Predicting Equatorial Electron Flux Measurements from low-Earth-orbit

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Abstract

The outer radiation belt is very dynamic, both spatially and temporally. One of the keys to understanding this dynamic variability is to understand the loss processes for radiation belt electrons. **Local precipitation loss due to pitch angle (PA) scattering by magnetospheric waves is the focus of our analysis.** Plasma waves can alter the course of a charged particle and influence a previously trapped electron from the magnetosphere to penetrate the Earth's upper atmosphere. Once in the upper atmosphere, a charge particle can ionize air molecules leading to the destruction of ozone and interfere with technological systems. It is critical that particle measurements from different platforms are inter-calibrated as these data are needed to validate increasingly important radiation belt models.

The proposed project aims to understand when and how electrons precipitate into the atmosphere based on different enabling local conditions and to establish a predictable relationship between low-Earth-orbit and high altitude orbit data. To do so, we use coordinated electron measurements from the Van Allen Probes, or Radiation Belt Storm Probes (RBSP), and the Polar Operational Environmental Satellites (POES) as inputs for a neural network. The two spacecraft should be measuring the same particle population when connected on the same magnetic field line.

Low earth orbit (LEO) missions, like POES, continue to provide continuous and more accessible monitoring of the radiation belts. It is becoming more essential to ensure that LEO data is a good proxy for high latitude data.

Introduction and Methodology

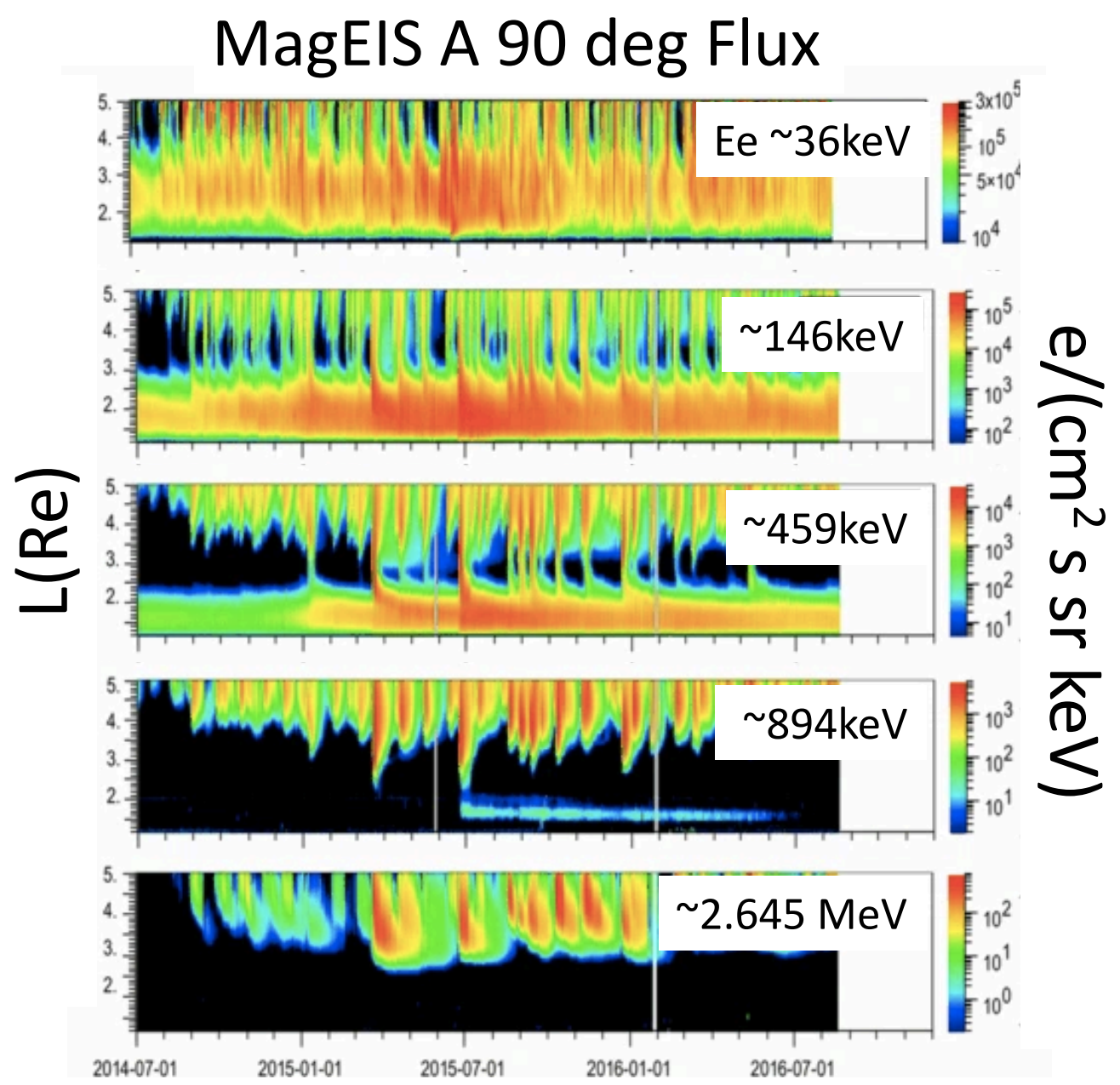


Figure 1: Electron Flux adapted from Baker et al (2018).[2] Lower energies (top), the radiation belts are more dynamic (e.g. more enhancements than the higher energies (bottom).

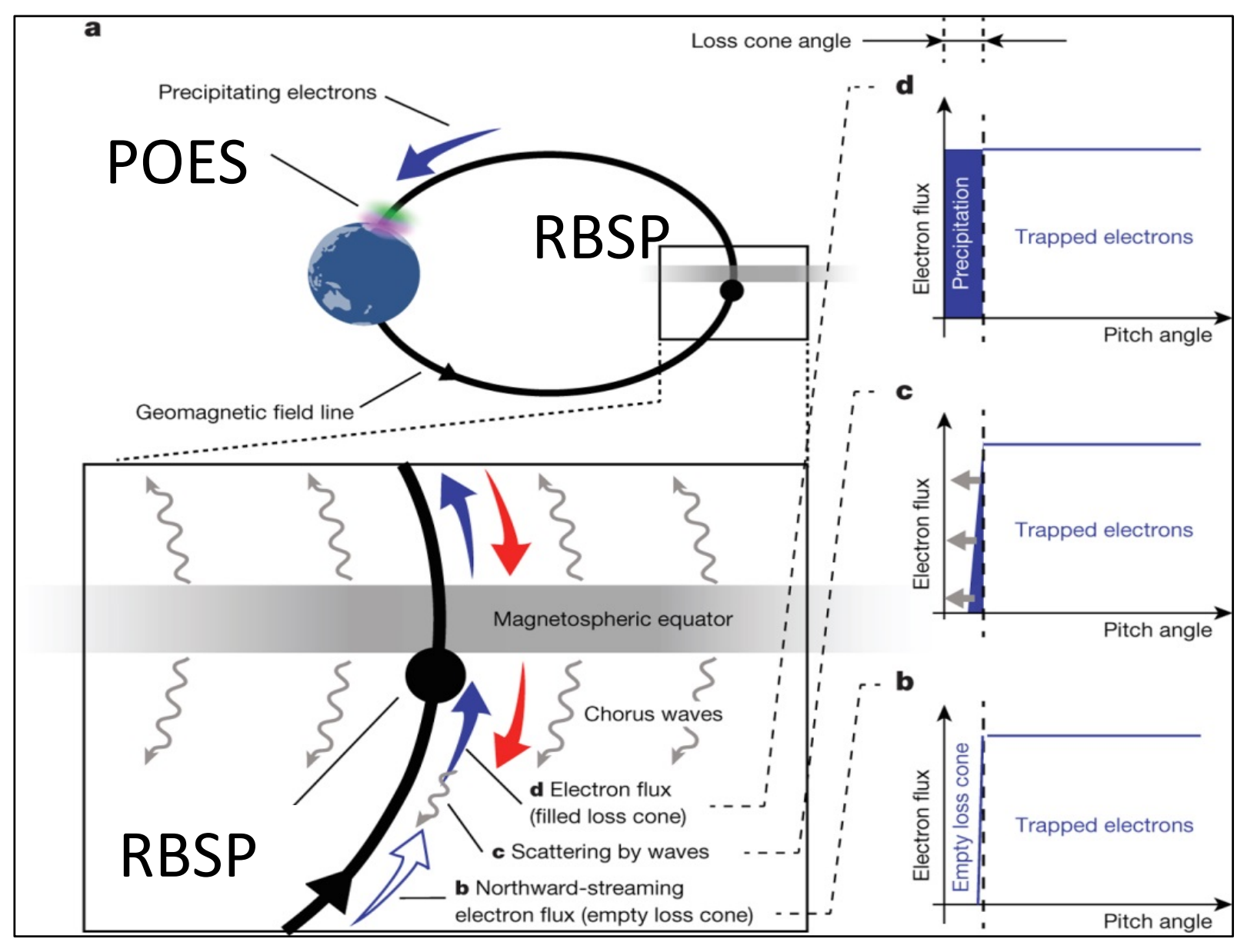


Figure 2: Electron scattering adapted from Kasahara et al (2018).[3] POES Telescope 0 measures precipitating electrons and Telescope 90 measures the trapped electrons.

Finding Conjunctions

Magnetic conjunctions are when POES(MetOp2) and RBSP(b) were on the same magnetic field line (Fig 2)

- **Conjunction criteria**: dL = 0.1 and dMLT = 0.5 hr
- **Date Range**: 01/01/2014 through 07/01/2019
- **Number of Total Conjunctions:** N_{TOT} = 61,740

We restricted the RBSP flux measurements to:

- **Lowest pitch angle bins:** PA < 16 deg and PA > 164 deg includes the flux from the loss cone containing the precipitation population.
- **High L-shells:** L >3 is the outer radiation belt, where plasma waves scatter electrons.
- **Energy Channels(4):** >30 keV, >100 keV, >300 keV, and >1 MeV, to match the 4 POES integral flux measurements

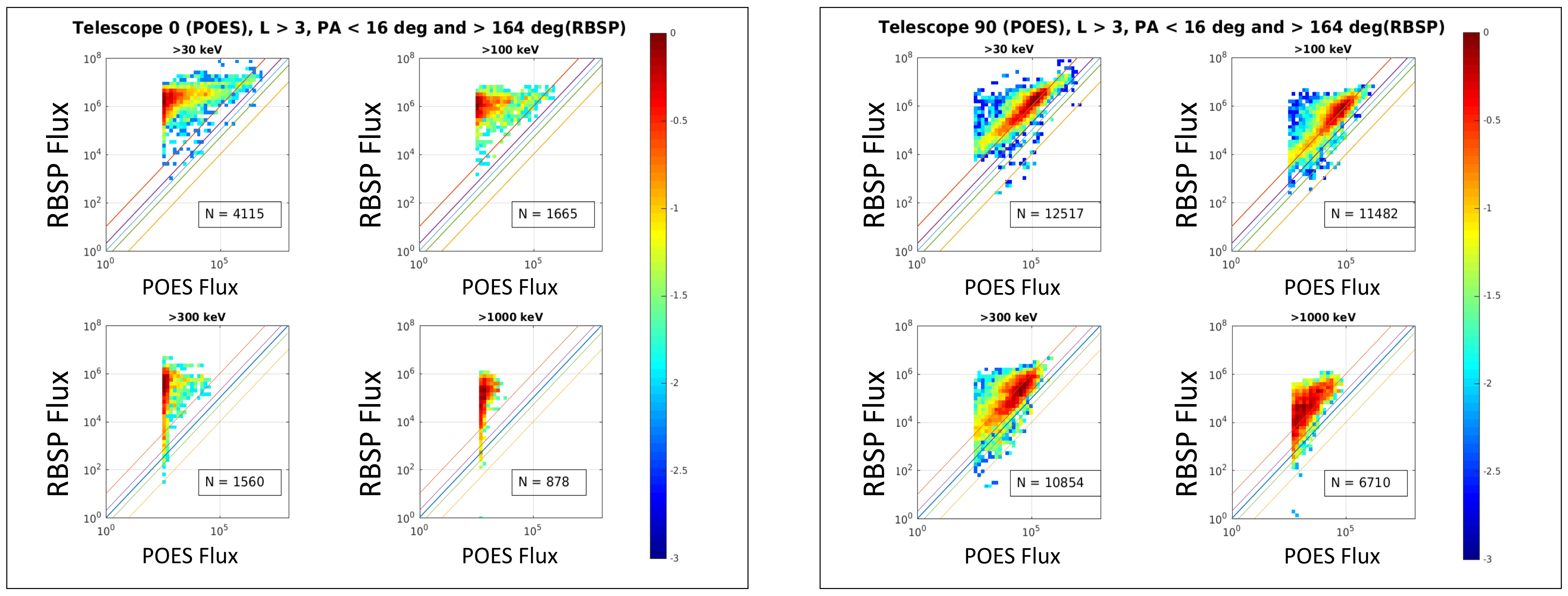


Fig 3 Normalized Histograms for RBSP vs POES flux for Tel 0 (left) and Tel 90 (right)

Q: Can we produce a neural network capable of predicting equatorial electron fluxes from LEO?

In Fig 3 **there is linear correlation between the electron fluxes measured on the RBSP and POES (Tel 90) spacecraft**. With the correlation lying along y = 1/10x, the two spacecraft are measuring the same particle population. **We can build a model using the E1 (>30 keV) channel to predict the equatorial PAD of RBSP using the POES flux (Tel 90 and 0).**

Neural Network Model and Result

Target Variables: Fit and characterize the electron PADs in the form of $\sin^n$ as a function of geomagnetic activity (Gu *et al.,* 2011).

$$J_D = \sin\alpha^N * C$$

Alpha is the equatorial pitch angle, J_D is the equatorial flux.
Convert to log space and then equate to $y = mx + b$ to obtain N and C which now represent the slope and y-intercept of this fit and serve as the target values.

$$\log J_D = N * \log(\sin\alpha) + \log C$$

Predictor Variables:

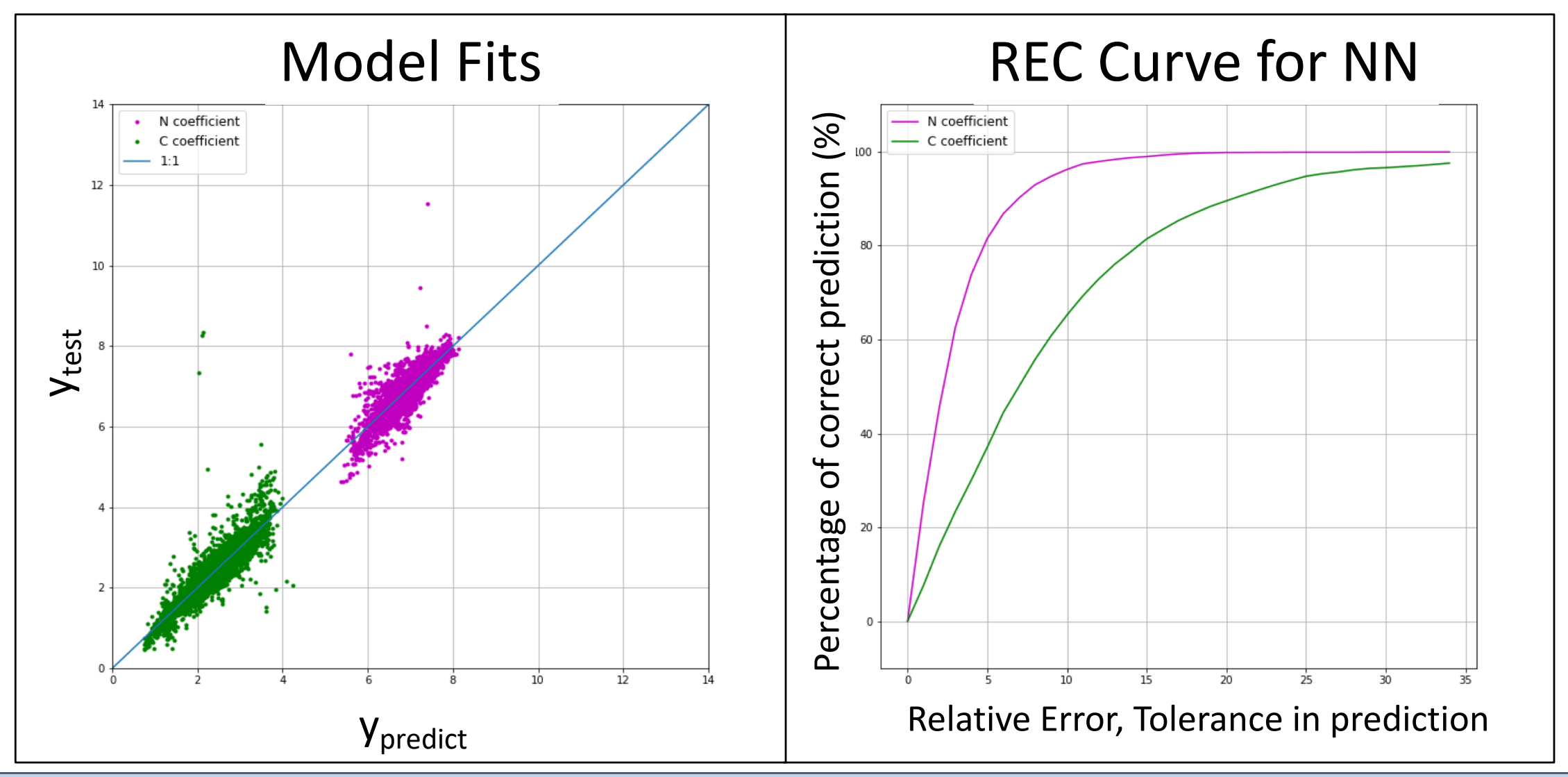
Predictor Variable	Full Name	Description	Units
log_flux0	log (Poes 0 Flux +1)	Logarithm of the electron flux (plus 1 to avoid infinity) from telescope 0, measuring precipitating electrons	Unitless, with flux in #/cm² *s*str
log_flux90	log (Poes 90 Flux +1)	Logarithm of the electron flux (plus 1 to avoid infinity) from telescope 90, measuring the trapped electrons	Unitless, with flux in #/cm² *s*str
L	L-shell	Refers to the length at which a magnetic field line intersects with Earth's equatorial plane	Earth radii
MLT	Magnetic Local Time	Refers to position similar to longitude, with midnight = 00 hr and noon = 12hr	hr
AE	Auroral Electrojet Index	Measure of Auroral Zone Magnetic Activity and used as an indicator of geomagnetic activity	nT
AE*	Auroral Electrojet Index Star	Maximum value of AE over three hours	nT

Model Info:

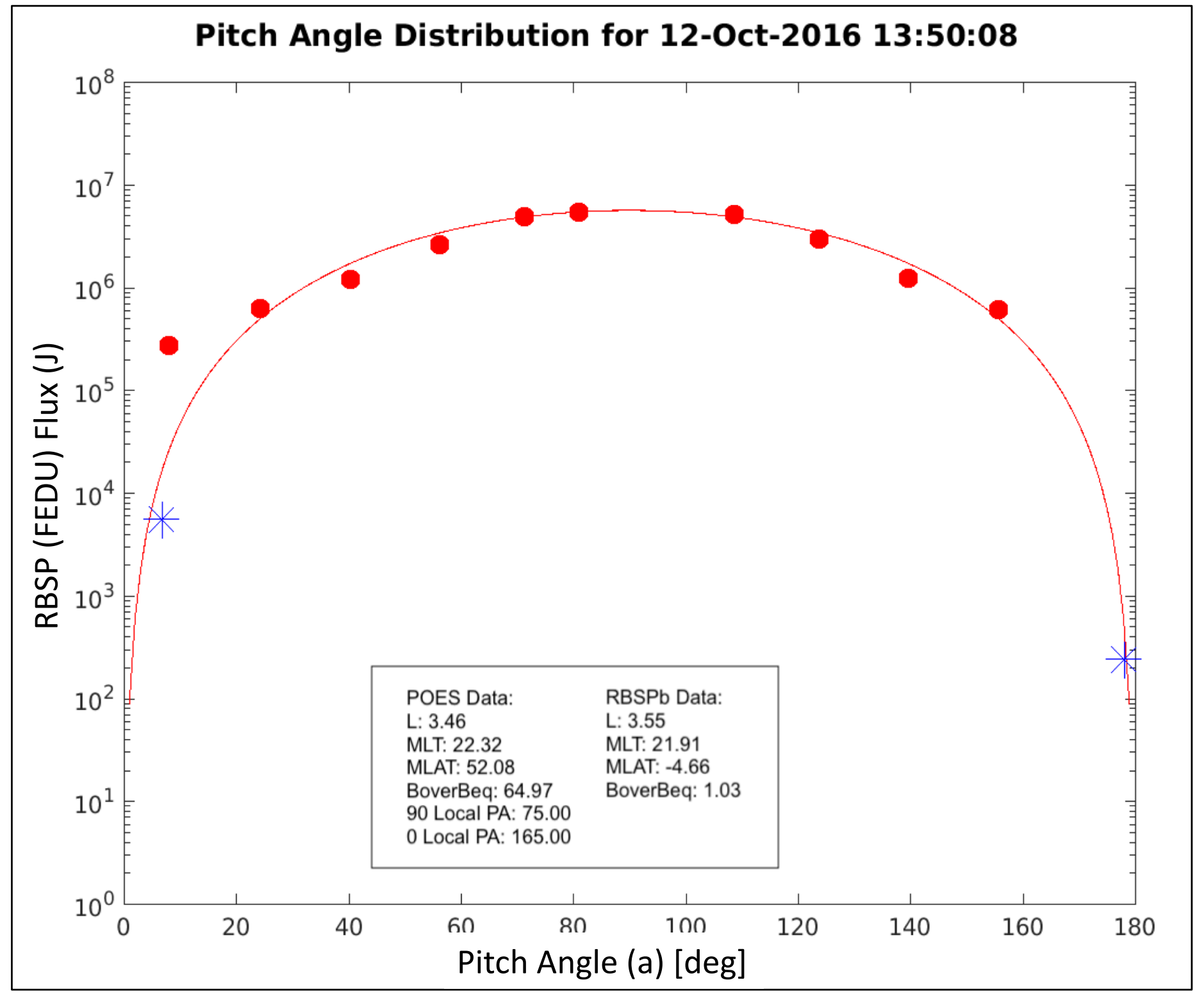
- Ran training dataset (70%) through the multi-layer perceptron regressor
- Tanh activation function and stochastic gradient descent solver
- 3 hidden layers with size = 150, 100, and 50, respectively

Error Metrics:

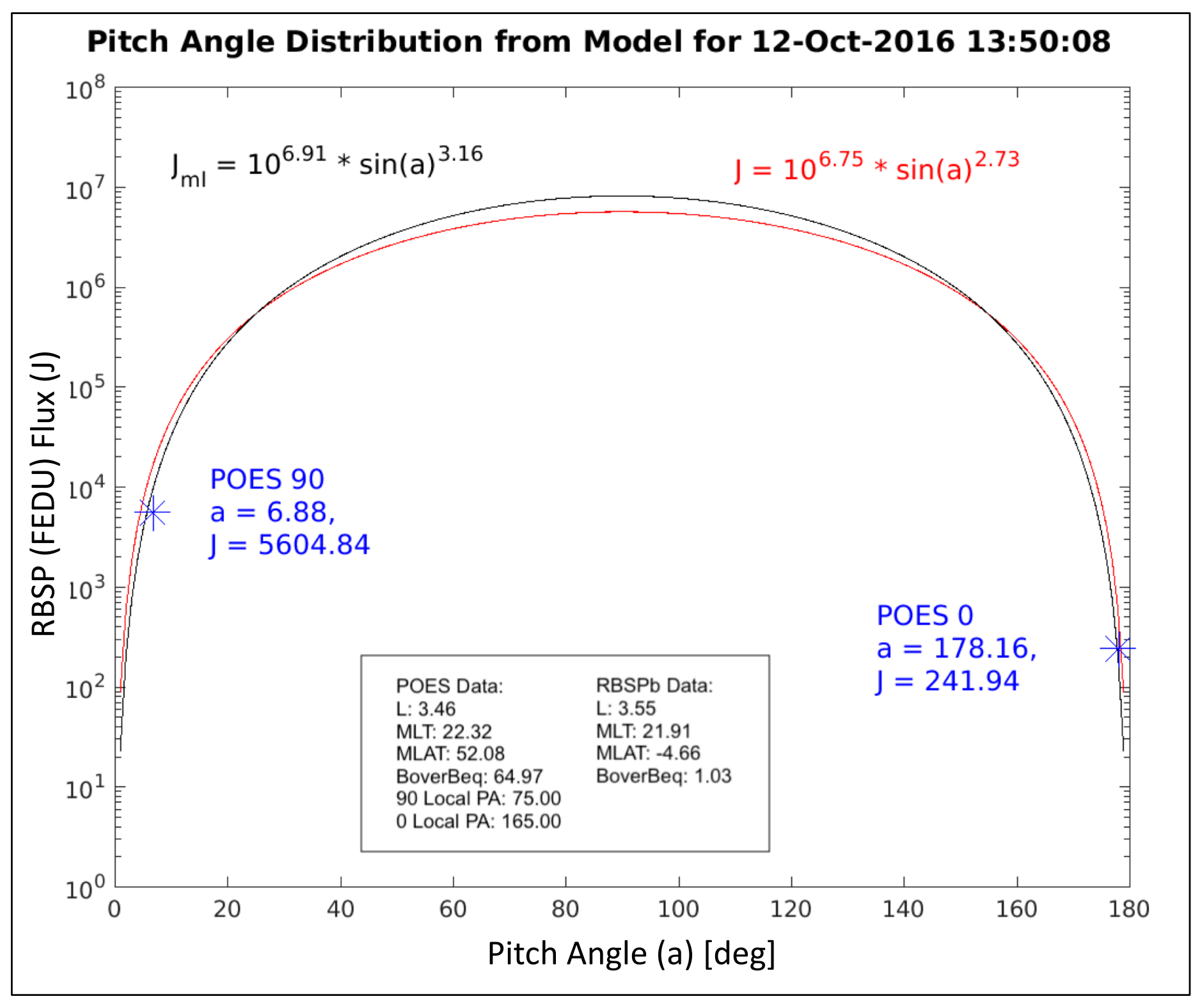
Error Metric	Value
R²	0.74
MSE	0.13
MAE	0.21



Candidate Conjunction:



Model Results:



Conclusions and Future Work

Conclusions:

With no input from RBSP, the model predicted the C and N values to be, C = 6.91 and N= 3.16 (compared to the test values, C = 6.75 and N = 2.73). The predicted fit had a coefficient of determination of R² = 0.93, **and therefore indicates the model can predict high altitude data from LEO data.**

Future Work:

Start investigating conjunctions on a case-by-case basis, **creating a database** in the process

- To be used as inputs into a future model

With promising results, we hope to expand this study by:

- Including **other available spacecraft data**, including the other Van Allen Probe (RBSPa) and 4 other POES satellites.
  - All energy channels (not just E1)
- Investigating local conditions at RBSP through **various predictor variables** (i.e. Kp)
- Examining **anomalous cases**
  - Checking inter-calibration issues between POES and RBSP
  - Investigating theoretical assumptions of particle precipitation

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