Appendix B Noise

KBR Technical Memorandum:

Noise Modeling Updates for Falcon 9 Block 5 Flight and Test Operations at SLC-40 (Revision 2)

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1.0 Introduction

The noise analysis described herein is an updated noise modeling study for Space Exploration Technologies Corporation (SpaceX's) planned Falcon 9 Block 5 flight and test operations at Space Launch Complex 40 (SLC-40) at Cape Canaveral Space Force Station (CCSFS) in Florida. Previously, noise estimates were made for Falcon 9 Block 5 operations at Launch Complex 40 (LC-40) using KBR's RNOISE[1] model and documented in Technical Note TN18-03[2]. The current noise modeling update was performed for two reasons: (1) the A-weighted Sound Exposure Level calculation was updated in RNOISE after recent model validation studies indicated the model was overpredicting compared with field measurements; after adjusting the energy accumulated at receiver locations, the modeled sound exposure levels now compare better with a variety of field measured sound exposure levels and (2) the annual operations cadence anticipated for SLC-40 has increased to 120 launches along with 34 booster landings and 40 static fire tests, all modeled as nighttime operations in this study to be conservative. These changes warranted updating the noise exposure maps for Falcon 9 Block 5 operations at SLC-40.

Most of the operations data for this study were obtained from SpaceX previously to conduct the modeling for TN18-03, including:

- Orbital launch trajectory for the Falcon 9 from liftoff to stage separation.
- Raptor engine operating data and nominal ascent thrust profile.

- Booster reentry and descent/landing trajectory from separation to landing with descent thrust profiles.
- Static fire test parameters for the Booster.
- Projected annual launch, landing, and static fire test operations at SLC-40.

Thus, the same operation parameters for a single Falcon 9 launch, booster landing, and static fire test were run through the updated version of RNOISE to generate single event noise exposure contours for each type of operation; sound exposure level was the only metric that changed, however, this effects the computation of Day-Night Average Sound Level (DNL) which is used for cumulative noise assessment (or Community Noise Equivalent Level (CNEL) for assessments in the state of California).

The primary modeling assumptions in this study are the use of a single value, over-land ground impedance model estimating soft ground cover, US standard atmosphere, and no modeling of terrain or other barriers.

RNOISE is a far field rocket noise model. The vehicle's position and attitude are known from the trajectory. Rocket noise source characteristics are known from the engine properties, with thrust and exhaust velocity being the most important parameters. The emission angle and distance to the receiver are known from the flight path and receiver position. Noise at the ground is computed accounting for distance, ground impedance[3], atmospheric absorption of sound[4], and uniform ground elevation. RNOISE propagates the full spectrum to the ground, accounting for Doppler shift from vehicle motion. It is a time simulation model, computing the noise at individual points or on a regular grid for every time point in the trajectory. Propagation time from the vehicle to the receiver is accounted for, yielding a spectral time history at the ground (including a range of frequencies from 1 Hz to 16 kHz). A variety of noise metrics can be computed from the calculated noise field and the metrics commonly used to assess rocket noise, and those presented in this memo, are described as follows.

FAA Order 1050.1F[5] specifies Day-Night Average Sound Level (DNL) as the standard metric for community noise impact analysis, but also specifies that other supplemental metrics may be used as appropriate for the circumstances. DNL is appropriate for continuous noise sources, such as airport noise and road traffic noise. The noise metrics used for rocket noise analysis are:

- DNL, as defined by FAA Order 1050.1F;
- SEL, the Sound Exposure Level, for individual events;
- LAmax, the maximum A-weighted overall sound pressure level (OASPL), for individual events; and
- Lmax, the maximum unweighted OASPL, for individual events.

LAmax is appropriate for community noise assessment of a single event, such as a rocket launch or static fire test. This metric represents the highest A-weighted integrated sound level for the event in which the sound level changes value with time. Slowly varying or steady sounds are generally integrated over a period of one second. LAmax is important in judging the interference caused by a noise event with conversation, TV listening, sleep, or other common activities. Similarly, Lmax is the highest unweighted integrated sound level for the event, used to assess the potential for structural damage. Although A-weighted maximum sound level provides some measure of the intrusiveness of the event, it does not completely describe the total event, because it does not include the duration that the sound is heard.

SEL is a composite metric that represents both the level of a sound and its duration. Individual time-varying noise events (e.g., aircraft overflights) have two main characteristics: a sound level that changes throughout the event and a period during which the event is heard. SEL provides a measure of the total acoustic energy transmitted to the listener during the event, but it does not directly represent the sound level heard at any given time. For example, during an aircraft flyover, SEL would include both the maximum noise level and the lower noise levels produced during onset and recess periods of the overflight. Mathematically, it represents the sound level of a constant sound that would, in one second, generate the same acoustic energy as the actual time-varying noise event. For a rocket launch, SEL is expected to be greater than LAmax.

Land use compatibility guidelines for LAmax, Lmax, and DNL are described following as they relate to hearing conservation, structural damage potential, and cumulative noise exposure, respectively.

Hearing Conservation

Occupational Safety and Health Administration (OSHA)[6] guidelines are to protect human hearing from long-term, continuous exposures to high noise levels and aid in the prevention of noise-induced hearing loss (NIHL). OSHA's permissible daily noise exposure limits include a LAmax of 115 dBA (slow response) for a duration of 0.25 hours or less. This is the criteria used in this study to evaluate areas around launch, landing, and static fire test sites that would require implementing a hearing conservation program, i.e., areas within the LAmax 115 dBA contour. This level was chosen as a conservative indicator of when a hearing conservation program should be implemented since all proposed flight and test operations, individually or together, are not expected to exceed 0.25 hours in duration on any given day.

Structural Damage Potential

The potential for structural damage due to launch, landing, and static fire test events is primarily assessed using the conclusions from a recent, applicable study to ascertain whether range activities (i.e., test, evaluation, demilitarization, and training activities of items such as weapons systems, ordinance, and munitions) would cause structural damage. The study concluded that structural damage becomes improbable below 140 dB [Maximum Un-weighted or linear Sound Level (Lmax)]. No glass or plaster damage is expected below 140 dB and no damage is expected below 134 dB[7]. A secondary method of assessing structural damage uses the potential for structural damage claims. An applicable study of structural damage claims from rocket static firing tests indicates that, based on Maximum Unweighted Sound Level (Lmax), approximately one damage claim will result per 100 households exposed at 120 dB and one damage claim per 1,000 households exposed at 111 dB[8]. For comparison purposes, all four of these structural damage criteria are shown as contours on all Lmax exposure maps presented in Section 2.

Land Use Compatibility Guidelines for Cumulative Noise Exposure

As previously mentioned, DNL represents the average sound level for annual average daily aircraft events which are used to assess cumulative noise exposure. FAA's published 14 Code of Federal Regulations (CFR) Part 150 defines land use compatibility guidelines for aviation noise exposure that are also applicable to rocket noise exposure. These guidelines consider land use compatibility for different uses over a range of DNL noise exposure levels, including the adoption of DNL 65 dBA as the limit for residential land use compatibility.

Estimated noise results for Falcon 9 launch, landing, and static fire test events at SLC-40 are presented in the following sections. These results include single event noise results, in terms of LAmax, SEL, and Lmax contours, for each type of operation or event (Section 2) and cumulative noise results, in term of DNL contours, for each type of operation, and all operations combined, for the anticipated cadence of 120 launches, 34 booster landings, and 40 static fire tests, all modeled as nighttime operations (Section 3).

2.0 Updated Single Event Noise Exposure Results for Falcon 9 Block5 Operations at SLC-40

Figures 1 through 3 show the single event noise contours for a Falcon 9 Block 5 launch at SLC-40. The maximum A-weighted overall sound pressure level (LAmax) contours are shown in Figure 1. The LAmax 115 dB contour (not shown but between the 110 dB and 120 dB contours), is entirely within the CCSFS and Kennedy Space Center (KSC) properties; areas within the 115 dB contour require implementation of a hearing conservation program. Figure 2 shows the A-weighted sound exposure level contours which are used to compute the DNL contours for the anticipated 120 annual nighttime launches (Section 3). The maximum unweighted OASPL contours shown in Figure 3 include the four criteria considered for structural damage assessment (i.e., the 111 dB and 120 dB Guest and Slone Criteria[8] and the 134 dB and 140 dB Fenton and Methold Criteria[7]. The 134 dB and 140 dB contours are within CCSFS property; therefore, damage is not expected to occur to any off-base structures. Using the 111 dB and 120 dB contours as more conservative guidelines, these contours are still within the CCSFS and KSC properties although some residential areas on KSC property are located within the Lmax 111 dB contour.

The same series of three single event noise exposure figures (LAmax, SEL, and Lmax) are shown for Falcon 9 Block 5 booster landings at SLC-40 in Figures 4 through 6. Booster landings generate less noise than Falcon 9 launches and all the noise contours shown in these figures are almost entirely within the CCSFS and KSC properties. No adverse noise impacts are expected from booster landings.

Similarly, Figures 7 through 9 show the same series of single event noise exposure figures for Falcon 9 Block 5 static fire tests at SLC-40. Booster static fire tests also generate less noise than Falcon 9 launches and all the noise contours shown in these figures are entirely within the CCSFS and KSC properties. No adverse noise impacts are expected from booster static fire tests.

Falcon 9 Orbital Launch Single Event Noise Levels at SLC-40

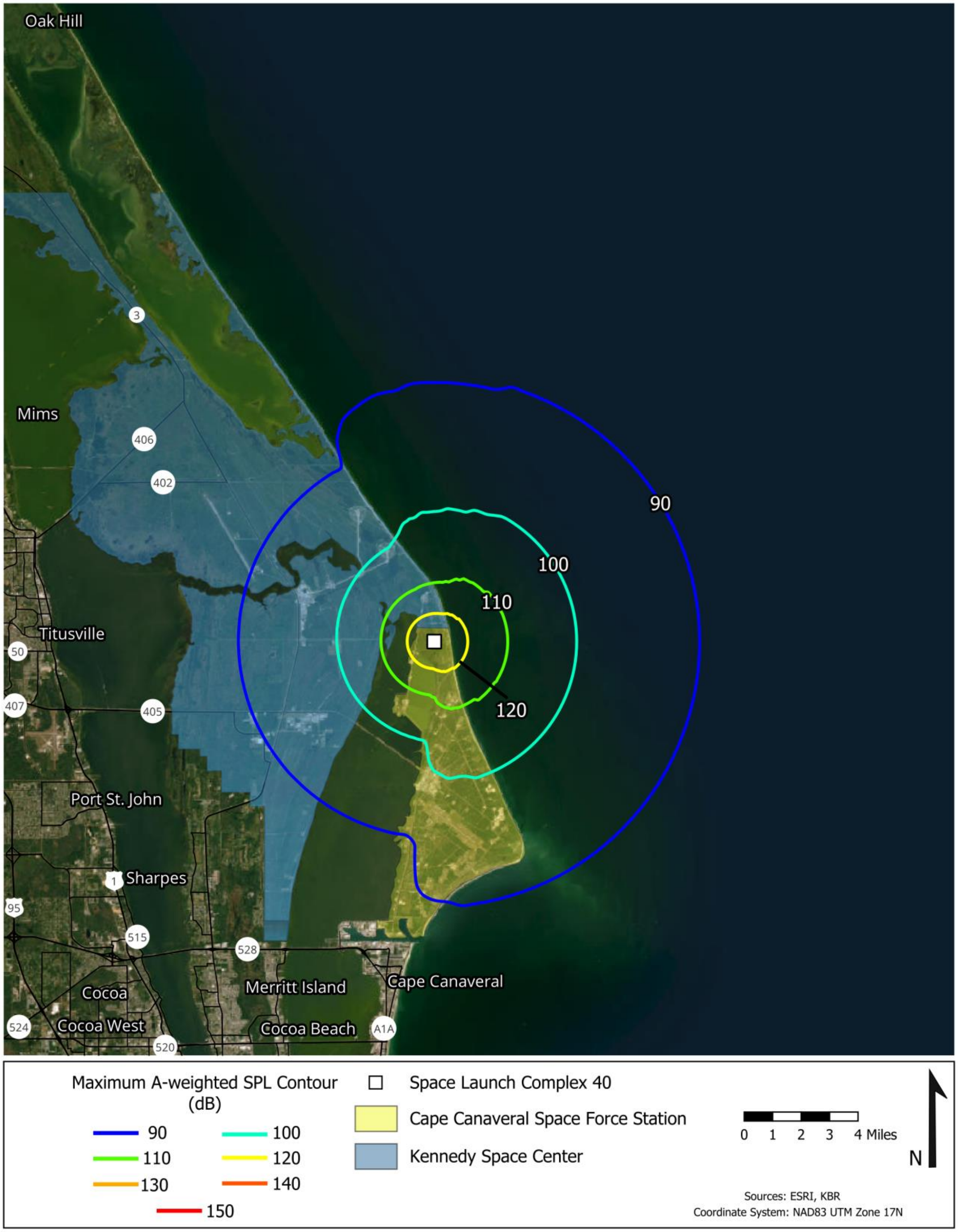


Figure 1. Falcon 9 Orbital Launch from SLC-40: Maximum A-Weighted Sound Levels

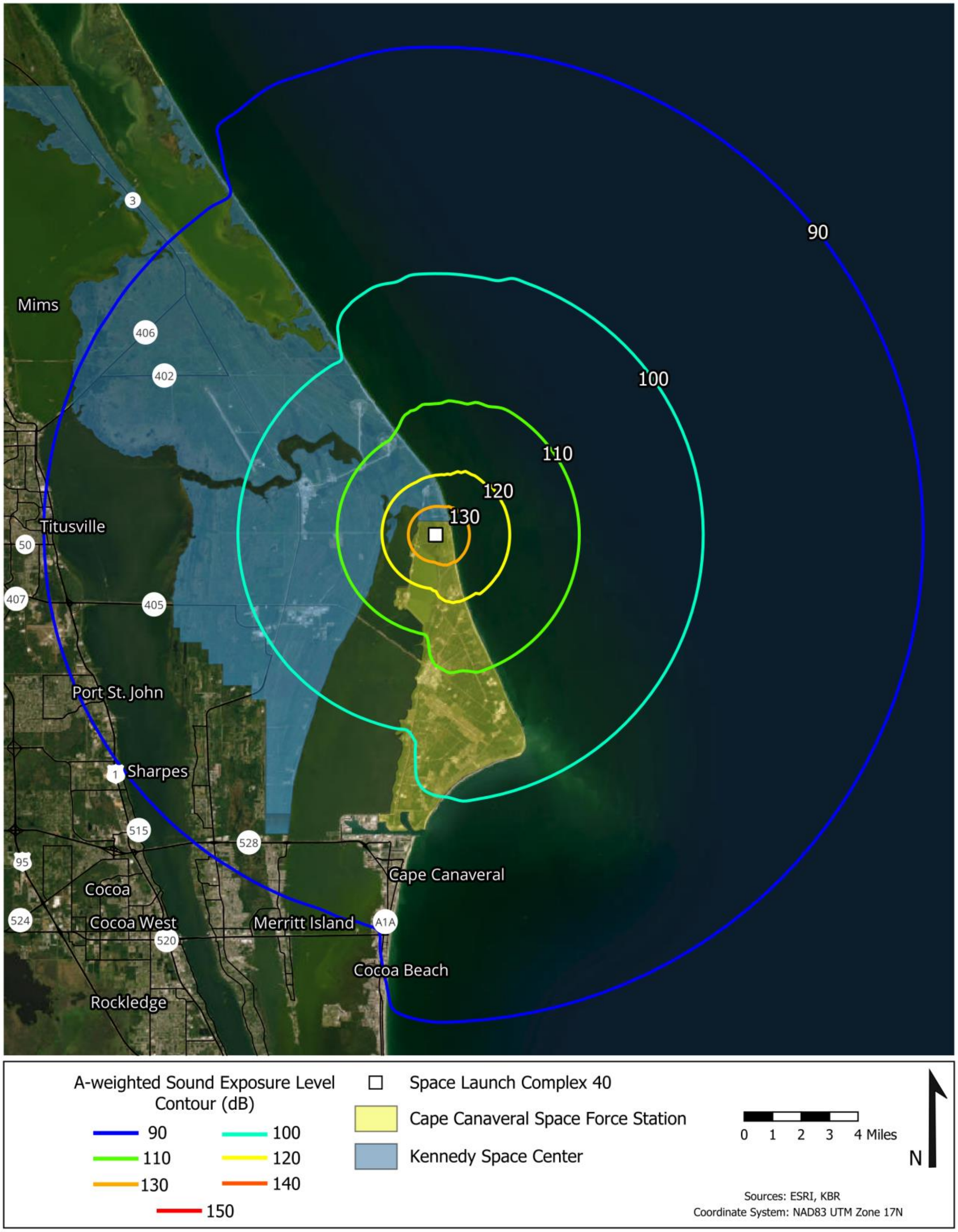


Figure 2. Falcon 9 Orbital Launch from SLC-40: Sound Exposure Levels

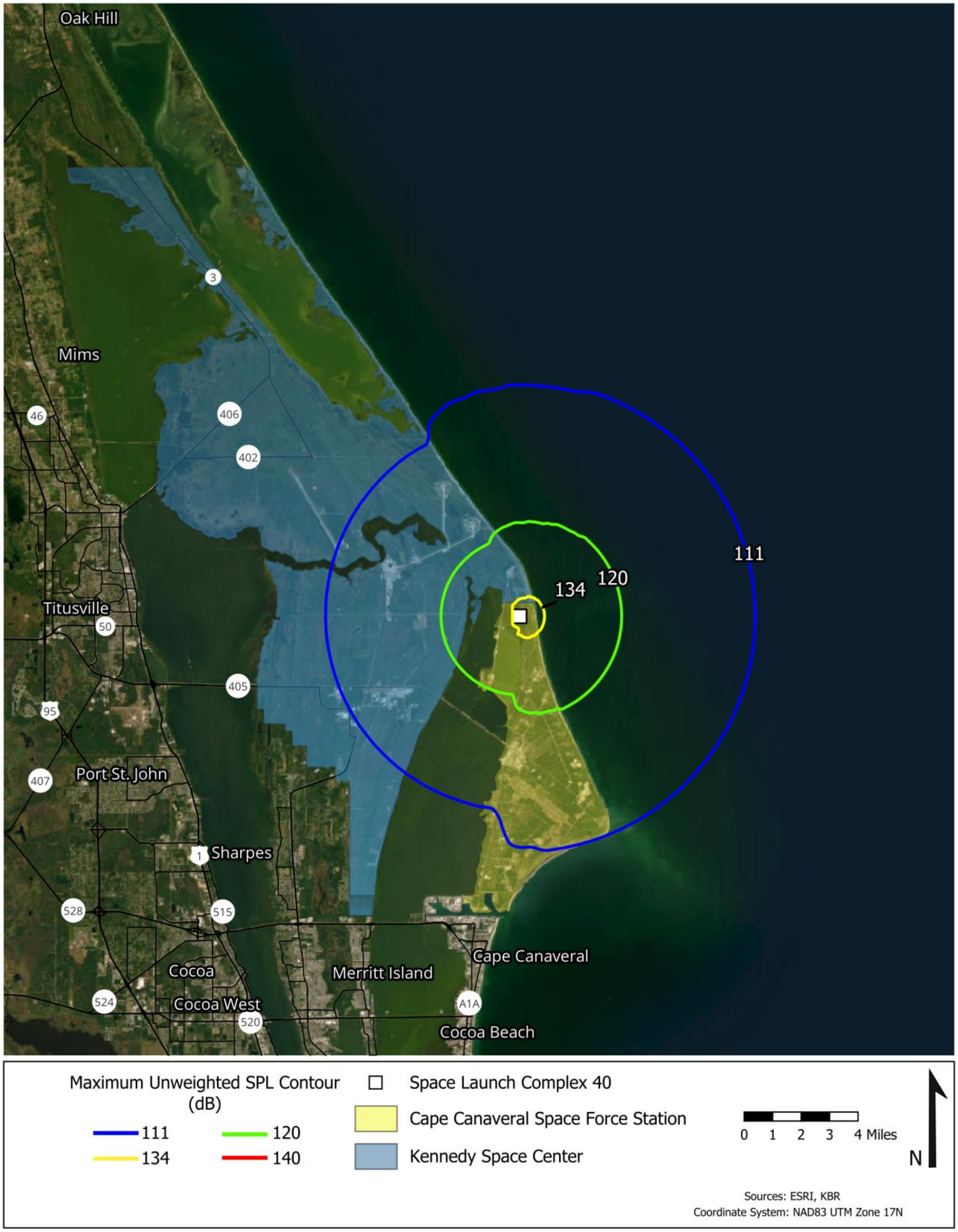


Figure 3. Falcon 9 Orbital Launch from SLC-40: Maximum Unweighted Sound Levels

Falcon 9 Booster Landing Single Event Noise Levels at SLC-40

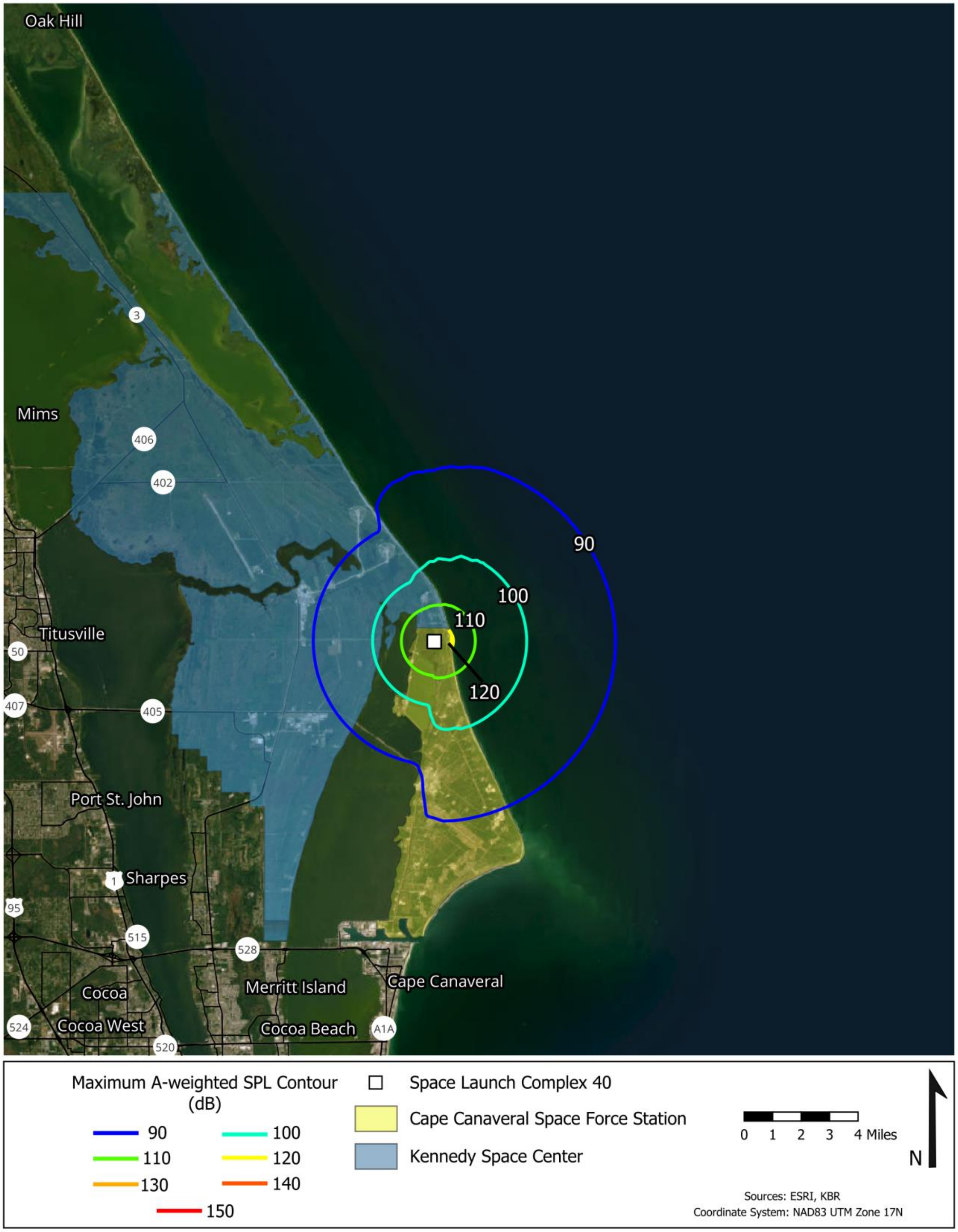


Figure 4. Falcon 9 Booster Landing at SLC-40: Maximum A-Weighted Sound Levels

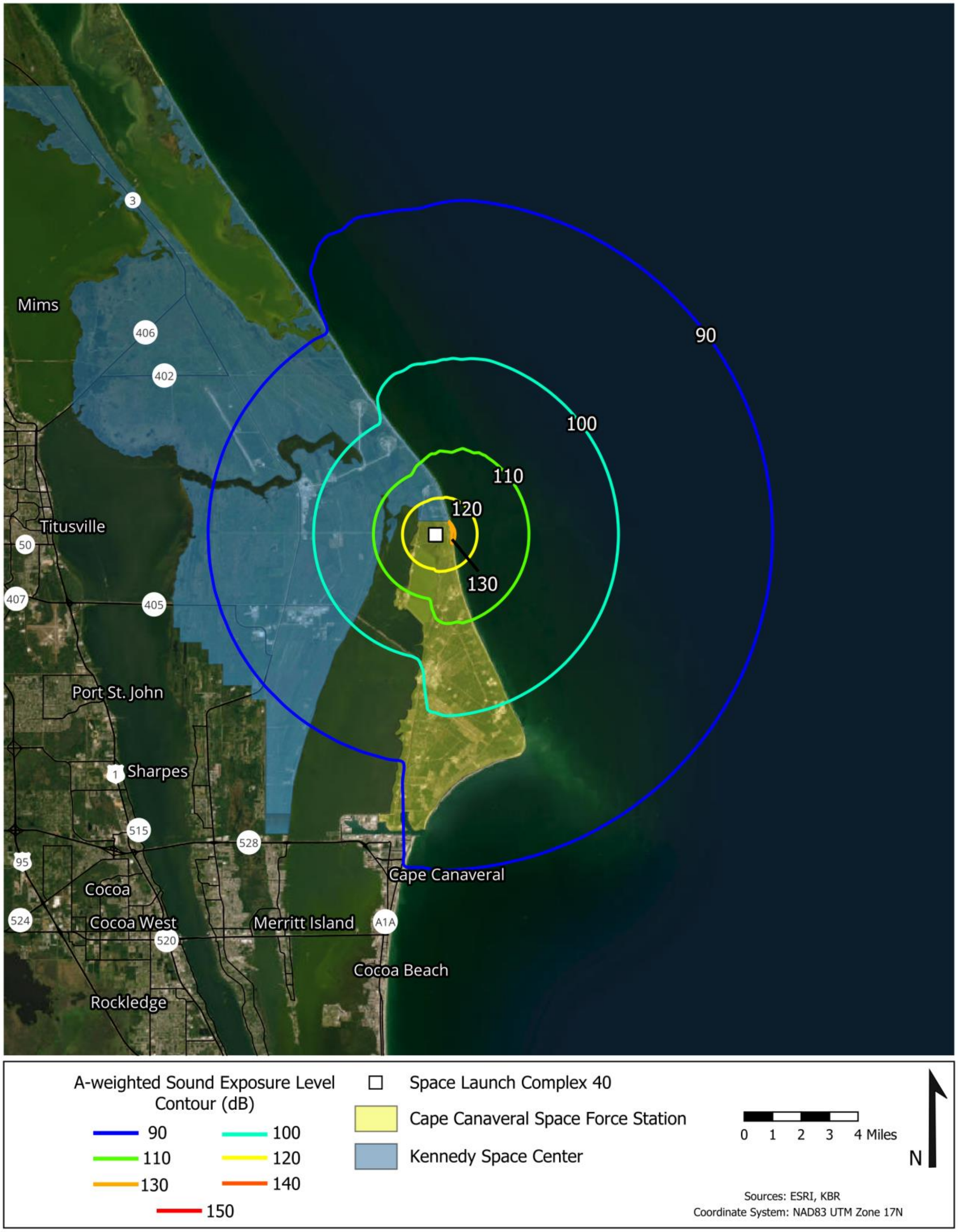


Figure 5. Falcon 9 Booster Landing at SLC-40: Sound Exposure Levels

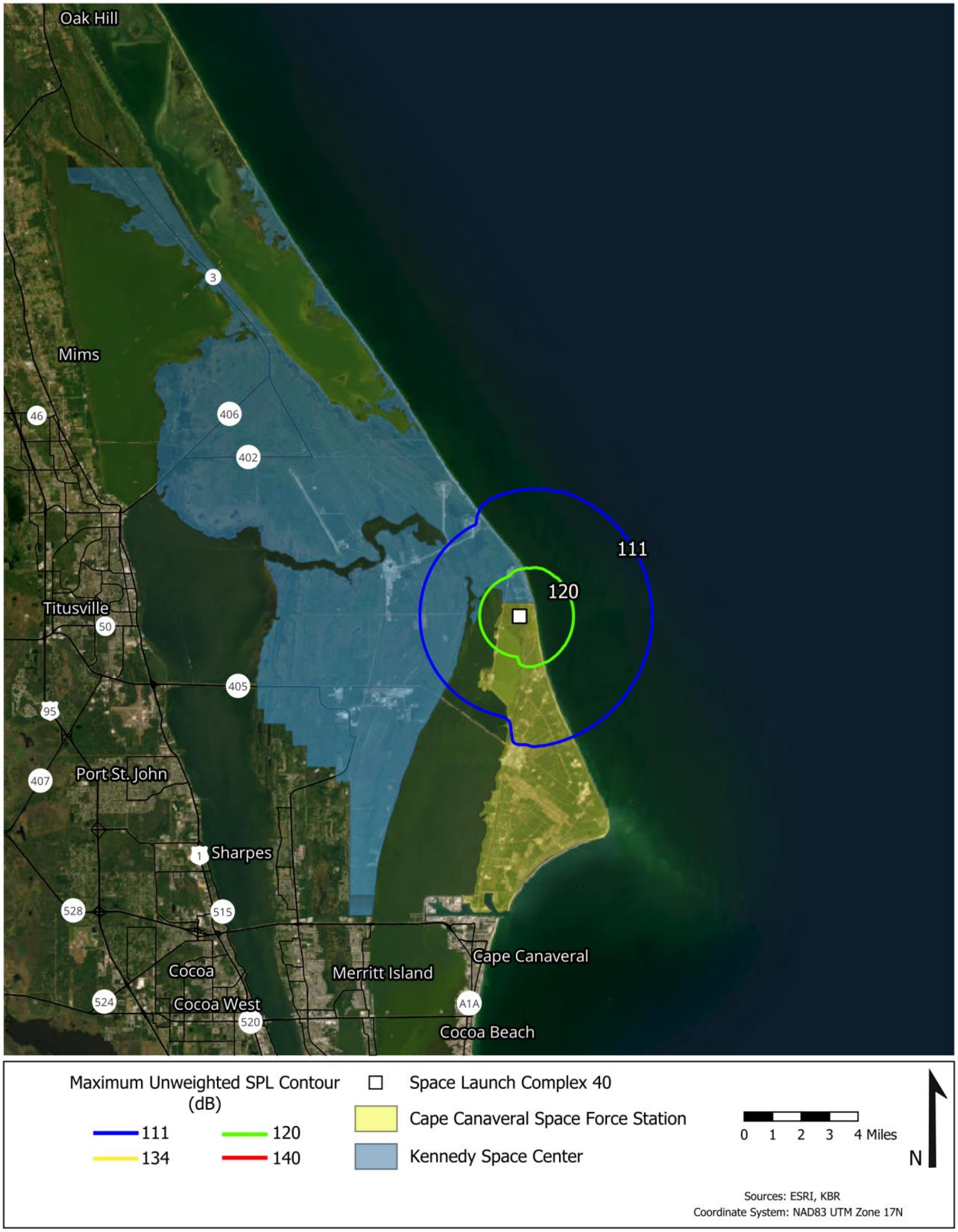


Figure 6. Falcon 9 Booster Landing at SLC-40: Maximum Unweighted Sound Levels

Falcon 9 Static Fire Test Single Event Noise Levels at SLC-40

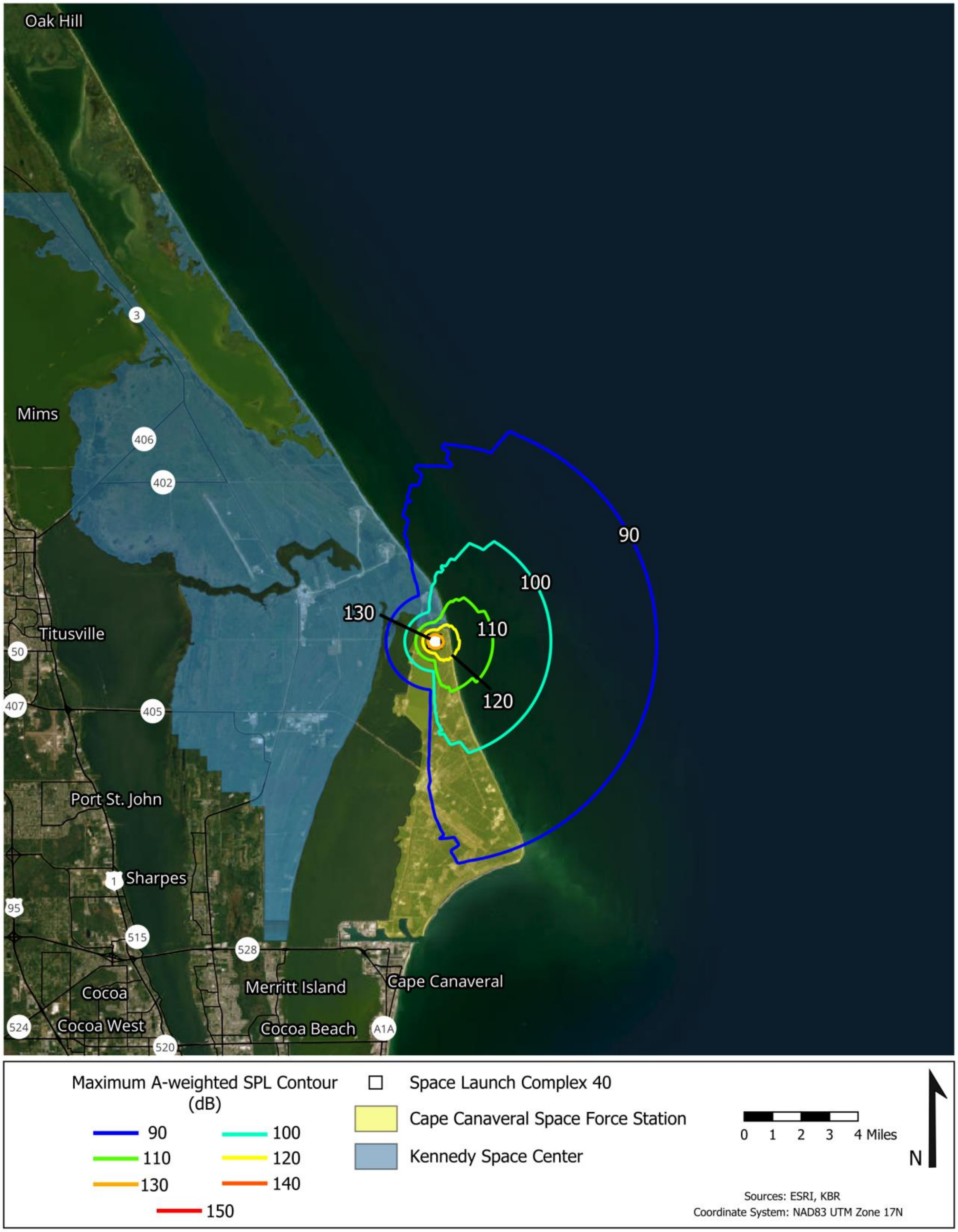


Figure 7. Falcon 9 Static Fire Test at SLC-40: Maximum A-Weighted Sound Levels

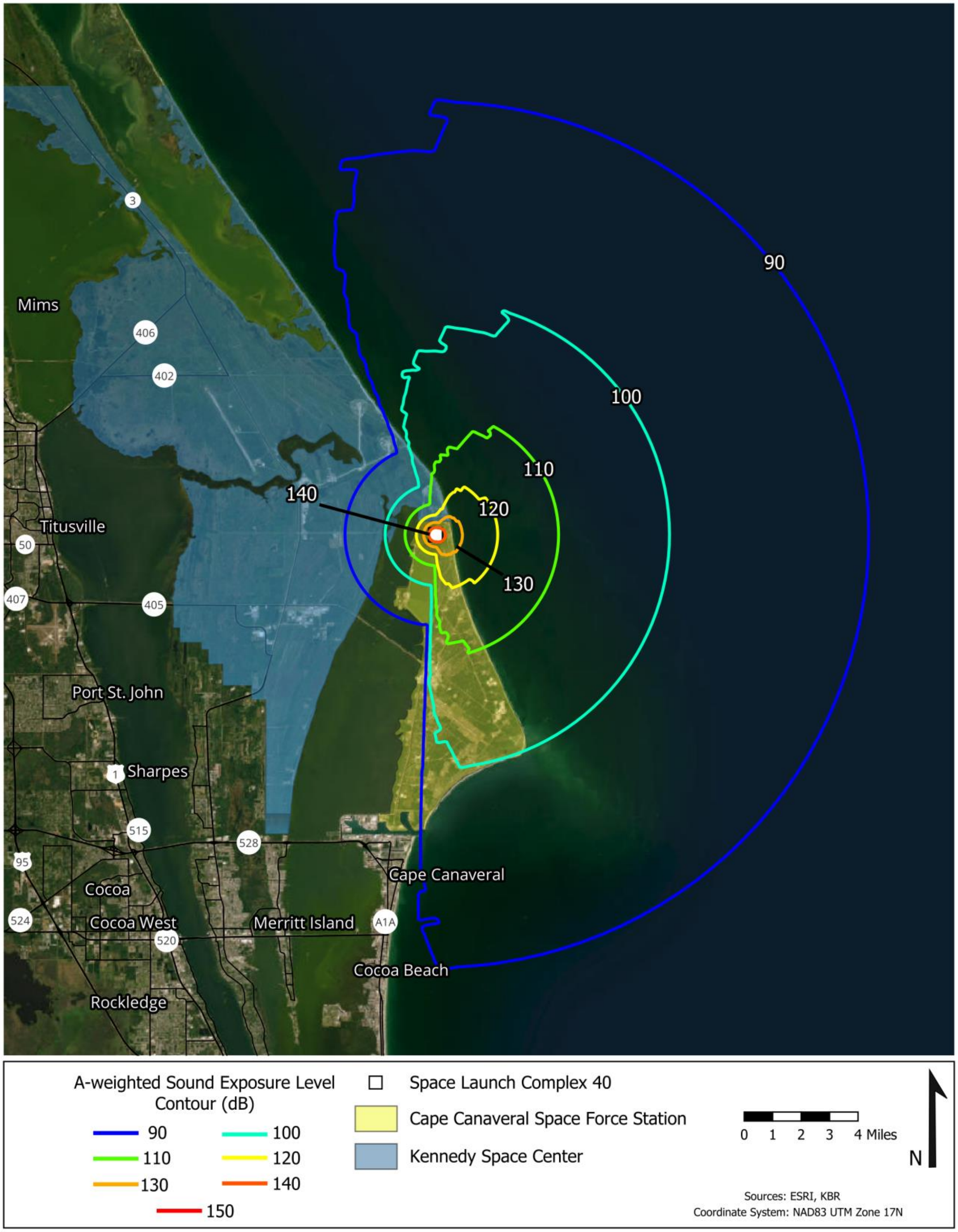


Figure 8. Falcon 9 Static Fire Test at SLC-40: Sound Exposure Levels

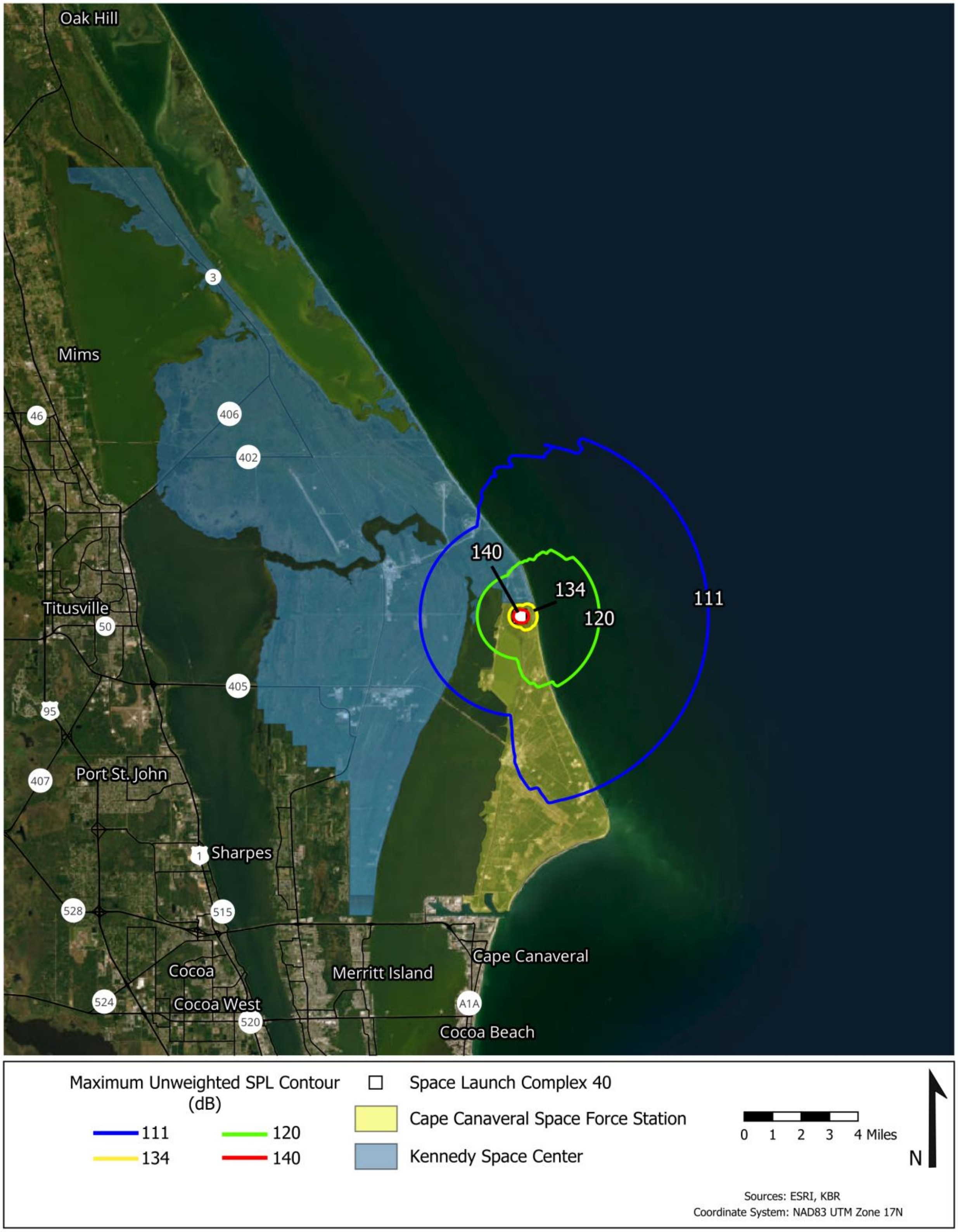


Figure 9. Falcon 9 Static Fire Test at SLC-40: Maximum Unweighted Sound Levels

3.0 Updated Cumulative Noise Exposure Results for Falcon 9 Block 5 Operations at SLC-40

The cumulative noise exposure results for Falcon 9 Block 5 operations at SLC-40 were also updated due to the revision to the SEL model in RNOISE and the change in operations cadence, which was increased to 120 launches, 34 booster landings, and 40 static fire tests, all modeled as nighttime operations. Cumulative noise levels are represented using the DNL metric where DNL 65 dBA is the applicable land use guideline. Figures 10 through 12 show the DNL 60, 65, 75, 85, and 95 dBA contours for Falcon 9 Block 5 launches, booster landings, and static fire tests, respectively whereas Figure 13 shows the same DNL contours for all these operations combined. All individual sets of DNL contours, for each type of operation, are within CCSFS and KSC properties as is the set of DNL contours for all operations combined. Comparing Figure 10 (DNL for launches) with Figure 13 (Combined DNL for all operations), it is evident that launch noise makes up most of the noise exposure for these combined operations. For all Falcon 9 Block 5 operations, individual or combined, the DNL 65 dBA contours are within the CCSFS and KSC properties.

Falcon 9 Orbital Launch Cumulative Noise Levels at SLC-40

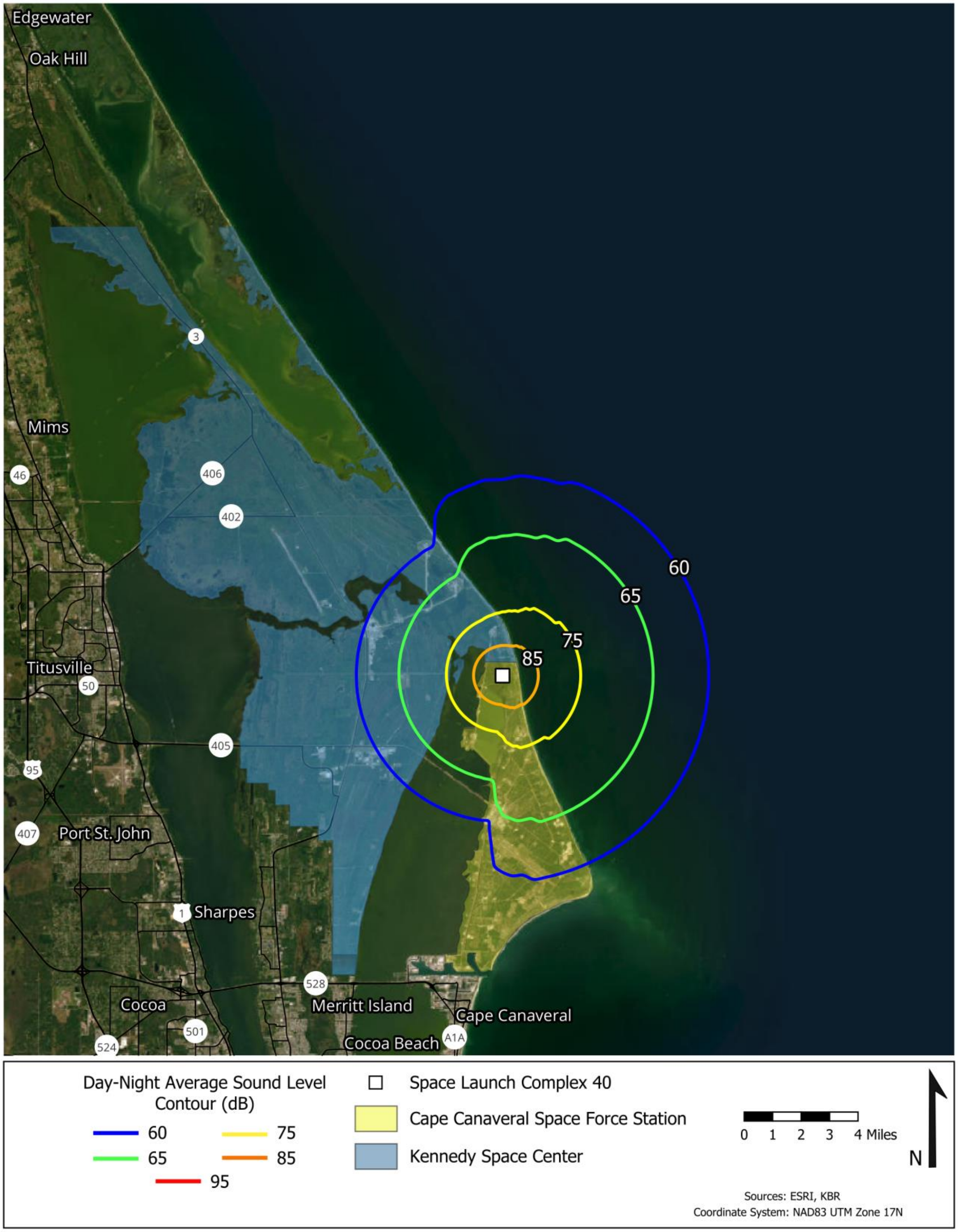


Figure 10. Falcon 9 Orbital Launches at SLC-40: Day-Night Average Sound Levels

Falcon 9 Booster Landing Cumulative Noise Levels at SLC-40

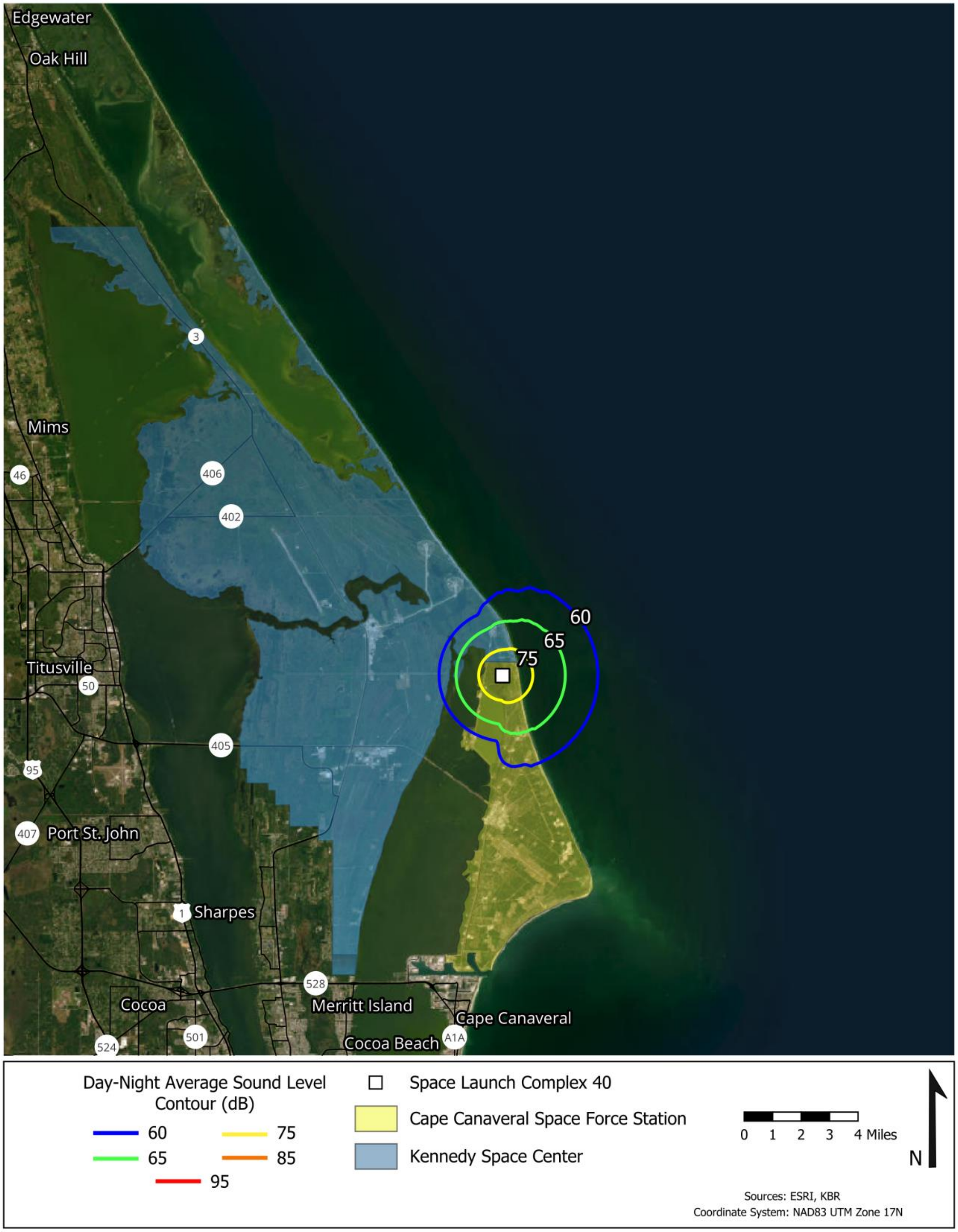


Figure 11. Falcon 9 Booster Landings at SLC-40: Day-Night Average Sound Levels

Falcon 9 Static Fire Test Cumulative Noise Levels at SLC-40

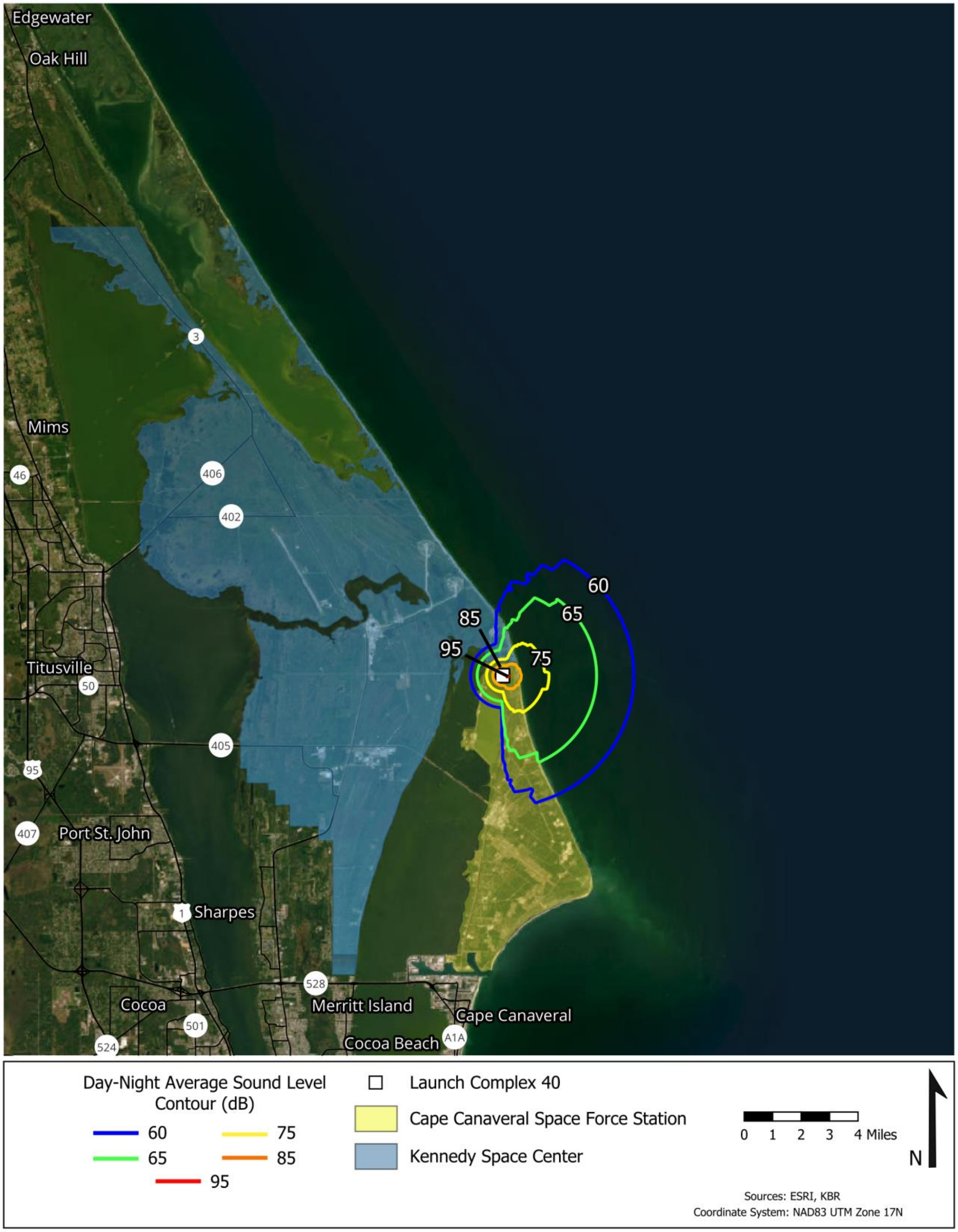


Figure 12. Falcon 9 Static Fire Tests at SLC-40: Day-Night Average Sound Levels

Falcon 9 Combined Operations Cumulative Noise Levels at SLC-40

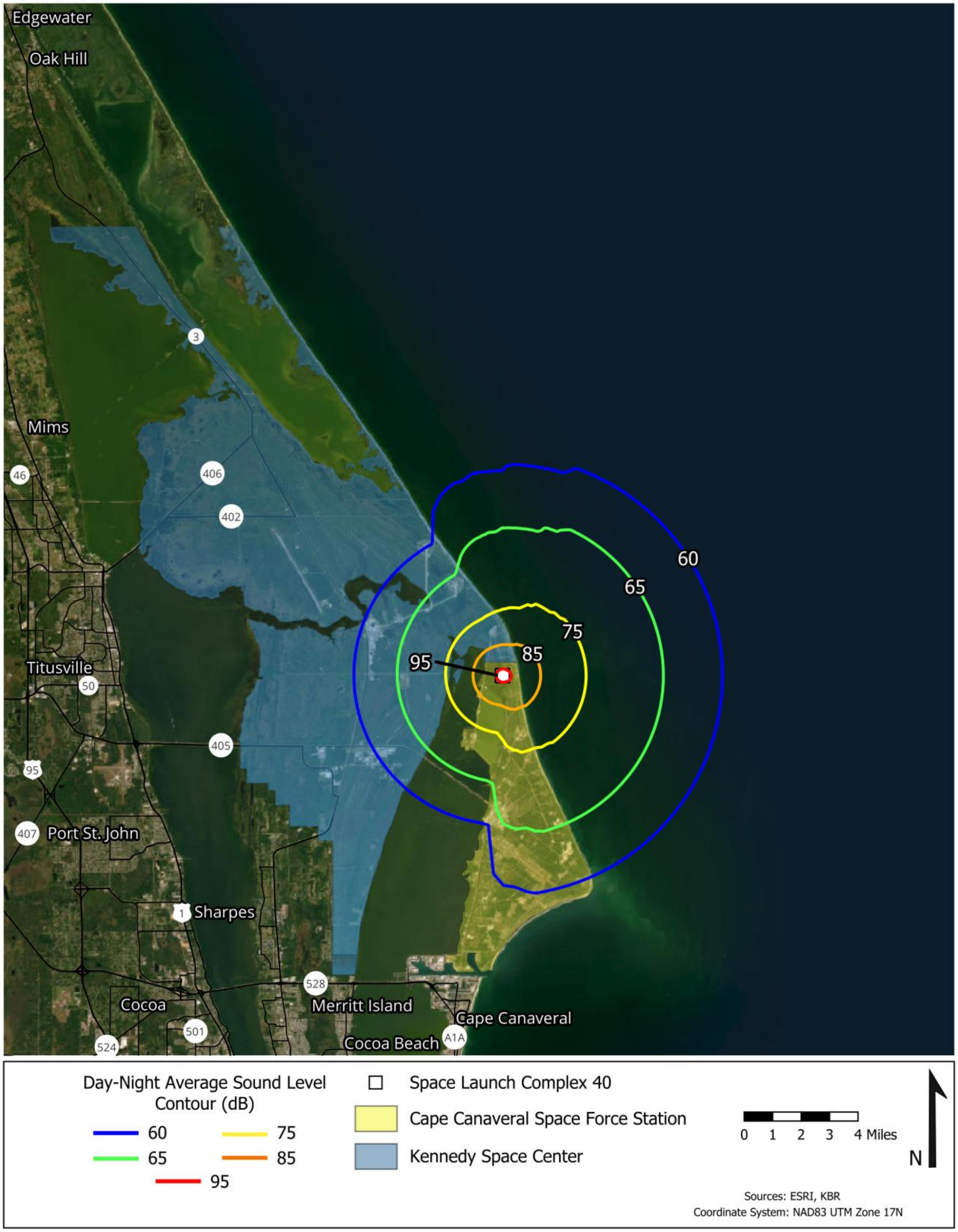


Figure 13. Falcon 9 Combined Launches, Landings, and Static Tests at SLC-40: Day-Night Average Sound Levels

4.0 References

1. Plotkin, K.J., “A model for the prediction of community noise from launch vehicles. (A),” J. Acoust. Soc. Am. 127, 1773, April 2010.

2. Bradley, K.B., “Rocket Noise Study for SpaceX Flight and Static Test Operations at Cape Canaveral Air Force Station and Kennedy Space Center”, KBR Technical Note 18-03, October 2018.

3. Chien, C.F. and W.W. Soroka. “Sound Propagation Along An Impedance Plane,” Journal of Sound and Vibration 43(1), 9-20, 1975.

4. “American National Standard Method for Calculation of the Absorption of Sound by the Atmosphere,” ANSI S1.26 (R2004).

5. U.S. Department of Transportation. Federal Aviation Administration Order 1050.1F “Environmental Impacts: Policies and Procedures,” 2015.

6. OSHA, "Federal Regulation Title 29 - Labor, Subtitle B, Chapter XVII, Part 1910 - Occupational Safety and Health Standards, Subpart G - Occupational Health and Environmental Control, 1910.95 -Occupational noise exposure," [Online]. Available: http://www.ecfr.gov/. [Accessed December 2020].

7. Fenton, R., and R. Methold. 2016. Mod Shoeburyness and Pendine noise and vibration study criteria for the assessment of potential building damage effects from range activities. June. Southdowns Environmental Consultants, Lewes, East Sussex, UK. 55 pp.

8. S. Guest and R. M. Slone Jr., “Structural Damage Claims Resulting from Acoustic Environments Developed During Static Firing of Rocket Engines,” San Antonio, Texas, April 1972.

SPACEX

MEMORANDUM **July 10, 2024**

TO: Federal Aviation Administration, Office of Commercial Space Transportation

FROM: Space Exploration Technologies

SUBJECT: Sonic Boom Analysis

Space Exploration Technologies (SpaceX) is proposing to increase its annual launch rate and land its Falcon launch vehicle at a new landing zone at SLC-40 at Cape Canaveral Space Force Station (CCSFS). SpaceX currently lands Falcon Landing Zones 1 and 2 at CCSFS, but the United States Space Force has indicated SpaceX's license for those sites will not be renewed.

An Environmental Assessment (EA) is being prepared for the Proposed Action. The EA is being prepared in accordance with the National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321 et seq.), Council on Environmental Quality NEPA-implementing regulations (40 CFR Parts 1500 to 1508), and FAA Order 1050.1F, Environmental Impacts: *Policies and Procedures*. In accordance with FAA Order 1050.1F, if a project involves commercial space launch vehicles reaching supersonic speeds, the potential for sonic boom impacts should be discussed. A sonic boom is expected to result from Falcon landings. SpaceX is proposing to use PCBOOM, an FAA-approved model, for predicting sonic booms from landings.

Previously, SpaceX and the U.S. Air Force adapted the sonic boom modeling used in the NASA technical paper 1122 with modifications, including expansion of the geometry and simplifying relations to estimate the wave propagation to the ground. That modeling approach along with field collected data was used to support the 2020 *Final Environmental Assessment and Finding of No Significant Impact for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Air Force Station*. This memo is intended to supplement the previous analysis due to the relocation of the landing zone.

Sonic Boom Modeling Approach

Previous work on predicting and measuring sonic boom magnitudes with the return to land of the Falcon 9 first stage has shown that a simplified model, grounded in measured data, has improved capability for general prediction over PCBOOM, unless specific flight atmospheric conditions are utilized. However, as PCBoom is an approved model by the Federal Aviation Administration's Office of Energy and Environment, PCBoom Version 6.6 was utilized.

SpaceX has derived initial predictions for sonic boom magnitudes and contours during Falcon first stage landings using the industry standard PCBOOM software. Primary inputs used with PCBOOM are the planned flight trajectories for return to land, a shape factor, and Falcon's length and weight. PCBOOM was run utilizing the Carlson mode of calculation, with a simple N-wave shaped, F-function for originating shock waves from the supersonic flight of the vehicle.

The Falcon first stage is a long, slender vehicle that travel through supersonic speeds at low angles of attack with engines facing into the flow. The Falcon first stage shape factor of 0.035 was derived by anchoring measured data across ten flights to sonic boom modeling with the Carlson method.

SpaceX Sonic Boom Data and Modeling

Sonic booms generated on ascent over the ocean, ascent for polar missions, and downrange landings were previously analyzed in the 2020 *Falcon Environmental Assessment and Finding of No Significant Impact for SpaceX Falcon Launches at Kennedy Space Center and Cape Canaveral Space Force Station* (FAA 2020), thus are not discussed in this analysis.

While sonic boom propagation is influenced by atmospheric conditions at the time of landing, Figure 1 represents a sample SpaceX modeled overpressure predictions for a Falcon first stage landing at SLC-40. The highest predicted overpressures are focused at the landing zone, ranging as high as 10 pounds per square foot (psf).

In general, sonic booms above 0.2 psf could be heard by someone who is expecting it and sonic booms greater than 0.5 psf would be expected to be noticed. Therefore, it is reasonable to assume people in and around the Space Coast region, such as Titusville, Merritt Island, Cape Canaveral, Cocoa, and other localities may notice sonic booms during landing events depending on atmospheric conditions at the time of launch and the specific landing trajectory.

Modeled peak overpressures were converted to an equivalent C-weighted DNL (CDNL) to determine significance with respect to human annoyance. Given that the sonic boom contours are expected to generally stay within the bounds of KSC and CCSFS, CDNLs were calculated for the 0.5, 1, and 2 psf overpressure contours assuming all 34 sonic booms occurred at night with a 10 dB penalty. The 0.5 psf overpressure events equate to a CDNL of 45.9 dBC, the 1 psf overpressure events equate to a CDNL of 51.9 dBC, and the 2 psf event equates to a CDNL of 57.9 dBC. These are all below the FAA's significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA). The potential for hearing damage (with regards to humans) is negligible, as the modeled sonic boom overpressure levels on populated areas off of KSC and CCSFS are low than the approximate 4 psf impulsive hearing conservation noise criteria.

For most launches, sonic booms generated from ascent would occur over the ocean thus would not contribute to the CDNL for landing events at SLC-40 (Figure 2). Sonic booms generated during ascent for a polar launch were previously analyzed in the 2020 EA, shown in Figure 3. These areas do not overlap with those that would experience sonic booms from landing events at SLC-40, thus would not contribute to that CDNL. The 2020 EA stated:

However, for the few launches with southern trajectories (up to six per year), sonic boom peak overpressures were modeled to occur over populated land near Vero Beach, Florida, with the vast majority experiencing peak overpressures of less than 1 psf. Figure 4-3 shows a narrow region north of Vero Beach with land area less than 3 square miles is predicted to receive overpressures of greater than 2 psf with less than 0.01 square miles experiencing 4.6 psf. The majority of the land area within the sonic boom footprint is expected to experience overpressures of around 0.25 psf, which is similar to distant thunder. The location of focus boom regions is highly dependent on the actual trajectory and atmospheric conditions, and it is unlikely any given location would experience the focus more than once over multiple events. A modeled peak overpressure of 4.6 psf translates to an equivalent C-weighted DNL (CDNL) of 51 dBC. Therefore, the proposed Falcon 9 polar launch operation does not pose a significant impact with regards to human annoyance as the noise exposure is less than the significance threshold of CDNL 60 dBC for impulsive noise sources (equivalent to DNL 65 dBA).

Figure 1. Sample Sonic Boom from Falcon Landing at SLC-40

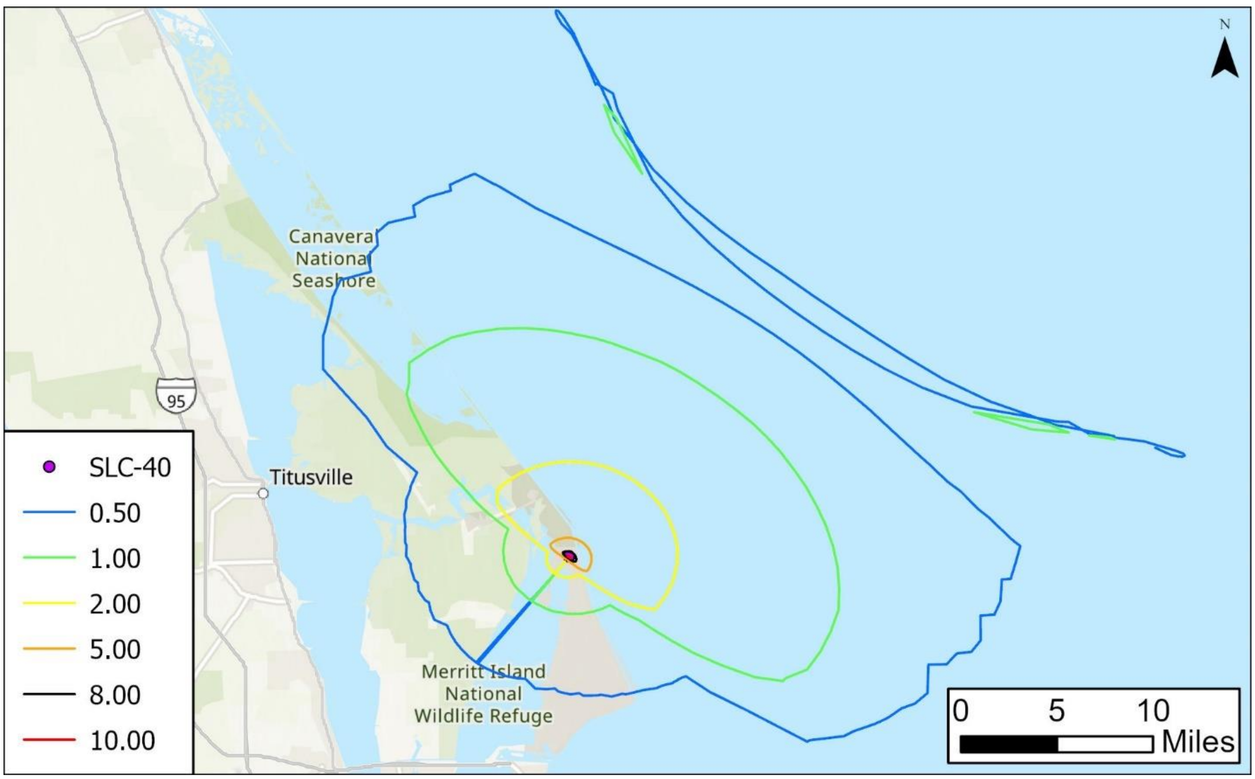


Figure 2. Sample Sonic Boom from Falcon Ascent from SLC-40

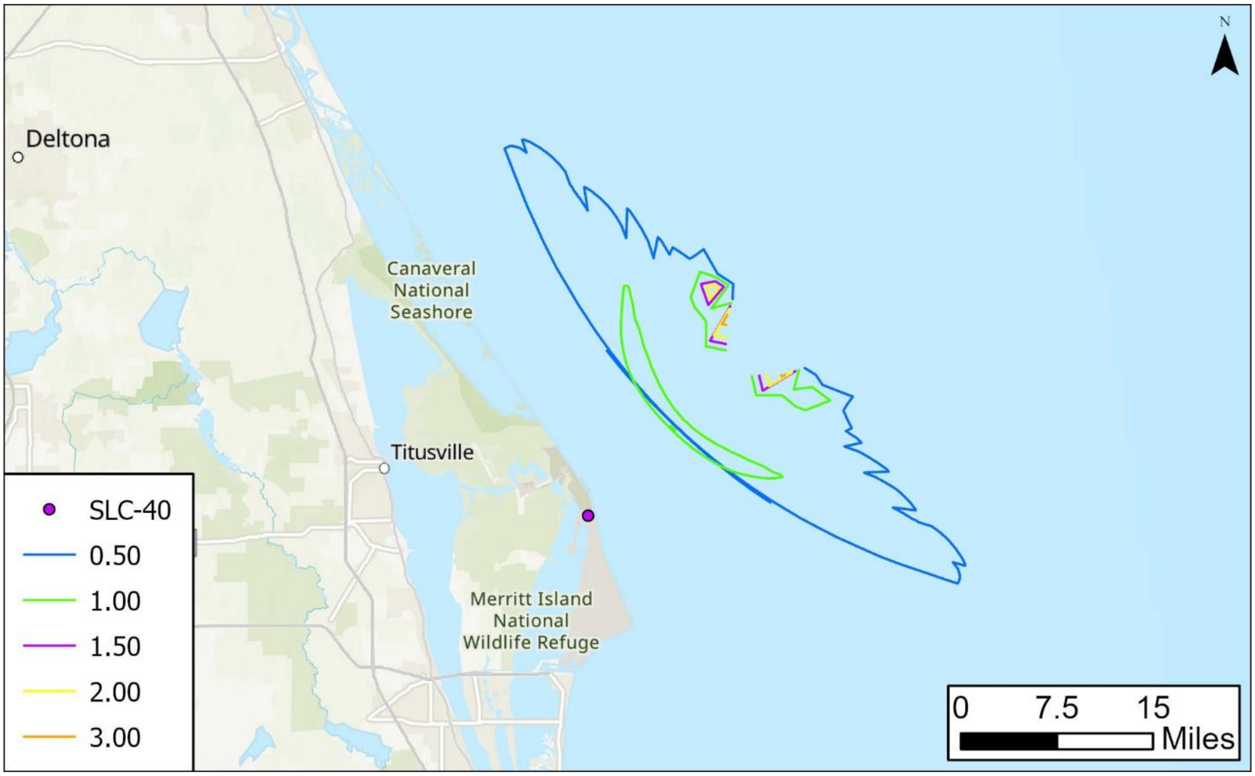
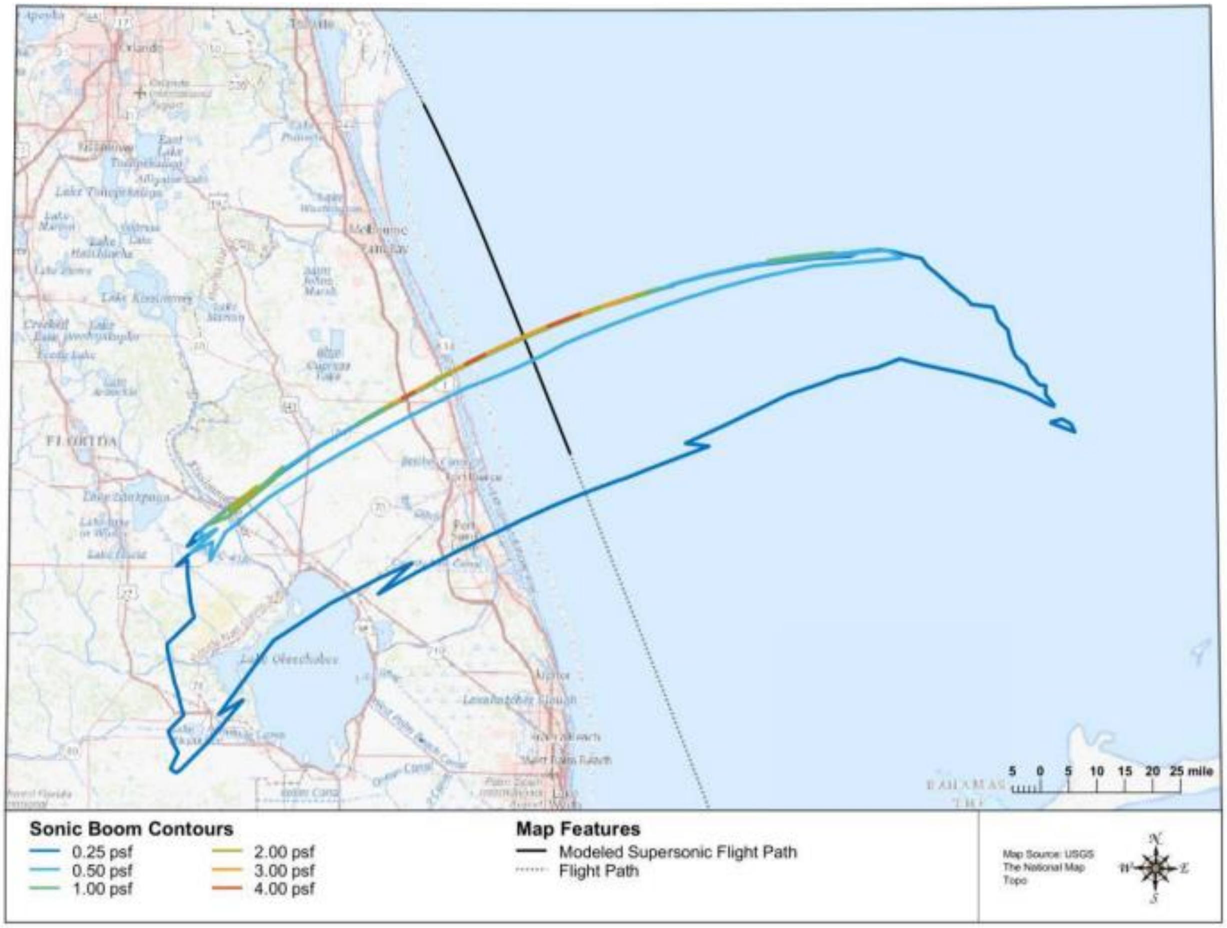


Figure 3. Predicted Sonic Boom Overpressure Contours for Falcon 9 Southern [Polar] Launch Trajectory



Source: 2020 EA