Severe weather analysis with real-time GNSS tropospheric products and radar reflectivity

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Introduction

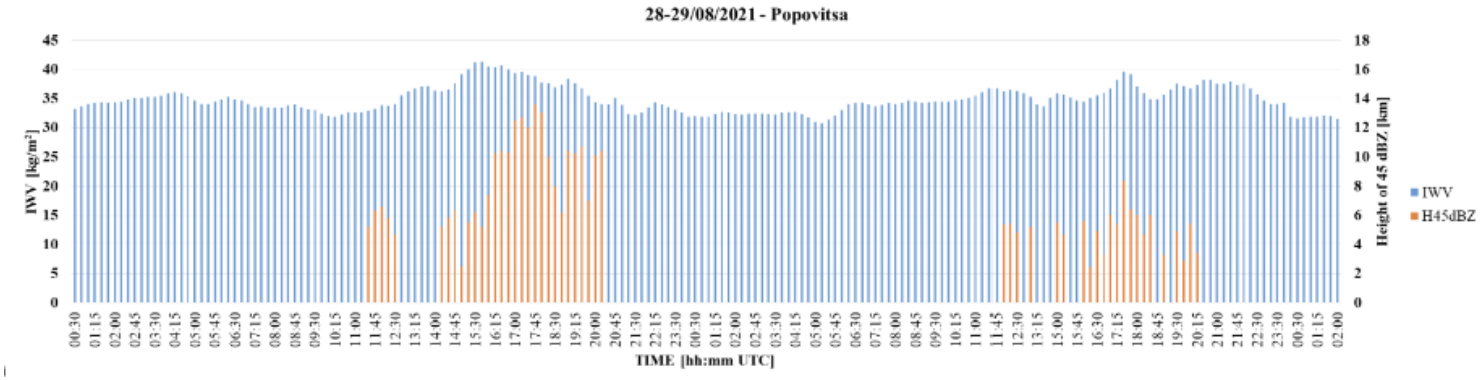
IWV & dBZ 2023
V. Pencheva
Introduction
Data & Methods
GNSS method
Radar data
Results
02-07.07
19-27.07
Conclusion

- WMO Nowcasting - detailed forecasting of local weather from 0 to 6 hours ahead
- Forecasted severe weather events: convective storms, locally forced precipitation events, blizzards, sand and dust storms, etc.
- Convective storm ingredients: instability + moisture + lifting

Supercell in mature stage developing over Sliven, Bulgaria, 12.06.2024

Motivation

- **Previously**: Guerova et. al, 2022. "GNSS Storm Nowcasting Demonstrator for Bulgaria" Remote Sensing 14/15, 3746.

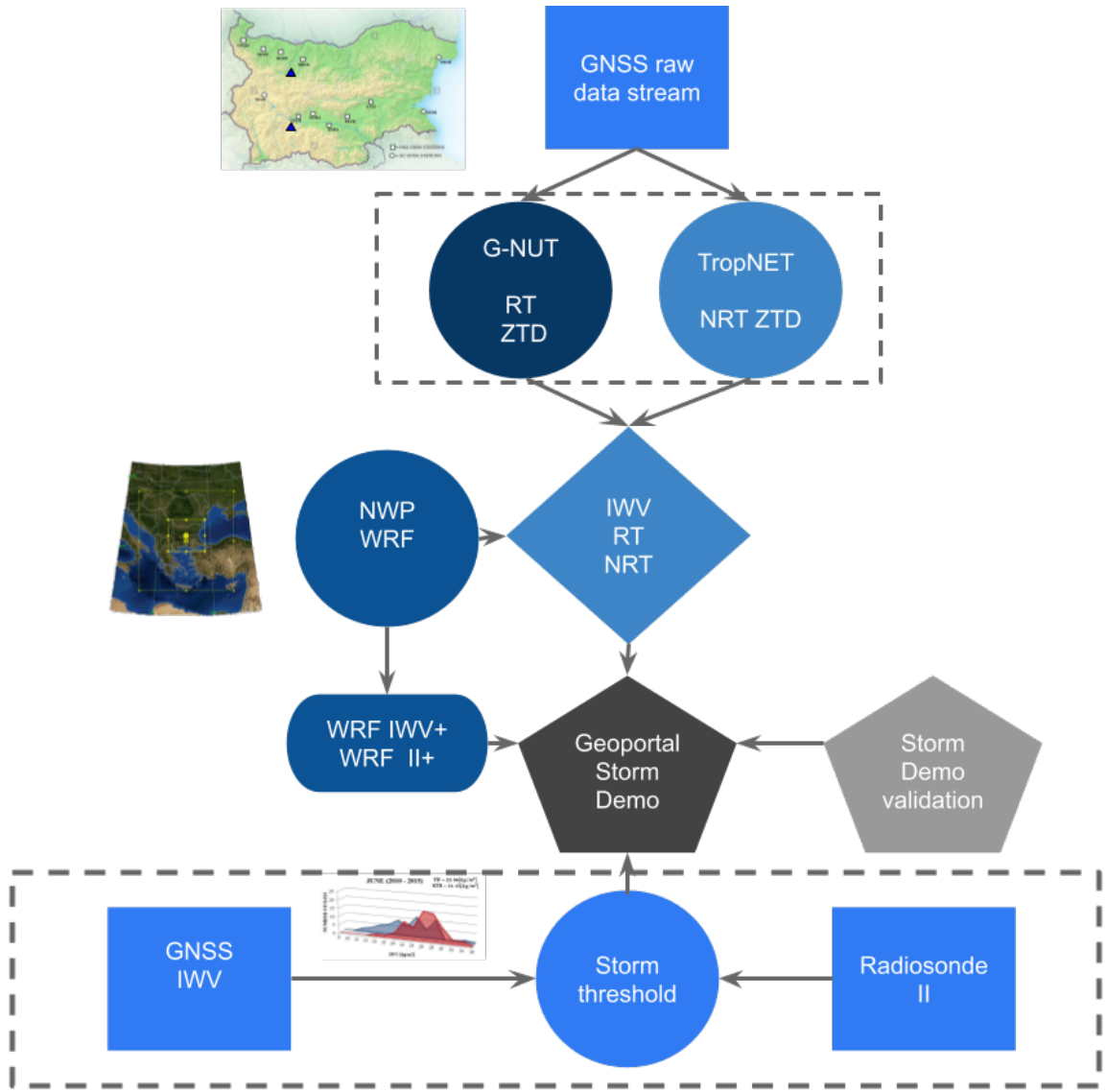


Station name	28 August 2021	29 August 2021
Popovitsa	0.56	0.14

Aims of the current research

- Analysis of the relation between water vapor in the troposphere and radar reflectivity (H45dBZ)
- Evaluation of integrated water vapor (IWV) serving as a useful tool in nowcasting of convective storms

GNSS Storm Nowcasting Demonstrator (Storm Demo)

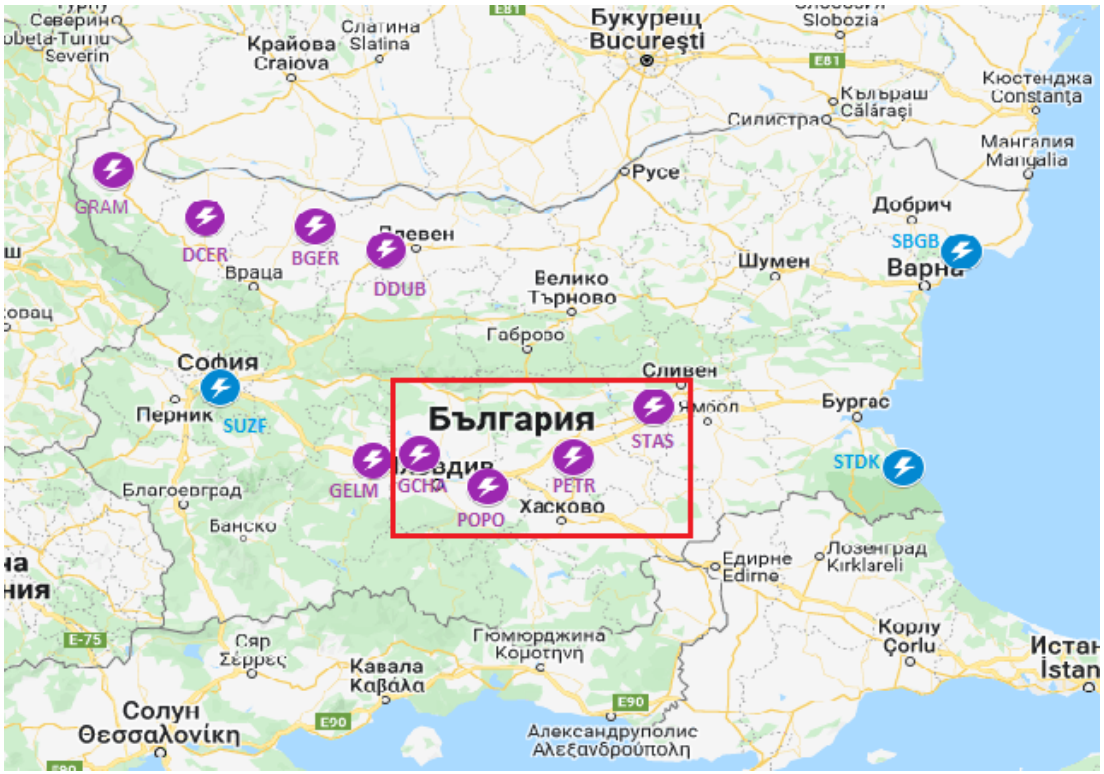


Integrated Water Vapor (IWV)

- Derivation of IWV from Zenith Wet Delay (ZWD):

$$IWV = \frac{10^6}{(\frac{k_3}{T_m} + k_2')R_v} ZWD, \qquad ZWD = ZTD - ZHD$$

- A total of 12 ground-based GNSS stations in Bulgaria



GNSS Tropospheric Gradients

Slant Total Delay (STD): $STD = 10^{-6} \int_S N(\vec{P})\, ds$

which depends on:

- the elevation ϵ of GNSS signal
- the azimuth α of GNSS signal

Assymmetric contribution to the total delay:

$$L(\epsilon, \alpha) = 10^{-6} \cdot m_0(\epsilon) \cdot cot(\epsilon) \cdot (G_{NS} \cdot cos(\alpha) + G_{EW} \cdot sin(\alpha))$$

where

- G_{NS} is North-South horizontal delay gradient
- G_{EW} is East-West horizontal delay gradient

Tropospheric delay gradient: $\vec{G} = \begin{pmatrix} G_{NS} \\ G_{EW} \end{pmatrix}$

Weather radar equations

- Radar reflectivity η and reflectivity factor Z:

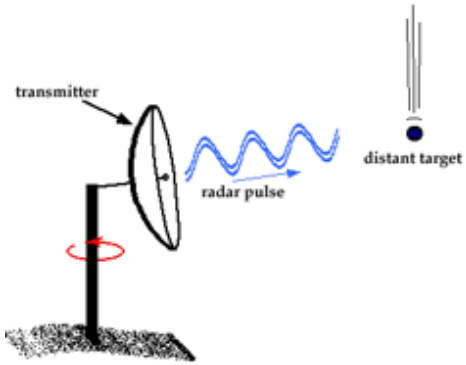
$$\eta = \frac{\pi^5}{\lambda^4}|K^2| \int_{D_{min}}^{D_{max}} D^6 N(D)\, dD, \qquad Z = \int_{D_{min}}^{D_{max}} D^6 N(D)\, dD$$

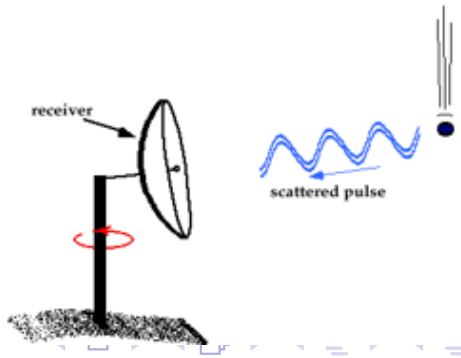
- Equivalent radar reflectivity factor Z_e:

$$Z_e = P_r \frac{R^2}{C|K^2|}, \qquad \text{dBZ} = 10 \log_{10} \left(\frac{Z_e \text{mm}^6 \text{m}^{-3}}{1 \text{mm}^6 \text{m}^{-3}} \right)$$

- Criteria for detection of hail cells (used in Bulgaria):

$$\Delta\text{H45dBZ} \geq 2\text{km} \qquad \Delta\text{H45dBZ} = \text{H45dBZ} - \text{H}_0$$



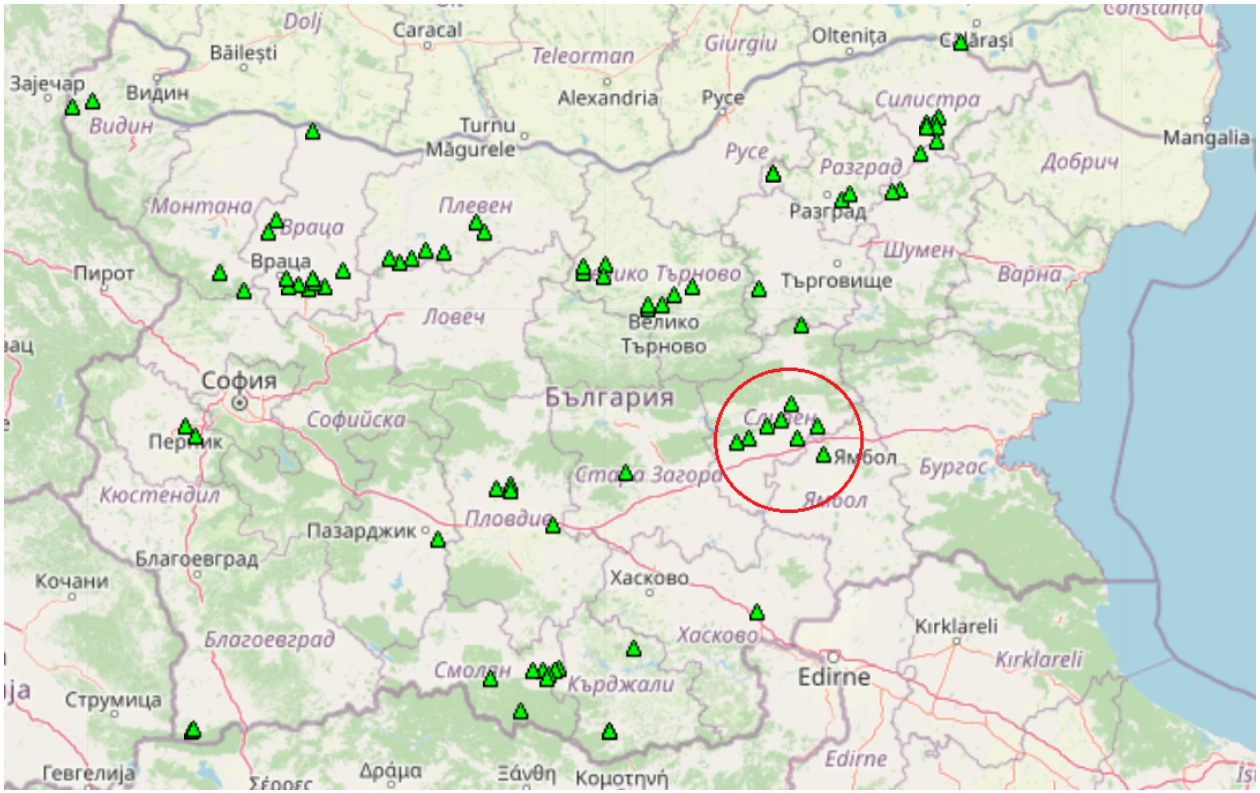


Severe weather events in Bulgaria 2023: IWV & dBZ

IWV & dBZ 2023
V. Pencheva
Introduction
Data & Methods
GNSS method
Radar data
Results
02-07.07
19-27.07
Conclusion

Reports for large hail ($\geq$ 2 cm) from European Severe Weather Database:

- 113 reports for 2023 over Bulgaria's territory
- 77 of which in July and August



Severe weather events in Bulgaria 2-4 July 2023

IWV & dBZ 2023

V. Pencheva

Introduction

Data & Methods

GNSS method

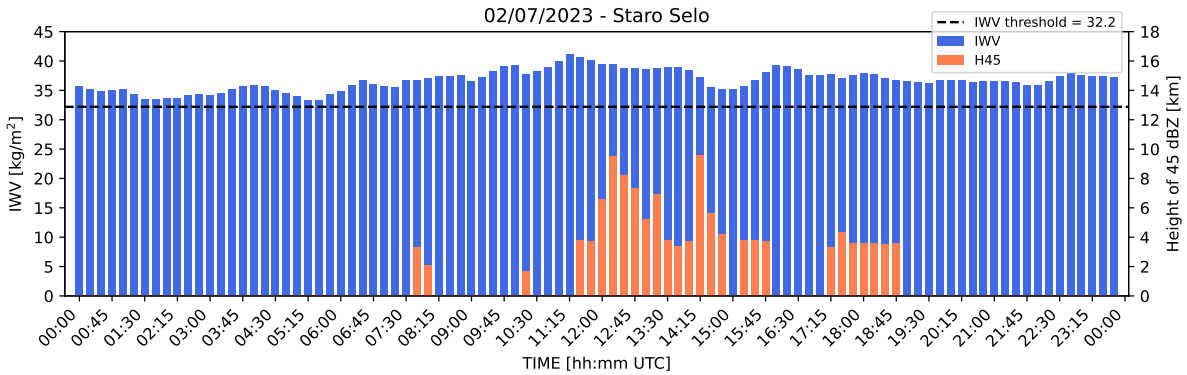
Radar data

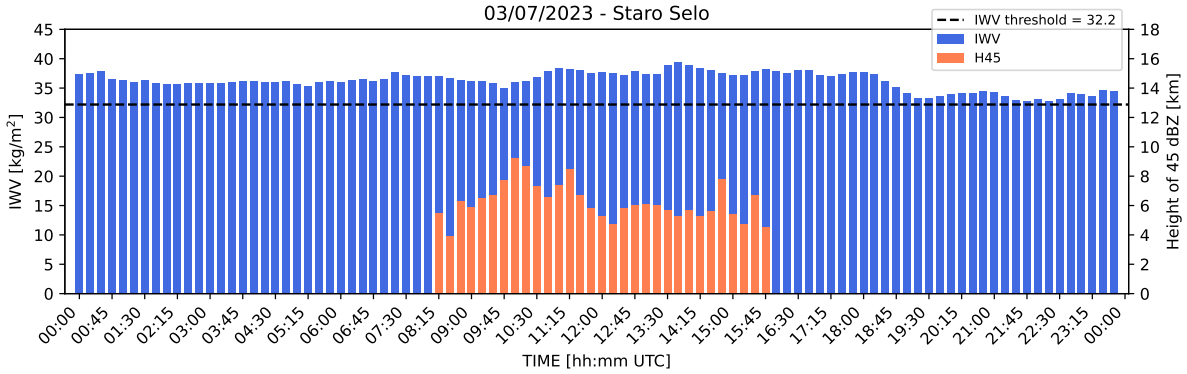
Results

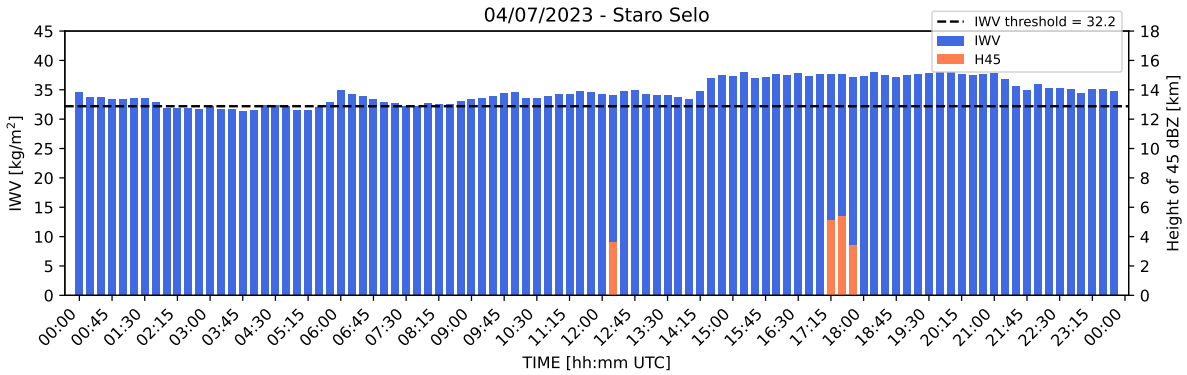
02-07.07

19-27.07

Conclusion







Severe weather events in Bulgaria 5-7 July 2023

IWV & dBZ 2023

V. Pencheva

Introduction

Data & Methods

GNSS method

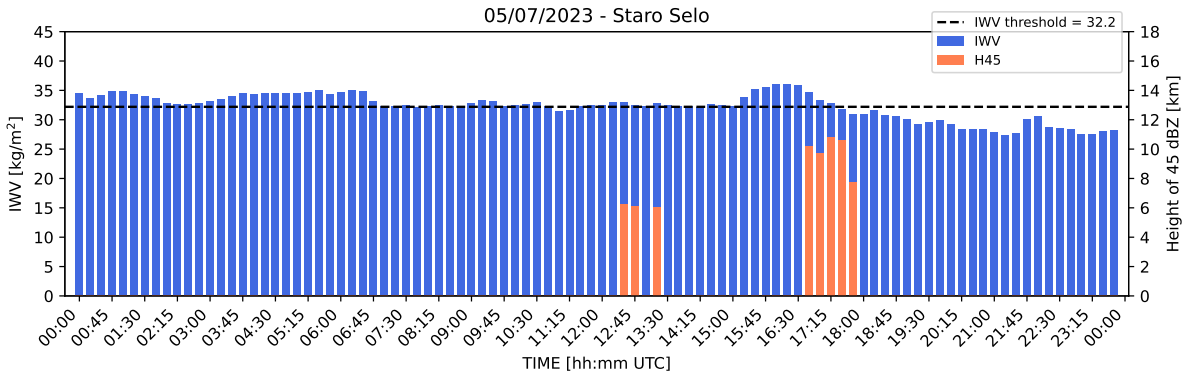
Radar data

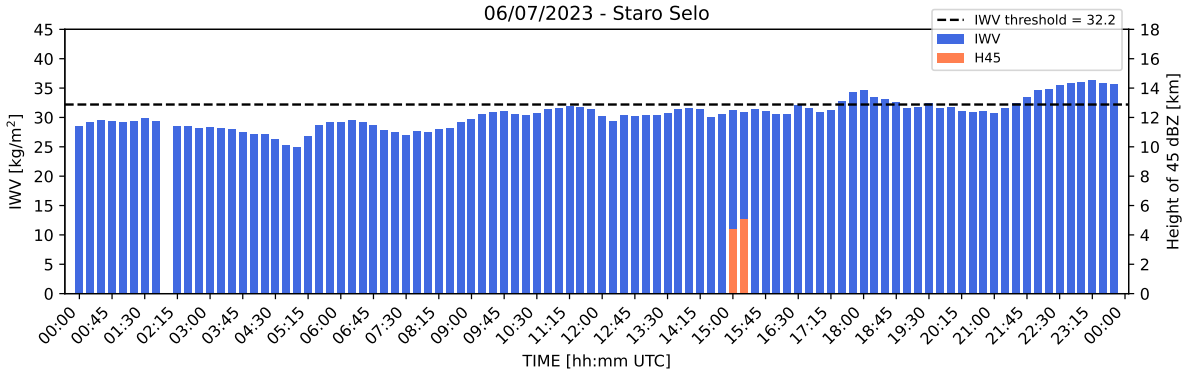
Results

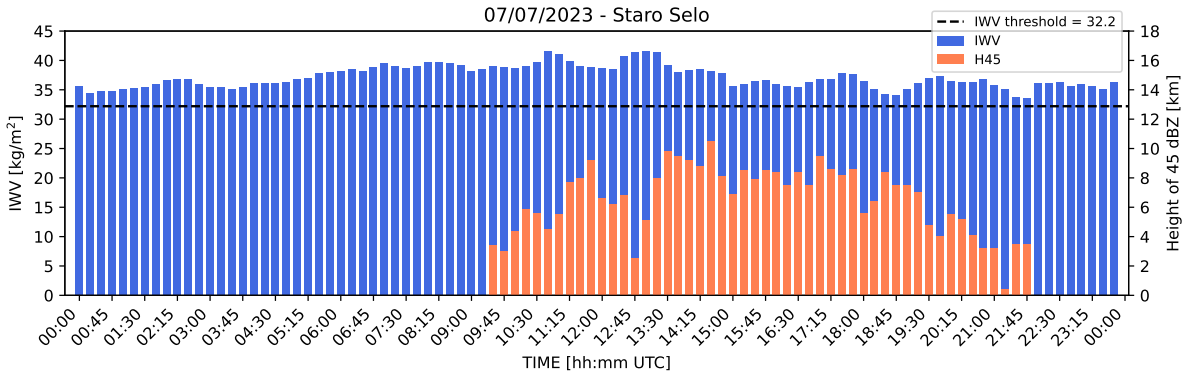
02-07.07

19-27.07

Conclusion







Severe weather events in Bulgaria 2-7 July 2023

IWV hourly variation [kg/m^2] between 6 and 16 UTC for three GNSS stations + daily average values for IWV, H45 and H_0:

Station name	02.07.23	03.07.23	04.07.23	05.07.23	06.07.23	07.07.23
Golyam chardak	0.57	0.29	0.43	0.07	0.15	-0.24
Petrovo	0.34	0.17	0.17	0.05	0.60	-0.41
Staro selo	0.45	0.18	0.28	0.14	0.14	-0.22
Daily average IWV [kg/m^2]	36.7	36.3	34.7	32.3	30.6	37.2
Daily average H45 [km]	4.5	5.4	4.4	7.6	4.8	5.0
Zero-degree isotherm H_0 [km]	3.7	3.9	4.4	4.3	4.0	3.9

Case study 5 July 2023

IWV & dBZ 2023

V. Pencheva

Introduction

Data & Methods

GNSS method

Radar data

Results

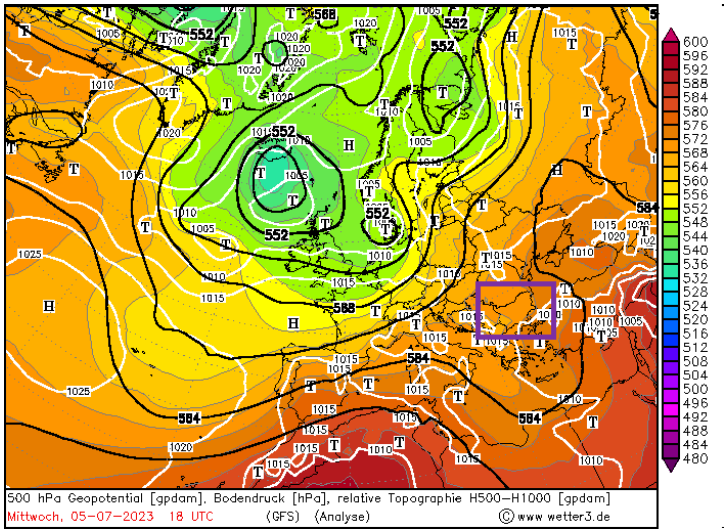
02-07.07

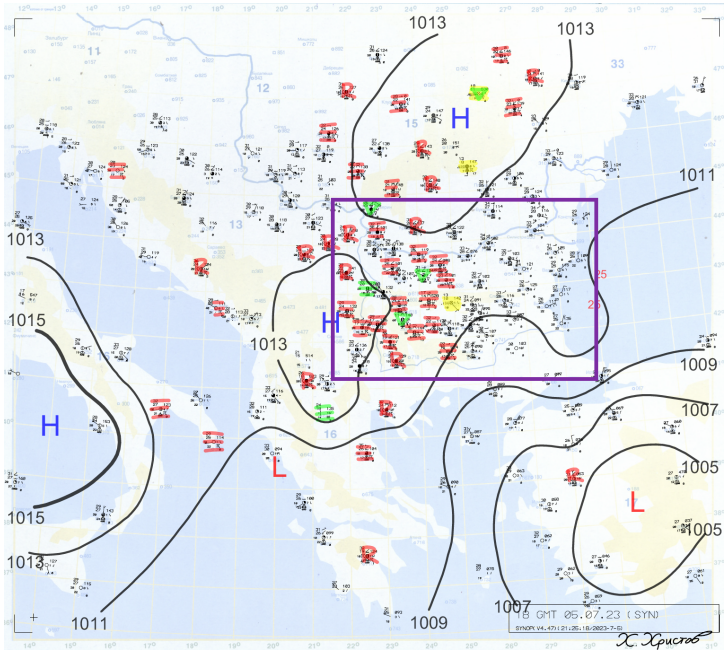
19-27.07

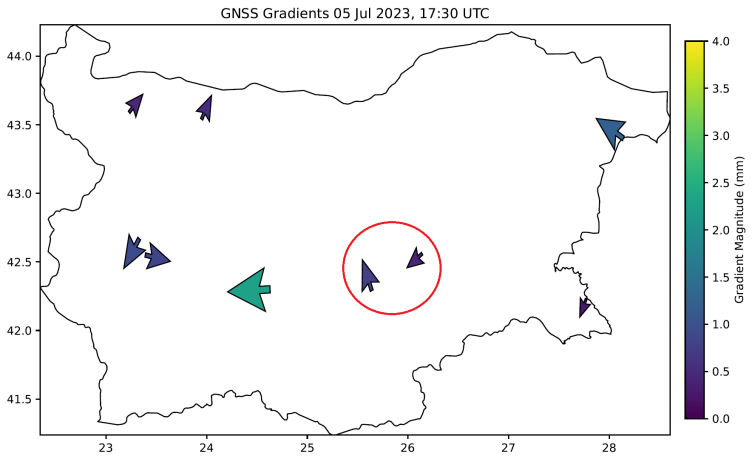
Conclusion

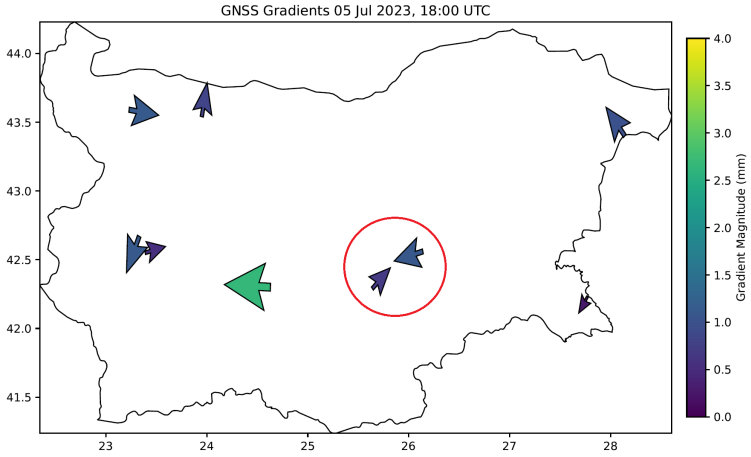
Source 1: www.wetter3.de

Source 2: NIMH Bulgaria









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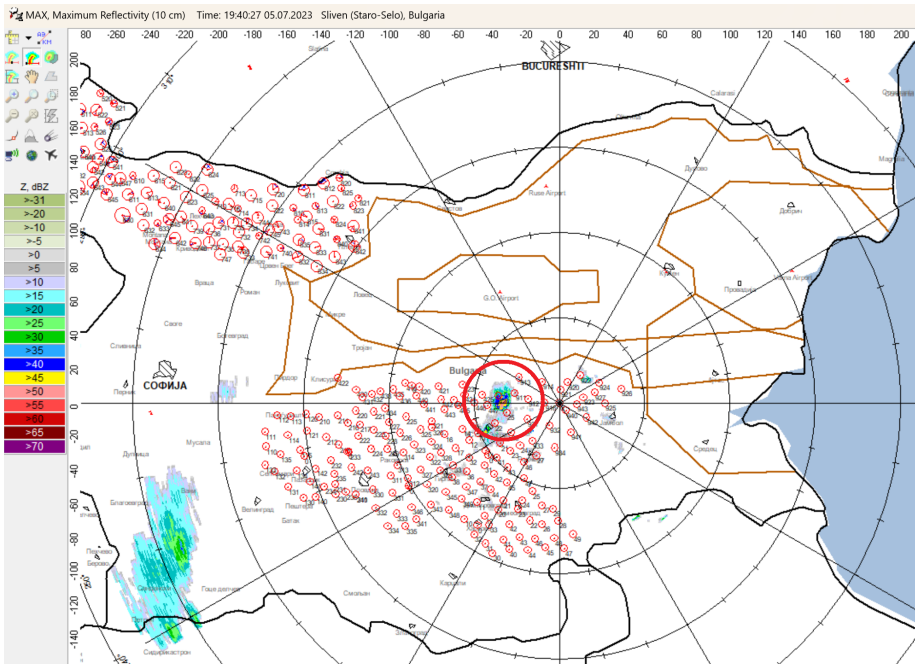
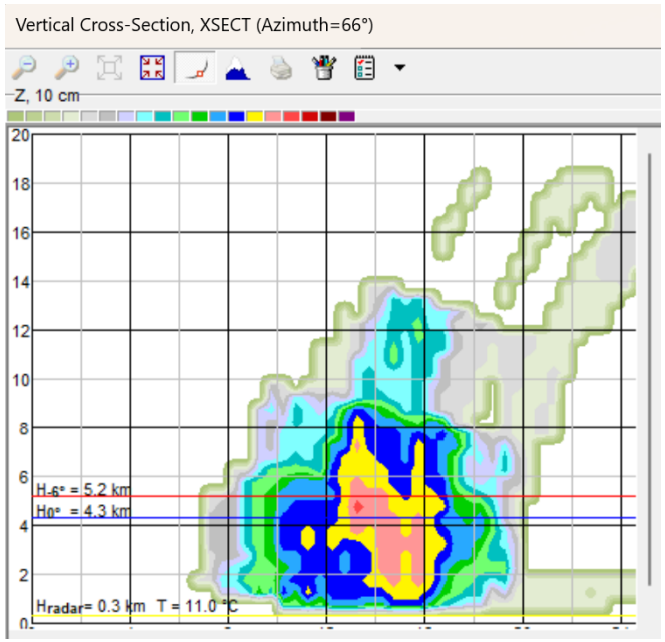
Radar image + vertical cross-section of a convective cell at 16:36 UTC 5.07.2023





Severe weather events in Bulgaria 19-27 July 2023

IWV & dBZ 2023

V. Pencheva

Introduction

Data & Methods

GNSS method

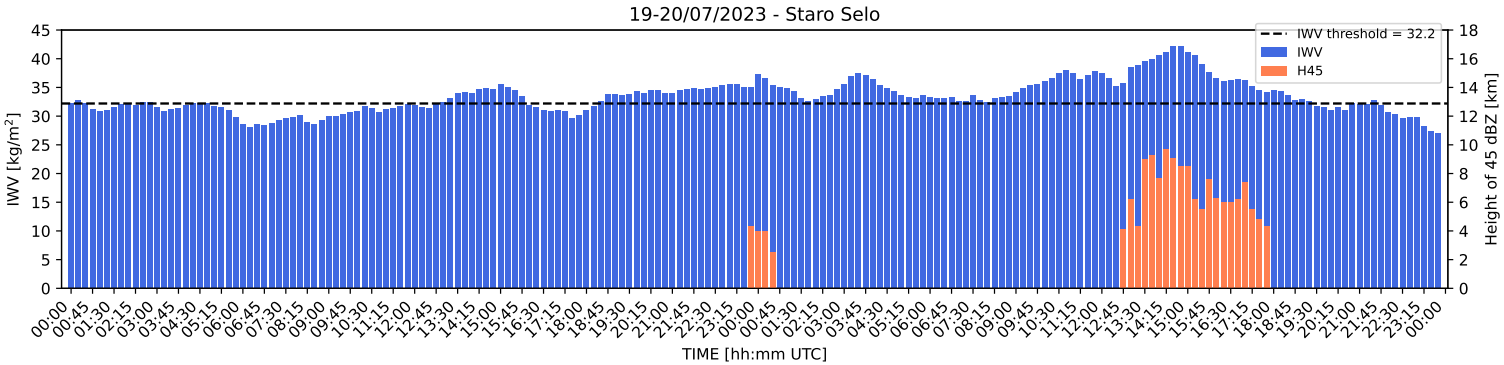
Radar data

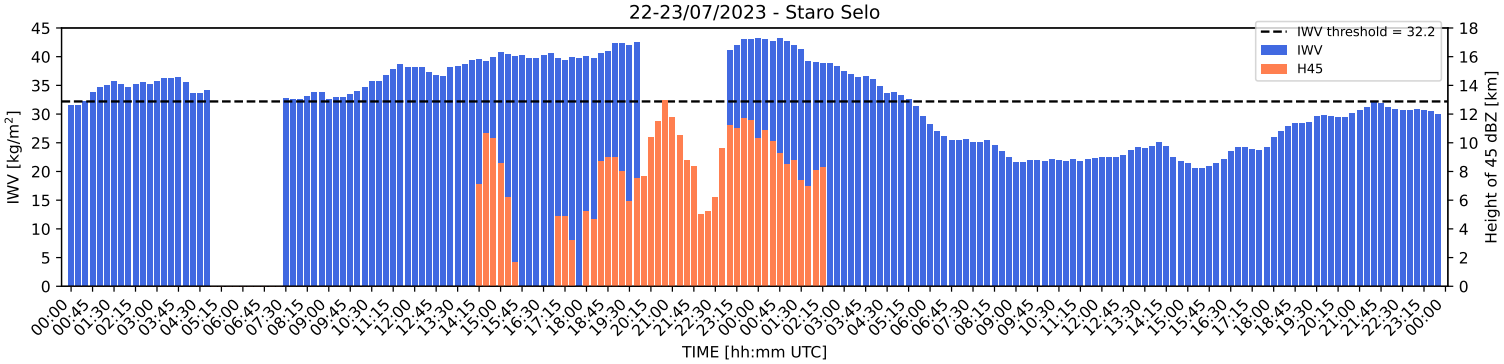
Results

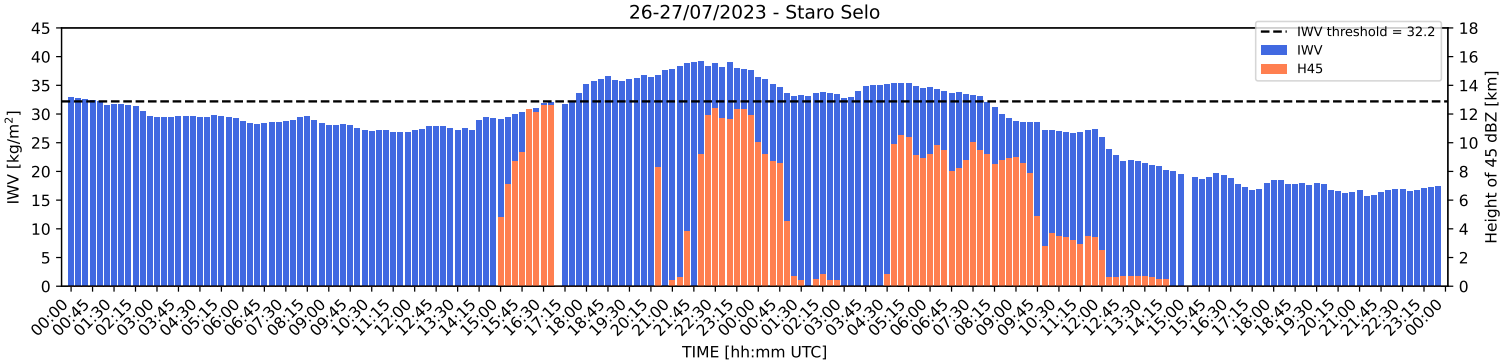
02-07.07

19-27.07

Conclusion







Severe weather events in Bulgaria 19-27 July 2023

IWV & dBZ 2023

V. Pencheva

Introduction

Data & Methods

GNSS method

Radar data

Results

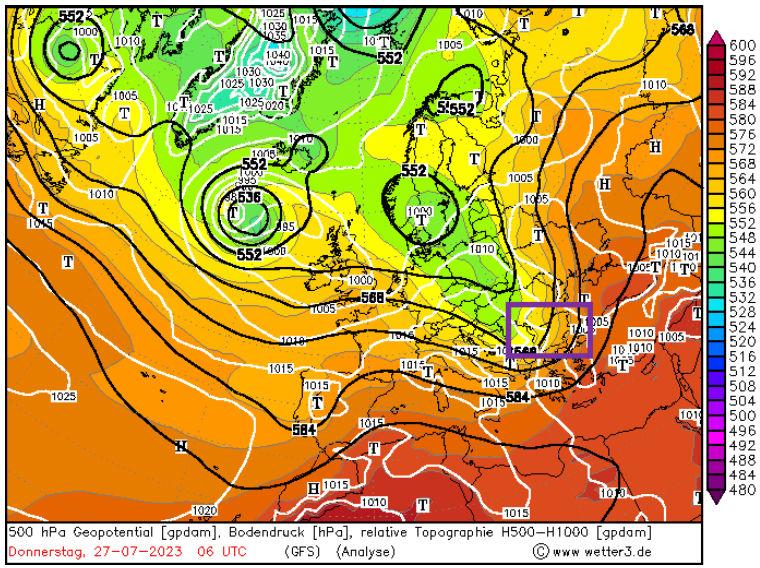
02-07.07

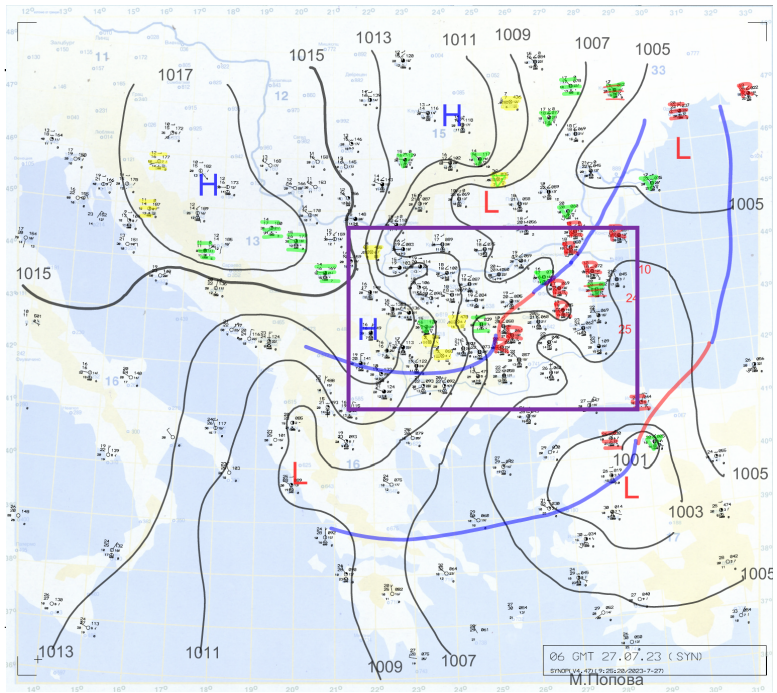
19-27.07

Conclusion

Station name	19.07.23	20.07.23	21.07.23	22.07.23	23.07.23	24.07.23	25.07.23	26.07.23	27.07.23
Golyam chardak	0.64	-0.34	0.22	0.80	-0.04	-0.08	0.15	0.58	-1.54
Petrovo	0.70	0.98	0.15	0.83	-0.99	0.75	0.37	0.07	-1.82
Staro selo	0.34	0.59	0.54	0.74	-0.67	0.58	0.16	0.21	-1.51
Daily average IWV [kg/m^2]	32.2	34.7	30.0	37.2	28.5	29.5	33.1	31.4	25.5
Daily average H45 [km]	3.7	5.6	0.0	7.3	8.6	0.0	0.0	9.0	6.0
Zero-degree isotherm H_0 [km]	4.3	4.2	4.3	4.4	4.6	4.5	4.5	4.4	3.4

Case study 26-27 July 2023





Case study 26-27 July 2023

IWV & dBZ 2023

V. Pencheva

Introduction

Data & Methods

GNSS method

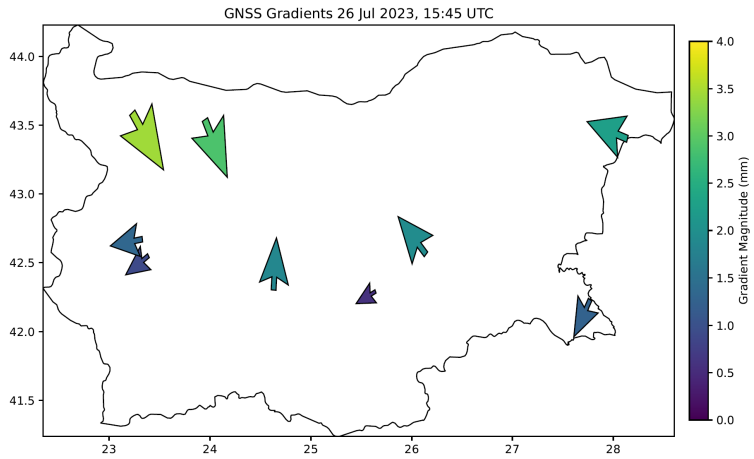
Radar data

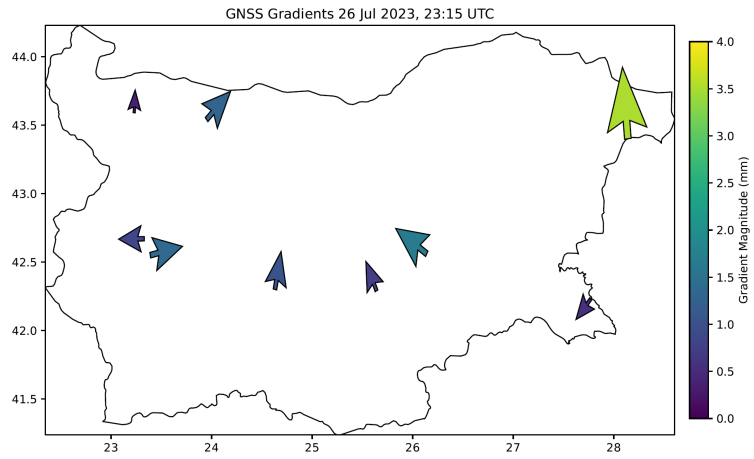
Results

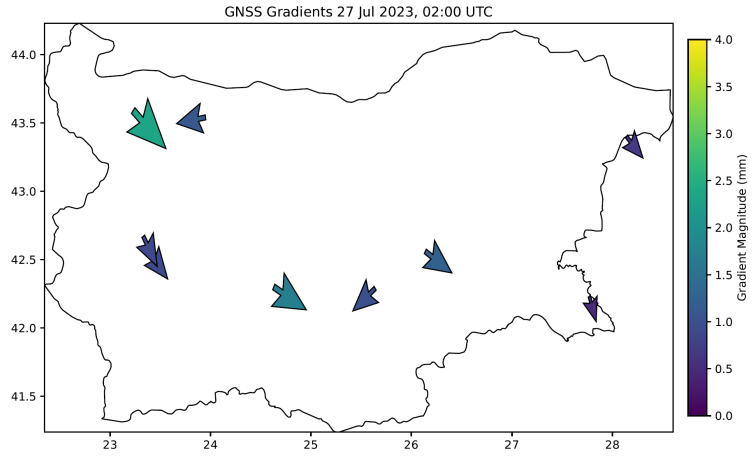
02-07.07

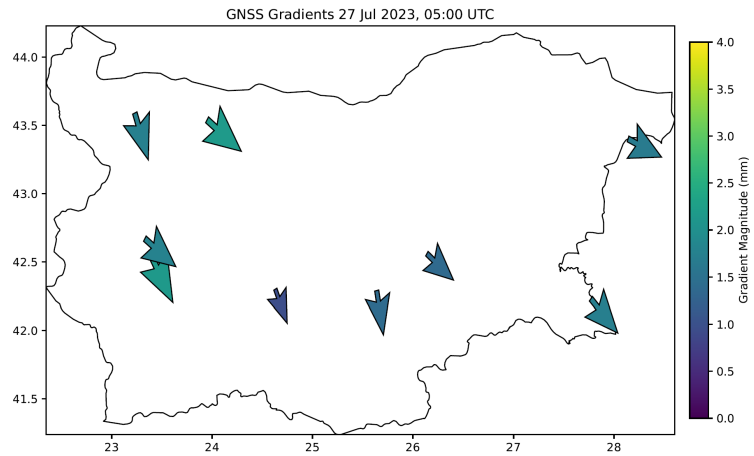
19-27.07

Conclusion



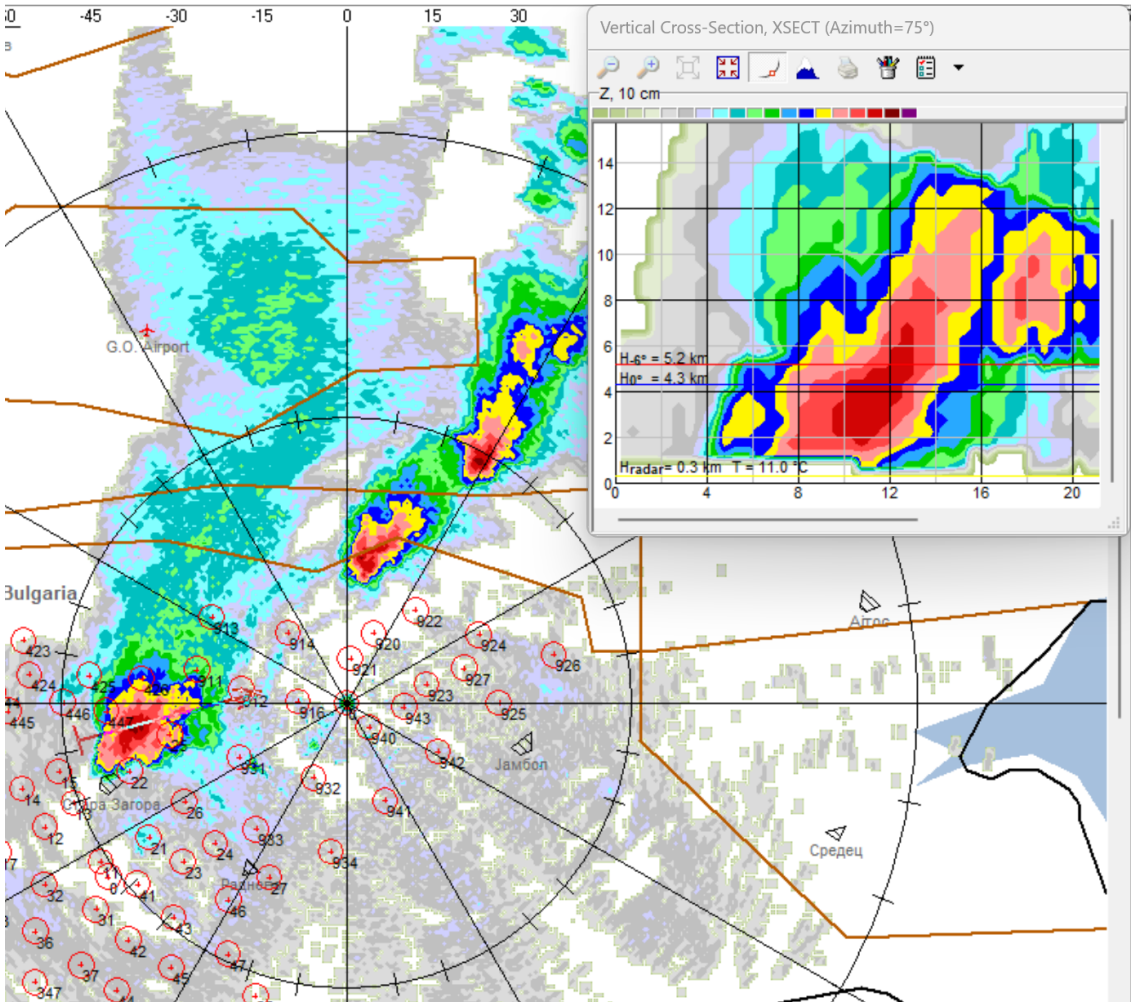






Case study 26-27 July 2023

Radar image + vertical cross-section of a convective cell at 22:18 UTC 26.07.2023



Conclusion

From the obtained results, the following conclusions can be made:

- Analysis of 3 weeks with severe weather with GNSS IWV and gradients clearly indicated the need of high temporal resolution
- High daily average IWV correlates with high values of H45 but in the case of frontal passage this relation does not hold
- GNSS derived gradients during frontal passage are well pronounced but for local convection gradient convergence is also detected
- Currently, GNSS Storm Demo real-time data for Bulgaria is with temporal resolution of 5 min but low spatial resolution

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THANK YOU!