Discovering relationships between FAC and TEC

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NASA Jet Propulsion Laboratory, California Institute of Technology

Tony Mannucci, Olga Verkhoglyadova, Xing Meng
NASA JPL

NASA Data Science Group – Chris Mattmann
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Main points

Gain understanding of possible TEC<->FAC relationship

1. Event studies
2. Expansive data study

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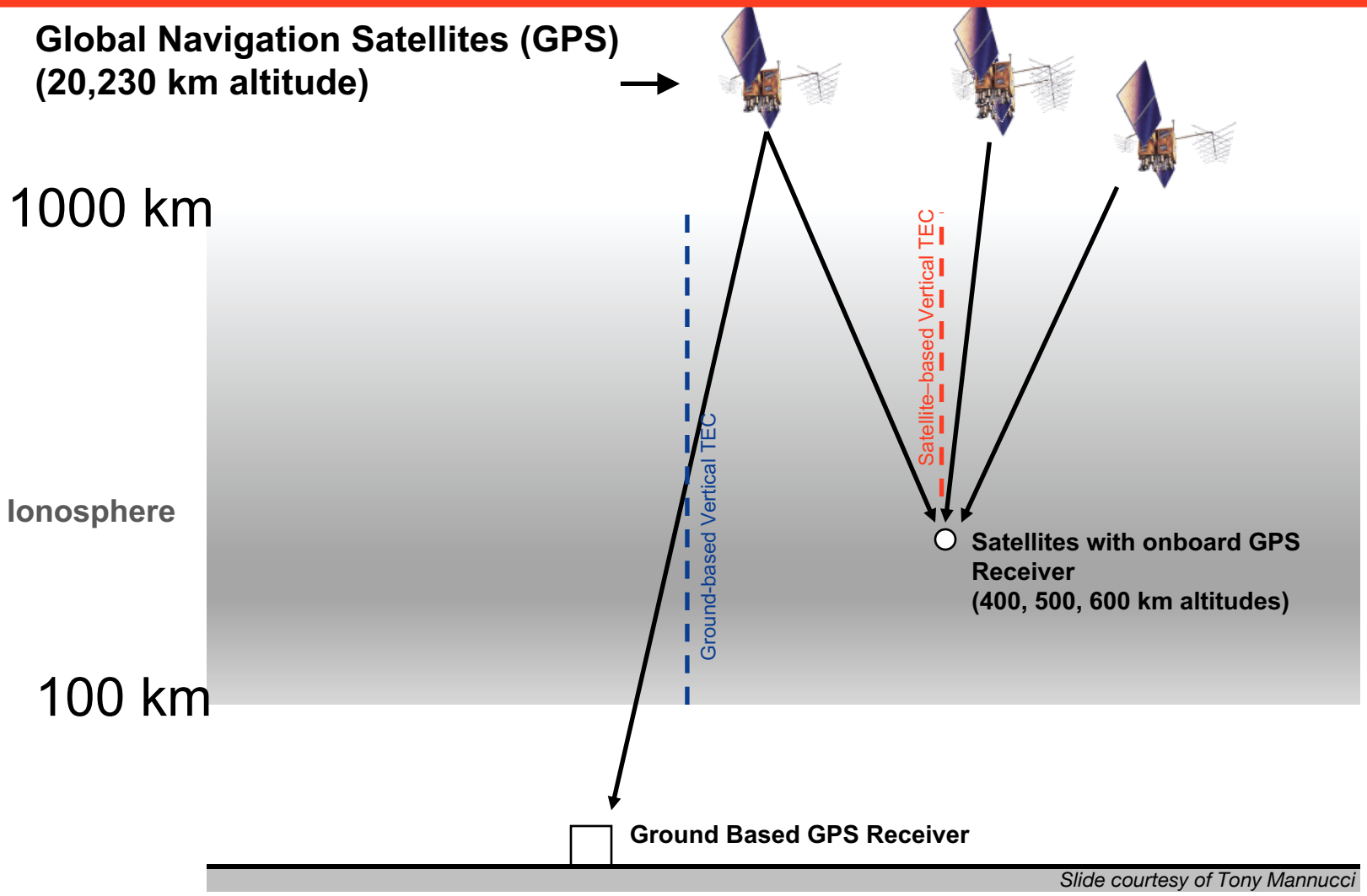
} **Convergence enables new frontier…**

Expand relationships with machine learning approaches

- Large-scale relationship: AMPERE<->VTEC
- Small-scale relationship: Swarm<->TEC variability

Overview of TEC data:
Technique



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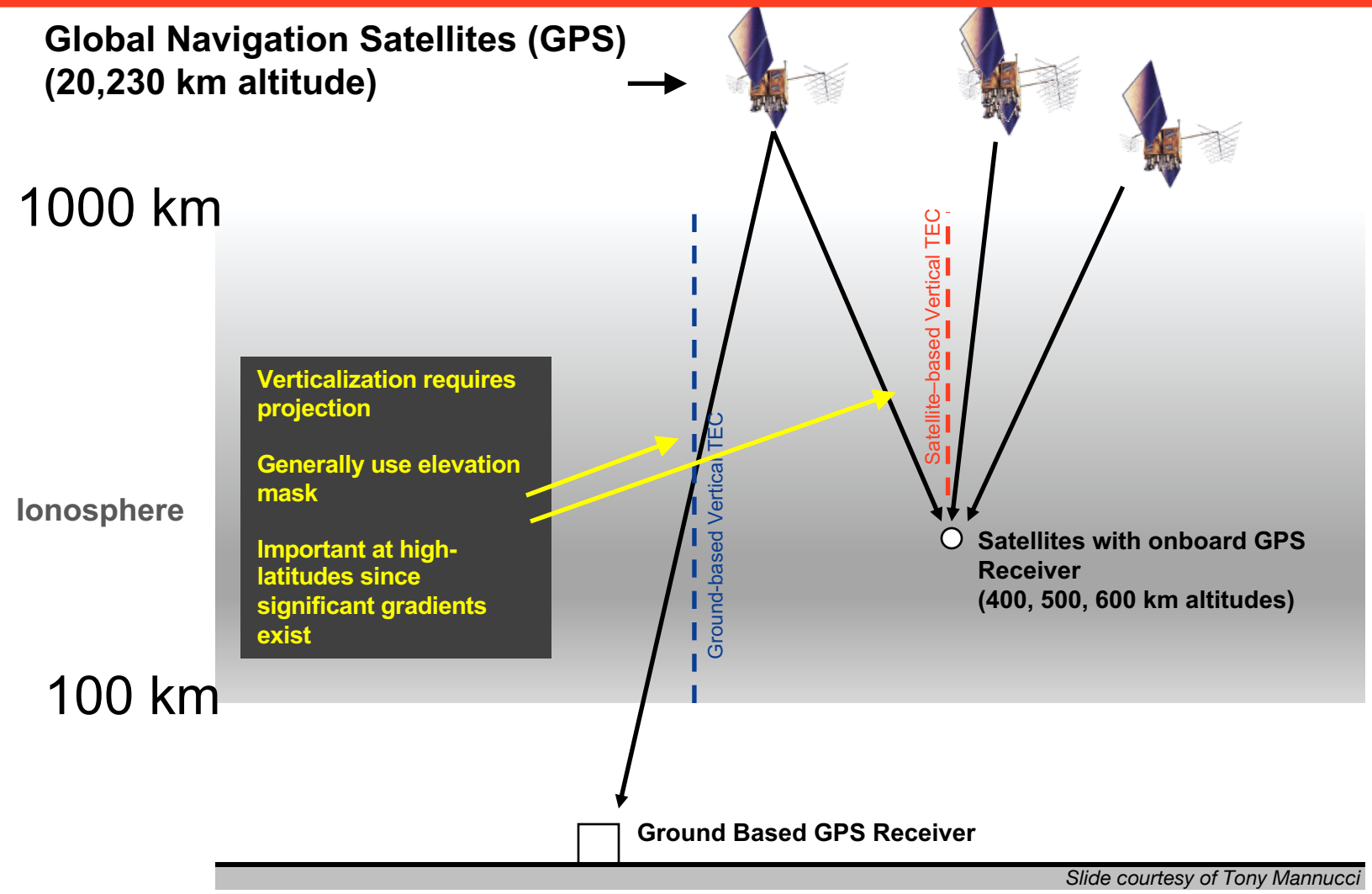
CPAESS JPL



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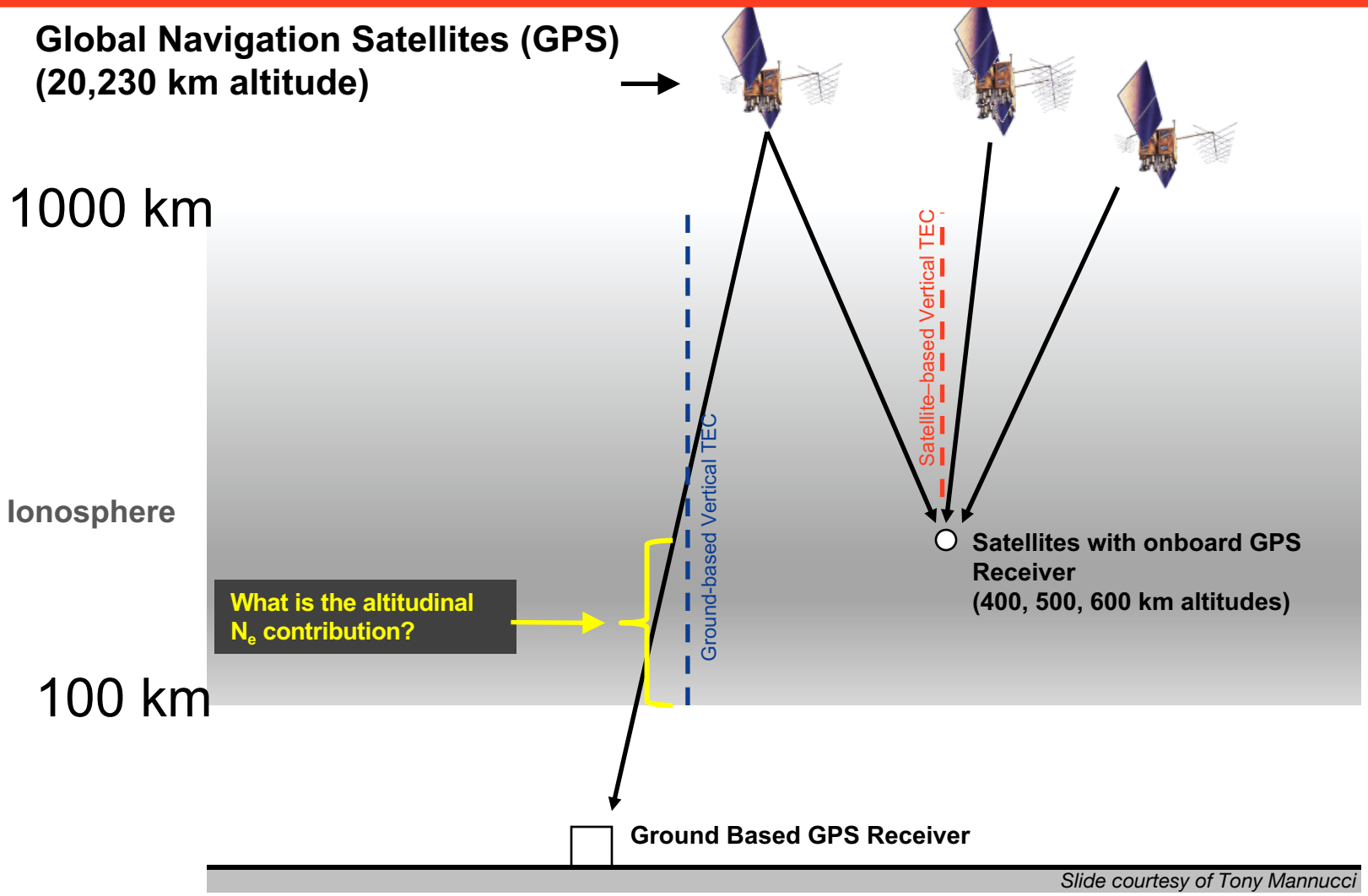

Overview of TEC data

MIT Haystack Madrigal Upper Atmospheric Science Database: Global ground-based GPS receivers

- Resolution: receiver network combined into 1^{o}x1^{o} lat. *x* long. maps at 5-minute cadence

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  - ❖ Greenland Network of GNSS receivers (GNET)
  - ❖ Canadian High Arctice Ionospheric Network (CHAIN)
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Relationships with several in… to ground-based receivers capa… constellation (GPS, GLONAS…

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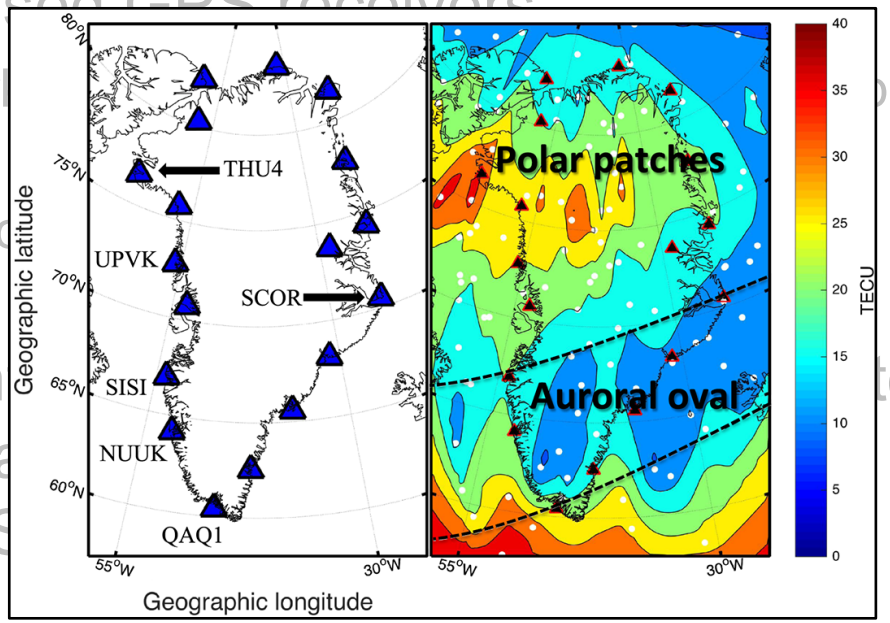

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Important to involve JPL given their expertise with GNSS signals to study the ionosphere

Overview of TEC data

Numerous satellite missions…

- TerraSAR-X (~500 km)
- Swarm constellation (~460 & 520 km)
- CASSIOPE (elliptical: 350x1500 km)
- GRACE (~400-450 km)
- CHAMP (~400 km)
- Numerous others

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Variable resolutions dependent on satellite orbit and capability of onboard GNSS receiver

Overview of TEC data

"The key signature that shows the TEC increases [at high-latitude] to be due to auroral particle precipitation is the irregular and fluctuating nature of the pattern' [*Mendillo, 2005*]

Key to distinguish:

- Local (M-I induced) and non-local (ionospheric horizontal transport-induced) TEC variations
- M-I induced and more regular solar radiation induced TEC structuring

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Our foci

Overview of TEC data

Possible M-I mechanisms relating TEC and FAC:

- Neutral composition change
- Particle precipitation from plasmasphere and ring current

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Strong likelihood of connection, so initial investigation focused here

Overview of TEC data

Possible M-I mechanisms relating TEC and FAC:

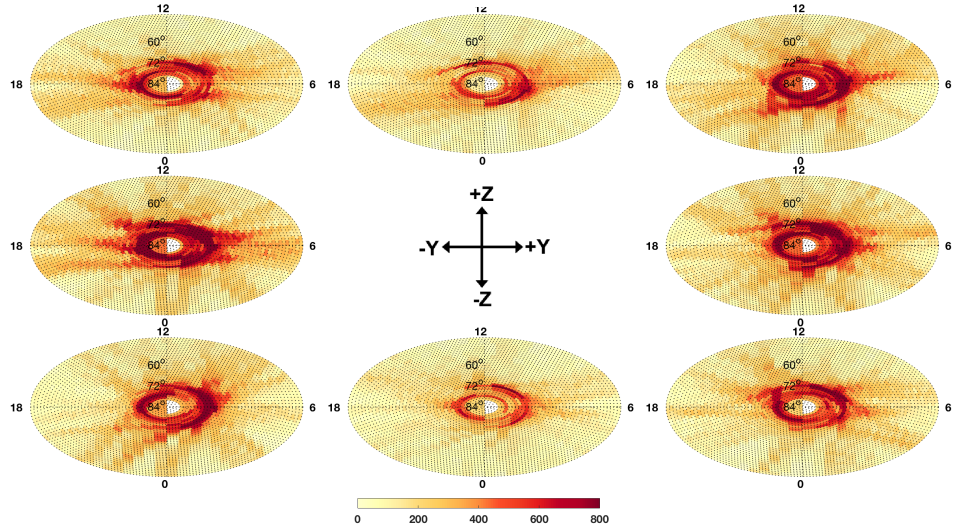
- Neutral composition change
- Particle precipitation from plasmasphere and ring current

Any relationship found will also address lack of ability to specify high-latitude ionospheric drivers

Swarm FACs Multi-scale statistical results:
Observation density

Statistical Results - April 22, 2014 Event - Extension

Northern Hemisphere
Nov 2014 – Mar 2015



Northern Hemisphere
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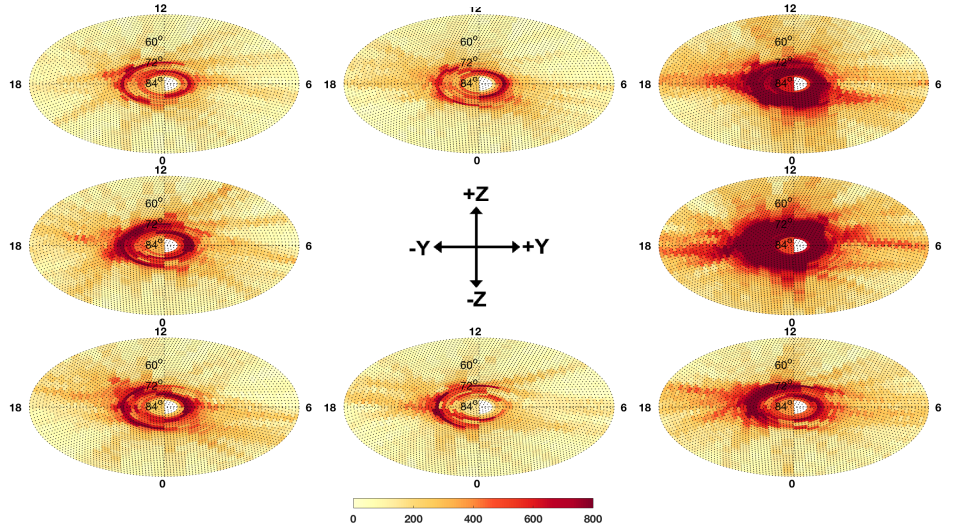

Swarm FACs Multi-scale statistical results:
50 km MLAT scale size medians

Statistical Results - April 22, 2014 Event - Extension

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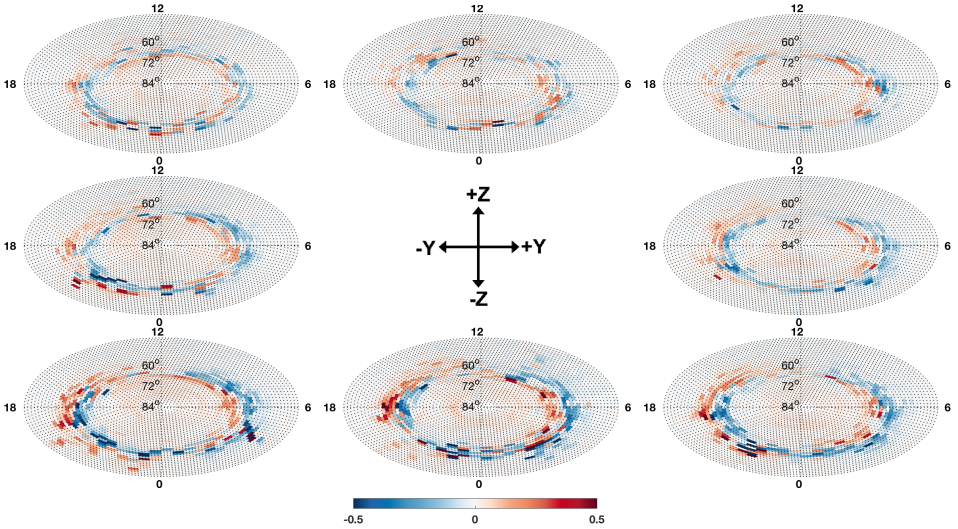

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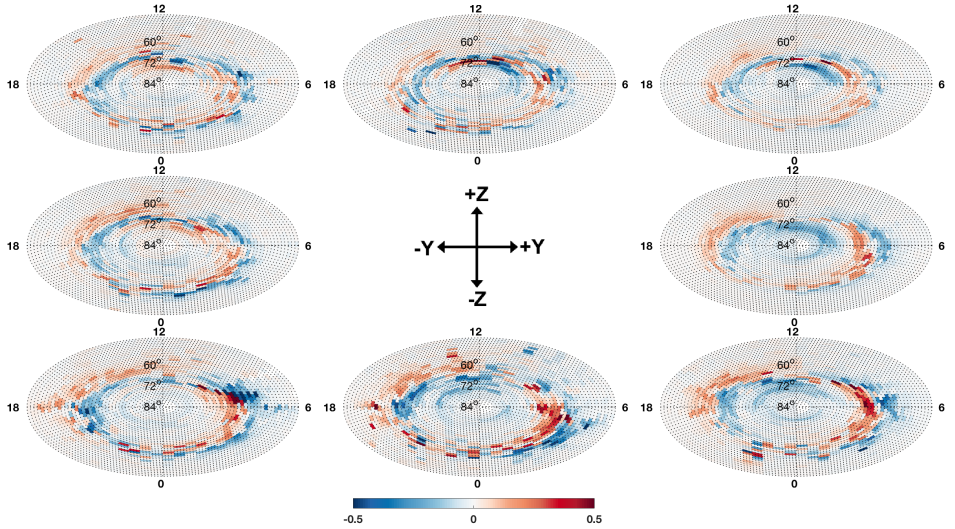

Swarm FACs Multi-scale statistical results:
50 km MLAT scale size bin variances

Statistical Results - April 22, 2014 Event - Extension

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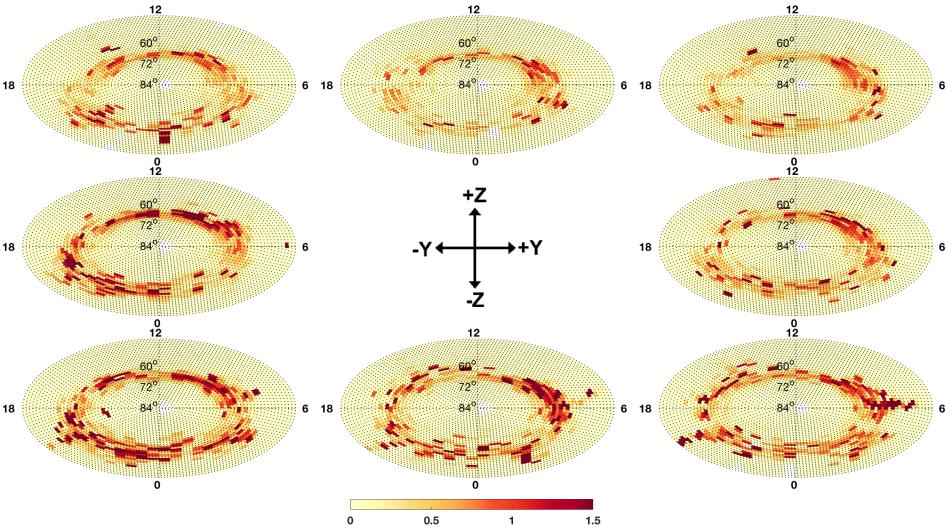

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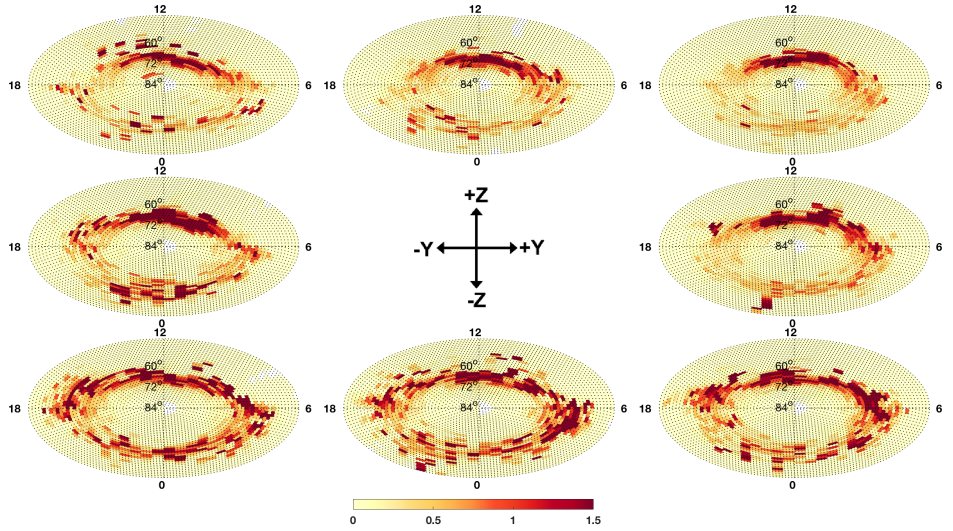

Swarm FACs Multi-scale statistical results:

400 km MLAT scale size medians

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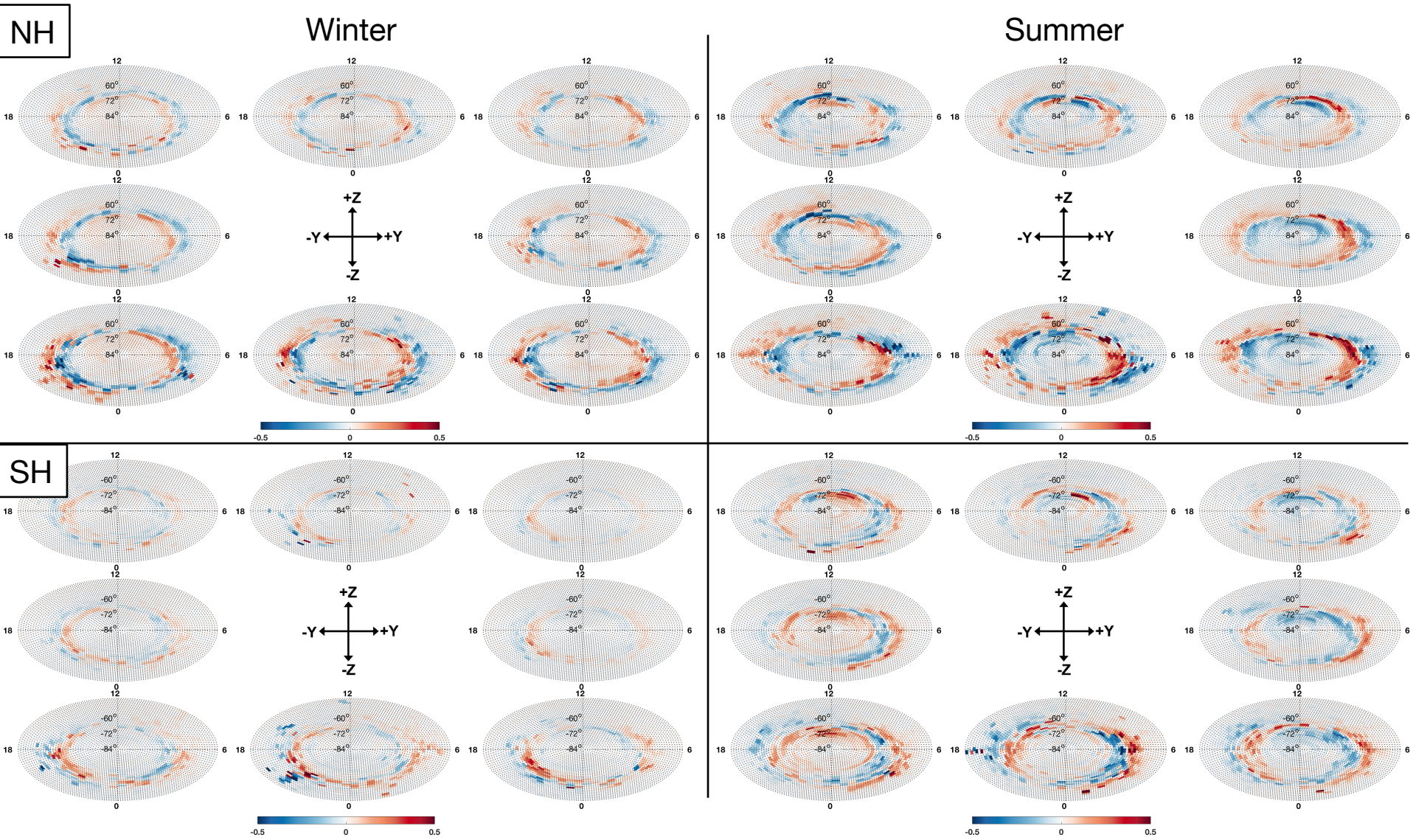
Statistical Results - April 22, 2014 Event - Extension



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Statistical Results - April 22, 2014 Event - Extension

Northern Hemisphere
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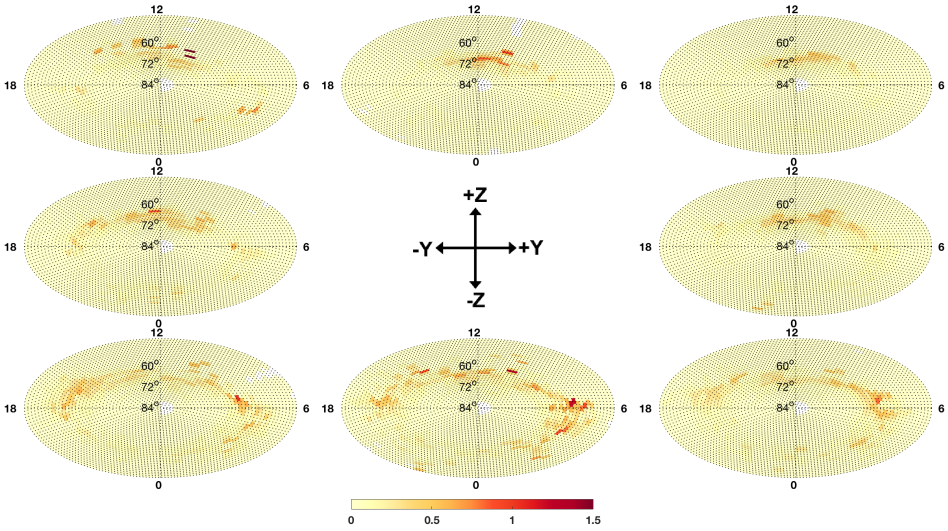

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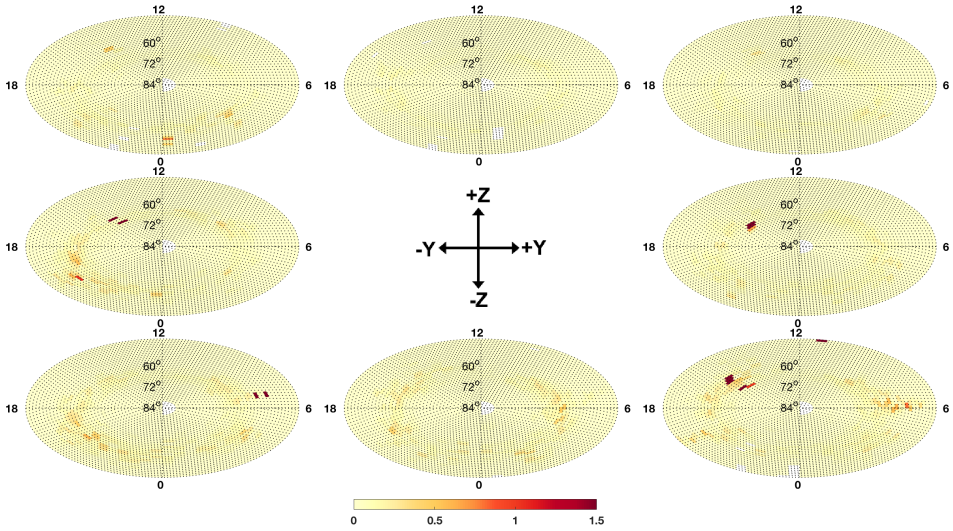
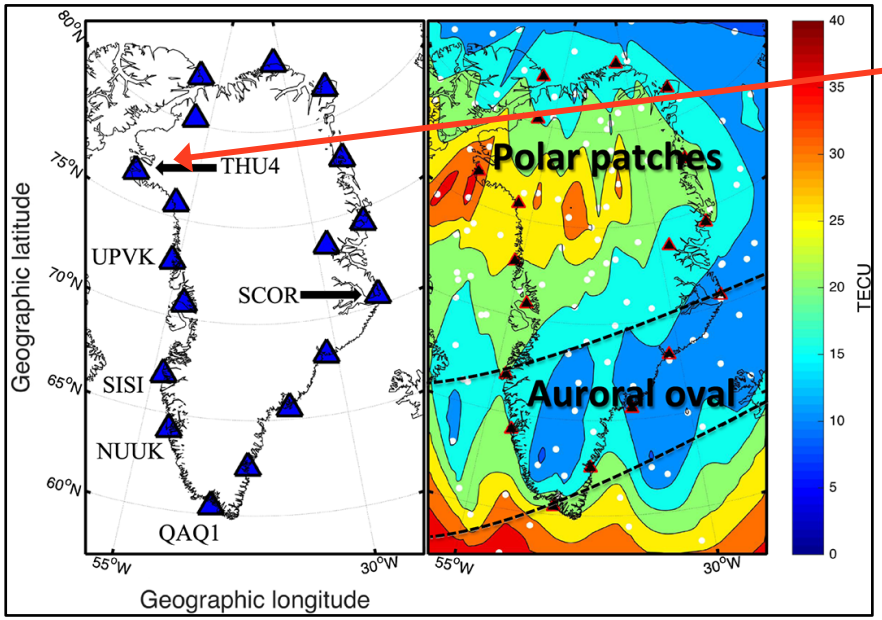
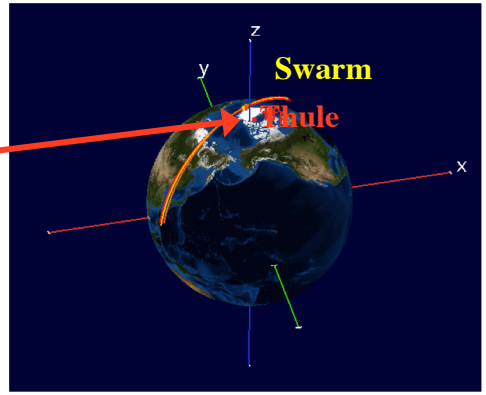


How to examine observable signatures of FAC in TEC?

Statistical Results - **April 22, 2014 Event** - Extension





Dunlop, M. W., J.-Y. Yang, Y.-Y. Yang, C. Xiong, H. Lühr, Y. V. Bogdanova, C. Shen, N. Olsen, Q.-H. Zhang, J.-B. Cao, H.-S. Fu, W.-L. Liu, C. M. Carr, P. Ritter, A. Masson, and R. Haagmans (2015), Simultaneous field-aligned currents at Swarm and Cluster satellites. Geophys. Res. Lett., 42, 3683–3691. doi: 10.1002/2015GL063738.

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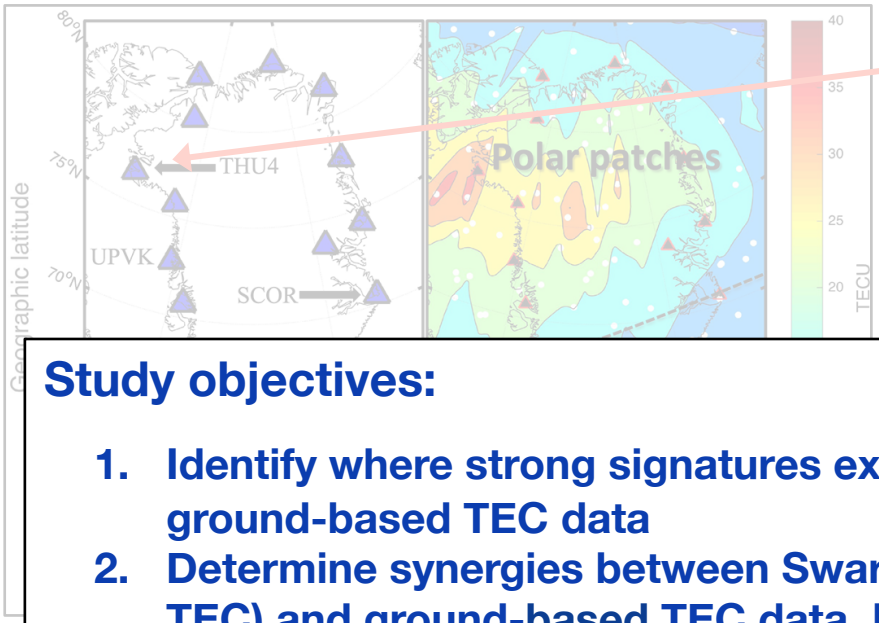

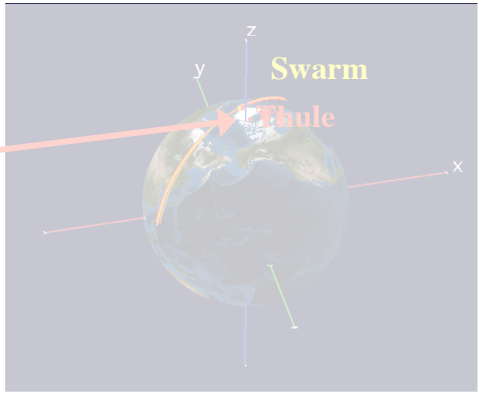

Study objectives:

1. Identify where strong signatures exist in Swarm and ground-based TEC data
2. Determine synergies between Swarm (both FAC and TEC) and ground-based TEC data. Understand where additional data are most impactful (AMPERE, CASSIOPE RO, high-latitude LEO-based TEC)

Xiong, H. Lühr, Y. V. Bogdanova, C. Shen, N. Olsen, Q.-H. Zhang, J.-B. Cao, H.-S. Fu, W.-L. Liu, C. M. Carr, P. Ritter, A. Masson, and R. Haagmans (2015), Simultaneous field-aligned currents at Swarm and Cluster satellites. Geophys. Res. Lett., 42, 3683–3691. doi: 10.1002/2015GL063738.

April 22, 2014:
Qualitative analysis

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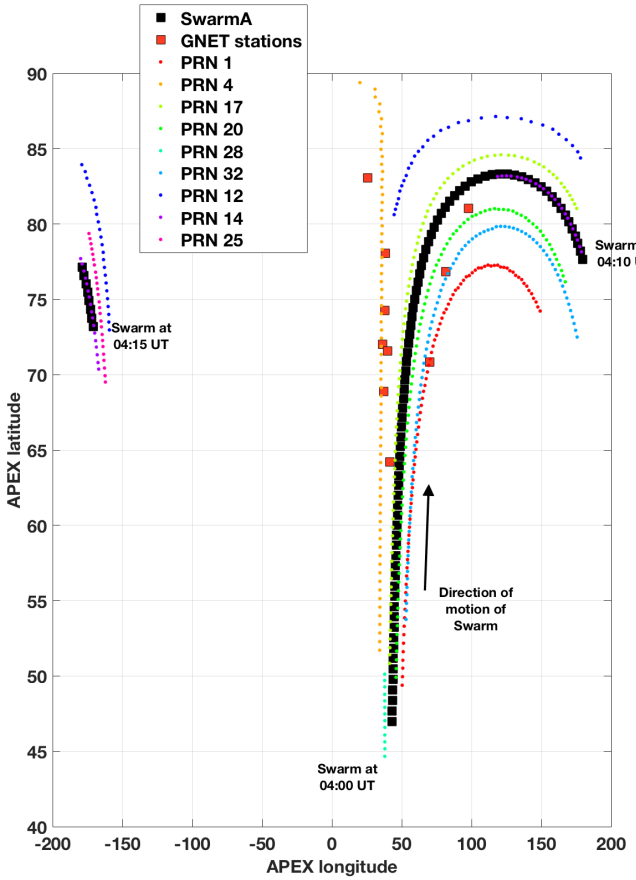

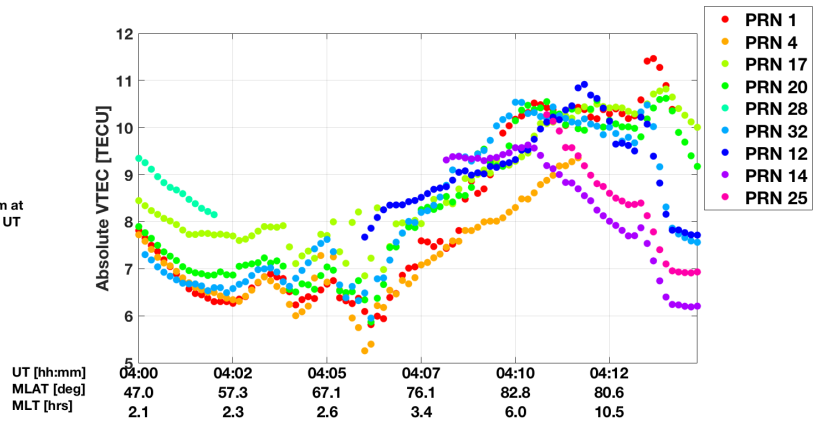

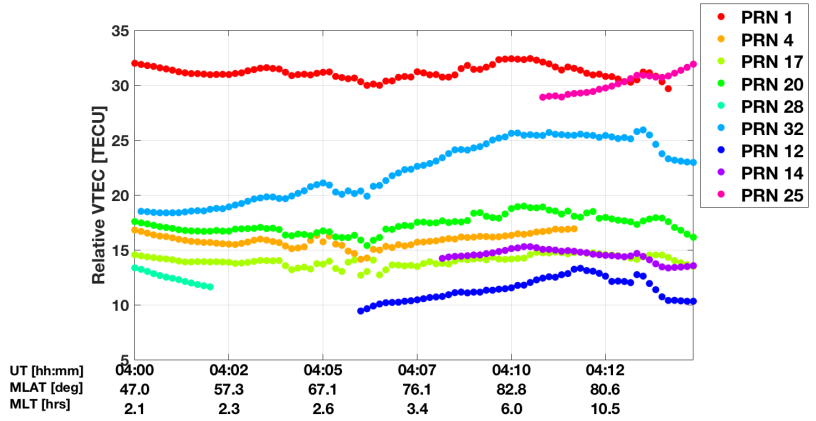

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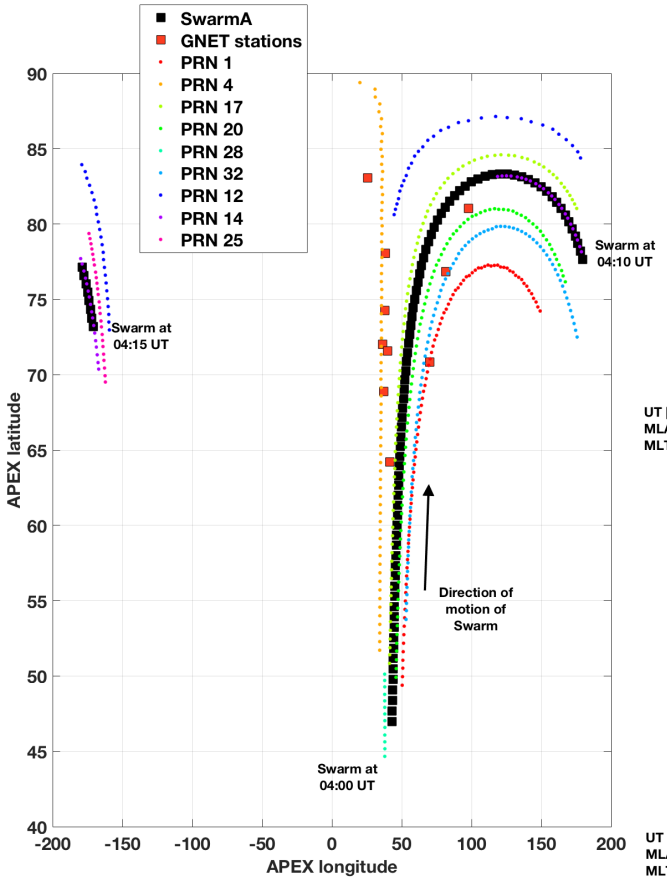

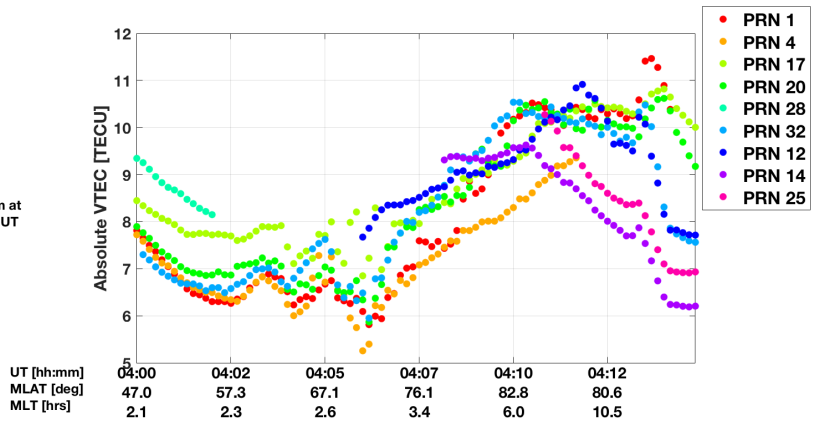

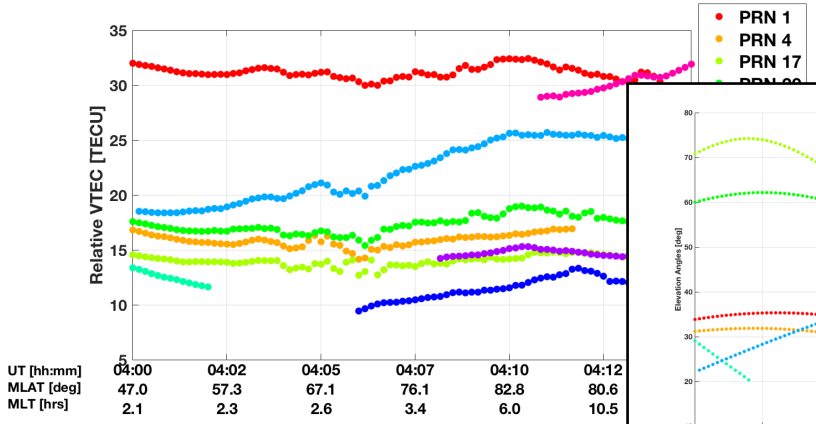

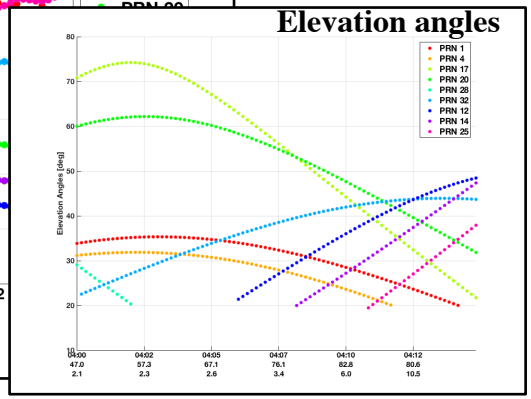

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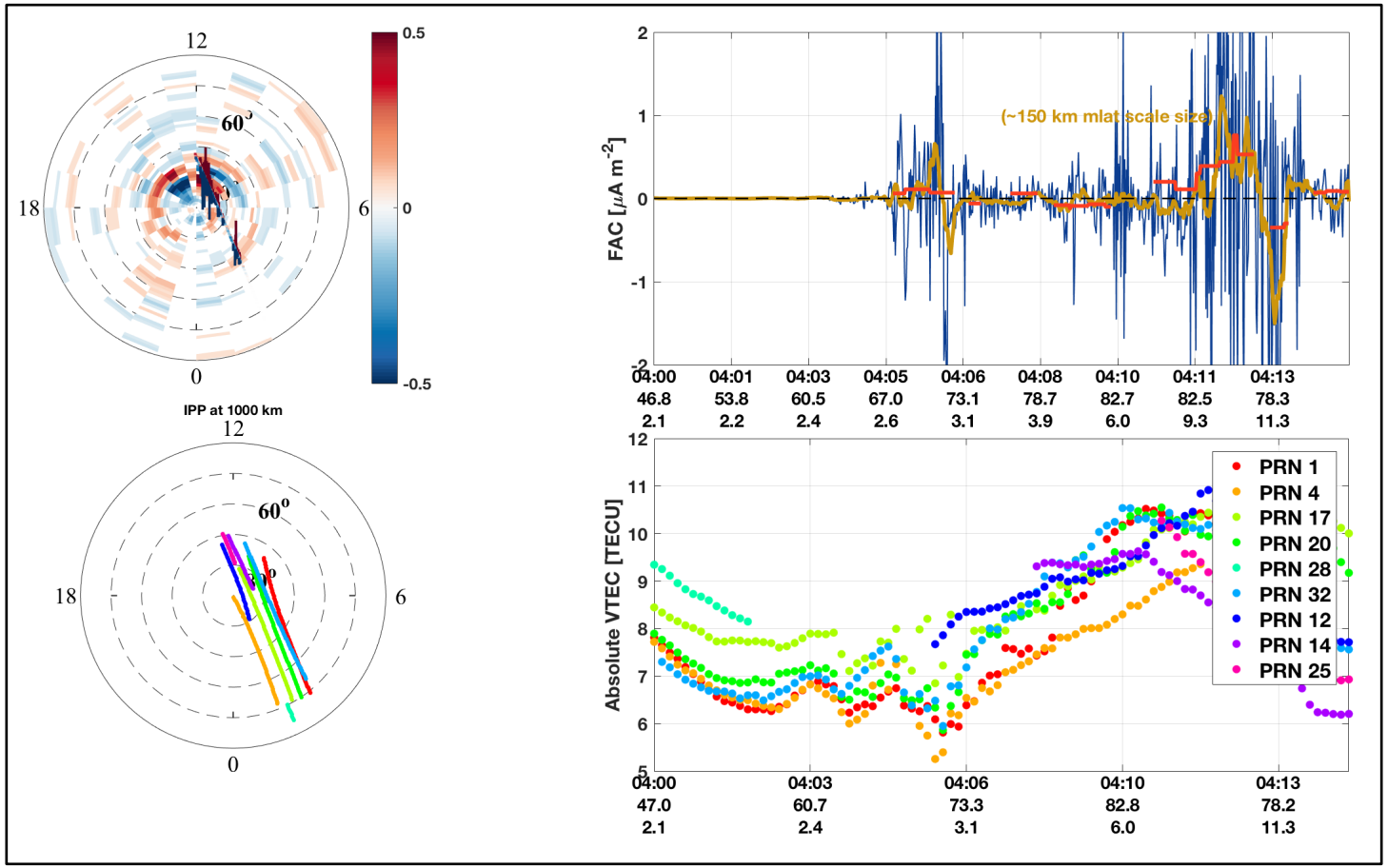

April 22, 2014:
Quantitative analysis

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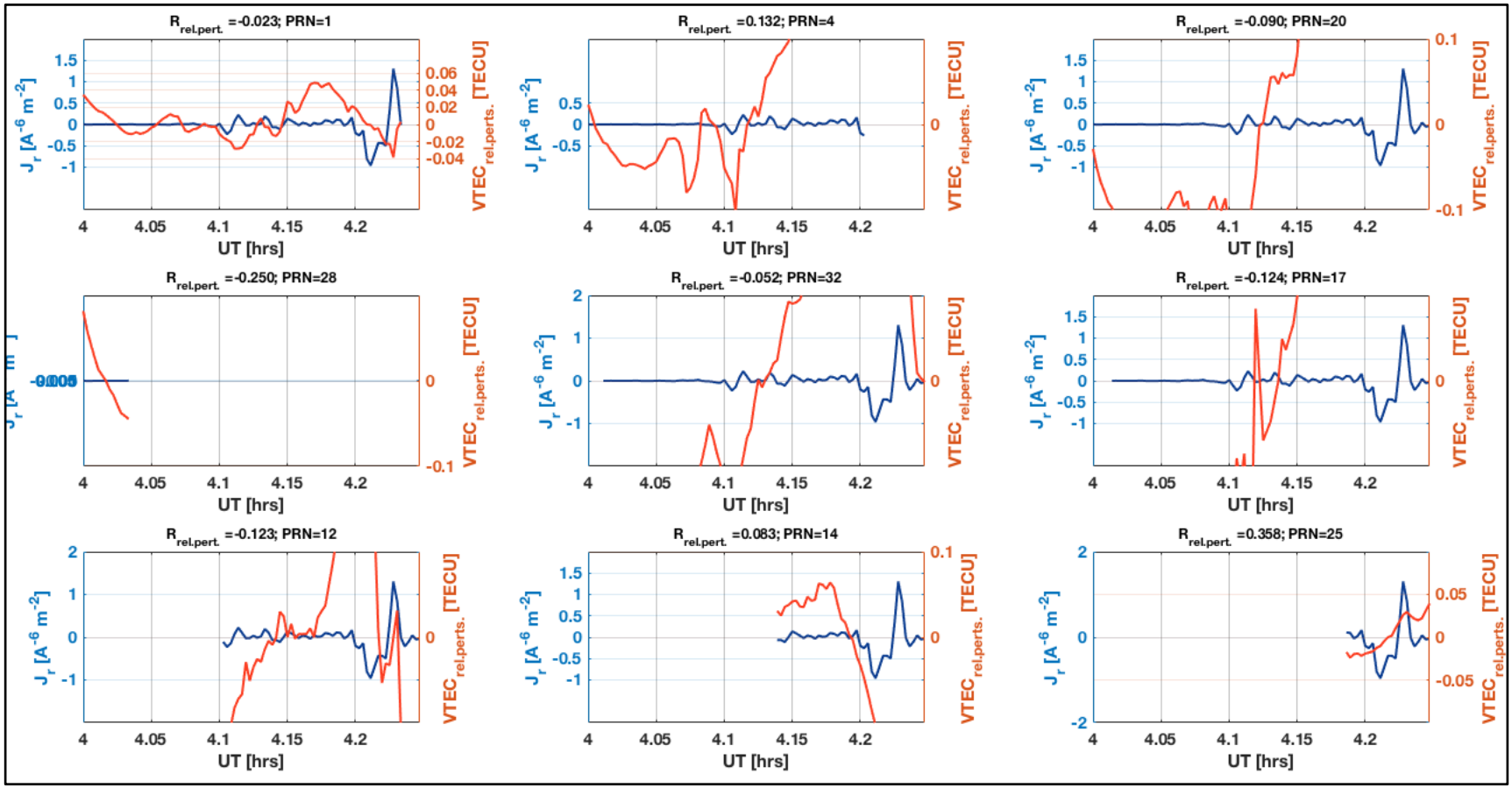
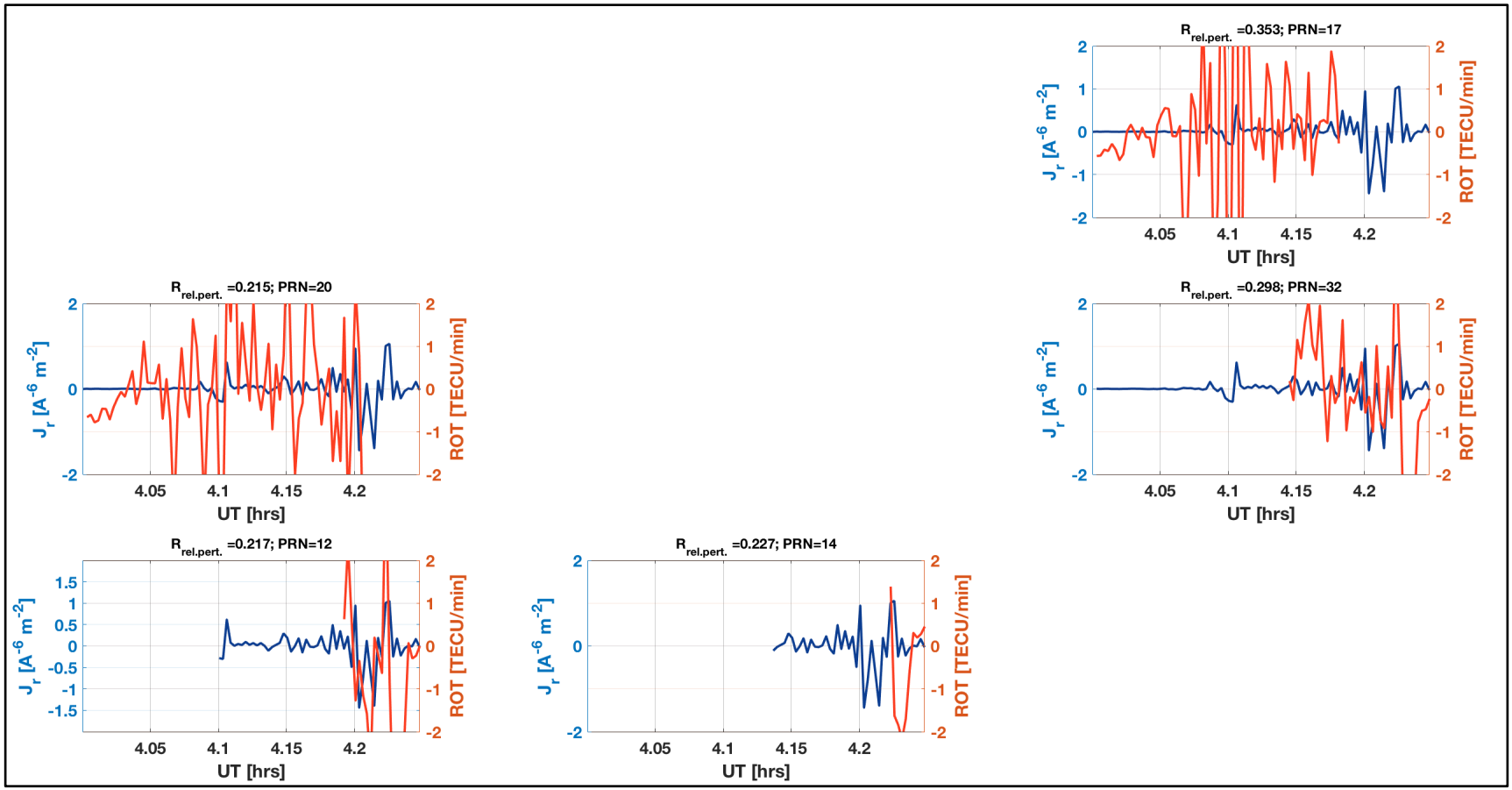
Statistical Results - **April 22, 2014 Event** - Extension

Linear correlations between Swarm A 50 km MLAT scale sizes and TEC relative perturbations



April 22, 2014:
Quantitative analysis

Linear correlations between Swarm A 50 km MLAT scale sizes and Rate of TEC (ROT)



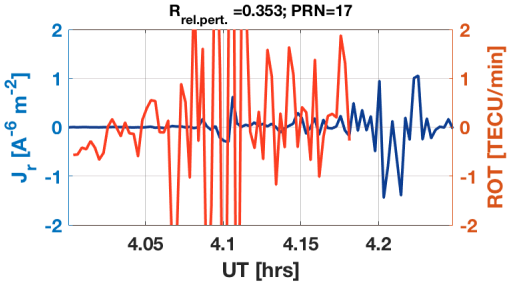
April 22, 2014:
Quantitative analysis

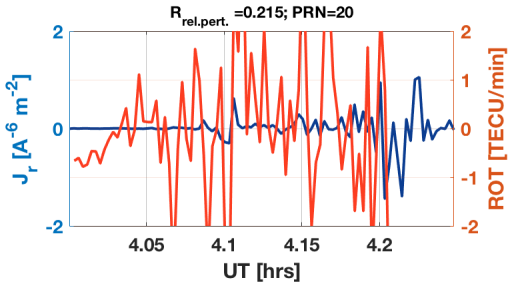
Linear correlations between Swarm A 50 km MLAT scale sizes and Rate of TEC (ROT)

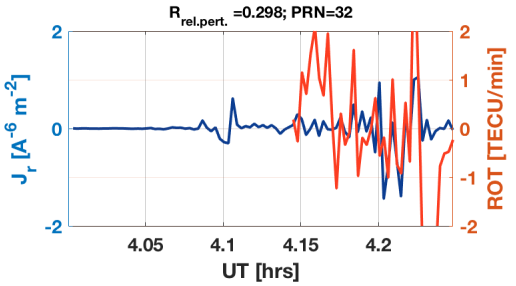
Elevation mask of 40º applied

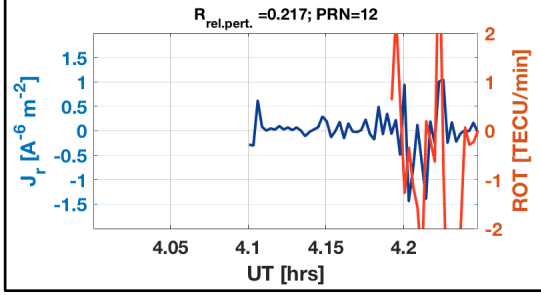
Increased correlations with ROT

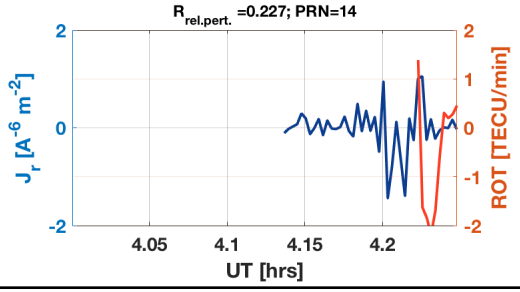
Expanded statistics needed











April 22, 2014:
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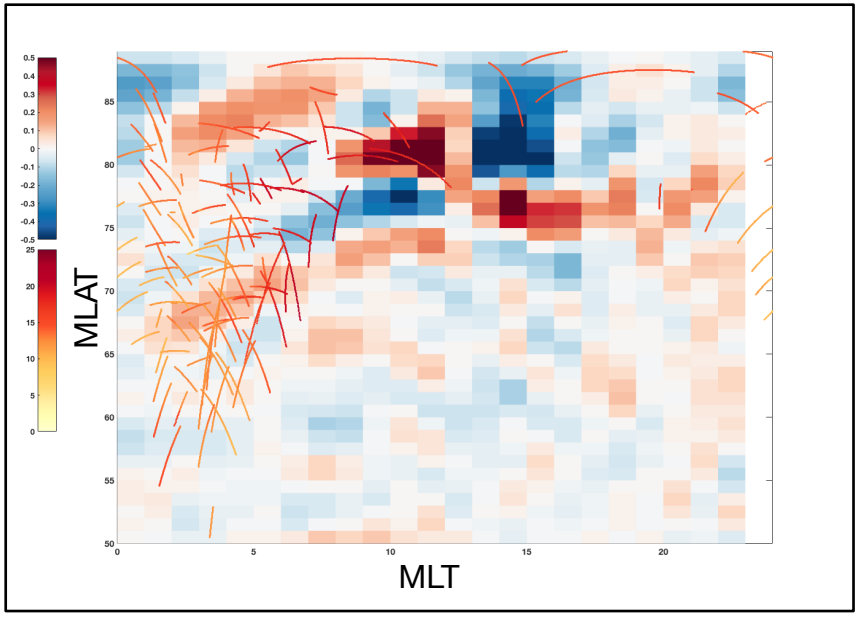
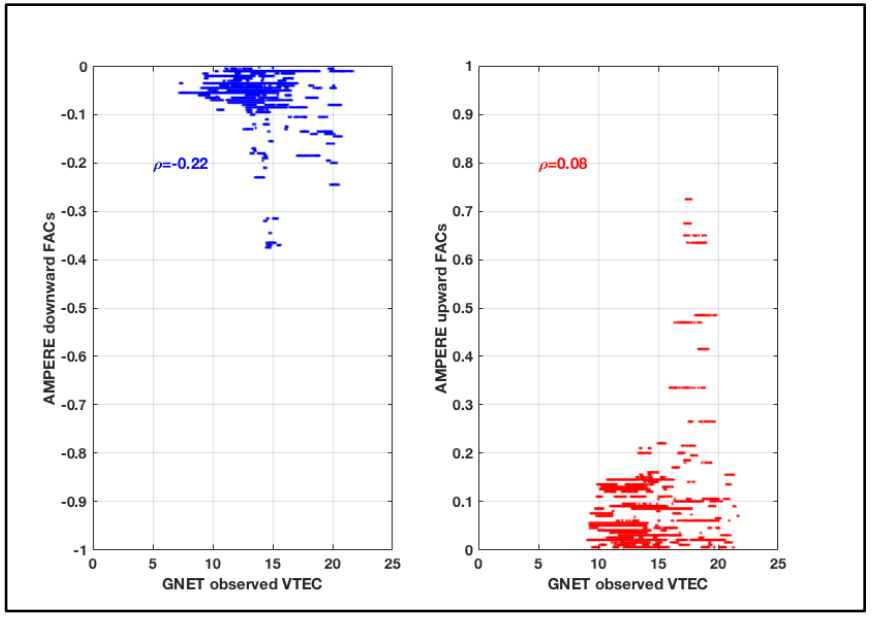
Examination of AMPERE FACs and ground-based VTEC





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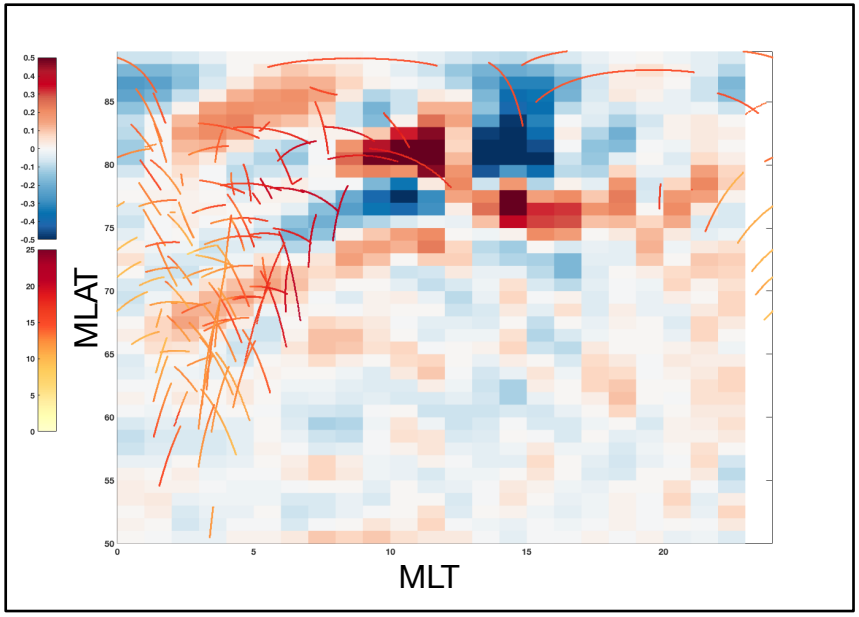

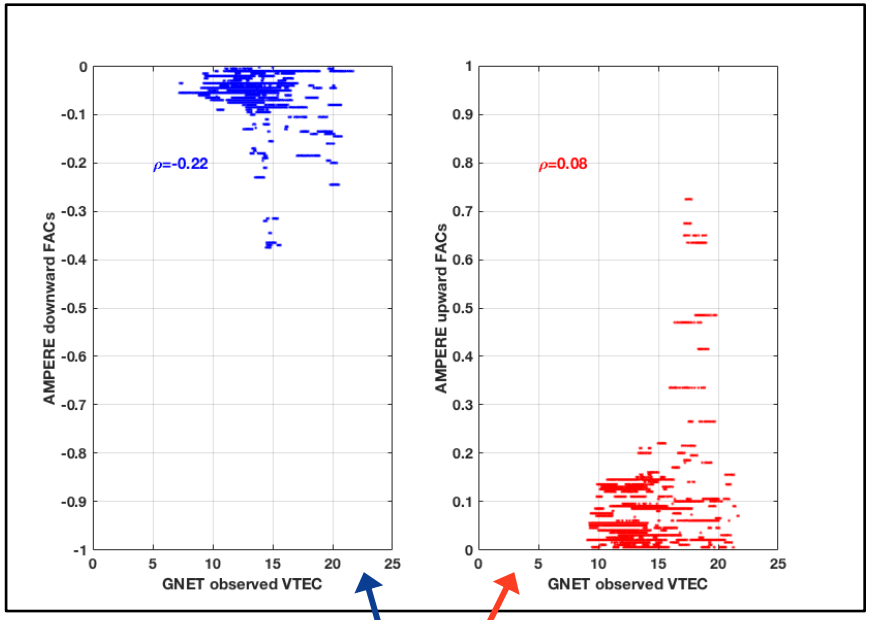

Relationships likely not linear

Additional event studies

Would also like to examine Juusola et al. [2016] event

Spoke with Kirsti Kauristie and Heikki Vanhamäki at Swarm meeting regarding this event

Juusola, L., W. E. Archer, K. Kauristie, J. K. Burchill, H. Vanhamäki, and A. T. Aikio (2016), Ionospheric conductances and currents of a morning sector auroral arc from Swarm-A electric and magnetic field measurements, Geophys. Res. Lett., 43,

Extension

Broader context: Wide-ranging exploration of high-latitude TEC and relationships with important variables of high-latitude MIT system

SQ #1: What observable signatures exist?

SQ #2: Can available TEC data be used to understand multi-scale ionosphere?

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- Explore potential nonlinear correlations (network analysis?)
- Machine learning approach with large amounts of data

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Correlations to explore:

Large-scales → AMPERE—VTEC
Small-scales → Swarm—TEC variability

Extension

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Convergence of data-intensive and event-specific approaches

Expansive study of Swarm FAC-TEC data

Based on extensive investigation of 2015 Swarm data

Do general FAC-TEC relationships exist?

How do we allow signals in these data to emerge?

Candidates for characteristic cases of FAC-TEC connection in Swarm data

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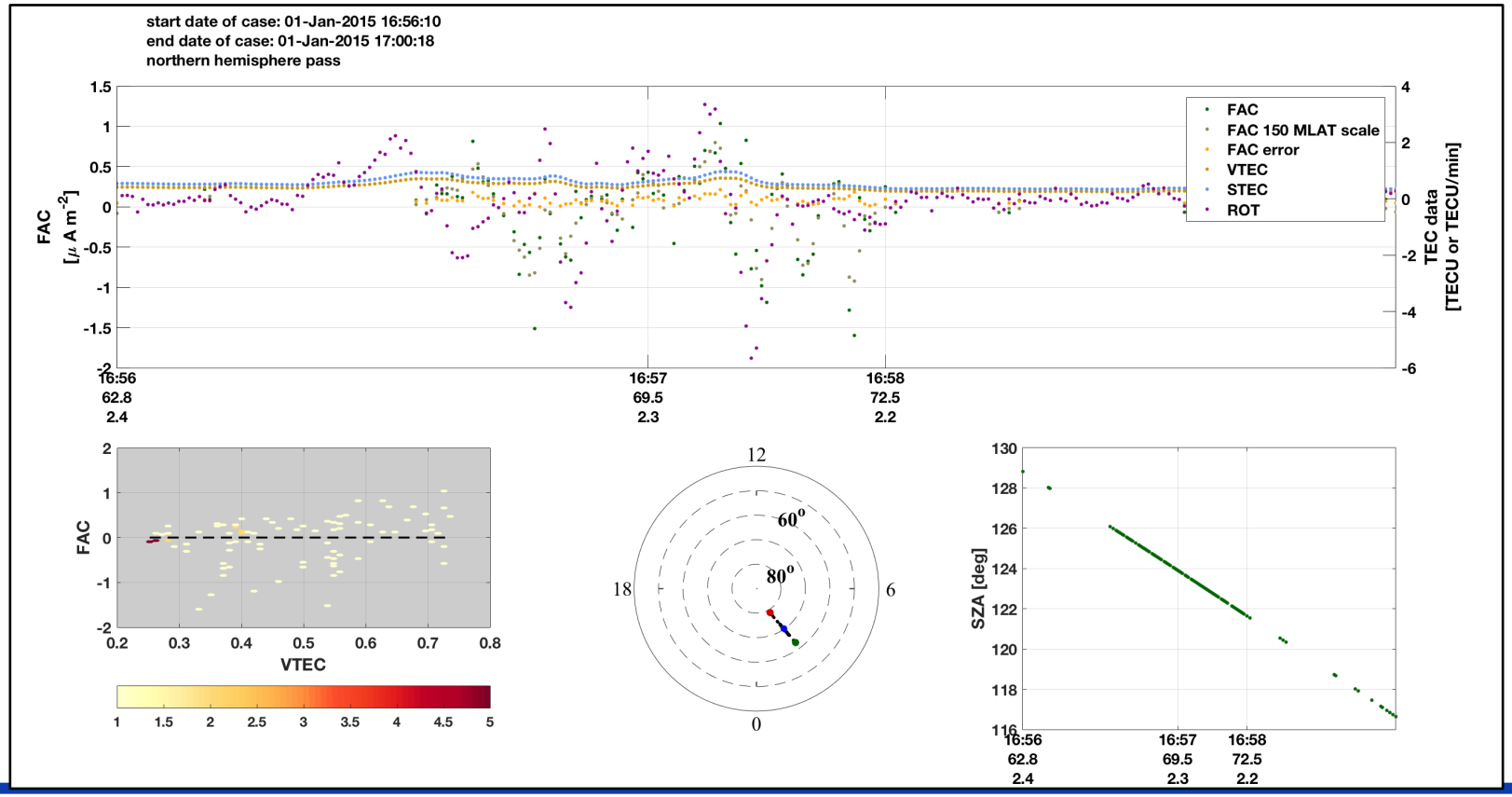
Case 1: Large SZA (e.g. nightside), moderate FAC dynamic range, located primarily in auroral zone

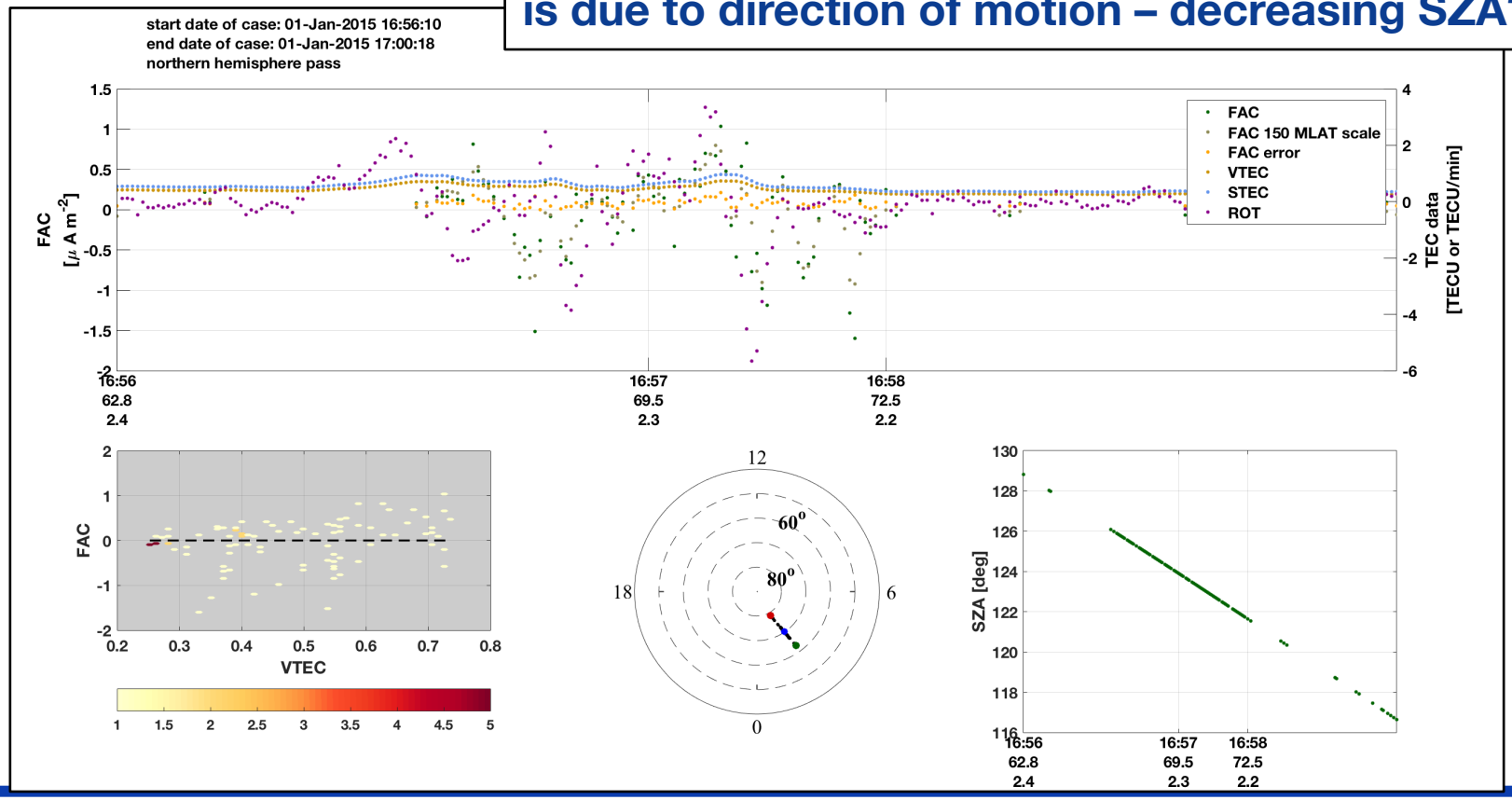


Candidates for characteristic cases of FAC-TEC connection in Swarm data

Case 1: Large SZA (e.g. r
primarily in auror

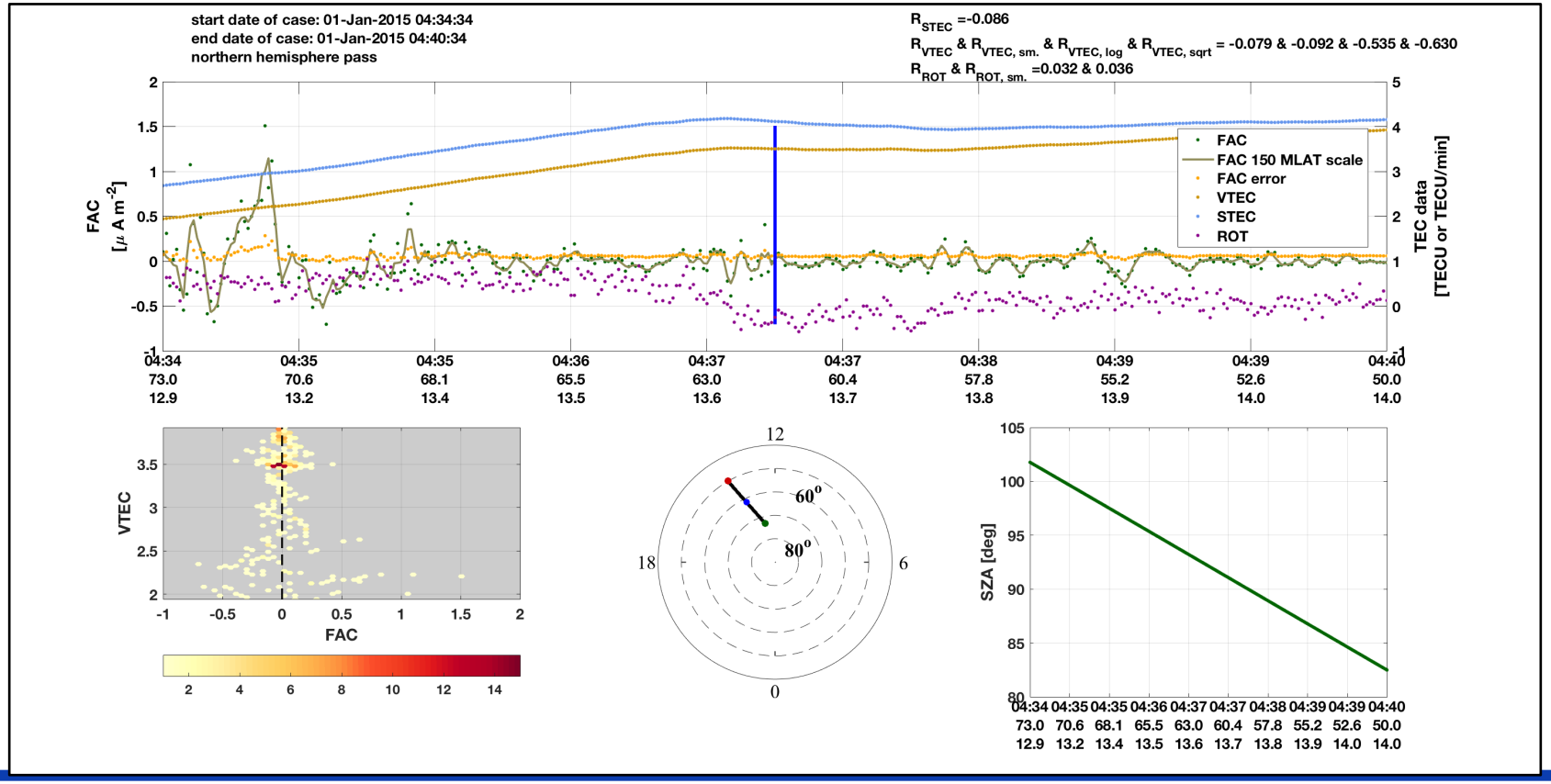
Correlations are considered high for highly dynamic unfiltered Swarm data (~0.2-0.3)

Negative correlation of ROT with FAC (maybe this is due to direction of motion – decreasing SZA?)



Candidates for characteristic cases of FAC-TEC connection in Swarm data

Case 2: Solar illuminated pass (SZA < 100 throughout), small-to-moderate FAC dynamic range, relationship likely not causal but instead TEC enhanced as illumination increases and FAC not playing large role)



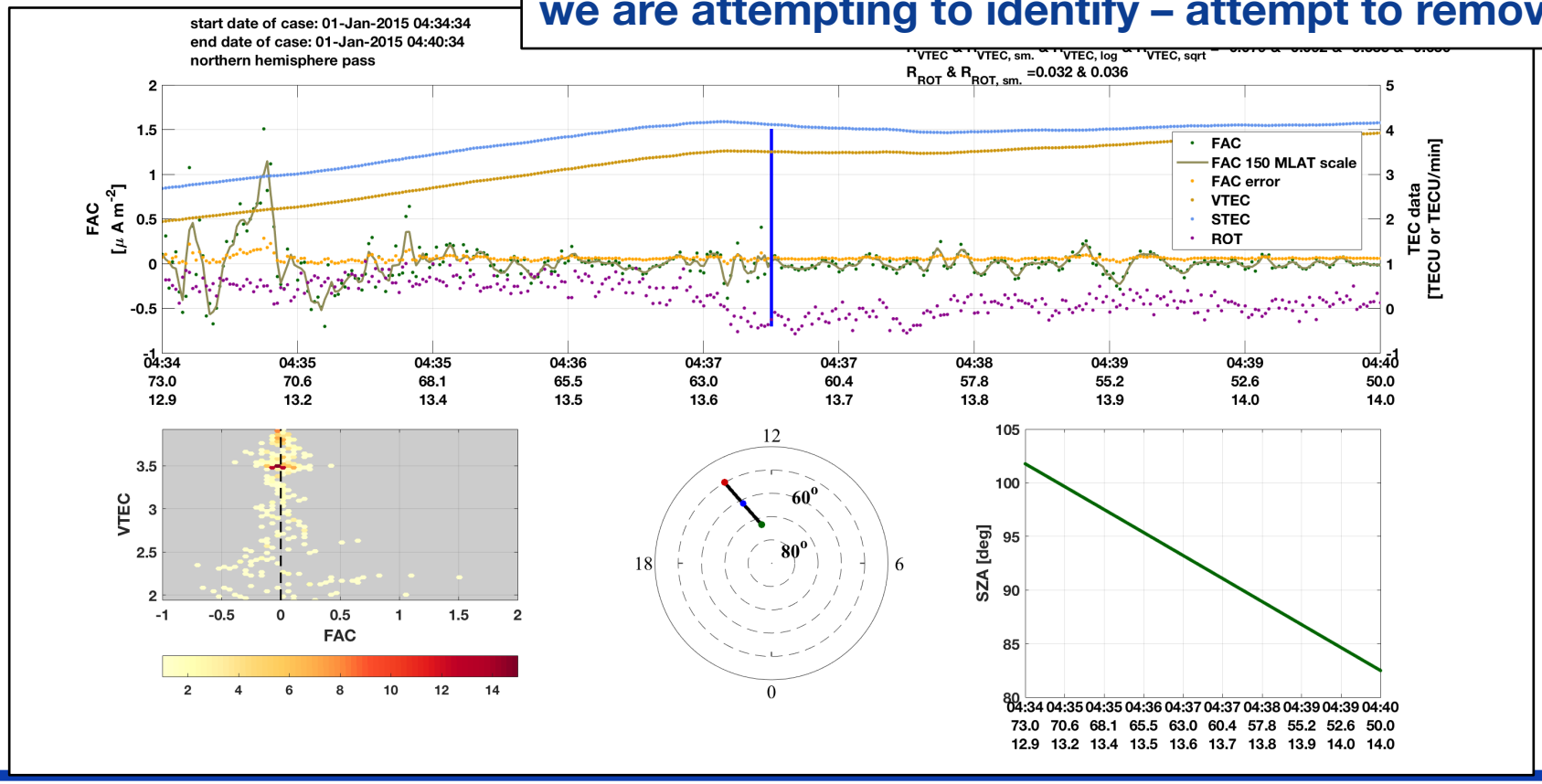
Candidates for characteristic cases of FAC-TEC connection in Swarm data

Statistical Results April 22, 2014 Event **Extension**

Case 2: Solar illuminated
dynamic range, r
enhanced as illu

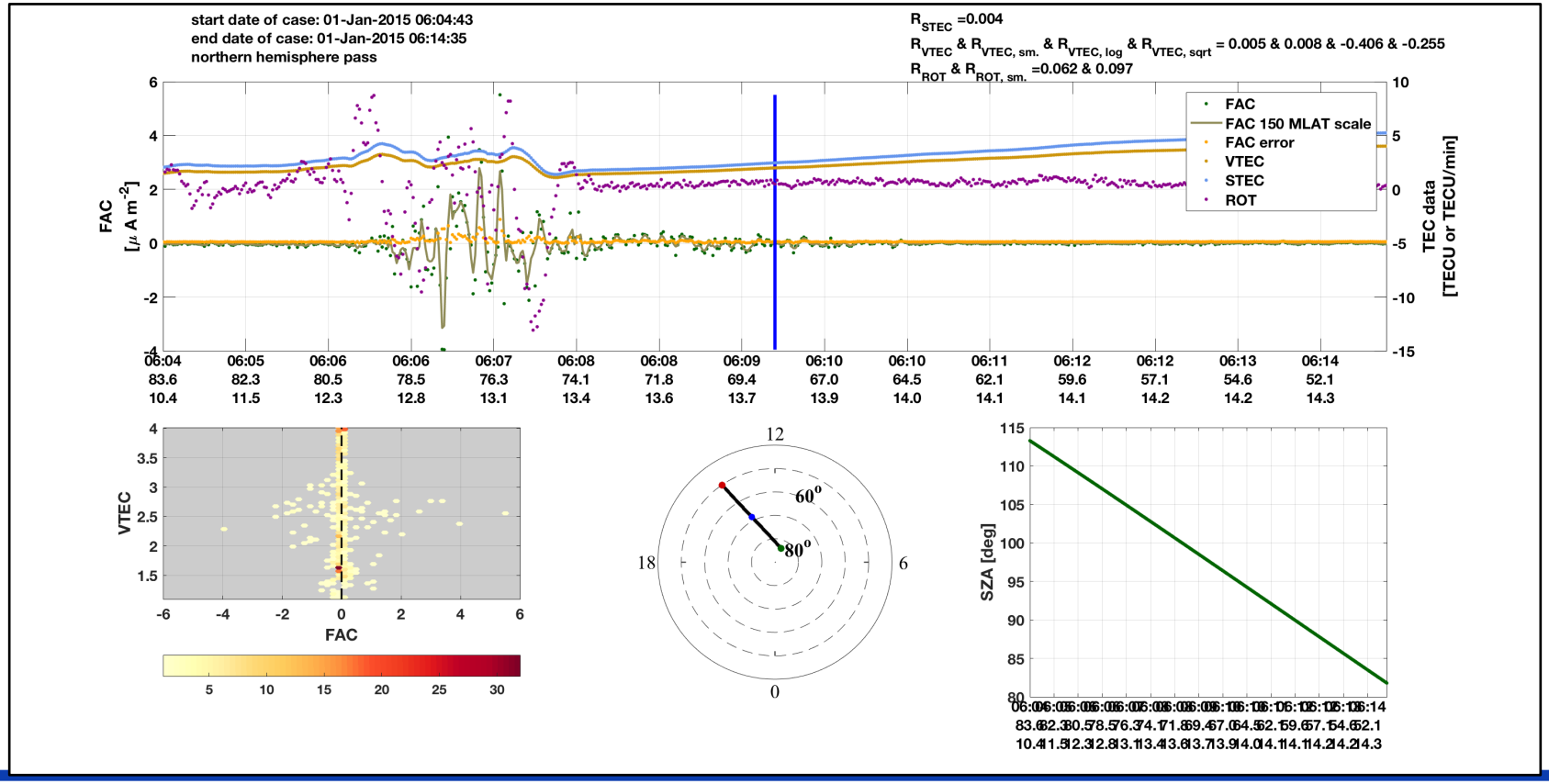
Negative correlation of abs(FAC) indicative of motion into areas of greater solar illumination

Likely would obfuscate broad statistical patterns we are attempting to identify – attempt to remove?



Candidates for characteristic cases of FAC-TEC connection in Swarm data

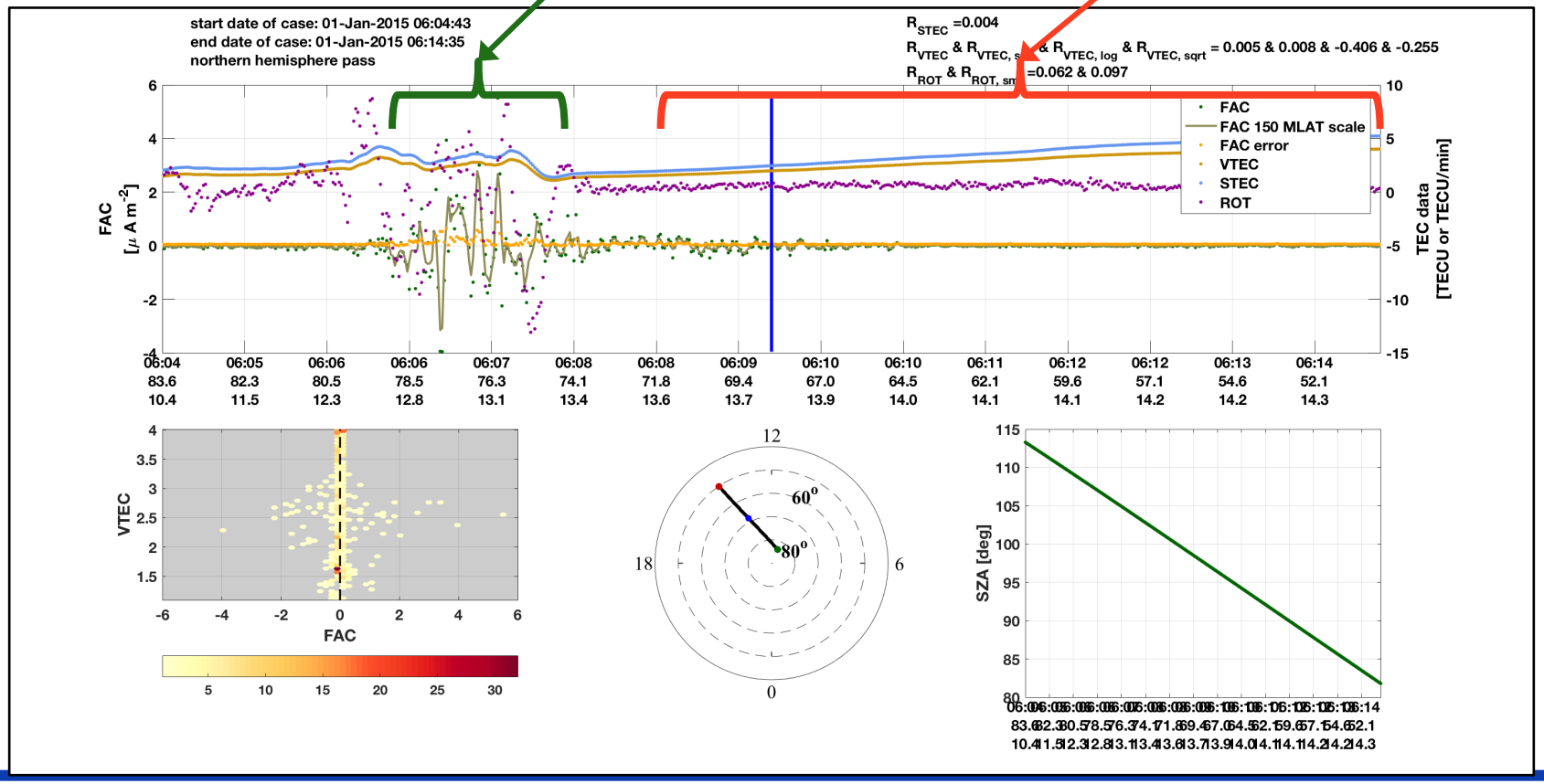
Case 3: Dual-influence (both illumination effect and additional effect generating FAC and TEC variability) variable FAC dynamic range, convoluted relationship



Candidates for characteristic cases of FAC-TEC connection in Swarm data

Case 3: Dual-influence (b
FAC and TEC va
relationship

Polar Cap causes one relationship, solar illumination causes another (convoluted result)



Candidates for characteristic cases of FAC-TEC connection in Swarm data

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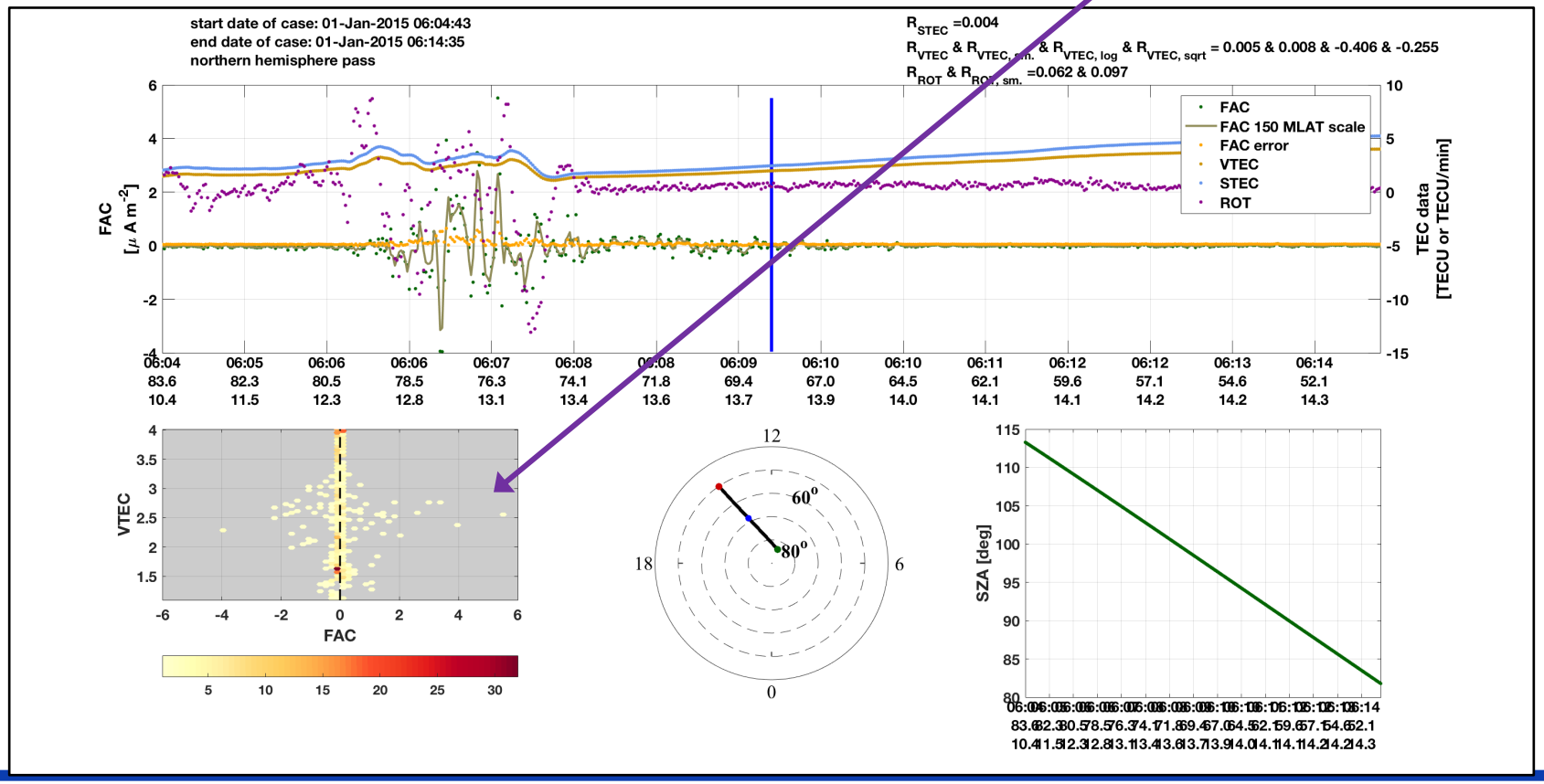
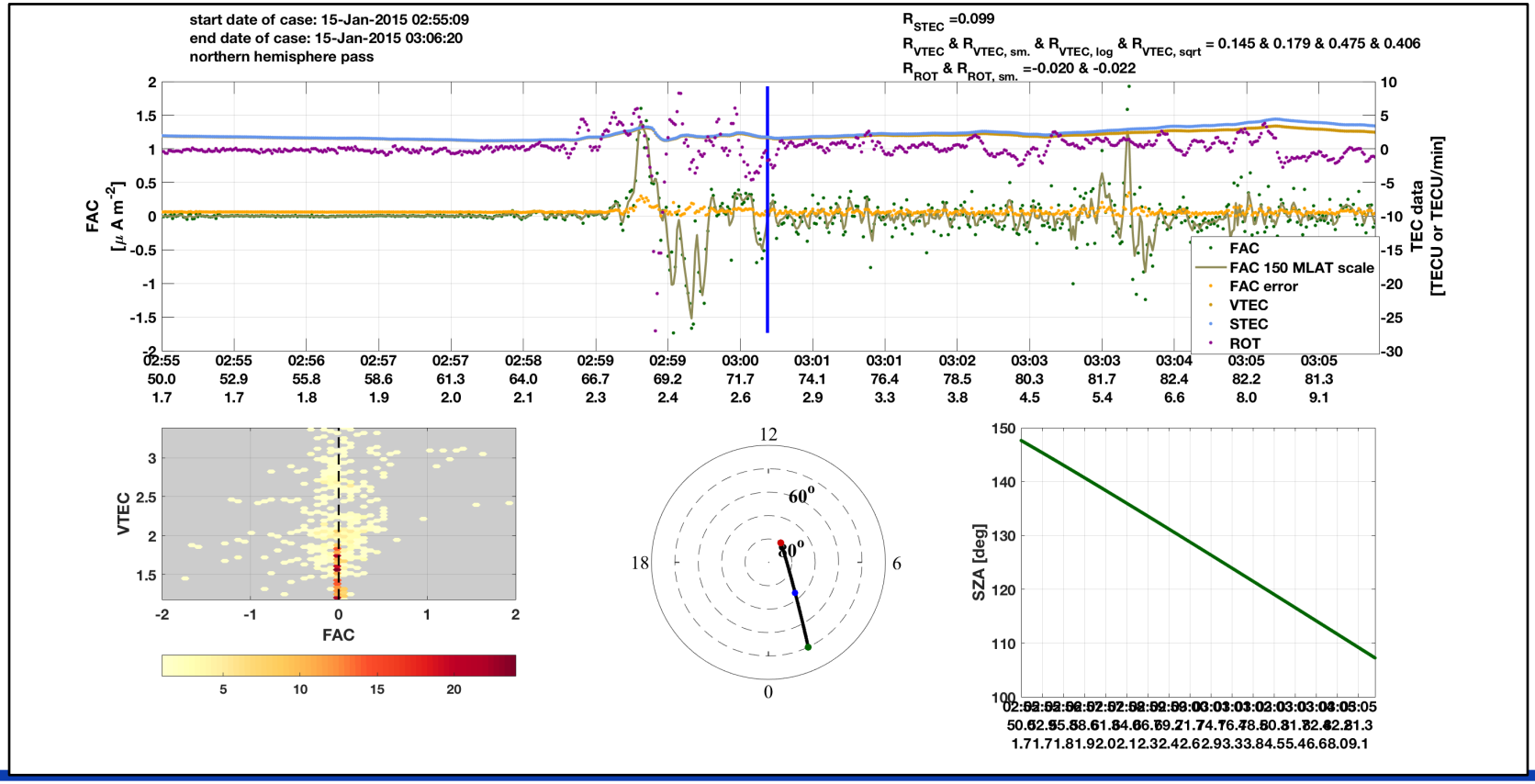


Candidates for characteristic cases of FAC-TEC connection in Swarm data

Case 4: Nightside auroral oval and negligible solar influences, expected FAC relationship



Candidates for characteristic cases of FAC-TEC connection in Swarm data

Statistical Results - April 22, 2014 Event - **Extension**

Case 4: Nightside auroral oval and negligible solar influences, expected FAC relationship