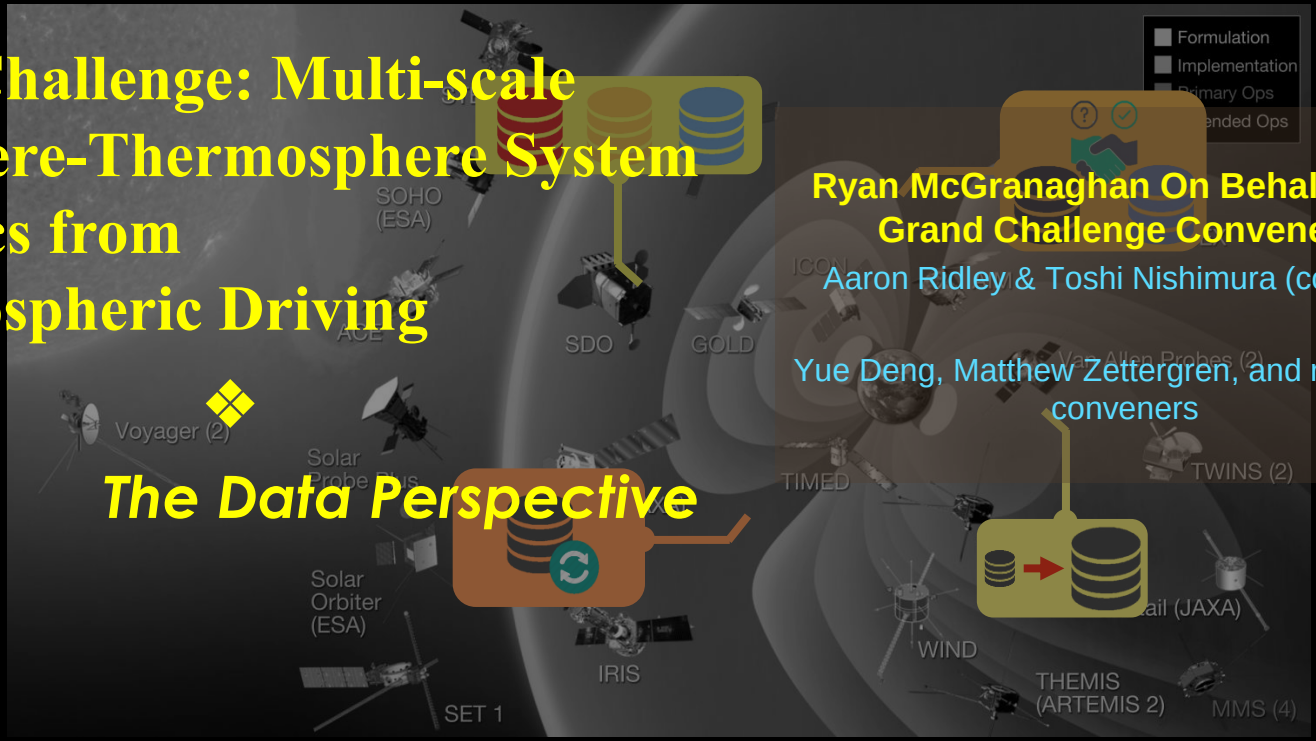
Grand Challenge: Multi-scale Ionosphere-Thermosphere System Dynamics from Magnetospheric Driving

❖

The Data Perspective



Ryan McGranaghan On Behalf of the Grand Challenge Conveners:

Aaron Ridley & Toshi Nishimura (co-leads)

Yue Deng, Matthew Zettergren, and rest of GC conveners

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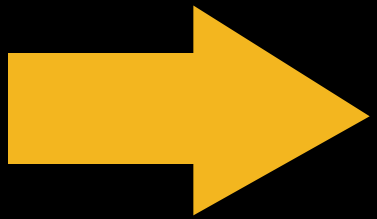
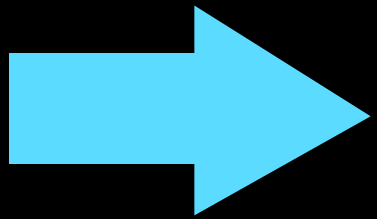
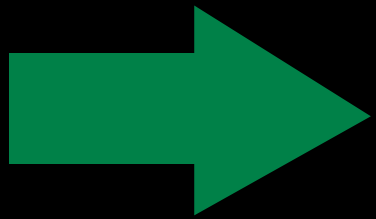
Blueprint for today



What is the current state of multi-scale geospace understanding?



Why is now the right time for a Grand Challenge with emphasis on data-driven approaches?



What approach will our Grand Challenge take from the data perspective?

What is the current state of multi-scale geospace understanding?

Large-scale model

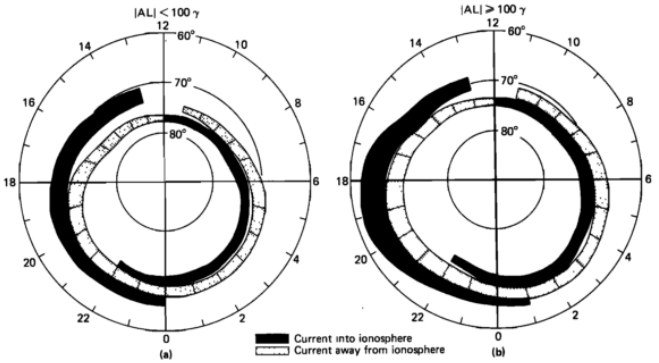
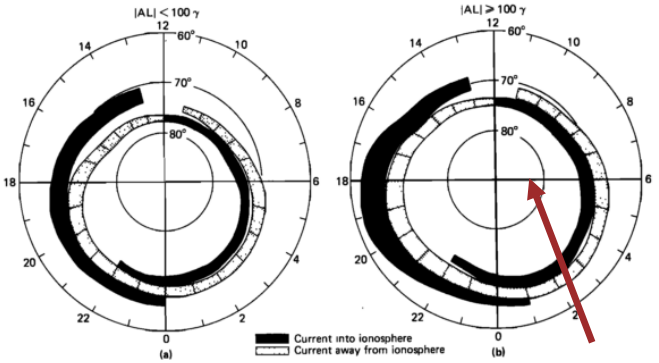


Fig. 13. A summary of the distribution and flow directions of large-scale field-aligned currents determined from (*a*) data obtained from 439 passes of Triad during weakly disturbed conditions ($|AL| < 100\ \gamma$) and (*b*) data obtained from 366 Triad passes during active periods ($|AL| \geq 100\ \gamma$).

Iijima and Potemra [1978]

- ✔ Characteristics
- ✔ Dependence on controlling parameters

Large-scale model



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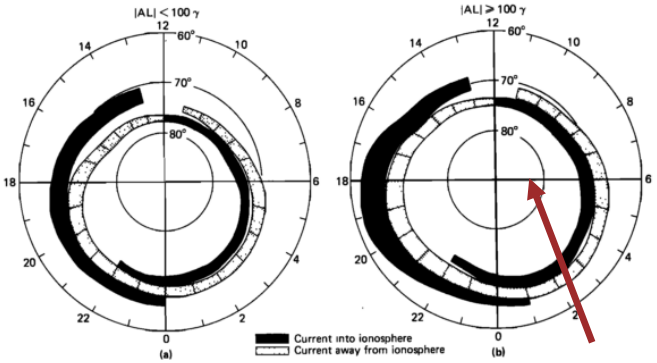

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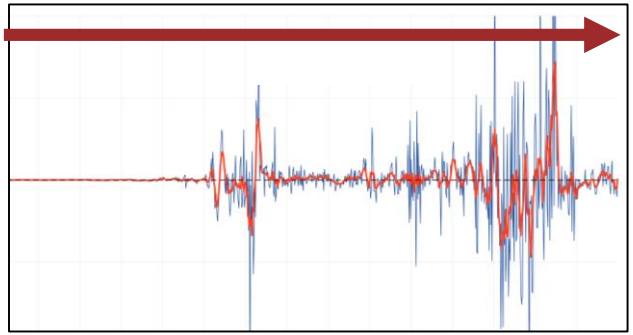
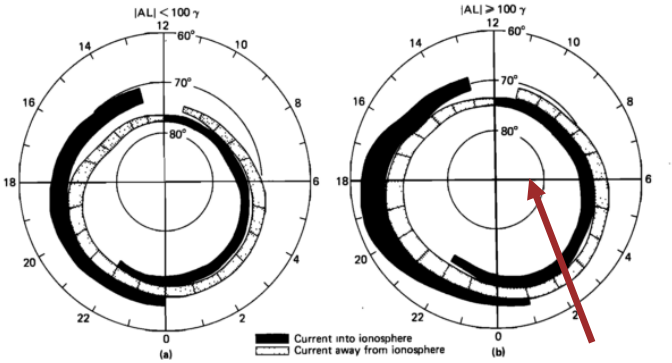


Small-scale reality

Large-scale model



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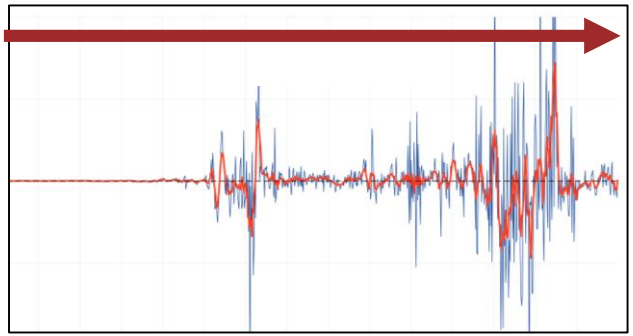
Iijima and Potemra [1978]

- X Characteristics
- X Dependence on controlling parameters
- X Relationship between scales



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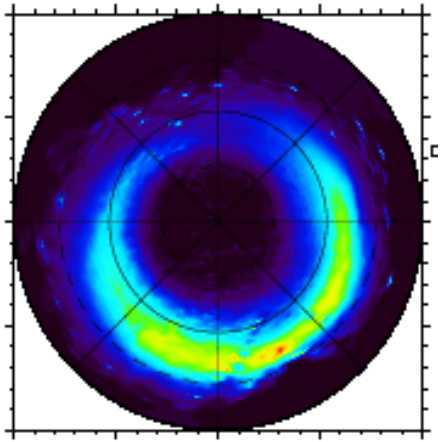

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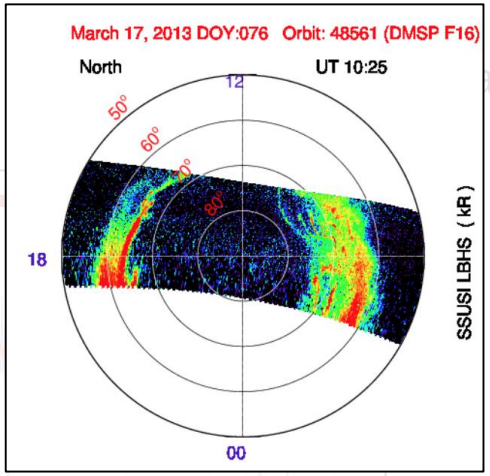
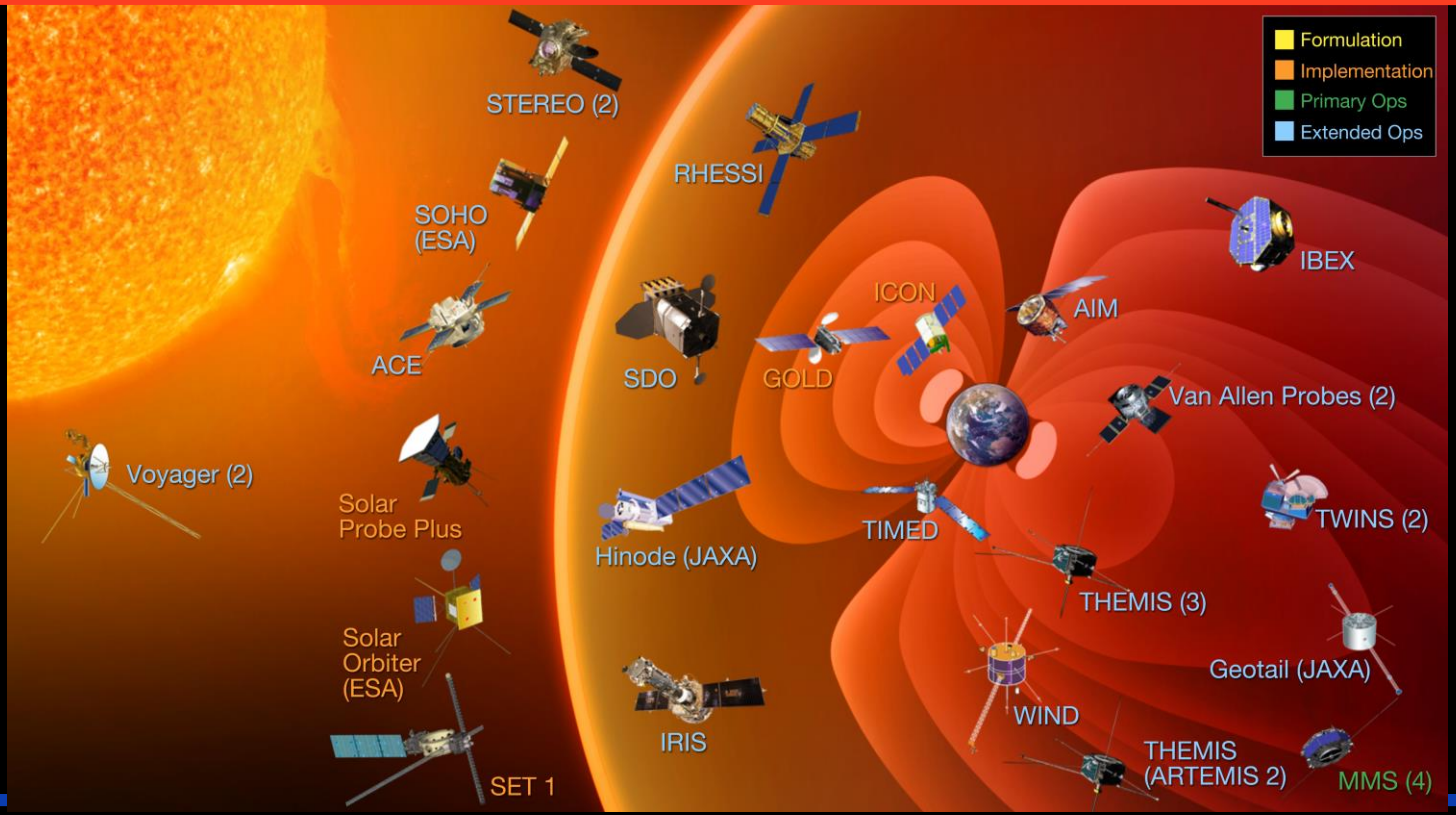


Figure courtesy of L. Paxton

Why is now the right time for a Grand Challenge with emphasis on data-driven approaches?


Formulation
Implementation
Primary Ops
Extended Ops
STEREO (2)
RHESSI
SOHO (ESA)
IBEX
ICON
AIM
ACE
SDO
GOLD
Van Allen Probes (2)
Voyager (2)
Solar Probe Plus
TWINS (2)
Hinode (JAXA)
TIMED
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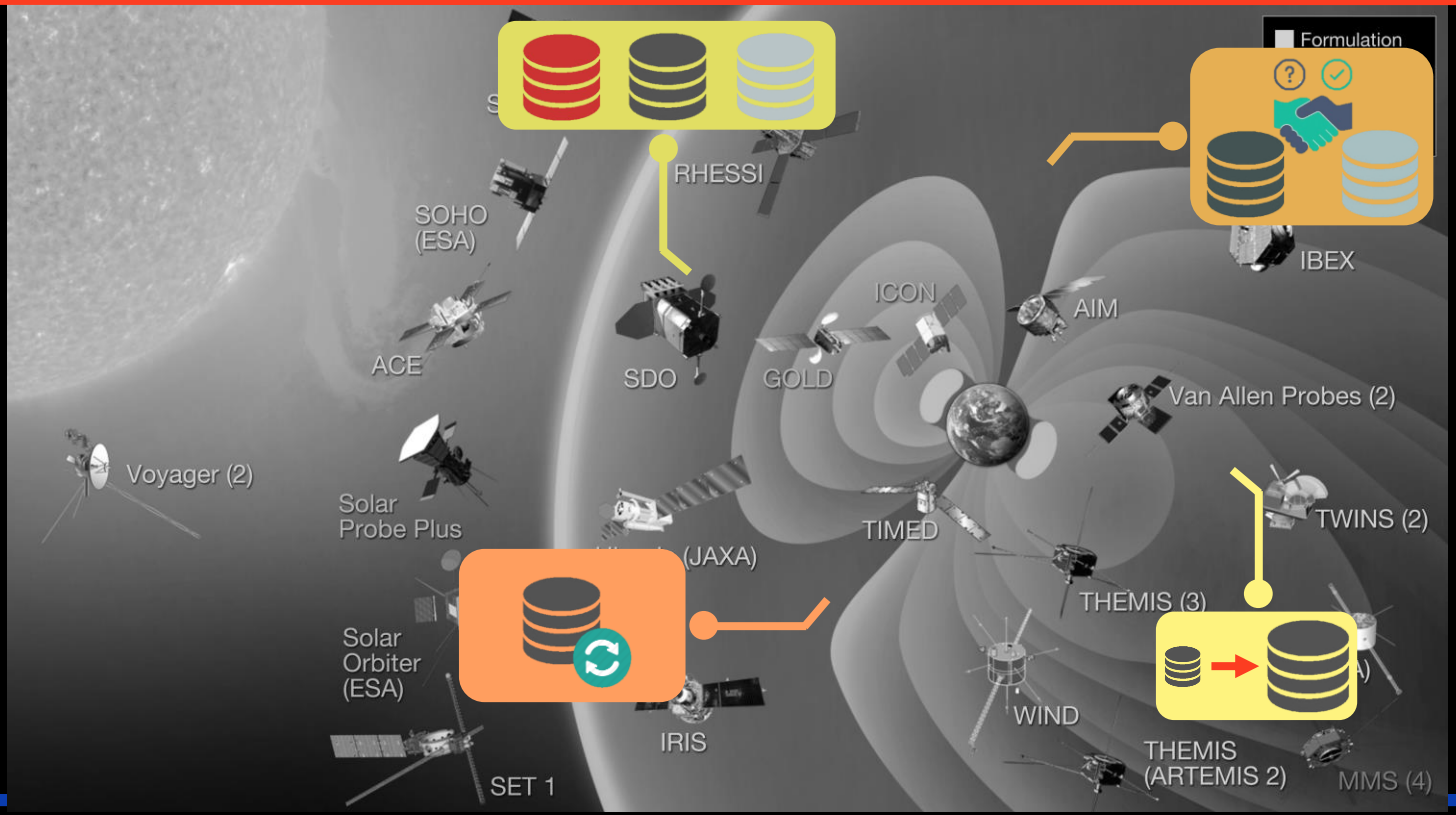
Geotail (JAXA)
WIND
IRIS
THEMIS (ARTEMIS 2)
MMS (4)
SET 1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SET 1

Multi-scale highlight #1: Flow channels

Zou et al., [2016]

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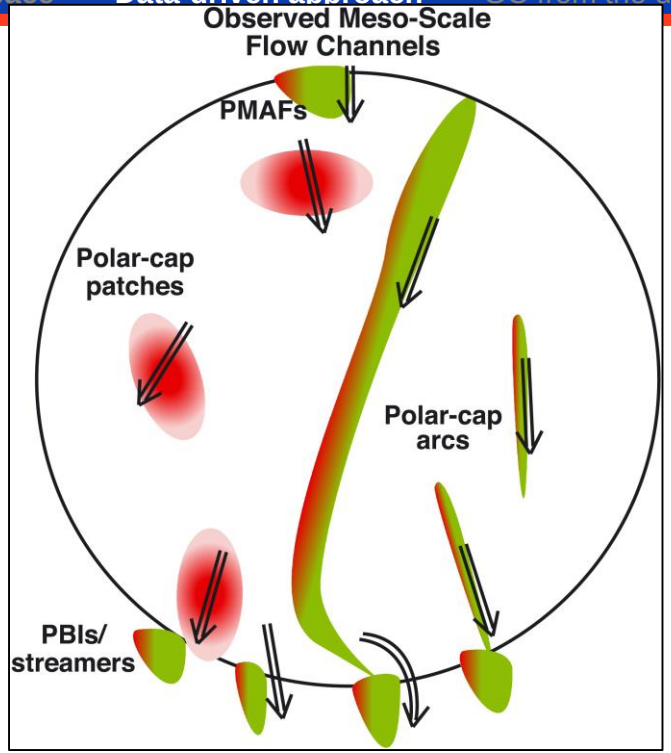
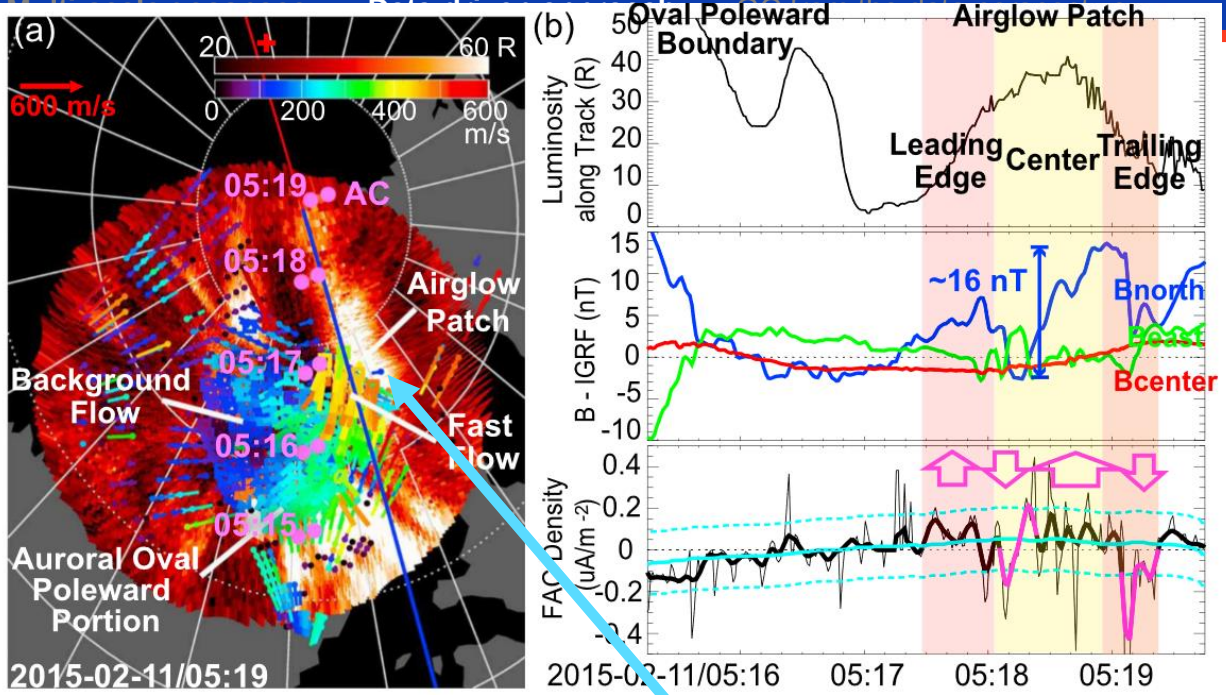


Lyons et al., [2016]

$$\text{Mesoscale} \equiv \sim 100 - 500 \text{ km}$$

Multi-scale highlight #1: Flow channels

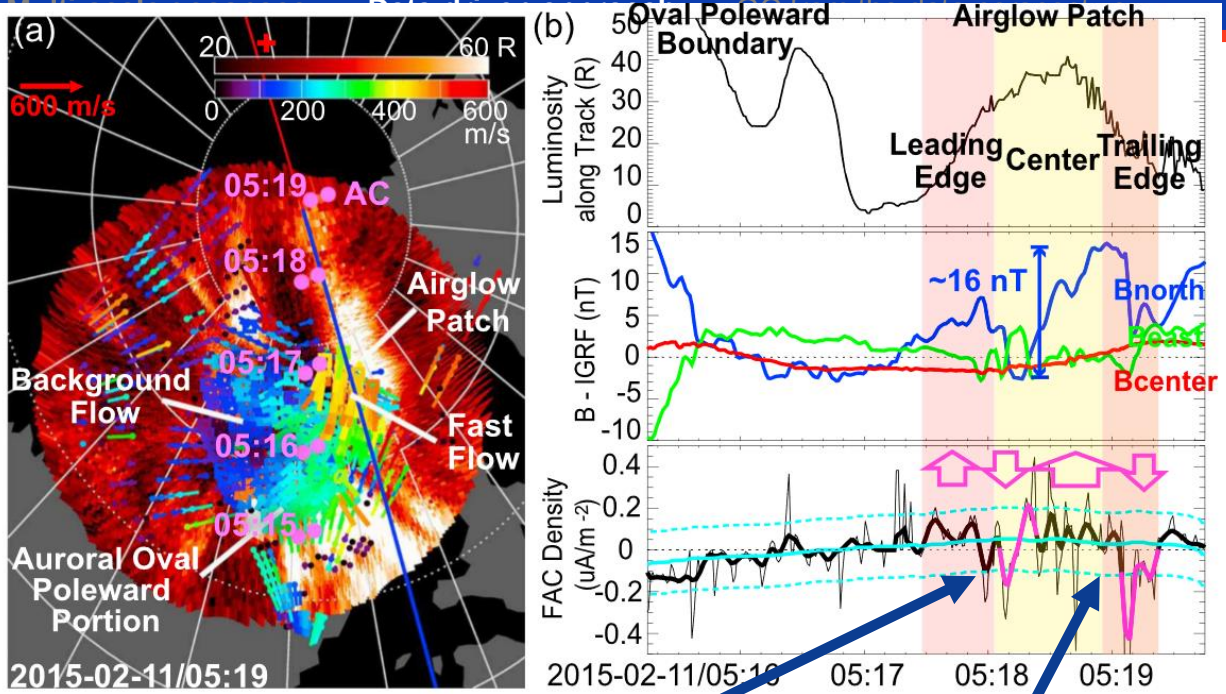
Zou et al., [2016]



Plasma patches transported across the polar cap by flow channels

Multi-scale highlight #1: Flow channels

Zou et al., [2016]



Flow channels are associated with localized field-aligned currents

Multi-scale highlight #2: Localized precipitation and FACs

McGranaghan et al., [2017]

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Small-scale reality − Large-scale model = Degree of departure

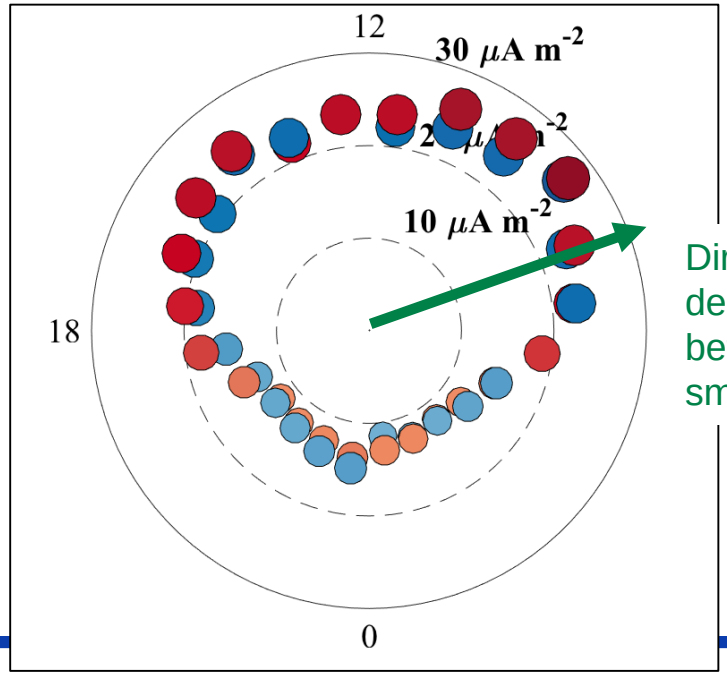
Multi-scale highlight #2: Localized precipitation and FACs

McGranaghan et al., [2017]

Small-scale reality − Large-scale model = Degree of departure

- Away from ionosphere (upward FAC)
- Toward ionosphere (downward FAC)

Size indicates magnitude



Direction of increasing departure (difference between large and small scales)

Multi-scale highlight #2: Localized precipitation and FACs

McGranaghan et al., [2017]

Small-scale reality − Large-scale model = Degree of departure

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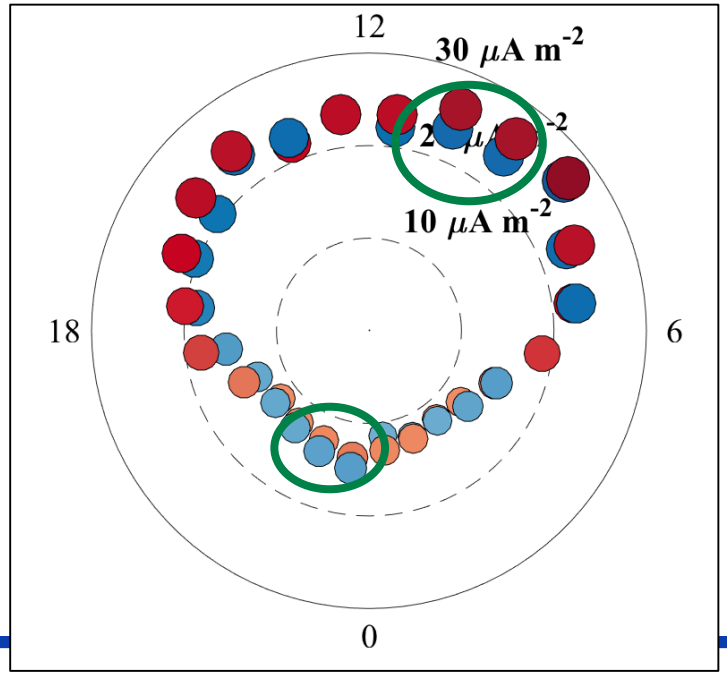

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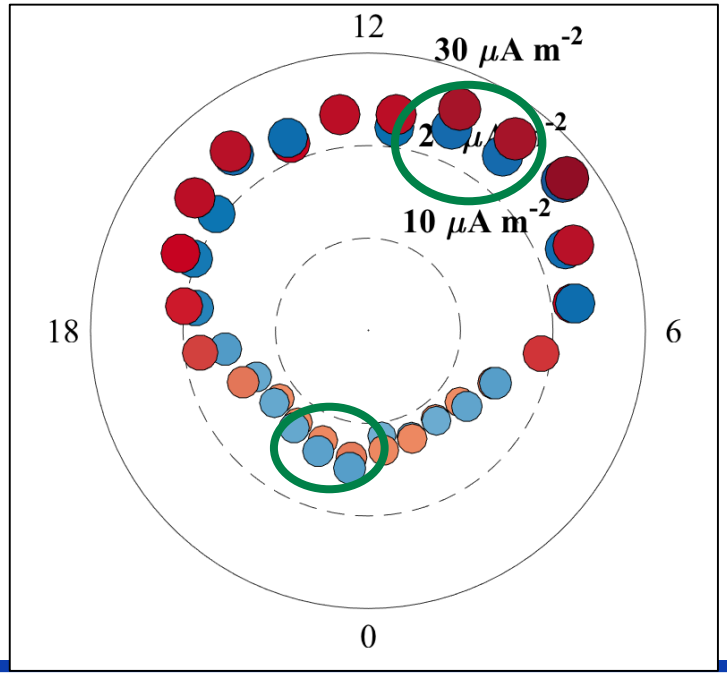

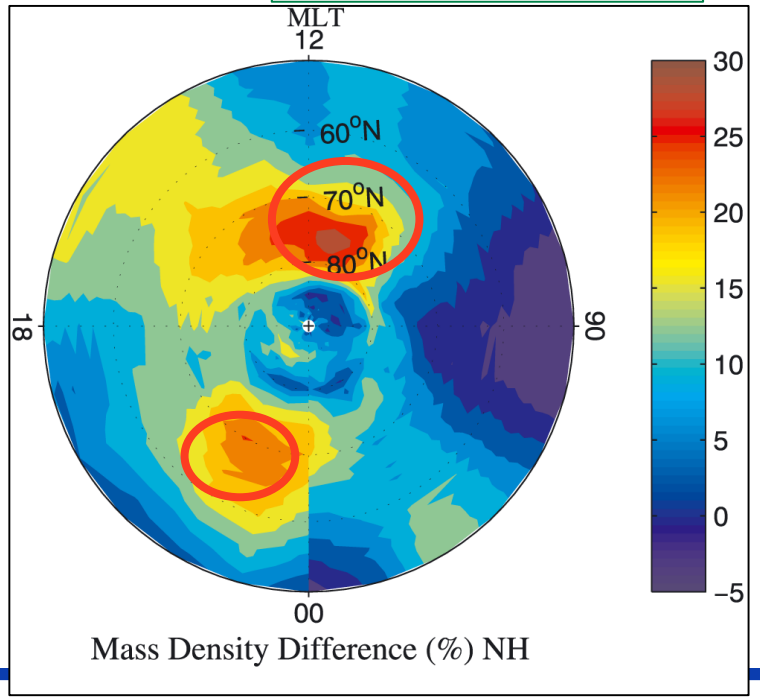

Liu et al., 2005

Multi-scale highlight #3: Thermospheric response

Kervalishvili and Lühr, [2013]

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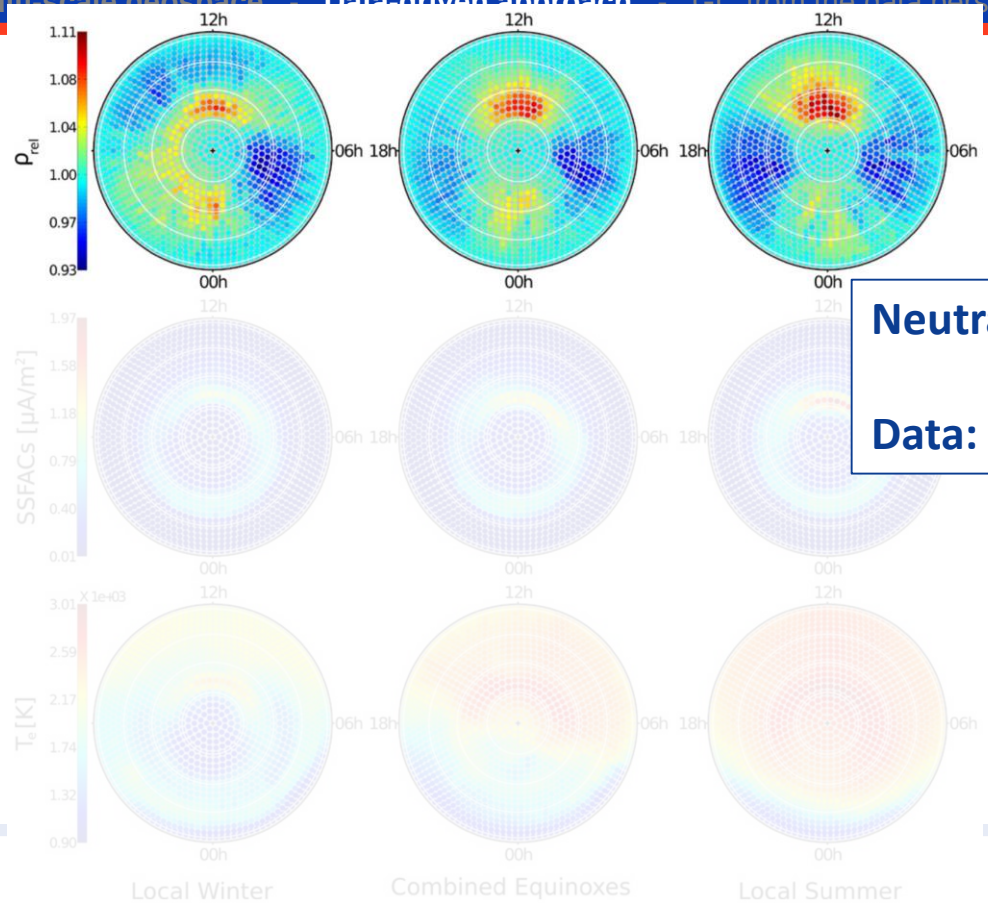

Neutral density anomalies

Data: CHAMP

Multi-scale highlight #3: Thermospheric response

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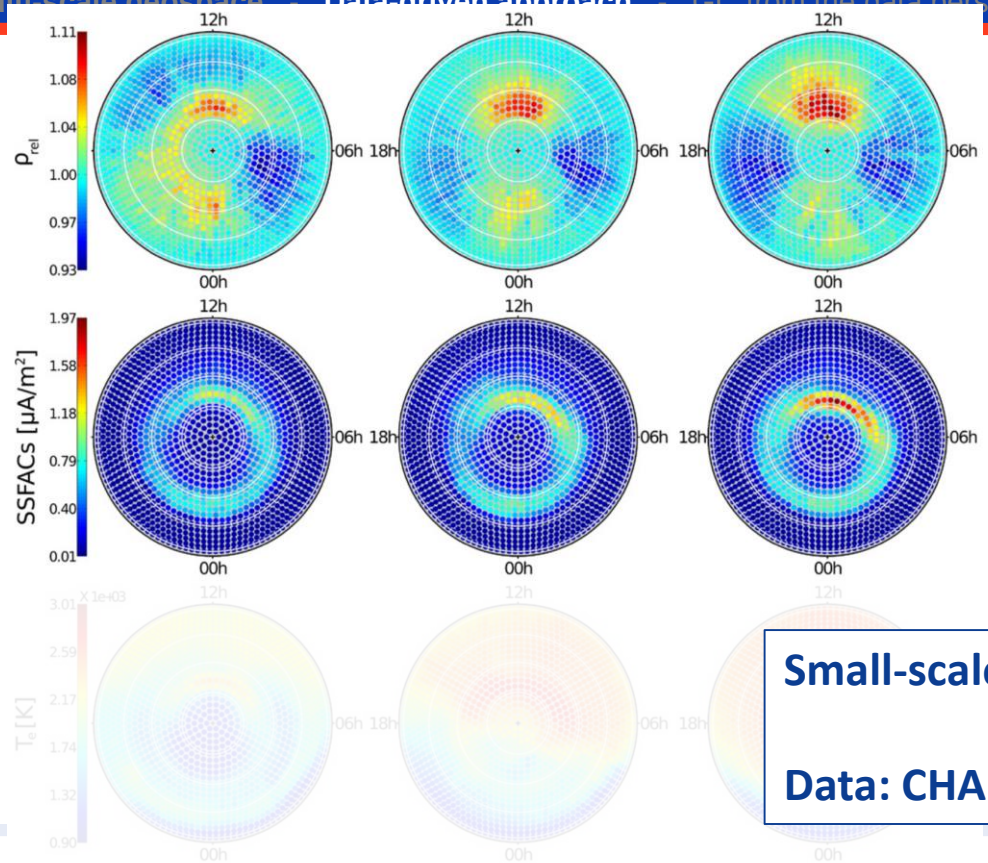
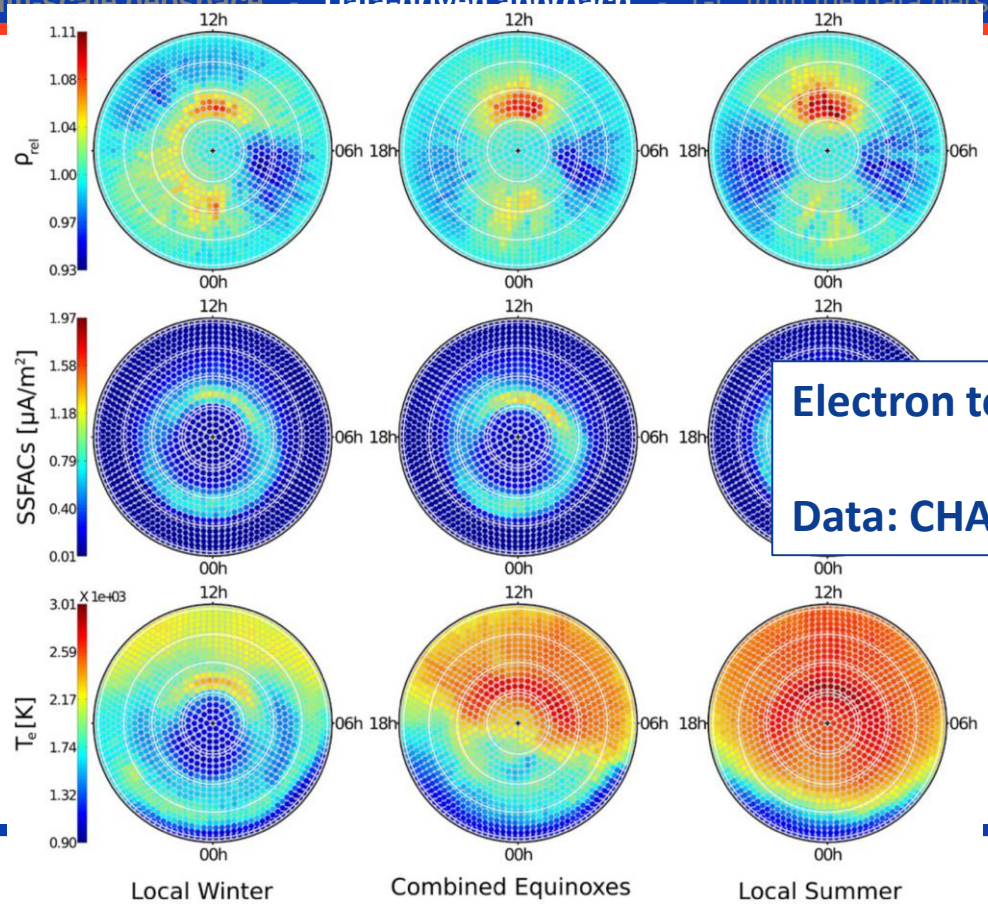


Small-scale FACs (~10 km scale)

Data: CHAMP

Multi-scale highlight #3: Thermospheric response

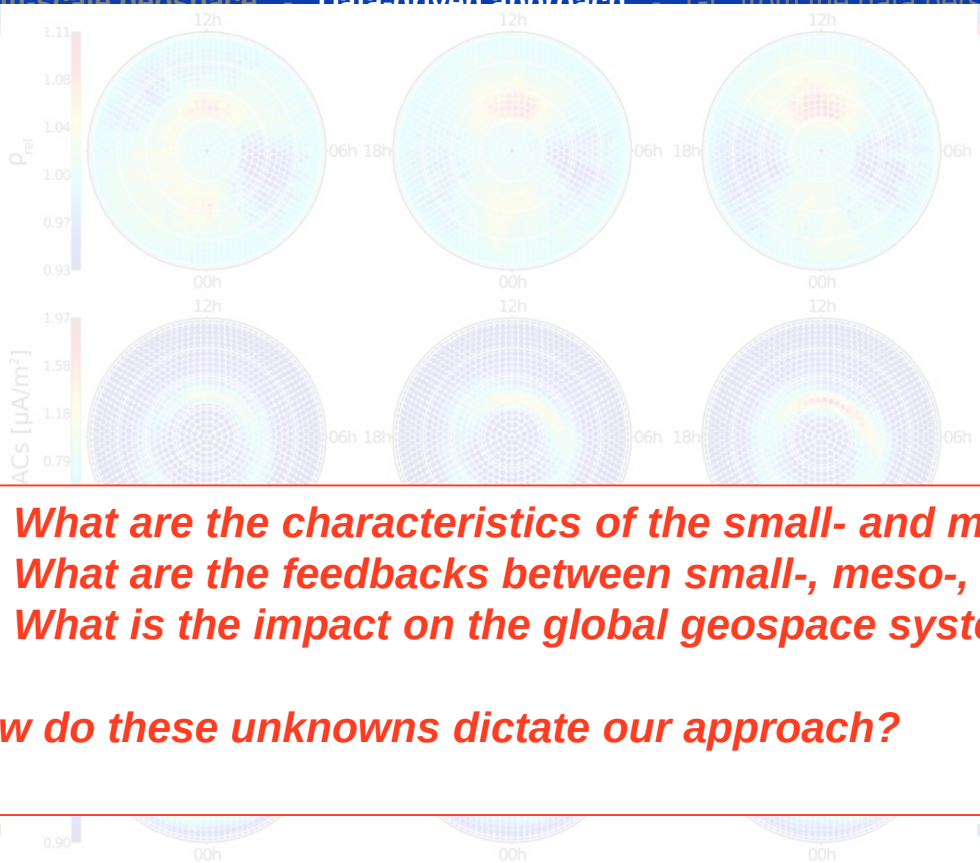
Kervalishvili and Lühr, [2013]



Electron temperature

Data: CHAMP

What's next?



1. *What are the characteristics of the small- and meso-scales?*
2. *What are the feedbacks between small-, meso-, and large-scales?*
3. *What is the impact on the global geospace system?*

How do these unknowns dictate our approach?

What approach will our Grand Challenge take from the data perspective?

Coordinated and fused observations: A *network* of data

- RISR-C & RISR-N
- Imagers
- Global Navigation Satellite Systems (GNSS) signals
- SuperDARN
- SuperMAG
- Satellite—based data

Coordinated and fused observations: A *network* of data

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Timely integration with:

- Cusp Grand Challenge Initiative
- ICON & GOLD
- Increased access to space (e.g., cubesats)

Challenges (opportunities) for data-driven approach to multi-scale studies

Data `wrangling'

- Often the most time consuming portion of research
- 'Re-inventing the wheel' and a lack of re-usability of analysis tools and prepared data

Handling the diversity of data

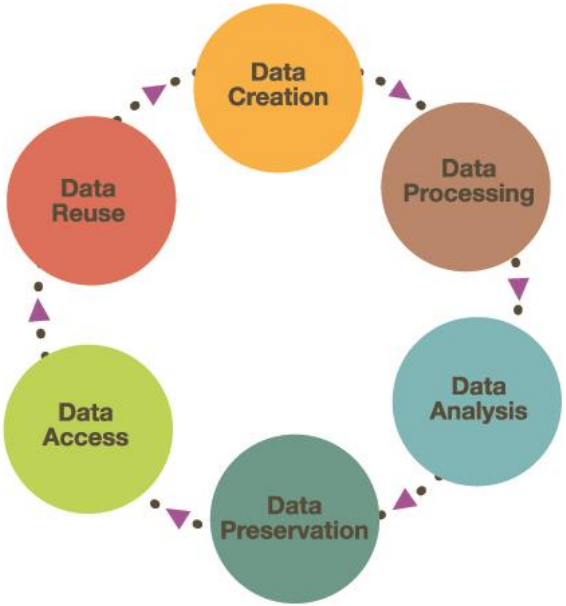
- Uncertainties need to be robustly incorporated into analyses
- Requirement to perform robust multi-observation studies and for model-data fusion

Available and transparent analysis tools

- Critical to facilitate interdisciplinary collaboration
- Conducive to more rapid progress

Data Science paradigm:

Address the *full data lifecycle*



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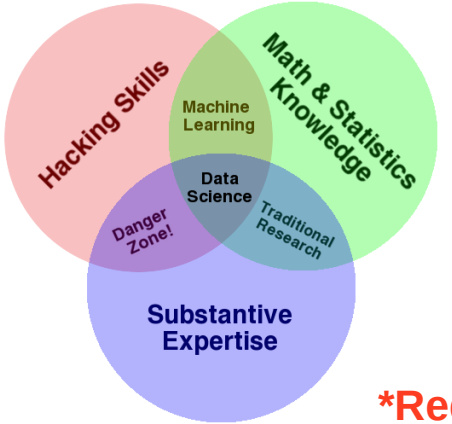

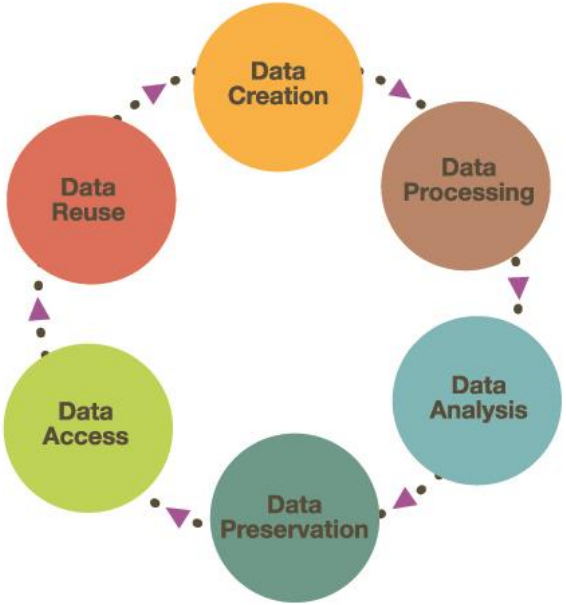

***Requires radically interdisciplinary approach**

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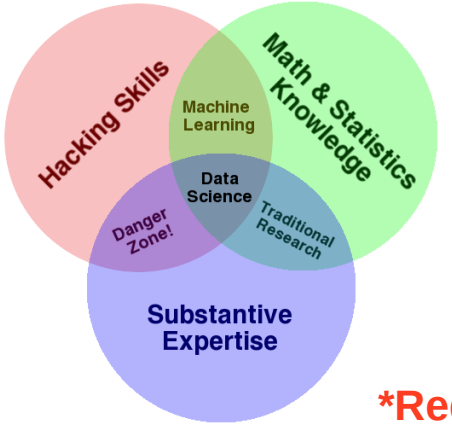


Please bring thoughts, ideas, and discussion items to 1st workshop session ***today 1:30-3:30 PM in Mesa A/Hilton***

***Requires radically interdisciplinary approach**

Concluding remarks

We have briefly overviewed multi-scale geospace from the data perspective

- Previous data-driven efforts illustrate potential to create new understanding

Massive potential through data-driven science, but achieving success is challenging

- Data Science paradigm offers potential solution
- Requires improvement to the *entire data lifecycle*

Concluding remarks

We have briefly overviewed multi-scale geospace from the data perspective

- Previous data-driven efforts illustrate potential to create new understanding

Massive potential through data-driven science, but achieving success is challenging

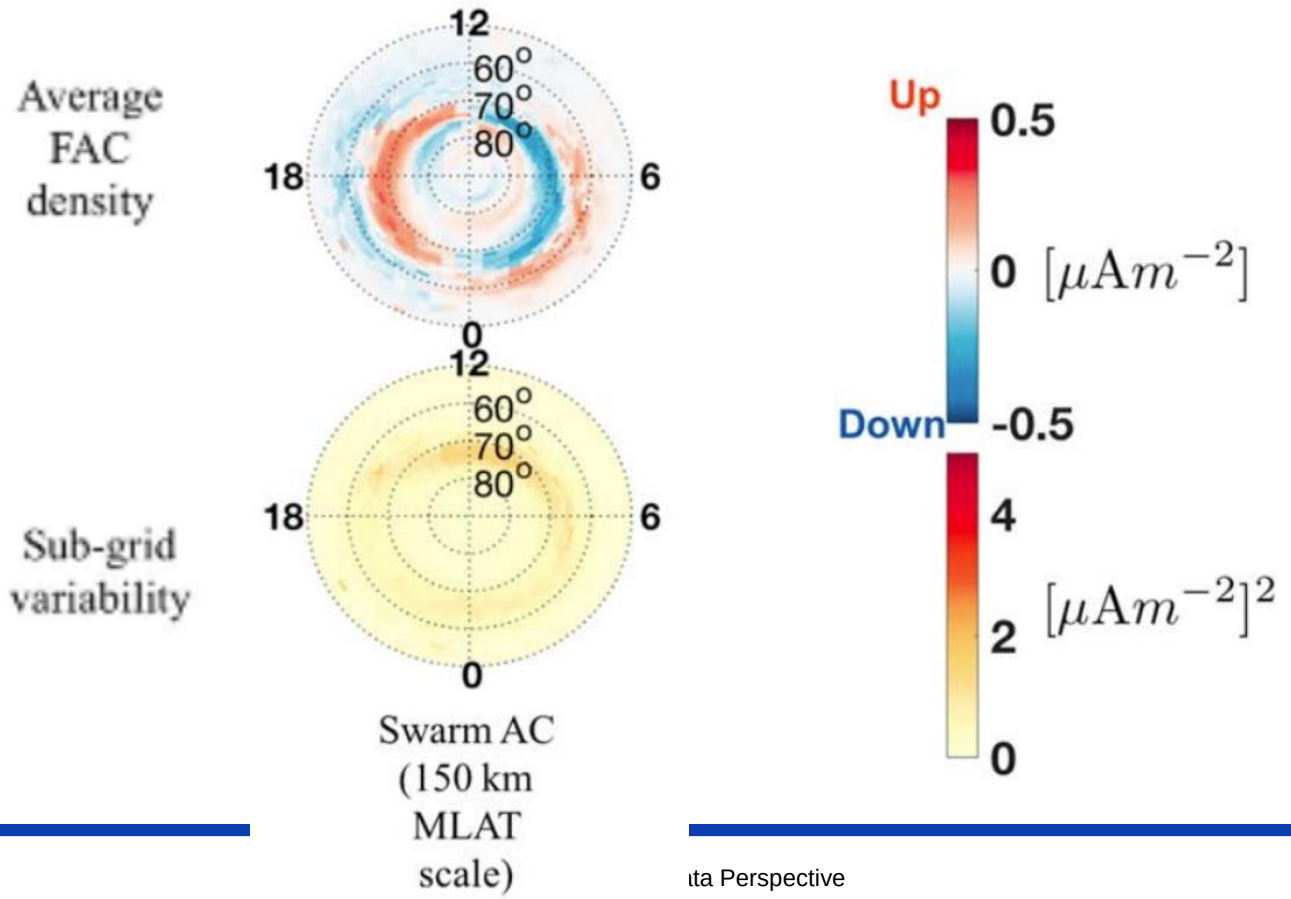
- Data Science paradigm offers potential solution
- Requires improvement to the *entire data lifecycle*

`New Frontier' in multi-scale geospace possible at intersection of traditional approaches and state-of-the-art data-driven sciences and technologies

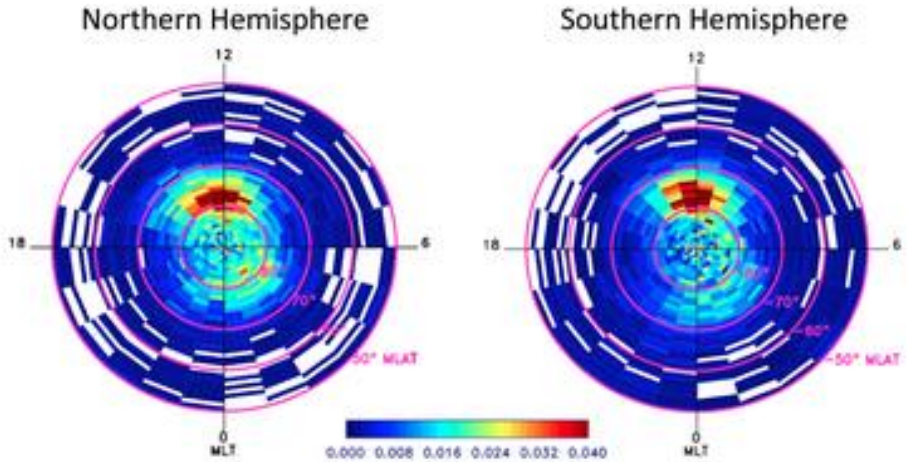
McGranaghan, R. M., Bhatt, A., Matsuo, T., Mannucci, A. J., Semeter, J. L., & Datta-Barua, S. (2017). Ushering in a new frontier in geospace through data science. *Journal of Geophysical Research: Space Physics*, 122, 12,586–12,590. https://doi.org/10.1002/2017JA024835

Backup slides

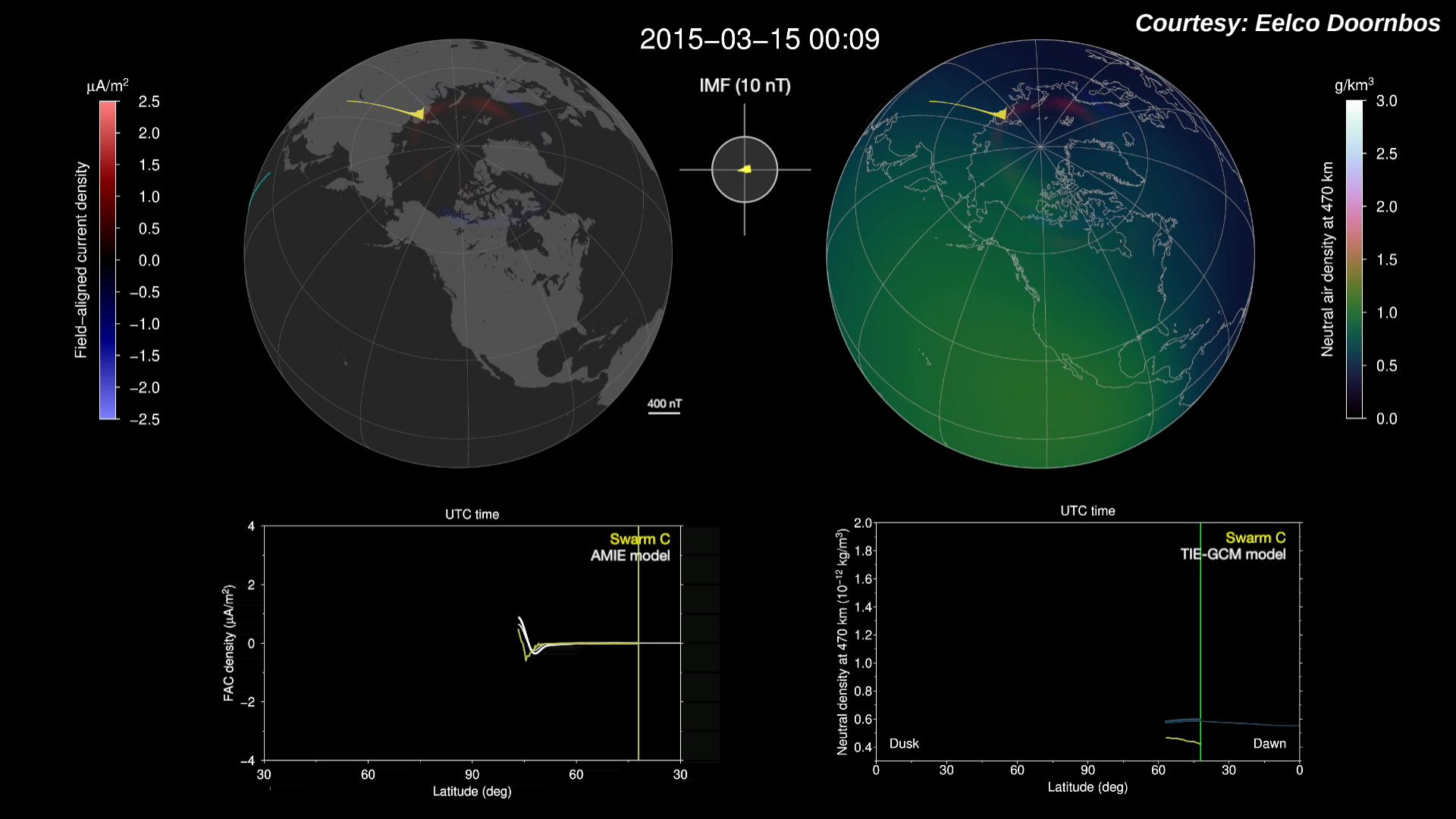
Distribution of 150-km scale field-aligned currents over the globe



CHAMP neutral density maxima occurrences

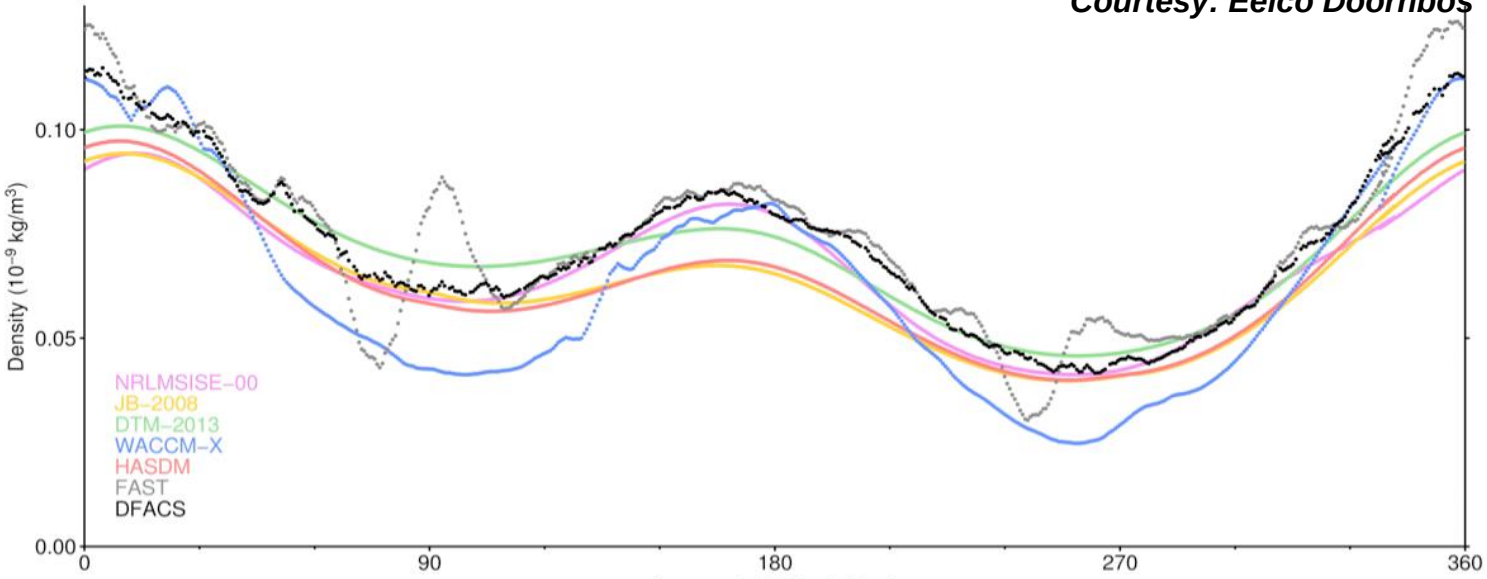


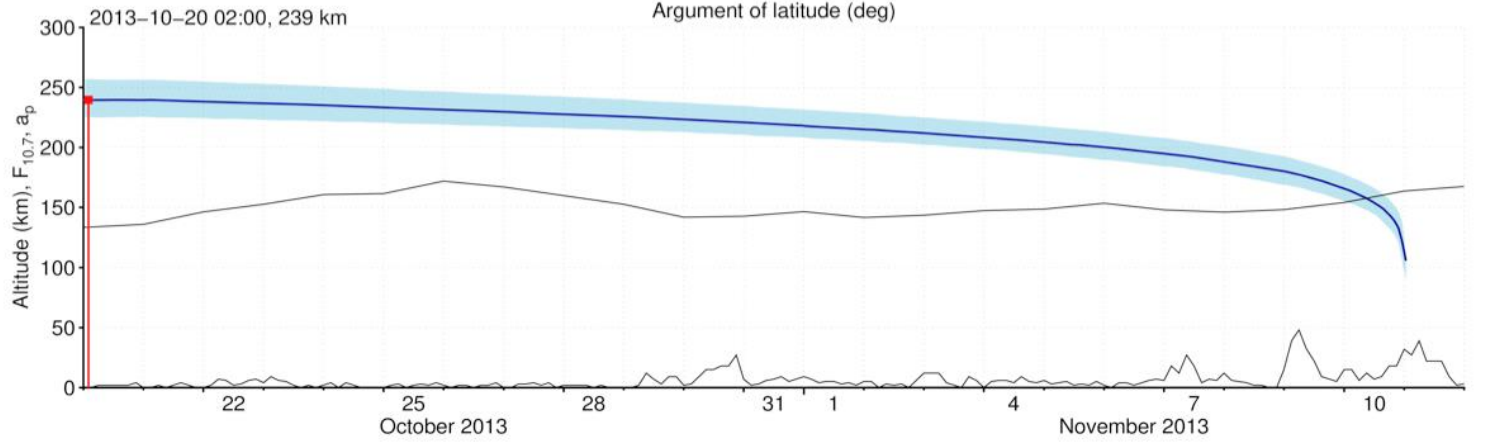
Huang et al., [2017]



Courtesy: Eelco Doornbos
2015–03–15 00:09
IMF (10 nT)
μA/m²
Field–aligned current density
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
400 nT
g/km³
Neutral air density at 470 km
3.0
2.5
2.0
1.5
1.0
0.5
0.0
UTC time
Swarm C
AMIE model
FAC density (μA/m²)
Latitude (deg)
UTC time
Swarm C
TIE-GCM model
Neutral density at 470 km (10⁻¹² kg/m³)
Dusk
Dawn
Latitude (deg)

Courtesy: Eelco Doornbos





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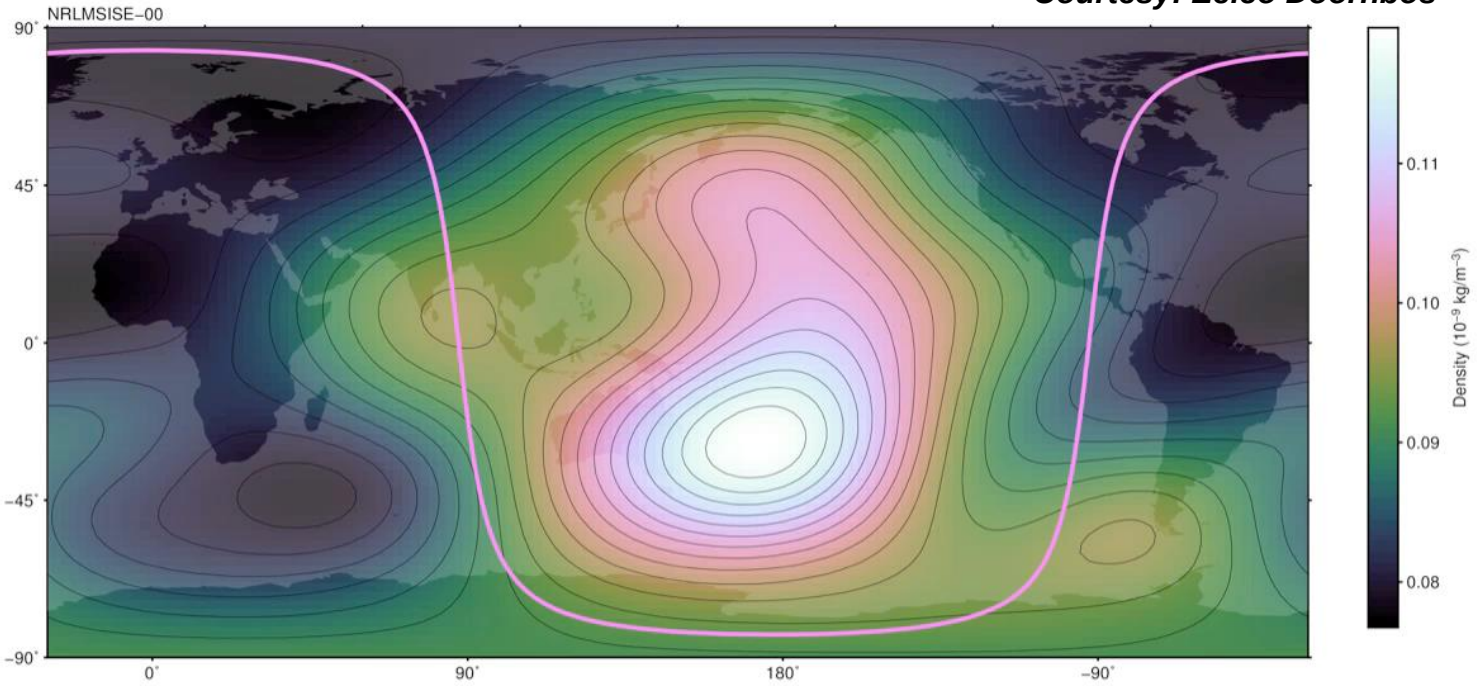

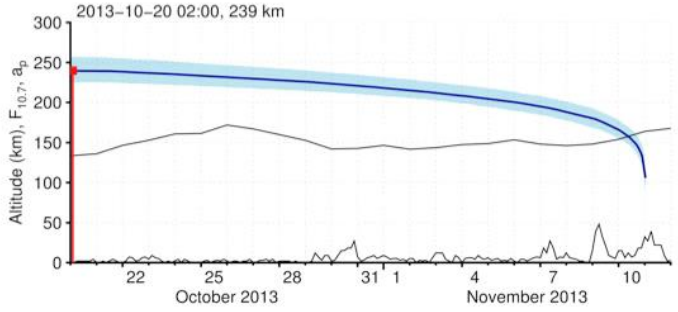

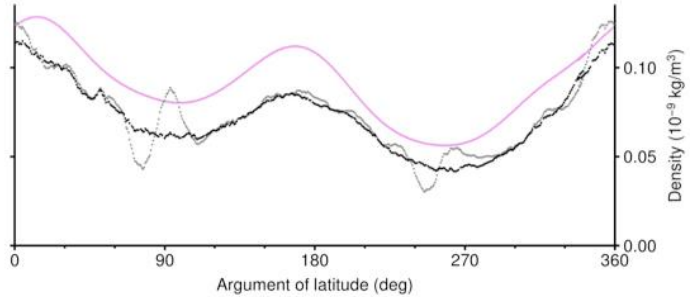

Coordinated and fused observations: A *network* of data

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- Imagers
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Timely integration with Cusp Grand Challenge tiative, ICON, and GOLD

How can model output and observations be used cooperatively?

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Data Science Approach

Data archives → Data workflows

Coordinated and fused observations: A *network* of data

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- Imagers
- Satellite-based data

Consider the full data lifecycle:

Collection -> Processing -> Analysis -> Visualization -> Accessibility

Data Science Approach

Data archives → Data workflows

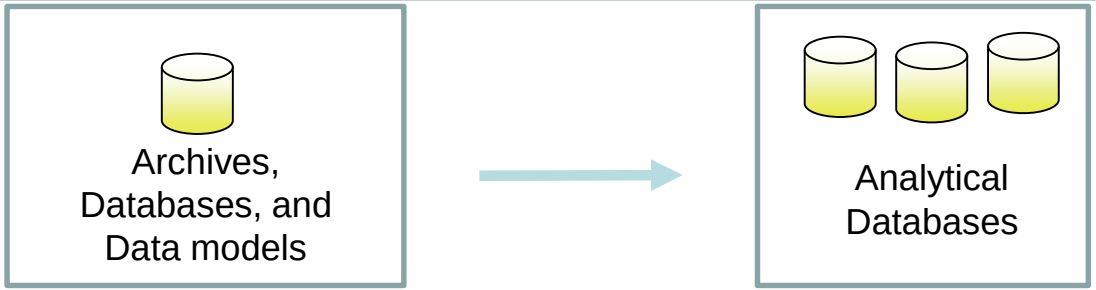
Data Science Approach

Front-end

Analysis tools

Interactive analysis (e.g., visualization)

Analytics-as-a-Service (Statistics, Machine learning, Search)



Information Models

Workflows

Scalable Computing Infrastructure

Back-end