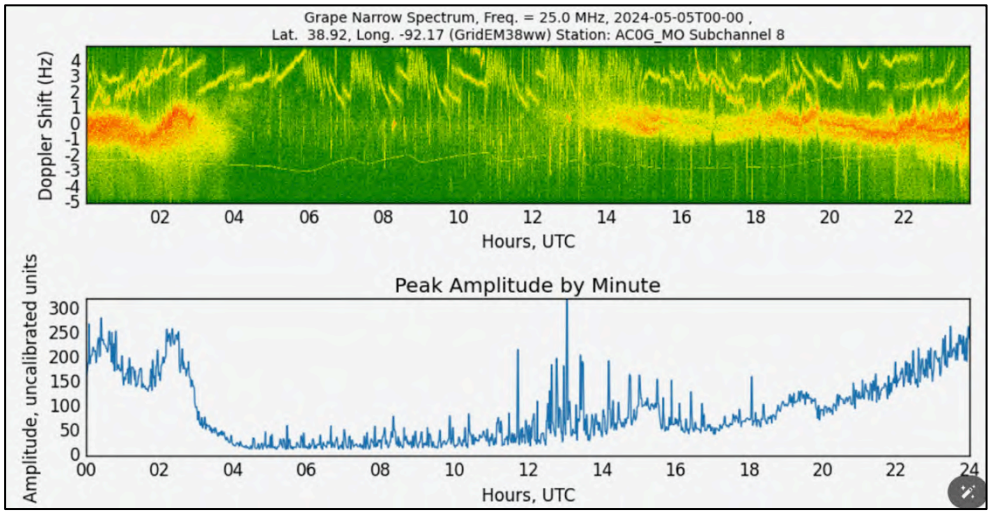
A description of propagation and anomalous Doppler features seen on nine bands 2.5 MHz to 25 MHz from WWV and CHU observed via the RX888 'Grape' at AC0G, Missouri.

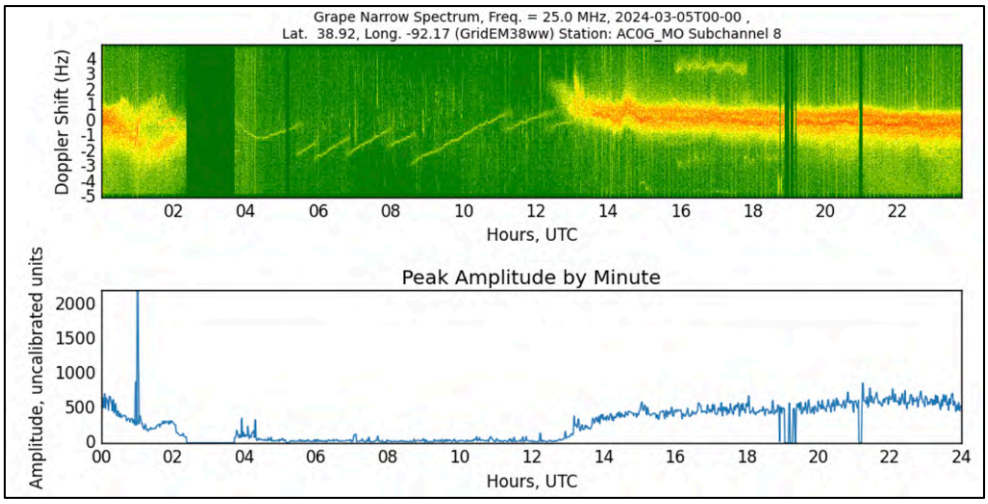
Michael Hauan, AC0G, sought my opinion on anomalous frequency variations at 25 MHz on his RX888 Mk II 'Grape' system. He wrote: "*I have no explanation for them…. WWV/H or not? If so, what's the path*?"

Michael's RX888 MkII 'Grape' reports to the HamSci PSWS database[1] using Rob Robinett's WsprDaemon program[2] that uses KA9Q radio[3] for spectrum capture and demodulation. The anomalous frequency variations are the ramps in the 25 MHz image below for 5 May 2024. The image for 5 March 2024 (bottom) also shows anomalous signals but different in detail.

In seeking to identify possible sources of the 25 MHz anomalies I thought it best to start from scratch: to write a commentary on the propagation features visible in the Doppler traces for the whole set of 'Grape' frequency standard plots from AC0G from 2.5 MHz to 25 MHz for 5 May 2024. My rationale was that this might help build a knowledge base for this path, and indeed others, of what the obvious modes of one- and multi-hop F and E layer propagation, and less well recognised modes such as two-hop sidescatter and possibly ionospheric forward scatter look like on these Doppler spectrograms. While weak replica Doppler traces have been identified provisionally as sidebands from 1-second ticks, and a local precision oscillator has been identified as the cause of anomalous zero-Doppler traces at 10 MHz and 20 MHz, the cause of the 25 MHz anomalies remains a mystery.

Assessments are supported and illustrated using PyLap[4] ray tracing for the WWV-AC0G path.





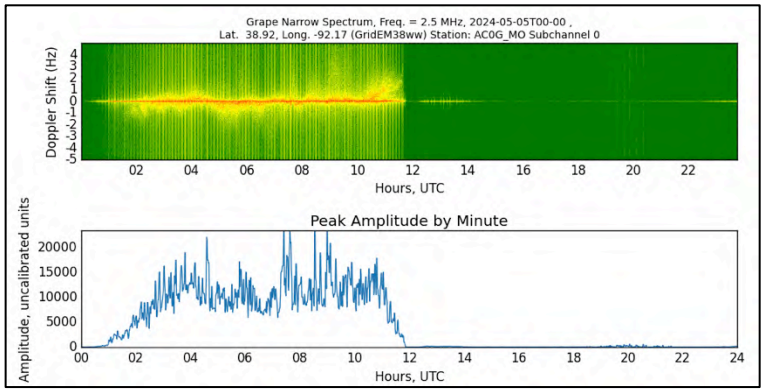
[1] Michael's data is on PSWS site at https://pswsnetwork.caps.ua.edu/observations/observation_list/ filter for RX888 and AC0G_MO
[2] https://github.com/rrobinett/wsprdaemon
[3] https://github.com/ka9q/ka9q-radio
[4] https://github.com/HamSCI/PyLap

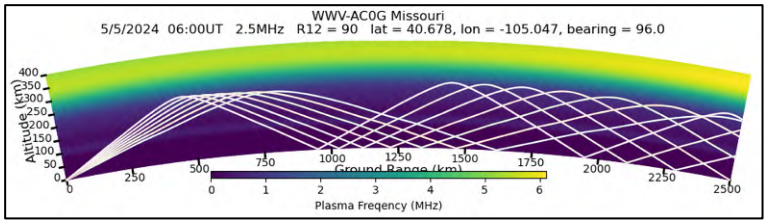
Notes on 2.5 MHz to 25 MHz RX888 'Grape' observations from AC0G on 5 May 2024

AC0G is ~1120 km at a bearing of 096° from WWV [40.678°N 105.047°W], ~1520 km at 248° from CHU [45.33°N 75.75°W] and ~6570 km at 057° from WWV (H) [21.988°N 159.763°W].

Vertical lines and broad areas of yellow suggest overload/splatter out of these bands - leave for another time / discussion with others. A useful approach may be to make 'Noise Power Ratio' measurements[5] as advocated by Adam Farson VA7OJ. I can't find any NPR measurements for an RX888.

WWV 2.5 MHz



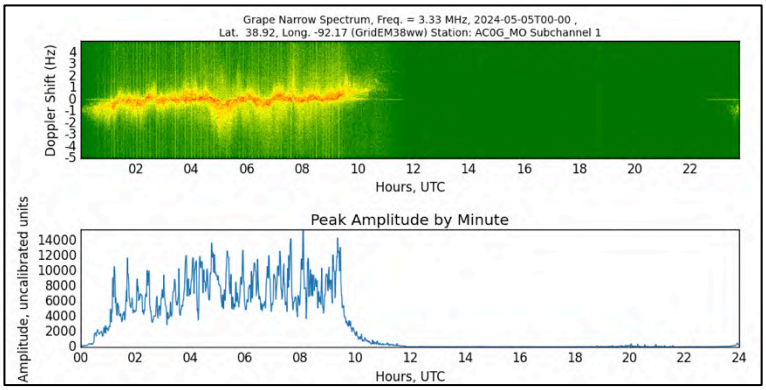


Nighttime only propagation. Strongest signal had essentially no Doppler variation until before dawn. Was initially thought to be E layer propagation. However, ray trace at 06:00 UTC showed propagation via F layer one-hop. (Still have a feeling that there may also have been E layer propagation. Or, was there instrument error - might imbalance between I and Q give rise to a DC component at 0 Hz?).

Weaker signal with quasi-periodic variations may be two-hop sidescatter. Rise of positive Doppler from the weaker signal before dawn starting ~10:00 UTC with the no-Doppler stronger signal still present.

Anomalies/Peculiar signals: No 25 MHz-like anomalies

CHU 3.33 MHz

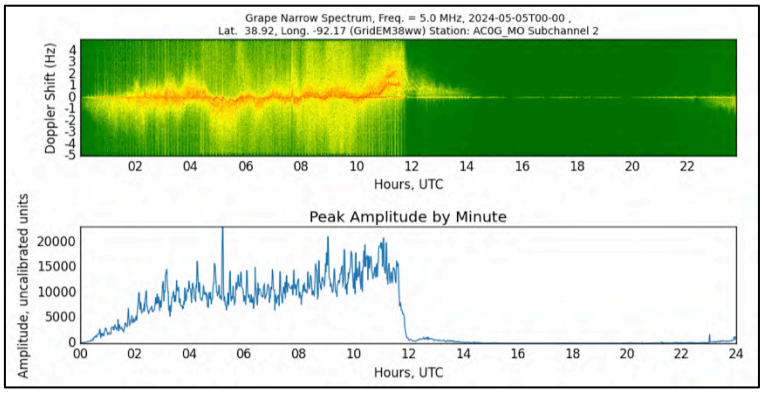


Night time only. Feint zero Doppler signal, suggests E layer propagation, or see above for the possibility of a DC component from an IQ imbalance.

Quasi-periodic variations characteristic of propagation via F layer, some trace of refraction layer descent before dawn from its positive Doppler.

Anomalies/Peculiar signals: No 25 MHz-like anomalies

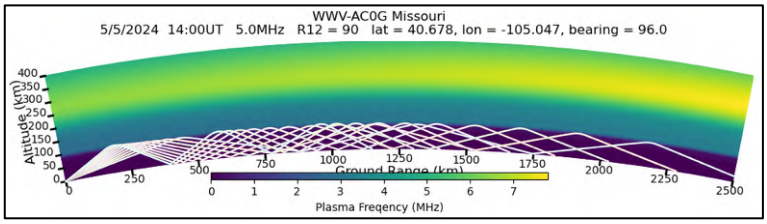
WWV 5 MHz

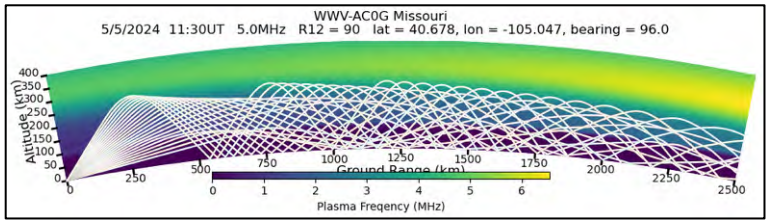


Feint zero Doppler present throughout 24 hr suggests E layer propagation. Ray trace for 14:00 UTC confirms E layer propagation at that time, and likely whenever zero Doppler present at 5 MHz.

Quasi-periodic variations characteristic of F layer propagation at night, confirmed by ray tracing (not shown).

[5] https://www.ab4oj.com/test/docs/npr_test.pdf

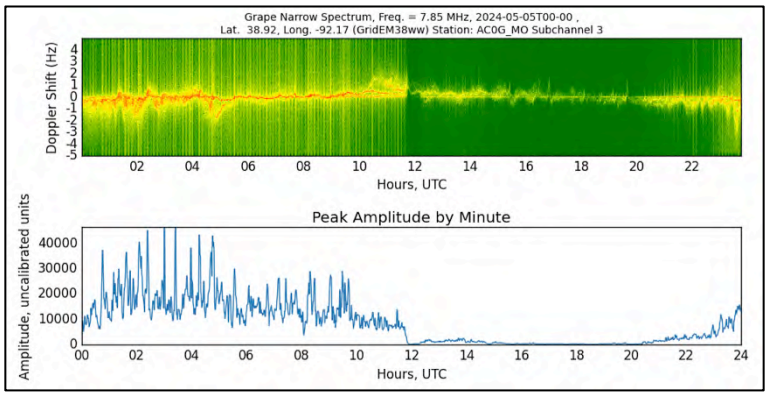




Clear multi-hop propagation as MUF rose toward dawn shown by multi-valued Doppler shift, while significant zero Doppler line suggests E layer propagation was also present, nicely confirmed in the ray trace for 11:30 UTC. Multi-hop propagation via F layer persisted as a weak signal after dawn, probably via two-hop sidescatter.

Anomalies/Peculiar signals: No 25 MHz-like anomalies

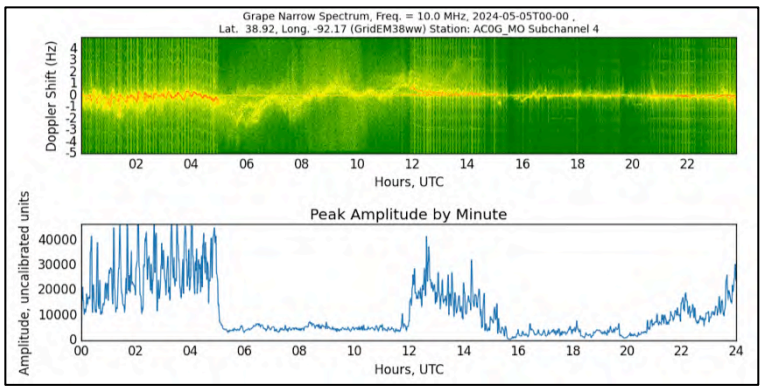
CHU 7.85 MHz

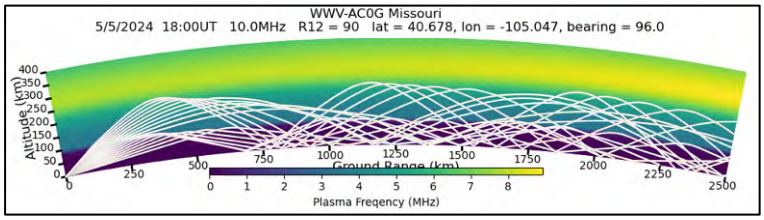


Zero Doppler signal emerged before dawn at ~ 09:00 UTC, persisted until strongest signal dropped away at ~11:30 UTC. Strongest signal showed little Doppler, less than WWV at
5 MHz. Was this one hop? There was a secondary, weaker, higher-Doppler signal, was this two-hop?

Anomalies/Peculiar signals: 7.85 MHz is the first band on which we see clear replicas of the main Doppler shift pattern at 1 Hz intervals (+ve and -ve) but *only* when vertical banding was present, which in turn suggests ADC overload. However, banding was only present when the CHU signal level was high, therefore it is also true that the replicas were only visible when CHU signal was high. Replicas were very noticeable at 10 MHz between 00:00 UTC – 05:00 UTC and are described fully below. No 25 MHz-like anomalies

WWV 10 MHz



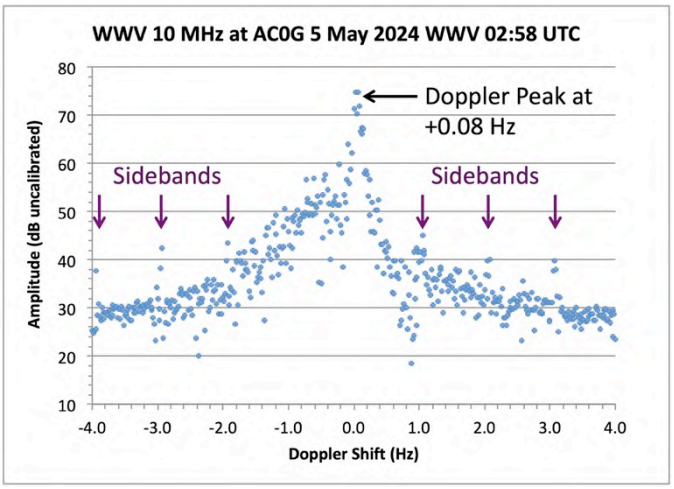


Weak zero Doppler signal throughout the day. Makes one think there may be a local source of precise 10 MHz? Yes - AC0G's shack has a 10 MHz timing signal to three Open-HPSDR radios. Or in the data acquisition was there an IQ imbalance leading to a DC offset result in an FFT peak at 0 Hz? Was E layer propagation present at some times, in addition to possible local 10 MHz sources? Ray tracing showed E layer propagation was indeed possible, at 18:00 UTC in this example, when AC0G at 1120 km range was between the F2 layer one- and two-hop ray landing zones.

From ~22:00 UTC there was a strong signal, with substantial fading, until a sudden drop at ~05:00 UTC. Ray tracing, not shown, identified the mode as one-hop. Weaker signal persisted until ~12:00 UTC. At ~06:00 UTC multi-hop and fuzzy half-cycle of Doppler shift. Compare the fuzzy individual variations with the sharp, narrow spectral

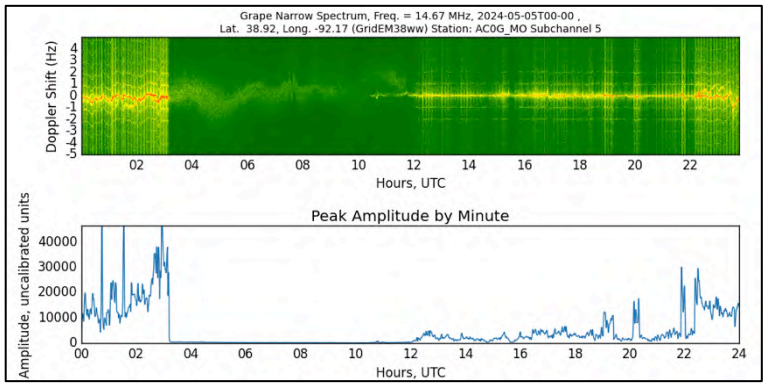
width line before 05:00 UTC. Weak signal, and what looks like wider spectral width, makes me think this was two-hop sidescatter; ray tracing showed AC0G was within the skip zone. Converting the amplitudes either side of 05:00 UTC to dB gave a 30 dB difference typical of two-hop sidescatter. (Is there a reason the amplitude scales are linear?)

Positive Doppler, that looks like one-hop, starts around 11:00 UTC with a low amplitude then rose in amplitude with multi-hop appearing and a stronger signal at zero Doppler. Ray tracing showed three-hop propagation from WWV (H) was possible from ~12:00 to ~16:00 and could be the weak, high Doppler trace, occurring at the same time as the one-hop from WWV until AC0G entered the skip zone between F2 layer one- and two-hops from WWV. Useful to note here that multi-hop may well have been present before we could see it as Doppler trace separation.



Anomalies/Peculiar signals: Replicas of the one-hop Doppler traces were clear at 1 Hz intervals. Discussion with fellow amateurs suggested these were 1 Hz spaced sidebands from the one-second interval time ticks present on all the standard time signals. This makes sense. However, it begs the question of why they were only visible on 7.85 MHz and 14.67 MHz CHU and 10 MHz WWV. Extracting the data from the digital_rf format files enables spectra to be calculated. An example at 02:58 UTC (left) when sideband replica Doppler traces were visible showed the replicas to 30–35 dB down from the carrier. Perhaps it is this low level that hides them at other frequencies. No 25 MHz-like anomalies

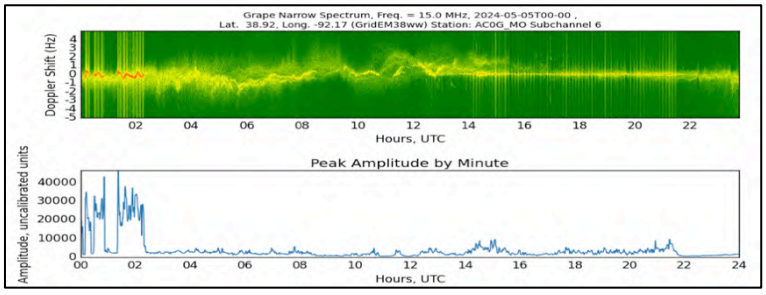
CHU 14.67 MHz



F2 layer propagation until band closed when MUF dropped ~03:00 UTC. Replicas were also present at 1 Hz intervals. After sudden amplitude drop, to a lower level than with WWV, spectral width increased (the fuzz trace), likely two-hop sidescatter. On this path on this day the evening refracting layer descent was during side-scatter propagation. Ray tracing is needed to help identify the propagation mode from 12:00 UTC until ~22:00 UTC. Possible instances of sporadic E at ~19:00 UTC, ~20:00 UTC and ~22:00 UTC?

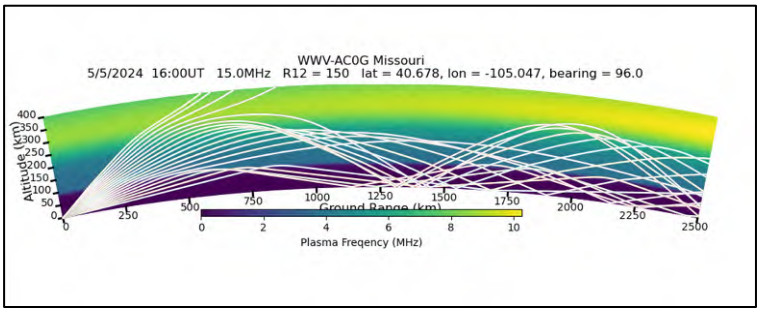
Anomalies/Peculiar signals: Replicas at 1 Hz intervals from one-second ticks. No 25 MHz-like anomalies

WWV 15 MHz



From ~ 22:00 UTC F2 layer propagation was present until the band closed ~02:30 UTC. However, ray tracing put AC0G in the skip zone all day at 15 MHz. The applicable effective sunspot number for 5 May, 90, needed to be increased to 150 for F2 propagation WWV to AC0G.
Fuzzy, broad spectral width signals were

present at the same time as sharp, narrow spectral width F2 layer signal. Likely this was the much weaker two-hop sidescatter signal, persisting after one-hop skip distance increased beyond AC0G. The central fuzzy trace sharpened somewhat after 10:00 UTC, and persisted, while weakening, throughout the day.



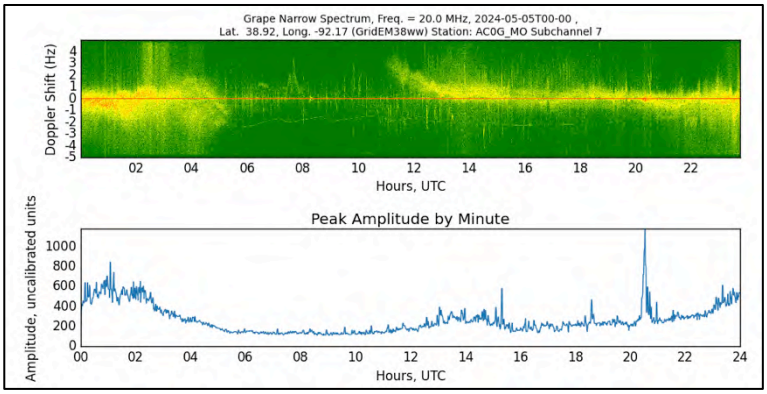
Zero Doppler trace was present from ~13:00 UTC, likely E layer propagation as shown in this ray trace at 16:00 UTC.

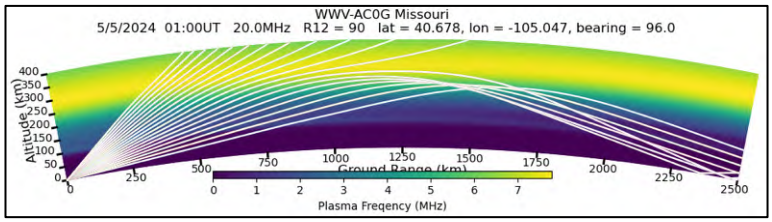
Ray tracing (not shown) suggested three-hop propagation from WWV(H) was possible around 14:00 UTC, with sporadic reception as ray landing spots were well separated, spanning ~ 400 km with 1000 km gaps.

[There is a nice comparison with FST4W signals on the reverse path KD0EAG to N6GN/K at 14.097 MHz that reinforces the idea that from ~13:00 UTC propagation was via E layer. FST4W results showed flat ~ 0 Hz Doppler and median 10.5 mHz frequency spread. Having now seen the PyLap ray trace, there's a nice story here of confident interpretation of low spread and low Doppler from FST4W as E layer propagation.]

Anomalies/Peculiar signals: No replicas at 1 Hz spacing, although amplitude much the same as CHU at 14.67 MHz. No 25 MHz-like anomalies

WWV 20 MHz





Important to note that at 20 MHz the maximum (linear) amplitude was only about 1000 units, in contrast to maxima of 10000+ on lower frequencies. This raises the question of the colour spectrum plot scale. Is its scale 'linear'? Do some colours span larger ranges than others? What dynamic range does it span? It is clear the scale is auto-scaling. That is, red/orange at 20 MHz is not the same amplitude value as at 10 MHz or15 MHz. What this means is that there is substantial 'colour gain' at 20 MHz and even more so at 25 MHz. AC0G is a low noise location, so we do not see noise speckle, but I suspect we see weak traces in light green and yellow-green at 20 MHz that would have been in the darker background green on lower frequencies.

There was a thin, essentially perfectly flat red line at zero Doppler throughout the day. Ray tracing showed no E layer propagation. Recall that there was a 'weak' (with a different colour scale span) zero Doppler signal at 10 MHz, and that there is a 10 MHz source at AC0G - this is the most likely explanation, made more visible by the higher colour gain.

Was the Doppler signal seen through most of the day (11:00 UTC to 05:00 UTC) two-hop sidescatter? The ray trace for 01:00 UTC showed the skip zone at ~ 2300 km. For two-hop sidescatter 3D ray trace modelling over a 24 hr cycle would be interesting.

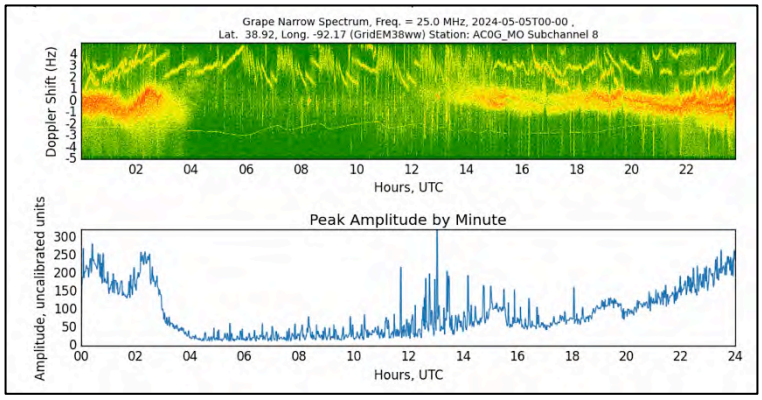
The skip zone was 3300 km at 05:00 UTC in a ray trace (not shown), while no rays (down to 2°) were refracted at 08:00 UTC. The very weaker (non-zero Doppler) trace between 05:00 UTC and 11:00 UTC was not, I think, an anomaly. At what signal level and other conditions might ionospheric forward scatter become important? Ionospheric forward scatter is too weak to be seen at the transmit power of FST4W/WSPR

stations, but might account for the feint trace between 05:00 UTC and 11:00 UTC given 2.5 kW WWV transmit power at 20 MHz.

Comparing this record to the reverse path KD0EAG to N6GN/K on 21 MHz is instructive. Only between 20:30 UTC and 21:00 UTC were FST4W spots decoded on that path at 21 MHz. That time coincides with the amplitude spike to over 1000 on the WWV to AC0G record. Was that the only interval of F2 layer, or perhaps sporadic E, propagation?

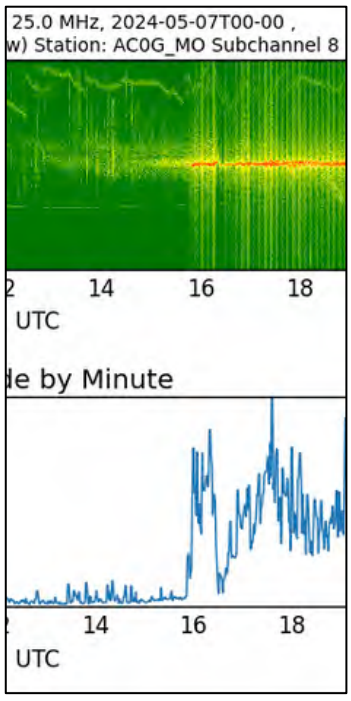
Anomalies/Peculiar signals: There was a thin, weak line with a saw tooth-like shape present, centred about -2 Hz with a period of about 100 minutes, clearest from 05:00 UTC and 11:00 UTC but present throughout I think, although after ~12:00 UTC it seemed to lose its triangular form. This thin line was also present at 25 MHz, with exactly the same phase, but at a larger frequency offset. The offset ratios were 20:25, the same as the frequency ratio. One might argue for an OCXO or TCXO somewhere at 5 MHz, 2.5 MHz or 1 MHz (possibly lower) and these were the harmonics, and we see the pattern of temperature correction and an offset. We'd not see this very weak trace at 15 MHz and 10 MHz as the colour gain has been turned up high at 20 MHz and 25 MHz. No 25 MHz-like anomalies

WWV 25 MHz



Propagation between ~13:00 UTC and ~03:00 UTC was most likely two-hop sidescatter. Ray tracing (not shown) put the skip zone at over 3000 km at 01:00 UTC. The fuzzy weak trace between 03:00 UTC and 13:00 UTC was perhaps ionospheric scattering?

Anomalies/Peculiar signals: The signal amplitude was lower than at 20 MHz and there was more 'colour gain'. This might be why we saw the saw tooth artefact at ~ -2 Hz more clearly on 25 MHz than on 20 MHz. Then we have the peculiar signals that Michael asked about. On this day they were yellow in amplitude and positive in Doppler shift, but on other days they were weaker and with negative Doppler (see the bottom image on page 1). Here are some thoughts:



- On 5 May sharp-toothed ramps to more positive frequency with sudden falling edge to a lower frequency. Periods of tens of minutes to an hour or so.
- Shorter period ramps with the opposite polarity.
- Intervals of 10s of minutes with higher-frequency variations, several cycles per hour.
- Over a day there was no drift, peculiar signals stay within a band, e.g. 2–5 Hz on 5 May.
- These look too 'ugly' to be a) the output of a local 25 MHz OCXO or TCXO or b) a harmonic of a lower frequency OCXO/TCXO.
- They look too stable in mean frequency over 24 hours to be the 25 MHz output or harmonic of a local plain crystal oscillator.
- I do not think these peculiar signals arrived via ionospheric propagation. In early May 2024 there were numerous M- and X-class solar flares some of which produced marked radio blackouts over the continental USA. One, at about 16:30 UTC on 7 May produced a characteristic sharp drop then slower recovery in amplitudes at AC0G of WWV and CHU signals above 5 MHz. As far as I can say from the spectrogram for 25 MHz (left), the amplitude of the peculiar signal was not affected. It was weak before and after the event, and, if

propagated via the ionosphere, I would have expected it to disappear during the dramatic fall in amplitude of the WWV signal.

- This 'not via the ionosphere' conclusion is supported by noting the complete absence of peculiar signals at 25 MHz at quiet sites KPH, KFS and N8GA.
- The absence of the peculiar signals at KPH, KFS, N8GA, also using RX888 Mk II receivers, does not *completely* close off the possibility that it is an RX888 artefact. If it is related to an internal oscillator in the RX888, despite my comments to the contrary above (too dirty for a TCXO, too stable over a day for an XO), it may just be that, given unit-to-unit variations, the particular RX888 at AC0G has a spurious signal within +/- 5 Hz of 25 MHz.

Suggestions as to what these peculiar signals could be are most welcome.

Acknowledgement

I am grateful to Michael Hauan, AC0G, for his RX888 Mk II 'Grape' data and his suggestion and encouragement to investigate the anomalous signals, to Rob Robinett, AI6VN, for the WsprDaemon data path to the PSWS server, to Phil Karn, KA9Q, for the signal processing within WsprDaemon and to Bill Engelke, AB4EJ, and colleagues for the HamSci PSWS database. I'm grateful to the University of Scranton and HamSci for making PyLap available. PHaRLAP was created by Dr Manuel Cervera, Defence Science and Technology Group, Australia and incorporates the International Reference Ionosphere /dat/iri2016/00_iri2012-License.txt)