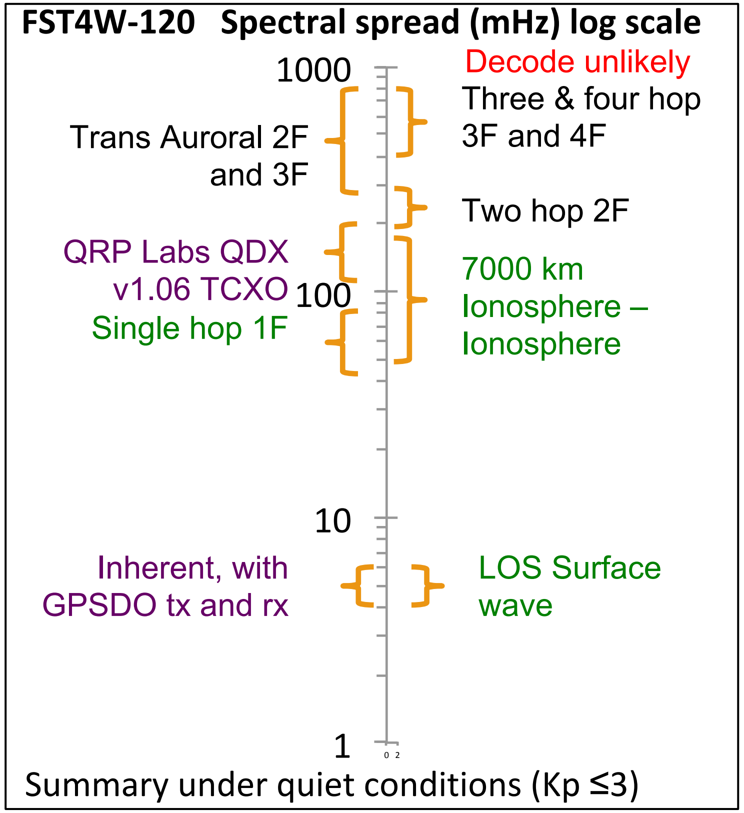
References

Fenwick, R.B. and Villard Jr, O.G. 1963.. *J. Geophys. Res*, *68*(20): 5659-5666.

Luetzelschwab, C. An Ionosphere-Ionosphere Mode on 20m Long Path. *DX Magazine*, Sep/Oct 2003.

gwyn@autonomousanalytics.com

Summary: FST4W real-time propagation analysis



- FST4W, certainly its 120 s option, is usable for global paths at HF, it is *not* just a LF or MF mode.
- Its option to estimate Spectral Spread makes it more of a Propagation *Analyzer* than a mere Propagation *Reporter* as with WSPR.
- Simple Spreading *vs.* SNR (or signal level) plots show clusters attributable to different propagation modes.
- The prevalence of two-hop side scatter on paths of 40 – 1000 km on 14 MHz was a surprise.
- Ionosphere-Ionosphere modes identifiable by their low spreading.
- Acquiring spectral spreading with FST4 could identify changes in propagation modes during solar eclipses.

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