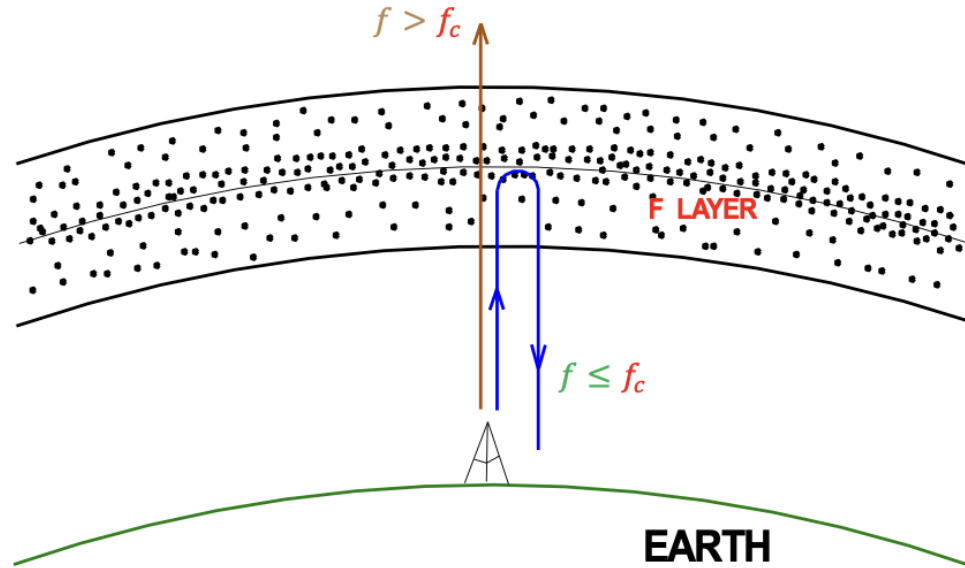
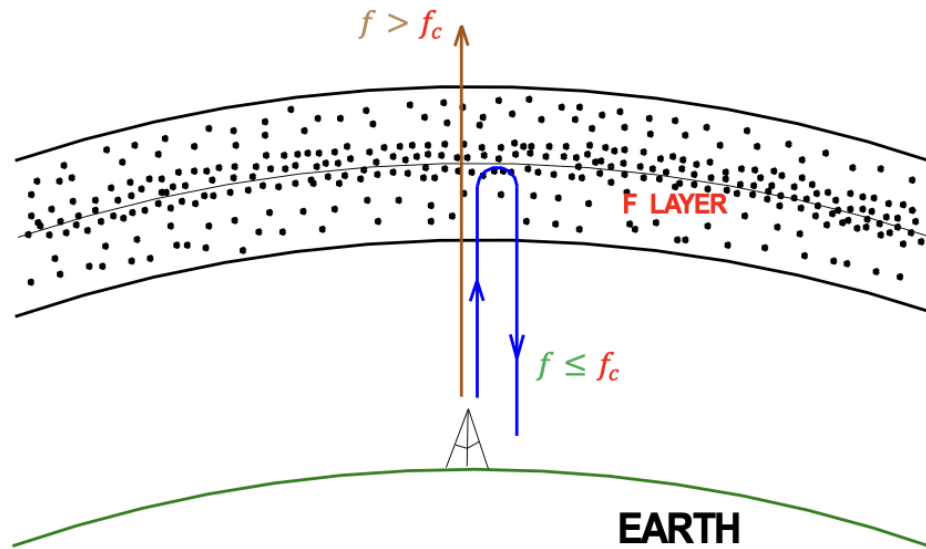


NVIS vs Critical Frequency



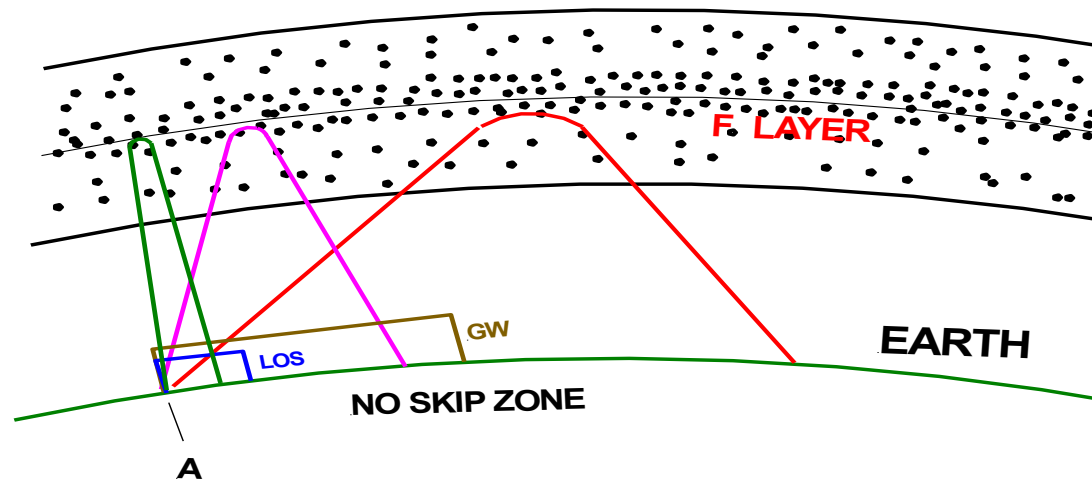
Ken Larson KJ6RZ
May 1, 2025
www.skywave-radio.org

Critical Frequency



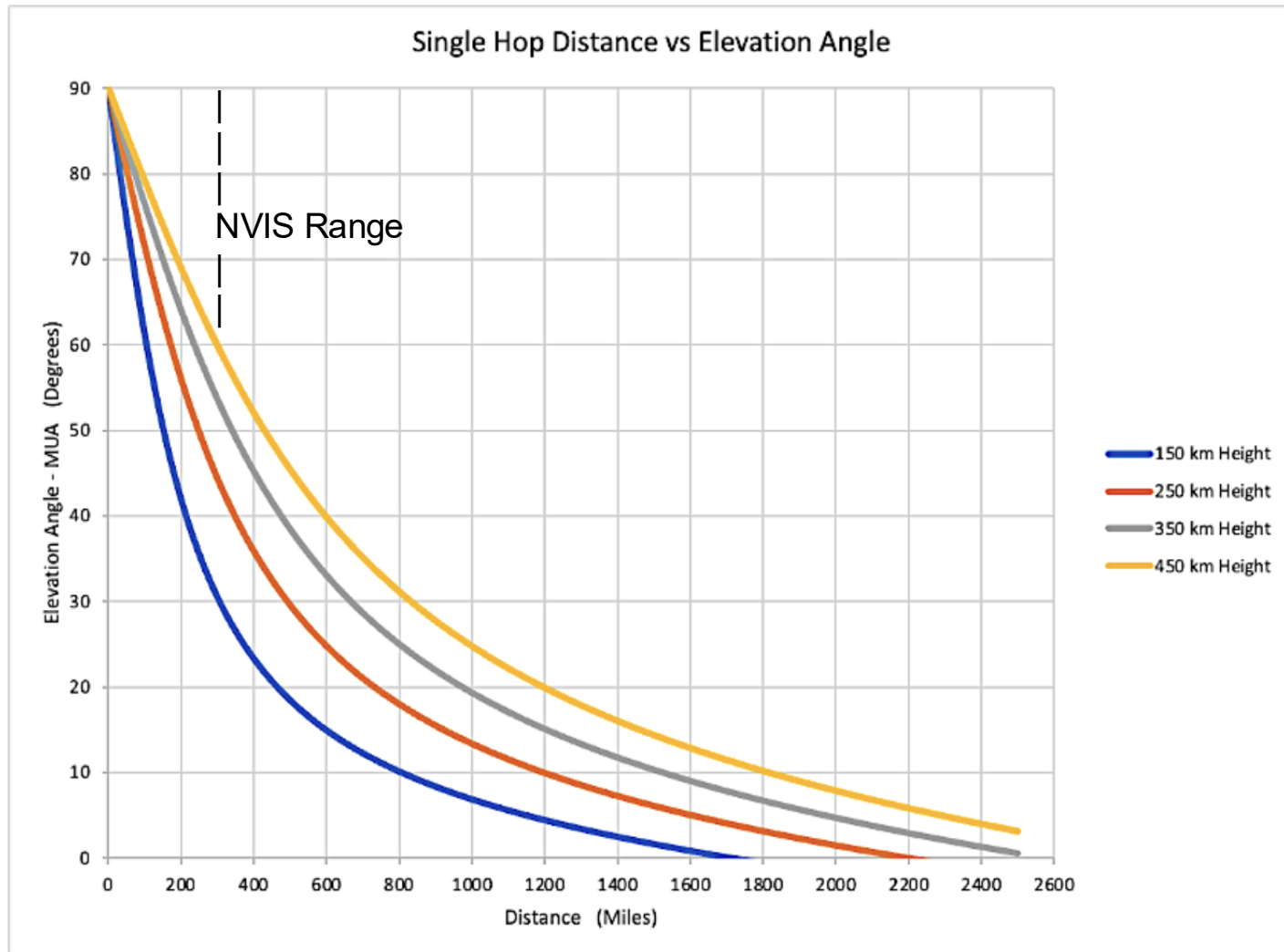
- Critical Frequency f_c is the highest frequency signal that can be transmitted straight up and reflected back down to Earth, illustrated by the blue trace
- All signals lower in frequency than f_c will also be reflected back to Earth
- But, signals higher in frequency transmitted straight up will penetrate the ionosphere and be lost to outer space as illustrated by the brown trace

NVIS Propagation



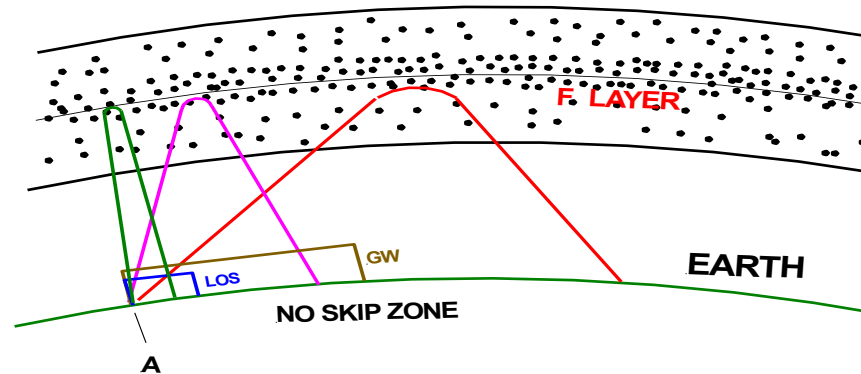
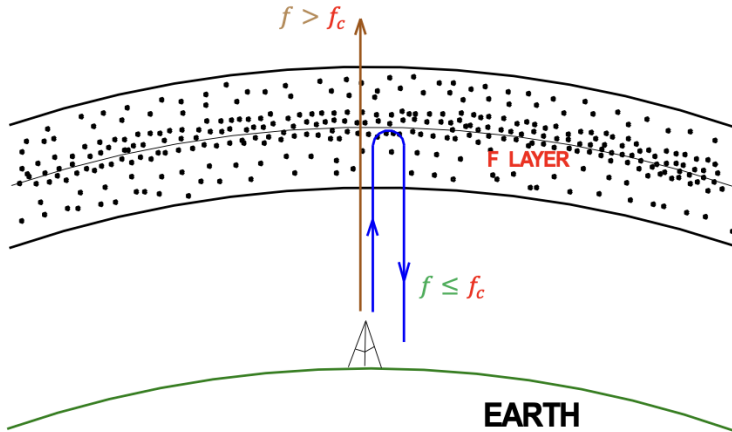
- Signals transmitted at high elevation angles, generally greater than 60° , are classified as Near Vertical Incident Skywave (NVIS) transmissions (green, magenta, and red signal paths)
- NVIS provides short range propagation well suited to emergency communications
- NVIS transmissions cover a distance from a few miles out 200 miles or so from the transmitting station
- NVIS competes with Line of Sight (LOS) and Ground Wave (GW) propagation for close in HF communications producing potentially harmful multipath interference

NVIS Range



- At an elevation angle of 60° , the NVIS propagation range is 200 to 300 miles

NVIS Propagation vs Critical Frequency



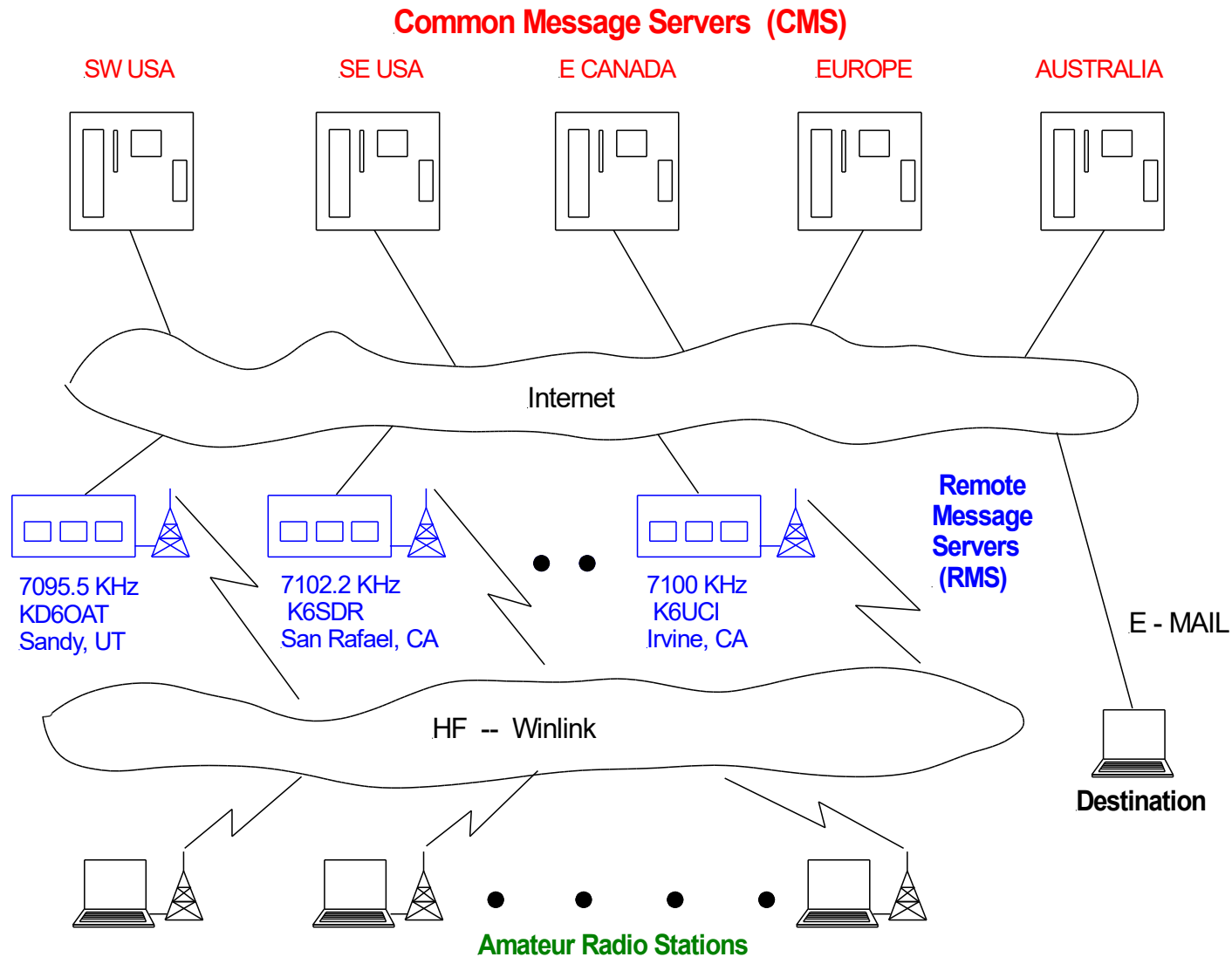
- NVIS propagation is only possible if the critical frequency f_c is above the NVIS transmitting frequency $f \rightarrow$ this makes sense
- Critical frequency is the highest frequency that can be transmitted straight up and reflected back to Earth
- A higher frequency signal transmitted nearly straight up (an NVIS signal) will penetrate the ionosphere and be lost to outer space
- Thus NVIS communications is only possible for frequencies below the critical frequency as verified by the follow set of tests

NVIS vs Critical Frequency Test

Date:	4/2/25						
	Sun Rise	5:38	Sun Set	18:15	SFI	180	NVIS vs Critical Frequency
					fcF2	9 MHz	
					X-Ray	C1.3	
					Kp	3.67	
					Proton	3.01	
					SSN	158	
Time PDT	Frequency MHZ	Call	Distance Miles	Contact Duration (sec)	Power Watts	Antenna	Comments
1806	7.1021	W6BI	11	16	25	Yellow	Simi Valley, CA
1807	7.1065	KD6LLB	13	18			Oxnard, CA
1819	7.1015	NR6V	20	16			Northridge, CA
1825	7.1005	AJ7C	31	23			Culver City, CA
1830	7.1000	KN6BKT	48	18			San Gabriel, CA
1813	7.1060	N7OP	52	24			Lancaster, CA
1815	7.0835	KF6NYM	55	16			Santa Barbara, CA
1831	7.1000	K6UCI	73	18			Irvine, CA
1821	7.0997	N0CSM	213	17			Pahrump, NV
1832	7.1020	K00000	252	18			North Las Vegas, NV
1833	7.1000	K9ONR	311	18			Walnut Creek, CA
1834	7.1015	KD7NHC	320	28			Wellington, NV (SE Carson City)
1824	7.1022	K6SDR	332	18			San Rafael, CA

- NVIS vs Critical Frequency test 18:06 thru 18:24 PDT April 2, 2025, Antenna: 40 meter inverted V with apex at 32 ft, VARA digital protocol used to connect to Winlink RMS stations (next slide)
- Contact duration is the time to connect to a RMS station, send a message, and disconnect
- For this test a contact consisted of a Connect followed by a Disconnect since the message field was empty, i.e. it did not contain any text
- A contact test duration greater than 40 seconds is considered a very poor connection unsuitable for sending text messages
- An ABORT occurred if a connection started but could not be completed
- NC = No Connection, the station could not be contacted

Winlink Network

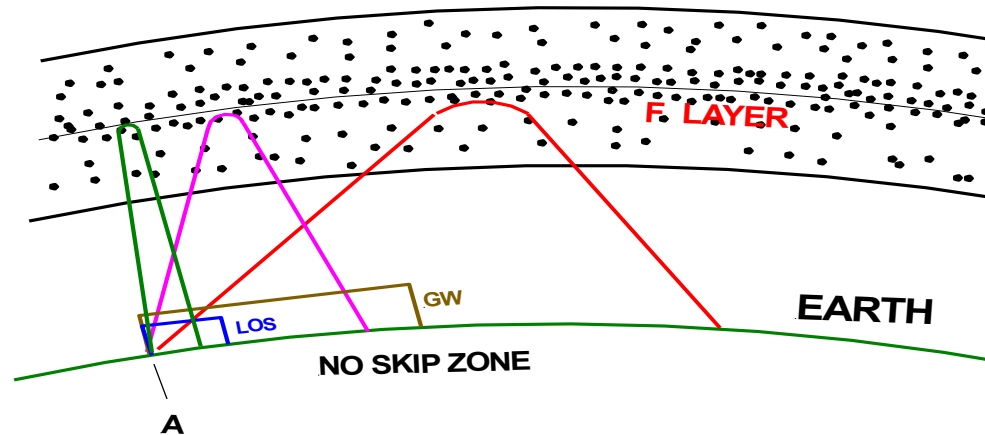


Summary NVIS vs Critical Frequency

Date:	4/2/25				SFI	180	
					X-Ray	C1.4	
					Kp	3	
					Proton	2.06	
					SSN	158	
		Contact Duration (sec)	Contact Duration (sec)		Contact Duration (sec)	Contact Duration (sec)	
		at	at		at	at	
Call	Miles	fcF2 = 9 MHz	fcF2 = 8 MHz	Freq NVIS	fcF2 = 6.5 MHz	fcF2 = 5.5 MHz	Comments
W6BI	11	16	18	7.1021	38	38	Simi Valley, CA
KD6LLB	13	18	18	7.1065	28	101	Oxnard, CA
NR6V	20	16	16	7.1015	ABORT	NC	Northridge, CA
AJ7C	31	23	22	7.1005	ABORT	ABORT	Culver City, CA
KN6BKT	48	18	19	7.1000	ABORT	NC	San Gabriel, CA
N7OP	52	24	24	7.1060	NC	NC	Lancaster, CA
KF6NYM	55	16	16	7.0835	36	51	Santa Barbara, CA
K6UCI	73	18	16	7.1000	87	86	Irvine, CA
N0CSM	213	17	19	7.0997	NC	NC	Pahrump, NV
K00000	252	18	18	7.1020	18	86	North Las Vegas, NV
K9ONR	311	18	30	7.1000	NC	NC	Walnut Creek, CA
KD7NHC	320	28	28	7.1015	26	126	Wellington, NV (SE Carson City)
K6SDR	332	18	16	7.1022	47	26	San Rafael, CA

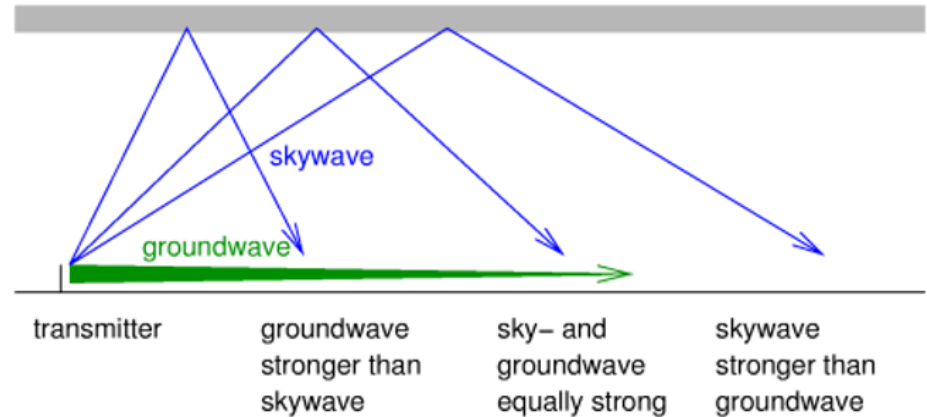
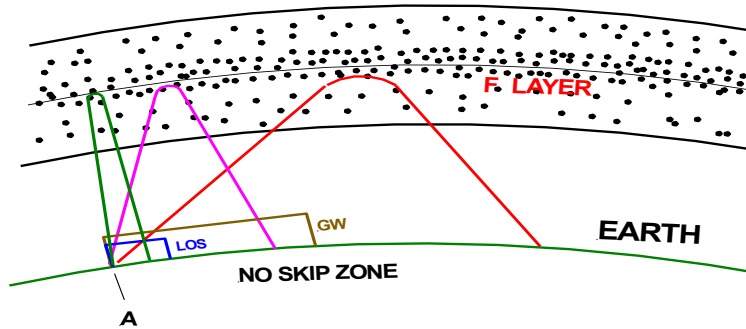
- In this test connections were excellent at critical frequencies (f_c F2) **above** the 40 meter NVIS operating frequency of ~ 7.1 MHz, as illustrated by f_c F2 at 8 and 9 MHz
- At critical frequencies of 8 and 9 MHz most contact durations were less than 25 seconds
- Connections were either impossible (ABORT and NC) or extremely poor (contact durations much greater than 40 seconds) when the critical frequency was **below** the 40 meter NVIS operating frequency, that is at critical frequencies of 6.5 and 5.5 MHz

Line of Sight and Ground Wave Propagation



- Line of Sight (LOS) and Ground Wave (GW) propagation are always present
- The distance covered by HF line of sight propagation is essentially the same as 2 meter LOS
- The range of ground wave propagation increases as the electrical conductivity of the ground increases. It is greatest over sea water and smooth flat fertile ground
- The range of ground wave propagation over smooth flat ground on 40 meters is ~ 50 miles and 15 – 20 miles in regions with low mountains
- Simi Valley and Oxnard were certainly in GW range accounting for communications with these two locations even when $f_c < f_o$, although the quality was poor (long durations)
- Santa Barbara could have been in GW range since some of the propagation path to Santa Barbara was over highly conductive ocean water

NVIS Multipath Interference

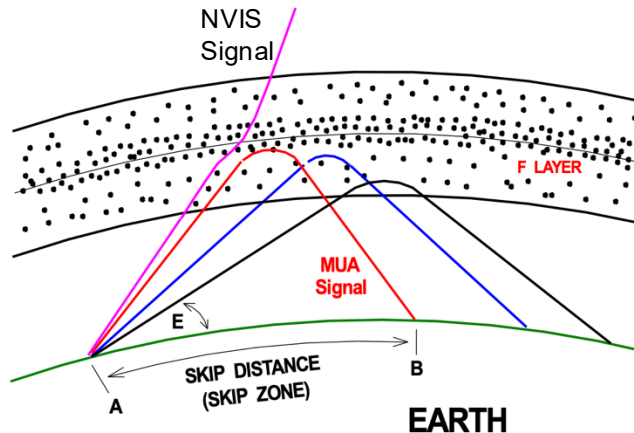


source: PA3FWM

- Multipath interference between line of sight (LOS), ground wave (GW), and NVIS propagation can occur disrupting communicating with close in stations
- Simi Valley, Oxnard, and perhaps Santa Barbara were susceptible to multipath interference
- However, this did not seem to be a problem
- At $f_c > f_o$ NVIS signals were apparently much stronger than GW resulting in no multipath interference and good connections
- When NVIS disappeared, $f_c < f_o$, communications reverted to poor GW propagation

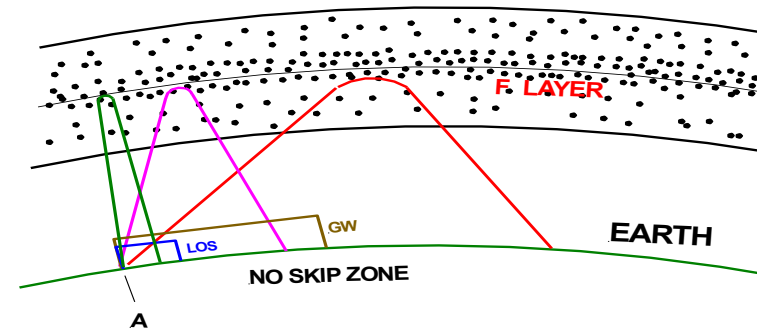
Presence of a Skip Zone

Oblique Propagation



Skip Zone Present if $f_c < f_o$.

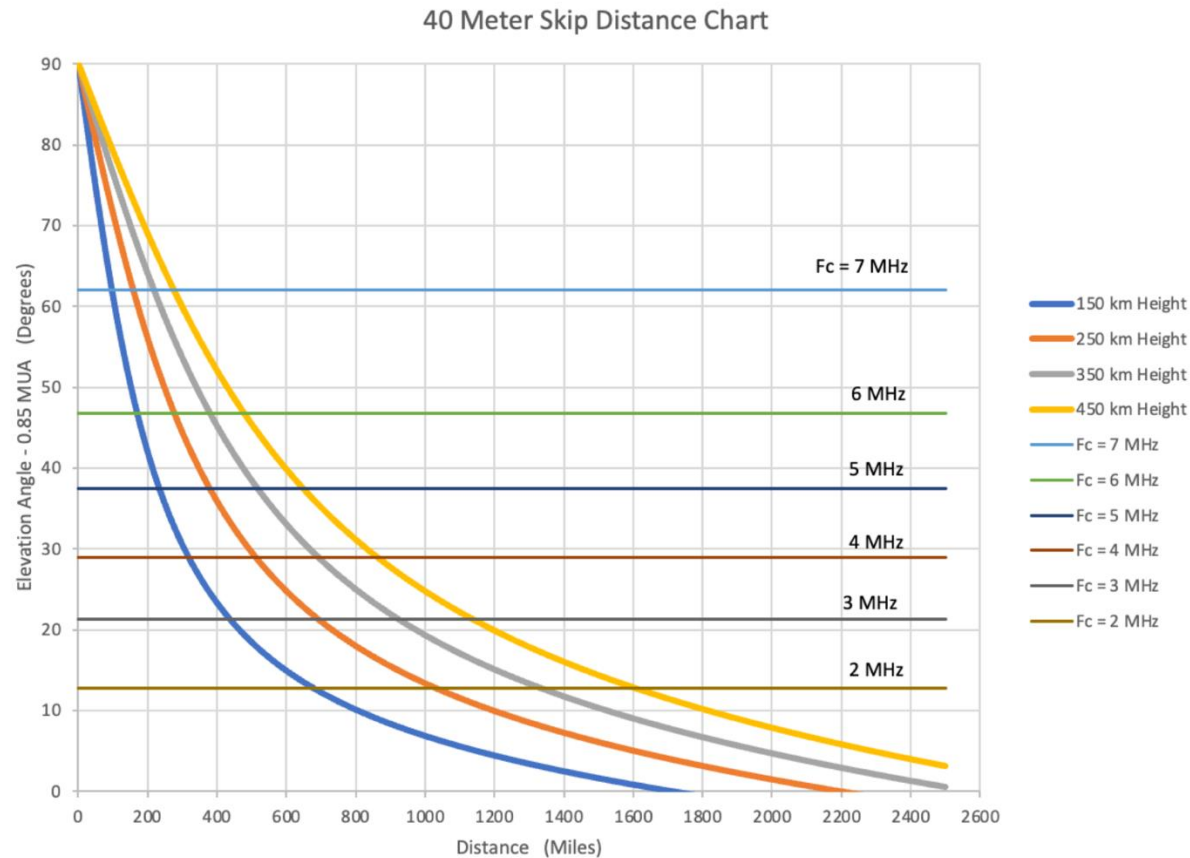
NVIS Propagation



No Skip Zone if $f_c > f_o$

- A skip zone always exists when the ionosphere's critical frequency f_c is **below** the station's operating frequency f_o that is if $f_c < f_o$
- NVIS signals are lost to outer space when a skip zones is present
- There will not be a skip zone if the critical frequency is **above** the operating frequency $f_c > f_o$
- In this case all transmitted signals return to Earth including NVIS signals

40 Meter Skip Distance



- At the time of the test with $5.5 \text{ MHz} < f_c < 6.5 \text{ MHz}$ a skip zone was present
- At the ionosphere's height of around 350 km, the skip zone was about 300 to 450 miles
- San Rafael at 332 miles could have been at the outer edge of the skip zone accounting for some what shorter San Rafael contact durations

9 MHz NVIS vs Critical Frequency Data

Date:	4/2/25						
					SFI	180	NVIS vs Critical Frequency
	Sun Rise	5:38	Sun Set	18:15	fcF2	9 MHz	
					X-Ray	C1.3	
					Kp	3.67	
					Proton	3.01	
					SSN	158	
Time PDT	Frequency MHz	Call	Distance Miles	Contact Duration (sec)	Power Watts	Antenna	Comments
1806	7.1021	W6BI	11	16	25	Yellow	Simi Valley, CA
1807	7.1065	KD6LLB	13	18			Oxnard, CA
1819	7.1015	NR6V	20	16			Northridge, CA
1825	7.1005	AJ7C	31	23			Culver City, CA
1830	7.1000	KN6BKT	48	18			San Gabriel, CA
1813	7.1060	N7OP	52	24			Lancaster, CA
1815	7.0835	KF6NYM	55	16			Santa Barbara, CA
1831	7.1000	K6UCI	73	18			Irvine, CA
1821	7.0997	N0CSM	213	17			Pahrump, NV
1832	7.1020	KO0OOO	252	18			North Las Vegas, NV
1833	7.1000	K9ONR	311	18			Walnut Creek, CA
1834	7.1015	KD7NHC	320	28			Wellington, NV (SE Carson City)
1824	7.1022	K6SDR	332	18			San Rafael, CA

- At a critical frequency of 9 MHz
- 40 meter (7.1 MHz) NVIS contacts were very good throughout a 332 mile range, with most durations < 20 sec
- 40 meter NVIS operation was very good at a 9 MHz critical frequency

8 MHz NVIS vs Critical Frequency Data

Date:	4/2/25				SFI	180	
					fcF2	8 MHz	
					X-Ray	C1.2	
					Kp	3.67	
					Proton	3.08	
					SSN	158	
Time PDT	Frequency MHz	Call	Distance Miles	Contact Duration (sec)	Power Watts	Antenna	Comments
1934	7.1021	W6BI	11	18	25	Yellow	Simi Valley, CA
1935	7.1065	KD6LLB	13	18			Oxnard, CA
1945	7.1015	NR6V	20	16			Northridge, CA
1946	7.1005	AJ7C	31	22			Culver City, CA
1950	7.1000	KN6BKT	48	19			San Gabriel, CA
1939	7.1060	N7OP	52	24			Lancaster, CA
1940	7.0835	KF6NYM	55	16			Santa Barbara, CA
1951	7.1000	K6UCI	73	16			Irvine, CA
1956	7.0997	N0CSM	213	19			Pahrump, NV
1941	7.1020	KO0OOO	252	18			North Las Vegas, NV
1944	7.1000	K9ONR	311	30			Walnut Creek, CA
1953	7.1015	KD7NHC	320	28			Wellington, NV (SE Carson City)
1943	7.1022	K6SDR	332	16			San Rafael, CA

- At a critical frequency of 8 MHz
- 40 meter (7.1 MHz) NVIS contacts very good throughout the typical 200 mile NVIS range, with most durations < 20 sec
- Contacts not quite as good at ranges over 300 miles
- 40 meter NVIS operation also very good at a critical frequency of 8 MHz

6.5 MHz NVIS vs Critical Frequency Data

Date:	4/2/25				SFI	180	
					fcF2	6.5 MHz	
					X-Ray	C1.5	
					Kp	3.67	
					Proton	2.72	
					SSN	158	
Time PDT	Frequency MHZ	Call	Distance Miles	Contact Duration (sec)	Power Watts	Antenna	Comments
2130	7.1021	W6BI	11	38	25	Yellow	Simi Valley, CA
2131	7.1065	KD6LLB	13	28			Oxnard, CA
2134	7.1015	NR6V	20	ABORT			Northridge, CA
2136	7.1005	AJ7C	31	ABORT			Culver City, CA
2140	7.1000	KN6BKT	48	ABORT			San Gabriel, CA
2143	7.1060	N7OP	52	NC			Lancaster, CA
2145	7.0835	KF6NYM	55	36			Santa Barbara, CA
2146	7.1000	K6UCI	73	87			Irvine, CA
2149	7.0997	N0CSM	213	NC			Pahrump, NV
2150	7.1020	KO0OOO	252	18			North Las Vegas, NV
2152	7.1000	K9ONR	311	NC			Walnut Creek, CA
2153	7.1015	KD7NHC	320	26			Wellington, NV (SE Carson City)
2156	7.1022	K6SDR	332	47			San Rafael, CA

- A critical frequency of 6.5 MHz was just below the 7.1 MHz operating frequency
- NVIS contacts should not be possible since the critical frequency was below the operating frequency
- This was generally the case for stations 20 miles and further away
- For these stations connections could not be completed (Abort), could not be made at all (NC), or the quality was very poor

More on 6.5 MHz NVIS vs Critical Frequency Data

Date:	4/2/25				SFI	180	
					fcF2	6.5 MHz	
					X-Ray	C1.5	
					Kp	3.67	
					Proton	2.72	
					SSN	158	
Time PDT	Frequency MHZ	Call	Distance Miles	Contact Duration (sec)	Power Watts	Antenna	Comments
2130	7.1021	W6BI	11	38	25	Yellow	Simi Valley, CA
2131	7.1065	KD6LLB	13	28			Oxnard, CA
2134	7.1015	NR6V	20	ABORT			Northridge, CA
2136	7.1005	AJ7C	31	ABORT			Culver City, CA
2140	7.1000	KN6BKT	48	ABORT			San Gabriel, CA
2143	7.1060	N7OP	52	NC			Lancaster, CA
2145	7.0835	KF6NYM	55	36			Santa Barbara, CA
2146	7.1000	K6UCI	73	87			Irvine, CA
2149	7.0997	N0CSM	213	NC			Pahrump, NV
2150	7.1020	KO0OOO	252	18			North Las Vegas, NV
2152	7.1000	K9ONR	311	NC			Walnut Creek, CA
2153	7.1015	KD7NHC	320	26			Wellington, NV (SE Carson City)
2156	7.1022	K6SDR	332	47			San Rafael, CA

- Communications with Simi Valley (11 mi), Oxnard (13 mi), and Santa Barbara (55 mi mostly over the ocean) were likely completed by ground wave propagation
- 40 meter operation not very good at a critical frequency of 6.5 MHz

5.5 MHz NVIS vs Critical Frequency Data

Date:	4/2/25				SFI	180	
					fcF2	5.5 MHz	
					X-Ray	C1.4	
					Kp	3	
					Proton	2.06	
					SSN	158	
Time PDT	Frequency MHz	Call	Distance Miles	Contact Duration (sec)	Power Watts	Antenna	Comments
2314	7.1021	W6BI	11	38	25	Yellow	Simi Valley, CA
2315	7.1065	KD6LLB	13	101			Oxnard, CA
2318	7.1015	NR6V	20	NC			Northridge, CA
2321	7.1005	AJ7C	31	ABORT			Culver City, CA
2324	7.1000	KN6BKT	48	NC			San Gabriel, CA
2325	7.1060	N7OP	52	NC			Lancaster, CA
2327	7.0835	KF6NYM	55	51			Santa Barbara, CA
2330	7.1000	K6UCI	73	86			Irvine, CA
2331	7.0997	N0CSM	213	NC			Pahrump, NV
2332	7.1020	KO0OOO	252	86			North Las Vegas, NV
2335	7.1000	K9ONR	311	NC			Walnut Creek, CA
2336	7.1015	KD7NHC	320	126			Wellington, NV (SE Carson City)
2339	7.1022	K6SDR	332	26			San Rafael, CA

- A critical frequency of 5.5 MHz was considerably below the 7.1 MHz operating frequency
- At this critical frequency 40 meter NVIS contacts should not be possible
- This is pretty much the case
- Communications with Simi Valley, Oxnard, and possibly Santa Barbara were most likely by means of ground wave propagation
- A relatively good connection was achieved to San Rafael 332 miles away

Conclusion

Date:	4/2/25				SFI	180	
					X-Ray	C1.4	
					Kp	3	
					Proton	2.06	
					SSN	158	
		Contact Duration (sec)	Contact Duration (sec)		Contact Duration (sec)	Contact Duration (sec)	
		at	at		at	at	
Call	Miles	fcF2 = 9 MHz	fcF2 = 8 MHz	Freq NVIS	fcF2 = 6.5 MHz	fcF2 = 5.5 MHz	Comments
W6BI	11	16	18	7.1021	38	38	Simi Valley, CA
KD6LLB	13	18	18	7.1065	28	101	Oxnard, CA
NR6V	20	16	16	7.1015	ABORT	NC	Northridge, CA
AJ7C	31	23	22	7.1005	ABORT	ABORT	Culver City, CA
KN6BKT	48	18	19	7.1000	ABORT	NC	San Gabriel, CA
N7OP	52	24	24	7.1060	NC	NC	Lancaster, CA
KF6NYM	55	16	16	7.0835	36	51	Santa Barbara, CA
K6UCI	73	18	16	7.1000	87	86	Irvine, CA
N0CSM	213	17	19	7.0997	NC	NC	Pahrump, NV
KO0OOO	252	18	18	7.1020	18	86	North Las Vegas, NV
K9ONR	311	18	30	7.1000	NC	NC	Walnut Creek, CA
KD7NHC	320	28	28	7.1015	26	126	Wellington, NV (SE Carson City)
K6SDR	332	18	16	7.1022	47	26	San Rafael, CA

- 40 meter NVIS operations very good at critical frequencies above the NVIS operating frequency of 7.1 MHz
- Good quality 40 meter communications was not possible at critical frequencies below the NVIS operating frequency of 7.1 MHz