ENHANCED PROPAGATION MICROWAVE EVENTS

A PRIMER / WIDE AREA OPENING CASE-STUDIES

JOE JURECKA – N5PYK

NATIONAL WEATHER SERVICE

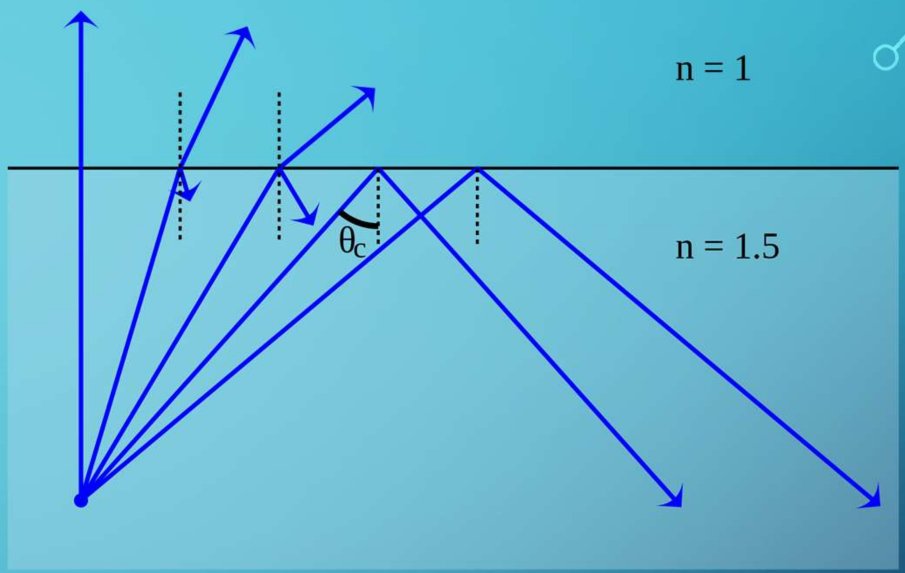
LUBBOCK, TEXAS

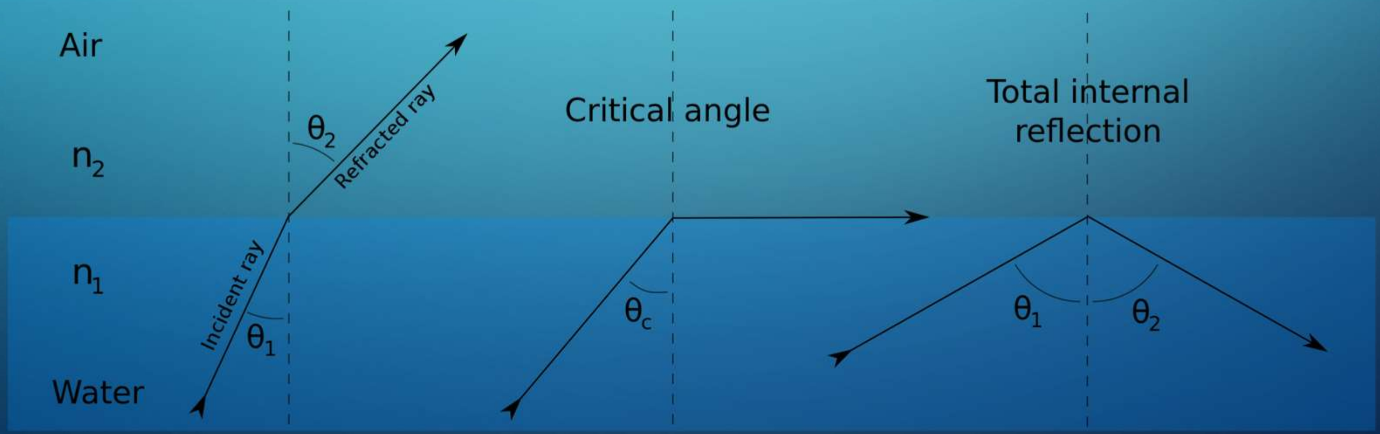
MOTIVATION

- Who doesn't like a great band opening?
- How does it work?
- What weather patterns support large-scale openings?
- Why are some openings larger and stronger than others?

SNELL'S LAW

$$\frac{sin\theta_2}{sin\theta_1} = \frac{n_1}{n_2}$$



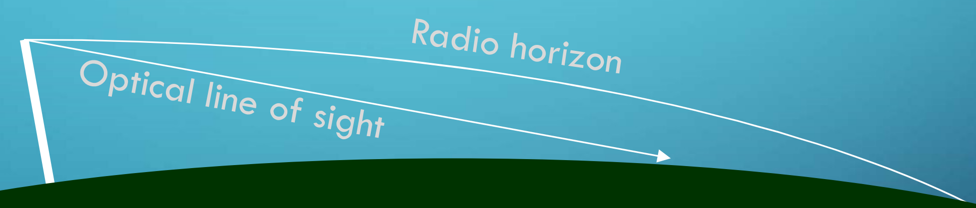


https://en.wikipedia.org/wiki/Snell%27s_law

K-FACTOR

Ratio of effective radius of radio wave ray vs. radius of earth (6370km)

K=radius of propagation/radius of earth



Normally about a 1.4X distance multiplier on VHF.

Important for understanding enhanced propagation

SCHEMATIC OF PROFILE (REFRACTION)

THE BASIS FOR OPENINGS

$$N = \frac{77.6}{T[P + \frac{4810(E_s)(RH)}{T}]}$$

‡FREEMAN

N=Refractivity

Es=Saturation Water vapor pressure (hPa)

P=Atmospheric pressure (hPa)

T=Temperature (Kelvin)

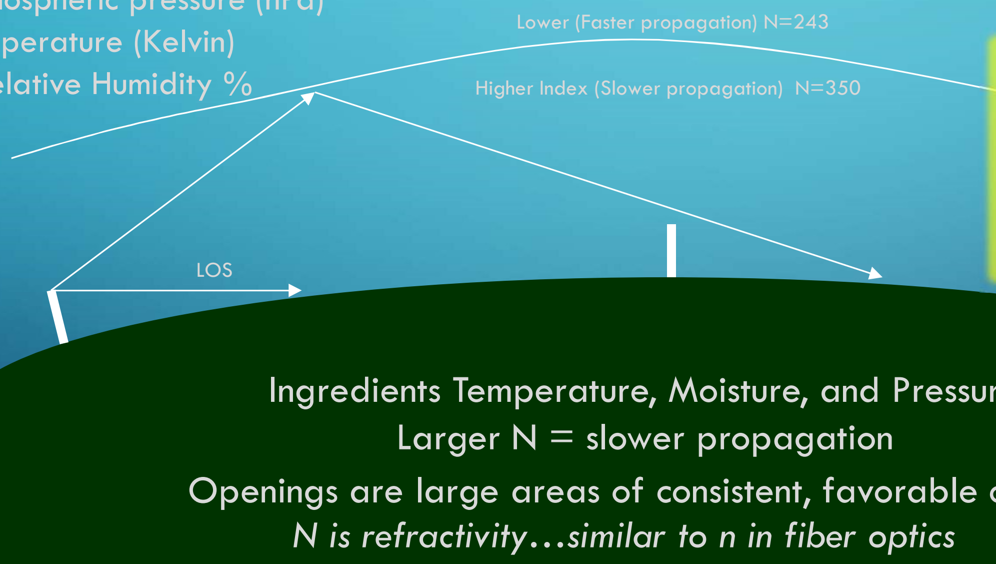
RH=Relative Humidity %

K≈1/{[1+(ΔN/Δh)/157]}

K=K-factor

N=Refractivity

h=height (km)



Radio waves are "bent" toward area of higher index of refraction (higher N, lower velocity)

Ingredients Temperature, Moisture, and Pressure

Larger N = slower propagation

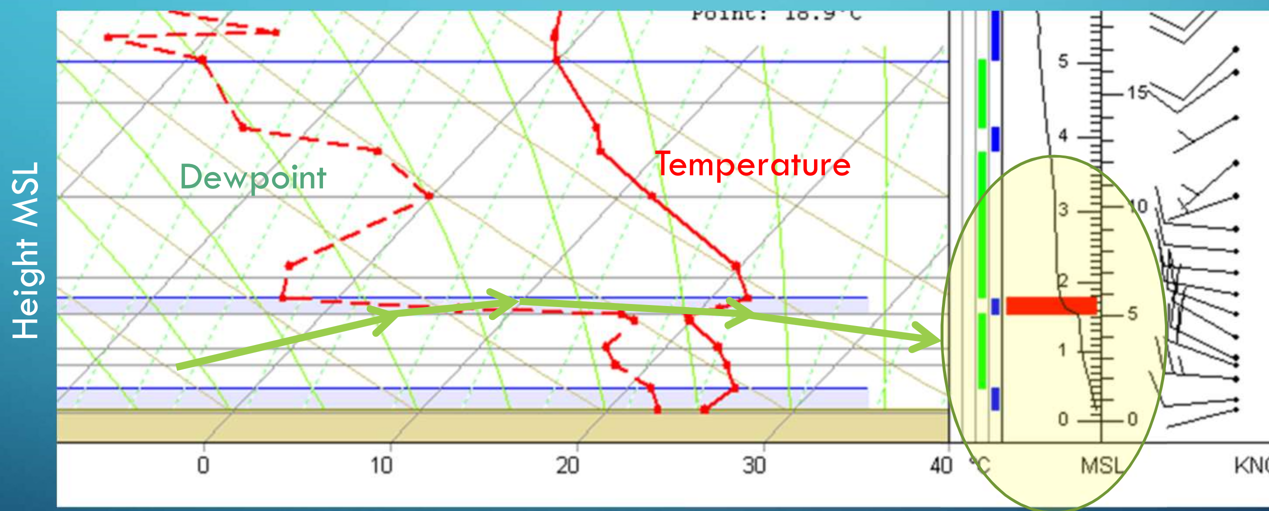
Openings are large areas of consistent, favorable conditions

N is refractivity…similar to n in fiber optics

N≈(n-1)*10^6 where n=ratio of speed of propagation to speed of light

LOCAL ENHANCEMENT (TROPOSPHERIC REFRACTION)

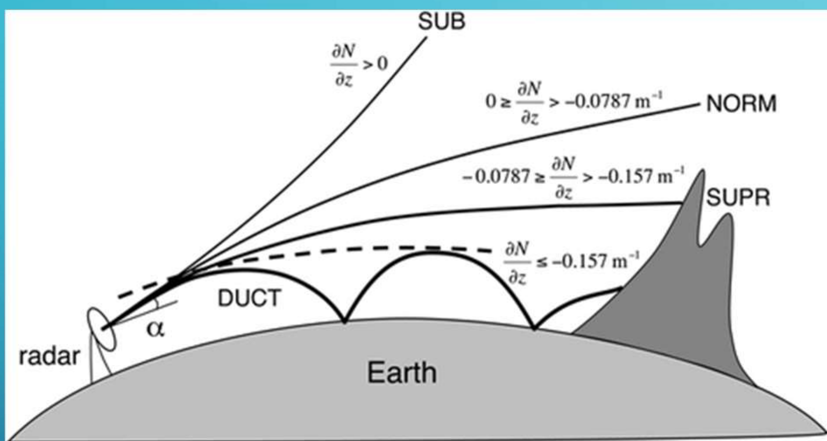
- Accomplished with single hop off inversion layer aloft
- Often a single thermal inversion layer aloft…sometimes very close to the ground
- Not generally spatially widespread



Very useful on microwave on spring and summer mornings and evenings!

REFRACTION MODES

REFRACTION CATEGORIES



The different propagation regimes of a ground-based radar beam emitted with a small tilt angle a above the horizontal plane: subrefraction (SUB), normal refraction (NORM), superrefraction (SUPR), and ducting (DUCT). The corresponding values of refractivity gradient ›N/›z are indicated above each beam path. The dashed line indicates the top of the duct.

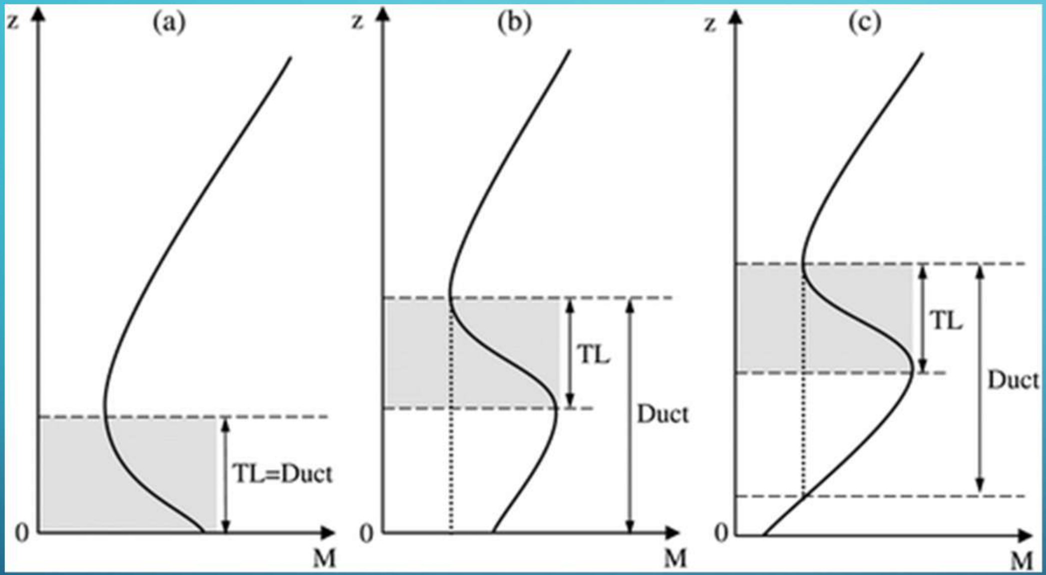
Change of N with height	Mode
$\partial N/\partial z > 0$	Subrefraction
$0 >= \partial N/\partial z > -0.0787\ m^{-1}$	Normal refraction
$-0.0787 >= \partial N/\partial z > -0.157\ m^{-1}$	Superrefraction
$-0.157 >= \partial N/\partial z$	Ducting

Steiner and Smith (2002)

https://journals.ametsoc.org/doi/full/10.1175/2008JAMC1961.1

THERMAL PROFILES

Duct thickness is a factor for usable frequencies



. Duct types as a function of the shape of the M vertical profile: (a) surface duct, (b) S-shaped surface duct, and (c) elevated duct. Gray shading identifies the trapping layer (TL)

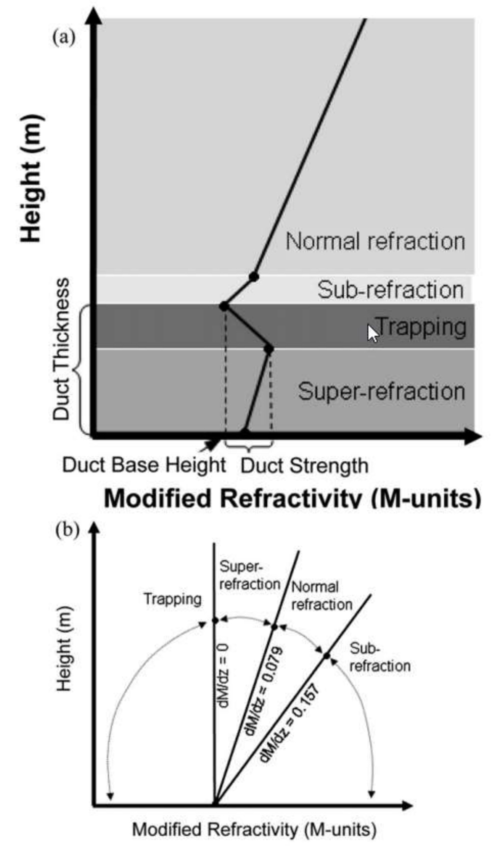


FIG. 1. Schematic representation of (a) modified refractivity profile labeled with refractive layers and duct characteristics (duct strength, base height, and thickness) and (b) the three slope values (dM/dz) that delineate the four refractivity regimes: subrefraction, normal refraction, superrefraction, and trapping.

https://journals.ametsoc.org/doi/full/10.1175/2008JAMC1961.1
https://journals.ametsoc.org/doi/pdf/10.1175/2010JAMC2415.1

INVERSION THICKNESS VS. FREQUENCY

Inversion Thickness		LUF	
Feet	*Metres*	*Band*	*M/GHz*
50	15	µW	11.67 GHz
100	30	µW	3.35 GHz
150	46	UHF	1615 MHz
200	61	UHF	962 MHz
300	91	UHF	464 MHz
400	122	VHF	276 MHz
500	152	VHF	185 MHz
600	183	VHF	133 MHz
700	213	VHF	101 MHz
800	244	VHF	79 MHz
900	274	VHF	64 MHz
1000	305	VHF	53 MHz
1100	335	VHF	45 MHz
1200	366	VHF	38 MHz
1300	396	VHF	33 MHz
1400	427	SW	29 MHz
1500	457	SW	26 MHz

From http://www.dxinfocentre.com/propagation/luf.htm

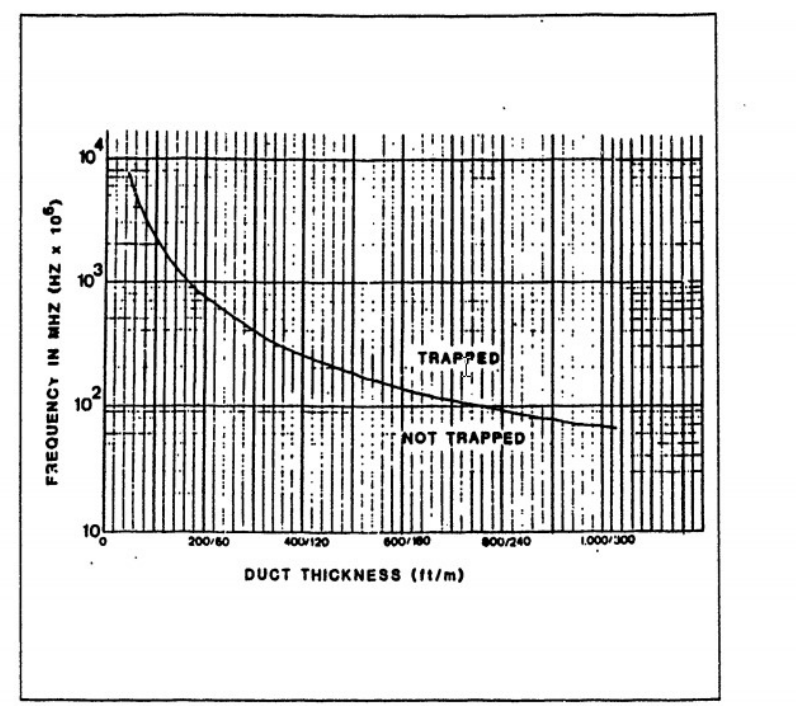
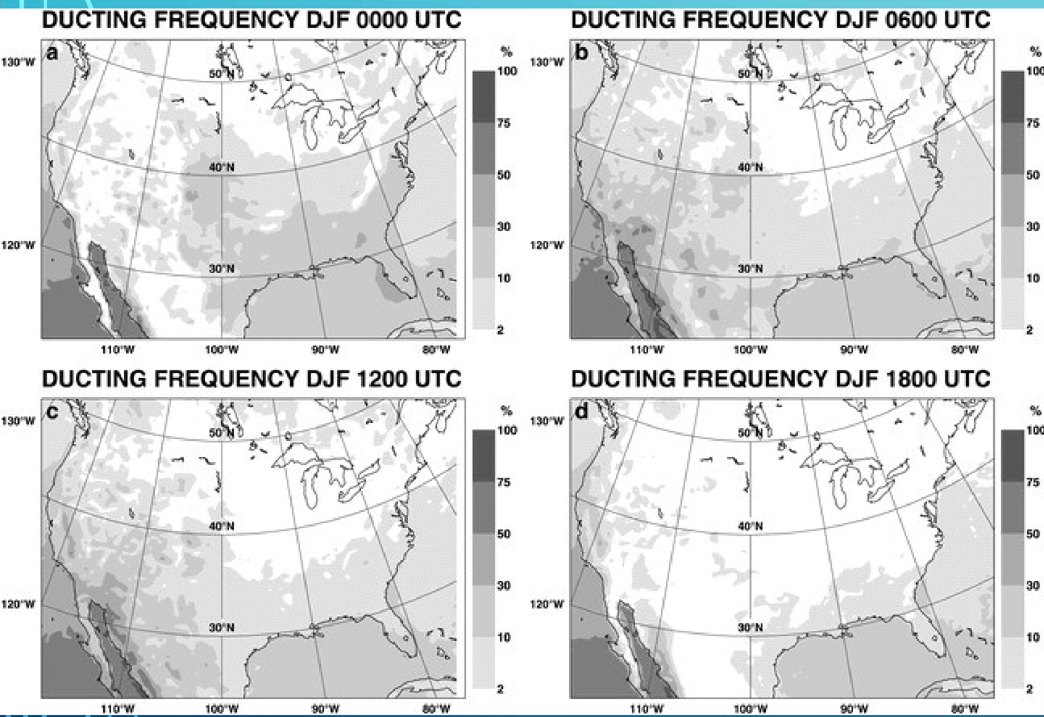
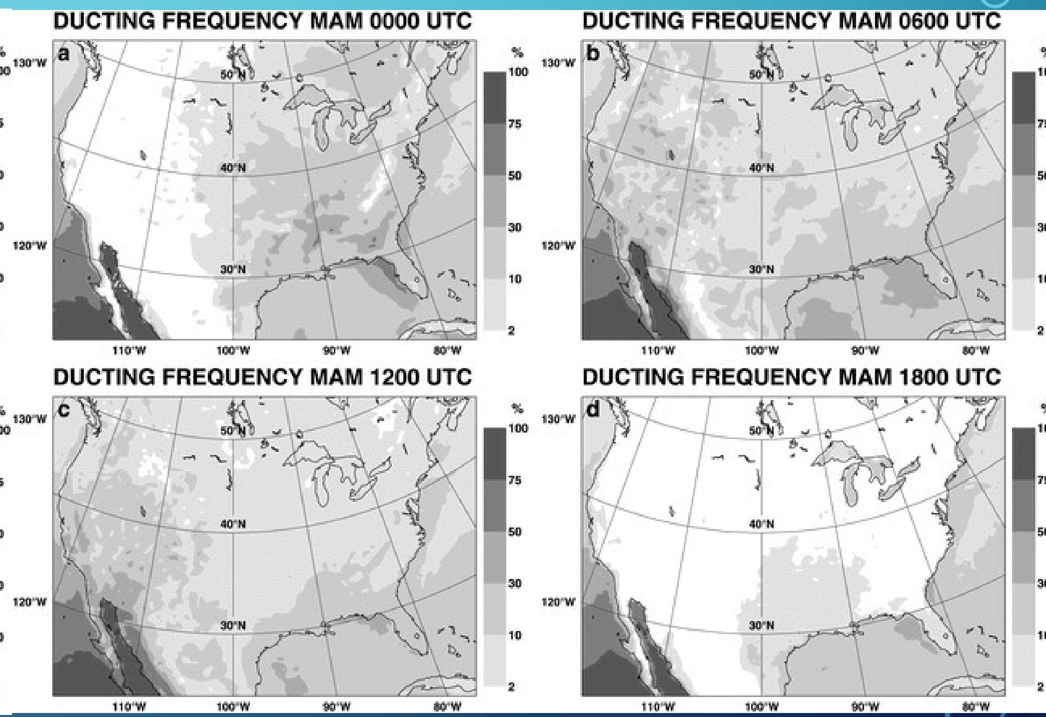


Figure 6. Frequencies Trapped with Respect to Duct Thickness

https://apps.dtic.mil/dtic/tr/fulltext/u2/a034073.pdf

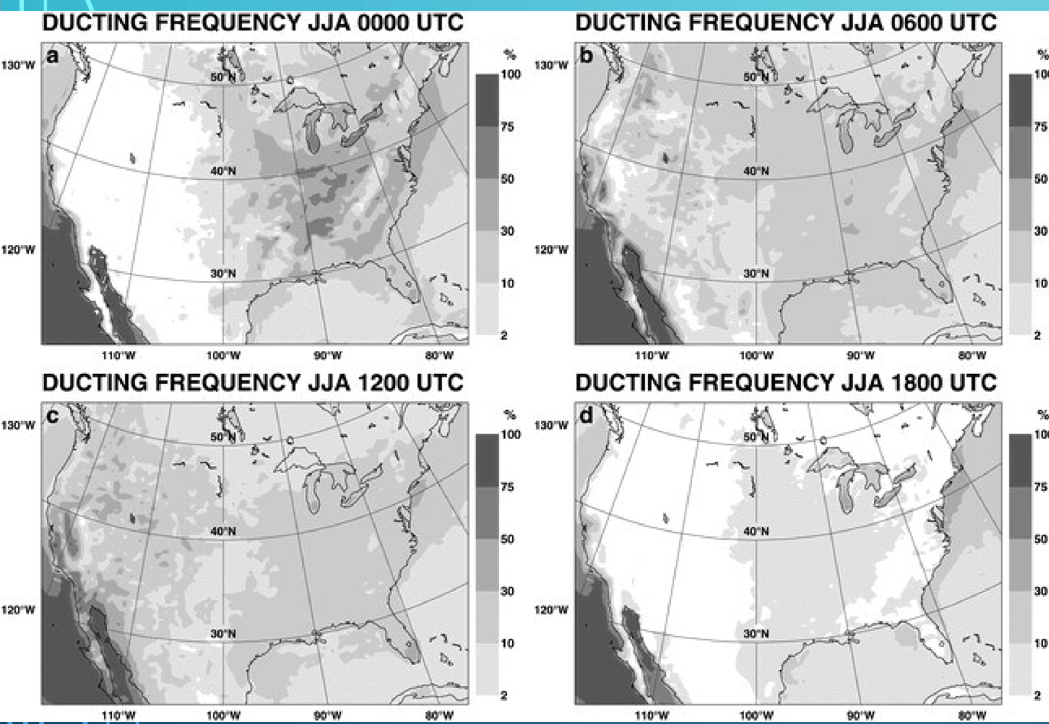
DUCTING FREQUENCY

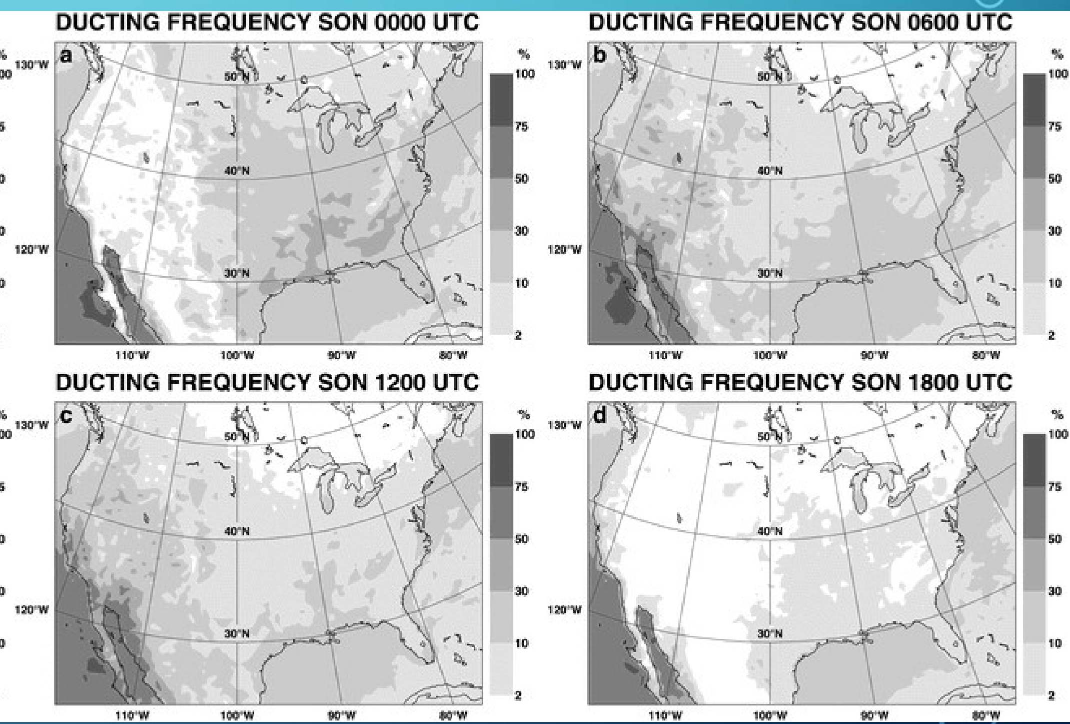




https://journals.ametsoc.org/doi/full/10.1175/2008JAMC1961.1

DUCTING FREQUENCY



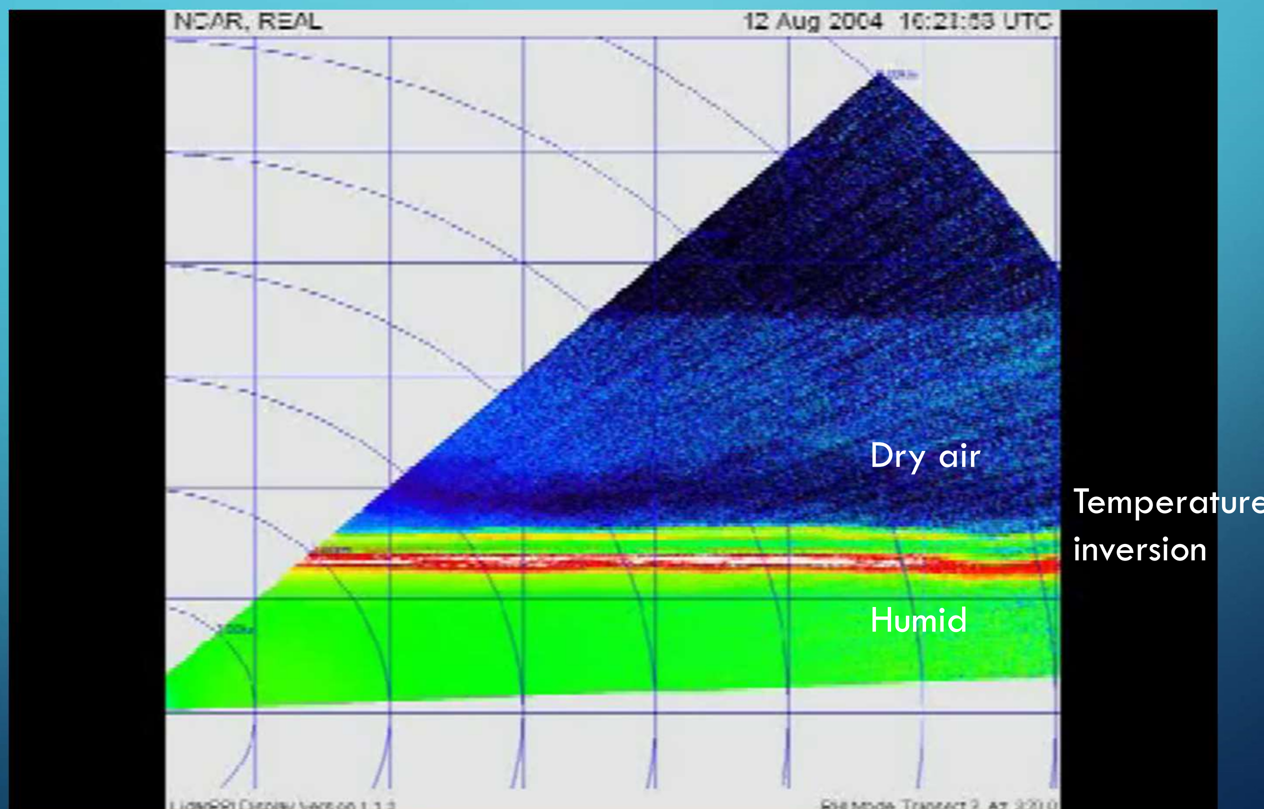


https://journals.ametsoc.org/doi/full/10.1175/2008JAMC1961.1

THE MIRAGE:
A VISUAL ANALOGY FOR MICROWAVE REFRATCION

- https://media.mnn.com/assets/images/2017/03/desert-mirage.jpg.638x0_q80_crop-smart.jpg

LIDAR VERTICAL CROSS SECTION



KWAJALEIN

A sphere with a known radar cross section was dropped at a range of 25km

Note the sharp signal increase below 30m due to the low level evaporation duct over the sea

Was noted that frequencies below S band were not enhanced

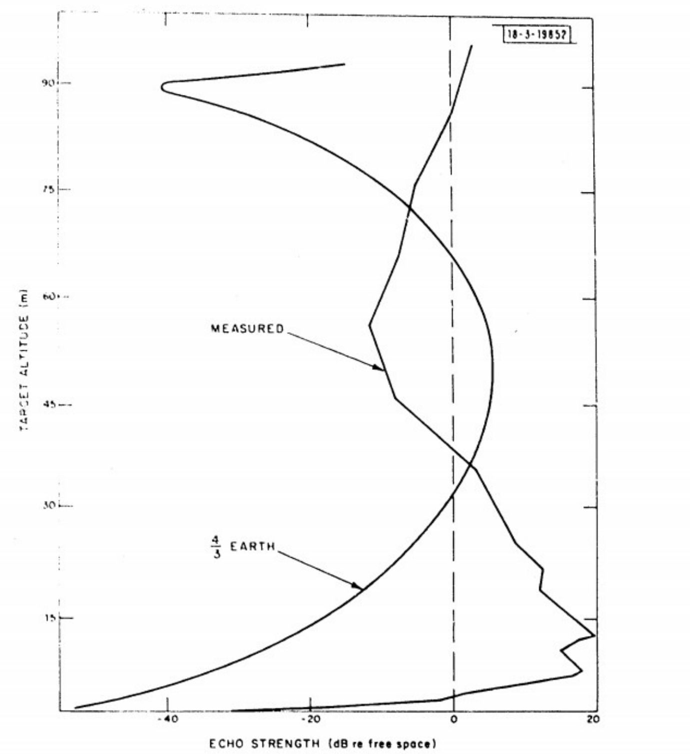
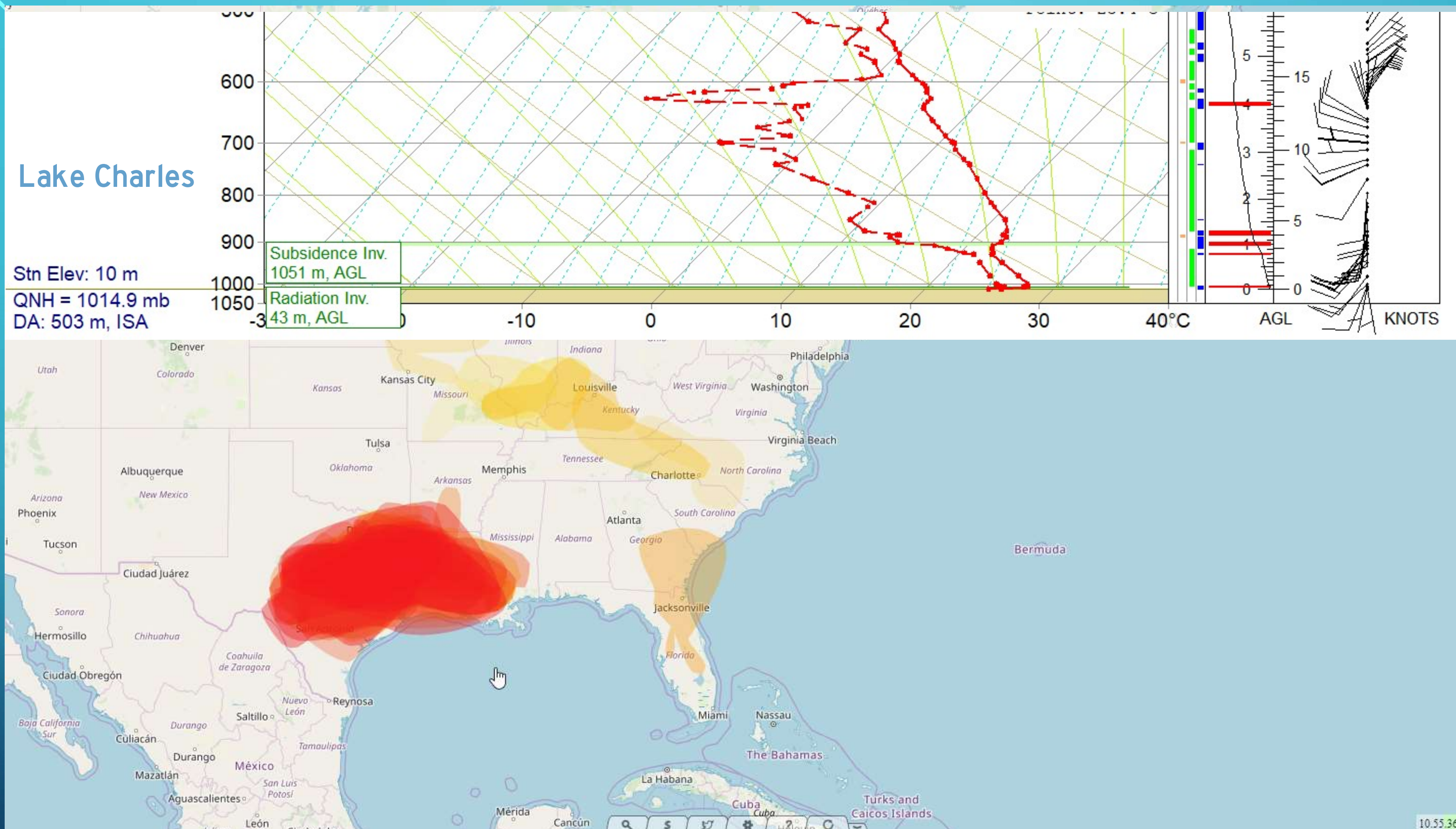


Fig. 1. Measured and calculated returns at ALCOR from a sphere dropped over the sea; range 24.7 km, altitude of ALCOR antenna 11 m. ALCOR data furnished by L. Thurman and M. Rockowitz, Lincoln Laboratory.

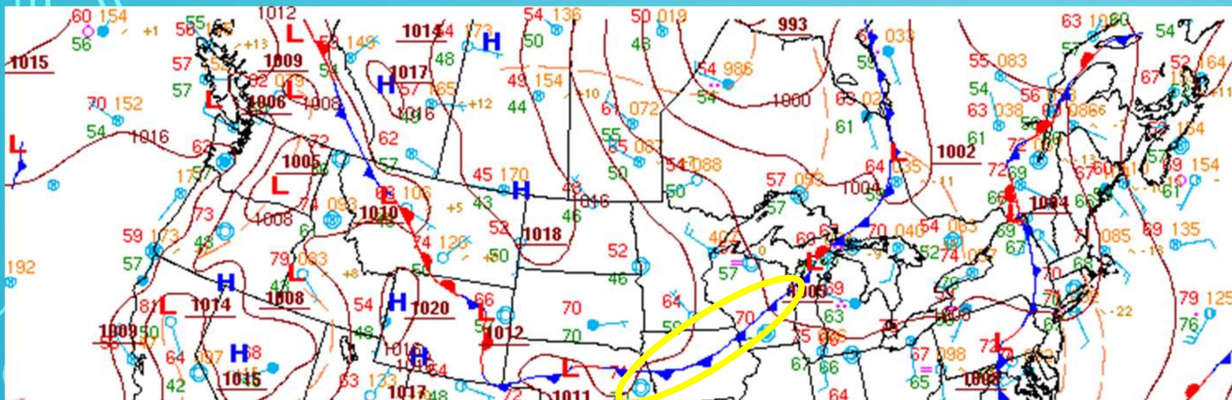
https://apps.dtic.mil/dtic/tr/fulltext/u2/a057117.pdf

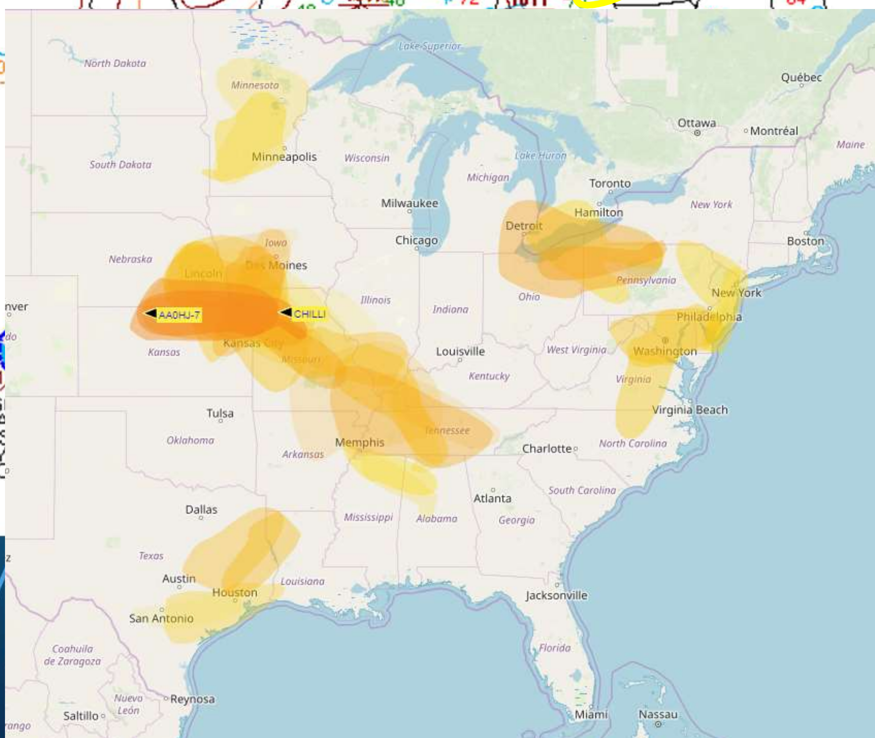

Lake Charles
Stn Elev: 10 m
QNH = 1014.9 mb
DA: 503 m, ISA
Subsidence Inv.
1051 m, AGL
Radiation Inv.
43 m, AGL
600
700
800
900
1000
1050
-10
0
10
20
30
40°C
AGL
KNOTS
Denver
Kansas City
Louisville
Philadelphia
Washington
Virginia Beach
Tulsa
Memphis
Charlotte
Albuquerque
Atlanta
Phoenix
Tucson
Ciudad Juárez
Jacksonville
Bermuda
Hermosillo
Ciudad Obregón
Reynosa
Saltillo
Miami
Nassau
The Bahamas
Culiacán
Durango
México
Mazatlán
La Habana
Cuba
Mérida
Cancún
Aguascalientes
León
Turks and
Caicos Islands

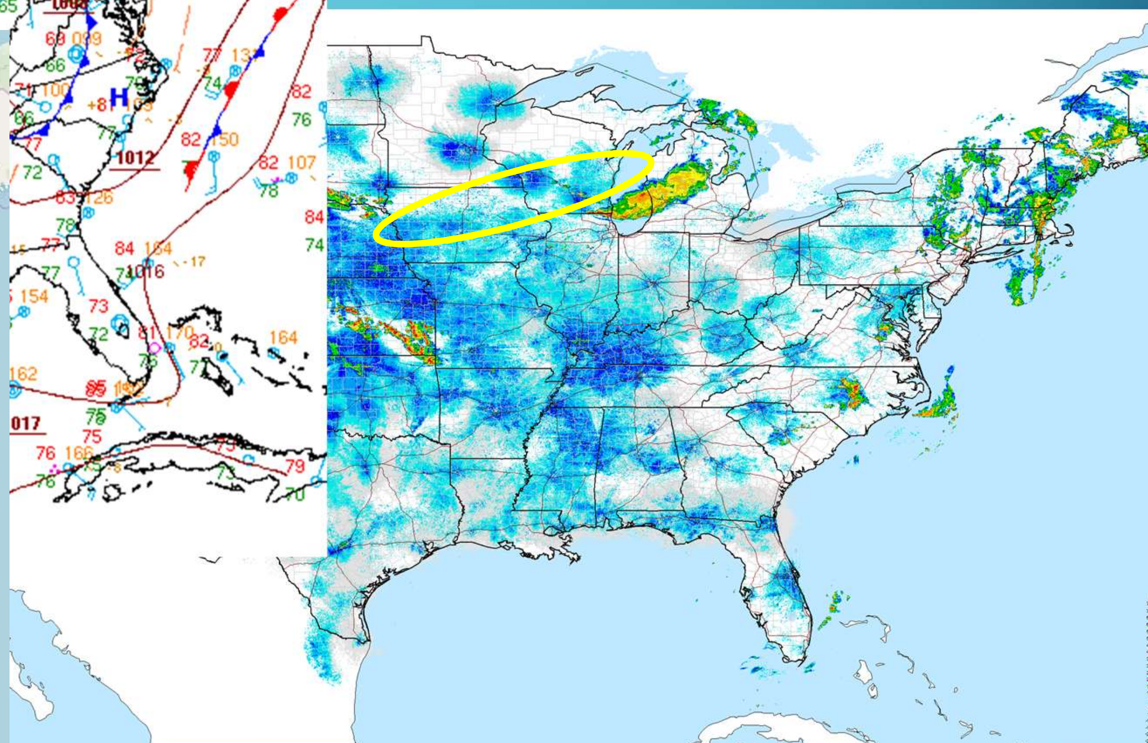
10AUG19 11Z

TROPOSPHERIC DUCTING

- Can enable contacts over distances of over a thousand miles.
- RF signal is propagated in duct
- Much variance exists on where signal exits the duct
- Signal can pass right over some users (elevated trapping ducts) such that it is possible to work stations from Texas to Florida but not into Mississippi

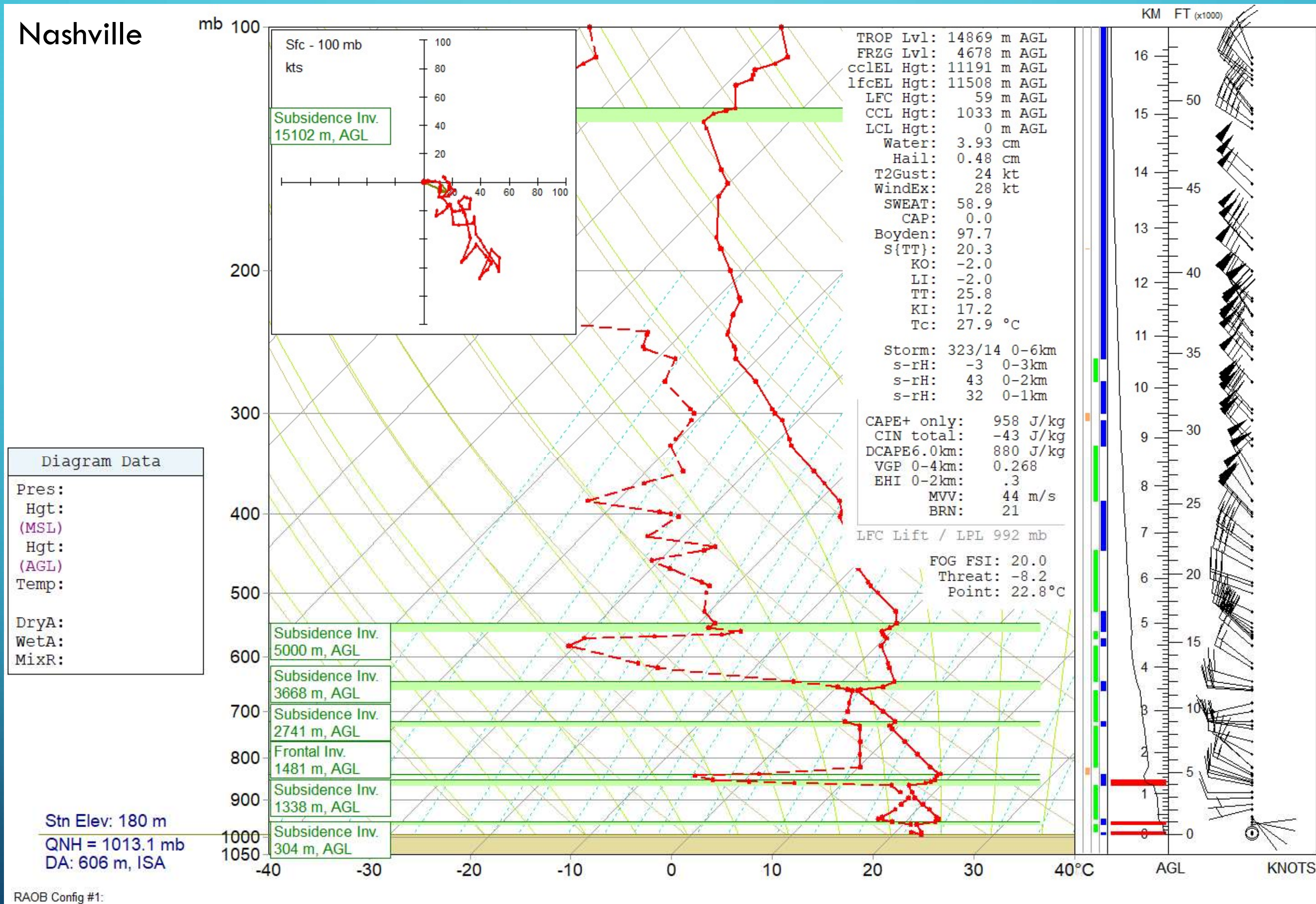






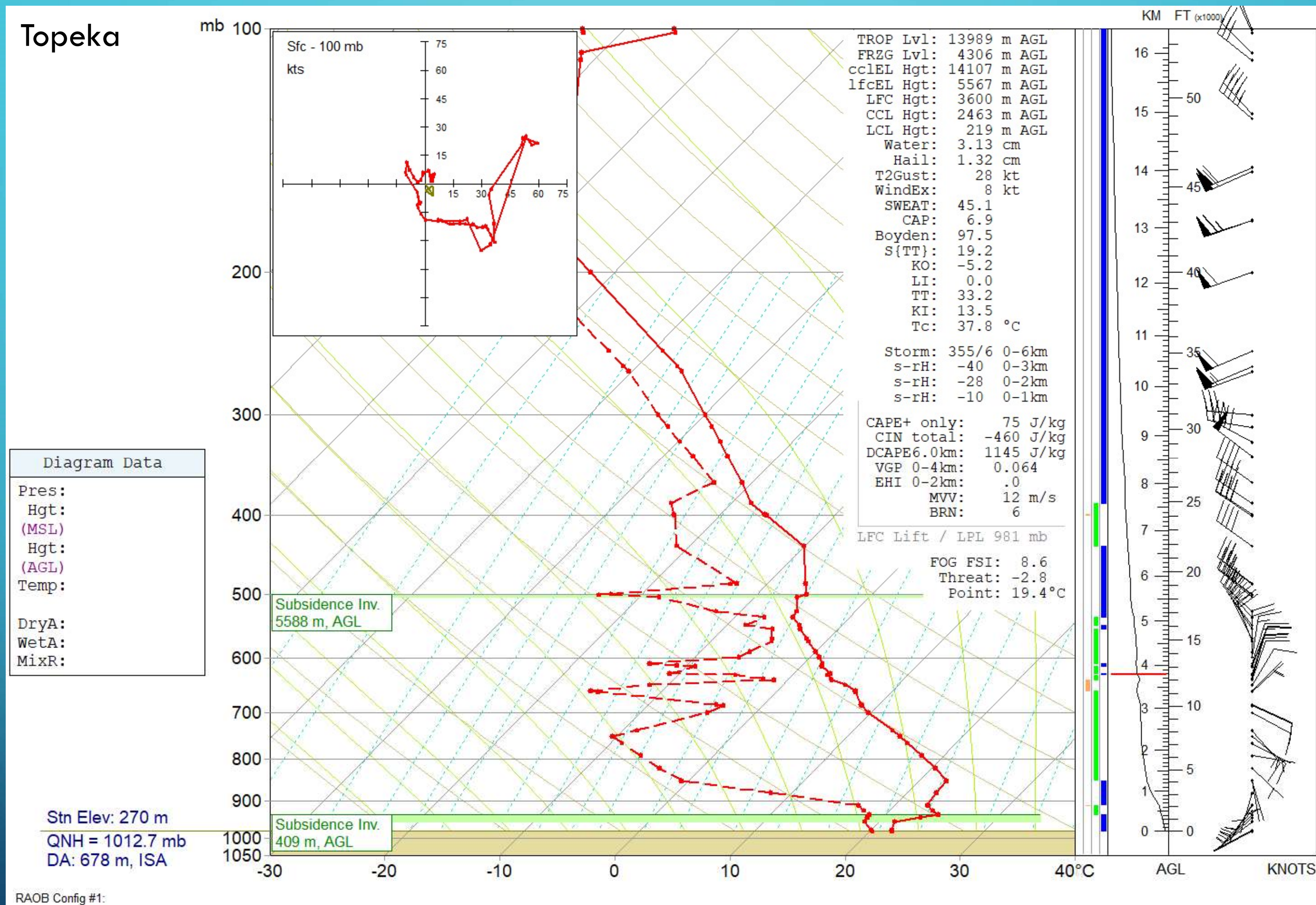
CONUS Radar Mosaic

Enhancement occurs where the weather is not!

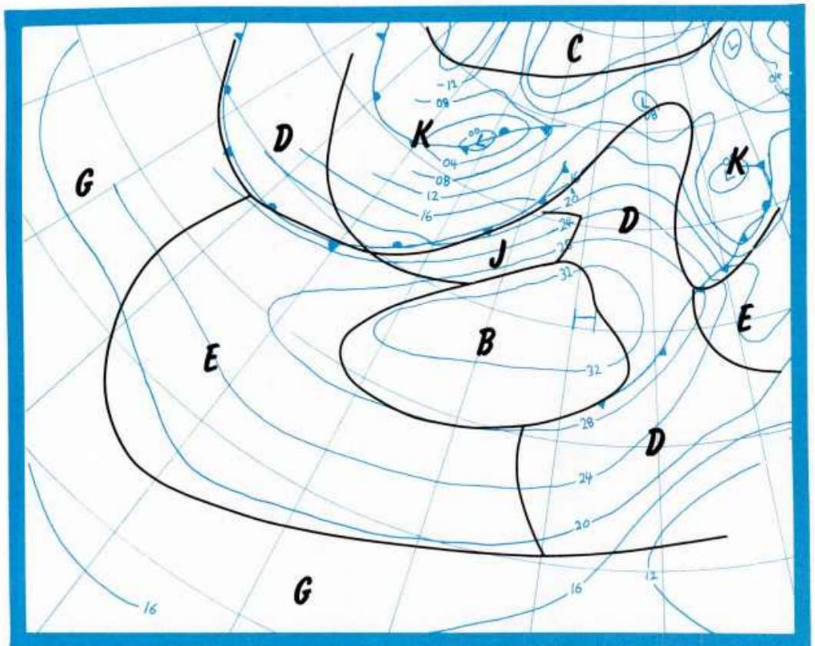


https://www.spc.noaa.gov/exper/soundings/

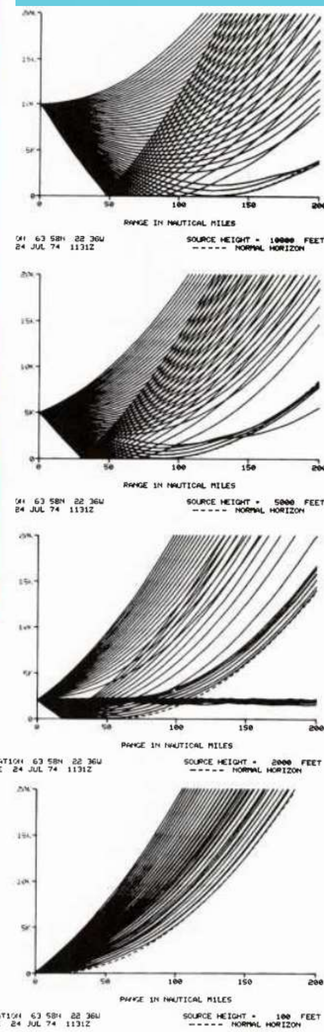
Topeka



Sfc - 100 mb
kts
TROP Lvl: 13989 m AGL
FRZG Lvl: 4306 m AGL
cclEL Hgt: 14107 m AGL
lfcEL Hgt: 5567 m AGL
LFC Hgt: 3600 m AGL
CCL Hgt: 2463 m AGL
LCL Hgt: 219 m AGL
Water: 3.13 cm
Hail: 1.32 cm
T2Gust: 28 kt
WindEx: 8 kt
SWEAT: 45.1
CAP: 6.9
Boyden: 97.5
S{TT}: 19.2
KO: -5.2
LI: 0.0
TT: 33.2
KI: 13.5
Tc: 37.8 °C
Storm: 355/6 0-6km
s-rH: -40 0-3km
s-rH: -28 0-2km
s-rH: -10 0-1km
CAPE+ only: 75 J/kg
CIN total: -460 J/kg
DCAPE6.0km: 1145 J/kg
VGP 0-4km: 0.064
EHI 0-2km: .0
MVV: 12 m/s
BRN: 6
LFC Lift / LPL 981 mb
FOG FSI: 8.6
Threat: -2.8
Point: 19.4°C
Diagram Data
Pres:
Hgt:
(MSL)
Hgt:
(AGL)
Temp:
DryA:
WetA:
MixR:
Subsidence Inv.
5588 m, AGL
Subsidence Inv.
409 m, AGL
Stn Elev: 270 m
QNH = 1012.7 mb
DA: 678 m, ISA
mb
KM
FT (x1000)
AGL
KNOTS
40°C
RAOB Config #1:



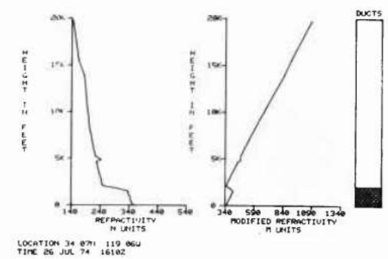
North Atlantic, Summer. High pressure covers most of the Atlantic; weak frontal systems traverse northern areas.



A-A Holes and fading possible for systems up to 10,000 feet. Ducting also possible for systems between 1,500 and 2,300 feet.

PROFILE TYPE B

Very strong surface-based duct with top near 2,000 feet. Moderate elevated temperature inversion. Subtropical air mass.

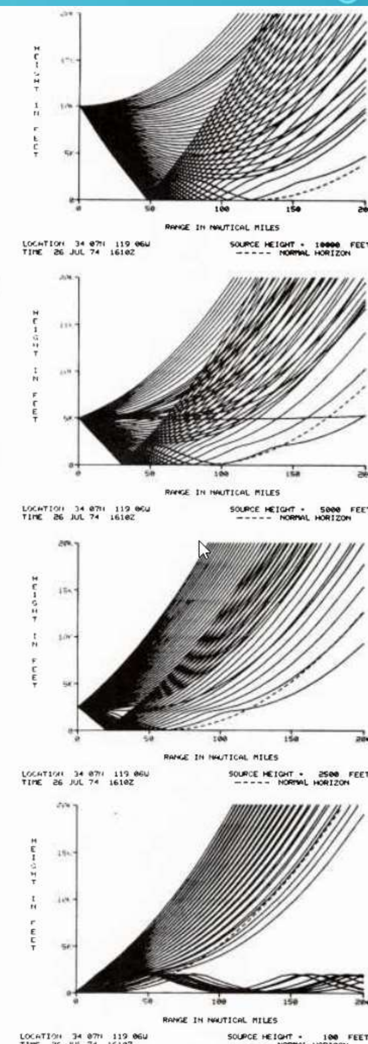


SYSTEMS COVERAGE

S-S Ducting and greatly extended range.

S-A Slightly extended range.

A-A Near normal for systems well above duct. Some holes and fading for systems slightly above duct. Ducting, holes and fading possible for systems within duct (below 2,000 feet).



THE SOUNDING IS ONLY PART OF THE STORY

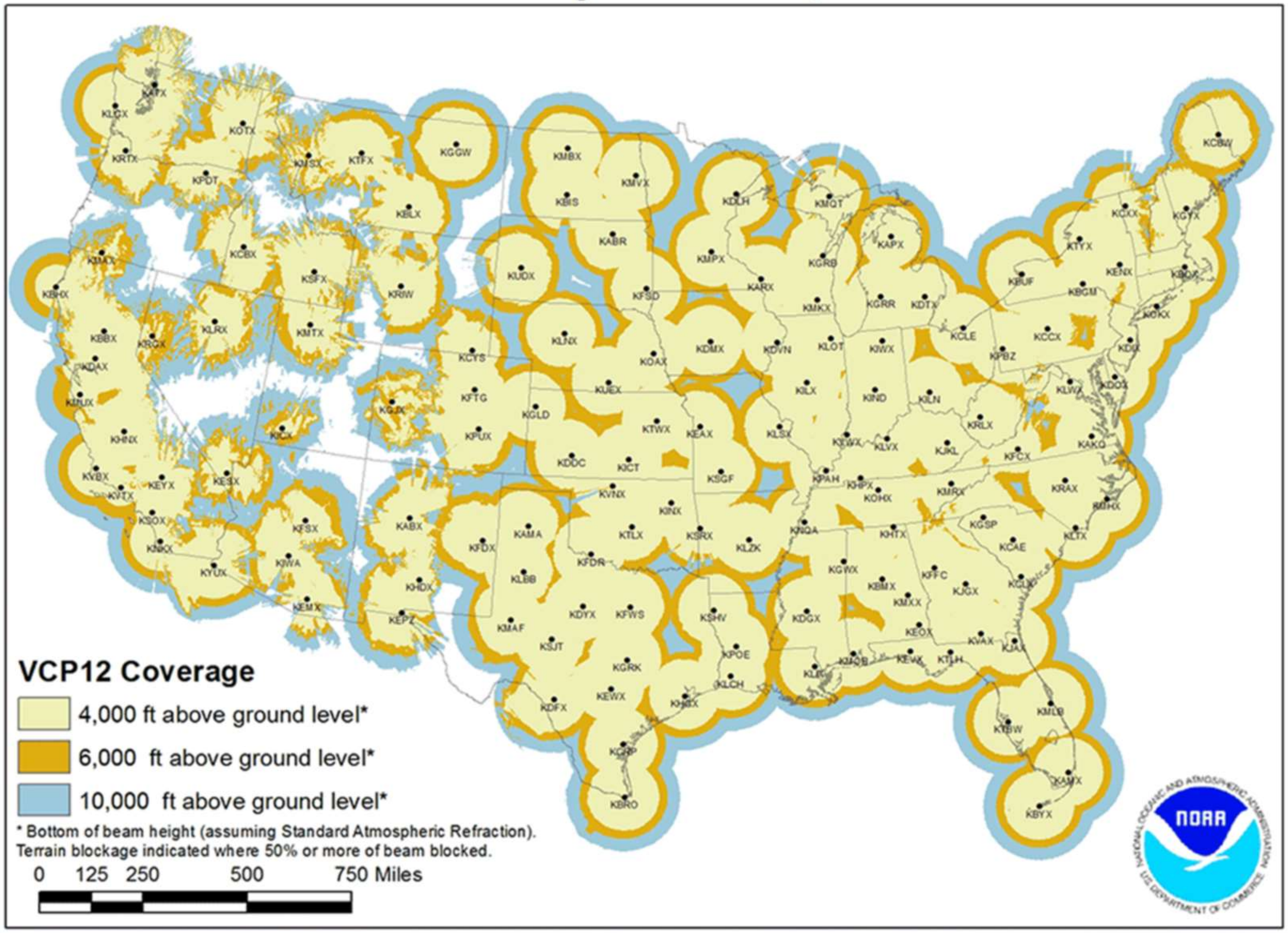
- Like in the mirage example, the weather must be very stable to propagate effectively.

Imagine the following analogy of an inversion (akin to a mirror)

Good
Still subject to multipath fading
(Fresnel zones)

Unfavorable

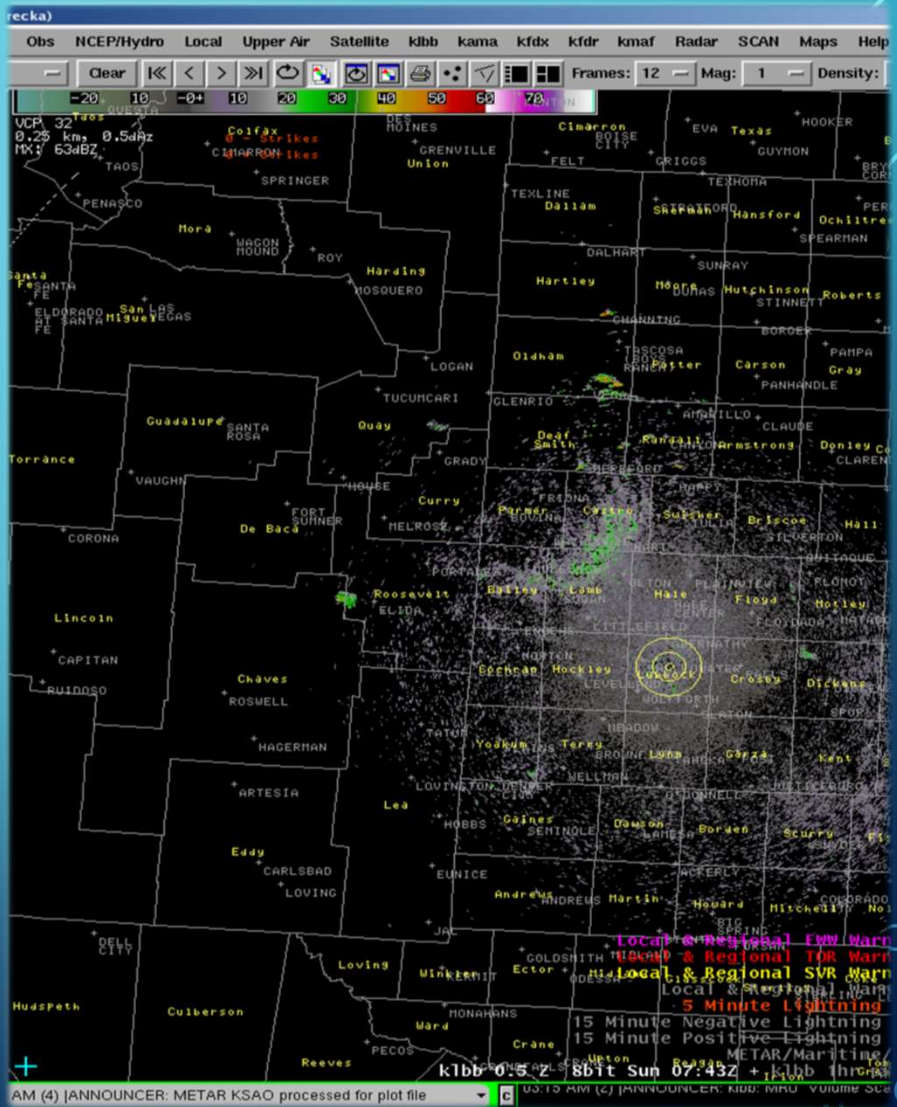
NEXRAD Coverage Below 10,000 Feet AGL



EFFECTS ON WEATHER RADAR

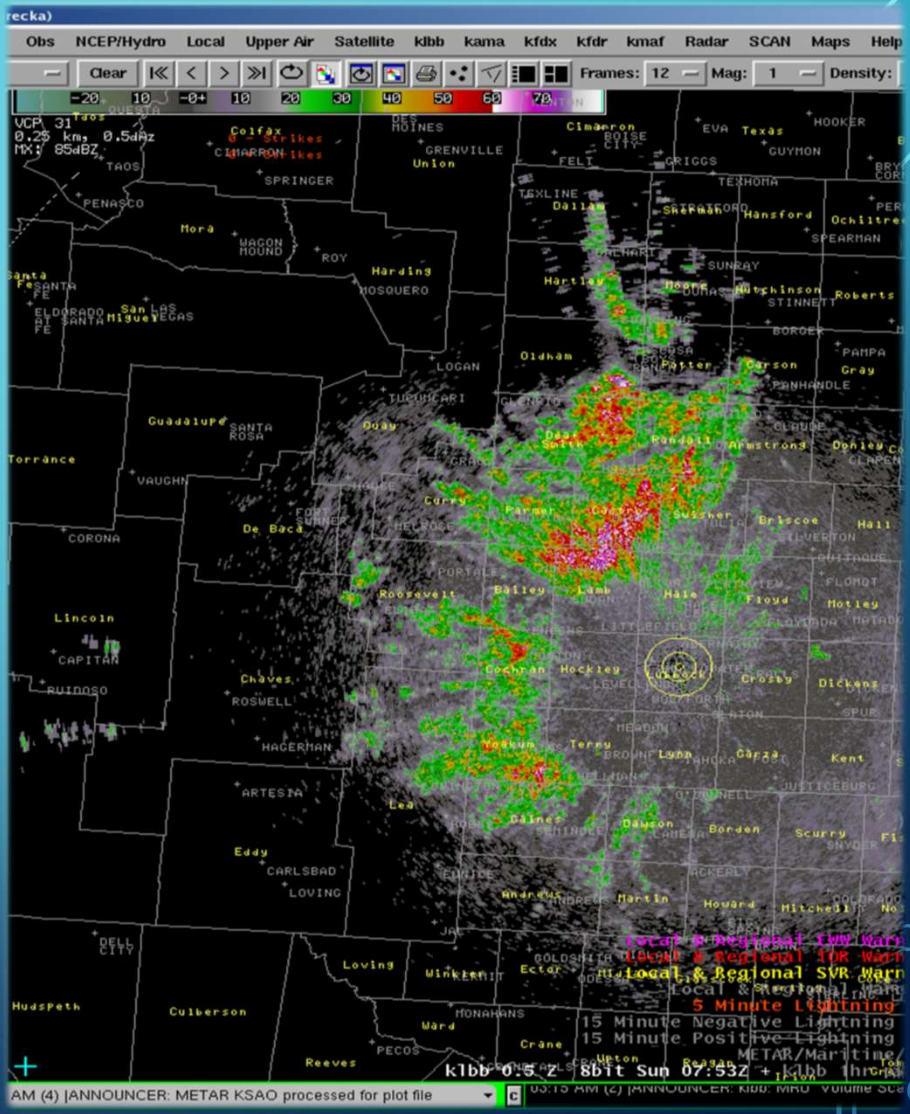
Image of WSR-88D radar data with Gaussian Model Adaptive Processing (GMAP) enabled under super-refraction conditions

$F_0 \sim 3$ GHz



EFFECTS ON WEATHER RADAR

10 minutes later with clutter suppression disabled

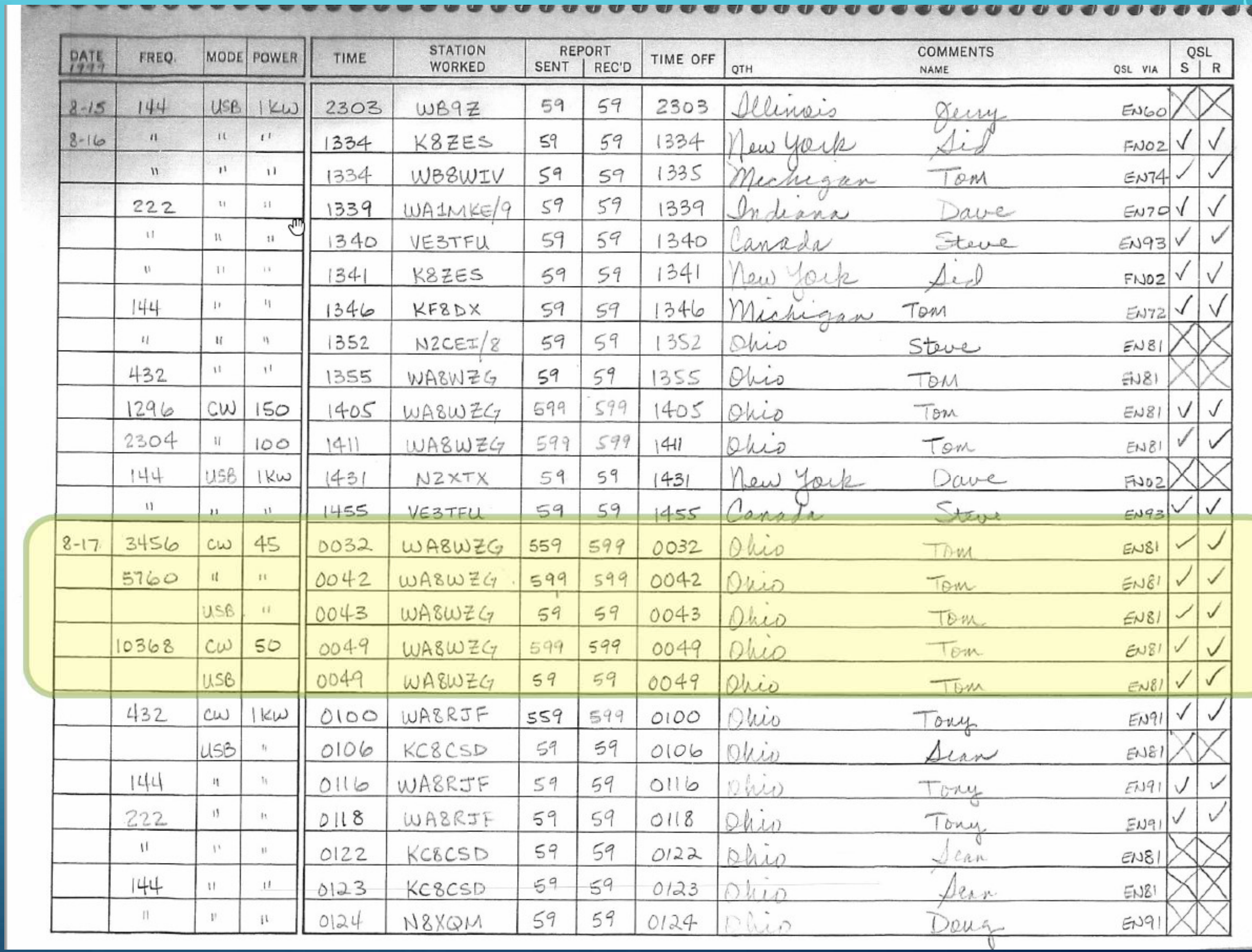


CASE STUDIES

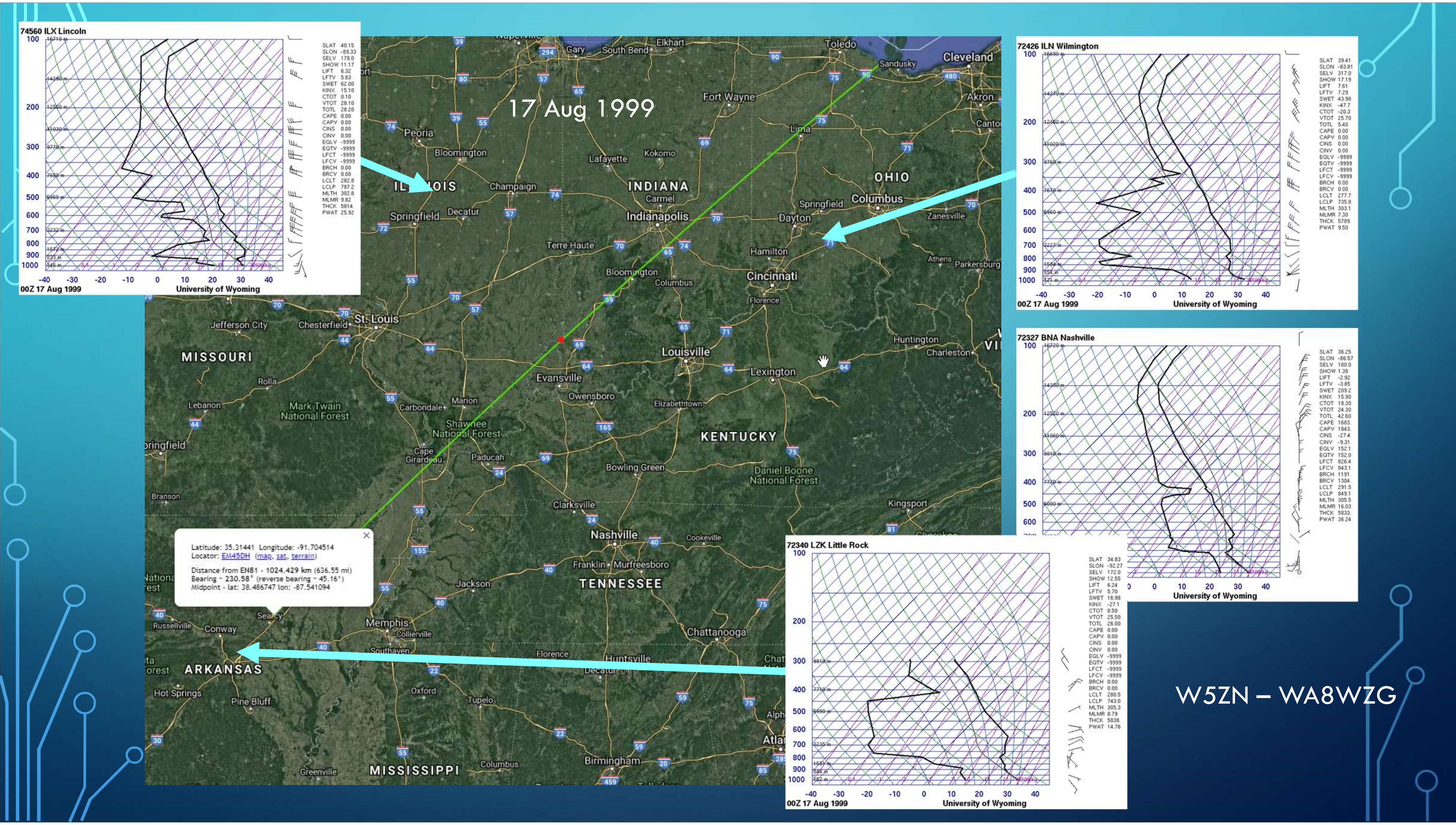
10 GHZ AND UP

W5ZN (EM45dh)
to
WA8WZG (EN81om)

17 Aug 1999 (0032Z-0049Z)

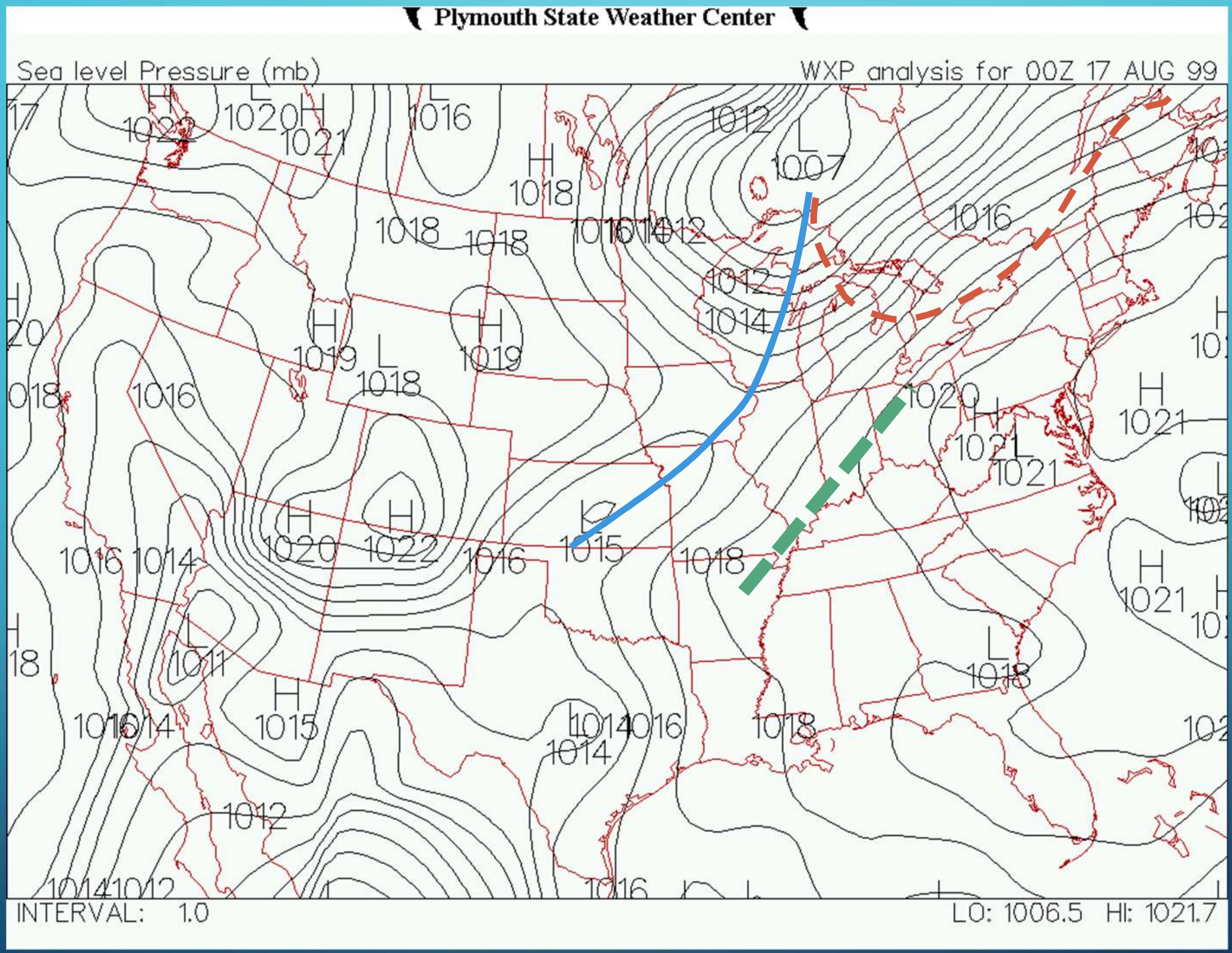


DATE 1999	FREQ.	MODE	POWER	TIME	STATION WORKED	REPORT SENT	REPORT REC'D	TIME OFF	QTH	NAME	QSL VIA	QSL S	QSL R
8-15	144	USB	1KW	2303	WB9Z	59	59	2303	Illinois	Jerry	EN60	X	X
8-16	"	"	"	1334	K8ZES	59	59	1334	New York	Sid	FN02	✓	✓
	"	"	"	1334	WB8WIV	59	59	1335	Michigan	Tom	EN74	✓	✓
	222	"	"	1339	WA1MKE/9	59	59	1339	Indiana	Dave	EN70	✓	✓
	"	"	"	1340	VE3TFU	59	59	1340	Canada	Steve	EN93	✓	✓
	"	"	"	1341	K8ZES	59	59	1341	New York	Sid	FN02	✓	✓
	144	"	"	1346	KF8DX	59	59	1346	Michigan	Tom	EN72	✓	✓
	"	"	"	1352	N2CEI/8	59	59	1352	Ohio	Steve	EN81	X	X
	432	"	"	1355	WA8WZG	59	59	1355	Ohio	Tom	EN81	X	X
	1296	CW	150	1405	WA8WZG	599	599	1405	Ohio	Tom	EN81	✓	✓
	2304	"	100	1411	WA8WZG	599	599	1411	Ohio	Tom	EN81	✓	✓
	144	USB	1KW	1431	N2XTX	59	59	1431	New York	Dave	FN02	X	X
	"	"	"	1455	VE3TFU	59	59	1455	Canada	Steve	EN93	✓	✓
8-17	3456	CW	45	0032	WA8WZG	559	599	0032	Ohio	Tom	EN81	✓	✓
	5760	"	"	0042	WA8WZG	599	599	0042	Ohio	Tom	EN81	✓	✓
		USB	"	0043	WA8WZG	59	59	0043	Ohio	Tom	EN81	✓	✓
	10368	CW	50	0049	WA8WZG	599	599	0049	Ohio	Tom	EN81	✓	✓
		USB		0049	WA8WZG	59	59	0049	Ohio	Tom	EN81	✓	✓
	432	CW	1KW	0100	WA8RJF	559	599	0100	Ohio	Tony	EN91	✓	✓
		USB	"	0106	KC8CSD	59	59	0106	Ohio	Sean	EN81	X	X
	144	"	"	0116	WA8RJF	59	59	0116	Ohio	Tony	EN91	✓	✓
	222	"	"	0118	WA8RJF	59	59	0118	Ohio	Tony	EN91	✓	✓
	"	"	"	0122	KC8CSD	59	59	0122	Ohio	Sean	EN81	X	X
	144	"	"	0123	KC8CSD	59	59	0123	Ohio	Sean	EN81	X	X
	"	"	"	0124	N8XQM	59	59	0124	Ohio	Doug	EN91	X	X



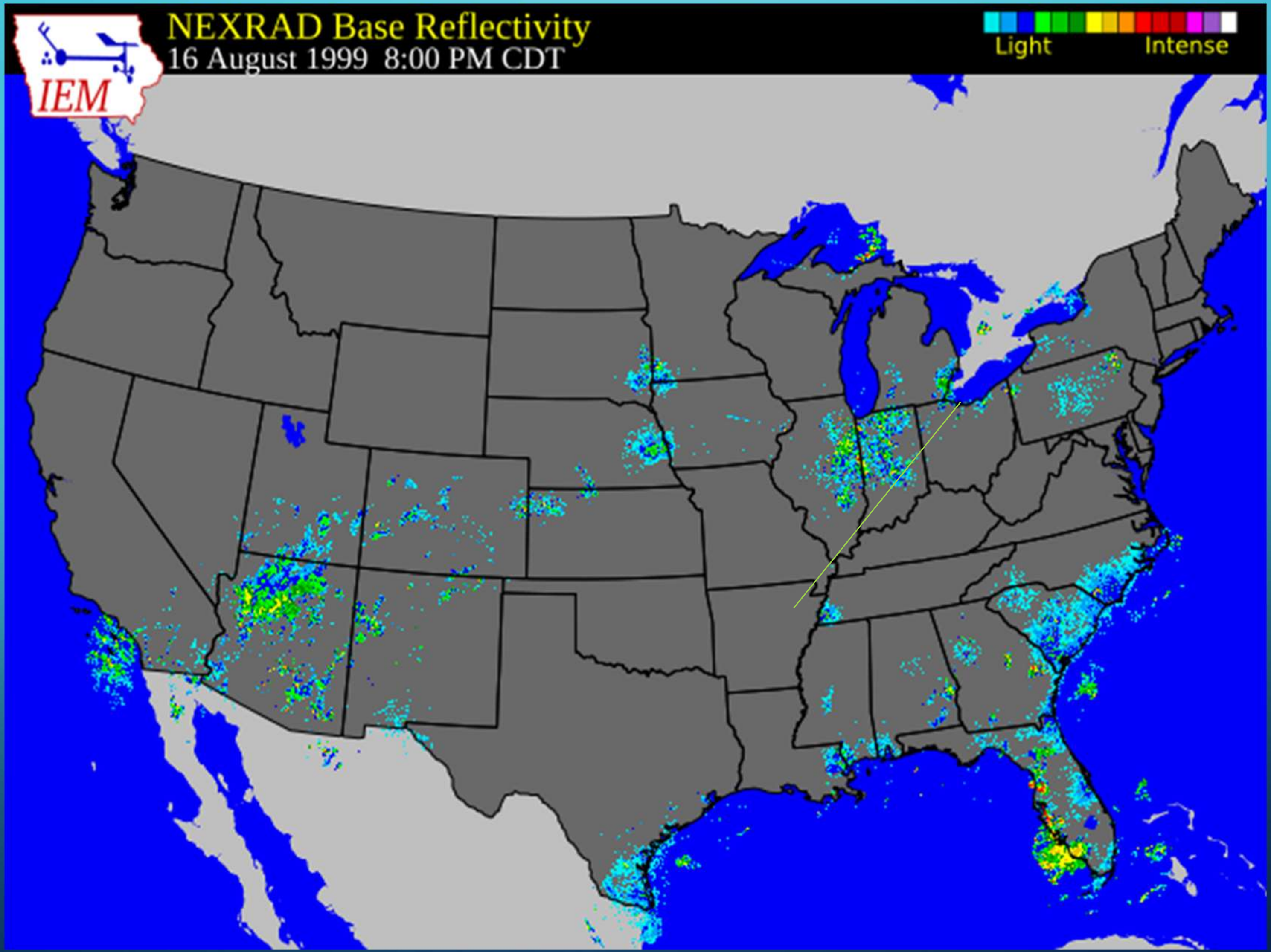
17 Aug 1999
74560 ILX Lincoln
00Z 17 Aug 1999
University of Wyoming
72426 ILN Wilmington
00Z 17 Aug 1999
University of Wyoming
72327 BNA Nashville
University of Wyoming
72340 LZK Little Rock
00Z 17 Aug 1999
University of Wyoming
Latitude: 35.31441 Longitude: -91.704514
Locator: EM45DH (map, sat, terrain)
Distance from EN81 - 1024.429 km (636.55 mi)
Bearing ~ 230.58° (reverse bearing ~ 45.16°)
Midpoint - lat: 38.486747 lon: -87.541094
W5ZN – WA8WZG

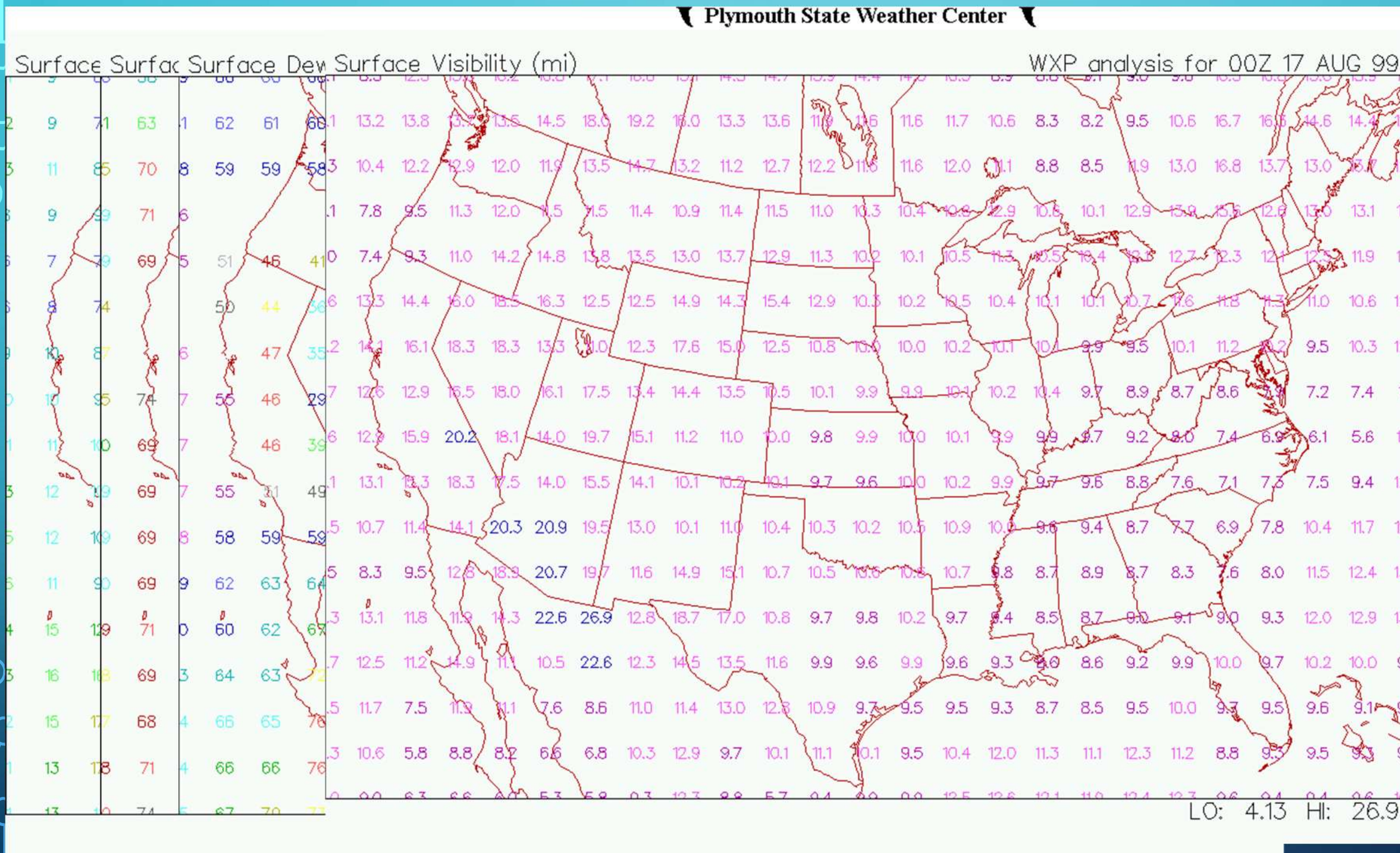
17 Aug 1999 0032Z



W5ZN – WA8WZG

https://vortex.plymouth.edu/myo/sfc/ctrmap-a.html


NEXRAD Base Reflectivity
16 August 1999 8:00 PM CDT
IEM
Light
Intense


Plymouth State Weather Center
Surface
Surfac
Surface Dew
Surface Visibility (mi)
WXP analysis for 00Z 17 AUG 99
LO: 4.13 HI: 26.9

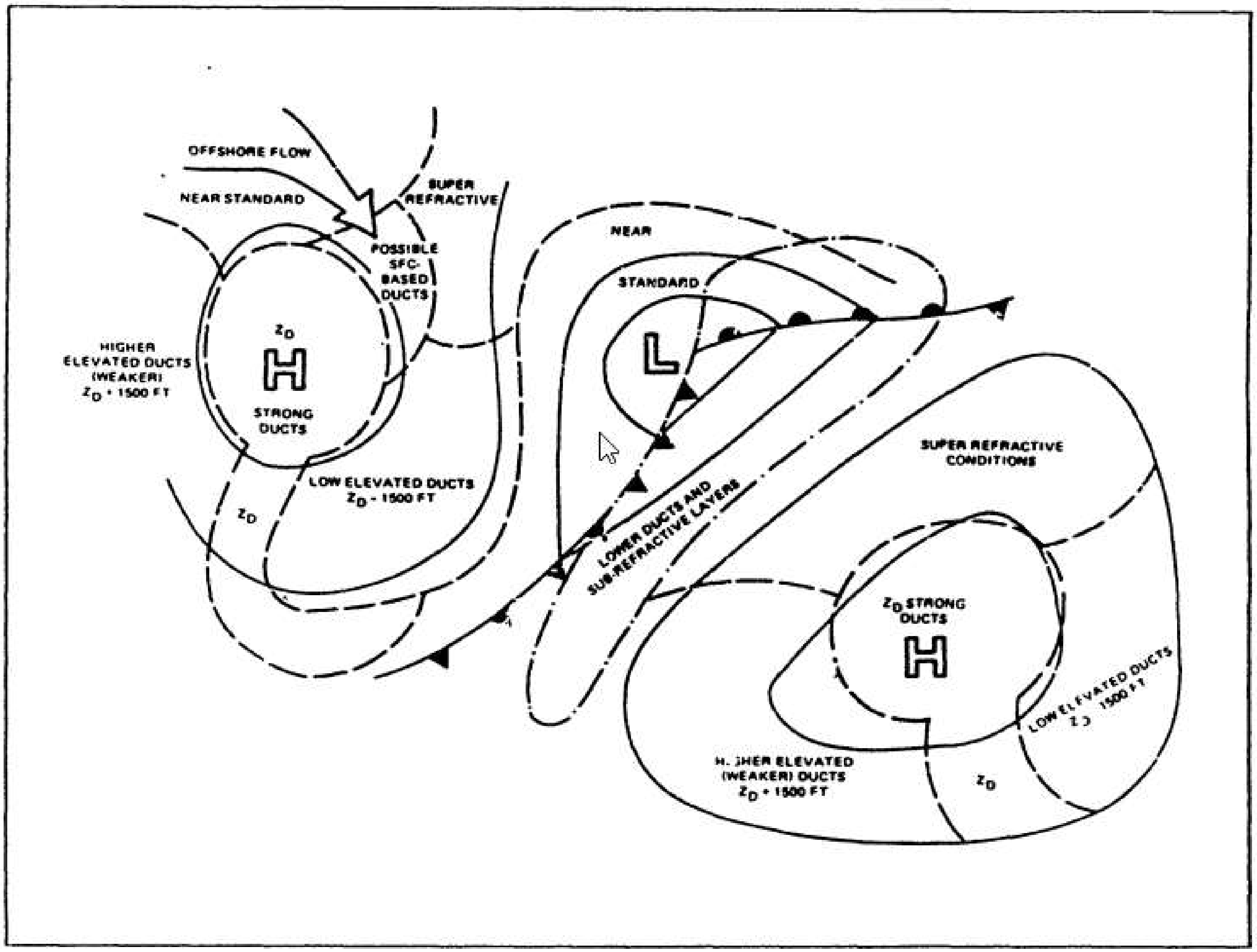
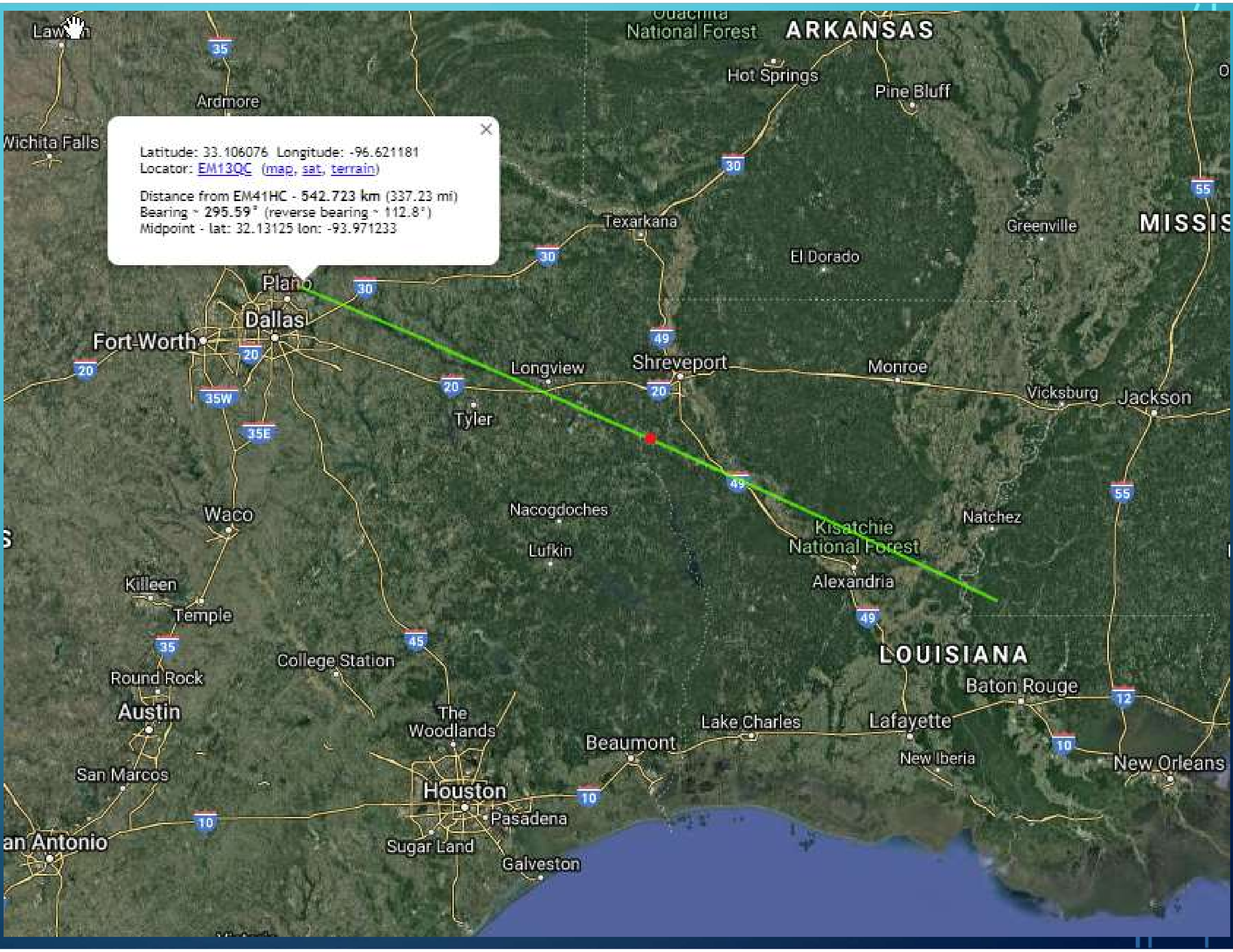


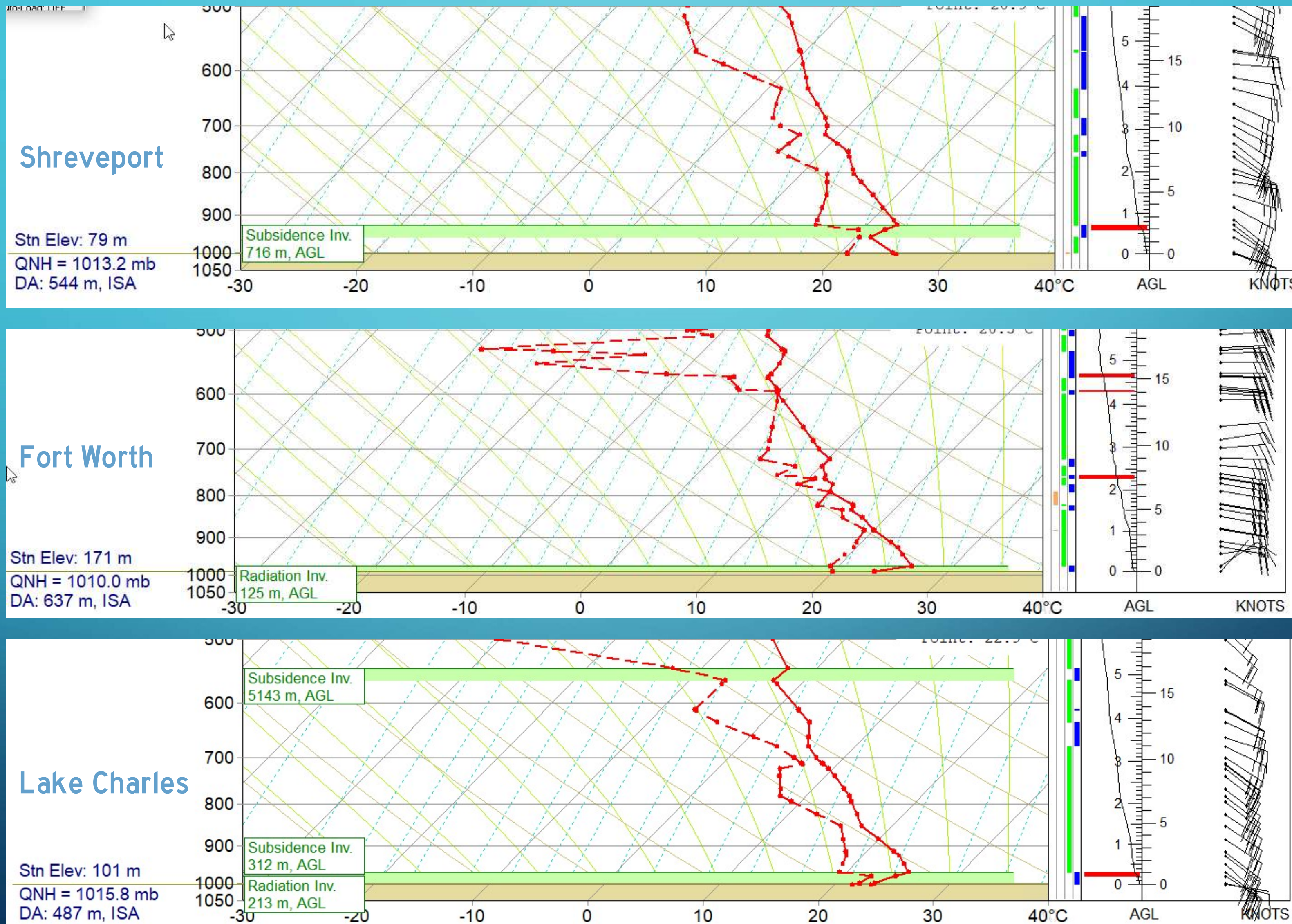
Figure 21. Model of Synoptic-Refractive Relationship

Culberson (1990)

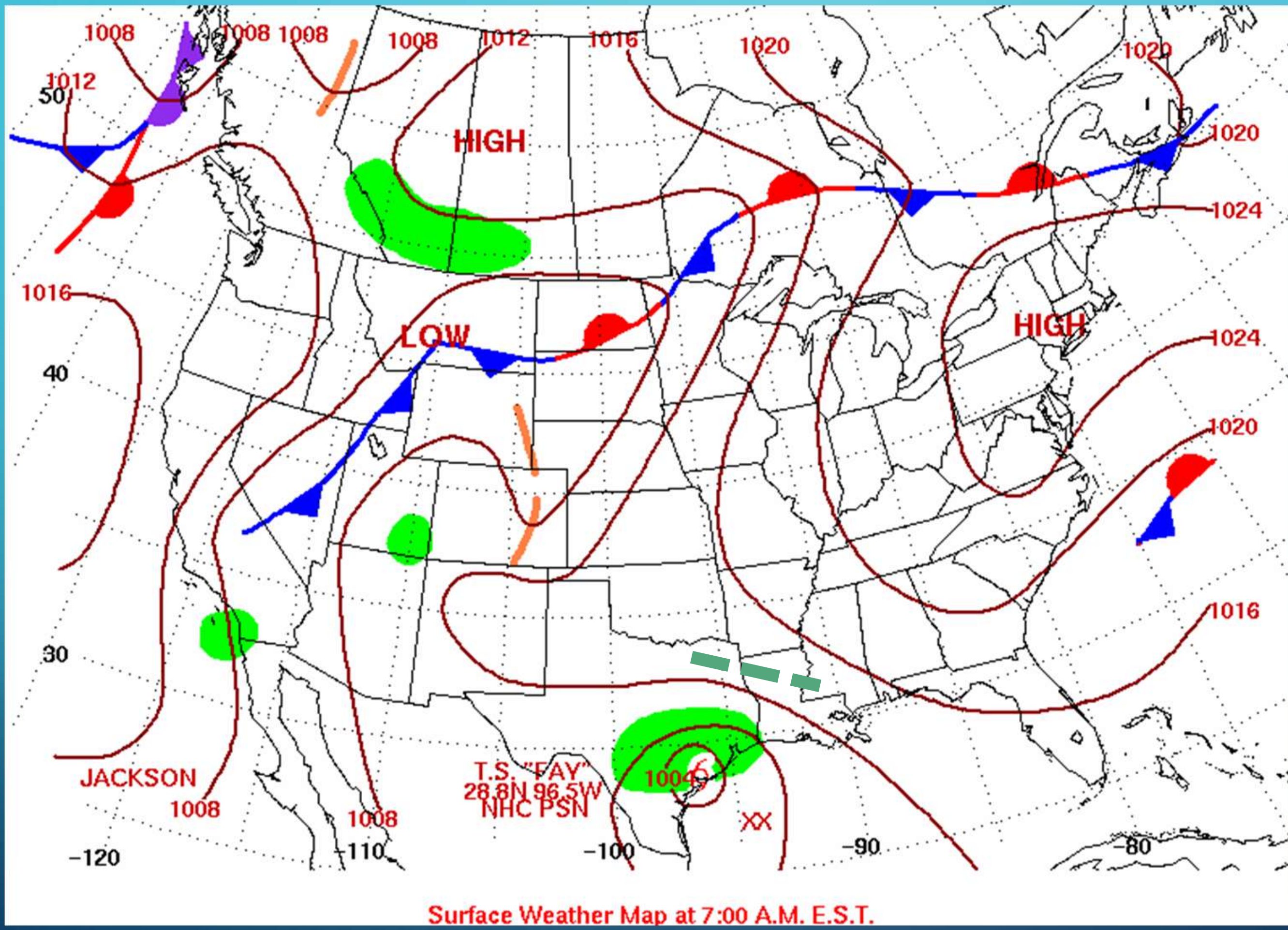
7 Sept 2002
24 GHz US Record
W5LUA-WW2R
1215Z
10G & 24G



7 Sept 2002
12Z

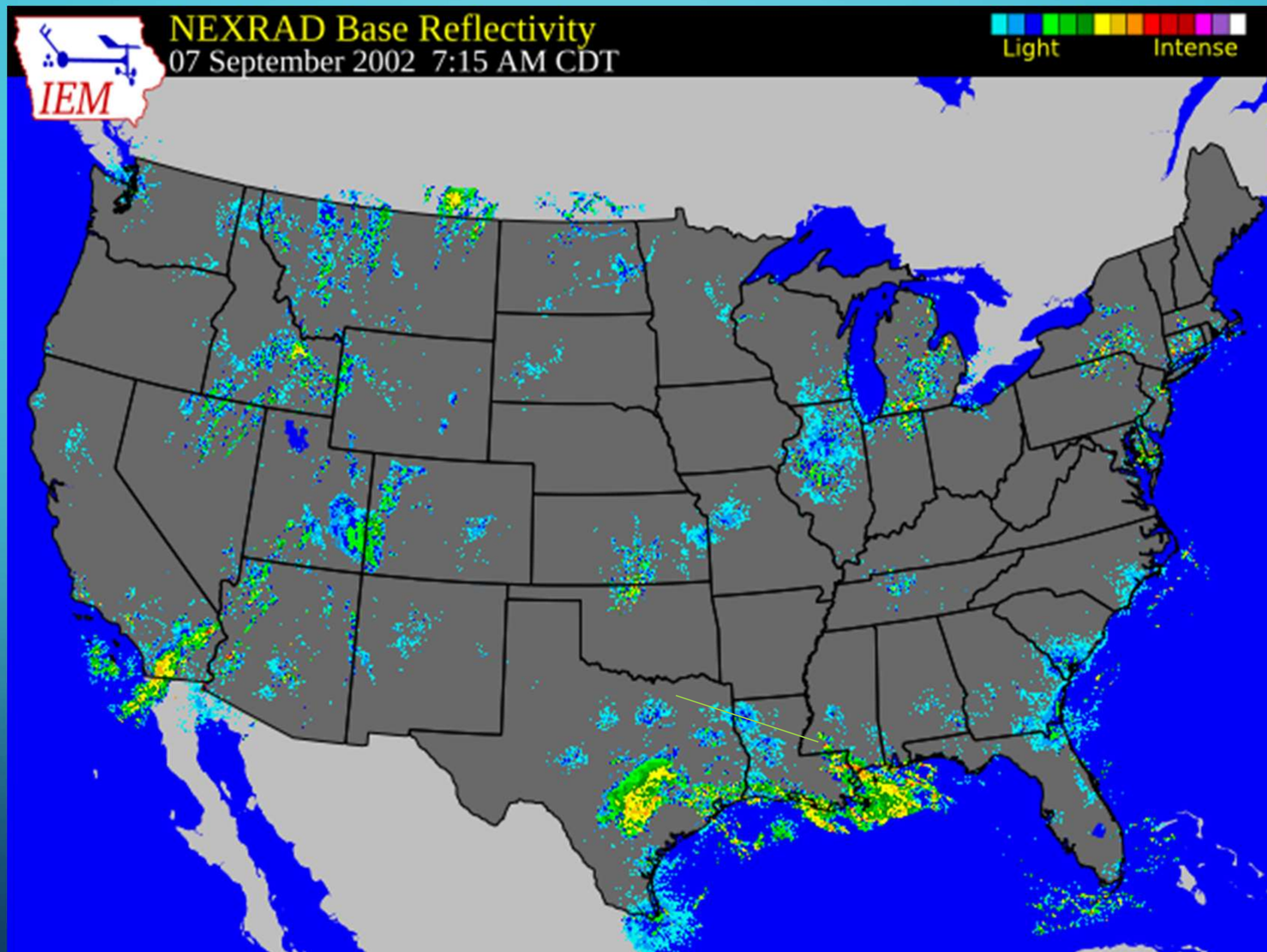


7 Sept 2002

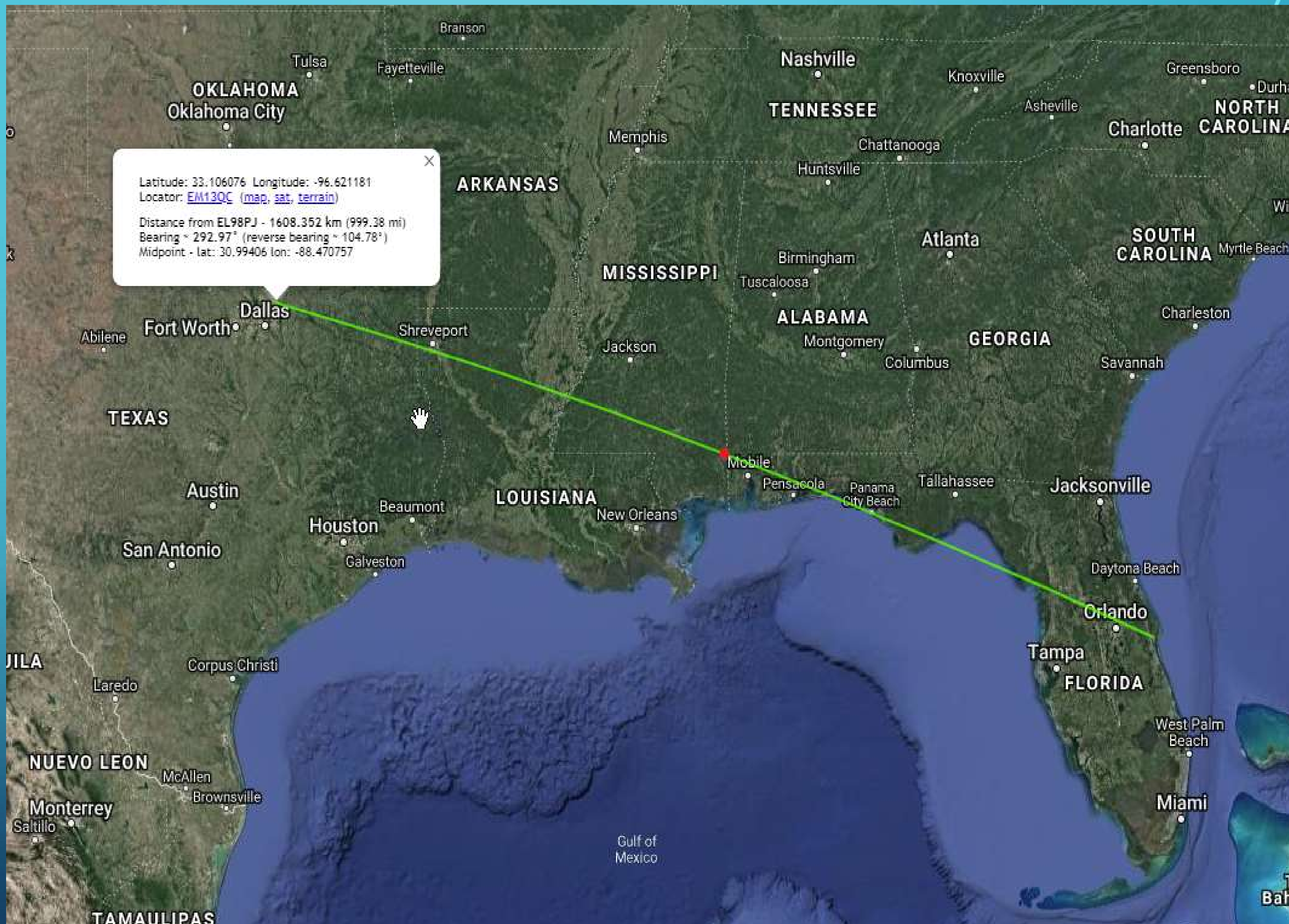


https://www.wpc.ncep.noaa.gov/dailywxmap/index_20020907.html

W5LUA – WW2R/R


IEM
NEXRAD Base Reflectivity
07 September 2002 7:15 AM CDT
Light
Intense

4 June 2012
10 GHz
W5LUA-K0VXM
1148Z



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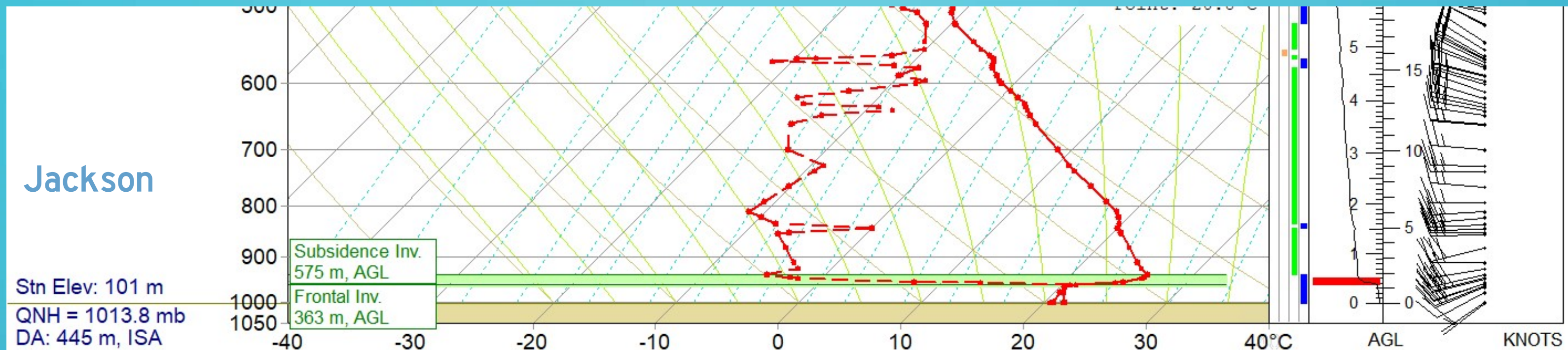

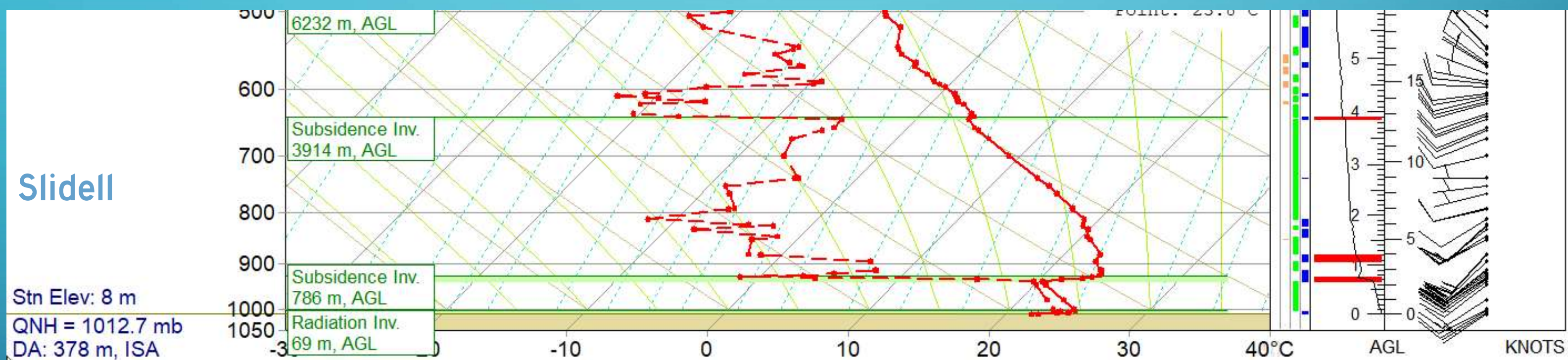

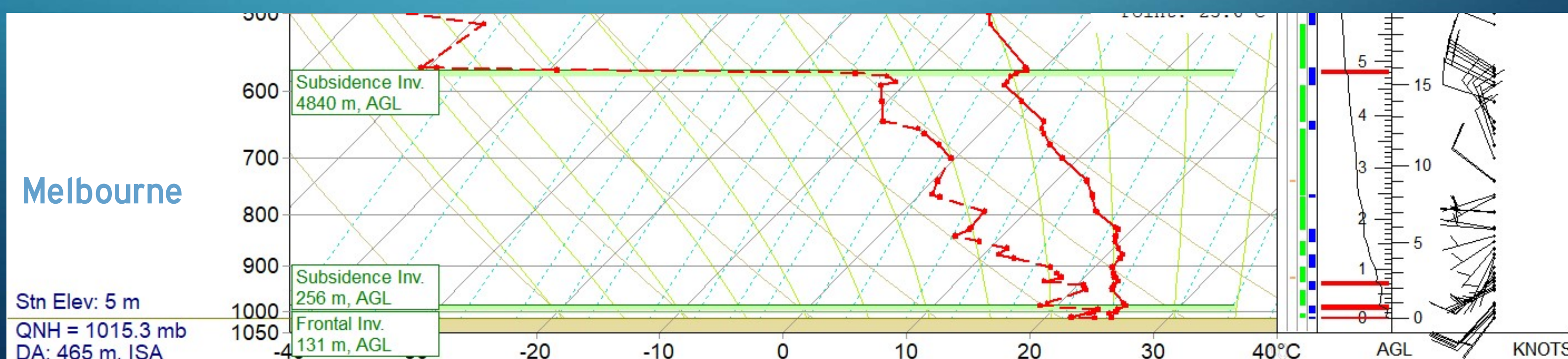

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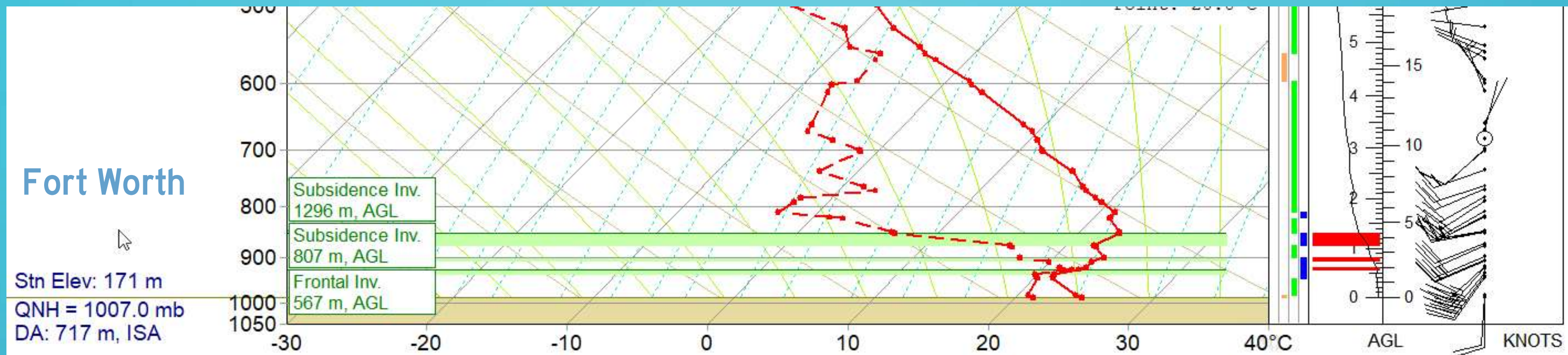

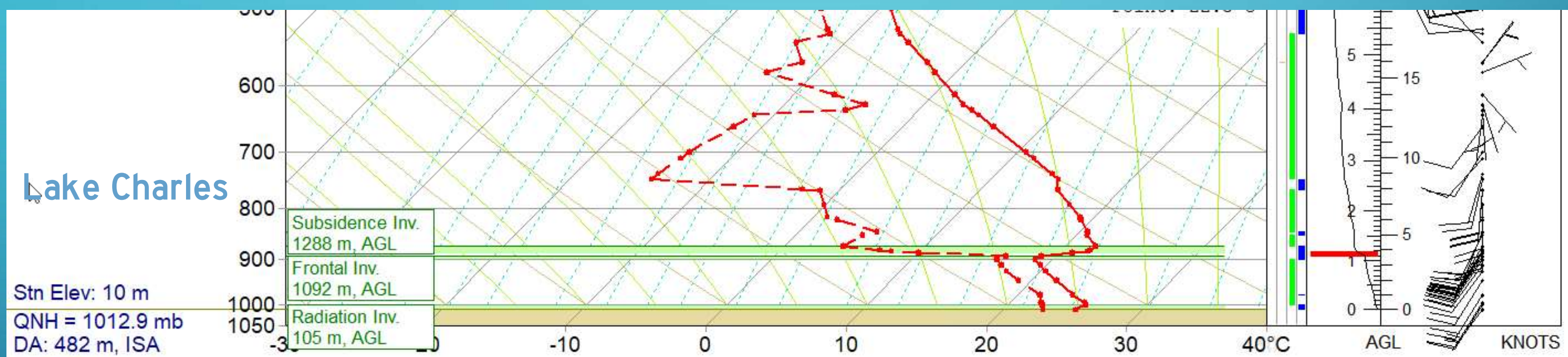

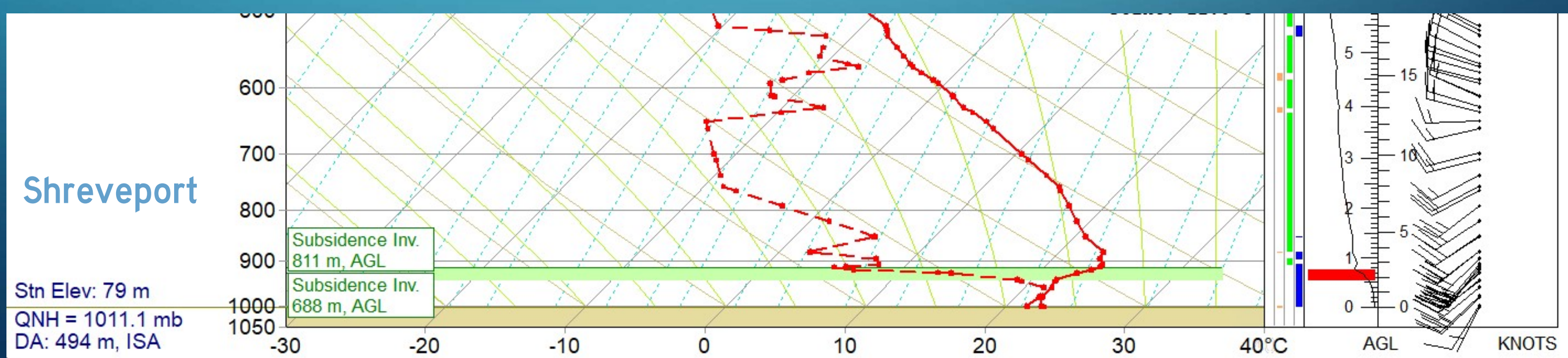

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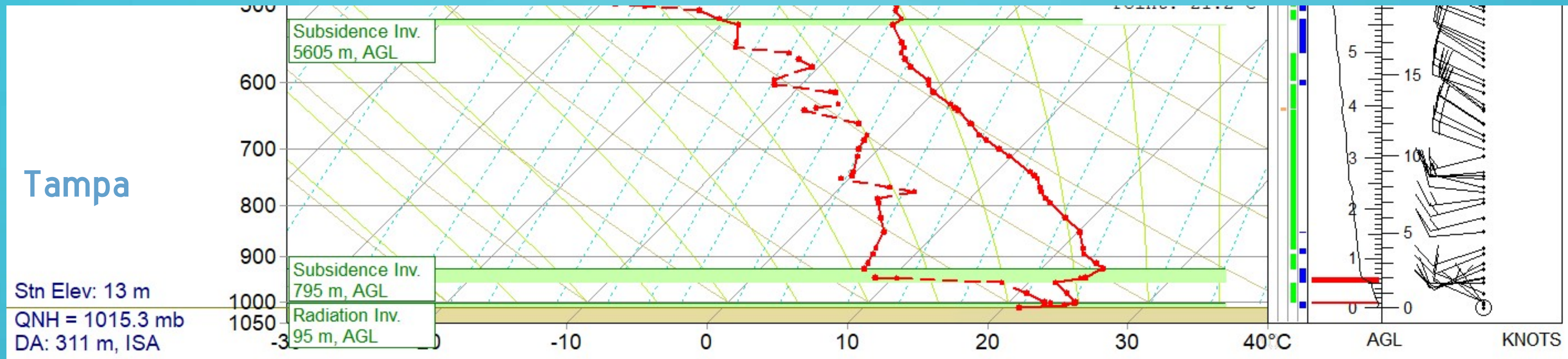

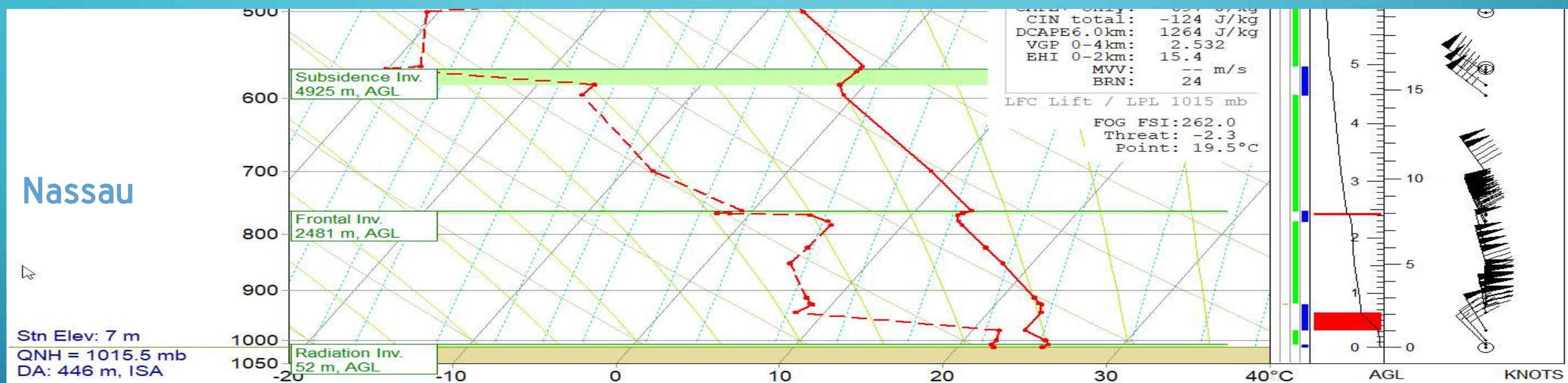

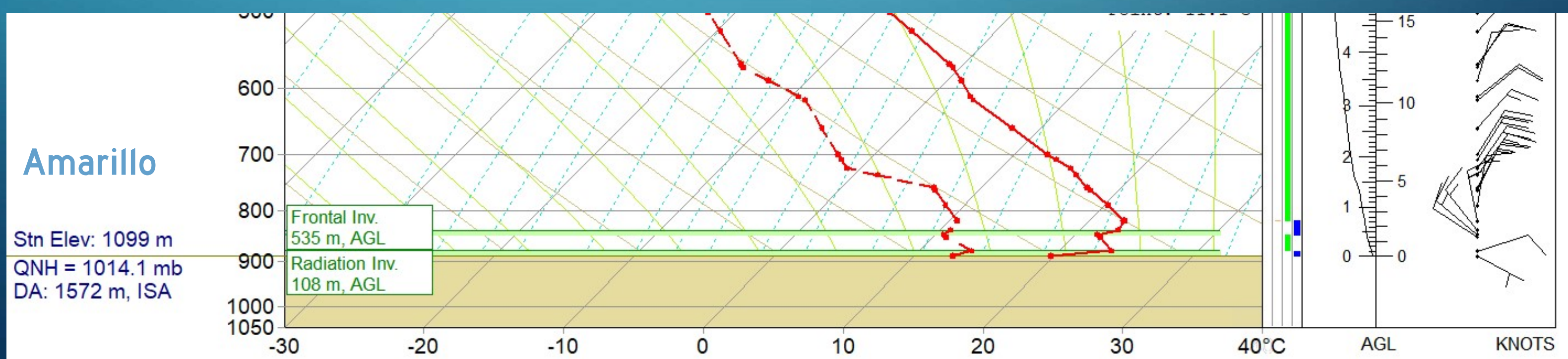

4 June 2012
10 GHz
W5LUA-K0VXM
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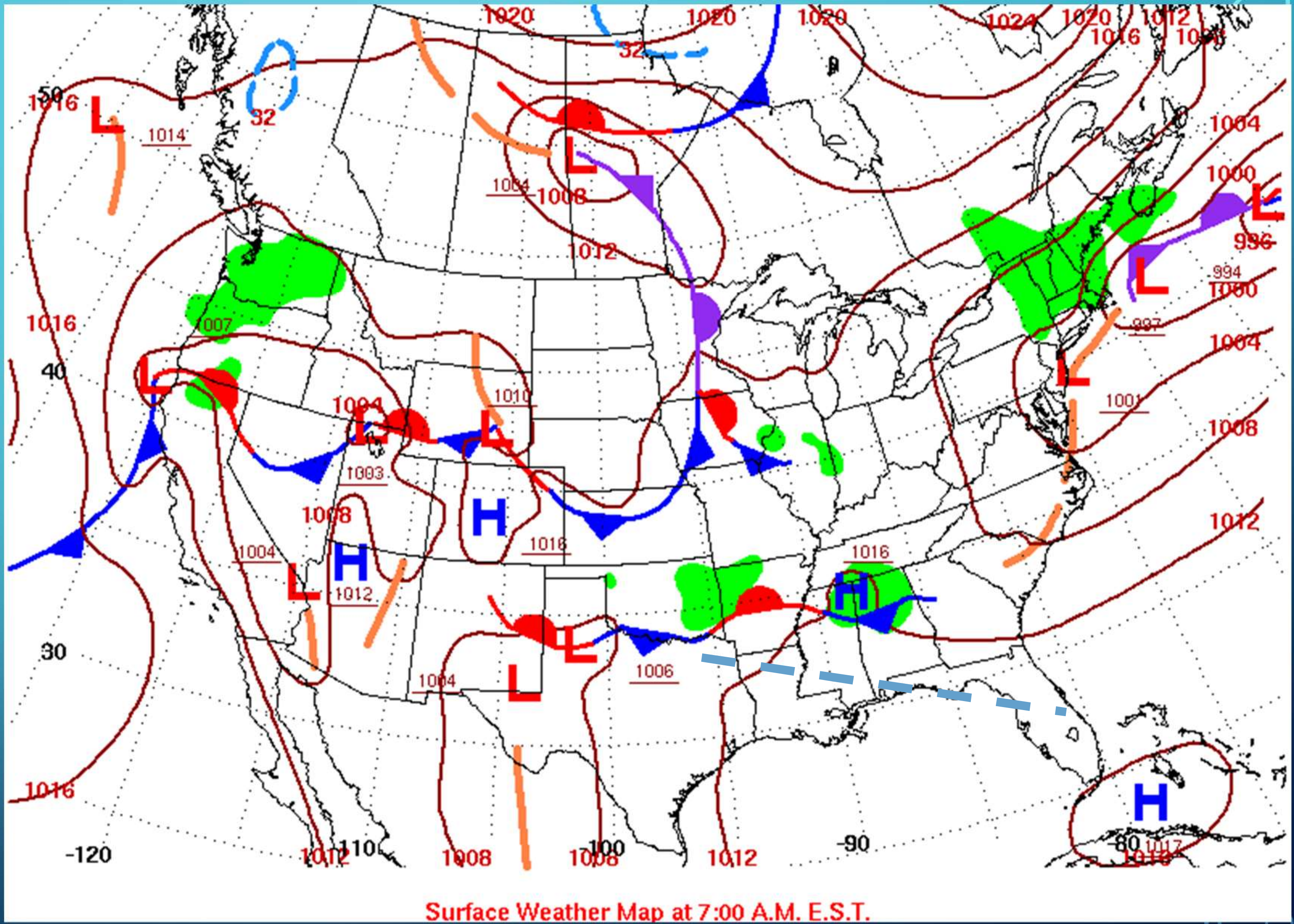

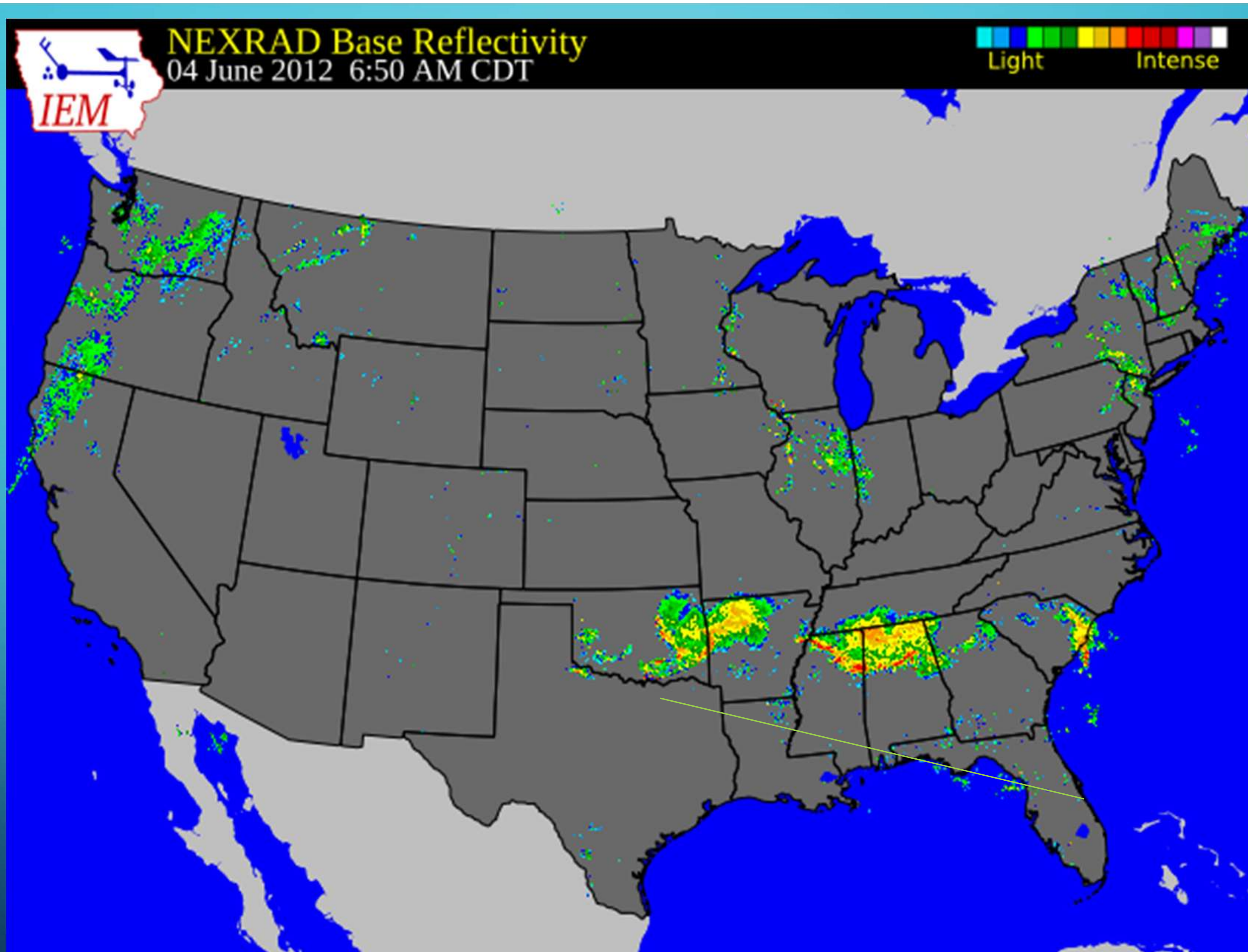
NEXRAD Base Reflectivity
04 June 2012 6:50 AM CDT
Light
Intense
IEM

PACMISTESTCENT'S THUMB RULES (MARITIME) 1/3

Factors favorable to Elevated Duct Occurrence

1. Location within SE and SW quadrants of subtropical highs (for Bermuda area, SW and NW quadrants)
2. Anticyclonic curvature of surface isobars
3. Decreasing distance to center of high
4. Increasing surface pressure (especially PS > 1015 mB)
5. T_{sfc}-T_{700} < 15°C or T_{700} = 5 to 10°C
6. Location outside active frontal zone

These are maritime rules and some variations exist for over-land paths

Ref: TP 000005

PACMISTESTCENT'S THUMB RULES (MARITIME) 2/3

Factors favorable to Elevated Duct Occurrence

7. Presence of well-defined haze-layers
8. Presence of stratus clouds (not accompanied by rain. Draizzle from stratus is acceptable) *Note: Overland amateur contacts seem to favor clear skies*
9. Extensive stratus or stratocumulus sheet observed on visual or infrared satellite imagery with granular or cellular appearance
10. Evidence of a temperature inversion
11. Weak winds aloft
12. Lack of extensive and thick mid-level cloudiness

These are maritime rules and some variations exist for over-land paths

Ref: TP 000005

PACMISTESTCENT'S THUMB RULES (MARITIME) 3/3

Factors favorable to Surface Based (Non-evaporative) Ducts

1. Warm (temperatures higher than sea surface temperature), dry offshore flow
2. Stratus or fog deck with top at 1,000' or below
3. Large hole within stratus covered areas as observed on satellite imagery, or similar stratus-surrounded clear region extending seaward from continent
4. Stars or moon dimly visible through dense surface fog
5. Very smooth, white and uniform stratus observed on visual satellite imgery (as compared with more typical granular or cellular appearance)

Additional guidance and point system available within reference document

Ref: TP 000005

SUMMARY

Many factors must align for great microwave DX

- Vertical refractivity gradient
- Appropriate duct thickness
- Very stable duct region
- Homogenous conditions across a wide area
- Generally observed with mostly clear skies on-land

WHAT TO LOOK FOR LAND BASED OPENINGS

- Strong high pressure areas generally to the east of path
- Draping Stationary front north of the desired path
- Low surface wind speeds (often < 10 mph)
- Moist surface conditions (often dewpoints > 59°F (15°C) or higher)
- Temperature inversion in soundings
- Evidence of ducting in thermal profile

SPECIAL THANKS TO…

W5LUA - Al Ward

W5ZN – Joel Harrison

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