WSPR* as a Tool for Understanding HF Propagation: A work in progress

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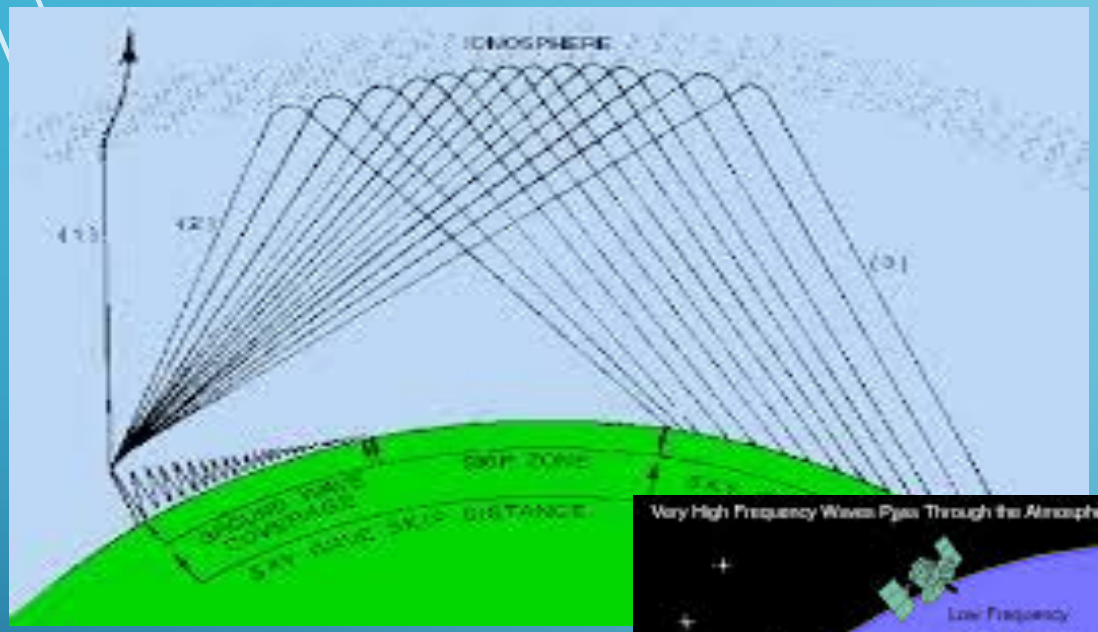
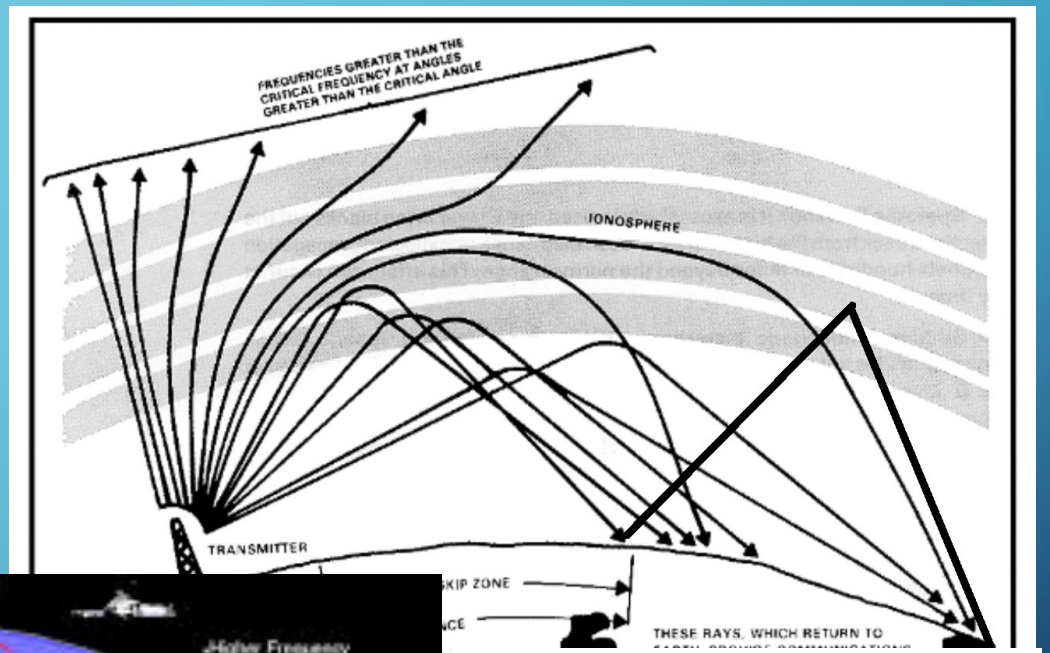
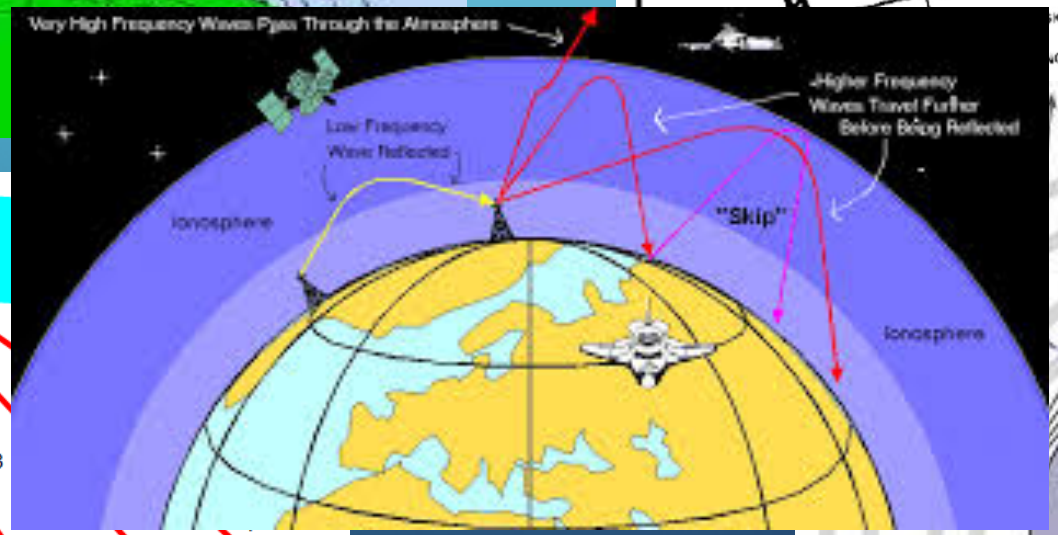
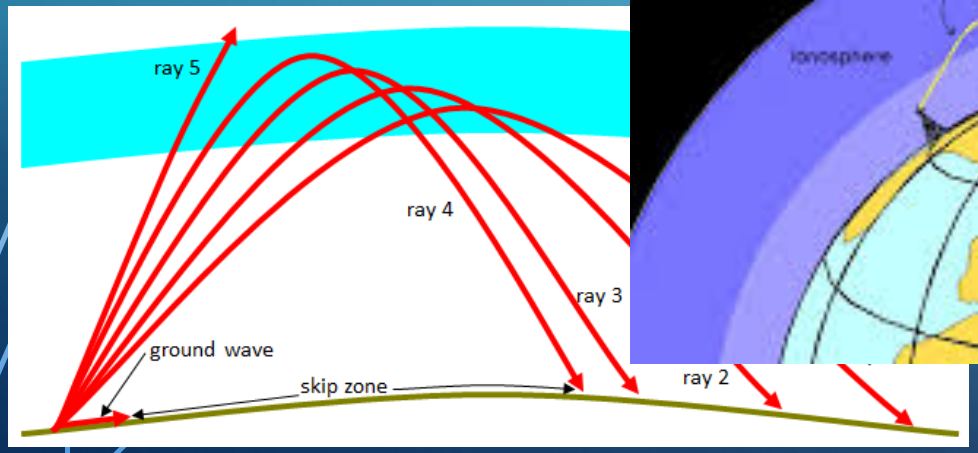
*Weak Signal Propagation Reporter

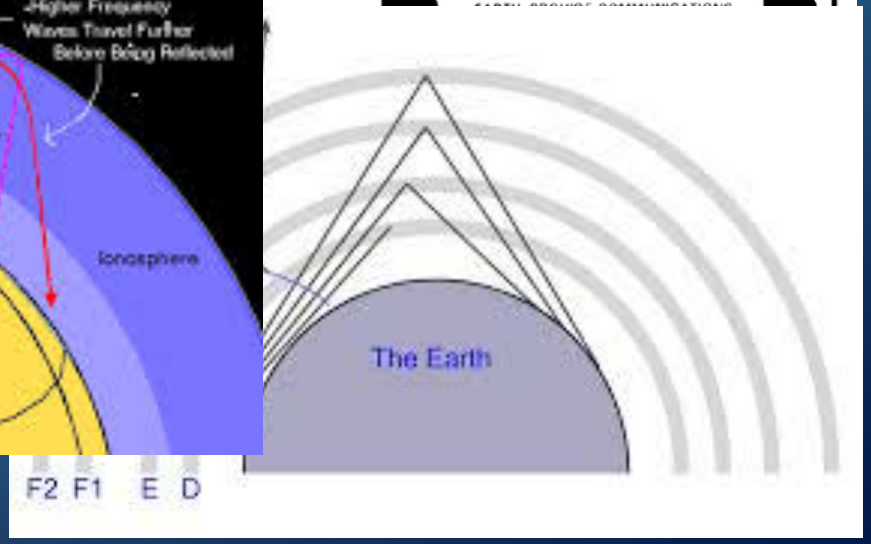
Typical Conceptual Diagrams for HF Propagation



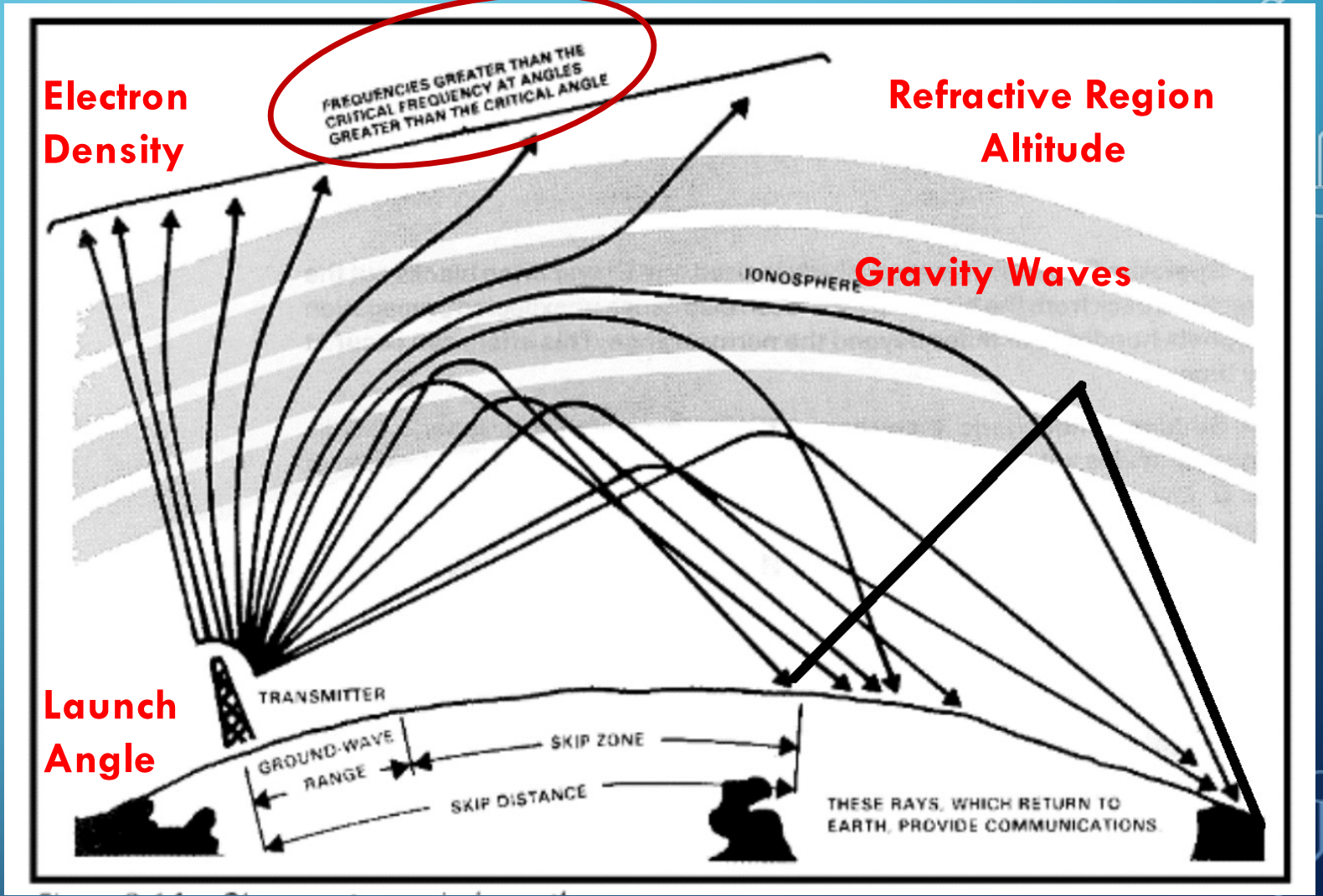








Conceptual diagrams help us visualize the effects of various parameters and processes on radio wave propagation, but don't provide numbers.



HTTP://WWW.GLOBALSECURITY.ORG/INTELL/LIBRARY/POLICY/ARMY/FM/24-18/24180016.GIF

Some diagrams show launch angle and propagation distance with numbers, but not for antennas I have.

Dipole at 100'
4-el Yagi at 160'

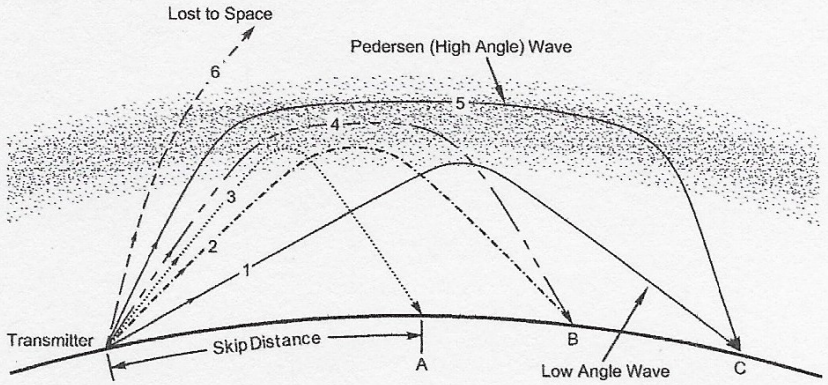


Fig 24—Very simplified smooth-Earth/ionosphere diagram showing how the ground range from transmitter to receiver can vary as the elevation angle is gradually raised. The Pedersen wave, launched at a relatively high angle, has the same ground range as the low-angle wave #1, but is weaker because it travels for a long distance in the ionosphere.

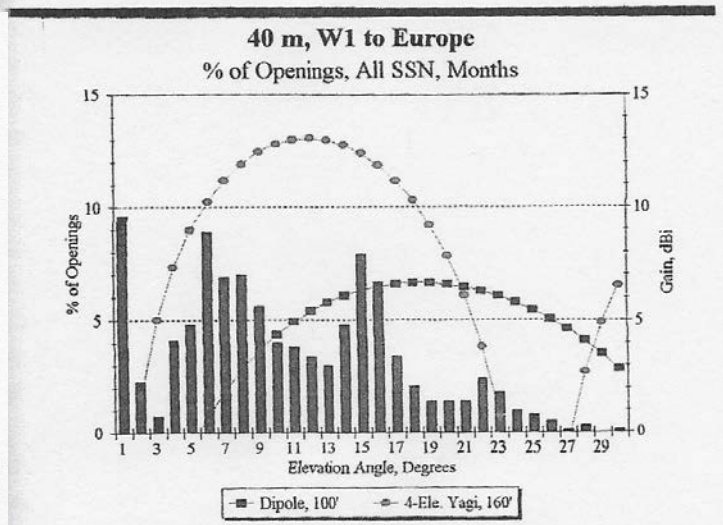


Fig 36—40-meter graph of the percentage of all openings from New England to Europe versus elevation angles, together with overlays of elevation patterns over flat ground for a 100-foot high dipole and a large 4-element Yagi at 160 feet. Achieving gain at very low elevation angles requires very high heights above ground.

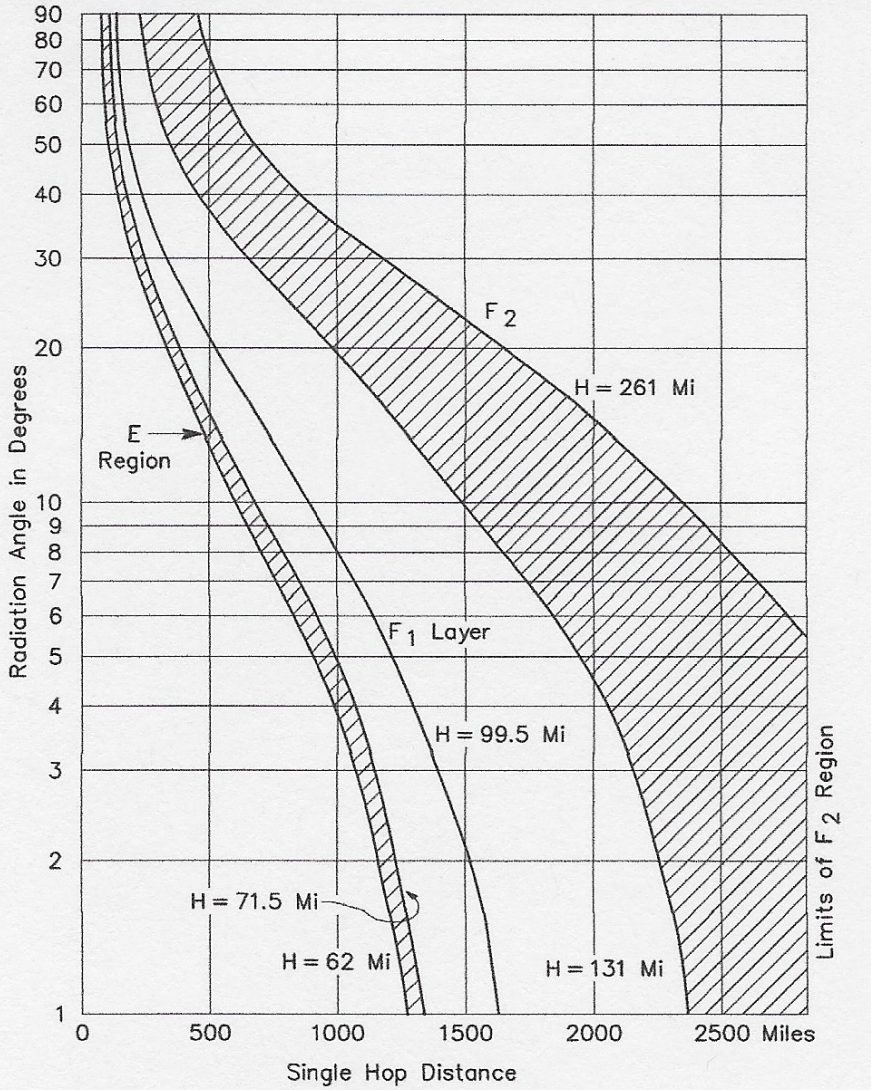
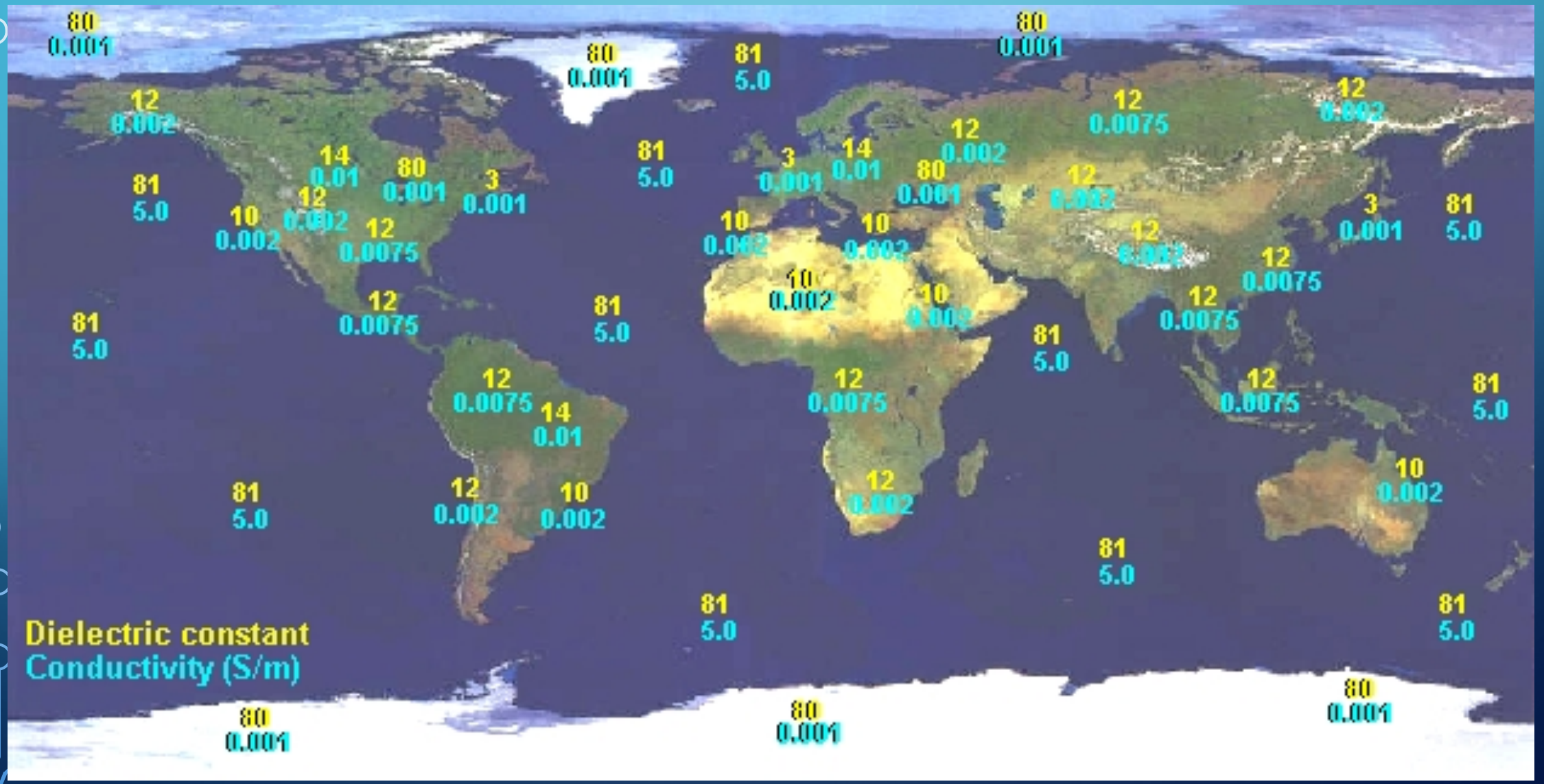


Fig 28—Distance plotted against wave angle (one-hop transmission) for the nominal range of heights for the E and F2 layers, and for the F1 layer.

ARRL ANTENNA BOOK

Ground and ocean characteristics also affect propagation.

From AstroSurf.com http://www.astrosurf.com/luxorion/qsl-hf-tutorial-nm7m6.htm



QUESTION

- There are many conceptual diagrams about propagation
- And WSPR is intended for propagation studies

- How could I use WSPR to bring some numbers to the concepts in a simple format that improves my understanding of propagation?

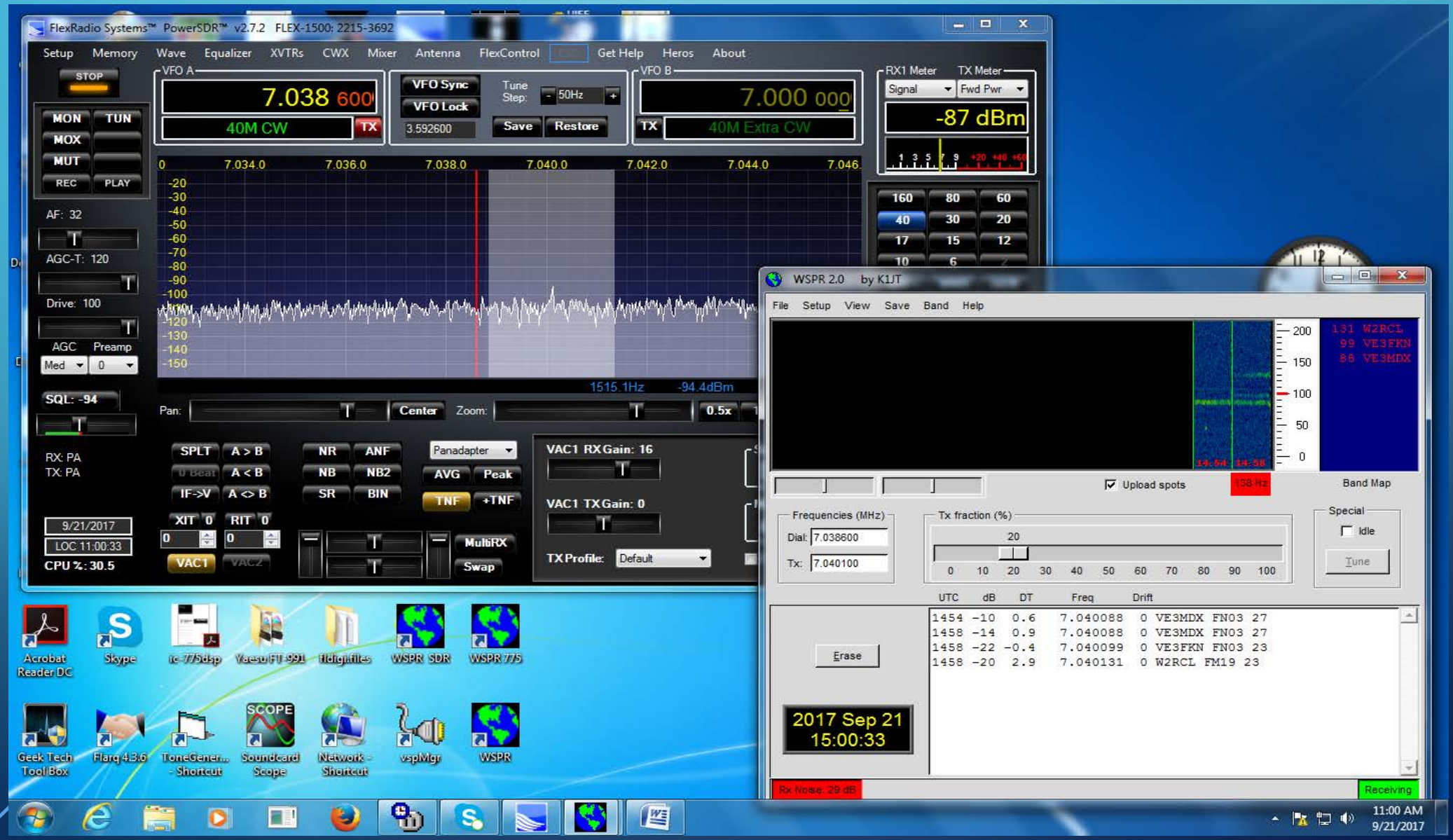
PROCEDURE

- Power output is one variable that is easily changed. Power levels used:

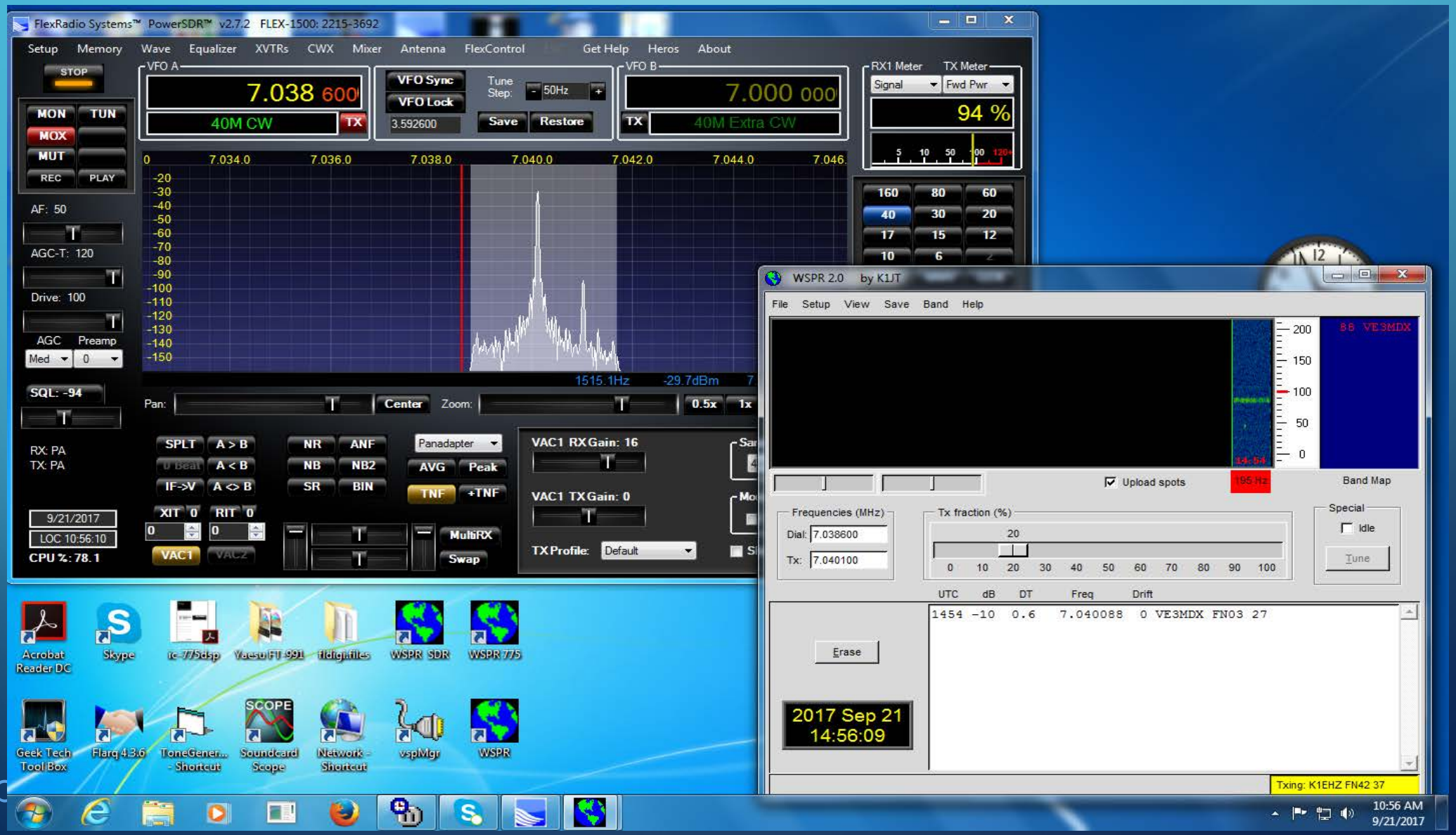
  100mw, 200mw, 500mw, 1w, 2w, 5w, 10w, 20w and 50w.

- WSPR signals were transmitted on 40m for 24 hours at each power level.
- Unique spots and total spots per 24 hours were downloaded from WSPRNet.org.
- Unique spot reports show one spot per station per 24 hours, and include azimuth plus other usual parameters in total spot data files.
- 24-hour runs were repeated on all power levels except 50w, and not necessarily on successive days in an effort to capture diverse ionosphere conditions.

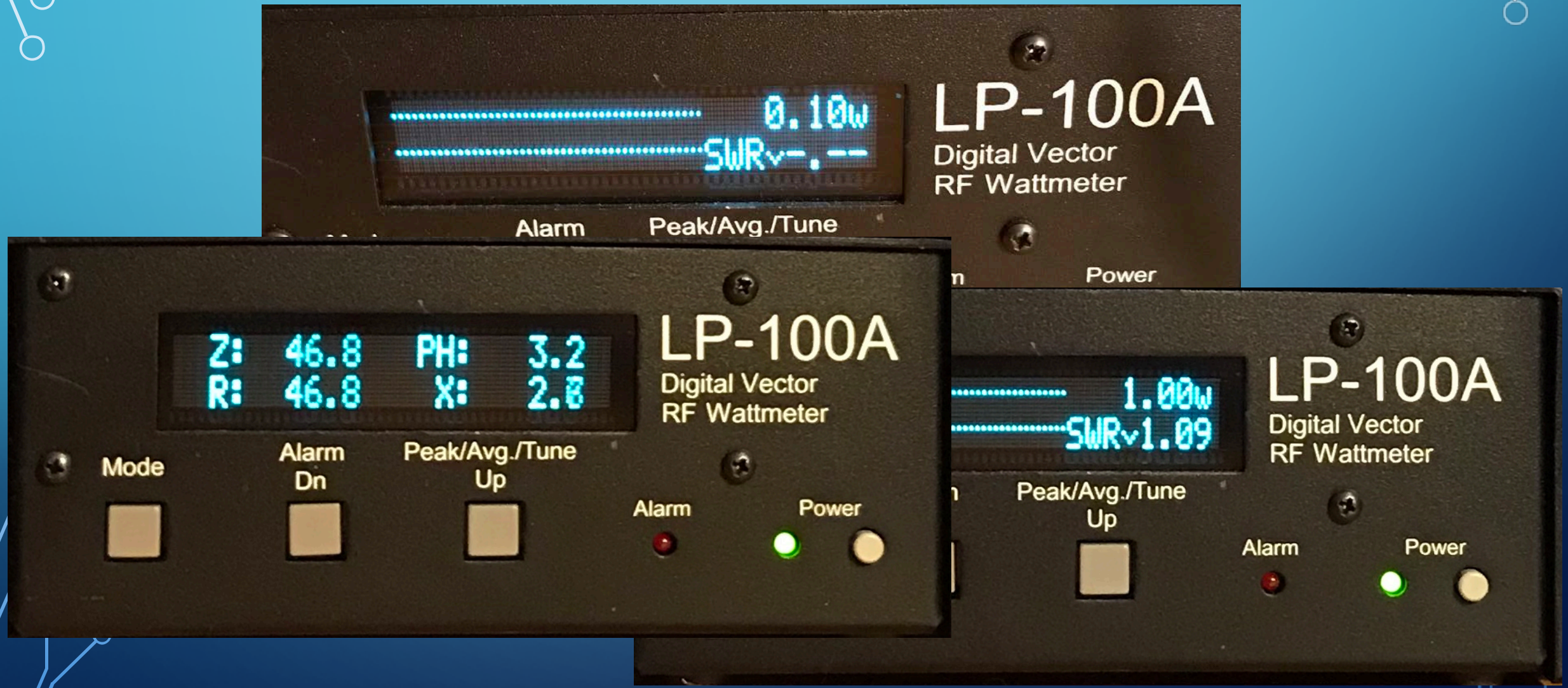
FLEX 1500 & WSPR RECEIVING ON 40M



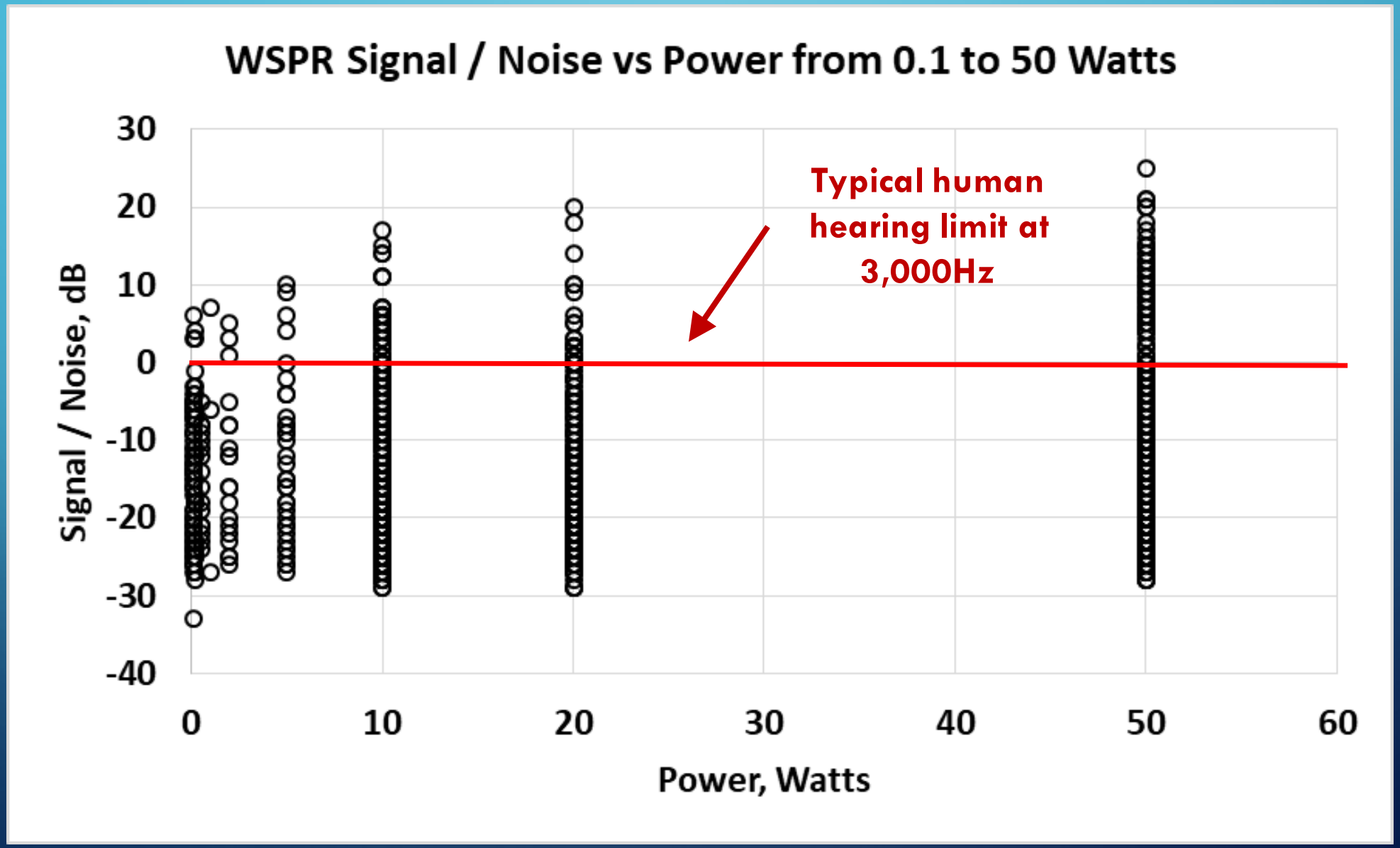
FLEX 1500 & WSPR TRANSMITTING ON 40M



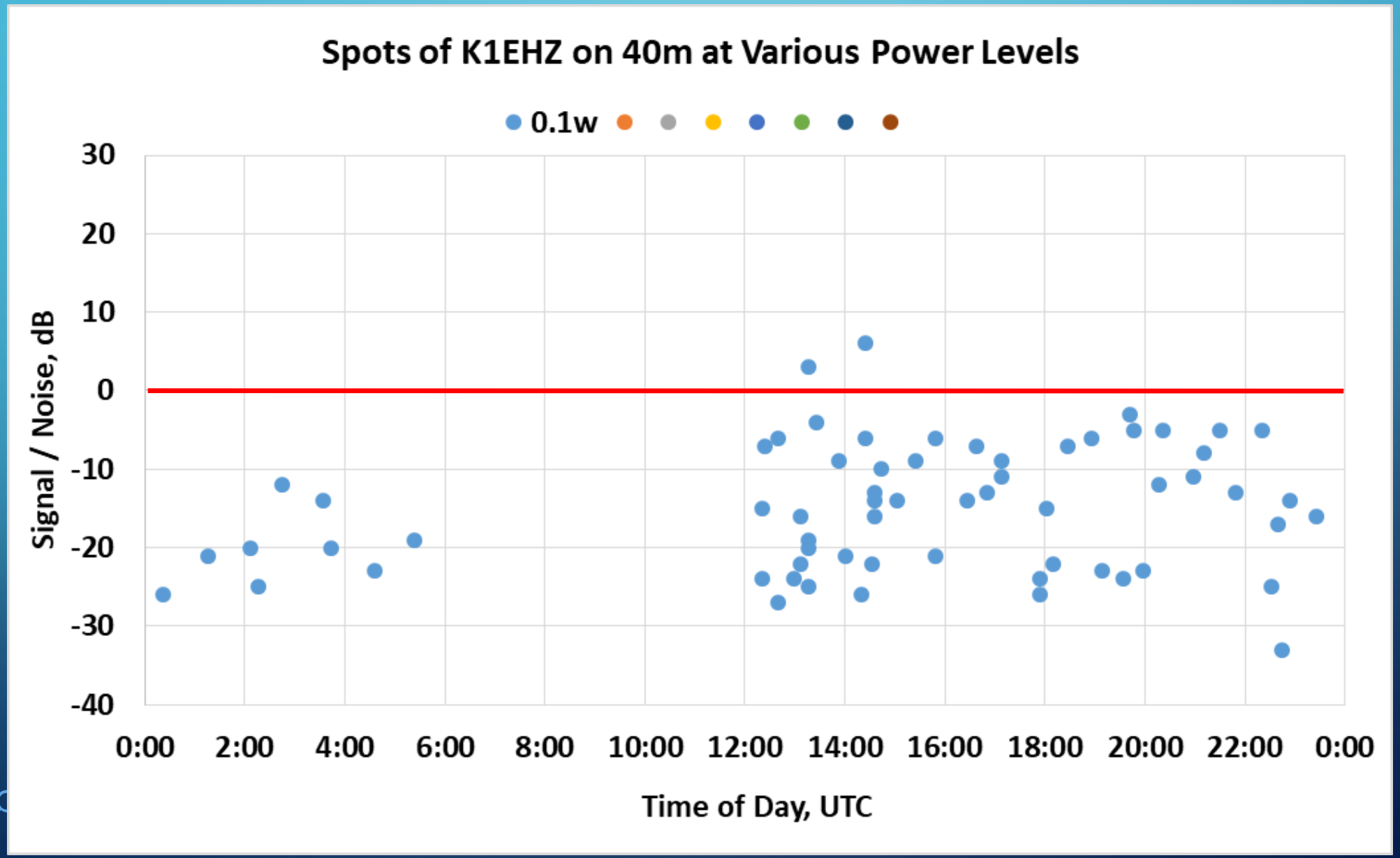
Monitoring Power and Antenna Characteristics



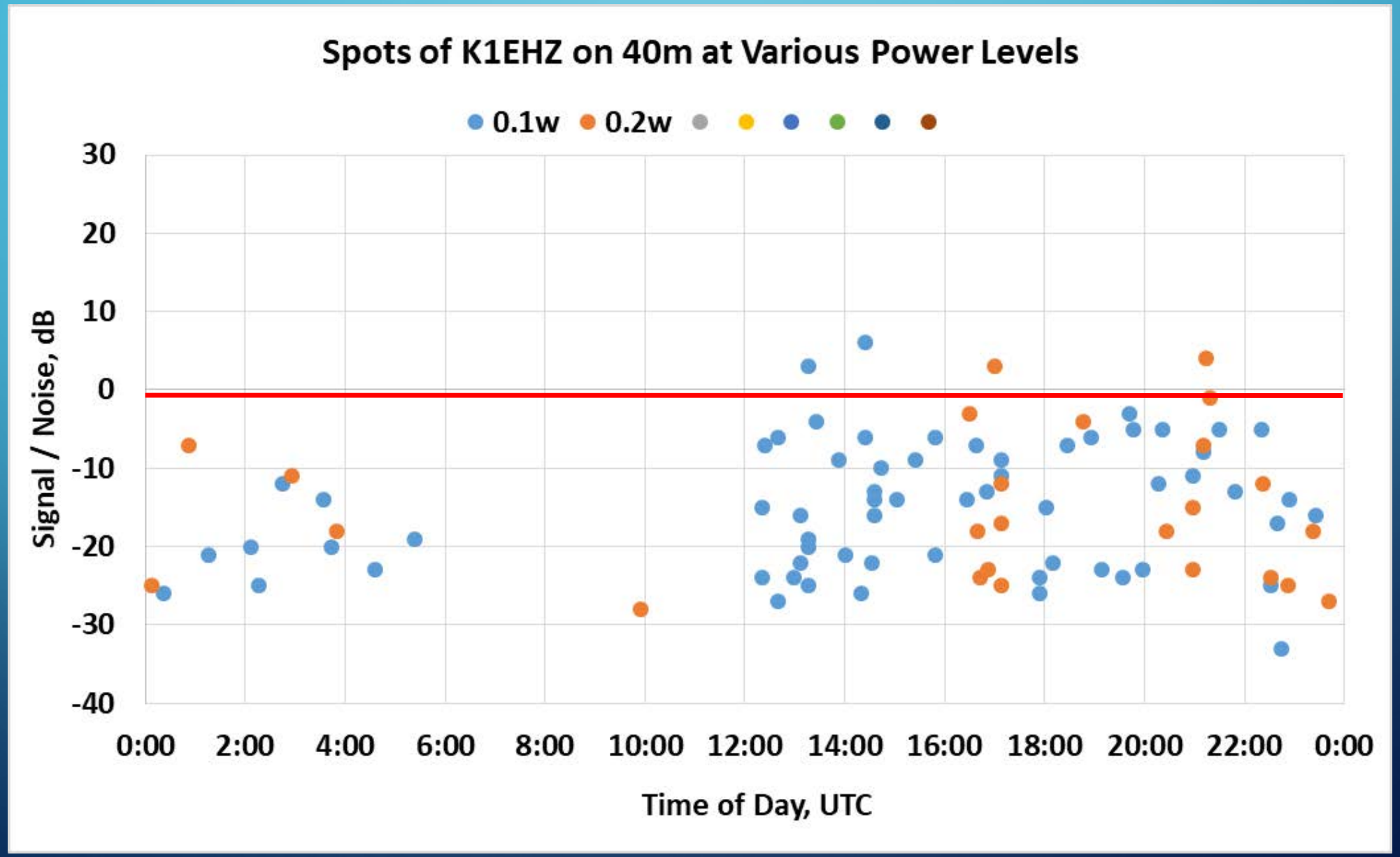
24hr WSPR Propagation at Various Power Levels



24HR WSPR UNIQUE SPOTS (1 SPOT PER STATION PER 24HRS)



24HR WSPR PROPAGATION AT VARIOUS POWER LEVELS



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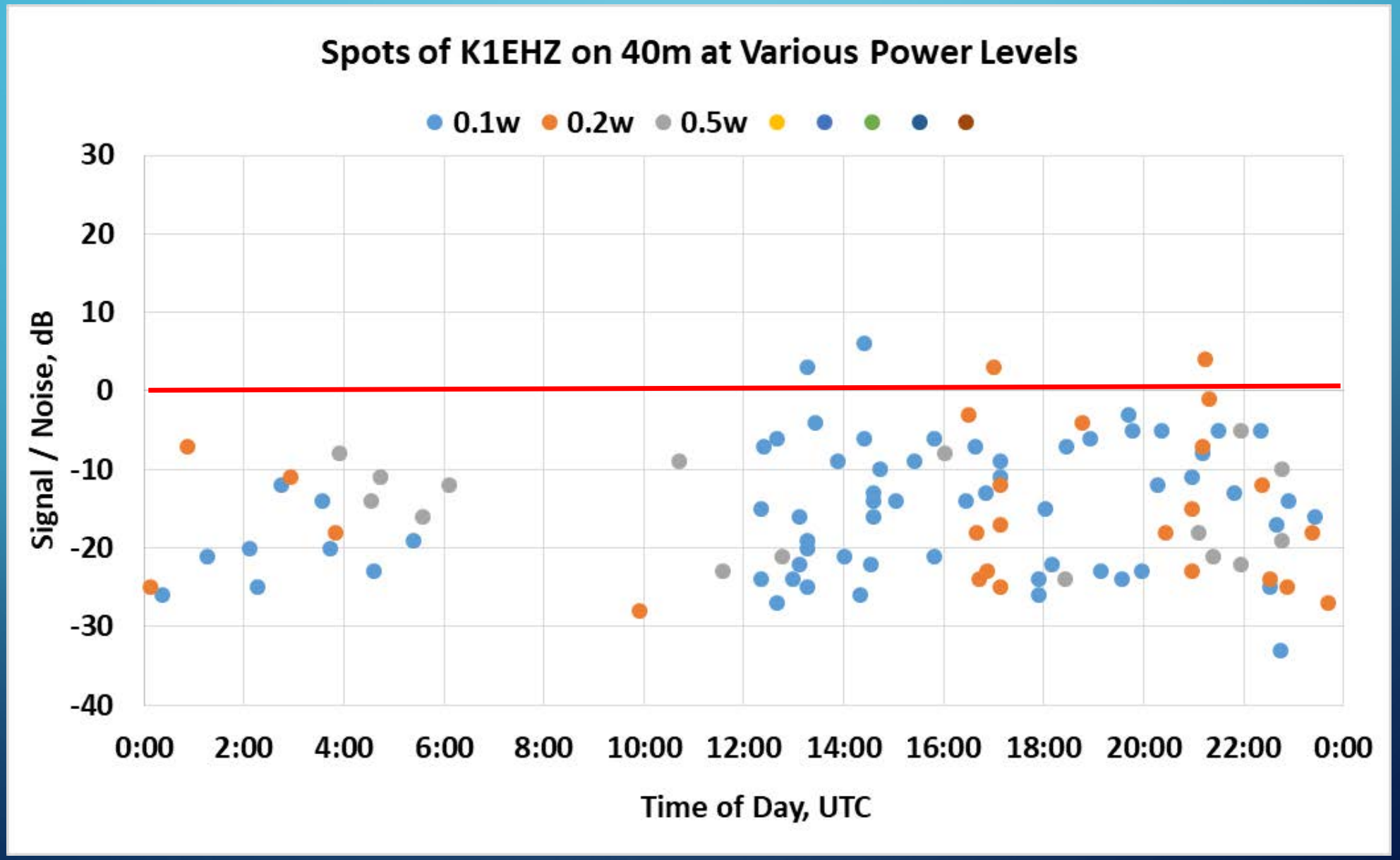

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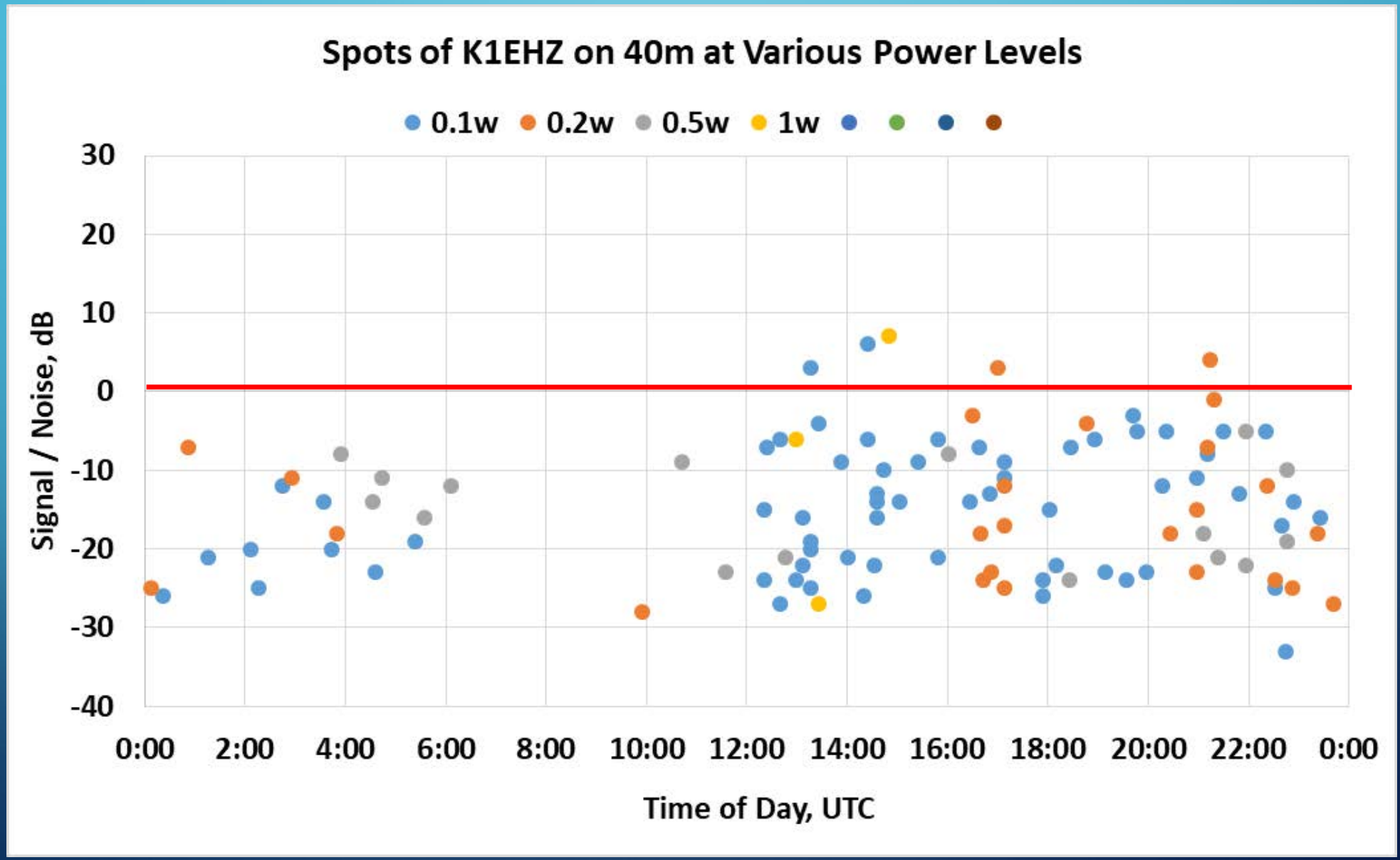

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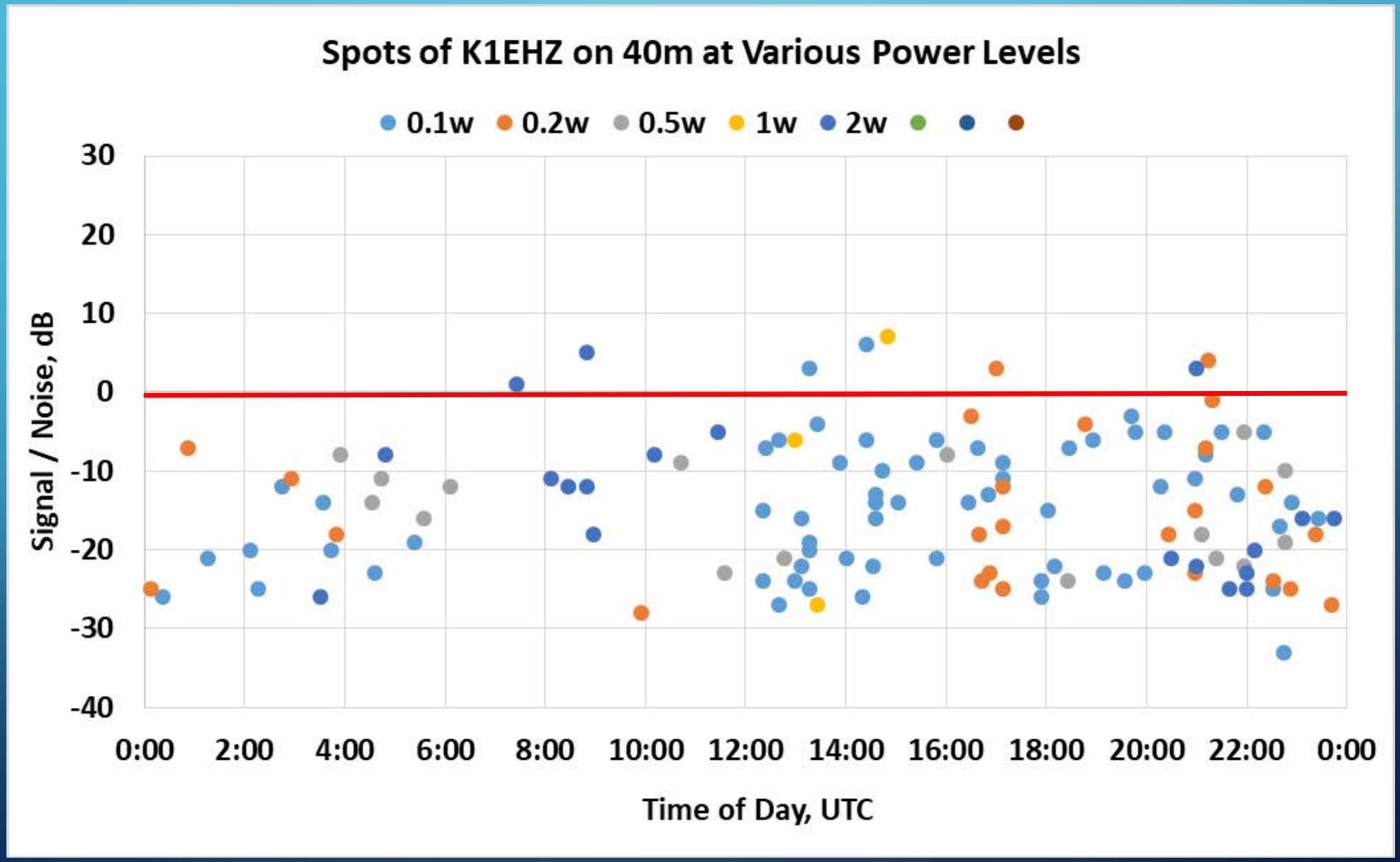

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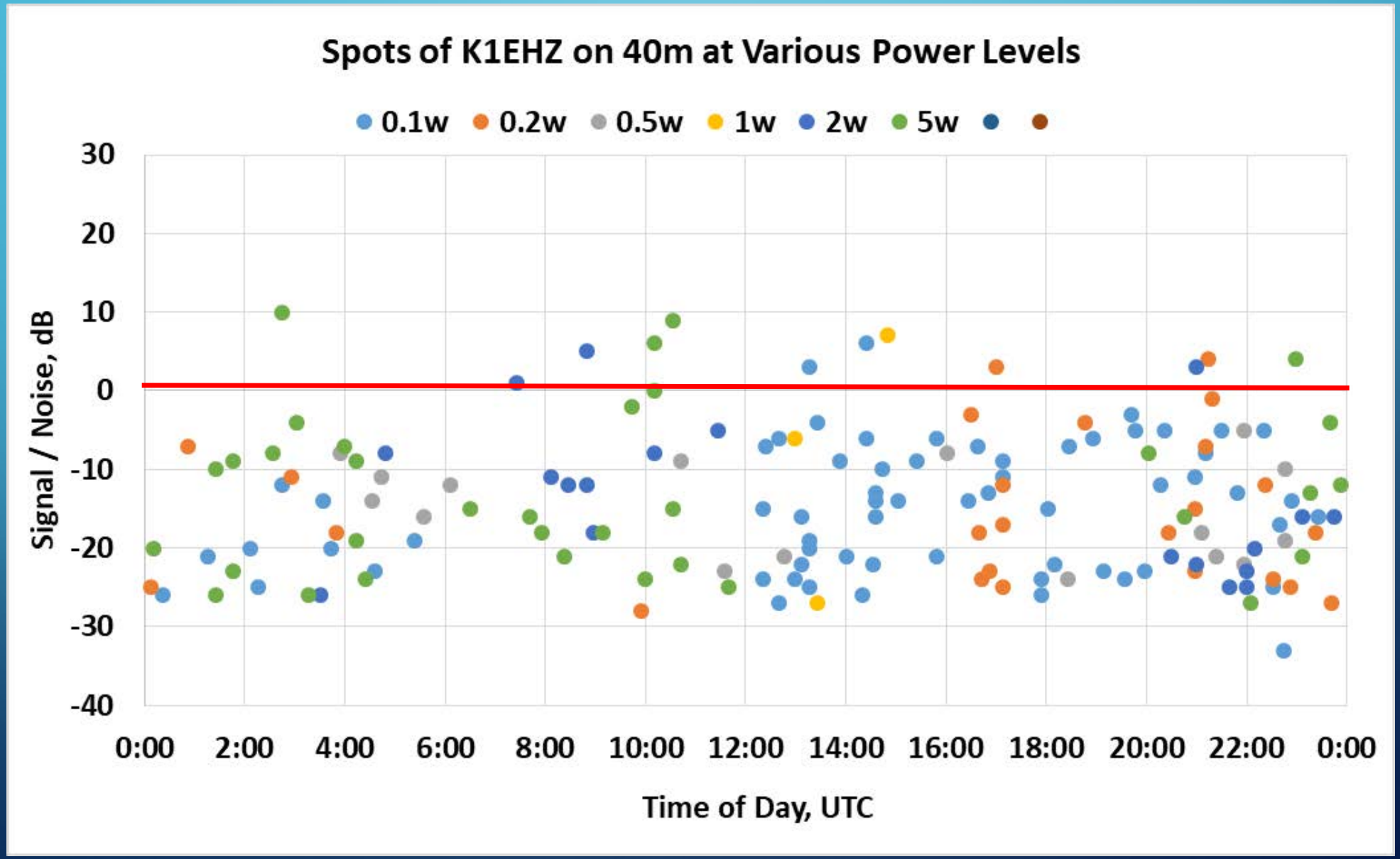

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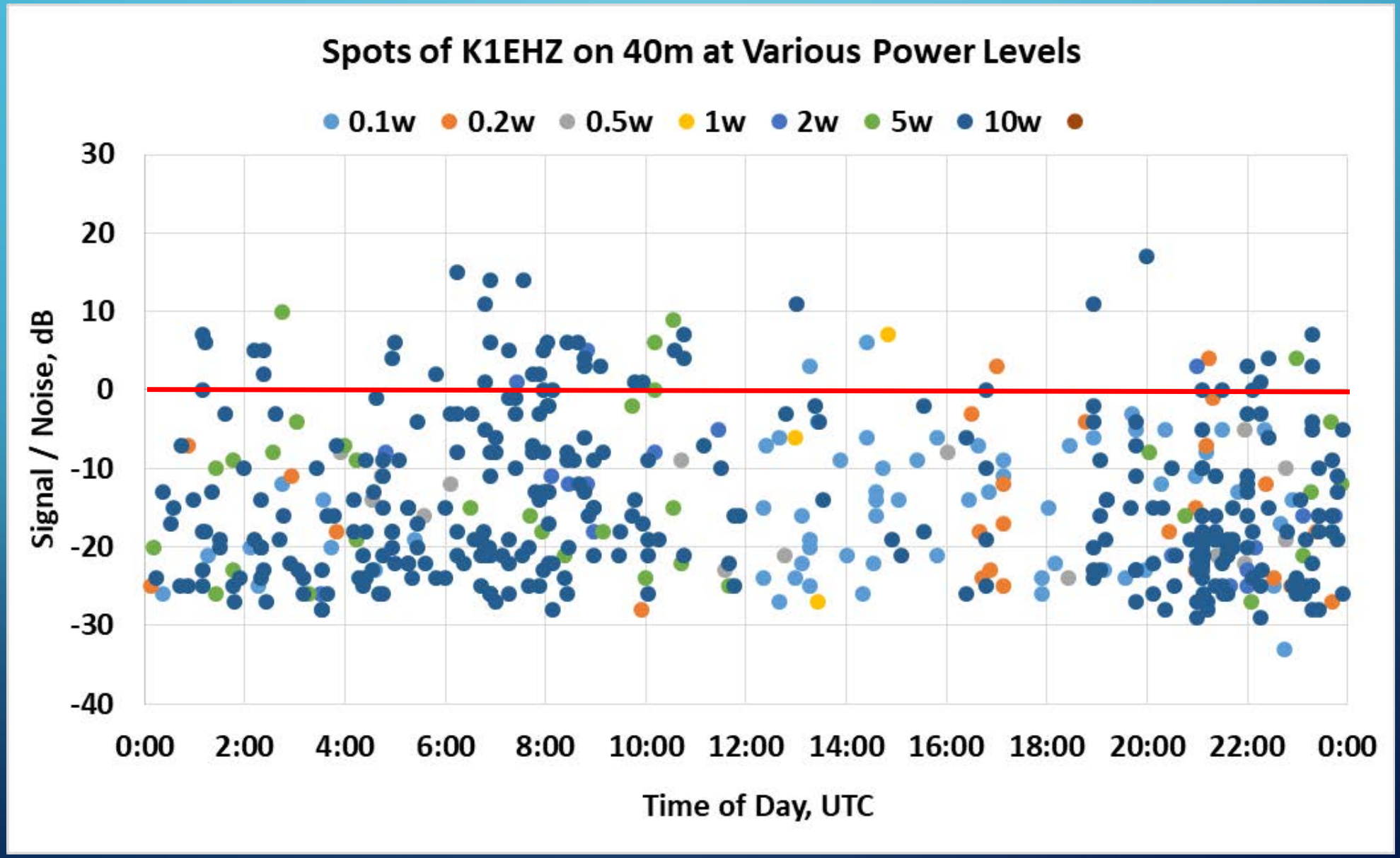

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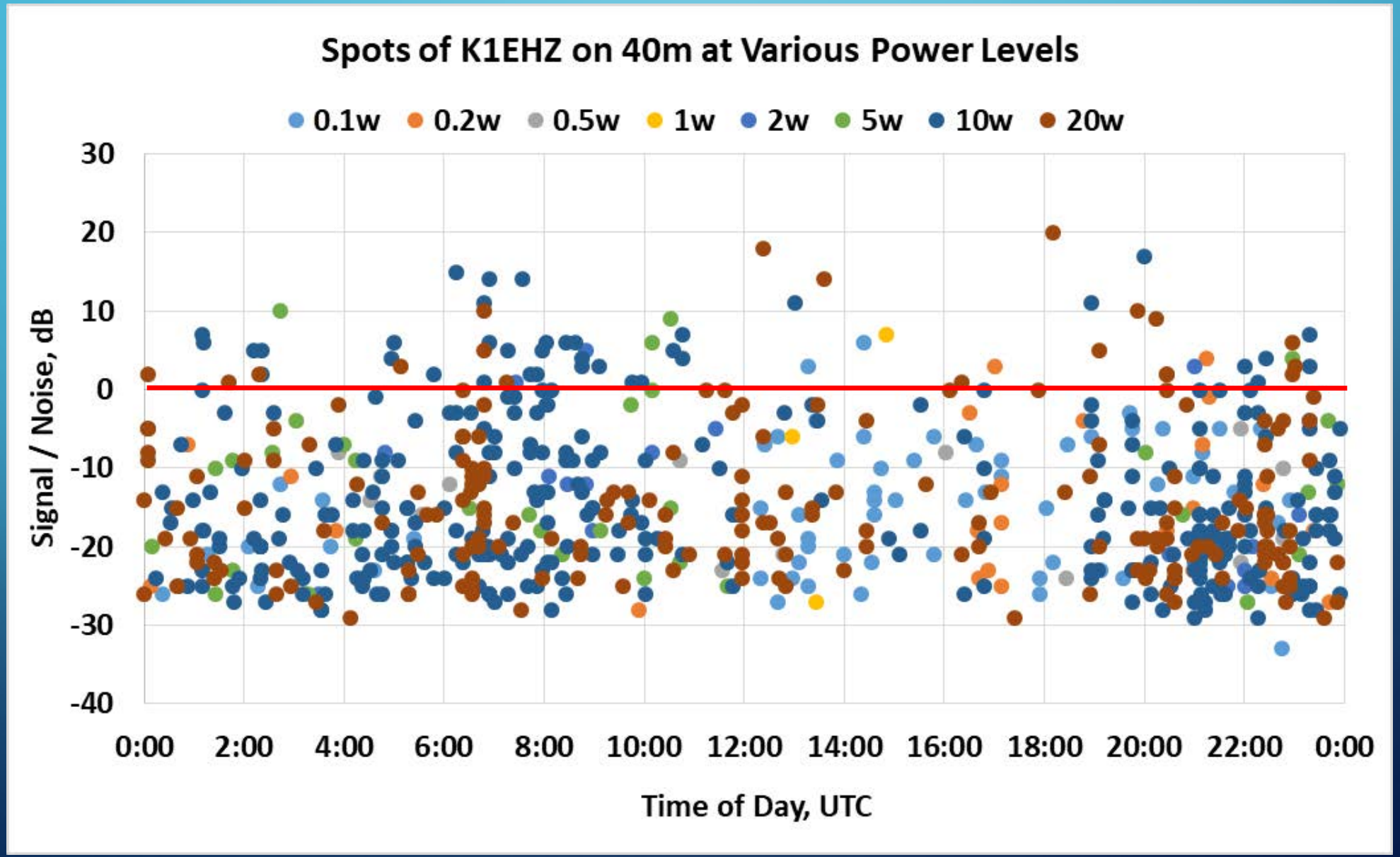

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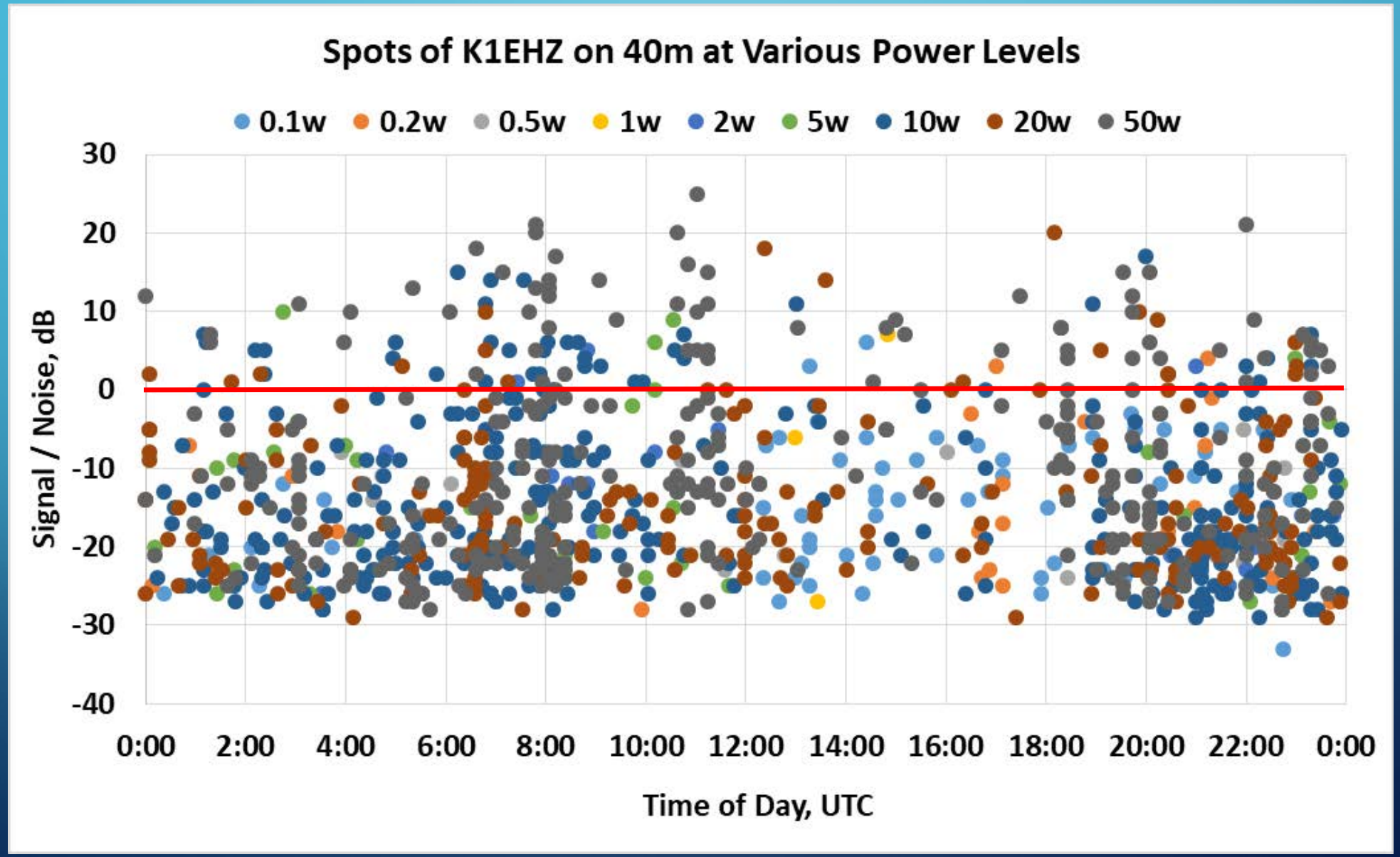


- Increasing power provides more spots and covers greater distance, within limits.

- This result
  - is expected,
  - is not very interesting, and
  - doesn't improve my understanding of propagation.

- A simple model is needed to organize thinking and guide data analysis.
  - Complex ionosphere dynamics are not included in a simple model.

- What information is readily available?
  - WSPR data that include distance, direction, time and signal to noise ratio.
  - Antenna radiation patterns and parameters from an EZNEC model.
  - Ionosphere refractive region altitude and MUF from ionograms.

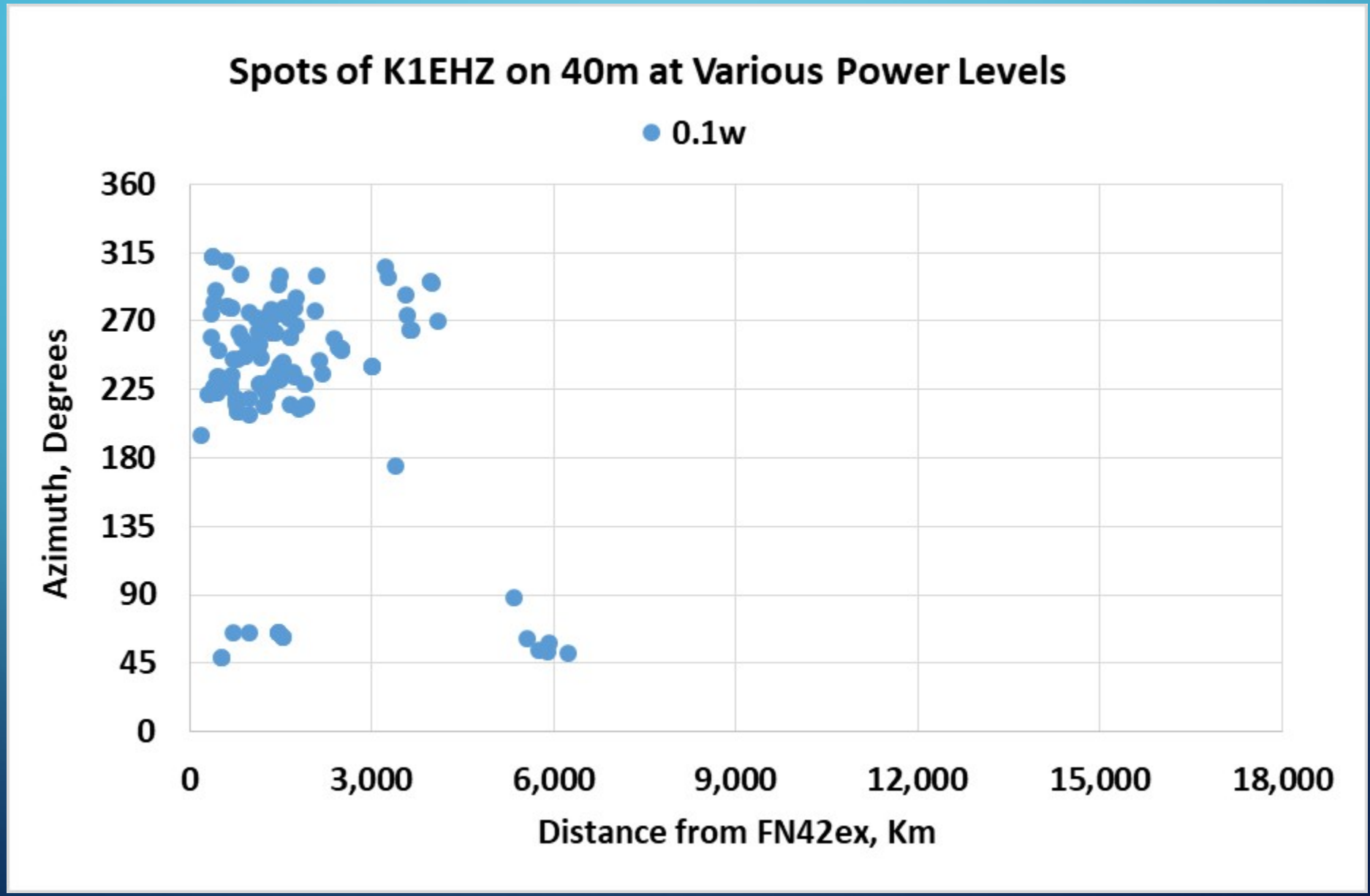
- **Simple, flat Earth geometrical model**
  - Analytical model, not a predictive model.
  - Patterns and relationships are more important.
  - Precision and accuracy are less important in this context.
  - The data are the data – How did they come to be that way?

Lots of data.

What to focus on?

Start with distance and direction.

DISTANCE AND DIRECTION AT VARIOUS POWER LEVELS



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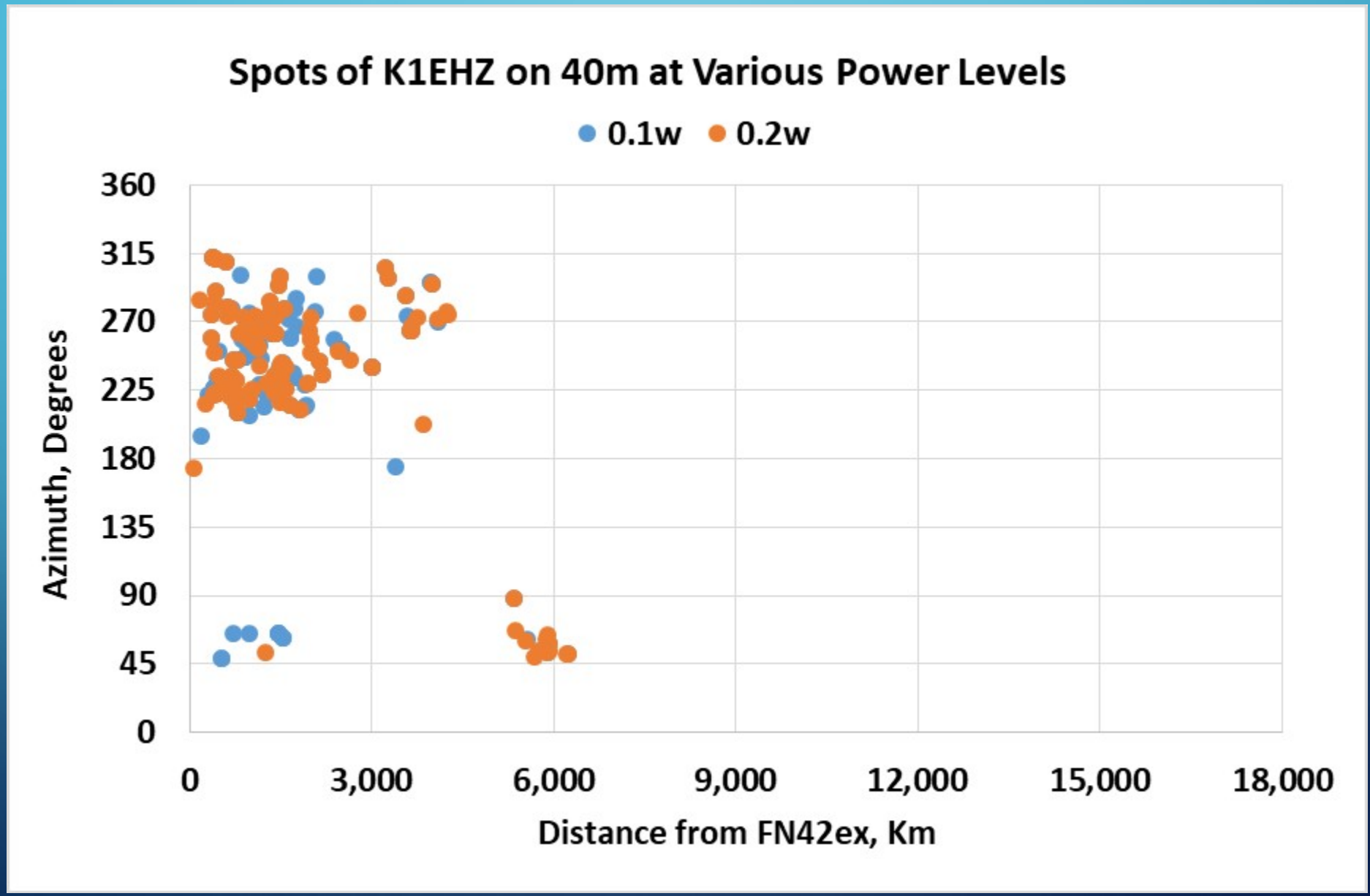

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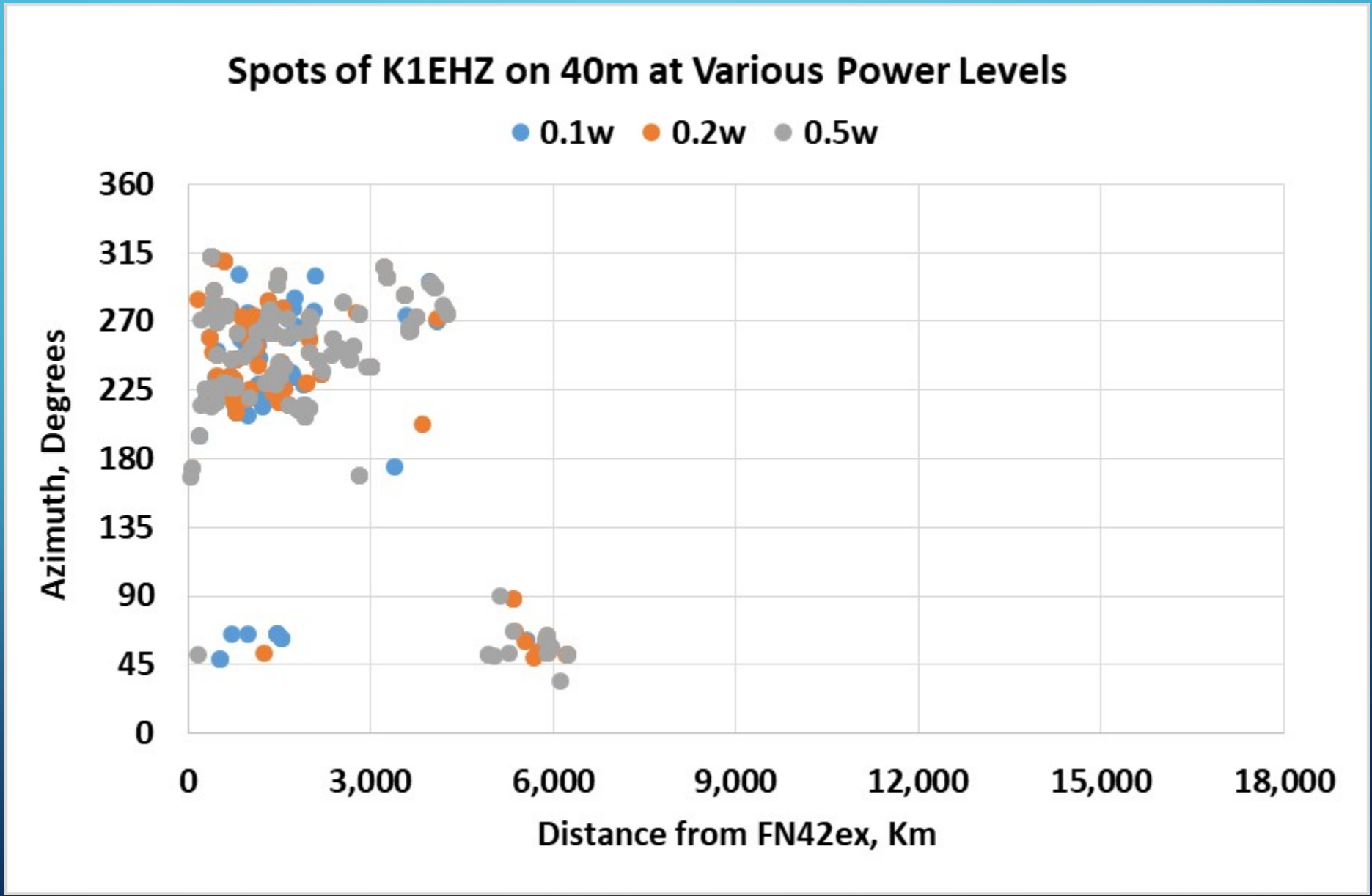

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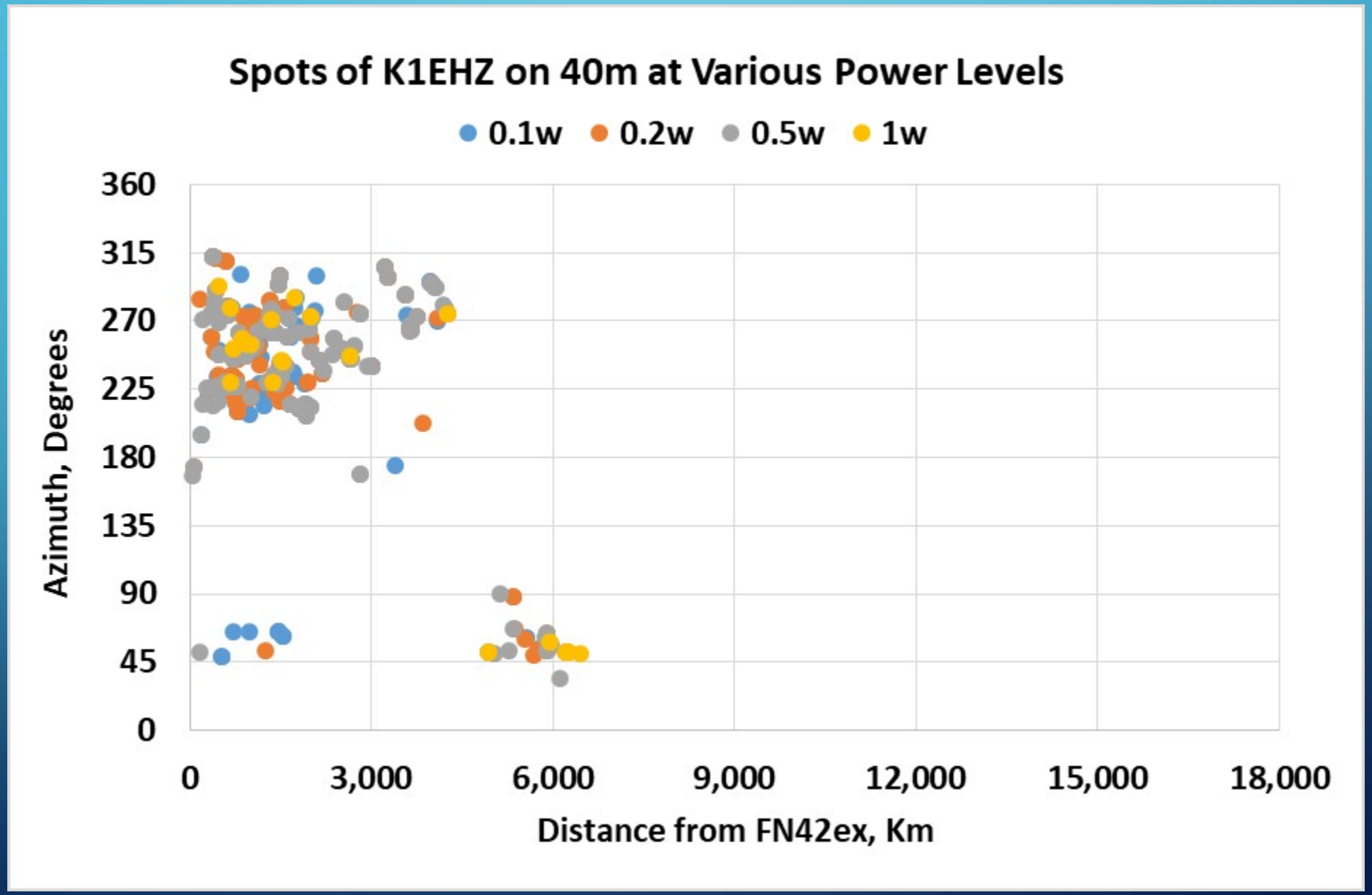

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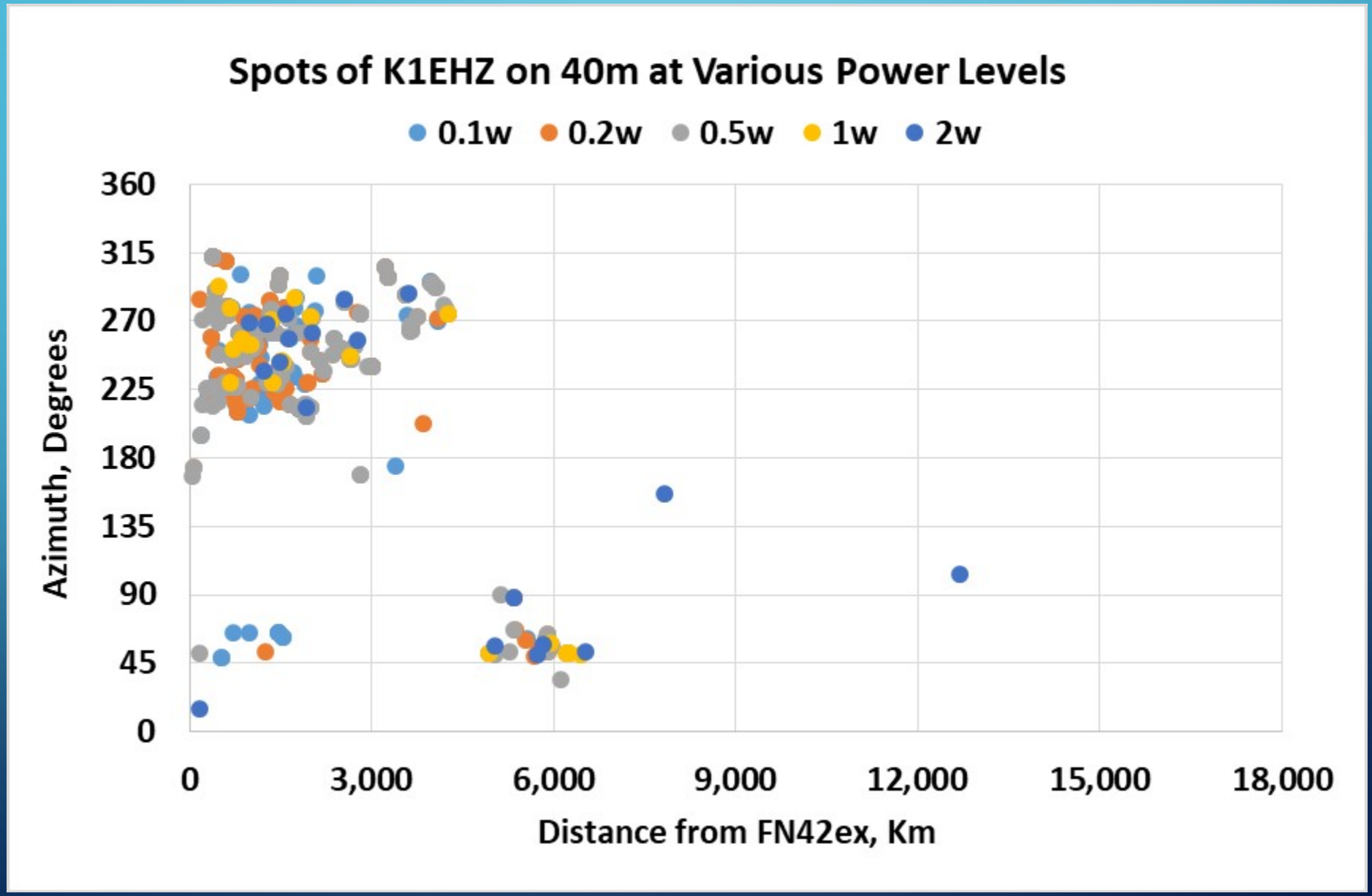

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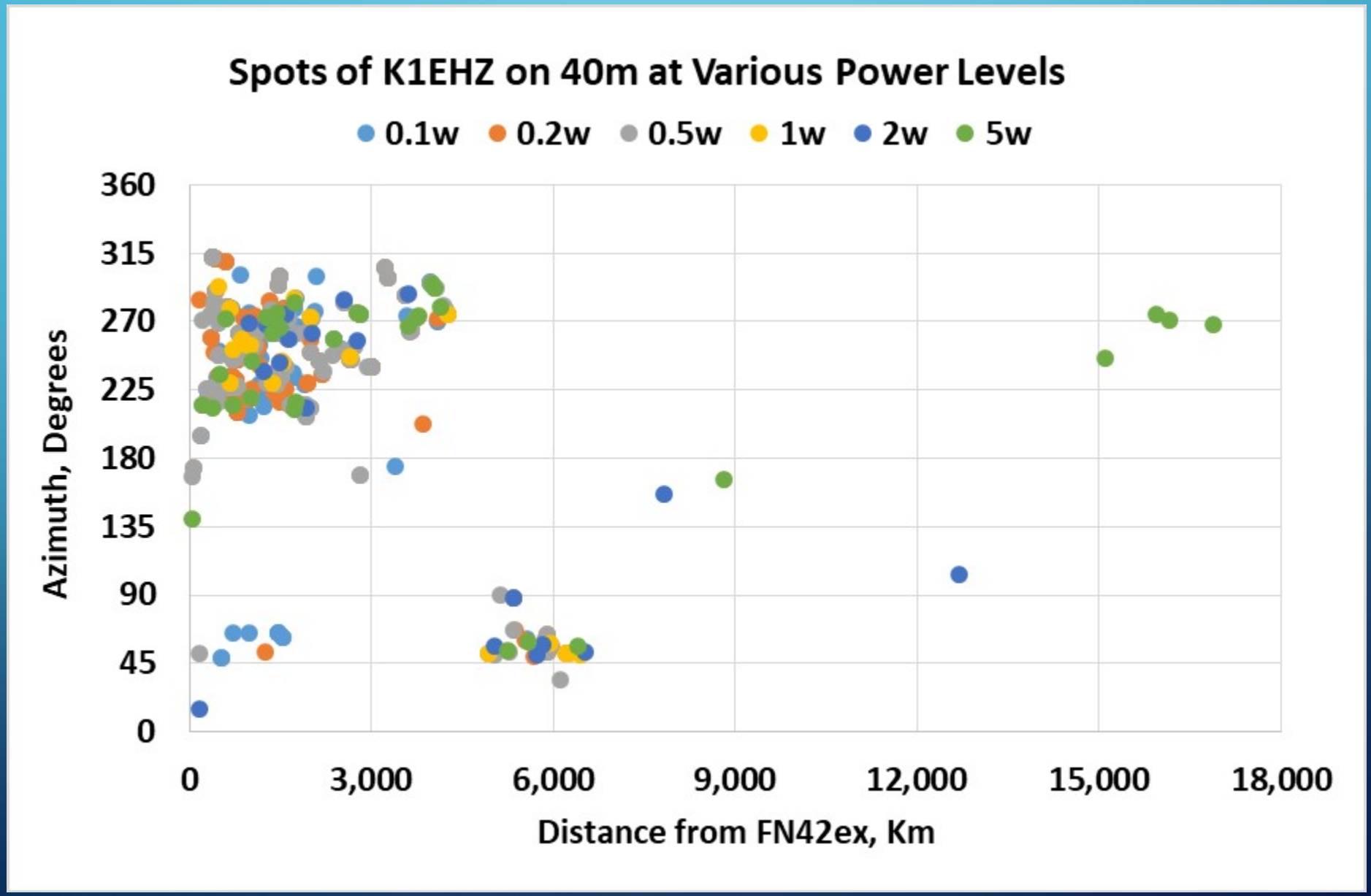

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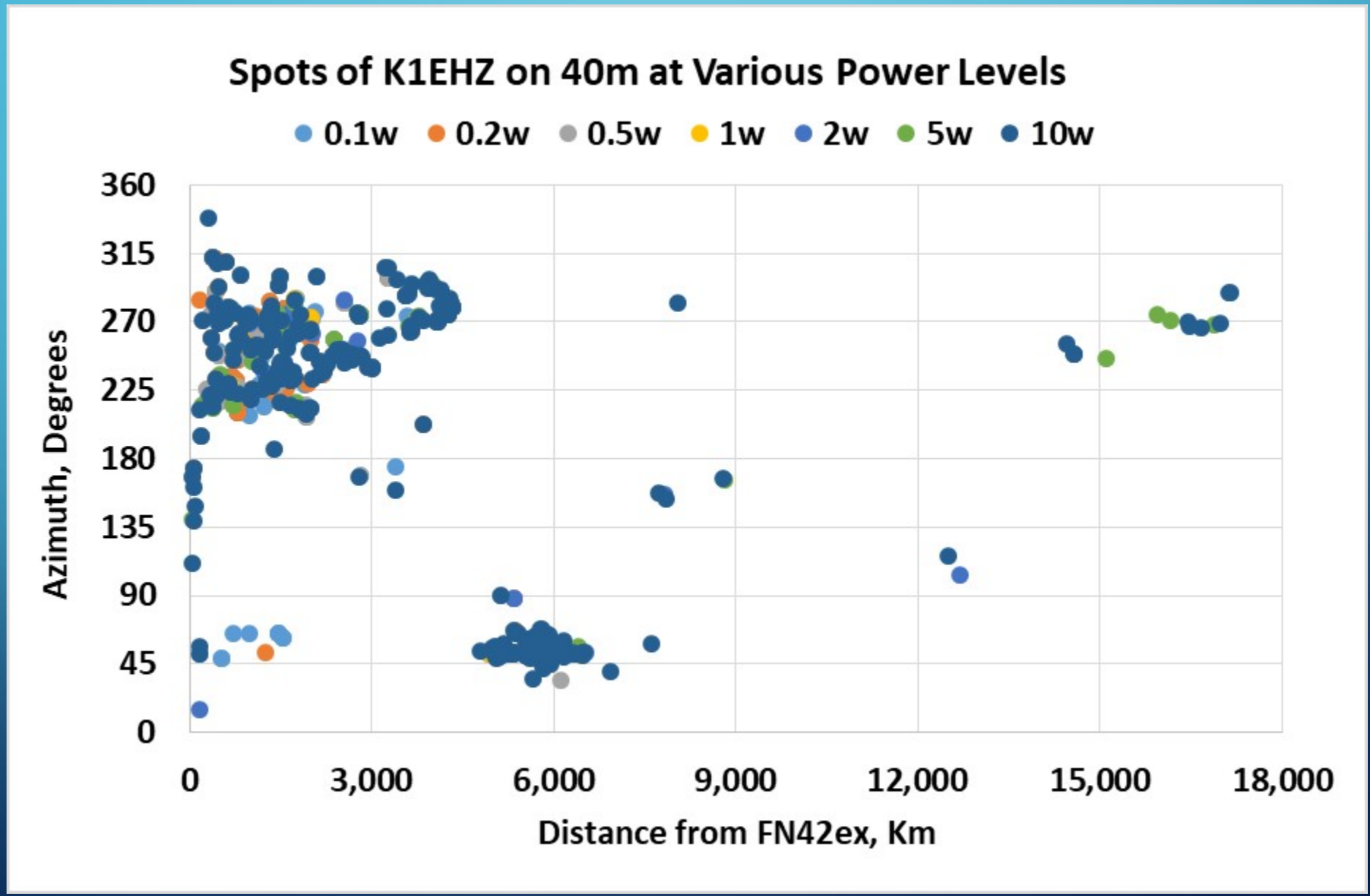

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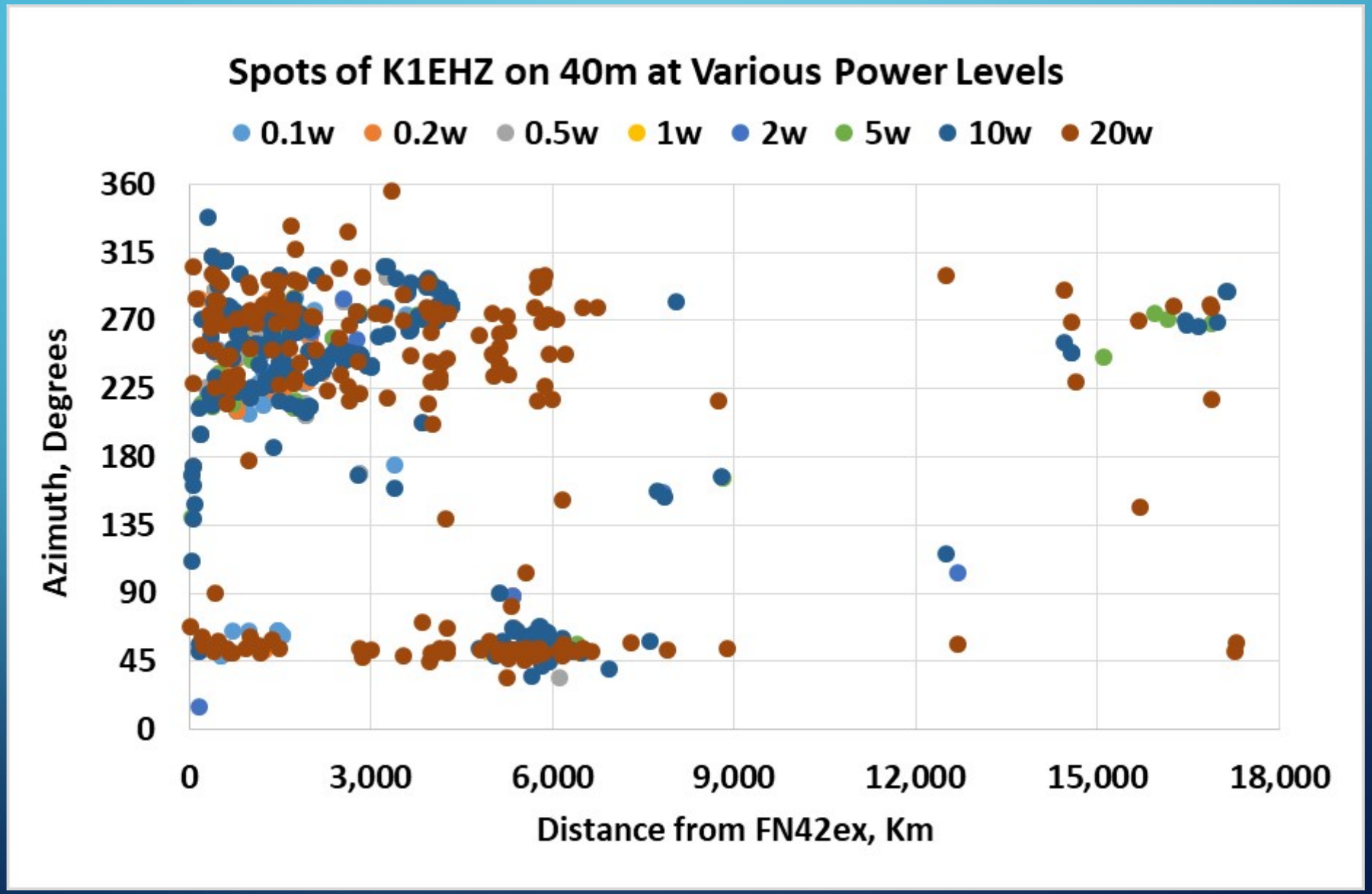
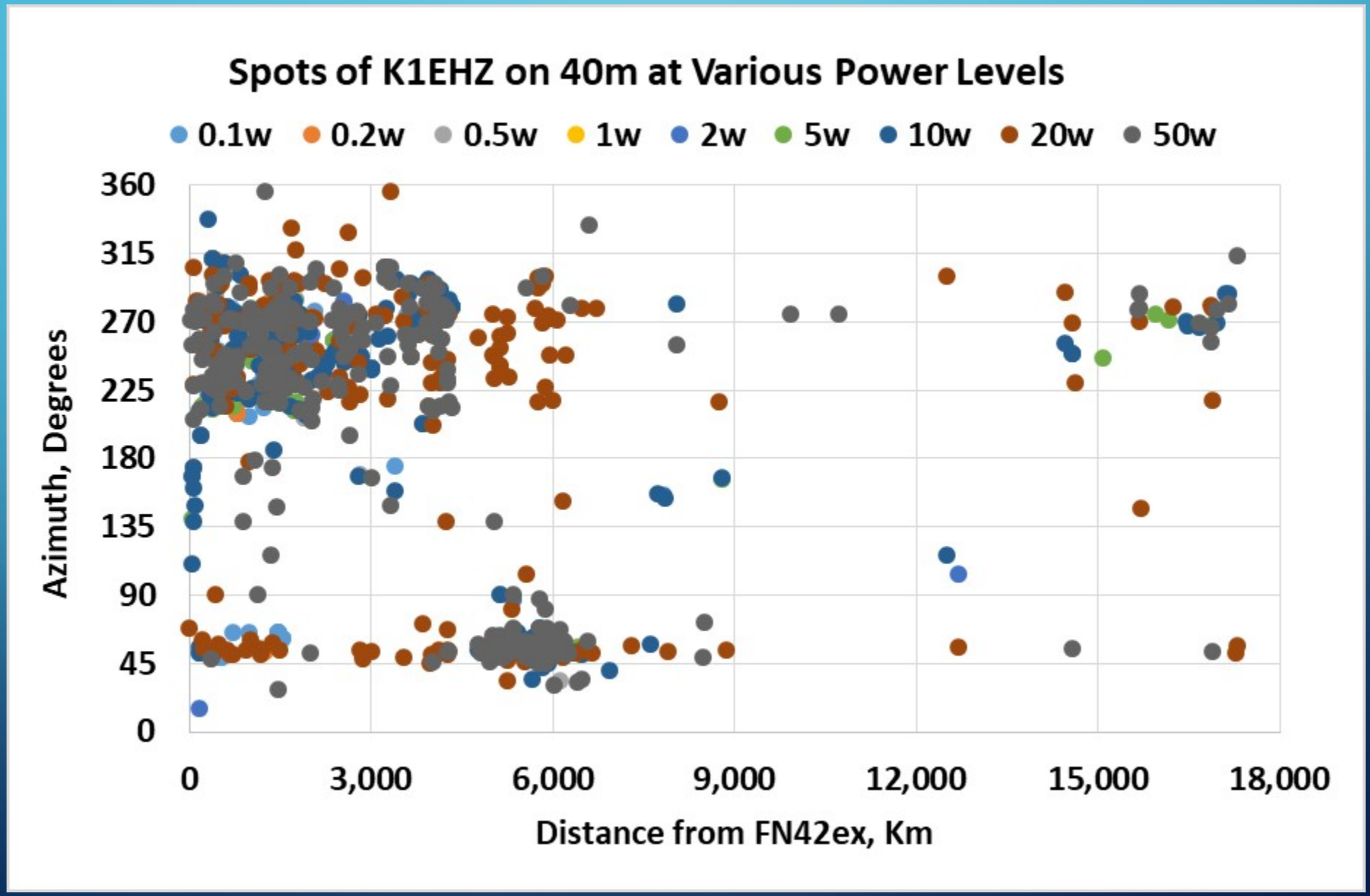
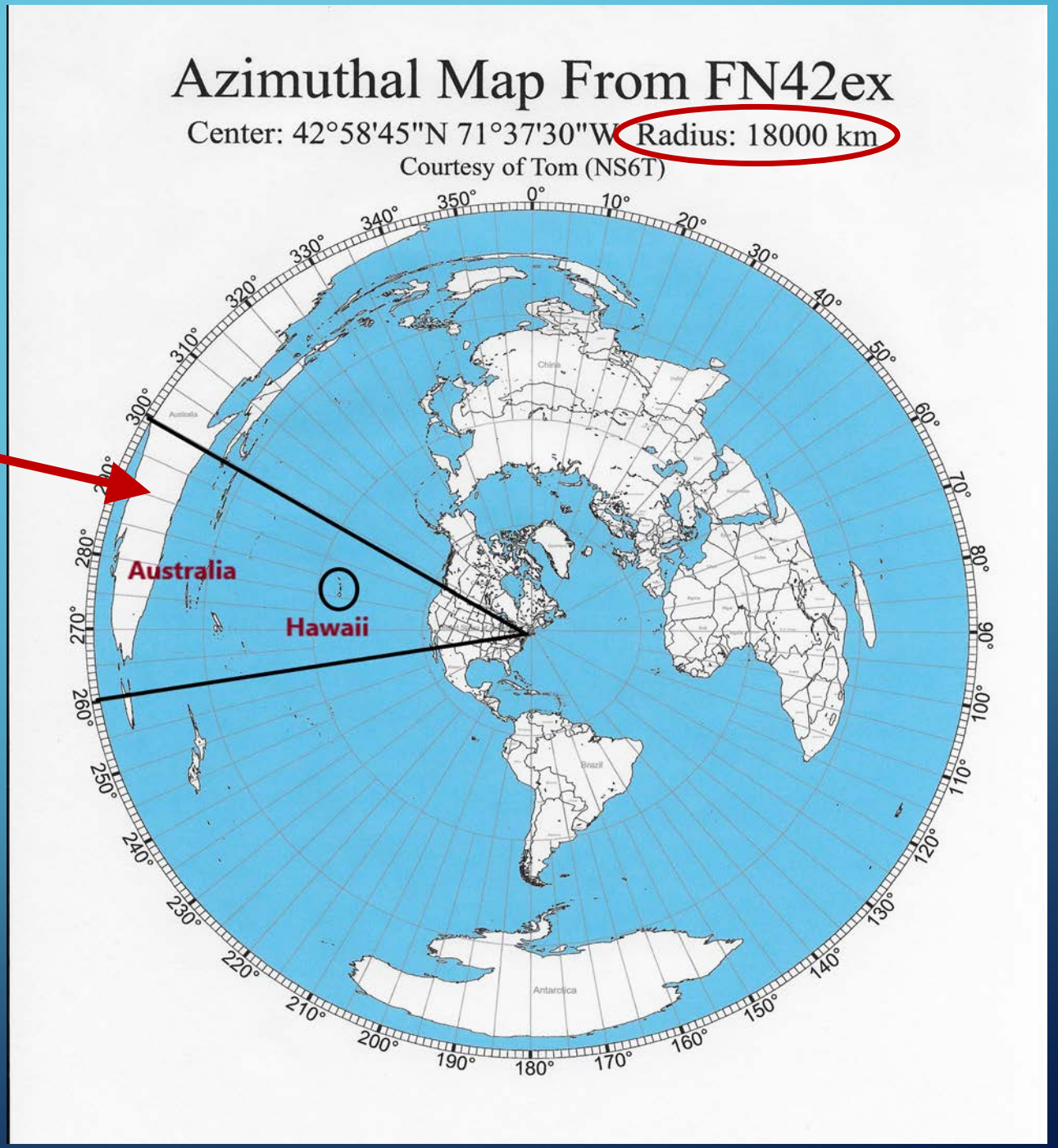


DISTANCE AND DIRECTION AT VARIOUS POWER LEVELS



Longest range for land-based station locations.

Highest probability for interesting results in this general direction.

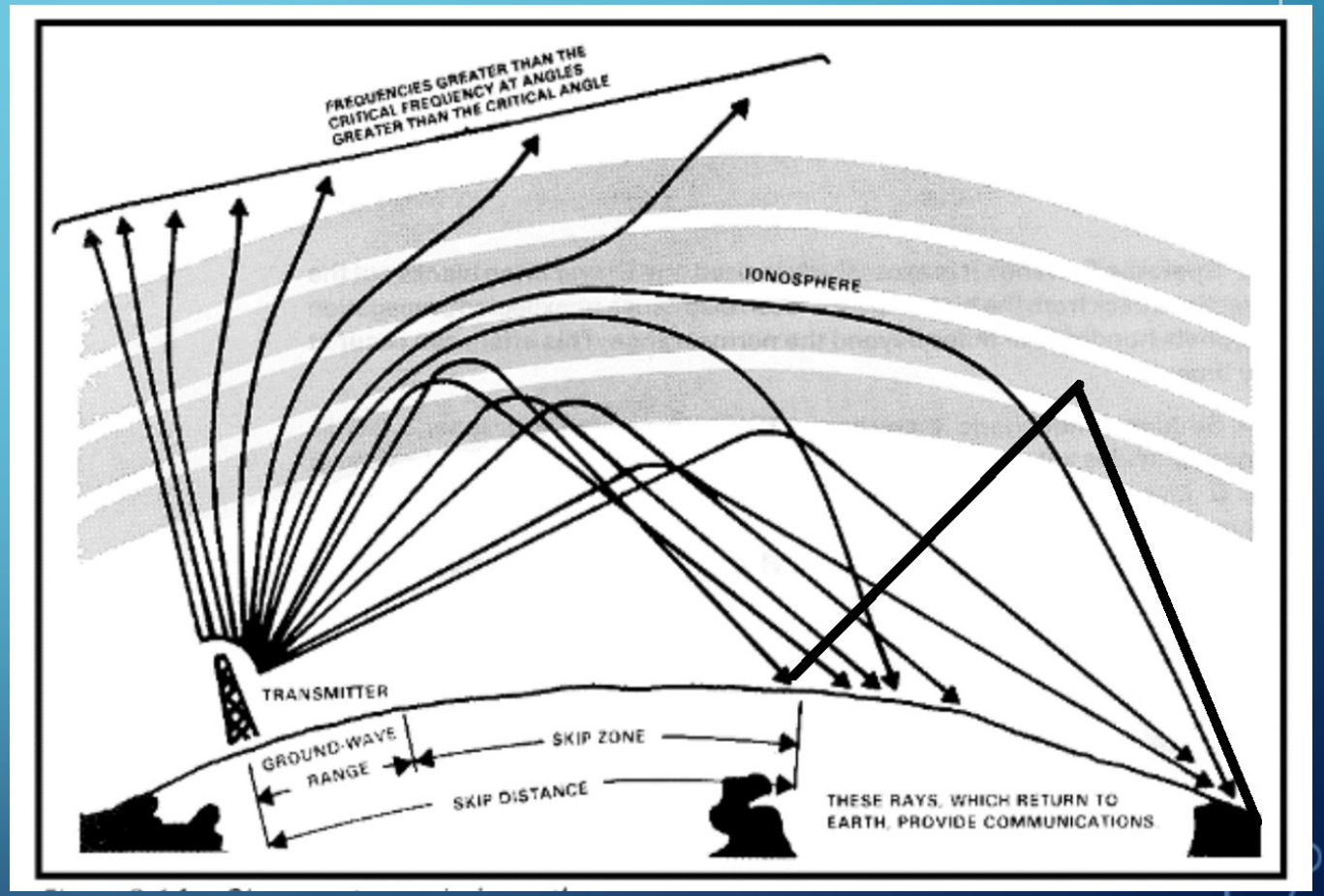


SKYWAVE PROPAGATION

HTTP://WWW.GLOBALSECURITY.ORG/INTELL/LIBRARY/POLICY/ARMY/FM/24-18/24180016.GIF

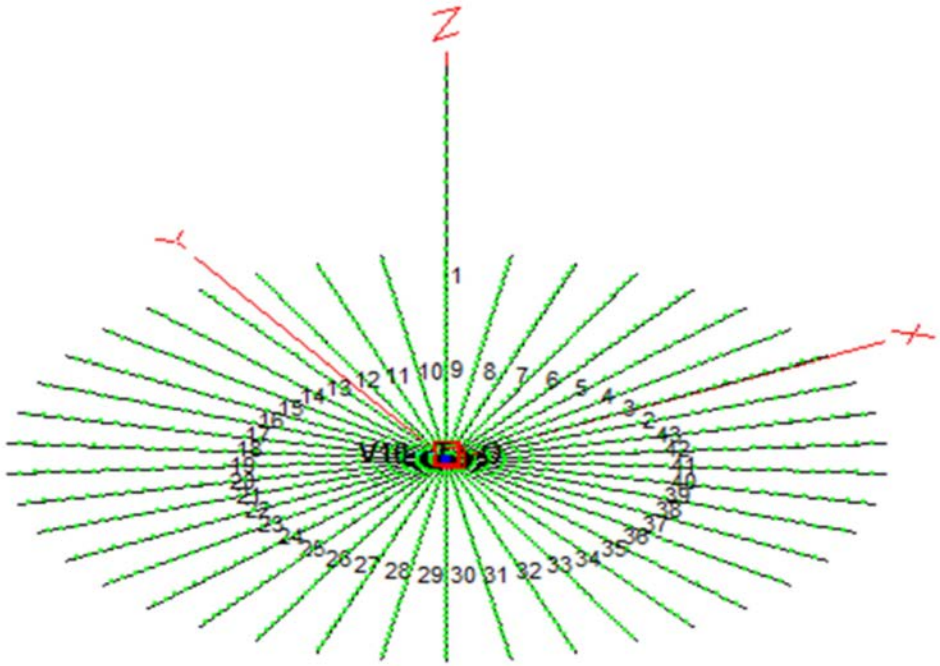
Variables to Consider:

- Power
- MUF
- Launch Angle
- Refractive
- Layer Altitude

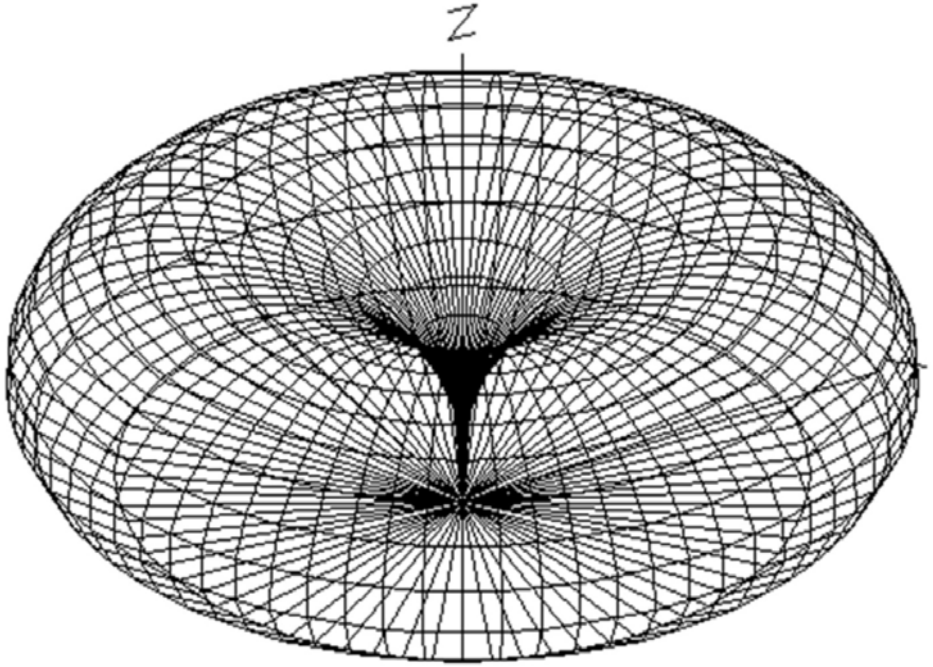


EZNEC MODEL OF THE VERTICAL ANTENNA

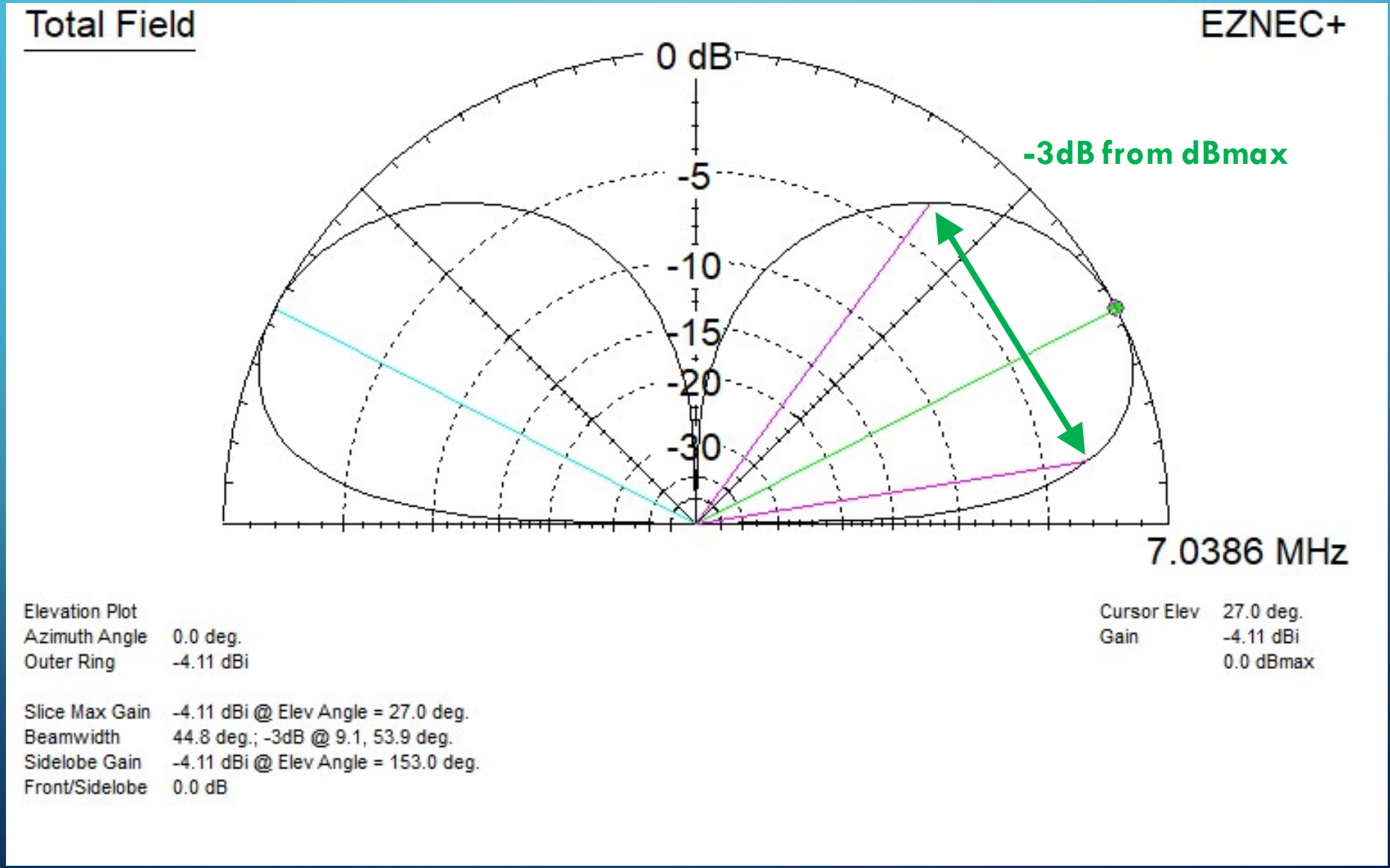
31' VERTICAL WITH 42 RADIALS



3D RADIATION PATTERN



VERTICAL ANTENNA RADIATION ANGLES



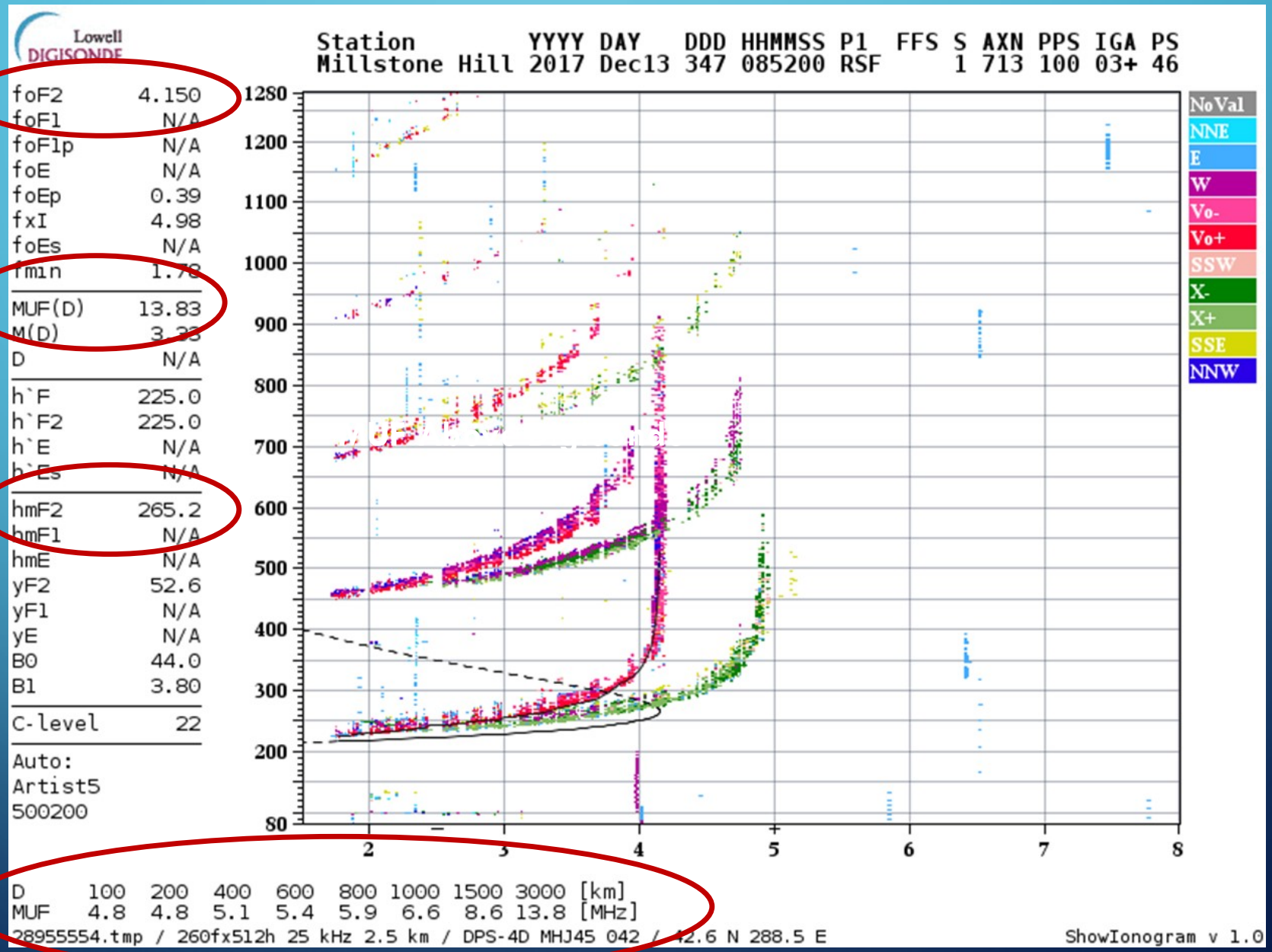
IONOSONDE DIAGRAM

Critical Frequency Above Digisonde

3,000km MUF

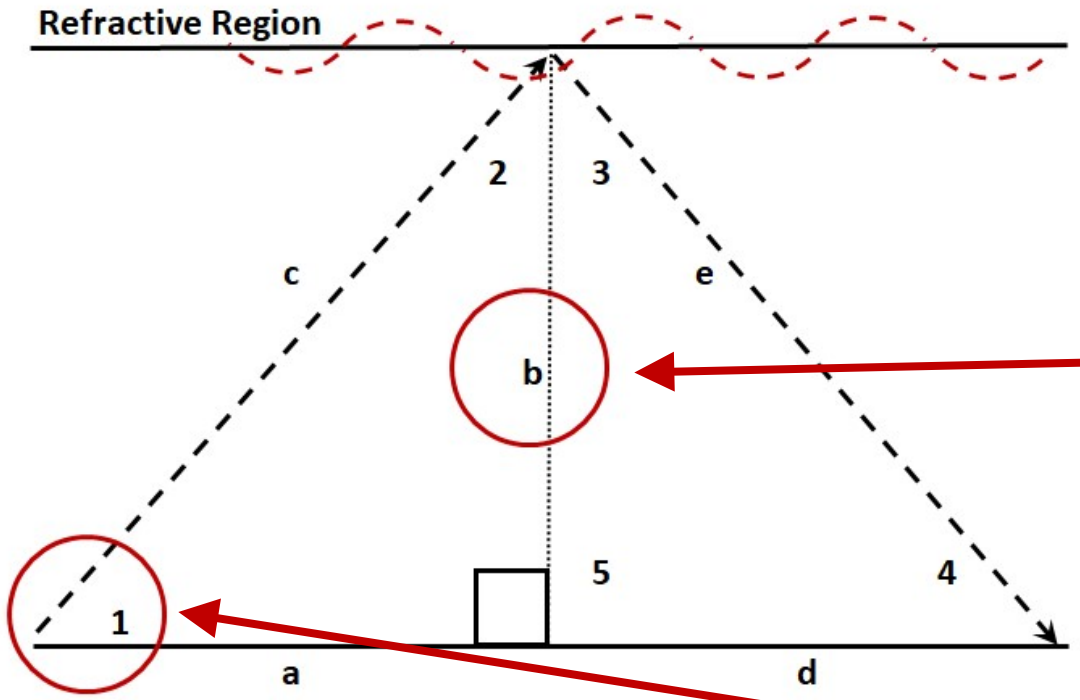
Peak Altitude of the F2 Region

MUF at Various Distances



FLAT EARTH PROPAGATION ESTIMATE

Understanding that the Earth is Curved and Ionosphere Gravity Waves Exist



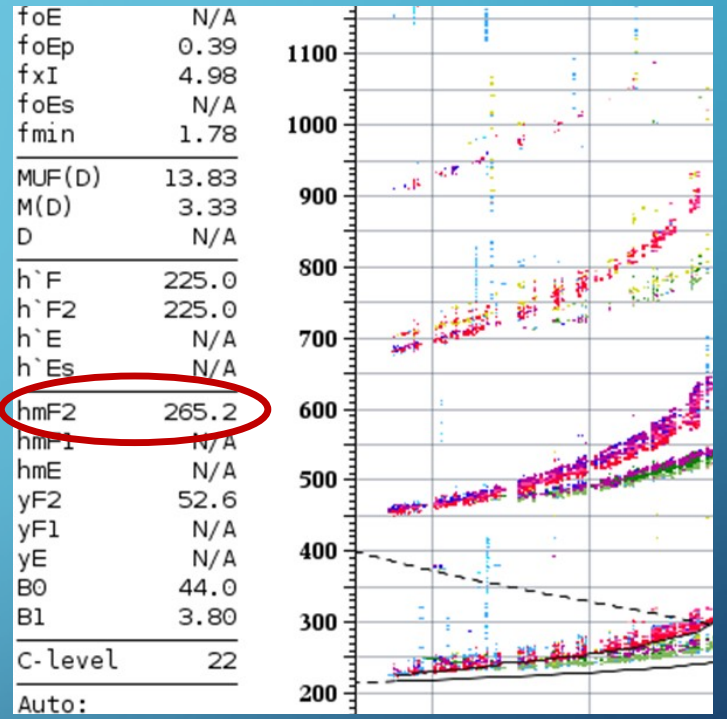
Angle 1 = RF Launch Angle from Antenna

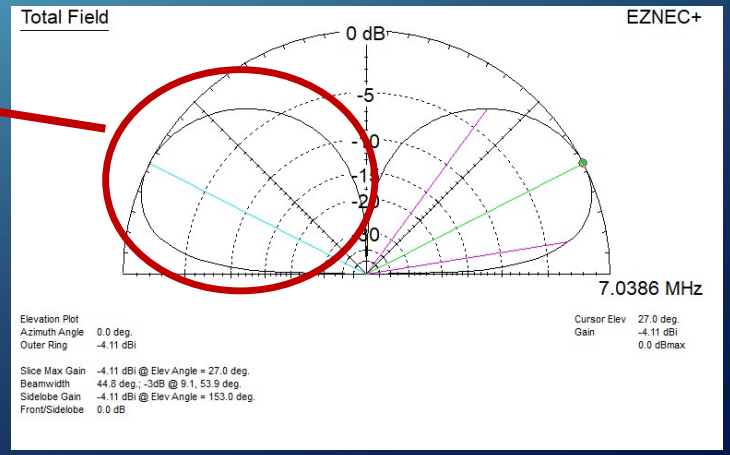
b = Altitude of Peak Electron Density from Ionosonde

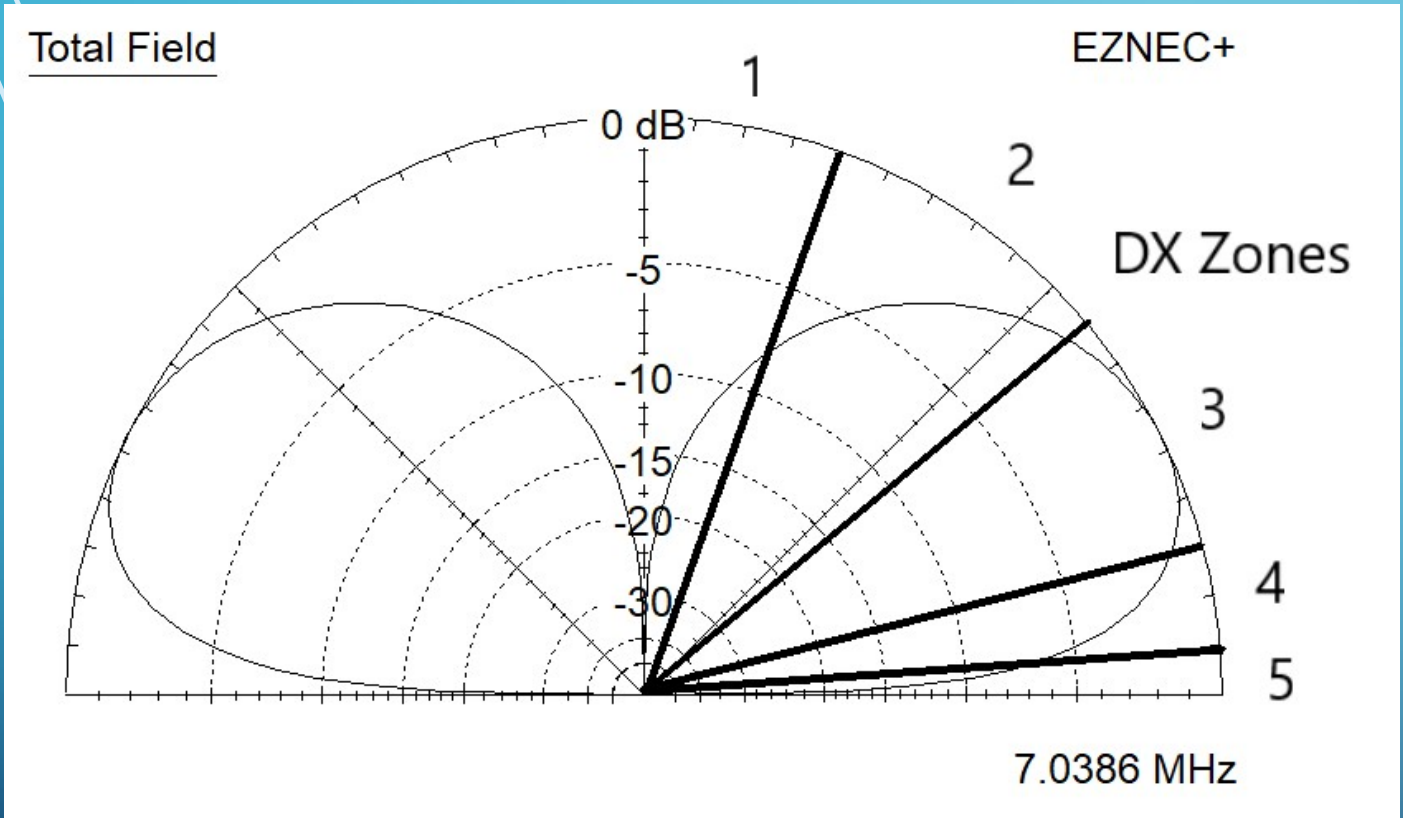
c = b/Sin Angle 1

a = Sqrt(c^2 - b^2)

Skip Distance = a + d







DX Zones

1 – Very High Angle (NVIS)

Shortest Distance

Very Low Radiated Power

2 – High Angle

Short Distance

Medium Radiated Power

3 – Medium Angle

Medium Distance

High Radiated Power

4 – Low Angle

Long Distance

Medium Radiated Power

5 – Very Low Angle

Very Low Radiated Power

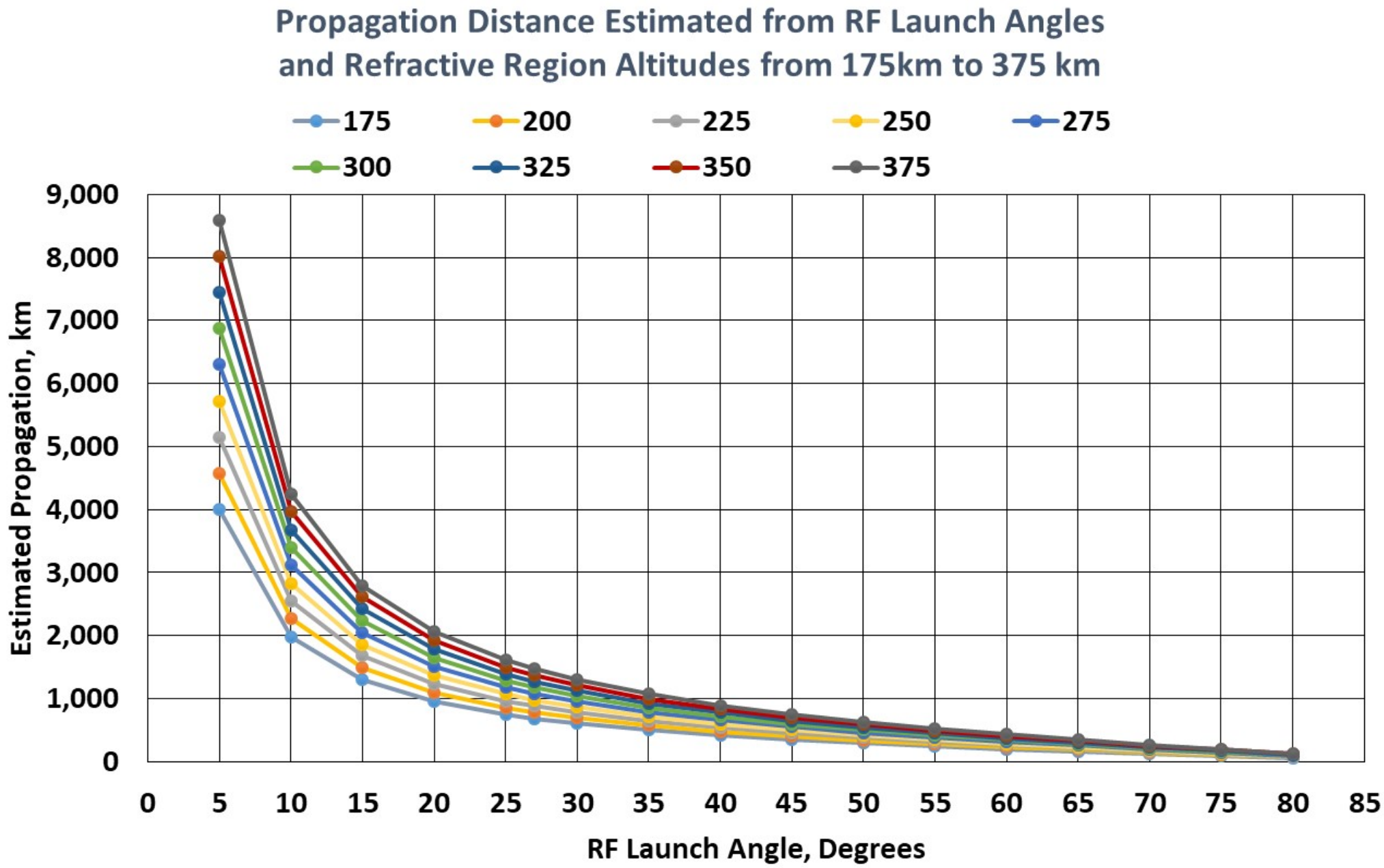
Theoretically Very Long Distance

Realistically Ground Wave Distance Over Land

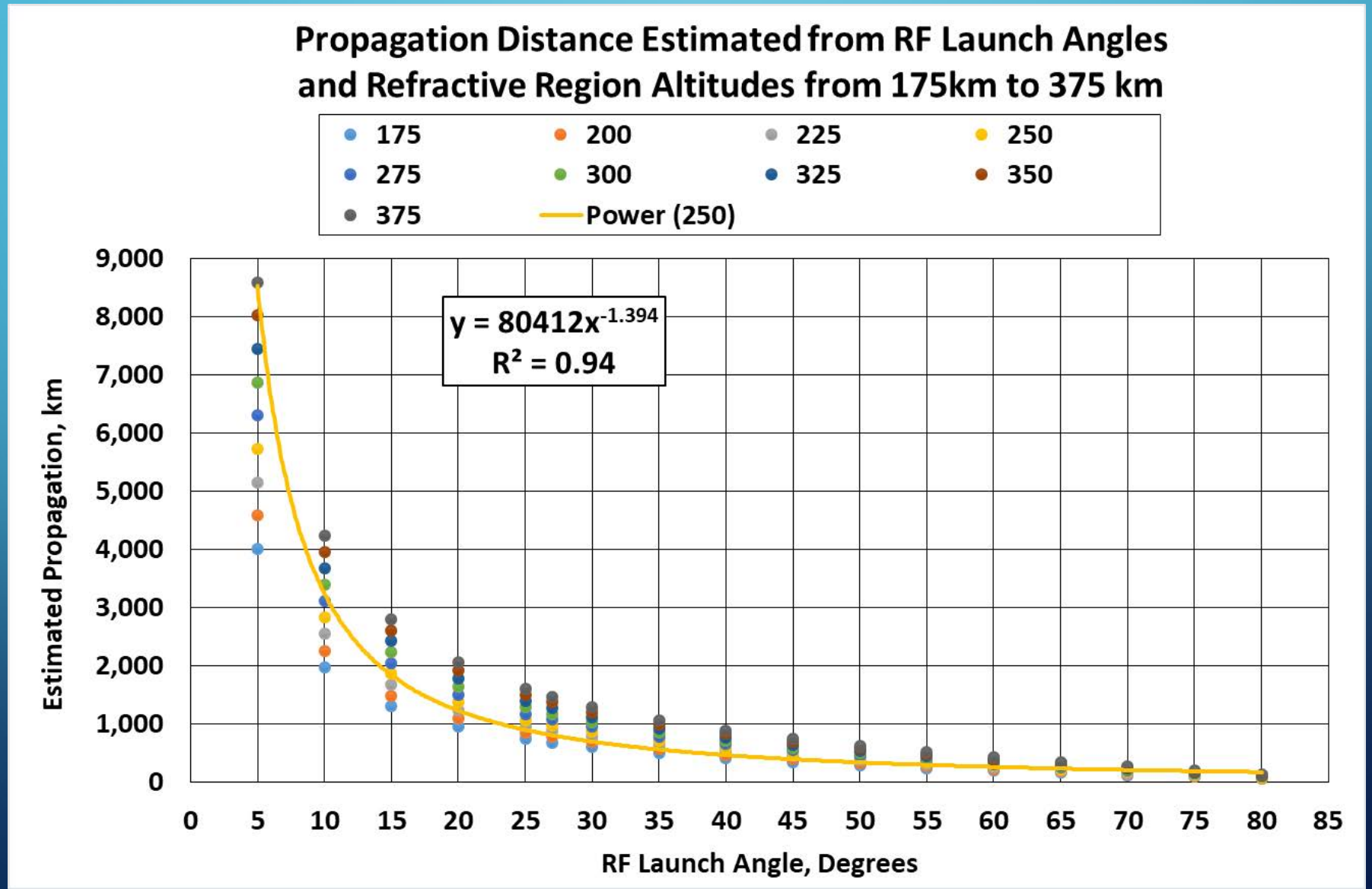
Possible Longer Distance Over Sea Water

Single skip distances calculated with the flat Earth geometrical model for a range of launch angles and refractive region altitudes.

DX Zone	Launch Angle	Refractive Region Altitude, Km								
		175	200	225	250	275	300	325	350	375
1	80	61	70	79	88	96	105	114	123	131
	75	94	107	120	134	147	161	174	187	201
	70	127	145	163	181	200	218	236	254	272
2	65	164	187	210	234	257	280	304	327	350
	60	202	231	260	289	318	346	375	404	433
	55	245	280	315	350	385	420	455	490	525
	50	294	336	378	420	462	504	545	587	629
	45	350	400	450	500	550	600	650	700	750
	40	418	478	537	597	657	717	776	836	896
3	35	499	571	642	713	785	856	927	999	1,070
	30	606	693	779	866	953	1,039	1,126	1,212	1,299
	27	*687*	*785*	*883*	*981*	*1,079*	*1,178*	*1,276*	*1,374*	*1,472*
	25	750	857	964	1,071	1,178	1,285	1,392	1,500	1,607
	20	962	1,099	1,236	1,374	1,511	1,649	1,786	1,923	2,061
4	15	1,305	1,492	1,678	1,865	2,051	2,238	2,424	2,610	2,797
	10	1,981	2,264	2,547	2,830	3,113	3,396	3,679	3,962	4,245
5	5	4,008	4,580	5,153	5,725	6,298	6,870	7,443	8,015	8,588

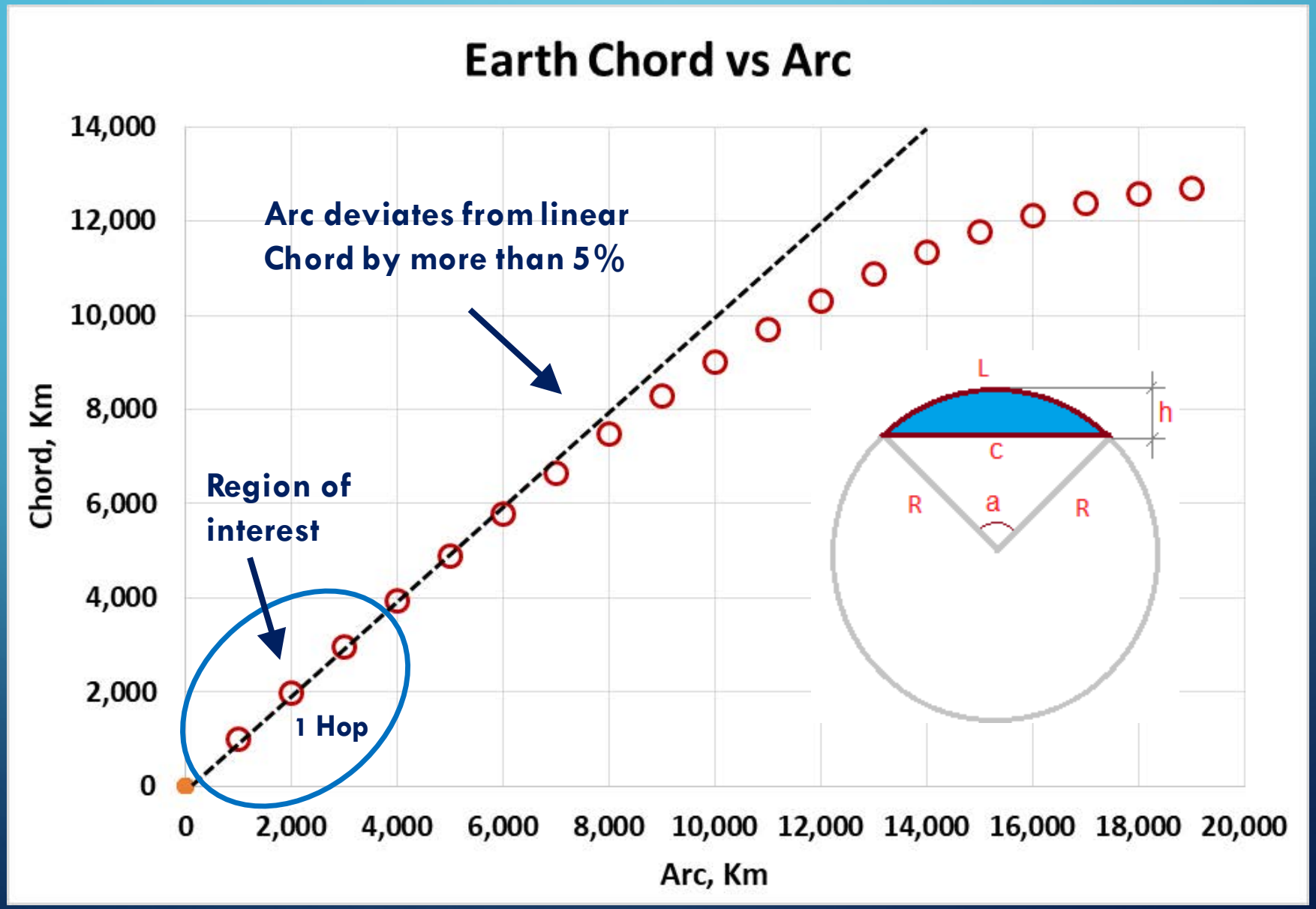

Propagation Distance Estimated from RF Launch Angles and Refractive Region Altitudes from 175km to 375 km
175
200
225
250
275
300
325
350
375
Estimated Propagation, km
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
RF Launch Angle, Degrees

Example of best fit equation to propagation estimates for 250km refractive region altitude.

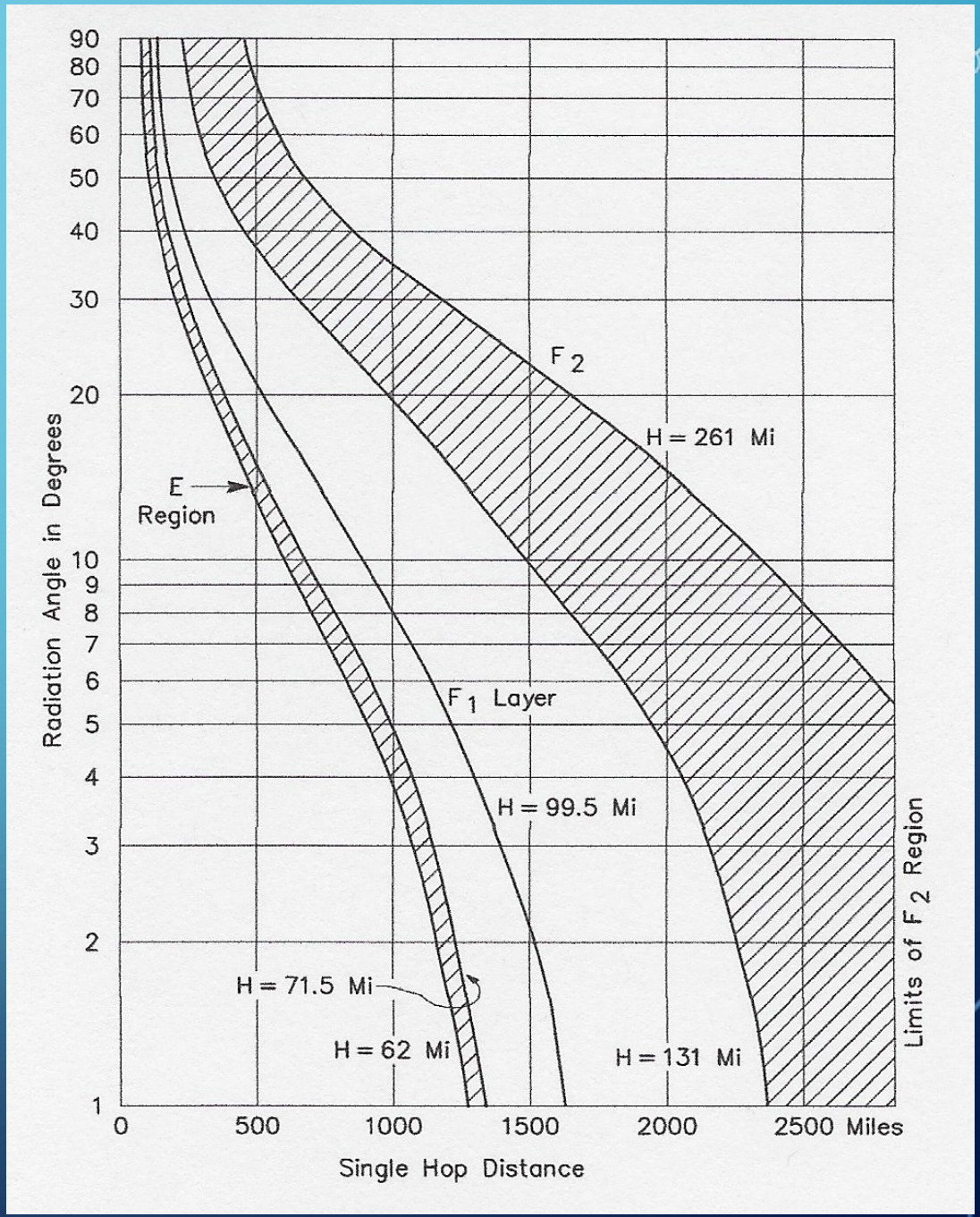


How Close is the Flat Earth Model to Reality?

https://planetcalc.com/1421/



How does the flat Earth approach compare to this representation from the ARRL Antenna Book?



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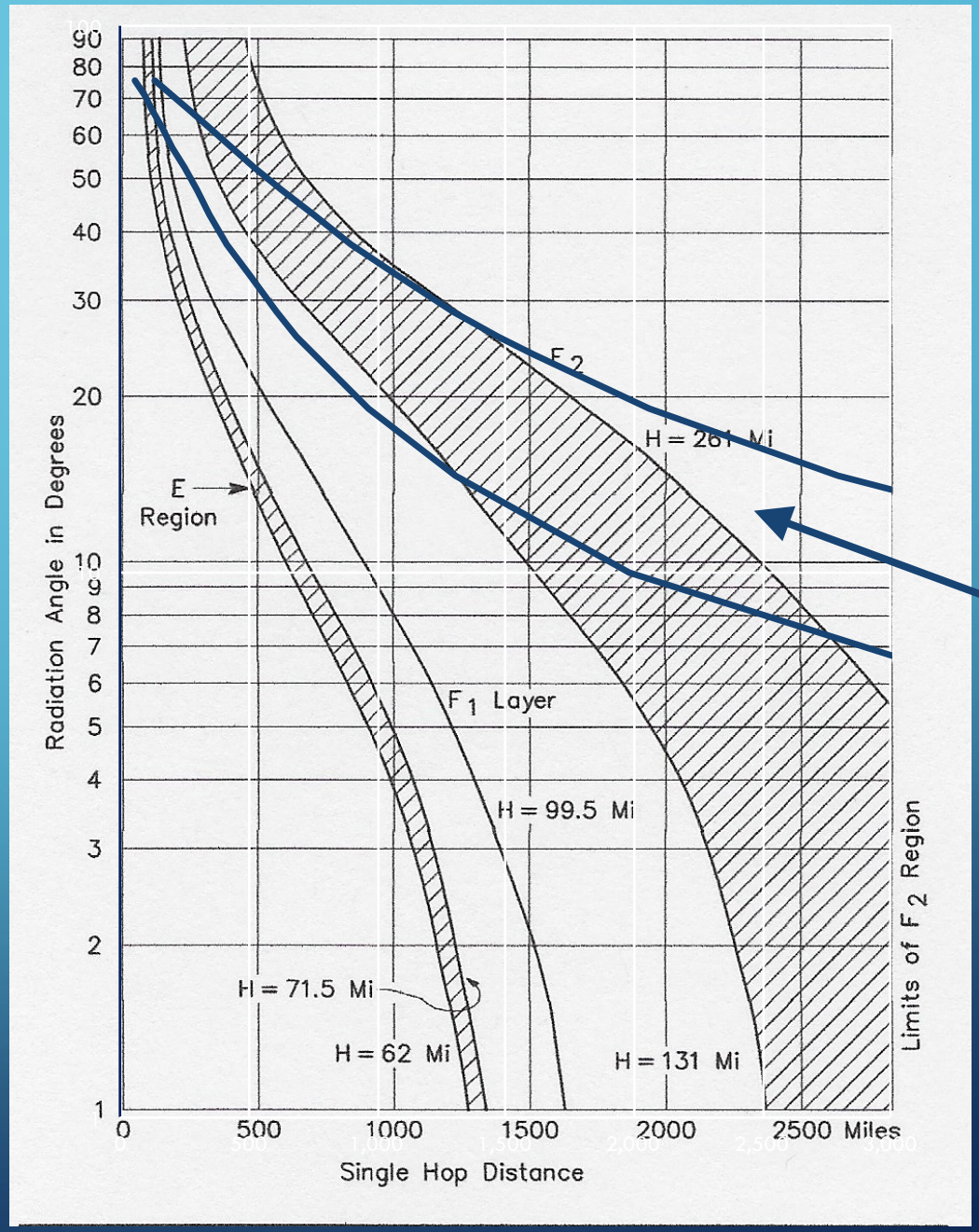
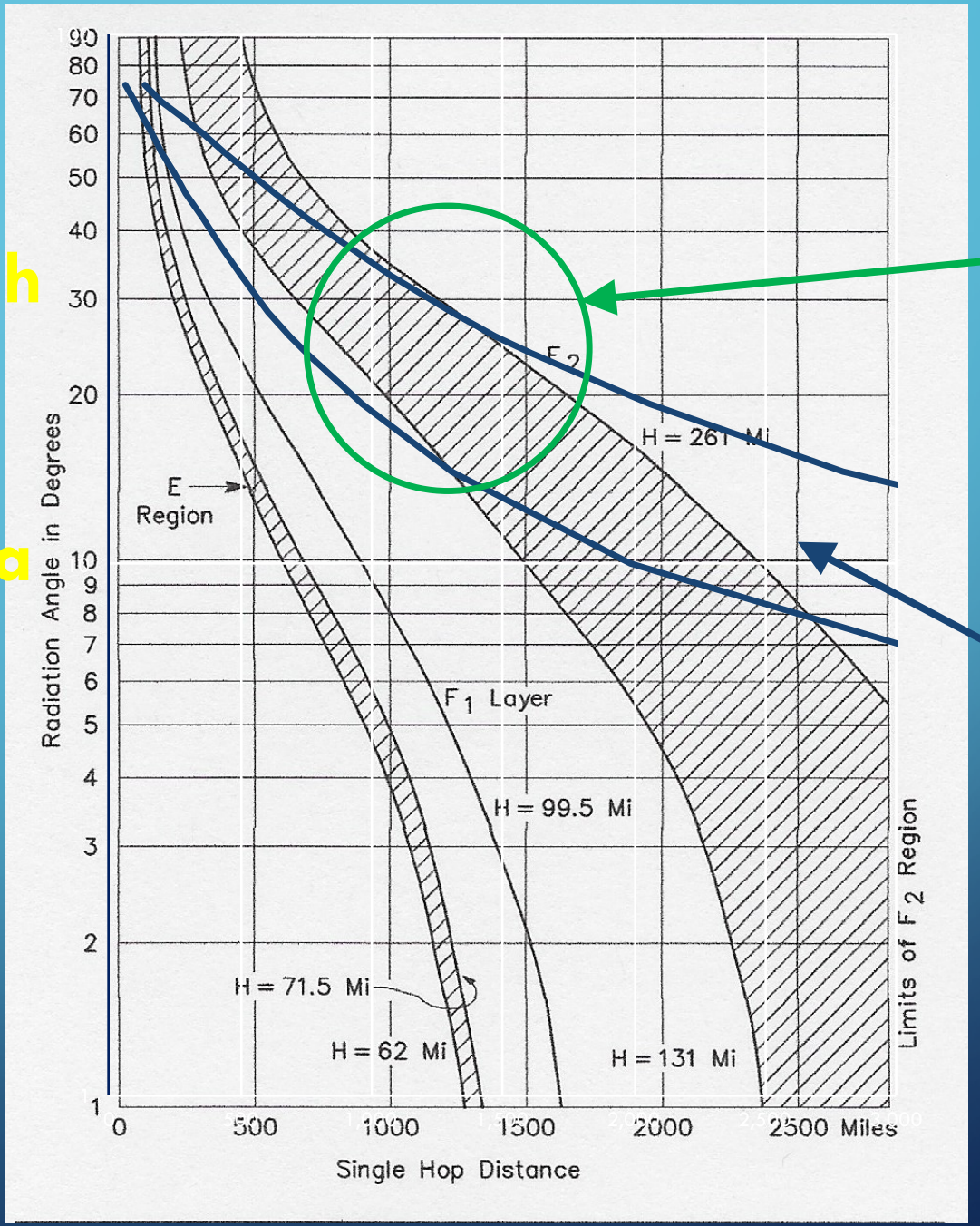


Flat Earth Model F2 Region (hmF2) Altitude 175 to 375Km

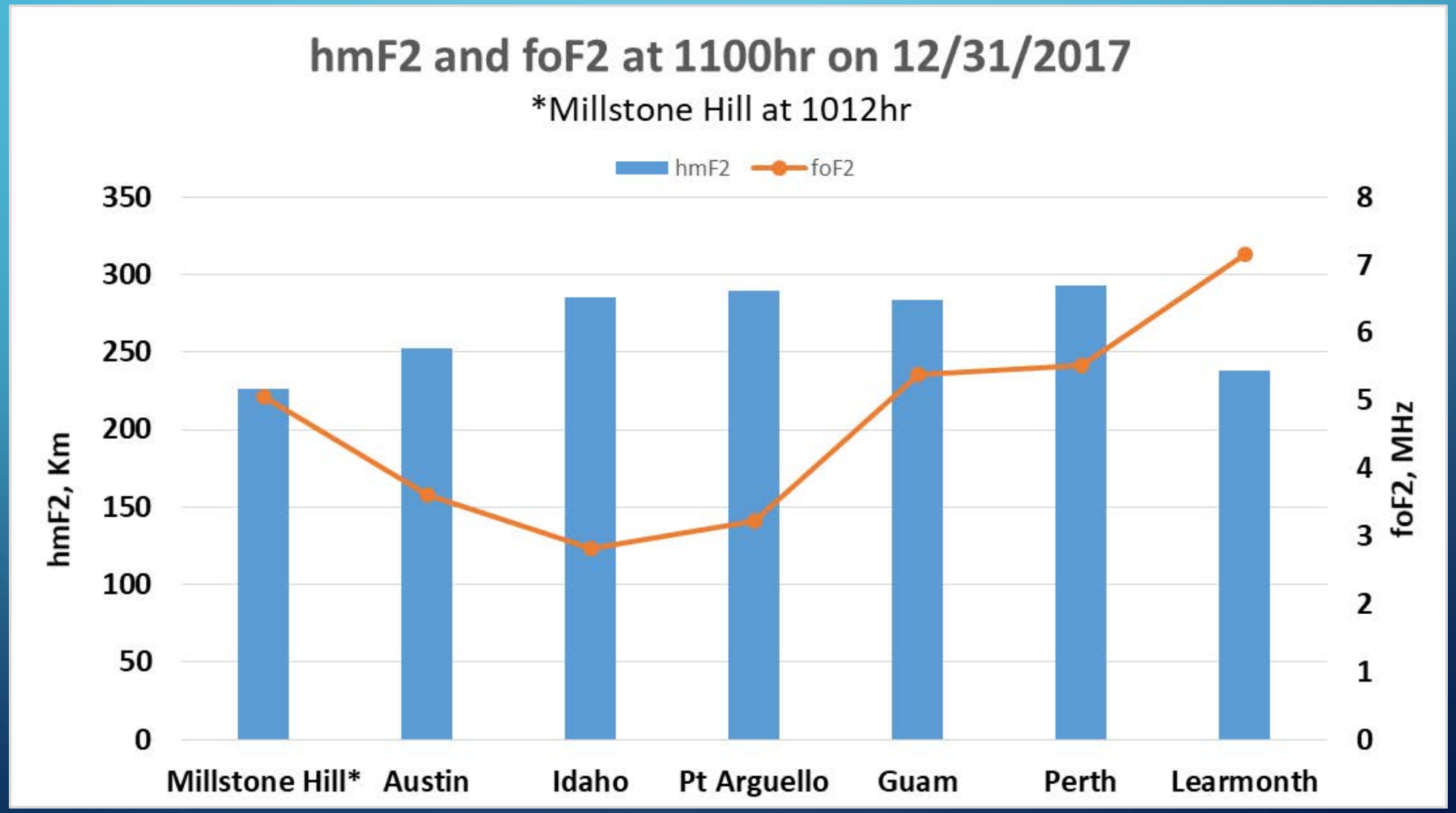
Flat Earth approach compares reasonably well in the antenna sweet spot.



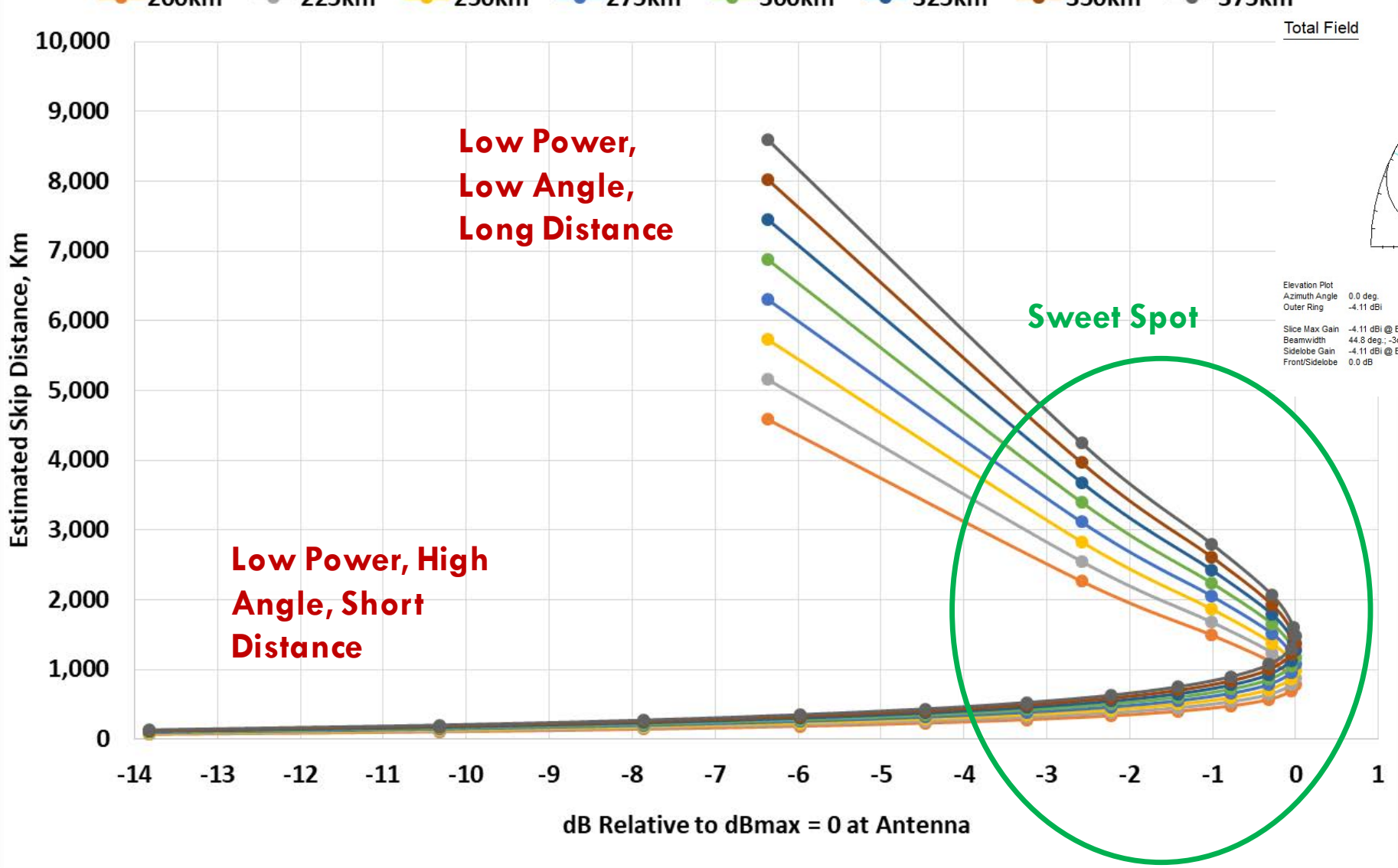
Antenna Sweet Spot 15° to 45°

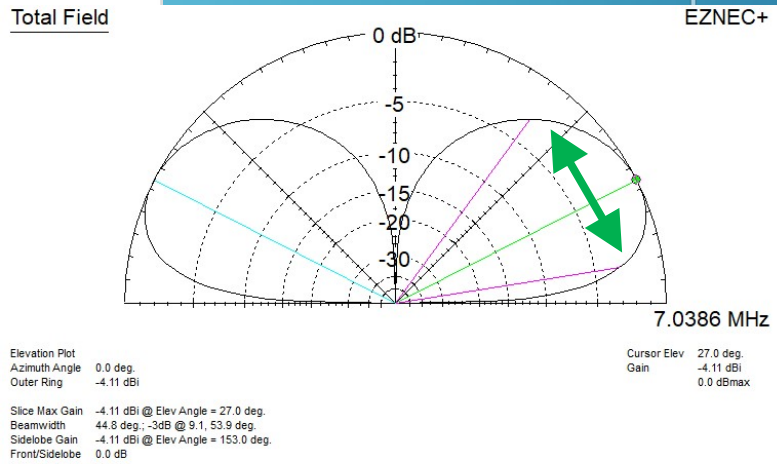
Flat Earth Model F2 Region 175 to 375Km

During one time period the hmF2 varies 25% across the study area, which is acceptable for purposes of this exercise.

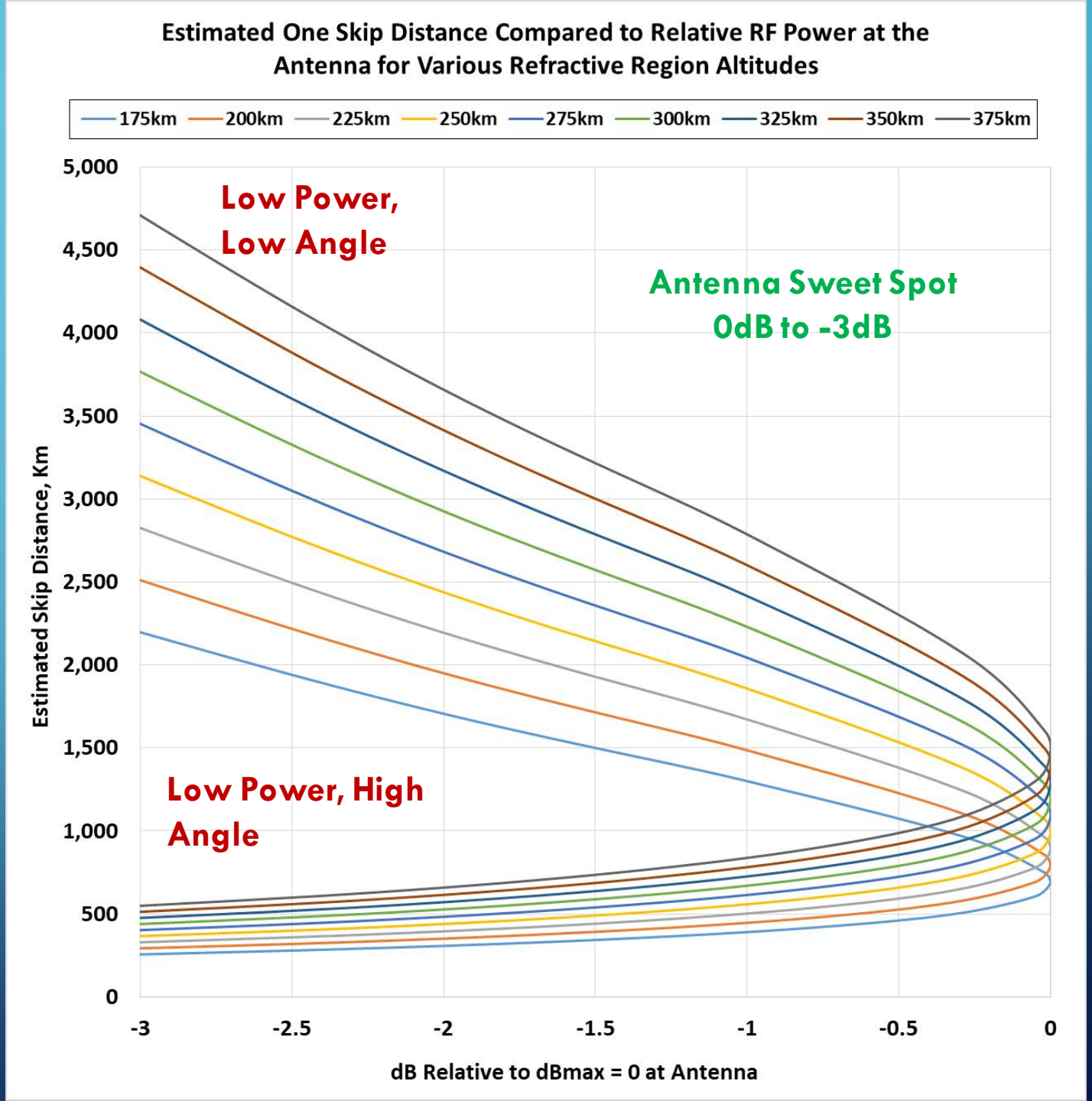


Estimated One Skip Distance Compared to Relative RF Power at the Antenna for Various Refractive Region Altitudes

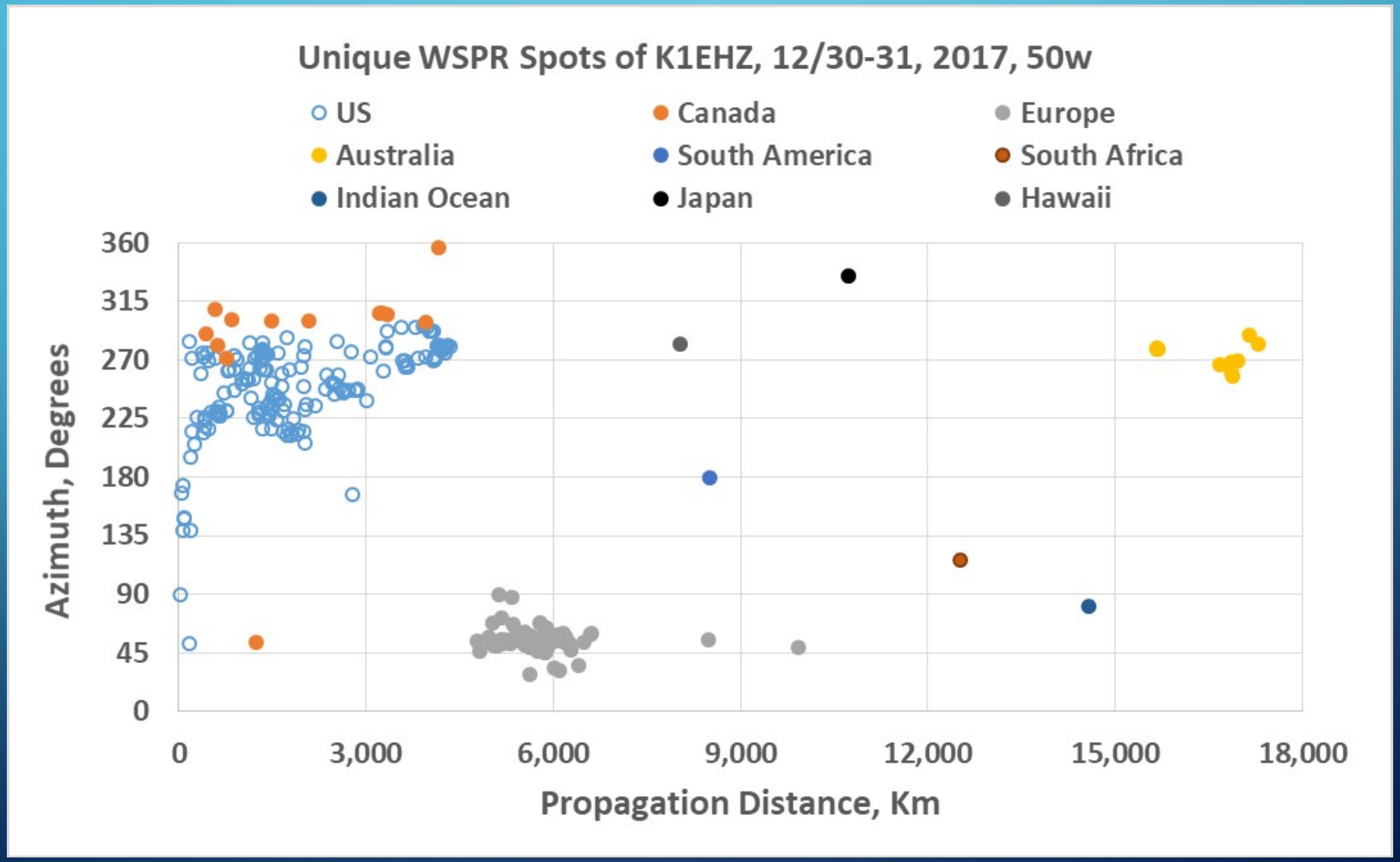




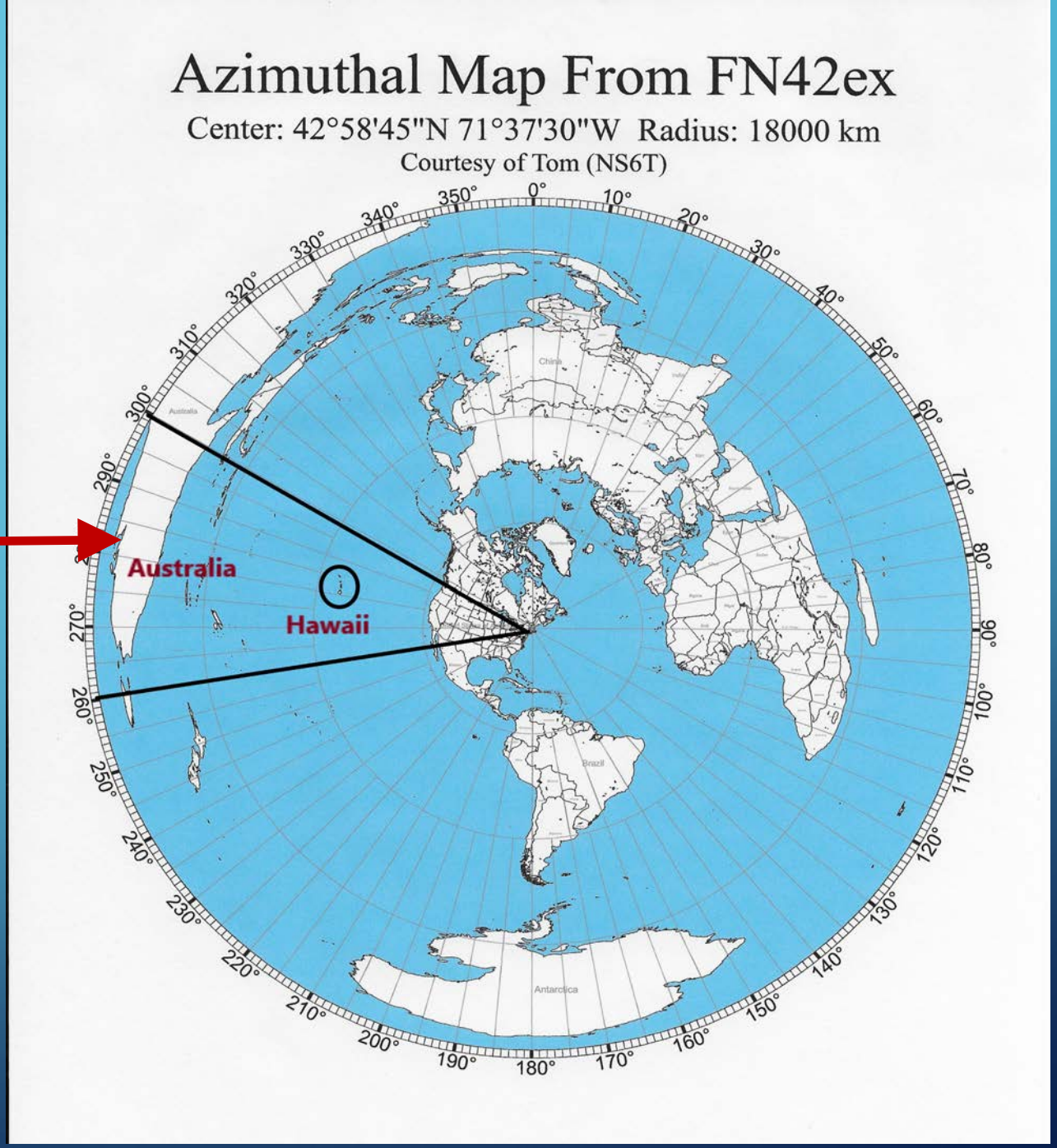
hmF2 altitude range accounts for a factor of 2 in distance for sweet spot power range

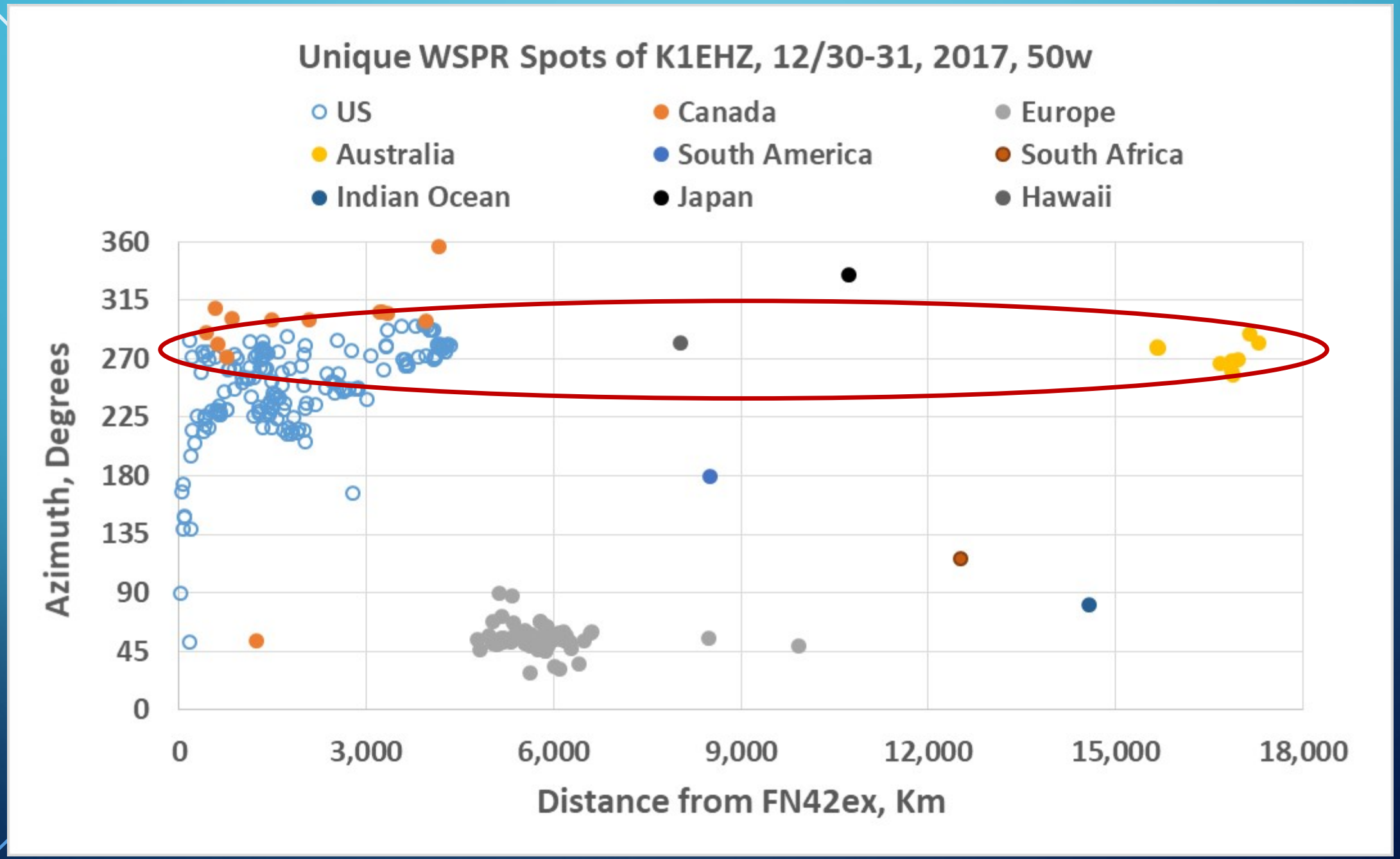


Comparing data and the flat Earth model

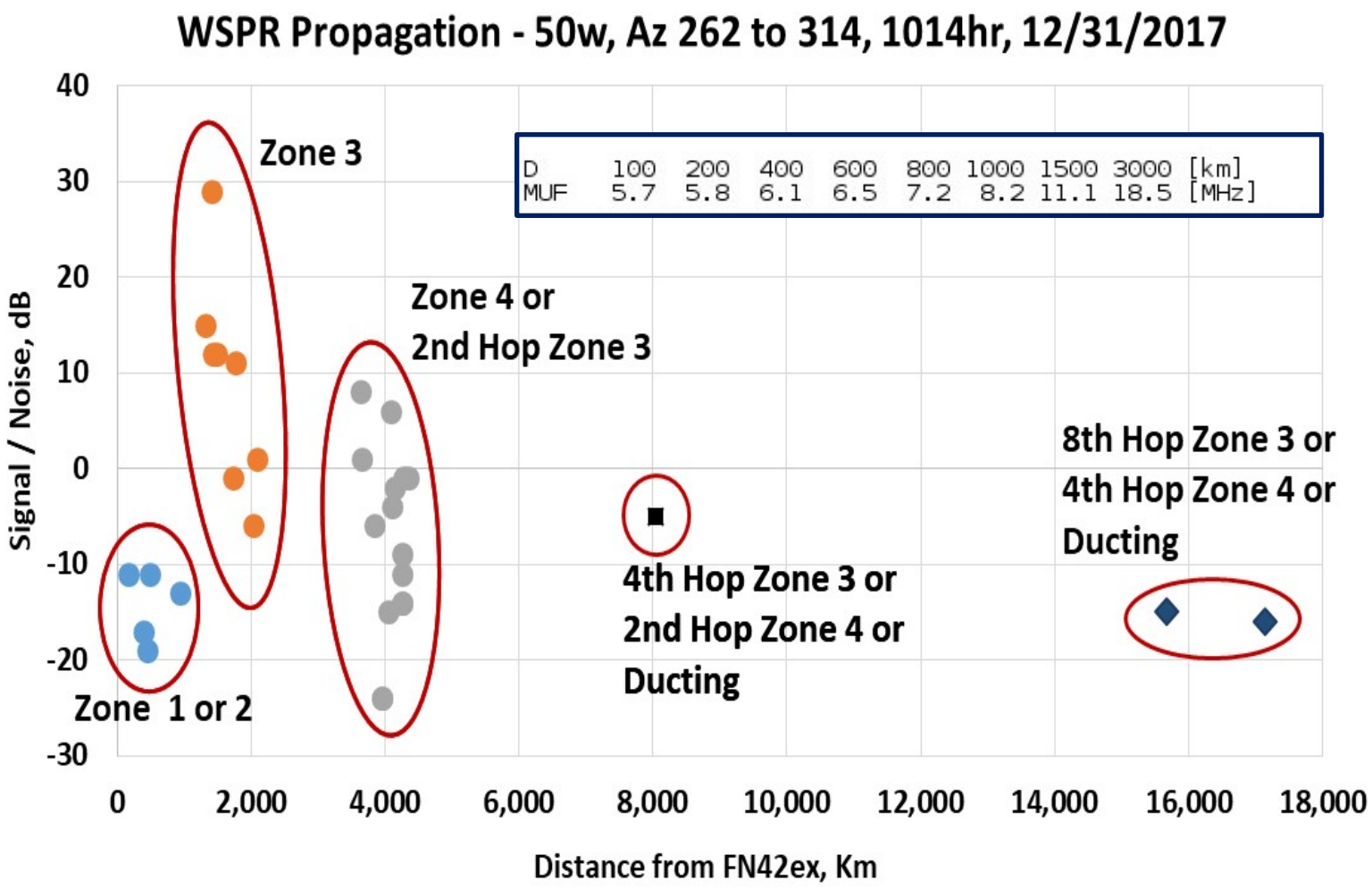


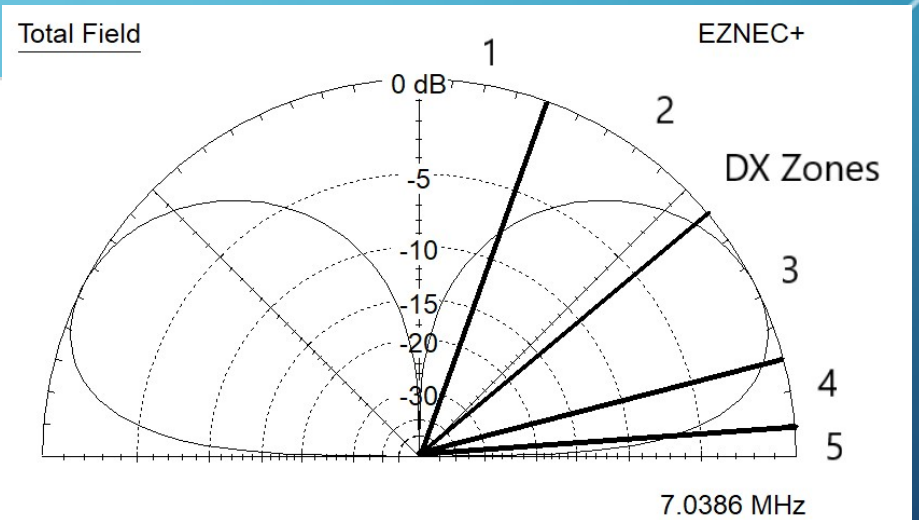
Choose data in this azimuth range




Unique WSPR Spots of K1EHZ, 12/30-31, 2017, 50w
US
Canada
Europe
Australia
South America
South Africa
Indian Ocean
Japan
Hawaii
360
315
270
225
180
135
90
45
0
Azimuth, Degrees
0
3,000
6,000
9,000
12,000
15,000
18,000
Distance from FN42ex, Km

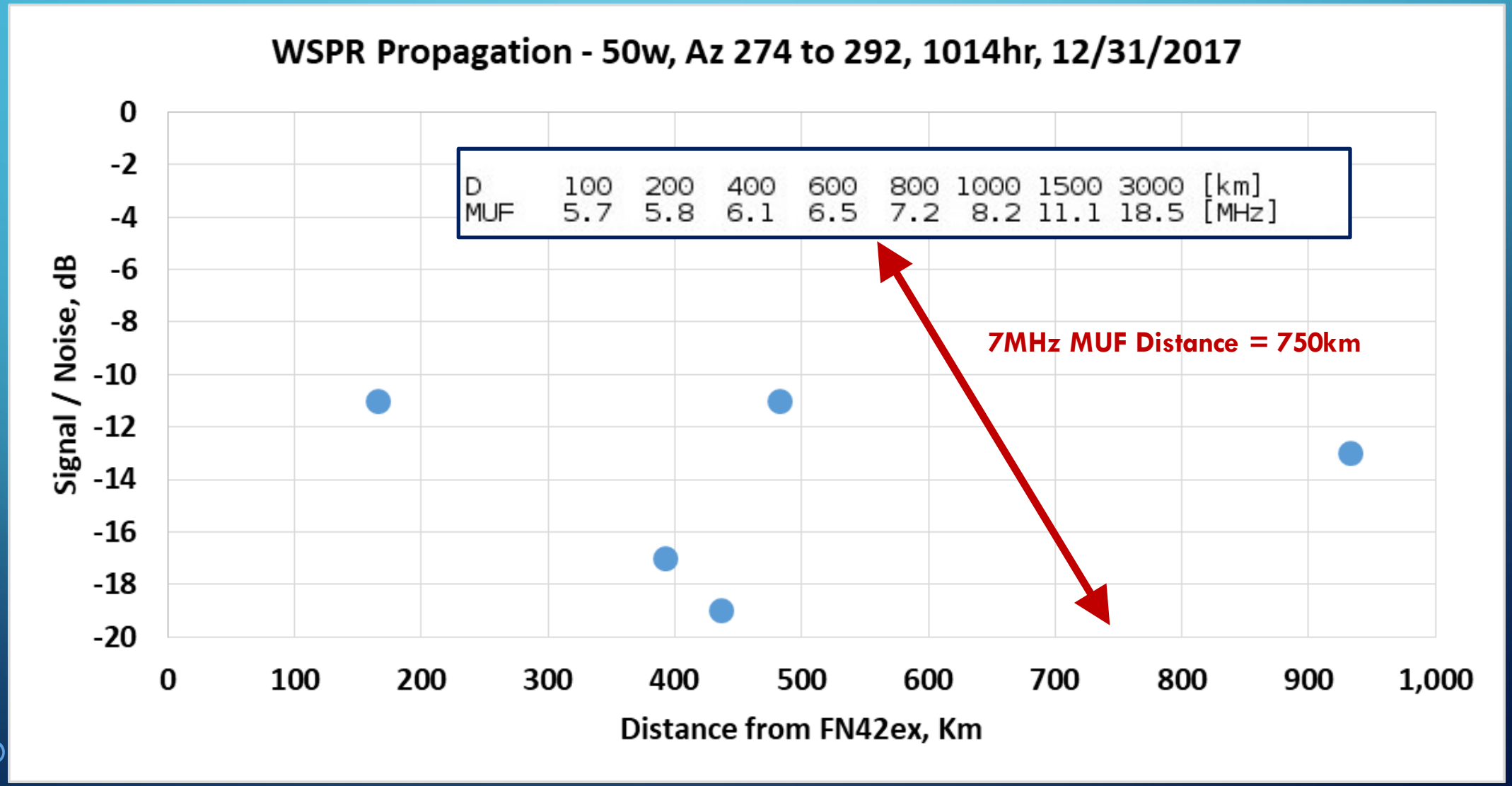
WSPR SKIP DISTANCE AT 50W COMPARED TO FLAT EARTH SKIP DISTANCE (REFRACTIVE REGION ALTITUDE 226KM)



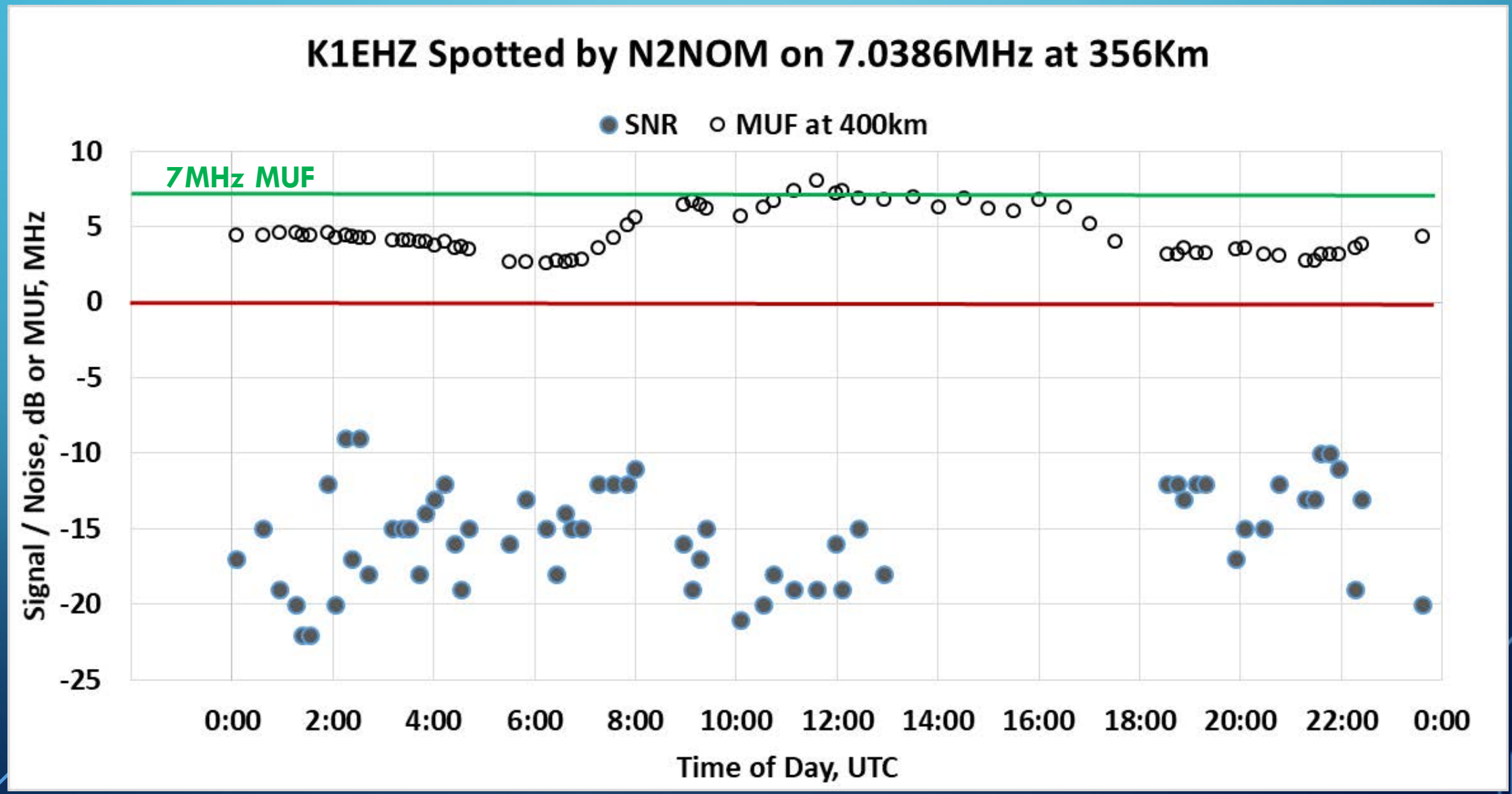


DX Zone	Launch Angle	Refractive Region Altitude, Km								
		175	200	225	250	275	300	325	350	375
1	80	61	70	79	88	96	105	114	123	131
	75	94	107	120	134	147	161	174	187	201
	70	127	145	163	181	200	218	236	254	272
2	65	164	187	210	234	257	280	304	327	350
	60	202	231	260	289	318	346	375	404	433
	55	245	280	315	350	385	420	455	490	525
	50	294	336	378	420	462	504	545	587	629
	45	350	400	450	500	550	600	650	700	750
	40	418	478	537	597	657	717	776	836	896
3	35	499	571	642	713	785	856	927	999	1,070
	30	606	693	779	866	953	1,039	1,126	1,212	1,299
	27	*687*	*785*	*883*	*981*	*1,079*	*1,178*	*1,276*	*1,374*	*1,472*
	25	750	857	964	1,071	1,178	1,285	1,392	1,500	1,607
	20	962	1,099	1,236	1,374	1,511	1,649	1,786	1,923	2,061
4	15	1,305	1,492	1,678	1,865	2,051	2,238	2,424	2,610	2,797
	10	1,981	2,264	2,547	2,830	3,113	3,396	3,679	3,962	4,245
5	5	4,008	4,580	5,153	5,725	6,298	6,870	7,443	8,015	8,588

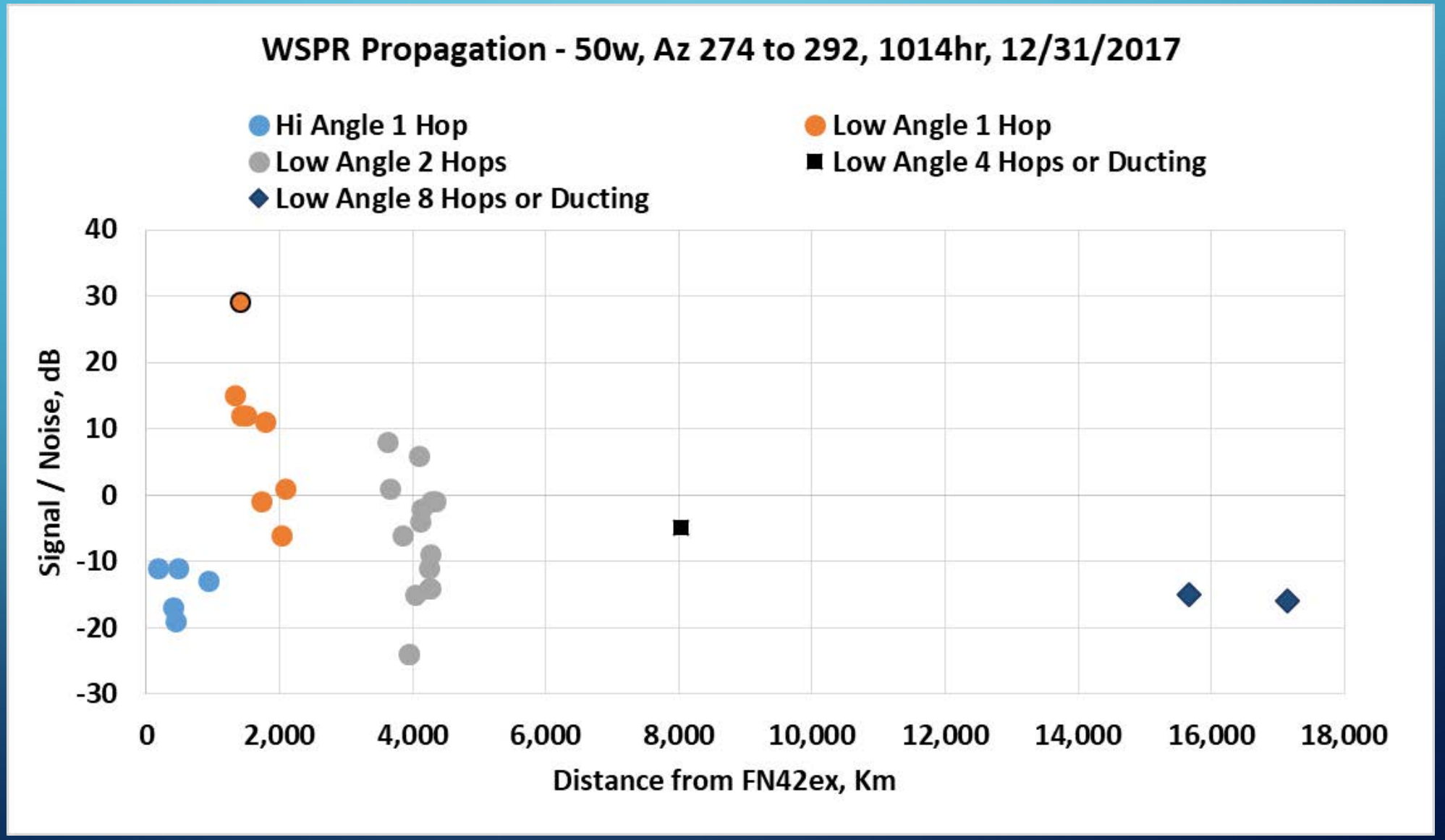
Short range spots from the previous slide show propagation at 7MHz, which is above the calculated MUF for this distance.



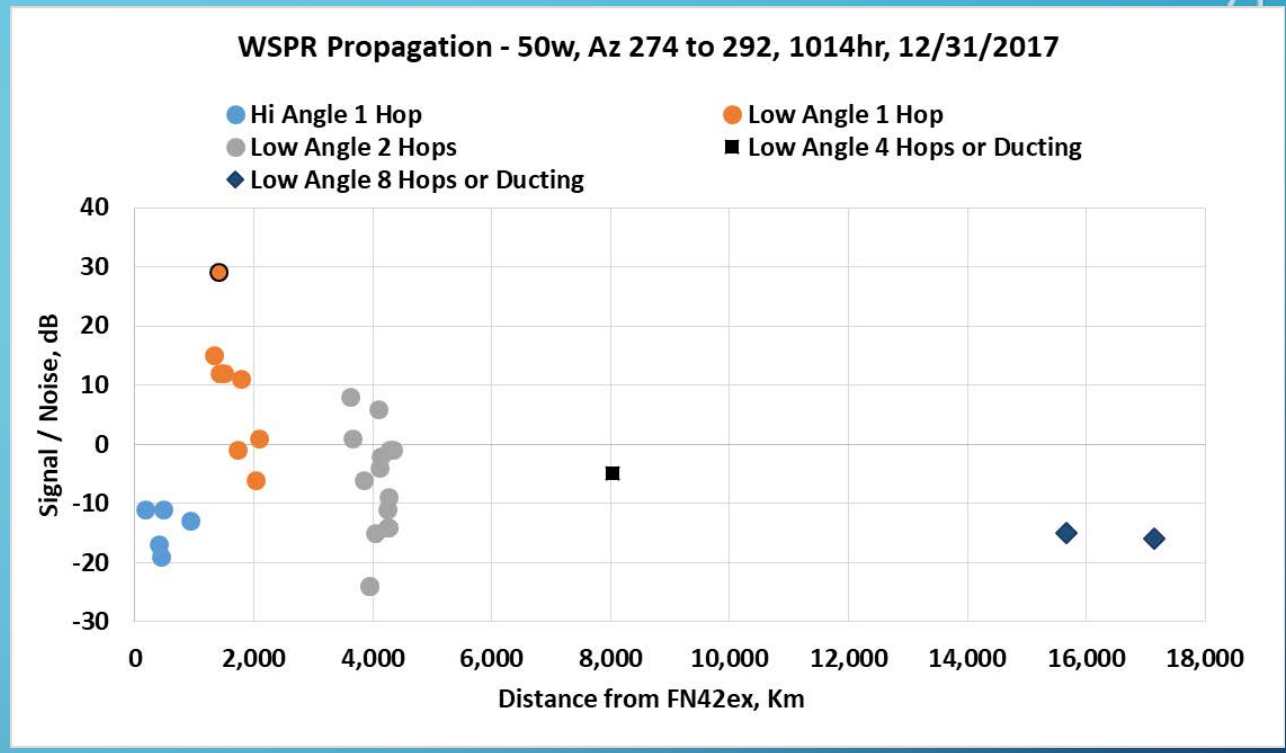
Propagation at 7MHz persists when the calculated MUF is below 7MHz -– an unexpected observation in this study.

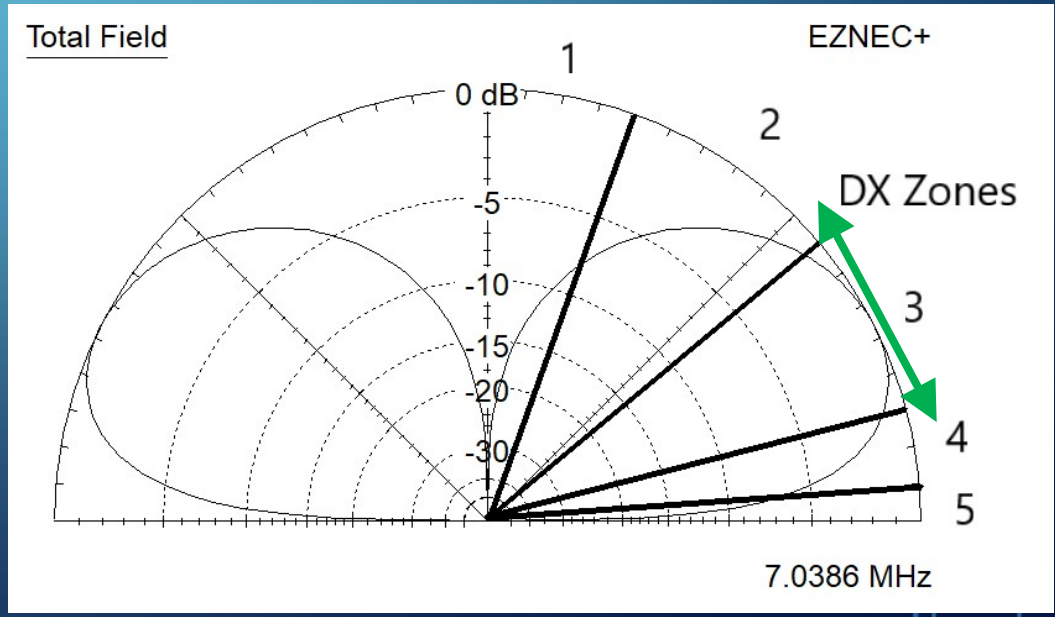


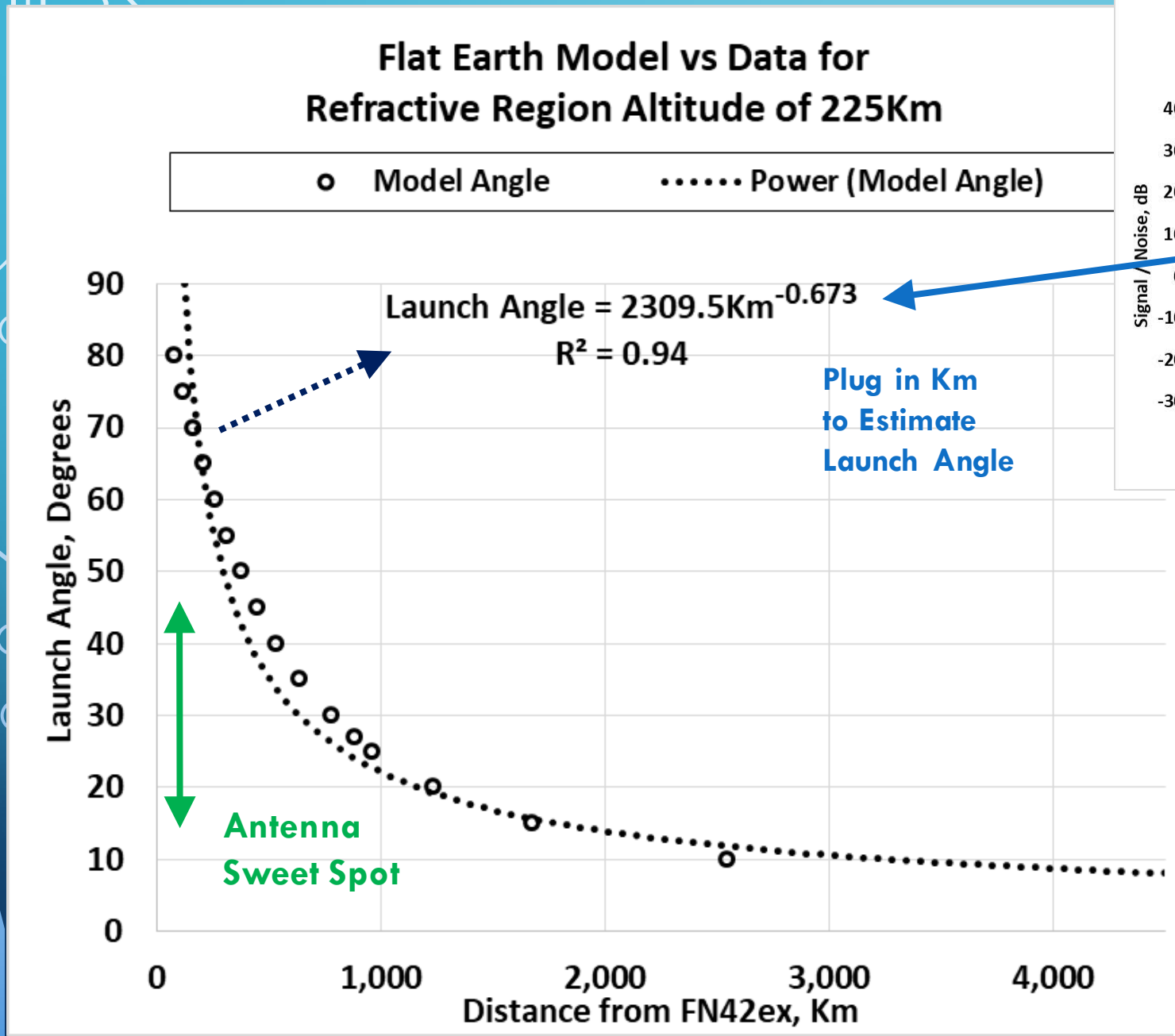
Characterizing the data with the flat Earth model.

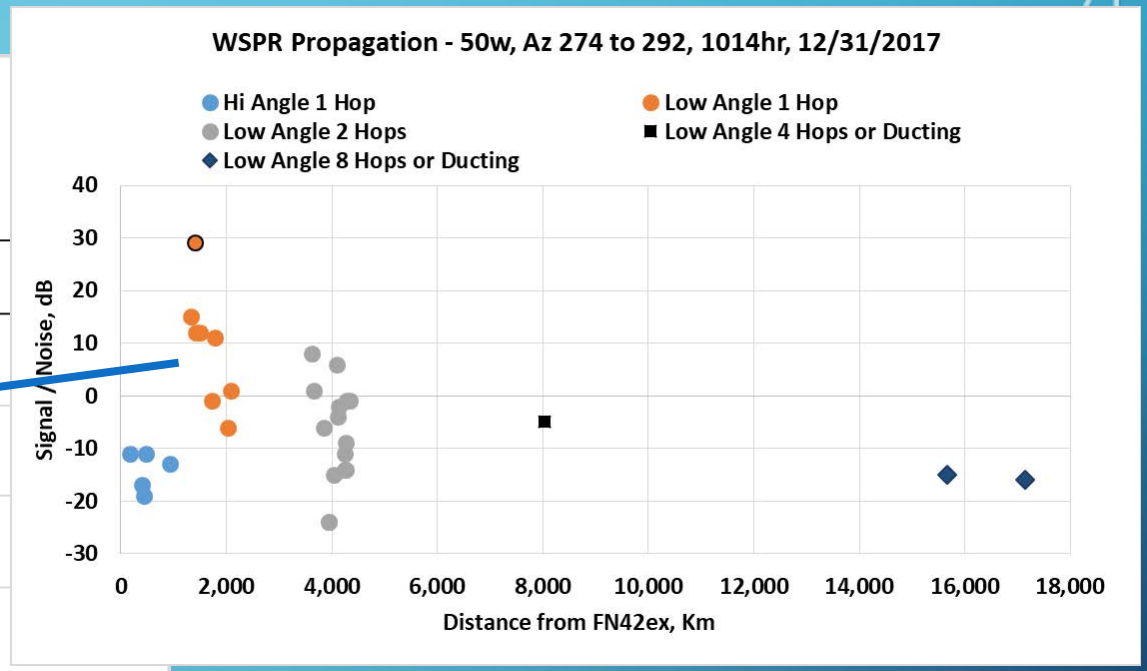


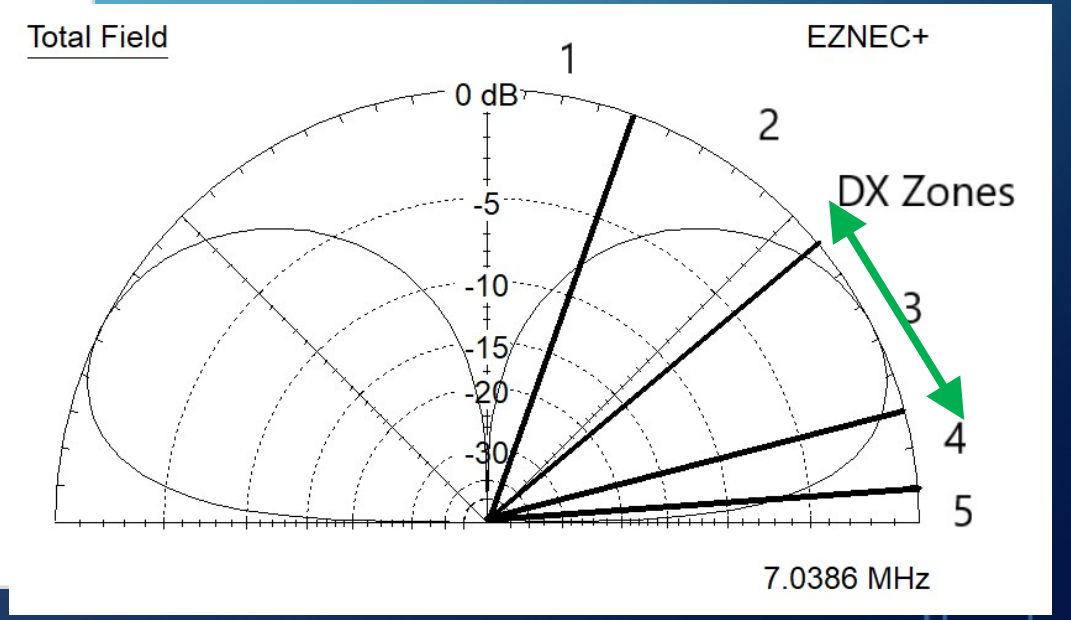
Using the flat Earth estimates we can relate the distance of the data spots to launch angles from the antenna, and see how reasonable the guesses are for the number of hops.

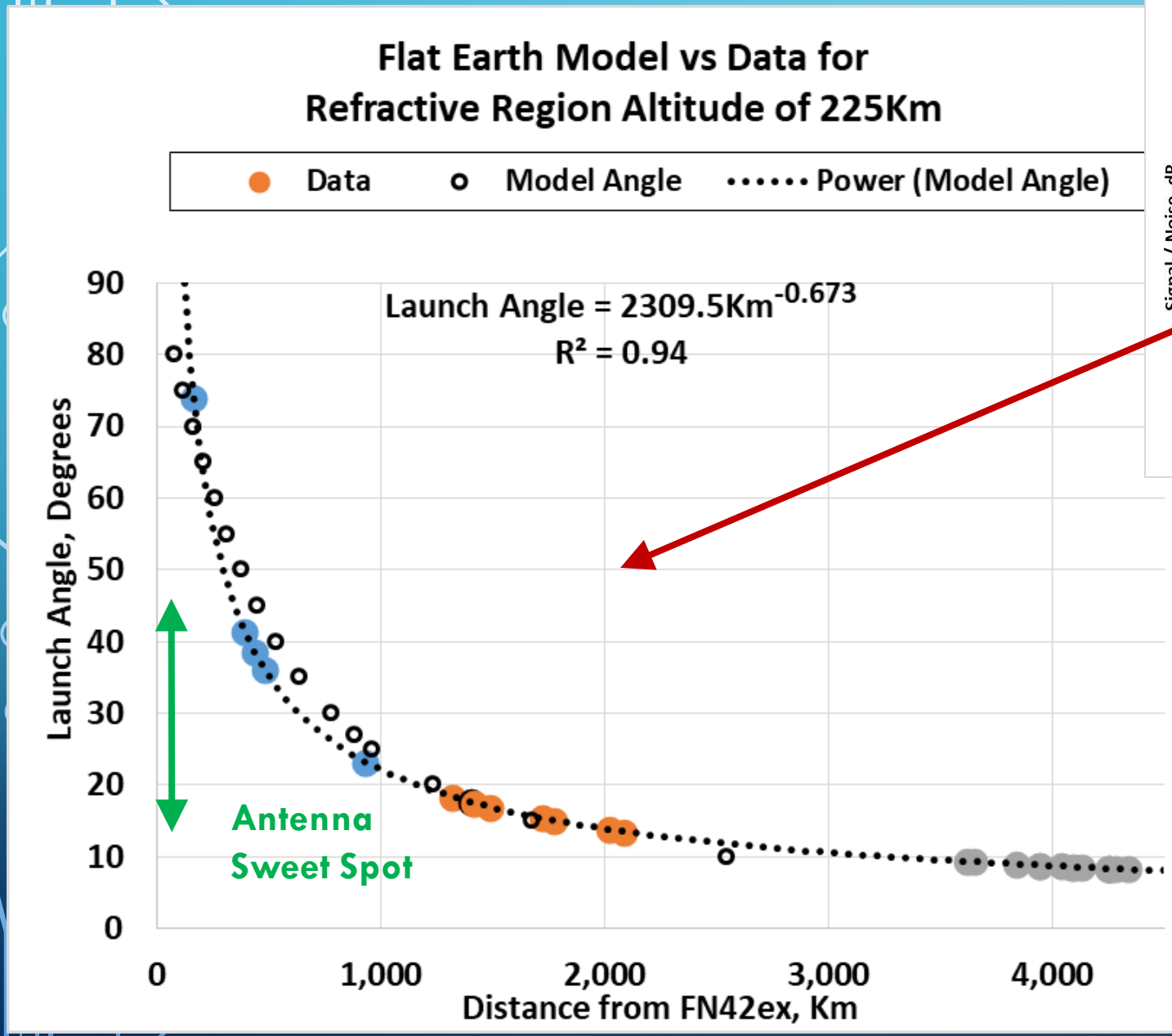





Flat Earth Model vs Data for
Refractive Region Altitude of 225Km
Model Angle
Power (Model Angle)
Launch Angle = 2309.5Km^-0.673
R² = 0.94
Plug in Km
to Estimate
Launch Angle
Launch Angle, Degrees
Antenna
Sweet Spot
Distance from FN42ex, Km
0
10
20
30
40
50
60
70
80
90
0
1,000
2,000
3,000
4,000


WSPR Propagation - 50w, Az 274 to 292, 1014hr, 12/31/2017
Hi Angle 1 Hop
Low Angle 1 Hop
Low Angle 2 Hops
Low Angle 4 Hops or Ducting
Low Angle 8 Hops or Ducting
Signal / Noise, dB
Distance from FN42ex, Km
40
30
20
10
0
-10
-20
-30
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000


Total Field
EZNEC+
0 dB
-5
-10
-15
-20
-30
1
2
3
4
5
DX Zones
7.0386 MHz


Flat Earth Model vs Data for
Refractive Region Altitude of 225Km
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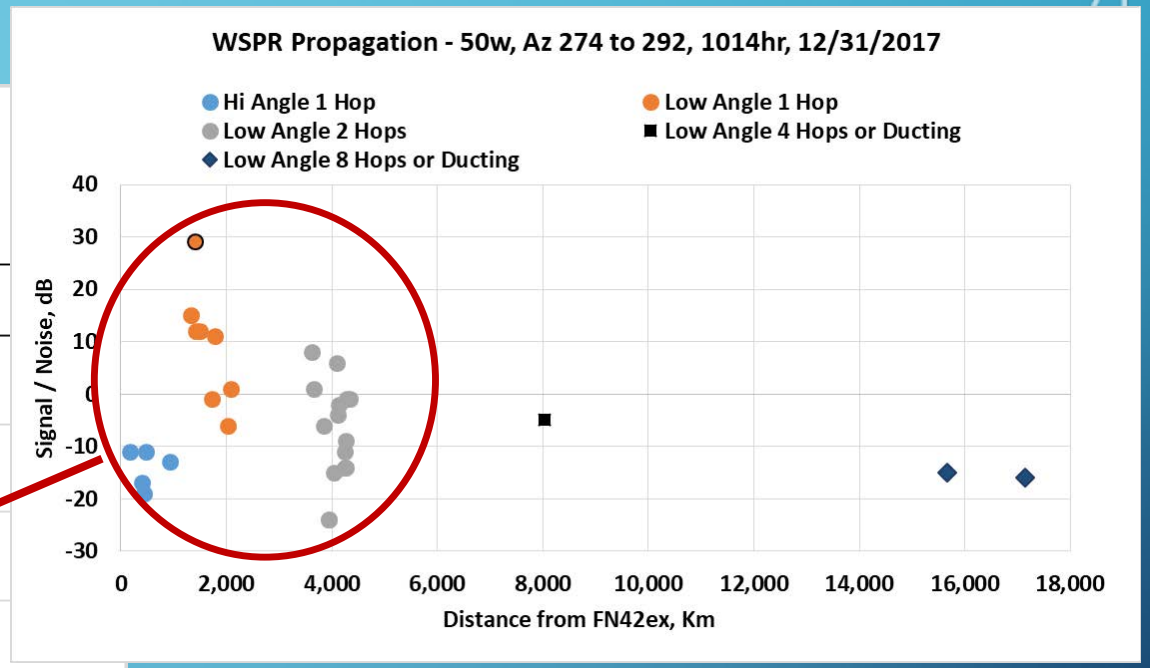
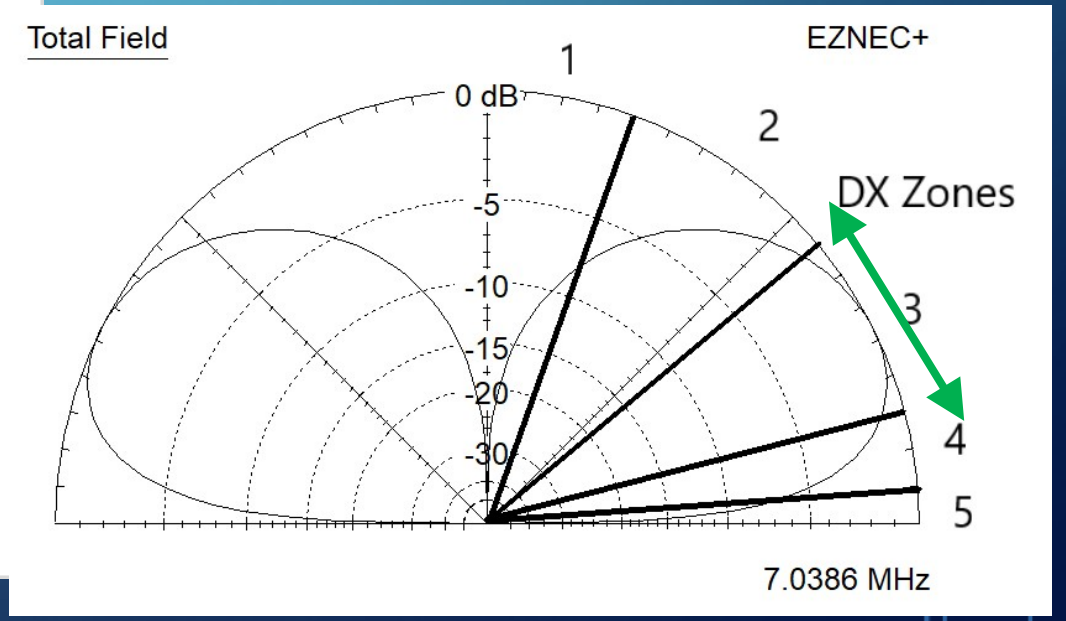
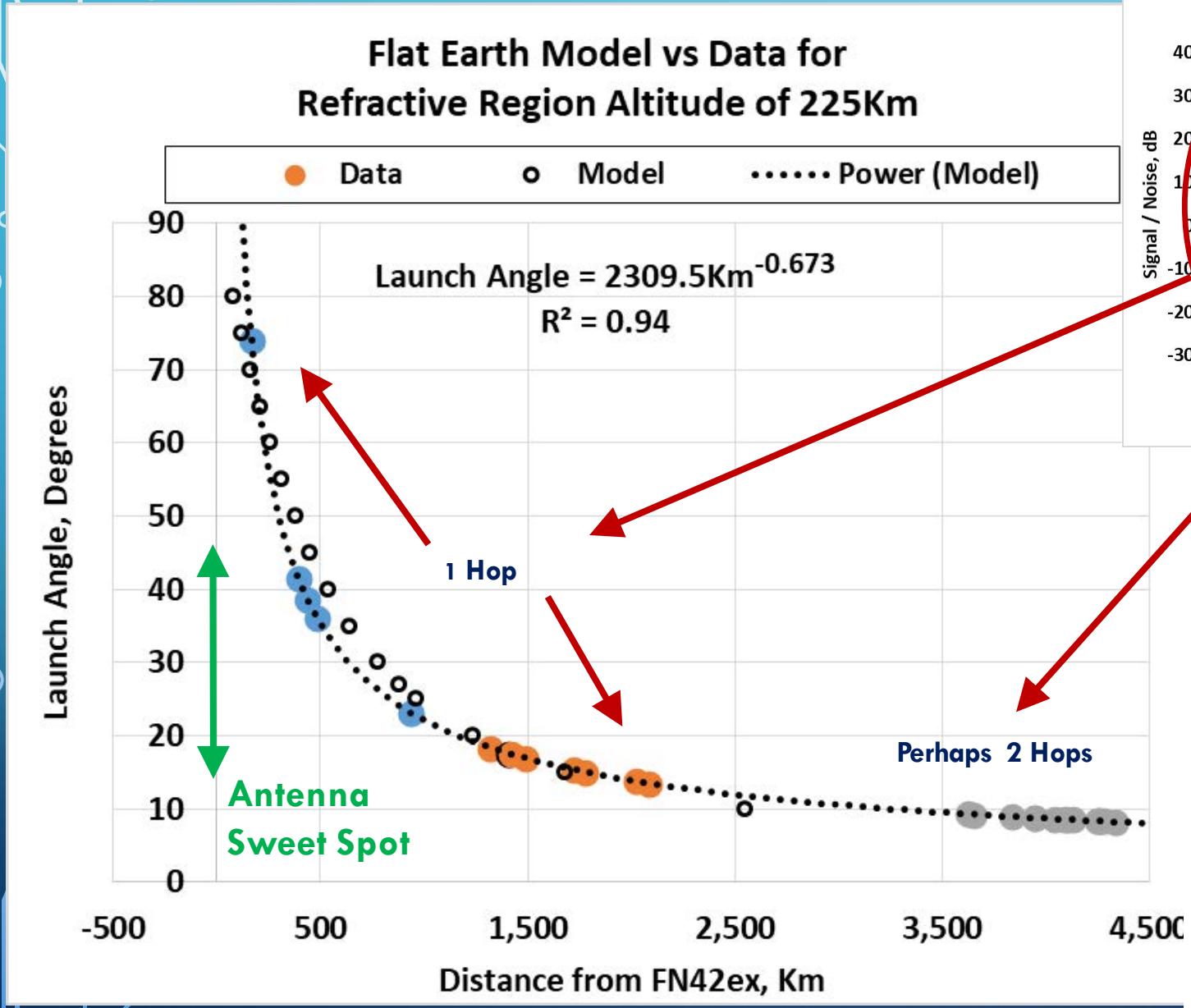
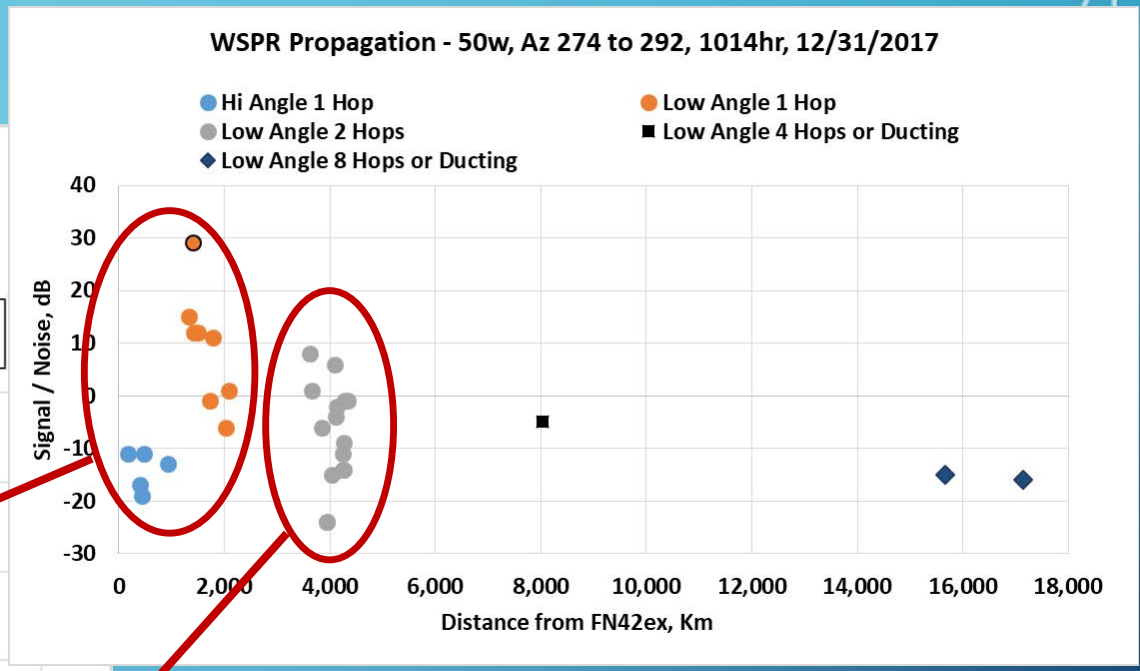
Model Angle
Power (Model Angle)
Launch Angle = 2309.5Km^-0.673
R² = 0.94
Launch Angle, Degrees
Distance from FN42ex, Km
Antenna
Sweet Spot
0
10
20
30
40
50
60
70
80
90
0
1,000
2,000
3,000
4,000


WSPR Propagation - 50w, Az 274 to 292, 1014hr, 12/31/2017
Hi Angle 1 Hop
Low Angle 1 Hop
Low Angle 2 Hops
Low Angle 4 Hops or Ducting
Low Angle 8 Hops or Ducting
Signal / Noise, dB
Distance from FN42ex, Km
40
30
20
10
0
-10
-20
-30
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000


Total Field
EZNEC+
0 dB
-5
-10
-15
-20
-30
1
2
3
4
5
DX Zones
7.0386 MHz


Flat Earth Model vs Data for
Refractive Region Altitude of 225Km
Data
Model
Power (Model)
Launch Angle = 2309.5Km^-0.673
R² = 0.94
Launch Angle, Degrees
90
80
70
60
50
40
30
20
10
0
1 Hop
Perhaps 2 Hops
Antenna
Sweet Spot
-500
500
1,500
2,500
3,500
4,500
Distance from FN42ex, Km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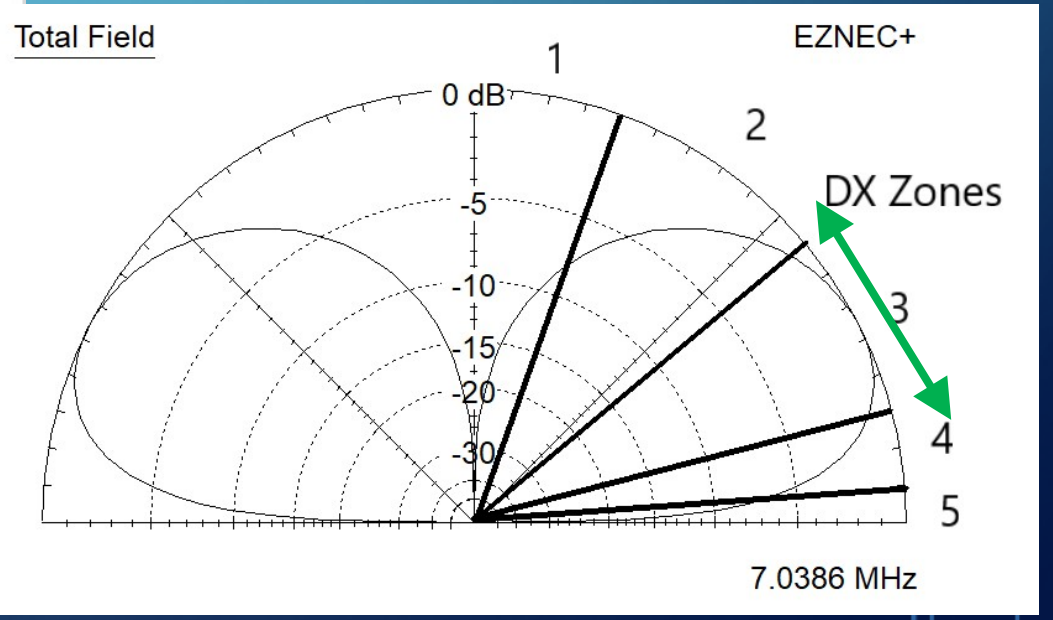
Low Angle 4 Hops or Ducting
Low Angle 8 Hops or Ducting
Signal / Noise, dB
40
30
20
10
0
-10
-20
-30
0
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
Distance from FN42ex, Km


Total Field
EZNEC+
0 dB
-5
-10
-15
-20
-30
1
2
3
4
5
DX Zones
7.0386 MHz

SUMMARY – FLAT EARTH ANALYTICAL MODEL

- Flat-Earth model helps to visualize patterns and relationships
  - And to estimate range boundaries for propagation,
  - But being simple it does not account for complex ionosphere dynamics.
- Range of refractive region altitudes accounts for factor of 2 in model distance
  - Altitude varied about 25% across the study area at one moment in time.
- Flat Earth analytical model is a small step up from conceptual models and suits my purposes over one skip distance.
- Patterns for lower power levels similar to those for 50w.

SUMMARY - MUF

The International Telecommunications Union states

"...instantaneous basic MUFs may only be determined from the examination of oblique incidence ionograms measured over the propagation path. An approximation to this may be obtained by using well placed vertical incidence soundings and assuming ionospheric homogeneity along the path."

Ionospheric homogeneity is a key assumption in a dynamic environment.

SUMMARY - MUF

- Propagation above the MUF can be persistent.
  - Is it only ionosphere variability away from the digisonde?
  - Or is it plausible that very low levels of RF scatter or refraction in the ionosphere could support communication above maximum useable frequencies and at negative signal / noise ratios?
- Implications for digital communications, especially emergency communications related to ARES, RACES, etc