Purpose: This memorandum is an attachment to the Northrop Grumman Systems Corporation FCC experimental radio license application for NG-16 Cygnus spacecraft.

Scope: This memorandum provides a data summary in support of the FCC Office of Engineering and Technology (OET) e-File system application. The data is submitted in support of the following application:

Description	Number
FCC File Number	0875-EX-ST-2021

Data Summary: The attached charts summarize the NG-16 Cygnus spacecraft power flux density (PFD) performance during each phase of the mission on a nominal trajectory to the International Space Station (ISS). The mission phases covered in this summary are the Approach (to the ISS), Berthed (at the ISS), and Departure (from the ISS). The PFD algorithm has been updated to match the equations presented in the NASA Space Network User's Guide, Revision 10, Appendix D. The specific equation is the one used for Total Power in the Reference Bandwidth (PtB) of an NRZ waveform. This equation is listed as Equation D-6. The main parameters used in these PFD calculations are the NG-16 Cygnus spacecraft's expected nominal mission trajectory (Azimuth, Elevation, Range, and Altitude) to the ISS from the Wallops Island, Virginia launch pad. PFD calculations use NG-16 transmitter data along with the NG-14 as-flown trajectory. Each NG-16 Cygnus transmitter EIRP was used in the PFD calculations. The PFD limit line shown on each plot is specified in ITU-R Radio Regulations S21.16, Table S21-4 Power Flux Density Limits.

Attachment 2 to this application gives more details on the PFD limit exceedances identified in the data summary but in each case the exceedance is below the 16 dB relaxation granted in Section 2 of the NTIA Report 84-152. The PFD results presented herein assume on-orbit Cygnus operation where the primary emitter is radiating for the duration of a scheduled communication pass which is controlled by the mission timeline and the mission phase (approach, berthed, and departure).

The NG-16 Cygnus spacecraft will transmit in the Spacecraft Operations Service S-Band. This band is allocated to the US Federal Government and covers 2200 to 2290 MHz. The band allocation is consistent with operations for the ISS cargo delivery service. The Cygnus spacecraft RF communication subsystem operates with multiple data rates and different modulation schemes. Table 1 below lists the primary RF communication links along with the phase of the mission in which they are active.

Table 1. Mission Primary RF Communication Links

					Mission Phase (Active)			
Link Operation	Carrier Frequency (MHz)	NTIA Emission Designator	NGIS Designation	Modulation Scheme	In-Orbit-Test	ISS Approach	ISS Berth	ISS Departure
Space-to-Space (Cygnus-to-TDRS SMA)	2287.5	6M16G1D	TDRS SMA	SQPN		√		√
Space-to-Space (Cygnus-to-TDRS SSA)	2287.5	6M16G1D	TDRS SSA	SQPN	√	√	√	√
Space-to-Ground (Cygnus-to-GN)	2287.5	4M98G1D	GN At 6 Mbps	SQPSK		√	√	√
Space-to-Ground (Cygnus-to-GN)	2287.5	3M00G1D	GN At 3 Mbps	SQPSK		√	√	√
Space-to-Space (Cygnus-to-ISS)	2203.2	5M93G1D	CLS At 36 kbps (LowRate)	SQPN	√	√		√

The detailed PFD results are shown below for each phase of the NG-16 Cygnus mission. The . maximum PFD limit is -144 dBW/m^2/4kHz. PFD limit exceedances are provided as ground track plots in Appendix A of this document, and in tabular format in Attachment 2.

1. Approach to the ISS Phase

This approach phase of the mission starts after the Cygnus spacecraft separates from the Antares launch vehicle. Initially, spacecraft telemetry will be downlinked via TDRS. Later, spacecraft telemetry will be downlinked via TDRS and directly to ground stations. When the spacecraft is sufficiently close to the ISS (~150 km), the Cygnus-to-ISS communication link is activated (CLS), providing a second path for spacecraft telemetry.

Figure 14 shows the spacecraft altitude during the approach phase.

PFD summaries for the applicable telemetry links are provided below. This results assume nominal performance from the Antares launch vehicle (i.e., nominal Cygnus orbit insertion).

a) Figure 1 shows the PFD results when using TDRS SSA (emission designator 6M16G1D).
   - Figure 16 of Appendix A shows the PFD exceedances as ground track plots
   - Table 1 of Attachment 2 shows the PFD exceedances in tabular format

b) Figure 2 shows the PFD results when using TDRS SMA (emission designator 6M16G1D).
   - Figure 17 of Appendix A shows the PFD exceedances as ground track plots
   - Table 2 of Attachment 2 shows the PFD exceedances in tabular format

c) Figure 3 shows the PFD results when using GN at 6 Mbps (emission designator 4M98G1D).
   - Figure 18 of Appendix A shows the PFD exceedances as ground track plots
   - Table 3 of Attachment 2 shows the PFD exceedances in tabular format

d) Figure 4 shows the PFD results when using GN at 3 Mbps (emission designator 3M00G1D).
    - Figure 19 of Appendix A shows the PFD exceedances as ground track plots
    - Table 4 of Attachment 2 shows the PFD exceedances in tabular format

e) Figure 5 shows the PFD results when using CLS at 36 kbps (emission designator 5M93G1D).
    - Figure 20 of Appendix A shows the PFD exceedances as ground track plots
    - Table 5 of Attachment 2 shows the PFD exceedances in tabular format

2. Berthed at the ISS Phase

This phase of the mission starts after the Cygnus vehicle is grappled by the ISS robotic arm and berthed to the ISS. Soon after the spacecraft is berthed, the Cygnus-to-ISS communication link (CLS) is deactivated. While the spacecraft is berthed, spacecraft telemetry is downlinked via TDRS or directly to ground stations.

PFD summaries for the applicable telemetry links are provided below.

a) Figure 6 shows the PFD results when using TDRS SSA (emission designator 6M16G1D).

b) Figure 7 shows the PFD results when using GN at 3 Mbps (emission designator 3M00G1D).

c) Figure 8 shows the PFD results when using GN at 6 Mbps (emission designator 4M98G1D).

3. Departure from the ISS Phase

The departure phase of the mission starts after the Cygnus spacecraft is unberthed from the ISS and released by the ISS robotic arm. Prior to departure, the Cygnus-to-ISS communication link (CLS) is activated. Following release by the robotic arm, a series of departure burns are performed to maneuver the spacecraft away from the ISS. The Cygnus-to-ISS communication link (CLS) is deactivated once the spacecraft is ~30 km from the ISS. Once the desired spacecraft orbit is achieved, secondary payload operations begin, lasting for a few days up to several weeks. Following the completion of secondary payload operations, a series of burns are performed to lower the spacecraft's perigee. A final reentry burn is then performed to put the spacecraft on a controlled reentry path into the Earth's atmosphere. The TDRS and ground station telemetry links are used throughout the departure phase.

Figure 15 shows the spacecraft altitude during the departure phase.

PFD summaries for the applicable telemetry links are provided below.

a) Figure 9 shows the PFD results when using TDRS SSA (emission designator 6M16G1D).
    a. Figure 21 of Appendix A shows the PFD exceedances as ground track plots
    b. Table 9 of Attachment 2 shows the PFD exceedances in tabular format

b) Figure 10 shows the PFD results when using TDRS SMA (emission designator 6M16G1D).
    a. Figure 22 of Appendix A shows the PFD exceedances as ground track plots
    b. Table 10 of Attachment 2 shows the PFD exceedances in tabular format

c) Figure 11 shows the PFD results when using GN at 6 Mbps (emission designator 4M98G1D).
    a. Figure 23 of Appendix A shows the PFD exceedances as ground track plots
    b. Table 11 of Attachment 2 shows the PFD exceedances in tabular format

d) Figure 12 shows the PFD results when using GN at 3 Mbps (emission designator 3M00G1D).
    a. Figure 24 of Appendix A shows the PFD exceedances as ground track plots
    b. Table 12 of Attachment 2 shows the PFD exceedances in tabular format

e) Figure 13 shows the PFD results when using CLS at 36 kbps (emission designator 5M93G1D).
    a. Figure 25 of Appendix A shows the PFD exceedances as ground track plots
    b. Table 13 of Attachment 2 shows the PFD exceedances in tabular format

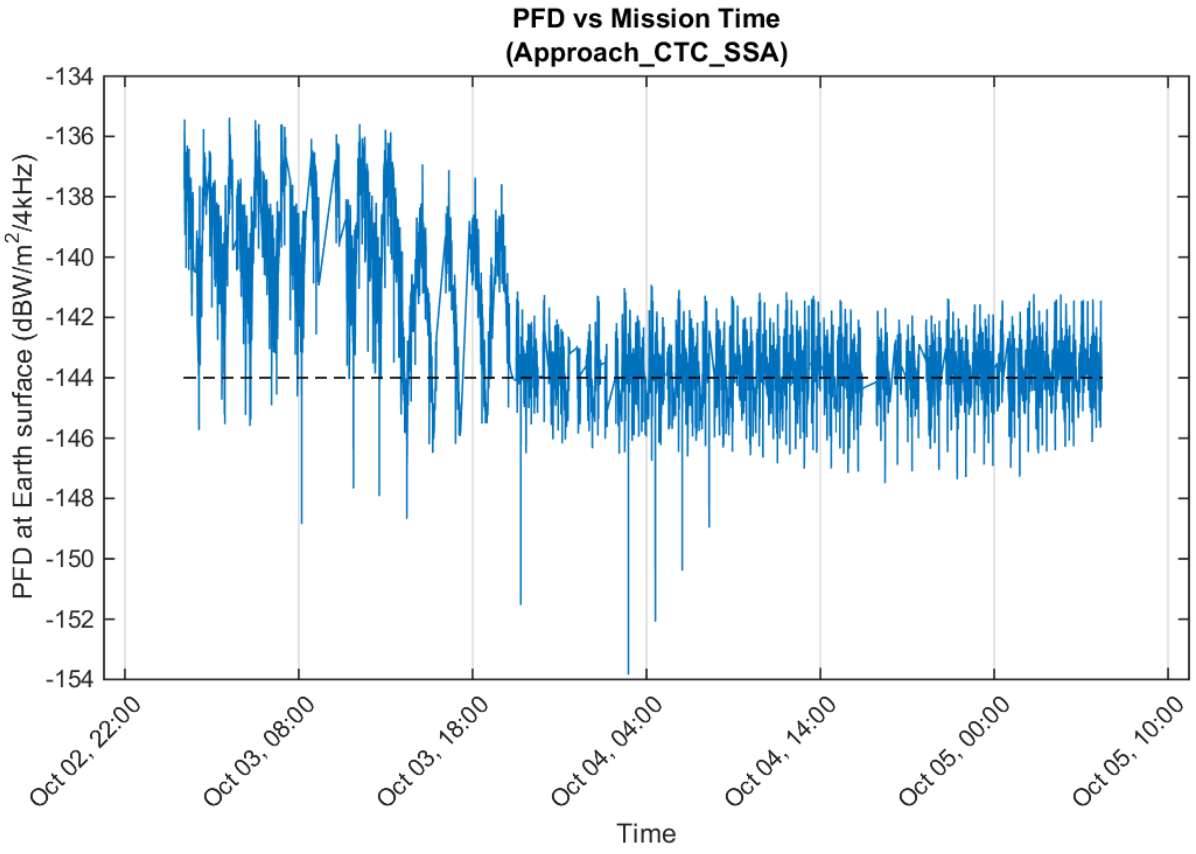

Figure 1. Cygnus NG-16 PFD During Approach, TDRS SSA (6M16G1D Emitter)

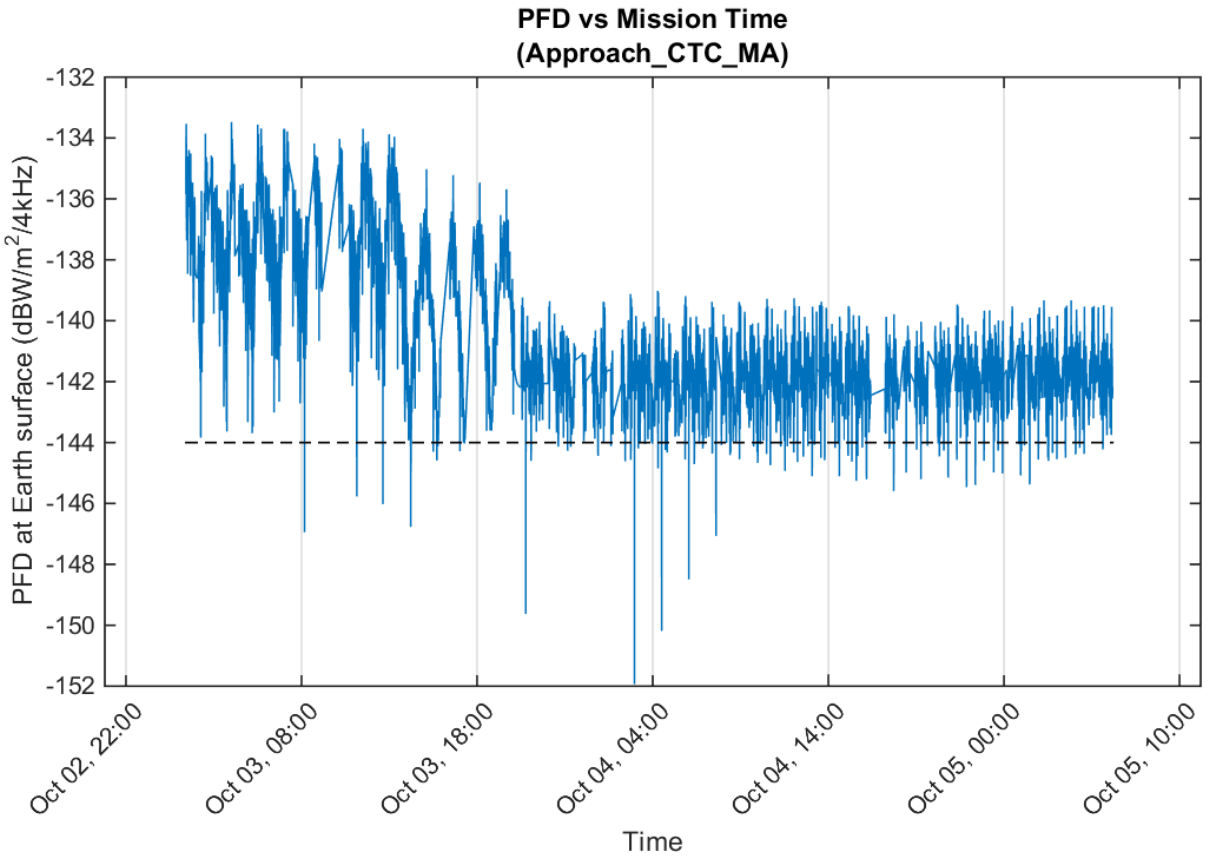

Figure 2. Cygnus NG-16 PFD During Approach, TDRS SMA (6M16G1D Emitter)

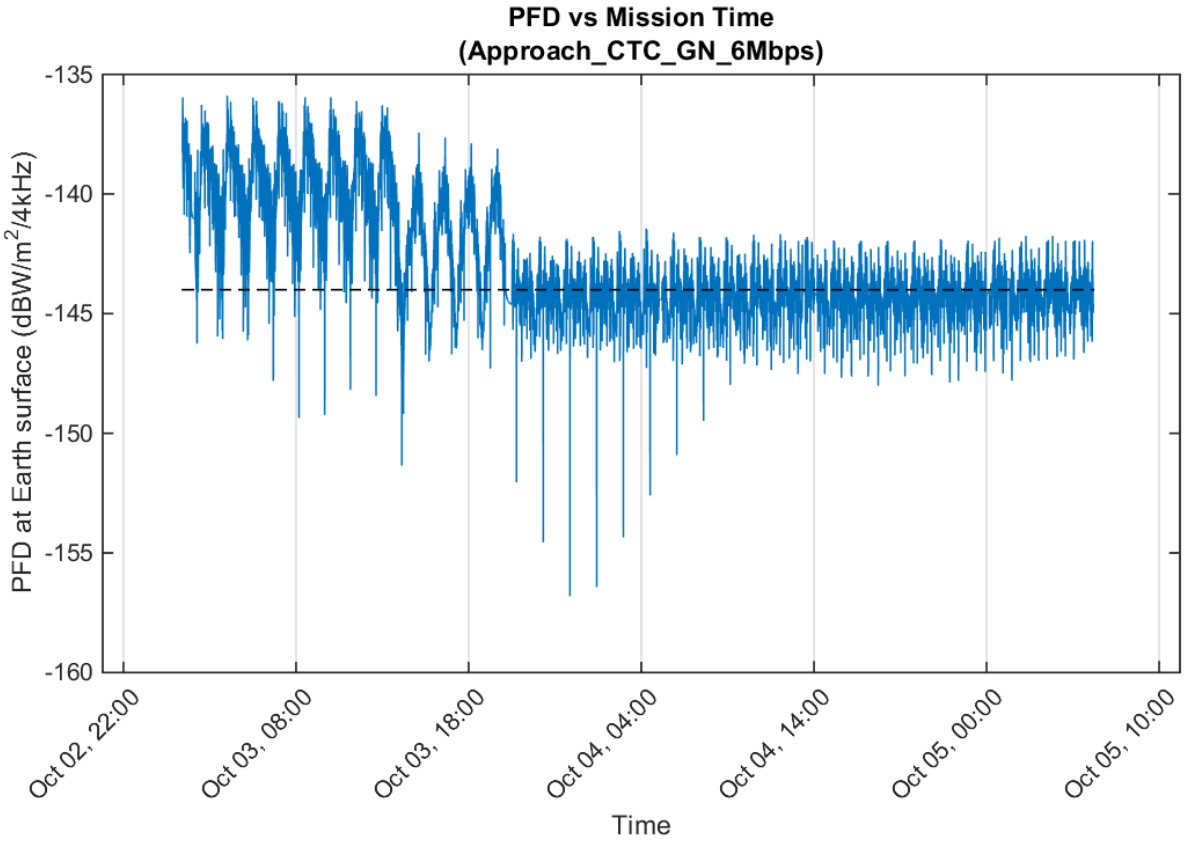

Figure 3. Cygnus NG-16 PFD During Approach, GN at 6 Mbps (4M98G1D Emitter)

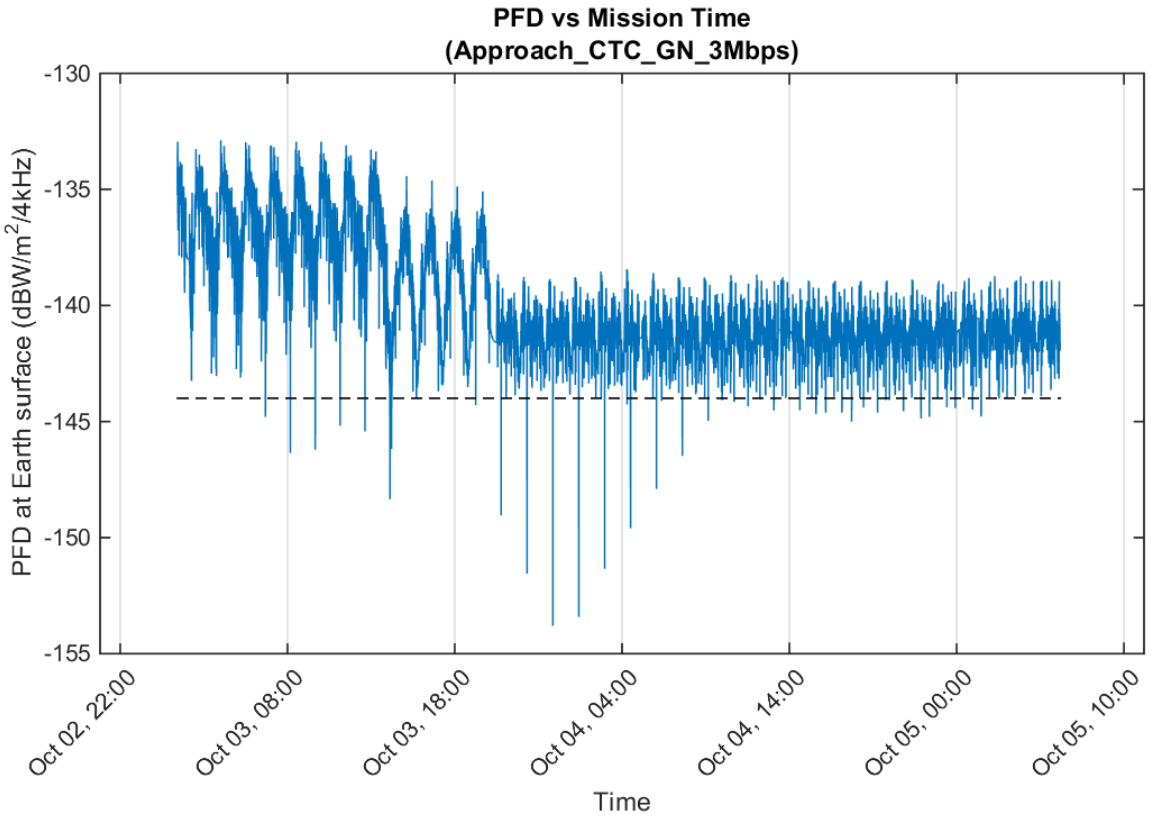

Figure 4. Cygnus NG-16 PFD During Approach, GN at 3 Mbps (3M00G1D Emitter)

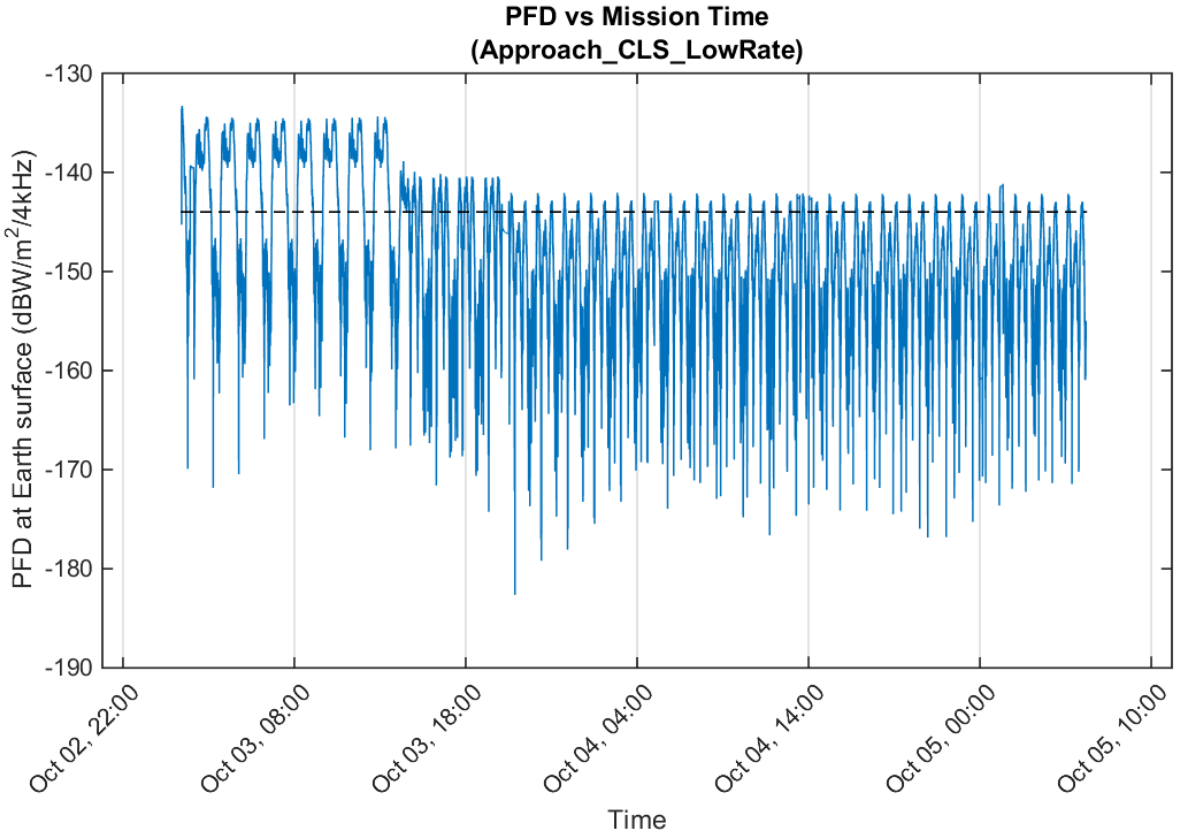

Figure 5. Cygnus NG-16 PFD During Approach, CLS at 36 kbps (5M93G1D Emitter)

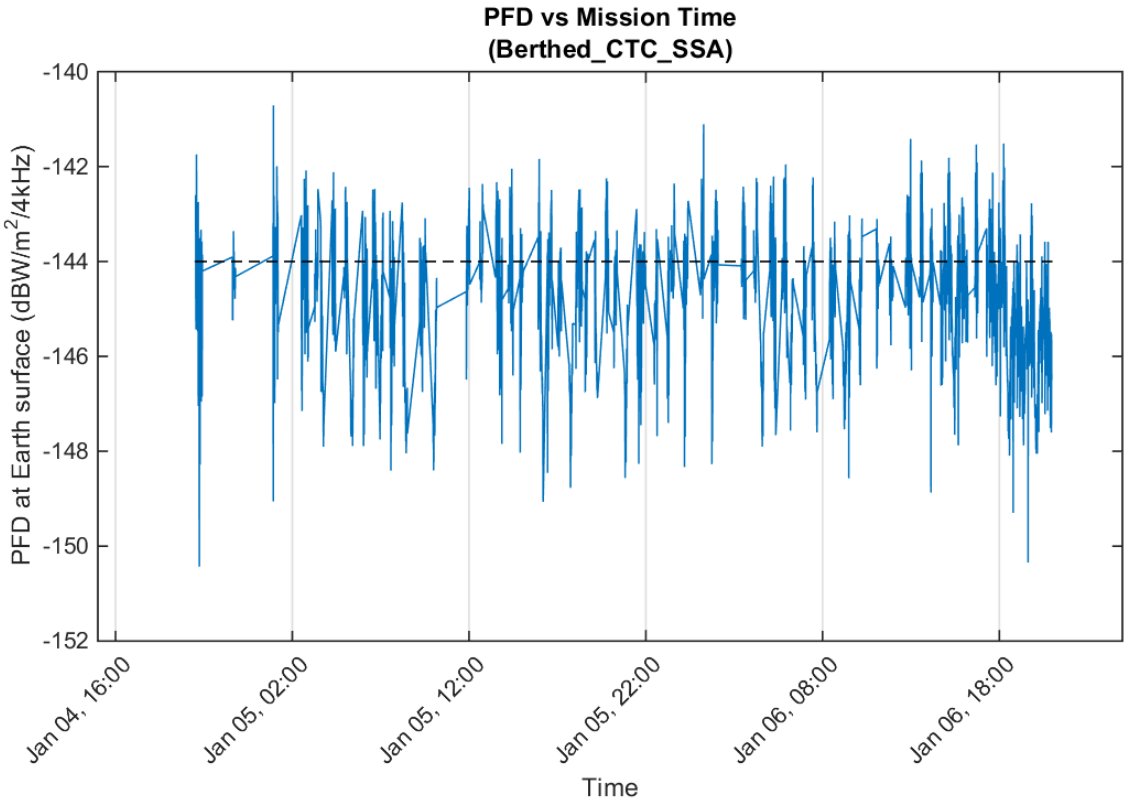

Figure 6. Cygnus NG-16 PFD During Berthed Phase, TDRS SSA (6M16G1D Emitter)

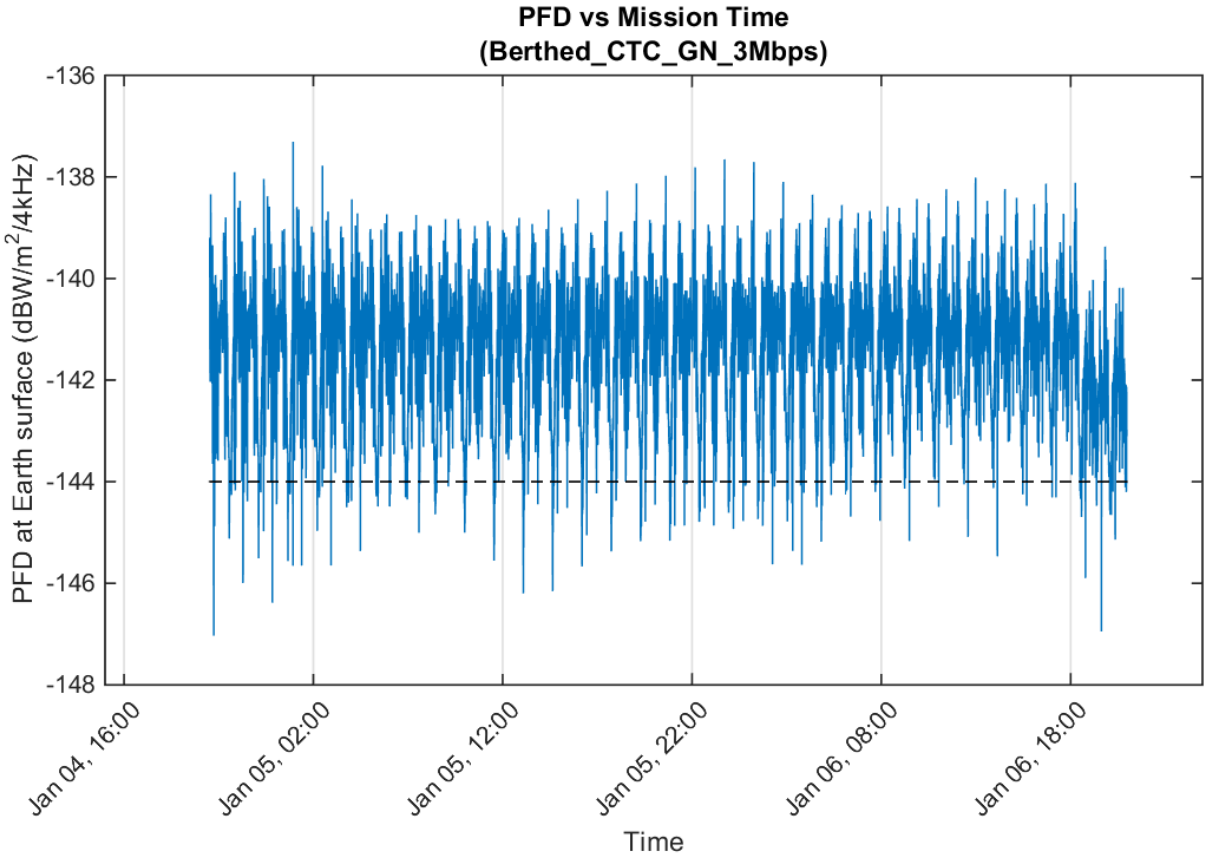

Figure 7. Cygnus NG-16 PFD During Berthed Phase, GN at 3 Mbps (3M00G1D Emitter)

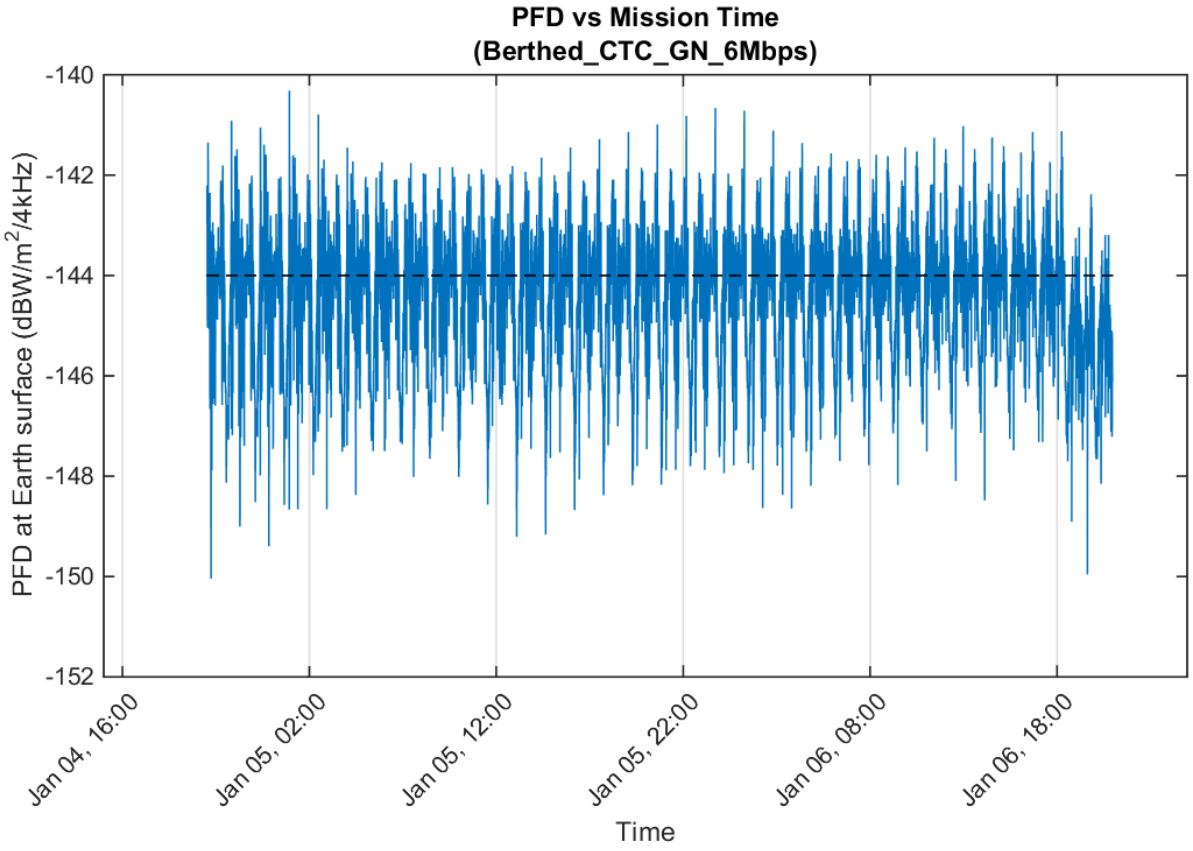

Figure 8. Cygnus NG-16 PFD During Berthed Phase, GN at 6 Mbps (4M98G1D Emitter)

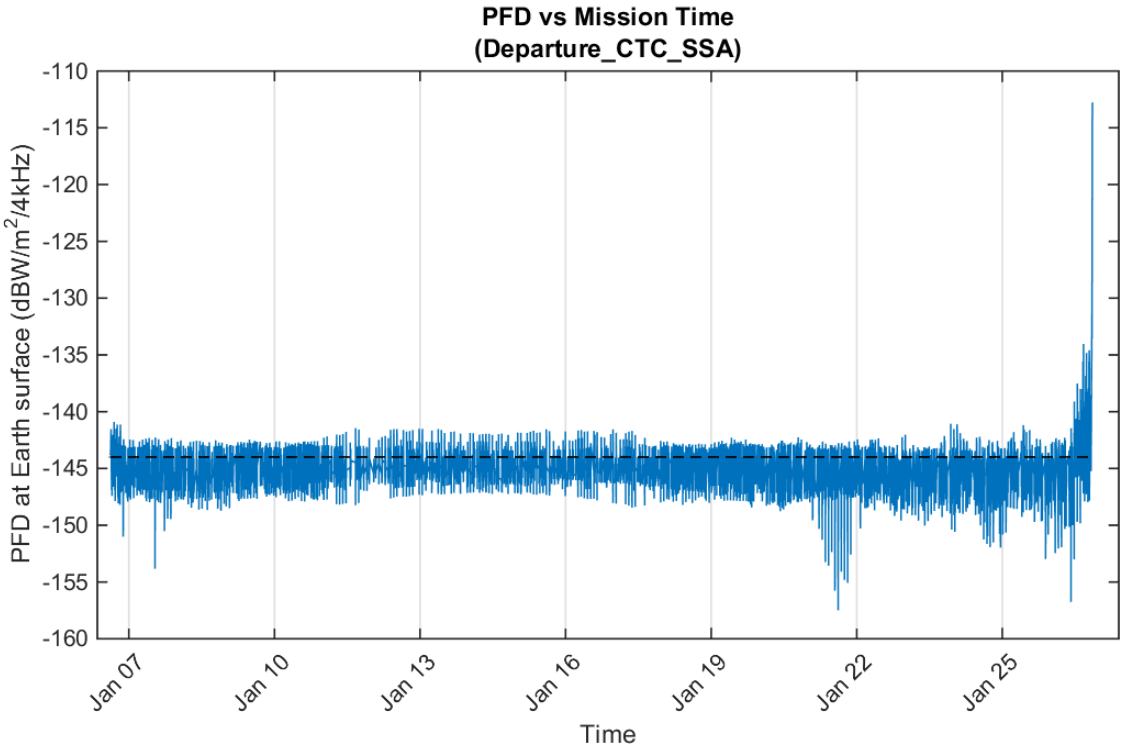

Figure 9. Cygnus NG-16 PFD During Departure Phase, TDRS SSA (6M16G1D Emitter)

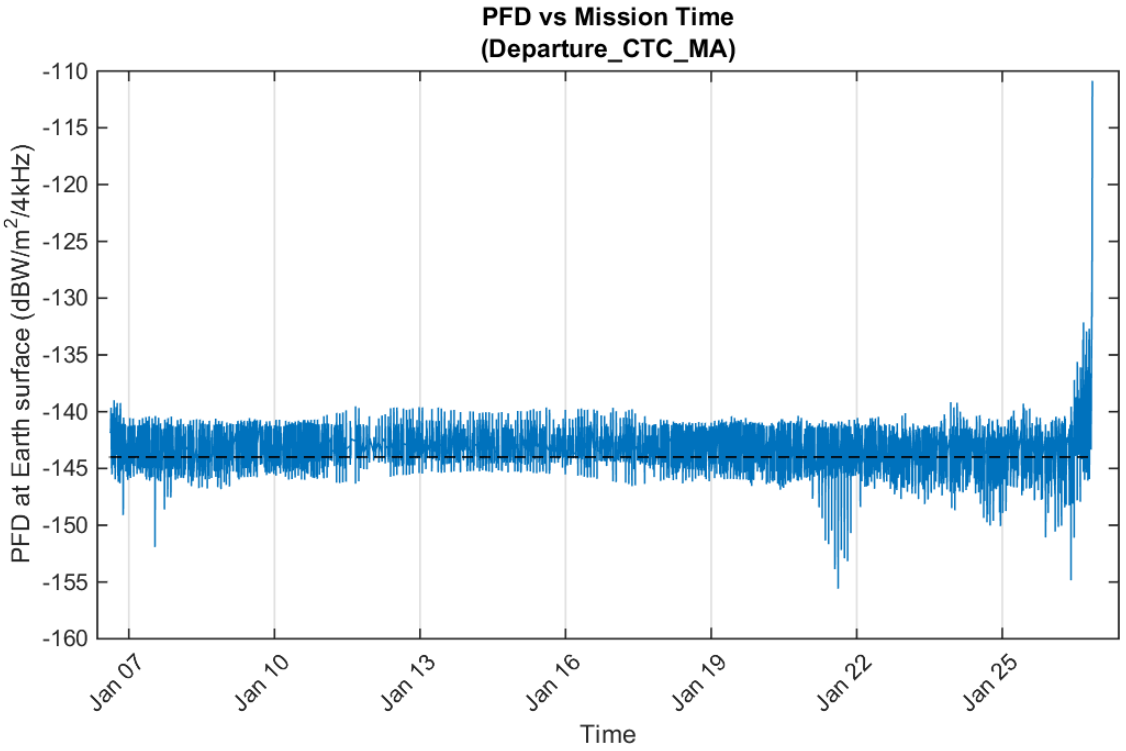

Figure 10. Cygnus NG-16 PFD During Departure Phase, TDRS SMA (6M16G1D Emitter)

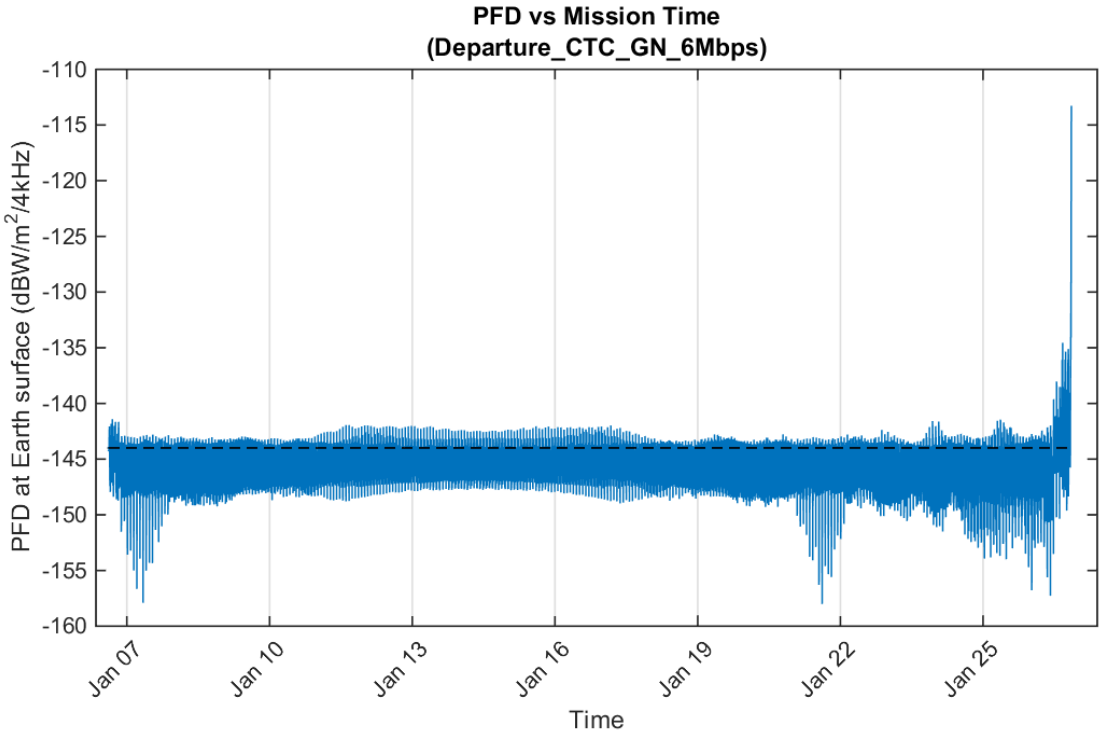

Figure 11. Cygnus NG-16 PFD During Departure Phase, GN at 6 Mbps (4M98G1D)

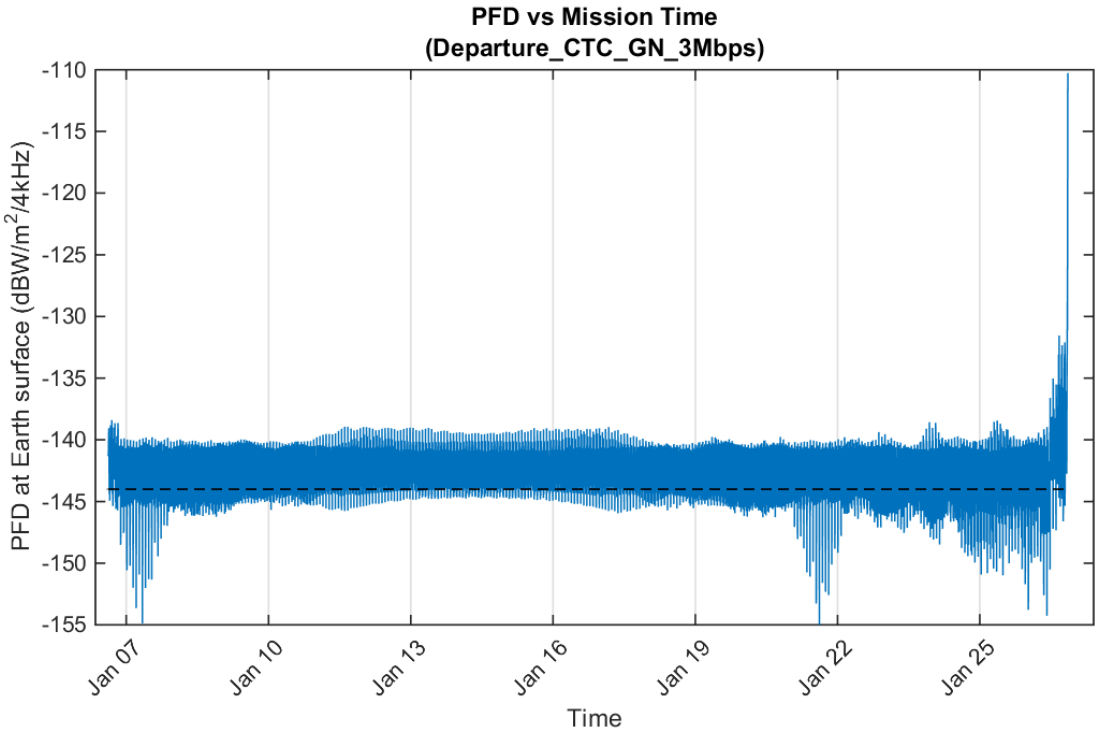

Figure 12. Cygnus NG-16 PFD During Departure Phase, GN at 3 Mbps (3M00G1D Emitter)

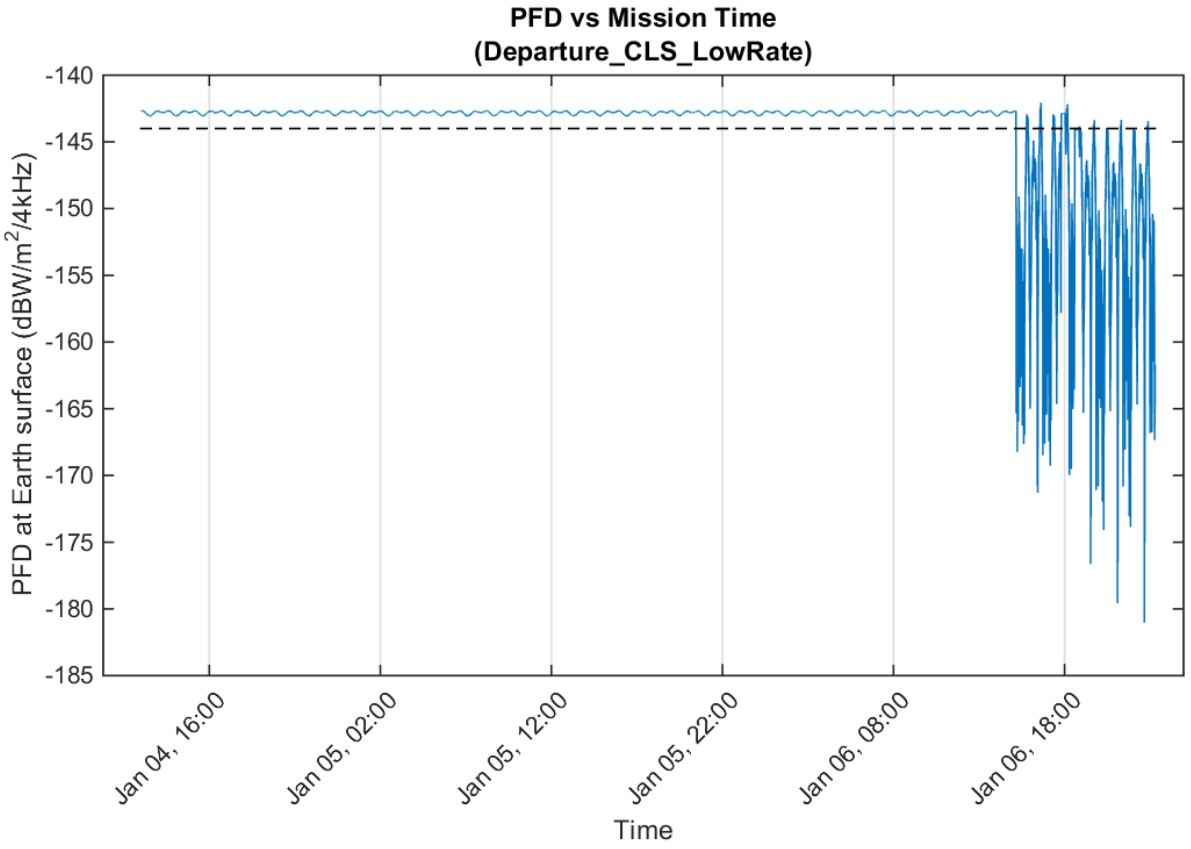

Figure 13. Cygnus NG-16 PFD During Departure Phase, CLS at 36 kbps (5M93G1D Emitter)

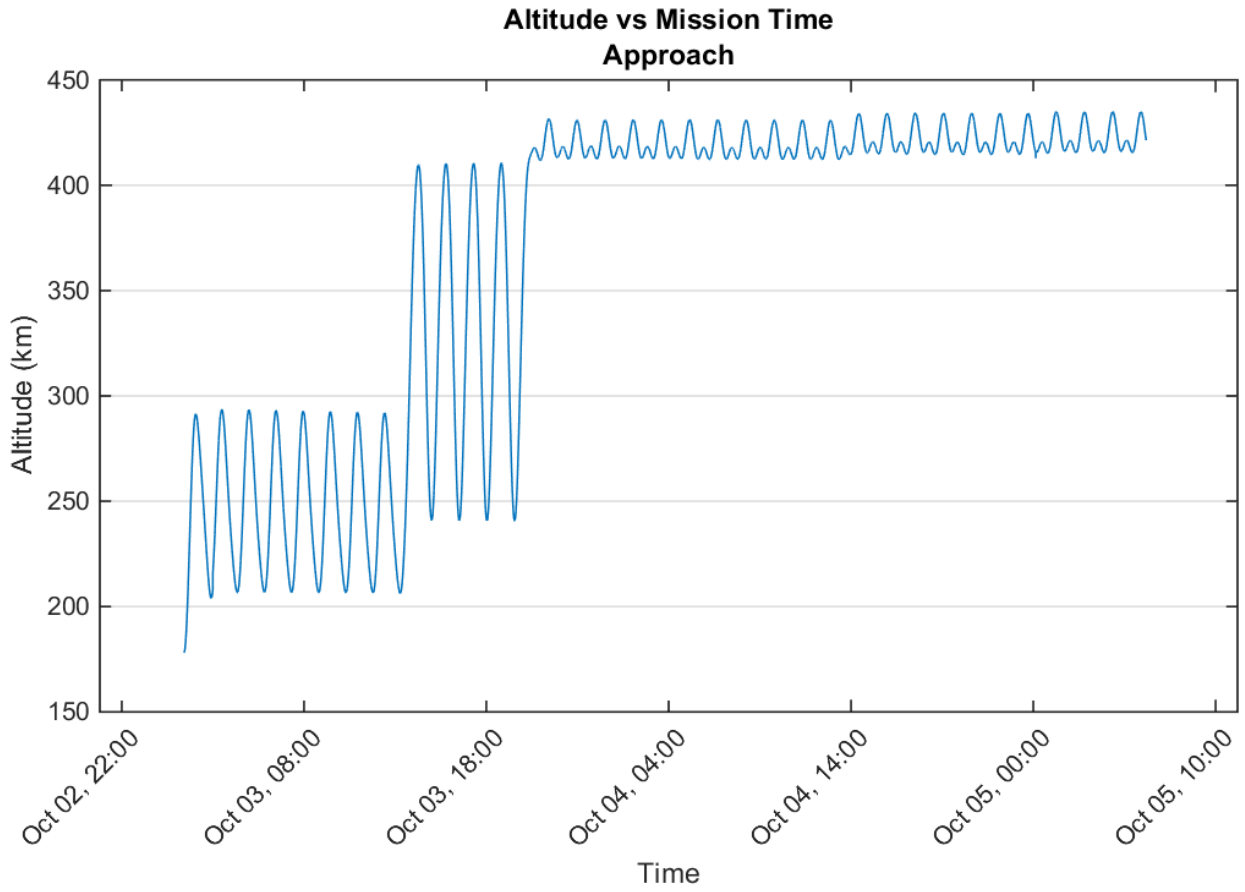

Figure 14. Cygnus NG-16 Altitude vs. Mission Time (Approach)

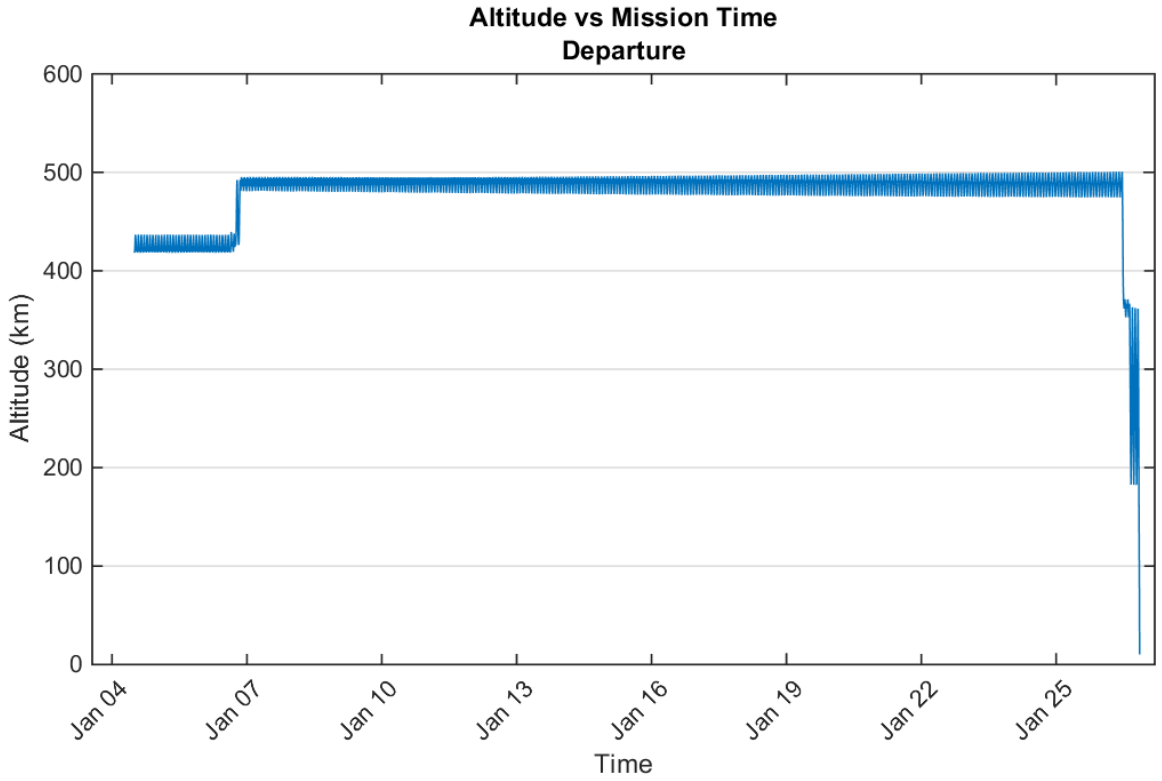

Figure 15. Cygnus NG-16 Altitude vs. Mission Time (Departure)

Appendix A

(Ground Track Plots of PFD Exceedances during Mission Phases)

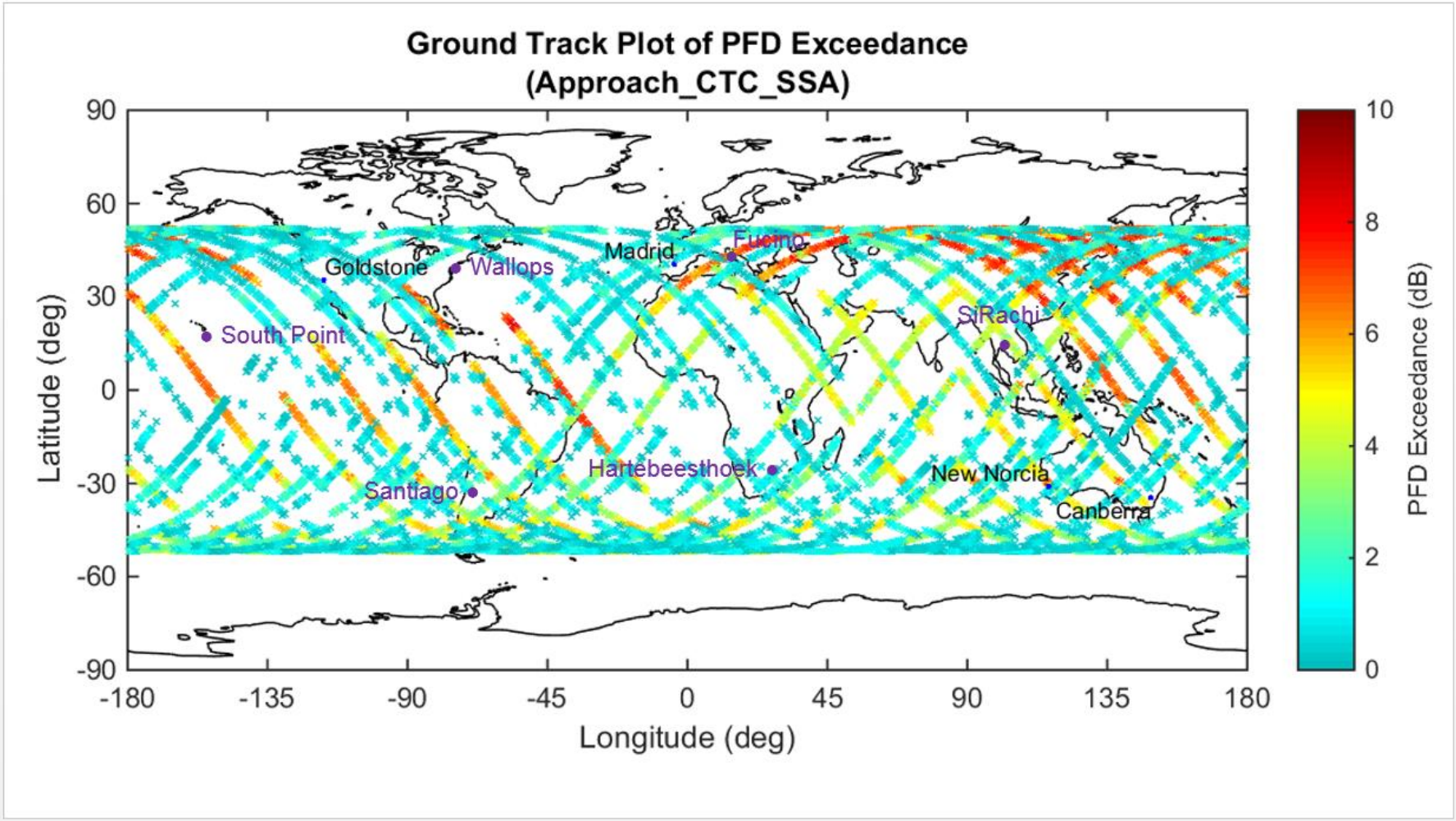

Figure 16. Cygnus NG-16 PFD Limit Exceedances During Approach, TDRS SSA (6M16G1D Emitter)

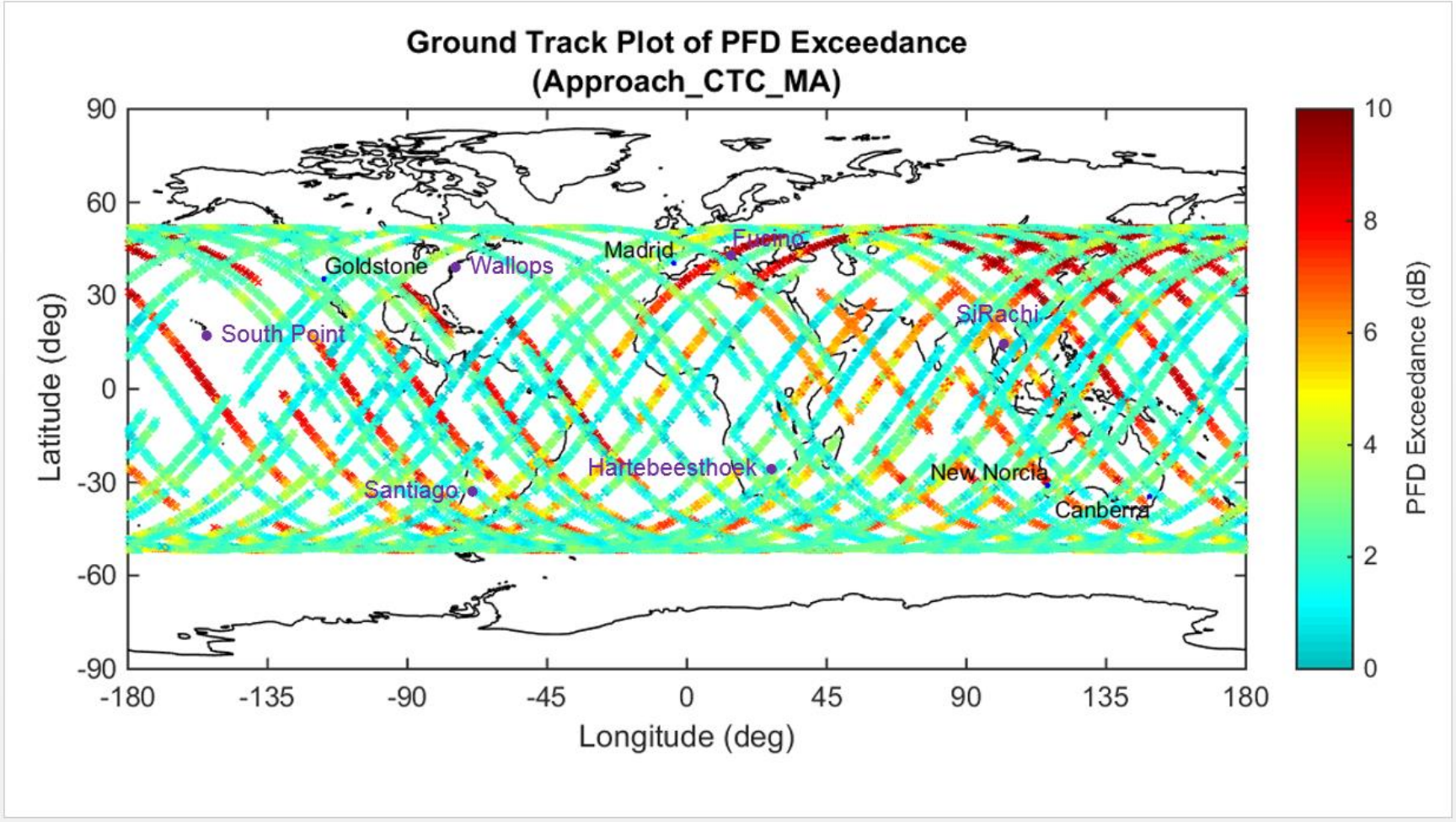

Figure 17. Cygnus NG-16 PFD Limit Exceedances During Approach, TDRS SMA (6M16G1D Emitter)

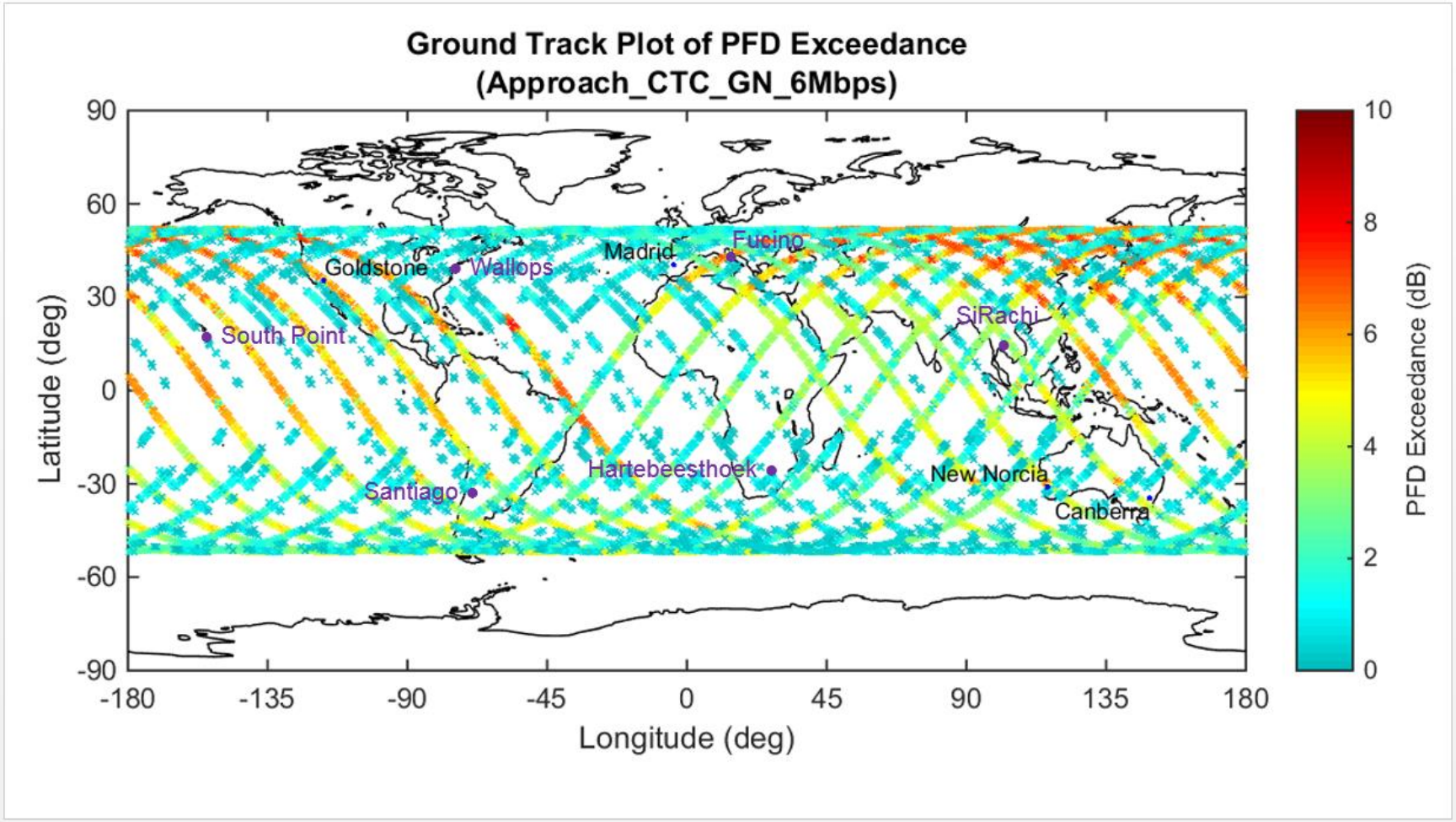

Figure 18. Cygnus NG-16 PFD Limit Exceedances During Approach, GN at 6 Mbps (4M98G1D Emitter)

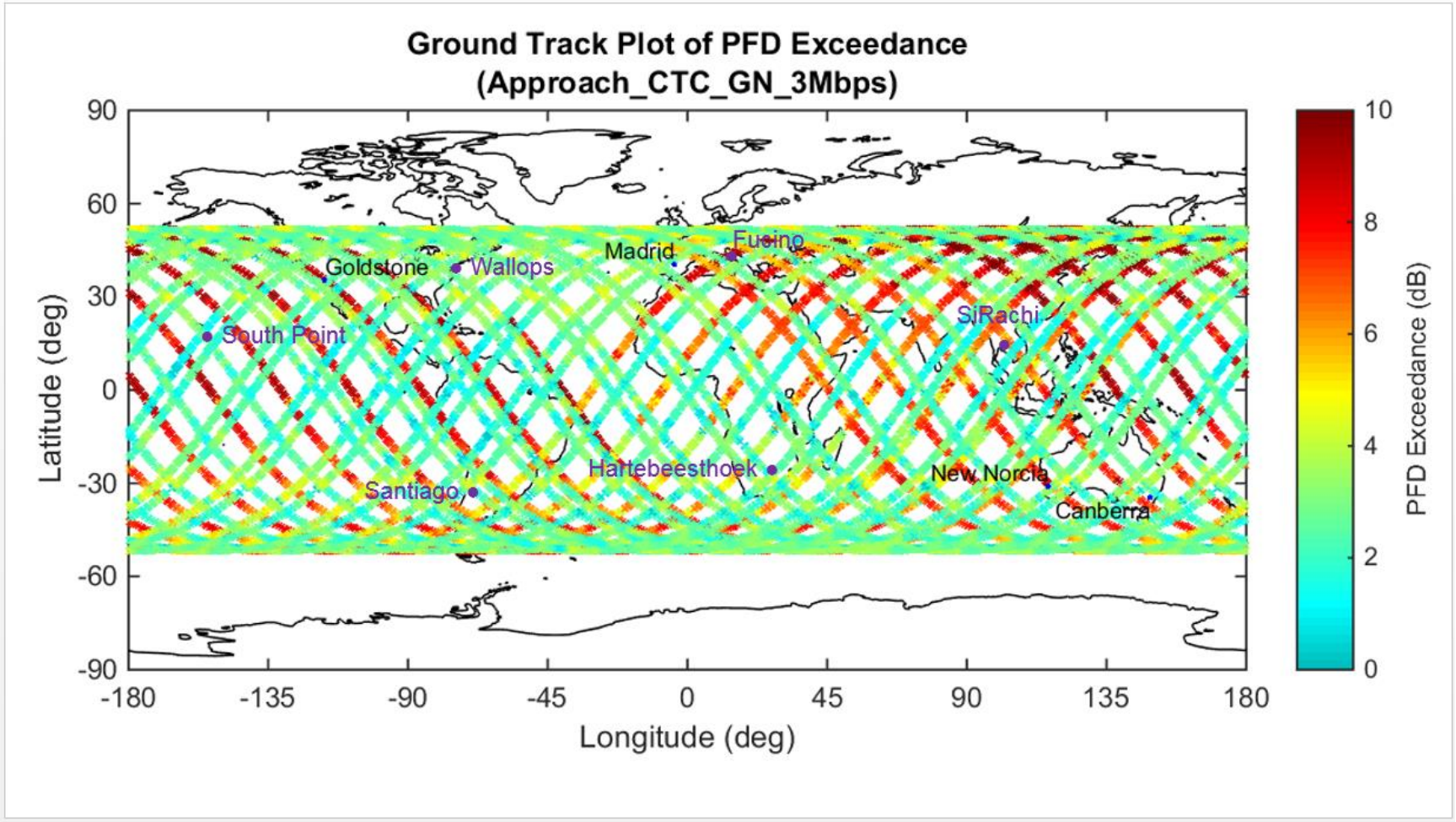

Figure 19. Cygnus NG-16 PFD Limits Exceedance During Approach, GN at 3 Mbps (3M00G1D Emitter)

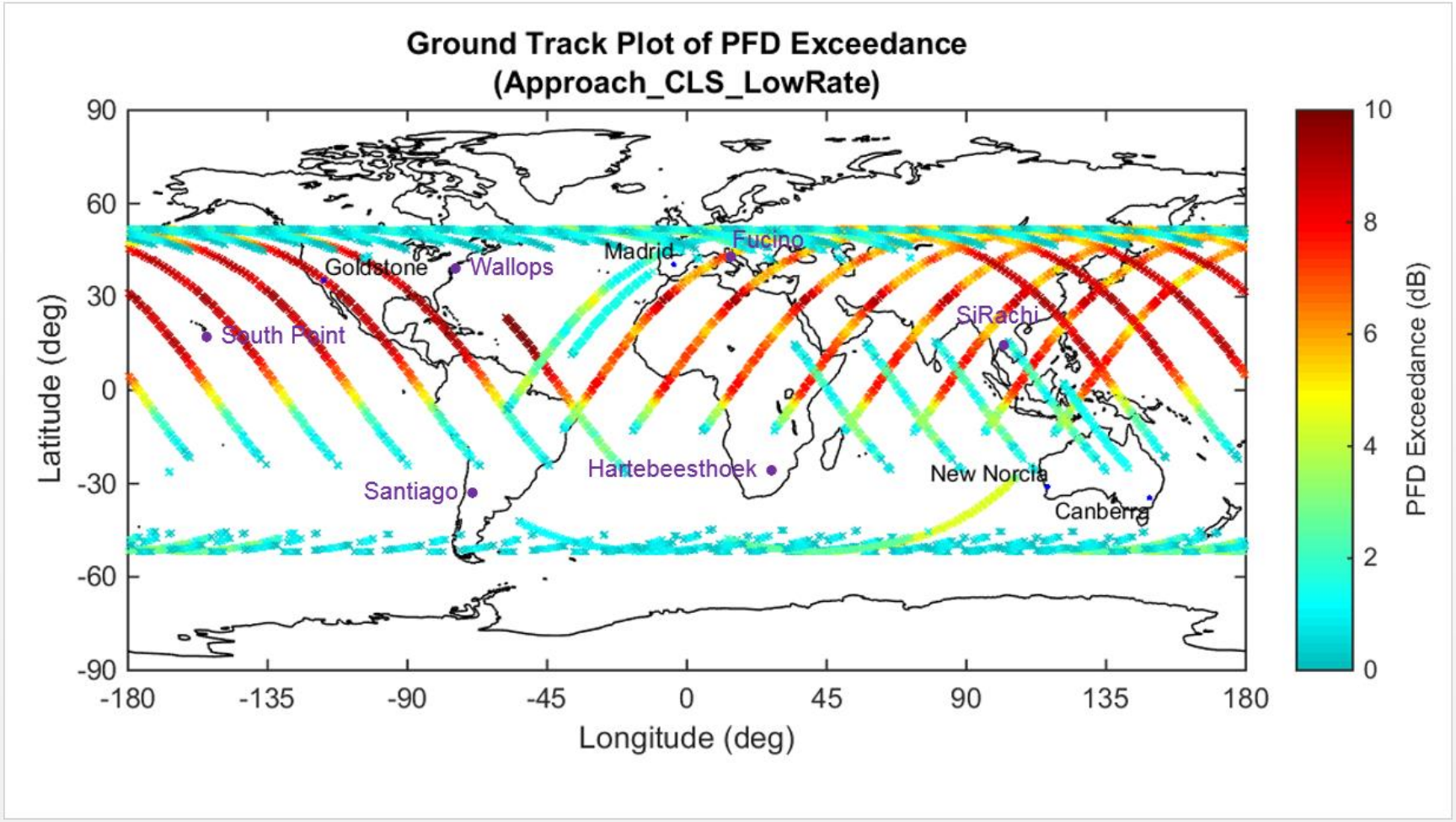

Figure 20. Cygnus NG-16 PFD Limit Exceedances During Approach, CLS at 36 kbps (5M93G1D Emitter)

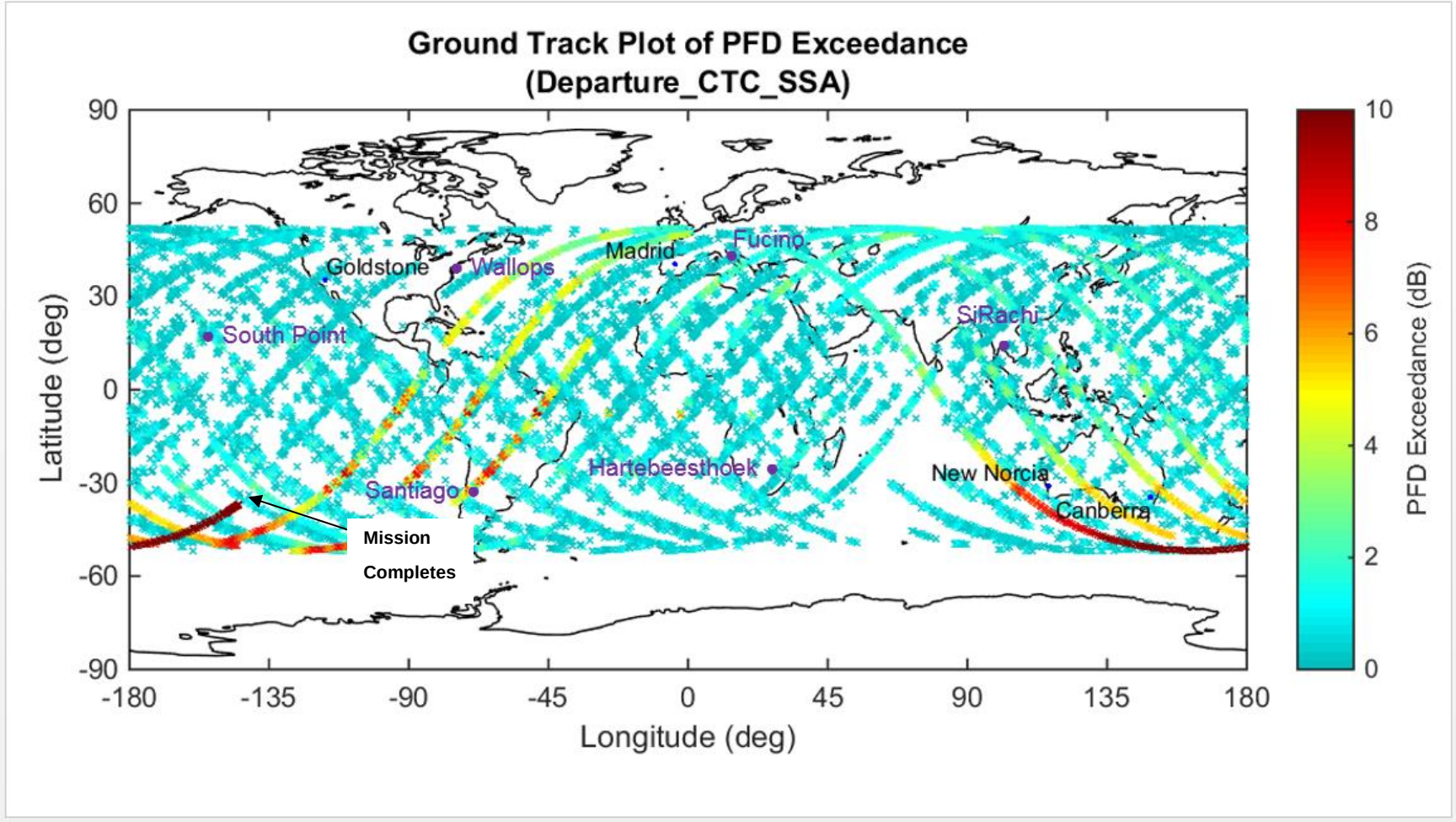

Figure 21. Cygnus NG-16 PFD Limit Exceedances During Departure, TDRS SSA (6M16G1D Emitter)

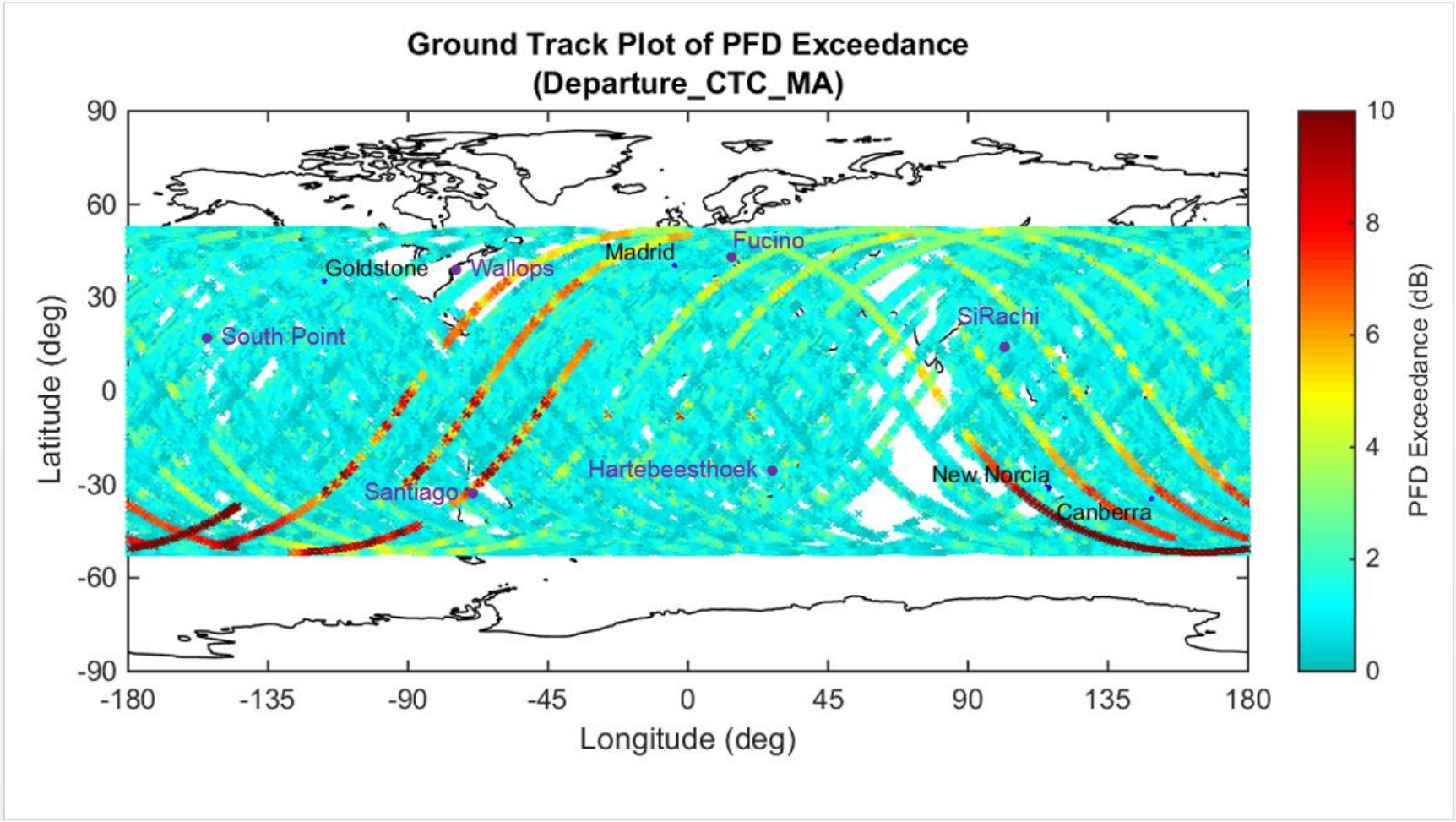

Figure 22. Cygnus NG-16 PFD Limit Exceedances During Departure, TDRS SMA (6M16G1D Emitter)

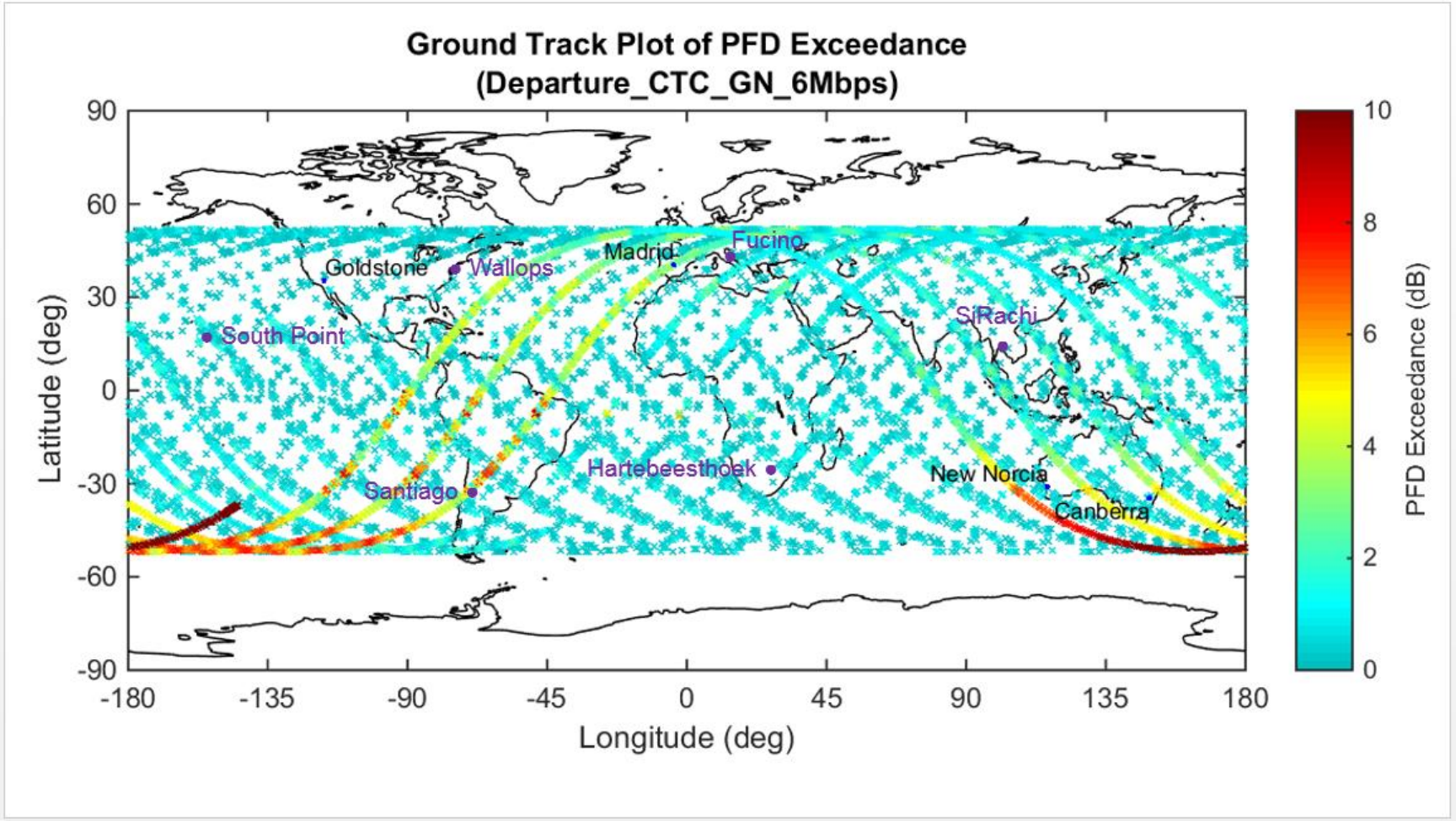

Figure 23. Cygnus NG-16 PFD Limit Exceedances During Departure, GN at 6 Mbps (4M98G1D Emitter)

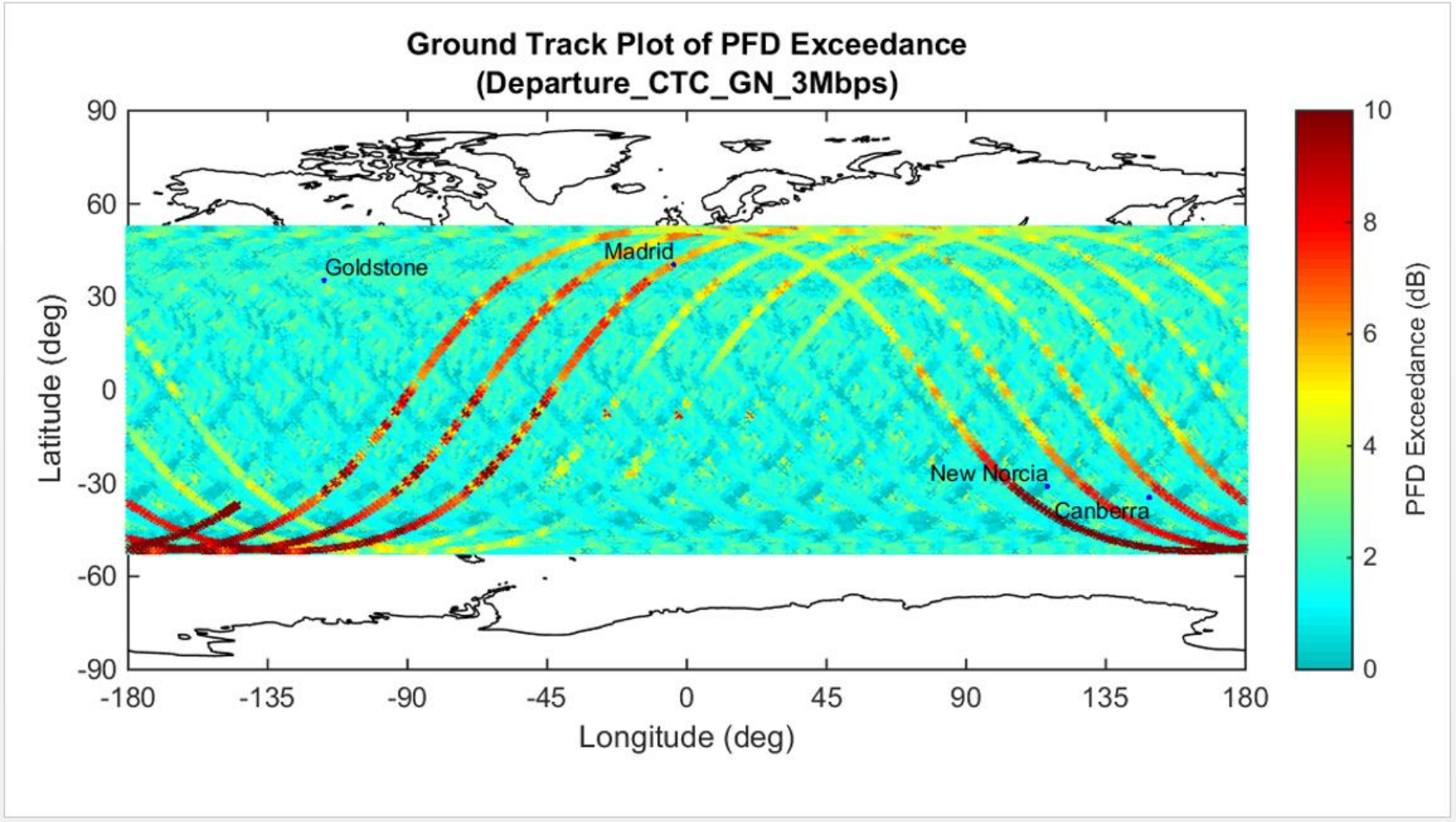

Figure 24. Cygnus NG-16 PFD Limit Exceedances During Departure, GN at 3 Mbps (3M00G1D Emitter)

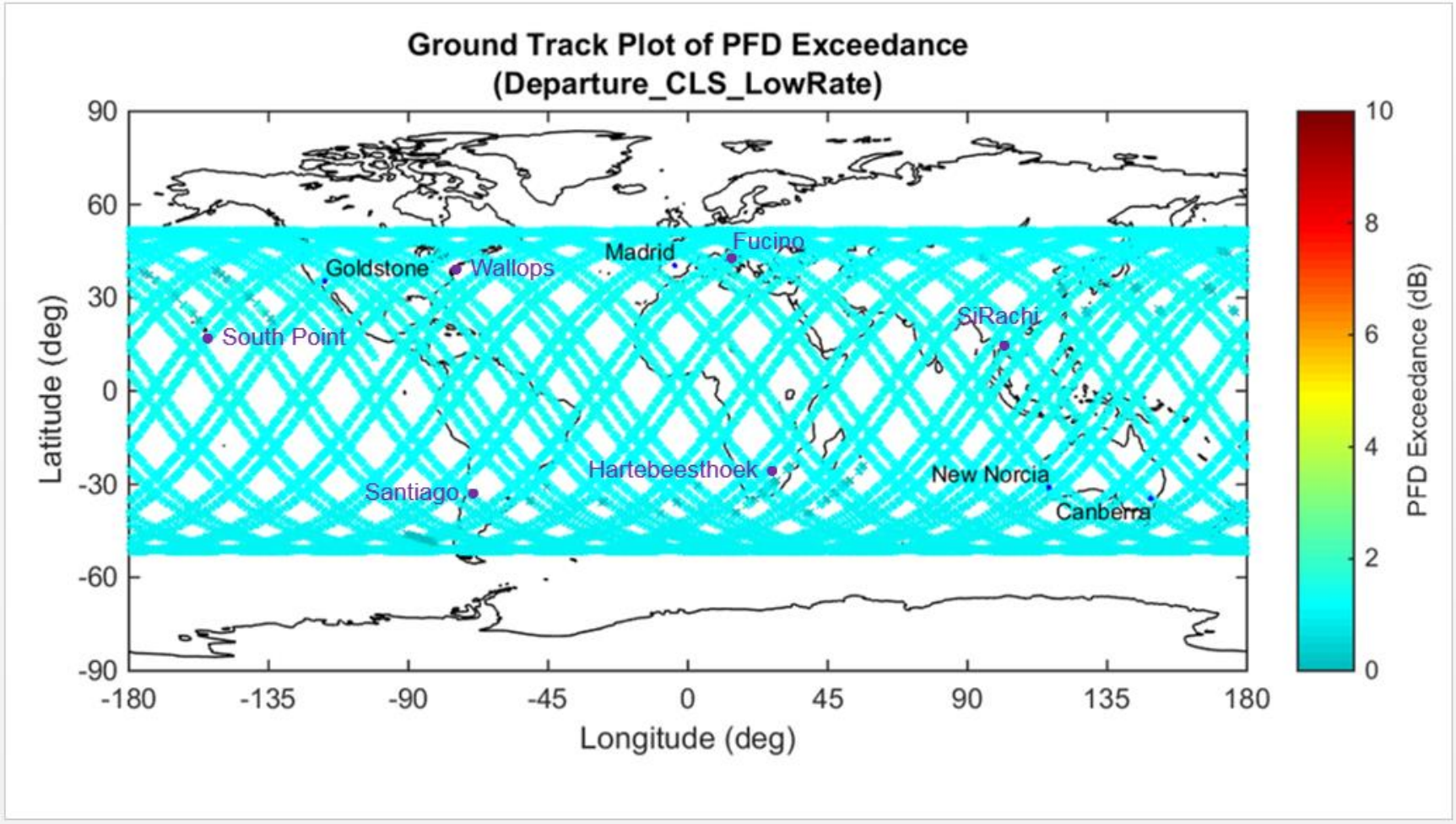

Figure 25. Cygnus NG-16 PFD Limit Exceedances During Departure, CLS at 36 kbps (5M93G1D Emitter)