Computer Modeling of Loran-C Additional Secondary Factors

Janet Blazyk, MS
David Diggle, PhD
Avionics Engineering Center
Ohio University, Athens, OH

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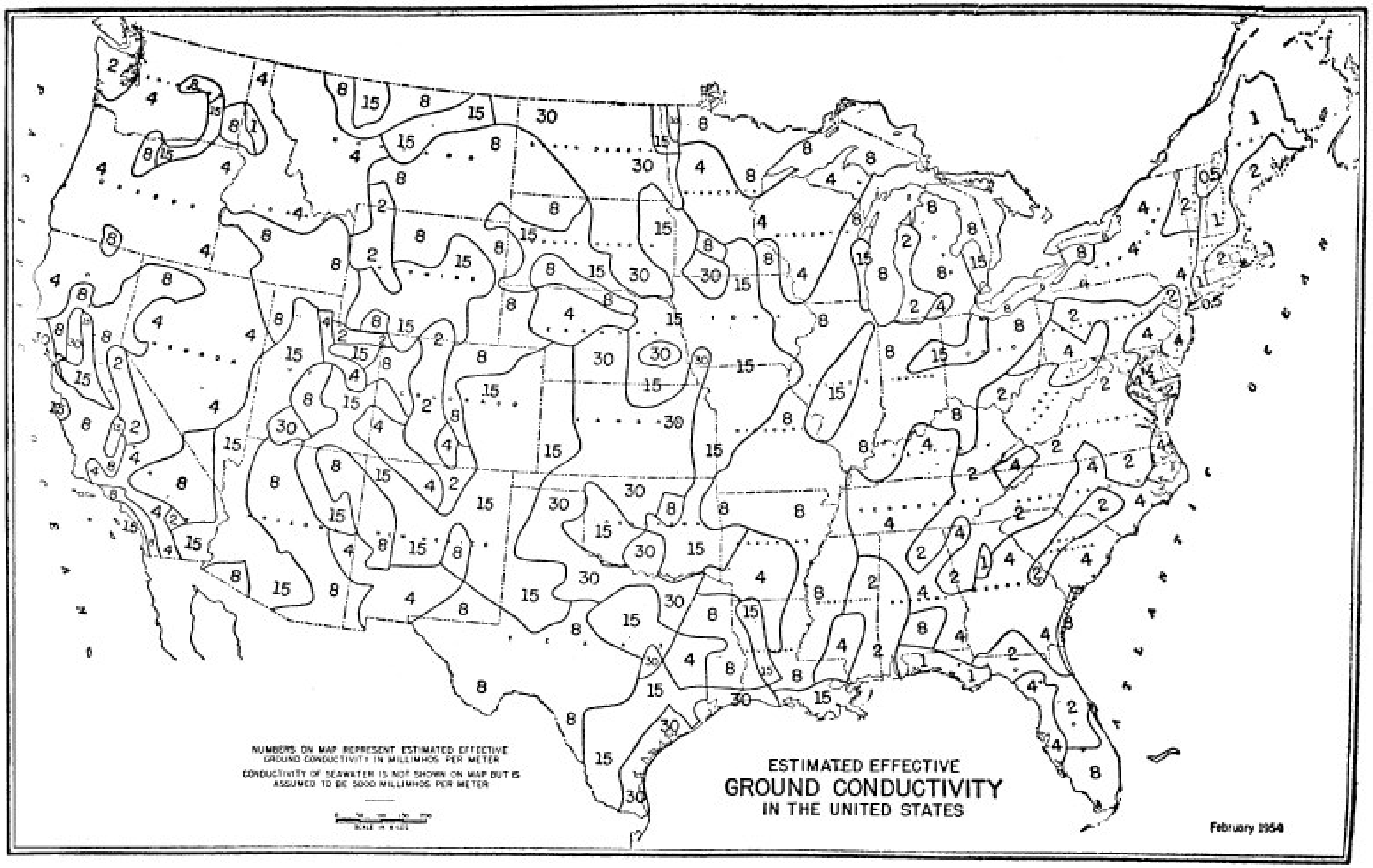
BALOR Computer Program

- Models Loran-C propagation over ground.
- Computes field strength, ASF, and ECD.
- Considers terrain elevation and ground conductivity.
- Developed by Paul Williams and David Last, University of Wales, Bangor, UK.
- The name "BALOR" comes from BAngor LORan.
- The Avionics Engineering Center at Ohio University took over maintenance of the BALOR software in March 2005.

Factors Affecting Loran-C Propagation

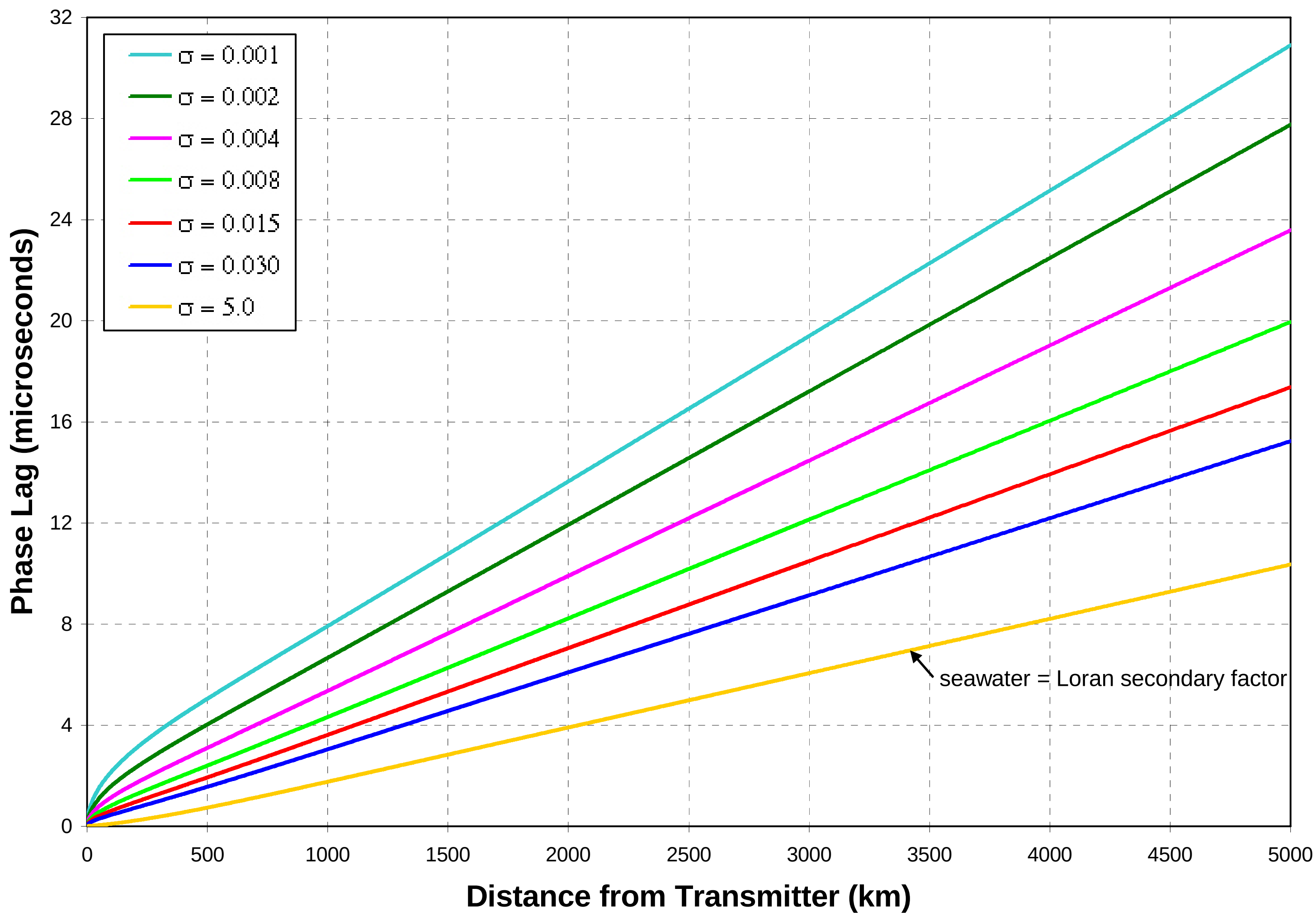
- Primary Factor (PF) – accounts for the speed of propagation through the atmosphere, rather than through a vacuum.
- Secondary Factor (SF) – accounts for the time difference for a signal traveling over a spherical seawater surface, rather than through the atmosphere.
- Additional Secondary Factor (ASF) – accounts for the time difference for a signal path that is at least partly over terrain, rather than all seawater, as well as any other factors that may come into play.
- ASFs are affected by
  - Ground conductivity
  - Changes in terrain elevation
  - Receiver elevation
  - Temporal changes (seasons, time-of-day, local weather)

US Ground Conductivity Map

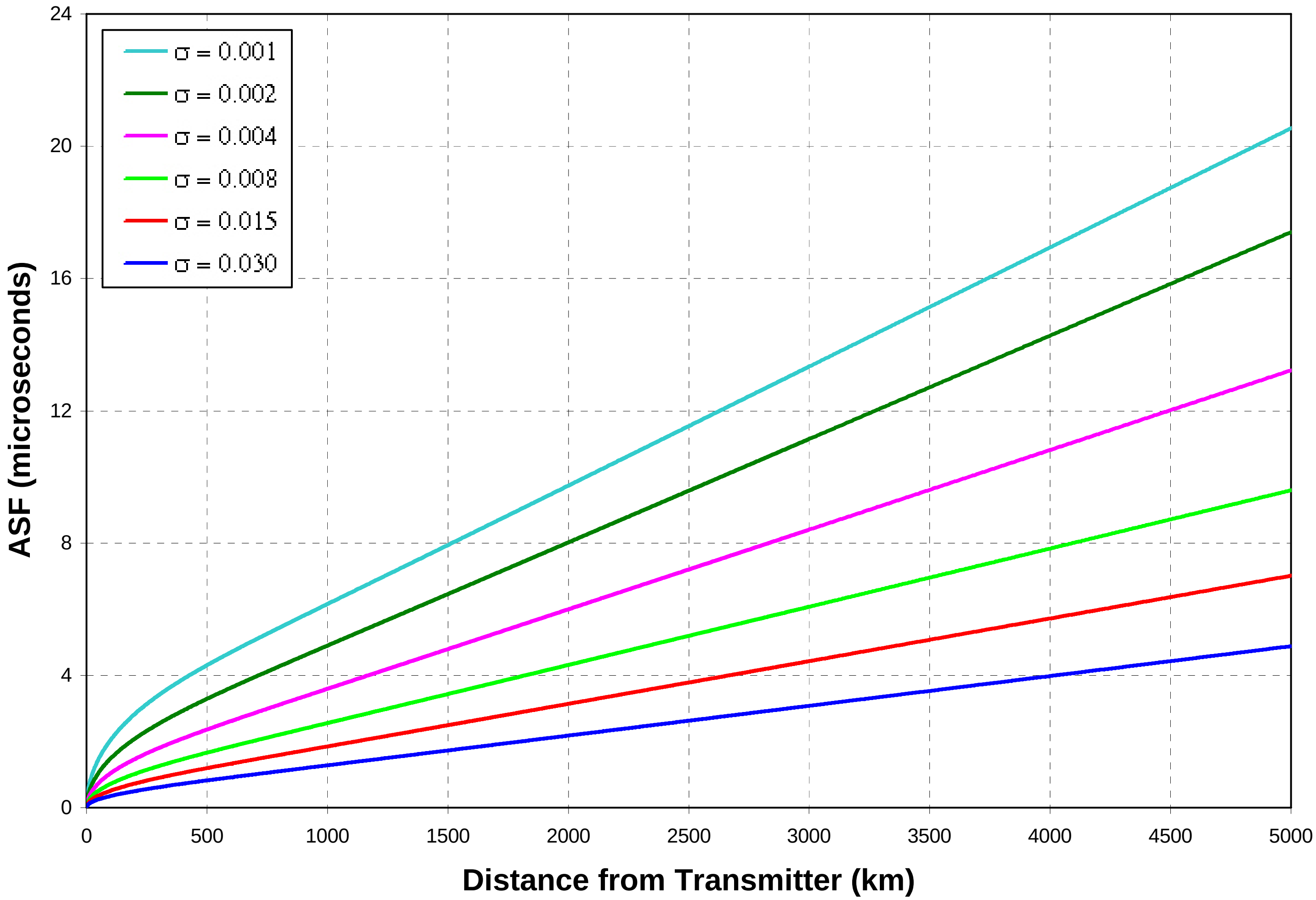


“M3 map” from CFR Radio and Television Rules (47 CFR 73.170)

Phase of attenuation in relation to conductivity

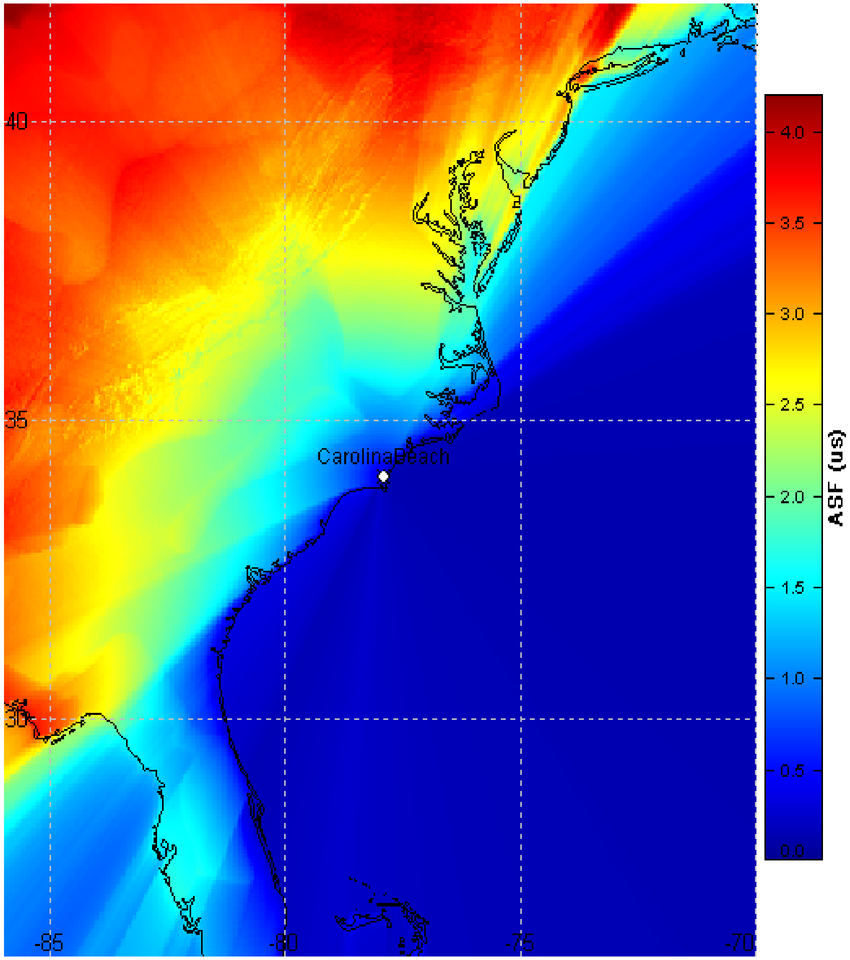


Additional secondary factor in relation to conductivity



Sample BALOR plot of predicted ASFs

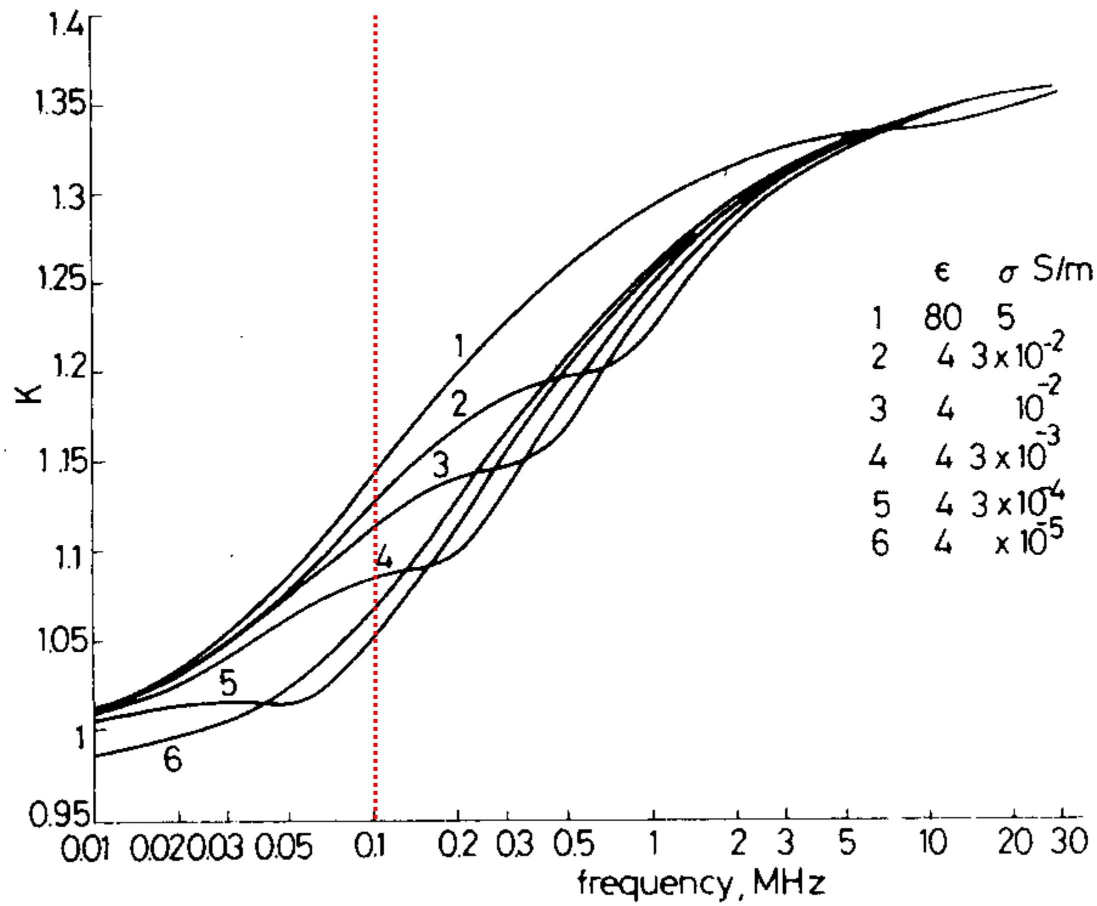
- BALOR predicts ASFs that are corrections to single-station TOA values.
- The transmitter here is Carolina Beach.
- Note how ASF values are very low over the ocean, but generally higher and more variable over land.



Effective earth radius

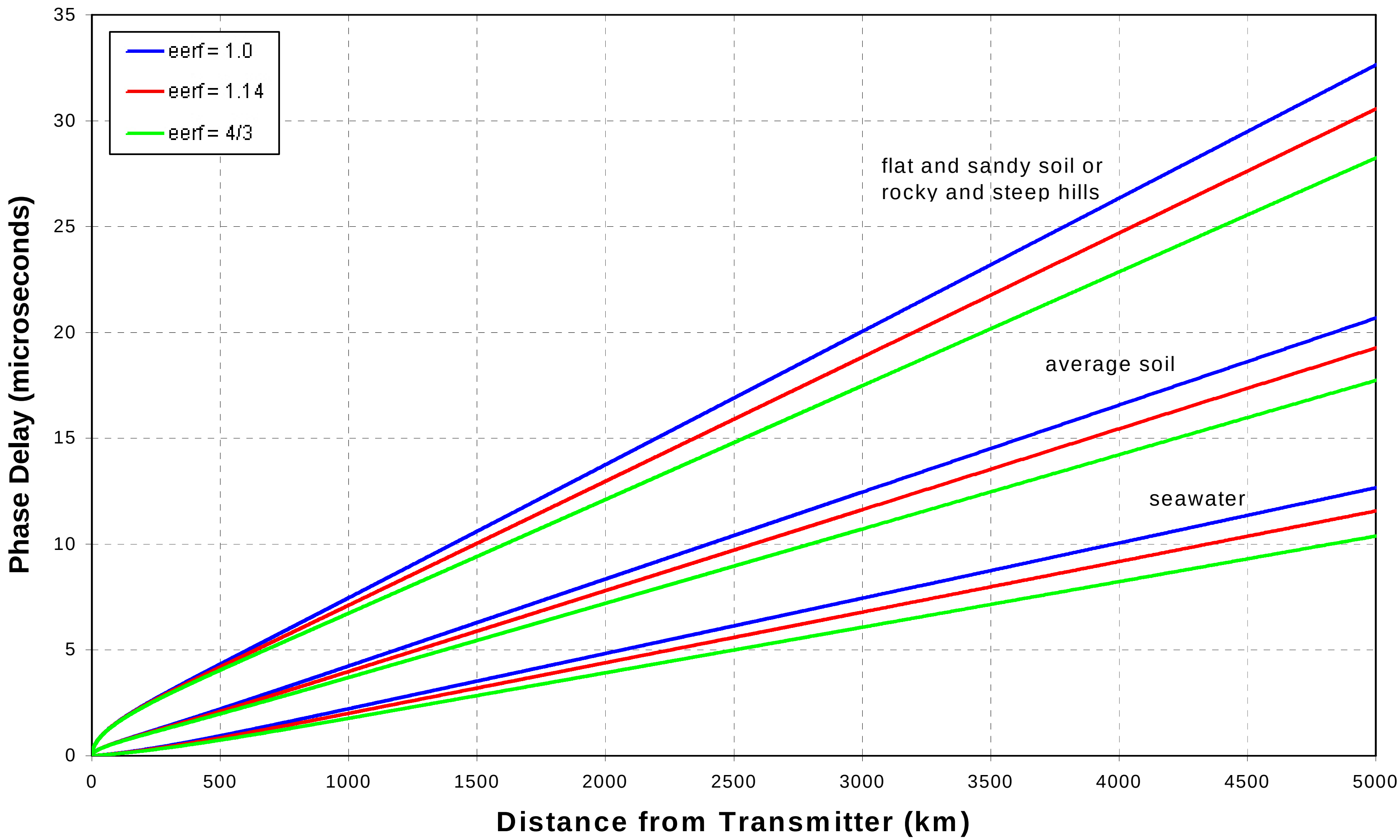
- Except at very low frequency, radio waves are refracted by the atmosphere to some extent.
- If we assume a linear vertical lapse rate, then this effect may be modeled by multiplying the actual earth radius by some factor, which we will call the effective earth radius factor (eerf).
- The traditional value for the eerf is 4/3, but the value should probably be smaller for lower frequencies such as the Loran frequency.
- (The inverse, the vertical lapse rate, is also commonly used. In this case, the traditional value is clearly 0.75.)

Effective Earth Radius Factor



From S. Rotheram, IEE Proc., Vol. 128, Pt. F, No. 5, October 1981

Effect of effective earth radius on phase delay

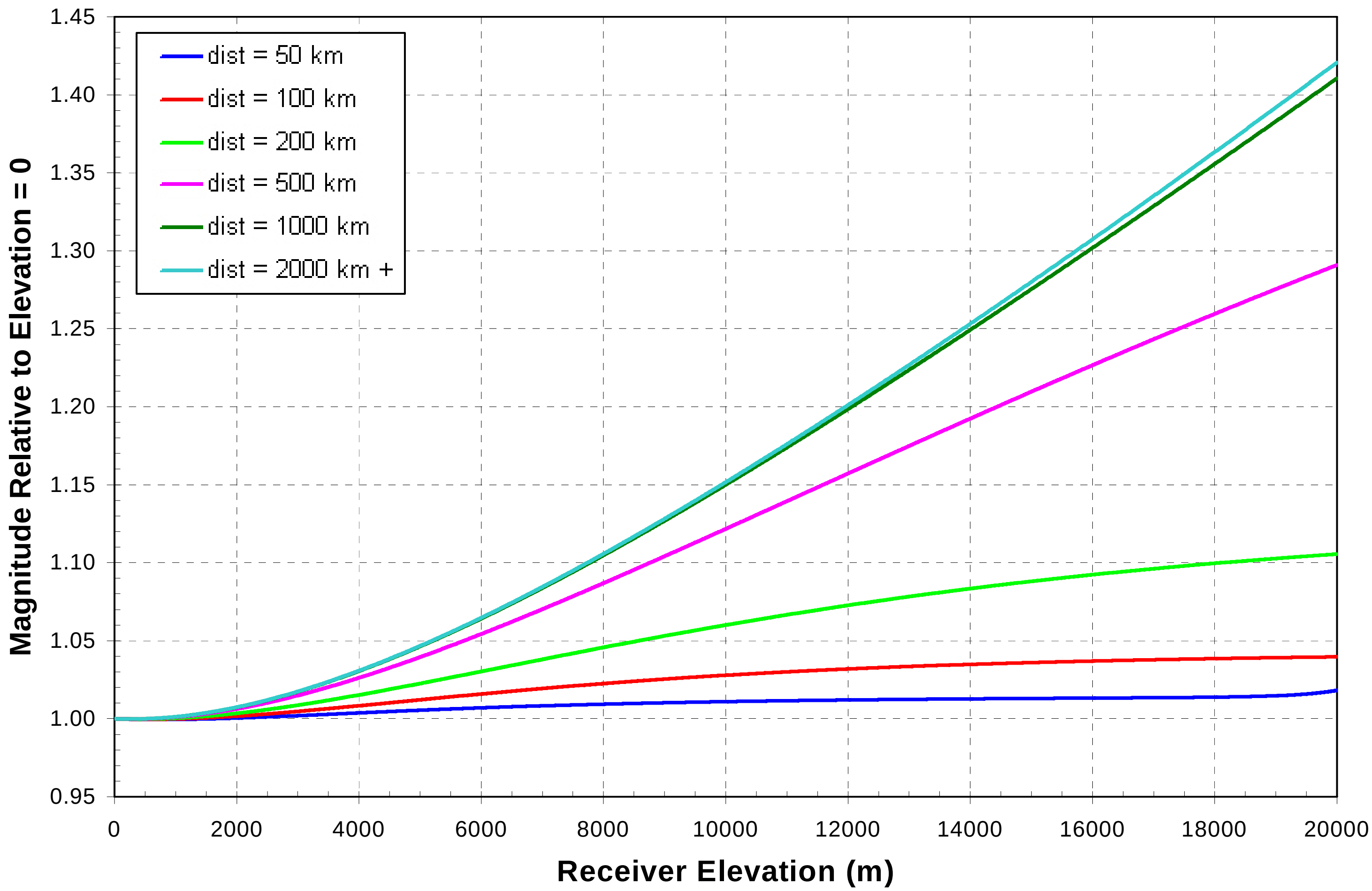


Height Gain Factor

- This factor comes into play in two ways:
  - First, it is part of the solution for irregular terrain – if a point is on a hill, it is as if it were a raised transmitter or receiver.
  - Second, if we are actually modeling an elevated receiver, say in an aircraft, then we need to apply the height gain factor again to the ground-based solution.
- The height gain factor is a complex function of height, distance, and ground conductivity.

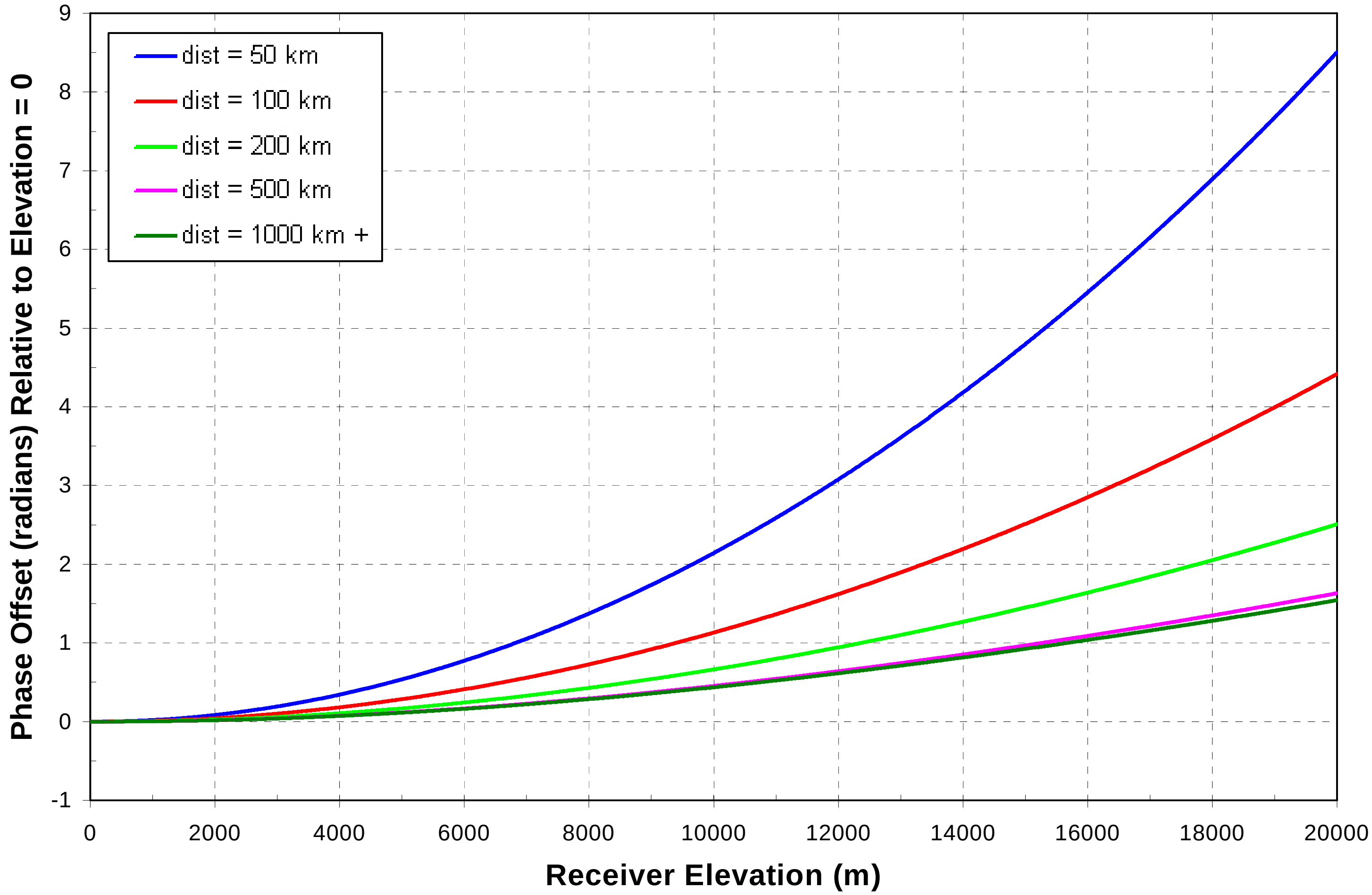
Relative magnitude of attenuation vs. receiver height

a_e=1.14a, sigma=5S/m, epsilon=80



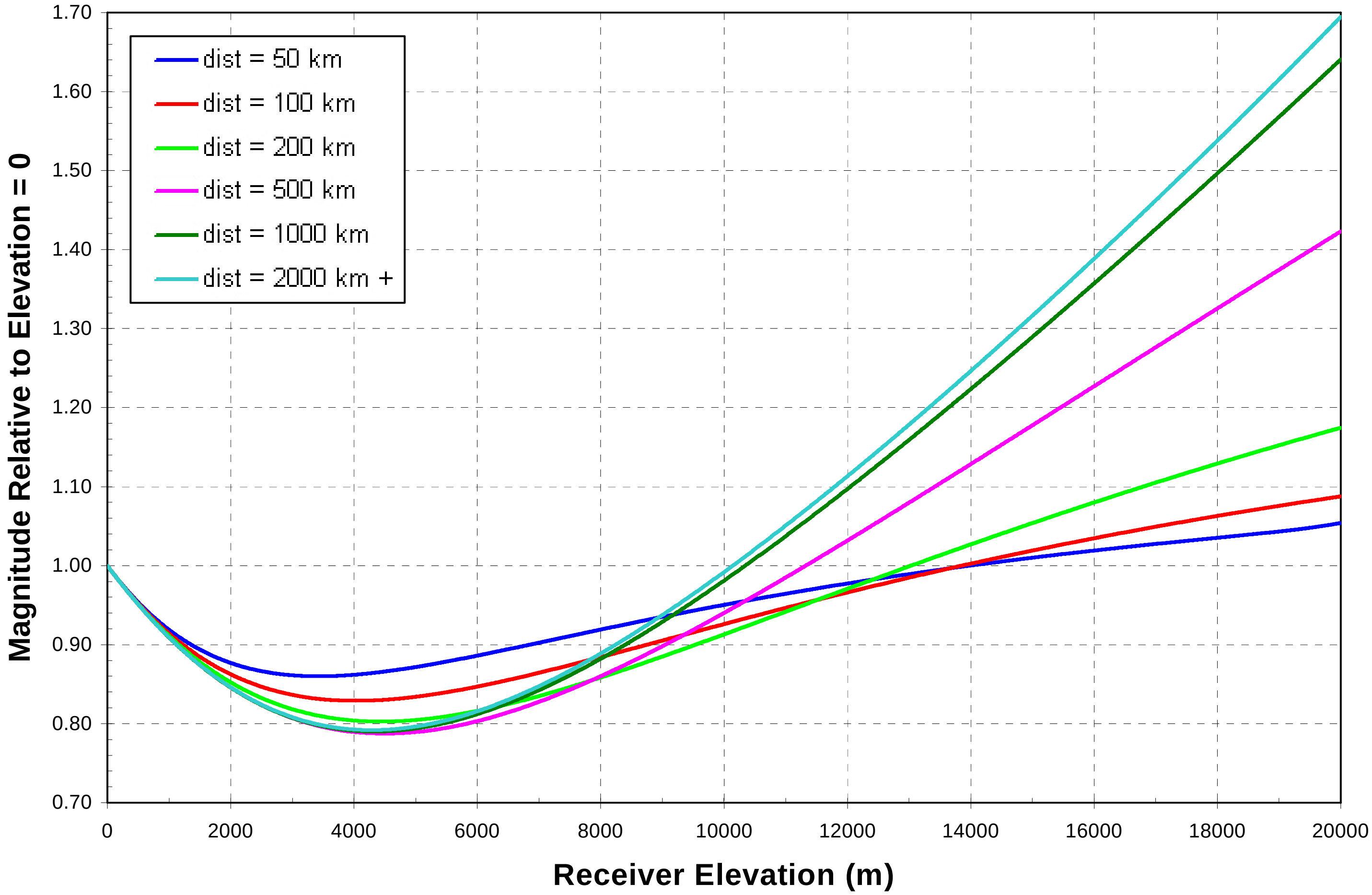
Phase offset vs. receiver height

ae=1.14a, sigma=5S/m, epsilon=80



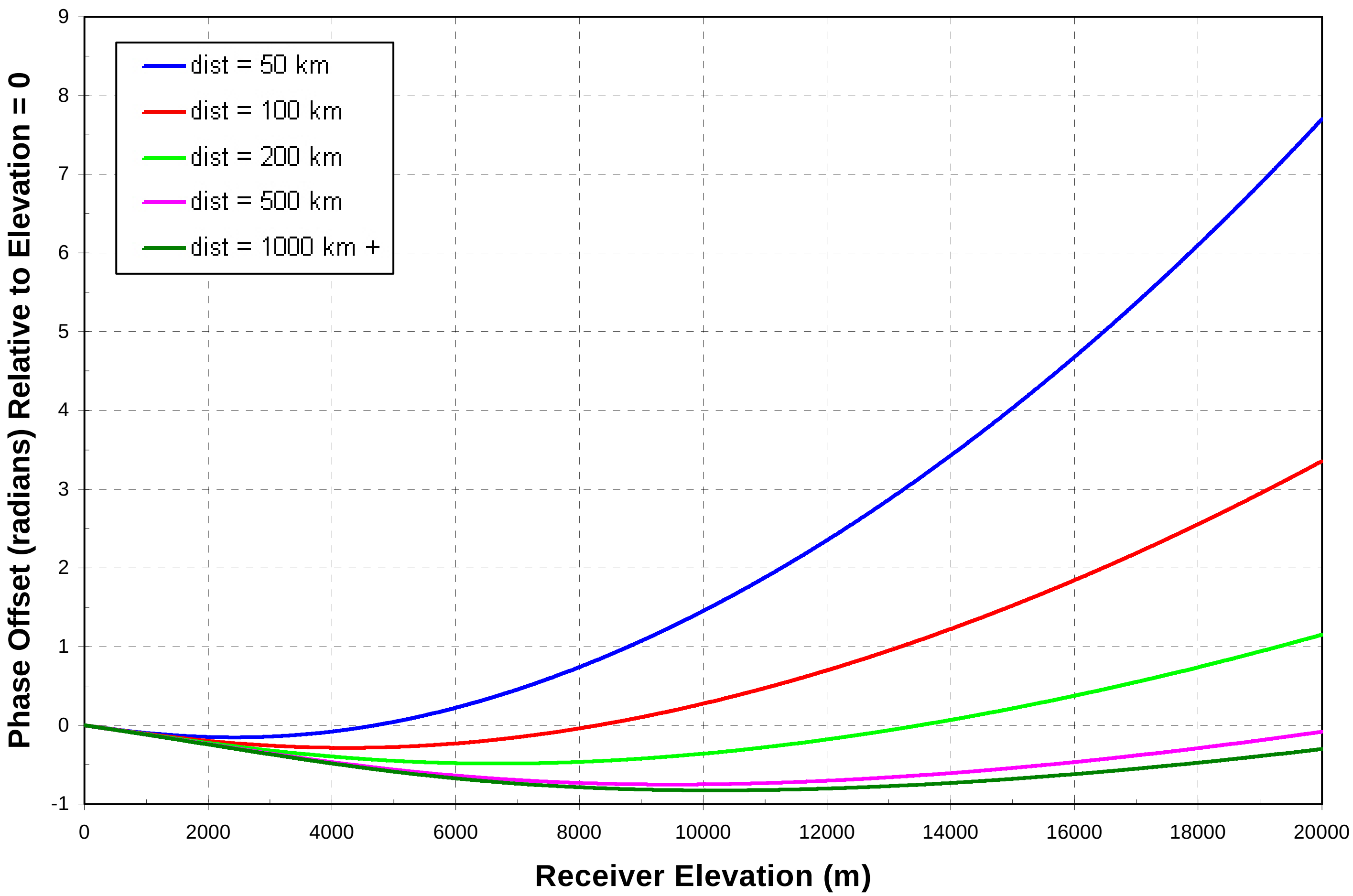
Relative magnitude of attenuation vs. receiver height

a_e=1.14a, sigma=0.001S/m, epsilon=15



Phase offset vs. receiver height

ae=1.14a, sigma=0.001S/m, epsilon=15



“Worst Case Path” Examples

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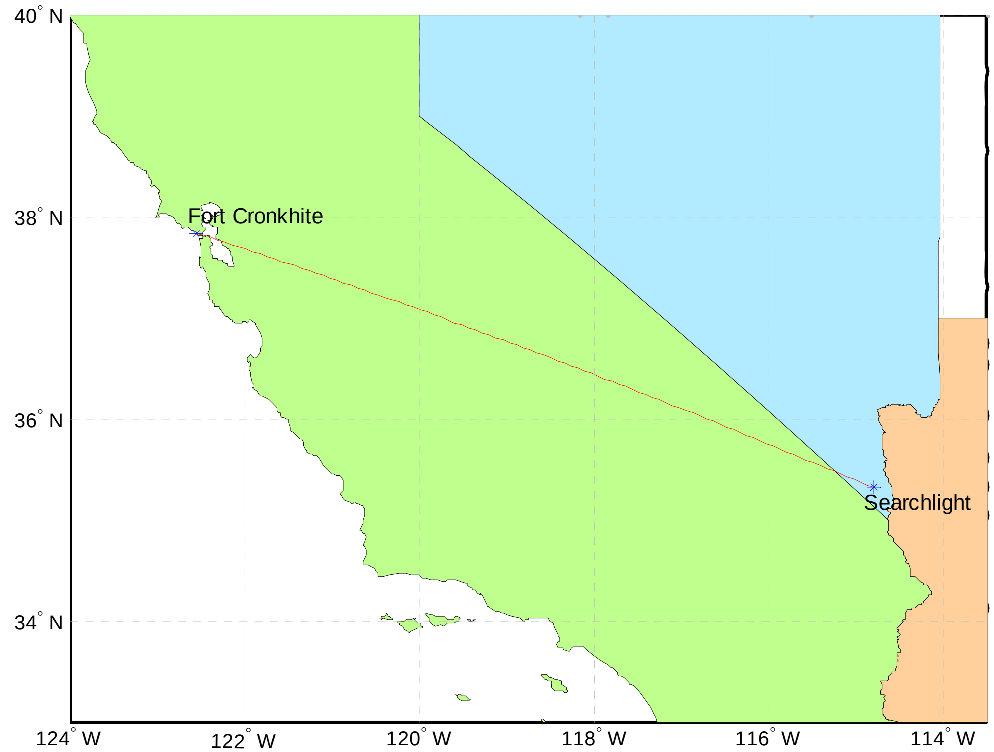
"Worst Case Path"

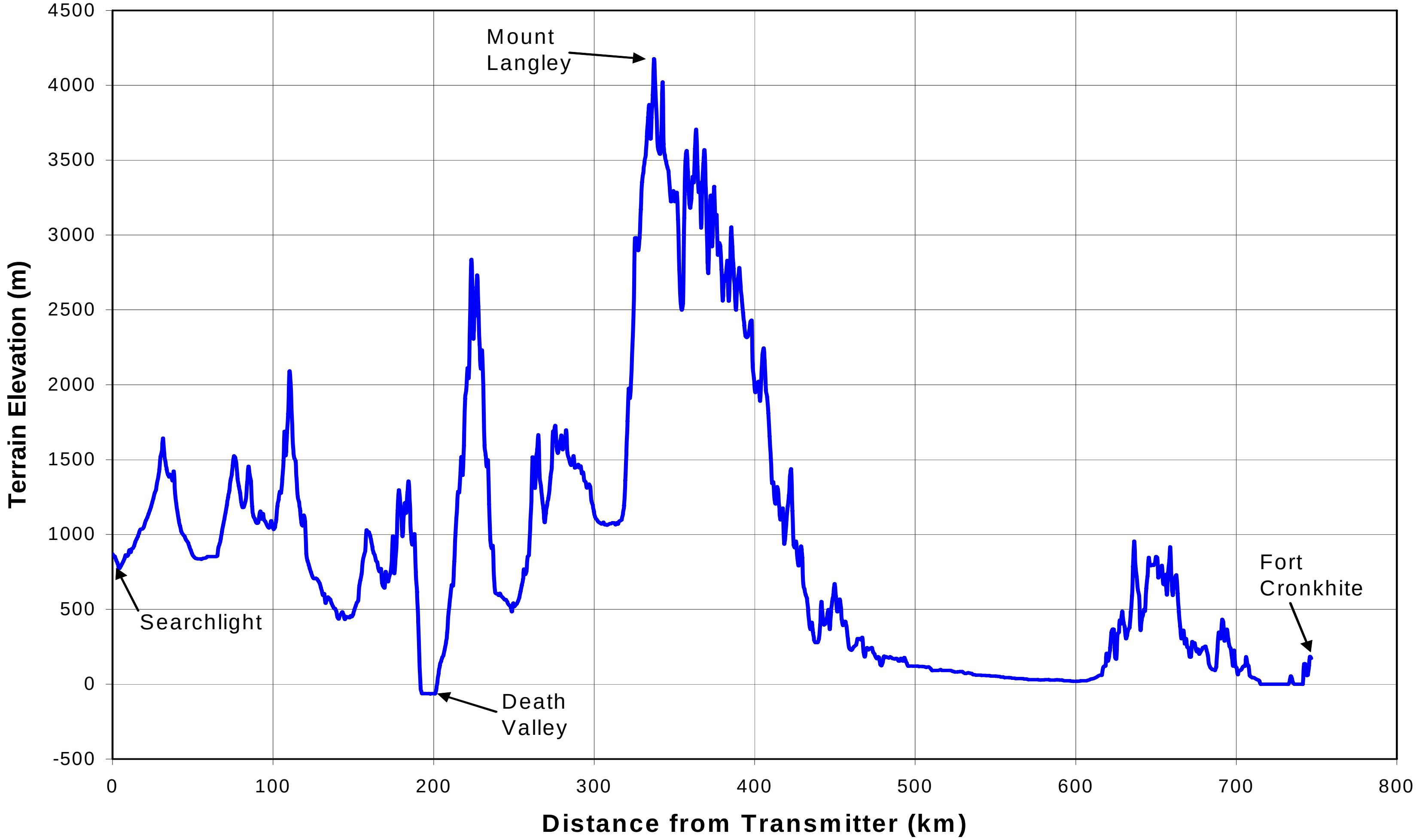
In their 1979 report, Burt Gambill and Kenneth Schwartz described a path along the radial from the Loran transmitter at Searchlight to Fort Cronkhite, near San Francisco Bay.

Because of the extremes in terrain along the path, they called it the "Worst Case Path", or WCP.

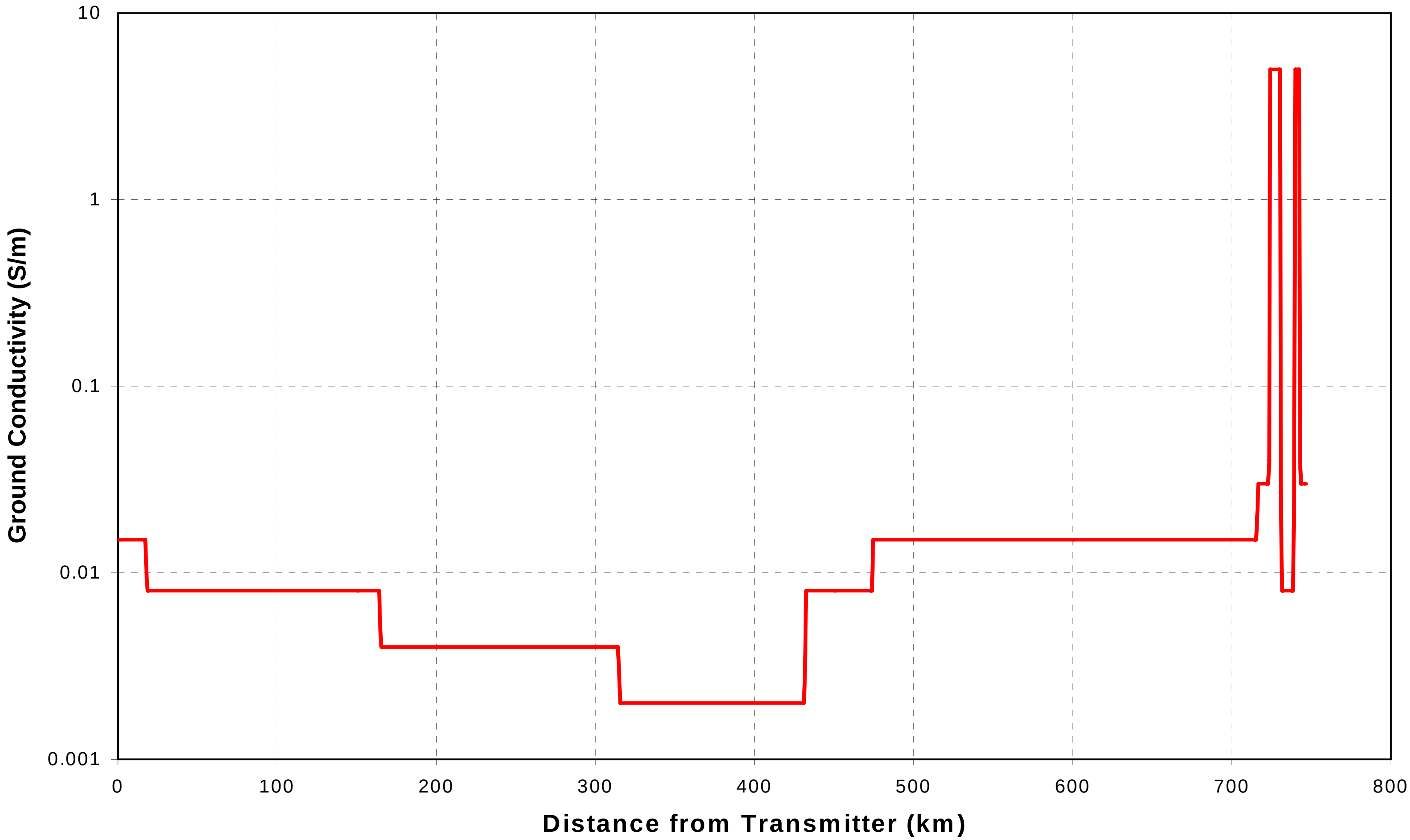
It makes a nice example, so we will make use of this path as well.



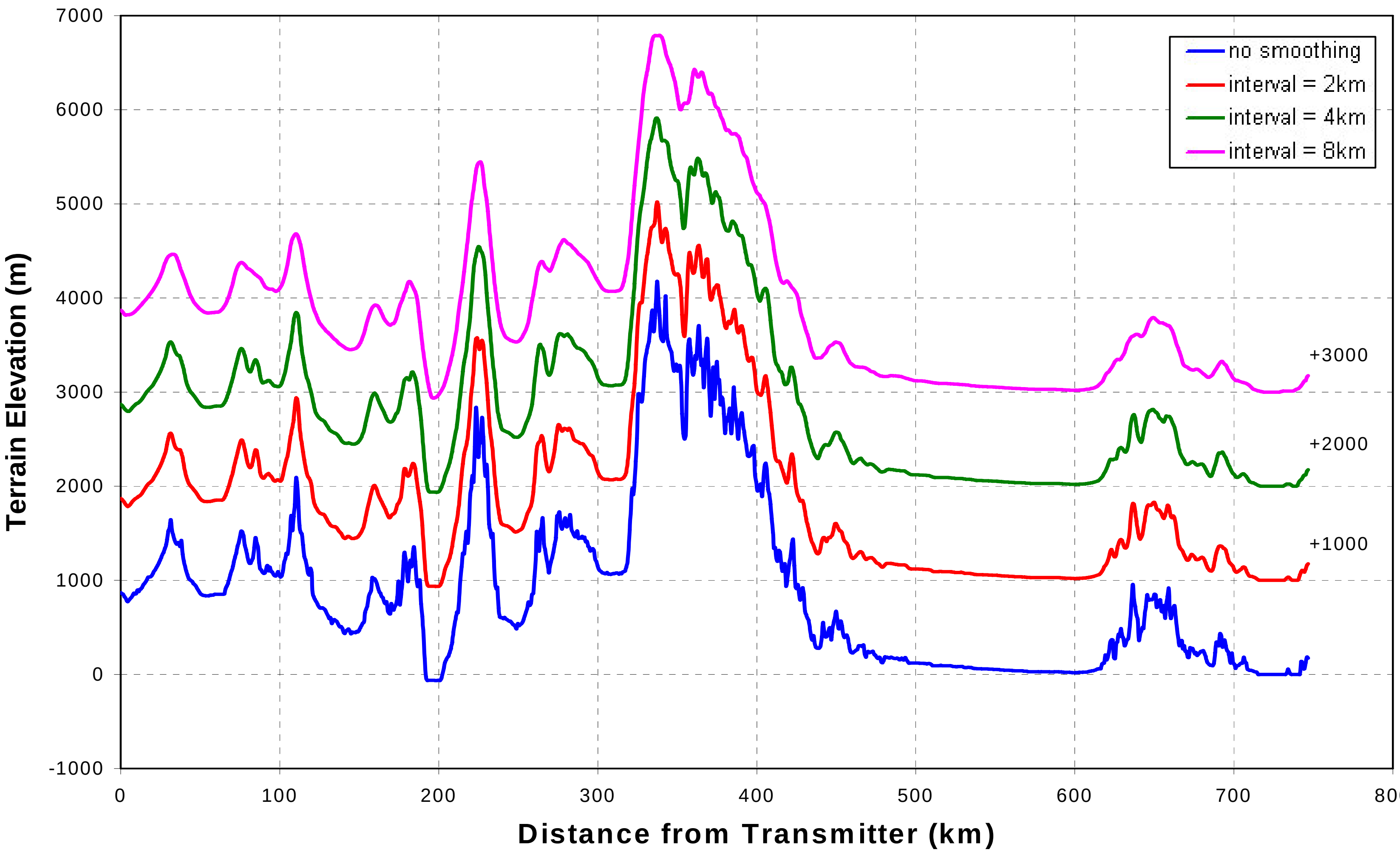
Terrain Elevation over “Worst Case Path”



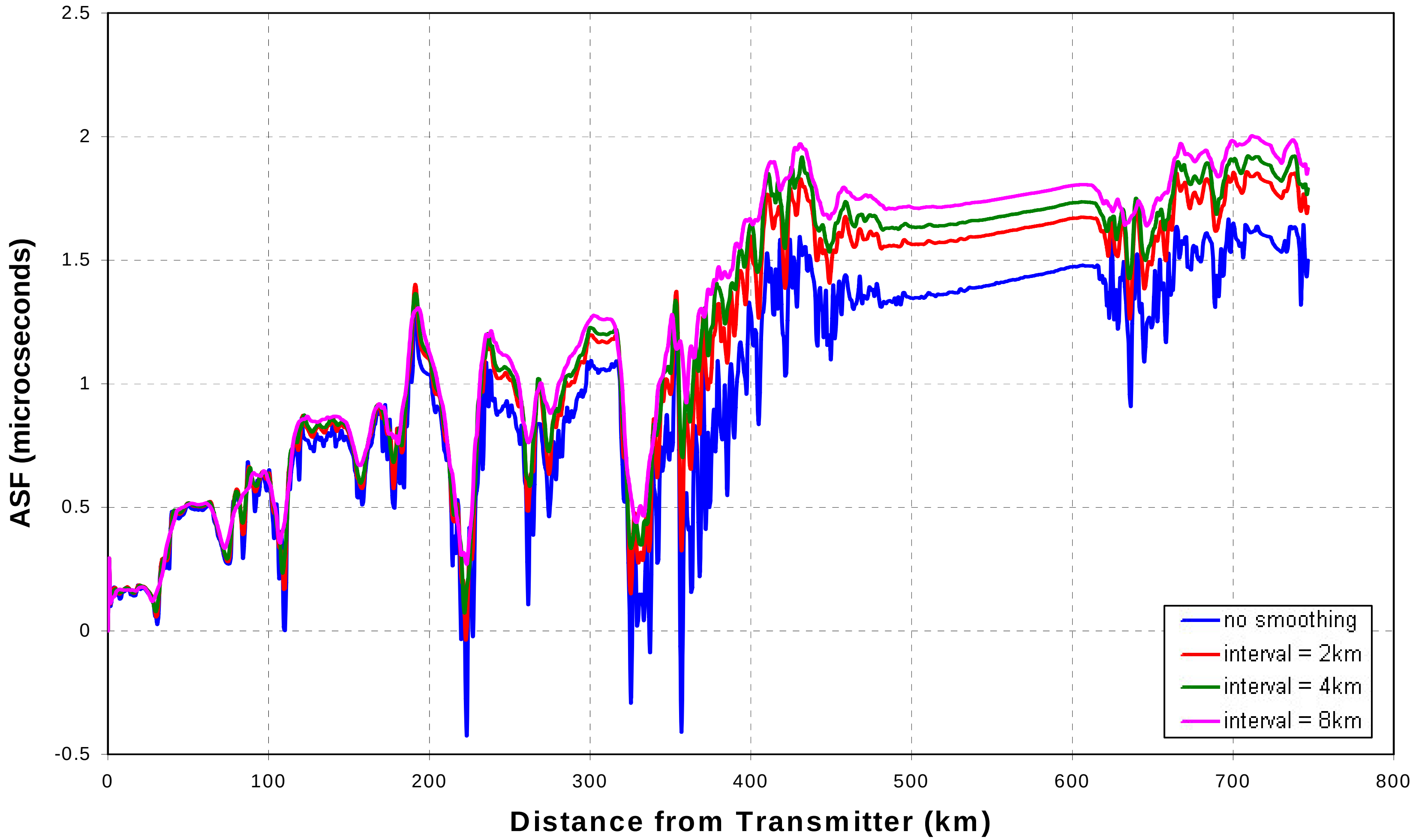
Ground Conductivity over "Worst Case Path"



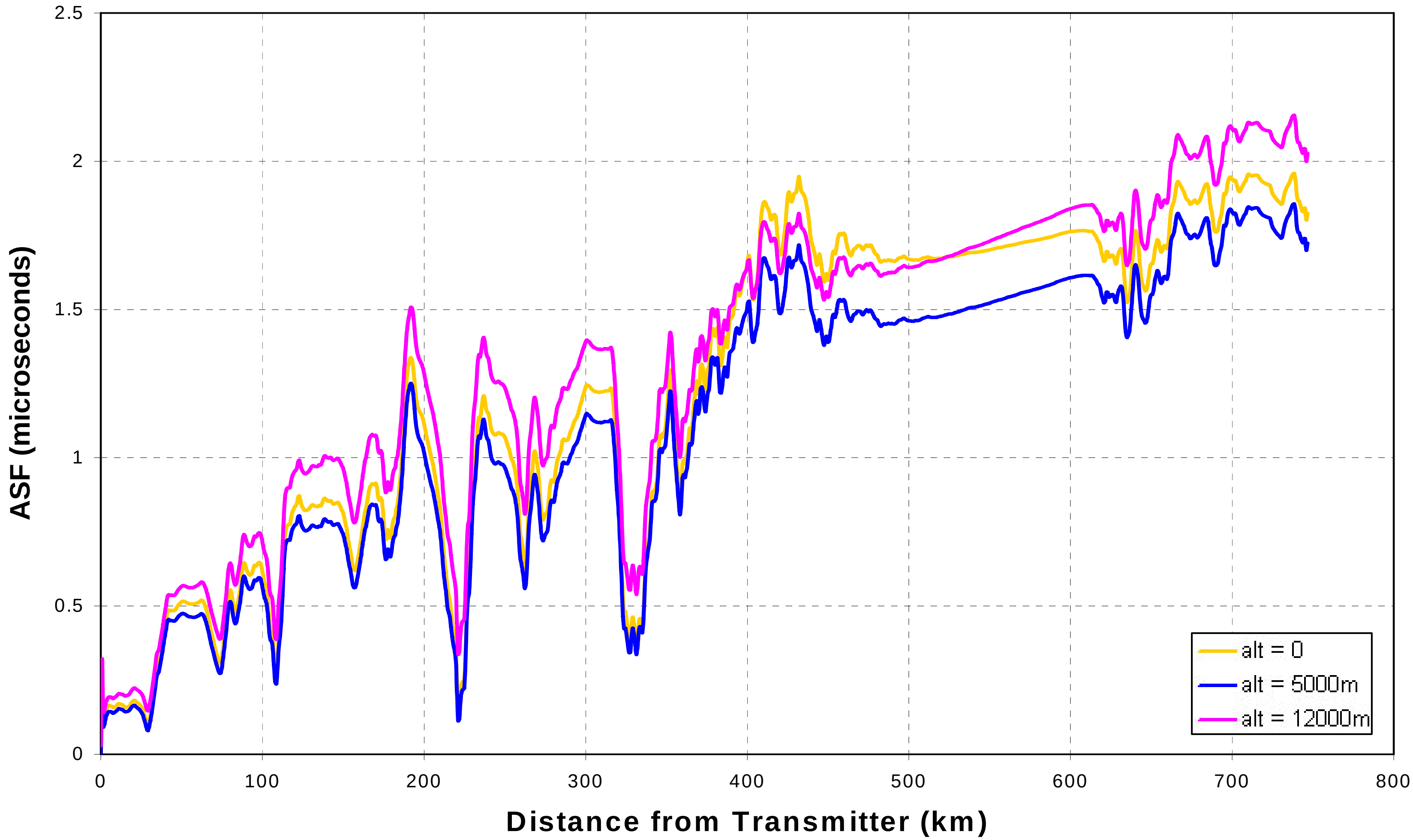
Terrain Smoothing over "Worst Case Path"



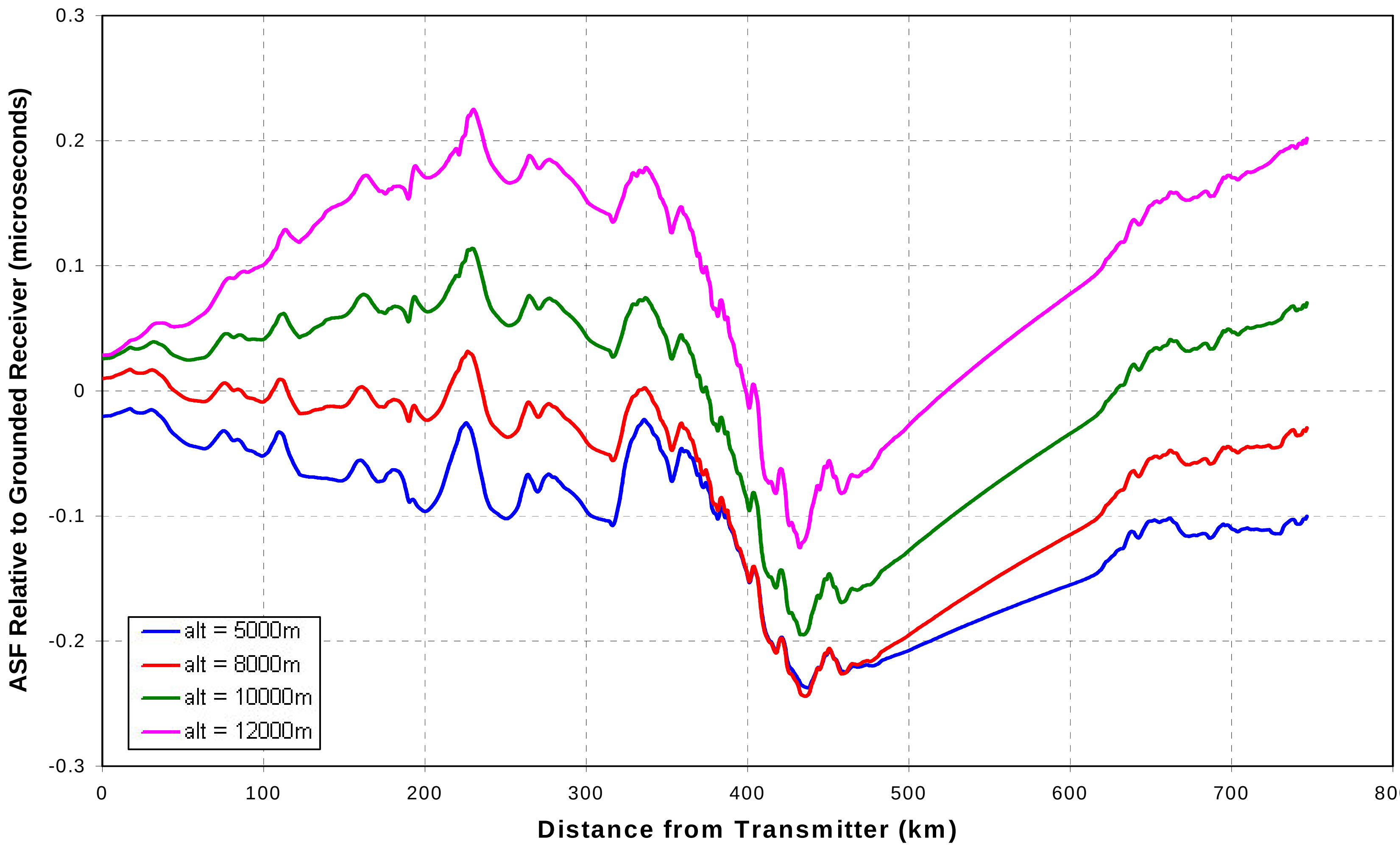
Effect of Terrain Smoothing over WCP



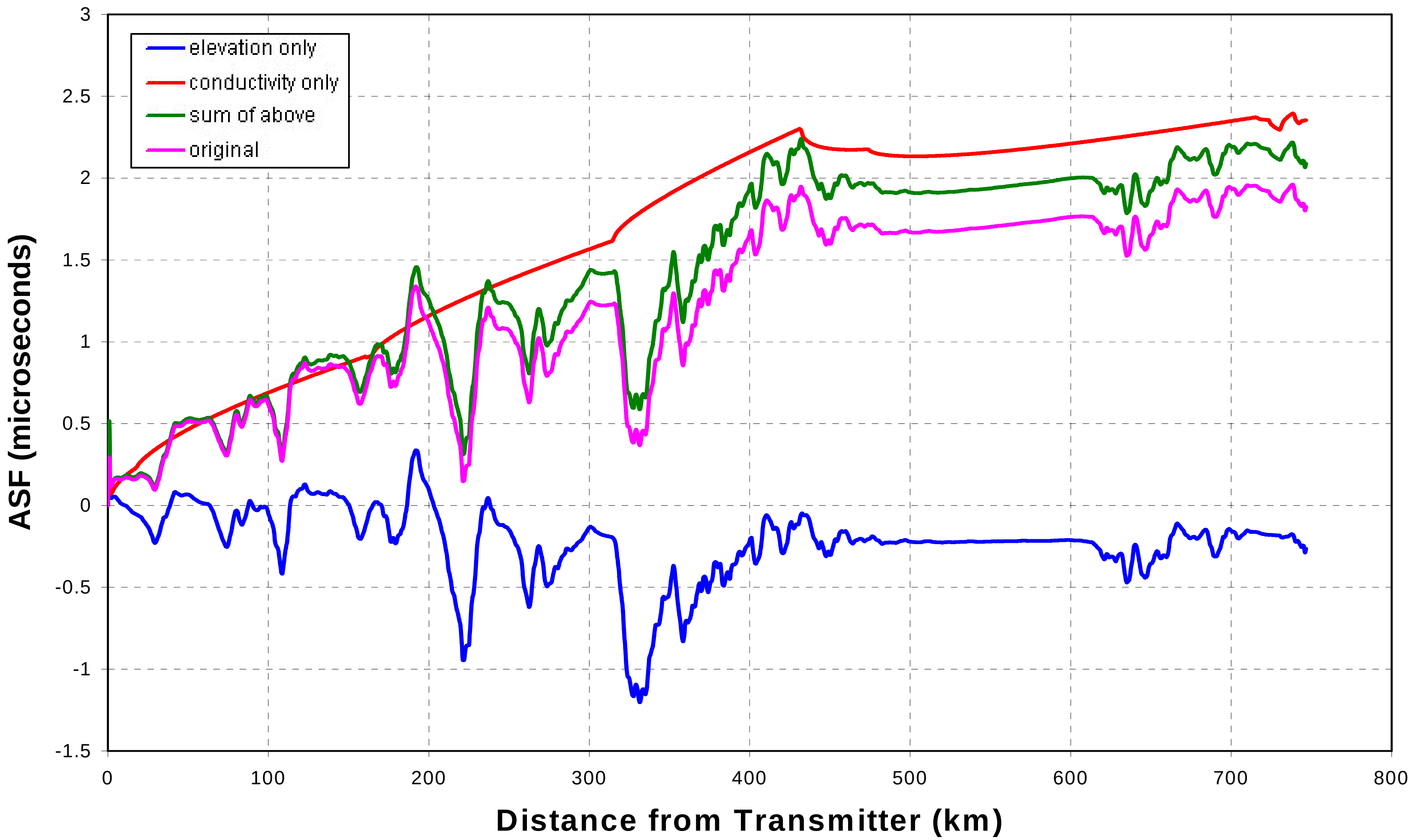
Effect of Receiver Altitude on ASFs over WCP



Effect of Receiver Altitude on ASFs over WCP



Terrain Contributions to ASFs over WCP



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Reality Checks

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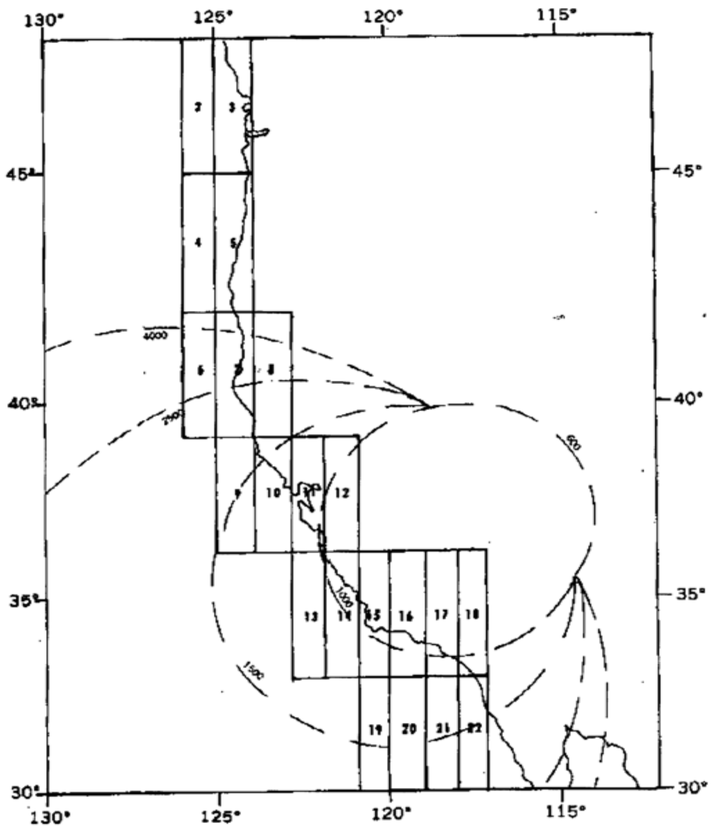
Loran-C Correction Tables

- Published by NOAA
- Show ASF corrections to TD values for master-secondary pairs
- Cover US coastal confluence zones
- Data represents the results of a computer program, adjusted to fit measured data

Sample Loran-C correction table data

1Y

PAGE INDEX FOR SECONDARY PHASE CORRECTIONS FOR 9940-Y



Corrections on each page cover an area three degrees in latitude and one degree in longitude and are in increments of five minutes of arc. Dashed lines show hyperbolic lane expansion in feet per microsecond.

9940-Y 13Y

LATITUDE NORTH	123° 0'	55	50	45	40	35	30	25	20	15	10	5	122° 0'
36° 0'	-0.3	-0.3	-0.3	-0.2	-0.2	-0.3	-0.3	-0.2	-0.1	-0.0	0.0	0.0	0.1
55	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.1	0.0	0.0	0.1	0.1	0.1
50	-0.2	-0.2	-0.1	-0.2	-0.2	-0.1	-0.1	0.1	0.1	0.1	0.1	0.2	0.2
45	-0.2	-0.2	-4.8	-0.2	-0.1	-0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
40	-0.1	-0.1	-0.1	-0.1	-0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
35	-0.2	-0.1	-0.0	-0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
30	-0.1	-0.0	0.0	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
25	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4
20	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.4
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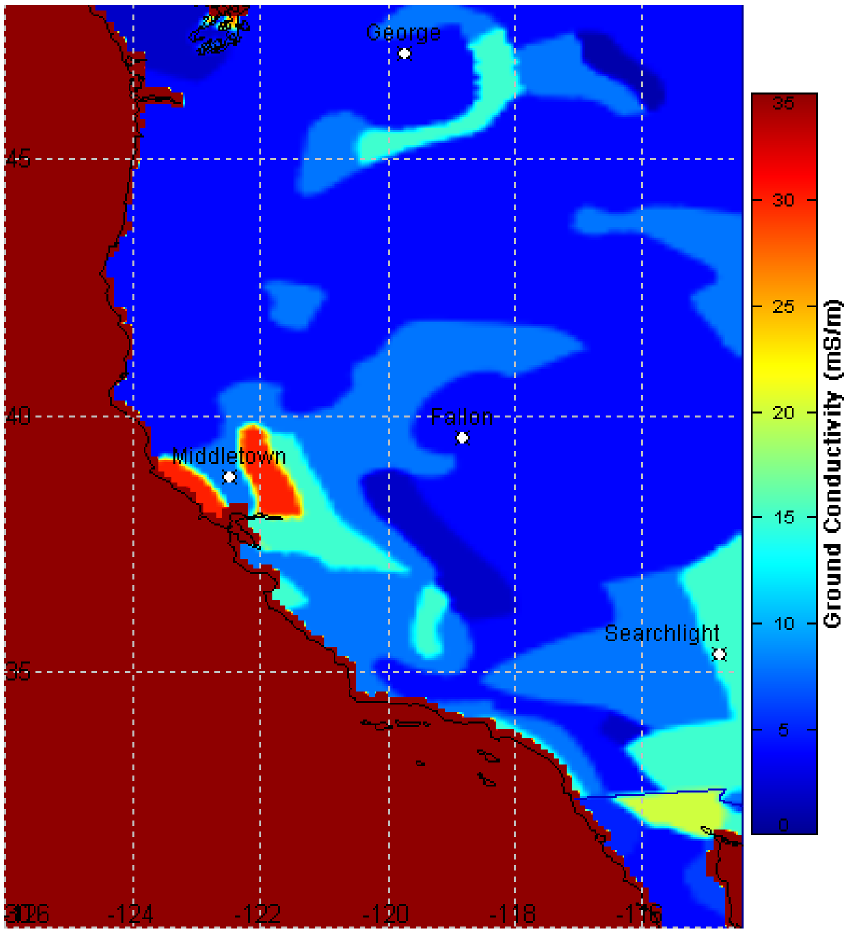
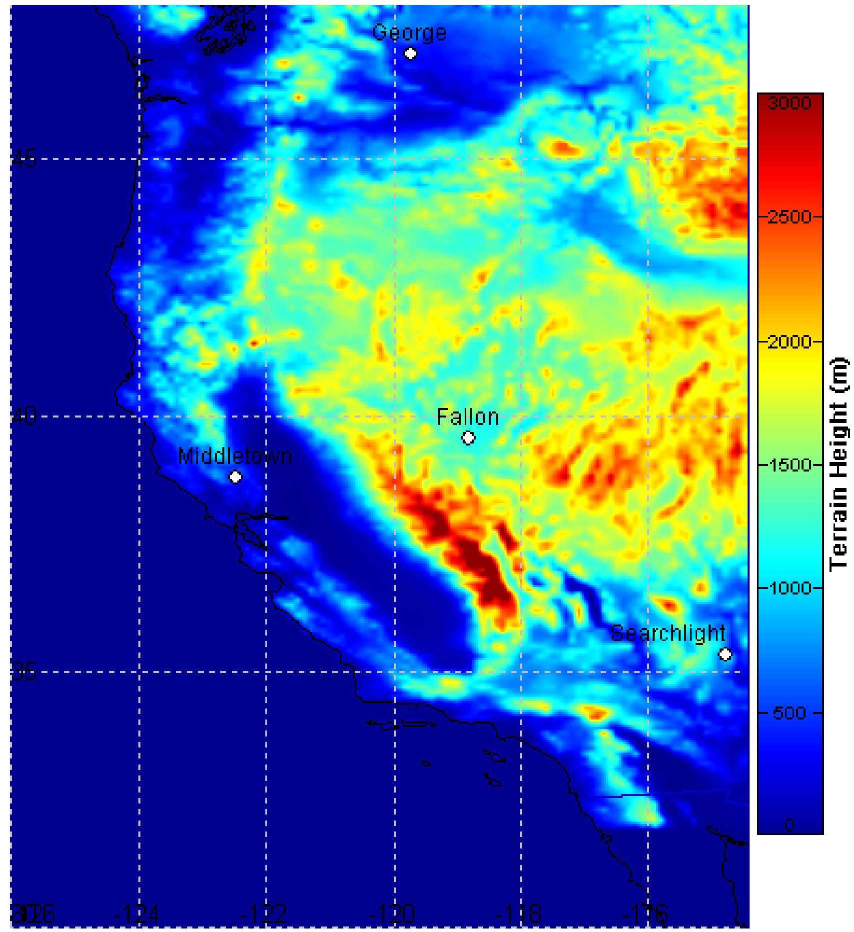
10	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3
5	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.4
35° 0'	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.3
55	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.3
50	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.4	0.4	0.3	0.3
45	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.3	0.2	0.2
40	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.3	0.3	0.3
35	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.3	0.4	0.3	0.3
30	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.4	0.3	0.2	0.2	0.4
25	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.2	0.2	0.2	0.4
20	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.3
15	0.4	0.4	0.5	0.5	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.4	0.3
10	0.4	0.4	0.5	0.4	0.4	0.4	0.3	0.3	0.2	0.3	0.4	0.3	0.3
5	0.5	0.5	0.5	0.4	0.4	0.3	0.3	0.2	0.3	0.5	0.5	0.4	0.4
34° 0'	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.5	0.5	0.5
55	0.6	0.5	0.6	0.6	0.4	0.5	0.4	0.5	0.6	0.6	0.5	0.5	0.5
50	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.5	0.7	0.6	0.6	0.6	0.7
45	0.6	0.6	0.5	0.5	0.5	0.5	0.6	0.8	0.8	0.7	0.7	0.7	0.7
40	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.8	0.7	0.7	0.6	0.6	0.7
35	0.8	0.6	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.7	0.6	0.6	0.6
30	0.8	0.6	0.6	0.6	0.6	0.8	0.8	0.6	0.6	0.6	0.7	0.7	0.7
25	0.6	0.6	0.6	0.5	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.7
20	0.6	0.6	0.5	0.6	0.8	0.8	0.6	0.6	0.6	0.6	0.6	0.6	0.6
15	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
10	0.5	0.6	0.6	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
5	0.6	0.6	0.6	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.6	0.6	0.6
33° 0'	0.6	0.6	0.7	0.7	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.6
	123° 0'	55	50	45	40	35	30	25	20	15	10	5	122° 0'

LONGITUDE WEST

Terrain in the US West Coast region

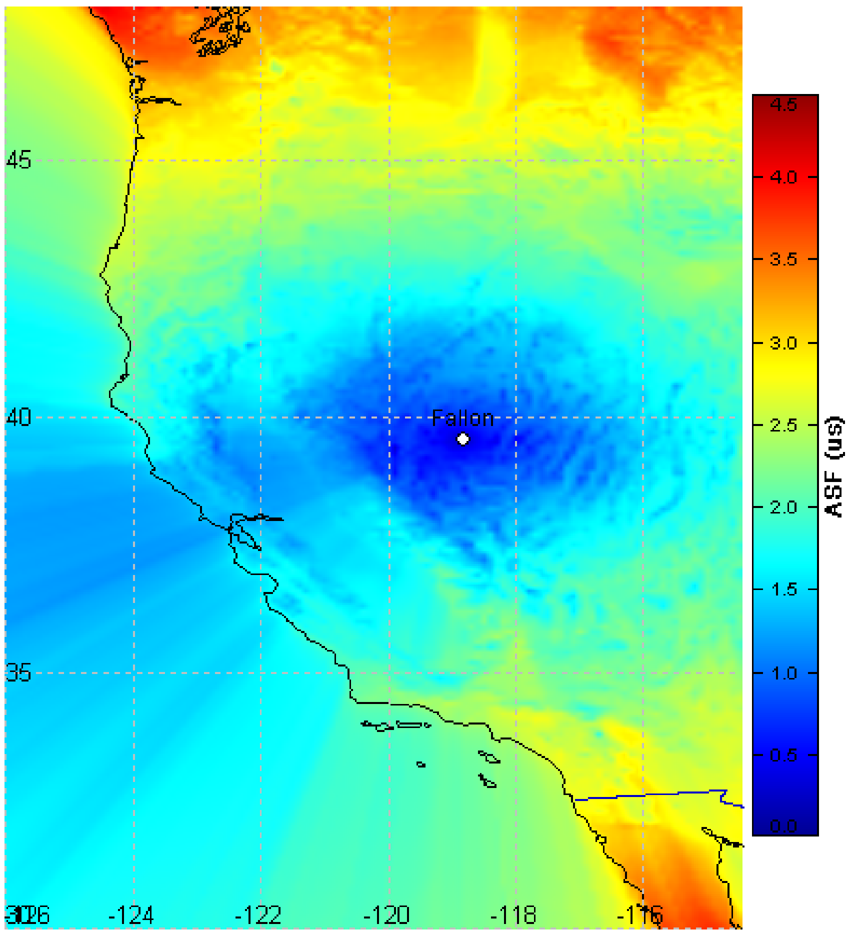


Ground conductivity

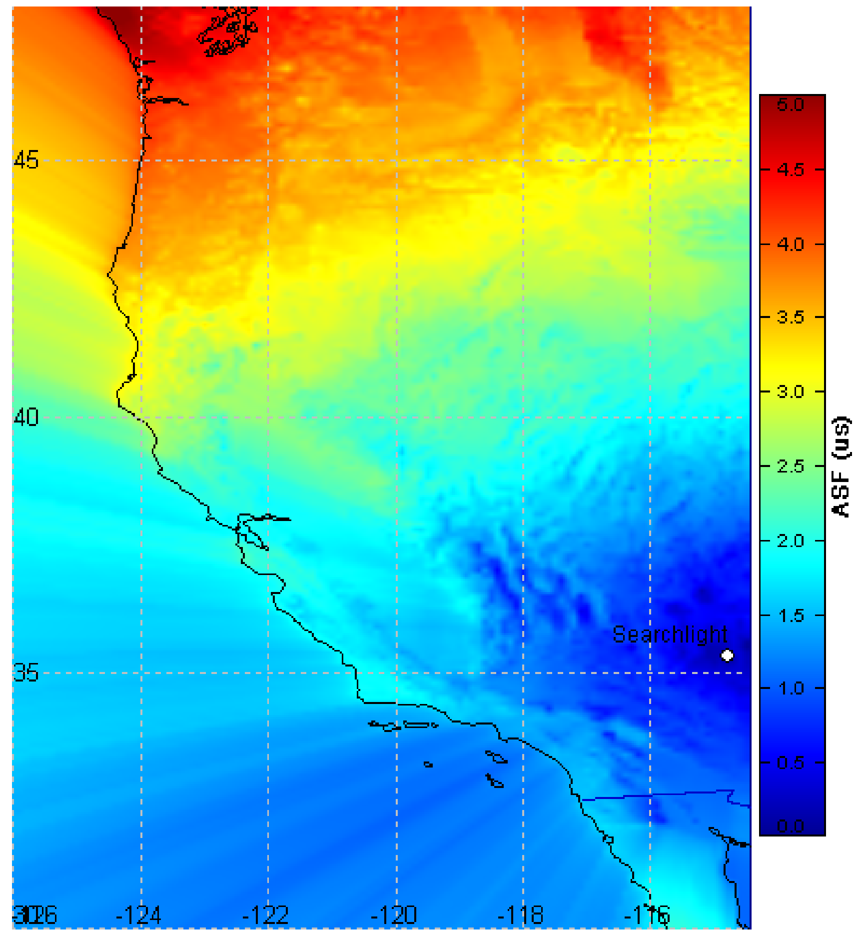


Terrain elevation

Calculated ASFs for Fallon and Searchlight

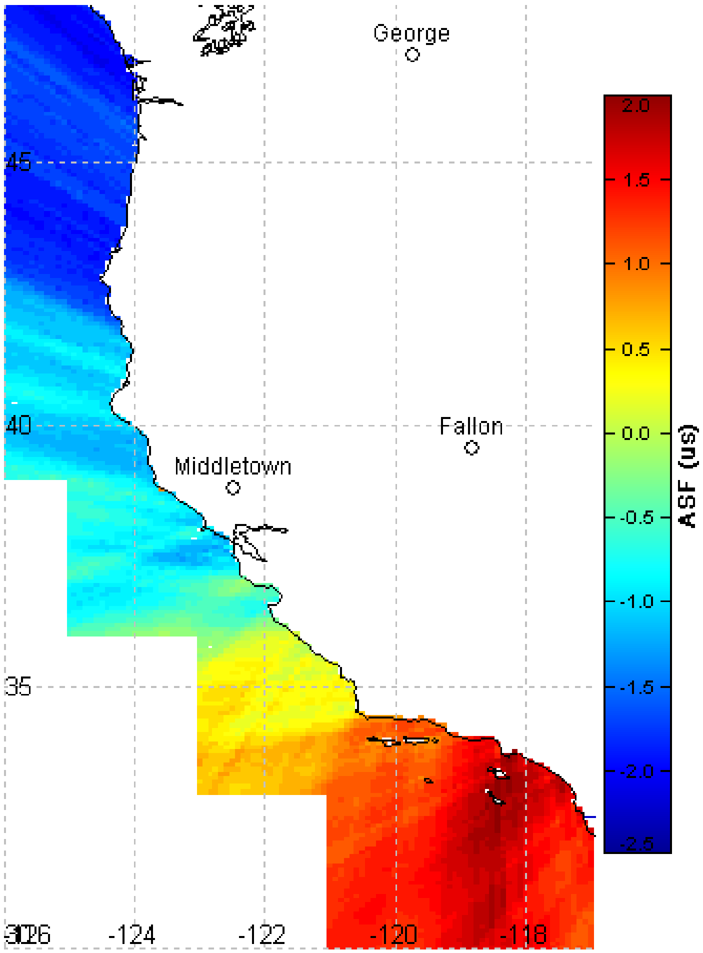


Fallon

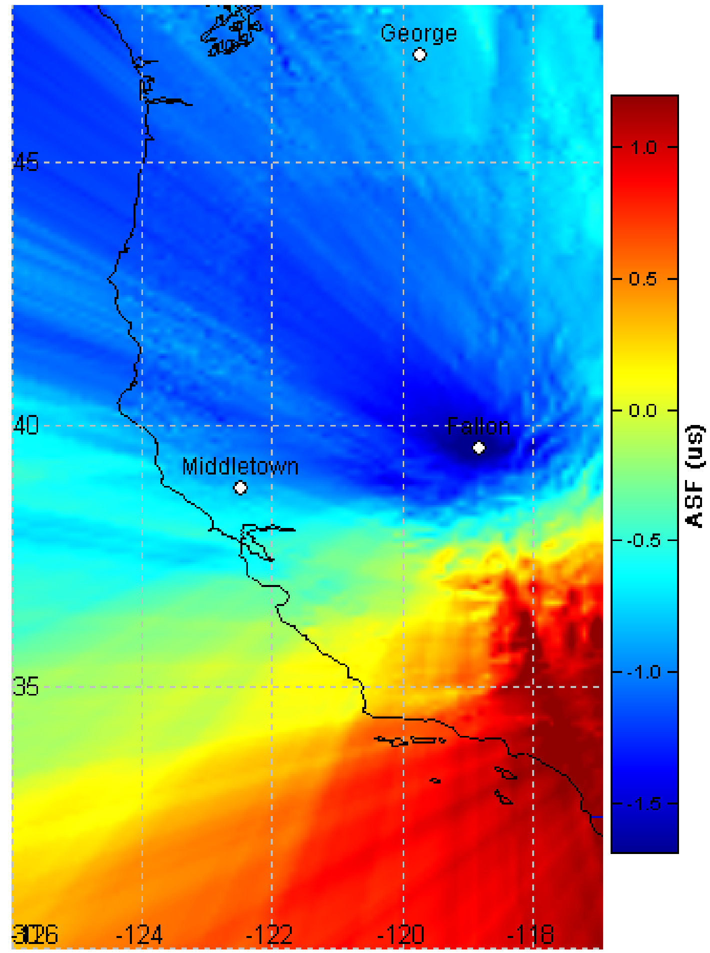


Searchlight

Correction table data vs. BALOR results



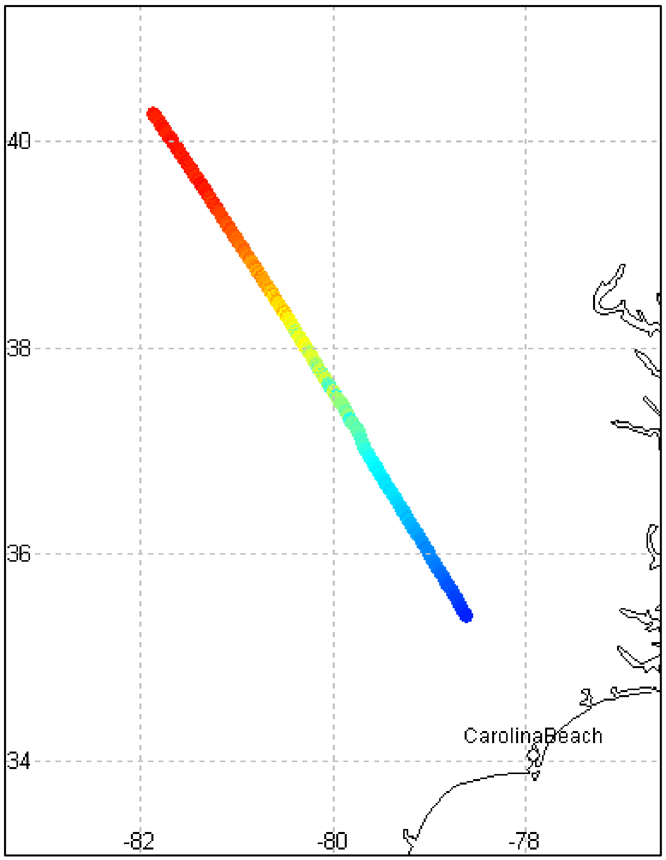
Loran-C correction table data

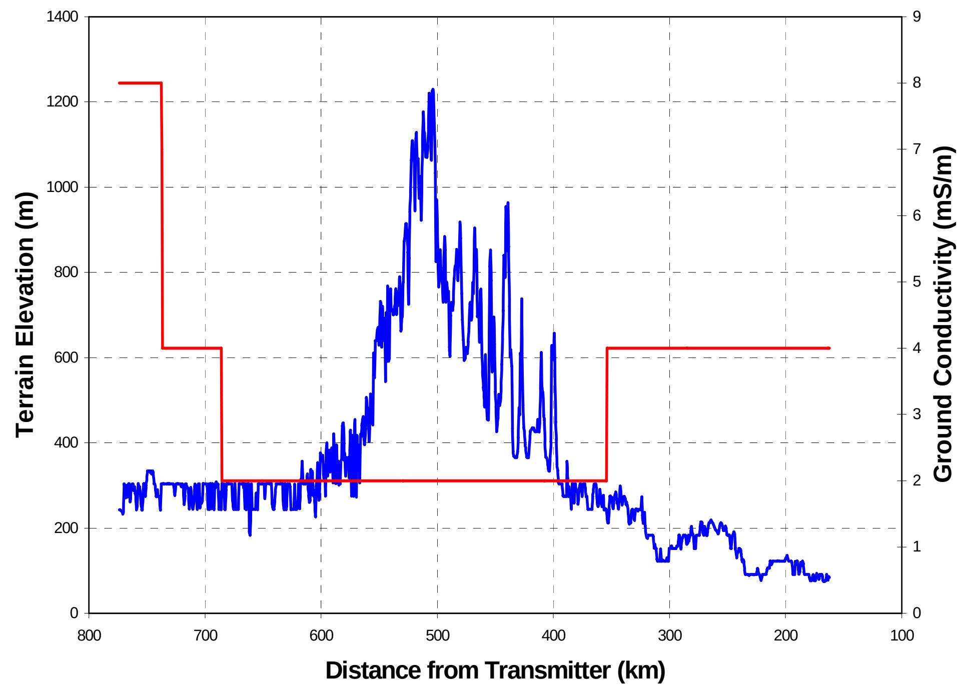


Relative ASF data from BALOR

Flight path from Ohio toward Carolina Beach

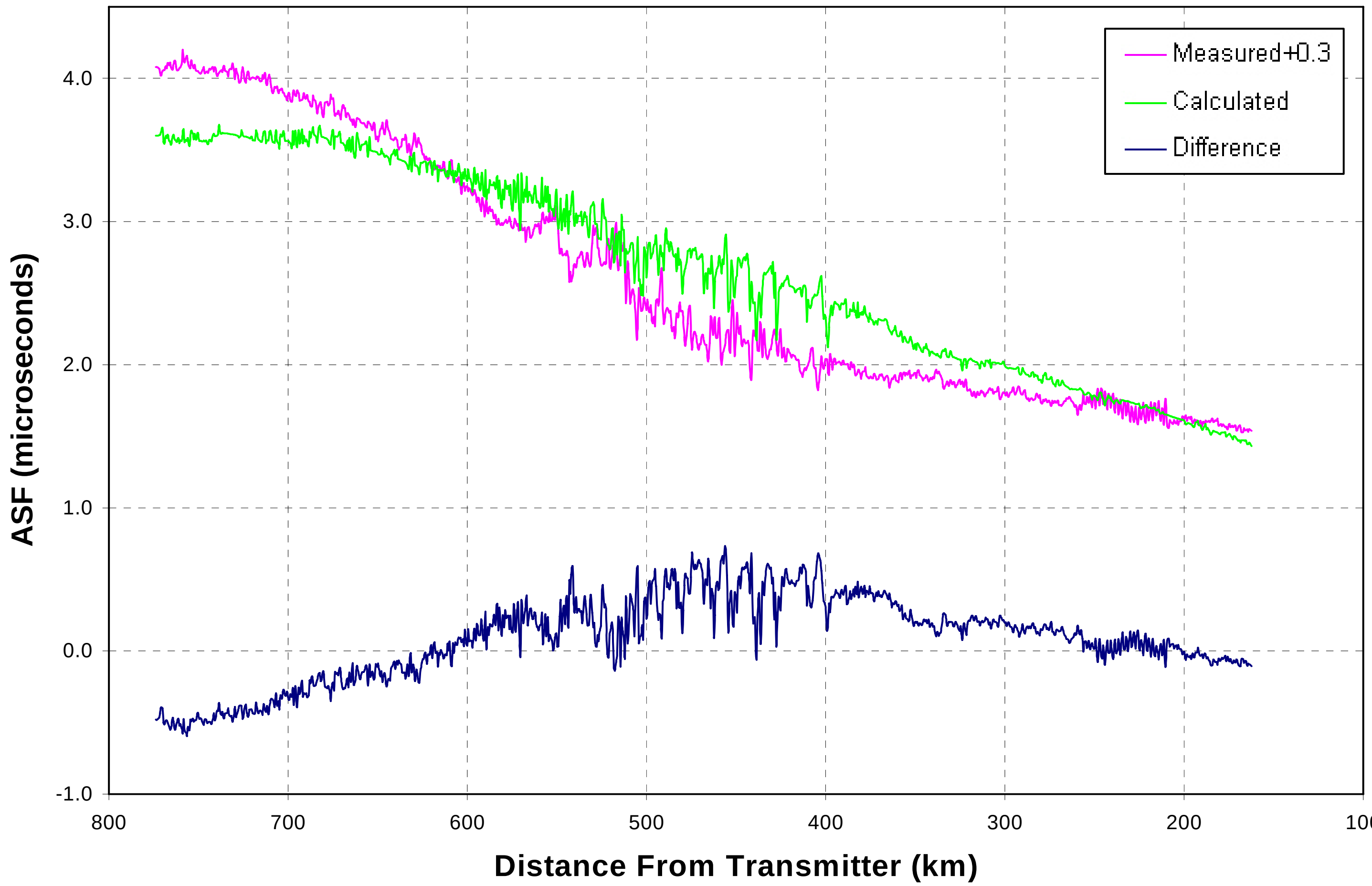
transmitter is Carolina Beach; aircraft is King Air; 8/29/07





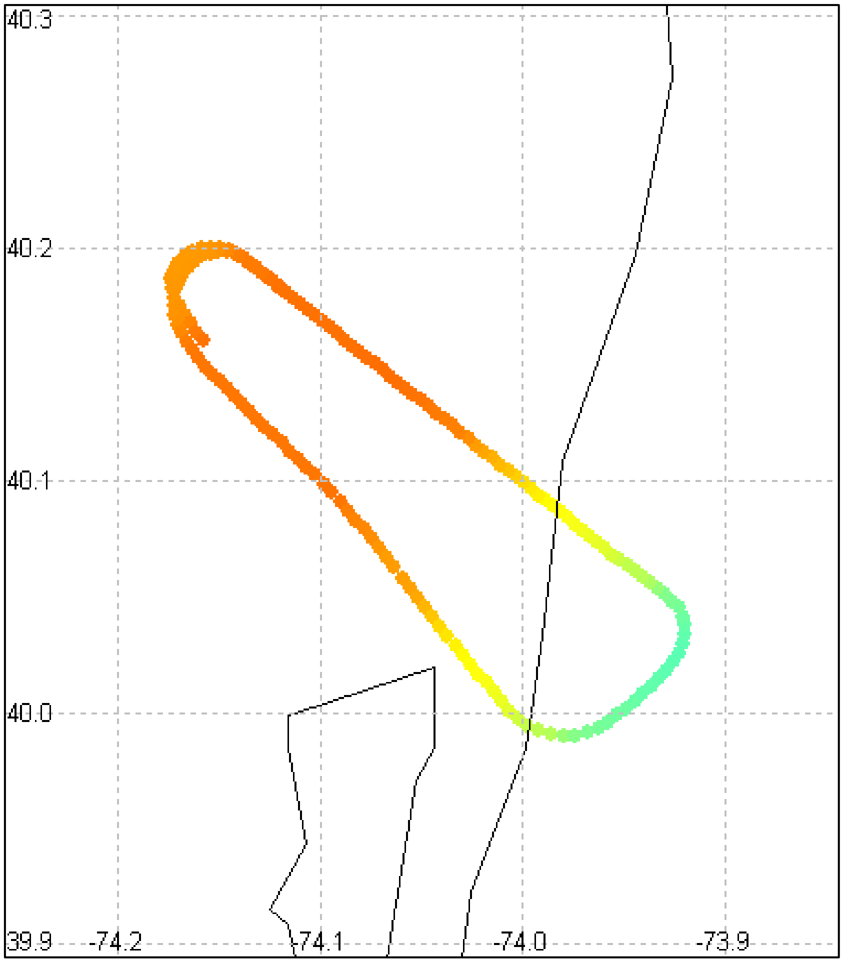
The plot at left shows flight path; the color represents ASFs. Terrain elevation and conductivity are shown above.

Comparison of measured and calculated ASFs for flight from Ohio toward Carolina Beach

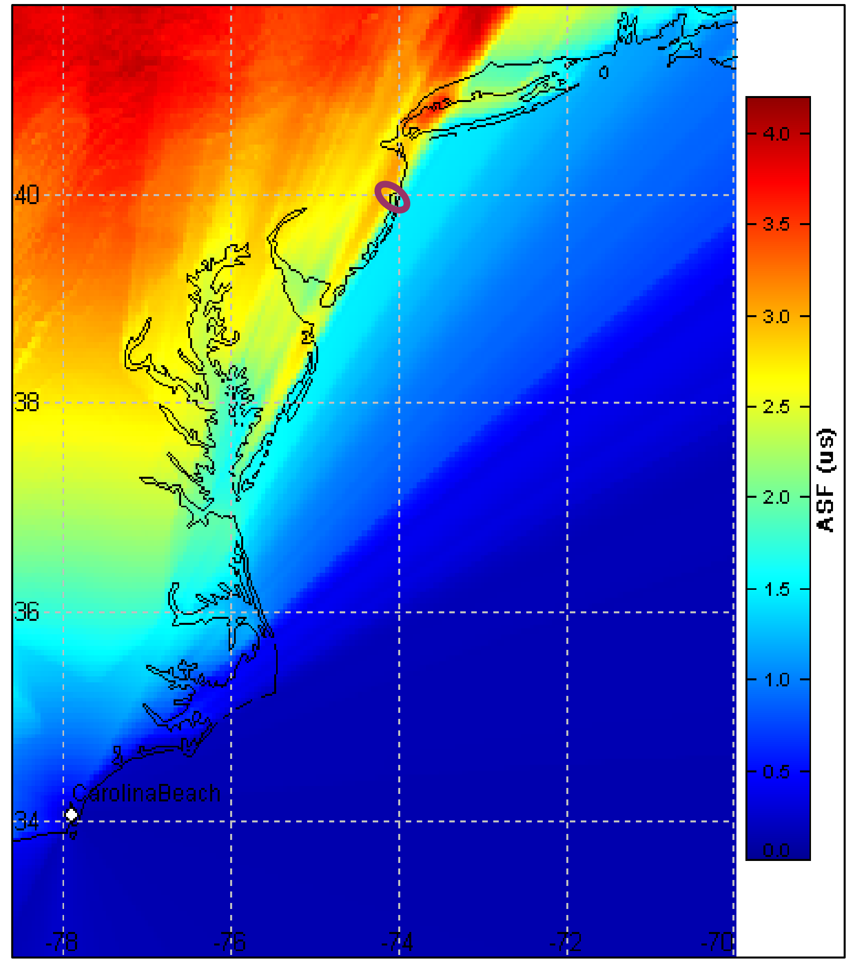


Approach to Allaire Airport, Belmar/Farmingdale, NJ

transmitter is Carolina Beach, aircraft is King Air; 4/10/07

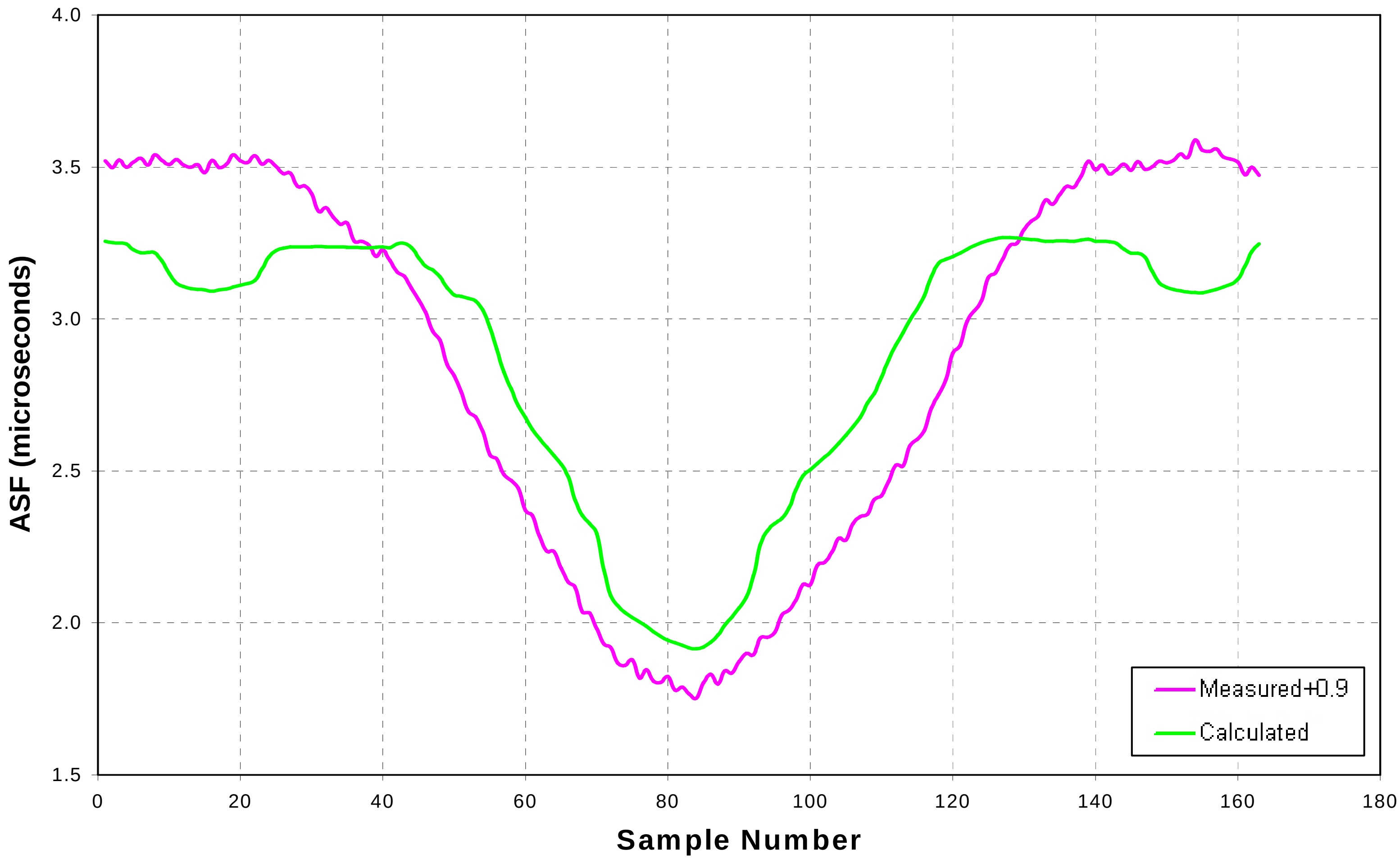


Flight Path



Calculated Map of ASFs

Comparison of measured and calculated ASFs from Carolina Beach during approach to Allaire, NJ



Closing

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Conclusions

- Further comparisons between BALOR and actual measured data are required.
- It may not be possible to obtain extremely accurate ASF predictions, due to lack of detail and possible bias in the conductivity database.
- Nevertheless, we should be able to eliminate any bias or scale errors from the BALOR model itself.
- Even in its current state, BALOR is a useful tool for large scale mapping of predicted ASFs.
- More accurate results could be produced by adjusting the BALOR maps to fit measured data points.

Acknowledgements

- Mitchell Narins, FAA, sponsor
- David Diggle, OU Avionics Engineering Center, supervisor
- Wouter Pelgrum, Exian Navigation Solutions, developer of the Loran TOA Measurement System (TMS)
- Paul Williams and David Last, originators of the BALOR model

Questions?