Commercial Space Operations Noise Modeling

Micah Downing, Ph.D.
Micah.Downing@BlueRidgeResearch.com
Blue Ridge Research and Consulting

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Blue Ridge Research and Consulting
Michael James, M.S.
Alexandria Salton, M.S.
Micah Downing, Ph.D.

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Airport Cooperative
Research Program (ACRP)

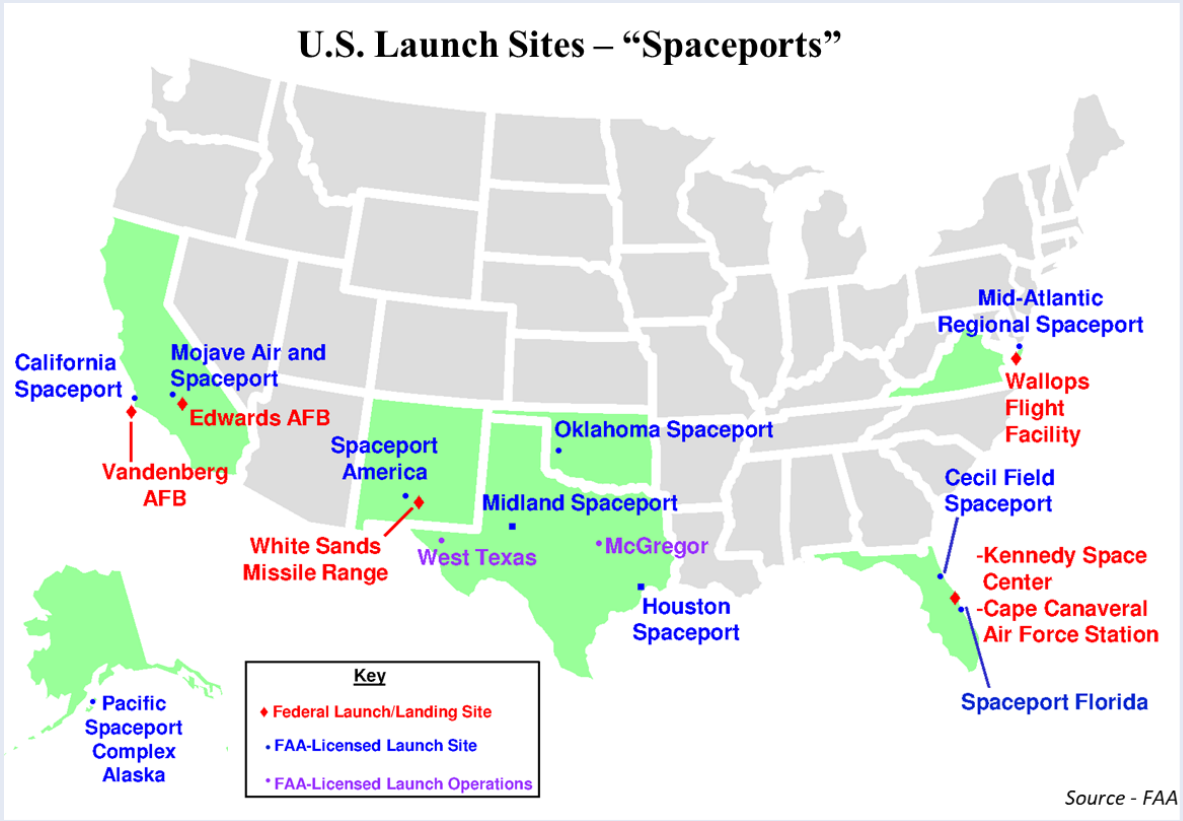
Background

Commercial Space

Vehicle Types

Noise Modeling

Acquisition of a site/vehicle license or experimental permit is a Federal Action subject to environmental review



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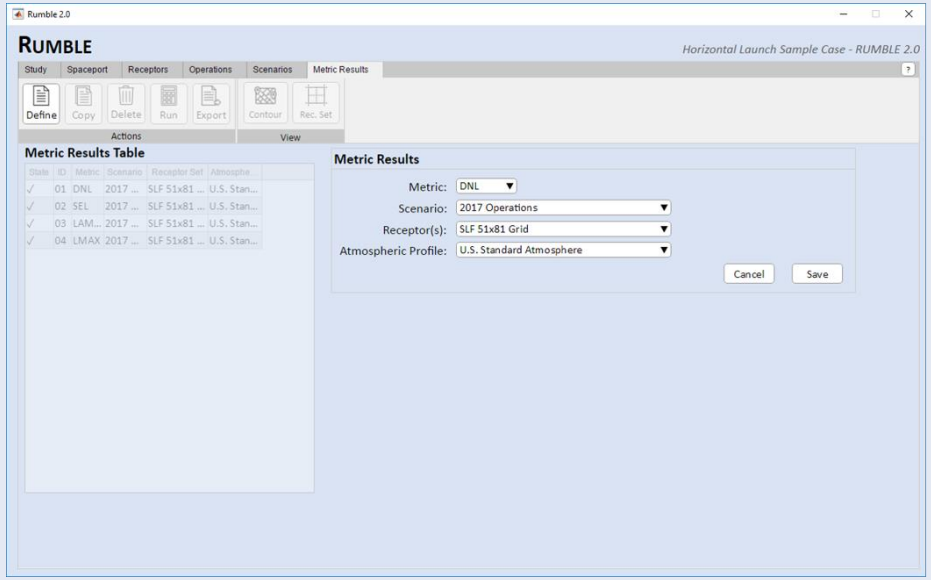
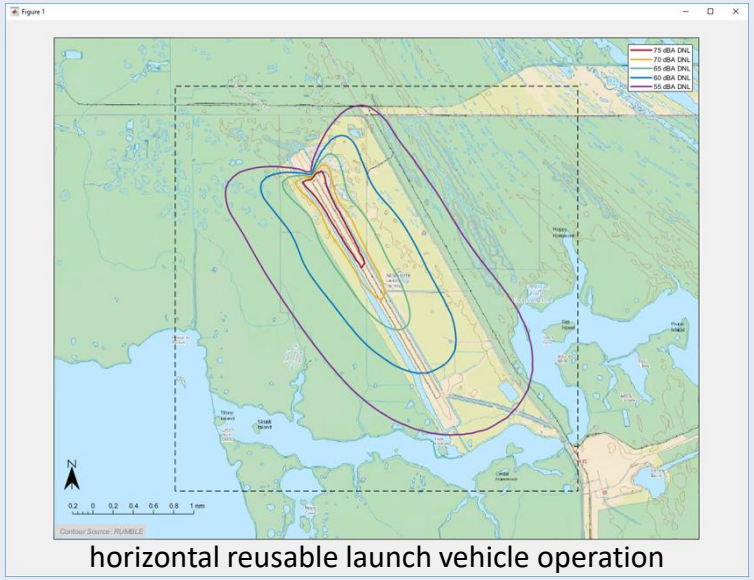
RUMBLE : BRRC's Launch Vehicle Acoustic Simulation Model





horizontal reusable launch vehicle operation

- Relevant to environmental analysis of commercial space operations
- Efficient/accurate noise model
- Database of vehicle and engine/motor parameter

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AEDT Integration

- **Workflow –** Modified RUMBLE program workflow to be more closely linked with AEDT. Adopted relevant names and element order prescribed by ASIF format.
- **User model input –** Transitioning to xml file format (open source) to benefit from hierarchical structure, simplicity to read/edit (plain text), and data identification capabilities.
- **Model output –** Noise Model ASCII Grid Format (NMAGF) files have been modified to ensure users can import and combine RUMBLE NMAGF files and AEDT metric results within the AEDT user interface.
- **Database management –** Adopted database organization used by AEDT so that rocket elements can easily be integrated into the existing database.
- **User-interface –** Developed a RUMBLE graphical user interface to allow users to run the tool in a simplified mode and view results.

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Interim AEDT Integration

DATABASE

```
<?xml version="1.0" encoding="utf-8"?>
<DATABASE>
    <aircraft>
    <airframe>
    <engine>
</DATABASE>
```

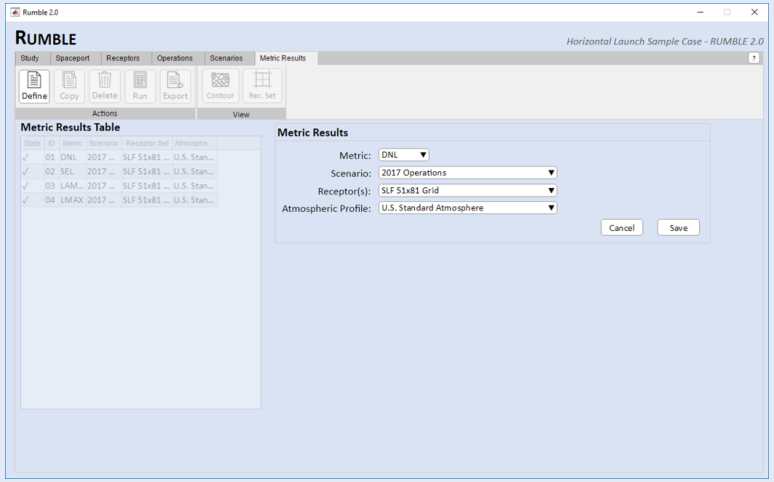
INPUT (XML)

```
<?xml version="1.0" encoding="utf-8"?>
<RocketNoiseModelInputXml>
    <case>
    <veh>
    <trj>
    <ops>
    <atm>
    <rec>
        <name>KSC 50x50 Grid</name>
        <type>Cartesian Grid</type>
        <Xcount>50</Xcount>
        <Ycount>50</Ycount>
        <Xspc>1215.224</Xspc>
        <Yspc>1215.224</Yspc>
        <h0>5</h0>
        <latitude>28.5263250291538</latitude>
        <longitude>-80.6969485022122</longitude>
        <altitude>0</altitude>
        <reference>LowerLeft</reference>
    </rec>
    <met>
</RocketNoiseModelInputXml>
```

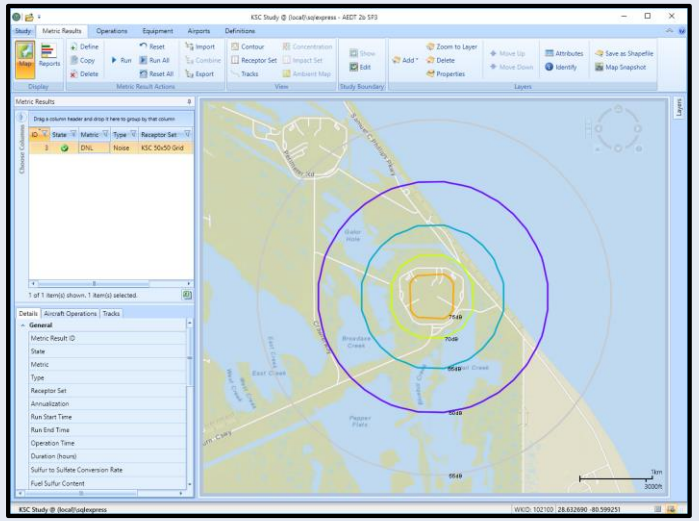
OUTPUT (GRD or SHP)

```
{TITL Grid Vers 2 3}
{CART -80.728615 28.522218 0 0 FEET 0}
{MTRC "DNL" "dBA"}
{DPAL 2500
(-80.728615,28.522218) 29.809186
(-80.724831,28.522218) 30.089225
(-80.721047,28.522218) 30.368087
(-80.717263,28.522218) 30.647154
(-80.713479,28.522217) 30.927786
(-80.709695,28.522217) 31.205843
(-80.705910,28.522216) 31.483105
(-80.702126,28.522215) 31.759119
(-80.698342,28.522215) 32.038023
(-80.694558,28.522214) 32.310791
(-80.690774,28.522213) 32.582487
(-80.686990,28.522212) 32.851297
(-80.683206,28.522210) 33.117441
```

RUMBLE



AEDT



Commercial Space Noise Modeling: RUMBLE

- Modeling Methodology
- User Interface
- Map Results
- Simulation

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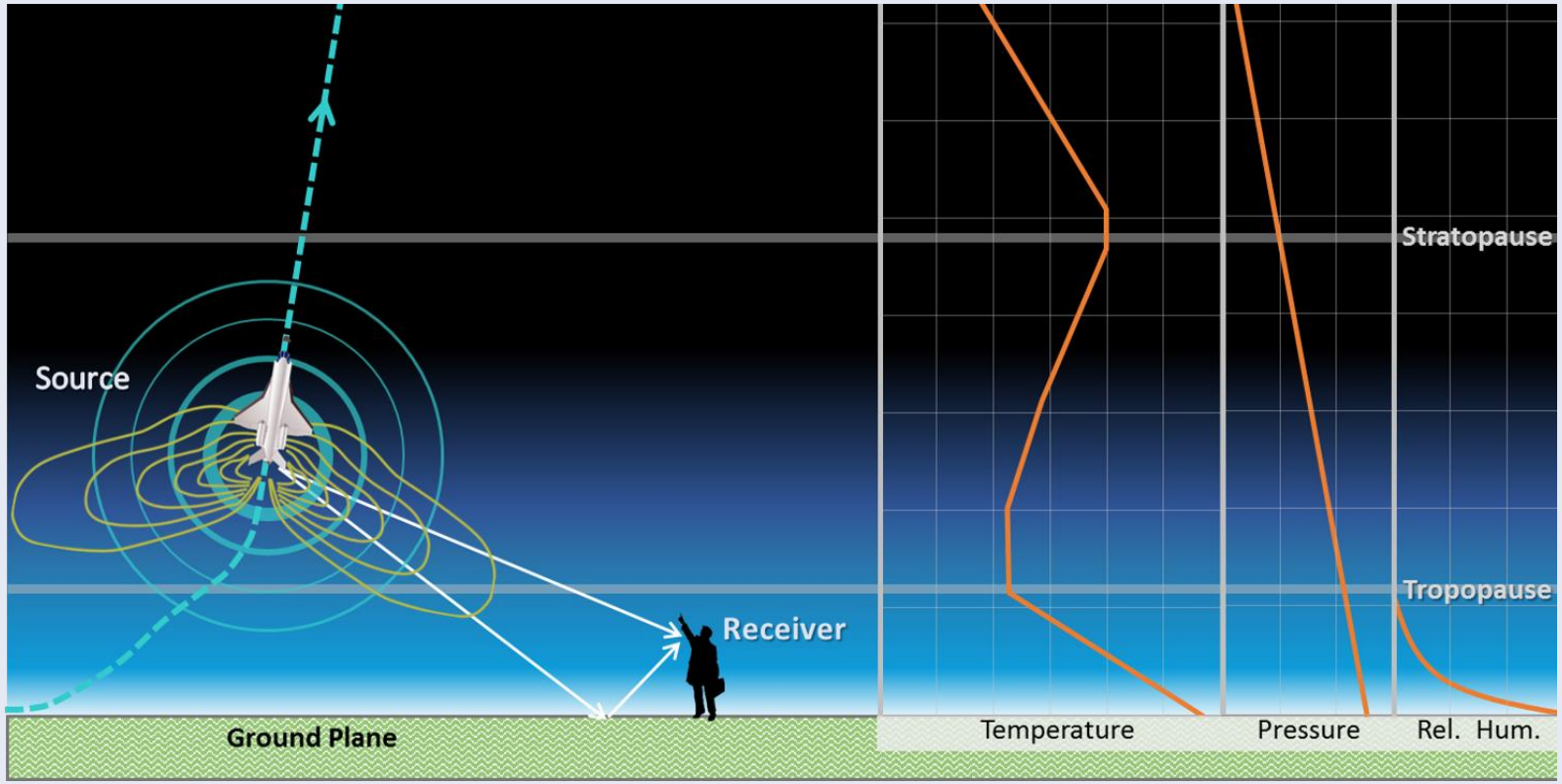

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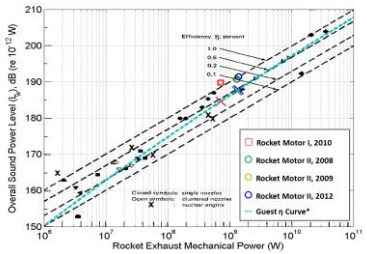
Acoustic Power

Overall sound power based on rocket-specific parameters



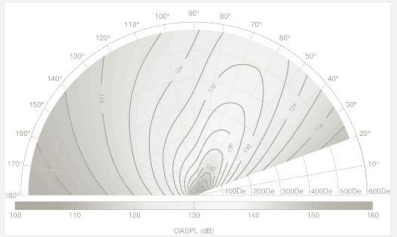
Forward Flight Effect

Rocket exhaust and ambient airflow travel in the same direction

- Decreased relative velocity
- Decreased jet mixing and resultant noise

Directivity

Acoustic power is concentrated in specific directions and the sound pressure observed will depend on the angle from the source to the receiver.



Doppler Effect

Doppler Effect changes the frequency of a wave for an observer moving relative to its source

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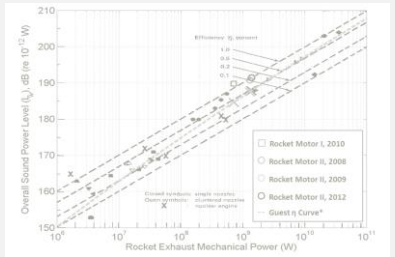

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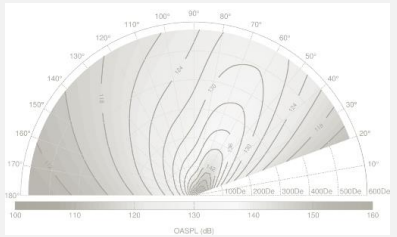

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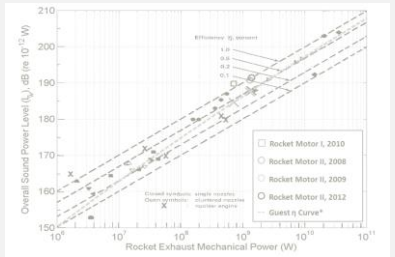

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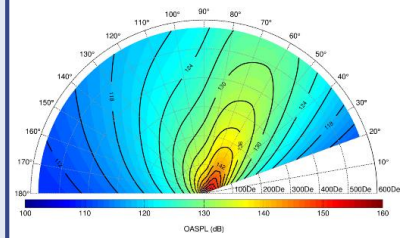

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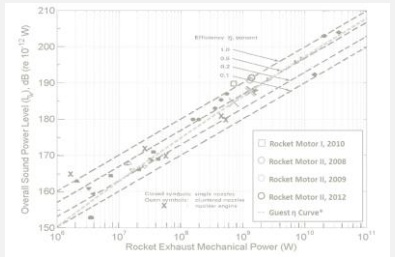

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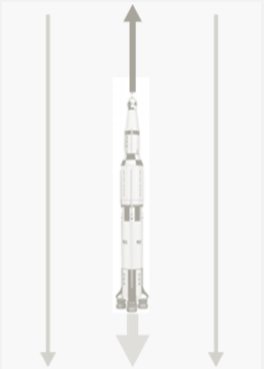

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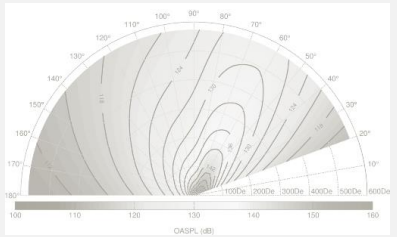

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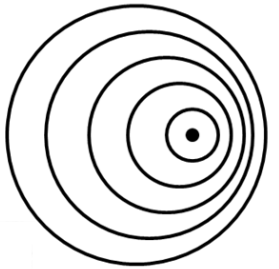

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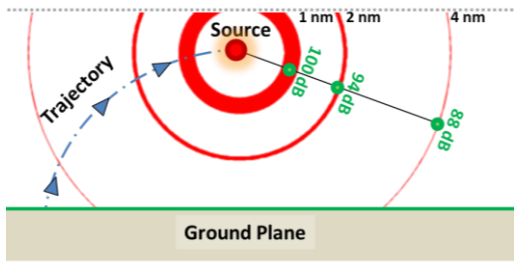
Geometric Spreading

Assumes a point source that radiates with a spherical field.

$$SPL_{b,p} = L_{w,b} - 10\,log(4\pi R^2) + DI(b,\theta)$$

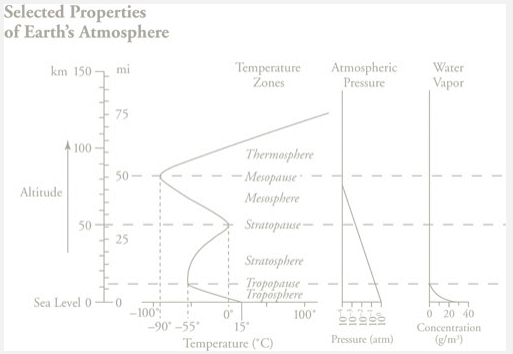
R : distance from source to receiver location



Atmospheric Absorption

Sound attenuation as a function of the temperature, humidity, and pressure of the atmosphere.

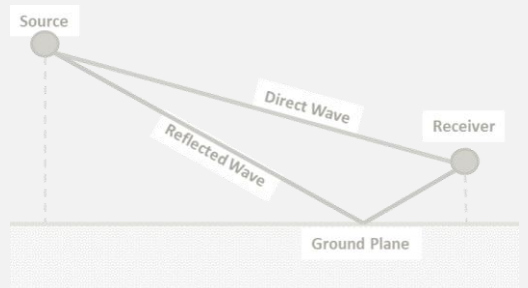
- Method: ANSI S1.26-1995
- Sum of attenuation through each layer



Ground Interference

Accounts for the combination of a direct wave (source to receiver) and a reflected wave (source to ground to receiver)

- Includes atmospheric turbulence



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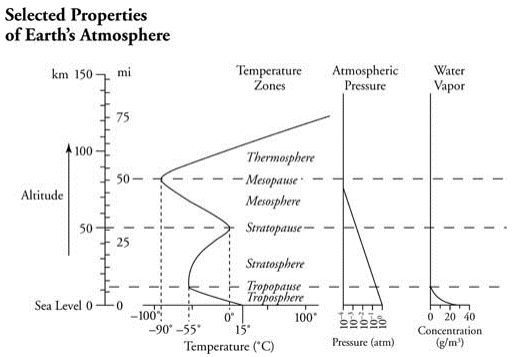

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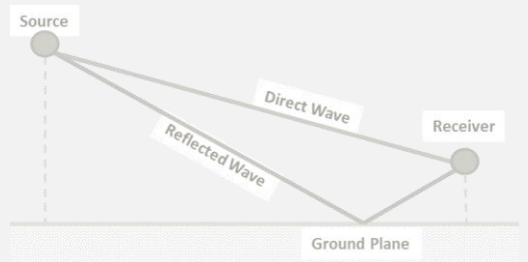

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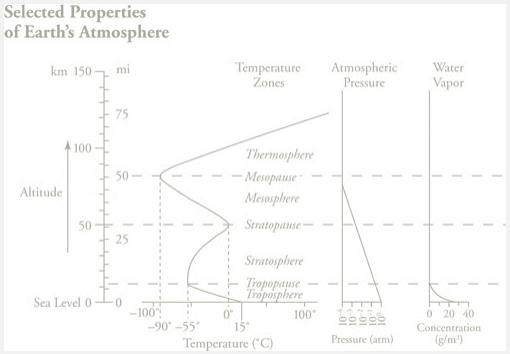

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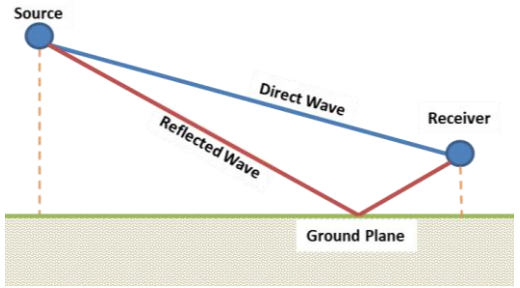

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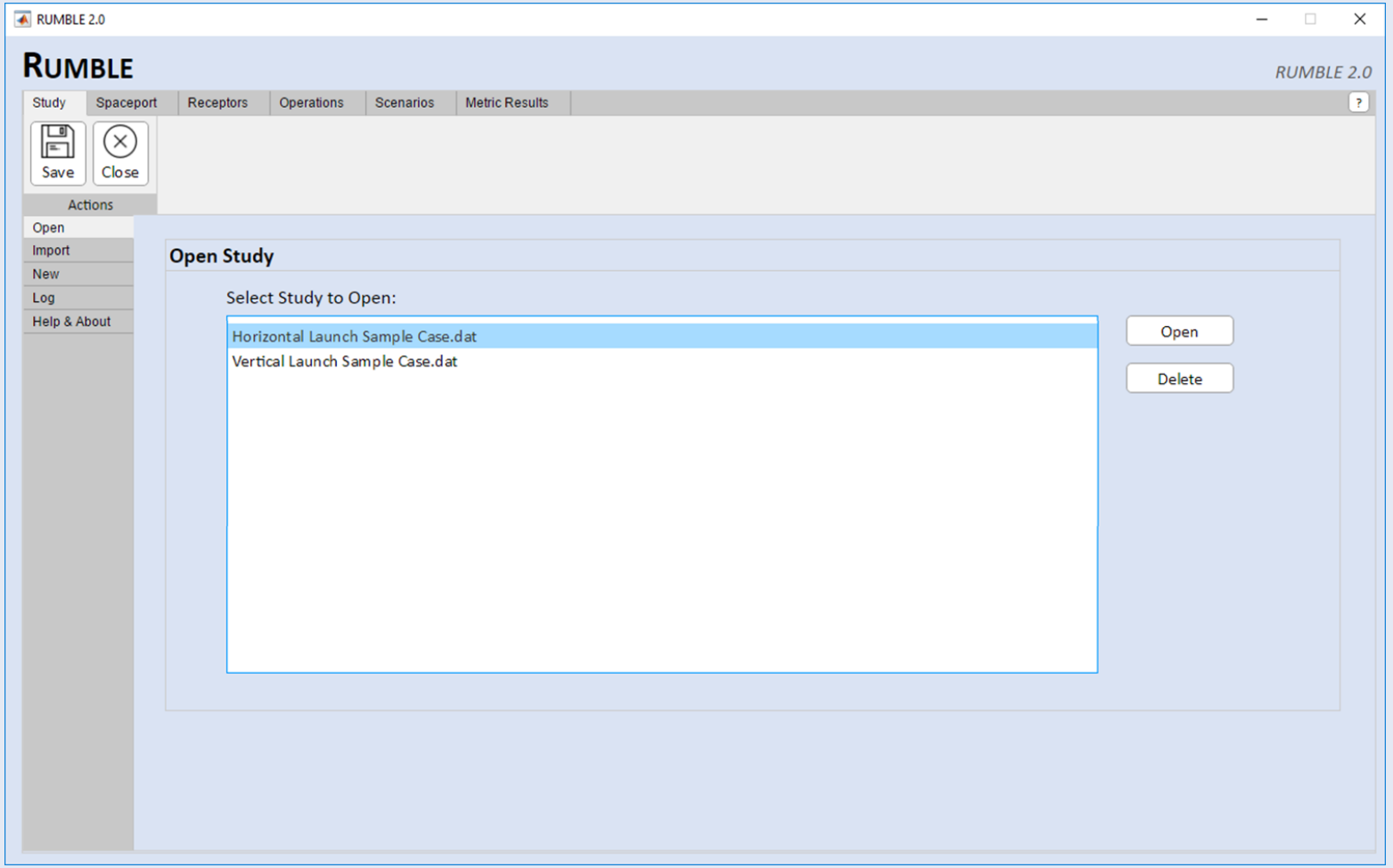

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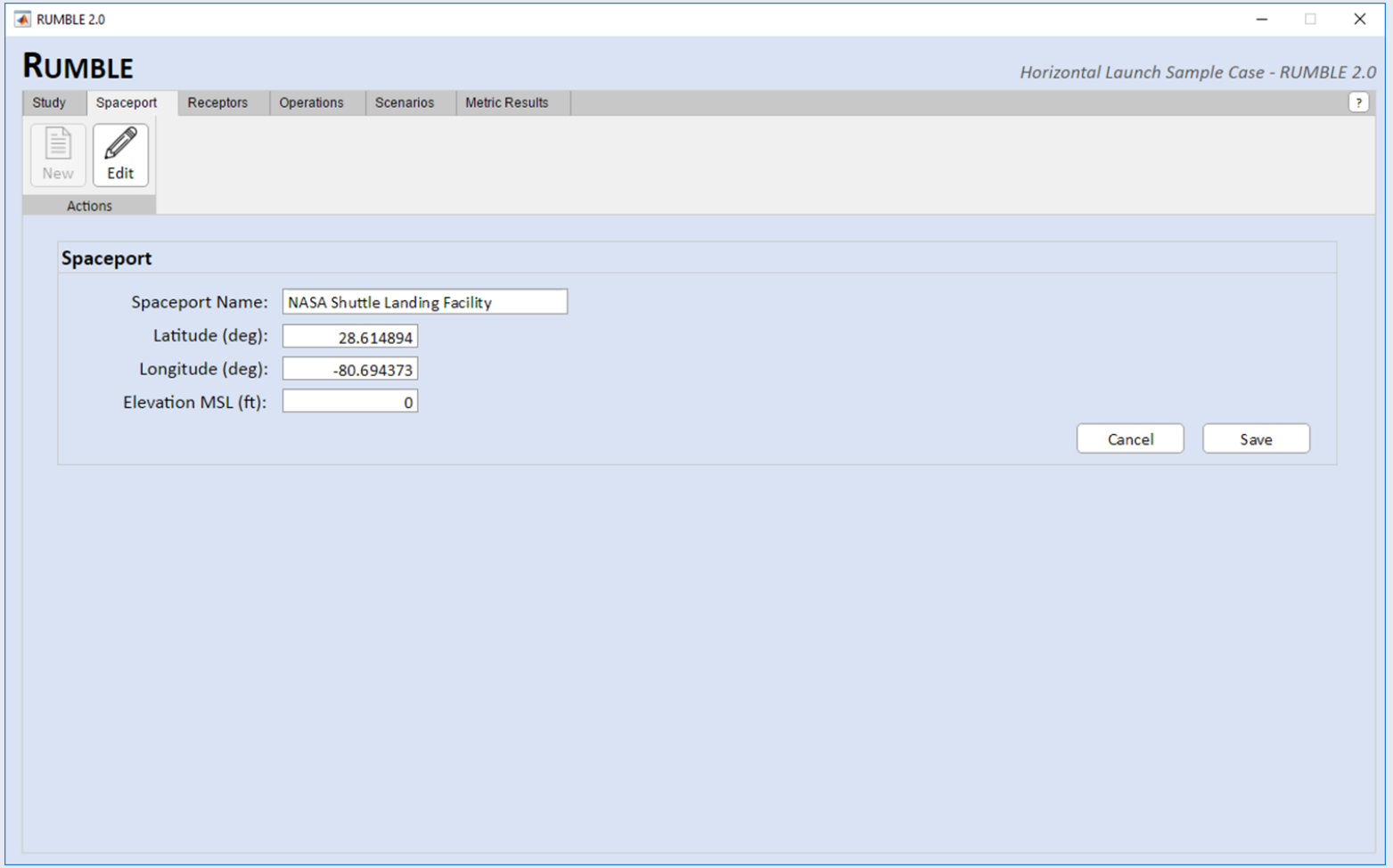

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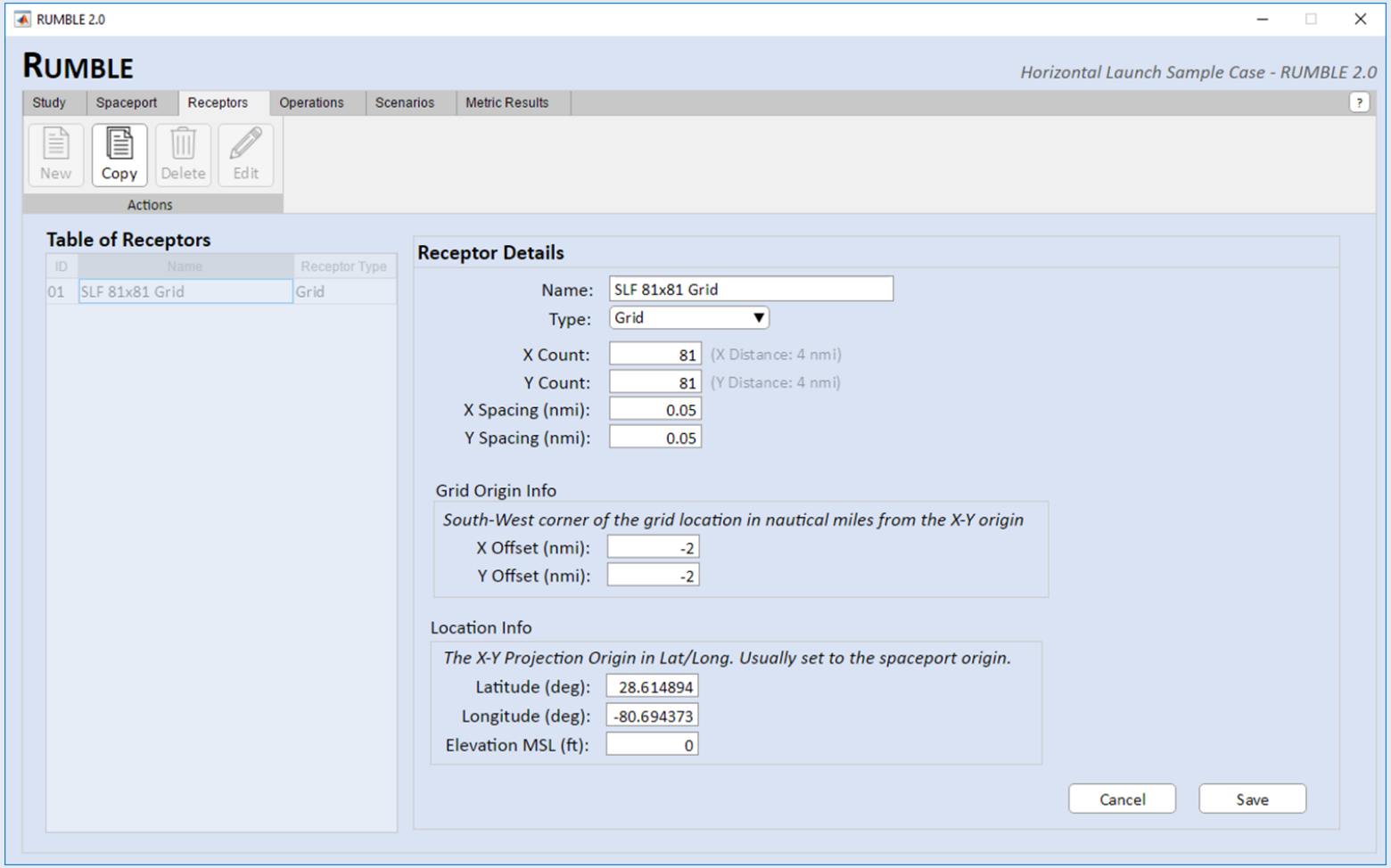

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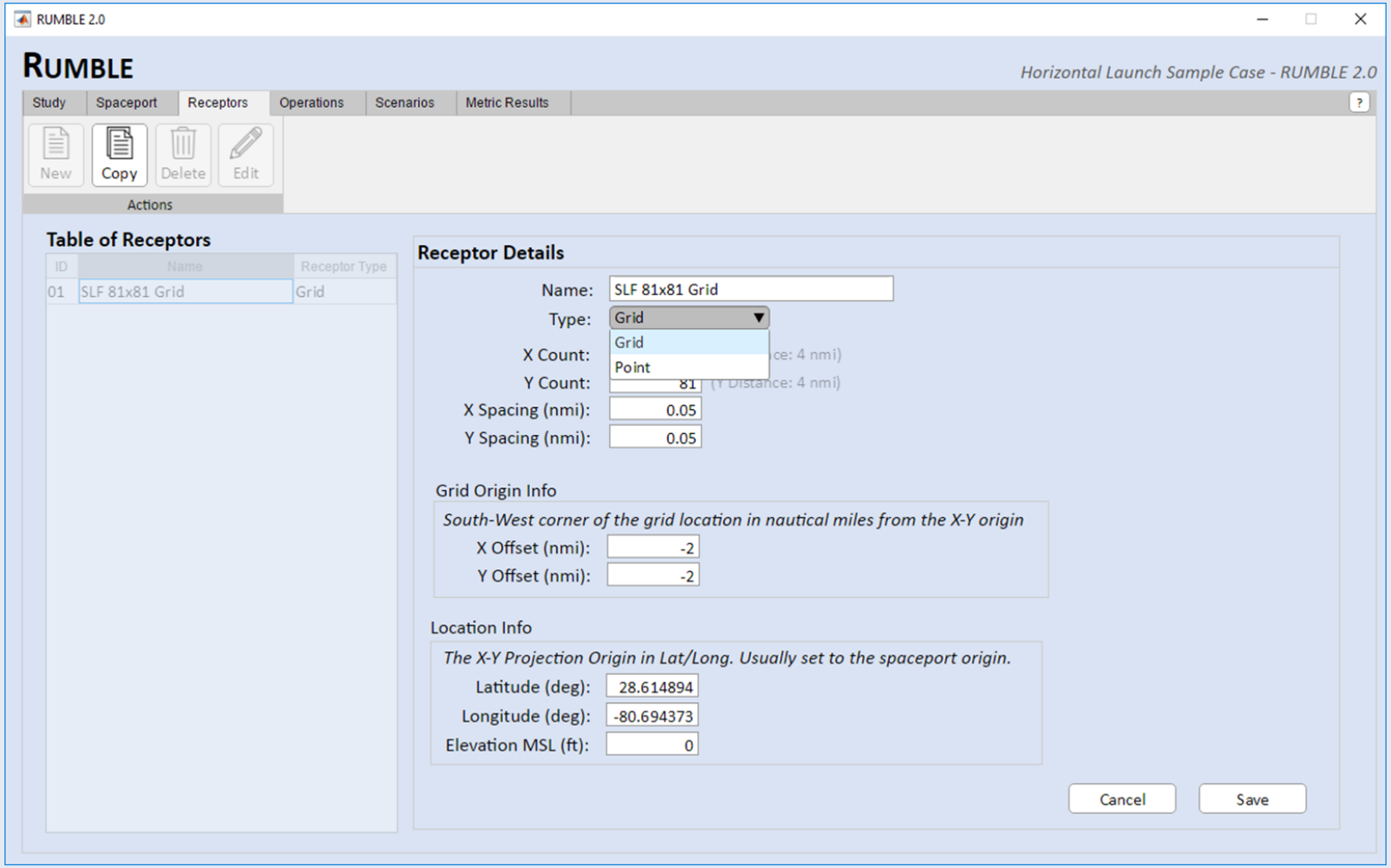

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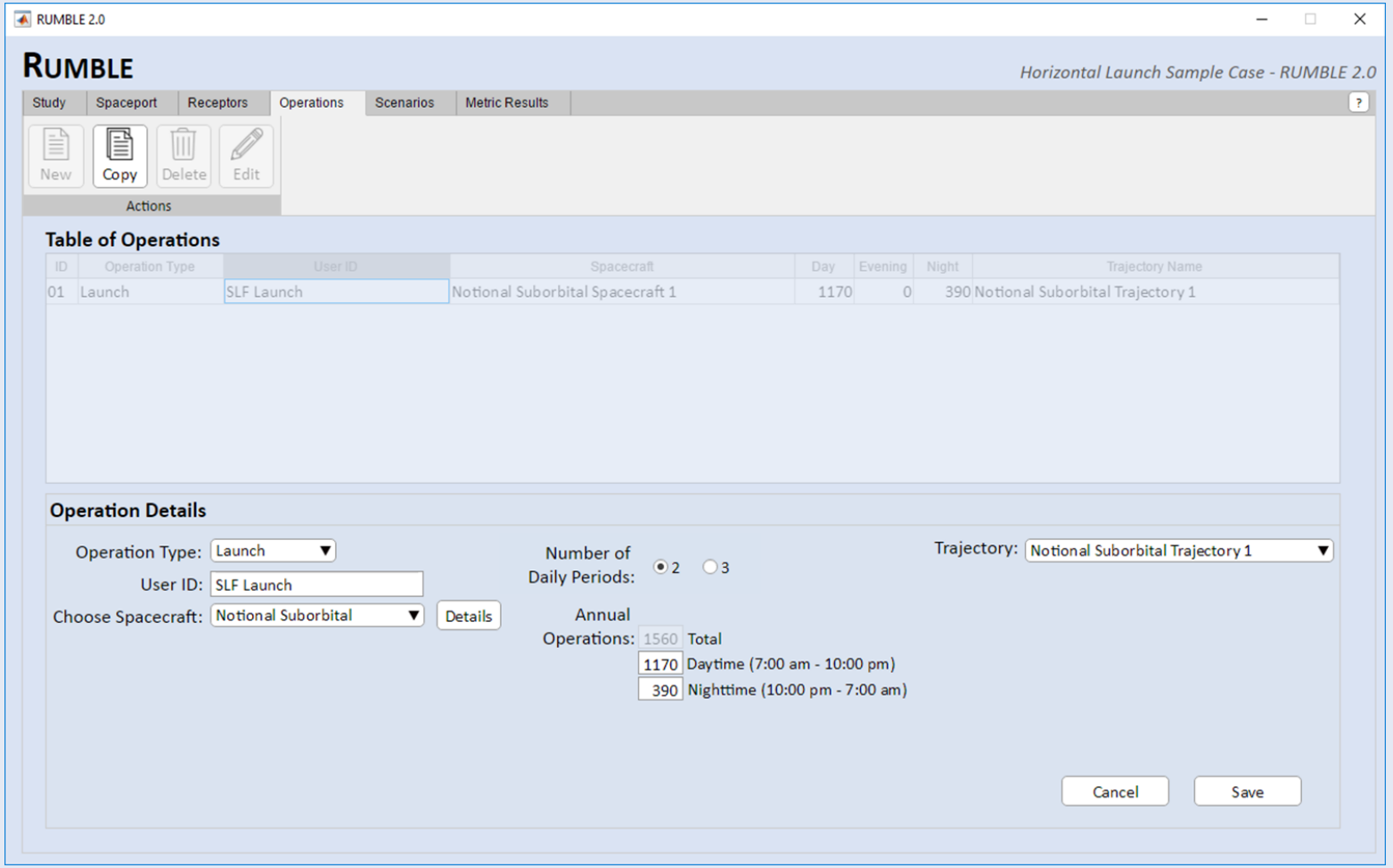

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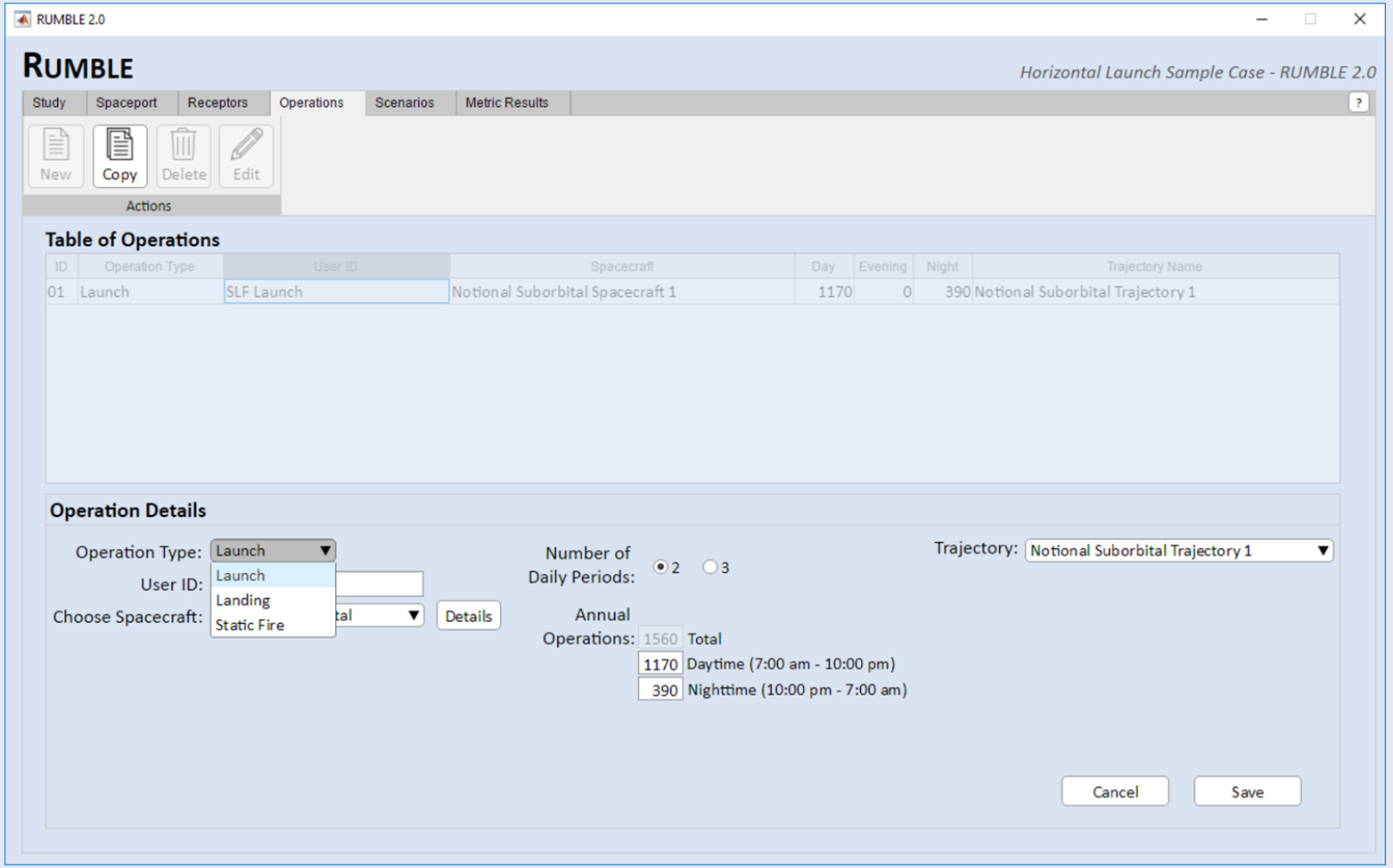

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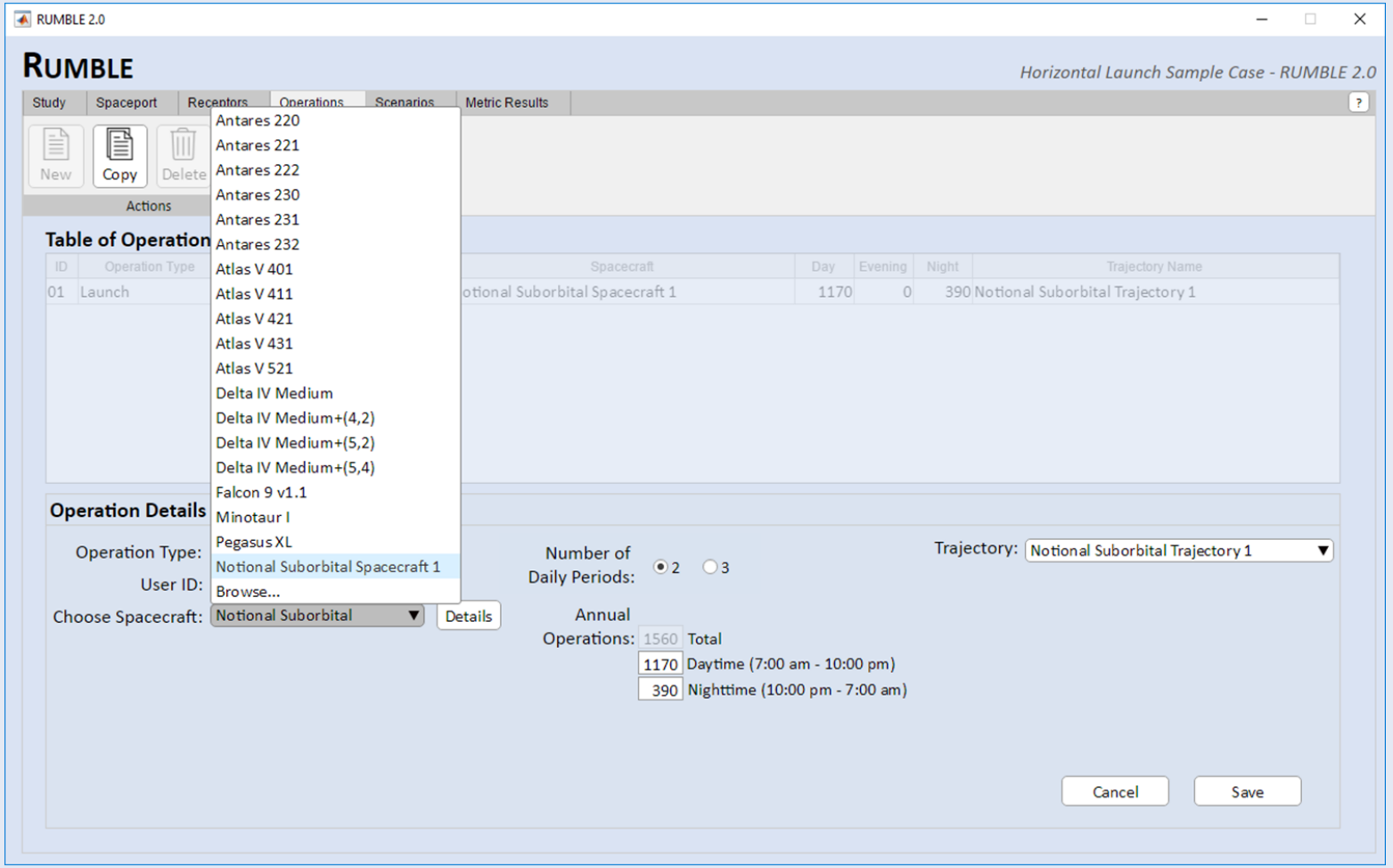

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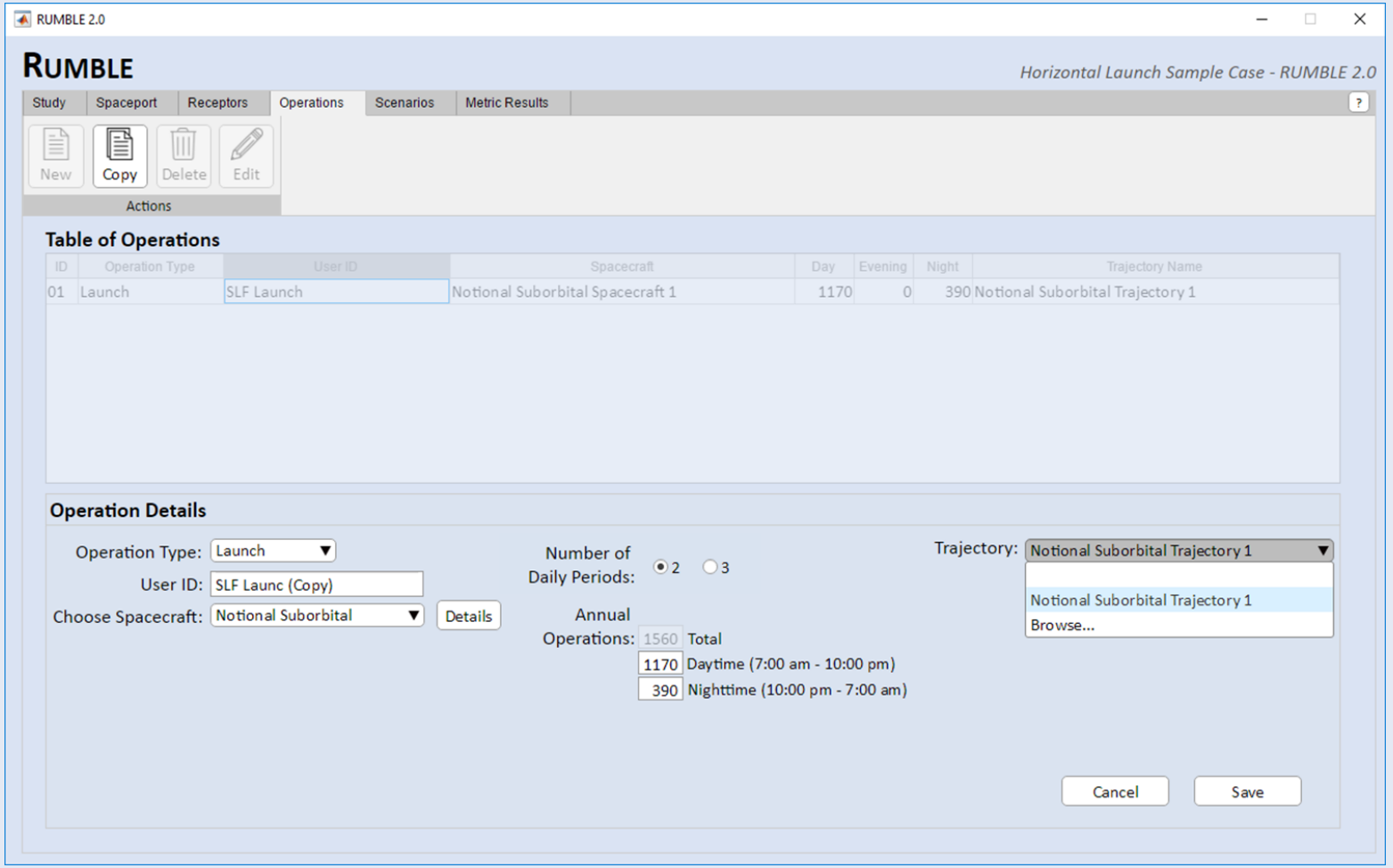

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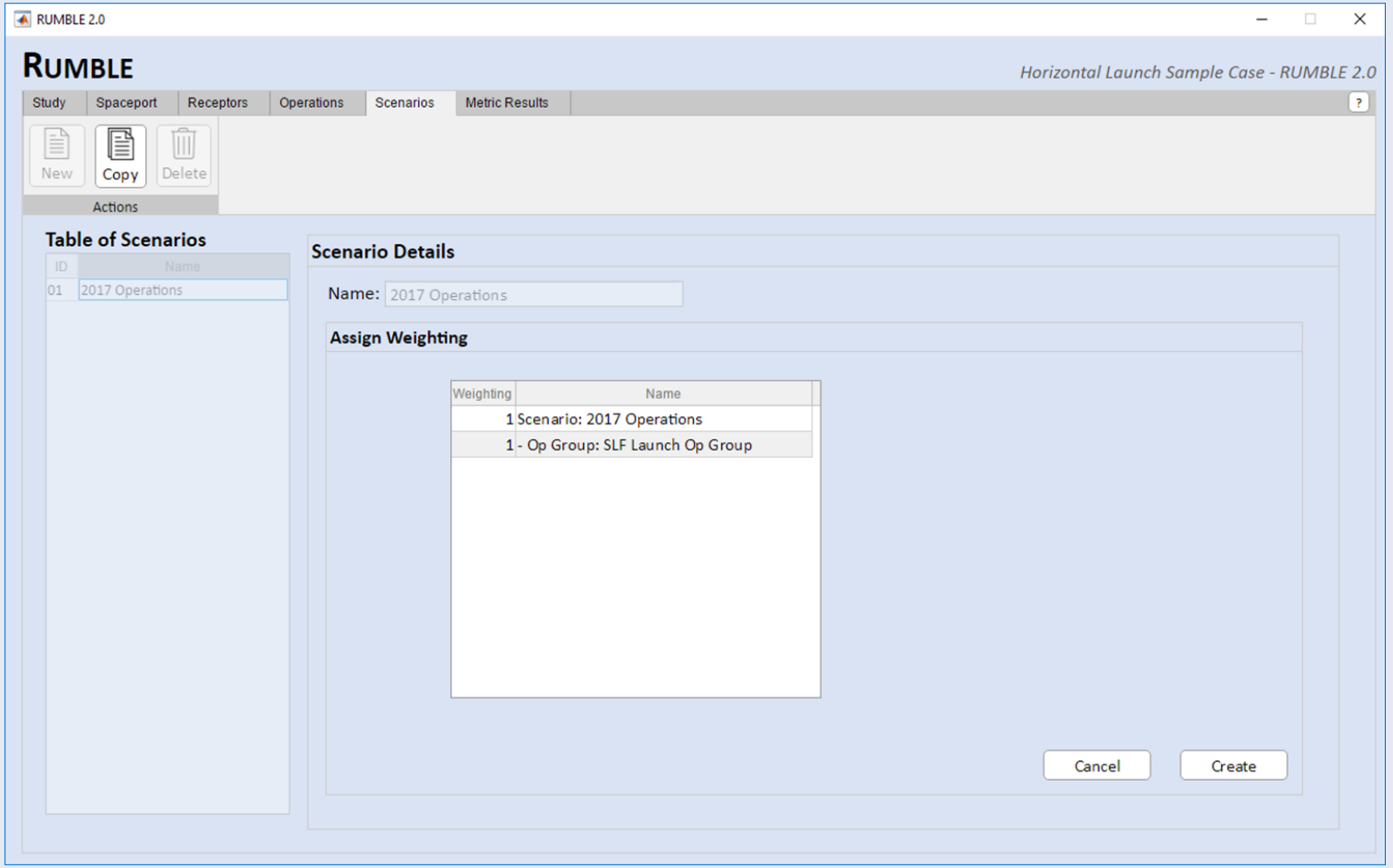

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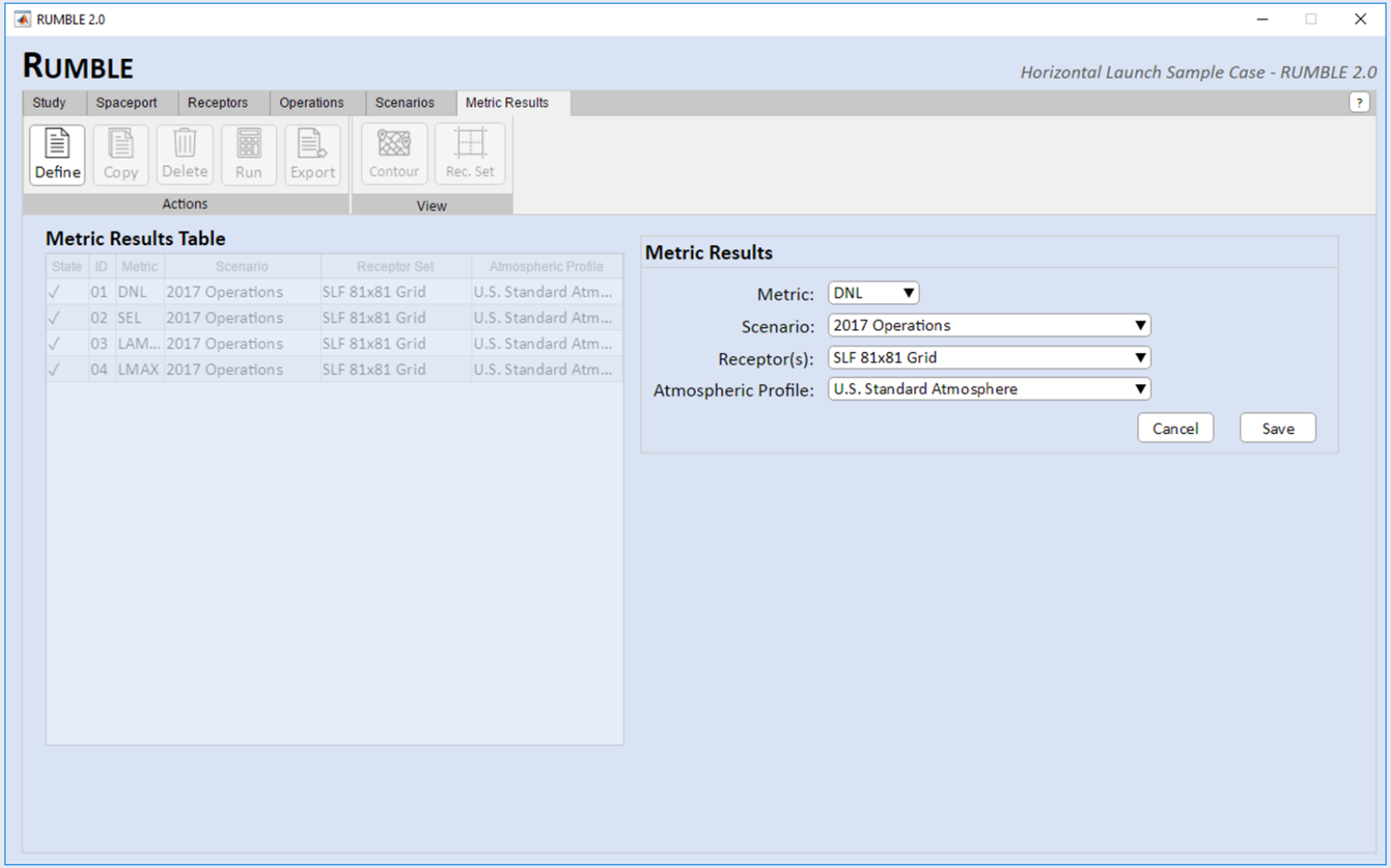

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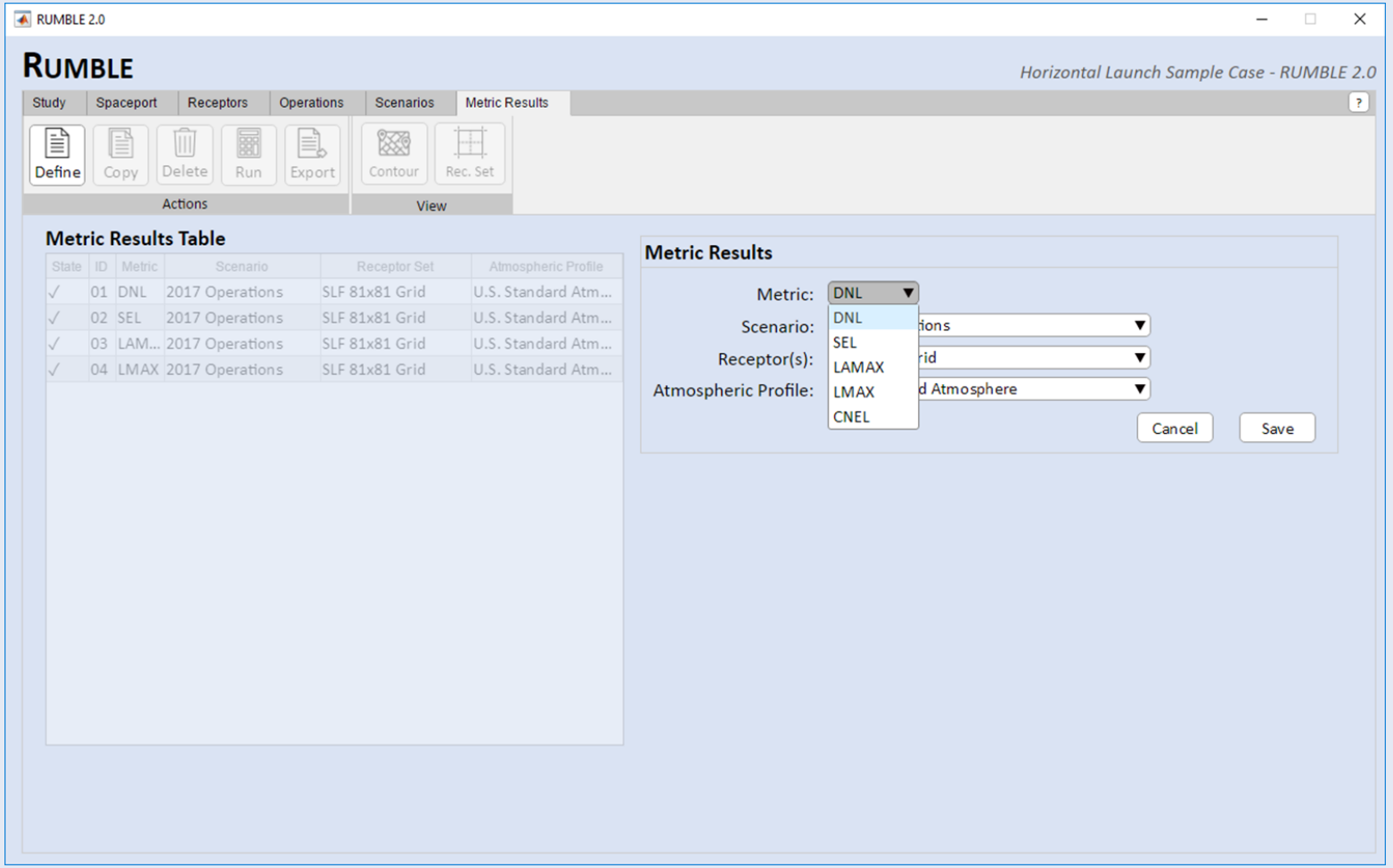

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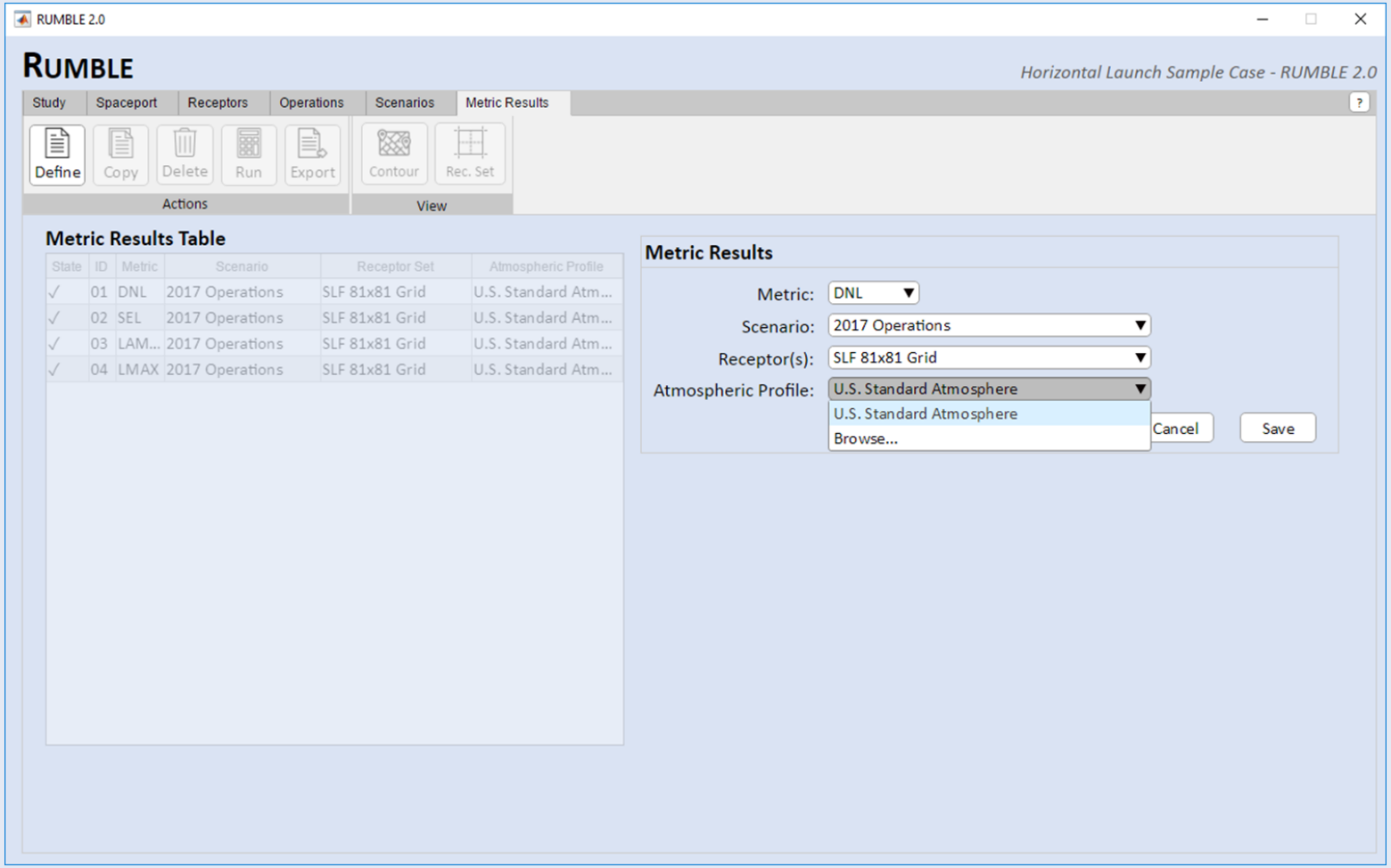

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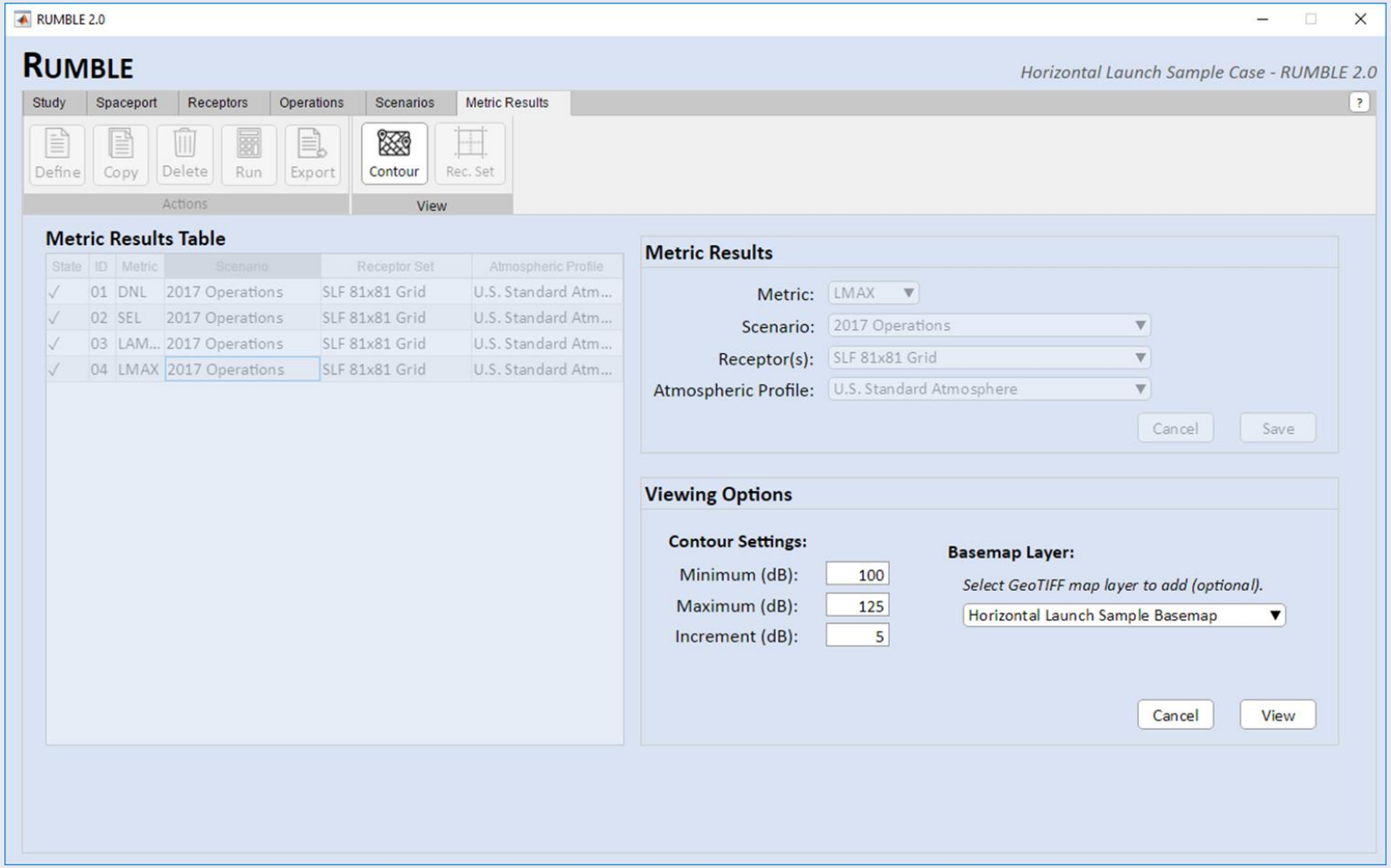

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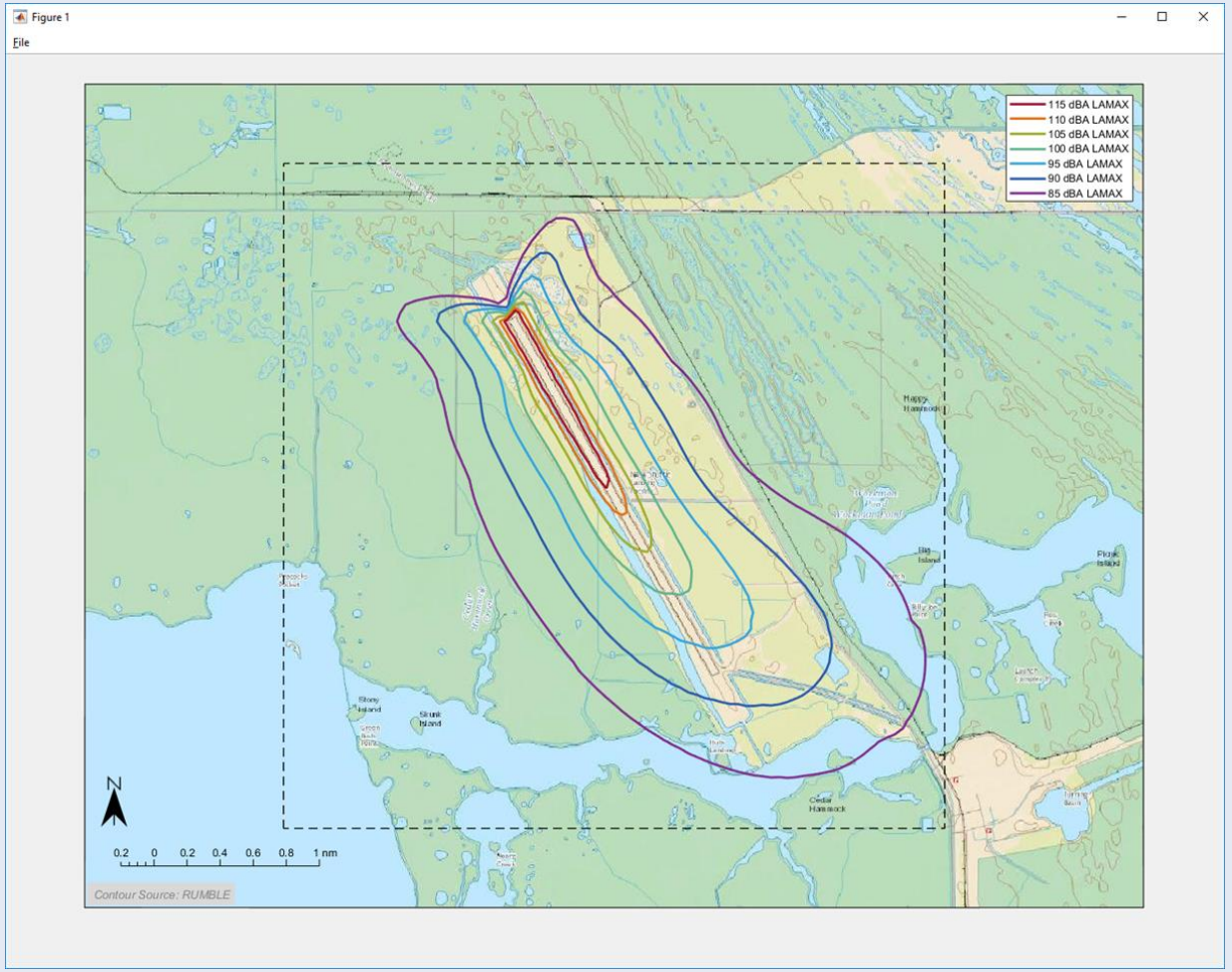

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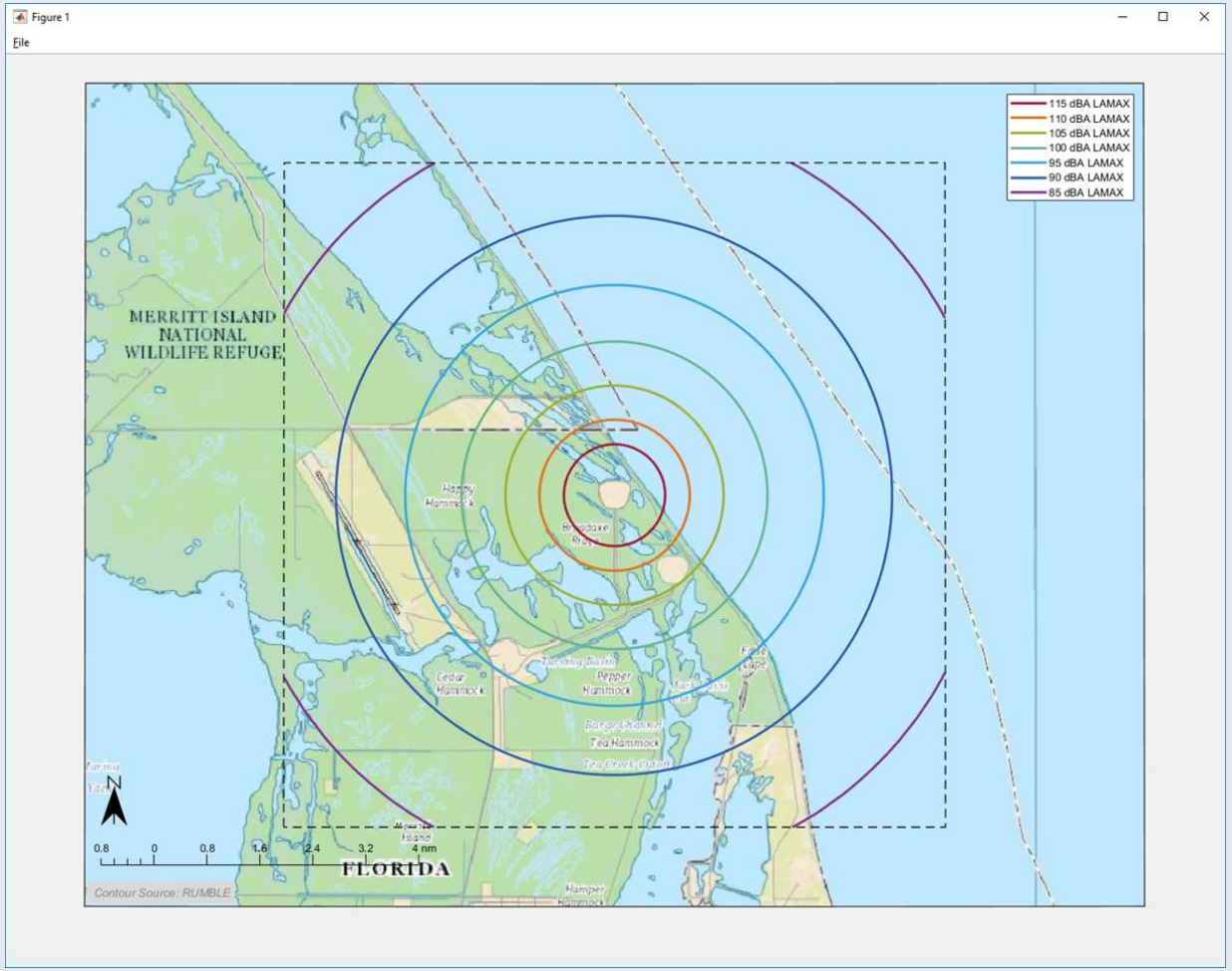
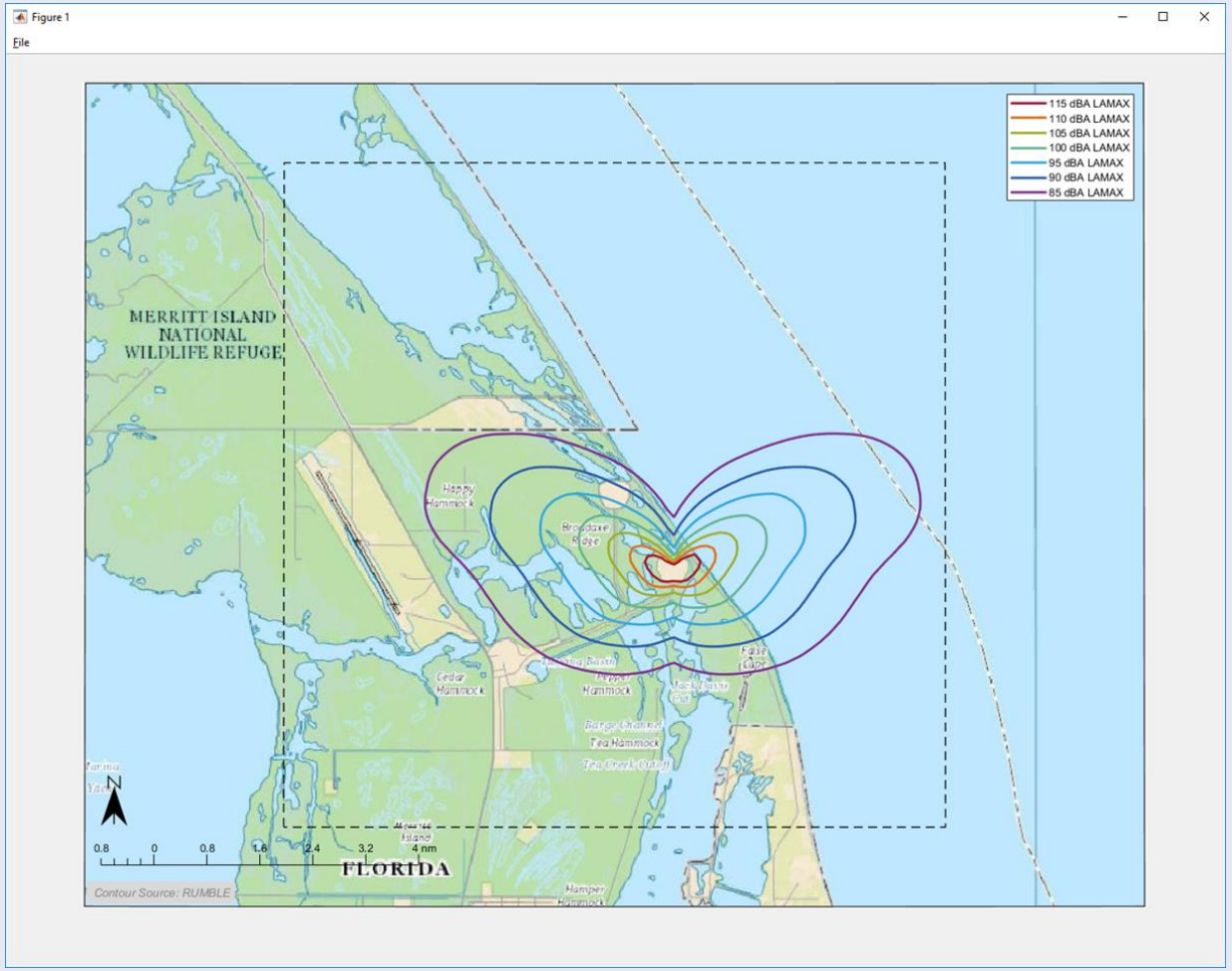


Commercial Space Noise Modeling: RUMBLE

- Modeling Methodology
- User Interface
- Map Results
- Simulation



Commercial Space Noise Modeling: RUMBLE

- Modeling Methodology
- User Interface
- Map Results
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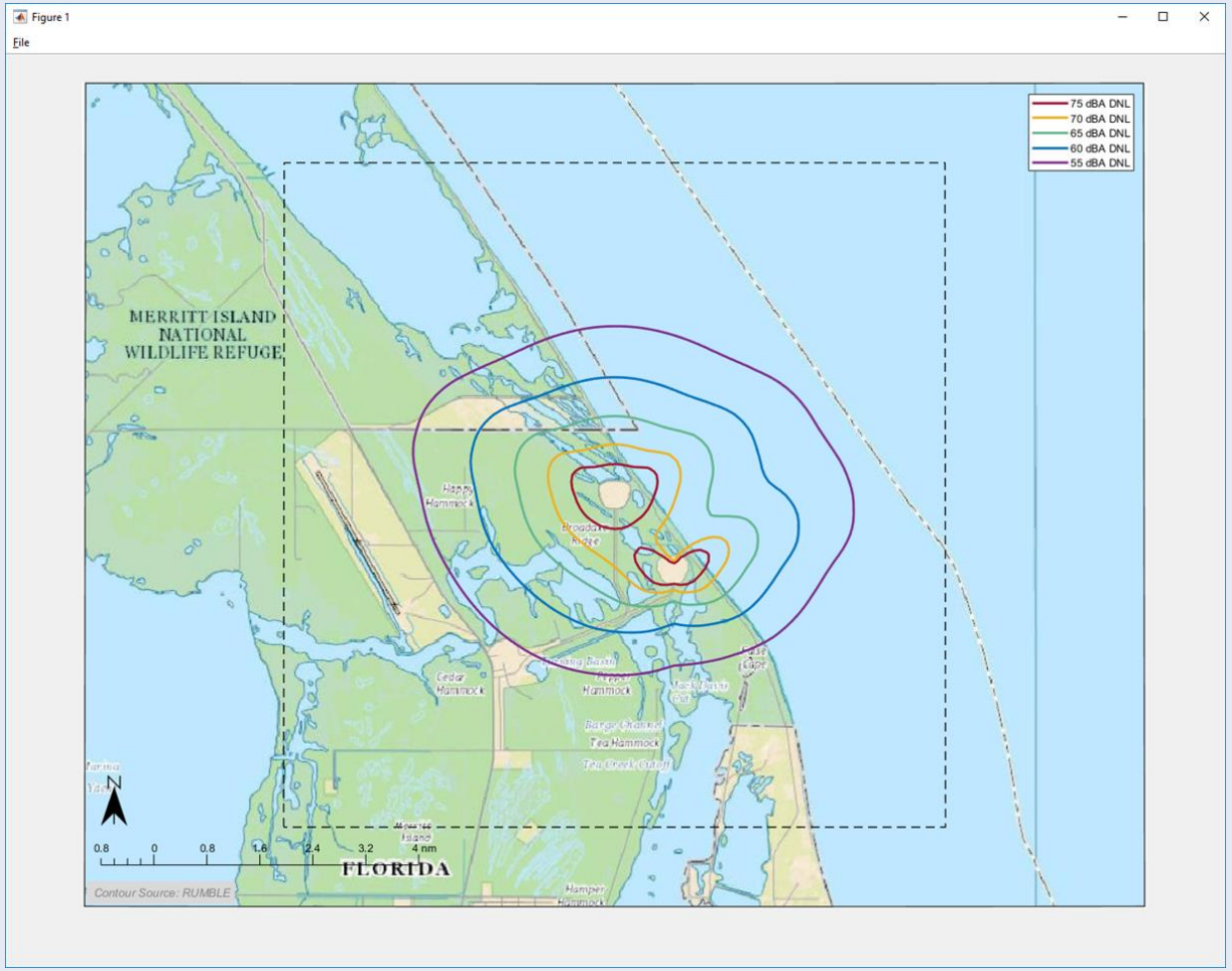

Commercial Space Noise Modeling: RUMBLE

- Modeling Methodology
- User Interface
- Map Results
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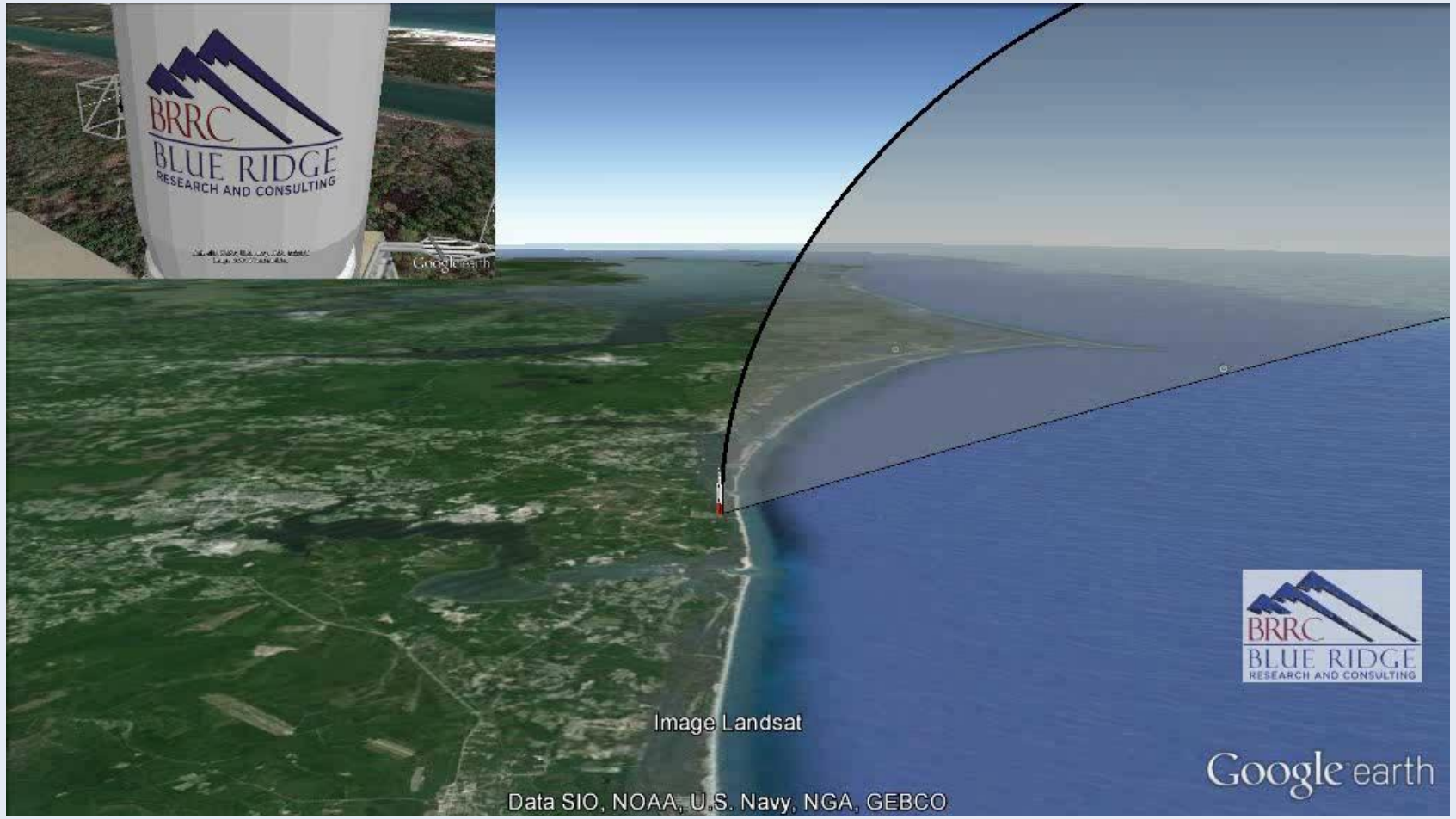


Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

Commercial Space Noise Measurements Objectives

- Develop community noise measurement protocol
- Conduct a measurement campaign
- Compile database of rocket propulsion noise

Antares 230

Falcon 9

Delta IV Heavy

Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

- Antares 230
- 2 x RD-181 engines - LOX/Kerosene
- 12 Nov 2017, 7:19 AM
- MARS Pad 0A
- CYGNUS CRS 0A-8E
- ISS Re-supply

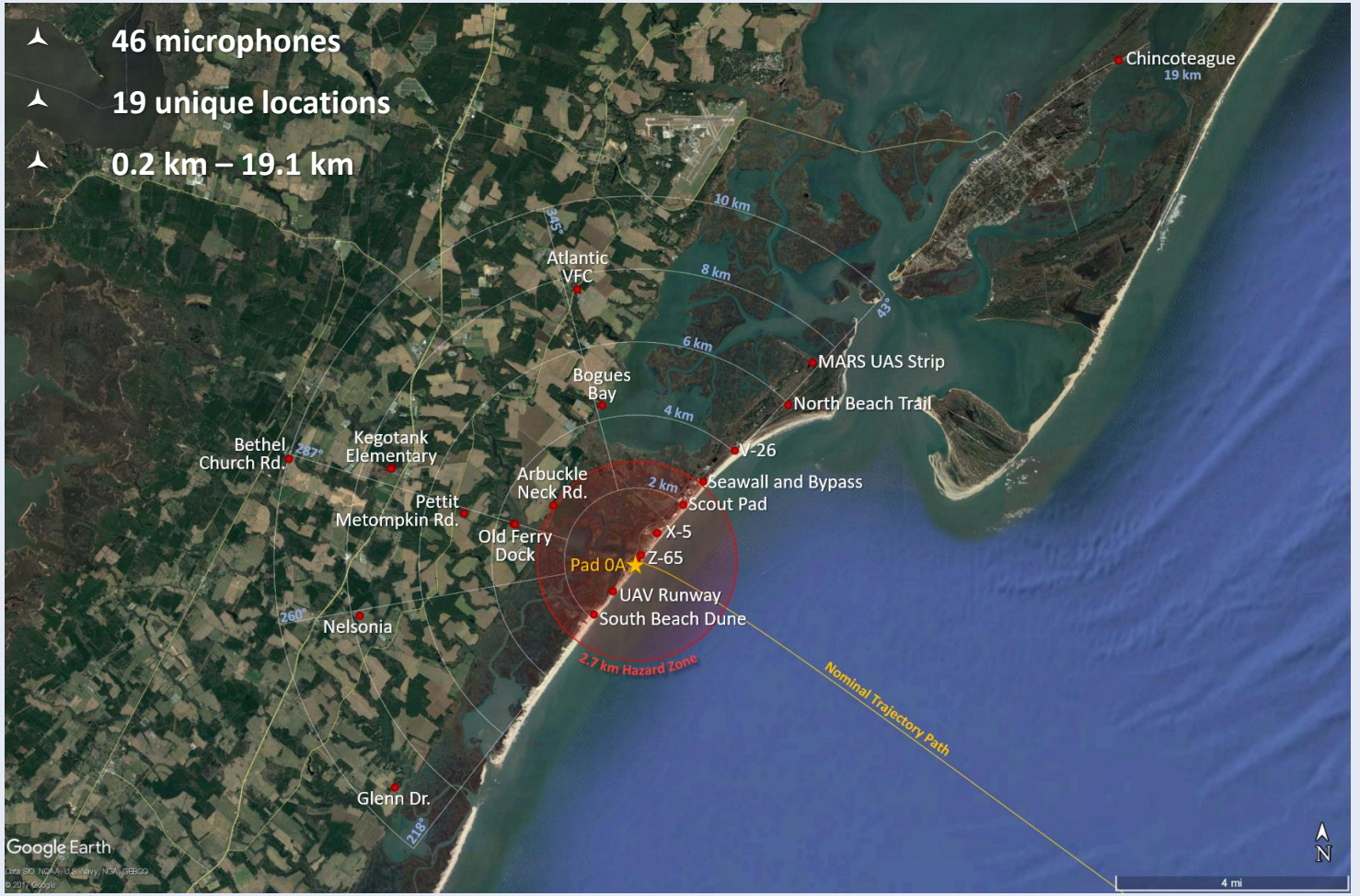
Credit: Michael James

Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling



Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

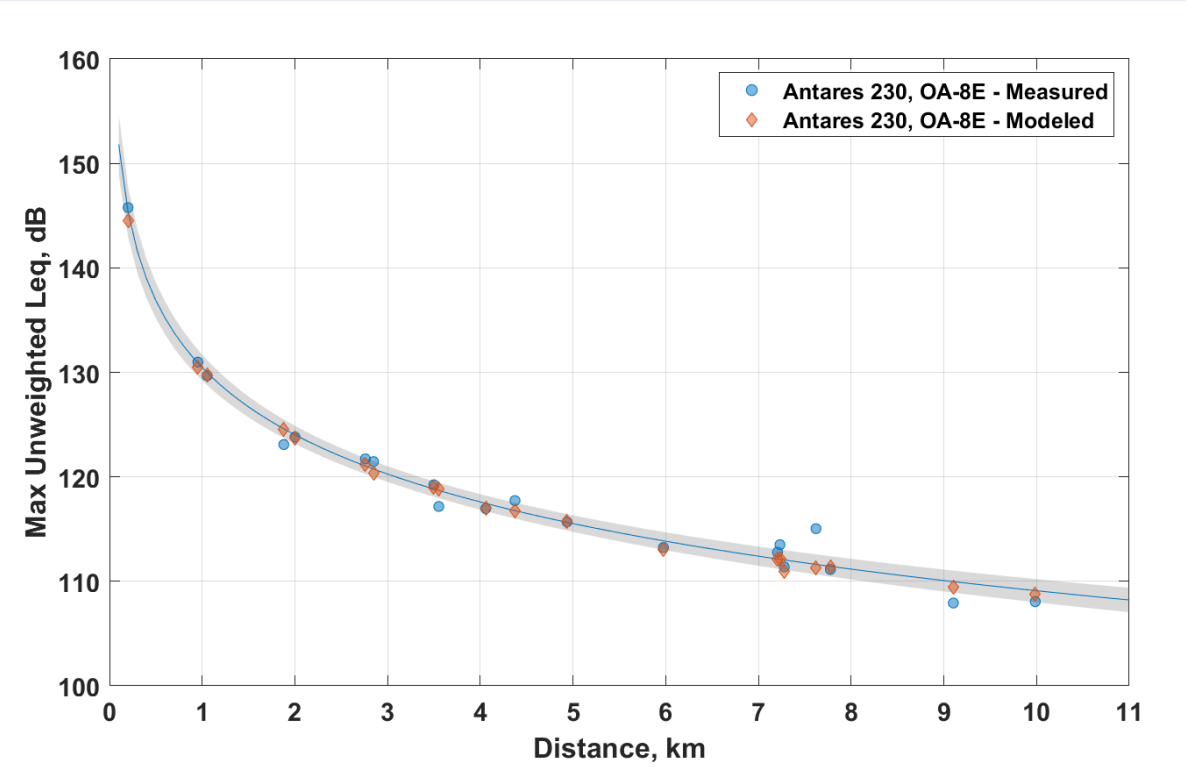
Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

- Measured vs Modeled maximum unweighted L_{eq}
  - As-flown trajectory
  - Atmospheric profile
- Note, locations are at different azimuthal angles
- Blue line and grey area represents logarithmic fit of measured data and its 95% confidence intervals
- **Good agreement between measured and modeled max unweighted Leq**



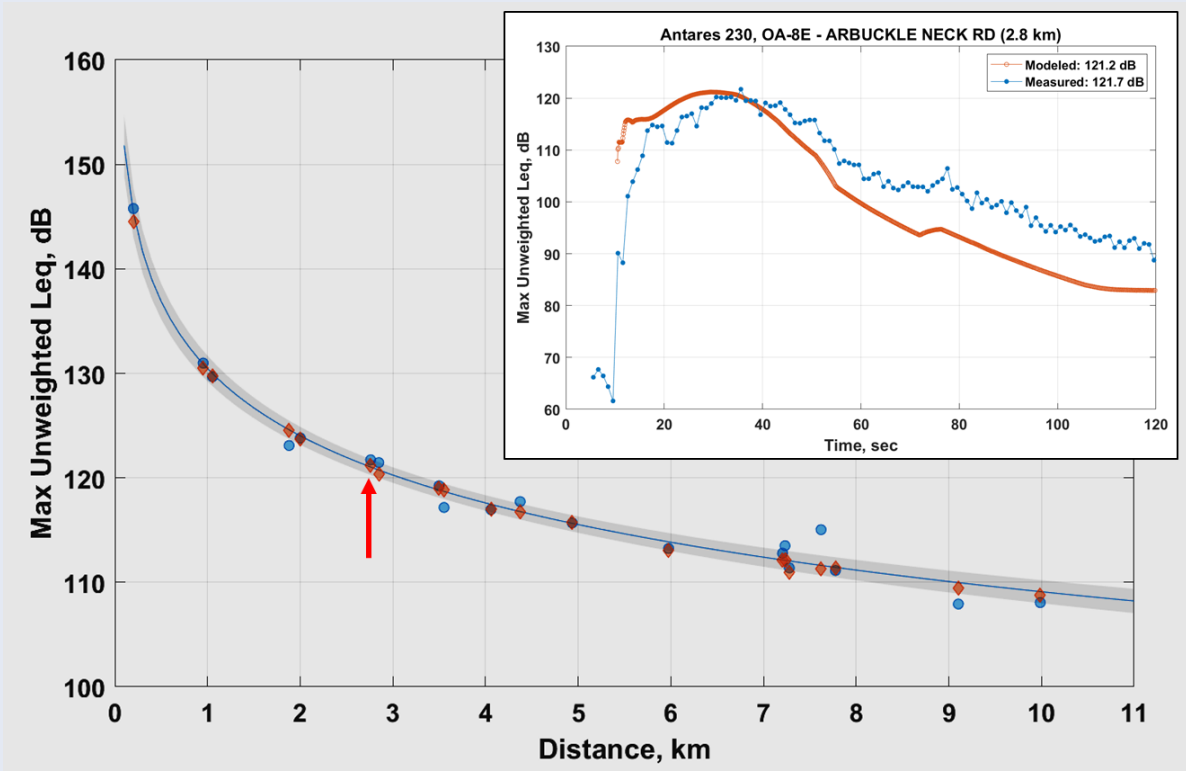
Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

- Predicts overall maximum correctly but time of peak directivity is off
- Time history comparison shows that model does not accurately predict
  - Initial ramp up
  - Fall off



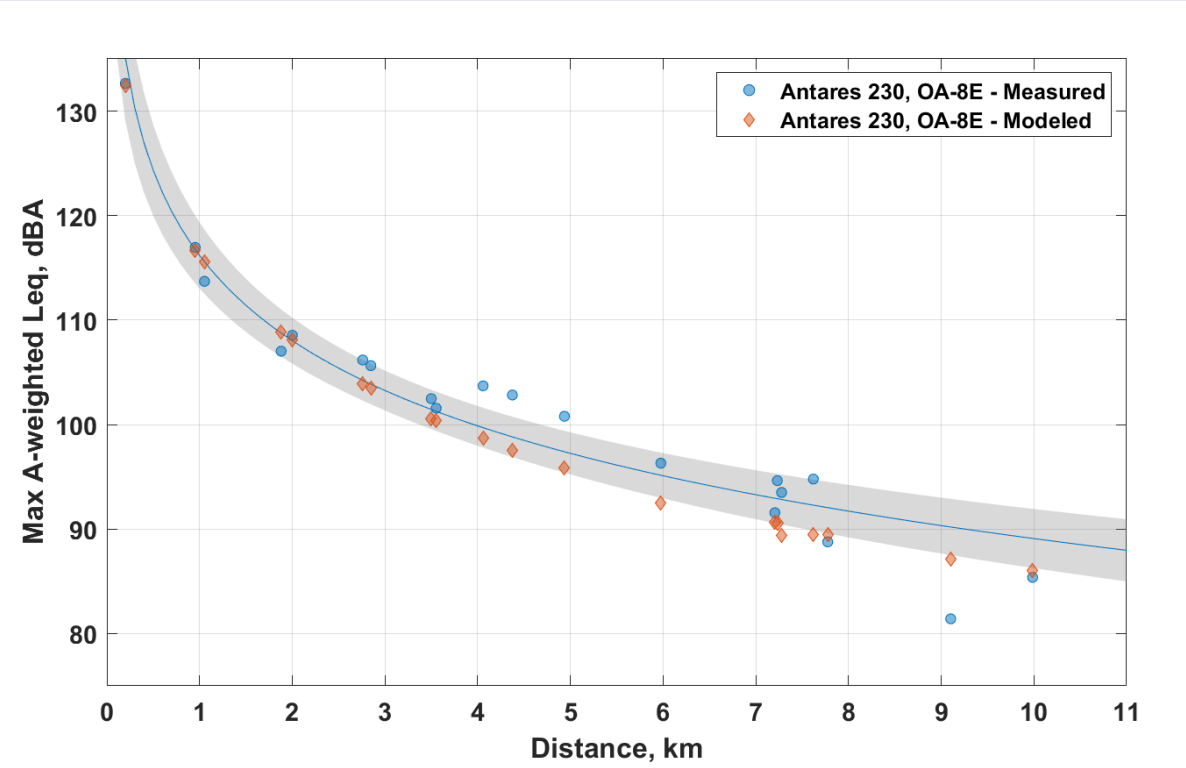
Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

- Measured vs Modeled maximum A-weighted L_{eq}
  - As-flown trajectory
  - Atmospheric profile
- Note, locations are at different azimuthal angles
- Blue line and grey area represents logarithmic fit of measured data and its 95% confidence intervals
- **Model underpredicts the maximum A-weighted Leq for measurement locations between 2.5 and 8 km**



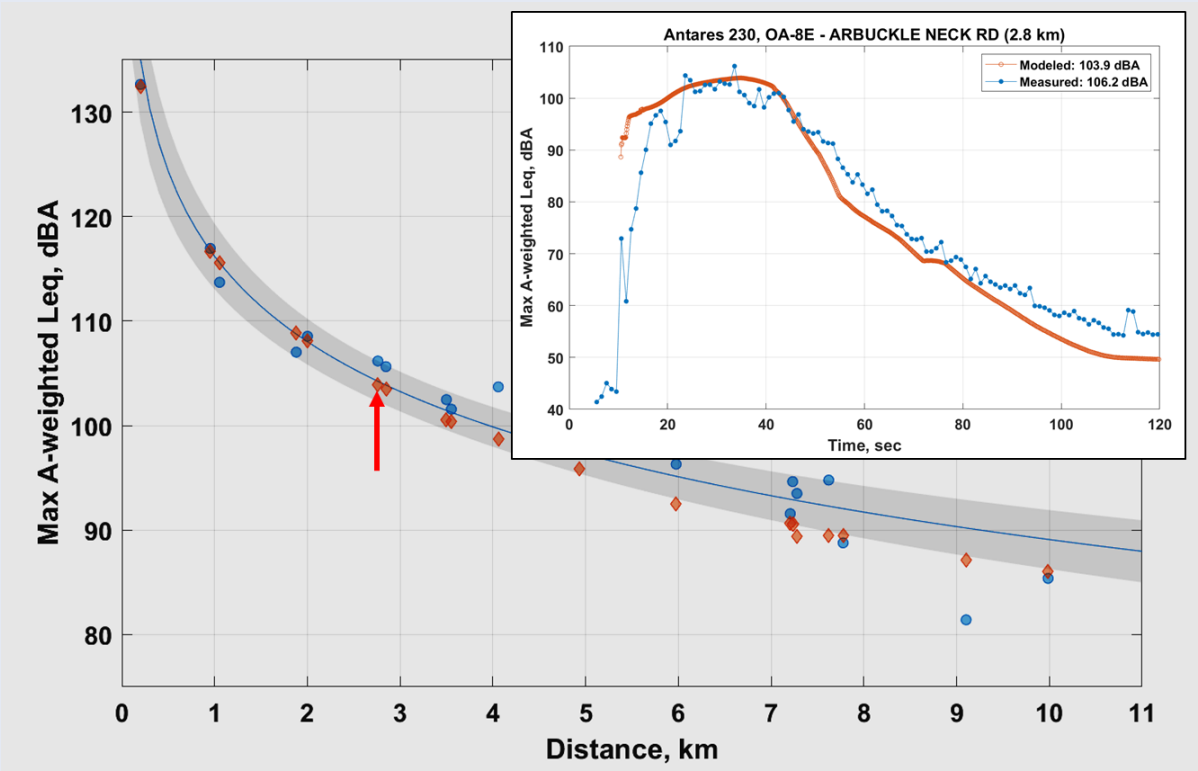
Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

- Appears to predict time of peak directivity well, but the measured maximum A-weighted Leq is determined by brief periods of higher levels versus the smooth model levels
- Time history comparison shows that model does not accurately predict
  - Initial ramp up



Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling

Commercial Space Vehicle Emissions Modeling

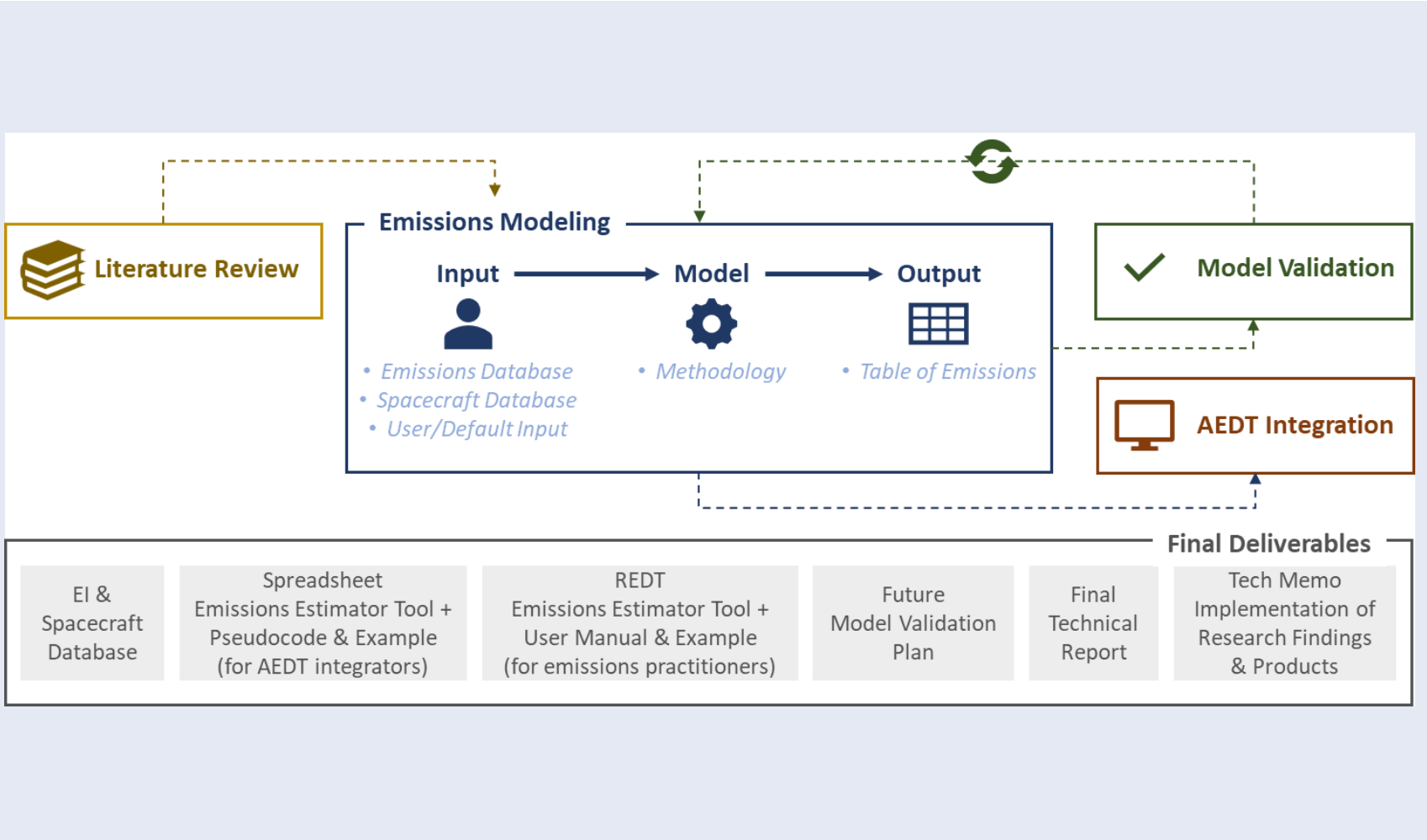
- The objective of this research is to develop a method to estimate emissions from commercial space vehicle operations.
- The method should:
  - Allow users to estimate emissions for existing and emerging commercial space vehicles, engines, and propellants;
  - Allow users to estimate emissions both below and above the mixing height;
  - Be incorporated into RUMBLE and a simple (e.g., spreadsheet) emissions estimator tool to allow for easy estimations; and
  - Be designed with the intent to be integrated with AEDT.

Current/Future Commercial Space Efforts

Noise Measurements

Noise Model Validation

Emissions Modeling



Questions?

Credit: Michael James