EUROPEAN SPACE WEATHER WEEK 2024

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DLR

Validation results of the Swarm ionospheric indices NeGIX and TEGIX

J. Andrés Cahuasquí, Mainul Hoque, Norbert Jakowski, Stephan Buchert, Dmytro Vasylyev, Grzegorz Nykiel, Martin Kriegel, Paul David, Youssef Tagargouste, Lars Tøffner-Clausen, Jens Berdermann

German Aerospace Center (DLR),
Swedish Institute of Space Physics (IRF),
Technical University of Denmark (DTU)

For contact and collaboration: **Andres.Cahuasqui@dlr.de**

Main points of the presentation

1 Reminder about the Swarm DISC Project MIGRAS

2 Introduction of the ionospheric gradient indices for the topside ionosphere using Swarm data – NeGIX and TEGIX

3 NeGIX and TEGIX: from definition to validation

4 NeGIX and TEGIX: operational Swarm product
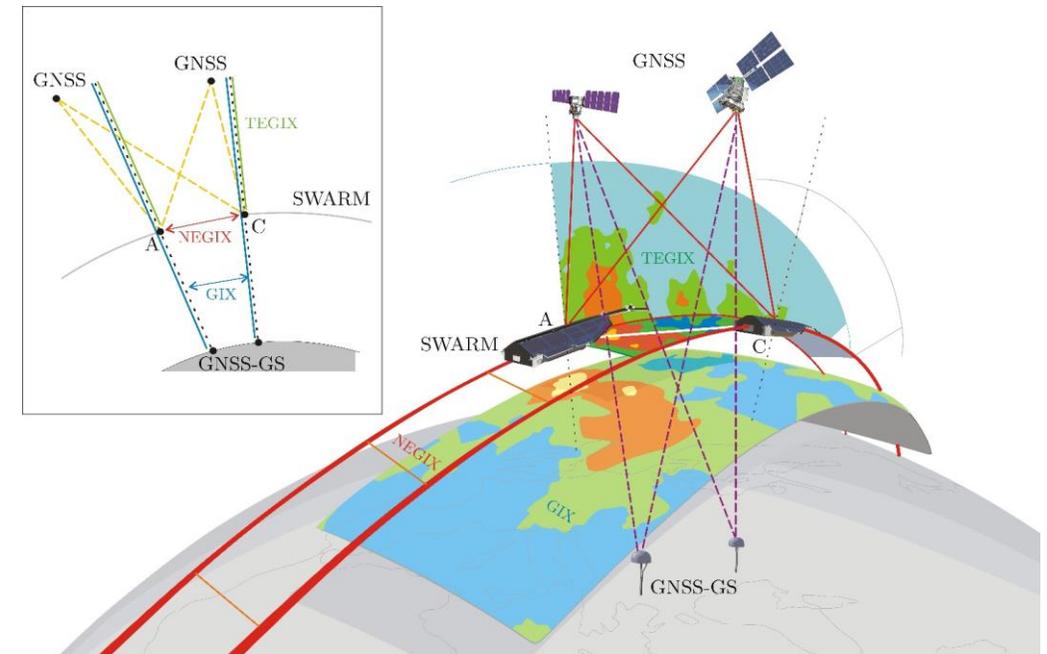
5 Conclusions

Monitoring Ionospheric GRAdients using Swarm – MIGRAS (Swarm DISC Subcontract SW-CO-DTU-GS-133)

DLR has developed a cluster of ionospheric indices and products for the characterization of the ionospheric perturbation degree. They are based on ground-based GNSS measurements:

- Disturbance Ionosphere IndeX Spatial Gradient – DIXSG

- Gradient Ionospheric indeX – GIX

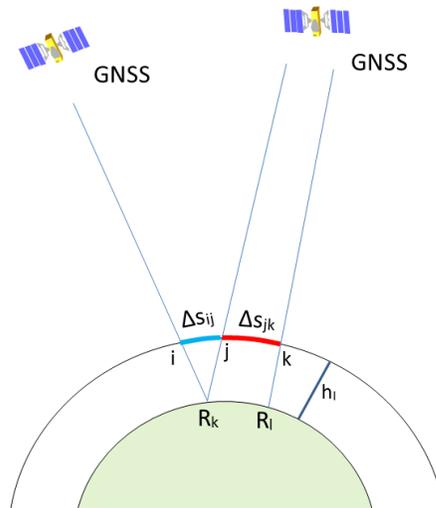- Sudden Ionospheric Disturbance indeX – SIDX

Space-based observations with Swarm offer a broad spectrum of data for space weather monitoring and research. The MIGRAS project has aimed at:

- broadening the Swarm data products, tools and services for monitoring small- to mid-scale irregularities – in the order of about 100 km

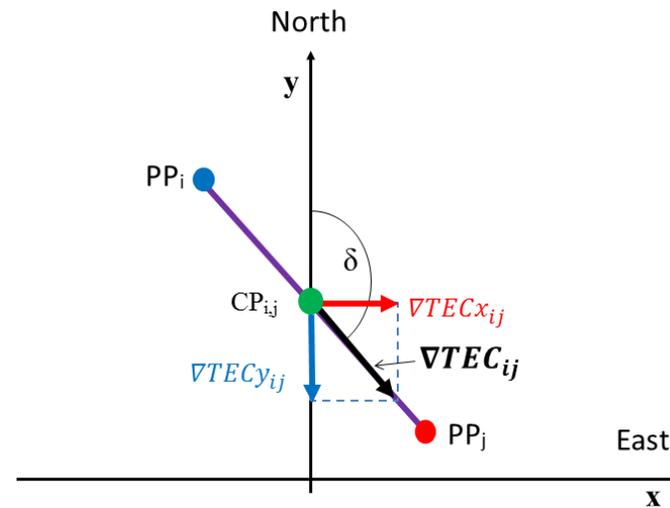- **developing two new data products using Swarm satellites A and C – NeGIX and TEGIX**

NeGIX and TEGIX are developed following the approach of the ground-based Gradient Ionospheric indeX (GIX)*

GIX is a spatial TEC gradient for the regional characterization of ionospheric perturbations from medium to large scales (about 30-300 km)

$$\langle \nabla TECx \rangle = \frac{1}{N_C} \sum_{i=1}^{N_C} \nabla TECx_{ij}$$

$$\langle \nabla TECy \rangle = \frac{1}{N_C} \sum_{i=1}^{N_C} \nabla TECy_{ij}$$

$$\nabla TEC_{ij} = (VTEC_i - VTEC_j) \cdot \frac{1}{\Delta s_{ij}}$$

$$\nabla TEC_{Xij} = \nabla TEC_{ij} \cdot \sin \delta \quad \text{(zonal)}$$

$$\nabla TEC_{Yij} = \nabla TEC_{ij} \cdot \cos \delta \quad \text{(meridional)}$$

$$GIX = \langle \nabla TEC \rangle = \sqrt[2]{\langle \nabla TECx \rangle^2 + \langle \nabla TECy \rangle^2}$$

$$GIXS \equiv \sigma(\nabla TEC) = \sqrt[2]{(\langle \nabla TEC^2 \rangle - \langle \nabla TEC \rangle^2)}$$

NeGIX

spatial Ne-gradient index product based on Langmuir probe observations

- It is the statistical measurement (mean, standard deviation, 95-percentile) of gradient vectors that characterize the electron density structure of the ionosphere over a selected area along the Swarm orbit

- It is defined at an altitude of ca. 460 km (Swarm positions)

- It uses in-situ electron density data from Langmuir probes onboard Swarm A and Swarm C satellites (Level-1 data EFIA_LP_1B with 0.5 second resolution)

- It combines Ne-measurements between same satellite and also in the longitudinal (zonal) direction between different satellites

- It has a resolution of 0.5 degrees along the satellites track (latitudinally), or 8 seconds
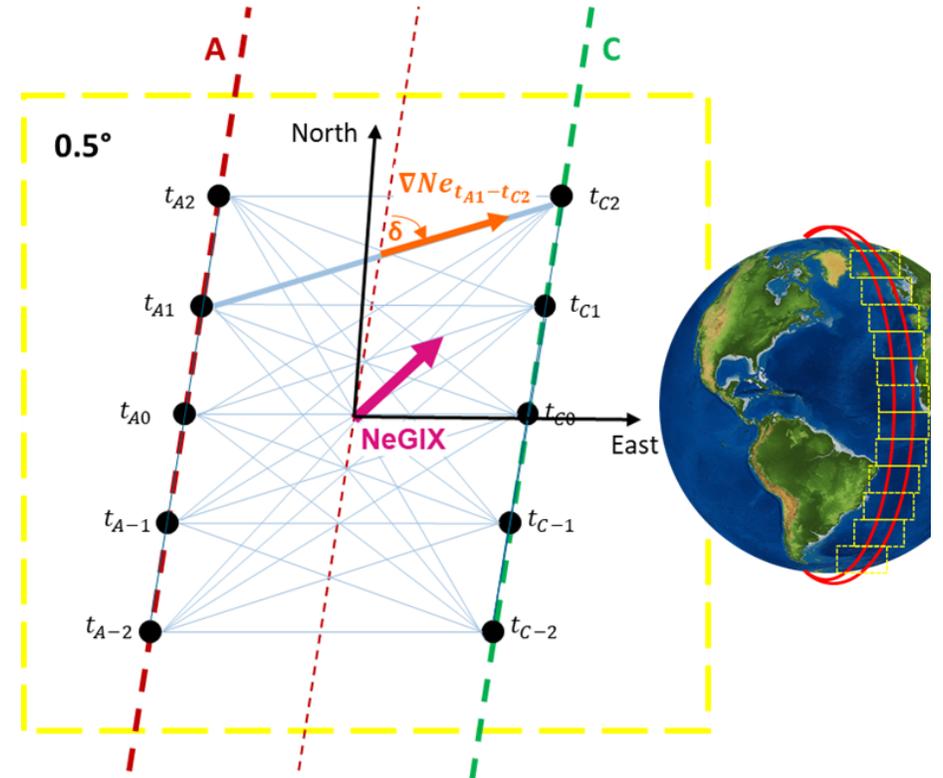
NeGIX and TEGIX: MIGRAS products for the characterization of the topside ionosphere using Swarm A and C
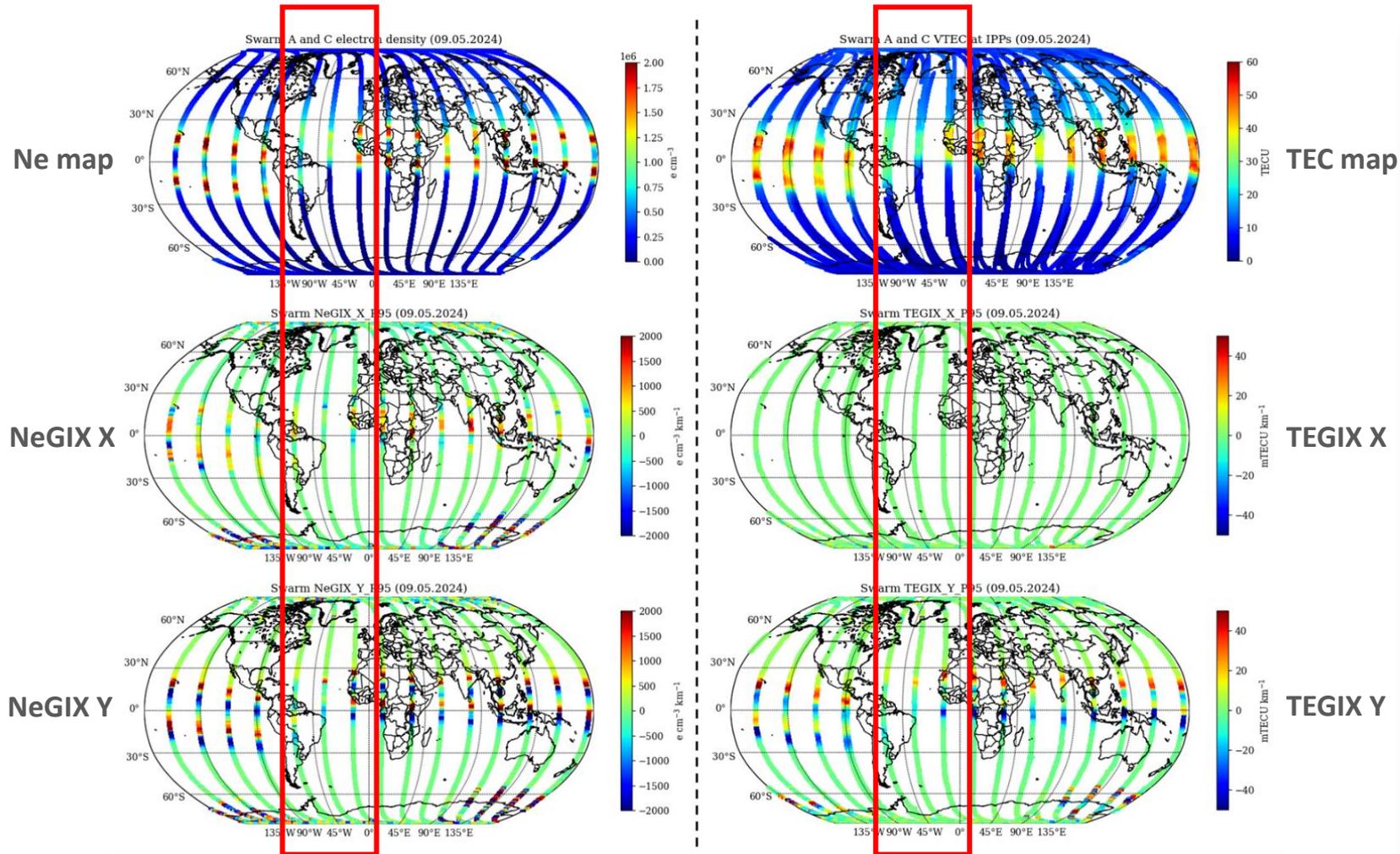
TEGIX

spatial TEC-gradient index product based on Swarm GNSS Precise Orbit Determination observations

- It is the statistical measurement (mean, standard deviation, 95-percentile) of gradient vectors that characterize the topside TEC-structure of the ionosphere over a selected area along the Swarm orbit

- It is defined at an altitude of ca. 660 km

- It uses absolute/calibrated Vertical Total Electron Content (VTEC) obtained from POD data of Swarm-A and Swarm-C satellites (Level-2 data TECATMS_2F with 1 second resolution)

- To avoid Differential Code Biases (DCB) from Swarms A and C, it combines only ionospheric pierce points (IPPs) from the same Swarm satellite

- It has a resolution of 0.5 degrees along the satellites track (latitudinally), or 8 seconds
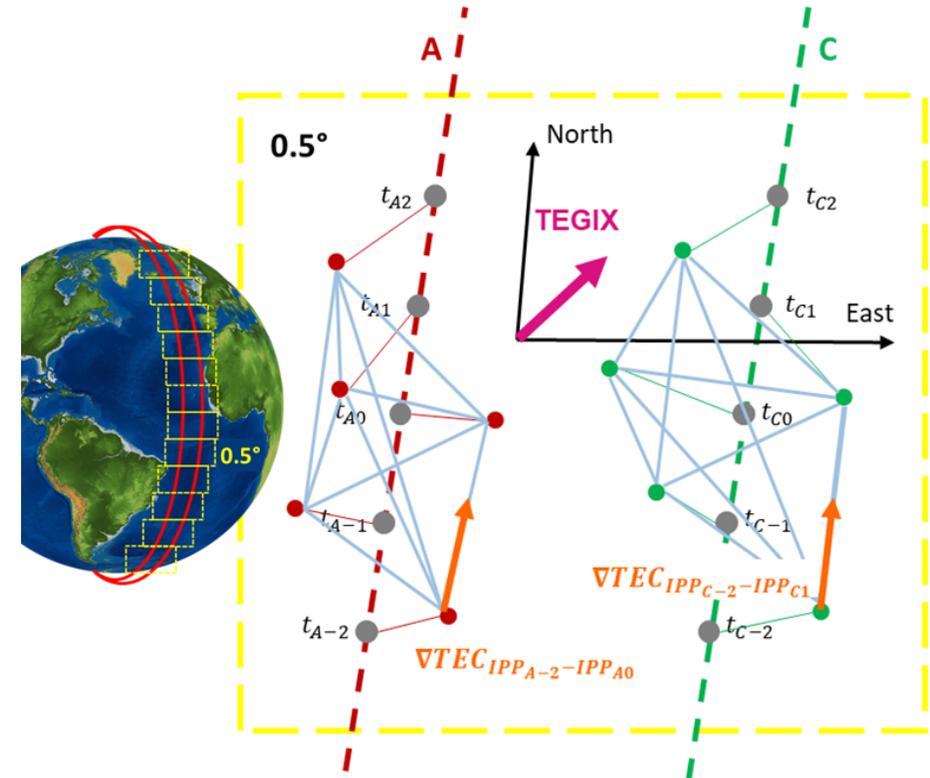
Validation of products: NeGIX and TEGIX during the quiet geomagnetic conditions of May 9th, 2024

Ne map

Swarm A and C electron density (09.05.2024)

TEC map

Swarm A and C VTEC at IPPs (09.05.2024)

NeGIX X

Swarm NeGIX_X P95 (09.05.2024)

TEGIX X

Swarm TEGIX_X P95 (09.05.2024)

NeGIX Y

Swarm NeGIX_Y P95 (09.05.2024)

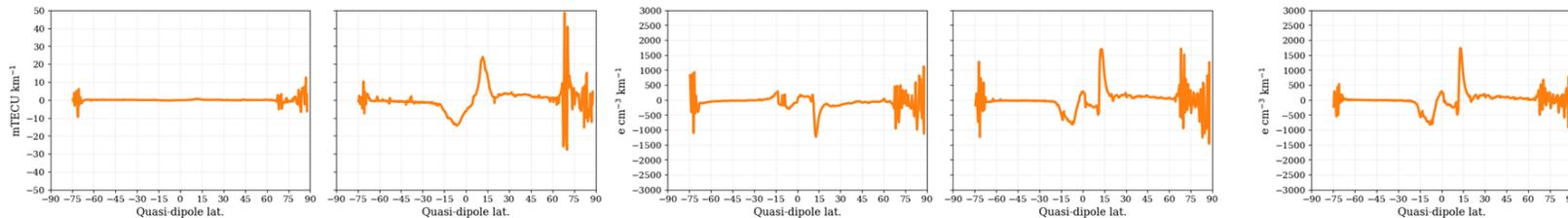**TEGIX Y**

Swarm TEGIX_Y P95 (09.05.2024)

- For the quiet day of May 9th, 2024 (eq. pass at 19.3h LT), NeGIX and TEGIX clearly characterize the double equatorial crests observed in the Swarm Langmuir probe in-situ data and the TEC data

- In addition to the meridional structures, also the zonal gradient (NeGIX X P95) presents variability due to ionospheric perturbations in a range of about 170 km (separation between Swarm A and C for this date)

- The meridional gradients also identify ionospheric variability in sub-auroral latitudes

Validation of products: NeGIX and TEGIX during the quiet geomagnetic conditions of May 9th, 2024
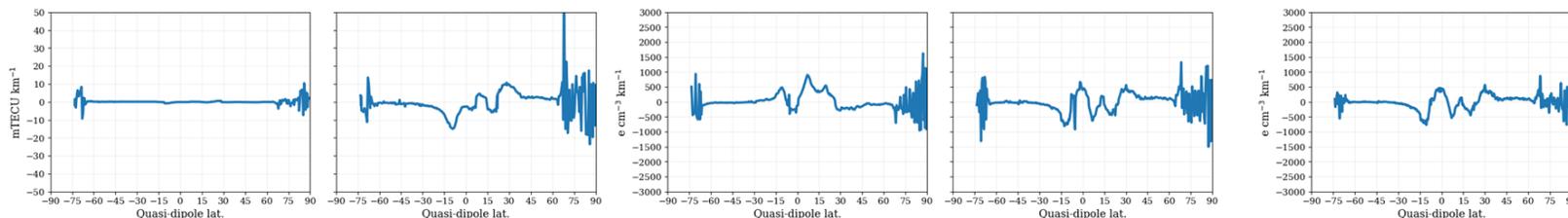

May 9th, 2024 – Orbit at 20:03 UT, along 13°W
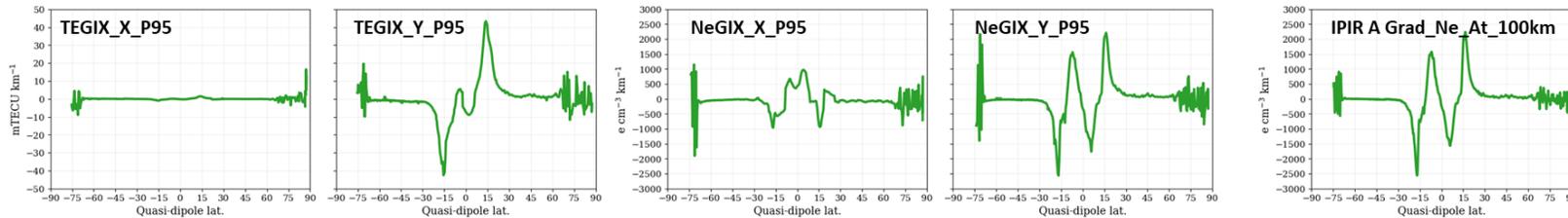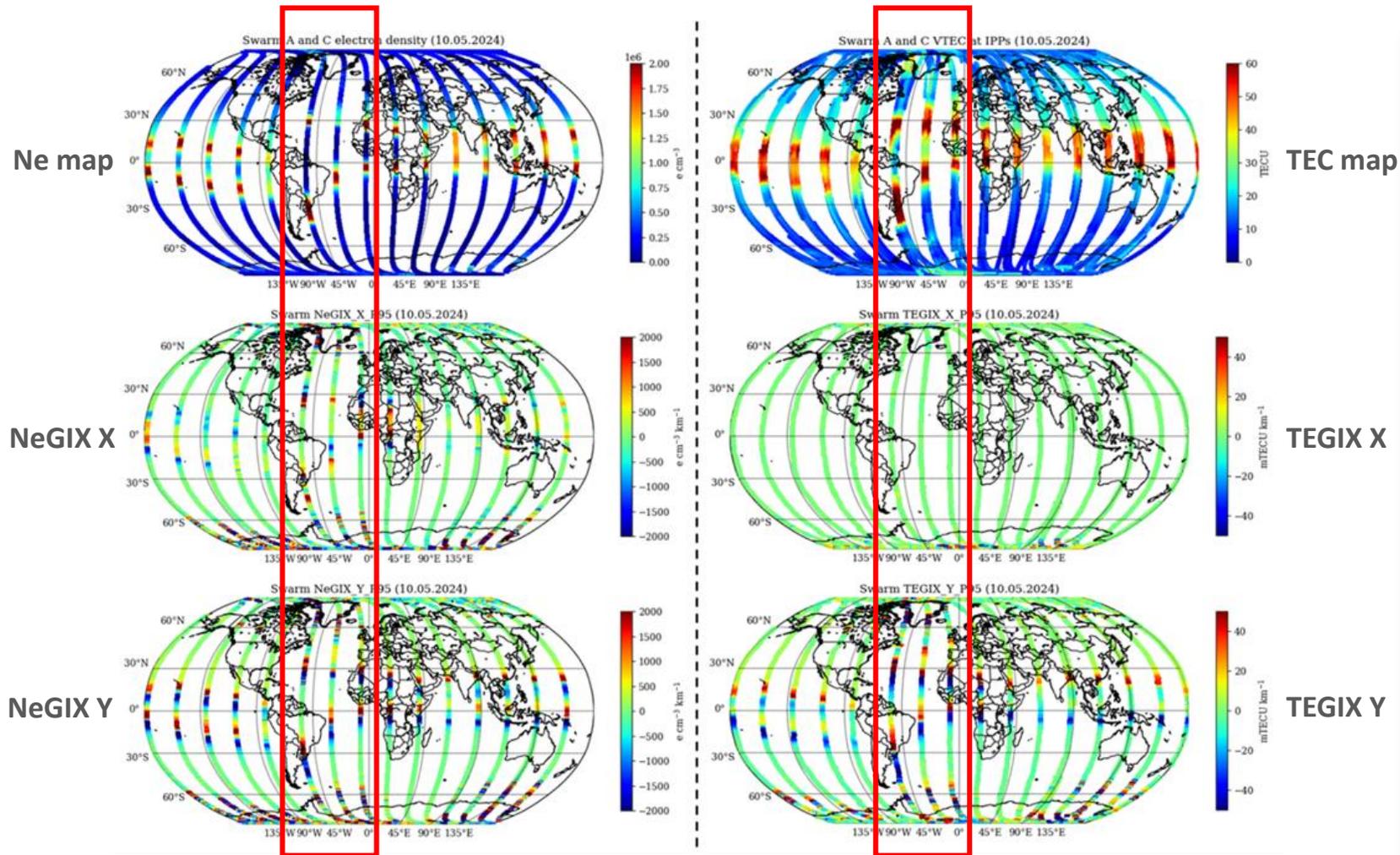
May 9th, 2024 – Orbit at 21:37 UT, along 36°W

May 9th, 2024 – Orbit at 23:11 UT, along 60°W

- The meridional (Y) components of TEGIX and NeGIX show the double equatorial crests observed in the Swarm Langmuir probe in-situ data and the TEC data
- NeGIX Y and TEGIX Y show comparable trends, although with differences due to their product definition
- NeGIX shows gradients in the zonal (X) direction – especially in equatorial- and high-latitudes
- TEGIX X is not expected to show strong indices due to the definition of data combination and geometry of measurements
- Comparison with the Swarm IPIR data products validates the estimation of our gradients in the meridional direction
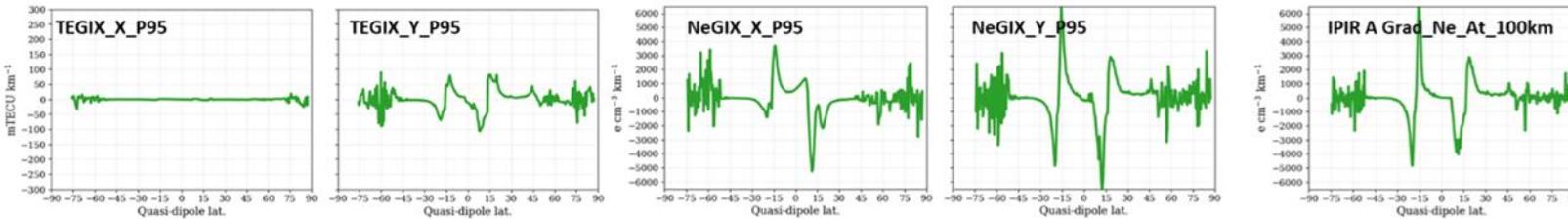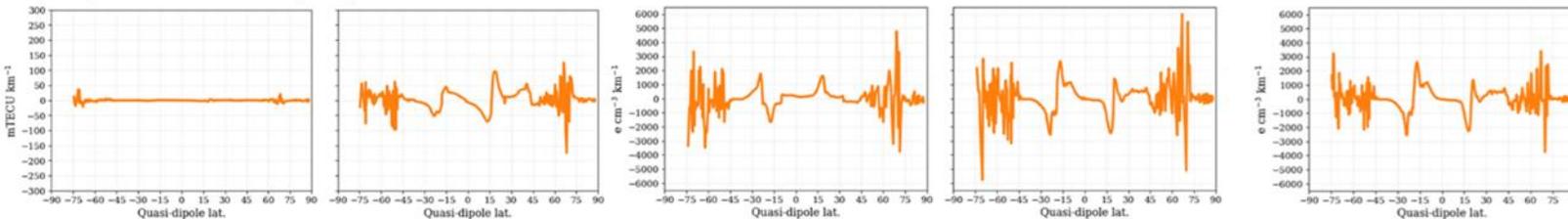
Ne map

NeGIX X

NeGIX Y

TEC map

TEGIX X

TEGIX Y

- For the storm day of May 10th, 2024 (eq. pass at 19.2h LT), the Swarm electron density and TEC data show enhancement in amplitude and extension.
- NeGIX and TEGIX clearly characterize the double equatorial crests observed in the Swarm Langmuir probe in-situ data and the TEC data
- In addition to the meridional structures, also the zonal gradient (NeGIX X P95) presents variability due to ionospheric perturbations in a range of about 170 km (separation between Swarm A and C for this date)
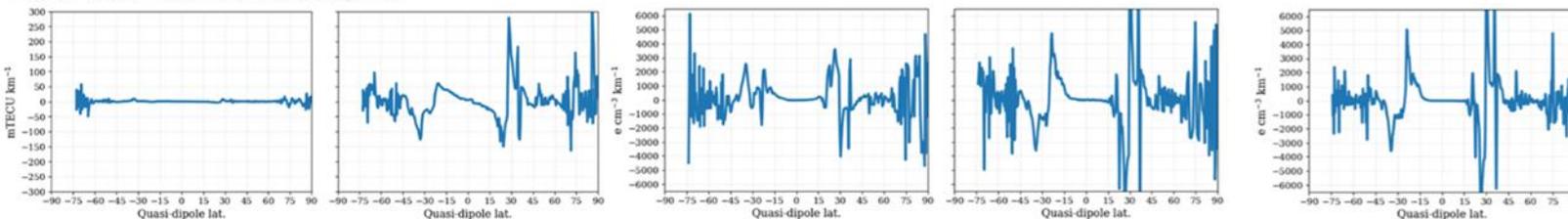- The meridional gradients also identify ionospheric variability in mid- and high-latitudes

May 10th, 2024 – Orbit at 19:34 UT, along 7°W
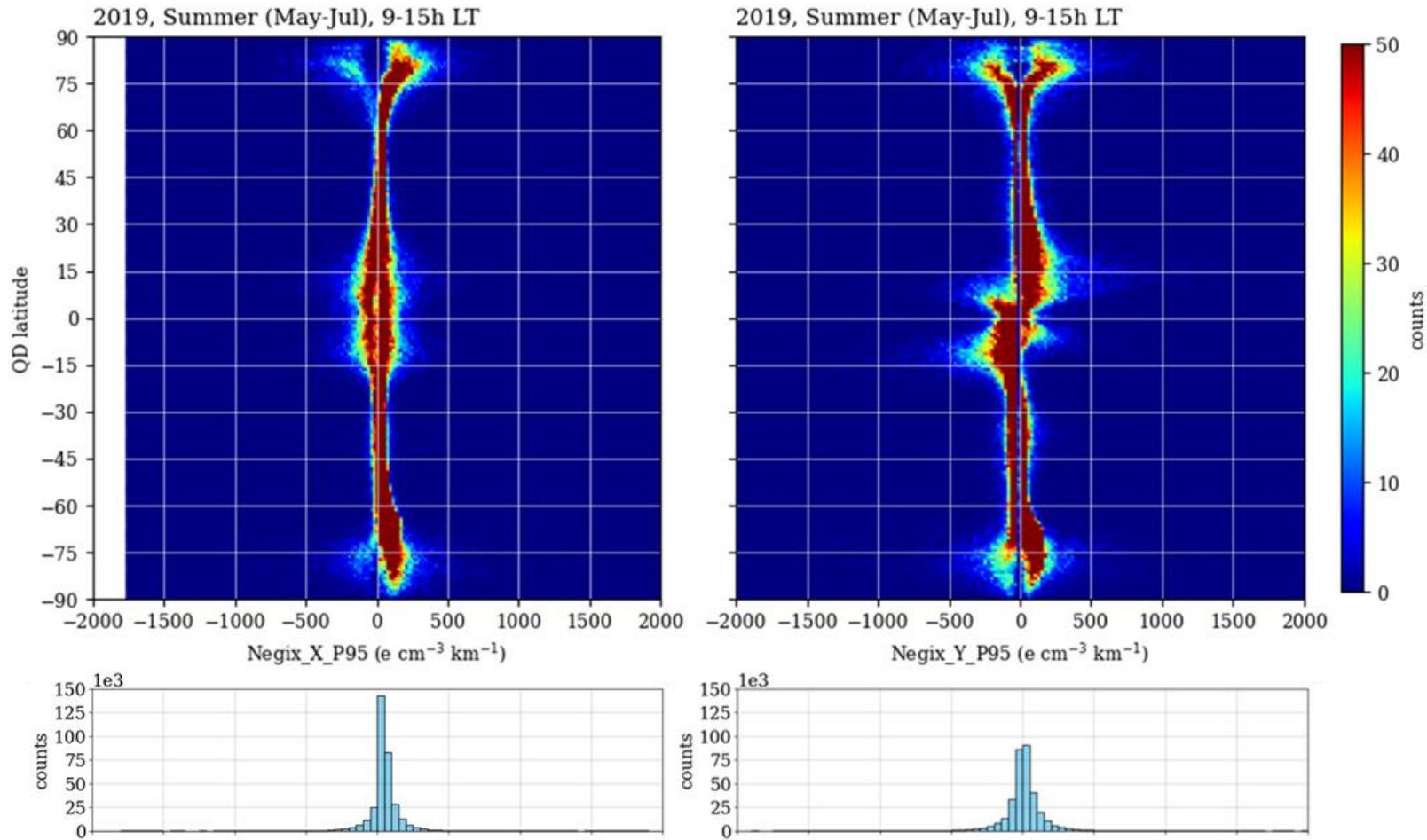May 10th, 2024 – Orbit at 21:08 UT, along 30°W
May 10th, 2024 – Orbit at 22:42 UT, along 54°W

- The meridional (Y) components of TEGIX and NeGIX show the double equatorial crests observed in the Swarm Langmuir probe in-situ data and the TEC data
- NeGIX Y and TEGIX Y show comparable trends, although with differences due to their product definition
- NeGIX shows gradients in the zonal (X) direction – especially in equatorial- and high-latitudes
- TEGIX X is not expected to show strong indices due to the definition of data combination and geometry of measurements
- Comparison with the Swarm IPIR data products validates the estimation of our gradients in the meridional direction

2019, Summer (May-Jul), 9-15h LT

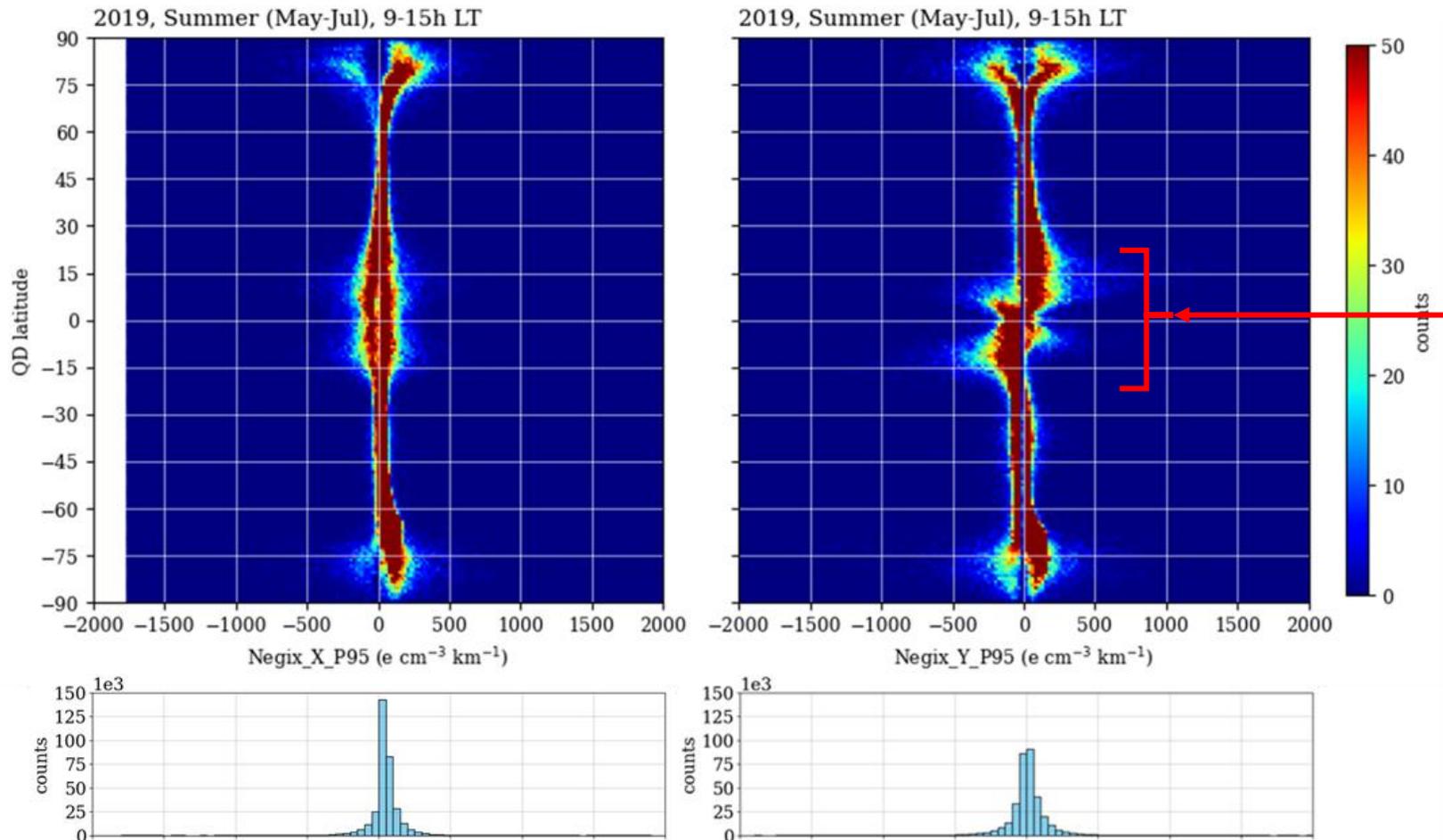2019, Summer (May-Jul), 9-15h LT

The 3-month density plots of NeGIX values as a function of quasi-dipole magnetic latitude show:

- Small gradient values (red-color distribution and slim histogram distribution)

- Equatorial ionospheric crests depicted in the zonal (X) and meridional (Y) components of NeGIX

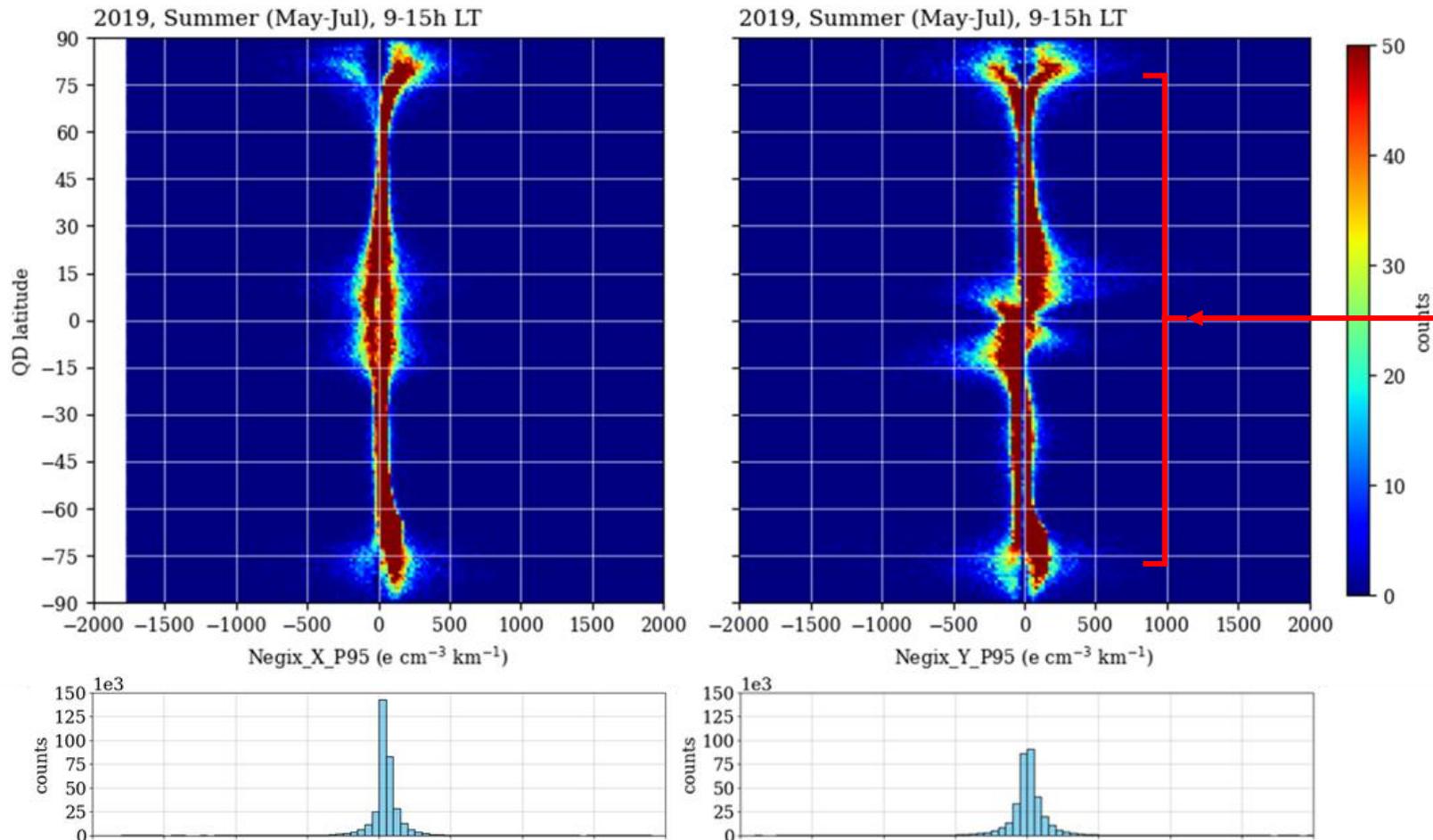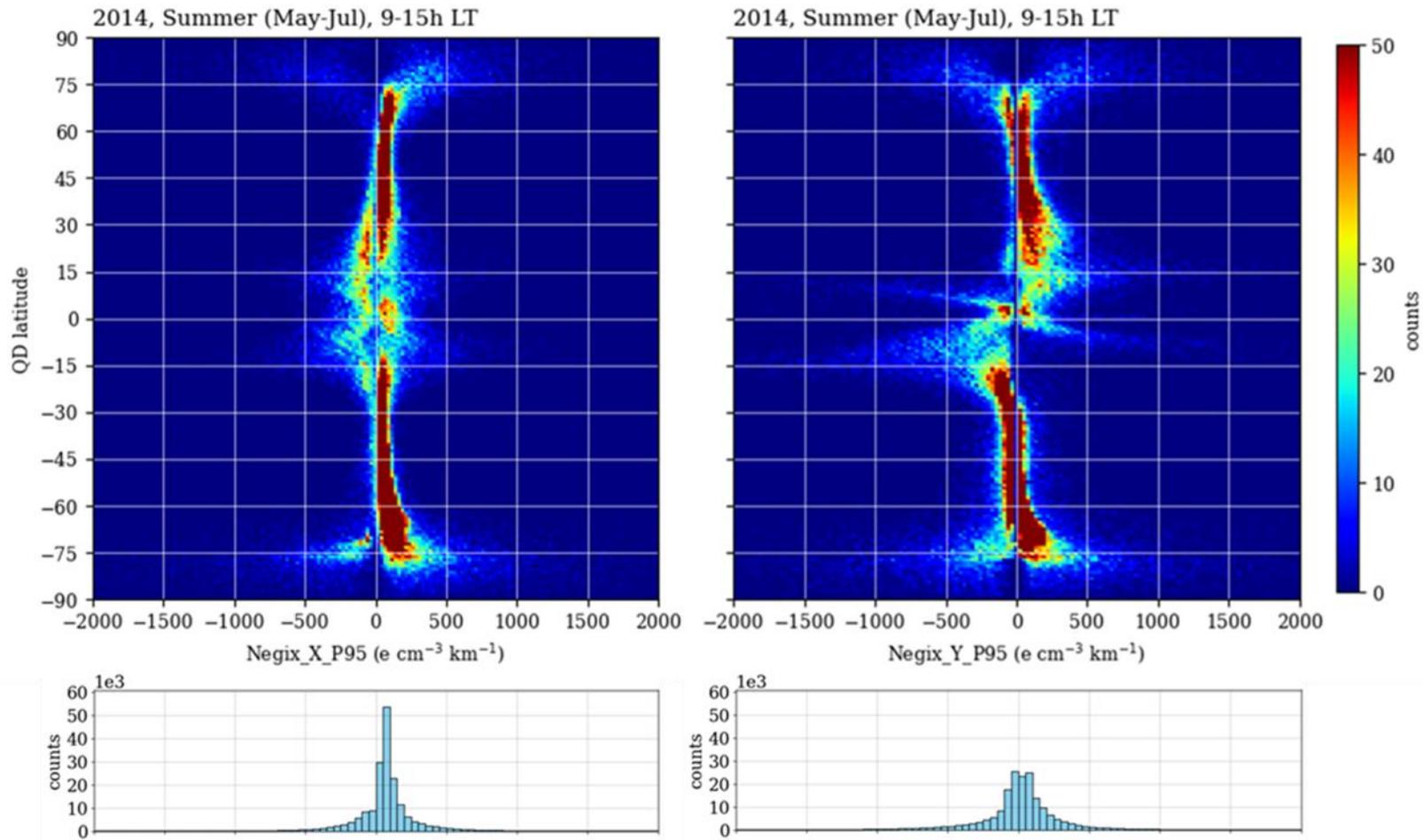- Strong variability and gradients at high-latitudes

Validation of products: NeGIX during diurnal LT of summer 2019 (solar minimum)

The 3-month density plots of NeGIX values as a function of quasi-dipole magnetic latitude show:

- Small gradient values (red-color distribution and slim histogram distribution)

- Equatorial ionospheric crests depicted in the zonal (X) and meridional (Y) components of NeGIX

- Strong variability and gradients at high-latitudes

2019, Summer (May-Jul), 9-15h LT

2019, Summer (May-Jul), 9-15h LT

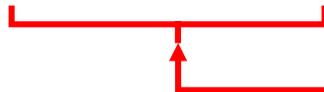The 3-month density plots of NeGIX values as a function of quasi-dipole magnetic latitude show:

- Small gradient values (red-color distribution and slim histogram distribution)

- Equatorial ionospheric crests depicted in the zonal (X) and meridional (Y) components of NeGIX

- **Strong variability and gradients at high-latitudes**

2014, Summer (May-Jul), 9-15h LT
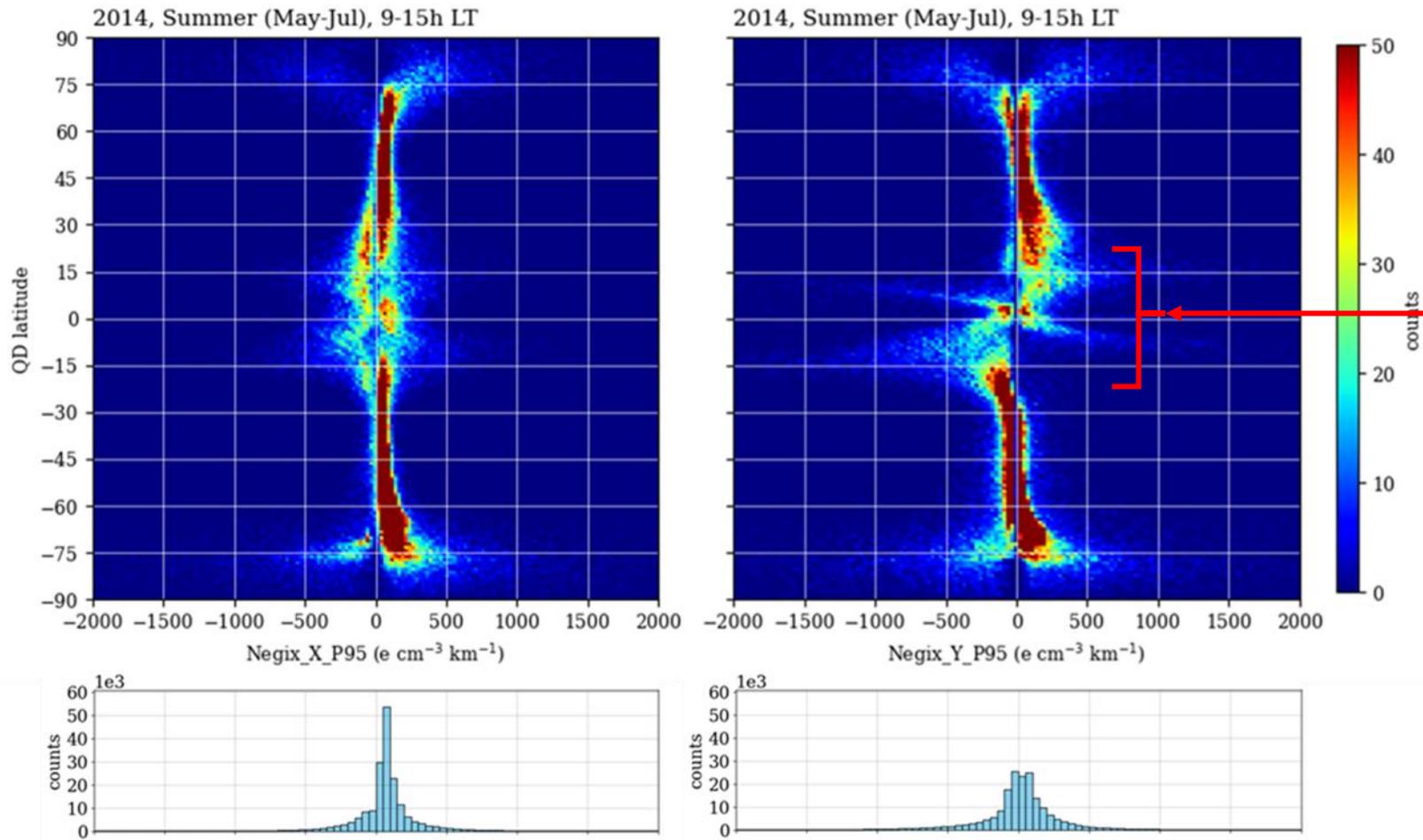
2014, Summer (May-Jul), 9-15h LT

The 3-month density plots of NeGIX values as a function of quasi-dipole magnetic latitude show:

- Large gradient values (dispersed colormaps and extended histogram distribution)

- Equatorial ionospheric crests depicted in the zonal (X) and meridional (Y) components of NeGIX with extended and dispersed values

- Strong variability and gradients at high-latitudes

2014, Summer (May-Jul), 9-15h LT

2014, Summer (May-Jul), 9-15h LT

The 3-month density plots of NeGIX values as a function of quasi-dipole magnetic latitude show:

- Large gradient values (dispersed colormaps and extended histogram distribution)

- Equatorial ionospheric crests depicted in the zonal (X) and meridional (Y) components of NeGIX with extended and dispersed values

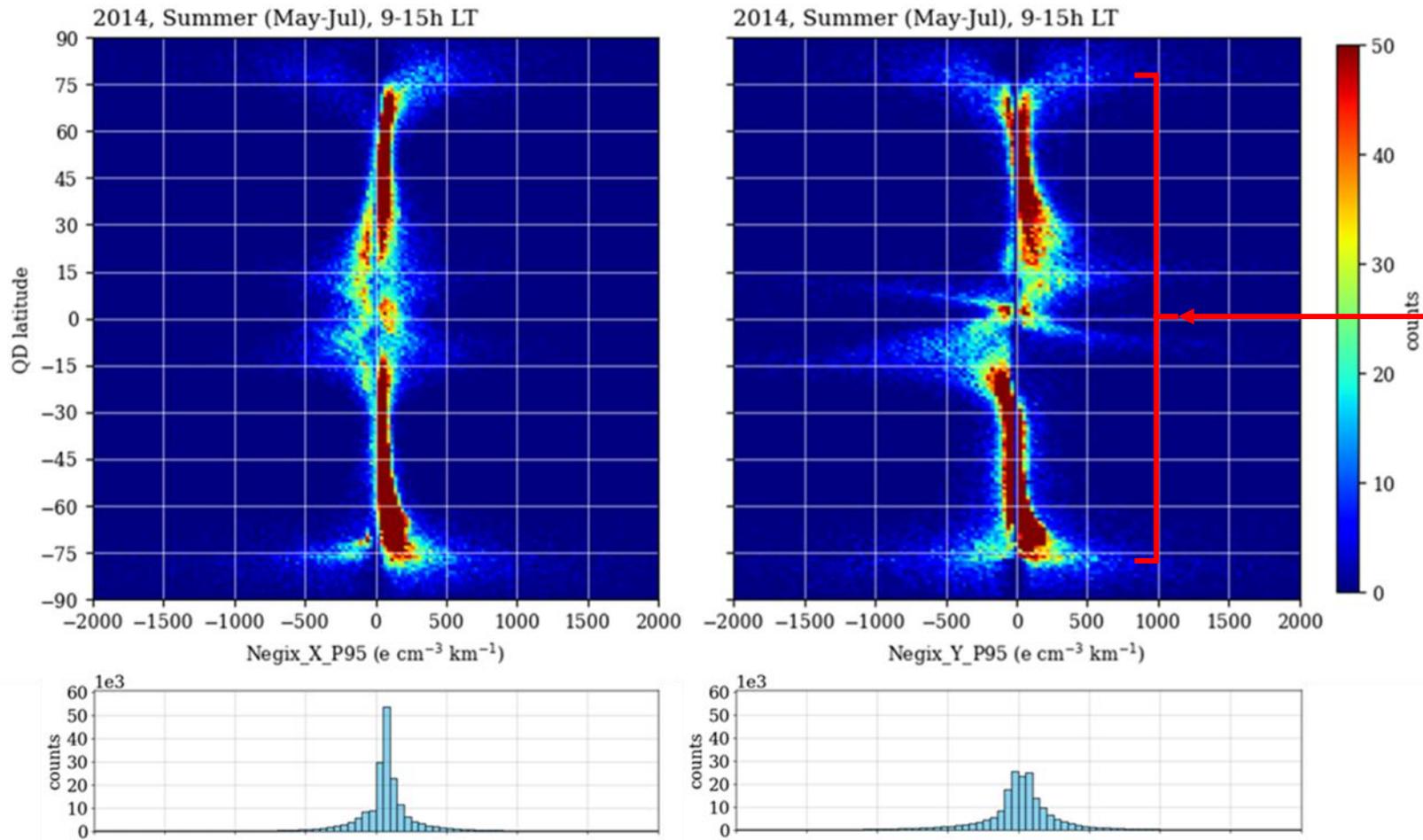- Strong variability and gradients at high-latitudes

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2014, Summer (May-Jul), 9-15h LT

2014, Summer (May-Jul), 9-15h LT

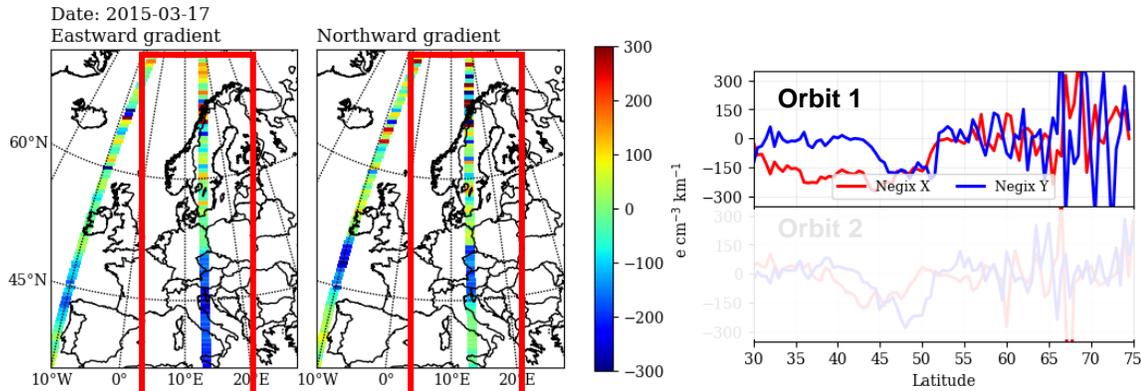The 3-month density plots of NeGIX values as a function of quasi-dipole magnetic latitude show:

- Large gradient values (dispersed colormaps and extended histogram distribution)

- Equatorial ionospheric crests depicted in the zonal (X) and meridional (Y) components of NeGIX with extended and dispersed values

- Strong variability and gradients at high-latitudes

Validation of products: comparison of NeGIX and TEGIX to the ground-based index GIX over Europe
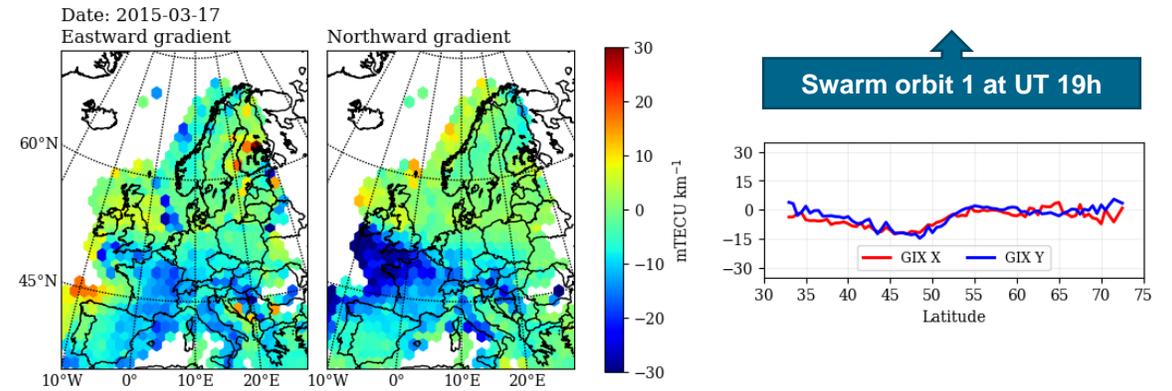
St. Patrick's Day storm on March 17th, 2015 (Dst down to -230 nT, Swarm eq. pass at 19.8h LT)

ESWW2024 – SWR4.2 – J. Andrés Cahuasquí

Validation of products: comparison of NeGIX and TEGIX to the ground-based index GIX over Europe

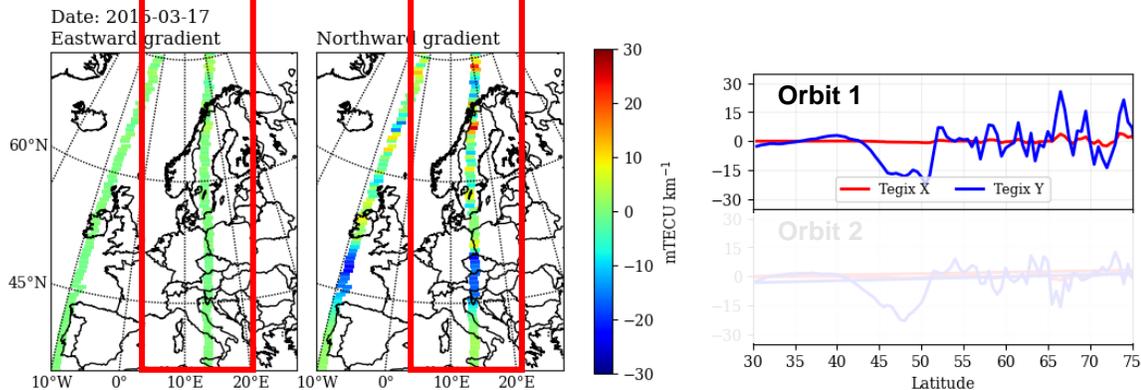**St. Patrick's Day storm on March 17th, 2015** (Dst down to -230 nT, Swarm eq. pass at 19.8h LT)
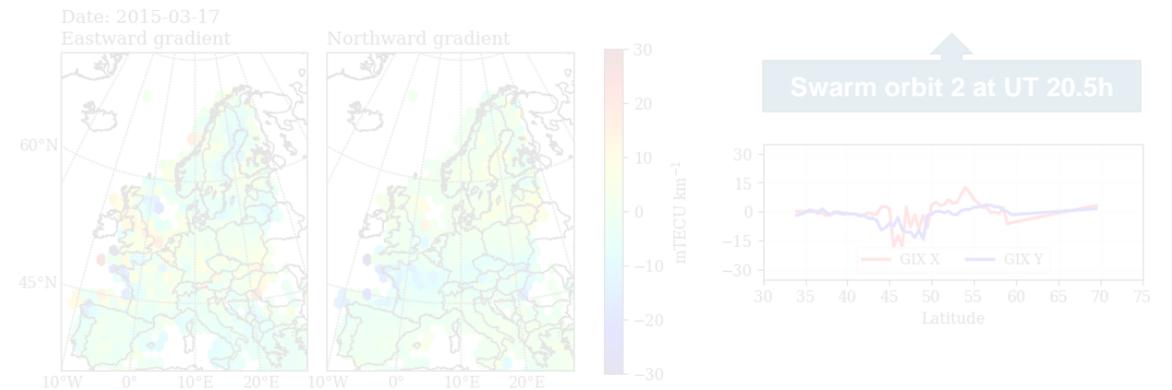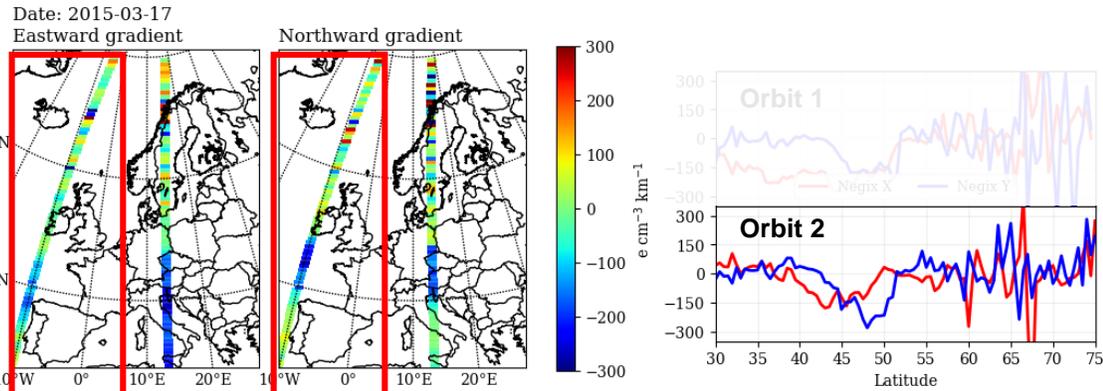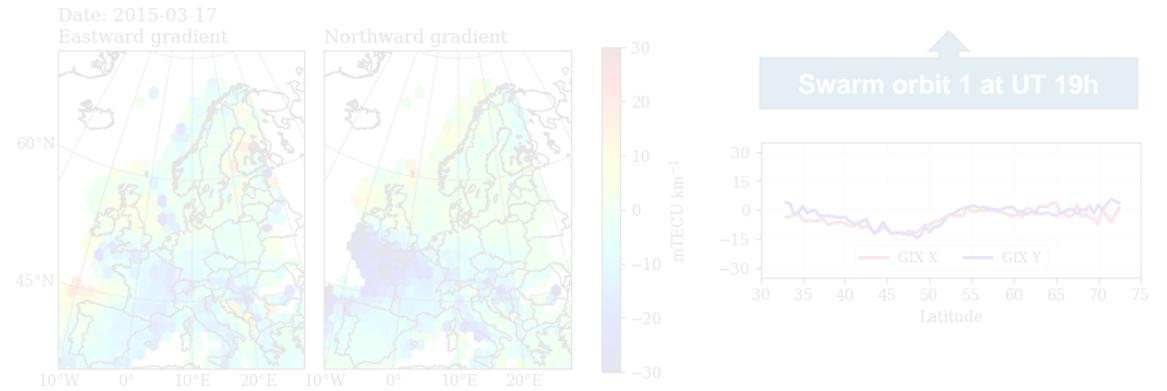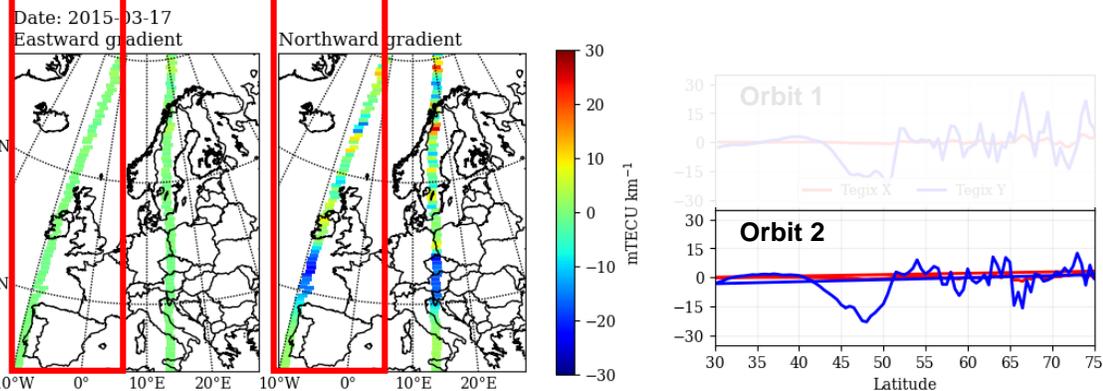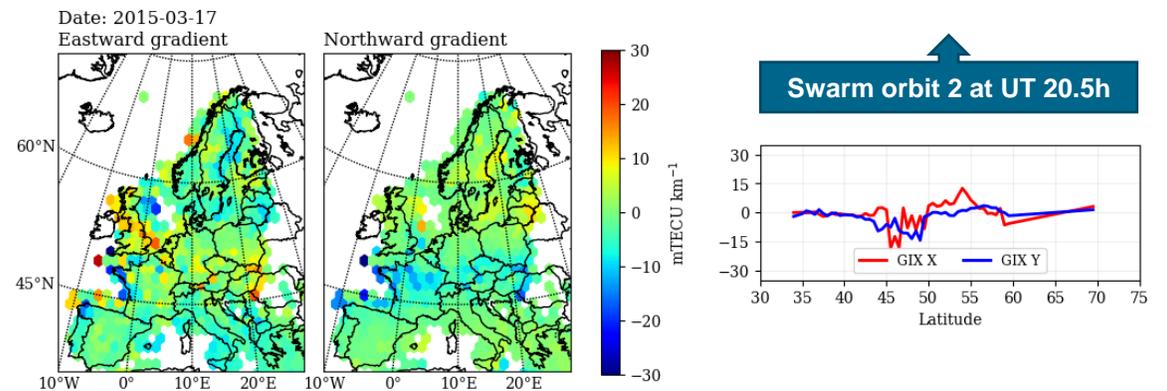
Operational services and availability of NeGIX and TEGIX
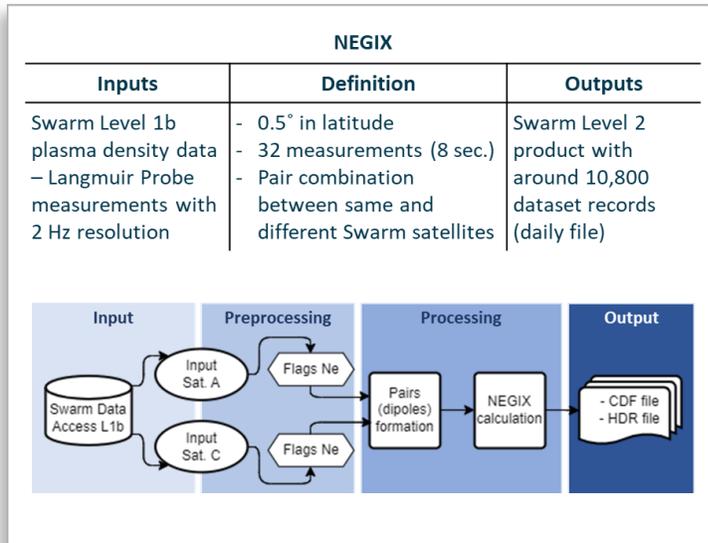

NEGIX		
Inputs	**Definition**	**Outputs**
Swarm Level 1b plasma density data – Langmuir Probe measurements with 2 Hz resolution	- 0.5° in latitude - 32 measurements (8 sec.) - Pair combination between same and different Swarm satellites	Swarm Level 2 product with around 10,800 dataset records (daily file)

TEGIX		
Inputs	**Definition**	**Outputs**
Swarm Level 2 TEC data – measurements with 1 Hz resolution	- 0.5° in latitude - measurements (8 sec.) - Pair combination only between same Swarm satellites	Swarm Level 2 product with around 10,800 dataset records (daily file)

- The MIGRAS products have been developed in compatibility with the Swarm-DTU requirements and ViRES ecosystem (as an external data source), thus leveraging data exploration tools that are already available and accepted by a wide user community.
- Implementation of HAPI interface, basic interface/routes implemented, adaption of TEGIX/NEGIX modules
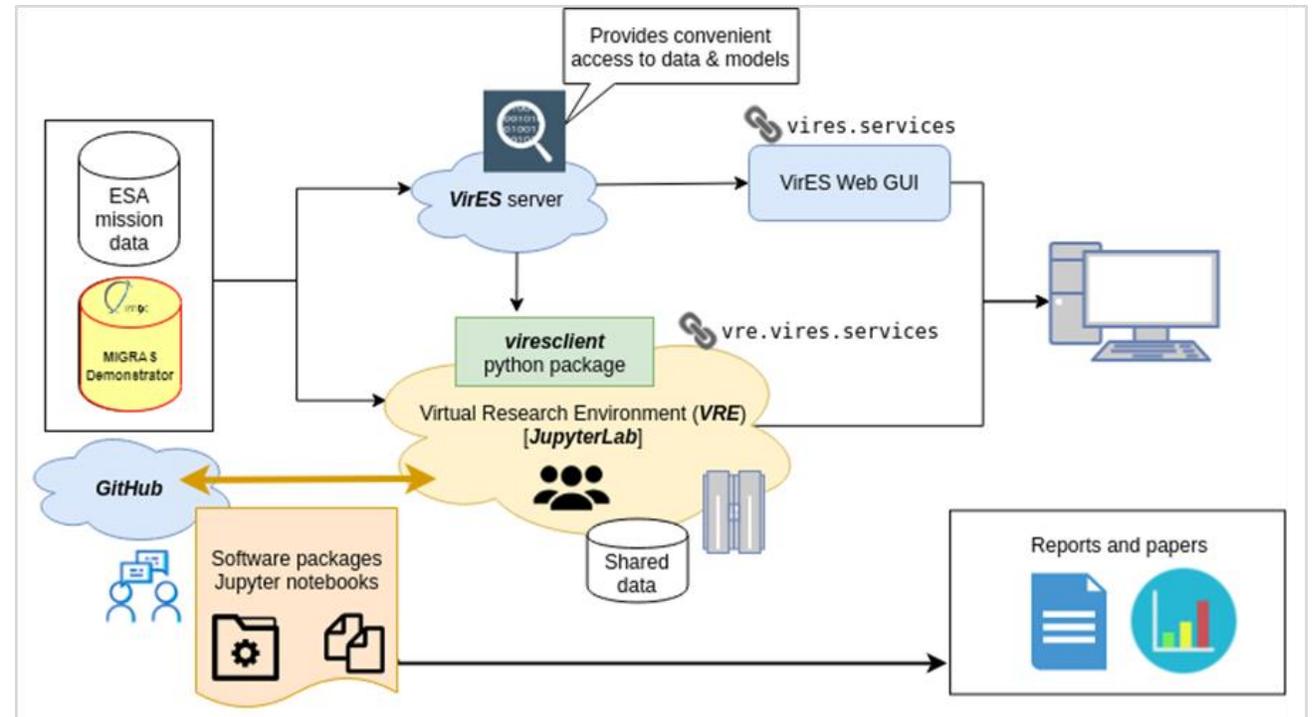
Applications of MIGRAS data products

SWR4-p20

Ionospheric perturbation indices and correlation with GNSS positioning results during geomagnetic storms

Author(s): *Mohammed Mainul Hoque, Norbert Jakowski, Juan Andrés Cahuasquí, Grzegorz Nykiel*

Institute for Solar-Terrestrial Physics, DLR, Neustrelitz, Germany

SWR4-p47

Scintillations in the southern Europe during the geomagnetic storm of June 2015: analysis of a plasma bubbles spill-over using ground-based data

Author(s): *Anna Morozova, Luca Spogli, Rayan Imam, Emanuele Pica, Juan Andrés Cahuasquí, Mohammed Mainul Hoque, Norbert Jakowski, Daniela Estaço*

IA-UC, University of Coimbra, Portugal;
INGV, Rome, Italy;
Institute for Solar-Terrestrial Physics, DLR, Neustrelitz, Germany;
Departamento de Física da University of Aveiro, Aveiro, Portugal

SWR4-p49

Extension of scintillation modeling capabilities with the GISM to polar regions

Author(s): *Dmytro Vasylyev, Juan Andrés Cahuasquí, Mohammed Mainul Hoque, Norbert Jakowski, Martin Kriegel, Paul David, Youssef Tagargouste, Stephan Buchert, Jens Berdermann*

Institute for Solar-Terrestrial Physics, DLR, Neustrelitz, Germany;
Swedish Institute of Space Physics, Uppsala, Sweden

Summary

- Two new products: TEGIX (Spatial TEC gradients Product) and NEGIX (Spatial Ne gradients Product) have joined the family of ionospheric indices developed at DLR

- We have exploited the broad capacity and coverage of Swarm satellites A and C, and used Swarm GPS and Langmuir probe observations, respectively, for the definition of the new products

- Validation analysis and comparison with existing ground-based (e.g. GIX) and Swarm products (e.g. IPIR) show that TEGIX and NEGIX correlate very well, and are capable of characterizing the state of the ionosphere during quiet and perturbed geomagnetic conditions

- Scientific applications of the MIGRAS products have started (e.g. NEGIX for scintillation modelling shows promising results utilizing the phase gradient screen approach) and collaboration is very encouraged

- Availability of MIGRAS products will be possible via DLR-IMPC at impc.dlr.de and Swarm data interfaces

Thanks to **SWARM DISC** **DTU**

For contact and collaboration: **Andres.Cahuasqui@dlr.de**

Name des Vortragenden, Institut, Datum