New Opportunities in 24-GHz Rain Scatter

ANDY FLOWERS, K0SM
NTMS FEB 2025

Agenda

- Exciting breakthroughs in 24 GHz rain scatter (and higher) over the last few months.
  - More stations with real power than ever before
  - Means more opportunities to try stuff
- Review atmospheric attenuation on 24 GHz…and how it's been lying to us
- A case study of summertime 24 GHz scatter DX QSO
  - 3D view of path loss at 24GHz
  - Use real upper-atmosphere weather measurements
- Convince you that exciting DX on 24 GHz (higher) rain scatter is possible in the summer
  - Some tips on how to do it

What’s rain scatter?

Use precipitation as a scattering volume to make long distance contacts.

Same physics as a weather radar, except we use more than just the back-scattered energy.

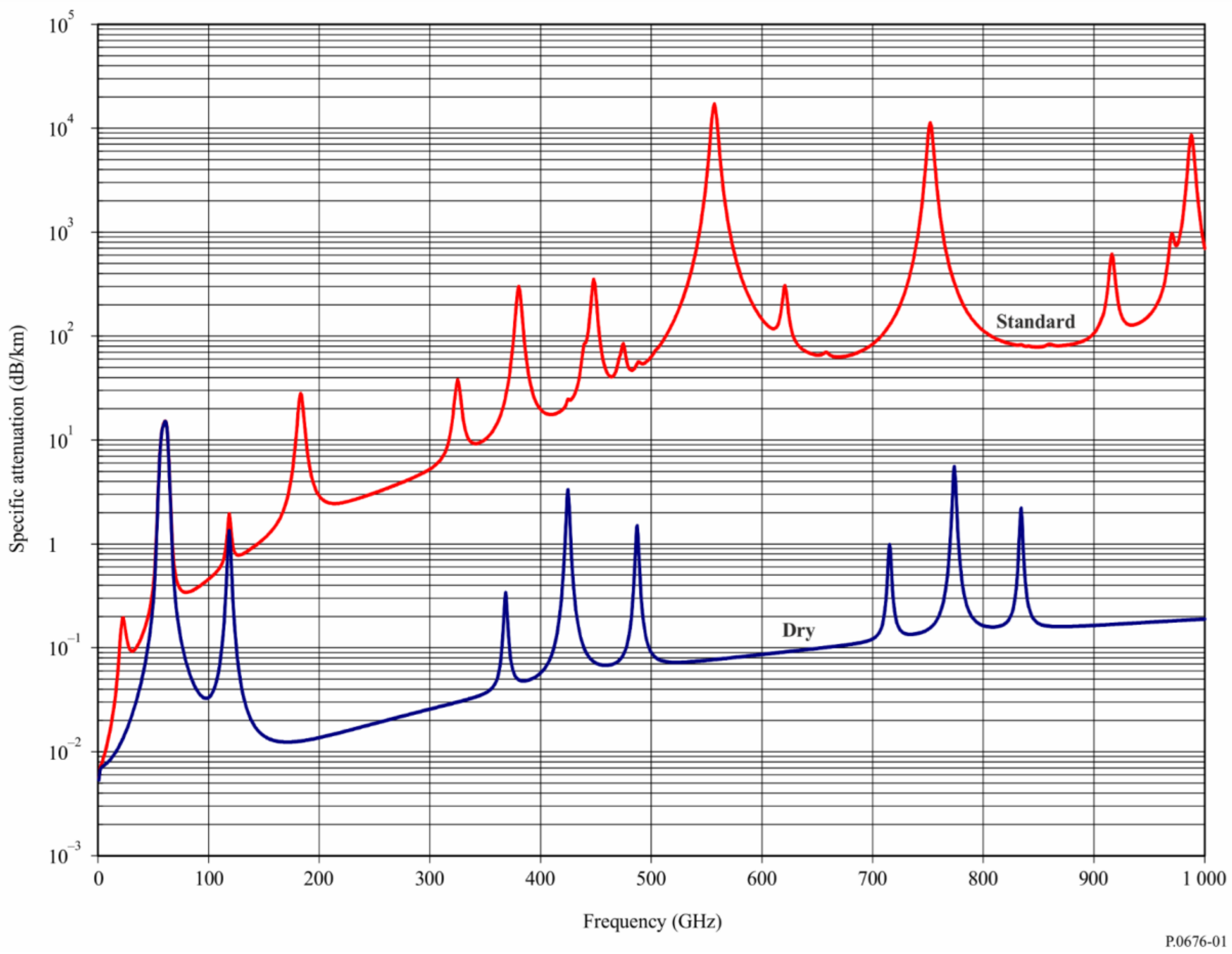
If rain is above horizon for two stations they might be able to scatter to each other

10 GHz is the prime DX band, but it can be observed down to 900 MHz up to at least 78 GHz with available amateur equipment.

Today, I’ll be talking about the high frequency stuff.

High microwaves have personalities: atmospheric attenuation

- All far-field RF is “square law”: -6dB for every doubling of distance in free space
- We don’t DX in “free space”:
  - 10 GHz: Clear air is almost free space! This is why it’s a great rain-scatter band
  - 24 GHz: H_2O vapor in air adds to path loss—signals die off faster than square law depending on amount
  - 47,78 GHz: Both O_2 and H_2O contribute to path loss, but in differing amounts.
- Atmospheric attenuation: can largely be ignored below 15 GHz.
- In general, atmospheric attenuation increases as we travel toward 1 THz



Attenuation vs. Frequency

Additional attenuation above about 15 GHz due to gasses becomes significant.

Shows STP with 50% RH and with 0% RH (dry)

Water vapor responsible for most absorption in open air atmosphere

(From ITU-R P.676)

10 GHz rain scatter

- DX out to 1000km+ (600km common) with severe WX in the summer when we see 50,000ft storm tops
- Best DX possible when storm is on horizon for both stations and nothing in the way
- Atmospheric attenuation isn't noticeable:
  - ~0.02dB/km at ground level on humid summer day
  - Total path loss to/from rain almost entirely square law: "Double the distance, lose 6dB"

24 GHz rain scatter: The Good

- From WA1MBA’s 2019 MUD paper:
  - The scattering of liquid water drops is proportional to f^4 with Rayleigh scattering assumptions.
- Same precipitation is around 12dB louder at 24 GHZ compared to 10 GHz, all else equal.
- See Tom’s 2019 MUD paper for details

24 GHz rain scatter: The Bad

- Forward scatter has to travel through a volume of precipitation. The extra scattering reduces signal coming out of the other side precipitation volume
- Heavy rain example from WA1MBA’s 2019 MUD paper
  - 1 dB/km @ 10 GHz
  - 2.5 dB/km @ 24 GHz
- “Rain fade” is worse at 24 GHz (approximately proportional to $f^{1.9}$)

24 GHz rain scatter: The Ugly

- 24 GHz loss dominated by H_2O vapor in atmosphere…more water vapor means more loss.
  - Square law plus some attenuation per distance travelled
  - Path loss is square law: "Double the distance, lose 6dB"
  - Atmospheric attenuation: "Double the distance, lose twice the dB's!"
- Signals die off more quickly with distance based on (mostly) water vapor content
- When it's raining the air is as humid as it can be!
- Convective thunderstorms tend to happen in warm, humid weather when the air is capable of holding more water in vapor form

24 GHz rain scatter: More Ugly

Atmospheric H_2O *vapor* dominates path to and from the scattering volume:

- Extra 0.40 dB per kilometer at ground level on worst days
- Common experience in summer: very loud signals at 200km on 10GHz and *nothing* on 24 GHz
- One strategy has been to operate when it's colder (less water vapor), and try shorter paths

24 GHz: Atmospheric loss example

- Hot, uncomfortably muggy summer afternoon that makes T-storms:
  - 95°F ground temp, 75°F ground dewpoint (53% RH), 1030mb pressure:
  - Surface atmospheric loss at 24 GHz: 0.36dB/km
  - This is 35dB worse than 10 GHz over 100km
  - This is 70dB worse than 10 GHz over 200km
- We think: *To work a "normal distance" 400km RS QSO, I would need 140 dB SNR on 10 GHz to over come this path loss.*
- *Focus on humidity and frequent failure even when 10 GHz signals are loud has discouraged 24 GHz operation in general, and rain scatter attempts specifically.*

24 GHZ SPIRIT ANIMAL

It’s all a lies!

- Commercial LOS link budgets on the ground can use equations like this.
- Rain scatter happens tens of thousands of feet in the air where the atmosphere is very different.
- Even temperature inversions (tropo) happen several thousand feet up
- *Temperature, pressure, and absolute humidity are not constant over these paths*

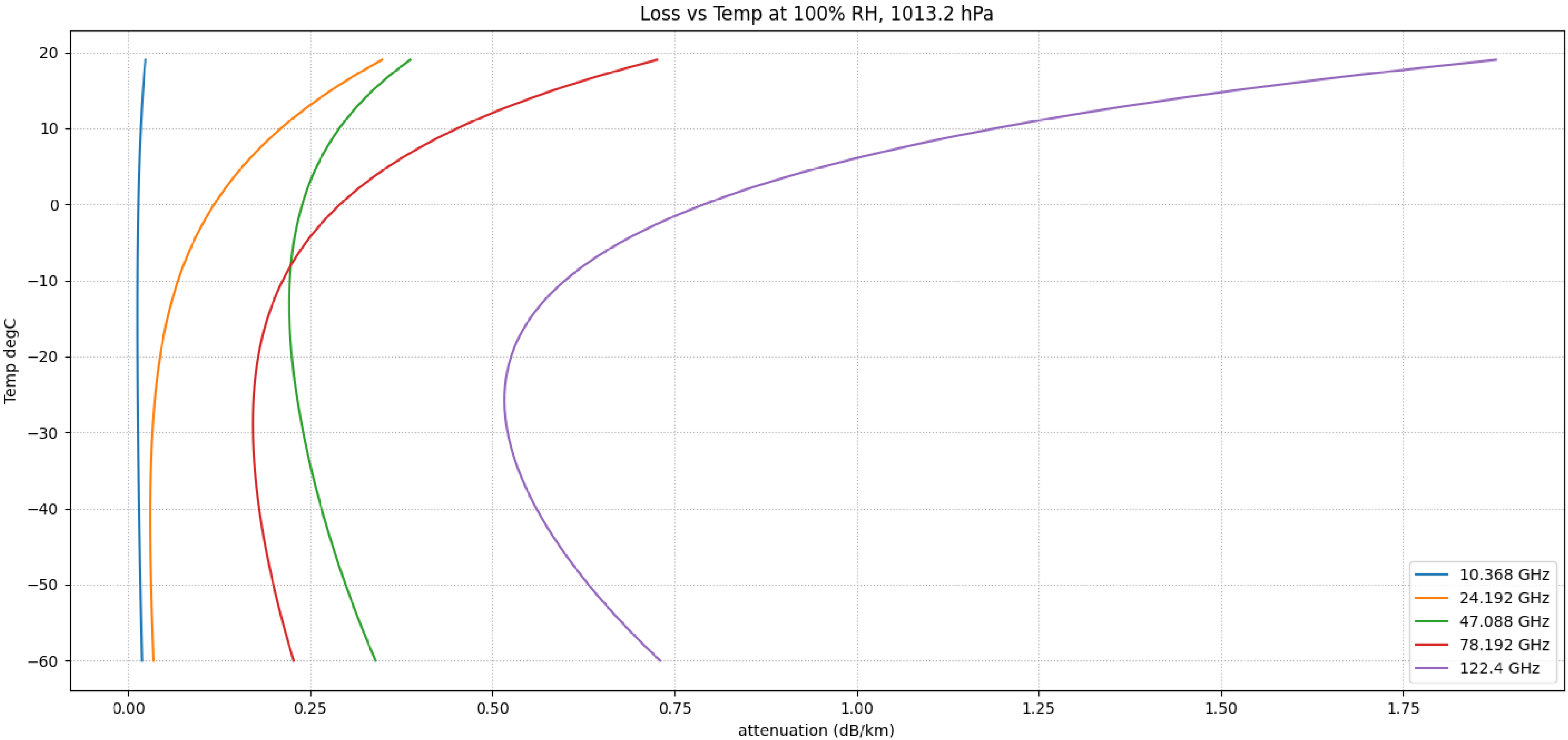
Caution Ahead!

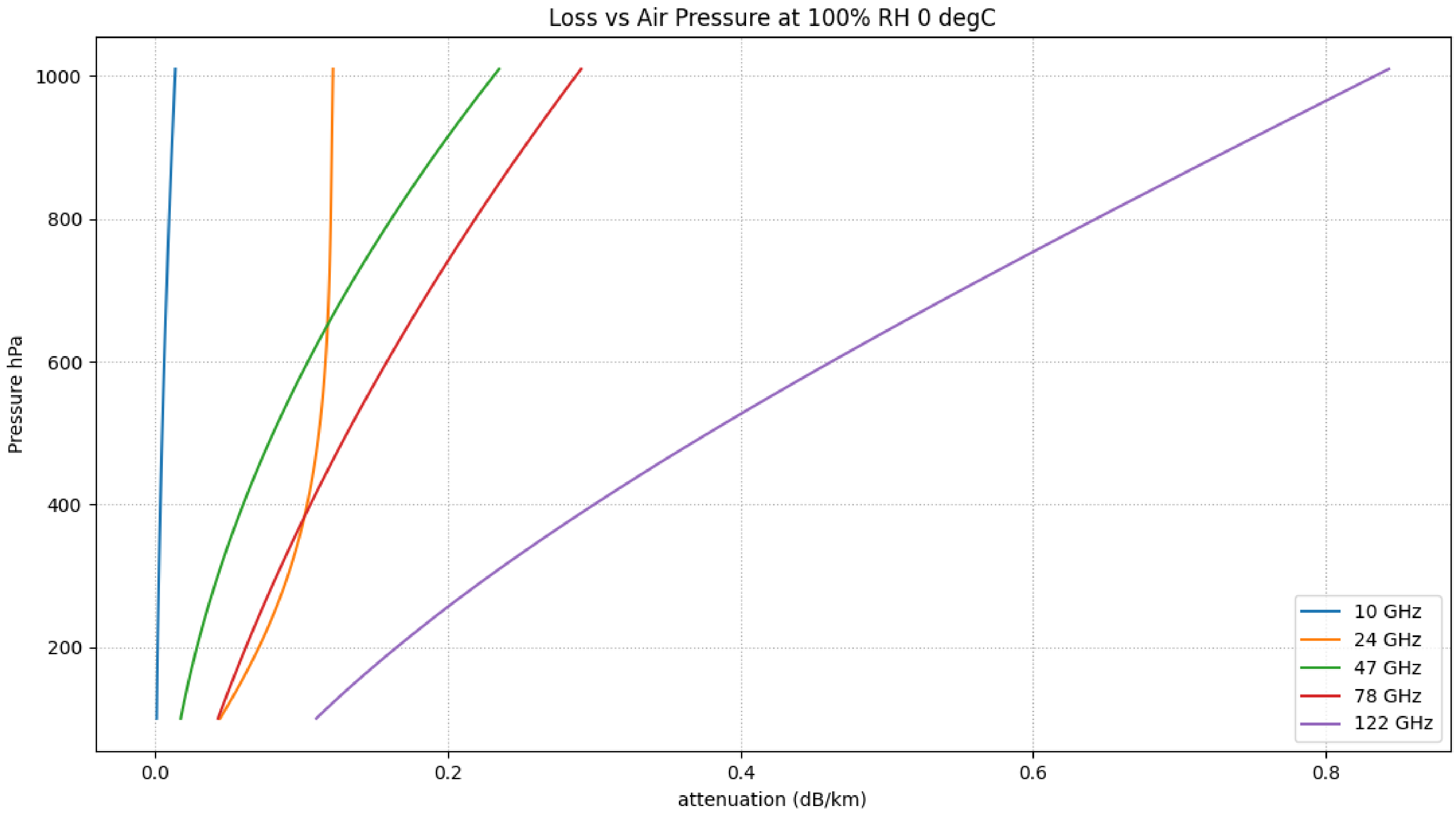
Mass, pressure, temperature, humidity are all related.

PV=nRT (except for the water which isn't an ideal gas here!)

In the absence of other constraints, if you change one you don't know how the others will react.

So, we hold the other things constant to compare two variables. Real weather doesn't do this, but it might help us understand some basic relationships.


Loss vs Temp at 100% RH, 1013.2 hPa
Temp degC
20
10
0
−10
−20
−30
−40
−50
−60
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
attenuation (dB/km)
10.368 GHz
24.192 GHz
47.088 GHz
78.192 GHz
122.4 GHz


Loss vs Air Pressure at 100% RH 0 degC
Pressure hPa
1000
800
600
400
200
0.0
0.2
0.4
0.6
0.8
attenuation (dB/km)
10 GHz
24 GHz
47 GHz
78 GHz
122 GHz

Okay….now *practical* thermodynamics:

- Air can only hold so much water as a gas (vapor) at a given temperature.
- If there is more water than this (say because saturated air rose in altitude for some reason and it cooled adiabatically) you get liquid or solid water precipitating out—tiny water droplets or ice crystals….it’s a cloud.
- If water is forced from gas into liquid state (condensation), its *latent heat* is added to the air. The air cools less than it otherwise would have.
- Latent heat might cause the air to still be buoyant. It rises more and water condenses. If it’s still buoyant it rises some more….if and how much depends on the vertical temperature- and humidity profile of the air.
- If it’s a runaway process you have a *cumulonimbus* cloud! Maybe rain and a big storm if this goes on long enough!

More practical thermodynamics

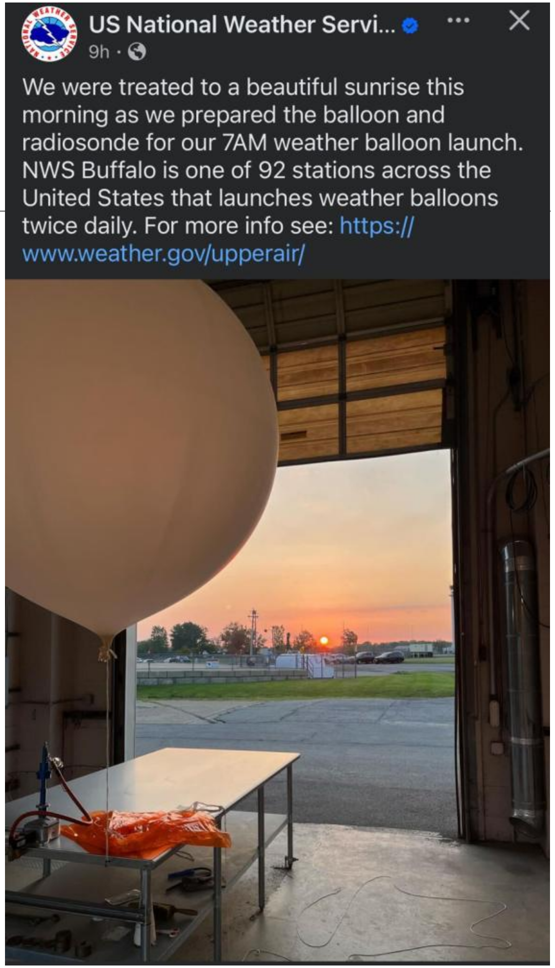
- Thunderstorms are big towers of saturated (i.e., 100% RH) air. All those helpful scattering particles are flying around in it.
- 100% RH in air at 300hPa/-20C is very different from 100% RH at 1000hPa/+20C on the ground!
- Dewpoint, temperature, total air pressure can be converted into *absolute humidity*: kg_{H2O}/m^3
  - Find mixing ratio first (mass of water per mass dry air), then mass per volume based on density and pressure
- Atmospheric loss calculated in dB/km from absolute humidity and frequency (ITU-R P.676)
- Calculations used here leverage python libraries:
  - *metpy* for thermodynamics
  - *itur* for RF path loss

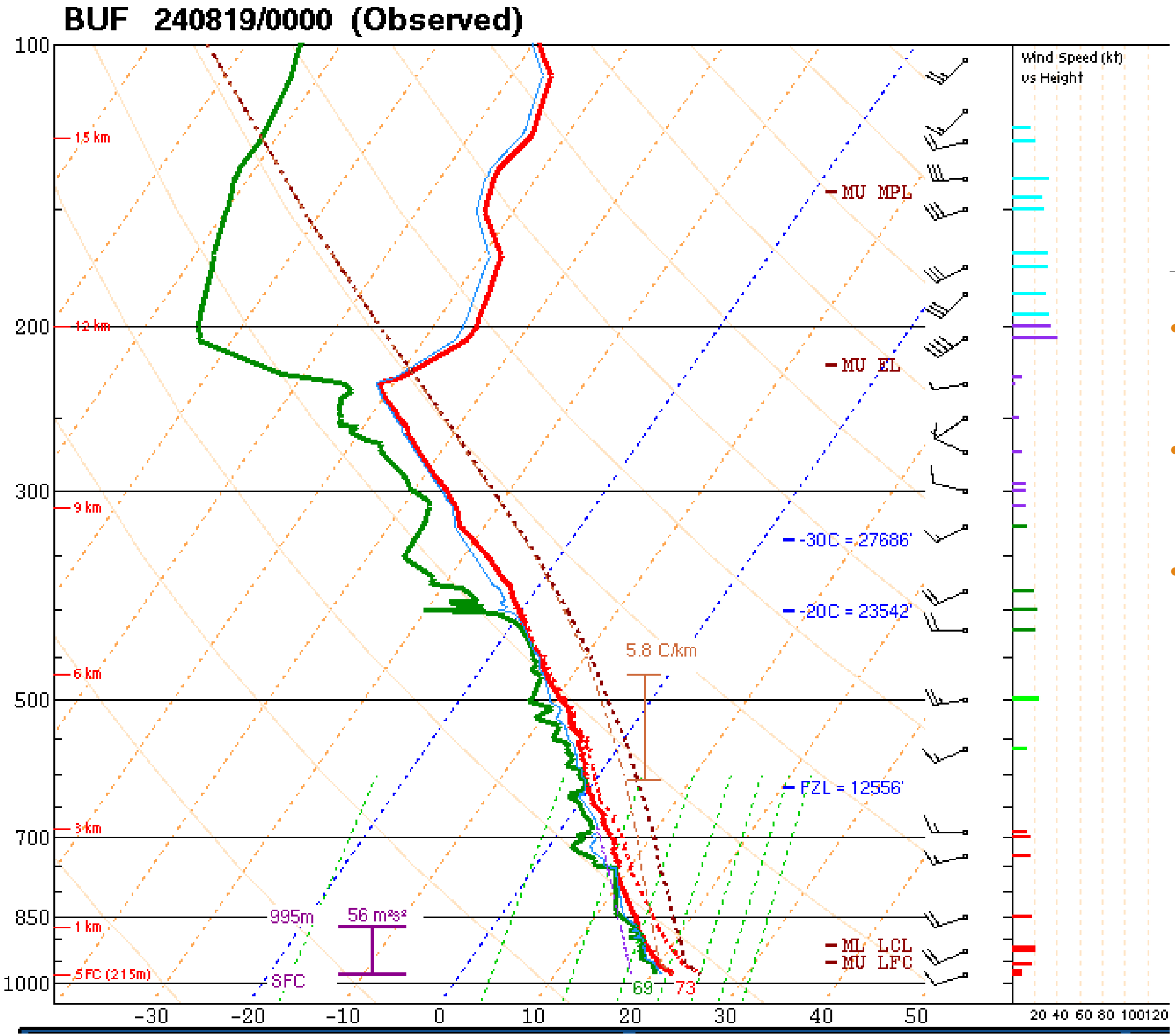
Let’s get real

- What started this presentation: VE3KH worked K0SM/KE2AIZ (180km) August 2024 off thunderstorm close to K0SM
- Let’s model the RF path in 3D using actual humidity and temperature measurements by altitude.
- Make some assumptions to simplify things:
  - 50,000 foot storm (it probably wasn’t this tall)
  - Assume rain shaft is a constant density from top to bottom (scatters equally well at all altitudes)
  - Stations at sea level
  - Calculate straight line path to storm
  - Calculate atmospheric attenuation over this path

Weather data: radiosondes

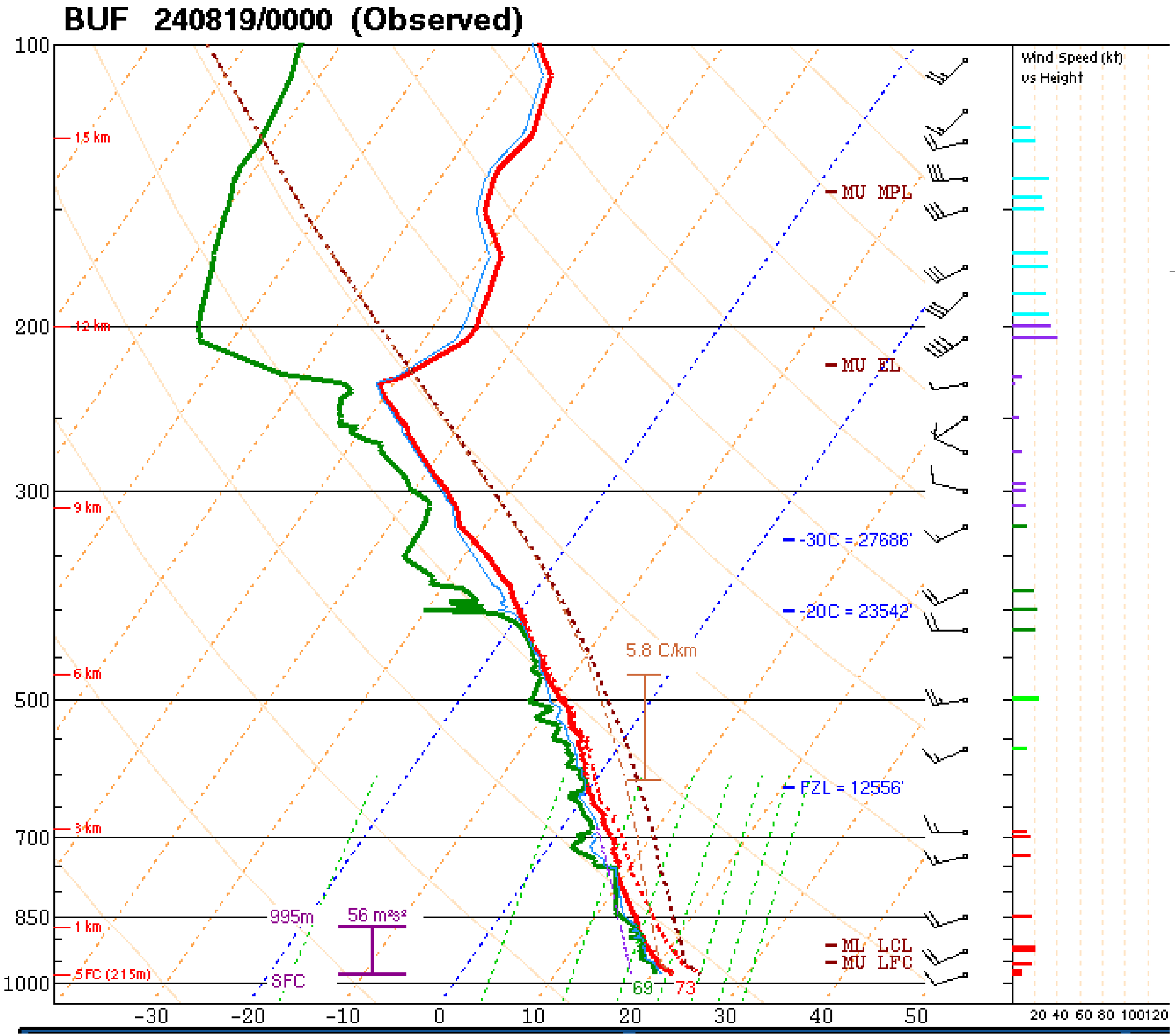
- This is what a weather balloon carries
- Measures pressure, temperature, dewpoint, and wind periodically during ascent.
- Atmospheric pressure is very good proxy for altitude, so we can get temperature and dewpoint with altitude.





Skew-T

- Temperature and dew point is plotted on special graph paper
- Y-axis is log pressure (= linear altitude)
- Temperature on x-axis "skewed" at 45 degrees
  - Makes typical lapse rates more vertical on page



Skew-T

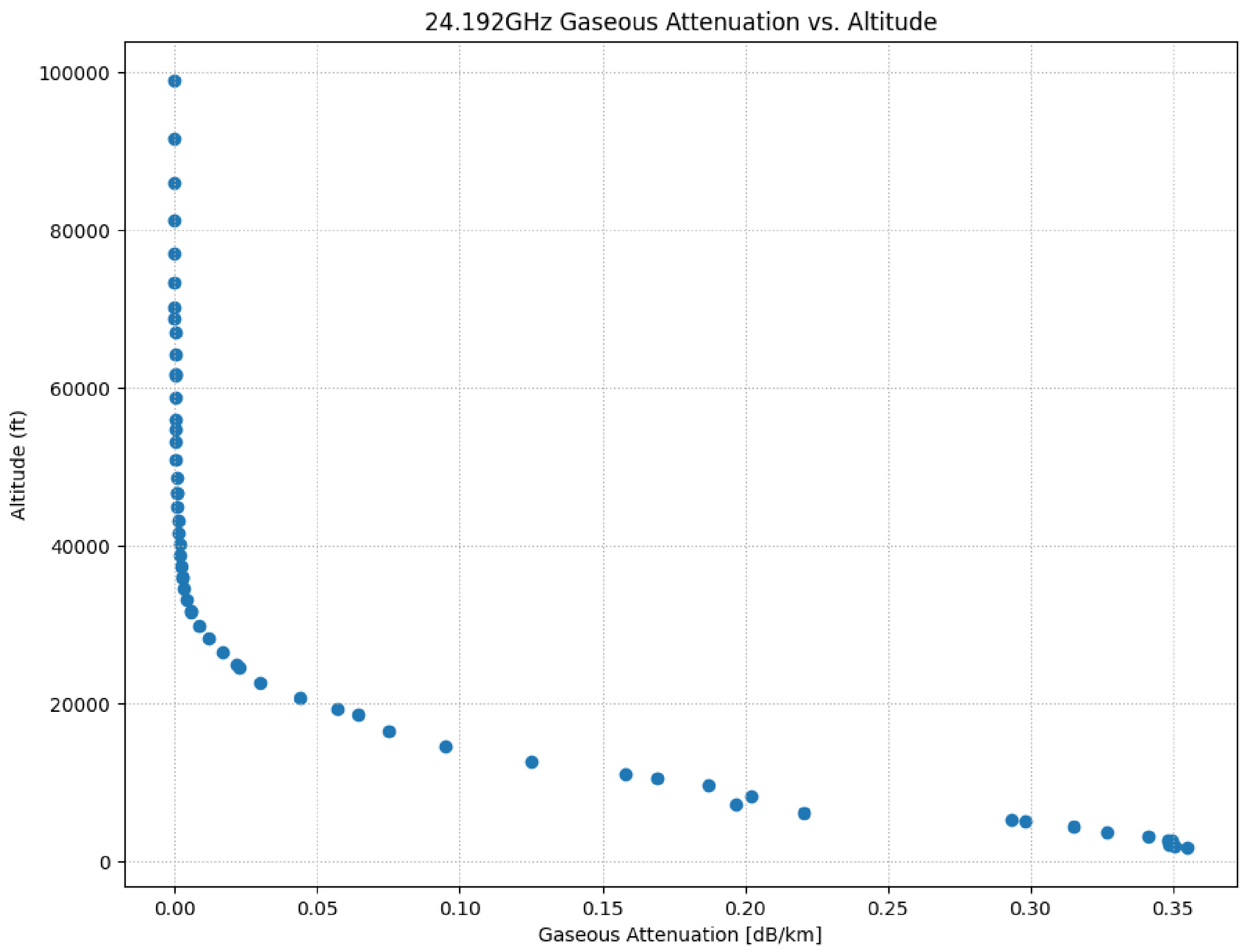
This shows T-storm weather during 10GHz contest

Air is 100% RH up to 30,000ft

This radiosonde was likely launched into rain or just after.

Temperature and dewpoint drop with pressure (altitude)

What is relationship between 24GHZ atmospheric attenuation and altitude?



Altitude makes a big difference!

Best of both worlds:

- Pressure drops!
- Dew point drops!

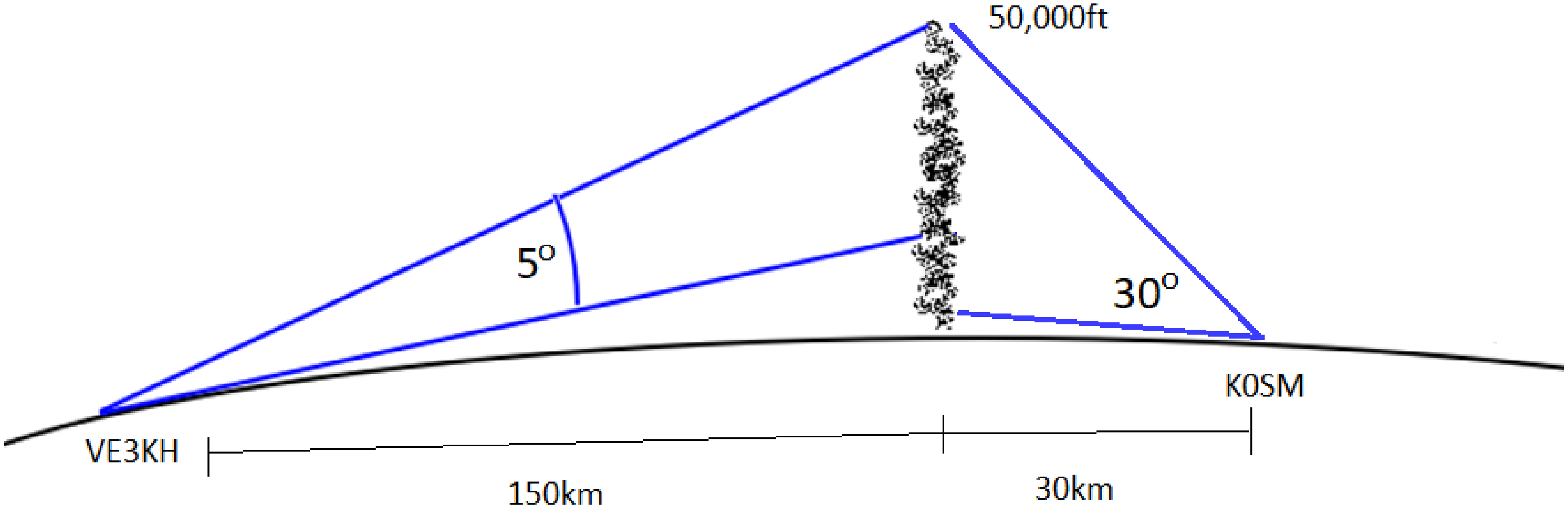
We lose less signal if the RF travels at higher altitudes

Maybe we should point the antennas up?

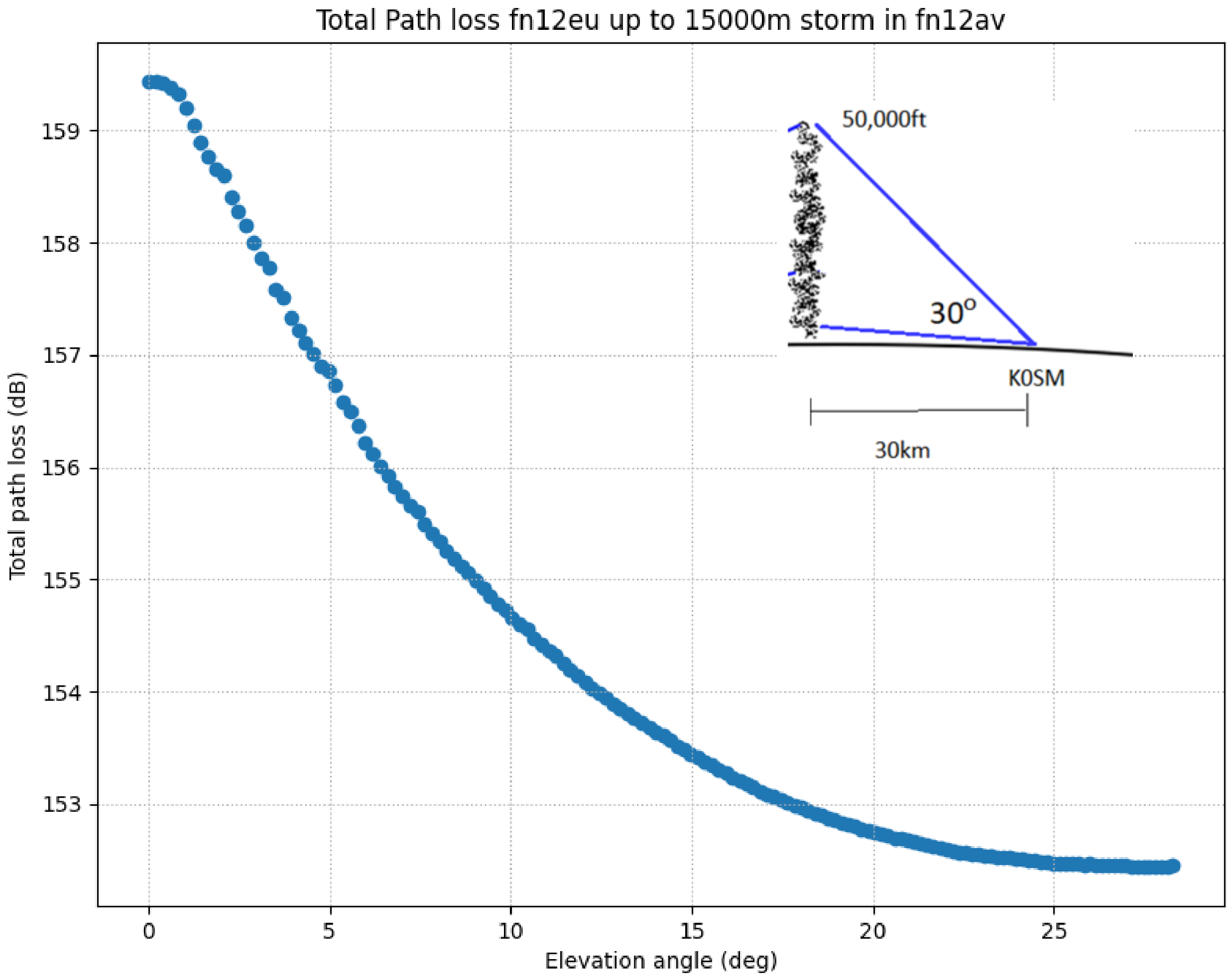
Path-loss computational method

- Use Buffalo radiosonde data from NOAA for dewpoint, temperature, pressure, altitude near time of QSO
- Numerical integration of path loss for each elevation angle:
  - Divide path into 100 segments
  - Calculate atmospheric path loss for each segment based on absolute humidity and segment length using pressure/dewpoint measurements from radiosonde
  - Sum up the loss of each ray to find total path loss at that elevation angle
  - Find the ray with the lowest cumulative loss.

Find the least attenuation at 24 GHz among all possible elevation angles



*not drawn to scale



K0SM to storm (30km)

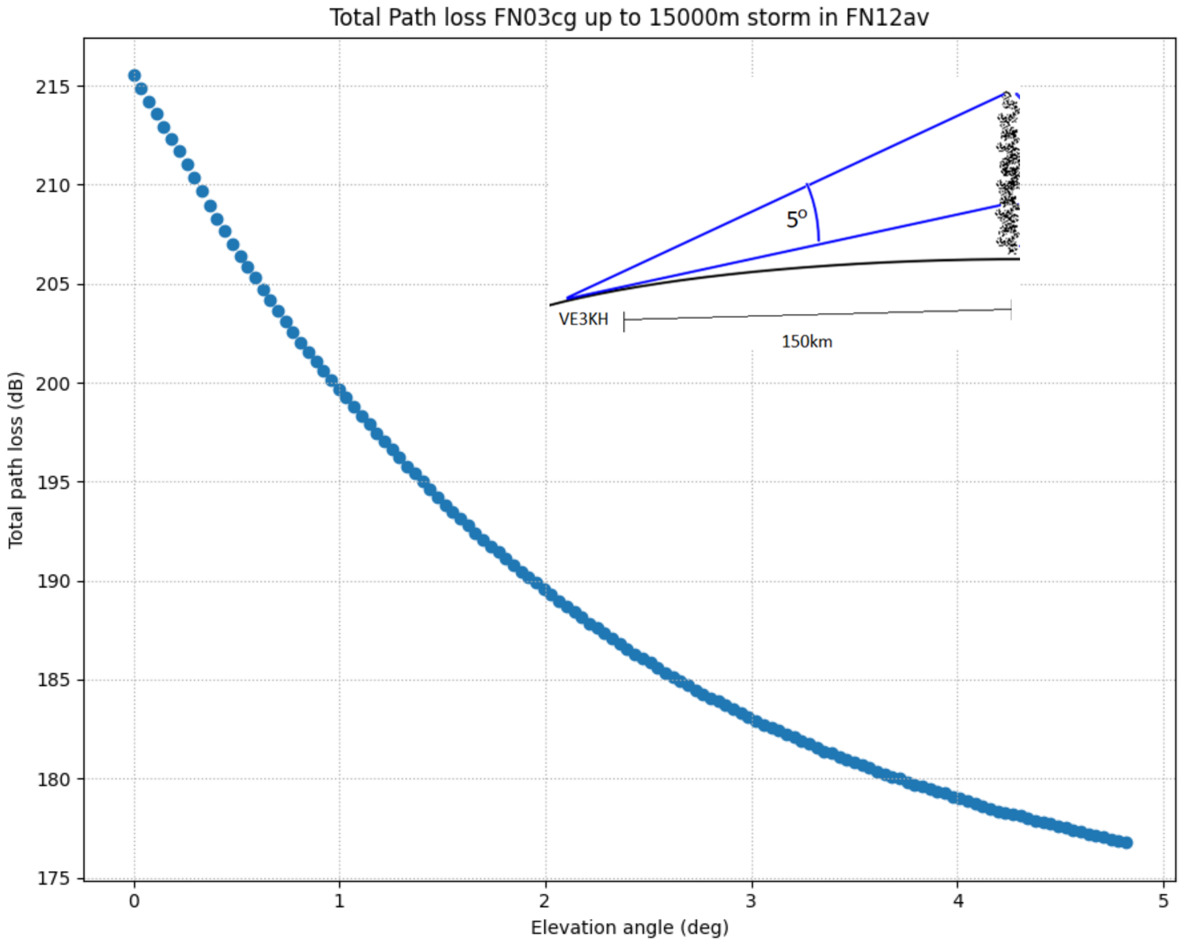
Storm spans about 30° above the horizon

Path loss less at higher elevations.

8dB more energy gets to the storm at 25° elevation

Low air pressure->less loss!

Lower dewpoint->less loss!



VE3KH to storm (150km)

Storm only spans horizon to +5° at Kevin's QTH

He has a lot more air to travel through to get there.

The effect of elevating the antenna is *tremendous:*

40dB!

Observations

- There is a cumulative 48dB improvement when stations point at the top of the storm compared to the horizon. The difference would be more extreme if K0SM were farther from storm:
  - On a 300km path (2x150km) this makes an 80dB difference
  - Pointing at the horizon is probably pretty useless except on the shortest paths
- What *actually* happened back in Augst:
  - K0SM pointed at the visible anvil, somewhere around 30 degrees or so (estimate)
  - K0SM dashed and waved it around up there until Kevin said “I just saw something!”, then zeroed in
  - VE3KH found signal up around 4-5 degrees elevation and we peaked
  - Antennas on 24GHz are on the order of 1-deg beamwidth, pointing was critical at K0SM. Had to keep moving dish because storm was so close
  - Doppler shift 2.4 times more than 10 GHz. *Very* spread out.

More 24 GHz rain-scatter QSOs!

Experiments with VE3KH in September confirm extreme path loss difference between horizon and a few degrees up is real.

K0SM/KE2AIZ worked VE3KH (twice, ~180km), W2FU/WA2TMC (twice, 230km), VA3ELE/VA3TO (248km) via rain scatter in 10 GHz and Up Contest. More with NG3W in October!

- Signals were loud once we got the elevation dialed in.
- Early Fall thunderstorms, nothing severe or even very tall for the longest QSOs (<30,000 ft), 80F ground temp
- Elevation between 2 and 6 degrees on both sides depending on rain location and height.

European RS DX on 24 GHz notably reports significant elevation on both sides.

10 GHz and Up 2024

These were all RS QSOs with K0SM and KE2AIZ

VA3ELE was on NBFM!

Best DX by Band in Kilometers

Call	Best DX
24 GHz	
K6MG	259
KB6BA	259
KØSM	248
KE2AIZ	248
VA3ELE	248
W2FU	235
WA2TMC	225
N9JIM	213
W6QIW	213
AA9IL	187

Doppler effects

Side scatter spreads the signal much more than on 10 GHz. This lowers effective SNR.

- My 100km QSO with NG3W had 45 degree off direct: pulsing white noise in the 3 KHz passband.

World 24G rain scatter record happened on a 15-20 degree bend:

LX1DB: "The report from my side 43S was due to the fact that the signal was very wide in spectrum and even with the relative high field strength not easy to read[.]" (Scatterpoint, July-Aug 2008)

We should figure this out *before* we need it: turn off the AGC, ride the RF gain, use the AM filter? What works best in this scenario with your radio?

- We can experiment with our gear using backscatter signals on 10 GHz
- I need to upgrade from an FT-290/II!

Start small: What does it take to break some NA records?

Stations	Date	Distance
W5LUA (EM13qc) - WW2R/5 (EM41hc)	07-Sep-02	543 km
WB6CWN/6 (DM04ms) - AD6FP/6 (CM88ws)	21-Aug-10	526 km
KC6QHP/6 (DM04ms) - AD6FP/6 (CM98qf)	22-Aug-10	412 km
K6GZA/6 (CM97hm) - AD6FP/6 (DM04ms)	16-Sep-00	375 km
AD6FP/6 (CM97hm) - W6QI/6 (DM04ms)	20-Aug-05	375 km

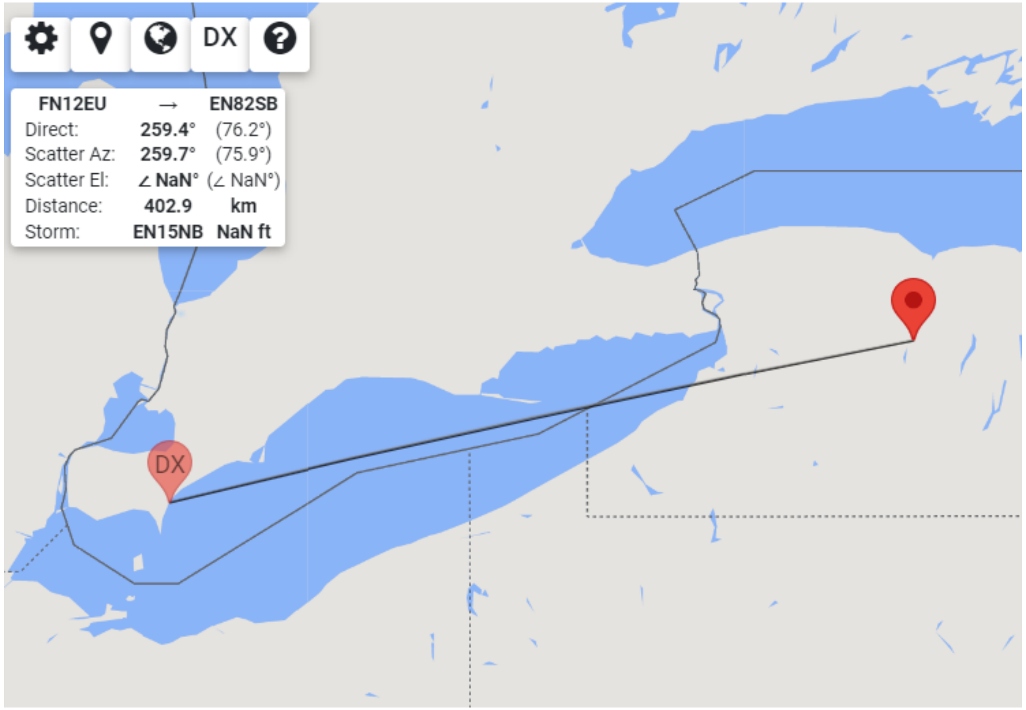
These are all tropo, most between mountains. W5LUA/WW2R probably a morning radiation inversion and some extra EIRP.

Most of these records are pretty old (same is true in Europe)

Current NA 24G RS record is only 289 km.

How about 400km as a goal this year?

Example 400km path (FN12eu-EN82sb)



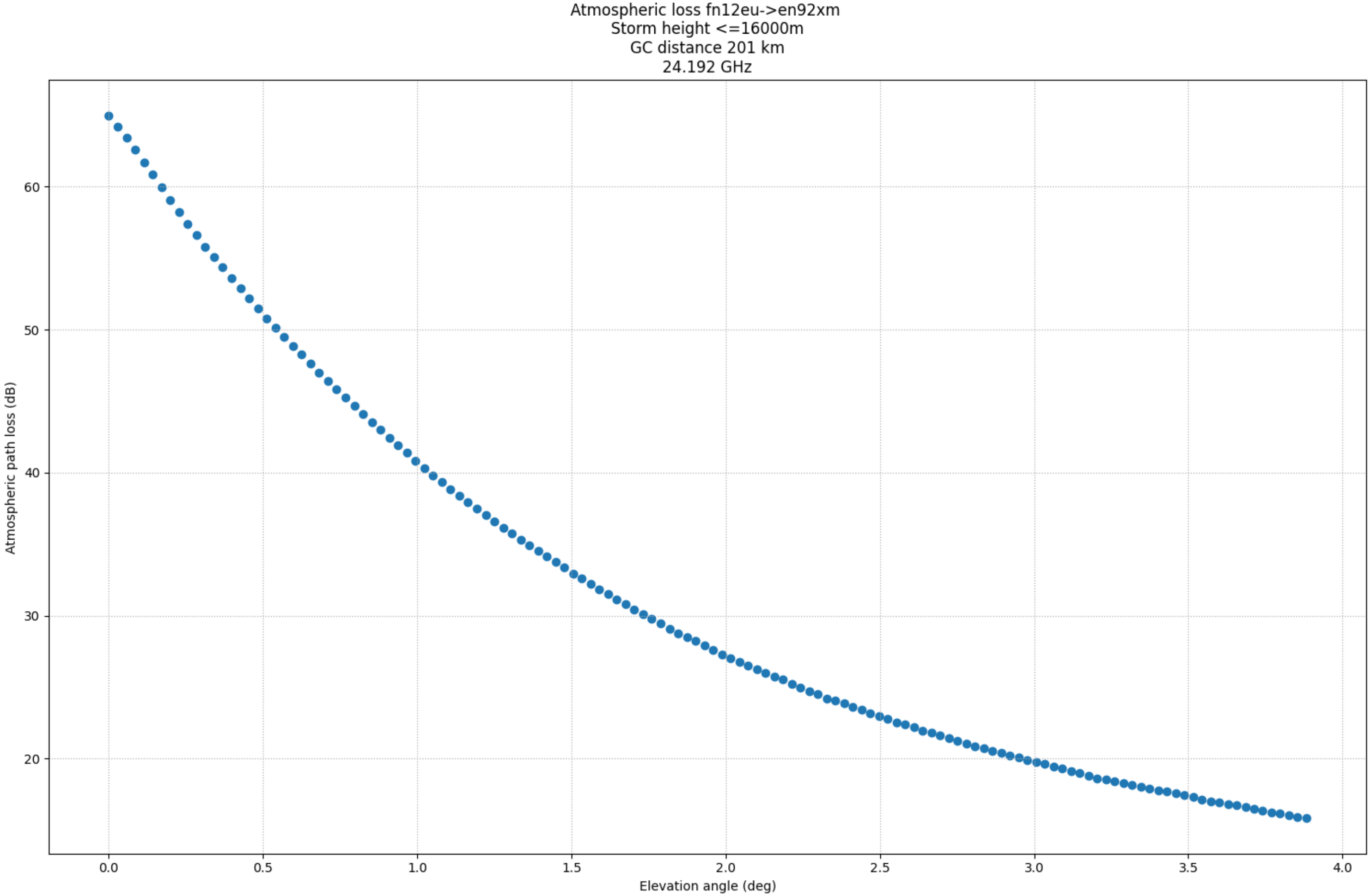
55,000ft storm top

Assume no atmospheric refraction

- Summertime refraction often one degree, and this only helps

We'll calculate 1-way path loss, total forward scatter atmospheric path loss twice this amount on a symmetrical path.

How does it compare to previous QSOs?



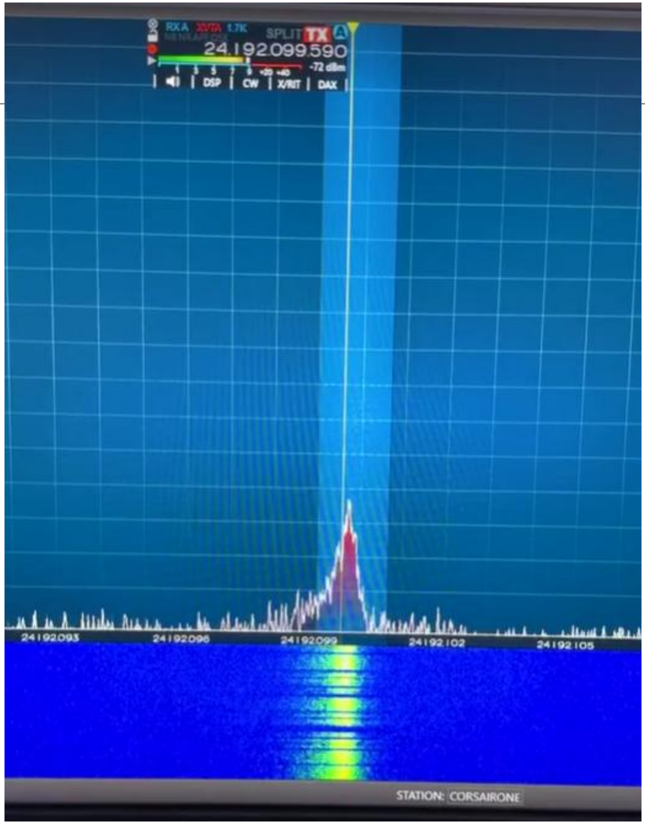
400km 24 GHz

About 17dB each way, 35dB total gaseous loss

About 15dB more than our 24 GHz ~200km QSOs

We’ve already seen this much SNR with non-severe T-storms!

This will work, if we point up around 4 degrees.



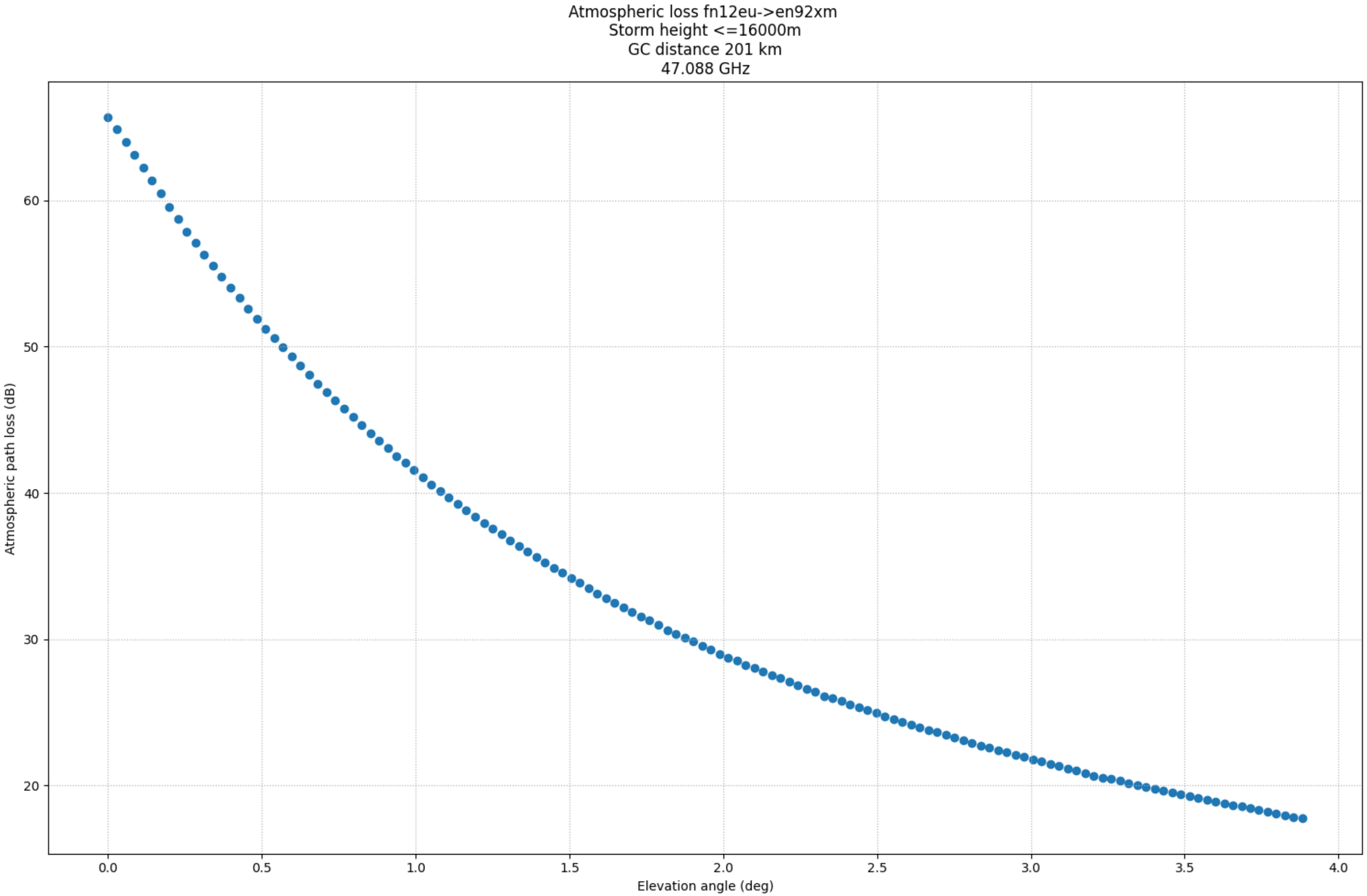
225 km

NG3W at VE3KH on 24 GHz CW

15-20dB+ SNR

30,000 ft T-storm

6-Oct-2024



400km 47 GHz?

Not much worse than 24 GHz!

Challenges:

- Doppler
- Higher NF
- Smaller apertures?
- Less power?

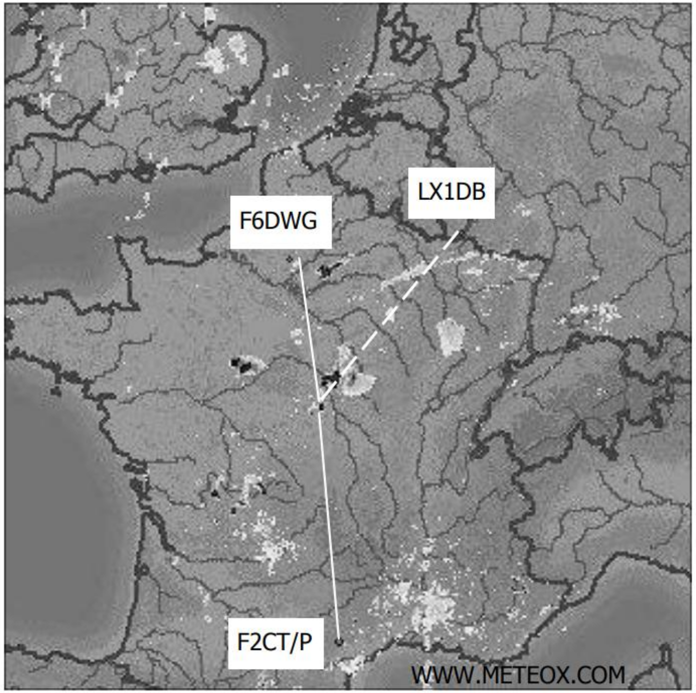
Probably doable with better stations

344.8 km is current record

24 GHZ rain-scatter operating tips

- Elevation adjustment is required on 24 GHz
- Realtime feedback for alignment (phone, 10G NBFM, etc.)
- Antenna alignment is a 2-dimensional problem:
  - Beamwidths are narrow: stations must illuminate same part of rain in AZ and EL
  - Approximately equidistant stations should use same elevation—coordinate!
- Might need to fish around to find the best spot with storm geometry/thickness—especially if close to the rain
- This has worked: peaking on 10 GHz near the direct path (minimum spreading), then elevate antennas on 24 GHz
- My experience: rain scatter over 150km has been 2+ degrees elevation, usually more
- Inclinometer is helpful to get started!
- Use wide bandwidth in the RX and RIT for doppler spreading and shift!
  - Rain scatter is no place for narrow CW filters! If you have 6 kHz you might need it
  - Something to try on wide signals: turn off the AGC and ride RF gain

The 24G RS world record (24 June 2008)



Marc F6DWG continues....

"The QSO was made on 24th June at 2001GMT- I am in JN19AJ near Beauvais. I think we were using an extremely BIG storm because Guy was booming on 3cm 59RS++ . I have never seen such an extremely strong signal before on 10GHz !! I have determined the SCP to be JN17LO, 176°. After pointing my dish to the maximum on 3cm, I was transmitting on 24048.100 for one minute, and I received an SMS from F2CT - "Je t'entends" (I am hearing you). Guy was calling me on my frequency but at first I got nil from him. To copy him, I used 4 degrees of elevation on my dish. His signal was very weak occupying around 5kHz bandwidth, a very strange RS signal, maybe because of the very long distance..637kms ! The maximum RST was 41S on both sides and after the final rogers, I lost him in the noise."

Notice that F6DWG elevated *after* signals were detected at 637km

F6DWG around 400m ASL

F2CT/P 1000m (this helps)

QSO with LX1DB (710km) one hour later.

(From *Scatterpoint,* Jul-Aug 2008)

Conclusions:

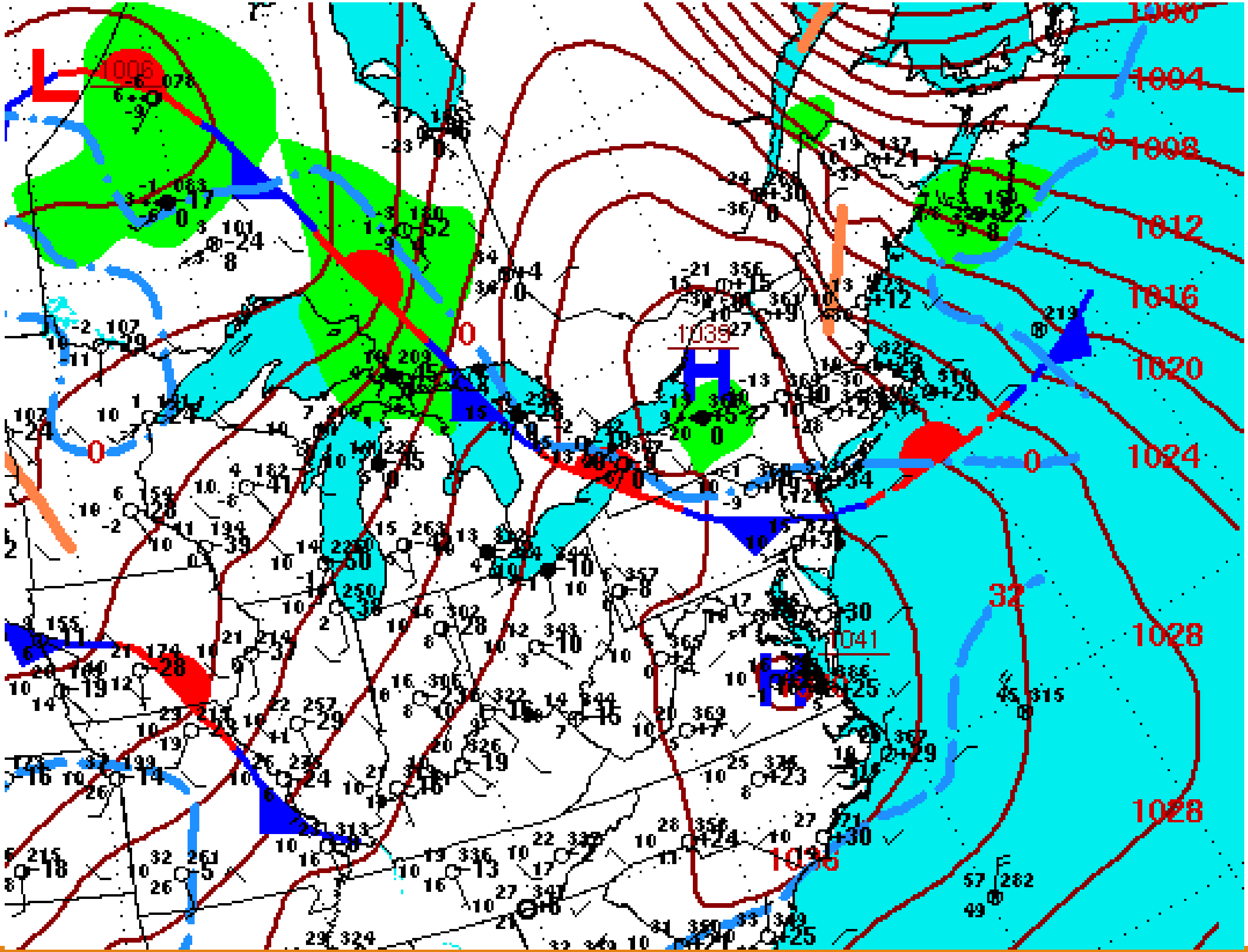
- We *MUST* elevate antennas to beat the atmospheric loss!
- 24GHz on the tower? Add an actuator to allow 10 degrees of elevation
- “High reflectivity” and “High altitude” are good candidates key for record-breaking DX
  - White dots on rainscatter.com, white triangles candidates for records
- Both stations should aim at or near the storm top; best tradeoff between forward scatter energy, and atmospheric loss is likely up there somewhere.
  - Geometric elevation to storm top shown on rainscatter.com. Good starting point.
- Cooler WX on ground will still help, but we don’t usually see convective T-storms with dewpoints below 55 degrees on the ground. (Back side of Spring/Fall cold front might be good.)
- I think 300km should be routine with T-storms if both stations know to elevate antennas
- We’re gonna break some records in the next 12 months!

Q/A

Extras

Wintertime case study

- VA3TO/VA3ELE → K2UA 253km, EN93qj to FN12fs Feb 4, 2023
- We can look at Buffalo NWS sounding from 2 hours before the QSO to get vertical profile of weather and calculate atmospheric attenuation
- Allows us to calculate loss along the RF path to and from the scattering volume as it passes through different layers of air



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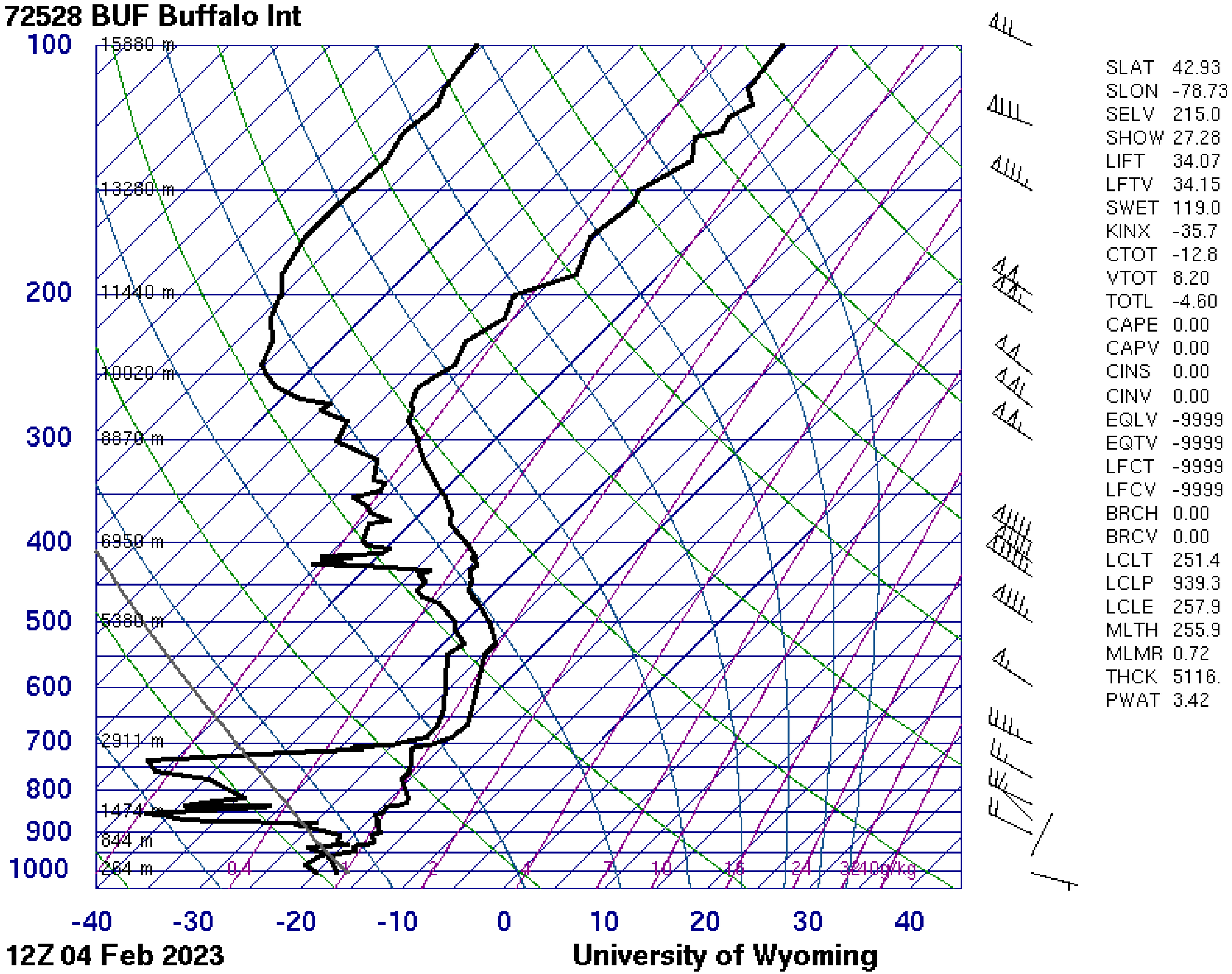
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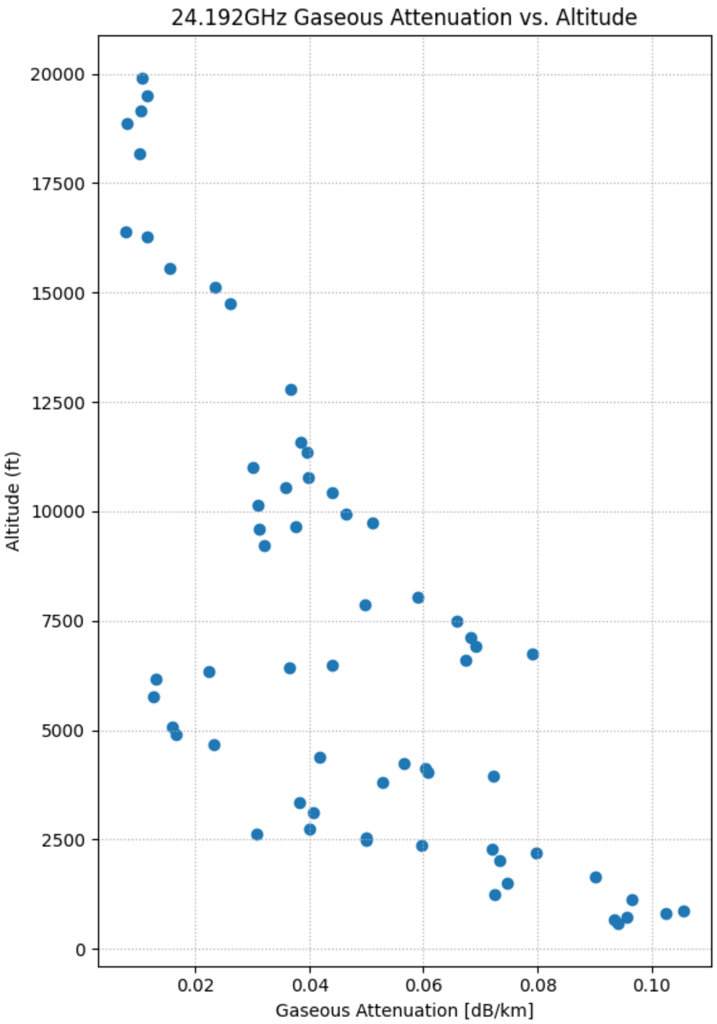
12Z 04 Feb 2023
University of Wyoming
SLAT 42.93
SLON -78.73
SELV 215.0
SHOW 27.28
LIFT 34.07
LFTV 34.15
SWET 119.0
KINX -35.7
CTOT -12.8
VTOT 8.20
TOTL -4.60
CAPE 0.00
CAPV 0.00
CINS 0.00
CINV 0.00
EQLV -9999
EQTV -9999
LFCT -9999
LFCV -9999
BRCH 0.00
BRCV 0.00
LCLT 251.4
LCLP 939.3
LCLE 257.9
MLTH 255.9
MLMR 0.72
THCK 5116.
PWAT 3.42

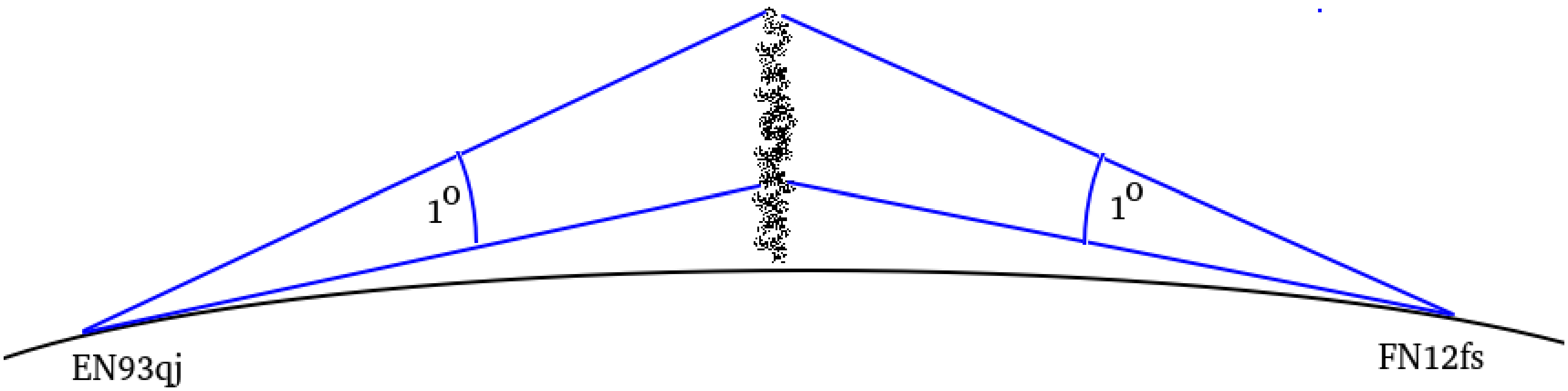


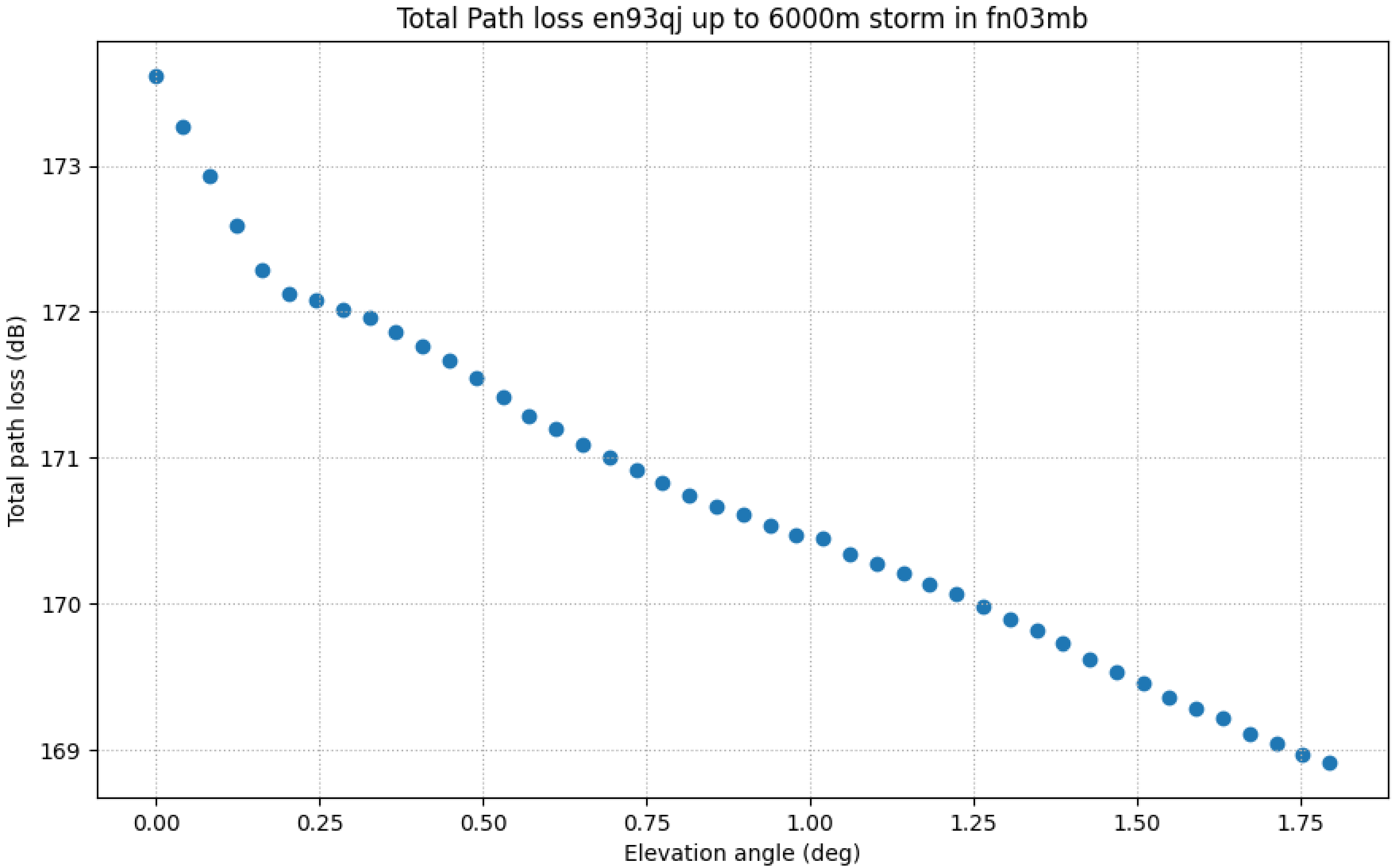
Atmospheric loss vs. altitude 1200z 4-Feb-2023

The weather

- It’s very cold. Ground temp -18C.
- RF path is along cold side of weak stationary front.
- Inversion at 700mb (3000m) is warm/cold boundary
- Light snow starts at 3000m (10000 ft) where DP = T
- Snow falls, so scatter can happen from ground up to 3000m elevation.
  - Up to 1 deg elevation for each station assuming scatter at midpoint

What elevation angle has minimum path loss?

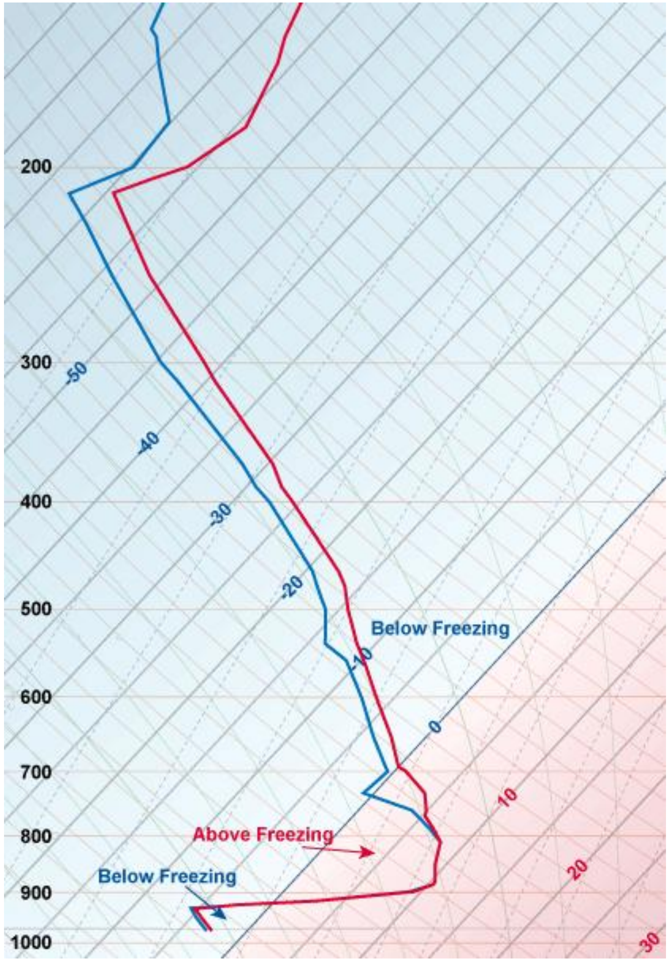


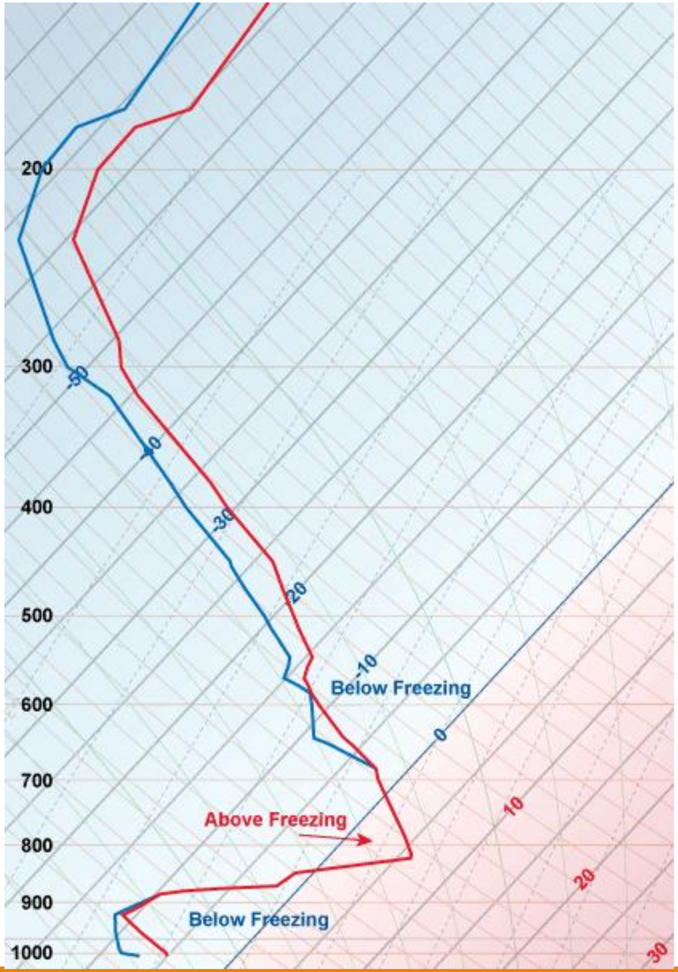


Total Path loss en93qj up to 6000m storm in fn03mb
Total path loss (dB)
173
172
171
170
169
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
Elevation angle (deg)

Conclusions

- 1 degree elevation is worth about 3dB each side (6dB total), assuming scattering is uniform in air column
- Loss would be even lower if snow were higher than 10000 feet
- This is all due to reduction in water vapor along RF path
  - There is *very little water vapor* at these temperatures and it is still worth 6dB to elevate
  - Signals are weak: dry snow has a terrible scattering efficiency compared to liquid water
- Melting layer “bright band” would increase signals 10’s of dB
- VA3ELE/P worked K2UA and K0SM on a similar path with similar signals at +20C (rain) in September 2023. More H_2O vapor loss but better scattering medium?





Freezing rain (L)

Graupel (R)

700hPa = 10,000ft

(NOAA images)