

Direction Finding with TDoA on KiwiSDR Net: An Introduction

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Direction finding (DF) by „Time Difference of Arrival“, or TDoA, is a method, in use for more than half a century by professionals.¹ Thanks to the work of Christoph Mayer et al., it became available in summer 2018 for everyone and for free via the renowned KiwiSDR net.

Available from July this year, the renowned [KiwiSDR](#) net of worldwide scattered software-defined receivers offers a direction finding tool under extension “TDoA” . Christoph Mayer, author of the main part of the software, delivers a full view on the background of this system – and much more – on his website “[Signal Monitoring and Analysis](#)”.

In this paper, I would like to share my first experiences with TDoA. As this is not a “fire and forget” tool delivering reliable results within some kilometers, I will first give a short introduction into the general concept, followed by some examples.

Handle with care! had been my driving motivation in writing this text, as this stunning tool needs some knowledge to get reliable results. It looks that easy, and most results may look convincing, but you always have to evaluate them.

Triangulation: 300 km per Millisecond

The basic idea of this tool is triangulation by measuring the time of flight of a signal, received at different locations.

Electromagnetic waves – light and HF among them – travel at a speed of 300 km per millisecond. If you receive a transmitter at two different stations, the signal will reach each station at a different time (well, there are exceptions ...). As you don't know the absolute transmitting time, you get only the *time difference of arrival* of this signal at both stations.

To measure this time difference, you have to tune two separated receivers to exactly the same station. Then the software takes a probe of 30 seconds of the content of this transmission. It is saved as I/Q stream, precisely tagged with GPS timestamps. In the next step, both I/Q recordings are compared to find the time difference of arrival. This process is called “cross correlation”, and it delivers the time difference – *Figures 1 to 3* overleaf are showing this process in general.

¹ See e.g. „Hyperbolic Direction Finding with Sferics of Transatlantic Origin“, Bedford, USA, from 1962 at: <http://www.dtic.mil/dtic/tr/fulltext/u2/a286621.pdf>

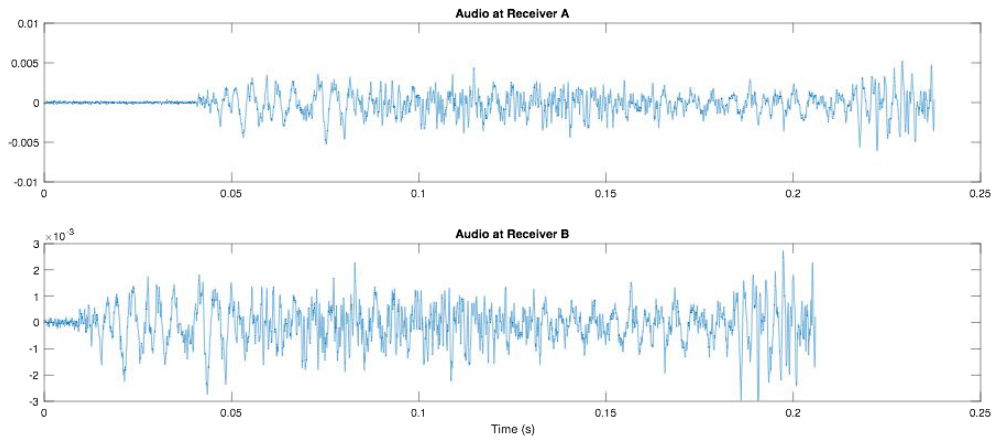


Figure 1: Received audio from two receivers differs in time: receiver A hears the signal first (and a bit stronger), receiver B with a time lag.

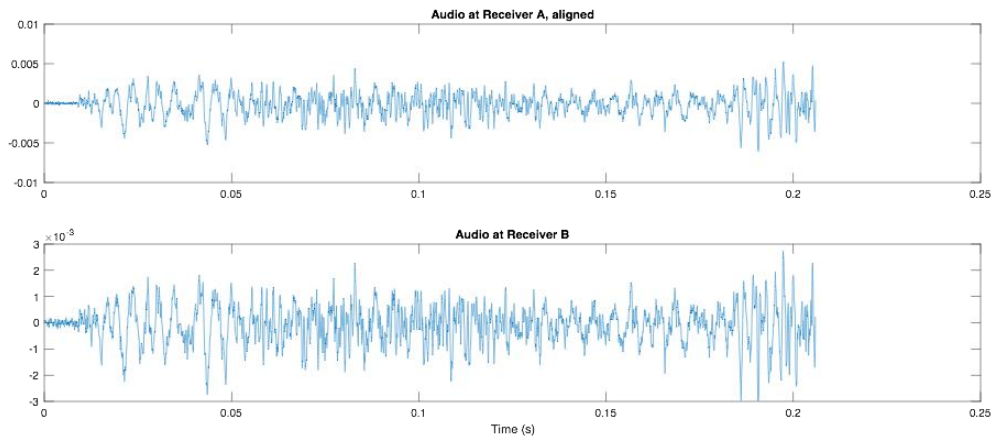


Figure 2: Both recordings are aligned. This process is called “cross correlation”, and ...

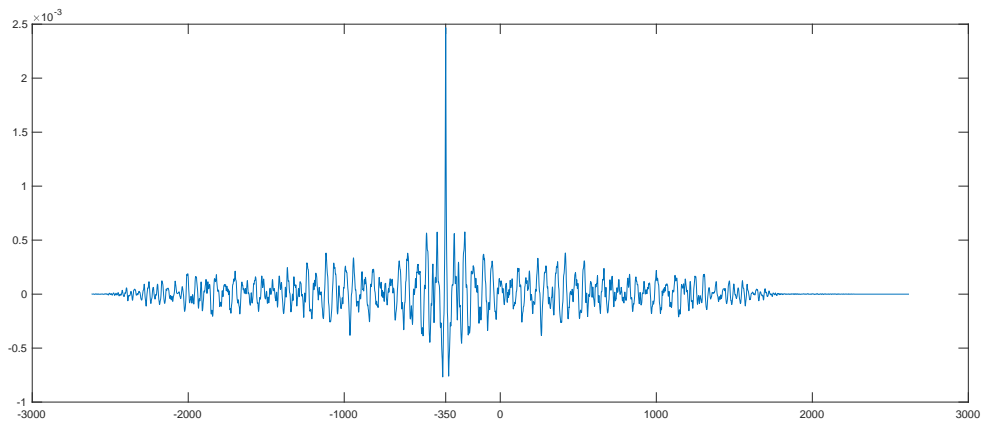


Figure 3: ... it delivers a sharp peak at exactly the time difference, here -0,035 seconds.

All you know by the calculation of the time difference of arrival of just one pair of receivers is, that the station must be located *anywhere* on a special curve (hyperbole), drawn on a map – see *Figure 4*. Although the software will try to do an estimation of the location even from just two receivers (here: 59.20N/6.20W), you need *at least a third station* to calculate each time difference of arrival of the resulting pairs of receivers. Then you can draw several hyperboles on the map, that hopefully meet in just one point: that of the transmitter's location. *Figure 5* shows an example, where *three hyperboles* do meet in the region of the transmitter.



Figure 4: Each pair of receiver will draw a hyperbole onto a map – a curve of all possible positions of a transmitter, matching the same “time difference of arrival” of this pair. Here an example with receivers “Emerald” and “DL0073SWL” on 198 kHz (BBC4), July 25th, 2018, 09:30 UTC.

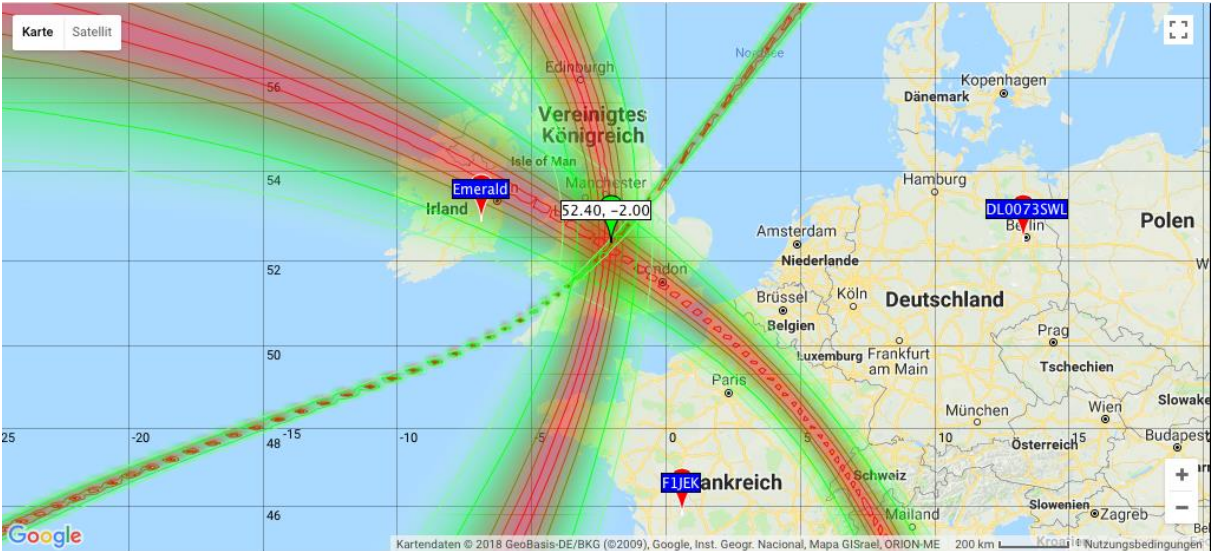


Figure 5: Adding a third receiver (“F1JEK”) to this process will draw three hyperboles - Emerald/F1JEK as the most sharp line and Emerald/DL0073SWL plus F1EJK/DL0073SWL.

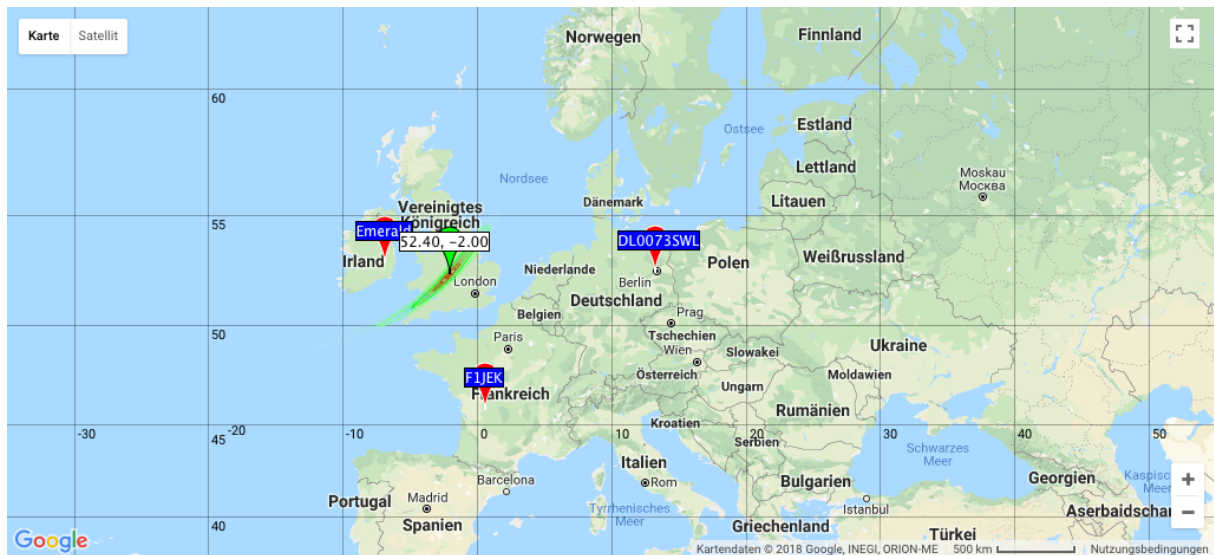


Figure 6: The result of measurement, cross-correlation and computation is a small region ...



Figure 7: ... with the most likely location of the transmitter duly marked. In this case with a deviation of just < 10 km south-west.

This direction finding on *long wave* really nails the station. You see from *Figure 5* that the *width* of the hyperboles is an indicator for the reliability of the results: the sharper, the better. Choose your receivers accordingly.

In this example, we used a long wave station with the same and stable propagation to all receivers. This makes direction finding by TDoA in most cases a no-brainer – but beware of co-channel interference at some receiver!

On HF, however, you have also to take *ionospheric propagation* into account. Let's have a look at how to cope with this mechanism.

Time is Distance

I don't want to go too much into the details of HF propagation, but just the basic facts:

- HF is reflected (recte: refracted) at different layers of the ionosphere.
- By this, the signal is zig-zagging from transmitter to the ionosphere and earth to the transmitter.
- This way is longer than the great circle distance between transmitter and receiver.
- There may be a mixture of modes/paths, causing selective fading. This is indicated by (undulating) trenches within the spectrogram of a signal.

From these points you may derive at least two recommendations to measure mainly the actual location and not propagation itself that almost undoubtedly will give wrong clues:

- All receivers should show a *similar* propagation to the transmitter.
- Reception at all receivers should be stable, at least of fair strength and preferably with as few multipath propagation as possible.

Figure 8 shows “flight of time” of an HF signal at an one-hop propagation around Hamburg.

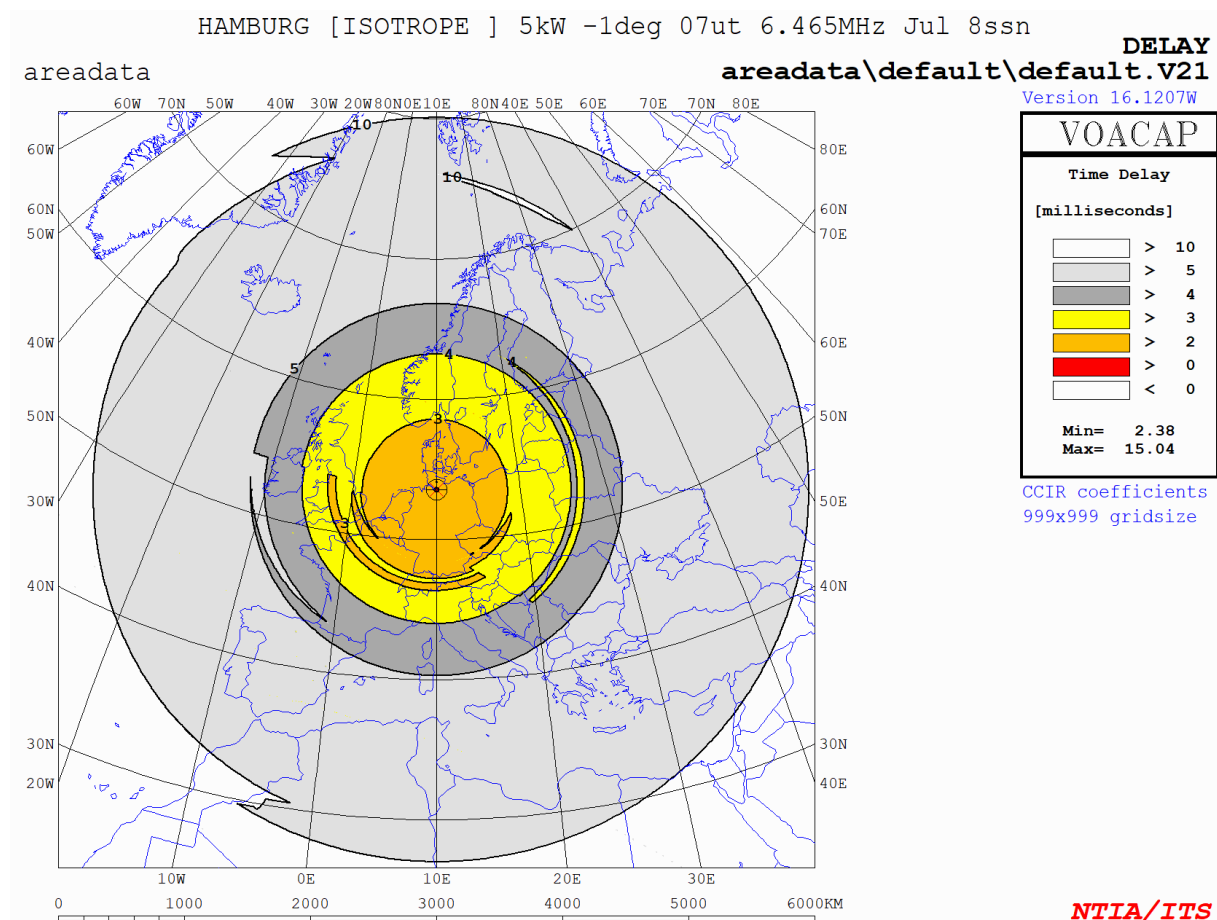


Figure 8: Distribution of “time of flight” from/to Hamburg on the given data.

Iteration: “Try and try, you’ll succeed at last” (Jimmy Cliff, 1972)

If you have some experience in setting up the receivers to reliably find *already known locations*, you are ready to set sails into the unknown. There sometimes you may feel like the Bellman in “The Hunting of the Snark” (Lewis Carroll, 1876) having at hand [just a map showing: nothing](#).

As direction finding is mainly about propagation, you should first answer the following question:

- At given date, time, frequency and location: What *regions* can be received *at all*?

Let’s take an example:

I received a CIS-12 signal on July, 25th 2018 on 6.465 kHz at 06:30 UTC at DF0KL’s receiver in Northern Germany. The signal is at fair-good strength with only slight multipath. This has been set up in [Proppy](#), web-based service of VoACAP, still dubbed “the gold-standard” in propagation software. The calculation gives a footprint, showing the maximum of “base circuit reliability” (BCR) of 70 to 80 % within the first hop zone around the receiver – the just not fully closed circle in *Figure 9* below. This can be also read as “regions of most probable locations of a stable signal with just slight multi-path”.



Figure 9: Judging from the stable reception, the transmitter should be most likely located in a zone of 70 % base circuit reliability.

This gives an idea from which regions we can expect a signal. With this basic knowledge, I set up three receivers for doing a first direction finding – see *Figure 10*. This first measurement has to be refined in (here) three successive steps (*Figures 11 to 13*) to approach the most likely receiver’s location, eventually turning out to be most likely the Kaliningrad port of Baltysk (*Figure 14*). This result matches all relevant conditions like propagation, CIS-12 mode and the well-defined contour of the spot.

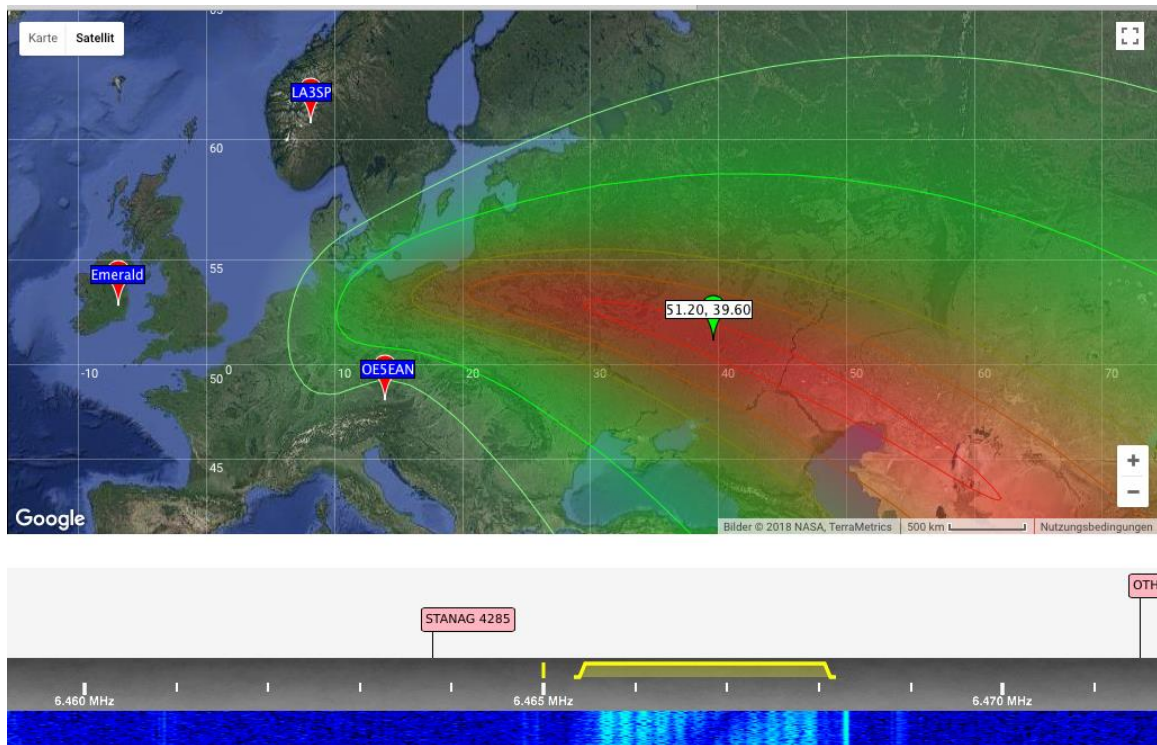


Figure 10: A CIS-12 signal on 6465 kHz – a first try with the marked receivers points to “the East”, but giving not a particular spot. Obviously, “Emerald” receiver is blurring the picture because of propagation.

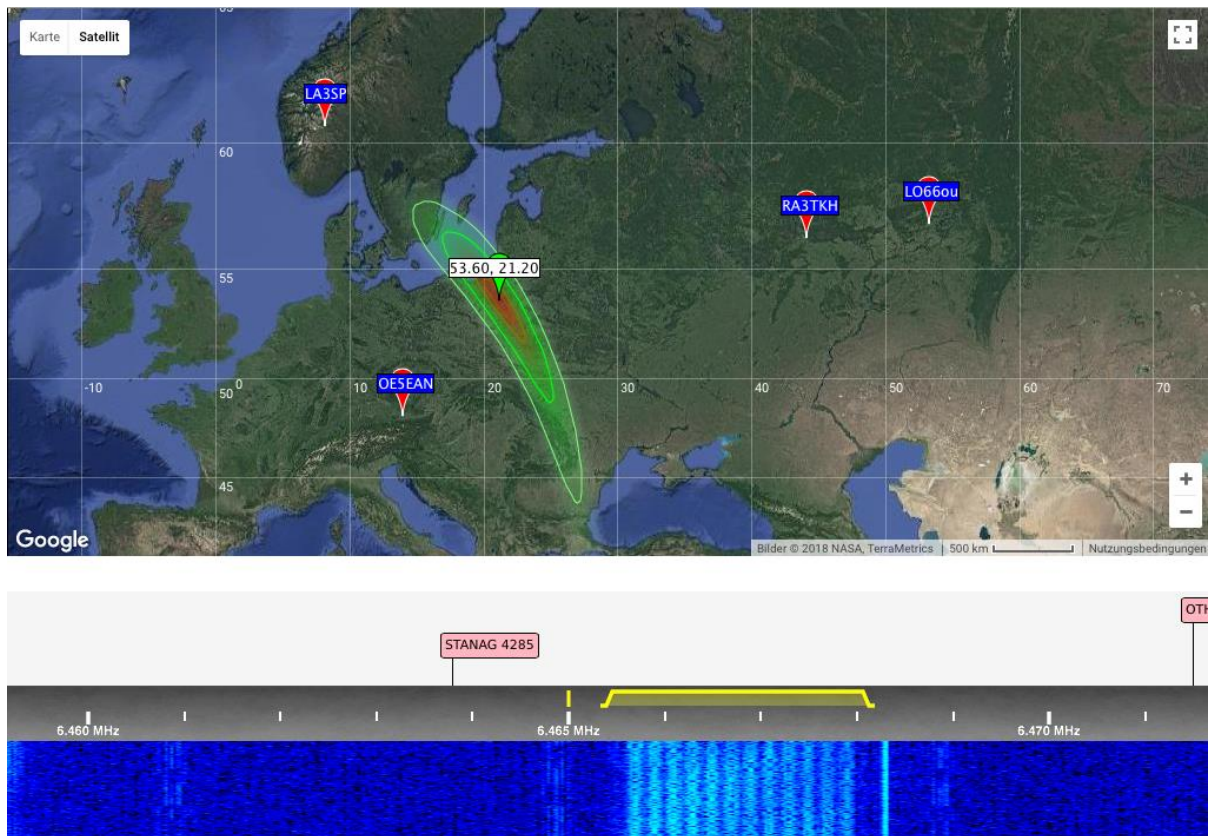


Figure 11: Changing “Emerald” receiving site for two stations in Russia, gives a more precise idea.

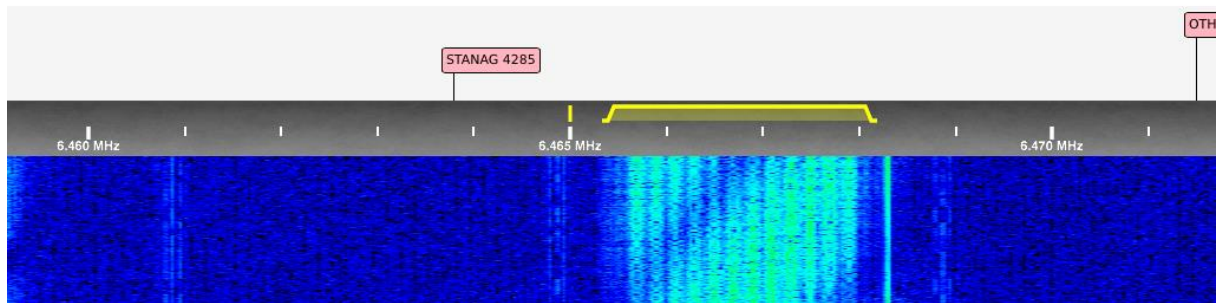
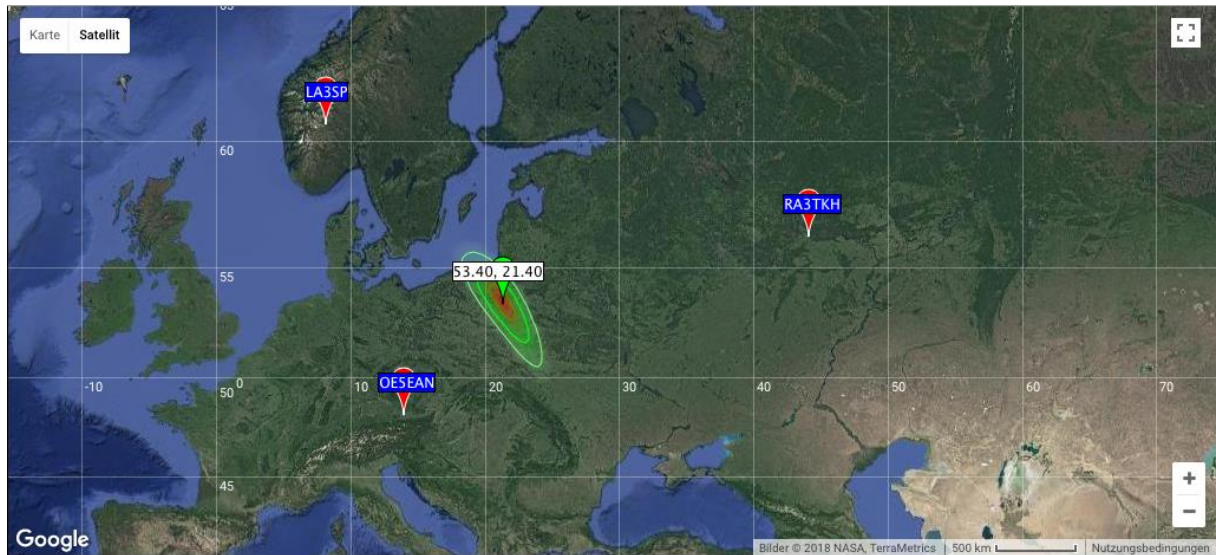


Figure 12: Optimizing it further, even sharpens the spot. The transmitter's location should be most likely in northeast Poland, where the borders to Kaliningrad, Lithuania, Belarus and Ukraine are not far from it. But that's not the end: Having the CIS mode in mind, "Kaliningrad" turns out to be the most likely location, see next Figures.

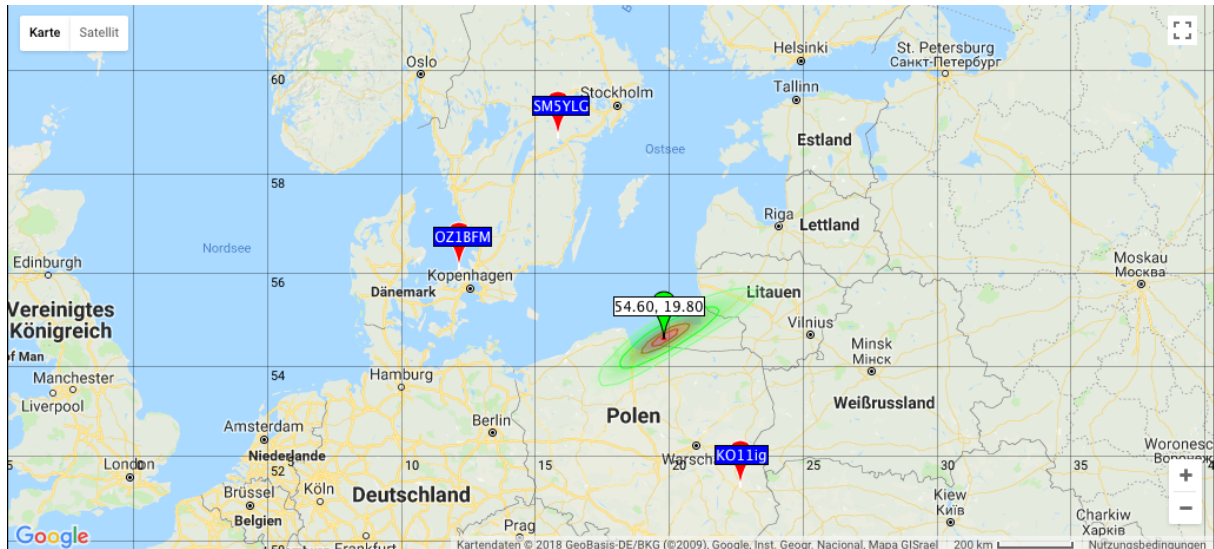


Figure 13: A proper re-arrangement of receivers turns the spot a bit to the northeast ...

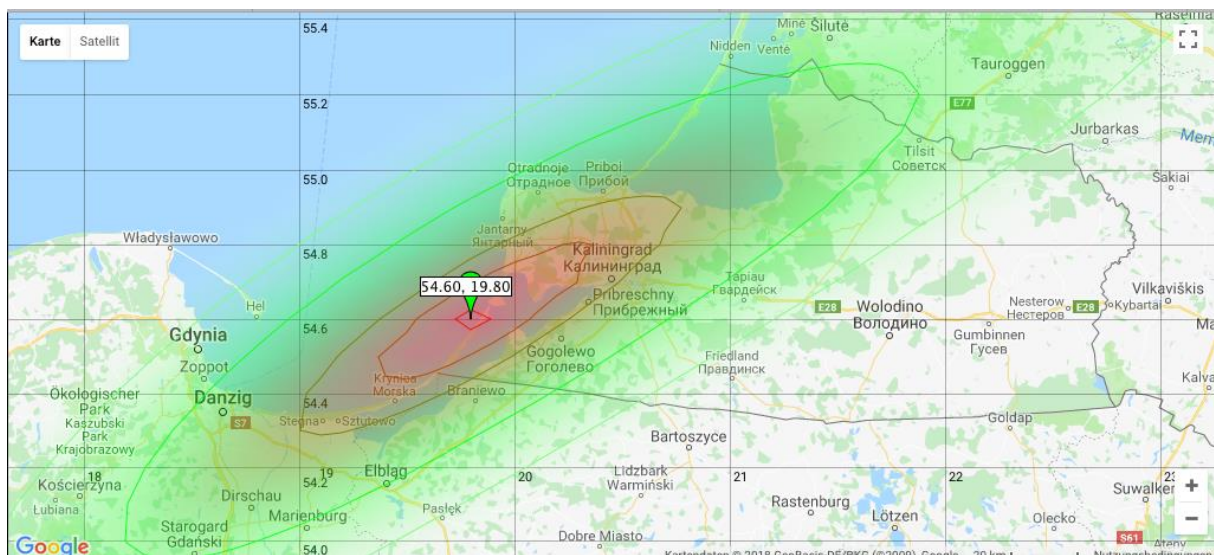


Figure 14: ... where a still closer look seems to point directly to the busy Russian Navy port of Baltysk [ex: Pillau], still closed to visitors.

If you compare the above screenshot (Figure 14) to our starting position at Figure 10, you see that you must invest some thoughts on propagation and other circumstances to get reliable results of TDoA.

On the following pages, you will find some examples posing different challenges.

Last, but not least: A big hand to all smart people who made the dream of “TDoA for Everyone” become reality. I consider it the most important achievement to DX after SDRs putting on the internet. KiwiSDR has it all – excellent receivers with the experimenter’s in mind (GPS timestamps), many locations, smart software authors and an avid community.

- 2613,7 kHz German Navy Rostock (Hohe Düne) STANAG4285 – 23JUL2018, 17:00 UTC

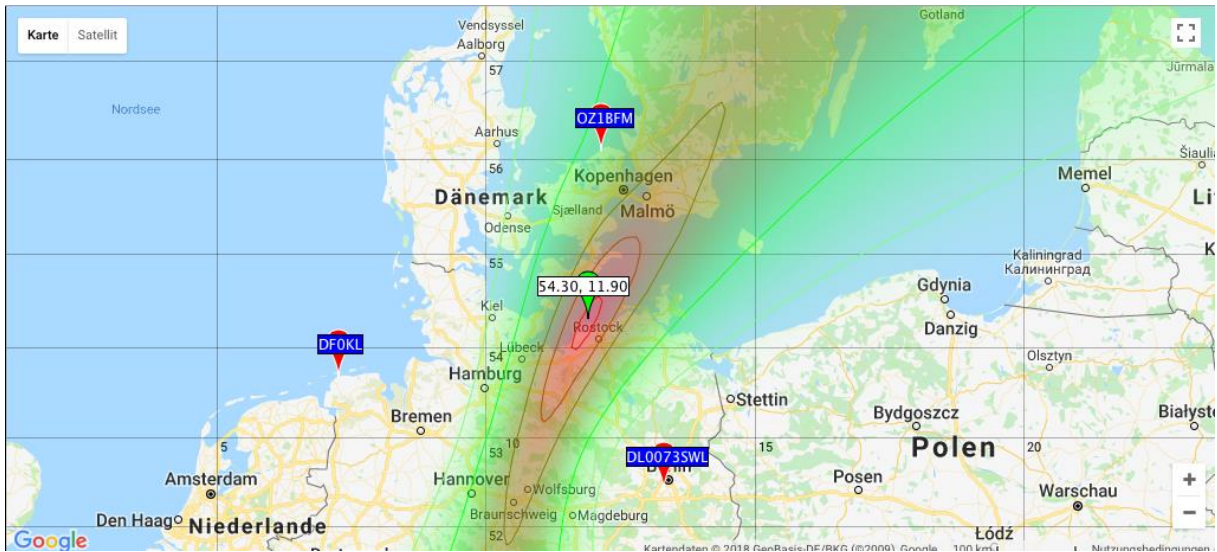


Figure 15: The actual location of the transmitter is a bit east of Rostock. TDoA with three receivers places it about 20 km northwest. But you can distinguish clearly from other location of German Navy, like Glücksburg, Cuxhaven or Wilhelmshaven.



Figure 16: On location at Hohe Düne, near Rostock.

- 4288,6 French Navy Saissac STANAG4285 – 24JUL2018, 05:40 UTC

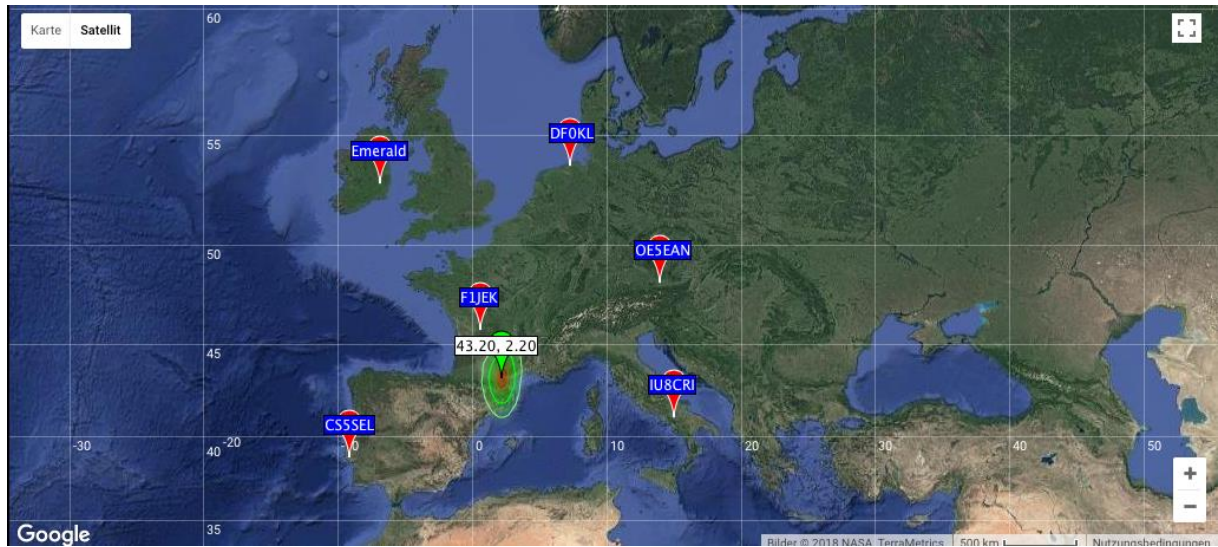


Figure 17: Six receivers do form a well-defined spot ...

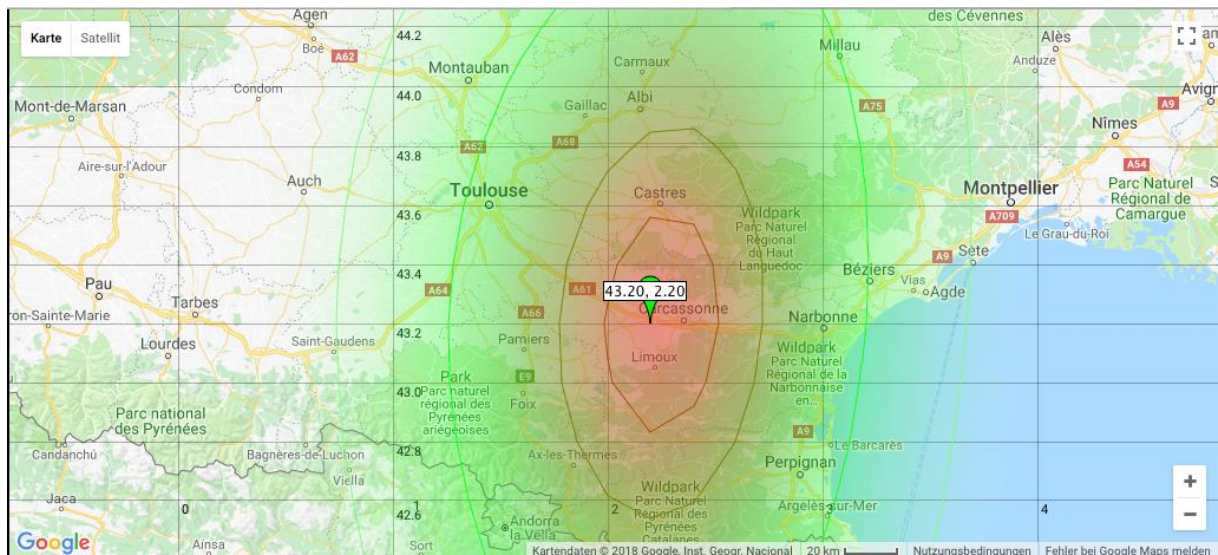


Figure 18: ... which hits a point just 5 km south of the actual transmitter's location.

- **4299,2 British Navy Crimmond STANAG4285 24JUL2018, 05:30 UTC**
Roland Prösch lists them as Bergen/Norway²



Figure 19: Five receivers see this signal coming from the northeast of Scotland, with just ...

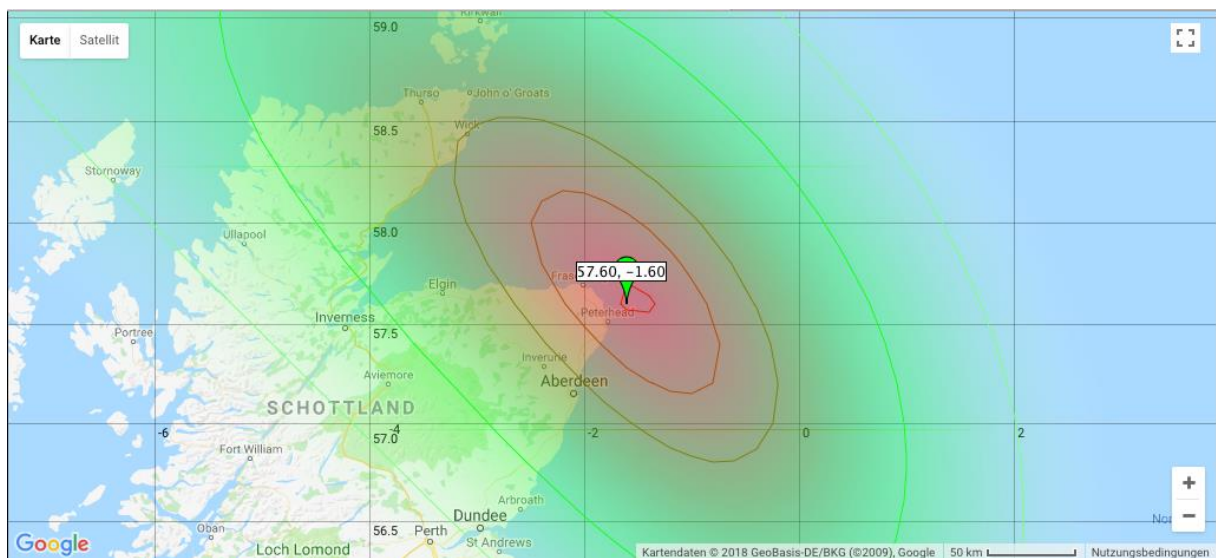


Figure 20: ... a few kilometers north-east of the actual location of this British Navy station at Crimmond on the mainland.

² Frequency Handbook for Radio Monitoring HF, Edition 2013. By Roland Proesch, Hamburg

- 6498,1 kHz Dutch Navy Goeree Island – 23JUL2018, 13:30 UTC

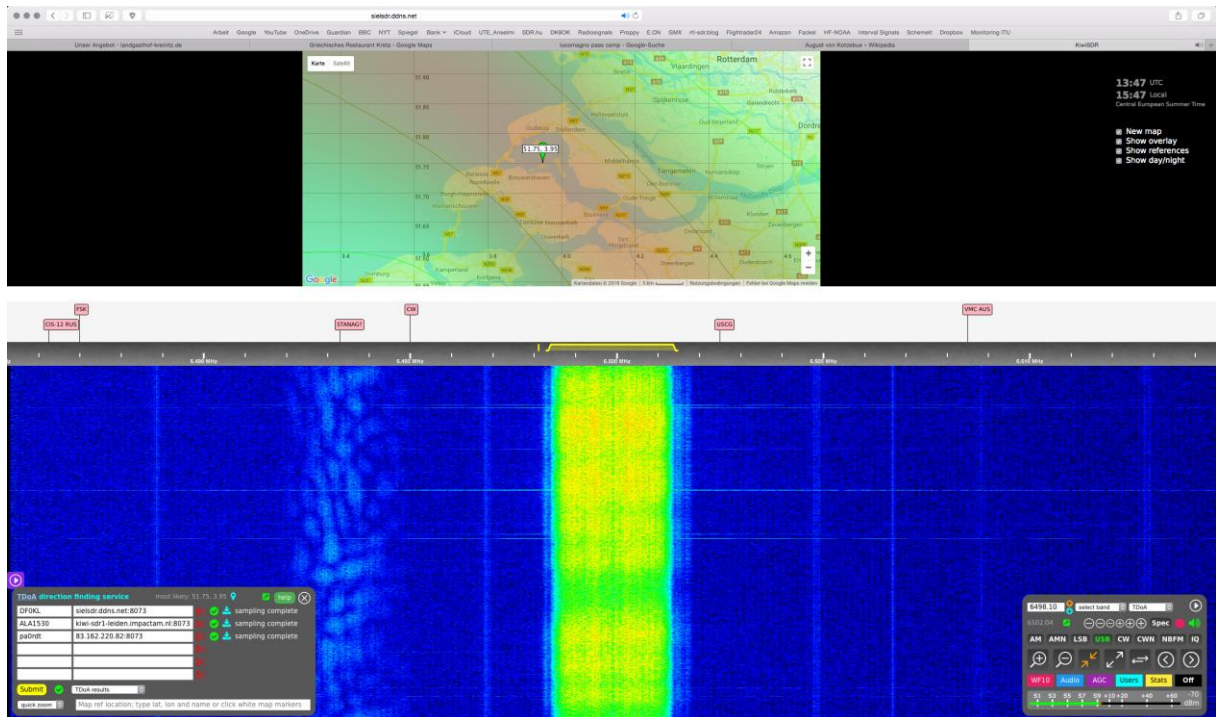


Figure 21: Near-ground wave propagation of this signal at DF0KL in North Germany.



Figure 22: By the aid of two other receivers nearby, the actual location on Goeree Island is nearly exactly hit.

- **8170,2 kHz Sweden? STANAG4285 23JUL2018 15:30 UTC**
Roland Prösch lists them as Bergen/Norway³

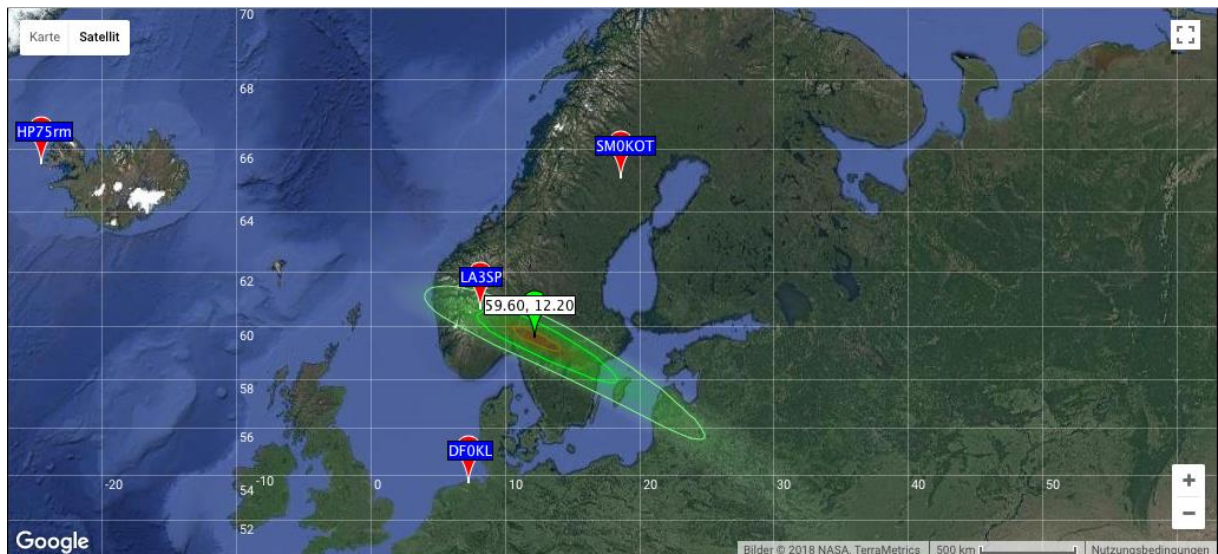


Figure 23: Listed as Bergen, the most likely position of this transmitter seems to be in Southern Sweden – following this TDoA arrangement. I tried many receivers, but the spot refused to change into North Norway ...

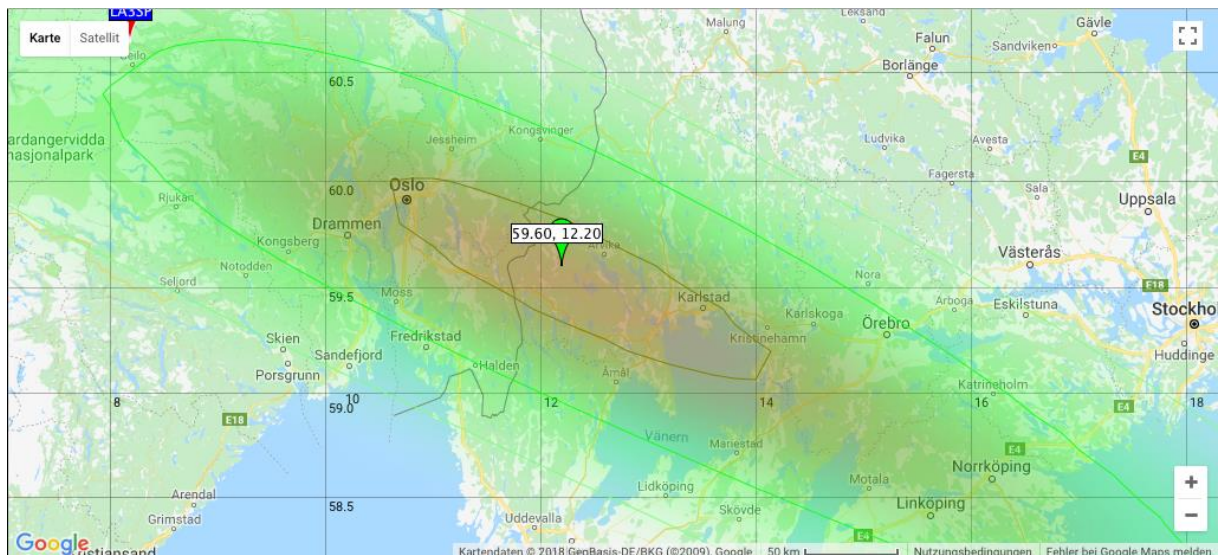


Figure 24: Although many measurements had been made with many different receivers, a location halfway between Oslo (Norway) and Karlstad (Sweden) turns out the most likely transmitter's location.

³ Frequency Handbook for Radio Monitoring HF, Edition 2013. By Roland Proesch, Hamburg

- 11836,5 Russian Navy, Sewastopol Area, CIS-12, 17JUL2018, 17:40 UTC

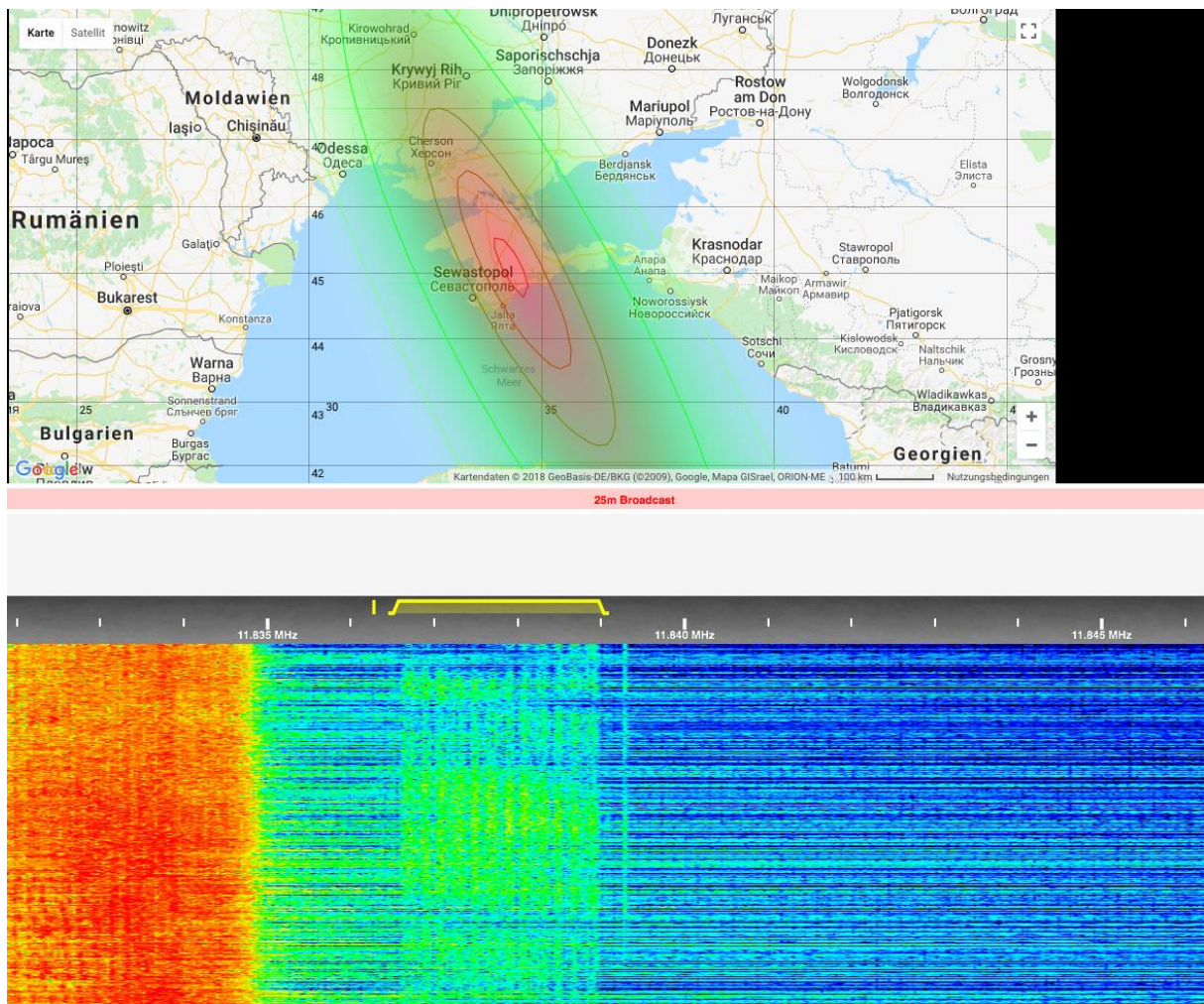


Figure 25: A triangle of OE5EAN (Austria), SV8RV (Greece) and RA3TKH (Russia) clearly places this weak and fading transmitter into the Sewastopol Area.

- 12666,5 kHz French Navy, Saissac STANAG4285 – 16JUL2018, 17:15 UTC

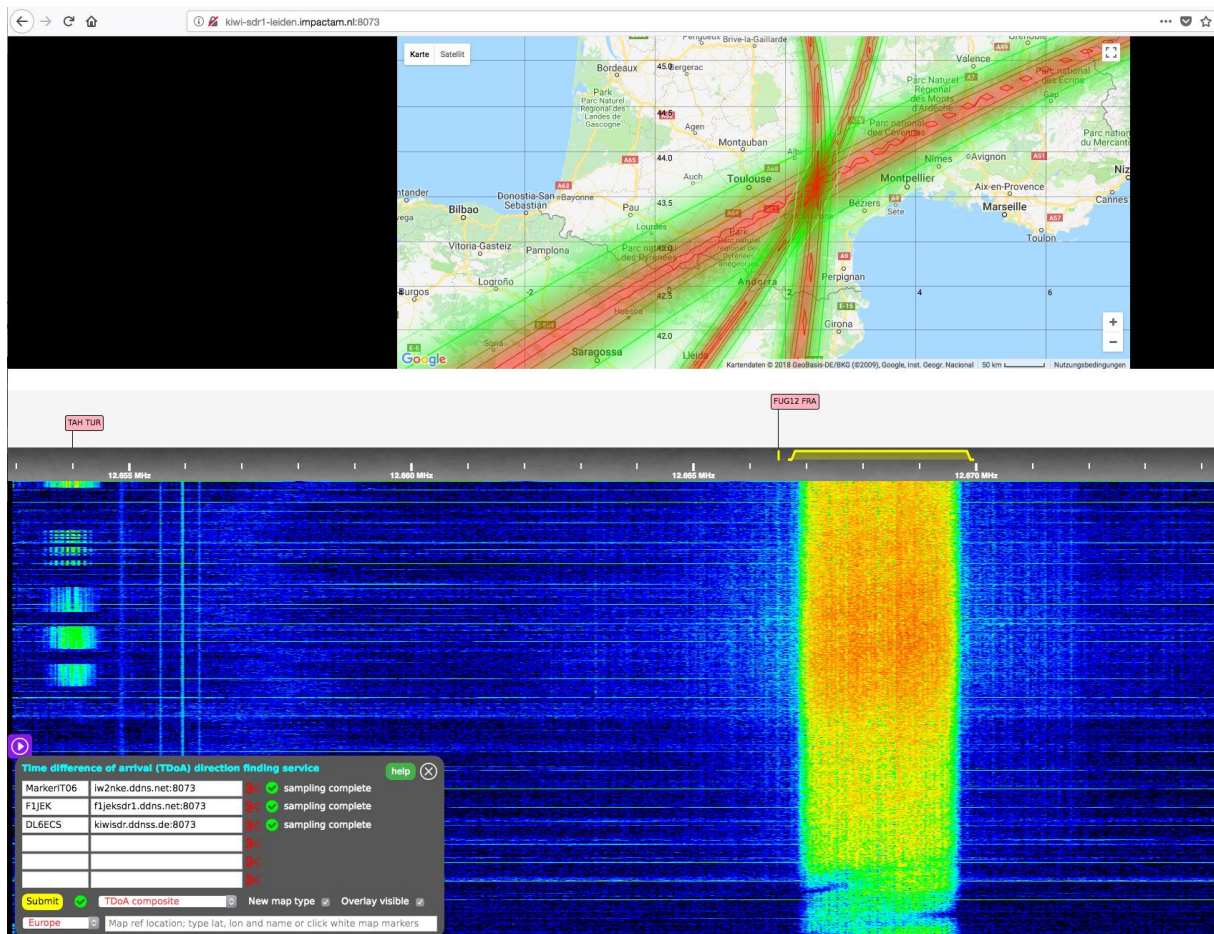


Figure 26: Again Saissac, but on a much higher frequency – see Figure 17 and 18 on page 11.

- 15200 kHz Radio Romania International, Galbeni, AM, 24JUL2018, 10:15 UTC

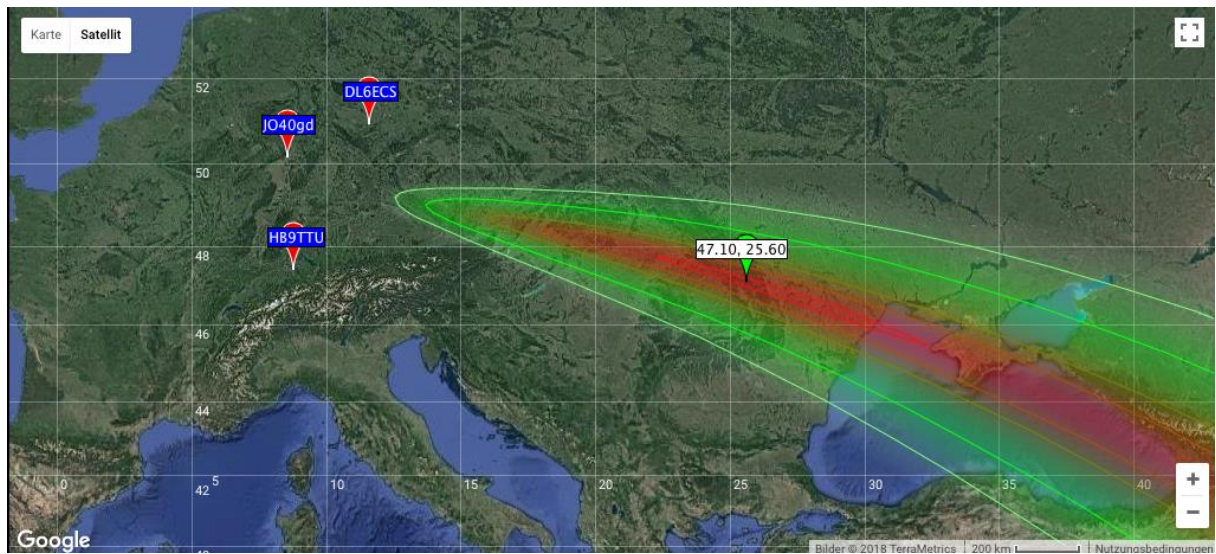


Figure 27: Here you see not a spot, but rather a comet-like trail. Calculation of the software

...

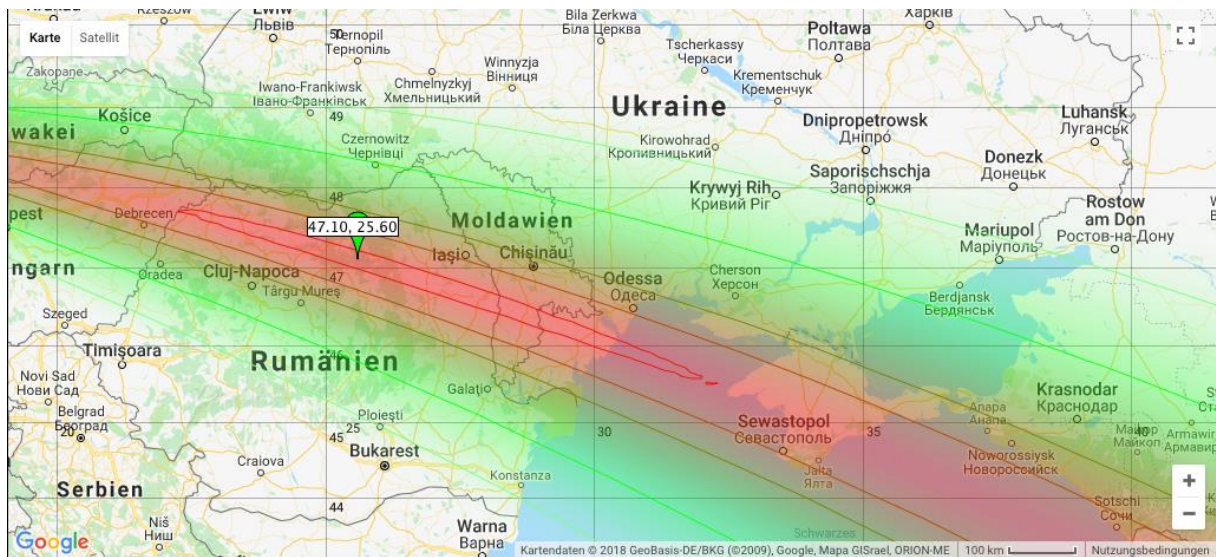


Figure 28: ... sees the location between Cluj and Iasi. In fact, Galbeni is about 50 km south of it.

- 15275 Deutsche Welle, Talata/Malagasy, AM, 24JUL2018, 12:45 UTC

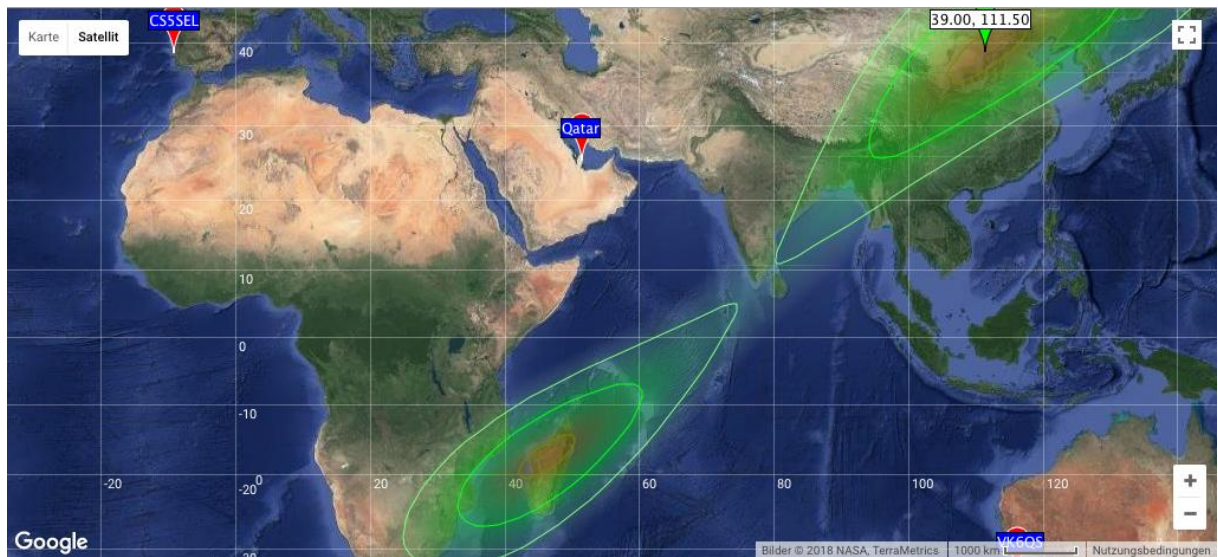


Figure 29: Here three receivers are located on three continents, namely Europe, Asia and Australia. The result are two spots, from which the software prefers the one near Inner Mongolia. In fact ...

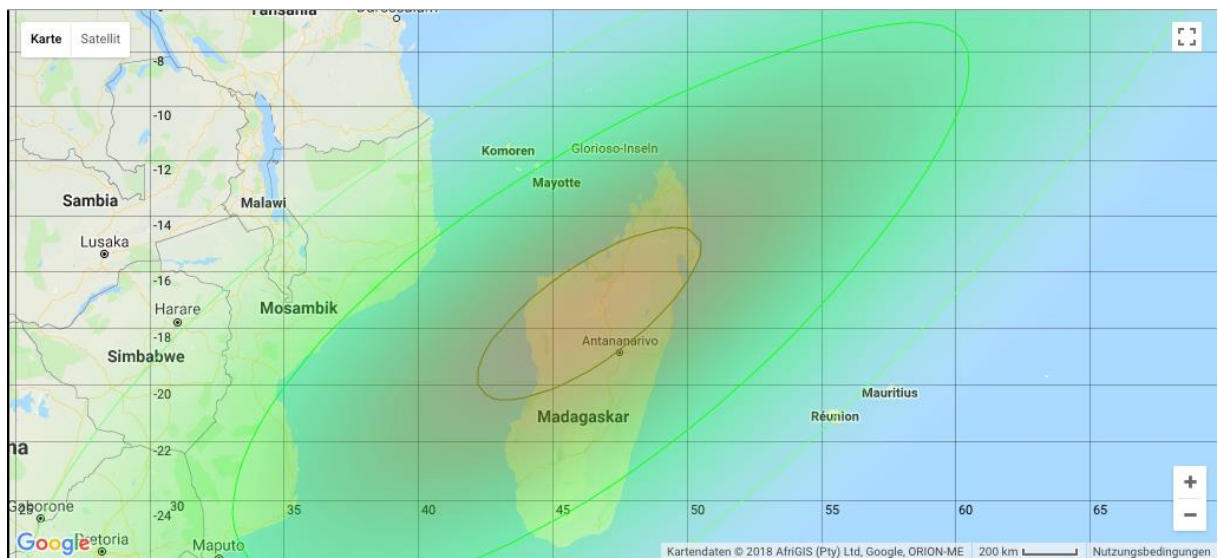


Figure 30: ... the real location within the other spot is quite correctly hit: it is Talata-Volonondry, some 15 kilometers north-east of Antananarivo. Not a bad result with such a challenging triangle for direction finding! BTW: This example largely overstretches the intentional use of this software. But, as said in the beginning, "handle with care" even then delivers stunning results!

- 15275 Deutsche Welle, Trincomalee/Sri Lanka, AM, 22JUL2018, 16:30 UTC



Figure 31: In this case, luck was not on our side. Although the (large) spot duly incorporates Trincomalee on the northeast coast of Sri Lanka, the calculated position is some 500 km southeast of the transmitter's site. Yes, no other arrangement gave a better match. That's not bad, but within only a few days we were spoiled.

- 15320 kHz Radio France International, Issoudun, AM, 18JUL2018, 08:30 UTC

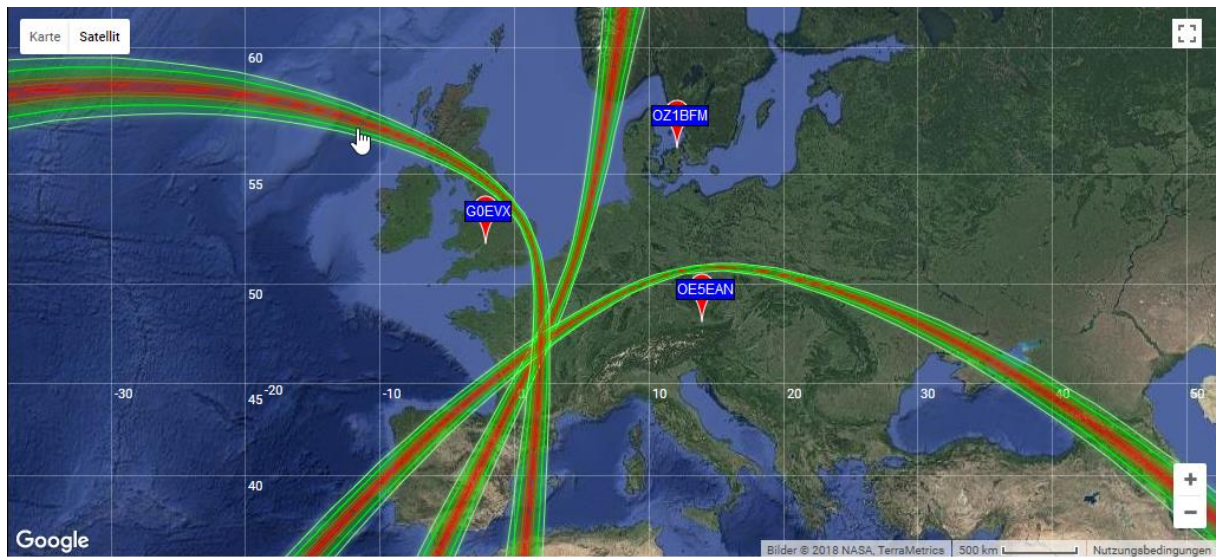


Figure 32: The three hyperboles from receivers in the U.K, in Denmark and in Austria meet at Issoudun.

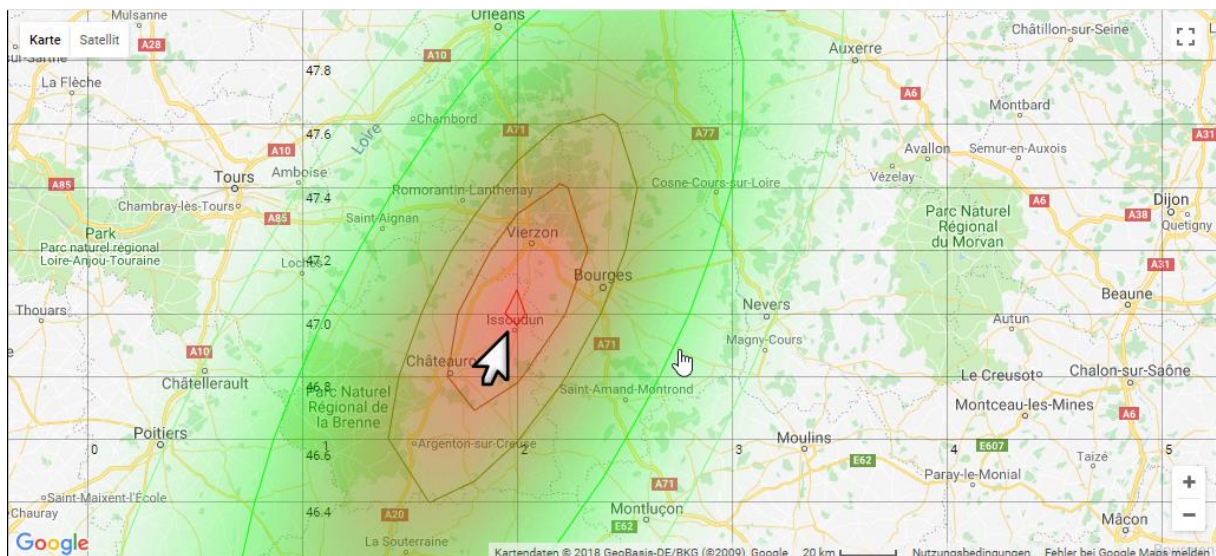


Figure 33: The actual transmitter's location at the tip of the arrow is missed by TDoA by less than 5 km – excellent!

- 15435 kHz Saudi Broadcasting Corporation, Al-Riyadh, AM, 18JUL2018, 08:30 UTC

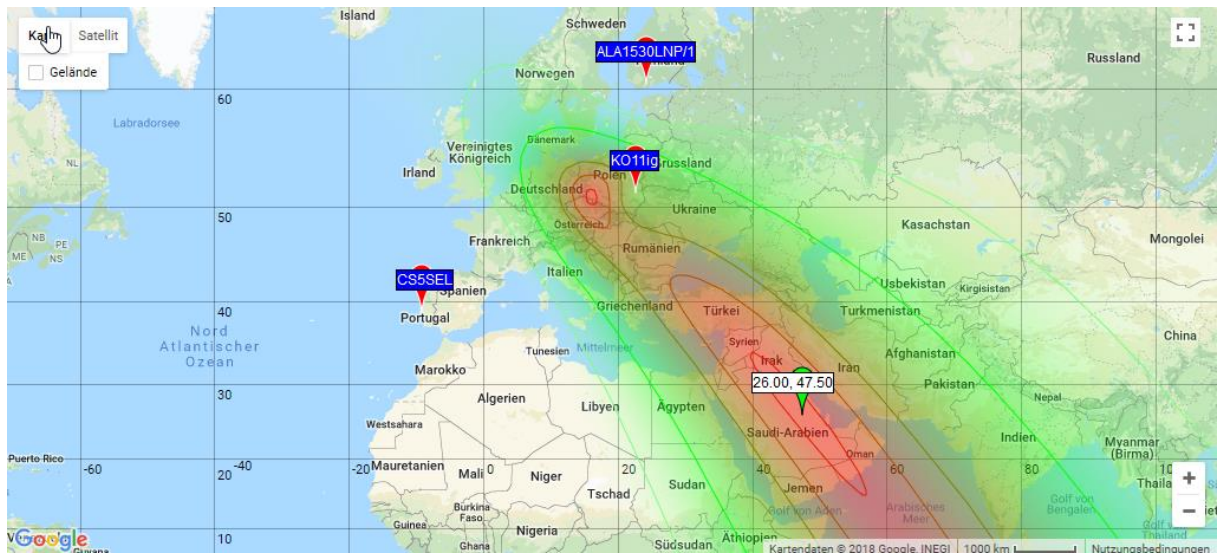


Figure 34: Three receivers for direction finding result in two spots of propable locations. The software votes correctly for Saudi Arabia ...

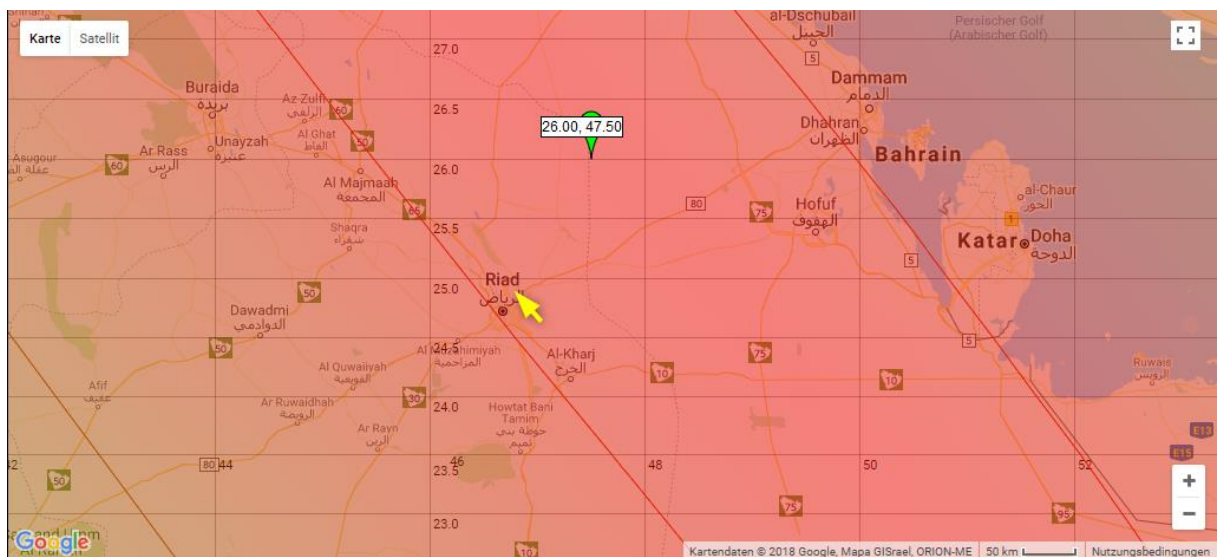


Figure 35: ... where the actual transmitter's location just northeast of the capital is missed by about 100 km. This was the best guess available, as many other receivers were tried.

- 15590 kHz China Radio International, Ürümqi, AM, 24JUL2018, 14:30 UTC



Figure 36: A first try with three receivers already points into the correct direction ...

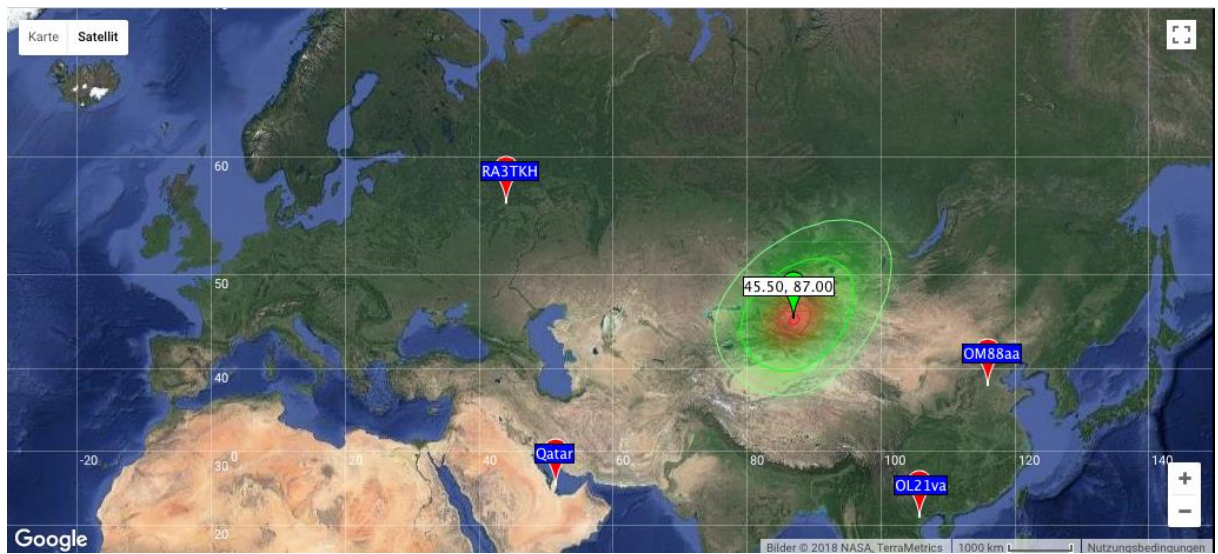


Figure 37: ... whereas an optimization to a really far-flung quadruple of receivers in Russia, Qatar, east China and Vietnam, nearly hits the transmitting towers of Ürümqi in Xinjiang, China at actually 44.15 N / 86.9 E.