Tornado hazard prediction with COSMO-Ru Parameters and indices

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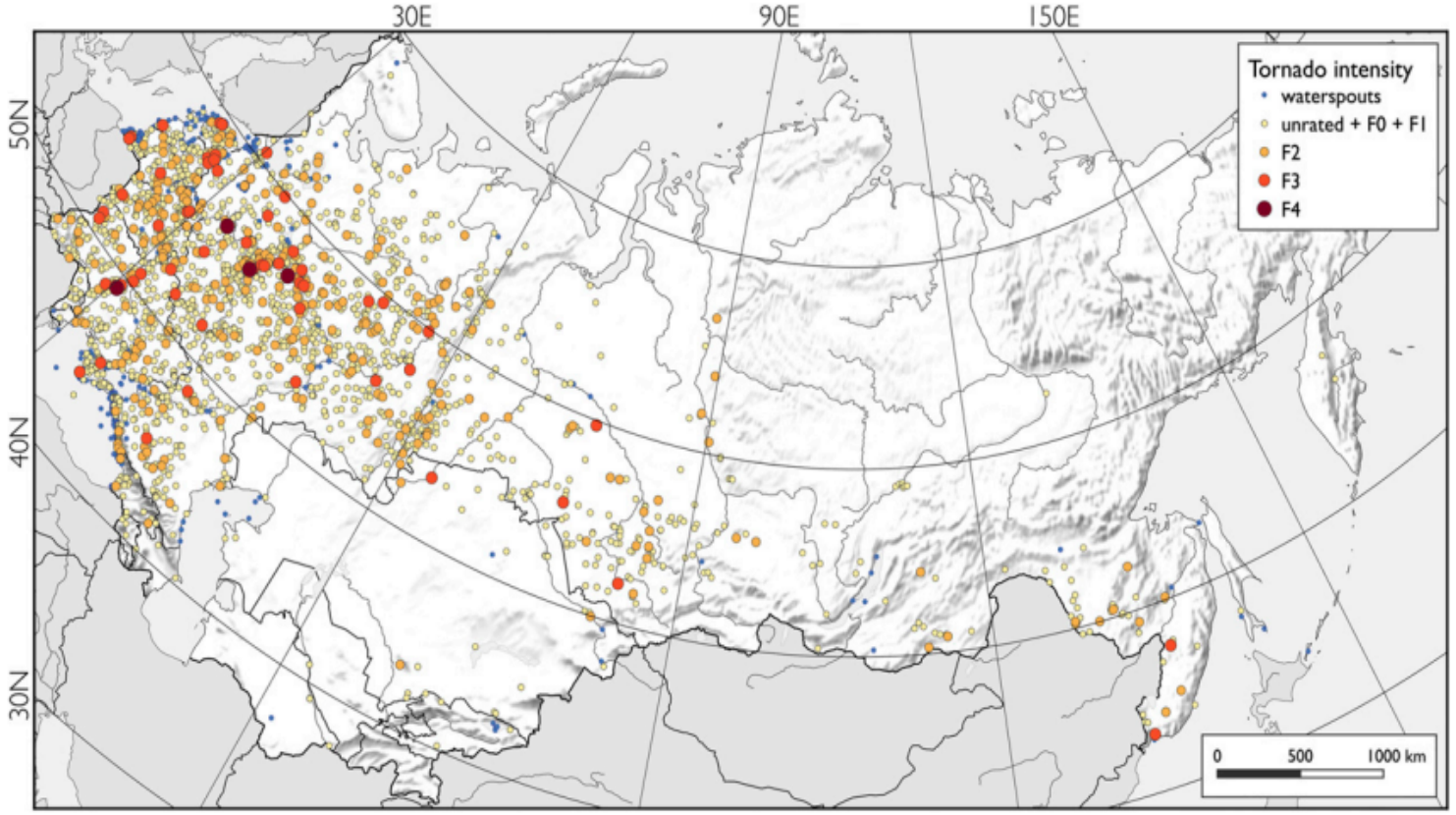
Tornado occurrence in Russia



*Spatial distribution of Tornadoes, observed over Northern Eurasia in 979-2016 [Chernokulsky et al, Monthly Weather Reviews, 2020 DOI:*10.1175/MWR-D-19-0251.1*]*

- Previous estimates of Tornado occurrence frequency in Russia [Snitkovsky, 1987] turned out to be severly undervalued.
- Recent research [Chernokulsky et al, 2020] showed that on average Russia experiences about 100-150 tornadoes per year. During some years the number can rise up to 350.
- About 10% of these tornadoes become significant (EF-2 or higher) and can cause serious damage and human deaths or injuries.

Tornado classifications

Non-mesocyclonic

A waterspout over the Black sea [https://vk.com/meteodnevnik]

Mesocyclonic

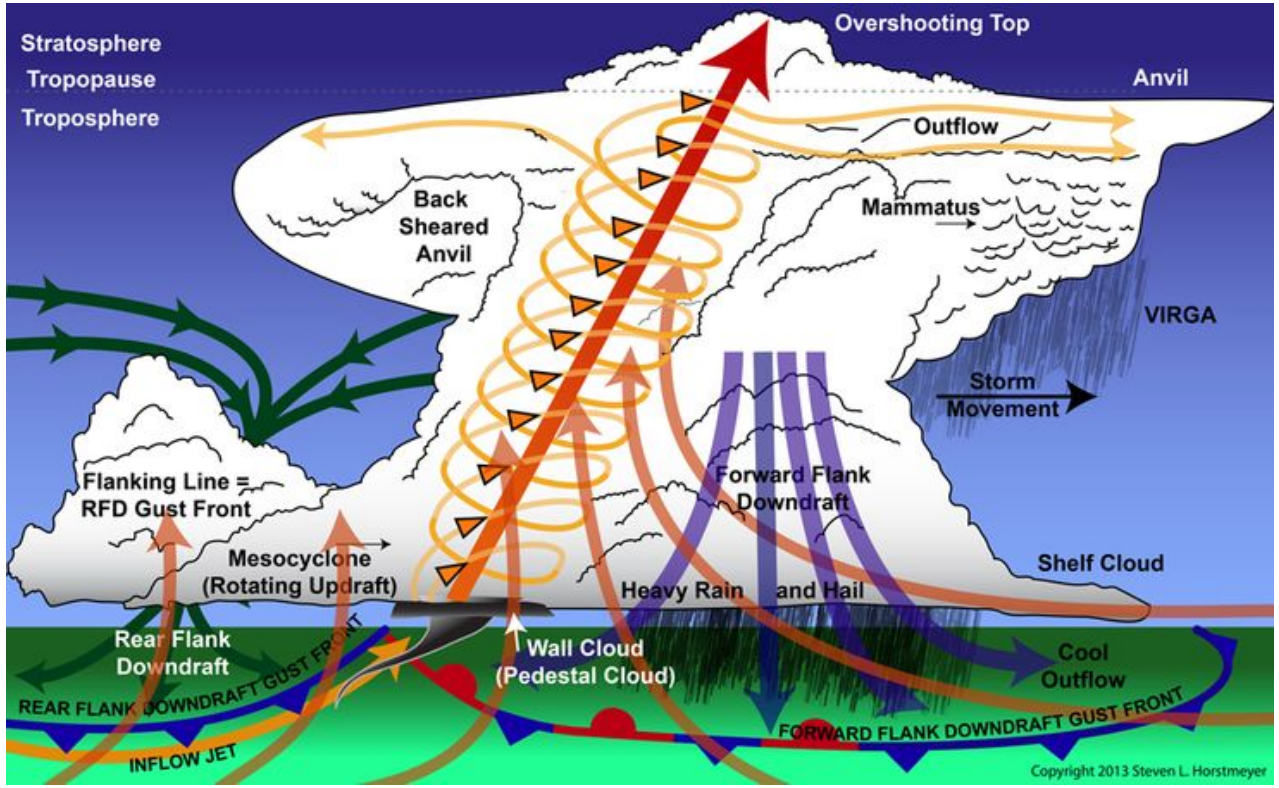
A mesocyclonic tornado over Vologda region, 2020 [https://vk.com/meteodnevnik]

The Enhanced Fujita Scale, 2007

Enhanced Fujita Scale Rating	Wind speed estimate (m/s)
EF-0	≤37
EF-1	38-49
EF-2	50-61
EF-3	62-74
EF-4	75-89
EF-5	≥90

Supercells & Mesoscale Convective Systems

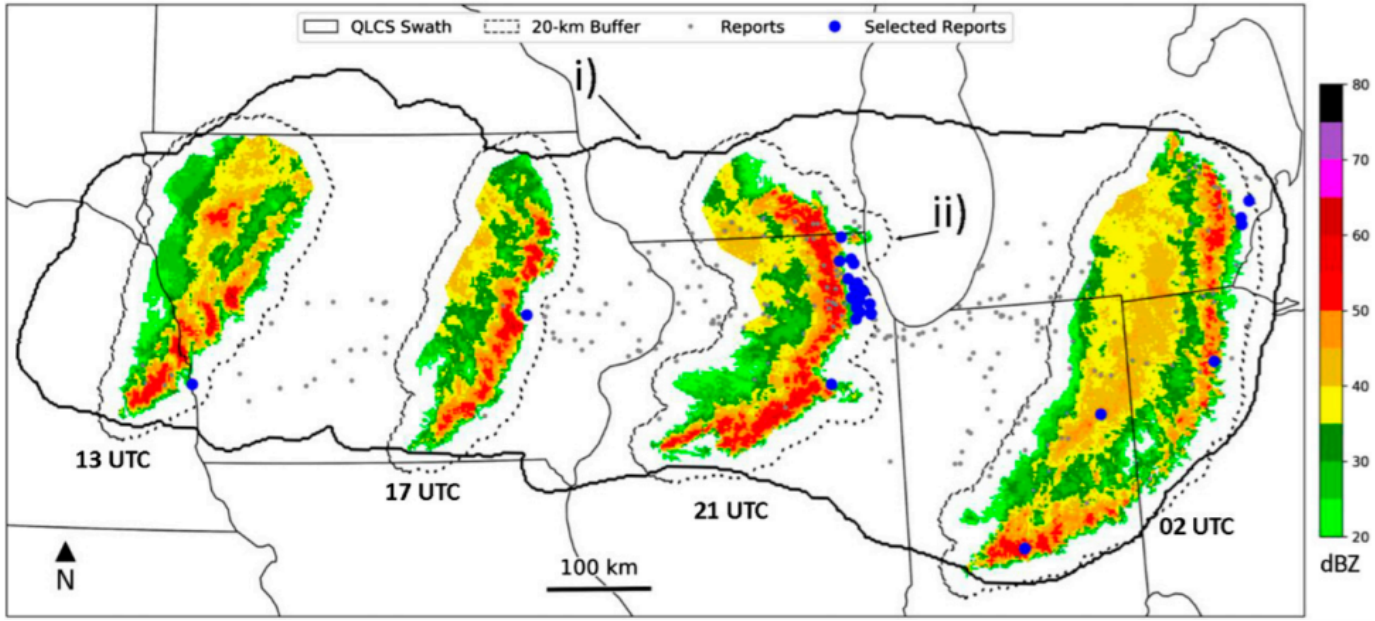
A **Supercell** is a thunderstorm characterized by the presence of a mesocyclone: a deep, persistently rotating updraft [Doswell, 1996]



A schematic cross-section of a mature supercell storm

- Initiate when storm updrafts (mostly single-celled) encounter strong vertical wind shear.
- Supercells can be long-lived (up to 6-8 hours) and can produce powerful microbursts, large hail, frequent lightning and heavy precipitation.
- Up to 30% of all supercells produce Tornadoes.
- Supercells are responsible for the majority of Significant and Violent tornadoes.

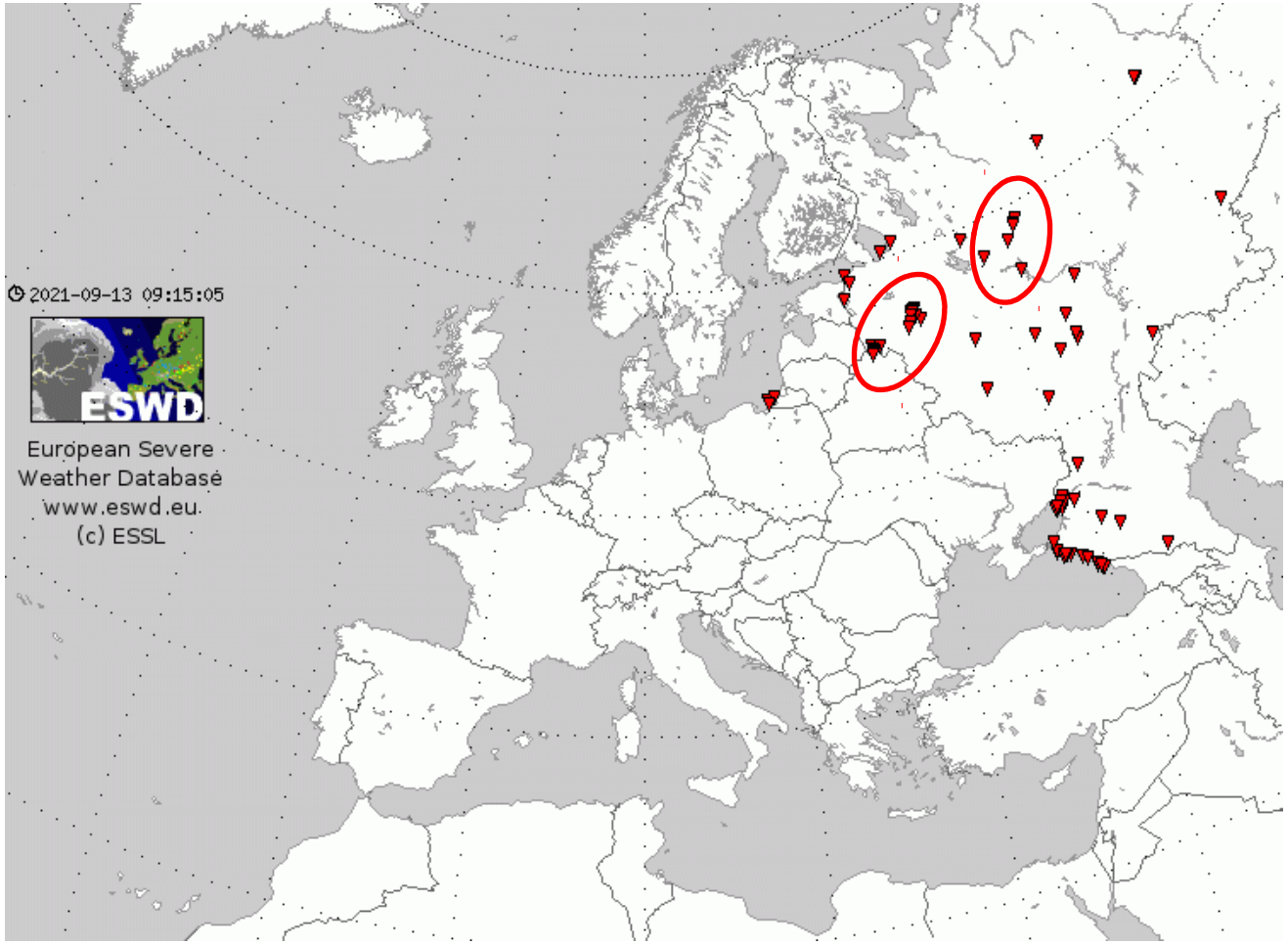
Supercells & Mesoscale Convective Systems



A composite radar image of a QLCS evolution [Ashley et.al, 2019]

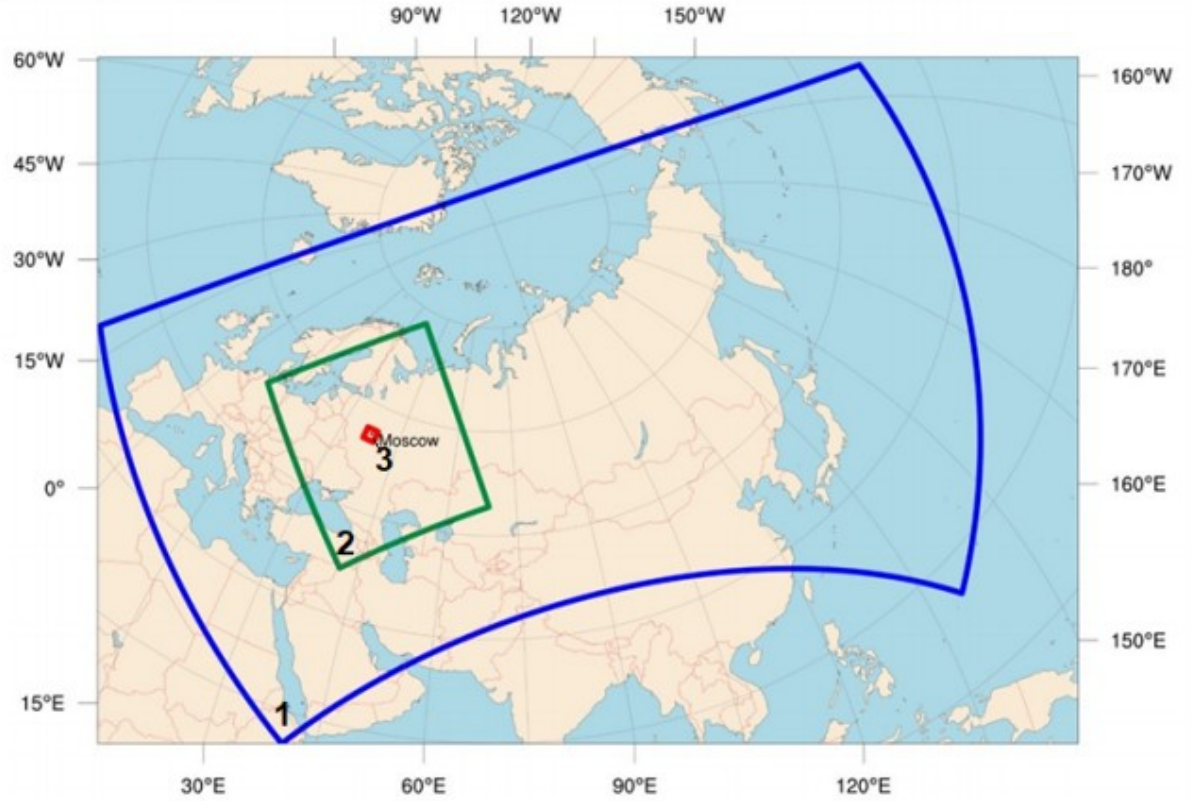
- Supercells can be embedded in developing Mesoscale convective systems.
- Quasi-Linear Mesoscale Convective Systems can generate mesosyclones (Line echo wave patterns).
- QLCS and “Bow Echo” Tornadoes tend to be short-lived and less intense, than Supercell-produced Tornadoes.
- Mesoscale Convective Systems often produce damaging downbursts and widespread straight-line winds

Tornado Season 2021 in Russia



- According to the European Severe Weather Database (ESWD), 85 tornado records took place in Russia in 2021.
- The most damaging outbreaks on the European part of Russia in 2021 were recorded on May 15 and August 2.

The COSMO-Ru Setup



The experiments were performed using global ICON 13km-grid initial and boundary data and downscaling to 1km-grid domains.

	6.6 km	2.2 km	1.1 km
Vertical layers	40	50	
Mircophysics scheme	Two-category ice scheme	Three-category ice scheme	
Convection scheme	Mass flux Tiedke scheme	Mass flux Tiedke scheme (Shallow convection scheme)	
Turbulence scheme	1-D TKE based diagnostic closure		
Time step [s]	50	20	5

All 2.2 km model simulations were performed with the Latent Heat Nudging scheme using radar data.

The Supercell Detection Index (SDI)

Equations from *[Wicker et. al, 2005]*:

$$SDI_{1,ij} := \rho_{ij}\overline{\zeta_{ij}}$$

$$SDI_{2,ij} := \begin{cases} \rho_{ij}|\overline{\zeta_{ij}}| & : \quad \omega > 0 \\ 0 & : \quad \omega \leq 0 \end{cases}$$

$\lvert SDI\rvert = 0.0003\ 1/s$	Minimal threshold for supercells
$\lvert SDI\rvert > 0.003\ \ 1/s$	Significant signal for supercells

Minimal threshold for supercells

$\lvert SDI\rvert = 0.0003\ 1/s$	Minimal threshold for supercells
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Significant signal for supercells

Vertical vorticity – Vertical velocity correlation:

$$\rho_{ij} := \frac{\langle \omega' \zeta' \rangle}{\left(\langle \omega'^2 \rangle_{ij} \langle \zeta'^2 \rangle_{ij}\right)^{\frac{1}{2}}}$$

Vertically averaged relative vorticity:

$$\overline{\zeta_{ij}} := (\nabla \times v)_z$$

The Significant Tornado Parameter (STP)

- Equation from *[Thompson et al, 2004]:*

$$STP = \left(\frac{MLCAPE}{1000\ \mathrm{J/kg}}\right)\left(\frac{SHR_6}{20\ \mathrm{m/s}}\right)\left(\frac{SRH_{0-1\,km}}{100\ \mathrm{m^2/s^2}}\right)\left(\frac{2000m\ - MLLCL}{1500\,m}\right)$$

Mixed Layer Convective Available Potential Energy

Bulk wind shear (0-6 km layer)

Storm-Relative Helicity (0-1 km layer)

Mixed Layer Lifted Condensation Level

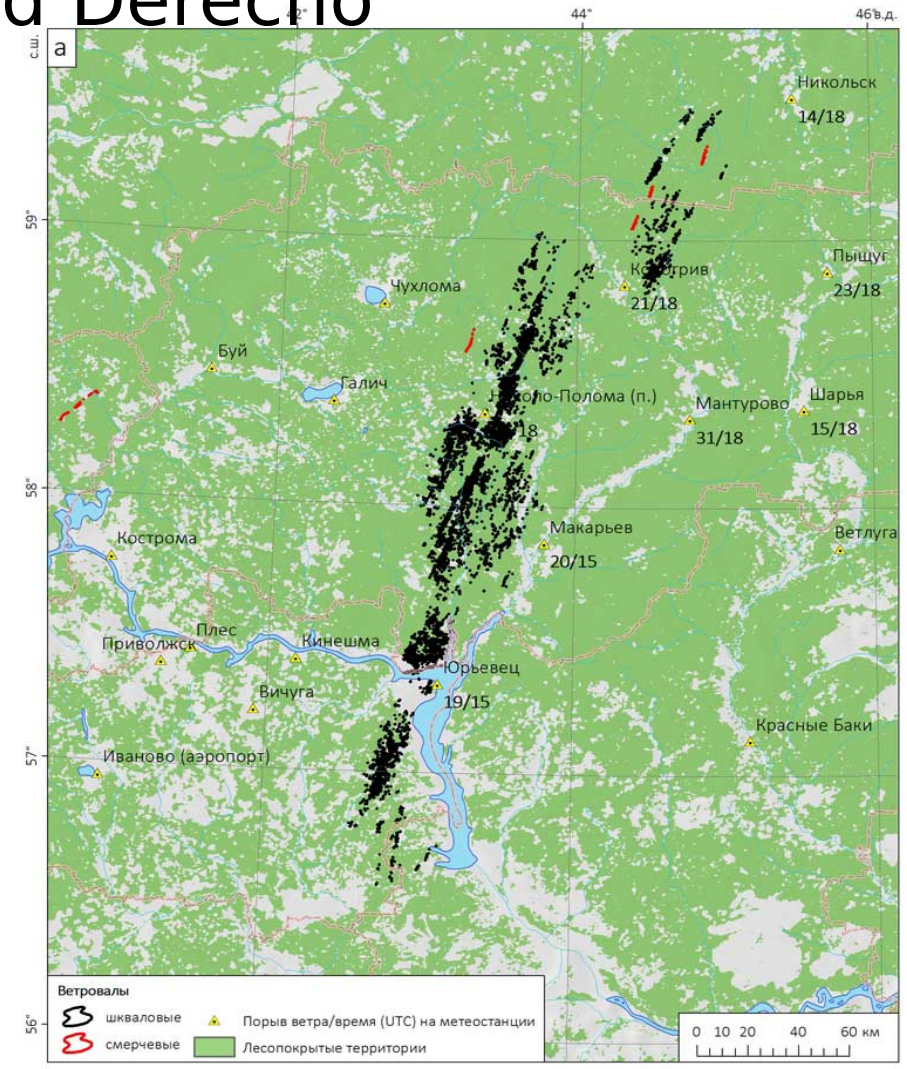
$$SRH_z = -\int_0^z (\vec{V} - \vec{C})\vec{k} \times \frac{d\vec{V}}{dz}\,dz$$

From *[Davies-Jones et al, 1990]*
Bunkers Storm Motion ($\vec{C}$) used *[Bunkers et al, 2000].*

Case 1. The May 15 Tornado outbreak and Derecho

- At least 6 tornadoes were recorded during the outbreak in Yaroslavl, Kostroma and Vologda regions.
- A long-lived QLCS caused a 360 km long area of forest damage. Recorded wind speeds exceeded 31 m/s.

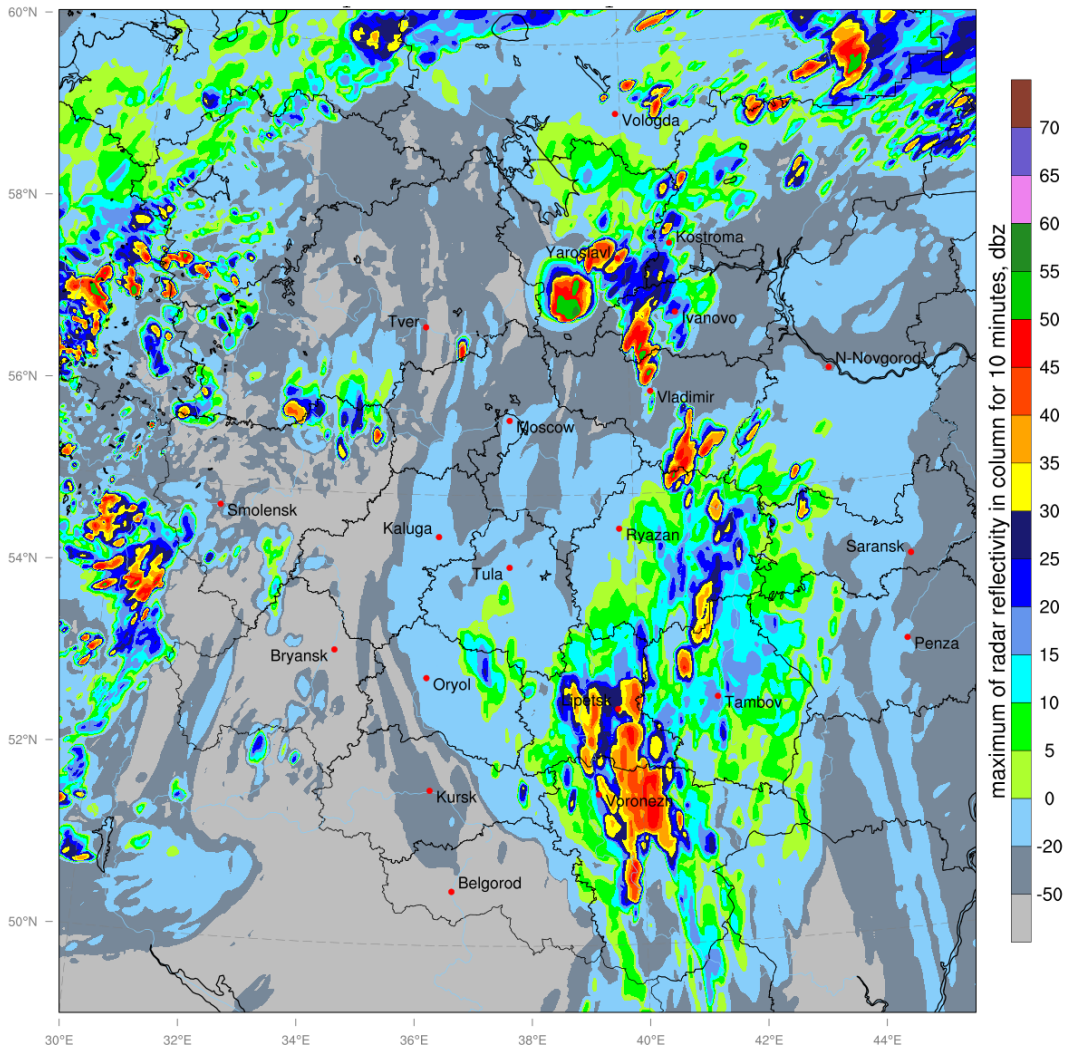
A supercell mesosyclone over Yaroslavl city (left) & Derecho-induced forest damage in Kostroma region (right). [meteoweb.ru]

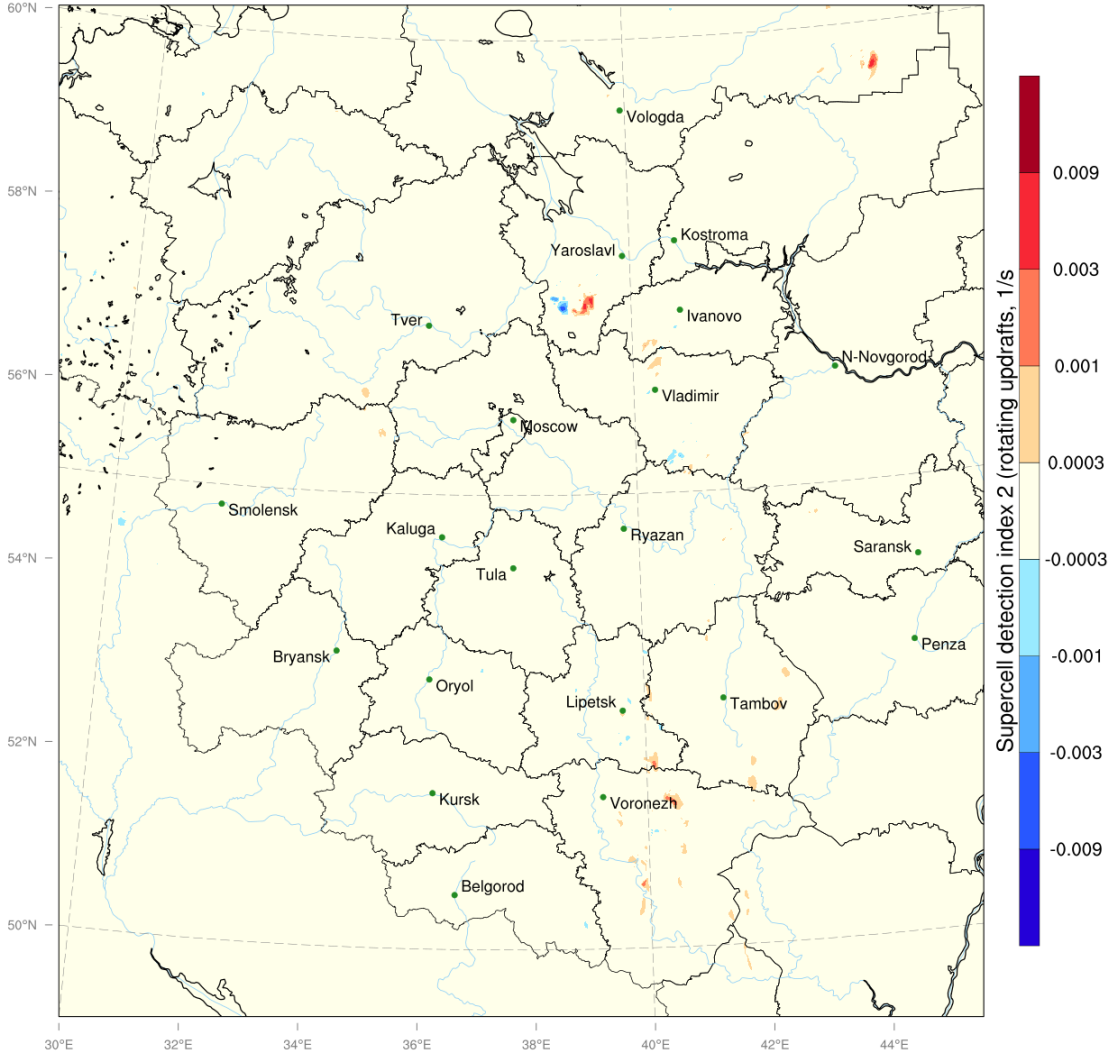


Tornado (red) and Derecho (black) induced tree fall patterns during May 15, 2021 outbreak. [Shikhov & Azhigov, 2021]

Case 1. The May 15 Tornado outbreak and Derecho

- 8:00 UTC COSMO-Ru (2.2 km) Simulated Radar Reflectivity & Supercell Detection index 2.





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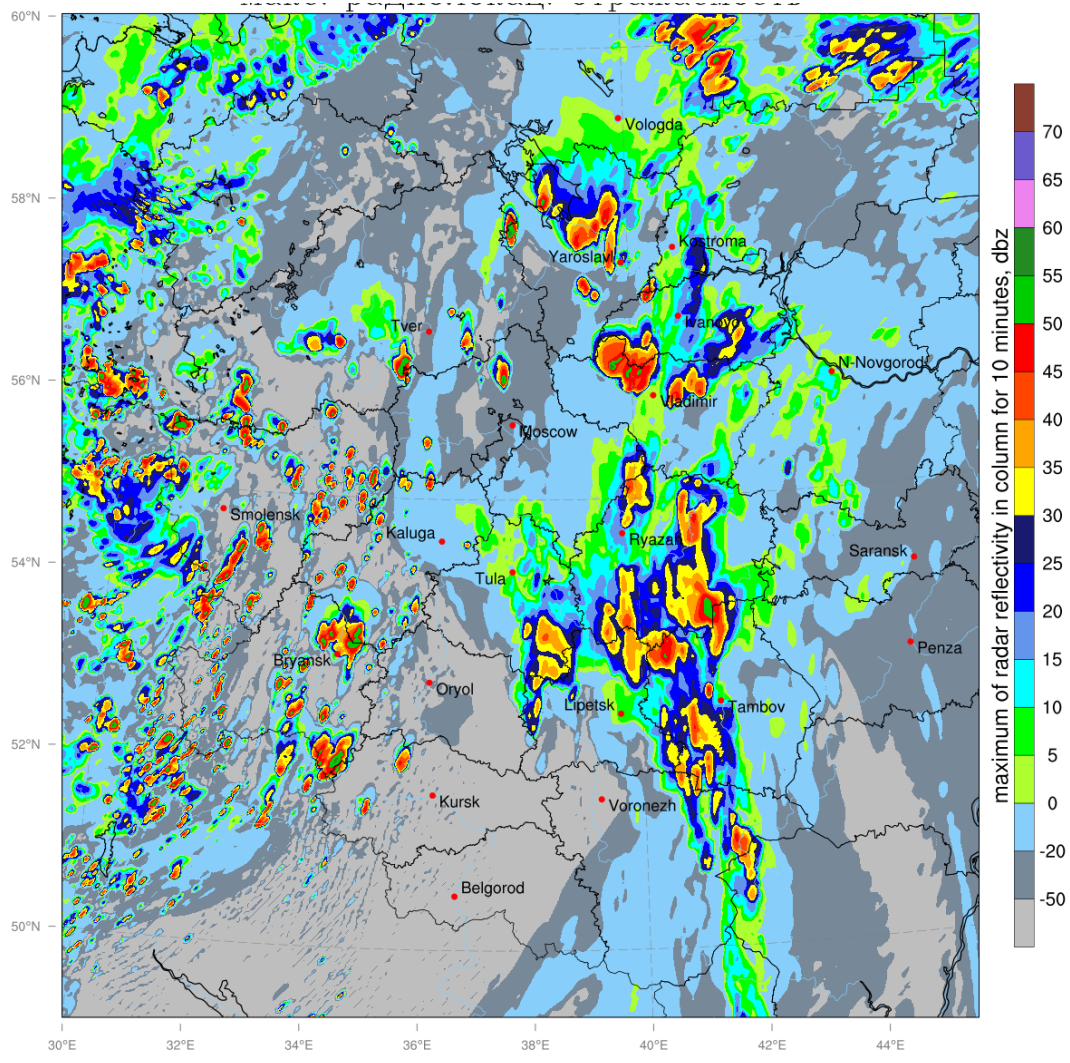

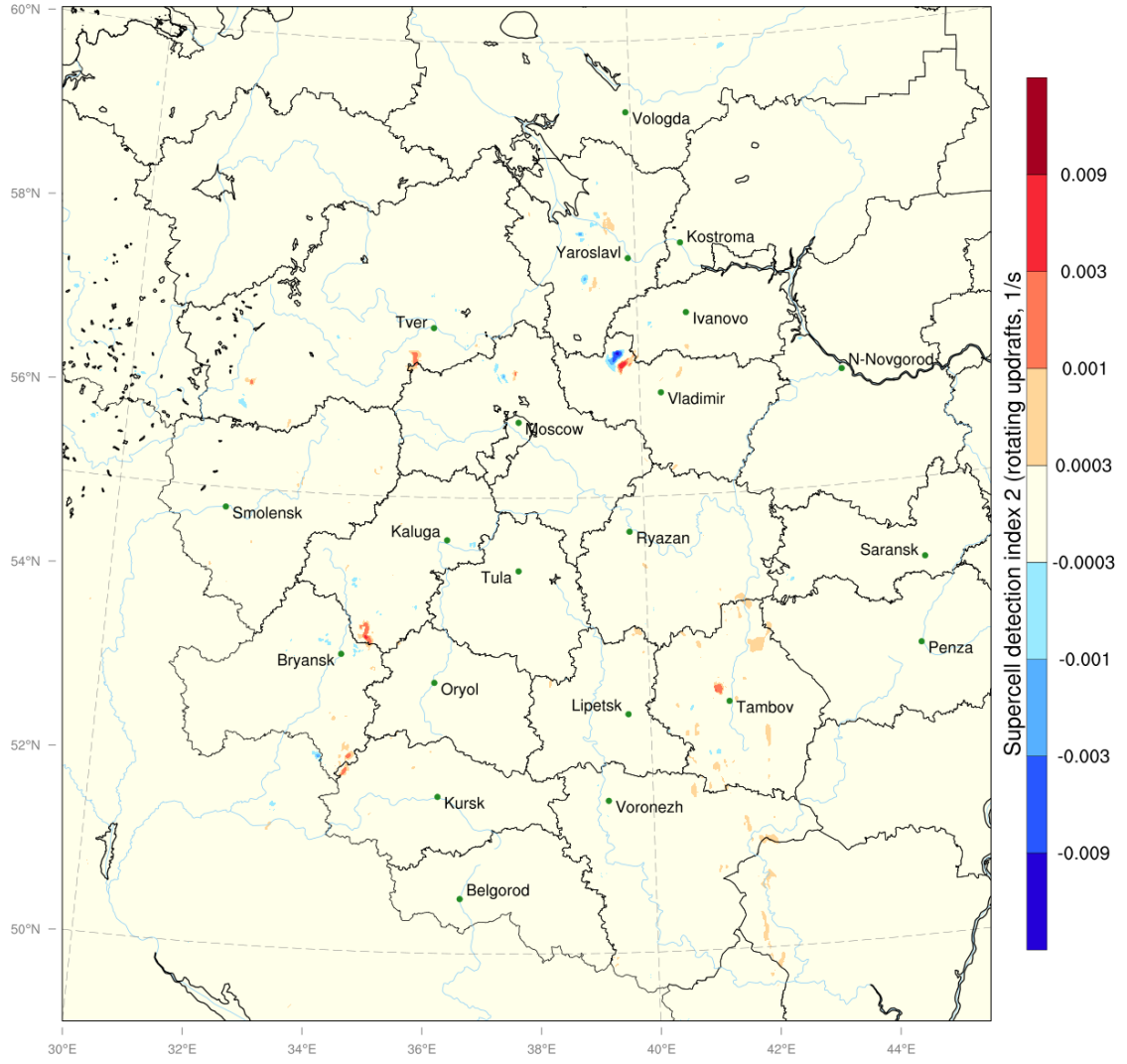

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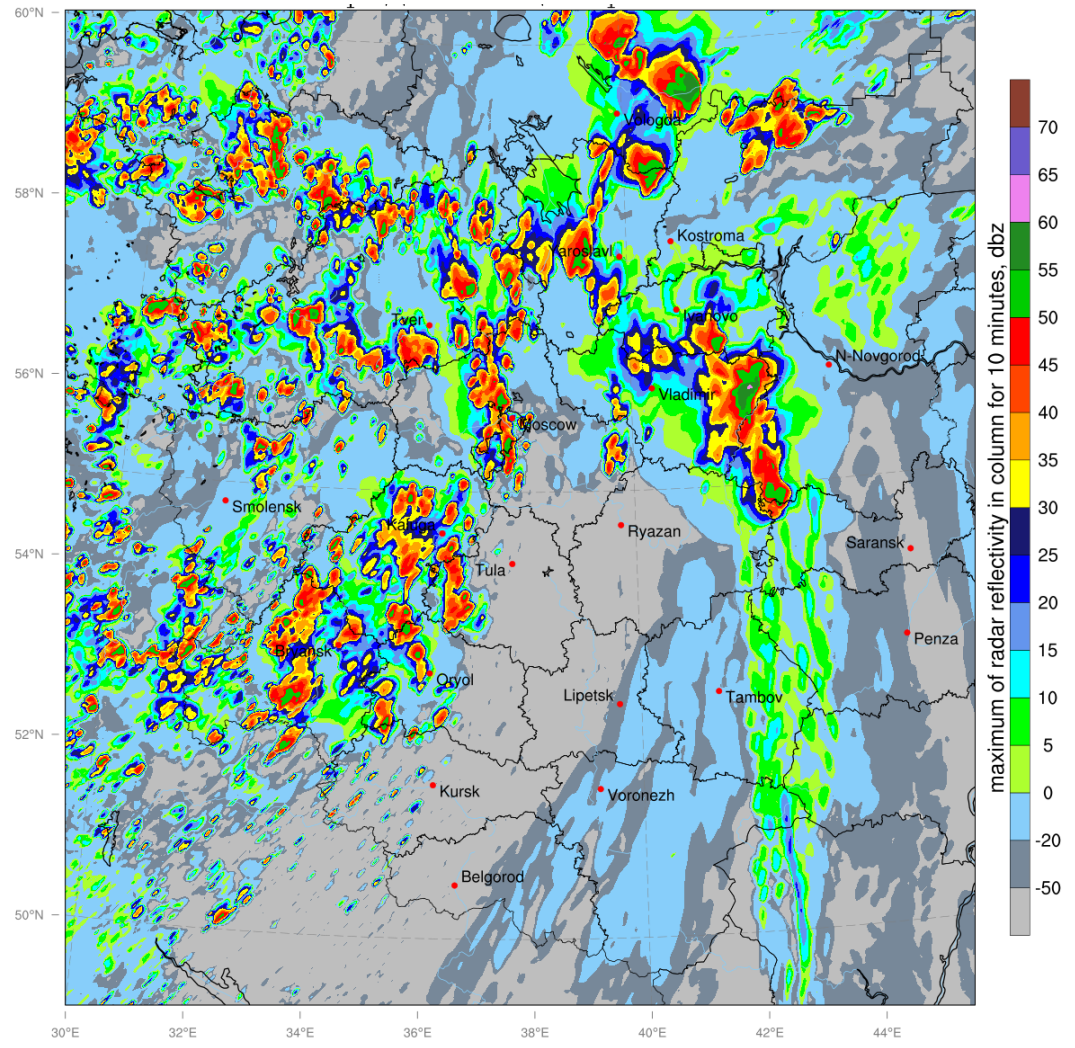
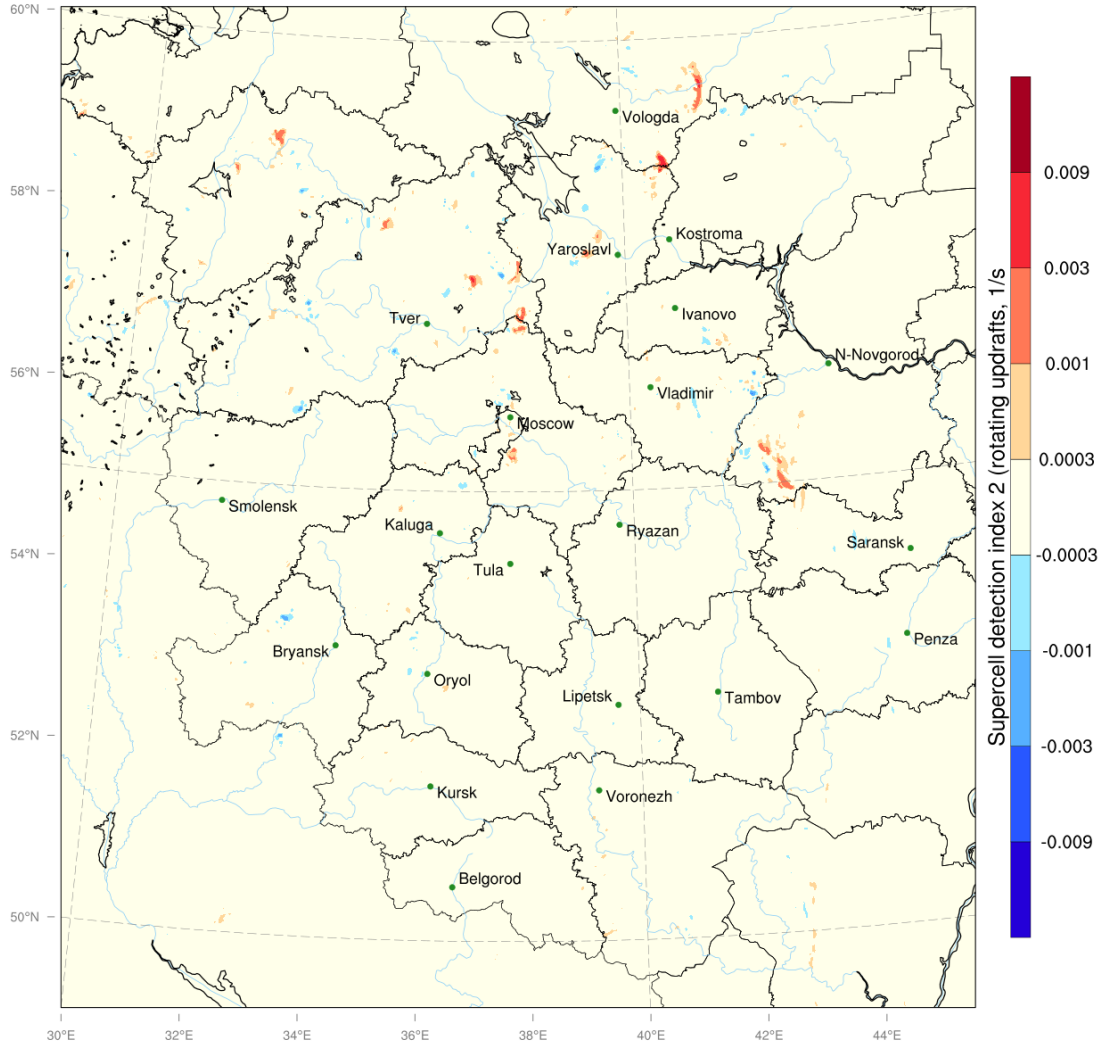
- 13:00 UTC COSMO-Ru (2.2 km) Simulated Radar Reflectivity & Supercell Detection index 2.





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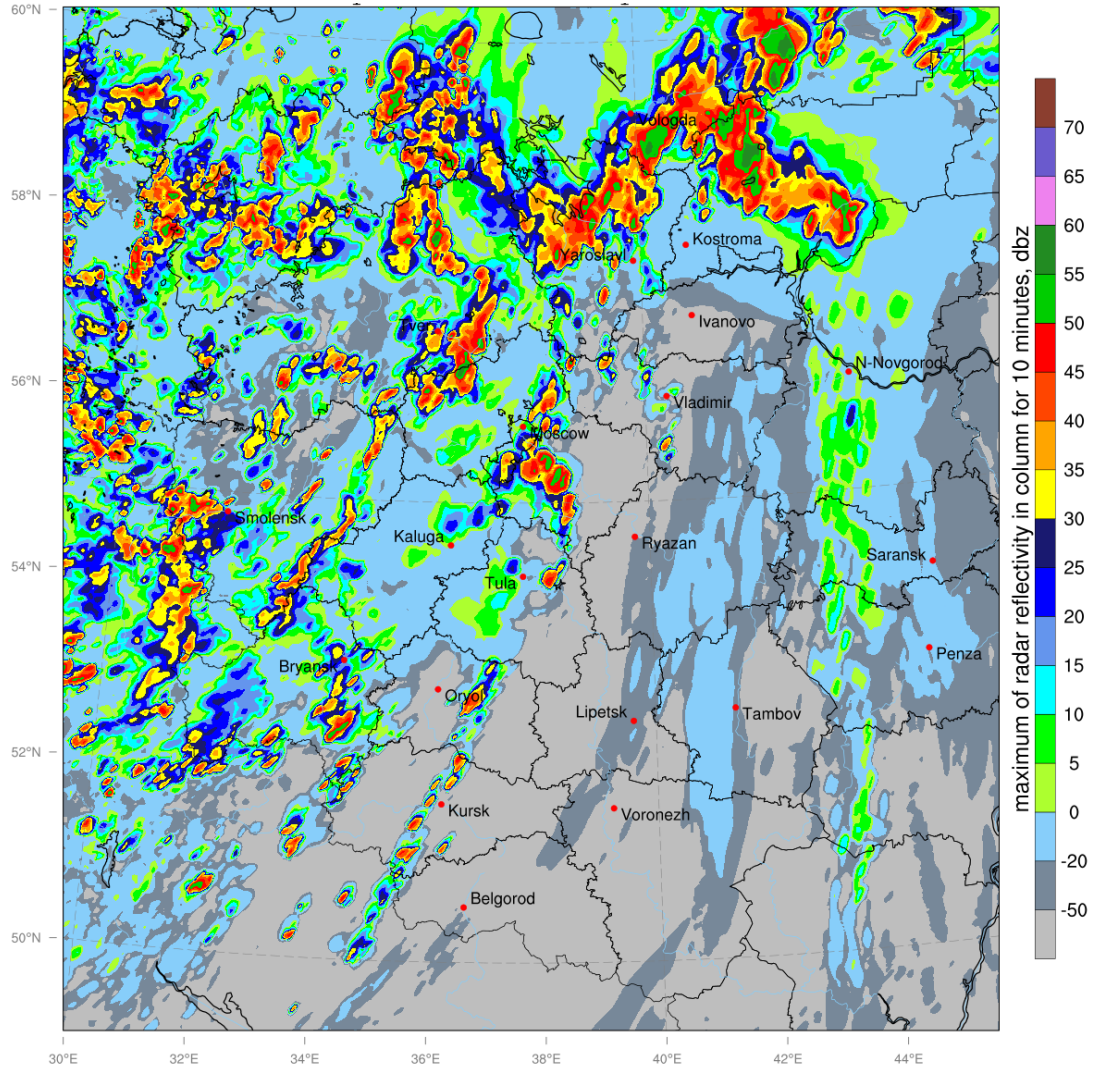

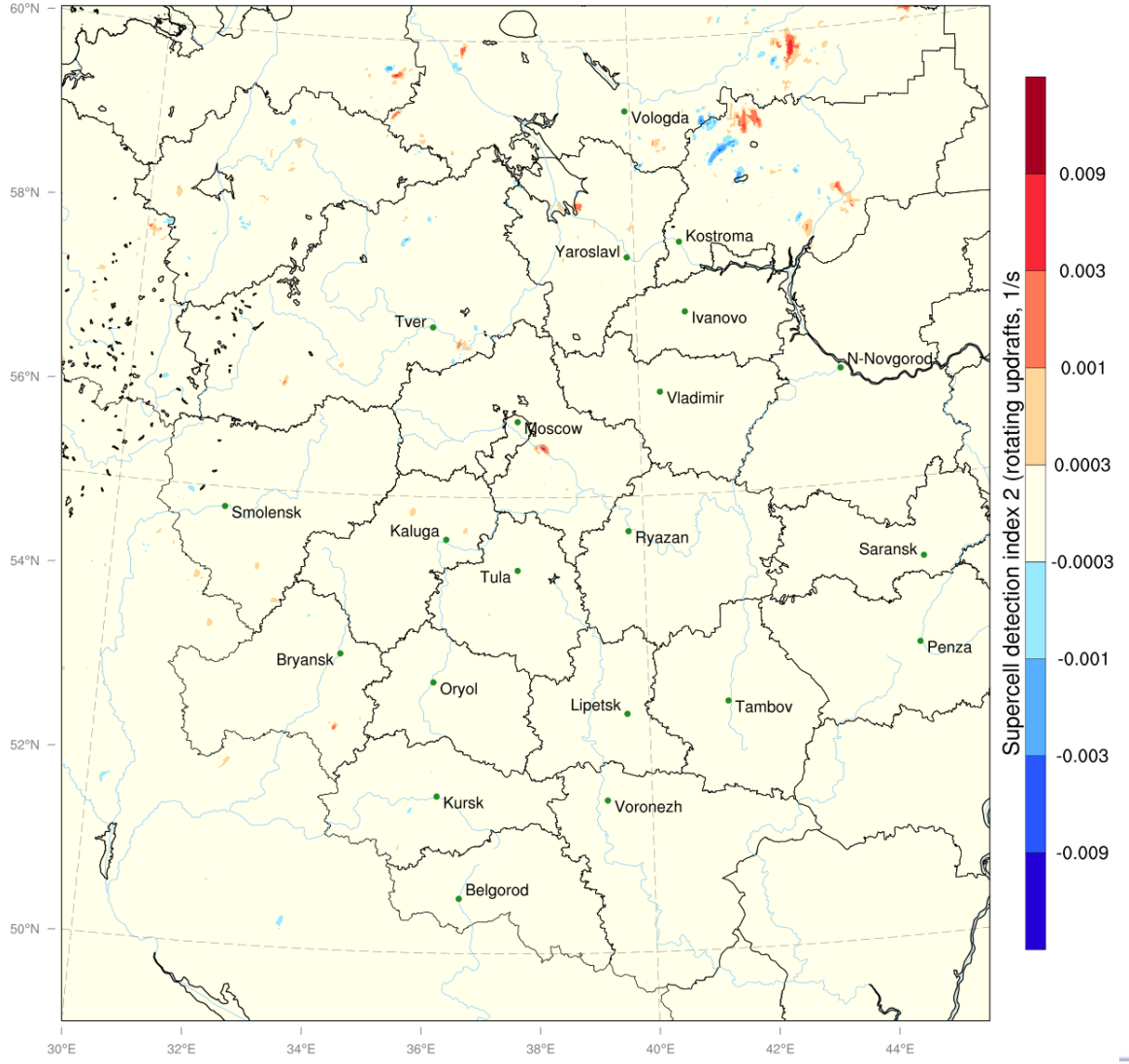

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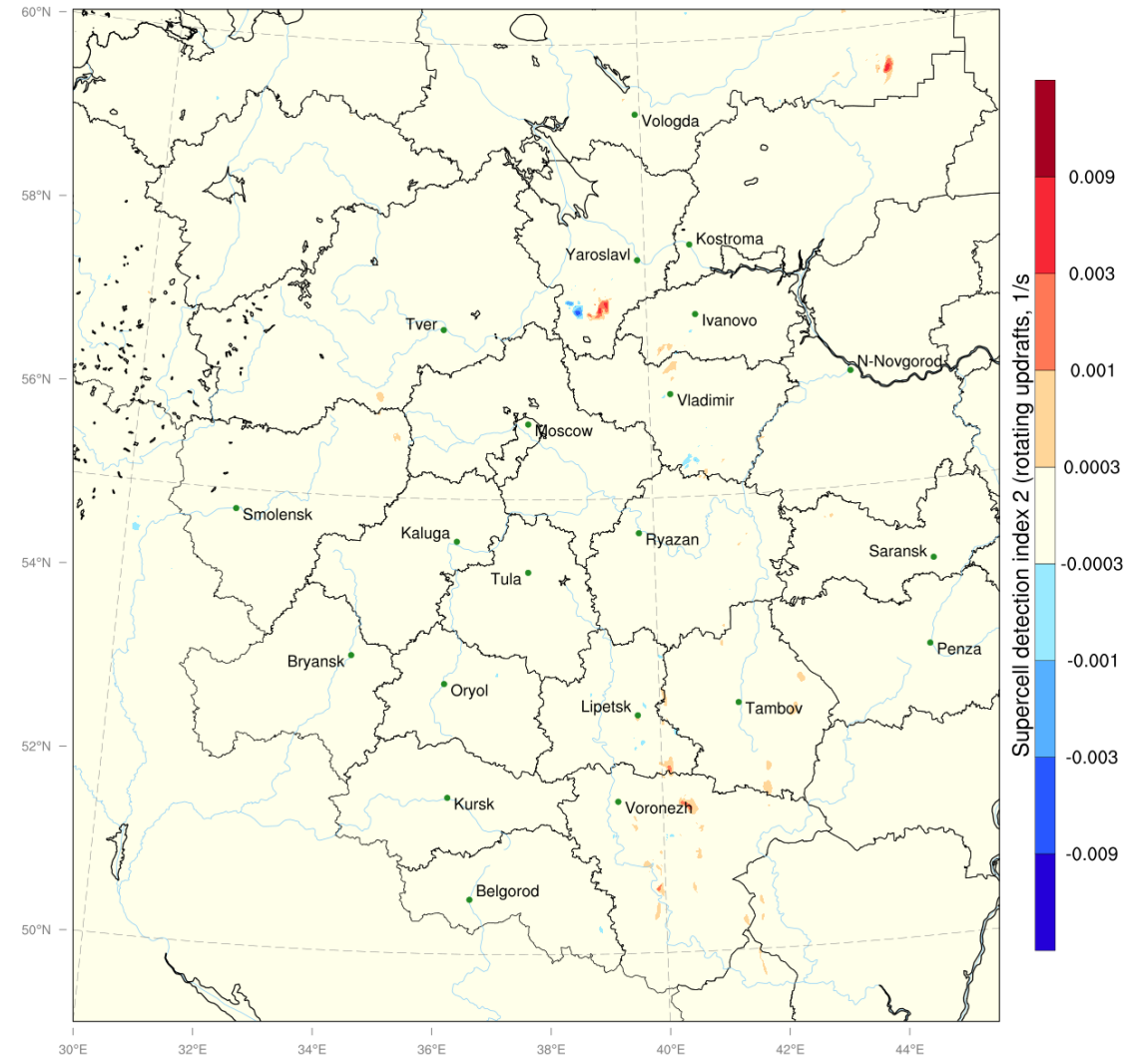
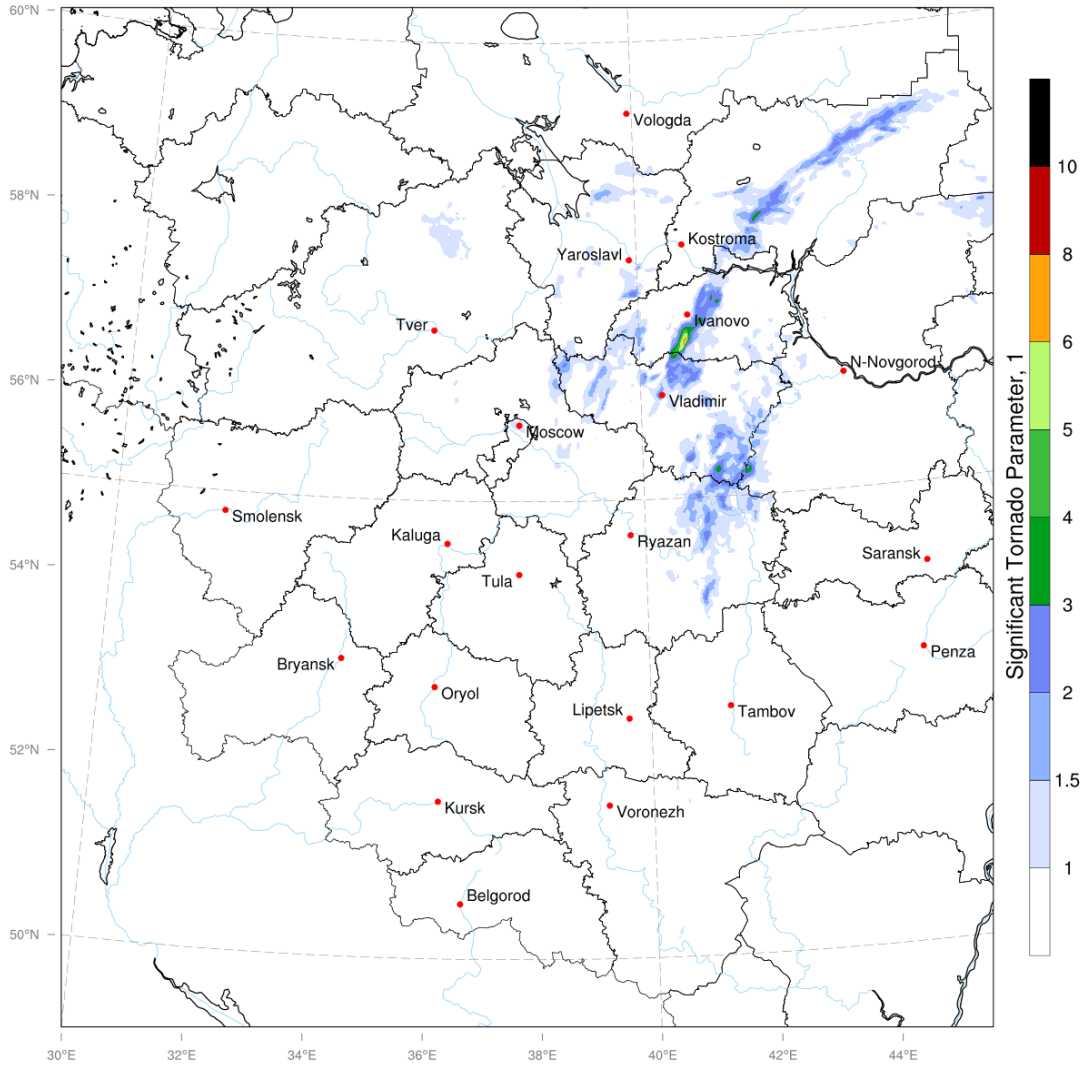
- 8:00 UTC COSMO-Ru (2.2 km) Supercell Detection index 2 & Significant Tornado Parameter.





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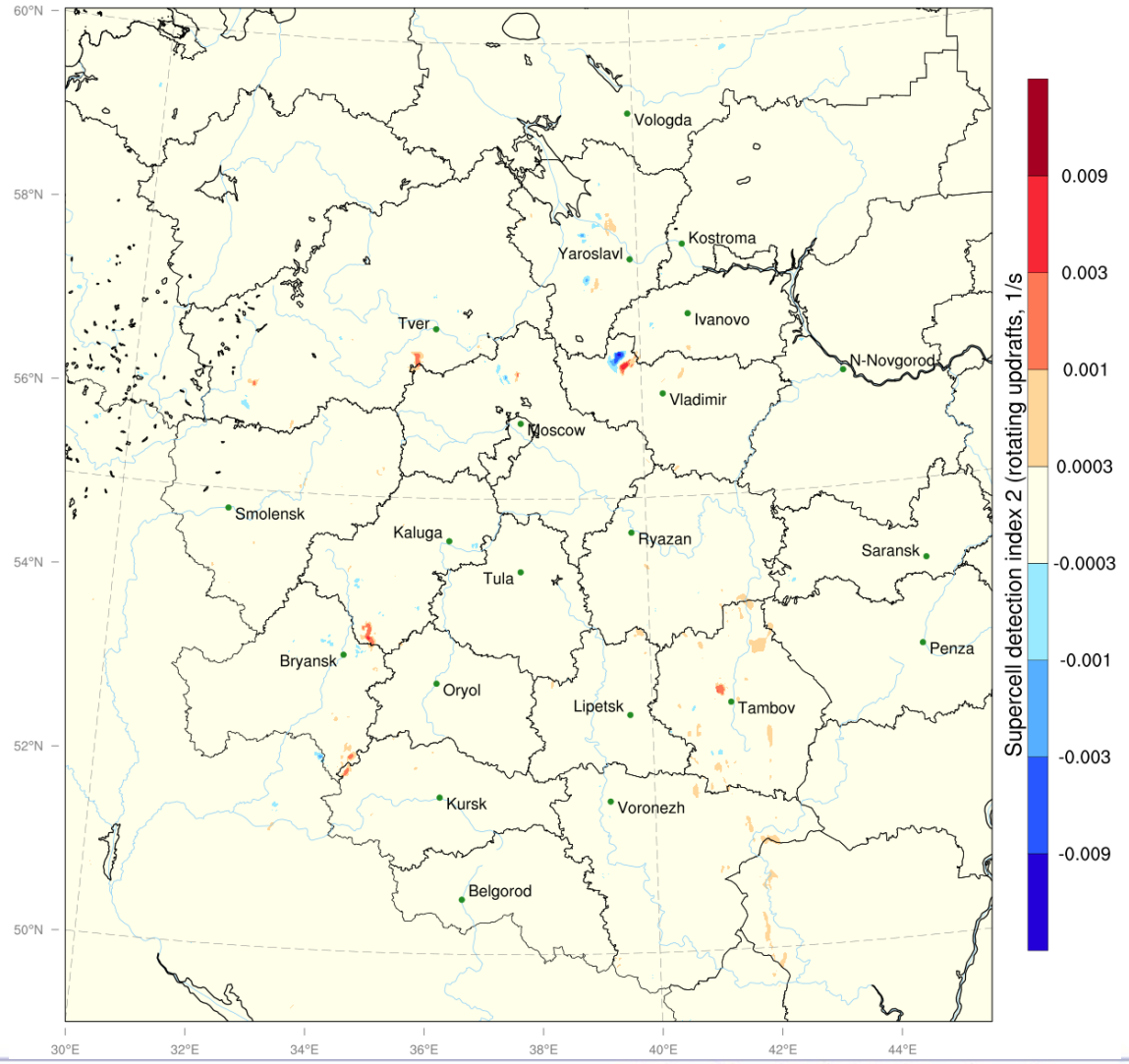

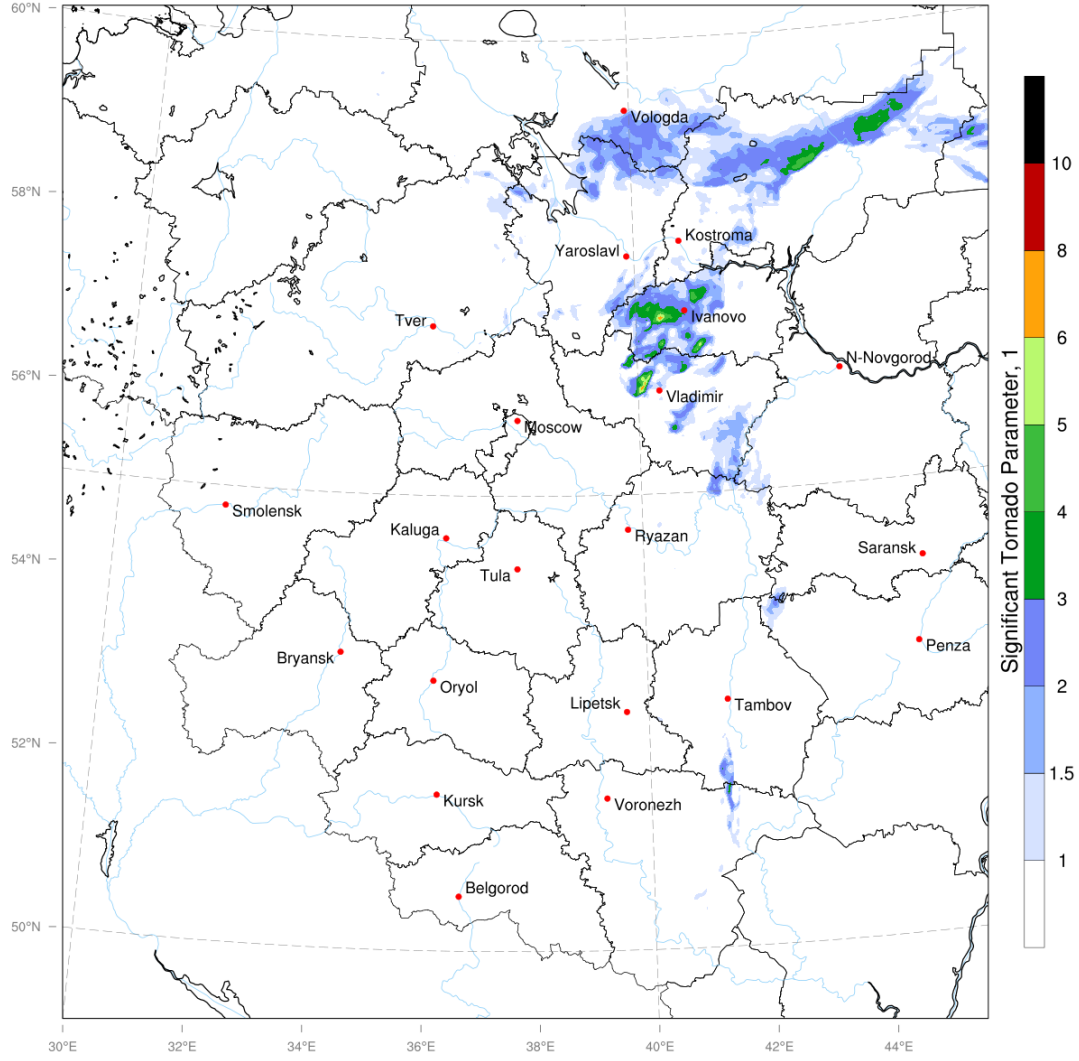

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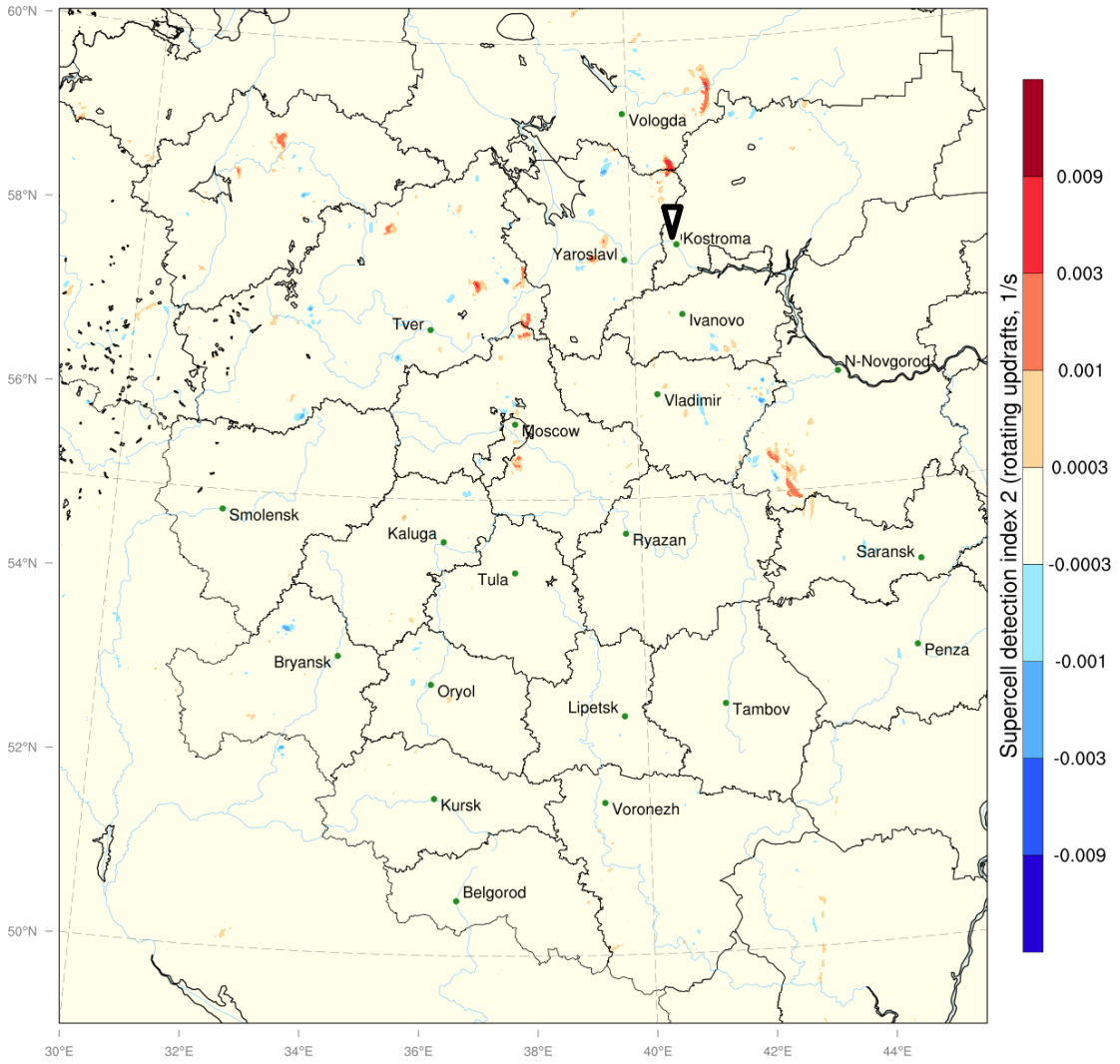
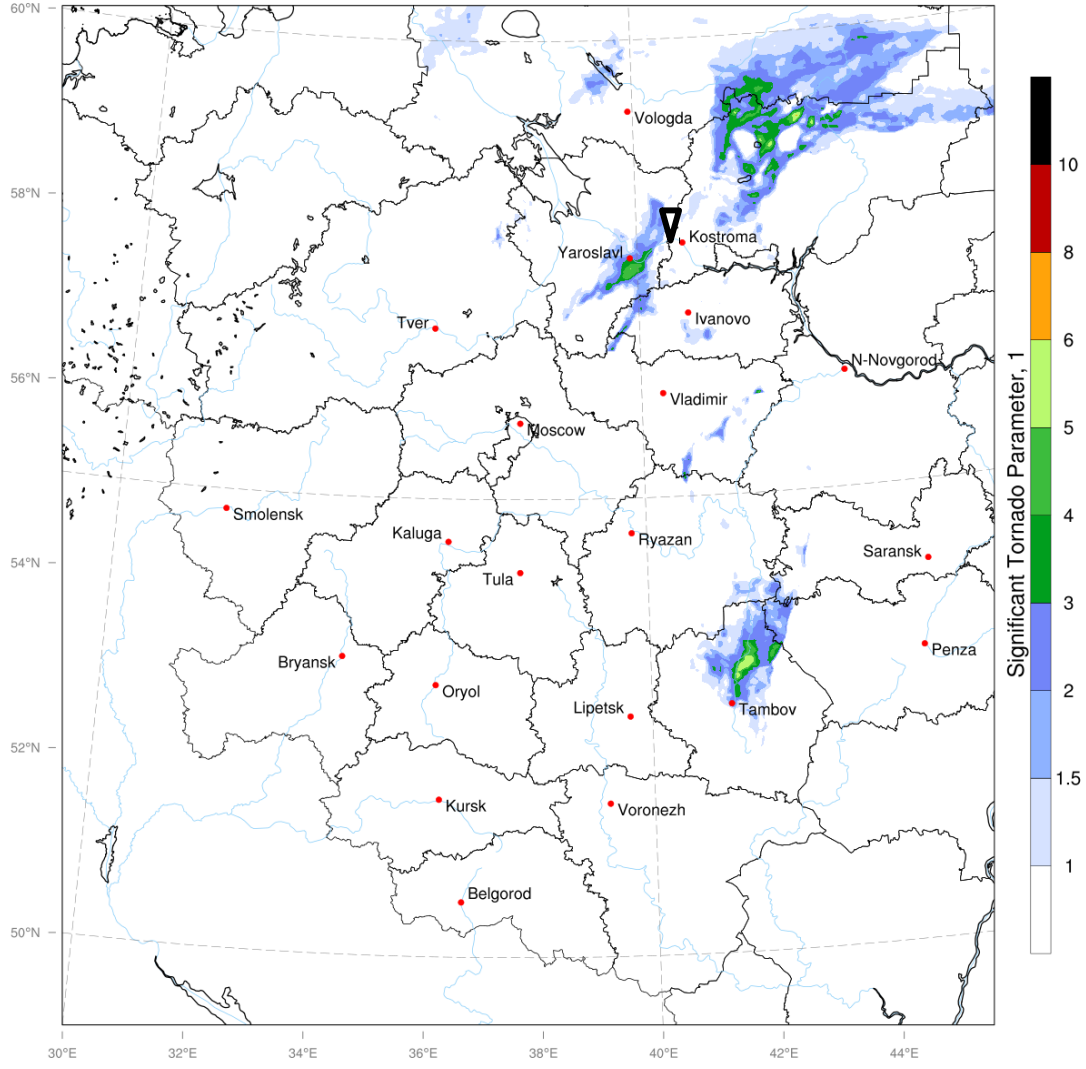
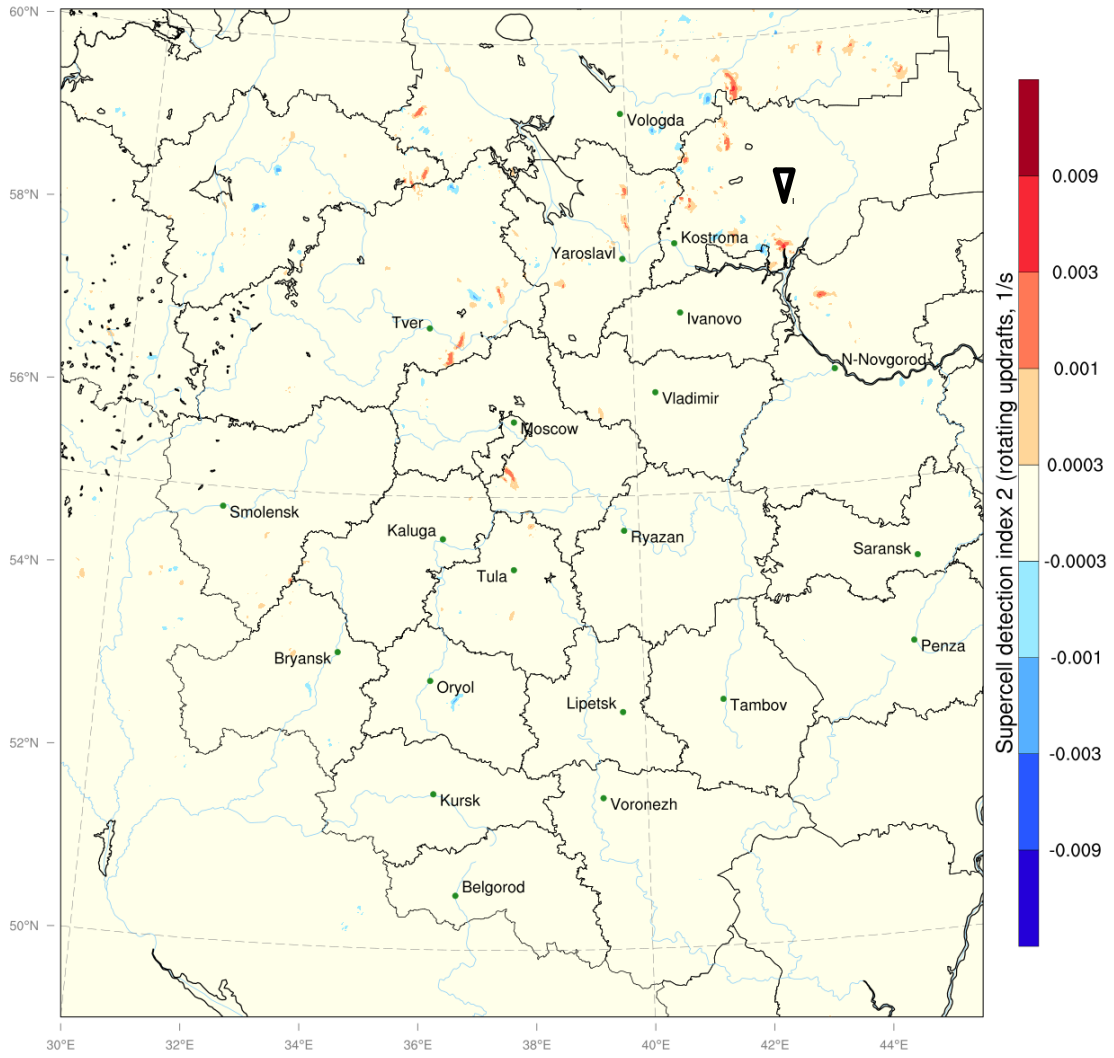
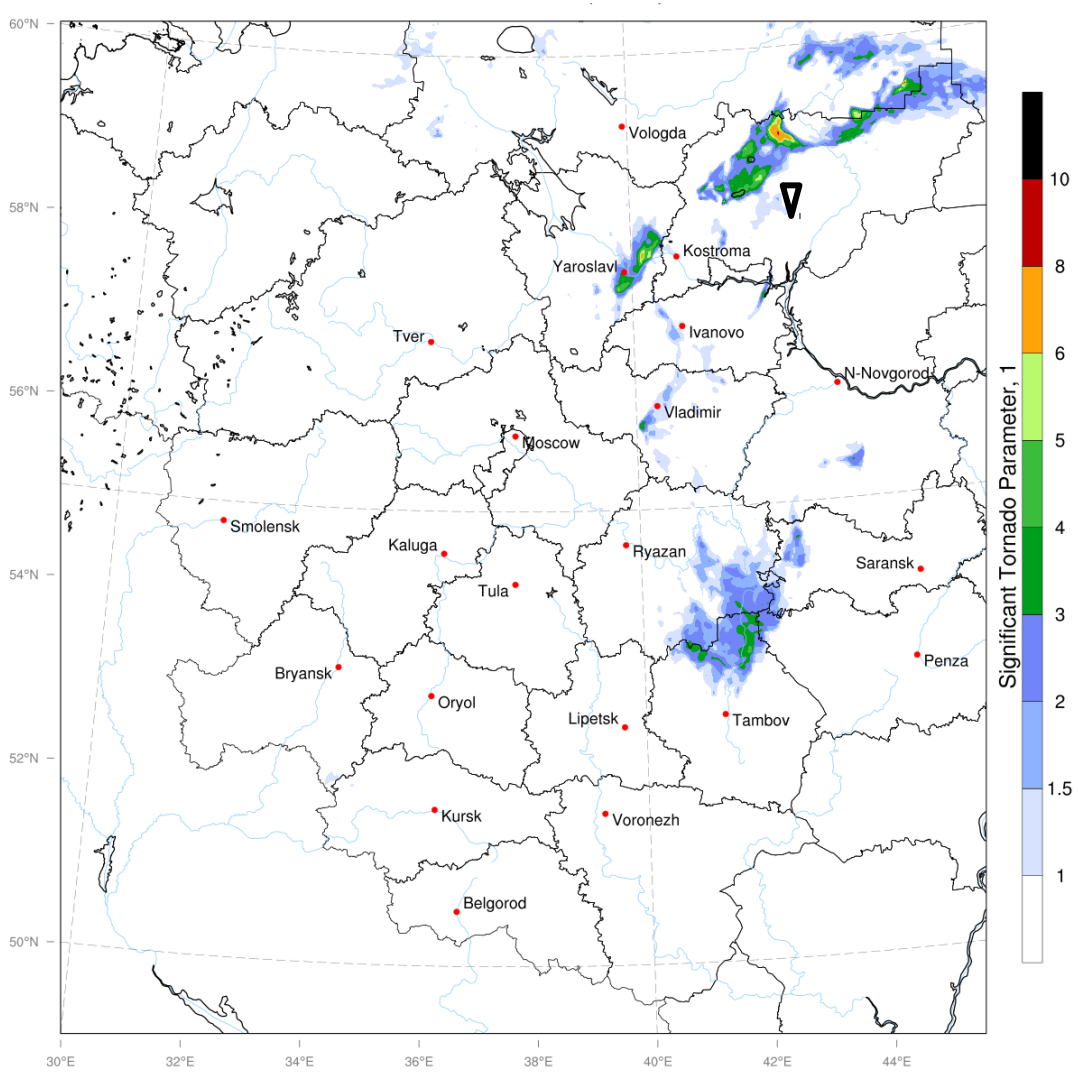




Case 1. The May 15 Tornado outbreak and Derecho

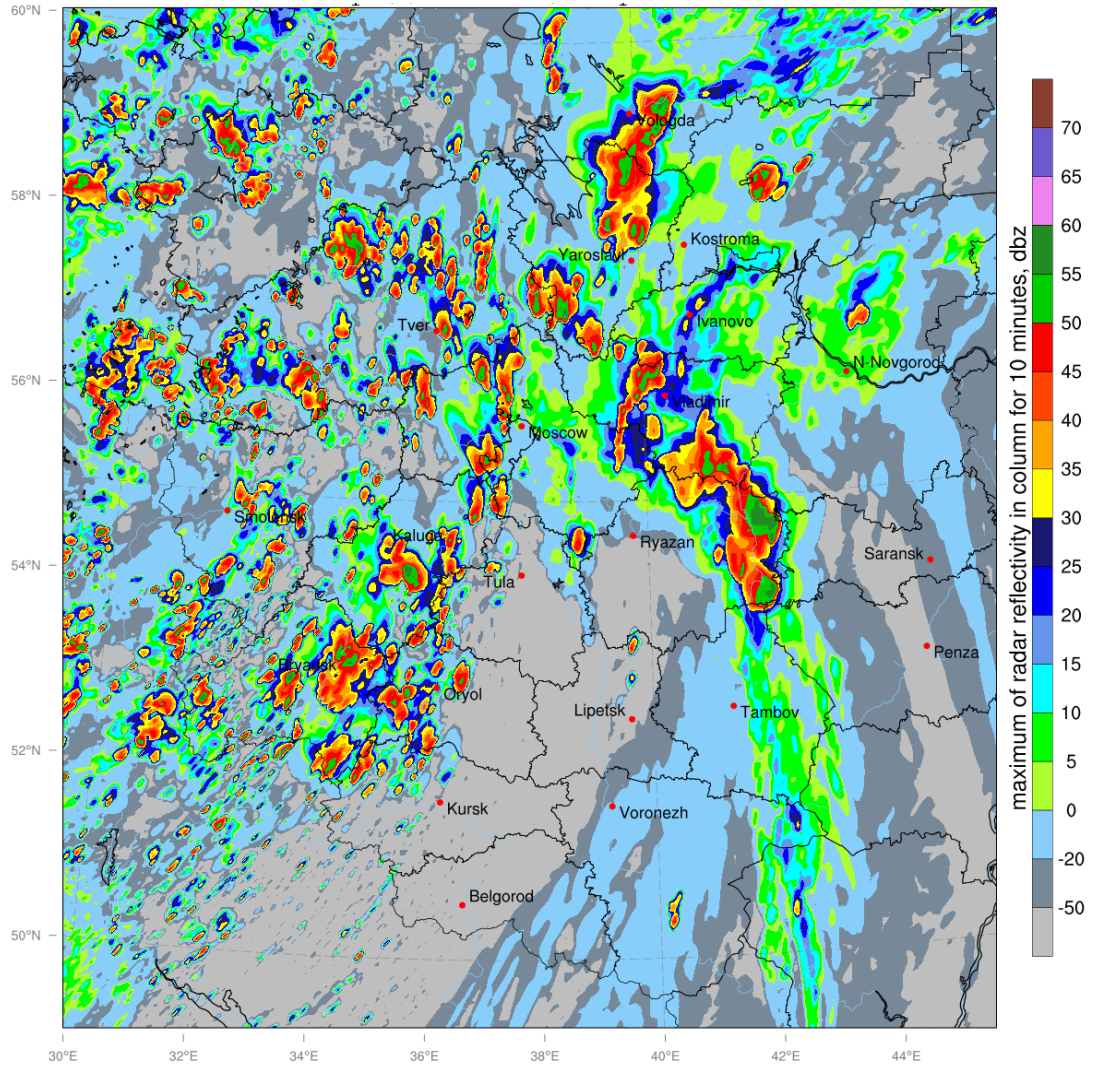
- 15:00 UTC COSMO-Ru (2.2 km) Supercell Detection index 2 & Significant Tornado Parameter.

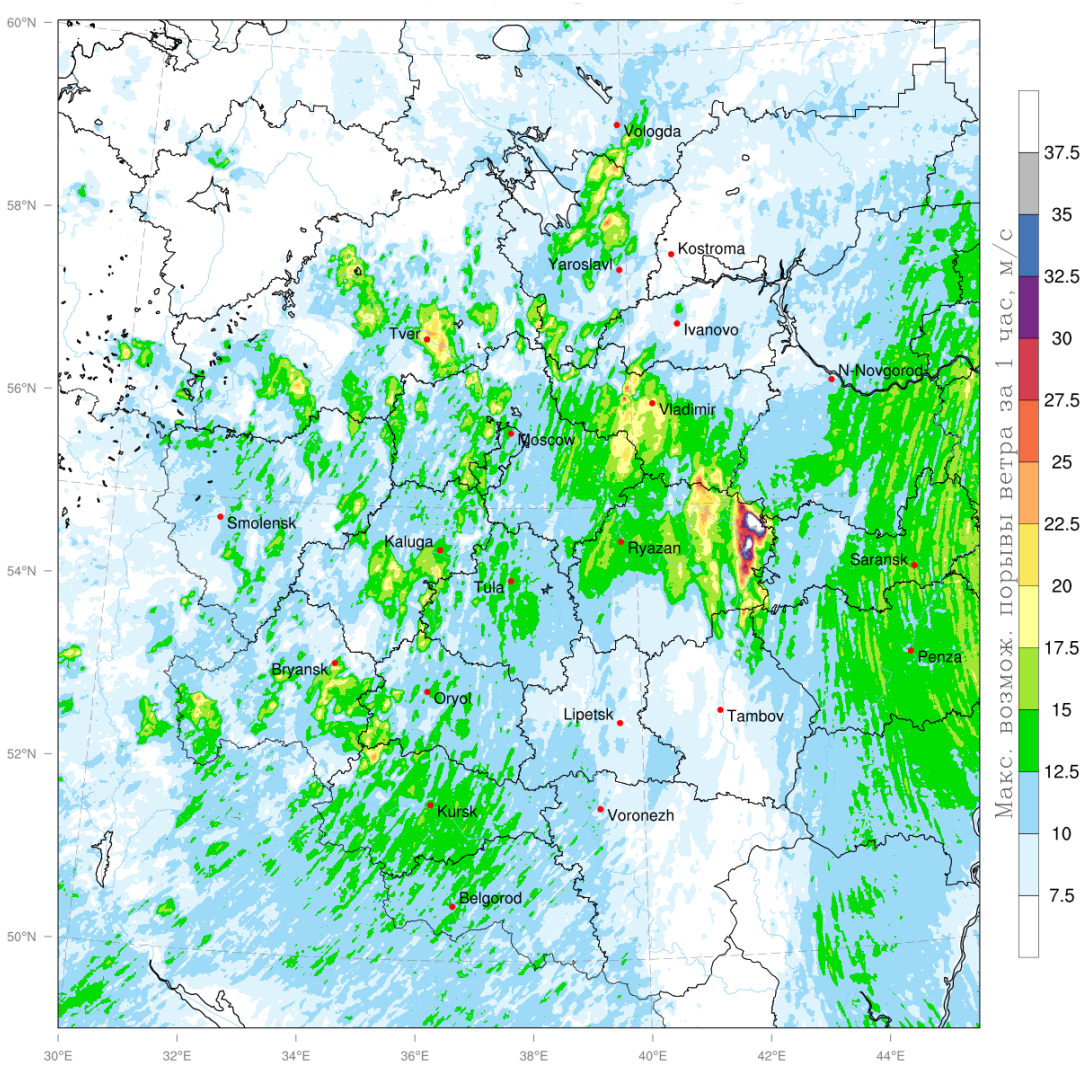




Case 1. The May 15 Tornado outbreak and Derecho

- 12:00 UTC COSMO-Ru (2.2 km) Simulated radar reflectivity & Maximum 10m AGL Wind Gust, m/s (VMAX10).





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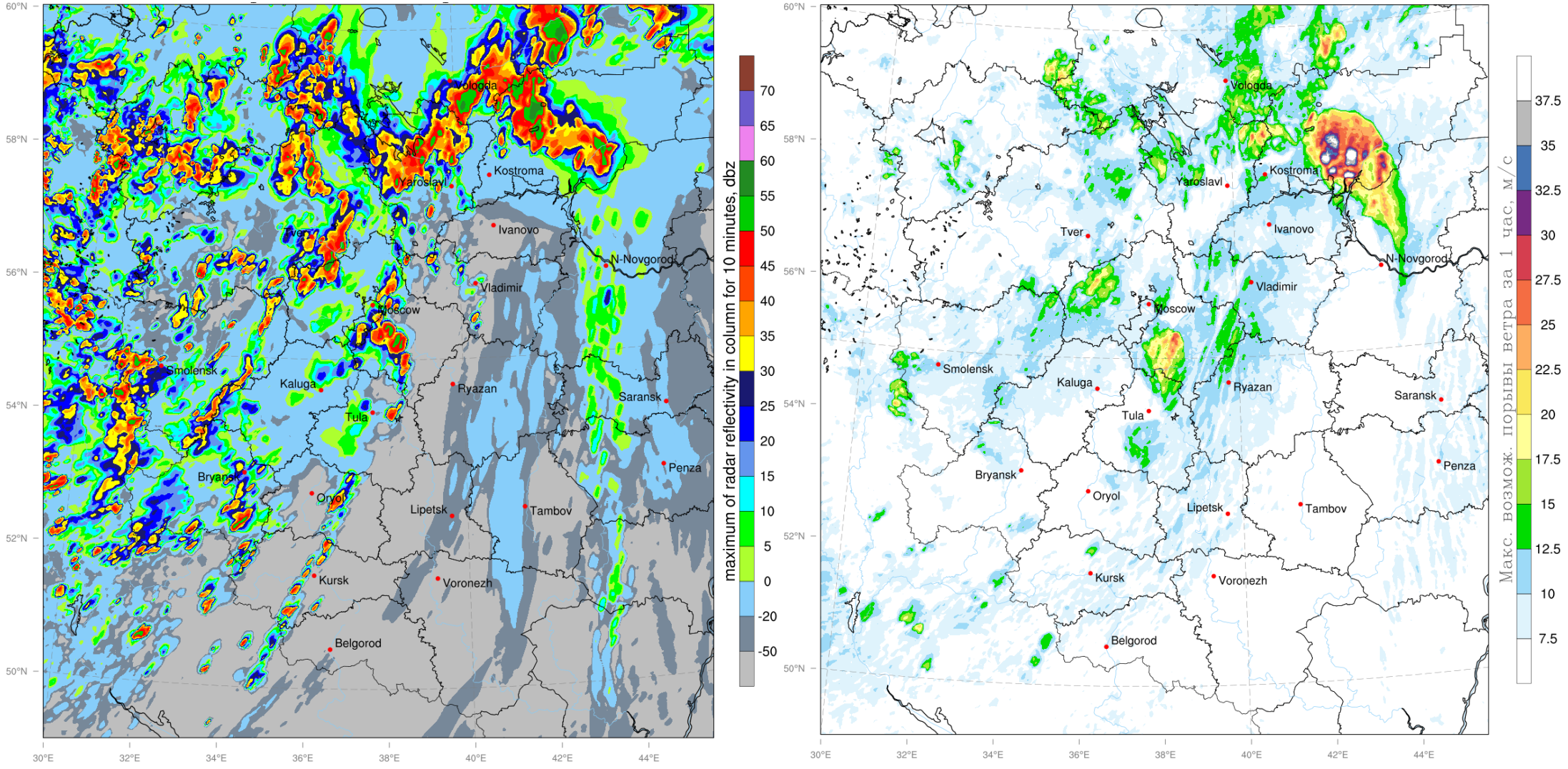
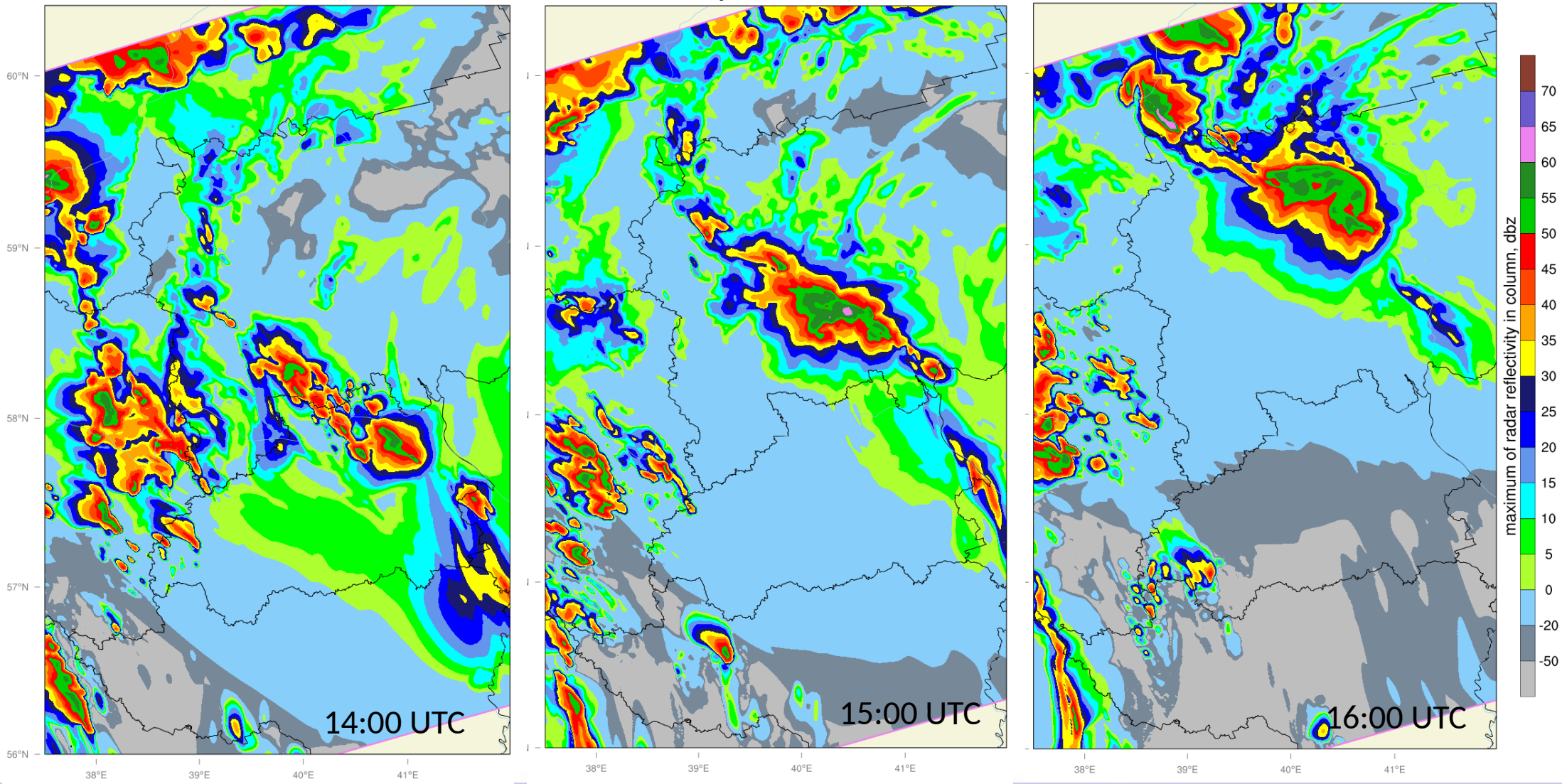


Case 1. The May 15 Tornado outbreak and Derecho

- COSMO-Ru (1 km) Simulated radar reflectivity.



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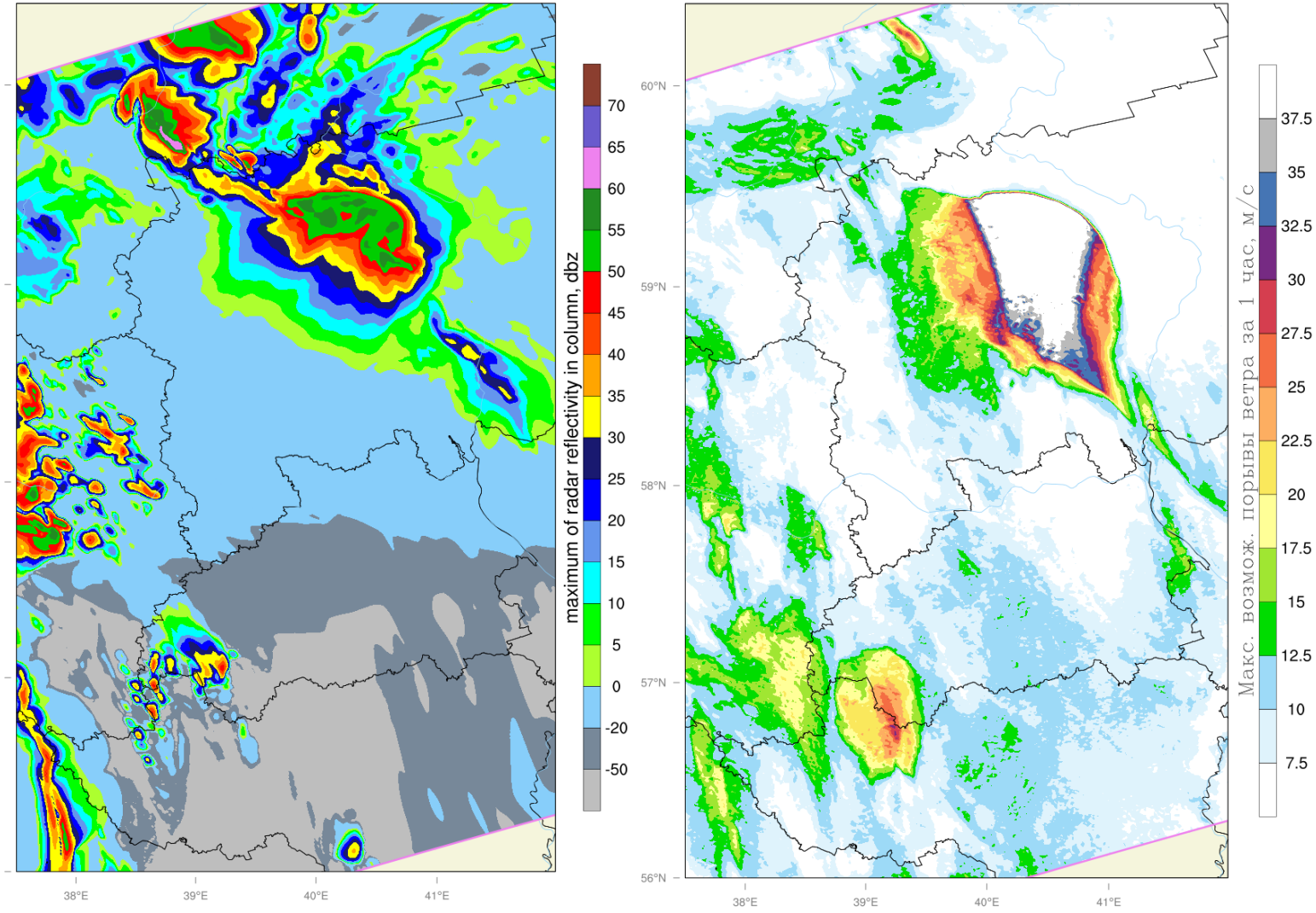


Case 2. The August 2 Tornado outbreak.

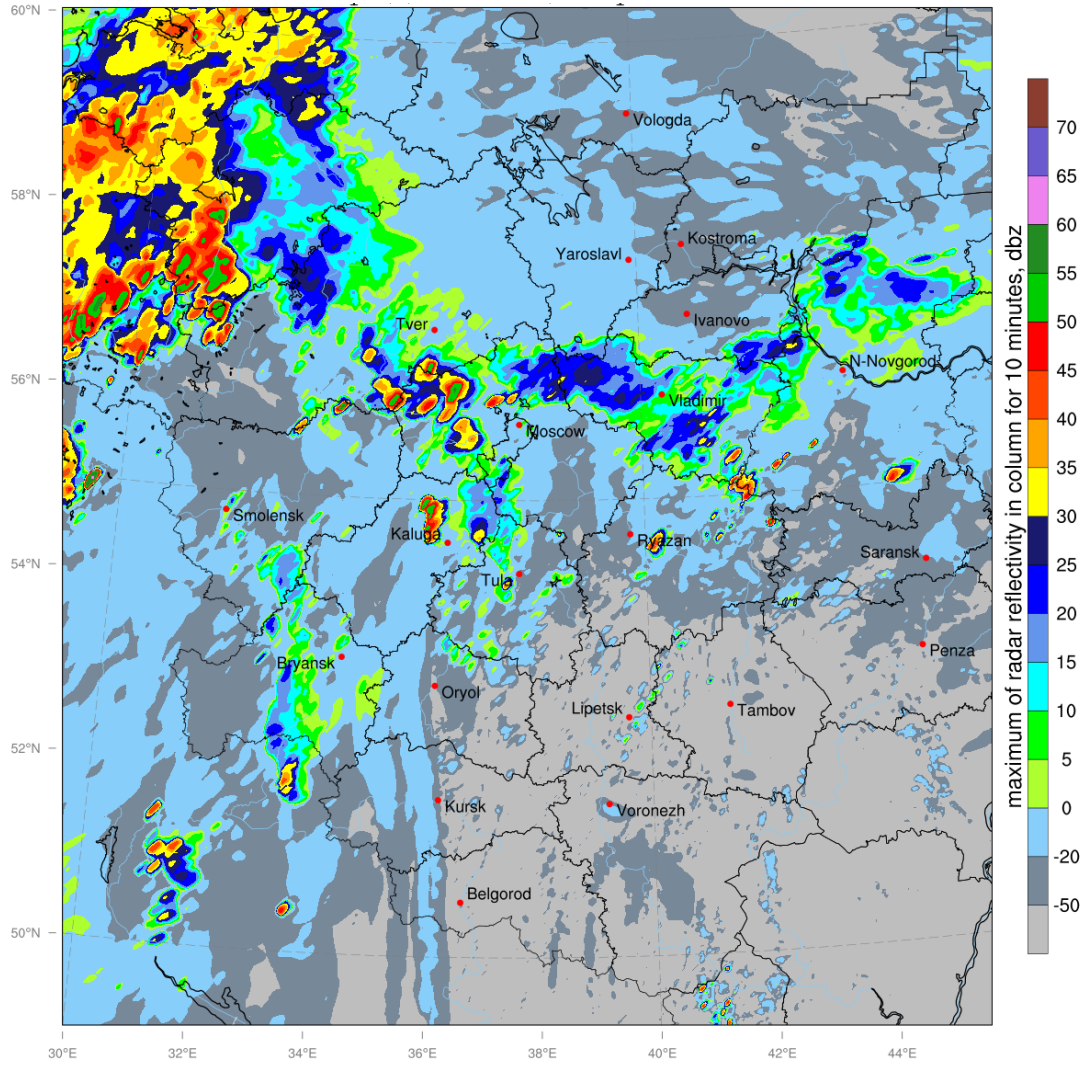
The Andreapol EF-3 Tornado begore hitting the town [https://vk.com/meteodnevnik]

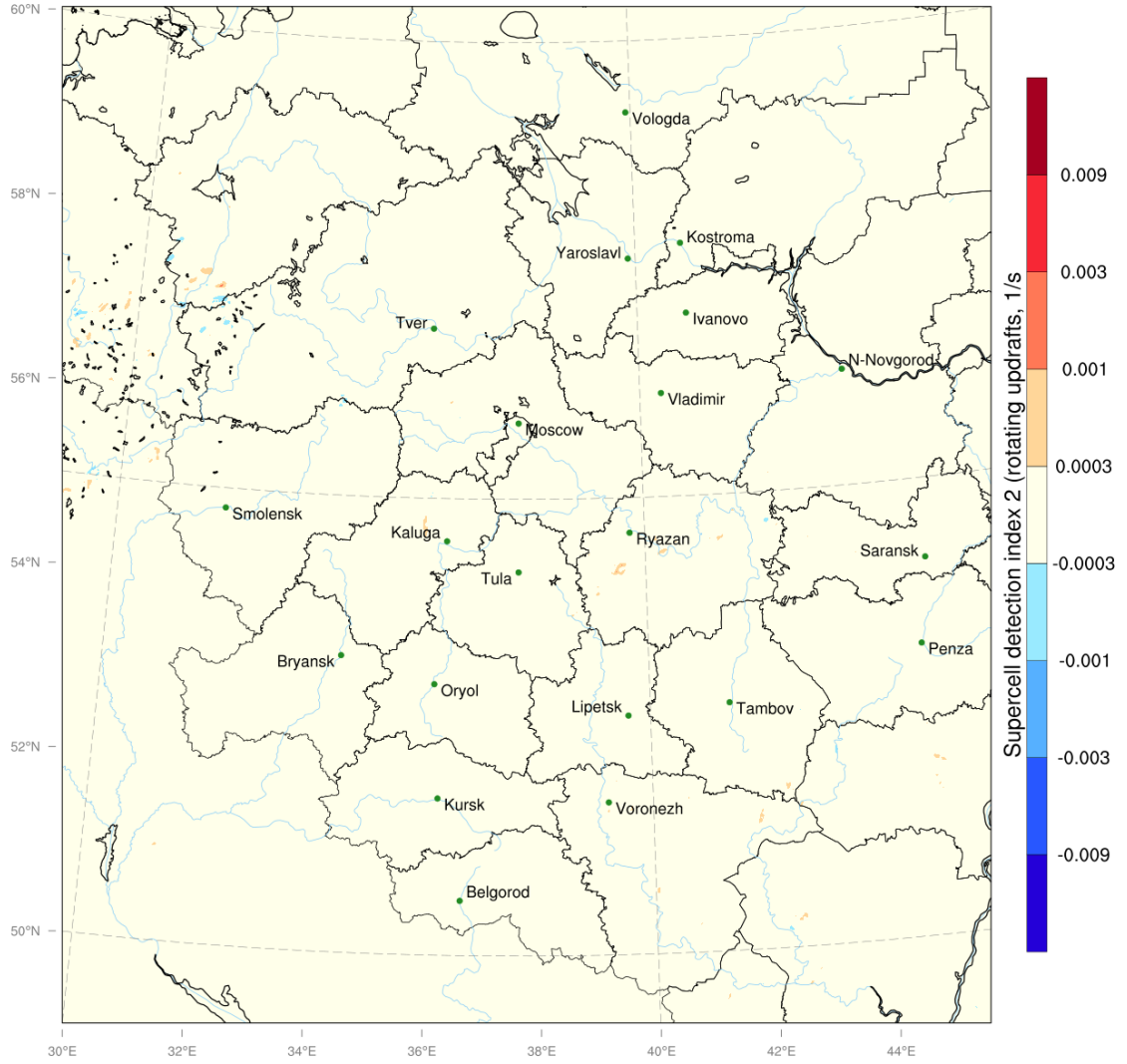
- Sattelite imagery analysis shows at least 22 Tornadoes touched down in Pskov and Tver regions during the outbreak.
- The strongest (EF-3) tornado of the outbreak hit Andreapol town (Tver region). Three casualties were reported.

Tornado-induced damage in Andreapol town [https://vk.com/meteodnevnik]

Case 2. The August 2 Tornado outbreak

- 10:00 UTC COSMO-Ru (2.2 km) Simulated radar reflectivity & Supercell Detection Index 2 (SDI_2)





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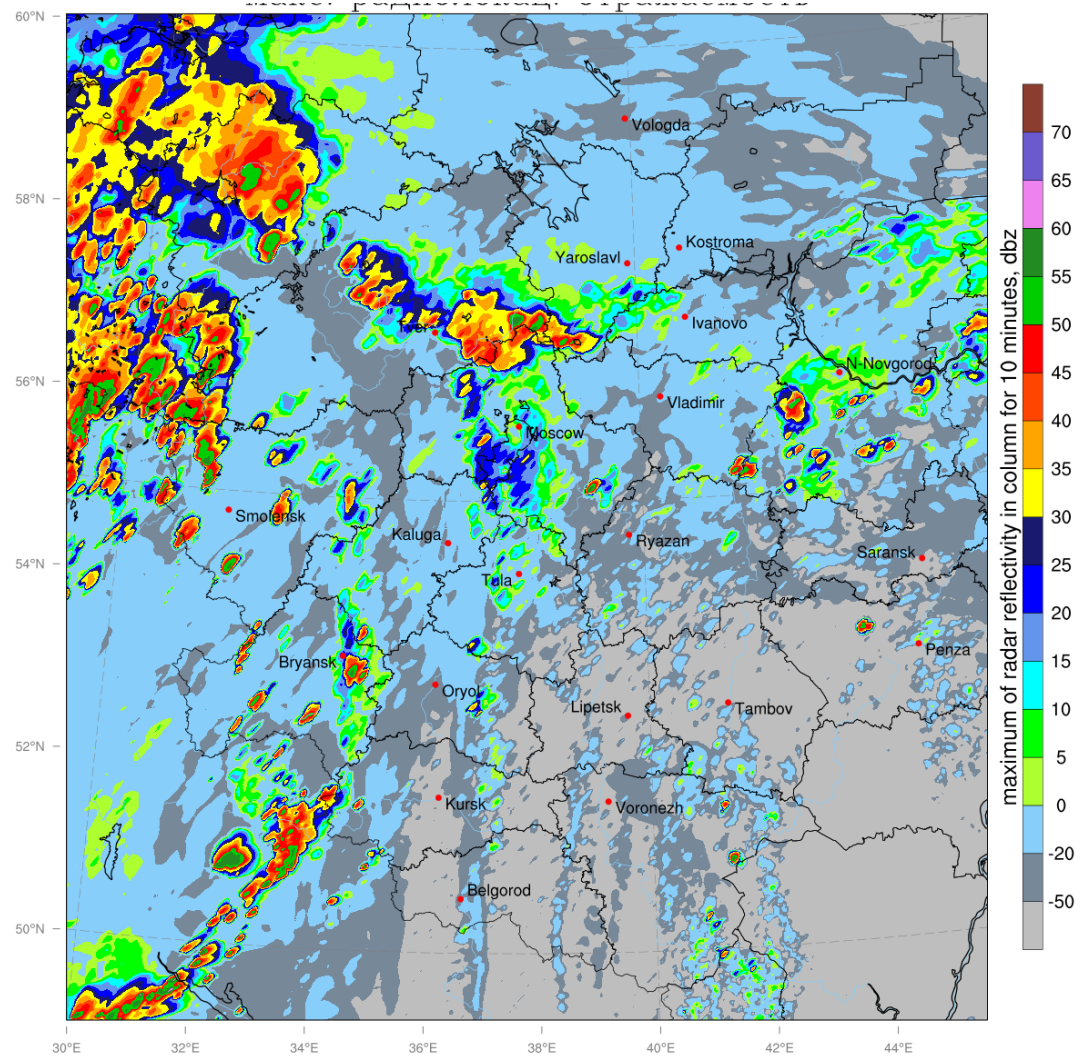

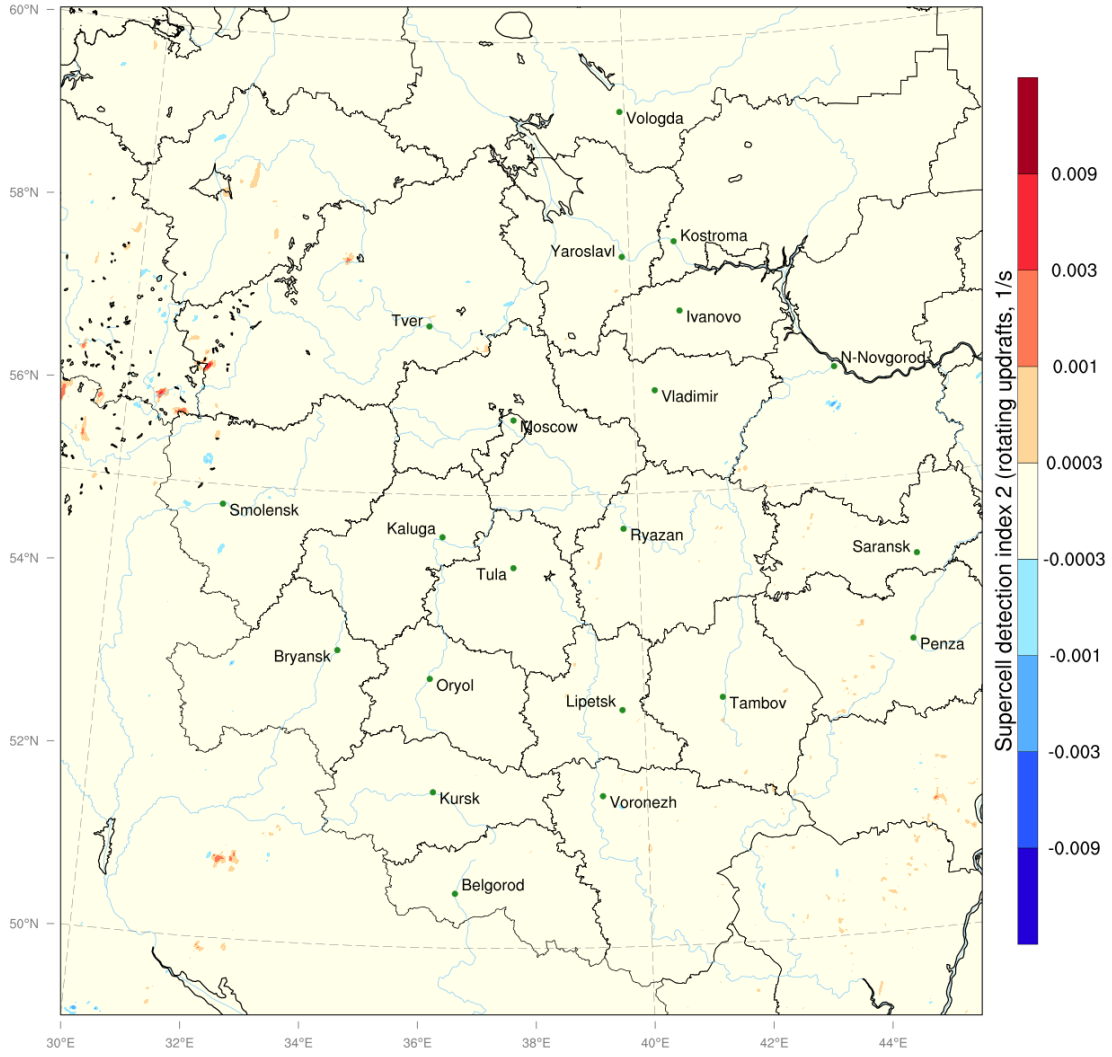

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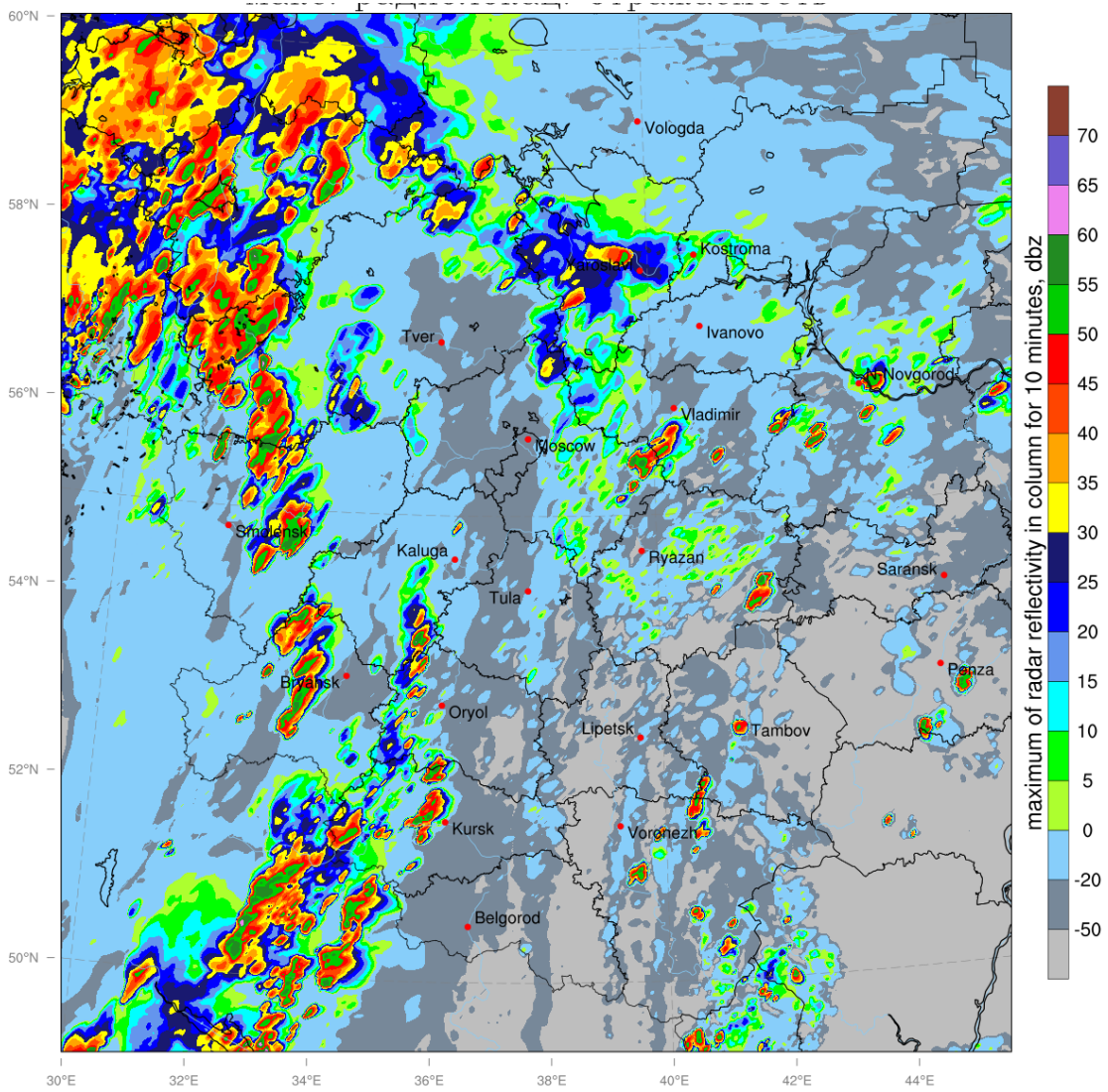
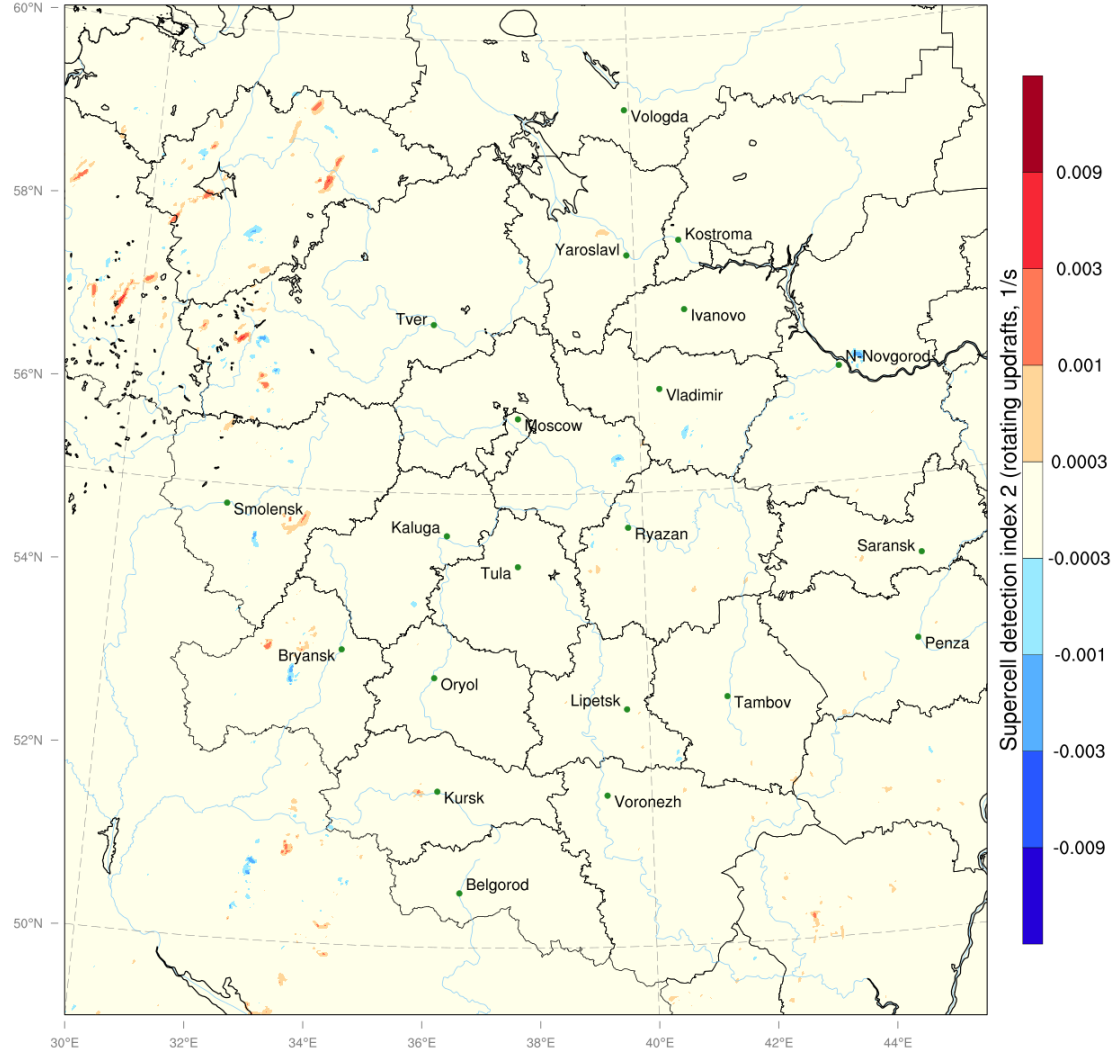
- 14:00 UTC COSMO-Ru (2.2 km) Simulated radar reflectivity & Supercell Detection Index 2 (SDI_2)





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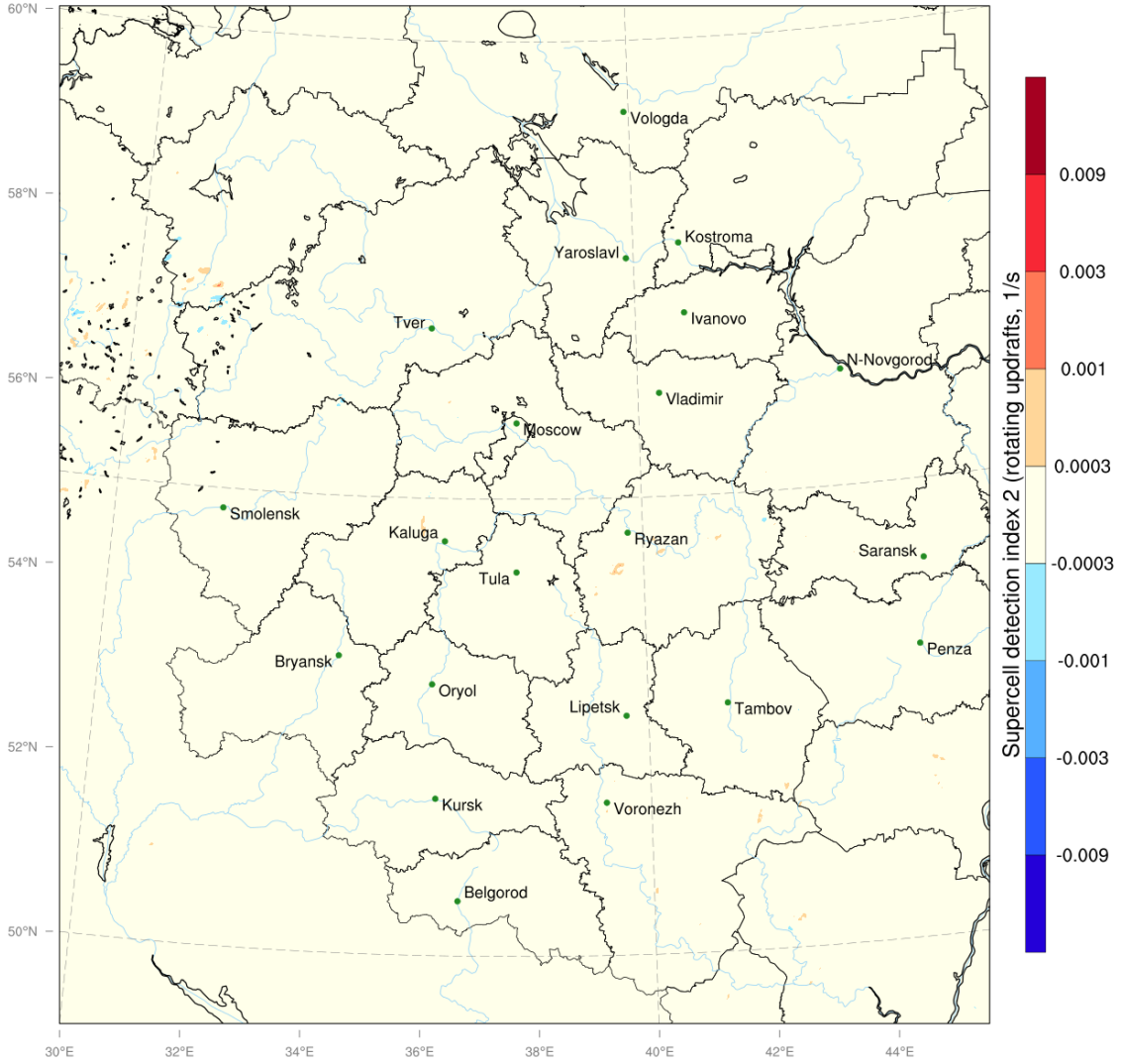
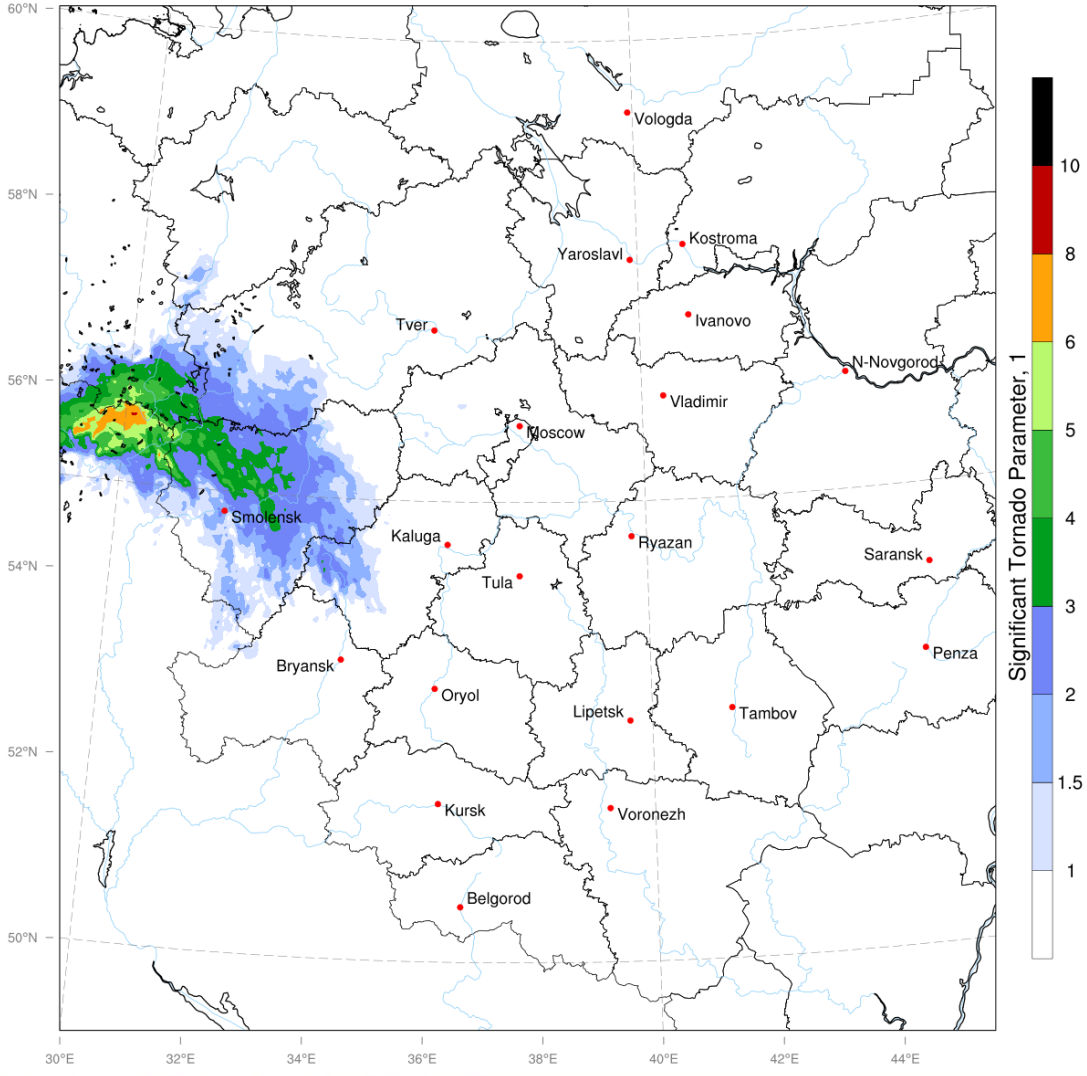
- 10:00 UTC COSMO-Ru (2.2 km) Supercell Detection Index 2 (SDI_2) & Significant Tornado Parameter





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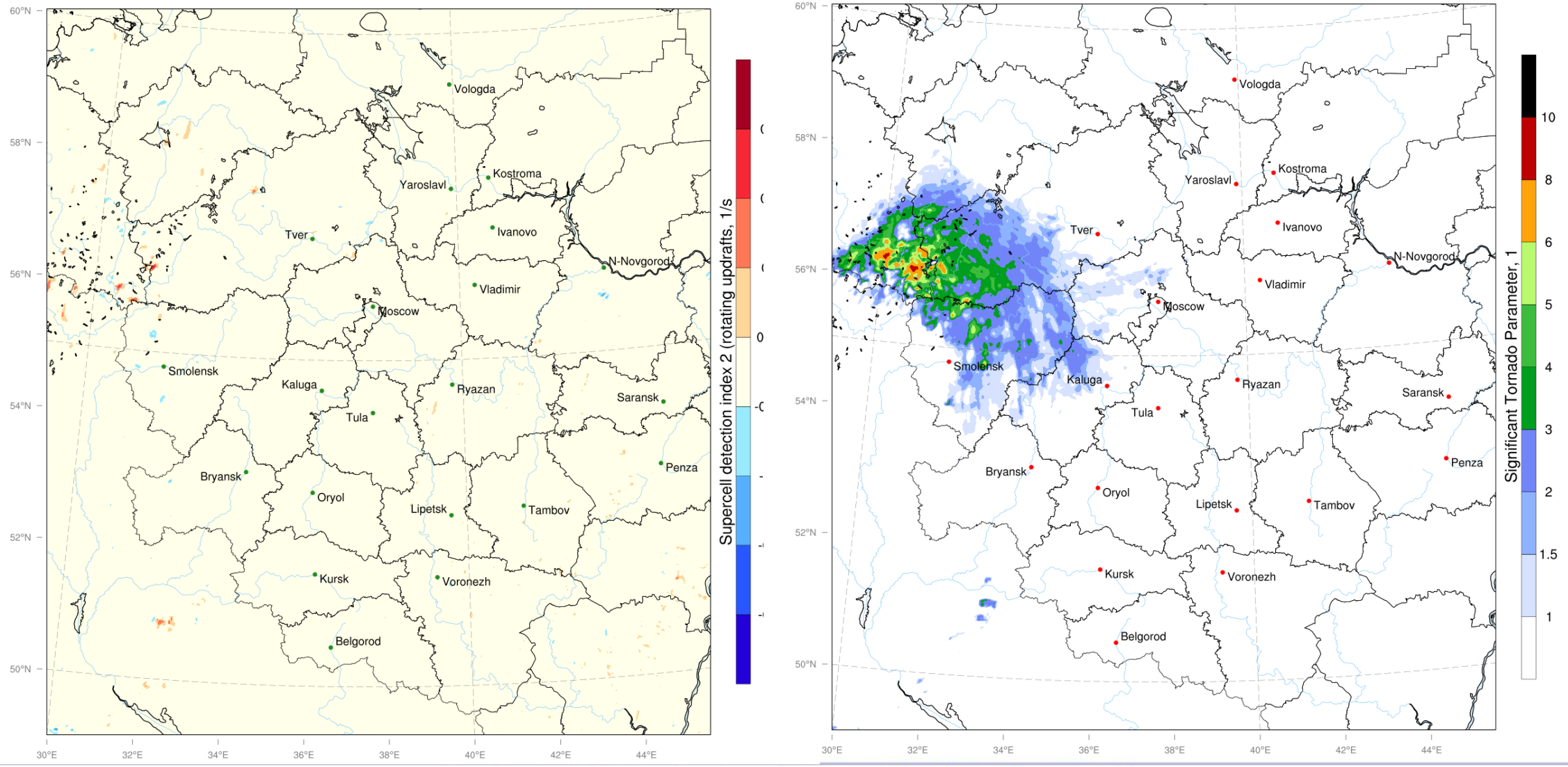

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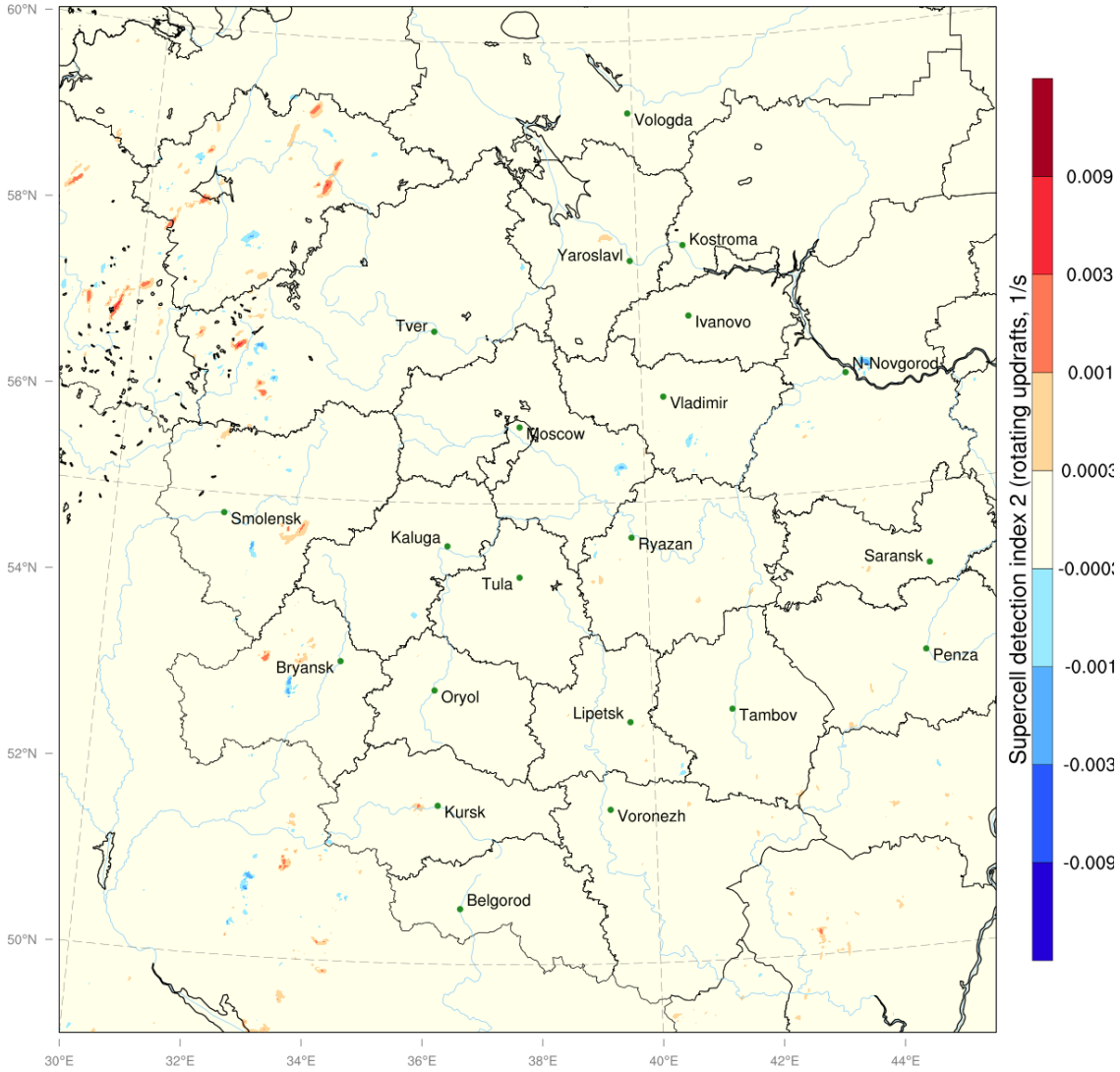
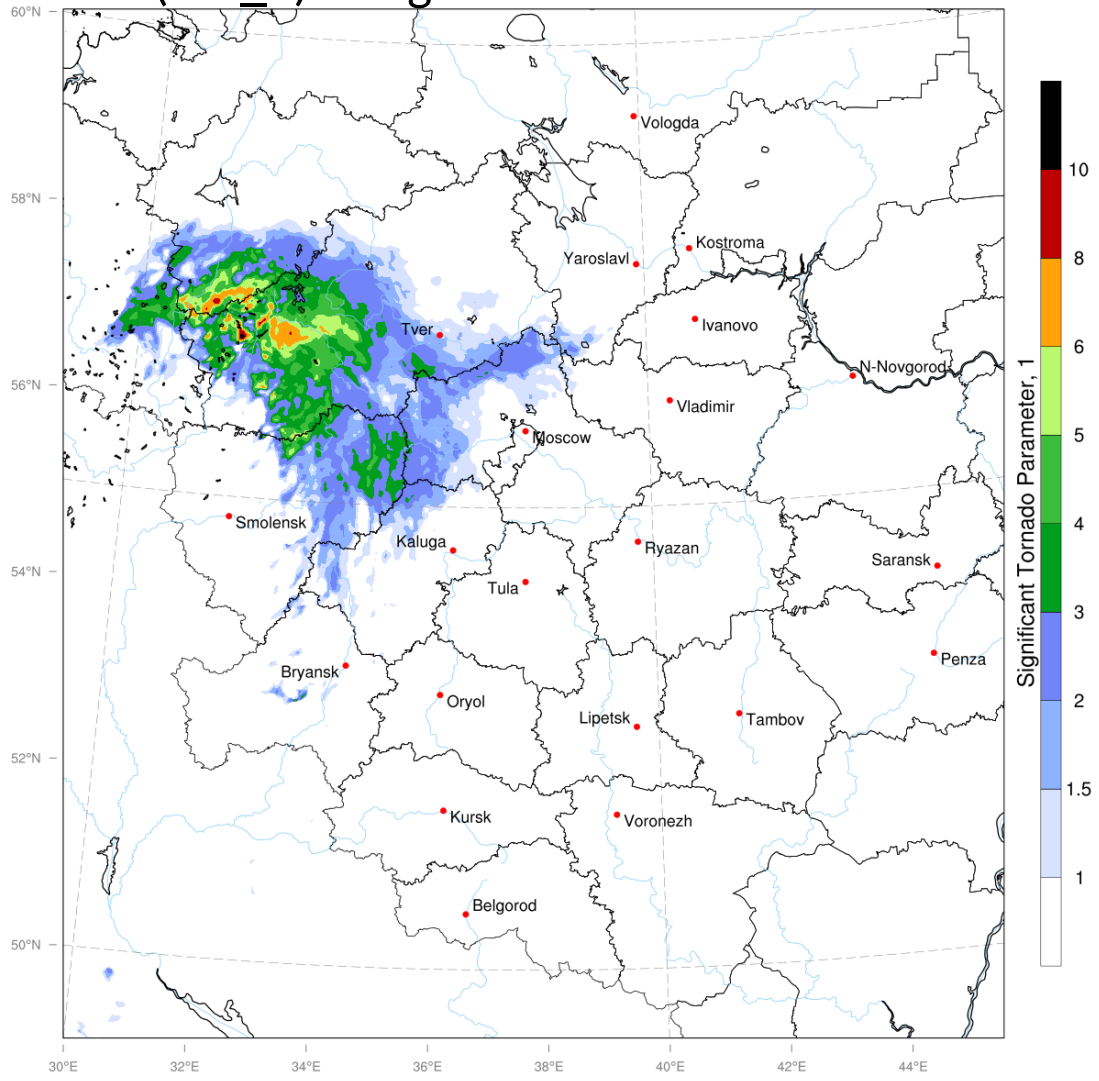
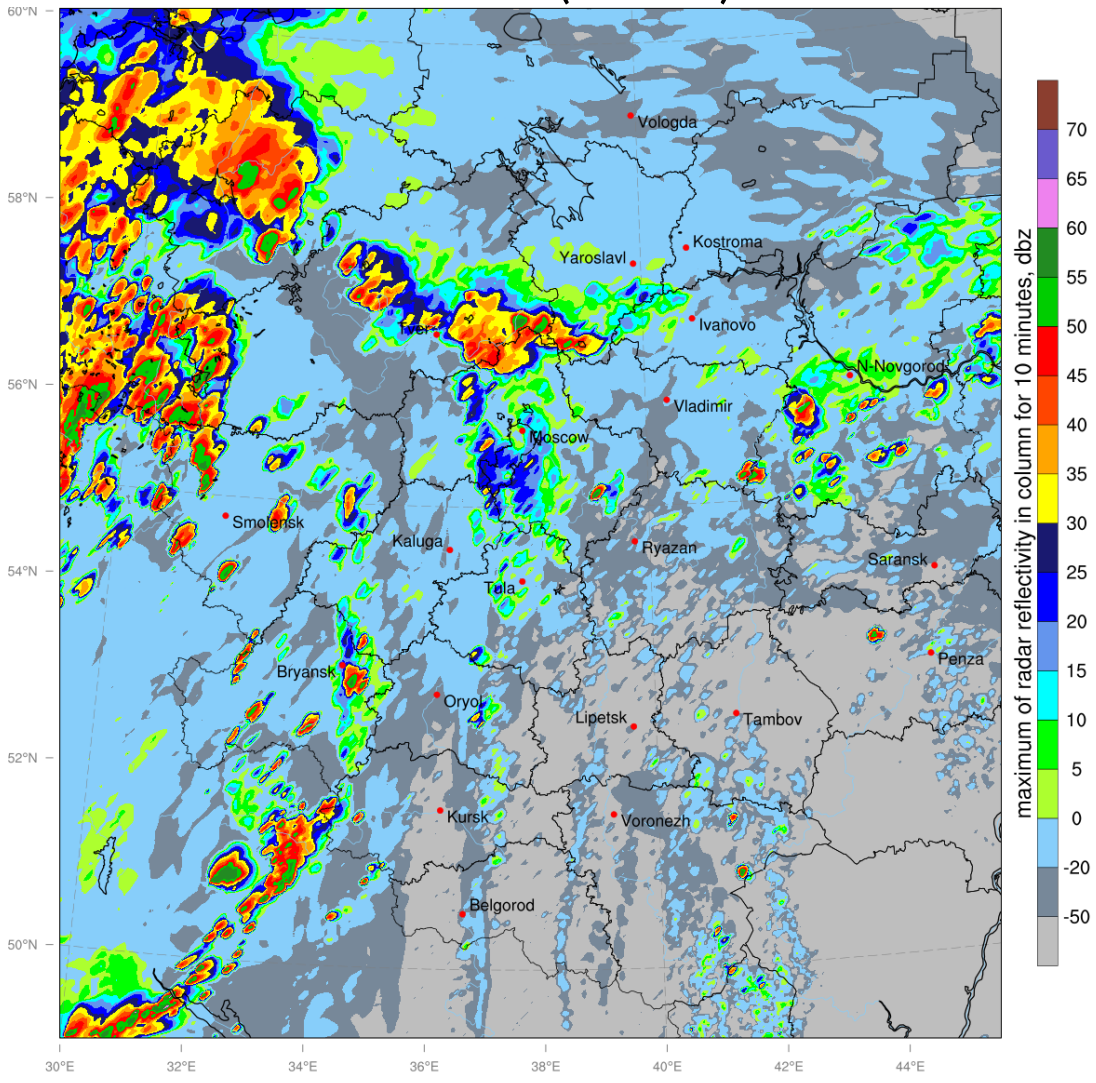
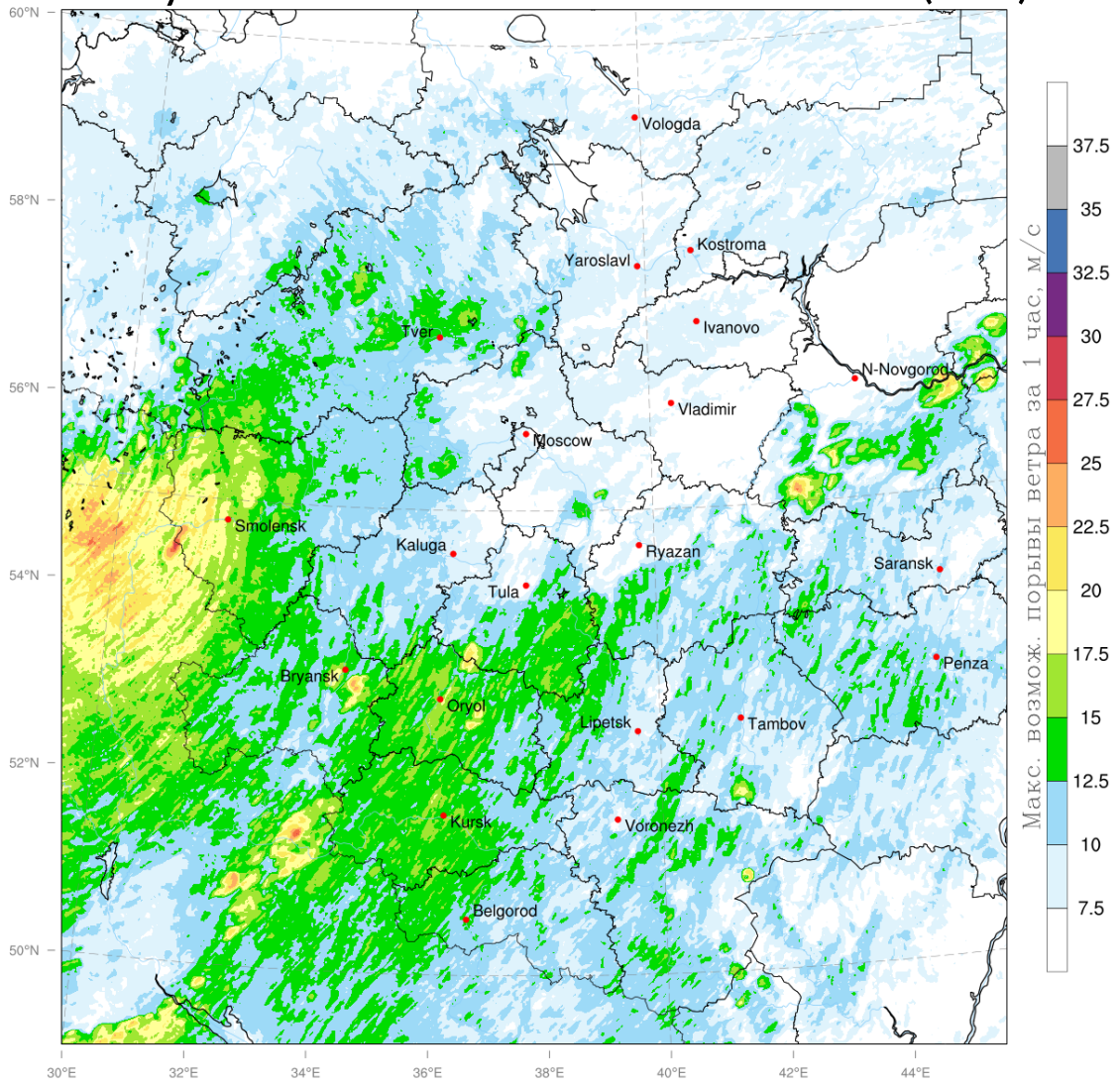




Case 2. The August 2 Tornado outbreak

- 12:00 UTC COSMO-Ru (2.2 km) Simulated radar reflectivity & Maximum 10m AGL Wind Gust (m/s)





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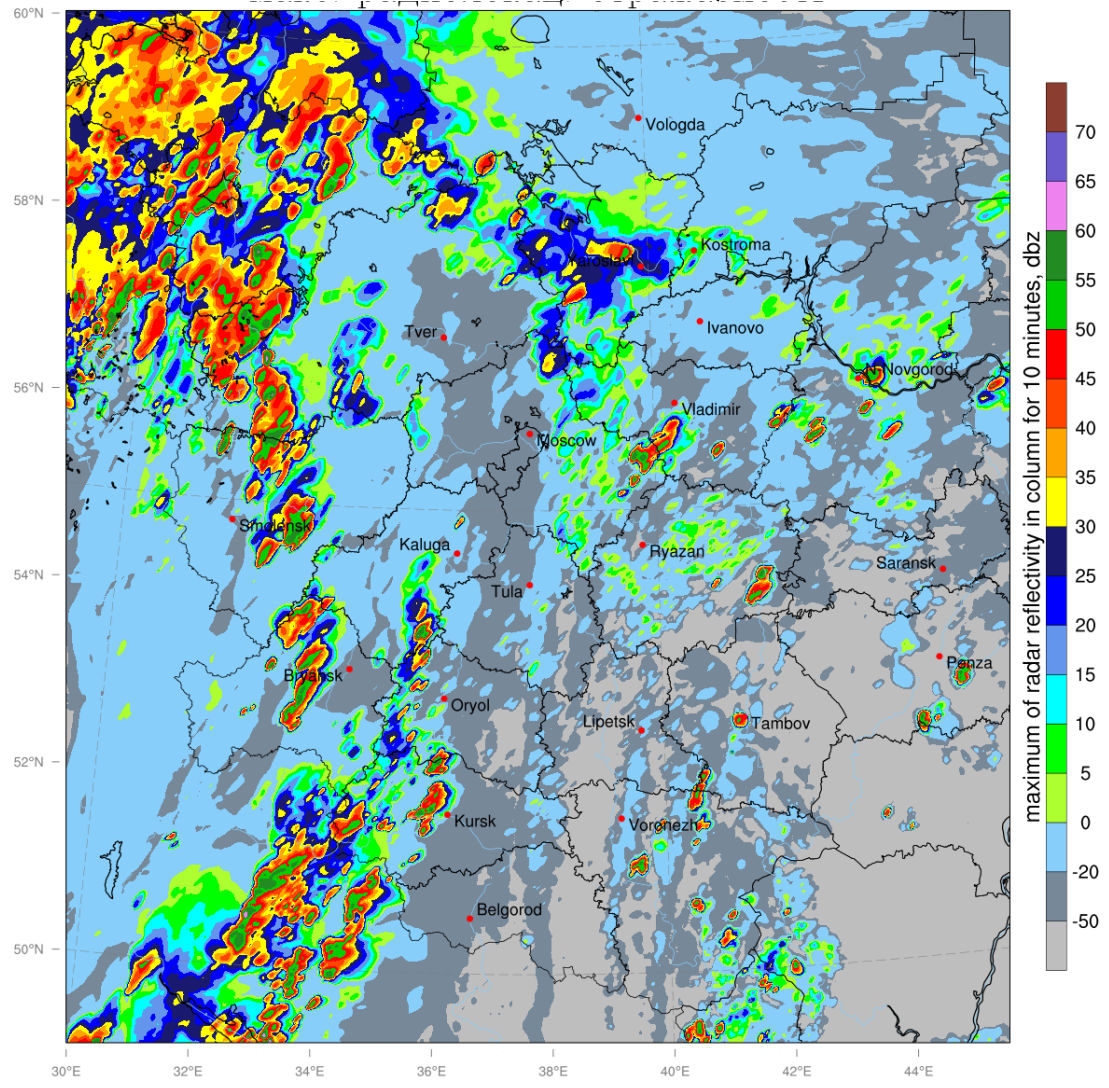
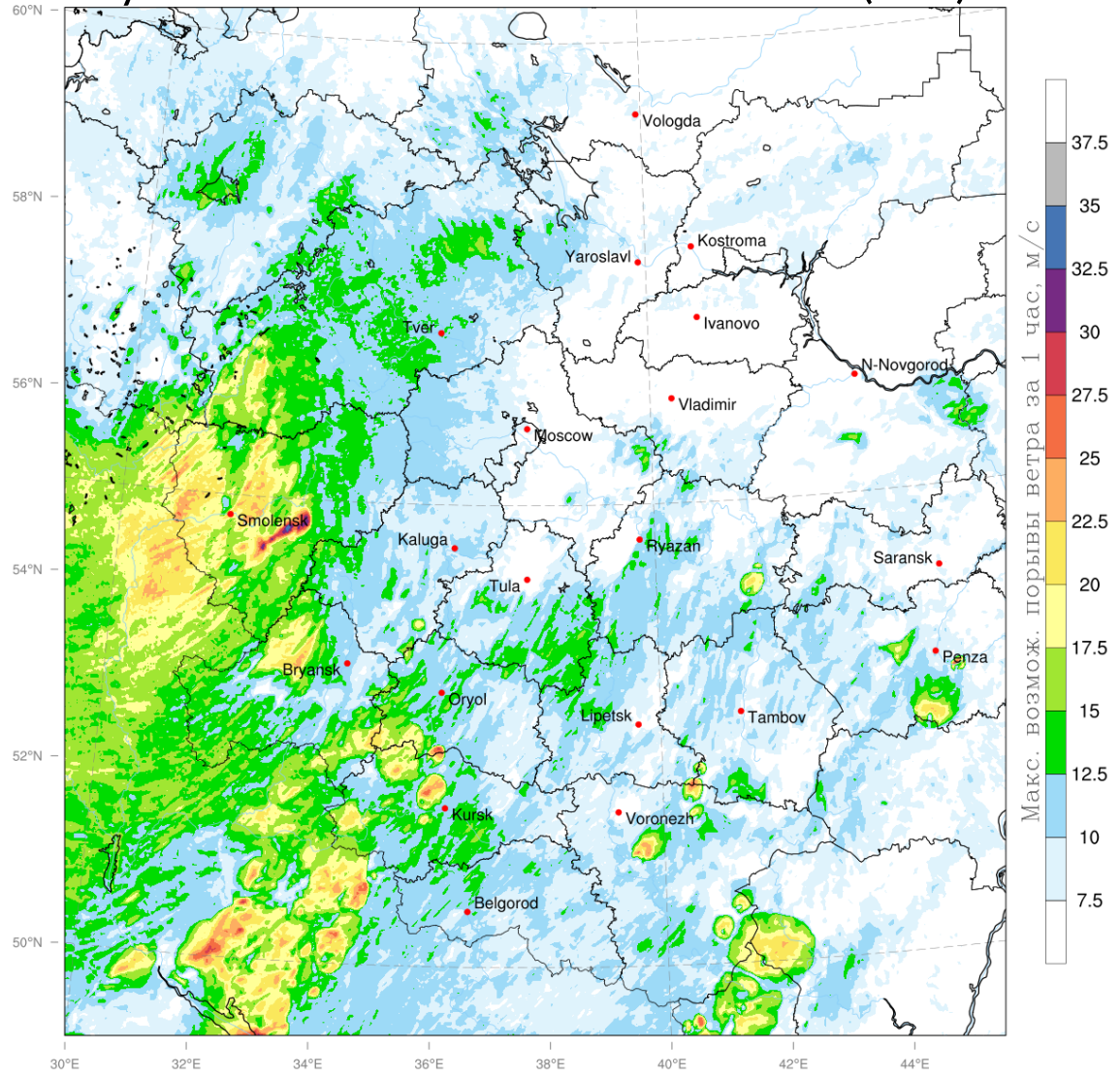
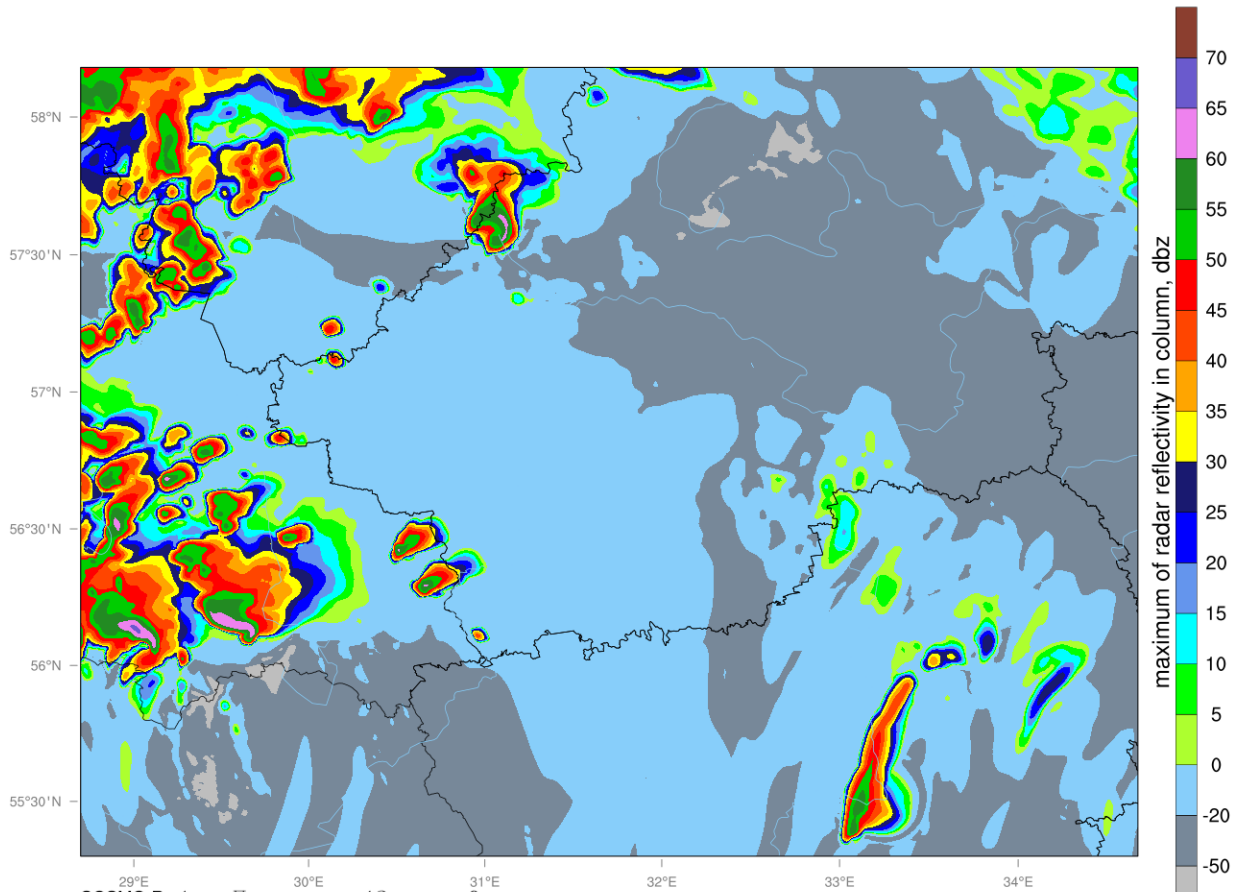
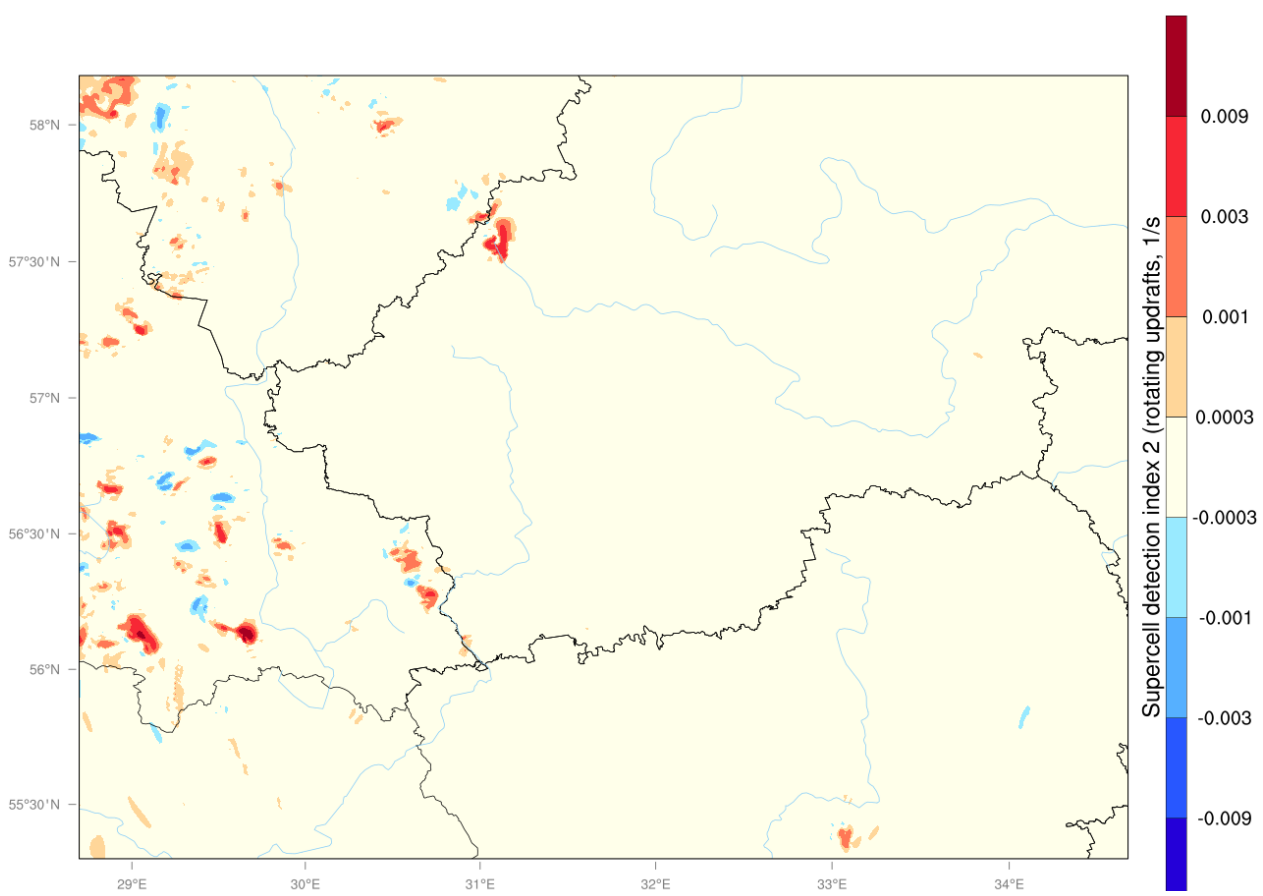




Case 2. The August 2 Tornado outbreak

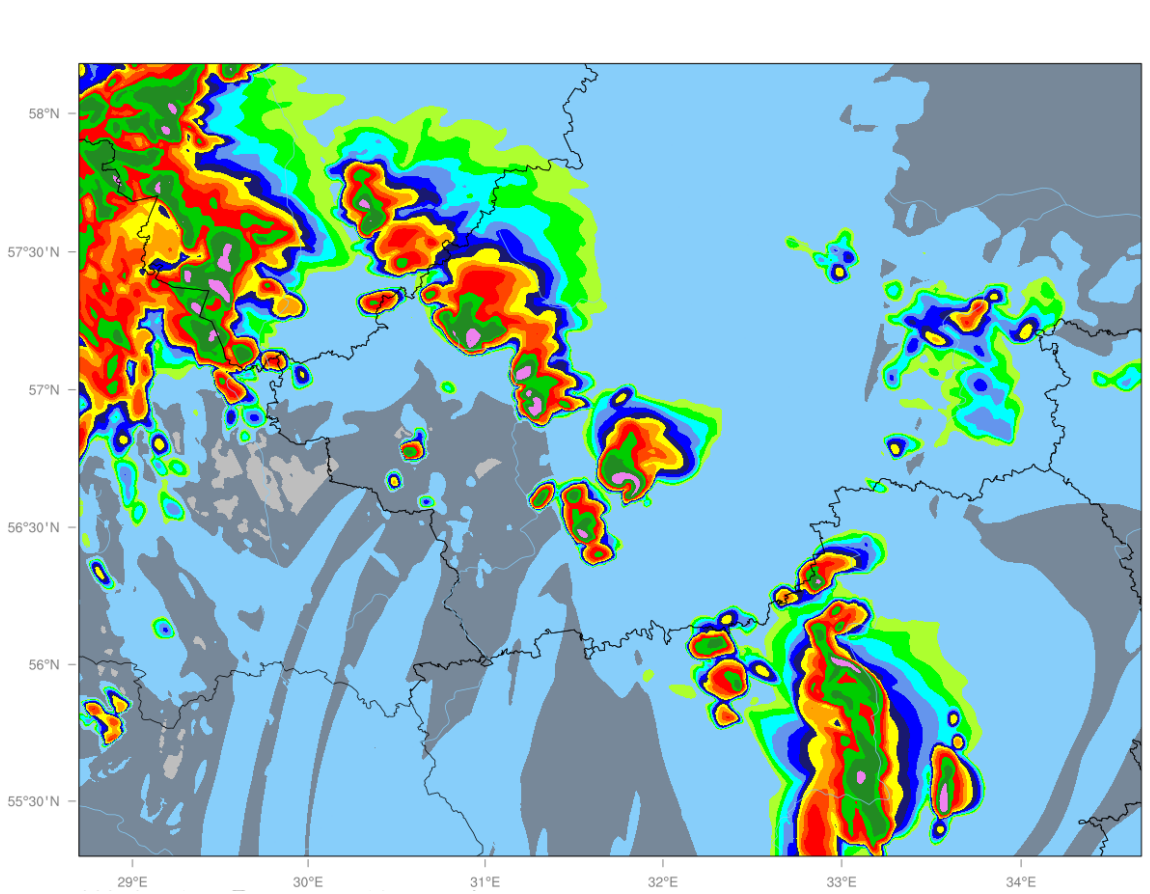
- 12:00 UTC COSMO-Ru (1 km) Simulated radar reflectivity & Supercell Detection Index 2 (SDI 2)

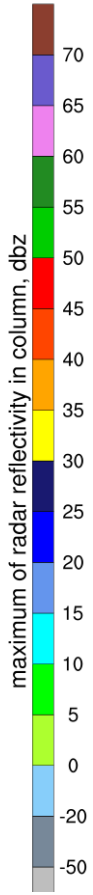


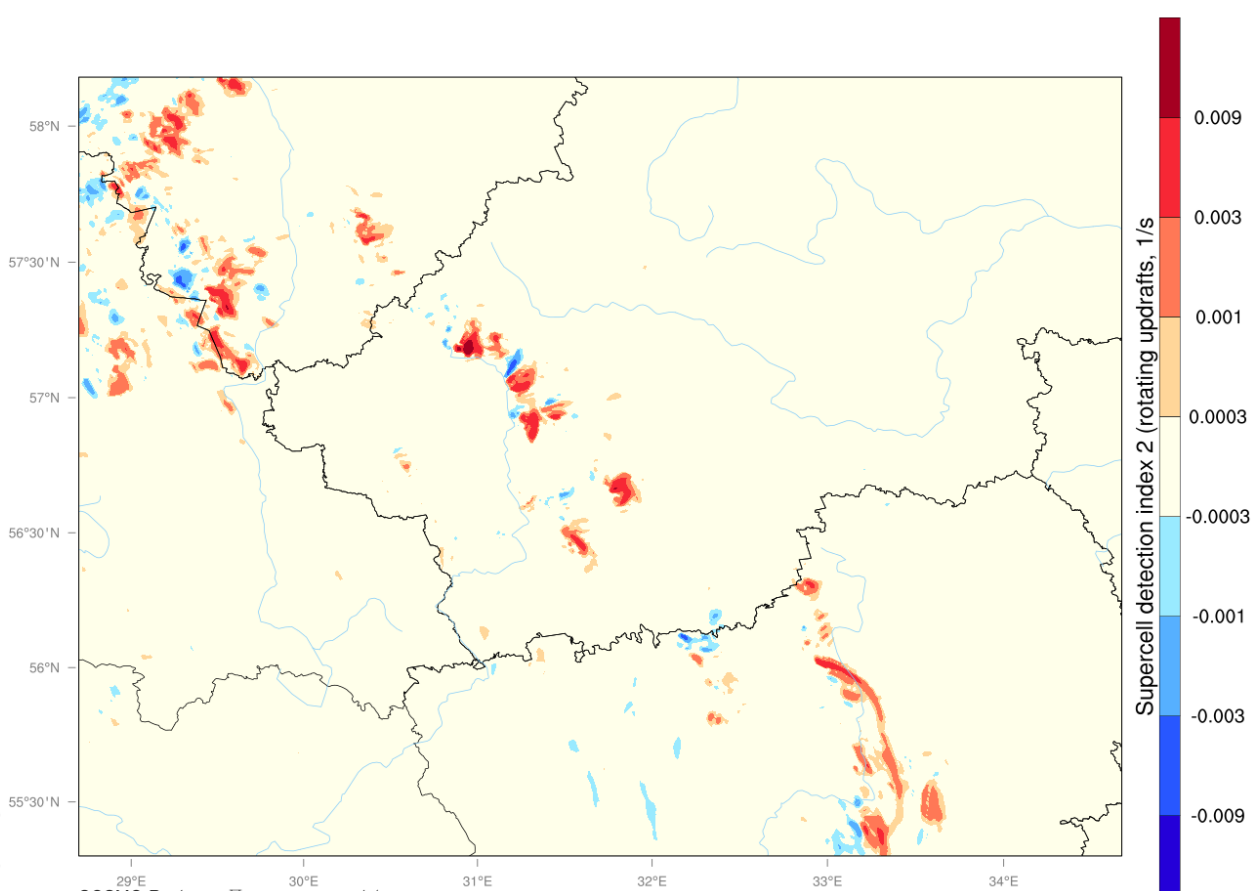


Case 2. The August 2 Tornado outbreak

- 14:00 UTC COSMO-Ru (1 km) Simulated radar reflectivity & Supercell Detection Index 2 (SDI 2)







Conclusions

- The comparison between simulated Significant Tornado Parameter values and the Supercell Detection index values in some cases can help exclude false alarms in Tornado risk prediction

- Experiments performed with COSMO-Ru with 1km spatial grid resolution show more distinct supercell and mesoscale convective systems compared to COSMO-Ru 2.2 km