A Review of Antipodal Propagation

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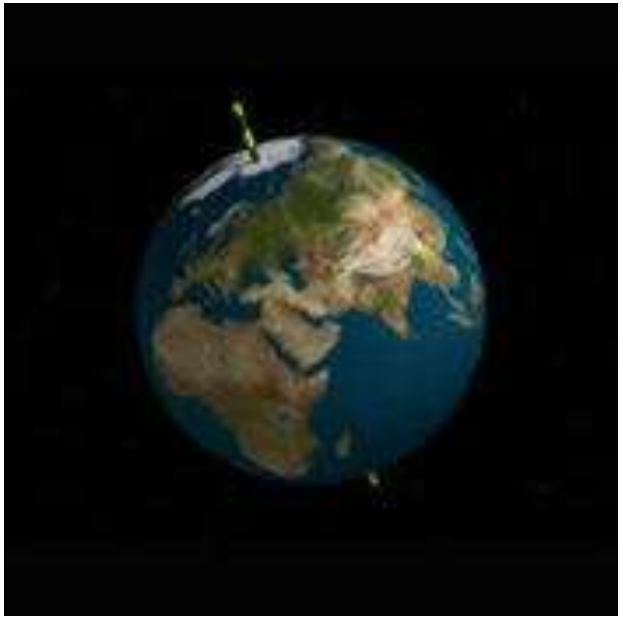
What's an Antipode?

- It's the QTH on the opposite side of the Earth from you
- Extend a line from your QTH thru the center of the Earth to the other side of the Earth
- Where it comes out on the other side of the Earth is your antipode
- To calculate your antipode
  - Reverse the sign of your latitude
  - Add 180^{o} to your longitude

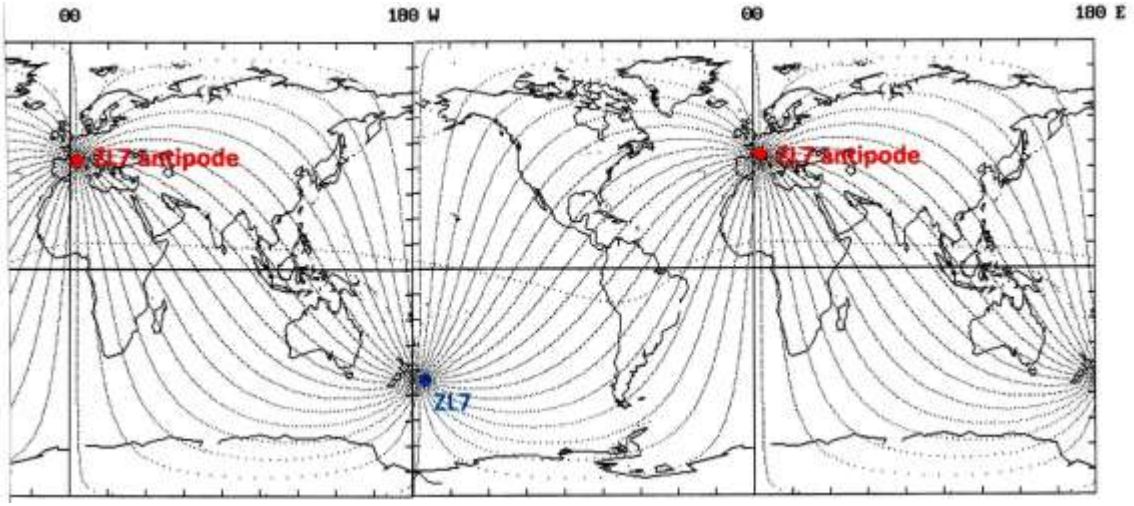


What's the Antipode of Milton Keynes?

- About 500 km southeast of New Zealand
- You'd end up getting wet (which would be okay as you would get kind of hot going thru the Earth)

Why This Topic?

- An e-mail from Roger G3SXW and Steve PJ4DX
- Roger's question was "how far away from the antipode does signal enhancement occur?"
- G3SXW and G3TXF were at ZL7 in Sept 2001



All great circle paths out of ZL7 meet at the ZL7 antipode in southern France

- Roger felt there was a distinct enhancement of U.K. signals (the U.K. is ~500 miles NNW of the antipode)

References

- (1) “An estimate of the size of the antipodal area in short-wave radio propagation”, Whale, JATP, Vol 9 No 2-3, August/September 1956
- (2) “An Experimental Investigation of Signal Strength in the Area Around a Transmitter’s Antipode”, Pipp and Webster, Radio Science, Vol 68D No 3, March 1964
- (3) “Measurements of Antipodal High-Frequency Radio Signals”, Banks, JGR, Vol 70 No 3, February 1965
- (4) Ionospheric Radio Propagation, Davies, 1965
- (5) “Radio-Wave Propagation to the Antipode”, Gerson, et al, Syracuse University Research Corp, February 1969

References continued

- (6) “Power distribution near the antipode of a short-wave transmitter”, Bold, JATP, Vol 31, April 1969
- (7) “The Influence of Chordal Paths on Signals Propagating to the near Antipode of an HF Radio Transmitter”, Bold, IEEE Trans A&P, AP-20 No 6, November 1972
- (8) “On the propagation of short waves over very long distances: predictions and observations”, Hortenbach and Rogler, Telecommunication Journal, Vol 46, June 1979
- (9) Ionospheric Radio, Davies, 1990
- (10) “Antipodal Propagation of Decameter Radio Waves”, Bryantsev, Radiophysics and Quantum Electronics, Vol 55 No 9, February 2013 (thanks NQ6Z for finding this one)

There are more, but these were sufficient to put together this presentation

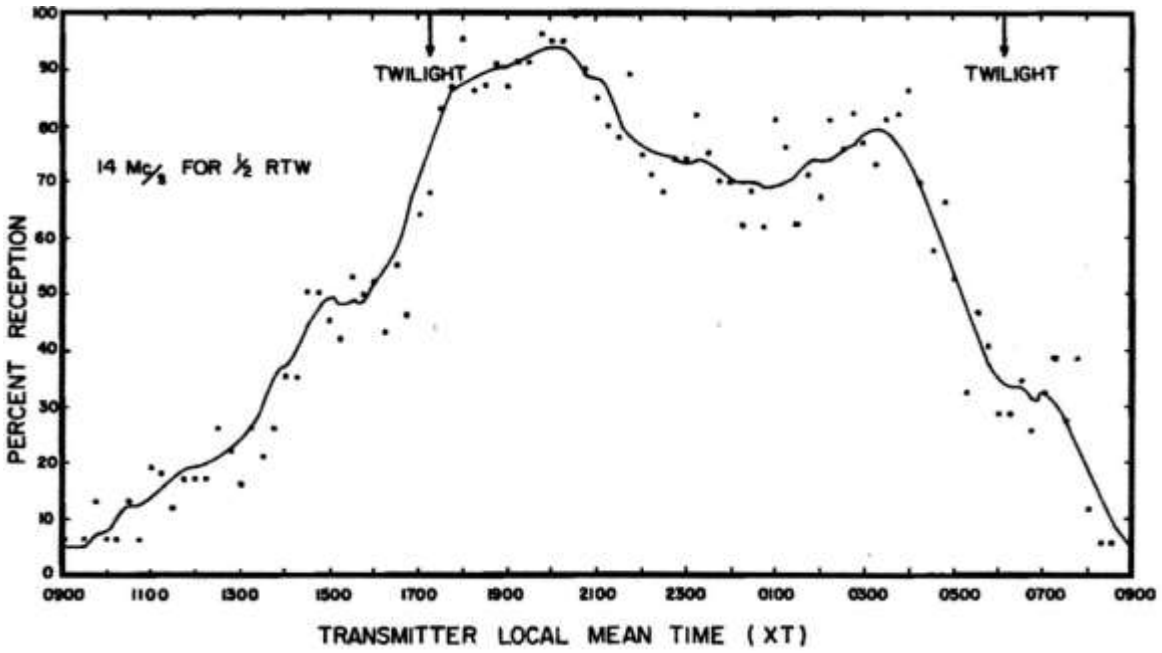
Topics

- I'll look at the following
  - Duration of openings
  - Amount of enhancement (focusing gain)
  - Area of enhancement
- I'll also discuss the contributions of chordal hops to antipodal propagation

Duration of Openings

Duration of Openings

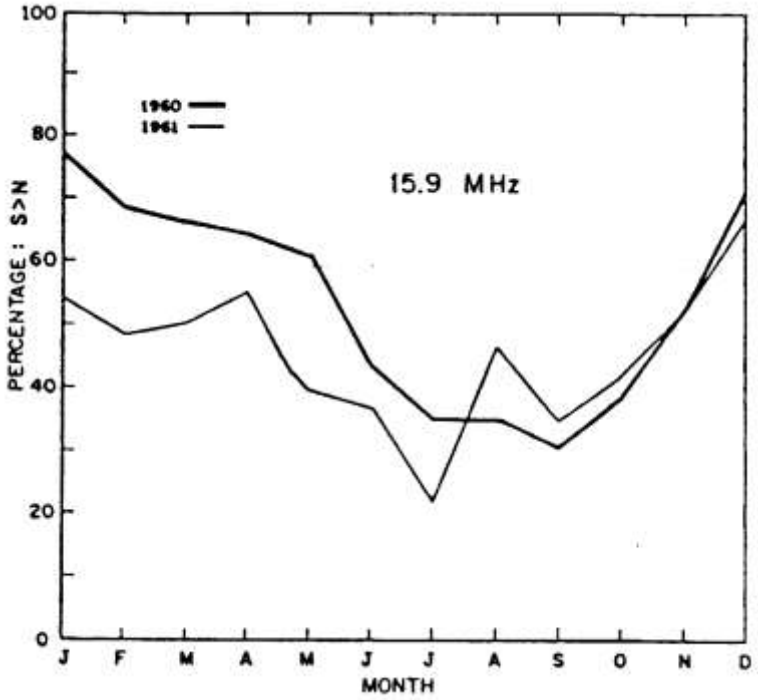
- Reference 3 (Measurements of Antipodal High-Frequency Radio Signals)
  - Transmitter in Texas, Receiver on ship in Indian Ocean at antipode
  - Many frequencies (data at 12, 14, 18 and 22 MHz)
  - October 1962, $R_{12} = 31$



Many hours of openings

Duration of Openings

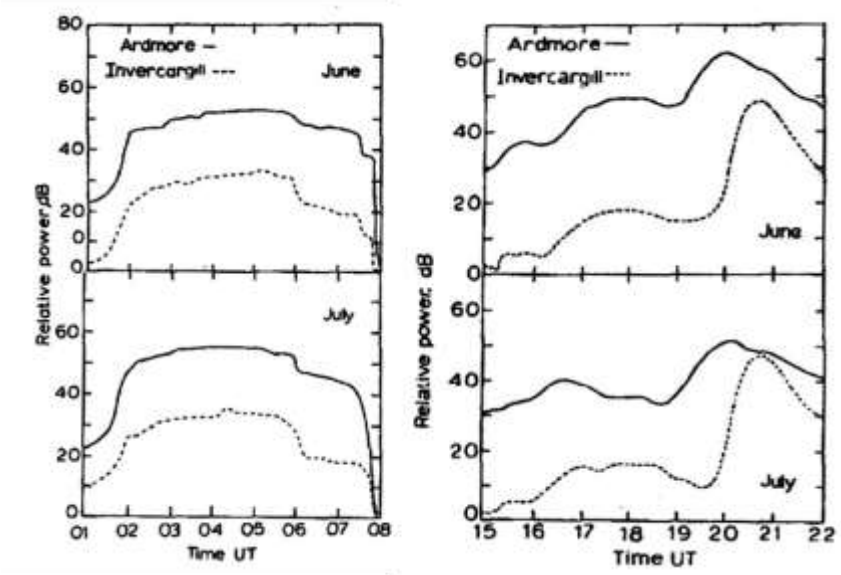
- Reference 5 (Radio-Wave Propagation to the Antipode)
  - Transmitter in Perth, Receiver in Bermuda (80 km from antipode)
  - 5.05 MHz, 15.905 MHz and 30.005 MHz
  - 1960 and 1961, R_{12} from 129 in 1/60 to 49 in 12/61



Many months of openings

Duration of Openings

- Reference 7 (The Influence of Chordal Paths on Signals Propagating to the near Antipode of an HF Radio Transmitter)
  - Transmitter in Tangier (Morocco), Receivers in Ardmore (New Zealand) and Invercargill (New Zealand)
  - 15.270 MHz
  - June and July 1969, R_{12} = 106

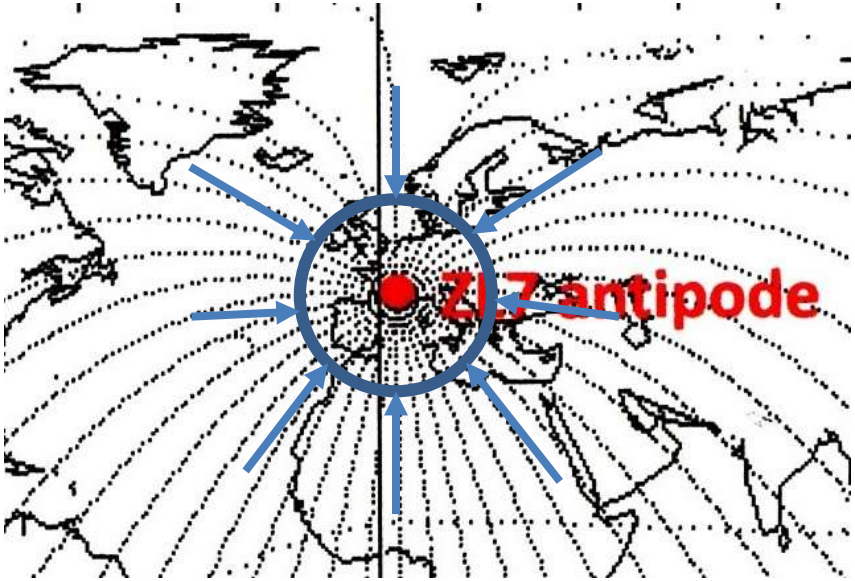


- **Ardmore is 156 km from antipode**
- **Invercargill is 1288 km from antipode**
- **Antipode has a bit more hours of openings**

Duration of Openings – Why?

- Use VOACAP to understand why duration of openings can be long
- But VOACAP (and all other programs) can't do predictions to the exact antipode because they don't know which heading to use
- Solution: draw a small radius circle around the antipode
  - I used 30 km
- Run predictions from ZL7 to points on this circle
- ZL7 is 44.0S/176.5W, antipode is 44.0N/3.5E
- I used eight points on the circle
- Smoothed sunspot number of 114 (Sept 2001)
- Plot signal powers $\geq$ -98 dBm (~S4)

ZL7 Antipode



30 km radius circle
NOT TO SCALE!

Into the antipode from the North, Northeast, East, Southeast, South, Southwest, West, Northwest

20-Meter Results at Antipode

Signals ≥ S4

incoming direction at antipode on 20m																								
	N					-85	-86	-86	-88	-96					-96	-89	-84	-85	-92	-94					
	NE					-89	-91								-93	-85	-84	-81	-77	-79	-86	-98			
	E					-92	-93									-91	-84	-82	-86	-79	-81	-93			
	SE			-97	-95	-95	-96									-96	-93	-98	-96	-83	-89	-92			
	S		-98	-87	-90	-87	-94												-87	-88	-90				
	SW		-98	-91	-85	-81	-76	-86	-89									-94							
	W		-92	-82	-78	-75	-74	-77	-83	-92								-88	-93						
	NW			-96			-84	-81	-83	-88								-88	-91	-88					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
												time, UTC													

- Duration of openings
  - Two directions (from the N and from the SE) give 11 hours of openings (per my ≥ S4 criteria)
  - All directions combined give 16 hours of openings

15-Meter Results at Antipode

Signals ≥ S4

incoming direction at antipode on 15m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N								-87	-85	-85	-85	-88	-90	-98				-79	-87	-98				
NE						-93	-86	-85	-88	-89	-89	-90	-93	-98					-79					
E					-98															-92	-87	-95		
SE	-90	-95			-91																-89	-90	-90	-89
S	-87	-84	-86			-83	-90	-97											-96	-89	-88	-91	-91	-90
SW	-85	-85	-85	-92		-98	-90											-97	-95	-93	-88	-89	-88	-87
W							-90	-94																
NW									-89	-85	-90						-92	-93						

time, UTC

- Duration of openings
  - One direction (from the SW) gives 13 hours of openings
  - All directions combined give 22 hours of openings

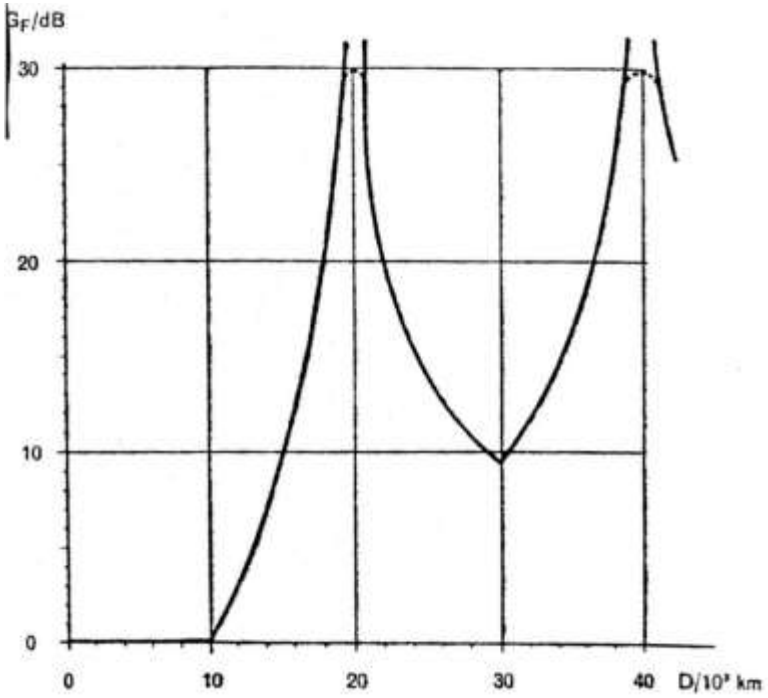
Summary: Duration of Openings

Duration of openings is longer at the antipode due to many available paths throughout the day

Amount of Enhancement

Amount of Enhancement

- Also known as focusing gain
- Perhaps you've seen this plot



Infinite gain at the antipode!

- Assumes a perfectly spherical Earth and a perfectly conducting shell around the Earth

Amount of Enhancement

- Kenneth Davies said:
  - *"Because of the large geographic variations in ionospheric structure, antipodal focusing does not appear to be of great practical importance"* in Ionospheric Radio Propagation 1965
  - *"If the Earth and ionosphere were perfectly smooth and concentric, energy could reach the antipode by all possible great circle paths. However, because of great geographic variations in ionospheric conditions, such focusing does not appear to be of great practical importance"* in Ionospheric Radio 1990
- So we have one end of the spectrum at infinite gain and the other end of the spectrum at no practical importance

Is there an in-between?

20-Meter Results at Antipode

Signals ≥ S4

incoming direction at antipode on 20m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
N					-85	-86	-86	-88	-96					-96	-89	-84	-85	-92	-94					
NE					-89	-91								-93	-85	-84	-81	-77	-79	-86	-98			
E					-92	-93									-91	-84	-82	-86	-79	-81	-93			
SE			-97	-95	-95	-96									-96	-93	-98	-96	-83	-89	-92			
S		-98	-87	-90	-87	-94												-87	-88	-90				
SW		-98	-91	-85	-81	-76	-86	-89									-94							
W		-92	-82	-78	-75	-74	-77	-83	-92								-88	-93						
NW			-96			-84	-81	-83	-88								-88	-91	-88					
												time, UTC												

- Focusing gain
  - At 0600 UTC, all eight directions are open
  - Signal strengths differ by up to 22 dB (-74 dBm to -96 dBm)
- For a “normal” path, VOACAP adds the median powers from each mode (1F2, 2E, 2F2, etc)
  - To paraphrase George Lane, there’s no theoretical justification for this, but there is good agreement with measurements
- If (big if) all 8 signals are in-phase, we get -71.3 dBm

At 0600 UTC, not just eight directions

15-Meter Results at Antipode

Signals ≥ S4

incoming direction at antipode on 15m																								
	N								-87	-85	-85	-85	-88	-90	-98				-79	-87	-98				
	NE						-93	-86	-85	-88	-89	-89	-90	-93	-98					-79					
	E					-98															-92	-87	-95		
	SE	-90	-95			-91																-89	-90	-90	-89
	S	-87	-84	-86			-83	-90	-97											-96	-89	-88	-91	-91	-90
	SW	-85	-85	-85	-92		-98	-90											-97	-95	-93	-88	-89	-88	-87
	W							-90	-94																
	NW									-89	-85	-90						-92	-93						
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		time, UTC																							

- Focusing gain
  - At six times (07z, 08z, 19z, 20z, 21z, 22z), four of the eight directions are open
    - One of the best appears to be 2100 UTC with -87, -89, -88 -88 dBm signals
  - If (big if) all 4 signals are in-phase, we get -81.9 dBm

At 2100 UTC, not just four directions

- VOACAP and Proplab Pro (ray tracing) do not have sufficient resolution to determine phase

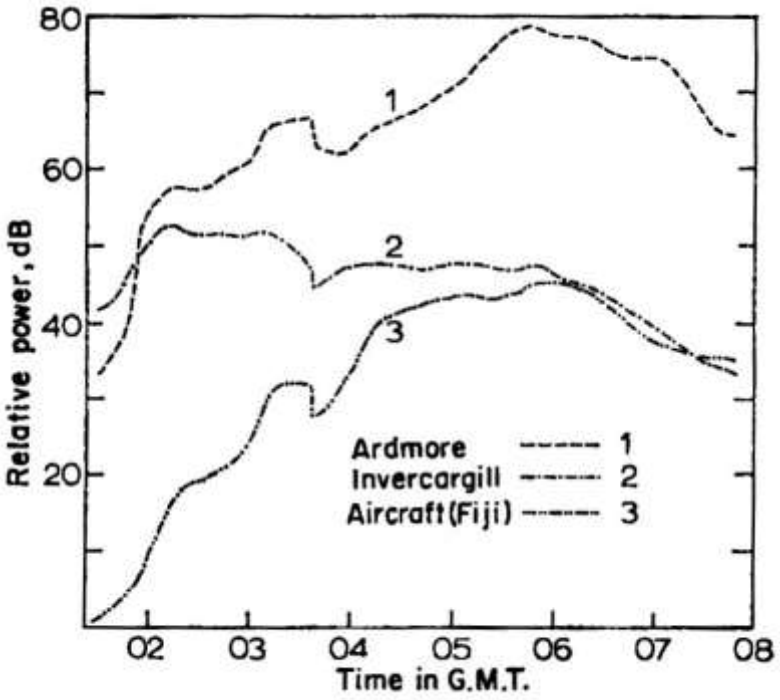
Amount of Enhancement

- Reference 5 (Radio-Wave Propagation to the Antipode)
  - Transmitter in Perth, Receivers in Bermuda (80 km from antipode), Rome, NY (1700 km from antipode) and Washington D.C. (1700 km from antipode)
  - 15.905 MHz and 30.005 MHz
  - 1960 and 1961, R_{12} from 129 in 1/60 to 49 in 12/61
- No data presented in terms of signal strength
  - But one of their conclusions was that the signal strength was higher at the antipode compared to the other two stations

Amount of Enhancement

- Reference 6 (Power distribution near the antipode of a short-wave transmitter)
  - Transmitter in Tangier (Morocco), Receivers in Ardmore (New Zealand – 156 km from antipode), Invercargill (New Zealand – 1288 km from antipode) and Fiji (2027 km from antipode)
  - 11.79 MHz
  - May 1968, R_{12} = 108

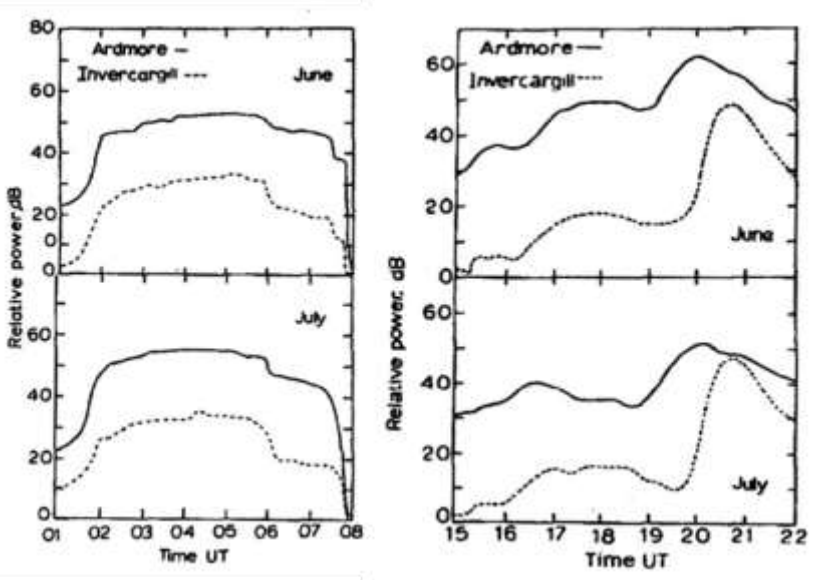
Antipode definitely has a stronger signal most of the time



Amount of Enhancement

- Reference 7 (The Influence of Chordal Paths on Signals Propagating to the near Antipode of an HF Radio Transmitter)
  - Transmitter in Tangier (Morocco), Receivers in Ardmore (New Zealand) and Invercargill (New Zealand)
  - 15.270 MHz
  - June and July 1969, R_{12} = 106

- **Ardmore is 156 km from antipode**
- **Invercargill is 1288 km from antipode**
- **Antipode has stronger signal by some 20 dB**



Summary: Amount of Enhancement

There appears to be a definite enhancement at the antipode – one paper suggests 20 dB

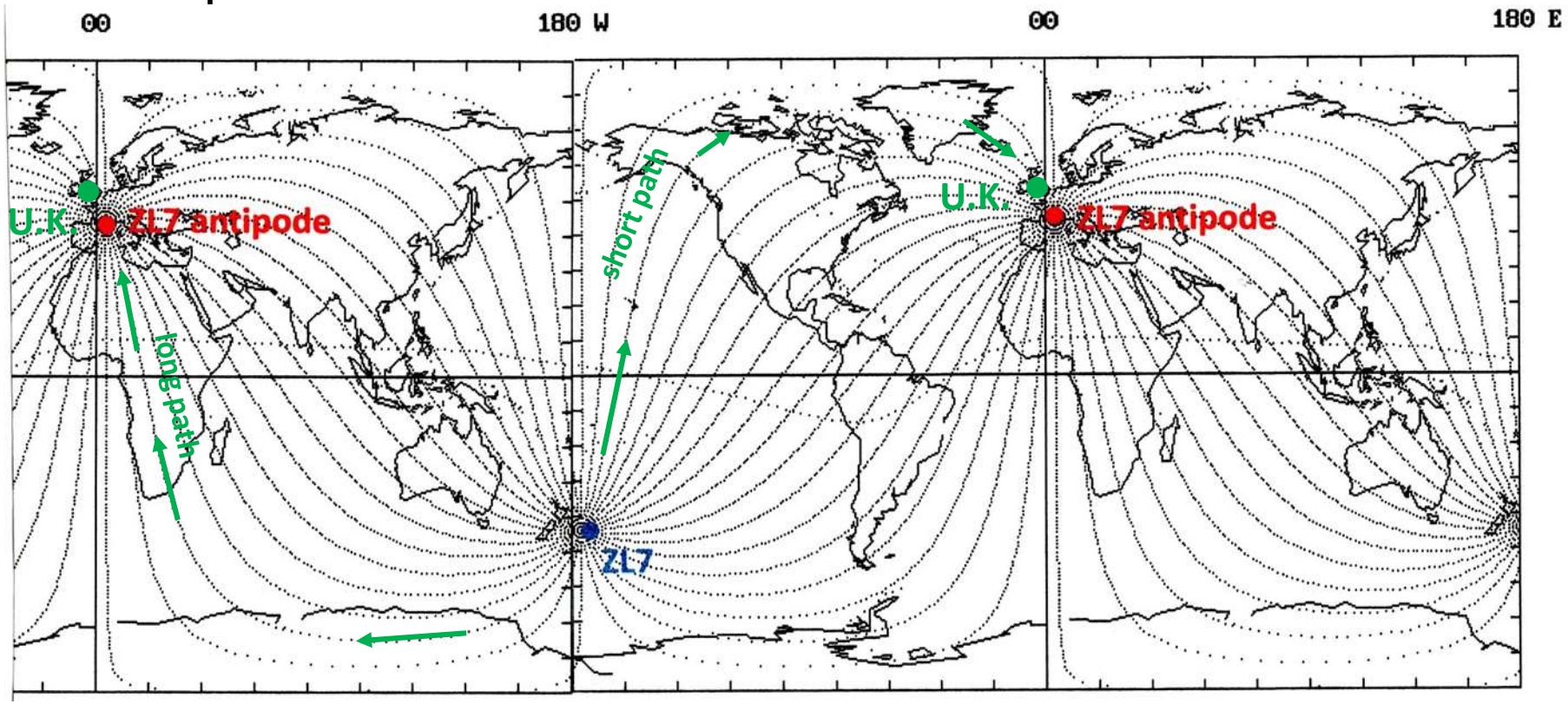
Area of Enhancement

Area of Enhancement

- Conclusions from the references
  - 550 km radius - reference 1 – theoretical
    - Criteria - no limit on direction of rays received
  - 500 km radius – reference 2 - measurement
    - Criteria - strength constant out to 500 km, then decreases
  - < 1700 km radius – reference 5 – measurement
    - Criteria unknown since strengths unknown
  - 500 km radius – reference 6 – theoretical
    - Criteria – less than 7 dB drop in strength
    - Introduces the concept of scattering into the area near the antipode
  - < 1288 km – reference 7 – measurement
    - Criteria - 20 dB difference in strength
  - 600 km radius – reference 8 – measurement
    - Criteria – less than 5dB drop in strength

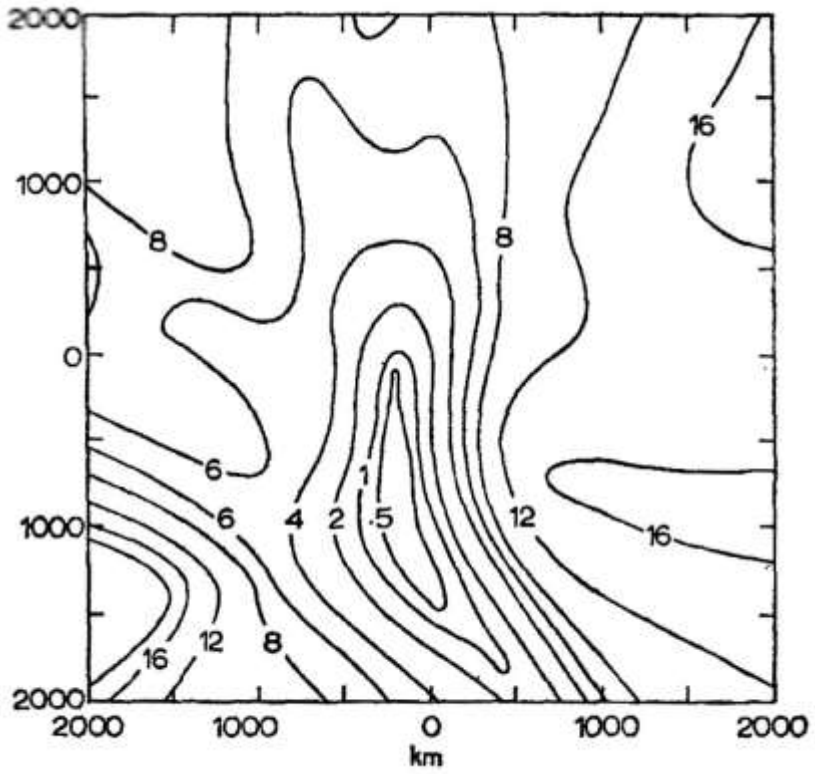
Area of Enhancement

- There are only two paths from ZL7 to the U.K.
  - Short path (20º) and long path (200º)
- How can there be an enhancement similar to that at the antipode?



Scatter Is Likely Involved

- Reference 6 goes into detail
  - Ground scatter and ionospheric scatter



- Theoretical power distribution at Tangier antipode (0,0) on 11.79 MHz at 0200 UTC in May 1968
- “2” is 2 dB down from max signal strength
- Area of enhancement is a subjective call

Summary: Area of Enhancement

Looks like it's within a 500-600 km or so radius of the antipode

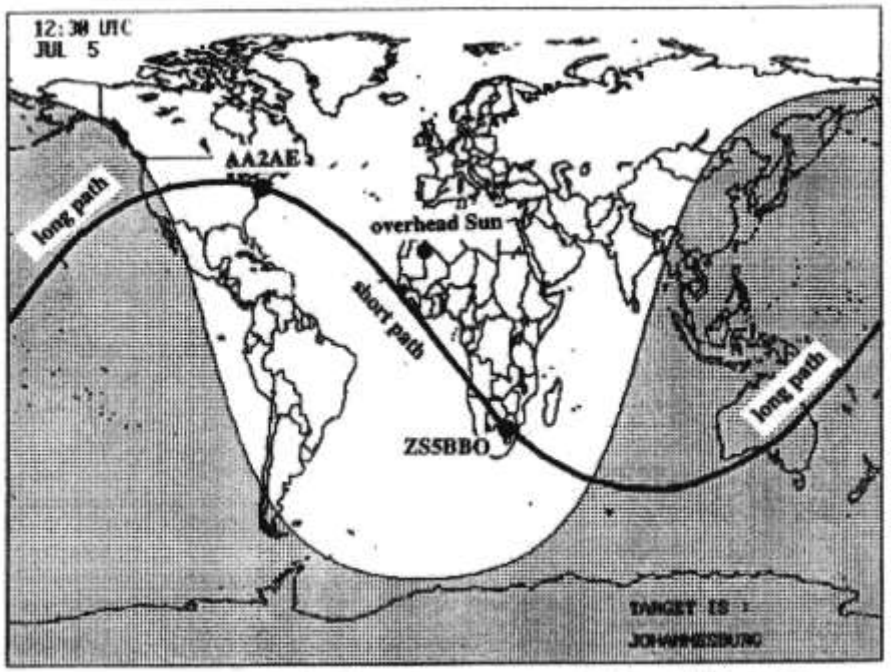
This is a subjective call – how much signal strength reduction is the criteria?

A Confusing Contributor

- Bold's 1972 paper - "The Influence of Chordal Paths on Signals Propagating to the near Antipode of an HF Radio Transmitter"
- What's a chordal path?
  - It's a path that does not incur as much absorption and ground reflection loss as a multi-hop path
  - Tilts in the ionosphere appear to enable a chordal path
  - Tilts occur at sunrise and at sunset

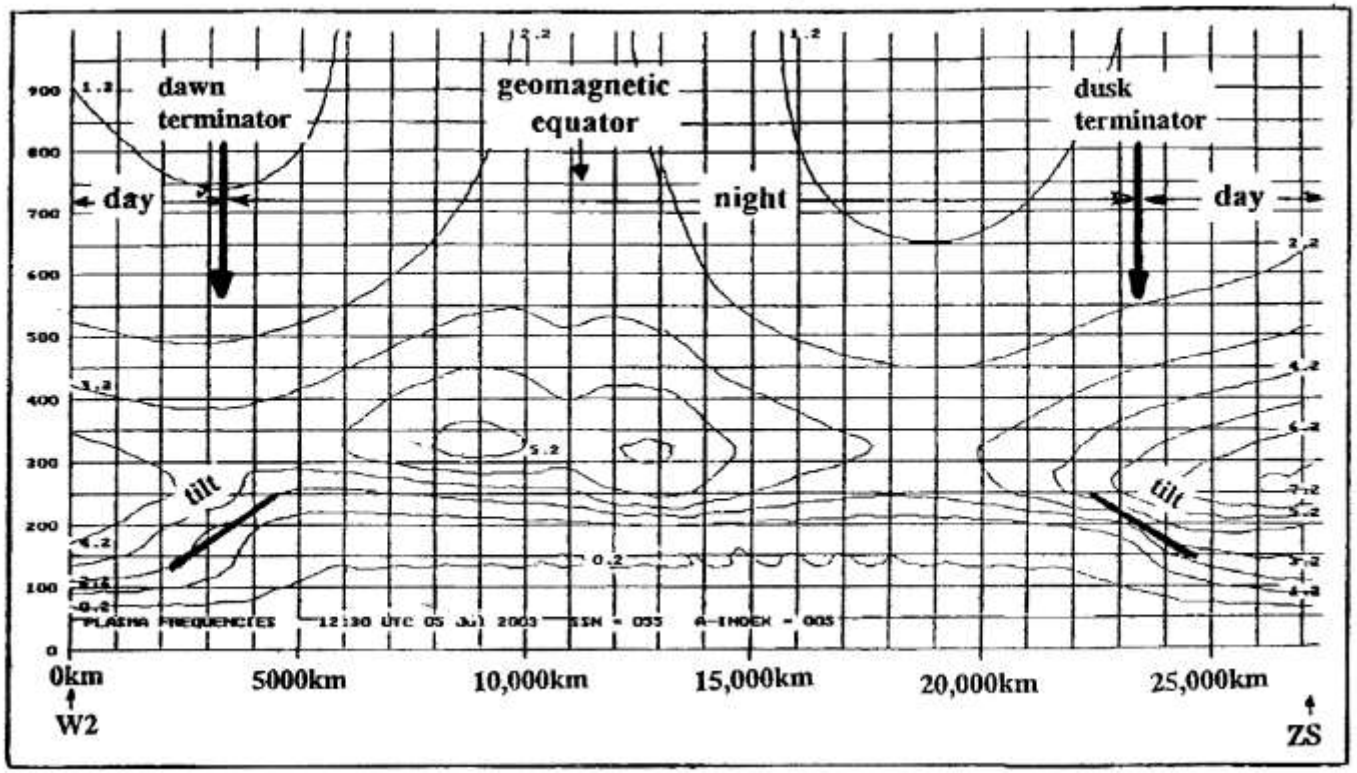
A 20m Long Path QSO

- In 2003 I analysed a 20m long-path QSO between W2 and ZS5



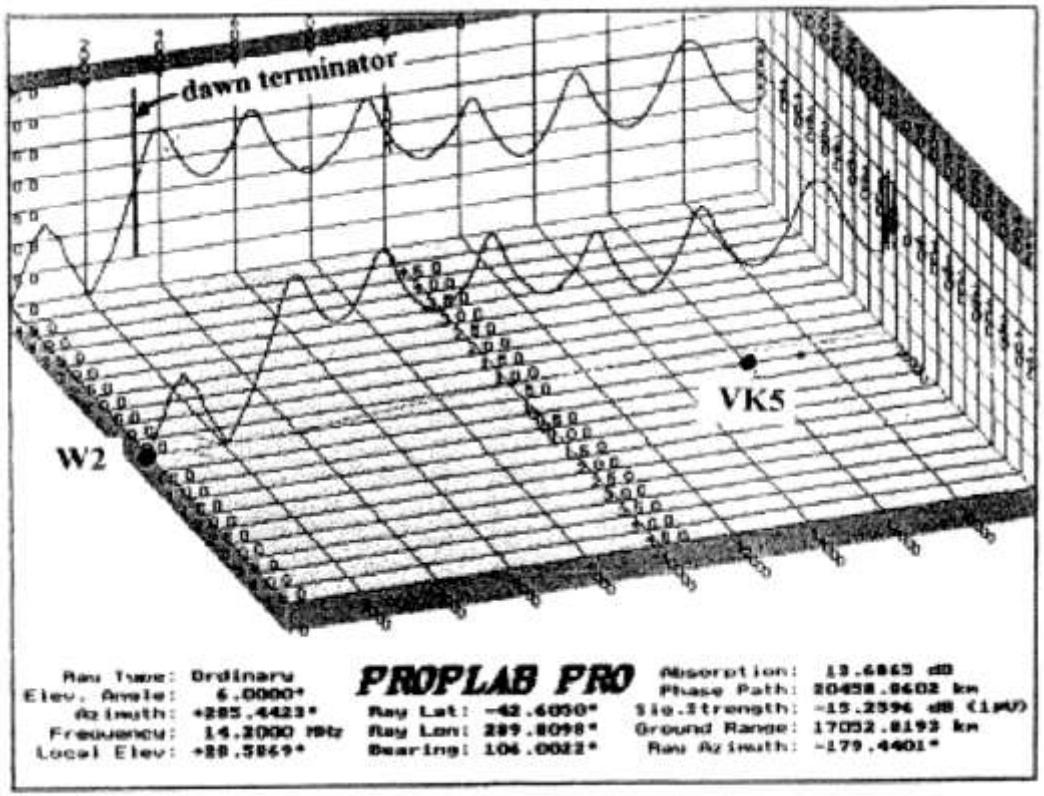
- W2 reported ZS5 signal at S7
- VOACAP short path – prediction below SØ
- VOACAP long path – better, but still below SØ

Ionosphere – W2 to ZS5



- Note the tilts at sunrise (W2 end) and at sunset (ZS5 end)

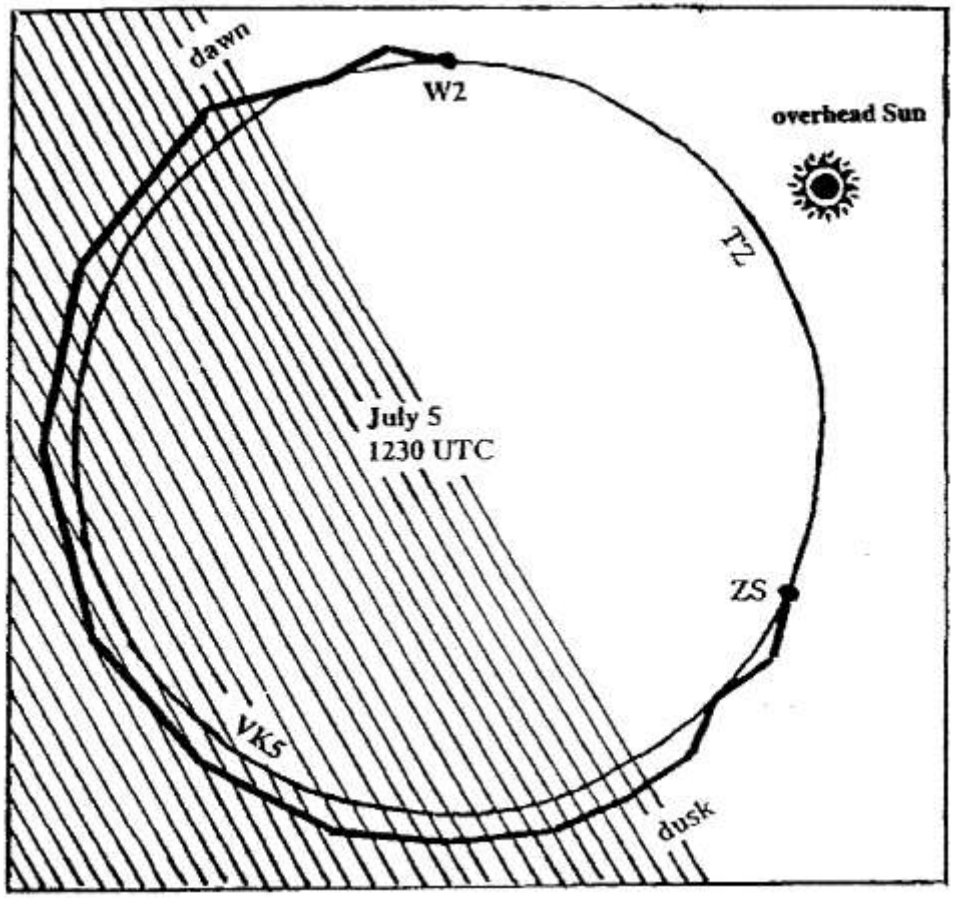
Ray Tracing – W2 to ZS5



- Less transits through absorbing region
- Less ground reflections
- Estimated signal strength now S6
- Chordal hops can increase signal strength

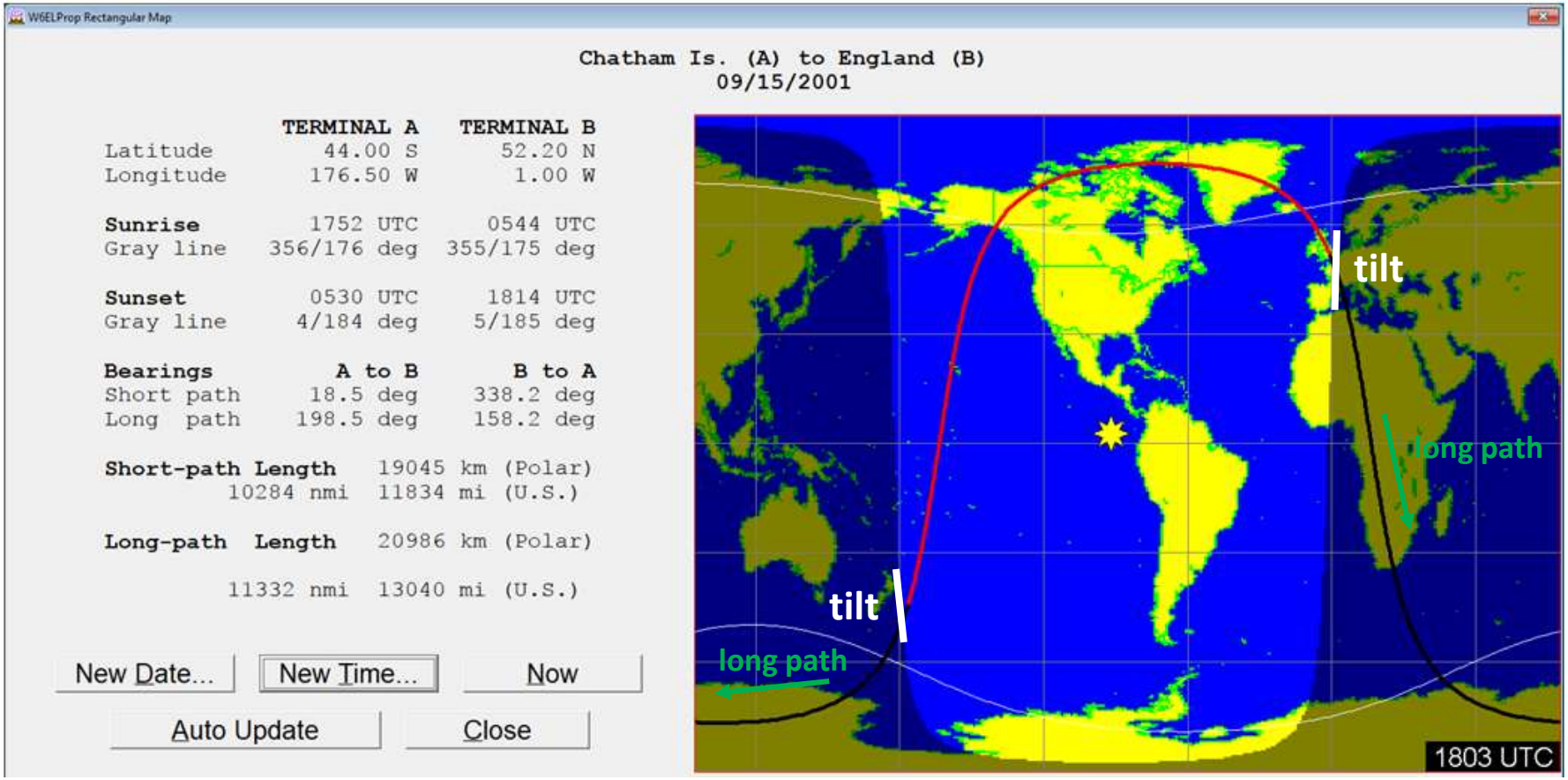
Ray trace out of W2 end
Tilts enable chordal hops
(ray trace out of ZS5 end is similar)

Chordal Hop Concept



- Are tilts in the ionosphere in the right place from ZL7 to the ZL7 antipode and to the U.K.?
- YES!

ZL7 to the U.K. Via Long Path



Similar tilts at ZL7 sunset and U.K. sunrise via short path

Chordal Hop Contribution

- Are the reported signal strength enhancements at and near antipodal locations due to focusing gain and/or chordal hops?
- I think the answer is both
  - Focusing gain (including scatter) is most prevalent and can occur over many hours
  - Chordal hops contribute for short periods when the locations are at sunrise/sunset

Overall Summary

- Antipodal enhancement can help
  - Longer duration openings
  - Enhancements up to 20 dB suggested
  - Enhancements out to 500-600 km or more from the antipode
- Contact me at k9la@arrl.net
- Visit my web site https://k9la.us
  - "*Propagation to the Antipode Revisited*" in the HF link
  - "*20M Ionosphere-Ionosphere Mode*" in the HF link

RSGB 2017 Convention