April 14, 2014

VIA ELECTRONIC FILING

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: IBFS File Nos. SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; SES-MOD-20121001-00872; IB Docket No. 12-340; RM-11681

Dear Ms. Dortch:

By this letter, LightSquared Subsidiary LLC ("LightSquared") submits two additional reports prepared by Alion Science and Technology (the "Alion Task 2 Reports"), which demonstrate that 4G LTE wireless operations could be conducted in the 1675-1680 MHz band on a shared basis with earth stations operated in that band by the National Oceanic and Atmospheric Administration ("NOAA"). These reports underscore the substantial public interest benefits that would flow from allowing LightSquared to share access to the 1675-1680 MHz band. Among other benefits, and as discussed below, making this spectrum for mobile broadband use in the manner contemplated by these reports would provide additional spectrum resources, demonstrate the efficacy of increased sharing spectrum between federal users and private users, and provide the certainty and stability necessary to drive investment and innovation in next-generation wireless networks. In light of the reports' favorable showing regarding the potential for sharing, LightSquared respectfully requests that the Commission issue an Allocation NPRM regarding shared commercial and federal use of the 1675-1680 MHz band.

A. The Alion Task 2 Reports Demonstrate that 4G LTE Wireless Operations Are Feasible in the 1675-1680 MHz Band

In September 2012, LightSquared proposed a "comprehensive solution" that would permit the terrestrial use of the uplink portion of the L Band at 1626.5-1660.5 MHz while resolving issues raised by the GPS industry with respect to the terrestrial use of the downlink portion of the L Band at 1525-1559 MHz.[1] A central element of that solution involves LightSquared's permanent relinquishment of terrestrial rights at 1545-1555 MHz, and substantial delay in exercising its rights to use 1526-1536 MHz terrestrially, in exchange for the right to

[1] *See* Joint Written Statement of Julius P. Knapp, Chief, OET, FCC, and Mindel De La Torre, Chief, International Bureau, FCC, Before the House Oversight and Investigations Subcommittee (Sept. 21, 2012).

employ downlinks in alternative (non-L Band) spectrum at 1670-1680 MHz.[2] To facilitate the Commission's ability to grant the requested spectrum rights, LightSquared also petitioned the Commission to amend the U.S. Table of Frequency Allocations to add a primary allocation permitting non-Federal terrestrial mobile use of the 1675-1680 MHz band, which currently is used for NOAA for certain purposes (the "Allocation Petition").[3]

LightSquared explicitly recognized that its use of the 1675-1680 MHz band would be contingent upon its ability to share that spectrum with NOAA—consistent with recent policies favoring such sharing between commercial and governmental users[4]—and/or relocate certain NOAA facilities to alternative spectrum (*e.g.*, operate radiosondes in the 400 MHz band). In order to demonstrate that such use would be technically feasible, last year LightSquared sought and obtained special temporary authority ("STA") from the Commission to allow it to ascertain: (i) the technical compatibility of 4G LTE wireless base stations in the 1675-1680 MHz band with existing federal spectrum operations in and around that frequency range, and (ii) the technical compatibility of conducting radiosonde operations in the 400.15-406 MHz band with existing spectrum operations in and around that frequency range.

LightSquared worked with Alion and NOAA to evaluate these issues. More specifically, "Task 1" assessed the feasibility of relocating NOAA radiosondes out of the 1675-1680 MHz band, and "Task 2" delineated appropriate coordination zones around current and planned NOAA earth stations operating in spectrum in, and adjacent to, the 1675-1680 MHz band. On January 30, 2014, LightSquared submitted Alion's final report with respect to Task 1 to the Commission (the "Alion Task 1 Report").[5] That report concludes that it would be feasible to relocate NOAA's radiosondes from the 1675-1683 MHz band,[6] and further notes that "[w]ith the feasibility of the radiosonde relocation established, the viability of spectrum sharing with NOAA systems within this band is confirmed, subject to the establishment of necessary protection zones

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2 *See* IBFS File Nos. SAT-MOD-20120928-00160; SAT-MOD-20120928-00161; and SES-MOD-20121001-00872; *see also* LightSquared Petition for Rulemaking, RM-11683 (filed Sep. 28, 2012).

3 LightSquared Petition for Rulemaking, RM-11681 (filed Nov. 2, 2012) ("Allocation Petition").

4 *See, e.g.*, Presidential Memorandum for the Heads of Executive Departments and Agencies, *Expanding America's Leadership in Wireless Innovation*, 78 Fed. Reg. 37431 (June 20, 2013) (stating that where technically and economically feasible, spectrum sharing can and should be used to enhance efficiency among all users and to expedite commercial access to additional spectrum bands).

5 *See* Alion Science and Technology, *Assessment of the Viability of Relocating National Weather Service Radiosonde Operations from the 1675-1683 MHz Band to the 400.15-406 MHz Band* (Jan. 2014) ("Alion Task 1 Report"), *attached to* Letter from LightSquared to FCC, RM-11681 (Jan. 30, 2014).

6 Although LightSquared has proposed to allow commercial operations in the 1675-1680 MHz band, NOAA radiosondes currently operate in the wider 1675-1683 MHz band.

around NOAA meteorological satellite earth stations, which will remain operational within this band over the long-term."[7]

The Alion Task 2 Reports, which are attached hereto, addresses technical parameters for establishing coordination zones around NOAA earth stations, and confirm the viability of the proposed sharing in the 1675-1680 MHz band. More specifically, the reports define appropriate coordination zones around both currently operational (legacy) NOAA GOES satellites and the next-generation GOES-R satellite slated to become operational within the next few years. The Commission could require prior coordination of any 4G LTE base stations proposing to operate within these zones in order to ensure the protection of ongoing NOAA operations (in a manner similar to the approach taken by the Commission in the recent *AWS-3 Report and Order*[8]). Terrestrial downlink operations could occur at commercially-viable power levels outside those zones without the need for coordination. Based on the data contained in the Alion Task 2 Reports, it is predicted that commercial terrestrial operations could proceed unencumbered over roughly 84 percent of the land area and cover at least 78 percent of the population of the United States. Even greater coverage would be possible within established zones following the completion of coordination.

Together, the Alion Task 1 and Task 2 Reports demonstrate that the relocation of NOAA radiosondes from the 1675-1680 MHz band is technically feasible and that shared use of that band by a commercial terrestrial wireless operator is feasible while still protecting NOAA earth stations.

B. Issuance of an Allocation NPRM Would Advance the Commission's Objectives of Relieving Spectrum Scarcity and Encouraging Investment and Innovation by Wireless Service Providers

Completion of an Allocation NPRM would create significant public interest benefits—advancing the Commission's spectrum policy priorities by freeing additional spectrum for mobile broadband use. Soaring consumer demand for wireless broadband service is placing significant strain on existing wireless networks.[9] As the Commission observed in its recent *AWS-3 Report and Order*, "[t]he rapid adoption of smartphones and tablet computers, combined with deployment of high-speed 3G and 4G technologies, is driving more intensive use of mobile

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7 Alion Task 1 Report at 40.

8 *See Amendment of the Commission's Rules with Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, FCC 14-31, GN Docket No. 12-185, at ¶ 11 (Mar. 31, 2014) ("*AWS-3 Report and Order*").

9 *See, e.g.*, CONNECTING AMERICA: THE NATIONAL BROADBAND PLAN, at 85, 93 (2010) (recognizing that "increased spectrum demands are primarily an urban phenomenon," and identifying urban areas as particularly high congestion areas) ("*National Broadband Plan*").

networks, so much so that the total number of mobile wireless connections now exceeds the total U.S. population."[10]

Existing spectrum resources are insufficient to meet this demand and therefore are inadequate to facilitate consumer access to the innovative wireless services and applications that otherwise would be available to them. For this reason, Chairman Wheeler recently underscored "the important national interest in making available additional spectrum for flexible use" to relieve capacity constraints.[11] More generally, the Commission has recognized that "[e]nsuring that sufficient spectrum is available for incumbent licensees, as well as for potential entrants, is critical to promoting competition, investment, and innovation."[12]

There is spectrum available in the L Band which should play a central role in ameliorating the existing shortage of terrestrial wireless spectrum. LightSquared's "comprehensive solution" permits the Commission finally to bring the L Band and related spectrum resources into terrestrial use, as was determined to be in the public interest over a decade ago.

Issuing an NPRM would contribute to the certainty and stability necessary to drive the efficient use of *all* wireless spectrum and encourage investment in innovative next-generation broadband communications networks. As previous Commission chairmen have noted, "[w]ireless infrastructure doesn't build itself."[13] Rather, wireless infrastructure "requires many billions of dollars in investment—overwhelmingly by private companies."[14] Thus, it is critical that the Commission remain focused on "strengthening incentives for investment in mobile infrastructure"—including "regulatory certainty and predictability."[15] By issuing the requested NPRM and taking other appropriate action to implement LightSquared's "comprehensive solution," the Commission would advance its objective of taking all necessary steps to ensure that spectrum that potentially could be used for terrestrial broadband purposes is put into broadband service for the public benefit.

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10 *AWS-3 Report and Order* ¶ 3.

11 Chairman Thomas Wheeler, *The Path to a Successful Incentive Auction* (Dec. 6, 2013), *available at* http://www.fcc.gov/blog/path-successful-incentive-auction-0.

12 *Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993*, 28 FCC Rcd 3700, at ¶ 86 (2013); *see also National Broadband Plan* at 75, 85 (recommending that the Commission make 500 MHz of spectrum available for broadband use by 2020, of which 300 MHz should be below 3.7 GHz, and promote access to unused and underutilized spectrum).

13 *See, e.g.,* Julius Genachowski, Chairman, Federal Communications Commission, Remarks as Prepared for Delivery, GSMA Mobile World Congress, at 3 (Feb. 27, 2012).

14 *Id.*

15 *Id.* at 3, 4.

Accordingly, LightSquared respectfully requests that the Commission issue an NPRM in response to the Allocation Petition and take all other appropriate actions to facilitate the grant of the other elements of LightSquared's "comprehensive solution."

/s/ Jeff Carlisle
Jeff Carlisle
Executive Vice President for
Regulatory Affairs and Public Policy
LightSquared Subsidiary LLC

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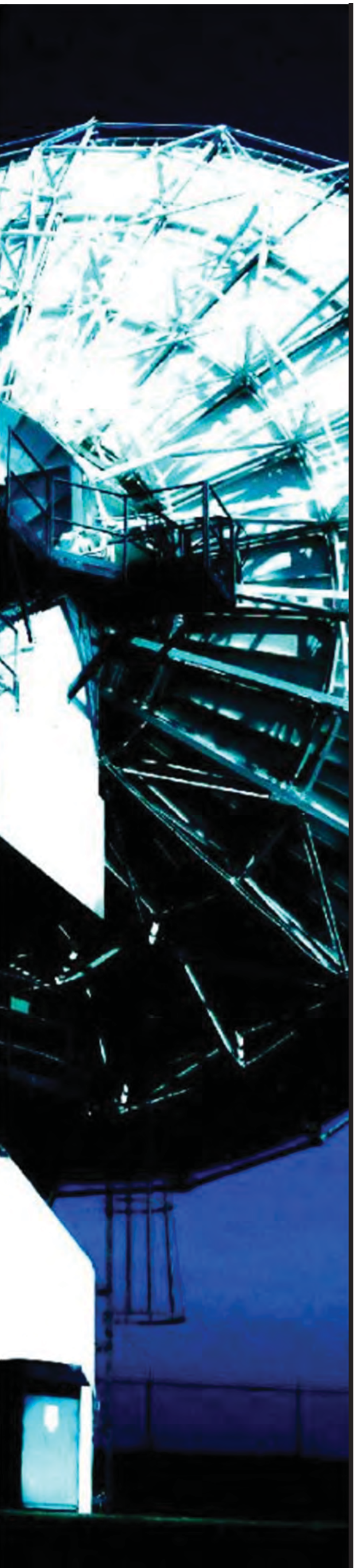
Alion Science and Technology

Assessment of the Potential for LightSquared Broadband Base Stations in the 1670-1680 MHz Band To Interfere with Select NOAA Legacy Ground Locations

RESED-14-004

February 2014



Consulting Report

ASSESSMENT OF THE POTENTIAL FOR LIGHTSQUARED BROADBAND BASE STATIONS IN THE 1670-1680 MHZ BAND TO INTERFERE WITH SELECT NOAA LEGACY GROUND LOCATIONS

Prepared for:

NOAA/LightSquared

RESED-14-004
February 2014

Use and Disclosure of Data

Further dissemination only as directed by LightSquared

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This report is approved for release and publication from Alion Science and Technology Corporation, Technology Solutions Group, Systems Engineering Operation.

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14. ABSTRACT LightSquared is proposing to use the 1670 to 1680 MHz frequency band to support Fourth Generation Long-Term Evolution (4G-LTE) wireless network downlink operations. LightSquared has obtained rights to the 1670 to 1675 MHz band that was previously auctioned to Crown-Castle. The National Oceanic and Atmospheric Administration (NOAA) uses multiple frequencies in the 1675 MHz to 1710 MHz band for various space-to-earth downlinks from geostationary and polar satellites. Prior to launch, NOAA used the designation GOES-N, O, and P for the satellites which then became operational as GOES-13, 14, and 15, and as a group are referred to in this report as GOES-Legacy systems. The GOES-Legacy series operates multiple downlinks with center frequencies from 1676 - 1694.5 MHz. This report presents the analysis of potential interference to NOAA GOES-Legacy earth stations from LightSquared LTE base stations. GOES-R is not analyzed or addressed in this report and instead will be in a supplemental report to follow.					
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EXECUTIVE SUMMARY

LightSquared is proposing to use the 1670 to 1680 MHz frequency band to support Fourth Generation Long-Term Evolution (4G-LTE) wireless network downlink operations (i.e., base station transmitters to mobile user equipment) within the United States. LightSquared has obtained rights to the 1670 to 1675 MHz band that were previously auctioned to Crown Castle. This analysis covers the Geostationary Operational Environmental Satellites (GOES) legacy systems only. GOES-R is not analyzed or addressed in this report and instead will be in a supplemental report to follow.

The National Oceanic and Atmospheric Administration (NOAA) uses multiple frequencies in the 1675 MHz to 1710 MHz band for various space-to-earth downlinks from geostationary and polar satellites. The weather balloon radiosondes use the 1675 – 1683 MHz portion of the L-band. The polar satellites use the 1695 – 1710 MHz portion of the L-band. Prior to launch, NOAA used the designation GOES-N, O, and P for the satellites which then became operational as GOES-13, 14, and 15, and as a group are referred to in this report as GOES-Legacy systems. The GOES-Legacy series operates multiple downlinks with center frequencies from 1676 - 1694.5 MHz. In the near future, NOAA will launch a new GOES-R series of satellites. This report does not address the GOES-R series because it is in development and complete characteristics needed for analysis were not available. The future auction of the NOAA polar band frequencies (1695 – 1710 MHz) forced the GOES-R spectrum to be shifted downward into the radiosonde band so that GOES-R will occupy the spectrum from 1679.7 – 1694.5 MHz. A prior analysis, Alion report on Task #1, assessed the potential to move weather balloon radiosondes to the 403 MHz band.[1]

For LightSquared to implement their proposed broadband network, an assessment was needed to determine the potential for LightSquared network base stations operating in the 1670 to 1680 MHz frequency band to interfere with NOAA satellite downlink operations in the 1675 to 1710 MHz frequency band at select ground locations in the United States (US) and Puerto Rico. To achieve this, modeling and simulation analyses were performed to assess the potential interference power from a LightSquared base station to each NOAA receiver at selected ground stations and to determine maximum separation distances necessary to mitigate the predicted interference.

A list of separation distances for the NOAA ground locations are provided in the table below. It should be noted that for each NOAA location, the calculated distance in a particular azimuthal direction to

[1] A. Furlow, R. Leck, and I. McClymonds, *Assessment of the Viability of Relocating National Weather Service Radiosonde Operations from the 1675 - 1683 MHz Band to the 400.15 - 406 MHz Band*, RESED-14-003, Annapolis Junction, MD: Alion Science and Technology, January 2014.

mitigate LightSquared base station interference will vary as a function of the terrain surrounding the location. As such, the distances provided below are a compilation of the maximum distance predicted for each individual Sensor Data (SD) link.

List of largest protection distances by Site

Location	Data Link	GOES Satellite Orbital Location	Maximum separation Distance, km*
Fairbanks, AK	SD	135 W	208
Greenbelt, MD	SD	75 W	434
Wallops, VA	SD	75 W	450

* These values represent the point along each calculated interference mitigation contour that is the greatest distance from the NOAA ground location for each link analyzed. For all other points on the calculated contour, the distance will not be greater than this value.

At the conclusion of the Task 2 work item, LightSquared and NOAA agreed that Alion should undertake additional analysis in order to consider the following items that could impact the final boundaries of the protection zones: 1). Aggregate impacts of multiple LightSquared cell sites on GOES-R rebroadcast (GRB) and data collection platform report (DCPR-1) links; 2). Impacts of large signal overload analysis. These additional analyses do not introduce any new earth station locations already included in this Task 2 report; however, because GRB and GOES-R implementation of DCPR-1 are closer in frequency to the proposed LightSquared deployment, this will create larger protection zones for some or all of the relevant earth stations. Upon completion of the additional analysis, a supplement to this report with the relevant results will be issued.

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GLOSSARY

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AGL	Above Ground Level
AOA	Angle of Arrival
AOD	Angle of Departure
CDA	Command and Data Acquisition
DCPR	Data Collection Platform Report
DRGS	Direct Readout Ground Station
E-UTRA	Evolved Universal Terrestrial Radio Access
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EMWIN	Emergency Managers Weather Information Network
FIR	Finite-impulse-response
FDR	Frequency-dependent rejection
GOES	Geostationary Operational Environmental Satellite
GOES-R	GOES-R Series
GRB	GOES-R Rebroadcast (Sensor Data)
IMT-A	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LRIT	Low-Rate Information Transmission
LTE	Long Term Evolution
LTE-A	Long Term Evolution - Advanced
MSAM	Microcomputer Spectrum Analysis Models
NOAA	National Oceanic and Atmospheric Administration
NTIA	National Telecommunications and Information Administration
RF	Radio Frequency
SD	Sensor Data
UE	User Equipment
US	United States

BACKGROUND

LightSquared is proposing to use the 1670 – 1680 MHz frequency band to support Fourth Generation Long-Term Evolution (4G-LTE) wireless network downlink operations (i.e., base station transmitters to mobile user equipment) within the United States. LightSquared has obtained rights to the 1670 – 1675 MHz band that were previously auctioned to Crown Castle.

LightSquared currently operates a network in the 1670-1675 MHz band utilizing DVB-H (Direct Video Broadcast- Handheld) technology. Meteorological satellite use of the 1670 to 1675 MHz frequency band is protected at NOAA ground locations at Wallops (VA), Fairbanks (AK), and Greenbelt (MD) by the FCC rules underlying LightSquared's authorization for the DVB-H network. These rules define coordination zones of 100 kilometers for the Wallops and Fairbanks locations, and 65 kilometers for the Greenbelt location.

The National Oceanic and Atmospheric Administration (NOAA) uses multiple frequencies in the 1675 MHz - 1710 MHz band for space-to-earth links from geostationary and polar satellites. Radiosondes (weather balloons) use the 1675 – 1683 MHz portion of the L-band. The polar satellites use the 1695 – 1710 MHz portion of the L-band. The Geostationary Operational Environmental Satellites (GOES) series operates multiple downlinks with center frequencies from 1676 MHz to 1694.5 MHz. Prior to launch NOAA used the designation GOES-N, O, and P for the satellites which then became operational as GOES-13, 14, and 15, and as a group are referred to in this report as GOES-Legacy systems. In the near future, NOAA will launch a new GOES-R series of satellites. The GOES-R links in the 1670 – 1680 MHz band will be addressed in a supplement to this report. The future auction of the NOAA polar band frequencies (1695 – 1710 MHz) requires the GOES-R spectrum to be shifted downward into the radiosonde band so that GOES-R will occupy the spectrum from 1679.7 – 1694.5 MHz. A prior analysis, Alion report on Task #1, assessed the potential to move weather balloon radiosondes to the 403 MHz band.[2]

It was agreed upon by LightSquared and NOAA that an analysis was necessary to assess the ability of LightSquared to operate in the 1670 - 1680 MHz band without adversely impacting current and future operation of NOAA satellite system downlinks in the 1675 - 1710 MHz band. NOAA requires satellite bit error rate less than 10^{-10}, 99.99% of the time. This equates to 53 minutes per year (4 - 5 mins/month) for allowable interference.

[2] A. Furlow, R. Leck, and I. McClymonds, *Assessment of the Viability of Relocating National Weather Service Radiosonde Operations from the 1675 - 1683 MHz Band to the 400.15 - 406 MHz Band*, RESED-14-003, Annapolis Junction, MD: Alion Science and Technology, January 2014.

Alion Science and Technology Corporation (Alion) was contracted by LightSquared to perform an analysis of the potential for interference. Alion is a leader in the field of spectrum management with over 70 years of experience and a multitude of tools in place to provide spectrum services in the areas of planning, management, modeling and simulation, measurements and testing, consultation, and electromagnetic compatibility (EMC) design.

OBJECTIVE

The objective of these analyses was:

- To assess the potential interference from LightSquared network base station transmissions to GOES-Legacy satellite ground station operations in the US and Puerto Rico between 1675 - 1695 MHz
- To calculate maximum separation distances that will be used by NOAA to determine the extent of protection zones for Greenbelt, MD, Fairbanks, AK, and Wallops, VA earth stations.

A follow-on effort will assess the future GOES-R system that requires a 3 MHz shift downward closer to the 1680 MHz (upper limit of the proposed LightSquared band). A supplemental report will be prepared to address the protection zones for GOES-R links.

APPROACH

For each NOAA ground station, an interference assessment was performed to determine maximum separation distances around the three stations – Greenbelt, MD, Fairbanks, AK, and Wallops, VA. The assessment consisted of the following:

- Available technical and operational characteristics for NOAA receivers at the selected locations
- Technical and operational characteristics for LightSquared-defined systems
- ITU specifications defining NOAA satellite receive system interference thresholds for each signal
- The use of the Visualyse software tool to model, simulate, and analyze radio frequency (RF) signal interactions

SYSTEM DESCRIPTIONS

NOAA Receive Systems

The NOAA ground stations receive and process the satellite signals. NOAA provided a list of ground stations that is presented in Table 1 for assessment. Table 1 provides the location, antenna diameter, gain, and height above ground level (AGL) in meters.

Table 1. NOAA Earth Station parameters

NOAA Ground Stations	Latitude	Longitude	Antenna Diameter, m	Antenna Gain, dBi	Antenna Feedpoint Height, AGL, m
Bay St. Louis, MS	30°21' 23" N	89° 36' 41" W	5	36.8	4
Boise, ID	43°36' 53" N	116° 15' 08" W	7	39.7	8
Boulder, CO	39°58' 39" N	105° 16' 27" W	6.1	37.6	3
Cincinnati, OH	39°06' 10" N	84° 30' 35" W	5	36.8	65
Columbus, MS	33°32' 04" N	88° 30' 06" W	5	36.8	4
Fairbanks, AK	64°58' 22" N	147° 30' 02" W	21	50.6	15.5
Ford Island/Pearl Harbor, HI	21°22' 12" N	157° 57' 44" W	5	36.8	3
Greenbelt, MD	39°00' 02" N	76° 50' 29" W	16.4	48.4	11.8
Miami, FL	25°45' 16" N	80° 23' 01" W	6.1	38.5	7
Monterey, CA	36°35' 34" N	121° 51' 20" W	4.5	35.9	2.5
Omaha, NE	41°20' 56" N	95° 57' 34" W	5	36.8	3
Rock Island, IL	41°30' 57" N	90° 33' 52" W	5	36.8	3
Sacramento, CA	38°35' 50" N	121° 32' 34" W	5	36.8	3
San Juan, PR	18°25' 26" N	66° 06' 51" W	3.8	34.4	3.4
Sioux Falls, SD	43°44' 06" N	96° 37' 32" W	7.5	33	4
St Louis, MO	38°35' 26" N	90° 12' 24" W	5	36.8	3
Suitland, MD	38°51' 07" N	76° 56' 12" W	9.1	41.4	21
Vicksburg, MS	32°20' 47" N	90° 50' 10" W	5	36.8	3
Wallops, VA	37°56' 45" N	75° 27' 43" W	16.4	48.4	12.2

LightSquared Transmit Systems

Antennas

LightSquared provided the product specification sheet for the antenna that is planned for use, the Argus HPX308R, and the remaining parameters are detailed in Table 2. It should be noted that the Alion analysis used the omnidirectional antenna pattern contained within ITU-1336 instead of the Argus parameters listed below.

Table 2. LightSquared transmission parameters

Frequency	1675 MHz
Bandwidth	10 MHz
Transmit Power	14 dBW (25W)
Gain	18 dBi
Horizon Gain with 3° down tilt	16.6 dBi
EIRP	30.6 dBW
Mechanical Tilt	0°
Horizontal Beam width	65°
Vertical Beam width	8.5°
Antenna Height Above Ground Level	45m (single entry case) at feed point
Antenna Horizontal Pointing Angle	3 sector - 0, 120, 240° [1]
Antenna Vertical Pointing Angle	3° down tilt

[1] The analysis presented in this document assumes an omnidirectional antenna pattern (maximum gain pointed to relevant NOAA earth station). The analysis does not consider the effects of the three-sectored configuration which would reduce the received interferer power at the NOAA earth stations in many instances.

Emission Mask

The emission mask of a transmitter is derived from power spectral density (PSD). PSD is defined as the way in which signal power is distributed over a frequency range such as 4.4 Watts per MHz (W/MHz). The emission mask indicates the attenuation that is applied to the actual PSD to comply with limits on adjacent-band and out-of-band emission. The proposed LightSquared emission is nominally 10 MHz, from 1670 – 1680 MHz, centered around a tuned frequency of 1675 MHz, with 0.5 MHz guard band on the high and low ends. The mask used for this assessment, agreed upon by Alion and LightSquared, is consistent with the 3GPP specification for LTE-A base station transmitters.[3] While there is no maximum base station transmitter power in the specification, there is a requirement that the out-of-band emission be no greater than -13 dBm in a 1 MHz bandwidth. For this assessment, a transmitter power of 25W (14 dBW) was used with an antenna gain of 16.6 dBi to produce an effective isotropic radiated power (EIRP) of 60.6 dBm as shown in Figure 1.

[3] 3GPP TS 36.104 V10.2.0 (2011-04)

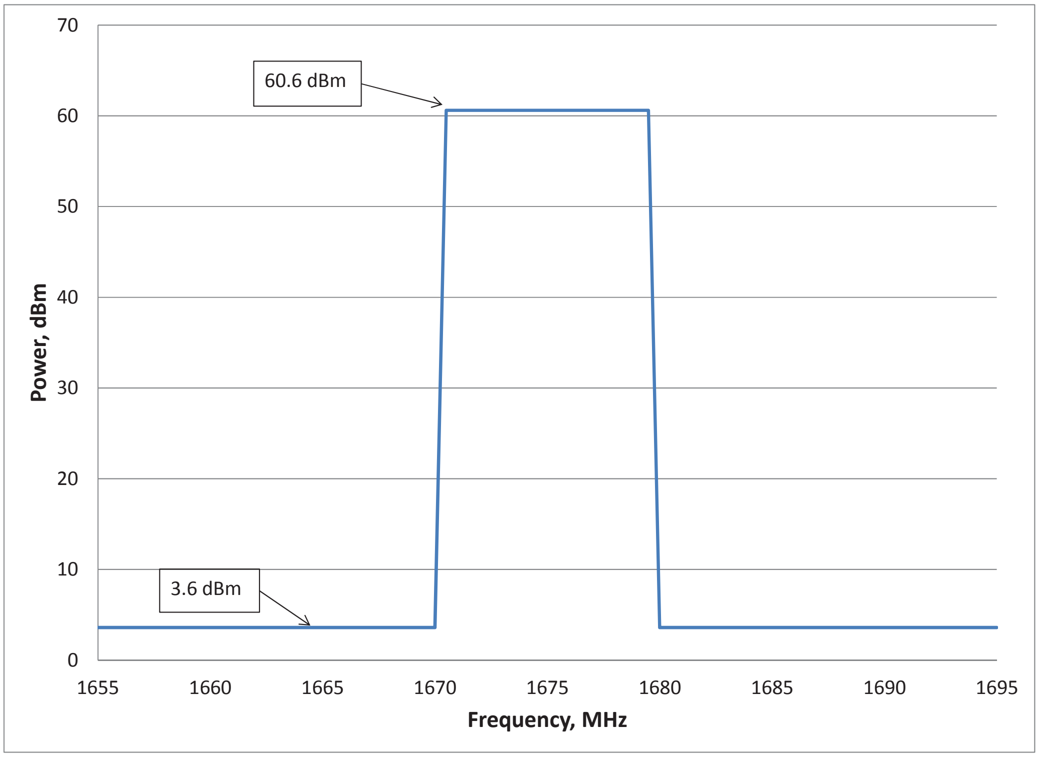


Figure 1. LightSquared EIRP emission mask for 25W transmitter with 16.6 dBi gain from antenna in Table 2

LTE/LTE-Advanced

LTE and LTE-Advanced versions 10, 11, 12, or 14 (LTE-A) are mobile broadband communications standards for 4th Generation (4G) systems.[4,5] LTE-A was approved by the International Telecommunication Union (ITU) as International Mobile Telecommunications Advanced (IMT-A) (also known as Evolved Universal Terrestrial Radio Access [E-UTRA]). LTE-A is standardized by the 3rd Generation Partnership Project (3GPP), whose documents are available on the internet. The standards are known as "releases." Releases 8 and 9 are for LTE and Releases 10 and above are for LTE-A. LTE-A is backwards compatible with LTE. Some of the main benefits of LTE-A over LTE are peak data rates of 1 Gbps for downlink and 500 Mbps for uplink, improved spectrum efficiency (of 30 bps/Hz for downlink and 15 bps/Hz for uplink), improved cell edge user throughput, and higher average user throughput. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast

[4] See, for example, the list of ITU-R Recommendations on IMT, http://www.itu.int/ITU-R/index.asp?category=information&rlink=imt-advanced-rec&lang=en

[5] 3GPP, *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 11)*, 3gPP TS 36.101 V11.0.0, 2012-03

streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency division duplexing (FDD) and time-division duplexing (TDD).

GOES-LEGACY System

The GOES satellite system consists of three satellites in geostationary orbit, two of which are operationally active and the other in on-orbit storage. This assessment considered the two active satellites which are GOES-13, located at an orbital longitude of 75^{o}W, and GOES-15, located at an orbital longitude of 135^{o}W.

Downlinks

There are seven different types of NOAA GOES-Legacy signals, five of which were assessed as part of this effort. The remaining two are not utilized by NOAA, therefore, do not need to be analyzed. These signals are identified in Table 3. The Sensor Data (SD) is the primary downlink to the Wallops, VA, Greenbelt, MD, and Fairbanks, AK. The SD occupies 5.2 MHz of bandwidth centered at 1676 MHz, and will be completely overlapped by the LightSquared transmission at 1670-1680 MHz. Therefore, primary attention was given to analyzing the separation distances required to prevent harmful interference at the aforementioned stations. All other NOAA signals are outside the primary LightSquared transmission band and were analyzed for adjacent band interference. Emergency Managers Weather Information Network (EMWIN) and Low Rate Information Transmit (LRIT) downlinks were not analyzed for this study because these links do not have NOAA users.

Table 3. Data links and frequencies

Data Link	Center Frequency, MHz
Sensor Data (SD)	1676.0
Multi-Use Datalink (MDL)	1681.478
GOES Variable Format (GVAR)	1685.7
Command and Data Acquisition (CDA) Telemetry (Tlm)	1694.0
Data Collections Platform Report, Band #1 (DCPR-1)*	1694.5
Emergency Managers Weather Information Network (EMWIN)	1692.7 (no NOAA users)
Low Rate Information Transmit (LRIT)	1691.0 (no NOAA users)
*DCPR-2 not analyzed	

Antenna Characteristics

The NOAA ground stations use different antennas with size and gain based on location and desired receive link. Measured pattern data was not available for each antenna. In cases where data wasn't available, International Telecommunication Union (ITU) recommendation ITU-R S.465-5, "*Reference earth-station radiation pattern for use in coordination and interference assessment in the frequency range from 2 GHz to about 30 GHz*", was used to model the antenna gain pattern for the analyses. The specifications were obtained from equipment technical data as well as the NOAA antenna handbook.

Hurricane Rated Antennas. At the NOAA Wallops, VA, and Greenbelt, MD ground locations, the 16.4-meter antennas are designed with additional support bracing to withstand hurricane force winds. This additional bracing causes an increase in the side lobe gain of the antennas. To determine the effects of the additional bracing, NOAA had previously employed two methods. The first method involved comparing measurements to manufacturer supplied data. The second method was based on modeling the antenna with stiffening in a computer model to simulate gain pattern results. Figure 2 shows the estimated antenna pattern data compared against ITU-R S.465.5 for a 16.4m antenna. The adjusted manufacturers calculated value model data was used in the analysis.

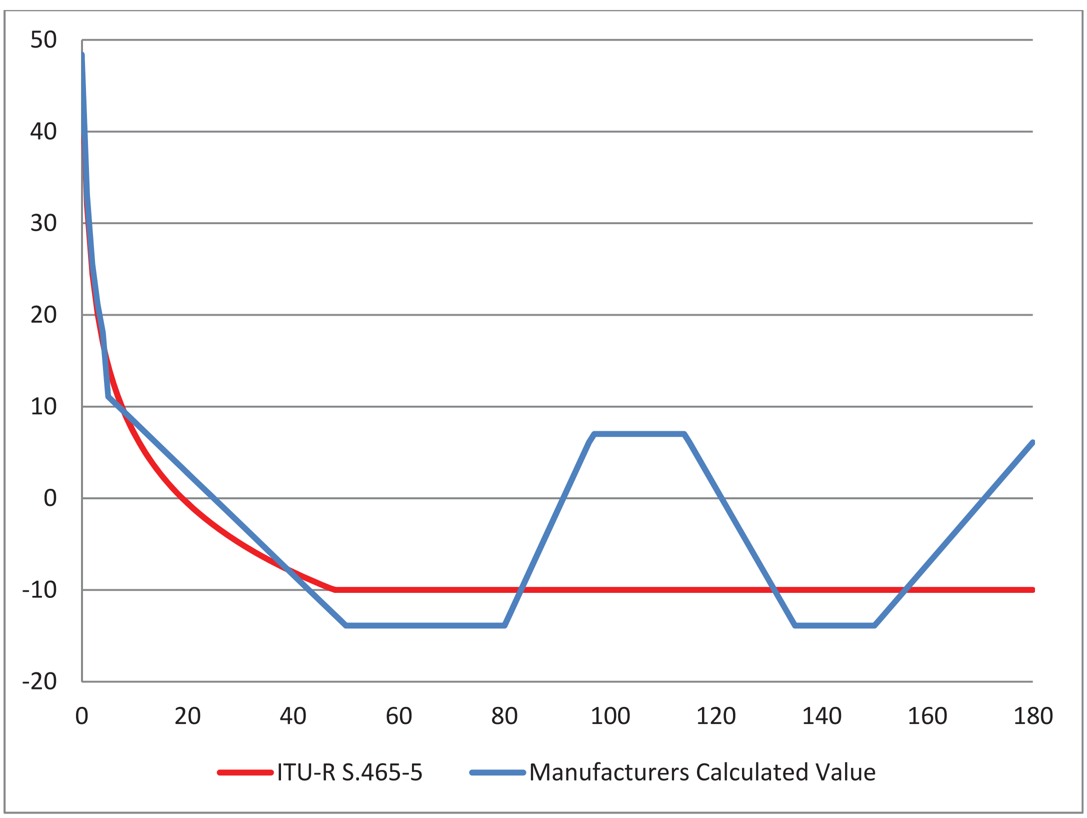


Figure 2. Hurricane-rated antenna pattern comparison, Azimuthal angles of 0-180°

ASSESSMENT METHODOLOGY

This effort assessed the potential for LightSquared LTE network base stations transmitting in the 1670 to 1680 MHz frequency band to interfere with NOAA receivers at selected ground locations in the US and Puerto Rico. The assessment utilized single-entry (i.e., one LightSquared base station to one NOAA receiver) analysis. The single entry analysis modeled the source interferer and victim receiver such that the separation distance was increased until the receive level at the victim was equal to the interference threshold. These distances were calculated using Visualyse, a modeling, simulation, and analysis software tool developed by Transfinite Systems Limited. Visualyse, in area mode analyses, analyzes the interfering source throughout a set area, with respect to a resolution (e.g.- 1 km) set by the user.

Signal propagation path loss was calculated using the ITU-R P.452 RF model and 30-second digital terrain elevation data. For each NOAA downlink, two interference thresholds are specified—designated *long term* and *short term*.

ANALYSIS

Modeling RF Propagation to Predict Interference Power and Determine Separation Distances

Propagation mechanisms that reduce signal loss and thereby extend the range of interfering signals are of special concern when applied to an interference assessment. The result will be an increase in required separation distances from victim receivers, a required reduction in power of interfering transmitters, or perhaps other remediation measures applied to the system responsible for the interference. It is important to use a dedicated interference model, such as P.452, to perform such an assessment. Propagation models designed for analyzing and optimizing desired-signal links are not appropriate. Anomalous propagation mechanisms, especially super-refractivity and ducting, cannot be depended upon to provide the consistent operation that is sought in a desired-signal analysis. These mechanisms can, however, create sporadic and objectionable interference for periods of time that, while relatively brief, are still significant.

Predictions of the atmospheric conditions capable of causing anomalous propagation are based on measured data, accumulated over large areas and for long periods of time. The ITU has collected such data from a number of sources worldwide. Summaries of the empirical observations, along with modeling algorithms based on the data, are made available as ITU-R Recommendations.[6,7] The data sets are often exploited by deriving statistical distributions that show the variation, about a mean or median value, of transmitted RF signals that are subjected to anomalous propagation environments.

In this analysis, the dominant propagation mechanism, insofar as it results in the largest separation zones, is ducting. The ITU data documents an atmospheric discontinuity over much of North America, at an altitude of roughly 1200 meters, for as much as 10% of the time. This condition is capable of causing at least partial reflection of RF transmissions, along with the range extension characteristic of super-refractivity. The frequency of occurrence, duration, power, and geographic extent of interfering signals delivered via such a mechanism is predicted by the Visualyse software, based on algorithms and data provided by the ITU.

Propagation by ducting is capable of delivering signals that are stronger than propagation through free-space. This is caused by the reflection mechanism, which redirects part of the transmitted power that would otherwise propagate into space, back towards the Earth. The effect is to minimize the spreading that causes power to weaken as the square of distance, as predicted by the free-space equation.

For additional information on RF propagation, please refer to Appendix B.

Propagation Model

The propagation model selected for this analysis was ITU-R P.452, which is an interfering signal model developed specifically for analyzing RF links that have the potential to interfere with existing RF systems.[8] Since it is an interference model, P.452 considers anomalous propagation mechanisms that that would not be relevant for desired-signal links.

There are many mechanisms by which RF energy can propagate from an interfering transmitter to a victim receiver. These mechanisms include:

- Free-space
- Diffraction
- Refractivity

[6] ITU-R Recommendation P.453-10, “The radio refractive index: its formula and refractivity data,” International Telecommunication Union, 2012.
[7] ITU-R Recommendation P.834-6, “Effects of tropospheric refraction on radiowave propagation,” International Telecommunication Union, 2007.
[8] ITU-R Recommendation P.452-15, “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz,” International Telecommunication Union, 2013.

- Super-refractivity
- Ducting

All of these propagation mechanisms are included in the P.452 model. These mechanisms, and their significance regarding the calculated separations, are discussed in this section. A more thorough explanation of the physics of electromagnetic propagation at radio frequencies can be found in a number of technical publications.[9.]

The P.452 model used in this analysis is implemented in the Visualyse software product, which is designed specifically for this purpose. Visualyse combines analysis techniques with empirical data to provide predictions that are grounded in the physics of electromagnetic radiation, as well as the supporting reality of measured data. The screenshots for Visualyse are provided in Appendix C along with a more detailed discussion of free space propagation, diffraction, refractivity, super-refractivity, and ducting.

Interference Analysis

The calculated interference level at the NOAA receiver was a function of the antenna gain coupling and the signal path propagation loss that an interfering signal will incur between the interfering transmitter and the victim receiver. This is expressed in Equation 1:

$$I = P_t + G_t + G_r - L_p(d) - FDR(\Delta f)$$

(Equation 1)

where

I = interfering signal level at the victim receiver, dBm

P_t = Power of the interfering transmitter, dBm

G_t = Antenna gain of interfering transmitter in direction of victim receiver, dBi

G_r = Antenna gain of victim receiver antenna in direction of interfering transmitter, dBi

$L_p(d)$ = Path loss between interfering transmitter and victim receiver, dB

$FDR(\Delta f)$ = Frequency-dependent rejection of the interfering signal by the victim receiver, dB

where, $\Delta f = f_t - f_r$

f_t = Tuned center frequency of the interfering transmitter, MHz

f_r = Tuned center frequency of the victim receiver, MHz

[9] Lewis, C.A., Johnson, J.T., Teixeira, F.L., "Radiowave Propagation, Physics and Applications," John Wiley & Sons, 2010

and

$$FDR(\Delta f) = 10 \log \frac{\int_0^\infty P(f) \mathrm{d}f}{\int_0^\infty P(f) \left| H(f + \Delta f) \right|^2 \mathrm{d}f} \quad \text{dB}$$

(Equation 2)

where $P(f)$ = Power spectral density of the interfering signal equivalent intermediate frequency
$H(f)$ = Frequency response of the victim receiver

Replacing I in Equation 1 with the interference threshold criteria (I_{th}) and rearranging terms yields,

$$L_p(d) = P_t + G_t + G_r - FDR(\Delta f) - I_{th} \text{ dB}$$

(Equation 3)

Solving equation 3 for the value of *d* determines the required protection distance. Detailed descriptions of the interference assessment components are presented in the subsections below.

Interference Thresholds

Recommendations ITU-R SA.1160 and ITU-R SA.1163 provide interference criteria for sharing and coordination for the satellite services data links. The interference thresholds specify the maximum in-band, interference power that can be tolerated by the receivers without resulting in unacceptable performance. To refine this approach, the ITU specifies a long-term and a short-term threshold per link. The interference power can exceed the long-term threshold no more than 20% of the time; it can exceed the short-term threshold no more than 0.025% of the time depending on the data link.

The interference thresholds used in this analysis are derived and published by the ITU in a number of recommendations.

In SA.1022-1[10] the procedure for deriving the thresholds is presented. System noise is considered as well as interference from external sources. The need for considering both the uplink and downlink for relay systems is identified.

In SA.1159-3[11] the performance objective upon which the thresholds are based are introduced. For digital systems, the performance objective addresses both the quality of the data, and the availability of the system. Data quality is expressed as a maximum bit-error rate (BER), and availability is expressed as the percent of time the system is expected to operate at or below the maximum BER.

In SA.1160-2,[12] 1161,[13] 1162,[14] 1163,[15] and 1164[16] thresholds for specific links are derived. The concept of BER-plus-availability is extended such that two thresholds are derived for each system. The thresholds are based on a low BER, which must prevail most of the time, and a higher BER, which although permitted, is limited to a very small fraction of time. The thresholds are derived from the target BER values, then expressed in terms of interference power *I*, in dBW or dBm:

$I_{\text{long-term}}$, to be exceeded no more than 20% of the time
$I_{\text{short-term}}$, to be exceeded no more than 0.025% of the time

For certain critical links, such as telemetry, the short-term limit is reduced to 0.011%.

In P.452-15,[17] a procedure for predicting interference levels for terrestrial links is developed. The procedure considers several modes of propagation, including free-space, diffraction, atmospheric attenuations, refractivity, and ducting. This procedure is implemented the analysis software product *Visualyse*, developed by Transfinite, LLC.

[10] ITU Recommendation ITU-R SA.1022-1, “Methodology for determining interference criteria for systems in the Earth exploration-satellite and meteorological-satellite services,” International Telecommunication Union, 1999
[11] ITU Recommendation ITU-R SA.1159-3, “Performance criteria for data dissemination and direct data readout in the Earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit,” International Telecommunication Union, 2006
[12] ITU Recommendation ITU-R SA.1160-2, “Interference criteria for data dissemination and direct data readout in the Earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit,” International Telecommunication Union, 1999.
[13] ITU Recommendation ITU-R SA.1161-1, “Sharing and coordination criteria for data dissemination and direct data readout in the Earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit,” International Telecommunication Union, 1999
[14] ITU Recommendation ITU-R SA.1162, “Performance criteria for service links in data collection and platform location systems in the Earth exploration-satellite and meteorological-satellite services,” International Telecommunication Union, 2003
[15] ITU Recommendation ITU-R SA.1163-2, “Interference criteria for service links in data collection systems in the Earth exploration-satellite and meteorological-satellite services,” International Telecommunication Union, 1999
[16] ITU Recommendation ITU-R SA.1164-2, “Sharing and coordination criteria for service links in data collection systems in the Earth exploration-satellite and meteorological-satellite services,” International Telecommunication Union, 1999
[17] ITU Recommendation ITU-R SA.1165, “Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz,” International Telecommunication Union, 2013

These interference criteria were specified in the sources provided in Table 4 and used for the small-signal analyses.

Table 4. NOAA GOES Earth Station ITU thresholds

Data Link	Long-Term Threshold (20% of the time)	Short-Term Threshold (% of the time)	Notes	Source
DCPR & CDA Tlm	-194 dBW per 100 Hz	-181.5 dBW per 100 Hz (0.025%)		SA.1163[a]
SD & MDL	–153.8[b] dBW per 2.6 MHz	–148.6 dBW per 2.6 MHz (0.025%)	Direct data readout High gain antenna	SA.1160[c]
GVAR	–167.5 dBW per 4 kHz	–160.4 dBW per 4 kHz (0.025%)	Data dissemination Low gain antenna	SA.1160
GVAR	–153.4 dBW per 2.11 MHz	-148.1 dBW per 2.11 MHz (0.025%)	Data dissemination High gain antenna	SA.1160

[a] SA.1163: Sharing and coordination criteria for service links in data collection systems in the Earth exploration-satellite and meteorological-satellite services
[b] The analysis in this report assumes a 3.3 db higher gain antenna than found in the relevant ITU-R documents. If the ITU-R documents would have used the higher antenna gain in calculation of the ITU-R the interference threshold, the result would have been an approximate 6 dB increase in interference thresholds. This antenna gain, or the possible 6 dB increase, could not be confirmed and should not be assumed to be solution to reducing protection distances.
[c] SA.1160: Interference criteria for data dissemination and direct data readout systems in the earth exploration-satellite and meteorological-satellite services using satellites in the geostationary orbit

The thresholds are specified in units of dBW with respect to a reference bandwidth. In some cases, the reference bandwidth is not the same as the actual receiver bandwidth. In these cases, it is necessary to adjust the thresholds to compensate for the difference in reference bandwidth. The necessary correction factor was calculated for the relevant downlinks. The final short term thresholds used in the analysis are listed in Table 5. Long term thresholds are also shown for reference.

Table 5. Interference thresholds for LightSquared-to-NOAA downlinks

Data Link	Frequency, MHz	Long-Term Threshold, dBW	Short-Term Threshold, dBW
GOES SD	1676.0	-156.8	-151.6
GOES MDL	1681.5	-156.8	-151.6
GOES GVAR	1685.7	-153.4	-148.1
GOES CDA Tlm	1694.0	-178.0	-165.6
GOES DCPR-1	1694.5	-183.2	-170.8

GOES-Legacy Receiver Selectivity

The receiver selectivity is determined primarily by the filter with the narrowest bandwidth that precedes the demodulator in the processing chain. This is often referred to as a pre-detection filter. For the digital modulation techniques employed by the NOAA GOES-Legacy systems, the standard practice is to use a pre-detection filter with a square-root raised-cosine frequency response. This is explained in depth in Appendix D.

FDR

Frequency-dependent rejection (FDR) is a measure of the rejection produced by the victim receiver selectivity curve to the unwanted emission spectra of an interfering transmitter. More detailed information on FDR can be obtained from Recommendation ITU-R SM.337-6. Three inputs are required to compute FDR:

- **Emission Mask.** This is the normalized power spectral density of the transmitted signal, specified with respect to the transmitter tuned frequency.

- **Selectivity Curve.** This is the normalized frequency response of the receiver, specified with respect to the receiver tuned frequency. Note that the overall frequency response is due to several filter stages, but is dominated by the stage just before the demodulator.

- **Off-tuning.** This is the difference between the transmitter and receiver tuned frequencies.

FDR is computed by performing a numerical integration of the inputs, in the frequency domain, to determine the fraction of emitter power that is rejected by the receiver filters (see (Equation 2). A number of software implementations of this procedure are available. The FDR program used for this analysis is part of a suite of RF analysis tools called Microcomputer Spectrum Analysis Models (MSAM), developed by National Telecommunications and Information Administration (NTIA). This software is freely available from the NTIA website. Once calculated, FDR is applied to the interference link budget. The effect is to reduce the interfering signal power at the receiver. In the following subsections, the process for determining the inputs is presented, and the FDR results are summarized.

Off-Tuning

FDR was calculated for each of the GOES-Legacy links. These links each have a unique center frequency and bandwidth. Frequency overlap occurs in only two instances: (1) GOES-Legacy Sensor Data (SD) and (2) GOES-R DCPR-1. However, GOES-R is not analyzed in this document, but is part of an analysis that is underway and will be included in a supplemental report. Frequency overlap values are shown in Table 6 and depicted in Figure 3.

Table 6. LightSquared transmitter and NOAA GOES-Legacy frequency overlap

System	Data Link	Center Frequency, MHz	Bandwidth, kHz	Band Overlap? Yes/No
Light Squared	---	1675	10000	Not Applicable
GOES	CDA Tlm	1694	4	No
GOES	DCPR-1	1694.5	1.2	No
GOES	MDL	1681.5	200	No
GOES	GVAR	1685.7	2110	No
GOES	SD	1676	1312	Yes

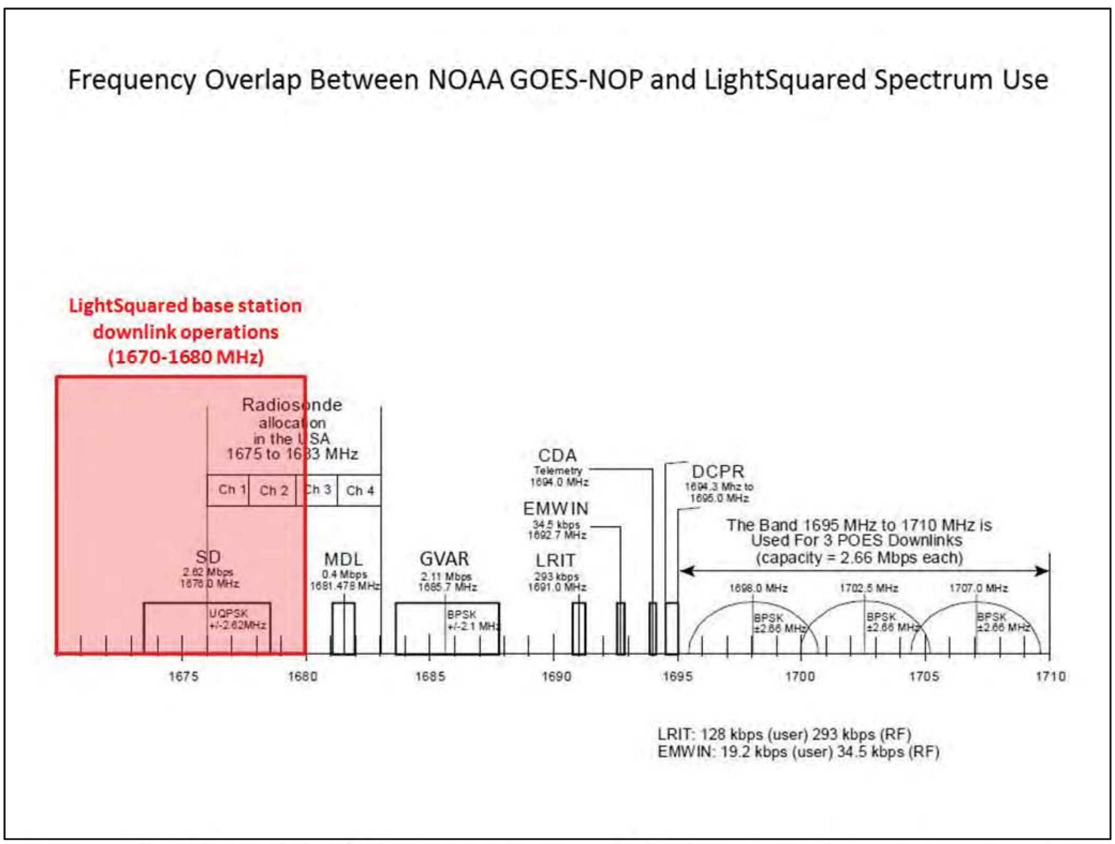


Figure 3. NOAA GOES-Legacy signals and LightSquared frequency overlap

The GOES data links will have differing levels of FDR to the LightSquared base station transmitters based upon the emission spectra, receiver selectivity, and frequency offsets. As previously noted, FDR is applied to the interference link budget. Since the Visualyse propagation modeling software has a provision for entering a pre-computed FDR value, the FDR values were computed in advance and then entered into the Visualyse program to be applied to the interference link budgets. The calculated values of FDR for all of the LightSquared-to-NOAA downlinks are presented in Table 7.

Table 7. FDR for LightSquared-to-NOAA downlinks

Data Link	Frequency, MHz	Off-Tuning, MHz	FDR, dB
GOES SD	1676.0	-1.0	8.6
GOES MDL	1681.5	-6.5	68.4
GOES GVAR	1685.7	-10.7	66.5
GOES CDA Tlm	1694.0	-19.0	79.1
GOES DCPR-1	1694.5	-19.5	81.0

Analysis Methods

For this single station analysis, one LightSquared transmit station was analyzed against one NOAA earth receive station using the propagation probability as specified in the ITU criteria. This provides the effects of introducing one interferer into the environment.

Single Station Area Analysis Overview

To determine the distance at which the LightSquared transmit power may exceed the NOAA earth station interference threshold, the scenario was modeled in the Visualyse software. The area analysis option was used, which calculates the interference from a single transmitter to a single receiver. This tool conducts the analysis by moving a transmit station over a grid of user selected resolution and size to determine if the levels calculated exceed the set threshold. A 30 arc-second grid level was used and the resolution varied from 1 km to 5 km depending on the separation zone size. The receive station is stationary at the location specified. The resulting output is a map with a contour line designating the area where a transmitter with the assumed characteristics would not exceed the set interference threshold.

LightSquared Base Station Antenna Directivity

For modeling purposes, the analysis utilized the antenna values contained in ITU 1336 which were assumed to be omnidirectional instead of using the three directional sectors (at 0, 120, and 240 degrees) that are typical of all LTE networks. In assuming this, worst case results were obtained for the GOES-Legacy analysis as the full radiated power would not be directed to the victim receiver from every LightSquared site. Vertically, the transmit antenna was modeled with a 3-degree down-tilt.

Terrain

Terrain data is taken into account for the area analysis. 30 arc-second terrain data was utilized within the propagation model for all links.

Clutter

Clutter use was investigated for these analyses but was excluded. The effect of clutter was not added due to a substantial cost to obtain the clutter database, the expectation of low impact, and that anomalous propagation would supersede the clutter analyses.

RESULTS

SD ANALYSIS FOR WALLOPS, VA

Figure 4 presents the analysis result for the Wallops, VA, Sensor Data Link for GOES-15. Refer to Tables 5 and 7 for specific threshold and FDR values. Once the simulation was complete, the Visualyse software produced a file that was then transferred into ArcGIS to plot the separation distance contour. The red contour line represents the closest, allowable, distance that will allow NOAA to maintain a 99.99% error free downlink for SD based upon the input parameters utilized. Figures 5 and 6 represent the maximum separation distances for Greenbelt, MD and Fairbanks, AK.

Figure 4. Wallops, VA, GOES 75W Sensor Data maximum separation distance result

SD ANALYSIS FOR GREENBELT, MD

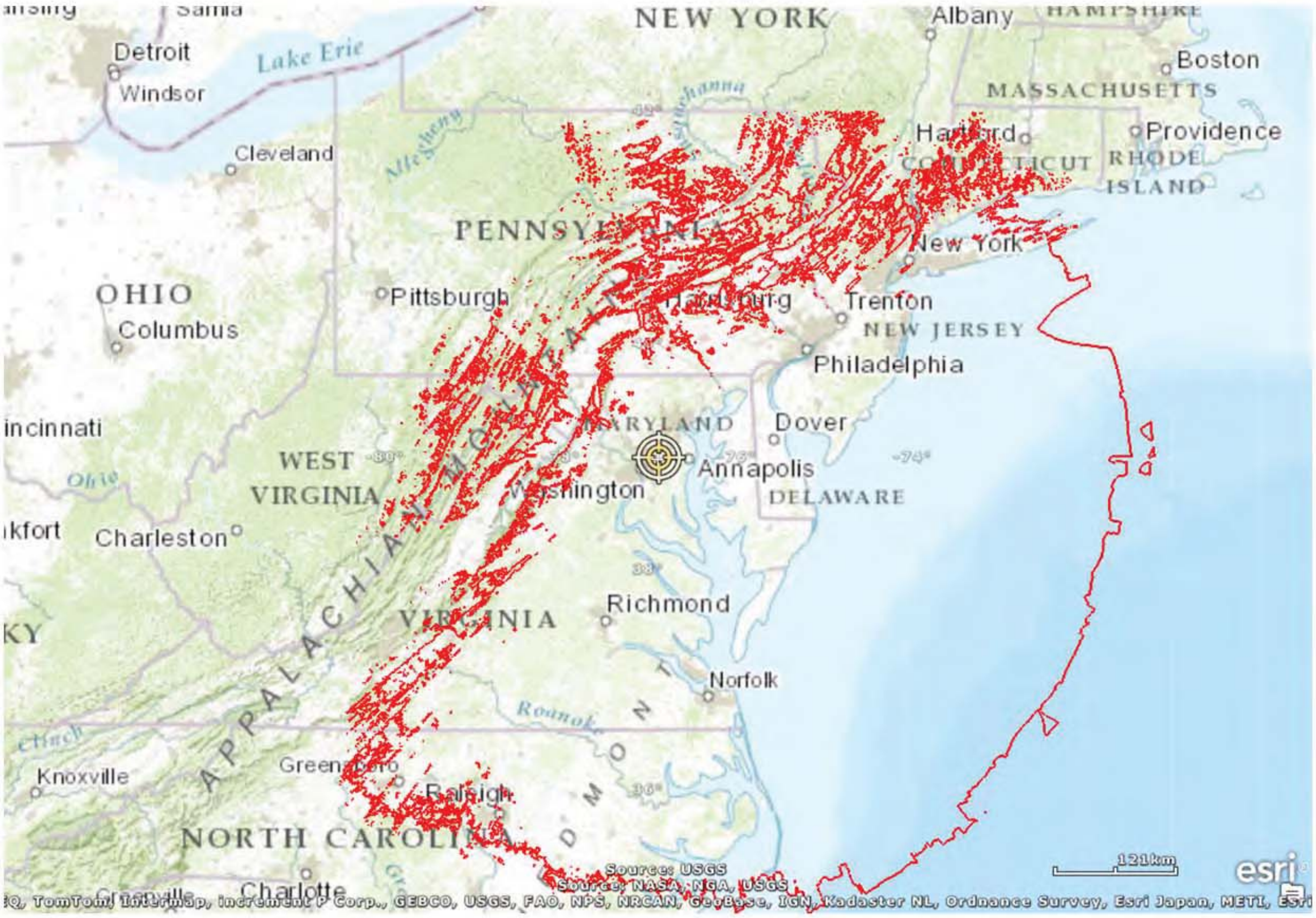


Figure 5. Greenbelt, MD, GOES 75W Sensor Data maximum separation distance result

SD ANALYSIS FOR FAIRBANKS, AK

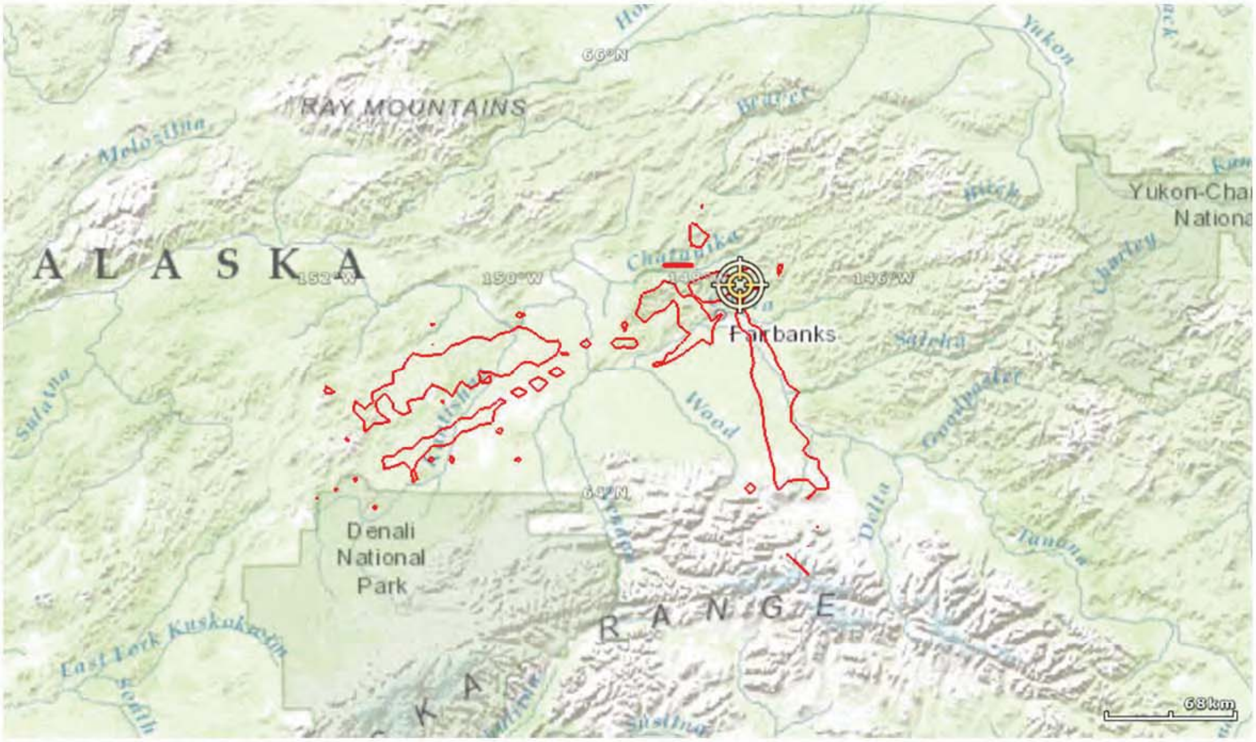


Figure 6. Fairbanks, AK, GOES 135W Sensor Data maximum separation distance result

The three sites in Table 8 have the largest protection zones due to the existence of the SD link, which has the greatest susceptibility to interference from an LTE network in the 1670-1680 MHz band. The remaining NOAA site analyses are located in Appendix D.

Table 8. Interference thresholds for LightSquared-to-NOAA downlinks

Location	Data Link	GOES Satellite Orbital Location	Legacy Separation Distance, km
Fairbanks, AK	SD	135 W	208
Greenbelt, MD	SD	75 W	434
Wallops, VA	SD	75 W	450

At the conclusion of the Task 2 work item, LightSquared and NOAA agreed that Alion should undertake additional analysis in order to consider the following items that could impact the final boundaries of the protection zones: 1). Aggregate impacts of multiple LightSquared cell sites on GOES-R GRB and DCPR-1 links; 2). Impact of large signal overload analysis. These additional analyses do not introduce any new earth station locations already included in this Task 2 report; however, because GRB and GOES-R implementation of DCPR-1 are closer in frequency to the proposed LightSquared deployment, this will create larger protection zones for some or all of the relevant earth stations. Upon completion of the additional analysis, a supplement to this report with the relevant results will be issued.

APPENDIX A – LIGHTSQUARED EMISSION MASK

The proposed LightSquared emission is nominally 10 MHz, from 1670 MHz to 1680 MHz, centered around a tuned frequency of 1675 MHz, with 0.5 MHz guard band on the high and low ends. The mask used for this assessment, agreed upon by Alion and LightSquared, is consistent with the 3GPP specification for LTE-A base station transmitters.[18] While there is no maximum base station transmitter power in the specification, there is a requirement that the out-of-band emission be no greater than -13 dBm in a 1 MHz bandwidth. Subsequently, the required unwanted emissions attenuation will depend on the transmitter power. For this emission mask assessment, a nominal transmitter power of 40W was assumed. This equates to an average power, across the +/- 4.5 MHz band, of 4.44 W/MHz (6.5 dBW/MHz). The average power equals 36.5 dBm/MHz and, thus, the required attenuation to achieve -13 dBm at the out-of-band, or adjacent band, region is 49.5 dB. The LightSquared 10-MHz emission mask data points are listed in Table 9.

One of the inputs required for the Frequency Dependent Rejection (FDR) calculation is the power spectral density (PSD) of the transmitter, normalized to zero. The normalized PSD is also referred to as the emission mask, because it indicates the attenuation that is applied to the actual PSD to comply with limits on adjacent-band and out-of-band emission. The emission mask for the LightSquared analysis assumes the following PSD:

The emission mask for the LightSquared analysis assumes the following PSD:

Power: 40 W, $-4.5 \leq \Delta f \leq 4.5$ (equivalent to 4.4 W/MHz, and 6.5 dBW/MHz)

Adjacent band power: –43 dBW for $-25 \leq \Delta f \leq -5$, and $5 \leq \Delta f \leq 25$ (–13 dBm/MHz)

Out-of-band attenuation: 20 dB/decade

Table 9. LightSquared 10-MHz emission mask

Δf, MHz (Relative to 1675 MHz)	Attenuation, dB
-25.0	49.5
-5.0	49.5
-4.5	0
4.5	0
5.0	49.5
25.0	49.5

[18] 3GPP TS 36.104 V10.2.0 (2011-04)

This is plotted below:

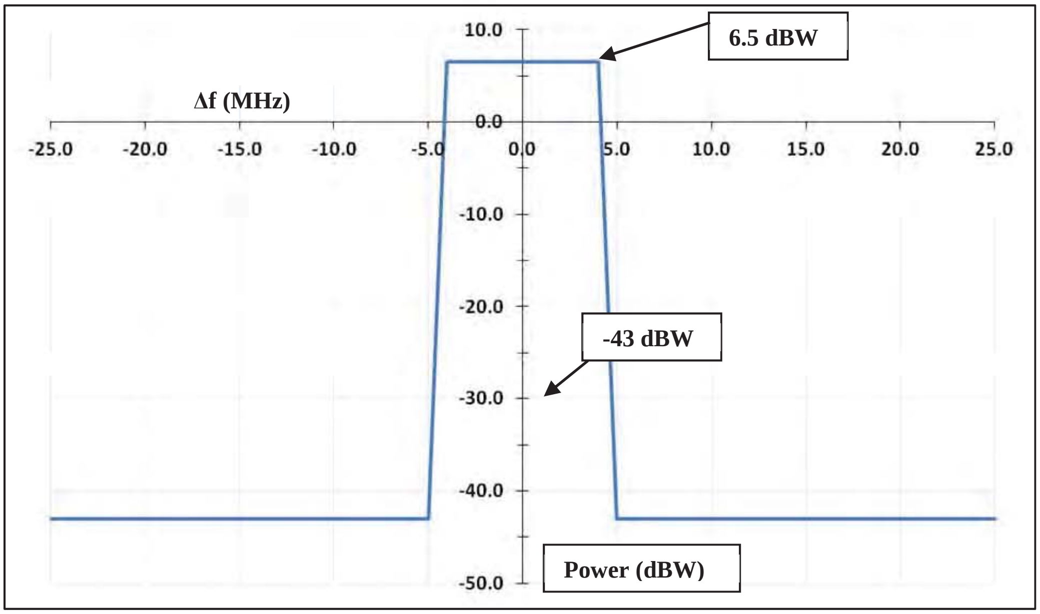
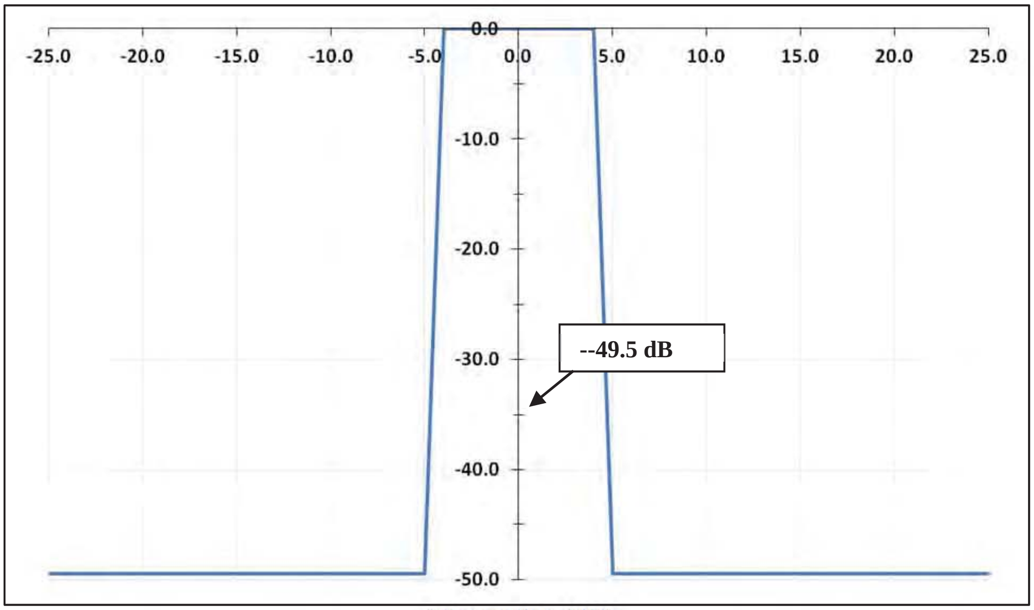


Figure 7. LightSquared 10-MHz emission mask

The normalized PSD—which is the FDR emission mask—indicates the attenuation required to bring the in-band power down to 0 dBW. Note that the vertical axis is labeled dB, rather than dBW.

Under the 3GPP specification, this mask will suffice for any base station power less than or equal to 40W. If the base station power is greater than 40W, the mask must provide attenuation sufficient to achieve the -13 dBm maximum out-of-band power.



Attenuation (dB)

Figure 8. LightSquared 10-MHz normalized emission mask

Figure 9 shows the emission mask from Figure 8 on a dBm scale.

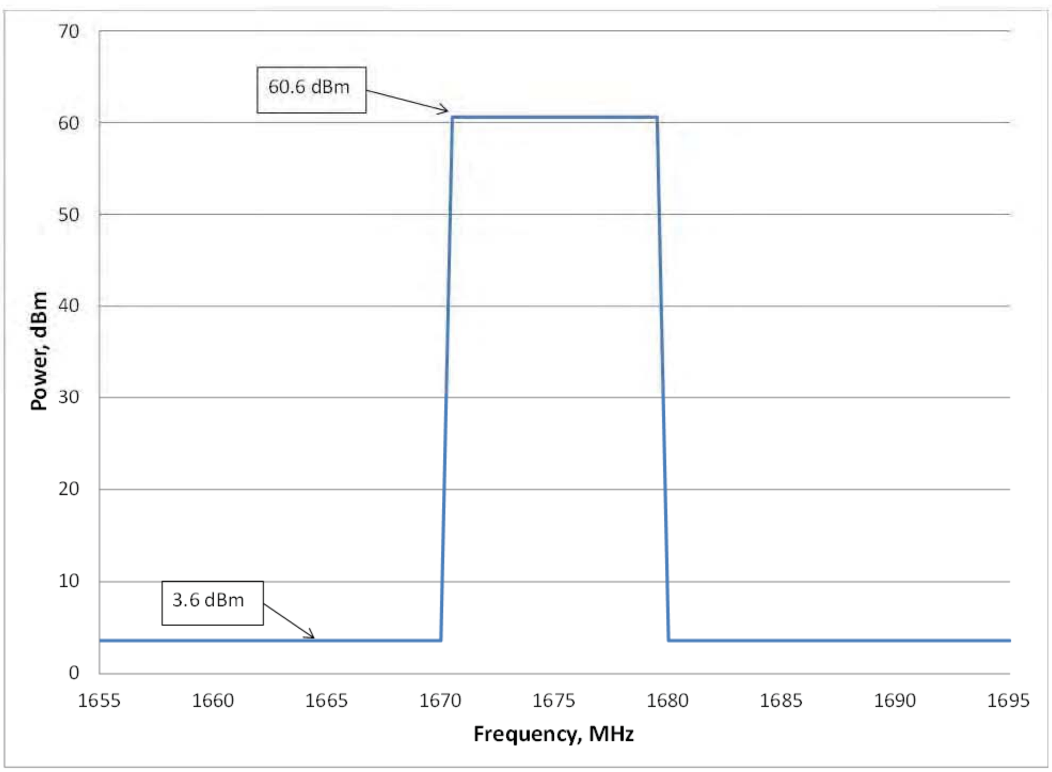


Figure 9. LightSquared EIRP emission mask for 25W transmitter with 16.6 dBi gain antenna

APPENDIX B – VISUALYSE SCREENSHOTS AND DETAILED DISCUSSION OF FREE SPACE PROPAGATION, DIFFRACTION, REFRACTIVITY, SUPER-REFRACTIVITY, AND DUCTING

The P.452 model used in this analysis is implemented in the Visualyse software product, which is designed specifically for this purpose. Visualyse combines analysis techniques with empirical data to provide predictions that are grounded in the physics of electromagnetic radiation, as well as the supporting reality of measured data. The screenshots for Visualyse are provided below.

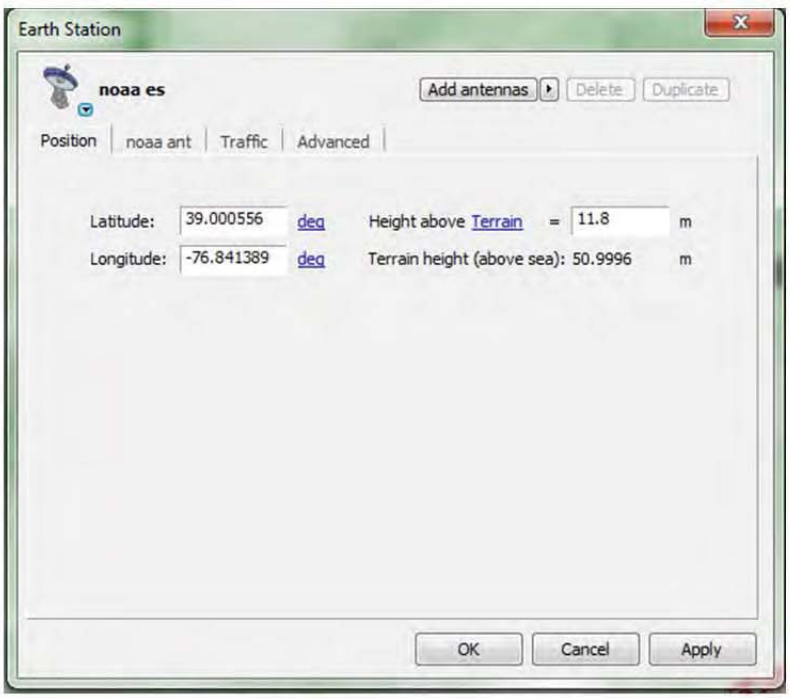


Figure 10. Earth station set-up

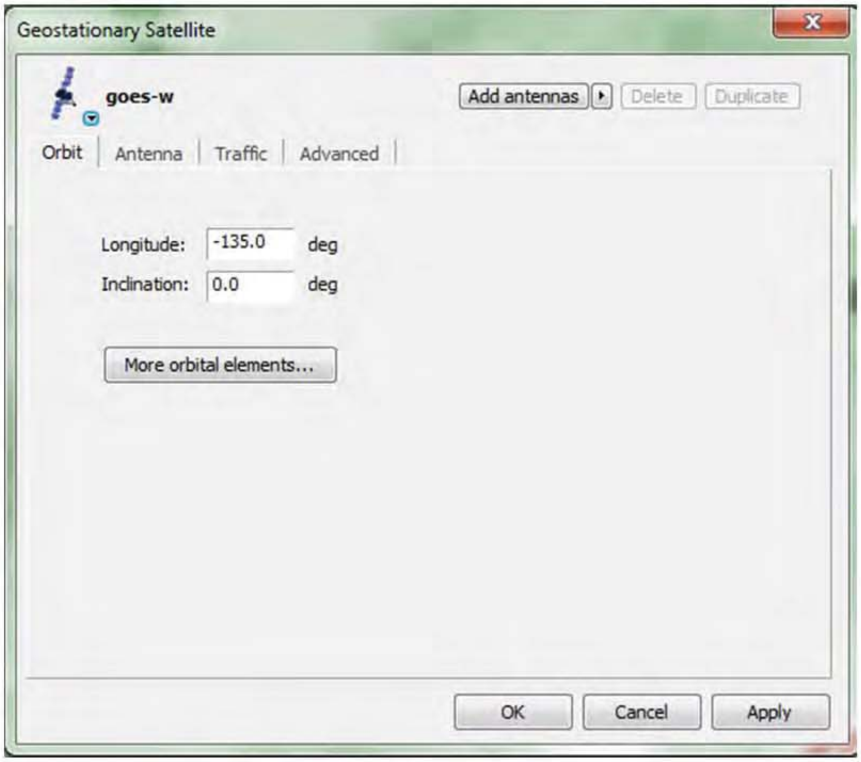


Figure 11. Satellite set-up

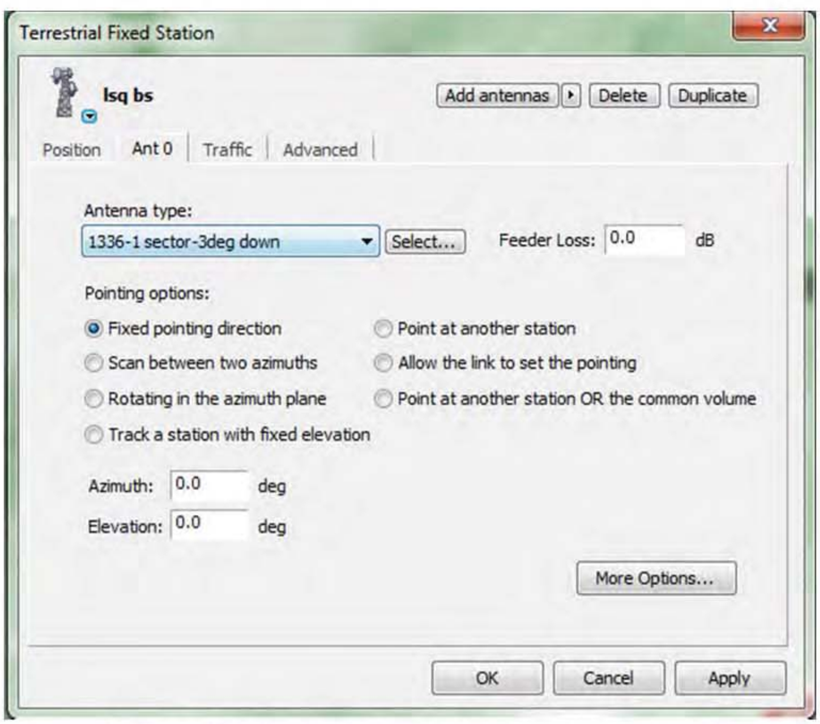


Figure 12. LightSquared base station set-up

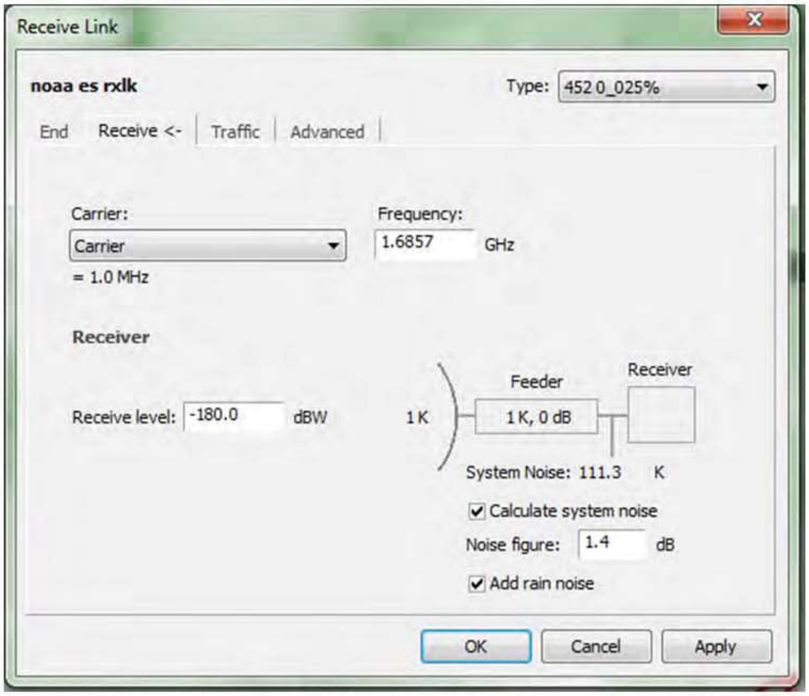


Figure 13. Receiver link set-up

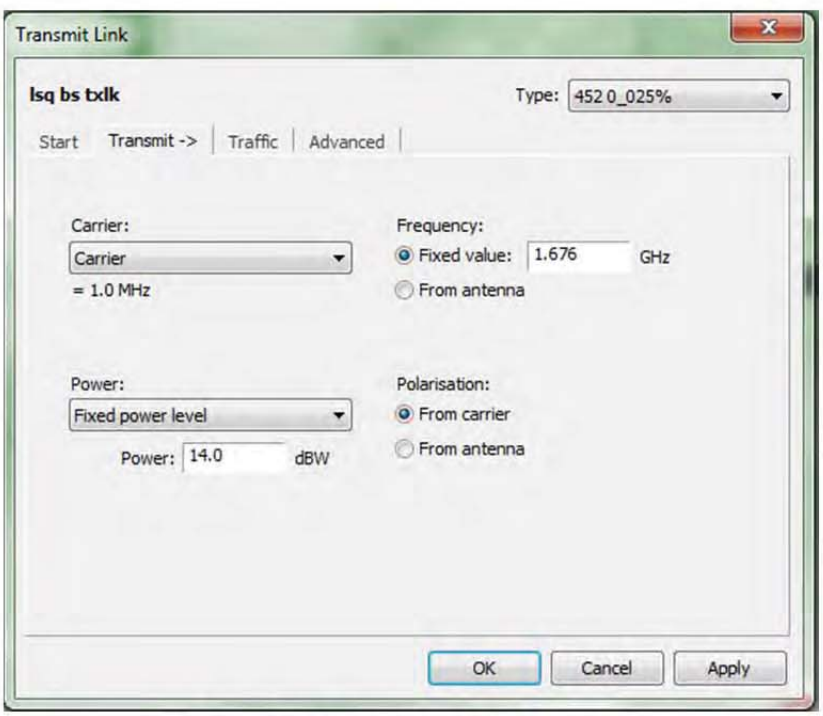


Figure 14. Transmit link set-up

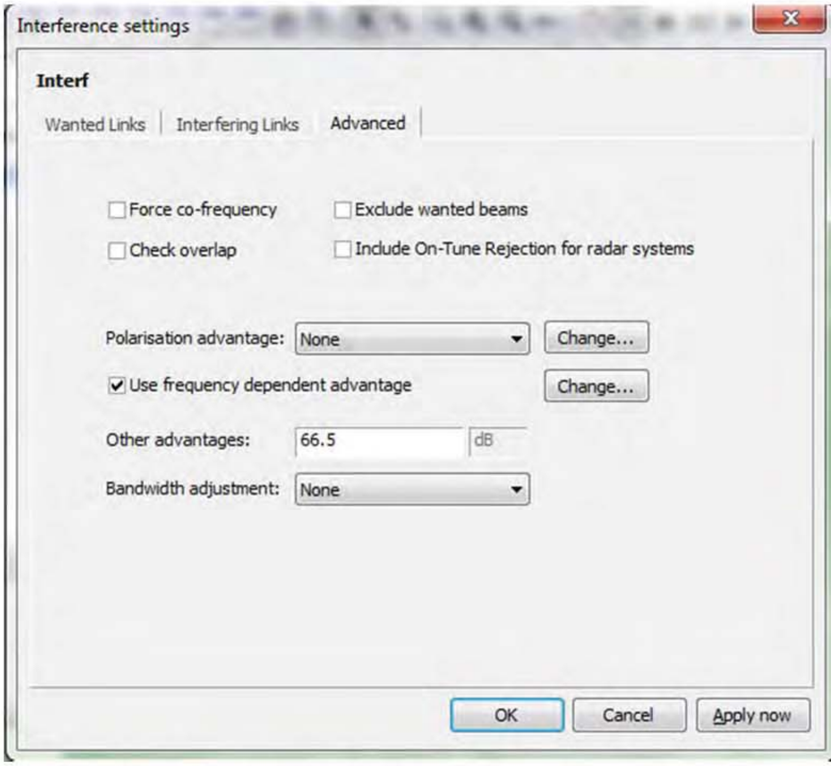


Figure 15. Interference set-up

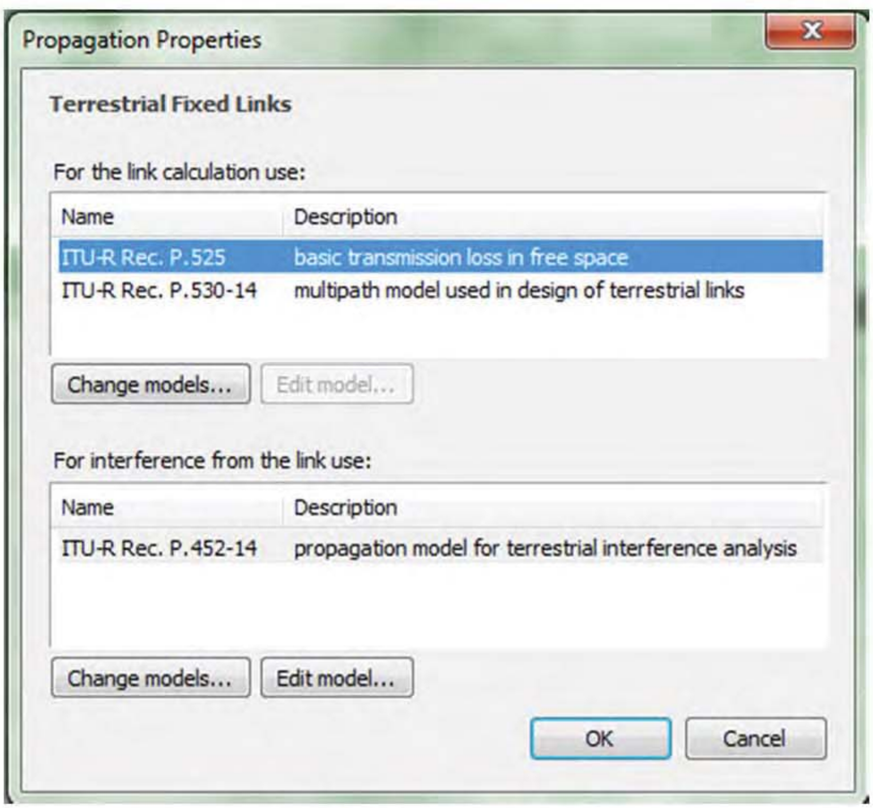


Figure 16. Propagation set-up

The Crane Rain Model is implemented with options to include the NASA data set. It is intended to be used for earth to space / space to earth paths. Either the climatic region or rain rate and rain height can be entered. The associated percentage of time can be either entered directly or generated at random for Monte Carlo analysis.

If the ITU Digitized World Map (IDWM) model is available, then it will extract the zone(s) required for Mode 1 calculations automatically; otherwise a single zone can be directly selected. The associated percentage of time can be either entered directly or generated at random for Monte Carlo analysis.
If the IDWM model is available then it will extract the rain rate, rain cell size, and vapor density required for Mode 2 calculations automatically, otherwise these fields can be entered directly.[19]

Free Space Propagation

The most simple and basic propagation mechanism is free space, which takes place in an idealized environment devoid of atmosphere or obstruction. The path loss associated with free-space propagation is due solely to the spreading of the electromagnetic radiation equally in all directions as the separation distance from the transmitter increases. Free-space path loss is given by

$$L_P = 20\log_{10} d + 20\log_{10} f + 92.5$$

(Equation 4)

where, $d =$ separation distance between transmitter and receiver, in km
$f =$ frequency, in GHz

The coefficient 20 in the distance-related term indicates that free-space path loss increases with the square of the distance.

Diffraction

If the free-space path is obstructed by natural or manmade objects, the RF signal could be completely blocked, but depending on the geometry and material properties of the obstruction, it is possible that some fraction of the signal can get through to the receiver. The primary propagation mechanism for this at L-band frequencies is diffraction. A diffraction path has at least two segments. The signal propagates from the transmitter to the radio horizon, which is the highest point of the obstructing object, and then it continues along a path to the receiver (or to the next radio horizon, if there are additional obstructions).

[19] Transfinite Systems Ltd., “Visualyse Professional Version 7 Technical Annex” Transfinite Systems Ltd, 2013

The two path segments are not collinear; the angle between the two is the diffraction angle, with which a certain amount of loss is associated. See Figure 4 for a comparison of free-space and obstructed path geometries. The overall path loss for such an obstructed path can be expressed as the free-space loss, plus the additional diffraction loss. If there are additional obstructions, additional segments and diffraction angles can be derived from the path geometry, and additional losses computed.

It is apparent from Figure 17 that the angle of the propagation path with respect to the transmitter is not the same for the free-space and diffraction cases, even when the antenna heights and locations are the same. This angle, called the angle of departure (AOD), is measured in the vertical plane, with respect to the local horizon. A similar situation prevails at the receiver, where it is seen that the angle of arrival (AOA) is changed when an obstruction is placed in the path.

In either the free-space or the diffraction case, the actual path angles might or might not correspond to the elevation angles of the transmitter and receiver antennas. Thus, the antenna gains, G_t and G_r, as defined in Equation 1, depend on the relationship between the physical elevation angles and the path angles. The locations, heights, and orientations of the antennas are input parameters, as are the radiation patterns. When the propagation modeling software is run, it performs the spherical calculations necessary to resolve the angles, and determines the effect on G_t and G_r. A similar calculation is made in the azimuthal plane, except that obstructions are unable to modify the direction of the propagation path. Thus, the path follows the great circle route in the azimuthal plane.

Note that even without additional obstructions, the Earth's horizon is a potential obstruction, capable of causing a significant amount of path loss.

Refractivity

Terrestrial radio frequency (RF) systems transmit RF signals through the Earth's atmosphere. The atmosphere is capable of refracting the transmitted signal so that it follows a curved rather than a straight path. In most cases, this curve tends to follow the curvature of the Earth somewhat. The degree of curvature of the signal path is usually (but not always) less, but it nevertheless results in a certain amount of transhorizon propagation.

This mechanism is explained by Snell's Law of Refraction, which states that an RF (or optical) path that crosses from one transmissive medium to another will change direction at the boundary according to a material property called the refractive index. This concept is shown in Figure 18.

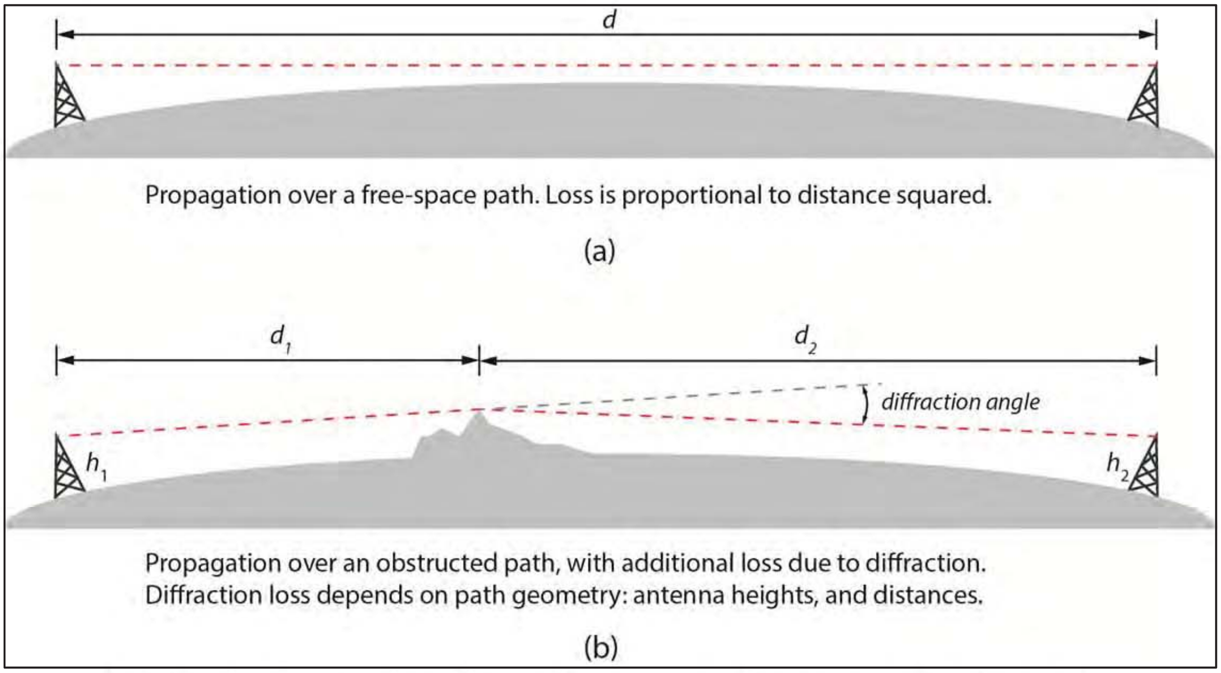


Figure 17. Propagation through free-space and obstructed environments

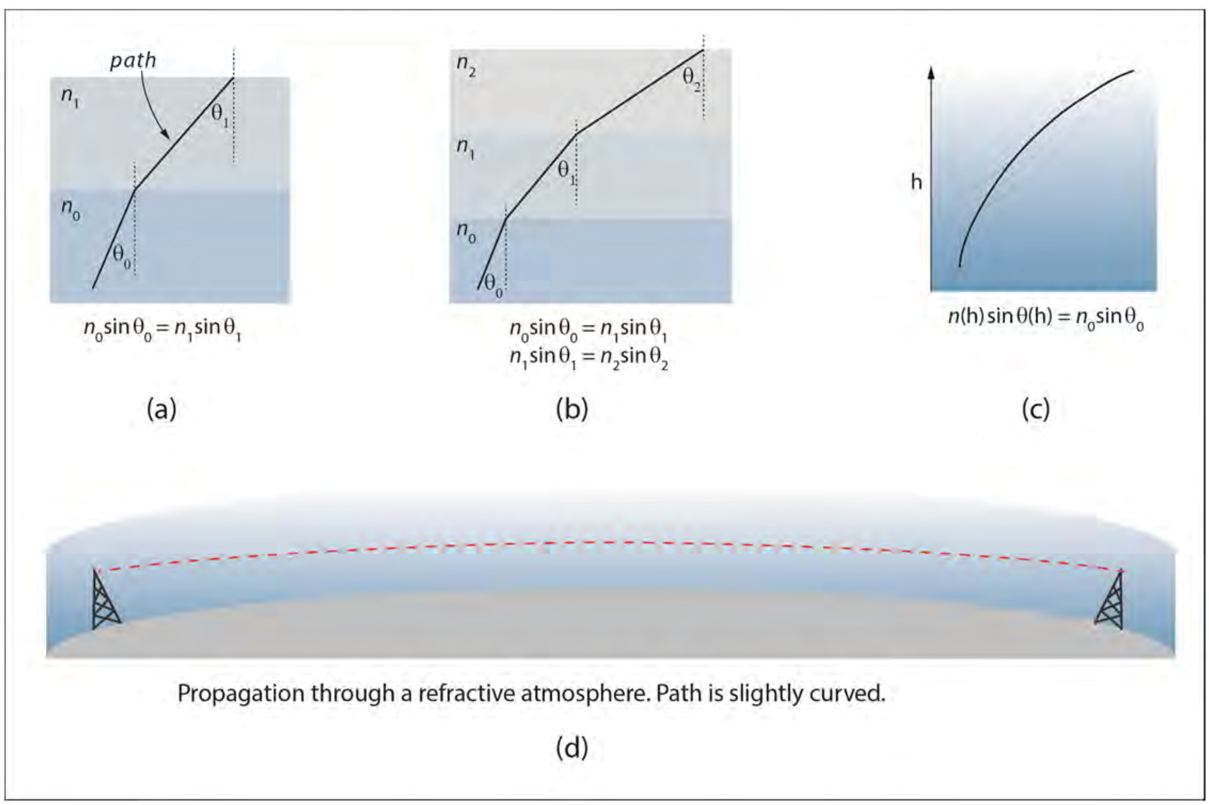


Figure 18. Snell's Law of Refraction

The basic geometry and formulation of Snell's law is shown in Figure 18(a). The change in direction is given by

$$n_0 \sin \theta_0 = n_1 \sin \theta_1$$

(Equation 5)

where n_0, n_1 = refractive index for medium 0 and 1
θ_0, θ_1 = propagation path angle in medium 0 and 1

In Figure 18 (b), the concept is extended to a third transmissive medium. In Figure 18(c) the concept is extended to the case of a transmissive medium in which the refractive index changes gradually, resulting in a path that is curved, rather than composed of multiple straight segments. It is important to note that it is the change in refractive index that causes the path to change direction. A homogeneous medium, with a constant refractive index, will not impart any change in direction.

The refractive index of the Earth's atmosphere depends on temperature, humidity, and barometric pressure, which vary with altitude. Therefore, the refractive index changes with altitude, resulting in an RF propagation path that is slightly curved, as shown in Figure 18 (d). Such a path is capable of clearing certain obstructions that would otherwise block the signal and introduce a diffraction loss.

The procedure for deriving refractivity from atmospheric measurements is provided in the ITU recommendations. The refractive index of the atmosphere near sea level is in the neighborhood of $n_0 = 1.000301$. It is more convenient to express this quantity in terms of "N-units," defined as

$$N = (n - 1) \times 10^6$$

(Equation 6)

The refractive index of 1.000301 can thus be expressed as 301 N-units. These units are typically used when presenting the results of refractivity measurements.

A typical set of measured data can be displayed graphically, as shown below Figure 19(a). Units are not shown, but the horizontal axis is typically N-units, while the vertical axis is in meters. The rate of change of the refractive index diminishes as altitude increases, which suppresses the tendency of an RF signal to follow a curved path. This behavior is shown below in Figure 19(b).

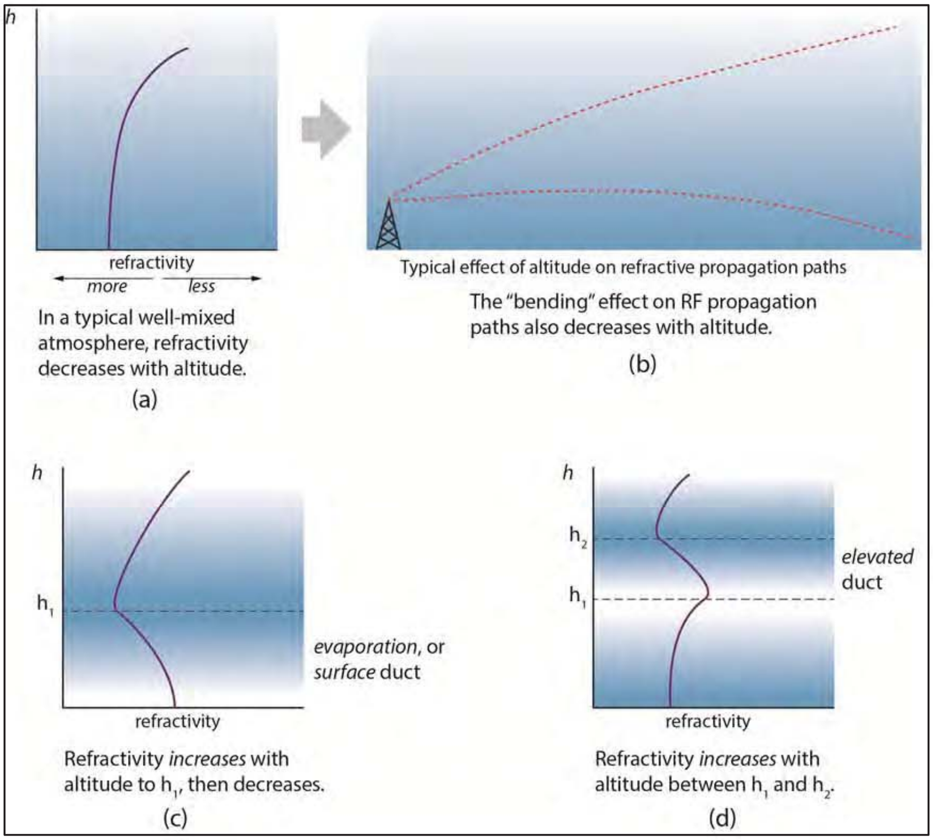


Figure 19. Refractivity in well-mixed and stratified atmospheres

Super-Refractivity

The Earth's atmosphere is not always as consistent as implied in Figure 19(a) and 19(b). Moving masses of air at different altitudes and with different characteristics will often persist for a time as discreet strata in a particular region, before mixing with other strata that may be at higher or lower altitudes. These strata can have very different refractive indices, which in turn can cause unusual propagation effects as signals pass from one stratum to another. This is shown in Figure 19(c), where a low-altitude air mass actually increases in refractivity until it reaches an altitude of h1, above which refractivity diminishes normally. Such an anomalous air mass can result in super-refractivity, where the bending and trans-horizon propagation of RF signals is exaggerated. In extreme cases, the strata can actually trap the RF signal, causing it to propagate even farther.

Ducting

An air mass that exhibits super-refractivity to the extent that it traps RF signals is called a duct. There are two principle types. A surface duct is an anomalous air mass located between the Earth's surface and altitude h1, as in Figure 19(c), while an elevated duct is located between altitudes h1 and h2, as in (d). Like refractivity, the trapping mechanism can be explained by Snell's law, which states that for incident angles less than a certain critical angle, there will be no transmission from one refractive medium to another, but instead reflection back into the original medium. This phenomenon is illustrated in Figure 20.

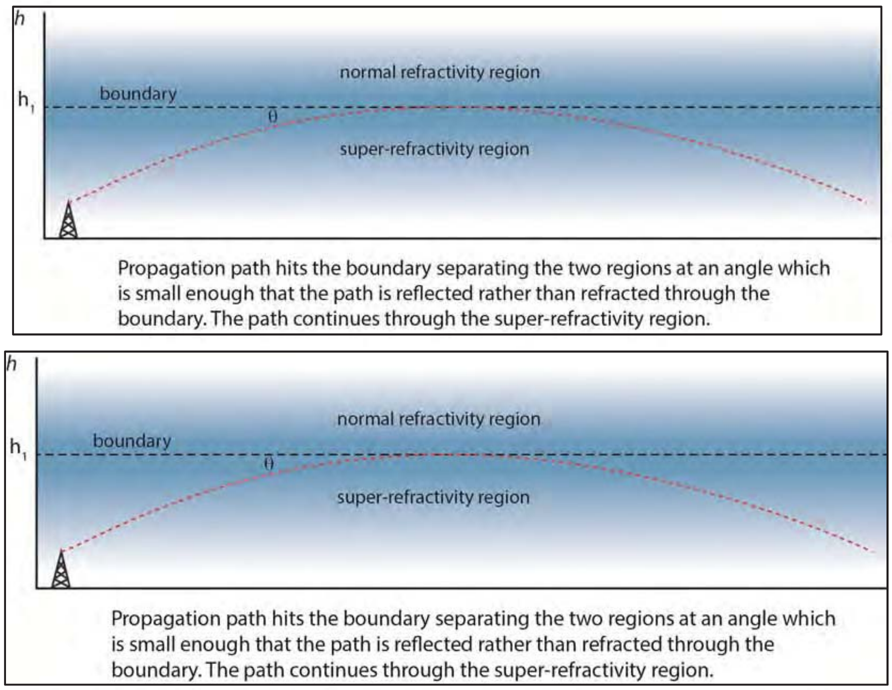


Figure 20. Trans-horizon propagation through a surface duct

This type of atmosphere can, as long as it persists, result in extreme trans-horizon propagation. The super-refractivity region itself is responsible for much of the extension of the propagation path, with the reflection off of the duct boundary contributing to the effect by returning the RF signal toward Earth, where it remains in the region of super-refractivity.

APPENDIX C – Receiver Selectivity

The receiver selectivity is determined primarily by the filter with the narrowest bandwidth that precedes the demodulator in the processing chain. This is often referred to as a pre-detection filter. For the digital modulation techniques employed by the NOAA GOES-Legacy systems, the standard practice is to use a pre-detection filter with a square-root raised-cosine frequency response. Invariably, this filter is identical to the one on the transmitter, so that together they provide a raised-cosine frequency response, the purpose of which is to impart a raised cosine shape to the digital pulses. The raised-cosine pulse shape has several benefits, chief among them being:

- The power in a single pulse is almost entirely contained in a bandwidth equal to the symbol rate.
- The pulse sequence can be easily demodulated by peak sampling, thereby avoiding inter-symbol interference.

The square-root raised-cosine filter is specified by its 3dB bandwidth, which is the symbol rate, and a roll-off factor, which determines how rapidly the filter response falls off outside the 3dB bandwidth. The roll-off factor is a number between 0 and 1.0. Typical values are 0.25, 0.35, 0.5, and 0.6. For these analyses, if the roll-off factor was not explicitly specified (as is often the case), a nominal value of 0.5 was used.

The frequency response of the square-root raised-cosine filter was determined by modeling the appropriate finite-impulse-response (FIR) filter, using the signal processing design software ScopeFIR. The frequency response is shown in Figure 21 for a normalized frequency of 1.0 kHz. This corresponds to a symbol rate of 1.0 k Symbols/s. This symbol rate is normalized to 1k just for plotting convenience. Replace 1k with your data rate R, re-scale the horizontal axis by fractions of R/1k, instead of 1k. Note that the -3 dB point is at 0.5, after which the response falls off rapidly.

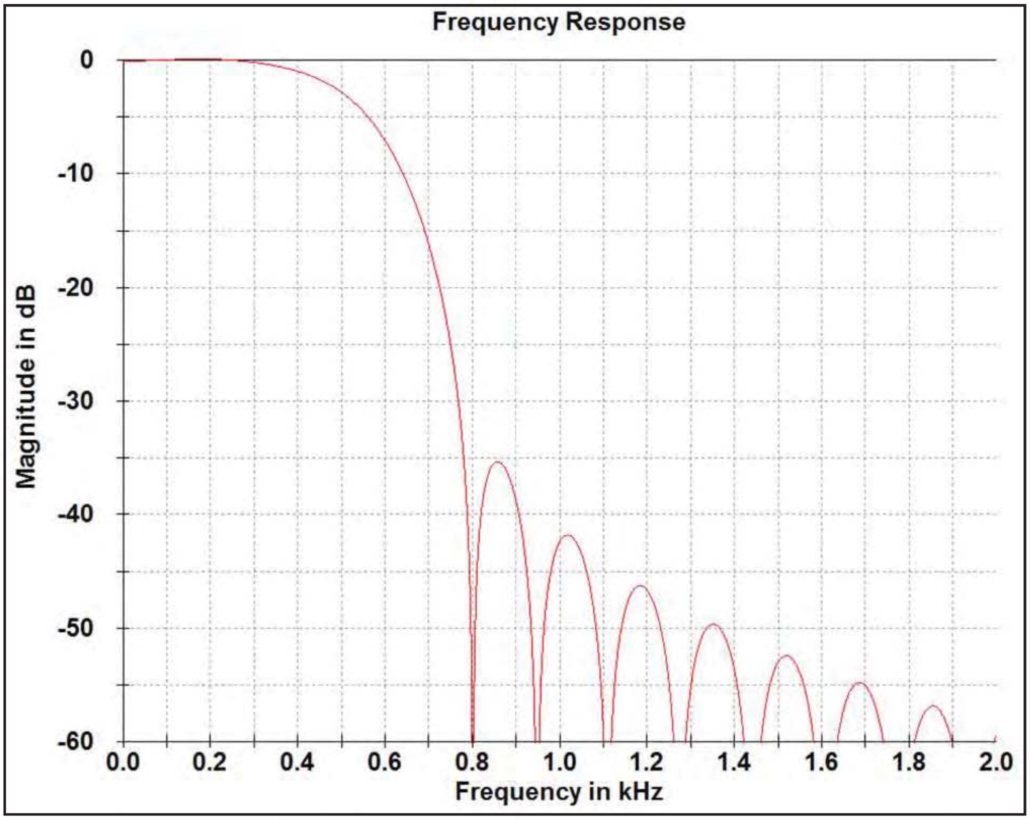


Figure 21. Frequency response of the square-root raised-cosine filter

Table 10. Receiver selectivity curve

Frequency (kHz)	0	± 0.25	± 0.5	± 0.75	± 1.0	± 1.5	± 2.0
Attenuation (dB)	0	0	3	25	42	52	56

Figure 21 shows a single-sided (baseband) response. The receivers in question are all band pass systems, hence the "±" in Table 10. The actual selectivity curve is thus represented by 13 points.

APPENDIX D – ANALYSIS SEPARATION DISTANCES FOR WALLOPS, VA, GREENBELT, MD, AND FAIRBANKS, AK SD LINKS

Table 11 shows a compilation of all links analyzed for the GOES-Legacy satellite links. These separation distances will be revised when the GOES-R systems have been analyzed.

Table 11. Separation distances for LightSquared-to-GOES-Legacy downlinks

Location	Data Link	GOES Satellite Orbital Location	Legacy Separation Distance, km[1]	Figure # of map
Fairbanks, AK	CDA Tlm	135 W	6	22
Fairbanks, AK	DCPR-1	135 W	6	23
Fairbanks, AK	GVAR	135 W	3	24
Greenbelt, MD	CDA Tlm	75 W	5	25
Greenbelt, MD	DCPR-1	75 W	9	26
Greenbelt, MD	GVAR	75 W	3	27
Wallops, VA	CDA Tlm	135 W	35	28
Wallops, VA	CDA Tlm	75 W	19	29
Wallops, VA	DCPR-1	135 W	24	30
Wallops, VA	DCPR-1	75 W	22	31
Wallops, VA	SD	135 W	435	32
Wallops, VA	GVAR	135 W	16	33
Wallops, VA	GVAR	75 W	14	34

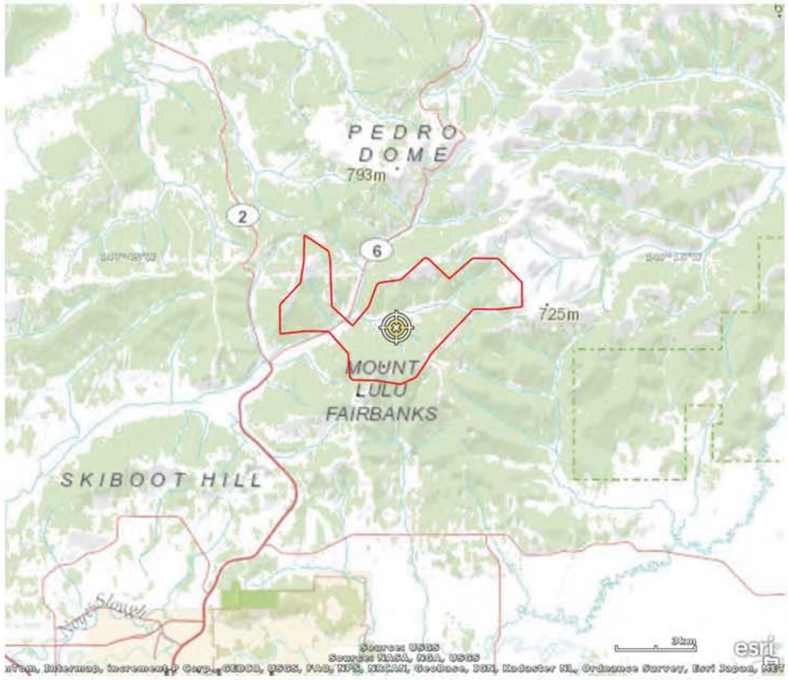


Figure 22. Fairbanks, AK CDA Tlm 135 W

Figure 23. Fairbanks, AK DCPR-1 135 W

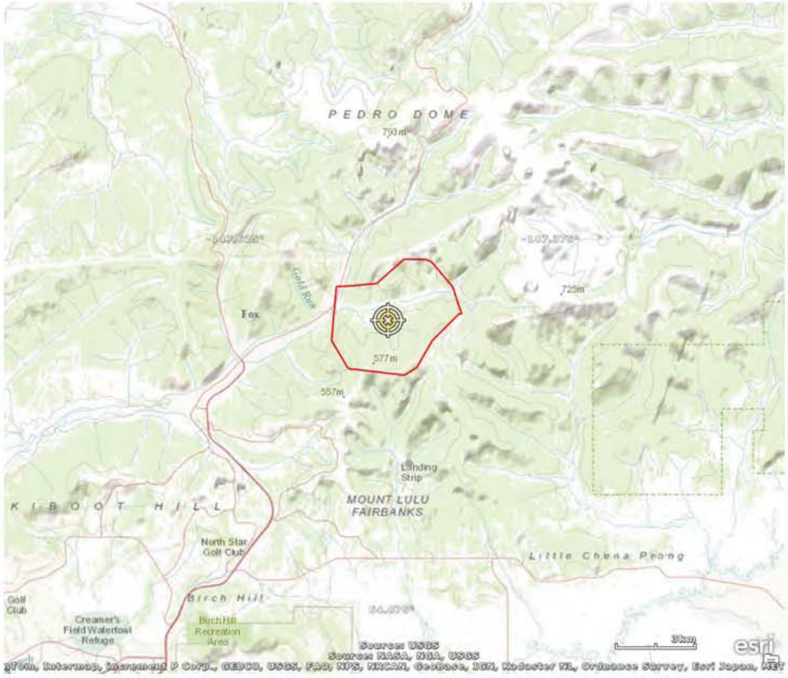


Figure 24. Fairbanks, AK GVAR 135 W

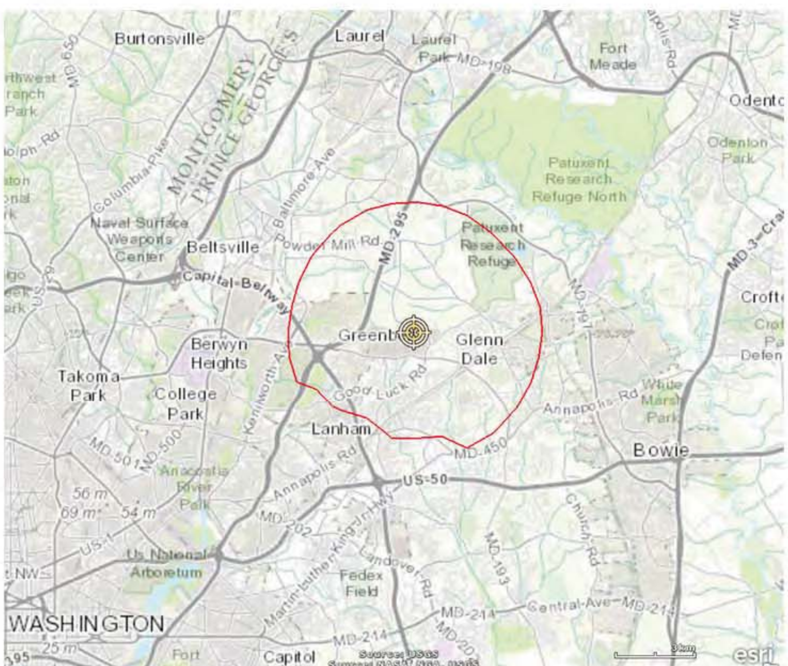


Figure 25. Greenbelt, MD CDA Tlm 75 W

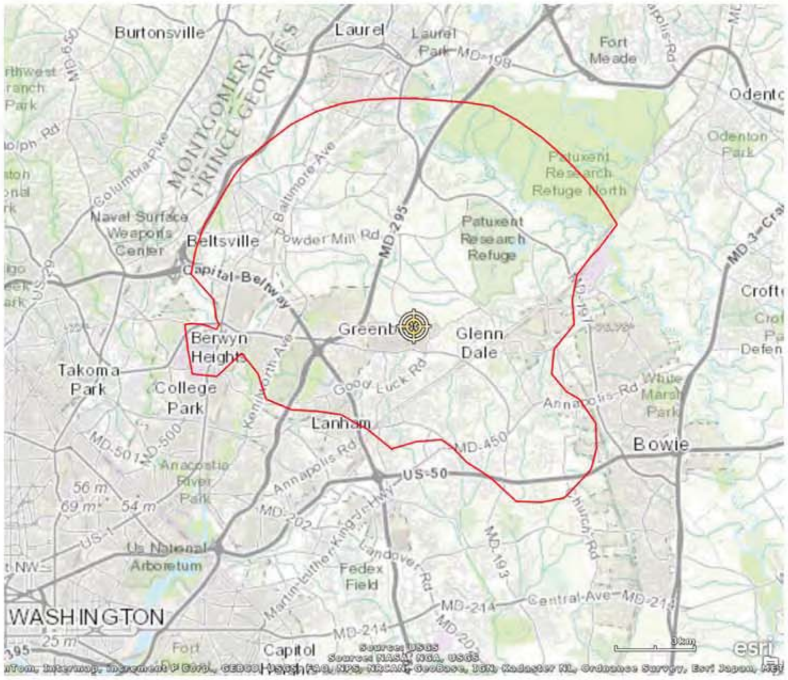


Figure 26. Greenbelt, MD DCPR-1 75 W

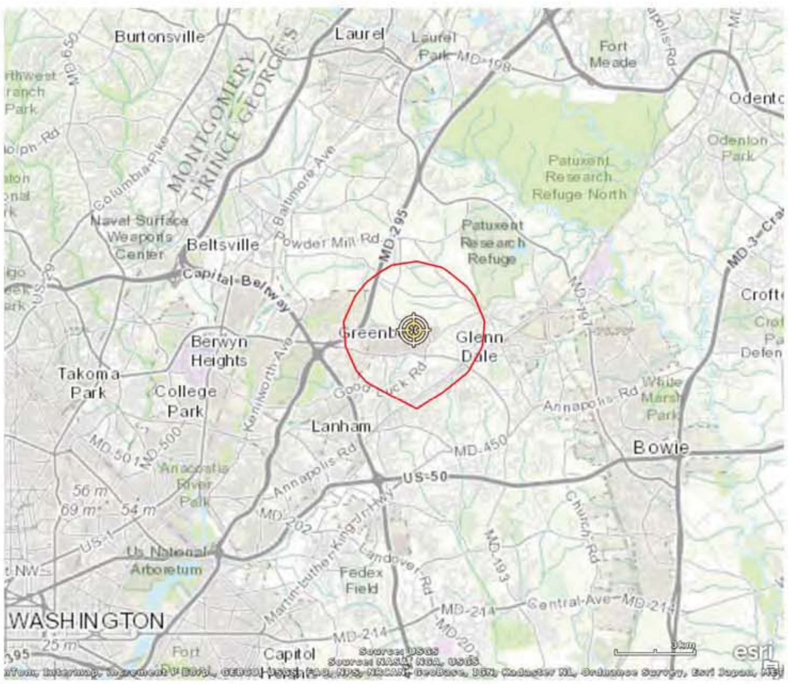


Figure 27. Greenbelt, MD GVAR 75 W

Figure 28. Wallops, VA CDA TLM 135 W

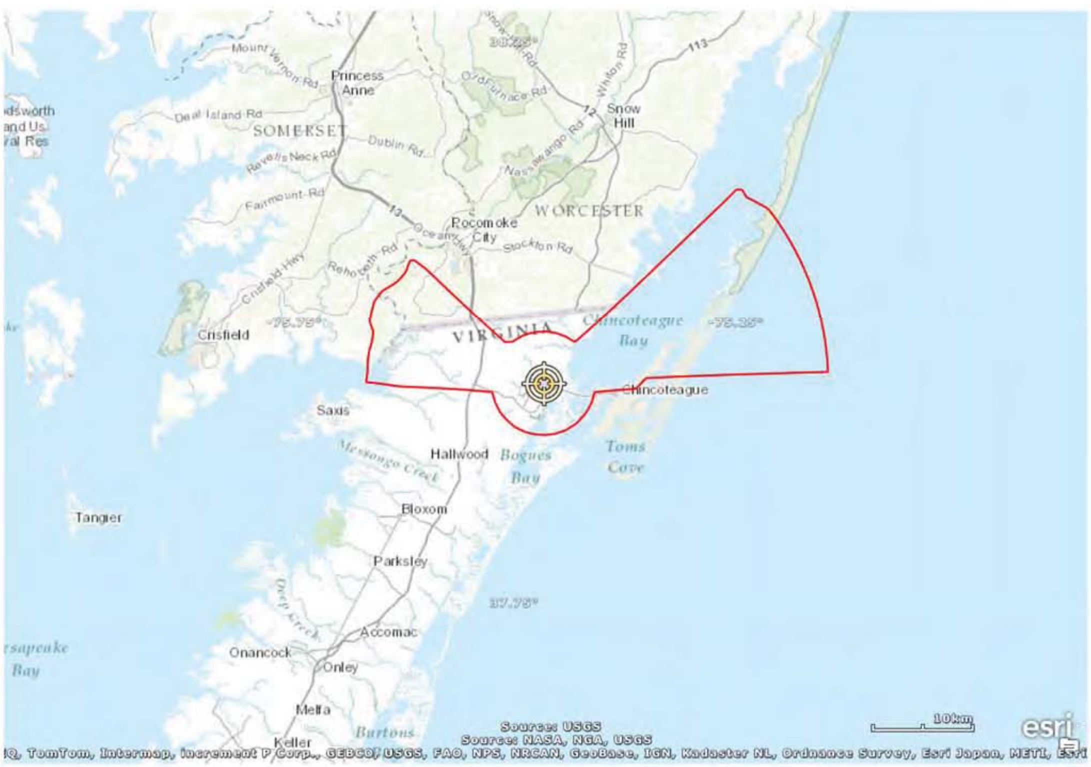


Figure 29. Wallops, VA CDA TLM 75 W

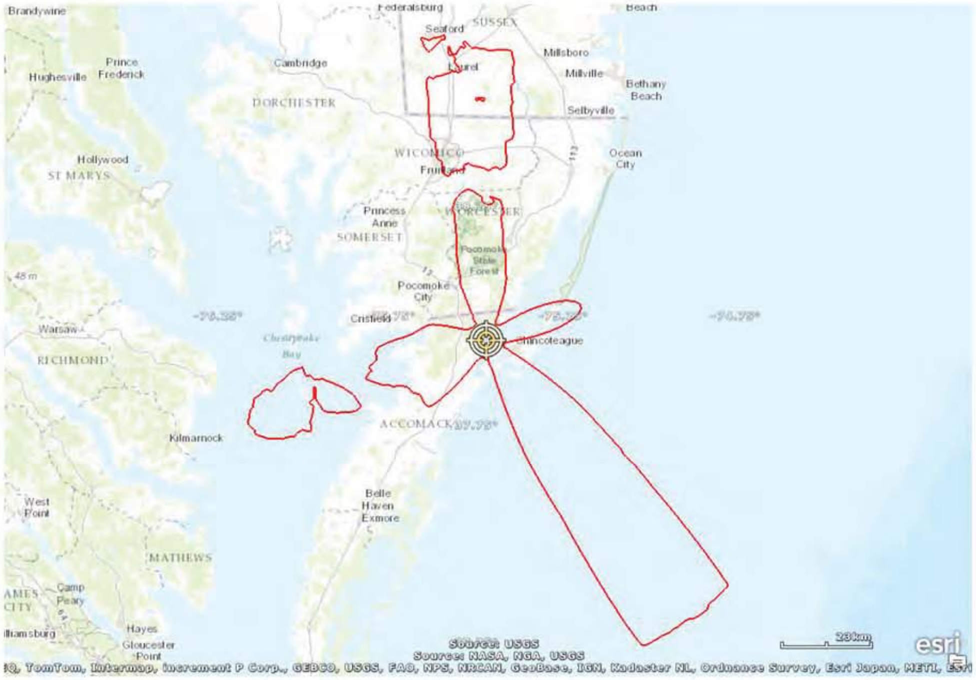


Figure 30. Wallops, VA DCPR-1 135 W

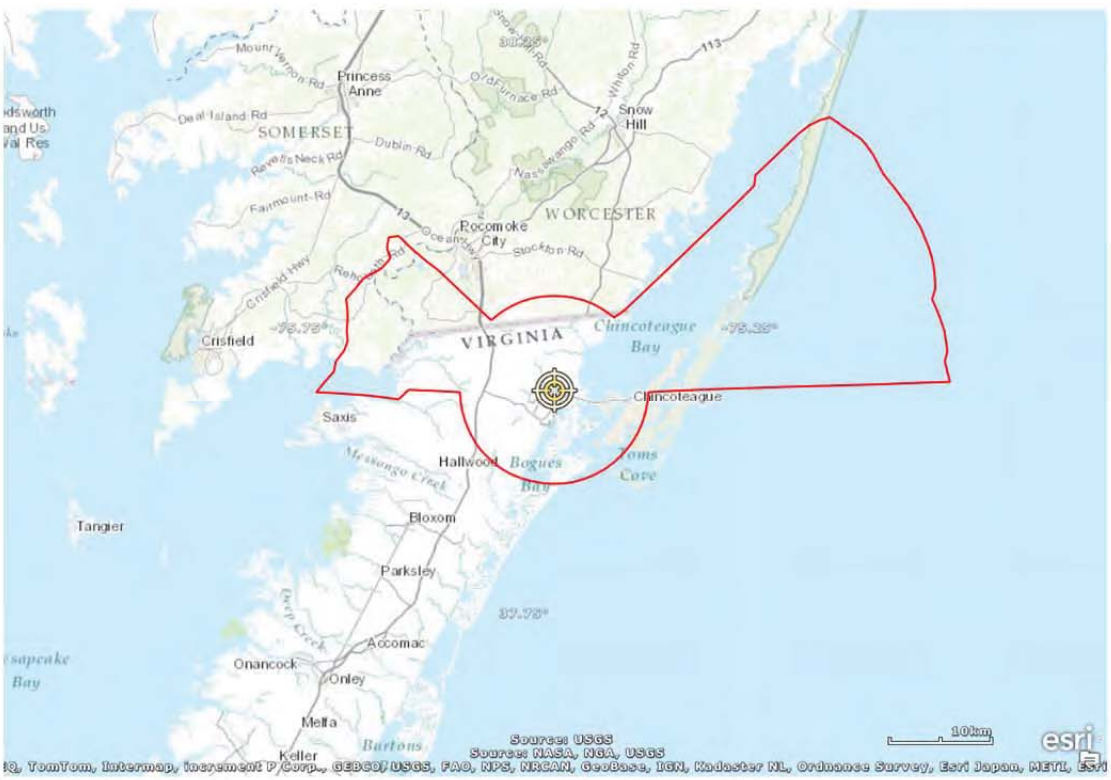


Figure 31. Wallops, VA DCPR-1 75 W

Figure 32. Wallops, VA SD 135 W

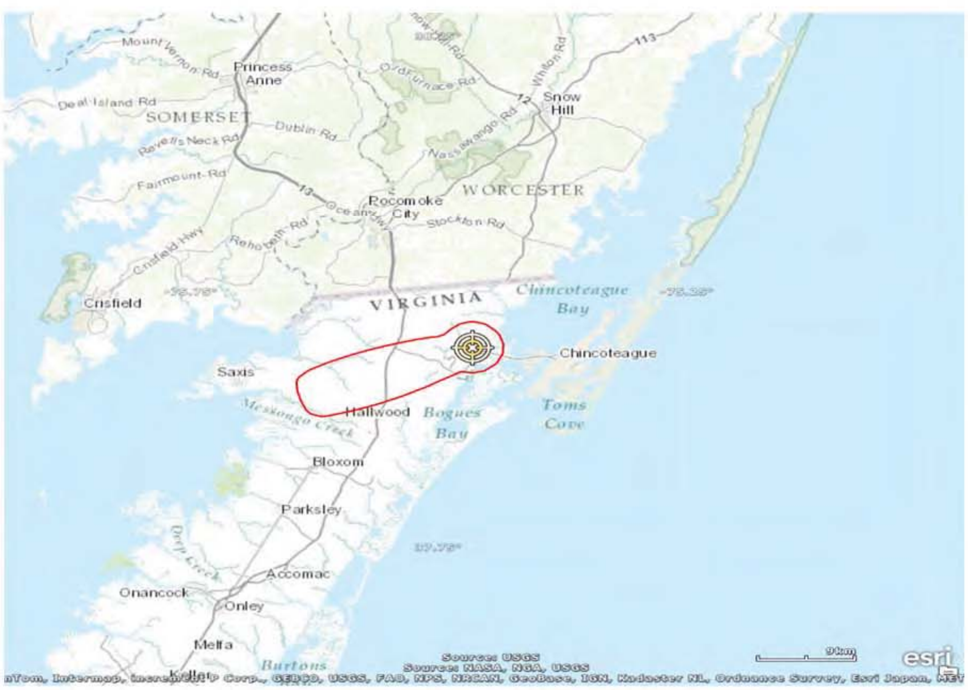


Figure 33. Wallops, VA GVAR 135 W

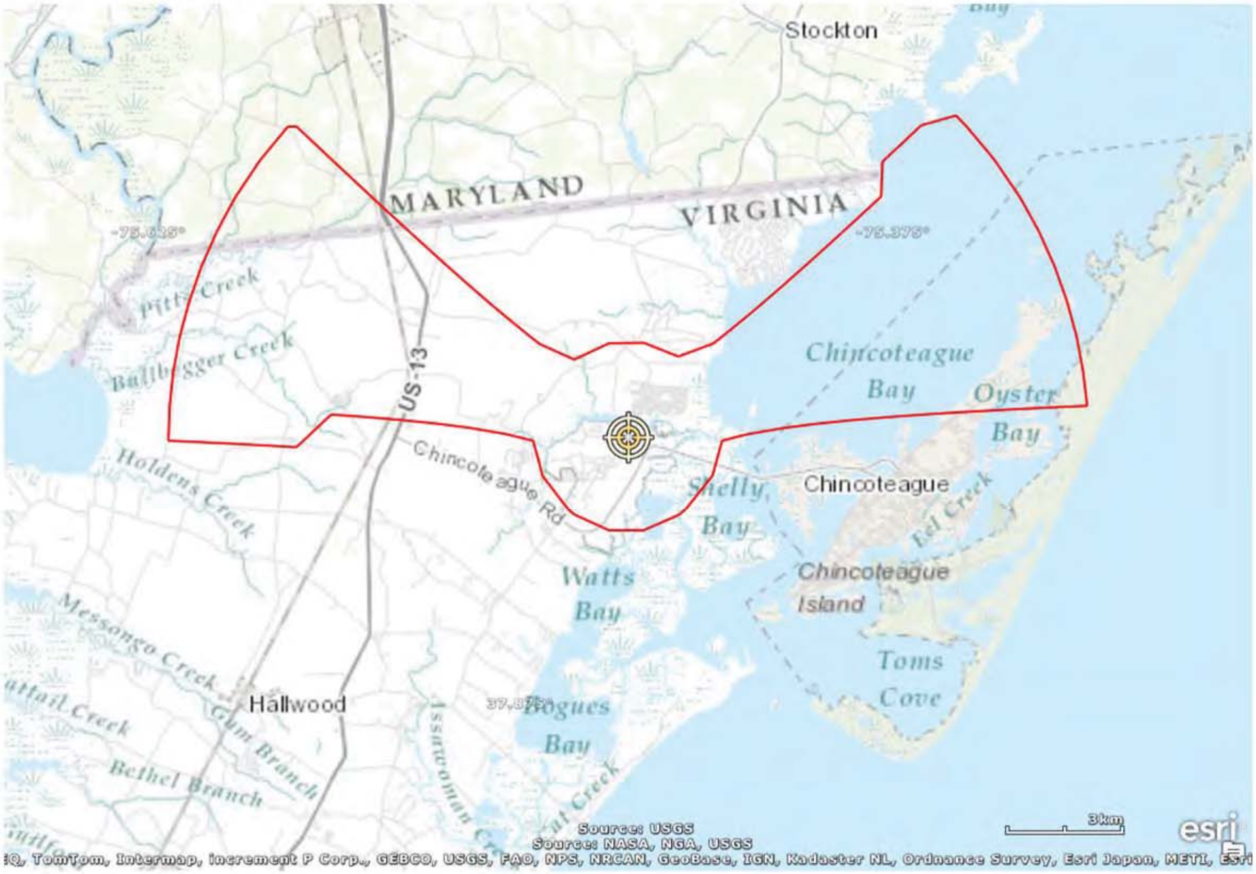


Figure 34. Wallops, VA GVAR 135 W

Table 12. Separation distances for LightSquared-to-GOES-Legacy downlinks

Location	Data Link	GOES Satellite Orbital Location	Maximum separation Distance, km	Figure # of map
Bay St. Louis, MS	DCPR-1 (DRGS)	75 W	9	35
Bay St. Louis, MS	DCPR-1 (DRGS)	135 W	15	36
Boise, ID	DCPR-1 (DRGS)	75 W	24	38
Boise, ID	DCPR-1 (DRGS)	135 W	14	37
Boulder, CO	GVAR	75 W	4	39
Boulder, CO	GVAR	135 W	3	40
Boulder, CO	MDL	75 W	6	41
Boulder, CO	MDL	135 W	4	42
Cincinnati, OH	DCPR-1 (DRGS)	75 W	11	44
Cincinnati, OH	DCPR-1 (DRGS)	135 W	20	43
Columbus, MS	DCPR-1 (DRGS)	135 W	10	45
Columbus, MS	DCPR-1 (DRGS)	75 W	10	46

Location	Data Link	GOES Satellite Orbital Location	Maximum separation Distance, km	Figure # of map
Ford Island/Pearl Harbor, HI	DCPR-1 (DRGS)	135 W	12	47
Miami, FL	GVAR	135 W	9	48
Miami, FL	GVAR	75 W	3	49
Monterey, CA	GVAR	135 W	4	50
Omaha, NE	DCPR-1 (DRGS)	135 W	10	51
Omaha, NE	DCPR-1 (DRGS)	75 W	15	52
Omaha, NE	GVAR	135 W	6	53
Omaha, NE	GVAR	75 W	4	54
Omaha, NE	MDL	135 W	6	55
Omaha, NE	MDL	75 W	5	56
Rock Island, IL	DCPR-1 (DRGS)	135 W	27	57
Rock Island, IL	DCPR-1 (DRGS)	75 W	10	58
Sacramento, CA	DCPR-1 (DRGS)	135 W	10	59
Sacramento, CA	DCPR-1 (DRGS)	75 W	17	60
San Juan, PR	DCPR-1 (DRGS)	135 W	58	61
San Juan, PR	DCPR-1 (DRGS)	75 W	10	62
Sioux Falls, SD	DCPR-1	75 W	12	63
Sioux Falls, SD	DCPR-1	135 W	25	64
St Louis, MO	DCPR-1 (DRGS)	135 W	10	65
St Louis, MO	DCPR-1 (DRGS)	75 W	12	66
Suitland, MD	GVAR	135 W	17	67
Suitland, MD	GVAR	75 W	3	68
Vicksburg, MS	DCPR-1 (DRGS)	135 W	15	69
Vicksburg, MS	DCPR-1 (DRGS)	75 W	9	70
DRGS – Direct Readout Ground Station				

Figure 35. Bay St. Louis, MS DCPR-1 75 W

Figure 36. Bay St. Louis, MS DCPR-1 135 W

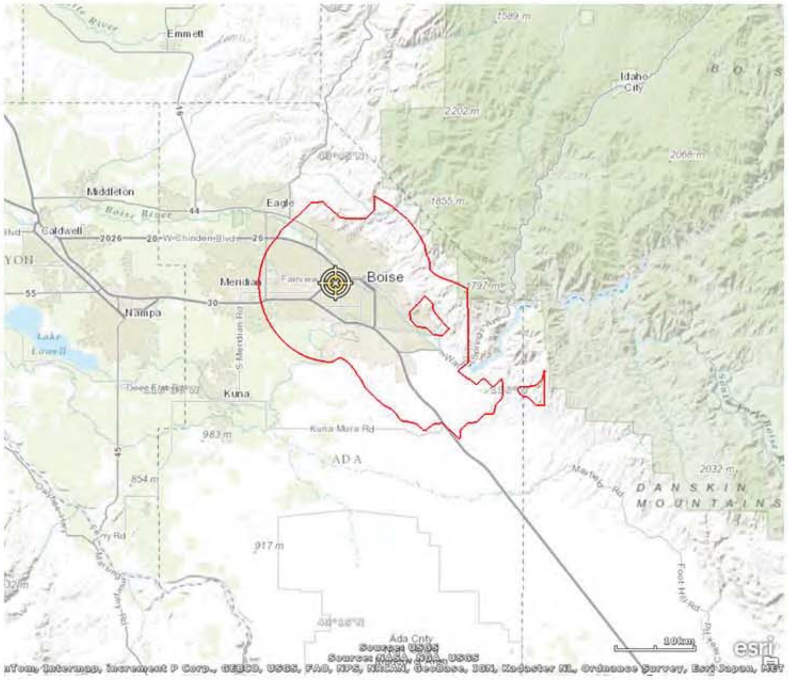


Figure 37. Boise, ID DCPR-1 75 W

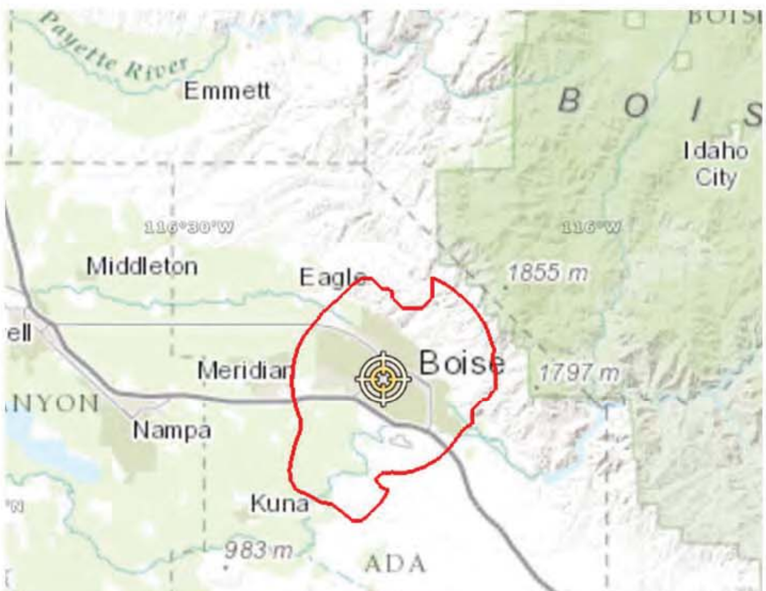


Figure 38. Boise, ID DCPR-135 W

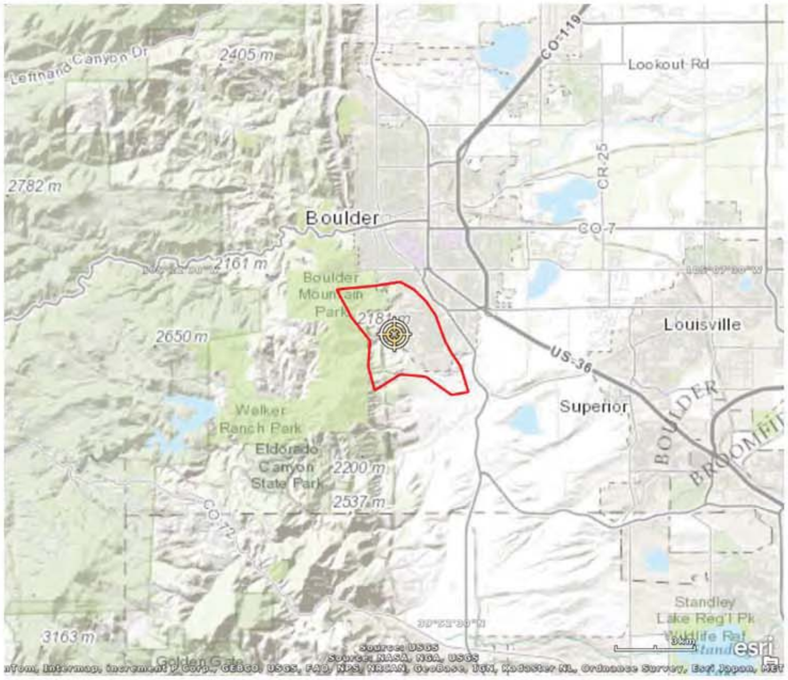


Figure 39. Boulder, CO GVAR 75 W

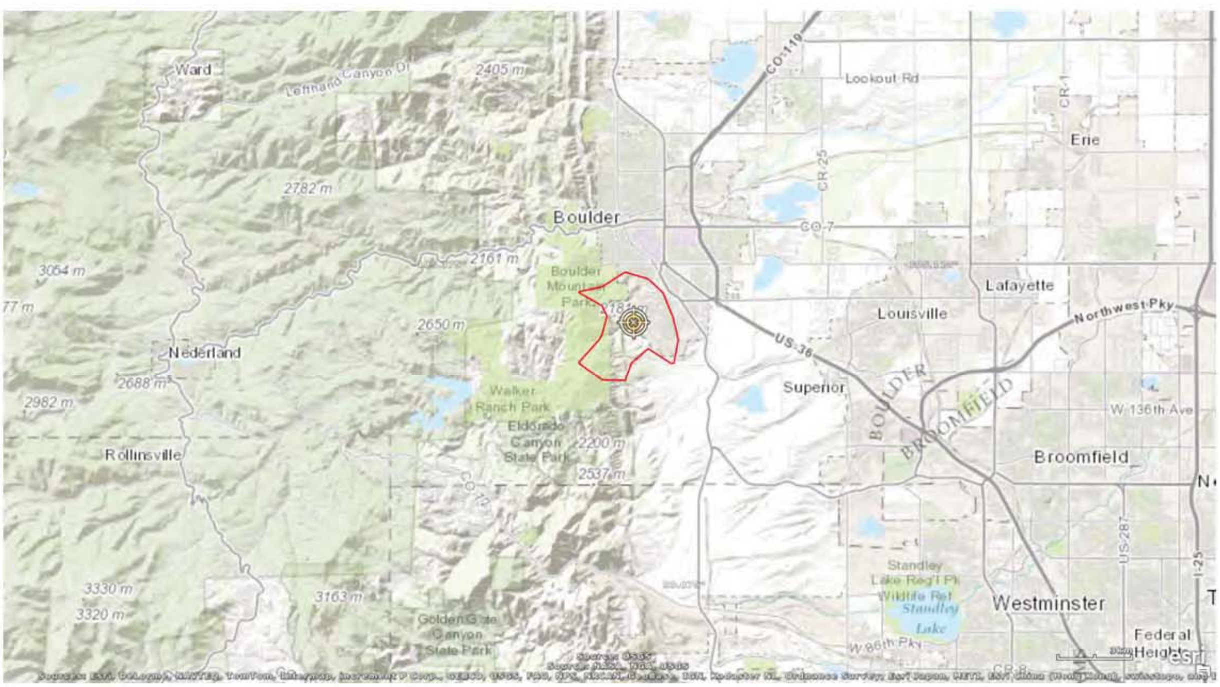


Figure 40. Boulder, CO GVAR 135 W

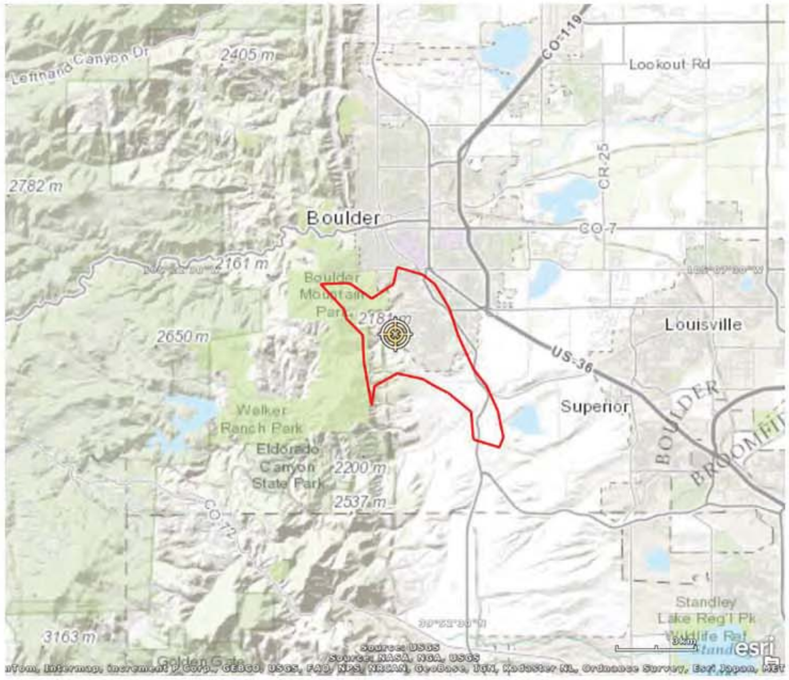


Figure 41. Boulder, CO MDL 75 W

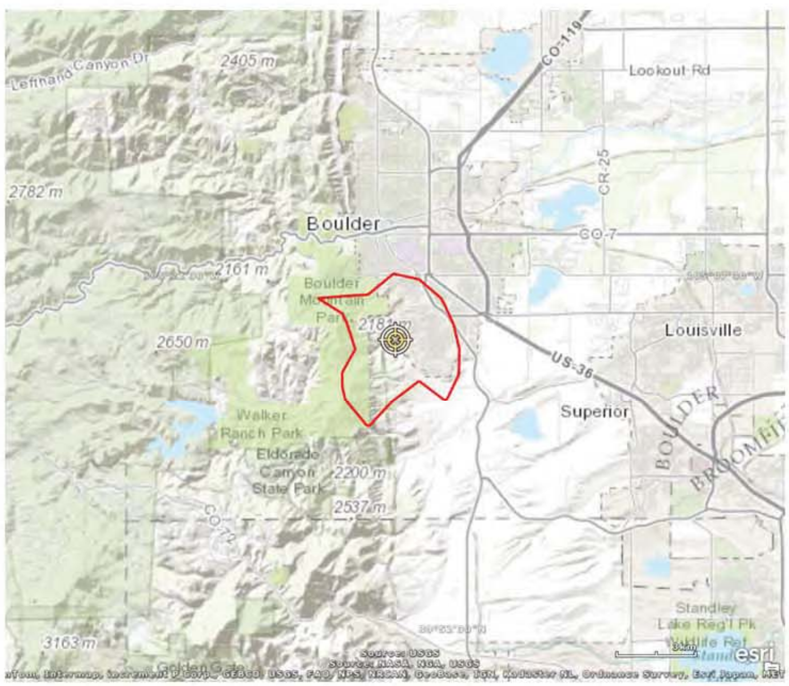


Figure 42. Boulder, CO MDL 135 W

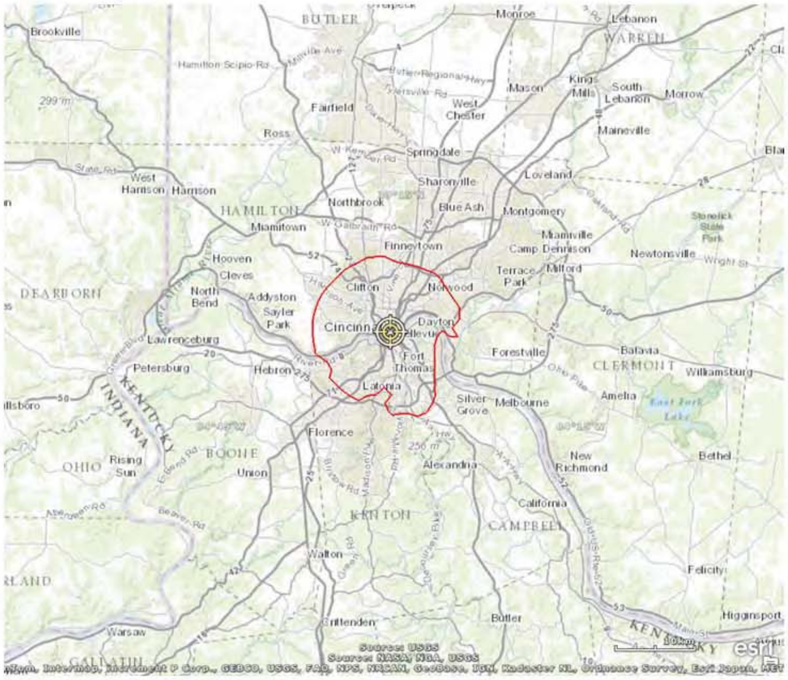


Figure 43. Cincinnati, OH DCPR-1 75 W

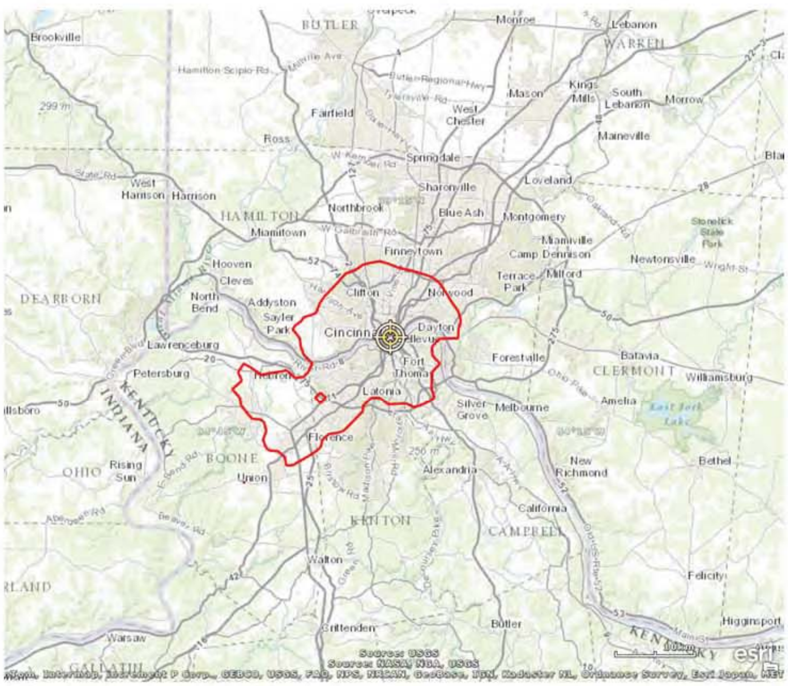


Figure 44. Cincinnati, OH DCPR-1 135 W

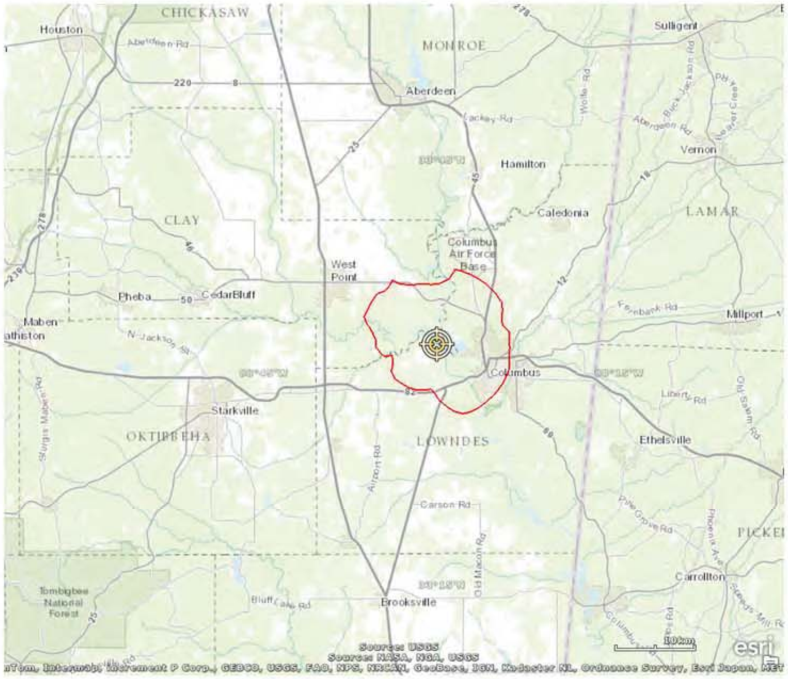


Figure 45. Columbus, MS DCPR-1 135 W

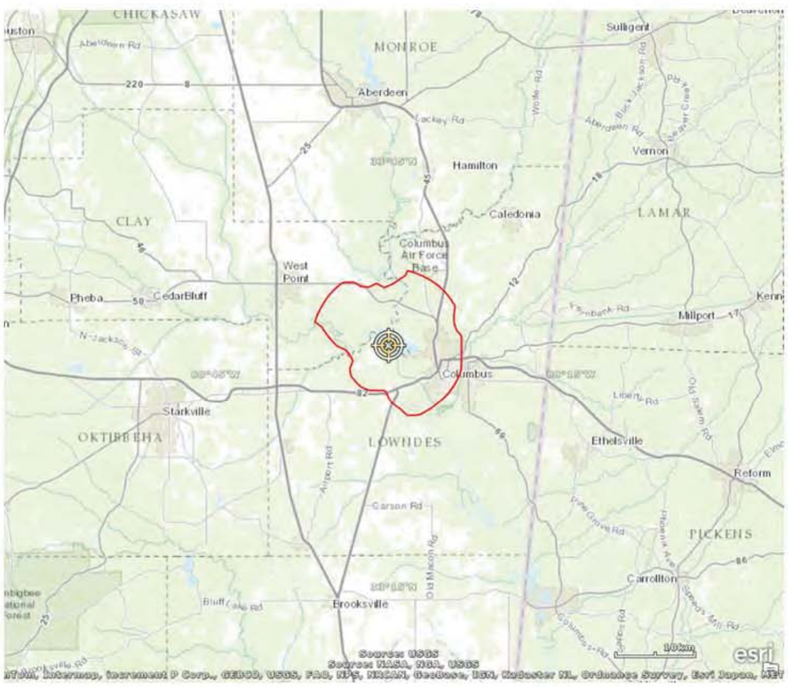


Figure 46. Columbus, MS DCPR-1 75 W

Figure 47. Ford Island, HI DCPR-1 135 W

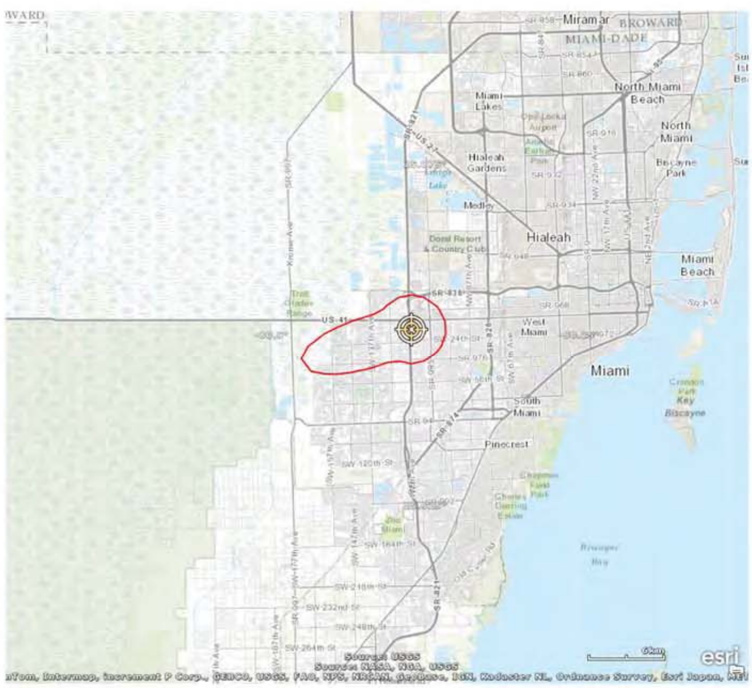


Figure 48. Miami, FL GVAR 135 W

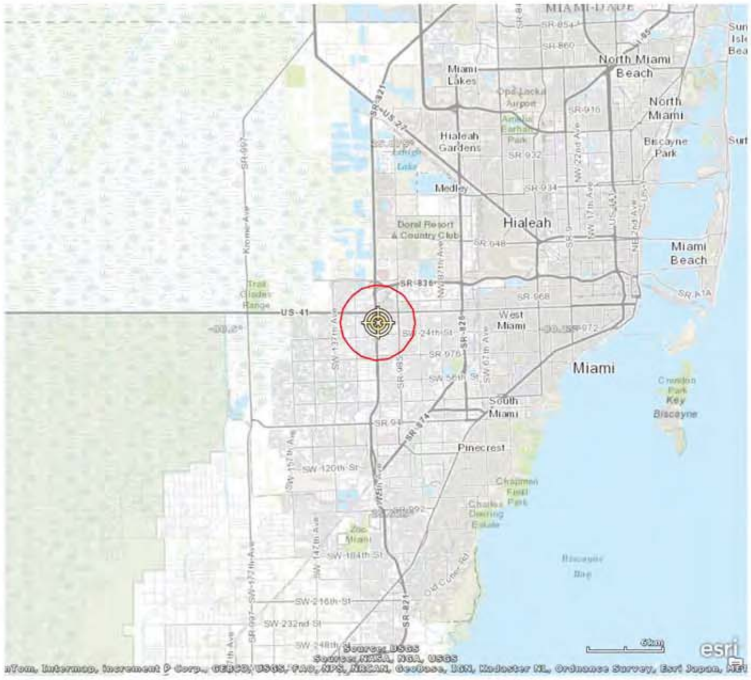


Figure 49. Miami, FL GVAR 75 W

Figure 50. Monterey, CA GVAR 135 W

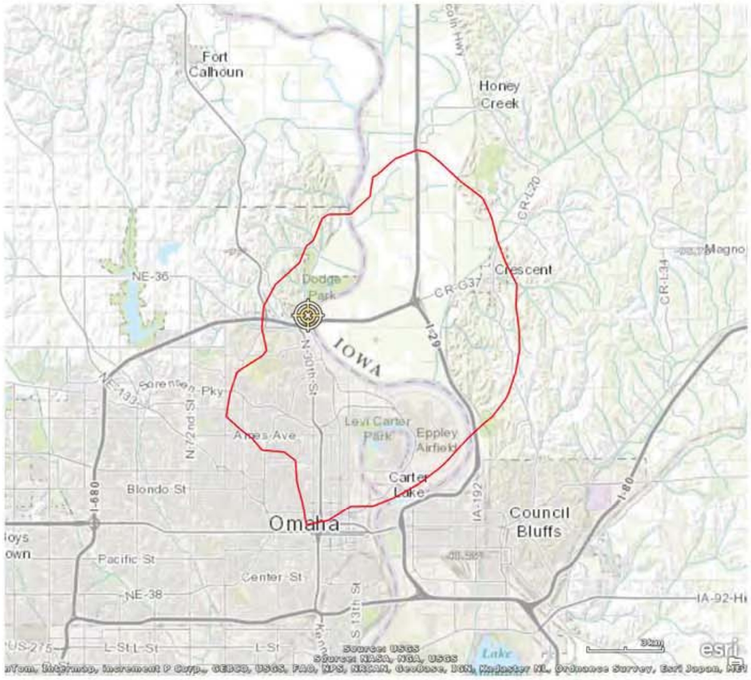


Figure 51. Omaha, NE DCPR-1 135 W

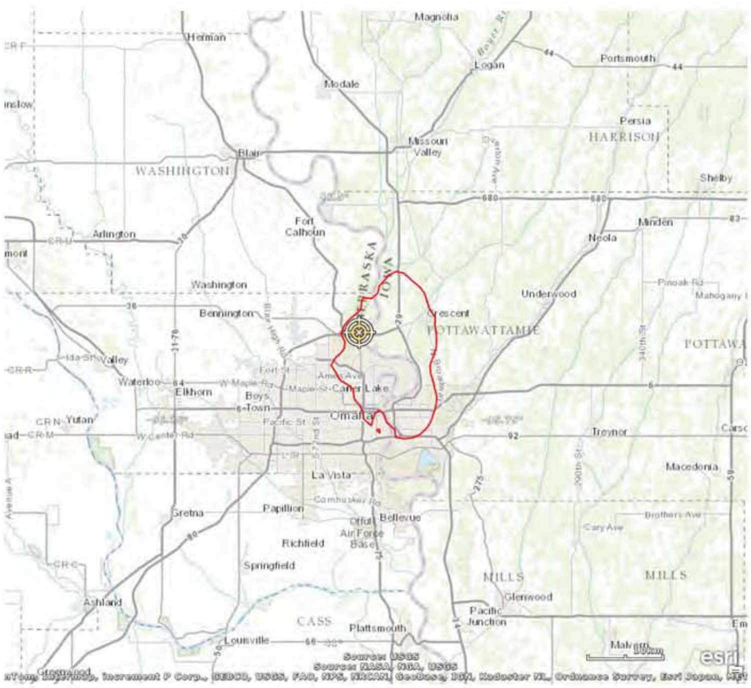


Figure 52. Omaha, NE DCPR-1 75 W

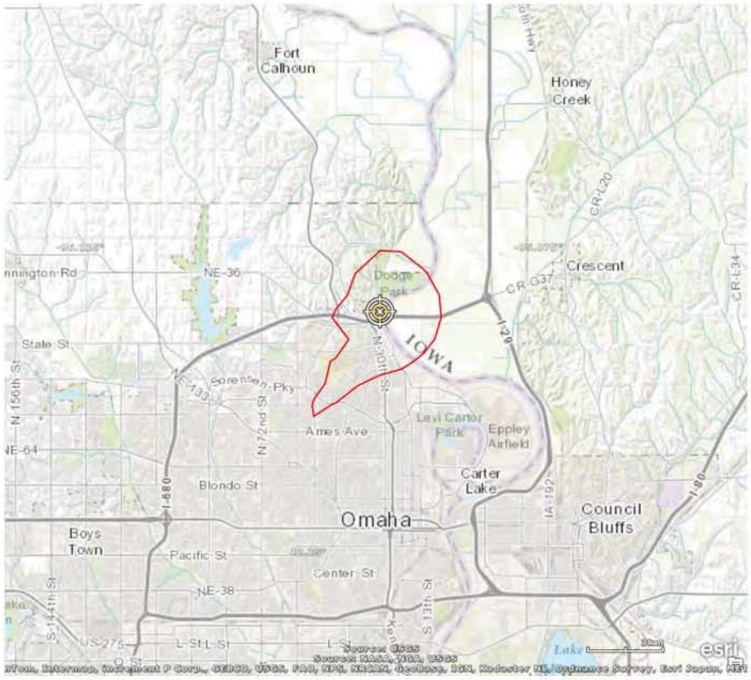


Figure 53. Omaha, NE GVAR 135 W

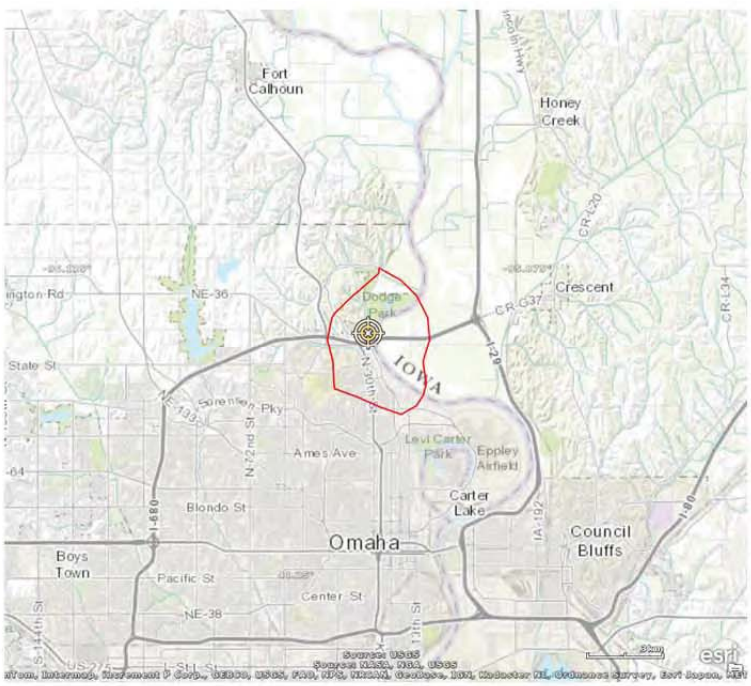


Figure 54. Omaha, NE GVAR 75 W

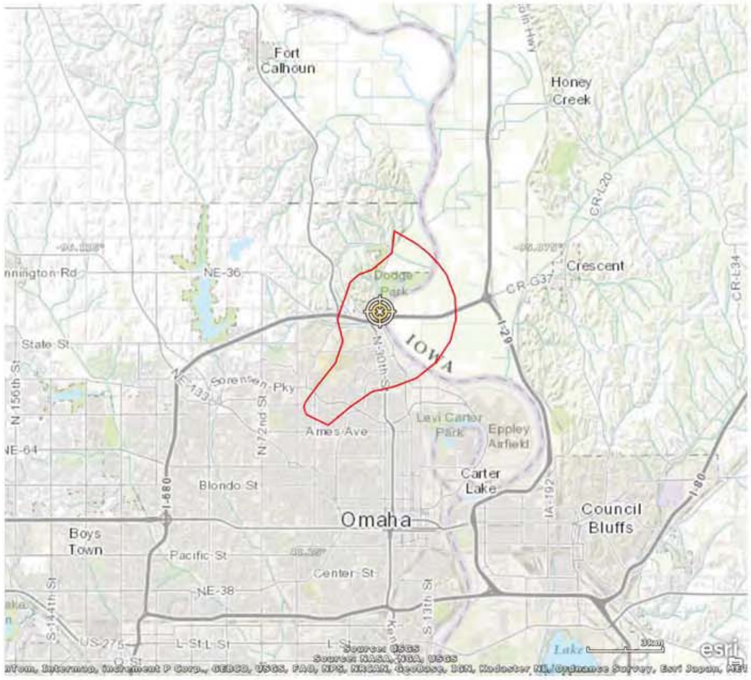


Figure 55. Omaha, NE MDL 135 W

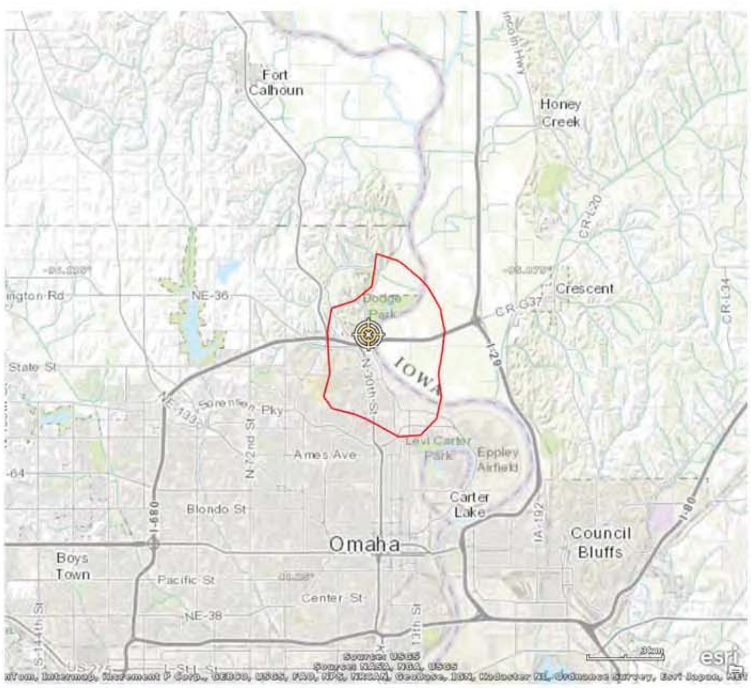


Figure 56. Omaha, NE MDL 75 W

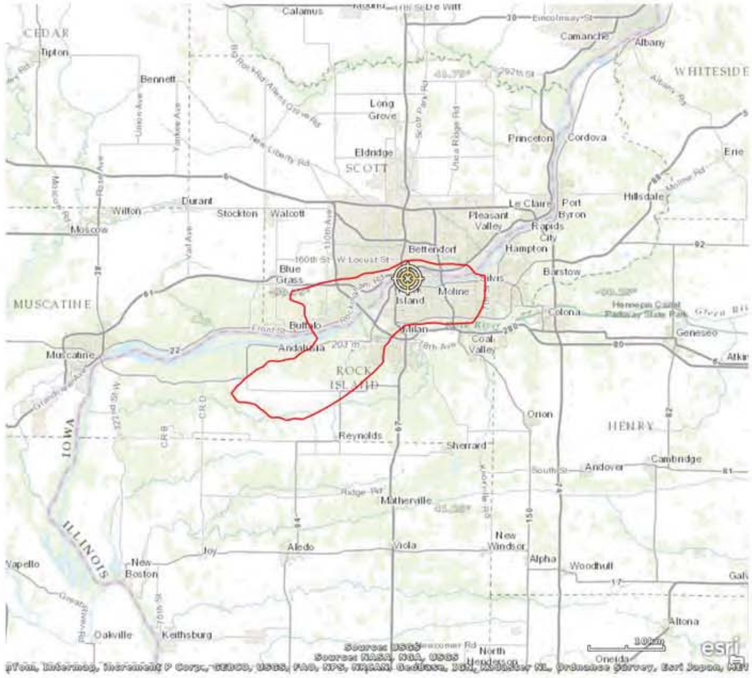


Figure 57. Rock Island, IL DCPR-1 135 W

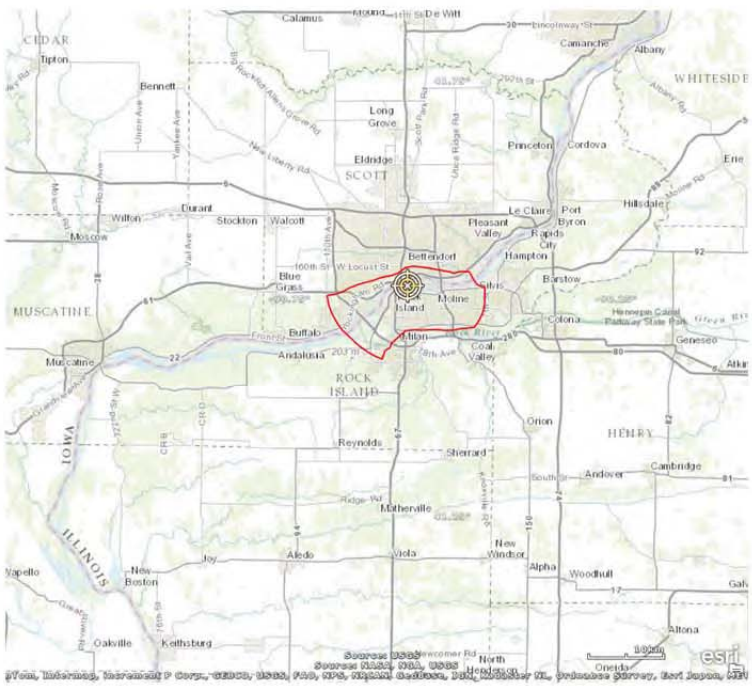


Figure 58. Rock Island, IL DCPR-1 75 W

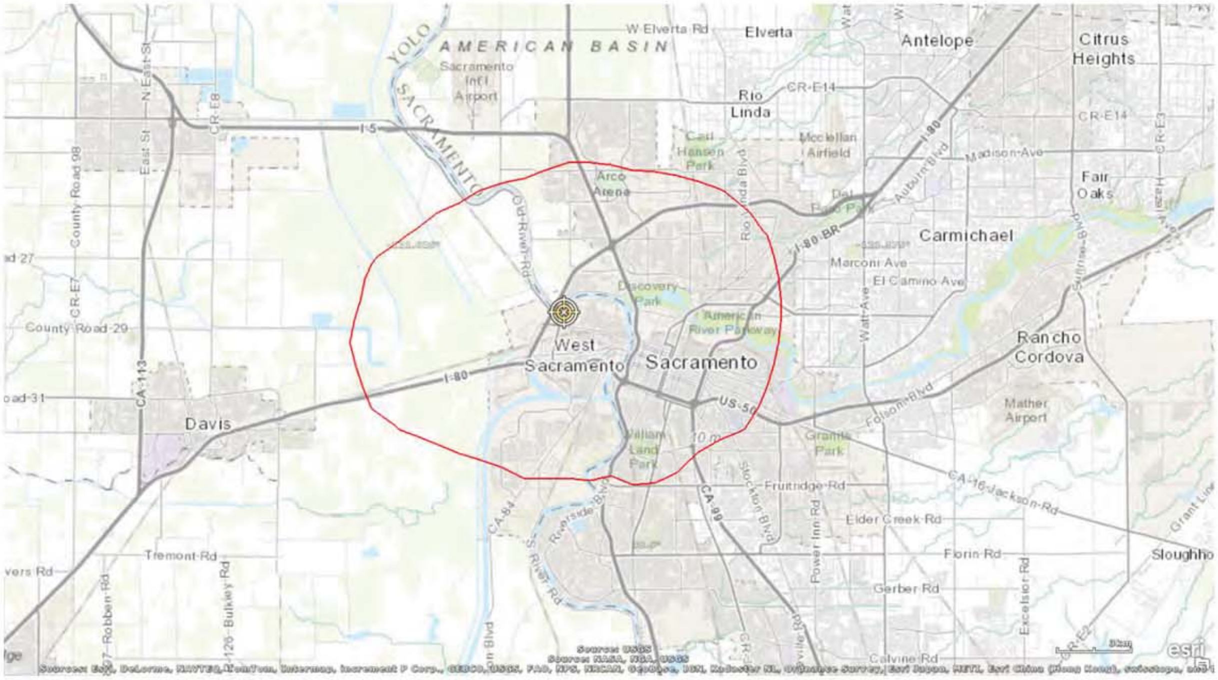


Figure 59. Sacramento, CA DCPR-1 135 W

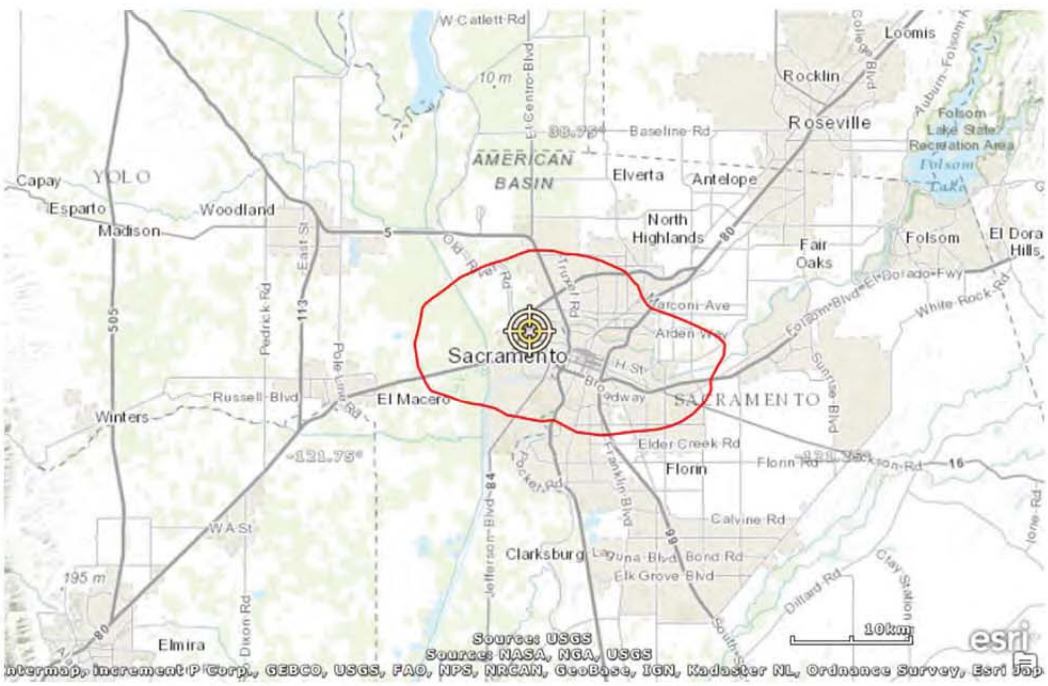


Figure 60. Sacramento, CA DCPR-1 75 W

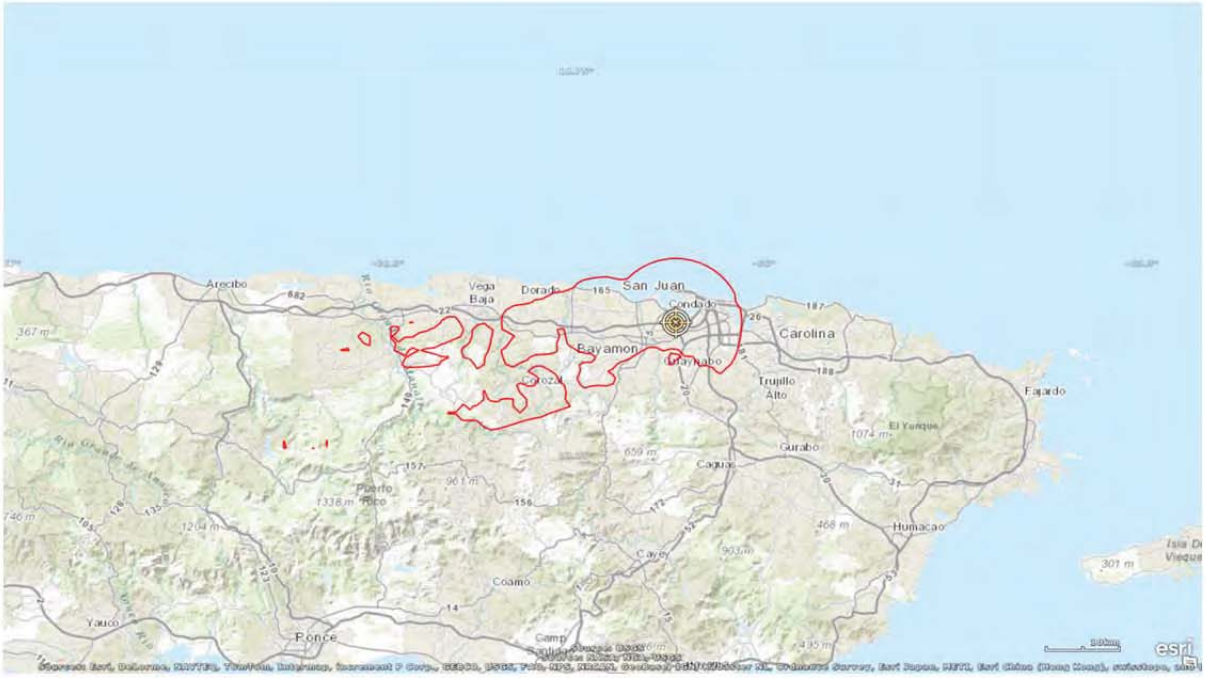


Figure 61. San Juan, PR DCPR-1 135 W

Figure 62. San Juan, PR DCPR-1 75 W

Figure 63. Sioux Falls, SD DCPR-1 75 W

Figure 64. Sioux Falls, SD DCPR-1 135 W

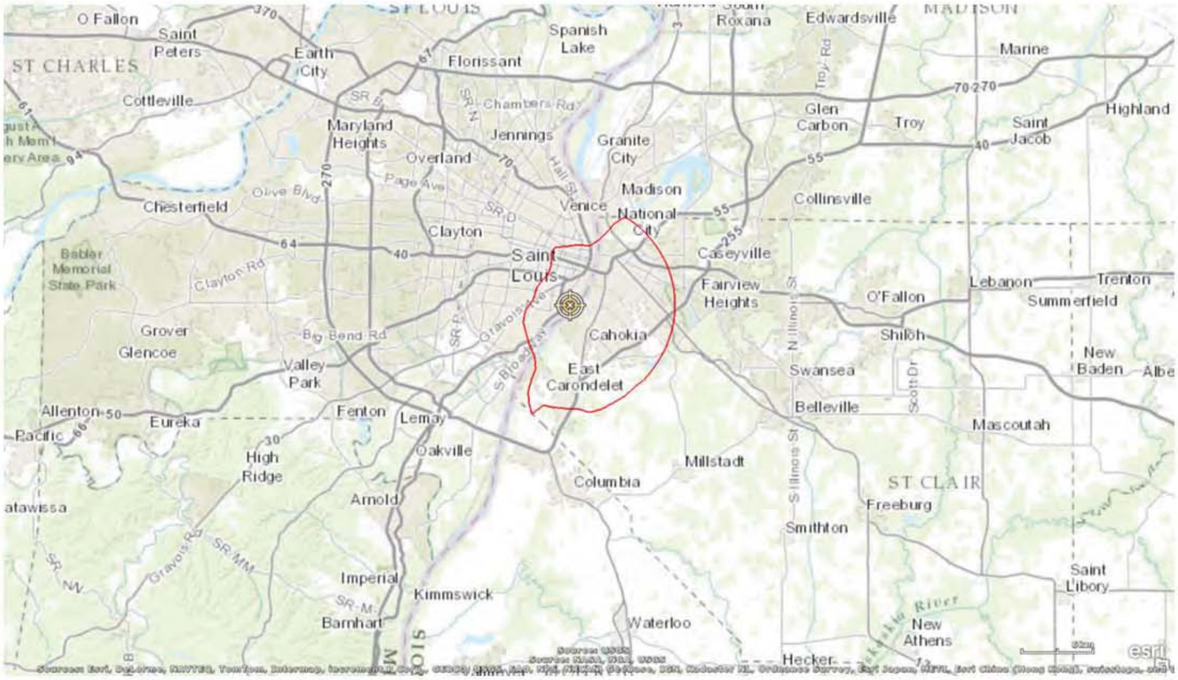


Figure 65. St. Louis, MO DCPR-1 135 W

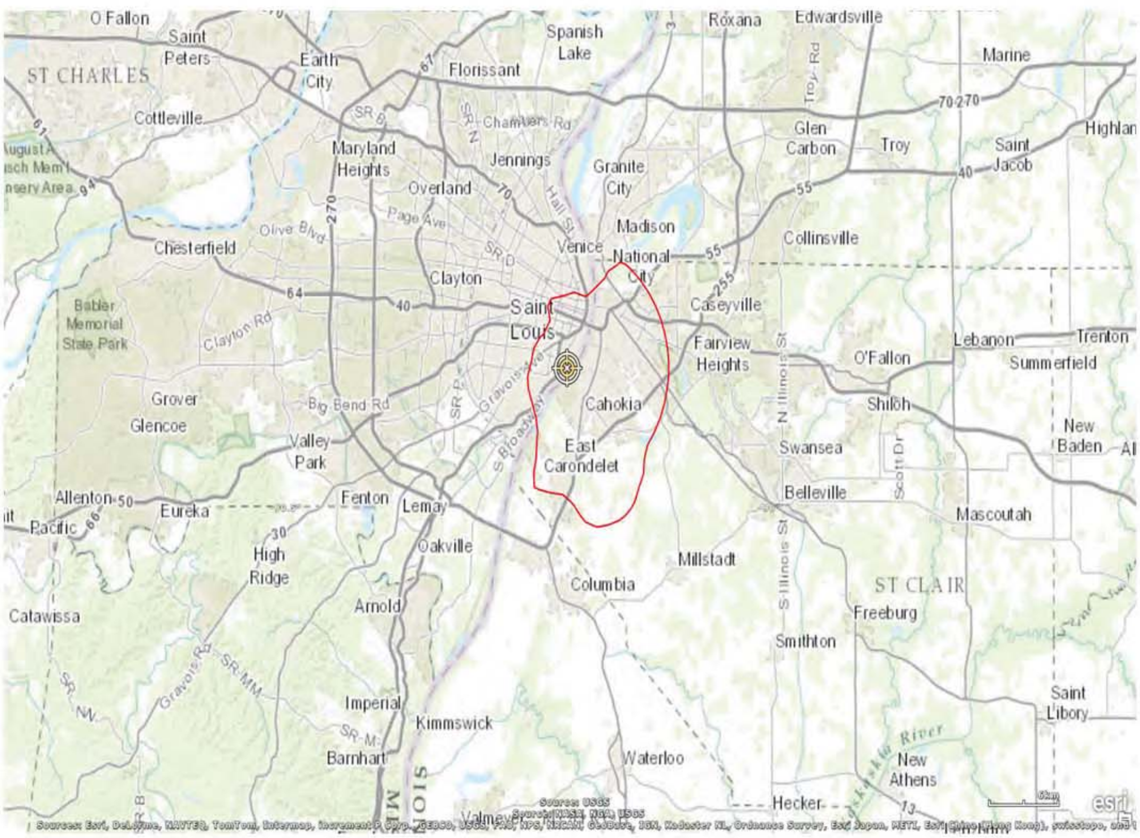


Figure 66. St. Louis, MO DCPR-1 75 W

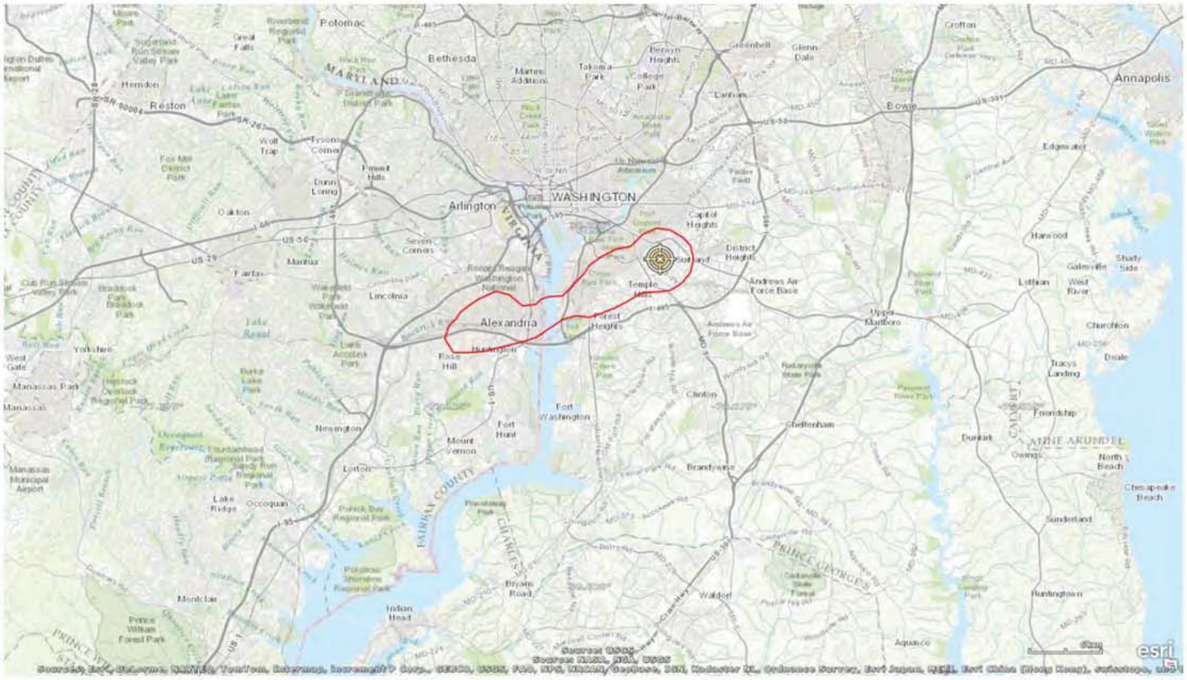


Figure 67. Suitland, MD GVAR 135 W

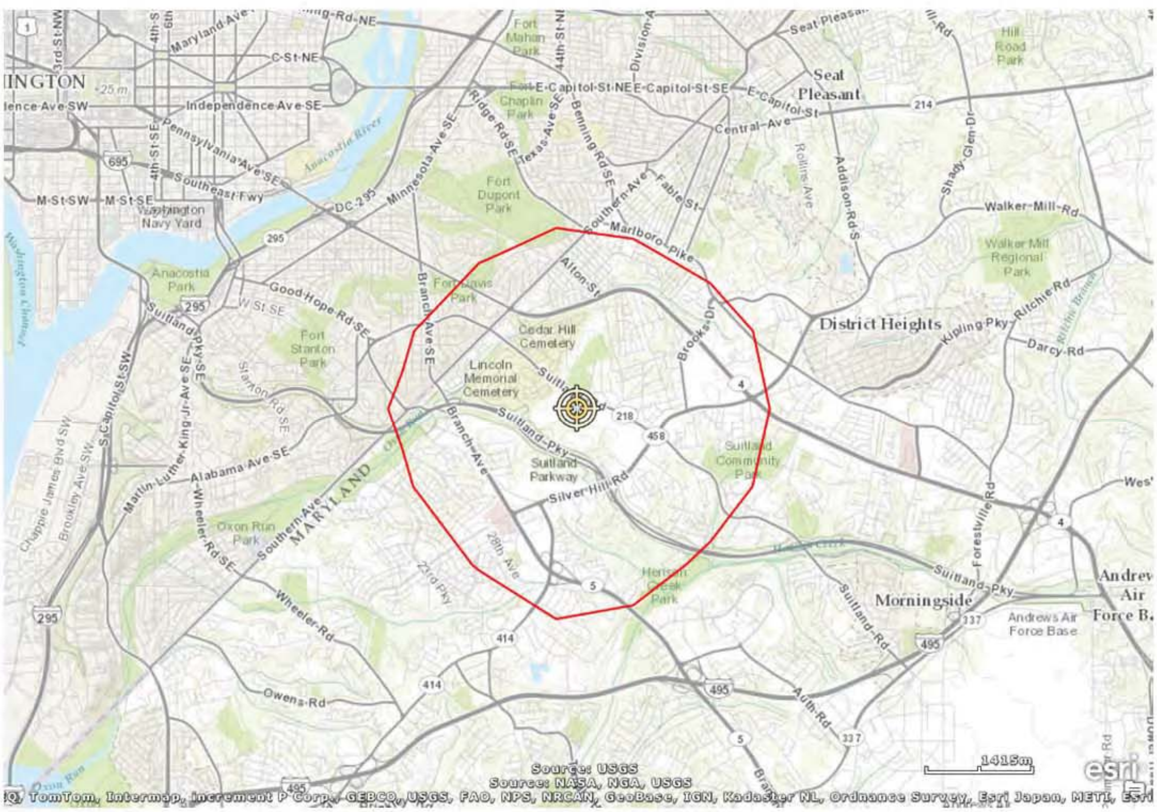


Figure 68. Suitland, MD GVAR 75 W

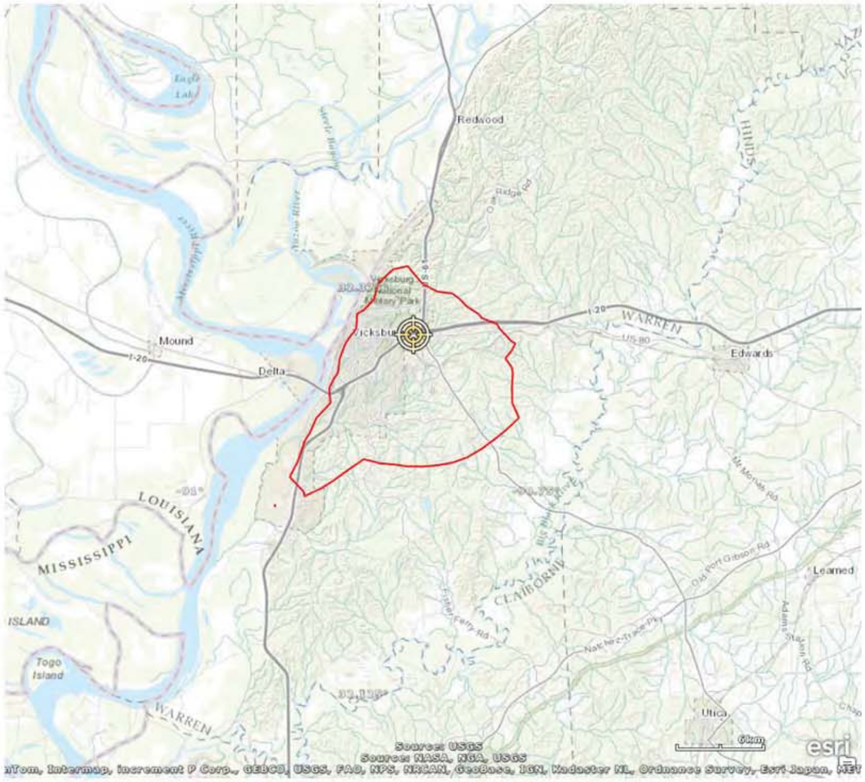


Figure 69. Vicksburg, MS DCPR-1 135 W

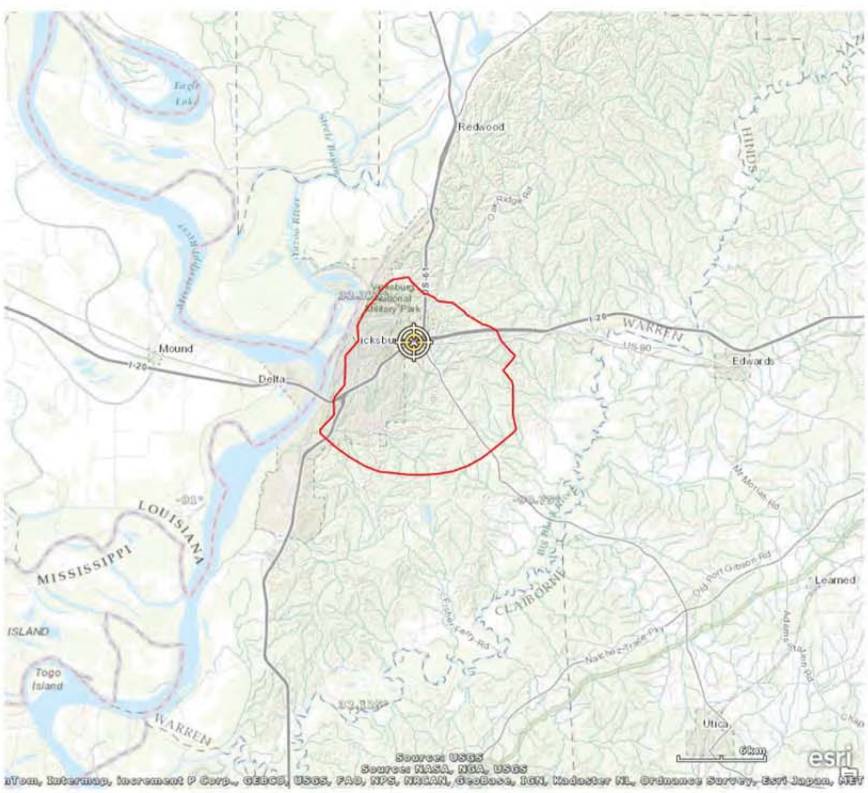


Figure 70. Vicksburg, MS DCPR-1 75 W

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Potential for LightSquared Broadband Base Stations in the 1670-1680 MHz Band To Interfere with Select NOAA GOES-R Ground Locations

RESED-14-005 (Supplement)

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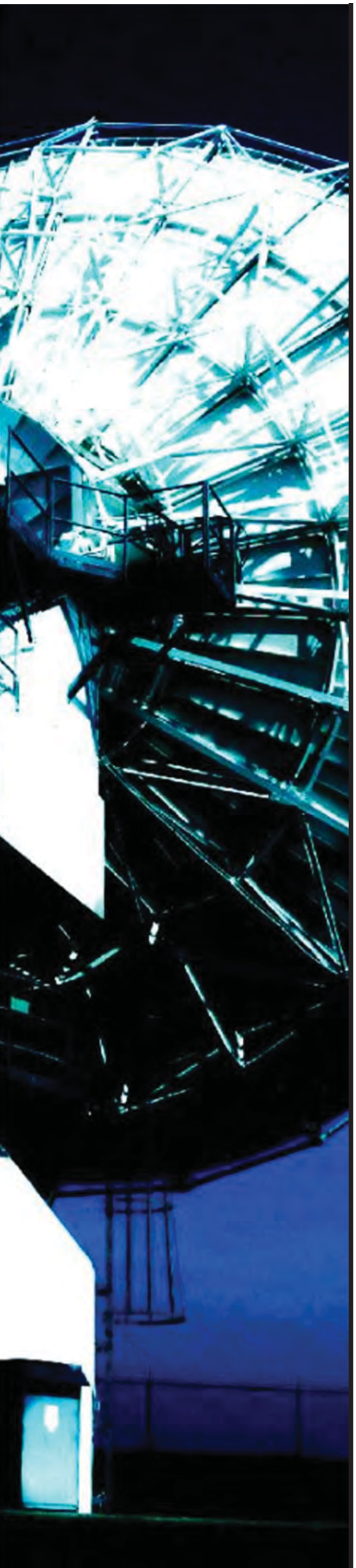

Consulting Report

POTENTIAL FOR LIGHTSQUARED BROADBAND BASE STATIONS IN THE 1670-1680 MHZ BAND TO INTERFERE WITH SELECT NOAA GOES-R GROUND LOCATIONS

Prepared for:

LightSquared

RESED-14-005 (Supplement)
April 2014

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14. ABSTRACT This is a supplement to the Task 2 report issued in February of 2014. This supplement analyzes the potential impact of a LightSquared broadband network on GOES-R rebroadcast and data collection platform report links. Alion performed a small-signal aggregate analysis of multiple LightSquared base stations as well as a strong-signal analysis which consisted of both single site and aggregate site calculations. The results of these analyses are the basis for protection distances around future GOES-R earth stations receiving one or both of these signals. This analysis has been completed based on a LightSquared base station peak transmit power of 25W with an 18 dBi gain antenna as well as a median RF interference propagation.			
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EXECUTIVE SUMMARY

LightSquared is proposing to use of the 1670 to 1680 MHz frequency band to support Fourth Generation Long-Term Evolution (4G-LTE) wireless network downlink operations (i.e., base station transmitters to mobile user equipment) within the United States. LightSquared has obtained rights to the 1670 to 1675 MHz band that were previously auctioned to Crown Castle.

It was agreed upon by LightSquared and the National Oceanic and Atmospheric Administration (NOAA) that an analysis was necessary to assess the ability of LightSquared to operate in the 1670 - 1680 MHz band without adversely impacting future operation of NOAA satellite system downlinks in the 1675 - 1710 MHz band.

NOAA uses multiple frequencies in the 1675 – 1710 MHz band for space-to-earth links from geostationary and polar satellites. Radiosondes (weather balloons) use the 1675 – 1683 MHz portion of the L-band. The polar satellites use the 1695 – 1710 MHz portion of the L-band. NOAA requires satellite bit error rate less than 10^{-10}, 99.99% of the time. This equates to 53 minutes per year (4 - 5 minutes per month) for allowable interference. In the near future, Geostationary Operational Environmental Satellites R-Series (GOES-R) will transmit multiple downlinks with frequencies from 1679.7 – 1694.5 MHz. The GOES-R DCPR and GRB links, operating at center frequencies 1679.9 MHz and 1686.6 MHz, are addressed in this supplemental report. In addition, Alion also performed two prior LightSquared interference assessments that are documented in Alion reports, RESED-14-003, *Assessment of the Viability of Relocating National Weather Service Radiosonde Operations from the 1675 – 1683 MHz Band to the 400.15 – 406 MHz Band*, and RESED-14-004, *Assessment of the Potential for LightSquared Broadband Base Stations in the 1670 – 1680 MHz Band to Interfere with Select NOAA Legacy Ground Locations*.

This document is a supplement to the Task 2 report issued in February of 2014. This follow-on assessment consists of the following:

1) Small-signal aggregate analyses of multiple LightSquared base stations on GOES-R rebroadcast (GRB) and data collection platform report (DCPR-1) links
2) Analyses of strong-signal effects such as gain compression, physical damage, and receiver intermodulation (IM) product generation; this is comprised of both single site and aggregate analyses for GOES-R systems.

In the prior Task 2 analyses for GOES-Legacy systems, the thresholds that were used were based from the ITU recommendations where the thresholds were specified for each signal and propagation conditions for P. 452 of P% equal to 0.011 - 0.025 % to provide 99.99% data availability. Additionally, NOAA and LightSquared determined that a 50% exceedence factor should be used for this analysis. ITU specifications defining NOAA satellite receive system interference thresholds were not yet developed for the new GOES-R system because the modulation and coding schemes are much more susceptible to interference. For the purpose of this analysis an I/N = -10 dB was used and anomalous propagation conditions were not specified. This analysis also shows that the NOAA system performance is near the Shannon limit. Therefore the system will degrade very quickly as the interference thresholds are approached and exceeded.

The distances provided in the results section show the worst cases of the aggregate small-signal analyses performed for each GOES-R site. The protection distances range from 19 – 92 km. The distances provided in the results section also show the worst cases of the single and aggregate strong-signal analyses performed for each GOES-R site. The protection distances range from 2 – 35 km.

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GLOSSARY

3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AGL	Above Ground Level
AOA	Angle of Arrival
AOD	Angle of Departure
CDA	Command and Data Acquisition
CSMAC	Commerce Spectrum Management Advisory Committee
DCPR	Data Collection Platform Report
DRGS	Direct Readout Ground Station
E-UTRA	Evolved Universal Terrestrial Radio Access
EIRP	Effective Isotropic Radiated Power
EMC	Electromagnetic Compatibility
EMWIN	Emergency Managers Weather Information Network
FIR	Finite-impulse-response
FDR	Frequency-dependent rejection
GC	Gain Compression
GOES	Geostationary Operational Environmental Satellite
GOES-R	GOES-R Series
GRB	GOES-R Rebroadcast (Sensor Data)
IM	Intermodulation
IMT-A	International Mobile Telecommunications Advanced
ITU	International Telecommunication Union
LRIT	Low-Rate Information Transmission
LTE	Long Term Evolution
LTE-A	Long Term Evolution - Advanced
MSAM	Microcomputer Spectrum Analysis Models
NOAA	National Oceanic and Atmospheric Administration
NTIA	National Telecommunications and Information Administration
RF	Radio Frequency
RLOS	Radio Line of Sight
SD	Sensor Data

UE	User Equipment
US	United States
WG	Working Group

BACKGROUND

LightSquared is proposing to use the 1670 – 1680 MHz frequency band to support Fourth Generation Long-Term Evolution (4G-LTE) wireless network downlink operations (i.e., base station transmitters to mobile user equipment) within the United States. LightSquared has obtained rights to the 1670 – 1675 MHz band that were previously auctioned to Crown Castle.

LightSquared currently operates a network in the 1670-1675 MHz band utilizing DVB-H (Direct Video Broadcast- Handheld) technology. Meteorological satellite use of the 1670 to 1675 MHz frequency band is protected at the National Oceanic and Atmospheric Administration (NOAA) ground locations at Wallops (VA), Fairbanks (AK), and Greenbelt (MD) by the Federal Communications Commission (FCC) rules underlying LightSquared's authorization for the DVB-H network. These rules define coordination zones of 100 kilometers for the Wallops and Fairbanks locations, and 65 kilometers for the Greenbelt location.

It was agreed upon by LightSquared and NOAA that an analysis was necessary to assess the ability of LightSquared to operate in the 1670 - 1680 MHz band without adversely impacting future operation of NOAA satellite system downlinks in the 1675 - 1710 MHz band. NOAA requires data availability 99.99% of the time. This equates to 53 minutes per year (4 - 5 minutes per month) for allowable interference. NOAA and LightSquared determined that a 50% exceedence factor should be used for this analysis.

NOAA uses multiple frequencies in the 1675 – 1710 MHz band for space-to-earth links from geostationary and polar satellites. Radiosondes (weather balloons) use the 1675 – 1683 MHz portion of the L-band. The polar satellites use the 1695 – 1710 MHz portion of the L-band. The Geostationary Operational Environmental Satellites R-Series (GOES-R) transmits multiple downlinks with center frequencies from 1679.7 – 1694.5 MHz. In the near future, NOAA will launch the new GOES-R series of satellites. The GOES-R links, operating at frequencies 1679.7 MHz and 1686.6 MHz, are addressed in this supplemental report. The future auction of the NOAA polar band frequencies (1695 – 1710 MHz) requires the GOES-R spectrum to be shifted 3 MHz downward into the radiosonde band so that GOES-R will occupy the spectrum from 1679.7 – 1694.5 MHz. A prior analysis, Alion report on Task 1, assessed the potential to move weather balloon

radiosondes to the 403 MHz band.[1] A second report on Task 2 was issued that used the ITU interference thresholds to assess the potential for interference to GOES-Legacy systems.[2]
In the prior Task 2 analyses for GOES-Legacy systems, the LightSquared signal would completely overlap the Sensor Data link at 1676 MHz that is received only at the primary CDA sites of Wallops, VA, Greenbelt, MD, and Fairbanks, AK. All other sites receiving the NOAA satellite signals had large frequency separations for GVAR and the other signals. When GOES-R totally replaces the GOES-Legacy systems, there will no longer be a sensor data link in L-band; however, the GRB signals will be adjacent to the LightSquared band, while the DCPR-1 will have a slight overlap with the LTE guard band.

OBJECTIVES

The objectives of these analyses are to:

- Determine the estimated interference thresholds and FDR for GRB and DCPR-1 for each GOES-R downlink in the band of concern.
- Assess the potential interference from LightSquared network base station transmissions to GOES-R satellite ground operations in the US and Puerto Rico between 1675 - 1695 MHz
    - To calculate small-signal (linear amplifier operation) separation distances that are projected to determine the extent of protection zones for a 50% exceedence factor
    - To calculate the strong-signal (non-linear amplifier operation) separation distances that will be used by NOAA to determine the extent of protection zones

APPROACH

This supplemental study consisted of two interrelated analyses. Both small-signal and strong-signal interactions were considered as potential interference mechanisms.

[1] A. Furlow, R. Leck, and I. McClymonds, *Assessment of the Viability of Relocating National Weather Service Radiosonde Operations from the 1675 - 1683 MHz Band to the 400.15 - 406 MHz Band*, RESED-14-003, Annapolis Junction, MD: Alion Science and Technology, January 2014.
[2] J. Greene, J. Zombek , *Assessment of the Potential for Lightsquared Broadband Base Stations in the 1670-1680 MHz Band to Interfere with Select NOAA Legacy Ground Locations*, RESED-14-004, Annapolis, Junction, MD: Alion Science and Technology, February 2014

The small-signal assessment consisted of the following:

- Available technical and operational characteristics for NOAA receivers at the selected locations
  - Assumptions were made for systems with inadequate technical data available
- Technical and operational characteristics for LightSquared-defined systems as detailed in the initial Task 2 report
- An I/N = -10 dB was used because the GOES-R modulation and coding schemes are much more sophisticated than those assumed in the ITU specifications defining existing NOAA satellite system receive system interference thresholds
- The use of the Visualyse software tool to model, simulate, and analyze radio frequency (RF) signal interactions including aggregate effects from potential multiple LightSquared base station deployments
- Median radio interference propagation was used (P% = 50)

The strong-signal assessment consisted of the following:

- Available technical and operational characteristics for NOAA filters and low noise amplifiers (LNA) at the selected locations
  - Assumptions were made for systems with inadequate technical data available
- Technical and operational characteristics for LightSquared-defined systems
- The use of the Matlab software to analyze radio frequency (RF) strong-signal interactions for single and aggregate effects from potential LightSquared base station deployments
- Free-space path loss was used

SYSTEM DESCRIPTIONS

LightSquared Transmit Systems

Antennas

Table 1 provides the parameters used to model the LightSquared base stations.

Table 1. LightSquared transmission parameters

Frequency	1675 MHz
Bandwidth	10 MHz
Transmit Power	14 dBW (25W)
Main beam Gain	18 dBi
Gain on Horizon (with 3° downtilt)	16.6 dBi
EIRP	32 dBW
Mechanical Tilt	0°
Horizontal 3dB Beam Width	65°
Vertical 3dB Beam Width	8.5°
Antenna Height Above Ground Level	45m (Rural), 30m (Urban) at feed point
Antenna Horizontal Pointing Angle	3 sector - 0°, 120°, 240° [1]
Antenna Vertical Pointing Angle	3° down tilt

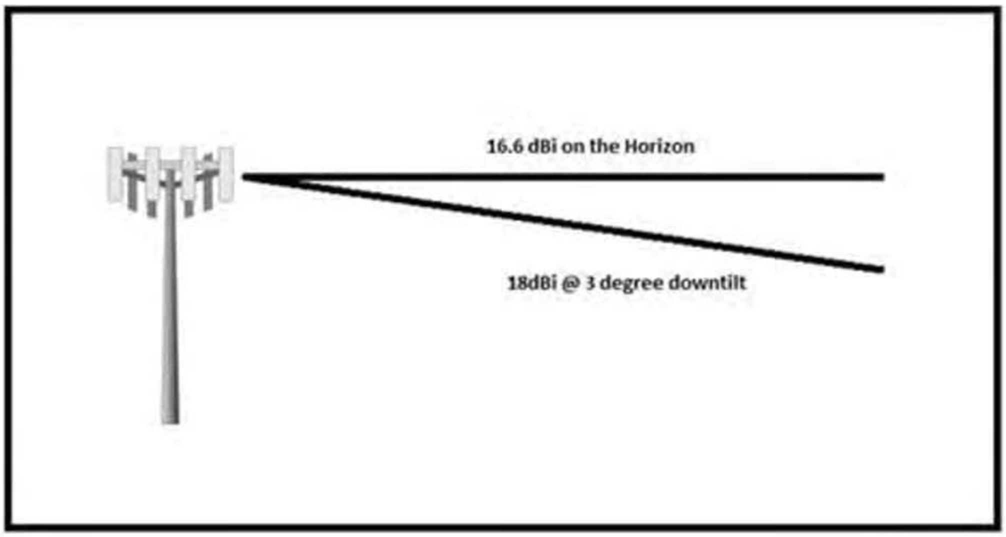

Figure 1. Notional diagram of elevation pattern

Emission Mask

The emission mask of a transmitter is derived from power spectral density (PSD). PSD is defined as the way in which signal power is distributed over a frequency range such as 4.4 Watts per MHz (W/MHz). The emission mask indicates the attenuation that is applied to the actual PSD to comply with limits on adjacent-band and out-of-band emission. The proposed LightSquared emission is nominally 10 MHz, from 1670 – 1680 MHz, centered around a tuned frequency of 1675 MHz, with 0.5 MHz guard band on the high and low ends. The mask used for this assessment, agreed upon by Alion and LightSquared, is consistent with the 3GPP specification for LTE-A base station transmitters.[3] The LightSquared emission mask is detailed in Appendix A. While there is no maximum base station transmitter power in the specification, there is a requirement that the out-of-band emission at the antenna input be no greater

[3] 3GPP TS 36.104 V10.2.0 (2011-04)

than -13 dBm in a 1 MHz bandwidth. For this assessment, a transmitter power of 25W (14 dBW) was used with an antenna gain of 18 dBi to produce an effective isotropic radiated power (EIRP) of 62 dBm.

LTE/LTE-Advanced

LTE and LTE-Advanced versions 10, 11, 12, or 14 (LTE-A) are mobile broadband communications standards for 4th Generation (4G) systems.[4,5] LTE-A was approved by the International Telecommunication Union (ITU) as International Mobile Telecommunications Advanced (IMT-A) (also known as Evolved Universal Terrestrial Radio Access [E-UTRA]). LTE-A is standardized by the 3rd Generation Partnership Project (3GPP), whose documents are available on the internet. The standards are known as “releases.” Releases 8 and 9 are for LTE and Releases 10 and above are for LTE-A. LTE-A is backwards compatible with LTE. Some of the main benefits of LTE-A over LTE are peak data rates of 1 Gbps for downlink and 500 Mbps for uplink, improved spectrum efficiency (of 30 bps/Hz for downlink and 15 bps/Hz for uplink), improved cell edge user throughput, and higher average user throughput. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both frequency division duplexing (FDD) and time-division duplexing (TDD). In both LTE and LTE-A, the transmission bandwidth consists of two, 500 kHz guard bands and the transmitted signal in a 10-MHz channel.

GOES-R System

This assessment considered the two future satellites which will be located at an orbital longitude of 75^{o} W and 137^{o} W.

Downlinks

Two types of signals were assessed as part of this effort as they posed the greatest interference risk. These signals are identified in Table 2. The lowest channel of the DCPR-1 link occupies 1.8 kHz of bandwidth centered at 1679.700375 MHz, and will be partially overlapped by the LTE guard band transmission. In cases where an earth station did not have a DCPR-1 link, GRB (1682.3 – 1690.9 MHz) was analyzed. Therefore, primary attention was given to analyzing the separation distances calculated to

[4] See, for example, the list of ITU-R Recommendations on IMT, http://www.itu.int/ITU-R/index.asp?category=information&rlink=imt-advanced-rec&lang=en

[5] 3GPP, *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 11*), 3gPP TS 36.101 V11.0.0, 2012-03

prevent harmful interference at the aforementioned stations for these two links. There are other signals such as Telemetry (Tlm), High Rate Information Transmission (HRIT), and Emergency Managers Weather Information Network (EMWIN) which were not analyzed.

Table 2. GOES-R data links and center frequencies

Data Link	Center Frequency, MHz
Data Collections Platform Report, Band 1 (DCPR-1)	1679.9
Goes Re-Broadcast (GRB)	1686.6

NOAA Receive Systems

The NOAA ground stations receive and process the satellite signals. NOAA provided a list of ground stations that is presented in Table 3 for assessment. Table 3 provides the location, link assessed, antenna diameter, gain, and height above ground level (AGL) in meters for GOES-R earth stations.

Table 3. NOAA Earth Station parameters

NOAA Ground Stations	Latitude	Longitude	GOES-R Link	Antenna Diameter, m	Antenna Gain, dBi	Antenna Feedpoint Height, AGL, m
Anchorage, AK	61° 09’ 22’’ N	149° 59’ 04’’ W	DCPR-1	4.8	36.6	3
Boise, ID	43° 36' 53" N	116° 15' 08" W	DCPR-1	7	39.7	8
Boulder, CO	39° 58' 39" N	105° 16' 27" W	GRB	6.1	37.6	3
College Park, MD	38° 58' 20’’ N	76° 55' 31’’ W	DCPR-1	3.8	34.4	3
Cincinnati, OH	39° 06' 10" N	84° 30' 35" W	DCPR-1	5	36.8	65
Columbus, MS	33° 32' 04" N	88° 30' 06" W	DCPR-1	5	36.8	4
Fairmont, WV	39° 26' 01" N	80° 11' 34" W	DCPR-1	16.4	47.3	12.2
Ford Island/Pearl Harbor, HI	21° 22' 12" N	157° 57' 44" W	DCPR-1	5	36.8	3
Kansas City, MO	39° 16' 40’’ N	94° 39' 44’’ W	DCPR-1	3.8	34.4	3
Miami, FL	25° 45' 16" N	80° 23' 01" W	GRB	6.1	38.5	7
Monterey, CA	36° 35' 34" N	121° 51' 20" W	GRB	4.5	35.9	2.5
Norman, OK	35° 10' 52" N	97° 26' 21’’ W	DCPR-1	4.8	36.6	13
Omaha, NE	41° 20' 56" N	95° 57' 34" W	DCPR-1	5	36.8	3
Rock Island, IL	41° 30' 57" N	90° 33' 52" W	DCPR-1	5	36.8	3
Sacramento, CA	38° 35' 50" N	121° 32' 34" W	DCPR-1	5	36.8	3
San Juan, PR	18° 25' 26" N	66° 06' 51" W	DCPR-1	3.8	34.4	3.4
Sioux Falls, SD	43° 44' 06" N	96° 37' 32" W	DCPR-1	7.5	33	4
St Louis, MO	38° 35' 26" N	90° 12' 24" W	DCPR-1	5	36.8	3
Suitland, MD	38° 51' 07" N	76° 56' 12" W	GRB	9.1	41.4	21
Stennis Space Center, MS	30° 21' 23’’ N	89° 36' 41’’ W	DCPR-1	5	36.8	4
Vicksburg, MS	32° 20' 47" N	90° 50' 10" W	DCPR-1	5	36.8	3

NOAA Ground Stations	Latitude	Longitude	GOES-R Link	Antenna Diameter, m	Antenna Gain, dBi	Antenna Feedpoint Height, AGL, m
Wallops, VA	37°56' 45" N	75° 27' 43" W	DCPR-1	16.4	48.4	12.2
White Sands, NM	32° 32' 35" N	106° 36' 43" W	GRB	16.4	47.3	12.6

Antenna Characteristics

The NOAA ground stations use different antennas with size and gain based on location and desired receive link. Measured pattern data was not available for each antenna. Since data was not available, the International Telecommunication Union (ITU) recommendation ITU-R S.465-5, "*Reference earth-station radiation pattern for use in coordination and interference assessment in the frequency range from 2 GHz to about 30 GHz*", was used to model the antenna gain pattern for the analyses.

ASSESSMENT METHODOLOGY

This effort assessed the potential for LightSquared LTE network base stations transmitting in the 1670 to 1680 MHz frequency band to interfere with NOAA receivers at selected ground locations in the US and Puerto Rico. This assessment analyzed three forms of interference: aggregate small-signal analysis (i.e., multiple LightSquared base stations to one NOAA receiver) for GOES-R systems; single-site strong-signal analysis; and aggregate strong-signal analysis. The aggregate analysis modeled the source interferers and victim receiver such that the separation distance was increased until the receive level at the victim was equal to the interference threshold. These distances were calculated using Visualyse, a modeling, simulation, and analysis software tool developed by Transfinite Systems Limited. Both the single site strong-signal and aggregate strong-signal analyses were calculated using Matlab. . The source interferers were compiled using Commerce Spectrum Management Advisory Committee (CSMAC) working group (WG) 5 cell site laydown. In some cases, this database was not well populated and a substitute cell tower distribution was used. These interferers were then placed into Visualyse for analysis.

Signal propagation path loss was calculated using the ITU-R P.452 RF model and 3-arcsecond digital terrain elevation data. For the small-signal aggregate analysis, I/N = -10 dB interference threshold was used. In addition, a P factor of 50% was used in this analysis.

In the initial Task 2 analyses for GOES-Legacy systems, the thresholds that were used were based on the ITU recommendations where the thresholds were specified for each signal and propagation conditions for P. 452 of P% equal to 0.011 - 0.025 % to provide 99.99% data availability. In this GOES-R analysis, there are no published thresholds, therefore an I/N of -10 dB was used as threshold. Also, since no propagation conditions were described, NOAA and LightSquared determined that an exceedence factor of 50% should be utilized in cases where aggregate interference from multiple sites is being assessed.

ANALYSIS

Modeling RF Propagation to Predict Interference Power and Determine Separation Distances

Anomalous propagation mechanisms that reduce signal loss and thereby extend the range of interfering signals are of special concern when applied to an interference assessment. The result may be an increase in required separation distances from victim receivers, a required reduction in power of interfering transmitters, or perhaps other remediation measures applied to the systems involved in the interference. It is important to use a dedicated interference propagation model, such as P.452, to perform such an assessment.

For additional information on RF propagation, please refer to Appendix B.

Propagation Model

In the initial Task 2 report, anomalous propagation from individual sites was the dominant factor for calculating separation distances required to maintain 99.99% data availability. In this analysis, the propagation model was restricted to exceedence equal to 50% for an aggregate assessment. The P. 452[6] model used in this analysis is implemented in the Visualyse software product, which is designed specifically for this purpose.

Small-Signal Interference Analysis

The calculated interference level at the NOAA receiver was a function of the antenna gain coupling and the signal path propagation loss that an interfering signal will incur between the interfering transmitter and the victim receiver. This is expressed in Equation 1:

$$I = P_t + G_t + G_r - L_p(d) - FDR(\Delta f)$$

(Equation 1)

[6] ITU-R Recommendation P.452-15, "Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz," International Telecommunication Union, 2013.

where I = interfering signal level at the victim receiver, dBm

P_t = power of the interfering transmitter, dBm

G_t = antenna gain of interfering transmitter in direction of victim receiver, dBi

G_r = antenna gain of victim receiver antenna in direction of interfering transmitter, dBi

$L_p(d)$ = path loss between interfering transmitter and victim receiver, dB

$FDR(\Delta f)$ = frequency-dependent rejection of the interfering signal by the victim receiver, dB

where, $\Delta f = f_t - f_r$

f_t = tuned center frequency of the interfering transmitter, MHz

f_r = tuned center frequency of the victim receiver, MHz

and

$$FDR(\Delta f) = 10 \log \frac{\int_0^\infty P(f)\,df}{\int_0^\infty P(f)\left|H(f+\Delta f)\right|^2 df} \quad \text{dB}$$

(Equation 2)

where $P(f)$ = power spectral density of the interfering signal equivalent intermediate frequency

$H(f)$ = frequency response of the victim receiver

Replacing I in equation 1 with the interference threshold criteria (I_{th}) and rearranging terms yields,

$$L_p(d) = P_t + G_t + G_r - FDR(\Delta f) - I_{th} \text{ dB}$$

(Equation 3)

Solving Equation 3 for the value of d determines the required protection distance. Detailed descriptions of the interference assessment components are presented in the subsections below.

Interference Thresholds

As stated previously, it was agreed that thresholds would be defined based on the criterion I/N ≤ -10 dB. The thresholds used in the analysis are listed in Table 4.

Table 4. Interference thresholds for LightSquared-to-NOAA downlinks

Data Link	Frequency, MHz	Long-Term Threshold, dBW
GOES-R DCPR-1	1679.7	-194.2
GOES-R DCPR-1 (DRGS)	1679.7	-196.1
GOES-R GRB	1686.6	-146.4

The GRB system organizes data into consecutive frames. Each frame contains 64800 bits, which includes information bits, error correction bits, control bits, and various metadata. A very low bit-error rate is required (on the order of 10^{-12}) to maintain the data integrity of the frames. A complex error detection and correction protocol is used to maintain the low bit error rate during operation. Although this protocol succeeds in providing the required performance, it does so by virtually eliminating a gradual region of transition during which performance can be said to be “marginal but acceptable.” The operating point (E_b/N_0) at which the GRB system operates without errors is less than 1 dB higher than the point at which all the frames are corrupted by uncorrected bit errors. Roughly 3 dB below this point, the system can experience loss of synchronization, which results in an outage condition while synch is reacquired. Figure 2 illustrates the narrow region between acceptable and unacceptable performance. A more detailed discussion of this topic is presented in Appendix C.

The synchronization requirement causes the GRB system to be susceptible to intermittent interference, since a short-duration interference pulse can cause an outage of much longer duration. Such an interferer is not adequately described by power and bandwidth; the duty cycle and pulse-repetition frequency (both of which might be random) must also be considered. The effect of intermittent interference on digital communication receivers has been investigated extensively and documented by NTIA and other agencies.[7]

[7] “Communications Receiver Performance Degradation Handbook,” JSC-CR-10-004, DISA/DSO/JSC, 2010.

To allow the GRB system to operate with high data integrity and availability, the probability of interference must be kept to a minimum. Interference thresholds must provide sufficient margin to avoid compromising the GRB operations. Thresholds should be defined for both continuous and intermittent interfering signals.

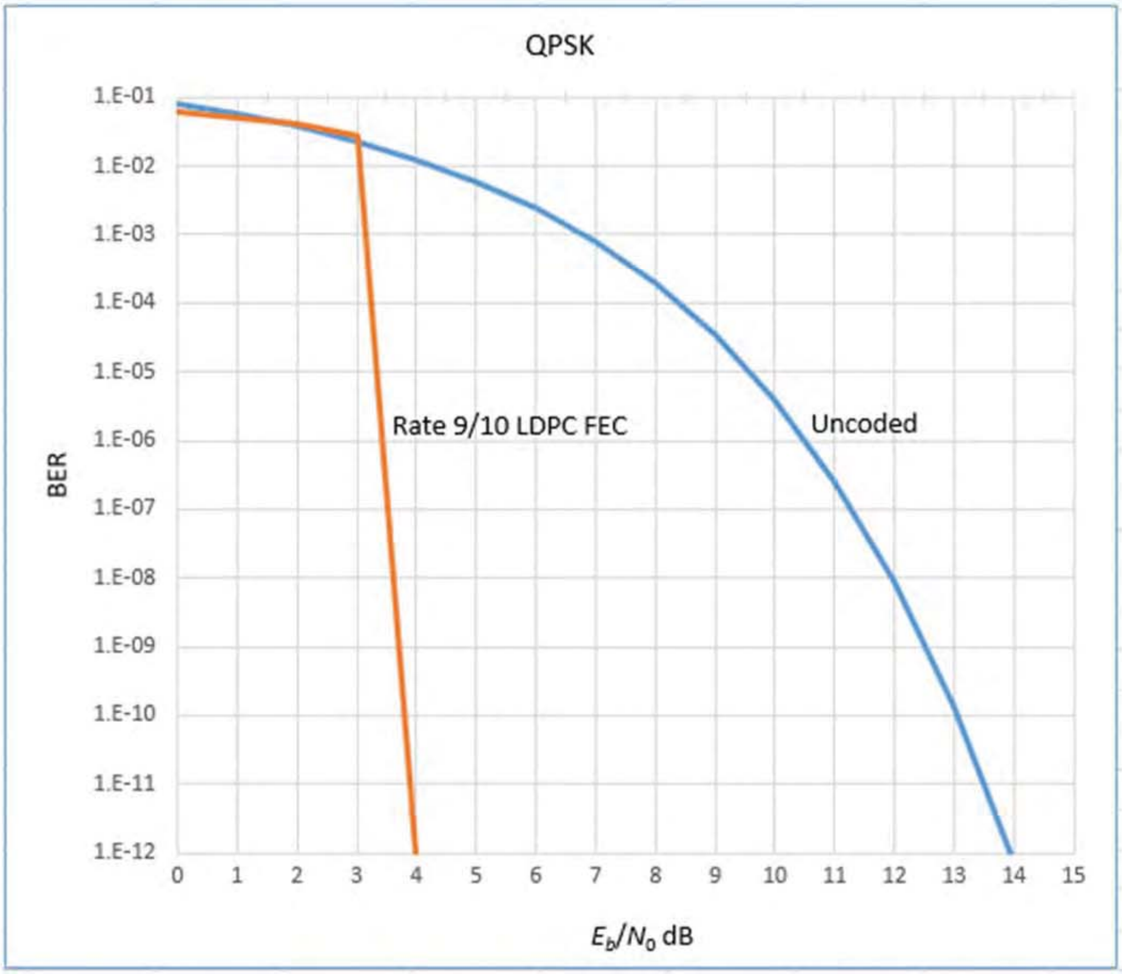

Figure 2. Comparing the performance of QPSK modulation with and without FEC coding

GOES-R Receiver Selectivity

The receiver selectivity is determined primarily by the filter with the narrowest bandwidth that precedes the demodulator in the processing chain. This is often referred to as a pre-detection filter. For the digital modulation techniques employed by the NOAA GOES-R systems, the standard practice is to use a pre-detection filter with a square-root raised-cosine frequency response. This is explained in depth in Appendix C.

FDR

Frequency-dependent rejection (FDR) is a measure of the rejection produced by the victim receiver selectivity curve to the unwanted emission spectra of an interfering transmitter. More detailed information on FDR can be obtained from Recommendation ITU-R SM.337-6. Three inputs are required to compute FDR:

- **Emission Mask.** This is the normalized power spectral density of the transmitted signal, specified with respect to the transmitter tuned frequency.
- **Selectivity Curve.** This is the normalized frequency response of the receiver, specified with respect to the receiver tuned frequency. Note that the overall frequency response is due to several filter stages, but is dominated by the stage just before the demodulator.
- **Off-tuning.** This is the difference between the transmitter and receiver tuned frequencies.

FDR is computed by performing a numerical integration of the inputs, in the frequency domain, to determine the fraction of emitter power that is rejected by the receiver filters (see Equation 2). A number of software implementations of this procedure are available. The FDR program used for this analysis is part of a suite of RF analysis tools called Microcomputer Spectrum Analysis Models (MSAM), developed by National Telecommunications and Information Administration (NTIA). This software is freely available from the NTIA website. Once calculated, FDR is applied to the interference link budget. The effect is to reduce the interfering signal power at the receiver. In the following subsections, the process for determining the inputs is presented, and the FDR results are summarized.

Off-Tuning

FDR was calculated for each of the GOES-R links. These links each have a unique center frequency and bandwidth. Frequency overlap occurs in only one instance: GOES-R DCPR-1. Frequency overlap values are shown in Table 5 and depicted in Figure 3.

Table 5. LightSquared transmitter and NOAA GOES-R frequency overlap

System	Data Link	Center Frequency, MHz	Bandwidth, kHz	Demodulator Bandwidth, kHz	Band Overlap? Yes/No
Light Squared	---	1675	10000	-	-
GOES-R	DCPR-1	1679.7	-	0.3 (3 dB)	Yes
GOES-R	GRB	1686.6	-	8666 (6 dB)	No

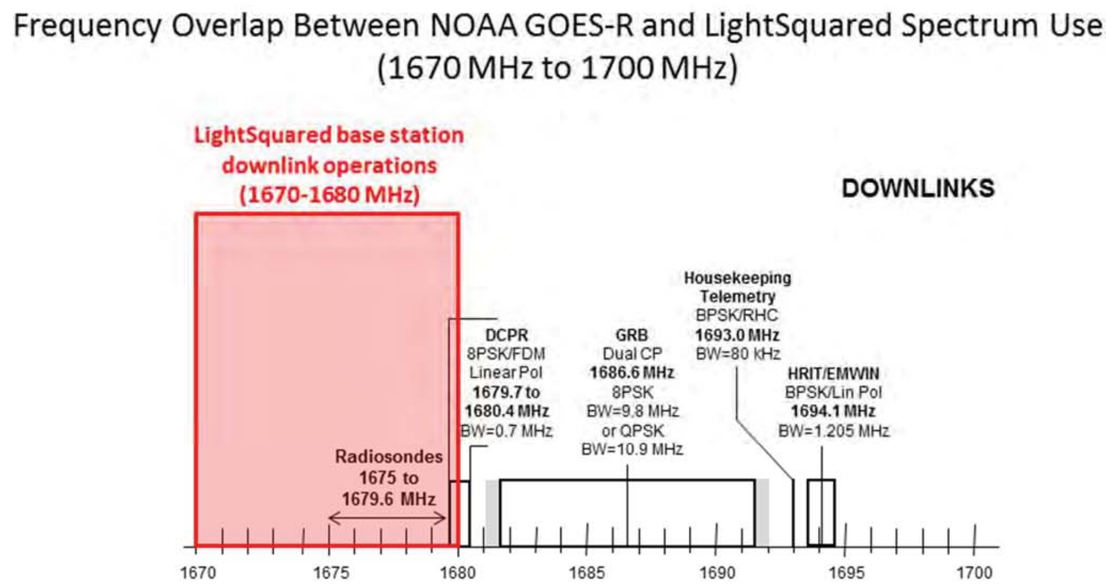

Figure 3. NOAA GOES-R signals and LightSquared frequency overlap

The GOES-R data links will have differing levels of FDR to the LightSquared base station transmitters based upon the emission spectra, receiver selectivity, and frequency offsets. As previously noted, FDR is applied to the interference link budget. Since the Visualyse propagation modeling software has a provision for entering a pre-computed FDR value, the FDR values were computed in advance and then entered into the Visualyse program to be applied to the interference link budgets. The calculated values of FDR for all of the LightSquared-to-NOAA downlinks are presented in Table 6.

Table 6. FDR for LightSquared-to-NOAA downlinks

Data Link	Frequency, MHz	Off-Tuning, MHz	FDR, dB
GOES-R DCPR-1	1679.7	-4.7	70.2
GOES-R GRB	1686.6	-11.6	51.5

Analysis Methods

Small-Signal Aggregate Analysis for GOES-R

Numerous base stations operating simultaneously as part of a wireless network comprise an aggregate interfering source. To determine the distance at which the LightSquared aggregate transmit power may exceed the NOAA earth station interference threshold, aggregate networks were modeled in the Visualyse software. The small-signal aggregate analysis modeled the source interferers and victim receiver such that the separation distance was increased until the receive level at the victim was equal to the interference threshold. The separation distances will never be able to exceed the radio line of sight due to P=50%.

Each simulation began with a network of base stations populated out to 100 km away from the NOAA earth station. The base stations were populated using the CSMAC WG-5 laydown supplied to WG-5 by the wireless industry. In cases where the CSMAC WG-5 laydown was inadequate, LightSquared provided a substitute cell tower distribution laydown. Each simulation began with all base stations active. The simulation then extended the diameter of the protection circle 1 km at a time, away from the victim, while turning off the closest interferers with each step. The remaining base stations were then used to calculate the aggregate interference to the victim receiver. This incremental process continued until the remaining base stations received signal decreased to the interference threshold. If future laydowns have significantly higher or lower density than the modeled laydown, additional analysis may be warranted.

LightSquared Base Station

Each site was populated with base stations extending to 100 km away from the NOAA earth station. The CSMAC WG5 laydown would characterize these base stations as either rural or urban. The rural sites were set to a height of 45m AGL while the urban sites were set to 30m for the purposes of this analysis.

LightSquared Base Station Antenna Directivity

For modeling purposes, the analysis utilized the antenna values contained in ITU 1336 with three directional sectors (at 0, 120, and 240 degrees) that are typical of all LTE networks.

Figure 4 is a three dimensional diagram of one sector with the z-axis (main beam gain of 18dBi) oriented vertically. The deployed antenna would have the beam pointed horizontally with 3-degree down tilt.

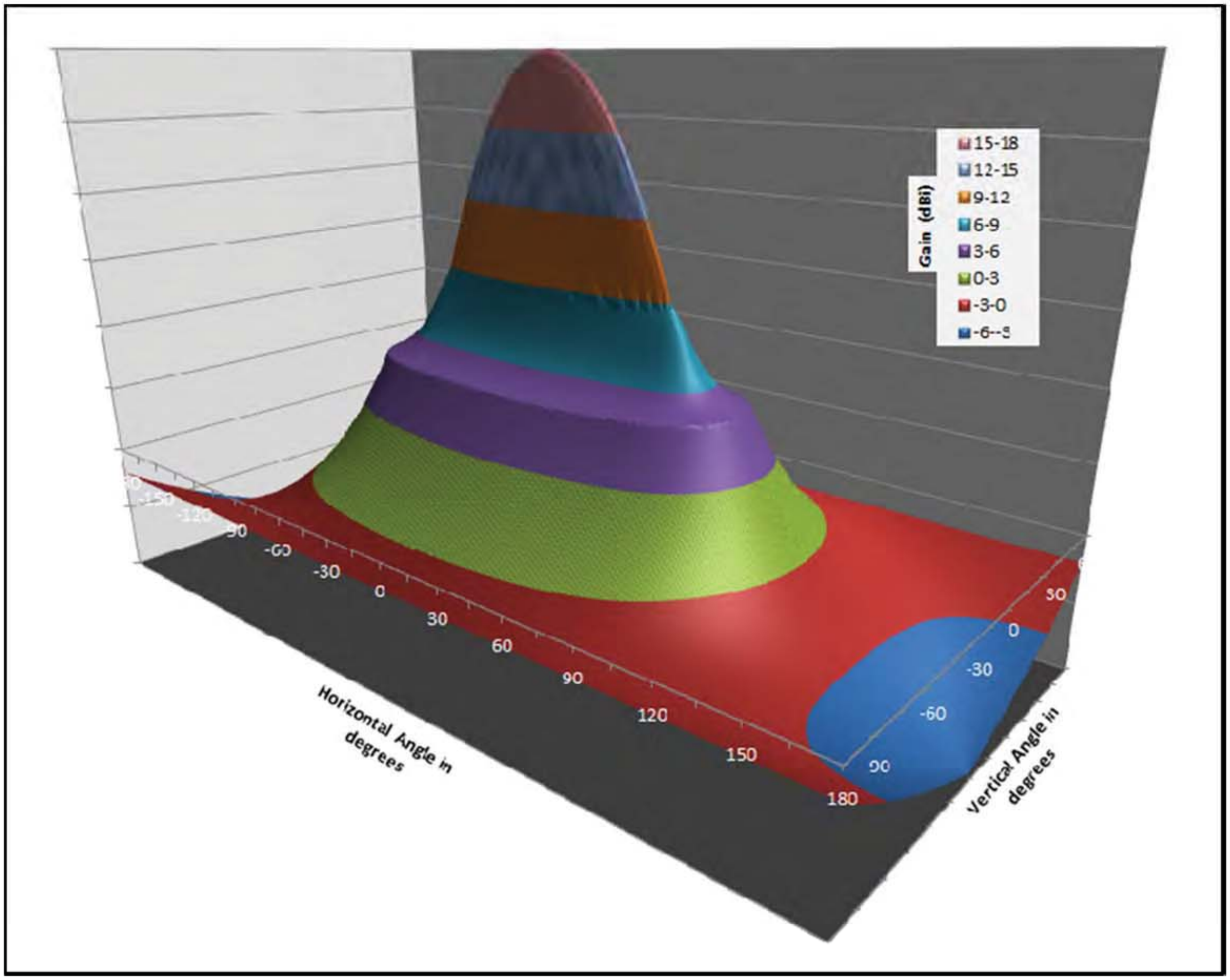

Figure 4. Three-sector antenna pattern

Figure 5 shows the effects each sectored antenna has on the other two sectors due to the combination of the side-lobe gains. This figure depicts the azimuthal gains on the horizon for a 3 degree down tilt antenna.

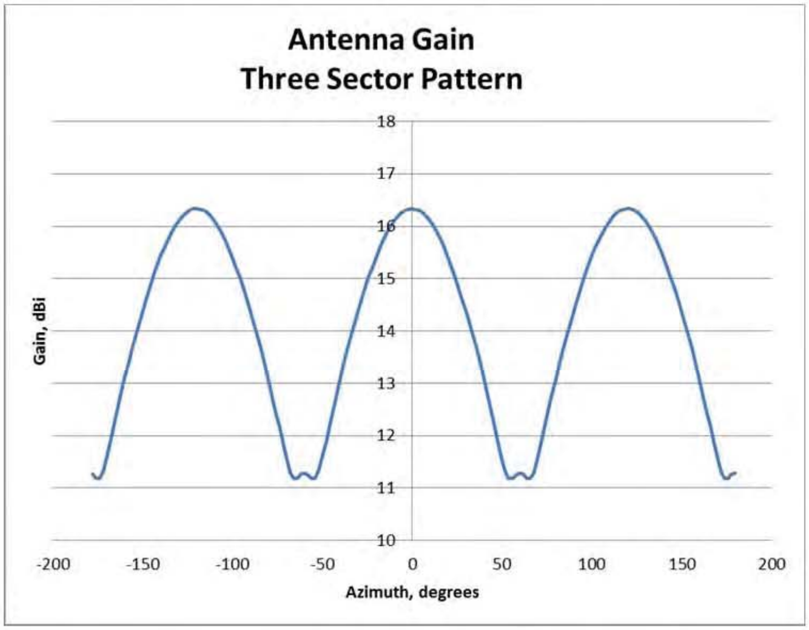

Figure 5. Azimuthal aggregate antenna gain for 3-sector pattern

Figure 6 confirms that at -3° elevation angle, the main beam gain is 18 dBi. At an elevation angle of 0°, the antenna has a gain of 16.6 dBi on the horizon.

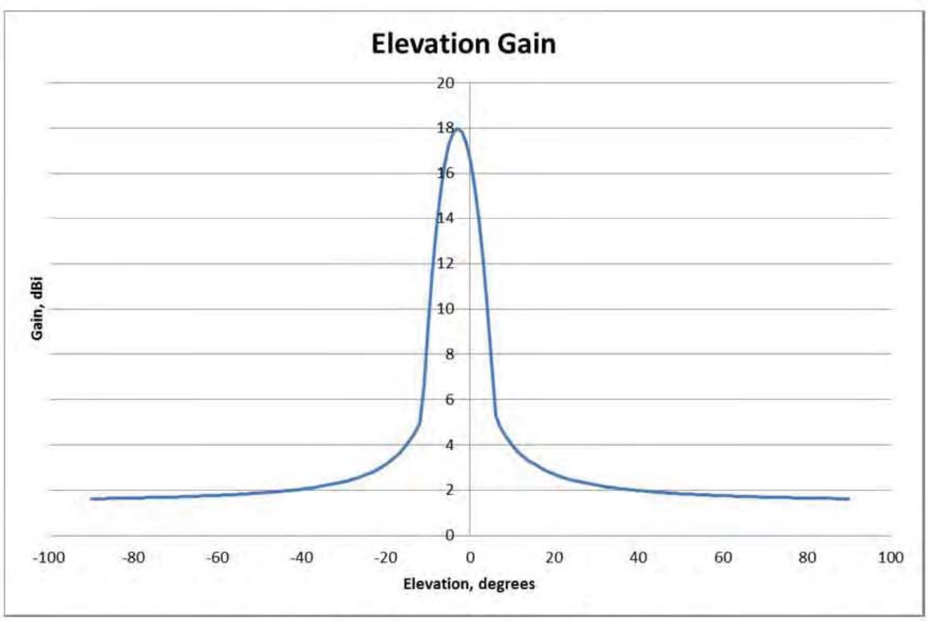

Figure 6. Elevation gain

Terrain

Terrain data is taken into account for the area analysis. 3 arc-second terrain data was utilized within the propagation model for all links.

Clutter

Clutter was not considered useful for this analysis.

Strong-Signal Interference Analysis

In addition to small-signal effects based on the ITU interference thresholds, interference can occur due to strong-signal effects such as gain compression, physical damage, and intermodulation (IM) products from non-linear operation of the low-noise amplifier (LNA).

The RF front end components in the NOAA receive systems are usually a filter and LNA. The filter acts as a pre-selector, reducing the effect of out-of-band noise and strong-signals but many NOAA systems have inadequate filters. The LNAs are designed to boost signals to an acceptable level for subsequent signal processing in the antenna system by down-convertors and demodulators, and/or analog to digital convertors (ADC). The LNAs in the receive systems RF stage are broadband. The LNA is specified in terms of bandwidth, noise performance, small-signal gain, 1-dB gain compression (GC) point, etc. The goal for the LNA is to provide sufficient gain for low-level signals to be usable by the demodulator/ receiver stages and to handle high-level signals without excessive distortion. Excessively strong-signals can bring on non-linear effects such as GC and IM. The third order intercept point (TOI) is the extrapolated input power level per signal that would cause the output third-order IM products to equal the linear output power. It is used as a measure of receiver power-handling capability. This is illustrated in Figure 7 and explained in greater detail on page 20.

The protection distances required to prevent strong-signal effects are typically within radio line-of-sight. Therefore, the received power levels were determined using free-space signal propagation loss.
The same NOAA earth station systems were the potential victims. RF filter attenuation may reduce the potential for degradation and was included in the assessment. No IF attenuation was considered for this analysis because gain compression and IM products occur prior to the IF filtering. The onset of non-linear interactions was assumed to be 10 dB below the 1-dB gain compression point.[8]

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8 ITU, *Sharing studies between IMT-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 and 4 500-4 800 MHz frequency bands, Report ITU-R M.2109,* 2007

For each potential interaction, two cases were considered: single transmitter and aggregate transmitters. For single transmitter interference, the interferer was moved away from the NOAA victim site until the interference was below the non-linear interference threshold. Aggregate interference assumed the same base station laydowns as the small-signal analysis and was performed in the same way except the thresholds used were those for the non-linear effects assessed.

Distances to mitigate potential non-linear effects were determined using the LNA characteristics from Table 7. No data was supplied for the last column ("All others") of Table 7; therefore, a Quorum antenna specification was used as a generic model due to its deployment at many NOAA sites. These detailed specifications have not been provided by NOAA.

Table 7. Input parameters used for non-linear analysis

System	GOES-R		
Parameter↓\Site→	**CDAS (Wallops & Fairmont)**	**NSOF**	**All others**
LNA/LNB Gain, dB	53	50.5	55*
1 dB Gain Compression Threshold, dBm	-30	-30	-50*
Third-Order Intercept, dBm	-20	-20	-40*
Damage, dBm	0	0	0*
Onset of Nonlinear Effects, dBm	-40	-40	-60*
*Assumed			

Attenuation due to RF filtering was included in the analysis. The RF filtering is presented in Table 8. The table values are the RF frequencies at which the specified attenuation is achieved.

Table 8. RF filtering (in MHz)

System	GOES-R		
Station Types	CDAS (Wallops & Fairmont)	NSOF	All others
Links→ Attenuation↓ (dB)	GRB, DCPR	GRB, DCPR	GRB, DCPR
60	1657.5	1663	1620*
20	1665	1670.5	1650*
3	1669	1674.5	1659*
0	1682.5	1688	1681.5*
3	1696	1701.5	1704*
20	1700	1705.5	1713*
60	1707.5	1713	1770*
*Assumed			

LNA Gain Compression and Physical Damage

The distance required to mitigate gain compression was determined using:

$$d = \left[10^{\frac{P_t + G_t + G_r - P_{gc} - L_{pwod}}{20}}\right] * 1000$$

(Equation 4)

where d = distance to mitigate, in m
P_t = transmit power of source, in dBm
G_t = gain of transmit antenna in direction of victim, in dBi
G_r = gain of receive antenna in direction of source, in dBi
P_{gc} = power at which gain compression occurs at the LNA input, in dBm
L_{pwod} = propagation losses for free space or P.452 at the incrementally specified distance

Equation 4 is also used to calculate the distance required to mitigate physical damage. The only change to the equation is that P_{gc} is replaced by the power level at which physical damage occurs. For free-space path loss equation 4 was solved analytically. For P. 452 path loss equation 4 was solved iteratively.

Intermodulation (IM) Interference

Under certain conditions, a non-linear device such as an amplifier can cause IM products that may cause interference. The analysis of IM uses a concept known as the third-order intercept (TOI) point. It is based upon the fact that as the desired signal level increases, the output rises at a slope of 1, and as the third-order IM product input levels increase, the interference signal output rises at a slope of 3. The point where the lines intersect is the TOI. Typically, an LNA will start to show non-linear behavior at an input level approximately 10 dB below the gain compression level. The onset of IM translated to the 3rd order results in an IM threshold that, if exceeded, will result in IM interference. This threshold is used to determine the protection distance to mitigate IM interference.

The potential for receiver IM was assessed for two-signal, third-order products as calculated using Equation 5. These IM products occur at frequencies given by:

$$F_{out} = \pm iF_1 \pm jF_2$$

(Equation 5)

where F_{out} = frequency of IM product
i = $\pm$1 or 2
F_1 = frequency of first source involved in IM product
j = $\pm$2 or 1
F_2 = frequency of second source involved in IM product

The required distance to mitigate IM was then determined using Equation 4 with P_{gc} replaced by the minimum power to cause IM at the LNA input. Figure 7 graphically illustrates the IM analysis concept. This example corresponds to GOES-R CDA systems. Note that IM products start at the same input level as for the onset of non-linear interactions.

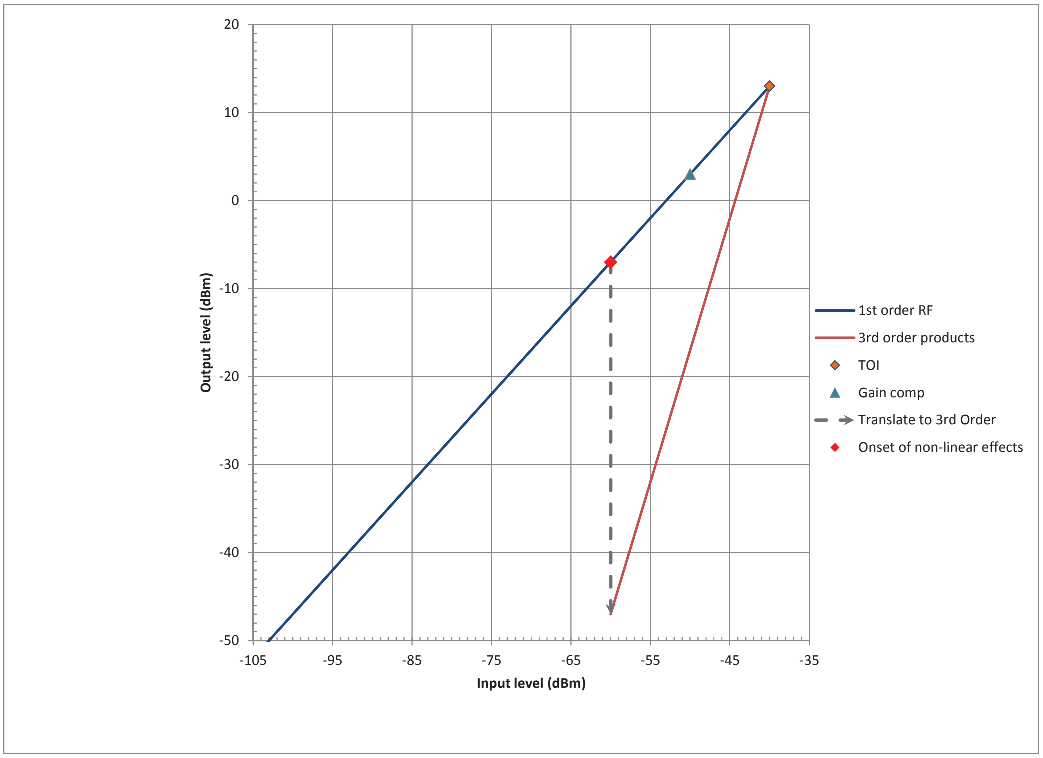


Figure 7. Intermodulation analysis example

RESULTS

The distances provided in Table 9 shows the **worst** case results of the aggregate analyses performed for each GOES-R site. In certain instances, the separation distances associated with each GOES-R satellite were the same. Complete results are presented in Appendix D.

Table 9. Small-signal (aggregate) analyses results for GOES-R Earth Stations

Location	Data Link	GOES-R Satellite Orbital Location	Separation Distance, km
Anchorage, AK	GRB	137 W	*
Boise, ID	DCPR-1 (DRGS)	75 W; 137 W	39
Boulder, CO	GRB	75 W	50
Cincinnati, OH	DCPR-1 (DRGS)	137 W	40
College Park, MD	DCPR-1 (DRGS)	137 W	38
Columbus, MS	DCPR-1 (DRGS)	75 W; 137 W	34
Fairmont, WV	DCPR-1	75 W; 137 W	66**
Ford Island/Pearl Harbor, HI	DCPR-1 (DRGS)	137 W	19
Kansas City, MO	DCPR-1 (DRGS)	75 W; 137 W	53
Miami, FL	GRB	75 W; 137 W	25

Location	Data Link	GOES-R Satellite Orbital Location	Separation Distance, km
Monterey, CA	GRB	137 W	15
Norman, OK	DCPR-1 (DRGS)	75 W; 137 W	41
Omaha, NE	DCPR-1 (DRGS)	75 W; 137 W	24**
Rock Island, IL	DCPR-1 (DRGS)	75 W; 137 W	21**
Sacramento, CA	DCPR-1 (DRGS)	75 W; 137 W	92
San Juan, PR	DCPR-1 (DRGS)	137 W	36
Sioux Falls, SD	DCPR-1 (DRGS)	75 W; 137 W	46
St Louis, MO	DCPR-1 (DRGS)	137 W	70
Stennis Space Center, MS	DCPR-1 (DRGS)	137 W	52
Suitland, MD	GRB	137 W	42
Vicksburg, MS	DCPR-1 (DRGS)	75 W; 137 W	37
Wallops, VA	DCPR-1	75 W; 137 W	49
White Sands, NM	GRB	75 W; 137 W	*

DRGS – Direct Readout Ground Station
* CSMAC WG-5 base station laydown not adequate for aggregate analysis; No third-party laydown provided
** Third-party laydown was used

Table 10 shows the **worst** case results of the strong-signal single site and aggregate analyses performed for each GOES-R site. Three sets of analyses were completed. This includes gain compression (GC), intermodulation (IM), and damage. Complete results are presented in Appendix E.

Table 10. Strong-signal analyses results for GOES-R Earth Stations

Location	Satellite	Separation Distance, km
Anchorage, AK	137 W	14 (single entry)
Boise, ID	75 W	11 (single entry)
Boulder, CO	75 W	18 (aggregate)
Cincinnati, OH	137 W	13 (aggregate)
College Park, MD	137 W	21 (single entry)
Columbus, MO	137 W	10 (single entry)
Fairmont, WV	75 W	2 (single entry)*
Ford Island/Pearl Harbor, HI	137 W	12 (aggregate)
Kansas City, MO	137 W	10 (single entry)
Miami, FL	137 W	17 (aggregate)
Monterey, CA	75 W	10 (single entry)
Norman, OK	137 W	8 (single entry)
Omaha, NE	137 W	10 (single entry)*
Rock Island, IL	137 W	12 (single entry)*
Sacramento, CA	75 W	29 (aggregate)

Location	Satellite	Separation Distance, km
San Juan, PR	137 W	35 (single entry)
Sioux Falls, SD	137 W	10 (single entry)*
St Louis, MO	137 W	13 (aggregate)
Stennis Space Center, MS	137 W	9 (single entry)
Suitland, MD	137 W	4 (aggregate)
Vicksburg, MS	137 W	9 (single entry)
Wallops , VA	137 W	3 (single entry)
White Sands, NM	75 W	6 (single entry)*
*WG5 base station laydown not adequate for aggregate analysis; use single entry protection distance		

CONCLUSIONS

This analysis has determined protection regions for select NOAA GOES-R earth stations in the presence of broadband base stations. The interactions considered included small-signal and strong-signal (non-linear) effects. Protection regions for small-signal effects range from 15 to 92 km. Protection regions for strong-signal effects range from 2 to 35 km. Protection regions vary depending on the specific earth station sites (including downlinks of concern, antenna heights, etc.), base station sites, and topography.

This analysis also shows that the NOAA system performance is near the Shannon limit. Therefore the system will degrade very quickly as the interference thresholds are approached and exceeded.

APPENDIX A – LIGHTSQUARED EMISSION MASK

The proposed LightSquared emission is nominally 10 MHz, from 1670 MHz to 1680 MHz, centered around a tuned frequency of 1675 MHz, with 0.5 MHz guard band on the high and low ends. The mask used for this assessment, agreed upon by Alion and LightSquared, is consistent with the 3GPP specification for LTE-A base station transmitters.[9] While there is no maximum base station transmitter power in the specification, there is a requirement that the out-of-band emission be no greater than -13 dBm in a 1 MHz bandwidth. Subsequently, the required unwanted emissions attenuation will depend on the transmitter power. For this emission mask assessment, a nominal transmitter power of 40W was assumed. This equates to an average power, across the +/- 4.5 MHz band, of 4.44 W/MHz (6.5 dBW/MHz). The average power equals 36.5 dBm/MHz and, thus, the required attenuation to achieve -13 dBm at the out-of-band, or adjacent band, region is 49.5 dB. The LightSquared 10-MHz emission mask data points are listed in Table 11.

One of the inputs required for the Frequency Dependent Rejection (FDR) calculation is the power spectral density (PSD) of the transmitter, normalized to zero. The normalized PSD is also referred to as the emission mask, because it indicates the attenuation that is applied to the actual PSD to comply with limits on adjacent-band and out-of-band emission. The emission mask for the LightSquared analysis assumes the following PSD:

The emission mask for the LightSquared analysis assumes the following PSD:

Power: 40 W, $-4.5 \leq \Delta f \leq 4.5$ (equivalent to 4.4 W/MHz, and 6.5 dBW/MHz)

Adjacent band power: –43 dBW for $-25 \leq \Delta f \leq -5$, and $5 \leq \Delta f \leq 25$ (–13 dBm/MHz)

Out-of-band attenuation: 20 dB/decade

Table 11. LightSquared 10-MHz emission mask

Δf, MHz (Relative to 1675 MHz)	Attenuation, dB
-25.0	49.5
-5.0	49.5
-4.5	0
4.5	0
5.0	49.5
25.0	49.5

[9] 3GPP TS 36.104 V10.2.0 (2011-04)

The normalized PSD—which is the FDR emission mask—indicates the attenuation required to bring the in-band power down to 0 dBW. Note that the vertical axis is labeled dB, rather than dBW.

Under the 3GPP specification, this mask will suffice for any base station power less than or equal to 40W. If the base station power is greater than 40W, the mask must provide attenuation sufficient to achieve the -13 dBm maximum out-of-band power.

Figure 10 shows the emission mask from Figure 9 on a dBm scale.

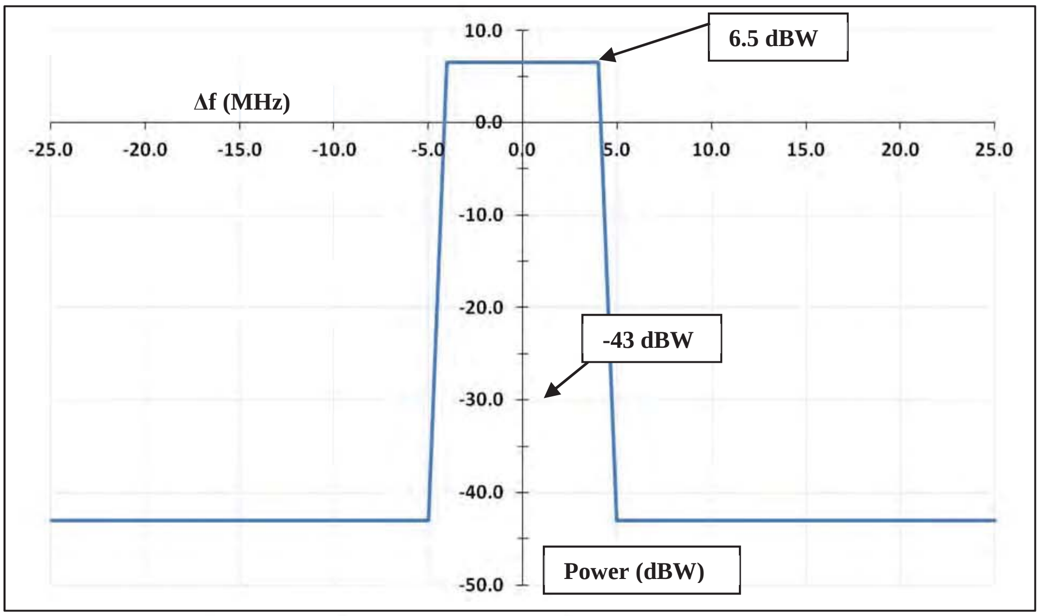
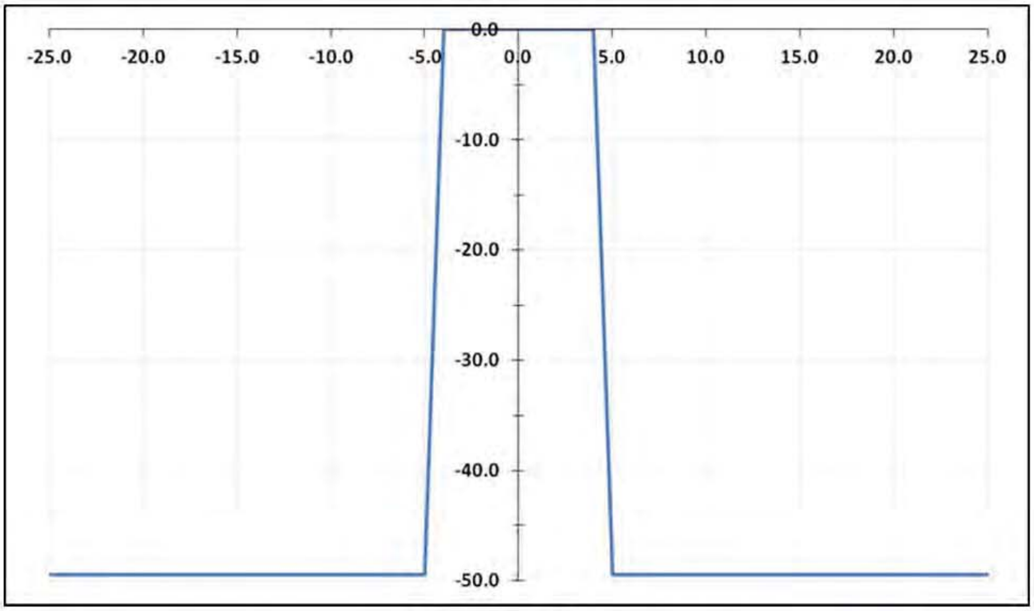


Figure 8. LightSquared 10-MHz emission mask



Attenuation (dB)

Figure 9. LightSquared 10-MHz normalized emission mask

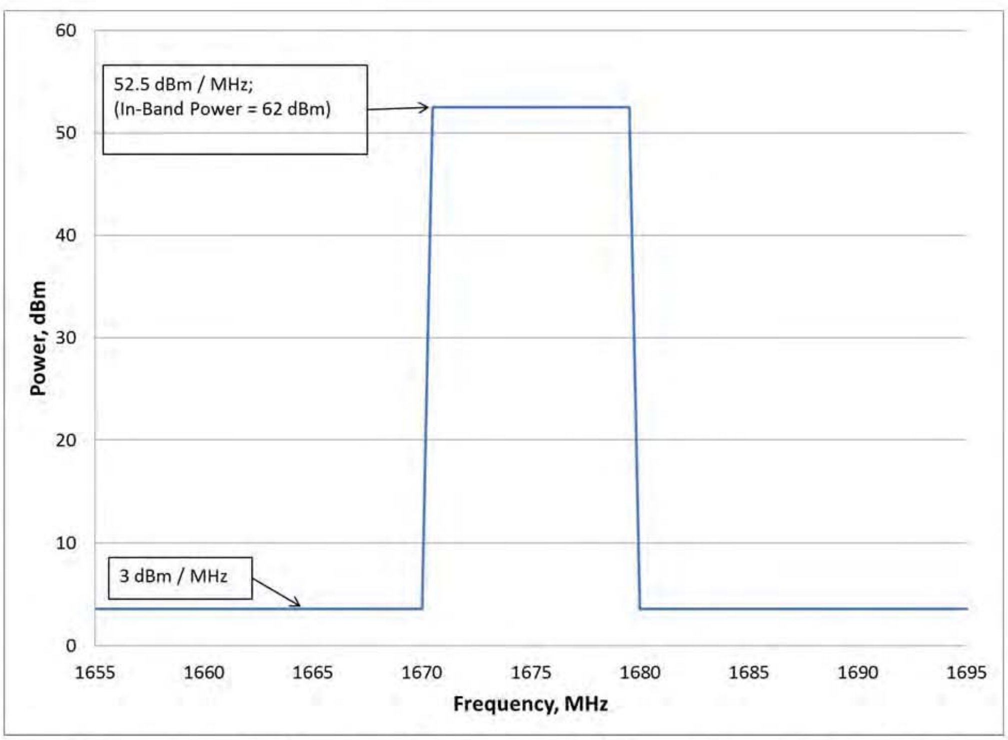


Figure 10. LightSquared EIRP emission mask for 25W transmitter with 18 dBi gain antenna

APPENDIX B – DISCUSSION OF FREE-SPACE PROPAGATION AND DIFFRACTION

Free-Space Propagation

The most simple and basic propagation mechanism is free-space, which takes place in an idealized environment devoid of atmosphere or obstruction. The path loss associated with free-space propagation is due solely to the spreading of the electromagnetic radiation equally in all directions as the separation distance from the transmitter increases. Free-space path loss is given by:

$$L_P = 20\log_{10} d + 20\log_{10} f + 92.5$$

(Equation 6)

where, $d =$ separation distance between transmitter and receiver, in km
$f =$ frequency, in GHz

The coefficient 20 in the distance-related term indicates that free-space path loss increases with the square of the distance.

Diffraction

If the free-space path is obstructed by natural or manmade objects, the RF signal could be completely blocked, but depending on the geometry and material properties of the obstruction, it is possible that some fraction of the signal can get through to the receiver. The primary propagation mechanism for this at L-band frequencies is diffraction. A diffraction path has at least two segments. The signal propagates from the transmitter to the radio horizon, which is the highest point of the obstructing object, and then it continues along a path to the receiver (or to the next radio horizon, if there are additional obstructions). The two path segments are not collinear; the angle between the two is the diffraction angle, with which a certain amount of loss is associated. The overall path loss for such an obstructed path can be expressed as the free-space loss, plus the additional diffraction loss. If there are additional obstructions, additional segments and diffraction angles can be derived from the path geometry, and additional losses computed.

The angle of the propagation path with respect to the transmitter is not the same for the free-space and diffraction cases, even when the antenna heights and locations are the same. This angle, called the angle of departure (AOD), is measured in the vertical plane, with respect to the local horizon. A similar situation prevails at the receiver, where it is seen that the angle of arrival (AOA) is changed when an obstruction is placed in the path.

In either the free-space or the diffraction case, the actual path angles might or might not correspond to the elevation angles of the transmitter and receiver antennas. Thus, the antenna gains, G_t and G_r, as defined in Equation 1, depend on the relationship between the physical elevation angles and the path angles. The locations, heights, and orientations of the antennas are input parameters, as are the radiation patterns. When the propagation modeling software is run, it performs the spherical calculations necessary to resolve the angles, and determines the effect on G_t and G_r. A similar calculation is made in the azimuthal plane, except that obstructions are unable to modify the direction of the propagation path. Thus, the path follows the great circle route in the azimuthal plane.

Note that even without additional obstructions, the Earth's horizon is a potential obstruction, capable of causing a significant amount of path loss.

APPENDIX C – RECEIVER SELECTIVITY, GRB, AND DCPR

The receiver selectivity is determined primarily by the filter with the narrowest bandwidth that precedes the demodulator in the processing chain. This is often referred to as a pre-detection filter. For the digital modulation techniques employed by the NOAA GOES-R systems, the standard practice is to use a pre-detection filter with a square-root raised-cosine frequency response. Invariably, this filter is identical to the one on the transmitter, so that together they provide a raised-cosine frequency response, the purpose of which is to impart a raised cosine shape to the digital pulses. The raised-cosine pulse shape has several benefits, chief among them being:

- The power in a single pulse is almost entirely contained in a bandwidth equal to the symbol rate.
- The pulse sequence can be easily demodulated by peak sampling, thereby avoiding inter-symbol interference.

The square-root raised-cosine filter is specified by its 3dB bandwidth, which is the symbol rate, and a roll-off factor, which determines how rapidly the filter response falls off outside the 3dB bandwidth. The roll-off factor is a number between 0 and 1.0. Typical values are 0.25, 0.35, 0.5, and 0.6. For these analyses, if the roll-off factor was not explicitly specified (as is often the case), a nominal value of 0.5 was used.

The frequency response of the square-root raised-cosine filter was determined by modeling the appropriate finite-impulse-response (FIR) filter, using the signal processing design software ScopeFIR. The frequency response is shown in Figure 10 for a normalized frequency of 1.0 kHz. This corresponds to a symbol rate of 1.0 k Symbols/s. This symbol rate is normalized to 1k just for plotting convenience. Replace 1k with your data rate R, re-scale the horizontal axis by fractions of R/1k, instead of 1k. Note that the -3 dB point is at 0.5, after which the response falls off rapidly.

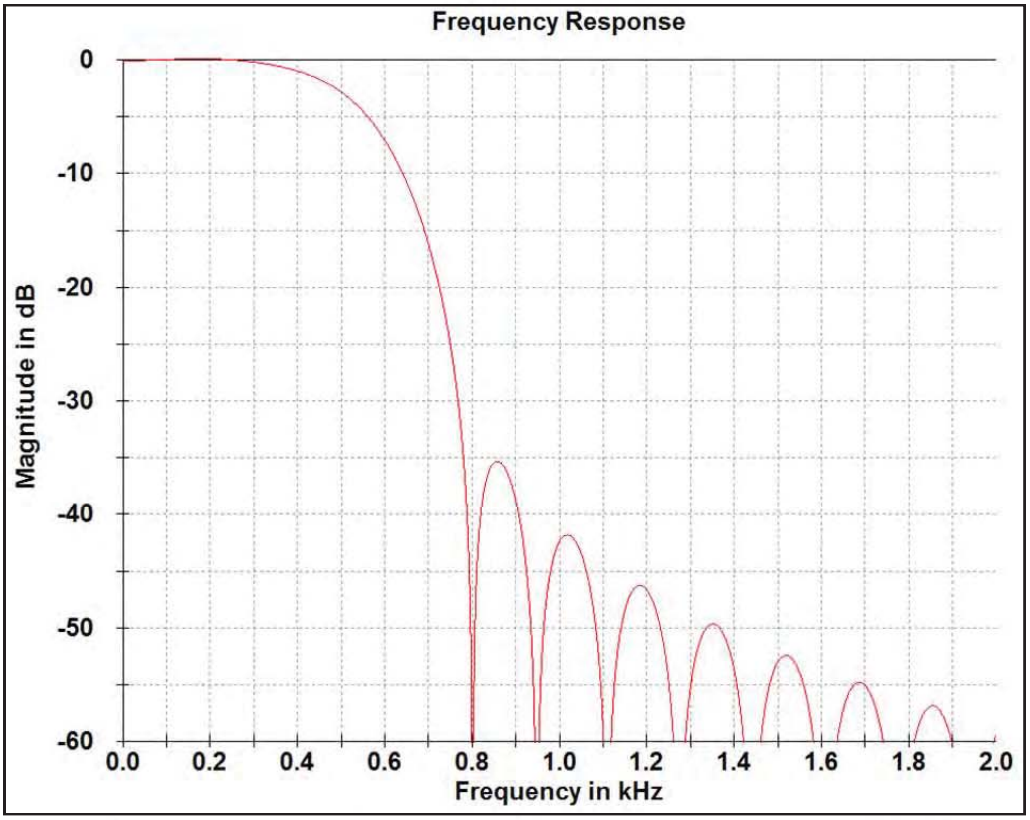


Figure 11. Frequency response of the square-root raised-cosine filter

Table 12. Receiver selectivity curve

Frequency (kHz)	0	± 0.25	± 0.5	± 0.75	± 1.0	± 1.5	± 2.0
Attenuation (dB)	0	0	3	25	42	52	56

Figure 11 shows a single-sided (baseband) response. The receivers in question are all band pass systems, hence the "±" in Table 12. The actual selectivity curve is thus represented by 13 points.

The GRB Receiver

The GRB system utilizes two cross-polarized carriers. The information rate is 15.5 Mb/s per polarization. Additional bits are added for error correction, synchronization, and metadata. Two modulation types are under consideration—QPSK and 8PSK—which transmit 2 bits/symbol and 3 bits/symbol, respectively. The final symbol rate depends on the error-correction code as well as the modulation type. NOAA is considering: rate 9/10 coding with QPSK, and rate 2/3 coding with 8PSK. Transmitted symbol rates are R_s = 8666 kSymbols/s, and R_s = 7827 kSymbols/s, respectively. NOAA will not make a final decision until the satellite is in orbit and tested. The QPSK option requires more bandwidth than the 8PSK option, but the difference is slight, and there is no conflict with the emission designator or IF bandwidth.

The sampled IF output provides the digital input to the square-root raised-cosine (SRRC) filter, which matches the SRRC filter on the transmitter. The selectivity of the SRRC filter is determined primarily by the roll-off, which NOAA specifies to be 0.25. The demodulator and FEC decoder work as a unit to deliver an error-corrected output for further processing.

Frequency Dependent Rejection

Of the various processing modules, the ones with the greatest impact on FDR are the IF filter and the SRRC filter, or more specifically, the overall selectivity. The selectivity of the IF filter is specified explicitly by NOAA in Table 13.

Table 13. IF selectivity of GRB receiver

IF Bandwidth, kHz	Selectivity, dB
±4350	-3
±5450	-20
±8666	-60

The selectivity of the SRRC filter is a function primarily of the symbol rate and roll-off, both of which are specified, and to a lesser extent the oversampling rate and number of taps, neither of which is specified. The symbol rate determines the 3 dB bandwidth. Since a larger bandwidth results in less FDR, it is safer to assume the QPSK option for the FDR calculation. The selectivity is determined by the frequency response of the SRRC filter, which is easily derived by Matlab, Mathematica, or an application designed for modeling digital filters, such as ScopeFIR. Using the latter application, the selectivity for the SRRC filter required for R_S = 8666 kSymbols/s QPSK is specified in Table 14.

Table 14. SRRC filter selectivity

SRRC Filter BW, kHz	Selectivity, dB
0	0
±2167	0
±4333	-3
±6500	-27
±8666	-35
±17332	-43
±34664	-48

The selectivity's of the IF filter and the SRRC filter are plotted in Figure 12.

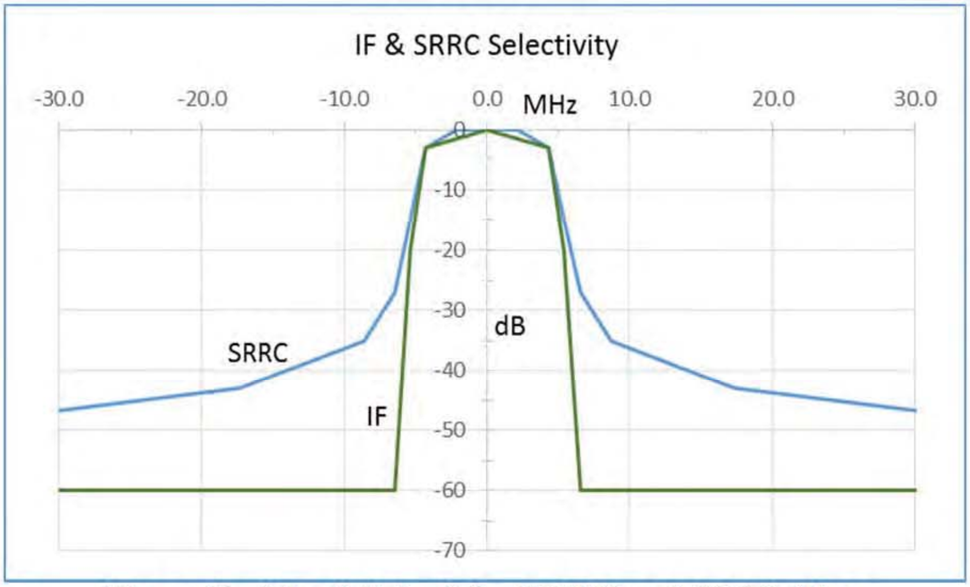


Figure 12. Selectivity's of the GRB IF and SRRC filters

Clearly, the IF filter provides the more aggressive attenuation profile. This selectivity is sufficient to avoid aliasing when the IF output is sampled by the A/D converter. Consequently, no additional anti-aliasing filter was assumed for the GRB receiver. If there one included in the DVB-S2 module (there probably is), it could provide additional attenuation.

The two selectivity's can be combined to give the overall selectivity for the GRB receiver. The selectivity data is listed in Table 15, and plotted in Figure 13.

Table 15. Overall selectivity of the GRB receiver

Bandwidth, kHz	Selectivity, dB
0	0
±2167	-1.5
±4333	-6
±5400	-35
±6500	-87
±8666	-95
±17332	-103
±34664	-108

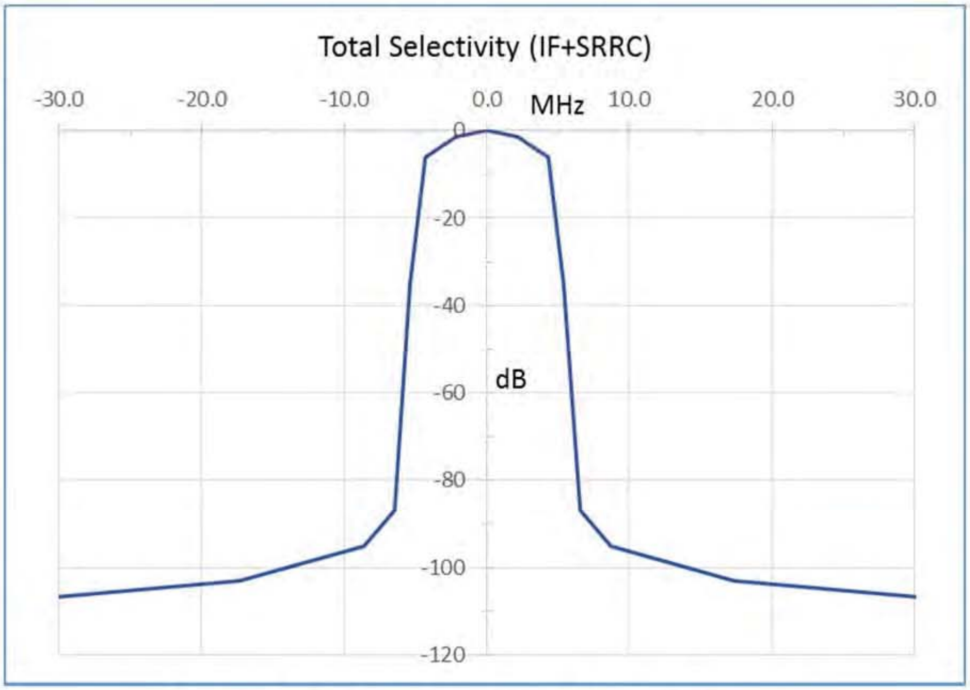


Figure 13. Selectivity plot of the GRB receiver

The FDR calculation requires three inputs:

Emission mask—provided by Figure 7, and the 3GPP specification.
Selectivity data—listed in Table 15.
Off-Tuning—emitter and receiver center frequencies separated by 11.6 MHz

For this scenario, FDR is calculated to be 51.5 dB. A graphical representation of FDR is shown in Figure 14, where the interference is limited to the region indicated.

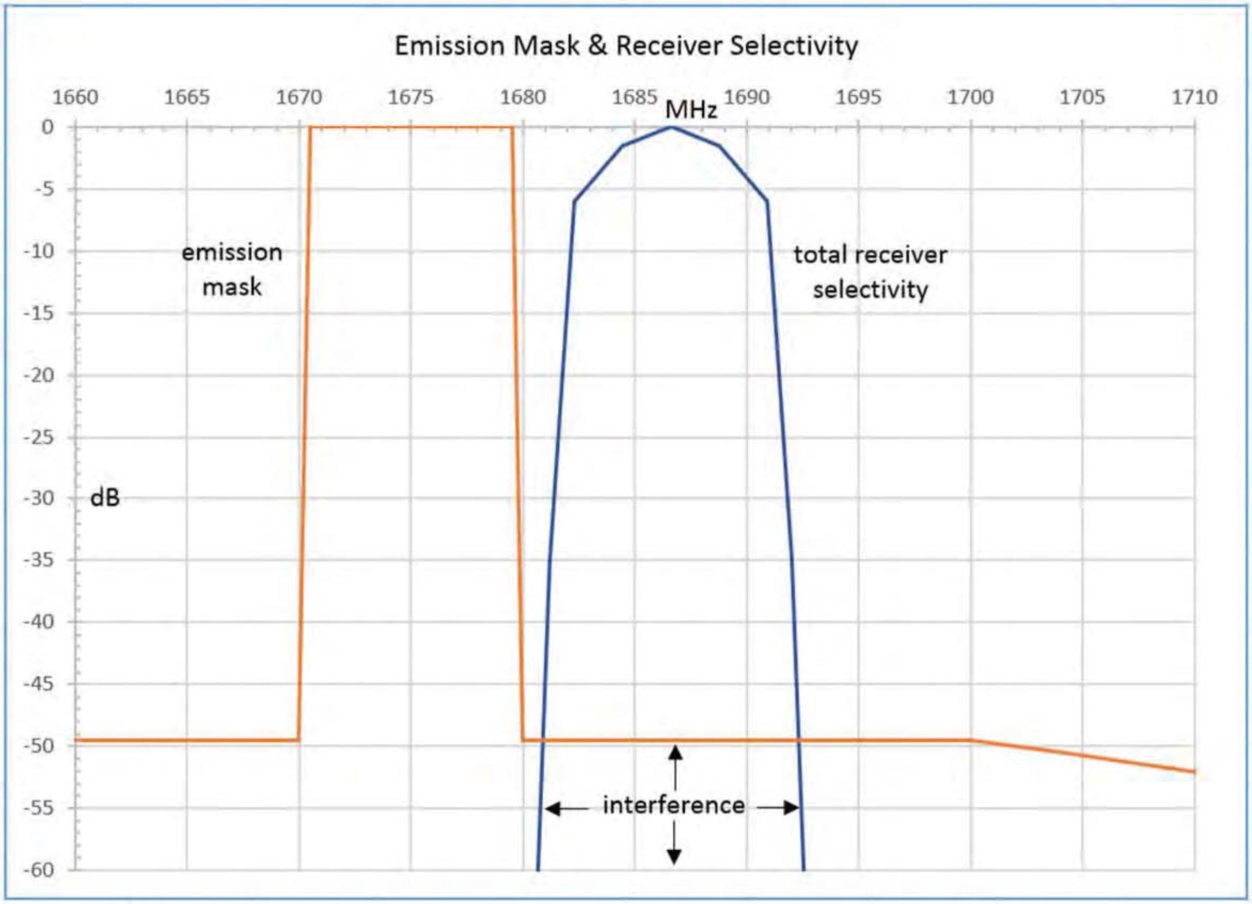


Figure 14. Illustration of FDR for the GRB receiver

The optimized bandwidth of the GRB IF filter, combined with the SRRC filter selectivity, provide effective rejection of much of the interference from the LightSquared emitter.

Error Correction in the GRB System

A number of error-control measures are incorporated into the DVB-S2 standard, including forward error correction (FEC), interleaving, and residual error detection. Error detection is of limited usefulness, since the GRB receiver lacks the means to request retransmission of the corrupted data. The receiver can simply discard the data. The error-correction capabilities, on the other hand, offer considerable benefit when compared to without this capability. The FEC coding methodology employed by DVB-S2 is based on low-density parity-check codes, which provide data communication near the Shannon limit without introducing unreasonable system complexity.

The DVB-S2 system is frame-based, meaning that the frame-error rate (FER) is a more meaningful measure of performance than the bit-error rate (BER). Nevertheless, the BER is used by the ITU as a basis for establishing interference thresholds, so it is useful to derive the BER from FER specifications.

Reference 2 recommends FER = 10^{-7} as the maximum acceptable error rate for DVB-S2 systems. This is sometimes referred to as the quasi error-free (QEF) rate, which gives the (erroneous) impression that it is conservative, and that acceptable operation at a somewhat degraded rate might be realistic. The ITU thresholds themselves support such a view. The ITU recommends two thresholds for a satellite downlink: a long-term threshold that marks the boundary between QEF and marginal performance, and a short-term threshold, that marks the boundary between marginal and unacceptable performance.

Systems operating near the Shannon limit do not exhibit a meaningful region of marginal performance; they function without error until the limit is reached, then they abruptly stop working altogether. Often such systems lose frame-level or even bit-level synchronization, and must idle while sync is re-acquired. Consider for example the contrast between the rate 9/10 QPSK link and an uncoded QPSK link. The QEF performance of FER = 10^{-7} corresponds to BER = 10^{-12}. Uncoded QPSK requires E_b/N_0 = 13.8 dB to achieve this rate, while the coded QPSK system requires only 3.9 dB.[10] The performance curves are shown in Figure 15.

Typical ITU thresholds for QPSK are based on

BER $\leq 10^{-8}$, to be exceeded no more than 20% of the time

BER $\leq 10^{-3}$, to be exceeded no more than 0.025% of the time

This corresponds to a difference of 5 dB in uncoded QPSK. By contrast, the coded system degrades from QEF to unacceptable performance over a 1 dB range, at which point loss of sync is a real possibility.

The ITU has not recommended interference thresholds for the GRB system as of this writing. It is suggested that NOAA propose a single threshold for this system, calculated to limit to a very small value the probability that the E_b/N_0 will fall below the QEF threshold.

[10] "A Companion Guide to DVB-S2," Tandberg Television, Ltd., 2004

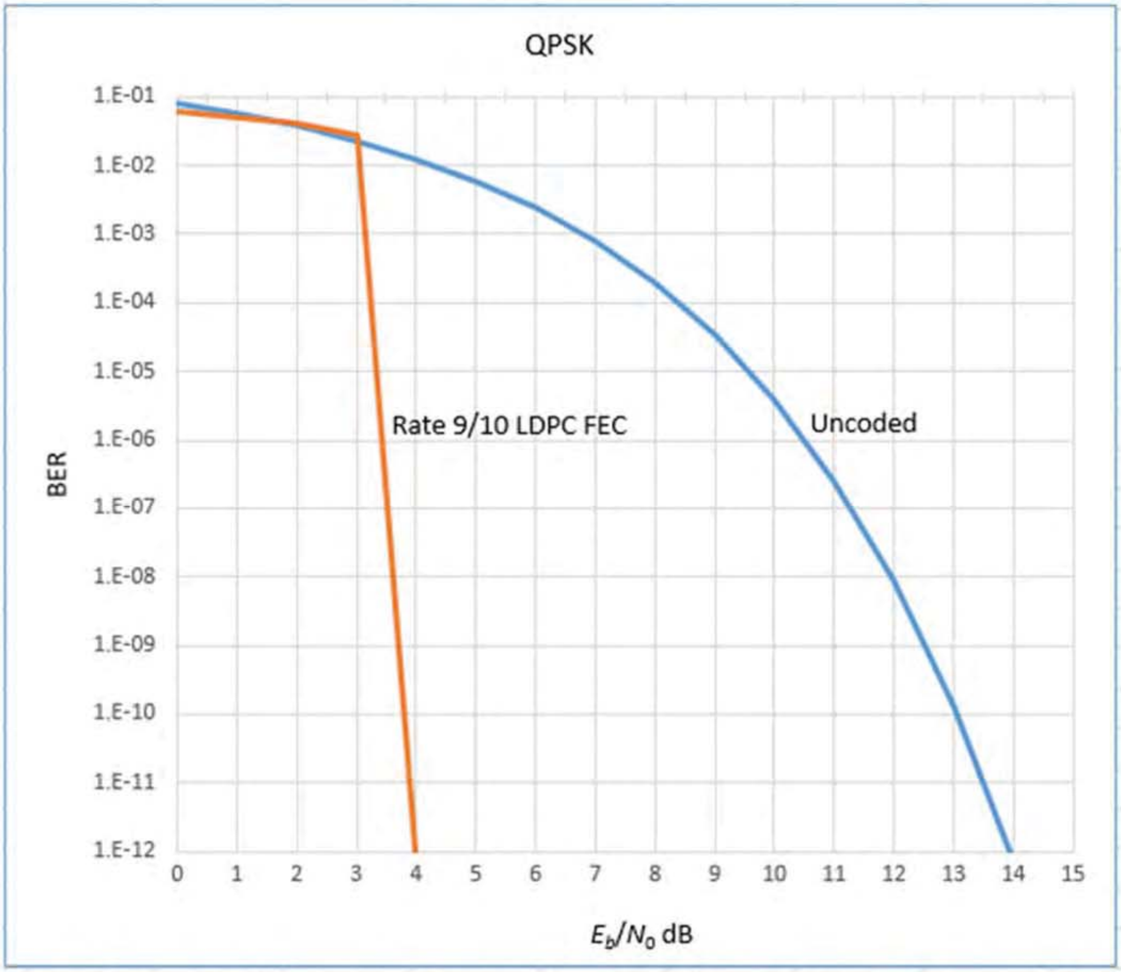


Figure 15. Comparing the performance of QPSK modulation, with and without FEC coding

The DCPR-1 Receiver

The DCPR downlink designed for domestic use is designated DCPR-1. The signal, which comprises a 933 750 Hz channels, has the following characteristics:

- Center frequency—1679.7 MHz
- Modulation—QPSK
- Data rates—300 bps, 1200 bps
- Pre-detection filter—SRRC, roll-off = 1.0

Note that there is a partial overlap of the DCPR receiver bandwidth with the uppermost guard band of the LightSquared emission. The selectivity of an individual DCPR-1 channel is a set by the frequency response of the SRRC filter. For the 300 bps channel, this selectivity is shown in Table 16.

Table 16. DCPR-1 300 bps selectivity

SRRC Filter BW kHz	Selectivity, dB
0	0
±0.040	-1
±0.080	-3
±0.110	-9
±0.150	-33
±0.300	-40
±0.600	-45

Inputs to the FDR calculation are

- Normalized LightSquared emission mask
- Receiver selectivity data
- Off-tuning, which is 4.7 MHz

The FDR is calculated to be 70.2 dB. There is no significant difference for the 1200 bps channel. Most of the FDR is due to the relative bandwidths of the emitter and receiver.

APPENDIX D – SMALL-SIGNAL AGGREGATE ANALYSIS PLOTS FOR GOES-R

Table 17 shows a compilation of all links analyzed for the GOES-R satellite links. These separation distances have been revised from the initial Task 2, GOES Legacy report.

Table 17. Small-signal (aggregate) analyses results for GOES-R Earth Stations

Location	Data Link	GOES-R Satellite Orbital Location	Separation Distance, km	Figure #
Anchorage, AK	GRB	137W	*	*
Boise, ID	DCPR-1 (DRGS)	75 W	39	16
Boise, ID	DCPR-1 (DRGS)	137 W	39	16
Boulder, CO	GRB	75 W	50	17
Boulder, CO	GRB	137 W	44	18
Cincinnati, OH	DCPR-1 (DRGS)	75 W	21	19
Cincinnati, OH	DCPR-1 (DRGS)	137 W	40	20
College Park, MD	DCPR-1 (DRGS)	75 W	33	21
College Park, MD	DCPR-1 (DRGS)	137 W	38	22
Columbus, MS	DCPR-1 (DRGS)	75 W	34	23
Columbus, MS	DCPR-1 (DRGS)	137 W	34	23
Fairmont, WV	DCPR-1	75 W	66**	24
Fairmont, WV	DCPR-1	137 W	66**	24
Ford Island/Pearl Harbor, HI	DCPR-1 (DRGS)	137 W	19	25
Kansas City, MO	DCPR-1 (DRGS)	75 W	53	26
Kansas City, MO	DCPR-1 (DRGS)	137 W	53	26
Miami, FL	GRB	75 W	25	27
Miami, FL	GRB	137 W	25	27
Monterey, CA	GRB	75 W	14	28
Monterey, CA	GRB	137 W	15	29
Norman, OK	DCPR-1 (DRGS)	75 W	41	30
Norman, OK	DCPR-1 (DRGS)	137 W	41	30
Omaha, NE	DCPR-1 (DRGS)	75 W	24**	31
Omaha, NE	DCPR-1 (DRGS)	137 W	24**	31
Rock Island, IL	DCPR-1 (DRGS)	75 W	21**	32
Rock Island, IL	DCPR-1 (DRGS)	137 W	21**	32
Sacramento, CA	DCPR-1 (DRGS)	75 W	92	33
Sacramento, CA	DCPR-1 (DRGS)	137 W	92	33
San Juan, PR	DCPR-1 (DRGS)	75 W	36	34
San Juan, PR	DCPR-1 (DRGS)	137 W	46	35
Sioux Falls, SD	DCPR-1 (DRGS)	75 W	46	36
Sioux Falls, SD	DCPR-1 (DRGS)	137 W	46	36

Location	Data Link	GOES-R Satellite Orbital Location	Separation Distance, km	Figure #
St Louis, MO	DCPR-1 (DRGS)	75 W	58	37
St Louis, MO	DCPR-1 (DRGS)	137 W	70	38
Stennis Space Center, MS	DCPR-1 (DRGS)	75 W	47	39
Stennis Space Center, MS	DCPR-1 (DRGS)	137 W	52	40
Suitland, MD	GRB	75 W	36	41
Suitland, MD	GRB	137 W	42	42
Vicksburg, MS	DCPR-1 (DRGS)	75 W	37	43
Vicksburg, MS	DCPR-1 (DRGS)	137 W	37	43
White Sands, NM	GRB	75 W	*	*
White Sands, NM	GRB	137 W	*	*
Wallops, VA	DCPR-1	75 W	49	44
Wallops, VA	DCPR-1	137 W	49	44
DRGS – Direct Readout Ground Station * CSMAC WG-5 base station laydown not adequate for aggregate analysis; No third-party laydown provided ** Third-party laydown was used				

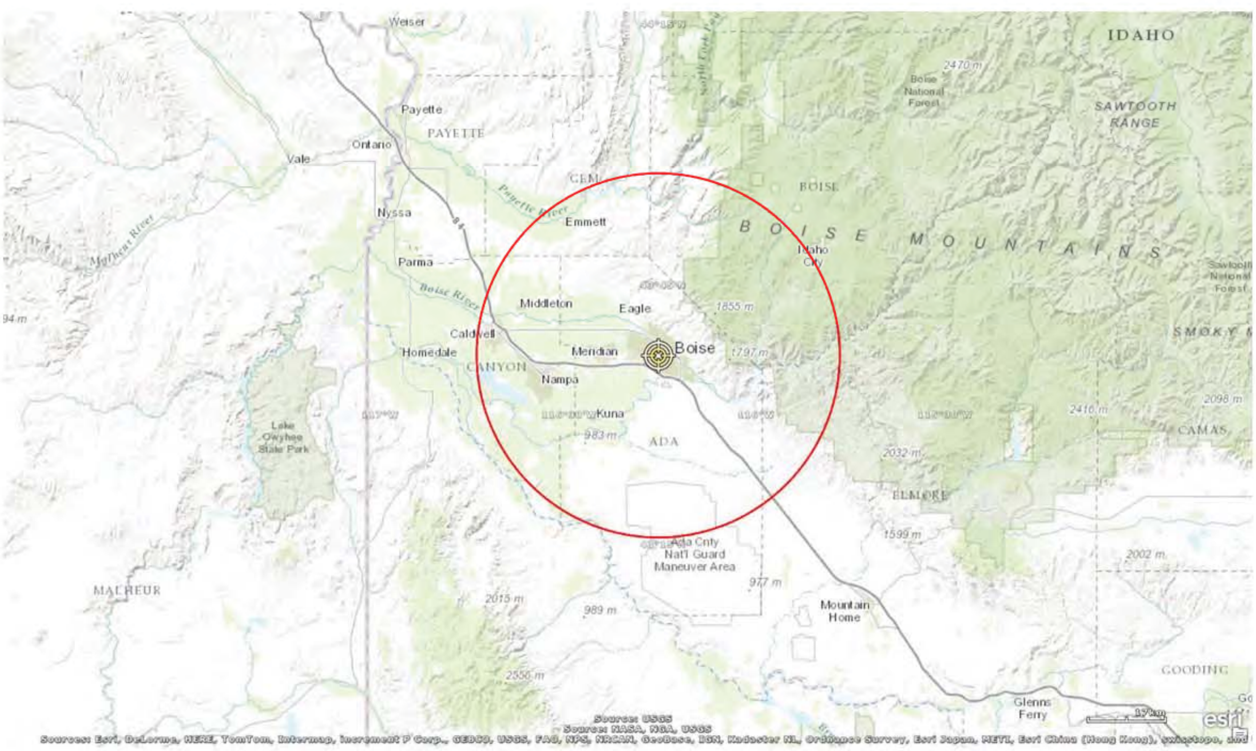


Figure 16. Boise, ID DCPR-1 75 W and 137 W

Figure 17. Boulder, CO GRB 75 W

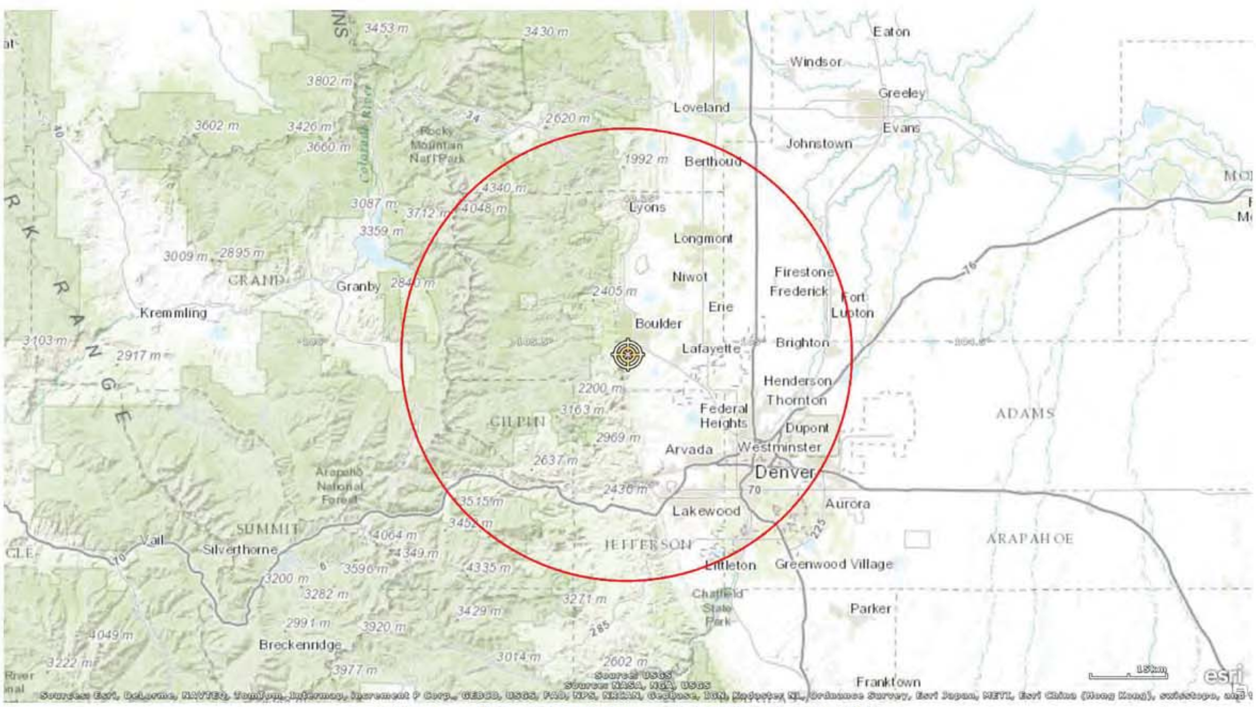


Figure 18. Boulder, CO GRB 137 W

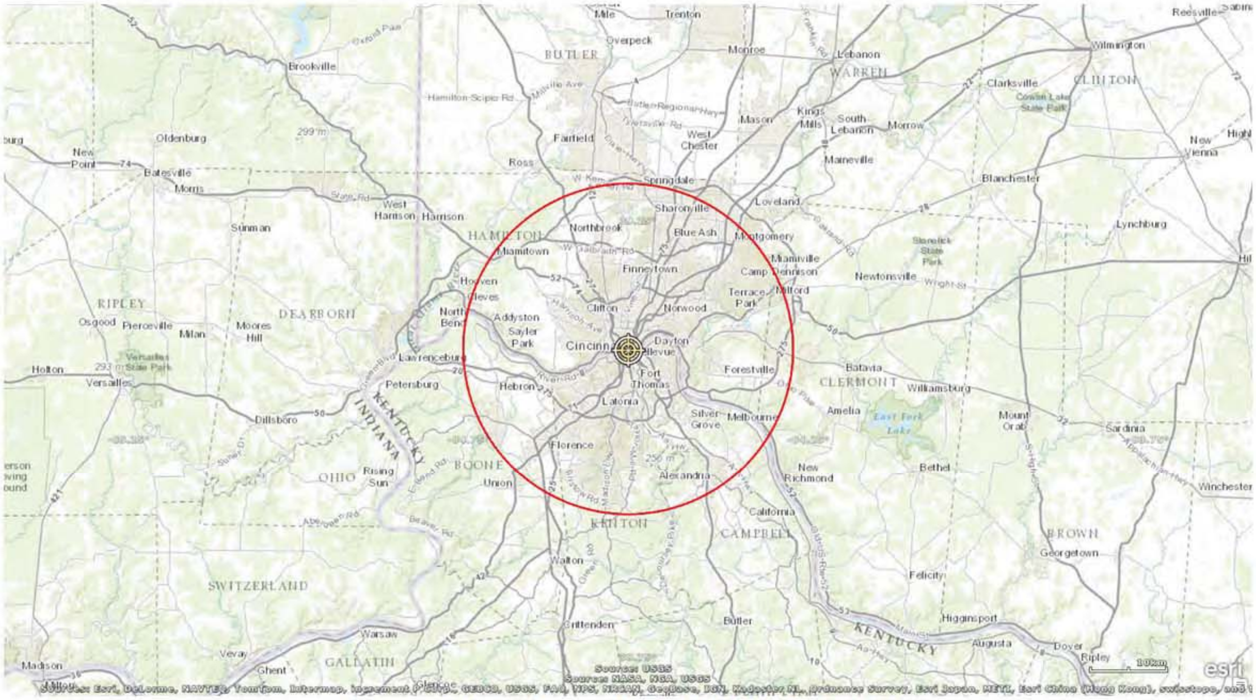


Figure 19. Cincinnati, OH DCPR-1 75 W

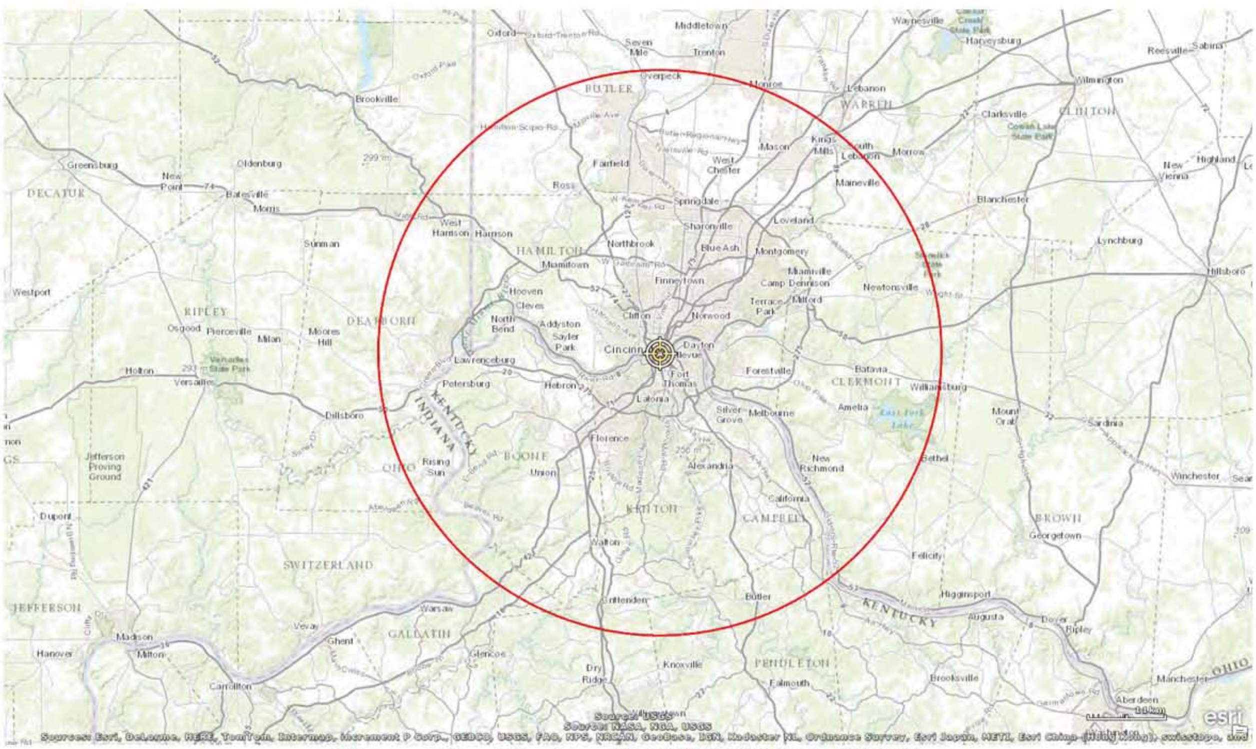


Figure 20. Cincinnati, OH DCPR-1 137 W

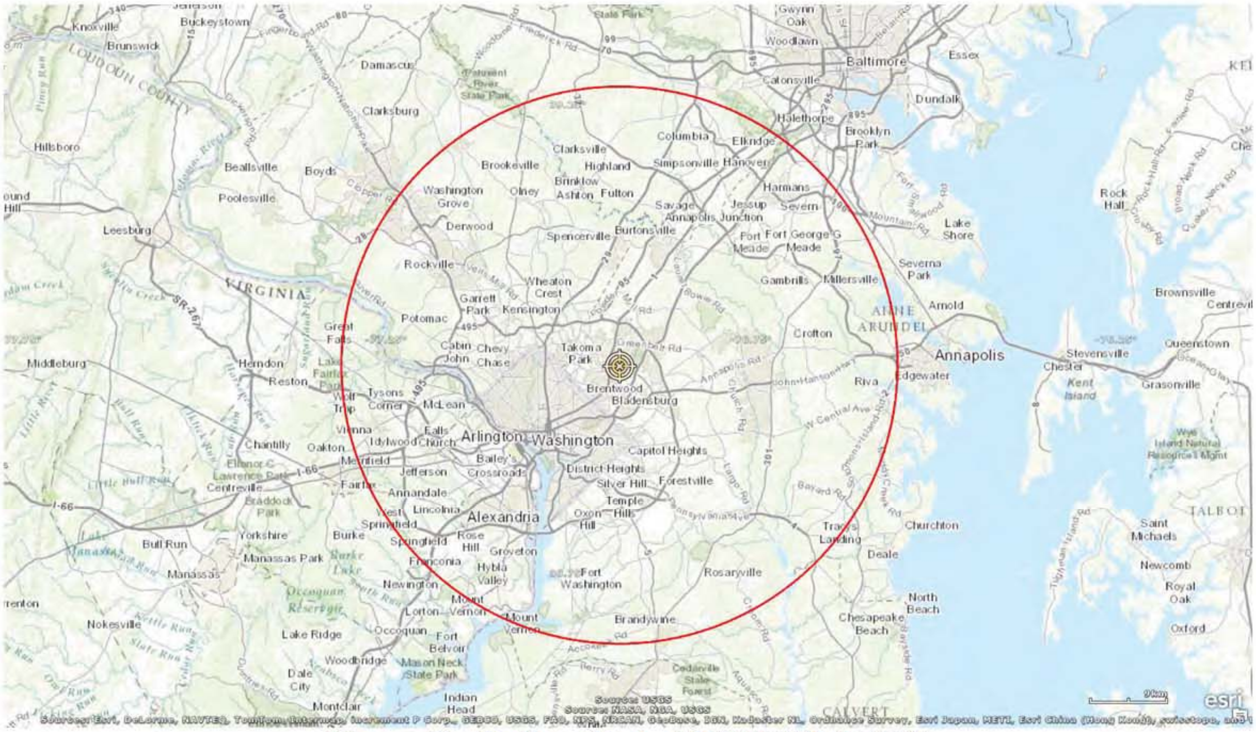


Figure 21. College Park, MD DCPR-1 75 W

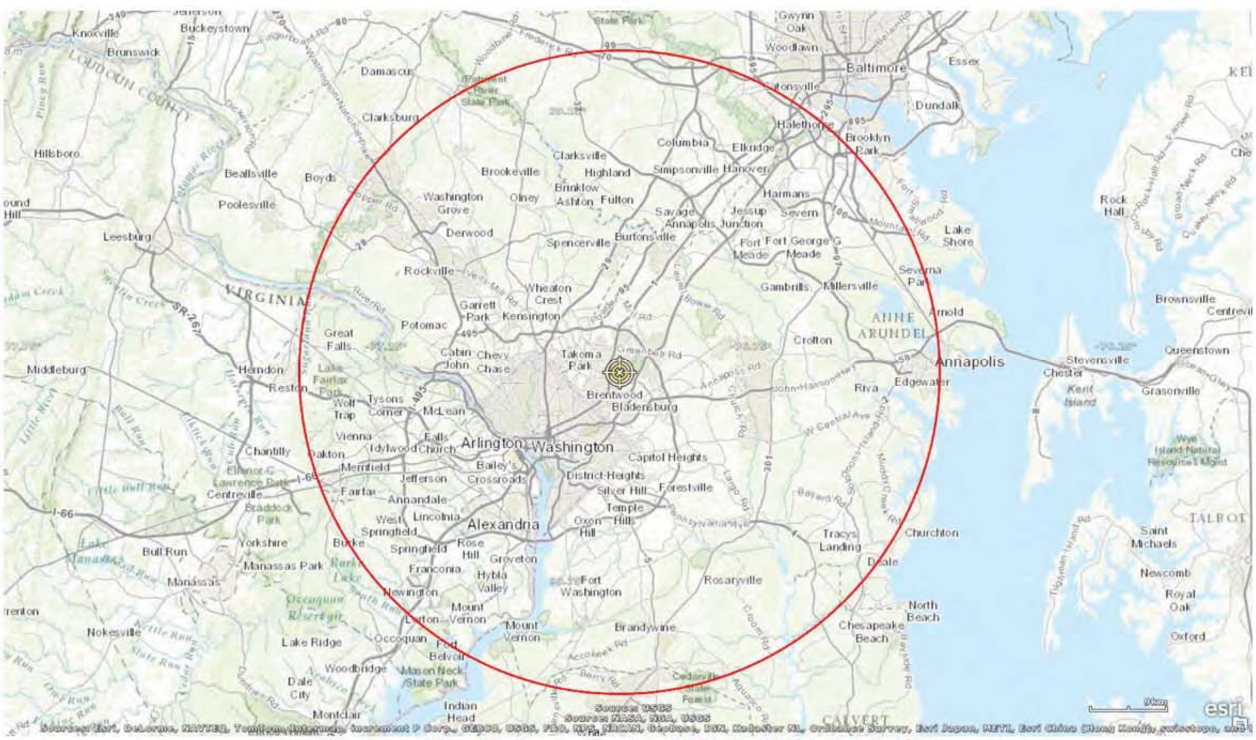


Figure 22. College Park, MD DCPR-1 137 W

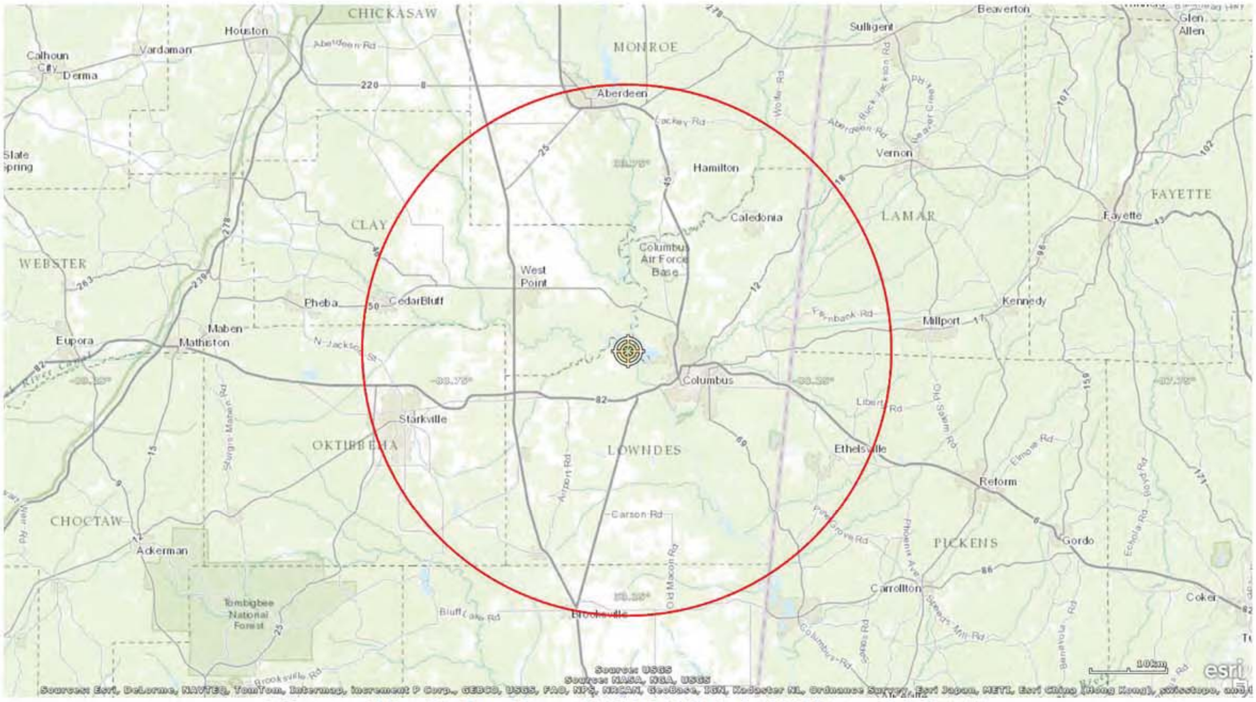


Figure 23. Columbus, MS DCPR-1 75 W and 137 W

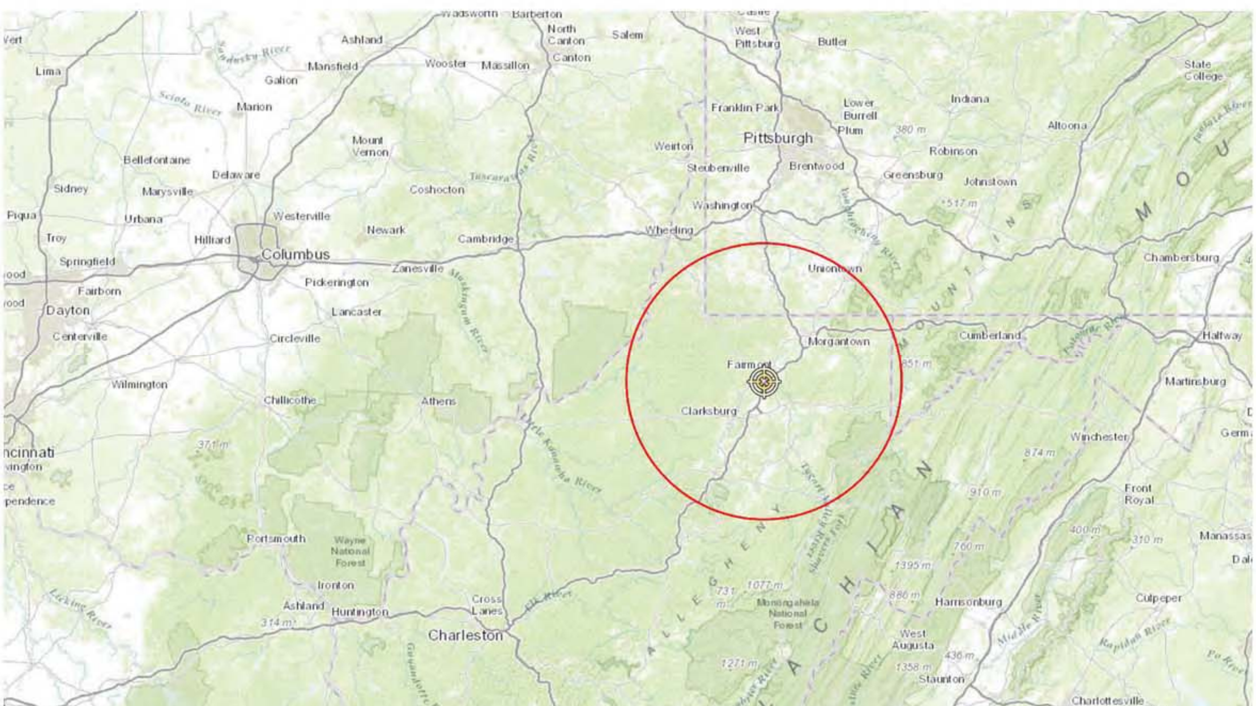


Figure 24. Fairmont, WV DCPR-1 75 W and 137 W

Figure 25. Ford Island, HI DCPR-1 137 W

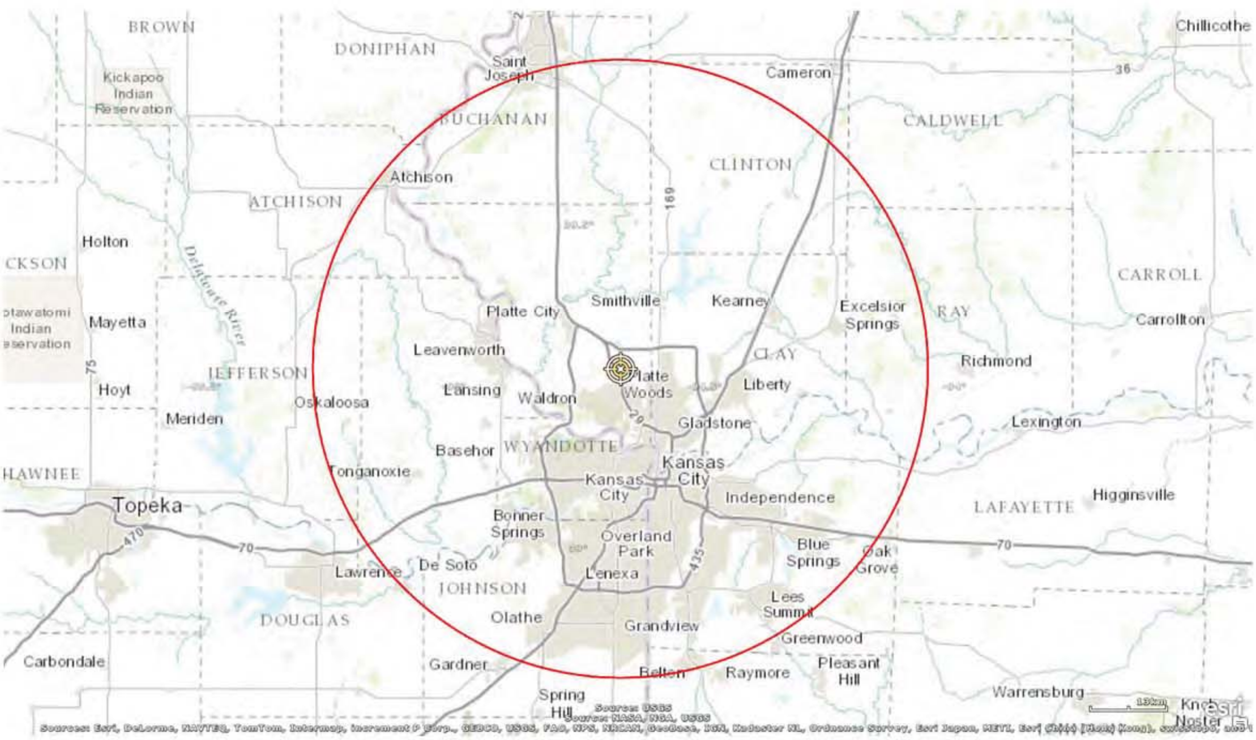


Figure 26. Kansas City, MO DCPR-1 75 W and 137 W

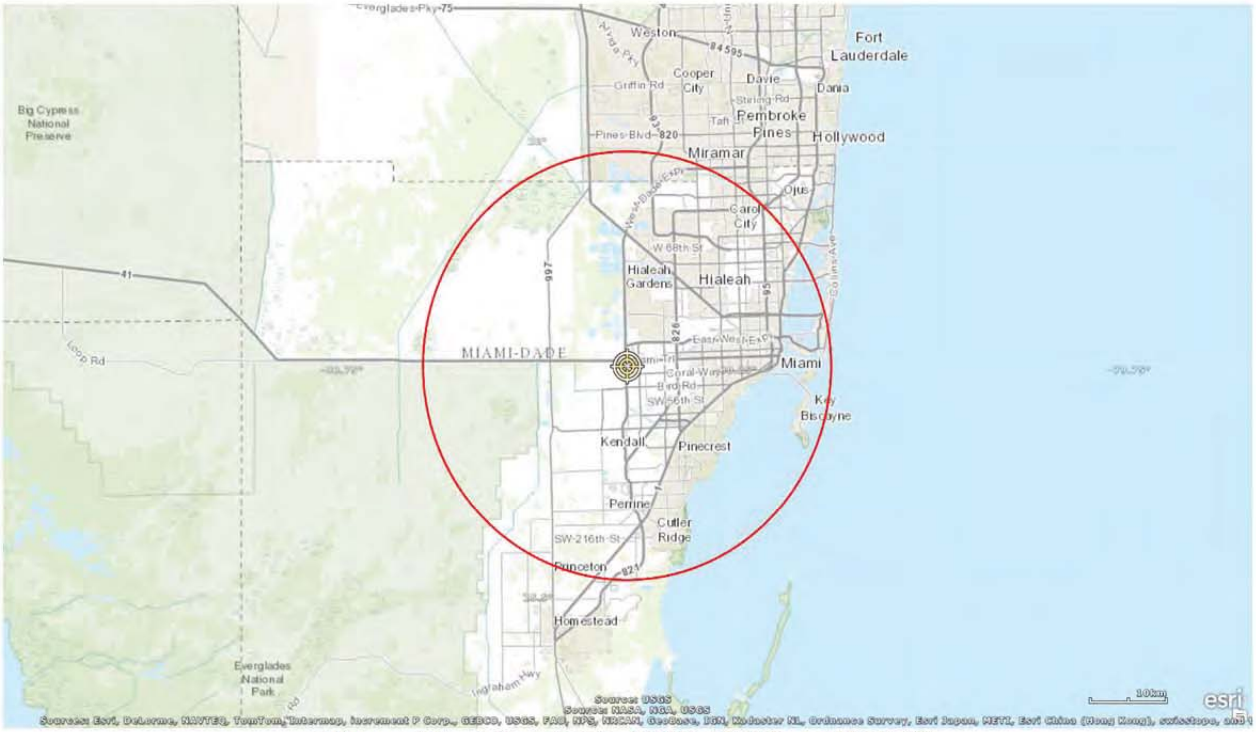


Figure 27. Miami, FL GRB 75 W and 137 W

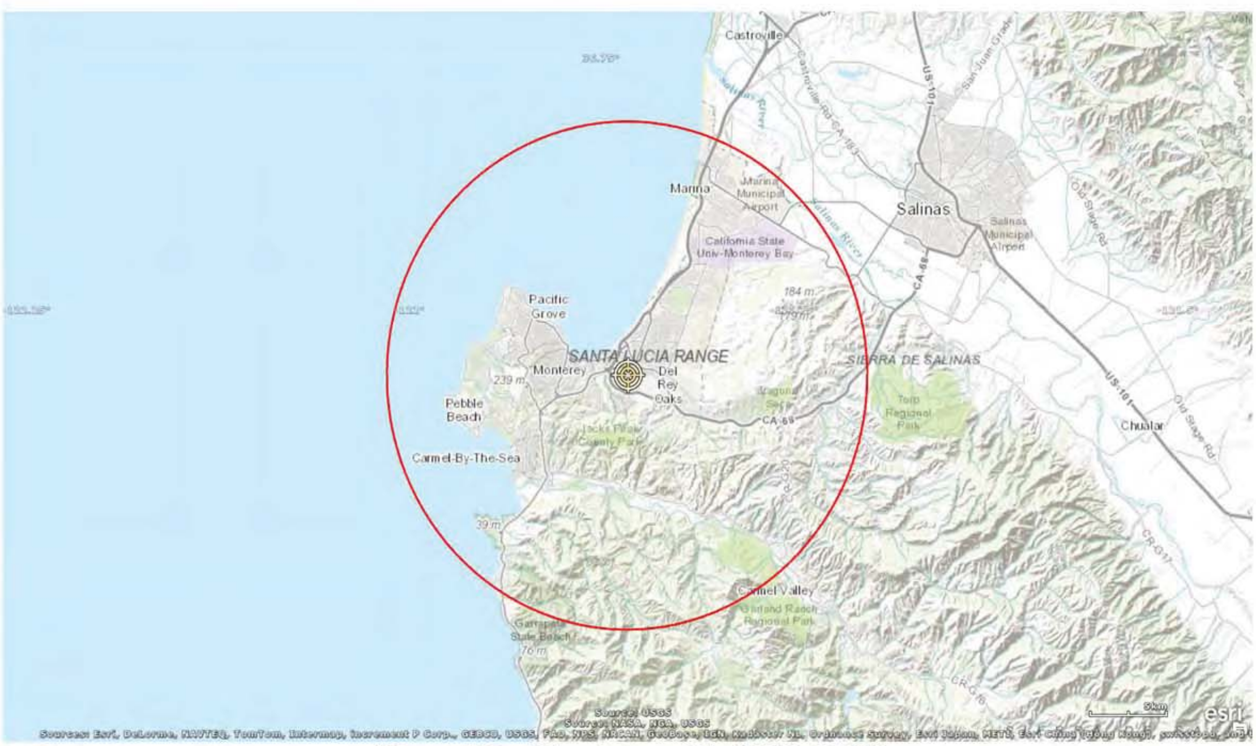


Figure 28. Monterey, CA GRB 75 W

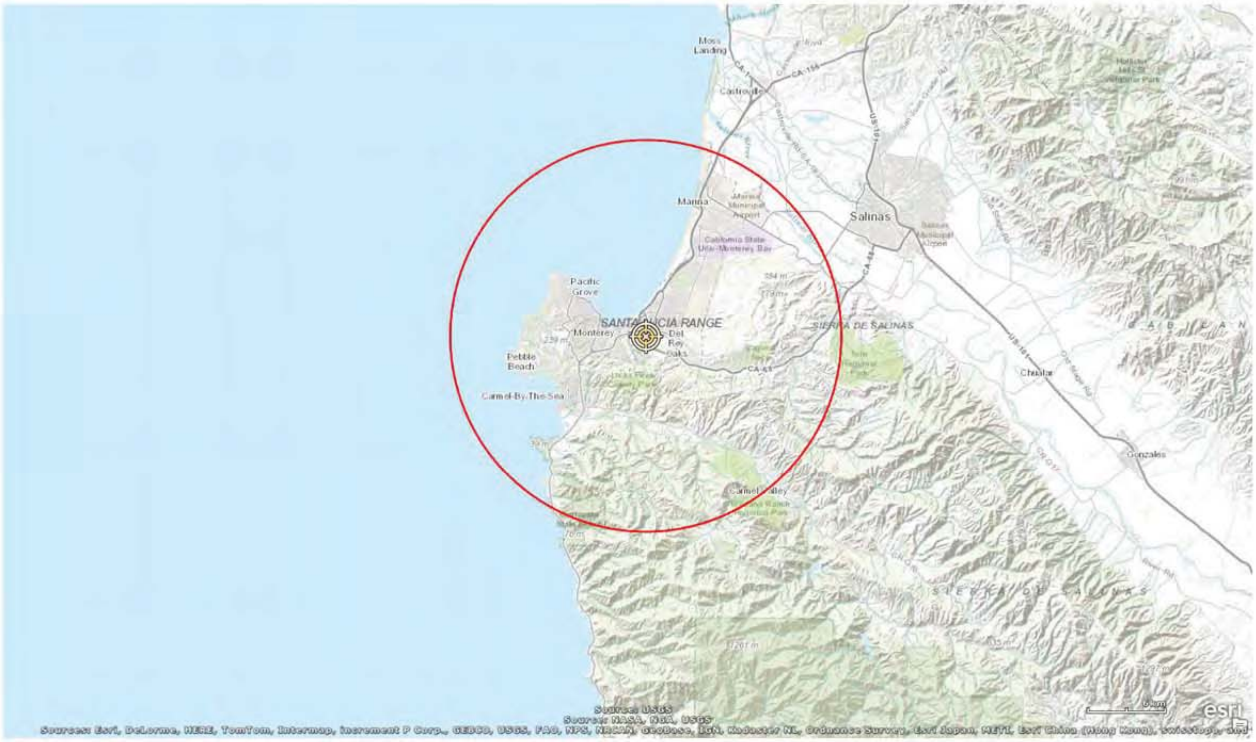


Figure 29. Monterey, CA GRB 137 W

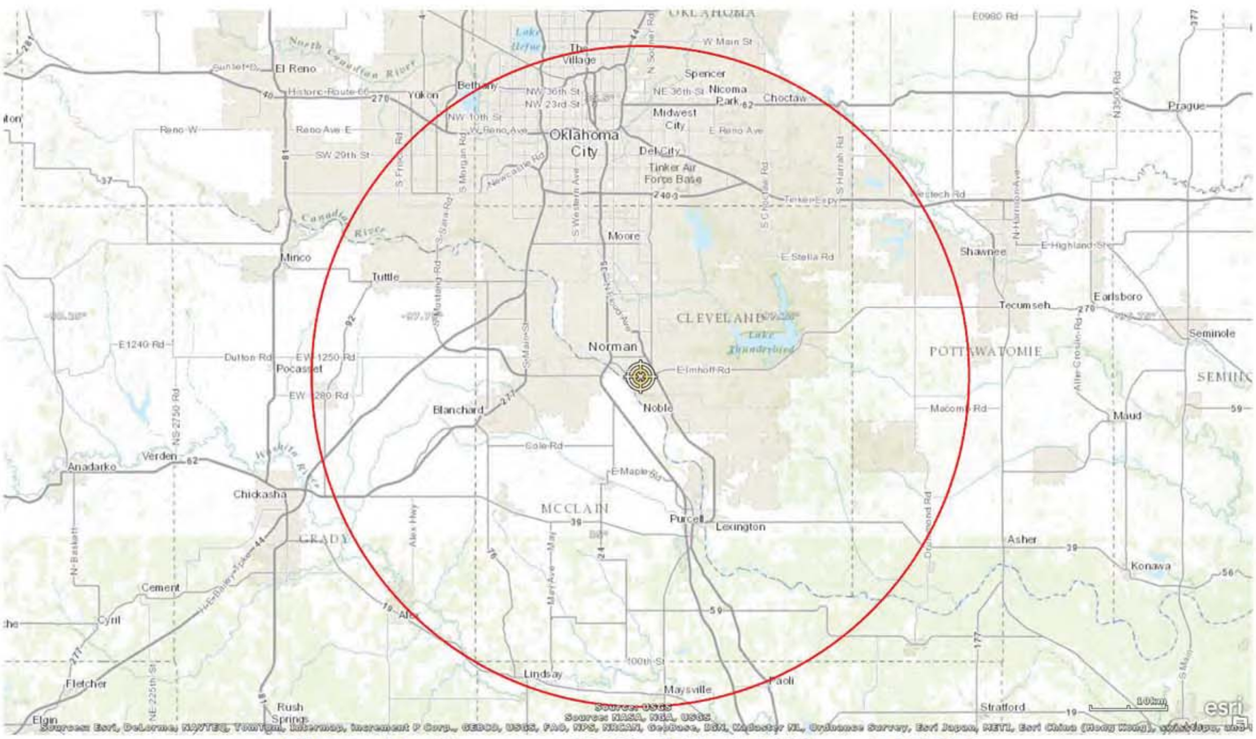


Figure 30. Norman, OK DCPR-1 75 W and 137 W

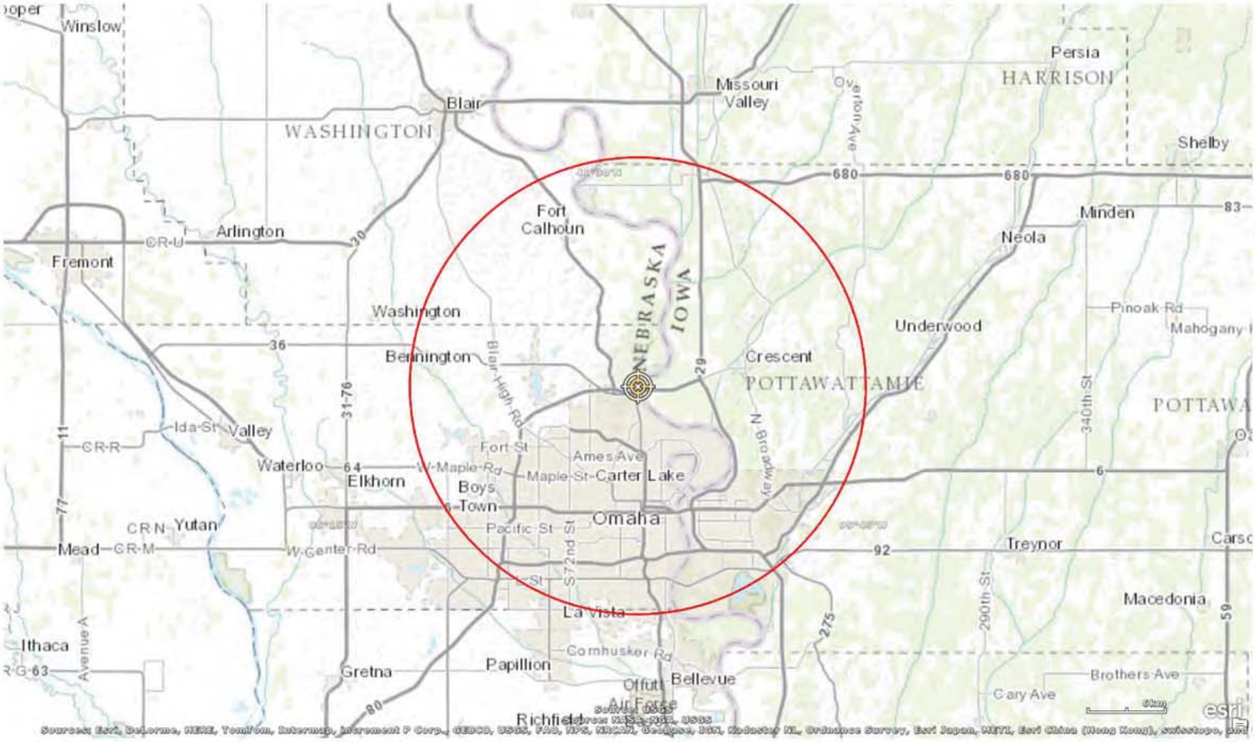


Figure 31. Omaha, NE DCPR-1 75 W and 137 W

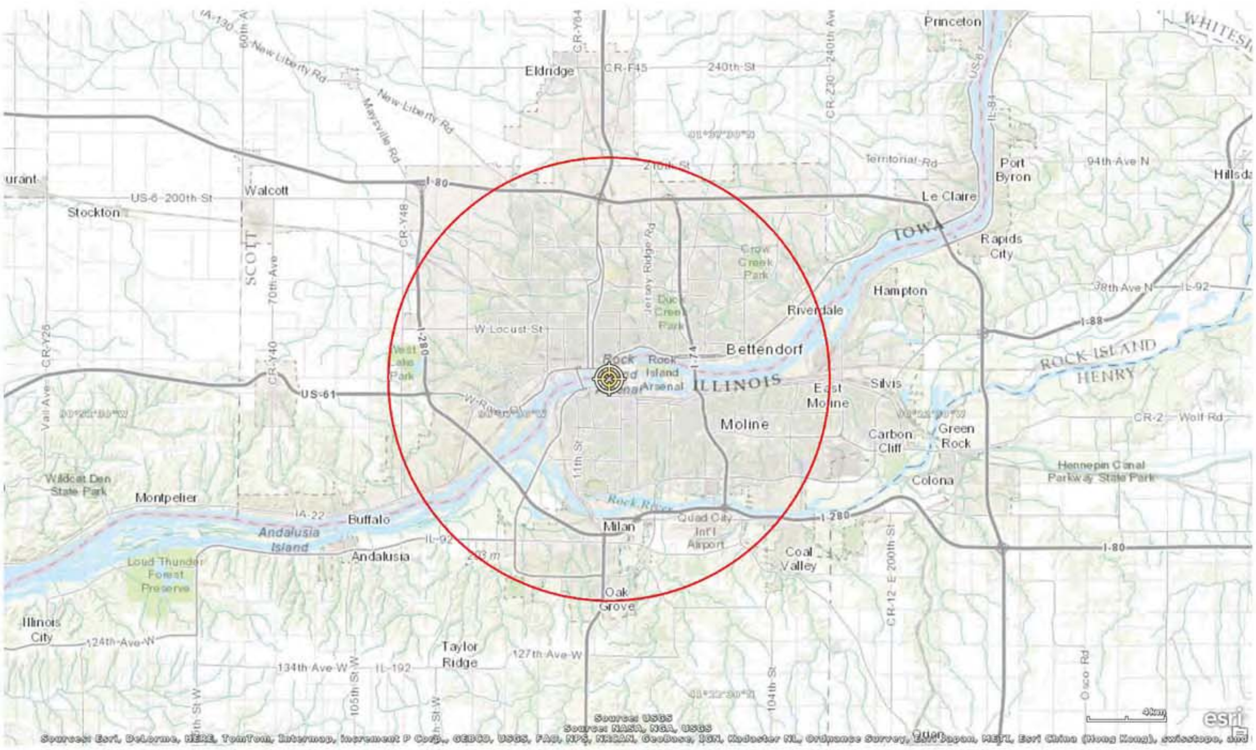


Figure 32. Rock Island, IL DCPR-1 75 W and 137 W

Figure 33. Sacramento, CA DCPR-1 75 W and 137 W

Figure 34. San Juan, PR DCPR-1 75 W

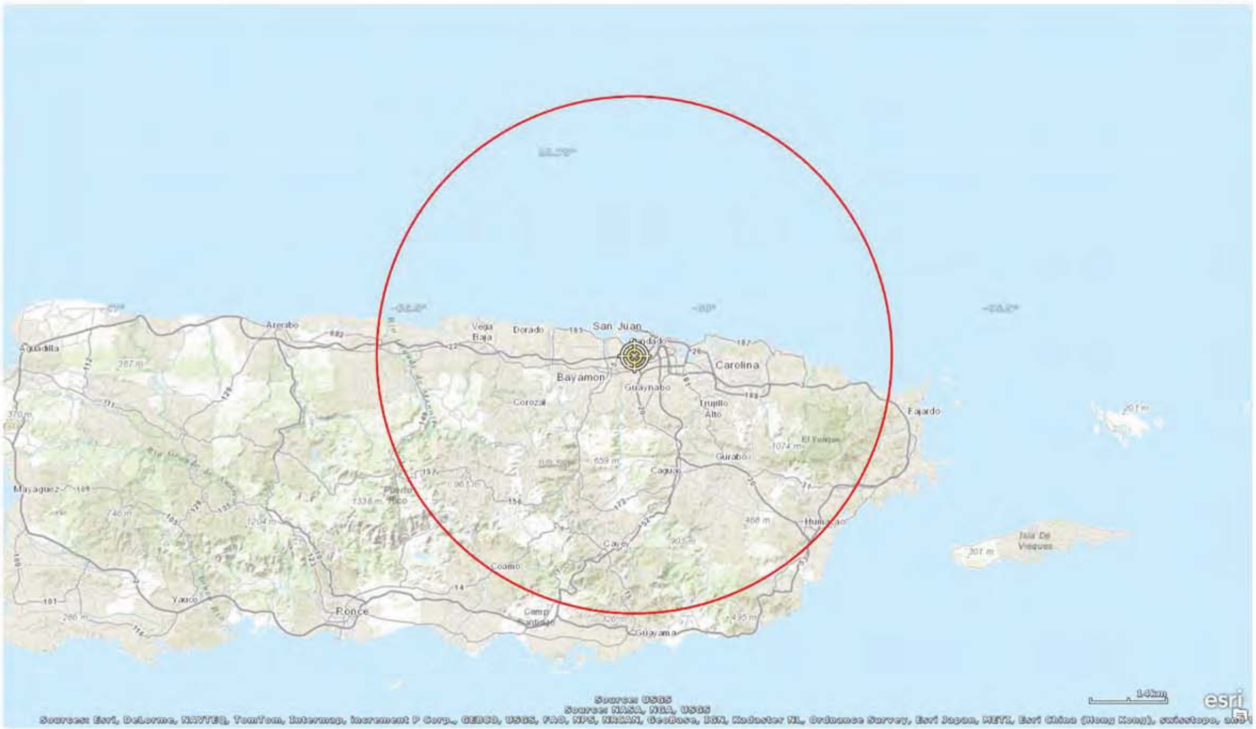


Figure 35. San Juan, PR DCPR-1 137 W

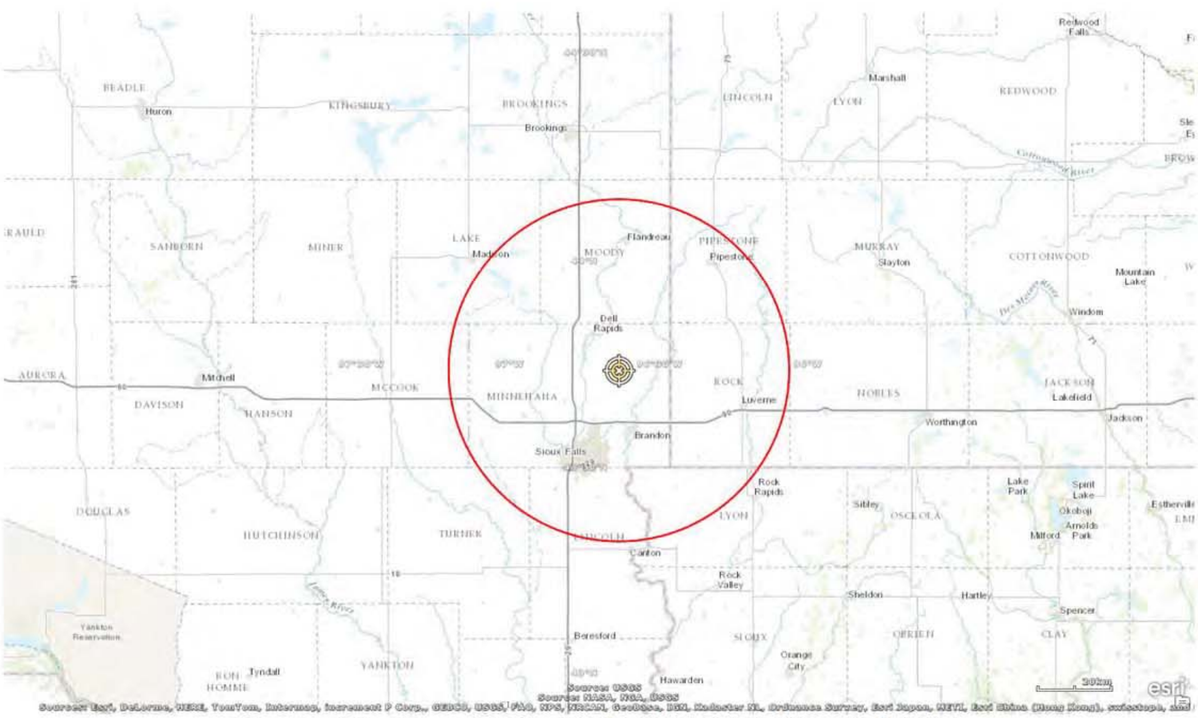


Figure 36. Sioux Falls, SD DCPR-1 75 W and 137 W

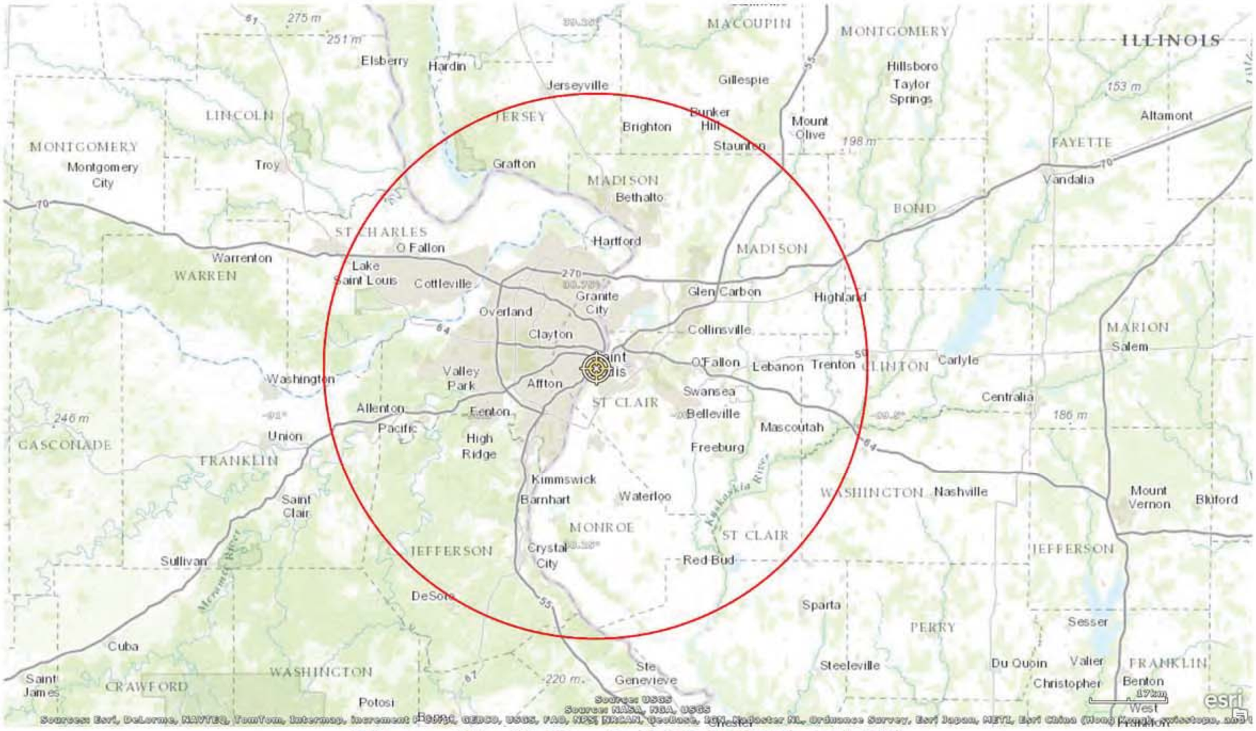


Figure 37. St. Louis, MO DCPR-1 75 W

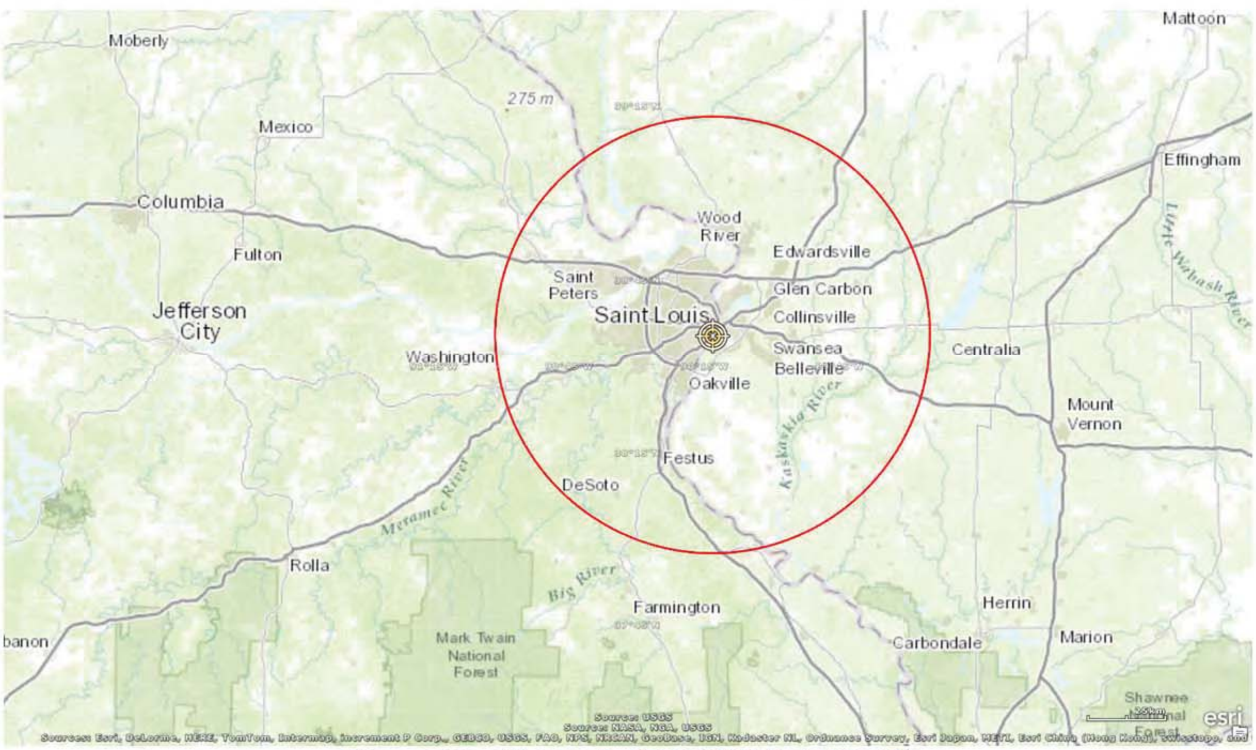


Figure 38. St. Louis, MO DCPR-1 137 W

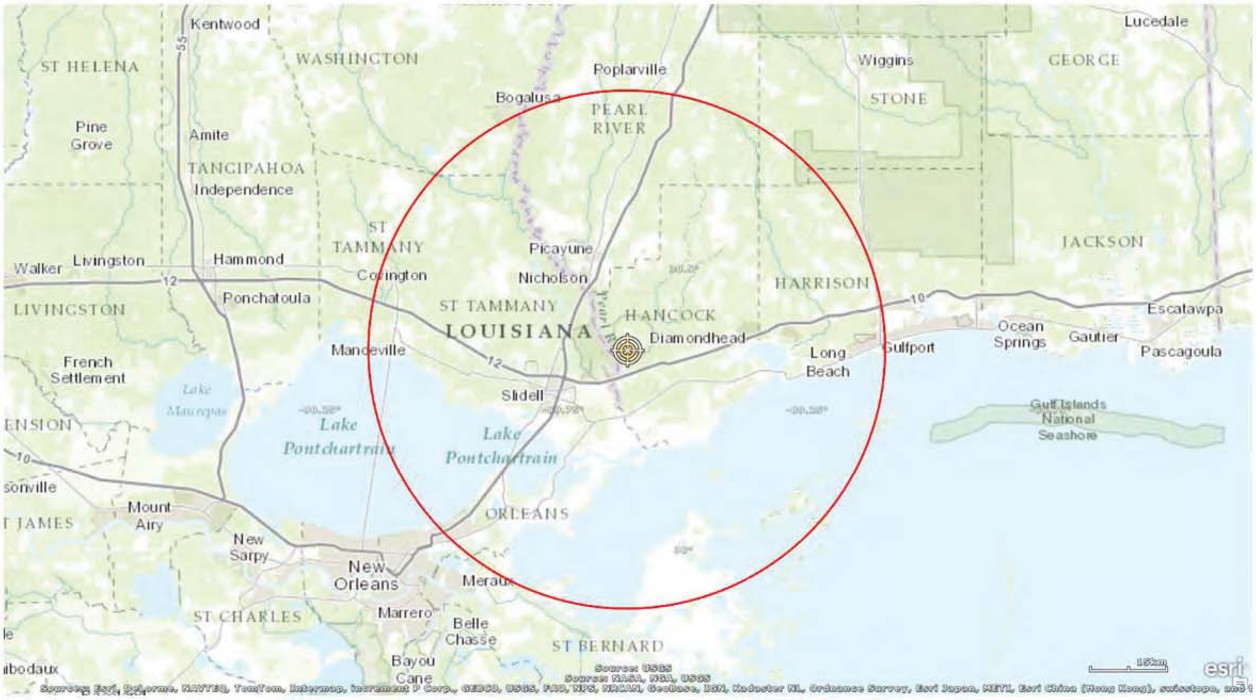


Figure 39. Stennis Space Center, MS DCPR-1 75 W

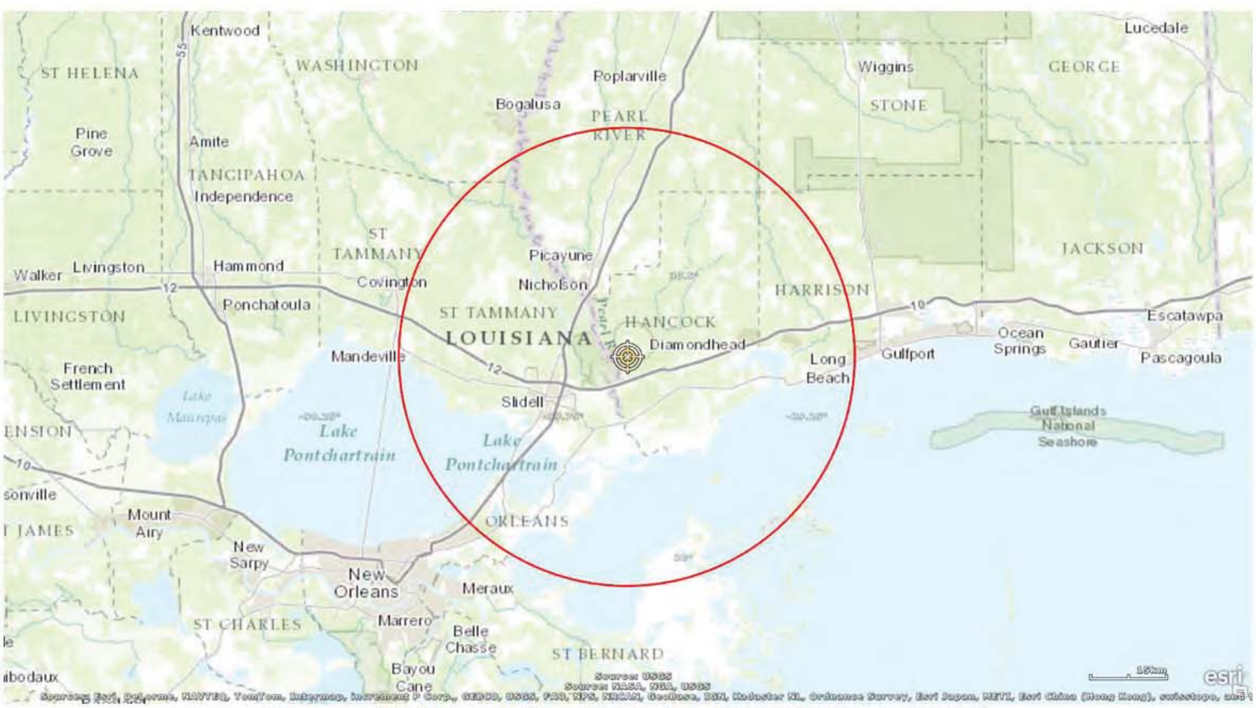


Figure 40. Stennis Space Center, MS DCPR-1 137 W

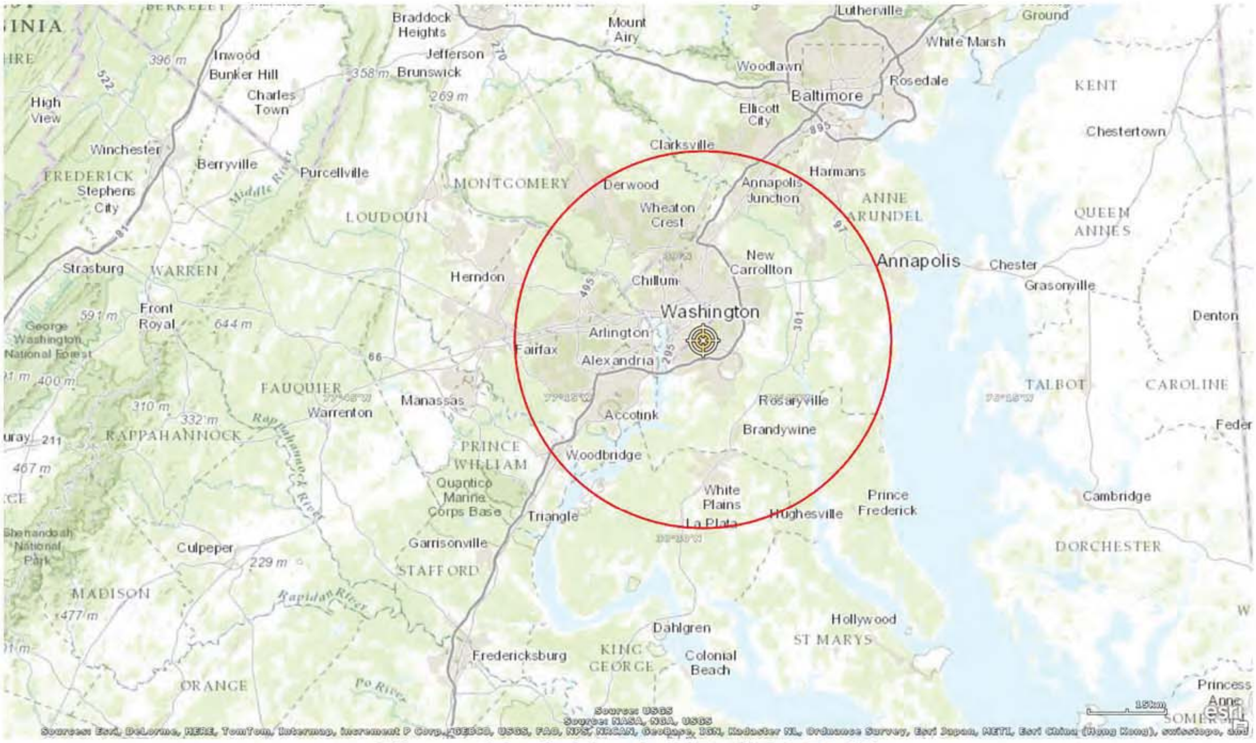


Figure 41. Suitland, MD GRB 75 W

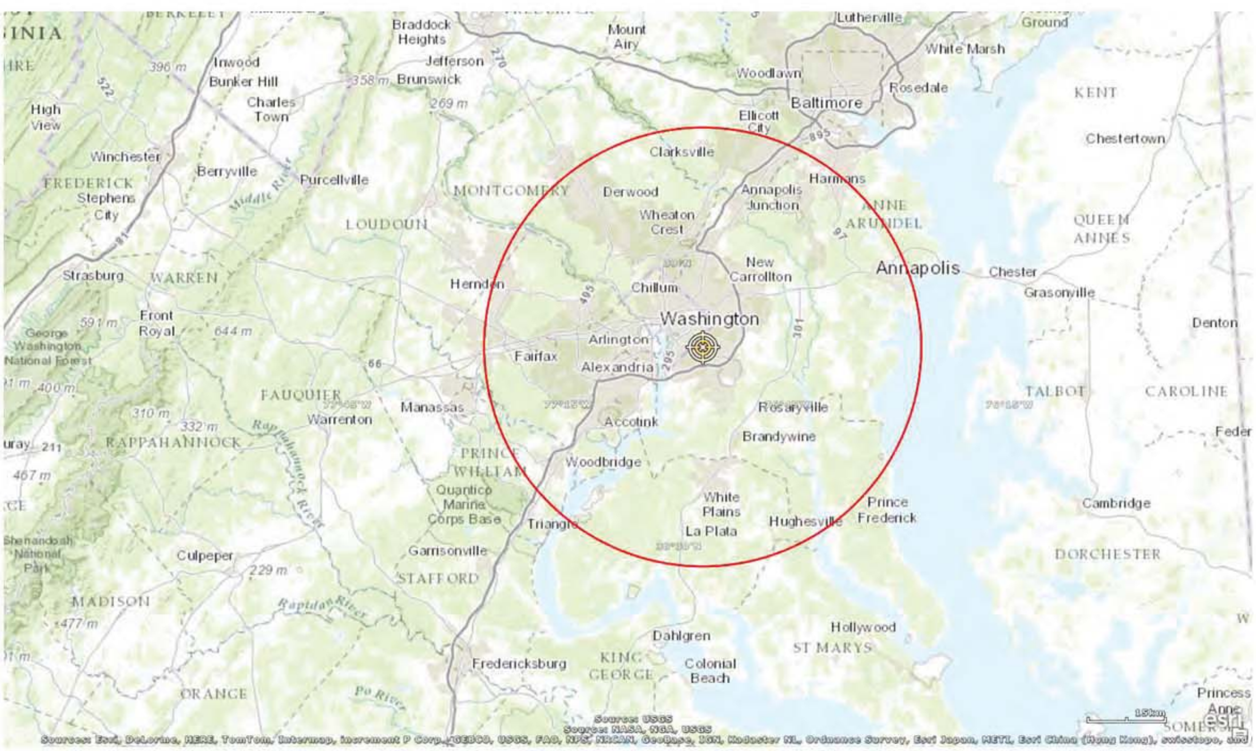


Figure 42. Suitland, MD GRB 137 W

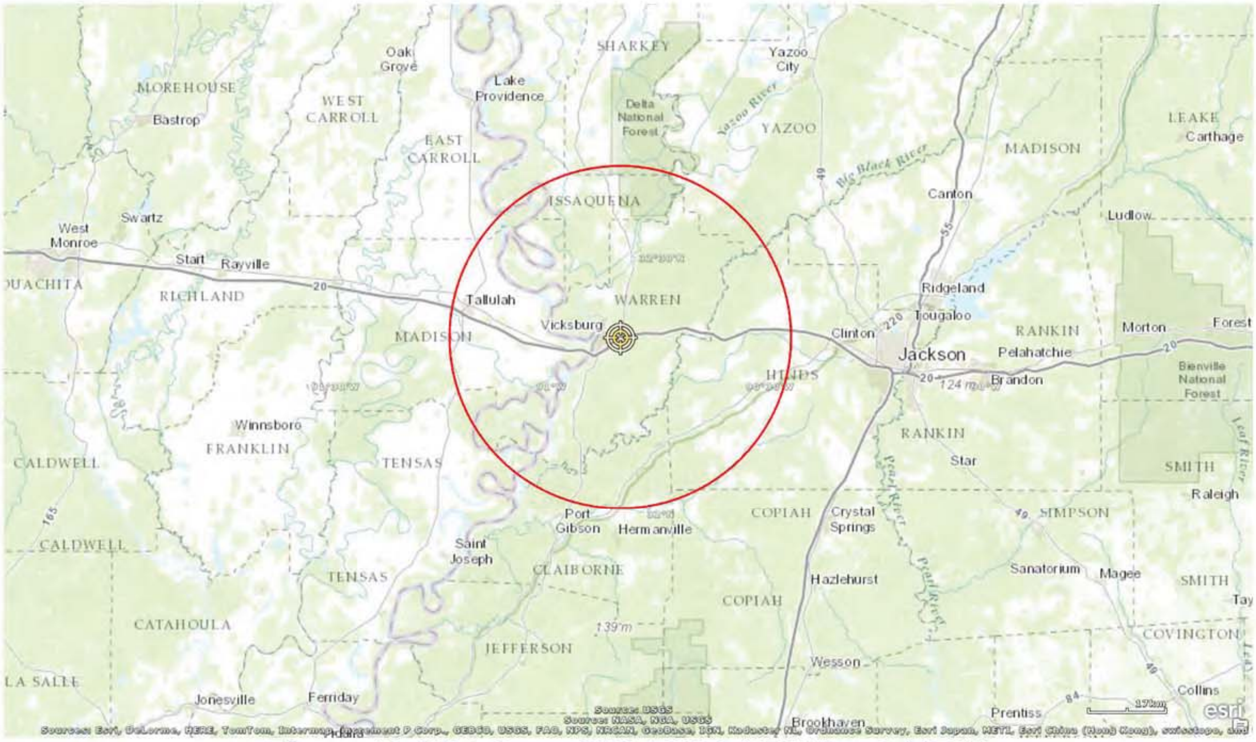


Figure 43. Vicksburg, MS DCPR-1 75 W and 137 W

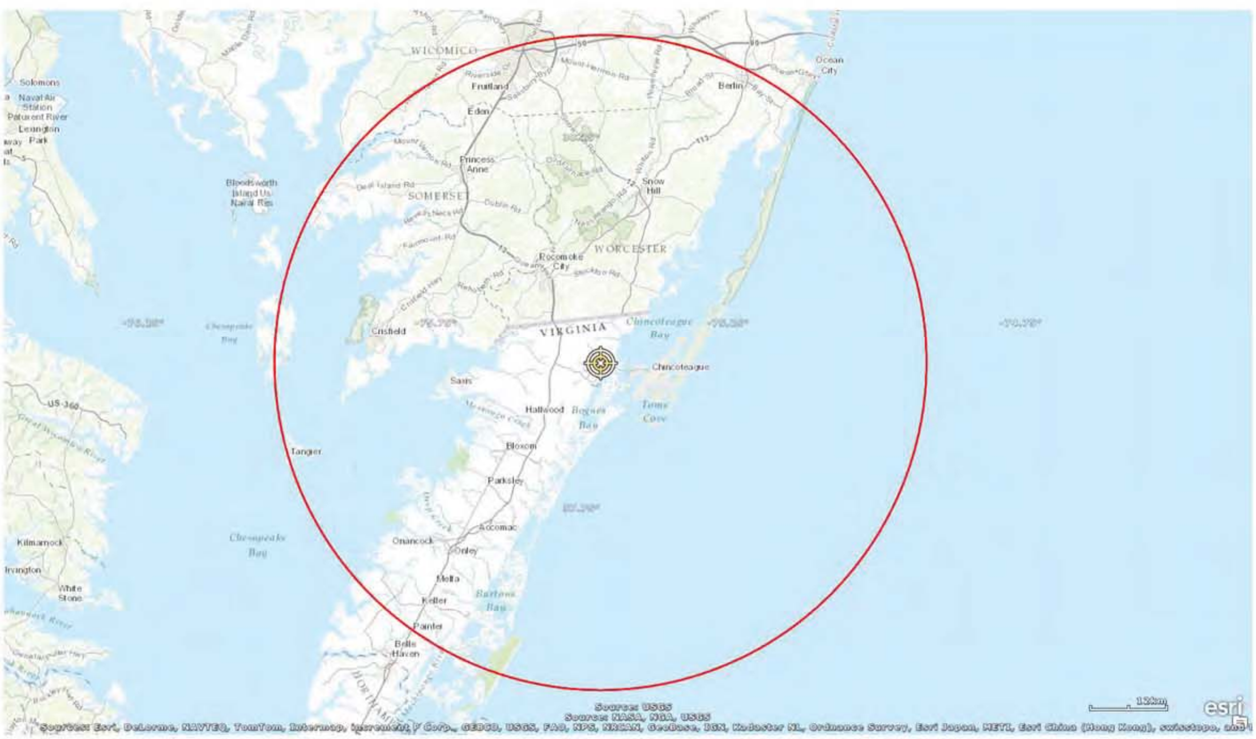


Figure 44. Wallops, VA DCPR-1 75 W and 137 W

APPENDIX E – STRONG-SIGNAL SINGLE AND AGGREGATE ANALYSIS GOES-R

For all sites listed below in Table 18, no aggregate damage separation distances were available as the CSMAC WG-5 laydown did not provide base stations close enough to exceed the threshold under investigation.

Table 18. Strong-signal (single and aggregate) analyses results for GOES-R Earth Stations

Location	Earth Station Az (deg)	Earth Station El (deg)	Satellite	Single-Entry Onset of Nonlinear Interactions and IM separation distance, km	Aggregate Onset of Nonlinear Interactions and IM separation distance, km	Single-Entry GC separation distance, km	Aggregate GC separation distance, km	Single-Entry Damage separation distance, km
Anchorage, AK	165.3	19.9	137 W	13.54	*	4.51	*	0.13
Boise, ID	208.8	35.5	137 W	6.64	10	2.28	5	0.06
Boise, ID	128.2	25.1	75 W	10.14	10	3.42	5	0.10
Boulder, CO	223.9	33.4	137 W	7.15	17	2.45	2	0.07
Boulder, CO	137.7	34.3	75 W	6.94	18	2.38	2	0.07
Cincinnati, OH	244.2	20.0	137 W	12.78	13	3.87	6	< 0.01
Cincinnati, OH	165.1	43.7	75 W	4.70	13	1.34	5	< 0.01
College Park, MD	250.1	14.4	137 W	20.25	14	6.63	8	0.18
College Park, MD	176.9	44.8	75 W	5.02	13	1.75	6	0.05
Columbus, MO	244.0	25.7	137 W	9.85	6	3.32	*	0.09
Columbus, MO	156.5	48.4	75 W	4.58	6	1.60	*	0.04
Fairmont, WV	247.4	16.7	137 W	1.77	*	0.69	*	0.12
Fairmont, WV	171.9	44.0	75 W	0.57	*	0.09	*	0.04
Ford Island/Pearl Harbor, HI	133.6	55.5	137 W	4.58	12	1.56	6	0.03
Kansas City, MO	235.2	27.2	137 W	9.20	7	3.12	2	0.09
Kansas City, MO	150.6	40.2	75 W	5.73	7	1.98	3	0.05
Miami, FL	254.0	21.6	137 W	12.15	17	4.04	10	0.10
Miami, FL	167.8	59.3	75 W	4.56	17	1.55	9	0.03
Monterey, CA	204.4	44.6	137 W	5.05	8	1.76	4	0.05
Monterey, CA	119.2	25.5	75 W	9.97	8	3.37	4	0.10
Norman, OK	235.1	31.7	137 W	7.56	7	2.54	2	0.06
Norman, OK	144.4	42.7	75 W	5.25	7	1.80	2	0.04
Omaha, NE	232.8	26.7	137 W	9.39	11	3.18	3	0.09
Omaha, NE	149.9	37.6	75 W	6.2	11	2.14	3	0.06
Rock Island, IL	237.8	23.1	137 W	11.25	7	3.78	3	0.11
Rock Island, IL	157.2	39.5	75 W	5.85	7	2.02	3	0.06
Sacramento, CA	203.9	42.5	137 W	5.36	28	1.86	9	0.05
Sacramento, CA	120.6	24.6	75 W	10.39	29	3.50	10	0.10
San Juan, PR	263.7	9.5	137 W	34.40	13	10.99	10	0.29
San Juan, PR	206.3	66.1	75 W	4.58	10	1.56	6	0.02

Location	Earth Station Az (deg)	Earth Station El (deg)	Satellite	Single-Entry Onset of Nonlinear Interactions and IM separation distance, km	Aggregate Onset of Nonlinear Interactions and IM separation distance, km	Single-Entry GC separation distance, km	Aggregate GC separation distance, km	Single-Entry Damage separation distance, km
Sioux Falls, SD	230.9	25.6	137 W	9.91	*	3.34	*	0.09
Sioux Falls, SD	150.2	35.1	75 W	6.73	*	2.31	*	0.06
St Louis, MO	239.6	24.4	137 W	10.48	13	3.53	4	0.10
St Louis, MO	156.5	42.6	75 W	5.34	13	1.85	3	0.05
Stennis Space Center, MS	245.1	28.1	137 W	8.84	6	3.00	* 5.37	0.09
Stennis Space Center, MS	152.7	51.2	75 W	4.58	* 5.37	1.56	* 5.37	0.04
Suitland, MD	250.1	14.4	137 W	1.78	4	0.68	*	0.10
Suitland, MD	176.9	45.0	75 W	0.48	1	0.07	*	0.03
Vicksburg, MS	242.8	28.1	137 W	8.81	3	2.99	*	0.09
Vicksburg, MS	152.1	48.6	75 W	4.58	3	1.59	*	0.04
Wallops , VA	179.2	46.0	75 W	0.54	*	0.09	*	0.04
Wallops , VA	251.6	13.6	137 W	2.24	*	0.87	*	0.15
White Sands, NM	227.5	40.0	137 W	5.69	*	1.94	*	0.04
White Sands, NM	131.2	39.1	75 W	5.84	*	1.99	*	0.04

* CSMAC WG-5 base station laydown for aggregate analysis did not exceed threshold for specific mechanism ; use single entry protection distance

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