Modes of Propagation on 6 Meters

Carl Luetzelschwab K9LA
e-mail: k9la@arrl.net
website: https://k9la.us

Heathkit Sixer HW-29A

More Vintage 6m Rigs

Gonset 6m Communicator

Heathkit SB-110

Heathkit Shawnee HW-10

Heathkit Seneca VHF-1

Knight TR-106 (W9XT e-mail)

If you've used one of these or the Sixer, I'd love to hear your story – k9la@arrl.net

Agenda

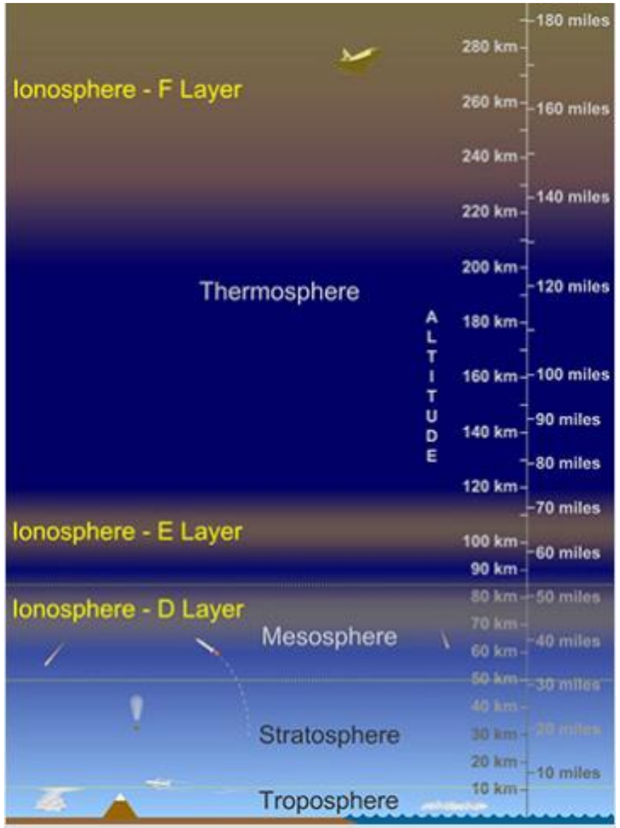
- Fundamentals of the atmosphere and the ionosphere
- List of 6m modes
    - I think I caught them all – or at least most of them ☺
- Review of all these modes
- Antenna considerations
    - Is there an optimum height?
- Cycle 25 status
    - How fast is Cycle 25 rising?
- References
    - Certainly not all of them, but a good start (I hope)

Fundamentals of the Atmosphere and the Ionosphere

How Does 50 MHz RF Get Back to Earth?

- Refraction
  - In the atmosphere
  - In the ionosphere
    - Amount of refraction (bending) inversely proportional to $(\text{frequency})^2$
    - The higher the frequency, the less the refraction – higher frequency needs more electrons
- Reflection in the ionosphere
  - Conductivity (σ) of an electron density is $\dfrac{4.5\text{E-9}\ N_{e/m3}}{\text{freq}_{\text{Hz}}}$
  - Many electrons needed for even poor conductivity at 50 MHz - most likely to occur with sporadic-E or a major auroral event
- Scatter
  - In the atmosphere
  - In the ionosphere
  - Results in more loss

Refraction in the Atmosphere/Ionosphere



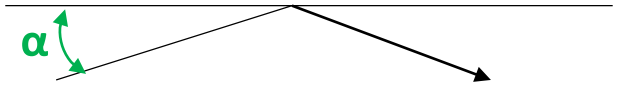
Regions of the ionosphere, showing the D, E and F layers.

Credit: UCAR Center for Science Education staff (Randy Russell)

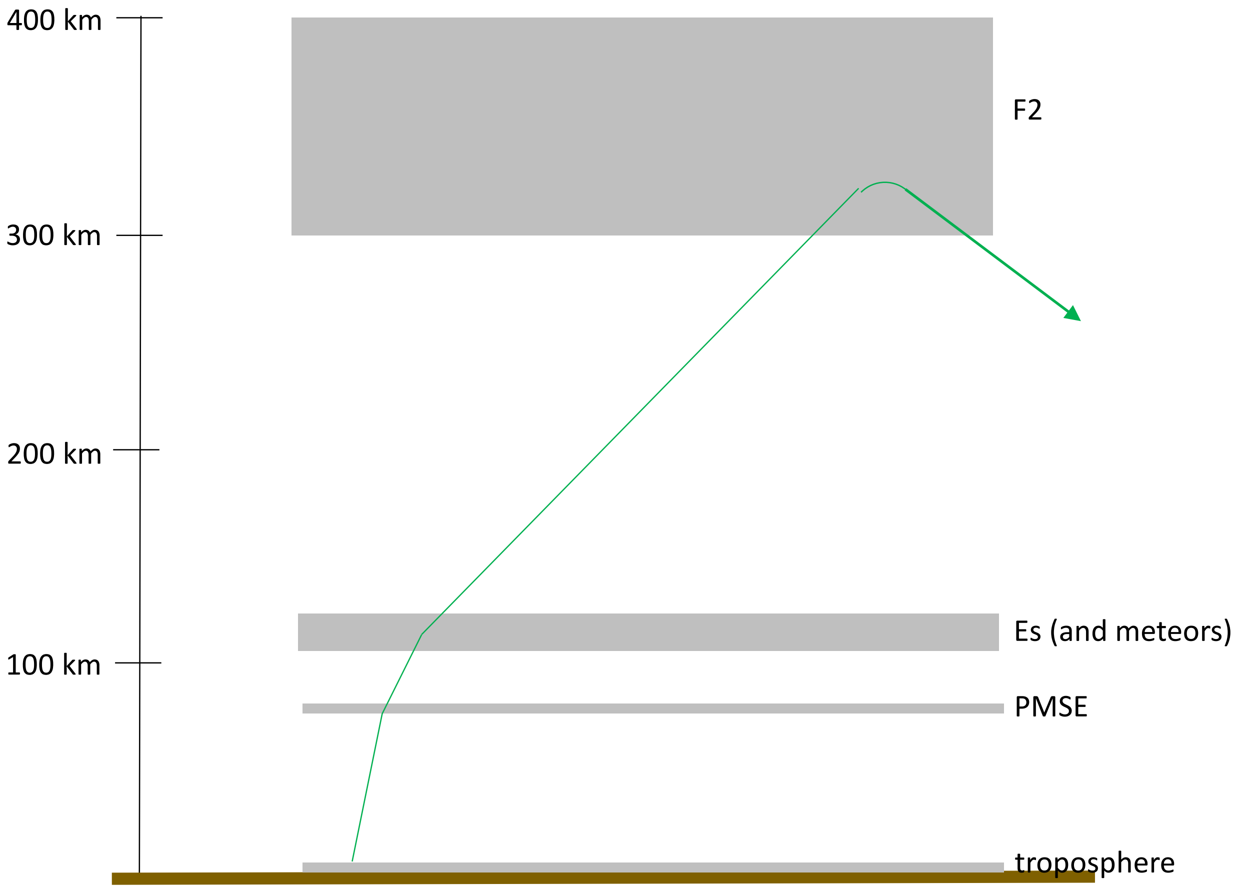
- Index of refraction of the atmosphere with no refraction (no bending) is 1.0 and an increasing number increases the refraction
    - Depends on pressure, temperature, water vapor
- Index of refraction of the ionosphere with no refraction is 1.0 and a decreasing number increases the refraction
    - Depends on electron density
    - The ionosphere has two indices of refraction – one for the ordinary wave and one for the extraordinary wave (but at 50 MHz, pretty much the same)
        - Due to the ionosphere being immersed in a magnetic field

Layers of the Atmosphere/Ionosphere

- We usually think of refraction from only one layer
- Each layer could bend the RF a bit
- What's important is the grazing angle on the highest layer



the smaller the α, the higher the MUF



List of 6m Modes

6m Modes

NON-ATMOSPHERIC AND NON-IONOSPHERIC

- line-of-sight
- ground wave

ATMOSPHERIC

- tropospheric scatter
- tropospheric ducting
- SSSP
- meteor scatter

IONOSPHERIC

- aurora/auroral-E
- ionospheric scatter
- E hops
- sporadic-E
- F2 hops
- TEP
- Ducting/chordal hops
- combos of E & F hops
- above-the-MUF
- skewed paths

EXTRATERRESTRIAL

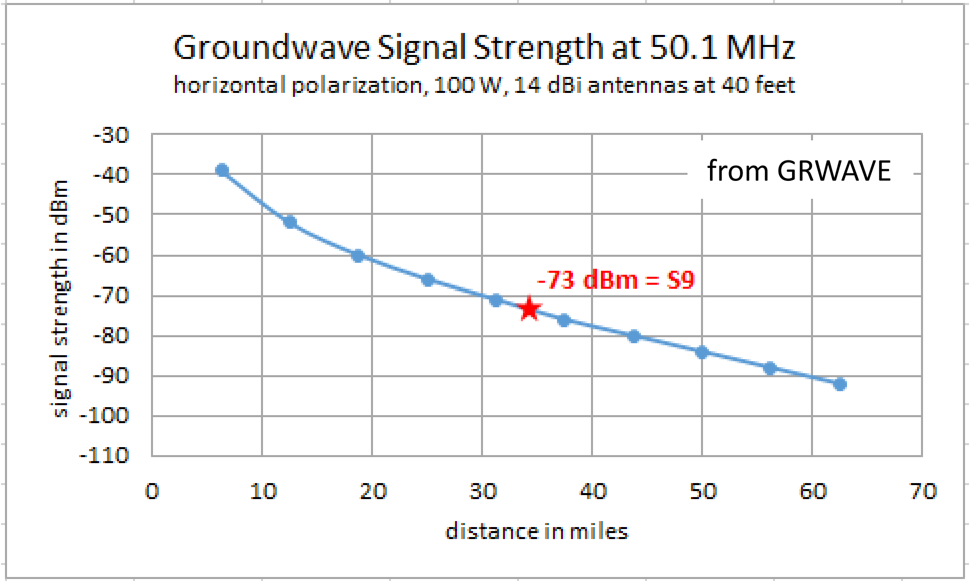
- moon bounce

Review of the Modes

Line-of-Sight and Groundwave

- Line-of-sight
  - Distance = $1.415\sqrt{H_{xmt}} + 1.415\sqrt{H_{rcv}}$
    - Distance in miles, H in feet
    - Antennas at 40 feet >> 18 miles
    - Includes atmospheric refraction
  - Does not include obstructions to horizon

- Groundwave
  - From the CCIR program GRWAVE
    - CCIR is International Consultative Committee for Radiocommunications (part of the ITU)
  - 60 miles or so
    - I don't know how believable these results are



Tropospheric Scatter

- Nomogram for estimating loss
  - Dean O. Morgan W2NNT, Tropospheric Scatter Techniques for the Amateur, QST, March 1957
  - Isotropic antennas
- Use Q65
- $Pr_{dBm} = Pt_{dBm} + G_{t\text{-}ant} + G_{r\text{-}ant} - \text{loss} + 14$

from nomogram

receive signal power

Q65 advantage over CW

Example: 1kW and 14 dBi antennas gives 1000 miles with Pr = -126.2 dBm

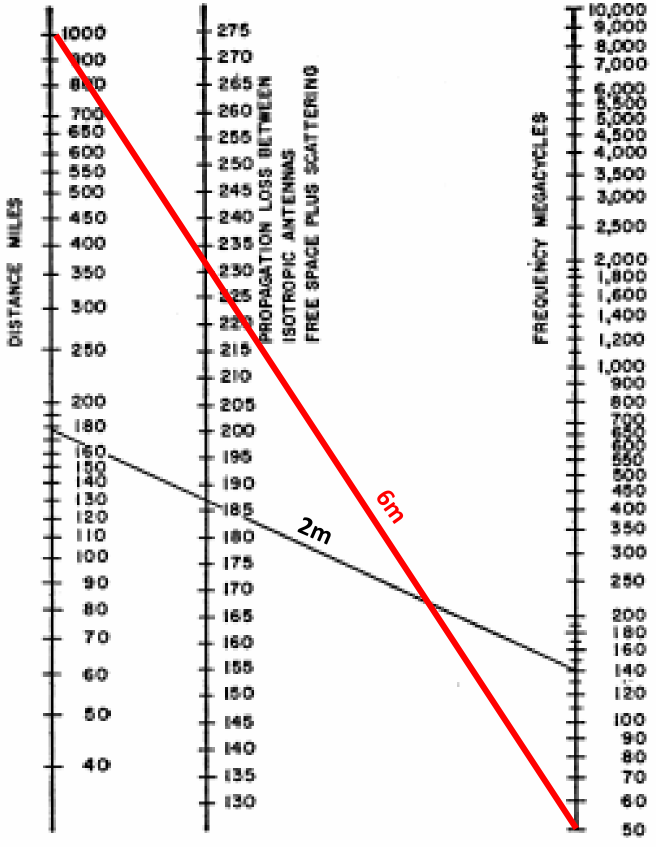
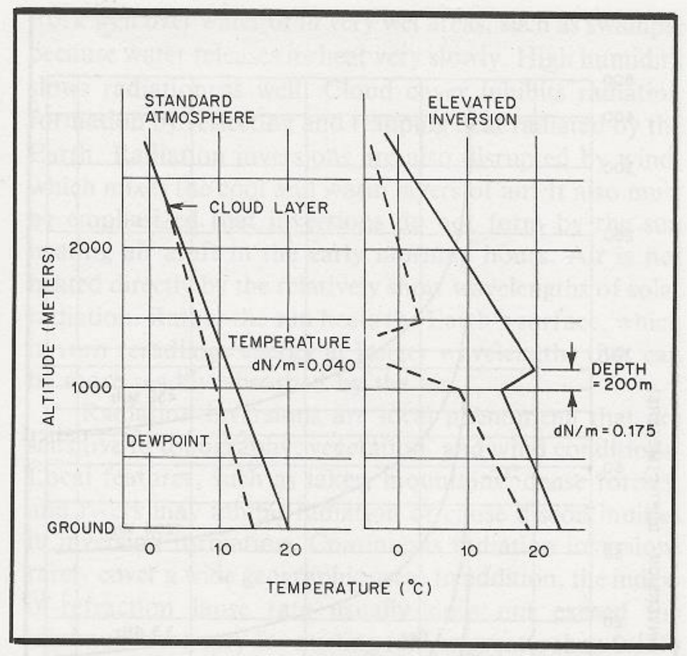


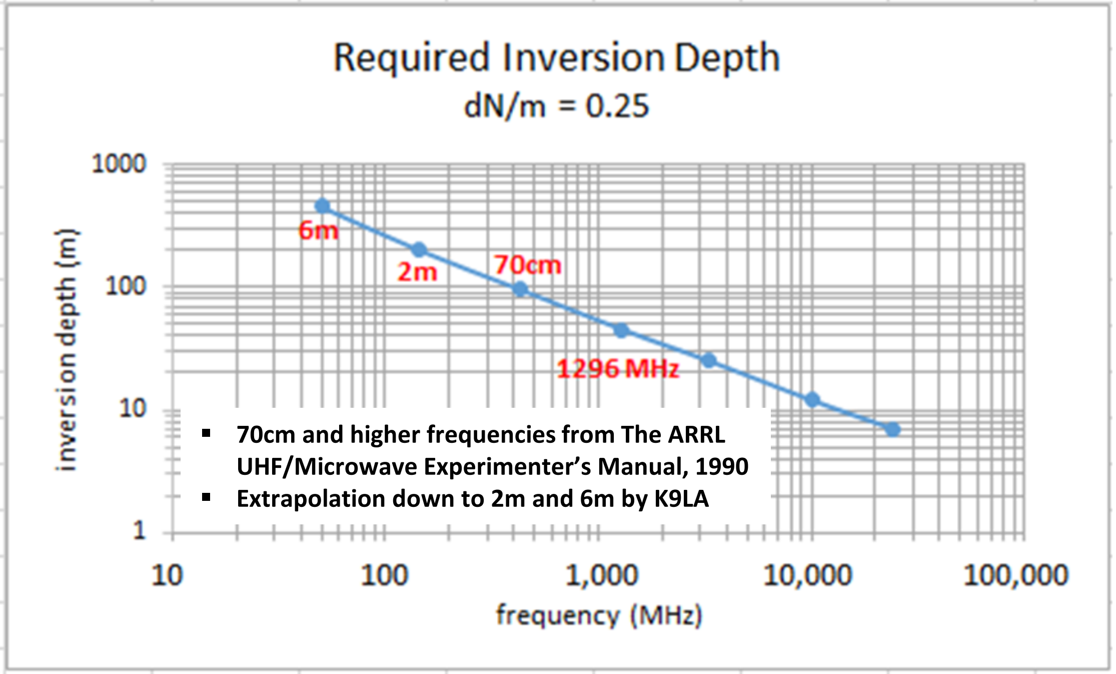
Fig. 4 — Nomogram for estimating performance of a scatter circuit. Slanting line represents example given in text.

Tropospheric Ducting

- Typical inversion depth is 200 meters
- Inversion depth needed for 6m is around 450 km per plot below
- K7CW (WA) heard long-lasting opening that extended from Alaska to Southern CA in the June VHF Contest in the early 1970s
  - Believes it was tropospheric ducting



from The ARRL UHF/Microwave Experimenter's Manual, 1990



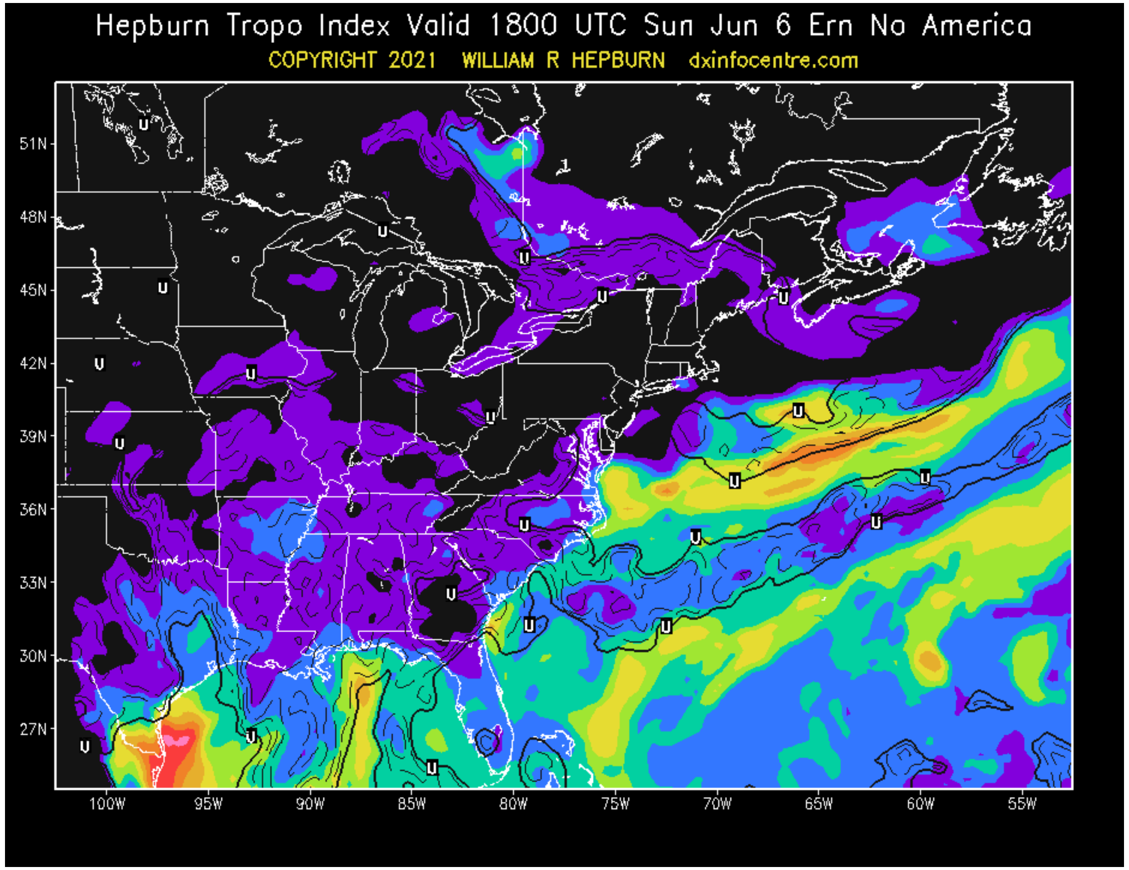
- 70cm and higher frequencies from The ARRL UHF/Microwave Experimenter's Manual, 1990
- Extrapolation down to 2m and 6m by K9LA

Hepburn Tropo Maps

- Predictions for tropospheric ducting

- How accurate are these?

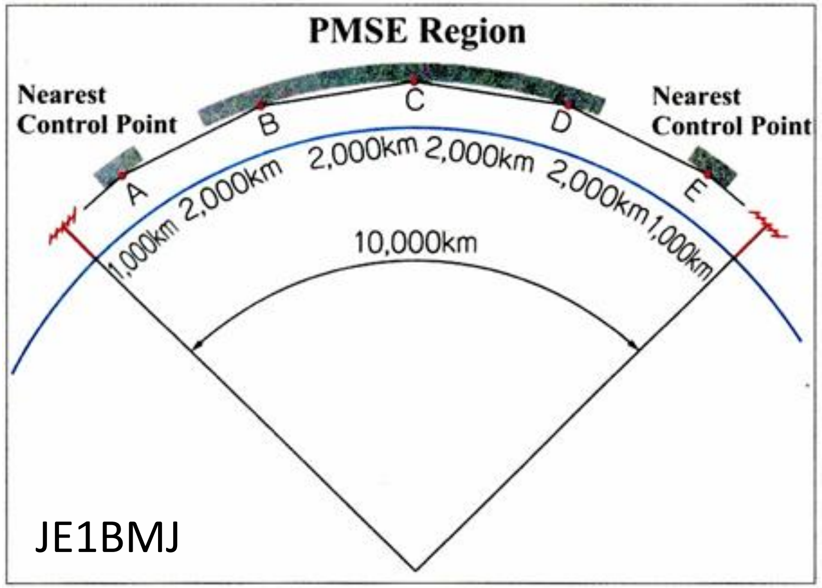
https://www.dxinfocentre.com/tropo.html

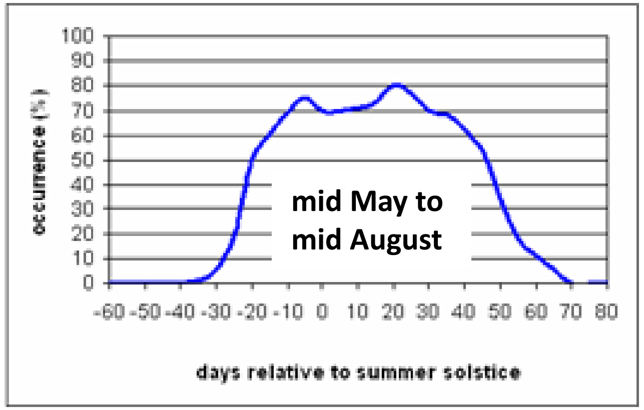


0	1	2	3	4	5	6	7	8	9	10+
NIL	MARGINAL	FAIR	MODERATE	HIGH	STRONG	VERY STRONG	INTENSE	VERY INTENSE	EXTREME	EXTREME

Short-path Summer Solstice Propagation

- SSSP hypothesized by JE1BMJ in his article in Six News (UK Six Metre Group, English translation)
- Tied to Polar mesospheric summer echoes (PMSE)
  - Radar echoes between 80-90 km in altitude from mid May through mid August in the Arctic
  - The peak PMSE height is slightly below the summer mesopause temperature minimum at 88 km, and above the noctilucent cloud (NLC) layer at 83–84 km
- How do you tell the difference between PMSE and Es?

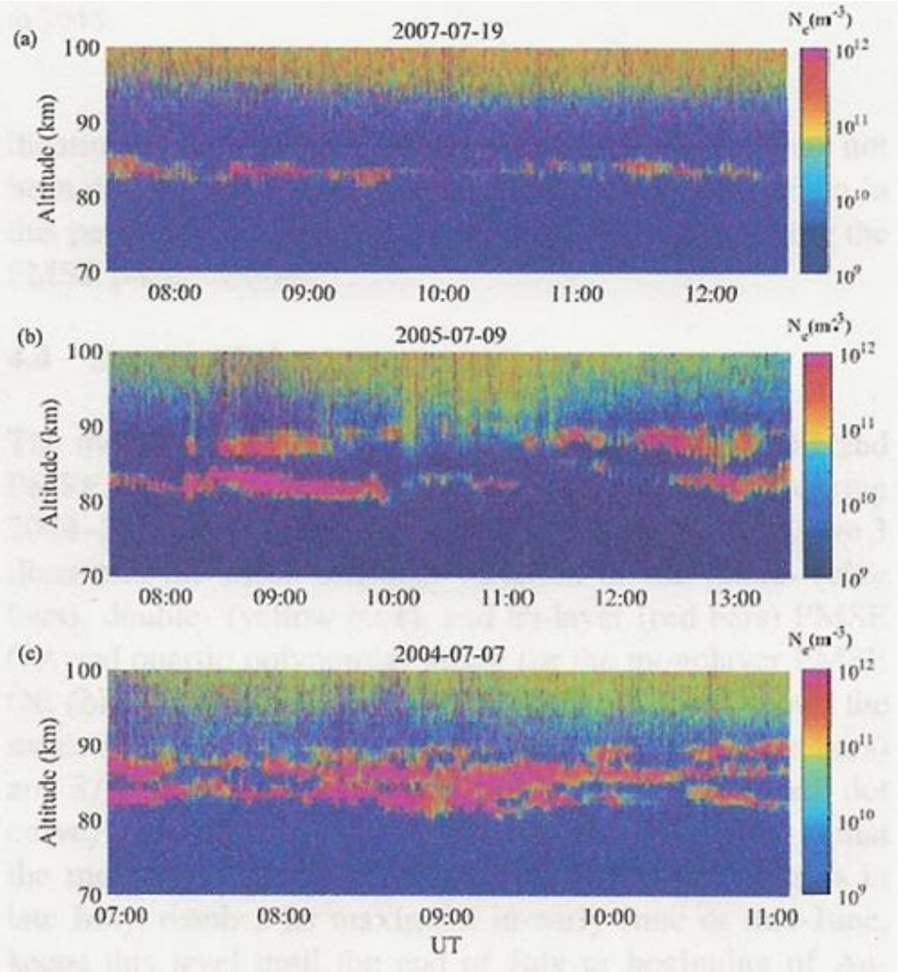




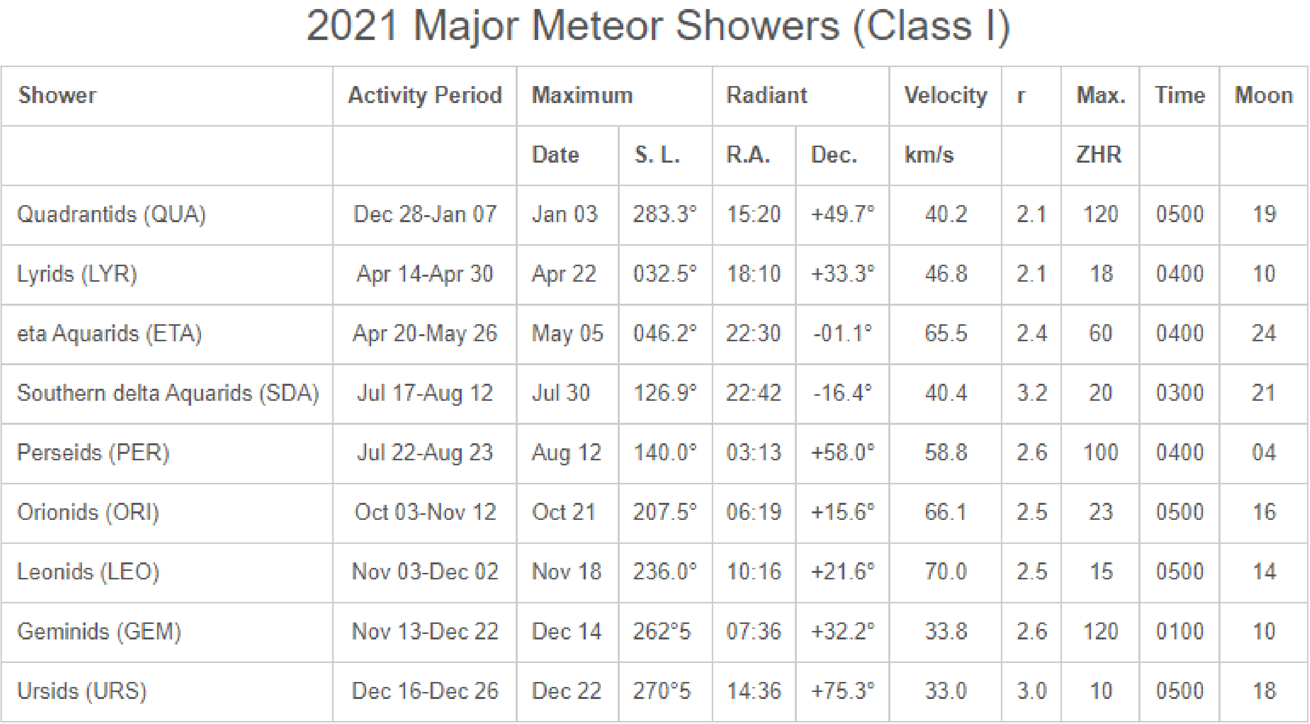
R. Latteck, W. Singer, R. J. Morris, D. A. Holdsworth, and D. J. Murphy; *Observation of polar mesosphere summer echoes with calibrated VHF radars at 69^o in the Northern and Southern hemisphere*; Geophysical Research Letters; Volume 34; L14805; July 2007.

Electron Density of PMSE

- Ge, Li, Xu, Zhu, Wang, Meng, Ullah and Rauf; *Characteristics of the layered polar mesospheric summer echoes occurrence ratio observed by EISCAT VHF 224 MHz radar*; Annales Geophysicae; 37, 417-427, 2019
- Max electron densities can be around 1E12 e/m^3
  - Critical frequency approximately 9 MHz
  - For low elevation angles, M-factor for a layer at 85 km is around 6 (MUF = M-factor times critical frequency)
- PMSE can support 6m
- Three layers may help per slide 7/bullet 2



Meteor Scatter



2021 Major Meteor Showers (Class I)

Shower	Activity Period	Maximum		Radiant		Velocity	r	Max.	Time	Moon
		Date	S. L.	R.A.	Dec.	km/s		ZHR		
Quadrantids (QUA)	Dec 28-Jan 07	Jan 03	283.3°	15:20	+49.7°	40.2	2.1	120	0500	19
Lyrids (LYR)	Apr 14-Apr 30	Apr 22	032.5°	18:10	+33.3°	46.8	2.1	18	0400	10
eta Aquarids (ETA)	Apr 20-May 26	May 05	046.2°	22:30	-01.1°	65.5	2.4	60	0400	24
Southern delta Aquarids (SDA)	Jul 17-Aug 12	Jul 30	126.9°	22:42	-16.4°	40.4	3.2	20	0300	21
Perseids (PER)	Jul 22-Aug 23	Aug 12	140.0°	03:13	+58.0°	58.8	2.6	100	0400	04
Orionids (ORI)	Oct 03-Nov 12	Oct 21	207.5°	06:19	+15.6°	66.1	2.5	23	0500	16
Leonids (LEO)	Nov 03-Dec 02	Nov 18	236.0°	10:16	+21.6°	70.0	2.5	15	0500	14
Geminids (GEM)	Nov 13-Dec 22	Dec 14	262°5	07:36	+32.2°	33.8	2.6	120	0100	10
Ursids (URS)	Dec 16-Dec 26	Dec 22	270°5	14:36	+75.3°	33.0	3.0	10	0500	18

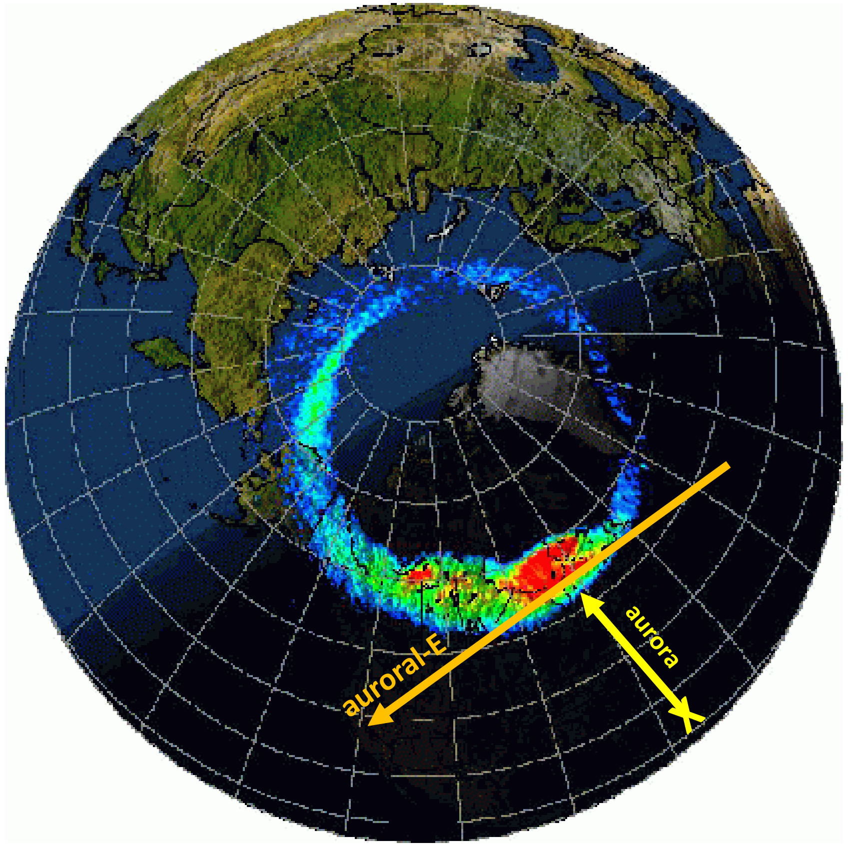
from the American Meteor Society

- S.L. is solar longitude
  - 0 is spring equinox
  - 90 is summer solstice
  - 180 is autumnal equinox
  - 270 is winter solstice
- r
  - 2.0 is bright
  - 3.5 is faint
- ZHR is zenith hourly rate
- Moon is age of the moon in days
  - 0 is new, 7 is first quarter, 15 is full, 22 is last quarter
  - Best when < 10 or > 25

Use MSK144

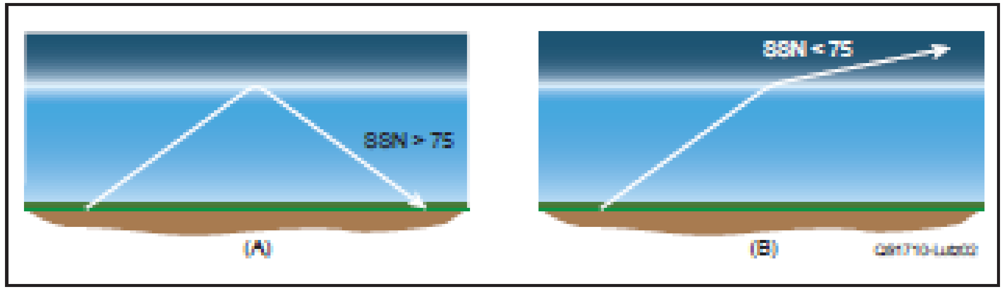
Aurora and Auroral-E

- Aurora can occur when the K index is ≥ 5
  - Higher probability when K > 5
  - Point your antenna north-ish
  - Use CW
- Auroral-E
  - Does this happen?
  - If so, is it similar to 15m/10m auroral-E?
    - Late afternoon in the fall months
  - Path is tangential to auroral oval



Ionospheric Scatter

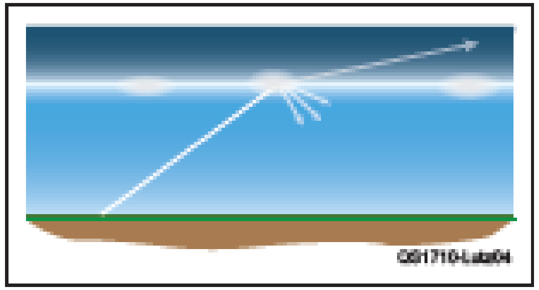
From slide 5, scatter results in more loss



op freq less
than the MUF

op freq greater
than the MUF

normal view of refraction



what can
really happen

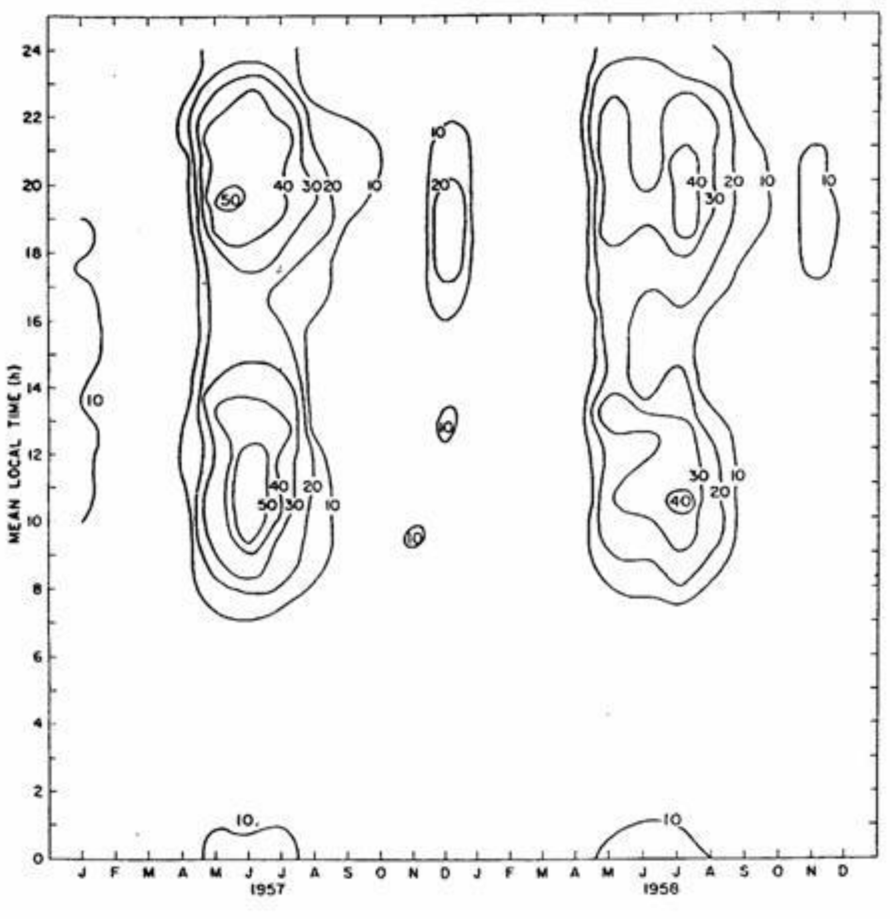
result can be above-the-MUF
propagation but with more loss

E Hops

- MUF = M-factor times foE
- Normal E region M-factor is a bit above 5
  - For low elevation angles and a maximum electron density around 105 km
    - Results in a low angle of incidence on the E region
- Thus foE needs to be around 10 MHz for 50 MHz refraction
  - Not very common
- If anywhere, it's at solar max in the equatorial ionosphere around local noon (solar zenith angle near 0^o)

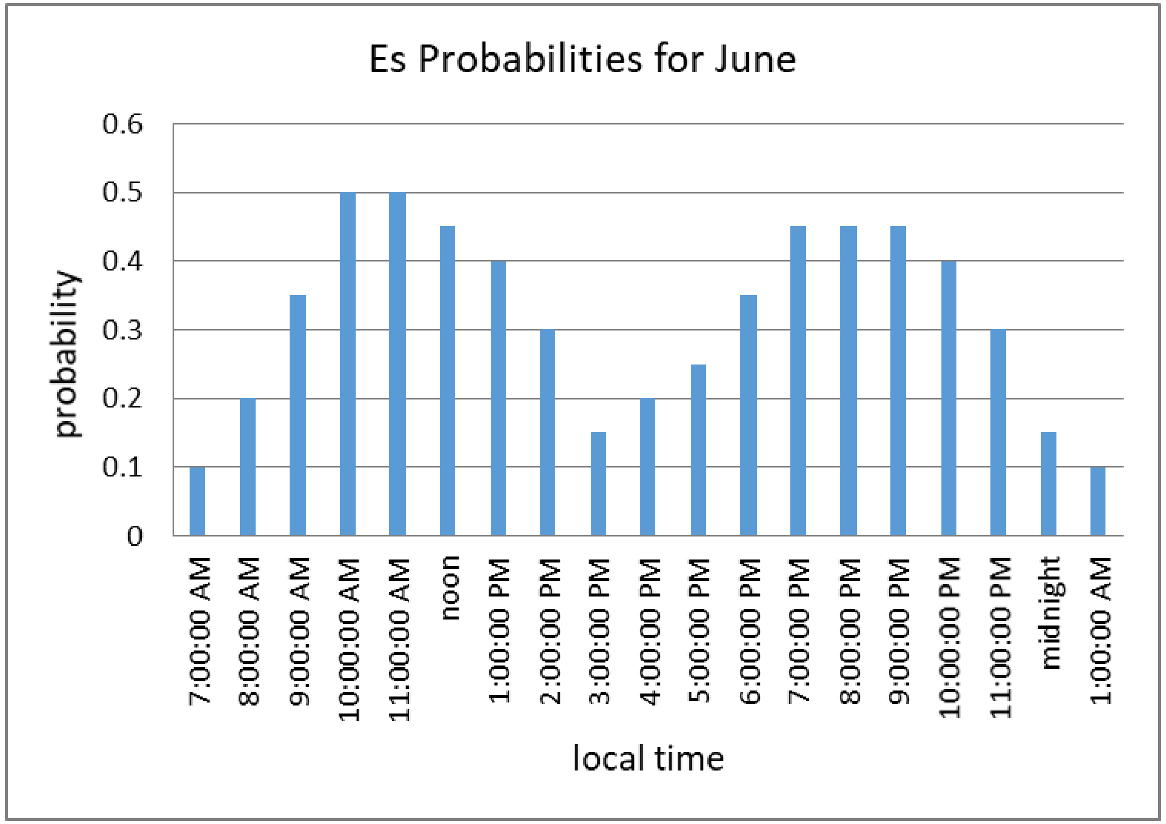
Sporadic-E

- It’s called sporadic-E because we can’t predict it
- We know the general pattern with respect to month and local time
- We don’t know on which days it will occur
- Summer is best
- Bi-modal probability
  - Late morning (local)
  - Early/late evening (local)
- Bi-modal probability can allow long distance QSOs



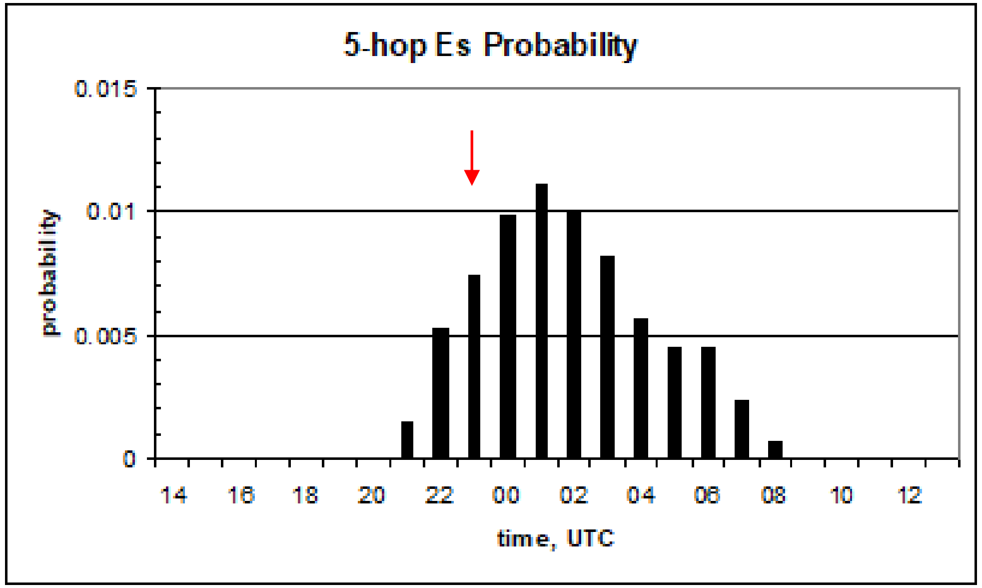
Another Look at Sporadic-E Probability

from data on previous slide



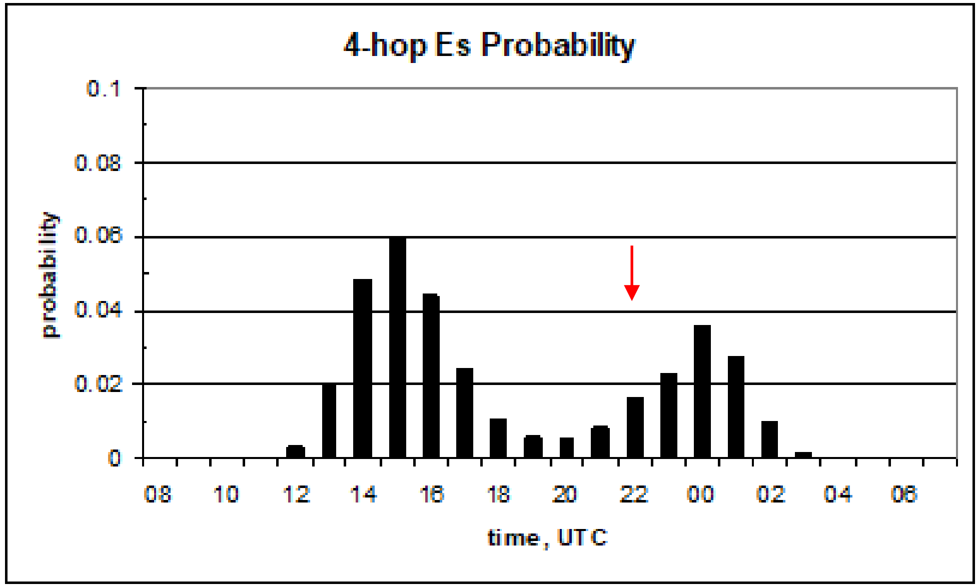
Predicting Best Times for Sporadic-E

- NØJK (KS) to JA7QVI in early June
  - 9700 km
- Break path into five segments
- Use probabilities on previous slide for each segment vs local time
- Multiply probabilities of the five segments together at each time
- NØJK worked JA7QVI at 2345 UTC on June 4 (2006)



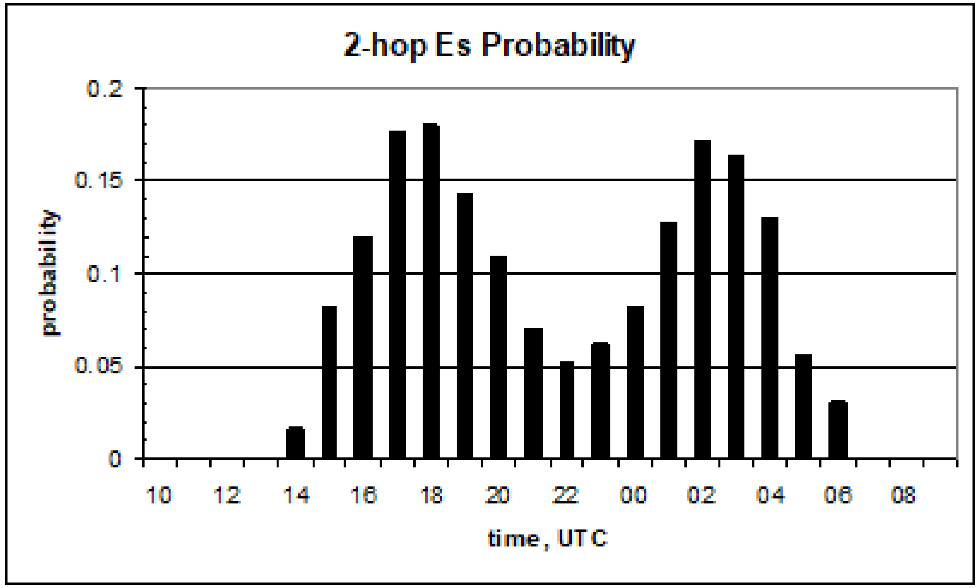
Predicting Best Times for Sporadic-E

- N4KZ (KY) to CT3 in early June
  - 6052 km
- Break path into four segments
- Use probabilities on earlier slide for each segment vs local time
- Multiply probabilities of the four segments together at each time
- N4KZ worked CT3 at 2208 UTC on June 9 (2006)
  - Other Midwest stations confirm two opportunities

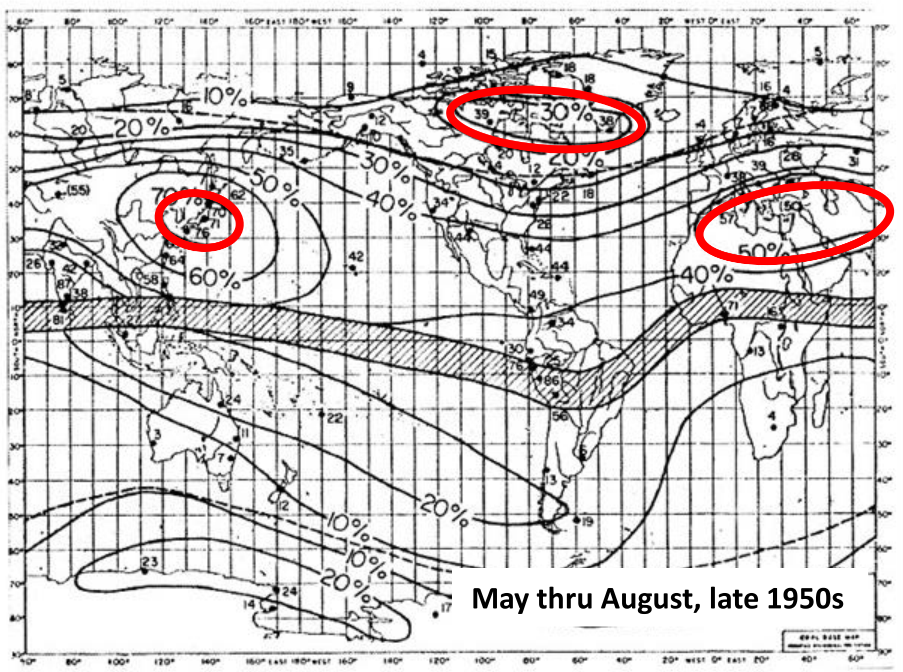


Predicting Best Times for Sporadic-E

- W7 to W2 in late June (Field Day!)
  - 3166 km
- Break path into two segments
- Use probabilities on earlier slide for each segment vs local time
- Multiply probabilities of the two segments together at each time

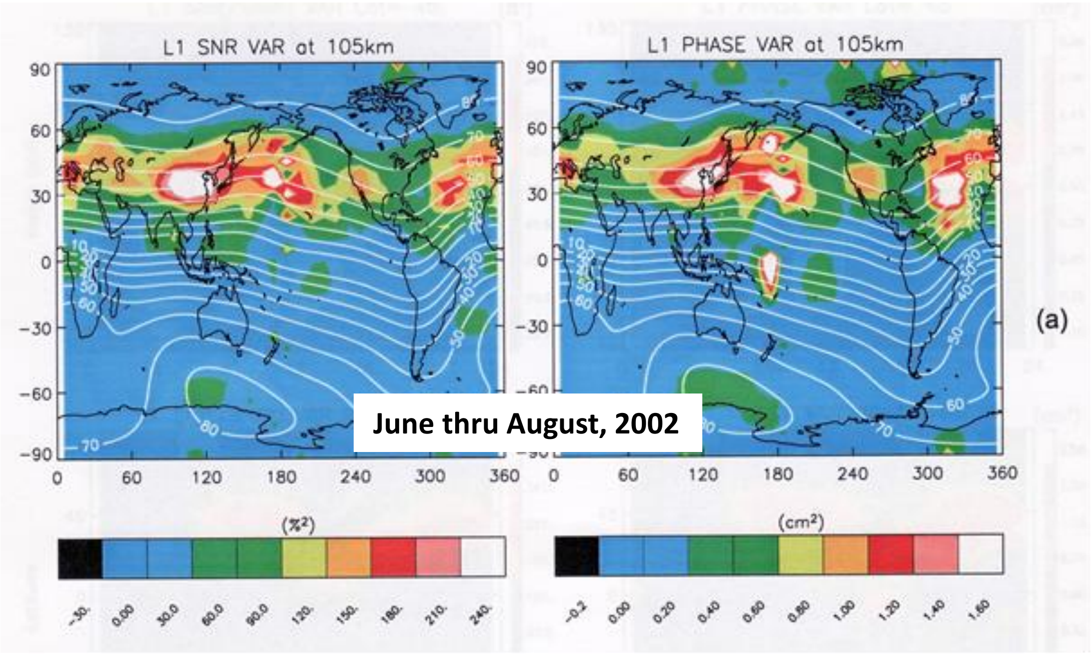


Change in Sporadic-E Over the Years



May thru August, late 1950s

H. I. Leighton, A. H. Shapely and E. K. Smith; *The Occurrence of Sporadic E during the IGY*; Central Radio Propagation Laboratory, National Bureau of Standards, Boulder Colorado



June thru August, 2002

Dong L. Wu, Chi O. Ao, George A. Hajj, Manuel de la Torre Juarez and Anthony J. Mannucci; *Sporadic E morphology from GPS-CHAMP radio occultation*; Journal of Geophysical Research, Vol 110, A01306, doi:10,1029/2004JA010701, 2005

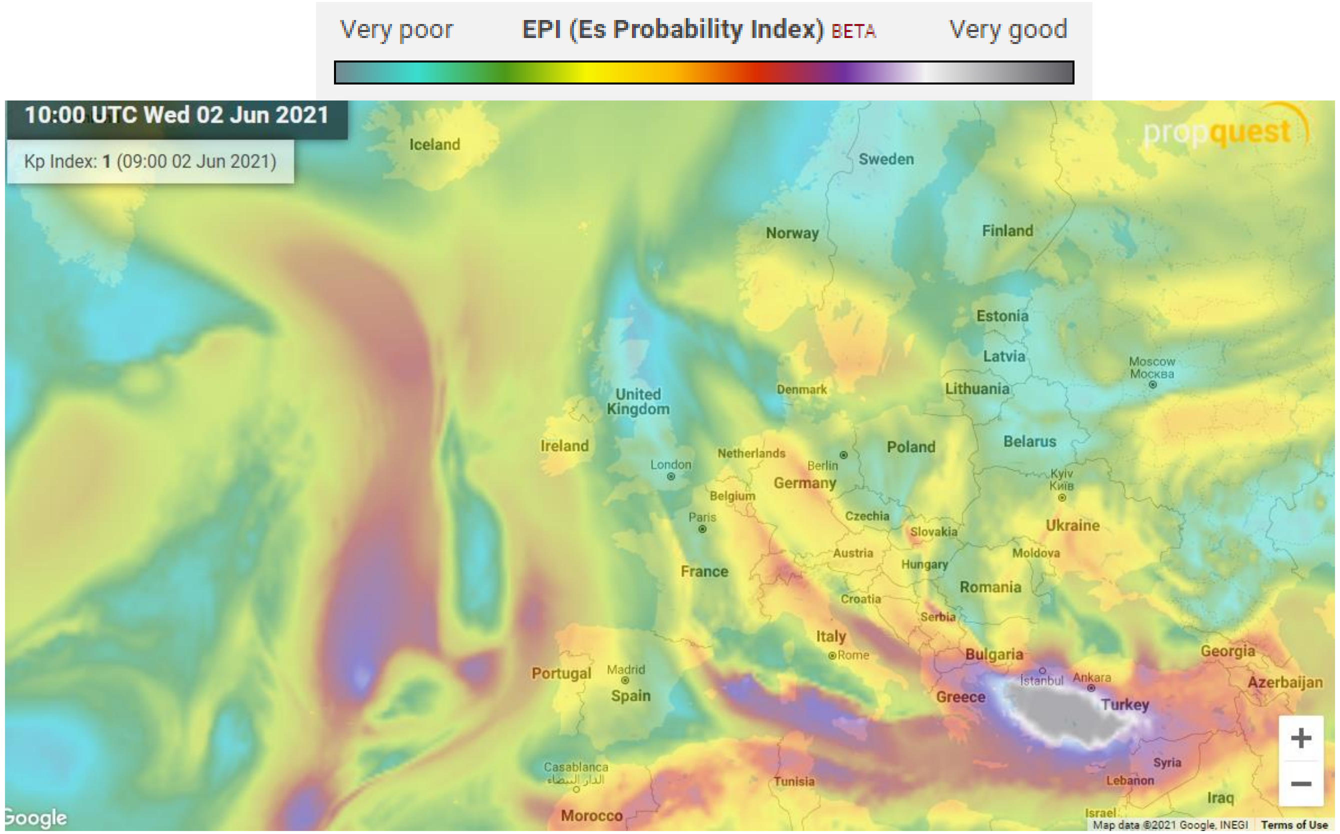
- It appears that Es has shifted west from JA to SE Asia
- North America has shifted, too

But how good is the early data??

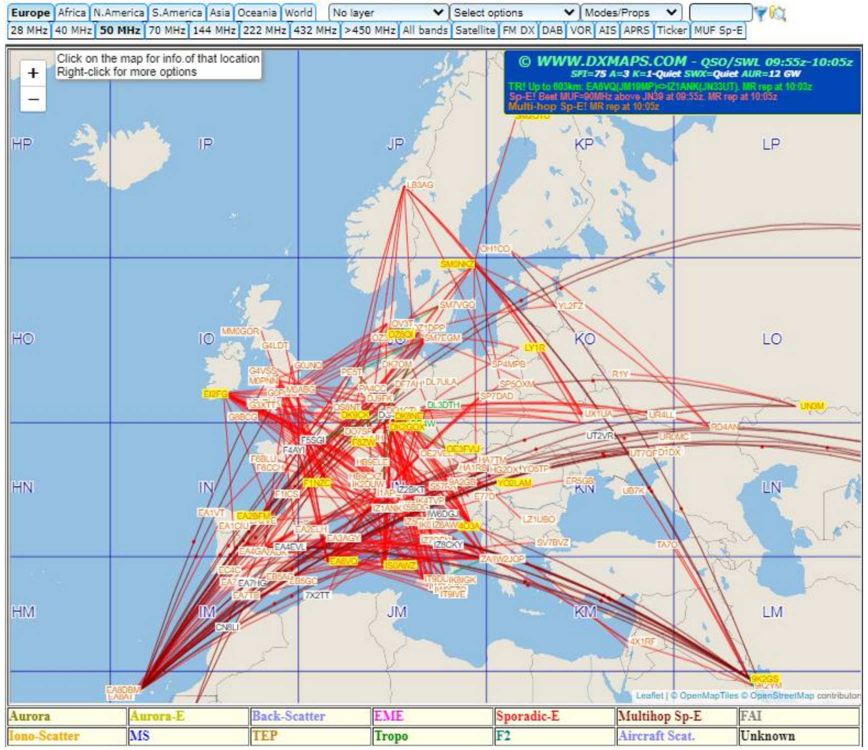
Sporadic-E and Weather in the Troposphere

- There appears to be a tie between terrestrial tropospheric weather and sporadic-E
- Recent work in this area by G3YLA and K1YOW (and probably others)
- Jim Bacon G3YLA – retired BBC meteorologist
  - Generates a daily Es Prediction Index (EPI)
  - http://propquest.co.uk/map.php
- Joe Dzekevich K1YOW
  - https://hamsci.org/sites/default/files/publications/202011_CQ_Dzekevich_K1YOW_SporadicE.pdf

G3YLA's EPI vs dxmaps.com



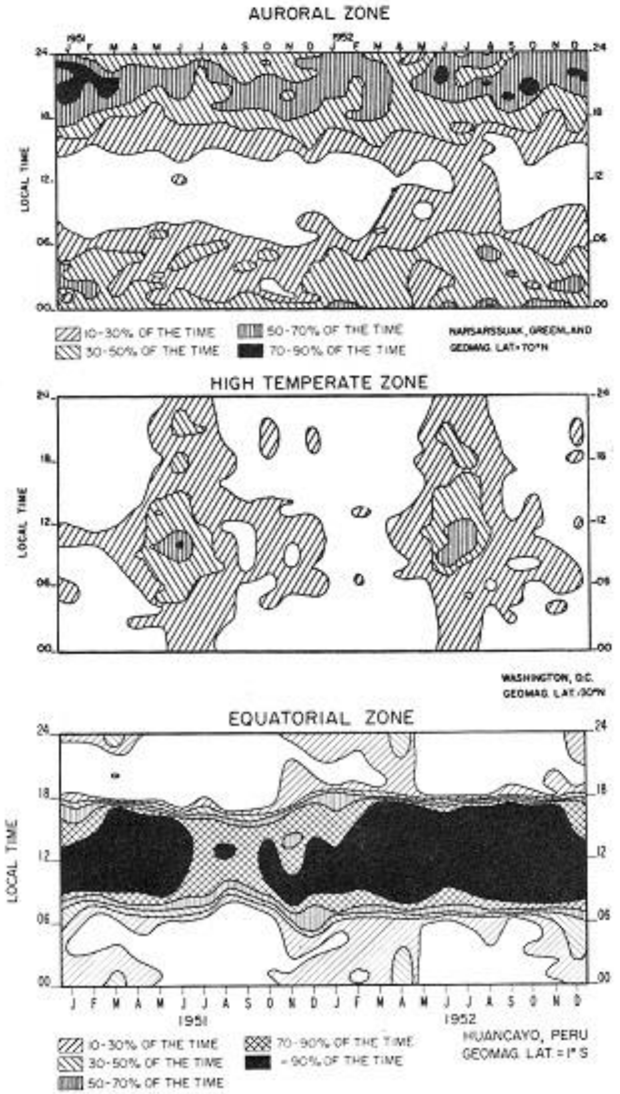
EPI, June 2, 1000 UTC



© WWW.DXMAPS.COM - QSO/SWL 09:55z-10:05z
SFI=75 A=3 K=1-Quiet SWX=Quiet AUR=12 GW
TR! Up to 803km: EA6VQ(JM19MP)<>IZ1ANK(JN33UT). MR rep at 10:03z
Sp-E! Best MUF=90MHz above JN39 at 09:55z. MR rep at 10:05z
Multi-hop Sp-E! MR rep at 10:05z

dxmaps.com, June 2, 0955-1005 UTC

Sporadic-E by Latitude



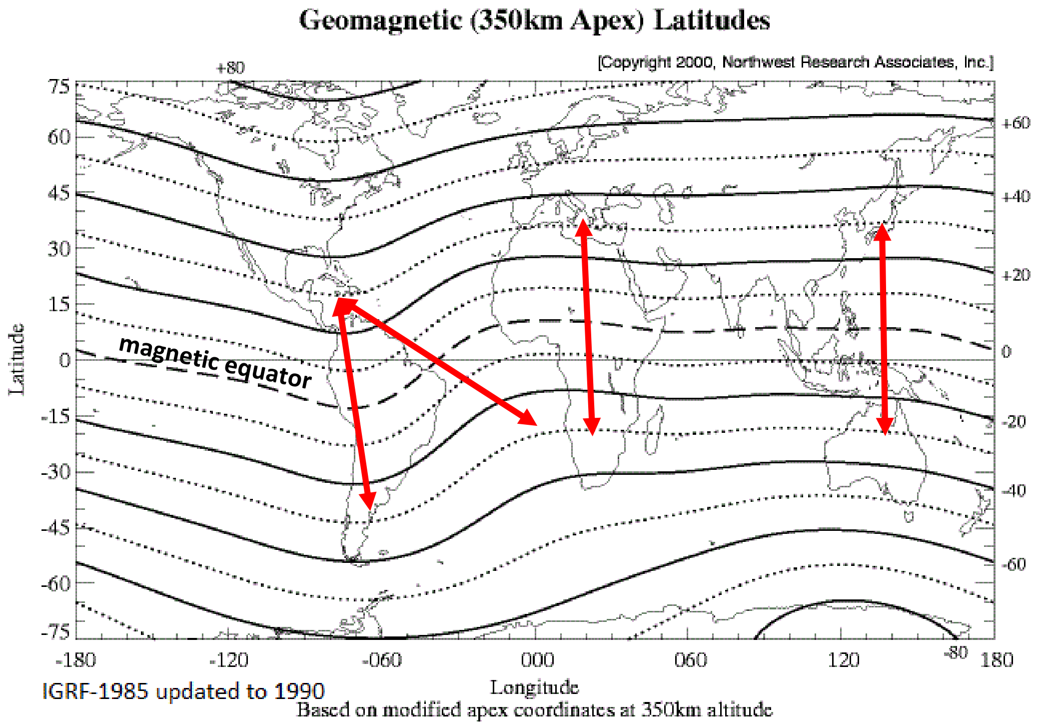
- From Kenneth Davies, Ionospheric Radio, 1990
- Auroral zone Es mostly a nighttime event
- High temperate zone (middle plot) is similar to probabilities on slide 21
- Lots of Es in the equatorial zone around local noon time
  - Any path that crosses the equator around local noon should consider Es

F2 Hops

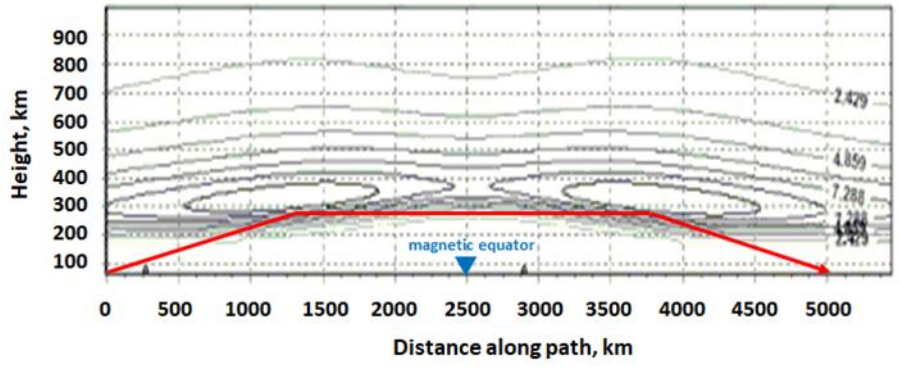
- MUF = M-factor times foF2
- F2 region M-factor is a bit above 3
  - For low elevation angles and a maximum electron density around 300 km
    - Results in a low angle of incidence on the F2 region
- Thus foF2 needs to be around 16 MHz for 50 MHz refraction
- In the northern hemisphere, this can occur with a high sunspot number (around solar max) in the fall and winter in the late morning and afternoon
- Cycles 19, 21 and 22 were especially good
  - Other cycles at a lower probability
  - Even Cycle 24 had some F2 during the second peak though it was a small cycle
    - There’s hope for Cycle 25 – maybe only a couple months around solar max
    - Of course the digital modes offer a bit higher probabilities

Trans-Equatorial Propagation

- Extremely long paths across the magnetic equator with no ground reflection – see image below
- Best in the equinox months
- More sunspots help
- Best from late afternoon through early evening

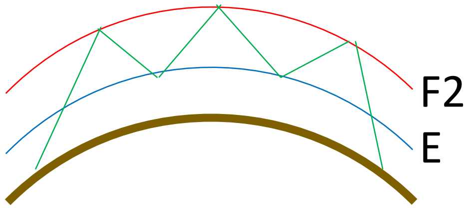


ionospheric signature of TEP

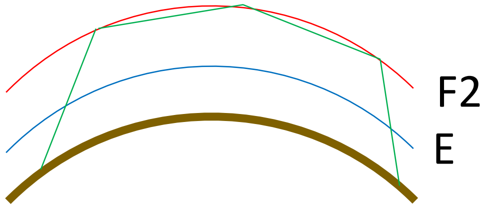


most of us in the continental US require a link to TEP – either an F2 hop or an Es hop

Ducting/Chordal Hops



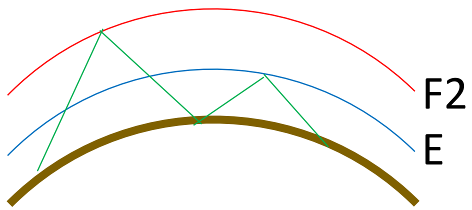
ducting



chordal hop
either via Es or F2 (maybe E?)

- Might be tough to discern from regular hops
- Ray tracing may help
  - But the model of the ionosphere is a monthly median model (kind of the average over a month's time frame)

Combos of E and F Hops



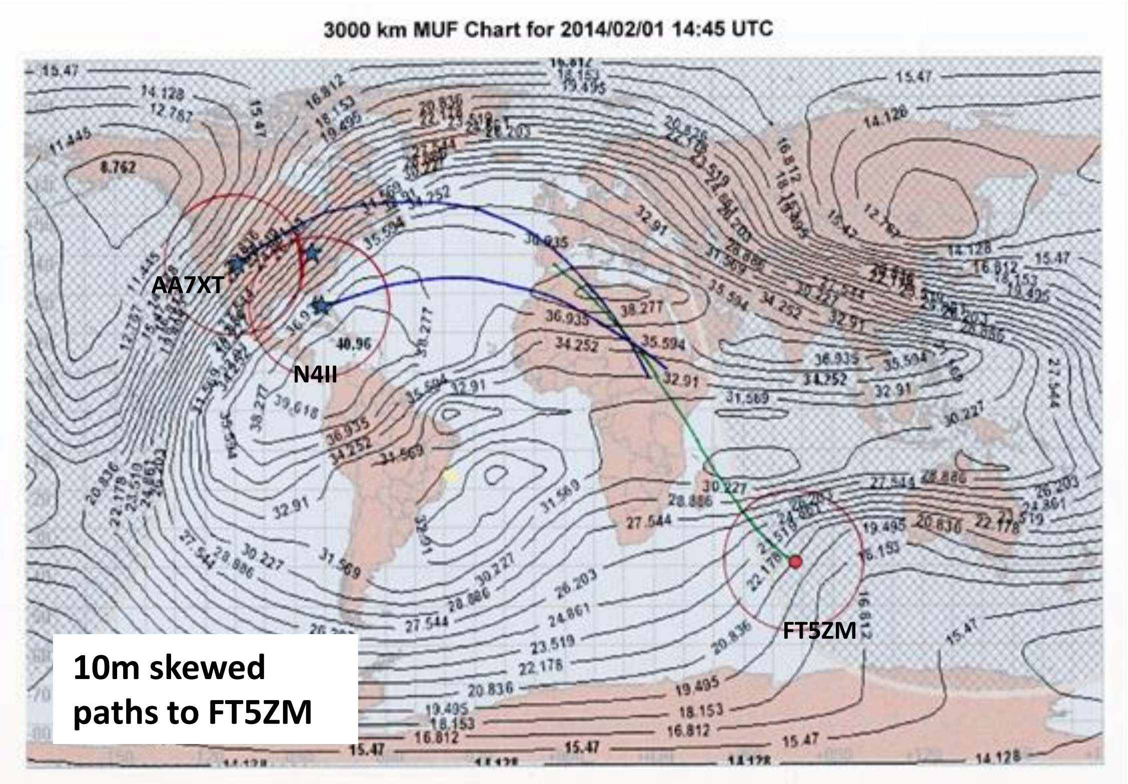
Again, it might be tough to discern from regular hops unless an extremely in-depth analysis is done

Above-the-MUF

- Normally we think the operating frequency needs to be <u>below</u> the MUF – see slide 19
- But QSOs do occur when the operating frequency is <u>above</u> the MUF
  - Believed to be due to some form of scatter
- Several equations
  - Wheeler – 8 dB loss at 50 MHz when MUF = 40 MHz
  - ITU – 23 dB loss at 50 MHz when MUF = 40 MHz
  - Gibson & Bradley – 33 dB loss at 50 MHz when MUF = 40 MHz
- Loss due to above-the-MUF propagation may not be as bad as one might think due to minimal absorption on 50 MHz
  - Amount of ionospheric absorption is inversely proportional to $(\text{frequency})^2$
- I believe this is a factor in the advantage of the digital modes on the higher bands

Skewed Paths

- Most of the time, RF follows a great circle path (gcp)
- If it doesn't, look for electron density gradients that knock the RF off of one gcp and onto another gcp
  - F2 region (especially near the equator)
  - Es
- The FT5ZM DXpedition in 2014 is a great example of skewed paths on 10m
  - https://k9la.us/Skewed_Paths_to_FT5ZM_on_10-Meters.pdf



10m skewed paths to FT5ZM

- short gcp from N4II to FT5 is to the southeast
- short gcp from AA7XT to FT5 is to the west
- both pointed to North Africa on 10m – the alleged skew point
  - very high electron density and gradients

6m Moon Bounce

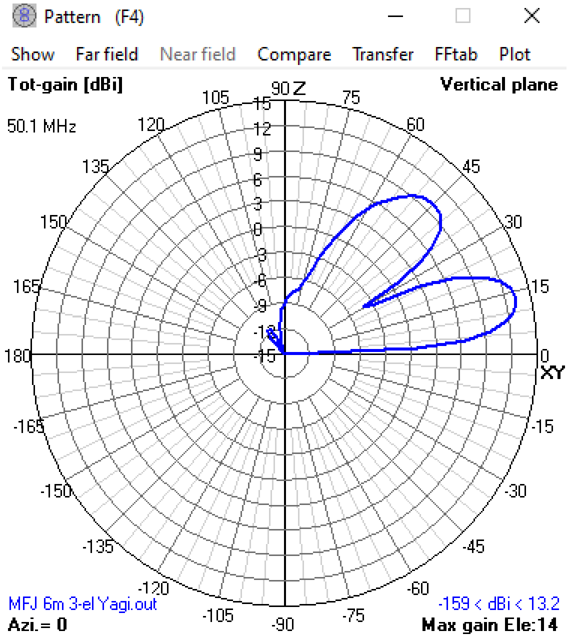
- Typical EME path loss on 50 MHz is approximately 243 dB
  - Rough estimate for CW: Pr = 61.8 (1kW) + 20 (G_T) + 20 (G_R) - 243 = -141.2 dBm
    - MDS: -174 + 27 (500 Hz bw) + 2 (NF) = -145 dBm >> 3.8 dB SNR
  - Rough estimate for JT65: Pr = 61.8 +20 + 20 – 243 = -141.2 dBm
    - MDS: -174 + 27 + 2 – 10 (JT65 advantage over CW) = -155 dBm > > 13.8 dB SNR >> smaller antennas acceptable

- http://www.bigskyspaces.com/w7gj/Welcome_to_6m_EME.htm
- https://stationproject.blog/wp-content/uploads/2020/05/2020-April-Tech-Night-Getting-Started-in-EME.pdf

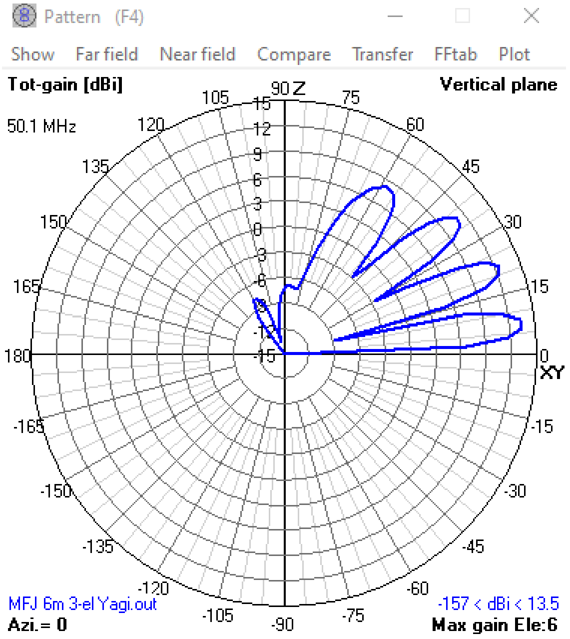
Antenna Considerations

3-Element 6m Yagi Patterns

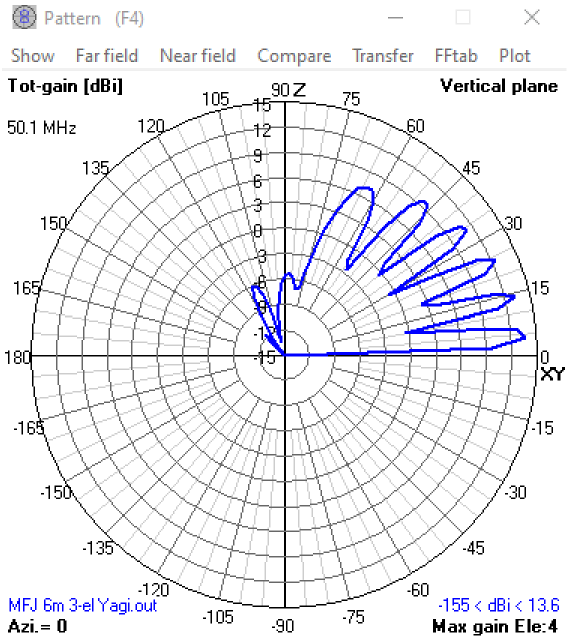
elevation patterns from 4nec2 by Arie Voors


Tot-gain [dBi]
50.1 MHz
Vertical plane
MFJ 6m 3-el Yagi.out
Azi.= 0
-159 < dBi < 13.2
Max gain Ele:14

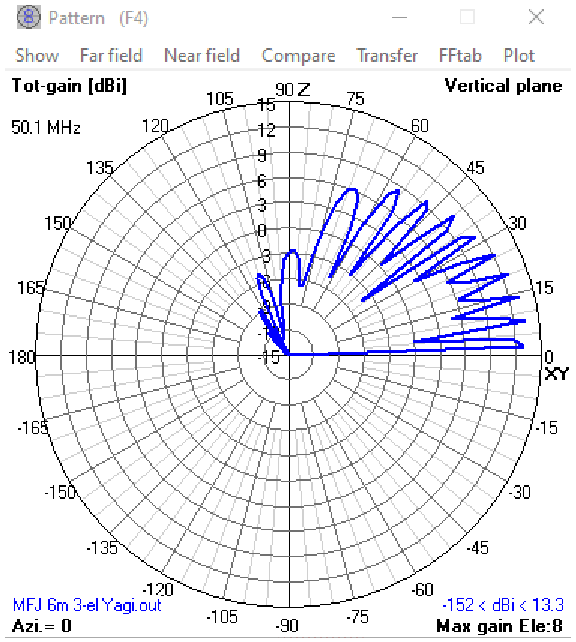
at 20 feet


Tot-gain [dBi]
50.1 MHz
Vertical plane
MFJ 6m 3-el Yagi.out
Azi.= 0
-157 < dBi < 13.5
Max gain Ele:6

at 40 feet


Tot-gain [dBi]
50.1 MHz
Vertical plane
MFJ 6m 3-el Yagi.out
Azi.= 0
-155 < dBi < 13.6
Max gain Ele:4

at 60 feet

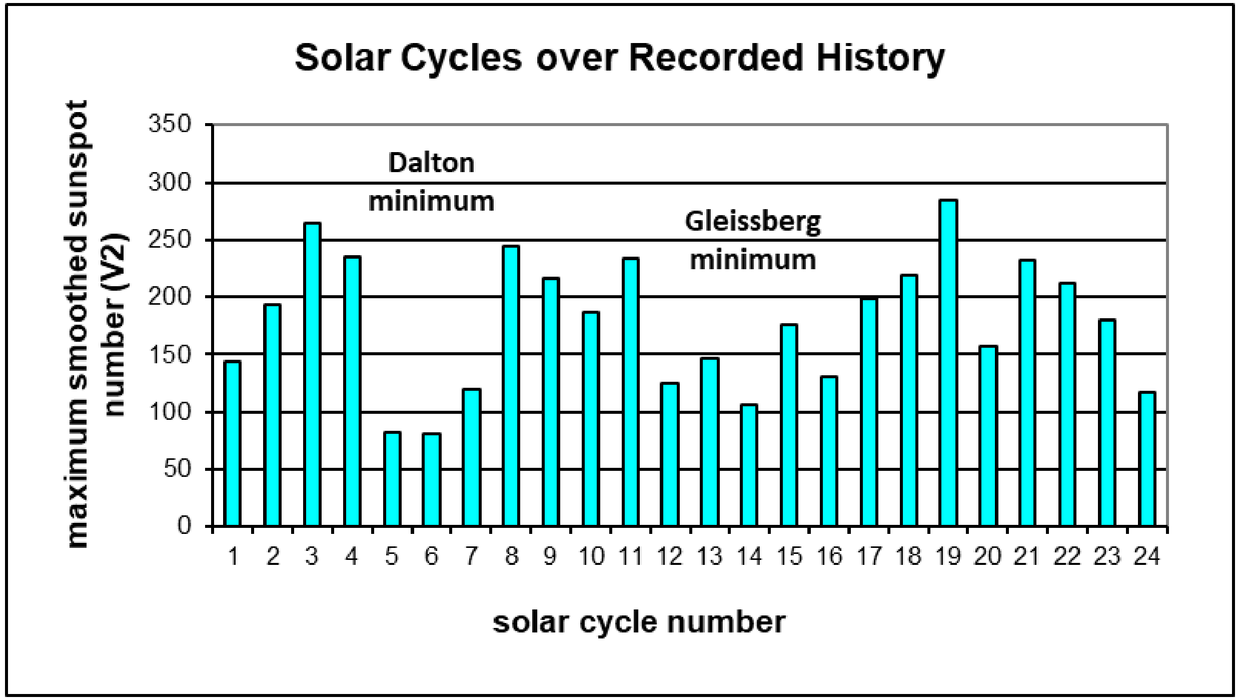

Tot-gain [dBi]
50.1 MHz
Vertical plane
MFJ 6m 3-el Yagi.out
Azi.= 0
-152 < dBi < 13.3
Max gain Ele:8

at 100 feet

- W2PV believed the best height for an HF Yagi was 1.5λ – that's 30 feet on 6m
- High antenna on 6m can be advantageous – go for a stack of 6m Yagis
  - Energy at lower angles critical on 6m – could take advantage of a higher MUF

Cycle 25 Status

Recorded History

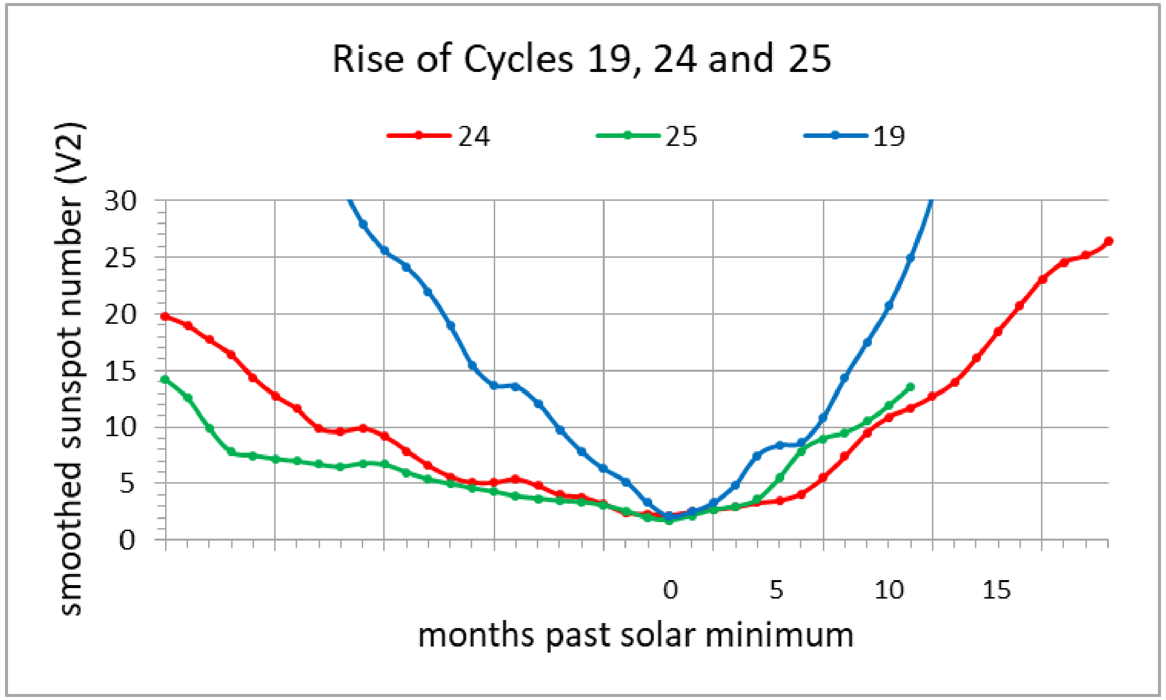


Cycle 24 was the smallest in our lifetimes and the 4th smallest in recorded history

Critical question – will Cycle 25 get us out of the third period of small cycles?

The Rise of Cycle 25

- Data from Cycles 1 thru 24 show that a big cycle rises faster than a small cycle
- After 11 months of data, Cycle 25 is rising a bit faster than Cycle 24
- So far June 2021 has been good for sunspots



References

Books, Papers, Websites, Videos, Columns

- https://www.k5nd.net/wp-content/uploads/2020/08/Six-Meters-eBook-V5.pdf
- K6MIO papers (and others) at https://www.qsl.net/wa3mej/Articles/Library.html
- WB2AMU/WB6NOA, *VHF Propagation - A Practical Guide for Radio Amateurs*, CQ, 2004
- UK Six Meter Group at https://www.uksmg.org/landing.php
- EI7GL blog at https://ei7gl.blogspot.com/
- G0KYA, *Radio Propagation Explained*, RSGB, 2016
- Propagation chapters of the ARRL Handbook and the ARRL Antenna Book
- *The World Above 50 MHz* column, NØJK, QST
- *VHF-UHF Contesting!* column, NØJK, NCJ
- VHF PLUS column, N4DTF, CQ magazine
- Recent G3XTT presentation at https://www.youtube.com/watch?v=TVJDWJwOmhQ

I'm sure there are many more sources for 6m propagation and the various modes

Summary

- Many modes on 6m
  - Probably because 6m is not like HF, where most propagation is via E and F modes
- Some modes are easy
- Some modes are more difficult
  - Now that’s an understatement ☺
- This is like Amateur Radio in general – many different aspects of 6m propagation to keep you interested and busy