Second TNA Users Meeting

3 June 2025 | RMI, Brussels, Belgium

SUNDIAL

Characteristics of traveling ionospheric disturbances over Europe during HSS/CIR driven storm on Mar. 30 – Apr. 6, 2023 from GNSS, LOFAR and ionosonde data

Sergii Panasenko, PhD

Institute of Atmospheric Physics CAS, Prague, Czechia

Dalia Obrazová (Burešová)
Jaroslav Urbář

Hanna Rothkaehl
Barbara Martyjasiak
Mariusz Pozoga
Helena Ciechowska

Maaijke Mevius
Kasia Beser

ÚSTAV FYZIKY ATMOSFÉRY AV ČR

CBK PAN

ASTRON

SUNDIAL project

Characteristics of CIR-driven Storm indUced traveling ioNospheric Disturbances over mid-latitude Europe from Ionosonde And LOFAR data (SUNDIAL)

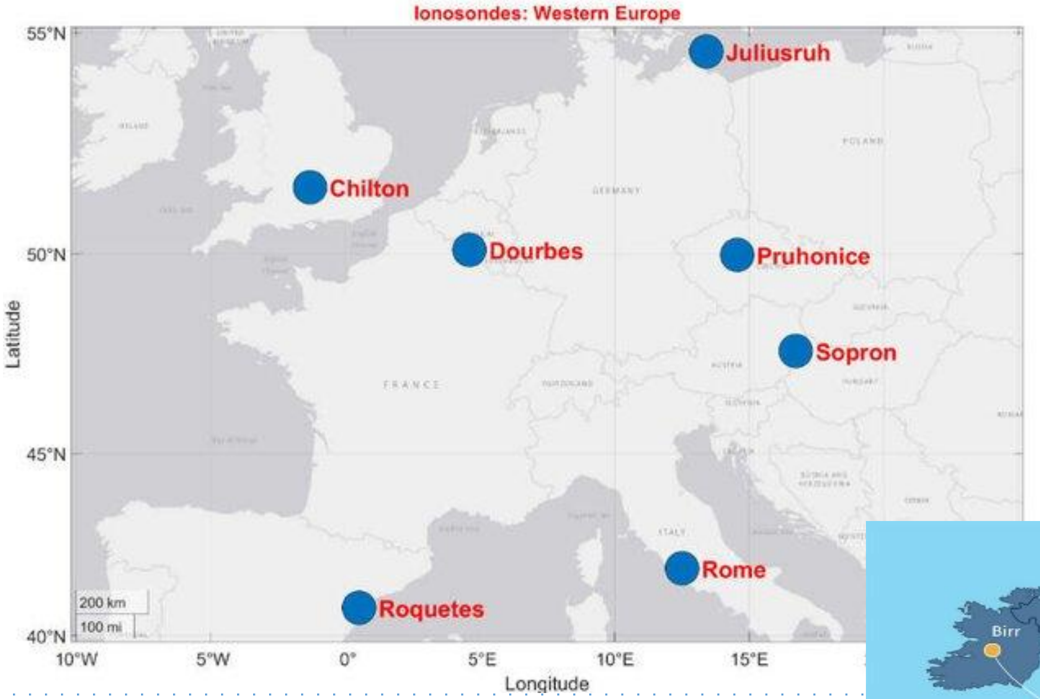
Motivation. The magnetic storms usually caused by coronal mass ejections (CME) and corotating interaction regions / high-speed stream (CIR / HSS) drivers which can affect the ring current and also the course and duration of auroral activity in different ways. Moreover, despite the greater energy output of CME-driven storms, the magnetospheric coupling and total energy input are often more geoeffective for the magnetic storms driven by CIR / HSS events.

The overarching goal of this investigation was to explore the relationship between pulse-like enhancements in auroral activity, triggered by high-energy inputs from the magnetosphere into the atmosphere and ionosphere during CIR-driven events, and the TIDs observed over mid-latitude Europe. For this purpose, we conducted a detailed case study of one CIR / HSS-driven geomagnetic storm that occurred from March 30 to April 6, 2023, and identified and characterized the resulting TIDs using a number of remote sensing facilities.

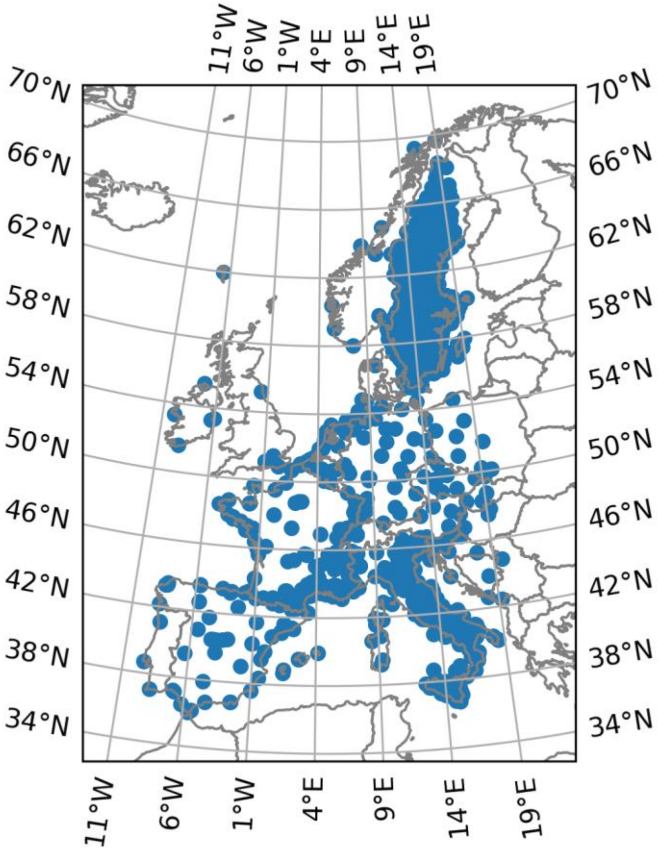
The broader impact of this work lies in advancing our understanding of how CIR-driven magnetic storms contribute to energy deposition in the upper atmosphere and ionosphere, and how this energy is subsequently transferred to mid-latitudes via wave processes. The findings from this case study may also support the future development and refinement of global atmospheric and ionospheric circulation models.

Facilities

Ionosondes



GNSS receiver network



LOFAR

Planned to employ:

Incoherent scatter radars;

Continuous Doppler Sounding System (CDSS).

Workflow

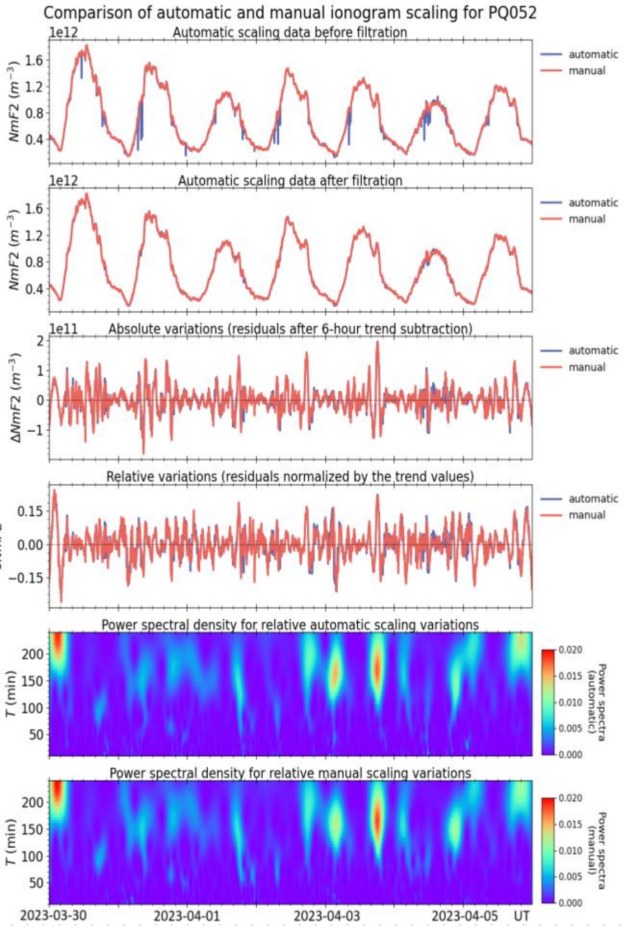
The preparatory steps involved a comprehensive comparison between automatically and manually scaled ionograms obtained from several European ionosondes during both magnetically quiet and disturbed periods. These efforts also focused on estimating detrended slant and vertical TEC values for each satellite–receiver pair and removing pulse interferences from GNSS data using statistical criteria. A thorough data quality check was conducted based on predefined quality rules tailored to specific tasks, and statistical threshold values were established to guide effective data filtration.

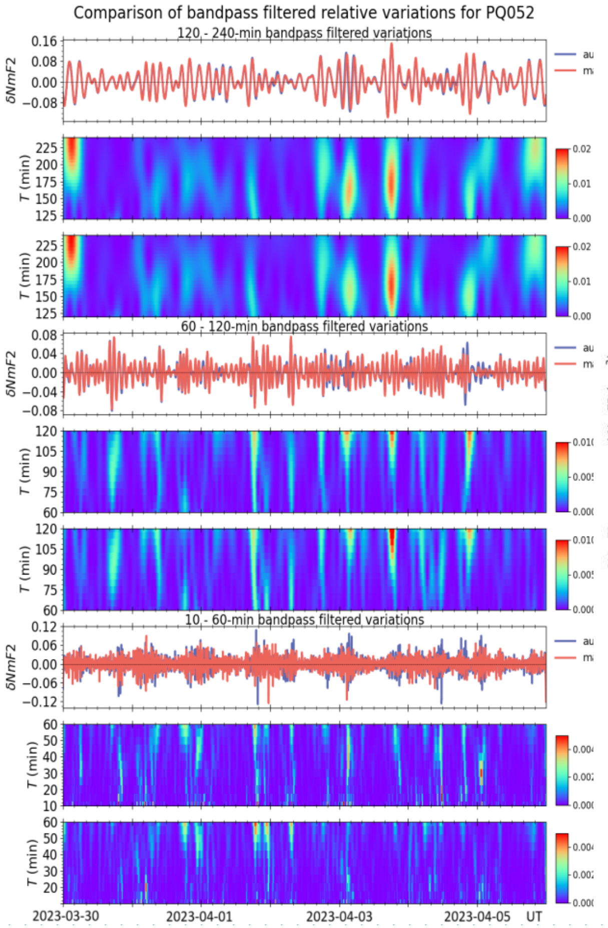
The steps undertaken during the course of the project included the selection of an appropriate CIR / HSS-driven magnetic storm event, ensuring the availability of data from all employed facilities and minimizing the influence of other high-energy natural or artificial TID sources to avoid contamination of results. These efforts also involved refining and expanding the unified methodology for TID detection and characterization. Further activities included retrieving TID characteristics, investigating the relationship between TID occurrence and auroral activity indices, and disseminating the results.

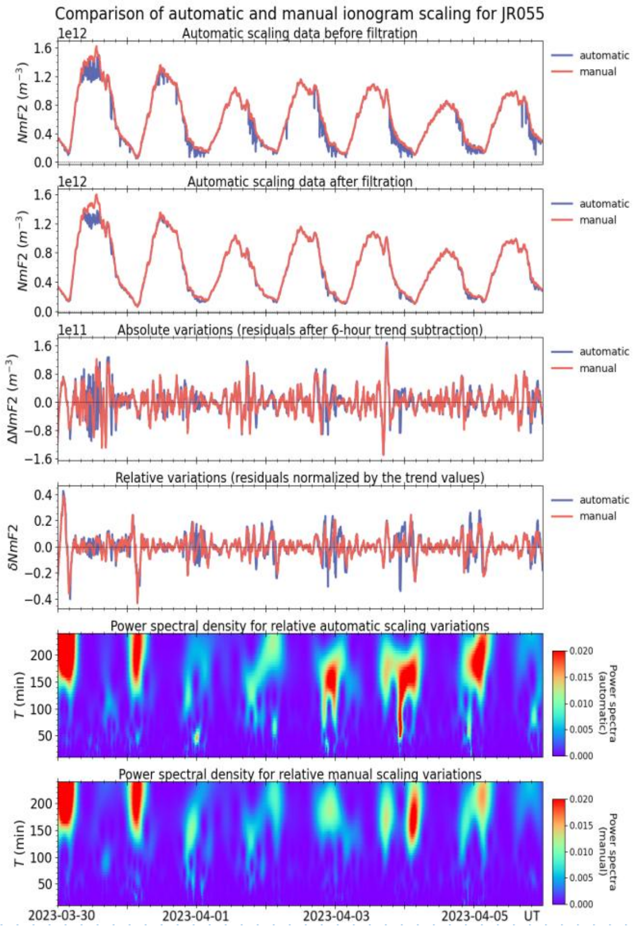
The follow-up tasks will focus on the continued integration of LOFAR, ionosonde, GNSS, CDSS and incoherent scatter data to enable a thorough statistical analysis of multiple CIR-driven events. This will support the development of a more refined TID detection methodology and facilitate a comprehensive examination of TID signatures across various ionospheric parameters in both temporal and spatial domains. The results will be disseminated through joint publications, including papers in leading international journals as well as presentations at conferences and symposia.

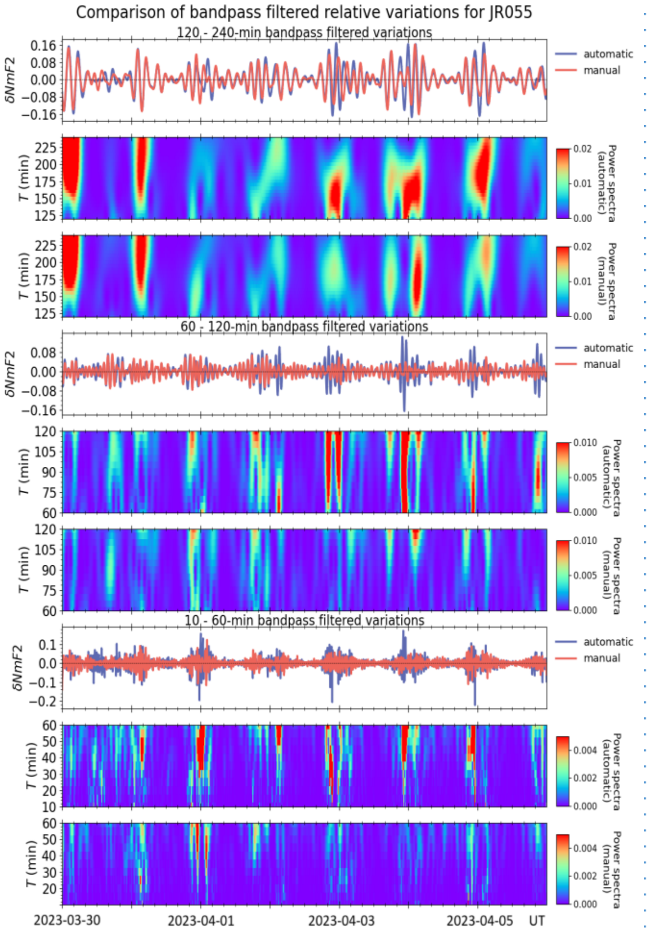
Preparatory steps

Ionosonde data





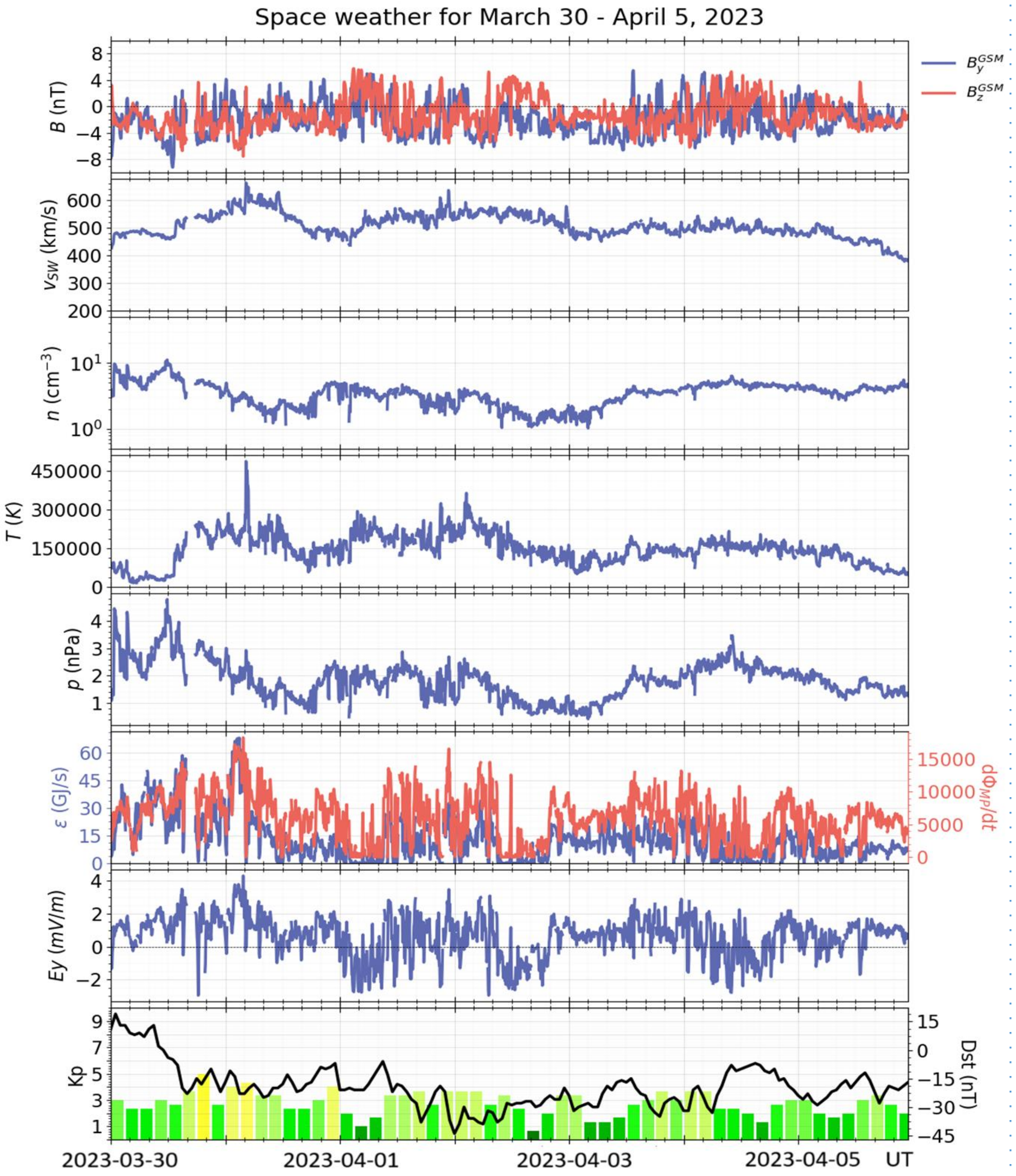


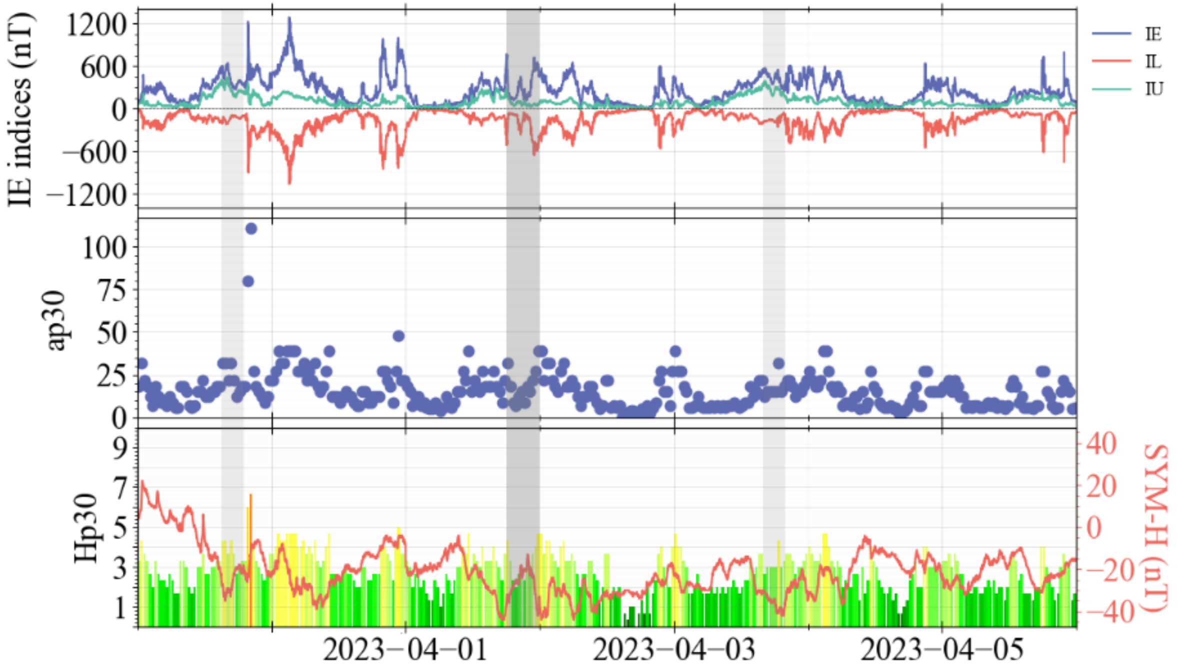


These figures demonstrate that automatically scaled data have limited utility for TID characterization and are generally suitable only for detecting large scale TIDs (with periods over 60 minutes) over midlatitude ionosondes. The automatically scaled Pruhonice ionosonde data are appropriate for large scale TID characterization for the selected event. However, the Juliusruh automatically scaled ionosonde data suffer on underestimation even during magnetically quiet days providing wrong fluctuations in a broad period range from 10 to 240 minutes

On-going steps

Space weather conditions



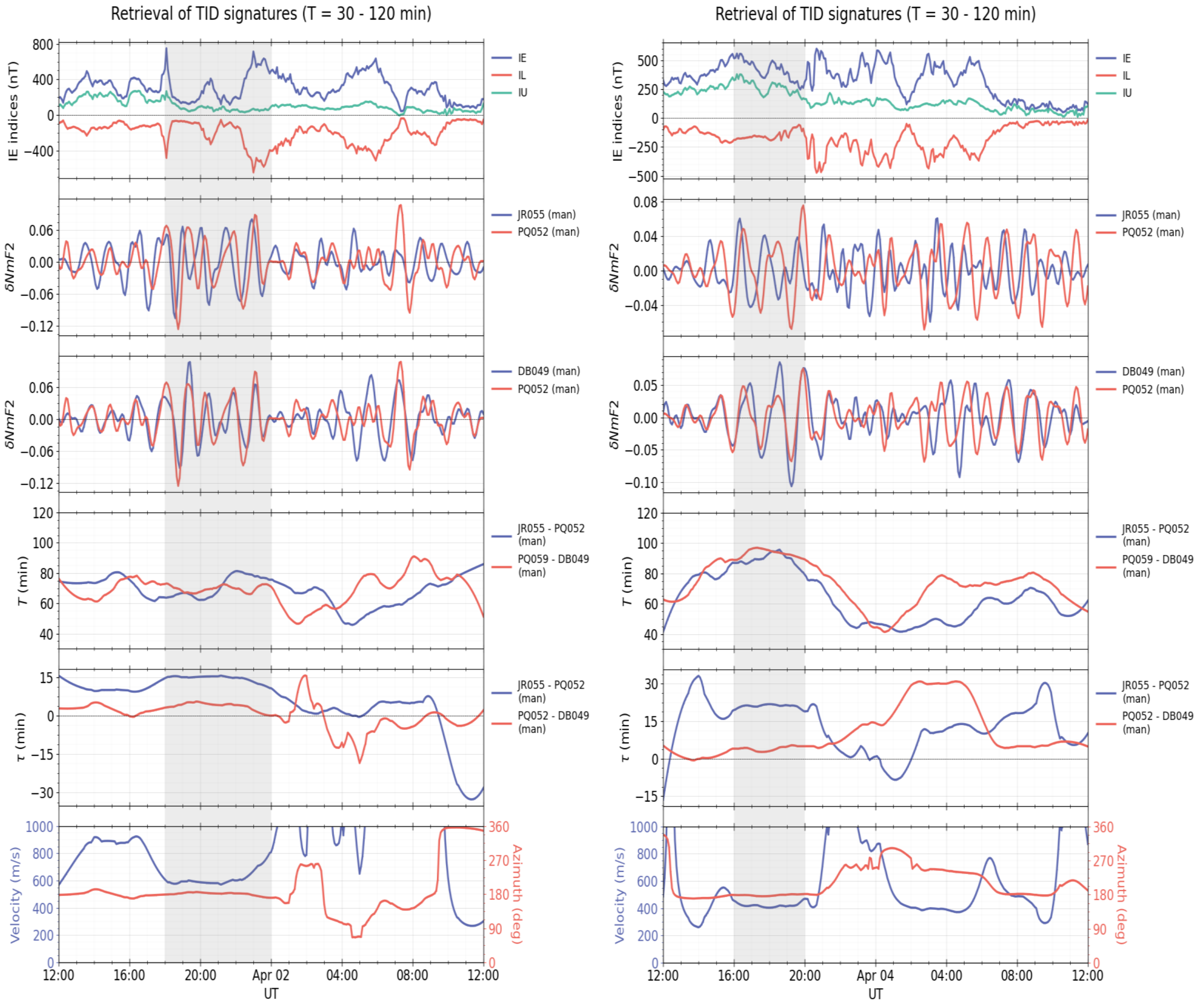


It is shown that Hp30 index usually was less than 5 and minimal SYM-H values were about – 40 nT. This CIR / HSS driven storm was minor and characterized by relatively long duration (about 6 days).

During the selected magnetic storm event, three time intervals were identified in which southward-propagating TIDs were confidently detected using both ionosonde and GNSS techniques. Further. We will focus in detail on two such intervals (18 – 24 UT on April 1, 2023 and 16 – 20 UT on April 1, 2023).

On-going steps

Ionosonde-derived TID characteristics

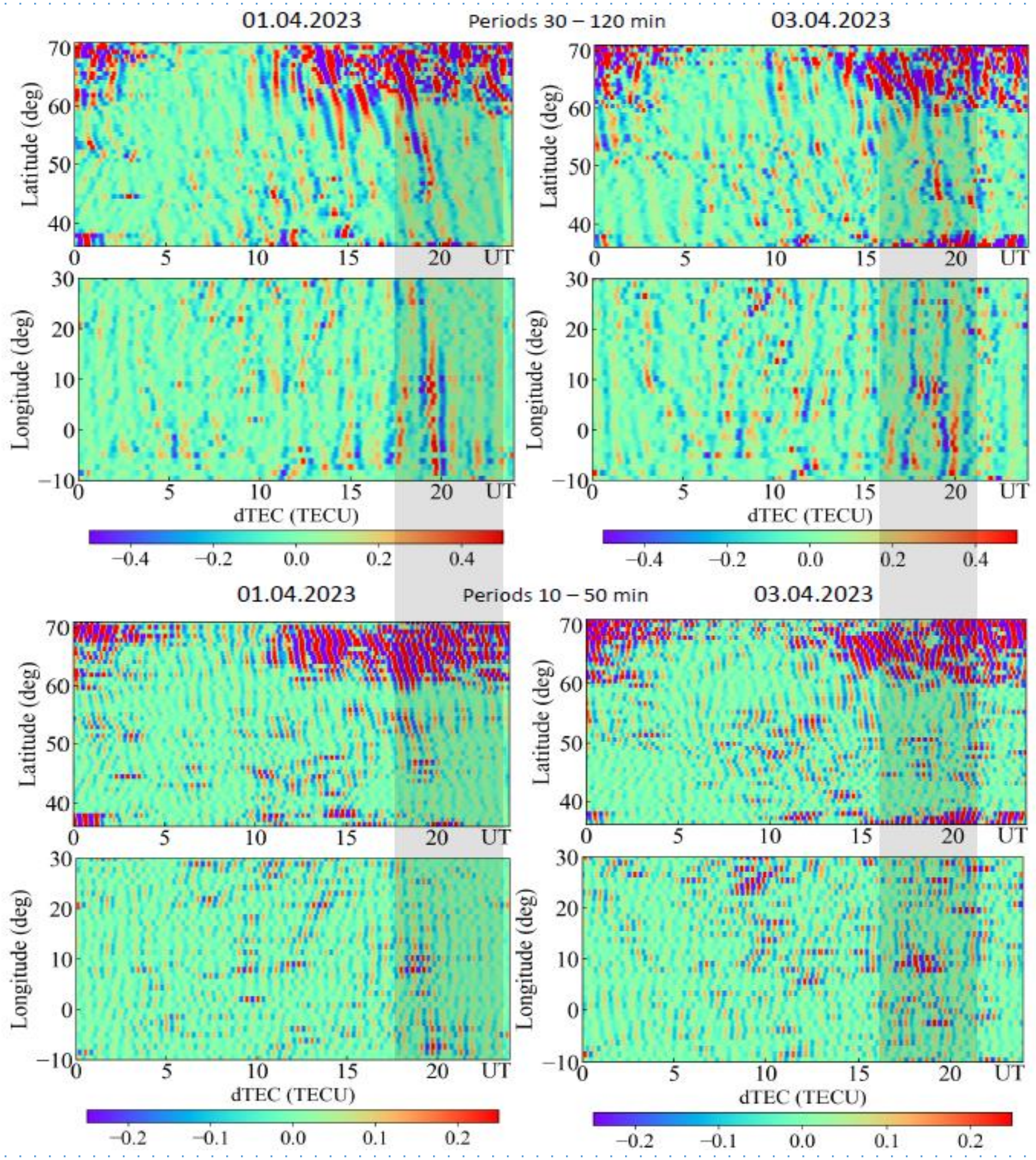


Temporal variations of several TID characteristics, including bandpass filtered relative changes in electron density at the F2 peak altitude (δNmF2), dominant periods T, the magnitude of the horizontal phase velocity and its direction (azimuth, measured clockwise from the North). Manually scaled data from the Pruhonice Juliusruh and Dourbes ionosondes were used to estimate the horizontal phase velocity.

The observed large-scale TIDs have periods of 50 – 80 minutes and horizontal phase velocities ranging from 400 to 600 m/s. The corresponding horizontal wavelengths are estimated to be between 1300 and 3500 km. This figure also illustrates a variable time delay of 1 – 4 hours between the enhancement of auroral activity and the onset of TIDs at mid-latitudes.

On-going steps

GNSS-derived TID characteristics



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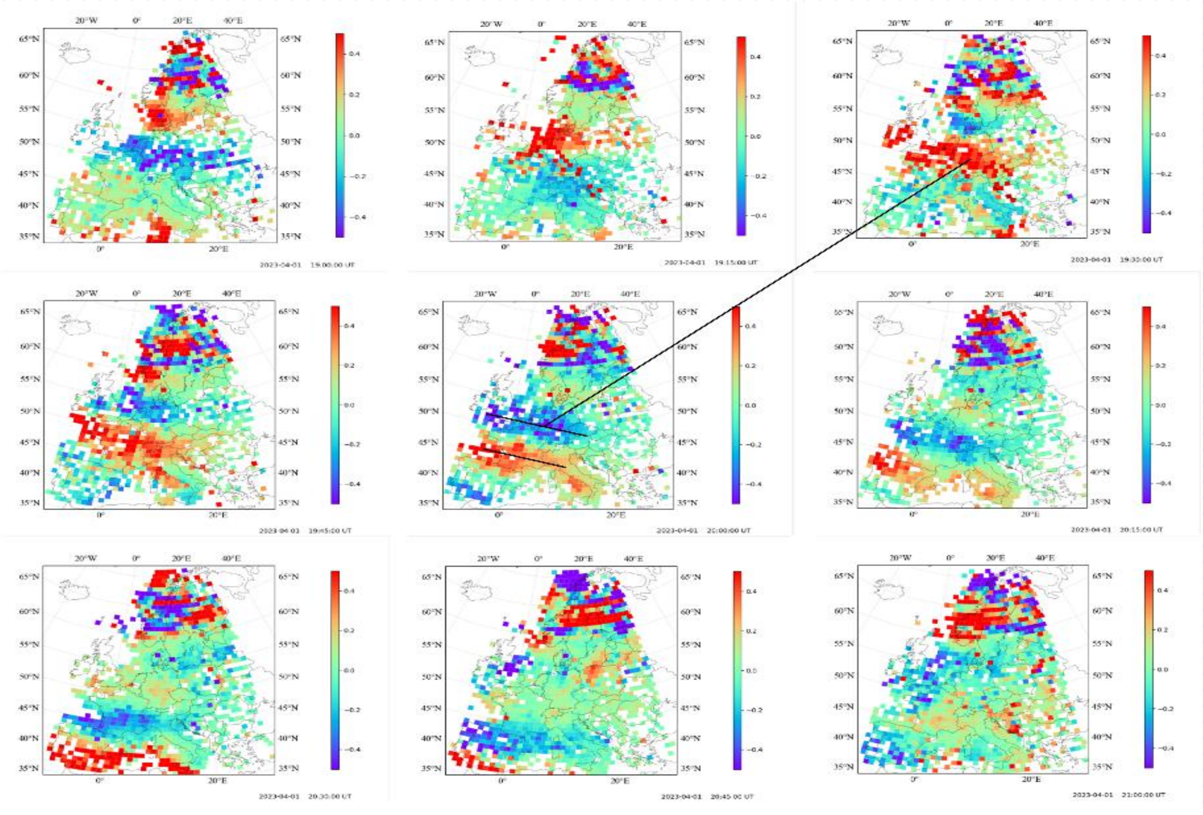
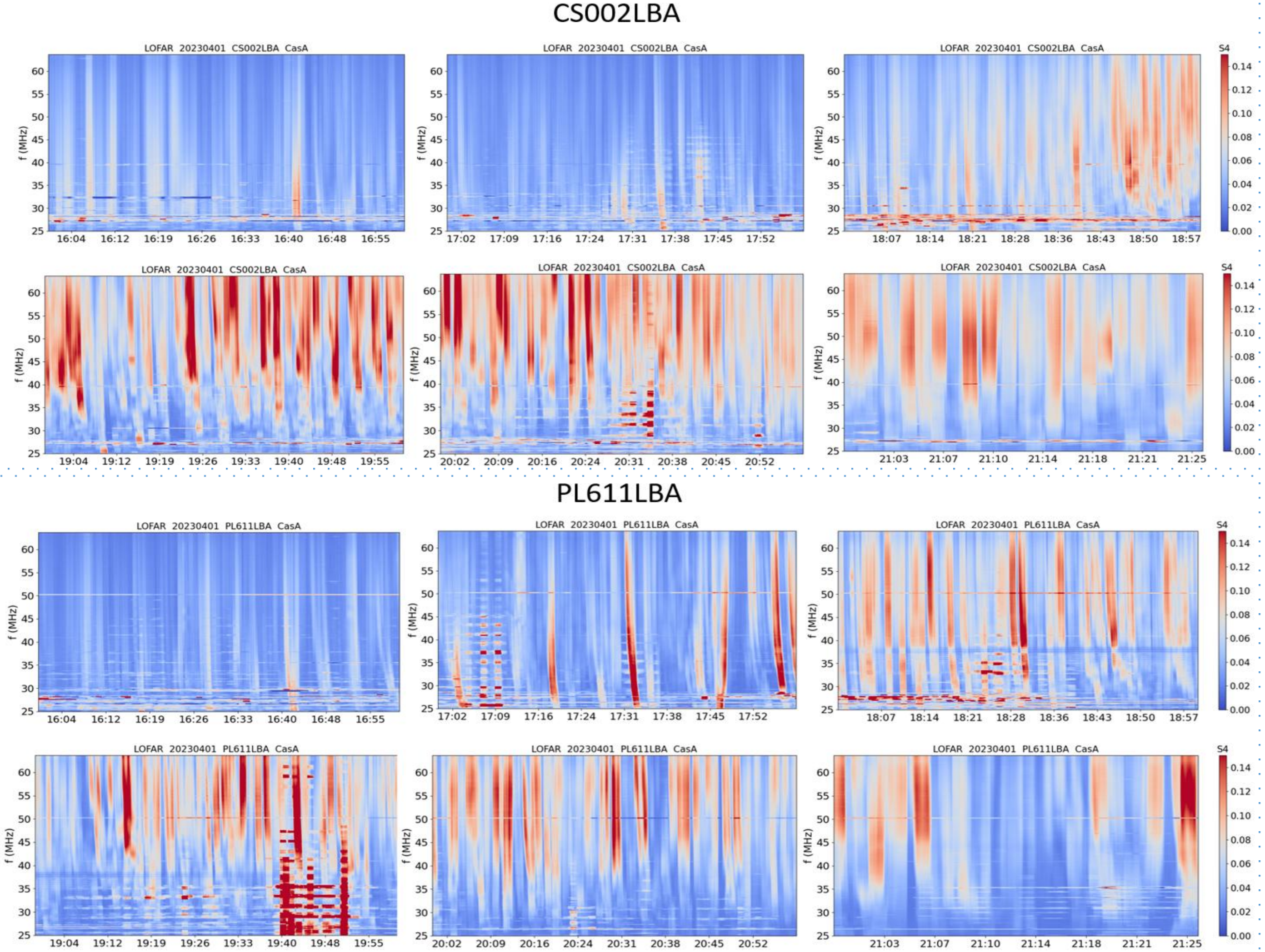
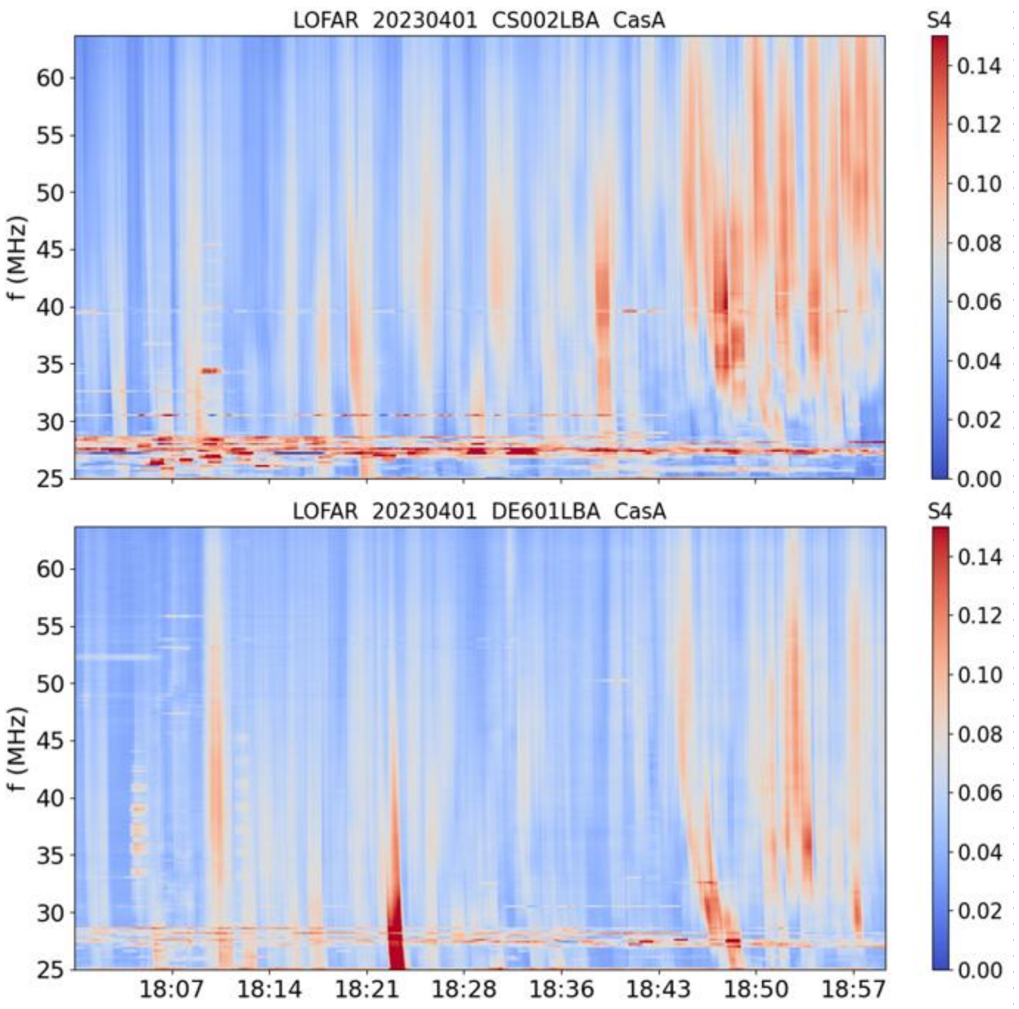


Keograms and maps clearly indicate enhanced activity of both large- and medium-scale TIDs during selected intervals and a predominantly southward propagation direction, suggesting that the TID sources were located at high latitudes. Estimations of large-scale TID characteristics yielded the dominant periods of 60 mins and horizontal phase velocity of 650 m/s, resulting in a horizontal wavelength of 2340 km.

On-going steps

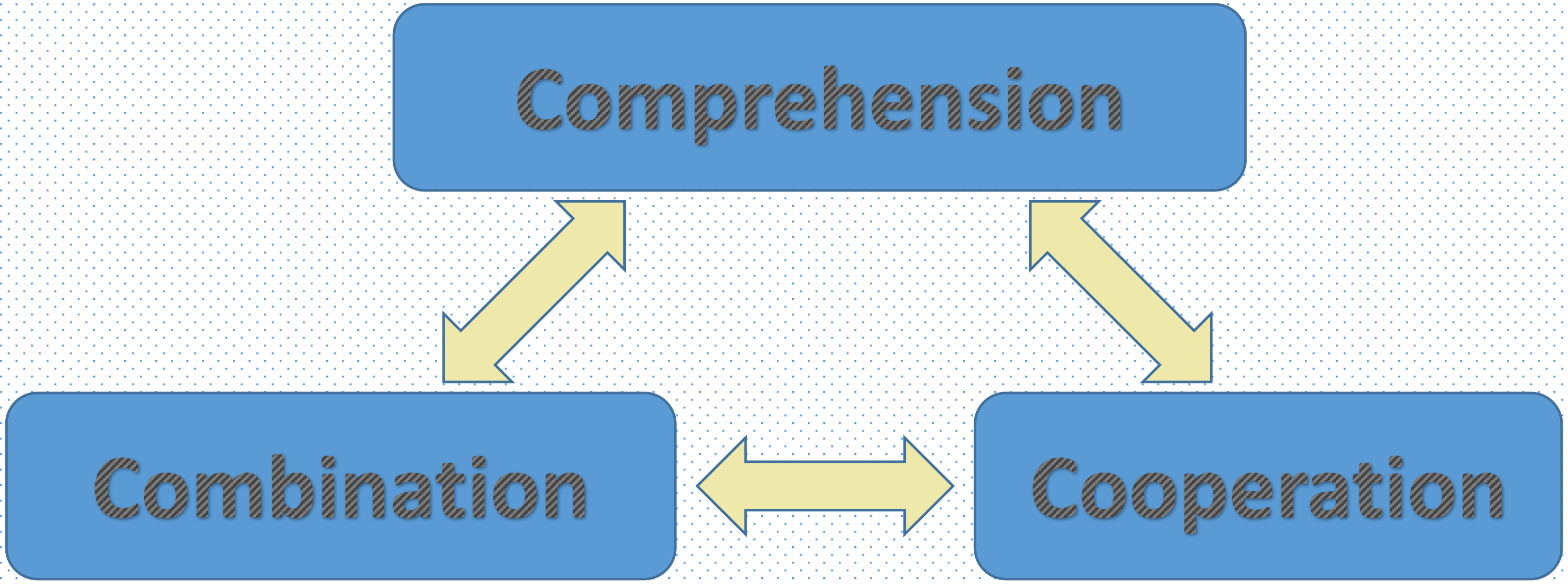
LOFAR observations





We detected an enhancement in the S4 scintillation index beginning around 17:30 – 18:00 UT on April 1, 2023. This increase in scintillation activity may be attributed to two potential sources: the passage of the solar terminator and intensified auroral activity. We also revealed similarities in certain S4 index features with a noticeable time delay at the more southerly station (DE601LBA). This temporal offset may indicate the southward propagation of small-scale ionospheric irregularities, possibly linked to TID activity.

PITHIA-NRF TNA added value



Combination – facilities, data, methodologies.

Cooperation – organizations, scientists, analysis, results.

Comprehension – new knowledge on geospace processes

The added value provided by the TNA program included expert consultations and several joint in-person and online seminars attended by scientists from the Institute of Atmospheric Physics and the CBK/PAS Node. Thanks to these fruitful discussions and collaborative efforts, a number of new results were achieved and validated. Additionally, the TNA facilitated access to LOFAR data and analysis scripts, as well as the LOFAR facility itself, enabling in-depth investigations of TIDs over Europe triggered by CIR/HSS-driven storm events.

PITHIA
e-Science Centre

This centre is really useful for scientists since it provides necessary data sets, models and workflows which can be utilized for joint analysis, interpretation, publications, etc.

It would be better to have more "seamless" combination of experimental data and models, flexible settings, "user-friendly" interface and selection options for all the available parameters.