IS TROPOSPHERIC DUCTING A MYTH?

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Central States VHF Society Conference 2025

What this presentation is about:

- **Radio-wave propagation in troposphere using ray tracing**
- **Critical examination of existing thinking about ducting**
- **Propose an alternative explanation**

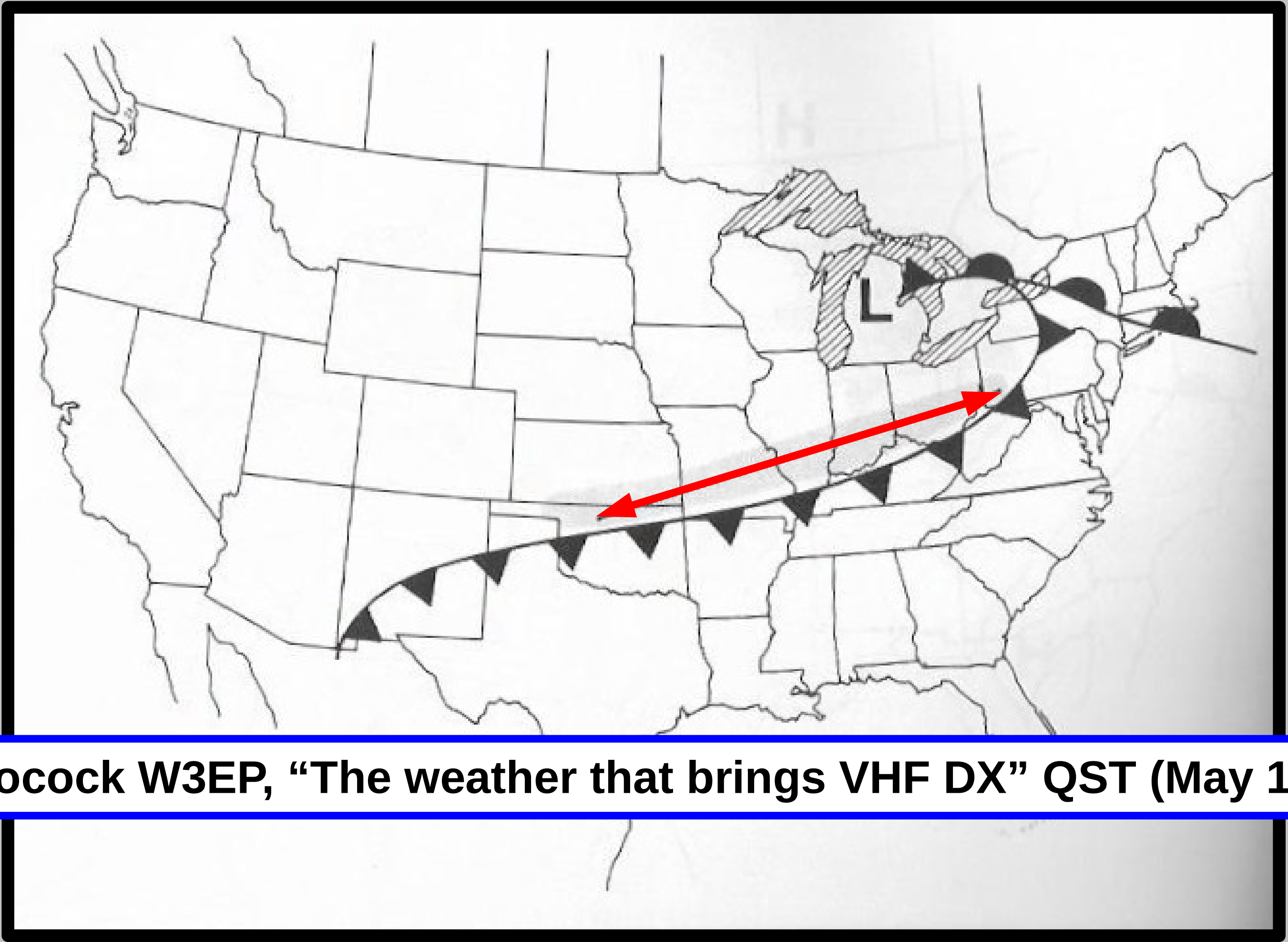
What is Tropo-Ducting?

An <u>explanation</u> for long-haul DX observed at VHF+

Characteristics of the DX path:

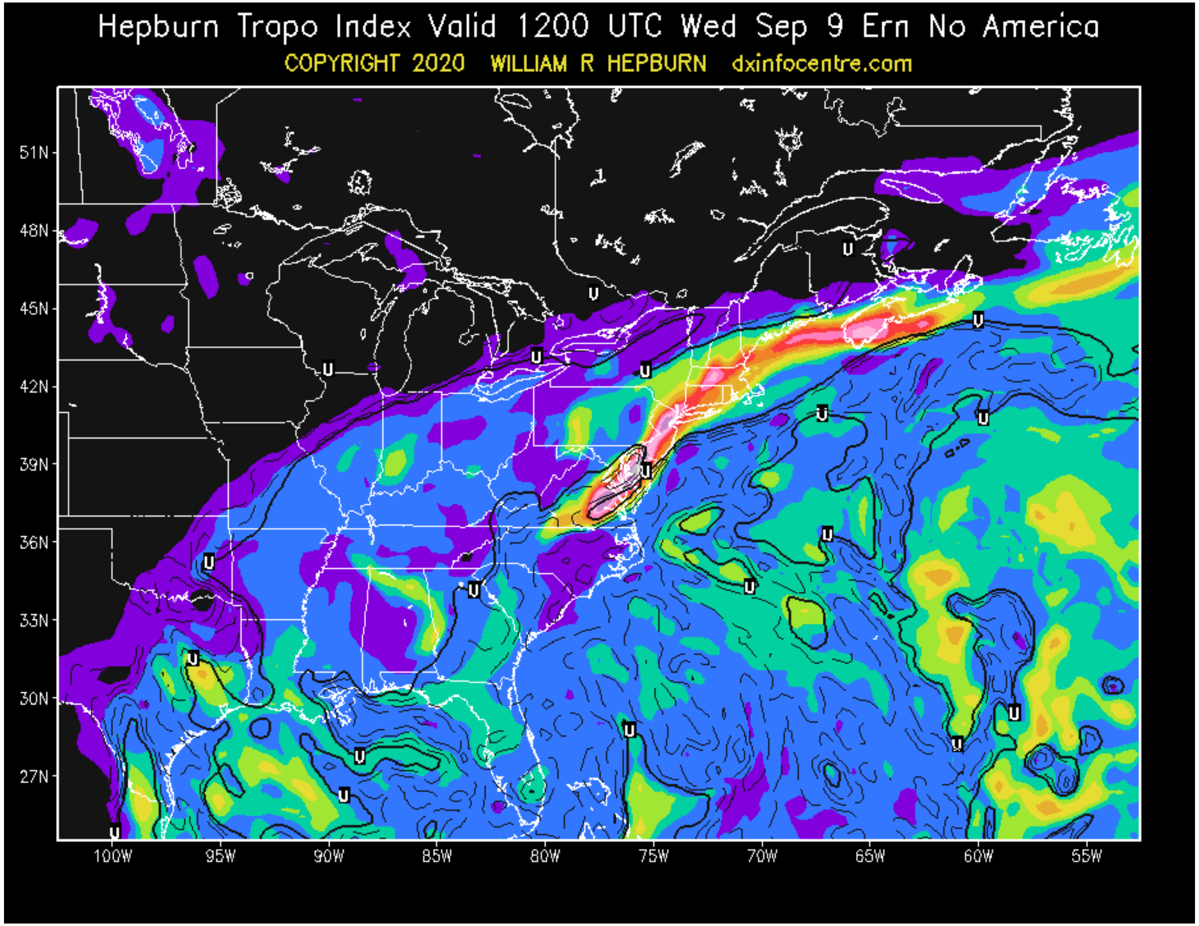
- **Higher frequencies work better; no ducting below 50 MHz**
- **Paths can exceed 1000 km**
- **Rare occurrence; form along weather fronts**
- **Openings may last for hours or even days**

THREE-HOUR UHF OPENING BEHIND COLD FRONT*

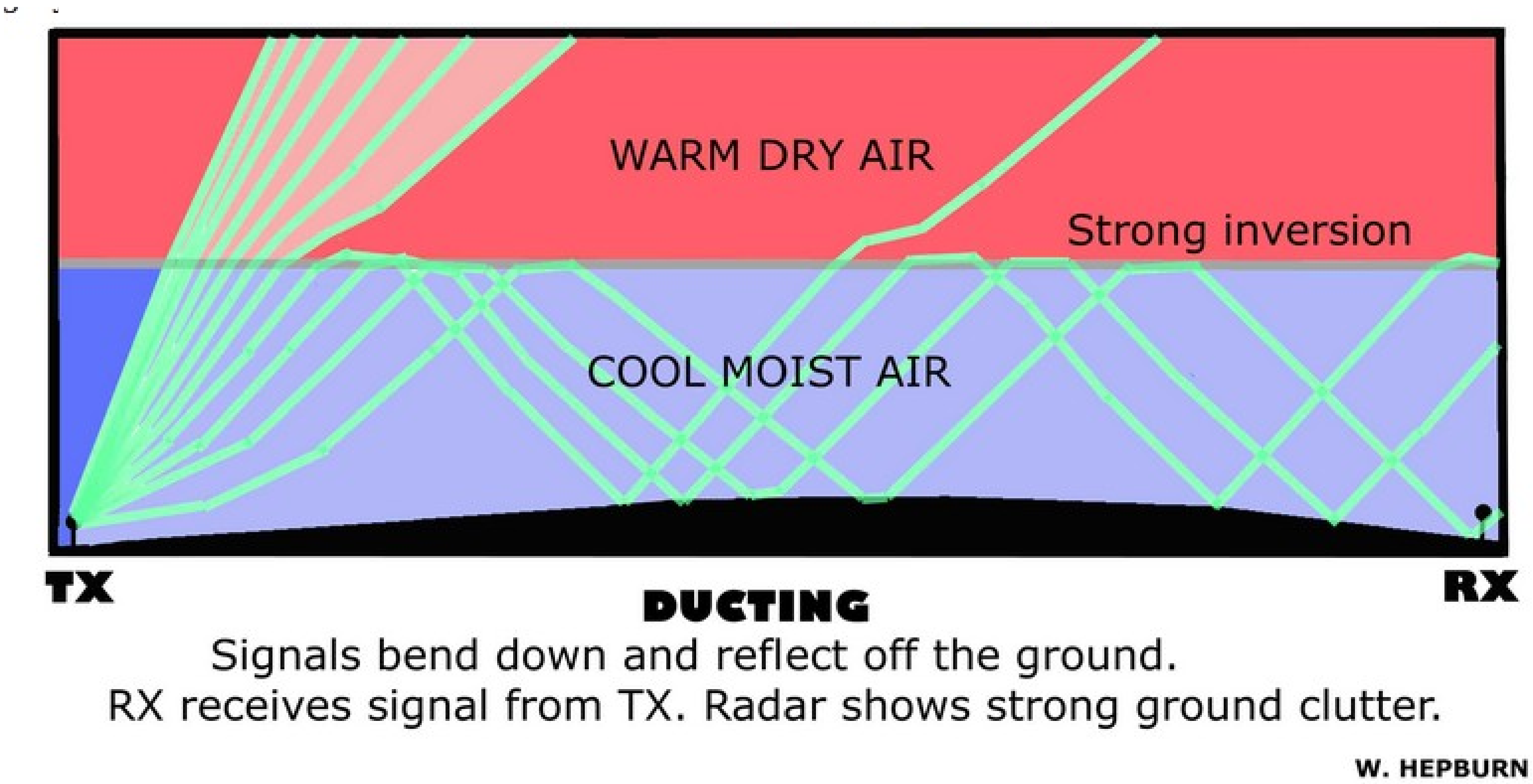


*E. Pocock W3EP, “The weather that brings VHF DX” QST (May 1983)

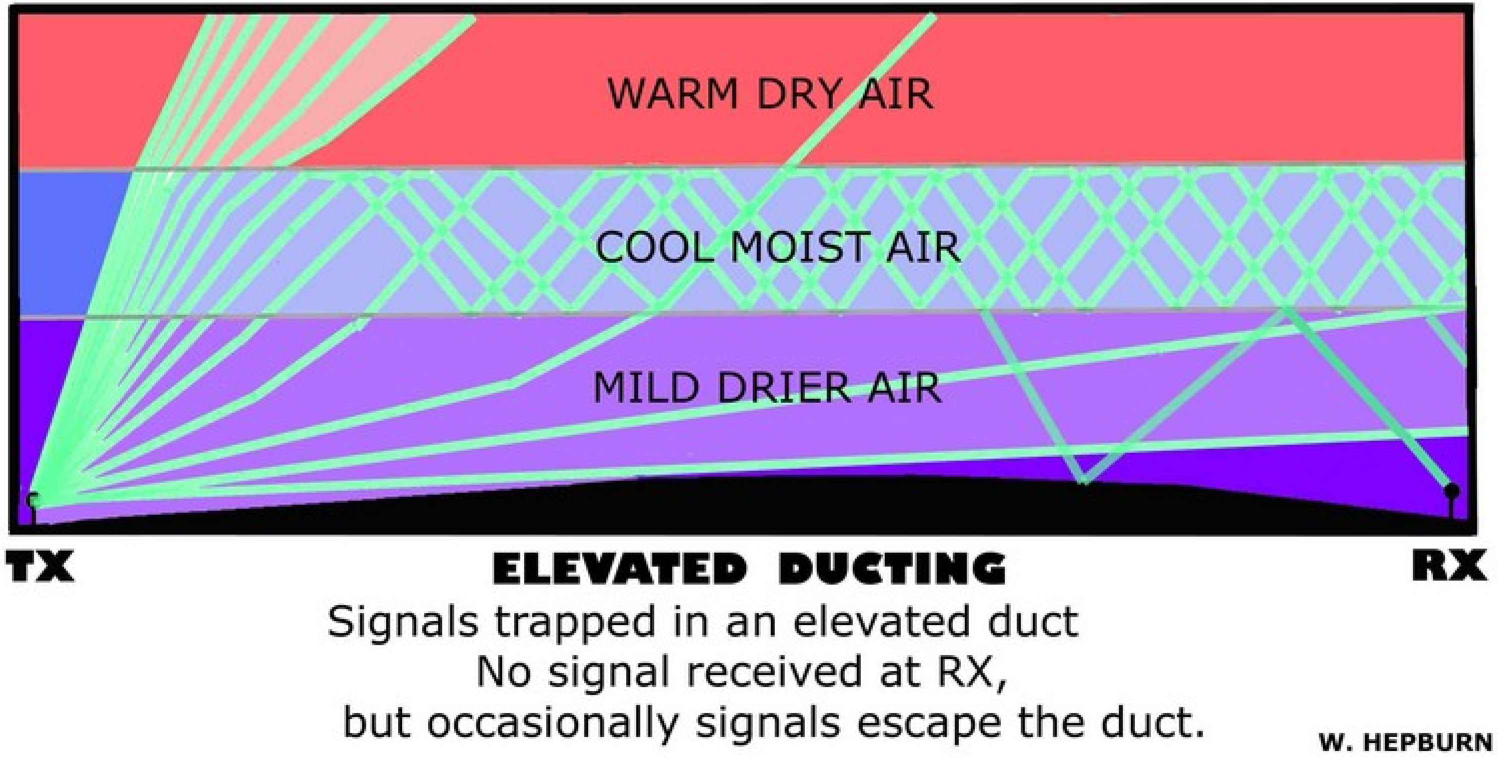
Online Hepburn Tropo Index Maps



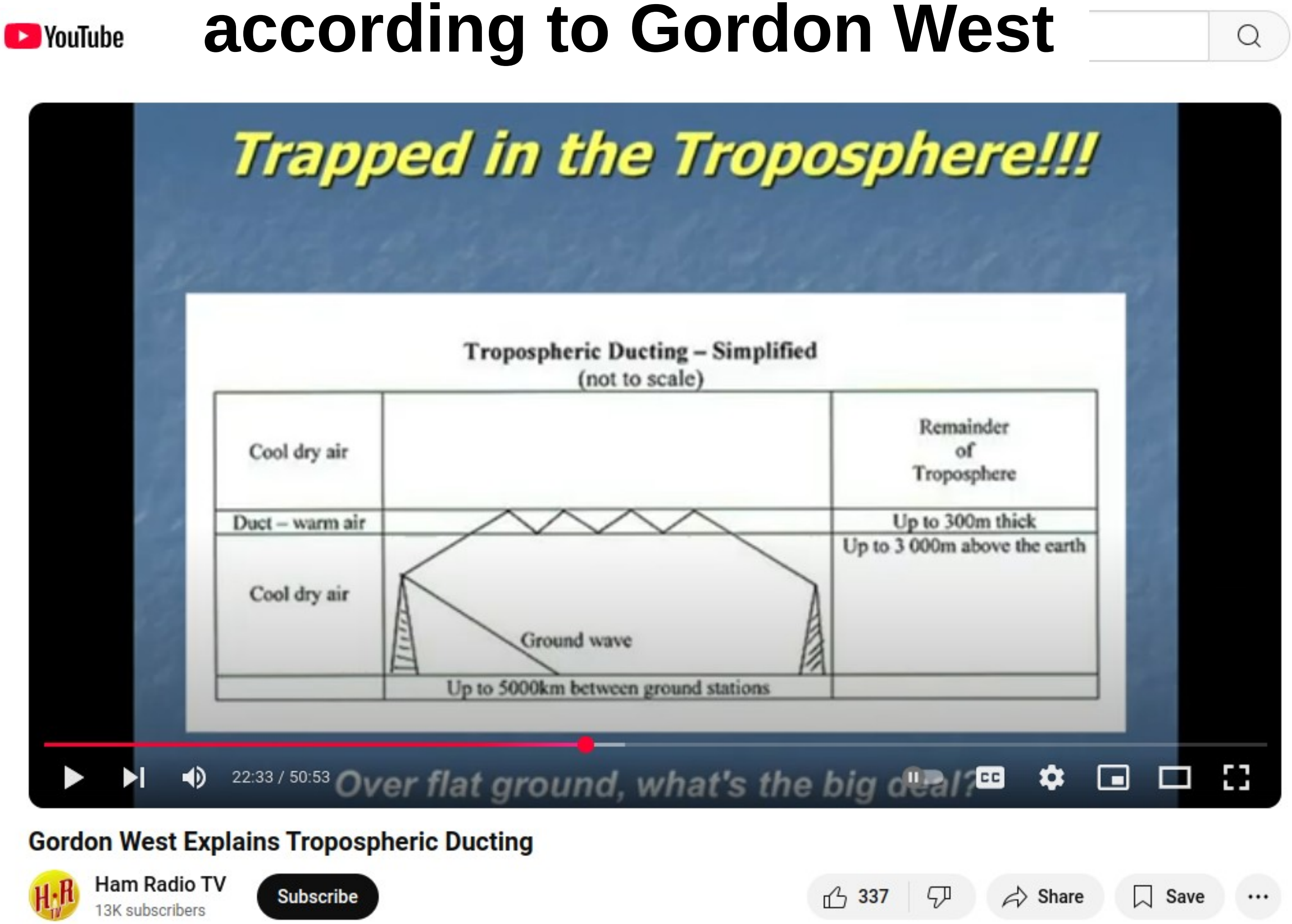
Ground-based duct according to W. Hepburn



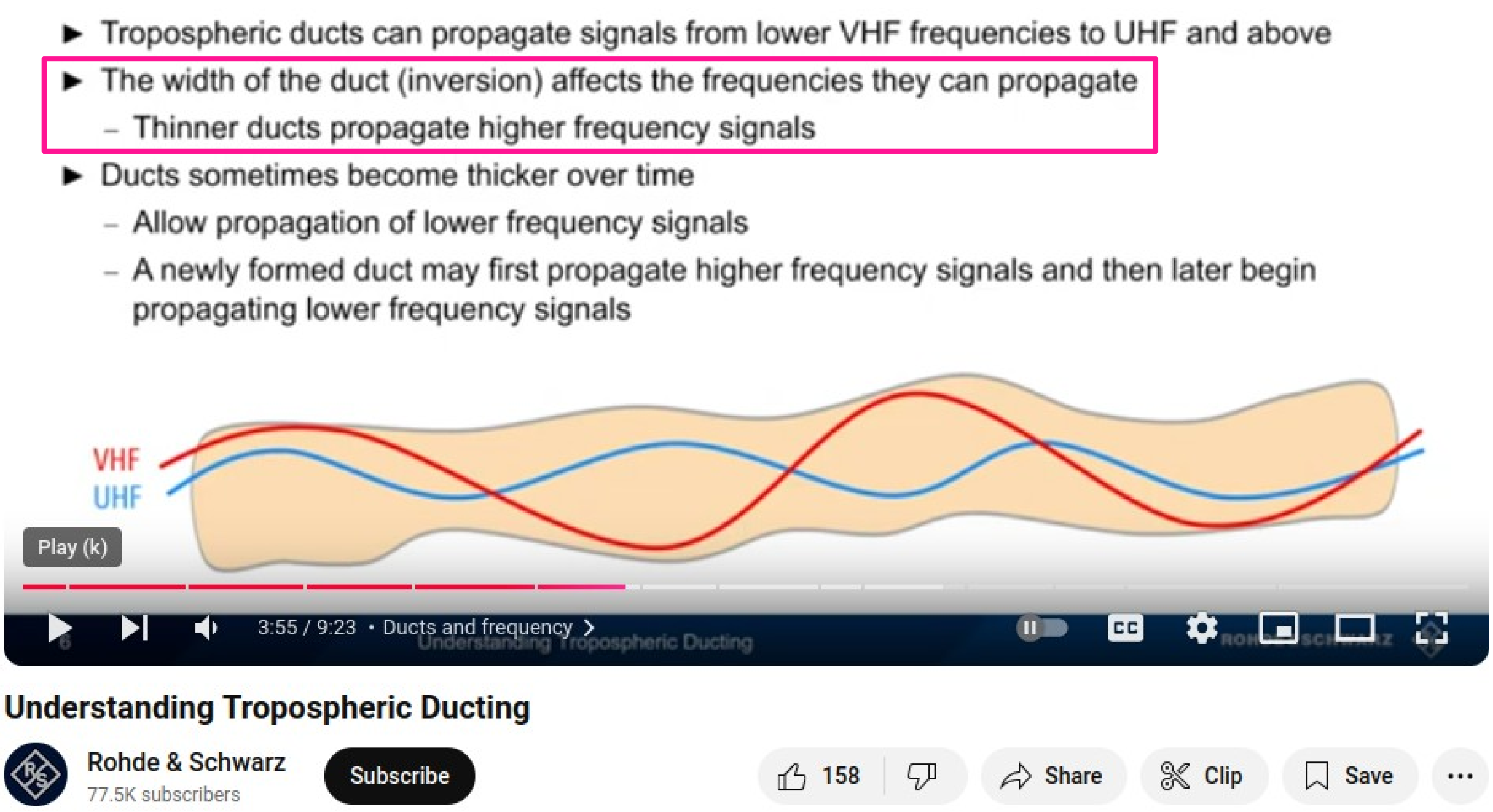
Elevated duct-waveguide according to W. Hepburn



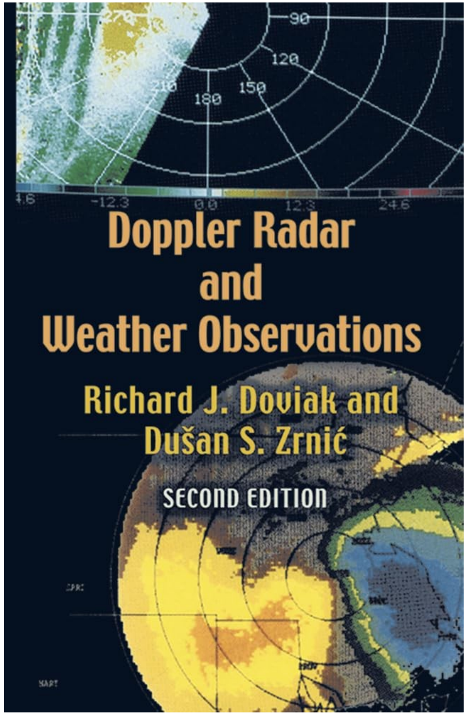
Elevated duct-waveguide according to Gordon West

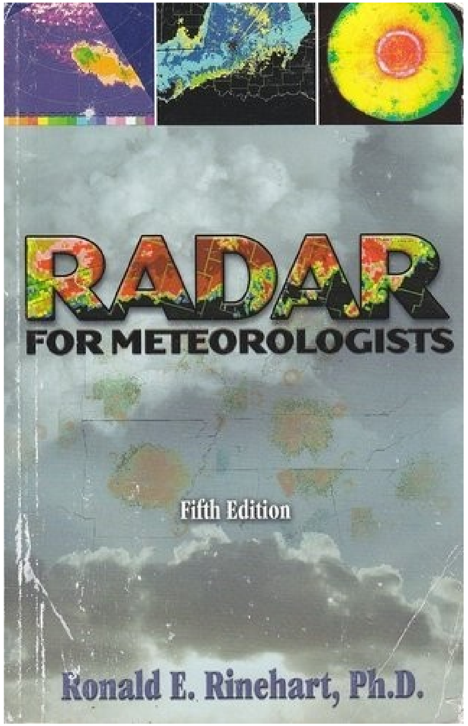


Ducting according to Rohde & Schwarz



Radar and radio waves can be analyzed using techniques of optical physics





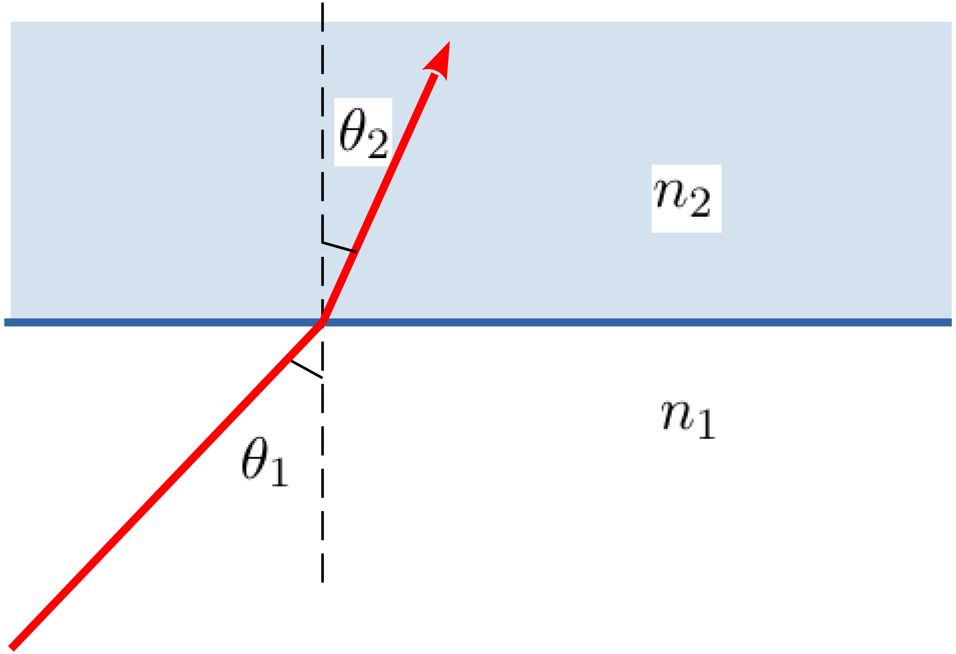
REFRACTION: Deflection in the path of an electromagnetic wave as it passes through different media

Index of refraction

Air: 1.0

Water: 1.33

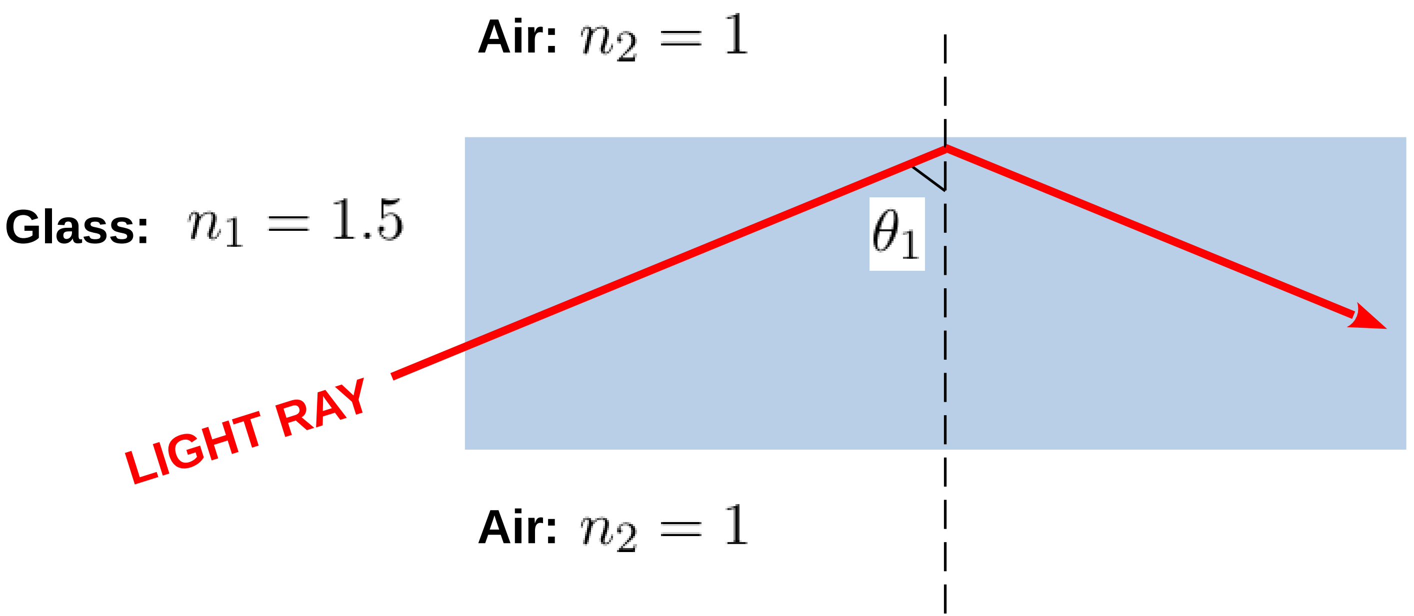
Glass: 1.5



Willebrord Snellius:
1580--1626

Snell's Law of Refraction: $n_1 \sin \theta_1 = n_2 \sin \theta_2$

Total Internal Reflection in Glass Optical Fiber

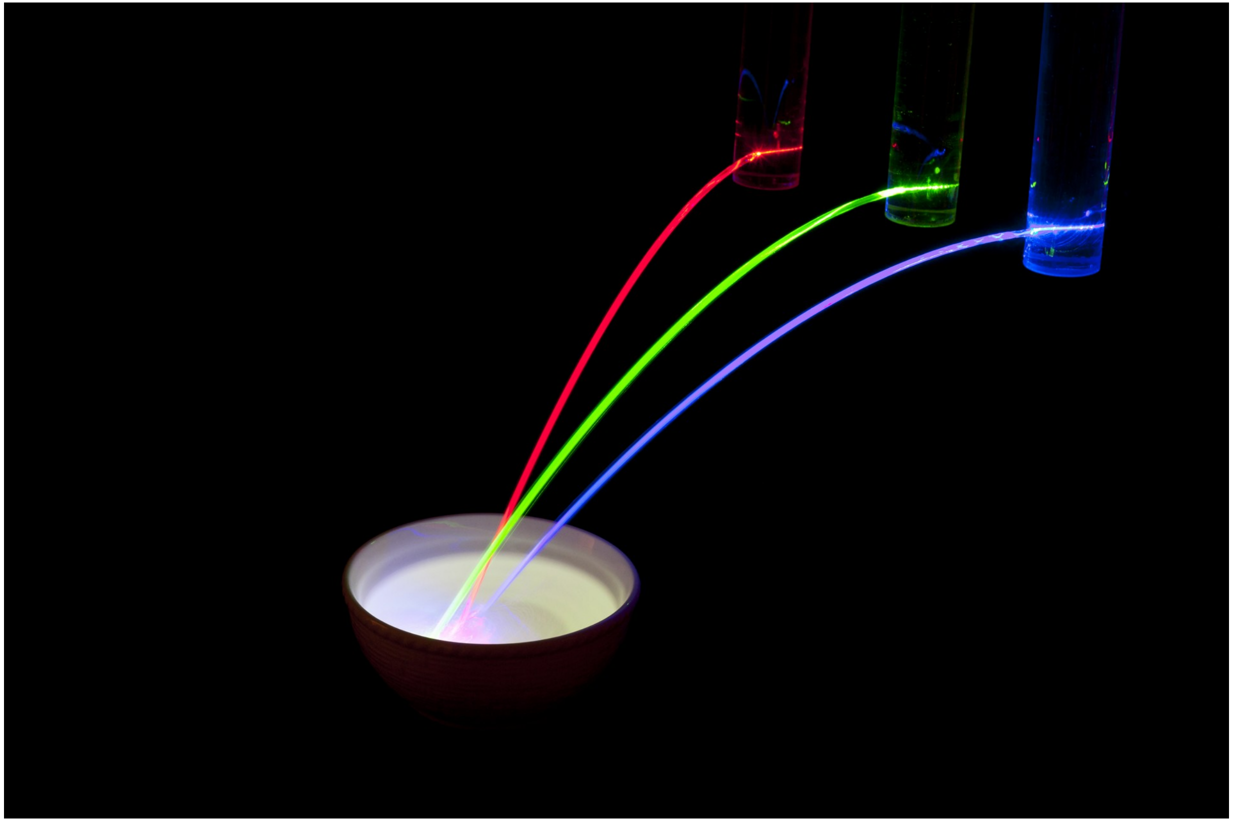


For $\theta_1 > 41^o$ Snell's Law has no solution!

No refraction occurs at boundary – these rays are completely reflected

TOTAL INTERNAL REFLECTION:

Laser light launched into liquid Laminar flow streams



Courtesy of Dr Alexander Albrecht, UNM Physics & Astronomy

PROPERTIES OF THE TROPOSPHERE

Lower atmosphere: 0–15 km

Negligible plasma density. No ionization

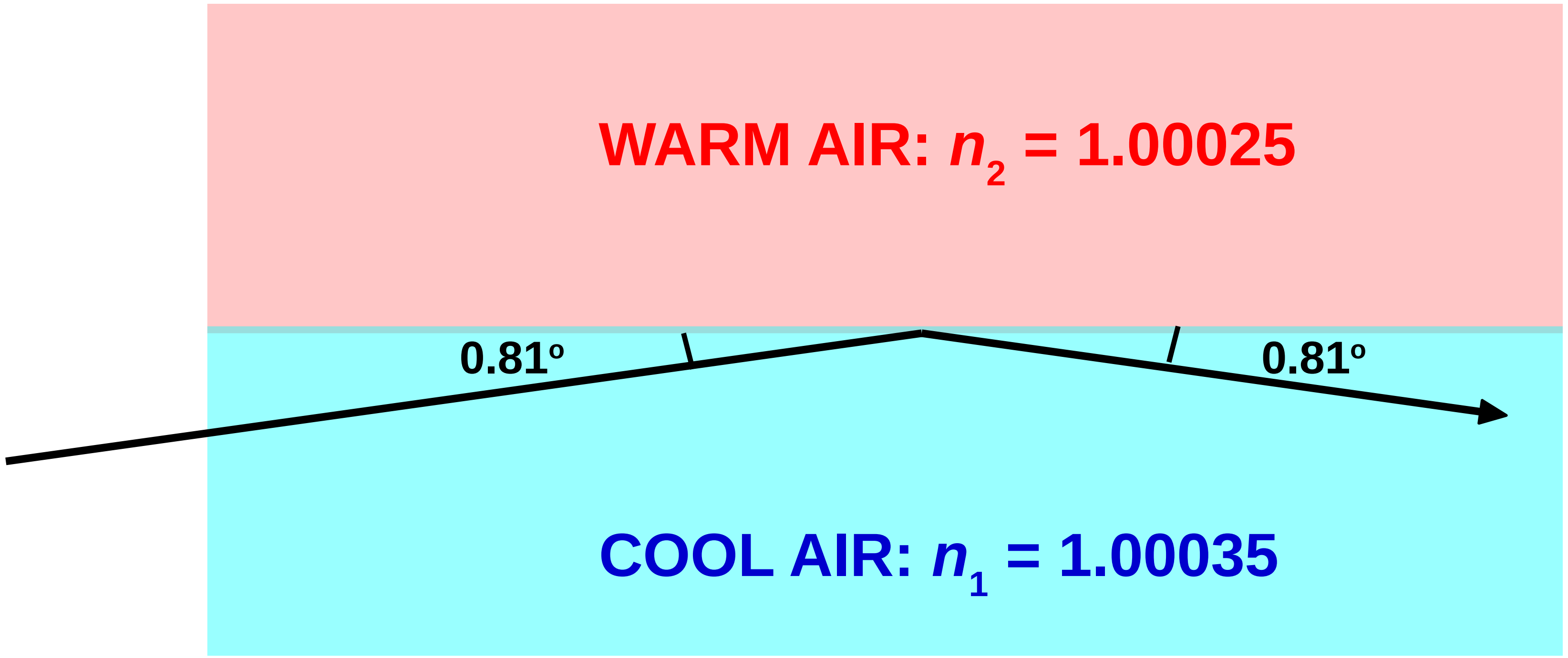
Refractive index depends on temperature, pressure, humidity

Variation of index is minuscule*: 1.00025 – 1.00035

Refractive index does ***NOT*** depend on radio frequency

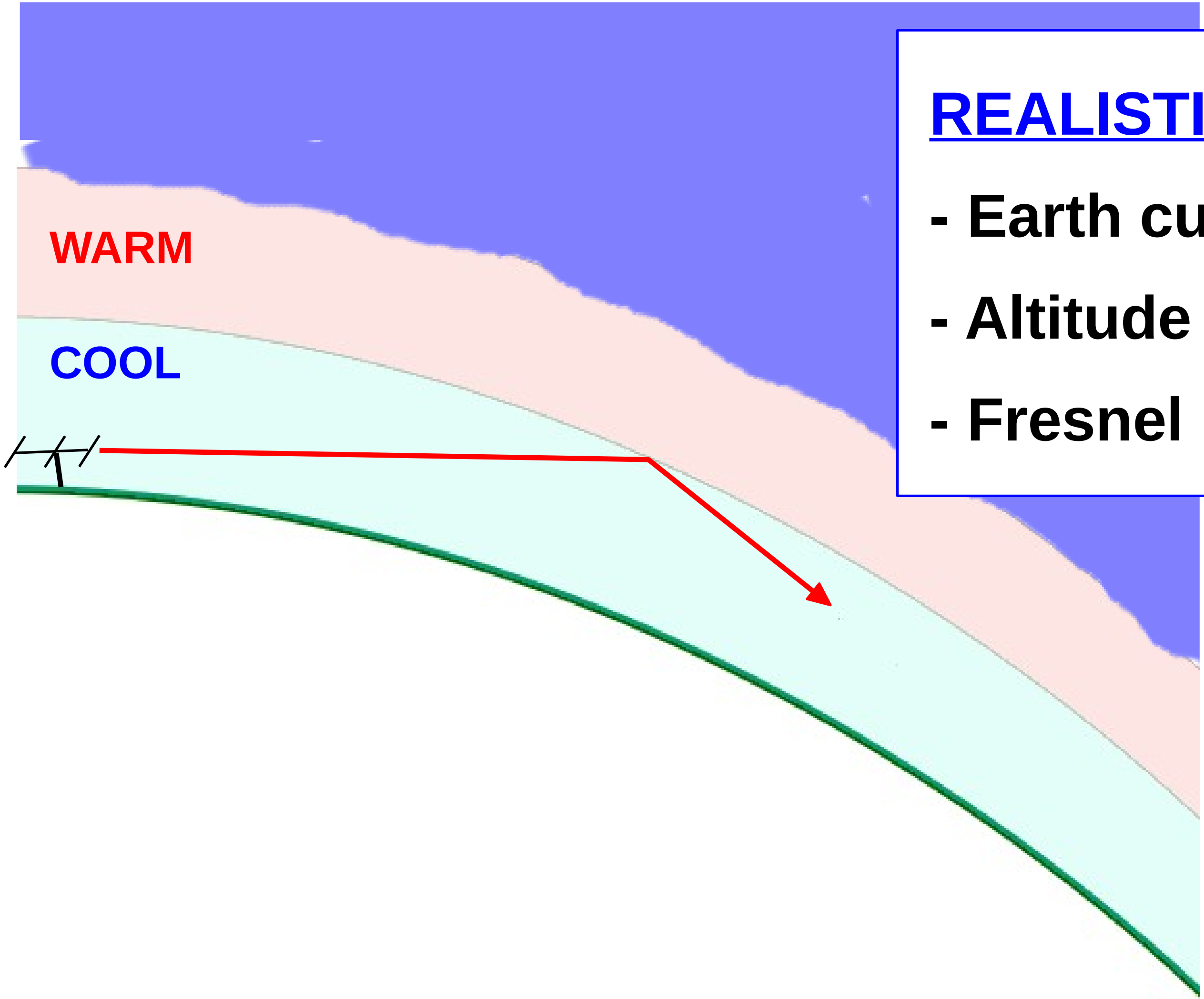
*Index of vacuum space: 1.00000

Critical angle is 89.2 degrees at planar inversion boundary*



Only angles ≤ 0.81 degrees are reflected!

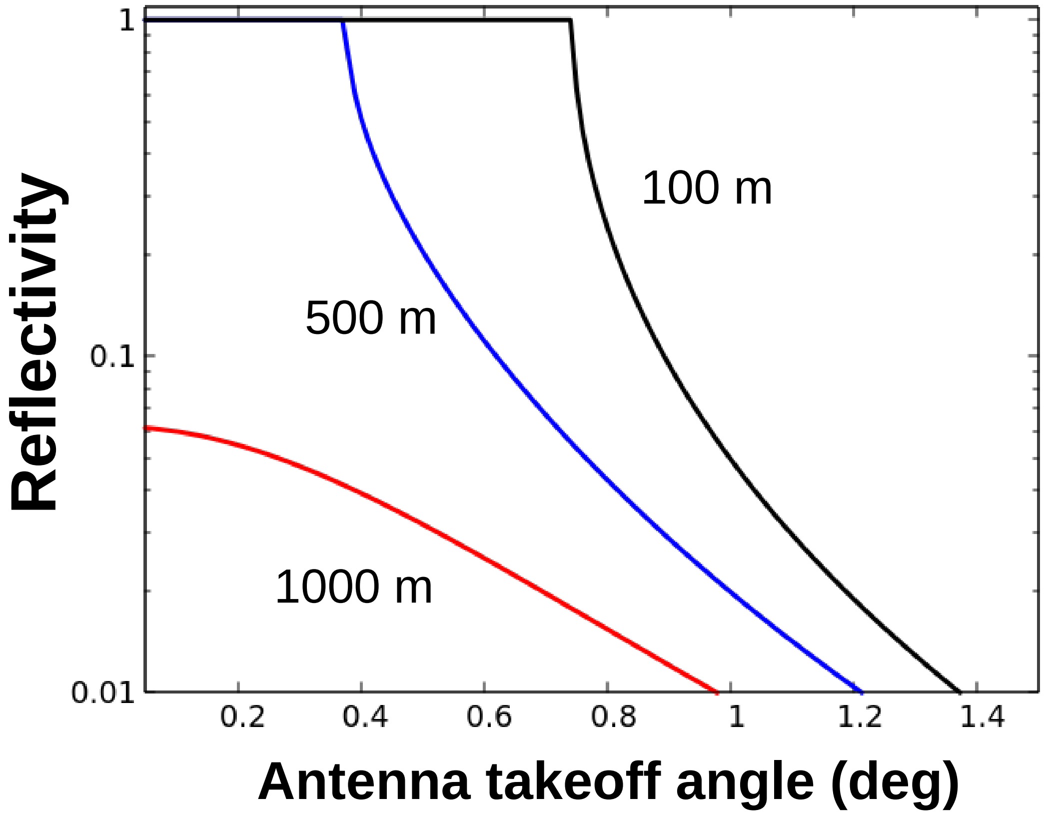
*See Friis et al, Bell Systems Technical Journal (1957)



REALISTIC MODEL INCLUDES:

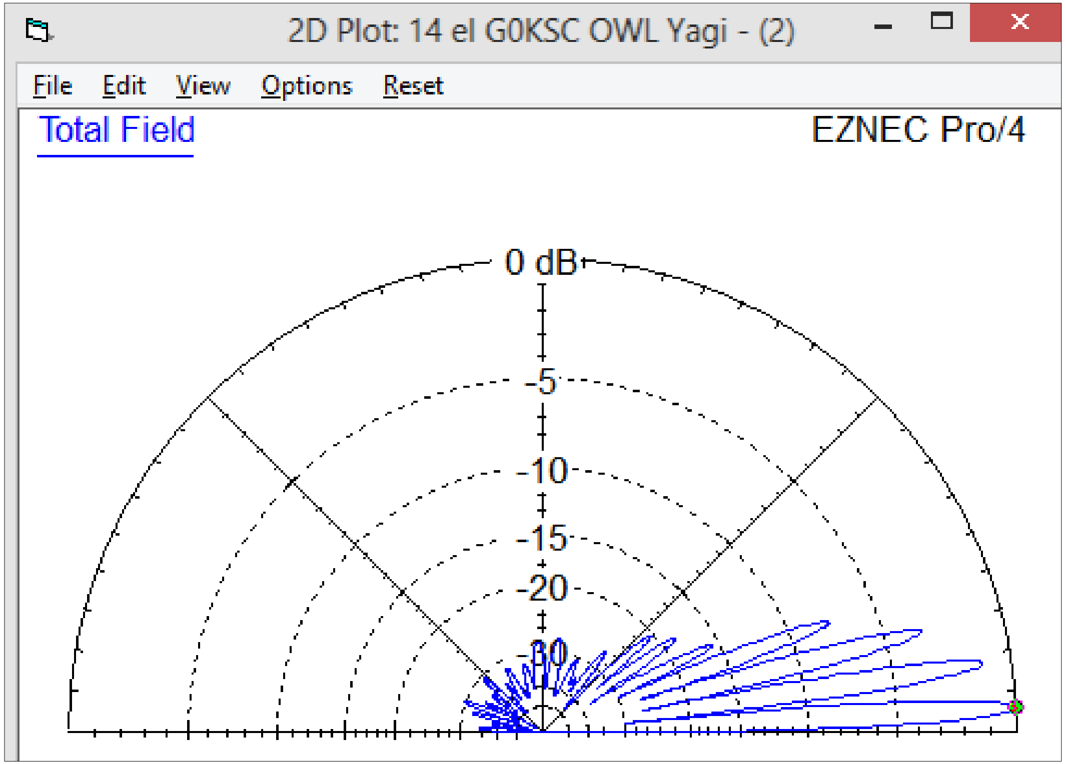
- Earth curvature
- Altitude of boundary
- Fresnel reflection

Calculation for three different inversion layer altitudes



High reflection only possible with extreme grazing angles and very low altitude inversions!

PROBLEM 1: Obstacles and ground reflections inhibit horizontal (0 degrees) antenna radiation



G0KSC 14-element LFA 144 MHz*

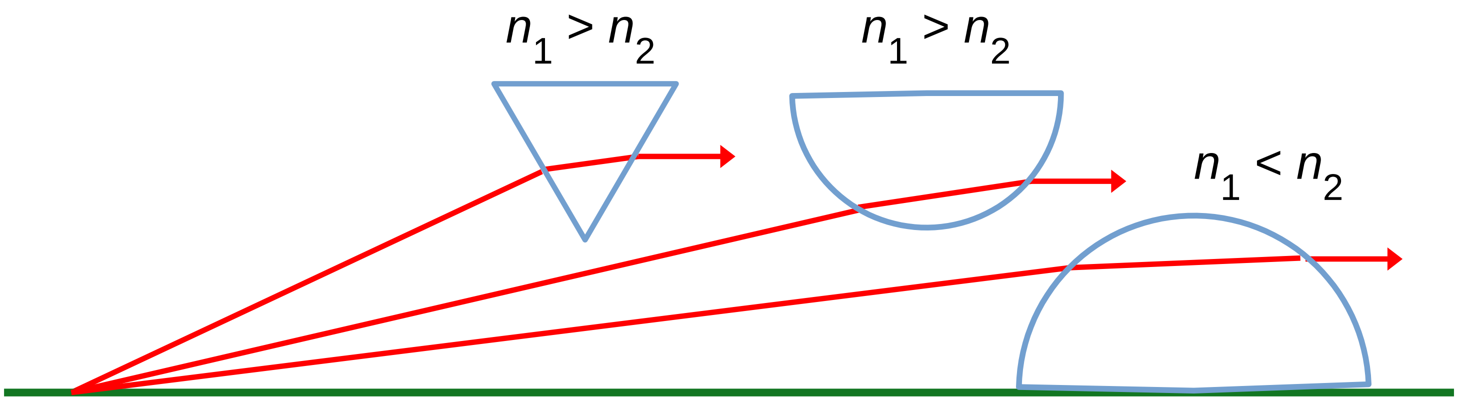
Yagi mounted at height 10m

Primary lobe at **2.9 degrees** elevation

Very poor coupling into duct !

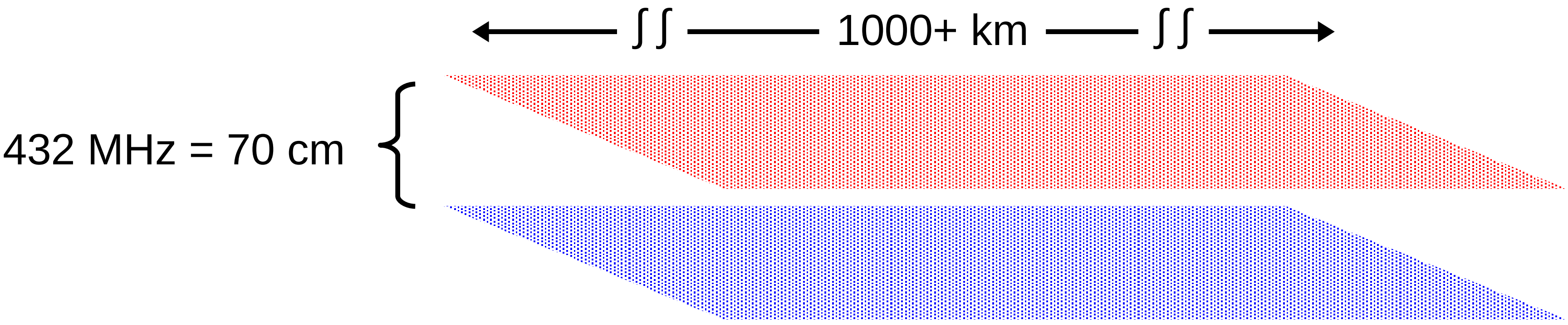
*g0ksc.co.uk

Can properly shaped air masses help couple antenna radiation into the duct?



Even in best case, refraction in air is too weak to bend rays needed amount

PROBLEM 2: Does the waveguide picture of a tropo-duct make sense?

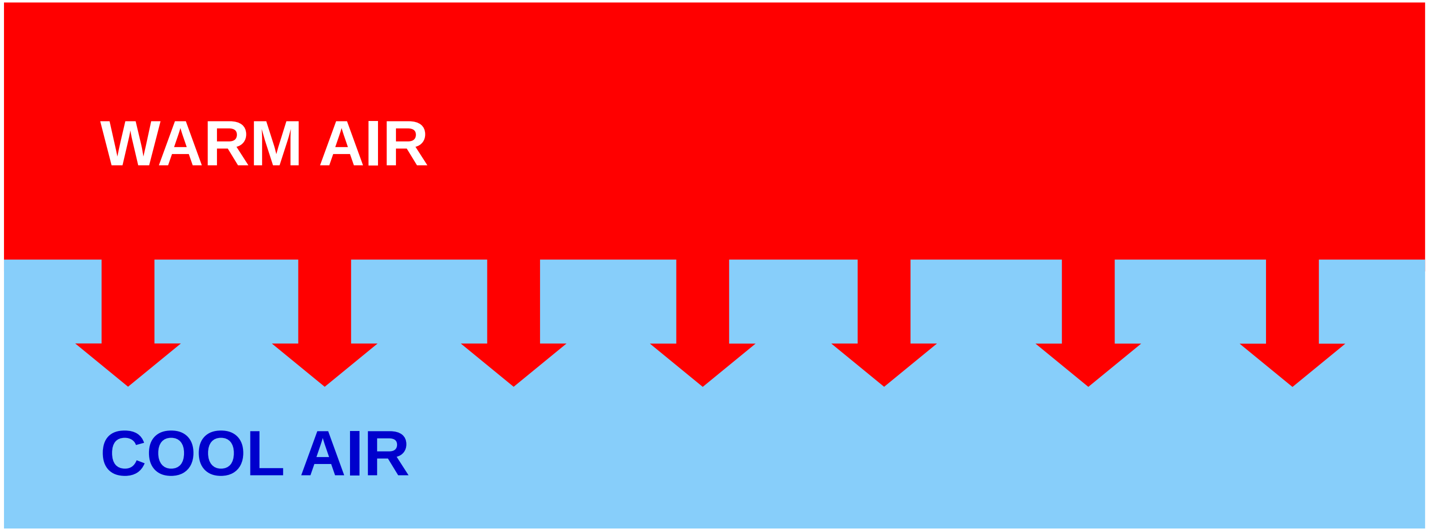


Waveguide cutoff requires spacing of about one wavelength

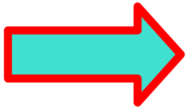
Surface flatness < $\lambda/10$

Can this structure be maintained for hours or even days?

Realistic thermal boundary



Convective air currents quickly smear out the interface

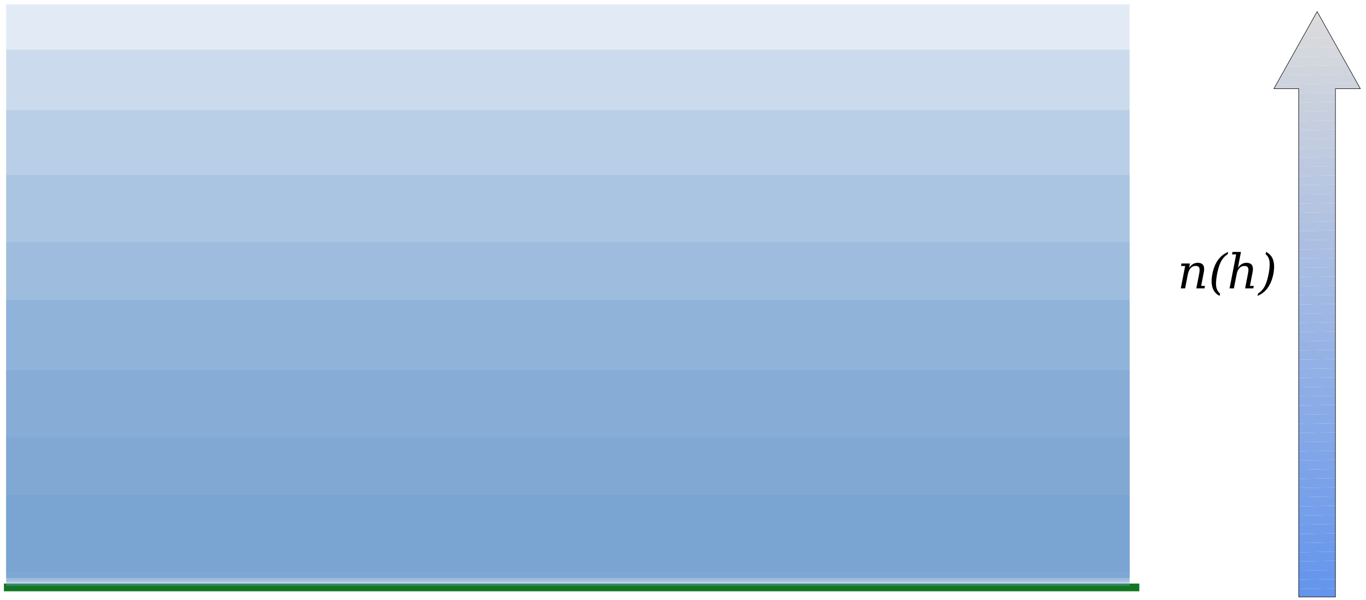


Waveguide-like ducting is physically implausible

Another explanation?

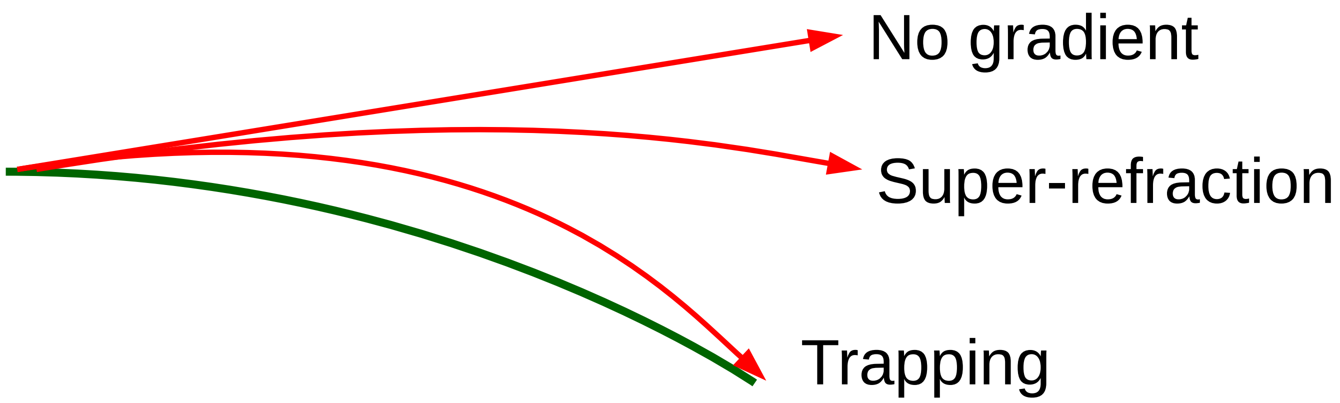
Refractive Index Gradient:

Index decreases continuously with altitude



Index Gradient: **Well known in radar**

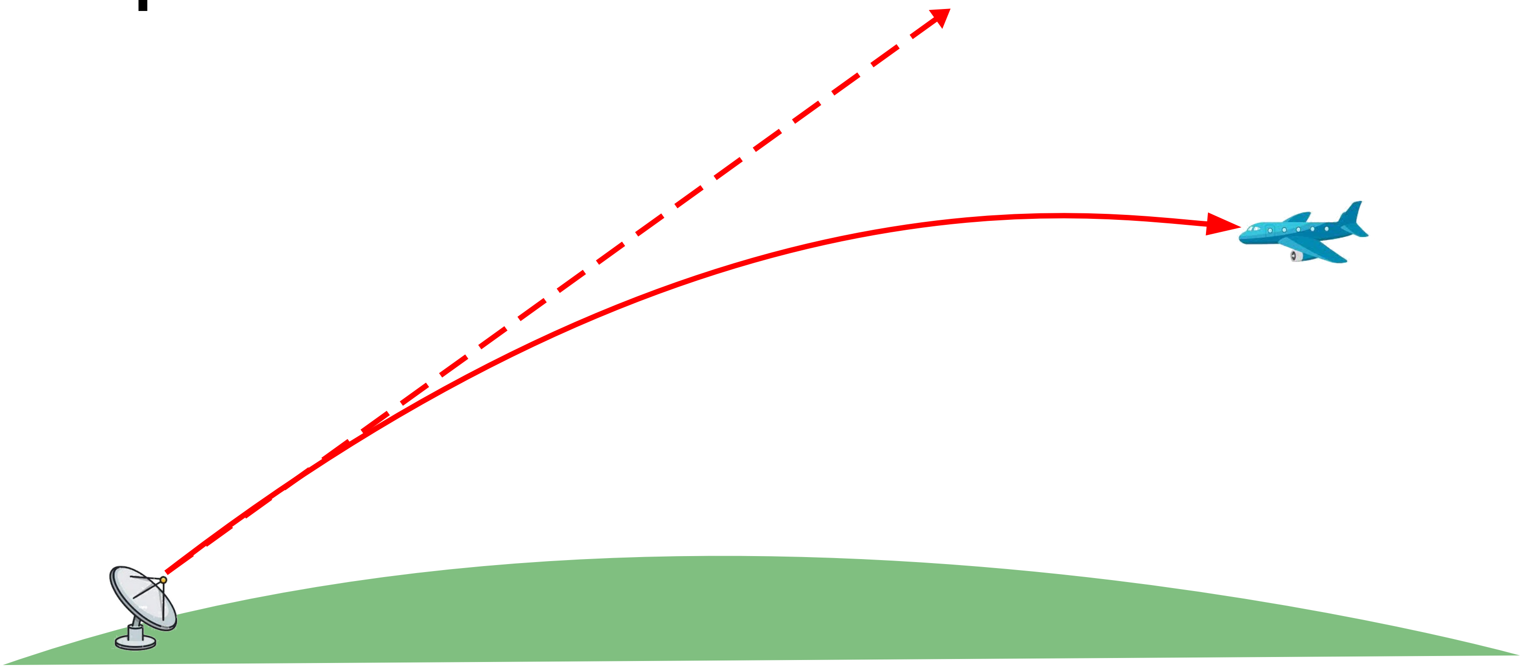
Causes rays to bend



Gradient in nominal conditions: -39×10^{-6} km^{-1}

Ray bending but no trapping

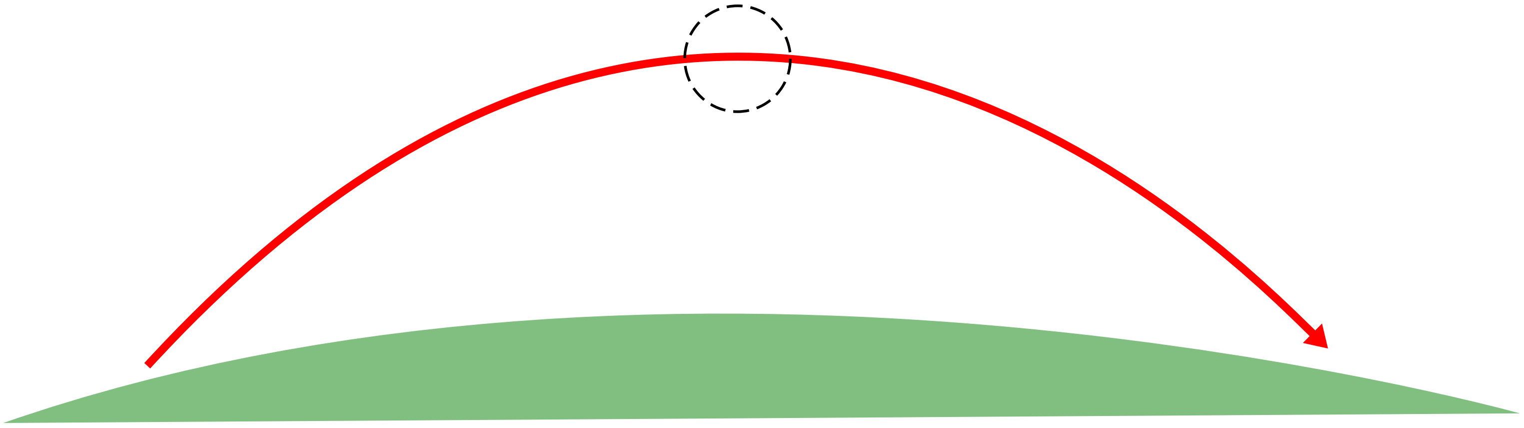
Implications for radar



Trapping is caused by total internal reflection at path apex

Critical angle attained between adjacent index layers

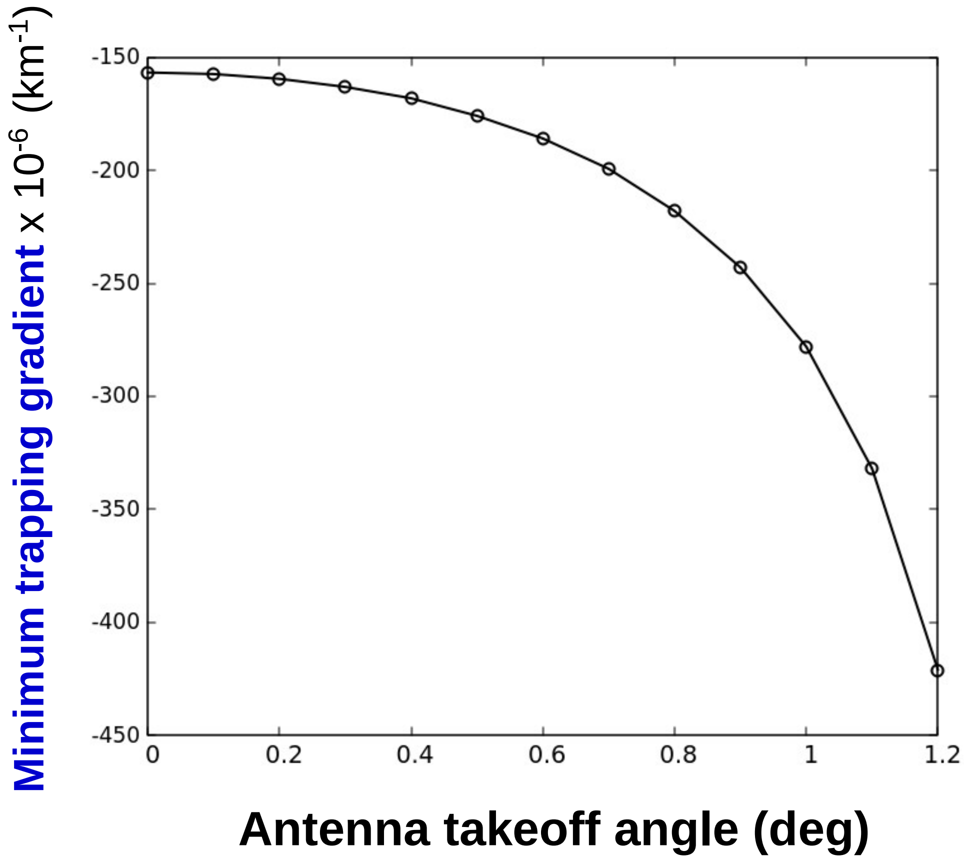
Reflection back to earth surface



Beyond line-of-sight communication possible

TRAPPING **depends critically on antenna takeoff angle!**

Calculate minimum index gradient needed to induce trapping



MINIMUM TRAPPING GRADIENT

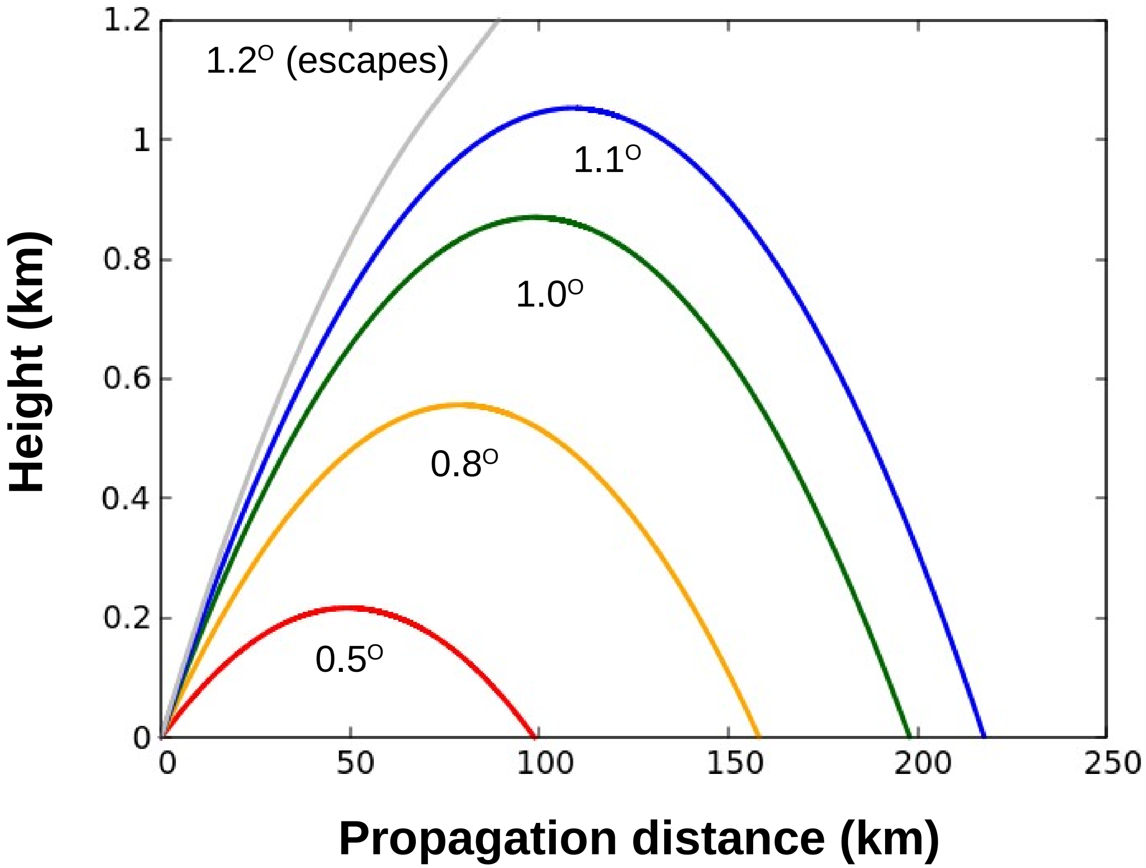
0 degrees: $-157 \times 10^{-6}\ km^{-1}$

1 degree: $-278 \times 10^{-6}\ km^{-1}$

Nominal: $-39 \times 10^{-6}\ km^{-1}$

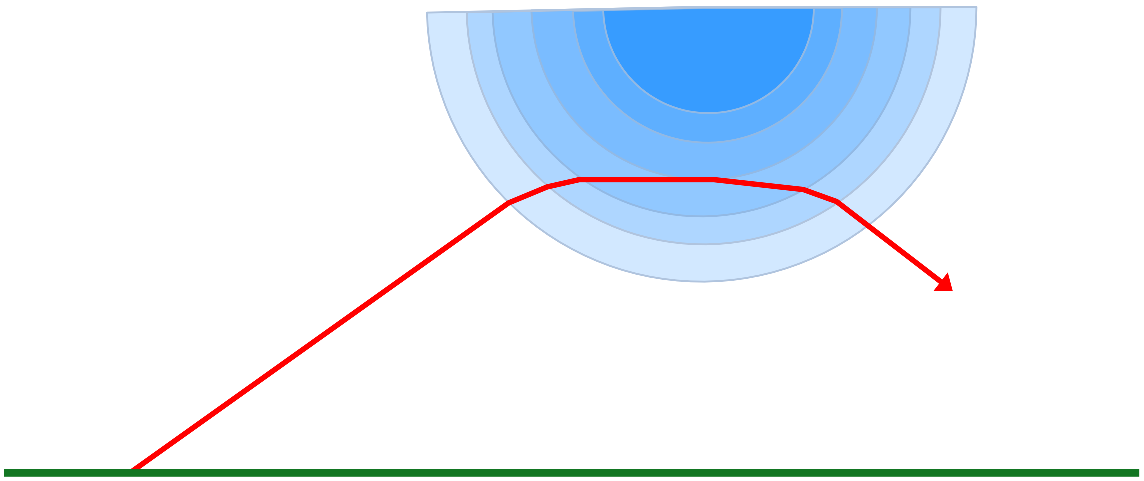
Set the refractive index gradient at: -332×10^{-6} km^{-1}

Calculate ray paths for takeoff angles 0.5 – 1.2 degrees

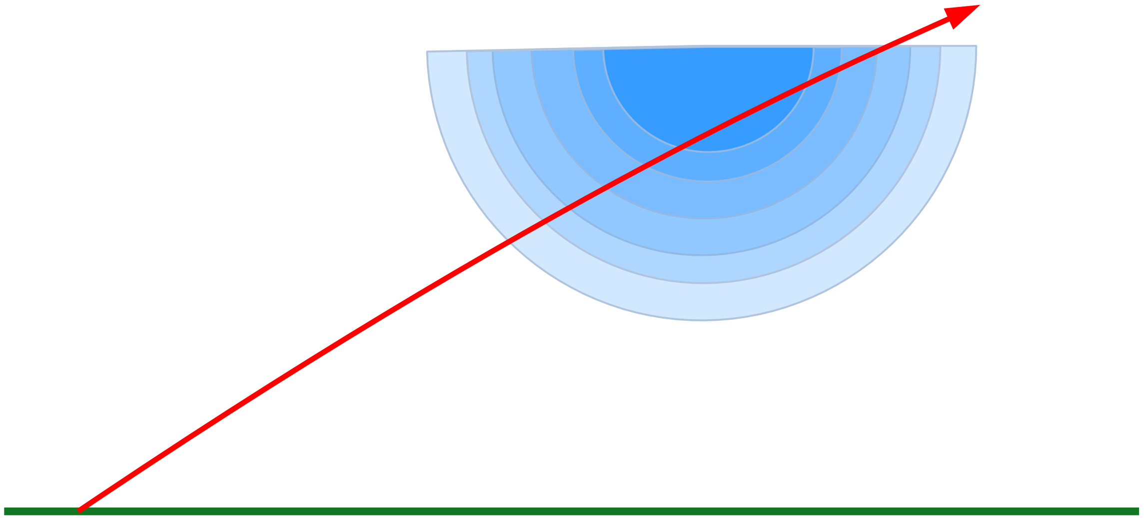


Can we combine these concepts?

Refractive index gradient inside shaped air mass



No, this doesn't work…



Analysis shows index variations in atmosphere are insufficient to adequately bend radio waves

SUMMARY

1) Refraction in troposphere is extremely weak and independent of frequency

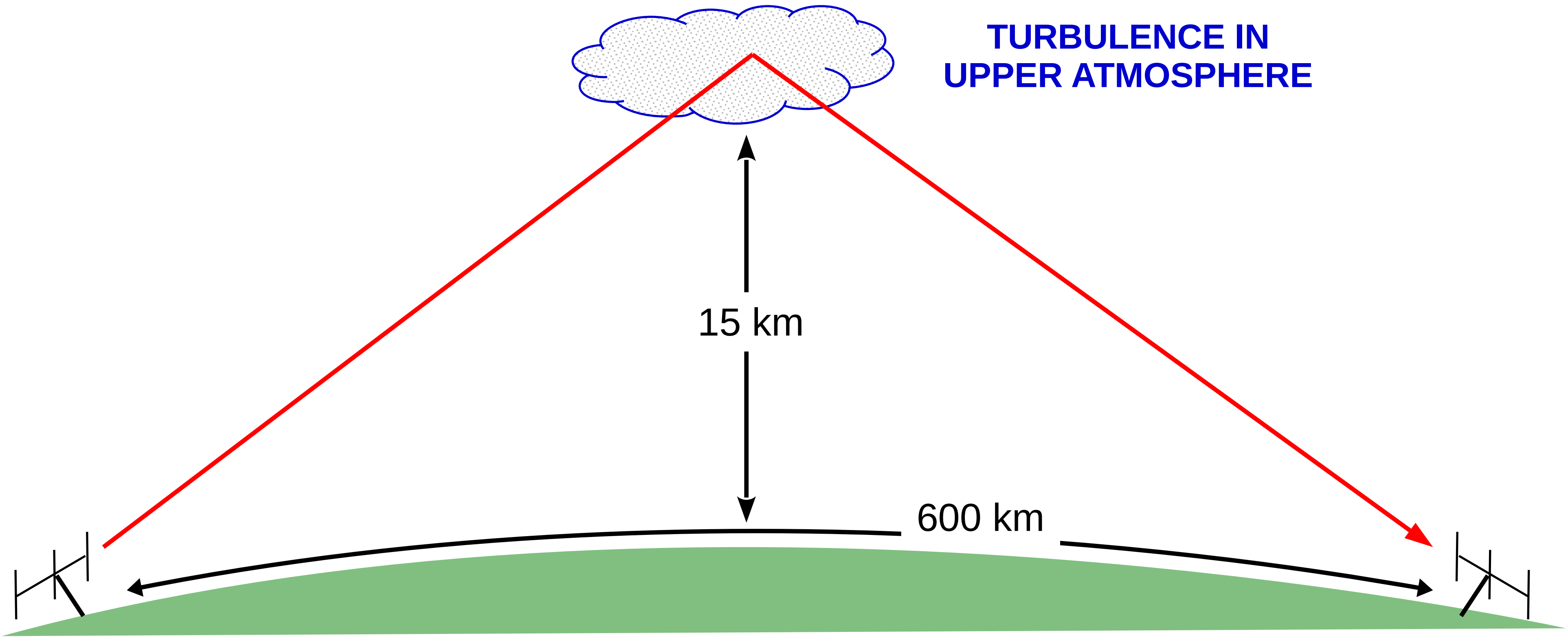
2) Waveguide-Duct model of VHF+ DX:

- Requires nearly horizontal antenna takeoff angles
- Requires smooth, long-term-stable thermal boundaries

3) Trapping model of VHF+ DX:

- Requires nearly horizontal antenna takeoff angles
- Requires enormous, long-term-stable refractive index gradients
- Can’t explain observed frequency dependence

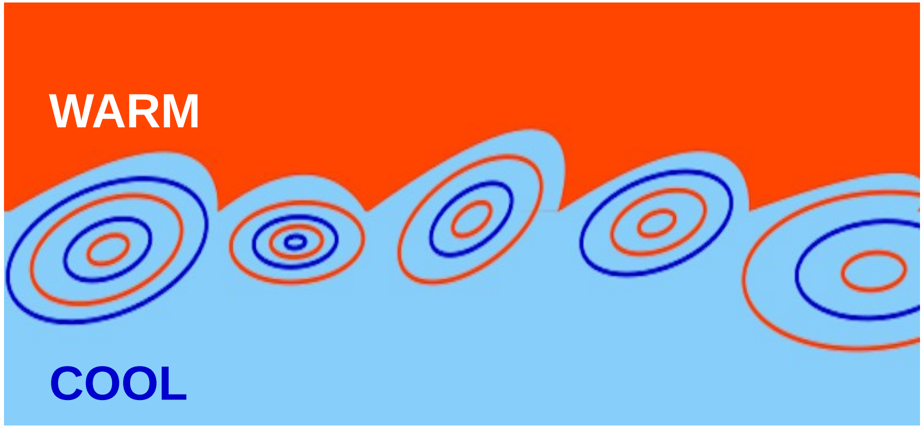
Tropo-scatter: Two well-equipped VHF+ stations can *routinely* communicate over significant path lengths



Weather occurs at lower altitude

What should we expect when a warm air layer overruns cool air?

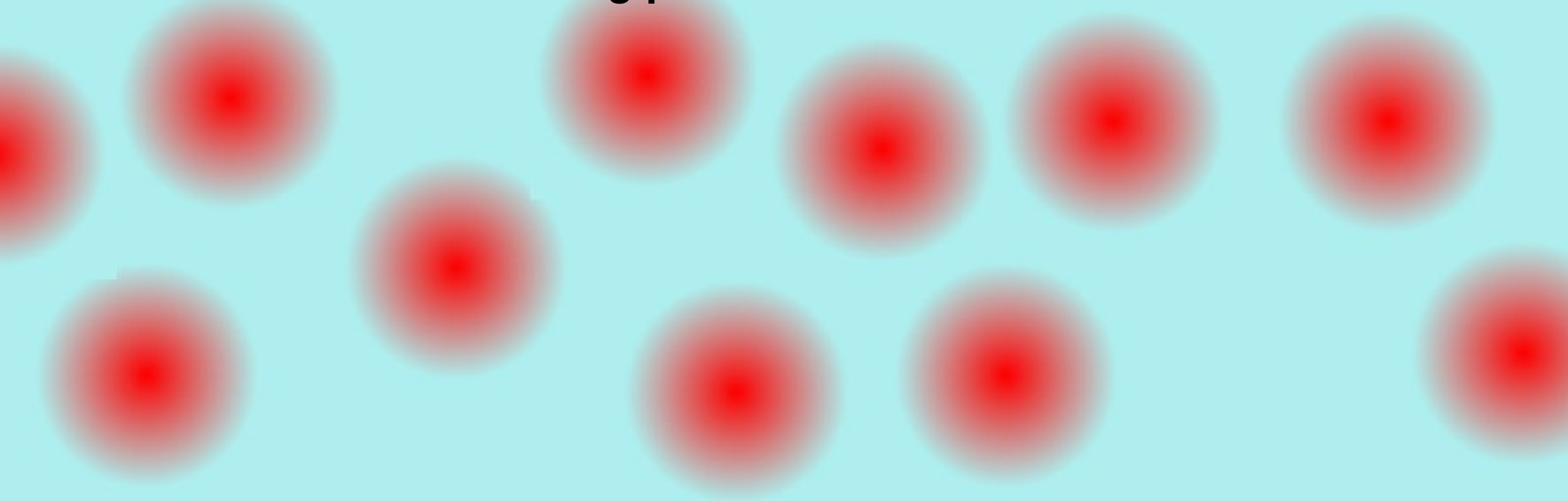
THIS?



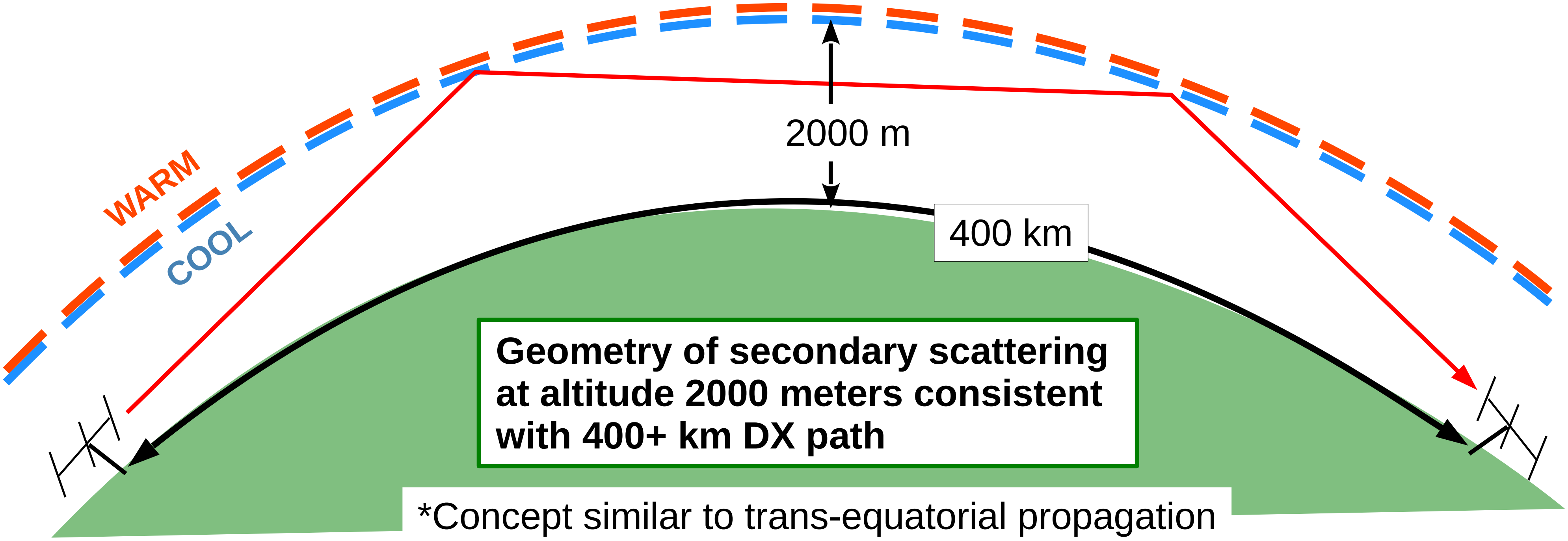
OR THIS?

Turbulent Interface:

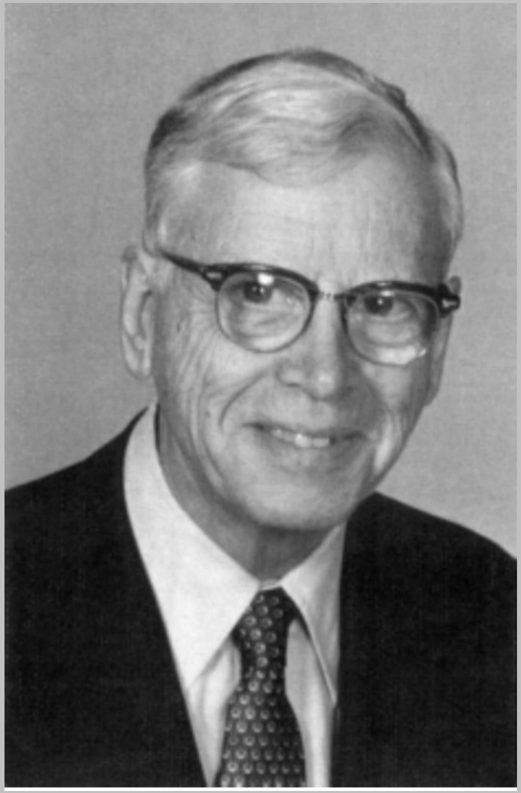
Extended volume containing pockets or blobs of cool-warm air mixtures



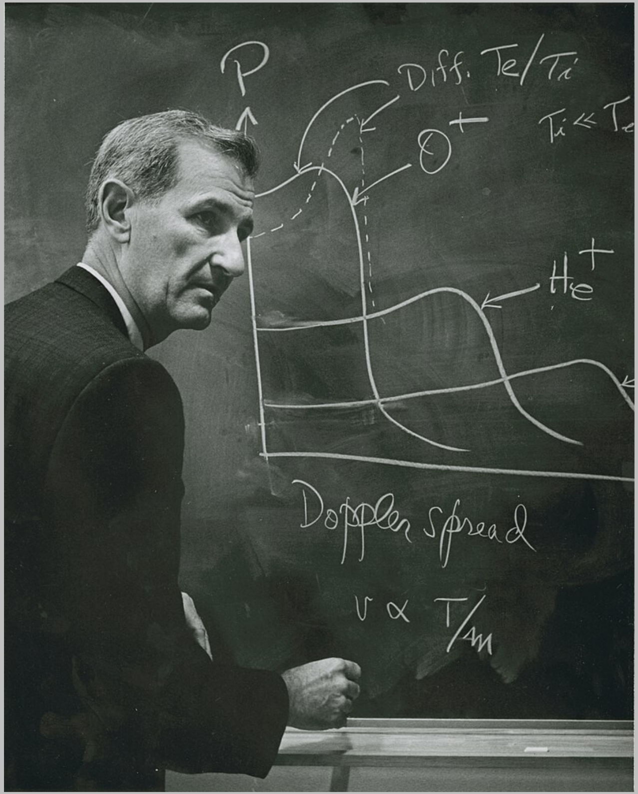
Is tropo-ducting actually chordal scattering* along the turbulent weather front?



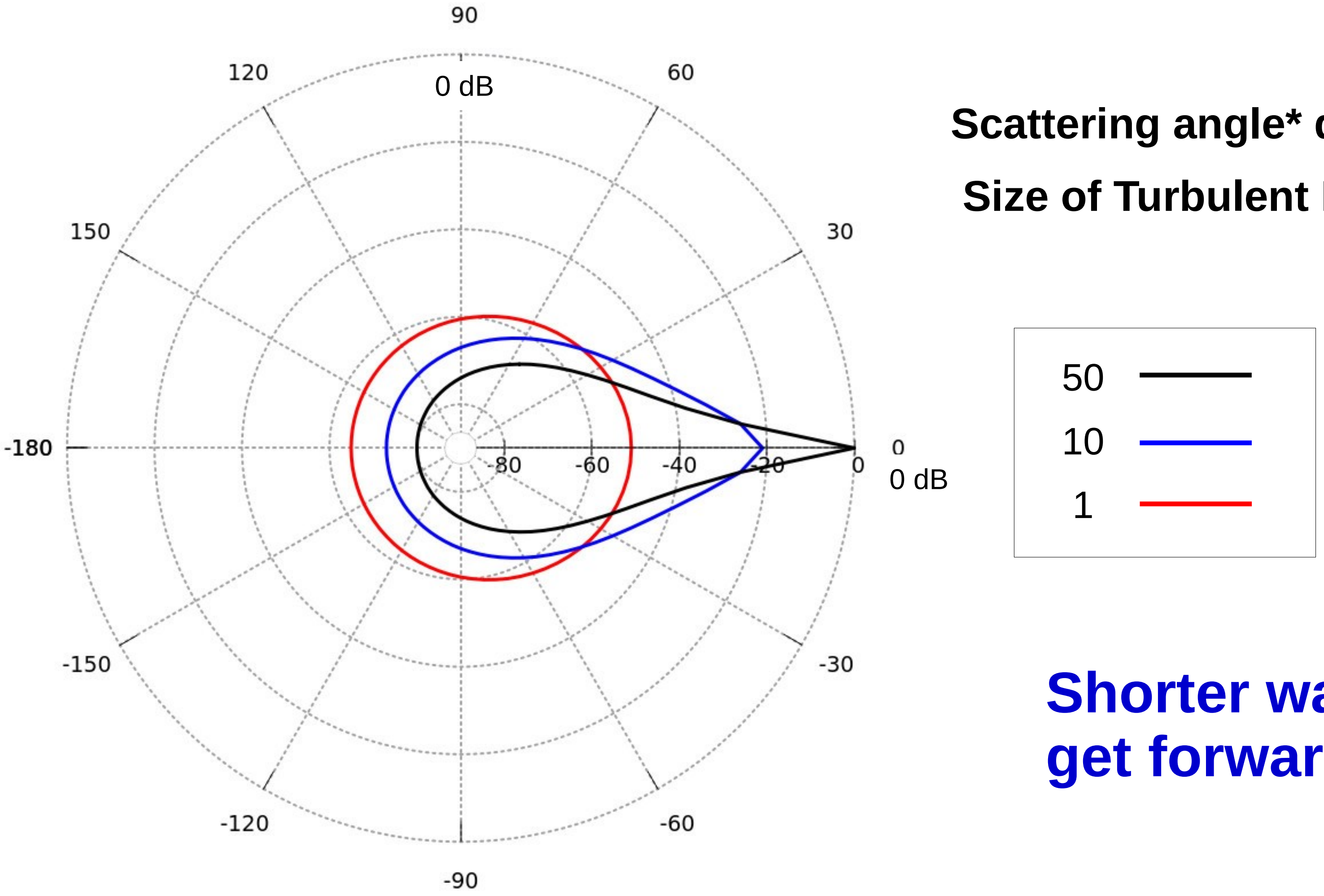
“A Theory of Radio Scattering in the Troposphere” (1950)



Henry Booker (1910–1988)



William Gordon (1918–2010)



Scattering angle* depends on the ratio:

Size of Turbulent Blobs ÷ Wavelength

Shorter wavelengths get forward-scattered

* Scattered angle is relative to incident ray path

LOOSE ANALOGY:

Stone skipping on pond surface

OTHER ADVANTAGES OF SCATTERING MODEL

1) Efficiency increases at lower altitude due to higher air density

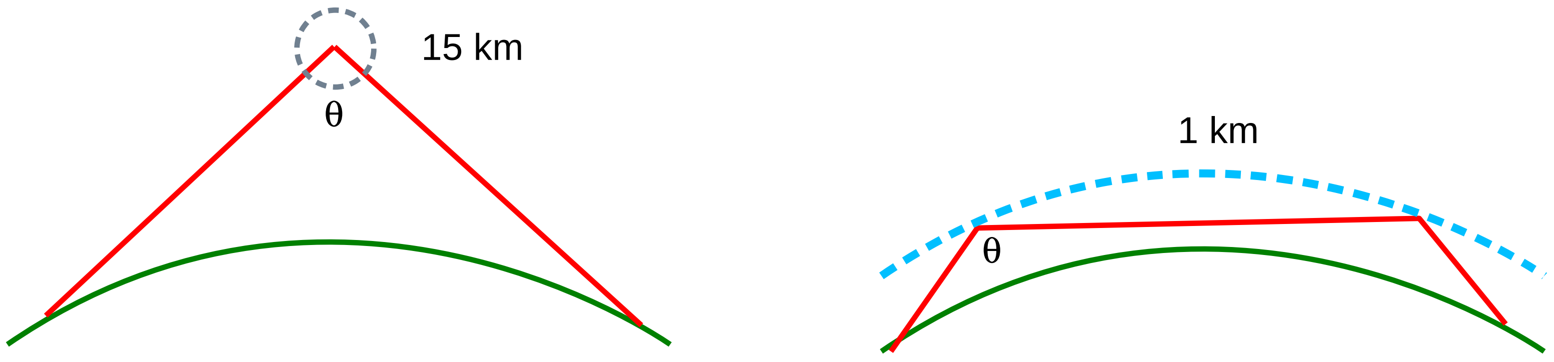
Scales as Δn^2 which primarily depends on temperature

Turbulent mixing of warm and cool air

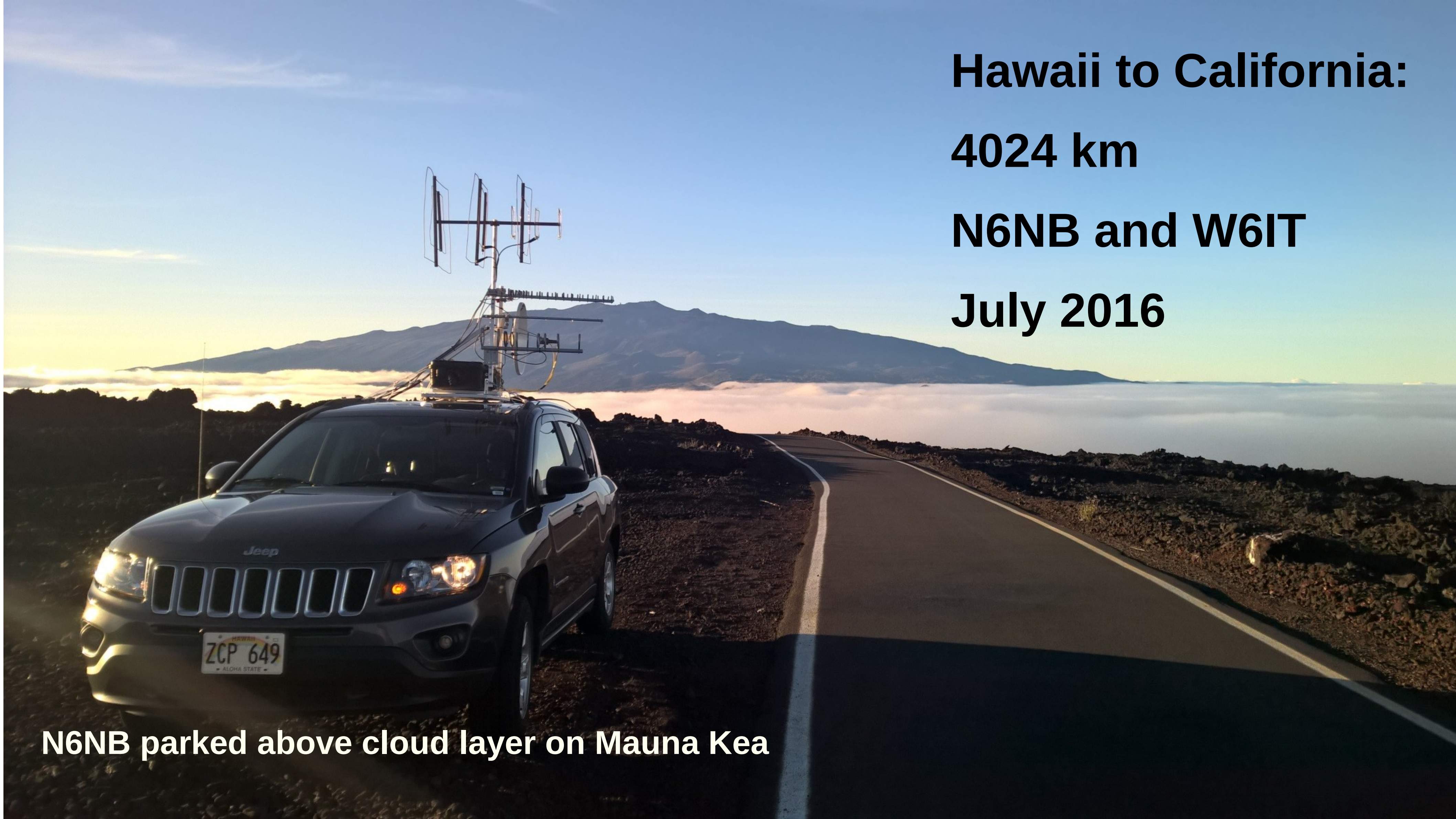
2) Frequency-dependence of DX path explained

Scattering inversely proportional to wavelength: $1/\lambda$

Normal Tropo-Scatter vs Proposed Chordal Scattering



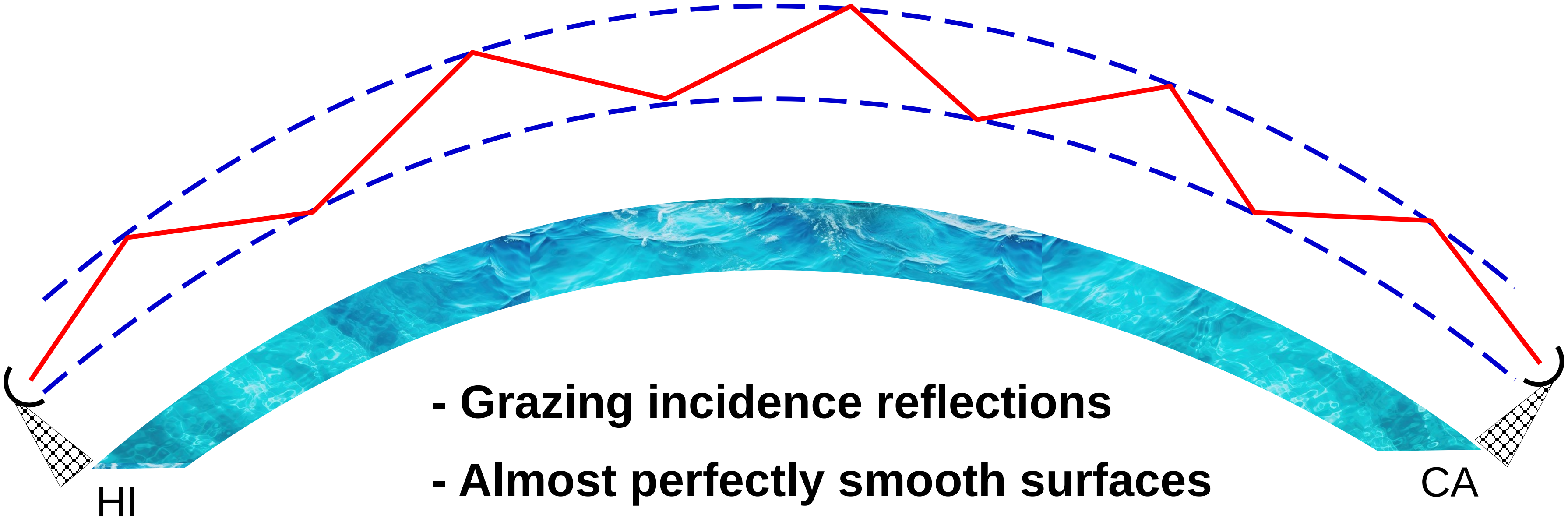
	NORMAL	CHORDAL
Scatter sites	1	2 or more
Scatter altitude	Up to 15 km Low density air: Weaker scattering	< 1 km High density air: Stronger scattering
Scatter angle (θ)	Smaller: Weaker forward scattering	Wider: Stronger forward scattering
Temperature variation	Minimal: Weak scattering	Turbulent mixing of dense cool and warm air: Strong scattering


Hawaii to California:
4024 km
N6NB and W6IT
July 2016
Jeep
ZCP 649
N6NB parked above cloud layer on Mauna Kea

<u>Proposed Explanation:</u> Elevated Duct

Thickness: ~ 200 m (1974 study by USN)

40 hops & 78 reflections needed to span path*



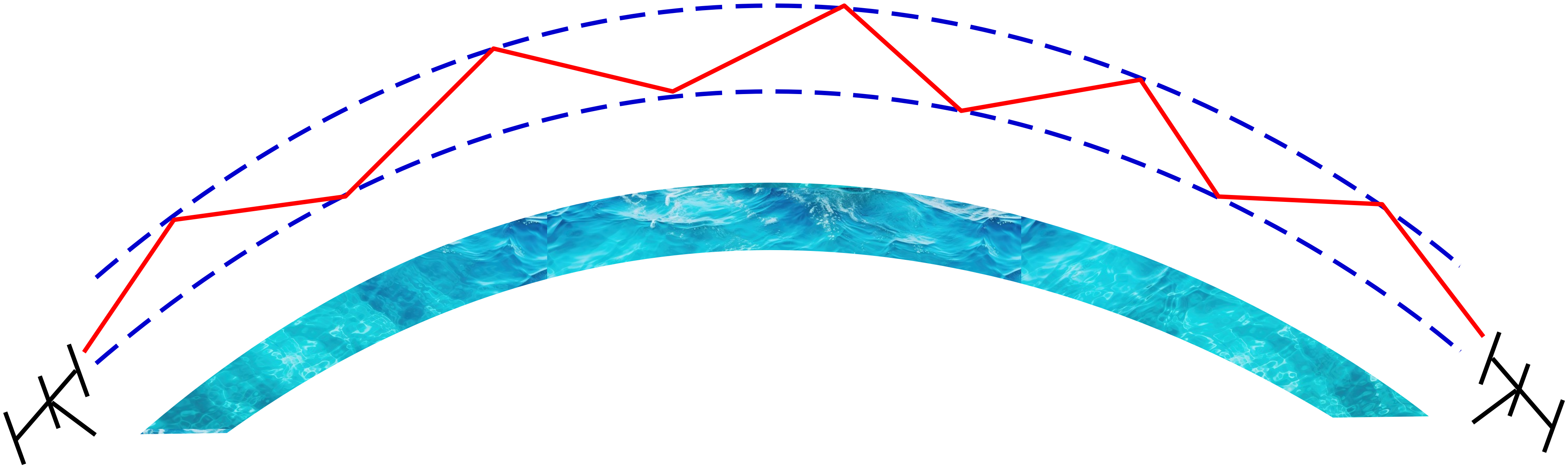
- Grazing incidence reflections

- Almost perfectly smooth surfaces

- Any disturbance of size λ destroys path

* Drawing not to scale

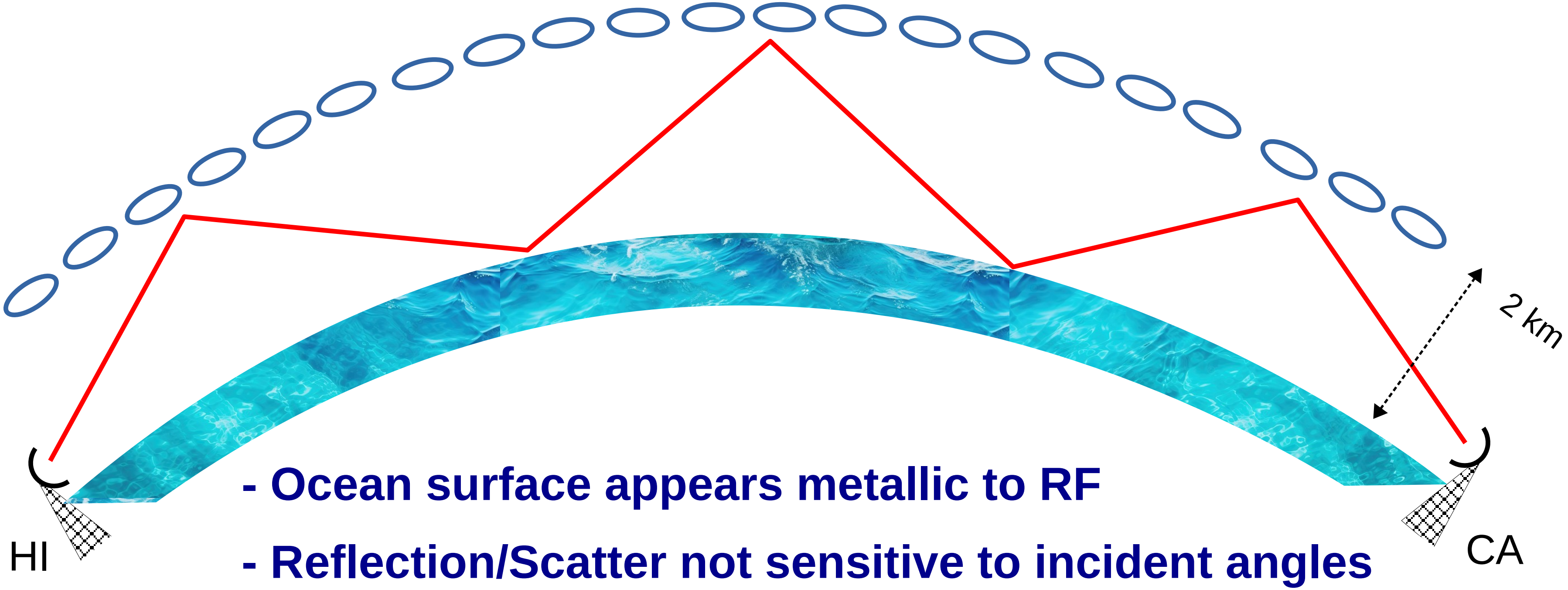
Elevated Duct should generate big signals on HF!



Signals 1.8 – 50 MHz will see enhanced propagation

Better Explanation: Troposcatter + Seawater Reflection

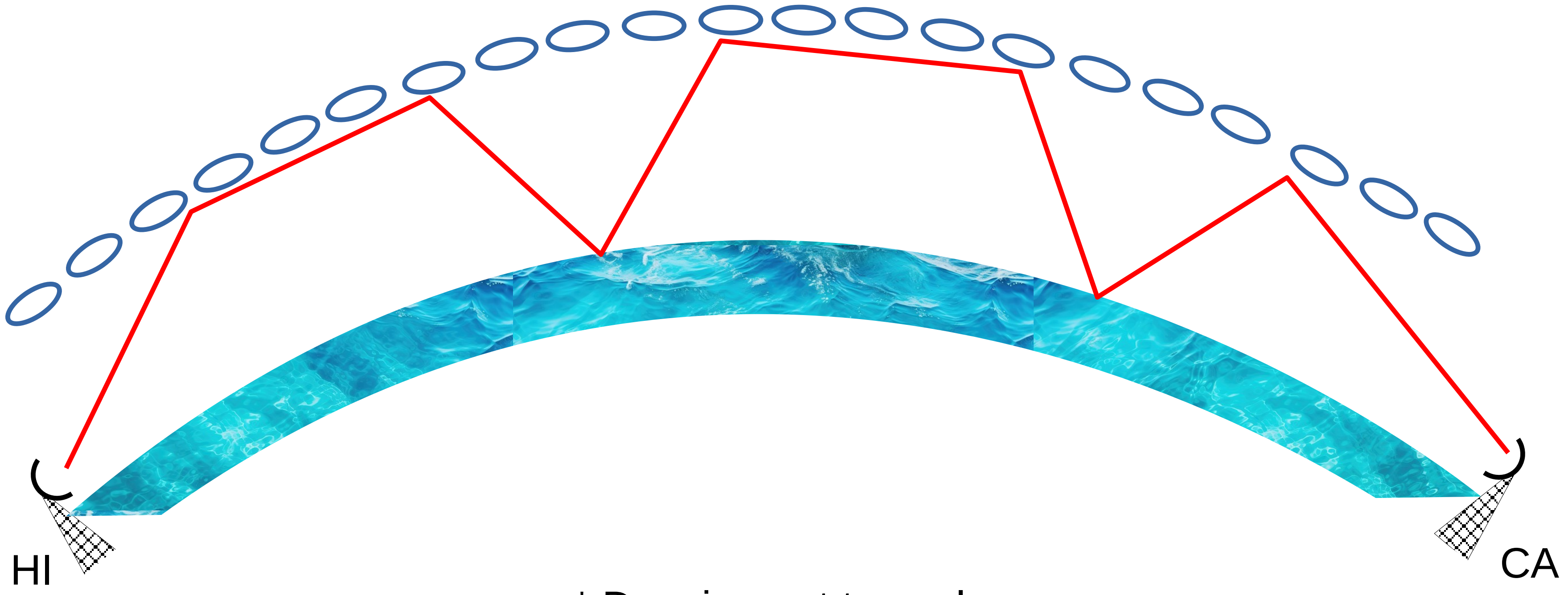
Path covered in 12 hops*



- **Ocean surface appears metallic to RF**
- **Reflection/Scatter not sensitive to incident angles**
- **Scatter efficiency scales as 1/λ**

* Drawing not to scale

Combination of Chordal Forward Scattering and Seawater Reflection*



* Drawing not to scale

CONCLUSIONS

1) Waveguiding and ducting cannot be reconciled with known refraction of the lower atmosphere

2) Extreme DX that occurs at VHF+ frequencies may be explained by scattering from turbulent pockets of warm-cool air mixtures that are present along extended weather fronts