

How does WSPR detect Aircraft over long Distances?

Technical Paper

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1. Introduction.

Heinrich Hertz proved the existence of electromagnetic waves in 1889, as theoretically predicted by James Maxwell in 1865. In 1904 Christian Hülsmeyer demonstrated with his Telemobiloskop, that it was possible to detect ships passing along the River Rhine by using radio wave transmissions reflected back to a receiver. In June 1934, large vessels passing through the Kiel Harbour were detected by Doppler-beat interference at a distance of about 2 km using a split anode magnetron producing 70 W at a frequency of 600 MHz. In October 1934, strong reflections were observed from an aircraft that happened to fly through the beam. From then on separate developments of radar for detecting ships and aircraft evolved. Since the demonstration by Robert Watson-Watt and Arnold Wilkins in February 1935 detecting a Handley Page Heyford aircraft by using radio signals from BBC Daventry, radar systems are now used around the world for aircraft detection and tracking.

Marconi made his first trans-Atlantic radio transmission in 1901, before ionospheric propagation was proven. Edward Appleton proved the existence of the ionosphere in 1927, as theoretically predicted by Carl Gauss in 1839. Global radio communications using High Frequency (HF) signals and ionospheric propagation are now standard practice. Amateur radio enthusiasts use the Weak Signal Propagation Reporter (WSPR), which implements a protocol designed for probing potential propagation paths with low-power transmissions. Stations with internet access can automatically upload their reception reports to a central database called WSPRnet. WSPRnet reports the Signal to Noise Ratio (SNR) referenced to a 2,500 Hz bandwidth of the received signal; typical values are -30 dB to +20 dB. WSPRnet also reports the received frequency; typical values are around the centre frequency for the selected band. A temporary change in the SNR or received frequency by more than 0.75 of a standard deviation (SD) measured over a ± 3 hour time period can be caused by an aircraft crossing the propagation path. The measured drift of the transmitted signal as seen by the receiver is also recorded; typical values are -3 Hz/minute to +3 Hz/minute. This is mostly of use to make the transmitting station aware of systematic drift of the transmitter. When there is no systematic drift, a temporary drift can be caused by an aircraft crossing the propagation path.

The WSPRnet technique is, in its simplest form, statistical post processing of the meta-data from a communications link. We combine the reflection of radio waves by aircraft as used in radar, with ionospheric propagation and the WSPR protocol to detect and track aircraft over long distances. There were 1.4 million WSPR signals recorded in 2023 with a propagation distance over 18,000 km, with an average transmission power of 756 mW.

In a previous technical paper, we have shown how WSPR signals can reliably detect aircraft over short distances [1]. A total of nine flights were analysed with commercial aircraft including Boeing, Airbus, Embraer and Canadair flying at altitudes between 7,350 feet and 37,000 feet in the vicinity of the WSPR link between the transmitter W8AC and the receiver N8GA.

A major advantage of using WSPR transmissions is the global coverage. WSPR is a multi-static system. There were around 6 million distinctive links between WSPR transmitters and receivers from around the world with a propagation distance greater than 3,000 km recorded in the WSPRnet database in 2023. WSPR is also a multi-frequency system. There are an increasing number of amateur radio enthusiasts who have automated the operation of multiple transmitters and receivers simultaneously at multiple transmission frequencies. At the estimated position of an aircraft, a number of WSPR signals can contribute to the overall picture of the disturbances caused by the presence of the aircraft during the time the aircraft passes through the propagation path of the WSPR transmissions.

The acquired WSPR signal is a complex time series obtained by orthogonal detection. If integrated over a time domain for a period during which the scatterer is assumed to be coherent (in other words keeping a steady wave structure) weak radio signals can be received with a greater sensitivity by reducing the effective noise. Coherent integration yields a signal power improvement of N^2 and a noise increase of N , for a net SNR improvement of N . Longer coherent integration intervals provide the additional processing gain required for the detection and processing of such weak signals as WSPR. The SNR calculation is dependent on the coherent integration time (T_{cint}).

The 110.6 seconds integration time of the WSPR receiver smooths out the short term dynamics of the ionosphere. The original Joe Taylor noise estimation algorithm within `wsprd` (which is the WSPR decoding program within `wsjt-x`) takes all of the individual Fast Fourier Transform (FFT) frequency binned estimates, sorts them in increasing order of level, and takes the level at the 30th percentile of all frequency bins as the noise level. WSPR Daemon chose to use the total power in the lowest 30%, scaled, as the noise estimate rather than just the 'spot' value at 30% as in `wsprd`. WSPR Daemon also has a RMS noise estimate, from the quietest 50 milliseconds between transmissions.

Ionospheric propagation is dependent on solar activity. The Solar Flux Index (SFI) measures the sun's radio emissions at a wavelength of 10.7 cm (2,800 MHz). A higher SFI generally indicates better HF propagation conditions. On 11th November 2023, when we conducted experiments detecting an aircraft, the SFI was 142 sfu, which is quite high due to the intensifying solar cycle 25. The sun spot number was 79 (source Solar Influences Data Centre).

The Proplab Pro V3.2 software uses the IRI2007 International Reference Ionosphere to determine the ionospheric propagation path and tilts during refraction in the ionosphere. The software incorporates a topographic database of the Earth's surface to analyse ray path propagation and tilts at each reflection point on the Earth's surface over multiple hops between the Earth's surface and the ionosphere. These reflection points are called Interim Landing Points (ILPs).

The short range WSPR transmissions analysed were predominantly single hop ionospheric propagations. The key difference in long range WSPR transmissions is that these will be predominantly multi hop ionospheric propagations. Each time a radio signal is refracted in the ionosphere there will be a signal loss and each time a radio signal is reflected from the Earth's surface back to the ionosphere there will be a signal loss. The WSPR protocol provides the evidence that a radio signal from a particular transmitter was decoded at the receiver and the key data are recorded in the WSPRnet historic database.

WSPR transmission and receiver antenna locations are not precise in the WSPRnet database. A 4 character Maidenhead Grid locator is highly inaccurate with a precision no better than ± 120 km. A 6 character Maidenhead Grid locator is significantly inaccurate with a precision of ± 5 km. The antenna location problem can be solved with an accurate antenna database sourced from each antenna owner, which we have now implemented, with latitude and longitude to 6 decimal places (accuracy better than 1 m).

The ability to detect an aircraft depends on the reflection of radio waves, based on the Radar Cross Section (RCS) of the target. On 11th November 2023, we conducted experiments detecting an Airbus A330-300 aircraft, which has a wing area of 363.1 m². The RCS is dependent on a number of factors including the size of the target relative to the wavelength of the WSPR signal and the angle of incidence of the WSPR propagation. The Australian Defence Science and Technology Group (DSTG) has modelled the RCS of a similar sized commercial aircraft, a Boeing 777 with a wing area of 427.8 m² (18% greater than an A330-300) and found a RCS of up to 45 dB m², dependent on season, local solar time, frequency, polarisation, incident wave azimuth and elevation [2]. A RCS of 45 dB m² is the equivalent of 63,106 m² at a typical WSPR wave length in the 20 m band (14 MHz). Calculating the RCS of an aircraft at HF is going to add little value, as WSPR is an encoded communications link and not a detection system such as radar. The important fact is that the RCS of an aircraft is large and the radio wave is reflected.

In this technical paper, we will show how WSPR signals can reliably detect aircraft over long distances.

2. Aircraft Traffic.

In 2023 there were on average 21,538 aircraft in the air at any one time. This figure includes commercial passenger and cargo flights, private flights and military flights, but not stealth military flights. This figure varies significantly from year to year, season to season, weekday to weekday and depends on the time during the day. The seasonal peak in 2022 was in the summer season on the 21st July. The weekday peak is on Thursday, but sometimes on Friday. The daily peak is around 15:00 UTC.

There are a variety of different aircraft, but the traffic is dominated by commercial passenger flights. These are usually divided into 3 categories short, medium and long haul flights and each airline has its own definition. Typically short haul flights are under 3 hours and under 1,600 km, long haul are over 6 hours and over 4,000 km and medium haul flights are in between.

The average number of short haul aircraft in the air at any one time is 452, making 4.75 flights per day and the average flight time is 1.16 hours. The average number of medium haul aircraft in the air at any one time is 14,495, making 5.15 flights per day and the average flight time is 2.88 hours. The average number of long haul aircraft in the air at any one time is 6,591, making 2 flights per day and the average flight time is 8.58 hours.

Short haul flights spend the majority of time in the ascent and descent phases of flight and minority of time in the cruise phase of flight. Long haul flights spend the majority of the time in the cruise and minority of time in the ascent and descent phases of flight.

A typical long range WSPR ionospheric transmission takes 5 hops and covers a great circle distance of around 15,000 km. A typical propagation reaches heights above the Earth's surface of between 60 km and 400 km and spends on average an estimated 9.7% of its time within altitudes operated by commercial aircraft.

3. Coherent Integration Time.

There is general acceptance of the statement that the ionosphere is subject to a host of dynamical processes, including atmospheric gravity waves, Alfvén waves and fast mode magneto-hydrodynamic waves, meteor trail formation and decay, plasma instabilities on many spatial and temporal scales, and sudden ionospheric disturbances resulting from impulsive solar events.

If we were designing the WSPR protocol for aircraft detection and not for propagation purposes, we would have chosen an on-the-air period of say 20 or 30 seconds, where more disturbances (both amplitude and frequency) would have been noticed. The WSPR transmission time is 110.6 seconds and exceeds the Coherent Integration Time (CIT) of the ionosphere, which is typically no more than 60 seconds [2].

In the paper titled "The Universal Digital Ionosonde" by Klaus Bibl and Bodo Reinisch, published in Radio Science in 1978, they used various time windows from 2 seconds to 64 seconds in steps of 2, 4, 8, 16, 32 and 64 seconds [3]. The US National Oceanic and Atmospheric Administration (NOAA) concluded in their Digisonde Manual that with the application of spectral integration (which is a byproduct of the Fourier transform used to create a Doppler spectrum) it is possible to coherently integrate pulse echoes for tens of seconds under nearly all ionospheric conditions [4].

In 1956 the Naval Research Laboratory concluded a definitive set of experiments that showed that the ionosphere is generally sufficiently stable for an HF sky wave radar to succeed for over-the-horizon aircraft detection [5].

4. Long Distance WSPR Detection of Aircraft - Overview.

Global flight routes are not uniformly distributed. There are large concentrations of flights over North America, Europe and China. Not all flight routes operate regularly and Figure 1 represents the sum of all flight routes. Similarly global WSPR signals are not uniformly distributed. At any particular time, there are large concentrations of signals over North America and Europe, but not China as shown in the snapshot of short path propagations in Figure 2. In general there is an alignment between the global distribution of flight routes and WSPR signals.



Figure 1: Global Flight Routes.

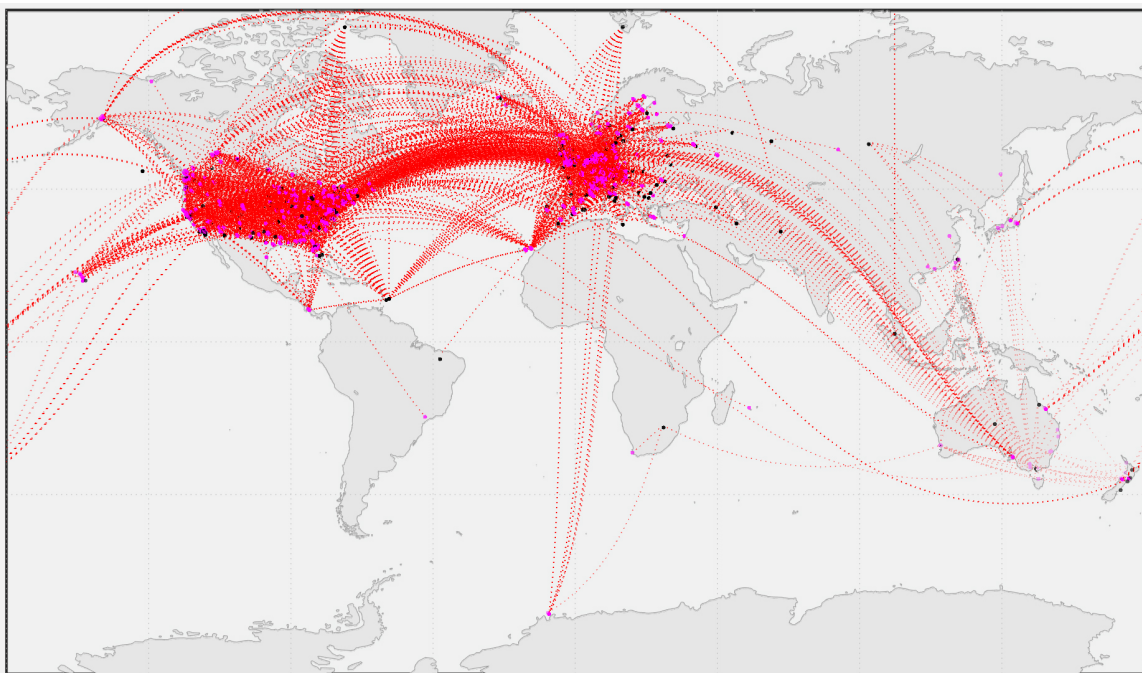


Figure 2: Example Two Minute Global WSPR Signals on 3rd November 2023 at 18:00 UTC.

5. Long Distance WSPR Detection of Aircraft - Method.

Turkish Airlines flight THY161 departed Antananarivo Airport, Madagascar on 11th November 2023 at 13:45 UTC and arrived in Plaine Magnien Airport, Mauritius at 15:09 UTC. The passenger flight was operated by an Airbus A330-300. We chose a flight across the southern Indian Ocean for three reasons, firstly because of the distance from the majority of global flight routes and secondly because of the distance from the majority of WSPR stations and thirdly because of the applicability of the results to the case of the disappearance of MH370, which is known to have crashed in the southern Indian Ocean.

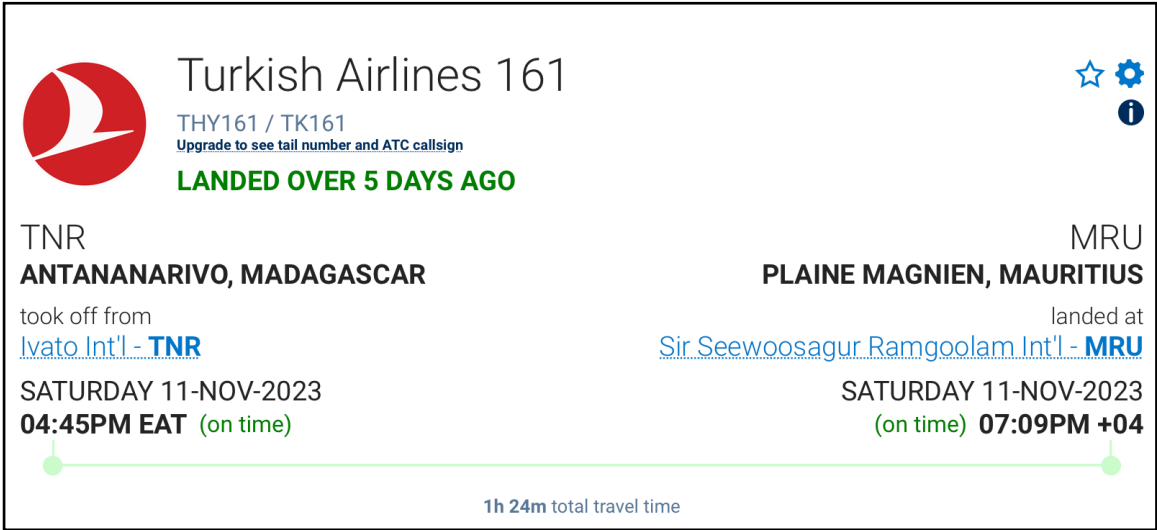


Figure 3: Turkish Airlines flight THY161 on 11th November 2023 Departure and Arrival Times.

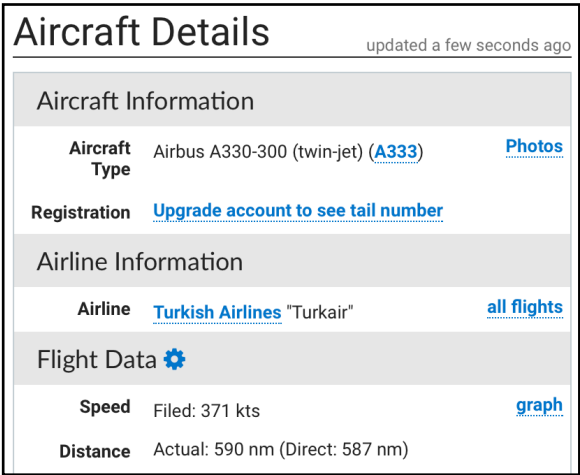


Figure 4: Turkish Airlines flight THY161 on 11th November 2023 Aircraft and Flight Data.

The aircraft was first detected 3 minutes after take off at an altitude of 9,045 feet by a WSPR transmission from call sign IK5ZAI in Italy over a propagation distance of around 7,900 km. The transmission frequency of 14.097017 MHz is well within the Maximum Usable Frequency (MUF) at 13:48 UTC.

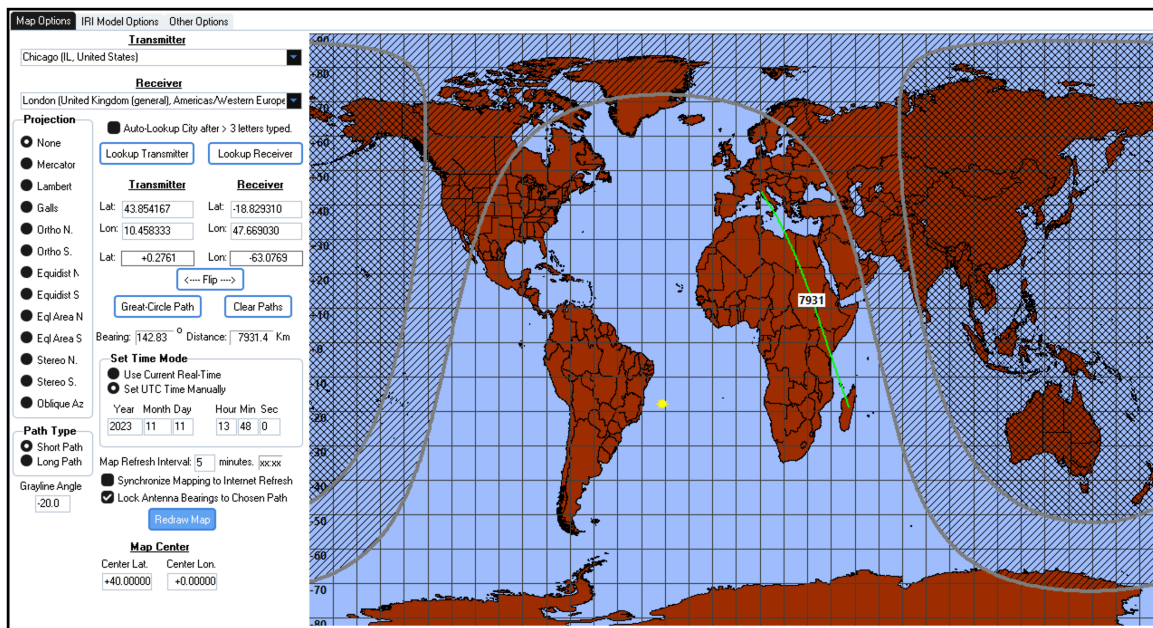


Figure 5: Propagation path from IK5ZAI to THY161 at 13:48 UTC.

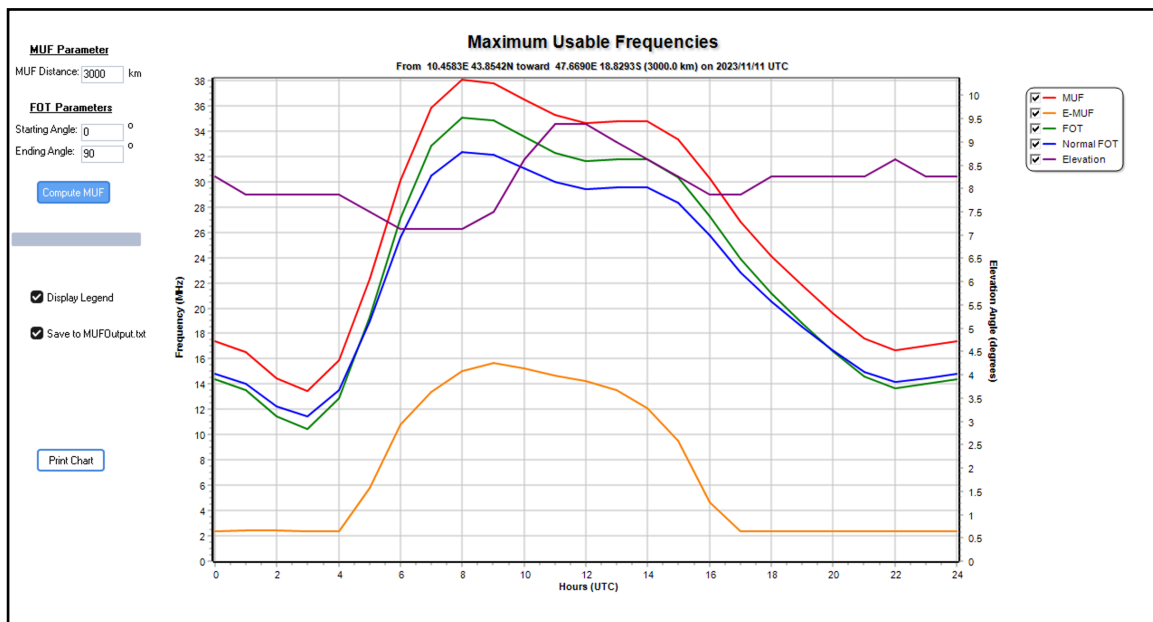


Figure 6: The transmission frequency of 14.097017 MHz is well within the MUF at 13:48 UTC.

The propagation to the aircraft comprises 3 hops at an elevation angle of 7.97°. The 2D ray tracing in Figure 7 shows the signal reaches altitudes between 140 km and 240 km above the surface of the Earth. The WSPR transmission is then reflected back at the aircraft to a receiver call sign M0VSE in the UK. At the same time, the WSPR transmission from call sign WJ8A in the US also detects the aircraft and is reflected back to a receiver call sign W7CRK also in the US as shown in Figure 8 (transmitters marked in black, receivers marked in magenta).

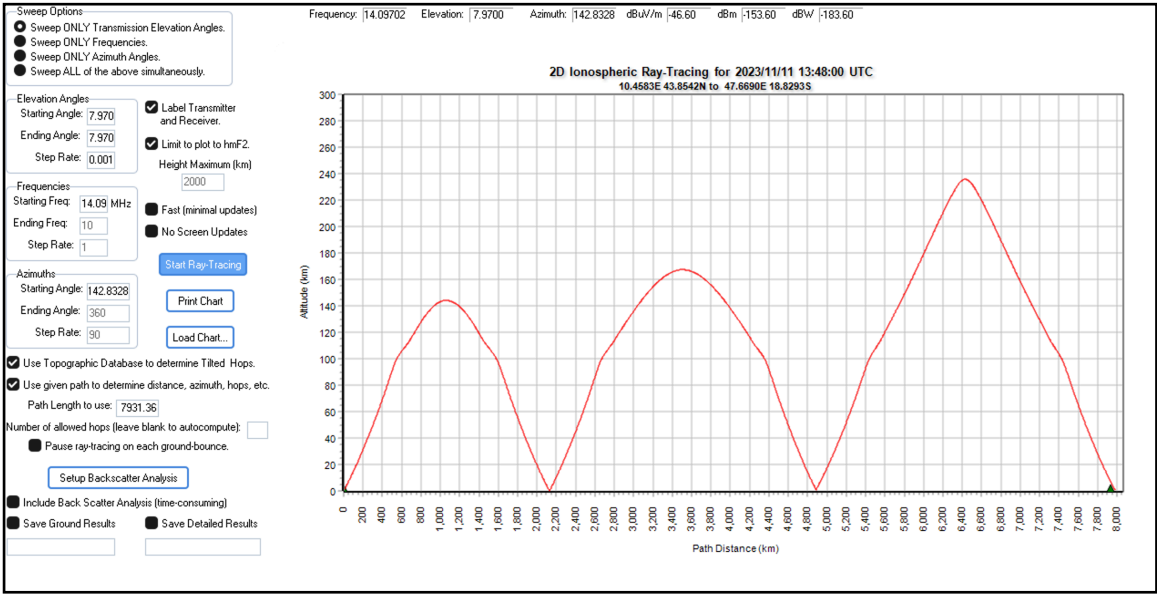


Figure 7: Propagation from IK5ZAI to THY161 in 3 hops at 13:48 UTC.

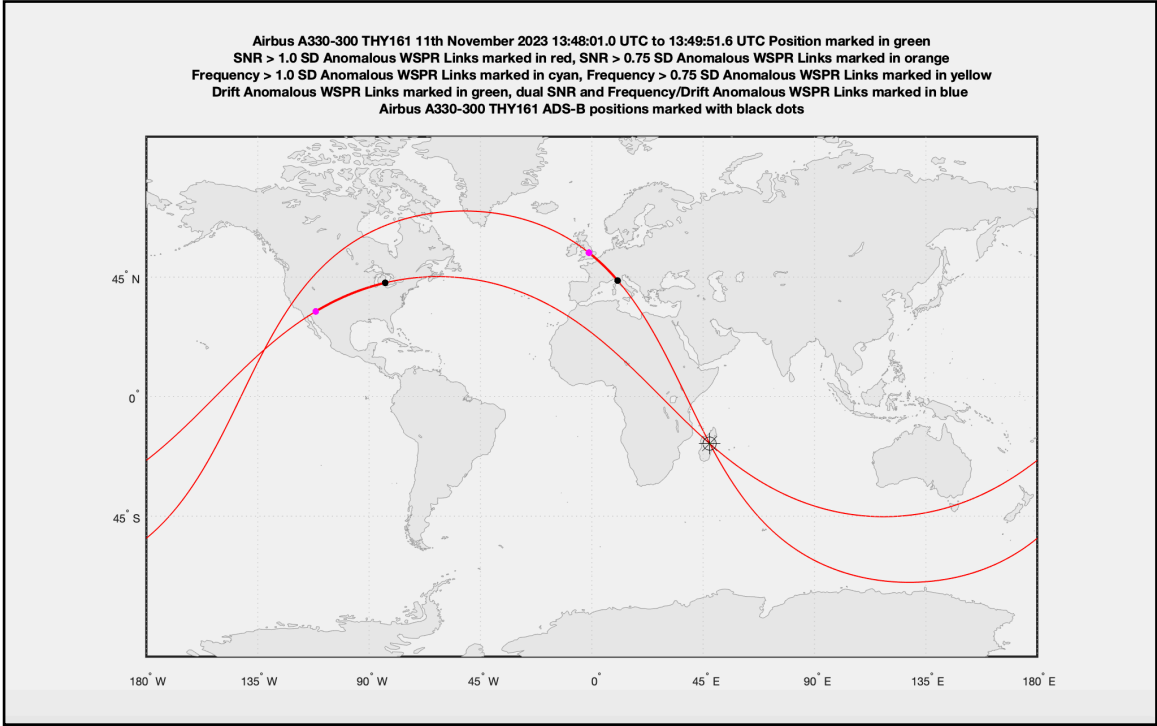


Figure 8: IK5ZAI-THY161-M0VSE and WJ8A-THY161-W7CRK at 13:48 UTC.

WSPR operates in a number of different wavelength bands. In each band, the band width is 200 Hz. The most frequently used bands for long distance propagation are the 20 m (14 MHz) band and the 40 m (7 MHz) band. In 2023, there were 122.0 million WSPRnet transmissions in the 20 m band with a propagation distance over 3,000 km with a centre frequency at 14,097,100 Hz and 65.0 million in the 40 m band with a propagation distance over 3,000 km with a centre frequency at 7,040,100 Hz.

The most commonly received frequency in each band is either precisely at the centre frequency or very close. In the 20 m band, 96.7% (40 m band, 97.5%) of the frequencies of the WSPR received signals are within the ± 100 Hz band width.

WSPR OPERATIONAL FREQUENCIES

Operational WSPR frequencies.

Note that all channels use the upper sideband.

Band (Mtr)	Dial Frequency (MHz)	Lower Band Pass Frequency (MHz)	Upper Band Pass Frequency (MHz)	Band Width (Hz)
33400m	0.0072	0.0087	0.0089	200
2200m	0.1360	0.1374	0.1376	200
600m	0.4742	0.4756	0.4758	200
160m	1.8366	1.8380	1.8382	200
80m	3.5926	3.5940	3.5942	200
60m	5.2872	5.2886	5.2888	200
40m	7.0386	7.0400	7.0402	200
30m	10.1387	10.1401	10.1403	200
20m	14.0956	14.0970	14.0972	200
17m	18.1046	18.1060	18.1062	200
15m	21.0946	21.0960	21.0962	200
12m	24.9246	24.9260	24.9262	200
10m	28.1246	28.1260	28.1262	200
6m	50.2930	50.2944	50.2946	200
4m	70.0910	70.0924	70.0926	200
2m	144.4890	144.4904	144.4906	200

Channel bandwidth used is 6 Hz and the transmission time is 110.6 sec. The length of a single tone is 0,6827 s and maximum allowed drift is about 1 Hz.

Figure 9: WSPR operational frequencies.

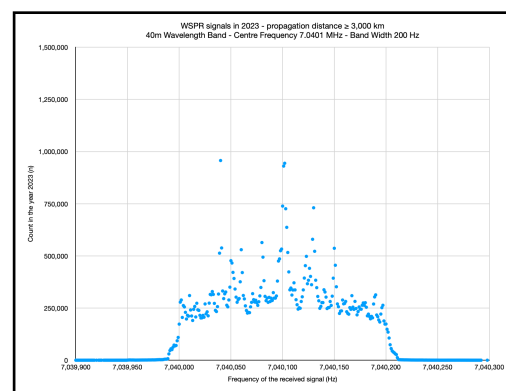
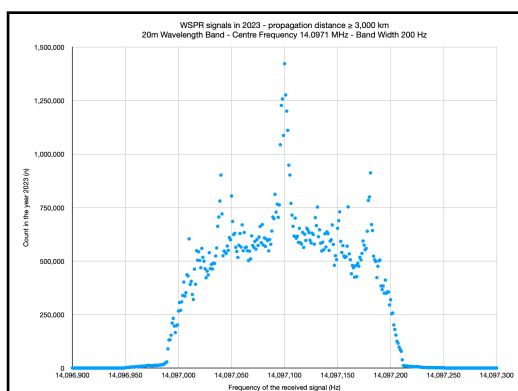


Figure 10 and 11: WSPR received frequencies in the 20 m and 40 m bands over 3,000 km in 2023.

There were 1.7 billion signals recorded in the WSPRnet database in 2023. The majority (51.4%) were transmissions at 23 dBm (199.5 mW). The next most popular transmission power level (15.8%) was 37 dBm (5.0119 W). The most popular transmission frequency band was 7 MHz (29.5%) closely followed by the 14 MHz band (29.2%).

The composition of the WSPRnet database for 2023 is shown in Table 1. The number of WSPR signals reduces as the mean propagation distance increases. At propagation distances $\geq 15,000$ km the 14 MHz band is clearly more popular. At propagation distances $\geq 9,000$ km the transmission power of 37 dBm for both the 7 MHz and 14 MHz band is clearly more popular. The mean SNR ranges from -23.0 dB to -10.4 dB, but the mode SNR (the most common SNR value) ranges from -25 dB to -16 dB. The mode SNR value is not greatly influenced by either transmission power or transmission frequency.

Distance (km)	Transmission Power (dBm)	Transmission Frequency Band (MHz)	Count WSPR Signals (n)	Mean SNR (dB)	Mode SNR (dB)
≥ 0	All	All	1,706,561,768	-15.1	-21
≥ 0	23	All	876,398,501	-16.4	-22
≥ 0	37	All	270,140,566	-12.1	-20
≥ 0	All	7	502,755,913	-13.9	-19
≥ 0	All	14	498,488,502	-15.0	-21
≥ 0	23	7	263,729,050	-15.3	-20
$\geq 3,000$	23	7	26,772,759	-20.2	-23
$\geq 6,000$	23	7	8,739,877	-21.0	-23
$\geq 9,000$	23	7	1,445,297	-22.0	-24
$\geq 12,000$	23	7	839,159	-22.3	-24
$\geq 15,000$	23	7	276,141	-23.0	-25
$\geq 18,000$	23	7	33,518	-22.6	-24
≥ 0	37	7	77,847,298	-10.4	-16
$\geq 3,000$	37	7	18,046,156	-15.7	-19
$\geq 6,000$	37	7	8,590,092	-17.2	-20
$\geq 9,000$	37	7	2,434,235	-18.8	-21
$\geq 12,000$	37	7	1,706,791	-18.6	-21
$\geq 15,000$	37	7	666,337	-19.0	-22
$\geq 18,000$	37	7	85,228	-19.3	-22
≥ 0	23	14	242,575,259	-16.2	-21
$\geq 3,000$	23	14	47,717,097	-19.3	-22
$\geq 6,000$	23	14	18,140,881	-19.9	-23
$\geq 9,000$	23	14	4,714,983	-20.5	-23
$\geq 12,000$	23	14	3,167,490	-20.7	-23
$\geq 15,000$	23	14	1,803,959	-20.6	-23
$\geq 18,000$	23	14	274,748	-20.5	-23
≥ 0	37	14	81,314,304	-12.1	-19
$\geq 3,000$	37	14	29,012,041	-15.3	-20
$\geq 6,000$	37	14	16,888,500	-15.4	-21
$\geq 9,000$	37	14	8,601,316	-14.8	-20
$\geq 12,000$	37	14	7,683,515	-14.4	-20
$\geq 15,000$	37	14	5,822,542	-13.6	-19
$\geq 18,000$	37	14	174,303	-17.6	-20

Table 1: WSPRnet database composition in 2023.

6. Summary of Results.

We analysed 194 WSPR signals passing within the vicinity of flight THY161. There were 44 WSPR anomalies comprising 19 SNR anomalies, 21 frequency anomalies and 4 drift anomalies (there were nine dual SNR and frequency anomalies and one triple SNR, frequency and drift anomaly). Anomalies were found in each phase of the flight: climb, cruise and descent at 13 out of 14 different points in time. This represents an average of 3 anomalies for each of the 14 WSPR two minute timeframes analysed.

The aircraft was tracked using ADS-B data supplied by FlightAware.com and compared to the position given by the WSPRnet anomalies every two minutes. The aircraft took off at 13:45 UTC and was picked up 3 minutes later at 13:48 UTC. The aircraft was tracked until 13:54 UTC until it went out of range of the ADS-B receiver at Antananarivo Ivato International Airport. The aircraft was then tracked in the cruise from 14:12 UTC, when it came within range of Reunion Island and the ADS-B receiver at Roland Garros Airport. Finally the aircraft was tracked in the descent from 14:42 UTC, when it also came in range of Mauritius Island and the ADS-B receiver at Sir Seewoosagur Ramgoolam International Airport at Plaine Magnien.

The Transmitter (Tx) and Receiver (Rx) latitude and longitude are derived from the master antenna locations database. The best source data for antenna location is the radio amateur who implemented the antenna.

DateTime (UTC)	Phase	Altitude (feet)	ROC (fpm)	Ground Speed (knots)	Track (°T)	Tx Call Sign	Tx Latitude	Tx Longitude	A/C Latitude	A/C Longitude	Rx Call Sign	Rx Latitude	Rx Longitude
11/11/2023 13:48	Climb	9,045	2,689	311	104	IK5ZAI	43.854167	10.458333	-18.829310	47.669030	MOVSE	52.629012	-1.173170
11/11/2023 13:48	Climb	9,045	2,689	311	104	WJ8A	43.107866	-83.478299	-18.829310	47.669030	W7CRK	33.142311	-111.595776
11/11/2023 13:50	Climb	14,745	1,859	324	103	N4JJS	35.574676	-78.752053	-18.868760	47.847370	W3PM	34.733252	-86.793483
11/11/2023 13:52	Climb	18,660	1,823	368	103	N5WNE	39.071732	-108.621190	-18.913160	48.047970	KN6SWE	33.133020	-117.116029
11/11/2023 13:52	Climb	18,660	1,823	368	103	W7GW	41.842735	-88.182208	-18.913160	48.047970	KV6X	35.728333	-105.876667
11/11/2023 13:52	Climb	18,660	1,823	368	103	AE9J	39.762715	-86.528071	-18.913160	48.047970	KQ2Y	41.587202	-73.489578
11/11/2023 13:54	Climb	22,438	1,830	393	102	W2RCL	39.483972	-76.713314	-18.960720	48.267310	K5CGM	35.979679	-95.940236
11/11/2023 13:54	Climb	22,438	1,830	393	102	WA3DNM	39.916931	-75.513685	-18.960720	48.267310	K6RFT	37.284974	-91.884973
11/11/2023 13:54	Climb	22,438	1,830	393	102	DG8GAD	48.424295	9.883156	-18.960720	48.267310	DC8EO	51.242870	6.383676
11/11/2023 13:54	Climb	22,438	1,830	393	102	M0YXM	51.633576	0.613647	-18.960720	48.267310	I0UVN	41.494185	13.087928
11/11/2023 14:12	Cruise	39,000	0	483	100	K4RCC	35.308816	-83.181297	-19.390415	50.716205	K5XL	32.651894	-97.138745
11/11/2023 14:14	Cruise	39,000	0	483	100	K5MGF	34.478333	-106.376667	-19.437143	50.994967	K9YWO	41.554177	-87.514538
11/11/2023 14:18	Cruise	39,000	0	483	100	GM8HHC	55.933397	-3.212872	-19.529095	51.551116	SWL/HU1UB	51.562500	4.791667
11/11/2023 14:18	Cruise	39,000	0	483	100	GM4DTH	55.933637	-3.212246	-19.529095	51.551116	DJ6DK	48.954211	8.476274
11/11/2023 14:20	Cruise	39,000	0	483	100	K7POF	34.729167	-112.458333	-19.574245	51.828499	N0QBH	45.228632	-95.016025
11/11/2023 14:20	Cruise	39,000	0	483	100	DD3DJ	51.467114	7.223209	-19.574245	51.828499	DL7UP	48.074814	11.690467
11/11/2023 14:22	Cruise	39,000	0	483	100	KK5PY	36.936534	-94.871696	-19.619829	52.111155	WA3TTS	40.556377	-80.041814
11/11/2023 14:22	Cruise	39,000	0	483	100	AE7YQ	31.990560	-111.124455	-19.619829	52.111155	N9AGL	42.166247	-87.984026
11/11/2023 14:42	Descent	38,539	-808	495	95	AA6RF	34.024412	-117.494027	-20.049580	54.934590	ND7M	36.238621	-116.061132
11/11/2023 14:44	Descent	35,187	-2,367	500	99	K7ZOO	32.242612	-110.929397	-20.090848	55.223552	KV6X	35.728333	-105.876667
11/11/2023 14:44	Descent	35,187	-2,367	500	99	AA7US	31.940239	-110.291445	-20.090848	55.223552	KX4AZ/T	44.114303	-85.459621
11/11/2023 14:44	Descent	35,187	-2,367	500	99	AC1JS	44.156031	-68.386033	-20.090848	55.223552	K9AN	40.110872	-88.196993
11/11/2023 14:44	Descent	35,187	-2,367	500	99	HG7RED	47.381915	18.904830	-20.090848	55.223552	TF4M	65.682012	-23.575432
11/11/2023 14:44	Descent	35,187	-2,367	500	99	OZ7IT	55.249752	12.300820	-20.090848	55.223552	KA7OEI-1	41.604167	-112.291667
11/11/2023 14:44	Descent	35,187	-2,367	500	99	KI7DX	40.692416	-111.810330	-20.090848	55.223552	N6RY	33.151951	-117.316667
11/11/2023 14:46	Descent	31,335	-2,350	495	98	AC1JS	44.156031	-68.386033	-20.125860	55.470840	K9AN	40.110872	-88.196993
11/11/2023 14:46	Descent	31,335	-2,350	495	98	W1/AJ8S	44.229167	-70.958333	-20.125860	55.470840	WA2ZKD	43.126880	-77.584834
11/11/2023 14:46	Descent	31,335	-2,350	495	98	S54MI	45.510481	13.689823	-20.125860	55.470840	G00HK	54.888132	-1.530681
11/11/2023 14:46	Descent	31,335	-2,350	495	98	KD0PXX	41.293507	-96.012207	-20.125860	55.470840	KV6X	35.728333	-105.876667
11/11/2023 14:48	Descent	26,965	-1,805	462	98	VE1BLL	44.817949	-63.588764	-20.168660	55.793120	KD2OM	42.969759	-77.425284
11/11/2023 14:48	Descent	26,965	-1,805	462	98	KX4DQ	36.027084	-86.761952	-20.168660	55.793120	EA8/DF4UE	28.646300	-13.872378
11/11/2023 14:48	Descent	26,965	-1,805	462	98	G4TNU	51.669603	-0.556612	-20.168660	55.793120	IK0XFA	45.812336	9.226504

Table 2: Summary of results showing Transmitters, Receivers and Aircraft Positions.

The Distance, Initial Bearing (IB) and Final Bearing (FB) of the great circle path between the Transmitter (Tx) and the Aircraft (A/C) and between the Aircraft (A/C) and Receiver (Rx) were calculated using a Vincenty geodesic iterative method.

The average total propagation distance projected onto the Earth's surface from the Tx to A/C and back to Rx is 27,761.9 km (minimum 16,699.0 km, maximum 36,300.2 km). A distance of 16,699.0 km takes 0.0557 ms at the speed of light and a distance of 36,300.2 km takes 0.1210 ms. When compared to the 110.6 seconds of the WSPR receiver time window the propagation times are negligible.

The average difference between the FB from Tx to A/C and the IB from A/C to Rx is -179.996726° (minimum -180.294278°, maximum -179.676877°). A perfect reflection at the aircraft would be -180.0°. We find the reflection is always 180.0° ±0.323°.

DateTime (UTC)	Phase	Tx Call Sign	Rx Call Sign	Tx-A/C IB (°T)	Tx-A/C Dist. (km)	Tx-A/C FB (°T)	A/C-Rx IB (°T)	A/C-Rx Dist. (km)	A/C-Rx FB (°T)	ΔA/C Tx FB -A/C Rx IB	Tx-A/C-Rx (km)
11/11/2023 13:48	Climb	IK5ZAI	MOVSE	142.691808	7,909.3	152.460610	332.464268	9,209.3	313.977246	-180.003658	17,118.6
11/11/2023 13:48	Climb	WJ8A	W7CRK	74.832439	14,732.0	131.807903	312.102181	17,417.2	236.944068	-180.294278	32,149.2
11/11/2023 13:50	Climb	N4JJS	W3PM	84.879618	14,494.8	121.041968	301.074216	15,233.2	260.222001	-180.032248	29,728.0
11/11/2023 13:52	Climb	N5WNE	KN6SWE	51.288873	16,847.6	140.133613	320.389423	17,856.3	226.036974	-180.255810	34,703.9
11/11/2023 13:52	Climb	W7GW	KV6X	71.608345	15,178.8	131.571917	311.750563	16,855.2	240.309074	-180.178646	32,034.0
11/11/2023 13:52	Climb	AE9J	KQ2Y	75.143486	15,111.1	128.167510	308.118497	13,991.4	263.696008	-179.950987	29,102.5
11/11/2023 13:54	Climb	W2RCL	K5CGM	82.862656	14,311.7	125.848374	305.965580	16,046.9	250.935433	-180.117206	30,358.6
11/11/2023 13:54	Climb	WA3DNM	K6RFT	83.377421	14,203.8	126.254897	306.345526	15,657.3	253.054387	-180.090629	29,861.0
11/11/2023 13:54	Climb	DG8GAD	DC8EO	142.544736	8,381.1	154.699095	334.700023	8,783.0	319.869572	-180.000928	17,164.1
11/11/2023 13:54	Climb	M0YXM	I0UVN	134.949947	9,086.5	152.272154	332.264740	7,612.5	324.058673	-179.992586	16,699.0
11/11/2023 14:12	Cruise	K4RCC	K5XL	80.802173	15,185.7	121.280299	301.400864	16,507.4	252.876211	-180.120565	31,693.0
11/11/2023 14:14	Cruise	K5MGF	K9YWO	58.466134	17,234.9	131.789435	311.563369	15,407.1	250.361615	-179.773934	32,642.0
11/11/2023 14:18	Cruise	GM8HHC	SWL/HU1UB	129.500860	9,810.4	152.645610	332.660728	9,093.2	315.965606	-180.015118	18,903.6
11/11/2023 14:18	Cruise	GM4DTH	DJ6DK	129.501392	9,810.4	152.646020	332.633120	8,701.9	318.795189	-179.987100	18,512.3
11/11/2023 14:20	Cruise	K7POF	N0QBH	45.994758	17,731.7	141.108665	320.838098	15,846.9	237.538308	-179.729433	33,578.6
11/11/2023 14:20	Cruise	DD3DJ	DL7UP	137.812524	8,987.7	153.591868	333.591698	8,492.0	321.225323	-179.999830	17,479.7
11/11/2023 14:22	Cruise	KK5PY	WA3TTS	67.766800	16,286.3	128.174417	308.069435	14,937.9	257.166079	-179.895017	31,224.2
11/11/2023 14:22	Cruise	AE7YQ	N9AGL	53.955178	17,856.1	133.243865	312.920742	15,520.0	248.368235	-179.676877	33,376.1
11/11/2023 14:42	Descent	AA6RF	ND7M	26.969711	18,289.2	156.397563	336.311612	18,011.0	207.876385	-179.914050	36,300.2
11/11/2023 14:44	Descent	K7ZOO	KV6X	48.182703	18,090.1	137.811759	317.616347	17,484.1	231.192902	-179.804588	35,574.2
11/11/2023 14:44	Descent	AA7US	KX4AZ/T	50.369530	18,066.3	135.869506	315.553745	15,516.9	246.184994	-179.684239	33,583.2
11/11/2023 14:44	Descent	AC1JS	K9AN	81.363936	14,205.2	130.869595	310.926968	15,898.9	247.950795	-180.057373	30,104.1
11/11/2023 14:44	Descent	HG7RED	TF4M	144.702995	8,309.6	155.342966	335.341586	11,521.2	288.339810	-179.998619	19,830.8
11/11/2023 14:44	Descent	OZ7IT	KA7OEI-1	139.829102	9,282.8	156.905641	336.805807	17,347.9	209.612120	-179.900166	26,630.7
11/11/2023 14:44	Descent	KI7DX	N6RY	31.674678	17,414.5	154.889085	335.126901	18,383.9	208.133651	-180.237816	35,798.4
11/11/2023 14:46	Descent	AC1JS	K9AN	81.204159	14,227.3	130.883174	311.011055	15,921.0	247.740171	-180.127882	30,148.2
11/11/2023 14:46	Descent	W1/AJ8S	WA2ZKD	79.097713	14,428.5	131.383074	311.419065	14,976.5	254.494358	-180.035992	29,405.0
11/11/2023 14:46	Descent	S54MI	G0OHK	139.667241	8,406.2	151.073241	331.035824	9,906.5	307.901261	-179.962583	18,312.7
11/11/2023 14:46	Descent	KD0PXX	KV6X	57.107623	16,446.3	137.729128	317.888436	17,504.4	230.807227	-180.159308	33,950.7
11/11/2023 14:48	Descent	VE1BLL	KD2OM	84.197439	13,868.0	131.169186	311.218336	14,997.1	254.547122	-180.049150	28,865.1
11/11/2023 14:48	Descent	KX4DQ	EA8/DF4UE	74.085704	15,979.9	123.985560	303.837442	9,227.2	297.363715	-179.851881	25,207.0
11/11/2023 14:48	Descent	G4TNU	IK0XFA	128.363683	9,655.2	148.740370	328.737096	8,686.1	315.734990	-179.996726	18,341.3

Table 3: Summary of results showing Distance, Initial and Final Bearings.

The mean received SNR was -15.5 db with a SD of 9.5 dB (minimum -26 dB, maximum +12 dB).

The mean difference between the received frequency and the centre transmitted frequency of the selected WSPR band was 10 Hz with a SD of 64 Hz (minimum -98 Hz, maximum +105 Hz).

There were 19 SNR anomalies, mostly during the climb and descent phases. There were 21 received frequency anomalies, including every WSPR anomaly in the cruise phase and many in the descent phase. There were 4 drift anomalies, one in each of the climb and cruise phase and two in the descent phase.

DateTime (UTC)	Phase	Tx Call Sign	Rx Call Sign	Tx Power (dBm)	Tx Power (W)	Tx Band (MHz)	Tx Centre Frequency (Hz)	Rx Frequency (Hz)	Rx - Tx Frequency (Hz)	Mean ± 3 hrs Frequency (Hz)	SD ± 3 hrs Frequency (Hz)	AD Frequency (Hz)	AD Frequency (%)	Mean ± 3 hrs SNR (dB)	SD ± 3 hrs SNR (dB)	SNR (dB)	AD SNR (dB)	AD SNR (%)	Drift (Hz/min)
11/11/2023 13:48	Climb	IK5ZAI	M0VSE	23.0	0.1995	14.0	14,097,100	14,097,017	-83	14097017.2	2.0	0.2	10%	-25.0	2.0	-22.0	-3.0	-150%	0
11/11/2023 13:48	Climb	WJ8A	W7CRK	23.0	0.1995	10.0	10,140,200	10,140,227	27	10140226.2	1.3	-0.8	-61%	-16.2	5.2	-11.0	-5.2	-100%	0
11/11/2023 13:50	Climb	N4JJS	W3PM	23.0	0.1995	14.0	14,097,100	14,097,114	14	14097136.9	56.4	22.9	41%	-15.0	4.3	-8.0	-7.0	-163%	0
11/11/2023 13:52	Climb	N5WNE	KN6SWE	23.0	0.1995	7.0	7,040,100	7,040,117	17	7040145.0	72.6	28.0	39%	-24.0	2.3	-22.0	-2.0	-87%	0
11/11/2023 13:52	Climb	W7GW	KV6X	23.0	0.1995	14.0	14,097,100	14,097,188	88	14097108.8	66.5	-79.2	-119%	-20.2	5.9	-25.0	4.8	81%	2
11/11/2023 13:52	Climb	AE8J	KQ2Y	23.0	0.1995	18.0	18,106,100	18,106,136	36	18106100.0	51.2	-36.0	-70%	-14.0	4.9	-22.0	8.0	163%	0
11/11/2023 13:54	Climb	W2RCL	K5CGM	23.0	0.1995	7.0	7,040,100	7,040,118	18	7040116.8	1.0	-1.2	-113%	-21.6	4.5	-25.0	3.4	77%	0
11/11/2023 13:54	Climb	WA3DNM	K6RFT	37.0	5.0119	21.0	21,096,100	21,096,112	12	21096111.4	0.5	-0.6	-116%	5.2	5.0	12.0	-6.8	-136%	0
11/11/2023 13:54	Climb	DG8GAD	DC8EO	30.0	1.0000	10.0	10,140,200	10,140,143	-57	10140143.2	0.9	0.2	22%	-22.4	1.6	-24.0	1.6	97%	0
11/11/2023 13:54	Climb	M0YXM	I0UVN	23.0	0.1995	21.0	21,096,100	21,096,121	21	21096112.7	4.4	-8.3	-190%	-5.3	6.6	-4.0	-1.3	-20%	0
11/11/2023 14:12	Cruise	K4RCC	K5XL	23.0	0.1995	14.0	14,097,100	14,097,205	105	14097148.2	44.6	-56.8	-127%	-6.7	4.2	-6.0	-0.7	-16%	-1
11/11/2023 14:14	Cruise	K5MGF	K9YWO	23.0	0.1995	28.0	28,126,100	28,126,020	-80	28126072.4	49.3	52.4	106%	-22.2	3.4	-26.0	3.8	113%	0
11/11/2023 14:18	Cruise	GM8HHC	SWL/HU1UB	23.0	0.1995	10.0	10,140,200	10,140,182	-18	10140226.8	48.0	44.8	93%	-18.2	4.0	-14.0	-4.2	-105%	0
11/11/2023 14:18	Cruise	GM4DTH	DJ6DK	23.0	0.1995	14.0	14,097,100	14,097,014	-86	14097105.5	77.6	91.5	118%	-21.5	3.4	-23.0	1.5	44%	0
11/11/2023 14:20	Cruise	K7POF	N0QBH	23.0	0.1995	7.0	7,040,100	7,040,024	-76	7040087.4	54.6	63.4	116%	-13.4	5.8	-13.0	-0.4	-7%	0
11/11/2023 14:20	Cruise	DD3DJ	DL7UP	23.0	0.1995	7.0	7,040,100	7,040,059	-41	7040057.6	0.6	-1.4	-225%	-15.5	6.3	-17.0	1.5	24%	0
11/11/2023 14:22	Cruise	KK5PY	WA3TTS	23.0	0.1995	14.0	14,097,100	14,097,191	91	14097121.5	61.2	-69.5	-114%	-21.9	4.2	-19.0	-2.9	-69%	0
11/11/2023 14:22	Cruise	AE7YQ	N9AGL	23.0	0.1995	28.0	28,126,100	28,126,181	81	28126083.8	59.0	-97.2	-165%	-23.3	3.7	-25.0	1.7	47%	0
11/11/2023 14:42	Descent	AA6RF	ND7M	23.0	0.1995	7.0	7,040,100	7,040,174	74	7040090.8	56.0	-83.2	-149%	-12.4	4.3	-11.0	-1.4	-33%	0
11/11/2023 14:44	Descent	K7ZOO	KV6X	23.0	0.1995	3.0	3,570,100	3,570,202	102	3570105.0	60.1	-97.0	-161%	-6.6	10.3	-15.0	8.4	82%	0
11/11/2023 14:44	Descent	AA7US	KX4AZ/T	20.0	0.1000	14.0	14,097,100	14,097,108	8	14097099.9	49.4	-8.1	-16%	-18.1	4.5	-11.0	-7.1	-159%	0
11/11/2023 14:44	Descent	AC1JS	K9AN	23.0	0.1995	7.0	7,040,100	7,040,121	21	7040101.5	62.5	-19.6	-31%	-19.9	5.8	-26.0	6.1	104%	0
11/11/2023 14:44	Descent	HG7RED	TF4M	23.0	0.1995	18.0	18,106,100	18,106,002	-98	18106045.8	58.5	43.8	75%	-15.1	4.9	-7.0	-8.1	-166%	0
11/11/2023 14:44	Descent	OZ7IT	KA7OEI-1	37.0	5.0119	24.0	24,926,100	24,926,130	30	24926127.3	5.9	-2.7	-46%	-16.9	5.9	-20.0	3.1	51%	-1
11/11/2023 14:44	Descent	K17DX	N6RY	33.0	1.9953	7.0	7,040,100	7,040,146	46	7040144.9	0.9	-1.1	-120%	-4.2	9.5	2.0	-6.2	-65%	0
11/11/2023 14:46	Descent	AC1JS	K9AN	23.0	0.1995	10.0	10,140,200	10,140,113	-87	10140220.4	56.5	107.4	190%	-10.1	7.6	-18.0	7.9	104%	0
11/11/2023 14:46	Descent	W1/AJ8S	WA2ZKD	33.0	1.9953	7.0	7,040,100	7,040,161	61	7040161.0	0.0	0.0	0%	-5.3	4.0	-1.0	-4.3	-108%	0
11/11/2023 14:46	Descent	S54MI	G0OHK	37.0	5.0119	7.0	7,040,100	7,040,107	7	7040108.4	0.9	1.4	157%	-20.2	2.9	-23.0	2.8	95%	0
11/11/2023 14:46	Descent	KD0PXX	KV6X	30.0	1.0000	18.0	18,106,100	18,106,098	-2	18106098.0	0.0	0.0	0%	-6.1	2.9	-5.0	-1.1	-38%	-1
11/11/2023 14:48	Descent	VE1BL	KD2OM	23.0	0.1995	21.0	21,096,100	21,096,022	-78	21096108.3	62.7	86.3	138%	-15.4	5.0	-21.0	5.6	113%	0
11/11/2023 14:48	Descent	KX4DQ	EA8/DF4UE	23.0	0.1995	28.0	28,126,100	28,126,200	100	28126110.1	78.6	-89.9	-114%	-19.2	7.2	-22.0	2.8	39%	0
11/11/2023 14:48	Descent	G4TNU	IK0XFA	23.0	0.1995	10.0	10,140,200	10,140,278	78	10140215.7	64.8	-62.3	-96%	-20.9	6.5	-24.0	3.1	48%	0

Table 4: Summary of results showing the received SNR, received frequency and drift anomalies.

We have chosen to track an aircraft in the southern Indian Ocean travelling West to East on a track of around 100°T.

The aircraft will move away from the transmitter/receiver pair along a vector that has an angle between the great circle path of the propagation and the track of the aircraft of around 34° (minimum 18°, maximum 61°) for WSPR stations in the North America and around 52° (minimum 48°, maximum 56°) for WSPR stations in Europe.

The speed vector for a typical cruise speed of 483 knots is on average 366 knots and creates a reliable set of received frequency anomalies every two minutes during the cruise due to the Doppler shift.

DateTime (UTC)	Phase	Altitude (feet)	ROC (fpm)	Ground Speed (knots)	Track (°T)	Tx Call Sign	Rx Call Sign	Tx Power (dBm)	Tx Power (W)	Tx Band (MHz)	Tx Centre Frequency (Hz)	Rx Frequency (Hz)	Rx - Tx Frequency (Hz)	AD Frequency (%)	AD SNR (%)	Drift (Hz/min)	Tx-A/C FB - Track (°T)	Horizontal Speed Vector (knots)	Vertical Speed Vector (knots)	Speed Vector (knots)
11/11/2023 13:48	Climb	9,045	2,689	311	104	IK5ZAI	M0VSE	23.0	0.1995	14.0	14,097,100	14,097,017	-83	10%	-150%	0	48	206.2	26.6	204.5
11/11/2023 13:48	Climb	9,045	2,689	311	104	WJBA	W7CRK	23.0	0.1995	10.0	10,140,200	10,140,227	27	-61%	-100%	0	28	275.1	26.6	273.8
11/11/2023 13:50	Climb	14,745	1,859	324	103	N4JJS	W3PM	23.0	0.1995	14.0	14,097,100	14,097,114	14	41%	-163%	0	18	308.1	18.4	307.5
11/11/2023 13:52	Climb	18,660	1,823	368	103	N5WNE	KN6SWE	23.0	0.1995	7.0	7,040,100	7,040,117	17	39%	-87%	0	37	293.4	18.0	292.8
11/11/2023 13:52	Climb	18,660	1,823	368	103	W7GW	KV6X	23.0	0.1995	14.0	14,097,100	14,097,188	88	-119%	81%	2	29	323.2	18.0	322.7
11/11/2023 13:52	Climb	18,660	1,823	368	103	AE8J	KQ2Y	23.0	0.1995	18.0	18,106,100	18,106,136	36	-70%	163%	0	25	333.1	18.0	332.6
11/11/2023 13:54	Climb	22,438	1,830	393	102	W2RCL	K5CGM	23.0	0.1995	7.0	7,040,100	7,040,118	18	-113%	77%	0	24	359.4	18.1	359.0
11/11/2023 13:54	Climb	22,438	1,830	393	102	WA3DNM	K6RFT	37.0	5.0119	21.0	21,096,100	21,096,112	12	-116%	-136%	0	24	358.3	18.1	357.9
11/11/2023 13:54	Climb	22,438	1,830	393	102	DG8GAD	DC8EO	30.0	1.0000	10.0	10,140,200	10,140,143	-57	22%	97%	0	53	238.2	18.1	237.5
11/11/2023 13:54	Climb	22,438	1,830	393	102	M0YXM	I0UVN	23.0	0.1995	21.0	21,096,100	21,096,121	21	-190%	-20%	0	50	251.2	18.1	250.5
11/11/2023 14:12	Cruise	39,000	0	483	100	K4RCC	K5XL	23.0	0.1995	14.0	14,097,100	14,097,205	105	-127%	-16%	-1	21	450.1	0.0	450.1
11/11/2023 14:14	Cruise	39,000	0	483	100	K5MGF	K9YWO	23.0	0.1995	28.0	28,126,100	28,126,020	-80	106%	113%	0	32	410.5	0.0	410.5
11/11/2023 14:18	Cruise	39,000	0	483	100	GM8HHC	SWL/HU1UB	23.0	0.1995	10.0	10,140,200	10,140,182	-18	93%	-105%	0	53	293.1	0.0	293.1
11/11/2023 14:18	Cruise	39,000	0	483	100	GM4DTH	DJ6DK	23.0	0.1995	14.0	14,097,100	14,097,014	-86	118%	44%	0	53	293.1	0.0	293.1
11/11/2023 14:20	Cruise	39,000	0	483	100	K7POF	N0QBH	23.0	0.1995	7.0	7,040,100	7,040,024	-76	116%	-7%	0	41	363.9	0.0	363.9
11/11/2023 14:20	Cruise	39,000	0	483	100	DD3DJ	DL7UP	23.0	0.1995	7.0	7,040,100	7,040,059	-41	-225%	24%	0	54	286.7	0.0	286.7
11/11/2023 14:22	Cruise	39,000	0	483	100	KK5PY	WA3TTS	23.0	0.1995	14.0	14,097,100	14,097,191	91	-114%	-69%	0	28	425.8	0.0	425.8
11/11/2023 14:22	Cruise	39,000	0	483	100	AE7YQ	N8AGL	23.0	0.1995	28.0	28,126,100	28,126,181	81	-165%	47%	0	33	404.0	0.0	404.0
11/11/2023 14:42	Descent	38,539	-808	495	95	AA6RF	ND7M	23.0	0.1995	7.0	7,040,100	7,040,174	74	-149%	-33%	0	61	237.0	-8.0	237.1
11/11/2023 14:44	Descent	35,187	-2,367	500	99	K7ZOO	KV6X	23.0	0.1995	3.0	3,570,100	3,570,202	102	-161%	82%	0	39	389.6	-23.4	390.3
11/11/2023 14:44	Descent	35,187	-2,367	500	99	AA7US	KX4AZ/T	20.0	1.0000	14.0	14,097,100	14,097,108	8	-16%	-159%	0	37	400.0	-23.4	400.7
11/11/2023 14:44	Descent	35,187	-2,367	500	99	AC1JS	K9AN	23.0	0.1995	7.0	7,040,100	7,040,121	21	-31%	104%	0	32	424.6	-23.4	425.3
11/11/2023 14:44	Descent	35,187	-2,367	500	99	HG7RED	TF4M	23.0	0.1995	18.0	18,106,100	18,106,002	-98	75%	-166%	0	56	277.1	-23.4	278.1
11/11/2023 14:44	Descent	35,187	-2,367	500	99	OZ7IT	KA7OEI-1	37.0	5.0119	24.0	24,926,100	24,926,130	30	-46%	51%	-1	58	265.7	-23.4	266.7
11/11/2023 14:44	Descent	35,187	-2,367	500	99	KI7DX	N6RY	33.0	1.9953	7.0	7,040,100	7,040,146	46	-120%	-65%	0	56	280.4	-23.4	281.4
11/11/2023 14:46	Descent	31,335	-2,350	495	98	AC1JS	K9AN	23.0	0.1995	10.0	10,140,200	10,140,113	-87	190%	104%	0	33	415.7	-23.2	416.3
11/11/2023 14:46	Descent	31,335	-2,350	495	98	W1AJBS	WA2ZKD	33.0	1.9953	7.0	7,040,100	7,040,161	61	0%	-108%	0	33	413.3	-23.2	414.0
11/11/2023 14:46	Descent	31,335	-2,350	495	98	S54MI	G0OHK	37.0	5.0119	7.0	7,040,100	7,040,107	7	157%	95%	0	53	297.4	-23.2	298.3
11/11/2023 14:46	Descent	31,335	-2,350	495	98	KD0PXX	KV6X	30.0	1.0000	18.0	18,106,100	18,106,098	-2	0%	-38%	-1	40	380.7	-23.2	381.4
11/11/2023 14:48	Descent	26,965	-1,805	462	98	VE1BLL	KD2OM	23.0	0.1995	21.0	21,096,100	21,096,022	-78	138%	113%	0	33	386.7	-17.8	387.1
11/11/2023 14:48	Descent	26,965	-1,805	462	98	KX4DQ	EA8/DF4UE	23.0	0.1995	28.0	28,126,100	28,126,200	100	-114%	39%	0	26	415.3	-17.8	415.7
11/11/2023 14:48	Descent	26,965	-1,805	462	98	G4TNU	IK0XFA	23.0	0.1995	10.0	10,140,200	10,140,278	78	-96%	48%	0	51	292.4	-17.8	292.9

Table 5: Summary of results showing the Aircraft Ground Speed, Track and Speed Vector.

7. Long Distance WSPR Detection of Aircraft - Detailed Results.

The WSPR transmission has a duration of 110.6 seconds and the aircraft is first detected by two WSPR links transmitted continuously between 13:48:01 UTC and 13:49:51.6 UTC. In this timeframe the aircraft is in the climb phase and moves around 9.6 nmi and is marked in green. There are two SNR anomalies of -150% SD and -100% SD.

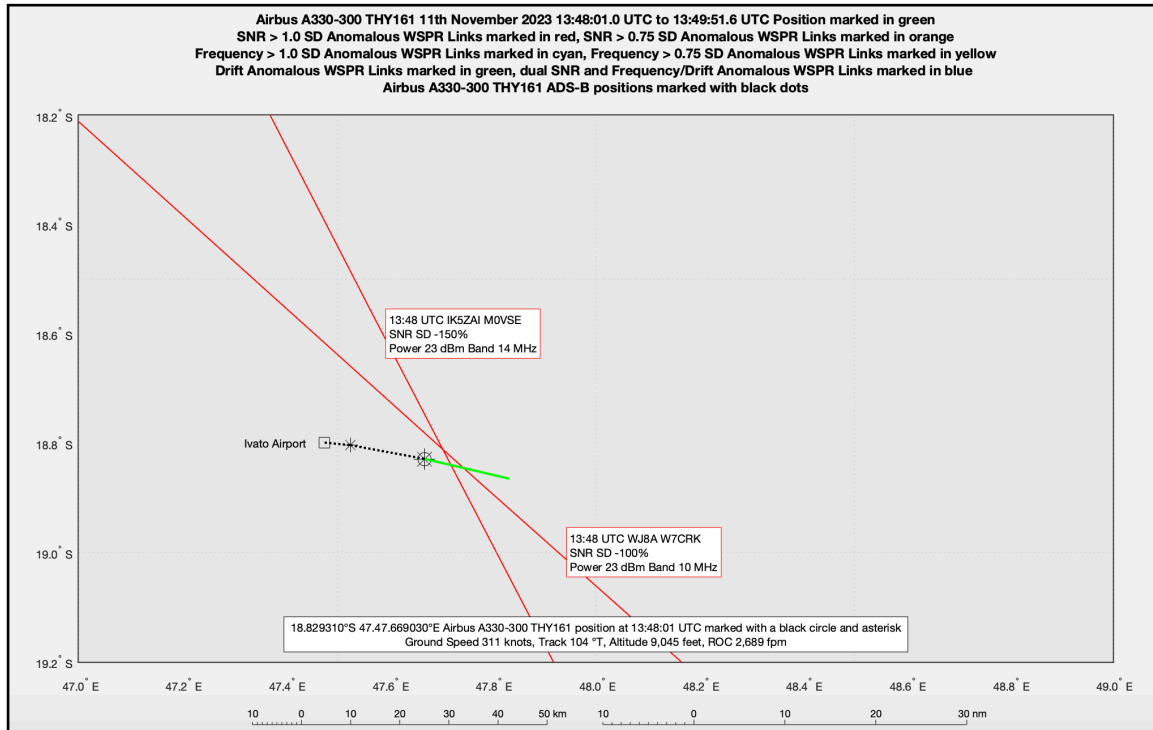


Figure 12: Flight THY161 crossing the WSPR paths IK5ZAI-MOVSE and WJ8A-W7CRK.

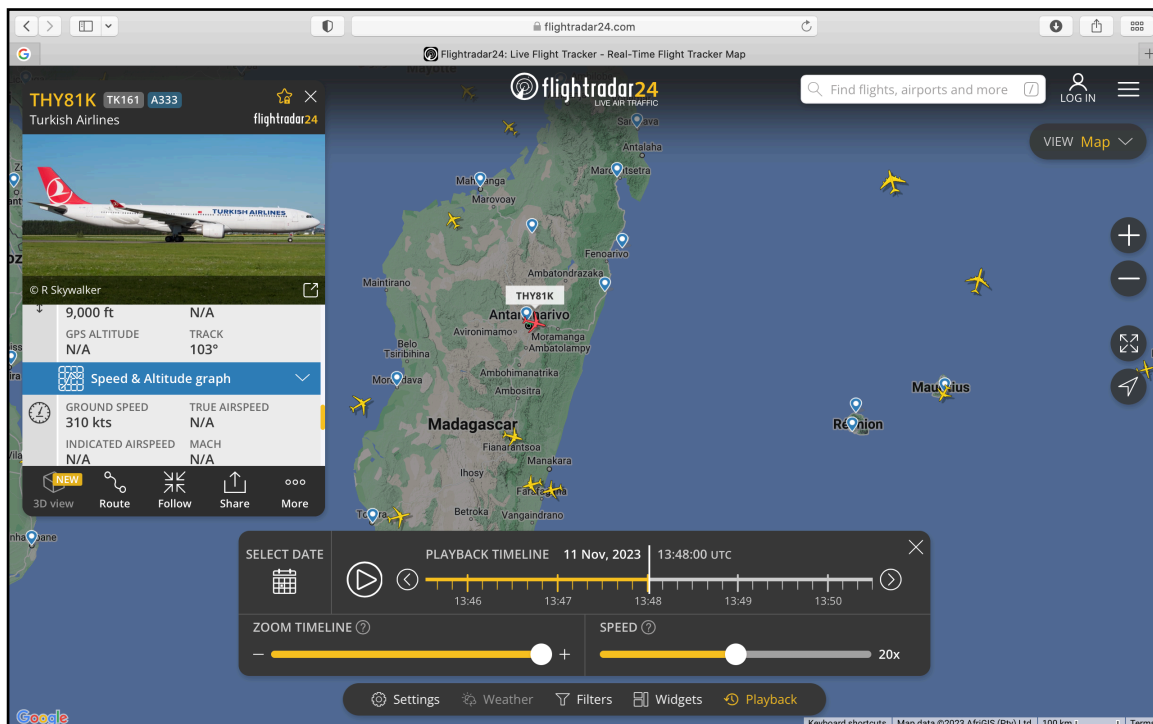


Figure 13: Turkish Airlines Flight THY161 as shown in flightradar24.com at 13:48 UTC.

The ADS-B data for flight THY161 is shown in flightaware.com starting on Saturday 11th November 2023 at 14:45:10 CET, which is 13:45:10 UTC. The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 13:48:01 UTC and 13:49:51.6 UTC.

Time (CET)	Latitude	Longitude	Course	kts	feet	Rate	Reporting Facility
Sat 02:45:10 PM	Departure (TNR) @ Saturday 04:45:10 PM EAT						FlightAware ADS-B (TNR / FMMI)
Sat 02:45:10 PM	-18.7985	47.4885	→ 100°	154	4,300		FlightAware ADS-B (TNR / FMMI)
Sat 02:45:26 PM	-18.8003	47.4993	→ 100°	148	4,975	2,438 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:45:42 PM	-18.8021	47.5109	→ 100°	152	5,600	1,809 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:46:00 PM	-18.8041	47.5246	→ 97°	169	6,000	1,103 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:46:16 PM	-18.8050	47.5391	→ 92°	194	6,225	1,360 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:46:43 PM	-18.8070	47.5660	→ 98°	222	6,975	1,656 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:47:04 PM	-18.8116	47.5919	→ 102°	249	7,550	1,324 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:47:34 PM	-18.8204	47.6306	→ 104°	294	8,100	1,600 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:48:04 PM	-18.8303	47.6733	→ 104°	313	9,150	2,810 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:48:53 PM	-18.8464	47.7459	→ 103°	309	11,800	3,146 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:49:26 PM	-18.8570	47.7941	→ 103°	308	13,450	2,654 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:49:58 PM	-18.8677	47.8426	→ 103°	320	14,675	1,863 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:50:28 PM	-18.8783	47.8903	→ 103°	344	15,375	1,825 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:50:58 PM	-18.8894	47.9401	→ 103°	352	16,500	2,225 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:51:28 PM	-18.9006	47.9910	→ 103°	358	17,600	2,075 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:51:58 PM	-18.9120	48.0427	→ 103°	367	18,575	1,825 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:52:28 PM	-18.9236	48.0954	→ 103°	378	19,425	1,800 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:52:58 PM	-18.9356	48.1498	→ 103°	385	20,375	1,950 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:53:28 PM	-18.9478	48.2058	→ 103°	389	21,375	1,975 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:53:58 PM	-18.9597	48.2616	→ 102°	392	22,350	1,850 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:54:28 PM	-18.9699	48.3187	→ 100°	399	23,225	1,650 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:54:58 PM	-18.9799	48.3770	→ 101°	407	24,000	1,525 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:55:28 PM	-18.9905	48.4356	→ 101°	417	24,750	1,675 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:55:58 PM	-19.0015	48.4964	→ 101°	428	25,675	871 ↑	FlightAware ADS-B (TNR / FMMI)
Sat 02:57:57 PM	-19.0399	48.7080	→ 101°				Estimated
Sat 02:58:59 PM	-19.0599	48.8184	→ 101°				Estimated

Table 6: Flight THY161 ADS-B data as shown in flightaware.com.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
13:47:34	0	-18.820400	47.630600	8,100	294	104	1,600
13:48:01	27	-18.829310	47.669030	9,045	311	104	2,689
13:48:04	30	-18.830300	47.673300	9,150	313	104	2,810
13:49:26	0	-18.857000	47.794100	13,450	308	103	2,654
13:49:51.6	25.6	-18.865560	47.832900	14,430	318	103	2,021
13:49:58	32	-18.867700	47.842600	14,675	320	103	1,863

Table 7: Flight THY161 ADS-B data interpolation at 13:48 UTC.

The WSPR data for the link IK5ZAI-M0VSE was downloaded for the time period starting 13:48:01 UTC $\pm$ 3 hours and the mean SNR of -25.0 dB and the SD of 2.0 dB were calculated. The actual SNR in the 13:48 UTC WSPR time slot is -22 dB, which represents a deviation of -3.0 dB from the mean by a factor of -1.50 SD or by a percentage of -150% SD.

The WSPR data for the link WJ8A-W7CRK was downloaded for the time period starting 13:48:01 UTC $\pm$ 3 hours and the mean SNR of -16.20 dB and the SD of 5.2154 dB were calculated. The actual SNR in the 13:48 UTC WSPR time slot is -11 dB, which represents a deviation of -5.20 dB from the mean by a factor of -1.00 SD or by a percentage of -100% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6605724636	2023-11-10 14:38:00	IK5ZAI	JN53fu	M0VSE	IO92jp	14097019	23	-24	0	1301	323	14	1.4A Kiwi	1
2	6606489671	2023-11-10 16:54:00	IK5ZAI	JN53fu	M0VSE	IO92jp	14097014	23	-27	0	1301	323	14	1.4A Kiwi	1
3	6610863044	2023-11-11 13:48:00	IK5ZAI	JN53fu	M0VSE	IO92jp	14097017	23	-22	0	1301	323	14	1.4A Kiwi	1
4	6611814747	2023-11-11 16:40:00	IK5ZAI	JN53fu	M0VSE	IO92jp	14097017	23	-26	0	1301	323	14	1.4A Kiwi	1
5	6616352460	2023-11-12 14:46:00	IK5ZAI	JN53fu	M0VSE	IO92jp	14097019	23	-26	0	1301	323	14	1.4A Kiwi	1
							14097017.2000	Mean	-25.0000						
							2.0494	SD	2.0000						
							0.2000	AD	-3.0000						
							10	AD%	-150						

Table 8: WSPR link data between IK5ZAI and M0VSE at 13:48 UTC $\pm$ 3 hours.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610075043	2023-11-11 10:48:00	WJ8A	EN83	W7CRK	DM43eg	10140227	23	-18	0	2720	255	10	2.6.1	1
2	6610266970	2023-11-11 11:36:00	WJ8A	EN83	W7CRK	DM43eg	10140226	23	-16	0	2720	255	10	2.6.1	1
3	6610460093	2023-11-11 12:24:00	WJ8A	EN83	W7CRK	DM43eg	10140227	23	-12	0	2720	255	10	2.6.1	1
4	6610856059	2023-11-11 13:48:00	WJ8A	EN83	W7CRK	DM43eg	10140227	23	-11	0	2720	255	10	2.6.1	1
5	6611526081	2023-11-11 15:48:00	WJ8A	EN83	W7CRK	DM43eg	10140224	23	-24	-1	2720	255	10	2.6.1	1
							10140226.2000	Mean	-16.2000						
							1.3038	SD	5.2154						
							-0.8000	AD	-5.2000						
							-61	AD%	-100						

Table 9: WSPR link data between WJ8A and W7CRK at 13:48 UTC $\pm$ 3 hours.

At 13:50 UTC there is a single SNR anomaly of -163% SD.

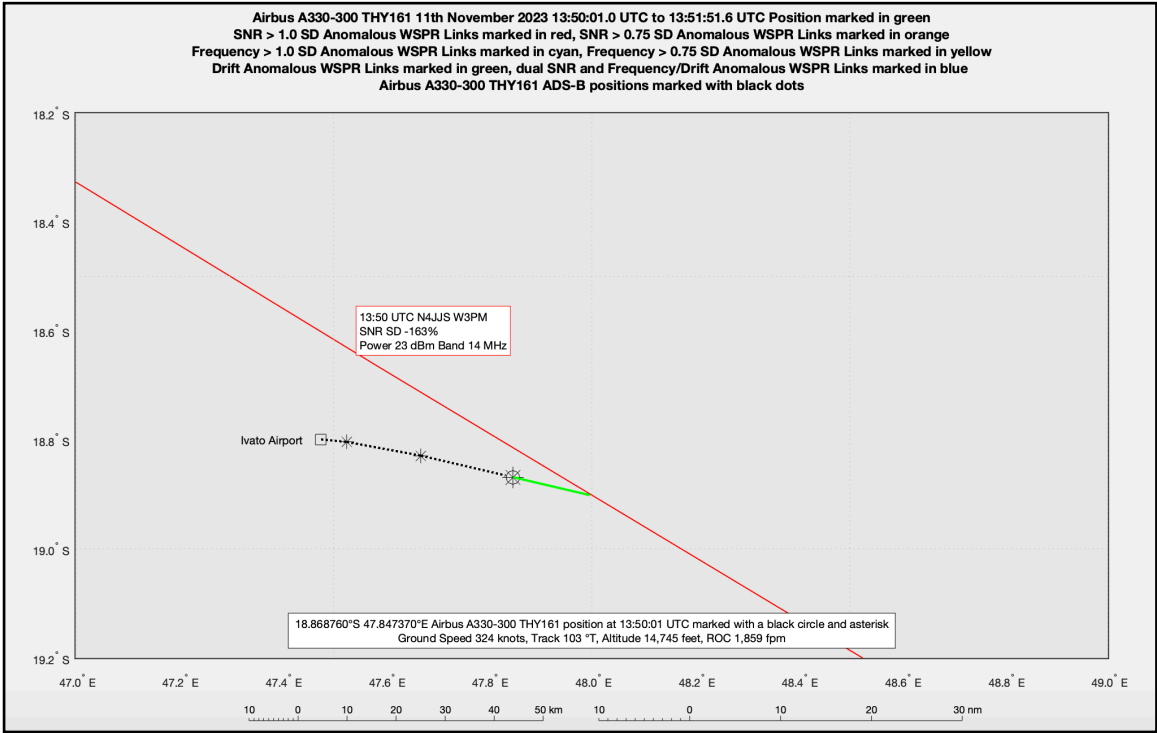


Figure 14: Flight THY161 crossing the WSPR path N4JJS-W3PM.

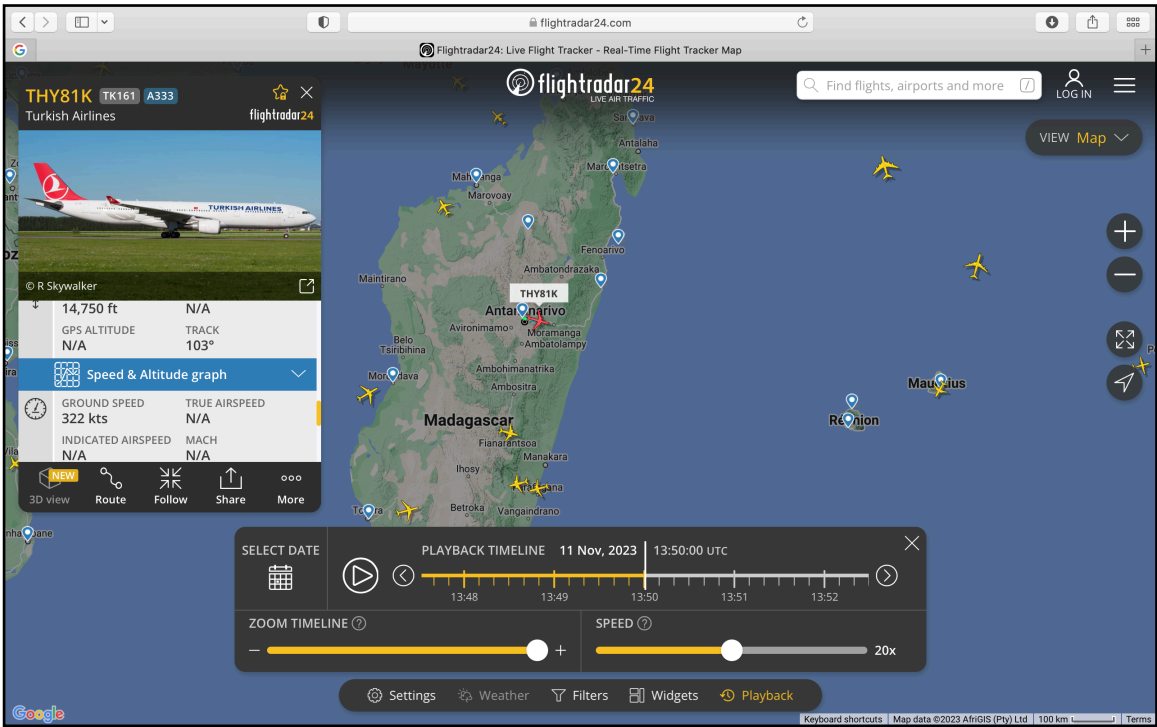


Figure 15: Turkish Airlines Flight THY161 as shown in flightradar24.com at 13:50 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 13:50:01 UTC and 13:51:51.6 UTC.

The WSPR data for the link N4JJS-W3PM was downloaded for the time period starting 13:50:01 UTC $\pm$ 3 hours and the mean SNR of -15.0 dB and the SD of 4.2817 dB were calculated. The actual SNR in the 13:50 UTC WSPR time slot is -8 dB, which represents a deviation of -7.0 dB from the mean by a factor of -1.63 SD or by a percentage of -163% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
13:49:58	0	-18.867700	47.842600	14,675	320	103	1,863
13:50:01	3	-18.868760	47.847370	14,745	324	103	1,859
13:50:28	30	-18.878300	47.890300	15,375	358	103	1,825
13:51:28	0	-18.900600	47.991000	17,600	358	103	2,075
13:51:50.6	22.6	-18.909188	48.029947	18,335	365	103	1,887
13:51:58	30	-18.912000	48.042700	18,575	367	103	1,825

Table 10: Flight THY161 ADS-B data interpolation at 13:50 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610883065	2023-11-11 13:50:00	N4JJS	FM05on	W3PM	EM64or	14097114	23	-8	0	733	265	14	WD_3.1.2	1
2	6610973519	2023-11-11 14:10:00	N4JJS	FM05on	W3PM	EM64or	14097082	23	-18	0	733	265	14	WD_3.1.2	1
3	6611096908	2023-11-11 14:30:00	N4JJS	FM05on	W3PM	EM64or	14097179	23	-15	0	733	265	14	WD_3.1.2	1
4	6611199728	2023-11-11 14:50:00	N4JJS	FM05on	W3PM	EM64or	14097047	23	-18	0	733	265	14	WD_3.1.2	1
5	6611325327	2023-11-11 15:10:00	N4JJS	FM05on	W3PM	EM64or	14097162	23	-18	0	733	265	14	WD_3.1.2	1
6	6611663460	2023-11-11 16:10:00	N4JJS	FM05on	W3PM	EM64or	14097183	23	-18	0	733	265	14	WD_3.1.2	1
7	6611866879	2023-11-11 16:50:00	N4JJS	FM05on	W3PM	EM64or	14097191	23	-10	0	733	265	14	WD_3.1.2	1
							14097136.8571	Mean	-15.0000						
							56.3839	SD	4.2817						
							22.8571	AD	-7.0000						
							41	AD%	-163						

Table 11: WSPR link data between N4JJS and W3PM at 13:50 UTC $\pm$ 3 hours.

At 13:52 UTC there are three anomalies, two SNR anomalies of -86% SD and +163% SD and one triple SNR of +81% SD, received frequency of -119% SD and drift anomaly of +2 Hz/minute.

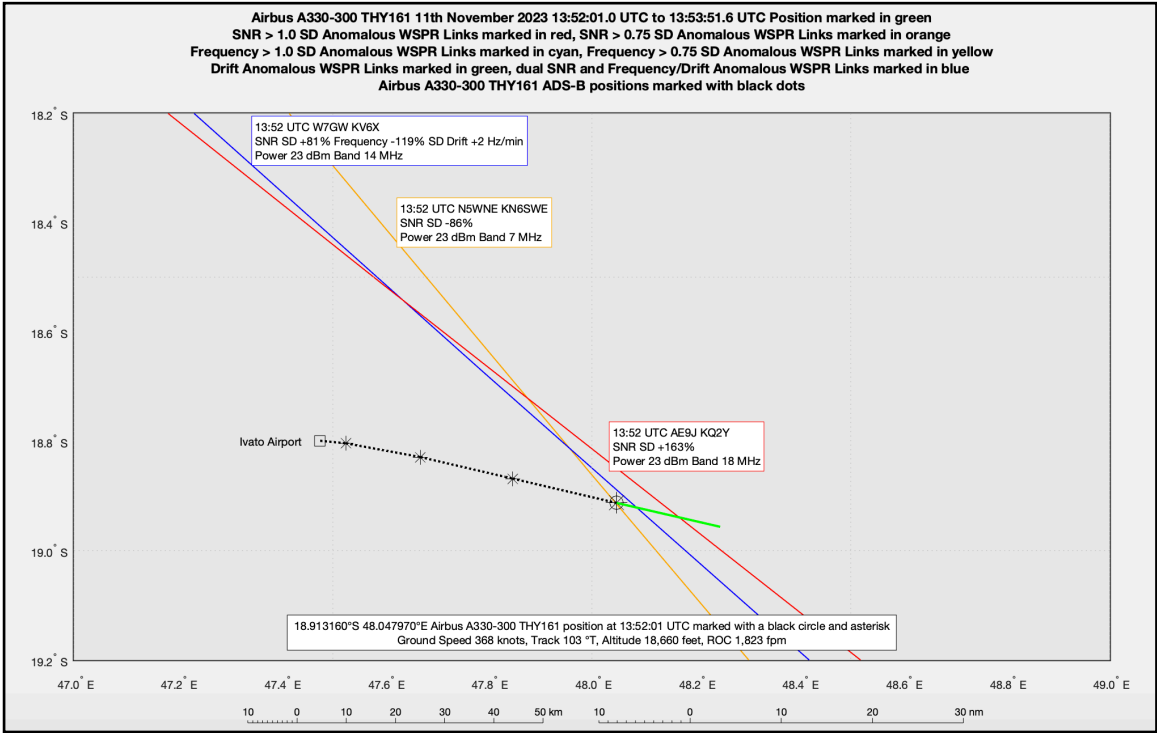


Figure 16: Flight THY161 crossing the WSPR paths W7GW-KV6X, N5WNE-KN6SWE and AE9J-KQ2Y.

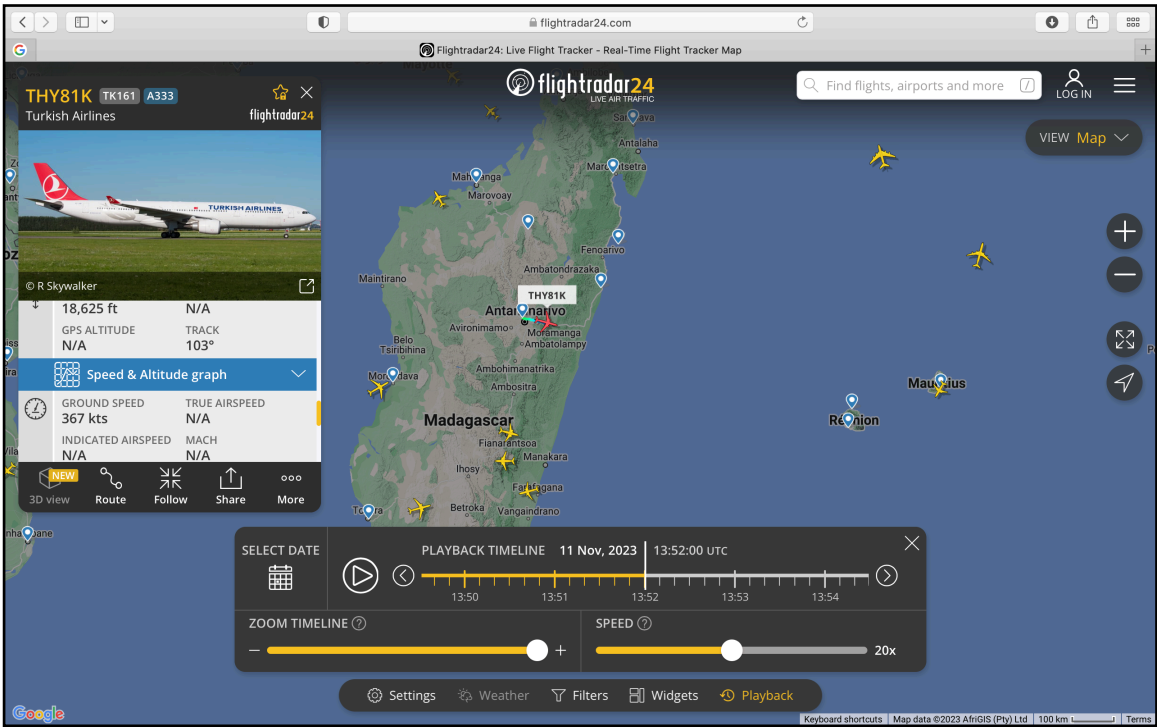


Figure 17: Turkish Airlines Flight THY161 as shown in flightradar24.com at 13:52 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 13:52:01 UTC and 13:53:51.6 UTC.

The WSPR data for the link AE9J-KQ2Y was downloaded for the time period starting 13:52:01 UTC $\pm$ 3 hours and the mean SNR of -14.0 dB and the SD of 4.8990 dB were calculated. The actual SNR in the 13:52 UTC WSPR time slot is -22 dB, which represents a deviation of +8.0 dB from the mean by a factor of +1.63 SD or by a percentage of +163% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
13:51:58	0	-18.912000	48.042700	18,575	367	103	1,825
13:52:01	3	-18.913160	48.047970	18,660	368	103	1,823
13:52:28	30	-18.923600	48.095400	19,425	378	103	1,800
13:53:28	0	-18.947800	48.205800	21,375	389	103	1,975
13:53:50.6	22.6	-18.956765	48.247836	22,110	391	102	1,881
13:53:58	30	-18.959700	48.261600	22,350	392	102	1,850

Table 12: Flight THY161 ADS-B data interpolation at 13:52 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610787526	2023-11-11 13:34:00	AE9J	EM69rs	KQ2Y	FN31gn	18106066	23	-11	0	1120	76	18	v1.2.1	1
2	6610877775	2023-11-11 13:52:00	AE9J	EM69rs	KQ2Y	FN31gn	18106136	23	-22	0	1120	76	18	v1.2.1	1
3	6610967841	2023-11-11 14:10:00	AE9J	EM69rs	KQ2Y	FN31gn	18106135	23	-9	0	1120	76	18	v1.2.1	1
4	6611167894	2023-11-11 14:46:00	AE9J	EM69rs	KQ2Y	FN31gn	18106076	23	-9	0	1120	76	18	v1.2.1	1
5	6611272550	2023-11-11 15:04:00	AE9J	EM69rs	KQ2Y	FN31gn	18106102	23	-16	0	1120	76	18	v1.2.1	1
6	6611482746	2023-11-11 15:40:00	AE9J	EM69rs	KQ2Y	FN31gn	18106075	23	-13	0	1120	76	18	v1.2.1	1
7	6611680191	2023-11-11 16:16:00	AE9J	EM69rs	KQ2Y	FN31gn	18106187	23	-20	0	1120	76	18	v1.2.1	1
8	6611776933	2023-11-11 16:34:00	AE9J	EM69rs	KQ2Y	FN31gn	18106023	23	-12	0	1120	76	18	v1.2.1	1
							18106100.0000	Mean	-14.0000						
							51.2417	SD	4.8990						
							-36.0000	AD	8.0000						
							-70	AD%	163						

Table 13: WSPR link data between AE9J and KQ2Y at 13:52 UTC $\pm$ 3 hours.

The WSPR data for the link W7GW-KV6X was downloaded for the time period starting 13:52:01 UTC $\pm$ 3 hours and the mean SNR of -20.20 dB and the SD of 5.8907 dB were calculated. The actual SNR in the 13:52 UTC WSPR time slot is -25 dB, which represents a deviation of +4.80 dB from the mean by a factor of +0.81 SD or by a percentage of +81% SD. The mean received frequency is 14,097,108.8 Hz and the SD is 66.5372 Hz. The actual received frequency in the 13:52 UTC WSPR time slot is 14,097,188 Hz, which represents a deviation of -79.20 dB from the mean by a factor of -1.19 SD or by a percentage of -119% SD.

The WSPR data for the link N5WNE-KN6SWE was downloaded for the time period starting 13:52:01 UTC $\pm$ 3 hours and the mean SNR of -13.80 dB and the SD of 3.2592 dB were calculated. The actual SNR in the 13:52 UTC WSPR time slot is -11 dB, which represents a deviation of -2.80dB from the mean by a factor of -0.86 SD or by a percentage of -86% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610683766	2023-11-11 13:12:00	W7GW	EN51vu	KV6X	DM75aq	14097072	23	-13	0	1680	252	14	WD_3.1.2	1
2	6610701557	2023-11-11 13:14:00	W7GW	EN51vu	KV6X	DM75aq	14097072	23	-15	0	1680	252	14	WD_3.1.2	1
3	6610884168	2023-11-11 13:52:00	W7GW	EN51vu	KV6X	DM75aq	14097188	23	-25	2	1680	252	14	WD_3.1.2	1
4	6611100641	2023-11-11 14:32:00	W7GW	EN51vu	KV6X	DM75aq	14097040	23	-26	0	1680	252	14	WD_3.1.2	1
5	6611774952	2023-11-11 16:32:00	W7GW	EN51vu	KV6X	DM75aq	14097172	23	-22	0	1680	252	14	WD_3.1.2	1
							14097108.8000	Mean	-20.2000						
							66.5372	SD	5.8907						
							-79.2000	AD	4.8000						
							-119	AD%	81						

Table 14: WSPR link data between W7GW and KV6X at 13:52 UTC $\pm$ 3 hours.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610171541	2023-11-11 11:12:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040227	23	-8	0	1007	232	7	2.5.4	1
2	6610202833	2023-11-11 11:20:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040114	23	-14	0	1007	232	7	2.5.4	1
3	6610234426	2023-11-11 11:28:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040096	23	-15	0	1007	232	7	2.5.4	1
4	6610265763	2023-11-11 11:36:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040081	23	-16	0	1007	232	7	2.5.4	1
5	6610795178	2023-11-11 13:36:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040223	23	-10	0	1007	232	7	2.5.4	1
6	6610833842	2023-11-11 13:44:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040052	23	-14	0	1007	232	7	2.5.4	1
7	6610878645	2023-11-11 13:52:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040117	23	-11	0	1007	232	7	2.5.4	1
8	6610916100	2023-11-11 14:00:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040083	23	-15	0	1007	232	7	2.5.4	1
9	6610956697	2023-11-11 14:08:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040227	23	-19	-2	1007	232	7	2.5.4	1
10	6611001198	2023-11-11 14:16:00	N5WNE	DM59qb	KN6SWE	DM13kd	7040230	23	-16	0	1007	232	7	2.5.4	1
							7040145.0000	Mean	-13.8000						
							72.6422	SD	3.2592						
							28.0000	AD	-2.8000						
							39	AD%	-86						

Table 15: WSPR link data between N5WNE and KN6SWE at 13:52 UTC $\pm$ 3 hours.

At 13:54 UTC there are four anomalies, one SNR anomalies of +97% SD, one received frequency anomaly of -190% SD and +163% SD and two dual anomalies with SNR of +77% SD, received frequency of -113% SD and with SNR of -136% SD, received frequency of -116% SD.

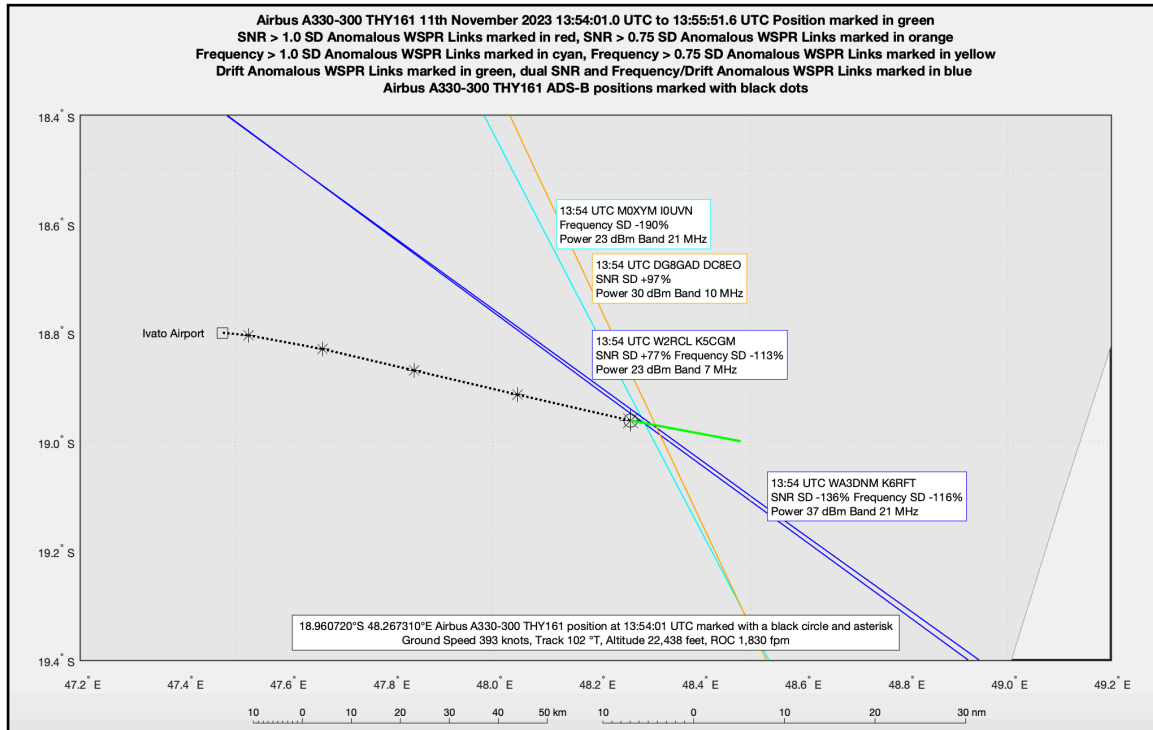


Figure 18: Flight THY161 crossing the WSPR paths M0XYM-I0UVN, DG8GAD-DC8EO, W2RCL-K5CGM and WA3DNM-K6RFT.

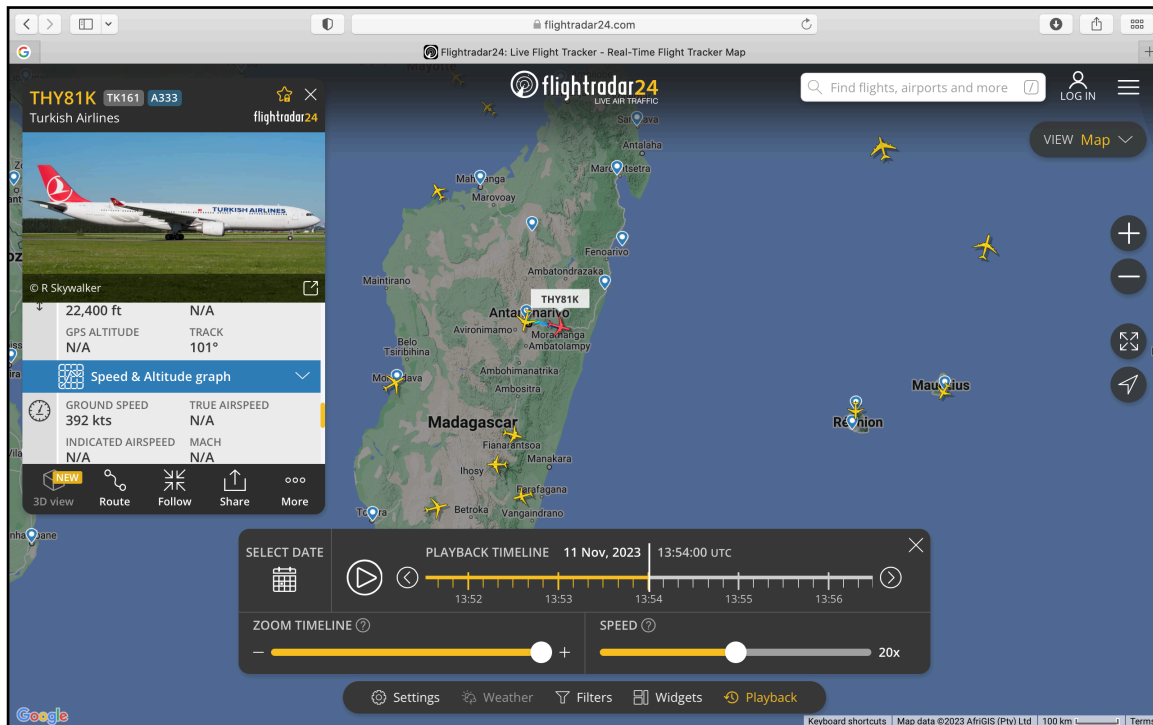


Figure 19: Turkish Airlines Flight THY161 as shown in flightradar24.com at 13:54 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 13:54:01 UTC and 13:55:51.6 UTC.

The WSPR data for the link M0XYM-I0UVN was downloaded for the time period starting 13:54:01 UTC $\pm$ 3 hours and the mean received frequency of 21,096,112.6818 Hz and the SD of 4.3795 Hz were calculated. The actual received frequency in the 13:54 UTC WSPR time slot is 21,096,121 Hz, which represents a deviation of -8.3182 Hz from the mean by a factor of -1.90 SD or by a percentage of -190% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
13:53:58	0	-18.959700	48.261600	22,350	392	102	1,850
13:54:01	3	-18.960720	48.267310	22,438	393	102	1,830
13:54:28	30	-18.969900	48.318700	23,225	399	100	1,650
13:55:28	0	-18.990500	48.435600	24,750	417	101	1,675
13:55:50.6	22.6	-18.998787	48.481403	25,447	425	101	1,069
13:55:58	30	-19.001500	48.496400	25,675	428	101	871

Table 16: Flight THY161 ADS-B data interpolation at 13:54 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6599297034	2023-11-09 11:04:00	M0XYM	JO01	I0UVN	JN61nl	21096108	23	5	1	1447	135	21	WD_3.0.8	1
2	6599530567	2023-11-09 12:04:00	M0XYM	JO01	I0UVN	JN61nl	21096113	23	-11	0	1447	135	21	WD_3.0.8	1
3	6599809014	2023-11-09 13:04:00	M0XYM	JO01	I0UVN	JN61nl	21096110	23	-4	0	1447	135	21	WD_3.0.8	1
4	6600121874	2023-11-09 14:04:00	M0XYM	JO01	I0UVN	JN61nl	21096114	23	-2	0	1447	135	21	WD_3.0.8	1
5	6600461862	2023-11-09 15:04:00	M0XYM	JO01	I0UVN	JN61nl	21096114	23	-3	0	1447	135	21	WD_3.0.8	1
6	6600807489	2023-11-09 16:04:00	M0XYM	JO01	I0UVN	JN61nl	21096109	23	-17	0	1447	135	21	WD_3.0.8	1
7	6604723874	2023-11-10 11:04:00	M0XYM	JO01	I0UVN	JN61nl	21096106	23	1	-1	1447	135	21	WD_3.0.8	1
8	6604970018	2023-11-10 12:04:00	M0XYM	JO01	I0UVN	JN61nl	21096113	23	0	0	1447	135	21	WD_3.0.8	1
9	6605235679	2023-11-10 13:04:00	M0XYM	JO01	I0UVN	JN61nl	21096111	23	-2	0	1447	135	21	WD_3.0.8	1
10	6605536772	2023-11-10 14:04:00	M0XYM	JO01	I0UVN	JN61nl	21096113	23	-9	0	1447	135	21	WD_3.0.8	1
11	6610107371	2023-11-11 10:54:00	M0XYM	JO01	I0UVN	JN61nl	21096105	23	-4	0	1447	135	21	1.4A Kiwi	1
12	6610598670	2023-11-11 12:54:00	M0XYM	JO01	I0UVN	JN61nl	21096115	23	-4	0	1447	135	21	WD_3.0.8	1
13	6610894322	2023-11-11 13:54:00	M0XYM	JO01	I0UVN	JN61nl	21096121	23	-4	0	1447	135	21	WD_3.0.8	1
14	6611223939	2023-11-11 14:54:00	M0XYM	JO01	I0UVN	JN61nl	21096121	23	-11	0	1447	135	21	WD_3.0.8	1
15	6615241915	2023-11-12 10:54:00	M0XYM	JO01	I0UVN	JN61nl	21096110	23	-11	0	1447	135	21	WD_3.0.8	1
16	6615479716	2023-11-12 11:54:00	M0XYM	JO01	I0UVN	JN61nl	21096111	23	-11	0	1447	135	21	WD_3.0.8	1
17	6615751918	2023-11-12 12:54:00	M0XYM	JO01	I0UVN	JN61nl	21096116	23	-5	0	1447	135	21	WD_3.0.8	1
18	6616063672	2023-11-12 13:54:00	M0XYM	JO01	I0UVN	JN61nl	21096117	23	-22	0	1447	135	21	WD_3.0.8	1
19	6616402335	2023-11-12 14:54:00	M0XYM	JO01	I0UVN	JN61nl	21096120	23	-7	0	1447	135	21	WD_3.0.8	1
20	6620891933	2023-11-13 10:54:00	M0XYM	JO01	I0UVN	JN61nl	21096110	23	3	0	1447	135	21	WD_3.0.8	1
21	6621131204	2023-11-13 11:54:00	M0XYM	JO01	I0UVN	JN61nl	21096111	23	1	-1	1447	135	21	WD_3.0.8	1
22	6621400783	2023-11-13 12:54:00	M0XYM	JO01	I0UVN	JN61nl	21096111	23	0	-1	1447	135	21	WD_3.0.8	1
							21096112.6818	Mean	-5.3182						
							4.3795	SD	6.5711						
							-8.3182	AD	-1.3182						
							-190	AD%	-20						

Table 17: WSPR link data between M0XYM and I0UVN at 13:54 UTC $\pm$ 3 hours.

The WSPR data for the link DG8GAD-DC8EO was downloaded for the time period starting 13:54:01 UTC $\pm$ 3 hours and the mean SNR of -22.40 dB and the SD of 1.6465 dB were calculated. The actual SNR in the 13:54 UTC WSPR time slot is -24 dB, which represents a deviation of +1.6 dB from the mean by a factor of +0.97 SD or by a percentage of +97% SD.

The WSPR data for the link WA3DNM-K6RFT was downloaded for the time period starting 13:54:01 UTC $\pm$ 3 hours and the mean received frequency of 21,096,111.40 Hz and the SD of 0.5164 Hz were calculated. The actual received frequency in the 13:54 UTC WSPR time slot is 21,096,112 Hz, which represents a deviation of -0.60 Hz from the mean by a factor of -1.16 SD or by a percentage of -116% SD. The mean SNR of +5.20 dB and the SD of 5.0067 dB were calculated. The actual SNR in the 13:54 UTC WSPR time slot is +12 dB, which represents a deviation of -6.80 dB from the mean by a factor of -1.36 SD or by a percentage of -136% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610811200	2023-11-11 13:38:00	DG8GAD	JN48	DC8EO	JO31ef	10140141	30	-23	-1	357	330	10	2.6.1	1
2	6610893806	2023-11-11 13:54:00	DG8GAD	JN48	DC8EO	JO31ef	10140143	30	-24	0	357	330	10	2.6.1	1
3	6610932810	2023-11-11 14:02:00	DG8GAD	JN48	DC8EO	JO31ef	10140144	30	-21	0	357	330	10	2.6.1	1
4	6610976423	2023-11-11 14:10:00	DG8GAD	JN48	DC8EO	JO31ef	10140143	30	-25	0	357	330	10	2.6.1	1
5	6611109886	2023-11-11 14:34:00	DG8GAD	JN48	DC8EO	JO31ef	10140143	30	-20	0	357	330	10	2.6.1	1
6	6611150761	2023-11-11 14:42:00	DG8GAD	JN48	DC8EO	JO31ef	10140143	30	-21	0	357	330	10	2.6.1	1
7	6611198055	2023-11-11 14:50:00	DG8GAD	JN48	DC8EO	JO31ef	10140143	30	-23	0	357	330	10	2.6.1	1
8	6611336232	2023-11-11 15:14:00	DG8GAD	JN48	DC8EO	JO31ef	10140144	30	-21	0	357	330	10	2.6.1	1
9	6611382828	2023-11-11 15:22:00	DG8GAD	JN48	DC8EO	JO31ef	10140144	30	-24	0	357	330	10	2.6.1	1
10	6611430635	2023-11-11 15:30:00	DG8GAD	JN48	DC8EO	JO31ef	10140144	30	-22	0	357	330	10	2.6.1	1
							10140143.2000	Mean	-22.4000						
							0.9189	SD	1.6465						
							0.2000	AD	1.6000						
							22	AD%	97						

Table 18: WSPR link data between DG8GAD and DC8EO at 13:54 UTC $\pm$ 3 hours.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610789570	2023-11-11 13:34:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096112	37	8	0	1448	263	21	WD_3.0.9	1
2	6610847419	2023-11-11 13:46:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096112	37	2	0	1448	263	21	WD_3.0.9	1
3	6610891504	2023-11-11 13:54:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096112	37	12	0	1448	263	21	WD_3.0.9	1
4	6610995945	2023-11-11 14:14:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096111	37	3	0	1448	263	21	WD_3.0.9	1
5	6611026799	2023-11-11 14:20:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096111	37	8	0	1448	263	21	WD_3.0.9	1
6	6611405249	2023-11-11 15:26:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096111	37	3	0	1448	263	21	WD_3.0.9	1
7	6611452131	2023-11-11 15:34:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096111	37	0	0	1448	263	21	WD_3.0.9	1
8	6611566700	2023-11-11 15:54:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096112	37	-3	0	1448	263	21	WD_3.0.9	1
9	6611673547	2023-11-11 16:14:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096111	37	12	0	1448	263	21	WD_3.0.9	1
10	6611780949	2023-11-11 16:34:00	WA3DNM	FM29fw	K6RFT	EM47bg	21096111	37	7	0	1448	263	21	WD_3.0.9	1
							21096111.4000	Mean	5.2000						
							0.5164	SD	5.0067						
							-0.6000	AD	-6.8000						
							-116	AD%	-136						

Table 19: WSPR link data between WA3DNM and K6RFT at 13:54 UTC $\pm$ 3 hours.

The WSPR data for the link W2RCL-K5CGM was downloaded for the time period starting 13:54:01 UTC $\pm$ 3 hours and the mean received frequency of 7,040,116.8276 Hz and the SD of 1.0375 Hz were calculated. The actual received frequency in the 13:54 UTC WSPR time slot is 7,040,118 Hz, which represents a deviation of -1.1724 Hz from the mean by a factor of -1.13 SD or by a percentage of -113% SD. The mean SNR of -21.5517 dB and the SD of 4.4848 dB were calculated. The actual SNR in the 13:54 UTC WSPR time slot is -25 dB, which represents a deviation of +3.4483 dB from the mean by a factor of +0.77 SD or by a percentage of +77% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610101422	2023-11-11 10:54:00	W2RCL	FM19	K5CGM	EM25ax	7040115	23	-22	0	1705	263	7	2.4.0	1
2	6610124164	2023-11-11 11:00:00	W2RCL	FM19	K5CGM	EM25ax	7040115	23	-23	0	1705	263	7	2.4.0	1
3	6610163028	2023-11-11 11:10:00	W2RCL	FM19	K5CGM	EM25ax	7040115	23	-19	0	1705	263	7	2.4.0	1
4	6610178539	2023-11-11 11:14:00	W2RCL	FM19	K5CGM	EM25ax	7040115	23	-15	0	1705	263	7	2.4.0	1
5	6610202327	2023-11-11 11:20:00	W2RCL	FM19	K5CGM	EM25ax	7040116	23	-18	0	1705	263	7	2.4.0	1
6	6610209067	2023-11-11 11:22:00	W2RCL	FM19	K5CGM	EM25ax	7040116	23	-22	0	1705	263	7	2.4.0	1
7	6610234024	2023-11-11 11:28:00	W2RCL	FM19	K5CGM	EM25ax	7040116	23	-25	0	1705	263	7	2.4.0	1
8	6610273583	2023-11-11 11:38:00	W2RCL	FM19	K5CGM	EM25ax	7040116	23	-23	0	1705	263	7	2.4.0	1
9	6610314691	2023-11-11 11:48:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-23	0	1705	263	7	2.4.0	1
10	6610329923	2023-11-11 11:52:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-20	0	1705	263	7	2.4.0	1
11	6610353883	2023-11-11 11:58:00	W2RCL	FM19	K5CGM	EM25ax	7040116	23	-16	0	1705	263	7	2.4.0	1
12	6610362429	2023-11-11 12:00:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-13	0	1705	263	7	2.4.0	1
13	6610417852	2023-11-11 12:14:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-18	0	1705	263	7	2.4.0	1
14	6610434729	2023-11-11 12:18:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-16	0	1705	263	7	2.4.0	1
15	6610460137	2023-11-11 12:24:00	W2RCL	FM19	K5CGM	EM25ax	7040116	23	-18	0	1705	263	7	2.4.0	1
16	6610487076	2023-11-11 12:30:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-16	0	1705	263	7	2.4.0	1
17	6610495136	2023-11-11 12:32:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-17	0	1705	263	7	2.4.0	1
18	6610585341	2023-11-11 12:52:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-24	0	1705	263	7	2.4.0	1
19	6610609810	2023-11-11 12:58:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-22	0	1705	263	7	2.4.0	1
20	6610648163	2023-11-11 13:06:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-20	0	1705	263	7	2.4.0	1
21	6610704007	2023-11-11 13:18:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-28	0	1705	263	7	2.4.0	1
22	6610754599	2023-11-11 13:28:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-20	0	1705	263	7	2.4.0	1
23	6610776341	2023-11-11 13:32:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-25	0	1705	263	7	2.4.0	1
24	6610804048	2023-11-11 13:38:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-25	0	1705	263	7	2.4.0	1
25	6610832959	2023-11-11 13:44:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-27	0	1705	263	7	2.4.0	1
26	6610878636	2023-11-11 13:52:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-26	0	1705	263	7	2.4.0	1
27	6610886484	2023-11-11 13:54:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-25	0	1705	263	7	2.4.0	1
28	6610906229	2023-11-11 13:58:00	W2RCL	FM19	K5CGM	EM25ax	7040118	23	-28	0	1705	263	7	2.4.0	1
29	6610990671	2023-11-11 14:14:00	W2RCL	FM19	K5CGM	EM25ax	7040117	23	-31	0	1705	263	7	2.4.0	1
							7040116.8276	Mean	-21.5517						
							1.0375	SD	4.4848						
							-1.1724	AD	3.4483						
							-113	AD%	77						

Table 20: WSPR link data between W2RCL and K5CGM at 13:54 UTC $\pm$ 3 hours.

The aircraft is detected between 14:12:01 UTC and 14:13:51.6 UTC. In this timeframe the aircraft is in the cruise phase at 39,000 feet and moves around 14.8 nmi and is marked in green. There is one received frequency anomaly of -127% SD and drift anomaly of -1 Hz/minute.

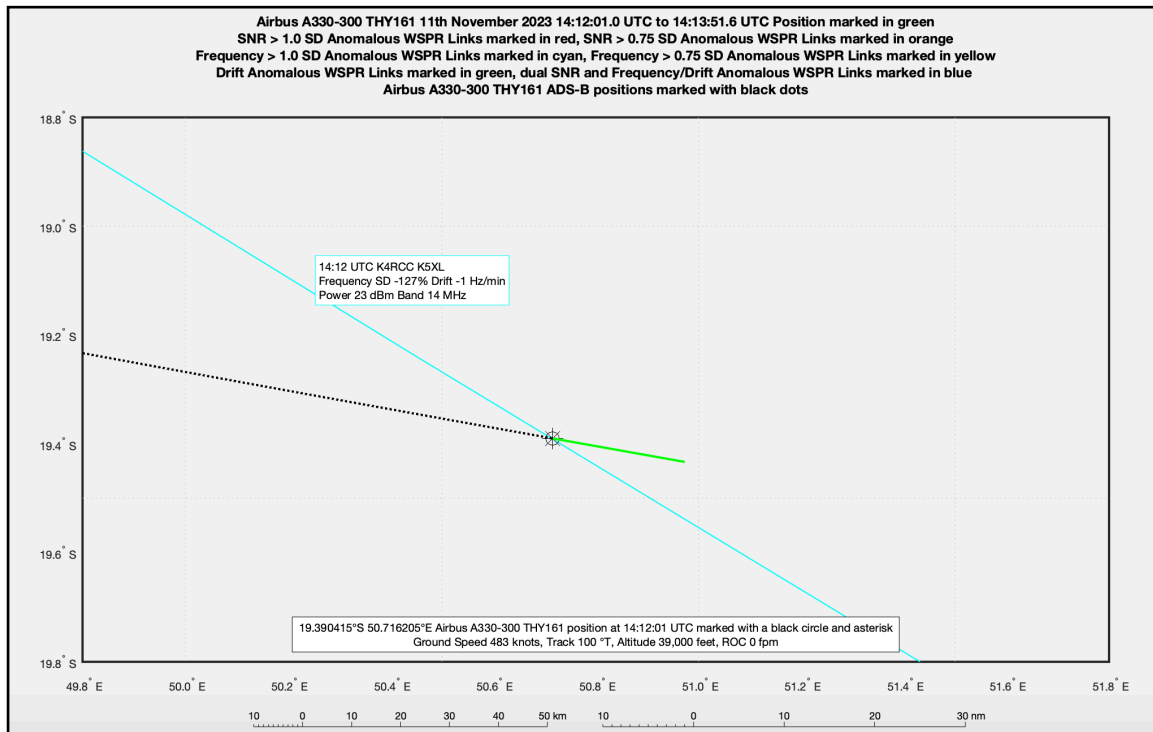


Figure 20: Flight THY161 crossing the WSPR path K4RCC-K5XL.

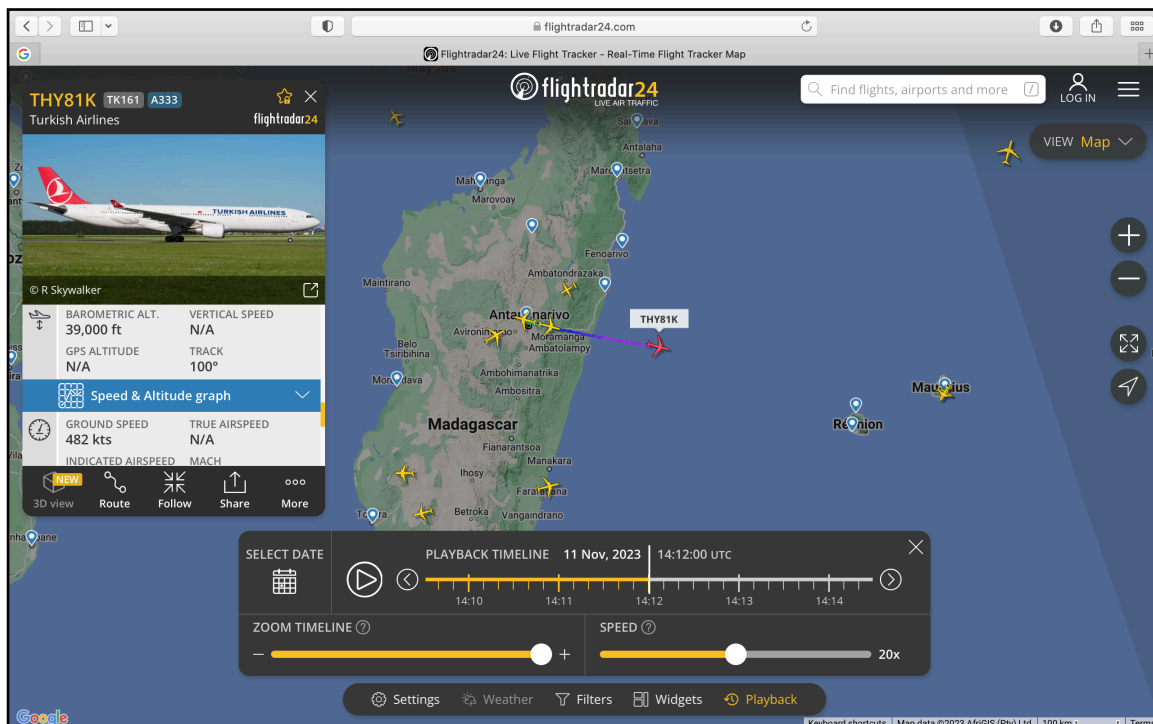


Figure 21: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:12 UTC.

The ADS-B data for flight THY161 is shown in flightaware.com starting on Saturday 11th November 2023 at 14:57:57 CET, which is 13:57:57 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:12:01 UTC and 14:13:51.6 UTC.

Time (CET)	Latitude	Longitude	Course	kts	feet	Rate	Reporting Facility
Sat 02:57:57 PM	-19.0399	48.7080	→ 101°				Estimated
Sat 02:58:59 PM	-19.0599	48.8184	→ 101°				Estimated
Sat 03:01:00 PM	-19.0985	49.0337	→ 101°				Estimated
Sat 03:02:53 PM	-19.1344	49.2349	→ 101°				Estimated
Sat 03:03:59 PM	-19.1553	49.3525	→ 101°				Estimated
Sat 03:05:00 PM	-19.1745	49.4611	→ 101°				Estimated
Sat 03:06:00 PM	-19.1933	49.5681	→ 101°				Estimated
Sat 03:07:00 PM	-19.2121	49.6750	→ 101°				Estimated
Sat 03:08:53 PM	-19.2473	49.8765	→ 101°				Estimated
Sat 03:09:56 PM	-19.2668	49.9889	→ 100°				Estimated
Sat 03:11:50 PM	-19.3861	50.6906	→ 100°	483	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:12:55 PM	-19.4116	50.8419	→ 100°	484	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:13:27 PM	-19.4241	50.9166	→ 100°	482	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:14:28 PM	-19.4475	51.0572	→ 100°	481	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:15:11 PM	-19.4640	51.1564	→ 100°	481	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:16:11 PM	-19.4871	51.2957	→ 100°	481	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:16:41 PM	-19.4986	51.3653	→ 100°	482	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:17:11 PM	-19.5102	51.4360	→ 100°	482	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:18:37 PM	-19.5427	51.6340	→ 100°	483	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:19:31 PM	-19.5633	51.7607	→ 100°	483	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:21:35 PM	-19.6101	52.0506	→ 100°	484	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:22:06 PM	-19.6217	52.1228	→ 100°	485	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:22:43 PM	-19.6357	52.2100	→ 100°	484	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:23:26 PM	-19.6518	52.3109	→ 100°	484	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:24:04 PM	-19.6655	52.3974	→ 100°	483	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:24:36 PM	-19.6773	52.4716	→ 100°	484	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:25:06 PM	-19.6884	52.5418	→ 100°	485	39,000		FlightAware ADS-B (RUN / FMEE)

Table 21: Flight THY161 ADS-B data as shown in flightaware.com.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:11:50	0	-19.386100	50.690600	39,000	483	100	0
14:12:01	11	-19.390415	50.716205	39,000	483	100	0
14:12:55	65	-19.411600	50.841900	39,000	484	100	0
14:13:27	0	-19.424100	50.916600	39,000	482	100	0
14:13:51.6	24.6	-19.433537	50.973301	39,000	482	100	0
14:14:28	61	-19.447500	51.057200	39,000	481	100	0

Table 22: Flight THY161 ADS-B data interpolation at 14:12 UTC.

The WSPR data for the link K4RCC-K5XL was downloaded for the time period starting 14:12:01 UTC $\pm$ 3 hours and the mean received frequency of 14,097,148.1905 Hz and the SD of 44.6224 Hz were calculated. The actual received frequency in the 14:12 UTC WSPR time slot is 14,097,205 Hz, which represents a deviation of -55.8095 Hz from the mean by a factor of -1.27 SD or by a percentage of -127% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610584409	2023-11-11 12:52:00	K4RCC	EM85ji	K5XL	EM12kp	14097121	23	-3	0	1317	261	14	2.6.1	1
2	6610678856	2023-11-11 13:12:00	K4RCC	EM85ji	K5XL	EM12kp	14097149	23	-2	-1	1317	261	14	2.6.1	1
3	6610774165	2023-11-11 13:32:00	K4RCC	EM85ji	K5XL	EM12kp	14097147	23	2	0	1317	261	14	2.6.1	1
4	6610878669	2023-11-11 13:52:00	K4RCC	EM85ji	K5XL	EM12kp	14097084	23	-11	0	1317	261	14	2.6.1	1
5	6610925585	2023-11-11 14:02:00	K4RCC	EM85ji	K5XL	EM12kp	14097210	23	-1	0	1317	261	14	2.6.1	1
6	6610979351	2023-11-11 14:12:00	K4RCC	EM85ji	K5XL	EM12kp	14097205	23	-6	-1	1317	261	14	2.6.1	1
7	6611034009	2023-11-11 14:22:00	K4RCC	EM85ji	K5XL	EM12kp	14097173	23	-4	0	1317	261	14	2.6.1	1
8	6611091102	2023-11-11 14:32:00	K4RCC	EM85ji	K5XL	EM12kp	14097079	23	-10	0	1317	261	14	2.6.1	1
9	6611146334	2023-11-11 14:42:00	K4RCC	EM85ji	K5XL	EM12kp	14097099	23	-5	0	1317	261	14	2.6.1	1
10	6611206783	2023-11-11 14:52:00	K4RCC	EM85ji	K5XL	EM12kp	14097181	23	-7	0	1317	261	14	2.6.1	1
11	6611261139	2023-11-11 15:02:00	K4RCC	EM85ji	K5XL	EM12kp	14097156	23	-4	0	1317	261	14	2.6.1	1
12	6611320183	2023-11-11 15:12:00	K4RCC	EM85ji	K5XL	EM12kp	14097113	23	-10	0	1317	261	14	2.6.1	1
13	6611376998	2023-11-11 15:22:00	K4RCC	EM85ji	K5XL	EM12kp	14097160	23	-14	0	1317	261	14	2.6.1	1
14	6611435430	2023-11-11 15:32:00	K4RCC	EM85ji	K5XL	EM12kp	14097171	23	-5	0	1317	261	14	2.6.1	1
15	6611492673	2023-11-11 15:42:00	K4RCC	EM85ji	K5XL	EM12kp	14097196	23	-4	0	1317	261	14	2.6.1	1
16	6611602589	2023-11-11 16:02:00	K4RCC	EM85ji	K5XL	EM12kp	14097064	23	-8	0	1317	261	14	2.6.1	1
17	6611710880	2023-11-11 16:22:00	K4RCC	EM85ji	K5XL	EM12kp	14097160	23	-10	0	1317	261	14	2.6.1	1
18	6611764525	2023-11-11 16:32:00	K4RCC	EM85ji	K5XL	EM12kp	14097090	23	-6	0	1317	261	14	2.6.1	1
19	6611820542	2023-11-11 16:42:00	K4RCC	EM85ji	K5XL	EM12kp	14097181	23	-14	0	1317	261	14	2.6.1	1
20	6611875291	2023-11-11 16:52:00	K4RCC	EM85ji	K5XL	EM12kp	14097195	23	-8	0	1317	261	14	2.6.1	1
21	6611969529	2023-11-11 17:12:00	K4RCC	EM85ji	K5XL	EM12kp	14097178	23	-10	0	1317	261	14	2.6.1	1
							14097148.1905	Mean	-6.6667						
							44.6224	SD	4.1513						
							-56.8095	AD	-0.6667						
							-127	AD%	-16						

Table 23: WSPR link data between K4RCC and K5XL at 14:12 UTC $\pm$ 3 hours.

At 14:14 UTC there is a dual anomaly, a SNR anomaly of +113% SD and a received frequency anomaly of +106% SD.

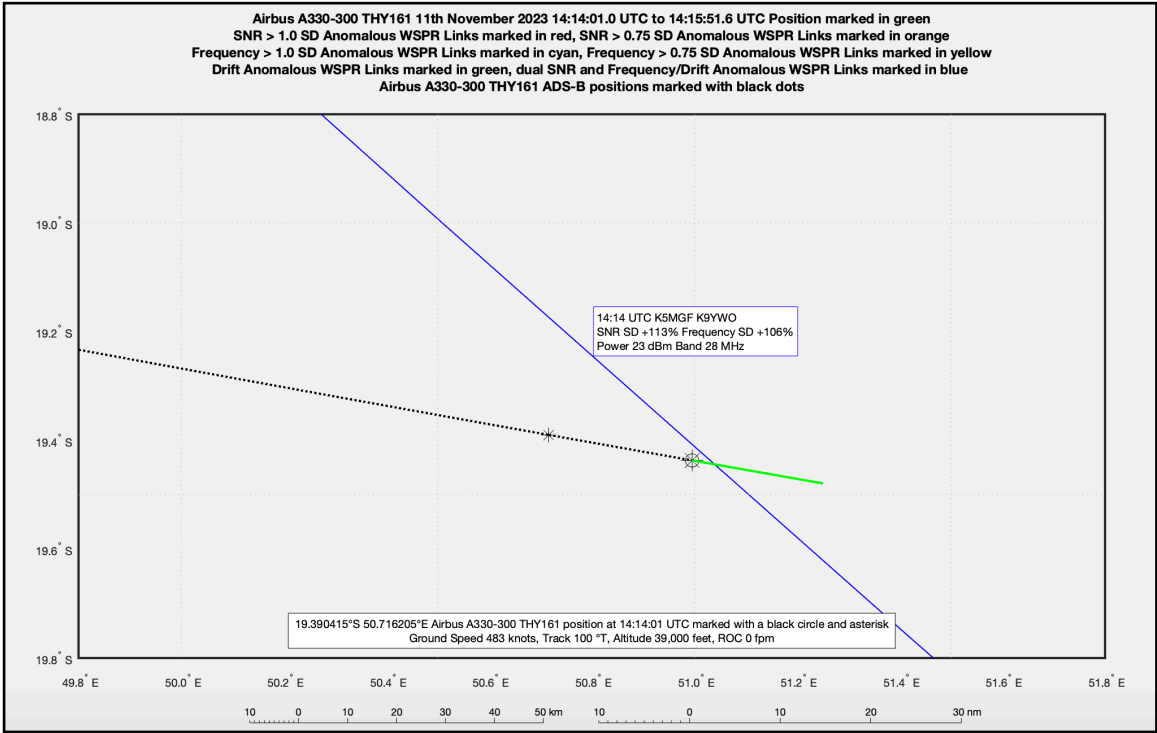


Figure 22: Flight THY161 crossing the WSPR path K5MGF-K9YWO.

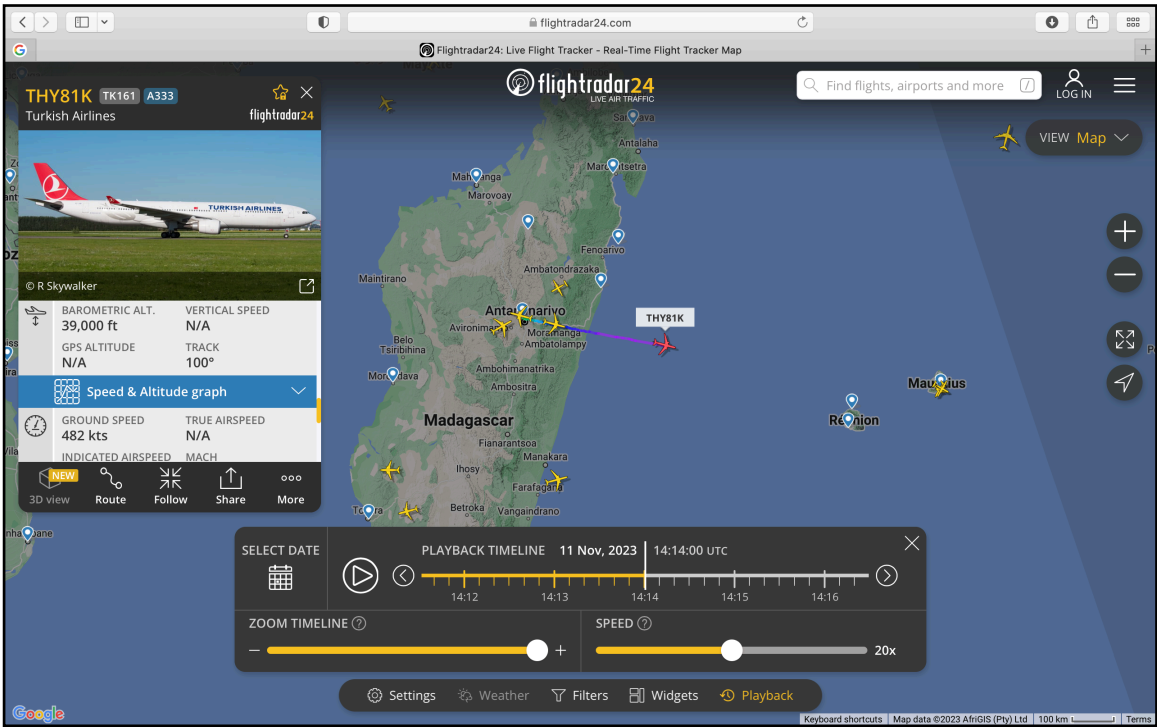


Figure 23: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:14 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:14:01 UTC and 14:15:51.6 UTC.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:13:27	0	-19.424100	50.916600	39,000	482	100	0
14:14:01	34	-19.437143	50.994967	39,000	481	100	0
14:14:28	61	-19.447500	51.057200	39,000	481	100	0
14:15:11	0	-19.464000	51.156400	39,000	481	100	0
14:15:51.6	40.6	-19.479631	51.250660	39,000	481	100	0
14:16:11	60	-19.487100	51.295700	39,000	481	100	0

Table 24: Flight THY161 ADS-B data interpolation at 14:14 UTC.

The WSPR data for the link K5MGF-K9YWO was downloaded for the time period starting 14:14:01 UTC $\pm$ 3 hours and the mean received frequency of 28,126,072.3704 Hz and the SD of 49.2860 Hz were calculated. The actual received frequency in the 14:14 UTC WSPR time slot is 28,126,020 Hz, which represents a deviation of +52.3704 Hz from the mean by a factor of +1.06 SD or by a percentage of +106% SD. The mean SNR of -22.2307 dB and the SD of 3.3555 dB were calculated. The actual SNR in the 14:14 UTC WSPR time slot is -26 dB, which represents a deviation of +3.7963 dB from the mean by a factor of +1.13 SD or by a percentage of +113% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6599853842	2023-11-09 13:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126014	23	-14	0	2512	104	28	2.5.4	1
2	6599954990	2023-11-09 13:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126022	23	-21	-1	2512	104	28	2.5.4	1
3	6600115824	2023-11-09 14:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126133	23	-18	0	2512	104	28	2.5.4	1
4	6600288240	2023-11-09 14:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126042	23	-18	0	2512	104	28	2.5.4	1
5	6600341570	2023-11-09 14:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126064	23	-28	0	2512	104	28	2.5.4	1
6	6600400852	2023-11-09 14:54:00	K5MGF	DM64II	K9YWO	EL96ck	28126099	23	-22	-1	2512	104	28	2.5.4	1
7	6600514283	2023-11-09 15:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126072	23	-18	0	2512	104	28	2.5.4	1
8	6600686018	2023-11-09 15:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126070	23	-25	-1	2512	104	28	2.5.4	1
9	6600748024	2023-11-09 15:54:00	K5MGF	DM64II	K9YWO	EL96ck	28126051	23	-17	0	2512	104	28	2.5.4	1
10	6600802361	2023-11-09 16:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126045	23	-23	-1	2512	104	28	2.5.4	1
11	6601026201	2023-11-09 16:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126042	23	-16	-1	2512	104	28	2.5.4	1
12	6601081092	2023-11-09 16:54:00	K5MGF	DM64II	K9YWO	EL96ck	28126050	23	-18	0	2512	104	28	2.5.4	1
13	6605530341	2023-11-10 14:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126154	23	-22	0	2512	104	28	2.5.4	1
14	6605638660	2023-11-10 14:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126020	23	-23	0	2512	104	28	2.5.4	1
15	6605748962	2023-11-10 14:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126081	23	-23	-1	2512	104	28	2.5.4	1
16	6605981779	2023-11-10 15:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126092	23	-24	0	2512	104	28	2.5.4	1
17	6606288830	2023-11-10 16:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126049	23	-23	0	2512	104	28	2.5.4	1
18	6606320942	2023-11-10 16:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126071	23	-25	0	2512	104	28	2.5.4	1
19	6606428174	2023-11-10 16:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126009	23	-15	0	2512	104	28	2.5.4	1
20	6606534144	2023-11-10 17:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126096	23	-22	0	2512	104	28	2.5.4	1
21	6610784059	2023-11-11 13:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126161	23	-22	0	2512	104	28	2.5.4	1
22	6610989620	2023-11-11 14:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126020	23	-26	-1	2512	104	28	2.5.4	1
23	6611157873	2023-11-11 14:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126016	23	-19	0	2512	104	28	2.5.4	1
24	6611271382	2023-11-11 15:04:00	K5MGF	DM64II	K9YWO	EL96ck	28125997	23	-28	-1	2512	104	28	2.5.4	1
25	6611930915	2023-11-11 17:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126102	23	-20	-2	2512	104	28	2.5.4	1
26	6611980049	2023-11-11 17:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126038	23	-27	0	2512	104	28	2.5.4	1
27	6615946984	2023-11-12 13:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126084	23	-22	-1	2512	104	28	2.5.4	1
28	6615999086	2023-11-12 13:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126166	23	-23	0	2512	104	28	2.5.4	1
29	6616056254	2023-11-12 13:54:00	K5MGF	DM64II	K9YWO	EL96ck	28126016	23	-21	0	2512	104	28	2.5.4	1
30	6616106425	2023-11-12 14:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126026	23	-26	-1	2512	104	28	2.5.4	1
31	6616219821	2023-11-12 14:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126094	23	-20	0	2512	104	28	2.5.4	1
32	6616278356	2023-11-12 14:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126070	23	-23	0	2512	104	28	2.5.4	1
33	6616333997	2023-11-12 14:44:00	K5MGF	DM64II	K9YWO	EL96ck	28125991	23	-23	0	2512	104	28	2.5.4	1
34	6616446827	2023-11-12 15:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126113	23	-26	-1	2512	104	28	2.5.4	1
35	6616621293	2023-11-12 15:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126015	23	-25	0	2512	104	28	2.5.4	1
36	6616677359	2023-11-12 15:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126076	23	-21	0	2512	104	28	2.5.4	1
37	6616792526	2023-11-12 16:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126043	23	-19	0	2512	104	28	2.5.4	1
38	6616849662	2023-11-12 16:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126108	23	-24	-1	2512	104	28	2.5.4	1
39	6616901488	2023-11-12 16:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126163	23	-26	-1	2512	104	28	2.5.4	1
40	6616957905	2023-11-12 16:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126147	23	-18	-1	2512	104	28	2.5.4	1
41	6617009177	2023-11-12 16:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126076	23	-22	-1	2512	104	28	2.5.4	1
42	6617112603	2023-11-12 17:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126042	23	-24	-1	2512	104	28	2.5.4	1
43	6621441290	2023-11-13 13:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126157	23	-22	0	2512	104	28	2.5.4	1
44	6621490723	2023-11-13 13:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126005	23	-22	-1	2512	104	28	2.5.4	1
45	6621538174	2023-11-13 13:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126135	23	-26	-1	2512	104	28	2.5.4	1
46	6621781435	2023-11-13 14:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126041	23	-20	-1	2512	104	28	2.5.4	1
47	6621833038	2023-11-13 14:24:00	K5MGF	DM64II	K9YWO	EL96ck	28126110	23	-20	0	2512	104	28	2.5.4	1
48	6621995369	2023-11-13 14:54:00	K5MGF	DM64II	K9YWO	EL96ck	28126146	23	-25	0	2512	104	28	2.5.4	1
49	6622047629	2023-11-13 15:04:00	K5MGF	DM64II	K9YWO	EL96ck	28126014	23	-19	-1	2512	104	28	2.5.4	1
50	6622104386	2023-11-13 15:14:00	K5MGF	DM64II	K9YWO	EL96ck	28126071	23	-21	-1	2512	104	28	2.5.4	1
51	6622213166	2023-11-13 15:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126162	23	-27	-1	2512	104	28	2.5.4	1
52	6622261669	2023-11-13 15:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126071	23	-25	-1	2512	104	28	2.5.4	1
53	6622519649	2023-11-13 16:34:00	K5MGF	DM64II	K9YWO	EL96ck	28126068	23	-26	-1	2512	104	28	2.5.4	1
54	6622568141	2023-11-13 16:44:00	K5MGF	DM64II	K9YWO	EL96ck	28126088	23	-26	-1	2512	104	28	2.5.4	1
							28126072.3704	Mean	-22.2037						
							49.2860	SD	3.3555						
							52.3704	AD	3.7963						
							106	AD%	113						

Table 25: WSPR link data between K5MGF and K9YWO at 14:14 UTC $\pm$ 3 hours.

At 14:16 UTC there are no WSPR propagations intersecting with the THY161 flight path.

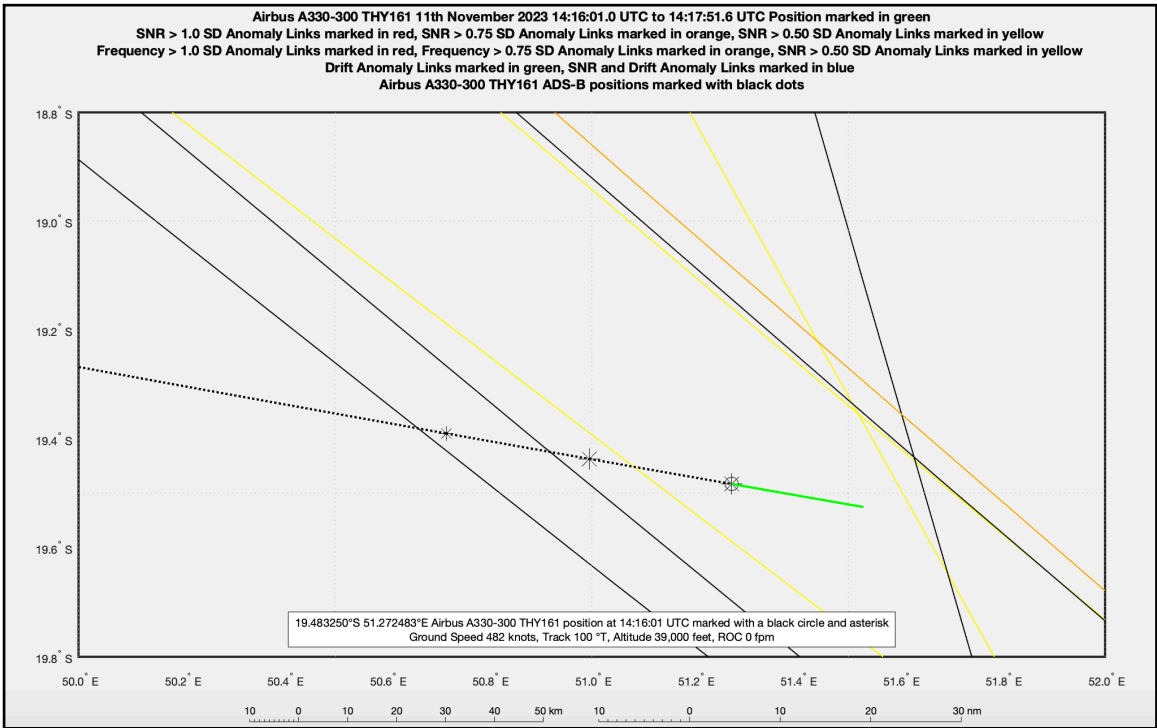


Figure 24: Flight THY161 at 14:16 UTC.

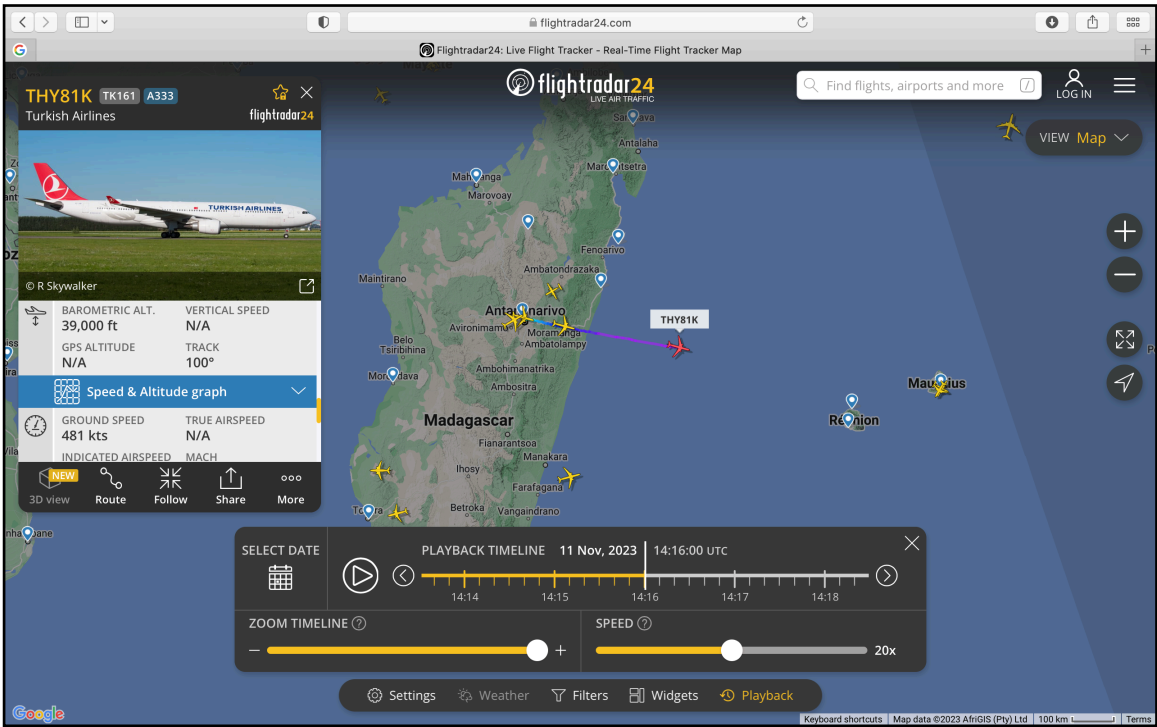


Figure 25: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:16 UTC.

At 14:18 UTC there are two anomalies, one received frequency anomaly of +118% and one dual anomaly with SNR of -105% SD and received frequency of +93% SD.

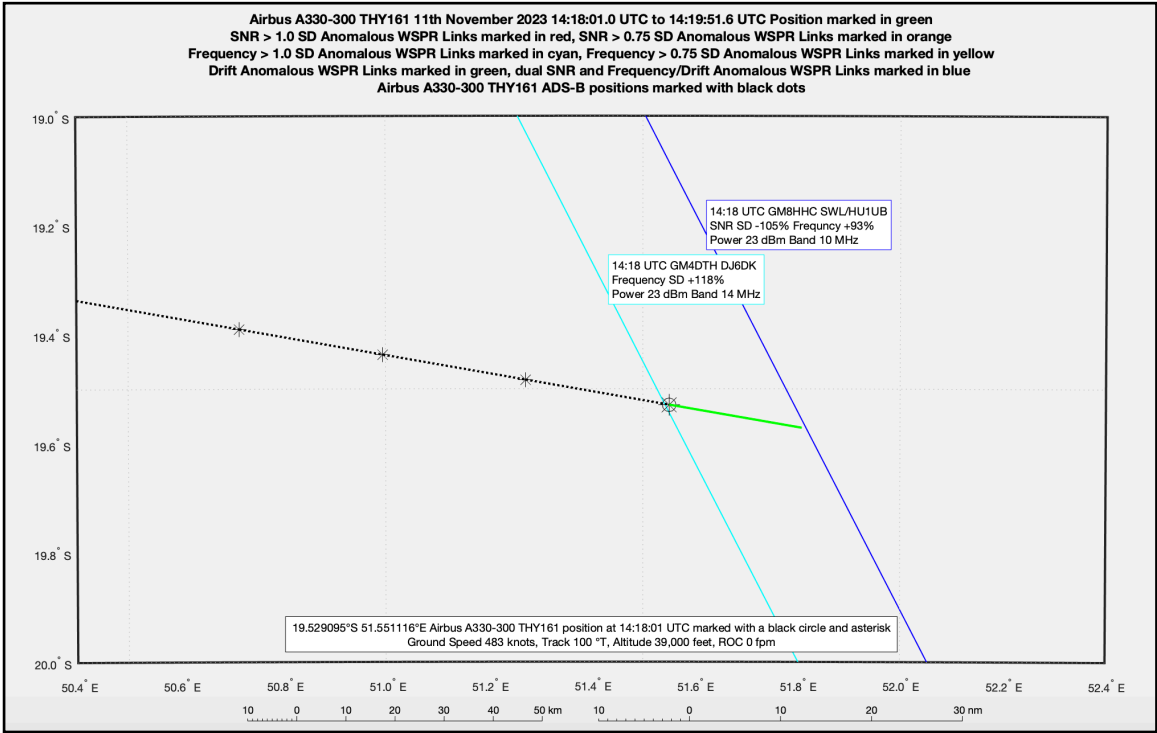


Figure 26: Flight THY161 crossing the WSPR paths GM4DTH-DJ6DK and GM8HHC-SWL/HU1UB.

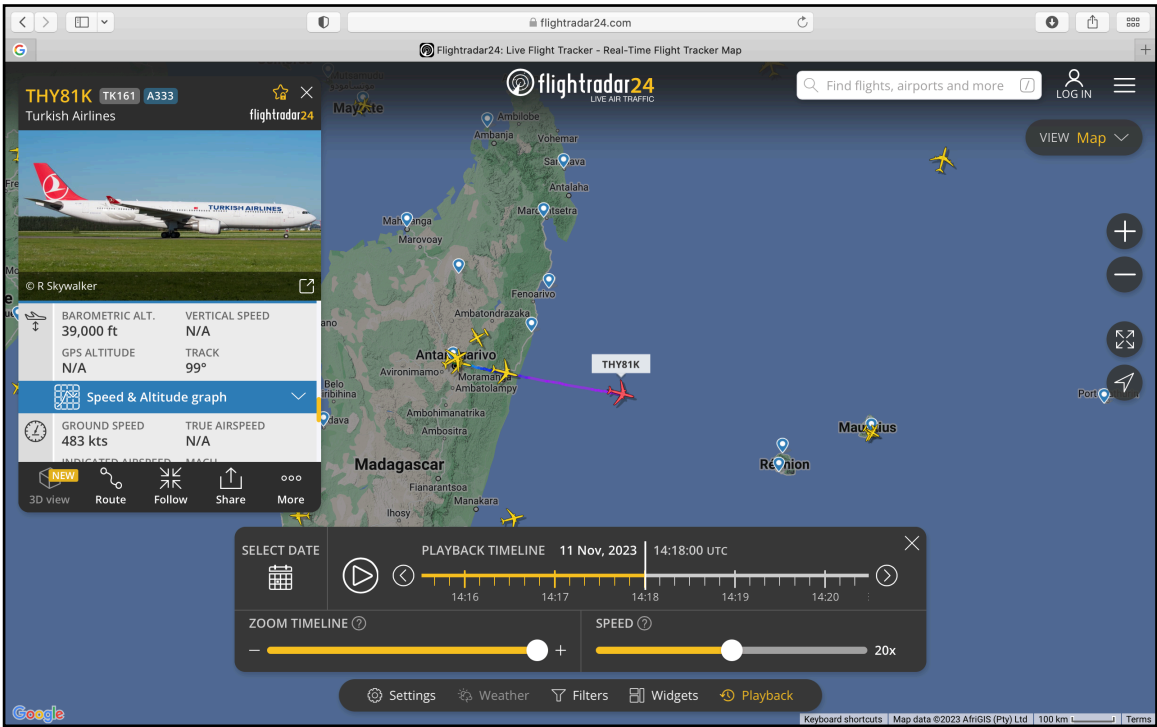


Figure 27: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:18 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:18:01 UTC and 14:19:51.6 UTC.

The WSPR data for the link GM4DTH-DJ6DK was downloaded for the time period starting 14:18:01 UTC $\pm$ 3 hours and the mean received frequency of 14,097,105.50 Hz and the SD of 77.5518 Hz were calculated. The actual received frequency in the 14:18 UTC WSPR time slot is 14,097,014 Hz, which represents a deviation of +91.50 Hz from the mean by a factor of +1.18 SD or by a percentage of +118% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track ("T)	ROC (fpm)
14:17:11	0	-19.510200	51.436000	39,000	481	100	0
14:18:01	50	-19.529095	51.551116	39,000	482	100	0
14:18:37	86	-19.542700	51.634000	39,000	483	100	0
14:19:31	0	-19.563300	51.760700	39,000	483	100	0
14:19:51.6	20.6	-19.571075	51.808861	39,000	483	100	0
14:21:35	124	-19.610100	52.050600	39,000	484	100	0

Table 26: Flight THY161 ADS-B data interpolation at 14:18 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610209462	2023-11-11 11:22:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097202	23	-21	0	1107	130	14	2.5.4	1
2	6610273511	2023-11-11 11:38:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097196	23	-20	0	1107	130	14	2.5.4	1
3	6610337512	2023-11-11 11:54:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097087	23	-19	0	1107	130	14	2.5.4	1
4	6610686248	2023-11-11 13:14:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097027	23	-21	0	1107	130	14	2.5.4	1
5	6610764513	2023-11-11 13:30:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097146	23	-23	0	1107	130	14	2.5.4	1
6	6611010346	2023-11-11 14:18:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097014	23	-23	0	1107	130	14	2.5.4	1
7	6611282397	2023-11-11 15:06:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097014	23	-21	-1	1107	130	14	2.5.4	1
8	6611377913	2023-11-11 15:22:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097051	23	-24	0	1107	130	14	2.5.4	1
9	6611643402	2023-11-11 16:10:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097198	23	-28	0	1107	130	14	2.5.4	1
10	6611731624	2023-11-11 16:26:00	GM4DTH	IO85jw	DJ6DK	JN48f	14097120	23	-15	0	1107	130	14	2.5.4	1
							14097105.5000	Mean	-21.5000						
							77.5518	SD	3.4075						
							91.5000	AD	1.5000						
							118	AD%	44						

Table 27: WSPR link data between GM4DTH and DJ6DK at 14:18 UTC $\pm$ 3 hours.

The WSPR data for the link GM8HHC-SWL/HU1UB was downloaded for the time period starting 14:18:01 UTC $\pm$ 3 hours and the mean received frequency of 10,140,226.80 Hz and the SD of 47.9798 Hz were calculated. The actual received frequency in the 14:18 UTC WSPR time slot is 10,140,182 Hz, which represents a deviation of +44.80 Hz from the mean by a factor of +0.93 SD or by a percentage of +93% SD. The mean SNR of -18.20 dB and the SD of 3.9815 dB were calculated. The actual SNR in the 14:18 UTC WSPR time slot is -14 dB, which represents a deviation of -4.20 dB from the mean by a factor of -1.05 SD or by a percentage of -105% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610210830	2023-11-11 11:22:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140300	23	-16	0	676	127	10		1
2	6610274924	2023-11-11 11:38:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140191	23	-15	0	676	127	10		1
3	6610338367	2023-11-11 11:54:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140294	23	-24	0	676	127	10		1
4	6610402996	2023-11-11 12:10:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140296	23	-17	0	676	127	10		1
5	6610470527	2023-11-11 12:26:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140270	23	-23	0	676	127	10		1
6	6610538498	2023-11-11 12:42:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140277	23	-19	0	676	127	10		1
7	6610611696	2023-11-11 12:58:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140173	23	-26	0	676	127	10		1
8	6610688547	2023-11-11 13:14:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140186	23	-14	0	676	127	10		1
9	6610768288	2023-11-11 13:30:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140221	23	-15	0	676	127	10		1
10	6610845853	2023-11-11 13:46:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140239	23	-17	0	676	127	10		1
11	6610929059	2023-11-11 14:02:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140196	23	-17	0	676	127	10		1
12	6611012496	2023-11-11 14:18:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140182	23	-14	0	676	127	10		1
13	6611103953	2023-11-11 14:34:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140160	23	-18	0	676	127	10		1
14	6611195949	2023-11-11 14:50:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140226	23	-13	-1	676	127	10		1
15	6611285097	2023-11-11 15:06:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140128	23	-16	0	676	127	10		1
16	6611379803	2023-11-11 15:22:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140246	23	-19	0	676	127	10		1
17	6611564350	2023-11-11 15:54:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140243	23	-24	0	676	127	10		1
18	6611647209	2023-11-11 16:10:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140216	23	-24	0	676	127	10		1
19	6611733789	2023-11-11 16:26:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140247	23	-19	0	676	127	10		1
20	6611821040	2023-11-11 16:42:00	GM8HHC	IO85	SWL/HU1UB	JO21jn	10140245	23	-14	0	676	127	10		1
							10140226.8000	Mean	-18.2000						
							47.9798	SD	3.9815						
							44.8000	AD	-4.2000						
							93	AD%	-105						

Table 28: WSPR link data between GM8HHC and SWL/HU1UB at 14:18 UTC $\pm$ 3 hours.

At 14:20 UTC there are two anomalies, one received frequency anomaly of +116% and one received frequency of -225% SD.

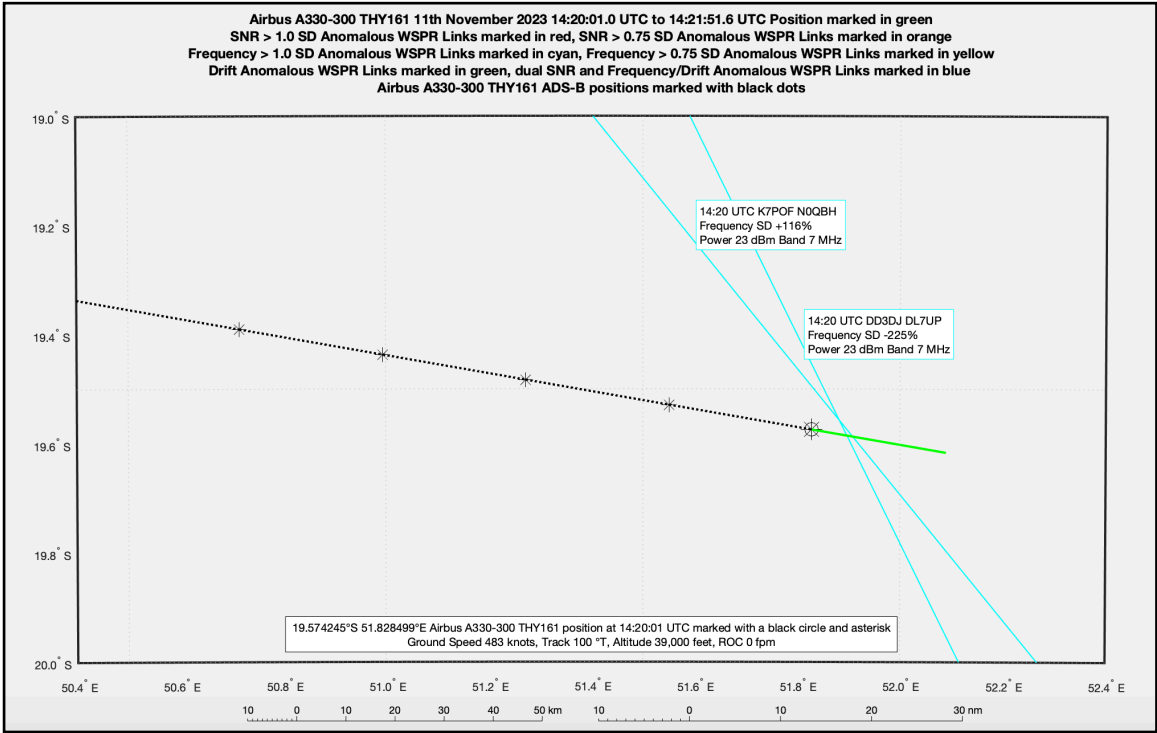


Figure 28: Flight THY161 crossing the WSPR paths K7POF-N0QBH and DD3DJ-DL7UP.

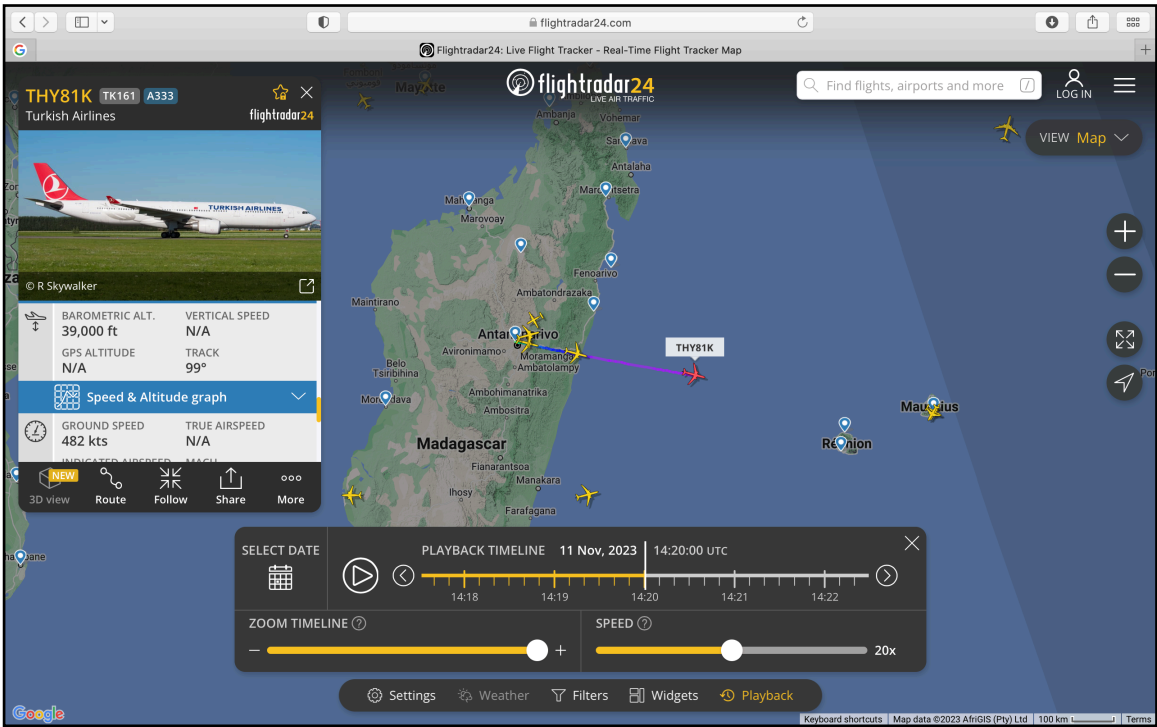


Figure 29: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:20 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:20:01 UTC and 14:21:51.6 UTC.

The WSPR data for the link K7POF-N0QBH was downloaded for the time period starting 14:20:01 UTC $\pm$ 3 hours and the mean received frequency of 7,040,087.3646 Hz and the SD of 54.6360 Hz were calculated. The actual received frequency in the 14:20 UTC WSPR time slot is 7,040,024 Hz, which represents a deviation of +63.3846 Hz from the mean by a factor of +1.16 SD or by a percentage of +116% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:19:31	0	-19.563300	51.760700	39,000	483	100	0
14:20:01	29	-19.574245	51.828499	39,000	483	100	0
14:21:35	124	-19.610100	52.050600	39,000	484	100	0
14:21:35	0	-19.610100	52.050600	39,000	484	100	0
14:21:51.6	16.6	-19.616312	52.089262	39,000	485	100	0
14:22:06	31	-19.621700	52.122800	39,000	485	100	0

Table 29: Flight THY161 ADS-B data interpolation at 14:20 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610202682	2023-11-11 11:20:00	K7POF	DM34sr	N0QBH	EN25if	7040110	23	-12	0	1881	46	7	2.6.1	1
2	6610272832	2023-11-11 11:38:00	K7POF	DM34sr	N0QBH	EN25if	7040108	23	-17	0	1881	46	7	2.6.1	1
3	6610345184	2023-11-11 11:56:00	K7POF	DM34sr	N0QBH	EN25if	7040122	23	-14	0	1881	46	7	2.6.1	1
4	6610418864	2023-11-11 12:14:00	K7POF	DM34sr	N0QBH	EN25if	7040011	23	-11	0	1881	46	7	2.6.1	1
5	6610656275	2023-11-11 13:08:00	K7POF	DM34sr	N0QBH	EN25if	7040151	23	-2	1	1881	46	7	2.6.1	1
6	6610743230	2023-11-11 13:26:00	K7POF	DM34sr	N0QBH	EN25if	7040094	23	-8	0	1881	46	7	2.6.1	1
7	6610833597	2023-11-11 13:44:00	K7POF	DM34sr	N0QBH	EN25if	7040160	23	-9	0	1881	46	7	2.6.1	1
8	6610926439	2023-11-11 14:02:00	K7POF	DM34sr	N0QBH	EN25if	7040009	23	-12	0	1881	46	7	2.6.1	1
9	6611020998	2023-11-11 14:20:00	K7POF	DM34sr	N0QBH	EN25if	7040024	23	-13	0	1881	46	7	2.6.1	1
10	6611123617	2023-11-11 14:38:00	K7POF	DM34sr	N0QBH	EN25if	7040120	23	-13	0	1881	46	7	2.6.1	1
11	6611329431	2023-11-11 15:14:00	K7POF	DM34sr	N0QBH	EN25if	7040125	23	-17	0	1881	46	7	2.6.1	1
12	6611436034	2023-11-11 15:32:00	K7POF	DM34sr	N0QBH	EN25if	7040011	23	-23	0	1881	46	7	2.6.1	1
13	6611538844	2023-11-11 15:50:00	K7POF	DM34sr	N0QBH	EN25if	7040091	23	-23	0	1881	46	7	2.6.1	1
							7040087.3846	Mean	-13.3846						
							54.6360	SD	5.7668						
							63.3846	AD	-0.3846						
							116	AD%	-7						

Table 30: WSPR link data between K7POF and N0QBH at 14:20 UTC $\pm$ 3 hours.

The WSPR data for the link DD3DJ-DL7UP was downloaded for the time period starting 14:20:01 UTC $\pm$ 3 hours and the mean received frequency of 7,040,057.6056 Hz and the SD of 0.6206 Hz were calculated. The actual received frequency in the 14:20 UTC WSPR time slot is 7,040,059 Hz, which represents a deviation of -1.3944 Hz from the mean by a factor of -2.25 SD or by a percentage of -225% SD. The results are shown in Table 31 on the next page.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610141174	2023-11-11 11:04:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-16	0	499	138	7		1
2	6610291774	2023-11-11 11:42:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-24	0	499	138	7		1
3	6610307999	2023-11-11 11:46:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-27	0	499	138	7		1
4	6610315922	2023-11-11 11:48:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-25	0	499	138	7		1
5	6610325325	2023-11-11 11:50:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-26	0	499	138	7		1
6	6610332856	2023-11-11 11:52:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-16	0	499	138	7		1
7	6610348583	2023-11-11 11:56:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-24	0	499	138	7		1
8	6610377945	2023-11-11 12:04:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-24	0	499	138	7		1
9	6610385875	2023-11-11 12:06:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-24	0	499	138	7		1
10	6610395348	2023-11-11 12:08:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-17	0	499	138	7		1
11	6610405474	2023-11-11 12:10:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-17	0	499	138	7		1
12	6610412557	2023-11-11 12:12:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-18	0	499	138	7		1
13	6610444755	2023-11-11 12:20:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-22	0	499	138	7		1
14	6610498636	2023-11-11 12:32:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-14	0	499	138	7		1
15	6610515297	2023-11-11 12:36:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-23	0	499	138	7		1
16	6610522810	2023-11-11 12:38:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-22	0	499	138	7		1
17	6610549318	2023-11-11 12:44:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-20	0	499	138	7		1
18	6610557722	2023-11-11 12:46:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-24	0	499	138	7		1
19	6610576913	2023-11-11 12:50:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-17	0	499	138	7		1
20	6610605815	2023-11-11 12:56:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-17	0	499	138	7		1
21	6610613230	2023-11-11 12:58:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-25	0	499	138	7		1
22	6610631132	2023-11-11 13:02:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-22	0	499	138	7		1
23	6610698819	2023-11-11 13:16:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-22	0	499	138	7		1
24	6610708494	2023-11-11 13:18:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040059	23	-18	0	499	138	7		1
25	6610719014	2023-11-11 13:20:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040059	23	-19	0	499	138	7		1
26	6610736810	2023-11-11 13:24:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-22	0	499	138	7		1
27	6610779983	2023-11-11 13:32:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-21	0	499	138	7		1
28	6610819294	2023-11-11 13:40:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040059	23	-8	0	499	138	7		1
29	6611005610	2023-11-11 14:16:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040059	23	-17	-1	499	138	7		1
30	6611026181	2023-11-11 14:20:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040059	23	-17	0	499	138	7		1
31	6611060147	2023-11-11 14:26:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-17	0	499	138	7		1
32	6611070913	2023-11-11 14:28:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-5	0	499	138	7		1
33	6611096328	2023-11-11 14:32:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-15	0	499	138	7		1
34	6611106577	2023-11-11 14:34:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-11	0	499	138	7		1
35	6611127795	2023-11-11 14:38:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-14	0	499	138	7		1
36	6611140494	2023-11-11 14:40:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-14	0	499	138	7		1
37	6611159961	2023-11-11 14:44:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-11	0	499	138	7		1
38	6611220012	2023-11-11 14:54:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-9	0	499	138	7		1
39	6611230806	2023-11-11 14:56:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-8	0	499	138	7		1
40	6611240519	2023-11-11 14:58:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-10	0	499	138	7		1
41	6611264325	2023-11-11 15:02:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-7	0	499	138	7		1
42	6611284269	2023-11-11 15:06:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-8	0	499	138	7		1
43	6611311969	2023-11-11 15:10:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-10	0	499	138	7		1
44	6611322957	2023-11-11 15:12:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-8	0	499	138	7		1
45	6611334860	2023-11-11 15:14:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-12	0	499	138	7		1
46	6611373728	2023-11-11 15:20:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-23	0	499	138	7		1
47	6611393077	2023-11-11 15:24:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-8	0	499	138	7		1
48	6611464727	2023-11-11 15:36:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-14	0	499	138	7		1
49	6611474128	2023-11-11 15:38:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-14	0	499	138	7		1
50	6611507655	2023-11-11 15:44:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-18	0	499	138	7		1
51	6611519755	2023-11-11 15:46:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-16	0	499	138	7		1
52	6611566309	2023-11-11 15:54:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-4	0	499	138	7		1
53	6611577280	2023-11-11 15:56:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-10	0	499	138	7		1
54	6611587132	2023-11-11 15:58:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-13	0	499	138	7		1
55	6611609300	2023-11-11 16:02:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-20	0	499	138	7		1
56	6611616214	2023-11-11 16:04:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-15	0	499	138	7		1
57	6611648341	2023-11-11 16:10:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-9	0	499	138	7		1
58	6611660823	2023-11-11 16:12:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-2	0	499	138	7		1
59	6611681853	2023-11-11 16:16:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040058	23	-8	0	499	138	7		1
60	6611723537	2023-11-11 16:24:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-15	0	499	138	7		1
61	6611734991	2023-11-11 16:26:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-11	0	499	138	7		1
62	6611758198	2023-11-11 16:30:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-10	0	499	138	7		1
63	6611768280	2023-11-11 16:32:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-10	0	499	138	7		1
64	6611789179	2023-11-11 16:36:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-10	0	499	138	7		1
65	6611823188	2023-11-11 16:42:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-12	0	499	138	7		1
66	6611831349	2023-11-11 16:44:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-14	0	499	138	7		1
67	6611853066	2023-11-11 16:48:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-11	0	499	138	7		1
68	6611864813	2023-11-11 16:50:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-5	0	499	138	7		1
69	6611885244	2023-11-11 16:54:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-14	0	499	138	7		1
70	6611915341	2023-11-11 17:00:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-29	0	499	138	7		1
71	6611999657	2023-11-11 17:18:00	DD3DJ	JO31ol	DL7UP	JN58ub	7040057	23	-17	0	499	138	7		1
							7040057.6056	Mean	-15.4789						
							0.6206	SD	6.2675						
							-1.3944	AD	1.5211						
							-225	AD%	24						

Table 31: WSPR link data between DD3DJ and DL7UP at 14:20 UTC ± 3 hours.

At 14:22 UTC there are two anomalies, one received frequency anomaly of -114% and one received frequency of -165% SD.

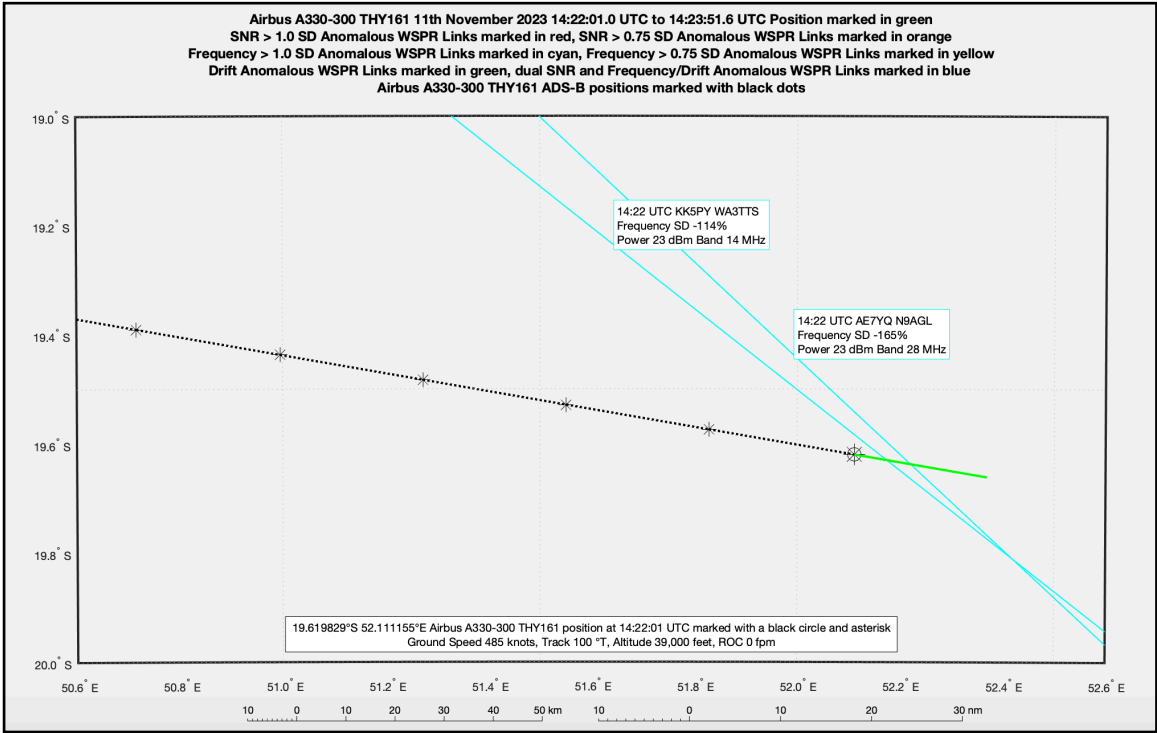


Figure 30: Flight THY161 crossing the WSPR paths KK5PY-WA3TTS and AE7YQ-N9AGL.

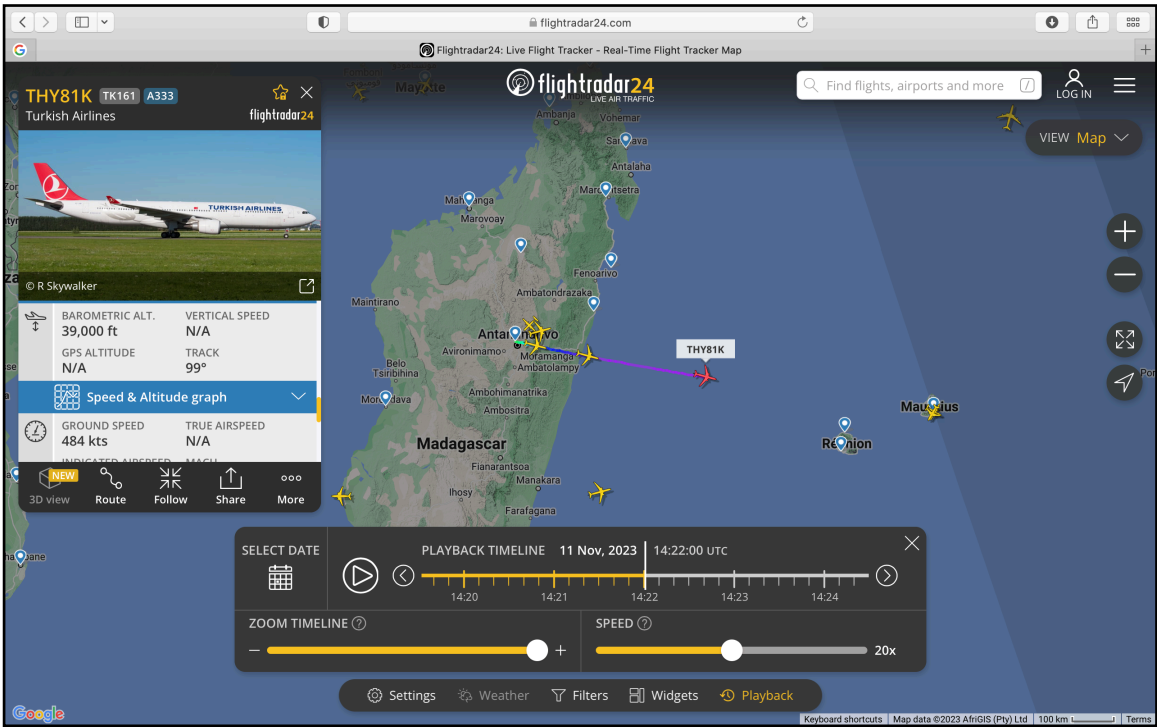


Figure 31: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:22 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:22:01 UTC and 14:23:51.6 UTC.

The WSPR data for the link KK5PY-WA3TTS was downloaded for the time period starting 14:22:01 UTC $\pm$ 3 hours and the mean received frequency of 14,097,121.4615 Hz and the SD of 61.2462 Hz were calculated. The actual received frequency in the 14:22 UTC WSPR time slot is 14,097,191 Hz, which represents a deviation of -69.5385 Hz from the mean by a factor of -1.14 SD or by a percentage of -114% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:21:35	0	-19.610100	52.050600	39,000	484	100	0
14:22:01	26	-19.619829	52.111155	39,000	485	100	0
14:22:06	31	-19.621700	52.122800	39,000	485	100	0
14:23:26	0	-19.651800	52.310900	39,000	484	100	0
14:23:51.6	25.6	-19.661029	52.369174	39,000	485	100	0
14:24:04	38	-19.665500	52.397400	39,000	485	100	0

Table 32: Flight THY161 ADS-B data interpolation at 14:22 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6599682508	2023-11-09 12:38:00	KK5PY	EM26	WA3TTS	EN90xn	14097137	23	-28	0	1380	66	14	2.5.0	1
2	6605273558	2023-11-10 13:12:00	KK5PY	EM26	WA3TTS	EN90xn	14097088	23	-22	0	1380	66	14	2.6.1	1
3	6605609886	2023-11-10 14:18:00	KK5PY	EM26	WA3TTS	EN90xn	14097056	23	-19	0	1380	66	14	2.6.1	1
4	6605987818	2023-11-10 15:24:00	KK5PY	EM26	WA3TTS	EN90xn	14097085	23	-16	0	1380	66	14	2.6.1	1
5	6606114350	2023-11-10 15:46:00	KK5PY	EM26	WA3TTS	EN90xn	14097186	23	-32	0	1380	66	14	2.6.1	1
6	6606237499	2023-11-10 16:08:00	KK5PY	EM26	WA3TTS	EN90xn	14097155	23	-20	0	1380	66	14	2.6.1	1
7	6610809033	2023-11-11 13:38:00	KK5PY	EM26	WA3TTS	EN90xn	14097196	23	-23	0	1380	66	14	2.6.1	1
8	6610922100	2023-11-11 14:00:00	KK5PY	EM26	WA3TTS	EN90xn	14096998	23	-24	-1	1380	66	14	2.6.1	1
9	6611038058	2023-11-11 14:22:00	KK5PY	EM26	WA3TTS	EN90xn	14097191	23	-19	0	1380	66	14	2.6.1	1
10	6615779189	2023-11-12 13:00:00	KK5PY	EM26	WA3TTS	EN90xn	14097072	23	-21	0	1380	66	14	2.6.1	1
11	6621806846	2023-11-13 14:18:00	KK5PY	EM26	WA3TTS	EN90xn	14097154	23	-22	-1	1380	66	14	2.6.1	1
12	6621923835	2023-11-13 14:40:00	KK5PY	EM26	WA3TTS	EN90xn	14097089	23	-19	0	1380	66	14	2.6.1	1
13	6622163814	2023-11-13 15:24:00	KK5PY	EM26	WA3TTS	EN90xn	14097172	23	-20	0	1380	66	14	2.6.1	1
							14097121.4615	Mean	-21.9231						
							61.2462	SD	4.2123						
							-69.5385	AD	-2.9231						
							-114	AD%	-69						

Table 33: WSPR link data between KK5PY and WA3TTS at 14:22 UTC $\pm$ 3 hours.

The WSPR data for the link AE7YQ-N9AGL was downloaded for the time period starting 14:22:01 UTC $\pm$ 3 hours and the mean received frequency of 28,126,083.7632 Hz and the SD of 58.9739 Hz were calculated. The actual received frequency in the 14:22 UTC WSPR time slot is 28,126,181 Hz, which represents a deviation of -97.2368 Hz from the mean by a factor of -1.65 SD or by a percentage of -165% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6611011774	2023-11-11 14:18:00	AE7YQ	DM41	N9AGL	EN62ad	28126181	23	-24	0	2361	53	28	2.5.4	1
2	6611033662	2023-11-11 14:22:00	AE7YQ	DM41	N9AGL	EN62ad	28126181	23	-25	0	2361	53	28	2.5.4	1
3	6611055207	2023-11-11 14:26:00	AE7YQ	DM41	N9AGL	EN62ad	28126059	23	-20	0	2361	53	28	2.5.4	1
4	6611076557	2023-11-11 14:30:00	AE7YQ	DM41	N9AGL	EN62ad	28126177	23	-20	0	2361	53	28	2.5.4	1
5	6611101590	2023-11-11 14:34:00	AE7YQ	DM41	N9AGL	EN62ad	28126082	23	-22	0	2361	53	28	2.5.4	1
6	6611123253	2023-11-11 14:38:00	AE7YQ	DM41	N9AGL	EN62ad	28125998	23	-24	0	2361	53	28	2.5.4	1
7	6611167987	2023-11-11 14:46:00	AE7YQ	DM41	N9AGL	EN62ad	28126122	23	-17	0	2361	53	28	2.5.4	1
8	6611190366	2023-11-11 14:50:00	AE7YQ	DM41	N9AGL	EN62ad	28126042	23	-22	0	2361	53	28	2.5.4	1
9	6611217154	2023-11-11 14:54:00	AE7YQ	DM41	N9AGL	EN62ad	28126022	23	-27	0	2361	53	28	2.5.4	1
10	6611237149	2023-11-11 14:58:00	AE7YQ	DM41	N9AGL	EN62ad	28126004	23	-21	0	2361	53	28	2.5.4	1
11	6611282361	2023-11-11 15:06:00	AE7YQ	DM41	N9AGL	EN62ad	28126049	23	-24	0	2361	53	28	2.5.4	1
12	6611306860	2023-11-11 15:10:00	AE7YQ	DM41	N9AGL	EN62ad	28126151	23	-23	0	2361	53	28	2.5.4	1
13	6611329860	2023-11-11 15:14:00	AE7YQ	DM41	N9AGL	EN62ad	28126136	23	-23	0	2361	53	28	2.5.4	1
14	6611353534	2023-11-11 15:18:00	AE7YQ	DM41	N9AGL	EN62ad	28126039	23	-29	0	2361	53	28	2.5.4	1
15	6611400849	2023-11-11 15:26:00	AE7YQ	DM41	N9AGL	EN62ad	28126098	23	-27	0	2361	53	28	2.5.4	1
16	6611423773	2023-11-11 15:30:00	AE7YQ	DM41	N9AGL	EN62ad	28126142	23	-24	0	2361	53	28	2.5.4	1
17	6611471632	2023-11-11 15:38:00	AE7YQ	DM41	N9AGL	EN62ad	28126166	23	-18	0	2361	53	28	2.5.4	1
18	6611491399	2023-11-11 15:42:00	AE7YQ	DM41	N9AGL	EN62ad	28126029	23	-25	0	2361	53	28	2.5.4	1
19	6611513517	2023-11-11 15:46:00	AE7YQ	DM41	N9AGL	EN62ad	28126101	23	-15	0	2361	53	28	2.5.4	1
20	6611536208	2023-11-11 15:50:00	AE7YQ	DM41	N9AGL	EN62ad	28126013	23	-25	0	2361	53	28	2.5.4	1
21	6611560240	2023-11-11 15:54:00	AE7YQ	DM41	N9AGL	EN62ad	28125999	23	-20	0	2361	53	28	2.5.4	1
22	6611621974	2023-11-11 16:06:00	AE7YQ	DM41	N9AGL	EN62ad	28126040	23	-24	0	2361	53	28	2.5.4	1
23	6611688013	2023-11-11 16:18:00	AE7YQ	DM41	N9AGL	EN62ad	28126015	23	-28	0	2361	53	28	2.5.4	1
24	6611731193	2023-11-11 16:26:00	AE7YQ	DM41	N9AGL	EN62ad	28126008	23	-20	0	2361	53	28	2.5.4	1
25	6611754621	2023-11-11 16:30:00	AE7YQ	DM41	N9AGL	EN62ad	28126135	23	-20	0	2361	53	28	2.5.4	1
26	6611777052	2023-11-11 16:34:00	AE7YQ	DM41	N9AGL	EN62ad	28126077	23	-23	0	2361	53	28	2.5.4	1
27	6611796986	2023-11-11 16:38:00	AE7YQ	DM41	N9AGL	EN62ad	28126090	23	-26	0	2361	53	28	2.5.4	1
28	6611818927	2023-11-11 16:42:00	AE7YQ	DM41	N9AGL	EN62ad	28126031	23	-29	0	2361	53	28	2.5.4	1
29	6611840211	2023-11-11 16:46:00	AE7YQ	DM41	N9AGL	EN62ad	28126103	23	-18	0	2361	53	28	2.5.4	1
30	6611862278	2023-11-11 16:50:00	AE7YQ	DM41	N9AGL	EN62ad	28126104	23	-19	0	2361	53	28	2.5.4	1
31	6611882168	2023-11-11 16:54:00	AE7YQ	DM41	N9AGL	EN62ad	28126165	23	-19	0	2361	53	28	2.5.4	1
32	6611904379	2023-11-11 16:58:00	AE7YQ	DM41	N9AGL	EN62ad	28126097	23	-27	0	2361	53	28	2.5.4	1
33	6611920270	2023-11-11 17:02:00	AE7YQ	DM41	N9AGL	EN62ad	28126174	23	-21	0	2361	53	28	2.5.4	1
34	6611939681	2023-11-11 17:06:00	AE7YQ	DM41	N9AGL	EN62ad	28126115	23	-27	0	2361	53	28	2.5.4	1
35	6611958591	2023-11-11 17:10:00	AE7YQ	DM41	N9AGL	EN62ad	28126082	23	-29	0	2361	53	28	2.5.4	1
36	6611980232	2023-11-11 17:14:00	AE7YQ	DM41	N9AGL	EN62ad	28126027	23	-29	0	2361	53	28	2.5.4	1
37	6611999930	2023-11-11 17:18:00	AE7YQ	DM41	N9AGL	EN62ad	28126015	23	-24	0	2361	53	28	2.5.4	1
38	6612017457	2023-11-11 17:22:00	AE7YQ	DM41	N9AGL	EN62ad	28126114	23	-26	0	2361	53	28	2.5.4	1
							28126083.7632	Mean	-23.2632						
							58.9739	SD	3.6884						
							-97.2368	AD	1.7368						
							-165	AD%	47						

Table 34: WSPR link data between AE7YQ and N9AGL at 14:22 UTC $\pm$ 3 hours.

The aircraft is detected between 14:42:01 UTC and 14:43:51.6 UTC. In this timeframe the aircraft is in the descent phase at 38,539 feet and moves around 15.2 nmi and is marked in green. There is one received frequency anomaly of -149% SD.

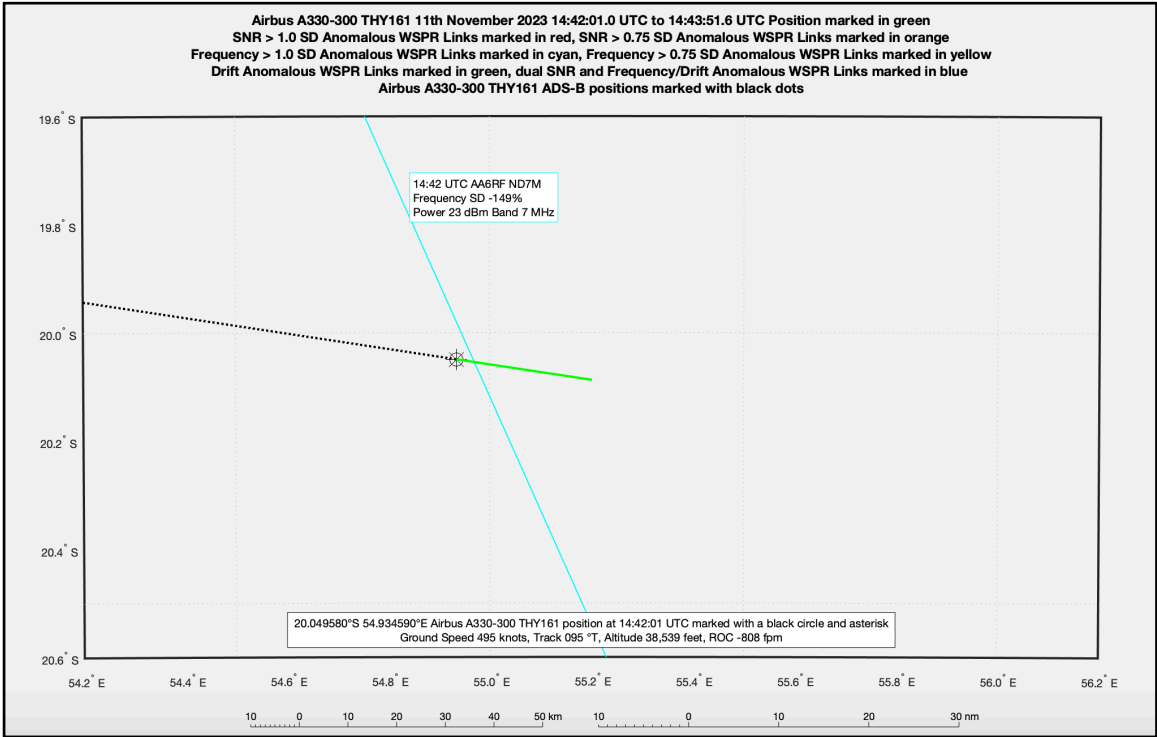


Figure 32: Flight THY161 crossing the WSPR paths AA6RF-ND7M.

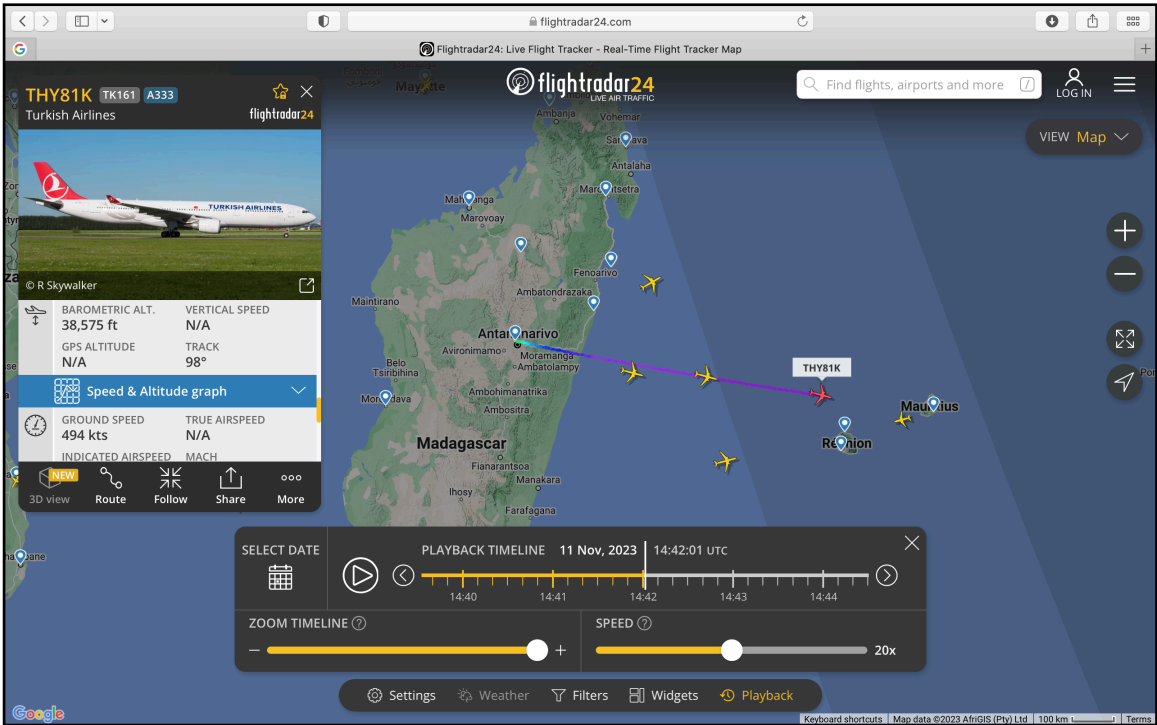
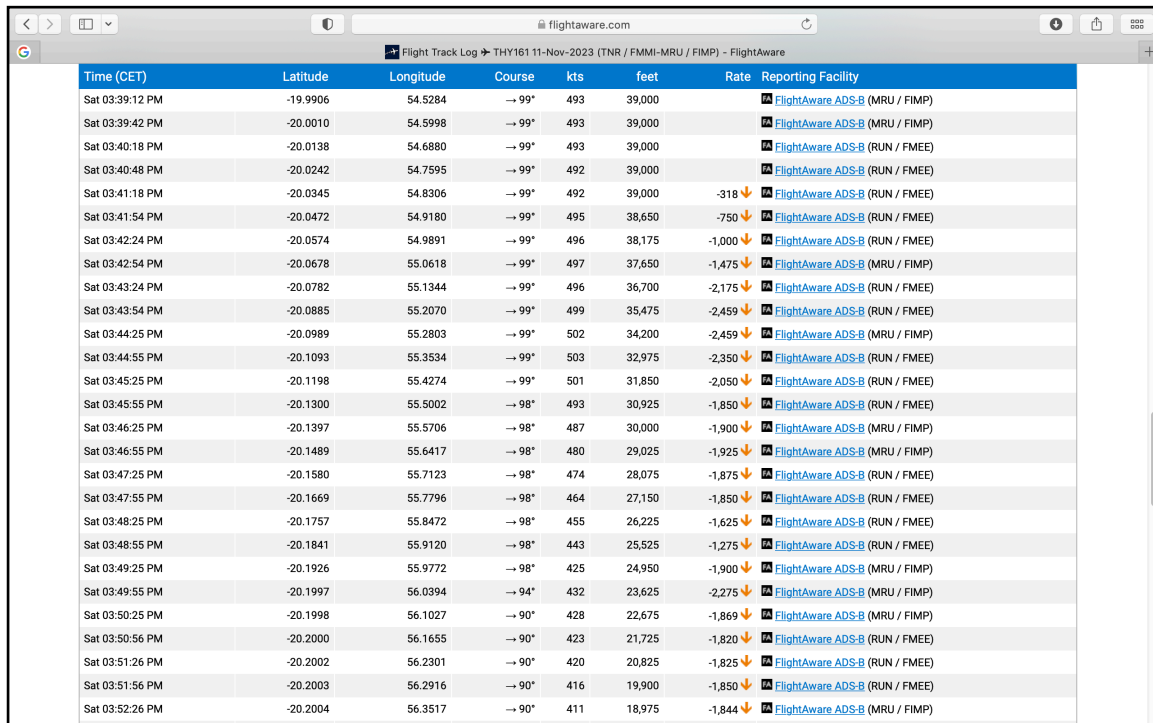


Figure 33: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:42 UTC.

The ADS-B data for flight THY161 is shown in flightaware.com starting on Saturday 11th November 2023 at 15:39:12 CET, which is 14:39:12 UTC. The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:42:01 UTC and 14:43:51.6 UTC.



Time (CET)	Latitude	Longitude	Course	kts	feet	Rate	Reporting Facility
Sat 03:39:12 PM	-19.9906	54.5284	→ 99°	493	39,000		FlightAware ADS-B (MRU / FIMP)
Sat 03:39:42 PM	-20.0010	54.5998	→ 99°	493	39,000		FlightAware ADS-B (MRU / FIMP)
Sat 03:40:18 PM	-20.0138	54.6880	→ 99°	493	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:40:48 PM	-20.0242	54.7595	→ 99°	492	39,000		FlightAware ADS-B (RUN / FMEE)
Sat 03:41:18 PM	-20.0345	54.8306	→ 99°	492	39,000	-318 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:41:54 PM	-20.0472	54.9180	→ 99°	495	38,650	-750 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:42:24 PM	-20.0574	54.9891	→ 99°	496	38,175	-1,000 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:42:54 PM	-20.0678	55.0618	→ 99°	497	37,650	-1,475 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:43:24 PM	-20.0782	55.1344	→ 99°	496	36,700	-2,175 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:43:54 PM	-20.0885	55.2070	→ 99°	499	35,475	-2,459 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:44:25 PM	-20.0989	55.2803	→ 99°	502	34,200	-2,459 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:44:55 PM	-20.1093	55.3534	→ 99°	503	32,975	-2,350 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:45:25 PM	-20.1198	55.4274	→ 99°	501	31,850	-2,050 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:45:55 PM	-20.1300	55.5002	→ 98°	493	30,925	-1,850 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:46:25 PM	-20.1397	55.5706	→ 98°	487	30,000	-1,900 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:46:55 PM	-20.1489	55.6417	→ 98°	480	29,025	-1,925 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:47:25 PM	-20.1580	55.7123	→ 98°	474	28,075	-1,875 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:47:55 PM	-20.1669	55.7796	→ 98°	464	27,150	-1,850 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:48:25 PM	-20.1757	55.8472	→ 98°	455	26,225	-1,625 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:48:55 PM	-20.1841	55.9120	→ 98°	443	25,525	-1,275 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:49:25 PM	-20.1926	55.9772	→ 98°	425	24,950	-1,900 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:49:55 PM	-20.1997	56.0394	→ 94°	432	23,625	-2,275 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:50:25 PM	-20.1998	56.1027	→ 90°	428	22,675	-1,869 ↓	FlightAware ADS-B (MRU / FIMP)
Sat 03:50:56 PM	-20.2000	56.1655	→ 90°	423	21,725	-1,820 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:51:26 PM	-20.2002	56.2301	→ 90°	420	20,825	-1,825 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:51:56 PM	-20.2003	56.2916	→ 90°	416	19,900	-1,850 ↓	FlightAware ADS-B (RUN / FMEE)
Sat 03:52:26 PM	-20.2004	56.3517	→ 90°	411	18,975	-1,844 ↓	FlightAware ADS-B (MRU / FIMP)

Table 35: Flight THY161 ADS-B data as shown in flightaware.com.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:41:54	0	-20.047200	54.918000	38,650	495	99	-750
14:42:01	7	-20.049580	54.934590	38,539	495	99	-808
14:42:24	30	-20.057400	54.989100	38,175	496	99	-1,000
14:43:24	0	-20.078200	55.134400	36,700	496	99	-2,175
14:43:51.6	27.6	-20.087676	55.201192	35,573	499	99	-2,436
14:43:54	30	-20.088500	55.207000	35,475	499	99	-2,459

Table 36: Flight THY161 ADS-B data interpolation at 14:42 UTC.

The WSPR data for the link AA6RF-ND7M was downloaded for the time period starting 14:42:01 UTC $\pm$ 3 hours and the mean received frequency of 7,040,090.80 Hz and the SD of 55.9767 Hz were calculated. The actual received frequency in the 14:42 UTC WSPR time slot is 7,040,174 Hz, which represents a deviation of -83.1818 Hz from the mean by a factor of -1.49 SD or by a percentage of -149% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6611152530	2023-11-11 14:42:00	AA6RF	DM14ga	ND7M	DM16xf	7040174	23	-11	0	277	27	7	WD_3.0.6	1
2	6611200945	2023-11-11 14:50:00	AA6RF	DM14ga	ND7M	DM16xf	7040072	23	-14	0	277	27	7	WD_3.0.6	1
3	6611289640	2023-11-11 15:06:00	AA6RF	DM14ga	ND7M	DM16xf	7040064	23	-9	0	277	27	7	WD_3.0.6	1
4	6611338759	2023-11-11 15:14:00	AA6RF	DM14ga	ND7M	DM16xf	7040084	23	-11	0	277	27	7	WD_3.0.6	1
5	6611384714	2023-11-11 15:22:00	AA6RF	DM14ga	ND7M	DM16xf	7040048	23	-5	0	277	27	7	WD_3.0.6	1
6	6611432049	2023-11-11 15:30:00	AA6RF	DM14ga	ND7M	DM16xf	7040104	23	-11	0	277	27	7	WD_3.0.6	1
7	6611478493	2023-11-11 15:38:00	AA6RF	DM14ga	ND7M	DM16xf	7040030	23	-13	0	277	27	7	WD_3.0.6	1
8	6611521778	2023-11-11 15:46:00	AA6RF	DM14ga	ND7M	DM16xf	7040131	23	-12	0	277	27	7	WD_3.0.6	1
9	6611568049	2023-11-11 15:54:00	AA6RF	DM14ga	ND7M	DM16xf	7040198	23	-9	0	277	27	7	WD_3.0.6	1
10	6611609087	2023-11-11 16:02:00	AA6RF	DM14ga	ND7M	DM16xf	7040020	23	-13	0	277	27	7	WD_3.0.6	1
11	6611653078	2023-11-11 16:10:00	AA6RF	DM14ga	ND7M	DM16xf	7040074	23	-2	0	277	27	7	WD_3.0.6	1
12	6611696843	2023-11-11 16:18:00	AA6RF	DM14ga	ND7M	DM16xf	7040023	23	-8	0	277	27	7	WD_3.0.6	1
13	6611738525	2023-11-11 16:26:00	AA6RF	DM14ga	ND7M	DM16xf	7040154	23	-14	0	277	27	7	WD_3.0.6	1
14	6611783503	2023-11-11 16:34:00	AA6RF	DM14ga	ND7M	DM16xf	7040025	23	-10	0	277	27	7	WD_3.0.6	1
15	6611825634	2023-11-11 16:42:00	AA6RF	DM14ga	ND7M	DM16xf	7040162	23	-18	0	277	27	7	WD_3.0.6	1
16	6611869221	2023-11-11 16:50:00	AA6RF	DM14ga	ND7M	DM16xf	7040111	23	-17	0	277	27	7	WD_3.0.6	1
17	6611910485	2023-11-11 16:58:00	AA6RF	DM14ga	ND7M	DM16xf	7040025	23	-13	0	277	27	7	WD_3.0.6	1
18	6611945681	2023-11-11 17:06:00	AA6RF	DM14ga	ND7M	DM16xf	7040157	23	-13	0	277	27	7	WD_3.0.6	1
19	6611984303	2023-11-11 17:14:00	AA6RF	DM14ga	ND7M	DM16xf	7040040	23	-15	0	277	27	7	WD_3.0.6	1
20	6612022287	2023-11-11 17:22:00	AA6RF	DM14ga	ND7M	DM16xf	7040107	23	-19	0	277	27	7	WD_3.0.6	1
21	6612057582	2023-11-11 17:30:00	AA6RF	DM14ga	ND7M	DM16xf	7040140	23	-19	0	277	27	7	WD_3.0.6	1
22	6612091936	2023-11-11 17:38:00	AA6RF	DM14ga	ND7M	DM16xf	7040055	23	-17	0	277	27	7	WD_3.0.6	1
							7040090.8	Mean	-12.4091						
							55.9767	SD	4.3167						
							-83.1818	AD	-1.4091						
							-149	AD%	-33						

Table 37: WSPR link data between AA6RF and ND7M at 14:42 UTC $\pm$ 3 hours.

At 14:44 UTC there are six anomalies, two SNR anomalies of +104% SD and -159% SD, one received frequency anomalies of -120% SD, two dual anomalies with SNR of +82% SD, received frequency of -161% SD and with SNR of -166% SD, received frequency of +75% SD and one drift anomaly of -1 Hz/minute.

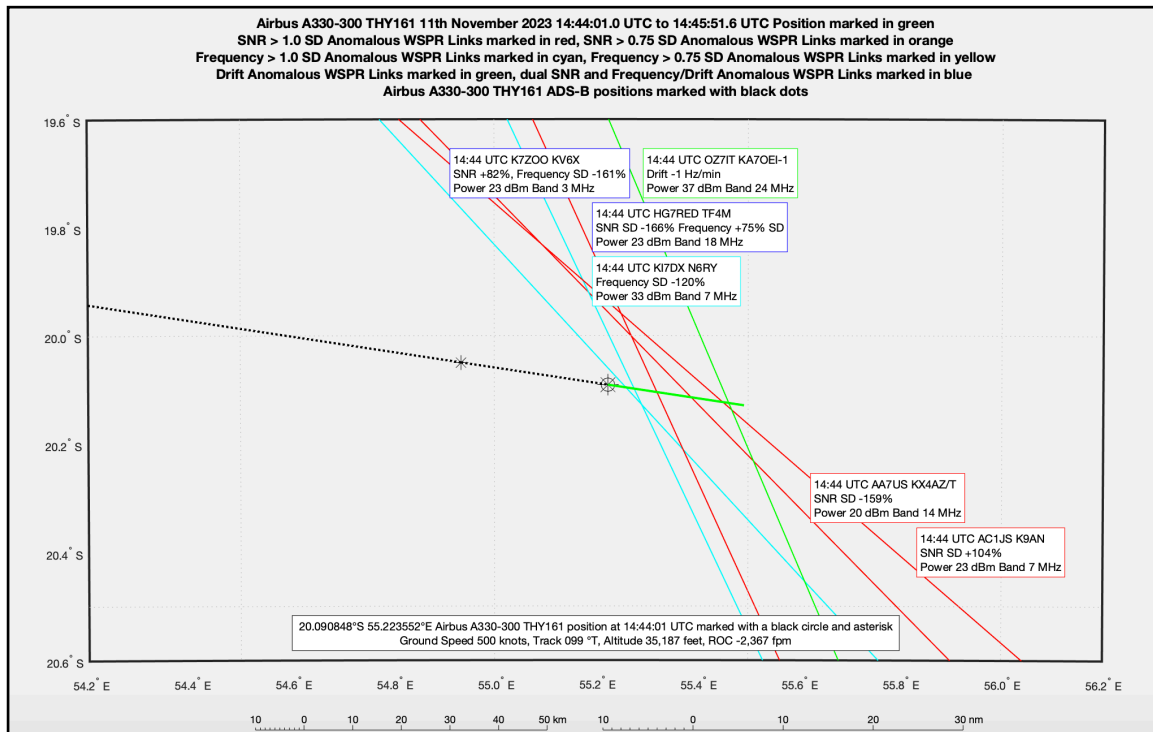


Figure 34: Flight THY161 crossing the WSPR paths K7ZOO-KV6X, OZ7IT-KA7OEI-1, HG7RED-TF4M, KI7DX-N6RY, AA7US-KX4AZ/T and AC1JS-K9AN.

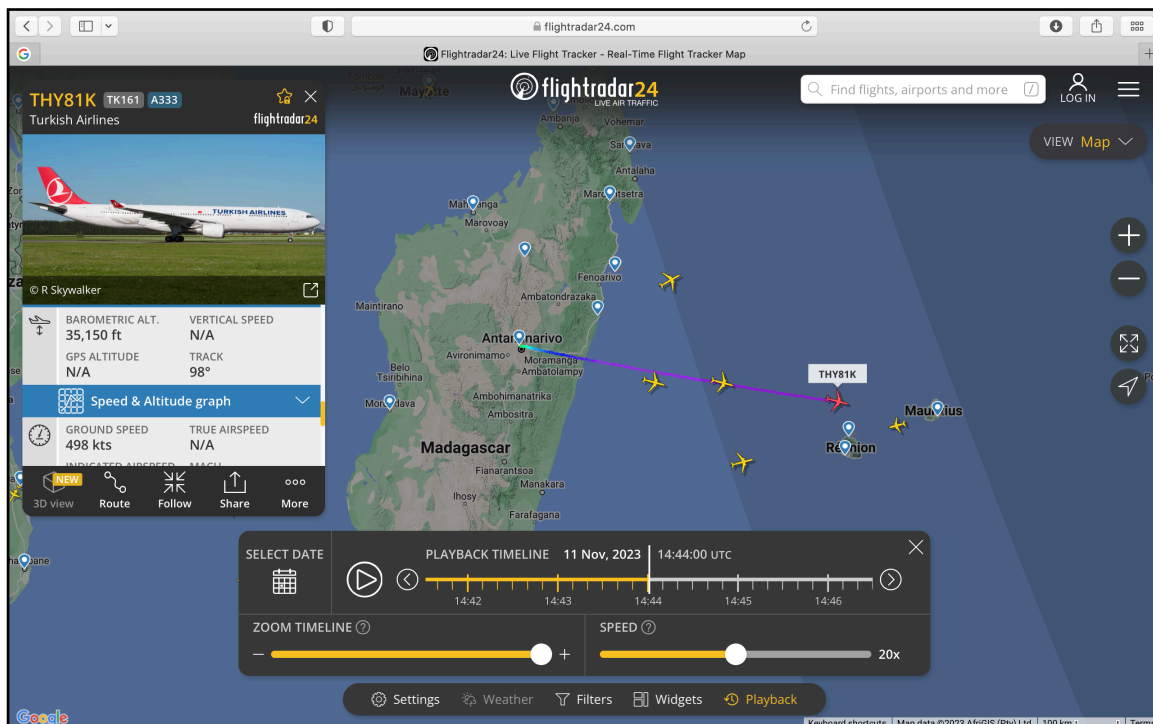


Figure 35: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:44 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:44:01 UTC and 14:45:51.6 UTC.

The WSPR data for the link HG7RED-TF4M was downloaded for the time period starting 14:44:01 UTC $\pm$ 3 hours and the mean received frequency of 18,106,045.750 Hz and the SD of 58.4826 Hz were calculated. The actual received frequency in the 14:44 UTC WSPR time slot is 18,106,002 Hz, which represents a deviation of +43.75 Hz from the mean by a factor of +0.75 SD or by a percentage of +75% SD. The mean SNR of -15.1250 dB and the SD of 4.8825 dB were calculated. The actual SNR in the 14:44 UTC WSPR time slot is -7 dB, which represents a deviation of -8.1250 dB from the mean by a factor of -1.66 SD or by a percentage of -166% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track ("T)	ROC (fpm)
14:43:54	0	-20.088500	55.207000	35,475	499	99	-2,459
14:44:01	7	-20.090848	55.223552	35,187	500	99	-2,367
14:44:25	31	-20.098900	55.280300	34,200	502	99	-2,050
14:45:25	0	-20.119800	55.427400	31,850	501	99	-2,050
14:45:51.6	26.6	-20.128844	55.491949	31,030	494	98	-1,873
14:45:55	30	-20.130000	55.500200	30,925	493	98	-1,850

Table 38: Flight THY161 ADS-B data interpolation at 14:44 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610382178	2023-11-11 12:04:00	HG7RED	JN97kj	TF4M	HP85fp	18106085	23	-16	0	3198	325	18	1.4A Kiwi	1
2	6610552153	2023-11-11 12:44:00	HG7RED	JN97kj	TF4M	HP85fp	18106129	23	-17	0	3198	325	18	1.4A Kiwi	1
3	6610562500	2023-11-11 12:46:00	HG7RED	JN97kj	TF4M	HP85fp	18106129	23	-16	0	3198	325	18	1.4A Kiwi	1
4	6610952923	2023-11-11 14:06:00	HG7RED	JN97kj	TF4M	HP85fp	18106011	23	-15	0	3198	325	18	1.4A Kiwi	1
5	6611164814	2023-11-11 14:44:00	HG7RED	JN97kj	TF4M	HP85fp	18106002	23	-7	0	3198	325	18	1.4A Kiwi	1
6	6611176128	2023-11-11 14:46:00	HG7RED	JN97kj	TF4M	HP85fp	18106002	23	-11	0	3198	325	18	1.4A Kiwi	1
7	6611409286	2023-11-11 15:26:00	HG7RED	JN97kj	TF4M	HP85fp	18106007	23	-15	0	3198	325	18	1.4A Kiwi	1
8	6611630473	2023-11-11 16:06:00	HG7RED	JN97kj	TF4M	HP85fp	18106001	23	-24	0	3198	325	18	1.4A Kiwi	1
							18106045.7500	Mean	-15.1250						
							58.4826	SD	4.8825						
							43.7500	AD	-8.1250						
							75	AD%	-166						

Table 39: WSPR link data between HG7RED and TF4M at 14:44 UTC $\pm$ 3 hours.

The WSPR data for the link OZ7IT-KA7OEI-1 was downloaded for the time period starting 14:44:01 UTC $\pm$ 3 hours and a non systematic drift anomaly of -1 Hz/minute was observed.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6600323565	2023-11-09 14:40:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926132	37	-22	0	8044	320	24	WD_3.0.9	1
2	6600436975	2023-11-09 15:00:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-16	0	8044	320	24	WD_3.0.9	1
3	6600700551	2023-11-09 15:46:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-18	0	8044	320	24	WD_3.0.9	1
4	6601244743	2023-11-09 17:24:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926131	37	-18	0	8044	320	24	WD_3.0.9	1
5	6606548005	2023-11-10 17:06:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926131	37	-27	0	8044	320	24	WD_3.0.9	1
6	6611159737	2023-11-11 14:44:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-20	-1	8044	320	24	WD_3.0.9	1
7	6611274545	2023-11-11 15:04:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-19	0	8044	320	24	WD_3.0.9	1
8	6611415727	2023-11-11 15:28:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-10	0	8044	320	24	WD_3.0.9	1
9	6611553121	2023-11-11 15:52:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-23	0	8044	320	24	WD_3.0.9	1
10	6616486533	2023-11-12 15:10:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-15	0	8044	320	24	WD_3.0.9	1
11	6616626355	2023-11-12 15:34:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-8	0	8044	320	24	WD_3.0.9	1
12	6616742458	2023-11-12 15:54:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-12	0	8044	320	24	WD_3.0.9	1
13	6617012982	2023-11-12 16:44:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926129	37	-20	0	8044	320	24	WD_3.0.9	1
14	6617135595	2023-11-12 17:08:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-20	0	8044	320	24	WD_3.0.9	1
15	6617244021	2023-11-12 17:30:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926130	37	-10	0	8044	320	24	WD_3.0.9	1
16	6622084868	2023-11-13 15:10:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926116	37	-24	0	8044	320	24	WD_3.0.9	1
17	6622205824	2023-11-13 15:32:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926115	37	-9	0	8044	320	24	WD_3.0.9	1
18	6622310054	2023-11-13 15:52:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926116	37	-8	0	8044	320	24	WD_3.0.9	1
19	6622668585	2023-11-13 17:04:00	OZ7IT	JO65df	KA7OEI-1	DN31u	24926118	37	-23	2	8044	320	24	WD_3.0.9	1
							24926127.2632	Mean	-16.9474						
							5.8958	SD	5.9299						
							-2.7368	AD	3.0526						
							-46	AD%	51						

Table 40: WSPR link data between OZ7IT and KA7OEI-1 at 14:44 UTC $\pm$ 3 hours.

The WSPR data for the link AC1JS-K9AN was downloaded for the time period starting 14:44:01 UTC $\pm$ 3 hours and the mean SNR of -19.90 dB and the SD of 5.8391 dB were calculated. The actual SNR in the 14:44 UTC WSPR time slot is -26 dB, which represents a deviation of +6.10 dB from the mean by a factor of +1.04 SD or by a percentage of +104% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610297934	2023-11-11 11:44:00	AC1JS	FN54	K9AN	EN50wc	7040163	23	-12	0	1639	259	7	2.7.0-rc3	1
2	6610339057	2023-11-11 11:54:00	AC1JS	FN54	K9AN	EN50wc	7040061	23	-13	0	1639	259	7	2.7.0-rc3	1
3	6610377486	2023-11-11 12:04:00	AC1JS	FN54	K9AN	EN50wc	7040124	23	-16	0	1639	259	7	2.7.0-rc3	1
4	6610417420	2023-11-11 12:14:00	AC1JS	FN54	K9AN	EN50wc	7040007	23	-12	0	1639	259	7	2.7.0-rc3	1
5	6610459056	2023-11-11 12:24:00	AC1JS	FN54	K9AN	EN50wc	7040109	23	-15	0	1639	259	7	2.7.0-rc3	1
6	6610504783	2023-11-11 12:34:00	AC1JS	FN54	K9AN	EN50wc	7040161	23	-14	0	1639	259	7	2.7.0-rc3	1
7	6610545041	2023-11-11 12:44:00	AC1JS	FN54	K9AN	EN50wc	7040014	23	-23	0	1639	259	7	2.7.0-rc3	1
8	6610598677	2023-11-11 12:54:00	AC1JS	FN54	K9AN	EN50wc	7040194	23	-15	0	1639	259	7	0.4.0	1
9	6610638517	2023-11-11 13:04:00	AC1JS	FN54	K9AN	EN50wc	7040124	23	-24	0	1639	259	7	2.7.0-rc3	1
10	6610691609	2023-11-11 13:14:00	AC1JS	FN54	K9AN	EN50wc	7040134	23	-15	0	1639	259	7	0.4.0	1
11	6610790825	2023-11-11 13:34:00	AC1JS	FN54	K9AN	EN50wc	7040144	23	-17	0	1639	259	7	0.4.0	1
12	6610893003	2023-11-11 13:54:00	AC1JS	FN54	K9AN	EN50wc	7040012	23	-18	0	1639	259	7	0.4.0	1
13	6610939748	2023-11-11 14:04:00	AC1JS	FN54	K9AN	EN50wc	7040034	23	-20	0	1639	259	7	0.4.0	1
14	6610996775	2023-11-11 14:14:00	AC1JS	FN54	K9AN	EN50wc	7040184	23	-23	0	1639	259	7	0.4.0	1
15	6611162693	2023-11-11 14:44:00	AC1JS	FN54	K9AN	EN50wc	7040121	23	-26	0	1639	259	7	0.4.0	1
16	6611223097	2023-11-11 14:54:00	AC1JS	FN54	K9AN	EN50wc	7040015	23	-24	0	1639	259	7	0.4.0	1
17	6611337416	2023-11-11 15:14:00	AC1JS	FN54	K9AN	EN50wc	7040066	23	-26	0	1639	259	7	0.4.0	1
18	6611453897	2023-11-11 15:34:00	AC1JS	FN54	K9AN	EN50wc	7040055	23	-28	0	1639	259	7	0.4.0	1
19	6611566982	2023-11-11 15:54:00	AC1JS	FN54	K9AN	EN50wc	7040148	23	-28	0	1639	259	7	0.4.0	1
20	6611617428	2023-11-11 16:04:00	AC1JS	FN54	K9AN	EN50wc	7040159	23	-29	0	1639	259	7	0.4.0	1
							7040101.4500	Mean	-19.9000						
							62.4765	SD	5.8391						
							-19.5500	AD	6.1000						
							-31	AD%	104						

Table 41: WSPR link data between AC1JS and K9AN at 14:44 UTC $\pm$ 3 hours.

The WSPR data for the link AA7US-KX4AZ/T was downloaded for the time period starting 14:44:01 UTC $\pm$ 3 hours and the mean SNR of -18.1053 dB and the SD of 4.4708 dB were calculated. The actual SNR in the 14:44 UTC WSPR time slot is -11 dB, which represents a deviation of -7.1053 dB from the mean by a factor of -1.59 SD or by a percentage of -159% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610600197	2023-11-11 12:54:00	AA7US	DM41	KX4AZ/T	EN74gc	14097180	20	-14	0	2633	51	14	WD_3.1.2	1
2	6610821433	2023-11-11 13:40:00	AA7US	DM41	KX4AZ/T	EN74gc	14097126	20	-18	0	2633	51	14	WD_3.1.2	1
3	6610863468	2023-11-11 13:48:00	AA7US	DM41	KX4AZ/T	EN74gc	14097071	20	-22	0	2633	51	14	WD_3.1.2	1
4	6610904667	2023-11-11 13:56:00	AA7US	DM41	KX4AZ/T	EN74gc	14097037	20	-23	0	2633	51	14	WD_3.1.2	1
5	6610942143	2023-11-11 14:04:00	AA7US	DM41	KX4AZ/T	EN74gc	14097117	20	-17	0	2633	51	14	WD_3.1.2	1
6	6610989316	2023-11-11 14:12:00	AA7US	DM41	KX4AZ/T	EN74gc	14097024	20	-13	0	2633	51	14	WD_3.1.2	1
7	6611076024	2023-11-11 14:28:00	AA7US	DM41	KX4AZ/T	EN74gc	14097156	20	-19	0	2633	51	14	WD_3.1.2	1
8	6611122506	2023-11-11 14:36:00	AA7US	DM41	KX4AZ/T	EN74gc	14097048	20	-17	0	2633	51	14	WD_3.1.2	1
9	6611164761	2023-11-11 14:44:00	AA7US	DM41	KX4AZ/T	EN74gc	14097108	20	-11	0	2633	51	14	WD_3.1.2	1
10	6611213520	2023-11-11 14:52:00	AA7US	DM41	KX4AZ/T	EN74gc	14097070	20	-13	0	2633	51	14	WD_3.1.2	1
11	6611258847	2023-11-11 15:00:00	AA7US	DM41	KX4AZ/T	EN74gc	14097133	20	-18	0	2633	51	14	WD_3.1.2	1
12	6611352538	2023-11-11 15:16:00	AA7US	DM41	KX4AZ/T	EN74gc	14097042	20	-21	0	2633	51	14	WD_3.1.2	1
13	6611397627	2023-11-11 15:24:00	AA7US	DM41	KX4AZ/T	EN74gc	14097127	20	-30	1	2633	51	14	WD_3.1.2	1
14	6611446041	2023-11-11 15:32:00	AA7US	DM41	KX4AZ/T	EN74gc	14097084	20	-12	1	2633	51	14	WD_3.1.2	1
15	6611580114	2023-11-11 15:56:00	AA7US	DM41	KX4AZ/T	EN74gc	14097166	20	-18	1	2633	51	14	WD_3.1.2	1
16	6611675249	2023-11-11 16:12:00	AA7US	DM41	KX4AZ/T	EN74gc	14097133	20	-20	0	2633	51	14	WD_3.1.2	1
17	6611795167	2023-11-11 16:36:00	AA7US	DM41	KX4AZ/T	EN74gc	14097061	20	-18	0	2633	51	14	WD_3.1.2	1
18	6611836551	2023-11-11 16:44:00	AA7US	DM41	KX4AZ/T	EN74gc	14097165	20	-20	0	2633	51	14	WD_3.1.2	1
19	6611995472	2023-11-11 17:16:00	AA7US	DM41	KX4AZ/T	EN74gc	14097050	20	-20	0	2633	51	14	WD_3.1.2	1
							14097099.8947	Mean	-18.1053						
							49.3760	SD	4.4708						
							-8.1053	AD	-7.1053						
							-16	AD%	-159						

Table 42: WSPR link data between AA7US and KX4AZ/T at 14:44 UTC $\pm$ 3 hours.

The WSPR data for the link K7ZOO-KV6X was downloaded for the time period starting 14:44:01 UTC $\pm$ 3 hours and the mean received frequency of 3,570,104.9845 Hz and the SD of 60.0756 Hz were calculated. The actual received frequency in the 14:44 UTC WSPR time slot is 3,570,202 Hz, which represents a deviation of -97.0155 Hz from the mean by a factor of -1.61 SD or by a percentage of -161% SD. The mean SNR of -6.5736 dB and the SD of 10.3144 dB were calculated. The actual SNR in the 14:44 UTC WSPR time slot is -15 dB, which represents a deviation of +8.4264 dB from the mean by a factor of +0.82 SD or by a percentage of +82% SD. The results are shown in Tables 43 and 44 on the next two pages.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
2	6610301729	2023-11-11 11:44:00	K7ZOO	DM42mf	KV6X	DM75aq	3570178	23	3	0	600	49	3	WD_3.1.2	1
3	6610310850	2023-11-11 11:46:00	K7ZOO	DM42mf	KV6X	DM75aq	3570107	23	3	0	600	49	3	WD_3.1.2	1
4	6610318661	2023-11-11 11:48:00	K7ZOO	DM42mf	KV6X	DM75aq	3570107	23	1	0	600	49	3	WD_3.1.2	1
5	6610326302	2023-11-11 11:50:00	K7ZOO	DM42mf	KV6X	DM75aq	3570138	23	1	0	600	49	3	WD_3.1.2	1
6	6610334208	2023-11-11 11:52:00	K7ZOO	DM42mf	KV6X	DM75aq	3570138	23	1	0	600	49	3	WD_3.1.2	1
7	6610342685	2023-11-11 11:54:00	K7ZOO	DM42mf	KV6X	DM75aq	3570033	23	0	0	600	49	3	WD_3.1.2	1
8	6610350777	2023-11-11 11:56:00	K7ZOO	DM42mf	KV6X	DM75aq	3570033	23	1	0	600	49	3	WD_3.1.2	1
9	6610358023	2023-11-11 11:58:00	K7ZOO	DM42mf	KV6X	DM75aq	3570168	23	2	0	600	49	3	WD_3.1.2	1
10	6610365512	2023-11-11 12:00:00	K7ZOO	DM42mf	KV6X	DM75aq	3570168	23	1	0	600	49	3	WD_3.1.2	1
11	6610373665	2023-11-11 12:02:00	K7ZOO	DM42mf	KV6X	DM75aq	3570094	23	0	0	600	49	3	WD_3.1.2	1
12	6610379590	2023-11-11 12:04:00	K7ZOO	DM42mf	KV6X	DM75aq	3570094	23	1	0	600	49	3	WD_3.1.2	1
13	6610389200	2023-11-11 12:06:00	K7ZOO	DM42mf	KV6X	DM75aq	3570128	23	4	0	600	49	3	WD_3.1.2	1
14	6610397973	2023-11-11 12:08:00	K7ZOO	DM42mf	KV6X	DM75aq	3570128	23	3	0	600	49	3	WD_3.1.2	1
15	6610405599	2023-11-11 12:10:00	K7ZOO	DM42mf	KV6X	DM75aq	3570122	23	0	0	600	49	3	WD_3.1.2	1
16	6610414237	2023-11-11 12:12:00	K7ZOO	DM42mf	KV6X	DM75aq	3570122	23	2	0	600	49	3	WD_3.1.2	1
17	6610422347	2023-11-11 12:14:00	K7ZOO	DM42mf	KV6X	DM75aq	3570079	23	4	0	600	49	3	WD_3.1.2	1
18	6610431289	2023-11-11 12:16:00	K7ZOO	DM42mf	KV6X	DM75aq	3570079	23	5	0	600	49	3	WD_3.1.2	1
19	6610439420	2023-11-11 12:18:00	K7ZOO	DM42mf	KV6X	DM75aq	3570006	23	3	0	600	49	3	WD_3.1.2	1
20	6610447574	2023-11-11 12:20:00	K7ZOO	DM42mf	KV6X	DM75aq	3570006	23	1	0	600	49	3	WD_3.1.2	1
21	6610455593	2023-11-11 12:22:00	K7ZOO	DM42mf	KV6X	DM75aq	3570187	23	3	0	600	49	3	WD_3.1.2	1
22	6610464171	2023-11-11 12:24:00	K7ZOO	DM42mf	KV6X	DM75aq	3570187	23	4	0	600	49	3	WD_3.1.2	1
23	6610472728	2023-11-11 12:26:00	K7ZOO	DM42mf	KV6X	DM75aq	3570109	23	3	0	600	49	3	WD_3.1.2	1
24	6610483516	2023-11-11 12:28:00	K7ZOO	DM42mf	KV6X	DM75aq	3570109	23	1	0	600	49	3	WD_3.1.2	1
25	6610491384	2023-11-11 12:30:00	K7ZOO	DM42mf	KV6X	DM75aq	3570107	23	3	0	600	49	3	WD_3.1.2	1
26	6610499754	2023-11-11 12:32:00	K7ZOO	DM42mf	KV6X	DM75aq	3570107	23	2	0	600	49	3	WD_3.1.2	1
27	6610508060	2023-11-11 12:34:00	K7ZOO	DM42mf	KV6X	DM75aq	3570014	23	3	0	600	49	3	WD_3.1.2	1
28	6610517261	2023-11-11 12:36:00	K7ZOO	DM42mf	KV6X	DM75aq	3570014	23	4	0	600	49	3	WD_3.1.2	1
29	6610524663	2023-11-11 12:38:00	K7ZOO	DM42mf	KV6X	DM75aq	3570008	23	2	0	600	49	3	WD_3.1.2	1
30	6610532016	2023-11-11 12:40:00	K7ZOO	DM42mf	KV6X	DM75aq	3570008	23	4	0	600	49	3	WD_3.1.2	1
31	6610541812	2023-11-11 12:42:00	K7ZOO	DM42mf	KV6X	DM75aq	3570173	23	2	0	600	49	3	WD_3.1.2	1
32	6610550613	2023-11-11 12:44:00	K7ZOO	DM42mf	KV6X	DM75aq	3570173	23	0	0	600	49	3	WD_3.1.2	1
33	6610561015	2023-11-11 12:46:00	K7ZOO	DM42mf	KV6X	DM75aq	3570020	23	1	0	600	49	3	WD_3.1.2	1
34	6610570856	2023-11-11 12:48:00	K7ZOO	DM42mf	KV6X	DM75aq	3570020	23	2	0	600	49	3	WD_3.1.2	1
35	6610580698	2023-11-11 12:50:00	K7ZOO	DM42mf	KV6X	DM75aq	3570096	23	3	0	600	49	3	WD_3.1.2	1
36	6610588971	2023-11-11 12:52:00	K7ZOO	DM42mf	KV6X	DM75aq	3570096	23	4	0	600	49	3	WD_3.1.2	1
37	6610598331	2023-11-11 12:54:00	K7ZOO	DM42mf	KV6X	DM75aq	3570183	23	2	0	600	49	3	WD_3.1.2	1
38	6610606718	2023-11-11 12:56:00	K7ZOO	DM42mf	KV6X	DM75aq	3570183	23	4	0	600	49	3	WD_3.1.2	1
39	6610615822	2023-11-11 12:58:00	K7ZOO	DM42mf	KV6X	DM75aq	3570071	23	4	0	600	49	3	WD_3.1.2	1
40	6610624547	2023-11-11 13:00:00	K7ZOO	DM42mf	KV6X	DM75aq	3570071	23	2	0	600	49	3	WD_3.1.2	1
41	6610633890	2023-11-11 13:02:00	K7ZOO	DM42mf	KV6X	DM75aq	3570035	23	2	0	600	49	3	WD_3.1.2	1
42	6610643146	2023-11-11 13:04:00	K7ZOO	DM42mf	KV6X	DM75aq	3570035	23	1	0	600	49	3	WD_3.1.2	1
43	6610652342	2023-11-11 13:06:00	K7ZOO	DM42mf	KV6X	DM75aq	3570073	23	3	0	600	49	3	WD_3.1.2	1
44	6610663890	2023-11-11 13:08:00	K7ZOO	DM42mf	KV6X	DM75aq	3570073	23	3	0	600	49	3	WD_3.1.2	1
45	6610674679	2023-11-11 13:10:00	K7ZOO	DM42mf	KV6X	DM75aq	3570184	23	0	0	600	49	3	WD_3.1.2	1
46	6610683946	2023-11-11 13:12:00	K7ZOO	DM42mf	KV6X	DM75aq	3570184	23	5	0	600	49	3	WD_3.1.2	1
47	6610690977	2023-11-11 13:14:00	K7ZOO	DM42mf	KV6X	DM75aq	3570188	23	3	0	600	49	3	WD_3.1.2	1
48	6610701510	2023-11-11 13:16:00	K7ZOO	DM42mf	KV6X	DM75aq	3570189	23	1	0	600	49	3	WD_3.1.2	1
49	6610711458	2023-11-11 13:18:00	K7ZOO	DM42mf	KV6X	DM75aq	3570065	23	2	0	600	49	3	WD_3.1.2	1
50	6610720568	2023-11-11 13:20:00	K7ZOO	DM42mf	KV6X	DM75aq	3570065	23	2	0	600	49	3	WD_3.1.2	1
51	6610730340	2023-11-11 13:22:00	K7ZOO	DM42mf	KV6X	DM75aq	3570003	23	0	0	600	49	3	WD_3.1.2	1
52	6610740012	2023-11-11 13:24:00	K7ZOO	DM42mf	KV6X	DM75aq	3570003	23	2	0	600	49	3	WD_3.1.2	1
53	6610751247	2023-11-11 13:26:00	K7ZOO	DM42mf	KV6X	DM75aq	3570022	23	3	0	600	49	3	WD_3.1.2	1
54	6610761708	2023-11-11 13:28:00	K7ZOO	DM42mf	KV6X	DM75aq	3570022	23	1	0	600	49	3	WD_3.1.2	1
55	6610771719	2023-11-11 13:30:00	K7ZOO	DM42mf	KV6X	DM75aq	3570144	23	1	0	600	49	3	WD_3.1.2	1
56	6610782093	2023-11-11 13:32:00	K7ZOO	DM42mf	KV6X	DM75aq	3570144	23	4	0	600	49	3	WD_3.1.2	1
57	6610793260	2023-11-11 13:34:00	K7ZOO	DM42mf	KV6X	DM75aq	3570082	23	3	0	600	49	3	WD_3.1.2	1
58	6610801438	2023-11-11 13:36:00	K7ZOO	DM42mf	KV6X	DM75aq	3570082	23	2	0	600	49	3	WD_3.1.2	1
59	6610812376	2023-11-11 13:38:00	K7ZOO	DM42mf	KV6X	DM75aq	3570112	23	2	0	600	49	3	WD_3.1.2	1
60	6610821183	2023-11-11 13:40:00	K7ZOO	DM42mf	KV6X	DM75aq	3570112	23	2	0	600	49	3	WD_3.1.2	1
61	6610830949	2023-11-11 13:42:00	K7ZOO	DM42mf	KV6X	DM75aq	3570188	23	3	0	600	49	3	WD_3.1.2	1
62	6610841186	2023-11-11 13:44:00	K7ZOO	DM42mf	KV6X	DM75aq	3570188	23	0	0	600	49	3	WD_3.1.2	1
63	6610852036	2023-11-11 13:46:00	K7ZOO	DM42mf	KV6X	DM75aq	3570182	23	3	0	600	49	3	WD_3.1.2	1
64	6610863124	2023-11-11 13:48:00	K7ZOO	DM42mf	KV6X	DM75aq	3570182	23	0	0	600	49	3	WD_3.1.2	1
65	6610874906	2023-11-11 13:50:00	K7ZOO	DM42mf	KV6X	DM75aq	3570185	23	0	0	600	49	3	WD_3.1.2	1
66	6610884712	2023-11-11 13:52:00	K7ZOO	DM42mf	KV6X	DM75aq	3570185	23	1	0	600	49	3	WD_3.1.2	1
67	6610895315	2023-11-11 13:54:00	K7ZOO	DM42mf	KV6X	DM75aq	3570183	23	-1	0	600	49	3	WD_3.1.2	1

Table 43: WSPR link data between K7ZOO and KV6X at 14:44 UTC ± 3 hours Part 1.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
68	6610904318	2023-11-11 13:56:00	K7ZOO	DM42mf	KV6X	DM75saq	3570183	23	-2	0	600	49	3	WD_3.1.2	1
69	6610915033	2023-11-11 13:58:00	K7ZOO	DM42mf	KV6X	DM75saq	3570059	23	-2	0	600	49	3	WD_3.1.2	1
70	6610923617	2023-11-11 14:00:00	K7ZOO	DM42mf	KV6X	DM75saq	3570059	23	-1	0	600	49	3	WD_3.1.2	1
71	6610933294	2023-11-11 14:02:00	K7ZOO	DM42mf	KV6X	DM75saq	3570022	23	-3	0	600	49	3	WD_3.1.2	1
72	6610941980	2023-11-11 14:04:00	K7ZOO	DM42mf	KV6X	DM75saq	3570022	23	-3	0	600	49	3	WD_3.1.2	1
73	6610953318	2023-11-11 14:06:00	K7ZOO	DM42mf	KV6X	DM75saq	3570097	23	-6	0	600	49	3	WD_3.1.2	1
74	6610965304	2023-11-11 14:08:00	K7ZOO	DM42mf	KV6X	DM75saq	3570097	23	-6	0	600	49	3	WD_3.1.2	1
75	6610977631	2023-11-11 14:10:00	K7ZOO	DM42mf	KV6X	DM75saq	3570089	23	-7	0	600	49	3	WD_3.1.2	1
76	6610989426	2023-11-11 14:12:00	K7ZOO	DM42mf	KV6X	DM75saq	3570089	23	-7	0	600	49	3	WD_3.1.2	1
77	6610999490	2023-11-11 14:14:00	K7ZOO	DM42mf	KV6X	DM75saq	3570162	23	-5	0	600	49	3	WD_3.1.2	1
78	6611008386	2023-11-11 14:16:00	K7ZOO	DM42mf	KV6X	DM75saq	3570162	23	-7	0	600	49	3	WD_3.1.2	1
79	6611020624	2023-11-11 14:18:00	K7ZOO	DM42mf	KV6X	DM75saq	3570125	23	-8	0	600	49	3	WD_3.1.2	1
80	6611031074	2023-11-11 14:20:00	K7ZOO	DM42mf	KV6X	DM75saq	3570125	23	-7	0	600	49	3	WD_3.1.2	1
81	6611041157	2023-11-11 14:22:00	K7ZOO	DM42mf	KV6X	DM75saq	3570066	23	-7	0	600	49	3	WD_3.1.2	1
82	6611052363	2023-11-11 14:24:00	K7ZOO	DM42mf	KV6X	DM75saq	3570066	23	-9	0	600	49	3	WD_3.1.2	1
83	6611064117	2023-11-11 14:26:00	K7ZOO	DM42mf	KV6X	DM75saq	3570186	23	-8	0	600	49	3	WD_3.1.2	1
84	6611076442	2023-11-11 14:28:00	K7ZOO	DM42mf	KV6X	DM75saq	3570186	23	-10	0	600	49	3	WD_3.1.2	1
85	6611088556	2023-11-11 14:30:00	K7ZOO	DM42mf	KV6X	DM75saq	3570133	23	-11	0	600	49	3	WD_3.1.2	1
86	6611100899	2023-11-11 14:32:00	K7ZOO	DM42mf	KV6X	DM75saq	3570133	23	-13	0	600	49	3	WD_3.1.2	1
87	6611112622	2023-11-11 14:34:00	K7ZOO	DM42mf	KV6X	DM75saq	3570130	23	-9	0	600	49	3	WD_3.1.2	1
88	6611121470	2023-11-11 14:36:00	K7ZOO	DM42mf	KV6X	DM75saq	3570131	23	-12	0	600	49	3	WD_3.1.2	1
89	6611133830	2023-11-11 14:38:00	K7ZOO	DM42mf	KV6X	DM75saq	3570052	23	-9	0	600	49	3	WD_3.1.2	1
90	6611142978	2023-11-11 14:40:00	K7ZOO	DM42mf	KV6X	DM75saq	3570053	23	-13	0	600	49	3	WD_3.1.2	1
91	6611153479	2023-11-11 14:42:00	K7ZOO	DM42mf	KV6X	DM75saq	3570202	23	-13	0	600	49	3	WD_3.1.2	1
92	6611165597	2023-11-11 14:44:00	K7ZOO	DM42mf	KV6X	DM75saq	3570202	23	-15	0	600	49	3	WD_3.1.2	1
93	6611176916	2023-11-11 14:46:00	K7ZOO	DM42mf	KV6X	DM75saq	3570068	23	-18	0	600	49	3	WD_3.1.2	1
94	6611191014	2023-11-11 14:48:00	K7ZOO	DM42mf	KV6X	DM75saq	3570068	23	-16	0	600	49	3	WD_3.1.2	1
95	6611203346	2023-11-11 14:50:00	K7ZOO	DM42mf	KV6X	DM75saq	3570200	23	-18	0	600	49	3	WD_3.1.2	1
96	6611214957	2023-11-11 14:52:00	K7ZOO	DM42mf	KV6X	DM75saq	3570200	23	-18	0	600	49	3	WD_3.1.2	1
97	6611226104	2023-11-11 14:54:00	K7ZOO	DM42mf	KV6X	DM75saq	3570041	23	-14	0	600	49	3	WD_3.1.2	1
98	6611236449	2023-11-11 14:56:00	K7ZOO	DM42mf	KV6X	DM75saq	3570041	23	-14	0	600	49	3	WD_3.1.2	1
99	6611248827	2023-11-11 14:58:00	K7ZOO	DM42mf	KV6X	DM75saq	3570086	23	-18	0	600	49	3	WD_3.1.2	1
100	6611258439	2023-11-11 15:00:00	K7ZOO	DM42mf	KV6X	DM75saq	3570085	23	-16	0	600	49	3	WD_3.1.2	1
101	6611270320	2023-11-11 15:02:00	K7ZOO	DM42mf	KV6X	DM75saq	3570015	23	-21	0	600	49	3	WD_3.1.2	1
102	6611280747	2023-11-11 15:04:00	K7ZOO	DM42mf	KV6X	DM75saq	3570015	23	-20	0	600	49	3	WD_3.1.2	1
103	6611291775	2023-11-11 15:06:00	K7ZOO	DM42mf	KV6X	DM75saq	3570155	23	-20	0	600	49	3	WD_3.1.2	1
104	6611304690	2023-11-11 15:08:00	K7ZOO	DM42mf	KV6X	DM75saq	3570155	23	-20	0	600	49	3	WD_3.1.2	1
105	6611317672	2023-11-11 15:10:00	K7ZOO	DM42mf	KV6X	DM75saq	3570094	23	-20	0	600	49	3	WD_3.1.2	1
106	6611329186	2023-11-11 15:12:00	K7ZOO	DM42mf	KV6X	DM75saq	3570094	23	-19	0	600	49	3	WD_3.1.2	1
107	6611341634	2023-11-11 15:14:00	K7ZOO	DM42mf	KV6X	DM75saq	3570026	23	-20	0	600	49	3	WD_3.1.2	1
108	6611352334	2023-11-11 15:16:00	K7ZOO	DM42mf	KV6X	DM75saq	3570026	23	-20	0	600	49	3	WD_3.1.2	1
109	6611364745	2023-11-11 15:18:00	K7ZOO	DM42mf	KV6X	DM75saq	3570155	23	-19	0	600	49	3	WD_3.1.2	1
110	6611376506	2023-11-11 15:20:00	K7ZOO	DM42mf	KV6X	DM75saq	3570155	23	-23	0	600	49	3	WD_3.1.2	1
111	6611387469	2023-11-11 15:22:00	K7ZOO	DM42mf	KV6X	DM75saq	3570115	23	-22	0	600	49	3	WD_3.1.2	1
112	6611398647	2023-11-11 15:24:00	K7ZOO	DM42mf	KV6X	DM75saq	3570115	23	-22	0	600	49	3	WD_3.1.2	1
113	6611410010	2023-11-11 15:26:00	K7ZOO	DM42mf	KV6X	DM75saq	3570097	23	-23	0	600	49	3	WD_3.1.2	1
114	6611422087	2023-11-11 15:28:00	K7ZOO	DM42mf	KV6X	DM75saq	3570097	23	-24	0	600	49	3	WD_3.1.2	1
115	6611434150	2023-11-11 15:30:00	K7ZOO	DM42mf	KV6X	DM75saq	3570013	23	-20	0	600	49	3	WD_3.1.2	1
116	6611446347	2023-11-11 15:32:00	K7ZOO	DM42mf	KV6X	DM75saq	3570013	23	-16	0	600	49	3	WD_3.1.2	1
117	6611457576	2023-11-11 15:34:00	K7ZOO	DM42mf	KV6X	DM75saq	3570122	23	-20	0	600	49	3	WD_3.1.2	1
118	6611467404	2023-11-11 15:36:00	K7ZOO	DM42mf	KV6X	DM75saq	3570122	23	-22	0	600	49	3	WD_3.1.2	1
119	6611480281	2023-11-11 15:38:00	K7ZOO	DM42mf	KV6X	DM75saq	3570171	23	-21	0	600	49	3	WD_3.1.2	1
120	6611490840	2023-11-11 15:40:00	K7ZOO	DM42mf	KV6X	DM75saq	3570171	23	-21	0	600	49	3	WD_3.1.2	1
121	6611499935	2023-11-11 15:42:00	K7ZOO	DM42mf	KV6X	DM75saq	3570045	23	-20	0	600	49	3	WD_3.1.2	1
122	6611512460	2023-11-11 15:44:00	K7ZOO	DM42mf	KV6X	DM75saq	3570045	23	-25	0	600	49	3	WD_3.1.2	1
123	6611524941	2023-11-11 15:46:00	K7ZOO	DM42mf	KV6X	DM75saq	3570170	23	-25	0	600	49	3	WD_3.1.2	1
124	6611536236	2023-11-11 15:48:00	K7ZOO	DM42mf	KV6X	DM75saq	3570170	23	-26	0	600	49	3	WD_3.1.2	1
125	6611547955	2023-11-11 15:50:00	K7ZOO	DM42mf	KV6X	DM75saq	3570069	23	-24	0	600	49	3	WD_3.1.2	1
126	6611591260	2023-11-11 15:58:00	K7ZOO	DM42mf	KV6X	DM75saq	3570112	23	-23	0	600	49	3	WD_3.1.2	1
127	6611620110	2023-11-11 16:04:00	K7ZOO	DM42mf	KV6X	DM75saq	3570117	23	-23	0	600	49	3	WD_3.1.2	1
128	6611655715	2023-11-11 16:10:00	K7ZOO	DM42mf	KV6X	DM75saq	3570193	23	-29	0	600	49	3	WD_3.1.2	1
129	6611677502	2023-11-11 16:14:00	K7ZOO	DM42mf	KV6X	DM75saq	3570051	23	-27	0	600	49	3	WD_3.1.2	1
130	6611687520	2023-11-11 16:16:00	K7ZOO	DM42mf	KV6X	DM75saq	3570051	23	-25	0	600	49	3	WD_3.1.2	1
							3570104.9845	Mean	-6.5736						
							60.0756	SD	10.3144						
							-97.0155	AD	8.4264						
							-161	AD%	82						

Table 44: WSPR link data between K7ZOO and KV6X at 14:44 UTC ± 3 hours Part 2.

The WSPR data for the link KI7DX-N6RY was downloaded for the time period starting 14:44:01 UTC $\pm$ 3 hours and the mean received frequency of 7,040,144.8889 Hz and the SD of 0.9280 Hz were calculated. The actual received frequency in the 14:44 UTC WSPR time slot is 7,040,146 Hz, which represents a deviation of -1.1111 Hz from the mean by a factor of -1.20 SD or by a percentage of -120% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6599526486	2023-11-09 12:04:00	KI7DX	DN40cq	N6RY	DM33sp	7040144	33	-28	0	785	185	7	2.7.0-rc2	1
2	6600454841	2023-11-09 15:04:00	KI7DX	DN40cq	N6RY	DM33sp	7040146	33	0	0	785	185	7	2.7.0-rc2	1
3	6605531956	2023-11-10 14:04:00	KI7DX	DN40cq	N6RY	DM33sp	7040145	33	2	0	785	185	7	2.7.0-rc2	1
4	6606212869	2023-11-10 16:04:00	KI7DX	DN40cq	N6RY	DM33sp	7040144	33	-2	0	785	185	7	2.7.0-rc2	1
5	6606636359	2023-11-10 17:24:00	KI7DX	DN40cq	N6RY	DM33sp	7040144	33	-9	0	785	185	7	2.7.0-rc2	1
6	6611156622	2023-11-11 14:44:00	KI7DX	DN40cq	N6RY	DM33sp	7040146	33	2	0	785	185	7	2.7.0-rc2	1
7	6611721234	2023-11-11 16:24:00	KI7DX	DN40cq	N6RY	DM33sp	7040146	33	-3	0	785	185	7	2.7.0-rc2	1
8	6611930463	2023-11-11 17:04:00	KI7DX	DN40cq	N6RY	DM33sp	7040144	33	-1	0	785	185	7	2.7.0-rc2	1
9	6616333509	2023-11-12 14:44:00	KI7DX	DN40cq	N6RY	DM33sp	7040145	33	1	0	785	185	7	2.7.0-rc2	1
							7040144.8889	Mean	-4.2222						
							0.9280	SD	9.5365						
							-1.1111	AD	-6.2222						
							-120	AD%	-65						

Table 45: WSPR link data between KI7DX and N6RY at 14:44 UTC $\pm$ 3 hours.

At 14:46 UTC there are four anomalies, one SNR anomaly of -108% SD, two dual anomalies with SNR of +95% SD, received frequency of +157% SD and with SNR of +104% SD, received frequency of +190% SD and one drift anomaly of -1 Hz/minute.

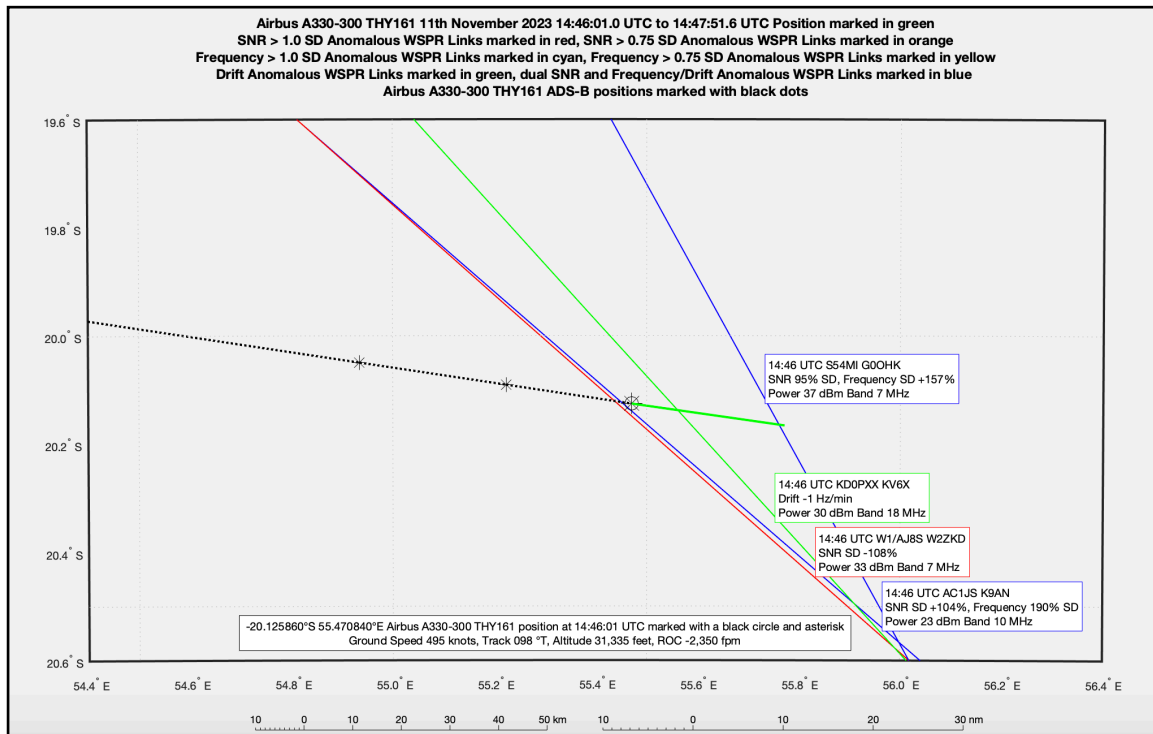


Figure 36: Flight THY161 crossing the WSPR paths S54MI-G00HK, KD0PXX-KV6X, W1/AJ8S-W2ZKD and AC1JS-K9AN.

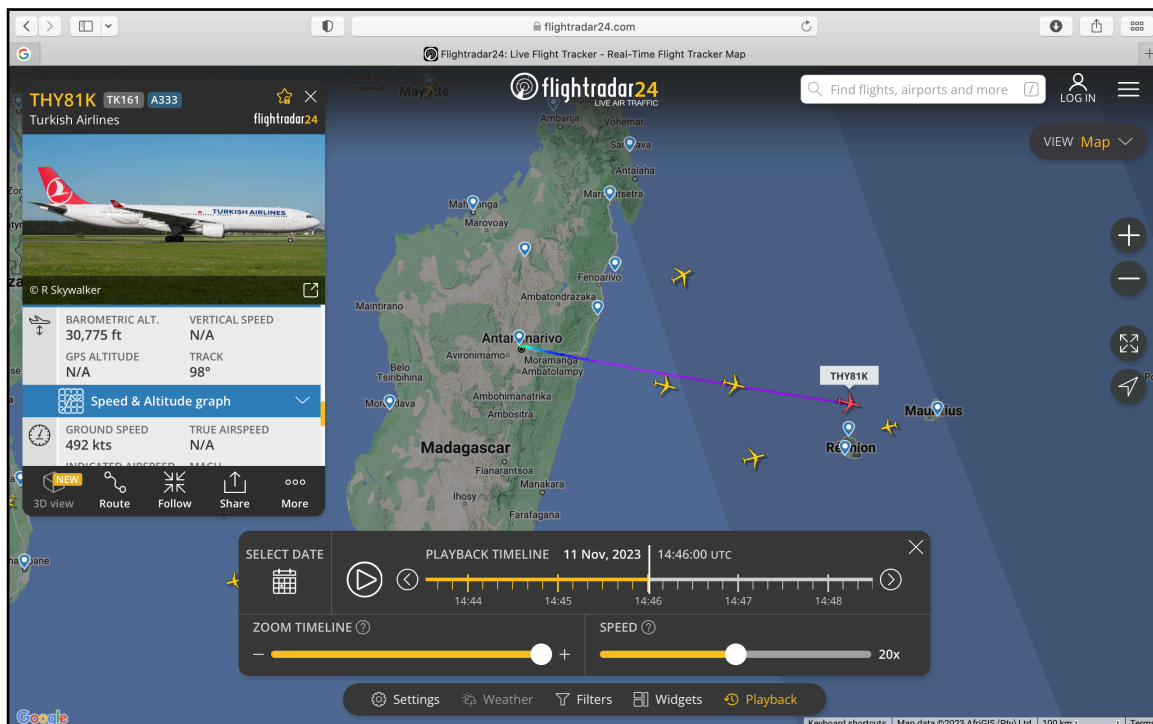


Figure 37: Turkish Airlines Flight THY161 as shown in flightradar24.com at 14:46 UTC.

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:46:01 UTC and 14:47:51.6 UTC.

The WSPR data for the link S54MI-G0OHK was downloaded for the time period starting 14:46:01 UTC $\pm$ 3 hours and the mean received frequency of 7,040,108.40 Hz and the SD of 0.8944 Hz were calculated. The actual received frequency in the 14:46 UTC WSPR time slot is 7,040,107 Hz, which represents a deviation of +1.40 Hz from the mean by a factor of +1.57 SD or by a percentage of +157% SD. The mean SNR of -20.20 dB and the SD of 2.9496 dB were calculated. The actual SNR in the 14:46 UTC WSPR time slot is -23 dB, which represents a deviation of +2.80 dB from the mean by a factor of +0.95 SD or by a percentage of +95% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:45:55	0	-20.130000	55.500200	30,925	493	98	-1,850
14:46:01	6	-20.125860	55.470840	31,335	495	98	-1,860
14:46:25	30	-20.109300	55.353400	32,975	503	99	-1,900
14:47:25	0	-20.158000	55.712300	28,075	474	98	-1,875
14:47:51.6	26.6	-20.165891	55.771973	27,255	465	98	-1,853
14:47:55	30	-20.166900	55.779600	27,150	464	98	-1,850

Table 46: Flight THY161 ADS-B data interpolation at 14:46 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6611167701	2023-11-11 14:46:00	S54MI	JN65um	G0OHK	IO94f	7040107	37	-23	0	1499	320	7	2.6.1	1
2	6611281973	2023-11-11 15:06:00	S54MI	JN65um	G0OHK	IO94f	7040108	37	-20	0	1499	320	7	2.6.1	1
3	6611940245	2023-11-11 17:06:00	S54MI	JN65um	G0OHK	IO94f	7040109	37	-23	0	1499	320	7	2.6.1	1
4	6612025077	2023-11-11 17:24:00	S54MI	JN65um	G0OHK	IO94f	7040109	37	-19	0	1499	320	7	2.6.1	1
5	6612117697	2023-11-11 17:46:00	S54MI	JN65um	G0OHK	IO94f	7040109	37	-16	0	1499	320	7	2.6.1	1
							7040108.4000	Mean	-20.2000						
							0.8944	SD	2.9496						
							1.4000	AD	2.8000						
							157	AD%	95						

Table 47: WSPR link data between S54MI and G0OHK at 14:46 UTC $\pm$ 3 hours.

The WSPR data for the link W1/AJ8S-WA2ZKD was downloaded for the time period starting 14:46:01 UTC $\pm$ 3 hours and the mean SNR of -5.3333 dB and the SD of 4.0 dB were calculated. The actual SNR in the 14:46 UTC WSPR time slot is -1 dB, which represents a deviation of -4.3333 dB from the mean by a factor of -1.08 SD or by a percentage of -108% SD.

The WSPR data for the link KD0PXX-KV6X was downloaded for the time period starting 14:46:01 UTC $\pm$ 3 hours and a non systematic drift anomaly of -1 Hz/minute was observed.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610315427	2023-11-11 11:46:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	0	0	549	260	7	WD_3.0.9	1
2	6610653184	2023-11-11 13:06:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-2	0	549	260	7	WD_3.0.9	1
3	6610758439	2023-11-11 13:26:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-3	0	549	260	7	WD_3.0.9	1
4	6611049017	2023-11-11 14:24:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-5	0	549	260	7	WD_3.0.9	1
5	6611174649	2023-11-11 14:46:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-1	0	549	260	7	WD_3.0.9	1
6	6611289806	2023-11-11 15:06:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-10	0	549	260	7	WD_3.0.9	1
7	6611682815	2023-11-11 16:16:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-8	0	549	260	7	WD_3.0.9	1
8	6611944679	2023-11-11 17:06:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-9	0	549	260	7	WD_3.0.9	1
9	6612122742	2023-11-11 17:46:00	W1/AJ8S	FN44mf	WA2ZKD	FN13ed	7040161	33	-10	0	549	260	7	WD_3.0.9	1
							7040161.0000	Mean	-5.3333						
							0.0000	SD	4.0000						
							0.0000	AD	-4.3333						
							0	AD%	-108						

Table 48: WSPR link data between W1/AJ8S and WA2ZKD at 14:46 UTC $\pm$ 3 hours.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6611142759	2023-11-11 14:40:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-5	0	1065	237	18	WD_3.1.2	1
2	6611153307	2023-11-11 14:42:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-4	0	1065	237	18	WD_3.1.2	1
3	6611175775	2023-11-11 14:46:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-5	-1	1065	237	18	WD_3.1.2	1
4	6611189681	2023-11-11 14:48:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-8	0	1065	237	18	WD_3.1.2	1
5	6611236013	2023-11-11 14:56:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-9	0	1065	237	18	WD_3.1.2	1
6	6611247815	2023-11-11 14:58:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-11	0	1065	237	18	WD_3.1.2	1
7	6611269782	2023-11-11 15:02:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-5	0	1065	237	18	WD_3.1.2	1
8	6611280254	2023-11-11 15:04:00	KD0PXX	EN11xh	KV6X	DM75aq	18106098	30	-2	0	1065	237	18	WD_3.1.2	1
							18106098.0000	Mean	-6.1250						
							0.0000	SD	2.9490						
							0.0000	AD	-1.1250						
							0	AD%	-38						

Table 49: WSPR link data between KD0PXX and KV6X at 14:46 UTC $\pm$ 3 hours.

The WSPR data for the link AC1JS-K9AN was downloaded for the time period starting 14:46:01 UTC $\pm$ 3 hours and the mean received frequency of 10,140,220.4444 Hz and the SD of 56.5203 Hz were calculated. The actual received frequency in the 14:46 UTC WSPR time slot is 10,140,113 Hz, which represents a deviation of +107.4444 Hz from the mean by a factor of +1.90 SD or by a percentage of +190% SD. The mean SNR of -10.1389 dB and the SD of 7.7636 dB were calculated. The actual SNR in the 14:44 UTC WSPR time slot is -18 dB, which represents a deviation of +7.8611 dB from the mean by a factor of +1.04 SD or by a percentage of +104% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610306617	2023-11-11 11:46:00	AC1JS	FN54	K9AN	EN50wc	10140191	23	7	0	1639	259	10	0.4.0	1
2	6610347283	2023-11-11 11:56:00	AC1JS	FN54	K9AN	EN50wc	10140167	23	-1	0	1639	259	10	0.4.0	1
3	6610385463	2023-11-11 12:06:00	AC1JS	FN54	K9AN	EN50wc	10140239	23	3	0	1639	259	10	0.4.0	1
4	6610427607	2023-11-11 12:16:00	AC1JS	FN54	K9AN	EN50wc	10140254	23	3	0	1639	259	10	0.4.0	1
5	6610469294	2023-11-11 12:26:00	AC1JS	FN54	K9AN	EN50wc	10140261	23	-3	0	1639	259	10	0.4.0	1
6	6610513790	2023-11-11 12:36:00	AC1JS	FN54	K9AN	EN50wc	10140292	23	-4	0	1639	259	10	0.4.0	1
7	6610555618	2023-11-11 12:46:00	AC1JS	FN54	K9AN	EN50wc	10140234	23	-9	0	1639	259	10	0.4.0	1
8	6610603121	2023-11-11 12:56:00	AC1JS	FN54	K9AN	EN50wc	10140200	23	-3	0	1639	259	10	0.4.0	1
9	6610648108	2023-11-11 13:06:00	AC1JS	FN54	K9AN	EN50wc	10140250	23	3	0	1639	259	10	0.4.0	1
10	6610697188	2023-11-11 13:16:00	AC1JS	FN54	K9AN	EN50wc	10140157	23	-6	0	1639	259	10	0.4.0	1
11	6610745209	2023-11-11 13:26:00	AC1JS	FN54	K9AN	EN50wc	10140107	23	-3	0	1639	259	10	0.4.0	1
12	6610797195	2023-11-11 13:36:00	AC1JS	FN54	K9AN	EN50wc	10140208	23	-7	0	1639	259	10	0.4.0	1
13	6610845436	2023-11-11 13:46:00	AC1JS	FN54	K9AN	EN50wc	10140253	23	0	0	1639	259	10	0.4.0	1
14	6610899112	2023-11-11 13:56:00	AC1JS	FN54	K9AN	EN50wc	10140271	23	-10	0	1639	259	10	0.4.0	1
15	6610946975	2023-11-11 14:06:00	AC1JS	FN54	K9AN	EN50wc	10140149	23	-10	0	1639	259	10	0.4.0	1
16	6611003038	2023-11-11 14:16:00	AC1JS	FN54	K9AN	EN50wc	10140166	23	-12	0	1639	259	10	0.4.0	1
17	6611056821	2023-11-11 14:26:00	AC1JS	FN54	K9AN	EN50wc	10140209	23	-13	0	1639	259	10	0.4.0	1
18	6611115924	2023-11-11 14:36:00	AC1JS	FN54	K9AN	EN50wc	10140274	23	-10	0	1639	259	10	0.4.0	1
19	6611169658	2023-11-11 14:46:00	AC1JS	FN54	K9AN	EN50wc	10140113	23	-18	0	1639	259	10	0.4.0	1
20	6611229606	2023-11-11 14:56:00	AC1JS	FN54	K9AN	EN50wc	10140167	23	-12	0	1639	259	10	0.4.0	1
21	6611284136	2023-11-11 15:06:00	AC1JS	FN54	K9AN	EN50wc	10140304	23	-15	0	1639	259	10	0.4.0	1
22	6611344762	2023-11-11 15:16:00	AC1JS	FN54	K9AN	EN50wc	10140191	23	-18	0	1639	259	10	0.4.0	1
23	6611402634	2023-11-11 15:26:00	AC1JS	FN54	K9AN	EN50wc	10140276	23	-14	0	1639	259	10	0.4.0	1
24	6611516693	2023-11-11 15:46:00	AC1JS	FN54	K9AN	EN50wc	10140303	23	-16	0	1639	259	10	0.4.0	1
25	6611574388	2023-11-11 15:56:00	AC1JS	FN54	K9AN	EN50wc	10140174	23	-13	0	1639	259	10	0.4.0	1
26	6611624121	2023-11-11 16:06:00	AC1JS	FN54	K9AN	EN50wc	10140292	23	-13	0	1639	259	10	0.4.0	1
27	6611681019	2023-11-11 16:16:00	AC1JS	FN54	K9AN	EN50wc	10140191	23	-15	0	1639	259	10	0.4.0	1
28	6611733992	2023-11-11 16:26:00	AC1JS	FN54	K9AN	EN50wc	10140231	23	-15	0	1639	259	10	0.4.0	1
29	6611789794	2023-11-11 16:36:00	AC1JS	FN54	K9AN	EN50wc	10140164	23	-11	0	1639	259	10	0.4.0	1
30	6611841749	2023-11-11 16:46:00	AC1JS	FN54	K9AN	EN50wc	10140131	23	-20	0	1639	259	10	0.4.0	1
31	6611894870	2023-11-11 16:56:00	AC1JS	FN54	K9AN	EN50wc	10140300	23	-17	0	1639	259	10	0.4.0	1
32	6611941035	2023-11-11 17:06:00	AC1JS	FN54	K9AN	EN50wc	10140247	23	-17	0	1639	259	10	0.4.0	1
33	6611990691	2023-11-11 17:16:00	AC1JS	FN54	K9AN	EN50wc	10140204	23	-20	0	1639	259	10	0.4.0	1
34	6612035692	2023-11-11 17:26:00	AC1JS	FN54	K9AN	EN50wc	10140306	23	-20	0	1639	259	10	0.4.0	1
35	6612079005	2023-11-11 17:36:00	AC1JS	FN54	K9AN	EN50wc	10140219	23	-18	0	1639	259	10	0.4.0	1
36	6612120428	2023-11-11 17:46:00	AC1JS	FN54	K9AN	EN50wc	10140241	23	-18	0	1639	259	10	0.4.0	1
							10140220.4444	Mean	-10.1389						
							56.5203	SD	7.5636						
							107.4444	AD	7.8611						
							190	AD%	104						

Table 50: WSPR link data between AC1JS and K9AN at 14:46 UTC $\pm$ 3 hours.

Airbus A330-300 THY161 11th November 2023 14:48:01.0 UTC to 14:49:51.6 UTC marked in green
SNR > 1.0 SD Anomalous WSPR Links marked in red, **SNR > 0.75 SD Anomalous WSPR Links** marked in orange
Frequency > 1.0 SD Anomalous WSPR Links marked in cyan, **Frequency > 0.75 SD Anomalous WSPR Links** marked in yellow
Drift Anomalous WSPR Links marked in green, **dual SNR and Frequency/Drift Anomalous WSPR Links** marked in blue
Airbus A330-300 THY161 ADS-B positions marked with black dots

The map displays the flight path of Airbus A330-300 THY161 from 14:48:01.0 UTC to 14:49:51.6 UTC. The aircraft's position is marked with a black circle and asterisk at 20.168660°S 55.793120°E. The flight path is shown as a series of connected line segments in various colors (green, cyan, yellow, blue) representing different WSPR link characteristics. Key WSPR links are highlighted with colored boxes: 14:48 UTC VE1BLL KD2OM (red), 14:48 UTC KX4DQ EA8/DF4UE (cyan), and 14:48 UTC G4TNU IK0XFA (yellow). The map also shows the aircraft's ground speed (462 knots) and track (098°T) at the initial position. The map includes latitude and longitude coordinates, a scale bar (0 to 30 nm), and a north arrow.

[illegible]

15th February 2024

The ADS-B data is interpolated to find the aircraft position at the start and end point of the WSPR signal between 14:48:01 UTC and 14:49:51.6 UTC.

The WSPR data for the link G4TNU-IK0XFA was downloaded for the time period starting 14:48:01 UTC $\pm$ 3 hours and the mean received frequency of 10,140,215.7273 Hz and the SD of 64.8384 Hz were calculated. The actual received frequency in the 14:46 UTC WSPR time slot is 10,140,278 Hz, which represents a deviation of -62.2727 Hz from the mean by a factor of -0.96 SD or by a percentage of -96% SD.

Time	Elapsed (secs)	Latitude	Longitude	Altitude (feet)	Speed (knots)	Track (°T)	ROC (fpm)
14:47:55	0	-20.166900	55.779600	27,150	464	98	-1,850
14:48:01	6	-20.168660	55.793120	26,965	462	98	-1,805
14:48:25	30	-20.175700	55.847200	26,225	455	98	-1,625
14:49:25	0	-20.192600	55.977200	24,950	425	98	-1,900
14:49:51.6	26.6	-20.198895	56.032351	23,775	431	94	-2,233
14:49:55	30	-20.199700	56.039400	23,625	432	94	-2,275

Table 51: Flight THY161 ADS-B data interpolation at 14:46 UTC.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610318668	2023-11-11 11:48:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140155	23	-26	1	967	129	10	WD_3.0.9	1
2	6610483501	2023-11-11 12:28:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140237	23	-25	0	967	129	10	WD_3.0.9	1
3	6610962241	2023-11-11 14:08:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140300	23	-24	0	967	129	10	WD_3.0.9	1
4	6611074134	2023-11-11 14:28:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140167	23	-6	1	967	129	10	WD_3.0.9	1
5	6611186717	2023-11-11 14:48:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140278	23	-24	0	967	129	10	WD_3.0.9	1
6	6611301166	2023-11-11 15:08:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140252	23	-22	0	967	129	10	WD_3.0.9	1
7	6611419877	2023-11-11 15:28:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140114	23	-27	0	967	129	10	WD_3.0.9	1
8	6611532822	2023-11-11 15:48:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140165	23	-12	0	967	129	10	WD_3.0.9	1
9	6611749464	2023-11-11 16:28:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140162	23	-23	0	967	129	10	WD_3.0.9	1
10	6611856279	2023-11-11 16:48:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140247	23	-23	0	967	129	10	WD_3.0.9	1
11	6611953694	2023-11-11 17:08:00	G4TNU	IO91rq	IK0XFA	JN45ot	10140296	23	-18	0	967	129	10	WD_3.0.9	1
							10140215.7273	Mean	-20.9091						
							64.8384	SD	6.4723						
							-62.2727	AD	3.0909						
							-96	AD%	48						

Table 52: WSPR link data between G4TNU and IK0XFA at 14:48 UTC $\pm$ 3 hours.

The WSPR data for the link KX4DQ-EA8/DF4UE was downloaded for the time period starting 14:48:01 UTC $\pm$ 3 hours and the mean received frequency of 28,126,110.10 Hz and the SD of 78.6094 Hz were calculated. The actual received frequency in the 14:48 UTC WSPR time slot is 28,126,200 Hz, which represents a deviation of -89.90 Hz from the mean by a factor of -1.14 SD or by a percentage of -114% SD.

The WSPR data for the link VE1BLL-KD2OM was downloaded for the time period starting 14:48:01 UTC $\pm$ 3 hours and the mean received frequency of 21,096,108.250 Hz and the SD of 62.7005 Hz were calculated. The actual received frequency in the 14:48 UTC WSPR time slot is 21,096,022 Hz, which represents a deviation of +86.250 Hz from the mean by a factor of +1.38 SD or by a percentage of +138% SD. The mean SNR of -15.3750 dB and the SD of 4.9839 dB were calculated. The actual SNR in the 14:48 UTC WSPR time slot is -21 dB, which represents a deviation of +5.6250 dB from the mean by a factor of +1.13 SD or by a percentage of +113% SD.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6610569324	2023-11-11 12:48:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126024	23	-27	0	6750	74	28	WD_3.0.9	1
2	6610912376	2023-11-11 13:58:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126151	23	-8	0	6750	74	28	WD_3.0.9	1
3	6610962000	2023-11-11 14:08:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126030	23	-22	0	6750	74	28	WD_3.0.9	1
4	6611142573	2023-11-11 14:38:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126202	23	-31	0	6750	74	28	WD_3.0.9	1
5	6611186450	2023-11-11 14:48:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126200	23	-22	0	6750	74	28	WD_3.0.9	1
6	6611300761	2023-11-11 15:08:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126152	23	-20	0	6750	74	28	WD_3.0.9	1
7	6611638959	2023-11-11 16:08:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126188	23	-21	0	6750	74	28	WD_3.0.9	1
8	6611804494	2023-11-11 16:38:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126027	23	-12	0	6750	74	28	WD_3.0.9	1
9	6611856965	2023-11-11 16:48:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126111	23	-11	0	6750	74	28	WD_3.0.9	1
10	6611955536	2023-11-11 17:08:00	KX4DQ	EM66	EA8/DF4UE	IL38bp	28126016	23	-18	0	6750	74	28	WD_3.0.9	1
							28126110.1000	Mean	-19.2000						
							78.6094	SD	7.1926						
							-89.9000	AD	2.8000						
							-114	AD%	39						

Table 53: WSPR link data between KX4DQ and EA8/DF4UE at 14:48 UTC $\pm$ 3 hours.

row	id	time	tx_sign	tx_loc	rx_sign	rx_loc	frequency	power	snr	drift	distance	azimuth	band	version	code
1	6611185715	2023-11-11 14:48:00	VE1BLL	FN84et	KD2OM	FN12g	21096022	23	-21	0	1126	264	21	WD_3.1.2	1
2	6611198791	2023-11-11 14:50:00	VE1BLL	FN84et	KD2OM	FN12g	21096022	23	-19	0	1126	264	21	WD_3.1.2	1
3	6611418127	2023-11-11 15:28:00	VE1BLL	FN84et	KD2OM	FN12g	21096109	23	-16	1	1126	264	21	WD_3.1.2	1
4	6611441294	2023-11-11 15:30:00	VE1BLL	FN84et	KD2OM	FN12g	21096109	23	-19	0	1126	264	21	WD_3.1.2	1
5	6611856954	2023-11-11 16:48:00	VE1BLL	FN84et	KD2OM	FN12g	21096114	23	-5	0	1126	264	21	WD_3.1.2	1
6	6611868522	2023-11-11 16:50:00	VE1BLL	FN84et	KD2OM	FN12g	21096115	23	-13	0	1126	264	21	WD_3.1.2	1
7	6612047144	2023-11-11 17:28:00	VE1BLL	FN84et	KD2OM	FN12g	21096188	23	-14	0	1126	264	21	WD_3.1.2	1
8	6612056350	2023-11-11 17:30:00	VE1BLL	FN84et	KD2OM	FN12g	21096187	23	-16	0	1126	264	21	WD_3.1.2	1
							21096108.2500	Mean	-15.3750						
							62.7005	SD	4.9839						
							86.2500	AD	5.6250						
							138	AD%	113						

Table 54: WSPR link data between VE1BLL and KD2OM at 14:48 UTC $\pm$ 3 hours.

8. Long Distance WSPR Detection of Aircraft - Discussion of Results.

WSPR signals detected aircraft over a mean distance of 13,744.6 km (minimum 7,909.3 km, maximum 18,289.2 km) from the transmitter. The mean propagation distance from transmitter to aircraft and back to the receiver was 27,761.9 km (minimum 16,699.0, maximum 36,300.2 km). The mean transmission power was 809.8 mW (minimum 100 mW, maximum 5.0119 W).

The reflected signal from the aircraft was in each case at 180° back along the same great circle path within $\pm 0.323^\circ$. WSPR signals are not always tilted during refraction in the ionosphere or during reflection on the Earth's surface.

There were 1.4 million WSPR signals recorded in 2023 with a propagation distance over 18,000 km, with an average transmission power of 756 mW. There were 15,768 WSPR signals recorded in 2023 with a propagation distance over 18,000 km and with a transmission power of 1 mW. WSPR signal transmission power can be very small and still achieve large propagation distances.

There is a limitation in the WSPRnet database that propagation distances are only computed along the great circle short path. The Earth's circumference measured around the equator is 40,075.017 km. The WSPRnet database will not record a propagation distance greater than 20,038 km. This is an artificial limit and it is erroneous to conclude that 20,038 km represents a maximum possible propagation distance. There is no theoretical limit to how far a radio wave can travel. We have communicated by radio with orbiters and rovers on Mars, which can be anywhere from 54.6 million km to 401 million km distant and the propagation can take up to 22.3 minutes. In 1978 the US Military Wide Aperture Research Facility (WARF) was used to conduct round-the-world (RTW) ionospheric propagations. RTW propagations were observed for up to 4 hours on eight different days. The RTW propagations were achieved with a reduced transmission power of 1 kW and increasing the transmission power to 20 kW did not change the number of RTW propagations observed. It takes around 135 ms for an ionospheric propagation to go around the world and variations of 1 or 2 ms were noted in the received signal.

In 1956 the Naval Research Laboratory concluded a definitive set of experiments that showed that the ionosphere is generally sufficiently stable for an HF sky wave radar to succeed for over-the-horizon aircraft detection. In 1978 Klaus Bibl and Bodo Reinisch conducted a number of experiments to determine the coherent integration time of the ionosphere. NOAA conclude that it is possible to coherently integrate pulse echoes for tens of seconds under nearly all ionospheric conditions.

The Australian DSTG has modelled the RCS of commercial aircraft and have shown that the RCS is enhanced for short wave transmissions as used by WSPR. The long coherent integration time estimated by the DSTG as up to 60 seconds and the enhanced RCS of commercial aircraft in the WSPR wavelength bands are two reasons why the long distance WSPR detection of aircraft is effective.

WSPR is a multi-static and multi-frequency system with global coverage. There are currently around 6 million distinctive links between WSPR transmitters and receivers from around the world recorded in the WSPRnet database with a propagation distance greater than 3,000 km.

We have previously demonstrated the opposite case of aircraft disturbance of WSPR signals, when the Tonga volcanic eruption occurred on 15th January 2022 at 04:26:30 UTC WSPR signals disappeared altogether. The epicentre was at 20.54°S 175.38°W at a depth of 33 km and the volcanic ash cloud covered an area up to 700 km in diameter. Six WSPR links between Hawaii and New Zealand disappeared from 04:40 UTC onwards. The first link re-appeared at 19:10 UTC, some 14 hours 50 minutes after it last appeared. The other links re-appeared within the next hour.

Anomalies were found in each phase of the flight: climb, cruise and descent at an average of 3 anomalies for each WSPR two minute timeframes analysed. There were 44 WSPR anomalies comprising 19 SNR anomalies, 21 frequency anomalies and 4 drift anomalies in 14 two minute WSPR time slots. The multi-static and multi-frequency global coverage is the reason why the long distance WSPR detection and tracking of aircraft is successful.

9. Implications for the Detection and Tracking of MH370.

The addition of the received frequency anomalies to the previous case study titled “MH370 Flight Path Analysis” published on 31st August 2023 does not change the flight path, but increases the total number of two minute WSPR time points defining the flight path from 65 to 130 (with 125 to 313 anomalies respectively). Between 7th March 2014 18:00 UTC and 8th March 2014 00:28 UTC, there were a total of 195 time points that were analysed, so this represents a very accurate path.

There is a change to the crash location probability map however, where the indications of a recovery from the descent of over -14,000 fpm at 00:19:37 UTC are now stronger. There are now 5 anomalous WSPR links intersecting at 29.128°S 99.934°E, which in our view is a very strong indication of a disturbance by an aircraft. There is no overlap between the MH370 crash location and the previous Ocean Infinity search area, which is marked in pink in Figure 41, there is a gap of 19.9 km (10.3 nmi) between the Ocean Infinity search area and the WSPR defined area. There is an overlap with the UWA Drift Analysis area, which is marked in yellow. The positions 28.782°S 99.362°E and 29.128°S 99.934°E are 91.6 km apart in distance and 6 minutes in flying time at 494.6 knots. There are no WSPR disturbances beyond 00:28 UTC.

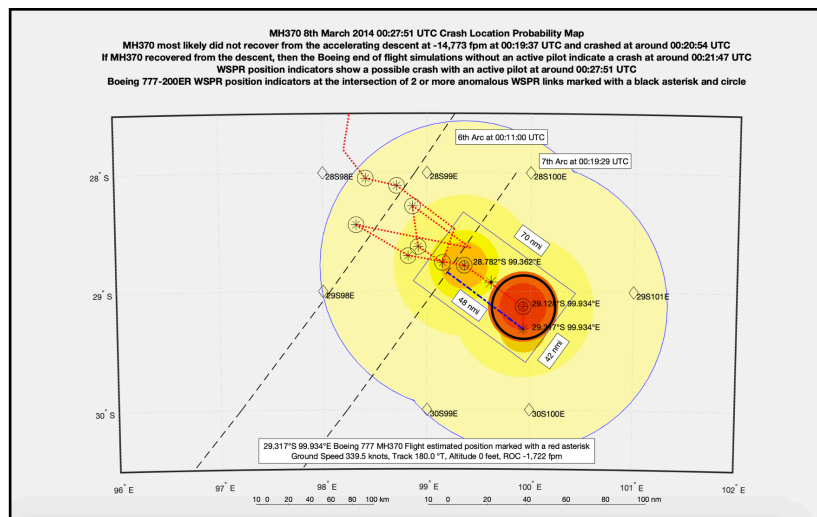


Figure 40: Revised MH370 Crash Location Probability Map.

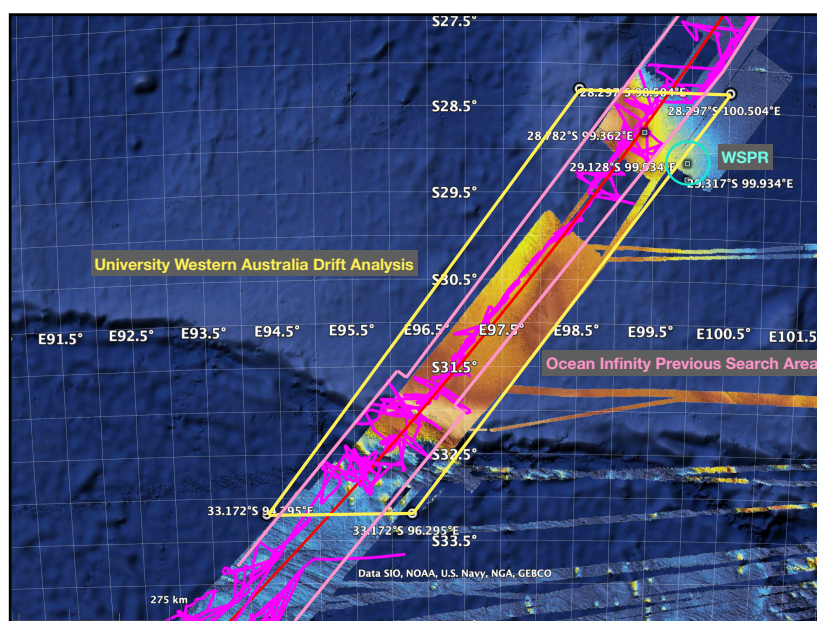


Figure 41: MH370 Crash Location and previously searched area.

10. Conclusion.

We have shown that WSPRnet radio signals can reliably detect and track aircraft over long distances to the other side of the globe. Anomalies in the WSPRnet data in the received signal level SNR, received frequency and frequency drift indicate a possible disturbance by an aircraft.

The propagation paths of the WSPR radio signals between the transmitters and the aircraft on one hand and between the aircraft and the receivers on the other hand align exactly along great circles

An average of three intersecting anomalous WSPR signals match the position of the target aircraft at each two minute WSPR time point. The precision of the great circle propagation paths was made possible because of an accurate antenna database, with location data sourced from each antenna owner.

WSPRnet is a multi-static and multi-frequency system with global coverage. There are currently around 6 million distinctive links between WSPR transmitters and receivers from around the world recorded in the WSPRnet database with a propagation distance greater than 3,000 km.

The long coherent integration time of the WSPRnet receivers, the enhanced radar footprint of modern aircraft in the WSPRnet wavelength bands and the global coverage of WSPRnet propagations ensure a high level of detection and reliable tracking of aircraft.

11. References.

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