2aNSb3
Simulations of X-59 sonic thumps and traditional sonic booms propagated around the world for three atmospheric models

William J. Doebler and Victor W. Sparrow
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Propagation simulations were conducted to predict the loudness of supersonic aircraft around the world

Talk Outline

- Motivation for the study of supersonic aircraft noise
- Overview of simulation process
  - Selection of
    - atmospheric models
    - aircraft and flight conditions
    - propagation locations
  - Bootstrap forest model to assess important factors
  - Multiple linear regression models to predict outside of the selected propagation locations
- Results
  - Comparison of predicted loudness for different atmospheric models
  - Comparison between N-waves and quiet supersonic signatures
  - Assessment of effects of climate zone on loudness
- Summary

Motivation: Civilian supersonic aircraft noise certification standards are under development and need to be globally effective

- Overland supersonic flight currently prohibited
- New technology reduces loudness of sonic booms
- New supersonic aircraft noise certification standards needed

- NASA X-59 aircraft
  - low-boom noise source for community noise surveys
  - will inform noise regulations
- Atmosphere influences effectiveness of low-noise supersonic aircraft design
- Noise regulations should be effective regardless of location

- Goal of this propagation simulation study:
  - Identify regions and climates that may experience increased loudness
  - Assess differences between
    - predictions from three atmospheric models
    - meteorological impacts on traditional N-wave sonic booms and shaped booms

Process flow for a sonic boom propagation study

Setup

Select:
- aircraft and flight conditions
- atmospheric model
- propagation locations
- timespan

→

Propagate

PCBoom 7.3
Enhanced Burgers
Module

→

Analyze

- Compute loudness and exposure region sizes
- Fit prediction models

Global propagation study details

Setup

Selections:

- Aircraft and flight conditions
  - X-59 (Quiet/Loud), B-58
  - 4 cardinal directions
- Atmospheric models
  - ERA5, CFSv2, GFS
- Propagation locations
  - 100 global locations
- Timespan
  - 1 year, every 6 hours

X-59
Quiet: Mach 1.4, 53200 ft
Loud: Mach 1.3, 43000 ft

B-58
Mach 1.4, 53200 ft

	ERA5	CFSv2	GFS
Horizontal Resolution	0.25° x 0.25°	0.5° x 0.5°	0.25° x 0.25°
Vertical Resolution	37 isobars from 1000 mbar to 1 mbar	37 isobars from 1000 mbar to 1 mbar	34 isobars from 1000 mbar to 0.4 mbar
Temporal Resolution	1 Hour	6 Hour	3 Hour
Ground Elevation	✓	✓	✓
Pressure			
Temperature			
Winds			
Humidity			

Global propagation parallelization details

Setup

Selections:

- Aircraft and flight conditions
  - X-59 (Quiet/Loud), B-58
  - 4 cardinal directions
- Atmospheric models
  - ERA5, CFSv2, GFS
- Propagation locations
  - 100 global locations
- Timespan
  - 1 year, every 6 hours

Propagate

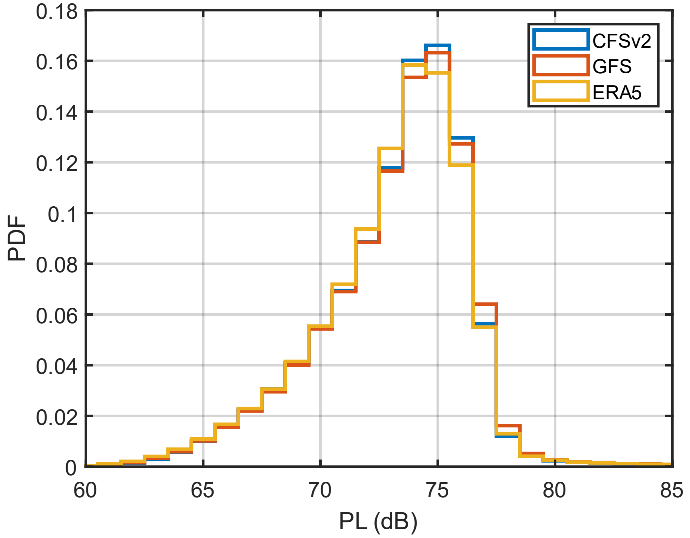
PCBoom 7.3
Enhanced Burgers
Module

- Write millions of PCBoom input files
- Set up parallelization
  - Create master list of all runs
  - Split list into batch segments
  - Assign batch segment to cluster computer
- Propagation over about 2 weeks
  - NASA Langley's K-cluster supercomputer
    - Hardware:
      - Intel Gold 6148 Skylake (Dual socket 20 core 2.40 GHz)
      - Intel E5-2697 V3 Haswell (Dual socket 14 core 2.60 GHz)
      - Intel E5-2670 Sandybridge (Dual socket 8 core 2.60 GHz)
    - 72-hour max per job
    - 3000 CPU limit for running jobs

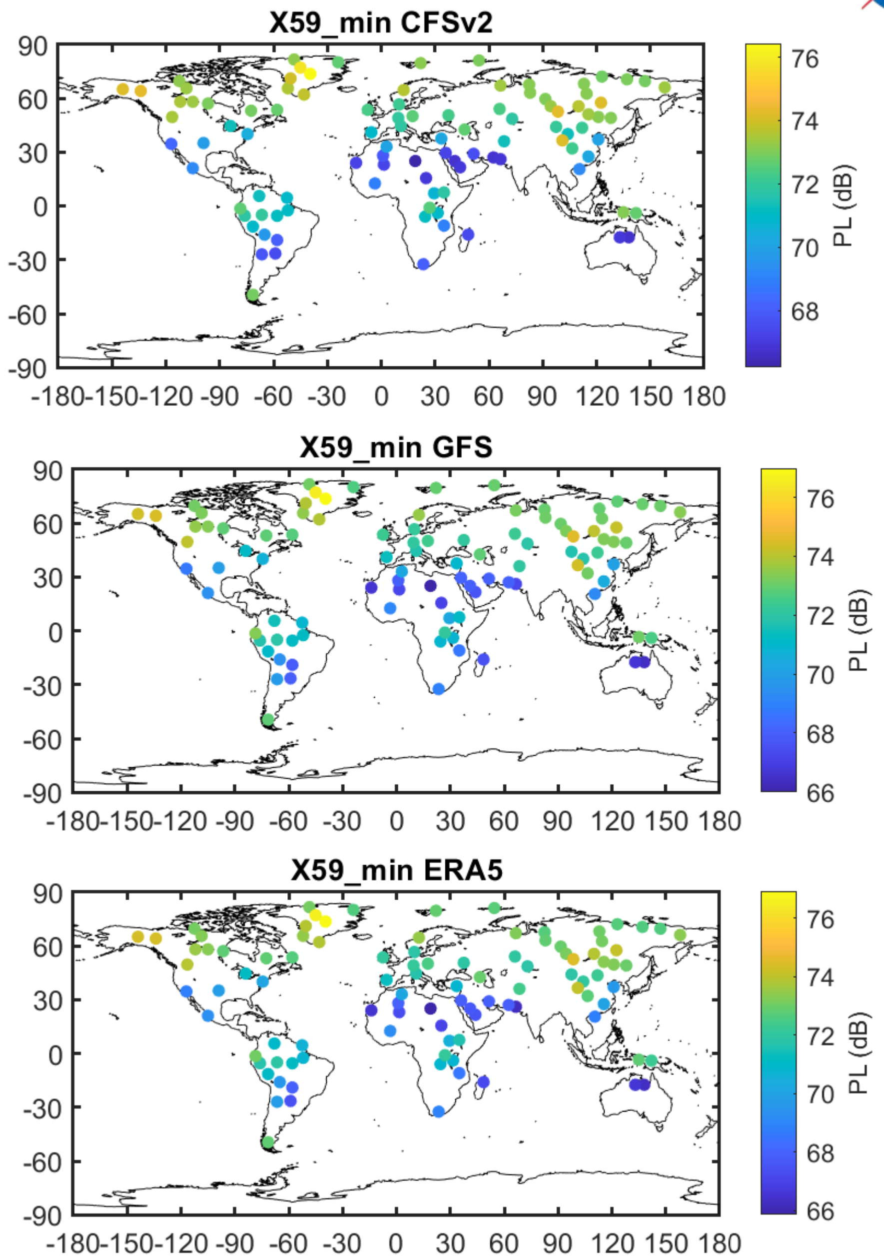
3 aircraft configurations x 4 aircraft headings x 3 atmospheric models
x 100 locations x 365 days x 4 atmospheric profiles per day
= 5.256 million carpets generated

Loudness predictions differ very little between three atmospheric models

- Results match well between atmospheric models
  - Example:

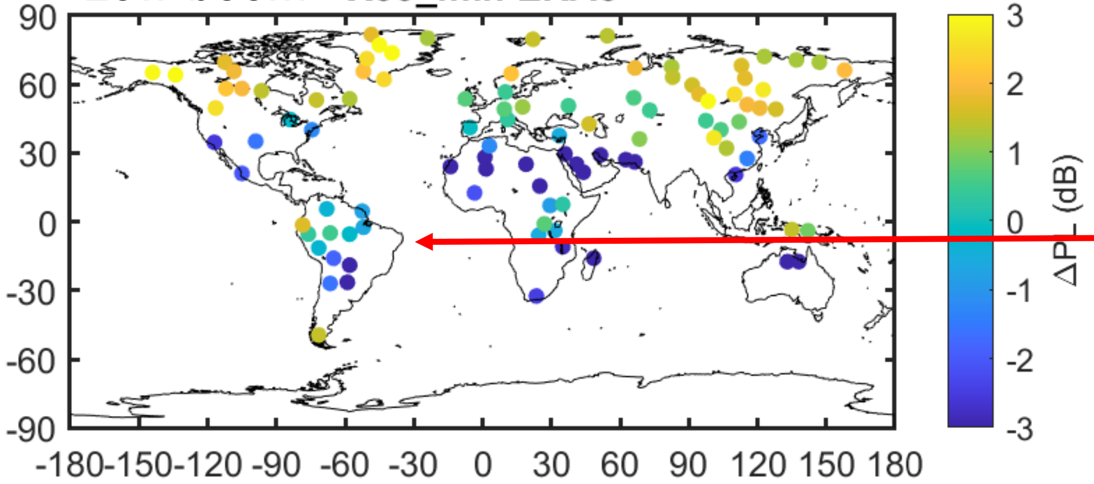


- Bootstrap forest model used for predictor screening
  - Predictors considered
    - Latitude, longitude, aircraft, heading, atmospheric model, ground elevation, climate zone, season, and time of day
  - Top 3 most important factors
    - Climate zone, season, latitude
  - Unimportant factors
    - Atmospheric model, time of day

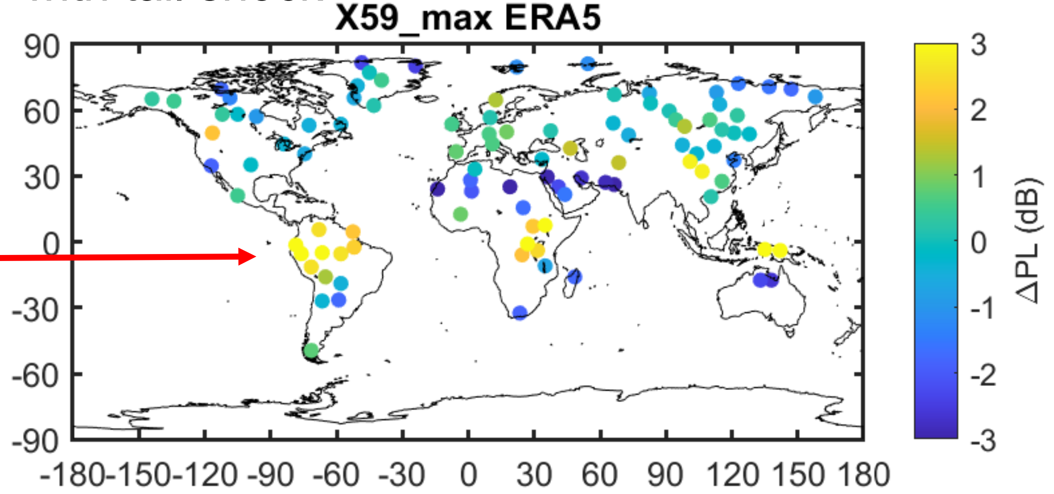


Differences in trends between are apparent between low-booms and N-waves

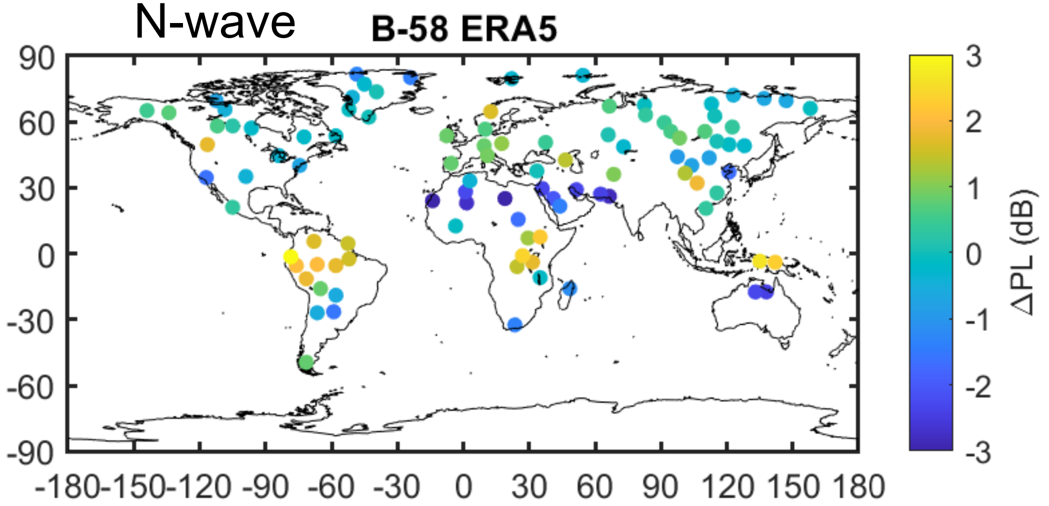
Low-boom



Shaped front
with tail shock



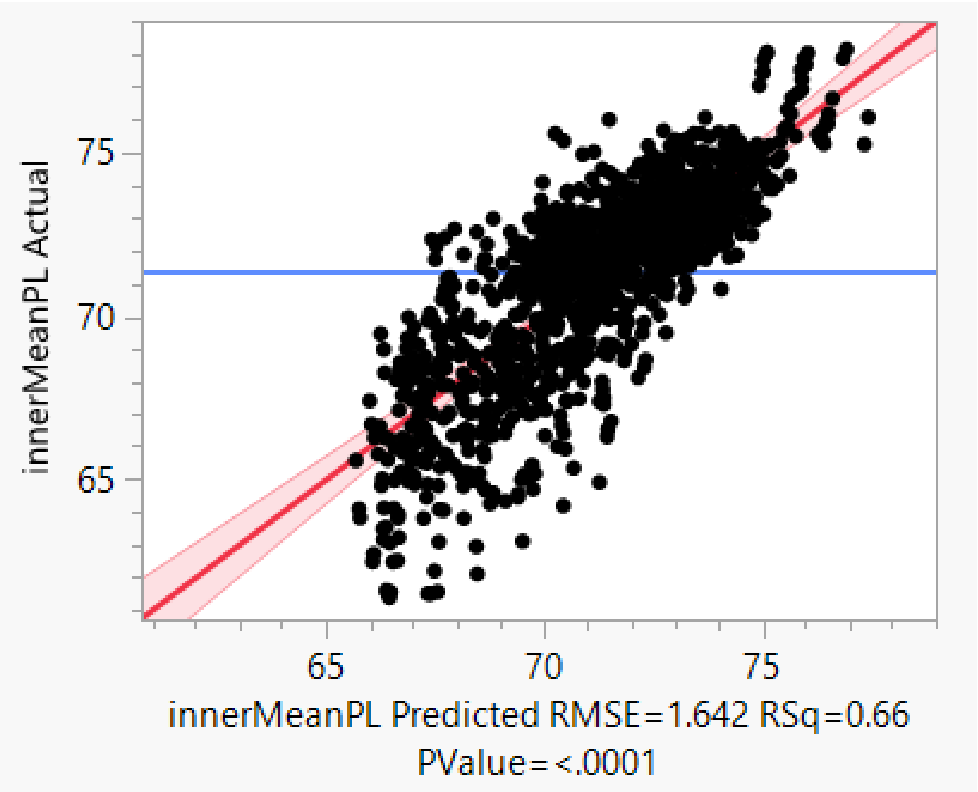
N-wave



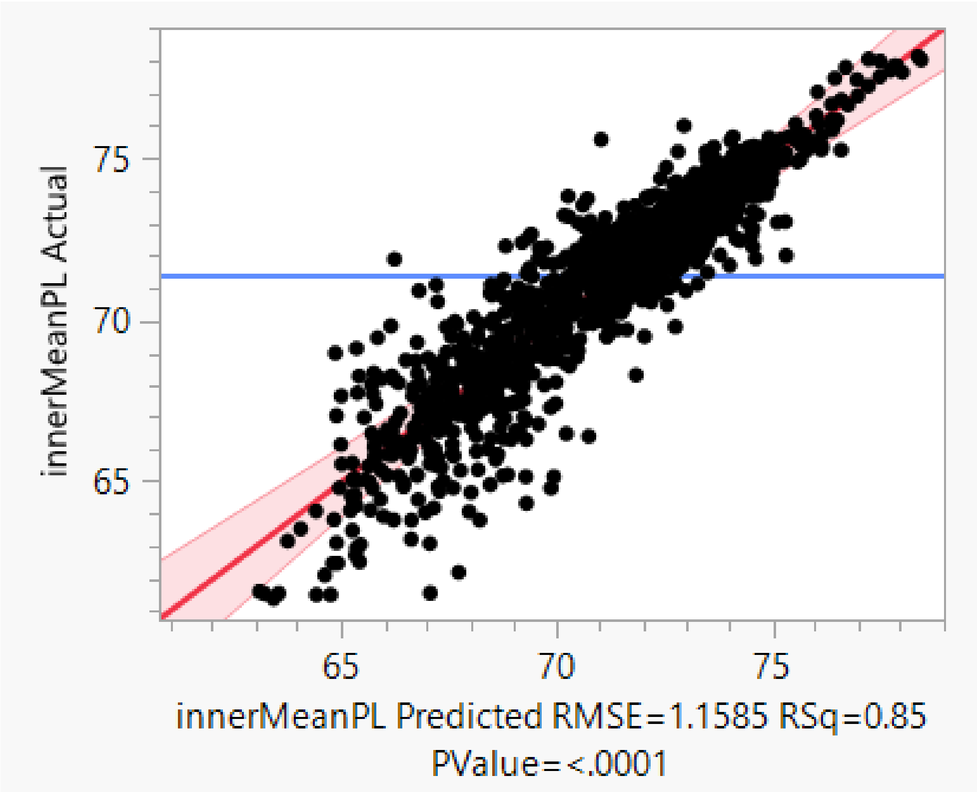
ΔPL is the difference
from the global mean

Multiple linear regression models fit to predict at additional locations

- Direct effects model

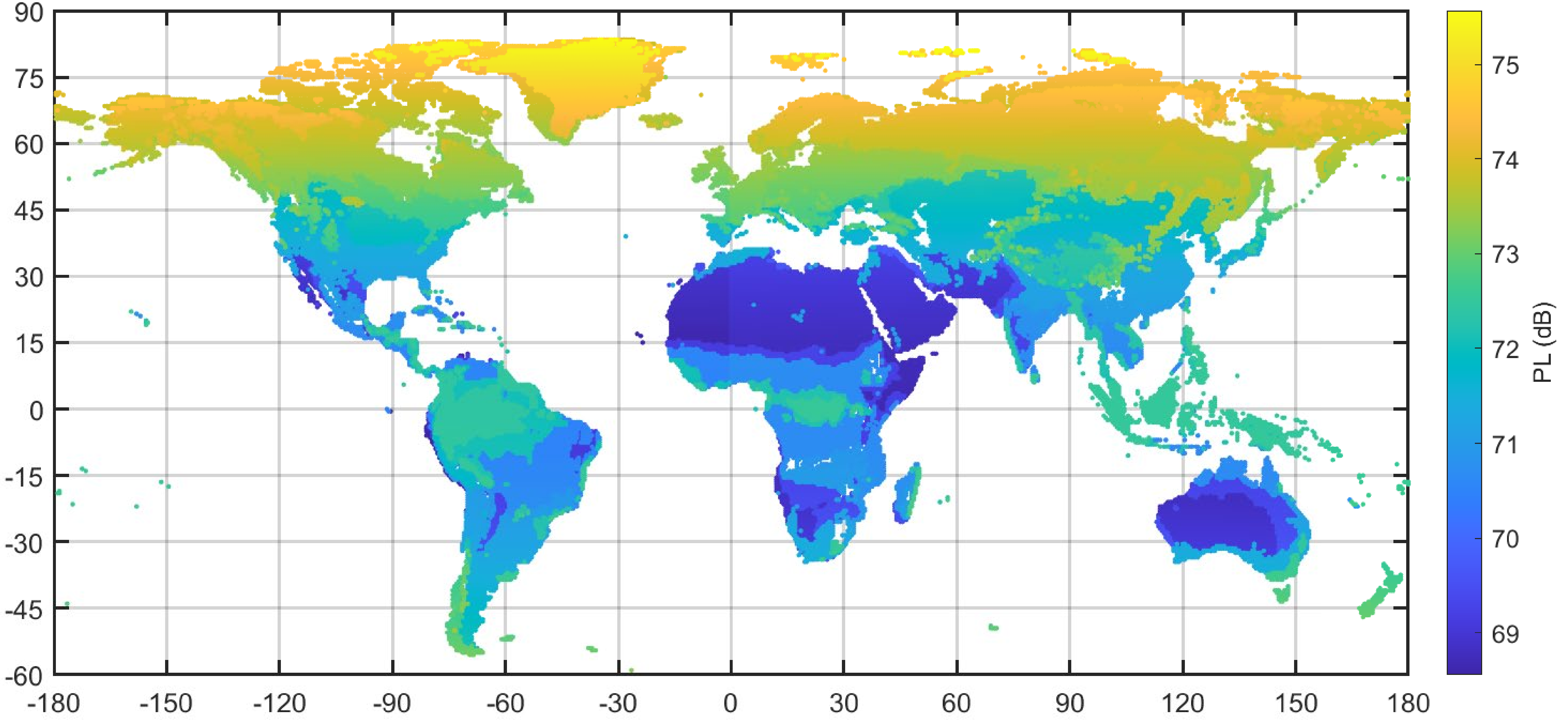


- Direct effects and single interactions model

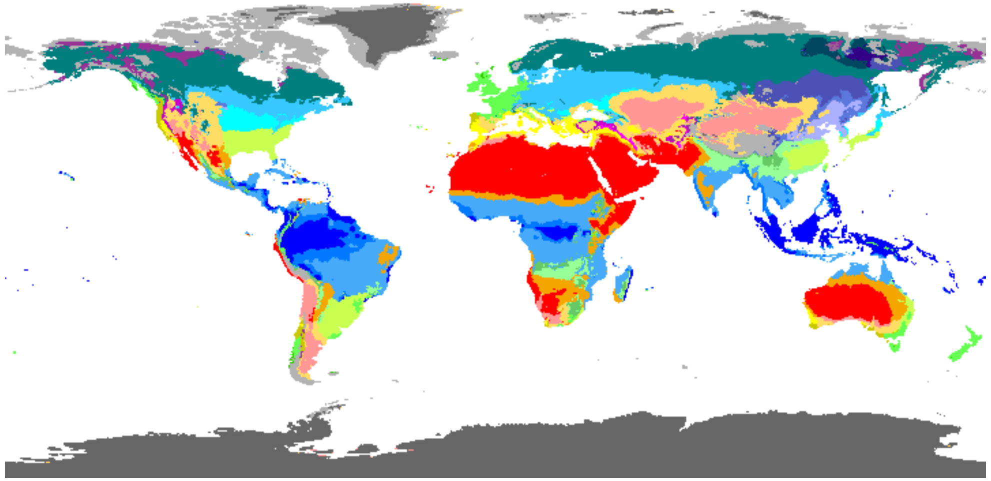


Global predictions from multiple linear regression models

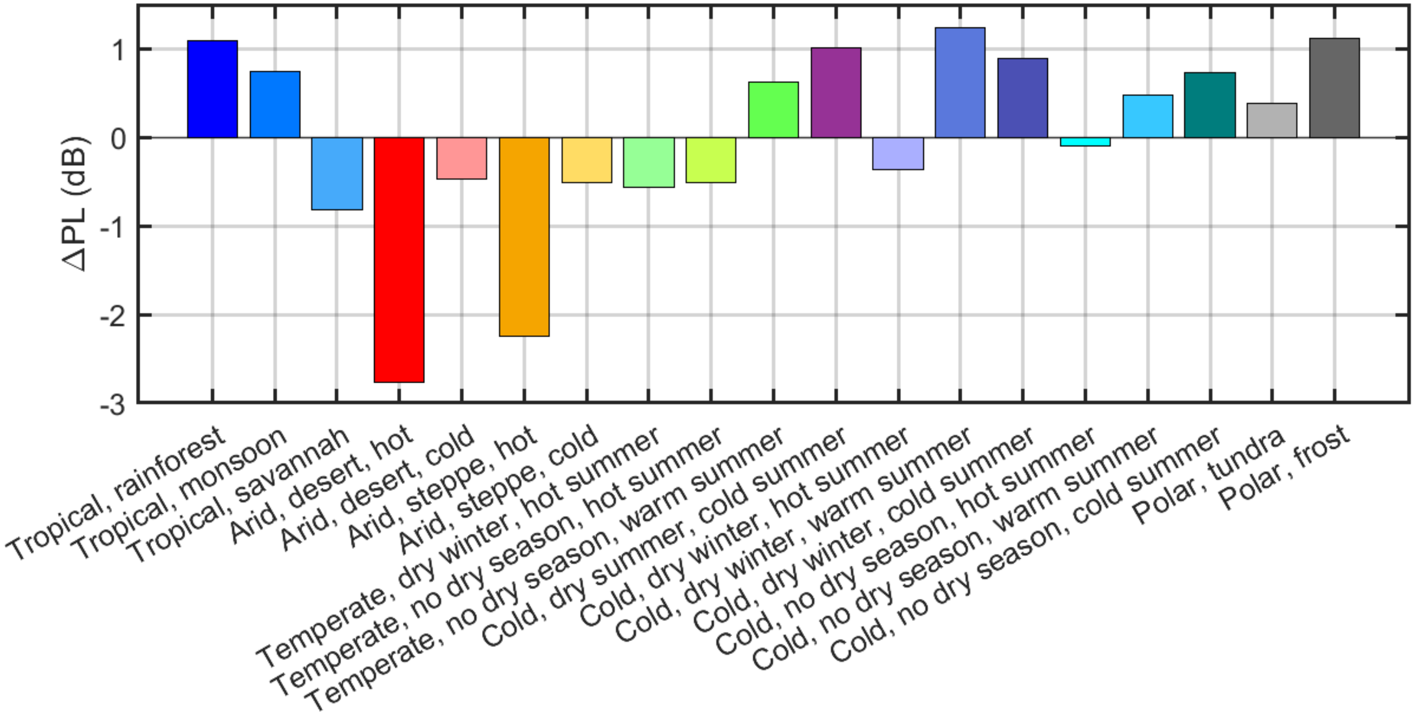
- Undertrack level X-59 quiet configuration, eastbound, winter

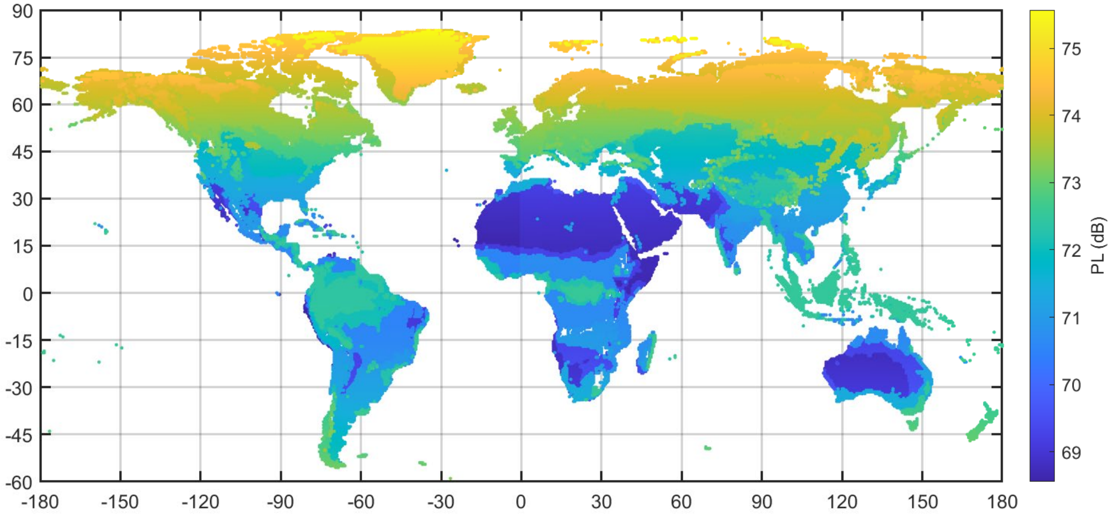


Impact of climate zone on X-59 low-boom mean PL



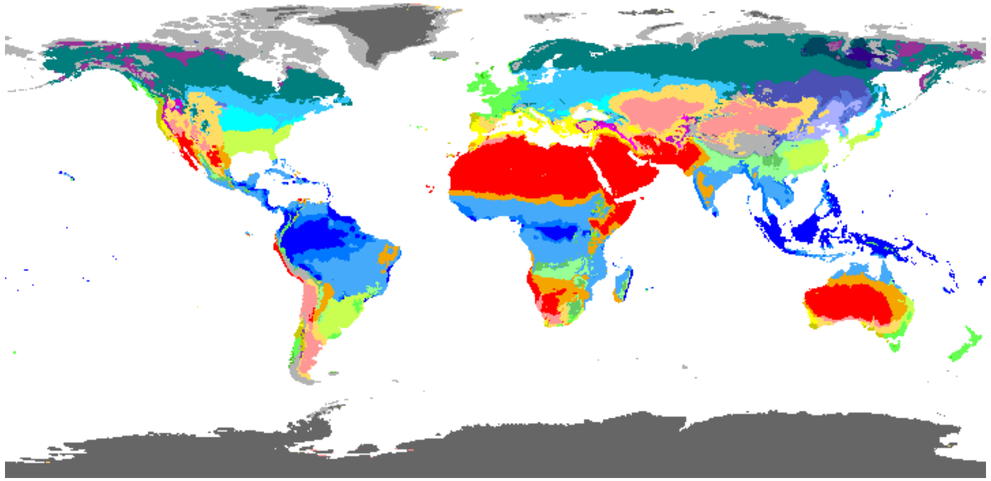
[Beck et al. (2018) Koppen-Geiger Zones](#)
doi: 10.1038/sdata.2018.214





Sort by ΔPL

Impact of climate zone on X-59 low-boom mean PL



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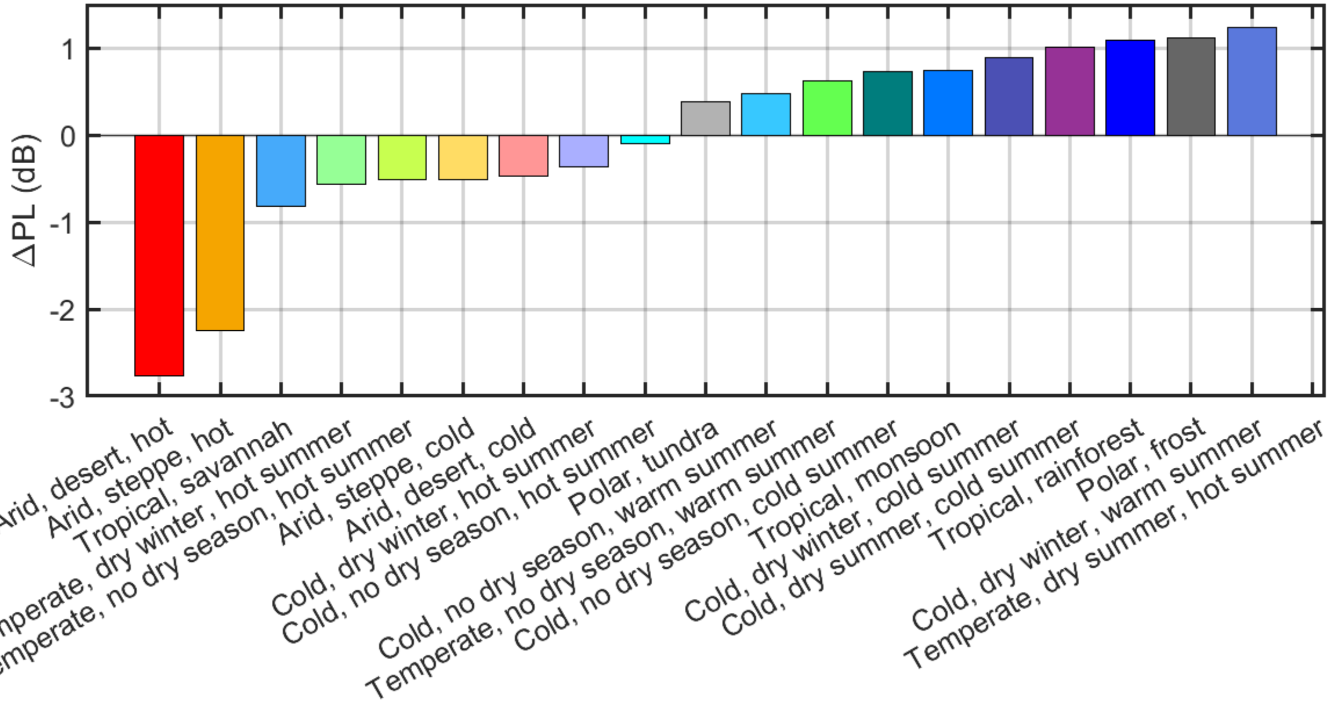
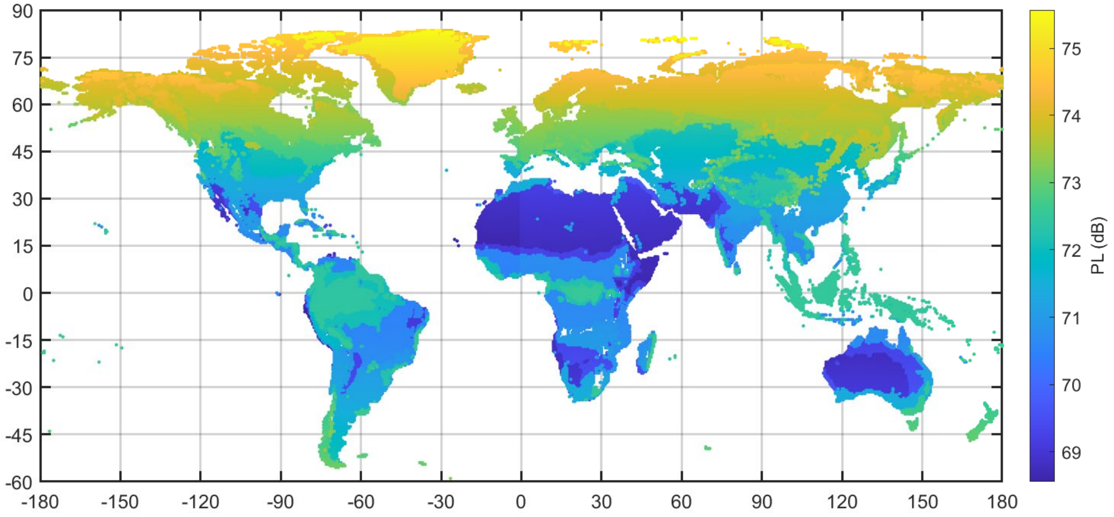
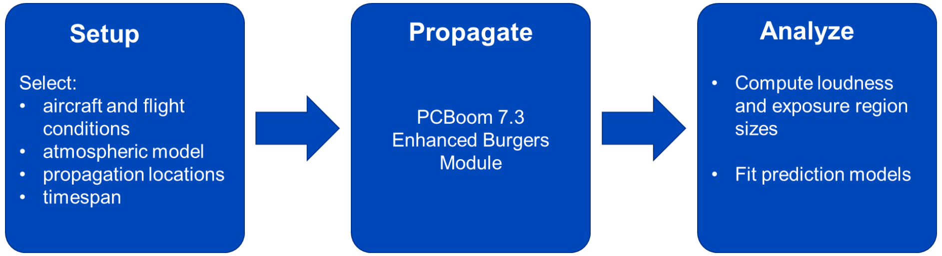
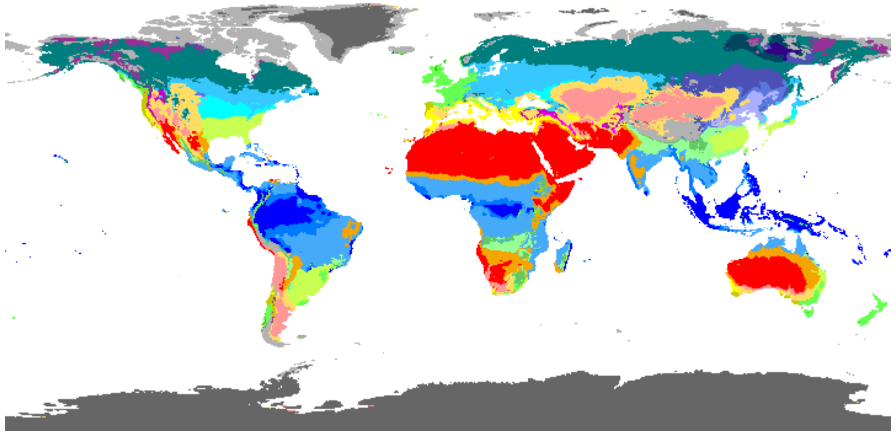


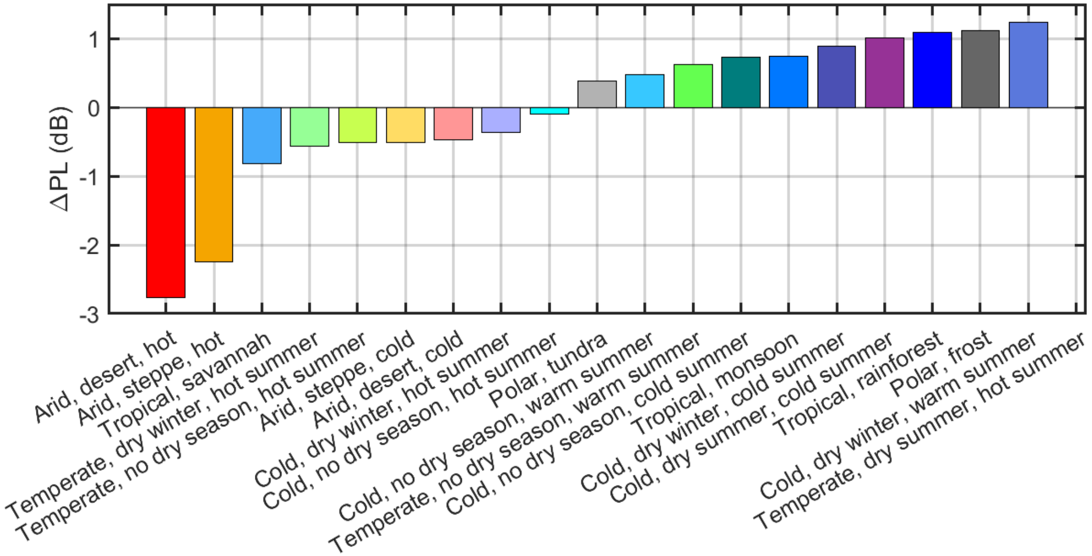


Summary

- Global sonic boom propagation study undertaken
  - Over 5 million sonic boom carpets generated
    - X-59 and an N-wave-producing aircraft
    - 100 locations
    - Carpets generated over 1 year, every 6 hours
    - 3 atmospheric models studied
- Modeling
  - Bootstrap forest predictor screening
    - Climate zone, season, and latitude were the most important
    - Atmospheric model was unimportant
  - Multiple linear regression models fit that allow global prediction
- Key Takeaways
  - Trends in low-boom loudness differ from N-waves
  - Climatic differences ranged between -3 and +1 dB from the mean
- These takeaways will be important to consider when setting future noise regulations



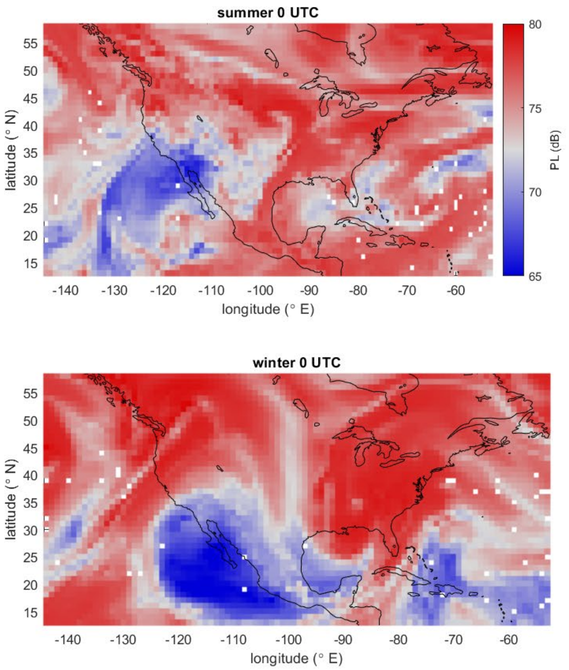


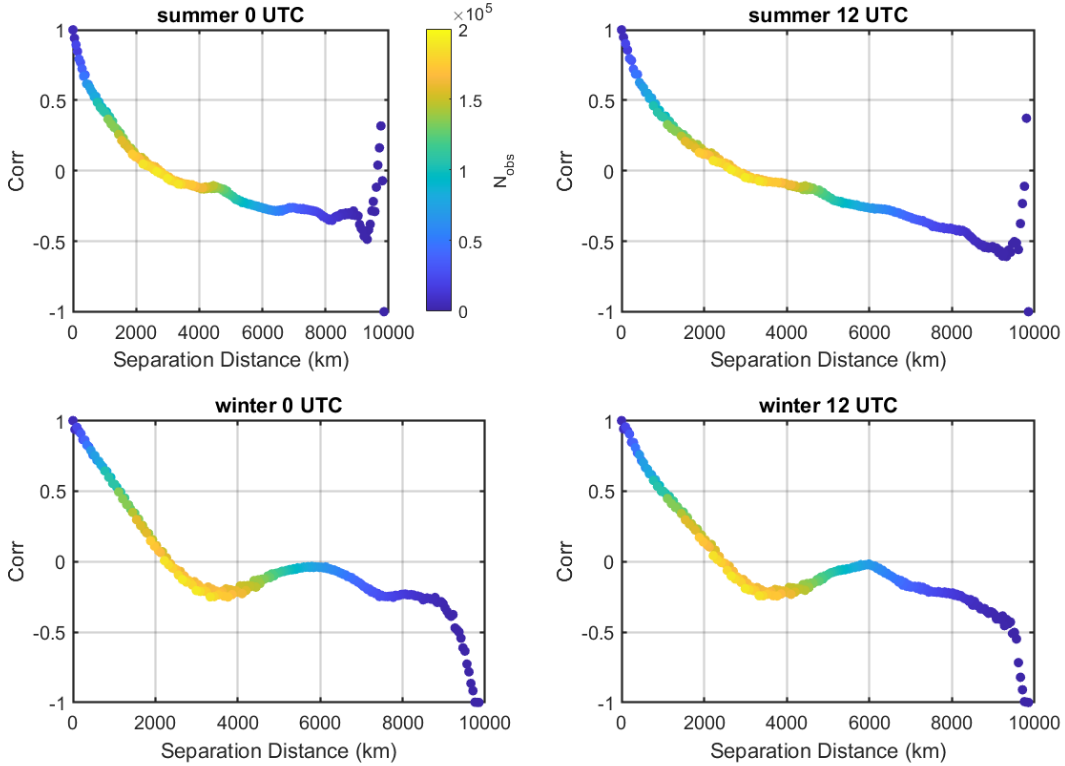


QUESST

BACK-UP

Separation distances: computing spatial correlation at fixed time



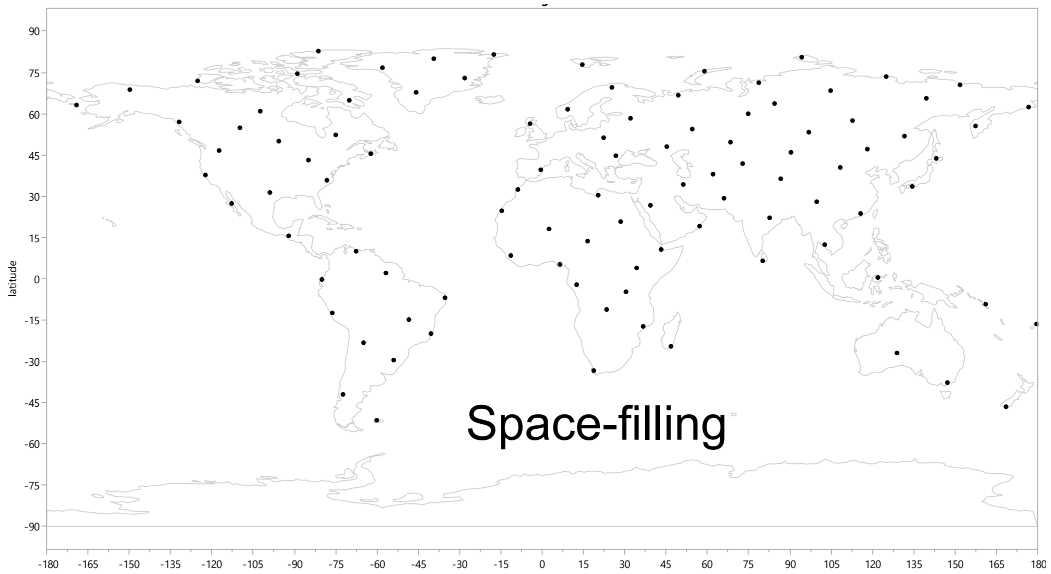


Analysis of data made available by
Leal et al. (2021) doi: 10.2514/1.J059209

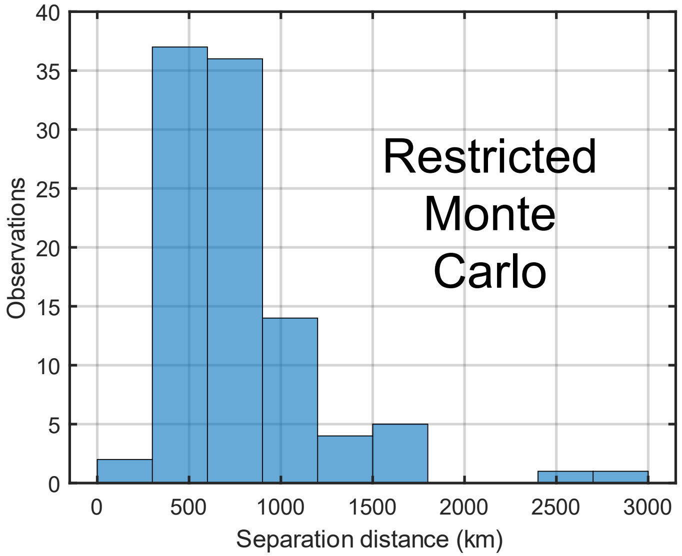
- Partial correlation is desirable for modeling
- Selected locations' correlation is too low?
  - Polka dot map plots, hard to interpolate between points.
- Selected locations' correlation is too high?
  - Waste of computational resources due to little information gain from point to point
- Correlation of 0.5 is observed between 675 and 1100 km
- Correlation of 0 is observed between 2350 and 2700 km

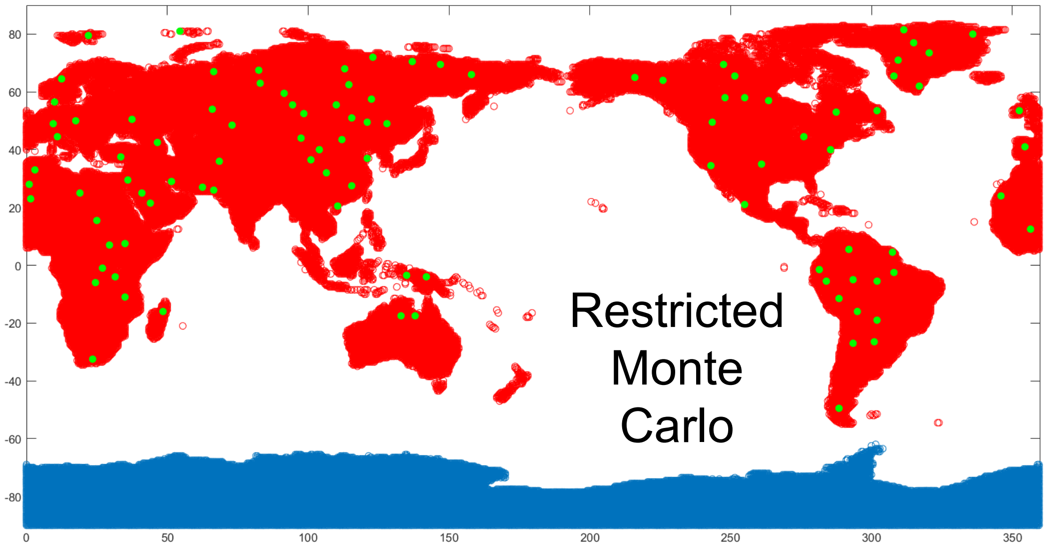
Space-filling vs Restricted Monte Carlo

- The space-filling approach pushed too many locations to be along the coast
- Used a restricted Monte Carlo approach instead, and required each point to be 400 km apart at minimum



Majority of selected locations are < 1100 km from nearest neighbor





Abstract

- Propagation simulations of sonic booms from supersonic aircraft through atmospheric data over time at fixed locations provides the opportunity to assess noise exposure statistics for different climate regions. Knowledge of climate-based differences in sonic boom noise exposure statistics is important to ensure that future civil supersonic aircraft noise certification standards are globally applicable and effective. In this presentation, simulated sonic booms from the NASA X-59 Quesst quiet supersonic aircraft and conventional supersonic aircraft were propagated through atmospheric data at 100 locations across the world using PCBoom. Noise exposure statistics are compared for propagation results from three different atmospheric databases (NOAA Global Forecast System, NOAA Climate Forecast System Version 2, and the ECMWF Reanalysis Version 5). These atmospheric models were chosen due to their global coverage, popularity, and database availability. Preliminary statistical models are fit to assess the impact of several factors including flight direction, season, ground elevation, and climate on noise exposure size and loudness. Areas with prevalence of higher noise due to their climate are identified, which could help inform future supersonic aircraft noise standards.