Annual Report 2021

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 Oberpfaffenhofen 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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Contents

Foreword

Dear Reader,

2021 was the second year of the COVID pandemic which continued to affect the operations of ESSL. All ESSL courses continued to be held online (Chapter 5), just like the ESSL Testbed (Chapter 4). However, the team also leveraged the new situation by addressing the need for remote education and continued the series of online webinars at the beginning of the convective season that was started in 2020, now rebranded as "Afternoons with Convection".

Two very major severe weather events occurred in 2021 received a lot of attention at ESSL. Extremely severe flooding occurred in July in the Eifel region of Germany and eastern Belgium on 14 and 15 July, and a violent tornado hit eastern Czechia on 24 June. Both events damaged hundreds of houses and caused a large n umber of injuries. ESSL staff worked very hard to record and assess the full extent of these events by entering information on their impacts in the European Severe Weather Database. In the case of the tornado, ESSL joined the efforts of the Czech Hydrometeorological Institute and others to survey the damage and offered their expertise.

Besides flooding and tornadoes, an unprecedented high number of 5375 hail reports were recorded in 2021. This begs the question of whether this is part of a trend or not. Past research at ESSL has shown that increases in severe hailstorms are to be expected, and further research has been the central topic of the CHECC project, carried out by ESSL within the German ClimXtreme research network. In 2021, Francesco Battaglioli succeeded to statistically model the occurrence of large hail and lightning, while we welcomed a new employee, Dr Homa Ghasemifard, to join the project team and study the relation of multi-annual severe weather evolution to changes in large-scale flow patterns. Another important aspect of severe weather is forecasting it. In 2021, we made important progress on this topic within the FWF PreCAST project, that ESSL's Austrian branch carries out jointly with ZAMG and with support of ECMWF. You can read more in Chapter 2.

An important new collaboration started in 2020 with EUMETSAT that requested ESSL to assist in preparing users for the new, third generation of geostationary meteorological satellites (Meteosat Third Generation, MTG). A three-year framework contract was agreed which details that ESSL will organize testbeds featuring data to be expected from the new sensors that these satellites will carry, and which will allow more frequently updated imagery, higher resolutions, and additional channels. Moreover, lightning detection from geostationary orbit will be available across Europe as well as frequent soundings of temperature and humidity. For more information, see Chapter 6.

While these data will be featured at ESSL Testbeds starting in 2022, a testbed edition was also carried out in 2021, albeit in online form. The testbed featured no fewer than 7 different products from DWD, ZAMG, and ECWMF. At the 2021 edition, 42 participants

contributed to the evaluation of forecast-supporting tools (see Chapter 3). One of the tools that was evaluated was the Extreme Forecast Index of ECMWF. This evaluation was carried out as one of several projects that ESSL carried out as part of a collaboration with ECMWF. Another such project that was started involved the Weather Data Displayer, ESSL's interface to display meteorological data at the Testbed and its courses. ESSL and ECMWF agreed to migrate the Displayer to the European Weather Cloud, a cloud-based service initiative by ECMWF and EUMETSAT. This work will be completed in 2022.

Administratively, there was not much news in 2021, except for the joining of a new institutional supporting member (Chapter 7). Financially, 2021 was a balanced year with small positive results for both ESSL (€ 954) and its Austria-based subsidiary (€ 5367). That said, the resources in 2021 were still too limited to allow for adequate payment of, in particular, the financial administration, which therefore was still done partly as voluntary work. In 2022, the financial situation should allow for increased employment, because of the increased work associated with the collaborations with EUMETSAT and ECMWF on topics that fit ESSL's expertise.

In 2022, preparations will also start for a new full edition of the European Conference on Severe Storms, which planned to take place in Bucharest from 8 – 12 May 2023. The ESSL team are very much looking forward to meeting international colleagues in person again at that occasion, or earlier.

Concluding, it is my pleasure to present you this Annual Report 2021 that describes ESSL's achievements in its fifteenth full business year.

Wiener Neustadt, 26 August 2022,

Dr Pieter Groenemeijer
ESSL Director
Chair of the Executive Board

1 Severe Weather in 2021

A key activity of ESSL is the collection of severe weather data in the European Severe Weather Database in cooperation with its partners throughout Europe. 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 2021, 27 338 new severe weather reports were added to the ESWD (Table 1-1), which is more than the 25 760 reports from the previous year, 2020.

The most frequently reported severe weather phenomenon w*as* severe wind gusts (12 256), followed by heavy rain (5 795) and large hail (5 375). Compared convective hazards to 2020, large hail showed the strongest increase of reports (+64.2%), followed by heavy rain (+46.8%).

Table 1-1. Severe Weather Reports collected in the European Severe Weather Database in 2021.

Report Type	Number of reports	%	% change relative to 2020
Severe wind gusts	12 256	44.8	- 15.3
Heavy rain	5 795	21.2	+ 46.8
Large Hail	5 375	19.7	+ 64.2
Damaging lightning strikes	1 375	5.0	- 11.6
Heavy snowfall/snowstorms	1 330	4.9	- 5.2
Tornadoes (incl. waterspouts)	904	3.3	+ 10.5
Avalanches	264	1.0	+ 68.2
Ice Accumulation	32	0.1	- 68.0
Lesser whirlwinds	7	< 0.1	- 56.3
Total	27 338		+ 6.1

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. It is not possible to infer multi-annual trends of hazard occurrence 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.

Figure 1-1. Trend of reports of the four convective hazards in the ESWD.

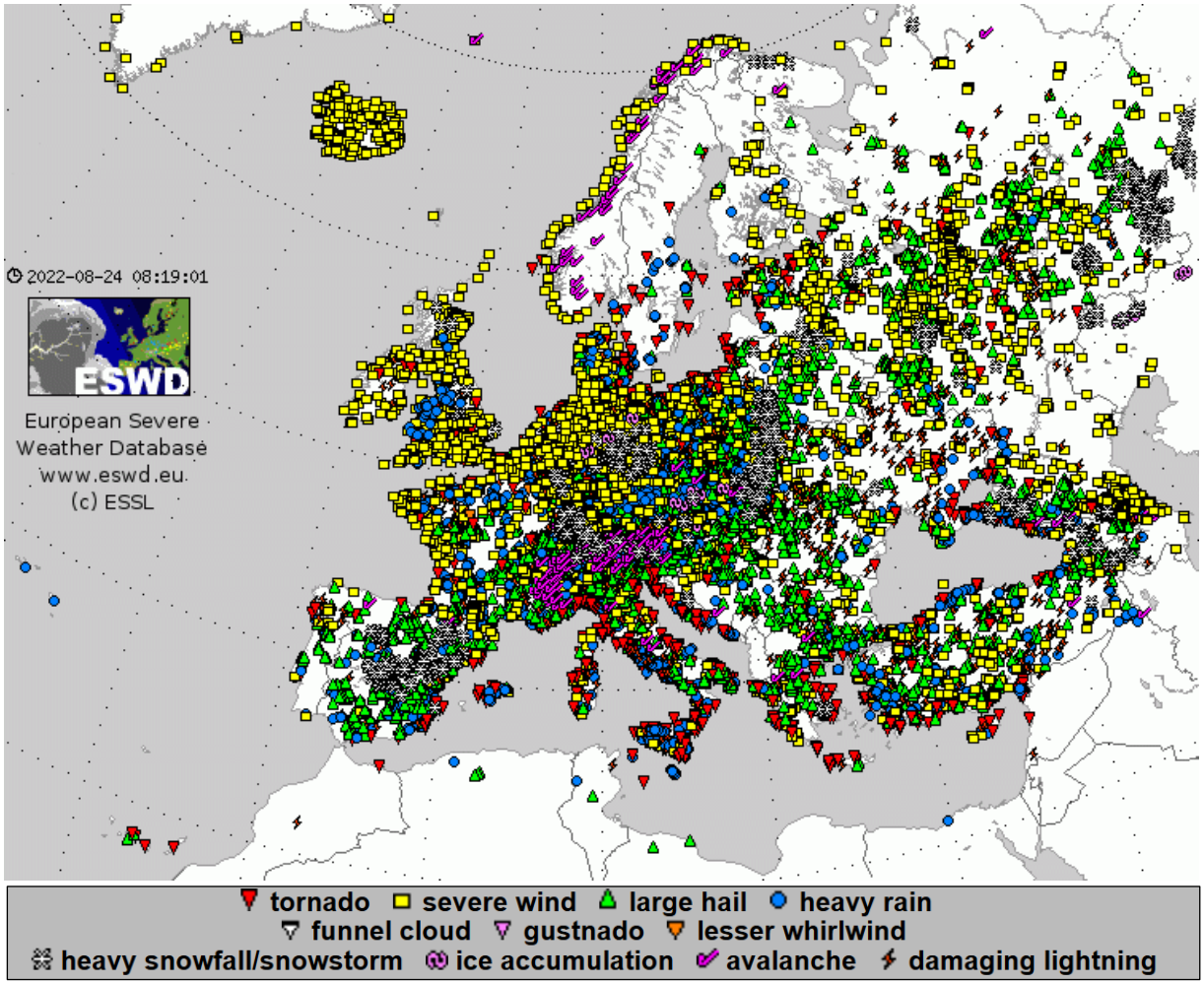

Figure 1-2. The 25 760 ESWD reports of events occurring in 2021.

Table 1-2. Quality control levels of ESWD reports from 2021.

Quality Control level	Number of reports	%
QC0: as received	0	0.0
QC0+: plausibility checked	2 908	10.6
QC1/QC2: report confirmed	24 430	89.4

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 2021 have been upgraded at least to QC0+ or QC1 (

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. It is not possible to infer multi-annual trends of hazard occurrence 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.**

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ESWD Partners

We like to stress the importance of the work of ESSL's partners in collecting and checking ESWD reports 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, like in 2020, tops the list of contributors. The coverage of severe weather events in Poland is particularly good as a result. In other countries valuable and significant contributions to the ESWD are made by the individuals and associations listed in the table. To show its gratitude, on a yearly basis ESSL sends individual volunteers awards, such as ESSL merchandise or a small financial award.

Table 1-3. Most active ESWD partners in 2021

Name	Country	Number of reports
1. Mr Igor Laskowski	Poland	6 759
2. Association MeteoNetwork/PRETEMP	Italy	1 595
3. Mr Nicholas Baluteau	France	616
4. Mr Bas van der Ploeg	Netherlands	359
5. Mr Markus Weggässer	Germany	275

6. Mr François Paul	France	271
7. Amateur Meteorological Society	Czechia	226
8. Niclas Lindberg Jensen	Denmark	182
9. Mr Mario Sekulić	Croatia	179
10. Mr George Papavasileiou	Greece	150

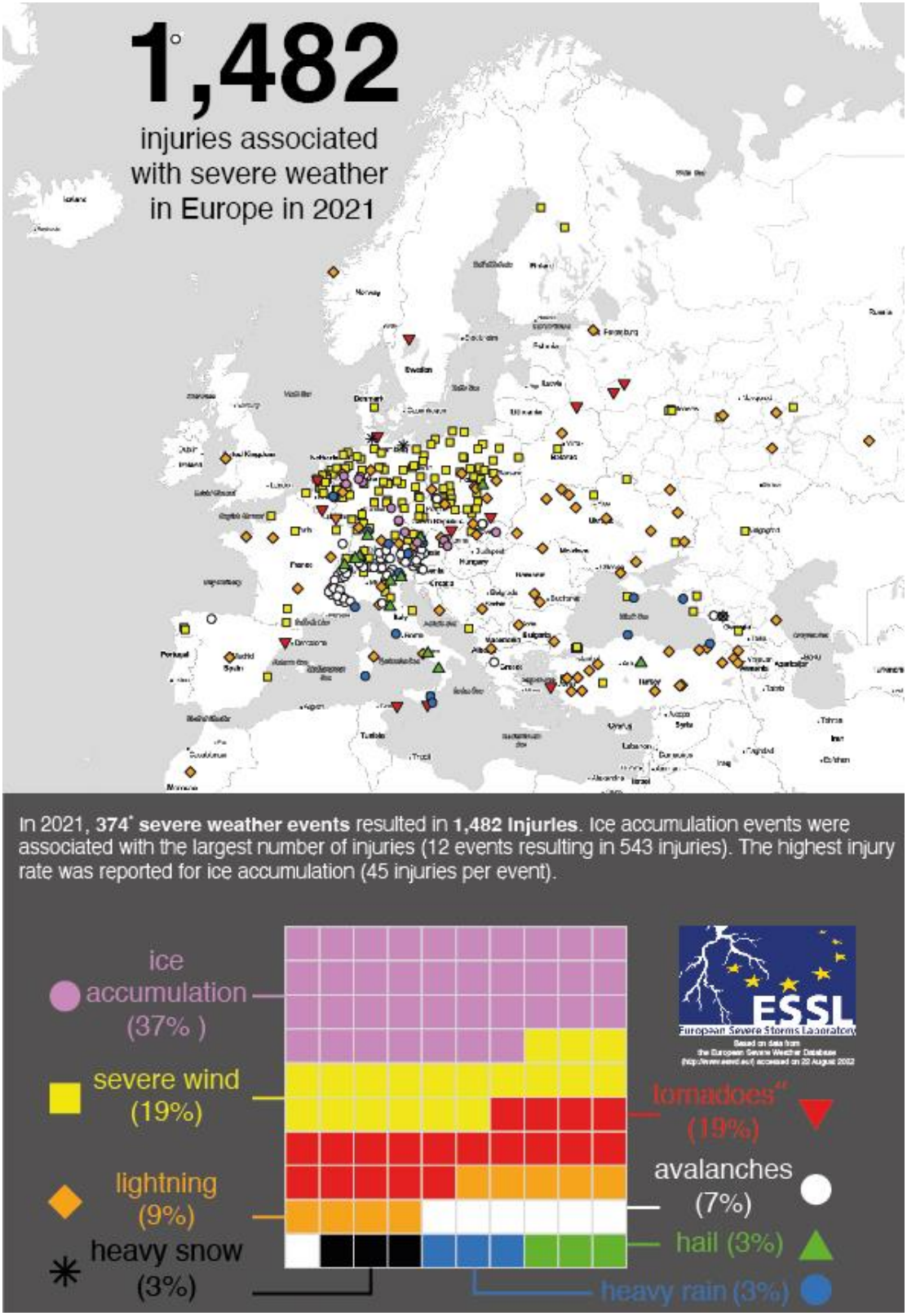


Figure 1-3. The spatial distribution of the ESWD severe weather reports in Europe, associated with injuries in 2021. Below, the percentage of injuries associated with each type of severe weather across the entire ESWD area, i.e., including Mediterranean Africa and Asia, and Central Asia (excluding categories < 1%).

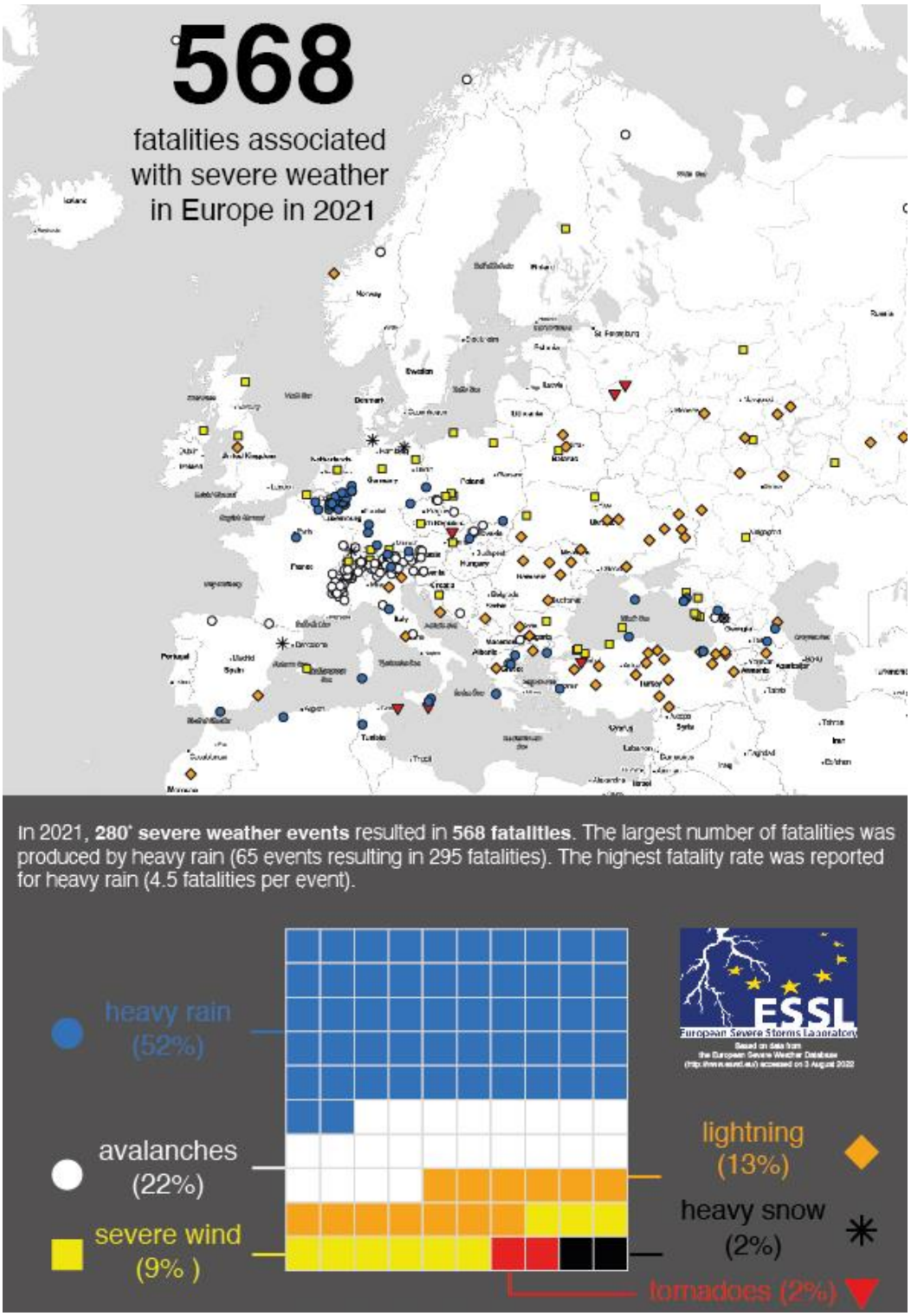


Figure 1-4. The spatial distribution of the ESWD severe weather reports in 2021 associated with fatalities. Below, the percentage of fatalities associated with each type of severe weather across the entire ESWD area, i.e., including Mediterranean Africa and Asia, and Central Asia (excluding categories < 1%).

Fatalities and Injuries

The severe weather reports of 2021 were associated with 1 482 injuries (Figure 1–3) and 568 fatalities (Figure 1–4)

The day with highest number of fatalities was 14 July 2021 when heavy rainfall caused severe flash floods in several narrow valleys mainly in Germany and Belgium, resulting in 192 fatalities. Especially the Ahr Valley in western Germany's Rhineland-Pfalz state was hit by a 7 to 8 metre high flash flood causing devastation along the river in the late evening. At least 132 people were reported dead from the areas along the Ahr River. Flash floods are known from the Ahr Valley area throughout the last centuries (for example on 13 June 1910: 52 fatalities, or on 21 July 1804: 63 fatalities), but the high number of the 2021 flood marks a record both for the Ahr River and for Germany.

In eastern Belgium, violent flash floods hit the region around Liège, resulting in 20 fatalities. Locations in Luxembourg and the southern Netherlands reported damage resulting from extreme rainfall and flooding, but no fatalities.

	Event type(s)	Date	Country	Fatalities
1	Heavy rain	14 July	Germany Belgium	192
2	Heavy rain	6 March	Algeria	9
3	Tornado	24 June	Czechia	6
4	Heavy rain	12 July	Kyrgyzstan	6
5	Heavy rain	11 August	Turkey	6
6	Heavy rain	14 July	Turkey	5
7	Snowstorm	23 September	Russia	5
8	Avalanche	14 January	Italy	4
9	Avalanche	8 May	France	4
10	Heavy Rain	5 July	Russia	4

Table 1-4. The ten days with most fatalities in 2021 recorded in the ESWD.

1.2 Damage survey after a violent tornado in Moravia, Czechia 24 June 2021

During the ESSL Testbed in 2021, which because of COVID-related restrictions took place fully online, the strongest tornado to hit Europe since at least 2015 developed in the border region of Austria, Czechia, and Slovakia, hitting a number of villages on the Czech side of the Slovak/Czech border. Although the Testbed participants and ESSL staff were aware of an extremely high potential of severe weather, the development of such a strong tornado came relatively unexpected since an important factor favoring violent tornadoes, low-level wind shear, seemed not to be extraordinarily high according to the model output available. Therefore, strong wind gusts and very large hail were thought to be much more likely severe weather phenomena.

As the news came in that an extraordinarily strong and potentially violent tornado had occurred, meaning that the intensity could have been F4 or IF4 on the (International) Fujita scale, ESSL's Dr Tomáš Púčik offered his expertise to the Czech Hydro Meteorological Institute and advised them on best practices to carry out a damage survey. With his help, a number of teams were assembled that in the following days surveyed the impacted region.

The survey took 3 days to complete with contributors from 7 institutions spanning 3 countries: CHMI, Meteopress, AMS, and AmperMeteo from Czechia, SHMU from Slovakia and ZAMG, and ESSL from Austria.

The survey established that the tornado reached **IF4 intensity** in several locations along the tornado path and that the tornado was up to 2.8 km wide in the beginning.

ESSL continued to collaborate with partners on the data gathered from the damage survey during the remainder of the year. Work was also ongoing concerning the meteorological conditions leading up to the tornado and ESSL contributed to a report on the tornado lead-authored by the CHMI (available in Czech language).

Key data of the tornado	
Tornado formation:	~17:14 UTC, 1 km east of Břeclav
Tornado decay:	17:53 UTC, 1 km south of Ratíškovice
Maximum intensity:	IF4
Path length:	27.1 km
Continuous path of ≥ IF2 damage:	15.3 km
Maximum path width:	~ 2800 m, east of Břeclav
Maximum width of ≥ IF2 damage:	590 m, in Hrušky
Minimum path width:	~ 250 m, in Hodonín
Impacted area (≥ IF0 damage):	21.9 km²
Area of ≥ IF2 damage:	6.1 km²

Figure 1-5. Debris impacts on the wall of a house in the tornado path.

A second report in English language detailing the damage produced has since been prepared and is available on the ESSL website.

ESSL researchers are since working on a meteorological analysis of the evolution of the tornado-producing storm.

1.3 ESWD Data Users and Partners

Users

ESWD data are used by a wide range of users. They include ESSL members who have access to the data as a benefit for members. In addition, ESSL receives a fair number of requests from potential new users, usually initiated by an e-mail sent to the address eswd@essl.org.

The interest in ESWD data has strongly increased in 2021 compared to previous years (Figure 1-66), both for non-commercial and for commercial use. 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.

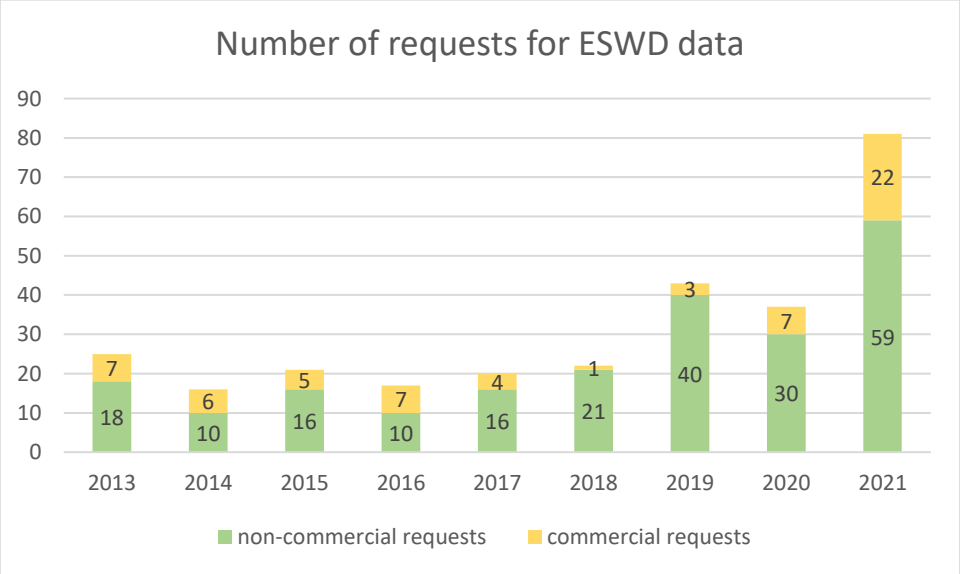


Figure 1-6. Number of requests for ESWD data by non-members.

2 Research

Two long-term research projects continued in 2021: The project CHECC deals with the changing risk of convective hazards as a result of climate change. The project PreCAST focuses on improving severe weather forecasts. In addition several smaller projects were done for ECMWF and a project started with the Danube University to evaluate a new lightning sensor.

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; National Severe Storm Laboratory; University of Poznań
ESSL employees:	Francesco Battaglioli, Homa Ghasemifard, Thilo Kühne, Pieter Groenemeijer

In 2021, the project CHECC was in full swing. This 3-year research project, funded by the German Ministry of Research and Education and part of the national ClimXtreme research network, focuses on the analysis of extreme climatological events. Within this project, ESSL improves statistical dynamical models to detect extreme convective events from reanalysis and climate model data, and develop new methods based on convection-permitting model simulations.

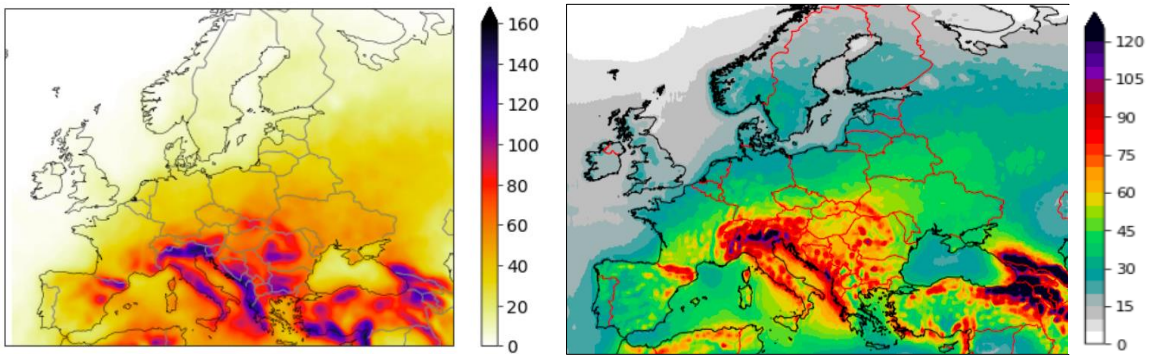


Figure 2-1. Observed (left) and modelled (right) annual number of lightning hours using a newly developed AR-CHaMo regression model in CHECC on the basis of the ERA5 reanalysis.

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.

First results include a rather accurate modelling of lightning rate (Figure 2-1) and of large hail (Figure 2–2) using an additive regression model

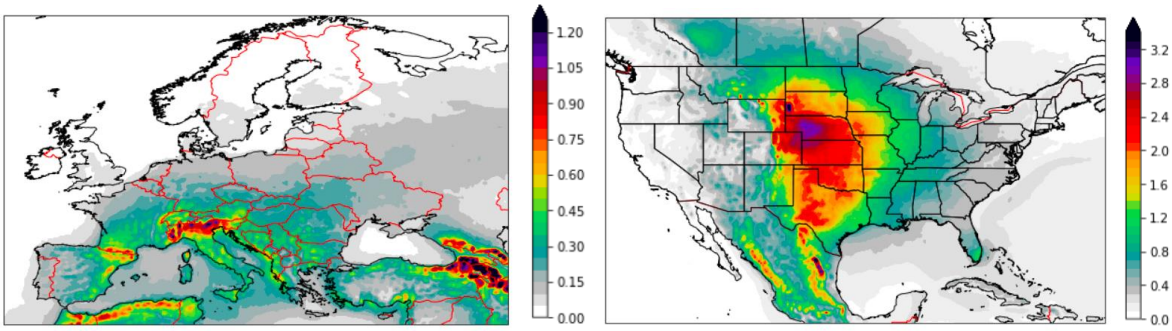


Figure 2-2. Annual number of hourly time blocks with hail ≥ 2 cm in their vicinity using a newly developed regression model in CHECC across Europe (left) and parts of North America (right).

The CHECC project is carried out by Thilo Kühne, who contributes with targeted ESWD data collection from old resources, by Francesco Battaglioli, who is a PhD student, and an additional employee to join ESSL in 2021, while Pieter Groenemeijer supervises the work.

In July 2021, a post doctoral researcher Dr Homa Ghasemifard joined the CHECC team. Her work will involve investigation the relation between severe weather occurrence and (change of) the large-scale weather patterns across Europe.

Francesco and Homa's office is located at the Institute of Meteorology of the Free University of Berlin which has kindly offered to host them. A collaboration with Dr Mateusz Taszarek (National Severe Storms Laboratory, USA; and University of Poznań, Poland), who support CHECC by providing convective parameters calculated from reanalysis data.

Next, the project work will focus on detecting and explaining temporal changes of the modelled convective hazard occurrence as well as on providing important input to the project PreCAST below.

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 Zentralanstalt für Meteorologie und Geodynamik (ZAMG)
Supported by:	European Centre for Medium-Range Weather Forecasts (ECMWF)
ESSL employees:	Tomáš Púčik, Pieter Groenemeijer

PreCAST is a collaborative project with ZAMG, lead by ESSL and supported by ECMWF with the aim of improving predictions of convective hazards. In this project, led by Dr Tomáš Púčik, the limitations of the predictive skill of NWP-based forecasts of convective hazards, such as large hail and severe wind, on timescales from hours to 10 days in advance are investigated. To do this, a probabilistic forecast system that blends short-range (1 - 72 hour) and medium-range (72 - 240 hour) forecasts, each using different approach.

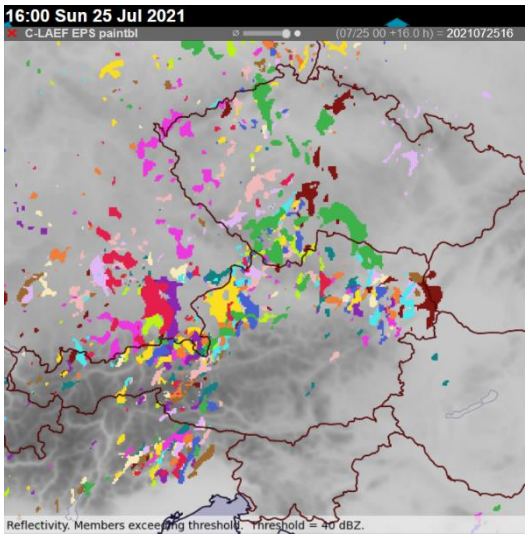


Figure 2-3. C-LAEF ensemble prediction of where reflectivity exceeds 40 dBZ, with each member in a different colour (a paintball plot).

For the medium range, the AR-CHaMo logistic modelling framework is used which was previously developed by ESSL and Munich RE, while for the short range, a convection-permitting ensemble with stochastic microphysics will be developed. In the project, ESSL collaborates with ECMWF to leverage its Ensemble Prediction System to do this. The ZAMG contribution focuses on the short forecast range for which they will leverage and enhance its convection-permitting ensemble forecast system C-LAEF by introducing stochastic physics.

In 2021, work on heavy rainfall and severe wind gust statistical models on the basis of AR-CHaMo was conducted. For severe wind gusts, the predictors involving strength of wind in the lower troposphere were found to be most useful. For heavy rainfall, it was found that large discrepancy in environments exists between central Europe and the coastlines of the Mediterranean Sea.

Furthermore, ZAMG colleagues implemented of a new stochastic parameter perturbation scheme in C-LAEF (SPP) whereby 13 parameters in different physics parameterizations are perturbed stochastically. The resulting ensemble forecasts have been integrated into

the ESSL Weather Data Displayer and an evaluation was carried out by during 4 ESSL Testbed weeks. The main finding was that C-LAEF storms are often large compared to observations which may be caused by producing too strong outflow out of convective storms.

2.3 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 will be developed, the long-term stability of which will be verified in varying environmental conditions.

For that purpose, the sensor will be installed at the ESSL Research and Training Centre in Wiener Neustadt to record the local electric field over time, and ESSL will monitor and evaluate the relation between the recorded electrostatic field to the occurrence of nearby lightning strikes in various types of thunderstorms and verify the sensor's suitability for deployment in an early warning system for lightning.

The sensor being developed in this project is based on a new type of conversion of the static electric field into a mechanical oscillation at a known frequency. Its underlying transduction method is based on the electrostatic force experienced by charges in E-fields. It does not require much power or space, which means that the sensor can be driven with a single coin battery for weeks and no conducting connections to the power grid are needed.

The evaluation phase that will be carried out by ESSL will take place mostly during the second half of the project period, in late 2022, 2023, and 2024.

2.4 Projects on severe weather forecasting with ECMWF

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

ESSL has been tasked with a series of small projects by ECMWF. They include the following tasks. First, an evaluation of the Extreme Forecast Index for CAPE and CAPESHEAR. This index is computed from ECMWF's Ensemble Prediction System to help its users better anticipate hazardous weather. This evaluation was conducted at the ESSL Testbed resulting in a report that was delivered to ECWMF.

Second, as a spin-off of the CHECC and PreCAST projects, a study was conducted of predictability of large hail, lightning and severe winds in the medium range using re-forecasts of the Ensemble Prediction System. This work was nearing completion by the end of 2021. A scientific manuscript for publication detailing the results will be completed in 2022.

In addition to these studies, ECWMF tasked ESSL to run an instance of the ESSL Weather Data Displayer in the European Weather Cloud.

The Weather Data Displayer is ESSL's web-based interface to visualize meteorological data for training and evaluation purposes. It features Numerical Weather Prediction data, as well as satellite and radar data and data from various nowcasting systems.

An important strength is that is can be quickly adapted to display additional evaluation data, which makes it an indispensable tool for the ESSL Testbeds.

The European Weather Cloud (EWC)

The EWC is an initiative by ECMWF and EUMETSAT, that will deliver data access and cloud-based processing capabilities to them and to the National Meteorological Services of their Member States.

The EWC addresses the increasing challenges to provide infrastructure to store, manage and process large datasets. Working on data in the cloud enables new types of capabilities including running software close to the data, rather than downloading vast amounts of data locally and needing a local infrastructure in support.

The work to migrate the Displayer to the European Weather Cloud started in Spring 2021 and was partly completed by the end of the year is and set to be completed in 2022.

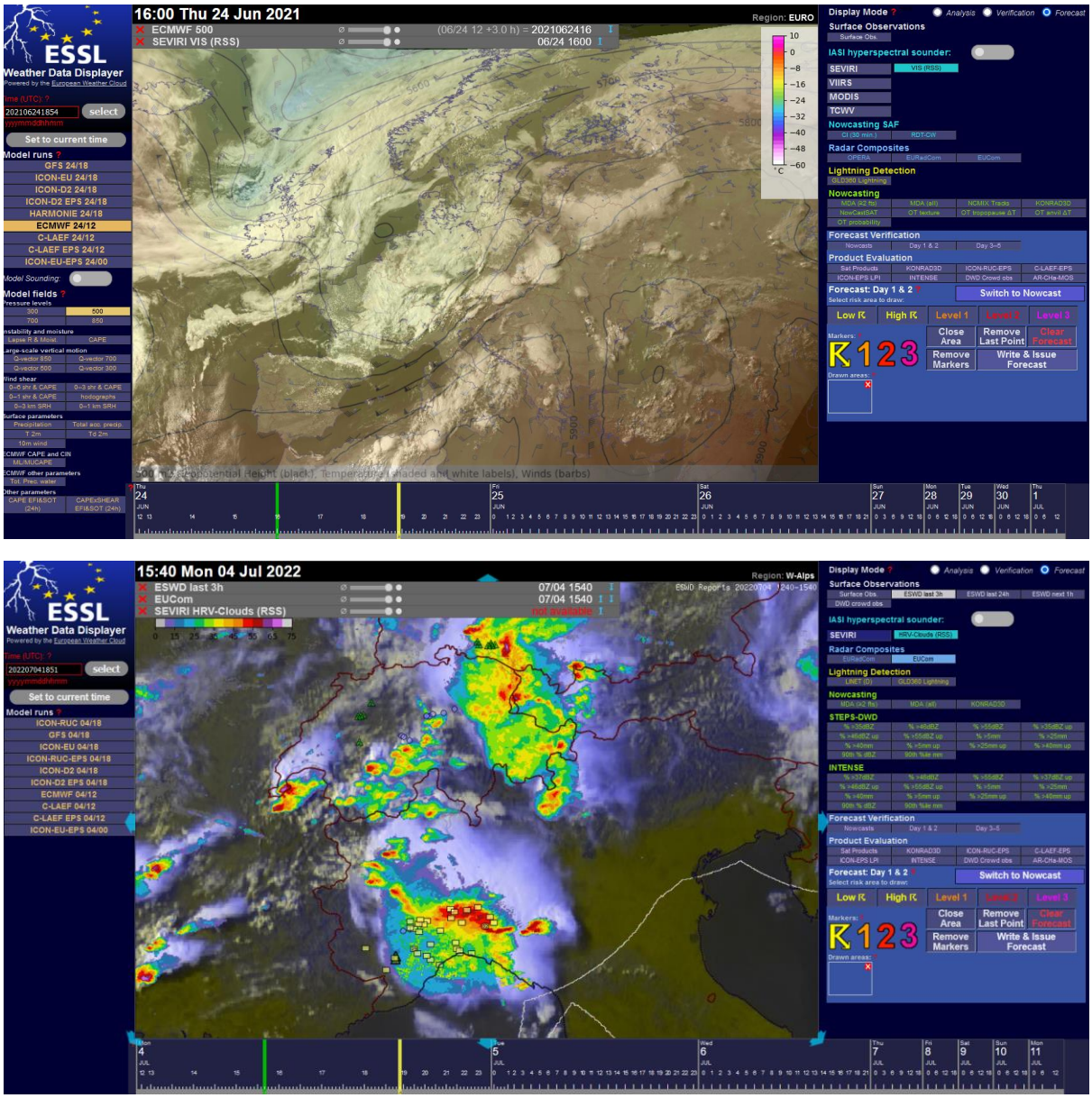


Figure 2-4. Screenshots of the ESSL Weather Data Displayer.

3 ESSL–EUMETSAT partnership

EUMETSAT and ESSL started a collaboration on the use of the next-generation satellite data in severe convective storm forecasting

ESSL has entered into a contract with EUMETSAT for three years to train forecasters of the national (hydro-) meteorological services of its member states. The training focuses on the use of products from the next-generation satellite missions Meteosat Third Generation (MTG) and EUMETSAT Polar System–Second Generation (EPS-SG) for the analysis and nowcasting of severe convective storms.

EUMETSAT and ESSL have started this contract on 1 June 2021 that is intended to pave the way for longer-term collaboration in support of the European meteorological community. ESSL will organize training testbeds for operational forecasters of Europe's weather services, introducing proxy, and later real, data from EUMETSAT's next-generation missions with a focus on severe convective storm forecasting. The aim is to totally train about 10–15% of the operational meteorological workforce in European weather services, or about 200–300 forecasters.

The testbeds are mainly organized at ESSL's Research and Training Centre in Wiener Neustadt (Austria) but can also be hosted by weather services with suitable facilities upon their request.

Besides the testbeds, expert workshops will be organized for a small number of people that include senior forecasters, product experts, senior trainers, science-to-operations staff, and experts from EUMETSAT. The aim of these workshops is to better understand novel capabilities for severe storm analysis and prediction, such as with the new 0.9 µm (see Figure 3-1) and 2.25 mm bands, the Lightning Imager, and the Infrared Sounder, and to develop training concepts and material. The first such workshops have since taken place in 2022.

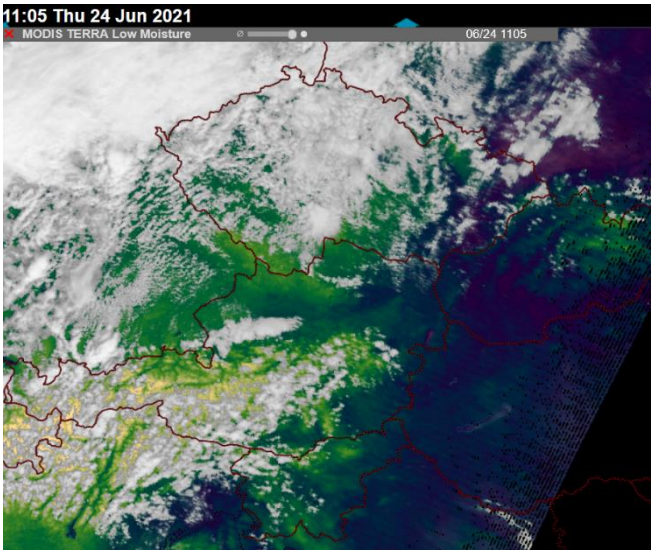


Figure 3-1. "Low Moisture" product showing moisture (purple) prior to the tornadic supercell across East Czechia in the afternoon of 24 June. This ESSL-developed product uses the 0.9 µm near-IR channel on MODIS that is absorbed by water vapor. Meteosat Third Generation will allow a similar product to be available every 10 or even 2.5 minutes.

4 ESSL Testbed 2021

The Testbed is ESSL's annually returning event that serves two aims: the evaluation of tools supporting the forecast or warning process and providing training in severe convection forecasting to its participants.

The ESSL Testbed 2021 took place during the weeks of 14 – 18 June, 21 – 25 June, 5 – 9 July, and 12 – 16 July 2021. This was the 10th edition of the ESSL Testbed, a series of testbeds that began in 2012. The first and fourth weeks were "regular" Testbed weeks, while the second and third were reserved for more expert participants, who have already been to the Testbed. Due to the ongoing COVID-19 situation, the program was conducted in purely online form as it was in 2020. The BlueJeans teleconferencing system was used to communicate with the participants, allowing the creation of break-out sessions for small sub-groups necessary for making forecasts, nowcasts, and product evaluations. Despite the lack of personal contact, the feedback received from participants was overwhelmingly positive. Compared to 2020, the ESSL Weather Data Displayer was significantly upgraded, allowing for a better combination of model and nowcast data, easier selection of subdomains, and making data layers transparent.

Altogether, fourty-six participants took part in the Testbed in addition to 5 ESSL staff members. The participants came from eighteen different countries: Germany, Austria, the Netherlands, Slovakia, Czechia, Finland, Poland, Croatia, Portugal, Romania, Spain, Italy, Serbia, Luxembourg, United Kingdom, Sweden, Argentina, Cyprus. This year, many of the participants were not forecasters, but developers of the products evaluated at the Testbed. This was true in particular for a large number of DWD employees who work within the project SINFONY of DWD that creates a Seamless INtegrated FOrecastINg sYstem.

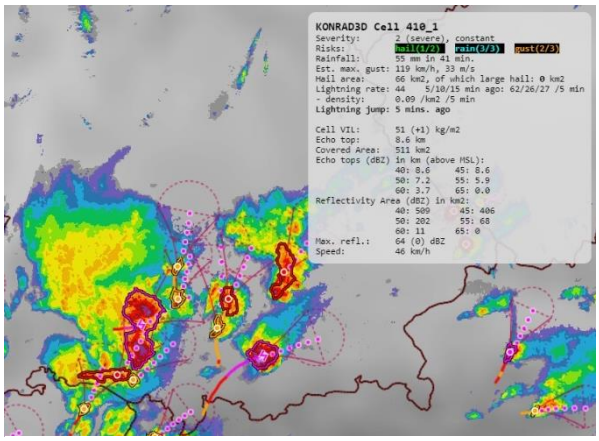


Figure 4-1. Visualization of KONRAD3D for the Testbed in the Weather Data Displayer

At the Testbed 2021, seven forecast-supporting products were evaluated, described below.

1. KONRAD3D (DWD)

Description: KONRAD3D is a developmental convective cell-detection and tracking algorithm that analyses the present state of a convective cell and gives a prediction of its movement in the next hour, along with a number of severity attributes.

Main finding: The power of KONRAD3D is the aggregation of cell attributes. Its cell motion forecasts are rather accurate. A number of cell properties, such as wind speed and the hail risk flag need further development and calibration.

2. C-LAEF (ZAMG)

Description: C-LAEF is the operational convection permitting ensemble prediction system of the Austrian weather service ZAMG.

Main finding: C-LAEF developed more storms than ICON-D2, and was more in line with radar observations, but it transitioned storms too quickly into linear systems, because of too strong outflows

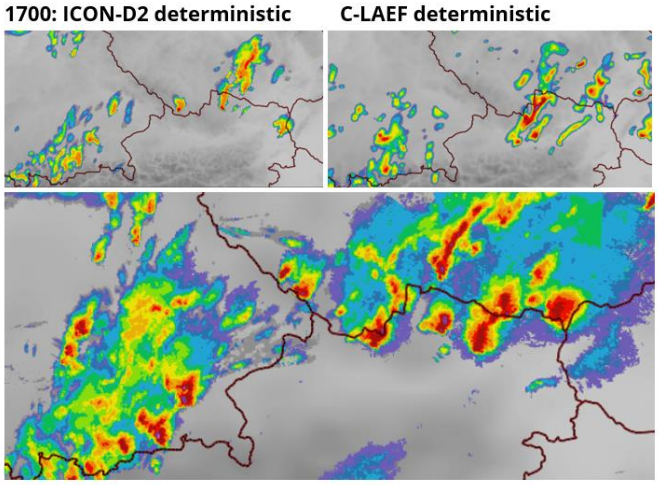


Figure 4-2. Comparison of ICON-D2 and C-LAEF reflectivity forecasts on 24 June 2021 at 1700 with radar (bottom), shortly before tornado touchdown with the easternmost cell.

3. ICON-D2-EPS (DWD)

Description: ICON-D2 is the DWD's new configuration of the ICON model at a convection-permitting resolution covering Germany and neighbouring areas with 2.2 km grid spacing.

Main finding: While the ICON-D2 model predicts temperature and moisture at the surface with high accuracy, it has a notable tendency to under forecast convective initiation, especially at some distance from weather systems.

4. CAPESHEAR-EFI (ECMWF)

Description: The Extreme Forecast Index (EFI) has been developed at ECMWF to inform users about how extreme an ensemble forecast is, by comparing the forecast distribution to the model climate (M-climate) distribution. It includes the Shift Of Tails (SOT) as an indicator for the most extreme deviations. EFI for CAPE and CAPESHEAR has been developed recently.

Main finding: With the CAPESHEAR EFI it is possible to anticipate severe convective weather episodes many days in advance. Across regions where high CAPESHEAR is rare, such as northern Europe, high EFI values do not imply that severe weather will occur.

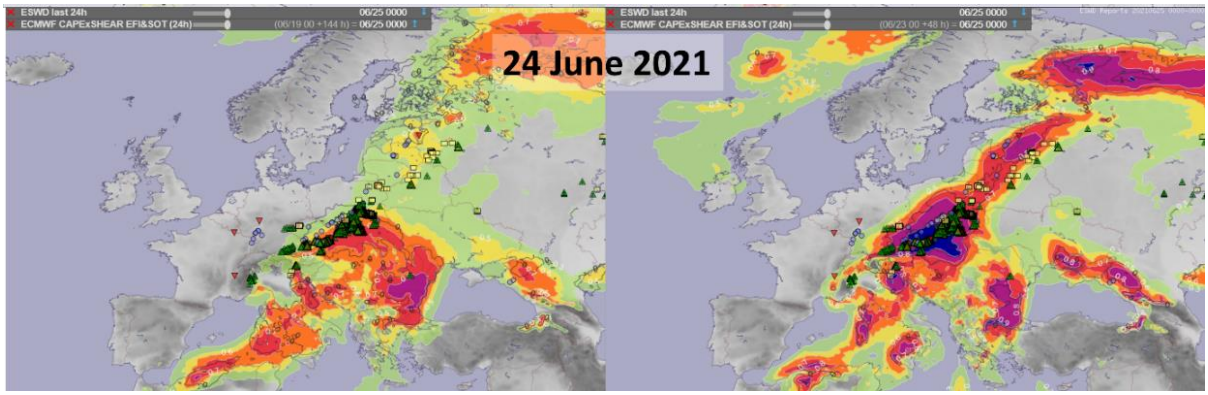


Figure 4-3. CAPESHEAR EFI forecasts for the severe weather situation on 24 June 2021 at lead times of 120–144 (left) and 24–48 (right) hours with severe weather reports overlaid.

5. Modified Lightning Potential Index – MLPI (DWD)

Description: For models resolving deep convection, such as ICON-D2, a lightning potential index (LPI) was developed in the past. The LPI is driven by the vertical velocity, and liquid water, snow, ice and graupel in the charge separation zone. This Modified LPI (MLPI) has been modified to help predict lightning with parameterized convection in the ICON-EU model.

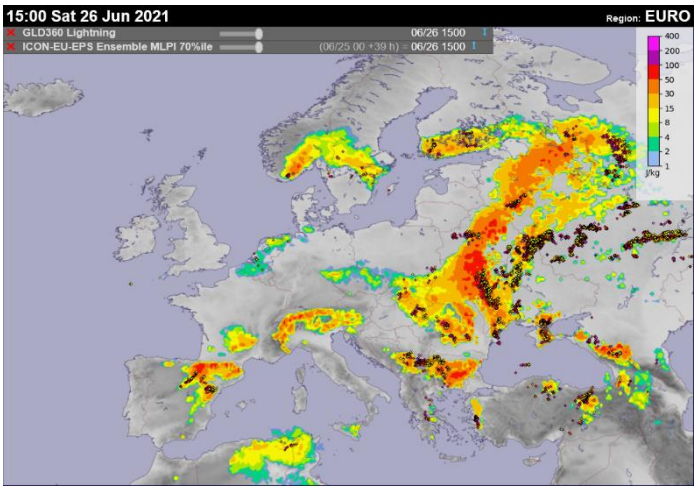


Figure 4-4. Forecast of the 70% percentile of MLPI with lightning detections (GLD360) for 26 June 2021 at 15:00 UTC.

Main findings: The MLPI does a fair job at prediction the location and timing of lightning. Nocturnal convection was often under-estimated. Some overestimation was noted with storms in environments with little buoyancy in the charge-separation zone. A number of preferences related to the visualization, such as threshold values to be displayed, were established.

6. NowCastSAT (DWD)

Description: Two NowcastSAT algorithm variants were evaluated that analyse the position and cloud top height of convective systems an yield an extrapolation in the near future.

Main findings: NowCastSAT's forecast of the future location of cells is fairly good when concentrating on a forecast range of less than 60 minutes. Lower performance was found for greater forecast ranges, especially when the intensity of cells changed, or new cells developed adjacent to the original storm system. Some false detections occurred, and the visualization can be made more intuitive.

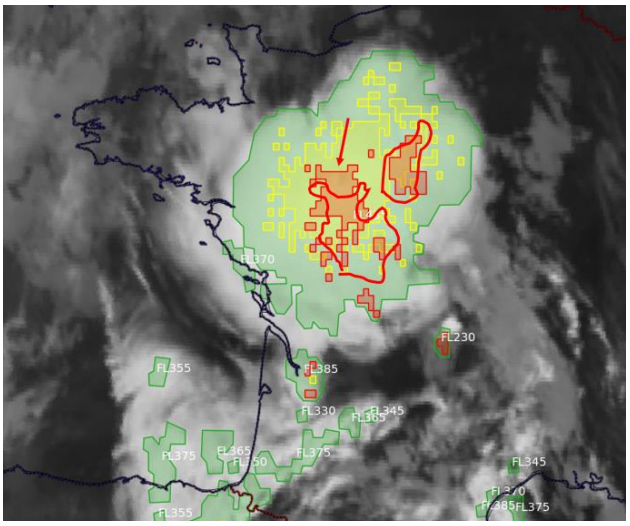
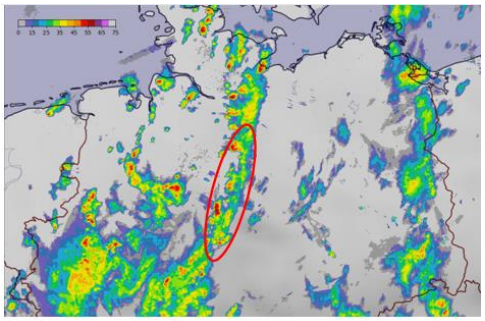
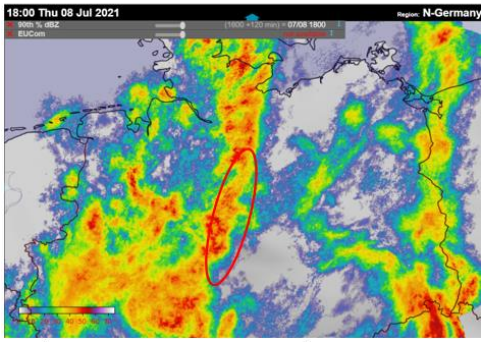


Figure 4-5. NowCastSAT (polygons) combined with IR10.8 satellite images on 17 June 2021 00:00 UTC across France. Red lines denote the + 60 minute forecast location of red polygons from 23 UTC.

7. STEPS-DWD (DWD)



8 July 2021 1600 UTC EuRadCom



8 July 2021 1600 UTC + 120 min
STEPS-DWD Probability 90th % dBZ

Description: STEPS-DWD is an advanced extrapolation algorithm of radar echoes that yields probabilistic nowcasts for the evolution of precipitation for the next two hours using an ensemble approach.

Main findings: The forecast performance was good overall. The best results were found for isolated cells that moved with a more or less constant speed and direction, and the intensity of which did not change much with time. For slow moving-storms considerable errors were noted.

Left: Figure 4-6. Comparison of STEPS probabilistic forecast (bottom) to observed radar reflectivity (top)

5 Training activities

In 2021, ESSL continued organizing the training activities in the online form due to the ongoing COVID-19 situation. A new format "Afternoons with convection" was tried out.

Overall, ESSL organized 5 training events lasting 5 days and 4 one day events. Three events were organized on demand for the individual meteorological institutes and two events were standard "Forecasting severe convection" and "Aviation forecasting of severe convection" courses.

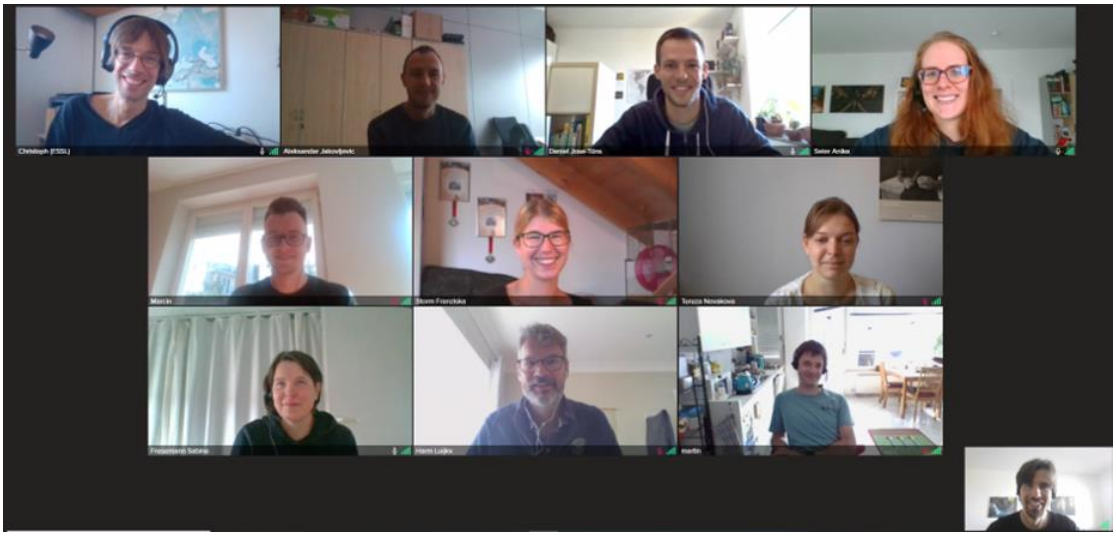


Figure 5-1. Group photo from the course for aviation meteorologists.

The first course was organized for the Catalonian meteorological institute between 15 and 19 February. The outline followed the standard "Forecasting severe convection" course but concentrated more strongly on the Mediterranean rainstorms, large hail, and lightning. There was a lot of discussion concerning the usage of the total lightning activity and lightning jumps for nowcasting severe storms as this topic is actively researched by some of the Catalonian forecasters.

The second course was organized for the Civil Protection Service of the Marche region (Italy) between 19 and 23 April. This region combines the effect of both the Adriatic Sea and the nearby Apennines and is prone to some severe hailstorms that develop in narrow zones of high CAPE values and strong shear. During the course, we discussed some of the supercell cases from the region. At the time of the writing of this Annual Report (late July 2022), the region has actually experienced one of such situations with hail up to 9 cm in diameter!

The third course was our standard “Forecasting Severe Convection” held between 3 and 7 May. The fourth course was the “Aviation forecasting of severe convection” between 4 and 8 October. ESSL worked on the course content to make the presentations more interactive and keep the participants “alive!”. The last course of 2021 was held for Cyprus between 22 and 26 November, making it the third course overall that was organized for this meteorological institute.

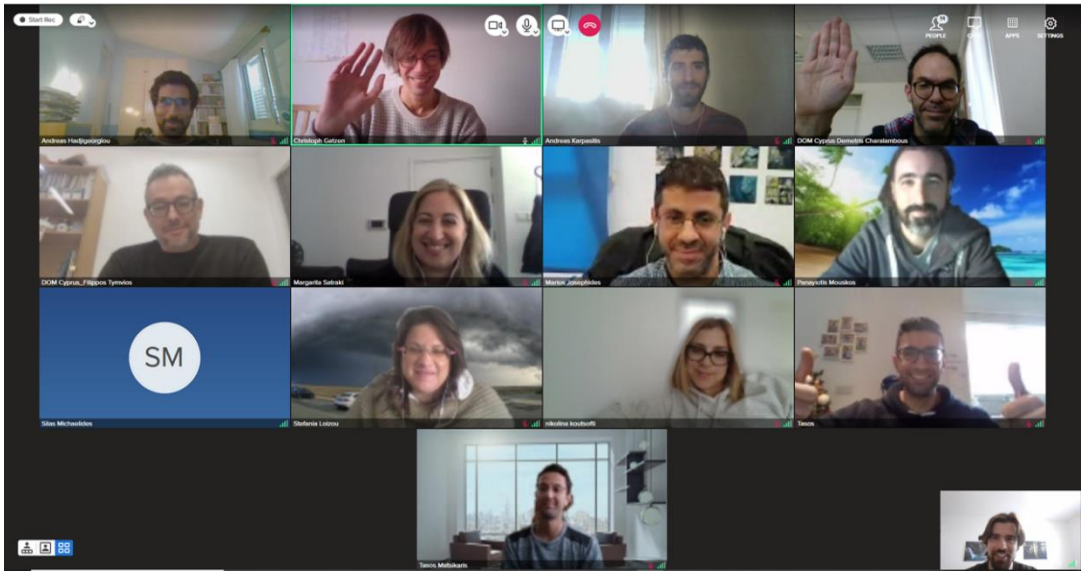


Figure 5-2. Group photo from the course for Cyprus meteorologists.

Afternoons with Convection

On three days in June, ESSL organized a series of short afternoon webinars on different topics related to convective storms. Each webinar contained a lecture by an invited expert, followed by a discussion of a selected case, where the presented theoretical concepts were applied. On 2 June, Matthew Kumjian gave a talk on forecasting large hail. On 9 June, John Peters presented his new research on the dynamics of supercells and on 30 June, Cameron Nixon showed how to use the hodographs to their fullest. Webinars attracted a lot of attention and each one of them was attended by more than one hundred people. The highest number of participants was 161. The recordings of the webinars can be found here.

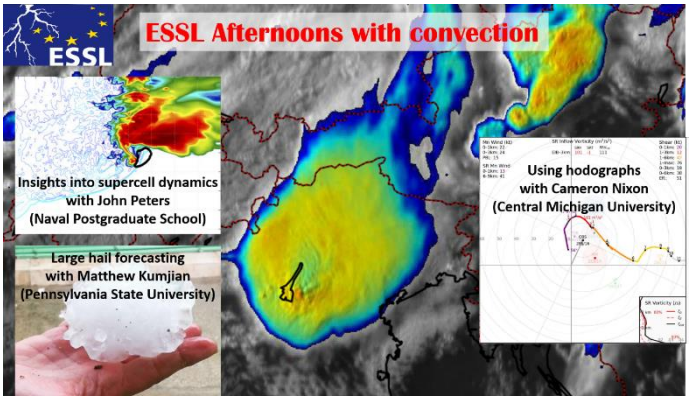


Figure 5-2. Advertisement for the Afternoons with convection

6 Publications and Communications

In 2021, ESSL employees gave fourteen invited presentations, a poster presentation, (co-)authored four reports and was featured in 27 media appearances. No peer-reviewed produced publications appeared in 2021, a result of ESSL focusing on new projects (PreCAST and CHECC) for which publications are expected in 2022.

6.1 Scientific and Invited Presentations

Oral presentations

- Pieter Groenemeijer: **Education and Training at ESSL in 2021 and 2022**, WGET meeting, 3 February 2021.
- Tomáš Púčik, Christoph Gatzen: **Deep moist convection in winter**, EUMETRAIN Snow Event week, 8 February 2021.
- Pieter Groenemeijer: **Severe convective storms in Europe: climate research and forecasting**. Colloquium of Institute of Marine and Atmospheric Physics, Utrecht, Netherlands, 16 February 2021.
- Christopher Castellano, Pieter Groenemeijer, Anja Rädler, Eberhard Faust, Tomáš Púcik: **Estimating changes in high-end hail losses in Europe using a hail event set**. 3rd European Hail workshop Karlsruhe, 16 March 2021.
- Tomáš Púčik, Pieter Groenemeijer: **Satellite products at the ESSL Testbed**. CWG meeting, 7 April 2021.
- Francesco Battaglioli, Pieter Groenemeijer, Uwe Ulbrich, Henning Rust, Tomáš Púčik: **Modelling convective hazards using ERA5 reanalysis across Europe**, German Insurance Association – GDV, 18 April 2021.
- Francesco Battaglioli, Pieter Groenemeijer, Tomáš Púčik, Uwe Ulbrich, Henning Rust, Thilo Kühne, and Mateusz Taszarek: **Modelling the occurrence of convective hazards using ERA5 reanalysis data**. EGU General Assembly, April 2021.
- Pieter Groenemeijer: **ESSL – EUMETSAT Testbeds on Severe Convective Storm Forecasting using next-generation satellite products**, MTG Forum, 29 June 2021.
- Tomáš Púčik, Pieter Groenemeijer: **Pan-European perspective on the severe weather outbreaks of June and July 2021: overview and forecasting challenges**. EUMETSAT conference, 21 September 2021
- Pieter Groenemeijer and Tomáš Púčik: **Convective winds in Europe and the International Fujita scale**, THUNDERR Workshop, Genoa, 4 – 8 October 2021.
- Tomáš Púčik, Christoph Gatzen: **Severe convective storms in winter**. SEEMET, 29 October 2021.

- Francesco Battaglioli, Pieter Groenemeijer, Tomáš Púčik, Uwe Ulbrich, Henning Rust, Thilo Kühne, and Mateusz Taszarek: **Convective Environments of Large Hail in Europe and the US: Challenges in Building a Global Hail Model**, AMS Early Career conference on Severe Local Storms, 5 November 2021.

- Pieter Groenemeijer: **Human capacity building: Preparing forecasters for their defining moment**. European Forum for Disaster Risk Reduction (EFDRR), Matosinhos, Portugal, 24 – 26 November 2021.

- Pieter Groenemeijer, Tomáš Púčik, Christoph Gatzen: **Evaluation of DWD Nowcast, Warning, and NWP products at the ESSL Testbed 2021**. ESSL online event, 7 December 2021.

Poster presentation

- Francesco Battaglioli: Convective Hazard Evolution Under Climate Change, *ClimXtreme General Kick-off Meeting,* 11 – 12 November 2020 (online).

6.2 Reports

- Pieter Groenemeijer, Tomáš Púčik and Christoph Gatzen: **Report on the evaluation of DWD Forecast and Warning products at the ESSL Testbed 2021**, ESSL Report 2021/01.
- Pieter Groenemeijer, Tomáš Púčik: **Report on the evaluation of the CAPE- and CAPESHEAR-EFI and SOT products at the ESSL Testbed 2021**, ESSL Report 2021/02.
- Pieter Groenemeijer, Tomáš Púčik: **Report on the evaluation of ICON-D2-EPS and C-LAEF at the ESSL Testbed 2021**, ESSL Report 2021/03.
- CHMI and co-authors, 2021: **Souhrnná zpráva k vyhodnocení tornáda na jihu Moravy 24.6.2021 (A summarizing report on the evaluation of the 24 June 2021 tornado in south Moravia):** Available at chmi.cz with this link.

6.3 Notable press communications and outreach activities

- Bogdan Antonescu: interviews for Digi24 (Romanian TV) on 3, 6, 11 and 25 June, 18 July, 13 and 17 August and on 5 September on severe weather in Europe, such as tornadoes, lightning, heat waves, hail, and the latest IPCC report.

- Tomáš Púčik: Un genovese ricerca eventi estremi all'Essl. Press release of ARPA-Liguria, https://www.arpal.liguria.it/tematiche/meteo/archivio-news/item/un-genovese-ricerca-eventi-estremi-all-essl.html, 13 June 2021.

- Bogdan Antonescu: Interviews for Digi24, Antena 1 (TV station), Antena 3 (TV station), România TV (TV station), RFI, TVR2 (TV station) about the Czech tornado, 25 June 2021.

- Pieter Groenemeijer: Interview for '1 Vandaag' (Dutch national TV) https://eenvandaag.avrotros.nl/item/tornado-tsjechie-richt-ravage-aan-pad-van-de-storm-was-uitzonderlijk/ and 'De Volkskrant' (Dutch newspaper) on tornado in Czechia, 25 June 2021.

- Tomáš Púčik: SME Podcast on the violent tornado of 24 June 2021. Nominated for the "Best Podcast of 2021" journalist award in Slovakia.

- Bogdan Antonescu: interview for "Adevărul" (newspaper) about tornadoes and severe weather in the context of climate change, 10 July 2021.

- Bogdan Antonescu: Interview for "Formula As" (weekly magazine) about lightning and lightning protection, 13 July 2021.
- Pieter Groenemeijer: Interview for 'Europa podcast' of BNR Nieuwsradio (Dutch radio) on severe weather in Europe, https://www.bnr.nl/podcast/europa-podcast, 20 July 2021.
- Bogdan Antonescu: 5 September discussion at Astra Film Festival with Teodora Tompea on climate change and severe weather.
- Bogdan Antonescu: 25 September "Fenomene climatice extreme" discussion together with Roxana Bojariu for Bucharest Science Festival (online).
- Bogdan Antonescu: 11 October interview for Radio France Internationale (RFI) (Romanian station) "Planeta Verde" on severe weather and climate change.
- Bogdan Antonescu: 03 November Seminar for Global Change Seminar Series (University of Edinburgh): "Tornadoes in Europe: History, climatology, and impact"
- Bogdan Antonescu: 03 November Press Club organized (online) by Guerrilla Verde (radio station) și Infoclima (NGO): "Extreme meteorological phenomena: Impact and strategies for resilience"
- Pieter Groenemeijer: 'Waarom uitgerekend deze tornado's zo veel vernieling hebben aangericht in de VS' Interview for newspaper 'de Volkskrant', 12 December 2021.

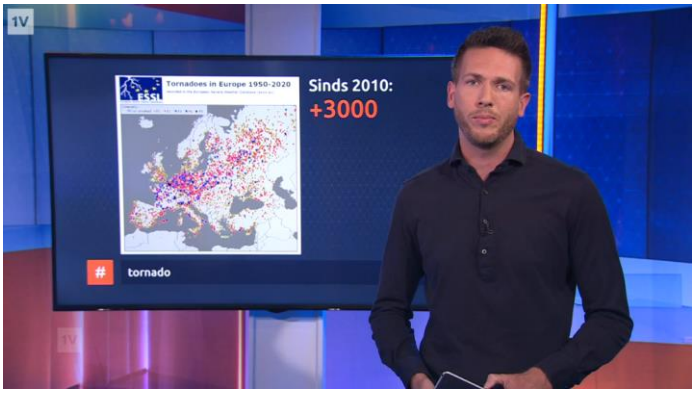


Figure 6-1. ESSL tornado risk map featured on Dutch national TV '1 Vandaag'.

6.4 Social Media

ESSL is active on Facebook and on its Twitter account @essl_ecss. Through this account, ESSL posts and shares news regarding ESSL's research, Testbed, training and ECSS activities.

As of writing, the number of Twitter account followers has increased in the last year to 2,756 followers (1,845 more followers compared with 2020). 29 times ESSL tweeted a message, that had typically a few thousand impressions and were retweeted 658 times. ESSL's Facebook account was used to post 16 messages during 2021. The ESSL's posts reached an audience of approximately 216,500 people in 2021.

7 Financial and Administrative Report

7.1 Employment and Payroll Accounting

In 2021, the European Severe Storms Laboratory e.V. directly employed two full time employees starting with the month of September (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 three persons (the Director full-time, the PreCAST researcher and 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 and the Treasurer.

As in previous years, an external payroll accountant (Andreas Schnaubelt in Schongau, Bavaria) was mandated during 2021 to take care of paperwork and bureaucratic handling of taxes and social insurances, which would otherwise have exceeded ESSL's internal administrative capacity.

7.2 Auditing of the Annual Accounts

In accordance with the Articles of Association, ESSL's finances for 2021 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."

7.3 Financial Status 2021

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 ClimXtreme. Furthermore, income from membership fees was important and necessary to cover overhead costs not covered by the project as well as costs for general ESSL activities not attributable to single

projects. 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 by members alternatively be requested from the ESSL Treasurer. 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 (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 2021:

ESSL obtained EUR 167,111 (2020: 176,526) in membership fees and EUR 94,000 (2020: 50,000) from scientific projects. ECSS income amounted to EUR 0 (2020: 0), because there was no conference in 2021 due to the Covid-19 pandemic. We are very thankful for donations of EUR 1,005 (2020: 1,502), underlining the worth of ESSL activities for the severe weather community.

Total income amounts to **EUR 262,117** (2020: 228,028).

Total expenses amount to **EUR 261,162** (2020: 211,511).

The dominant cost factors were direct personnel costs with EUR 154,405 (2020: 73,259), including taxes and social security, third party services by ESSL Science and Training (subsidiary in Wiener Neustadt, Austria) with EUR 82,684 (2020: 101,523) and, due to the pandemic, again low travel expenses with EUR 333 (2020: 3,960). Costs for the tax advisor and external bookkeeping add up to EUR 5,865 (2020: 6,450).

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 lumpsum costs for the Director and the Assistant to the Board were paid through this ESSL subsidiary at first hand (EUR 5,000 per month, in total EUR 60,000). Shared office, IT and server costs added up to EUR 22,684 (2020: 19,989).

At the end of the business year, liquid assets at ESSL's bank accounts amounted to EUR 54,443 (2020: 42,333). At the end of the year 2021, accounts receivables amounted to EUR 0 (2020: 0), deferred expenses (payments made for future accounting periods) to EUR 1,500 (2020: 1,500), deferred income (payments received for future accounting periods) to EUR 20,000 (2020: 9,900). Comparing liquid assets with mean monthly expenses it can be seen that ESSL was running with a small reserve for about 2 months only.

The **annual result is a positive EUR 954** (compare: positive 16,517 in 2020, positive 2,338 in 2019, negative 14,899 in 2018, positive 21,621 in 2017, positive 4,169 in 2016, positive

EUR 3,552 in 2015, negative EUR 3,957 in 2014, positive EUR 2,625 in 2013, negative 34,365 in 2012, positive EUR 7,093 in 2011, negative EUR 46,859 in 2010, positive EUR 60,599 in 2009).

The financial planning for 2022 foresees enough liquidity until the end of the year with a stable income situation based on the project ClimXtreme and membership fee income. At the end of 2022 there will again be little reserves.

Subsidiary 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 2021, the liquid assets at its bank account amounted to EUR 102,601 (2020: 88,638). After consideration of the current reserve for the ESSL Testbed the remaining annual result for the subsidiary association in 2021 was a positive EUR 5,367 (2020: 6,696 EUR, 2019: positive EUR 3,019, 2018: negative EUR 1,687).

The main income sources were the ESSL Testbed, the PreCAST project of the Austrian science fund FWF, projects with ECMWF and EUMETSAT, as well as basic funding from the federal state of Lower Austria. The main cost factors were personnel costs, office rental, IT infrastructure and running office costs. For the third time finances of ESSL-ST were audited by an external and sworn auditor (Scheicher und Partner Wirtschaftsprüfungs GmbH, Neunkirchner Str. 17/2, 2700 Wiener Neustadt), as this was an obligation for receiving funding from the Government of Lower Austria. The external auditor states (own translation from the German original) in formal wording:

"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."

The financial planning for 2022 again foresees a near neutral annual result.

7.4 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 2021, ESSL was happy to welcome one new institutional supporting member: RED (Risk, Engineering and Development) SpA from Italy.

The full member list as of 31 December 2021 can be found in Attachment A2.

7.5 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.

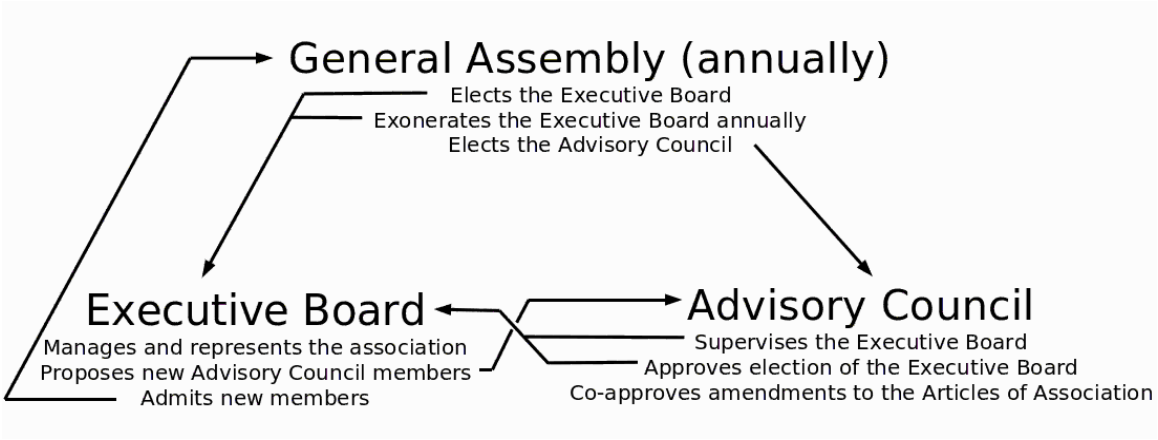


Fig. 6-1: Bodies of the ESSL. The Advisory Council consists of six members from two groups - three members each: (1) Science, (2) NMHS / EUMETNET.

Executive Board

In 2021, 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 2021, while at the General Assembly on 20 October 2021 all members of the board were re-elected for another 3-year term from 1 January 2022 to 31 December 2024.

Advisory Council

In 2021, the Advisory Council consisted of:

Dr. Martin Benko, chair (SHMÚ, Slovak Hydrometeorological Institute)
1 Jan. 2020 - 31 Dec. 2023 (second term), vice-chair since 1 Jan. 2016

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. 2019 - 31 Dec. 2022 (first term)

Appendix A1: Annual Accounts

The following presents in extract a copy of the "*Report on the Preparation of the Financial Statements for 2021*", as prepared by the financial auditor in Germany. Figures of the previous years were added for comparison.

	2021	2020	2019	2018
INCOME				
Membership fees institutional members and ESWD data fees	163.306,60	173.103,50	158.039,43	136.620,74
Membership fees personal members	3.805,00	3.422,72	3.961,06	3.427,62
Income from scientific meetings (ECSS)	0,00	0,00	89.306,36	0,00
Public project funding Federal Republic of Germany	94.000,00	50.000,00	167.594,46	188.052,36
Public project funding European Union	0,00	0,00	0,00	49.158,00
Applied research	0,00	0,00	0,00	33.700,00
Donations	1.005,00	1.502,18	190,00	1.100,00
German VAT on sales and refunds	0,00	0,00	2.748,97	4.940,06
Total income	**262.116,60**	**228.028,40**	**421.840,28**	**416.998,78**
EXPENSES				
Personnel	154.404,99	73.258,73	241.534,68	358.941,59
Depreciations	3.323,00	1.260,98	1.013,94	981,21
Costs related to scientific meetings (ECSS)	0,00	0,00	51.345,47	0,00
Travel costs	333,56	3.959,62	14.229,95	11.408,02
Office costs and insurance	2.091,98	2.242,53	615,72	1.231,16
Phone and data (internet) services	2.097,50	3.877,55	5.982,25	1.214,99
Tax advisor including software	5.865,00	6.450,23	6.320,02	6.116,52
Third party services by ESSL Science and Training, Austria	82.684,33	101.523,21	80.393,08	27.583,82
Director and administration personnel lumpsum	60.000,00			
Office, IT and server costs	22.684,33			
Value added tax	3.870,67	8.508,33	4.593,35	6.712,55
Third party services and other	6.491,33	10.429,90	13.473,63	17.707,73
Total expenses	**261.162,36**	**211.511,08**	**419.502,09**	**431.897,59**
Result	**954,24**	**16.517,32**	**2.338,19**	**-14.898,81**

Assets and Liabilities

	2021	2020	2019	2018
Fixed Assets (office equipment)	2.768,00	2.942,00	1.097,00	2.942,00
Current Assets				
Receivables	0,00	0,00	21.687,36	0,00
Bank balances	54.443,06	42.333,48	61.108,56	42.333,48
Deferred Expenses	1.500,00	1.500,00	1.500,00	1.500,00
Assets total	**4.268,00**	**46.775,48**	**85.392,92**	**46.775,48**
Equity (own capital)				
Retained earnings brought forward	35.974,87	35.974,87	19.457,55	19.457,55
Remaining result of the year	954,24	16.517,32	2.338,19	16.517,32
Deferred Income	20.000,00	9.900,00	19.895,00	9.900,00
Liabilities	1.781,95	900,61	46.040,37	900,61
Equity and Liabilities total	**58.711,06**	**63.292,80**	**87.731,11**	**46.775,48**

Appendix A2: Member list 2021

The following table shows all ESSL members as of 31 December 2021, sorted according to their ESSL-ID (which corresponds in ascending order to the beginning date of the ESSL membership). Members joining ESSL in 2021 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. Michael Kunz	GERMANY
Dr. Pieter Groenemeijer	*NETHERLANDS*	Erik Dirksen	GERMANY
Alois M. Holzer	*AUSTRIA*	Dr. Christoph Gatzen	GERMANY
Dr. Maria-Carmen Llasat-Botija	*SPAIN*	Dr. Kathrin Riemann-Campe	GERMANY
Dr. Romualdo Romero	*SPAIN*	Dr. Koji Sassa	JAPAN
Dr. Martin Setvák	*CZECH REPUBLIC*	Dr. Tomáš Pučik	CZECH REPUBLIC
Dr. Fulvio Stel	*ITALY*	Marcus Beyer	GERMANY
Jenni Rauhala	*FINLAND*	Dr. Lisa Schielicke	GERMANY
Thilo Kühne	GERMANY	Dr. Abdullah Kahraman	TURKEY
Helge Tuschy	GERMANY	Dr. John Allen	USA
Zhongjian Liang	GERMANY	Dr. Anja T. Rädler	GERMANY
Lionel Peyraud	SWITZERLAND	Dr. Darrel Kingfield	USA
Thomas Krennert	AUSTRIA	Stavros Dafis	FRANCE
Dr. Johannes Dahl	USA	Michou Baart de la Faille	NETHERLANDS
Martin Hubrig	GERMANY	Jannick Fischer	GERMANY
Dr. Oliver Schlenczek	GERMANY	Dr. Tanja Renko	CROATIA
Dr. Victor Homar Santaner	SPAIN	Dr. Mateusz Taszarek	POLAND
Dr. Sanjay Sharma	INDIA		
Dr. Bogdan Antonescu	ROMANIA		

Individual Supporting Members

Casper ter Kuile	NETHERLANDS
Jan Jacob Groenemeijer	NETHERLANDS

ESSL Supporters

Christopher Valois-Barthe	FRANCE
Nicola Carlon	ITALY

Institutional Full Members

DWD, Deutscher Wetterdienst	GERMANY
EUMETSAT	GERMANY
AUSTRO CONTROL	AUSTRIA
ZAMG, Zentralanstalt für Meteorologie und 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
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

Institutional Supporting Members

Münchener Rückversicherungs-Gesellschaft AG	GERMANY
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

CORELOGIC SARL	FRANCE
FM Global	USA
Nowcast GmbH	GERMANY
Impact Forecasting LLC - AON Central and Eastern Europe a.s.	CZECH REPUBLIC
Spekter GmbH	GERMANY
Berkshire Hathaway Specialty Insurance Company	USA
Arcturus B.V.	NETHERLANDS
Descartes Underwriting	FRANCE
riskine GmbH	AUSTRIA
FCM - Fermat Capital Management, LLC	USA
GIE AXA	FRANCE
GreenTriangle AG	SWITZERLAND
Genillard & Co GmbH	GERMANY
Banca d'Italia	ITALY
RED (Risk, Engineering and Development) SpA*	

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.