Using Autoencoders to Preserve Spectral Density Information

Ethan J. Sloan[1,3], Rafael Baez Ramirez[2,3]

Mentor: Carlos Michelén Ströfer[3]

[1]The University of New Mexico, esloan03@unm.edu

[2]The University of Texas at El Paso, rbaez2@miners.utep.edu

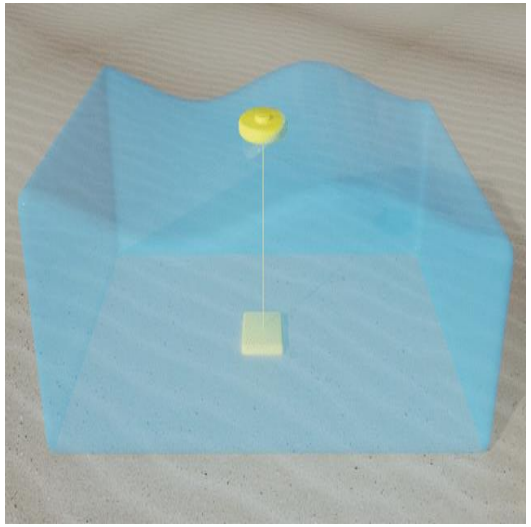
[3]Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

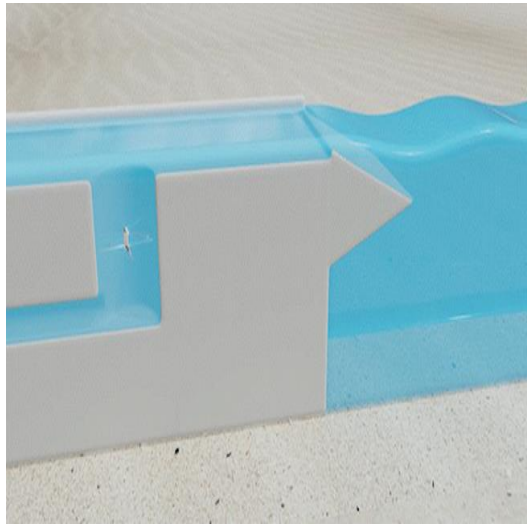
SAND2023-06766O

Wave Energy

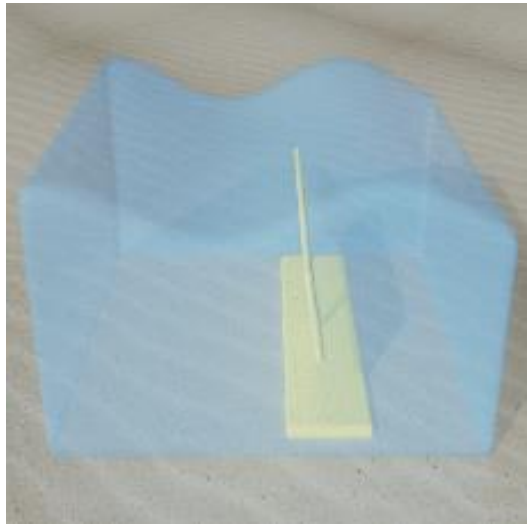
- Use ocean waves to generate useful energy
- Use wave energy converters (WECs)
- A few different designs



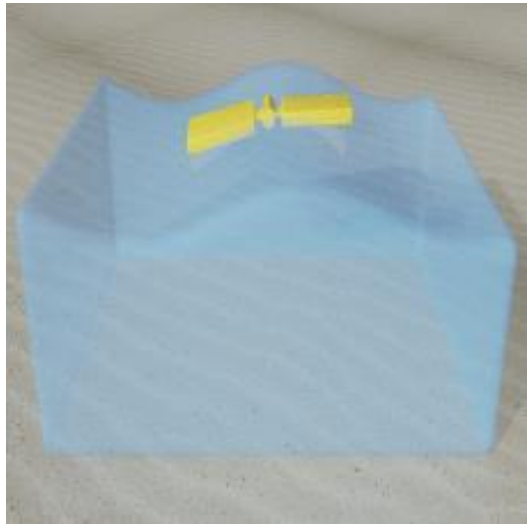
Point Absorber



Overtopping

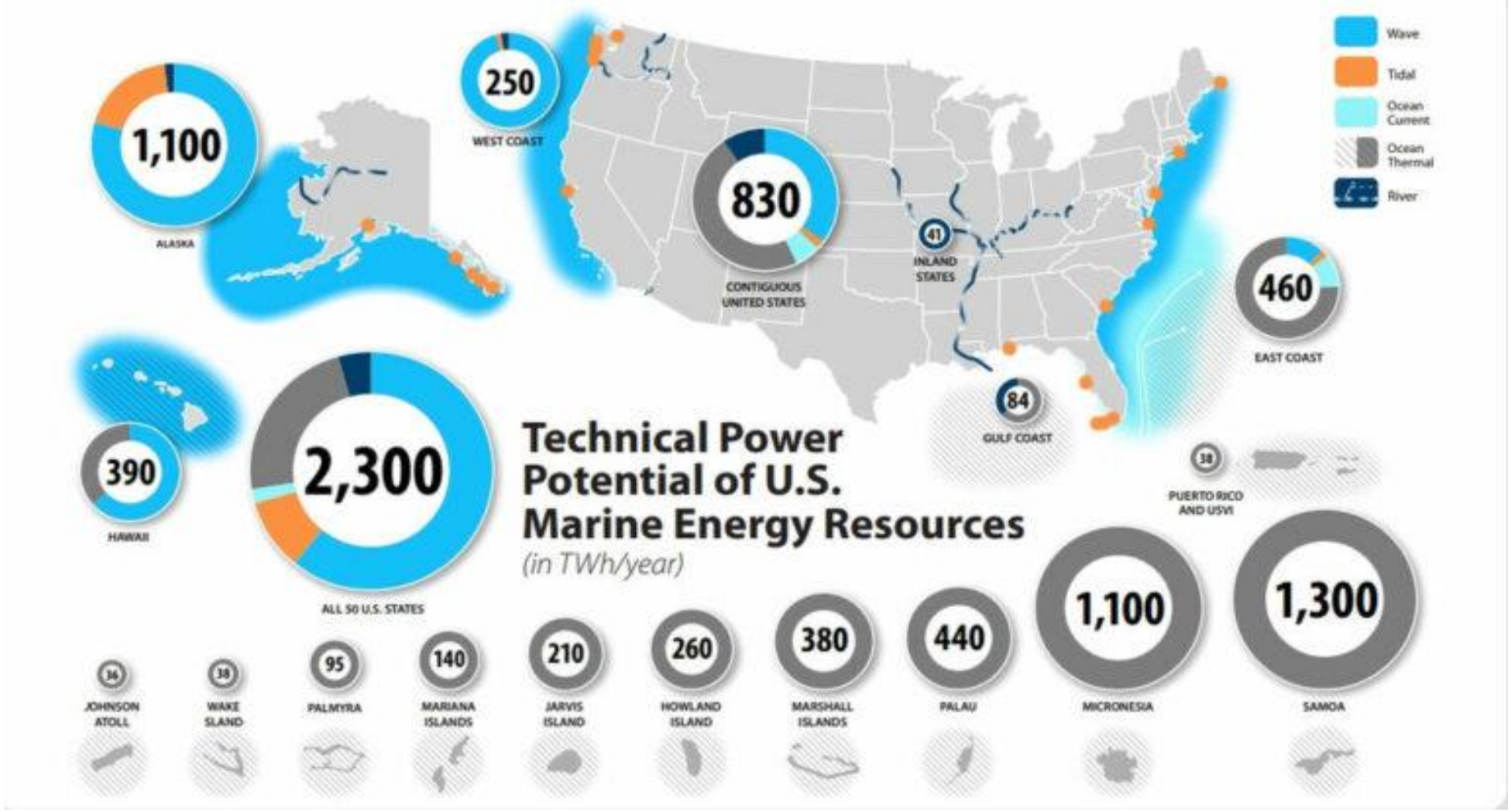


Surge Converter



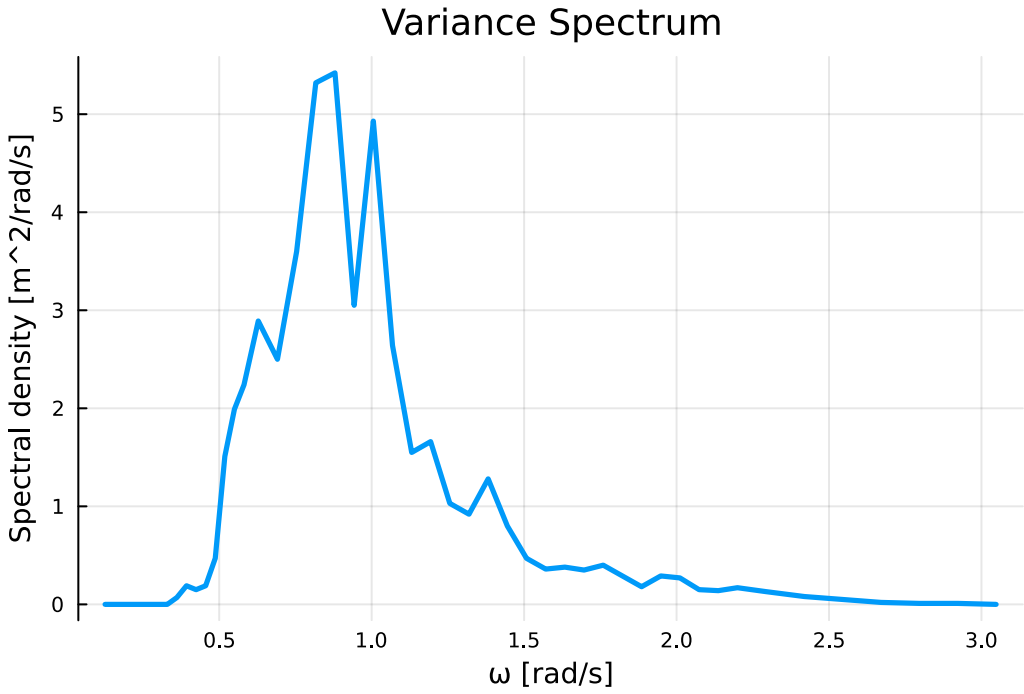
Attenuator

Wave Energy


Technical Power Potential of U.S. Marine Energy Resources
(in TWh/year)
Wave
Tidal
Ocean Current
Ocean Thermal
River
1,100
ALASKA
250
WEST COAST
830
CONTIGUOUS UNITED STATES
41
INLAND STATES
460
EAST COAST
84
GULF COAST
390
HAWAII
2,300
ALL 50 U.S. STATES
38
PUERTO RICO AND USVI
1,300
SAMOA
1,100
MICRONESIA
440
PALAU
380
MARSHALL ISLANDS
260
HOWLAND ISLAND
210
JARVIS ISLAND
140
MARIANA ISLANDS
95
PALMYRA
38
WAKE ISLAND
36
JOHNSON ATOLL

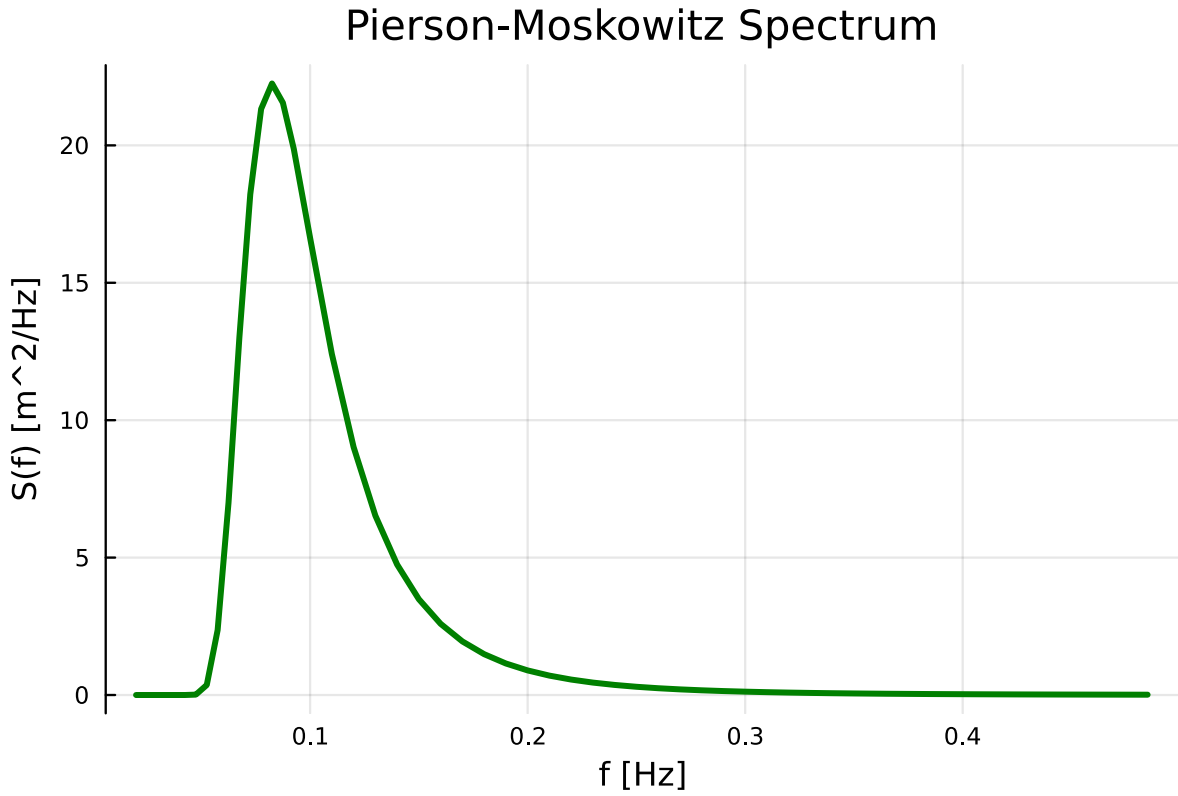
Variance Spectra

- Tell us about sea surface energy
- Energy ∝ variance
- Help estimate annual power production of WEC
- Fourier transform of sea surface
- Buoy measurements

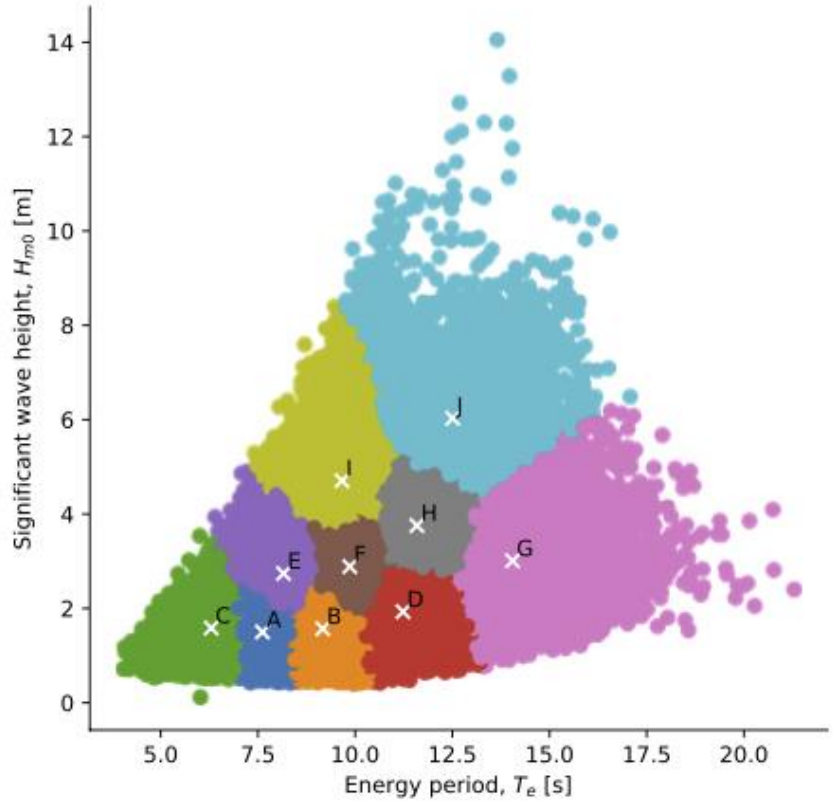


Describing Variance Spectra

- Use statistical information about spectra
    - * Significant wave height (H_s)
    - * Peak period (T_p)
    - * Energy period (T_e)
- Use parametric model
    - * Pierson-Moskowitz (PM)
    - * JONSWAP



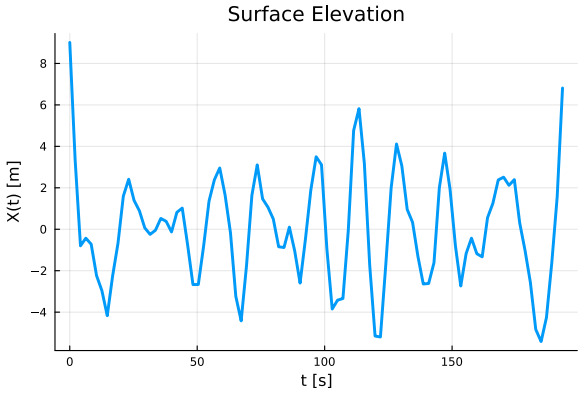
Grouping



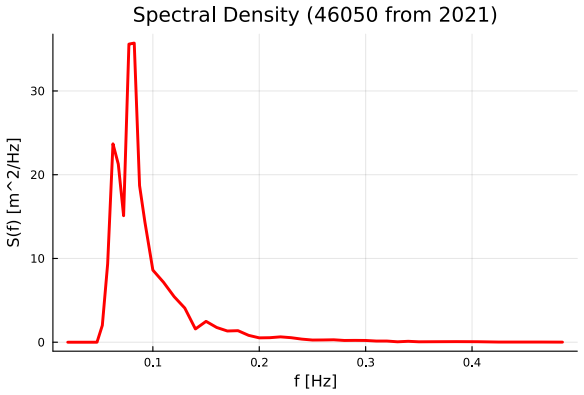
Average wave period, T_m (s)

Significant wave height, H_s (m)	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-16
0-0.5	0	1	0	1	1	0	0	0	0	0	0
0.5-1	18	132	290	387	262	137	28	8	0	0	0
1-1.5	0	291	434	763	929	718	395	103	7	0	0
1.5-2	0	32	333	696	1041	812	356	65	37	10	8
2-2.5	0	1	88	406	659	726	374	159	61	41	18
2.5-3	0	0	18	144	464	698	380	194	94	17	2
3-3.5	0	0	0	26	229	415	313	155	42	21	1
3.5-4	0	0	0	6	71	234	175	86	28	0	2
4-4.5	0	0	0	1	20	98	113	65	30	2	0
4.5-5	0	0	0	0	2	34	78	56	31	3	0
5-5.5	0	0	0	0	0	2	28	44	23	5	1
5.5-6	0	0	0	0	0	1	11	34	29	3	5
6-6.5	0	0	0	0	0	0	1	8	33	6	6
6.5-7	0	0	0	0	0	0	0	4	15	13	6
7-7.5	0	0	0	0	0	0	1	2	4	7	2
7.5-8	0	0	0	0	0	0	0	3	3	3	2
8-8.5	0	0	0	0	0	0	0	0	2	2	9
8.5-9	0	0	0	0	0	0	0	0	3	5	3
9-9.5	0	0	0	0	0	0	0	0	1	1	2
9.5-10	0	0	0	0	0	0	0	0	0	1	0
10-11	0	0	0	0	0	0	0	0	0	5	1
11-12	0	0	0	0	0	0	0	0	0	0	3
12-14	0	0	0	0	0	0	0	0	0	0	6

Loss of Information



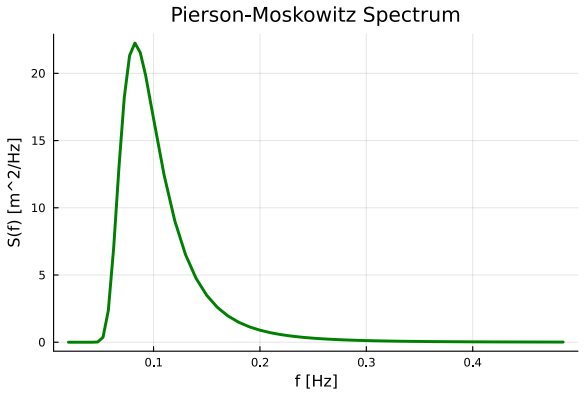
FT



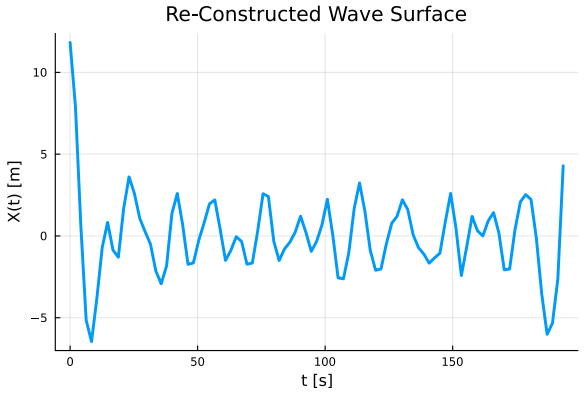
$$H_s = 4\sqrt{\int_{-\infty}^{\infty} S(\omega)d\omega}$$

$$T_p$$

Pierson-Moskowitz

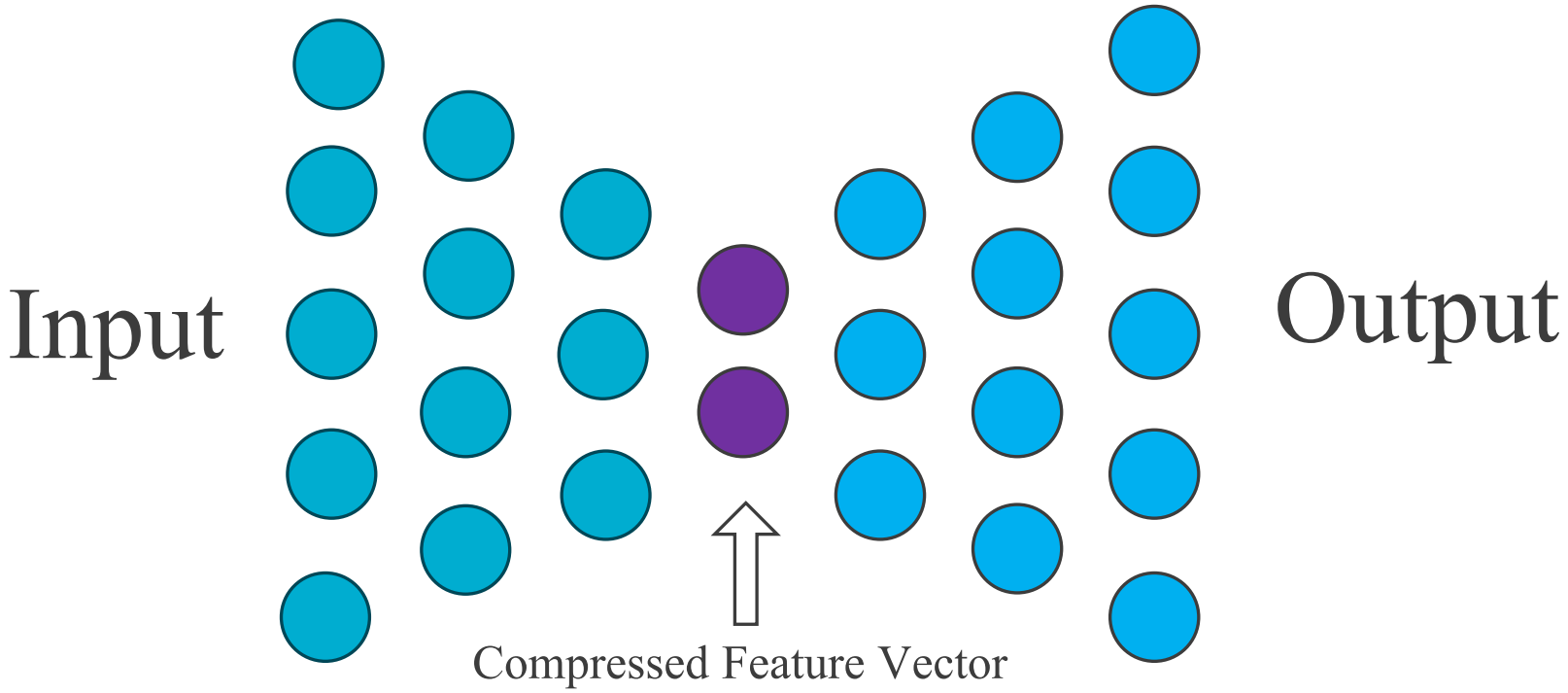


iFT



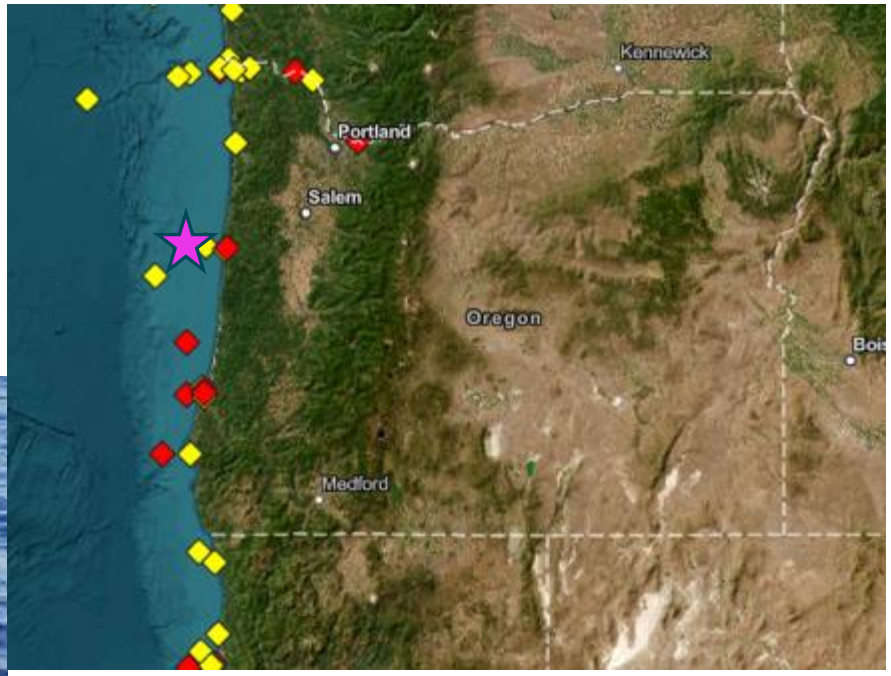
Autoencoders

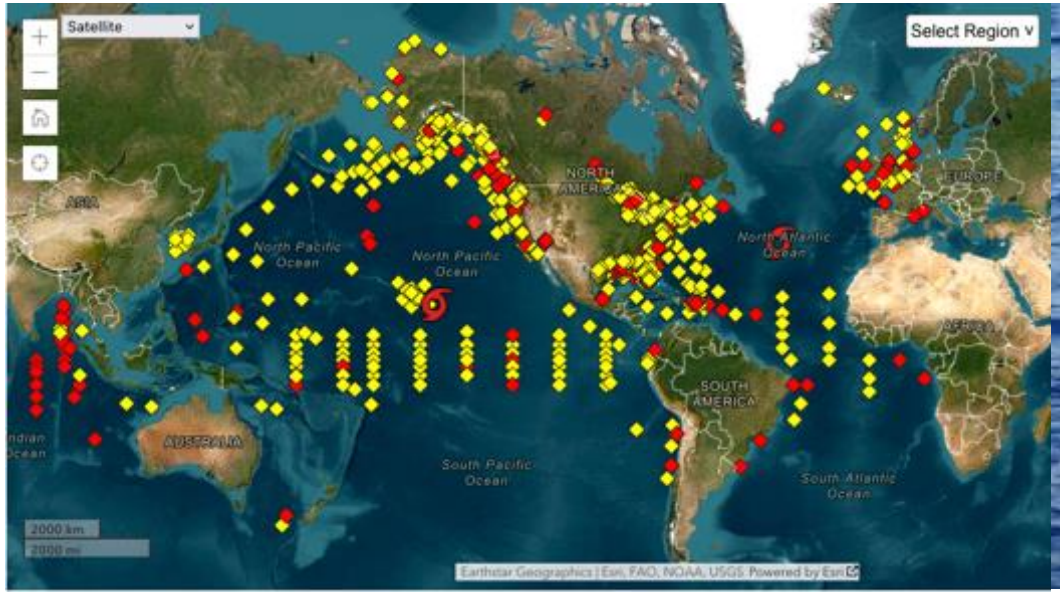
- Deep neural network with symmetric architecture
- Trained to encode and decode data

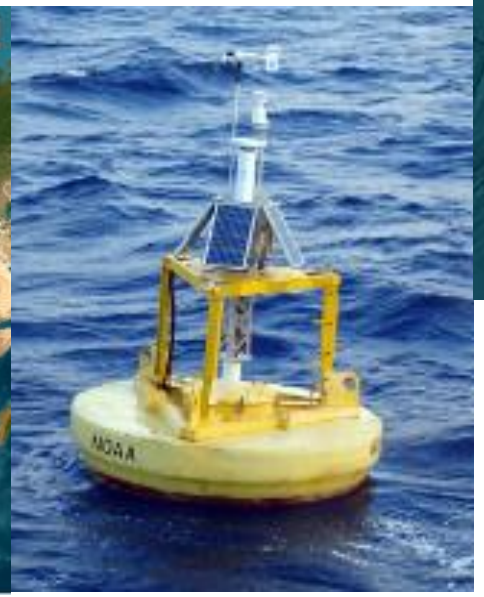


Goal

- Use autoencoder to find better parameters than H_s and T_p.
- Train and test with NDBC data from buoy 46050
    * Off coast of Newport, OR
    * Near PacWave testing station
    * Data from 2007-2022







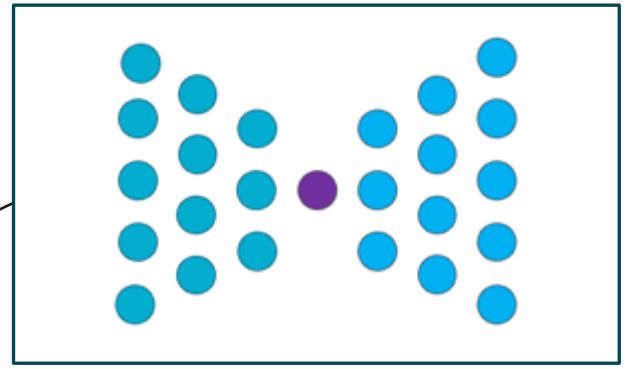
Results

- With energy + 1 learned parameter, outperforming PM model
- Hyperparameter tuning

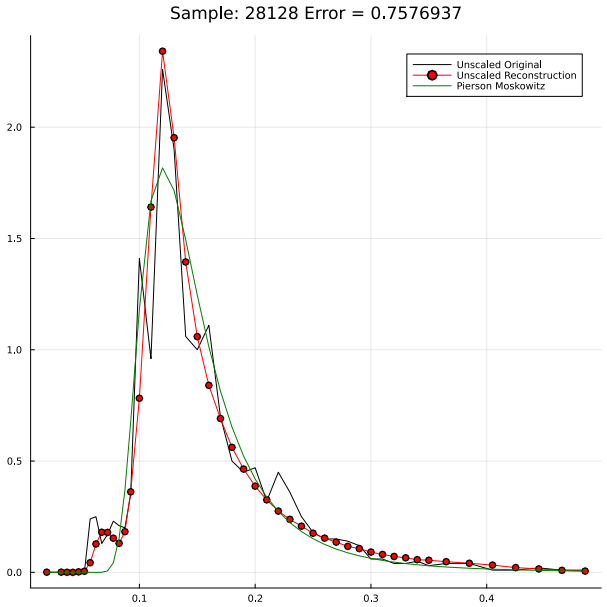
Type	Error
True vs Prediction [56.36% of PM]	5.63f0
True vs Pierson Moskowits	9.98

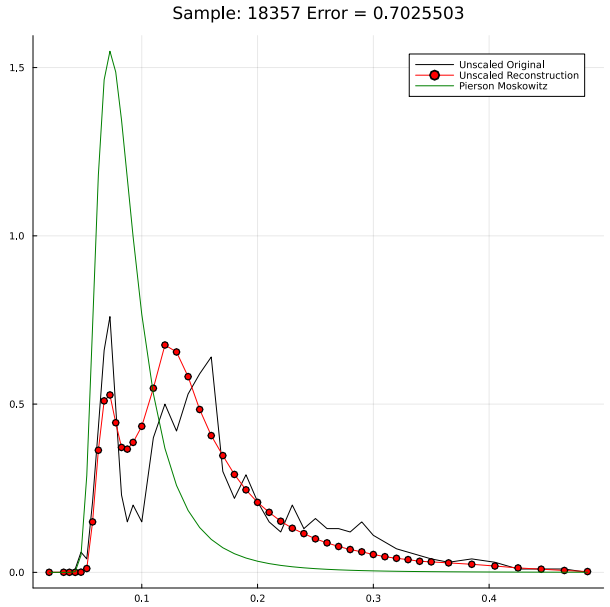
$$S(f; H_s, T_p) = \frac{H_s^2}{4}\left(\frac{1.057}{T_p}\right)^4 f^{-5} e^{-\frac{5}{4}(\frac{1}{fT_p})^4}$$

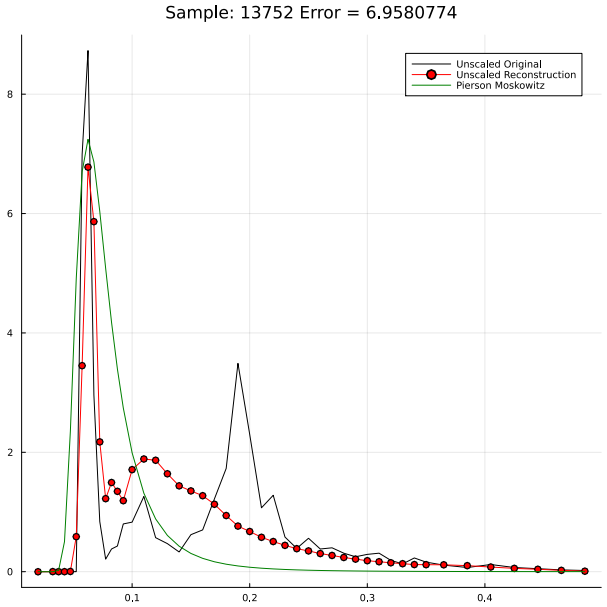
$$S(f; H_s, X_1)$$

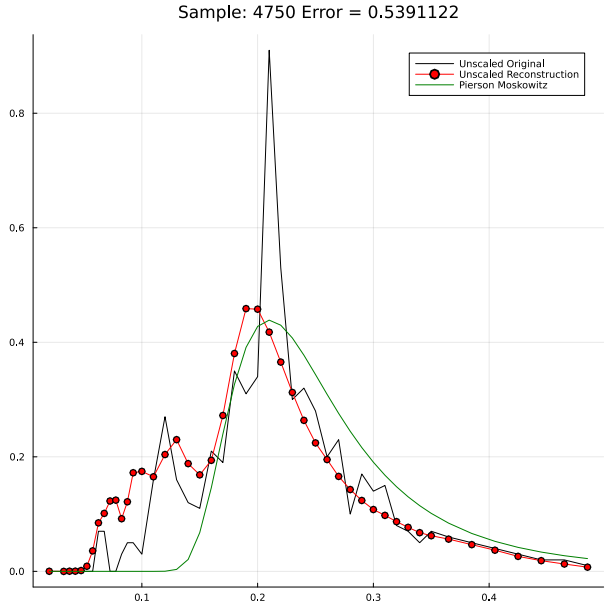


Results

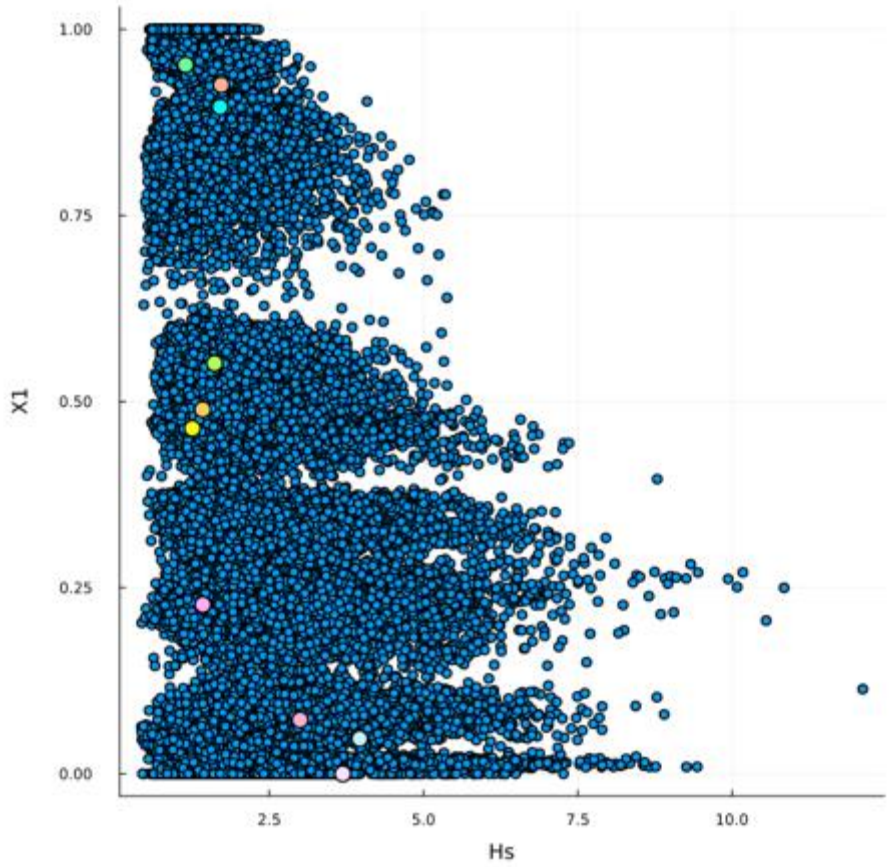

Sample: 28128 Error = 0.7576937
Unscaled Original
Unscaled Reconstruction
Pierson Moskowitz
0.0
0.5
1.0
1.5
2.0
0.1
0.2
0.3
0.4

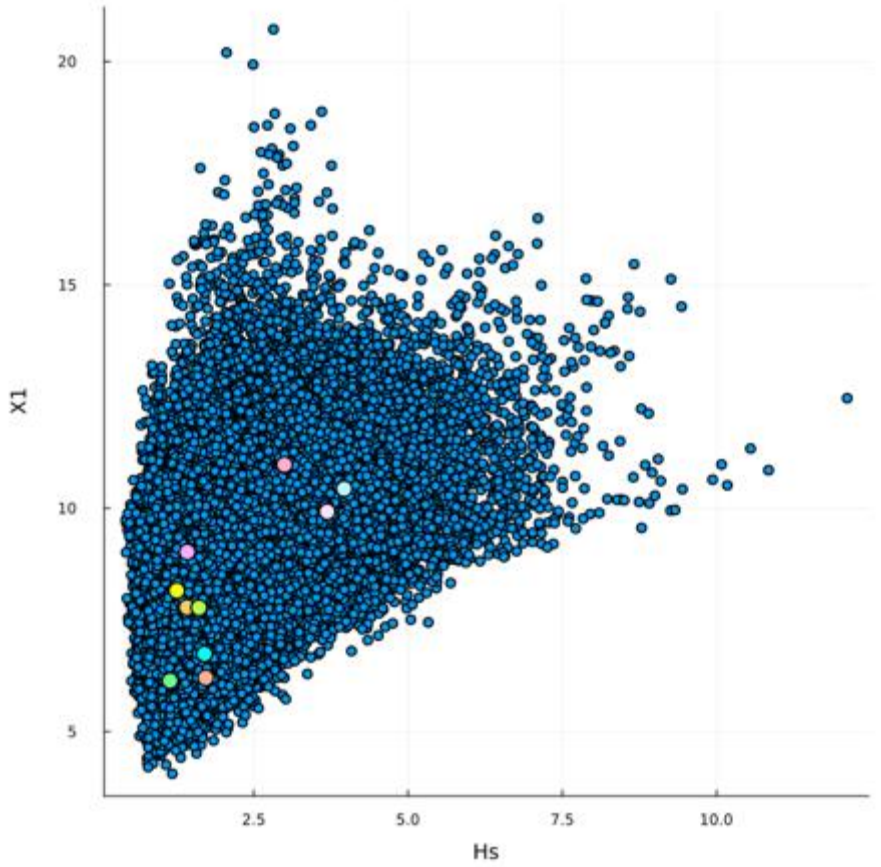

Sample: 18357 Error = 0.7025503
Unscaled Original
Unscaled Reconstruction
Pierson Moskowitz
0.0
0.5
1.0
1.5
0.1
0.2
0.3
0.4


Sample: 13752 Error = 6.9580774
Unscaled Original
Unscaled Reconstruction
Pierson Moskowitz
0
2
4
6
8
0.1
0.2
0.3
0.4


Sample: 4750 Error = 0.5391122
Unscaled Original
Unscaled Reconstruction
Pierson Moskowitz
0.0
0.2
0.4
0.6
0.8
0.1
0.2
0.3
0.4

Results



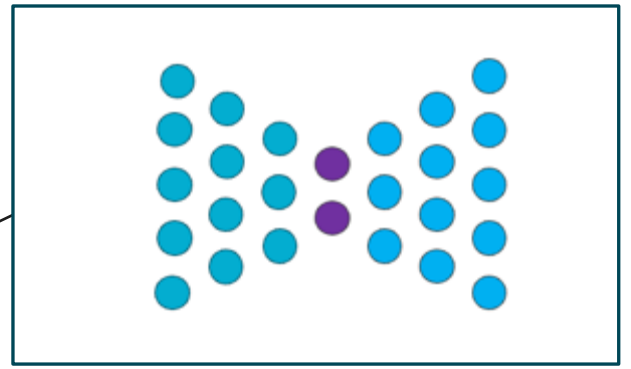


Next Steps

- More hyperparameter tuning
- Using 2 and 3 learned parameters
- Try to give meaning to parameters?

$$S(f; H_s, T_p) = \frac{H_s^2}{4}\left(\frac{1.057}{T_p}\right)^4 f^{-5} e^{-\frac{5}{4}(\frac{1}{fT_p})^4}$$

$$S(f; H_s, X_1, X_2)$$



Ethan J. Sloan

I have really enjoyed working with so many friendly and helpful people and having the opportunity to learn about scientific research in renewable energy technology. Working on this project has taught me a lot about computational methods in research and has given me a greater appreciation for it. I have also become comfortable in using useful and applicable mathematical methods that will be important in many kinds of research I may do in the future.

Rafael Baez Ramirez

I appreciate that all of the faculty and staff have been incredibly helpful, patient, and friendly to me. As the internship progressed, whenever there was any issues or I was unable to find the information required to continue working, there was always someone I could turn to for help. Whether that was my mentor or the other interns in the same office, everyone has helped me one way or another. My mentor was willing to help guide me and the other intern in learning the theory and methods to better understand the project. We spent the first few weeks catching up and understanding the concepts at work behind the project and my mentor was always offering to help if the other intern or I got stuck. The best part about the internship experience has been the friendliness of everyone I have gotten involved with. Everyone got along and were always willing to help others if they saw someone in need.

SWEPT Lab Tour

Appendix A

Pre-Processing:

- 135051 spectra

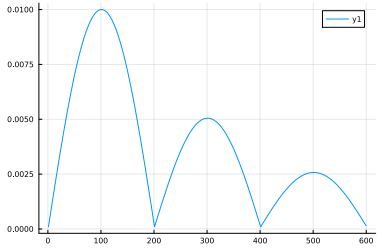
  *70% training, 30% testing

- Spectra scaled such that $\int_{f_i}^{f_f} S(f)df = 1$
- Data is shuffled before splitting

Appendix B

Hyperparameters:

- $Modified\ Softmax(\vec{x})_n = \frac{x_n}{\int_{x_i}^{x_f} x\ (t)dt}$
- 6 layers:
  * 32 ⇒ 16 ⇒ 1 ⇒ 16 ⇒ 32 ⇒ 47
- Activation functions: leakyrelu ⇒ leakyrelu ⇒ sigmoid ⇒ leakyrelu ⇒ leakyrelu ⇒ modified softmax
- Batch size: 2048
- Learning rate: Decaying sine learning rate
  *

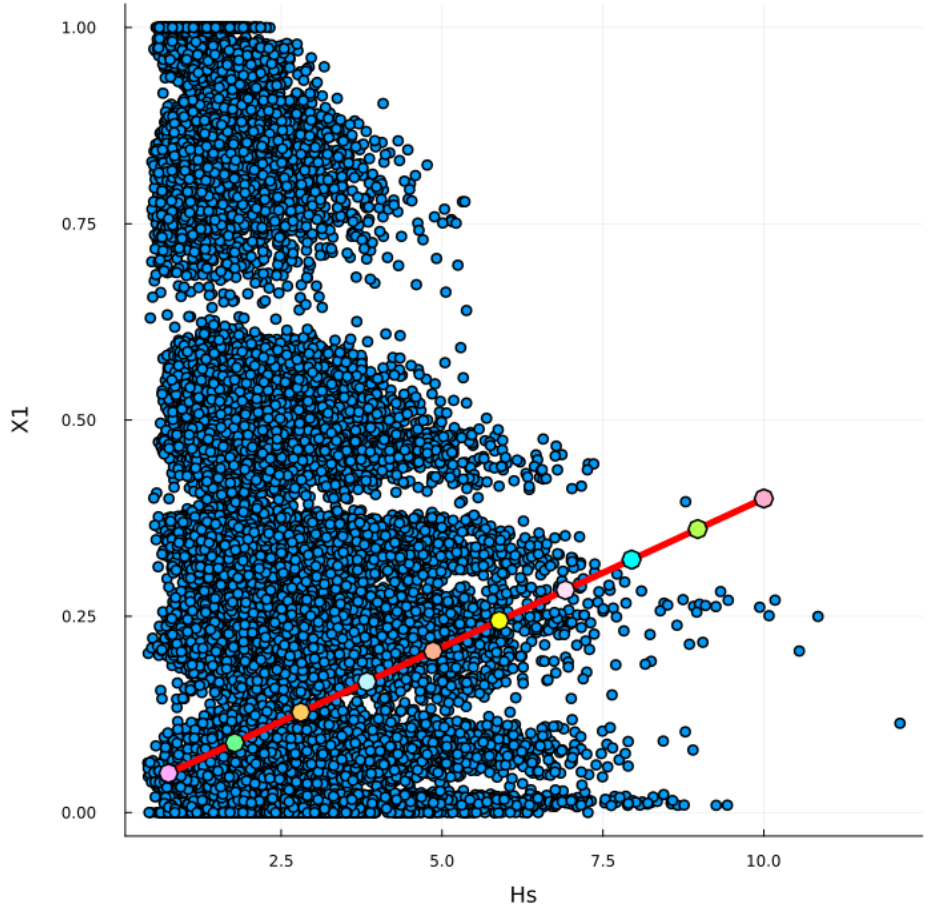


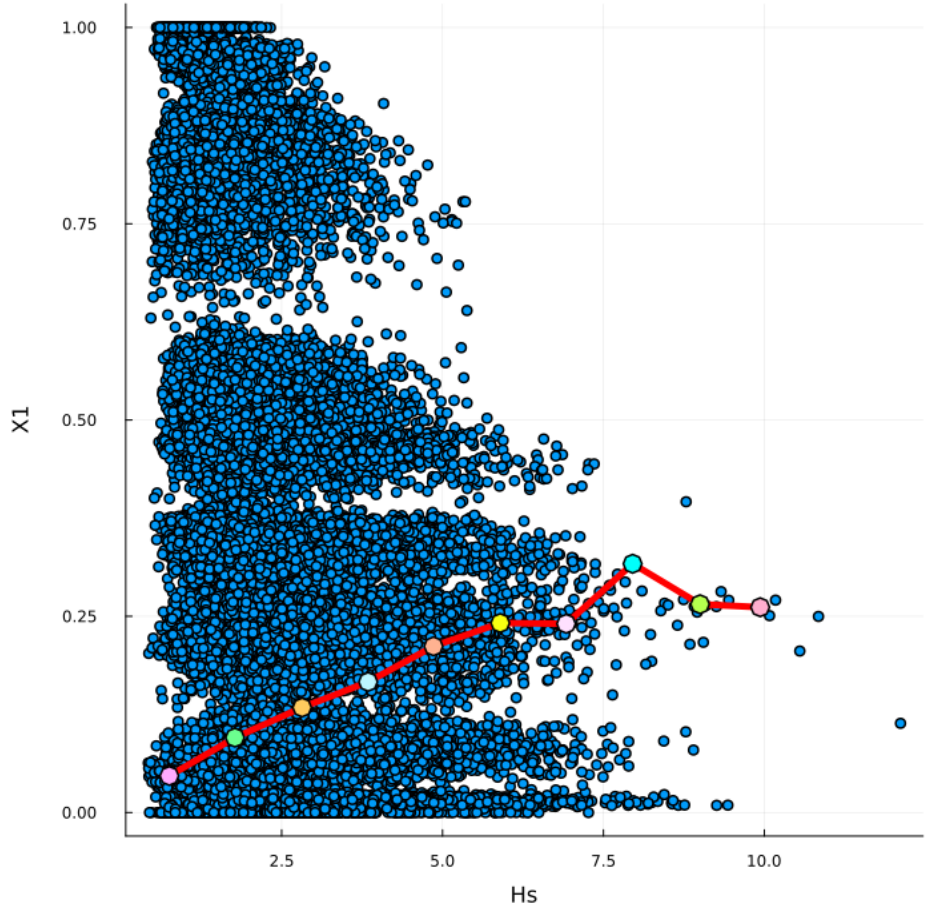
- Epochs: 1000
- Loss function: 10*MAE + 1*MSE
- ADAM optimizer

- Pre-train using PM data
  * Learning rate: 0.05
  * Batch size: 1024
  * Epochs: 1000

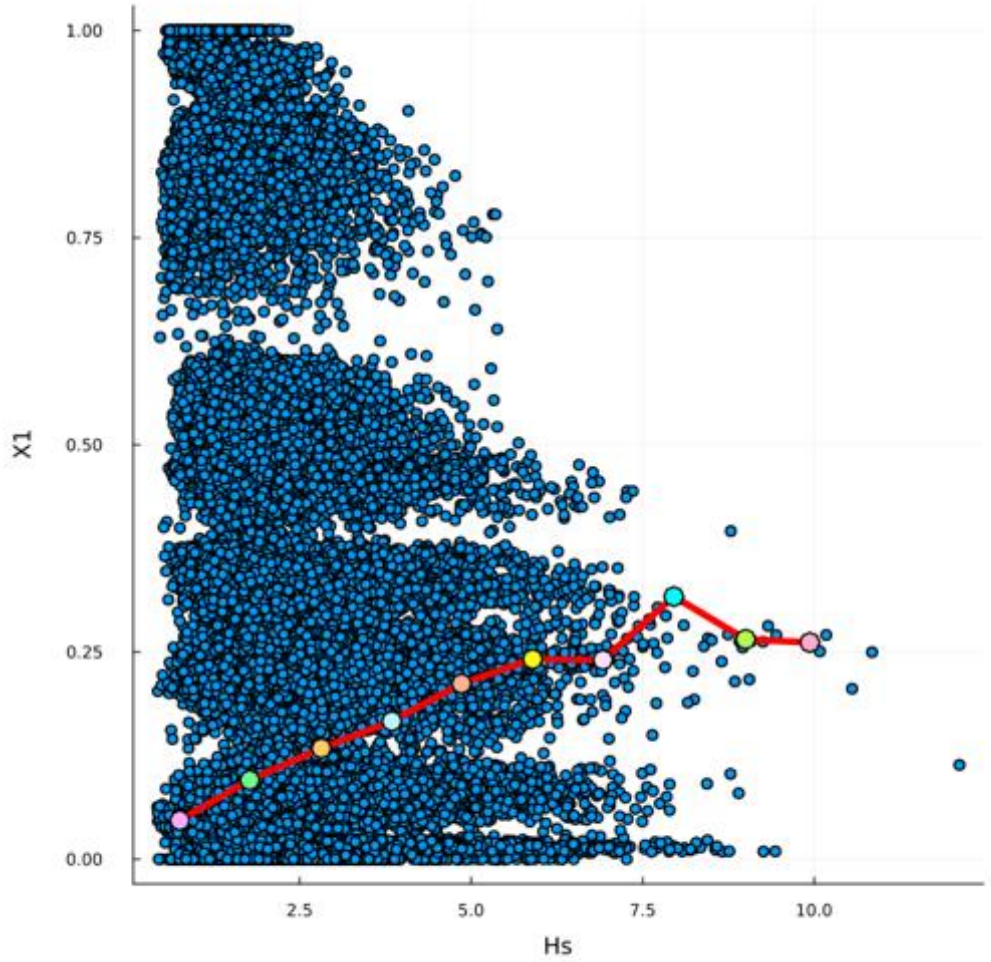
Appendix C

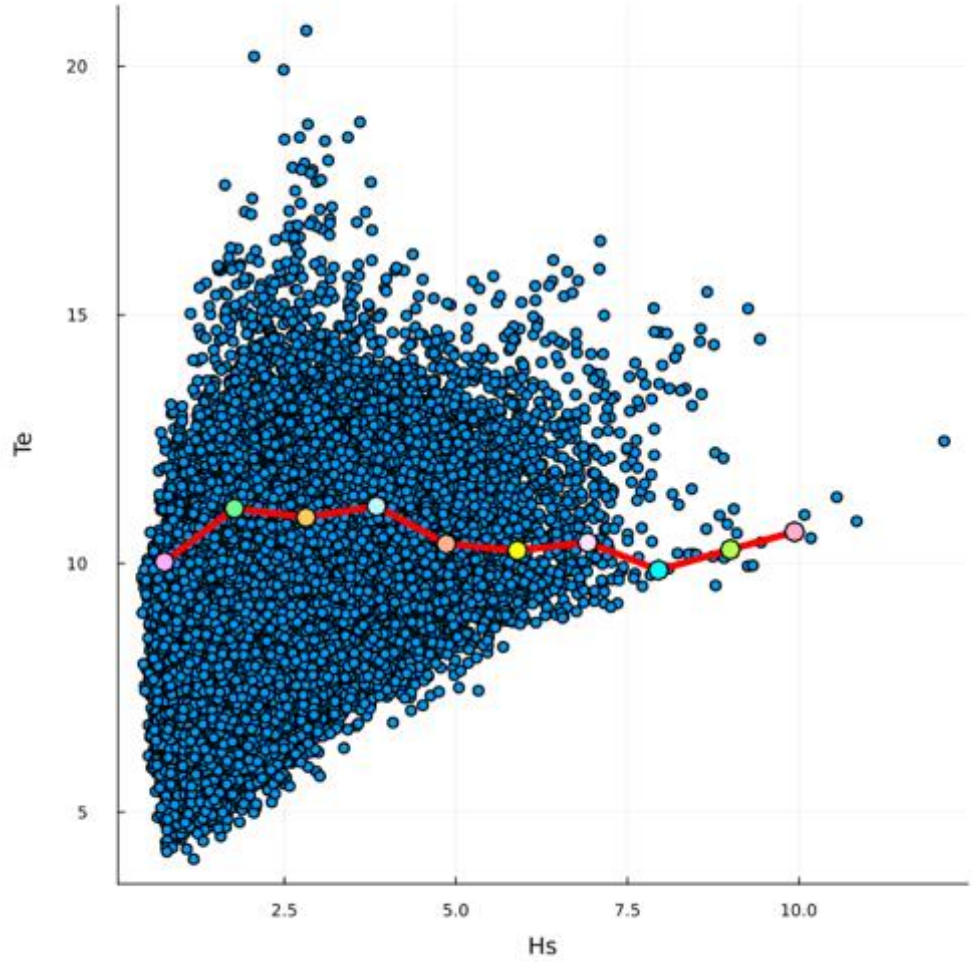
Parameter Comparisons:



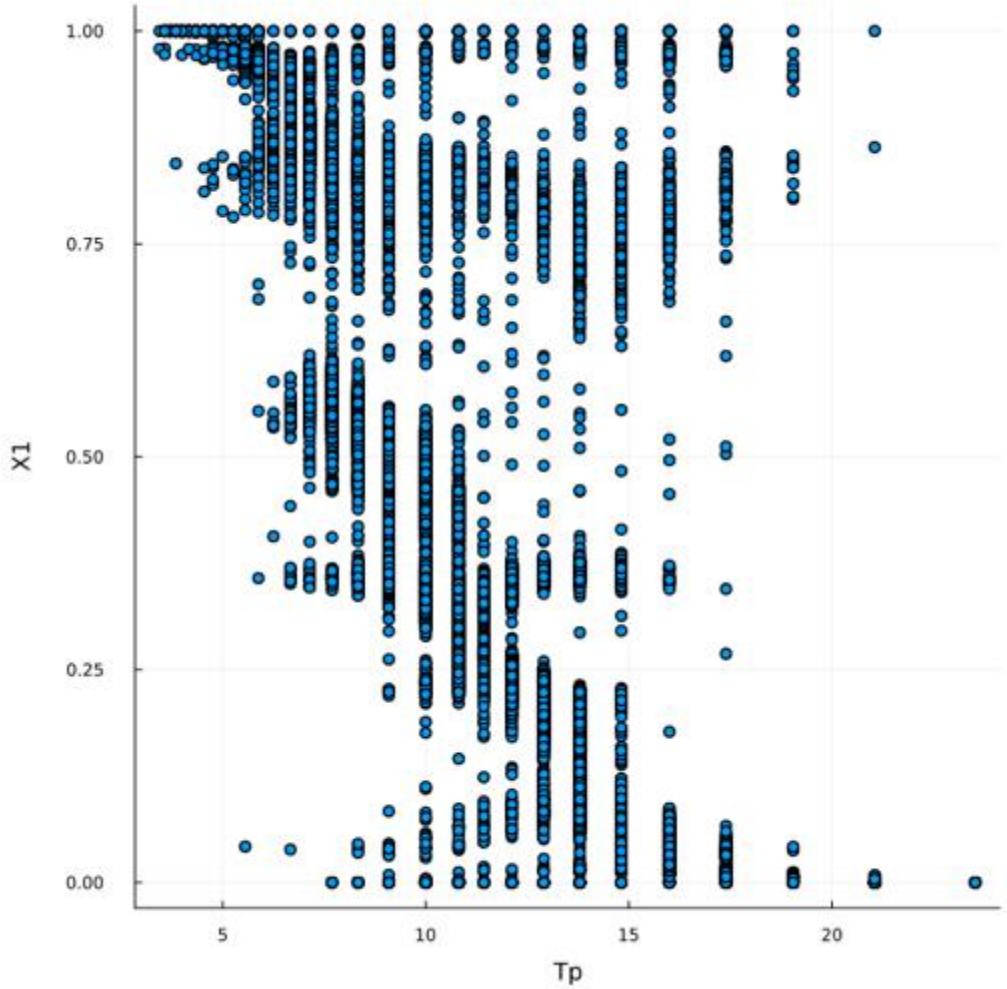


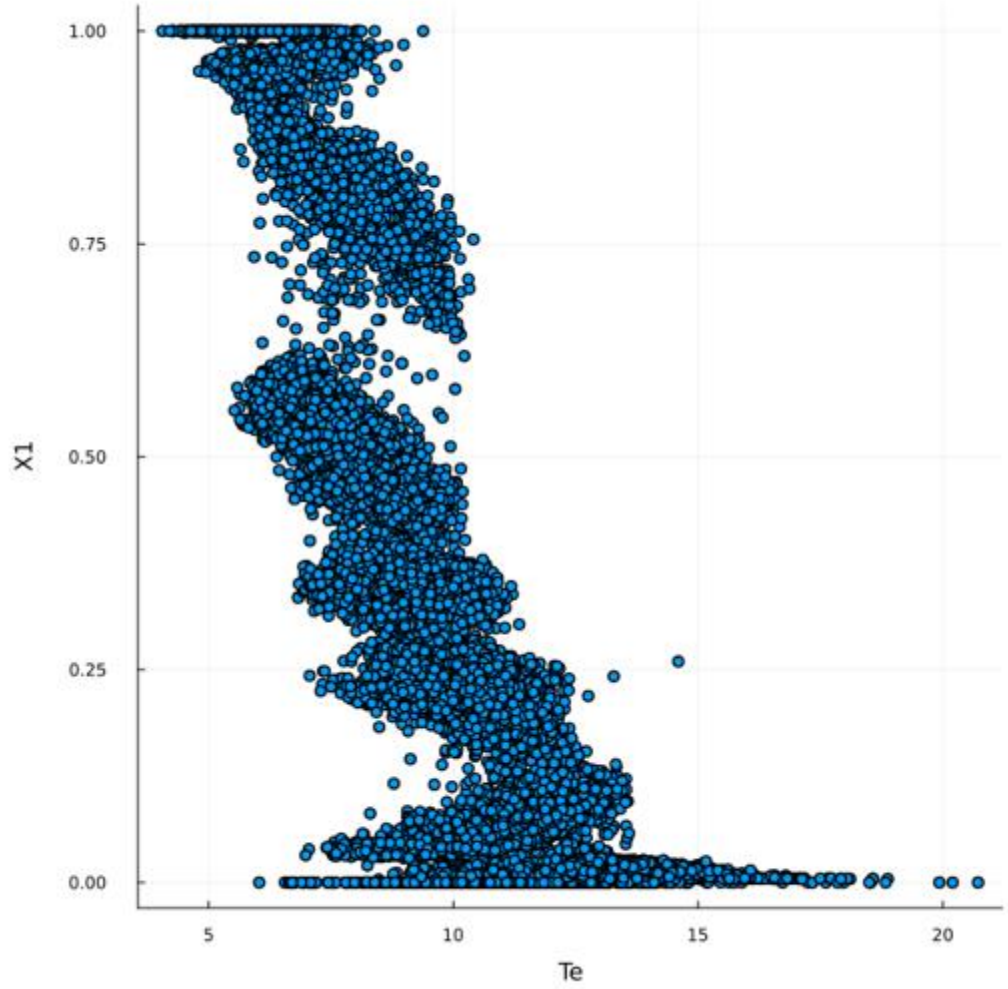
Appendix C





Appendix C


1.00
0.75
0.50
0.25
0.00
X1
5
10
15
20
Tp


1.00
0.75
0.50
0.25
0.00
X1
5
10
15
20
Te