Смерчевые и шкваловые ветровалы в лесах России/Stand-replacing windthrow events in Russian forests

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State of the art

- Severe wind events (windstorms, tornadoes, snow- and icestorms) are among the main causes of natural disturbances in boreal and temperate forests.
- Until recently, only broad estimates of wind-related damage in Russian boreal forests have been published
- Recent decades, wind-related forest damage increases in Western and Central Europe, that is probably associated with observed climate warming. There are no such estimates for the territory of Russia

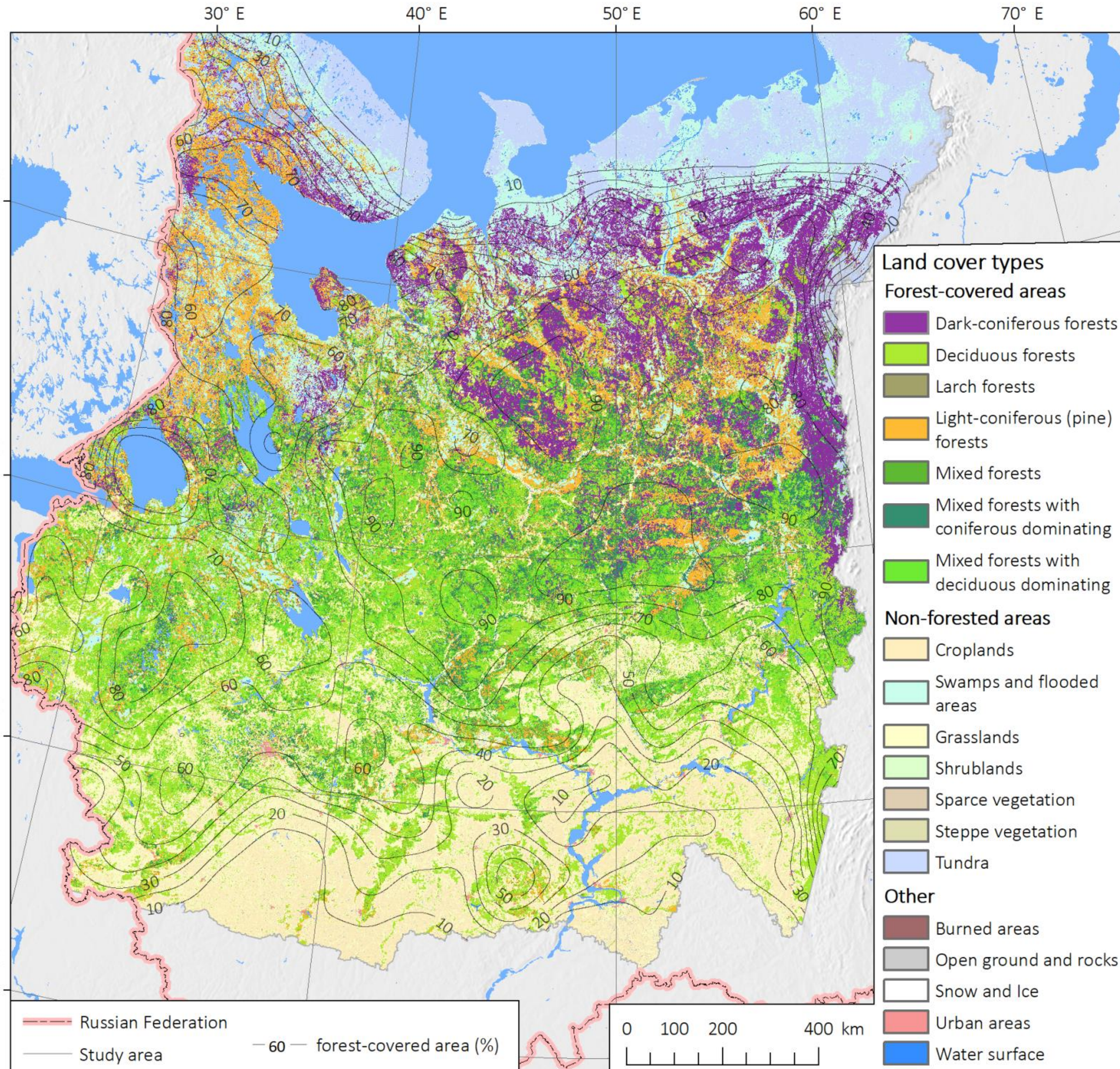
Objectives of our study

- Develop a GIS databases of windthrow events in forests of European Russia and Ural, and tornado-induced windthrow for the entire territory of Russia, based on publicly available satellite images (Landsat and Sentinel-2)
- Determine the contribution of various weather events to wind-related forest damage
- Improve the climatology of severe convective storms and tornadoes, collecting the data on hundreds of previously unknown storm events

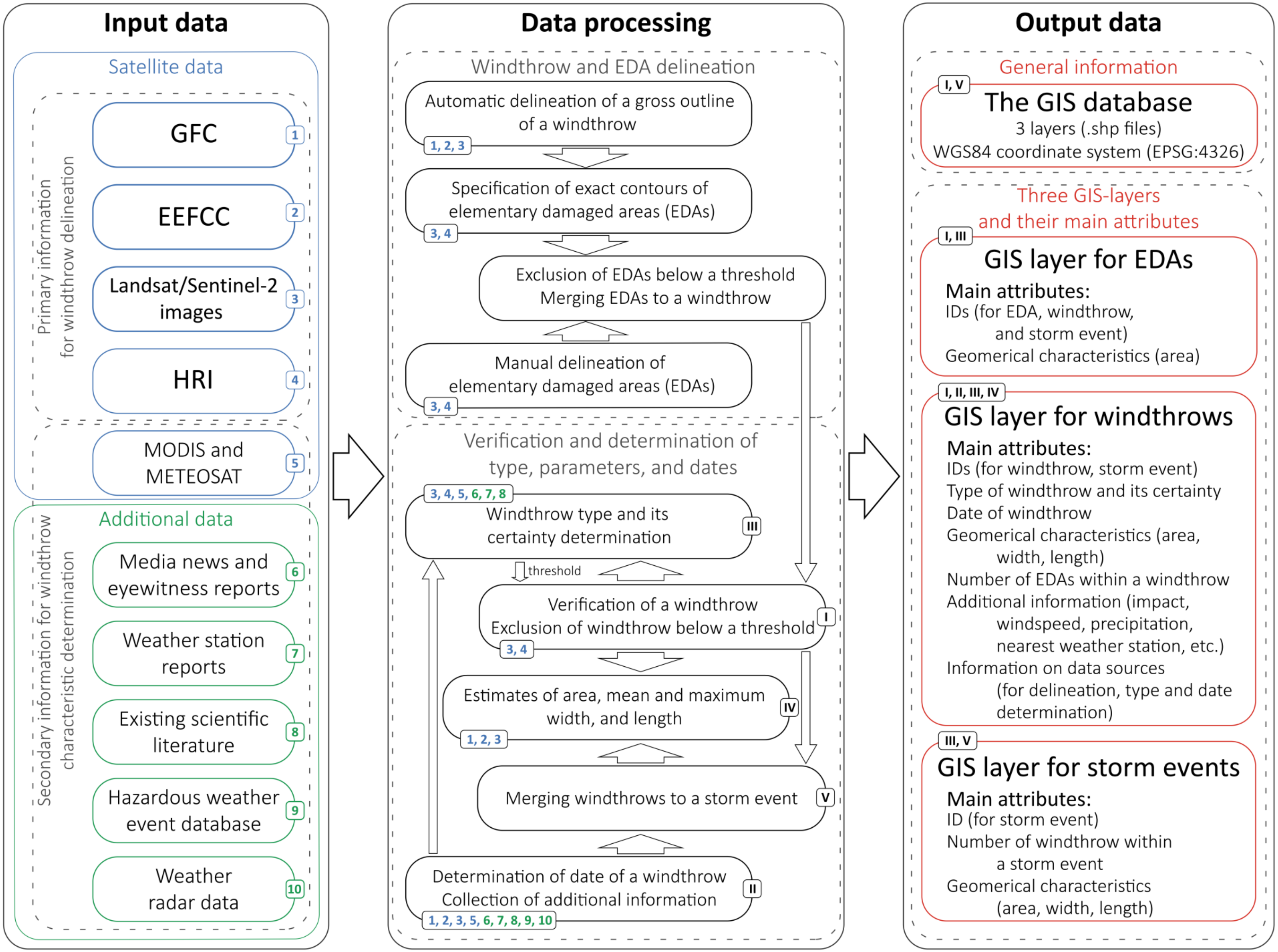
Main data sources

- Global Forest Change Map – 30-m resolution forest loss dataset for 2001-2020, with 1-year time step (Hansen et al., 2013)
- Eastern-Europe forest cover change (EEFCC) – 30-m resolution forest loss dataset for 1985-2012, available for Eastern Europe and European Russia only (Potapov et al., 2015)
- LANDSAT TM/ETM+/OLI, and Sentinel-2 images, obtained from USGS and EOS web services (https://earthexplorer.usgs.gov/ and https://eos.com/landviewer).
- High-resolution images from publicly available services Google Earth, Yandex.Maps, Bing Maps, ESRI and Here
- Data (3-hourly weather reports) from > 450 Russian weather stations for 1985-2010 period, downloaded from http://aisori.meteo.ru/ClimateR (reference stations only), and several publicly available services
- Monthly reviews of hazardous weather events occurred in Russia, published in the Russian Meteorology and Hydrology journal (http://mig-journal.ru/en/archive-eng)
- Severe weather reports from media news and social networks,
- Meteosat-8 satellite images (from 2010)
- Land cover/land use maps (Bartalev et al., 2016, Arino et al., 2008)

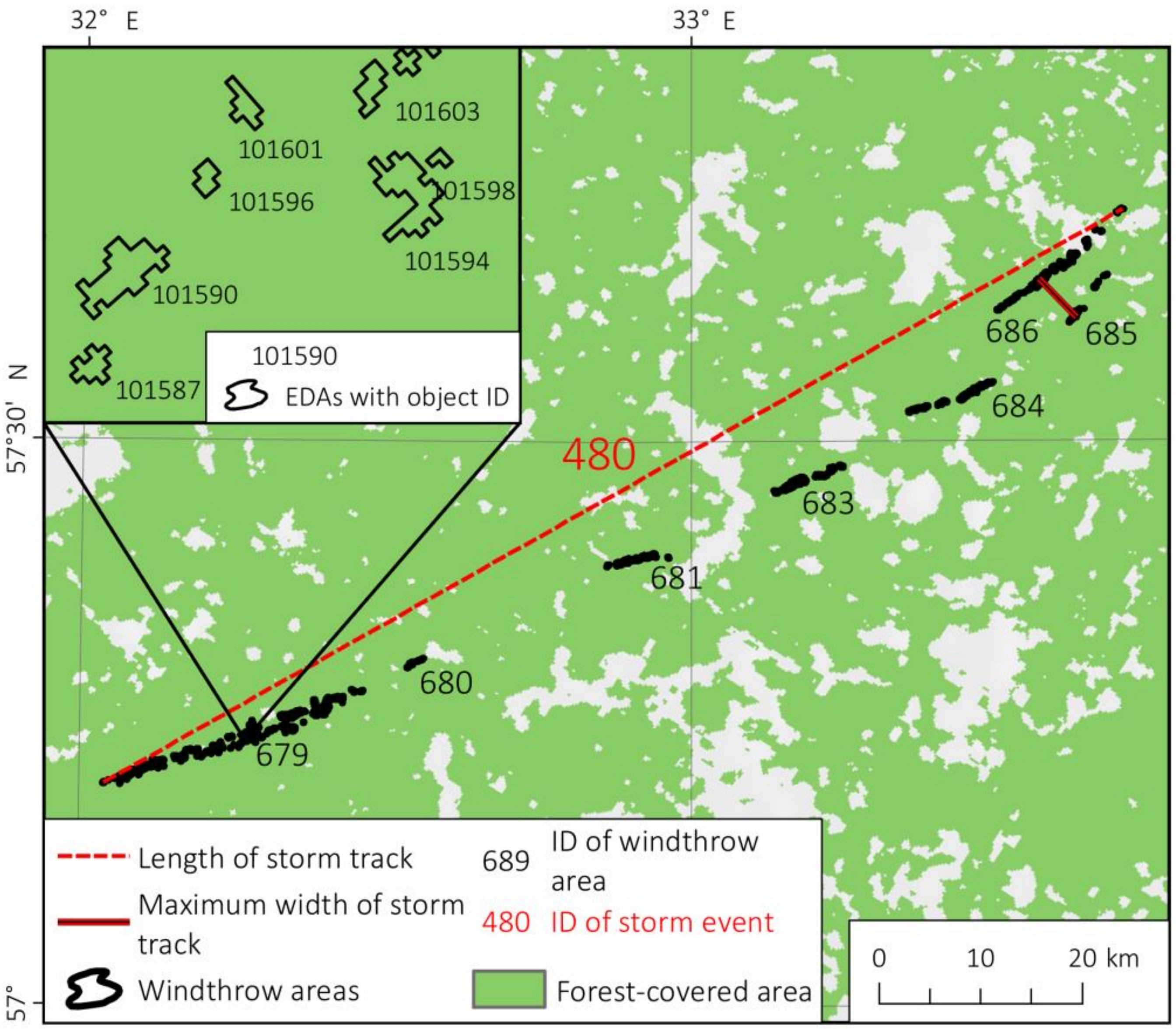
The main study area (forest zone in European Russia)



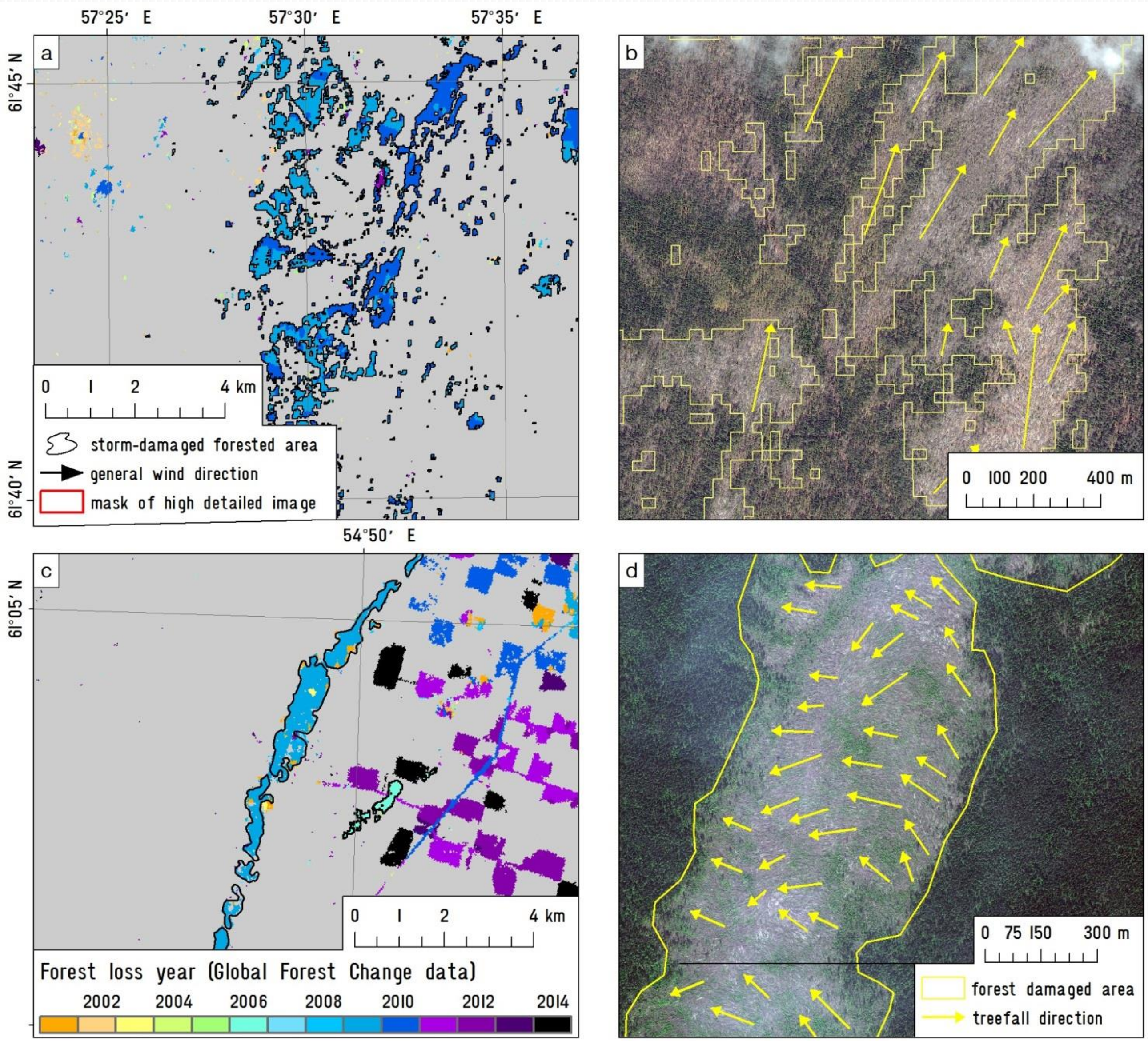
Workflow used for windthrow delineation and attribution



The example of three hierarchical levels of the windthrow database – elementary damaged areas, windthrow areas and storm event tracks



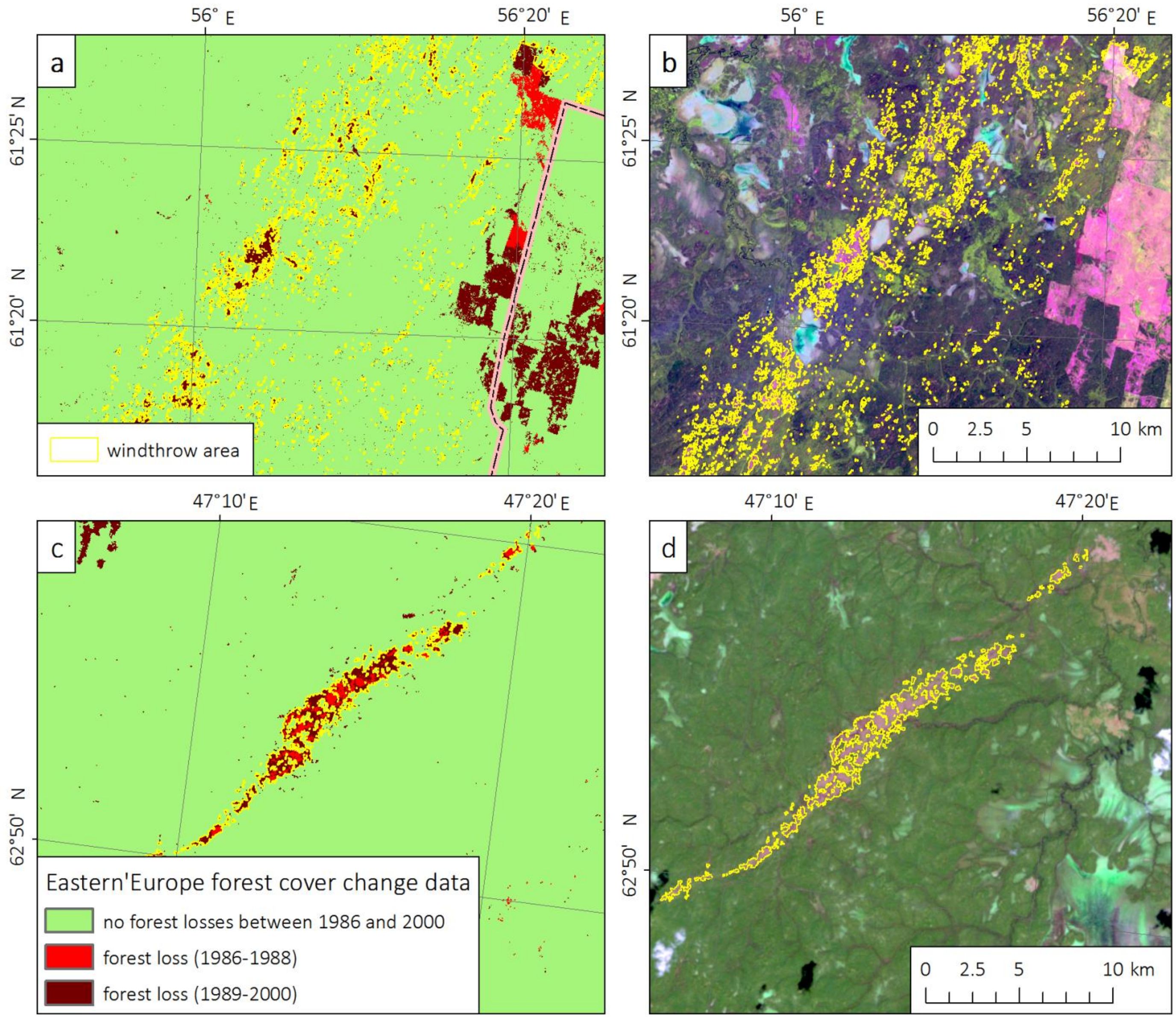
Windthrow identification with Global Forest Change data



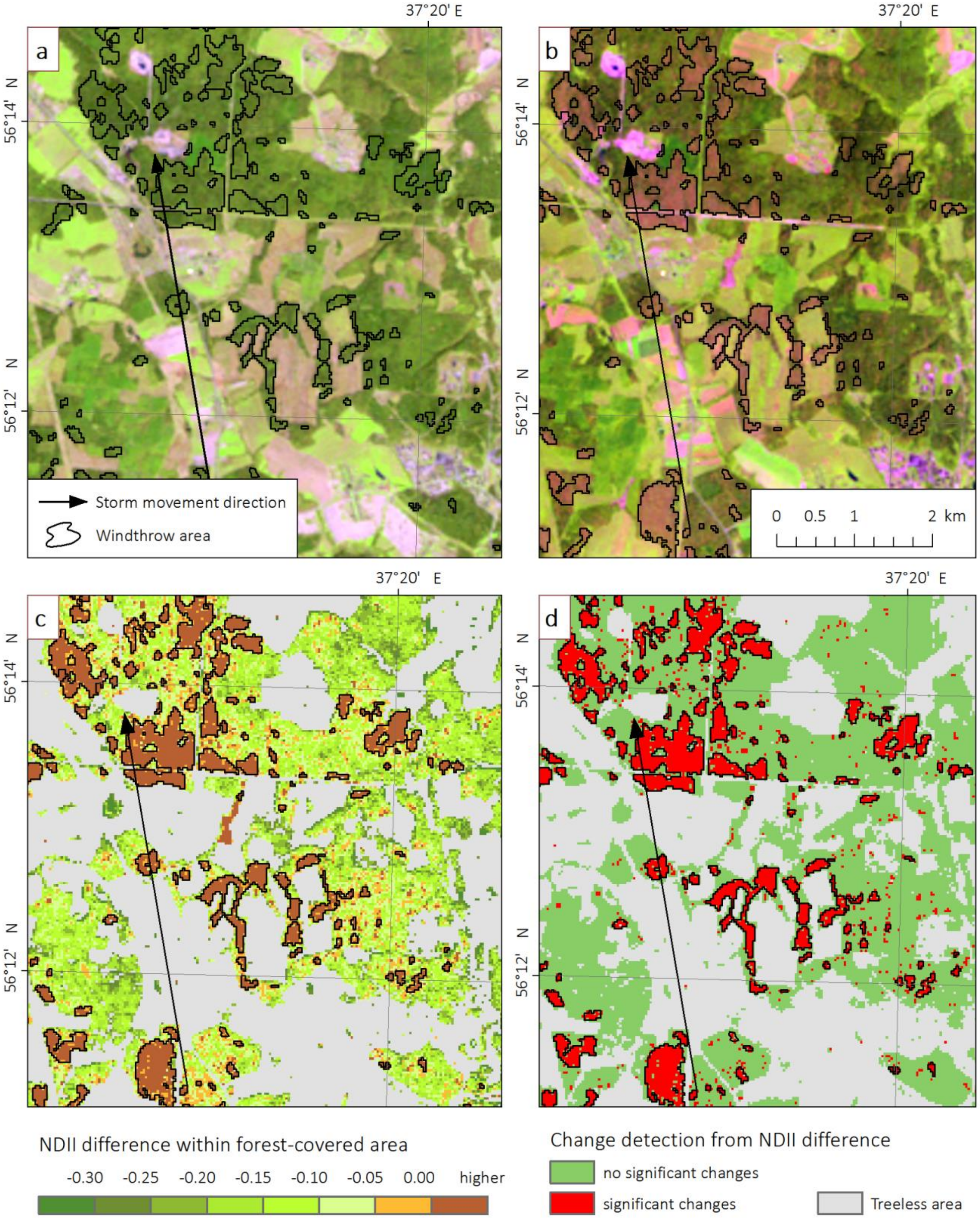
- We considered <u>**four types of weather events, causing windthrow**</u>

- Convective windstorm (squall or downburst)
- Tornado
- Non-convective windstorm
- Snowstorm

Windthrow identification with EEFCC data



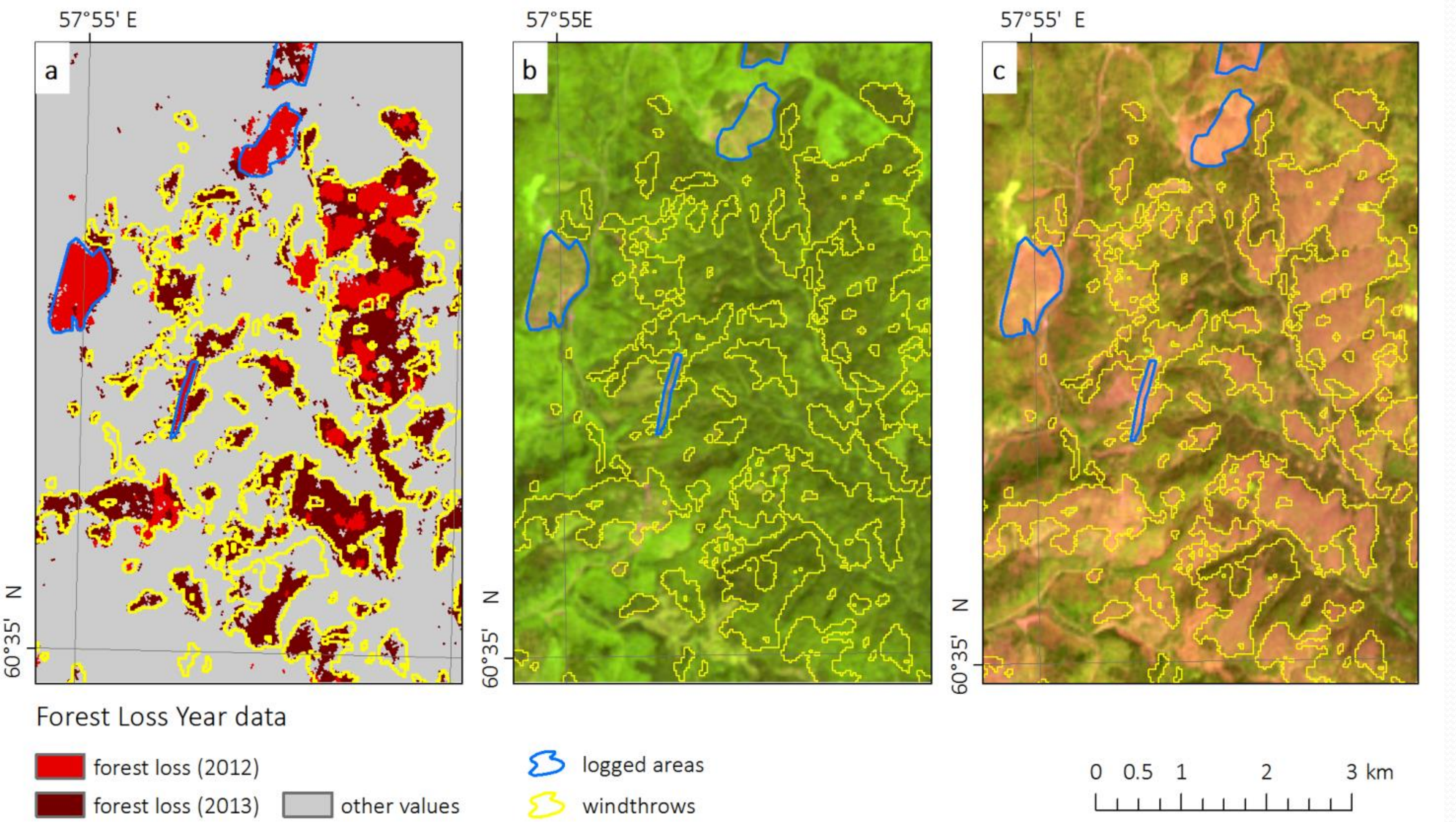
- Windthrow induced by convective storm (4 July 1992) – a, b
- Tornado-induced windthrow (24 July 1998) – c, d

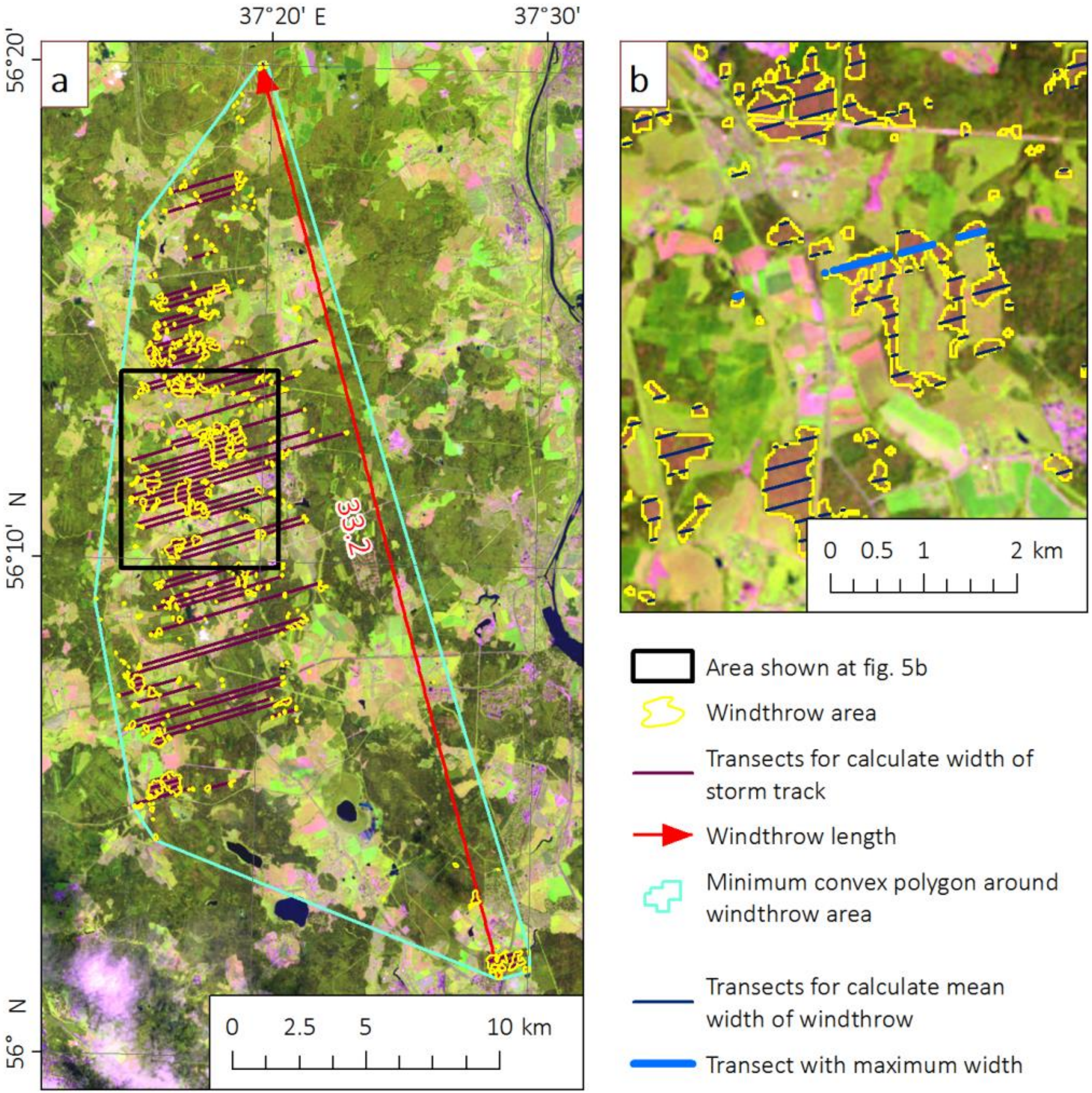


- NDII-based delineation of windthrow caused by 21 June 1998 Moscow windstorm

- Landsat-5 images obtained before and after the storm event — 11 May 1998 and 30 July 1998 (a, b)
- NDII difference within forest-covered area and (c) the areas with the substantial decrease of NDII (d).

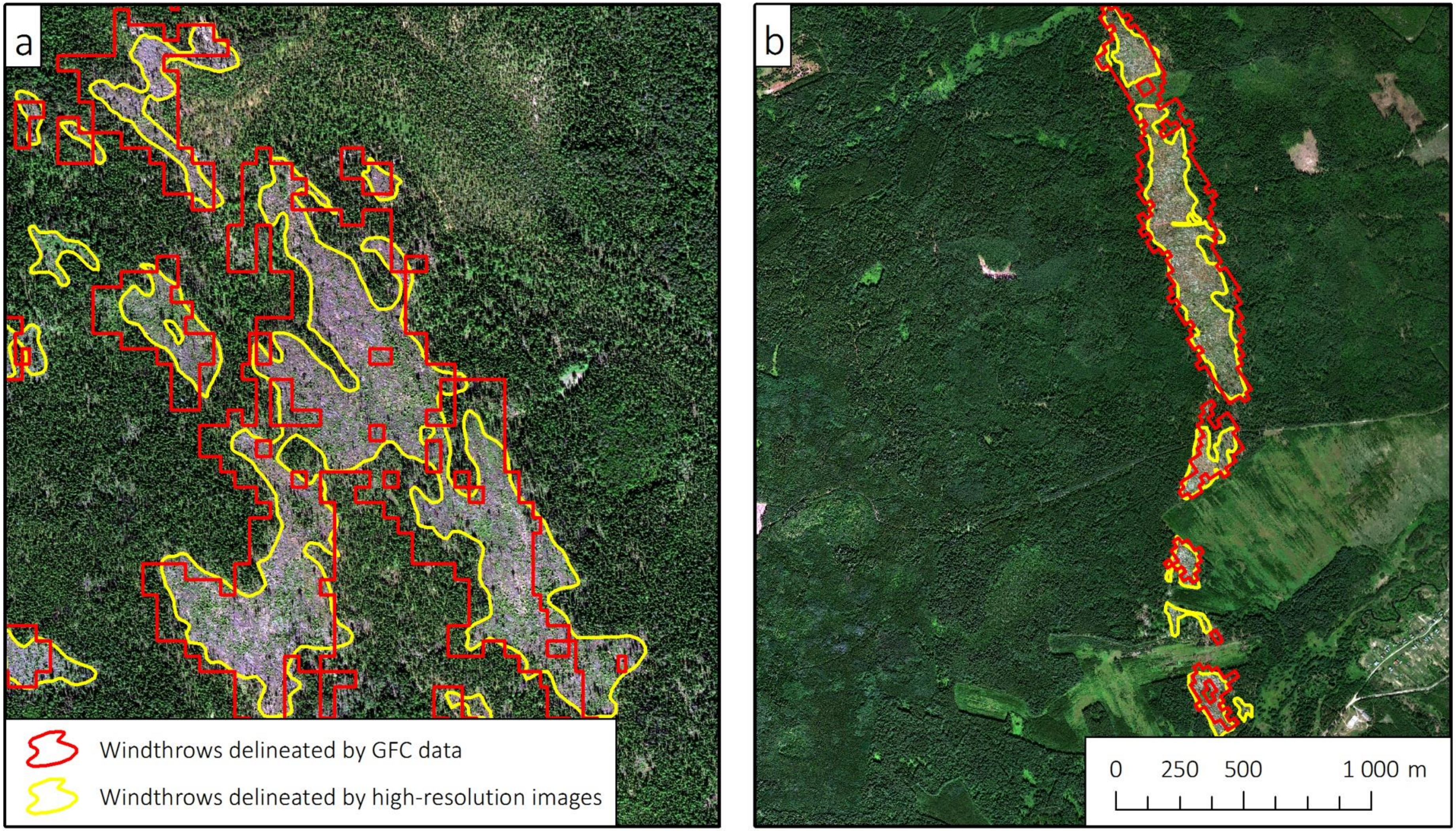
Separation of windthrow from logged areas based on Global Forest Change data (a), and Landsat images obtained before and (c) after (c) the storm event





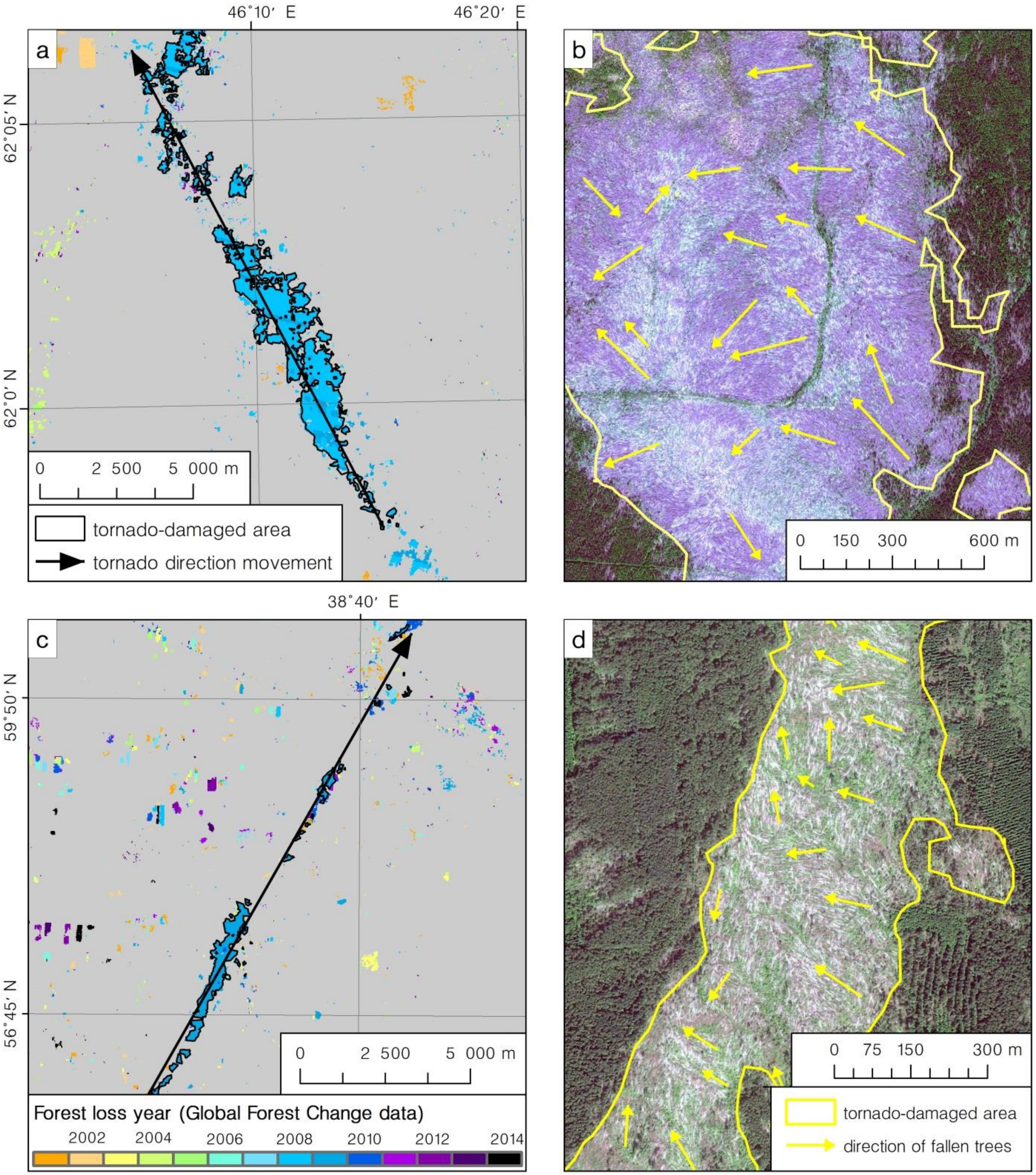
- A scheme for the determination of geometrical parameters of a windthrow based on the Landsat image, on the example of the windthrow caused by 21 June 1998 Moscow windstorm

Overlapping of windthrow areas extracted from the GFC dataset and delineated manually using high-resolution image for windthrow induced by convective windstorm (a) and tornado (b)

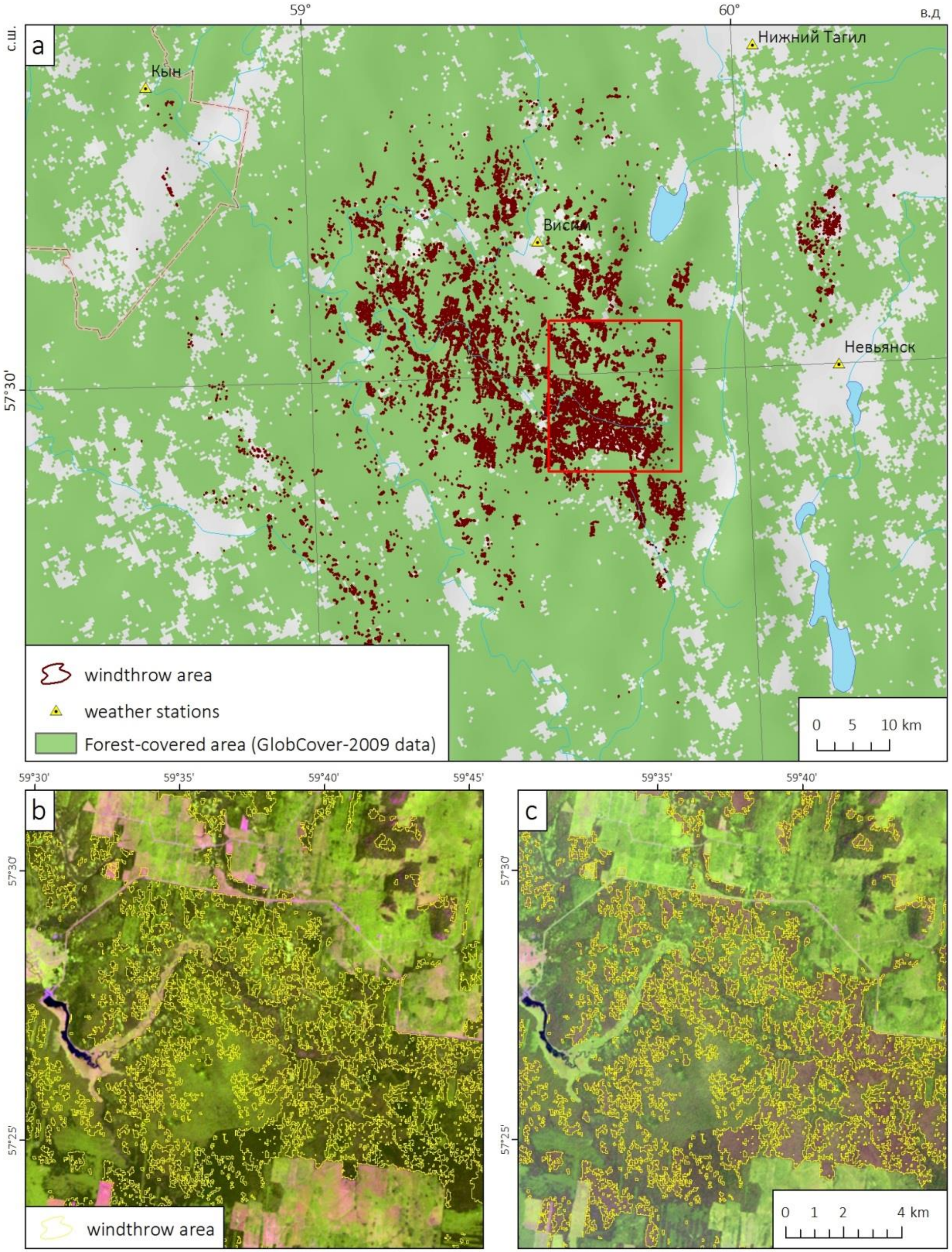


Windthrow induced by convective windstorm (15 June 2015)
Satellite image from ESRI web service

Windthrow induced by tornado (7 June 2009)
Satellite image from ESRI web service



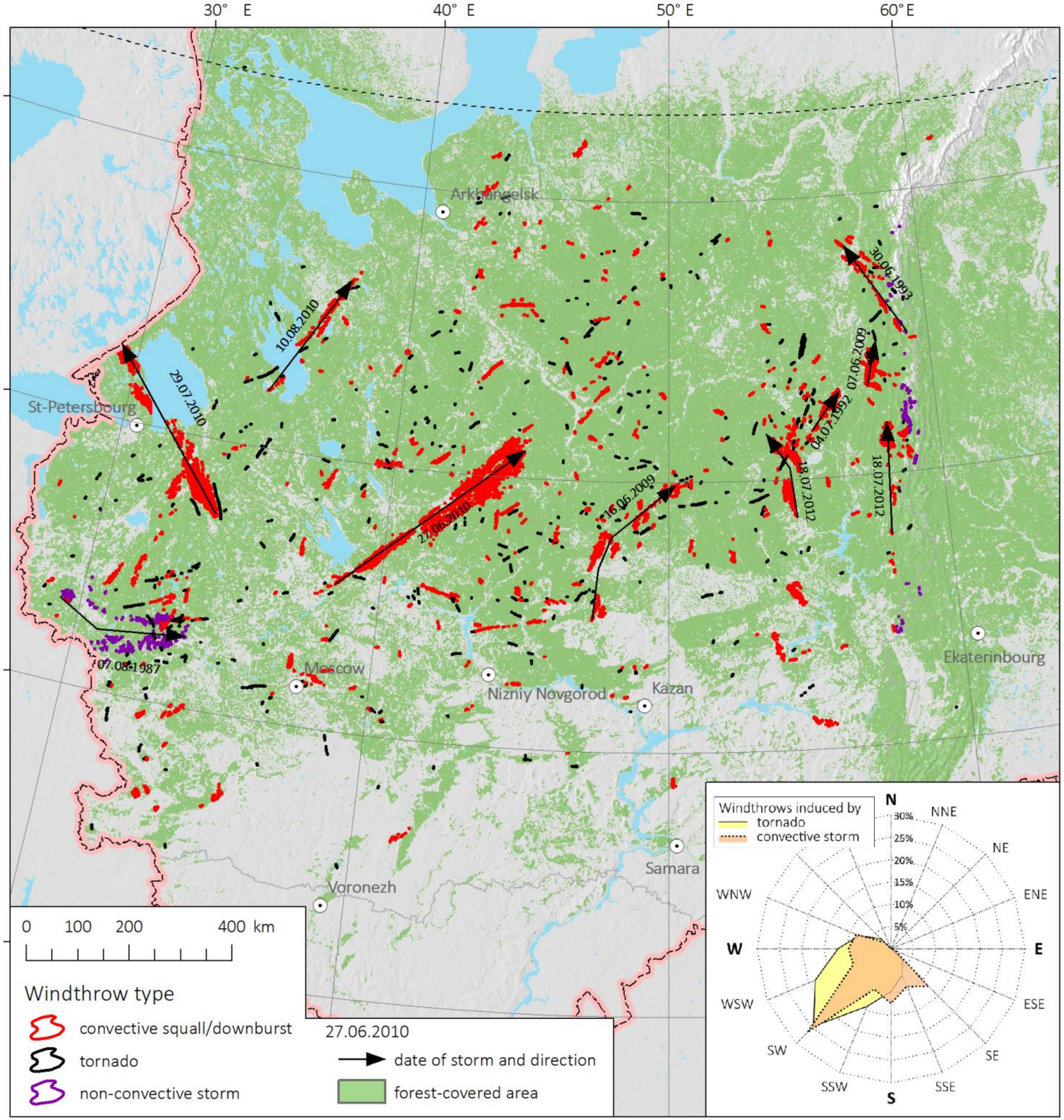
- **<u>Forest damage induced by EF3 tornadoes</u>** of 26 June 2008 and 03 June 2009: forest losses by GFC data (with year disaggregation) (a, c), and high-resolution images of tornado tracks, obtained on 27 June 2010 and 25 June 2010 (b, d).



- <u>Windthrow caused by catastrophic windstorm with snowfall 6 June 1995 in Middle Ural region (Visim reserve)</u>
- General view of the storm-affected area (a)
- And Landsat-5 (TM) images obtained before (2 June 1995) and after (c5 August 1995) the storm event (b, c)

Total number of windthrow of different types and corresponding forest damaged area (European Russia only, 1986-2017)

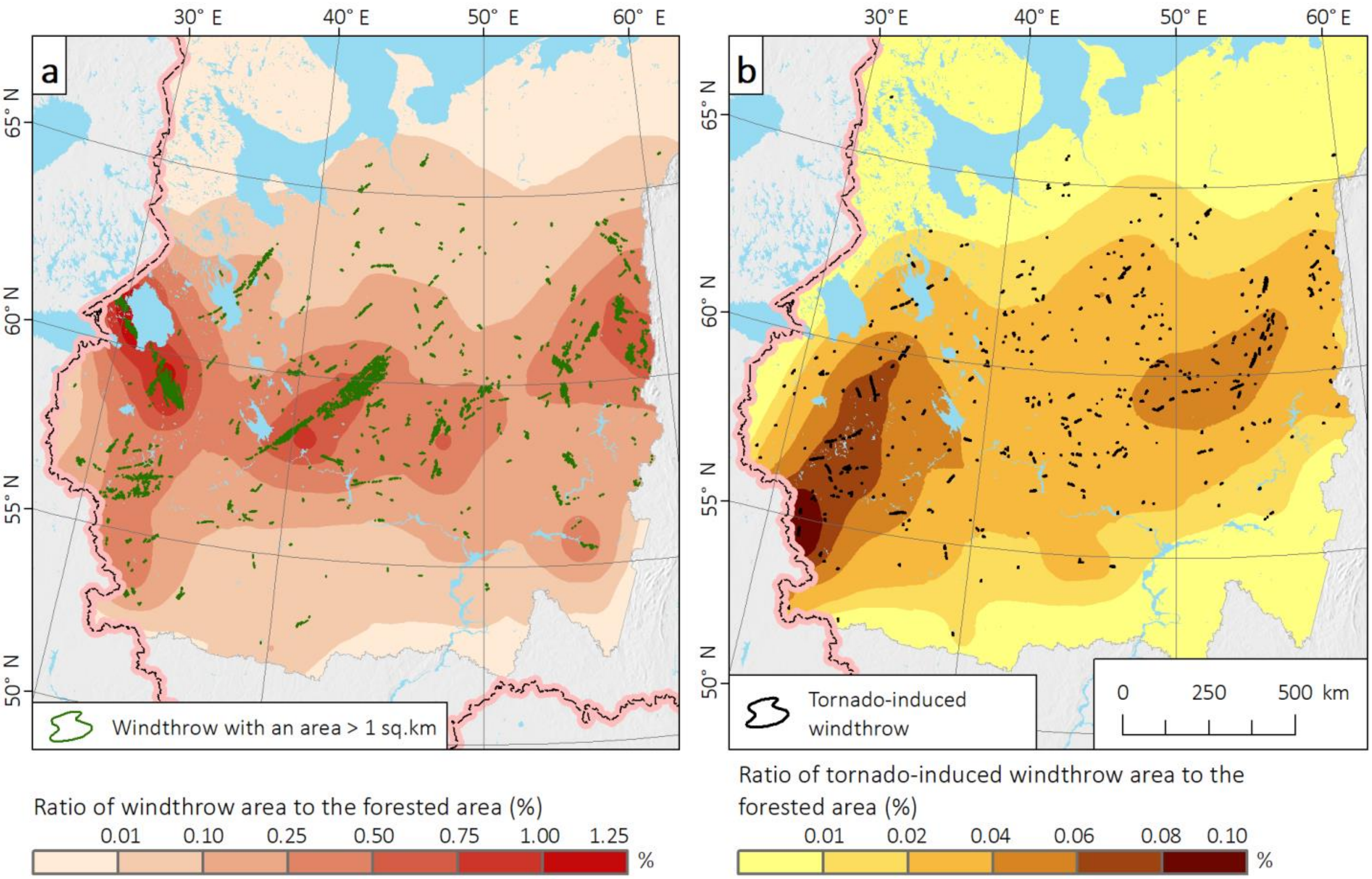
Windthrow type	Degree of certainty	Number of windthrow	Damaged area, km^2
Convective storm induced	High	270	2371.6
	Medium	25	7.6
Tornado-induced	High	295	300.4
	Medium	92	79.2
Non-convective storm induced	High	12	131.8
	Medium	6	5.9
Total	High	577	2803.8
	Medium	123	92.7



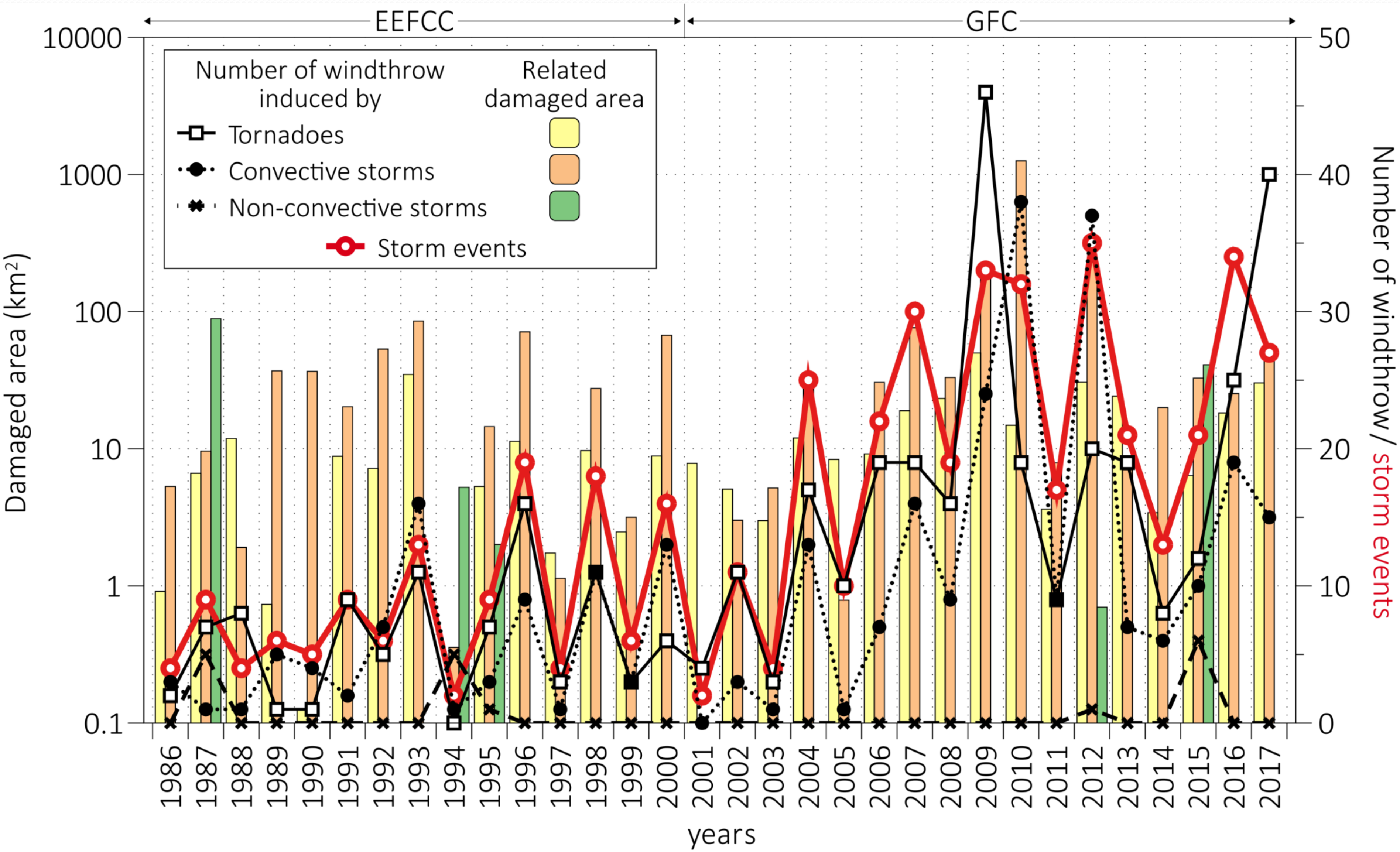
Spatial distribution of stand-replacing windthrow events in the ER in 1986-2017

- The ten most catastrophic windthrows with the largest damaged area are shown by arrows and indicated by the corresponding dates of windthrows.
- Forest-covered area is estimated according to the data from Bartalev et al. (2016).
- The inset shows the wind direction of storm events

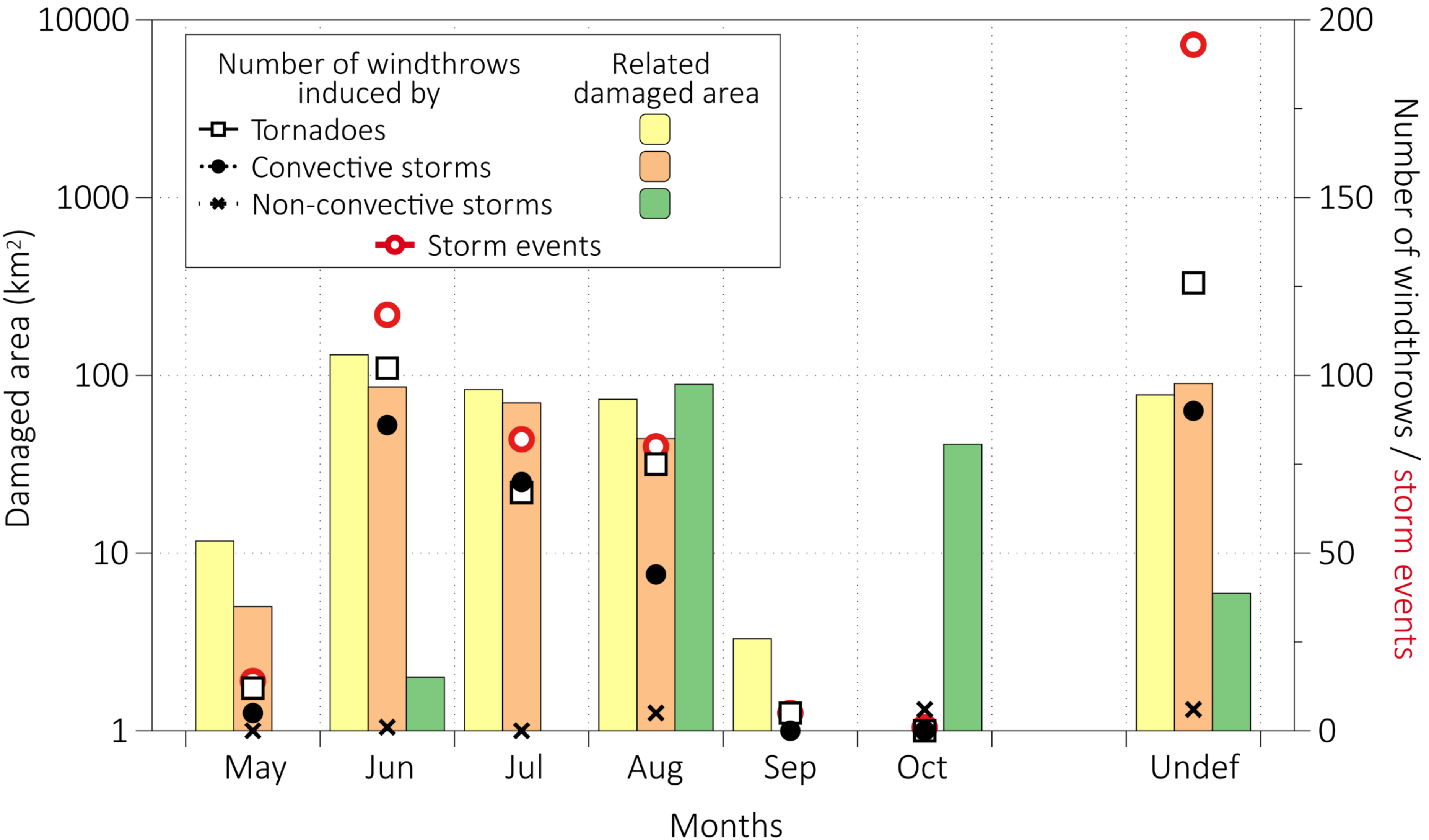
Ratio of damaged area to the forest-covered area for (a) all windthrow and (b) tornado-induced windthrow only



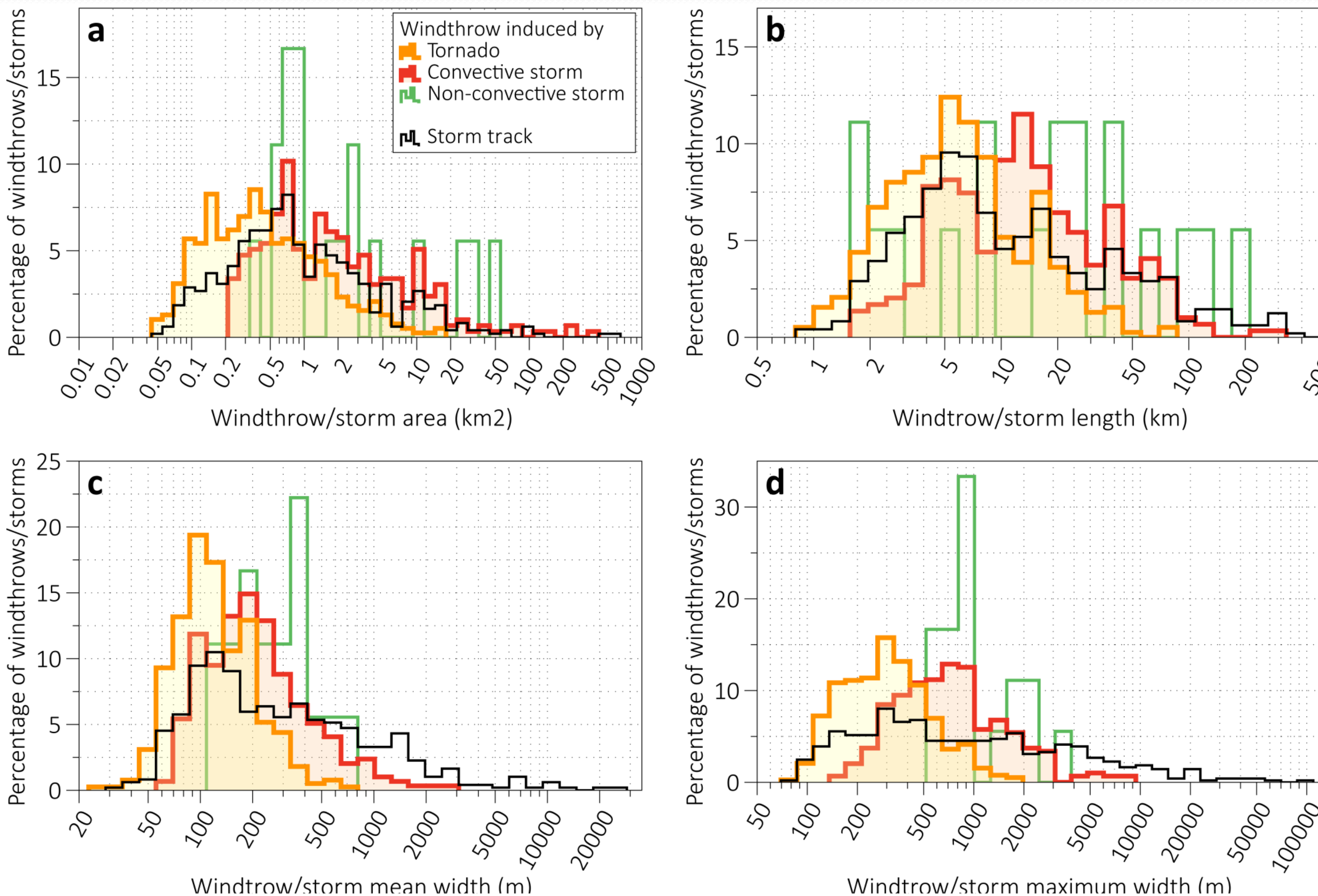
Inter-annual variability of the number of windthrow events, related damaged area, and number of storm events



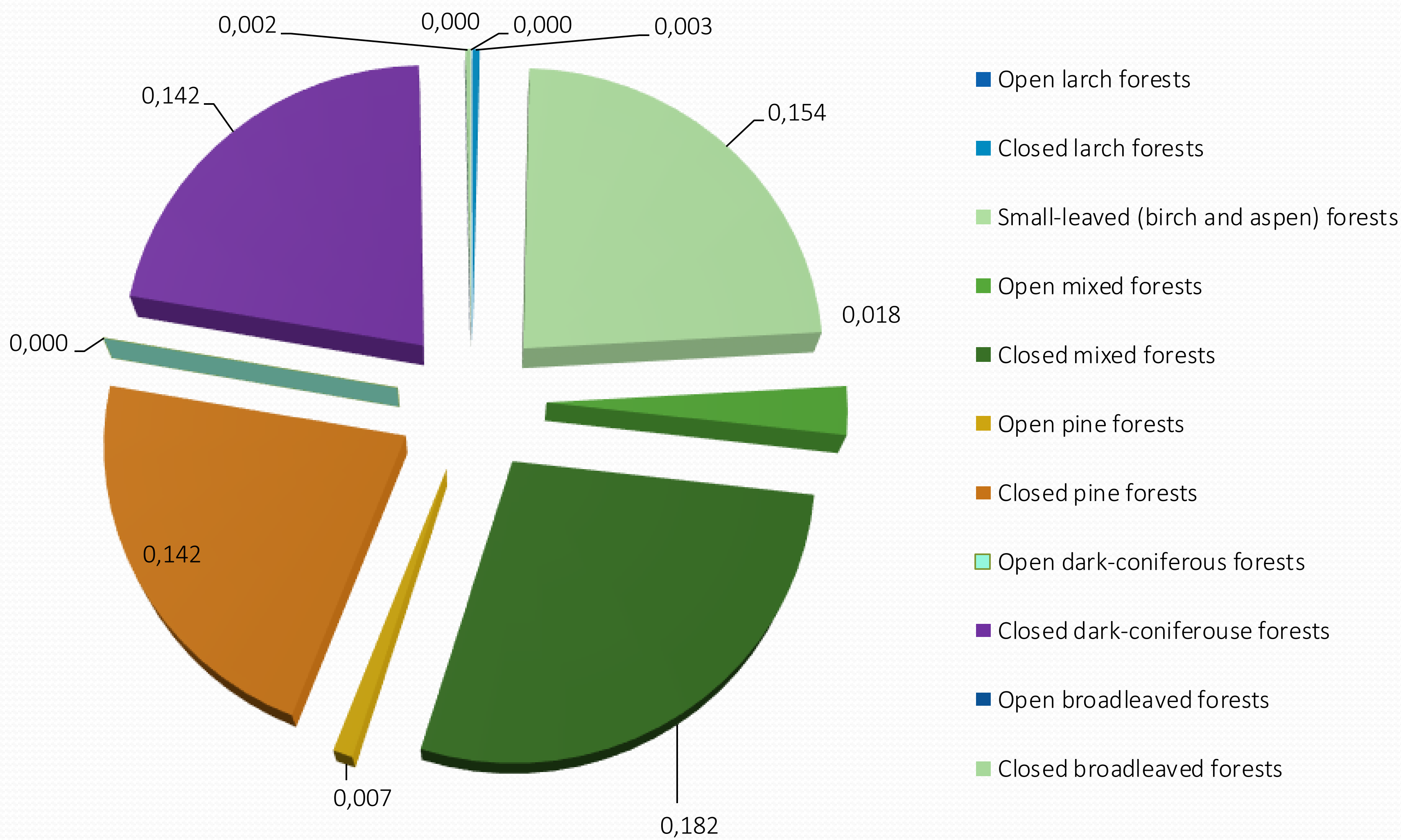
Annual cycle of the number of windthrow, related damaged area, and number of storm events



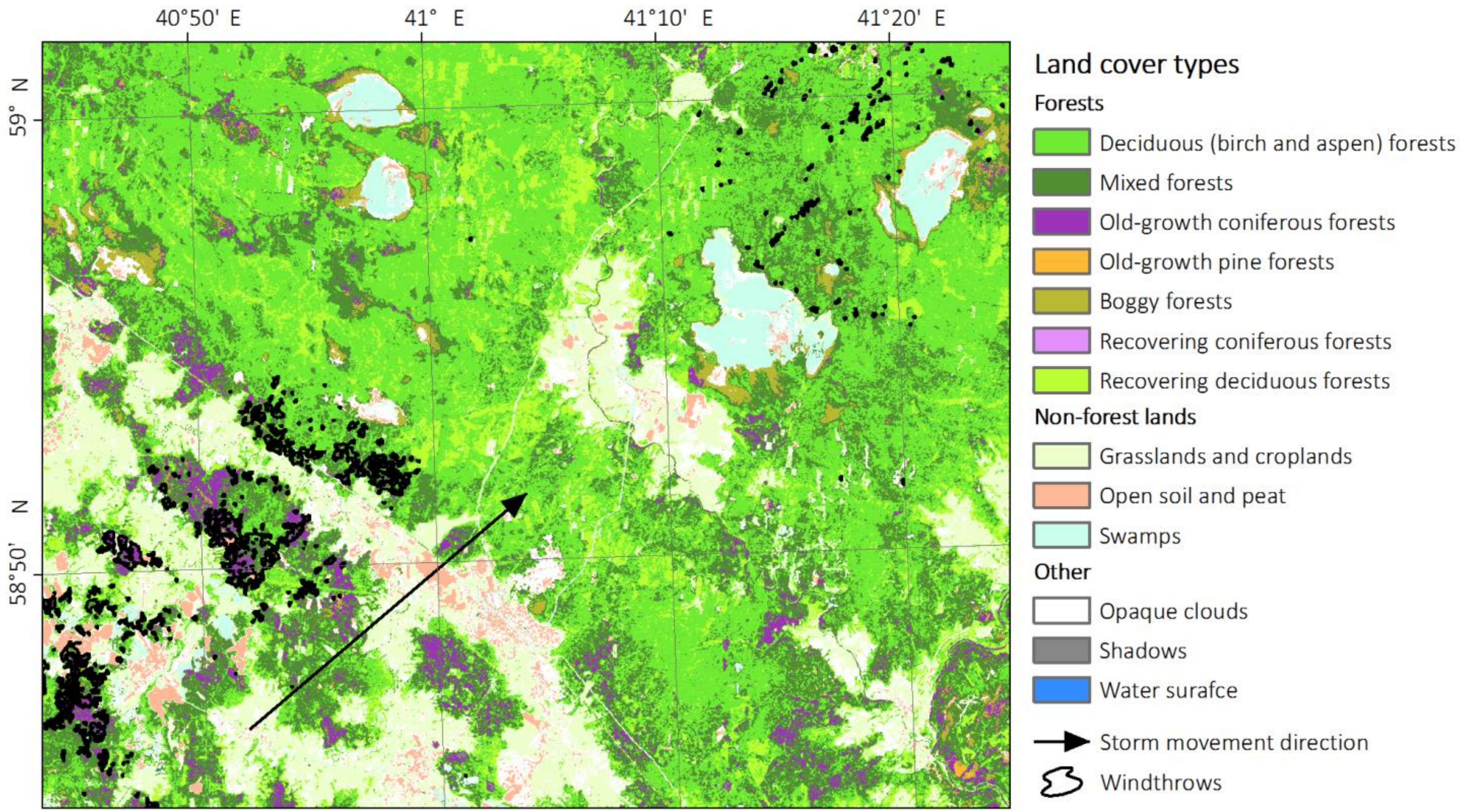
Distribution of geometric parameters of windthrow of different types and storm tracks



Distribution of the wind-damaged area in forests with various dominating tree species according to Russian Forest Type Maps (2004)



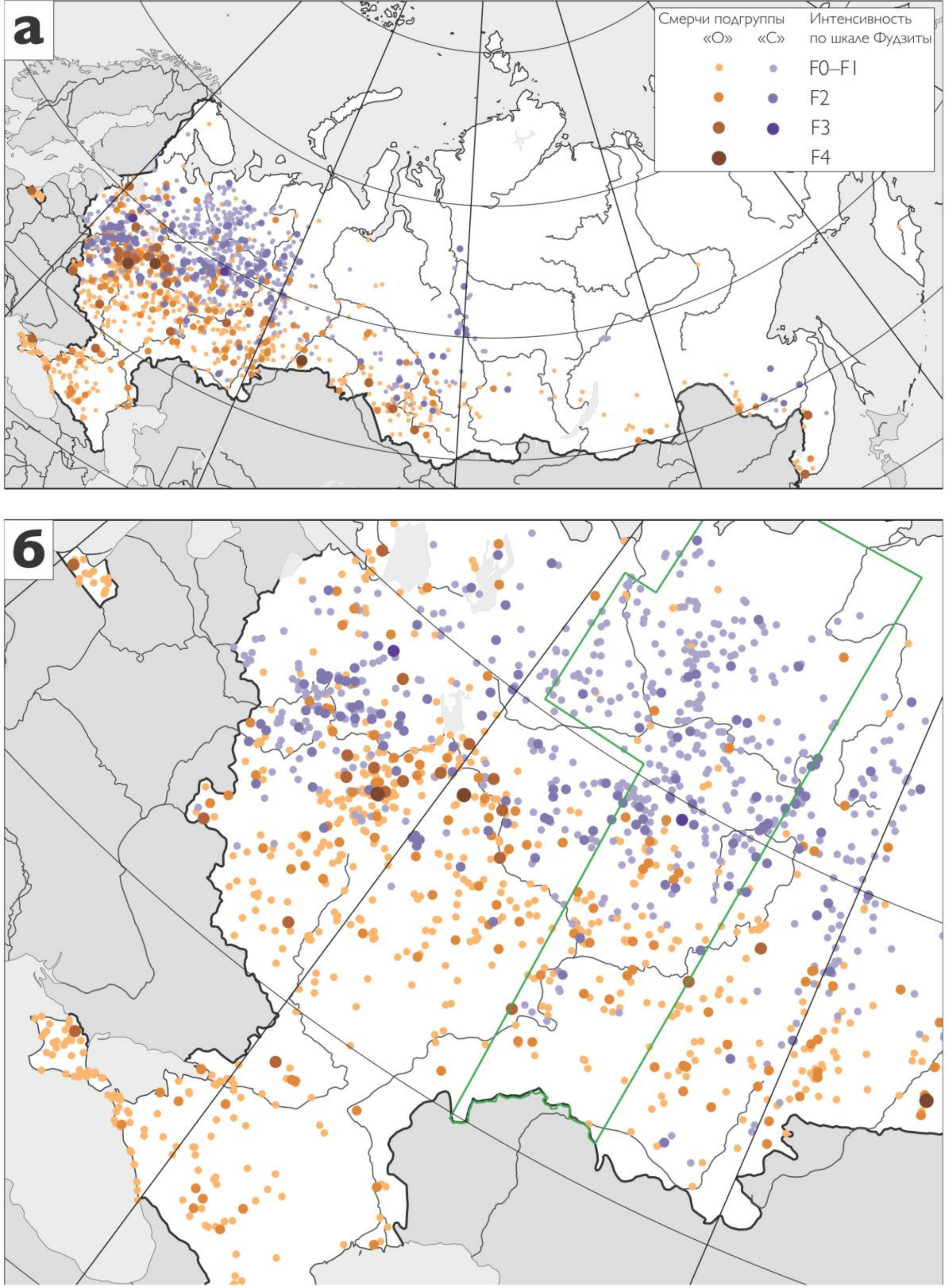
Variations of forest damage degree along the storm track (on the example of storm 27 June 2010), related to the dominant tree species (classified with Landsat images)



TOP-7 most severe windthrow events in the ER and Ural, 1986-2017

Date	Event type	Number of windthrow	Total area, ha	Length, km	Max width, km	Coordinates (start)	Coordinates (end)	Maximum reported wind gust and weather station
29 July 2010	Derecho	4	75548	626	38.3	58°35’ N 33°57’ E	61°22’E 29°22’N	30 m/s (22891)
27 June 2010	Derecho	3	50496	533	68.0	57°45’ N 38°28’ E	60°52’E 44°55’N	32 m/s (22974, 27229)
18 July 2012	Squall and tornadoes	25	21831	292	11.3	57°45’ N 38°28’ E	60°52’E 44°55’N	28 m/s (28105)
6 June 1995	Wet snow and severe wind	3	20093	147	70.1	56°57’ N 60°11’ E	57°53’ N 58°41’ E	26 m/s (28333)
16 June 2009	шквал	11	13192	250	24.7	57°26’ N 47°21’ E	59°58’E 50°40’N	30 m/s (27281)
7 June 2009	Squall and tornadoes	24	9896	267	19.9	59°23’ N 53°18’ E	62°17’E 57°46’N	25 m/s (76130 gauge)
07 August 1987	Non-convective storm	5	8889	256	45.8	56°38’ N 29°16’ E	56°32’ N 33°43’ E	28 m/s (26479)

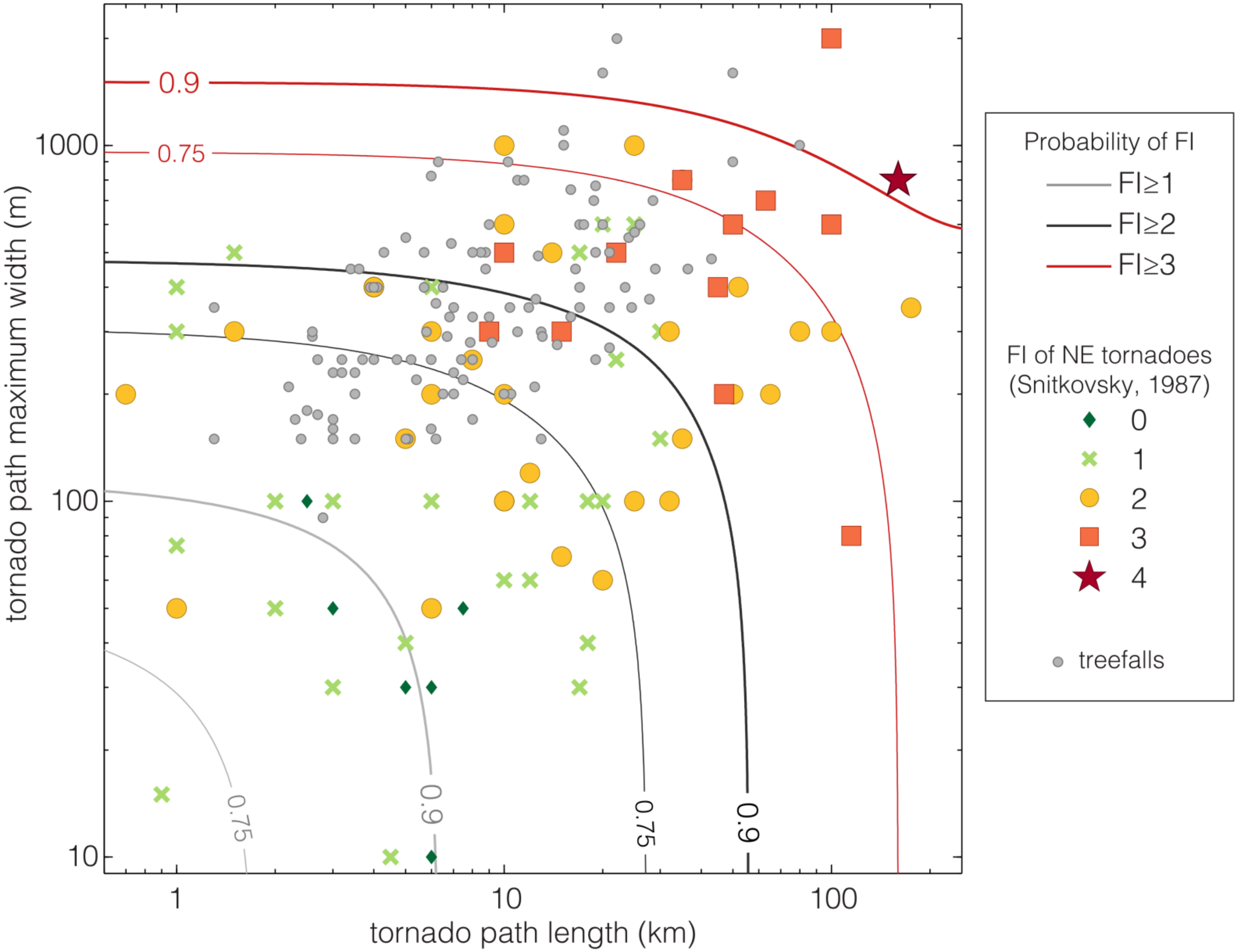
Use of satellite data to improve climatology of tornadoes in Northern Eurasia



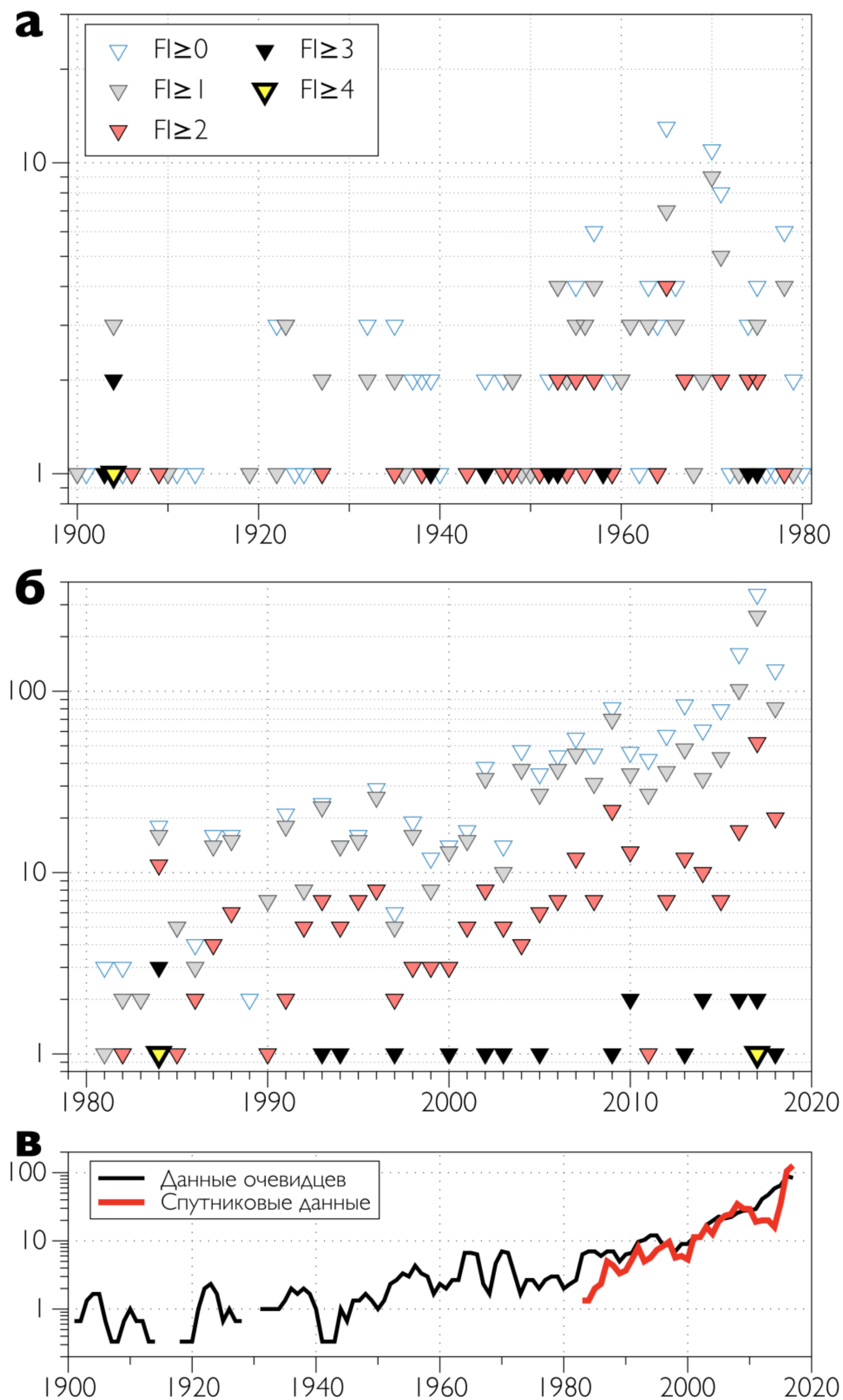
Distribution of tornado events on the entire territory of Russia and in European Russia for 1900-2018

770 tornado events have been confirmed with satellite data

Estimated probabilities of exceedance for different F-scale intensities (grey lines for F1, black lines for F2, red lines F3; thin lines for 0.75 probability and thick lines for 0.9 probability) calculated based on Weibull distribution parameters (Brooks, 2004).



Known tornado events (in the European part of fUSSR) are shown by colour symbols (different symbols for different Fujita intensity). Investigated satellite-derived tornado events are shown by grey symbols. Note the logarithmic scales



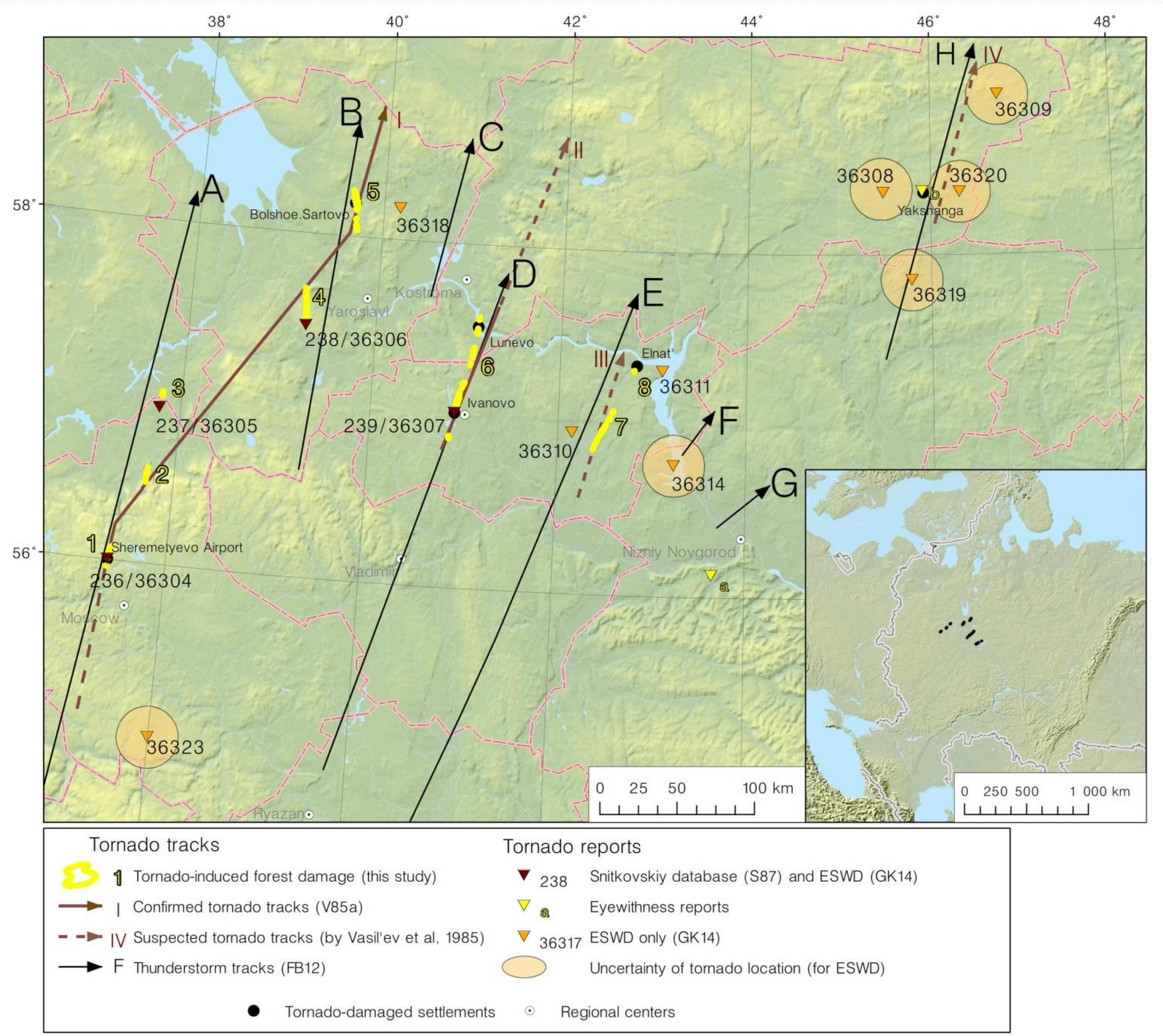
The number of tornadoes (over land only) of different intensity per year in Russia (a, b), a moving 3-year average of the annual number of tornadoes in Russia according to various data (c).

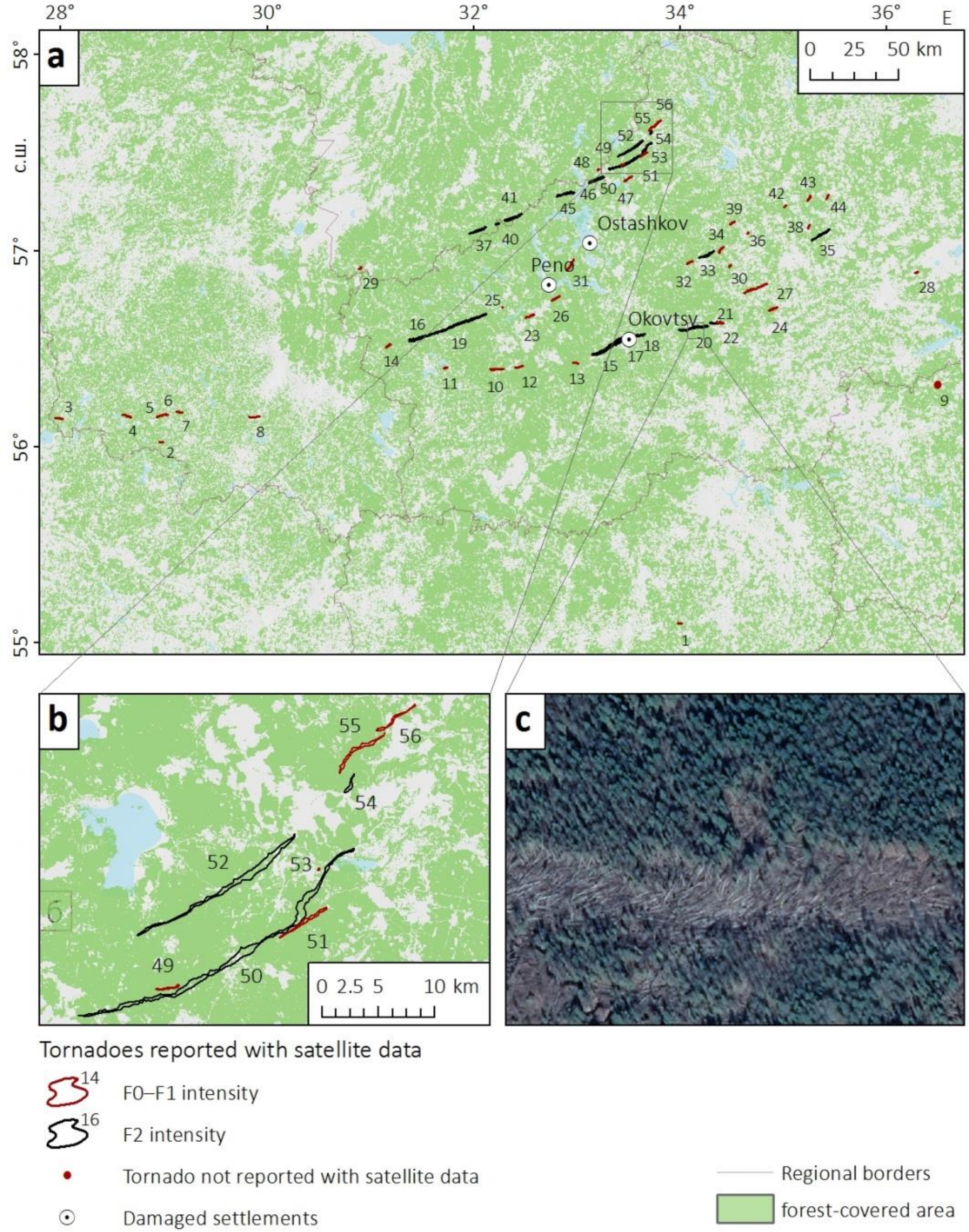
Case studies of windhrow events in the ER and Ural, 1986-2017

- 1984 Ivanovo tornado outbreak: determination of actual tornado tracks with satellite data
- The most severe tornado outbreaks in the ER, 1986-2017
- Derechos (long-lived convective storms) in the ER 27 June and 29 July 2010

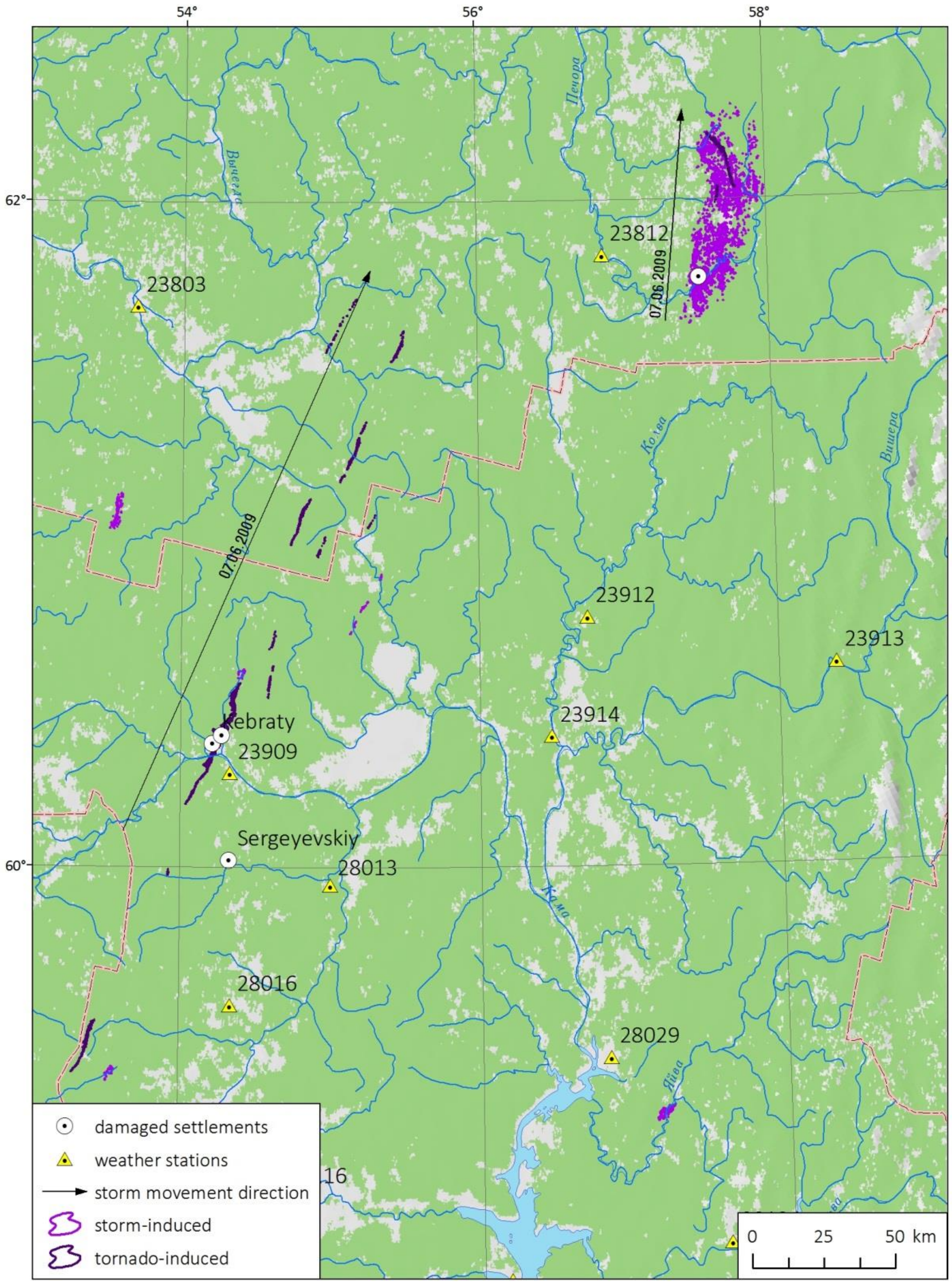
- Operational updating of the windthrow database, 2019-2020

Tornado and storm tracks on June 9, 1984 from different data sources



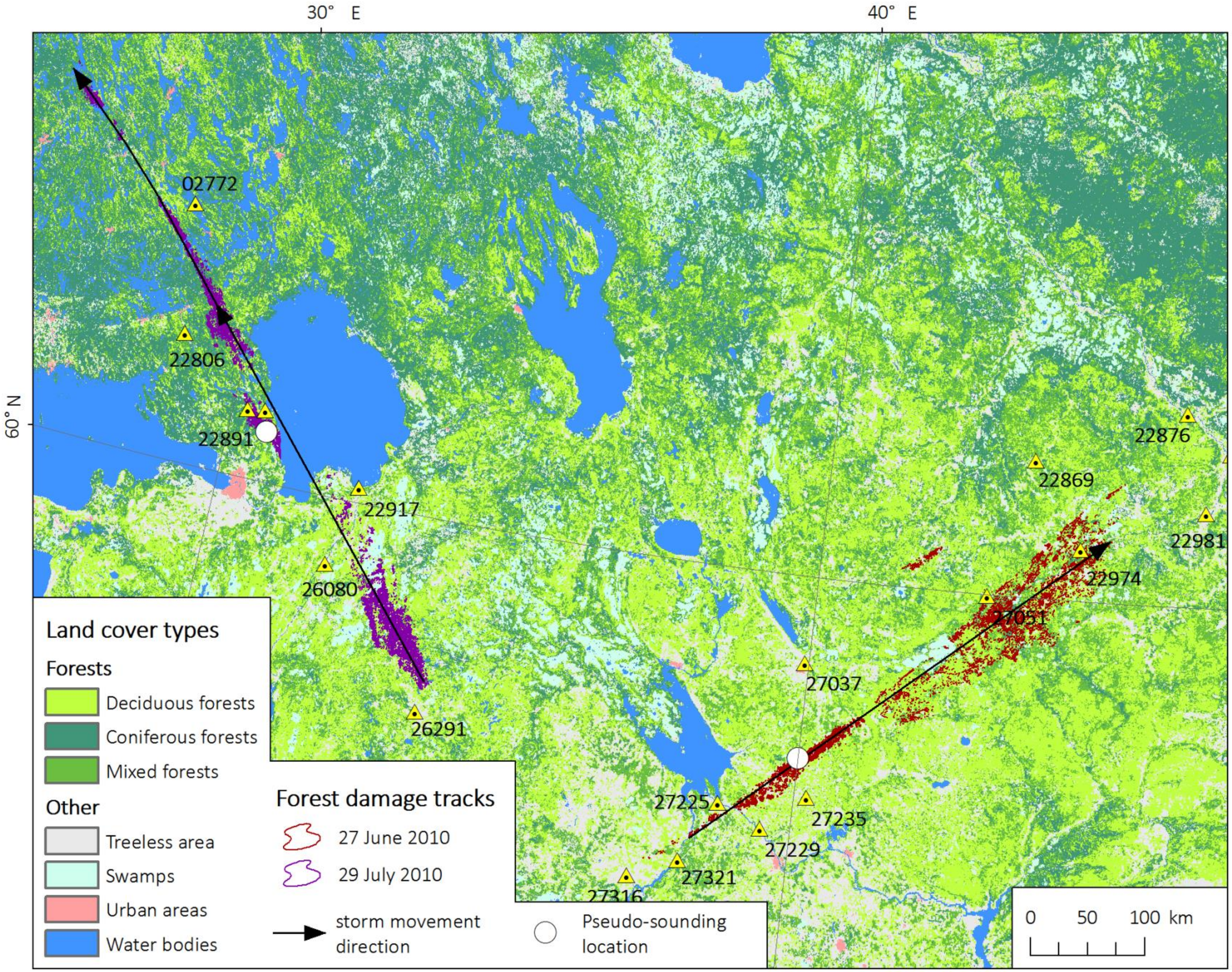


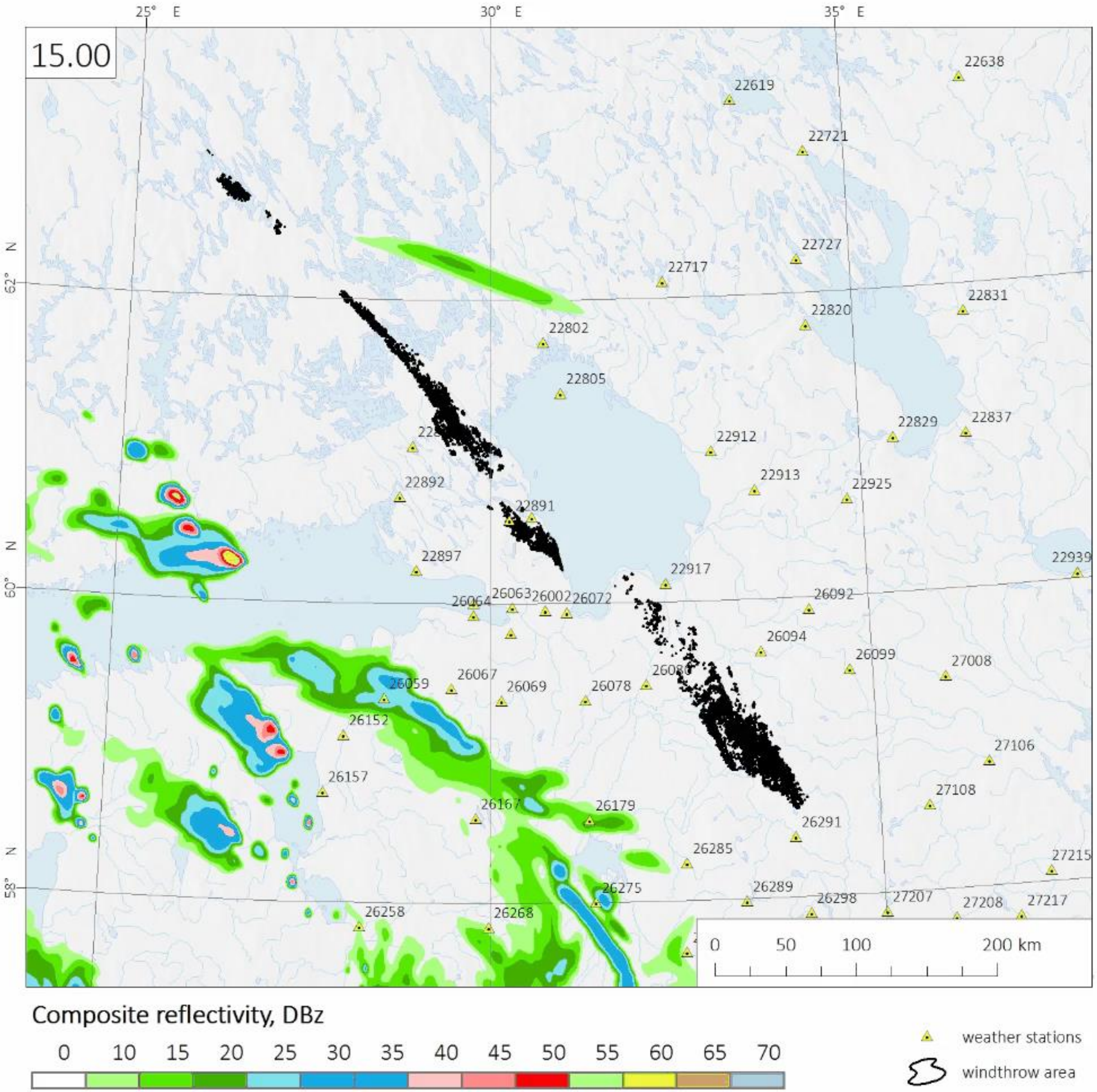
- Exceptional tornado outbreak on 2 August 2017, Tver’ region of Russia
- 52 tornado tracks have been reported with Sentinel-2 images and high-resolution data



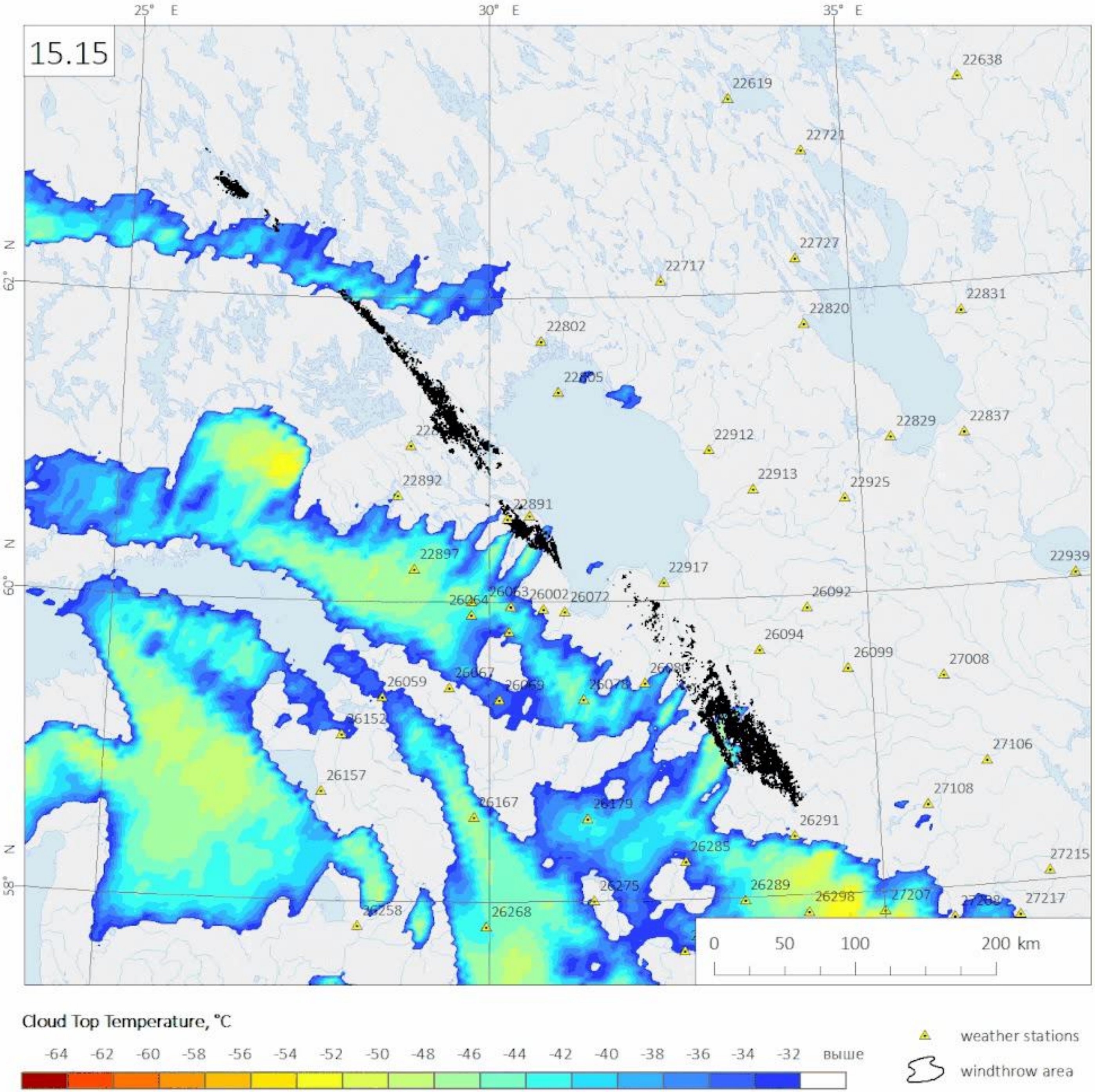
- Exceptional tornado outbreak on 7 June 2009, Perm Region and Komi Republic
- 19 tornado tracks, including several significant tornadoes (≥ EF2)

Storm tracks caused by derecho events 27 June and 29 July 2010





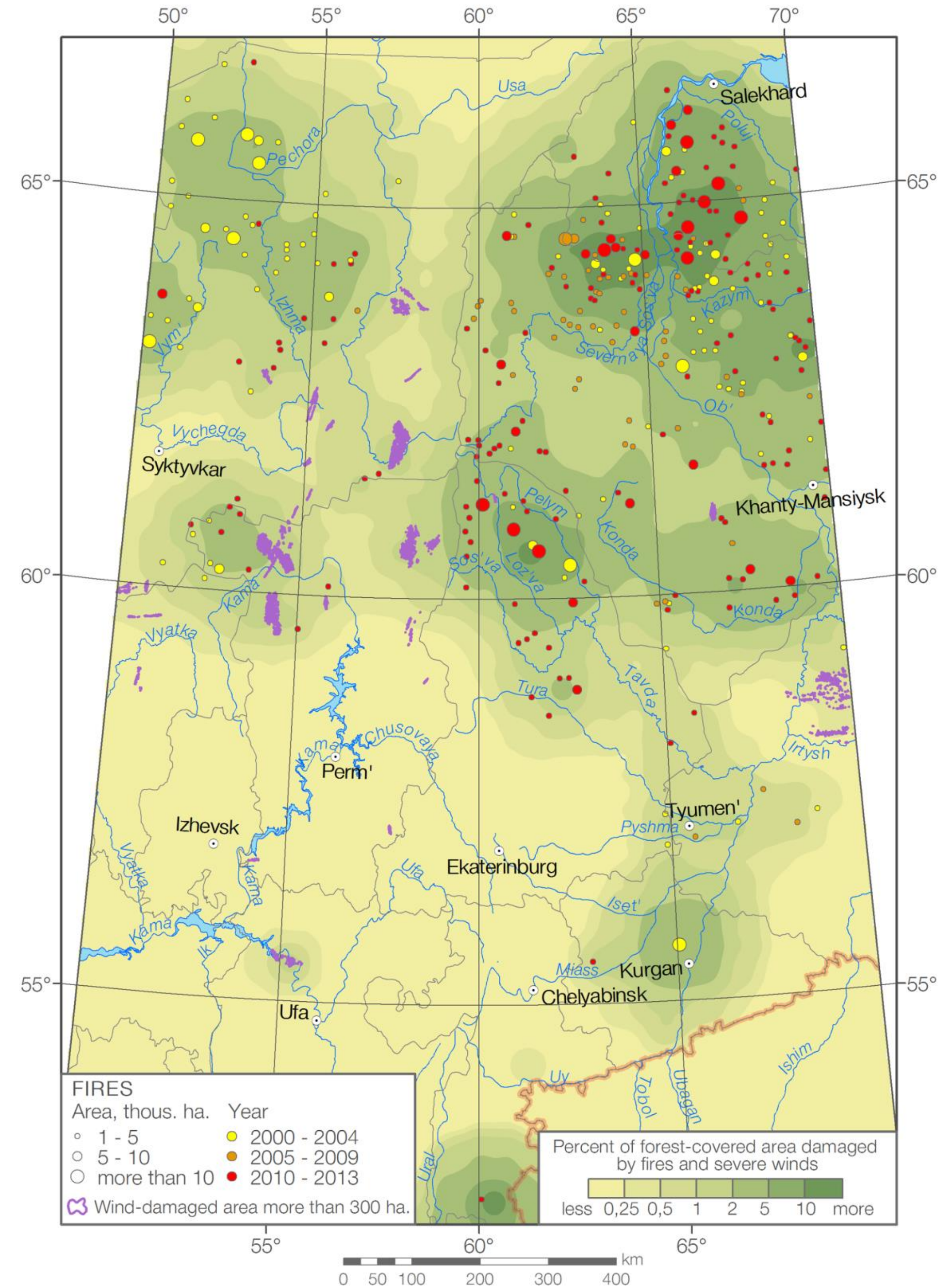
- WRF model simulation of storm event 29 July 2010



- Meteosat-8 animation of storm event 29 July 2010

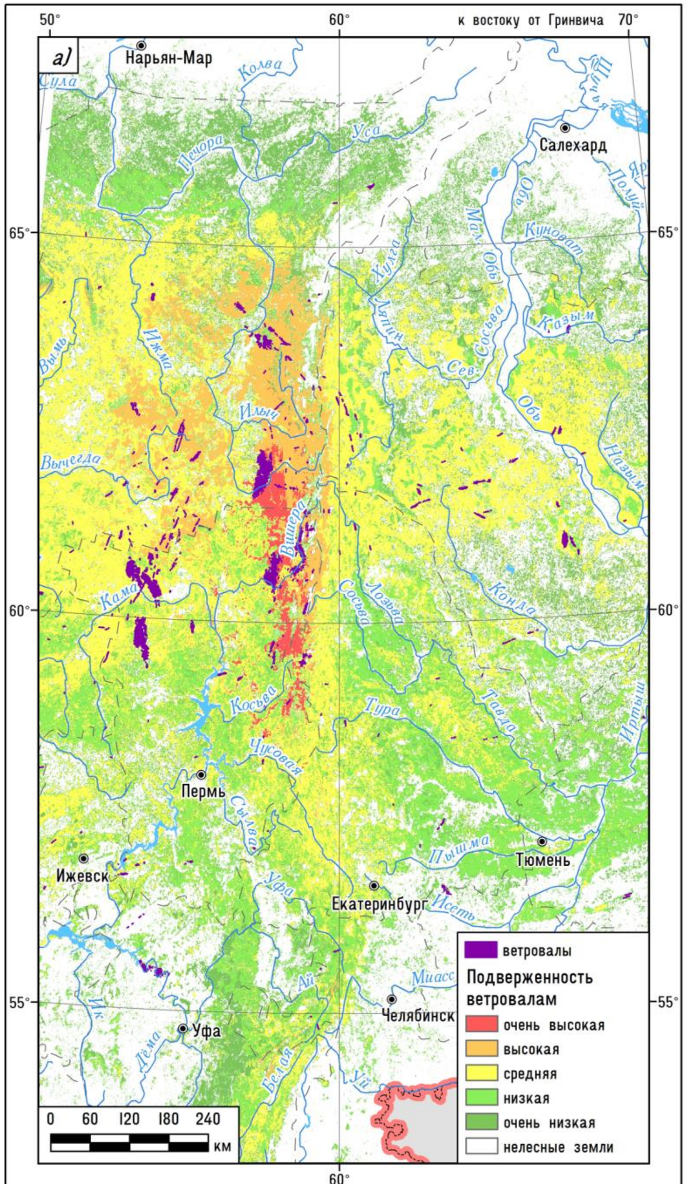
Comparison of wind-related and fire-related forest damage (on the example of the Ural region, Russia)

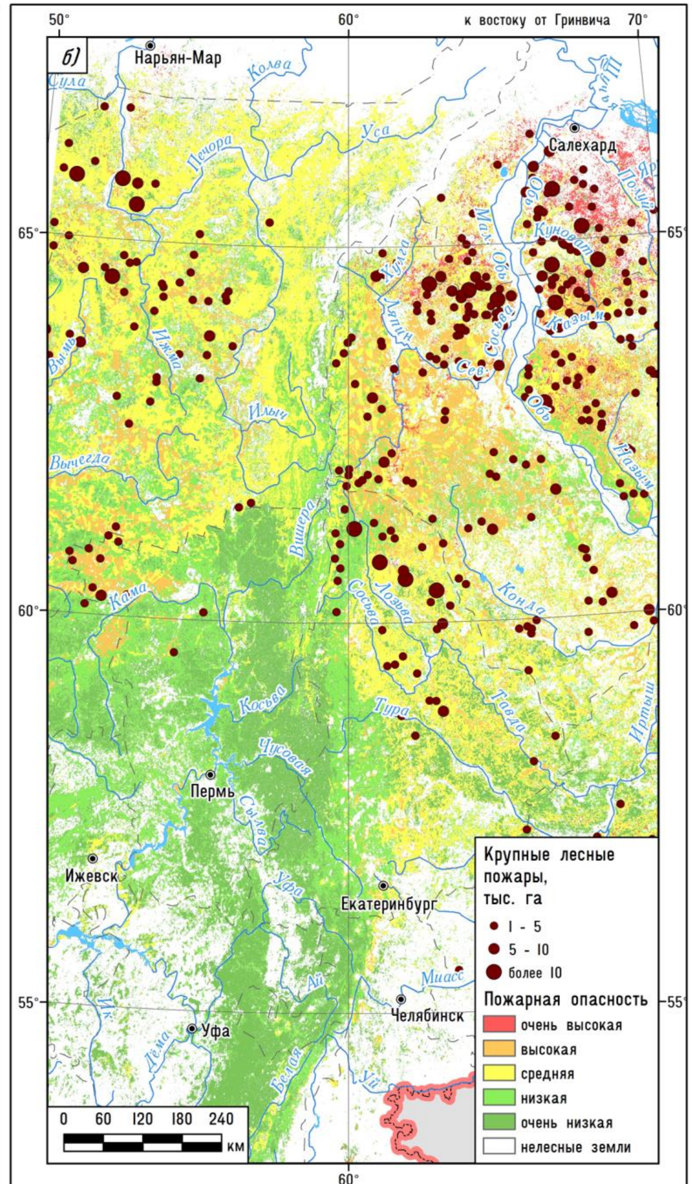
Land cover type (Russia's forest map, 2004)	Area (sq.km)	Burned area (sq.km/%)	Wind-damaged area (sq.km/%)
Non-forest lands	1 377 060	2529.1/0.18	-
Open dark-coniferous forests	64 708	1204.6/1.86	2.5/0.004
Open pine forests	42 012	1032.8/2.46	1.0/0.002
Open larch forests	18 614	698.7/3.75	0/0
Open broadleaf forests	7 165	0/0	0/0
Open mixed forests	70 792	361.9/0.51	5.6/0.008
Closed dark-coniferous forests	166 272	3094.1/1.86	**213.6/0.128**
Closed pine forests	118 931	3722.4/3.13	70.0/0.059
Closed larch forests	5 362	**365.0/6.81**	0/0
Closed broadleaf forests	18 405	1.4/0.01	0/0
Closed mixed forests	294 431	2451.2/0.83	221.2/0.075
Birch and aspen forests	198 375	299.3/0.15	46.5/0.023



- Fire- and wind-induced forest damage in the Ural region, 2001-2016
- Only large-scale burned areas (> 1000 ha) and windthrow areas (> 300 ha) are shown

Calculated probability of fire- and wind-related forest damage (on the example of the Ural region, Russia)

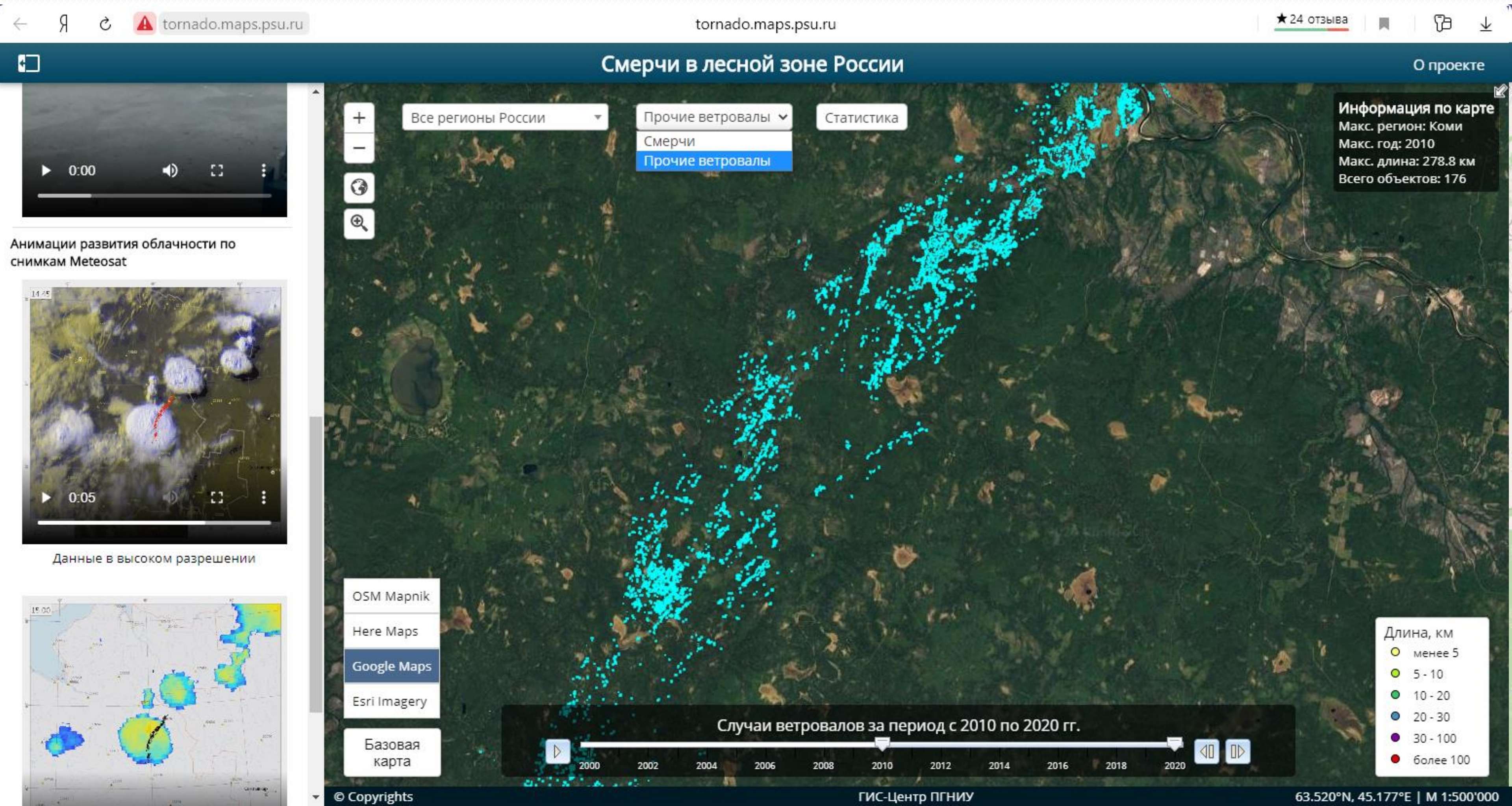




Main Conclusions

- The unique GIS databases of windthrow events for the European Russia and tornado events for the entire Russia havr been compiled
- More than 50% of windthrow events in the European Russia are tornadoes, but their damaged area is only 12.5% of the total area of stand-replacing windthrow.
- Two convective storm events 27 June and 29 July of 2010 are responsible for 38% of the total wind-induced forest damage in the ER
- The study of windthrow events substantially contributes to the climatology of severe storms and tornadoes in Russia.
- Further studies may be carried out to determine the contribution of climate variability to the inter-annual variability of wind-related forest damage, and to quantify the risk of windthrow in Russian boreal forests.
- **Data availability**
- A satellite-derived database for stand-replacing windthrows in boreal forests of the European Russia in 1986–2017 https://essd.copernicus.org/preprints/essd-2020-91/#discussion
- http://tornado.maps.psu.ru/ - online web map service (in Russian only)

Data updating and publication (http://tornado.maps.psu.ru/)



Main Publications

- Shikhov A.N., Chernokulsky A.V. (2018) A satellite-derived climatology of unreported смерчей in forested regions of northeast Europe // Remote Sensing of Environment. Vol. 204. PP. 553–567. URL: https://www.sciencedirect.com/science/article/pii/S0034425717304662
- Chernokulsky A.V., Shikhov A.N. (2018). 1984 Ivanovo tornado outbreak: Determination of actual tornado tracks with satellite data // Atmospheric Research 207, 111–121. URL: https://www.sciencedirect.com/science/article/pii/S0169809517311158
- Shikhov A.N., Perminova E.S., Perminov S.I. Satellite-based analysis of the spatial patterns of fire and storm-related forest disturbances in the Ural region, Russia // Natural Hazards. 2019. Vol. 97(1), P. 283-308. URL: https://link.springer.com/article/10.1007%2Fs11069-019-03642-z
- Chernokulsky A, Kurgansky M, Mokhov I, Shikhov A, Azhigov I, Selezneva E, Zakharchenko D, Antonescu B, Kühne T. Tornadoes in Northern Eurasia: from the Middle Age to the Information Era // Monthly Weather Review, 2020, Vol. 148, P. 3081–3111. URL: https://journals.ametsoc.org/mwr/article-abstract/148/8/3081/346006/Tornadoes-in-Northern-Eurasia-From-the-Middle-Age?redirectedFrom=fulltext
- Chernokulsky, A.; Shikhov, A.; Bykov, A.; Azhigov, I. Satellite-Based Study and Numerical Forecasting of Two Tornado Outbreaks in the Ural Region in June 2017 // Atmosphere 2020, 11, 1146. URL: https://www.mdpi.com/2073-4433/11/11/1146
- Shikhov A.N., Chernokulsky, A.V., Azhigov, I.O. and Semakina A.V. A satellite-derived database for stand-replacing windthrows in boreal forests of the European Russia in 1986–2017 //Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2020-91

Thank You for Your Attention

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