Loran ASF Variations as a Function of Altitude

ILA 34

Santa Barbara, CA

18-19 October 2005

Authors

- Dr. Gregory Johnson, Ruslan Shalaev, Christian Oates
  - Alion JJMA Maritime Sector
- Dr. Peter Swaszek
  - University of Rhode Island
- Capt. Richard Hartnett, PhD
  - US Coast Guard Academy
- Kevin Bridges
  - Federal Aviation Administration

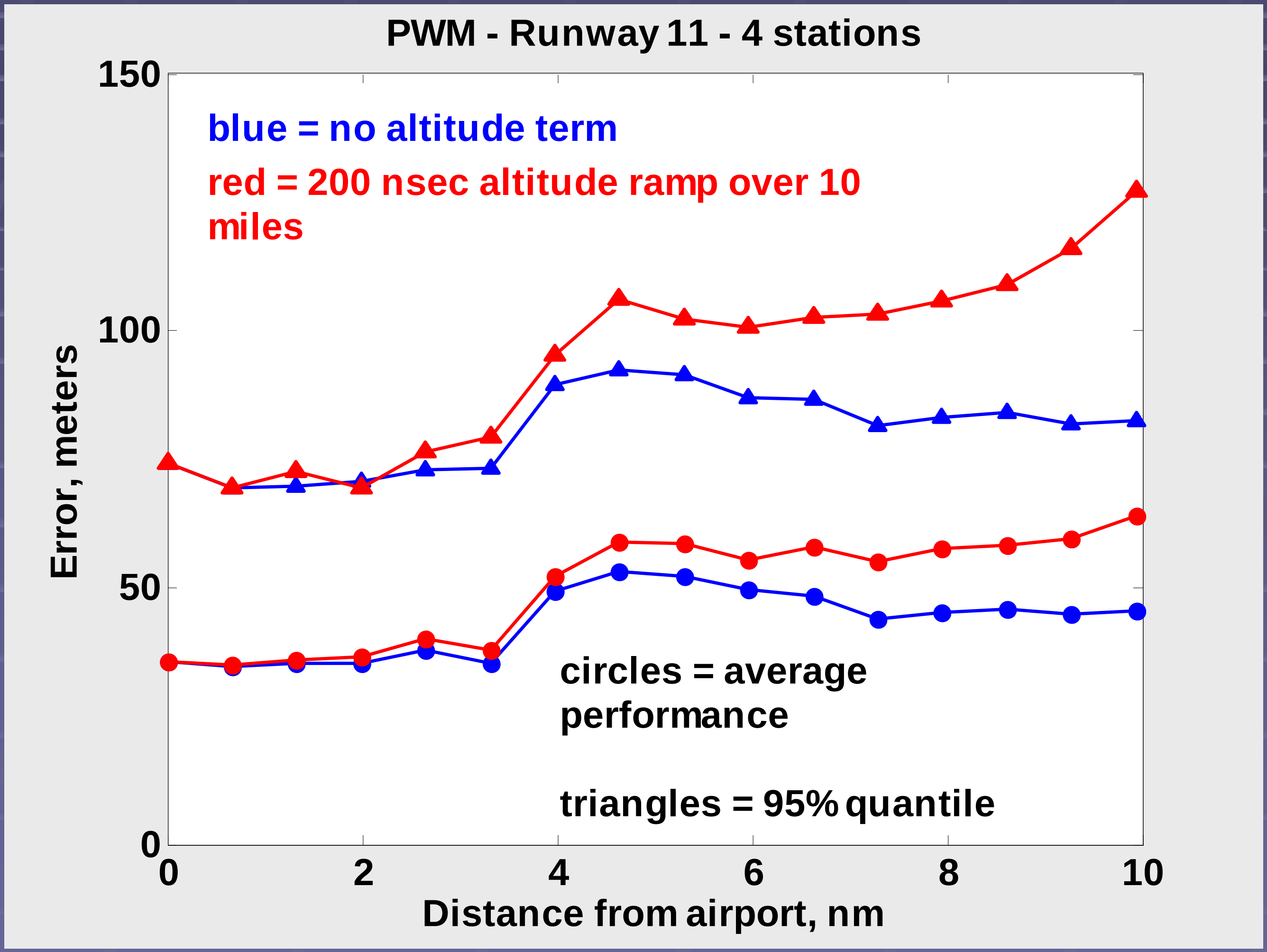
Outline

- Introduction to the Problem
  - ie why do we care?
- Previous Data
  - Summary of previous data showing effect
  - Oct 2004 flights
- Summary of Previous Research
- Physics
- Airship Test
- Conclusions / Future

Introduction

- Why is this a problem?
  - Airport ASF Methodology (described in previous paper) relies on bounding the total ASF “error” (difference from the reference ASF values).
  - Changes in ASF with altitude can impact this variance sufficiently to break the bounds or force the use of multiple reference ASF values.
  - Position domain bound is 120m to meet RNP 0.3

Altitude Impact on Position Error



Altitude Test History

- First noticed some effects ~2-3 yrs ago…
- Ideal ASF variation vs altitude test would be to stay in over one spot and slowly change altitudes.
- Not possible with the Convair so alternative method was devised
  - Fly as slowly as possible back and forth between 2 points
    - Only 2 headings for the test (important due to H-field antenna directional effects)
  - Fly each direction at the given altitude prior to moving up to the next altitude
  - Maintain the same ground track so any variation in the TOA at a given spot would be due to altitude only.

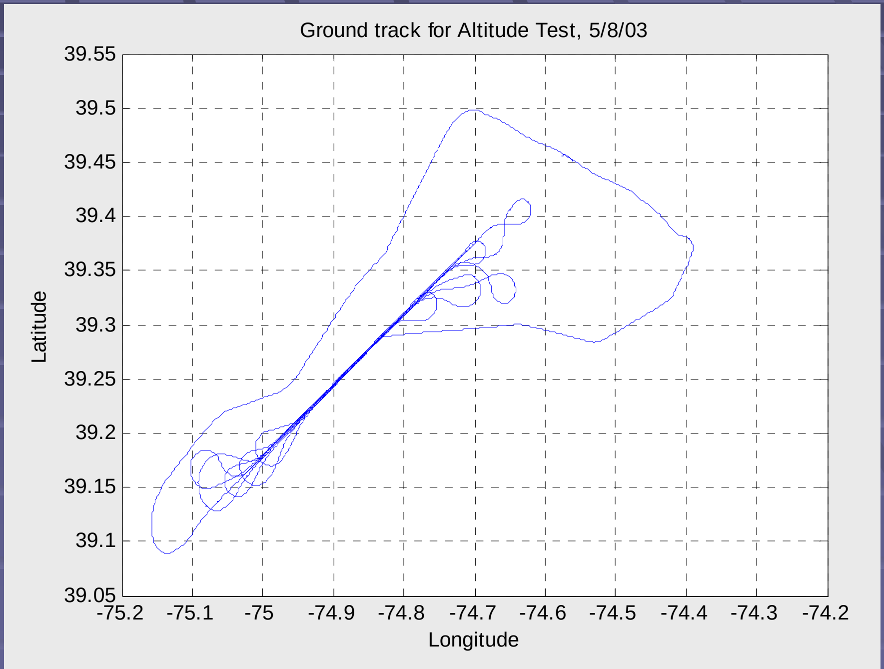
Initial Look

- **Altitude testing conducted in Jan 2003 during flight tests with FAATC**
  - See our, “FAA Loran-C Propagation Studies,” presented at ION NTM 2003
  - Unfortunately, the receiver was set to adjust the internal oscillator according to the strongest station so that the TOA measurements were not consistent.
    - So, although the test showed that the USCGA DDC receiver could be used in the aircraft, it also showed that the receiver would need to be stabilized with an external clock signal

Interior of Convair looking forward; CGA DDC receiver in rack.

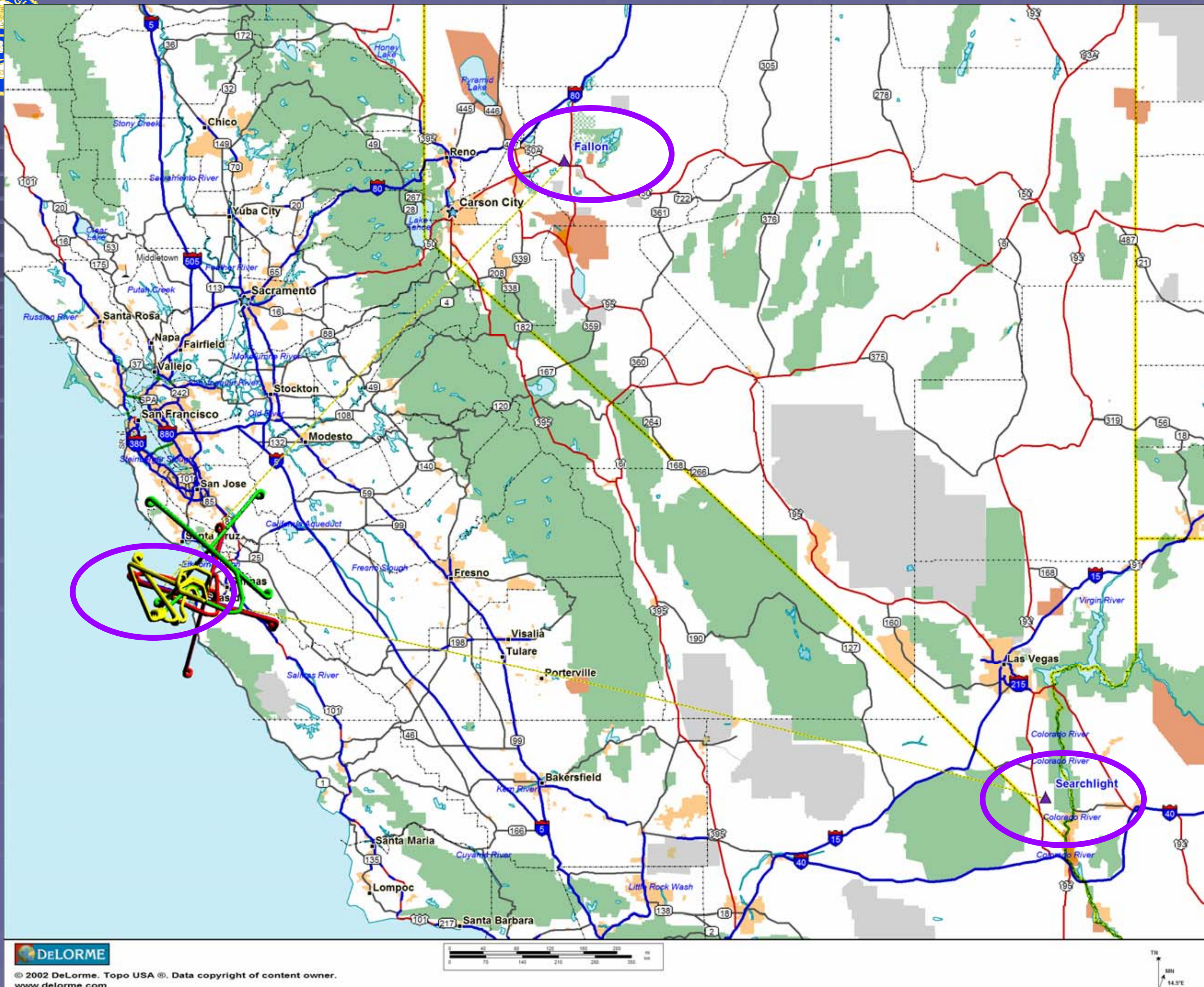
Revised Equipment

- Altitude test was repeated in May of 2003
  - Using the DDC receiver stabilized with an external 10MHz reference from the NovAtel GPS receiver.
  - A new version of the receiver was used which allowed each 1 second of data samples to be time-tagged to UTC. This allowed real TOA measurements to be made, independent of the receiver's clock.
- Altitudes from 2500 to 6500 ft.
- This test indicated some differences in ASF due to altitude of from 100-400ns.



Additional Testing

- During the Summer 2003 series of flight tests, Point Pinos, CA area
- Plane flew back and forth over the same ground track at various altitudes.
  - Two closest stations were Searchlight and Fallon
  - Legs were flown primarily North-South so ASF is plotted vs. Latitude
  - Two sets of plots, one for each direction due to the directional error in the H-field antenna
  - In the case of Searchlight there are some fairly large differences between 4500 and 9000 ft
  - In the case of Fallon, the differences are much less

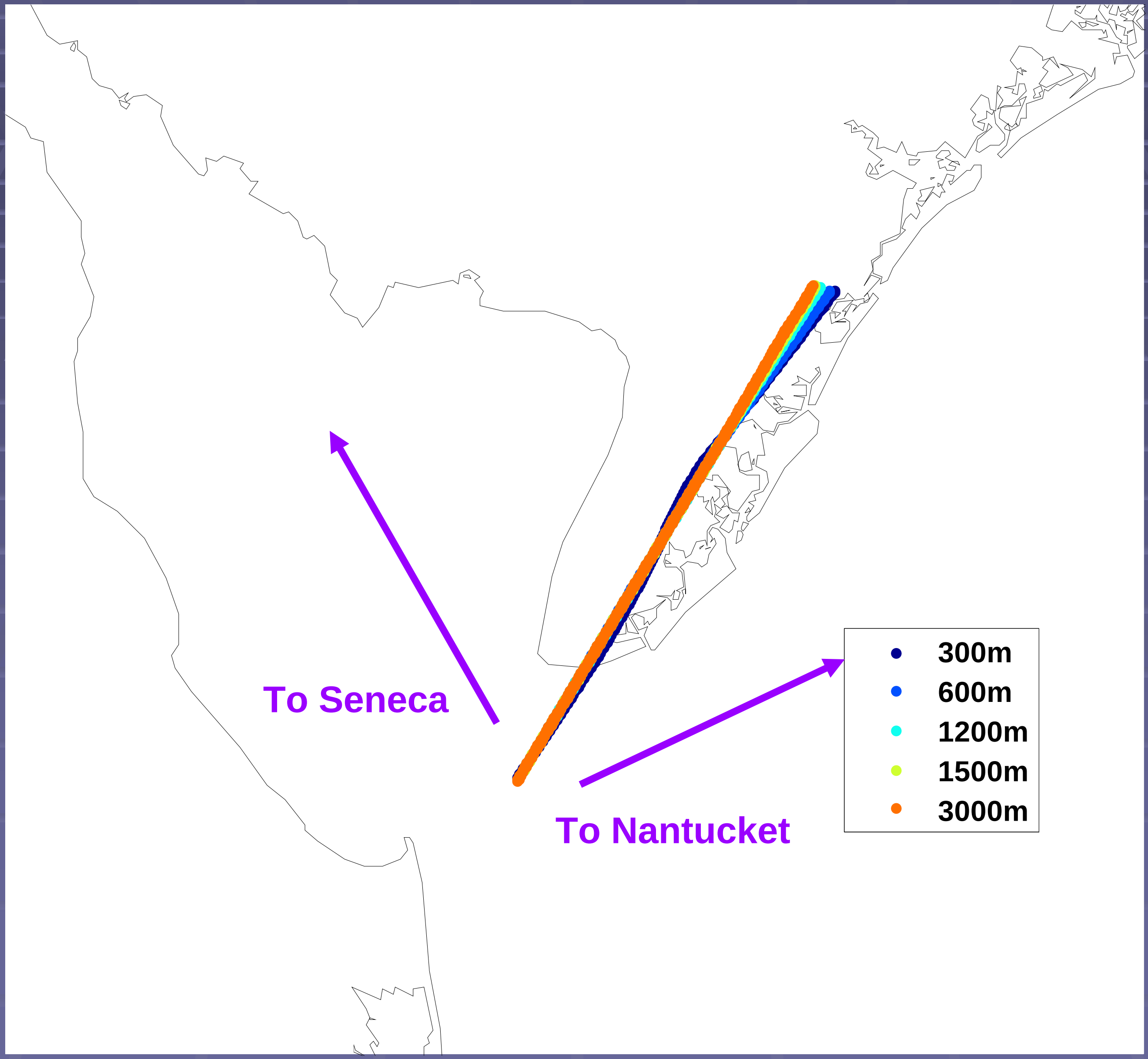

Fallon
Searchlight
Reno
Carson City
Chico
Yuba City
Sacramento
Santa Rosa
Napa
Fairfield
Vallejo
Stockton
San Francisco
Modesto
San Jose
Santa Cruz
Fresno
Visalia
Tulare
Porterville
Bakersfield
Santa Maria
Lompoc
Santa Barbara
Las Vegas
Pyramid Lake
Lake Tahoe
Sacramento River
Colorado River
Virgin River
Salinas River
Kern River
California Aqueduct
DELORME
© 2002 DeLorme. Topo USA ®. Data copyright of content owner.
www.delorme.com

ON
CHNOLOGY

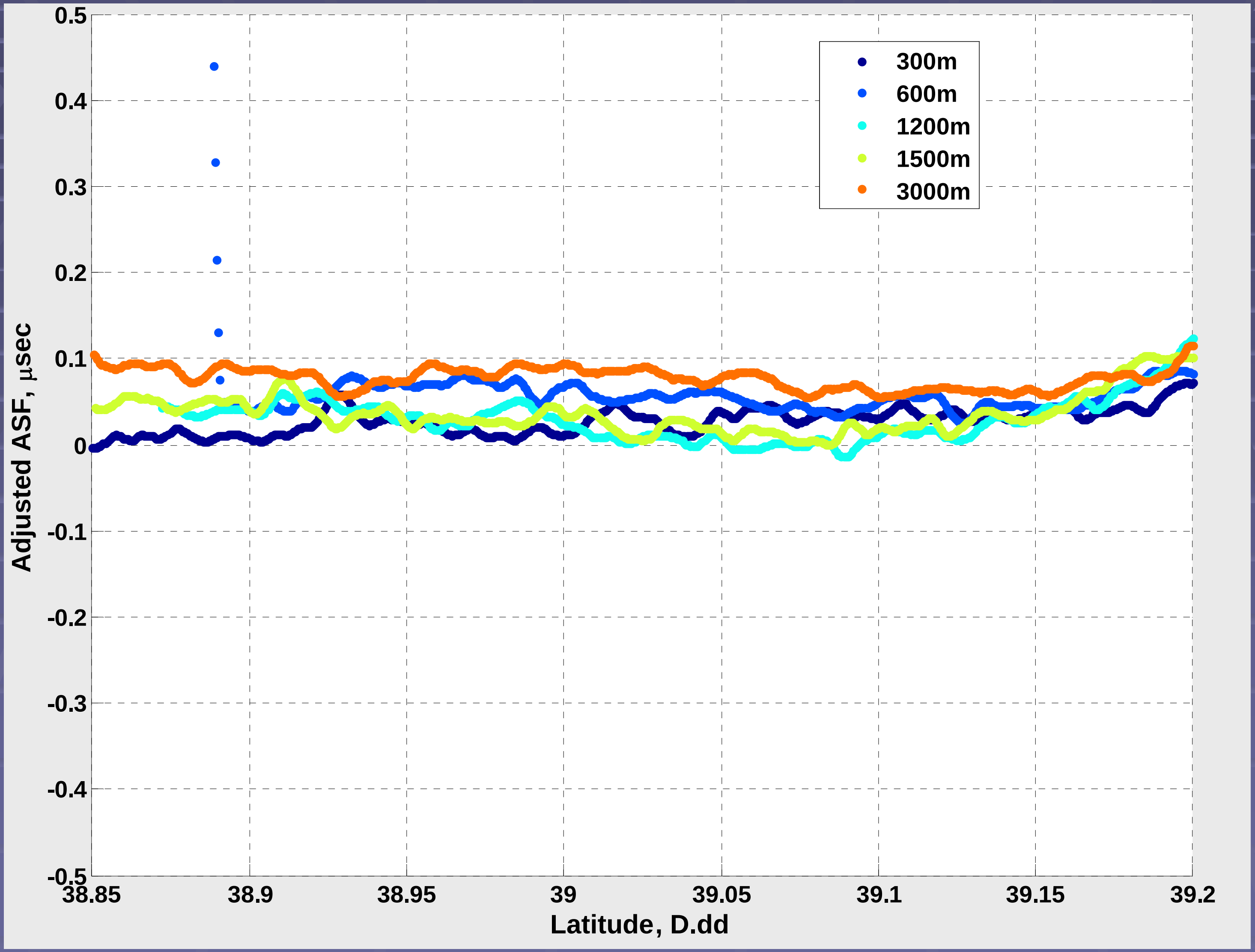
October 2004 Flights

- Most recent aircraft altitude test
  - Using the SatMate ASF measurement system on the Convair.
- Test was conducted in a similar manner to the previous (repeating ground tracks at various altitudes)
  - In the vicinity of the FAA technical Center in Atlantic City, NJ
- Accuracy of ASF results somewhat reduced due to the fact that the SatMate receiver did not use a stabilized clock reference and thus the results were somewhat corrupted by Doppler.
  - To alleviate this and the error from the directionality of the H-field antenna, results from only one direction are shown
- ASFs postprocessed taking into account receiver averaging delay
- Results from Nantucket and Seneca are shown
  - These should have about the same Doppler error as the angles from the Stations to the track are about the same (in opposite directions)
  - The altitude variation for Seneca is much more than that for Nantucket which makes sense as the path from Nantucket is almost entirely seawater. The most altitude effect should be seen on paths crossing the lowest conductivity ground

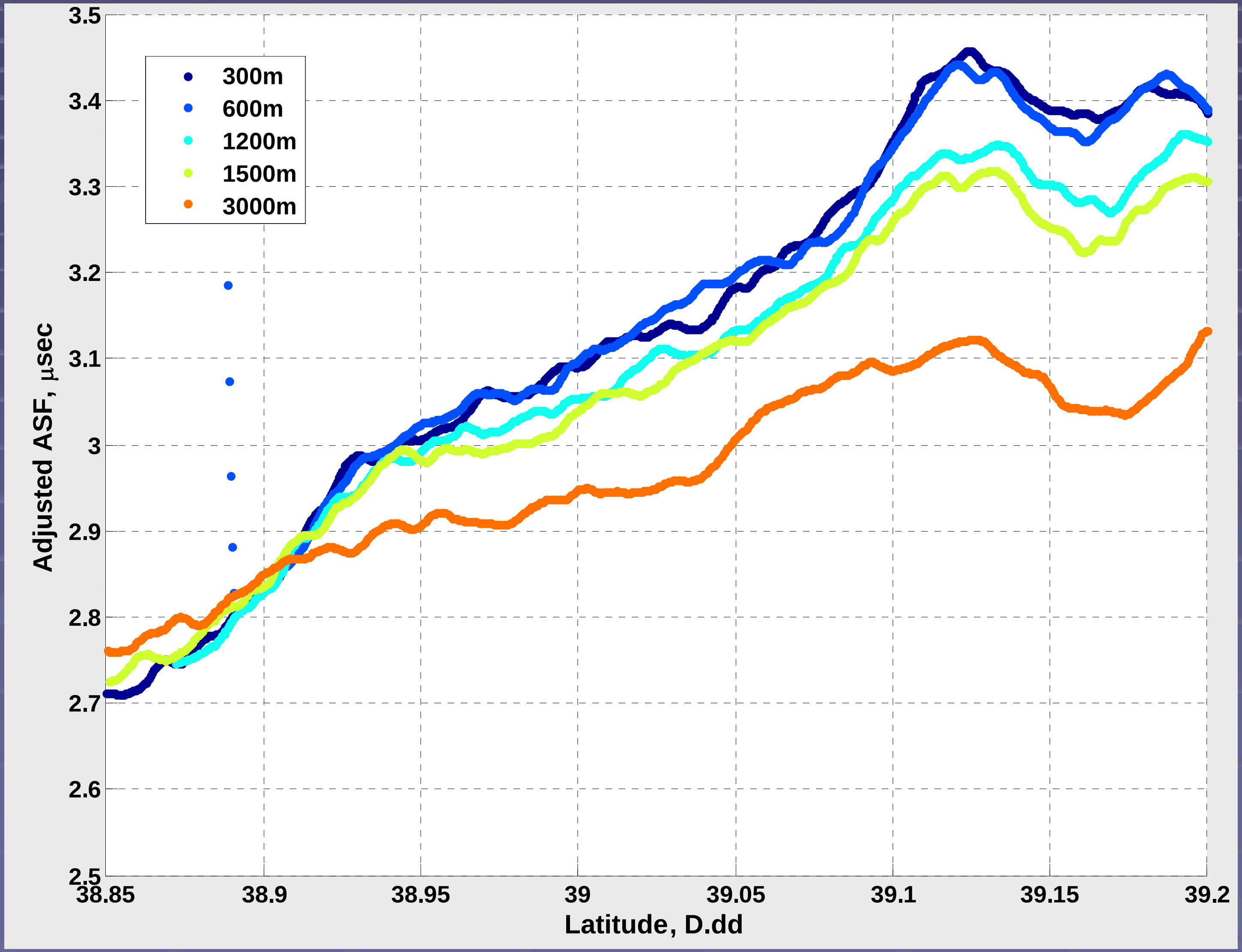
Southbound tracks



Nantucket, Southbound



Seneca, Southbound



Research by Others

- Altitude variations are reported on by Johler, et al
  - J. R. Johler, “Loran Radio Navigation Over Irregular, Inhomogeneous Ground With Effective Ground Impedance Maps,” Institute for Telecommunication Sciences, Boulder, CO Telecommunications Research and Engineering Report 22, November 1971
    - “…it is further concluded that the altitude correction must be determined from theory or measured in case of severe perturbations due to unusual local anomalies.”
  - L. B. Burch, R. H. Doherty, and J. R. Johler, “Loran Calibration by Prediction,” presented at Fourth Annual Technical Symposium, Wild Goose Association, Cockeysville, MD, 16-17 October 1975
    - Figure to right.

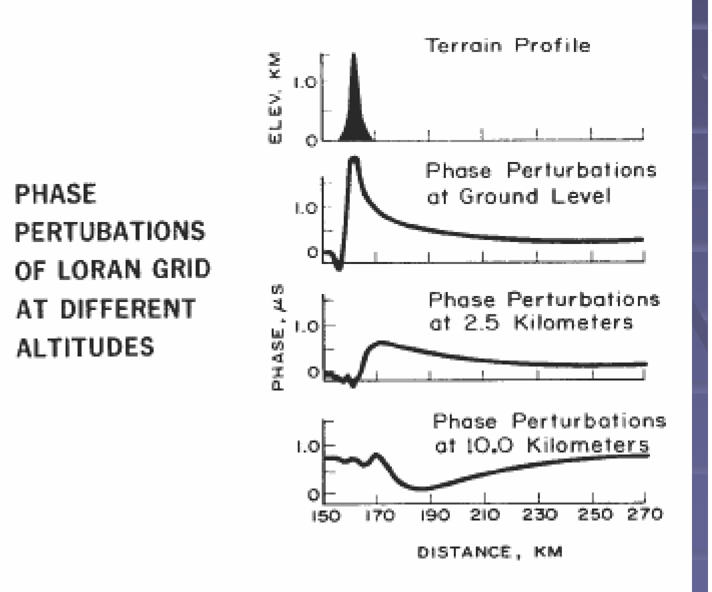
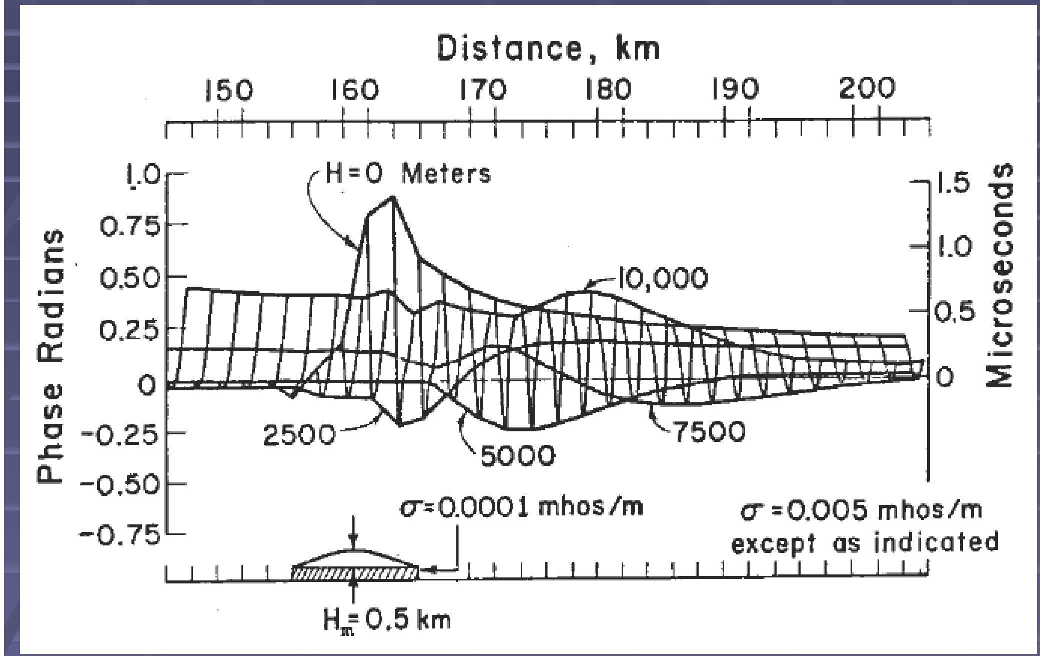


Figure 3. Predicted phase variations at three altitudes.

Research by Others (2)



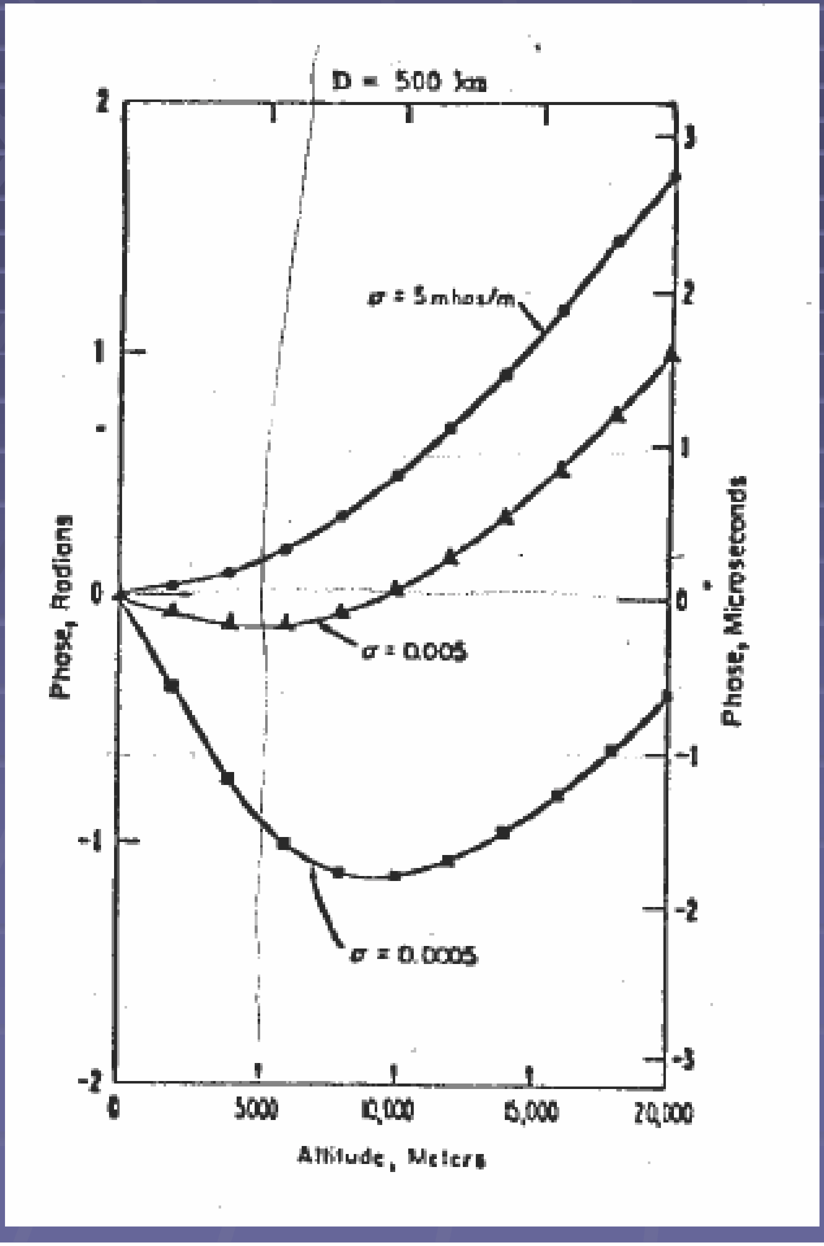
- J. R. Johler, "Prediction of Ground Wave Propagation Time Anomalies in the Loran-C Signal Transmissions over Land," AGARD meeting on "Propagation Limitations of Navigation and Positioning Systems" 1976

It is further concluded that such propagation anomalies are significant not only on the ground in the immediate vicinity of the anomaly, but also aloft and at great distance from the anomaly. It is also concluded that the type of antenna used by aircraft navigating on loran must be considered as to its effect on the secondary phase correction at shorter distance from the transmitter. It is also noted that the type of antenna is significant to even greater distance as the altitude of the aircraft is increased.

Research by Others (3)

- R. H. Doherty and J. R. Johler, “Analysis of Groundwave Temporal Variations in the Loran-C Radio Navigation System,” CO OT Technical Memorandum 76-222, 1976
    - Weather effects, vertical lapse rate and refractive index
- R. V. Gressang and S. Horowitz, “Description and Preliminary Accuracy Evaluation of a Loran Grid Prediction Program,” WGA (ILA) 7, 1978
    - refractive index of the atmosphere at the surface, and the lapse rate or rate of change of refractive index with altitude above the surface
- R. H. Doherty, L. W. Campbell, S. N. Samaddar, and J. R. Johler, “A Meteorological Prediction Technique for Loran-C Temporal Variations,” WGA (ILA) 8, 1979
    - Most important parameter is atmospheric vertical lapse factor, alpha
- C. P. Comparato and F. D. MacKenzie, “Studying the Dependence of Time Difference Values on Temperature Changes,” WGA (ILA) 16, 1987
    - Temporal fluctuations due to vertical lapse rate - altitude change (400ns)

Research by Others (4)



- W. F. O'Halloran and K. Natarajan, “A Semi-Empirical Method for Loran Grid Calibration/ Prediction,” JAYCOR, Woburn, MA 25 August 1983

Research by Others (5)

- S. N. Samaddar, "The Theory of Loran-C Ground Wave Propagation -- A Review," Navigation vol. 26, 1979

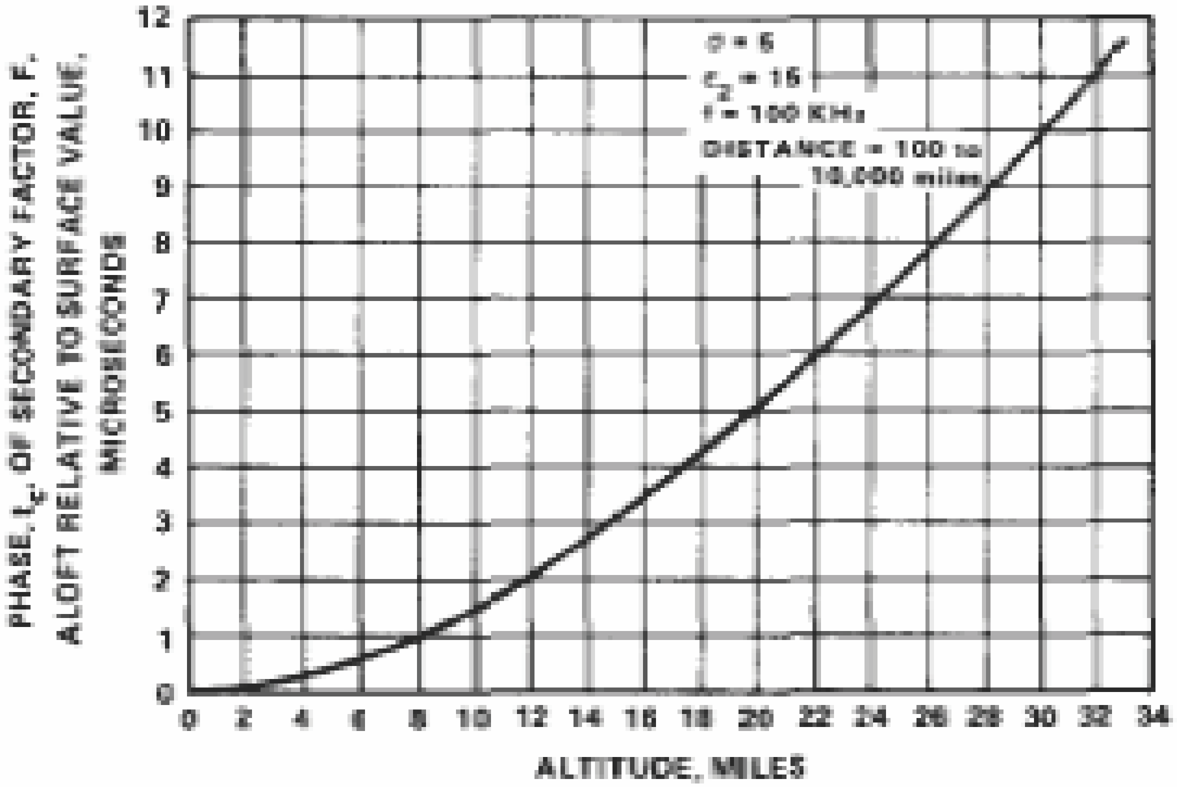
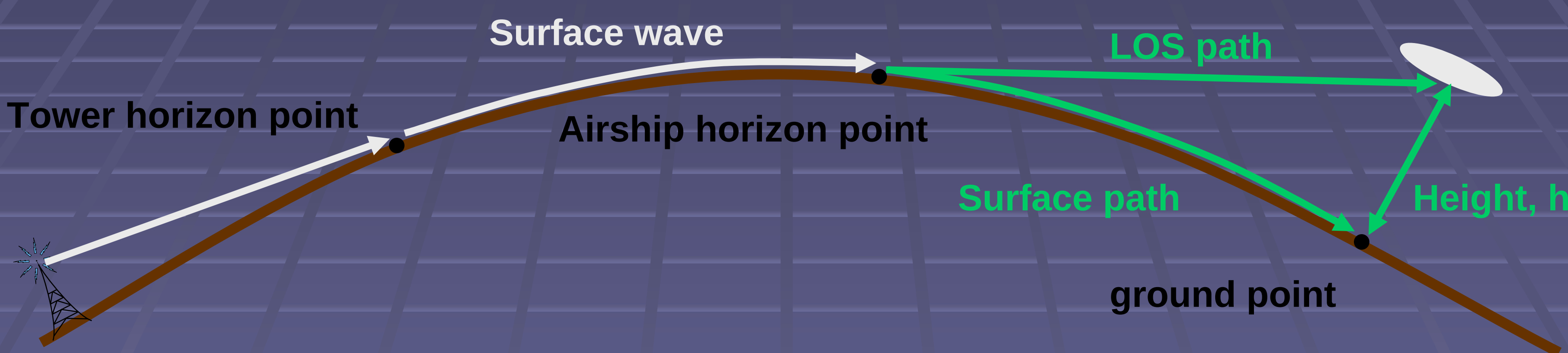


Fig. 6—Variation of phase of the secondary factor with altitude.

Physical Theory

- Extra path length
  - Straight-line LOS path transmitter to receiver vs. curved path over surface between ground points
- Less ASF accumulation
  - LOS path is propagation through atmosphere vs. over (less-conductive) ground
- Two cases
  - Over-the-horizon
  - Close to a tower

OTH Path Length

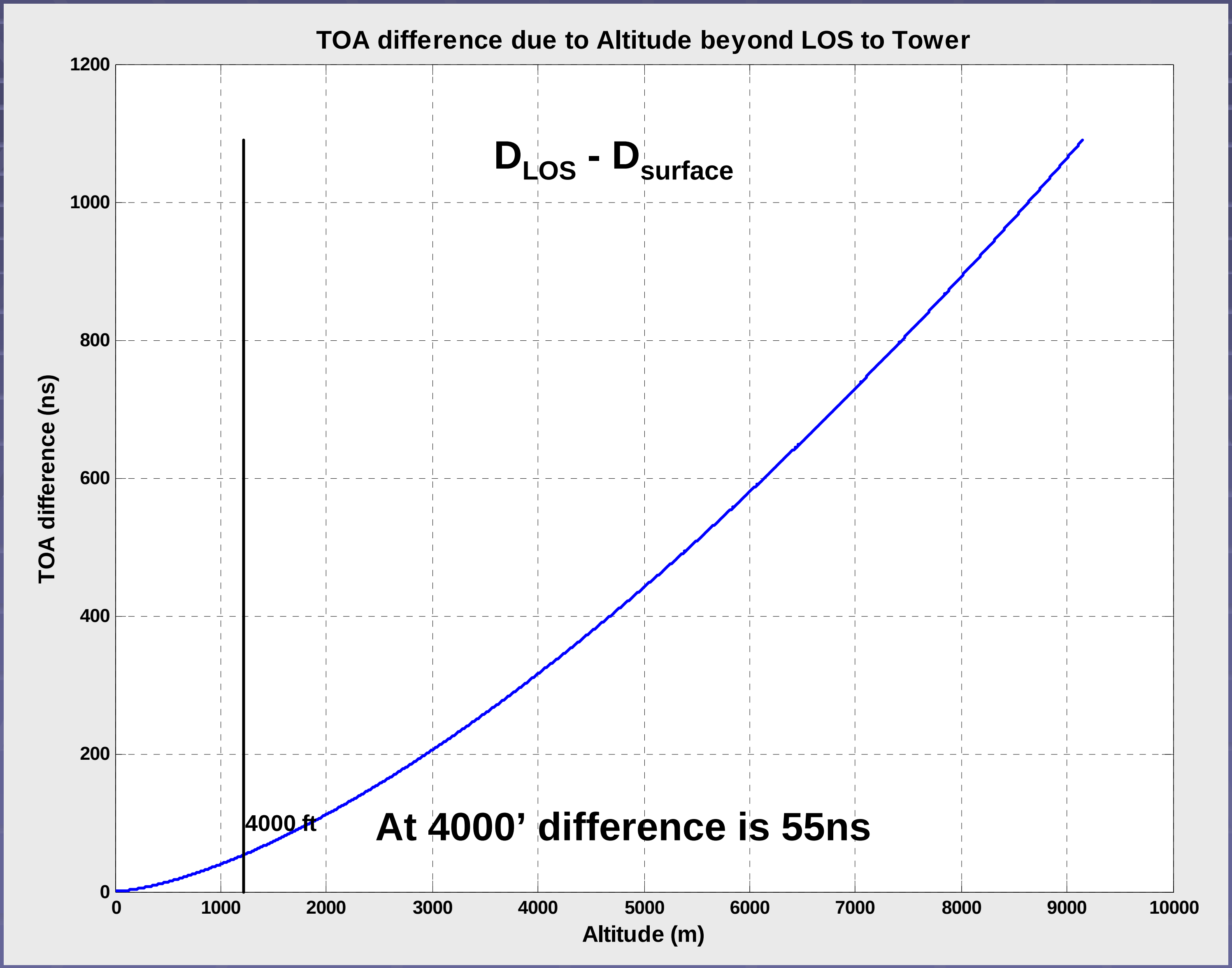


- Distance to airship horizon point is a function of altitude

$$D_{LOS} = \sqrt{(h + r_e)^2 - r_e^{\,2}}, \quad r_e = \text{earth radius}$$

$$D_{surface} = r_e \cdot \arctan\left(\frac{D_{LOS}}{r_e}\right)$$

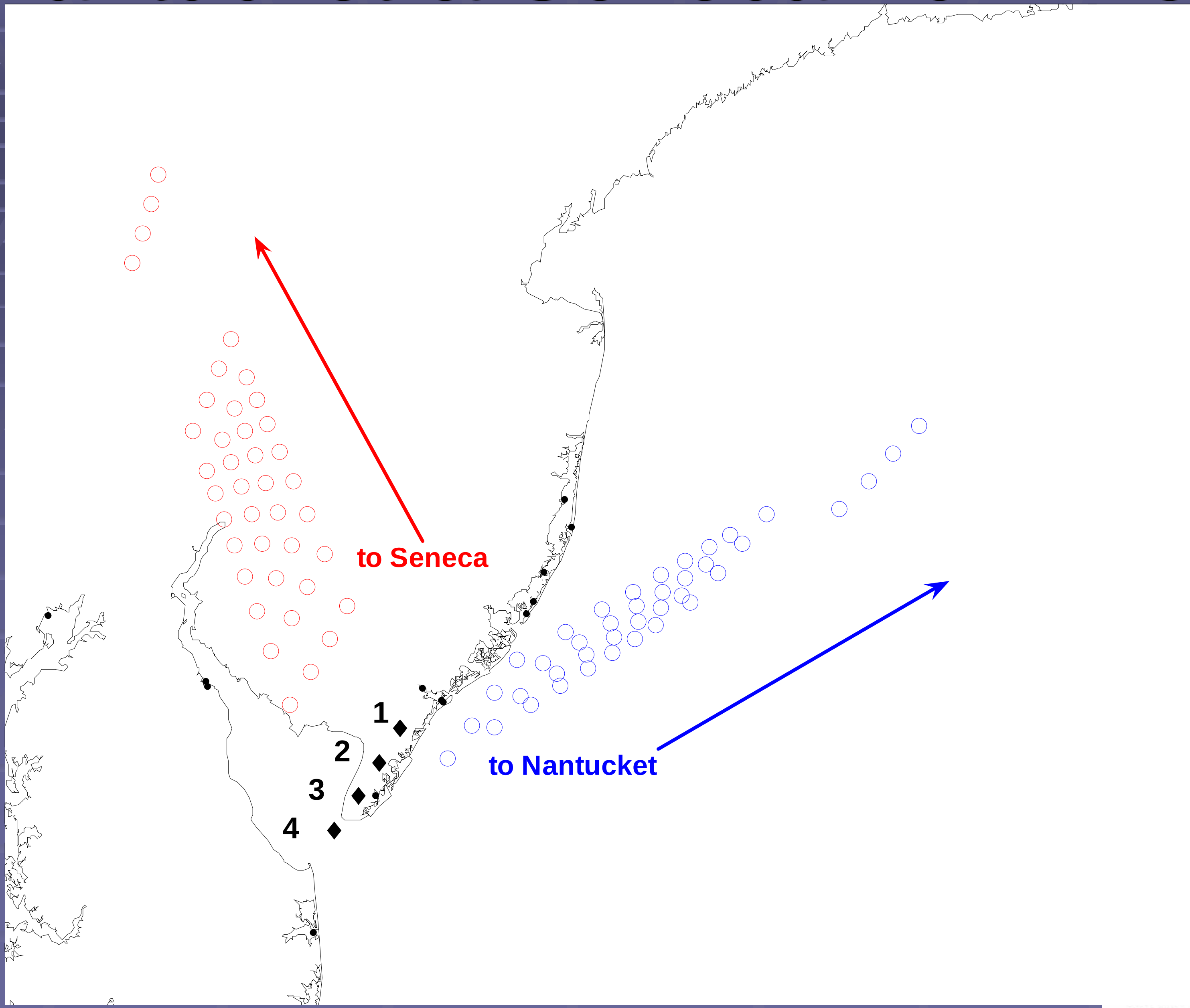
Extra Path Length



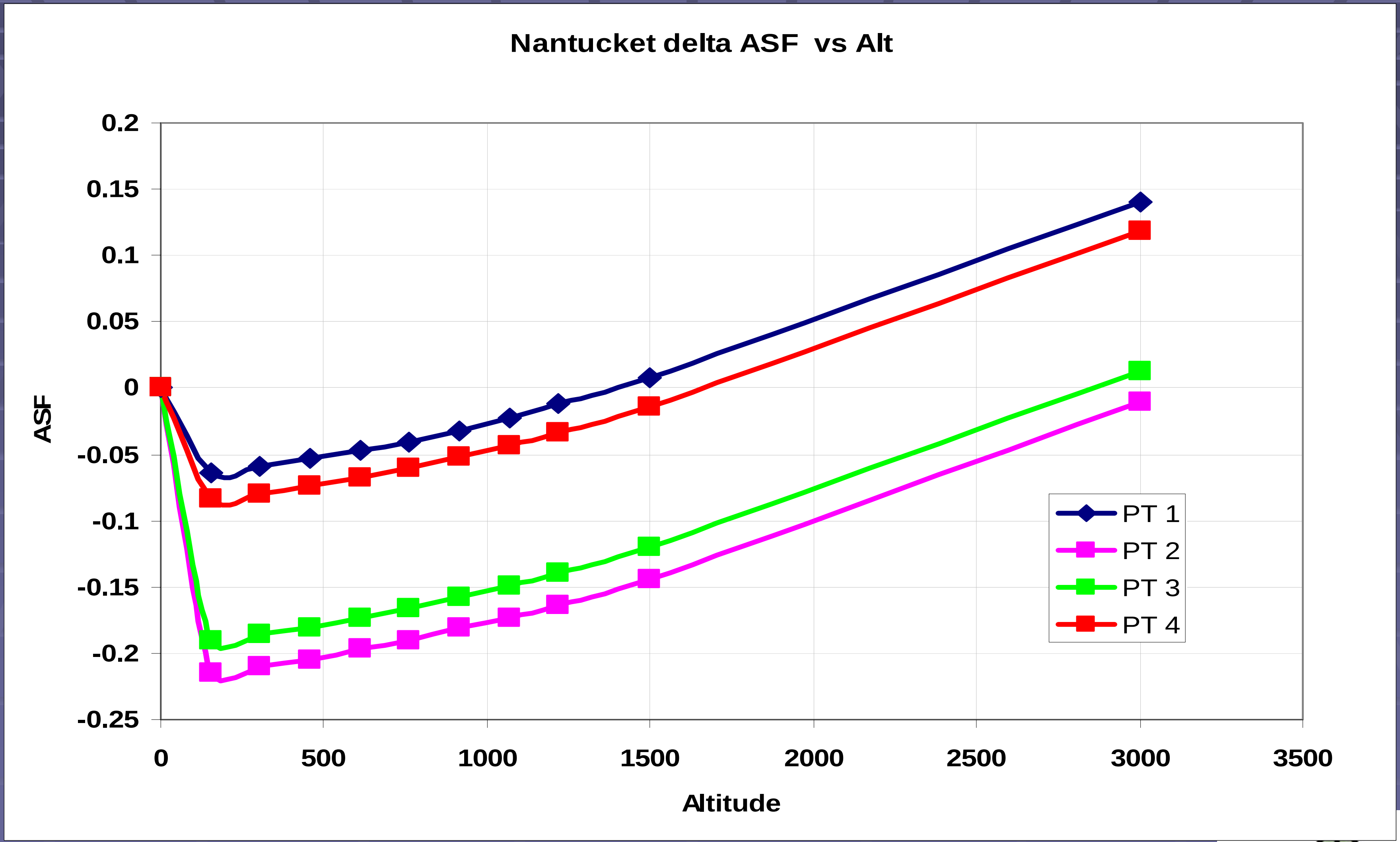
No ASF on Direct Path

- D_{LOS} has no ASF while $D_{surface}$ does….
- ASF predictions calculated using BALOR
  - Calculate ASF value to horizon point (function of altitude)
- Calculate LOS path distance (propagation time)
- Total predicted ASF = $ASF_{HP} + (D_{LOS-} D_{surface})$
- Done for four different initial starting points

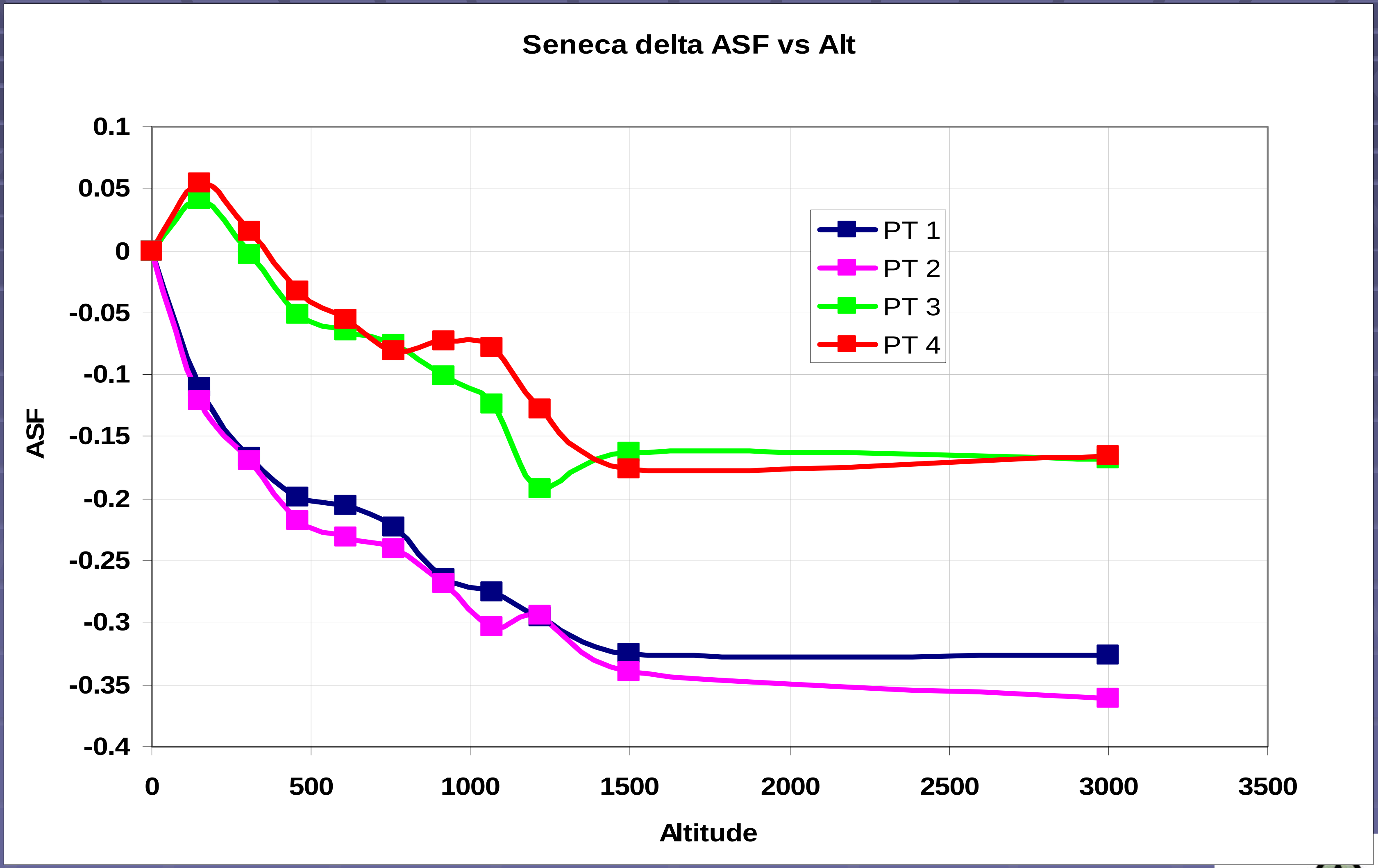
Nantucket & Seneca from ACY



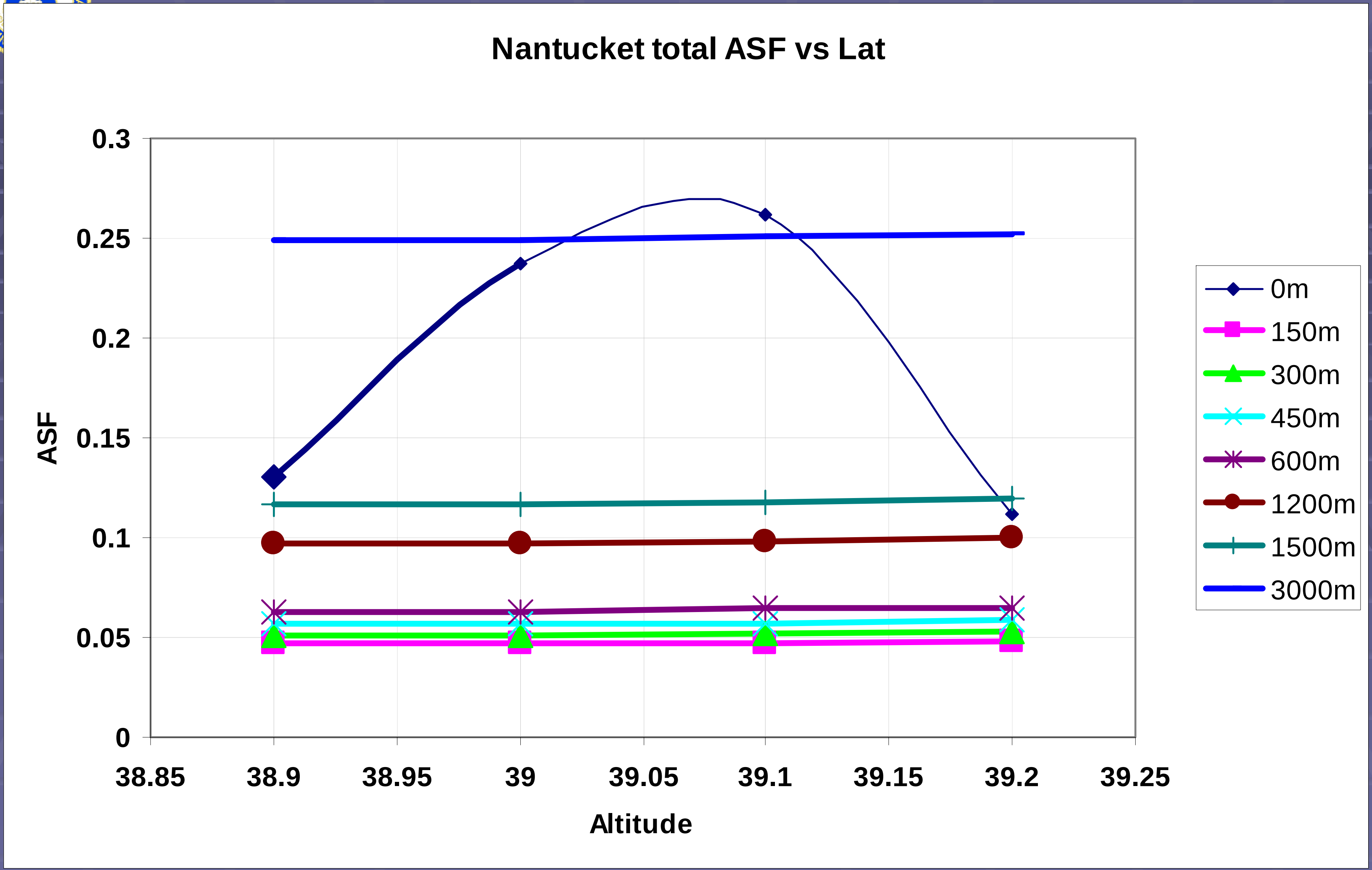
ASF difference on paths



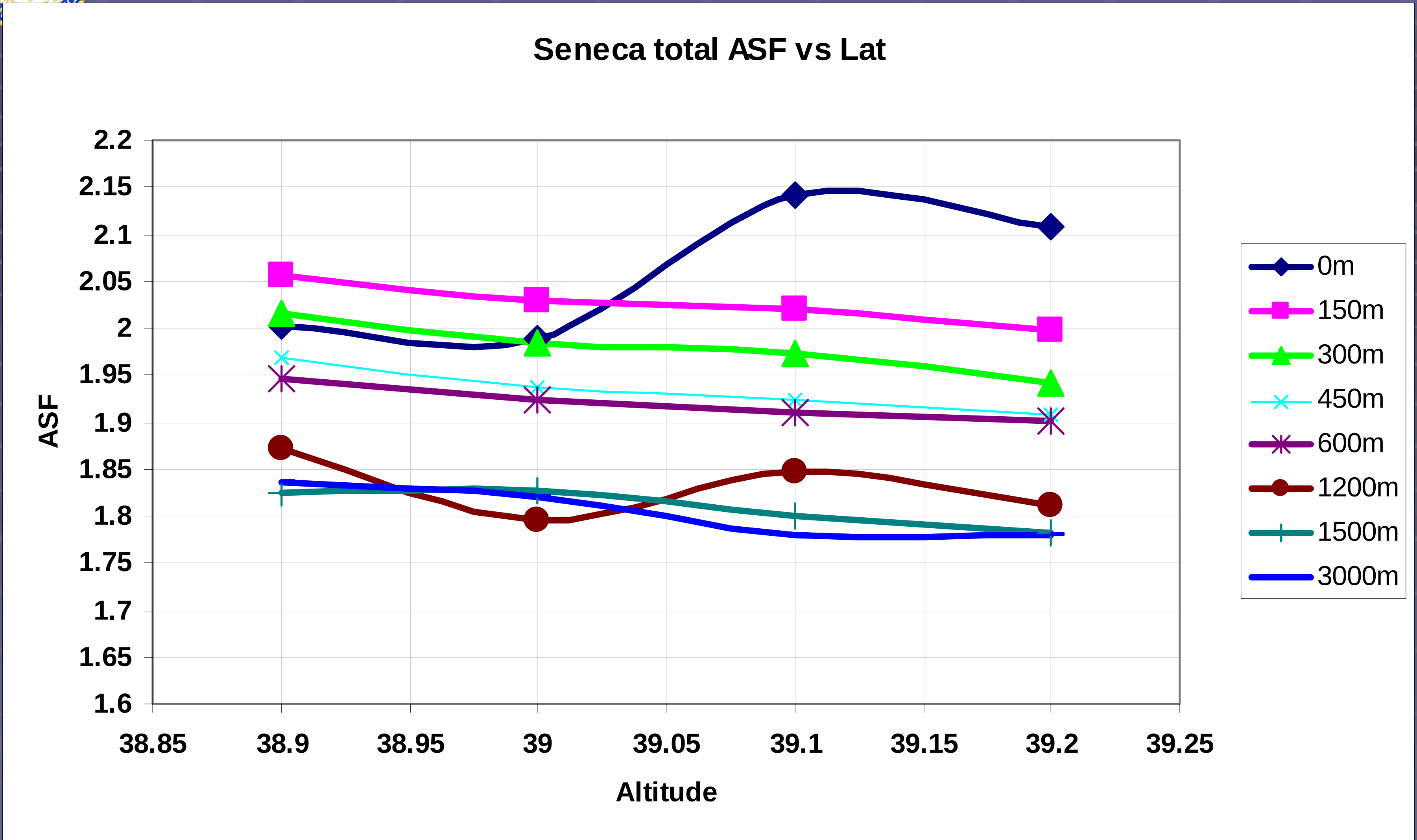
ASF difference on paths



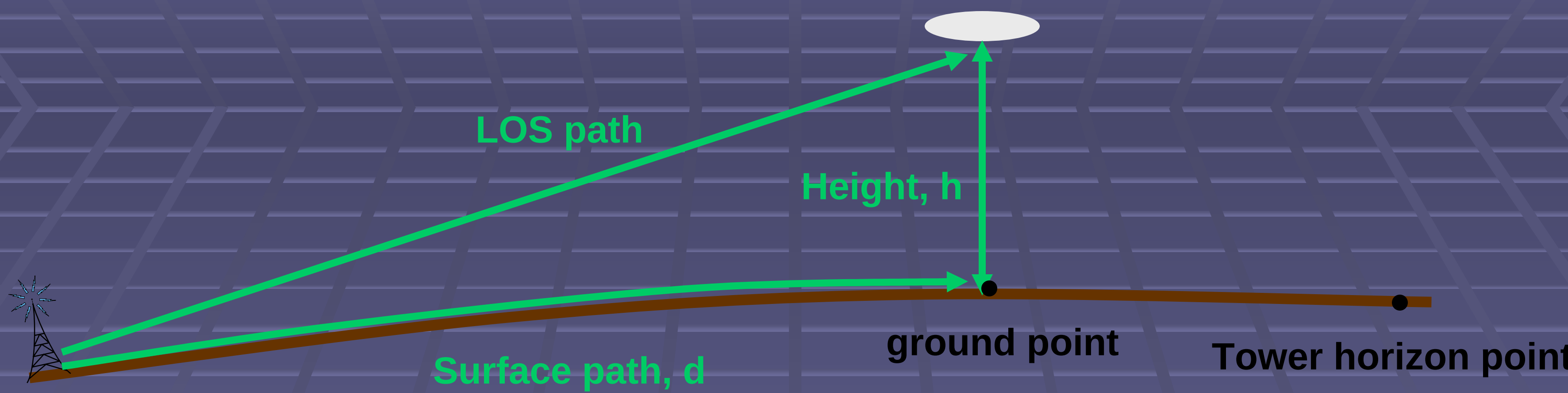
ALION
SCIENCE AND TECHNOLOGY



ALION
SCIENCE AND TECHNOLOGY


Seneca total ASF vs Lat
ASF
Altitude
2.2
2.15
2.1
2.05
2
1.95
1.9
1.85
1.8
1.75
1.7
1.65
1.6
38.85
38.9
38.95
39
39.05
39.1
39.15
39.2
39.25
0m
150m
300m
450m
600m
1200m
1500m
3000m

What about w/in LOS of Tower?



- At Horizon point:

$$D_{LOS} = \sqrt{(h + r_e)^2 - r_e^{\,2}}, \quad r_e = \text{earth radius}$$

$$D_{surface} = r_e \cdot \arctan\left(\frac{D_{LOS}}{r_e}\right)$$

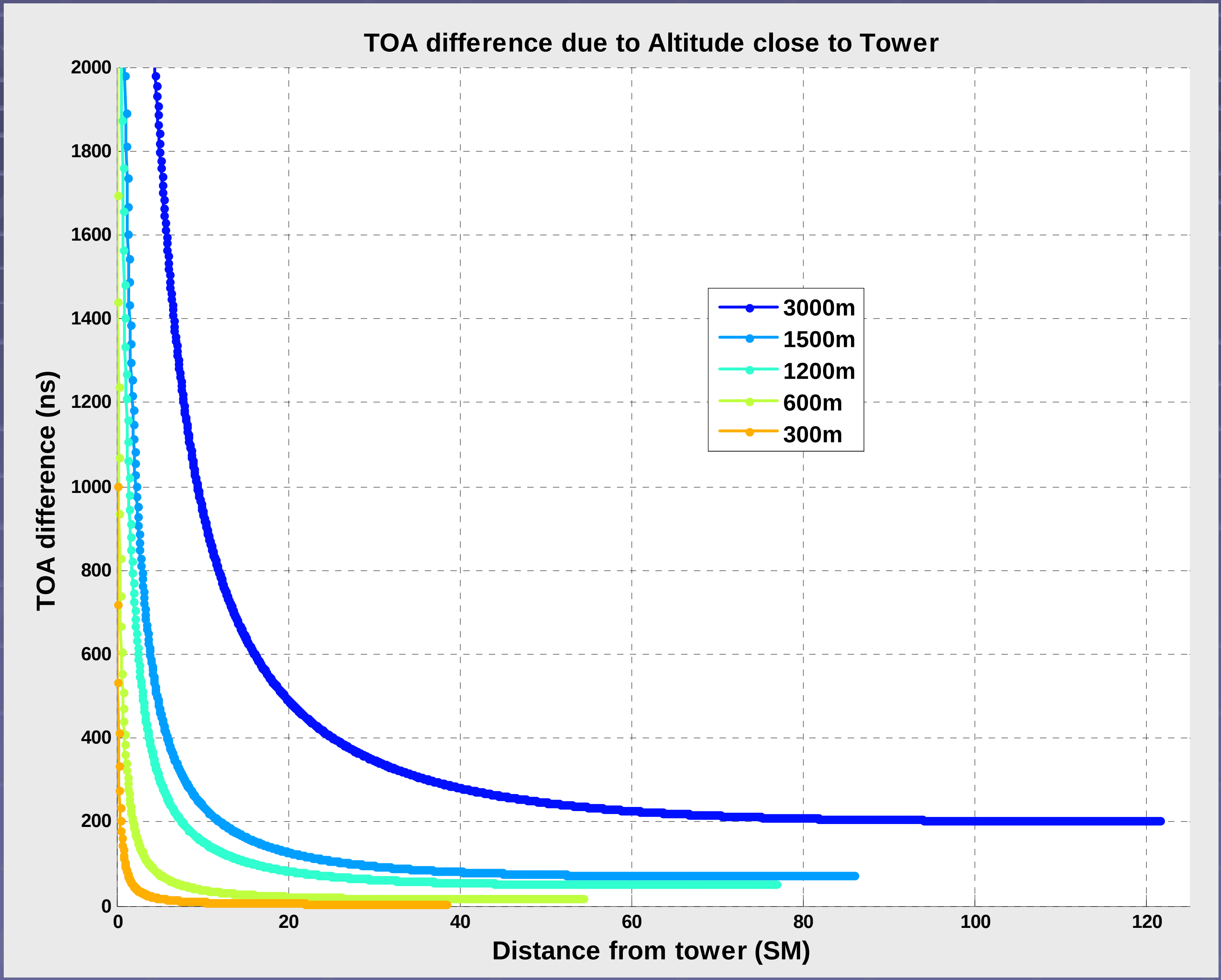
- d = 0 to Horizon Point (maximum)
- LOS path is function of both h and d

$$D_{LOS} \approx \sqrt{(h + r_e)^2 + r_e^2 - 2(r_e + h) r_e \cos(\theta)}, \quad \theta = \frac{d}{r_e}$$

$$\Delta Path = D_{LOS} - d$$

ALION
SCIENCE AND TECHNOLOGY

Close to Tower



Altitude Test

- Procedure
  - collect data at static points
  - Average over 30min period
  - 500 ft increments
  - E and H-field measurements
  - Ground reference for temporal corrections

- Analysis
  - Average ASF calculated for each altitude
  - Difference between airship and ground reference
  - Weather data will also be collected
  - Compare to theoretical predictions

ALION
SCIENCE AND TECHNOLOGY

Airship



ALION
SCIENCE AND TECHNOLOGY

Airship Test Results

- Equipment problems
- Reevaluated at FAATC
- Testing planned (then postponed due to wx)
- New date????
  - January in Clearwater…

Conclusions / Future

- Predictions align with measured data
- Airship testing to make more accurate measurements
- Depending upon ASF variation at an airport and the Station geometry, adding an altitude correction may lead to the use of multiple sets of static ASFs for an airport
- Predictions can be used to bound this problem

Acknowledgements

- US Federal Aviation Administration
  - Mitch Narins
- FAA Technical Center
  - Scott Shollenberger
  - Bob Erikson
- Alion Team
  - Mark Wiggins
  - Ken Dykstra
- ASF Working Group
  - Sherman Lo, Stanford University
  - Peter Morris, Northrop Grumman
  - Dave Diggle, Curt Cutright, Ohio University
  - Tom Gunther, Bob Wenzel, BAH
  - Jim Carroll, Volpe NTSC

Questions?

gwjohnson@alionscience.com

swaszek@ele.uri.edu

rhartnett@exmail.uscga.edu