Annual Report 2023

European Severe Storms Laboratory

About the Laboratory

The *European Severe Storms Laboratory e.V.* (ESSL e.V.) was founded as a private, non-profit research organisation in December 2006. It is a spin-off of German Aerospace Centre DLR in Weßling and relies on the expertise of its international team.

In Europe, severe thunderstorms inflict an estimated annual damage of about 5 billion euro and lead to dozens of fatalities. ESSL wants to make Europe more resilient to severe weather by...

- Performing fundamental and applied research on severe convective storms in Europe,
- Operating the European Severe Weather Database, ESWD,
- Organizing the European Conferences on Severe Storms, ECSS.

The *European Severe Storms Laboratory – Science & Training* is a subsidiary located in Wiener Neustadt, Austria, that pursues similar goals. It operates the Research and Training Centre, which is the venue of various courses, workshops and the ESSL Testbed. In addition to the goals above, it...

- Operates the ESSL Testbed, a facility to evaluate new forecast-supporting tools,
- Organizes various courses for various target groups, including weather forecasters, to enhance their understanding of convective storms.

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Foreword

Dear Reader,

In 2023, Europe was again affected by a large number of severe weather events, the most striking perhaps being the streak of supercell storms that produced extremely large hail across Northern Italy and the Northwest Balkans, leading to exceptional amounts of economic damage. These storms managed to break the European hail size record twice: First, a storm set a 16 cm record, to be exceeded only days later by a 19 cm hailstone in Azzano Decimo, Italy. The most fatal events in 2023 were of a different nature, however, occurring in the eastern part of the region covered by the European Severe Weather Database (ESWD), as devastating floods struck Georgia and Turkey. Because of both the abundance of severe weather, a growth of the network of voluntary reporters, and increased dedicated personnel resources within ESSL, no less than 64 542 reports (compared to 38 516 in 2022) were collected in the ESWD.

These reports provided a solid basis for the evaluation of novel forecasting and nowcasting techniques, including the various tools and models provided by DWD for evaluation at the ESSL Testbed and the AR-CHaMo models to predict severe storm hazards, which ESSL is developing in collaboration with ECMWF. Another important collaboration that continued in 2023 was with EUMETSAT, with whom a number of workshops were organized on various new capabilities of the Meteosat Third Generation (MTG) satellites. Experts on topics such as the detection of moisture or lightning by satellite were invited. The workshops led to recommendations on how to best introduce forecasters to the data. In joint ESSL-EUMETSAT Testbed weeks, a large number of forecasters were exposed to proxy products emulating some of the new MTG capabilities.

Other ESSL events in 2023 included four courses for forecasters, mostly taking place at the Research and Training Centre in Wiener Neustadt, and one on site at the Croatian Hydrometeorological Institute DHMZ in Zagreb. Furthermore, a workshop on severe weather warnings was organized in which not only forecasters, but also experts from disciplines such as the judiciary and philosophy were invited. Discussing how decision making proceeded in past severe weather events revealed several measures that could be taken to improve the dissemination and acceptance of warnings, some easier, some more difficult to implement. A study by Alois Holzer presented on that occasion used ESWD data to show that most fatalities of severe weather occur not in cities but in rural or remote areas, which has implications for impact-based forecasting, which often assumes that severe weather impacts are greatest where most people live.

A milestone was achieved in 2023 with the publication of the International Fujita scale, or IF-scale for short. This scale to rate tornado and wind damage was made the mandatory scale to rate these events in the ESWD from 1 September 2023 onwards. It resulted from a series of workshops and interactions with many stakeholders over the course of nine years. It was needed because the original Fujita scale, with some interpretation guidelines,

was not able to provide a sufficient level of accuracy and reproducibility, while other scales did not provide a usable alternative either because of these and/or other issues.

Chapter 2 details ESSL's achievements in other scientific areas, which led to the publication or initial submission of six peer-reviewed publications in 2023, along with a wide range of oral presentations and posters at various events. Indeed, as the communication of scientific research results is important, it is beneficial to know that ESSL's activities in this area have increased. Not only were five newsletters sent out, but ESSL employees gave several dozen interviews to written and broadcast media and ESSL has become increasingly active on social media, starting a LinkedIn account and being prominently present on both X/Twitter and Facebook.

Another highlight of 2023 was the organization of the European Conference on Severe Storms, which saw its 11th edition in Bucharest, Romania, in May. Being the first edition to be organized on site after the COVID19 pandemic, it was a great opportunity to personally meet many international colleagues active in the field of severe storms research. Looking back at the conference, I am sure that not only the excellent scientific contributions, and the great support of the Romanian assistants, but also the great traditional Romanian atmosphere - most prominently at the conference dinner – have made it a memorable event for many. The prestigious Nikolai Dotzek Award was presented to Martin Setvák, Kristopher Bedka, and Pao Wang for their work on storm-top features.

On the organizational side, ESSL implemented a Diversity Policy and Gender Equality Plan, which involved the appointment of an Equality Officer and a Confidant, as well as a number of procedures to ensure optimal safe working conditions for all and a focus on valuing and promoting diversity within the team.

Furthermore, ESSL was delighted to welcome Météo-France, a new, large institutional full member, as well as eight new supporting members. Financially, 2023 was a successful year with positive results for both ESSL e.V. (€ 95 355.95) and its Austria-based subsidiary (€ 73,682.08). These results will contribute to the establishment of a financial buffer, as requested by the members on several occasions going back to the 2015 General Assembly.

Concluding, I am delighted to present you with the Annual Report 2023, which describes ESSL's achievements in its seventeenth full business year.

Gouda, 20 August 2024,

Dr Pieter Groenemeijer
ESSL Director
Chair of the Executive Board

1 Severe Weather in 2023

A key activity of ESSL is the collection of severe weather data in the European Severe Weather Database in cooperation with its partners. The data forms the starting point of research within and outside of ESSL.

1.1 Evolution of the European Severe Weather Database

Event Types

In 2023, 64 542 new severe weather reports were added to the ESWD (**Table 1-1**), which is considerably more than the 38 516 reports from the previous year, 2022.

The most frequently reported severe weather phenomenon was severe wind gusts (41 507), followed by large hail (9 844) and heavy rain (8 494). Comparing convective hazards to 2022, heavy snowfall/snowstorms showed the strongest increase of reports (+155.6%), followed by severe wind gusts (+110.6%). This increase of hail reports was very remarkable as it occurred after a previous increase of +40.9% between 2021 and 2022.

Table 1-1. Reports entered in the European Severe Weather Database in 2023.

Report Type	Number of reports	%	% change relative to 2022
Severe wind gusts	41 507	64.3	+110.6
Large Hail	9 844	15.2	+19.1
Heavy rain	8 494	13.1	+18.9
Heavy snowfall/snowstorms	2 017	3.1	+155.6
Damaging lightning strikes	1 519	2.4	-0.5
Tornadoes (incl. waterspouts)	894	1.4	+11.9
Ice Accumulation	160	0.3	-6.4
Avalanches	117	0.2	-0.8
Total	64 542	100.0	+67.6

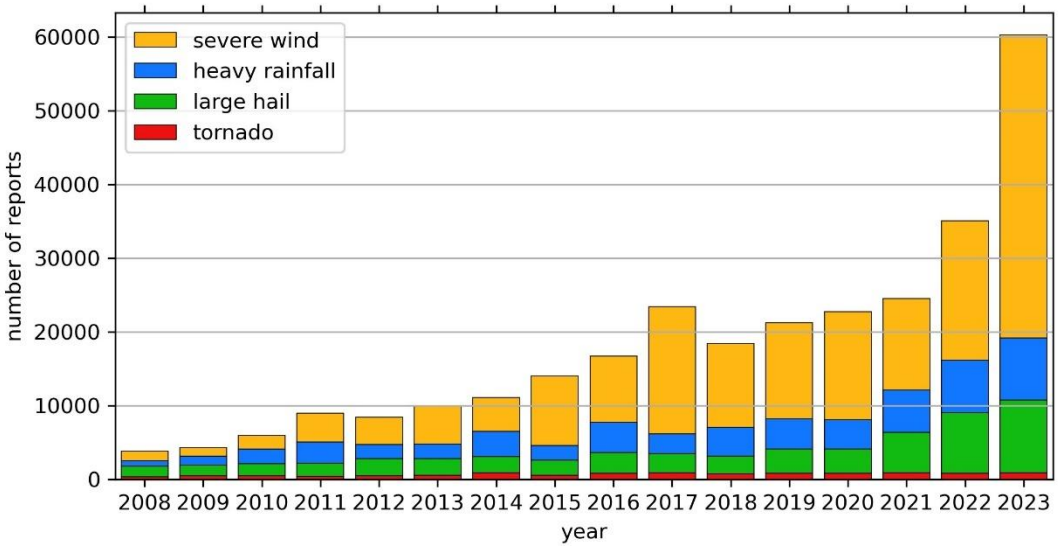

Figure 1-1 illustrates the evolution of the number of reports of the four convective weather hazards in the ESWD since 2008. The increase is probably mostly caused by the growth of the number of partners who report severe weather to ESSL and the increased resources spent on data collection by ESSL. The strong increase from 2022 to 2023 was at least in part due to the discovery of several new online resources that list impacts to the power grid. Both 2022 and 2023 stand out as years with a very large number of both hail and wind reports. As should be clear from the above, it is not possible to infer multi-annual trends of true hazard occurrence directly from these data because they are strongly influenced by effects not related to meteorology.

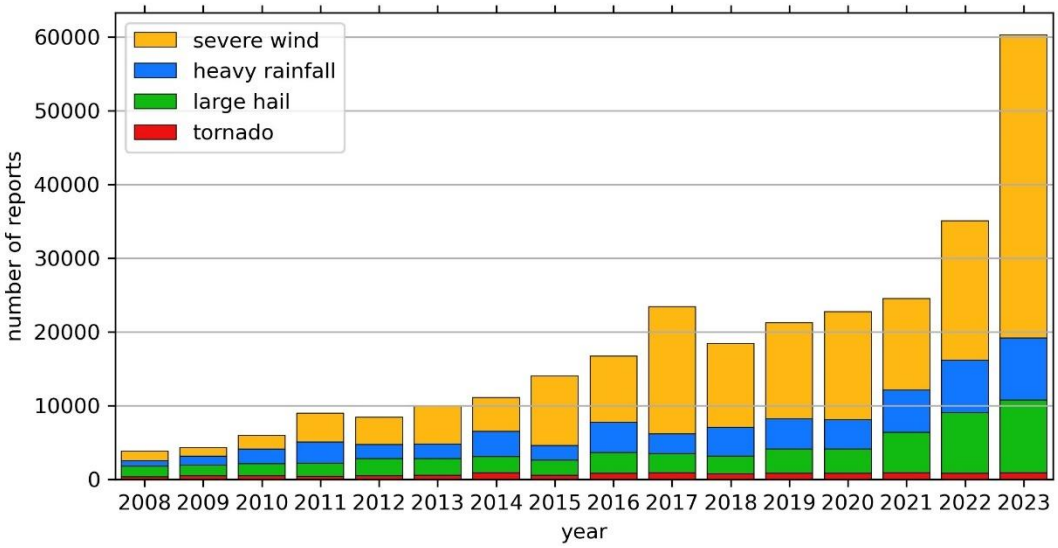

Figure 1-1. Trend of reports of the four convective hazards, severe wind, heavy rainfall, large hail, and tornado in the ESWD.

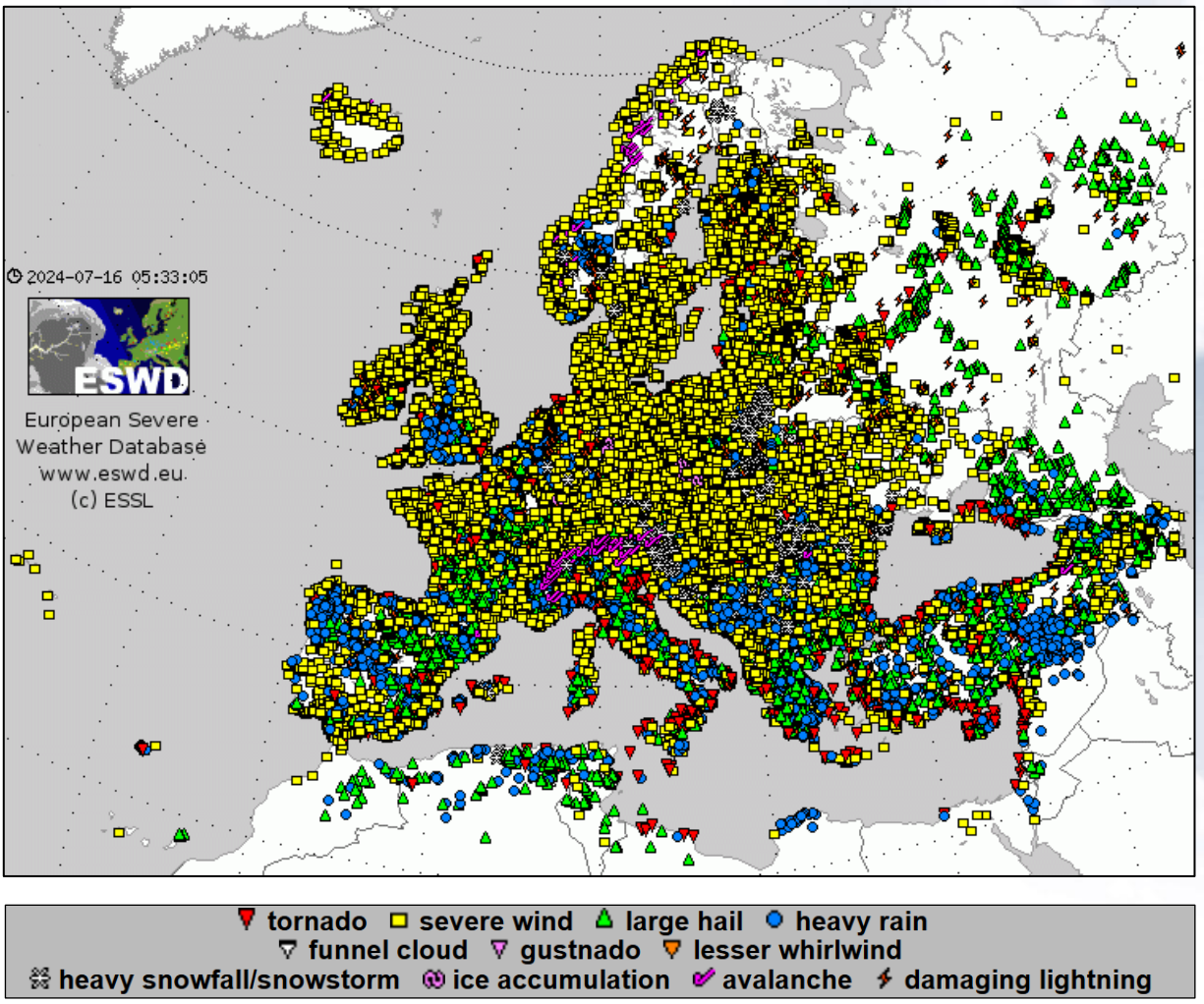

Figure 1-2. The 64 542 ESWD reports of events occurring in 2023.

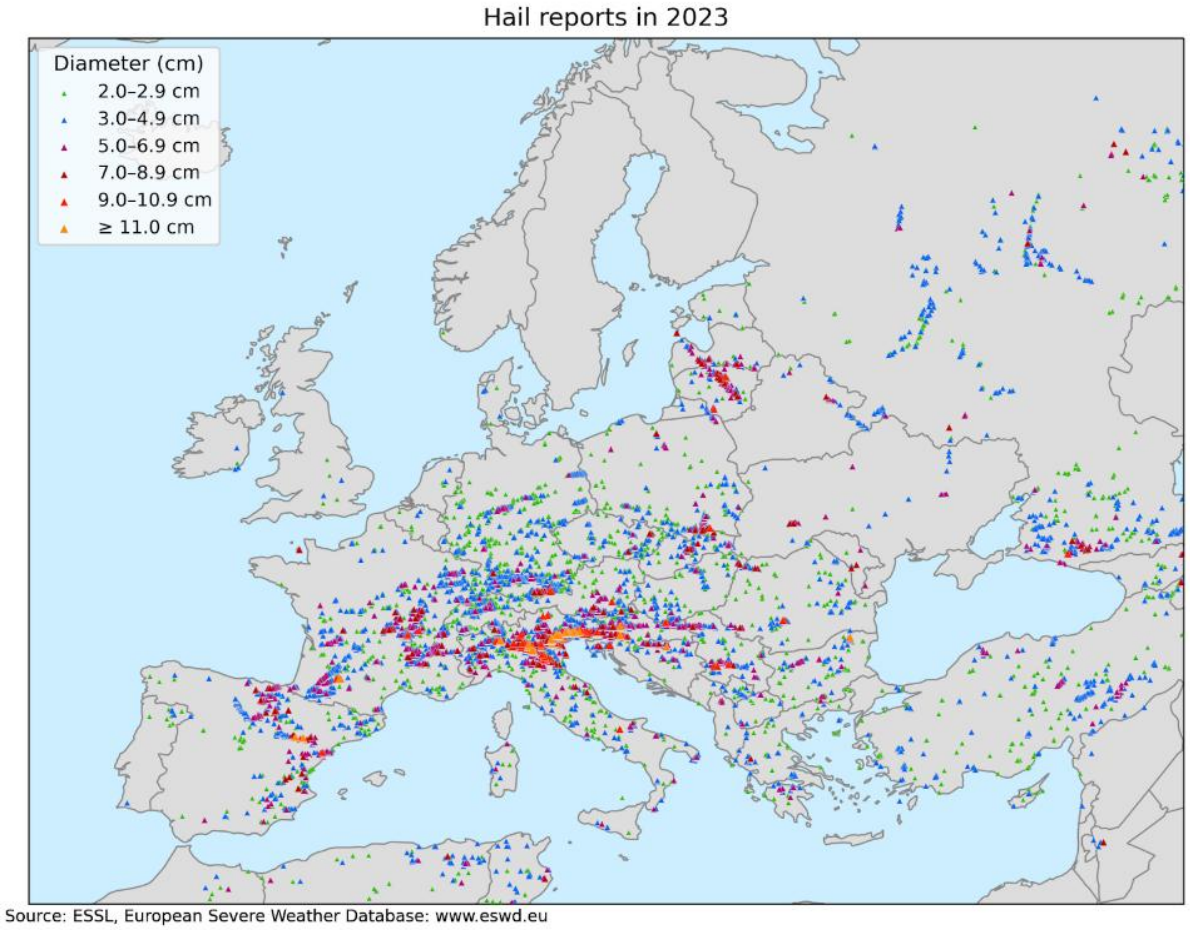

Figure 1-3. ESWD large hail reports of 2023.

A closer inspection of the hail reports for 2023 shows a further increase in events compared to previous years. The total number (as of 19 July 2024) counting 9844 hail reports of 2 cm in diameter or larger, marks a new record in the ESWD. On 24 July that year, a 19-cm hailstone was reported from Italy, which marks a new record for hail sizes in Europe. Giant hail (10 cm in diameter or larger) fell also in Bulgaria, Bosnia and Herzegovina, Croatia, Germany, France, Russia, and Spain.

Several long-track hailstorms were recorded, such as on 13 July when a "Five-State-Hailstorm" tracked about 690 km from Slovenia to western Romania. A look at the cumulative number of days on which hail of at least 5 cm is reported in the ESWD illustrates the increase: it also shows that the season in which very large hail is extending more into autumn than in recent years (Figure 1-4). However, the ESWD cannot prove that hail frequency is rising because better reporting may be increasing reports. The in-depth analysis using reanalysis data in the CHECC project (see Section 2.1) shows that the increase is likely not just a reporting effect.

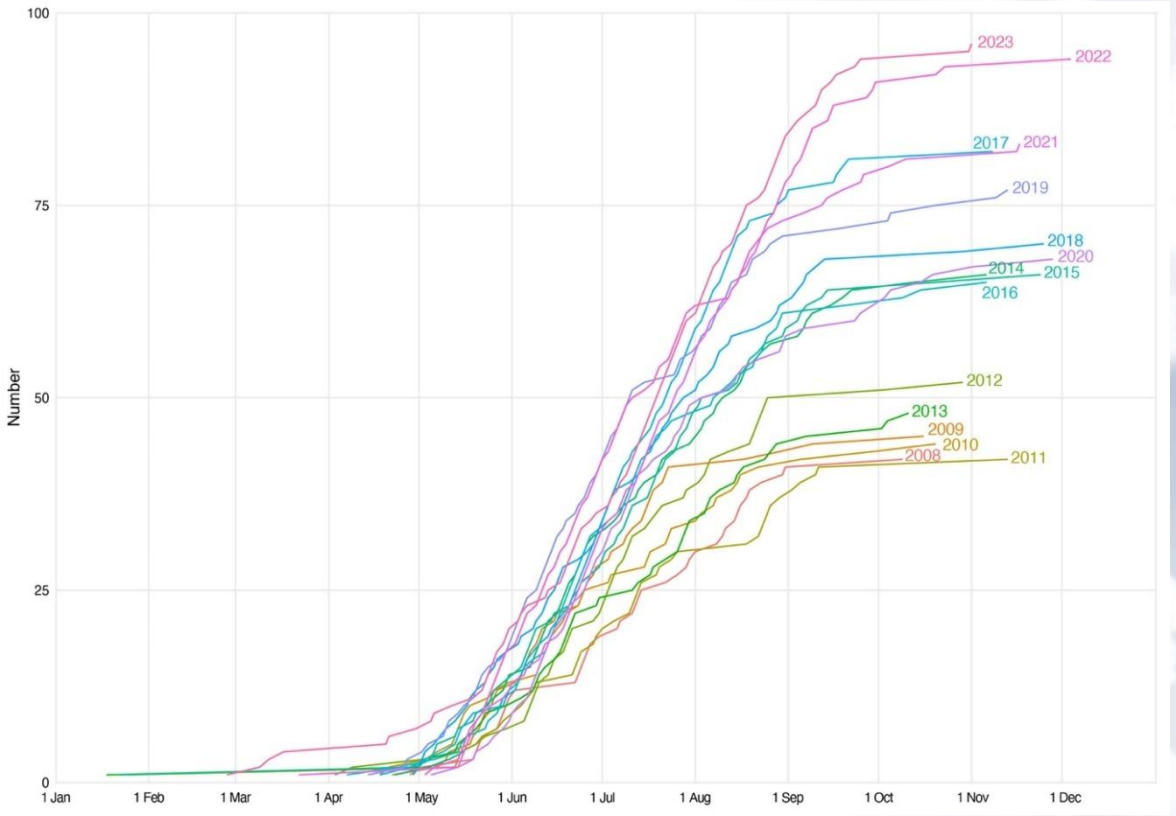

Figure 1-4. Cumulative number of days with hail of at least 5 cm diameter per year since 2008.

Quality Control

ESWD reports are checked for trustworthiness by ESSL's ESWD team and its partners. Any report that reaches ESSL from an untrusted source will initially be given the QC0 quality level, indicating that no check has been carried out. After checking, ESSL and its partners can assign any of three QC-levels to a report, based on the level of trustworthiness (plausible = QC0+, or confirmed by a reliable source = QC1) or whether – in rare cases – a full scientific case study has been carried out (QC2). Upgrading from one level to another is possible at any time as more or better information comes in to corroborate the report.

Table 1-2. Quality control levels of ESWD reports from 2023.

Quality Control level	Number of reports	%
QC0: as received	0	0
QC0+: plausibility checked	5 295	8.2
QC1/QC2: report confirmed by reliable source	59 257	91.8

All reports from 2023 have been upgraded at least to QC0+ or QC1. For 8.2% of reports, it was not possible to assign a higher rating than "plausibility checked".

Table 1-3. Most active ESWD partners in 2023

ESWD Partners

ESSL's partners both collect severe weather reports and check them for correctness. Such partners are individuals, associations, and weather services. ESSL's most active partners are listed in Table 1-3. The current leading contributor of severe weather events is the Association MeteoNetwork/PRETEMP, that feed their data automatically into the ESWD with recent, but also historical severe weather reports. The individual contributing the most severe weather reports is Mr. Nicolas Baluteau, who on his own managed to report 1488 occurrences of severe weather in France.

In many other countries, valuable and significant contributions to the ESWD are made by the individuals and associations listed in the table. On a yearly basis, ESSL sends individual volunteers ESSL merchandise, offers free participation in some ESSL events, or rewards them with a small financial compensation.

Name	Country	Number of reports
1. Association MeteoNetwork/PRETEMP	Italy	3 289
2. Mr Nicolas Baluteau	France	1 488
3. Mr Niclas Lindberg Jensen	Denmark & Norway	345
4. Mr Kairo Kiitsak	Estonia & Finland	221
5. Mr Bas van der Ploeg	Netherlands	198
6. Amateur Meteorological Society	Czechia	171
7. Mr Francois Paul	France	121
8. Mr Mario Sekulic	Croatia	105
9. Mr Igor Kibalchich	Ukraine	87
10. Slovak HydroMeteorological Institute	Slovakia	84

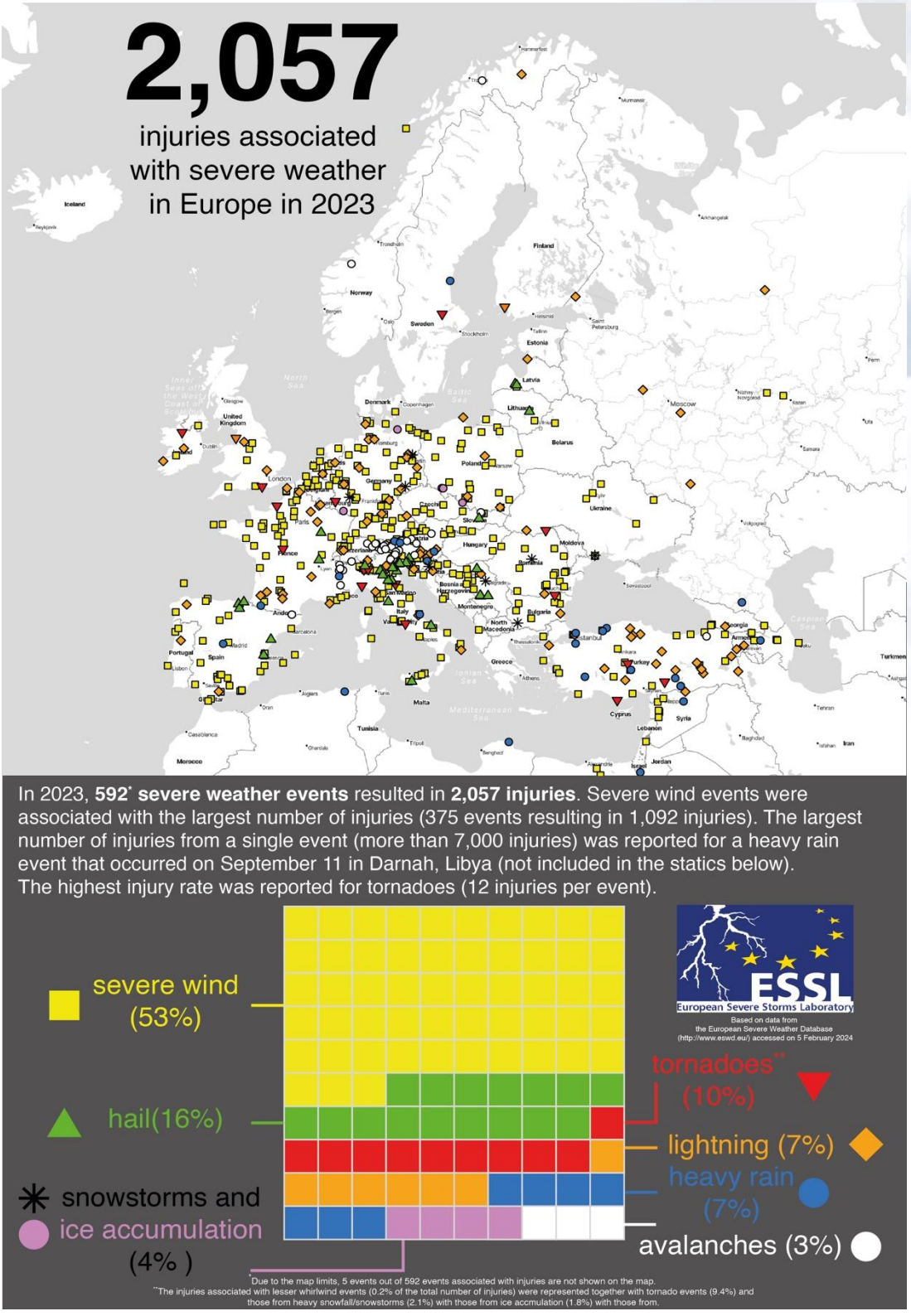

Figure 1-5. The spatial distribution of the ESWD severe weather reports in Europe, associated with injuries in 2023. Below, the percentage of injuries associated with each type of severe weather across the entire ESWD area, i.e., including Mediterranean Africa and Asia, and Central Asia (excluding categories < 1%).

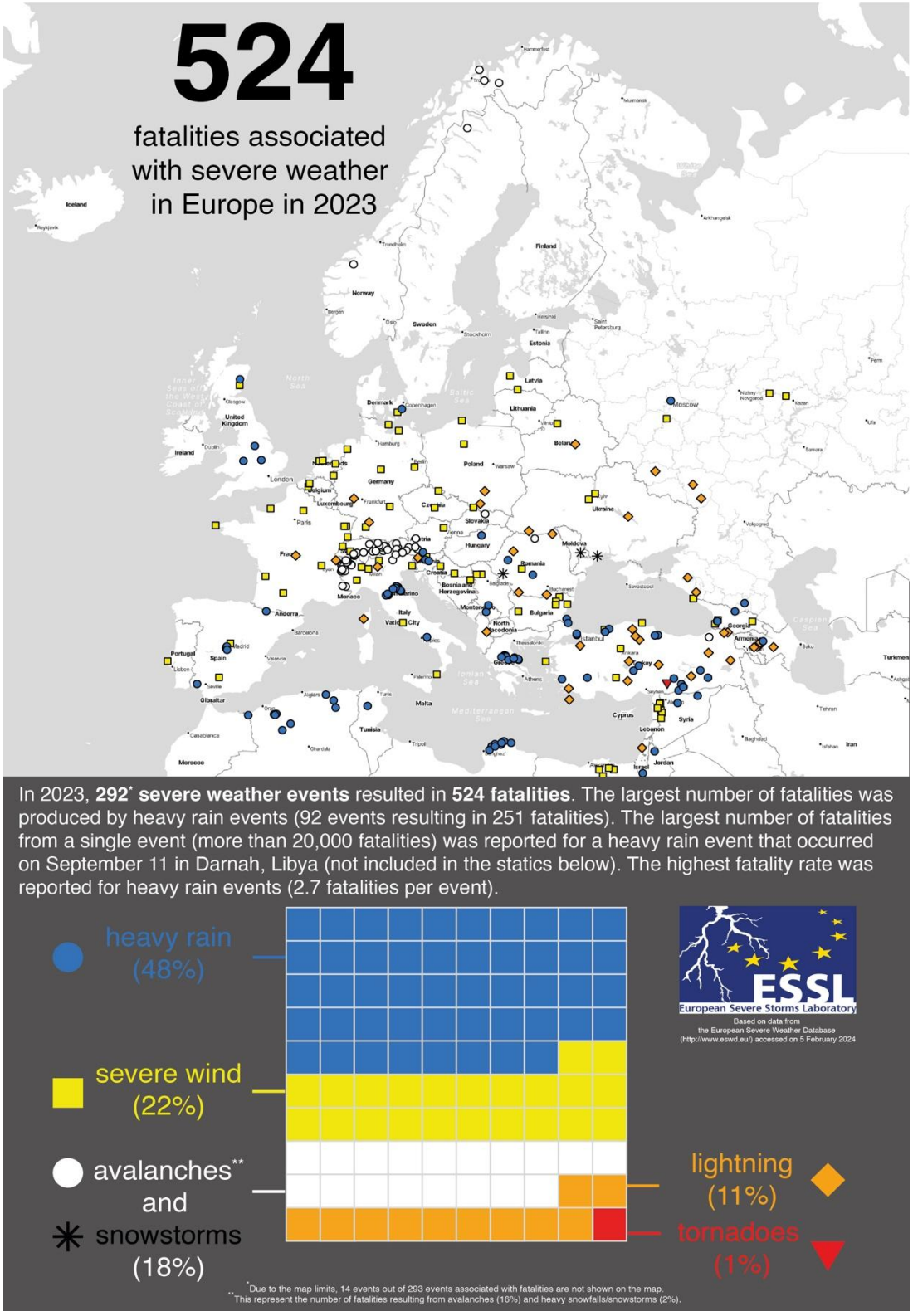

Figure 1-6. The spatial distribution of the ESWD severe weather reports in 2022 associated with fatalities. Below, the percentage of fatalities associated with each type of severe weather across the entire ESWD area, i.e., including Mediterranean Africa and Asia, and Central Asia (excluding categories < 1%).

Fatalities and Injuries

Severe weather in Europe has unfortunately led to a considerable number of fatalities. In total, recorded severe weather caused 2057 injuries (Figure 1–3) and 524 fatalities (Figure 1–4). The number of fatalities was much higher than in 2022, when 331 fatalities were reported.

Table 1-4. The severe weather fatalities in 2023 based on the event type recorded in the ESWD.

	Hazard(s)	Fatalities
1	Heavy Rain	202
2	Severe Wind	117
3	Avalanches	82
4	Lightning	59
5	Heavy Snowfall	15
6	Tornadoes	3
7	Ice Accumulation	1

1.2 Major severe weather events

Table 1-4 shows the distribution of severe weather-related fatalities based on event types. The events with the most fatalities in 2023 are listed in Table 1-5. For this table we considered compound events striking multiple adjacent countries on consecutive days. Interestingly, a range of events with very different nature arises. The single most deadly severe weather event defined in this manner was a landslide caused by heavy rainfall in Georgia, killing 32 people. The second event was a series of flash floods in southern Turkey, killing at least 20. The third event was an unusual snowstorm that hit the Odesa urban area, killing 12 people in its effects.

Table 1-5. The severe weather events with most fatalities in 2023 recorded in the ESWD. In this overview, an event is defined as a contiguous series of days with fatal severe weather in bordering countries.

	Hazard(s)	Date(s)	Location	Fatalities
1	Heavy Rain	02 Aug 2023	Shovi (Georgia)	32
2	Heavy Rain	15 Mar 2023	Sanliurfa / Adiyaman regions (Türkiye)	20
3	Heavy Snowfall	26 Nov 2023	Odesa (Ukraine)	12
4	Severe Wind	29 Jul 2023	Mariy Chodra N.P. (Russia)	9
5	Heavy Rain	20 Aug 2023	Moscow (Russia)	8
6	Avalanche	09 Apr 2023	Les Contamines-Montjoie (France)	6
7	Heavy Rain	05 Sep 2023	Igneada (Türkiye)	5
8	Severe Wind	02 Nov 2023	Torres Vedras (Portugal)	4
	Heavy Rain	19 Nov 2023	Batman (Türkiye)	4
	Severe Wind	28 May 2024	Sesto Calende (Italy)	4

1.3 ESWD Data Users

ESWD data are used by a wide range of users. ESSL receives a considerable number of requests from potential new users, usually initiated by sending an e-mail to the address eswd@essl.org.

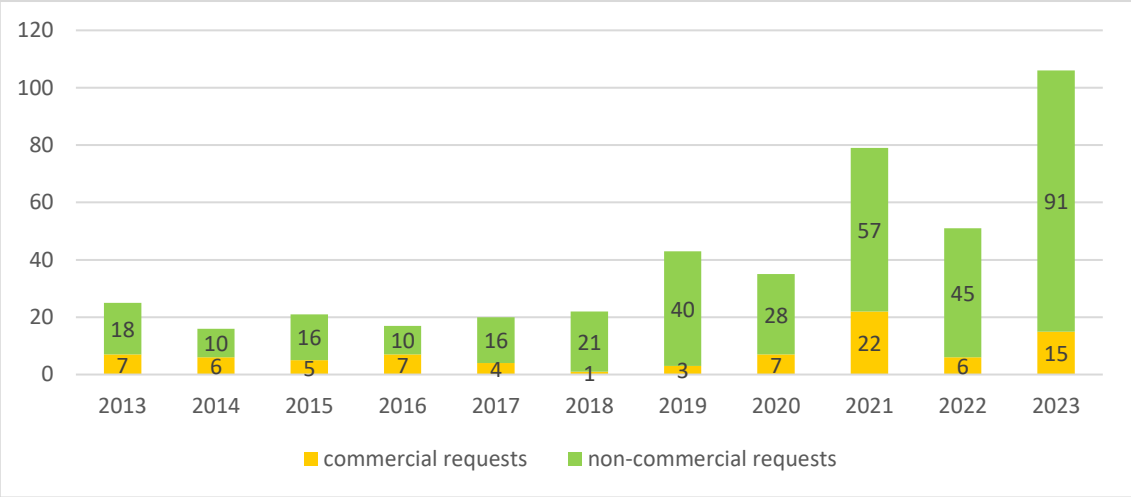

Figure 1-7. Number of requests for ESWD data by non-members.

Interest in ESWD data has strongly increased in recent years, and 2023 was exceptional (Figure 2-7). The requests are for both commercial (15 requests) and non-commercial (91 requests) purposes. Most requests, however, come from students or individual researchers who would like to use parts of the database to support their study. If the study is not driven by commercial interest and the researcher agrees to the User Agreement, ESSL will deliver the data free of cost. If the study has a dedicated budget, ESSL will request a financial contribution to support the ESWD data collection. When a commercial party would like to access the data, they are invited to join the association as a supporting member, or to purchase them from ESSL.

2 Research

In 2023, ESSL's research dealt with the changing risk of convective hazards as a result of climate change in the projects CHECC and CHECC-II, while improving severe weather forecasts was the focus of the project PreCAST and the ongoing collaboration with ECMWF.

2.1 Convective Hazard Evolution under Climate Change (CHECC & CHECC-II)

Federal Ministry of Education and Research

CLIMXTREME Climate Change and Extreme Events

FONA Research for sustainability

Grants:	€ 339 987 and € 216 154*
Funded by:	German Federal Ministry of Education and Research (BMBF)
Period:	March 2020 – February 2023 and August 2023 – September 2026*
Carried out by:	European Severe Storms Laboratory e.V. (ESSL), Weßling
Supported by:	Institute of Meteorology, Freie Universität Berlin; Mateusz Taszarek (University of Poznań)
ESSL employees:	Francesco Battaglioli, Homa Ghasemifard, Thilo Kühne, Pieter Groenemeijer

** For CHECC and CHECC-II respectively*

The CHECC and CHECC-II projects are two projects funded by the German Ministry of Research and Education and part of the national ClimXtreme research network which focuses on the analysis of extreme weather and climatological events.

In the first phase, which ended in February 2023, ESSL improved statistical dynamical models (AR-CHaMo) to detect extreme convective events from reanalysis and climate model data, using storm reports collected in the European Severe Weather Database and lightning detection data. Developing these models succeeded well for hail and lightning but proved more complicated for severe wind gusts and tornadoes. Among the key questions of CHECC was to find out how the frequency and intensity of (the most) extreme convective events and their interannual variability have changed in recent decades, and whether these changes depend on changes in circulation pattern occurrence. Many results of the first project phase, having been accomplished in 2022, were already featured in the Annual Report 2022 (click to download). In 2023, these results were accepted for publication in the *Journal of Applied Meteorology and Climatology* and submitted to *Environmental Research: Climate* and presented at the European Conference on Severe Storms in Bucharest in May 2023. Figure 2-1 shows the modelled trends of (very) large hail in Europe per season, showing that the most important changes in hail are in summer in South-Central Europe. Additionally, ESSL showed that these changes are not forced by changes in circulation patterns (Ghasemifard et al, 2024).

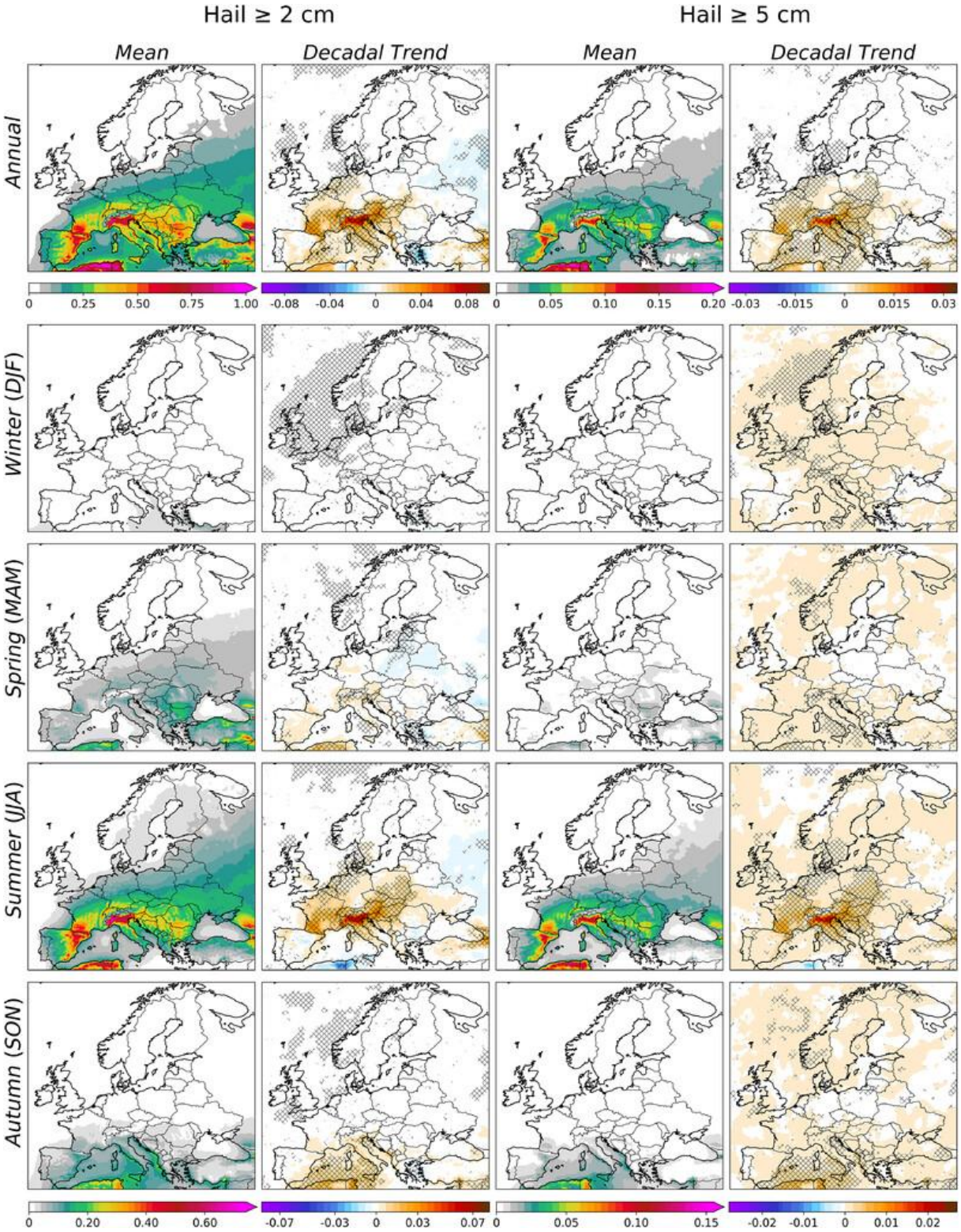

Figure 2-1. Projected seasonal number of hours with hail ≥ 2 cm (left) and hail ≥ 5 cm (right) within 40 km of a point, using the newly developed AR-CHaMo regression model in CHECC on the basis of the ERA5 reanalysis, lightning data, and training data from the European Severe Weather Database and US Storm report data. From Battaglioli et al. (2023), American Meteorological Society (License: CC-BY).

Within the second phase, i.e. CHECC-II, the research focuses on the changes to be expected in the future according to climate model projections, and the implications for local risk to be assessed by the creation of a set of extreme events. Event sets for convective hazards are collections of possible outcomes that downscale the coarse probabilistic predictions from climate models. To address the tornado hazard, the project continued to develop a European AR-CHaMo tornado model, which had started in the first phase of CHECC.

We trained the three-dimensional model for tornadoes F1 using tornado reports from the European Severe Weather Database (ESWD) over Central Europe between 2008 and 2019. Three parameters from the ERA5 reanalysis were selected as predictors: Storm-Relative Helicity (SRH) in the lowest 500 m above ground level (AGL), lapse rates in the lowest 1 km AGL and vertical vorticity at 10 m AGL. These parameters represent quantities known to be important for tornado formation. By applying the models retrospectively to the period 2008 - 2019, a projection of the climatological occurrence of tornadoes across Europe was obtained (Figure 2-2). This preliminary result still has some deficiencies, such as a likely underestimation of tornadoes in North Italy and, possibly, parts of Poland, while an overestimation may be present in southern Norway, Ireland, and Portugal means not all issues with modelling tornadoes have been tackled and further development is still ongoing as well as a case-by-case inspection at the ESSL Testbed (see Section 2.2 and Chapter 3).

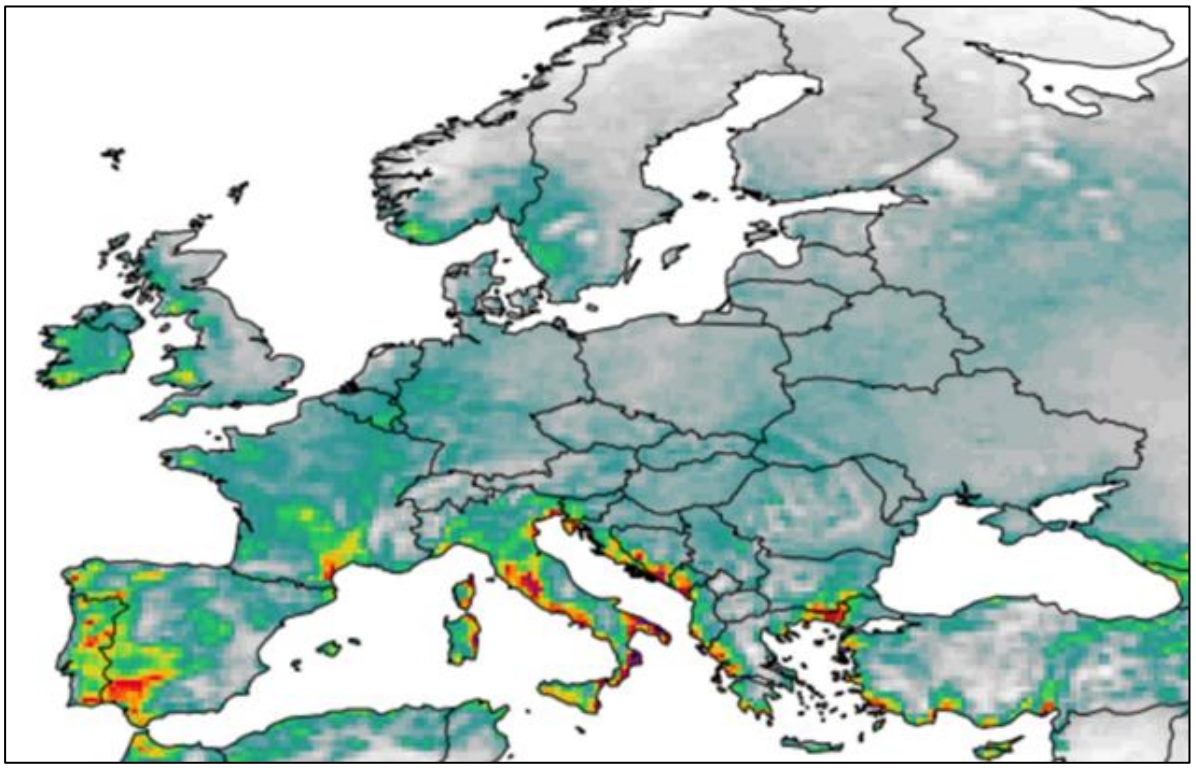

Figure 2-2. Projected occurrence of tornadoes with an intensity of (I)F1 or higher according to a preliminary model AR-CHaMo.

We are grateful to the Institute of Meteorology of the Free University of Berlin which kindly offered office space to host the CHECC scientists, and to the great collaboration with Dr Mateusz Taszarek (National Severe Storms Laboratory, USA; and University of Poznań, Poland) who supported CHECC by providing convective parameters calculated from reanalysis data.

2.2 Prediction of Convective hazards Across Spatio-Temporal Scales

Grant:	ESSL: € 293 010, total: € 483 280
Funded by:	FWF Der Wissenschaftsfonds (Austria)
Period:	1 September 2020 – 28 February 2025
Carried out by:	European Severe Storms Laboratory – Science and Training, Wiener Neustadt, and GeoSphere Austria
Supported by:	European Centre for Medium-Range Weather Forecasts (ECMWF)
ESSL employees:	Tomáš Púčik, Pieter Groenemeijer

The PreCAST project aims to improve the prediction of convective extreme events by blending medium-range models AR-CHaMo probabilistic model for hazard occurrence with convection permitting models for the short range. ESSL works on the development of AR-CHaMo while project partner GeoSphere Austria improves their C-LAEF convection permitting model ensemble.

In 2023, ESSL evaluated AR-CHaMo for lightning, large (≥ 2 cm), very large (≥ 5 cm) hail and tornadoes at the ESSL Testbed. The performance of the model on the record-breaking hail day of 19 June can be seen in Figure 2-3.

The Testbed participants found the AR-CHaMo forecasts useful but noted an overestimation of lightning risk in some situations. Furthermore, an overestimation of tornado risk during some of the deep cyclone cases in the Mediterranean was noted. The ESSL team continues to investigate how to improve the AR-CHaMo models to resolve these issues. In the autumn of 2023, a start was made with a statistical model for severe wind gusts, to be tested at the 2024 ESSL Testbed.

Parameters describing the strength of the flow in the bottom troposphere were found to be the most important. We also started work on setting up a code to apply the AR-CHaMo to the ensemble of the ECMWF's IFS. This is done in collaboration with Ivan Tsonevsky from ECMWF with the goal of evaluating the ensemble-based probabilities during the ESSL Testbed of 2024. In 2023, GeoSphere continued its work on improving the C-LAEF, including the new stochastic perturbation scheme. They developed a hail diagnostic using the verification of hail events based on the ESWD reports.

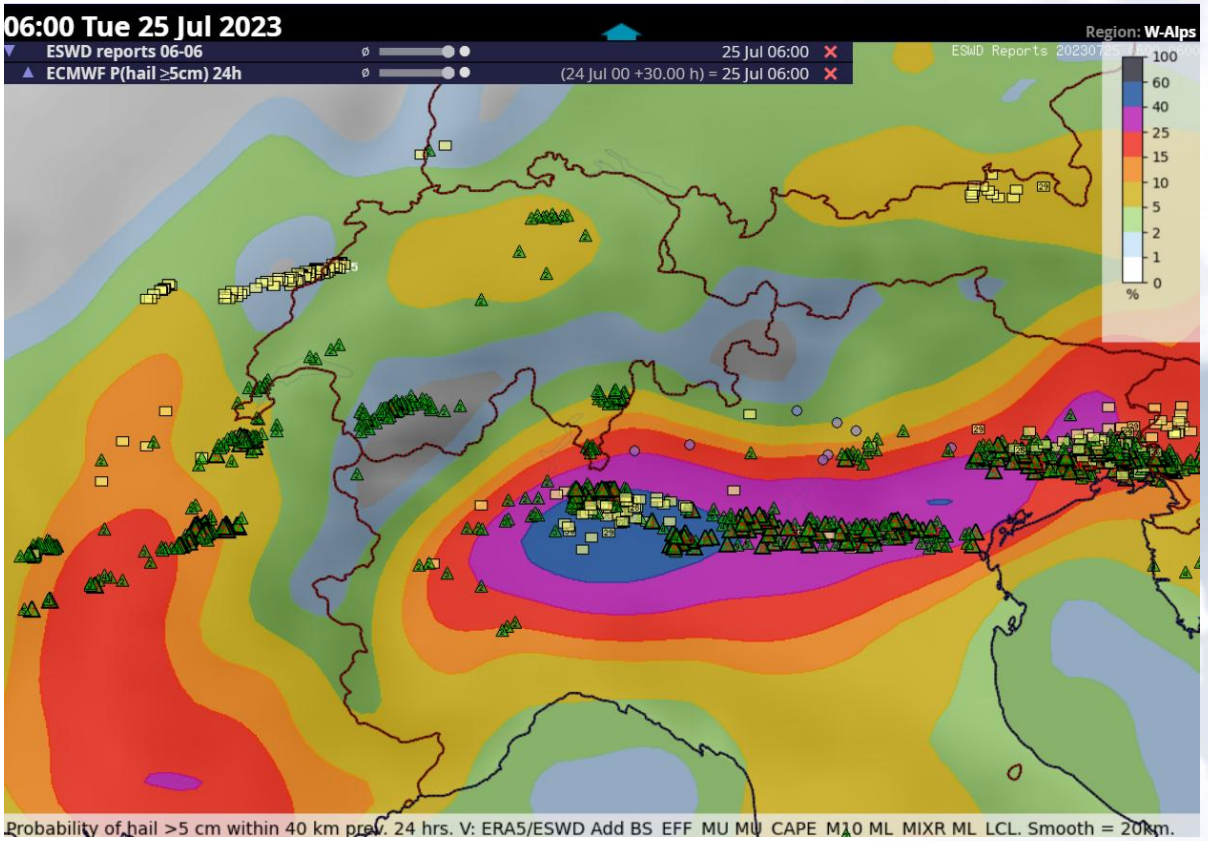

Figure 2-3. Accumulated 24 h probability of very large (≥ 5 cm) hail between 24 July 2023 06 UTC and 25 July 2023 06 UTC. ESWD reports are plotted for this period (Green triangles representing large hail and yellow squares severe wind gusts). Several giant-hail producing supercells tracked over N Italy on this day, setting a new European hail record with an estimated 19 cm hailstone.

2.3 Collaboration with ECMWF

Funded by:	European Centre for Medium-Range Weather Forecasts (ECMWF)
Period:	since 2021
Carried out by:	ESSL Science & Training, Wiener Neustadt
ESSL employees:	Francesco Battaglioli, Pieter Groenemeijer, Tomáš Púčik

The collaboration between ECMWF and ESSL was continued with a new two-year project starting in November 2022.

The focus of the work in 2023 included setting-up of routine medium-range forecasts for convective hazards (initially lightning and hail) on ECMWF's systems using its ensemble forecast system. This required job scheduling on ECMWF's high performance cluster and running code there, as well as in the European Weather

Figure 2-4. Ivan Tsonevsky (ECMWF), Francesco Battaglioli and Pieter Groenemeijer (ESSL) during a visit to ECMWF in October 2023.

cloud and on ESSL's systems. By the end of 2023, this work with the goal to evaluate these products at the ESSL Testbed 2024, was still ongoing.

Additionally, a publication on the results of an earlier initial experiment on medium-range hail and lightning forecasting developed using ECMWF's reforecasts in 2022 was finalized and ultimately accepted for publication (Battaglioli et al, 2023). Third, ESSL provided ECMWF with code to calculate several wind-shear related diagnostics from model-level data including various versions of storm-relative helicity. Fourth, ESSL carried out work to complete the migration of many processes supporting the ESSL's Weather Displayer to ECMWF's new European Weather Cloud infrastructure in Bologna. To discuss various matters in person, Francesco Battaglioli and Pieter Groenemeijer visited ECMWF's Ivan Tsonevsky from 2 to 6 October.

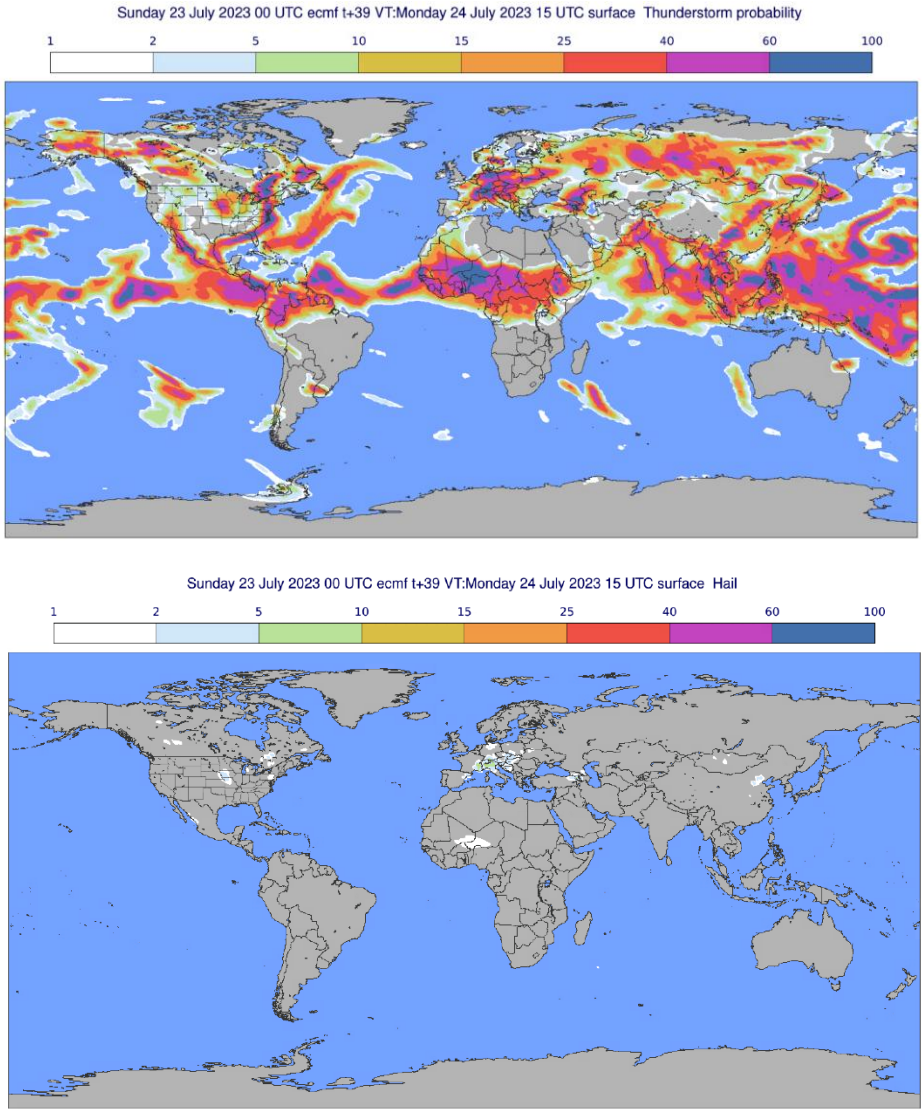

Figure 2-5. One of the first experimental probabilistic global thunderstorm and large hail forecasts produced in the project. These forecasts will be tested validated and bias corrected in 2024 and, ultimately, routinely provided by ECMWF.

2.4 Evaluation of a new lightning sensor

Grant:	ESSL: € 50 906, total: € 199 372
Funded by:	Province of Lower Austria
Period:	2021 – 2024
Carried out by:	Donau-Universität Krems
	ESSL Science & Training, Wiener Neustadt
ESSL employees:	Pieter Groenemeijer, Tomáš Púčik, Alois M. Holzer

In this cooperative project with the Department for Integrated Sensor Systems (DUK-DISS) of the Danube University Krems, a small and practical novel type of sensor for electrostatic fields is developed, the long-term stability of which was verified in varying environmental conditions.

The monitoring of the measurements has shown that the electric field is typically very similar at both sites and peaks in the electric field are typically synchronous with the detections of lightning strikes in the vicinity of the sensors. As can be expected, lightning strikes closer to the sites produce peaks with a higher amplitude. The signal of the sensor located at ESSL shows a comparatively high frequency oscillation that corresponds to the 16.7 Hz alternating current of the nearby (67 m) Austrian railway (Figure 2-6). This, however, does not pose a problem for the detection of electric fields that evolve much slower, nor the rapid jumps caused by nearby lightning which has a much greater amplitude.

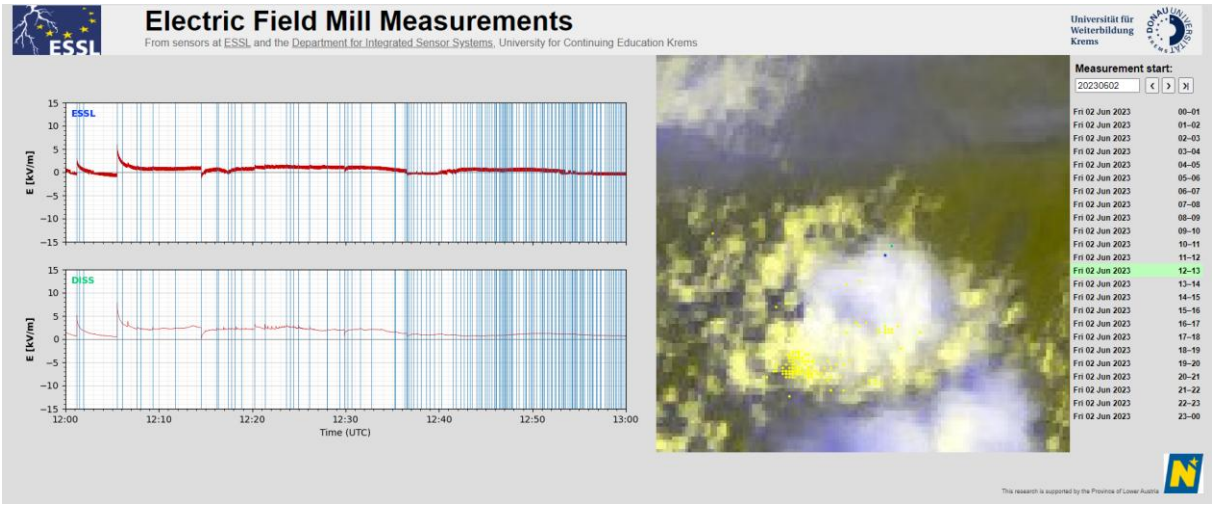

Figure 2-6. Measurements of the electric field by the Electric Field Mill installed at ESSL (top left) and DISS (bottom left), displayed next to a satellite image with lightning detections provided by ALDIS, on a specially developed webpage.

2.5 The International Fujita (IF-) scale and wind damage rating app

Since 1 September 2023, the European Severe Weather Database (eswd.eu) uses the International Fujita (IF) Scale for recording wind and tornado damage. All new wind and tornado events will, if they are rated, be using the IF-scale. ESSL initiated the development of the IF-scale in collaboration with partners from across Europe, including meteorologists from Slovakia, Austria, Spain, Czechia, and Germany, as well as forestry experts and engineers. It was developed because the original Fujita scale, which was still used until recently, only included a short damage description for each step of the scale and provided insufficient guidance for rating tornadoes in Europe.

IF scale class	Instantaneous 3D wind speed	
	m/s	km/h
IF0	25	90
IF0.5	33	120
IF1	40	150
IF1.5	50	180
IF2	60	220
IF2.5	70	250
IF3	80	290
IF4	105	380
IF5	130	470

Figure 2-7. Wind speed classes of the IF scale, denoted by one central value per class.

The development of the IF-scale was catalysed by the introduction of the Enhanced Fujita scale in the USA in 2007. This scale drastically reduced the wind speed estimates for higher wind speeds while simultaneously raising it for the F0/F1 boundary compared to the original F-scale: a change apparently motivated by a need to correct for biases in tornado rating practices in the USA. This development spurred many national adaptations, such as those for Japan and Canada, each with minor or major national wind speed adjustments.

Damage Indicator		Subclasses	Degrees of Damage
BS	Building - structure	A,AB,B,C,D,E,F	0,1A,1B,2
BR	Building - roof	A,AB,B,C,D,E,F	0,1,2
BN	Building - non-structural elements	SW,SS,TW,TS,HW,HS	0,1,2,3
BM	Building - anchoring	SM,SI,DB	1
VH	Road Vehicles	C,E,L,T	0,1,2,3,4
TR	Trees	W,A,S	0,1,2,3,4,5,6,7,8,9
TS	Tree stands	WA,S	0,1,2,3,4
WT	Wind turbines	A,S	0,1,2,3
GH	Greenhouses	W,A,S	0,1,2,3
TC	Train cars	S,F	0,1
MH	Mobile homes / static caravans	-	0,1,2,3,4,5
PT	Poles and towers	W,S,T	0,1,2
SP	Solar Panels	-	0,1
FC	Fences	W,S	0,1
FW	Free-standing walls	Z,A,AB,B,C,D,E,F	1,2
SN	Signs and billboards	T,M	0,1,2
SW	Connected scaffolding	-	1
CP	Carports / garages	-	1
SS	Service Station Canopies	-	0,1,2,3

Figure 2-8. List of Damage Indicators (DI) with various Degrees of Damage (DoD). Each combination of a DI and DoD is associated with one particular IF rating, which makes the tornado rating procedure reproducible.

The IF scale instead keeps the original F-scale wind speeds but defines them to refer to instantaneous three-dimensional wind speed at the height at which damage occurs, rather than the 3-second averaged horizontal wind speeds at 10 metres above ground level. The range of wind speeds from 25 (IF0) to 130 (IF5) fits the range of observed wind speeds in mobile doppler radar measurements and derived from tornado videos which lends some confidence that

the speed estimates are reasonable. The scale can easily be applied in different countries, as long as national building practices are translated to the building sturdiness classes that the IF-scale uses. The full IF-scale description can be found on the ESSL website (click to download pdf).

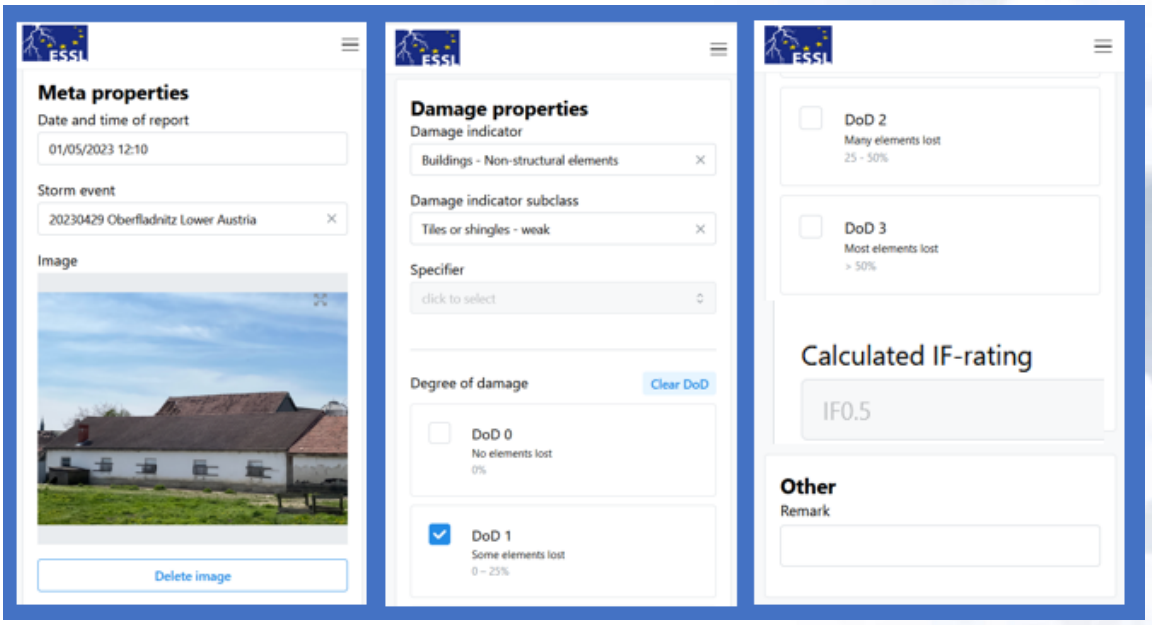

Figure 2-9. Screenshots of the IF-scale damage rating app.

ESSL developed an app that can be used in the field for rating and storing tornado and wind damage. Important features are the ability to store georeferenced photos with text comments and to immediately assign it an IF-scale rating. It is hoped that this will facilitate the collection of more detailed information on tornadoes and local wind damage and thereby increase our knowledge of such events.

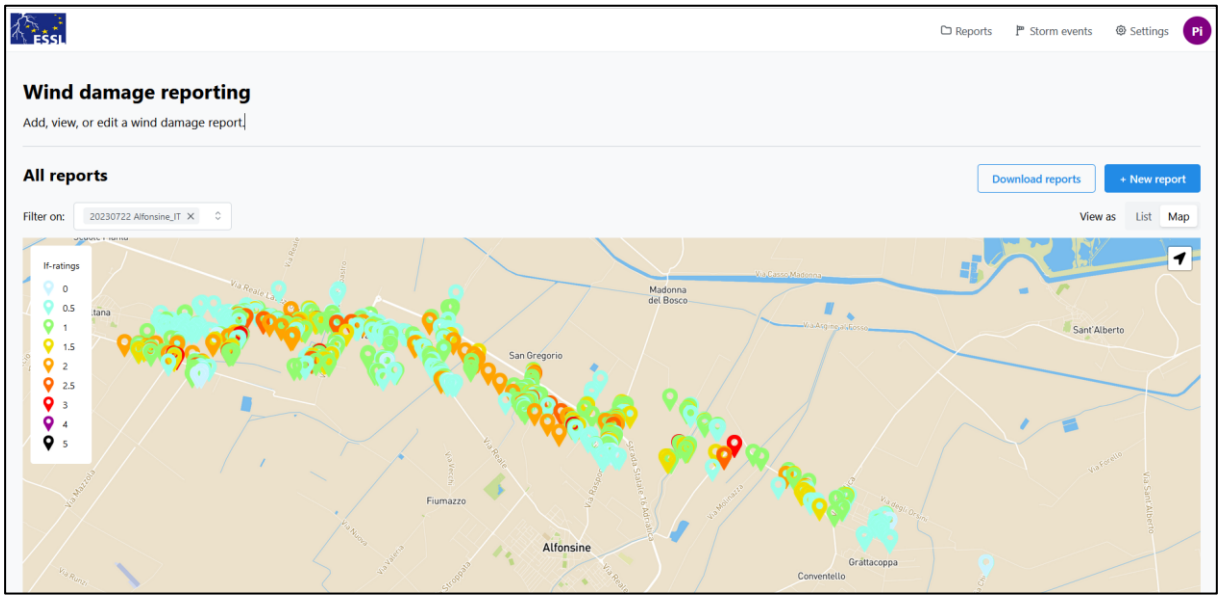

Figure 2-10. Screenshot from the wind damage app showing a detailed damage map produced by Federico Pavan (ESWD partner MeteoNetwork/PreTEMP).

3 ESSL Testbed 2023

The Testbed is ESSL's annual activity with two main aims: the evaluation of tools supporting the forecast or warning process and providing training in severe convection forecasting. Four of these weeks were organized in collaboration with EUMETSAT and featured a higher focus on satellite-based products. One of the EUMETSAT Testbed weeks was hosted by IMGW in Krakow, Poland.

Six Testbed weeks were organized during the 12th year of the ESSL Testbeds. Four Testbed weeks took place during the summer and two weeks during the autumn to cover for the Mediterranean activity. One of the Testbed weeks was reserved for more expert participants and was done in a hybrid mode, while all other weeks were done in the purely onsite format. Four weeks (the first two summer weeks and the two autumn weeks) were co-organized together with EUMETSAT, who sponsored the participation of forecasters. The 12 – 16 June Testbed week was hosted by IMGW and took place in beautiful Krakow, Poland. Overall, participants ranked the Testbed with an average grade of 9.45 out of 10 points.

Table 6. Testbed weeks in 2023.

Event	Date
EUMETSAT/ESSL Forecaster Testbed	5 – 9 Jun
EUMETSAT/ESSL Forecaster Testbed	12 – 16 Jun
ESSL Testbed	26 – 30 Jun
ESSL Testbed (Expert week)	3 – 7 Jul
EUMETSAT/ESSL Forecaster Testbed	25 – 29 Sep
EUMETSAT/ESSL Forecaster Testbed	9 – 13 Oct

The 2023 version of the ESSL data displayer brought an upgrade. To better facilitate the evaluation process, three different modes of data visualization, "verification", "analysis" and "forecast" mode were introduced. For example, verification allows to combine the forecast/nowcast product issued at a particular time in history with future radar/satellite/ESWD data.

Altogether 78 participants took part in the Testbed in addition to 5 ESSL staff members. The participants came from 26 different countries: Austria, Bulgaria, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland, Turkey, United Kingdom. Some of the participants were not forecasters but developers of the products evaluated at the Testbed.

Figure 3-1. Participants of the first EUMETSAT-ESSL Testbed held on 5-9 June 2023.

Numerous products were evaluated at the Testbeds. During the non-EUMETSAT Testbed weeks, participants concentrated on evaluating the various forecasting and nowcasting products from the DWD and the ESSL's AR-CHaMo models. During the EUMETSAT Testbeds, participants were looking at some of the future products from the MTG satellites emulated using instruments of the polar-orbiting satellites (MODIS and VIIRS). During these Testbeds, we also looked very closely at how to use the storm top features to nowcast severe weather.

Figure 3-2. Participants discussing the morning Day 1 forecasts during the ESSL-EUMETSAT Testbed week in Krakow, Poland.

3.1 Products at the ESSL Testbed

KONRAD3D-EPS (DWD)

Description: KONRAD3D is a nowcasting algorithm that enables an object-based ensemble prediction of convective cells detected in radar data. The basis for this is KONRAD3D cells for the domain of the German radar composite. The goal is to provide a probabilistic prediction of intensity changes for convective cells and to realistically estimate the uncertainties associated with this prediction.

Main finding: The main finding was that for well-organized convection, the system underestimates the lifetime of the cells. This is likely because on average, short-lived disorganized convection dominates the statistics. In their feedback, participants suggested scaling the expected lifetime of cells with their surrounding pre-convective environment, especially the vertical wind shear.

ICON-RUC-EPS (DWD)

Description: ICON-RUC-EPS is a high-resolution, convection-allowing ensemble run every hour with fast computation time and aggressive assimilation of radar and satellite observations, a separate hail hydrometeor class, and 5-minute output of simulated radar reflectivity fields.

Main finding: As last year, it was noted that the ICON-RUC-EPS frequently provided better short-term forecasts of storms compared to ICON-D2-EPS (Figure 3-3), especially concerning the timing of the convective initiation. The cores of the storms and the cold pools were again found to be too intense, compared to radar and surface observations. The relatively small size of the storm cores was hypothesized to cause their too-fast decay in the model.

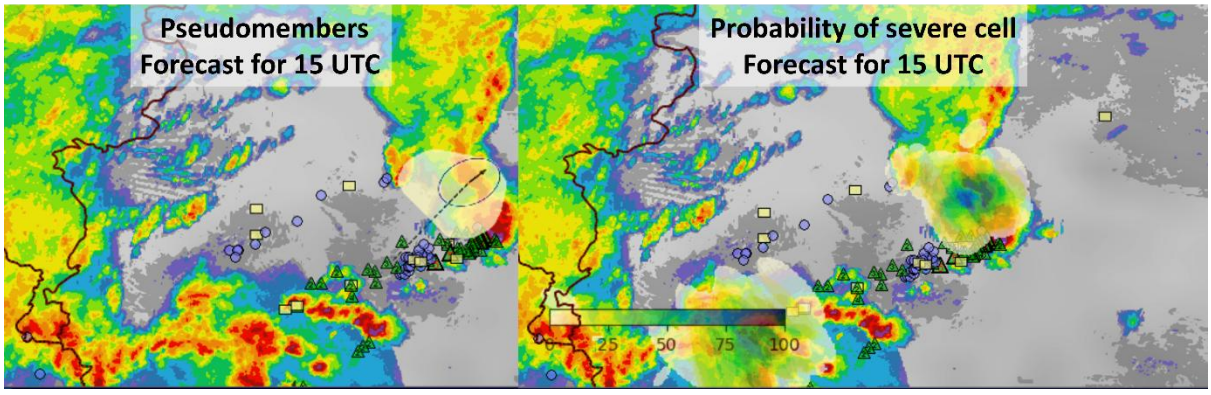

Figure 3-3. 22 June 2023 15 UTC observed radar reflectivity, ESWD reports in the last 3 hours and KONRAD3D-EPS forecast of pseudo members and severe cell probability initialized at 13 UTC.

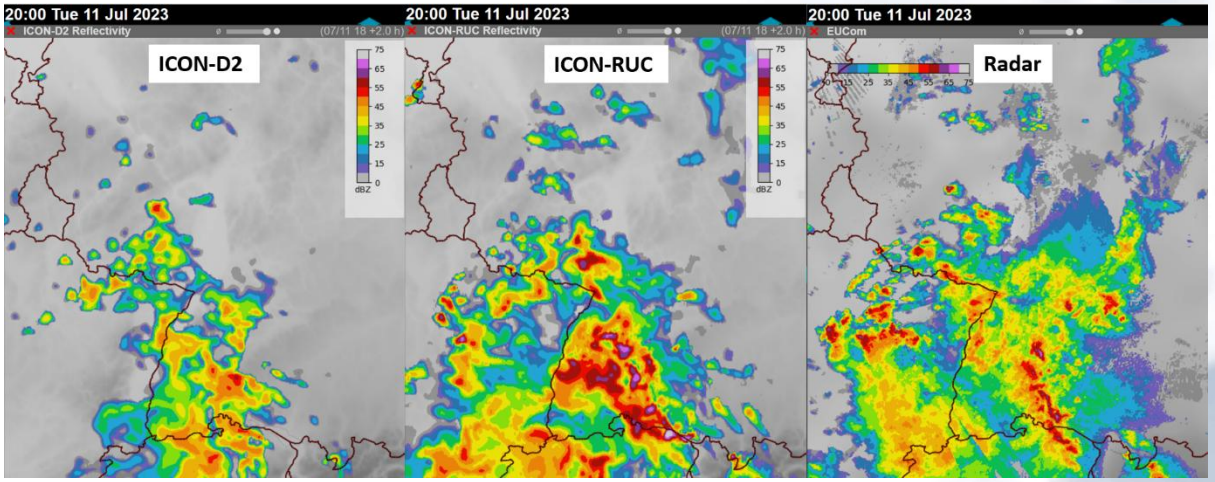

Figure 3-4. Comparison of ICON-D2 and ICON-RUC forecasts of radar reflectivity to observations.

KONRAD3D-SINFONY (DWD)

Description: KONRAD3D-SINFONY (Figure 3-5) is an object-based forecasting system for convective cells that is based on the combination of nowcasting (NWC) and numerical weather prediction (NWP). NWC is superior to NWP on the very-short range up to about two hours in predicting convective cells while NWP performs better afterwards. The NWC component is based on KONRAD3D-EPS while the NWP component is based on ICON-RUC-EPS.

Main finding: The main finding was that the inclusion of the NWP component increases the usefulness of the product compared to the pure NWC perspective (KONRAD3D-EPS). Participants appreciated the offered probabilistic products. However, even with the inclusion of the NWP component, the product still simulated too short lifetimes of cells. Furthermore, some jumpiness was noted with regards to cell's nowcasted intensity and location.

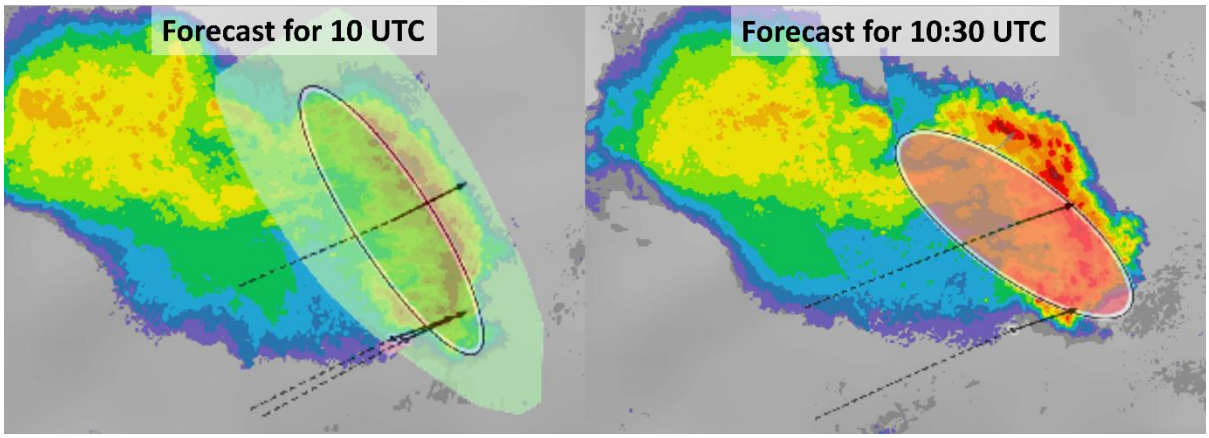

Figure 3-5. 21 June 2023 observed radar reflectivity and KONRAD3D-SINFONY pseudo member product nowcast initiated at 9 UTC.

Radar Maxima Product based on ICON-D2-EPS (DWD)

Description: The aim of this product is to provide a good "upscaled" forecast of the precipitation especially in situations where convection may occur. The Radar Maxima product tries to summarize the individual forecasts of the ensemble members to estimate the most probable locations of precipitation and their intensities rather quickly.

Main findings: Participants noted that the product was useful in some cases. Its usefulness is dependent on the success of the ICON-D2 EPS ensemble. The product was found to underestimate rather than overestimate precipitation and highlighted areas with precipitation were sometimes way too large.

AR-CHaMo (ESSL)

Description: AR-CHaMo (Additive Regressive Convective Hazard Model) calculates the probability of (severe) thunderstorm hazards based on the larger-scale, pre-convective environments. Each hazard uses a different set of predictors. In 2023, the predictions for probabilities of lightning, (very) large hail were tested, based on ECMWF, ICON-EU, and GFS forecasts (Figure 3-6).

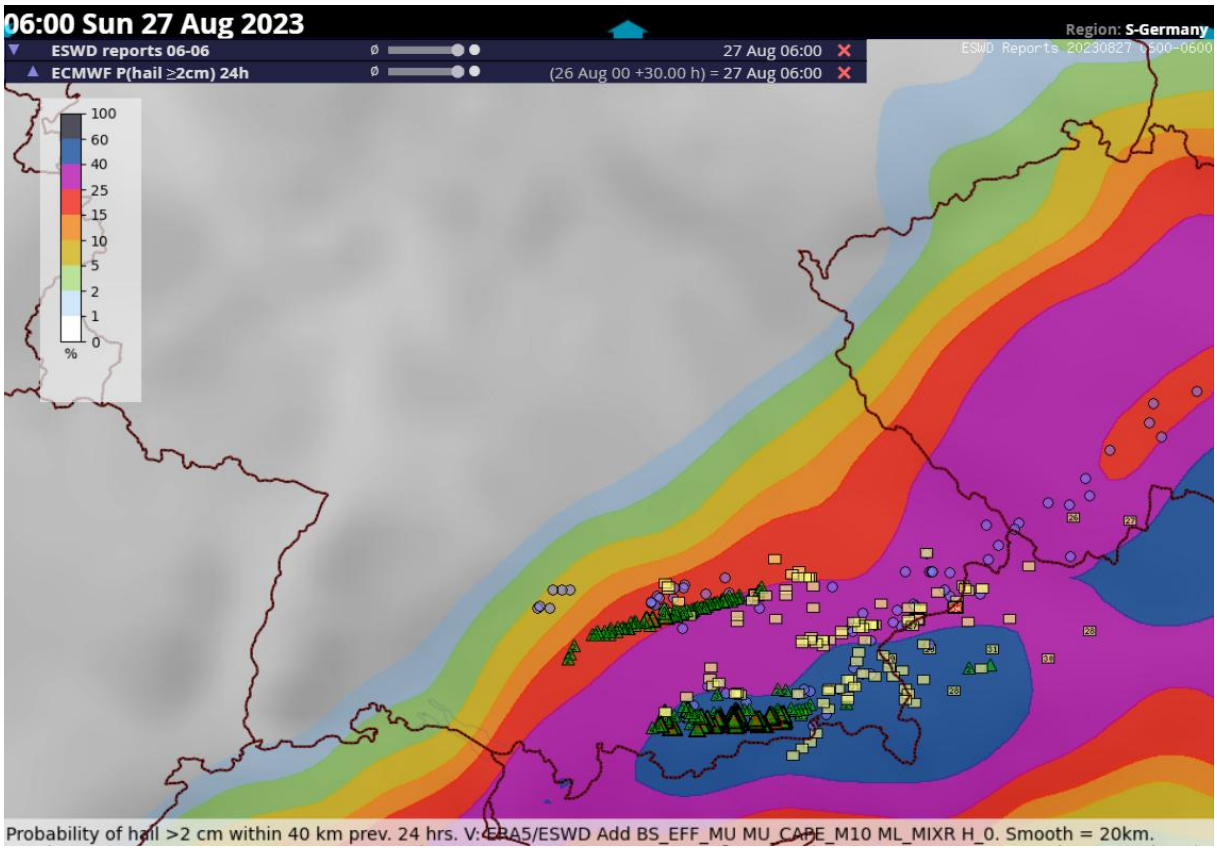

Figure 3-6. 24 hour accumulated probabilities of large hail on 26 August 2023 with severe weather reports overlaid.

Main finding: Participants found the large hail and lightning forecast to be rather good guidance. In some situations, false alarms occurred due to an overconfidence in convective initiation. Two early versions of the tornado model were occasionally

considered, too, but a thorough evaluation did not happen because of a lack of cases. Some overestimation in the tornado risk by both models was noted by the ESSL staff when considering cases occurring after the Testbed period.

The following products were specifically featured at the EUMETSAT/ESSL Forecaster Testbeds:

Low-level moisture product

Description: This product visualizes the ratio of two channels from the MODIS instrument, building on the idea of Hans-Peter Roesli, to detect areas with higher contents of low-level moisture.

Main findings: The participants found the product very useful even in a qualitative sense and indicated their high interest in having such a product provided with high temporal resolution by the Meteosat Third Generation instrument FCI (Flexible Combined Imager).

Figure 3-7. Total moisture product based on the MODIS on 6 July 2023 combined with the ESWD data showing the birth of the very large hail producing supercells north of the low-level moisture boundary.

New RGBs available from MTG

Description: Several new red-green-blue composite satellite images (RGBs) that will be available from MTG were generated using data from the VIIRS instrument. Testbed participants concentrated especially on the usefulness of the RGBs concerning the nowcasting of convection.

Main findings: As in 2022, participants found the cloud-phase RGB to be the most useful of the tested RGBs. Figure 3-7 shows the different microphysical stages of the clouds over Spain on 13 June. Yellow represents the clouds with small water droplets, purple represents the clouds with large droplets and ice crystals are represented by the blue colour.

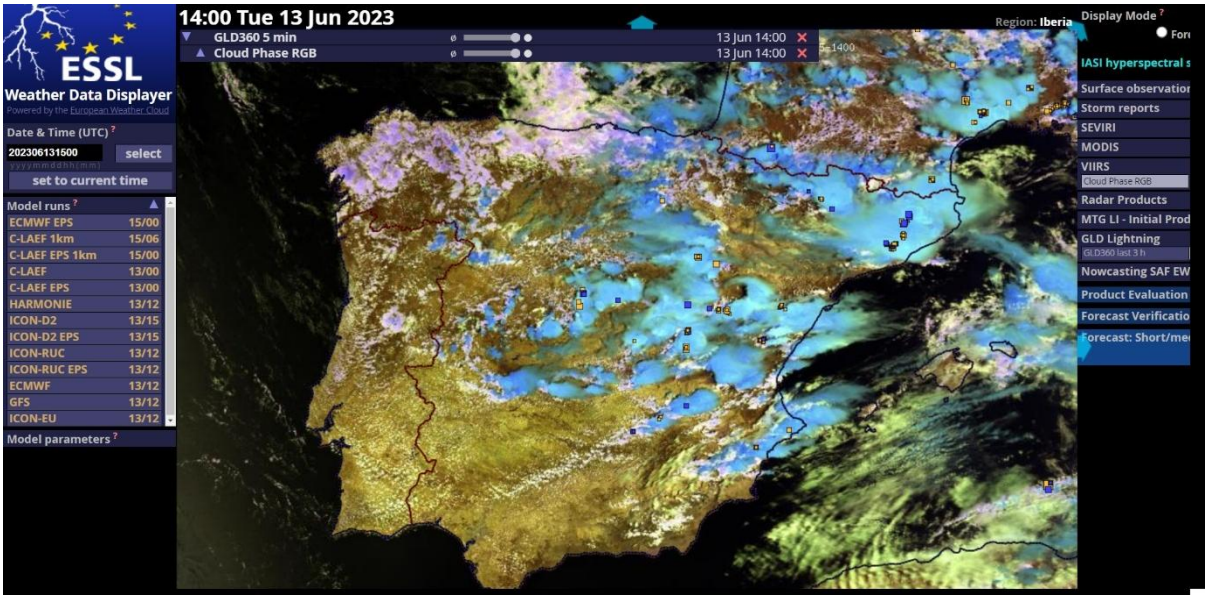

Figure 3-8. Cloud phase RGB generated using VIIRS instrument data on 13 June 2023 at 14 UTC.

Nowcasting SAF products

Description: Two products from the Nowcasting Satellite Application Facility (Nowcasting SAF) were evaluated at the ESSL-EUMETSAT Testbed during the autumn week. Participants looked at the CI (Convective Initiation) and CRRPh (Convective Rainfall Rate based on Physical characteristics) products.

Main findings: Participants found both the CRRPh and CI to be useful in most or at least half of the storm cases they looked at. For CI, participants mentioned its usefulness in the absence of any other mid- to upper-level clouds, but also spotted numerous false alarms. On average, CI offered 5 – 15 minutes of lead time prior to the other methods of detection of convective initiation. For CRRPh, participants asked for calibration in the regions with dense rain gauge observation networks.

4 The 11th European Conference on Severe Storms (ECSS2023)

The first on-site edition of the European Conferences on Severe Storms after the Corona pandemic was held in Bucharest with the help of local organizing partner MeteoRomania and support from the European Meteorological Society. Many researchers, operational forecasters, risk and emergency managers gathered to discuss various topics and themes concerning convective storms, their impact and risk assessment in relation to climate change. In total, the conference saw the participation of 180 people from 29 different countries who presented 79 talks and 88 posters in 11 different topic sessions.

Figure 4-1. Conference photo with the participants in front of the venue, the Institute of Statistics in Bucharest, Romania.

4.1 Nikolai Dotzek Award

During the conference dinner in the beautiful city centre of Bucharest, ESSL Director Pieter Groenemeijer, Deputy Director Bogdan Antonescu and Alois M. Holzer Director of Operations, presented the Nikolai Dotzek Award to three meteorologists for their outstanding contribution to the science of severe storms in the field of satellite meteorology: Pao Wang, Martin Setvák, and Kris Bedka. You can read more about this year's awardees and their work on ESSL's website.

Figure 4-2. Nikolai Dotzek Award winners Kris Bedka, Martin Setvák (represented by Michaela Valachová), and Pao Wang.

On the last day of the conference the following prizes were awarded:

Best Talk Jury Award ECSS2023 to Francesco De Martin, Silvio Davolio, Mario Marcello Miglietta, and Vincenzo Levizzani for their work
"A conceptual model for the development of tornadoes in the Po Valley"

Best Poster Jury Award ECSS2023 to Matthew Kumjian, Kelly Lombardo, Brice Coffer, and Johannes Dahl for their work *"What is a Mesocyclone?"*

Best Talk Audience Award ECSS2023 to Matthew Kumjian, Kelly Lombardo, Cameron Nixon and John Allen for their work *"Does Low-level Vertical Wind Shear Matter for Hail Production?"*

Best Poster Audience Award ECSS2023 to Marcus Beyer and Kathrin Wapler for their work *"Tornadic, hail and windstorms in Central Europe - when to expect what: a case study of the severe weather outbreak on 20 May 2022"*

Heino Tooming Award ECSS2023 to Jérôme Kopp, Agostino Manzato, Olivia Romppainen-Martius, Urs Germann, and Alessandro Hering for their work *"Unique observational data from an automatic hail sensor network in Switzerland"*

Figure 4-3. Awardees and awards committee members. Left top, from left to right: Matthew Kumjian, John Allen, Kelly Lombardo; Right top: Harold Brooks, Bogdan Antonescu (committee), Francesco De Martin; Left bottom: Bogdan Antonescu (committee), Agostino Manzato, Lisa Schielicke (committee); Right bottom: Brice Coffer, Matthew Kumjian, Kelly Lombardo.

5 Workshops and courses

In 2023, ESSL organized four courses for forecasters and four workshops. These expert workshops were part of the EUMETSAT-ESSL collaboration to prepare users for MTG.

5.1 Courses for forecasters

ESSL organized four training courses in 2023. The first course, *Aviation forecasting of severe convective storms* took place between 27 and 31 March. The next week ESSL trainers travelled to Zagreb, Croatia to give a tailored course for the DHMZ. The course lasted for 4 days and involved a lot of sweets during the coffee breaks as the temporary DHMZ residence is within the well known Kraš chocolate factory. Sweets were highly needed especially in the afternoon, when we tried to tackle a difficult problem that the forecasters here face: Will supercells coming from southern Austria and Slovenia survive as they move over Croatia? The third course, *Forecasting Severe convective storms*, took place on 24 to 28 April. The photo from the course still proudly hangs in our coffee break room. Because it's not so common to have a delicious tiramisu prepared by one of the participants! The last course was organized in late autumn, between 27 November and 1 December. One of the highlights of the course was the discussion on a major severe weather outbreak in Bulgaria from November that featured a derecho and a strong tornado.

Figure 5-1. Group photo from the course including "ESSL tiramisu".

All courses were split into a theoretical part with lectures in the morning and a practical part with case study exercises in the afternoon. The practical part is done in a quasi-operational mode and participants are asked to issue a forecast or nowcast, applying the concepts that were studied in the morning. The day is closed with a discussion on how the introduced forecasting concepts could be applied to the cases.

The case studies were done using the ESSL Weather Data Displayer and covered some of the most interesting weather events of the past year or two. For the 2023 courses, lecture material was again upgraded with recent findings from the scientific literature. This time, we added new material on elevated storms on Monday with an exercise on this subject. The expansion of this topic proved quite important during the summer 2023, when the record-breaking hailstorms in Italy on 23 July occurred that were, in fact, of an elevated nature!

5.2 ESSL-EUM Expert workshop on Lightning Detection

18 participants from Europe and the USA participated in this workshop from 28 February to 2 March 2023 in hybrid mode (on site in Wiener Neustadt and online). The sessions covered the physical basics of Lightning Imagers (LIs) with relevance to forecasting, experience with the GOES-GLM overseas and ISS-LIS, user uptake in the US after the first years of GOES-GLM, and optimal visualizations for nowcasting purposes. Pieter Groenemeijer, ESSL Director, expressed his happiness with the workshop because of expectations regarding the upcoming testbeds.

Figure 5-2. Participants of the Expert Workshop on Lightning Detection by Satellite.

Tomas Púčik, senior trainer at ESSL, found it important that LI data can be interpreted in the context of storm dynamics and physical processes in deep convection, as well as in the context of training forecasters. He distilled 3 ways to utilize the LI data: 1) thinking about what the data means; 2) eye candy for forecasters; 3) data being 'black-boxed' into products. Alois Holzer, the main workshop organizer, summarized that more information can be extracted from LI/GLM than previously expected by him. The LI bonus will not only be a better lightning coverage over the oceans. Regarding the "train the trainers" idea, it should be considered to invite US practitioners to the EUMETSAT-ESSL Testbeds to enable an easy exchange of forecaster experiences.

The most important outcome of the first LI expert workshop was a first draft of a "Proto Short Guide on the Use of MTG LI in Severe Convective Storm Forecasting" directed to forecasters as users.

5.3 ESSL-EUM expert workshop on storm top features as seen from satellite

This workshop from 5 to 7 September 2023 was held in hybrid mode and saw 11 participants from Europe, the USA, and Asia. Claudon, Houel and Moisselin from Météo-France presented the current version of storm top features in NWC SAF RDT. Cameron R. Homeyer from the University of Oklahoma presented that data fusion has demonstrated that derived cloud top products and key features (OTs & visible texture, mesoscale cloud-top AMVs, Enhanced Vs & above-anvil cirrus plumes) hold the most value for discriminating between severe and non-severe storms.

Figure 5-3. Hybrid (on site and online) discussions during the workshop.

Pao K. Wang from Taiwan discussed the main mechanisms responsible for observed storm top features. One of the key findings by Kris Bedka from NASA was that cross analysis with radar MESH indicates that the largest hail originates from updrafts that are colder, more prominent above the surrounding anvil, and wider than storms with smaller or non-existent hail.

Elisa Murillo, affiliated with NCAR, introduced a study that showed that the majority of AACP storms are severe, and the vast majority of significant severe weather is produced by AACP storms. Warm AACPs have a lower tropopause height and more frequent double tropopauses compared to the cold ones. Tomas Púčik from ESSL led a joint discussion of recent cases with interesting storm top features. The key workshop findings include:

- The temperature difference of the Overshooting Top (OT) dipole has a strong potential for both algorithms and manual nowcasting as a measure of updraft intensity and thereby severe weather potential.
- The size of the OT is another indicator of the severe weather potential, as wider updrafts are associated with stronger thunderstorms. It needs to be considered that the OT size detection is sensitive to the satellite resolution and to the used channel, it depends on the definition of the OT.
- There is a strong correlation between the existence of an Above Anvil Cirrus Plume (AACP) and large hail occurrence. For other convective hazards (strong wind events, heavy rain events, tornadoes) the correlation is much weaker. It is therefore difficult to predict strong wind and rain events from satellite data only, while to nowcasting potential for large hail is important.

5.4 ESSL-EUM Scoping Expert Workshop on early MTG imagery cases

This workshop was held on 14 and 15 November 2023. The participants discussed features visible in early pre-operational cases of MTG imagery. The format of the workshop didn't foresee classic talks or presentations but discussed uncalibrated MTG FCI test data cases of 13 July, 5 August, 2 October and 10 November 2023.

A fascinating example found in the Cloud Phase RGB of 13 July 2023 at 17:10 UTC over the Hungary-Serbia-Romania border region, was a signature of "deep blue eyes" present next to the main updraft cloud tower of an intense supercell. The interpretation of this signature was unclear. It could be related to large types of hydrometeors (raindrops, graupel or hail), or to shadow effects. In some examples of especially the larger deep blue areas, a shadow effect seems to be clearly present. In other examples, an influence of large hydrometeors cannot be ruled out.

Other topics discussed at the workshop included experimental ESSL Low Level Moisture imagery based on the 0.9 µm channel, detailed IR brightness temperature

structures, and partial side-views of severe convective storms, possible by the high resolution of the MTG FCI, when seen over high latitudes. The improved temporal and spatial resolution of infrared and visible imagery, as expected, allows for better detection and tracking of cloud top features related to severe convective storms, namely OTs, AACPs, cold Us/Vs and cold rings.

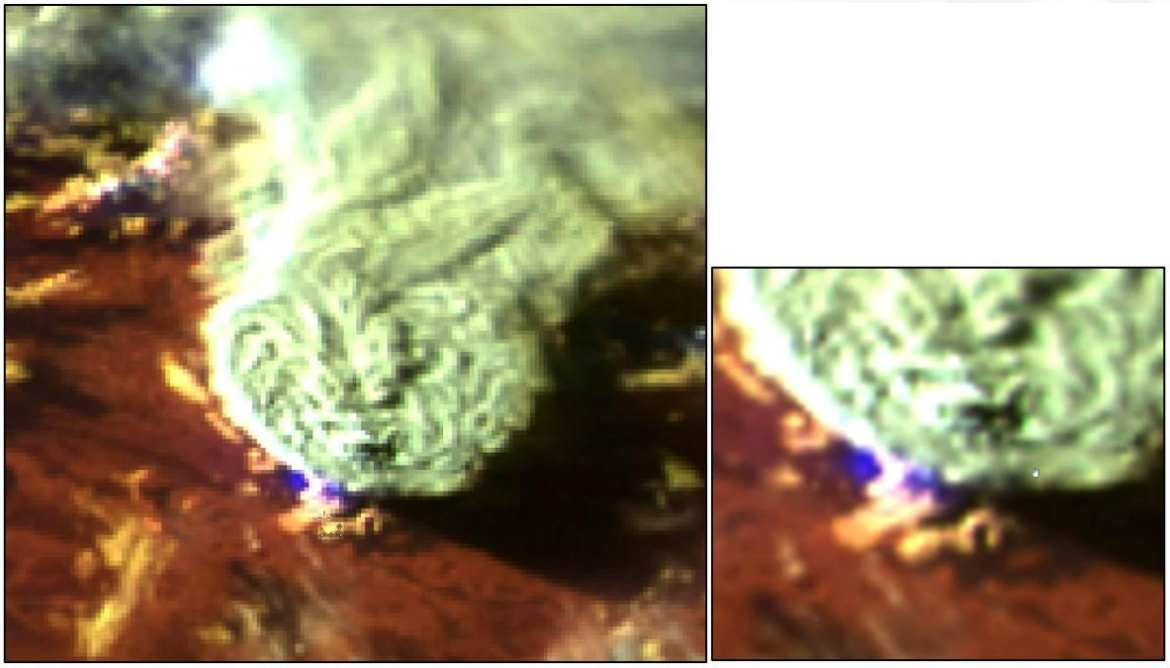

Figure 5-4. The "deep blue eyes" next to a storm updraft in FCI Cloud Phase RGB at 17:10 UTC on 15 July 2023 over the Hungary-Serbia-Romania border region, left without and right with smoothing.

5.5 ESSL Workshop on severe weather warnings

From 16 – 18 October 2023, the European Severe Storms Laboratory (ESSL) organized a workshop on weather warnings, bringing together 20 experts from various backgrounds, including weather forecasters, meteorology researchers, geo risk experts, a judge, and a philosopher. The primary challenges discussed related to the need for accurate, timely, and well-understood weather warnings.

Operational weather services consider the impacts of the adverse weather when issuing warnings, but this complexity can sometimes delay the warning process. In extreme events, a rudimentary impacts consideration based on default assumptions may be necessary to ensure timeliness. A presented study highlighted that while economic impacts are correlated with population density, human impacts are not, with most fatal severe weather-related events occurring in low-populated rural areas, possibly due to higher vulnerability, which has repercussions for warning decision making.

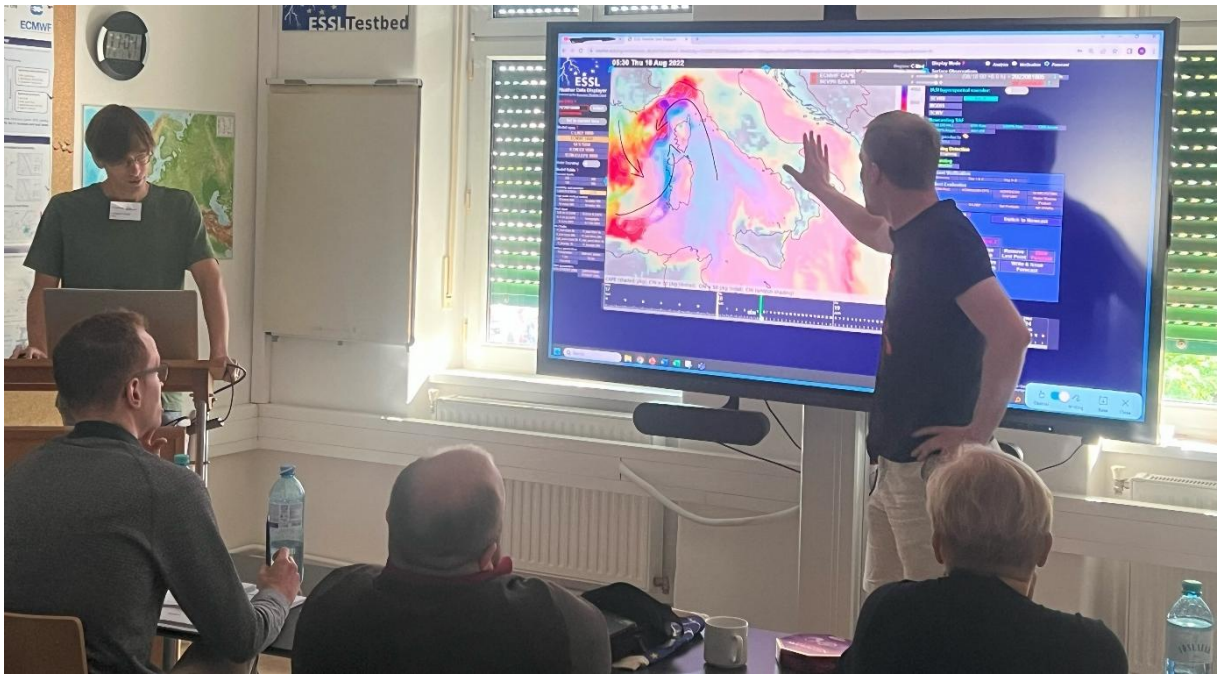

Figure 5-5. Discussion of a past severe weather case at the workshop.

Besides such considerations, the workshop identified several hurdles in the warning process, including the need for approval from higher management in some countries and time-consuming consultations with stakeholders in others, the necessity of which should be considered, especially for the most time-critical warnings.

A key conclusion was that different warning types are required for various timescales, where particularly rapid ones using cell-broadcast push-messages or public sirens may be considered for the most severe and fast developing hazards.

Regarding understanding, probabilistic information can lead to confusion, especially between area-related and pointwise probabilities. It was suggested that social science play an important role in improving warning communication clarity, emphasizing the use of well-understood language rather than technical terms or jargon.

The workshop proposed creating a document describing various warning types and their names to enhance international discussions. The question of whether the most impactful events should be warned at lower probability thresholds requires further discussion.

The full report is available here:

https://www.essl.org/cms/wp-content/uploads/ESSL-Report-2024-01.pdf

5.6 ESSL supports civil defence exercise

On July 5th ESSL represented by Alois Holzer, ESSL Director of Operations, supported a major civil defence exercise for the city and surrounding districts. Alois Holzer gave a lecture on tornado basics as a prelude for the management team of around 40 officials. The tornado scenario of the exercise concerned urban areas and the talk gave the

participating entities insight into the impacts of violent tornadoes. Recent events as well as some major historical cases were used to present possible threats and the sequence of events.

Figure 5-6. From left to right: Markus Biffl (Head of City Administration Wiener Neustadt), Alois M. Holzer (ESSL Director of Operations), Doris Hailzl (Head civil protection department and main organizer of exercise). Background: situation room for civil defence emergencies.

6 Publications and Communications

In 2023, ESSL employees contributed to 6 peer-reviewed publications, gave 26 oral presentations and several dozen interviews to written and broadcast media, presented 9 posters, and wrote 6 reports.

6.1 Peer-reviewed publications

* Authors employed or contracted by ESSL, or having an official function at ESSL are underlined.

Appearing in 2023:

- Battaglioli, F., P. Groenemeijer, I. Tsonevsky, and T. Púčik, 2023:
  Forecasting large hail and lightning using additive logistic regression models and the ECMWF reforecasts. *Nat. Hazards Earth Syst. Sci.*, **23**, 3651–3669, https://doi.org/10.5194/nhess-23-3651-2023

- Battaglioli, F., P. Groenemeijer, T. Púčik, M. Taszarek, U. Ulbrich, and H. Rust, 2023:
  Modelled multidecadal trends of lightning and (very) large hail in Europe and North America (1950–2021). *J. Appl. Meteor. Climatol.*, **62**, 1627–1653, https://doi.org/10.1175/JAMC-D-22-0195.1

Studies submitted in 2023, since having appeared in 2024:

- Púčik, T., D. Rýva, M. Staněk, M. Šinger, P. Groenemeijer, G. Pistotnik, R. Kaltenberger, M. Zich, J. Koláček, and A. Holzer, 2024:
  The violent tornado on 24 June 2021 in Czechia: damage survey, societal impacts and lessons learned. *Wea. Climate Soc.*, 16, 411–429. https://doi.org/10.1175/WCAS-D-23-0080.1

- Ghasemifard, H., P. Groenemeijer, T. Púčik and F. Battaglioli, 2024:
  Do changing circulation types raise the frequency of summertime thunderstorms and large hail in Europe? *Env. Research Climate,* **3**, 015008. https://doi.org/10.1088/2752-5295/ad22ec

- González-Alemán, J. J., D. Insua-Costa, E. Bazile, S. González-Herrero, M. M. Miglietta, P. Groenemeijer, and M. G. Donat, 2023:
  Anthropogenic Warming Had a Crucial Role in Triggering the Historic and Destructive Mediterranean Derecho in Summer 2022. *Bull. Amer. Meteor. Soc.*, **104**, E1526–E1532, https://doi.org/10.1175/BAMS-D-23-0119.1

- Wojciech, P., I. Laskowski, A. Surowiecki, E. Łupikasza, 2023**:** **Fatalities related to sudden meteorological events across Central Europe from 2010 to 2020**, *International Journal of Disaster Risk Reduction*, **88**, 103622. https://doi.org/10.1016/j.ijdrr.2023.103622.

Links to all peer-reviewed ESSL publications can be found on the ESSL website at https://www.essl.org/cms/publications/scientific-publications/.

6.2 Scientific and Invited Presentations

Oral presentations

1. Battaglioli, F., Groenemeijer, P., Púčik, T., Taszarek, M., Ulbrich, U., and Rust, H.: **Reconstructing Long-Term (1950-2021) Trends in Convective Hazards using Additive Logistic Regression Models**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-101, https://doi.org/10.5194/ecss2023-101, 2023.
2. Battaglioli, F., P. Groenemeijer, 2023: **Convective Hazard Evolution Under Climate Change (CHECC)**. ClimXtreme Kick-off Meeting, Teltow Stadt, Germany.
3. Ghasemifard, H., Groenemeijer, P., Púčik, T., and Battaglioli, F.: **Large-scale flow patterns and their relation to summer lightning in Europe**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-104, https://doi.org/10.5194/ecss2023-104, 2023.
4. González-Alemán, J.J., D. Insua-Costa, E. Bazile, S. González-Herrero, M. M. Miglietta, P. Groenemeijer, and M. G. Donat: **Attribution of the destructive Mediterranean derecho in 2022 to anthropogenic warming**, 3rd MedCyclones Workshop, 15–19 July, Frascati, Italy.
5. González-Alemán, J. J., Insua-Costa, D., Bazile, E., González-Herrero, S., Miglietta, M. M., Groenemeijer, P., and Donat, M. G.: **Relationship between anthropogenic climate change and the rare extreme derecho convective event over the Mediterranean Sea in summer 2022?**, EMS Annual Meeting 2023, Bratislava, Slovakia, 4–8 Sep 2023, EMS2023-333, https://doi.org/10.5194/ems2023-333, 2023.
6. González-Alemán, J.J., D. Insua-Costa, E. Bazile, S. González-Herrero, M. M. Miglietta, P. Groenemeijer, and M. G. Donat: **Attribution of the destructive Mediterranean derecho in 2022 to anthropogenic warming**, 17th Plinius Conference on Mediterranean Risks, Frascati, Italy, 18–21 October 2022.
7. Groenemeijer, P.: **Convection-permitting ensembles at the ESSL Testbeds**, Invited Presentation for EUMETNET Working Group on Short Range Numerical Weather Prediction, 8 – 9 February 2023, Rome, Italy.
8. Groenemeijer, P., A. M. Holzer, T. Púčik', T. Kühne: **Tornado and wind damage surveys: Survey strategy and the International Fujita scale Damage Survey Workshop**, Invited presentation at KNMI, 20 March 2023.
9. Groenemeijer, P., Holzer, A. M., Kühne, T., and Púčik, T.: **The International Fujita Scale and its implementation**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-151, https://doi.org/10.5194/ecss2023-151, 2023.
10. Groenemeijer, P., F. Battaglioli, and T. Púčik, 2023: **Stormforecast.eu: real-time automated forecasts for hail and lightning based on post-processed NWP**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023.

11. Groenemeijer, P.: **Deployment and migration of ESSL Weather Data Displayer in the European Weather Cloud**, European Weather Cloud User Workshop, 26 September, 2023.

12. Groenemeijer, P., A. M. Holzer, T. Púčik, and T. Kühne:
The International Fujita (IF) Scale, DWD Meeting on IF-scale, 6 November 2023.

13. Groenemeijer, P. and F. Battaglioli: **Severe convection in Europe: climate modelling and forecasting**, ARPA-L online seminar, 9 November 2023.

14. Holzer, A. M., Groenemeijer, P., Púčik, T., Bojinski, S., and Strelec-Mahović, N.:
EUMETSAT-ESSL Testbeds and Workshops for Meteosat Third Generation User Preparation, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-145, https://doi.org/10.5194/ecss2023-145, 2023.

15. Holzer, A., Austrian Climate Days (Österreichischer Klimatag) in Leoben, Austria, Conference Talk:
Adaptation-Beiträge des ESSL im Bereich konvektiver Unwetter, 12 April 2023

16. Holzer, A., Pre-ECSS lecture in Bucharest, Romania:
Media Communication of Meteorological Content, 7 May 2023

17. Holzer, A., ECSS talk in Bucharest, Romania: **EUMETSAT-ESSL Testbeds and Workshops for MTG User Preparation**, 12 May 2023

18. Holzer, A., EUMETSAT Conference in Malmö, Sweden: **EUMETSAT-ESSL Testbeds for MTG User Preparation**, 11 September 2023

19. Kühne, T., Antonescu, B., Groenemeijer, P., and Púčik, T.:
Lightning Fatalities in Europe (2001-2020), 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-146, https://doi.org/10.5194/ecss2023-146, 2023.

20. Púčik, T., Groenemeijer, P., Singer, M., Rýva, D., Stanek, M., Pistotnik, G., Kaltenberger, R., and Holzer, A.: **Damage survey, environment and storm-scale evolution of the giant hail and F4 tornado producing supercell on 24 June 2021**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-143, https://doi.org/10.5194/ecss2023-143, 2023.

21. Púčik, T., Groenemeijer, P., Taszarek, M., and Battaglioli, F.: **Pre-storm environments and storm-scale properties of the major hailstorms of 2021 and 2022 in Europe**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-124, https://doi.org/10.5194/ecss2023-124, 2023.

22. Tsonevsky, I., Groenemeijer, P., Battaglioli, F., and Púčik, T.: **Recent developments in convection forecasting at ECMWF**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-84, https://doi.org/10.5194/ecss2023-84, 2023.

23. Schreiner, T., 2023: **Die European Conference on Severe Storms (ECSS)**.
TSN Workshop 02 December 2023, Geosphere Austria, Wien.

24. Holzer, A., ESSL Weather Warning Workshop in Wiener Neustadt, Austria.
Where do people die in severe weather? A comparison with population density.
16 October 2023.

25. Holzer, A., Seminar of the Department of Integrated Sensor Systems at the University of Further Education Krems: **ESSL Klimaforschung und allgemeine Klimawandel-Basics**
25 October 2023.

26. Holzer, A., Seminar on the occasion of the official visit to Météo-France in Toulouse.
TIM - Thunderstorm Intensification from Mountains to Plains, High Density Field Campaign, 20 November 2023.

Poster presentations

27. Battaglioli, F., Groenemeijer, P., Tsonevsky, I., and Púčik, T.: **Forecasting Large Hail using Additive Logistic Regression Models and the ECMWF Reforecasts**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-103, https://doi.org/10.5194/ecss2023-103

28. Battaglioli, F., Púčik, T., Groenemeijer, P., and Taszarek, M.: **Identifying predictors of large hail, severe convective wind gusts, and tornadoes across Europe and North America: towards the development of global convective hazard models**. 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-128, https://doi.org/10.5194/ecss2023-128, 2023.

29. Groenemeijer, P., Battaglioli, F., and Púčik, T.: **Stormforecast.eu: real-time automated forecasts for hail and lightning based on post-processed NWP**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-169, https://doi.org/10.5194/ecss2023-169, 2023.

30. Kreitz, M., Gatzen, C., and Púčik, T.: **Analysis of the high-end derecho in Corsica in 2022**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-148, https://doi.org/10.5194/ecss2023-148, 2023.

31. Púčik, T., Groenemeijer, P., Taszarek, M., and Battaglioli, F.: **Pre-storm environments and storm-scale properties of the major hailstorms of 2021 and 2022 in Europe**. 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-124, https://doi.org/10.5194/ecss2023-124, 2023

32. Stanek, M., Salek M., Púčik T., Singer M., Rýva D., Horak J.: **The strongest tornado in modern Czech history.** 103rd AMS Annual meeting, Denver, Colorado, United States, 9 - 13 January 2023, https://ams.confex.com/ams/103ANNUAL/meetingapp.cgi/Paper/421188, 2023.

33. Surowiecki, A., Pilguj, N., Taszarek, M., Piasecki, K., and Púčik, T.: **Climatological aspects of quasi-linear convective systems across Europe**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-87, https://doi.org/10.5194/ecss2023-87, 2023.

34. Taszarek, M., Groenemeijer, P., Púčik, T., van der Velde, O., and Dafis, S.: **Evaluation of ESTOFEX convective outlooks from 2007 to 2021. Part 2: climatology and reliability of threat level polygons**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-167, https://doi.org/10.5194/ecss2023-167, 2023.

35. Ulbrich, S., Zschenderlein, P., Rempel, M., de Lozar, A., Púčik, T., and Blahak, U.: **Tornado in Czech Republic – An ICON-RUC case study**, 11th European Conference on Severe Storms, Bucharest, Romania, 8–12 May 2023, ECSS2023-138, https://doi.org/10.5194/ecss2023-138, 2023.

6.3 Reports and other publications

- Holzer, Alois and coauthors: **ESSL Expert Workshop on Severe Weather Warnings: from Expectations via Physical Ingredients to Impact-based Warnings and Beyond**, ESSL Report 2024/01 (link**)**.
- Christoph Gatzen, Tomáš Púčik, and Pieter Groenemeijer**:** **Report on the evaluation of DWD nowcast and warning products at the ESSL Testbed 2023,** ESSL Report 2023/02 (link).
- Holzer, Alois and coauthors: **Summary of the EUMETSAT-ESSL Expert Workshop on GOES-GLM and MTG-LI**, report commissioned by EUMETSAT**.**
- Holzer, Alois and coauthors: **Proto Short Guide on the Use of MTG LI in Severe Convective Storm Forecasting (version 1)**, commissioned by EUMETSAT.

- Holzer, Alois and coauthors: **Summary of the EUMETSAT-ESSL Expert Workshop on storm top features as seen from satellite,** report commissioned by EUMETSAT.
- Holzer, Alois and coauthors: **Summary of the EUMETSAT-ESSL Scoping Expert Workshop on early MTG imagery cases**, report commissioned by EUMETSAT.

6.4 Notable press communications and outreach activities

Bogdan Antonescu:

- Interview for "Planeta ești tu!" (Digi24, TV show) on the extreme events of 2022. 1 January.
- Interview for Digi24 (TV nrws) on tornadoes and climate change. 28 March.
- Interview for "Planeta ești tu!" (Digi24, TV show) on tornadoes and climate change. 2 April.
- Interview for Ecofrecvența (Radio France International) on extreme weather events and climate change. 5 May.
- Interview for Digi24 (TV news) on extreme weather events in Europe / ESTOFEX forecast. 13 July.
- 21 July interview for TVR Info (TV show) on climate change and extreme weather. 21 July.
- Interview for B1(TV news) on climate change and extreme weather. 22 July.
- Interview for Antena3 (TV news) on extreme weather events and climate change. 13 September.
- Newspaper article on tornadoes in Romania for HotNews (online newspaper). 19 November.
- Podcast with Cristian Presură - Schimbări Climatice și Fenomene Extreme în România. 13 December.

Francesco Battaglioli:

- Interview for Newspaper Il Dolomiti: Rispetto agli anni '50 le grandinate sul Nord Italia sono triplicate, gli esperti: "Fenomeni sempre più violenti e legati ai cambiamenti climatici", 22 July 2023. https://www.ildolomiti.it/ambiente/2023/rispetto-agli-anni-%E2%80%9850-le-grandinate-sul-nord-italia-sono-triplicate-gli-esperti-fenomeni-sempre-piu-violenti-e-legati-ai-cambiamenti-climatici
- Interview for Magazine Focus: Cade sempre più grandine in Europa e in Italia . Perché? E come difendersi?, 5 July 2023. https://www.focus.it/scienza/scienze/perche-cade-sempre-piu-grandine-in-Europa-e-nord-Italia

Pieter Groenemeijer:

- Liveblog Storm Poly, De Volkskrant, 5 July 2023. https://www.volkskrant.nl/nieuws-achtergrond/live-ook-donderdag-nog-problemen-op-het-spoor-meldt-de-ns-treinverkeer-op-sommige-trajecten-hervat~bd7a13e3/
- Past deze zomerstorm in een klimaattrend? Dat valt niet te zeggen, NRC, 5 July 2023. https://www.nrc.nl/nieuws/2023/07/05/past-deze-zomerstorm-in-een-klimaattrend-dat-valt-niet-te-zeggen-a4169017?t=1722442437
- Hagel: Geschosse aus Eis, Viola Kiel, Zeit Online, 29 August 2023. https://www.zeit.de/wissen/umwelt/2023-08/hagel-extremwetter-klimawandel-haeufigkeit-groesse/komplettansicht
- Ken uw wolk, De Volkskrant, 22 July 2023. https://www.volkskrant.nl/kijkverder/v/2023/ken-uw-wolk~v791506/
- Het was de warmste zomer ooit. Wat gebeurde er precies? Maarten Keulemans, De Volkskrant, 7 Sept 2023. https://www.volkskrant.nl/kijkverder/v/2023/dit-was-de-warmste-zomer-ooit-wat-gebeurde-er-precies~v889571/
- Warum Hagel häufiger und heftiger wird, Der Standard, 31 July 2023. https://www.derstandard.de/story/3000000181096/warum-hagel-haeufiger-und-heftiger-wird
- Here's why the US has more tornadoes than any other country, Allison Chinchar, CNN, 17 December 2023. https://edition.cnn.com/weather/us-leads-tornado-numbers-tornado-alley-xpn/index.html

Alois M. Holzer:

- Online presentation to a number of parties interested in TIM "TIM - Thunderstorm Intensification from Mountains to Plains, High Density Field Campaign", 12 February 2023.
- Introductory words on the occasion of an official ESSL visit at the situation room of the civil defence and firefighters in Amstetten in western Lower Austria. Title: "Überblick über die Aktivitäten des ESSL", 20 February 2023.
- Overview talk on the occasion of the official visit of the head of the civil defence department of the City of Wiener Neustadt, "The EUMETSAT-ESSL Testbed and other ESSL activities", 30 March 2023.
- EUMETSAT-ESSL Annual Online Forecaster Event. Talk: "Expert Workshops and the EUMETSAT-ESSL Testbed 2022", 20 April 2023.
- Regional Newspaper NÖN Title of the article: Experte erklärt: "Niederösterreich ist anfällig für Tornados", 9 May 2023. https://www.noen.at/niederoesterreich/chronik-gericht/naturgewalten-experte-erklaert-niederoesterreich-ist-anfaellig-fuer-tornados-366575756
- Online talk for the CGSlabs webinar hosted by CGSlabs in Ljubljana, Slovenia: "Statistics of extreme weather events in Europe and their impacts", 1 June 2023.
- Introductory talk at the civil defense exercise for the City of Wiener Neustadt and surrounding districts. Title: "Tornados - ein Überblick", 5 July 2023.
- News of the association Skywarn Austria. Article on the cooperation with ESSL: "Infos über Zusammenarbeit mit dem ESSL", 10 October 2023. https://www.skywarn.at/?cat=32

Tomáš Púčik:

- Interview on hail climatology. ZIB Magazin Klima, 1 July 2023.

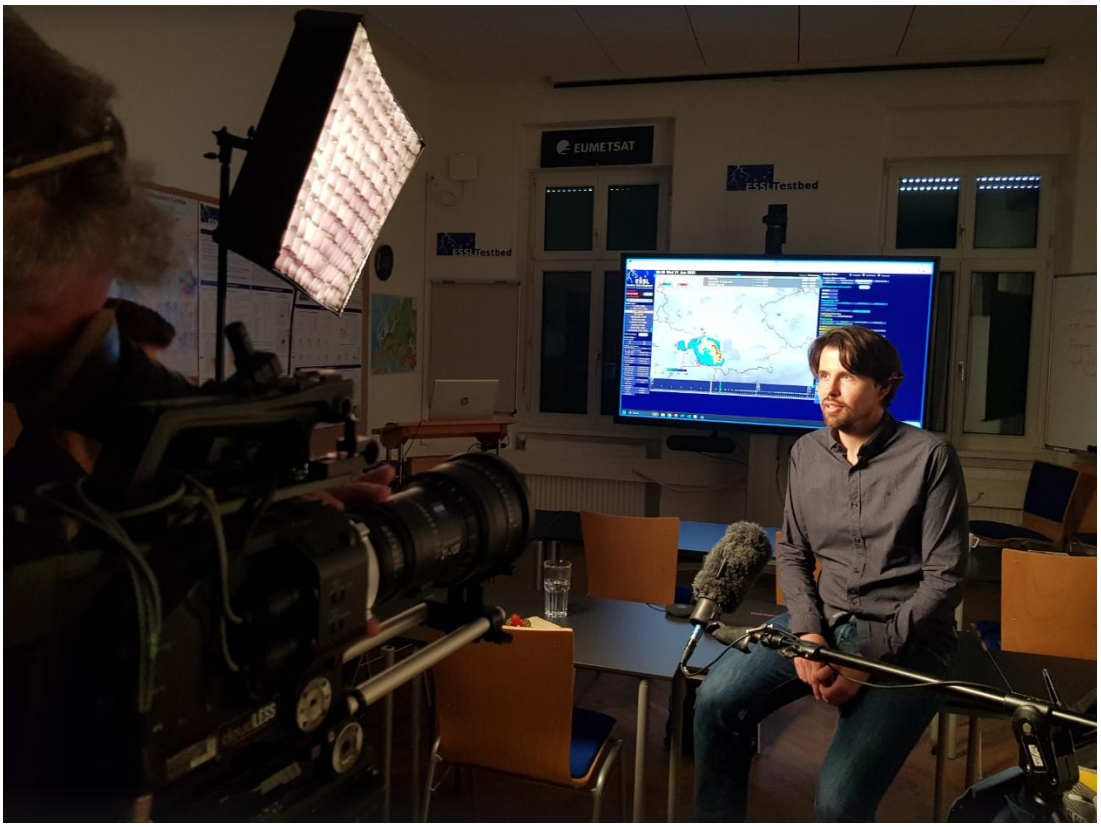

Figure 6-1. Tomáš Púčik being interviewed for ORF television.

6.5 Outreach and social Media

In addition to the publications above, ESSL sent out 5 Newsletters to its members, and newsletter subscribers. On social media, ESSL is active on LinkedIn, Facebook and X, where ESSL posts and shares news regarding ESSL's research, Testbed, training and other activities. LinkedIn which was launched in 2022 already reached approximately 2000 followers while the number of X account followers increases every year and is currently around 4277 followers (301 more followers than a year ago).

On LinkedIn ESSL mostly posts topics connected to research and our partnership with other meteorological organizations or companies involved with convection, climate change, insurance or similar activities that overlap with ESSL core interest. About 25 posts were published on LinkedIn, 12 posts on Facebook and 23 times ESSL tweeted a message on X platform in 2023. In addition, ESSL also retweeted many different messages from its employees. ESSL's Facebook and Twitter accounts have over 10 000 and 4 300 followers respectively.

By far the greatest reach of the ESSL posts on social media was related to the announcement of record-breaking hailstorms between 19 and 25 July 2023. The first announcement of the hail record broken on 19 July was reposted 300 times on Facebook, while the second announcement of the hail record broken on 24 July was reposted a whopping 1833 times. On Twitter, the hail record announcement was reposted 242 times with over 158,000 impressions and over 12,500 engagements. On LinkedIn it reached 3,724 impressions and was reposted 42 times. The announcements of the hail records were also spread as press releases and were published in journals across many European countries. A large audience also looked at the post concerning the damaging hailstorms of 2022. Hail has become an attractive topic in Europe! The post was linked to the blog on the topic. ESSL has published 11 news items on its webpage.

Figure 6-2. Hail record post on X, formerly Twitter.

7 Financial and Administrative Report

7.1 ESSL Diversity Policy and Gender Equality Plan

In 2023, the ESSL Executive Board decided on a Diversity Policy and Gender Equality Plan, which apply to both ESSL legal bodies. Such a plan is not only good for ensuring that there is an agreement on how ESSL as an organisation sees matters but is also required by some funding agencies. Indeed, for ESSL an important continuing challenge is to make sure a good gender balance exists among the personnel. But this is only one of many aspects covered by the Diversity Policy and Gender Equality Plan which is available on the ESSL website.

Among other items, the plan also formulates the roles of Equality Officer and Confidant, which have since been taken up by Katja Dorninger and Michou Baart de la Faille, respectively. The confidant can be approached confidentially by employees to discuss any work-related matters, while the Equality office will monitor the situation regarding diversity and equality within ESSL. Furthermore, the plan foresees annual meetings between employees and their supervisor on their work situation to be held in a structured way, with notes being taken to follow up on returning items from year to year. The aim of the plan is to create a healthy and happy work situation for all ESSL's employees.

7.2 Employment and Payroll Accounting

In 2023, the German non-profit research association "European Severe Storms Laboratory e.V." (ESSL e.V.) employed two full time employees (researchers for the project ClimXtreme), two part-time employees (ESWD quality control manager, testbed/training expert), and one so-called "Mini-Jobber" (for database programming), a form of minor employment according to German law. The Austrian non-profit research association "European Severe Storms Laboratory – Science and Training" (ESSL-ST) employed three full time employees (Senior Trainer and PreCAST Researcher, ESSL Director, ESSL Director of Operations), two part-time employees (Assistant to the Board, Senior Project Advisor and Head of External Relations), two minor employments (ESWD quality control support and ESWD user support). Other tasks were taken over by voluntary workers (i.e., without payment) most importantly the tasks of the three Deputy Directors.

As in previous years, external payroll accountants (Andreas Schnaubelt in Schongau, Bavaria for ESSL e.V. in Germany and Gneist Consulting Team Steuerberatungs GmbH in Wiener Neustadt for ESSL-ST in Austria) were mandated to take care of paperwork and bureaucratic handling of taxes and social insurances, which would otherwise have exceeded ESSL's internal administrative capacity.

7.3 Auditing of the Annual Accounts

In accordance with the Articles of Association, ESSL e.V.'s finances for 2023 were audited by the ESSL Advisory Council, based on the report on the annual accounts prepared by ESSL's tax advisor, Mr. Andreas Schnaubelt, Loewenstrasse 5, 86956 Schongau, Germany. This report states:

"Record of Income and Expenses

During our work no indications occurred which would give raise for objections against the correctness of the record.

Financial Statements

During our work no indications occurred which would give raise for objections against the correctness of the financial statements."

For ESSL-ST, the science funding agency of the government of Lower Austria requires a yearly external audit, which was done by WNW Scheicher & Partner GmbH Wirtschaftsprüfer in Wiener Neustadt. This external audit was done independently from and in addition to the audit by the two association-internal auditors foreseen by the legislation for each association in Austria.

The external auditor stated under the header "Determination of the legality of the financial statements" (translation from German original):

"During our audit procedures, we ascertained compliance with the legal provisions and supplementary provisions of the association's statutes. In the performance of our duties as auditors, we have not identified any facts that may jeopardize the existence of the audited association or significantly impair its development, or that indicate serious violations of the law or the association's statutes by the management body or employees. No material weaknesses in the internal control of the accounting process have come to our attention."

7.4 Organizational relationship between the two legal ESSL entities

ESSL consists of two legal entities, the "European Severe Storms Laboratory e.V.", in short ESSL e.V. (a non-profit association with seat in Weßling near Munich, Germany), and the "European Severe Storms Laboratory – Science and Training", in short ESSL-ST (a non-profit association with seat in Wiener Neustadt, Austria). The latter can be seen as a subsidiary and forms the legal body for the ESSL Research and Training Centre and its related activities like the ESSL Testbed.

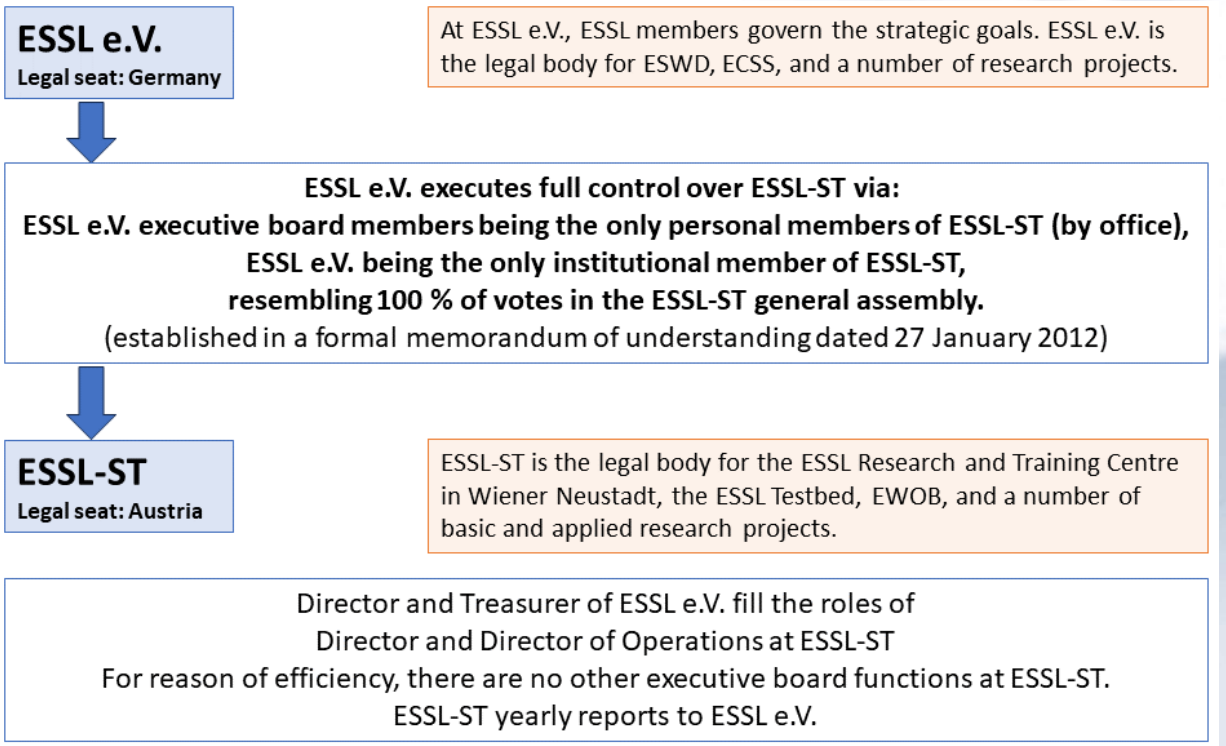

Figure 7-1. Schematic overview of the relationship between the two legal bodies of ESSL.

7.5 Financial Status 2023

European Severe Storms Laboratory e.V.

The accounting year was dominated by income from membership fees and basic as well as applied research projects. The detailed Annual Accounts were presented to the ESSL Advisory Council and can be inspected in their original format and in person by each member at our secretariat. Digital copies of the full document can be requested from the ESSL Treasurer by ESSL members. Attachment A1 provides a condensed version of these Annual Accounts.

As required by the German tax authorities, in the detailed accounting 'cost centres' distinguish between the ideational branch of ESSL (*Idealistic Purpose*, i.e., management of the association and its core activities) and its branches directly serving the statutory purposes of the ESSL (*dedicated activities*). No activities were booked under the commercial type of branch (*economic activities*; minor activities of this kind would have been permissible), thus fulfilling the requirements of the tax authorities.

The following key figures from the Annual Accounts characterize the business conditions in 2023:

ESSL e.V. obtained € 246,963 from institutional membership fees and ESWD data fees, € 147,000 from applied research, € 103,838 from the CHECC project funded by the German Ministry of Research, and € 64,441 from scientific meetings (ECSS). We are

thankful for personal membership fees of € 3,520 and donations of € 150, underlining the worth of ESSL activities for the severe weather community.

Total income amounts to **€ 580,728** (2022: € 354,728).

Total expenses amount to **€ 485,372** (2022: € 353,923).

The dominant cost factors were direct personnel costs with € 208,979, including taxes and social security; external costs related to scientific meetings (ECSS) of € 75,740; third party personnel lumpsums by ESSL-ST with € 60,000; office, IT and server costs shared with ESSL-ST € 51,796; other third-party and database services with € 31,223, and travel expenses with € 13,397.

The tight cooperation with the Austria-based association "European Severe Storms Laboratory – Science and Training" reduces costs for administrative work substantially since common services and their associated costs are shared between the two associations. Personnel costs for management and administration were paid through this ESSL subsidiary at first hand.

At the end of the business year, liquid assets at ESSL's bank accounts amounted to € 123,426 (2022: € 50,387). At the end of the year, accounts receivables amounted to € 822 (2022: € 0), deferred expenses (payments made for future accounting periods) to € 1,180 (2022: € 11,905), deferred income (payments received for future accounting periods) to € 13,000 (2022: € 25,000). Comparing liquid assets with mean monthly expenses it can be seen that ESSL e.V. was ending the business year with a small liquidity reserve for about 3 months only.

The annual operating result is a positive € 95,356 (compare: positive € 805 in 2022). A reserve for operating expenses (for the period before the membership fees are received in the following year) of € 83,030 was depicted in the "Assets and Liabilities" of ESSL e.V., and a free reserve of € 9,226 according to the legal and ESSL internal regulations. Due to retained earnings brought forward of 37,734, the remaining result of the year 2023 is € 0 (zero).

The financial planning for 2024 foresees enough liquidity until the end of the year with a stable income situation based on the project CHECC-II, and membership fee income.

European Severe Storms Laboratory - Science and Training

The annual accounts of the subsidiary association "European Severe Storms Laboratory – Science and Training" (ESSL-ST) can be summarized as follows:

At the end of the business year, liquid assets at its bank accounts amounted to € 200,555 (2022: € 126,873). The raw positive annual operating result is € 73,682 (2022: € 1,469.). The reserve for operating expenses for the ESSL Testbed (necessary, as important payments are only received after the testbed towards the end of the accounting year) was depicted as an amount of € 193,000. Comparing liquid assets with mean monthly

expenses it can be seen that ESSL-ST was ending the business year with a small liquidity reserve for about 4 months. The remaining result of the year 2023 is a positive € 682.

The main income source in 2023 was the ESSL Testbed with € 203,462 including the larger contributions from DWD and ECMWF. The cooperation on ESSL-EUMETSAT Testbeds and Expert Workshops related to the MTG User Preparation (EUMETSAT framework contract) resulted in income of € 151,285. Public project funding from the Austrian national science fund (FWF) amounted to € 78,977 (PreCAST project). This project funding undergoes an automatic yearly inflation adaptation, which is seen as a fair dealing, as salaries are increased by inflation too.

Mirroring the expenses at ESSL e.V., income at ESSL-ST from third party personnel lumpsums by ESSL e.V. amounts to € 60,000; office, IT and server costs shared with ESSL-ST to € 51,797. The only basic public funding ESSL is receiving amounts to € 46,107 (Government of Lower Austria – "Förderung Land NÖ Abt. Wiss. u. F."). The project on new lightning sensors with the Department of Integrated Sensor Systems (Univ. Krems) results in income of € 45,816, income from courses and trainings in income of € 32,055.

The main cost factors were personnel costs with € 433,466, direct Testbed expenses with € 55,856, office rent, seminar space rent and insurance with € 39,000, and travel costs with € 29,601.

Total income of € 686,684 (2022: € 547,216) meets total expenses of € 611,747 (2022: € 542,647). Thereby, the necessary liquidity reserve for operating expenses in the first months of the following year could be endowed as specified above. A tabular overview is provided in Appendix A1.

The financial planning for 2024 foresees a near neutral annual result.

7.6 ESSL Members

Members are at the core of ESSL and provide essential support to ESSL activities. Membership fees form an important source of income for ESSL. However, ESSL members are also important in catalysing the pursuit of the Association's goals. This type of support is sometimes provided in-kind and sometimes through financial support. In 2023, ESSL was happy to welcome a new institutional full member: Météo-France, the national meteorological service of France. The full member list as of 31 December 2023 can be found in Appendix A2.

7.7 Executive Board and Advisory Council

The Executive Board, the Advisory Council, and the General Assembly, which consists of all full members, constitute the three bodies forming the ESSL e.V.. Figure Figure 7-2 outlines some of their main responsibilities.

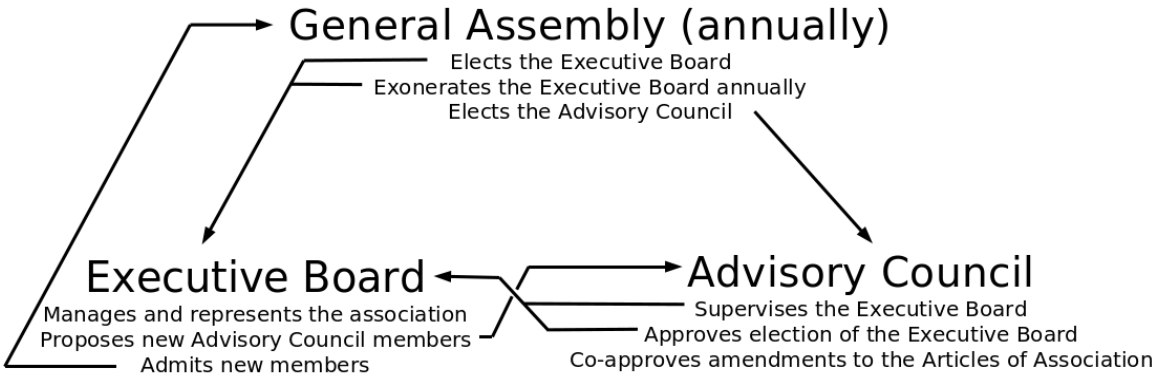

Figure 7-2. Bodies of the ESSL. The Advisory Council consists of six members from two groups - three members each: (1) Science, (2) NMHS / EUMETNET.

Executive Board

In 2023, the Executive Board consisted of:

Dr Pieter Groenemeijer, Director

Dr Bogdan Antonescu, Deputy Director

Ms Michou Baart de la Faille, Deputy Director

Dr Tanja Renko, Deputy Director

Mr Alois M. Holzer, Treasurer

These Executive Board members are elected for a term until 31 December 2024.

Advisory Council

In 2023, the Advisory Council consisted of:

Dr Martin Benko, chair (SHMÚ, Slovak Hydrometeorological Institute)
1 Jan. 2020 - 31 Dec. 2023 (second term)

Dr Marina Baldi (National Research Council, Italy)
1 Jan. 2021 – 31 Dec. 2024 (second term)

Dr Yvette Richardson (Penn State University, USA)
1 Jan. 2021 – 31 Dec. 2024 (second term)

Dr Sorin Cheval (University of Bucharest, Romania)
1 Jan. 2021 – 31 Dec. 2024 (second term)

Dr Uwe Ulbrich (Freie Universität Berlin, Germany)
1 Jan. 2020 – 31 Dec. 2023 (second term)

Mr Thomas Kratzsch, (DWD, Deutscher Wetterdienst, Germany)
1 Jan. 2023 - 31 Dec. 2026 (second term)

Appendix A1: Annual Accounts

The following presents in extract a copy of the "*Report on the Preparation of the Financial Statements for 2023*", as prepared by the financial auditor in Germany for ESSL e.V. (this page, figures of the previous years were added for comparison), and also the annual accounts as audited by the external auditor in Austria for ESSL-ST (next page).

European Severe Storms Laboratory e. V., Weßling

Income and Expenses

	2023	2022	2021
INCOME			
Membership fees institutional members and ESWD data fees	246.963,00	210.082,00	163.306,60
Membership fees personal members	3.520,00	3.995,00	3.805,00
Income from scientific meetings (ECSS)	64.441,75	0,00	0,00
Public project funding Federal Republic of Germany	103.838,01	134.000,00	94.000,00
Public project funding European Union	0,00	0,00	0,00
Applied research	147.000,00	0,00	0,00
Donations	150,00	355,00	1.005,00
German VAT on sales and refunds	14.815,50	6.296,50	0,00
Total income	**580.728,26**	**354.728,50**	**262.116,60**
EXPENSES			
Personnel	208.979,81	203.955,96	154.404,99
Depreciations	3.220,90	2.638,00	3.323,00
Costs related to scientific meetings (ECSS)	75.740,52	0,00	0,00
Travel costs	13.397,04	13.783,41	333,56
Office costs and insurance	316,44	180,93	2.091,98
Phone and data (internet) services	1.703,52	3.357,82	2.097,50
Tax advisor including software	6.209,26	3.866,08	5.865,00
Third party services by ESSL Science and Training, Austria			
Director and administration personnel lumpsum	60.000,00	60.000,00	60.000,00
Office, IT and server costs	51.796,54	30.756,81	22.684,33
Other third party services / data base service	31.223,65	21.495,00	
Value added tax	18.042,22	4.495,37	3.870,67
Third party services and other	14.742,41	9.393,86	6.491,33
Total expenses	**485.372,31**	**353.923,24**	**261.162,36**
Operating result	**95.355,95**	**805,26**	**954,24**

Assets and Liabilities

	2023	2022	2021
Fixed Assets (office equipment)	19.996,00	2.305,00	2.768,00
Current Assets			
Receivables	822,46	0,00	0,00
Bank balances	123.426,14	50.386,51	54.443,06
Deferred Expenses	1.179,75	11.904,98	1.500,00
Assets total	**145.424,35**	**64.596,49**	**58.711,06**
Equity (own capital)			
Retained earnings brought forward	37.734,37	36.929,11	35.974,87
Reserve for operating expenses	83.029,95	0,00	0,00
Free reserve	9.225,55	0,00	0,00
Remaining result of the year	0,00	805,26	954,24
Deferred Income	13.000,00	25.000,00	20.000,00
Liabilities	2.434,48	1.862,12	1.781,95
Equity and Liabilities total	**145.424,35**	**64.596,49**	**58.711,06**

European Severe Storms Laboratory - Science and Training Cost centres overview 2023		
	Income	**Expenses**
General business	- €	- 15,524.61 €
Membership fees and donations	4,889.31 €	- 500.00 €
Rent and insurance	4,663.59 €	- 39,000.26 €
Phone and internet	54.16 €	- 7,501.95 €
Testbed	7,571.68 €	- 55,856.41 €
DWD Testing, ECMWF	203,462.00 €	- €
EUMETSAT framework contract	151,285.00 €	- €
Seminars	32,054.98 €	- 2,901.26 €
Salaries (income: lump sums from ESSLeV)	60,000.00 €	- 433,465.71 €
Payroll accounting, tax advisor, external auditor	- €	- 8,175.47 €
Travel costs	2.40 €	- 29,601.43 €
Cost sharing with ESSLeV (infrastructure)	51,796.54 €	- €
Energy supply	- €	- 8,326.92 €
Asset management	5.09 €	- 578.65 €
PreCAST project	78,976.66 €	- €
Lightning sensor project	45,815.85 €	- €
ESWD and EWOB	- €	- 7,012.74 €
ECSS	- €	- 3,301.46 €
Public basic funding, Government of Lower Austria	46,107.18 €	- €
Totals	686,684.44 €	- 611,746.87 €

Cost centres overview irrespective of neutral bookings.

Annual Accounts	**1 Jan 2023**	**31 Dec 2023**
Bank accounts (very short term liquidity)	126,873.41 €	200,555.49 €
Savings (short and mid term liquidity)	39,238.00 €	42,596.00 €
Fixed Assets (corrected from 65,932.64 to 64,532.87 for 2022)	64,532.87 €	69,784.22 €
Total Assets	230,644.28 €	312,935.71 €
Annual operating result		**73,682.08 €**

Endowment of reserve for operating expenses 2024	73,000.00 €
Remaining positive result	**682.08 €**

Total reserve for operating expenses on 1 Jan. 2023	120,000.00 €
New total reserve for operating expenses on 31 Dec. 2023	193,000.00 €

Appendix A2: Member list 2023

The following table shows all ESSL members as of 31 December 2023, sorted according to their ESSL-ID (which corresponds in ascending order to the beginning date of the ESSL membership). Members joining ESSL in 2023 have an * next to their names. The founding members who are still members are *printed in italic font*. The given country corresponds to the main residence or statutory seat, not necessarily their nationality.

Individual Full members

Dr. Bernold Feuerstein	*GERMANY*	Erik Dirksen	GERMANY
Dr. Pieter Groenemeijer	*NETHERLANDS*	Dr. Christoph Gatzen	GERMANY
Alois M. Holzer	*AUSTRIA*	Dr. Kathrin Riemann-Campe	GERMANY
Dr. Romualdo Romero	*SPAIN*	Dr. Koji Sassa	JAPAN
Dr. Fulvio Stel	*ITALY*	Dr. Tomáš Púčik	AUSTRIA
Jenni Rauhala	*FINLAND*	Marcus Beyer	GERMANY
Thilo Kühne	GERMANY	Dr. Lisa Schielicke	GERMANY
Helge Tuschy	GERMANY	Dr. Abdullah Kahraman	UK
Zhongjian Liang	GERMANY	Dr. John Allen	USA
Lionel Peyraud	SWITZERLAND	Dr. Anja T. Rädler	GERMANY
Thomas Krennert	AUSTRIA	Dr. Darrel Kingfield	USA
Dr. Johannes Dahl	USA	Stavros Dafis, PhD	FRANCE
Martin Hubrig	GERMANY	Michou Baart de la Faille	NETHERLANDS
Dr. Oliver Schlenczek	GERMANY	Dr. Jannick Fischer	GERMANY
Dr. Victor Homar Santaner	SPAIN	Dr. Tanja Renko	CROATIA
Dr. Bogdan Antonescu	ROMANIA	Dr. Mateusz Taszarek	POLAND
Dr. Michael Kunz	GERMANY		

Individual Supporting Members

Casper ter Kuile	NETHERLANDS	Jan Jacob Groenemeijer	NETHERLANDS

Institutional Full Members

DWD, Deutscher Wetterdienst	GERMANY
EUMETSAT	GERMANY
AUSTRO CONTROL	AUSTRIA
GeoSphere Austria, previously Zentralanstalt für Meteorologie u. Geodynamik	AUSTRIA
NMA, National Meteorological Administration of Romania	ROMANIA
FMI, Finnish Meteorological Institute	FINLAND
CHMI, Czech Hydrometeorological Institute	CZECHIA
Institute for Hydrometeorology and Seismology of Montenegro	MONTENEGRO
DHMZ, Meteorological and Hydrological Service of Croatia	CROATIA
SHMÚ, Slovak Hydrometeorological Institute	SLOVAKIA
Consorzio LaMMA	ITALY
KNMI, Royal Netherlands Meteorological Institute	NETHERLANDS
ECMWF, European Centre for Medium-Range Weather Forecasts	INTERNATIONAL
Croatia Control, Croatian Air Navigation Services, Ltd	CROATIA
Cyprus Department of Meteorology	CYPRUS
RHMSS – Republic Hydrometeorological Service of Serbia	SERBIA
Institute for Meteorology and Climate Research	GERMANY
Met Office	UNITED KINGDOM

ARPAL – Agenzia Regionale per la Protezione dell'Ambiente Ligure	ITALY
TLUBN – Thüringer Landesamt für Umwelt, Bergbau und Naturschutz	GERMANY
IMGW–PIB, Institute for Meteorology and Water Management	POLAND
Dep. of Economics & Management "Marco Fanno", Università di Padova	ITALY
Met Éireann	IRELAND
Università di Genoa	ITALY
Fondazione CMCC	ITALY
Météo-France*	FRANCE

Institutional Supporting Members

Münchener Rückversicherungs-Gesellschaft AG	GERMANY
Gallagher Re	UNITED KINGDOM
Deutsche Rückversicherung	GERMANY
Marsh Ltd per Guy Carpenter Limited	UNITED KINGDOM
RMS - Risk Management Solutions	UNITED KINGDOM
Renaissance RE Services Ltd	BERMUDA
Factory Mutual Insurance Company - FM Global	USA
Nowcast GmbH	GERMANY
Impact Forecasting LLC - AON Central and Eastern Europe a.s.	CZECH REPUBLIC
Arcturus B.V.	NETHERLANDS
Descartes Underwriting	FRANCE
riskine GmbH	AUSTRIA
FCM - Fermat Capital Management, LLC	USA
GreenTriangle AG	SWITZERLAND
Genillard & Co GmbH	GERMANY
Banca d'Italia	ITALY
RED (Risk, Engineering and Development) SpA	ITALY
Monarch Weather Consulting	USA
A multinational financial services company	GERMANY
KD auto S.r.o. *	SLOVAKIA
PriceWaterhouseCoopers GmbH Wirtschaftsprüfungsgesellschaft*	GERMANY
Partner Reinsurance Europe SE Zurich Branch*	SWITZERLAND
Inova Autoservices Group SA*	SWITZERLAND
ALTACON d.o.o.*	CROATIA
Mitiga Solutions SL*	SPAIN
HOGO Rückversicherungsmakler- und beratung GmbH *	AUSTRIA
Gro Holdings, LLC*	USA

Honorary Members

Birgit Büsing	GERMANY
Gregor Dotzek	GERMANY
Armin Dotzek	GERMANY
Dr. Charles A. Doswell III	USA

ESSL has a partnership with the European Meteorological Society (EMS) through a Memorandum of Understanding, is member of the Climate Change Center Austria, and a participating organization in the GEO Group on Earth Observations.