Annual Report 2022

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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V.A.T. Number: DE 252519763

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Foreword

Dear Reader,

2022 is a year I look back to with satisfaction, as far as ESSL is concerned. After teaching two forecaster courses online in spring, we were happy the relaxation of COVID restrictions allowed us to welcome participants in person again to ESSL courses and workshops. We could proudly show them our refurbished and expanded Research and Training Centre in Wiener Neustadt, which is now suited for larger groups than before.

The new facilities were used to host several workshops and to organize the ESSL Testbed. Some of the workshops were part of ESSL's continuing collaboration with EUMETSAT to prepare forecasters for the Meteosat Third Generation (MTG) geostationary satellites. During workshops on moisture detection, storm top features, and satellite-based nowcasting tools, select groups of experts discussed the strategy of providing optimal training for MTG to European forecasters. At another dedicated workshop, we made significant progress with the development of the International Fujita scale, which has since, in 2023 been finalized. An overview of these events is presented in Section 4.

We also organized a new edition of the ESSL Testbed, which in 2022 took place in five different weeks, one of them -for the first time- in autumn. Three of those weeks were organised jointly with EUMETSAT and had a relatively strong focus on satellite products, while in other weeks participants focused on evaluating the use of nowcasting and warning tools, and short-range numerical weather prediction, as a range of products from the German Weather Service, DWD, was featured among others.

Weatherwise, 2022 featured a number of remarkable severe weather events. The year started with a series of windstorms affecting the British Isles, Benelux, Germany, and Poland in February, one of which boasted a cold front producing an outbreak of tornadoes in Poland. Regarding hail, 2022 turned out to be even more active than the already particularly active 2021 hail season. Along the periphery of a high pressure ridge across the western Mediterranean, repeated rounds of hailstorms tracked across Spain, France, and the Alpine countries into the northwest Balkans in June, July, and August. In addition, an intense and unusual midsummer convective windstorm, easily meeting the criteria of a derecho, affected the French island of Corsica, North Italy, and the Alpine countries, with measure wind gusts exceeding 200 km/h on August 18th. Besides these events, Italy was affected multiple times by deadly flash floods in autumn. An overview is presented in Section 1.

Important progress was made in a number of scientific projects. First, the results from the project CHECC - part of the German ClimXtreme research network - enabled us to put the observed exceptional hailstorm activity into context: Researcher Francesco Battaglioli derived trends of past hail occurrence modelled using the AR-CHaMo framework. Interestingly, important increases in hail probability over the last decades are projected to have occurred across the regions that were so strongly affected in 2022. Meanwhile his

colleague Homa Ghasemifard studied the causes for these changes and was able to conclude that these increases do not result from changes in large-scale circulation patterns.

In the Austria-funded project PreCAST, important progress could be made in making AR-CHaMo available for medium-range forecasting in collaboration with ECMWF. This resulted in a web site stormforecast.eu that provides daily forecasts of lightning and large hail. Within PreCAST ESSL's project partner GeoSphere (formally ZAMG) was able to make important improvements to their microphysical parameterizations of their convection-allowing ensemble model, that was featured at the ESSL Testbed.

As part of a collaborative project with the Danube University, an electric field mill was installed at the ESSL premises, which will help to evaluate the value of electric field sensors in anticipating lightning strikes.

All of the above results have been made possible by a slight growth of ESSL, as the Treasurer/Director of Operations joined ESSL's fully paid staff, and a slight increase of human resources was possible for the training and ESWD staff. Altogether ESSL employed approximately 8 full-time equivalents in the German association and its subsidiary in Austria combined. More details about the legal arrangement between these two associations can be found in Section 6.3.

On the administrative side, ESSL was happy to welcome four new institutional full members: the Irish meteorological service Met Éireann, Department of Economics & Management "Marco Fanno" of the University of Padova, the Department of Civil, Chemical and Environmental Engineering of the University of Genoa, and Fondazione CMCC, which is also known as the Euro-Mediterranean Centre on Climate Change (Chapter 6).

Financially, 2022 was a balanced year with small positive results for both ESSL e.V. (€ 805) and its Austria-based subsidiary (€ 1,469.28).

I am delighted to present you this Annual Report 2022 that describes ESSL's achievements in its sixteenth full business year.

Gouda, 12 September 2023,

Dr Pieter Groenemeijer
ESSL Director
Chair of the Executive Board

1 Severe Weather in 2022

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 2022, 38 516 new severe weather reports were added to the ESWD (Table 1-1), which is more than the 27 338 reports from the previous year, 2021.

The most frequently reported severe weather phenomenon was severe wind gusts (19 706), followed by heavy rain (7 144) and large hail (8 262). Comparing convective hazards to 2021, severe wind gusts showed the strongest increase of reports (+60.8%), followed by large hail (+53.7%). This increase of hail reports was very remarkable as it occurred after a previous increase of +64.2% between 2020 and 2021.

Table 1-1. Severe Weather Reports collected in the European Severe Weather Database in 2022.

Report Type	Number of reports	%	% change relative to 2021
Severe wind gusts	19 706	51.2	+60.8
Heavy rain	7 144	18.5	+23.3
Large Hail	8 262	21.5	+53.7
Damaging lightning strikes	1 527	4.0	+11.1
Heavy snowfall/snowstorms	789	2.0	-40.7
Tornadoes (incl. waterspouts)	799	2.1	-11.6
Avalanches	118	0.3	-55.3
Ice Accumulation	171	0.4	+434.4
Total	38 516	100.0	+ 40.9

Figure 1-1 shows how the number of reports of the four convective weather hazards in the ESWD has gradually increased since 2008. This increase is probably for a large part due to the growth of the network of partners who report severe weather to ESSL. That is why it is not possible to infer multi-annual trends of hazard occurrence directly from the data. That said, it can be seen that in some years, the fraction of reports of a particular hazard is much higher than in other years. For example, the years 2015 and 2017 were characterized by a relatively high number of severe wind reports. 2021 stands out as a year with a above average fraction of hail and heavy rainfall reports, and 2022 has a very large number of both hail and wind reports.

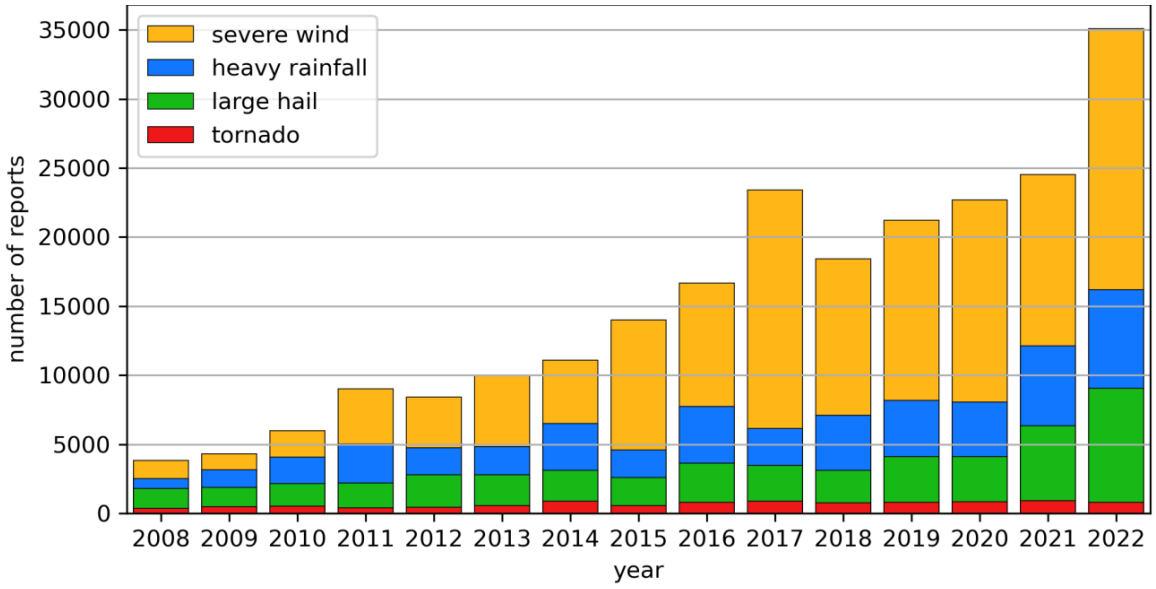

Figure 1-1. Trend of reports of the four convective hazards, severe wind, heavy rainfall, large hail, and tornado in the ESWD.

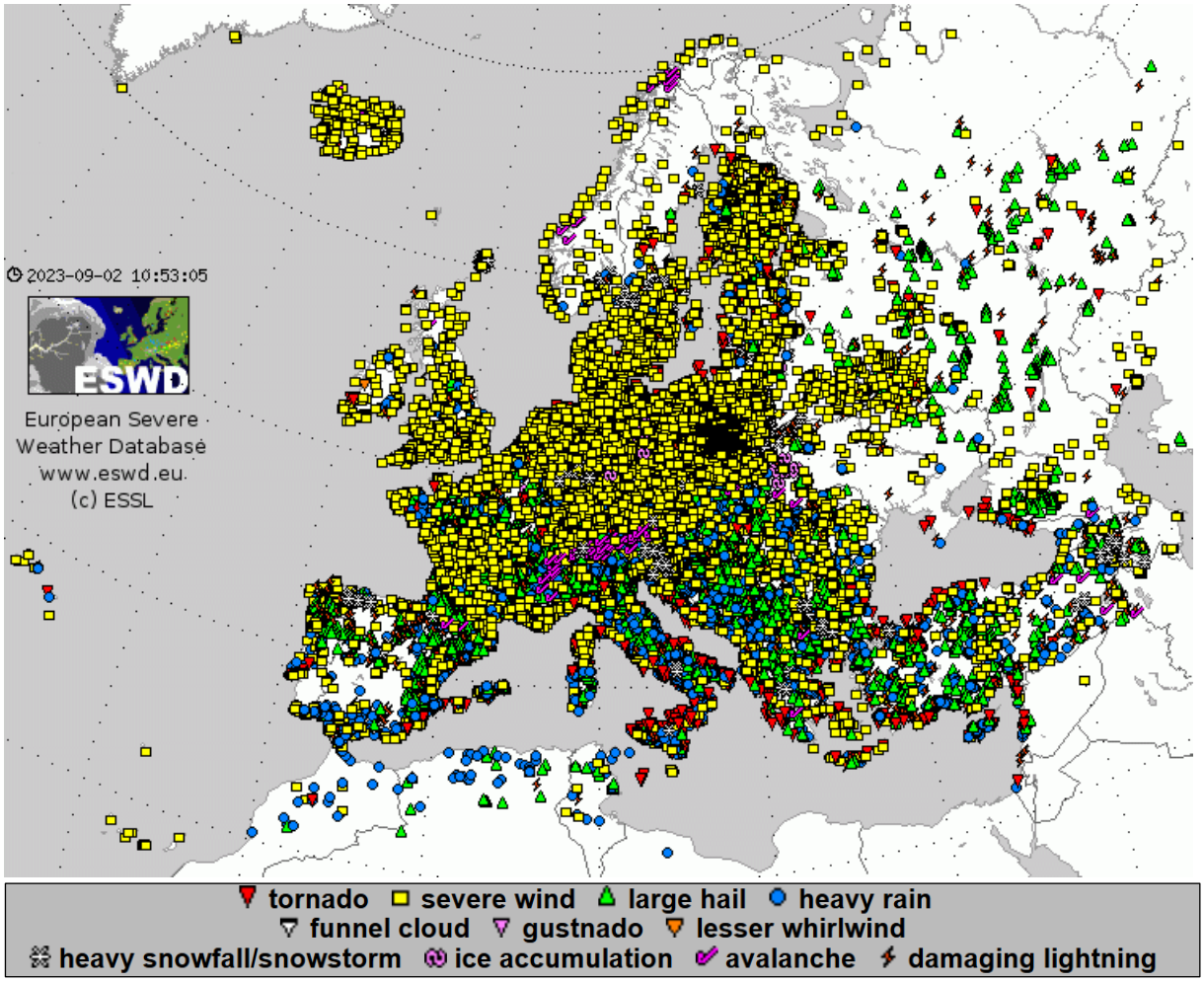

Figure 1-2. The 38 516 ESWD reports of events occurring in 2022.

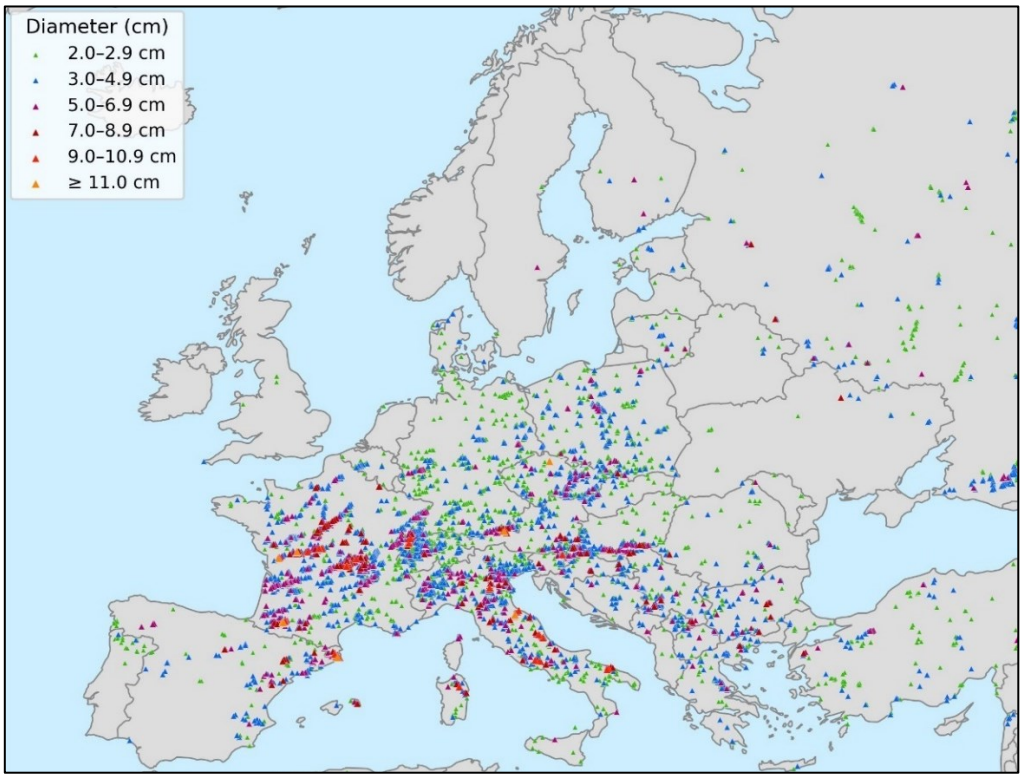

Figure 1-3. ESWD large hail reports of 2022.

Closer inspection of the hail reports of 2022 shows that these were often associated with long-track supercells across Northeast Spain, France, the Alpine region, and Italy, as well as Hungary and the Northwest Balkans (Figure 1-3). The swaths of hail, often larger than 5 cm, sometimes have a length of well over 100 km. 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). That said, it is not possible to prove that hail frequency is increasing by just using the ESWD, since the number of reports may be on the rise because of better reporting. 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.

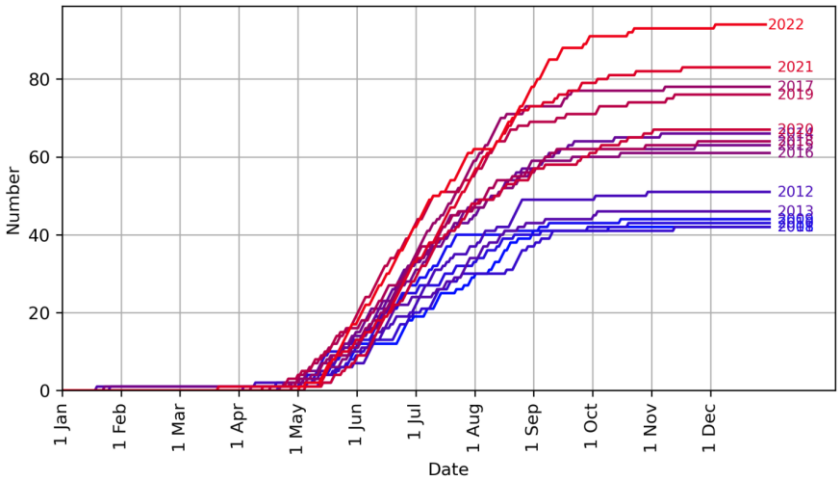

Figure 1-4. Cumulative number of days with hail of at least 5 cm diameter per year since 2008.

Table 1-2. Quality control levels of ESWD reports from 2022.

Quality Control level	Number of reports	%
QC0: as received	0	0.0
QC0+: plausibility checked	7 116	18.4
QC1/QC2: report confirmed by reliable source	31 400	81.6

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. All reports from 2022 have been upgraded at least to QC0+ or QC1. For 18.4% of reports, it was not possible to assign a higher rating than "plausibility checked".

Table 1-3. Most active ESWD partners in 2021

Name	Country	Number of reports
1. Association MeteoNetwork/PRETEMP	Italy	2 136
2. Mr Hendrik Sass	Germany	1 875
3. Mr Nicholas Baluteau	France	939
4. Amateur Meteorological Society	Czechia	633
5. Mr Niclas Lindberg Jensen	Germany	275
6. Mr Bas van der Ploeg	Netherlands	465
7. Mr Markus Weggässer	Germany	348
8. Mr Kairo Kiitsak	Estonia	337
9. Mr George Papavasileiou	Greece	145
10. Mr Thomas Pfeifhofer	Austria	134

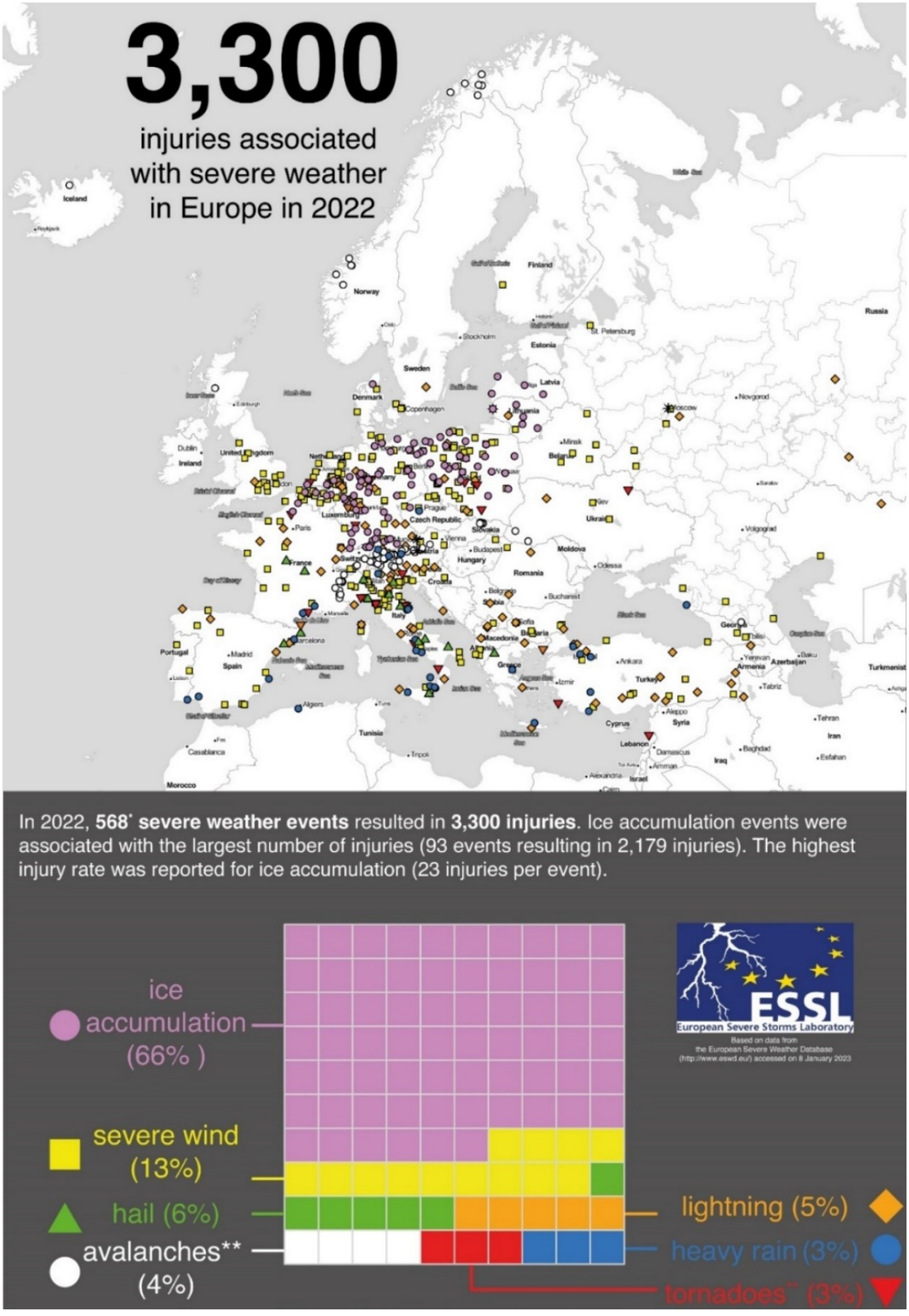

Figure 1-5. The spatial distribution of the ESWD severe weather reports in Europe, associated with injuries in 2022. Below, the percentage of injuries associated with each type of severe weather across the entire ESWD area, i.e., including Mediterranean Africa and Asia, and Central Asia (excluding categories < 1%).

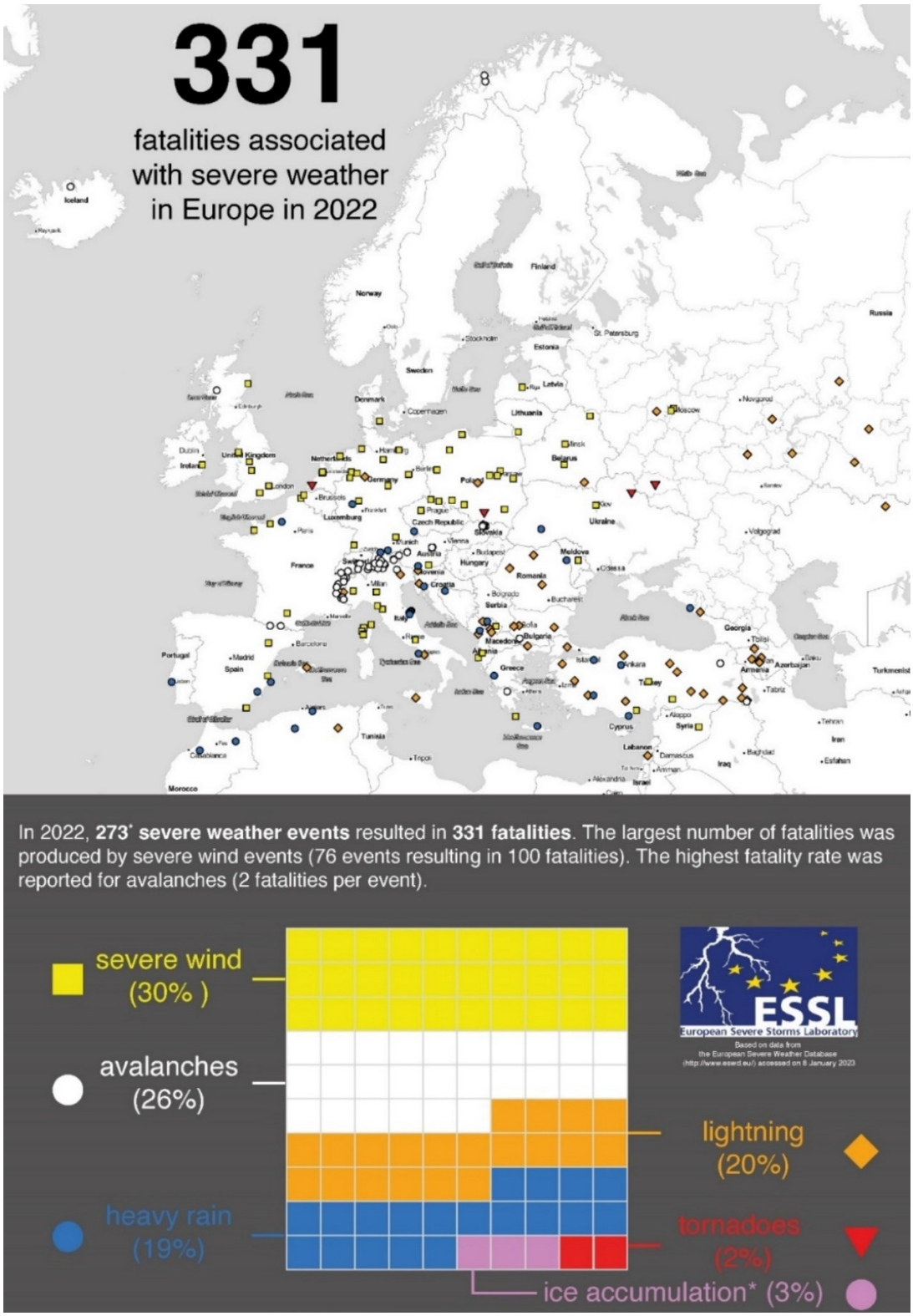

Figure 1-6. The spatial distribution of the ESWD severe weather reports in 2022 associated with fatalities. Below, the percentage of fatalities associated with each type of severe weather across the entire ESWD area, i.e., including Mediterranean Africa and Asia, and Central Asia (excluding categories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

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. Mr. Igor Laskowski from Poland, who topped the list in 2020 and 2021, agreed to join the ESSL team in 2022, and now adds to the severe weather collection from within ESSL. The current leading contributor of severe weather events is the Association MeteoNetwork/PRETEMP, that feed their data automatically into the ESWD. The individual with most severe weather reports is Mr Hendrik Sass, who on its own managed to report 1875 occurrences of severe weather in Germany.

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.

Fatalities and Injuries

Severe weather in Europe has unfortunately led to a considerable number of fatalities. In total, recorded severe weather caused 3300 injuries (Figure 1–3) and 331 fatalities (Figure 1–4). The number of fatalities was much lower than in 2021, when 568 fatalities were reported, of which 192 with severe flash floods in Germany and Belgium on 14 July of that year.

The events with most fatalities in 2022 are listed in Table 1-4. 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 series of wind storms that struck western and central Europe from 16 to 21 February, which produced widespread damage and tornadoes, and caused 22 fatalities. The second event was a series of days with fatal avalanches in the Alps. The third event was a highly unusual convective windstorm that developed in mid-August over the western Mediterranean and struck the Alps. On fourth and fifth place, a number of severe (flash) floods in Italy follow. In the next section, we highlight two of those events, as well as the unusual amount of hail in 2022.

	Hazard(s)	**Date(s)**	**Location**	**Fatalities**
1	Severe wind, Tornadoes	16 – 21 February	Ireland, UK, Benelux countries, France, Germany, Poland	29
2	Avalanches	4 – 8 February	France, Switzerland, Germany, Austria, Italy	22
3	Severe wind	18 August	France, Italy, Austria	12
4	Heavy rain	25 November	Campania, Italy	12
5	Heavy rain	15 September	Marche, Italy	12
6	Avalanches	3 July	Trentino/Alto Adige, Italy	10
7	Severe wind	15 May	Deir ez-Zor, Syria	7
8	Avalanches	5 February	Tyrol, Austria	5

9	Avalanches	12 January	Hakkari, Turkey	5
10	Heavy rain	12 October	Tiaret, Algeria	4

Table 1-4. The severe weather events with most fatalities in 2022 recorded in the ESWD. In this overview, an event is defined as a contiguous series of days with fatal severe weather in bordering countries.

1.2 Major severe weather events

Winter storms in Western and Central Europe

The deadliest cluster of severe weather in 2022, a series of three severe windstorms affected Europe in the period of 16 – 21 February 2022, resulting in 2814 reports of severe wind gusts to be submitted to the ESWD. The severe weather reports associated with the first storm, named "Dudley" or "Ylenia" also include a number of tornadoes, mostly in Poland (Figure 1-7).

On ESSL's news blog, Tomáš Púčik discusses what made this storm more prone to producing tornadoes than the following two for which no tornadoes were reported. An important reason was the orientation of low-level wind shear near the convective line that produced the tornadoes.

https://www.essl.org/cms/windstorms-and-tornado-outbreak-of-february-2022/

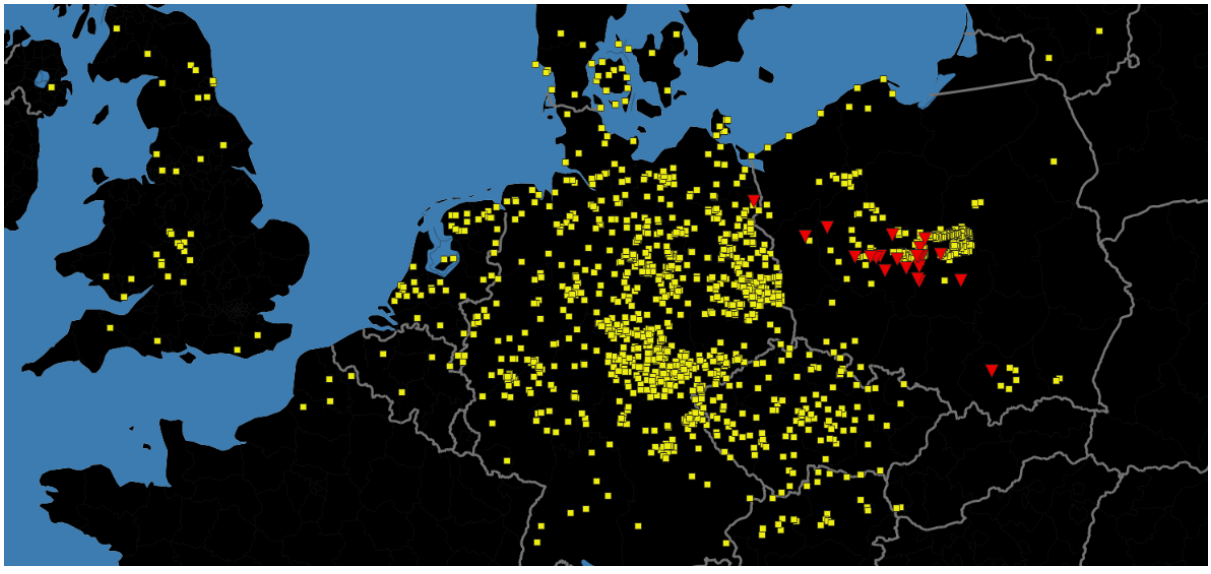

Figure 1-7. Severe wind (rectangles) and tornado (red triangles) reports associated with storm Dudley/Ylenia.

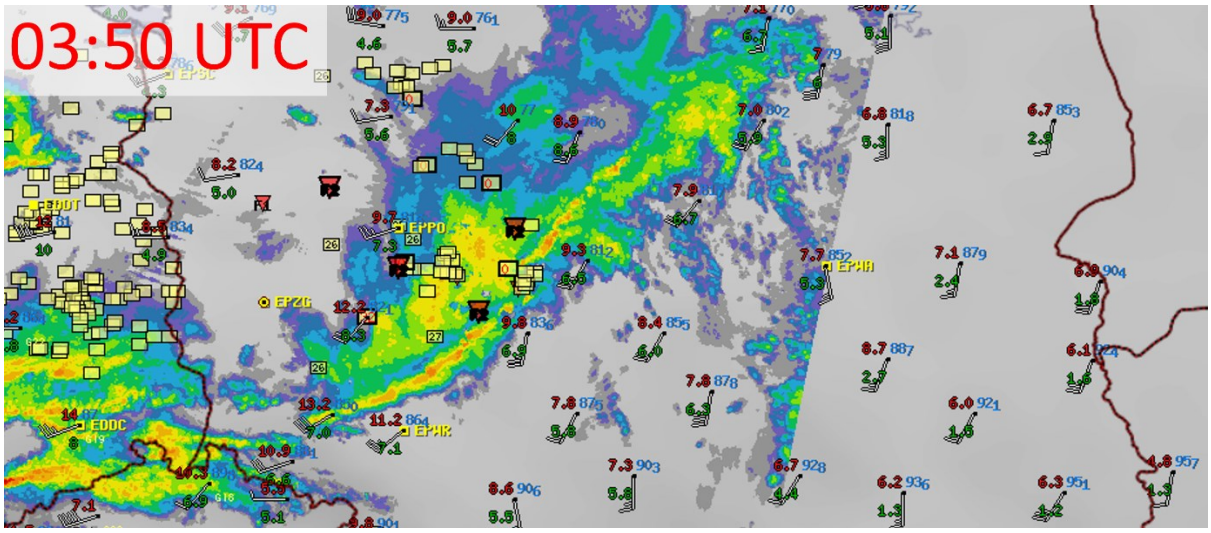

Figure 1-8. Surface observations of temperature, dewpoint, wind, radar reflectivity, and ESWD reports at 0350 UTC on 17 February 2022 across Poland.

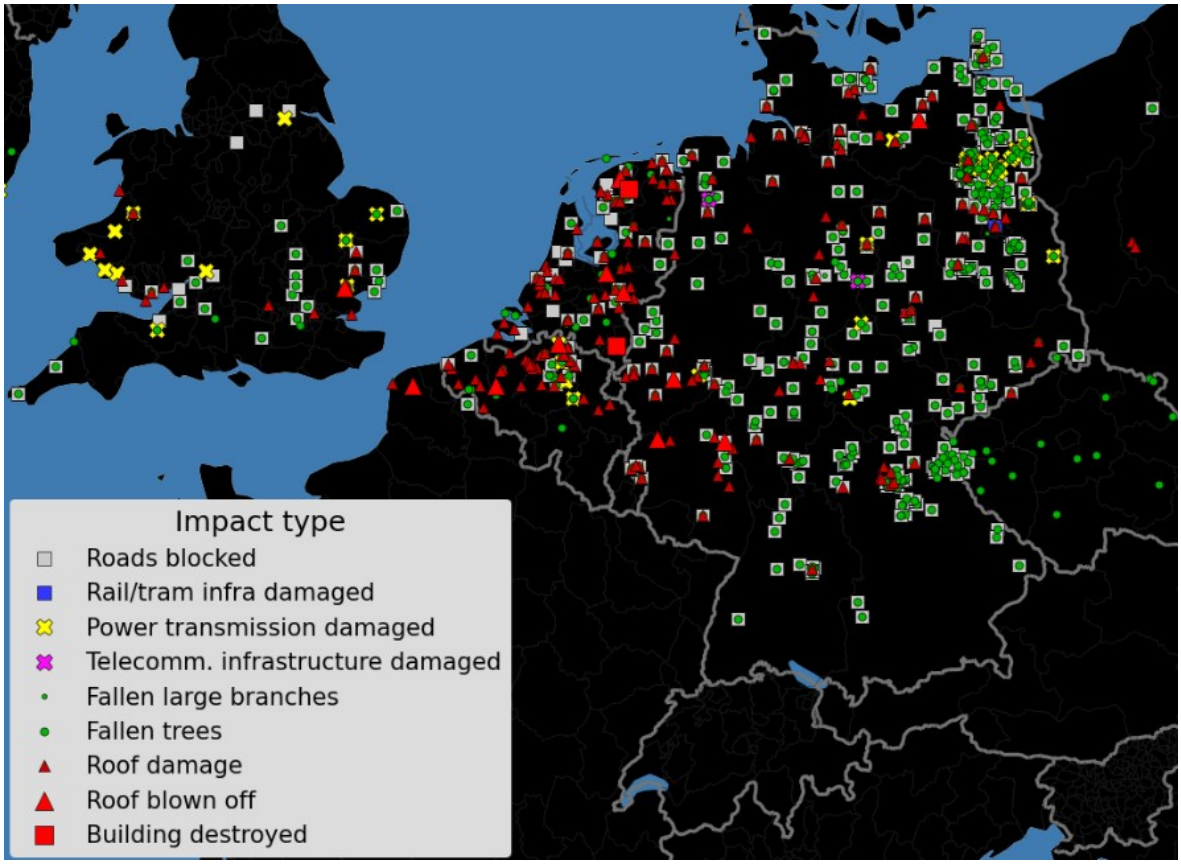

Figure 1-9. Various impacts recorded during storm Eunice on 18 and 19 February 2022. Symbols denoting several impacts can overlap.

The subsequent windstorm Eunice was, in many areas, even stronger than Dudley. This provided a good test case to investigate if the flags for severe weather impacts that have been introduced to the ESWD can be used to extract important information. The impacts recorded on 18 and 19 February show that these impacts differ per region. In the UK, many power transmission tower failures were recorded, while in the Netherlands and

Belgium roof damage dominates. Across Germany, additionally many fallen trees were reported, leading to blocked roads.

A Mediterranean Derecho

An unusually intense and early Mediterranean convective storm event occurred on 18 August 2022 as storms initiating across the western Mediterranean Sea clustered into a bow-echo moving east-north-eastward during the night and early morning. After dawn, the extremely powerful system reached the island of Corsica, where wind a gust of 62 m/s was measured by a station operated by Météo-France. The system was preceded by a supercell that produced very large hail along the coastline of eastern Liguria, Italy. The bow echo crossed Corsica, Northern Italy and would later cross the eastern Alps, to finally dissipate over Czechia. An important contributing factor to the system's intensity and longevity was likely the extreme instability that developed, and the fact that this air mass became uncapped. An important topic for further investigation is if a low-probability event like this becomes more likely as a result of global warming. ESSL contributed to a study on this topic, led by Madrid-based researcher Juan Jesús González-Alemán, that looked into simulations of the event by convection-permitting models, which showed a high sensitivity to the initial sea surface temperature, strongly suggesting that the marine heatwave in August 2022 was a strong contributor to the event's development.

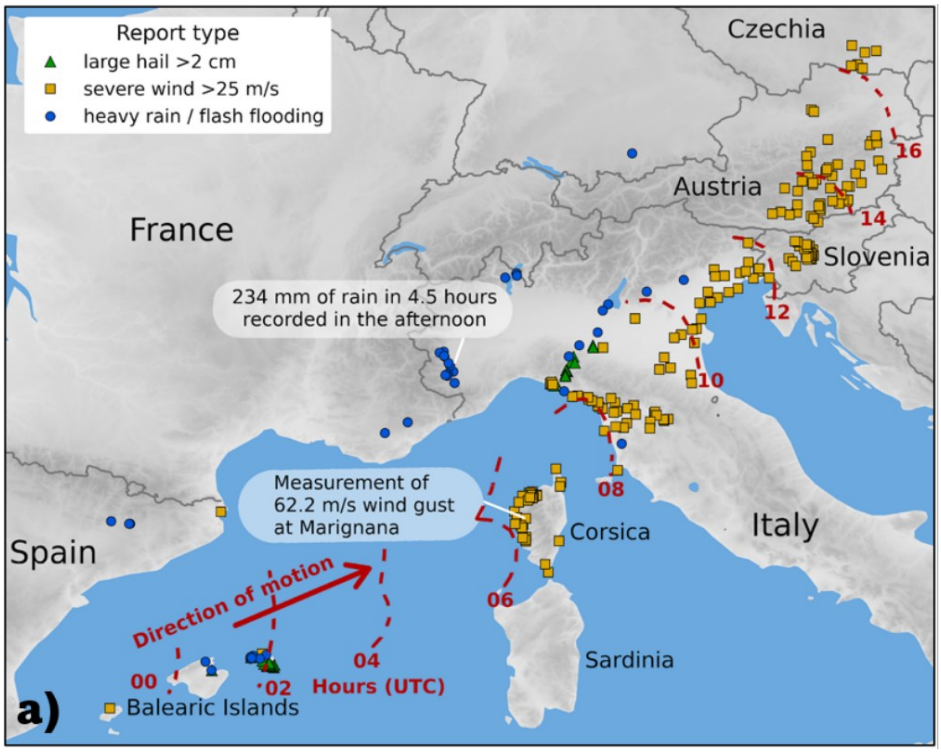

Figure 1-10. Severe weather reports (ESWD) with the derecho of 18 August 2022 and position of the system at various times (UTC). From: González Alemán et al (2023).

1.3 ESWD Data Users

ESWD data are used by a wide range of users. They include ESSL members who have access to the data as part of their membership, but ESSL also receives a considerable number of requests from potential new users, usually initiated by an e-mail sent to the address eswd@essl.org.

Interest in ESWD data has strongly increased in recent years, but 2022 was not exceptional (Figure 1-11). The requests include both use for commercial and for non-commercial 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. In case 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.

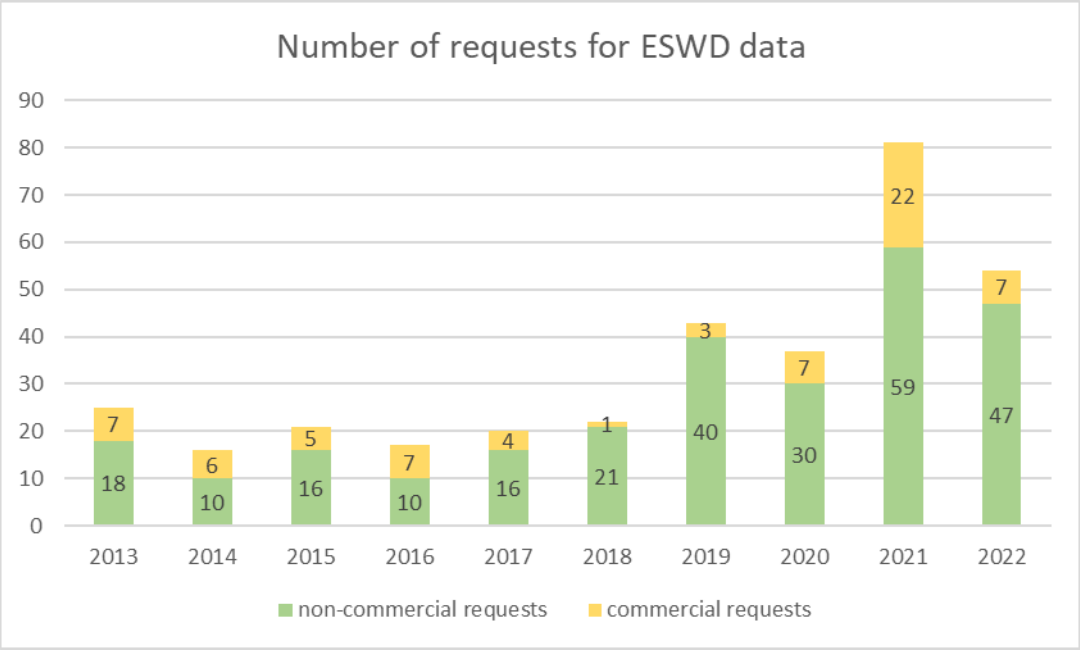

Figure 1-11. Number of requests for ESWD data by non-members.

2 Research

In 2022, ESSL's largest projects were the project CHECC, which deals with the changing risk of convective hazards as a result of climate change, and PreCAST, which focuses on improving severe weather forecasts. In addition, a project with the Danube University to evaluate a new lightning sensor continued.

2.1 Convective Hazard Evolution under Climate Change (CHECC)

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

CHECC is a 3-year research project, funded by the German Ministry of Research and Education and part of the national ClimXtreme research network which focuses on the analysis of extreme climatological events. Within the CHECC project, ESSL improves statistical dynamical models to detect extreme convective events from reanalysis and climate model data.

The key aim of CHECC is to statistically model the occurrence of convective hazards 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 robust trends of event frequency or their variability can be expected in the future.

After successfully modelling the large hail environment in 2021 (Figure 2-1), we obtained results on the trend of large hail occurrence in 2022, both for Europe and the United States (Figure 2-2). The projected changes show that the frequency of large hail increased substantially and significantly across large parts of Europe, most strongly across Northern Italy where a threefold increase in hail ≥ 5 cm is projected to have occurred in the period 1950 – 2020. This is mostly related to an increase in convective available potential energy. In contrast to the widespread increases in Europe, the trends across North America are weaker and downward in some areas.

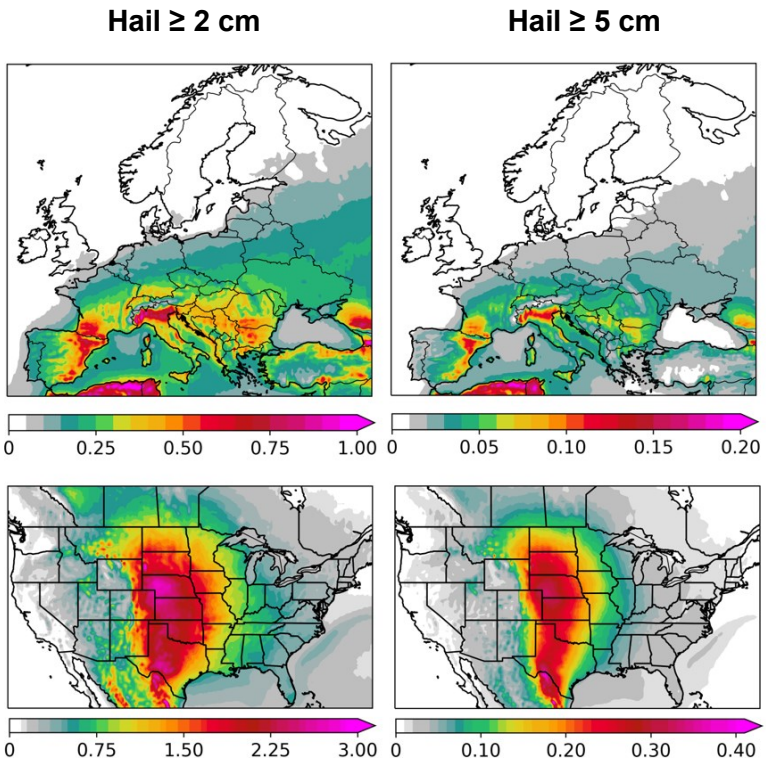

Figure 2-1. Projected annual number of hours with hail ≥ 2 cm (left) and hail ≥ 5 cm (right) within 40 km of a point, using the newly developed AR-CHaMo regression model in CHECC on the basis of the ERA5 reanalysis, lightning data, and training data from the European Severe Weather Database and US Storm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

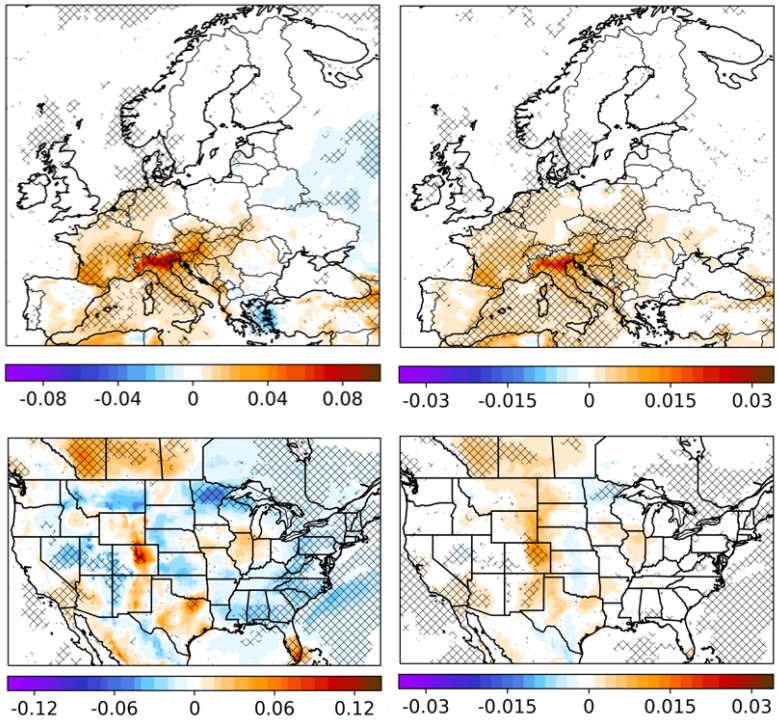

Figure 2-2. Projected decadal changes in the annual number of hours with hail ≥ 2 cm (left) and hail ≥ 5 cm (right) in the period 1950 – 2020, according to AR-ChaMo. From Battaglioli et al. (2023).

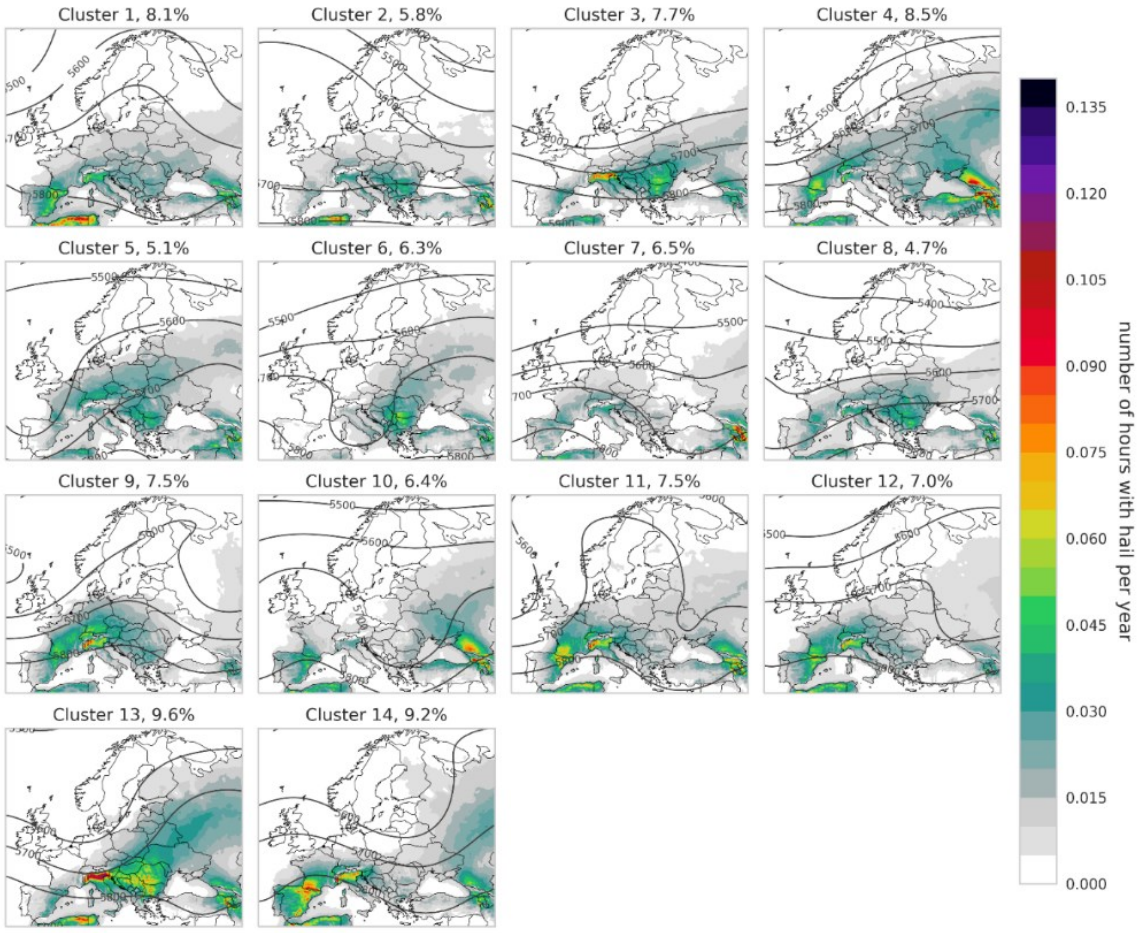

Figure 2-3. Dependence of hail (≥ 2 cm) probability modelled by AR-ChaMo per flow pattern cluster. From Ghasemifard et al. (2023).

Next, the relationship between hail trends in Europe and synoptic flow patterns was examined. By clustering all observed geopotential height fields using k-means clustering, the spatial pattern of hail probability was calculated for each cluster (Figure 2-3). By evaluating changes in the frequency of all clusters over the period 1950-2020, the portion of the trend that could be attributed to changes in flow patterns could be separated from the overall change. From this analysis it can be concluded that, although the occurrence of larger hail is strongly dependent on large-scale weather patterns (see Figure 2-3), the changes in the annual frequency of specific large-scale weather patterns during the 1950-2020 period are very small, so they had insignificant effects on hail frequency between 1950 and 2020 (Figure 2-4).

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.

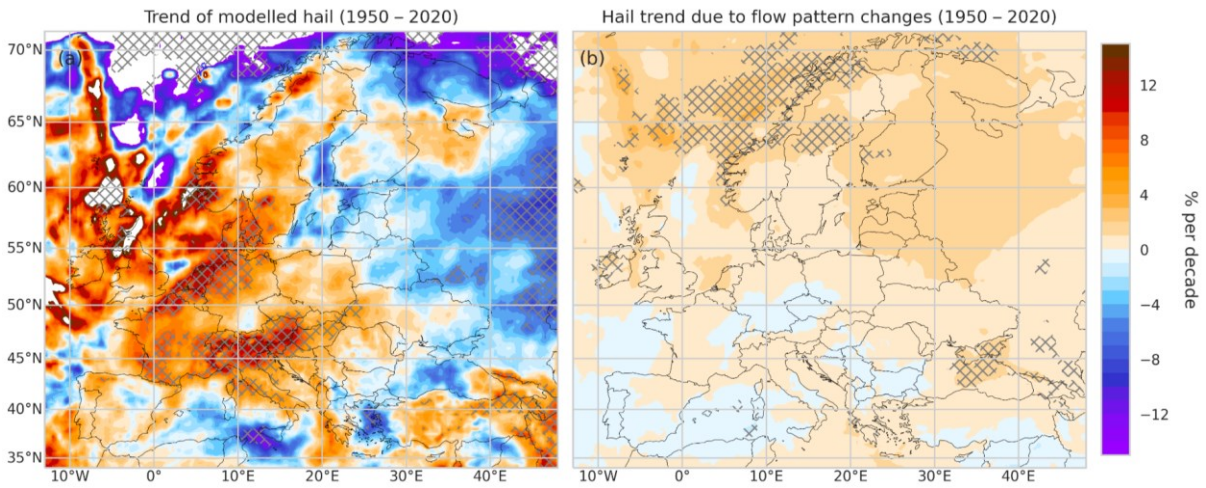

Figure 2-4. Estimated relative change of hail (≥ 2 cm) frequency according to AR-ChaMo (left) and the component due to flow pattern changes (right). From Ghasemifard et al. (2023).

2.2 Prediction of Convective hazards Across Spatio-Temporal Scales

FWF Der Wissenschaftsfonds.

Grant:	ESSL: € 293 010, total: € 483 280
Funded by:	FWF Der Wissenschaftsfonds (Austria)
Period:	1 September 2020 – 31 August 2024
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

During this year, statistical models for prediction of lightning and large hail were applied to the deterministic runs of ECMWF, ICON, and GFS models. The output was included in the ESSL data displayer and forecasters at the ESSL Testbed evaluated the performance of the models. 3 h and 24 h probabilities of lightning, hail ≥ 2 cm and hail ≥ 5 cm were provided. The feedback showed that the lightning is overforecast in the regions with high convective inhibition. Participants found the hail forecasts to be very reliable. Besides the hail, also tornado model development has been started in the second half of 2022.

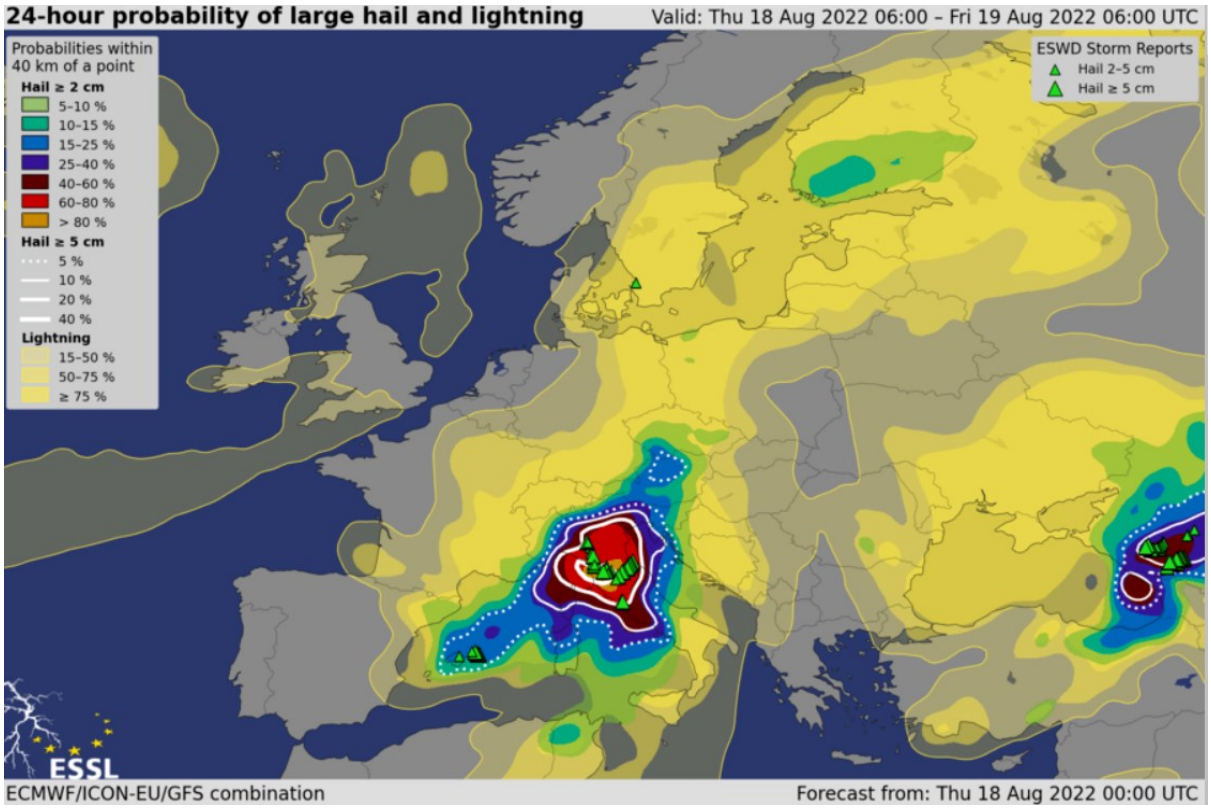

Figure 2-5. 24-hour probability of lightning, large and very large hail for 18 August 2022 combined with the ESWD reports of hail (from: stormforecast.eu).

As a first step towards developing ensemble forecasts of severe weather hazards, a prediction based on multiple NWP models was developed and visualized on the newly developed website stormforecast.eu. These forecasts display the mean probability from the three models (ECMWF/GFS/ICON). It is possible to view the past forecasts, including the verification using the large hail reports from the European Severe Weather Database. The site has become popular and has been used or referenced by many meteorologists across Europe.

The C-LAEF was featured as a product to be evaluated at the ESSL Testbed 2022 to collect feedback to guide the further development work at GeoSphere. Participants found the timing and the location of storms to be very good. The main recommendation was to use the tracks of updraft helicity instead of instantaneous values, which would be implemented at the ESSL Testbed 2023.

2.3 Collaboration with ECMWF

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

As a spin-off of the CHECC project and a preparation for the PreCAST project, ESSL

conducted an exploratory study on the predictability of large hail and lightning in the medium range using re-forecasts of the Ensemble Prediction System. The use of the reforecasts required the logistic AR-CHaMo models to be adapted and simplified in order to work with the limited number of fields stored from these reforecasts. Nevertheless, the models were shown to be highly skillful – even more so than the significant hail parameter – in forecasting hail occurrence up to 240 hours ahead. As can be expected, the forecasts show lower and more spread-out risk areas at increasing lead times (Figure 2-6). A preprint about this research can be found here: Battaglioli et al. (2023).

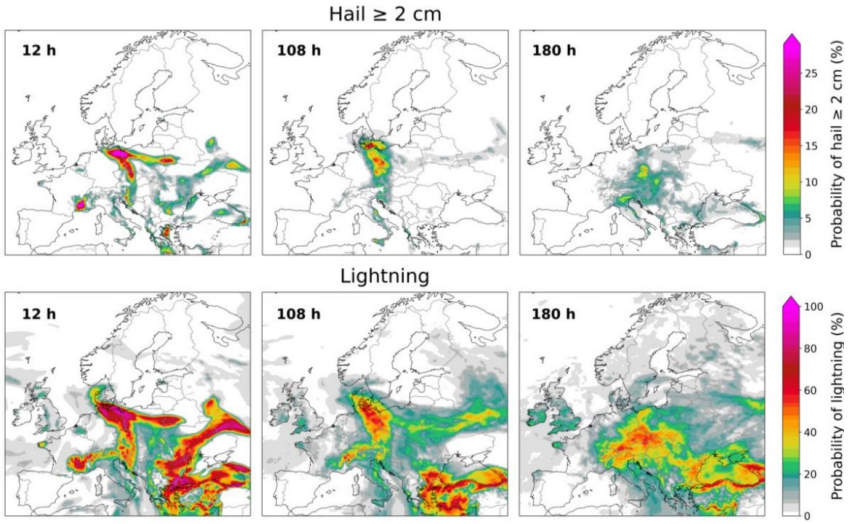

Figure 2-6. Lightning and large hail probability forecasts using the ECMWF Ensemble Forecast System with lead times of 12, 108 and 180 hours.

A second project with ECMWF concerned the inclusion of model-level data in the Weather Data Displayer's sounding tool, in particular to support ECMWF's use of the Displayer to investigate the performance of the IFS in severe weather situations.

This enhancement was implemented in the Displayer in December 2022. In the sounding and hodograph tool, fluctuations in temperature within thin vertical layers, and subtle wind changes with height are now visible (Figure 2-7).

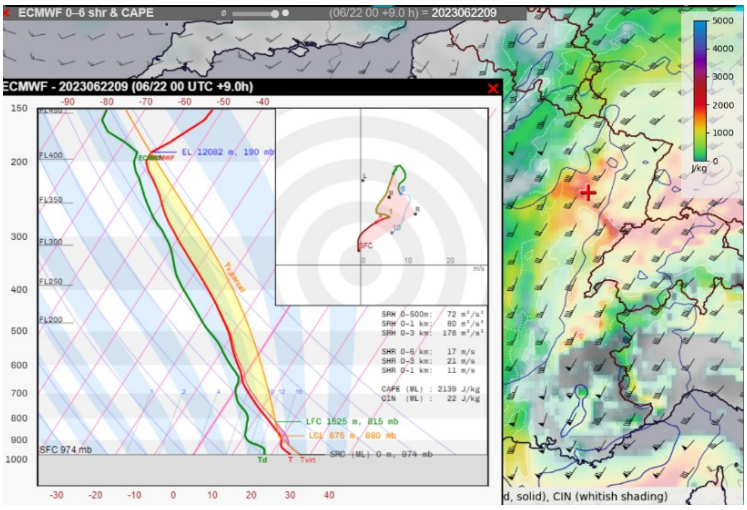

Figure 2-7. The high resolution model-level temperature, moisture, and wind profiles (in the hodograph) are now visible in the Displayer's sounding tool.

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 will be verified in varying environmental conditions.

In the autumn of 2022, an electric field mill was installed at the ESSL Research and Training Centre in Wiener Neustadt (Figure 2-8), in addition to a similar sensor that was already installed at the Department of Integrated Sensor Systems of the Donau-Universität, which is situated in the north of Wiener Neustadt.

The evaluation phase of the sensor, that will involve comparisons between the sensors and an analysis of the measurements with lightning detection networks, will take place in 2023, and 2024.

Figure 2-8. Electric Field Mill installed at the ESSL Research and Training Centre in Wiener Neustadt.

3 ESSL Testbed 2022

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. Three of these weeks were organized in collaboration with EUMETSAT and featured a higher focus on satellite-based products.

After two years of online activities, the Testbed returned to the premises of the ESSL research and training center in Wiener Neustadt. These had been refurbished and featured a new large seminar room increasing the capacity for a single event to 16 participants (Figure 3-1).

Figure 3-1. The new ESSL seminar room, here used at maximum capacity.

In addition, new workstations were installed as well as two large touchscreens (Figure 3-2). Participants were happy with the touch screens and used them heavily during the forecasting and nowcasting sessions.

Table 5. Testbed weeks in 2022.

Event	Date
ESSL Testbed	13 – 17 Jun
EUMETSAT/ESSL Forecaster Testbed	27 Jun – 1 Jul
ESSL Testbed	4 – 8 Jul
EUMETSAT/ESSL Forecaster Testbed	11 – 15 Jul
EUMETSAT/ESSL Forecaster Testbed	10 – 14 Oct

Two classic ESSL Testbed weeks and three ESSL-EUMETSAT Forecaster Testbeds took place in 2022 (Table 5). The autumn week was selected to cover the secondary severe weather season in the autumn in the Mediterranean Sea region.

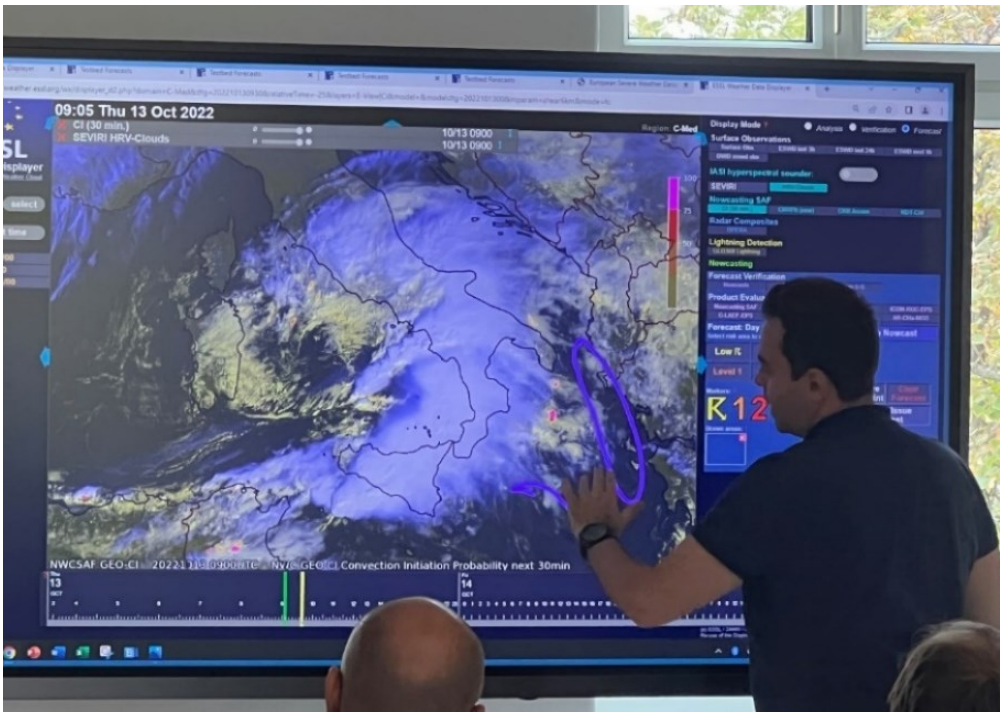

Figure 3-2. One of the new touchscreens used during a Testbed nowcasting session.

In the five testbed weeks, altogether 68 participants from 20 countries took part. The "Expert" week of 4 – 8 July was organized in hybrid mode with participants being present both online and onsite in Wiener Neustadt.

Figure 3-3. EUMETSAT Stephan Bojinski updating Testbed participants on planning and capabilities of the Meteosat Third Generation

The participants ranked the Testbed with an average grade of 9.37 out of 10, the highest grade so far. At the Testbed 2022, 10 products were evaluated, but not all products were considered in each week.

At the testbeds organized in cooperation with EUMETSAT, there was a strong on satellite products. During these weeks, a representative of EUMETSAT participated and introduced the MTG Programme to the participants (Figure 3-3).

The opposite was true for the other weeks in which there was more attention for the other products, such as the nowcast and forecast products from DWD. Many of those products are developments of DWD's SINFONY project, which stands for Seamless INtegrated FOrecastiNg sYstem. The Testbed week in autumn was dedicated to products from the Nowcasting Satellite Application Facility (Nowcasting SAF).

Figure 3-4. Participants of the EUMETSAT/ESSL Forecaster Testbed and ESSL staff in June.

For the EUMETSAT/ESSL forecaster testbeds (Figure 3-4), a survey was carried out to measure their impact. Participants were presented a questionnaire a few months after their participation. The survey results showed that participants overwhelmingly found the testbeds useful, helpful for their day-to-day work, and highly worthy of recommending others to participate. 75% of all participants said they were fully convinced it would be beneficial for their colleagues to participate, while the other 25% found it somewhat useful or quite useful.

3.1 Products at the ESSL Testbed of 2022

KONRAD3D (DWD)

Description: KONRAD3D is a convective cell-detection and tracking algorithm that analyses the present state of a convective cell and predicts its movement in the next hour and assigns a number of severity attributes and other cell-specific meta data.

Main finding: KONRAD3D has improved compared to last year and was well received. Participants recommended improving the severity assessment of different hazards (severe weather flags), especially for severe wind gusts. A hail size estimate based on the height of the reflectivity column developed by ESSL proved reasonably accurate.

C-LAEF (ZAMG/GeoSphere)

Description: C-LAEF is the operational convection permitting ensemble prediction system of the Austrian weather service GeoSphere. New in 2022 instantaneous values of updraft helicity were added as a parameter.

Main finding: The accuracy of timing and location of simulated storms was good. The most important suggestion from participants was the recommendation to use tracks of updraft helicity to identify the locations of supercells instead of instantaneous values.

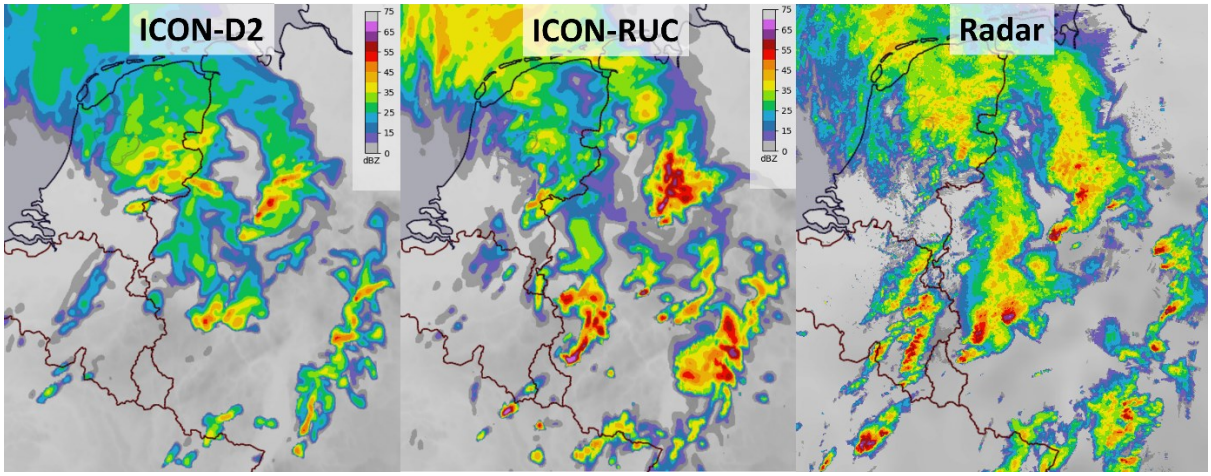

Figure 3-5. Comparison of ICON-D2 and ICON-RUC forecasts of radar reflectivity to observations.

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: ICON-RUC-EPS frequently provided better short-term forecasts of storms compared to ICON-D2-EPS (Figure 3-5). However, the cores of the storms and the cold pools were found to be often too intense, compared to radar and surface observations. It was hypothesized that may be caused by how the model treats the hail hydrometeor class.

AR-CHaMo (ESSL)

Description: The 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 2022, the predictions for probabilities of lightning and (very) large hail were tested, based on ECWMF, ICON-EU, and GFS forecasts (Figure 3-6).

Main finding: While participants found the large hail forecast to be very good, lightning forecasts had high false alarm rate in the environment with high CIN.

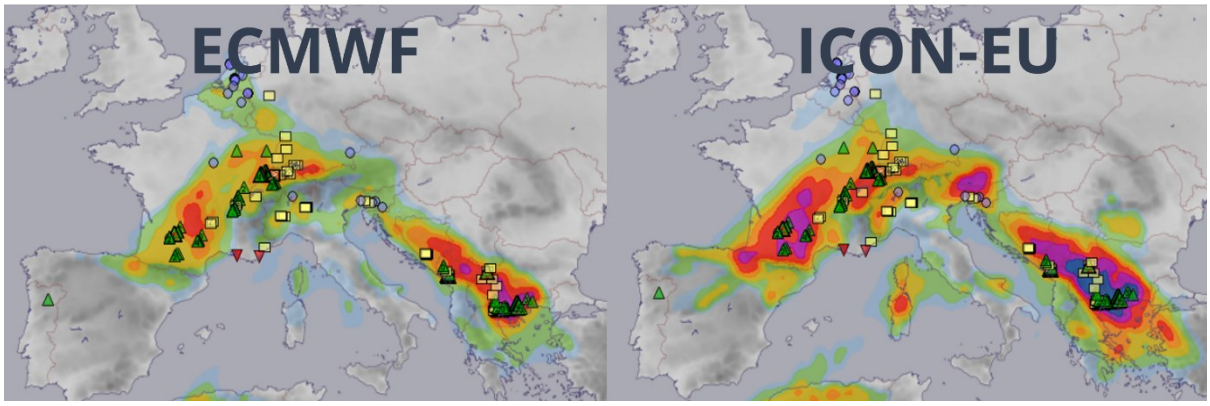

Figure 3-6. 24 hour accumulated probabilities of large hail on 25 June 2022 with severe weather reports overlaid.

Calibrated lightning probabilities based on ICON-EU-EPS (DWD)

Description: Calibrated lightning probabilities for 20 and 40 km radius from a point based on a Modified Lightning Potential Index were provided to the forecasters, with the main aim of finding out which probability metric was most useful.

Main findings: The product received a much better score than the comparable product featured at the 2021 Testbed edition. Participants appreciated the provided probabilities over raw index values. They also identified issues with the diurnal cycle and found an inconsistency between the 20 km and 40 km probabilities that warrants further study.

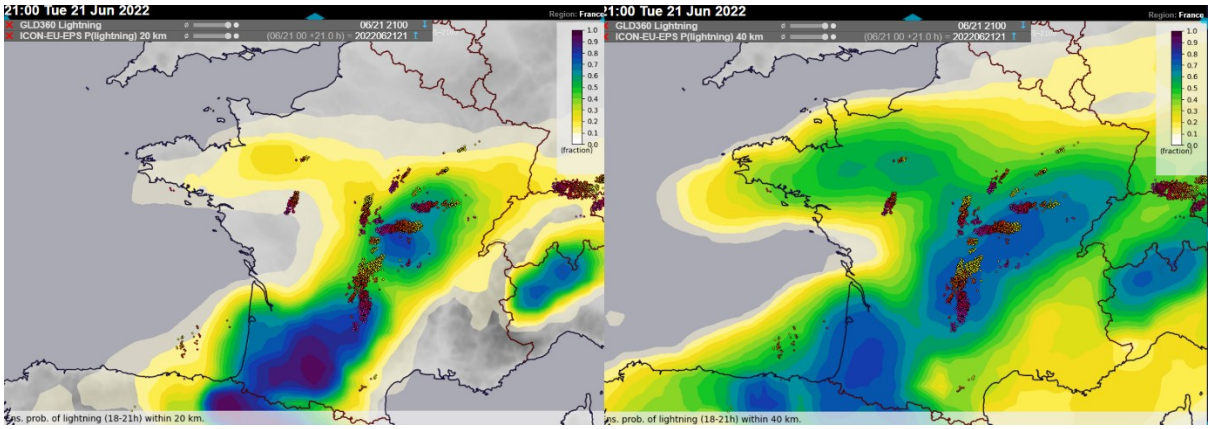

Figure 3-4. Lightning probabilities within 20 km (left) and 40 km (right) on 21 June 2022 combined with GLD360 lightning observations between 18 and 21 UTC.

INTENSE (DWD)

Description: INTENSE is an algorithm for the automated Nowcasting of precipitation based on radar composites. Unlike traditional approaches with just one "best-guess" realization, the algorithm operates as an ensemble approach and is based both on the radar and ICON-D2-EPS predictions.

Main findings: Participants noted the transition from radar-based to model-based predictions. Situations with a lack of precipitation at the time of forecast initialization were particularly challenging for the algorithm. Another point of improvement was a delay in the forecast precipitation.

Crowd sourced observations (DWD)

Description: A completely new type of product evaluated at the Testbed 2022 was the crowd-sourced observations, which were collected from the public using the WarnWetter App developed by the DWD.

Main findings: The participants found the observations very useful for nowcasting. The hail observations were found to be the most reliable. It was noted that the public often overestimates wind gusts and severity of heavy rainfall.

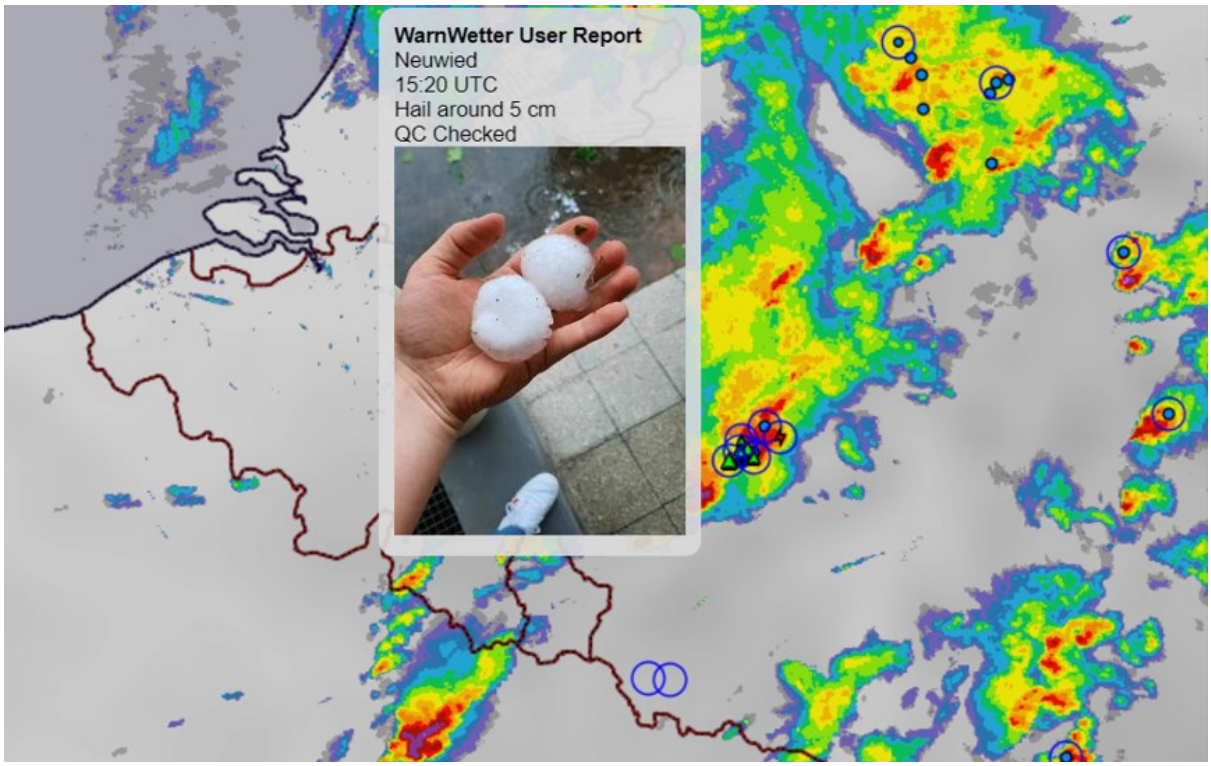

Figure 4-5. Crowd-sourced observations for the 5-minute period between 15:20 and 15:25 UTC on 20 May 2022.

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 the areas with higher contents of low-level moisture

Main findings: The participants found the product useful under the condition that a higher temporal resolution is available in the future to allow the tracking of low-level moisture advection. This higher frequency will be provided by the Meteosat Third Generation instrument FCI (Flexible Combined Imager).

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: Participants found the cloud-phase RGB to be the most useful of tested RGBs. It clearly shows the transition between the water – mixed and the ice phase of the convective clouds.

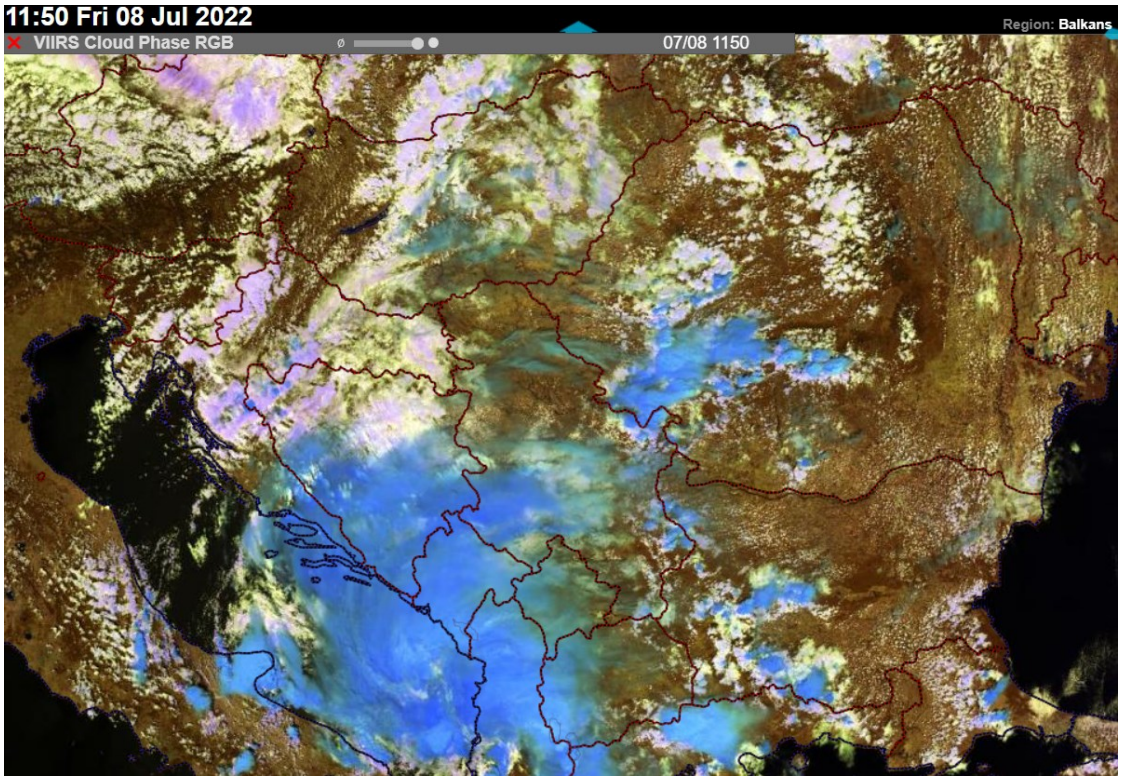

Figure 4-6. Cloud phase RGB generated using the VIIRS instrument data.

Nowcasting SAF products

Description: Three products from the Nowcasting Satellite Application Facility (Nowcasting SAF) were evaluated at the ESSL-EUMETSAT Testbed autumn week. Participants looked at the CI (Convective Initiation; Figure 3-7), RDT (Rapidly Developing Thunderstorms) and CRRPh (Convective Rainfall Rate based on Physical characteristics; Figure 3-8) products.

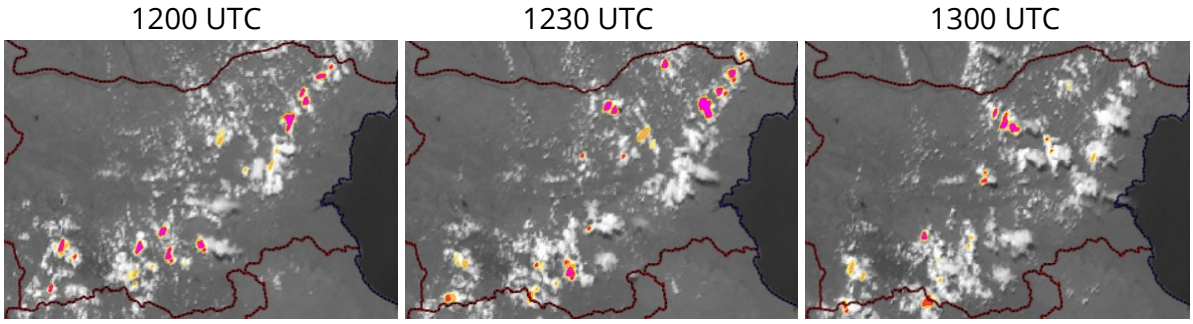

Figure 3-7. The Nowcasting-SAF convective initiation product overlaid on a series of visible satellite images spaced 30 minutes apart. The algorithm is designed to predict the probability of new storm initiation in the next 30 minutes.

Main findings: Participants found the CRRPh to be the most useful of the three tested products. The main limitation was that the area with detected precipitation was too large. For RDT, the jumpiness in the size of the detected storms and their intensity/life cycle was noted. For the CI product, a good performance was noted in areas with slow moving

cumulus fields under clear skies, but there was a high false alarm rate where thin cirrus moved over shallow clouds.

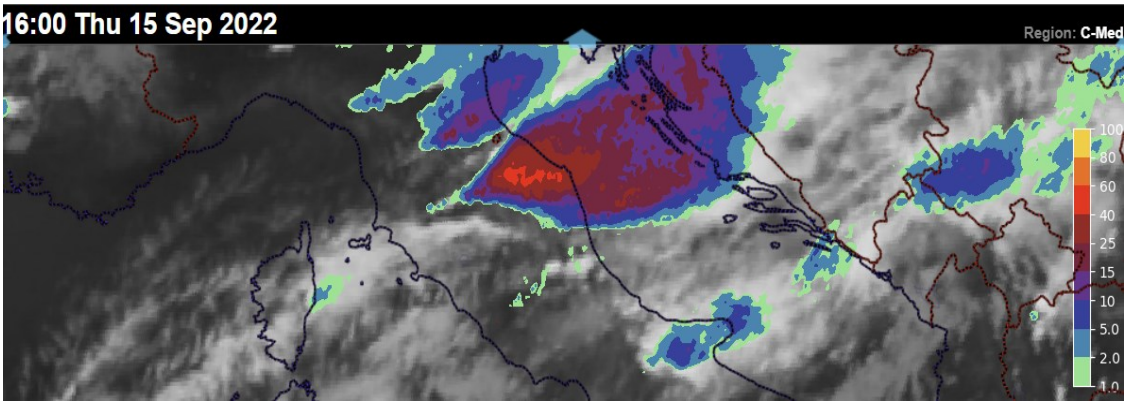

Figure 3-8. Visualisation of a 1-hour accumulated precipitation from the Nowcasting SAF CRRPh product for deadly flooding in Italy on 15 September in the Weather Data Displayer.

4 Workshops and courses

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

4.1 Courses for forecasters

ESSL organized two training courses in early 2022, a course *Forecasting severe convection* between 21 to 25 March and a course *Aviation Forecasting Severe Convection* between 4 and 8 April. 12 participants took part in the first and 9 participants in the second course, taught by Dr Tomáš Púčik and Dr Christoph Gatzen.

Both of these 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.

Figure 4-1. Group photo from the course for aviation meteorologists.

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 2022 courses, lecture material was upgraded with recent findings from the scientific literature. Also, topics such as convective initiation, forecasting coverage of storms and lightning now received more attention, especially in the course for aviation.

Besides these two courses, two short webinars were given for MeteoSwiss as part of their internal training on the topic of storm-top features and above-anvil cirrus plumes on 21 and 25 March.

4.2 Expert workshops for MTG

ESSL has been tasked by EUMETSAT to help prepare the user community for the new satellite products that the upcoming Meteosat Third Generation and EUMETSAT Polar System–Second Generation (EPS-SG) will bring.

As part of this multi-year collaboration, ESSL organizes expert workshops and EUMETSAT/ESSL Forecaster Testbeds (See chapter 3). ESSL's Weather Data Displayer was enhanced and a number of studies on the usage of satellite data were carried out. In 2022, ESSL organized four expert workshops and three EUMETSAT/ESSL forecaster Testbed weeks (Table 6).

At EUM Expert Workshops, selected experts present their knowledge on a specific topic and jointly investigate new products or proxy products by investigating cases and providing feedback in a workshop format. Product developers from EUMETSAT are also involved.

Table 6. Expert workshops organized in 2022 for the MTG User Preparation.

Date	Expert workshop topic	Location
2 – 4 Feb	Moisture retrievals	Online
16 – 17 May	Convective initiation and mature storm detection	Budapest, Hungary; hybrid
16 – 17 Nov	Moisture retrievals	ESSL, Wiener Neustadt, hybrid
29 Nov – 1 Dec	Selected Nowcasting-SAF products	ESSL, Wiener Neustadt, hybrid

Workshops on moisture retrieval from satellites

The two workshops on moisture retrievals highlighted the usefulness of the near infrared and visible channels with wavelengths around 0.91 µm and 0.86 µm. The ratio of those channels can be used to measure low-level moisture, which is one of the key ingredients for convective storms.

Since the Flexible Combined Imager (FCI) on the first MTG satellite features similar channels, atmospheric moisture can be monitored with high temporal frequency. This data can be combined with moisture retrievals using the longer wavelength thermal infrared, or with retrievals by the IRS infrared sounder that will become available after launch of the second MTG satellite. An important conclusion was that existing moisture retrieval algorithms should be adapted quickly to the FCI data as soon as it becomes available and their robustness in the presence of dust and cirrus clouds should be tested.

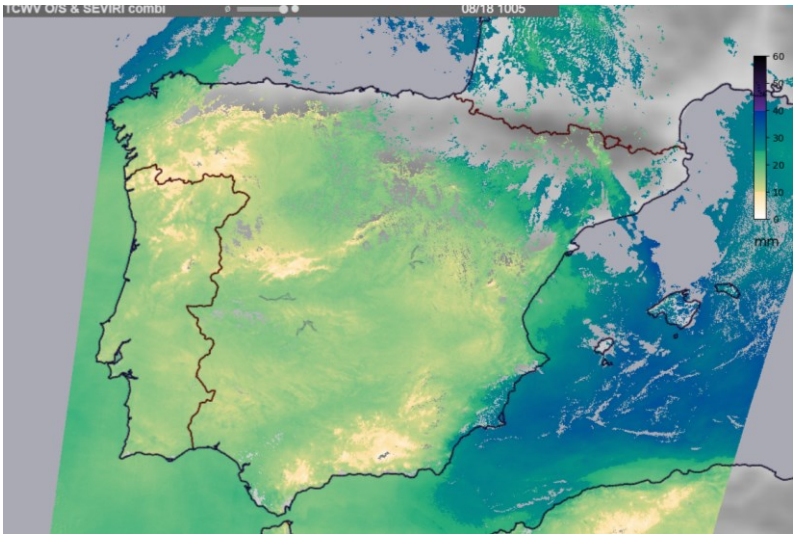

Figure 4-2. Total column water vapour, retrieved by an algorithm based on the OLCI SLSTR instruments (Courtesy: Jan El Kassar, FU-Berlin) visualized in the ESSL Weather Data Displayer.

Workshop on convective initiation and mature storm detection

This workshop, carried out as a side-event of EUMETSAT's Convection Working Group meeting, looked into a range of algorithms to detect and monitor developing or mature storms. Among other conclusions the usefulness of the Cloud Phase RGB (*Figure 3-6*) was confirmed, and feedback was collected on a number of Nowcasting SAF products. In addition, it was concluded that products identifying overshooting tops and cloud top texture could correctly identify the most active parts of convective storms prone to producing severe weather. Finally, a number of suggestions for improvement of ESSL's Weather Data Displayer were collected.

Workshop on selected Nowcasting SAF products

At this workshop, the utility of Nowcasting SAF products was reviewed. The conclusions included a number of suggestions to the Nowcasting SAF group, such as the addition of a storm tracking or predicted motion feature to the Convective Rain Rate (CRRPh) product. It was also suggested to develop a "forecaster-friendly" product combining information from various separate Nowcast-SAF products, such as the CRRPh rain rate with overshooting tops from the RDT product. The importance of highly frequent data was stressed as well. An improvement of the products and their utility is to be expected when 2.5-minute frequency data becomes available when the third MTG satellite will be launched.

4.3 Tornado and Wind Damage assessment workshop

In August, ESSL organized a new edition of its series of workshops on tornado and wind damage assessment in which participants from Italy, Poland, Czechia, Slovakia, Austria, the Netherlands, Canada took part in person, and remotely from the United States and Japan.

As a framework for doing this consistently, ESSL has led the development of the so-called International Fujita scale, that has since completed and implemented to become the new method and scale for rating tornado and wind damage in the European Severe Weather Database.

During the workshop, results from wind tunnel experiments were reviewed, and participants presented field case studies, problems with rating vegetation damage, and lessons from the violent tornado in Czechia on 24 June 2021, among other topics.

Figure 4-3. Participants of the workshop at one of the contruction sites to learn more about building regulations and practices from Dr. Jeindl.

The workshop included a visit to three different building sites in and around Vienna, where certified expert for structural analysis, and concrete and reinforced concrete construction Dr Ferdinand Josef Jeindl provided insight into typical building practices in the present and past. The workshop concluded with the decision that ESSL would make adaptations to the draft IF-scale guideline document that ESSL published earlier to be implemented in the European Severe Weather Database in 2023.

The first version of the scale which has since appeared can be found on the ESSL website: https://www.essl.org/cms/research-projects/international-fujita-scale/

4.4 Online Mini-European Conference on Severe Storms

Between 27 and 28 September, ESSL organized a small version of the European Conference on Severe Storms (mini-ECSS), because the pandemic situation over the past years led to the postponement of the regular ECSS until May 2023.

The mini-ECSS offered the opportunity for PhD students and early-career scientists to present their latest research. The online event was structured in four sessions with 20 participants from Europe, the United States, India, Brazil, and Australia showing their research on subjects such as the climatology of severe storms, hail studies, radar observations of storms, and the use of deep learning in severe storms detection.

Each afternoon, two invited speakers presented their research and insights on severe storm climatology and forecasting, convective initiation and also on severe storm warnings. The mini-ECSS attracted an audience of more than 50 international participants in each session.

In 2022, the preparations for the regular ECSS conference in May 2023 in Bucharest continued.

5 Publications and Communications

In 2022, ESSL employees contributed to 4 peer-reviewed publications, gave 20 oral presentations and 11 interviews, presented 4 posters, and wrote 6 reports.*

5.1 Peer-reviewed publications

Submitted in 2022 and since accepted for publication, or appearing in 2022:

- Pilorz, W., Laskowski, I., Surowiecki, A., & Łupikasza, E. (2023). **Fatalities related to sudden meteorological events across Central Europe from 2010 to 2020**. International Journal of Disaster Risk Reduction, **88**, 103622.
- Battaglioli, F., Groenemeijer, P., Púčik, T., Taszarek, M., Ulbrich, U., & Rust, H. (2023). **Modelled Multidecadal Trends of Lightning and (Very) Large Hail in Europe and North America (1950–2021)**. Accepted in Journal of Applied Meteorology and Climatology. Preprint: https://www.preprints.org/manuscript/202308.0314/v1
- Nimac, I., Cindrić Kalin, K., Renko, T., Vujnović, T., and Horvath, K.: **The analysis of summer 2020 urban flood in Zagreb (Croatia) from hydro-meteorological point of view**. Nat Hazards 112, 873–897 (2022). https://doi.org/10.1007/s11069-022-05210-4
- Ganachaud, A., Karina von Schuckmann, Andra Whiteside, Cecile Dupouy, Pierre-Yves Le Meur, Maeva Monier, Simon van Wynsberge et al., 2022: **Copernicus Ocean state report, issue 6**, Journal of Operational Oceanography 15, no. 1 (2022): 1-220. https://doi.org/10.1080/1755876X.2022.2095169 (ESSL co-author: Pieter Groenemeijer)

Studies started in 2022, having appeared in 2023:

- González-Alemán, J. J., Insua-Costa, D., Bazile, E., González-Herrero, S., Marcello Miglietta, M., Groenemeijer, P., & Donat, M. G. (2023). **Anthropogenic Warming Had a Crucial Role in Triggering the Historic and Destructive Mediterranean Derecho in Summer 2022**. *Bulletin of the American Meteorological Society*, 104(8), E1526-E1532.

5.2 Scientific and Invited Presentations

Oral presentations

1. Groenemeijer, P., 2022: **Severe convective storms in Europe and climate change**, Colloquium, Institute of Atmospheric and Cryospheric Sciences, University of Innsbruck, Austria, 19 January.
2. Púčik, T, 2022: **The 24th of June 2021 violent tornado in southern Moravia: risk communication, damage surveying, and forecasting**. EUMETRAIN wind event week, 1 March 2022. Recording: https://resources.eumetrain.org/resources/wind_ew_2022_s3a.html
3. Pieter Groenemeijer, Tomáš Púčik, Stephan Bojinski, Nataša Strelec Mahovic: **Using the Meteosat Third Generation Flexible Combined Imager 0.9 µm channel for improved nowcasting of convective storms**, European Nowcasting Conference 2022, 21 March.
4. Homa Ghasemifard: **Large-scale flow patterns and their relation to summer lightning in Europe**, International Symposium on Grids and Clouds (ISGC), 24 March 2022.
5. Battaglioli, F., P. Groenemeijer, T. Púčik, M. Taszarek, U. Ulbrich, and H. Rust, 2022: **Forecasting Large Hail Using Logistic Models and the ECMWF Ensemble Prediction System**. EGU General Assembly, Vienna, Austria, 23-28 April 2022.
6. Ghasemifard, H., Pieter Groenemeijer, Francesco Battaglioli, and Tomáš Púčik: **Dependence of lightning occurrence in Europe on large-scale flow patterns**, European Geosciences Union (EGU), Vienna, Austria, 23 – 27 May, 2022, https://doi.org/10.5194/egusphere-egu22-5346
7. Battaglioli, F., P. Groenemeijer, T. Púčik, and I. Tsonevsky, 2022: **Forecasting Large Hail Using Logistic Models and the ECMWF Ensemble Prediction System**. Using ECMWF Forecasts (UEF) 2022, Reading, UK, May 2022.
8. Ghasemifard, Homa, Francesco Battaglioli, Pieter Groenemeijer, Tomáš Púčik, Uwe Ulbrich, Henning Rust, Thilo Kühne, and Mateusz Taszarek, 2022: **Large-scale flow patterns and their relation to summer lightning in Europe, mini-European Conference on Severe Storms**, 27 September.
9. Battaglioli, F.: **Severe Convective Storms in Europe: Past, Present and Future**. Wroclaw, Poland, Polish Science Network, 28 September 2022.
10. Holzer, A.M., 2022: Panellist. **Panel discussion on the value of voluntary or private weather observations**. Extremwetterkongress, Hamburg, Germany, 29 September.
11. Groenemeijer P., 2022: **The ESSL Displayer in the European Weather Cloud**, European Weather Cloud User Workshop, ECMWF, 14 October.
12. Groenemeijer P., and T. Kühne, 2022: **The European Severe Weather Database**, DWD Munich Office, 19 October.
13. Groenemeijer, P., A. M. Holzer, and T. Púčik, 2022: **Development of the International Fujita (IF) scale to rate damage from tornadoes and convective winds**. 30th AMS Severe Local Storms Conference, Santa Fe, USA, 24 – 28 October.
14. Battaglioli, F., P. Groenemeijer, T. Púčik, M. Taszarek, U. Ulbrich, and H. Rust, 2022: **Logistic Modelling of (very) large hail across Europe and the United States (1950-2021)**. 30th AMS Severe Local Storms Conference, Santa Fe, USA, 24 – 28 October.
15. Groenemeijer, P., 2022: **Severe convection in Europe: Climate modelling and forecasting**. Workshop on Natural Hazards, Department of Engineering, University Western Ontario, London, Canada, 2 November 2022.
16. Holzer, A.M., 2022: **ESSL's European Severe Weather Database (ESWD) – its manifold uses as an example of citizen science and NGO participation**. WMO Regional Conference of the Regional Association VI on the Future Role of National Meteorological and Hydrological Services: Leadership and Management Geneva, Switzerland, 3 November.
17. Groenemeijer P., 2022: **ESSL and the European Severe Weather Database**, COST Action Mediterranean Cyclones, 25 November.

18. Battaglioli, F.: **Eventi Estremi e Cambiamento Climatico: Passato, Presente e Futuro. La nuova rete radarmeteorologica della Lombardia - Monitorare per informare e agire in tempo di crisi climatica**. Milan, Italy, December 2022.
19. Groenemeijer, P., and T. Púčik, 2022: **Atmospheric moisture and convective storms**, EUMETRAIN Water Vapour Products Event Week 2022, 12 December.
20. Tomáš Púčik, Pieter Groenemeijer, and Christoph Gatzen: **Evaluation of DWD tools at the ESSL Testbed 2022**, 13 December.

Poster presentations

1. Púčik, T., P. Groenemeijer, D. Rýva, M. Šinger, M. Staněk, and A. M. Holzer, 2022: **Surveying and forecasting the violent tornado of 24 June 2021 in southeastern Czechia**. 30th AMS Severe Local Storms Conference, Santa Fe, USA, 24-28 October.
2. Battaglioli, F., P. Groenemeijer, T. Púčik, and I. Tsonevsky, 2022: **Forecasting Large Hail Using Logistic Models and the ECMWF Ensemble Prediction System**. 330th AMS Severe Local Storms Conference, Santa Fe, USA, 24-28 October.
3. Battaglioli, F., P. Groenemeijer, T. Púčik, M. Taszarek, U. Ulbrich, and H. Rust: **Convective Hazard Evolution Under Climate Change (CHECC)**. ClimXtreme Final meeting, Offenbach am Main, Germany, November 2022.
4. Solazzo, E., F. Battaglioli, A. Iengo, and D. Sacchetti: **Severe Convective Storm Environments of Northwestern Italy: Differences between Coastal and Inland Areas**. 11th European Conference on Radar in Meteorology and Hydrology, Locarno, Switzerland, 29 August - 2 September.

5.3 Reports and non peer-reviewed publications

- Púčik, T., D. Rýva, M. Šinger, M. Staněk, and P. Groenemeijer, 2022: **Damage survey of the violent tornado in southwest Czechia on 24 June 2022**. https://www.essl.org/cms/wp-content/uploads/24-June-2021-violent-tornado-damage-assessment-.pdf
- Pieter Groenemeijer and Tomáš Púčik: **Summary of the ESSL-EUMETSAT Expert Workshop on moisture retrievals from satellites**
- Pieter Groenemeijer and Tomáš Púčik: **Summary of the EUMETSAT-ESSL Expert Workshop on Convective Initiation and Mature Storm Detection**
- Tomáš Púčik: **Summary of the second EUMETSAT-ESSL Expert Workshop on moisture retrievals from satellites**
- Alois M. Holzer: **Summary of the second EUMETSAT-ESSL Expert Workshop on selected NWC SAF products**
- Tomáš Púčik, Alois M. Holzer and Pieter Groenemeijer: **Synthesis of the first EUMETSAT-ESSL Testbeds**
- Christoph Gatzen, Tomáš Púčik, and Pieter Groenemeijer**: Report on the evaluation of DWD nowcast and warning products at the ESSL Testbed 2022**
- Francesco Battaglioli, Pieter Groenemeijer, Ivan Tsonevsky, and Tomáš Púčik, 2023: **Forecasting Large Hail and Lightning using Additive Logistic Regression Models and the ECMWF Reforecasts**, Natural Hazards and Earth System Sciences, preprint https://doi.org/10.5194/nhess-2023-40

5.4 Notable press communications and outreach activities

Bogdan Antonescu:

- Several interviews for Digi24 (Romanian TV) on 3 and 9 January on ESWD reports for 2021; 13 April on tornadoes in the USA; 13 and 18 June on extreme weather events in Europe; 30 July and 28 August on severe storms in Romania; 25 September on waterspouts in Europe; 20 October on convective storms in Europe in 2022.
- Interview for TVR1 (Romanian TV) and for Euronews Romania (Romanian TV) on severe storms in Europe.
- Deschis la cercetare (Open to research, podcast) on tornadoes in Romania.
- Starea Planetei (State of the planet, Youtube) on climate change and extreme weather events.

Pieter Groenemeijer:

- Interview De Volkskrant (Dutch newspaper), "This is how tornadoes like the one in Zierikzee develop", https://www.volkskrant.nl/wetenschap/dit-is-hoe-tornado-s-zoals-die-in-zierikzee-ontstaan~b614ab79/ 27 June 2022.
- Statement by ClimXtreme research group: "ClimXtreme position on damaging storm series Ylenia, Zeynep, Antonia in February 2022, internationally known as: Dudley, Eunice, Franklin" https://www.climxtreme.net/index.php/en/component/content/article/33-news/46-sturm-feb-2022?Itemid=486

Alois M. Holzer:

- Austrian Press Agency OTS release: "New weather satellite training centre in Lower Austria. Meteorologists from all over Europe are being prepared for the new satellite data in Wiener Neustadt. EUMETSAT started a cooperation with the Lower Austria-based ESSL." APA. 13 Dec 2022.
- Press report on webpage of Austrian newspapers NÖN and Kurier, and on ORF (Austrian Broadcasting Corporation) radio and online portal: "Wiener Neustadt: Training for new weather satellites". https://noe.orf.at/stories/3186240/ 14 December 2022.
- Newspaper report in Die Presse (print and online): "Science in Lower Austria. Thunderstorm hunt in Wiener Neustadt: the ESSL weather satellite training centre." https://www.diepresse.com/6229106/unwetter-jagd-in-wiener-neustadt-das-essl-wettersatelliten-trainingszentrum, 12 December 2022.

Tomáš Púčik:

- Interview for Slovak newspaper SME "Year 2022 has begun with a large number of destructive hailstorms, and we're heading for a new record (in Slovak)", 11 July, 2022. https://svet.sme.sk/c/22953639/meteorolog-Tomáš-Púčik-tornado-morava-leto-pocasie.html

5.5 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 Facebook and Twitter/X, where ESSL posts and shares news regarding ESSL's research, Testbed, training and ECSS activities. The number of Twitter/X account followers increased to 3976 followers (1220 more followers than a year ago). 33 times ESSL tweeted a message in 2022. ESSL also retweeted many different messages from its employees. ESSL's Facebook account, which has 9708 followers, reached an audience of approximately 200,000 people in 2022. In September 2022, ESSL opened a LinkedIn profile as well.

6 Financial and Administrative Report

6.1 Employment and Payroll Accounting

In 2022, the European Severe Storms Laboratory e.V. directly employed two full time employees (researchers for the project ClimXtreme), one part-time employee (ESWD quality control manager), and one so-called "Mini-Jobber" (for database programming), a form of minor employment according to German law. The joint Secretariat of ESSL e.V. and the European Severe Storms Laboratory – Science and Training was hosted by the latter and employed six persons (the Director and the Director of Operations full-time, the PreCAST researcher / senior trainer full-time, the Assistant to the Board part-time, and two employees for ESWD user support and ESWD quality control via mini-jobs). 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 Science and Training in Austria) were mandated during 2022 to take care of paperwork and bureaucratic handling of taxes and social insurances, which would otherwise have exceeded ESSL's internal administrative capacity.

6.2 Auditing of the Annual Accounts

In accordance with the Articles of Association, ESSL e.V.'s finances for 2022 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 Science and Training in Austria, 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 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."

6.3 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.

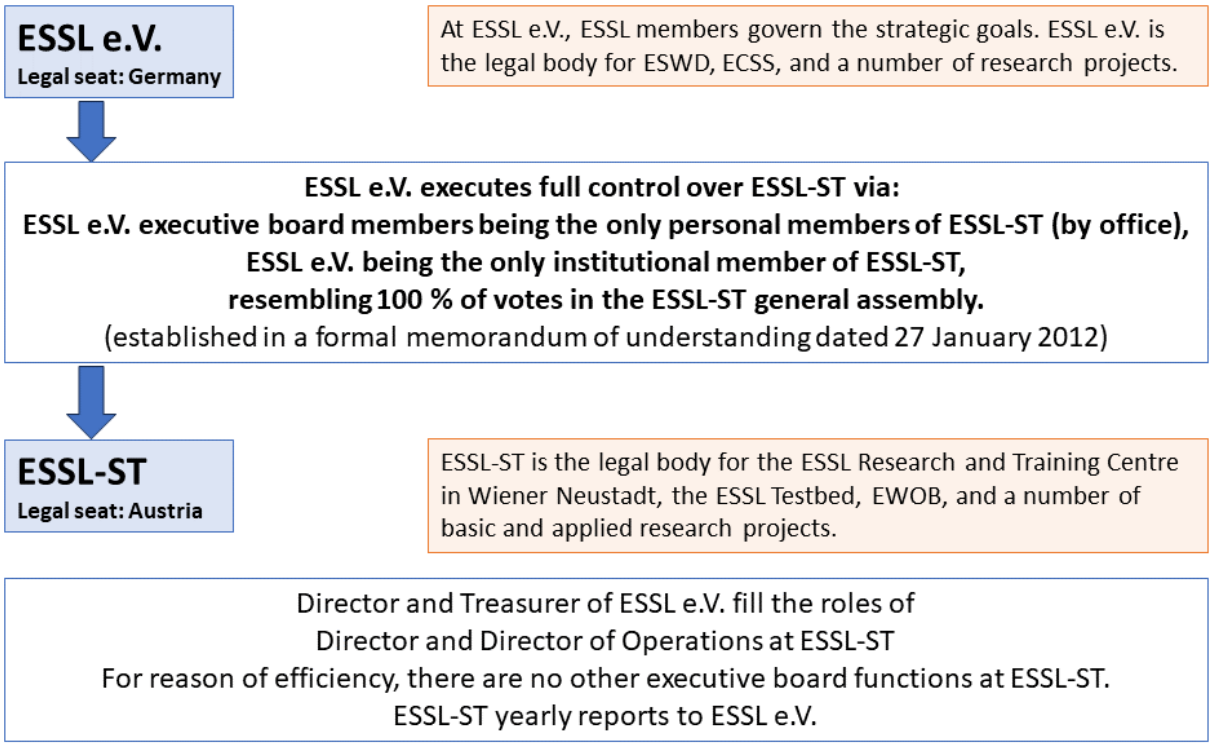

Figure 7-6-1. Schematic overview of the relationship between the two legal bodies of ESSL.

6.4 Financial Status 2022

European Severe Storms Laboratory e.V.

The accounting year was dominated by income from a project funded by the German Ministry of Education and Research, i.e., the project CHECC, and from membership fees. The detailed Annual Accounts were presented to the ESSL Advisory Council and can be inspected in the 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 easily fulfilling the requirements of the tax authorities.

The following key figures from the Annual Accounts characterize the business conditions in 2022:

ESSL obtained € 214,077 from membership fees (€ 173,077) and from the sale of ESWD and hazard model data (€ 41,000). The second largest income source was the CHECC project funded by the German Ministry of Research: € 134,000. We are very thankful for donations of € 355, underlining the worth of ESSL activities for the severe weather community.

Total income amounts to **€ 354,728** (2021: € 262,117).

Total expenses amount to **€ 353,923** (2021: € 261,162).

The dominant cost factors were direct personnel costs with € 203,956, including taxes and social security; third party services by ESSL Science and Training (subsidiary in Wiener Neustadt, Austria – personnel lumpsums) with € 60,000; office, IT and third party services with € 52,251; and travel expenses with € 13,783.

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. Shared office, IT and server costs added up to € 30,757.

At the end of the business year, liquid assets at ESSL's bank accounts amounted to € 50,387 (2021: € 54,443). At the end of the year, accounts receivables amounted to € 0 (2021: € 0), deferred expenses (payments made for future accounting periods) to € 11,905 (2021: € 1,500), deferred income (payments received for future accounting periods) to € 25,000 (2021: € 20,000). Comparing liquid assets with mean monthly expenses it can be

seen that ESSL e.V. was ending the business year with a small reserve for less than 2 months only.

The **annual result is a positive € 805** (compare: positive € 954 in 2021, positive € 16,517 in 2020, positive € 2,338 in 2019, negative € 14,899 in 2018).

The financial planning for 2023 foresees enough liquidity until the end of the year with a stable income situation based on the project CHECC and CHECC_II, and membership fee income.

European Severe Storms Laboratory - Science and Training

The financial result 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 € 126,873.41 (2021: € 136,808.41). The raw **positive annual result is € 1,469.28** (2021: € 25,366.57).

Of the liquid means, € 120,000 are foreseen as current reserve for the ESSL Testbed 2023.

The main income source in 2022 was the ESSL Testbed with € 294,903.39 including the larger contributions from EUMETSAT, DWD, and ECMWF. Income from our courses amounts to € 36,320.00. Public funding from the government of Lower Austria Science Support amounted to € 43,324.53. Public project funding from the Austrian national FWF amounted to € 74,845.00 (PreCAST project).

The main cost factors were personnel costs with € 349,307.97, office, seminar space rent and insurance with € 37,649.36, and travel costs with € 19,682.78.

The total income of € 547,216.97 approximately matches the expenses of € 542,647,63. A tabular overview is provided in Appendix A1.

The financial planning for 2023 again foresees a near neutral annual result.

6.5 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 by financial support. In 2022, ESSL was happy to welcome four new institutional full members: the Irish meteorological service Met Éireann, Department of Economics & Management "Marco Fanno", University of Padova, the Department of Civil, Chemical and Environmental Engineering of the University of Genoa, and Fondazione CMCC, which is also known as the Euro-Mediterranean Centre on Climate Change. The full member list as of 31 December 2022 can be found in Appendix A2.

6.6 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. Figure 6-1 outlines some of their responsibilities.

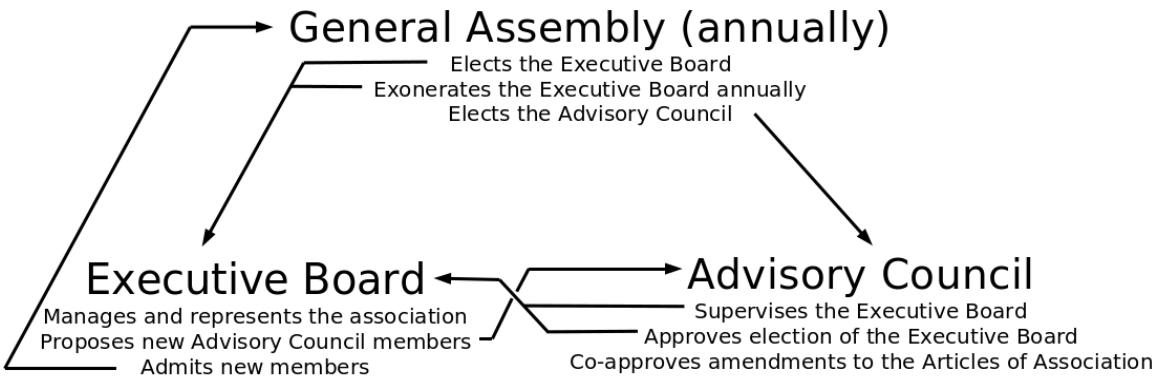

Fig. 6-1: Bodies of the ESSL. The Advisory Council consists of six members from two groups - three members each: (1) Science, (2) NMHS / EUMETNET.

Executive Board

In 2022, 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 2022, 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 2022*", 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

	2022	2021	2020	2019	2018
INCOME					
Membership fees institutional members and ESWD data fees	210.082,00	163.306,60	173.103,50	158.039,43	136.620,74
Membership fees personal members	3.995,00	3.805,00	3.422,72	3.961,06	3.427,62
Income from scientific meetings (ECSS)	0,00	0,00	0,00	89.306,36	0,00
Public project funding Federal Republic of Germany	134.000,00	94.000,00	50.000,00	167.594,46	188.052,36
Public project funding European Union	0,00	0,00	0,00	0,00	49.158,00
Applied research	0,00	0,00	0,00	0,00	33.700,00
Donations	355,00	1.005,00	1.502,18	190,00	1.100,00
German VAT on sales and refunds	6.296,50	0,00	0,00	2.748,97	4.940,06
Total income	**354.728,50**	**262.116,60**	**228.028,40**	**421.840,28**	**416.998,78**
EXPENSES					
Personnel	203.955,96	154.404,99	73.258,73	241.534,68	358.941,59
Depreciations	2.638,00	3.323,00	1.260,98	1.013,94	981,21
Costs related to scientific meetings (ECSS)	0,00	0,00	0,00	51.345,47	0,00
Travel costs	13.783,41	333,56	3.959,62	14.229,95	11.408,02
Office costs and insurance	180,93	2.091,98	2.242,53	615,72	1.231,16
Phone and data (internet) services	3.357,82	2.097,50	3.877,55	5.982,25	1.214,99
Tax advisor including software	3.866,08	5.865,00	6.450,23	6.320,02	6.116,52
Third party services by ESSL Science and Training, Austria			101.523,21	80.393,08	27.583,82
Director and administration personnel lumpsum	60.000,00	60.000,00			
Office, IT and server costs	30.756,81	22.684,33			
Other third party services / data base service	21.495,00				
Value added tax	4.495,37	3.870,67	8.508,33	4.593,35	6.712,55
Third party services and other	9.393,86	6.491,33	10.429,90	13.473,63	17.707,73
Total expenses	**353.923,24**	**261.162,36**	**211.511,08**	**419.502,09**	**431.897,59**
Result	**805,26**	**954,24**	**16.517,32**	**2.338,19**	**-14.898,81**

Assets and Liabilities

	2022	2021	2020	2019	2018
Fixed Assets (office equipment)	2.305,00	2.768,00	2.942,00	1.097,00	2.102,00
Current Assets					
Receivables	0,00	0,00	0,00	21.687,36	0,00
Bank balances	50.386,51	54.443,06	42.333,48	61.108,56	54.443,06
Deferred Expenses	11.904,98	1.500,00	1.500,00	1.500,00	1.500,00
Assets total	**64.596,49**	**58.711,06**	**46.775,48**	**85.392,92**	**58.045,06**
Equity (own capital)					
Retained earnings brought forward	36.929,11	35.974,87	35.974,87	19.457,55	35.974,87
Remaining result of the year	805,26	954,24	16.517,32	2.338,19	954,24
Deferred Income	25.000,00	20.000,00	9.900,00	19.895,00	20.000,00
Liabilities	1.862,12	1.781,95	900,61	46.040,37	1.781,95
Equity and Liabilities total	**64.596,49**	**58.711,06**	**63.292,80**	**87.731,11**	**58.711,06**

European Severe Storms Laboratory - Science and Training Cost centres overview 2022		
	Income	**Direct costs**
General business	239.40 €	- 21,865.34 €
Rent and insurance	6,700.81 €	- 37,649.36 €
Phone and internet	- €	- 9,579.84 €
Testbed, EUMETSAT, DWD testing, ECMWF	294,903.39 €	- 75,261.53 €
PreCast project	74,845.00 €	- €
Seminars	36,320.00 €	- 6,195.90 €
Salaries (income: lump sums from ESSLeV)	60,000.00 €	- 349,307.97 €
Payroll accounting, tax advisor, external auditor	- €	- 7,698.02 €
Travel costs	80.67 €	- 19,682.78 €
Cost sharing with ESSLeV (infrastructure)	30,756.81 €	- €
Energy supply	46.36 €	- 5,906.89 €
ESWD and EWOB	- €	- 9,500.00 €
Public basic funding, Government of Lower Austria	43,324.53 €	- €
Totals	547,216.97 €	- 542,647.63 €

Cost centres overview irrespective of neutral bookings and capital investment.

Annual Accounts	**1 Jan 2022**	**31 Dec 2022**
Bank accounts (very short term liquidity)	125,404.13 €	126,873.41 €
Savings (short and mid term liquidity)	24,150.00 €	39,238.00 €
Fixed Assets	55,155.52 €	65,932.64 €
Total Assets	204,709.65 €	232,044.05 €
Remaining assets increase after 8.6 % inflational correction		8,958.90 €
Annual bank accounts result		**1,469.28 €**
Annual operations result (net income - net costs)		**4,569.34 €**

Appendix A2: Member list 2022

The following table shows all ESSL members as of 31 December 2022, sorted according to their ESSL-ID (which corresponds in ascending order to the beginning date of the ESSL membership). Members joining ESSL in 2022 have an * next to their names. The eight 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*	Dr Anja T. Rädler	GERMANY
Dr Pieter Groenemeijer	*NETHERLANDS*	Dr Darrel Kingfield	USA
Alois M. Holzer	*AUSTRIA*	Dr Stavros Dafis	FRANCE
Dr Maria-Carmen Llasat-Botija	*SPAIN*	Michou Baart de la Faille	NETHERLANDS
Dr Romualdo Romero	*SPAIN*	Dr Jannick Fischer	GERMANY
Dr Martin Setvák	*CZECHIA*	Dr Tanja Renko	CROATIA
Dr Fulvio Stel	*ITALY*	Dr Mateusz Taszarek	POLAND
Dr Jenni Rauhala	*FINLAND*		
Thilo Kühne	GERMANY		
Helge Tuschy	GERMANY		
Zhongjian Liang	GERMANY		
Lionel Peyraud	SWITZERLAND		
Thomas Krennert	AUSTRIA		
Dr Johannes Dahl	USA		
Martin Hubrig	GERMANY		
Dr Oliver Schlenczek	GERMANY		
Dr Victor Homar Santaner	SPAIN		
Dr Bogdan Antonescu	ROMANIA		
Dr Michael Kunz	GERMANY		
Erik Dirksen	GERMANY		
Dr Christoph Gatzen	GERMANY		
Dr Kathrin Riemann-Campe	GERMANY		
Dr Koji Sassa	JAPAN		
Dr Tomáš Pučik	CZECHIA		
Marcus Beyer	GERMANY		
Dr Lisa Schielicke	GERMANY		
Dr Abdullah Kahraman	TURKEY		
Dr John Allen	USA		

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	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
SHMU, 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 – Argenzia Regionale Prodezione Ambiente Ligure	ITALY
TLUBN - Thüringer Landesamt für Umwelt, Bergbau und Naturschutz	GERMANY
IMGW–PIB, Institute for Meteorology and Water Management	POLAND
Department of Economics & Management "Marco Fanno", University of Padova*	ITALY
Met Éireann*	IRELAND
Department of Civil, Chemical and Environmental Engineering, University of Genoa*	ITALY

Fondazione CMCC*	ITALY

Institutional Supporting Members

Münchener Rückversicherungs-Gesellschaft AG	GERMANY
Arthur J. Gallagher (UK) Limited (before: Willis Ltd)	UNITED KINGDOM
Deutsche Rückversicherung	GERMANY
DLR - Deutsches Zentrum für Luft- und Raumfahrt	GERMANY
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.	CZECHIA
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

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.