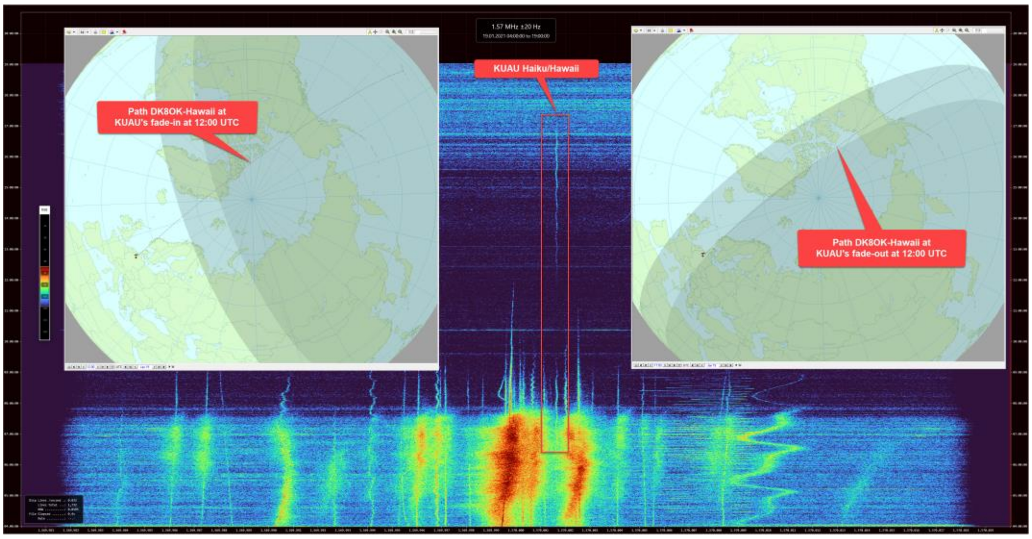

Figure 1: Aloha - the corkscrew-like trace winding around 1570.001678kHz [or so …] stems from KUAU, Haiku/Hawaii, received on January 19, 2021. Fade-in and fade-out are shown on the DX Atlas.

Offsets on Medium Wave – some Notes and Examples

DXing is listening. But stations do transport much more than just audio. This article takes into focus the carrier of Medium Wave stations – and "listening" to them. Surprisingly, they can tell a lot.

Even as a *listener*, I am always interested in the technical parameter of just a carrier. It all started with the advent of soundcards and software visualizing this demodulated carrier – tuned to a beat-note of, say, 1kHz, fed to the input of the PC. By this, high-resolution software revealed a bunch of formerly hidden effects, originating from the transmitter, the propagation channel, and the receiver itself. More than 20 years later, this technology took the next step. The following developments, combined, lead to some new perspectives:

- Software-defined radio (SDR) allow for directly analysing the I/Q stream. By this, you bypass stages like conventional IF filter, demodulator, AGC, A/D and D/A conversion within the soundcard; all adding noise, distortion, and other impairments to the signal before analysing it.
- The combination of highly stable oscillators (with the oven-controlled oscillator, or OXCO, leading the pack) exhibiting low phase noise and disciplined by satellite signals like GPS and GLONASS, guarantees for both unprecedented accuracy and stability, allowing for reproducible frequency measurements down to a millihertz – in general, at least.
- Resolution of software includes smart visual capabilities, and runs down to at least one millihertz, resulting in a 70dB "gain" compared to a 10kHz channel. Even more: as we concentrate on only the carrier, we nearly always get continuously 50% of the *peak* power of the signal and get not lost in the mushy audio of only one sideband – if harsh interference is experienced from the opposite one, as usual.

I did some experiments (standing on the shoulders of giants in this "looking-at-carriers" business) with ELAD's FDM-S3[1] receiver, featuring a GNSS-controlled OXCO[2]. Antenna at my location near Hanover, Northern Germany, is a vertical active dipole of 2 x 5m length, MD300DX[3]. *Figure 1* shows some result of this setup: reception of the carrier of KUAU/Hawaii, during a winter afternoon. It should also work as reading bait for the remaining text of this article …

Limits of Measurement – some Basics

If you want to measure something, you must know what you are measuring. The answer seems clear: You want to measure the *frequency of the carrier* of an AM broadcasting station. To do so, you must consider the whole chain from transmitter to receiver. Each stage influences your measurement to a specific degree – see *Figure 2*.

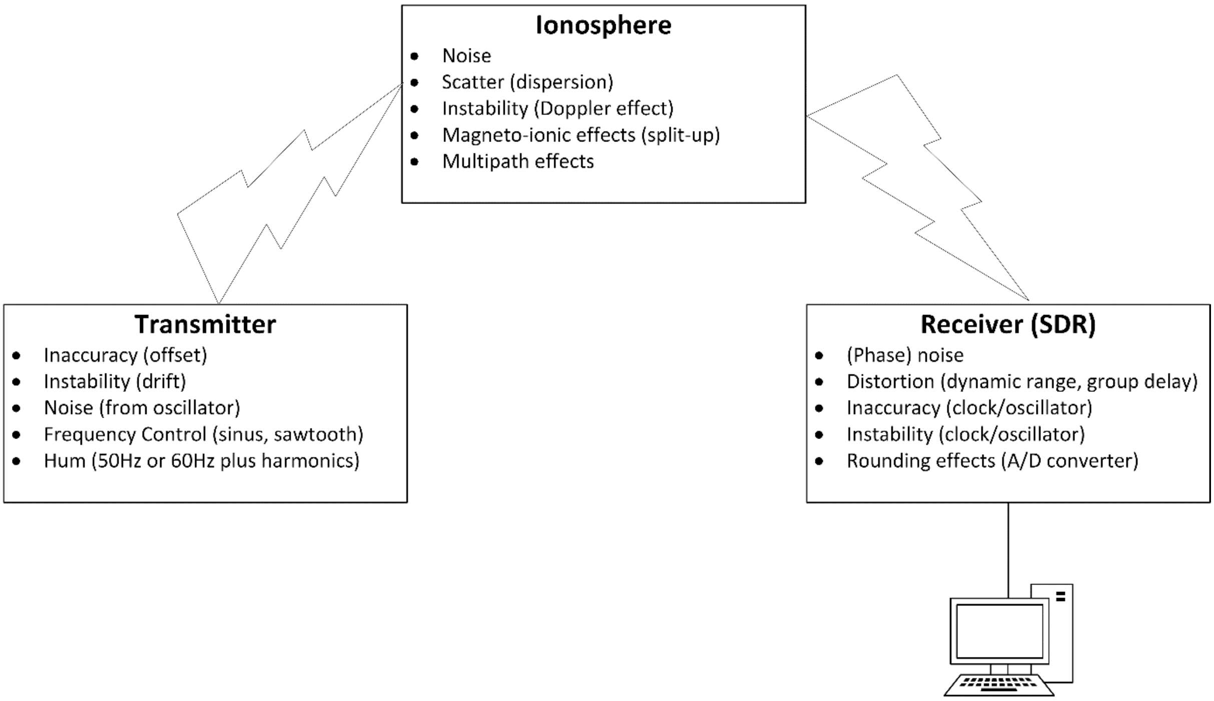

Figure 2: A selection of some typical impairments to a signal from transmitter to receiver.

As medium wave DXers, we mostly concentrate on the transmitter's carrier trace, shown in a spectrogram. On this, we measure offset and have a look at other features, like the frequency-control algorithm – being a sinus with KUAU at *Figure 1*. These factors may work as "fingerprinting" to identify a station or a type of transmitter. Not exactly like an identification being heard, but they are a strong hint which should be backed by specific times of sign-on and sign-off, plus fade-in and fade-out. More on that later.

The main question is: To what degree can the carrier's property be transferred to the receiver? The simple answer is: "On air, one millihertz, or 0.001Hz can be achieved regularly." To do so, we must take care for an accuracy and stability of the receiver better than a tenth of this. *Stability* is the property of a receiver to keep the frequency, set once, over a long time. *Accuracy* is the property of an exact frequency readout, down to one millihertz and more – see *Figure 3*. State-of-the-art is the combination of an oven-controlled oscillator, or OXCO, housed in an isolated case at a stabilized temperature of about +75°C. Its frequency *stability* is specified at ±0.01ppm/°C after 10 minutes warm-up, or ±0.01Hz at 1000kHz. But, as with all quartz-driven oscillators, also this one suffers from *aging*: ±0.05ppm/year according to specifications. GNSS – see *Figure 4* – compensates for this effect by adding *accuracy*: According to the measurement protocol of my FDM-S3, stability *and* accuracy are always well below 3×10^{-11} or the factor of 0.0000000003. So, we are very well equipped to determine stability as well as accuracy of a frequency down to at least one millihertz. Generally, at least. But in practice you must reckon with some other effects.

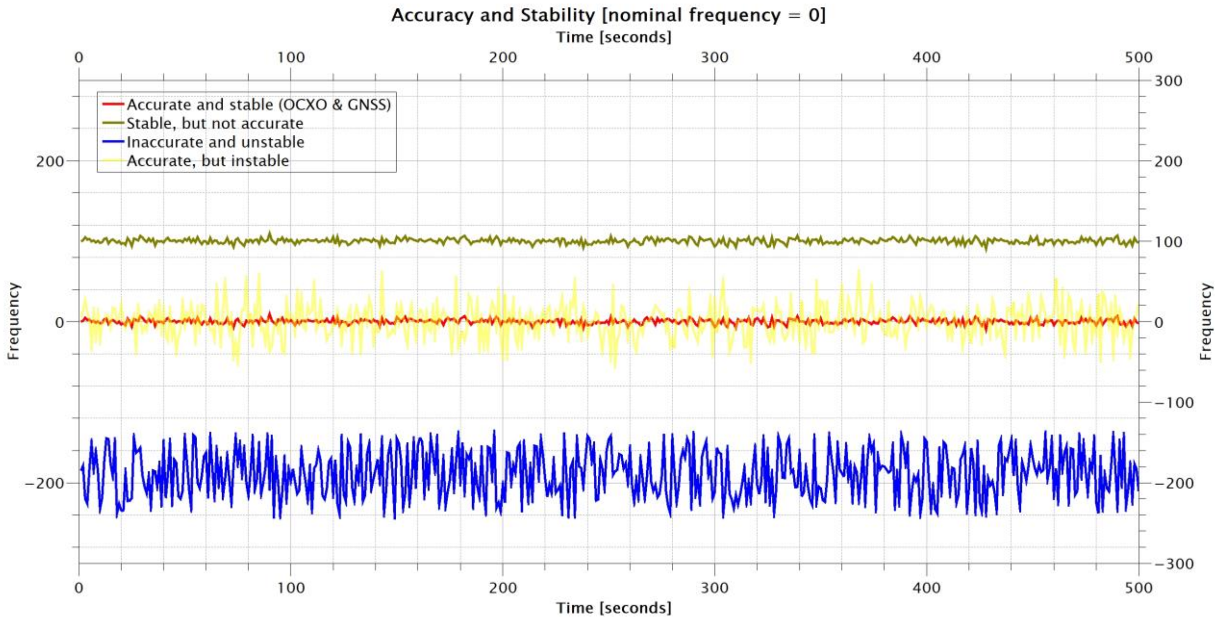

Figure 3: Stability and accuracy are different disciplines. Where an OXCO excels in stability, its GNSS control adds accuracy.

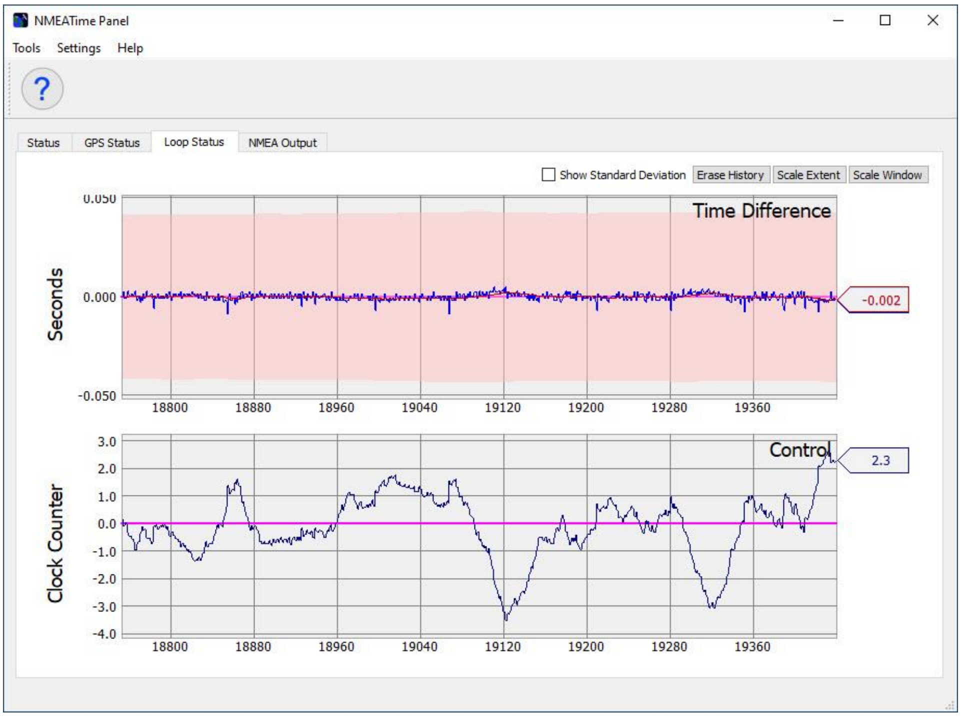

Figure 4: Software like NMEA Time Panel[4] shows many data, derived from the GNSS module. Among them are number of received satellites, their strengths, 3D position and time. The latter may also control the PC's clock, as shown here.

Stability and Accuracy in Practice

Let us start with an easy example: MSF Anthorn on 60kHz over 24 hours. UK's NPL guarantees frequency stability as well as accuracy in the range of at least $2x10^{-12}$. We have only very slight effects on the way from Anthorn to my location, see *Figure 5*, showing 24 hours on January 21, 2021, through a window of 4Hz width.

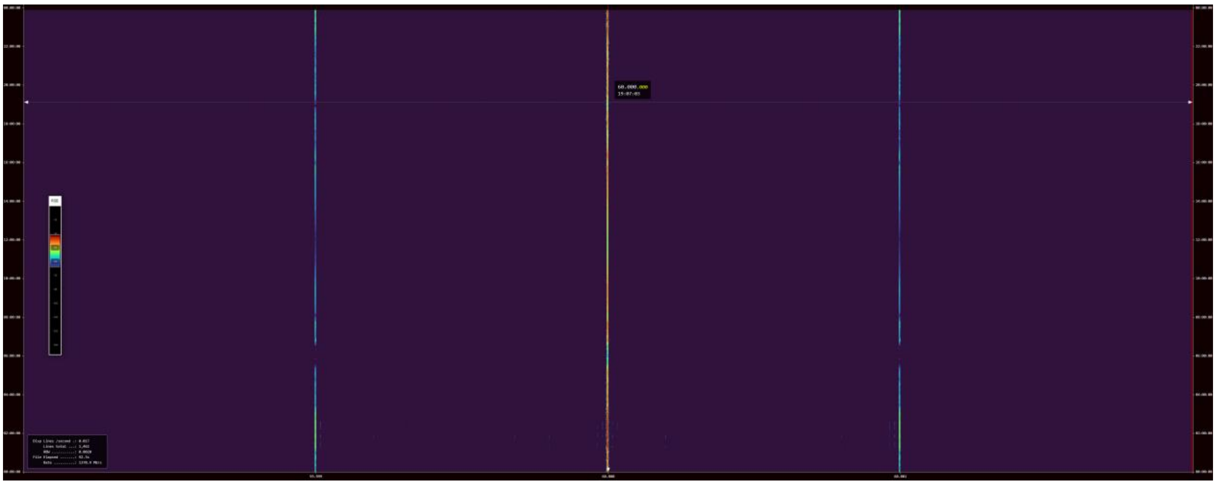

Figure 5: MSF Anthorn on 60kHz over 24 hours with 0.002Hz resolution in a 4Hz wide window – showing perfect accuracy as well as stability of transmitter, receiver, and propagation. The sidebands of ±1Hz stem from the one-second time beeps.

Compare this to 24 hours on 207kHz, following the trace of RÚV, transmitter Eiðar, *Figure 6*. It is neither stable, nor accurate. The frequency shivers from 207.001542kHz to 207.001676kHz, or nearly ±70 millihertz over 24 hours. The behaviour of the transmitter – MSF, as well as RÚV – can be easily reproduced thanks to the benevolent propagational characteristics on long wave.

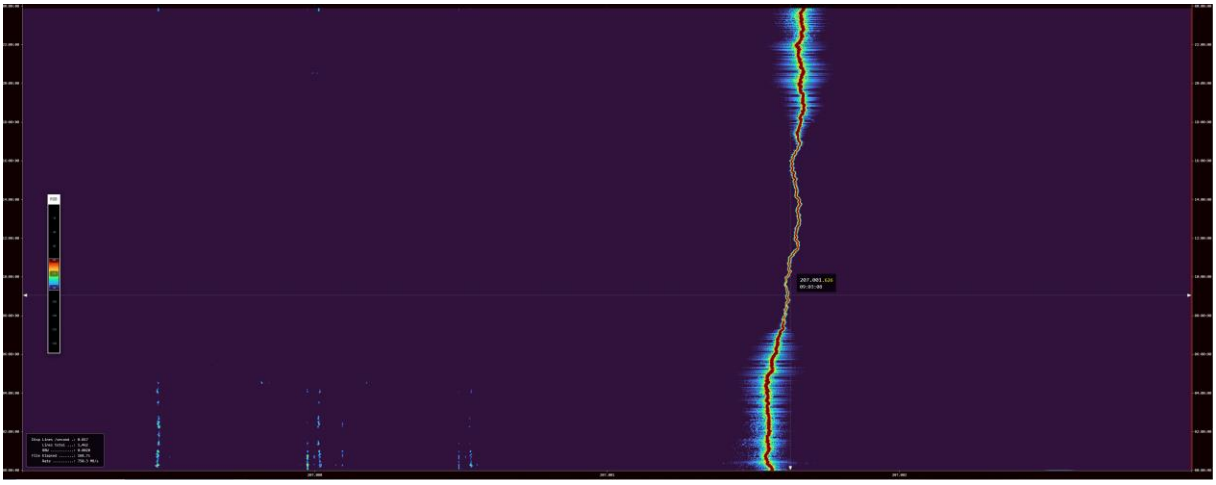

Figure 6: Shivering through 24 hours – the longwave broadcasting transmitter of RÚV at Eiðar.

However, things get more difficult, the higher the frequency. If you multiply the frequency by ten, some effects from Doppler and scatter also becomes tenfold.

Propagational Effects[5]

Obviously, you only rarely will see a thin, steady line of a carrier over 24 hours. Well known is the *diurnal variation* of signal strength which is controlled by the influence (ionisation) of sunlight. On medium wave, dusk, dawn, and darkness usually provide the best signal, favouring dusk, and dawn. After sunrise, the absorbing D-Layer builds up to vanish near or as the sun sets – often resulting in a “bathtub curve”, see *Figure 7*. This is valid generally for the first reflection point of the transmitter’s signal and the last, before reaching the receiver. But because this being high in the thin air, it sees the sun much earlier than the sunrise at sea level and much longer than the sunset at ground. From the height of the D layer (≈75km) the visibility extends by almost exactly 1000km. On the other side, one must consider some time needed for both ionisation and recombination of the molecules. Large and by, it often seems that both effects are balanced around the time of *local sunrise/sunset on ground*.

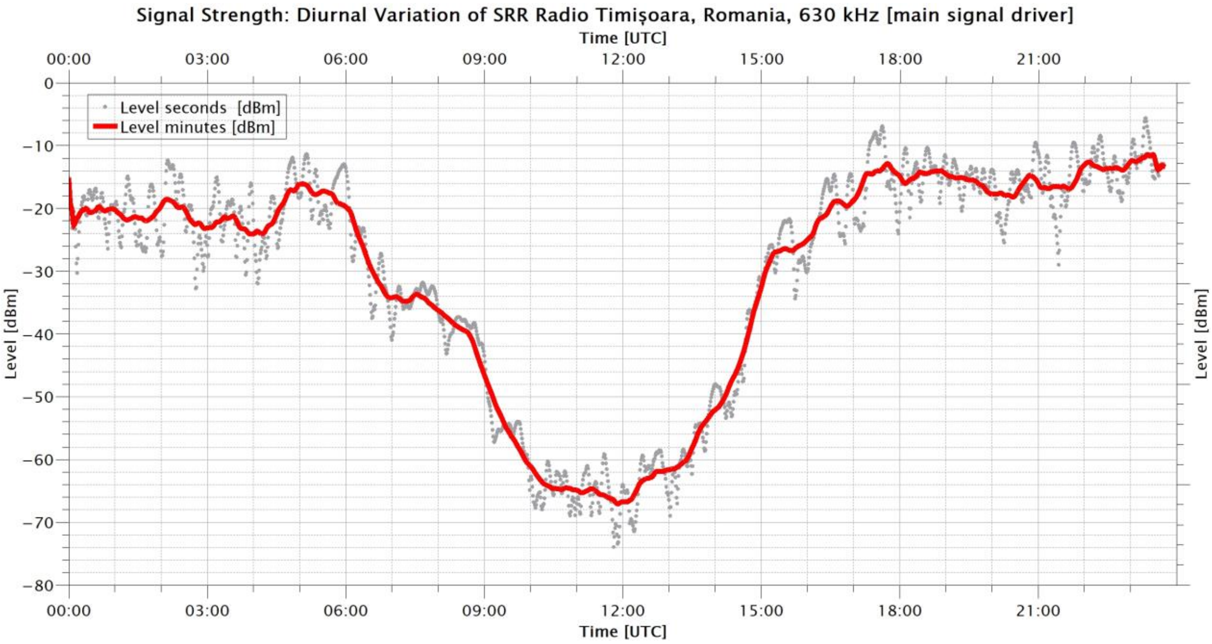

Figure 7: Transmitter Timișoara/Romania on 630kHz exhibits the typical "bathtub curve" showing coming and going of the absorbing D-layer of the ionosphere. Timișoara->Hanover, January 19, 2021. The 86.400 points in the background represent the signal strength at each second, the continuous line averages 60 seconds of these data to one value/minute. Visualised with QtiPlot[6].

By rule of the thumb: The path between transmitter and receiver generally should be in darkness to provide reception. *Figure 8*, in turn, shows that thanks to the vast system gain of our concept, this rule sometimes needs not be strictly fulfilled, especially in wintertime. It shows the fade-in of Radio Gotel/Nigeria, even when nearly the whole path still is in daylight. But the D-layer already feels the shadows of darkness, merely the loss of ionisation.

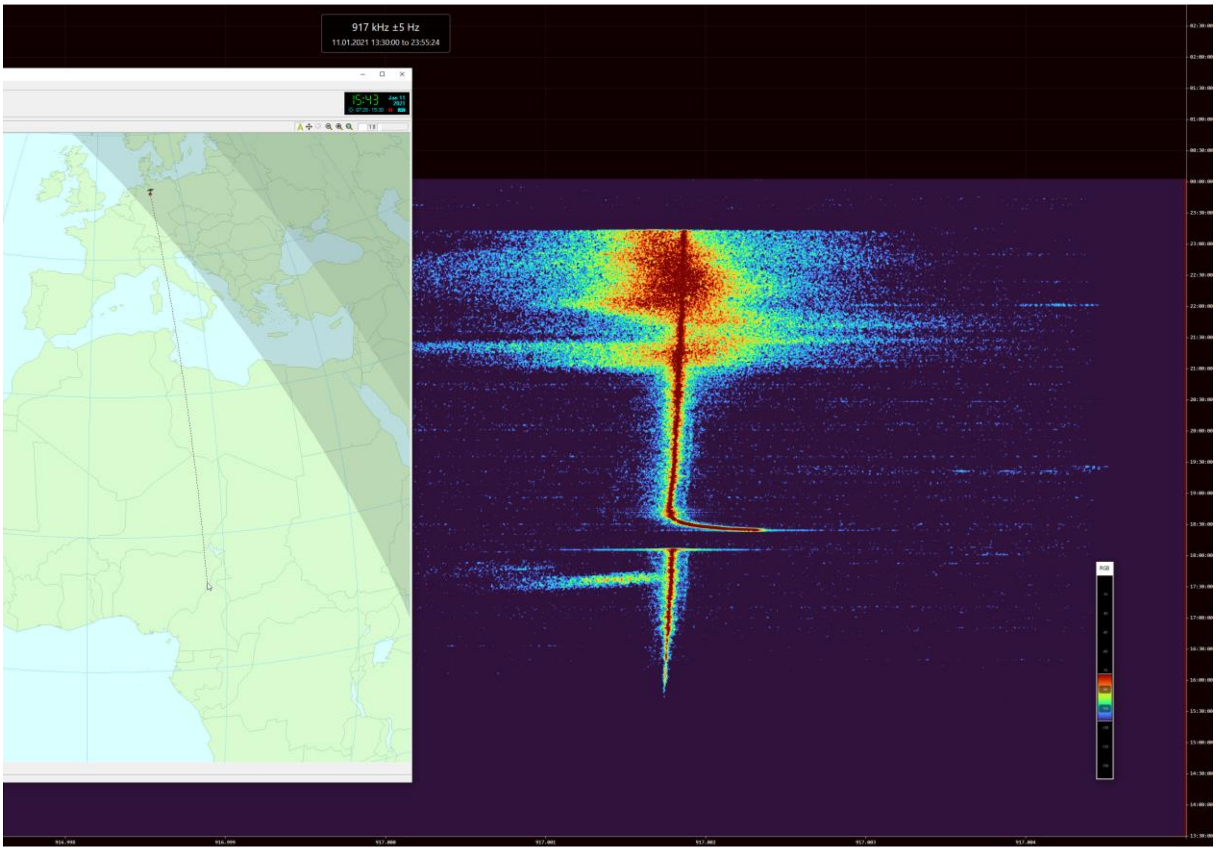

Figure 8: Radio Gotel from Jabura/Nigeria on 918kHz already becomes visible from about 16:00UTC with nearly the whole path in daylight. Wintertime and an exceptional system gain make this possible. See also a short power break of NEPA, Nigeria's National Electric Power Authority, or "No Electric Power Available" as they read the acronym.

At local sunrise, there can be often observed several effects – the carrier gets "clouded" and can show frequency changes. These effects are associated with Doppler shift (moving of ionospheric patches/layers) as well as scattering caused by irregularities of the ionosphere, most notably Travelling Ionospheric Disturbances, or TID. Whereas the Doppler shift, by *vertical* moving of reflecting layers like combining of F1- and F2-layer to one and lower F-layer when approaching darkness, is comparatively small, high wind speeds in these regions can cause a much faster *horizontal* movement of such regions. This, in turn, may cause a Doppler shift of about 1Hz or even higher in the medium wave range.

Figure 9 demonstrates this effect at two transmitters on 1422kHz, namely SRR Radio România Actualități from Râmnicu Vâlcea/Olănești (sunrise 05:55 UTC/sunset 15:12 UTC; distance 1433km)[7] and Radio Coran/Radio UFC/Radio Culture/Chaîne 3 from Ouled Fayet/Algeria (sunrise 06:58 UTC/sunset 17:00 UTC; distance 1840 km). Seen from midnight, sunrise first occurs at the Romanian transmitter, followed by the Algerian one with the seahorse-like pattern of the scatter towards the *higher* frequencies. Around each local sunset, first Romania sees darkness, followed by Algeria. Here, the scatter pattern turns towards the *lower* frequencies. In the insert at the right, contrast has been sharpened to additionally reveal a split-up of these carriers due to propagation into two paths.

This effect often helps to determine the *local sunrise/sunset* of a carrier. I marked what presumably is the carrier of MBC Radio 1 from Matiya/Malawi, sunrise 03:22 UTC; listed 02:00 to 22:00 UTC, but obviously on a 24 hours' service this Tuesday. See also *Figure 13*.

Here I am indebted to Jens Mielich, Head of the ionosonde at Juliusruh/Germany, who was so kind to comment on this observation. According to him, the observed Doppler shift of 1Hz on 1422kHz should have been caused by a refracting medium, moving at an (angular) speed of roughly 105m/s. At Juliusruh, he observed e.g., an ionospheric drift of 311m/s±93m/s from East towards West on January 19, 2021 at 04:19 UTC: "You will get a *positive* Doppler shift during a West/North drift, and a *negative* one at East/South drift." He adds that further investigations on a more longer time series are needed.

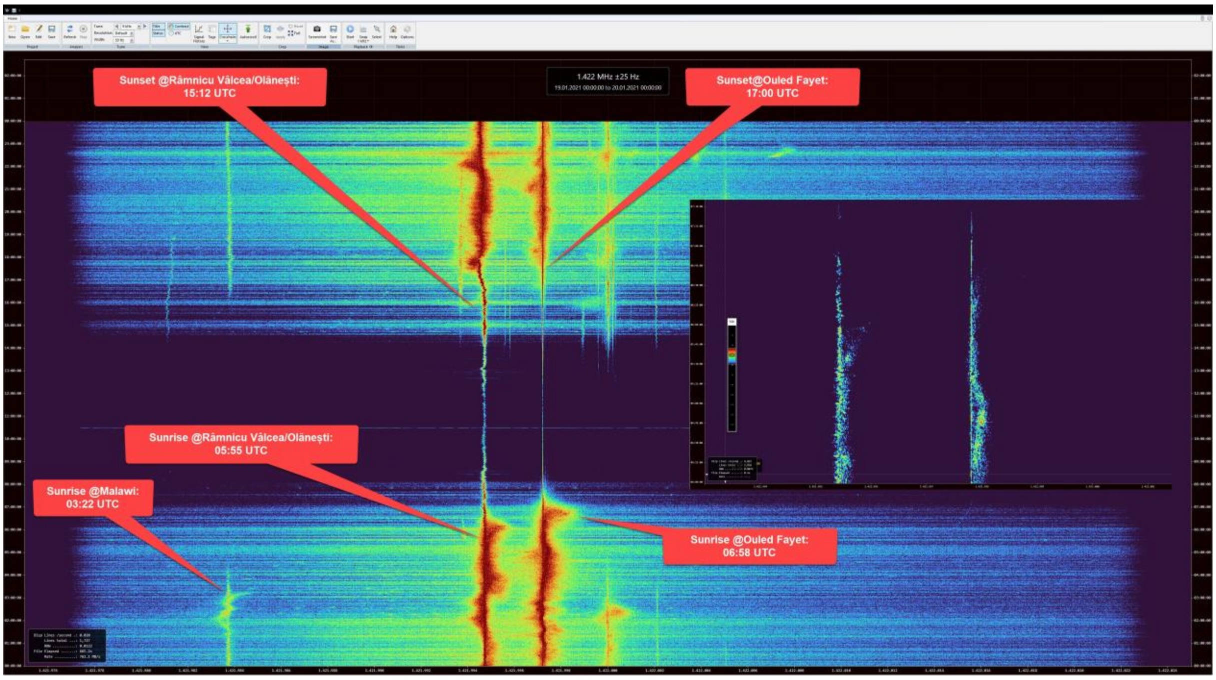

Figure 9: The two stronger carriers (Romania left, Algeria right) exhibit Doppler-shifted scatter; see text for a more detailed explanation.

Other propagational effects are mostly too difficult to be distinguished from technical impairments and are, additionally, not too much pronounced at these relatively low frequencies.

Identification of Stations

The gold standard for identification is an announcement of the station itself. But it is illusory to expect this from faint traces on the spectrogram. Some circumstantial evidence will help, among them:

- Nominal frequency and listed offset in the offset list of MWLIST[8] which cannot be praised highly enough.
- Sign-on/sign-off if a schedule is available – and if this is reliable.
- Fade-in/fade-out following the night zone on the globe, where software DX Atlas is a great help.

Just a few examples to illustrate these points:

If you face an *odd channel*, like 1550kHz for National Radio of the Sahrawi Arab Democratic Republic from Tindouf/Algeria, the case is almost clear – *Figure 10.*

Most stations deviate from their nominal channel by at least a few millihertz. It seems that so far only a few transmitters have synchronized their oscillator to GNSS. They mostly seem to use some quartz-based oscillator (with short-term variations/drift plus inherent long-term aging). A couple of transmitters show a distinctive control algorithm, resulting in e.g., corkscrew-like, or sawtooth traces – *Figure 11*. MWLIST provides many offsets which often may provide convincing hints to specific stations. Whereas the *relative* position of a specific station within the bunch of other stations sharing the same nominal channel is generally reliable, their *absolute* value faces some challenges.

Nearly all data in the past had been collected in a kind of dead reckoning: taking a reference signal of known accuracy and stability and comparing this the offset of other channels. Nowadays, OXCO/GNSS represents the state-of-art in this field – with some caveats, see chapter “How trustworthy is my readout?” later. Another challenge is the instability of carriers, and that propagational effects limit the resolution. The tremendous work put into the known offset list, however, has led to the best we have. But do not consider each entry as set-in stone – as you also should see your results with a grain of salt.

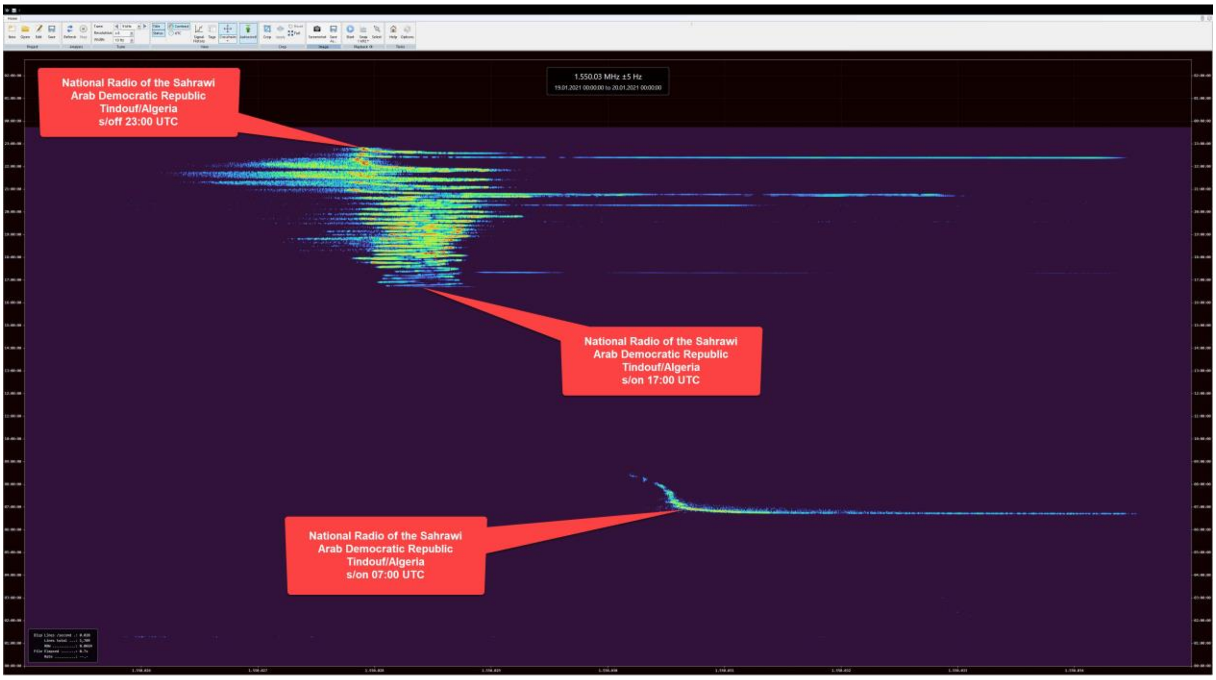

Figure 10: Swinging Sahara - National Radio of the Sahrawi Arab Democratic Republic dancing around 1550kHz.

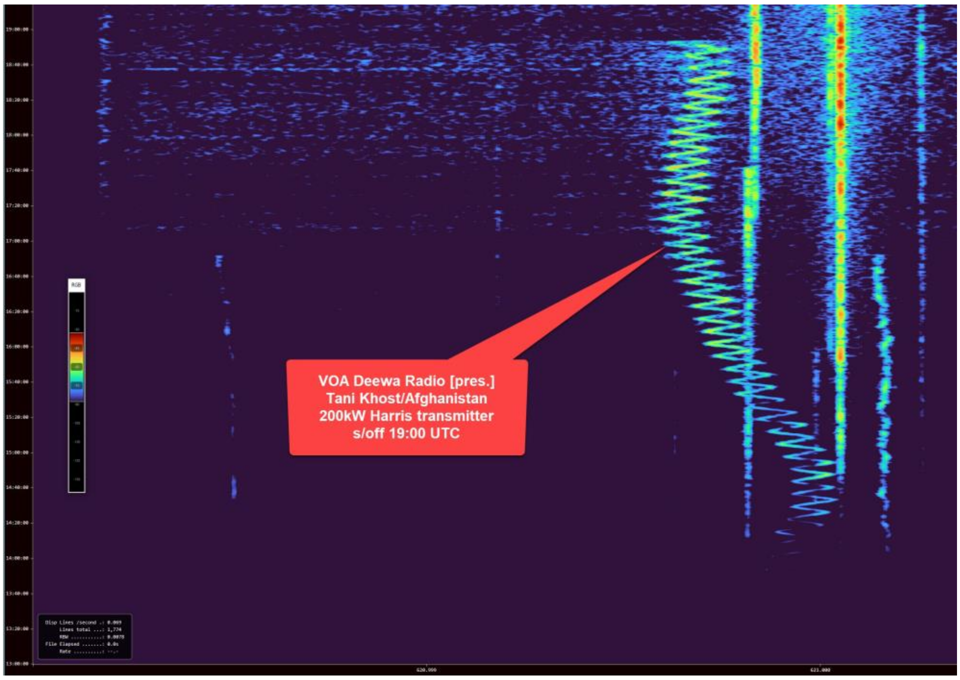

Figure 11: Most likely VOA Deewa Radio's Harris transmitter showing this double-sinus algorithm of frequency control, swinging between 620999,593 Hz and 621000,042 Hz in six hours. If you observe just at a specific point of time, you will not get the whole picture.

Schedules are in many cases reliable. Please bear in mind that we track *carriers*, not scheduled *content*. Often there is a warm-up phase of some minutes, and although most stations switch off when their programme being aired finishes, some of them still leave the carrier on air for a few minutes of silence. If you have caught both ends of a daily schedule – sign-on and sign-off, probably with a break during "in the wee, wee hours" (Chuck Berry, 1957), this is near-perfect.

Fade-in and *fade-out* should be almost obvious for a DXer. Caveat: Thanks to the high system gain of this method fade-in can be exceedingly early, and fade-out incredibly late!

Combining offsets, schedules and propagation will often give near-proof of receiving a specific station. *Figure 12* tries for some detective work without knowing specific offsets (because not available) but relying only on schedule and propagation. Crime scene takes place on 1233kHz, where we want to scrutinize two channels, one on 1232,9937 kHz, the other on 1232,9951kHz.

The s/off- and the s/on pattern match that of Chinese National Radio #17's Kazakh service. Incidentally, sunrise takes place in Qinghe at 01:42 UTC, and in Boertala at 02:04UTC – *Figure 13*. Boertala is listed with 10kW (stronger signal), Qinghe with 1kW. Unfortunately, the f/out time of other CNR17 transmitters on this channel is mostly covered by phase noise from Rádio Dechovka in the Czech Republic and Absolute Radio in the United Kingdom.

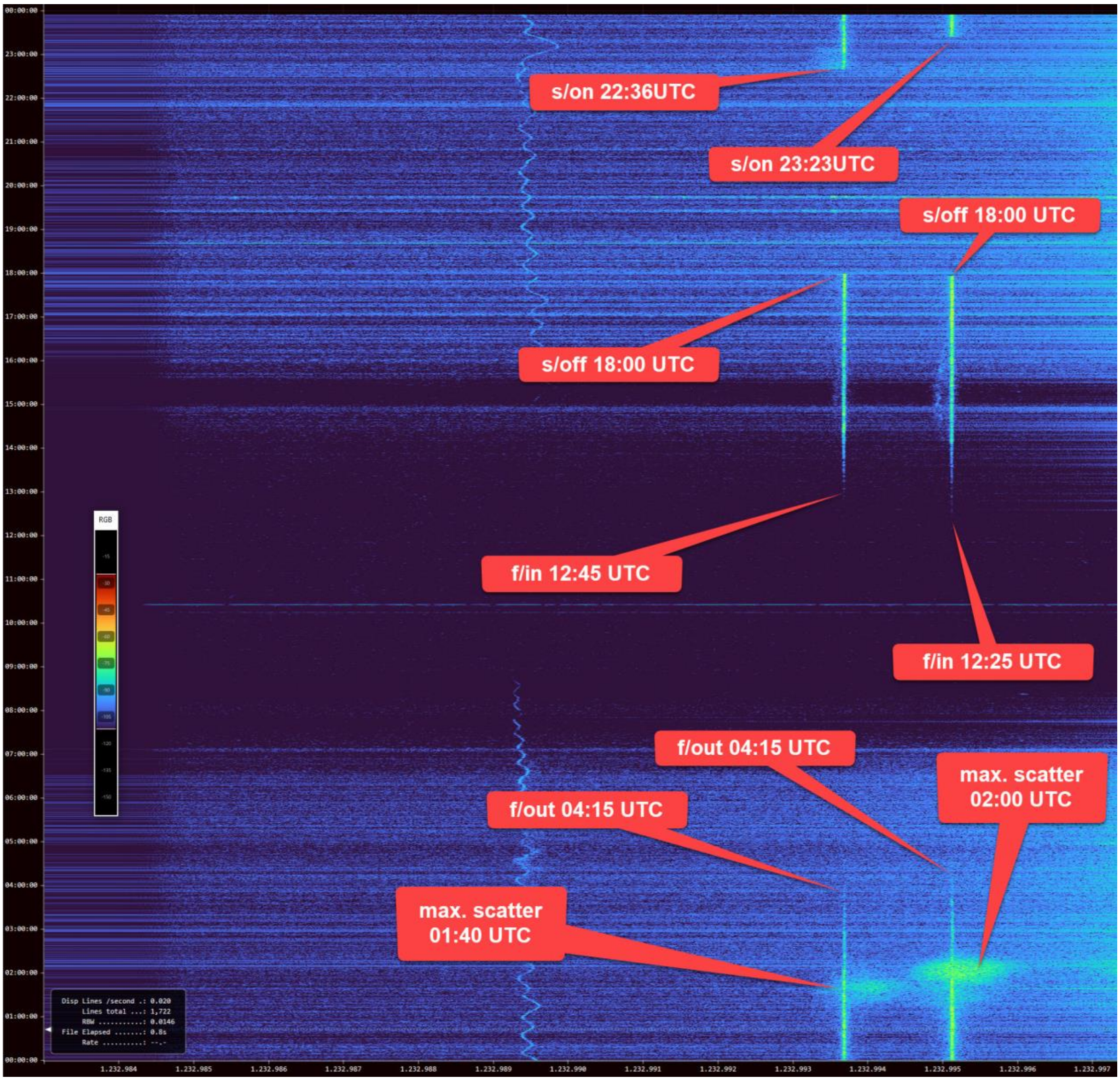

Figure 12: Distinctive scatter, associated with local sunrise at the transmitter, provides a strong hint towards the location.

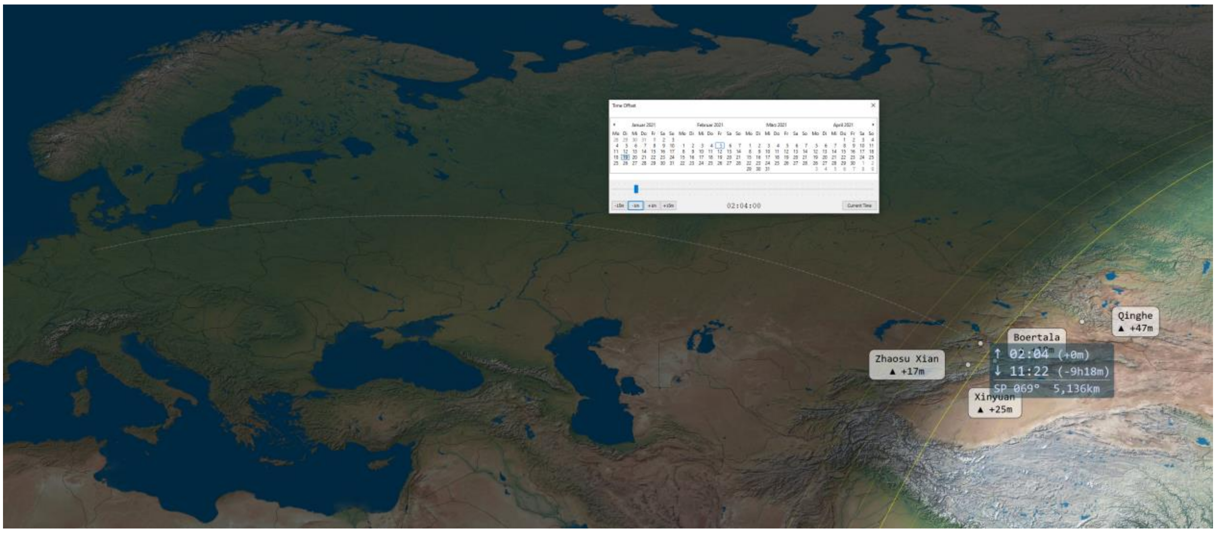

Figure 13: Some CNR17 locations and the terminator during sunrise in Boertala, see text. Visualized with free Simon's World Map.[9]

Rush Hour on Graveyard Channels

With our method, we can view deep into the medium wave: Some countries allocate specific frequencies for low-power station on medium wave, dubbed "graveyard channels". In the U.S., these channels like 1230, 1240, 1340, 1400, 1450 and 1490kHz are used by 150+ stations each, posing specific challenges for DXers to receive and identify. *Figure 14* shows the geographically distribution of 164 channels from coast to coast in the U.S. on 1340kHz – based on MWLIST, visualized with free Tableau Public software. More than 100 of them had been received on January 19, 2021 in Germany, plus some stations from Latin America – see *Figure 15.*

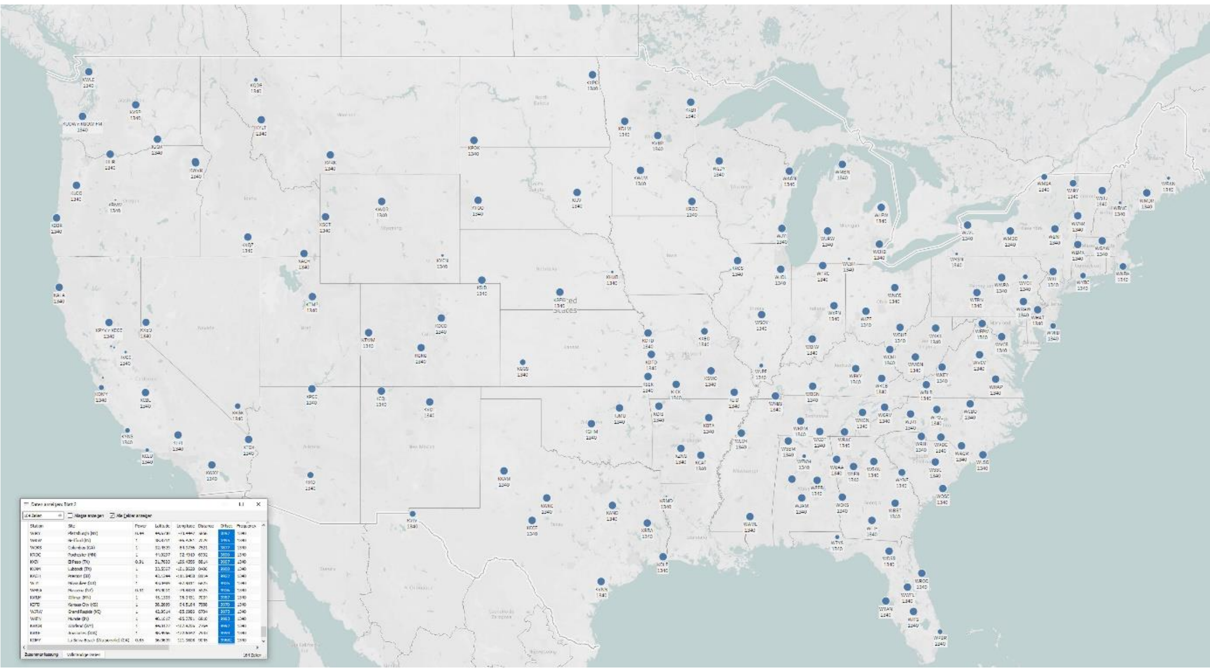

Figure 14: Graveyard channel 1340kHz, as listed on MWLIST; offset's column marked. Visualised with free Tableau Public[10].

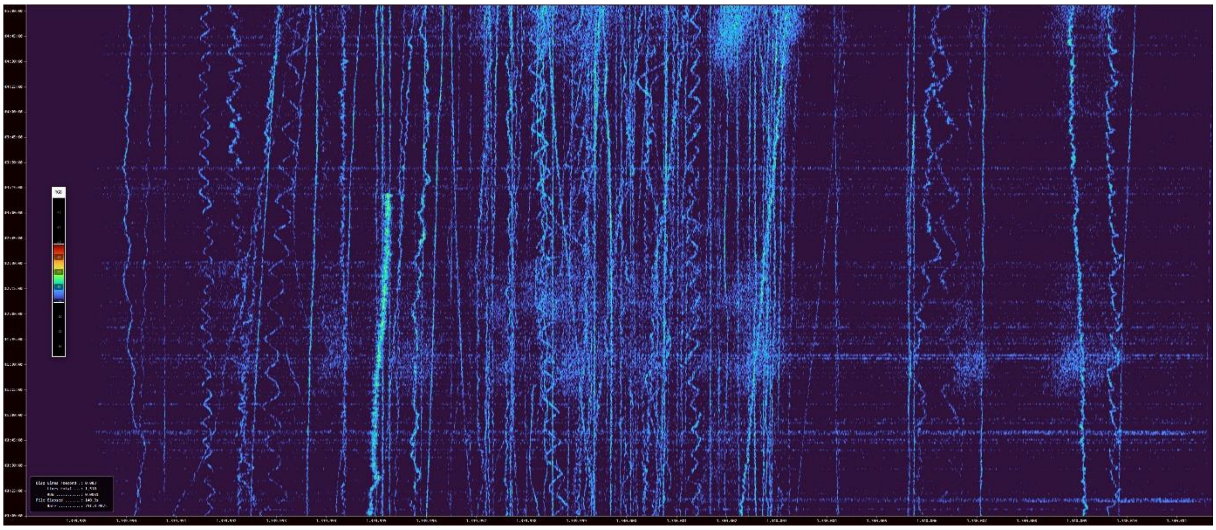

Figure 15: 100+ carriers on 1340kHz in a 25Hz window, received on January 19, 2021 in Germany.

Alternative Software: Carrier Sleuth and PskovNDB

All spectrograms above had been made with SDRC V3 software, see the last chapter for the workflow. By chance, late 2020/early 2021 there popped up some alternatives with some unique features. "Carrier Sleuth"[11] by Chris Smolinski works also on a Mac, digesting nearly each sort of HF-WAV file, also WAV RF64, recorded by SDRC V3 – *Figure 16.*

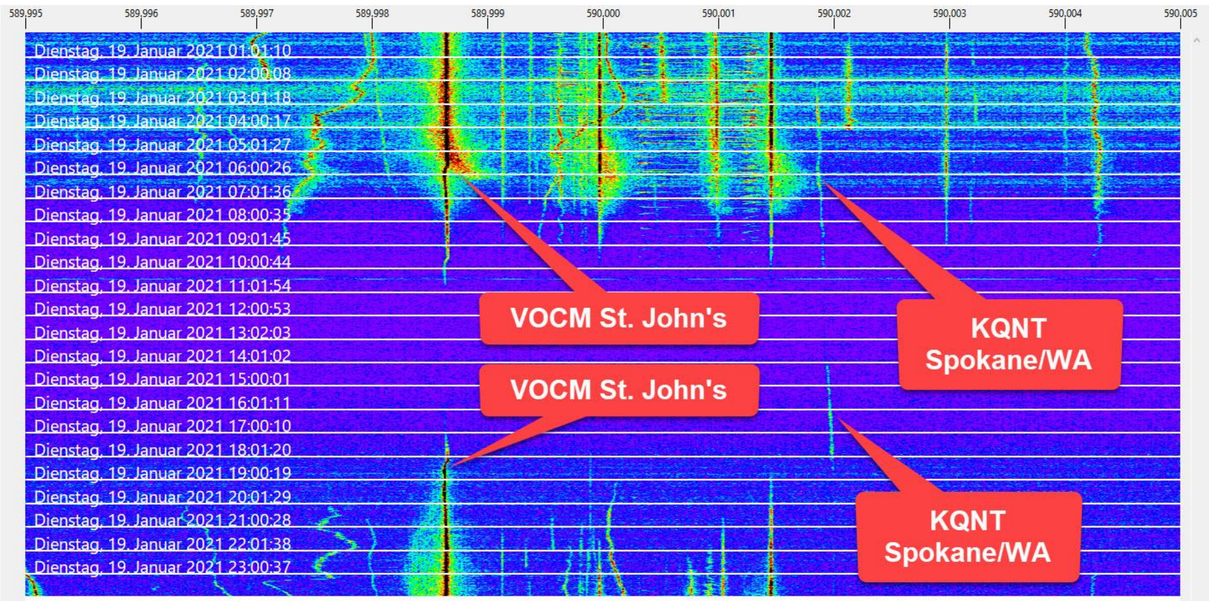

Figure 16: Carrier Sleuth turning its nose towards North America on 590kHz on January 19, 2021 over 24 hours in Germany. VOCM from Newfoundland is seen fading out at the receiver's local noon to again fade in at 17:00 UTC. A nice side-catch is KQNT from the West Coast, recognizable by the typical afternoon appearance of these locations.

Ivan Monogarov has upgraded his free PskovNDB[12], the world standard that revolutionized DXing of non-directional beacons, for the avid medium wave DXer. One of the outstanding features of this software is to follow the – strictly stable! – track of a station with a high selectivity, and to visualize it in a diagram. This diagram additionally shows the noise floor plus the signal strength of the complete channel (usually ±50Hz or ±100Hz, default) – see *Figure 17* and *18* for an example.

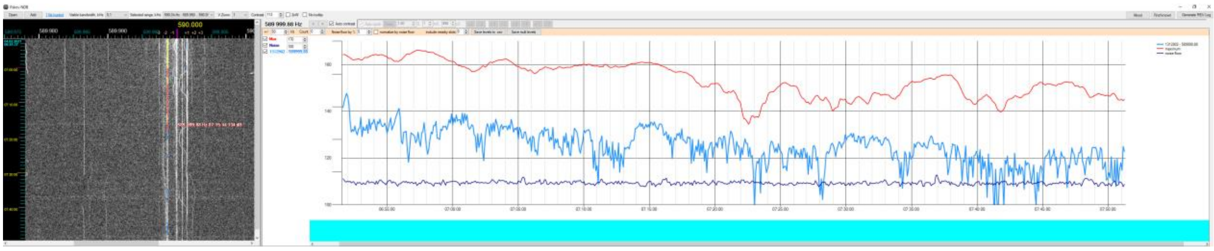

Figure 17: The blue line in the middle shows the signal strength of the carrier on 589999,98Hz (nominal channel: 590kHz). The bottom line marks the noise floor, whereas the upper line represents the power reevied on the whole channel at a bandwidth of ±100Hz around 590kHz.

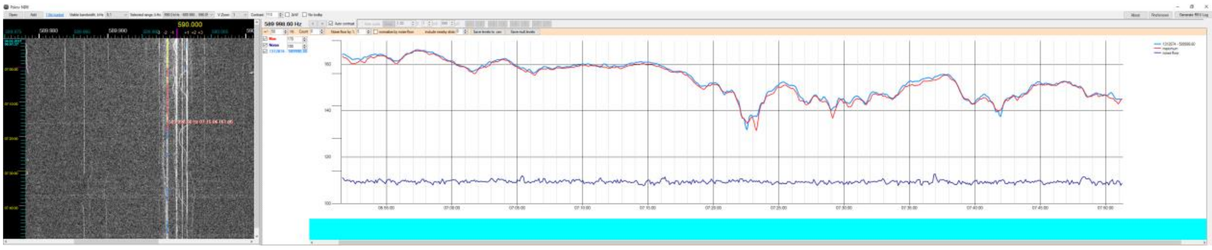

Figure 18: Here the cursor was set onto the strongest signal, 589998,60Hz. In the diagram you see that this signal, namely from VOCM in St. John's/Newfoundland, nearly fully dominates the channel.

It is out of scope of this introductory article to deal with either software in more detail. Take *Figure 19* as a most promising outlook: Ivan combined recordings of 1490kHz, taken from early November 2020 on 22 consecutive days, and combined them into one PskovNDB-diagram. So, you can see changing conditions and pick out when they were best. Ivan even found a method to find out noticeably short openings of just (several) ten seconds, where a signal may raise out of the noise, reaching different states of intelligibility - from distinguishing e.g. "When the Saints go marching in" from "Ferry cross the Mersey" to completely understand NPR news talk.

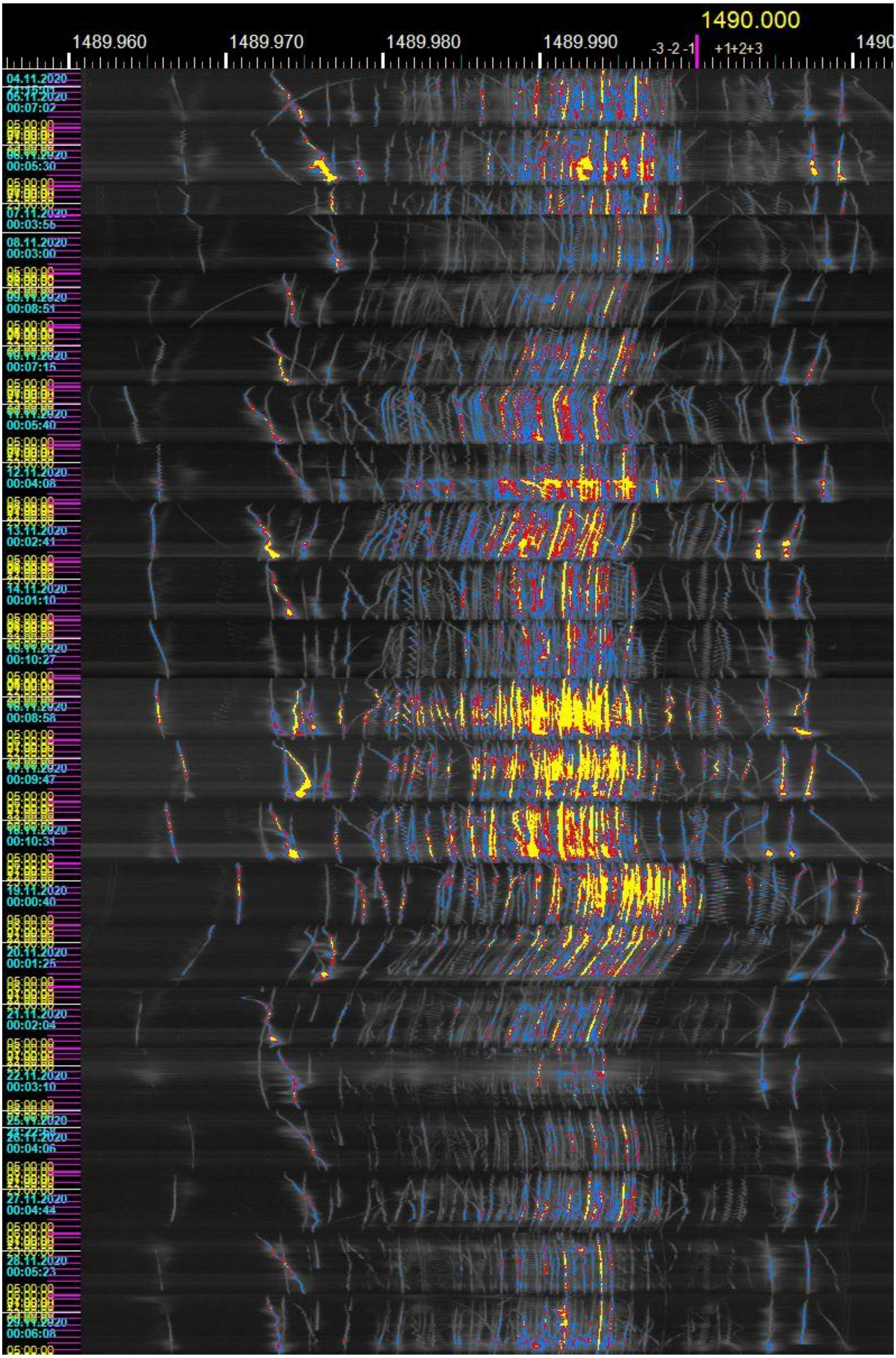

Figure 19: Screenshot of visualizing 1490kHz over 22 consecutive days by Ivan Monogarov, w/Pskov2.1a, by friendly permission.

How trustworthy is my readout?

If you go back to *Figure 2*, you will see that even with a setup of combining OCXO/GNSS there still are some remaining factors of uncertainty. In a discussion with Nick Patch-Hall [private communication], he raised the well-reasoned question: May the same WAV file lead to different frequency read-outs if processed by different software? And much to my dismay, he also gave the answer: “Yes!”

He found out that the read-out of different software, based on the same WAV file and the same station, differed by as much as 0.4Hz. Even more: The read-outs of one station but processed at different resolution and centre-frequencies by the same software, also differ from each other by some fraction of a Hertz!

To check this unrefreshing topic, I did four hours recording of the whole medium wave in the late morning with quiet conditions and picked out some 20 channels which produced a straight line over these four hours – no visible drift, no sinus- or sawtooth-like transmitter’s frequency control. Recording had been done with SDRC V3, chaining files of 1GB each. With SDRC V3’s Datafile Editor, some 20 channels were picked out with 1kHz bandwidth each. These were processed as follows:

- SDRC V3 File Analyser 3.0.27, build 2130:
  4Hz bandwidth, x8 resolution, 1000 lines; resulting in a resolution bandwidth of 0.007812Hz. Max. readout: .001Hz. See *Figure 20*.
- PskovNDB 2.1beta:
  Overnight plot mode, 0.046Hz resolution, see *Figure 21*.
- Carrier Sleuth 2.20.b3:
  FFT length 512K, Frequency Width 10Hz (smallest available). Max. readout .1Hz. See *Figure 22*.

As an example, only 1350kHz is shown below. It works as a convincing proxy for the other channels.

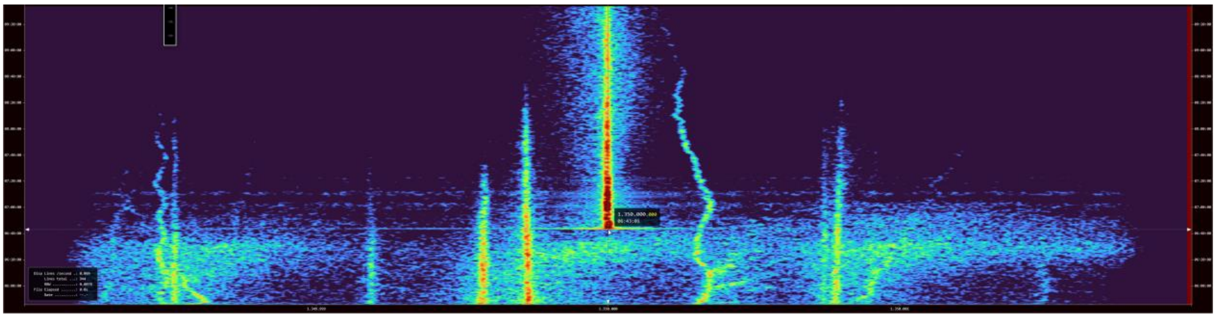

Figure 20: MR4 Nemzetiségi Adások from Győr/Sárás in Hungary is seen on exactly 1350.000000kHz via SDRC V3’s File Analyser; see read-out.

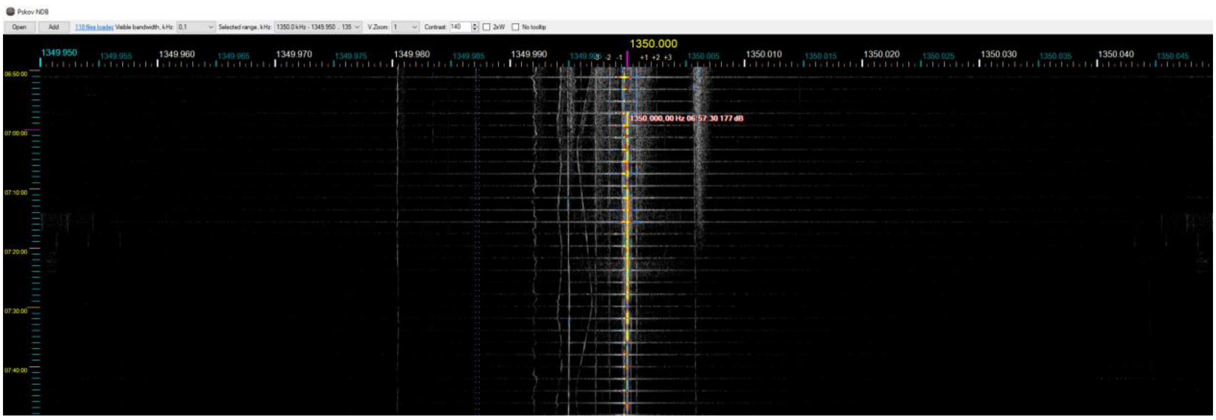

Figure 21: PskovNDB giving the same reading within its .01Hz resolution.

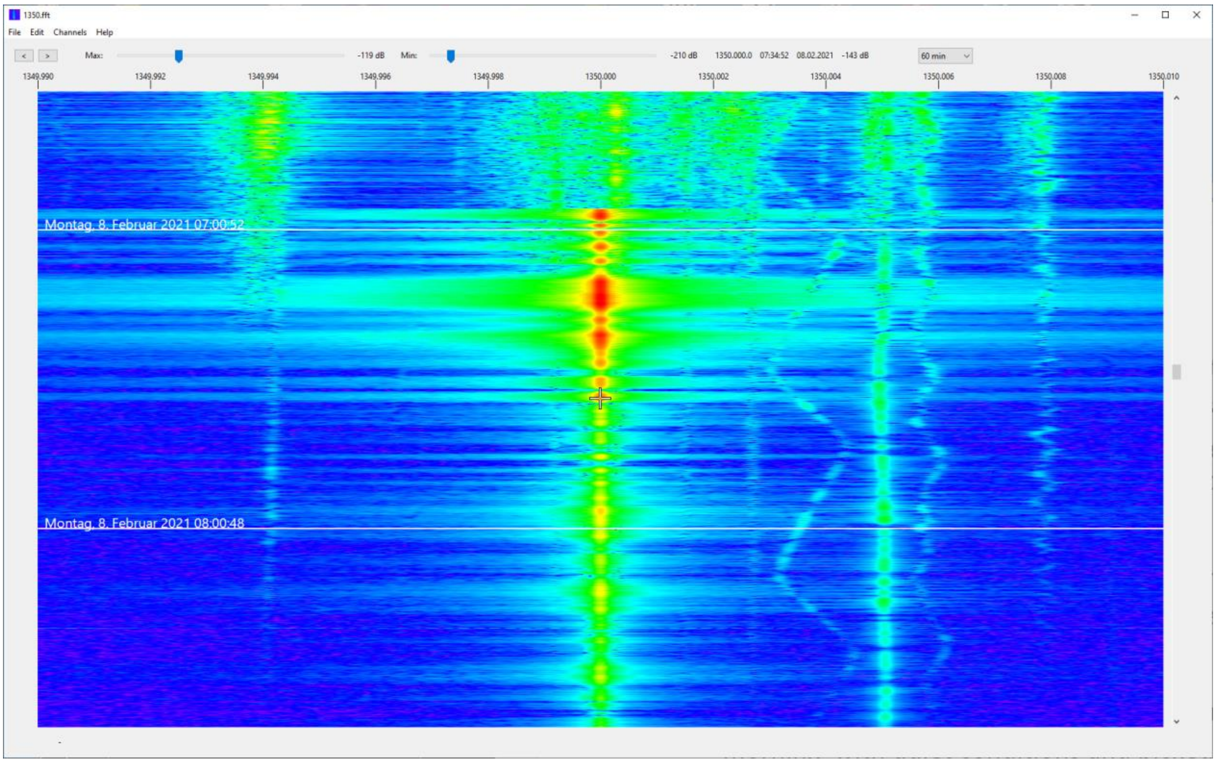

Figure 22: Carrier Sleuth software sees this transmitter also on the same frequency, in respect to its ±0.1Hz read-out resolution.

The result of this comparison is clear: in this case (same basic WAV file, specified software versions, given workflow, same PC/display), we get exactly the identical read-out at the given resolution. However, and this is where Nick's quite thought-provoking comment comes into play: It seems that OCXO/GNSS fixed just one possible error, only making visible others. So, when doing these measurements, both is needed: taking care, and more research.

Brute Force: A proven Workflow

As with cooking, *mise en place* – or: putting all things ready to hand before the real work starts – is the key to fast results also in DXing. There are many workflows, I just show you mine with SDRC V3[13], being brute force and possibly much overdone in many cases (e.g., in summertime):

- You do a recording of the whole medium wave band over 24 hours, scheduled, starting at midnight one day and ending at midnight the same day. This sets you back 531GB of hard disk capacity. Cheap HDDs work fine, more expensive SSDs will care for an even faster post-production.
- For a fast offset measurement of just the carriers, you cut this recording into pieces: each channel (9kHz and/or 10kHz, each just 1kHz wide).
  SDRC V3 provides a Data File Editor for this, where you should use the feature "Add Sequence" over a proper range, using a proper distance (9kHz or 10kHz) and width (1kHz) – see *Figure 23*.
  Caveat: Each 1kHz wide recording of just one channel/24 hours weighs 320MB. Yes, for this approach you need ample disk capacity.

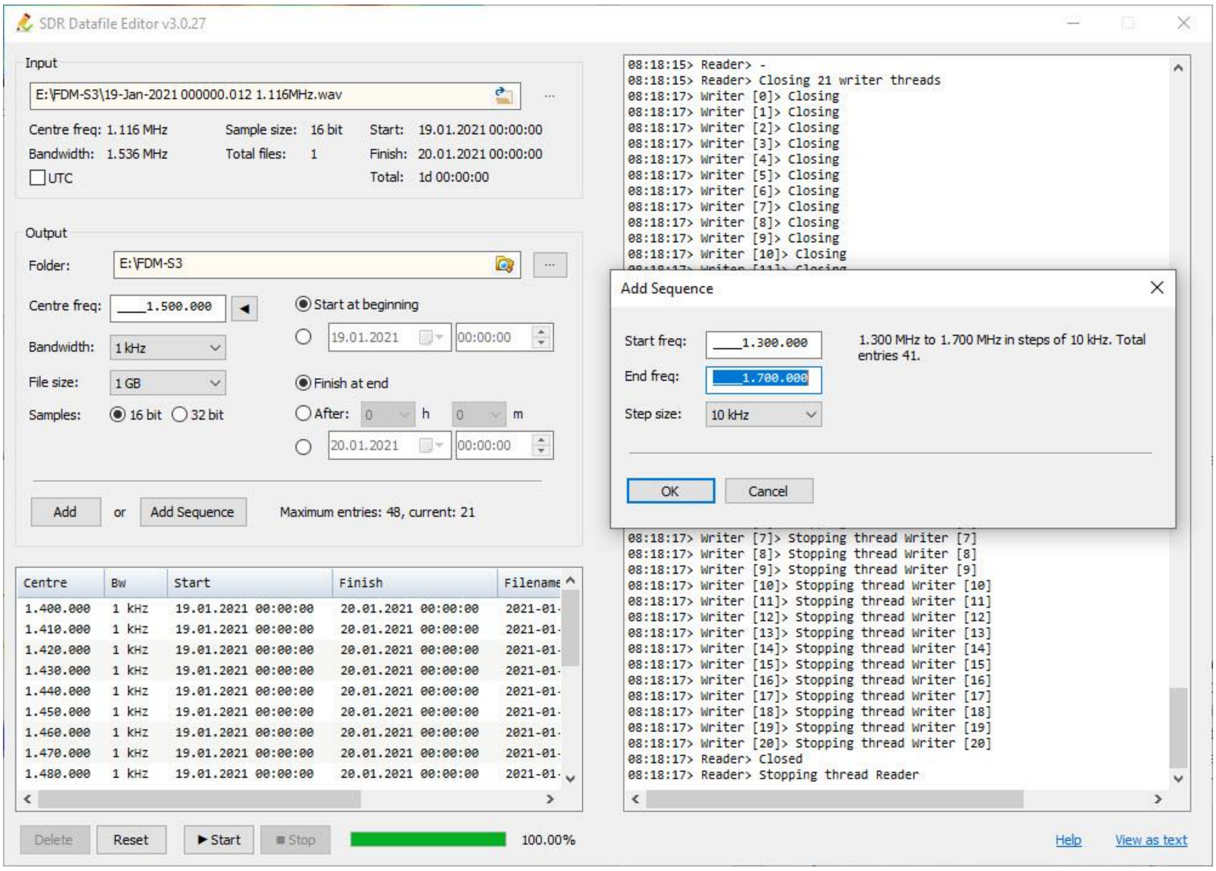

Figure 23: SDRC's Data File Editor cuts a big recording into handy pieces.

- To do a spectrogram, open the desired channel with SDRC's File Analyse module – menu "New". The "Select Recording" window will open (*Figure 24*).
- Locate and pick the file (channel) you like to analyse. You may need to change the folder and/or press "Reload" button to access the desired file and double-click it.
- Window "General Settings" will open – *Figure 25*. Do all your setting, starting from centre frequency to bandwidth, resolution etc. You may also limit the time of the spectrogram. Have also an eye on the automatically updated values for "Res.(olution) bandwidth" and "Page Size" in pixel, bottoms right.

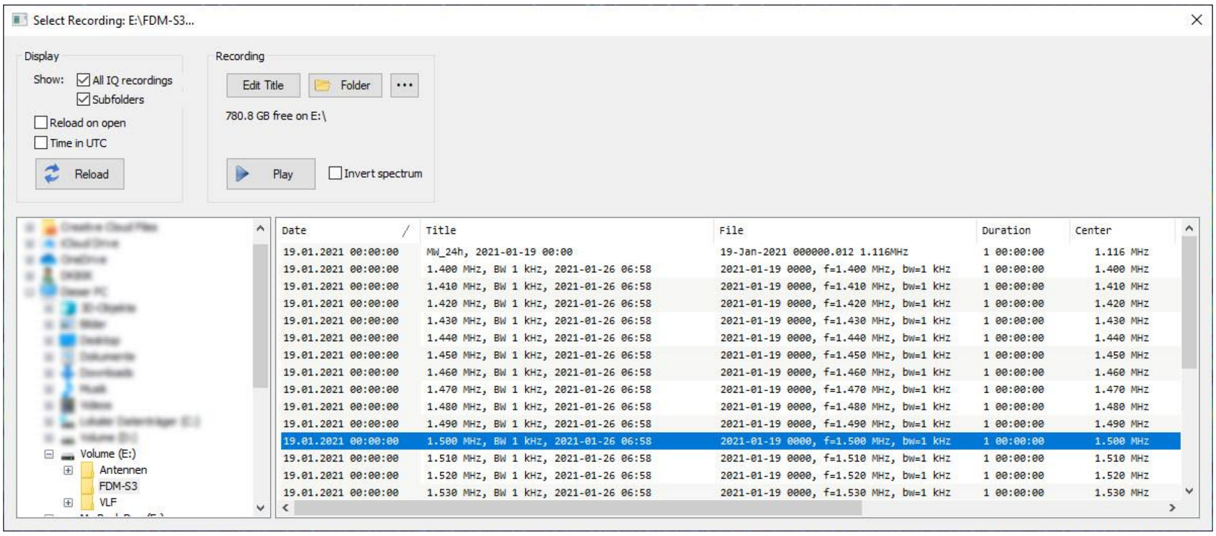

Figure 24: To do a spectrogram, first select the file/channel …

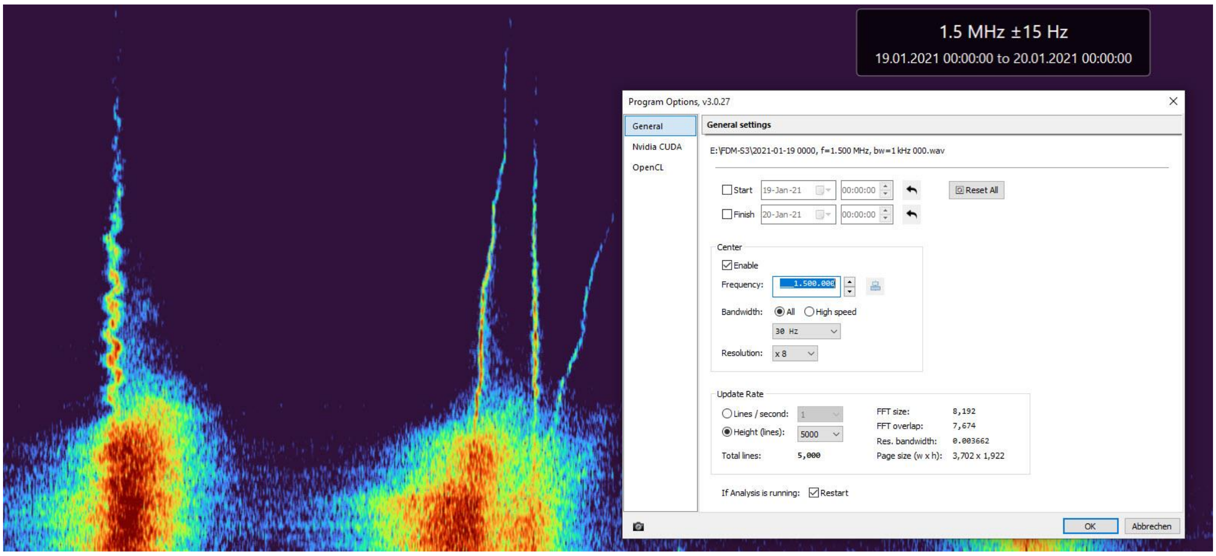

Figure 25: … tweak some General Settings in the windows of just this name, and after clicking OK the spectrogram will appear.

24 hours/1536kHz sounding too beefy like cracking a nut with a sledgehammer? Just give it a try with some two hours, or so, around sunset or sunrise to make this new field an easy start. You may also further restrict the recording bandwidth for just a feasibility study.

From where we have started

Last, but not least, a grateful look in the rear-view mirror: *Figure 23* shows the trace of standard time and frequency station CHU Ottawa/Canada on 7850kHz. Its signal has been visualized via the soundcard with SBSpectrum software, written by Peter Martinez, who also pioneered modern digital amateur radio communications back in 1998[14].

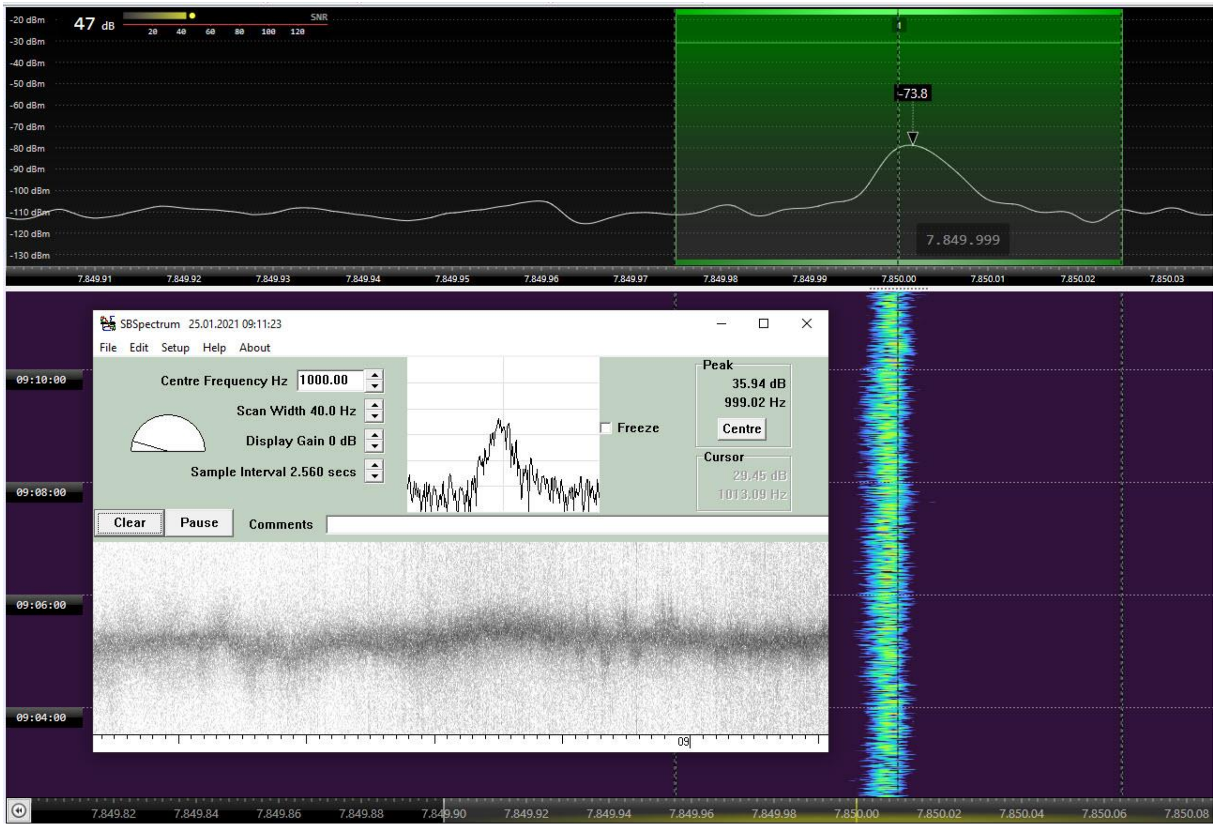

Figure 26: The trace of CHU on 7850kHz from about 08:30 to 09:10 UTC, as shown in the 40Hz window of SBSpectrum software (left window) – received in CW and demodulated with SDRC V3 software (background); AGC OFF. You see the dispersion of the signal as well as a considerable instability of the received (!) frequency due to ionospheric propagation.

Further reading: on my website[15], I have published two atlases, each with detailed screenshots of 9kHz- and 10kHz-channels, respectively, within a 50Hz small window. The 9kHz atlas also includes a bonus track with similar screenshots from Standard Time and Frequency Stations on VLF plus all broadcasting channels on longwave. You may download these whopping PDFs for free, save them on your PC, and open it with a PDF reader. At a zoom of up to 400%, they reveal many details and allow for a reading of offsets at a high resolution. They all stem from full 24 hours' recordings in Northern Germany, January 2021 – *Figure 27* shows one of the covers.

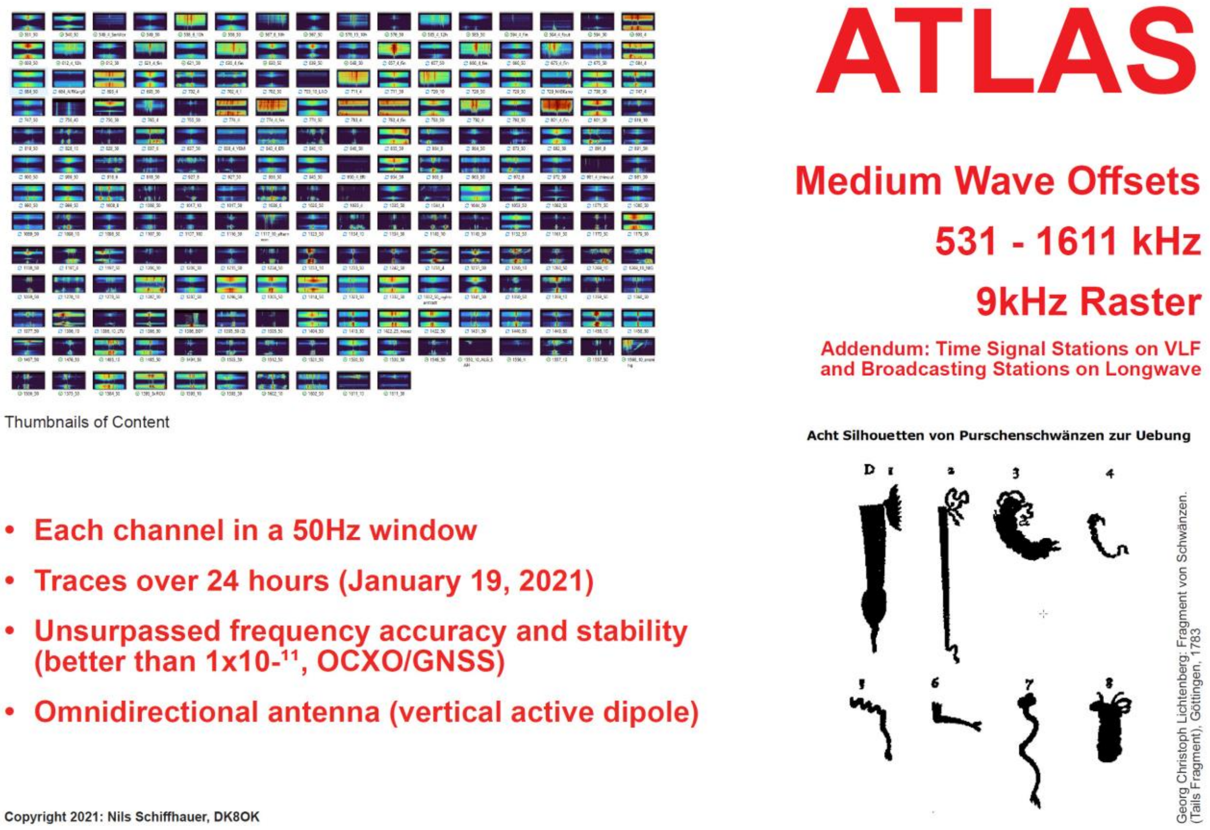

Figure 27: One of wo atlases provide a detailed overlook on each 9kHz- and 10kHz-channel, respectively, over a full period of 24 hours.

[1] https://www.eladit.shop/en-gb/Ricevitore-SDR-FDM-S3-p209053139
[2] See: https://tf.nist.gov/general/pdf/2297.pdf for the general concept
[3] https://www.bonito.net/hamradio/en/megadipol-md300dx-wideband-active-dipole/
[4] https://www.visualgps.net/#nmeatime2-content
[5] See also BBC Report BBC RD 1977/12: L.F. and M.F. Propagation: a study of sky-wave field-strength variation", P. Knight, BBC, March 1997. https://archive.org/details/bbc-rd-reports-1977-12/page/n9/mode/2up
[6] https://www.qtiplot.com/index.html
[7] https://www.timeanddate.com/sun/ provides excellent tool to determine sunrise/sunset and other sun-related data also based on locations on Open Street Map. It has been used here.
[8] https://www.mwlist.org/mwlist_quick_and_easy.php (click "Offset" on each channel)
[9] https://www.dit-dit-dit.com/world-map
[10] https://public.tableau.com/en-us/s/
[11] http://blackcatsystems.com/software/medium_wave_carrier_display_app.html
[12] Ivan supplies the newest version of PSKOV via his Yandex.Disk.He publishes the link within the newsgroups NDB and MWCIRCLE, or drop him a line at monogarov@gmail.com. More screenshots at: http://www.radioscanner.ru/forum/topic51492-2.html#msg1513565
[13] https://www.sdr-radio.com
[14] For a detailed discussion of this software, some applications and sources to get this even nowadays stunning software, see: https://www.qsl.net/zl1bpu/DOCS/Assessment%20of%20HF%20Antennae%20using%20Doppler%20Analysis.pdf
[15] https://dk8ok.org/