Medium-Scale Travelling Ionospheric Disturbances Produced by Severe Tropospheric Disturbances in August 2023

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URSI AP-RASC
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Solar-Terrestrial Centre of Excellence

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T-FORS

Overview

Introduction

This work was done as part of the project T-FORS "Travelling Ionospheric Disturbances Forecasting System", attempting to forecast appearance of TIDs.

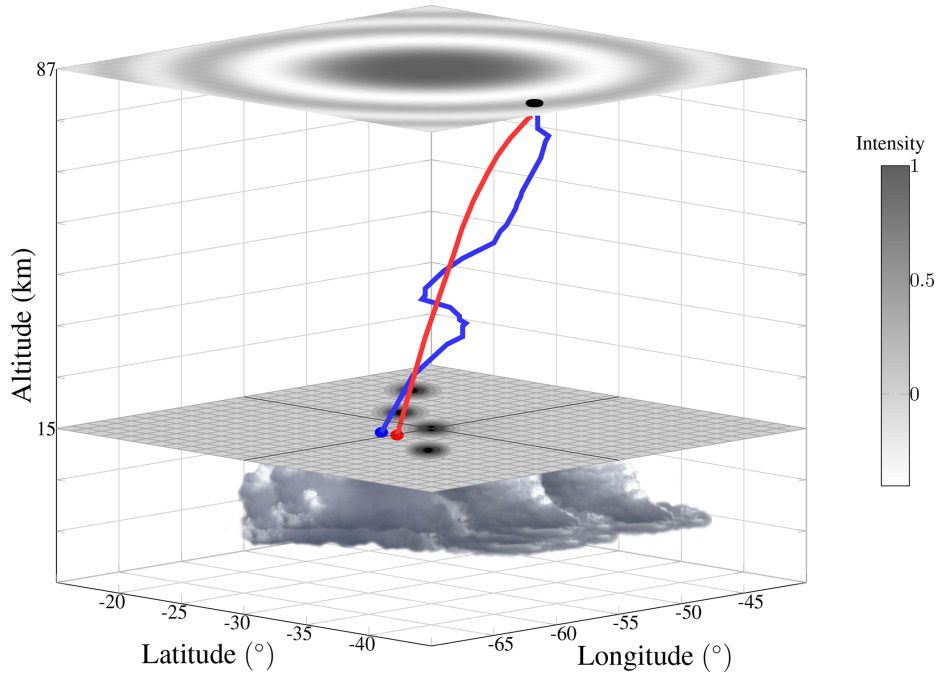
- Large scale TIDs: usually related to geomagnetic storms, forecasting system based on solar / L_1 / magnetic observations.
- Medium scale TIDs: caused by a variety of drivers.
  - Regular: solar terminator, tides,...
  - Irregular: earthquakes, large explosions,... including meteorological.

Most difficult forecasting are the irregular MSTIDs.

Here, we analyse a case study of MSTIDs driven by meteorological events in August 2023 in central Europe.

MSTIDS produced by tropospheric events

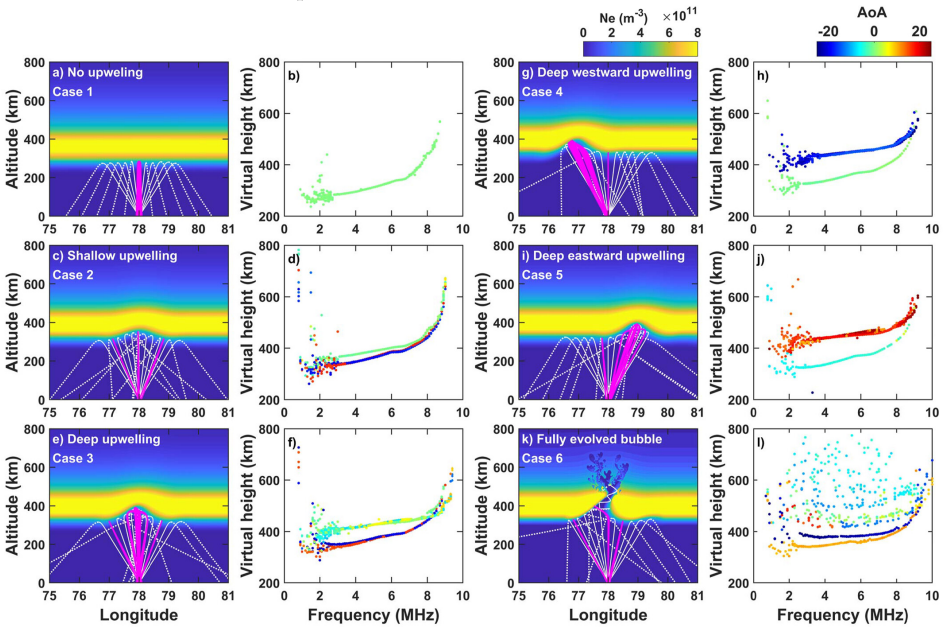
- Medium scale TIDs have wavelength of hundreds of km, periods of 15 to 90 minutes.
- Waves propagating from the lower atmosphere are severely distorted while travelling up.
- Wavelengths increase, sometimes also mode conversion.
- Waves tend to travel obliquely, so not always detected above the source.
- Vertical propagation affected by horizontal winds.



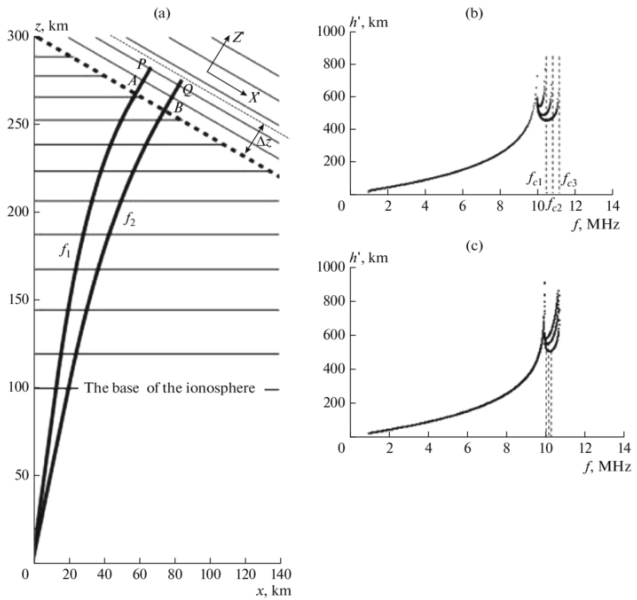
Credit: Nyassor *et. al* (2022)
doi:10.5194/acp-22-15153-2022

Signatures of MSTIDs in ionograms

Ray tracing shows how various trace distortions are produced by structures in the ionosphere.



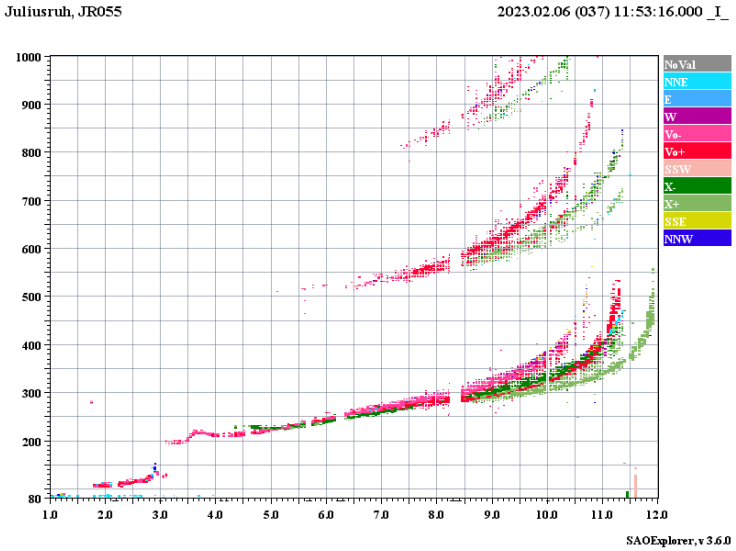
Credit: Ankita *et al.* (2025)
doi:10.1029/2024GL114119

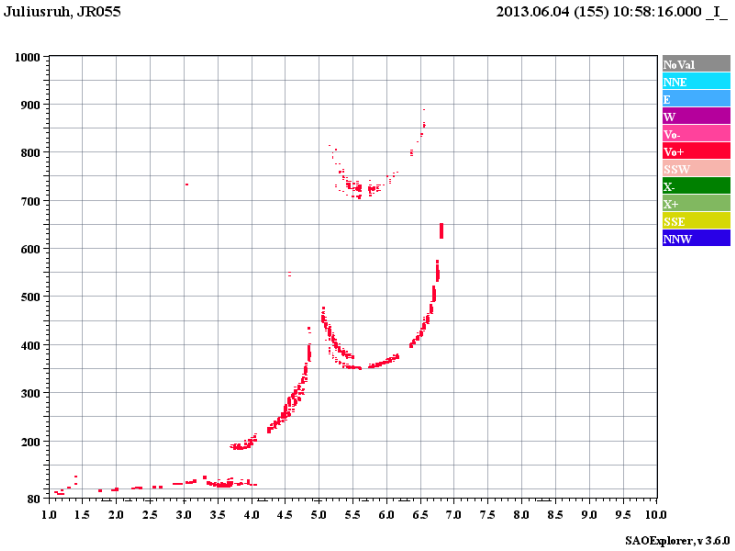


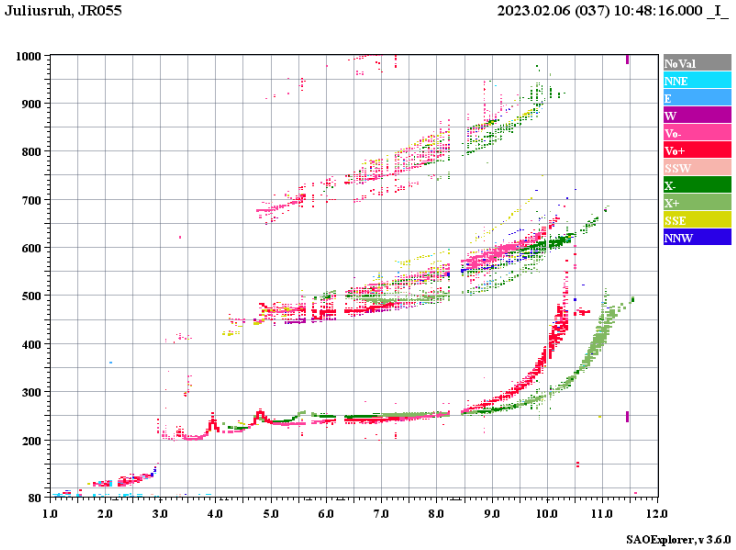
Credit: Laryunin (2018)
doi:10.1134/S0016793218020147

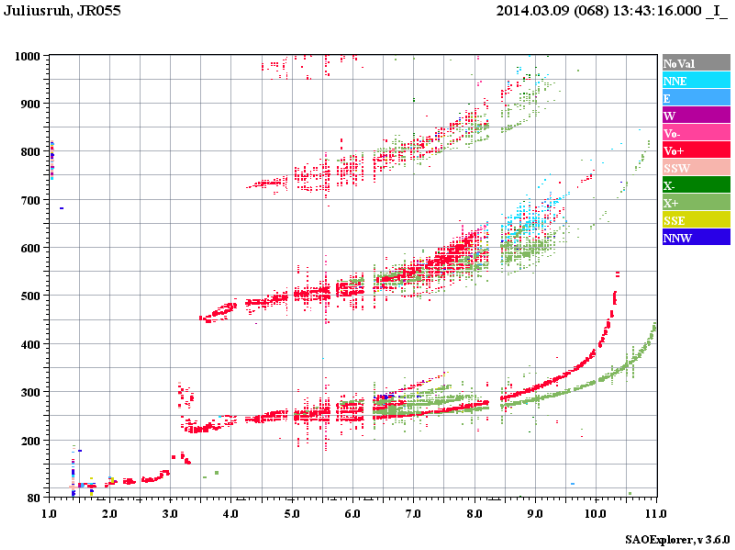
There are many different types of TID-related trace distortions: satellite traces, inside and outside cusps, forks, multi-cusp traces,...

Examples of MSTID signatures



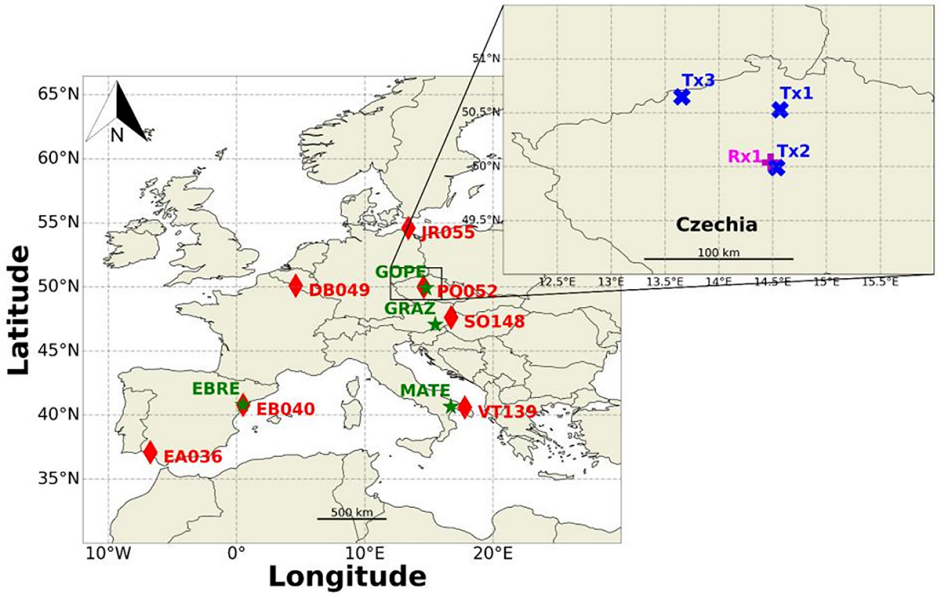






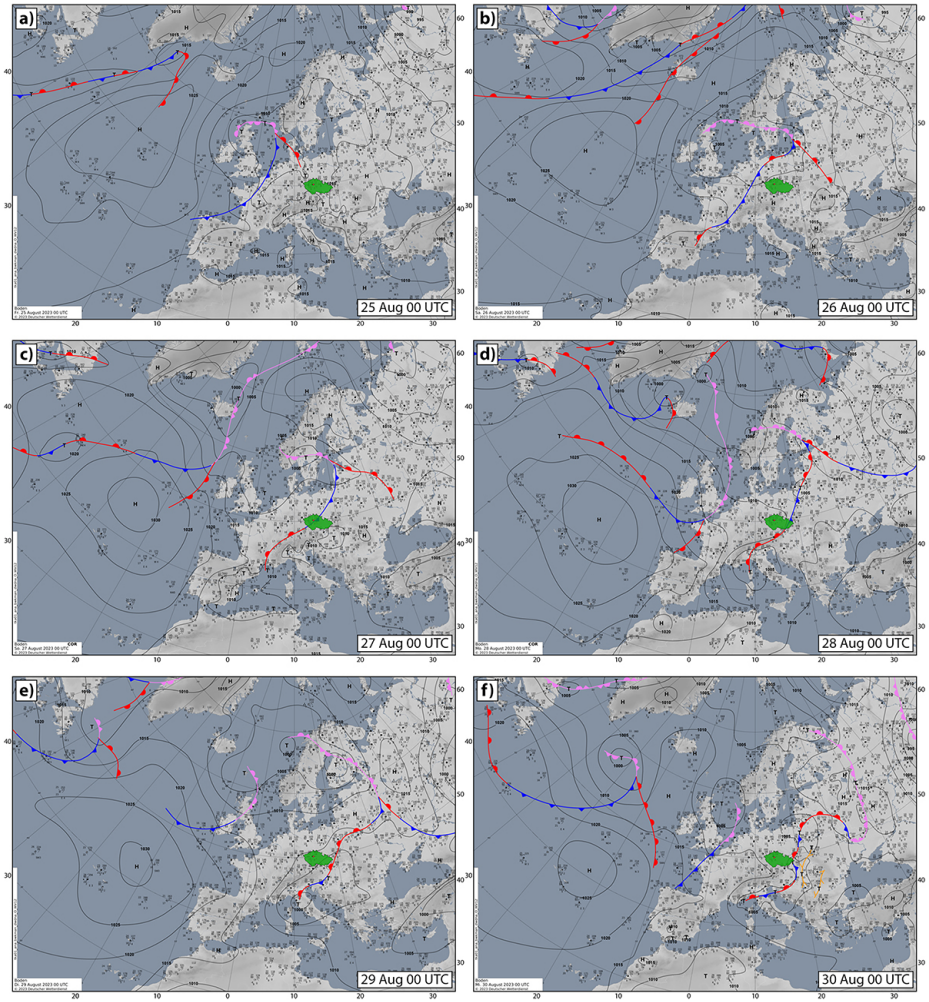
Our case study: 25–29 August 2023

We collected data from 7 ionosondes in Europe (as well as Doppler sounder system and GNSS receivers data).



- Ionograms for the period of interest were manually inspected.
- Classified as containing/not containing TID signature, or not detectable (e.g. due to *Es* layer).
- Ionograms showing MSTID presence are classified according to severity of trace distortion (from < 0.5 MHz to entire trace affected).

Augustus 2023 tropospheric conditions



- A cold front passed over central Europe from west to east between 25 and 30 August 2025, in some places slowed down by mountain ranges.

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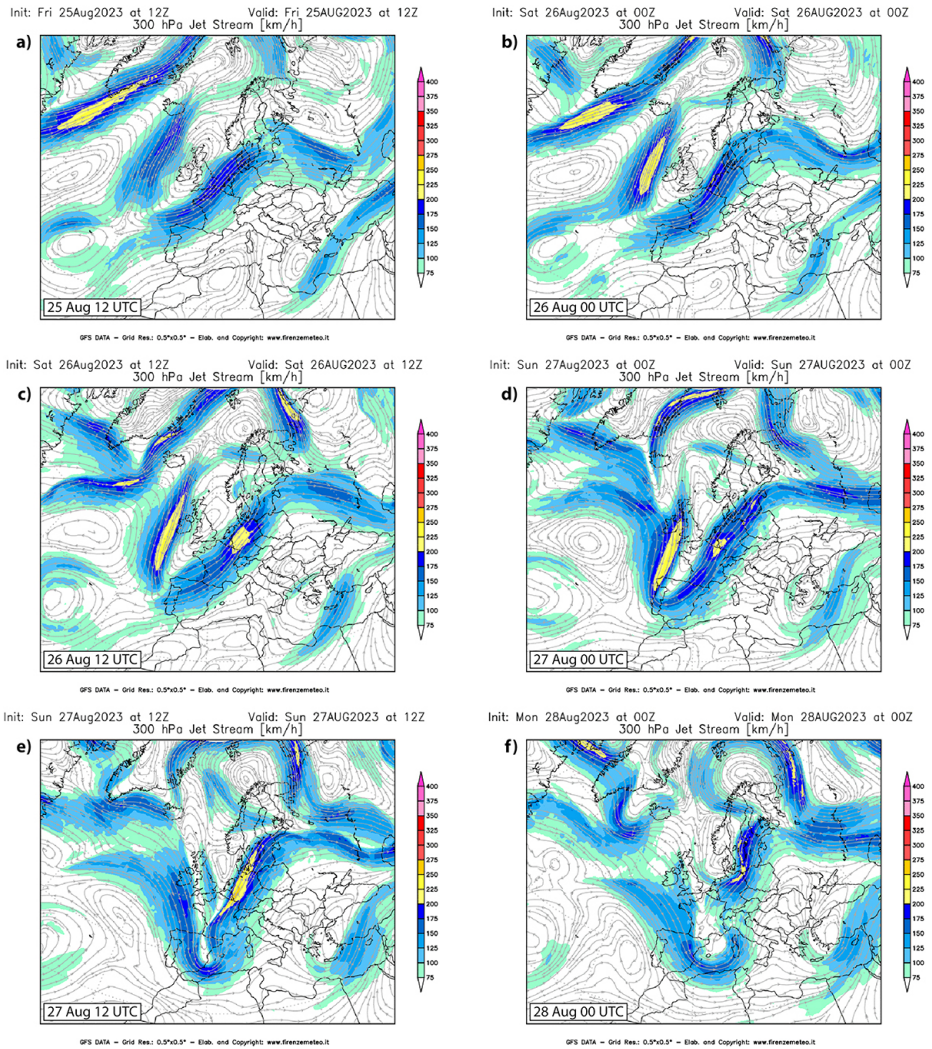

- A cold front passed over central Europe from west to east between 25 and 30 August 2025, in some places slowed down by mountain ranges.
- From 25 to 28 August, some exceptionally high summer jet stream velocities were reached over the same region.

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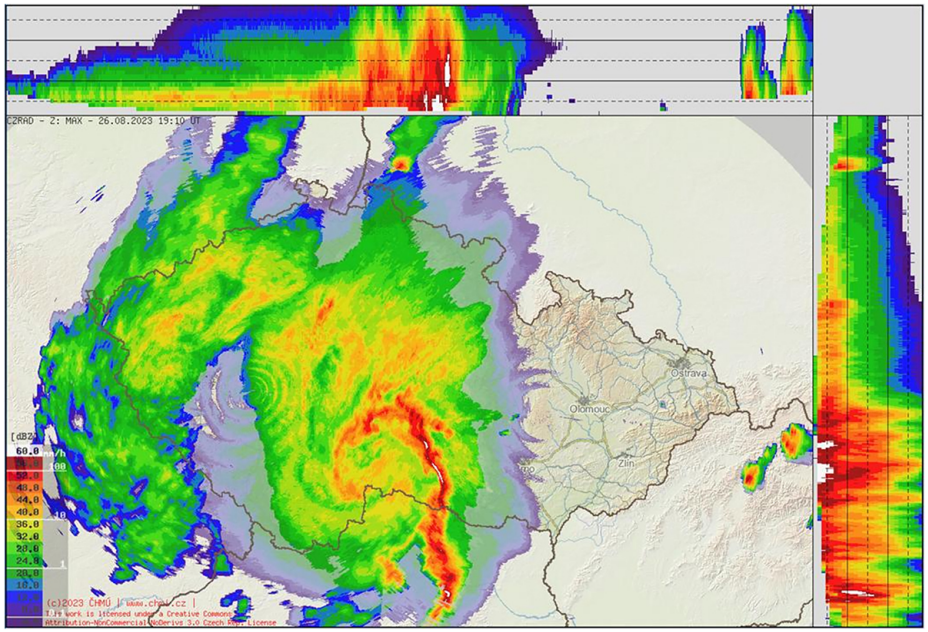
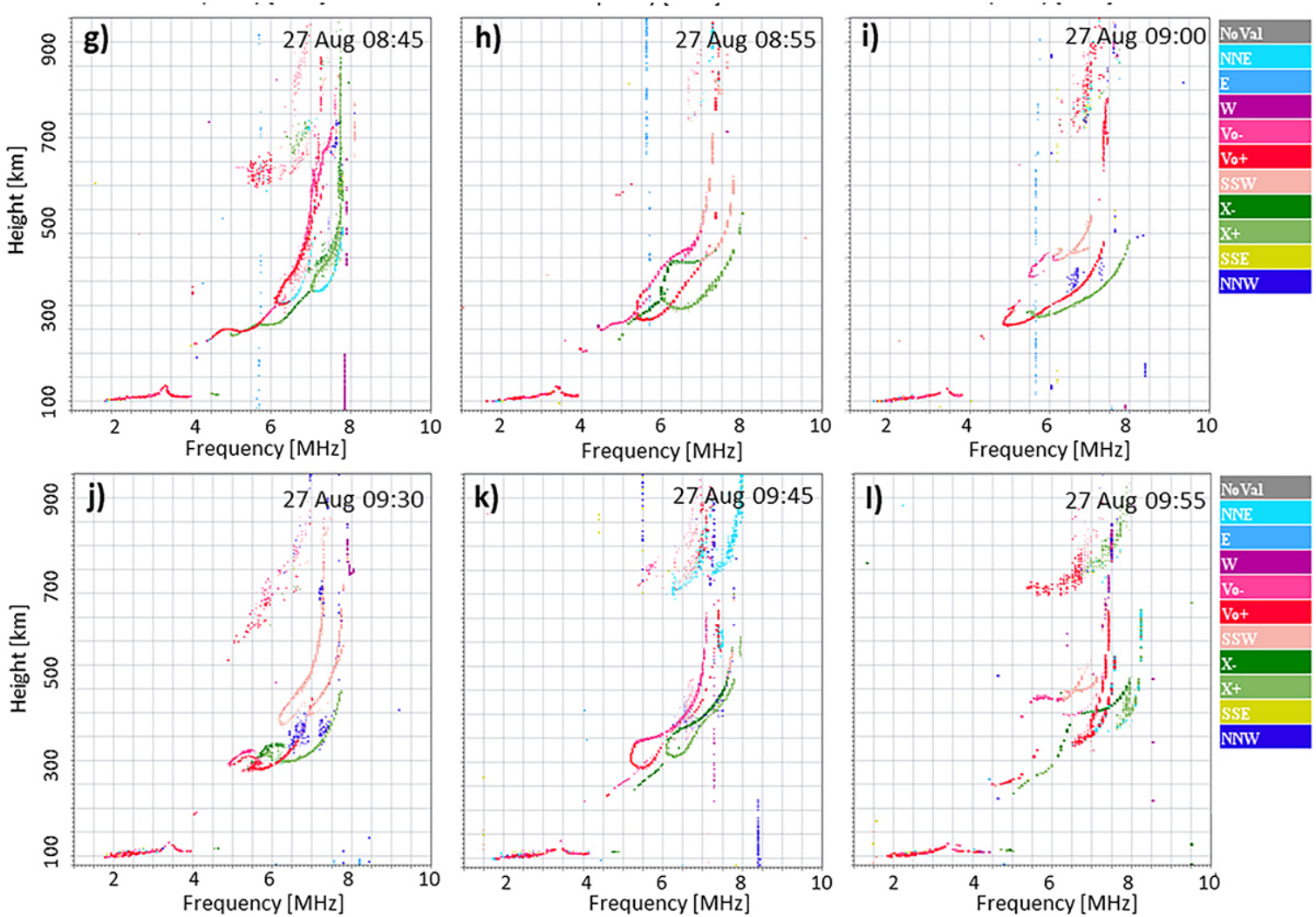


- A cold front passed over central Europe from west to east between 25 and 30 August 2025, in some places slowed down by mountain ranges.
- From 25 to 28 August, some exceptionally high summer jet stream velocities were reached over the same region.
- This was a strong tropospheric event, with 30-year temperature record in Czechia.

Examples of TID signatures in ionograms



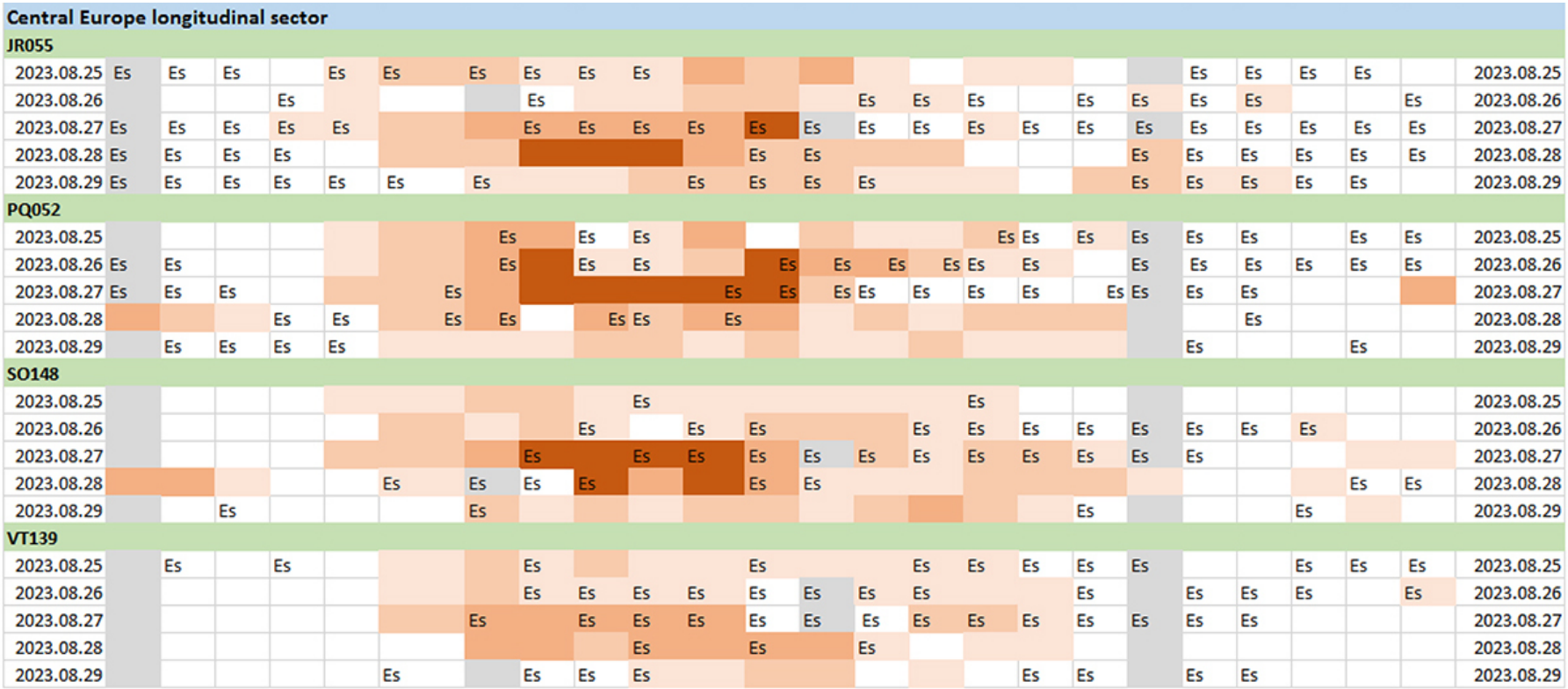
Ionograms recorded on 27 August in Průhonice (PQ052), Czechia, showing strong trace distortions.

Detection times of MSTID signatures

Date; UT->	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	<- UT; Date
	Irregularity < 0,5 MHz																								
	Irregularity > 0,5 MHz																								
	Irregularity > 1,5 MHz																								
	Most of the F trace is distorted																								
Western Europe longitudinal sector																									
DB049																									
2023.08.25	Es	Es	Es	Es	Es		Es	Es		Es		Es			Es	Es			Es	Es	Es	Es	Es	Es	2023.08.25
2023.08.26	Es	Es	Es				Es			Es		Es	Es	Es	Es	Es			Es	Es	Es	Es	Es		2023.08.26
2023.08.27					Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es					2023.08.27
2023.08.28				Es	Es	Es	Es	Es	Es	Es	Es				Es			Es	Es	Es	Es	Es	Es		2023.08.28
2023.08.29			Es	Es	Es	Es	Es						Es					Es	Es		Es		Es	Es	2023.08.29
EB040																									
2023.08.25	Es				Es	Es										Es	Es	Es	Es	Es	Es	Es	Es	Es	2023.08.25
2023.08.26					Es				Es													Es			2023.08.26
2023.08.27										Es	Es	Es							Es		Es	Es	Es		2023.08.27
2023.08.28																				Es	Es	Es	Es	Es	2023.08.28
2023.08.29						Es				Es												Es	Es	Es	2023.08.29
EA036																									
2023.08.25				Es	Es	Es	Es	Es			Es	Es					Es	Es		Es	Es	Es	Es	Es	2023.08.25
2023.08.26										Es	Es					Es	Es	Es	Es	Es	Es				2023.08.26
2023.08.27	Es							Es	Es	Es							Es	Es	Es	Es	Es	Es	Es		2023.08.27
2023.08.28																	Es				Es				2023.08.28
2023.08.29								Es				Es	Es	Es	Es										2023.08.29

Detection of TID signatures' strength by hour from 25 to 29 August, for different ionosondes ('Es' marks periods affected by sporadic layers).

Detection times of MSTID signatures

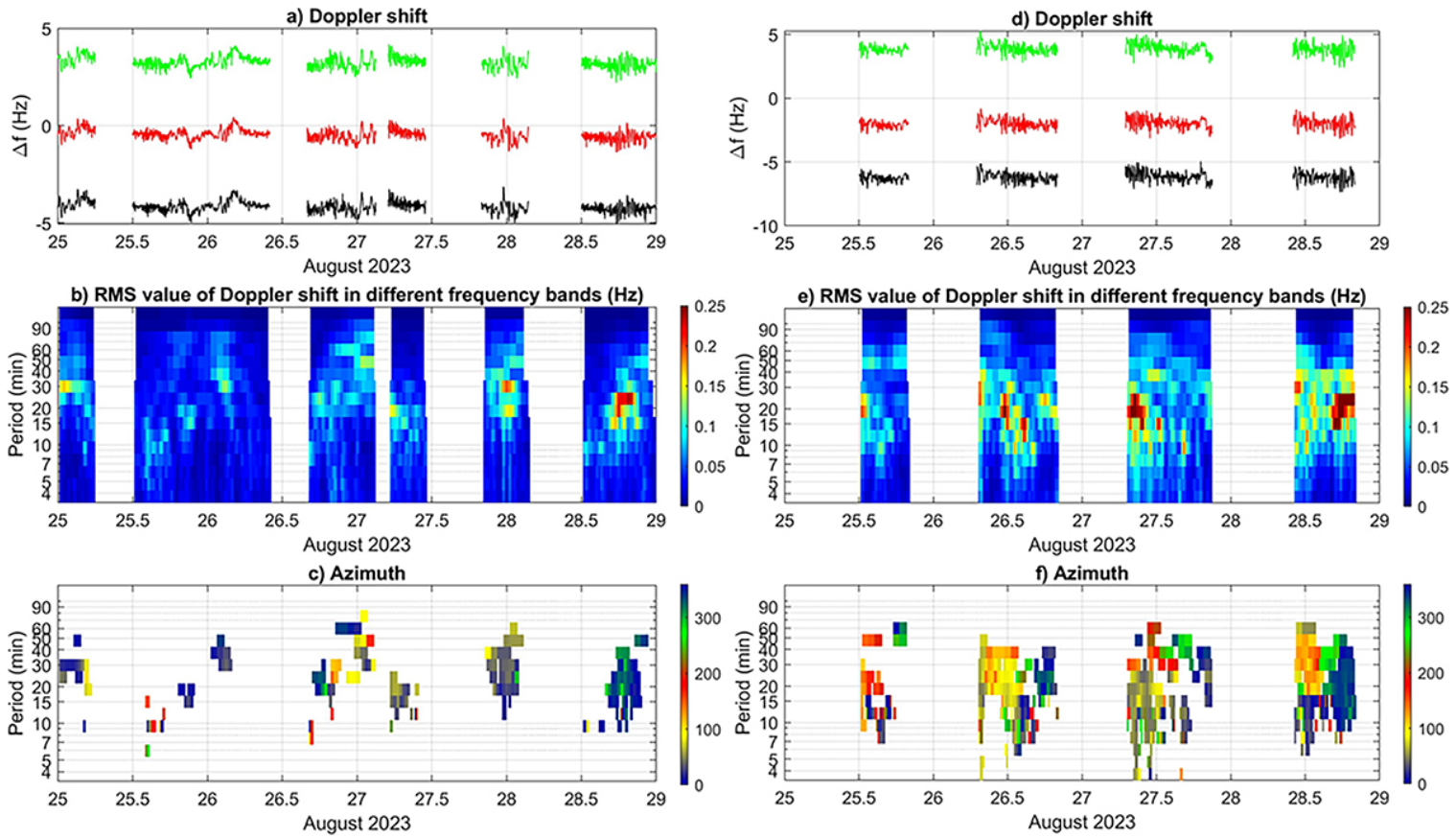


Central Europe longitudinal sector																									
JR055																									
2023.08.25	Es	Es	Es		Es	Es	Es	Es	Es	Es										Es	Es	Es	Es		2023.08.25
2023.08.26				Es				Es						Es	Es	Es		Es	Es	Es	Es			Es	2023.08.26
2023.08.27	Es	Es	Es	Es	Es			Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	2023.08.27
2023.08.28	Es	Es	Es	Es								Es	Es						Es	Es	Es	Es	Es	Es	2023.08.28
2023.08.29	Es	Es	Es	Es	Es	Es	Es				Es	Es	Es	Es					Es	Es	Es	Es	Es		2023.08.29
PQ052																									
2023.08.25							Es		Es	Es							Es	Es	Es	Es	Es	Es		Es	Es	2023.08.25
2023.08.26	Es	Es					Es		Es	Es		Es	Es	Es	Es	Es	Es		Es	Es	Es	Es	Es	Es	2023.08.26
2023.08.27	Es	Es	Es			Es						Es	Es	Es	Es	Es	Es	Es	Es	Es	Es				2023.08.27
2023.08.28				Es	Es	Es	Es			Es	Es	Es								Es					2023.08.28
2023.08.29		Es	Es	Es	Es														Es		Es				2023.08.29
SO148																									
2023.08.25										Es						Es									2023.08.25
2023.08.26									Es		Es	Es			Es	Es	Es	Es	Es	Es	Es	Es			2023.08.26
2023.08.27								Es		Es	Es	Es	Es	Es	Es	Es	Es	Es	Es						2023.08.27
2023.08.28						Es	Es	Es	Es			Es	Es									Es	Es		2023.08.28
2023.08.29			Es				Es											Es			Es				2023.08.29
VT139																									
2023.08.25		Es		Es				Es				Es			Es	Es	Es	Es	Es			Es	Es	Es	2023.08.25
2023.08.26								Es	Es	Es	Es	Es	Es	Es	Es			Es		Es	Es	Es		Es	2023.08.26
2023.08.27							Es		Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es	Es				2023.08.27
2023.08.28										Es		Es		Es											2023.08.28
2023.08.29						Es		Es	Es	Es						Es	Es		Es	Es					2023.08.29

Detection of TID signatures' strength by hour from 25 to 29 August, for different ionosondes ('Es' marks periods affected by sporadic layers).

TID propagation direction

Doppler sounder data from Czechia for the same period (left: 4.65 MHz, right 7.04 MHz).



Bottom panels show azimuth of detected waves' propagation direction.

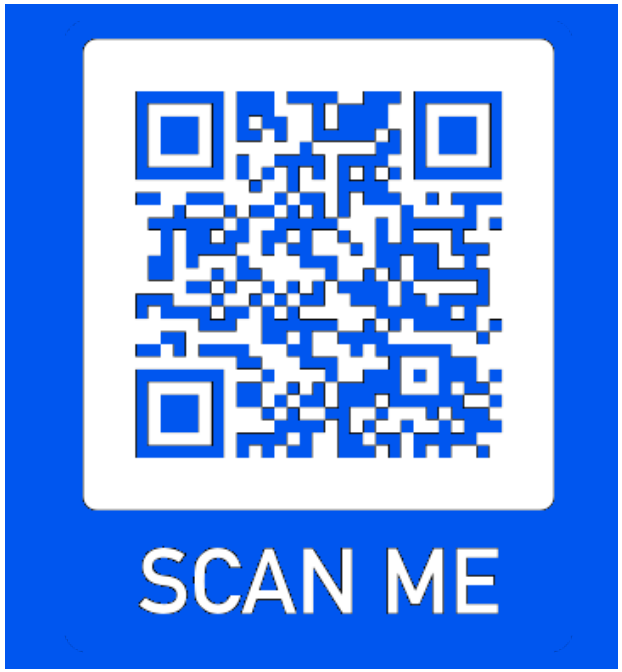
Conclusions

- Strong meteorological events affected the 25–29 August 2025 period: strong cold from over central Europe, combined with exceptional jet stream speeds.
- Most intense TID activity detected on August 27 between 06 and 13 UT, coinciding with peak of jet stream speed over central Europe.
- On 25 & 26, as well as 28 August also enhanced TID activity, coinciding with thunderstorms and mesoscale convective system in the same region.
- When identified, propagation direction mostly southward; TID effect remain very localised (compared to MSTIDs).

Very different tropospheric phenomena produce atmospheric gravity waves, which may propagate upwards to appear as TIDs.

For more details check out the paper

V. Barta, P. Potuznikova, P. Koucka-Knizova, J. Chum, J. Mielich, M. Guerra, *et al.* (2025): Multi-instrument analysis of medium-scale travelling ionospheric disturbances generated by an intense tropospheric jet-front system with severe convection in Europe in August 2023, *J. Space Weather Space Clim.* **15**, A23, doi:10.1051/swsc/2025025.



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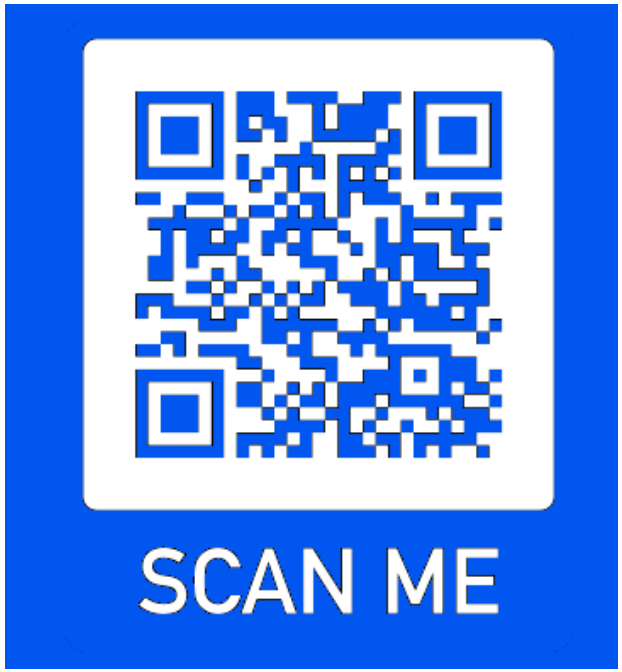

The end!

Questions, comments, suggestions?