

**Sandia
National
Laboratories**

Investigating Turbulent Wall Pressure Fluctuations using Machine Learning Techniques

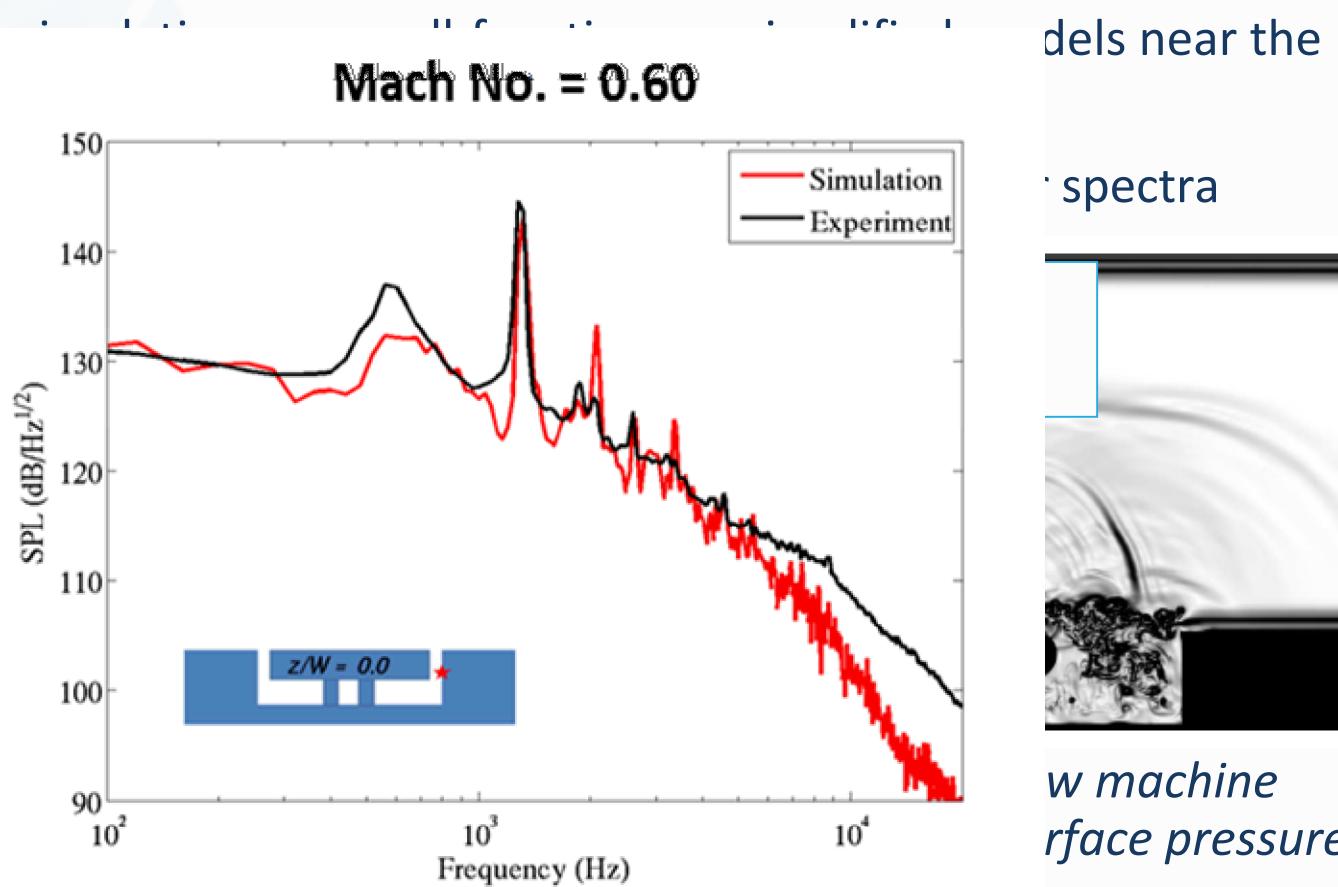
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Kenny Chowdhary, Jeff Fike

April 2017

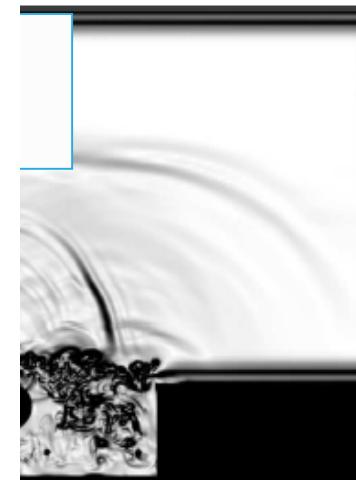
Motivation

- For fluid-structure interaction (FSI) applications, must be able to predict the pressure loading on a surface due to a turbulent flow
- Many turbulence models near the wall due to the wall due to the
- These near wall distributions



models near the

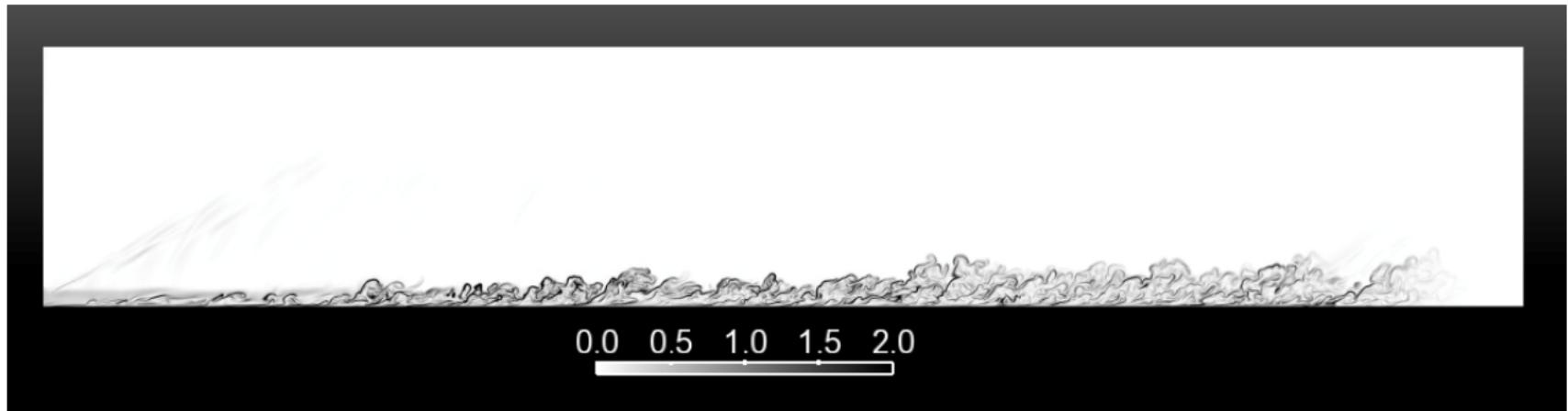
spectra



w machine
surface pressure

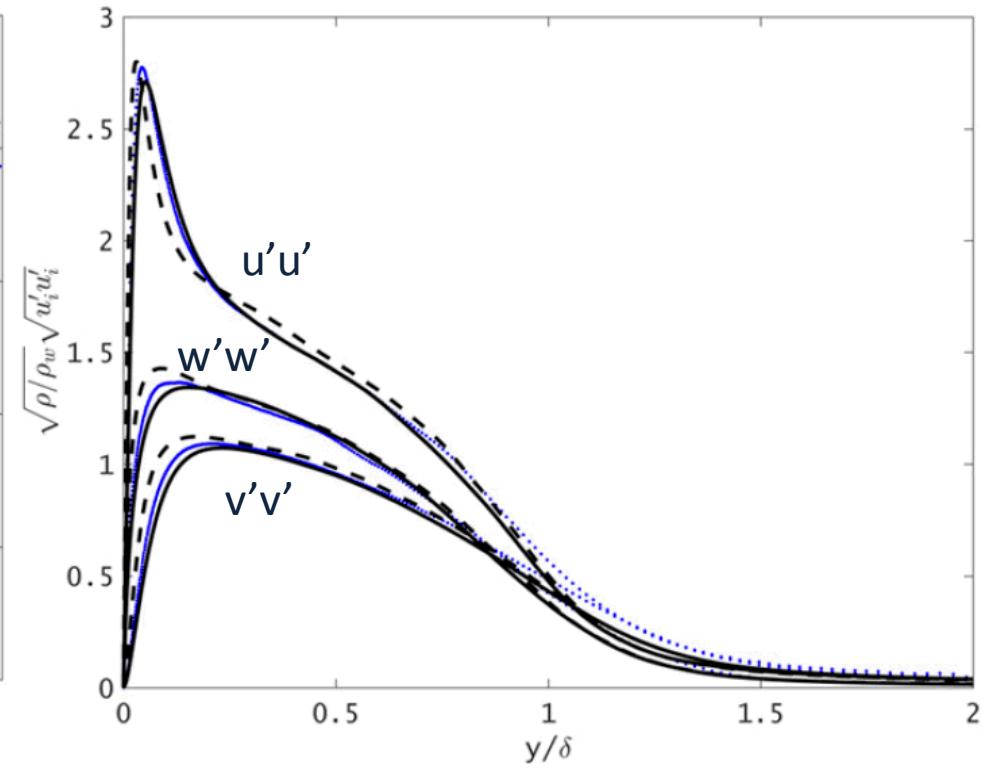
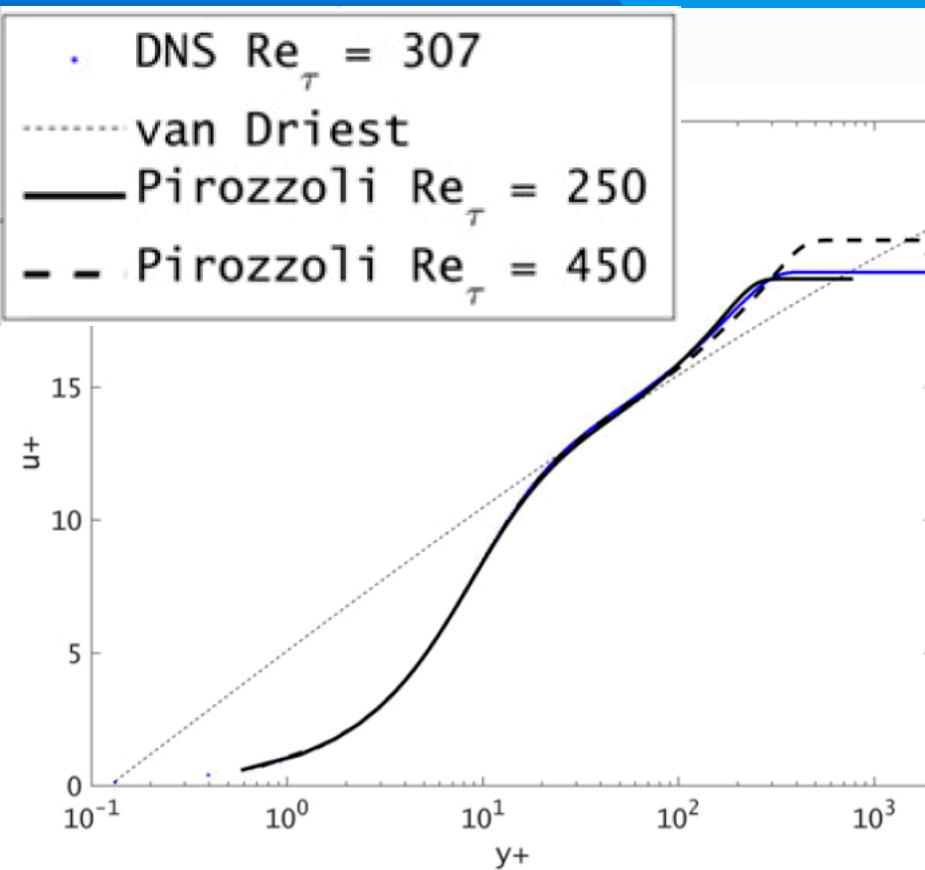
- Goal: Use a Direct learning can be to predict surface pressure fluctuations.

DNS Data Set



- Mach 2.0 compressible flat plate turbulent boundary layer
- Low-dissipation 5th order upwind biased flux-reconstruction scheme
- Fourth order explicit Runge Kutta time integration
- 100.7 M mesh cells
 - Near wall resolution: $\Delta x^+ < 5$, $\Delta y^+ < 0.2$, $\Delta z^+ < 4$
- $1075 < Re_\theta < 1310$
- Run for $> 1200\tau$ (where $\tau = \delta_0 / U_\infty$)

DNS “Verification”



- Our DNS: $Re_\tau = 302$
- Good agreement of mean velocity and Reynolds stress profiles with Pirozzoli et al. at $Re_\tau = 250, 450$

What is Machine Learning?

- Data-driven algorithms to discern patterns and make predictions on big, high-dimensional data
- Linear regression, support vector machines, neural networks

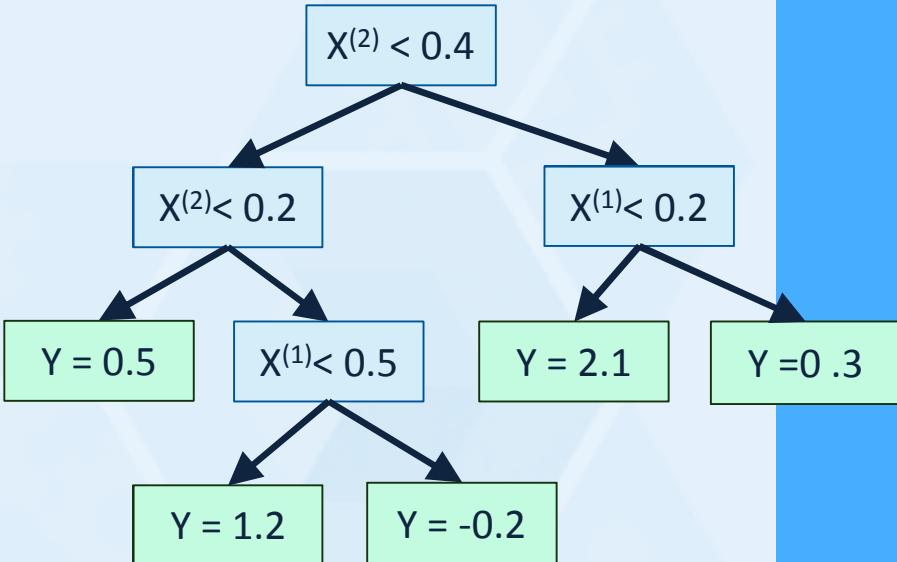
The image displays three screenshots illustrating machine learning applications:

- AOL News Feed:** Shows a "Inspired by your Wish List" section with book recommendations. The books include "THE INNER LIVES of MARKETS" by Ray Fisman and Tim Sullivan, "Who Gets What—and Why" by Alvin E. Roth, "PHISHING FOR PHOOLS" by George A. Akerlof and Robert J. Shiller, "THE SEVENTH SENSE" by Joshua Cooper Ramo, "OUT STEALING HORSES" by Peter Bergman, and "THE TEARDROP RECO" by Theda Skocpol and Vanessa Williamson.
- Amazon Prime Audio Series:** Shows the "Original audio series" section with an iPhone displaying an audio player interface. The series listed are "Powerful Blast Manhattan; Se" (ranked 1), "Ahmad Khan J Manhattan and" (ranked 2), "Manhattan Bo. F.B.I. Question" (ranked 3), "Chelsea Bombing: What We Know and Don't Know" (ranked 4), and "DOCTOR'S WORLD How Healthy Is Hillary Clinton? Doctors Weigh In" (ranked 5).
- Pandora Radio Station:** Shows a "Classical" radio station interface. The "Now Playing" list includes: Shuffle, Thumprint Radio, K-Pop Radio, Naturally 7 Radio, Moby Radio, Israel 'IZ' Kamakawiwi..., Robert Johnson Radio, I Heard It Through Th..., Bliss N Eso Radio, Francis Cabrel Radio, Hip hop, Electropop, and Classical. The currently playing track is "Malena" by Yo-Yo Ma on "We All Love Ennio Morricone".

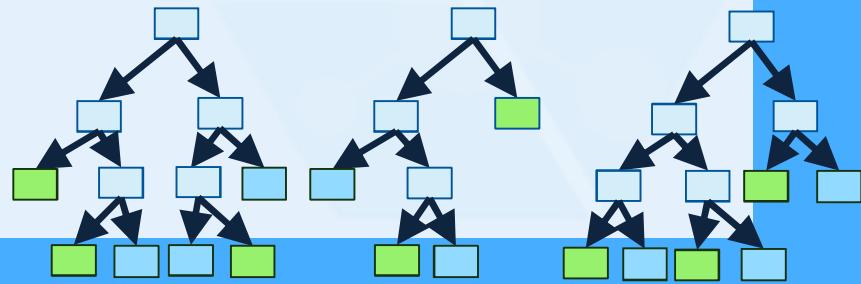
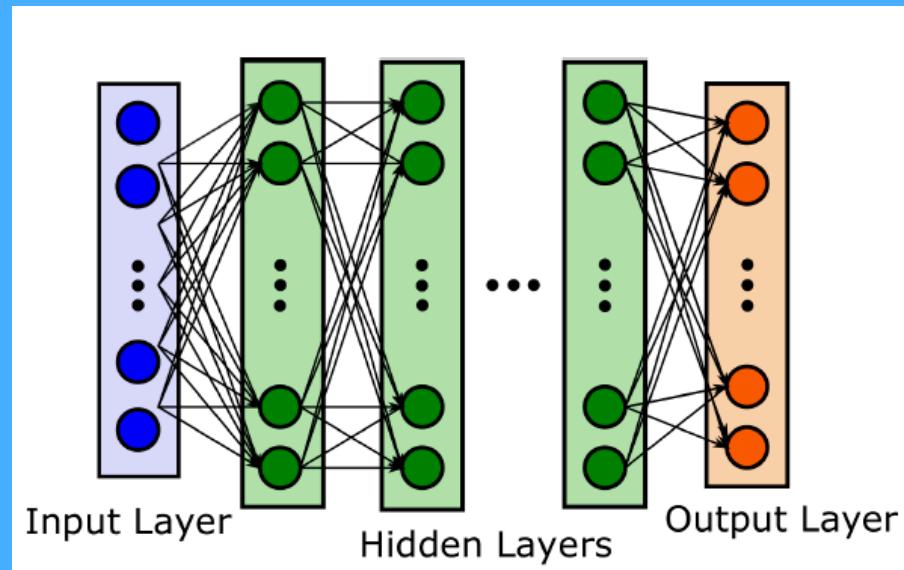
Machine Learning Algorithms



Random Forest



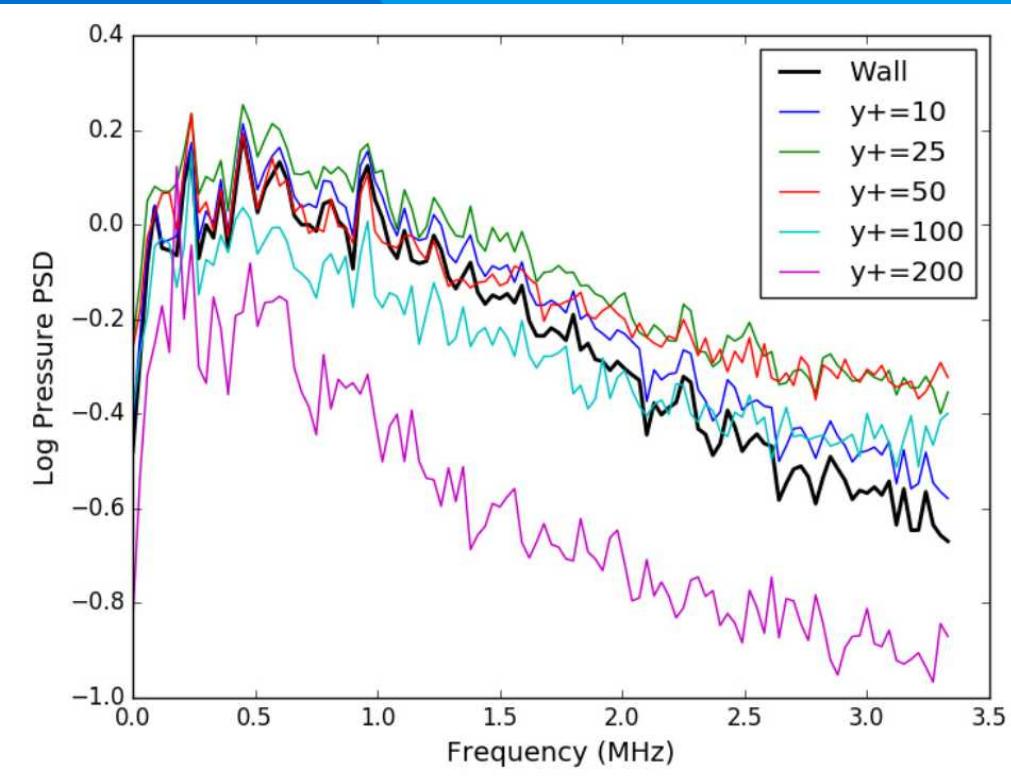
Neural Network



$$y = f(w^T x)$$

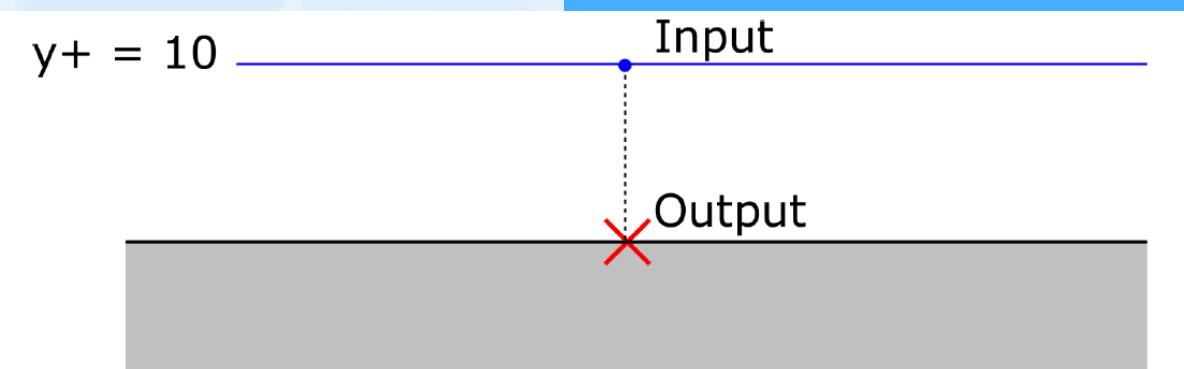


Machine Learning Framework



Given Pressure PSD at a point above the wall, can we predict the Wall Pressure PSD?

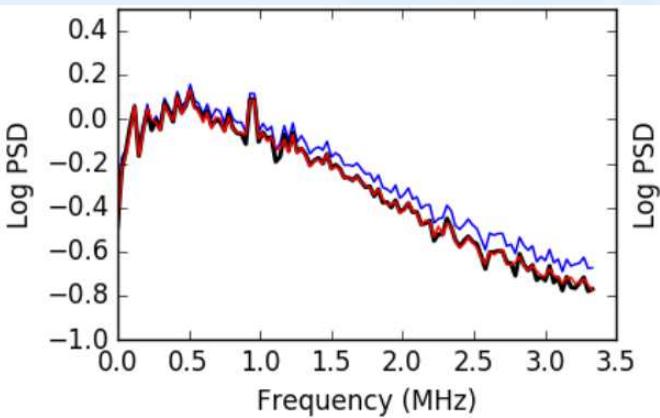
Split data sequentially into training and test set



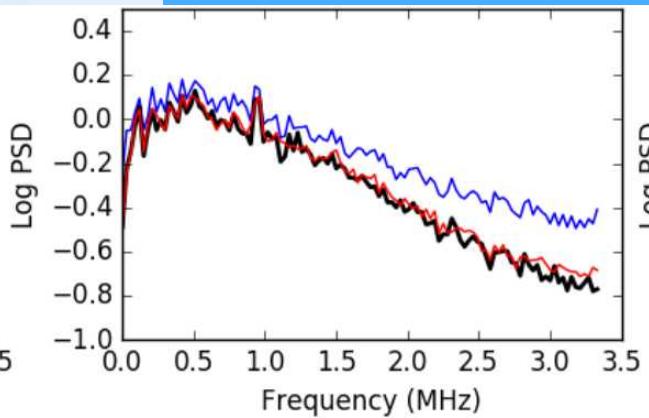
Random Forest Predictions



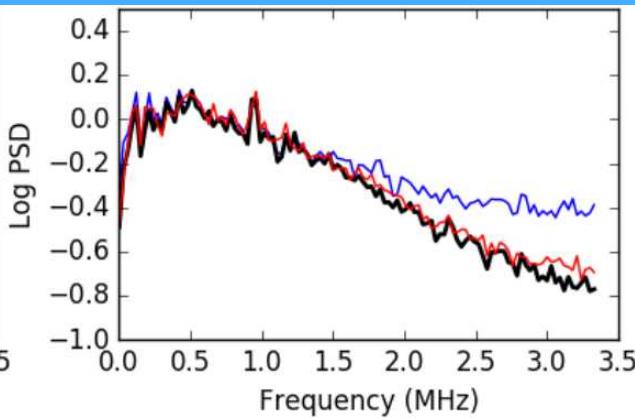
$y^+ = 10$



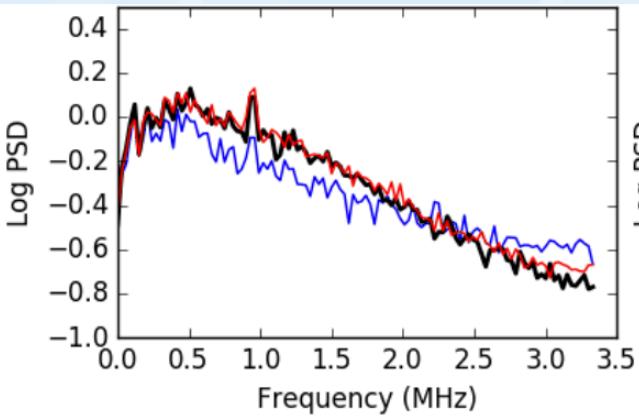
$y^+ = 25$



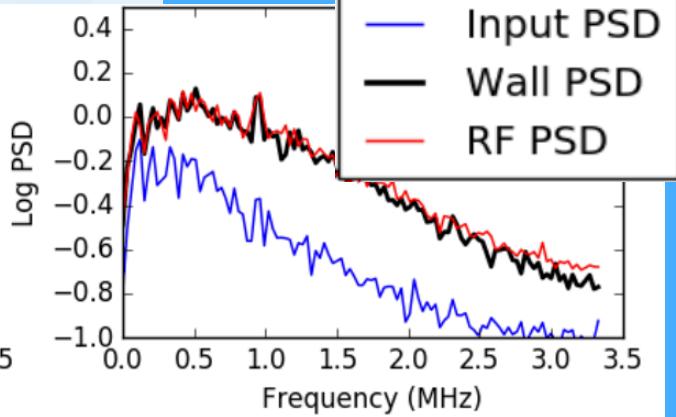
$y^+ = 50$



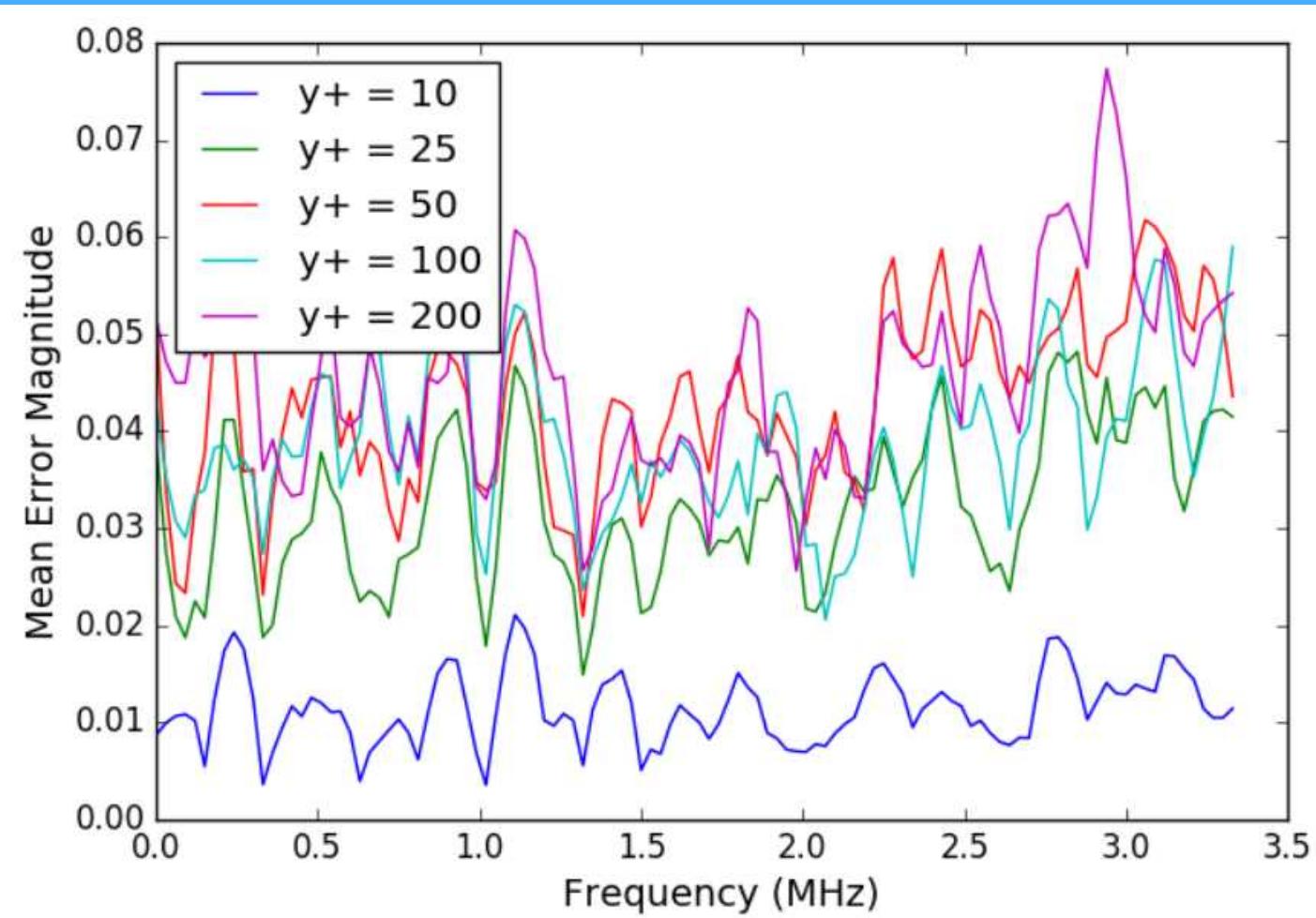
$y^+ = 100$



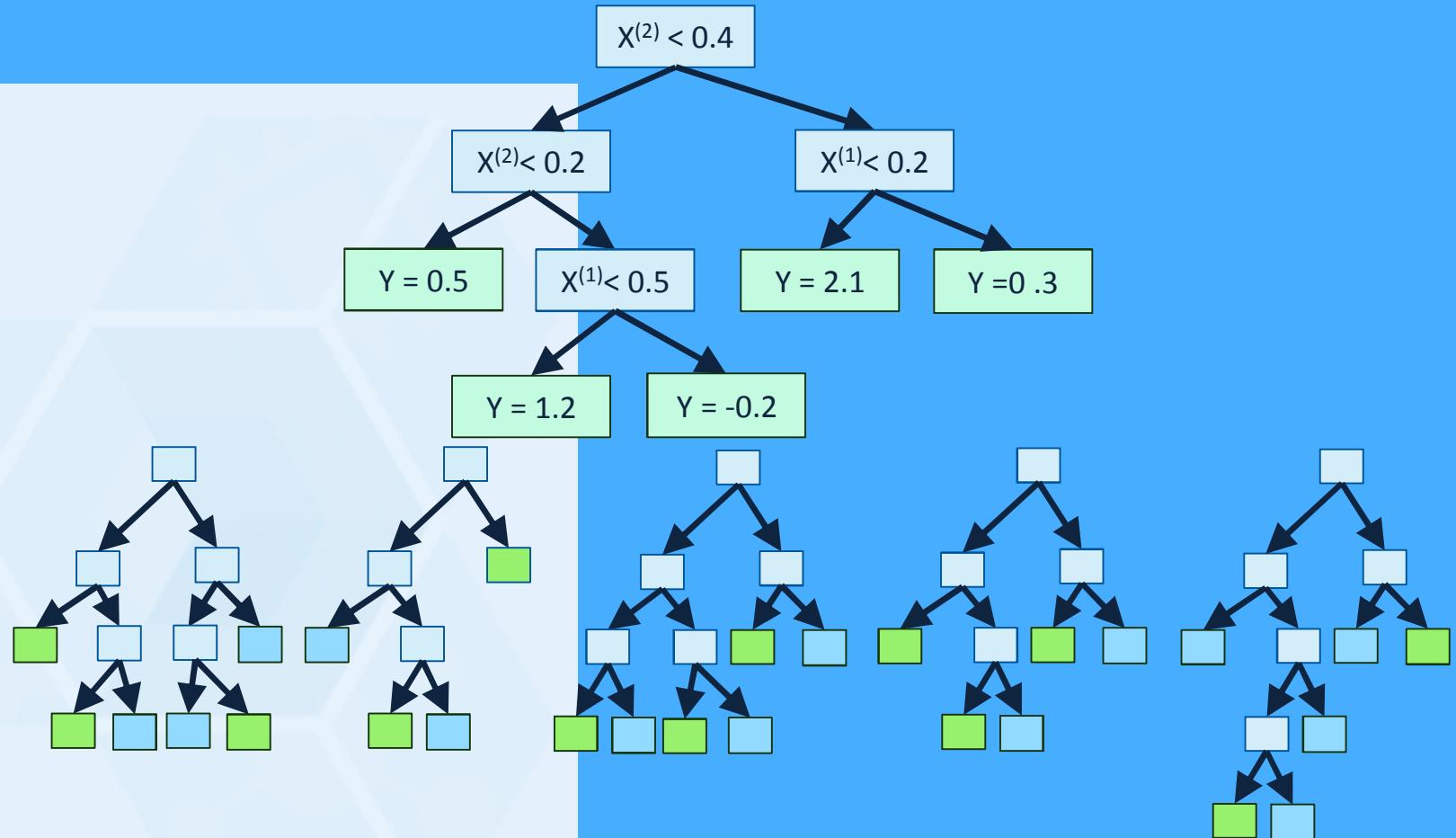
$y^+ = 200$



Frequency-Dependence of Random Forest Accuracy

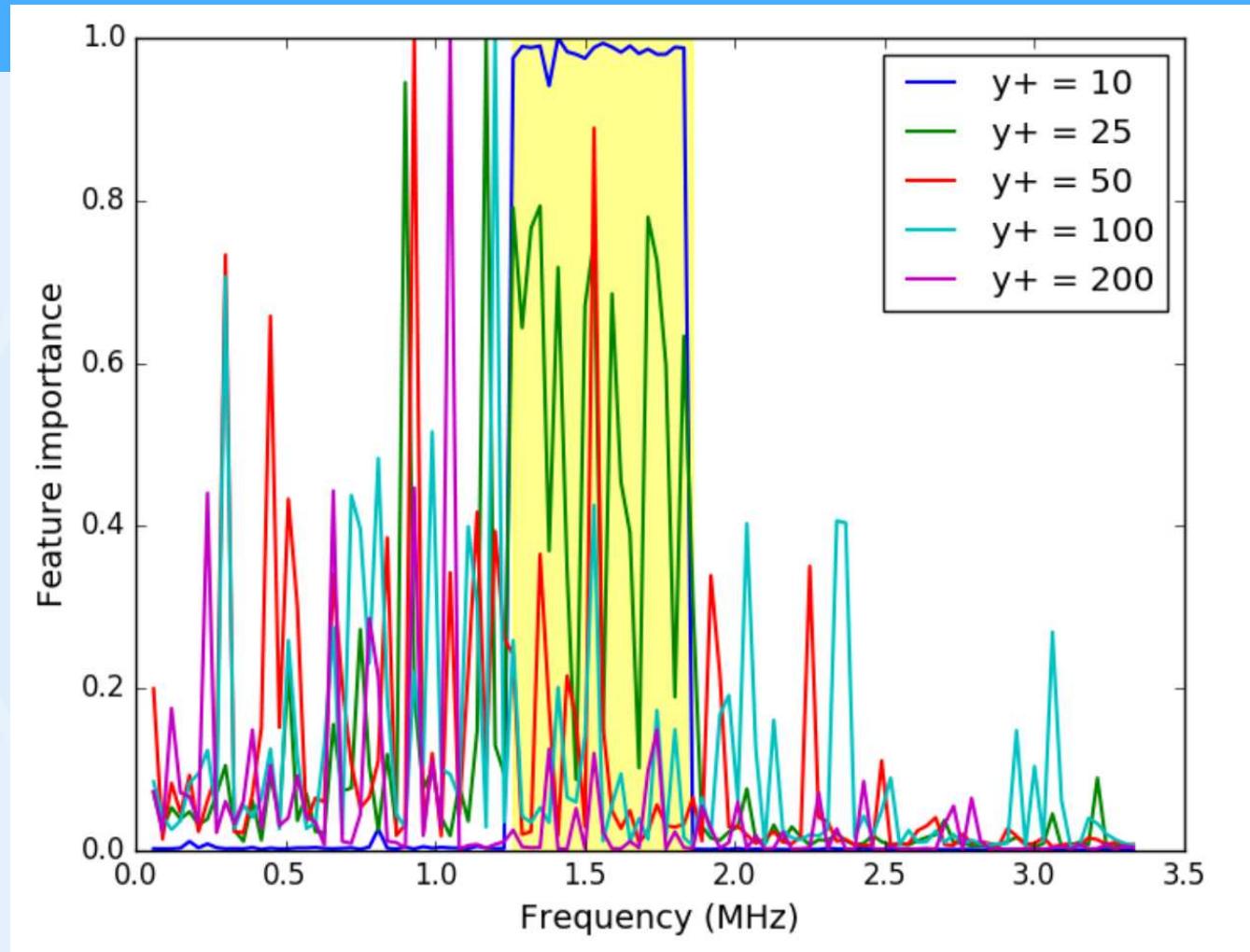


Random Forest Feature Importance



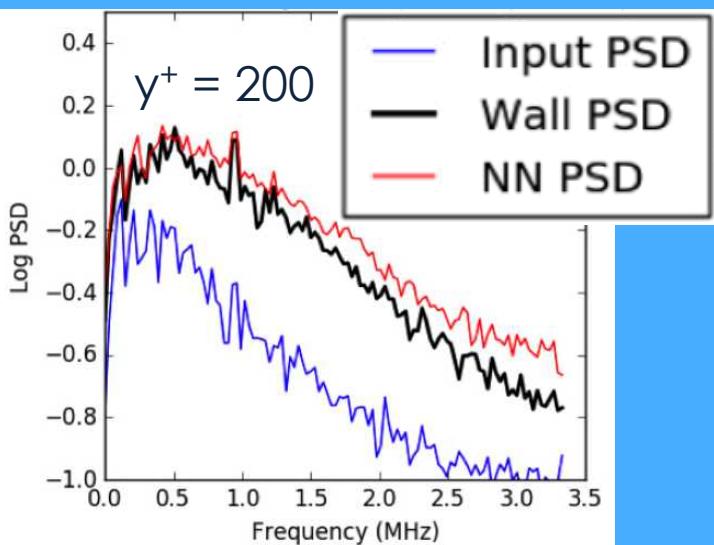
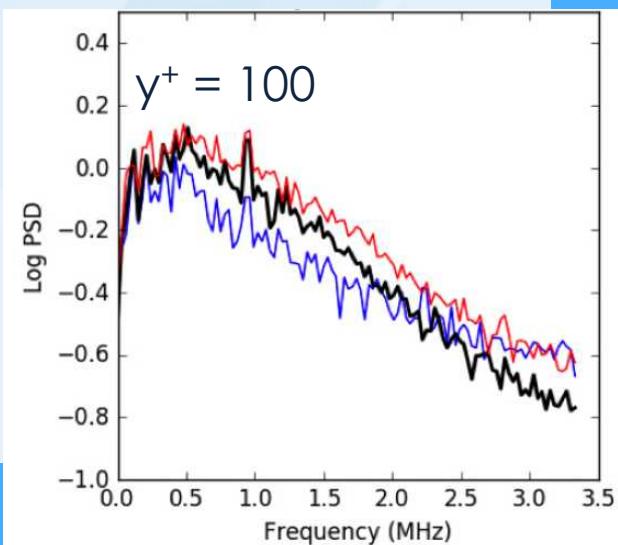
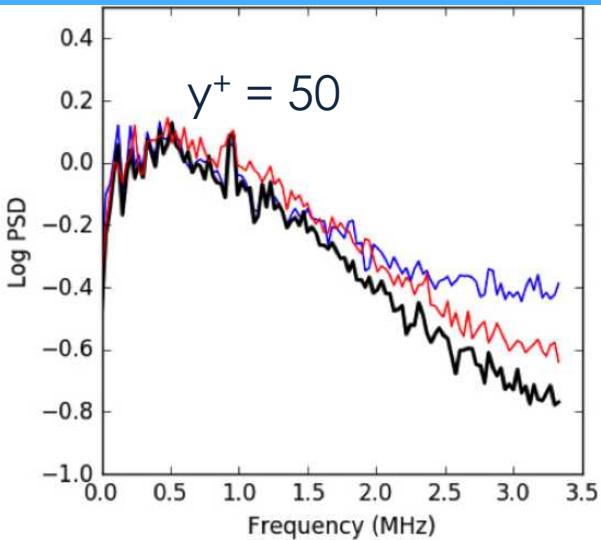
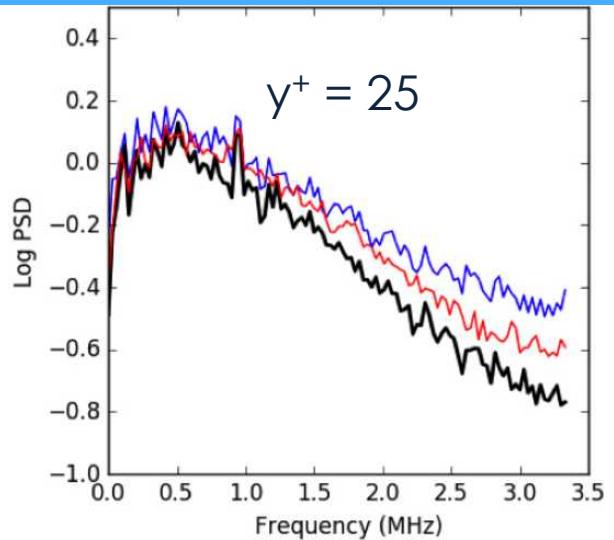
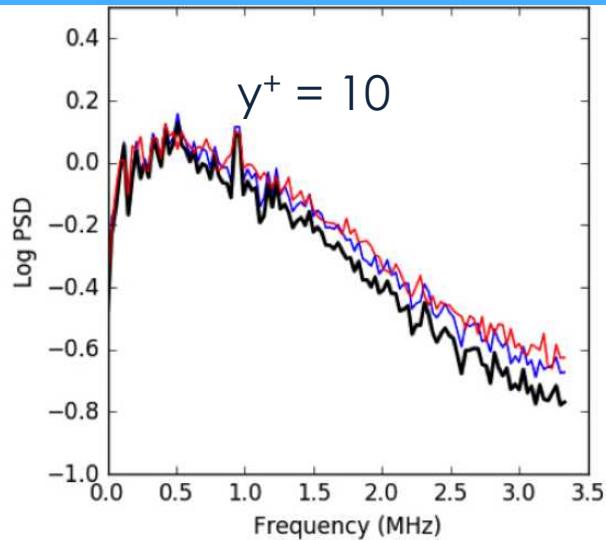
- Each split in decision tree is based on greedily maximizing the reduction in variance
- Feature importance is based on how often each feature is used in a split and the aggregated reduction in variance over those splits

Random Forest Feature Importance

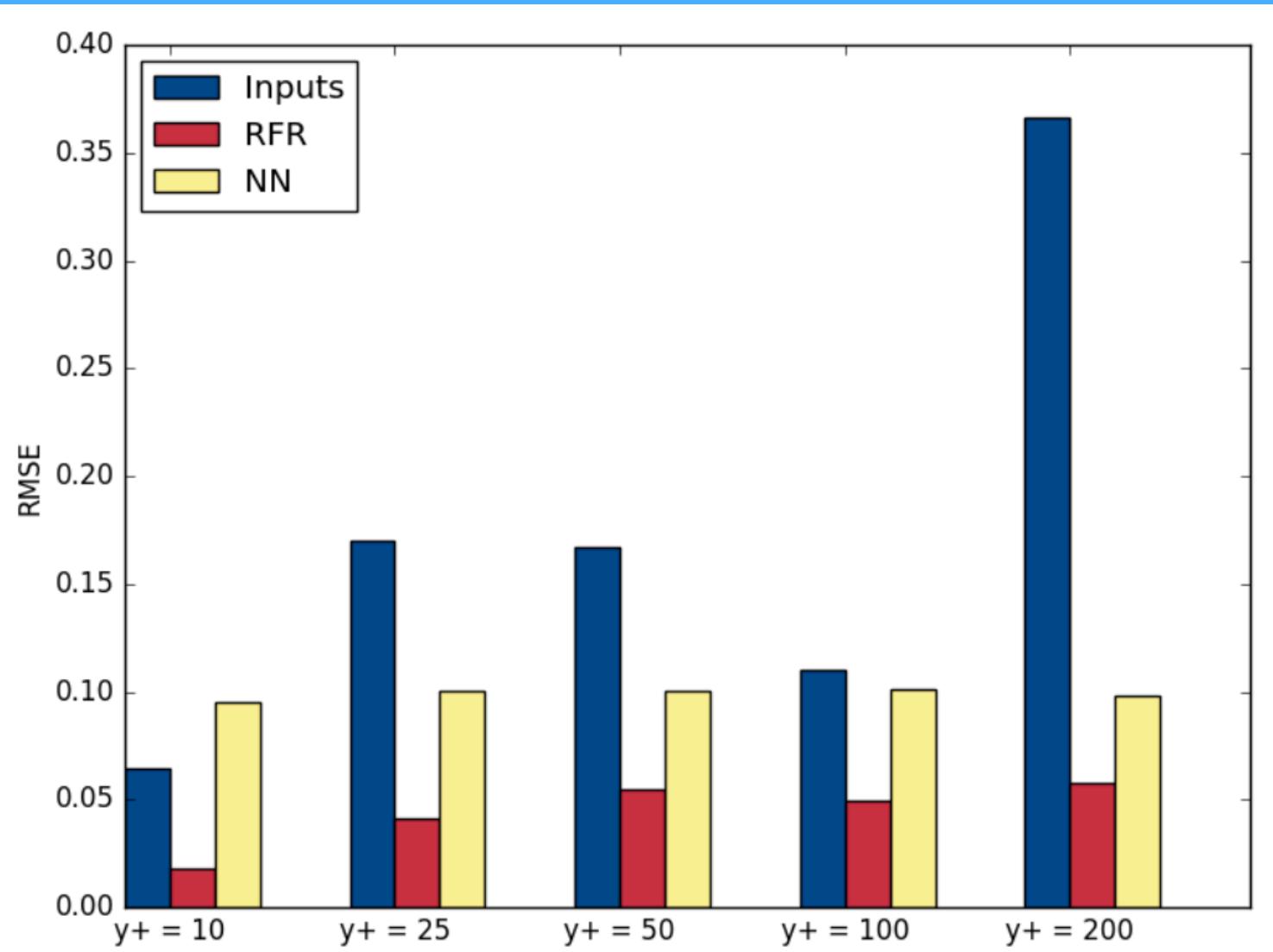




Neural Network Predictions



Machine Learning Performance



Conclusions

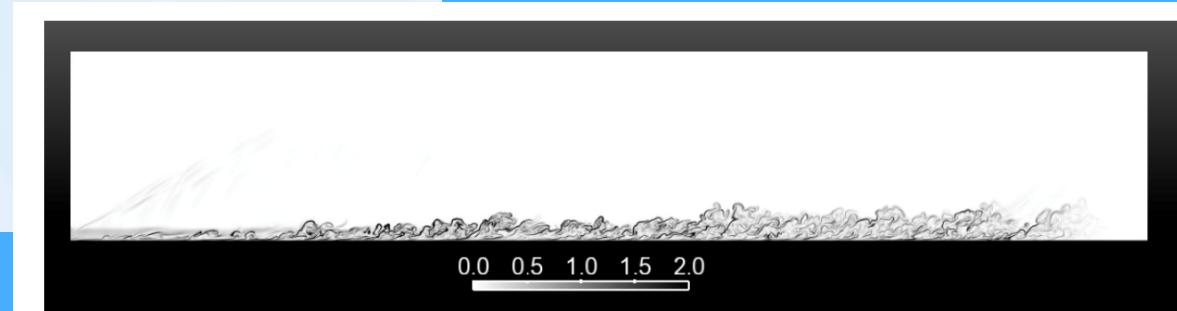
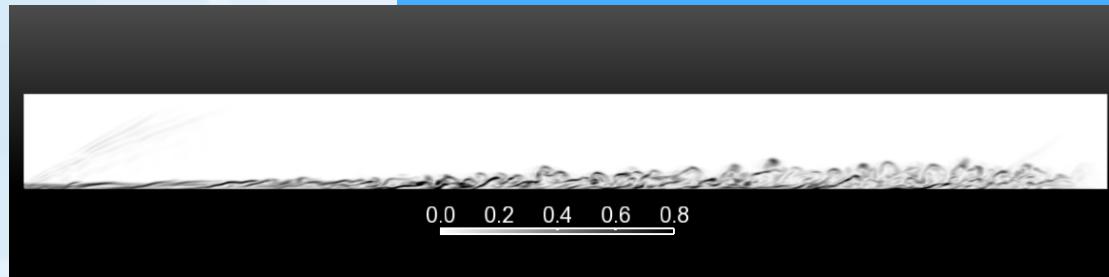


- Performed and validated a DNS of a compressible flat plate boundary layer
- Developed machine learning framework to predict wall pressure PSD given pressure PSD (or other inputs) above the wall
- Evaluated two different ML algorithms
 - Random Forest provided better performance than simple multi-layer perceptron neural network
- Evaluated machine learning performance using input data at different wall distances
 - Data out to $y^+ = 100$ allows accurate reconstruction of wall pressure PSD
 - Higher frequencies are harder to predict using information farther from the wall
 - These results suggest that it should be possible to create a data-driven wall model for the pressure PSD

Next Steps



- Train and validate across wider range of Mach numbers, different flow configurations
- Given WMLES data, try to predict DNS wall pressure PSD
- Evaluate more complex neural network architectures to see if improved neural network performance is achieved



Questions?

