Wallops Low Elevation Link Analysis for the Constellation Launch/Ascent Links

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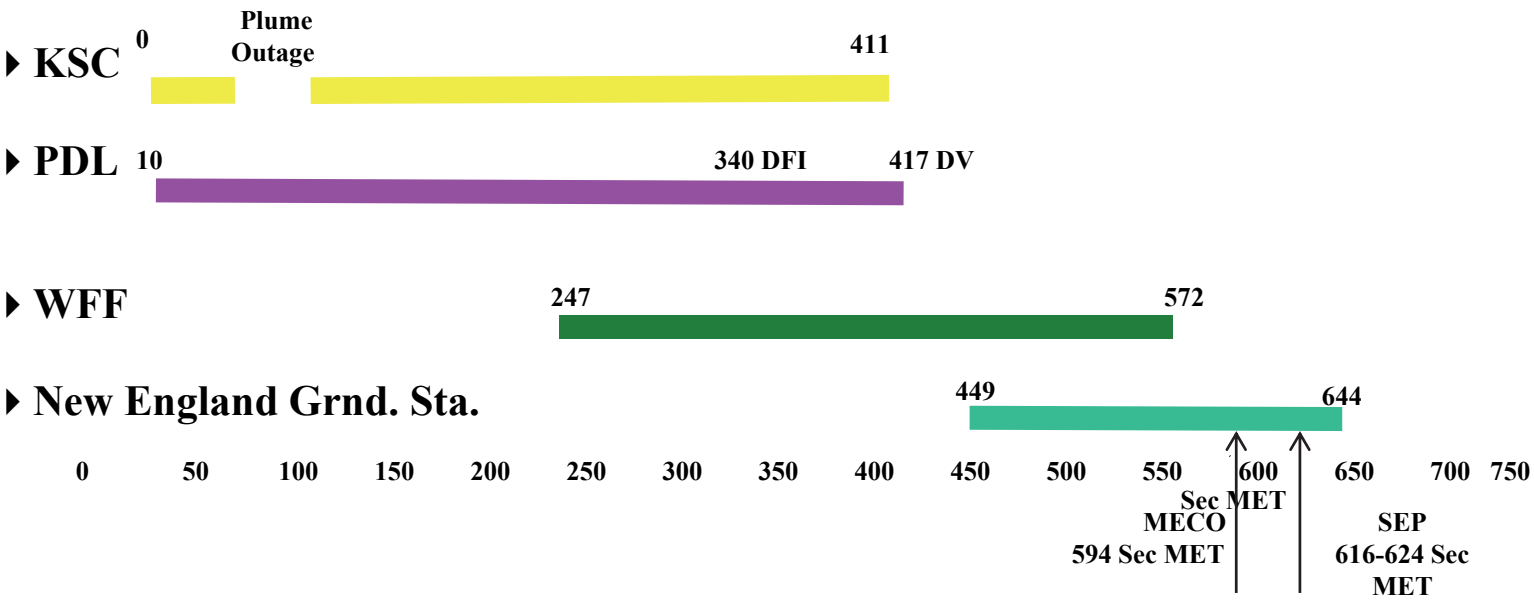
Part I:

Introduction and Summary of Results

Background

- **To execute the President's Vision for Space Exploration, the Constellation Program (CxP) was formed to build the next generation spacecraft Orion and launch vehicles Ares, to transport human and cargo to International Space Station (ISS), moon, and Mars**
- **This paper focuses on the detailed link analysis for Orion/Ares's launch and ascent links with Wallops' 11.3m antenna**
  - Orion's Dissimilar Voice link: 10.24 Kbps, 2-way
  - Ares' Developmental Flight Instrument link, 20 Mbps, downlink
- **Three launch trajectories are considered: TD7-E, F (Feb), and G (Aug)**
- **In certain launch scenarios, the critical events of main engine cutoff (MECO) and Separation occur during the low elevation regime of WFF's downrange – less than 5 degree elevation angle**
- **The goal of the study is to access if there is enough link margins for WFF to track the DV and DFI links**

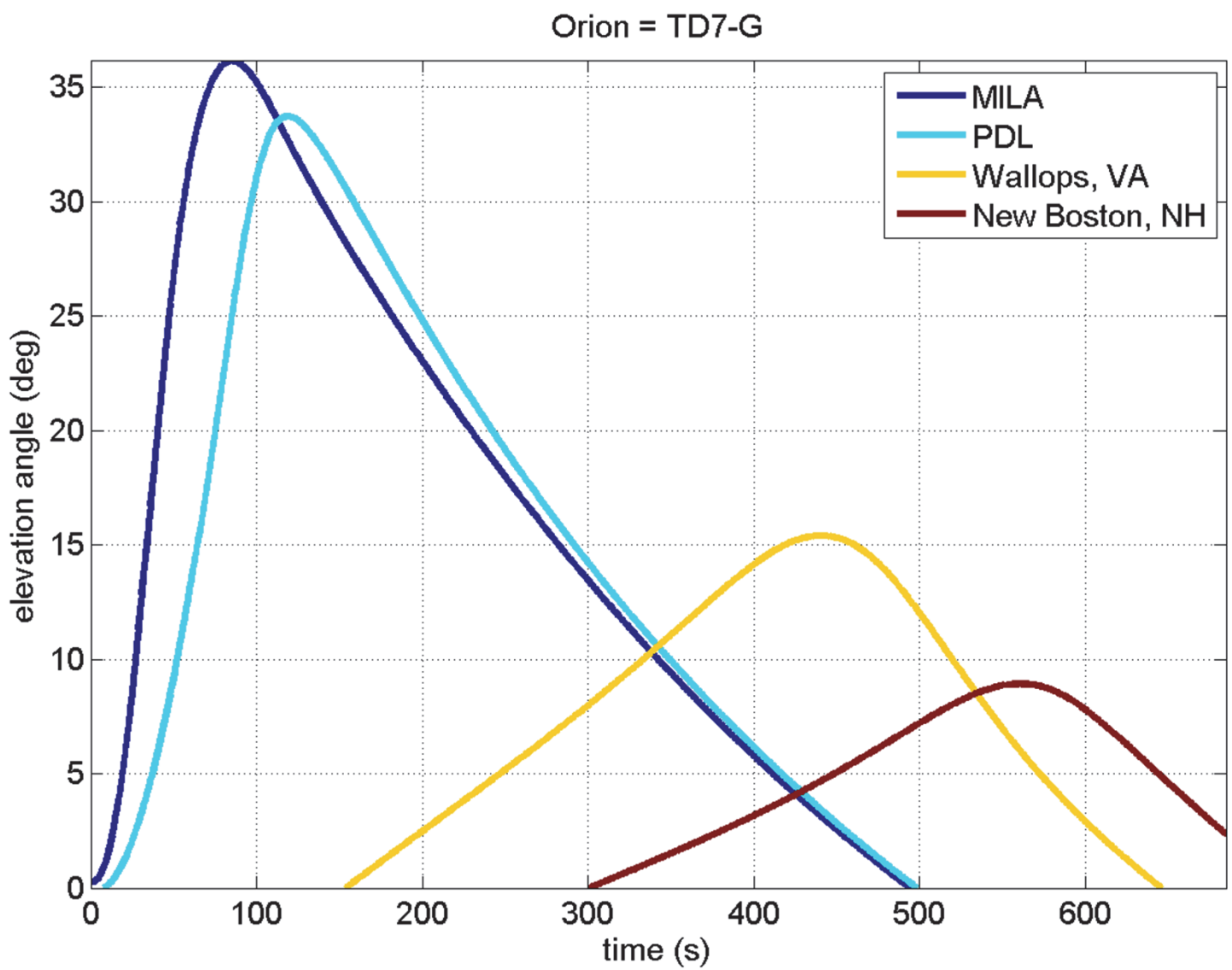
View Periods of KSC, PDL, WFF, New England (5º Elev)



NOTE:

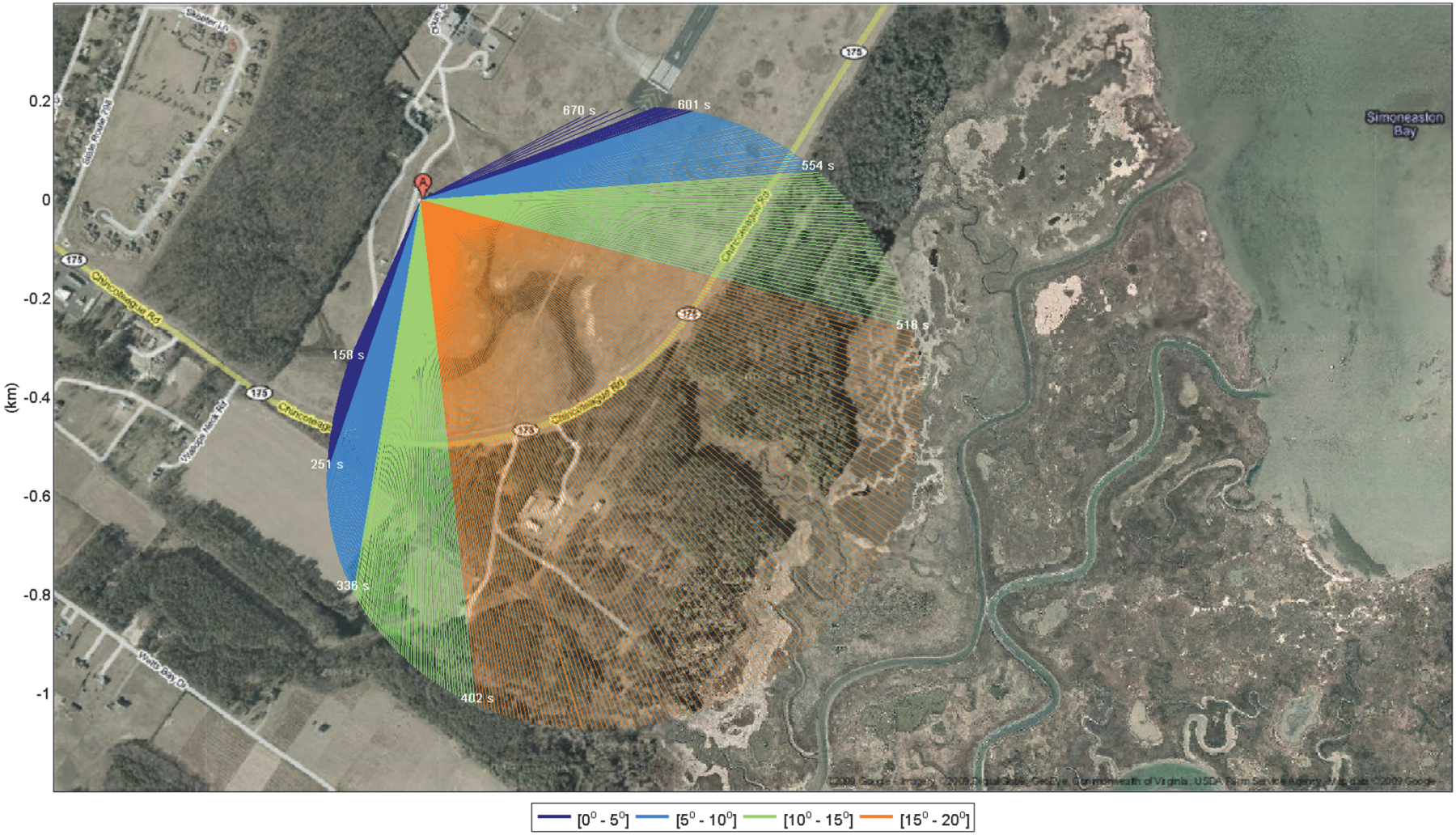
1. All times with the exception of KSC and PDL AOS are based on 5º elevation.
2. Times are worse case from trajectory TD7, E, F, &G,

Elevation Angle Profiles Based on TD7-G

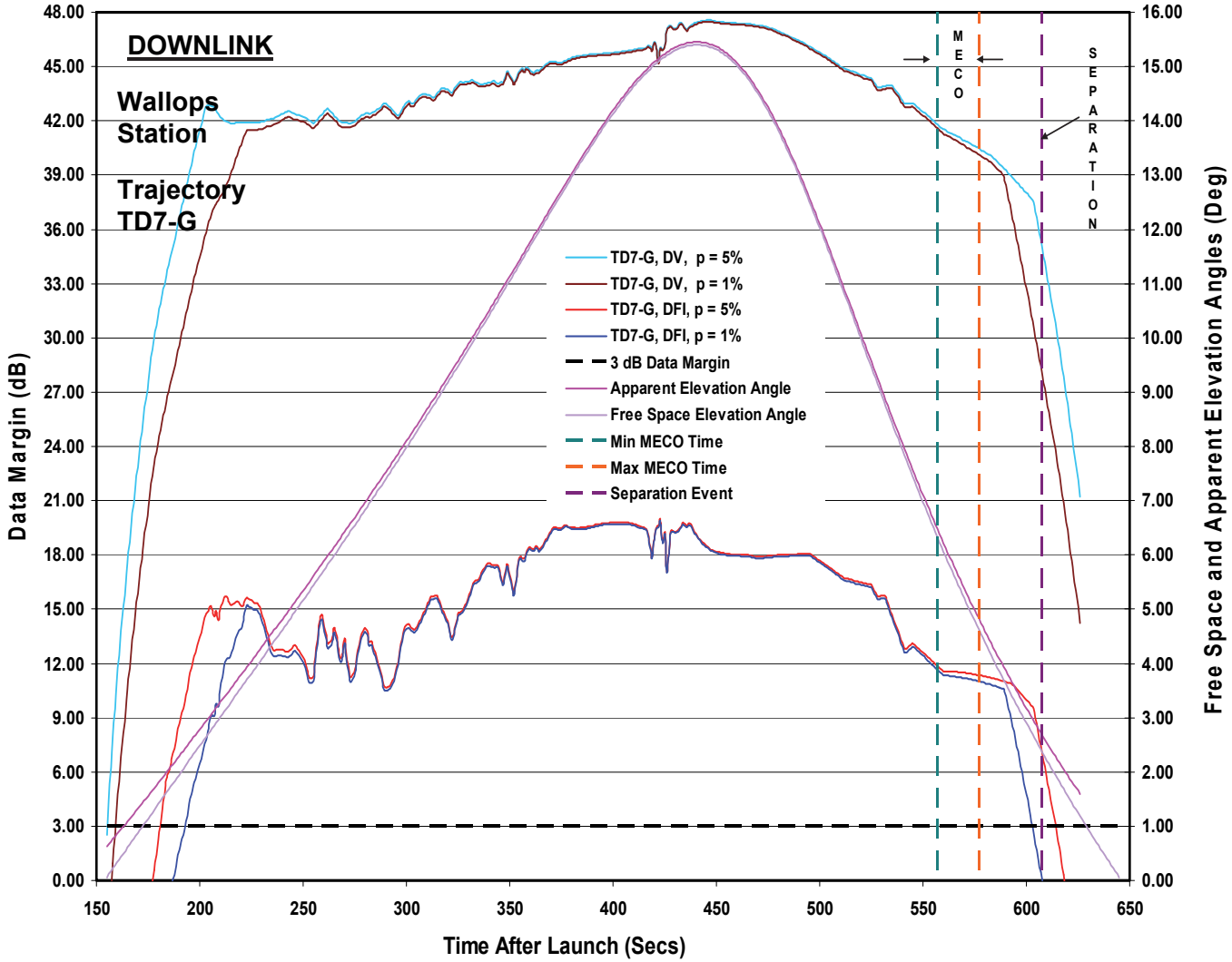


Azimuth & Elevation Angles @ WFF

Wallops Flight Facility Elevation to TR7-EMW-NE-ISS



Example: TD7-G DV and DFI Downlink



Summary of Results

- **For TD7-E trajectory (2/2015)**
  - DV downlink is closed (with > 3 dB margin) at 5° elevation and above
  - DV uplink is closed (with > 3 dB margin) at 5° elevation and above
  - DFI downlink is closed (with > 3 dB margin) at latest separation
- **For TD7-F (2/2015) and G (7/2015) trajectories**
  - DV downlink is closed at 5° elevation and above
  - DV uplink is closed at 5° elevation and above
  - DFI downlink is closed at latest separation for % time scintillation attenuation exceed 5%
  - DFI downlink has ~0 dB margin at latest separation for % time scintillation attenuation exceed 1%
- **Received STS-130 AGC data from R. Tye, analysis ongoing**

Part II:

Major Drivers and Challenges in Wallops' Low Elevation Angle Link Analysis

List of Drivers and Challenges

The Wallops' DV and DFI links at low elevation angle are not typical links; standard link analysis techniques and models might not apply

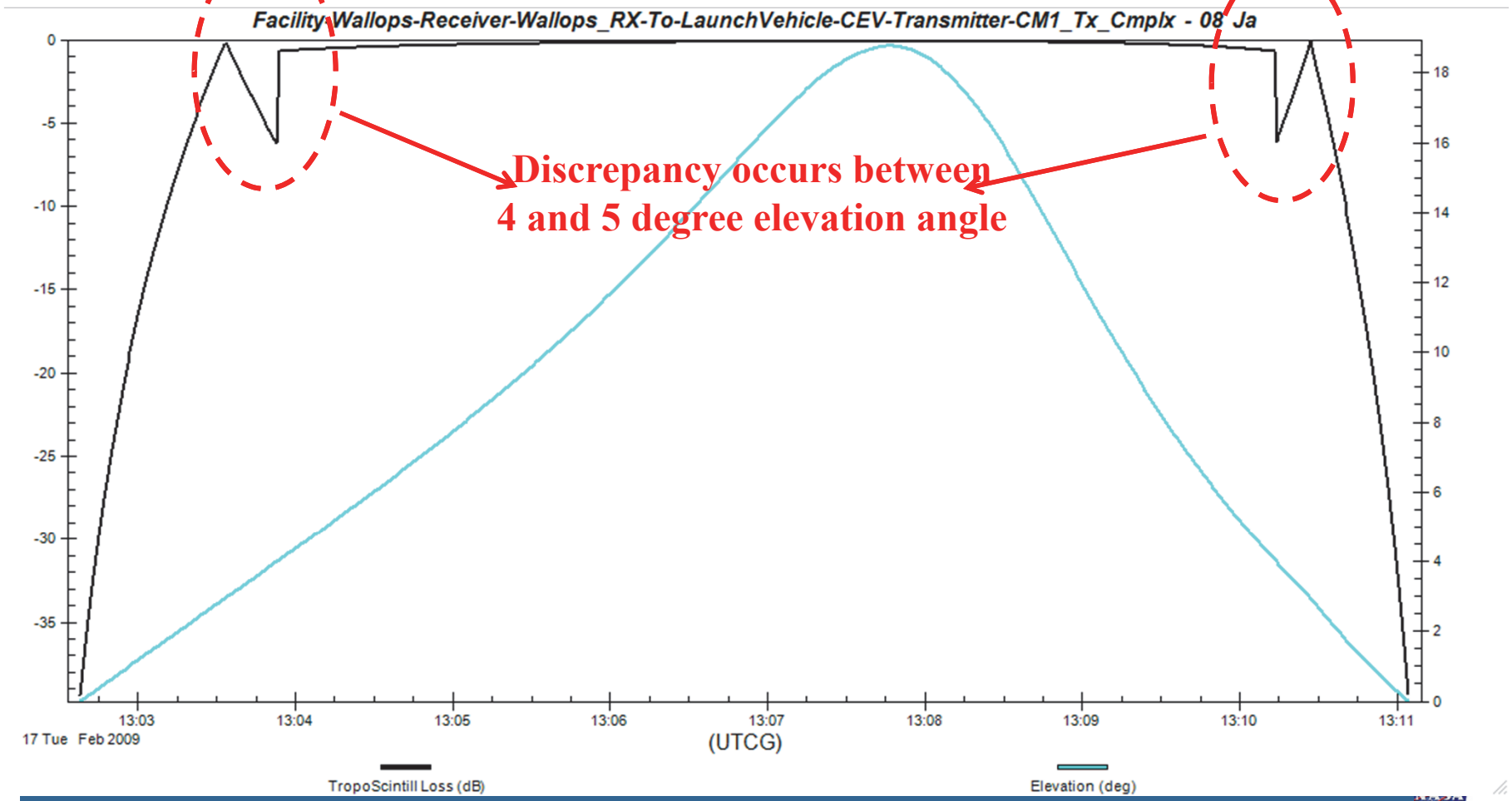
- **Idiosyncrasies of ITU tropospheric scintillation models**
- **Modeling the tail-end of spacecraft antenna patterns**
- **Use of apparent angle instead of true angle**
- **Use of Wallops measurements at low elevation angle**

Idiosyncrasies of ITU tropospheric scintillation models

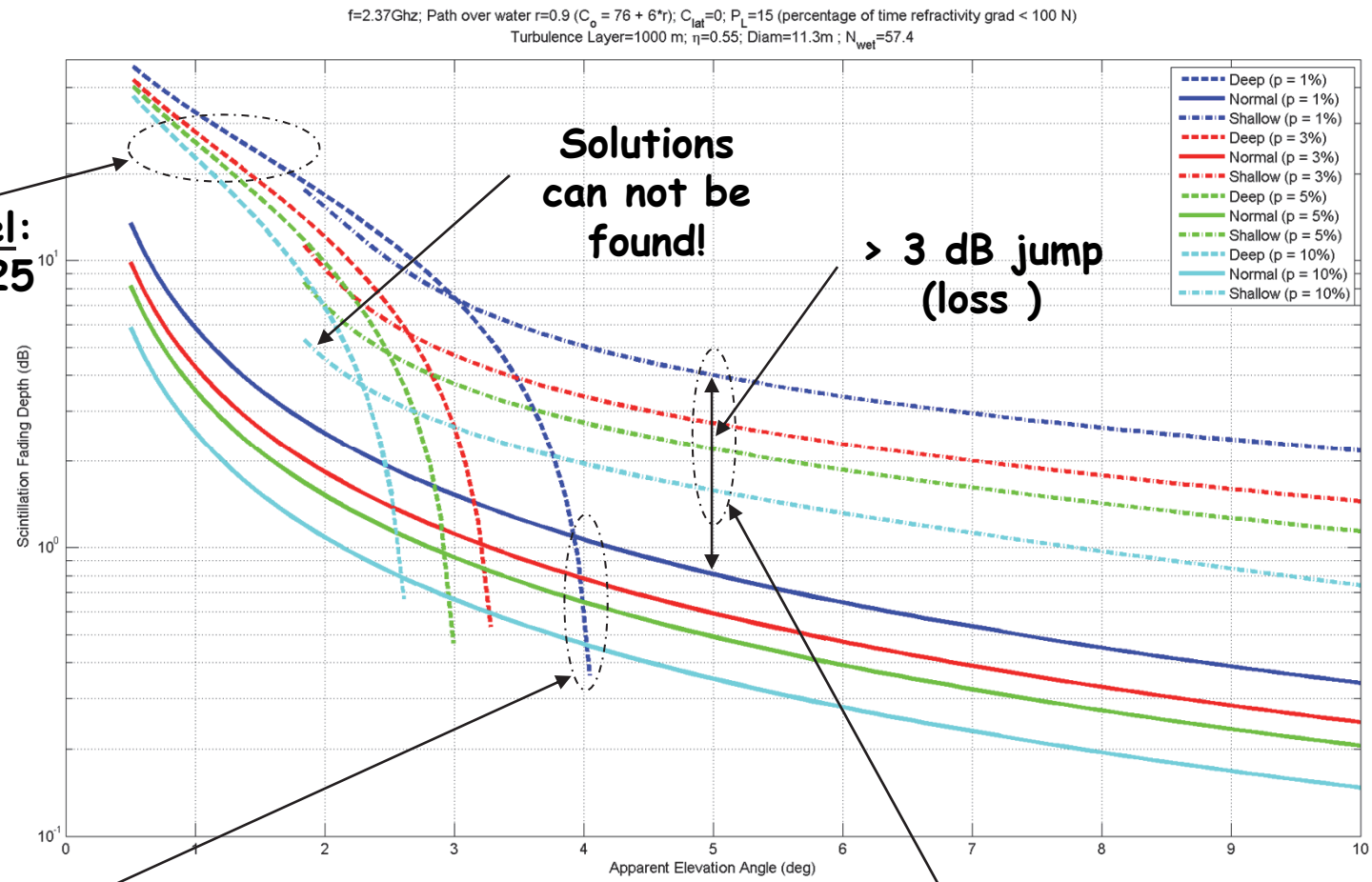
- **Tropospheric scintillation is the dominant impairment, yet existing ITU models are based on limited experimental and theoretical work and are problematic**
  - ITU normal fading model and shallow fading model overlaps at 4-5°
  - Existing ITU Recommendation uses ac hoc techniques, and does not always produce sensible results
  - Working with ITU-R Radiowave Propagation Study Group 3 (P. McKenna) to refine the models
  - New models received provisional approval from ITU to be adopted as new standard in late 2011 (ITU Meeting in Geneva, Oct 2011)
  - The new model has been validated using Wallops shuttle data and Goonhilly's measurement data
  - Detailed derivation of the new model is submitted for publication in the IEEE International Symposium of Antenna and Propagation, Spokane, Washington, July 2011

Illustration of ITU Model Idiosyncrasy using STK

- Scintillation loss profile for CxP launch/ascent generated by STK
- STK uses the standard ITU-R P.618-10 scintillation model



Issues in ITU-R P.618-10

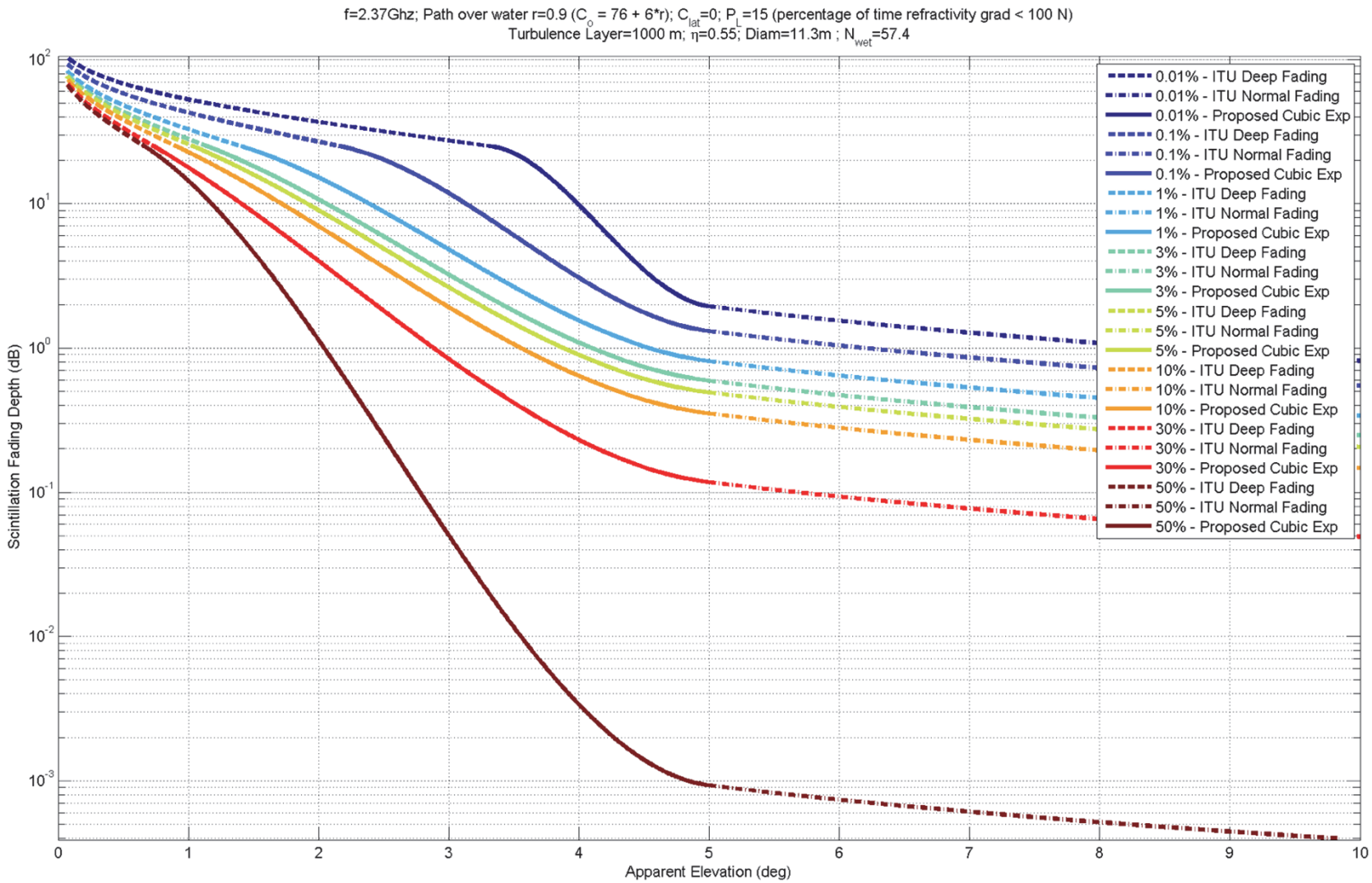


Deep fading model: valid for depths 25 dB and above

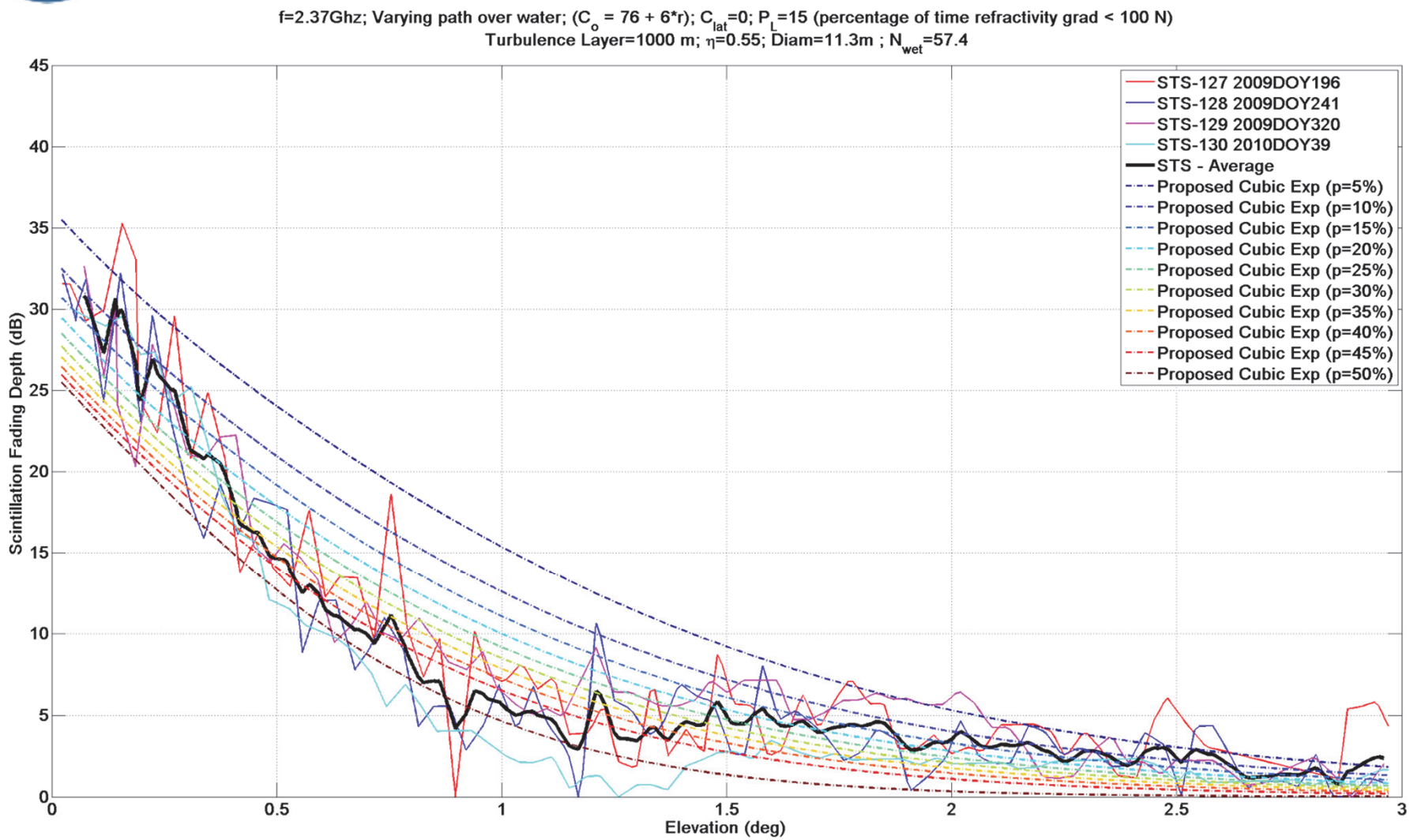
Normal fading model: not valid for elevations less than 4° (Max 50%)

Shallow fading model: does not extend from the deep fading model at 25 dB and does not match the normal fading model at 5° elevation

Corrected and Enhanced Scintillation Model



Validation of Model with Shuttle Measurements



Modeling the Tail-End of SC Antenna Patterns

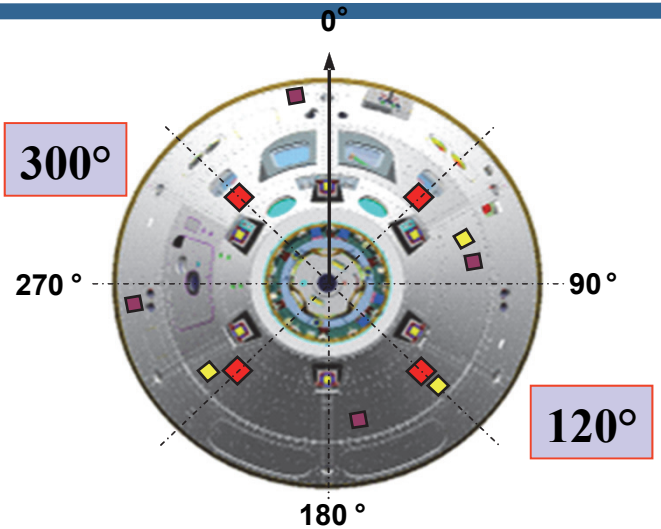
- ARES SRD has a requirement of 10° roll angle error

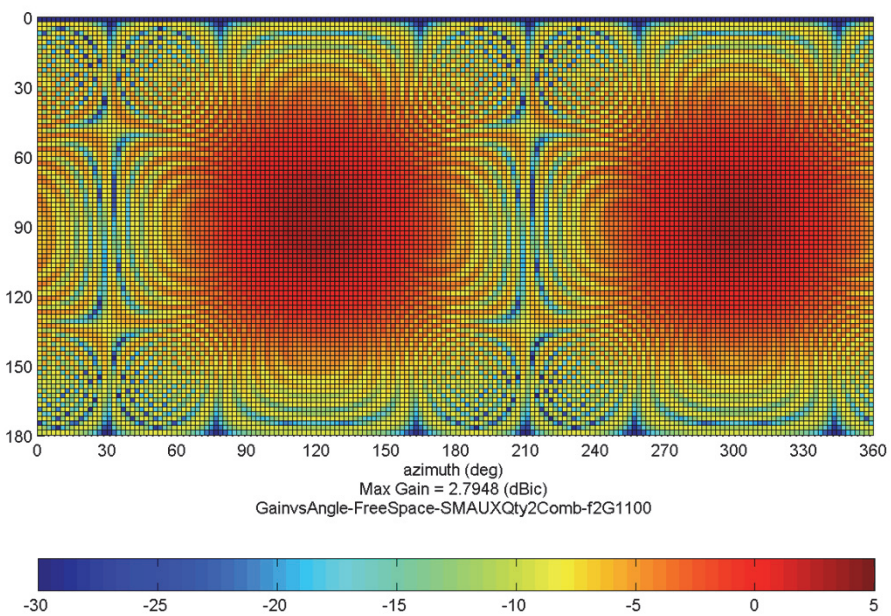
- In the vicinity of MECO and separation (L+550s to L+650s) WFF is looking at the tail part of the antenna patterns (both DV and DFI), which have many fringes and are sensitive to roll angle error

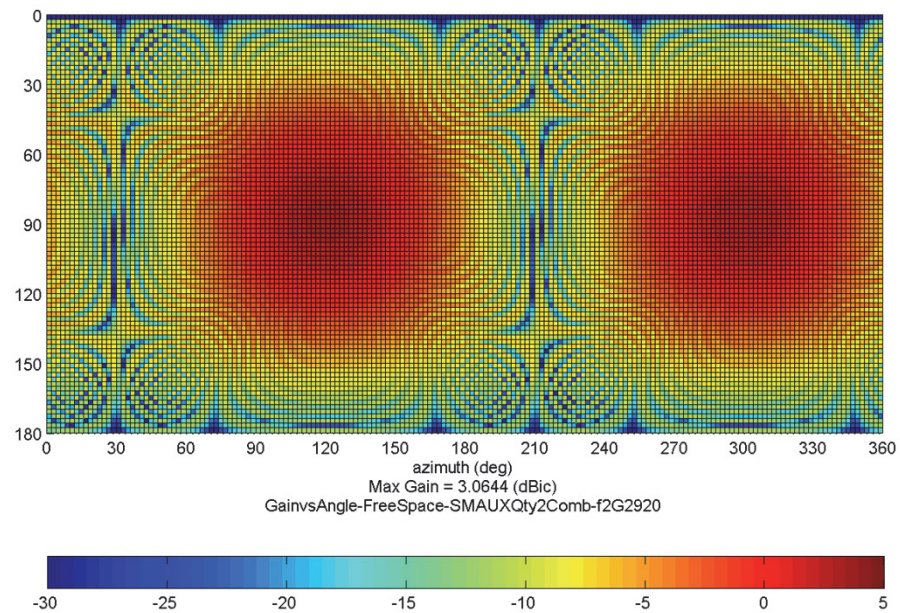
- Thus we need to use the worst antenna gain number within +10° and -10° roll angle error for link analysis

DV Launch/Early Ascent Antennas

Latest antenna patterns
From Julie Huffman (LM)

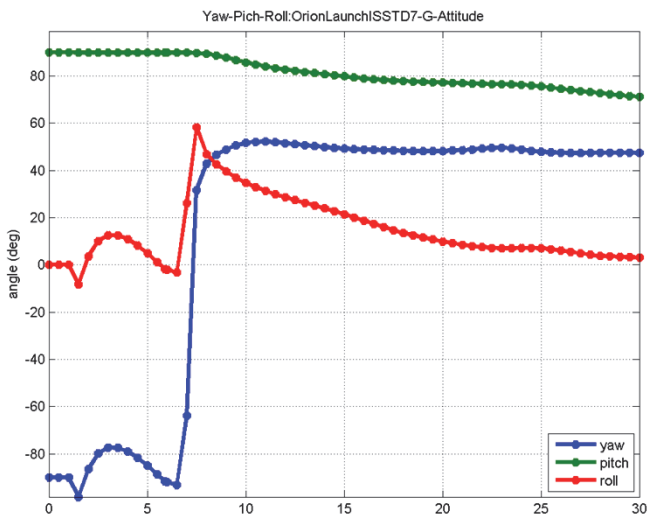




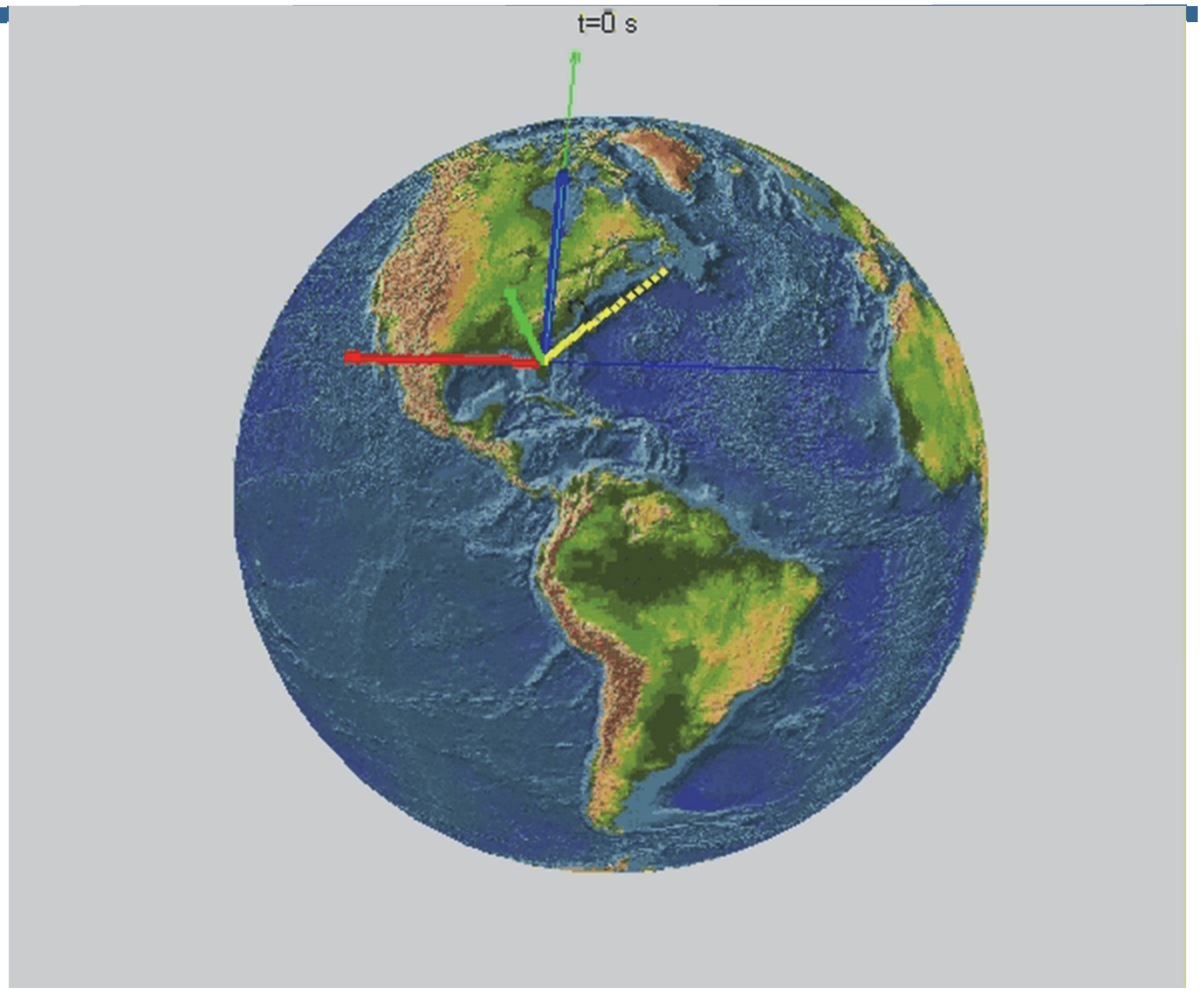


Orion Attitude (TD7-G)

```
stk.v.8.0
BEGIN Attitude
ScenarioEpoch 17 Feb 2009 13:00:00.0
NumberOfAttitudePoints 1371
CoordinateAxes Custom UseForPost
Sequence 321
AttitudeTimeEulerAngles
        0        -90        90       360
      0.5  -90.00016        90       360
        1  -90.00082        90       360
      1.5  -98.23038  89.99003  351.7674
```



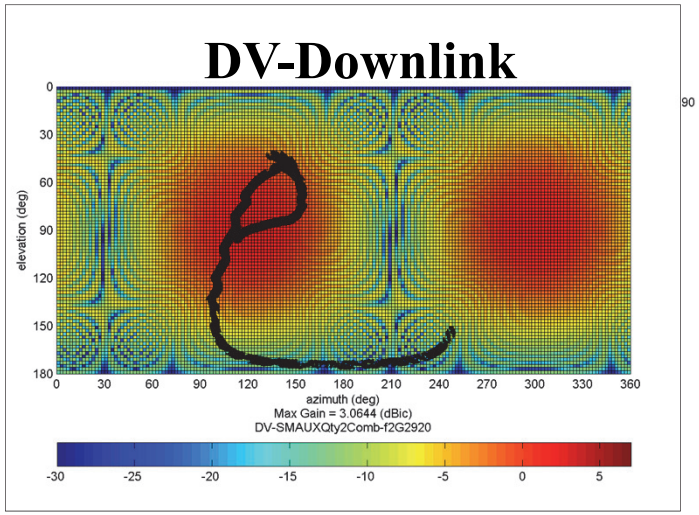
- LAS separation at L + 156 seconds
- MECO occurs at
  - TD7-E: min 562.5 s max: 584.0 s
  - TD7-F: min 558.5 s max: 579.5 s
  - TD7-G: min 556.9 s max: 577.7 s
  - Earlier than previous estimate by 10 seconds
- Separation at 30s later
  - TD7-E: latest is 614.0 seconds
  - TD7-F: latest is 609.5 seconds
  - TD7-G: latest is 607.7 seconds

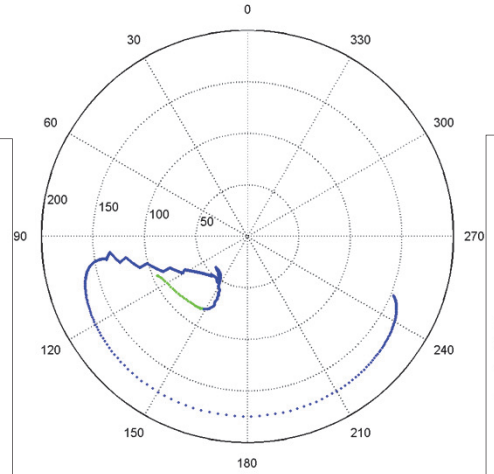


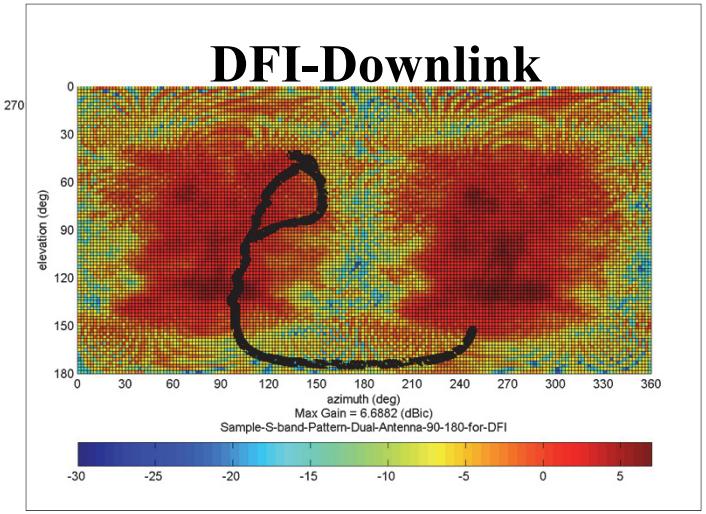
Thin green = tangential North (X+)
Thin blue = tangential East (Y+)
Yellow dots = Flight Path

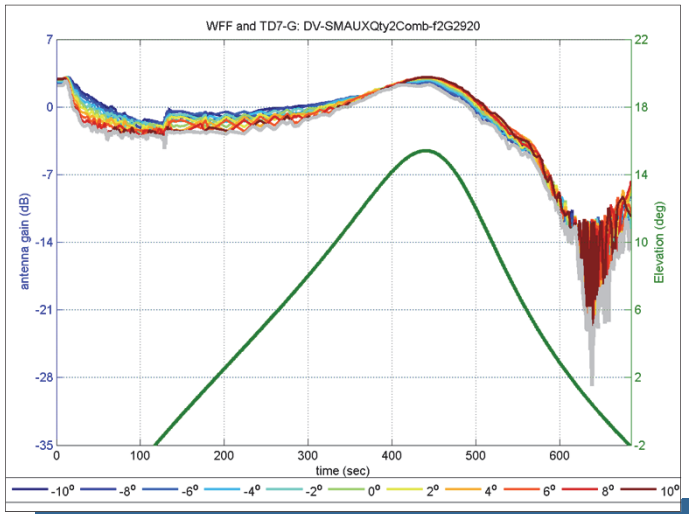
Bold green = Nose (X+)
Bold blue = (Y+)
Bold red = Window (Z+)

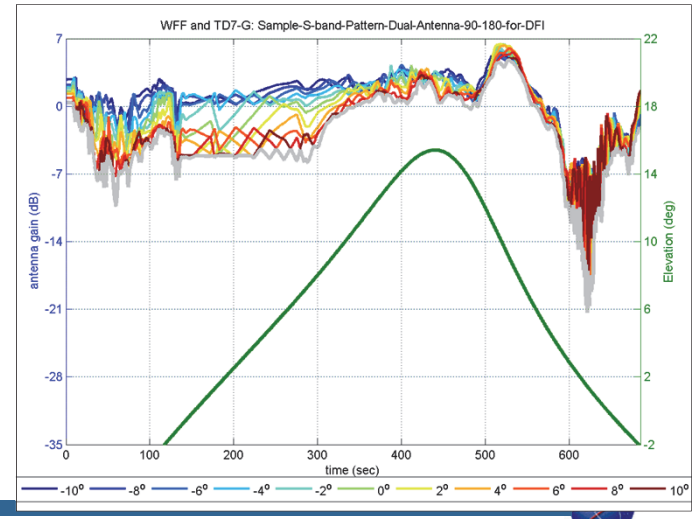
Example: TD7-G to WFF Downlink Gains



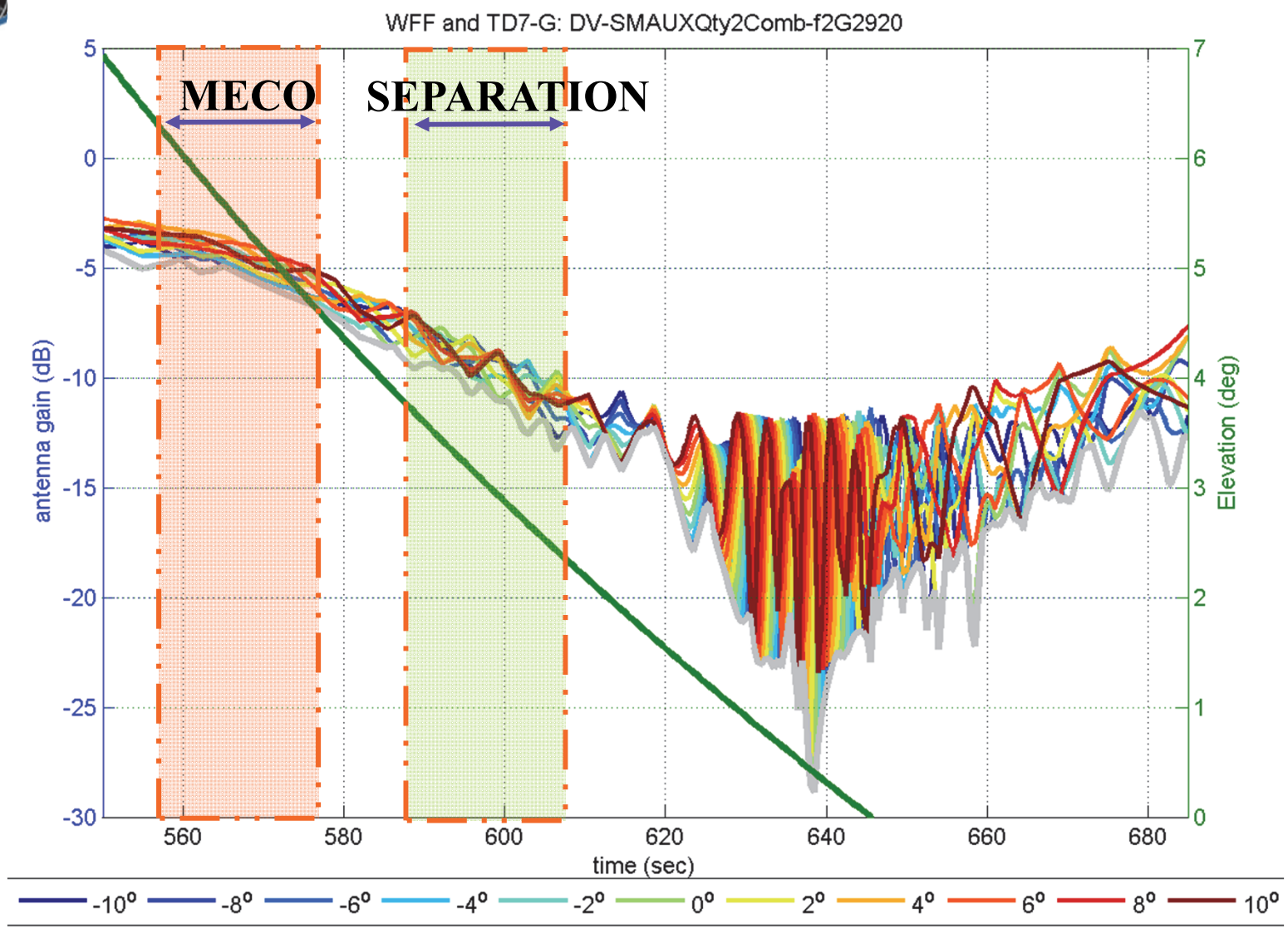




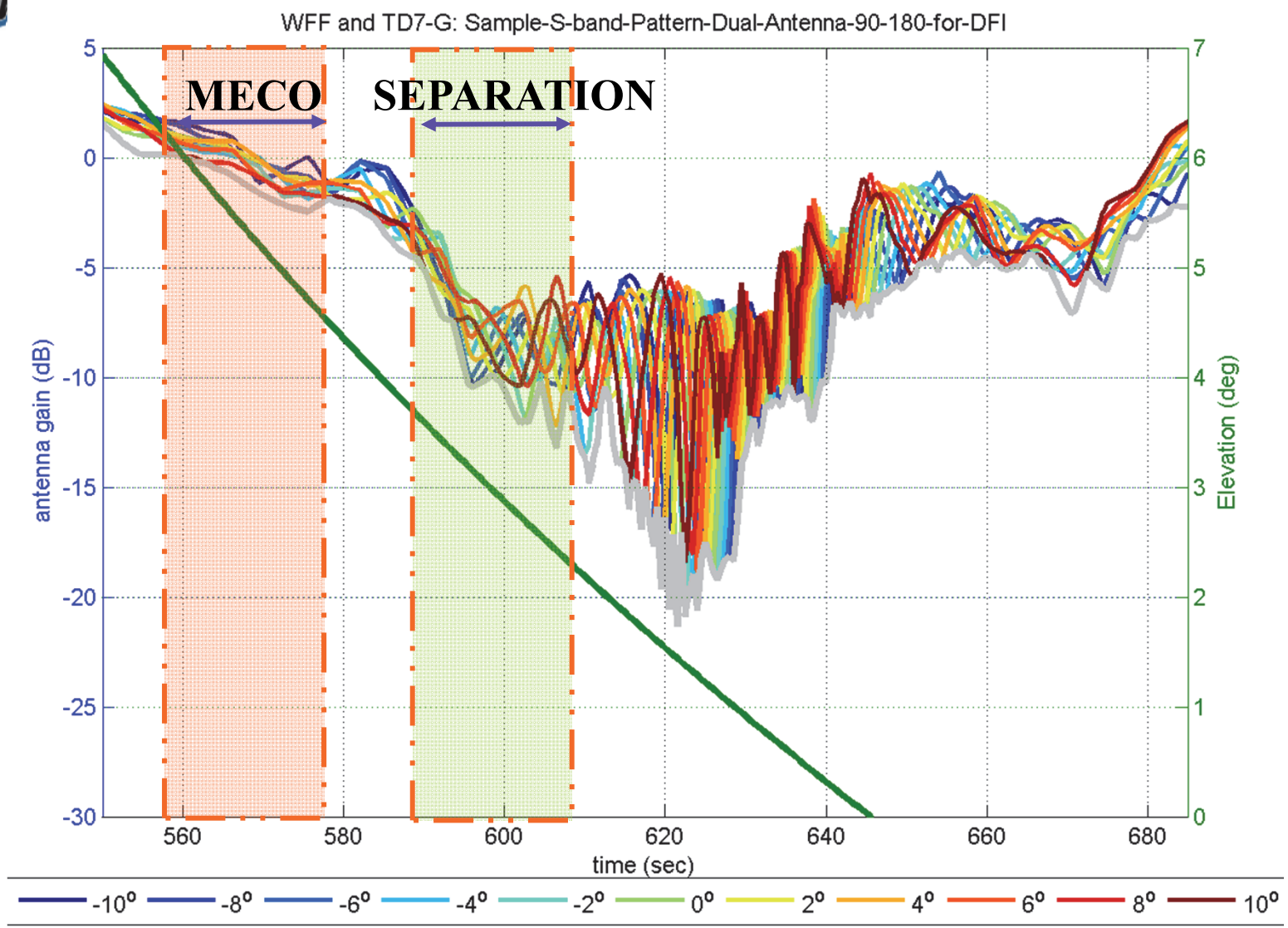




TD7-G to WFF DV Downlink Gains



TD7-G to WFF DFI Downlink Gains

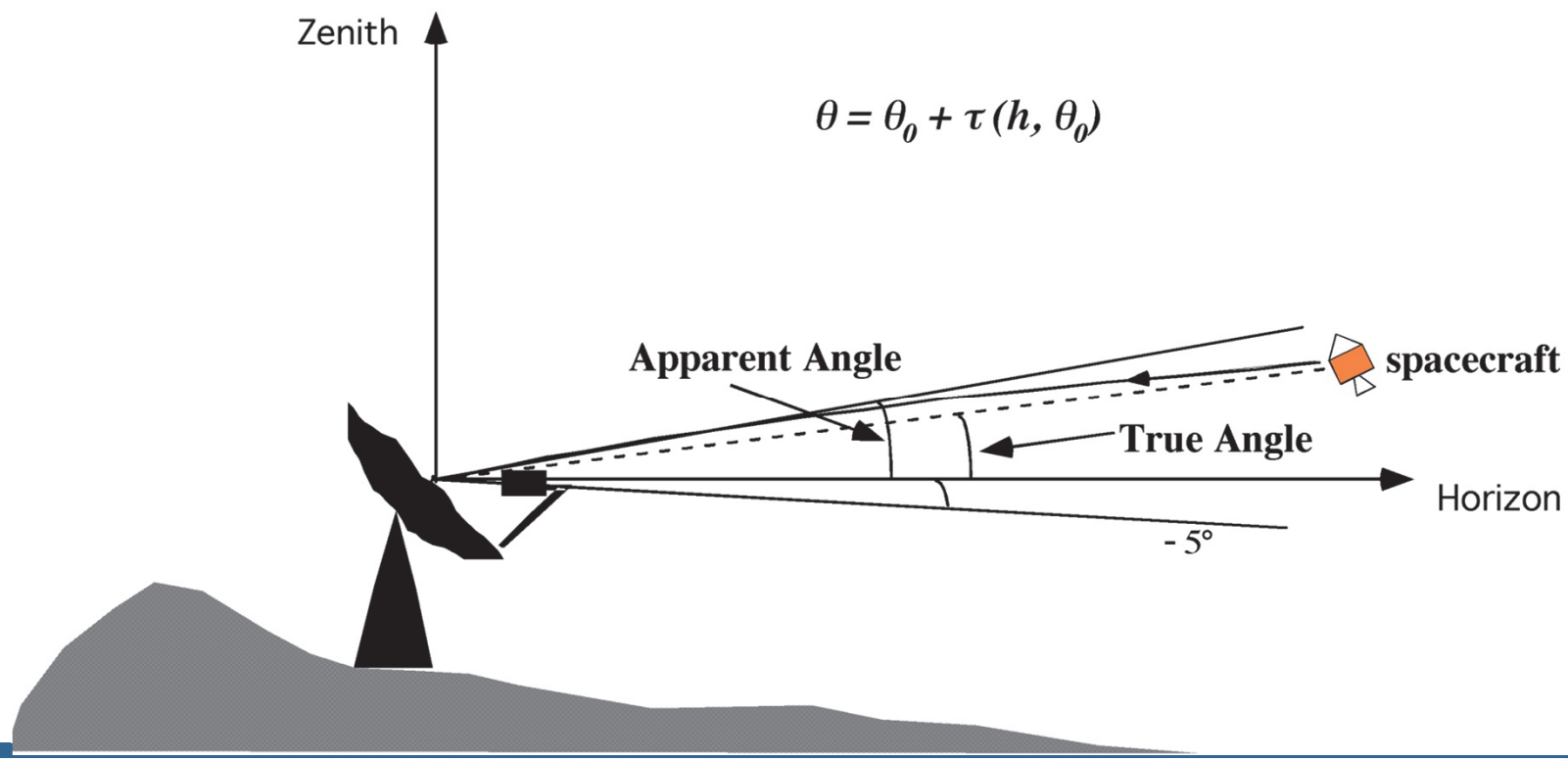


Use of Apparent Angle Instead of True Angle

Apparent Elevation Angle vs True Elevation Angle

At low elevation angle, due to the ray bending caused by the atomspheric gradient, the apparent elevation angle (θ) is usually larger than the true elevation angle (θ_0) of the target relative to the receiving station

$$\theta = \theta_0 + \tau(h, \theta_0)$$



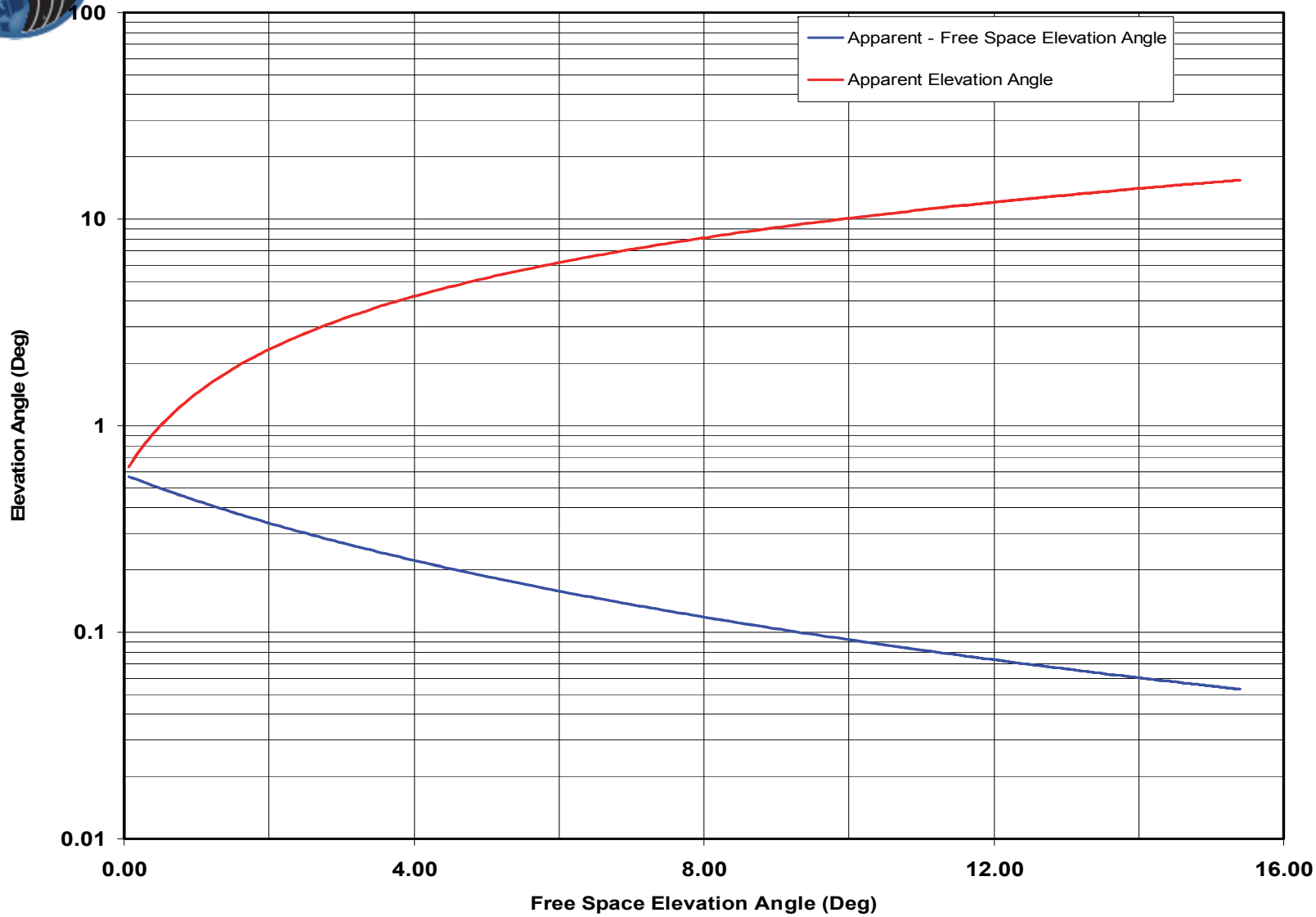
Detailed Calculation of apparent Angle (August)

- **The values of (degrees) have been evaluated under the condition of the reference atmosphere and it was found that the following numerical formula gives a good approximation:**

$$\theta_0 = \theta + 1/[1.728 + 0.5411\,\theta + 0.03723\,\theta^2 + h\,(0.1815 + 0.06272\,\theta \quad 0.01380\,\theta^2) + h2\,(0.01727 + 0.008288\,\theta)]$$

- **The following figure shows the relationship between the free space elevation angle of an antenna and the apparent elevation angle needed to communicate with the spacecraft.**

Difference Between Apparent Angle and True Angle



Use of WFF's Measurements at Low Elevation Angle

- **Measurements and Data Analysis of Wallops' 11.3m Antenna to Support Low Elevation Tracking of CxP DV and DFI Links**
  - Honeywell Team performed G/T measurements at low elevation angles on Nov 9-10, 2009
  - Additional G/T measurements was obtained on Jan 15, 2010 to refine the G and T models around 50-70° azimuth when MECO and separation occurs

- **Working with R. Tye and WFF Operation Team to prepare AGC and signal strength data measurements in the upcoming STS-130 Shuttle launch (February, 2010)**
  - Troposhperic scintillation is the dominant impairment of DV and DFI links at low elevation angle, yet existing ITU models are based on limited experimental and theoretical work and are problematic
  - Analysis of the shuttle data would help to refine the ITU models and provide more accurate link analysis for the DV and DFI links
  - This analysis will feed back to ITU to advance the state-of-the-art of modeling the tropospheric scintillation loss

Measurements and Data Analysis of Wallops' 11.3m Antenna

2250 MHz

Measurement 1 Low Elevation Angle Cold Sky Measurements						
Antenna Az	Antenna El	Cold (Sky) Measurement (dBm/Hz)	Hot (Sun) Measurement (dBm/Hz)	Y-Factor	G/T (dB/K)	Deg
171.2º	5º	-109.6	-93.92	15.68	20.75	
171.2º	4º	-109.6	-93.92	15.68	20.75	
171.2º	3º	-109.9	-93.92	15.98	21.06	
171.2º	2º	-110.1	-93.92	16.18	21.26	
171.2º	1º	-109.6	-93.92	15.68	20.75	
171.2º	0º	-107.8	-93.92	13.88	18.89	

2291.5 MHz

System Noise Temperature Increase as Elevation Angle Increase

Measurement 2 Low Elevation Angle Cold Sky Measurements						
Antenna Az	Antenna El	Cold (Sky) Measurement (dBm/Hz)	Hot (Sun) Measurement (dBm/Hz)	Y-Factor	G/T (dB/K)	Deg
175.1º	5º	-111.3	-93.92	17.38	22.63	
175.1º	4º	-111.3	-93.92	17.38	22.63	
175.1º	3º	-111.3	-93.92	17.38	22.63	
175.1º	2º	-110.8	-93.92	16.88	22.12	
175.1º	1º	-110.4	-93.92	16.48	21.71	
175.1º	0º	-107.8	-93.92	13.88	19.86	

2370.5 MHz

Measurement 3 Low Elevation Angle Cold Sky Measurements						
Antenna Az	Antenna El	Cold (Sky) Measurement (dBm/Hz)	Hot (Sun) Measurement (dBm/Hz)	Y-Factor	G/T (dB/K)	De
175.1º	5º	-111.6	-93.75	17.85	23.39	
175.1º	4º	-111.3	-93.75	17.55	23.08	
175.1º	3º	-110.8	-93.75	17.05	22.57	
175.1º	2º	-110.8	-93.75	17.05	22.57	
175.1º	1º	-110.4	-93.75	16.65	22.16	
175.1º	0º	-108.6	-93.75	14.85	20.31	

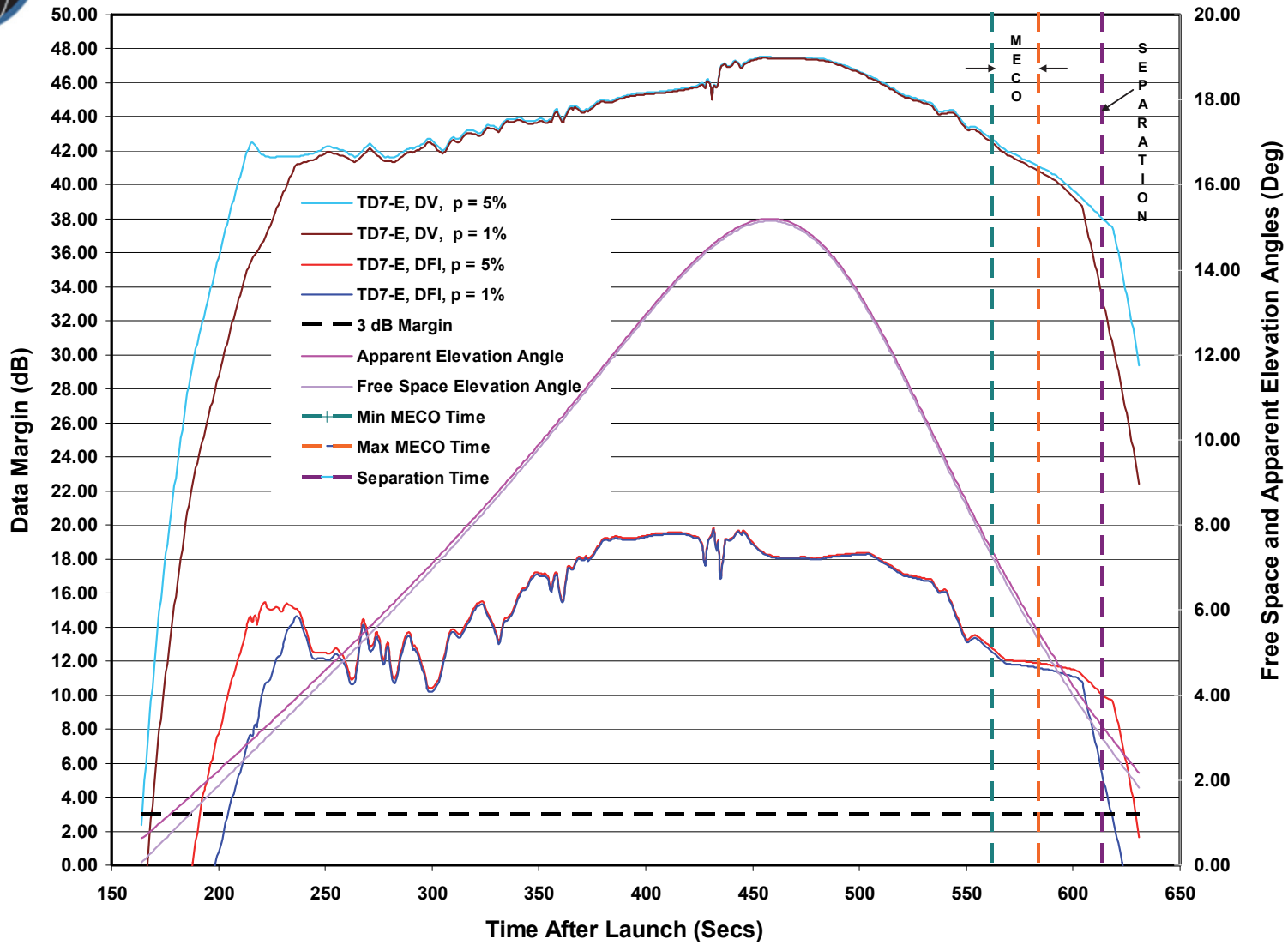
Concluding Remarks

- **We obtained much better understanding on analyzing the low elevation links, and the experience and techniques can be useful for future flight missions**

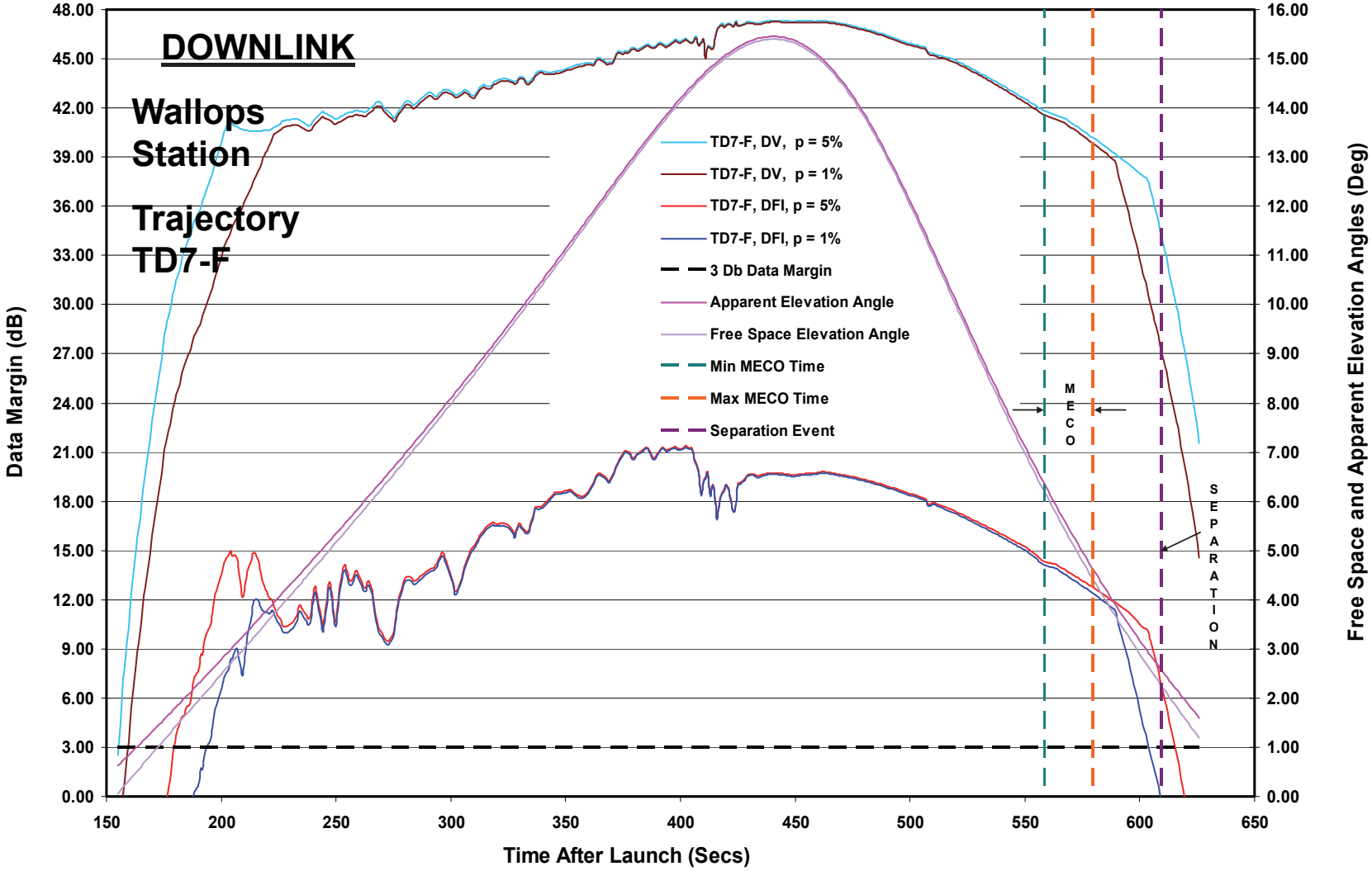
- **We identified the idiosyncrasies of the ITU tropospheric models, and this lead to ongoing collaboration between the SCaN Team and the ITU Team to refine and to advance the tropospheric scintillation modeling**

Backup

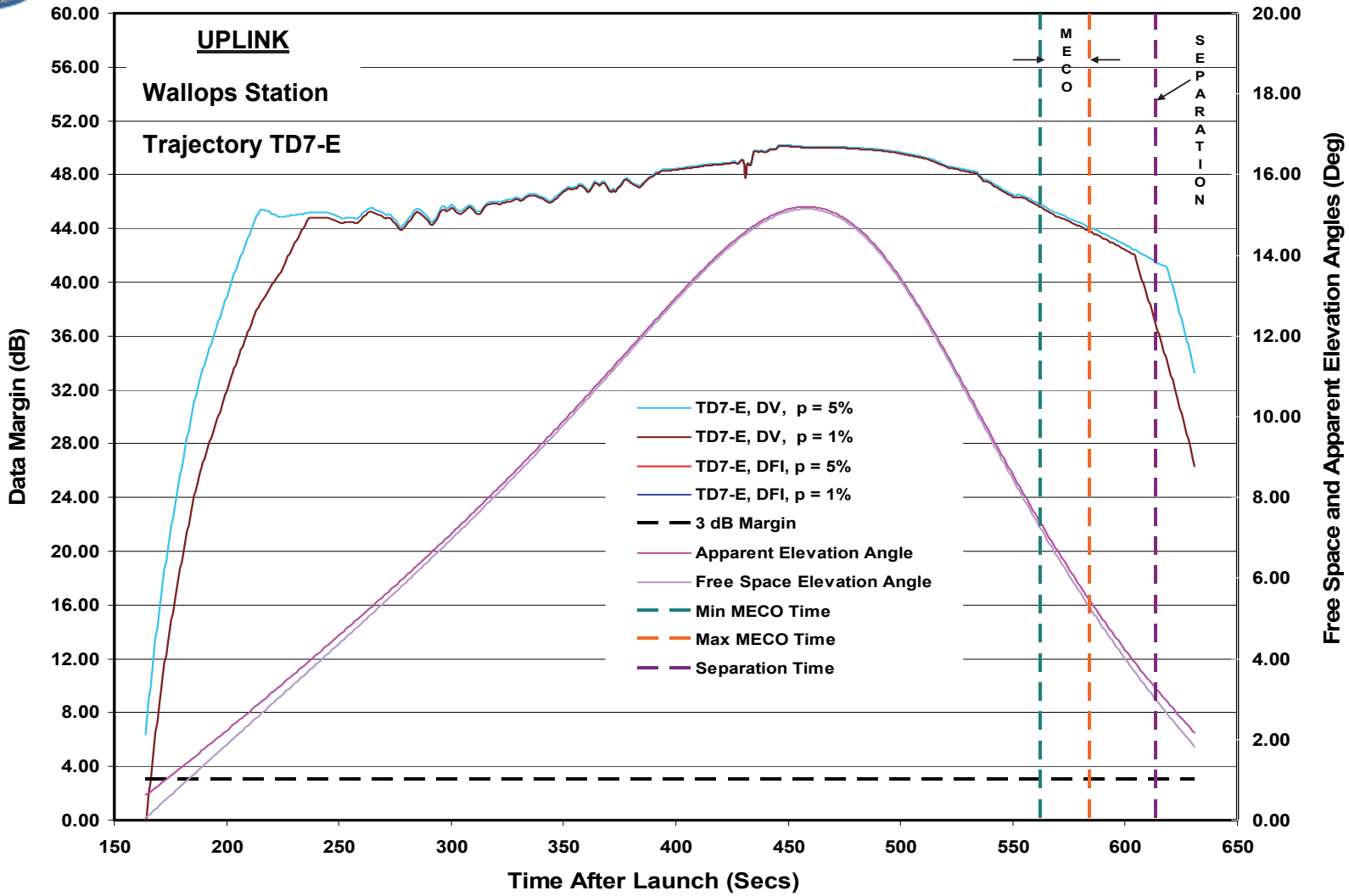
TD7-E DV and DFI Downlink



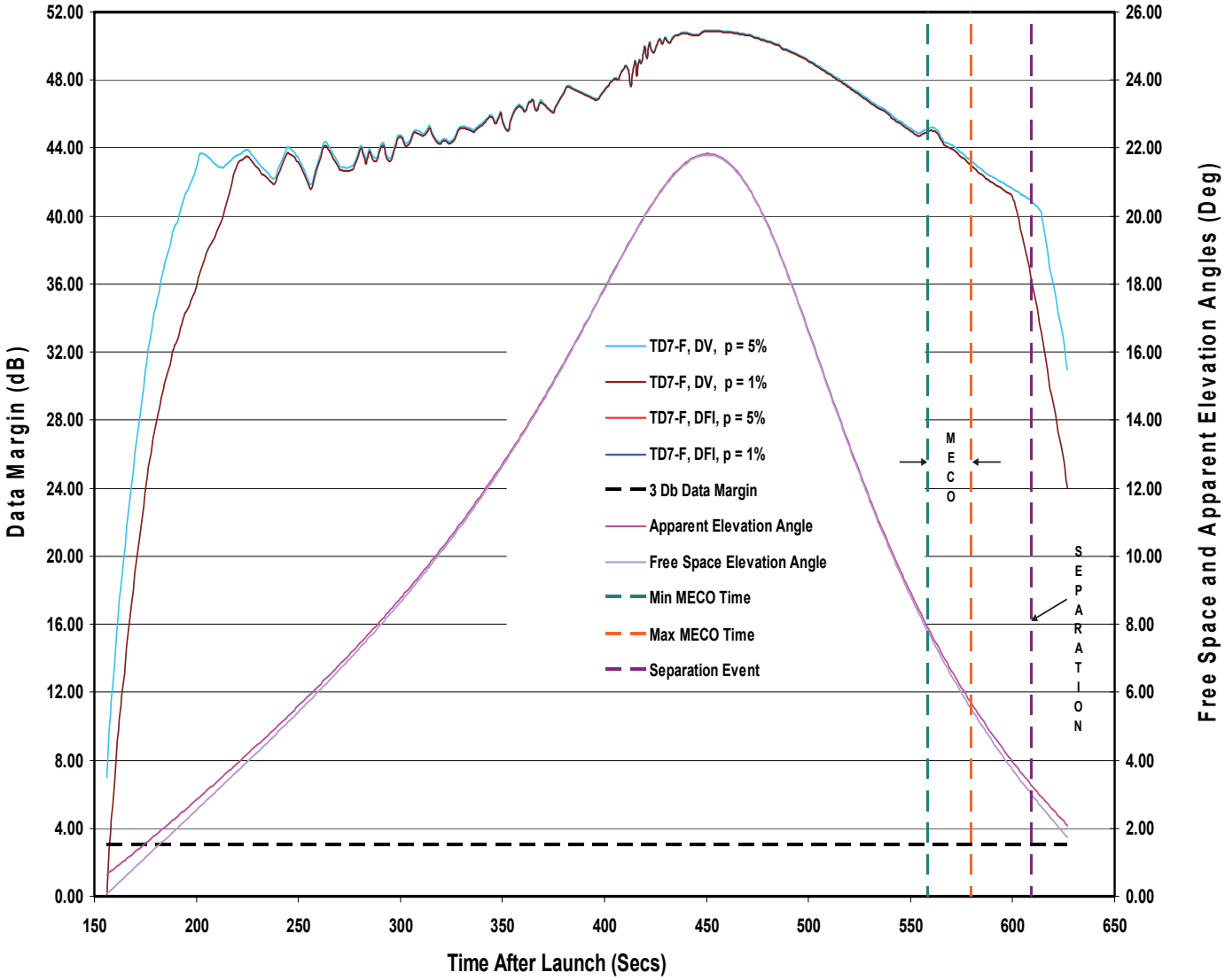
TD7-F DV and DFI Downlink



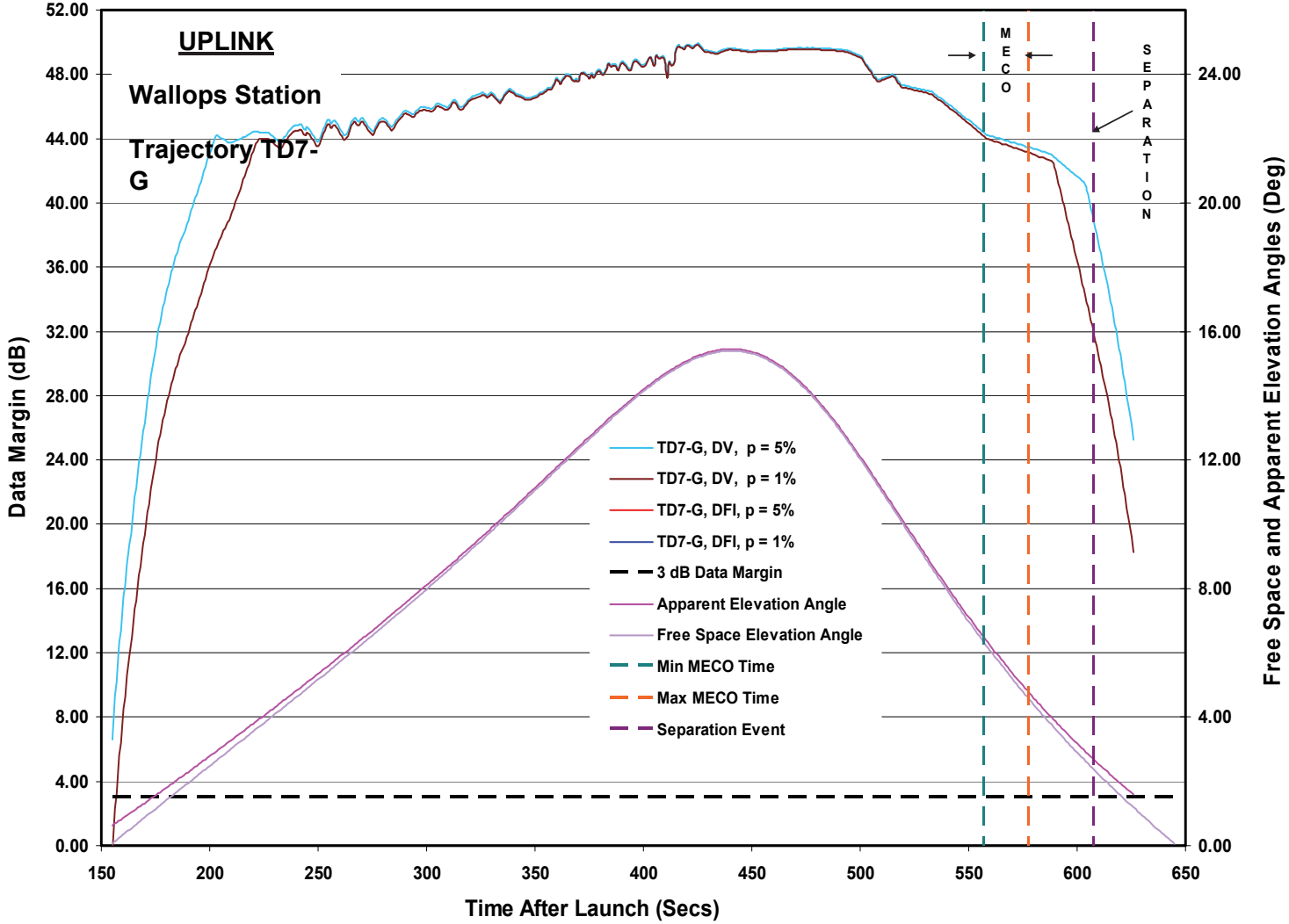
TD7-E DV Uplink



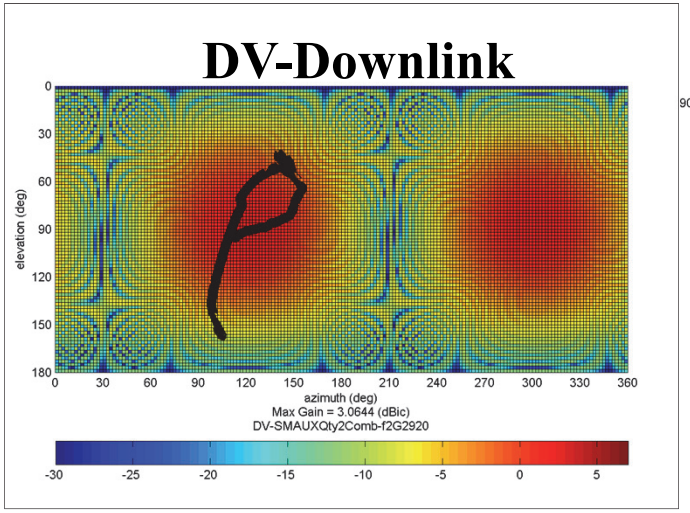
TD7-F DV Uplink

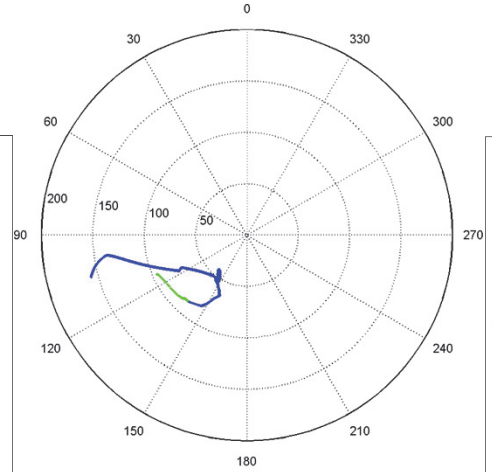


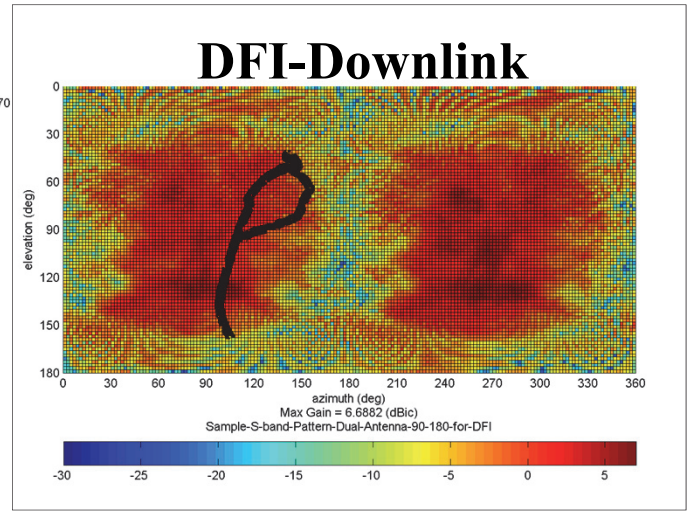
TD7-G DV Uplink

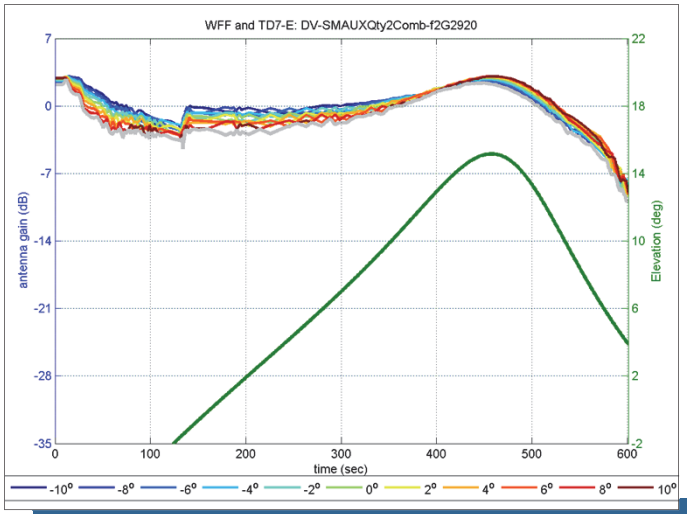


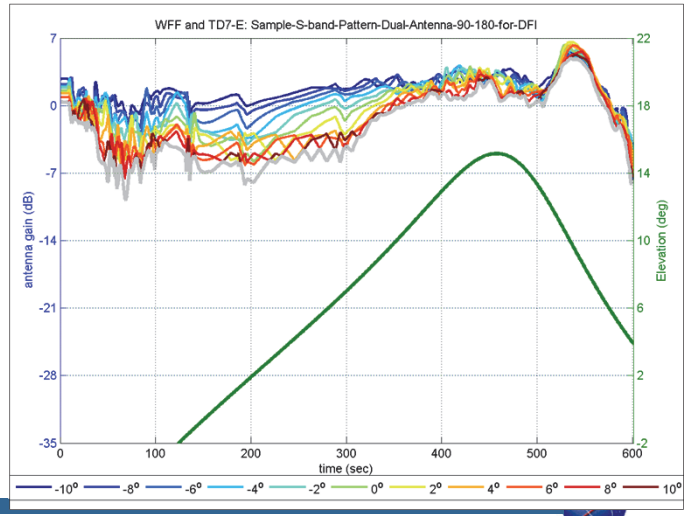
TD7-E to WFF Downlink Gains



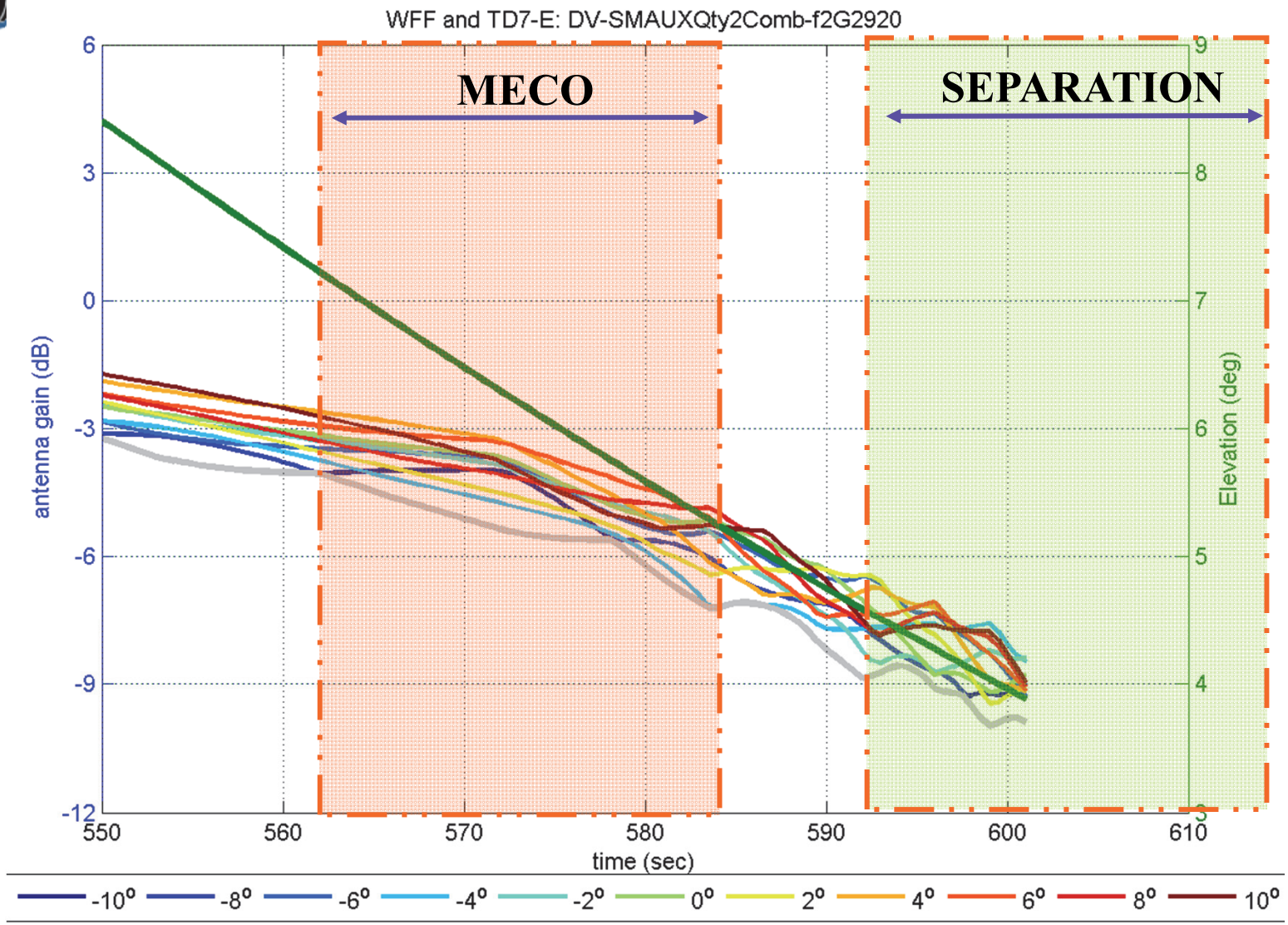




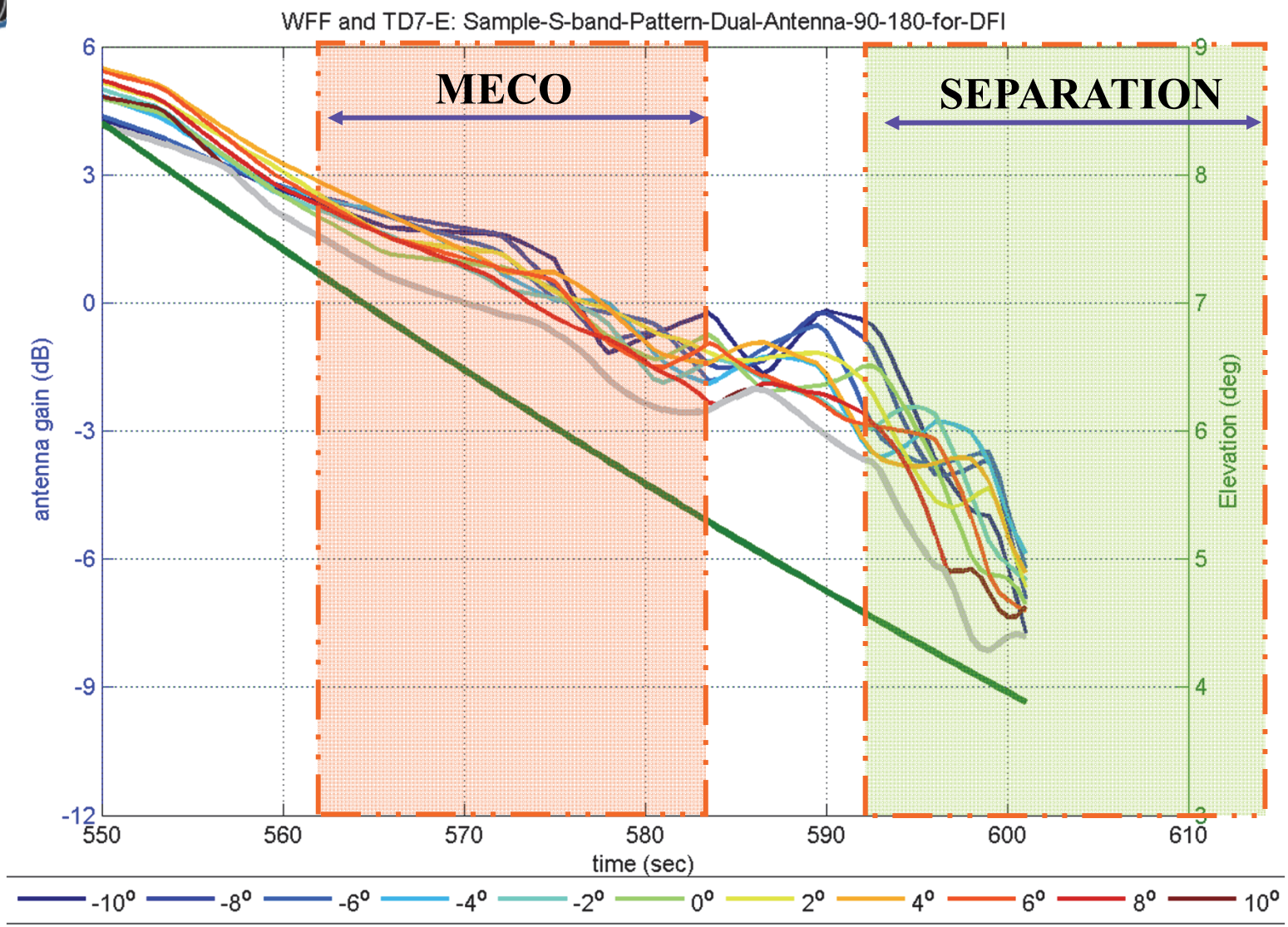




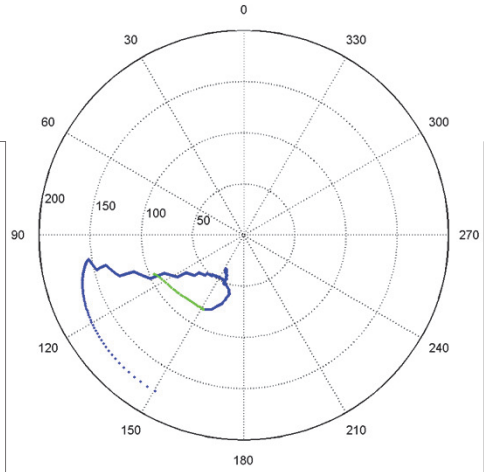
TD7-E to WFF DV Downlink Gains

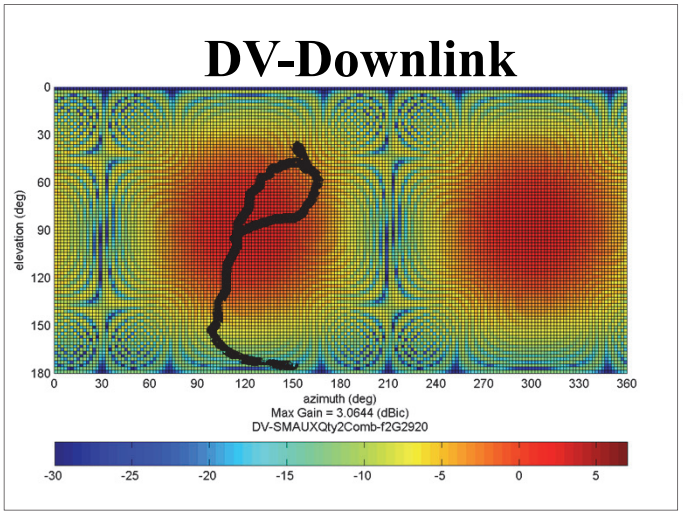


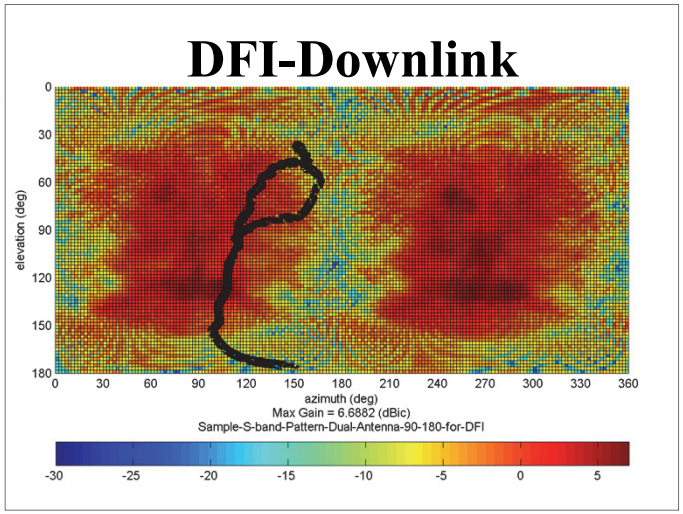
TD7-E to WFF DFI Downlink Gains

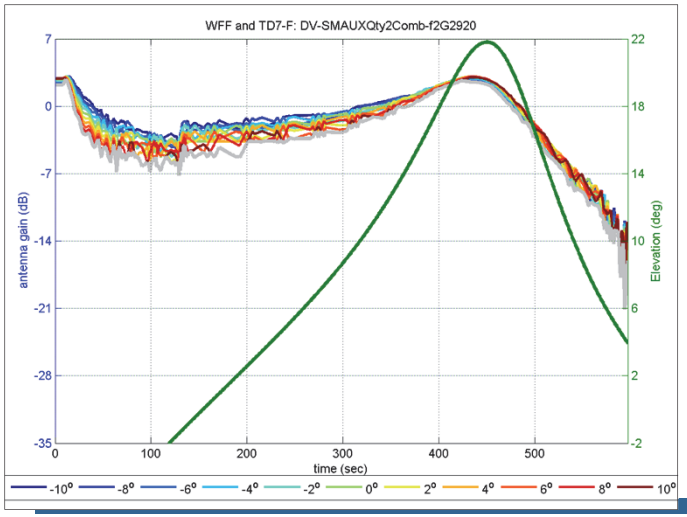


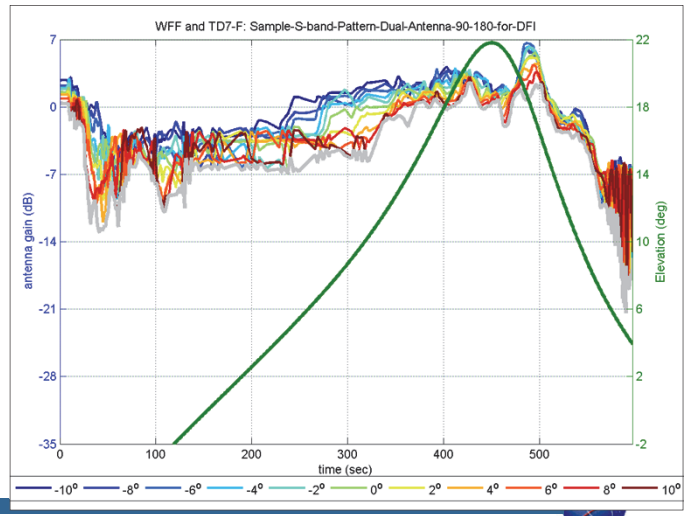
TD7-F to WFF Downlink Gains



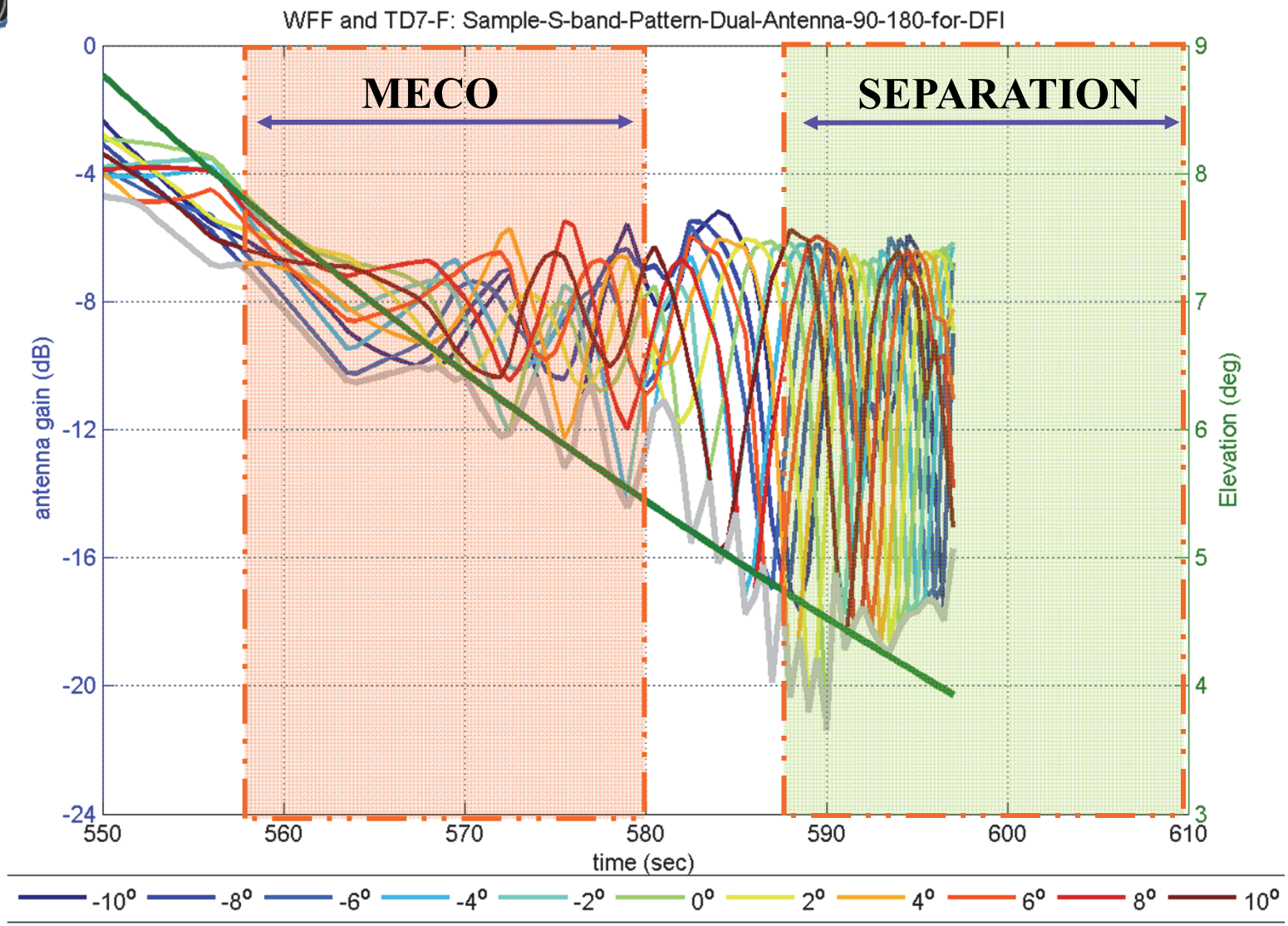
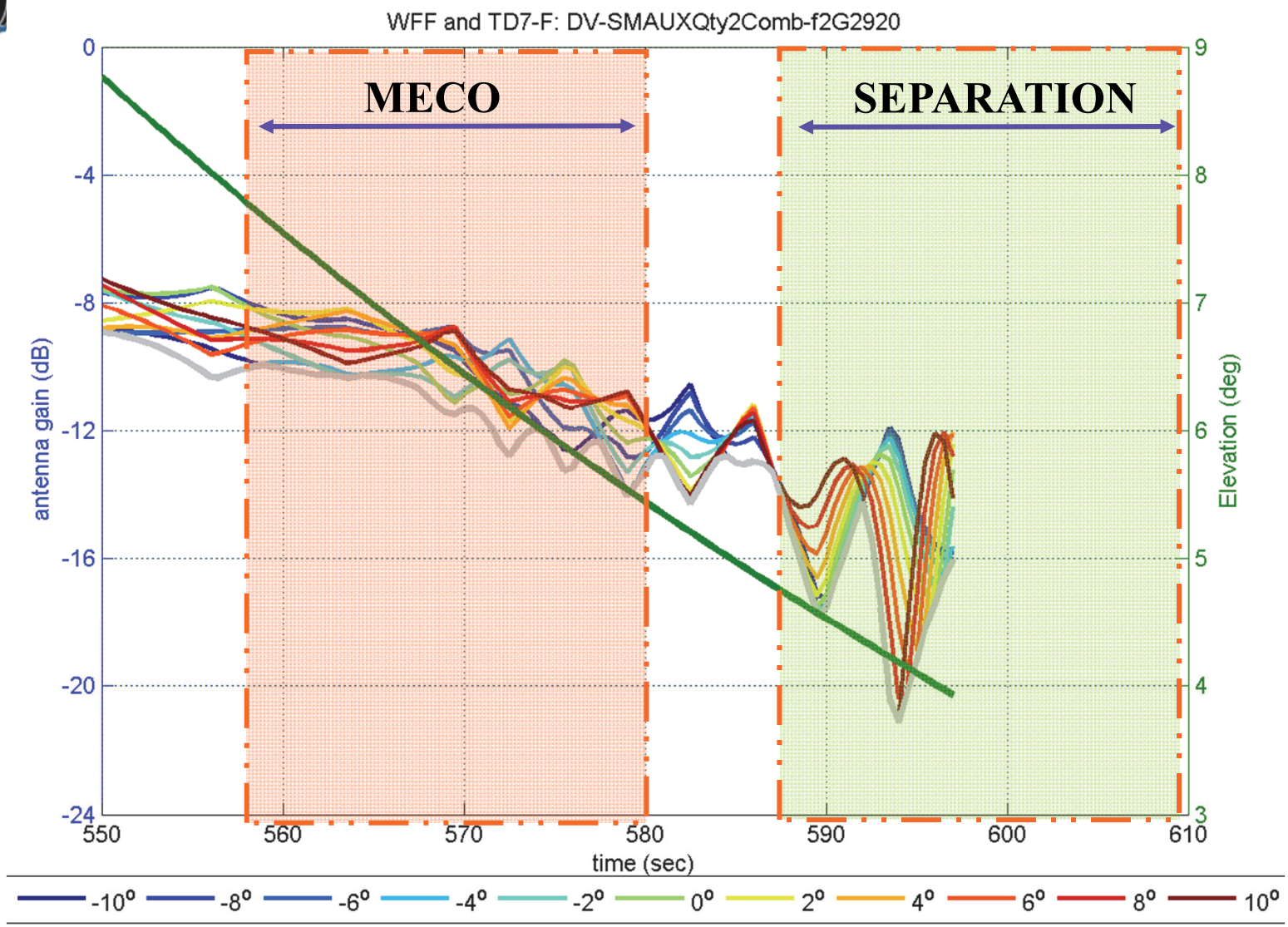








TD7-F to WFF DV Downlink Gains



TD7-F to WFF DFI Downlink Gains