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Evaluation of Machine Learning Algorithms for Satellite Operations Support

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Agenda

- Goals and background
- Machine learning tools overview
- Archiving subsystem – ease of data access
- Machine learning for telemetry data - concepts
- Analyzing data from Telenor fleet: techniques, algorithms and results
- Lessons learned and future development

Problem statement and background

- Goal: predict battery voltage levels through eclipse season to prevent a catastrophic power failure. We will be analyzing data from the past 7 years and using machine learning algorithms to attempt a realistic prediction.
- Secondary goal: gain experience in machine learning algorithms and their applicability to satellite telemetry data analysis.
- Ease of use of the algorithm was of paramount importance:
 - Quick implementation
 - Results that can be explained
 - Good defaults and as little requirement on data preparation as possible
- Lack of data science background – the work was done by a Satellite Engineer and a Software Engineer
 - We expect this is true for many organizations



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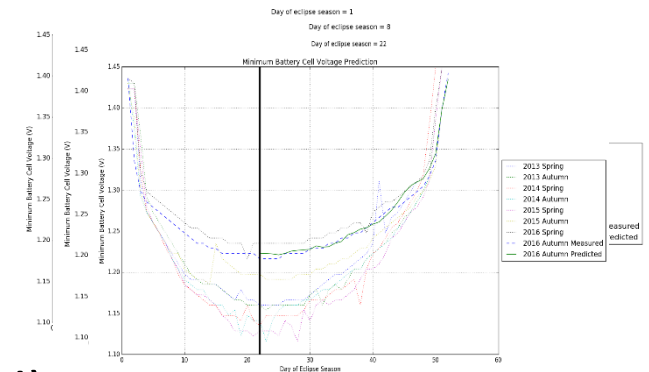
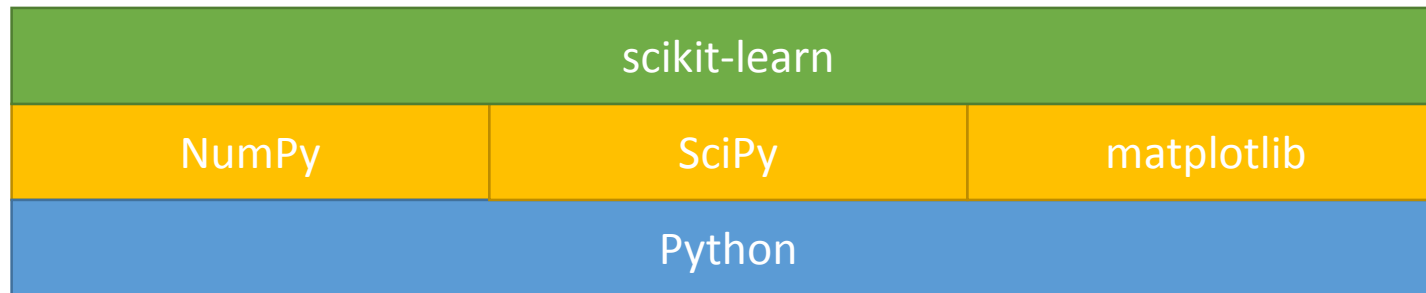
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Tools – Machine learning

- scikit-learn: open source library for machine learning
- Powerful and includes a wide range of algorithms and tools
- Used for all the work in this project



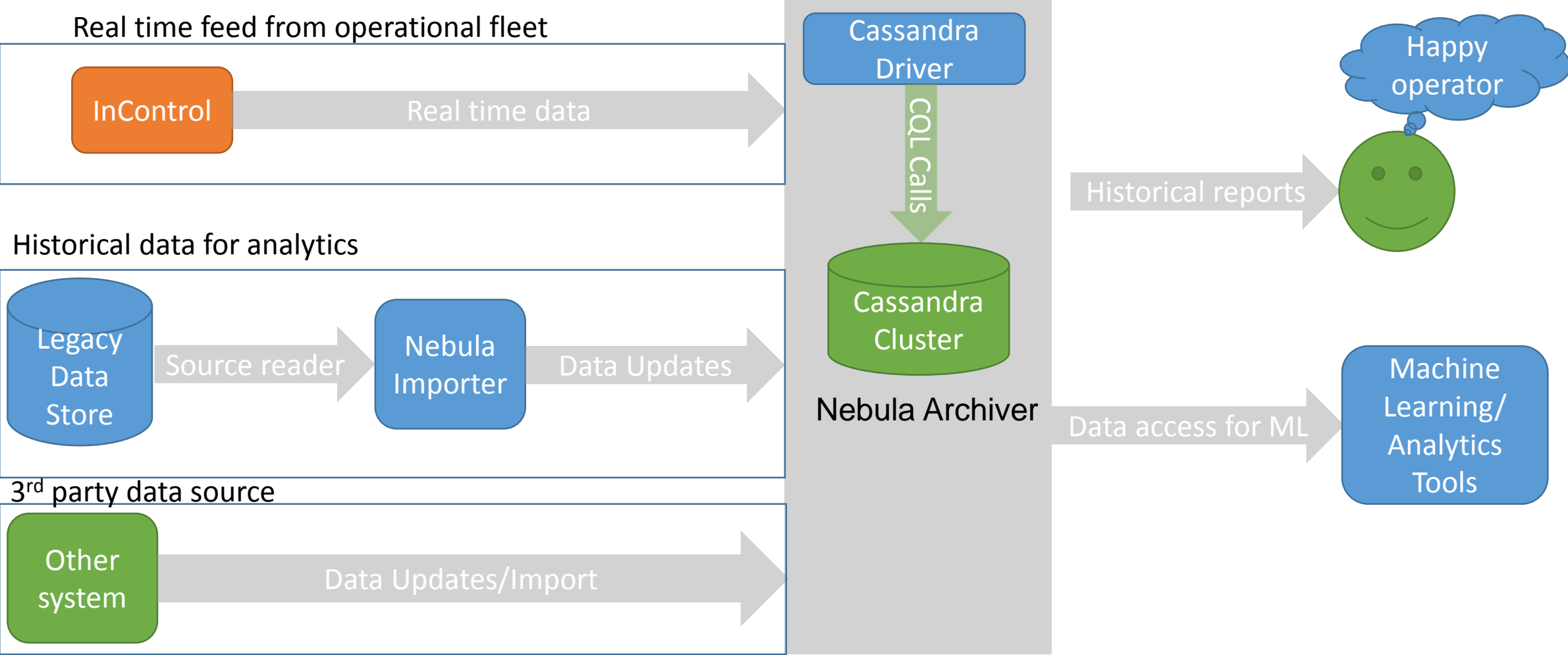
Many alternatives available in a variety of languages (not tested)

- Especially in Python and R
- Also: TensorFlow (Google), MSCNTK,
 - Including cloud based like Amazon AI

Data Storage – Nebula Archiver

- From proprietary to open
 - Legacy archiving based on closed, proprietary file formats
 - Data access possible only through proprietary APIs or GUIs
- Nebula Archiver – power to the user
 - Based on Cassandra No-SQL database (other DBs supported as needed)
 - Almost unlimited scalability
 - Lightning fast data access
 - Data laid out to match typical access patterns
 - Ease of access – just a few lines of python code needed to retrieve and plot data
 - Easily accessible from any programming platform

Nebula Archiver – high level architecture



Nebula Archiver - Benefits

- For the operator
 - Quick overview of large portions of data
[view 1 year of data in as little as a few seconds]
 - Reporting has no impact on the real time processing
- For the engineer
 - Very fast and simple access to stored data using open tools (python/java/js)
 - Use analytical tools without impacting the real time system
 - Almost unlimited scalability
- For the manager
 - Happy operator/engineer 😊
 - Reduced hardware cost and ability to expand storage subsystem as needs grow

Machine learning - concepts

- Machine learning: data analytics technique that uses historical data to predict future system behavior
- Supervised learning: using engineering knowledge in conjunction with data to train the algorithm
- Unsupervised learning: predicting future behavior without user input
- Classification: Automatic assignment of an event to a class based on historical data and other inputs
- Overfitting: learning the underlying data vs. trends in the data



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Regression Algorithms

Several different regression algorithms were tested:

- Linear regression – stochastic gradient descent
- State vector machine – linear, polynomial and radial basis function
- Random forest – extra trees regressor

Extra trees regressor produced the best results in most cases tested, especially for time series.

SVM RBF is faster and sometimes a good alternative.



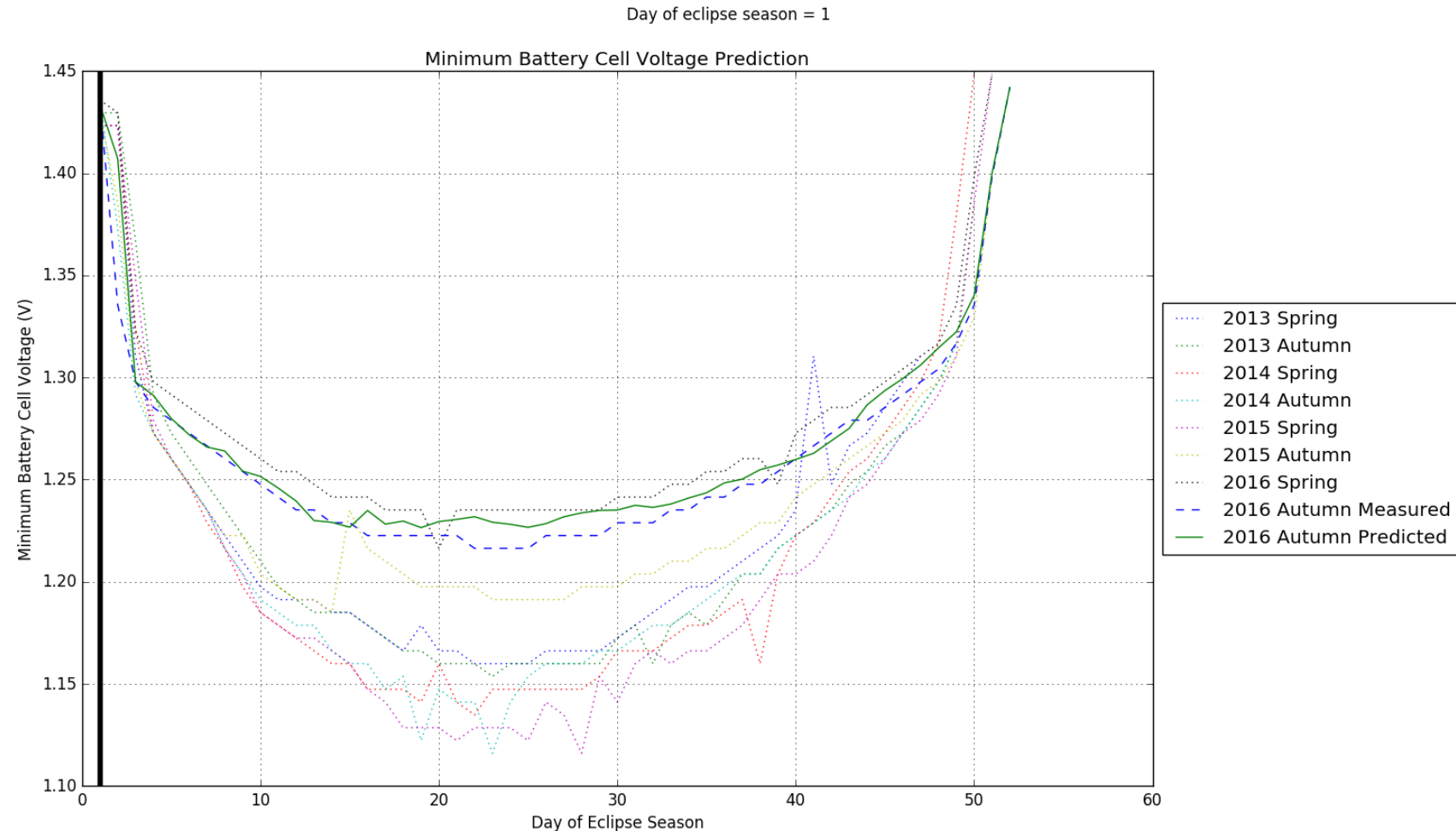
Regression Use Cases

- Monitoring battery cell voltage through eclipse seasons.
- Dynamic limits – potentially used for any predictable telemetry point.
- Predicting the attitude disturbance of momentum wheel unloads.
 - Based on the momentum stored on the wheels.

Regression Example – Battery Cell Voltages

Battery cell voltages are monitored during eclipse seasons.

No model has previously been found to reliably predict them.

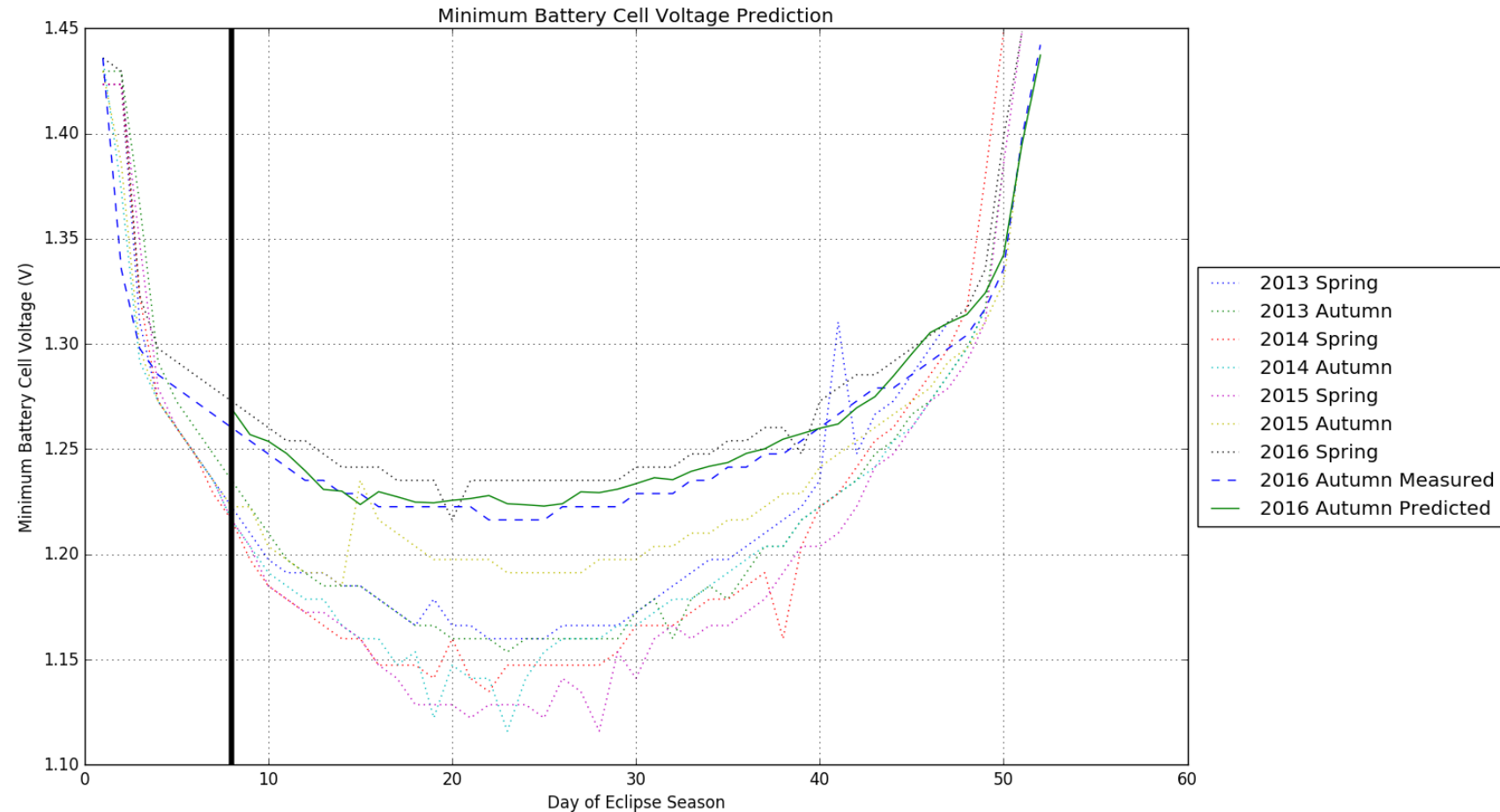


Regression Example – Battery Cell Voltages

Day of eclipse season = 8

Extra Trees
Regressor creates a
good prediction.

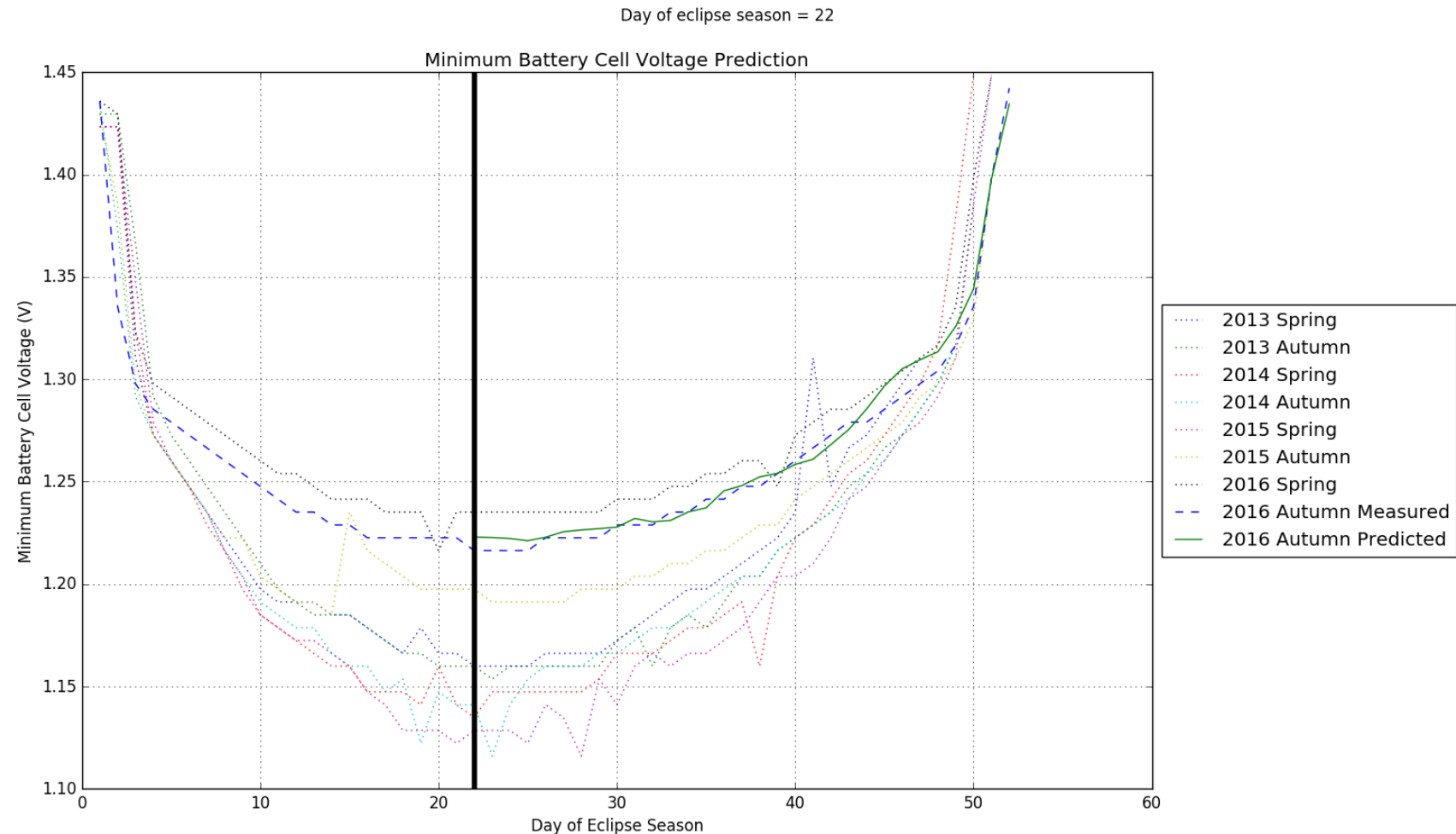
Model is updated
during the eclipse
season.



Regression Example – Battery Cell Voltages

Algorithm has learnt the data from seven previous eclipse seasons.

Uses temperature, power and load telemetry as well as cell voltages.

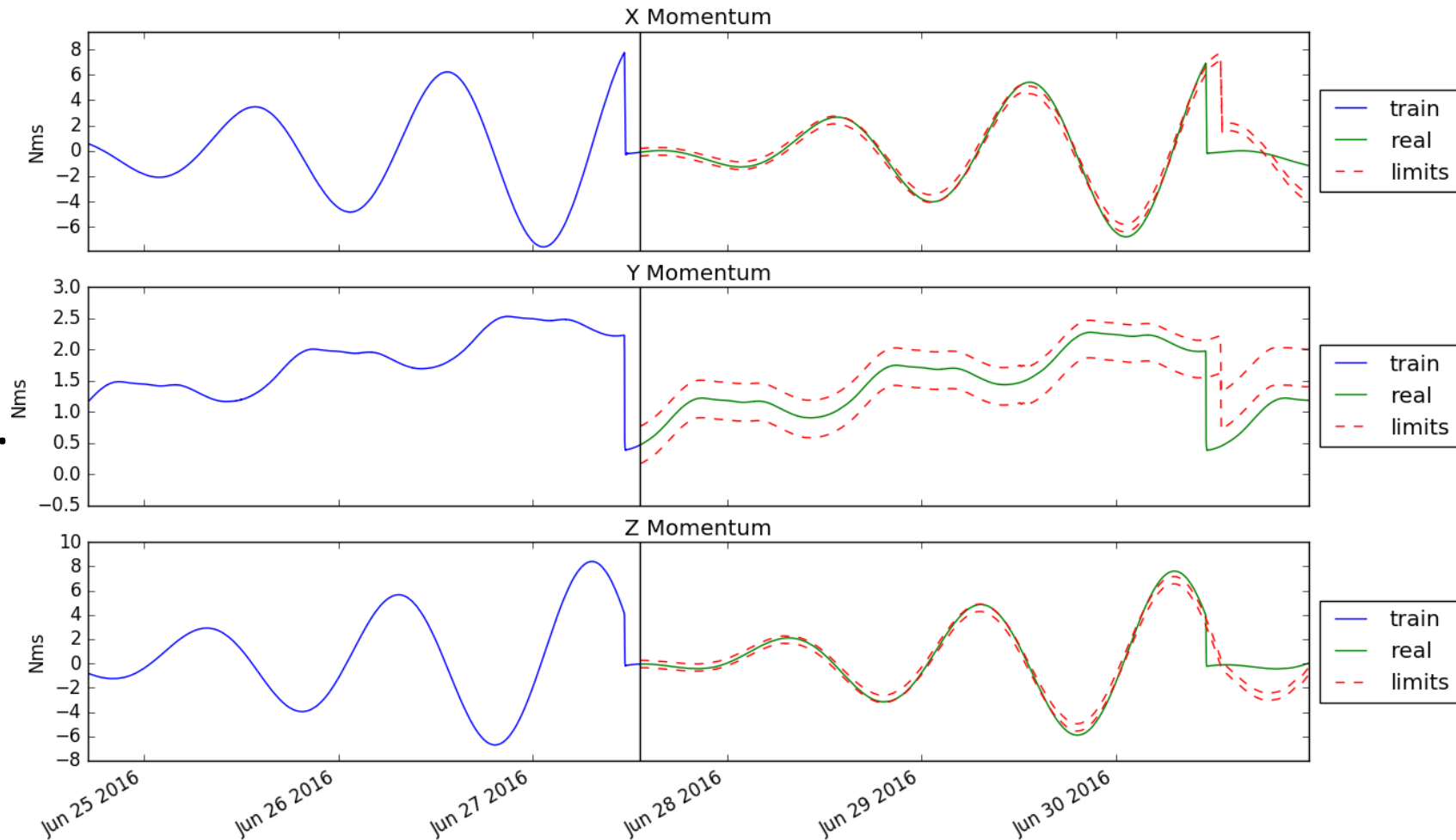


Regression Example – Dynamic Limits

Predicts the trends ahead and sets limits.

Prediction accuracy deteriorates with time.

More work needed to reduce false alarms.



Classification

Classification was tested for use in monitoring battery charging.

- Supervised training of previous charges to identify nominal charge characteristics for the various modes and states.
- More work needed to develop a useful tool.

Would be useful for further work in anomaly detection.

Lessons Learned and Future Directions

Lessons Learned:

- Challenge is to define the task and preprocess data.
- Some useful tools developed.
- Too few anomalies. Hard to train algorithms without failures.

Future Development:

- Expand and improve current tools
 - Plenty of other potential applications
- Anomaly detection
 - Dynamic limits, out of family behaviour, component degradation
- Investigate techniques for more general learning



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