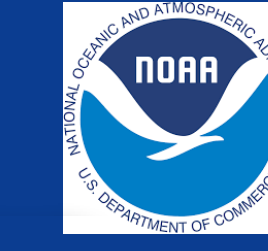
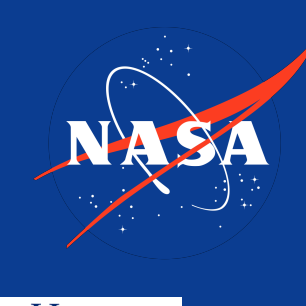


# Novel approaches to geospace particle transfer in the digital age: Progress through data science



## 2019 International Space Sciences Institute Team

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### This poster in 30 seconds...

1. Demonstrate a new 'state-of-the-art' particle precipitation model capable of mesoscale (substorm-scale) specification and prediction
2. Reveal progress enabled by 'data science' approach (i.e., considering the full data lifecycle)
3. Show that data science-driven mindset permits new models of collaboration

### Background and the need for data science

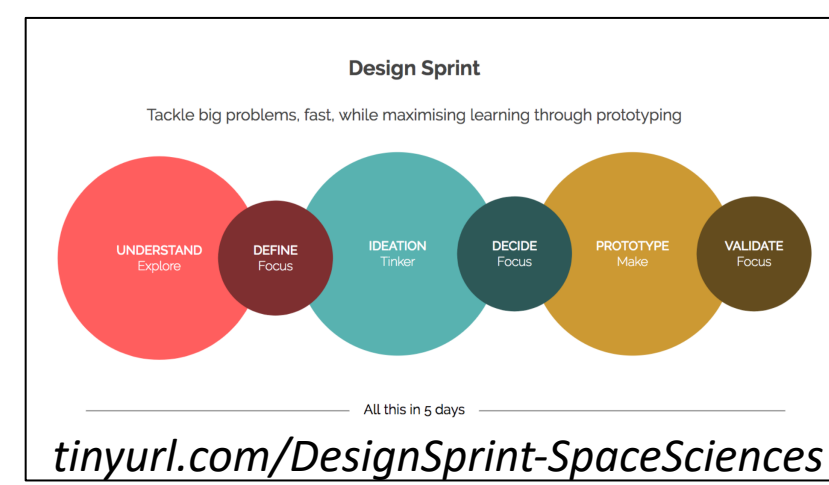
Energy and momentum transfer via particles between the magnetosphere and the ionosphere (particle precipitation down and ion outflow up) represents one of the great unresolved topics across Heliophysics and Space Weather, and an ideal use case to advance the systems science perspective.

We carried out a research team study at the International Space Sciences Institute (ISSI) to evaluate the existing data landscape for particle precipitation and ion outflow. Our focus was to bring to bear novel data science tools and technologies to produce profound new insight and capability for particle transport specification and prediction.

The result was not only cutting edge advances, but also the emergence of new ethos of novel collaboration for *radically* interdisciplinary teams, the utility of a data science-driven approach in the Earth and Space Sciences, and a flourishing Community of Practice (CoP). This poster reveals the particle precipitation component of the ISSI results.

### Unique approach to collaboration

Due to recent trends in the availability of data, we now face an exciting opportunity to progress space science understanding through the intersection of traditional approaches and state-of-the-art data science-driven sciences [McGranaghan et al., 2017]



We utilized data science (i.e., the full data lifecycle approach) and novel collaboration techniques from e.g., Silicon Valley to bring data scientists and scientists closer together

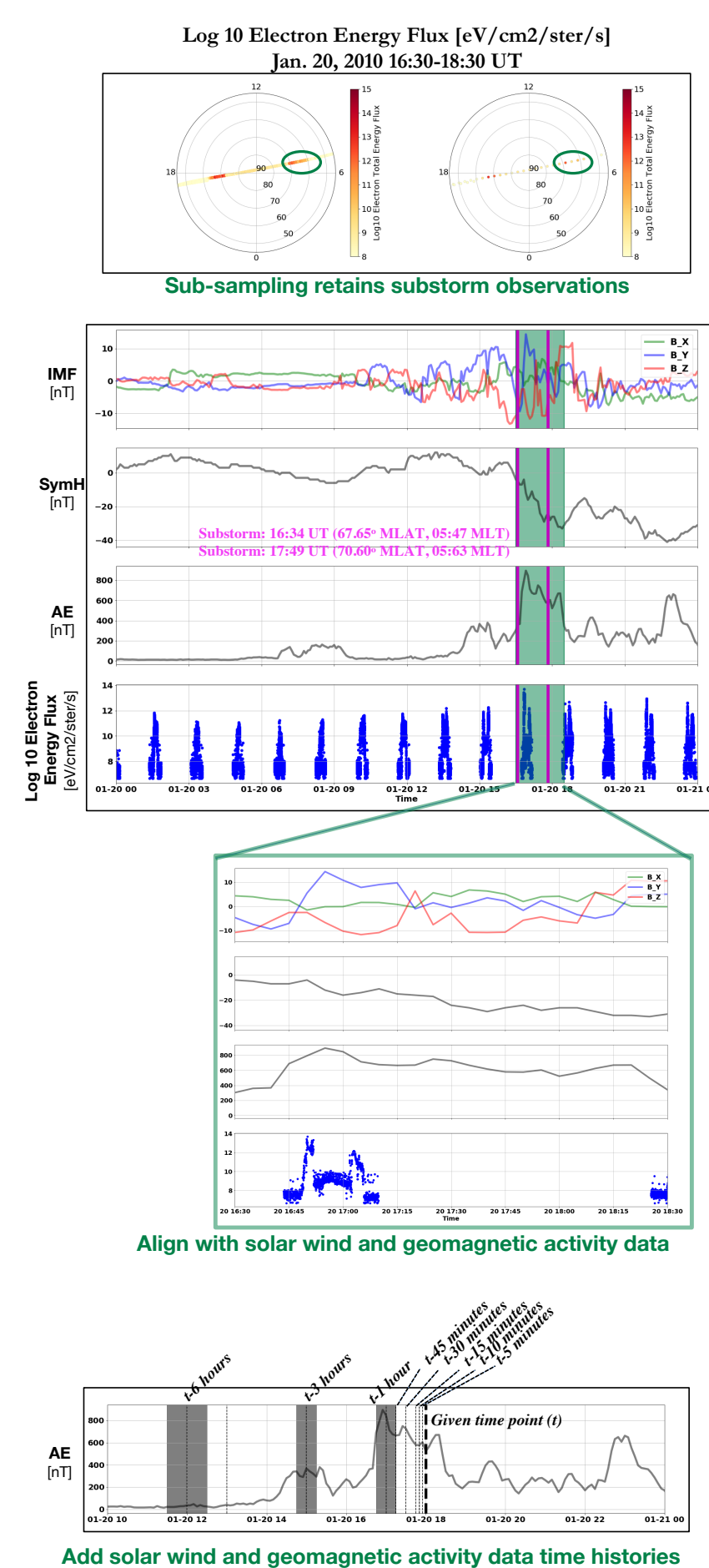
### The particle precipitation challenge

Different sets of input parameters used in the particle precipitation models rely of a difference in philosophy of approach and lead to a difference in capabilities

Existing models are limited in their ability to reproduce observed features that are associated with large spatial gradients and that occur rapidly

We present a new machine learning model (hereafter M2019) that utilizes the expressive power of deep neural networks to incorporate both solar wind and magnetosphere-ionosphere (MI) state descriptors and to be capable of specifying substorm-scale (space and time) phenomena

### Analysis Ready Data



Defense Meteorological Satellite Program (DMSP) in-situ particle precipitation observations

Collate solar wind and geomagnetic activity data as input 'features'

Reveal that data contain observations of substorm phenomena

Include time history of input features  
Compile into 'Analysis Ready Data' [McGranaghan et al., 2018]

## Progress on the grand challenges of space physics in the digital age Magnetosphere-Ionosphere particle transport at substorm-scale



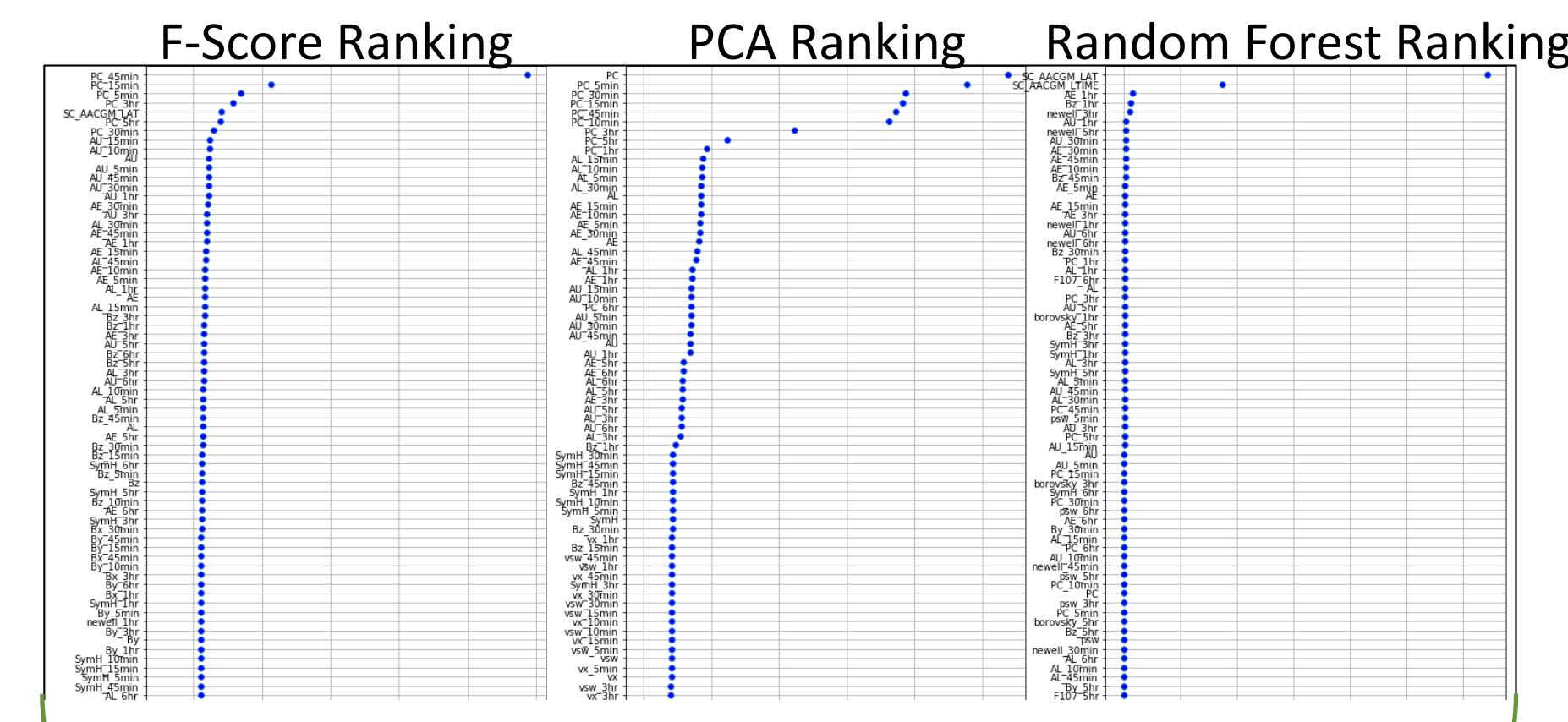
### A data-driven approach to the massive data and model design space

#### Explore critical questions with data science experiments

##### What input 'features' are most important?\*

\*The major improvements in precipitation models have always arisen from improved geophysical insights into the choice of organizing parameters' [Newell et al., 2015]

\*Explore the full results online



##### Aggregate Ranking

##### Key Discoveries

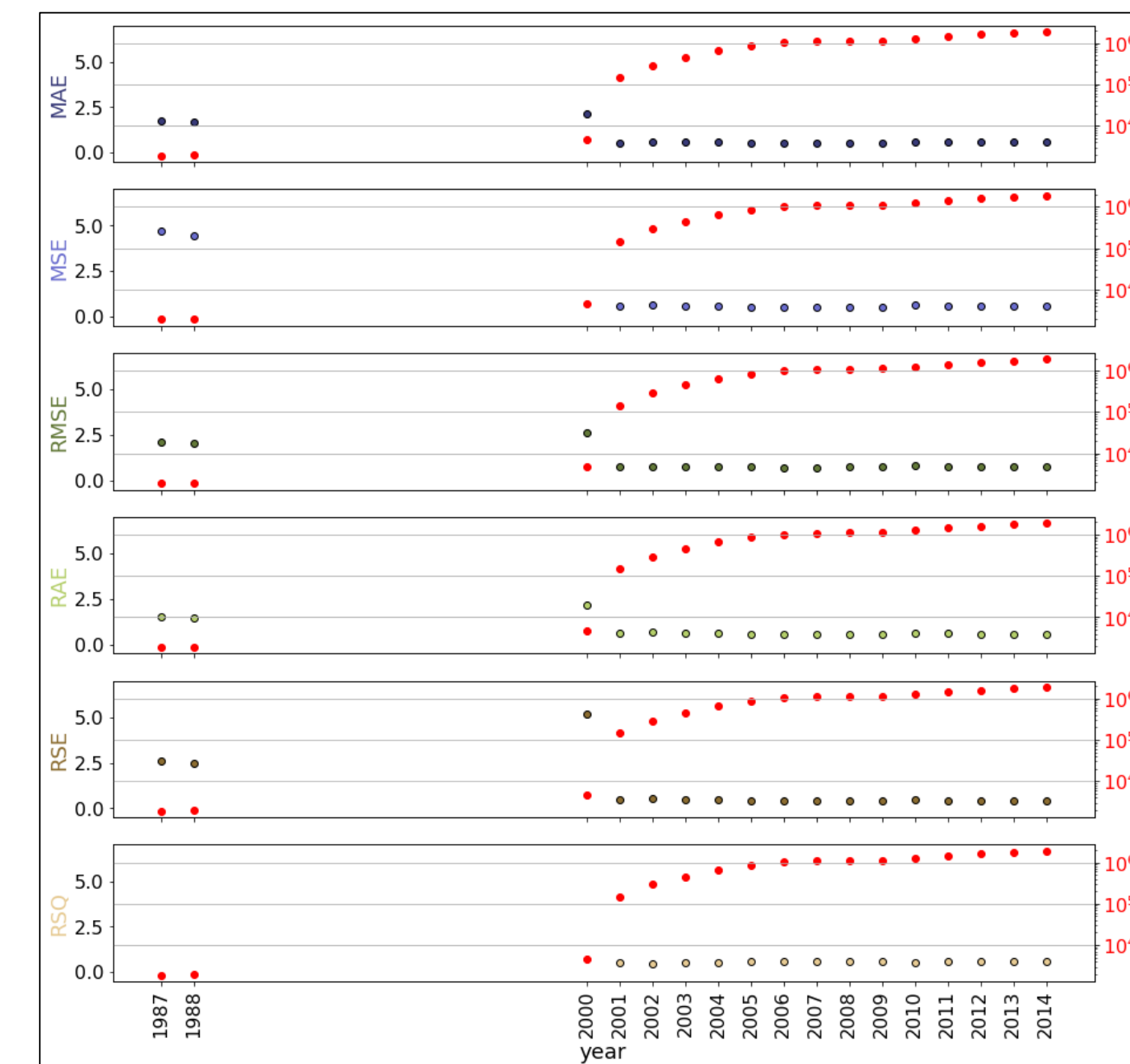
- AU/AL/AE, PC, and Sym-H indices (and their time histories) are important
- $P_{SW}$  and  $B_z$  solar wind variables and time histories are important
- $B_z/B_z$  relatively uninformative (likely due to assumption of hemispheric symmetry)
- Newell and Borovsky coupling functions are unimportant when individual solar wind variables and other geomagnetic activity indices are included (information is contained within other features)

##### What is the impact of data volume?

Add each year's observations cumulatively and assess ML model performance on novel data across standard assessment metrics

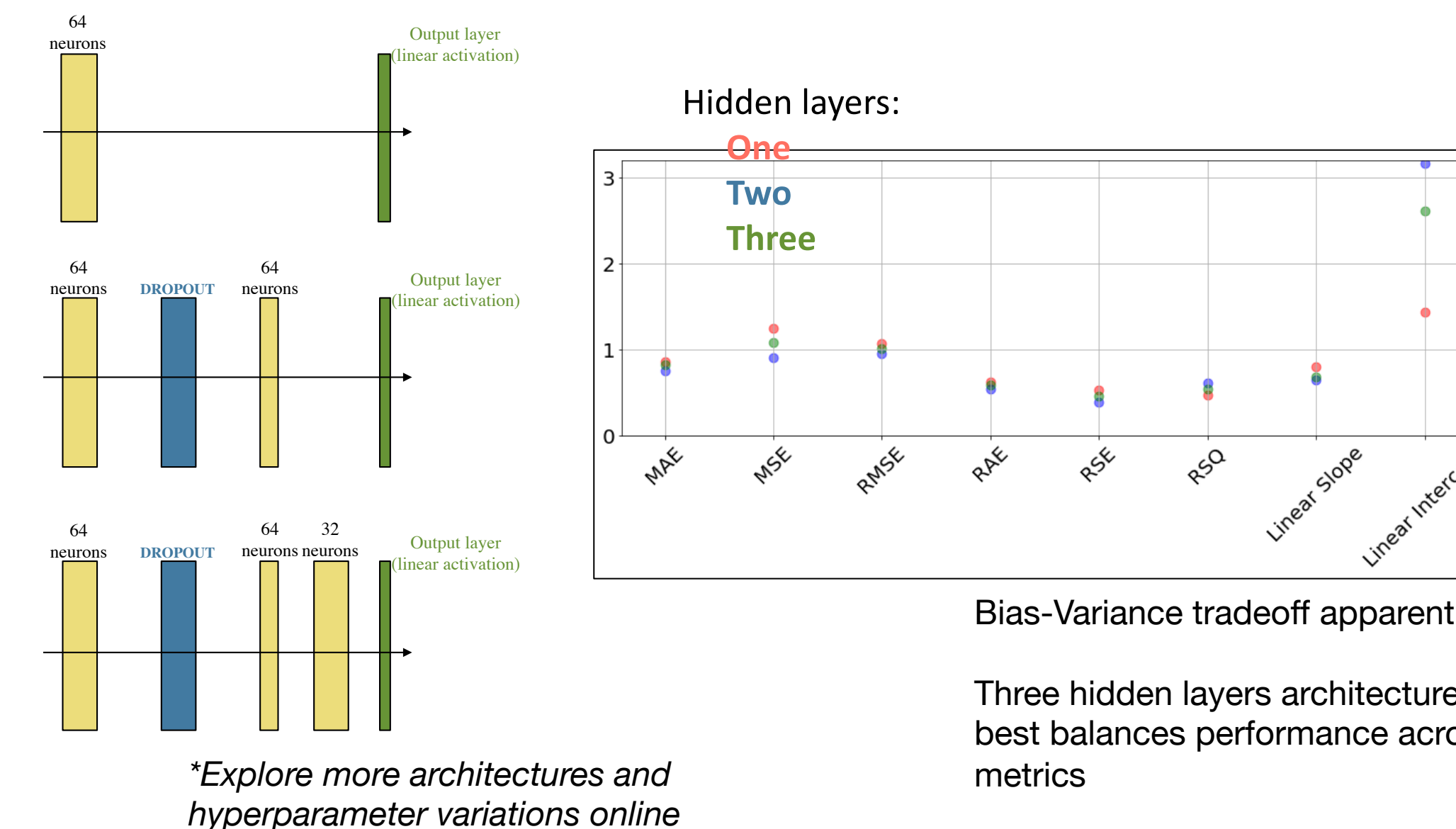
Higher data volumes reduce error over all metrics

Finer granularity needed at large volumes to determine benefit of additional DMSP data



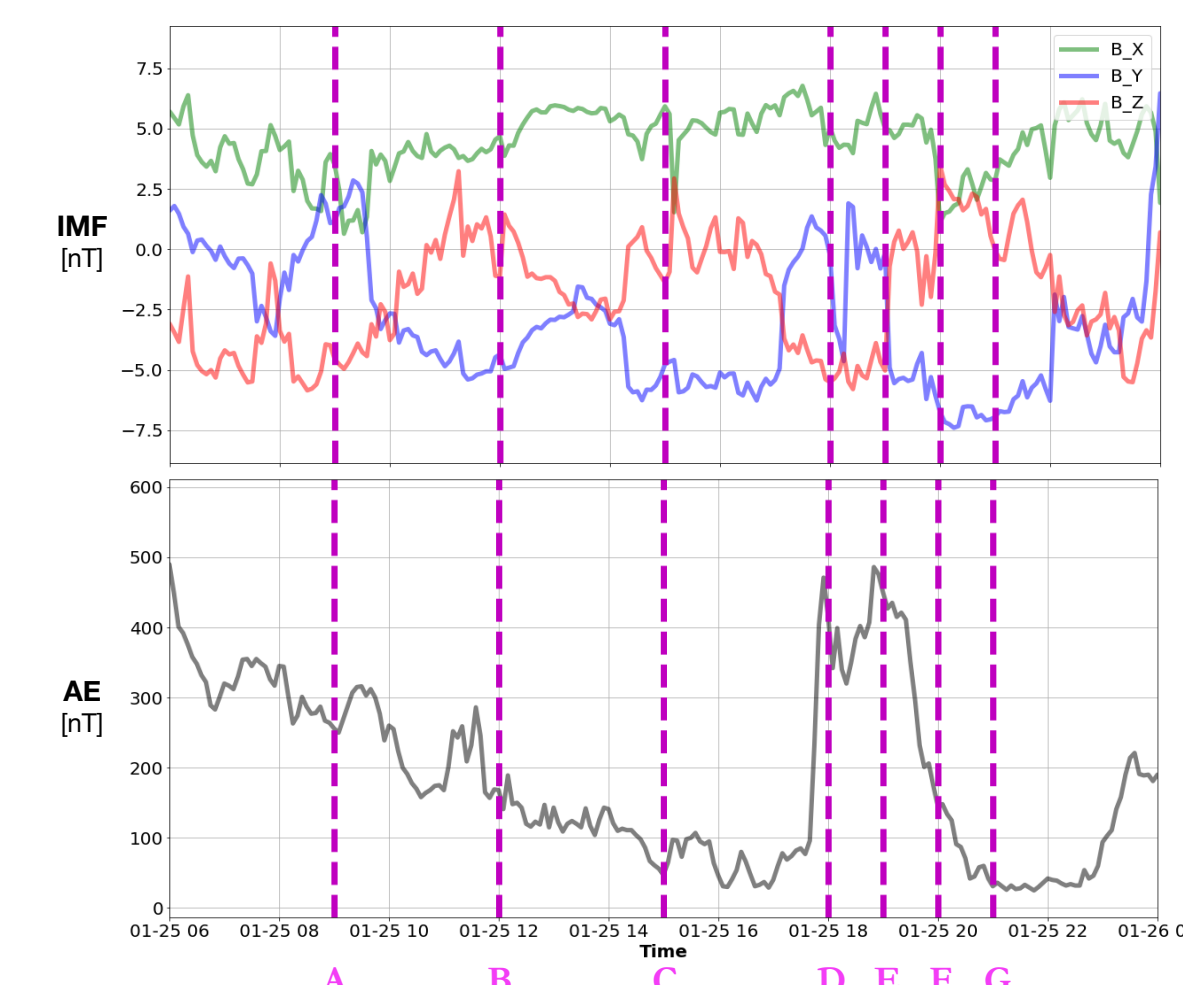
##### What is the impact of model hyperparameters?

Increasing the expressive power of a model is to expand the breadth of ideas that can be represented and communicated



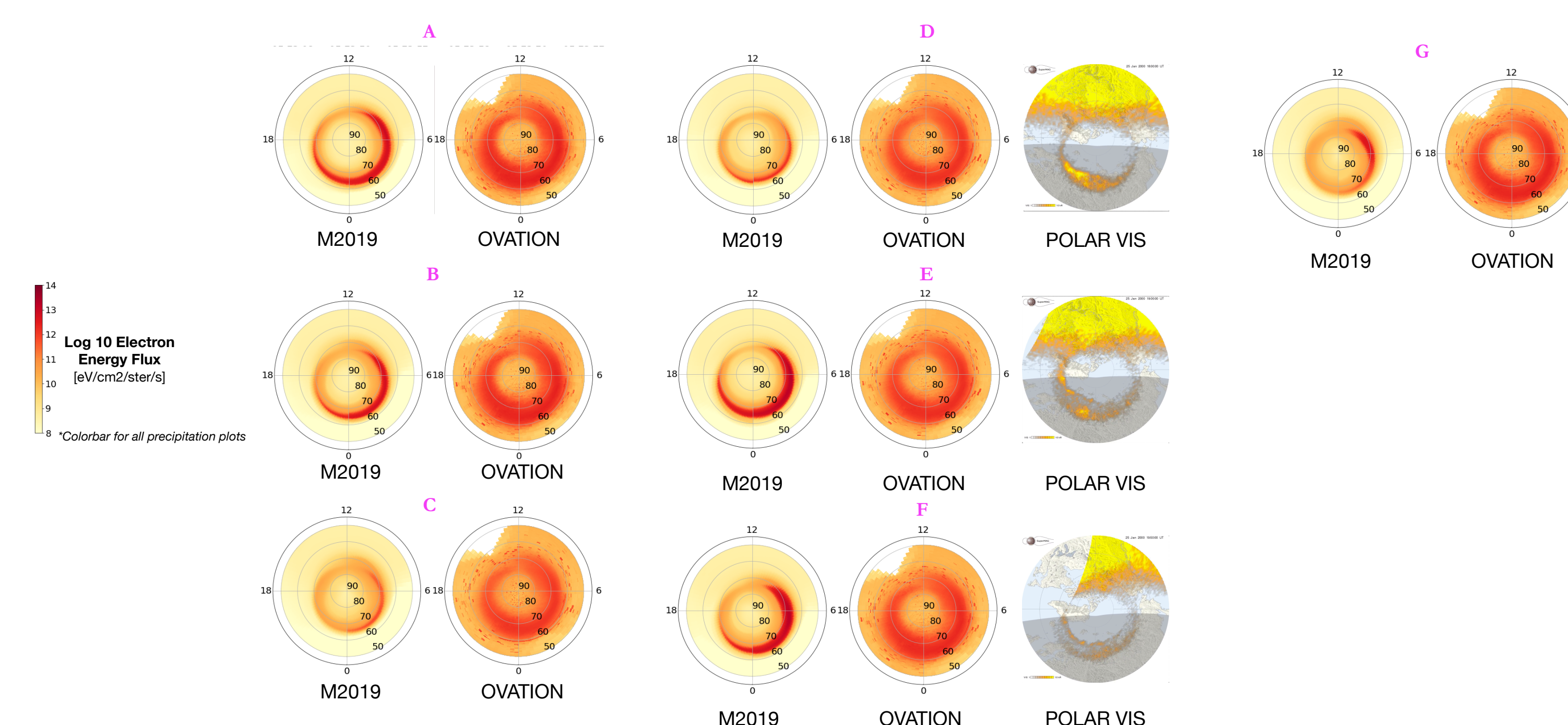
### Interrogating the model

#### Integrate physical understanding with the data science-driven approach\*



\*Explore our robust interrogation across multiple 'levels' online, including:

- Through standard assessment metrics on novel data [Liemohn et al., 2018]
- Capability to specify auroral boundaries and hemispheric power
- Capability to reproduce known physical phenomena
- With 'next-generation' metrics (e.g., image-to-image comparison metrics)



### What's next?

#### Scale and extend

##### Grow the database:

Fast Auroral SnapshoT (FAST) observations

##### Incorporate ground-based magnetometers:

'Greatest potential for predicting auroral power' [Newell et al., 2018]

##### Incorporate auroral imagery:

Space- and Ground-based

##### Compare with state-of-the-art magnetosphere model:

GAMERA precipitation

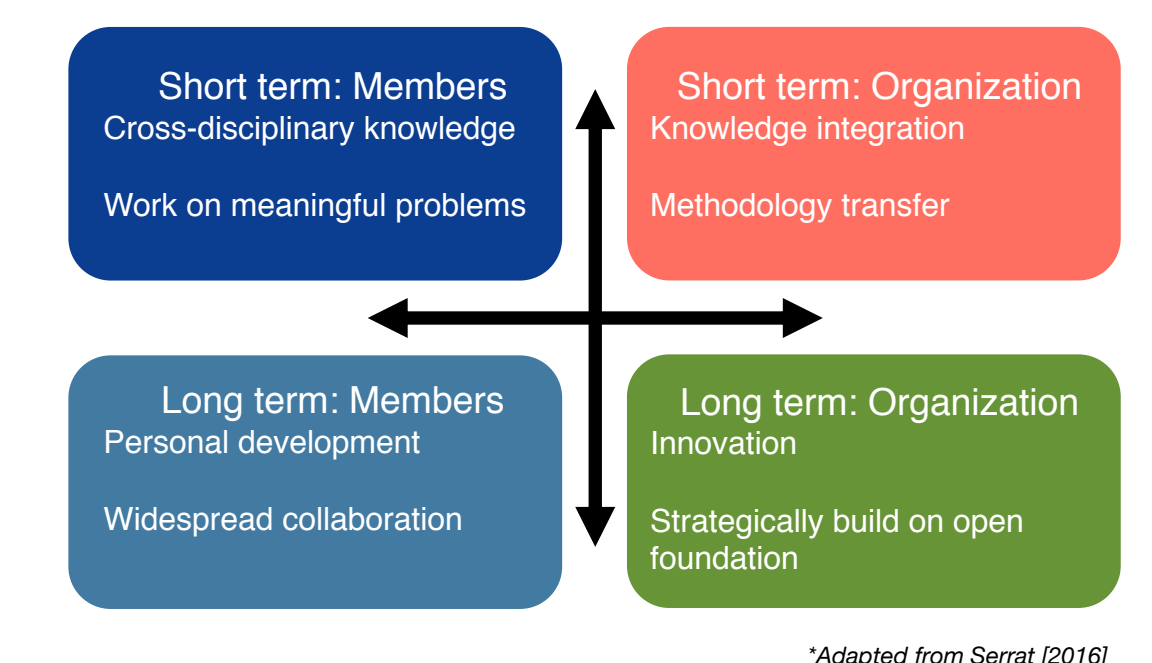
##### Explore with NASA Frontier Development Laboratory:

Potential new challenge concept in 2020 (proposed)

Additionally, our ISSI team's ethos of 'open by default' led to new data sets and software that will allow the community to amplify these efforts and join the community of practice...

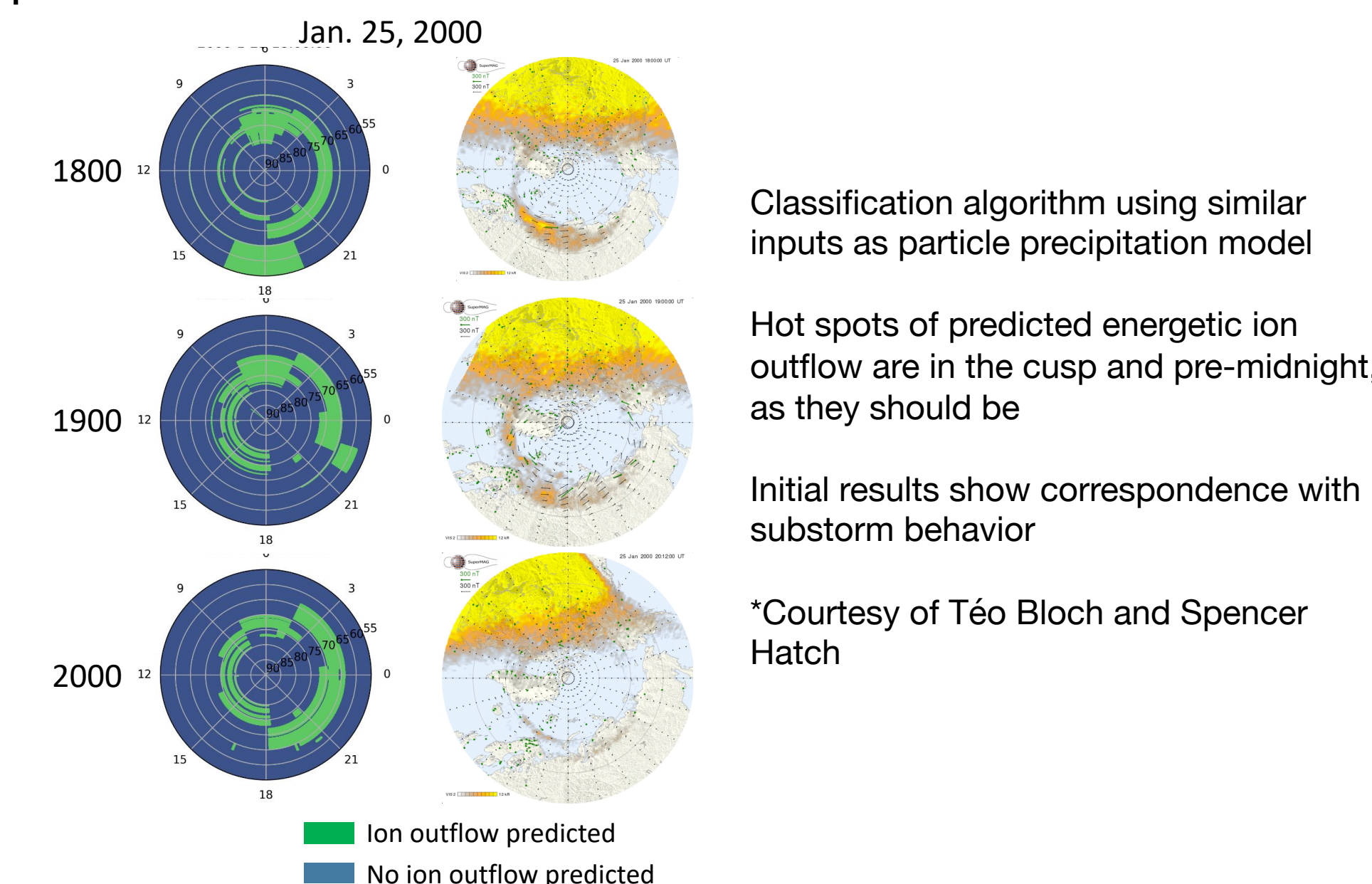
### A Flourishing Community of Practice

#### Community of Practice (CoP)



#### Can we transfer the methodology to other challenges?

##### Ionospheric ion outflow



Help shape a flourishing space physics community

#### Town Hall! Antidisciplinary: Science and engineering in the digital age

Join a *radically* interdisciplinary group to shape the *New Frontier* for the Earth and space sciences

Where:  
Thursday, 12 December 2019: 18:15 - 19:15  
Location: Moscone West, Room: 2003, L2

Abstract & Speakers: <https://tinyurl.com/McGranaghan-AGU-TH-Github>

### Acknowledgements

The International Space Sciences Institute and the *fantastic* Particle Transport Team (<http://www.issibern.ch/teams/multigeopartransfer/>)

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Full list of references and additional materials online (<https://github.com/rmcgranaghan/AGU2019>)