New Directions in Sporadic E Research:

ANALYZING SPORADIC E WITH A DEEP LEARNING NETWORK

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HAMSCI WORKSHOP, CASE WESTERN RESERVE UNIVERSITY

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OVERVIEW

- Because Sporadic E (6M) propagation depends on so many factors, it has not yet been possible to fully understand it (theories abound)
- Classical statistical analysis (e.g., multiple regression) works poorly (non-linearities)
- Recent techniques in Deep Learning (branch of AI) may yield results
- This is a progress report (work not yet complete)
    - Approach
    - Planned techniques
    - Possible results

SPORADIC-E

- Recent work shows that some Sporadic E is occurring most of the time
  - E_s often doesn't result in 6M propagation
  - You can tell this based on GPS occultation
  - Each GPS satellite produces two signals: L1 and L2 (1.575 GHz, 1.227 GHz)
  - L1 and L2 are measured at another Low Earth Orbit satellite
  - The ionosphere refracts these two signal differently: they take slightly different paths

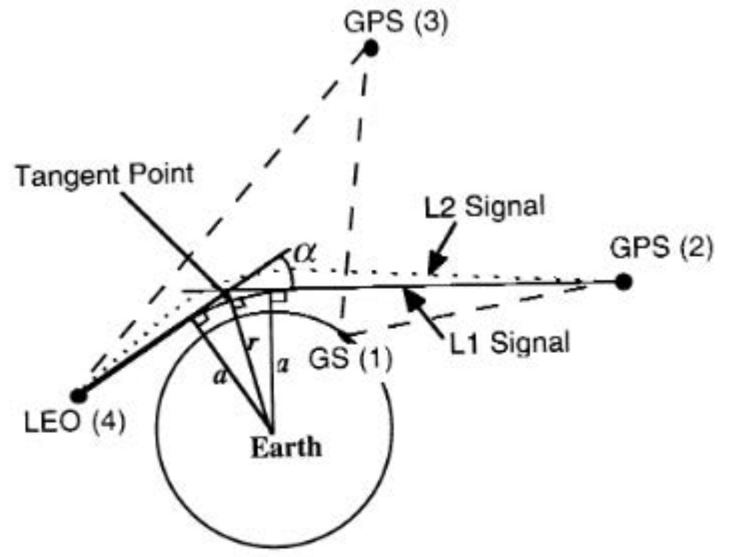


Fig. 1. GPS occultation geometry defining the tangent point, the asymptote miss distance, a, and depicting how the L1 and L2 signals travel slightly different paths due to the dispersive ionosphere. Also shown are the other non-occulting GPS transmitter and ground receiver used for calibration.

When the signals pass through areas of sporadic E, this changes the phase difference and SNR between the signals. You can calculate the amount of sporadic E this way.

SPORADIC-E: WHAT CAUSES IT?

- FACTOR 1

  Metallic ions from meteorite impacts are piled into layers by ionospheric wind shear combined with Lorentz force

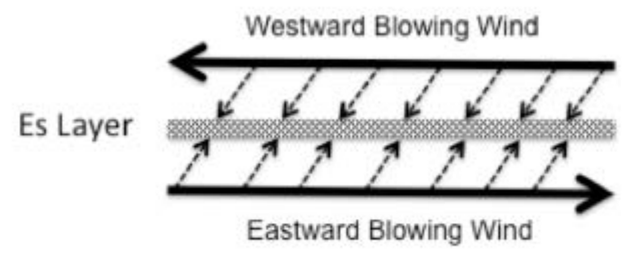


Figure 3: Two adjacent E-region winds blow in opposite directions – at right angles to the Earth's magnetic field (field pointing into the page) – the Lorentz force deflects the Fe^{+} ions with their free electrons down from the upper wind and up from the lower wind. This compresses the electrons into a thin Es layer or sheet (after Shalimov, et al., 1999).

SPORADIC-E: WHAT CAUSES IT?

FACTOR 2

Equatorial Electrojet: Electrons pushed by sun's ionization flow in a current from east to west above the equator

Earth's magnetic field then causes the flowing charged particles to drift to higher latitudes and then fall, enhancing electron density

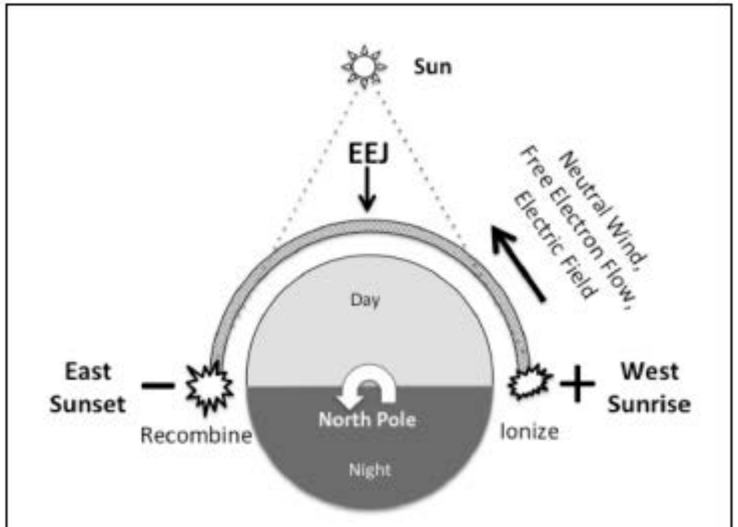


Figure 4: The Sun excites the Equatorial Electrojet (EEJ) and constantly produces a powerful free-electron current above the geomagnetic equator, from sunrise terminator to sunset terminator. This plays a critical role in midlatitude Es (and TEP-like F-region propagation as well).

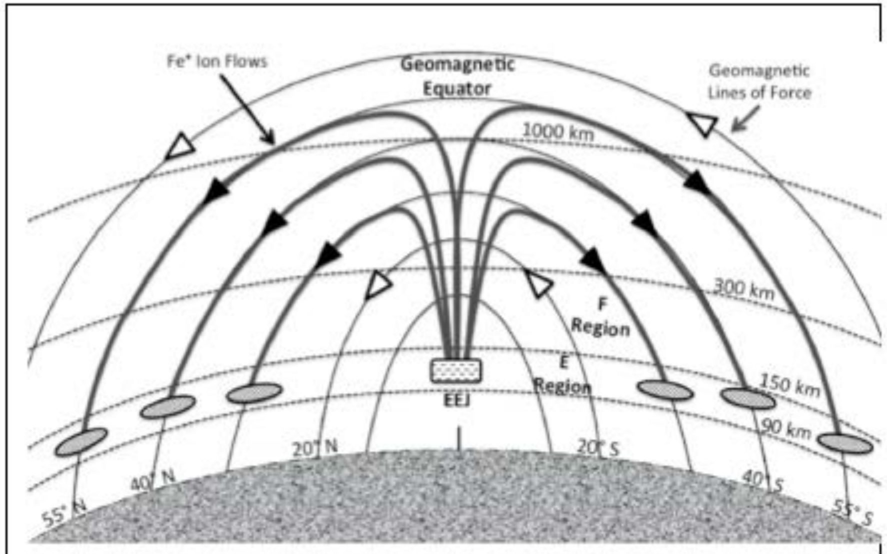


Figure 5: Looking eastward along the EEJ, the **ExB** effect causes both positive ions and free electrons to drift upward. The iron ions are of special interest. They reach extreme F-region heights, some as high as 4000 km. From there, they fall back downward along the Earth's magnetic field lines, until they reach the E region again, but *now at midlatitudes*. They enhance the locally produced Fe^+, and together attract more long-live free electrons, raising the Es MUF.

THERE MAY ALSO BE ADDITIONAL FACTORS

- *Upper Level Lows* may generate enough energy to push ions all the way up into ionosphere (J. Dzekovitch K1YOW QST article)
  - Directions of the jet stream happen to be such that they do not disrupt this flow
- *Ionospheric winds* may need to fall within certain ranges
  - Based on analysis of TIDI/TIMED satellite data
- *Geomagnetic and solar parameters* may also need to fall within certain ranges
- Since some E_s happens almost constantly, there must be *special cases* of E_s that result in 6M propagation.

WHY HAVE PREVIOUS ANALYSES NOT SHOWN GOOD CORRELATION TO SOME OF THE FACTORS?

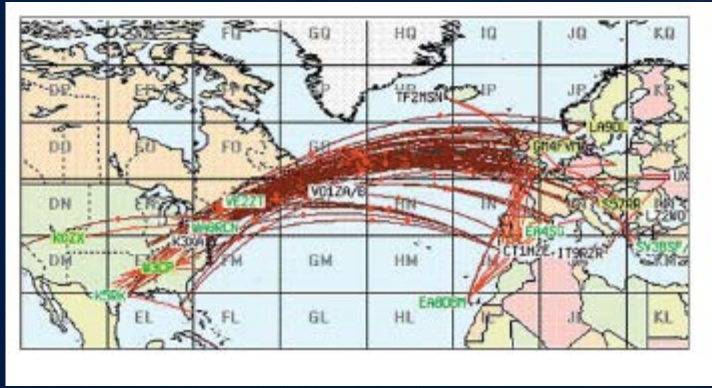
6M spot volumes (HamSCI HARC database) compared to a variety of NASA and NOAA data, but almost no linear correlations to anything

- We may not be looking at the *right factors* (satellite data, geomagnetics, etc., but critically did not include meteorite impact counts)
- Most analyses have used linear regression/multiple linear regression
  - OOPS. Phenomena possibly *non-linear*
- Propagation may be enhanced by specific *patterns* of factors
- Possible "*Goldilocks zone*" situation with one or more parameters
  - Too much or too little of one or more factors may prevent propagation
  - Example: Ionospheric windshear actually shows some negative correlation to propagation

EXAMPLE OF A NEW IDEA ABOUT E_S

- K1YOW theorizes that storms and/or Upper Level Lows may trigger E_s
- Dec. 2017 QST

2016-06-13



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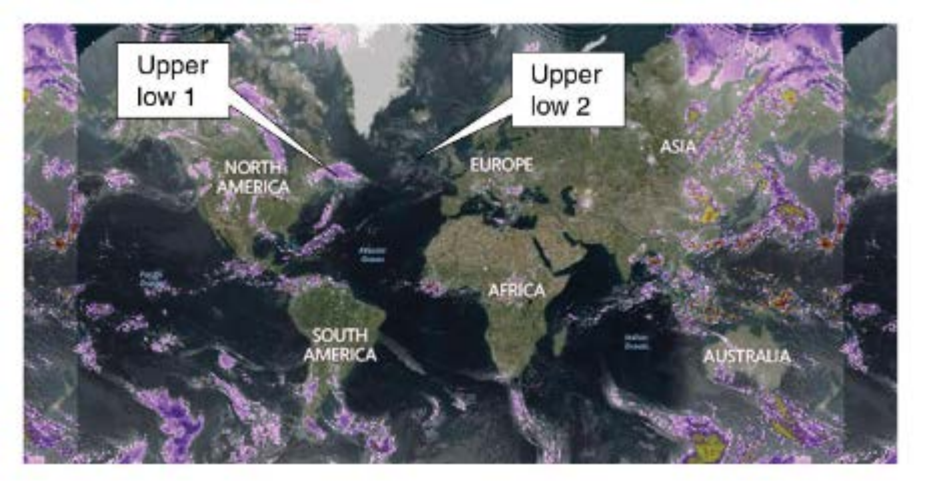
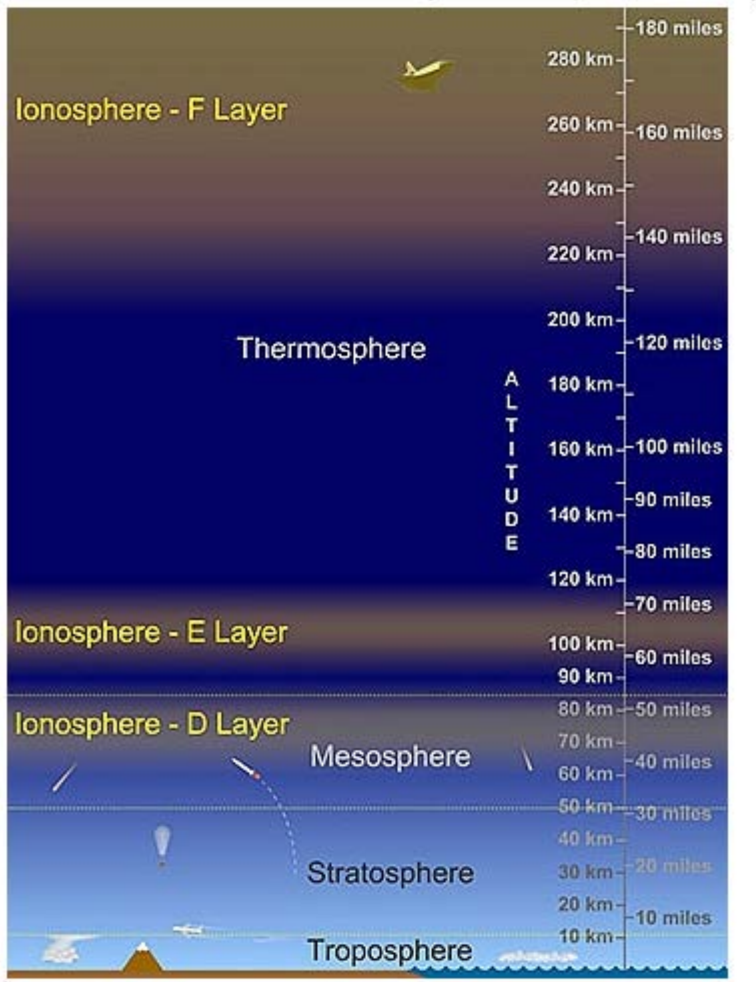


WHAT ABOUT UPPER LEVEL LOWS?

Need to analyze WX maps…
Can do this using image processing.
Why?

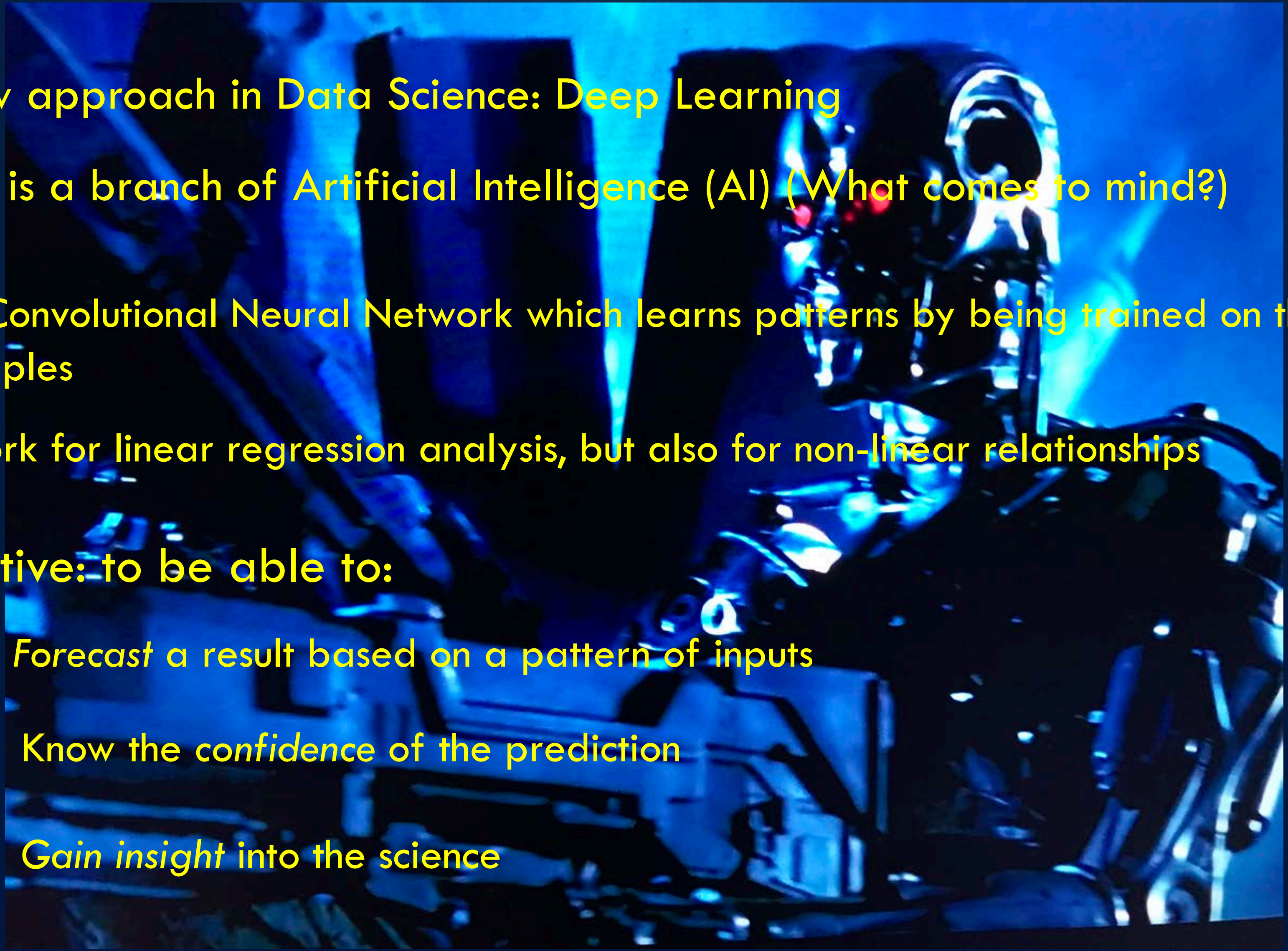
- Raw data is very hard to work with
- Finding what you need
- Multiplicity of data formats
- Interpretation

Besides the additional data types, maybe we also need a new approach to the data analysis itself.



(UCAR Center for Science Education)

HOW ELSE CAN WE ANALYZE THE DATA?



- New approach in Data Science: Deep Learning
- This is a branch of Artificial Intelligence (AI) (What comes to mind?)

Uses a Convolutional Neural Network which learns patterns by being trained on thousands of examples

Can work for linear regression analysis, but also for non-linear relationships

Objective: to be able to:

Forecast a result based on a pattern of inputs

Know the *confidence* of the prediction

Gain insight into the science

WHAT DATA TO USE?

- 6M spots from DXCluster, PSK Reporter, WSPRNet and Reverse Beacon Network – filter:
  - At least one of the stations must be North America; exclude TEP
  - What constitutes 6M E_s propagation? Using spot distance 1500km to 6200 km
    - (mostly excludes moonbounce but certainly leaves out some E_s)
  - NASA data (mostly solar) *
  - OMNI data *
  - SORCE irradiance *
  - GOES Extreme UV *

  * Coefficients from these factors may be near zero
- Meterorite impact data (RMOB)
- NOAA data (geomagnetics, WX events, WX maps)
  - Storms, upper level lows (ULL), vortices (Jet Stream)
- TIDI/TIMED satellite data: ionospheric wind shear

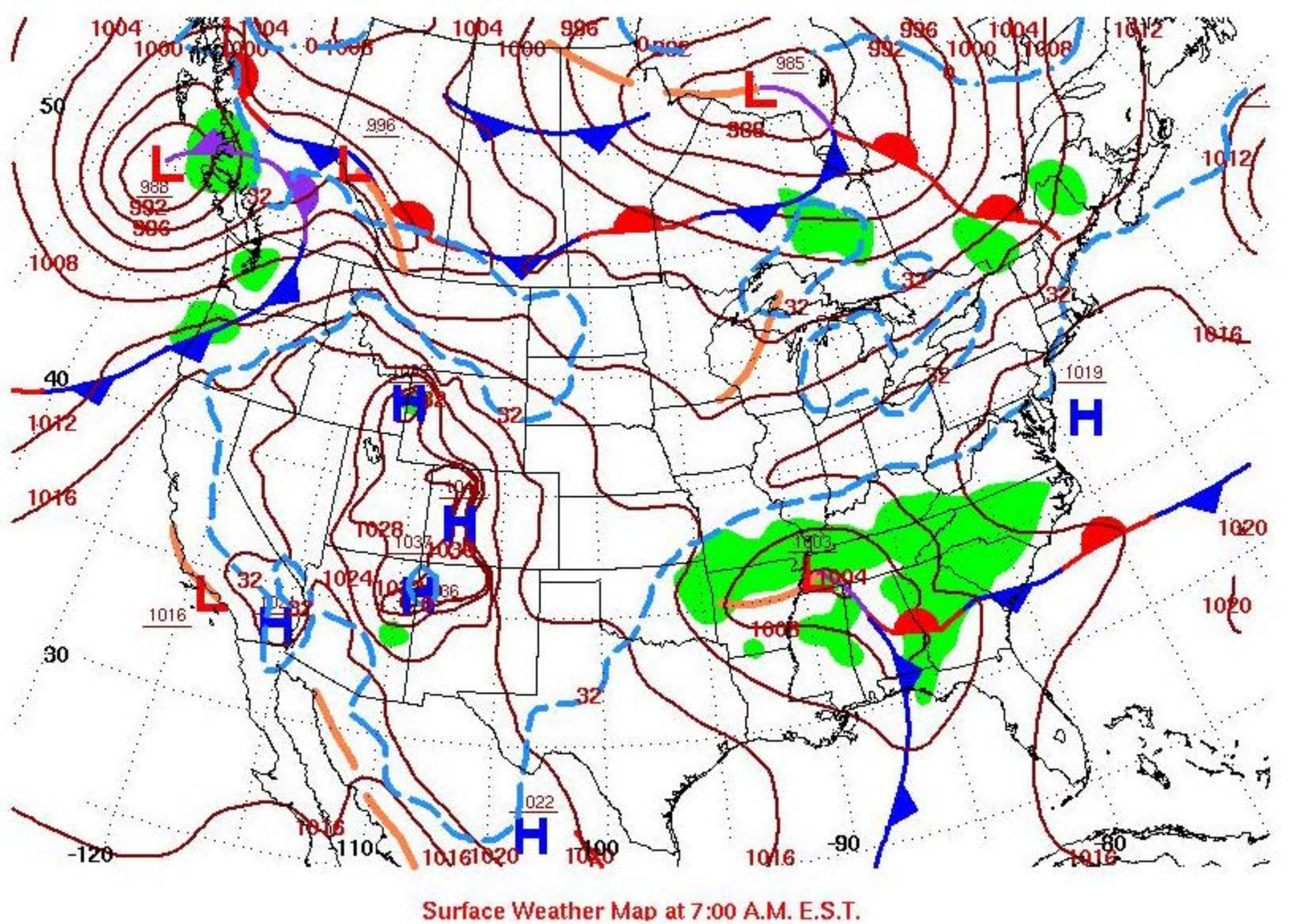
HOW DO WE BUILD AND USE A NEURAL NETWORK?

1. Collect and prepare data
    - Get data from various sources (requires care in selection)
    - Data in many different formats (CDF, NetCDF [HDF5], csv, RMOB, NASA sat, etc etc)
    - Clean the data (normalize; check for extreme outliers)
        - Ensure data applies to common geographic area
    - Summarize by Epoch (2 measurements per day, in this case)
2. What next?
    - Training (once for ULL detection, then a second step for the data analyzer)

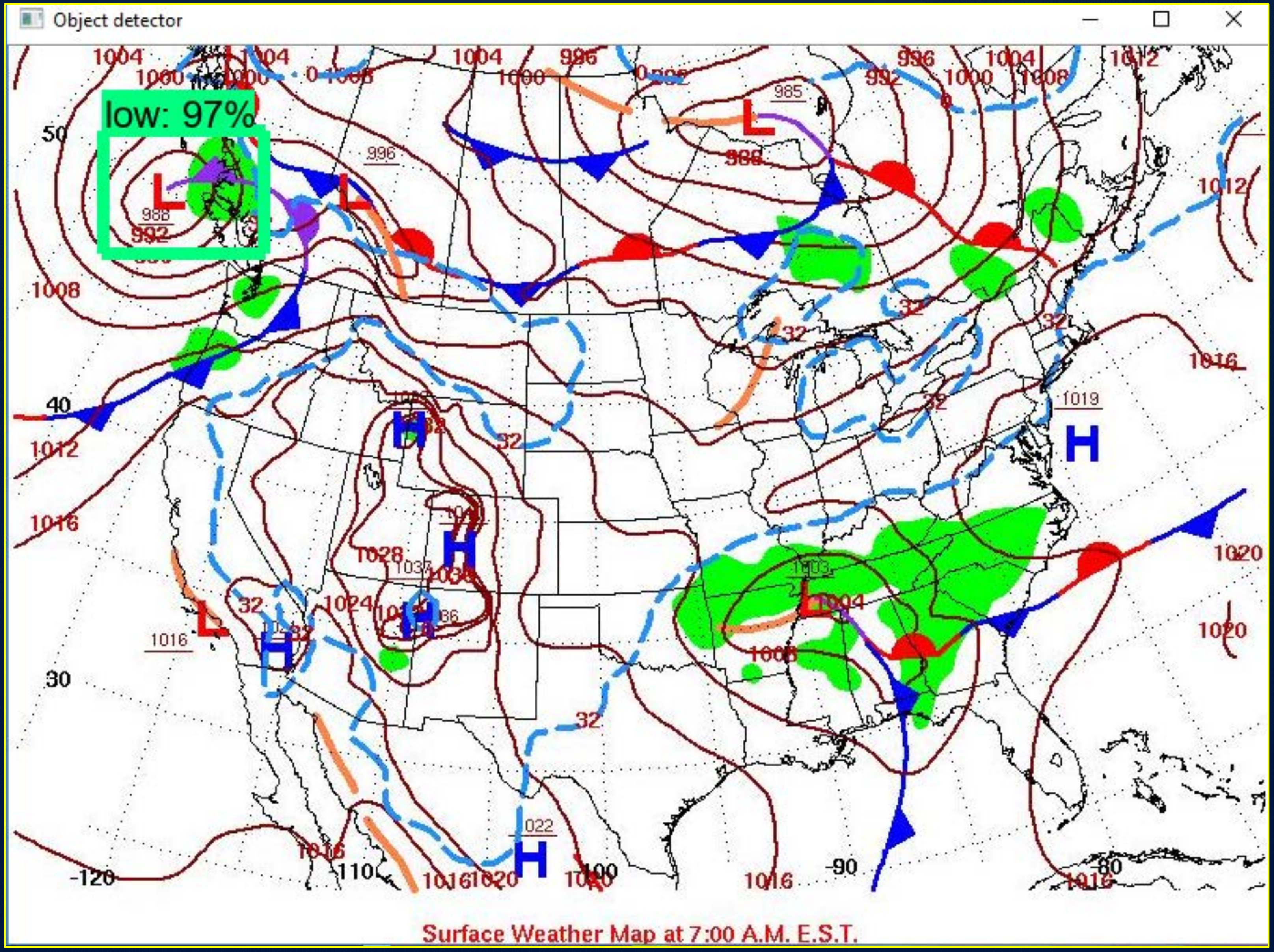
TRAINING – STEP 1

- Using TensorFlow GPU
  - freeware developed by Google; uses Python; can run with or without a GPU
- IMAGE PROCESSING - Train object recognizer to spot ULLs in WX maps
- TRAINING: Give object detector training package ~ 500 examples of an upper level low image; train object detector
- Use trained model to detect & count ULLs in years worth of WX maps

EXAMPLE OF A WX MAP BEFORE DETECTION



RESULTS OF DETECTION



These small, concentrated ULLs are what we are looking for

System will also give a count of #ULLs detected

TRAINING – STEP 2

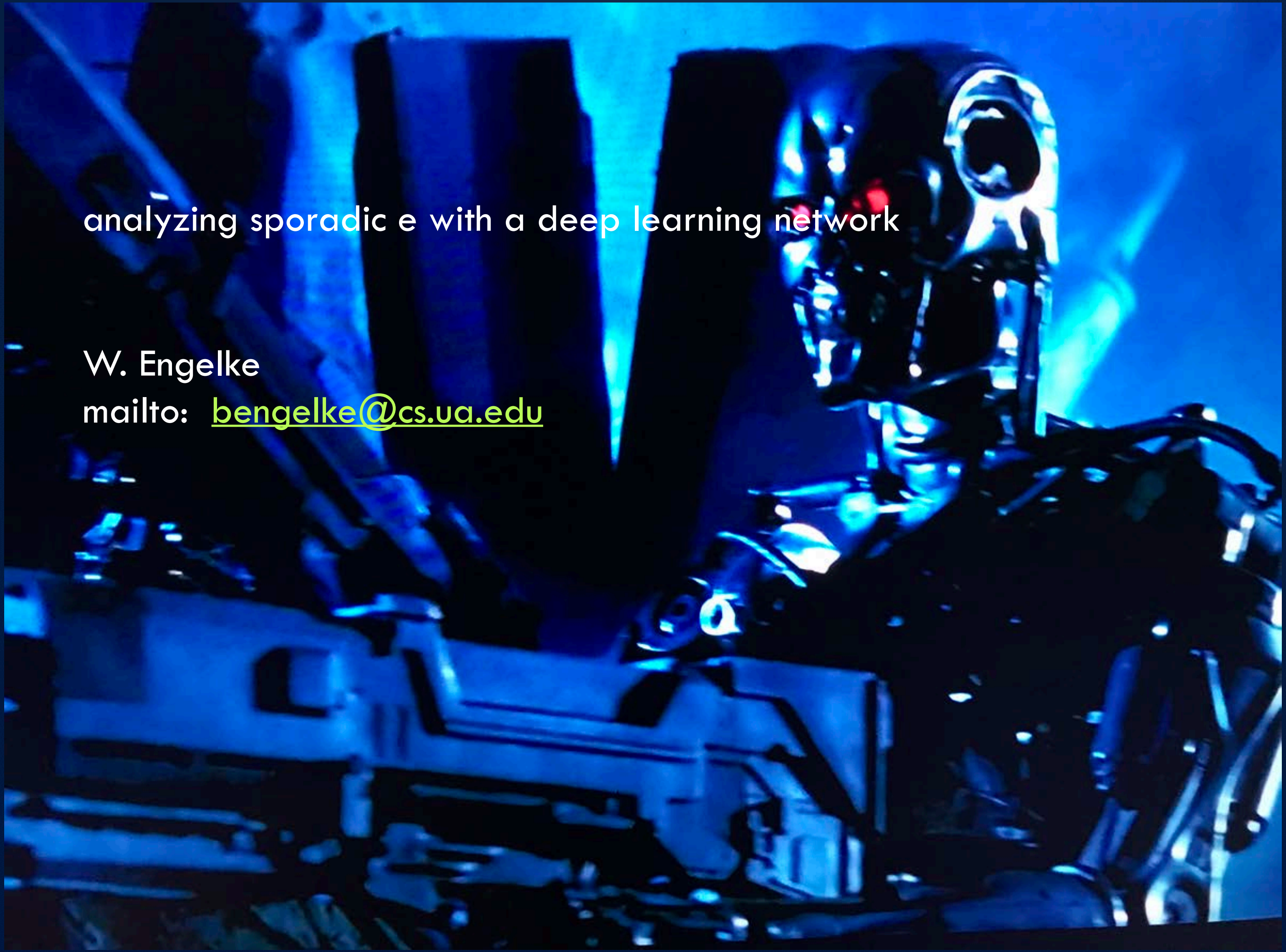
- Data now in columnar format, 2 lines per day
- Convolutional Neural Network training: split data into 3 parts, e.g.,
  - Training data – 70%
  - Test Data – 20%
  - Verification data – 10% (used in final testing phase)
- Optimizing training can be quite time-consuming
  - The detailed approach of the training has many options
- Training may take from hours to weeks using a PC with GPU

USING THE TRAINED MODEL

- Provide a set of measurements (same type as in the training data)
- Model will provide an estimate of 6M E_s spots
- Can do a sensitivity analysis
  - Vary different parameters to see which ones affect the output
  - Helps with understanding

OBJECTIVES

- To better understand the relationship between parameters (solar, terrestrial, etc.) and 6M E_s propagation
- Possibly to be able to forecast when a day is likely to have a high chance of E_s propagation – at least an hour or two before it happens
- To have results within 6 months or so



analyzing sporadic e with a deep learning network

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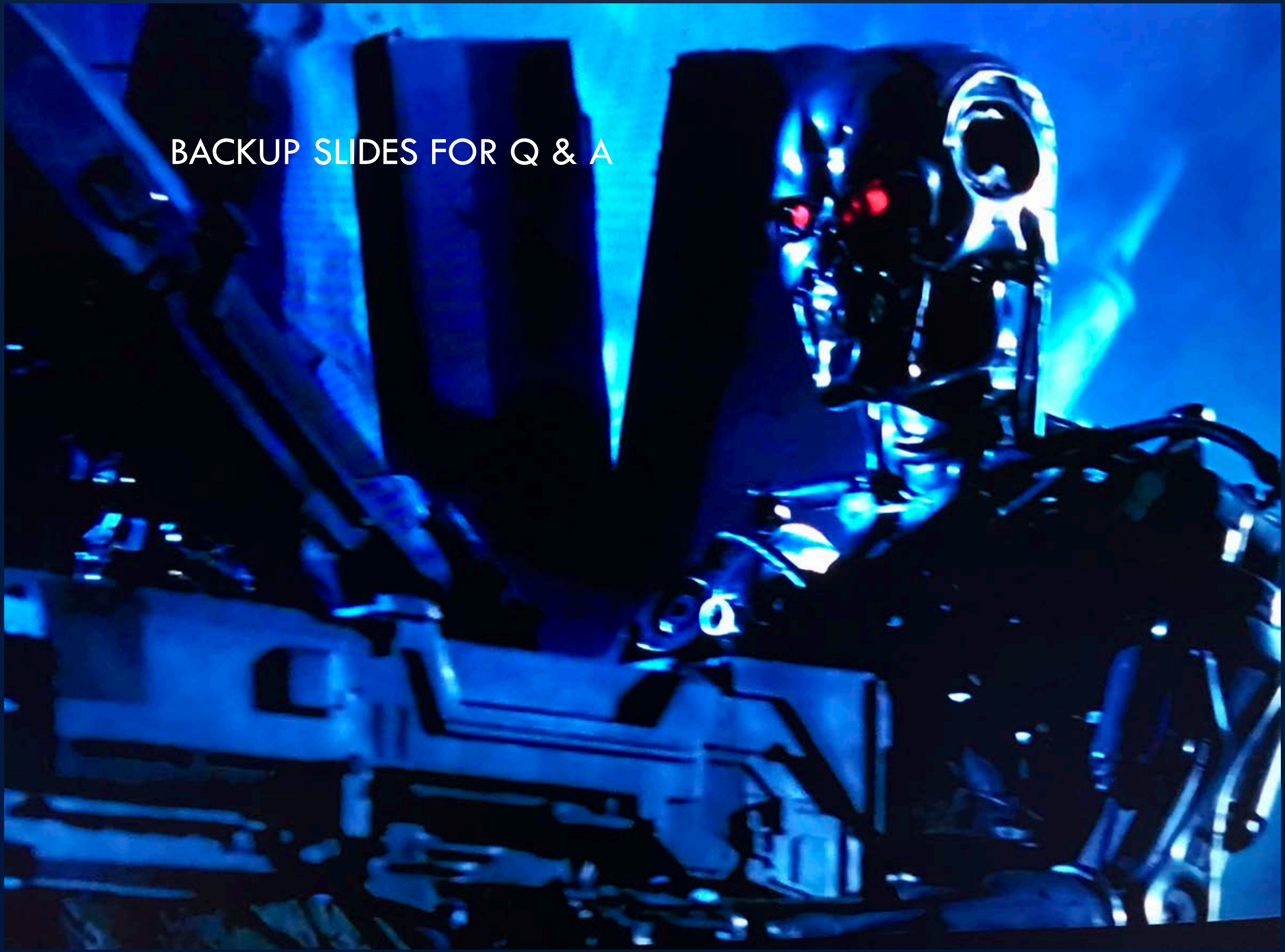
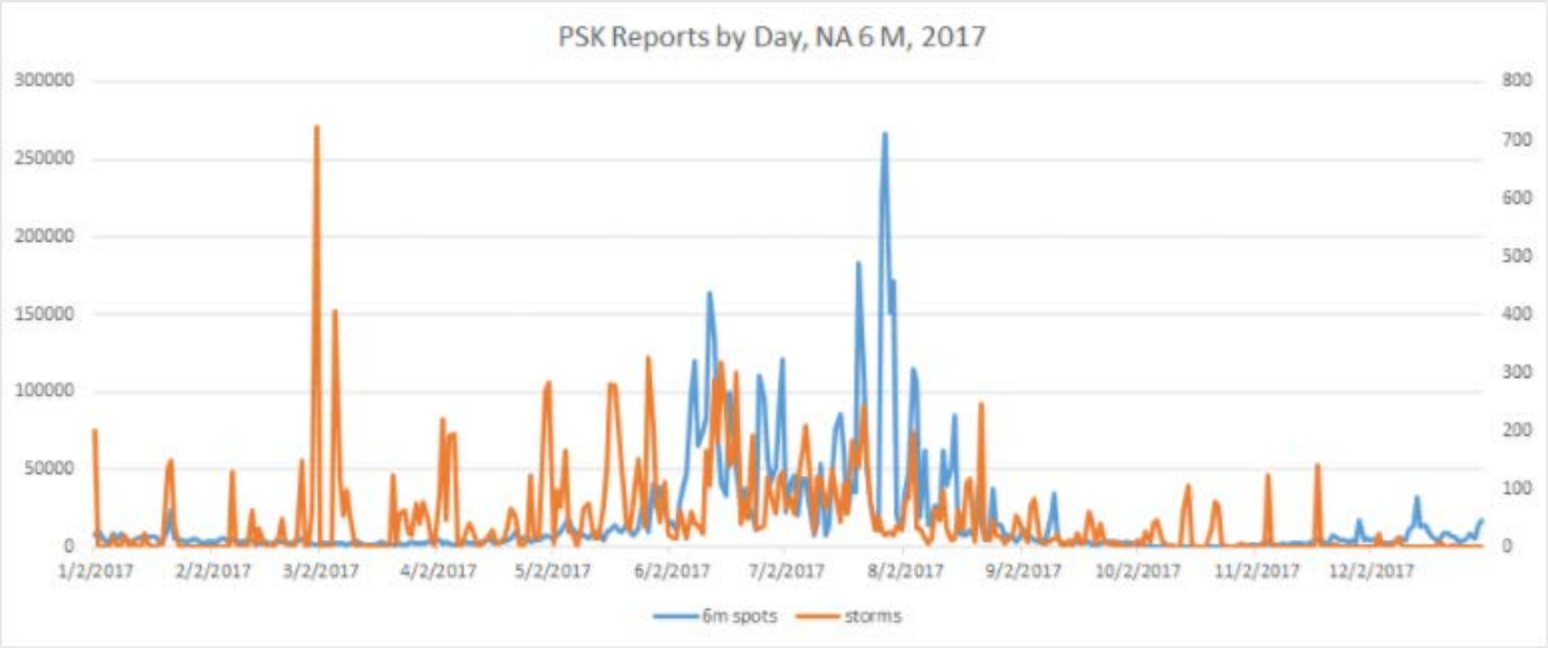
BACKUP SLIDES FOR Q & A



TRYING TO TEST THIS THEORY WITH DATA

Storm data is available from NOAA

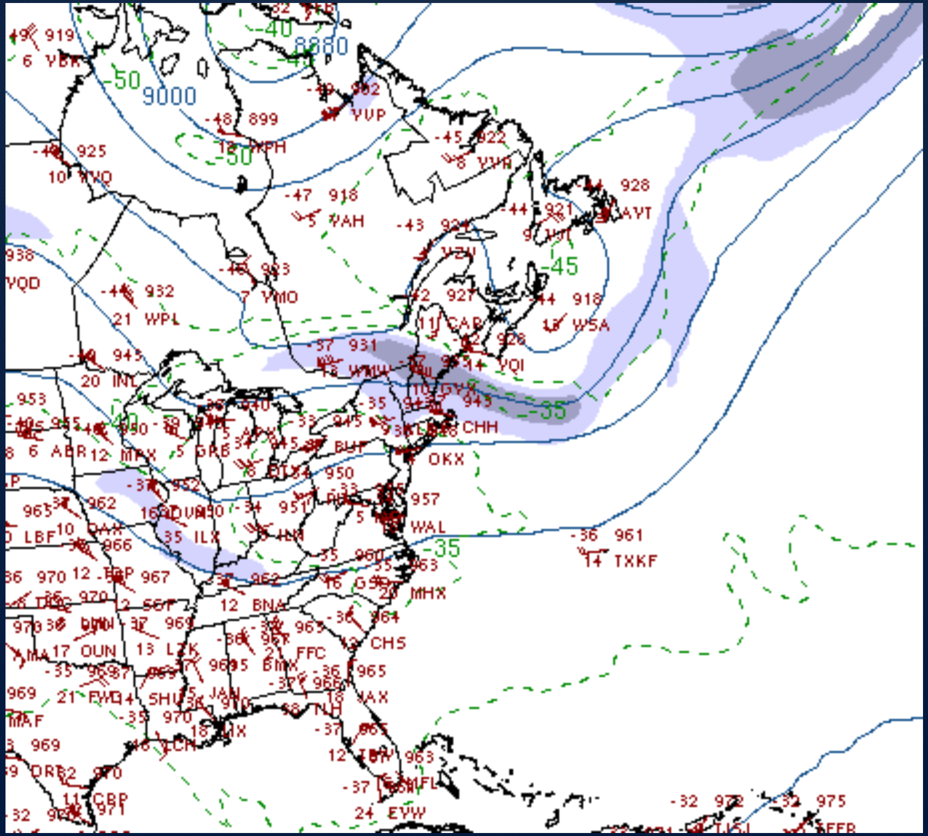


For above data, R= 0.23 - not much correlation between total storms and 6m, at least on PSK.

Initial analysis does not show correlation between storms and 6M propagation

IS THE JET STREAM INVOLVED?

On very active day of June 13, 2016, the jet stream curves around a ULL off coast of New England



MORE SPECIFICALLY….

So, for each day in the study period (2013 through 2018), we will have the following in a (csv) list:

- # 6M spots that appear to be sporadic E
- Average EUV Irradiance (where available)
- Avg. X-ray flux
- # meteors detected
- Avg. ionospheric winds at altitudes 87.5 km through 105 km
- # ULLs
- # storms (tornadoes, hurricanes, thunderstorms)
- Avg. Kp + other solar and geomagnetic parameters
- Influence of some (or many) of these on spots will be near zero; neural net will detect this and learn to ignore them