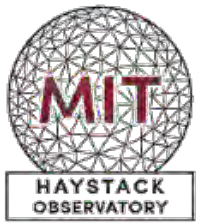
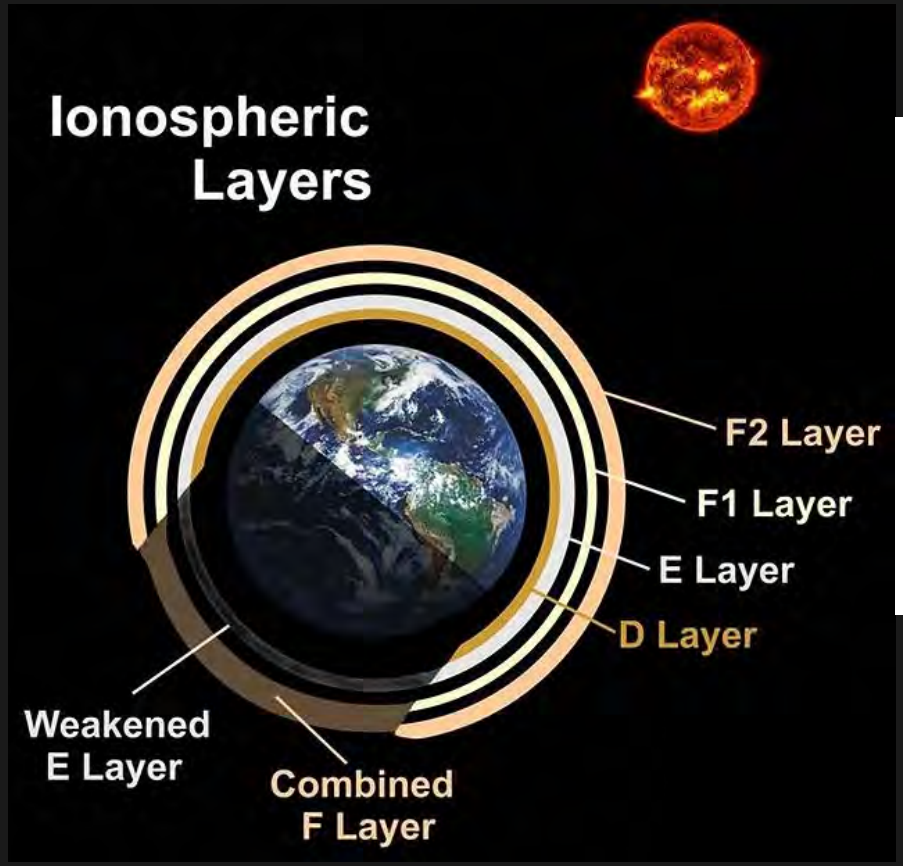
An Empirical Model of NmF2 Based on Ionosonde Observations

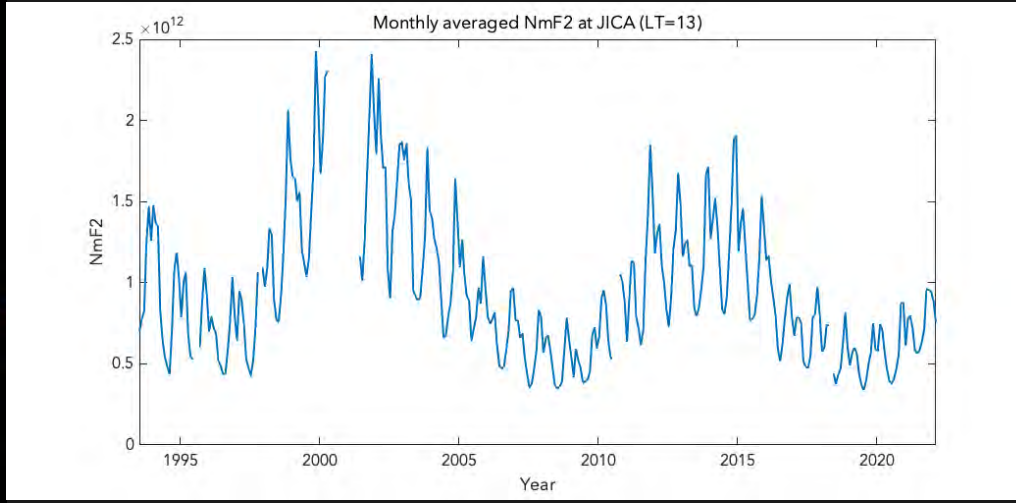
Fermin Redondo
Mentors: Larisa Goncharenko, Dupinder SIngh

Overview

1. Background
2. Empirical Model and Input Data
3. Creation of Metrics
4. Metrics and Results
5. Using Metrics to Investigate Solar Bands
6. Residuals
7. Future work

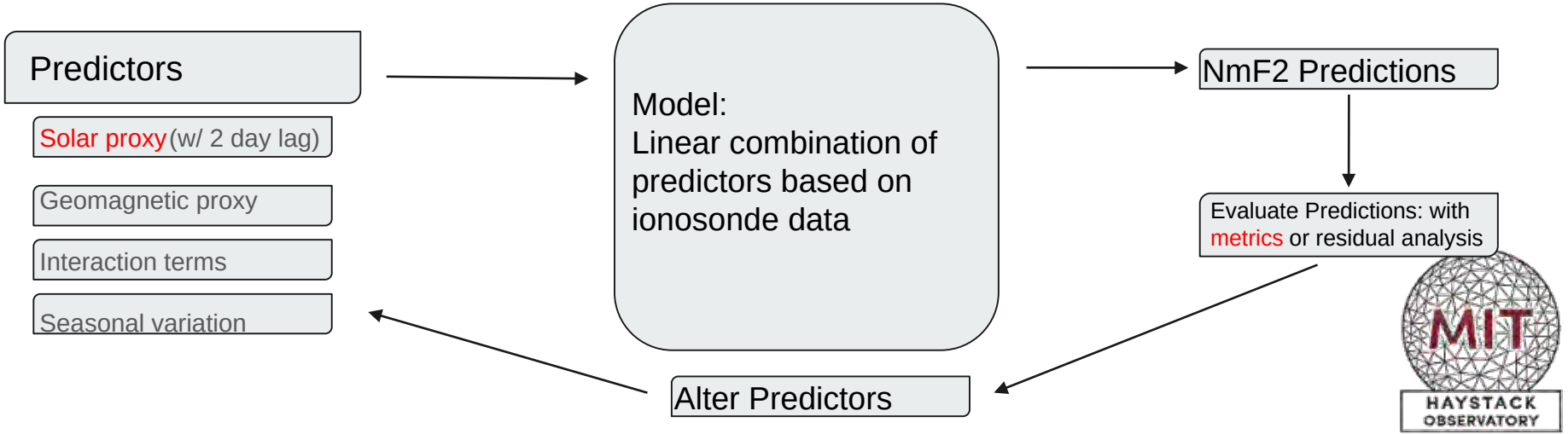



Ionospheric Layers
F2 Layer
F1 Layer
E Layer
D Layer
Weakened E Layer
Combined F Layer


Monthly averaged NmF2 at JICA (LT=13)
×10^12
2.5
2
1.5
1
0.5
0
NmF2
1995
2000
2005
2010
2015
2020
Year

Model Basics

- Local Empirical Model of Nm at F2 layer (NmF2)
- Uses
- data as observations



Data for the Model

- Ionosondes are radars that probe the ionosphere by sweeping a signal across HF frequencies
- Plasma has a critical frequency where it will reflect EM waves
- Frequency gives us number density

$$f_c = 8.979\sqrt{N_{\max}} \approx 9\sqrt{N_{\max}}$$

- Model was constructed using global ionosonde data from GIRO and WDC NICT

MIT HAYSTACK OBSERVATORY

Creation of Metrics

- We needed a way to evaluate the model performance
- Metrics are quantitative data -model comparisons
- Allow for greater physical insights than just qualitative observations and comparisons

Accuracy
Metrics: RMSE, MAPE
How to Read: The lower the better
Tells us: how close predictions are to observations

Precision
Metrics: PR, modeling yield
How to Read: if <1, model underpredicts
Tells us: how close the ranges of values are

Bias
Metrics: SSPB, MPE, Mean error
How to Read: 0 is ideal, if <0, model underpredicts
Tells us: if model systematically under/over predicts

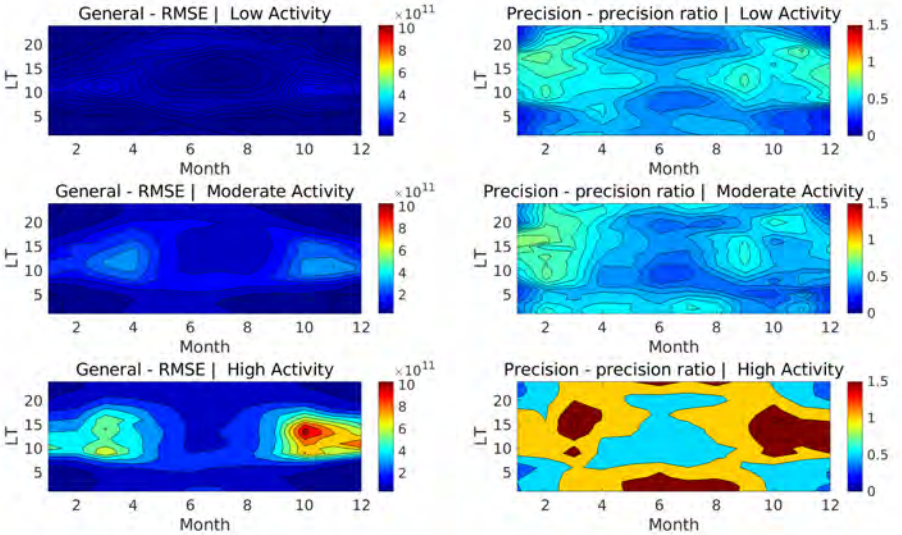
Association
Metrics: R, R^2
How to Read: The closer to 1, the better
Tells us: if predictions follow trends of observations

Skill Score
Metrics: PE, SSMSE
How to Read: >0, better, <0, doing very poorly, =0, nearly identical
Tells us: how two models compare in a given metric

MIT HAYSTACK OBSERVATORY

Observations from Metrics

- Metrics were divided into high, low and medium solar activity (50, 75 percentile)
- Calculated metrics in quiet time ionosphere, no geomagnetic storms (KP>3)
- Metrics are calculated for every hour of a month, eg. all the values at 1pm in January, for every year
- Does it hold for different locations?



WAKKANAI Data

HAYSTACK OBSERVATORY

Metric Comparison of Training and Test Data

- One of the first tasks I did was to attempt to compare the training and test data metrics
- Training data outperforms test data, but we still don't know why

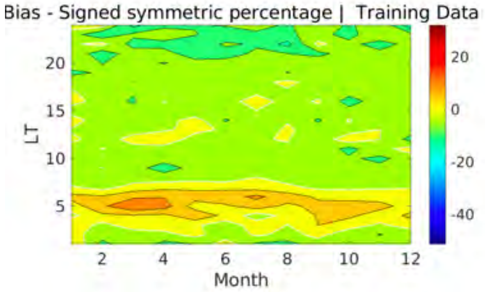
Data

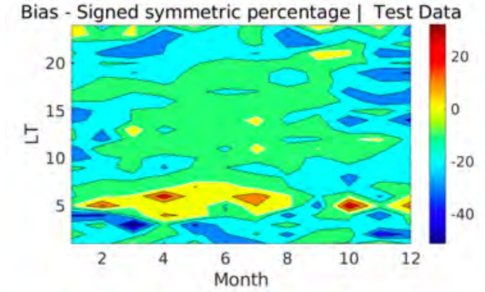
80%

20%

Training Data is used to create model

Model tries to predict test data

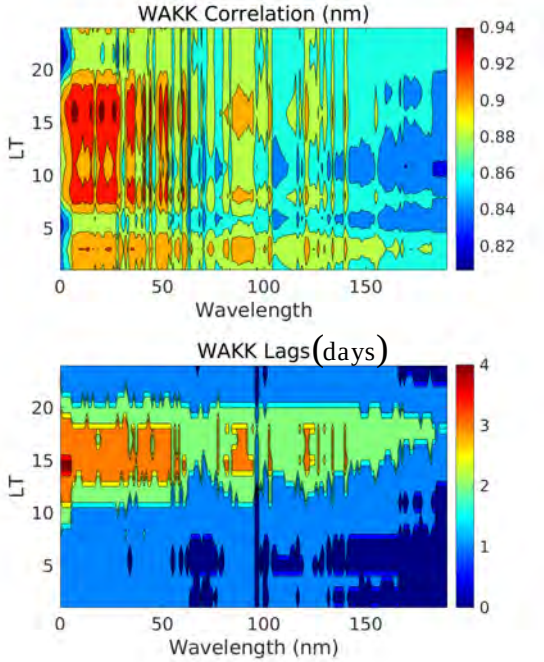




Wakkanai

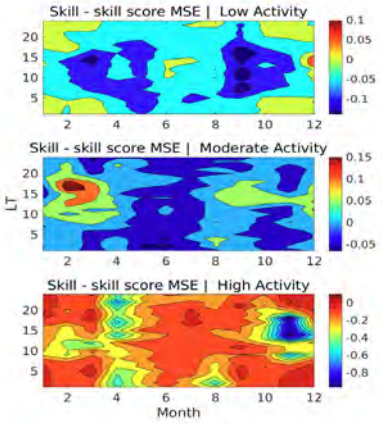
Model Performance of Different FISM BANDS

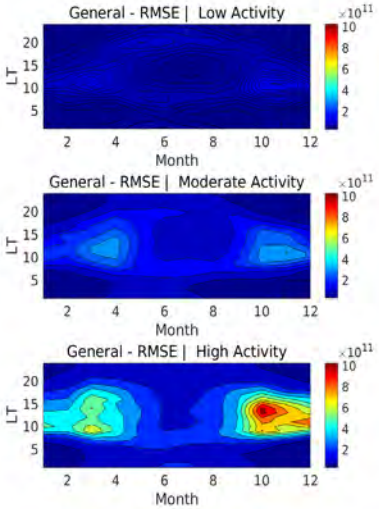
- FISM2 is main solar EUV model used, made of different wavelengths. Currently using (0-105.05 nm)
- Previous research shows that our models driven with FISM2 outperform our models driven with f10.7
- Compare the time series of observations vs each wavelength of FISM2 using cross correlation analysis, which shows how two time series correlate (have) and what the lag between these correlations is.
- The goal was to see which wavelengths had the most in common with the observations
- Helped me decide which wavelength bands and lags to try in model formulation
- Most common band across locations: 060 nm, lag of 1-3 days

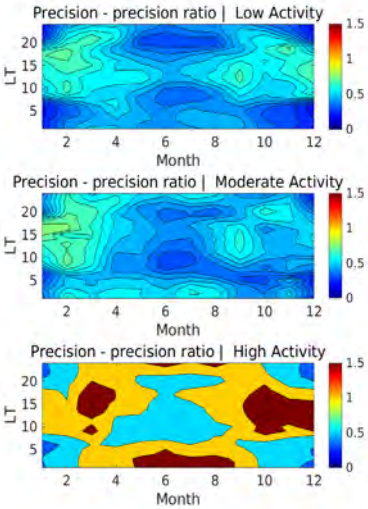


Conclusions about Wavelength Bands

- Research often comes with result that isn't exciting
- The metrics painted a picture the wavelength bands do not have that great of an effect or final predictions
- Skill Score values were very small and mostly negative, indicating same or worse performance
- 0-105.05 remains the wavelength band used in model
- Wuhan, Austin, Eglim, Wakkanai, Yamagawa, Jicamarca



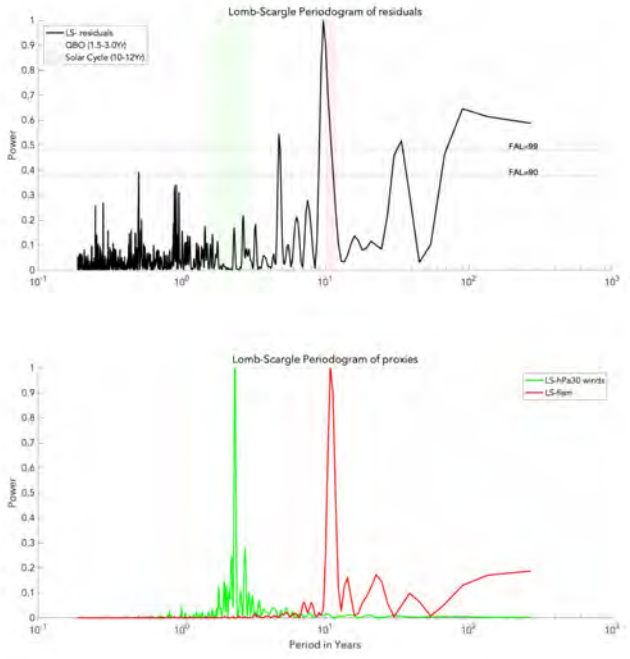




MIT HAYSTACK OBSERVATORY

Residual Analysis

- Residuals- difference between prediction and observation
- Periodicities in residuals reveal what is still missing from model, or couldn't be accounted for.
- Lomb Scargle- Helps to find periodicities in residuals for unevenly spaced data
- 11 year periodicity remaining



MIT HAYSTACK OBSERVATORY

Summary

- Empirical model is striving to predict NmF2 in nonstormy ionosphere
- I spent my summer developing and testing various metrics to compare model versions
- I used the metrics to evaluate the model, specifically its solar proxies
- I looked for better bands of FISM2 but did not find any
- Widespread adoption of different metrics used for evaluation is a goal for scientific community
- We can use residuals to find any remaining periodicities in the model

MIT HAYSTACK OBSERVATORY

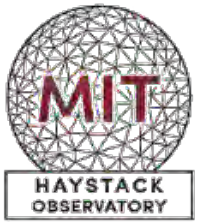
Future Work

- Continue residual analysis to find signals
- Continue using metrics to compare model performance
- Investigate FISM2 wavelengths at different time periods
  - Evaluation of FISM2 bands was done for all time periods
  - Evaluation at shorter time periods might reveal better results

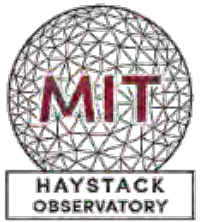
MIT
HAYSTACK OBSERVATORY

Final Thoughts and Acknowledgements

- REU was fantastic learning experience
- I learned so much about research and having a career in science
- Thank you to Larisa for having me here and providing guidance and mentorship
- Thank you to my fellow REU students for making this a great summer
- MIT Haystack Staff (Dianne, Nancy, Heidi, Drew, John Tsai, Don, Roxana)
- Special thank you to Dupinder Singh for so much help, advice, and patience
- NSF, for funding



Questions?



References

- Goncharenko, L. P., Tamburri, C. A., Tobiska, W. K., Schonfeld, S. J., Chamberlin, P. C., Woods, T. N., et al. (2021). A new model for ionospheric total electron content: The impact of solar flux proxies and indices. Journal of Geophysical Research: Space Physics,126, e2020JA028466. https://doi.org/10.1029/2020JA028466
- Michael W. Liemohn, Alexander D. Shane, Abigail R. Azari, Alicia K. Petersen, Brian M. Swiger, Agnit Mukhopadhyay, RMSE is not enough: Guidelines to robust data–model comparisons for magnetospheric physics,Journal of Atmospheric and Solar-Terrestrial Physics, Volume 218, 2021, 05624, ISSN 1364-6826, https://doi.org/10.1016/j.jastp.2021.105624.
- [1] Jacob T. VanderPlas. Understanding the lomb-scargle periodogram. The Astrophysical Journal Supplement Series, 236(1):16, may 2018.

MIT HAYSTACK OBSERVATORY