

Influence of Atmospheric Variability on Predicted Sonic Boom Metrics

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186th Meeting of the
Acoustical Society of America



QUEST



% Annoyed

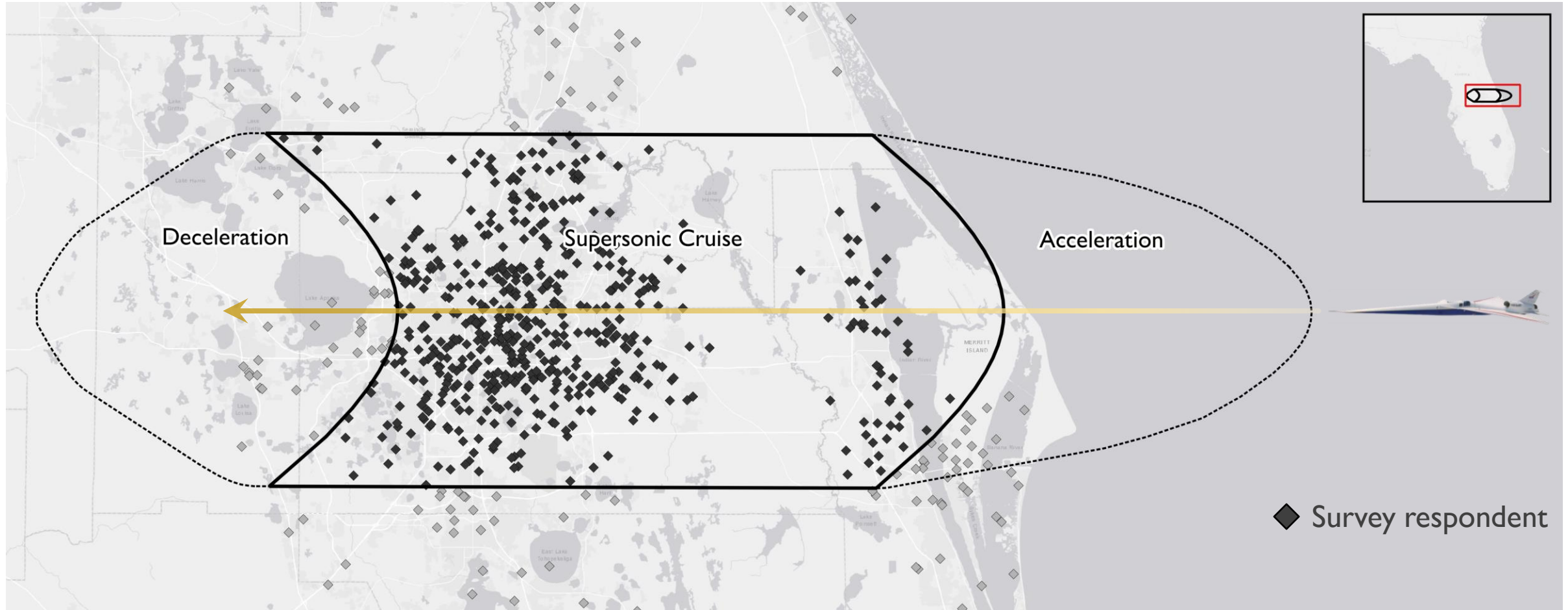


Noise exposure

Challenge: Estimate the Noise Exposure



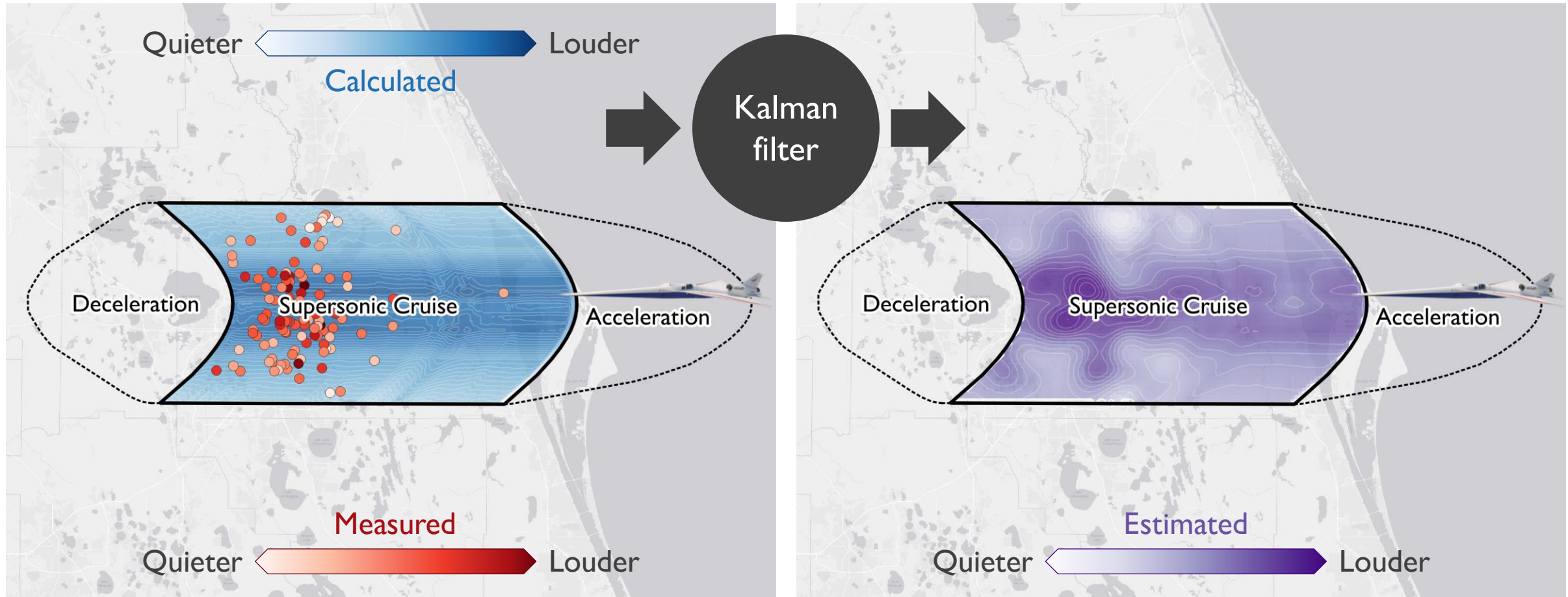
How to estimate the noise exposure and uncertainty across the sonic boom footprint?



Solution: Estimate the Noise Exposure



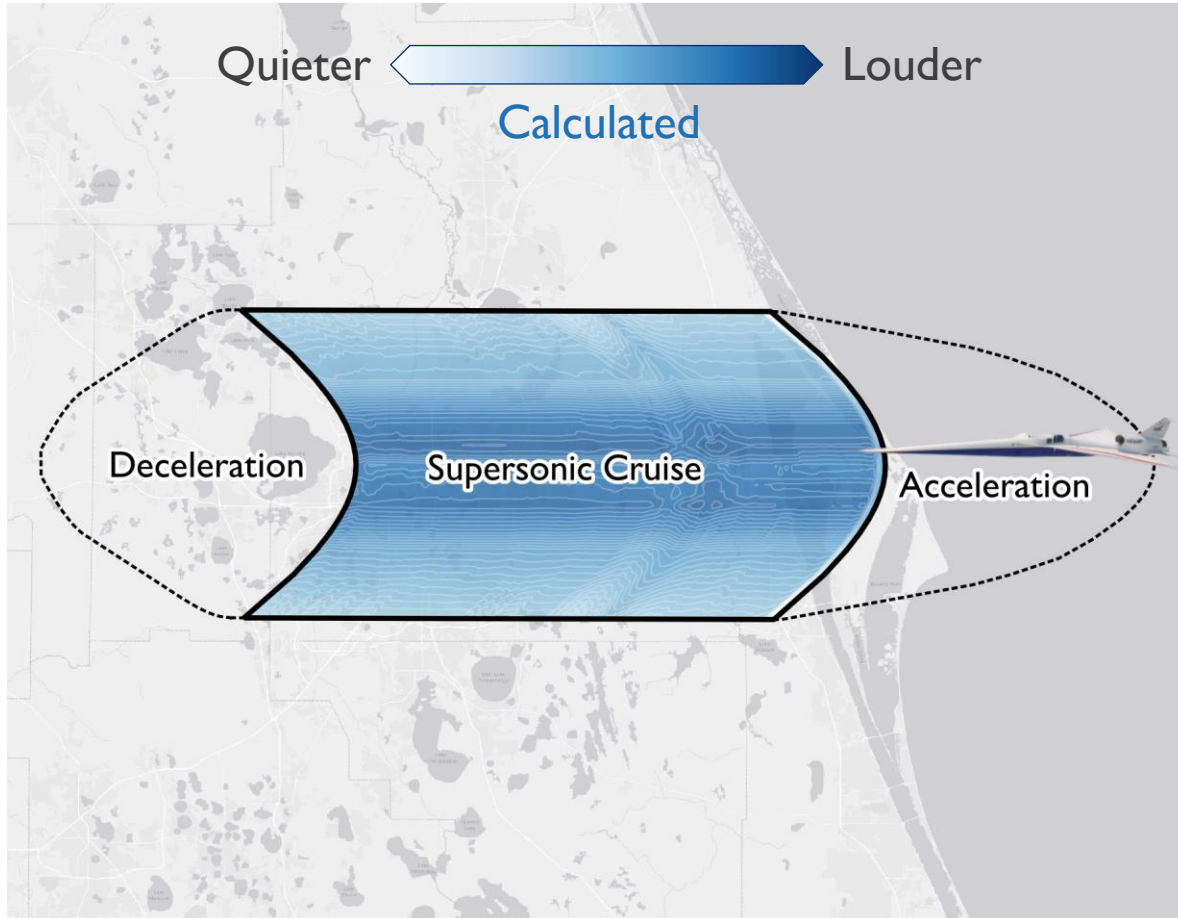
Combine the calculated and measured noise exposure data using a Kalman filter



Calculated Noise Exposure



Calculate the noise exposure using PCBoom



PCBoom:

NASA sonic boom propagation software

Inputs:

- ▶ Near-field pressure predictions
- ▶ Aircraft trajectory data
- ▶ Atmospheric profiles measured by weather balloons

Weather Balloon Measurements



Research question: where and when to launch weather balloons?

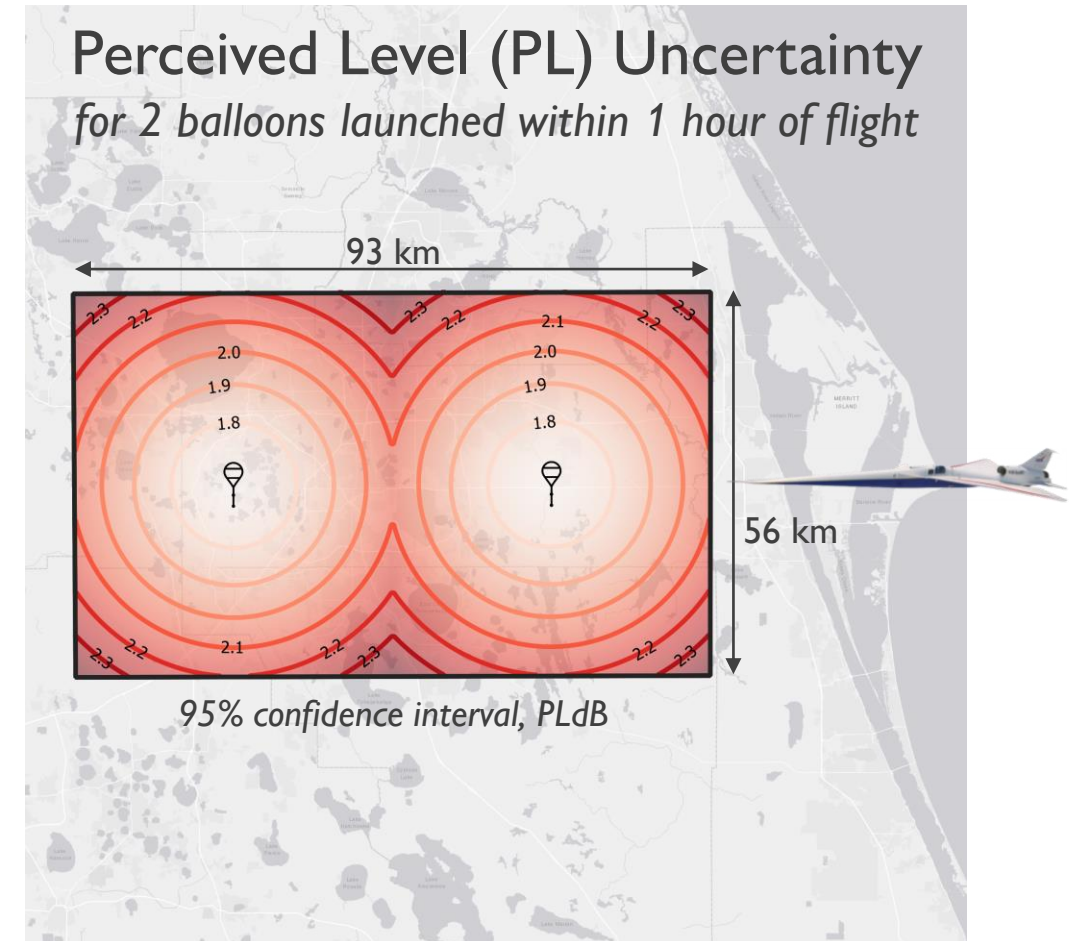
Challenge: the atmosphere varies with geographic location and time

Weather balloons
launched at limited
locations and times

Uncertainty in the
calculated noise
exposure

Research: quantify sensitivity of calculated PL
to geographic and temporal resolution of
weather balloons

Result: launch weather balloons from at least
two locations within one hour of each flight



Research Methodology

Objective: quantify sensitivity of calculated PL to geographic and temporal resolution

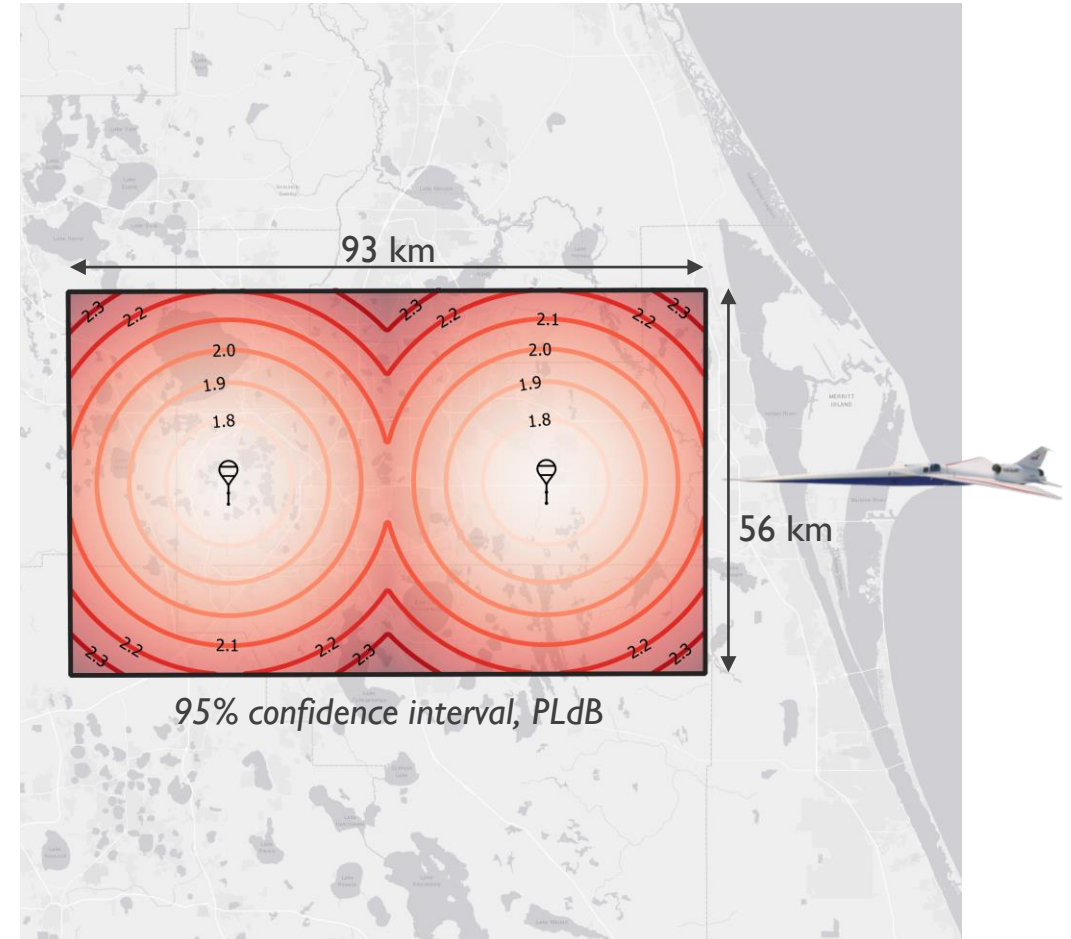
Process atmospheric profiles
at multiple locations and times

Calculate the “true” PL at a
selected location and time

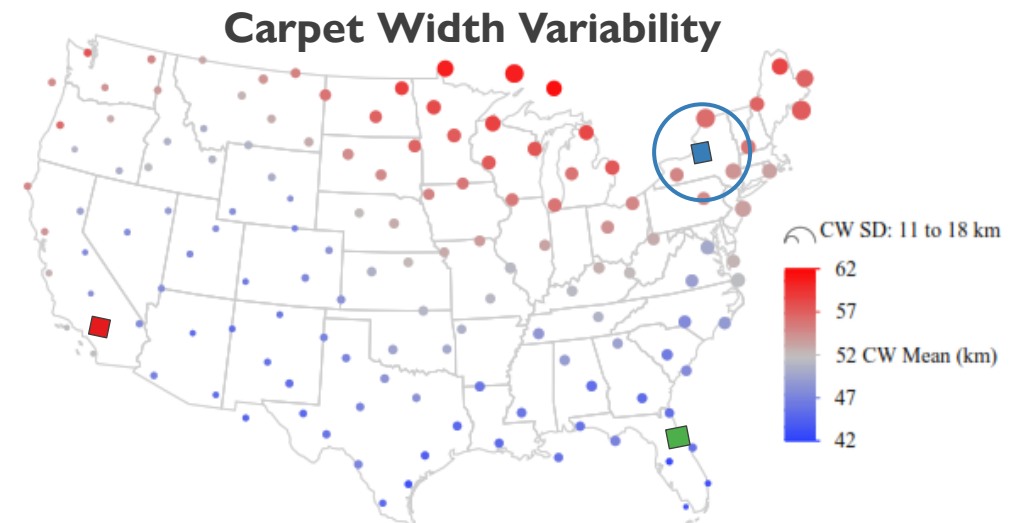
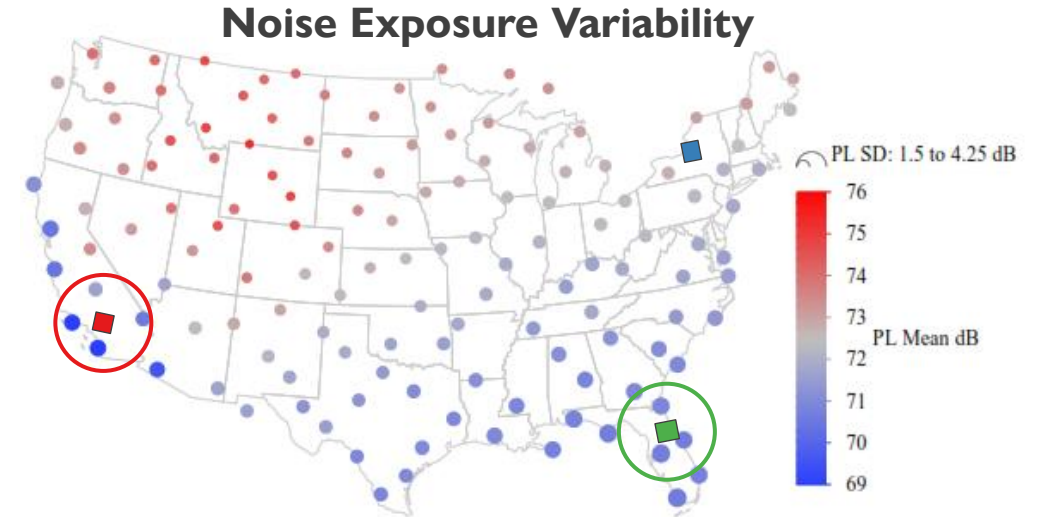
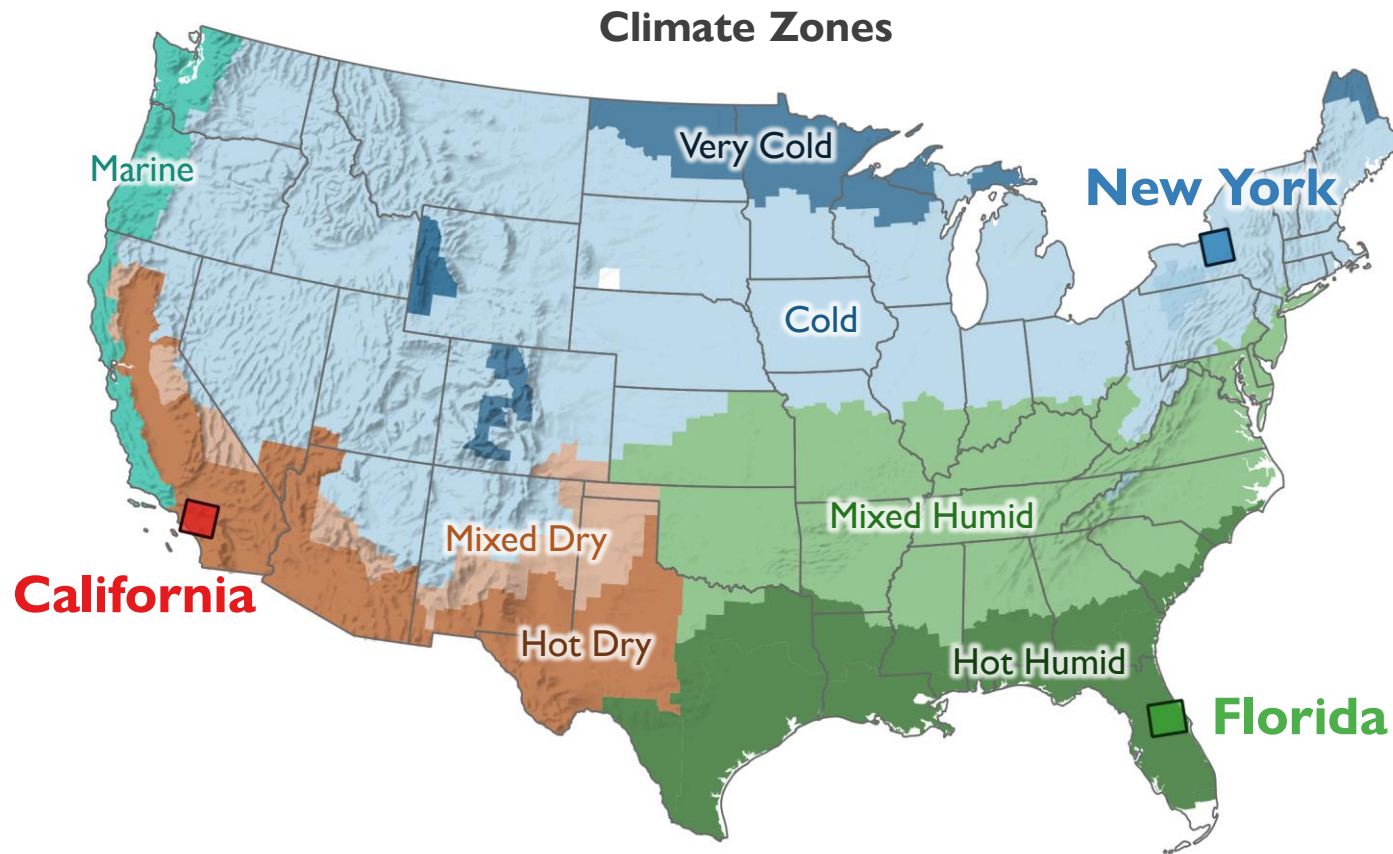
Calculate PL using
atmospheric profiles from
nearby locations and times

Calculate Δ between the
“true” PL and nearby
locations and times

Estimate PL error vs.
distance and time offset



Selected Geographic Regions



Atmospheric Profile Data

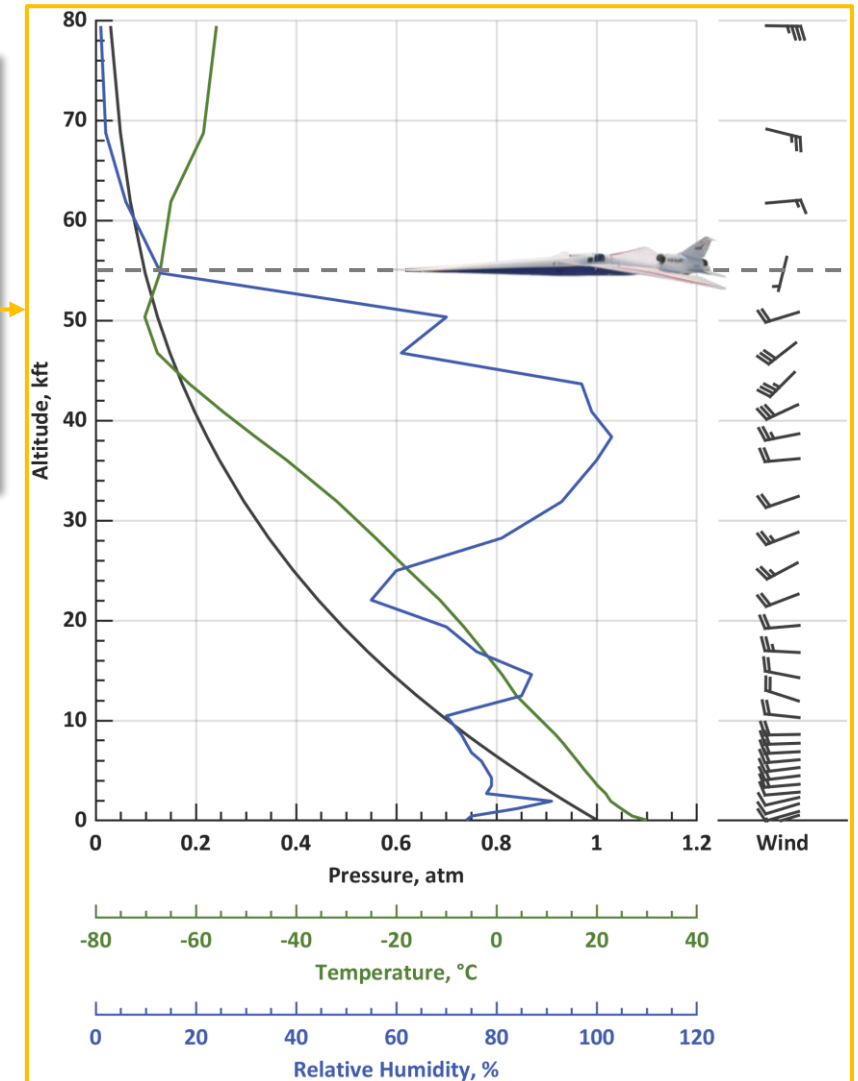
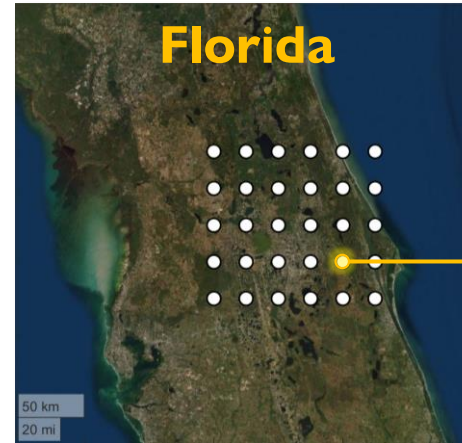


ERA5 reanalysis dataset:

- High geographic and temporal resolution
- Processed into vertical atmospheric profiles for PCBoom

Processed atmospheric profiles:

Variable	Number	Values
Regions	3	California, Florida, New York
Grid points	30	6 x 5 grid with 0.25° spacing
Dates	2,128	1 Jan 2016 – 28 Oct 2021
Hours	24	0000 – 2300 hours (UTC)
Total	4,596,480	



PCBoom Calculations



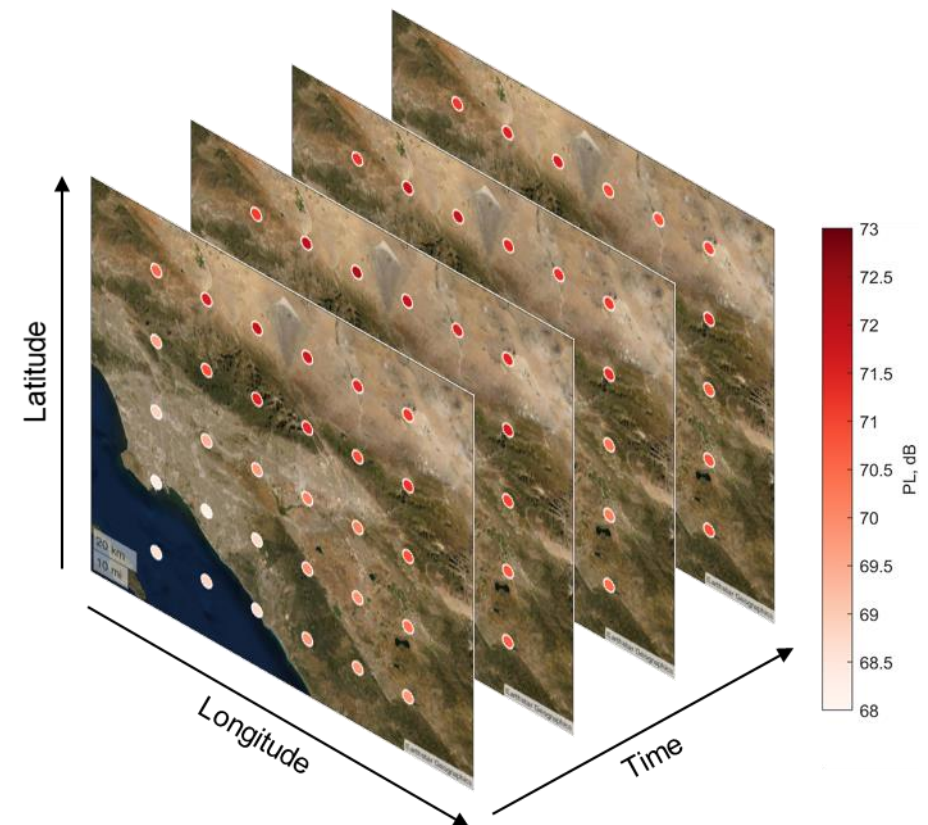
PCBoom setup:

- ▶ Enhanced Burgers solver
- ▶ Steady flight at Mach 1.4 and 53,200 ft
- ▶ Calculated undertrack PL at $\phi = 0^\circ$

Calculated PCBoom runs:

Variable	Number	Values
Regions	3	California, Florida, New York
Grid points	30	6 x 5 grid with 0.25° spacing
Dates	120	Random sample
Hours	24	0000 – 2300 hours (UTC)
Headings	4	North, South, East, West
Total	1,036,800	

Example: variable **Grid Points** and **Hours**
for a fixed **Region**, **Date**, and **Heading**



Effect of Meteorological Geographic Resolution

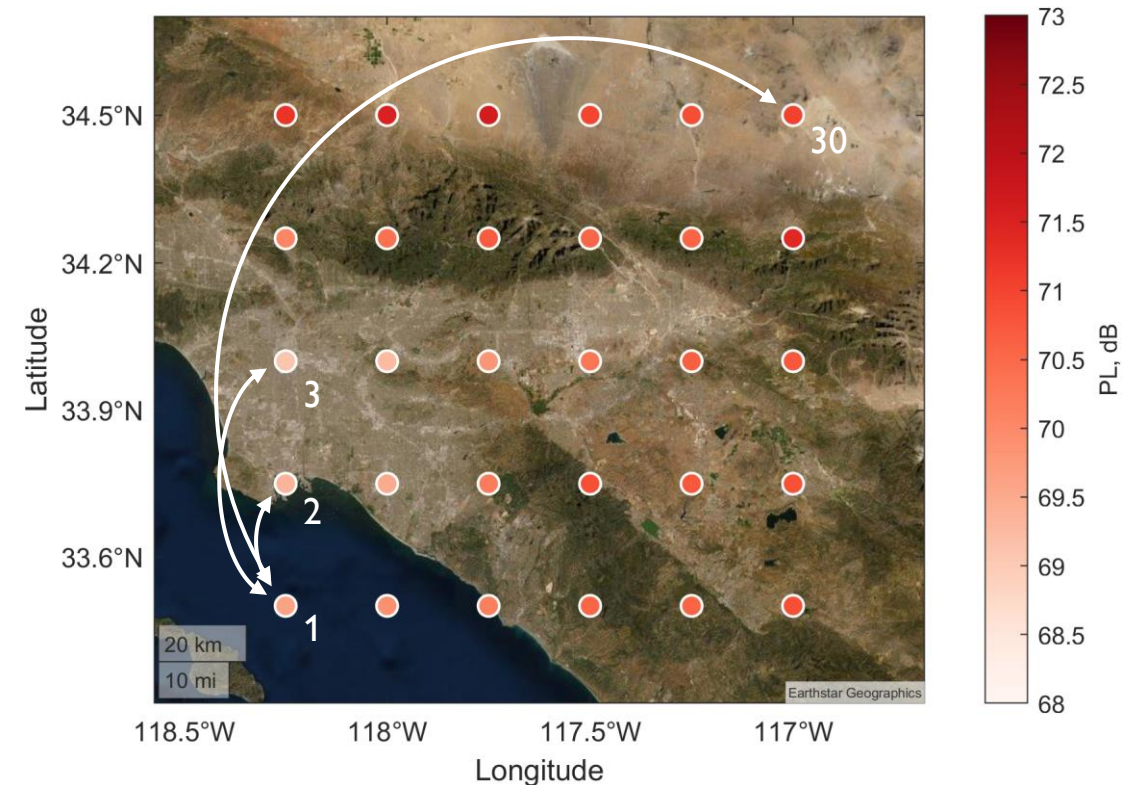


Calculate $\Delta PL_{i,j} = |PL_i - PL_j|$

- Between each pair of grid points
435 unique pairwise comparisons
- For each combination of parameters
11,520 unique combinations per region

Variable	Number	Values
Regions	3	California, Florida, New York
Grid points	30	6 x 5 grid with 0.25° spacing
Dates	120	Random sample
Hours	24	0000 – 2300 hours (UTC)
Headings	4	North, South, East, West

Example: compare **Grid Points**
for fixed other parameters



Effect of Meteorological Geographic Resolution

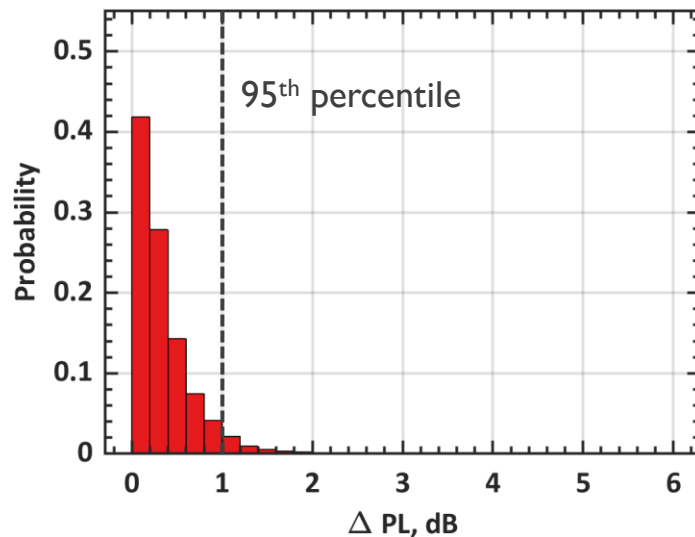


Plot histograms of undertrack ΔPL in the California region:

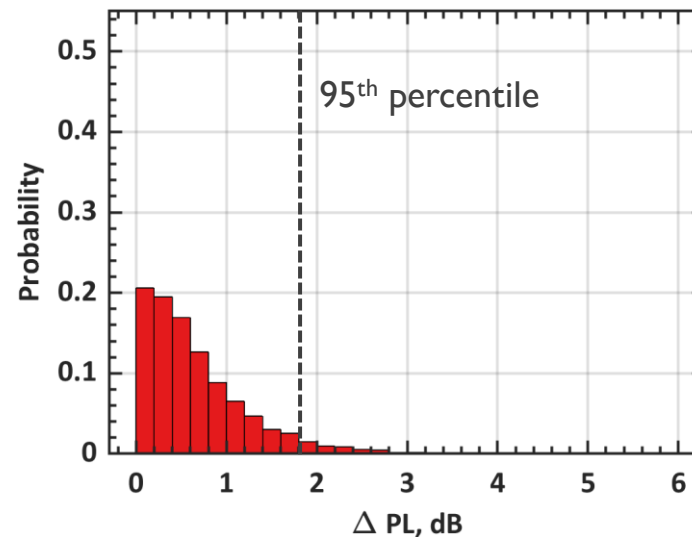
- One histogram per pair of grid points (435 histograms)
- One value per combination of parameters (11,520 values per histogram)

Calculate 95th percentile of undertrack ΔPL for each pair of grid points

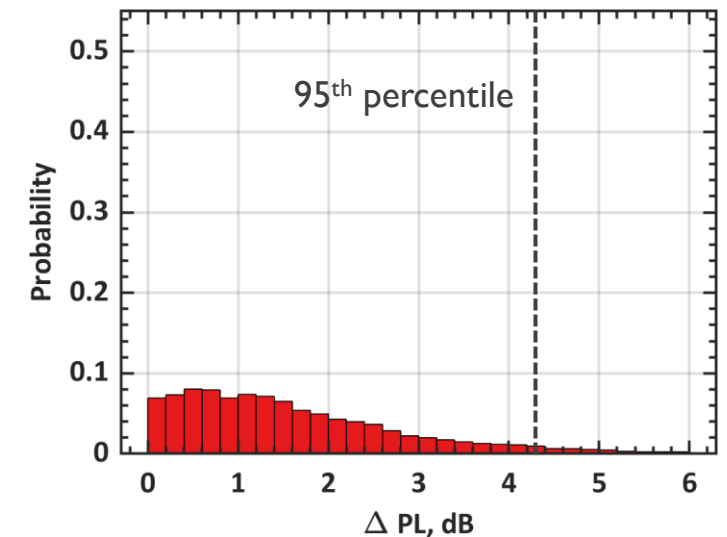
Grid points 1 $\leftrightarrow$ 2
(Distance = 27.7 km)



Grid points 1 $\leftrightarrow$ 3
(Distance = 55.5 km)



Grid points 1 $\leftrightarrow$ 30
(Distance = 160 km)



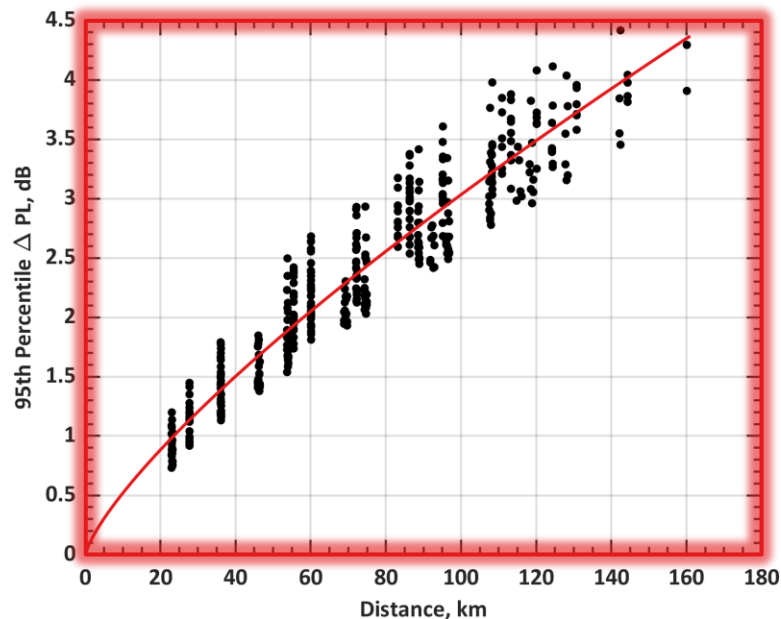
Effect of Meteorological Geographic Resolution

Plot 95th percentile of undertrack ΔPL vs. geographic distance

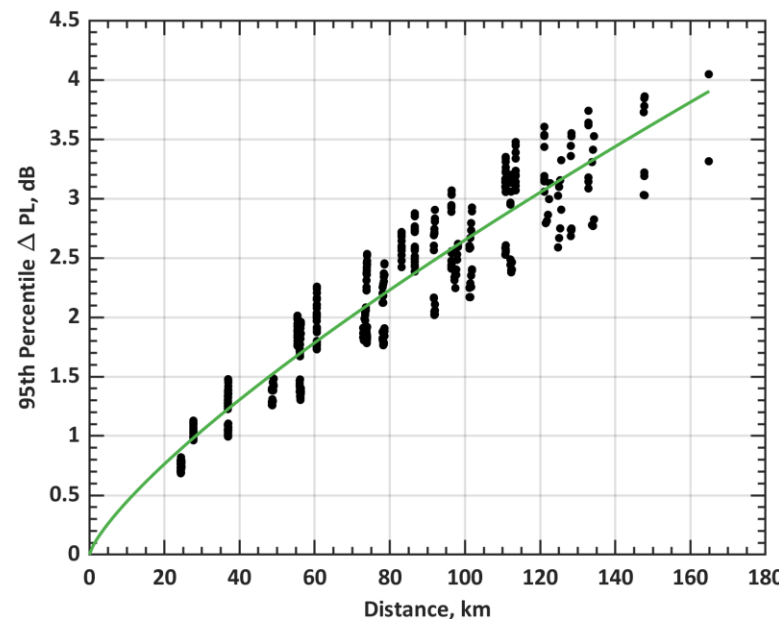
- One data point per pair of grid points (435 data points)
- Power law curve fit for each region

Quantify sensitivity of undertrack PL to geographic resolution of weather balloons

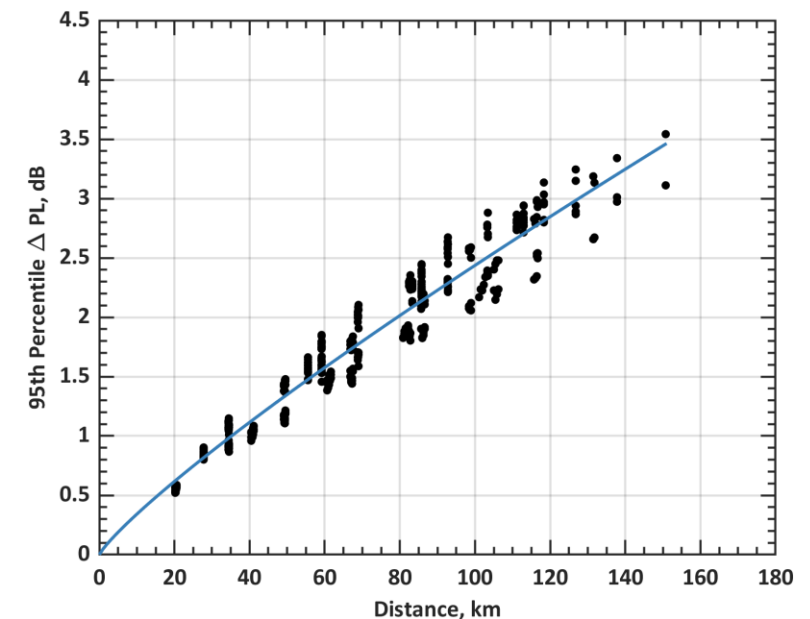
California



Florida



New York



Effect of Meteorological Temporal Resolution

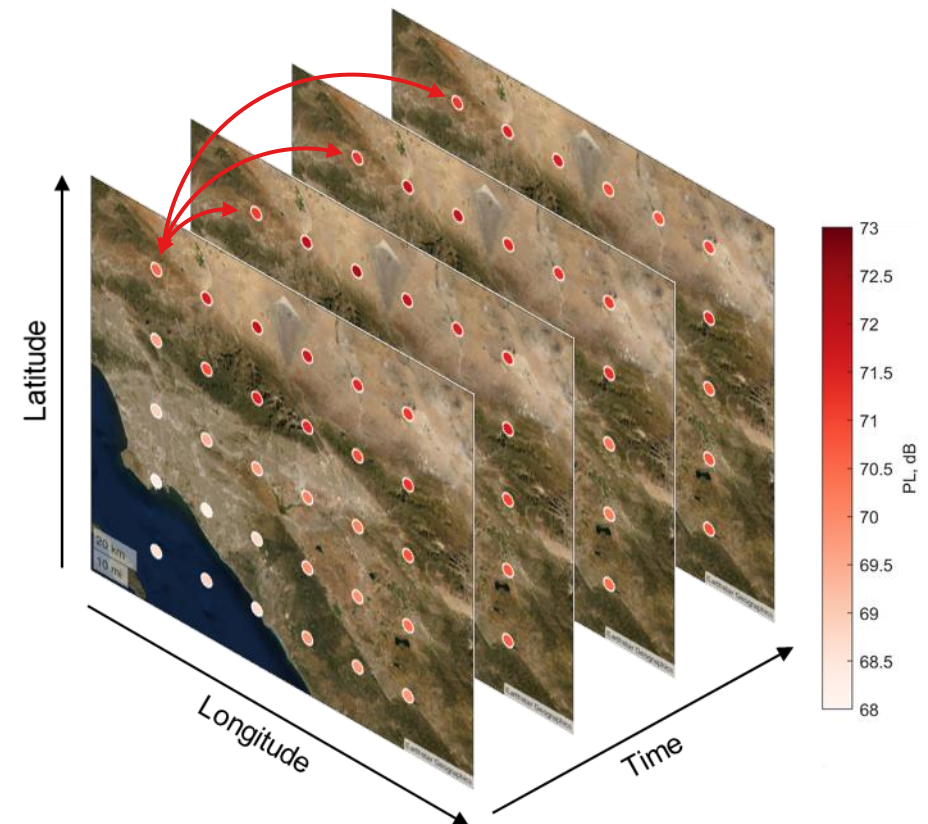


Calculate $\Delta PL_{i,j} = |PL_i - PL_j|$

- Between each pair of hours
276 unique pairwise comparisons
- For each combination of parameters
14,400 unique combinations per region

Variable	Number	Values
Regions	3	California, Florida, New York
Grid points	30	6 x 5 grid with 0.25° spacing
Dates	120	Random sample
Hours	24	0000 – 2300 hours (UTC)
Headings	4	North, South, East, West

Example: compare **Hours**
for fixed other parameters



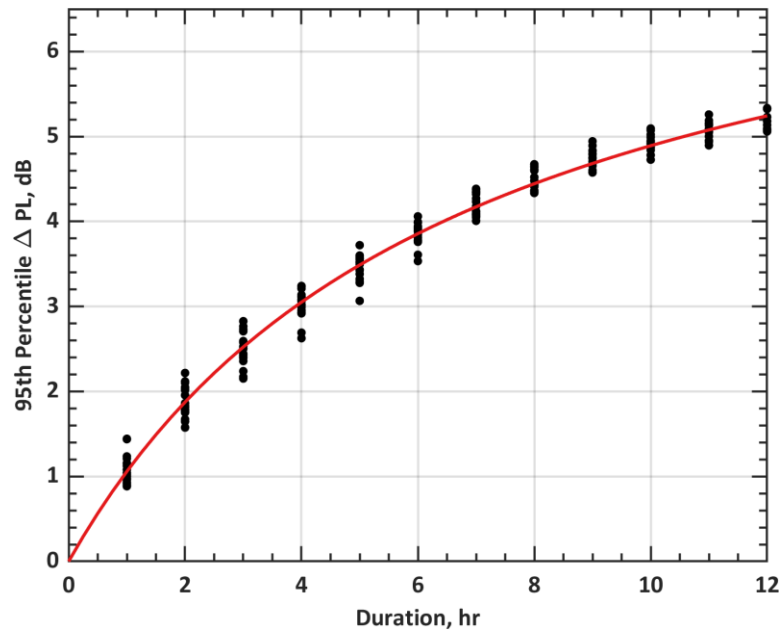
Effect of Meteorological Temporal Resolution

Plot 95th percentile of undertrack ΔPL vs. time elapsed

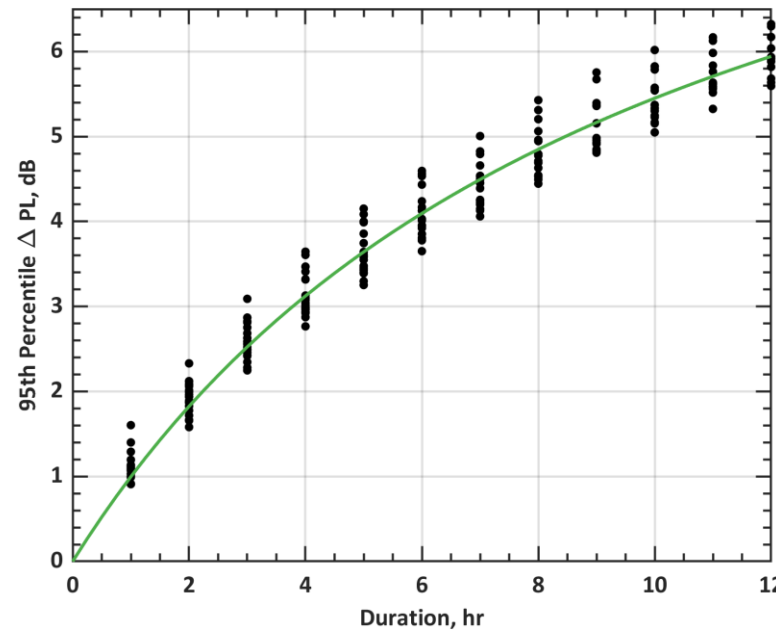
- One data point per pair of hours (276 data points)
- Rational curve fit for each region

Quantify sensitivity of undertrack PL to temporal resolution of atmospheric profiles

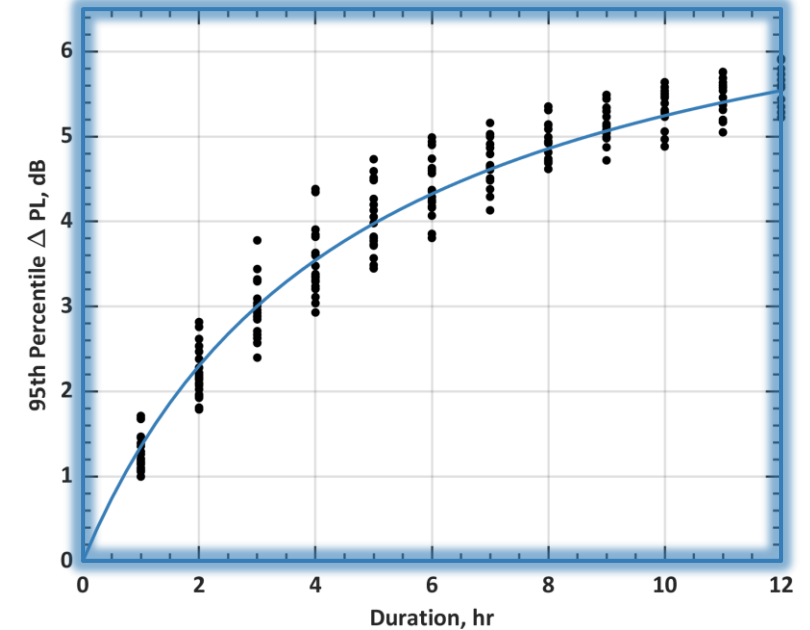
California



Florida



New York



Scaling to the Inner Sonic Boom Carpet



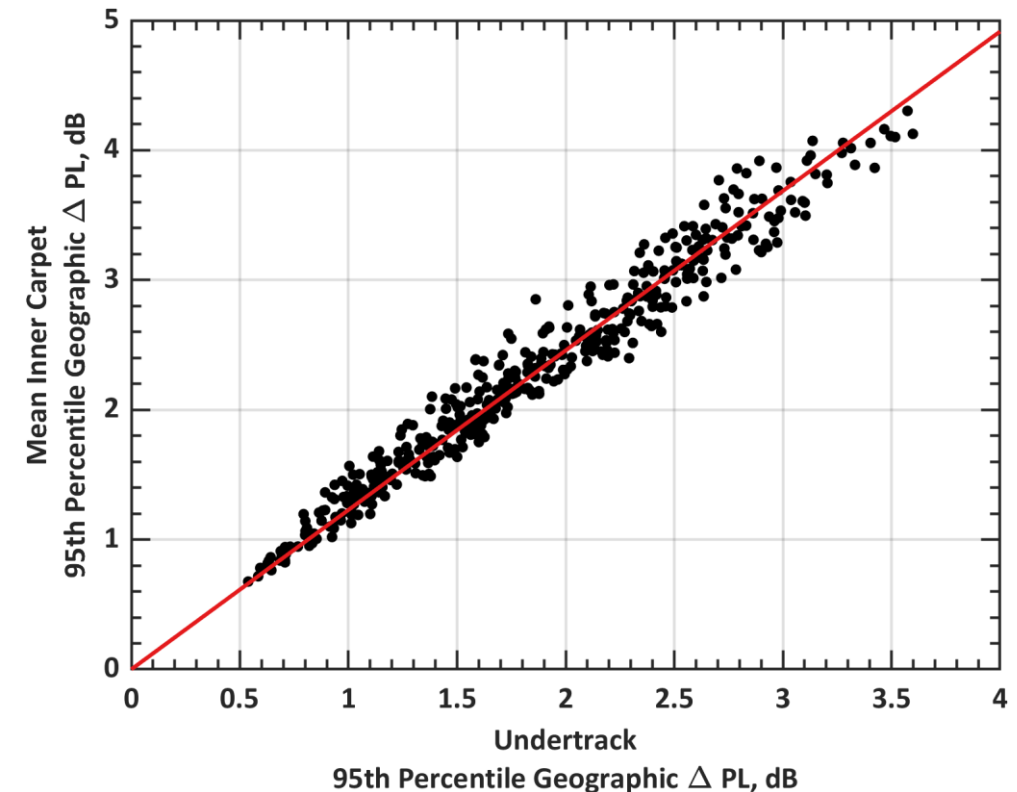
PCBoom setup:

- ▶ Enhanced Burgers solver
- ▶ Steady flight at Mach 1.4 and 53,200 ft
- ▶ Calculated carpet PL at all ϕ angles

Calculated PCBoom runs:

Variable	Number	Values
Regions	3	California, Florida, New York
Grid points	30	6 x 5 grid with 0.25° spacing
Dates	12	Random sample
Hours	24	0000 – 2300 hours (UTC)
Headings	4	North, South, East, West
Total	103,680	

Linear scaling from undertrack ΔPL to mean ΔPL across innermost 40 km of sonic boom carpet



Effect of Geographic and Temporal Resolution



Plot 95th percentile of undertrack ΔPL vs. geographic distance and time elapsed

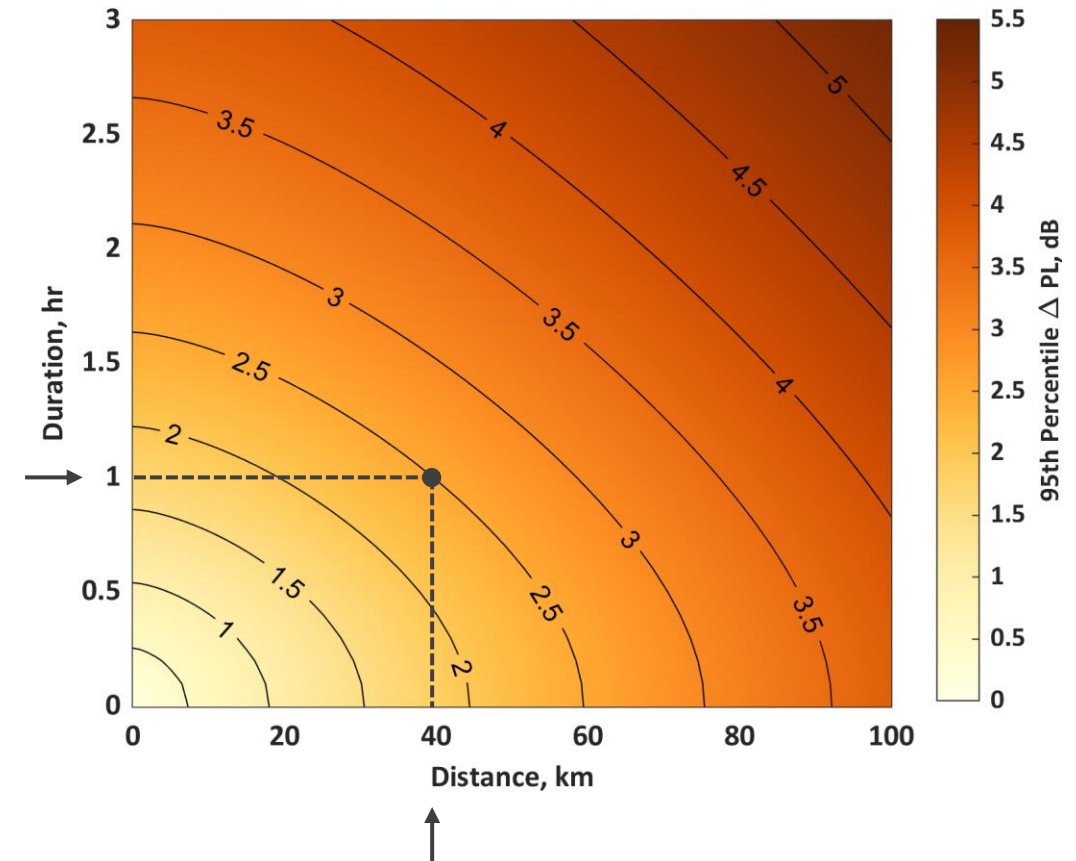
- Assume effects of geographic and temporal resolution are independent
- Use most conservative geographic and temporal resolution of the three regions

Example result:

If weather balloons are launched within one hour of each flight

And PL error should be less than 2.5 dB in 95% of weather conditions

Distance to the nearest weather balloon must be less than 40 km



Conclusions for Weather Balloon Measurements



Research question: where and when to launch weather balloons?

Challenge: the atmosphere varies with geographic location and time

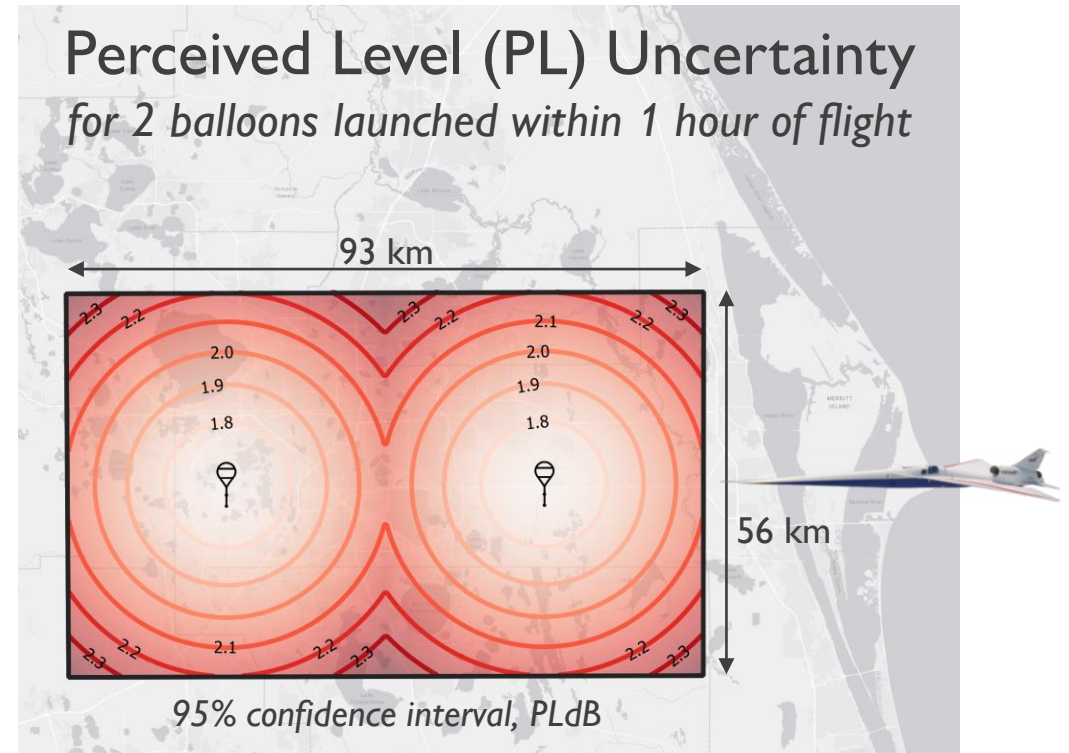
Weather balloons launched at limited locations and times

Uncertainty in the calculated noise exposure

Research: quantify sensitivity of calculated PL to geographic and temporal resolution of weather balloons

Result: launch weather balloons from at least two locations within one hour of each flight

Perceived Level (PL) Uncertainty for 2 balloons launched within 1 hour of flight



Future: include weather balloon uncertainty in the Kalman filter