Task 1. Challenges in observing Challenging/High Impact Weather (WG5 and WG4 related)

Question: How well high-impact weather is represented in the observations, including biases and random errors, and their sensitivity to observation density?

HIW phenomena studied: visibility range (fog), thunderstorms (w. lightning), intense precipitation, extreme temperatures and winds.

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This task considers which observations are necessary to verify HIW forecasts, as well as issues related to observation sparseness, quality, and thresholds. HIW prediction improvement depends crucially on availability of dense observations. The uncertainty is higher in new types of observations, and it becomes necessary to take it into account. The overview of methods to account for observation uncertainty is considered in paragraph 1.2. Often, the best way is to use several observational datasets to this purpose. For verification and postprocessing, the essential step is to find good correspondence between the forecast and observation, or reference. In [C. Marsigli et al, 2021], a framework for the verification of high-impact weather is proposed, including the definition of forecast and observations in this context and creation of a verification set. This was discussed at the IVMW2020 [https://jwgfvr.univie.ac.at/]. It was noted by T.Bullock [https://www.univie.ac.at/img-wien/jwgfvr/2020IVMWO_Outcomes&PhotoMosaic.pdf] that there is always some processing (both on observations and forecast) for enabling comparison. We need just to be clear on what is being done to the model output and/or obs prior comparison (e.g., conversion of radar reflectivities to rainfall rate, versus forward model to reproduce radar reflectivities).

It can be said that every weather has its impact. Starting with the least inconvenient, like

1. Inconvenience of carrying an umbrella/sun glasses,
2. Higher power bills,

through moderately troublesome:

3. Possibility of dispersion of atmospheric pollutants,

4. flight delays due to weather conditions

...

to very dangerous in consequences, like

n. Catastrophes in sea, land and air traffic

n+1. The destruction caused by a flood or a tornado.

To someone affected, any of these may seem “significant” at that moment. Some impacts are clearly more significant than others. There are four general categories of impacts:

1. Low-impact – minor inconvenience, small and local economic losses, etc.
2. Moderate-impact – minor damage, some social disruption, etc.
3. High-impact – damage, risks to health, broad economic impact, etc.
4. Extreme-impact – dramatic losses, deaths, injuries, major social disruption, etc.

Since every (kind of) weather has its impact, each weather element can be treated as an impact source. It's just a matter of scale.

- ”regular” elements – temperature, precipitation, wind speed…
- ”specific” elements – visibility limitations, thunderstorms, tornadoes, …

Observational data for each element can be obtained from a variety of sources. The main sources can be divided into:

1. **Data from SYNOP stations**
2. **Lightning Detection Networks (LDN)**
3. **Radar data, Doppler radar data**
4. **Satellite products**
5. **Nowcasting products used as reference data**
6. **Non-conventional data such as datasets derived from telecommunication systems, data collected from citizens, reports of impacts and claim/damage reports from insurance companies, social networks, data from cameras and images**
7. **Other data**

Below, an overview of these sources is given. This overview is far from being exhaustive, and, according to the purposes of PP AWARE, is focused on the types of observations used in the project tasks, namely, events of convective origin (extreme precipitation, lightning, convective cells, tornadoes) and fog. In [C. Marsigli et al, 2021], an overview of new observation types is given in more detail.

1. **Data from SYNOP stations[1],** climatological stations, rain gauges, telemetry stations includes measurements of, among others, the following values:

- *temperature, precipitation, visibility range/limitations, wind speed, wind gusts, occurrence of fog/haze, occurrence*
of thunderstorm with lightning (limited to a remark as "day with lighting" or similar).

These conventional observations remain the basic source of data for many HIW events, e.g., extreme precipitation, extreme temperatures and wind. They pass thorough quality control and are regular in time. There are long time series of synoptic measurements, which is important in the study of rare phenomena. However, the problem with these stations (both manned and unmanned) is that the measurement is valid only for the location of a particular station. The representativeness may be (artificially) extended up to some dozens of kilometers, but it is not necessarily valid for example for stations located in complex terrain etc. Some specific measurements (like fog/visibility range[2]) are being transferred, however, to more universal, mobile installations. Data of SYNOP stations: visual thunderstorm occurrence at a given obs time and between obs times in a radius 5 km.

Another problem with SYNOP observations is that they often do not permit full characterization of specific HIW phenomena, such as visibility limitations, thunderstorms, tornadoes. Thus, in Europe, 10 years ago, a list of new weather elements to be subject to routine verification was proposed by [Wilson and Mittermaier 2009]. Among others, visibility/fog, atmospheric stability indices and freezing rain were mentioned, and the observations needed for the verification of these additional forecast products were reviewed.

[1] An exemplary information from European/Polish SYNOP station after decoding a SYNOP (encoded) wire

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rrrr mm dz gg number n  dd ff vv ww w1w2   pppp ttt nh cl h     cm     ch tdtdtd a   ppp rrr
2020  3  3  6  01001 7 120  6 10  2    22 1013.2 1.1  7  5 3 -1000 -1000   -3.7 7  -0.6   0
tntntn txtxtx  tgtg sss ff_911   ddd ss_931 tststs ff_910   p0 rrr_24
  -0.2  -1000 -1000 0       12 -1000  -1000  -1000  -1000 1012      0
```

[2] Hautiere, Nicolas et al., 2006. Automatic fog detection and estimation of visibility distance through use of an onboard camera. Mach. Vis. Appl.. 17. 8-20. 10.1007/s00138-005-0011-1.

A general remark regarding LDN, and (even more) especially radar or satellite data, is as follows: for their correct use, a proper software is needed that will allow the data to be transferred to the appropriate (required) format.

2. Lightning Detection Networks

-Provide information about thunderstorms, lightnings

Lightning Detection Networks (LDNs) are based on lightning detectors that indicate electrical activity. The basic assumption made when creating LDN ensures that due to proper triangulation, it is possible to estimate the almost exact location of the flash. LDNs can detect dry thunderstorms. Furthermore, lightning detectors do not suffer from a masking effect and provide confirmation when a shower cloud has evolved into a thunderstorm.

If used as a proxi for a thunderstorm, a question arises: How many strokes are needed to detect the occurrence of a thunderstorm? The matching of the two entities in the verified pair should be checked before the computation of summary measures. Any thresholds used to identify the objects of the two quantities must also be studied to ensure that the identification and comparison is as unbiased (from the observation point of view) as possible [C. Marsigli et al., 2021]. In the present report, verification using LPI (lightning potential index) and LDN data is studied in tasks 3.1 and 3.2.

Global LDN: websites

The most popular global resources about lightning are:

- https://blitzortung.org, a worldwide social network for determining location of lightnings in real time. In figures below exemplary screenshots from the webpage in static and dynamic presentation.

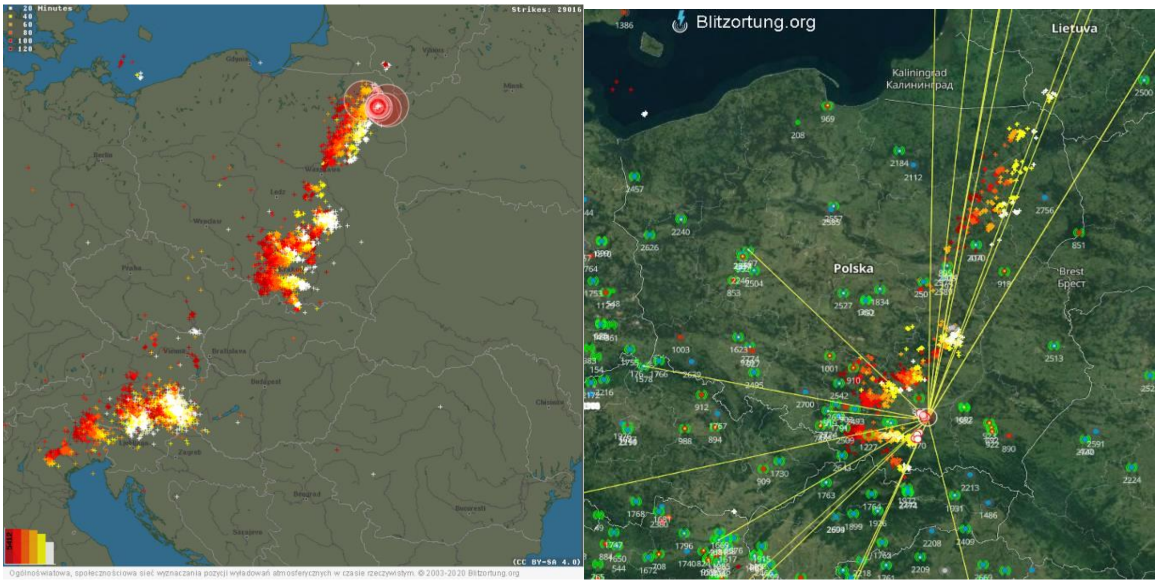


Figure 1. Webpage https://blitzortung.org. On the left – standard discharge image – locations marked with crosses, the more red the crosses are – the older occurrence of lightning. On the right, a dynamic map with additionally marked locations of the detectors and lines to the detectors that detected a specific discharge.

- http://wwlln.net/TOGA_network_global_maps.htm: Very Low Frequency sensors. Lightning stroke positions are shown as colored dots which "cool down" from blue for the most recent (occurring within the last 10 min) through green and yellow to red for the oldest (30-40 minutes earlier)

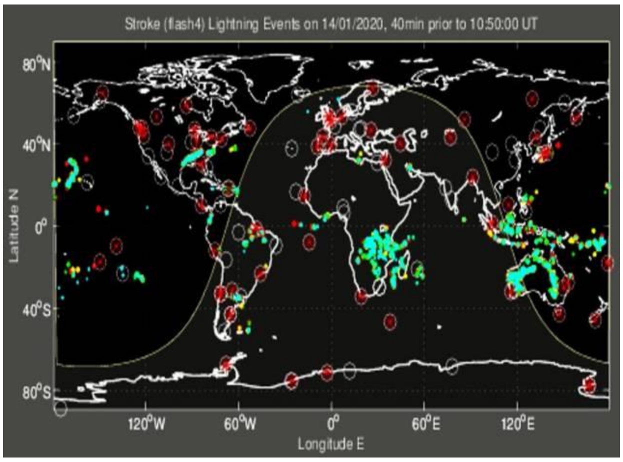


Figure 2. http://wwlln.net/TOGA_network_global_maps.htm

Regional LDNs

Regional lightning detection networks: Very Low Frequency sensors in the real time within 100-300 km radius, detect two types of lightnings: cloud-earth and intra-cloud.

In Poland LDN operated by NWS is called PERUN. It is basically identical to French SAFIR. (Surveillance et Alerte Foudre par Interférometrie Radioélectrique).

An exemplary information from PERUN LDN: time, location, flash type, intensity etc.

```
11/01/2011 00:24:50;0004FCFFFFFFFFFFFFFFFFFF;1;0;7561;538442;193454;0;218;0;0;0;0;0;0;7;10;0
11/01/2011 00:25:58;0004FCFFFFFFFFFFFFFFFFFF;1;0;6839;537325;196241;0;218;0;0;0;0;0;0;7;10;0
11/01/2011 00:26:35;0004FCFFFFFFFFFFFFFFFFFF;2;0;8280;536018;194977;0;203;0;0;0;0;0;0;7;10;0
11/01/2011 00:26:35;0004FCFFFFFFFFFFFFFFFFFF;2;0;8788;536502;190226;0;103;0;0;0;0;0;0;5;2;0
```

In Russia, the lightning detection system of Roshydromet ALVES 9.07 is used [Gubenko I. 2016; Snegurov A.V., Snegurov V.S. 2012]. In [Gubenko I. 2016], it is shown that the accuracy of regional Russian LDN is higher than WWLLN (comparison to SYNOP data).

Other examples of European LDNs are BLIDS (which stands for Blitz-Informationsdienst von Siemens), FLITS (in Netherlands and Belgium) or LINET, developed in Munich, Germany. In [C.Marsigli et al. 2021], other lightning detection networks are listed, and references to works with applications of LDN data in verification are given including spatial approach and combining different data sources.

3. Radar data, Doppler radar data

-Precipitation intensity and type, wind speed, lightning

Radar data and/or Doppler radar data are acquired from weather radar that indicates precipitation (in a standard mode) and wind field (in Doppler mode). Both phenomena are associated with thunderstorms and can help indicate storm strength. In general, weather radar will show a developing storm before a lightning detector does. However, weather radar also suffers from a masking effect by attenuation, where precipitation close to the radar can hide precipitation farther away. Moreover, if there is no precipitation (at all), availability of radar data declines rapidly in both standard and Doppler mode. This situation may occur in connection with the phenomenon of so-called dry thunderstorm. In this case lightning(s) may be also located outside any precipitation recorded by radar.

In addition to stationary (ground-located) installations for the detection of flashes, mobile devices are also used and carried on ships or airplanes. Large airliners are more likely to use weather radar than lightning detectors, since weather radar can detect smaller storms that also cause turbulence. Modern avionics for additional safety include lightning detection as well. For smaller aircraft, especially in general aviation (where the aircraft nose is not big enough to install a radome) lightning detectors can find and display IC and CG[3] flashes.

Digital radar systems now offer thunderstorm tracking surveillance. This provides users with the ability to acquire detailed information of each storm cloud being tracked. Thunderstorms are first identified by matching precipitation raw data received from the radar pulse to some sort of template preprogrammed into the system. In order for a thunderstorm to be identified, it has to meet strict definitions of intensity and shape that distinguish it from any non-convective cloud. Usually, it must show signs of organization in the horizontal and continuity in the vertical: a core (more intense center) to be identified/tracked by digital radar trackers.

Radar reflectivity fields are used for the estimation of the risk of tornadoes, and for verification of these events (see Task 4.1.2).

4. Satellite products

Occurrence of fog/haze, detection of convective storms, cloud properties (direct measurement of moisture and instability[4]), also via convective indices and CAPE

An advantage of the satellite products is that they provide data over data-sparse regions.

Satellite data detection of convective storms is based on direct measurement of moisture and instability,

- Intensity = IR + ((IR-NWP)-(WV-IR))[5]

with IR, NWP, WV being temperature obtained from different channels.

From the above equation, it is necessary to use the PA (e.g., the results of the global GFS model).

- convective indices, in general, can be a good prognostic tool if only forecasters could understand why values are approaching critical levels, like in the examples below:
  - Showalter Index – extreme instabilities for SI less than -6
  - Total Totals Index – severe storms with TTI greater than 50
  - K Index – high convective potential for K greater than 40

[3] IC – inter-cloud lightning, CG – cloud-to-ground flash
[4] infrared (IR) 10.8 µm and water vapor (WV) 6.2 µm channels
[5] da Silva et al., 2016. A method for convective storm detection using satellite data. Atmósfera 29 (4), 343-358

- SWEAT Index – severe phenomena possible for SWEAT greater than 300
- Lifted Index – extreme instabilities for LI less than -6
- CAPE – extreme values of 2500 and more

An example of thunderstorm verification for clouds based on satellite data is given in [Keller et al. 2015].

In RHM, a study on identification of the areas of deep convection based on satellite data is carried out [Shishov A.E., I.A. Gorlach 2020; Shishov A.E. 2021]. Based on calibrated radiative temperature from Seviri, Meteosat-11, using a threshold, a mask of deep convection areas is found. Then the cell shape is determined. The cells are traced in time based on the normalized overlapping area. Cell destroying is also taken into account. Then, the cell movement direction, deformation, and other characteristics are identified. Figure 3 gives an example of the areas of deep convection in the visualization system developed by the authors. It is planned to involve other data for deep convection area identification, such as surface obs (KH01, METAR) and COSMO-Ru / ICON-Ru prognostic fields. It is planned to study the feasibility of using this product as a reference for verification of a model analogue.

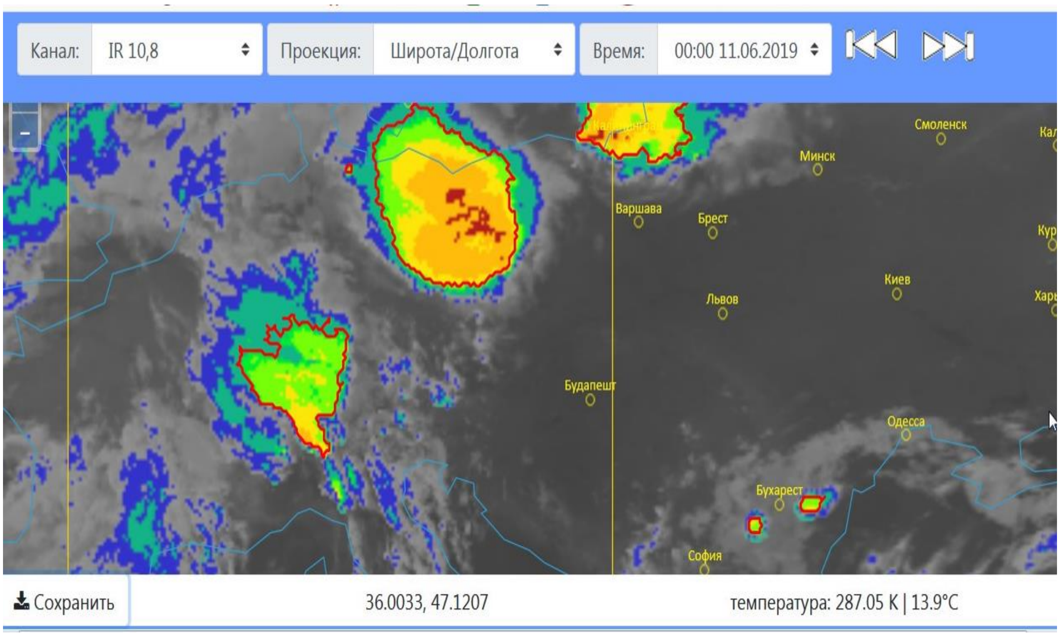


Figure 3. An example of the areas of deep convection in the visualization system

Satellite products are now widely used to derive the information about the **fogs and low stratus**, besides SYNOP reports containing visibility range/limitations. Problems of visibility measures from manual and automatic stations are described in [Wilson and Mittermaier

2009]. The main problem of point observations is that they are scarce and not sufficient to reproduce the spatial structure of fog.

In [Morales at al. 2013], verification is performed for low clouds in the model as proxi for fog *vs* cloud type product from satellite NWC-SAF as observations. In [Ehrler 2018, Westerhuis et al. 2018], liquid water path (LWP) in the model is compared vs satellite data (channel combination) to give a Cloud Confidence level. A paper is under preparation by the Russian team (N. Chubarova, Yu. Khlestova, et. al.), which compares model LWP using one- and two-moment physics COSMO scheme with satellite product.

Satellite images also enable reconstruction of tornadoes tracks by fallen trees (see also Task 4.1.2)

5. Nowcasting products used as reference data

National Meteorological Services develop tools for nowcasting, where data from different sources (satellite, radar, lightning, …) are integrated in a coherent framework. The detected variables/objects of nowcasting (thunderstorm cells, hail, …) can become observations against which to verify the model forecast. Thus, nowcasting products are proposed as observed data instead of prediction tools if we consider step 0 of the nowcasting algorithm as an "analysis".

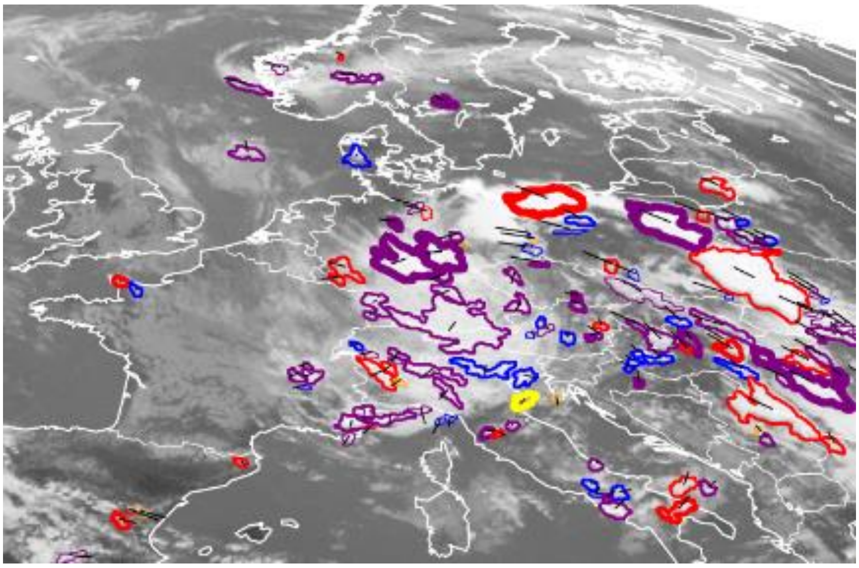


Figure 4. Nowcasting objects from KONRAD3D system

Advantage of this approach is high spatial continuity over vast areas and detection of high-impact weather phenomena, while the disadvantage is that some data have only a qualitative value. But qualitative evaluation could become quantitative by “relaxing” the comparison through neighbourhood/thresholding.

The link with the nowcasting groups should be strengthen to explore the possible usage of the variables/objects identified through nowcasting algorithms for forecast verification.

6. Non-conventional data

The number of applications of non-conventional data grows rapidly.

They include:

- Data from insurances
- Data from citizens (private meteostations, phones), cars
- Impact data (emergency calls, fire brigade operations) – high spatial resolution
- Social media (social networks, etc.)
- Data from cameras and photos

A detailed overview and examples of the studies using new non-traditional sources of data is given in [C. Marsigli et al. 2021].

The aim of the Second international verification challenge in 2021 (Run by WMO HIWeather Project and Joint Working Group on Forecast Verification Research) is to promote quantitative assessment of high-impact weather, hazards and impacts through the use of non-traditional observations [https://www.emetsoc.org/second-international-verification-challenge/].

Recognition of weather from cameras and photos widely relies on the use of machine learning. For example, in [Bin Zhao et al. 2018], the accuracy of several CNN-RNN Architectures for Multi-Label Weather Recognition from images was studied.

Figure 5. Weather recognition from images [Bin Zhao et al. 2018]

A quantitative estimate of weather variables from images was performed in (Wei-Ta Chu, Xiang-You Zheng, Ding-Shiuan Ding 2017). The average RMSE of temperature estimate was 1.98°C, of humidity, 7.13%, the accuracy of clouds and precipitation estimate was about 76%.

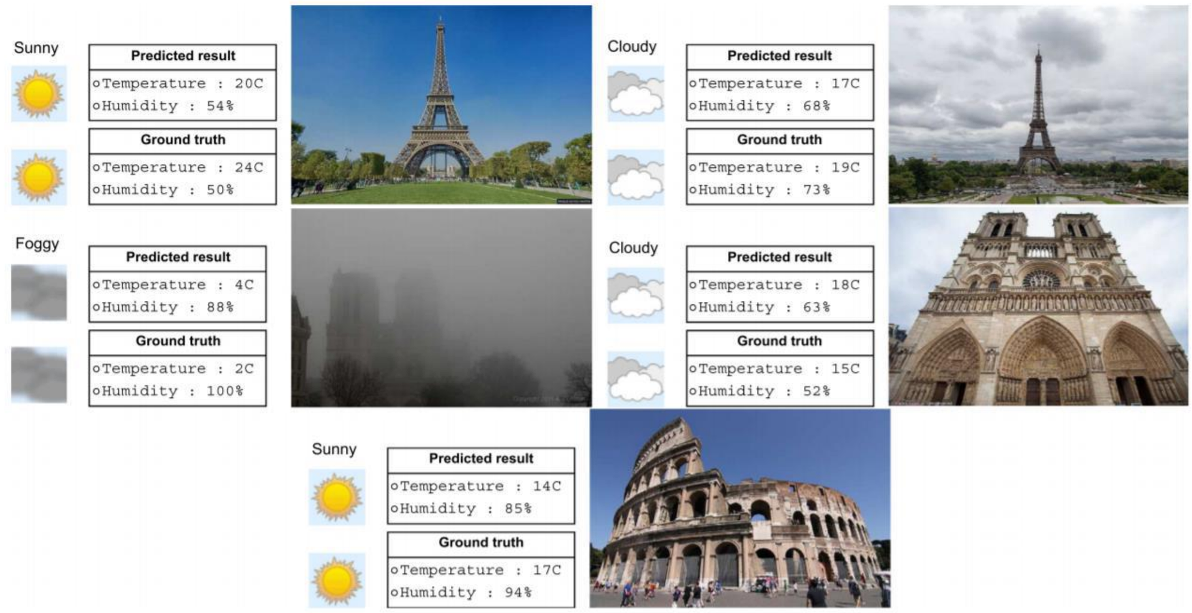
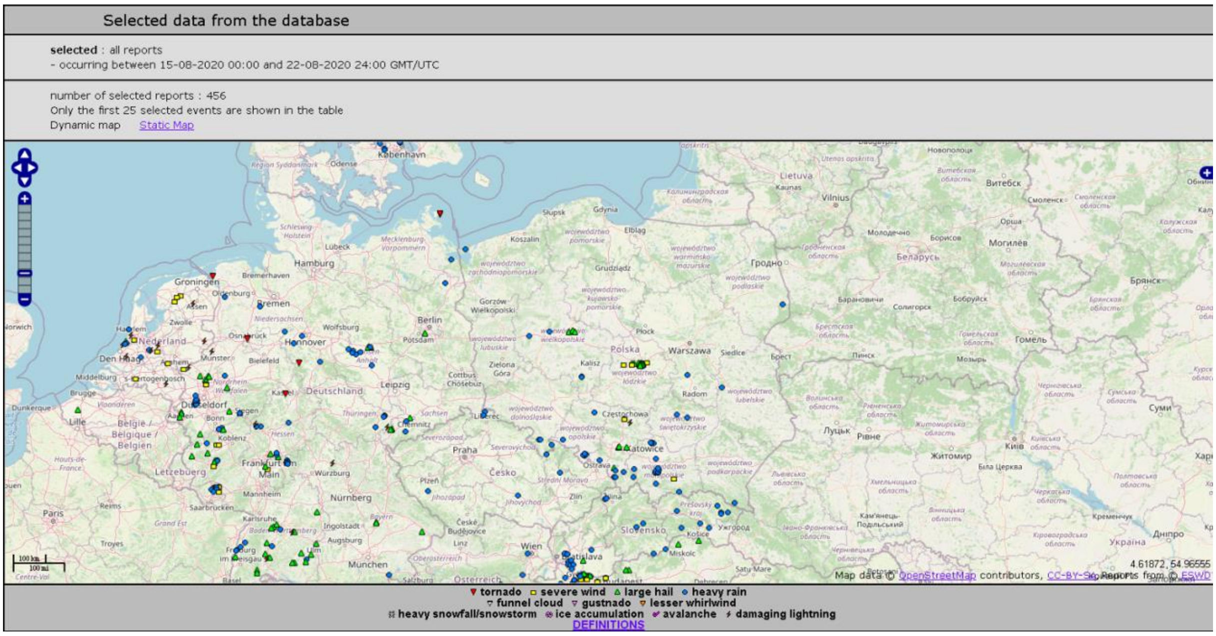


Figure 6. Weather variables determined from photographs [Wei-Ta Chu, Xiang-You Zheng, Ding-Shiuan Ding 2017]

7. Other data sources

Other data sources on CW / HIW (mostly storms, but not only) are mostly websites. A universal online resource is the European Severe Weather Database, https://eswd.eu, operated by European Severe Storms Laboratory.

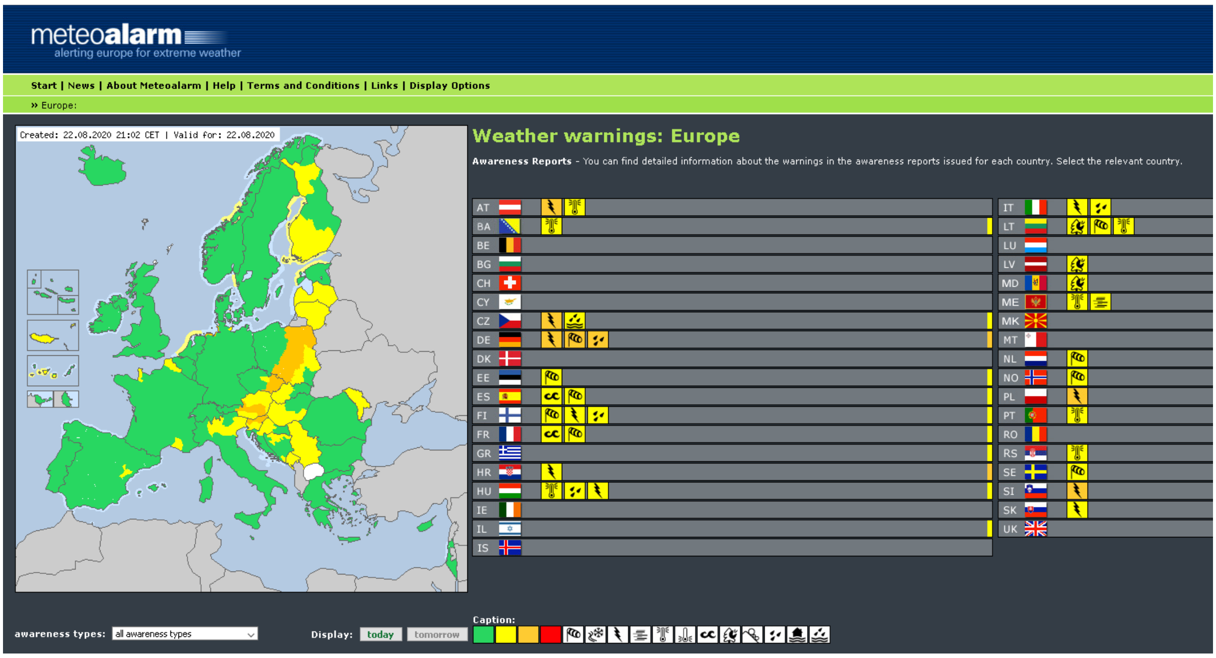


The information about single event (in general, phenomenon – not only lightning, but generalized HIW event) is presented in a table similar to the one below:

Event	Time and location	Other info/Quality Control
Heavy rain	Inwałd, Małopolskie, Poland (49.87N, 19.39E)<1 km 22-08-2020 (Saturday) 18:30 UTC(+/-15 min.)	based on information from: a report by a weather service, a report on a website, government-based sources/administrative organizations precipitation: 31.2 mm, duration: 0.5 hours Automatic IMWM-NRI weather station measured a rain amount of 31.2 mm in 30 minutes, 26.9 mm in 20 minutes and 20.2 mm in 10 minutes during passage of a thunderstorm. http://monitor.pogodynka.pl/#station/meteo/249190090 Reference: Monitor IMGW, 22 AUG 2020. report status: plausibility check passed (QC0+) contact: ***** ***

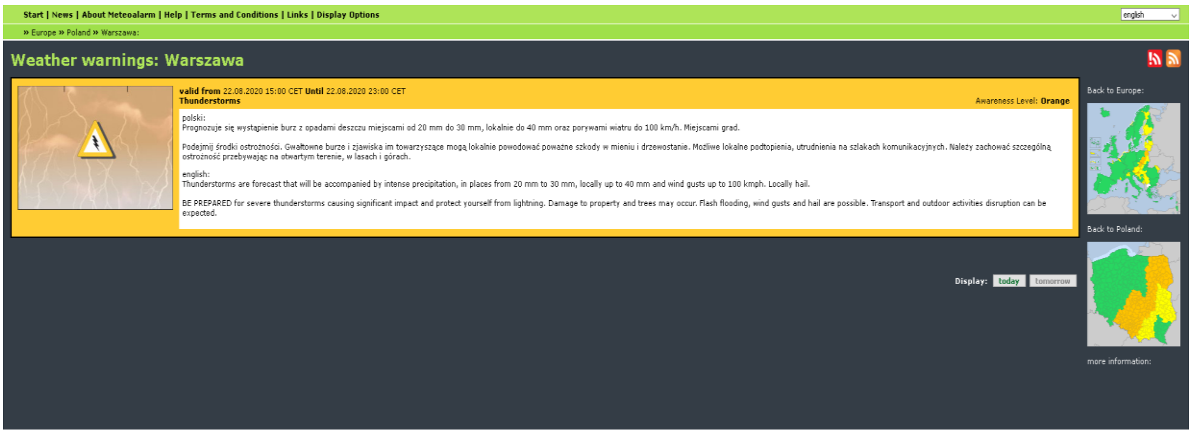
Similar information can be obtained from Meteoalarm – Severe Weather Warnings in Europe: https://www.meteoalarm.eu/

By using the dynamic structure of the resource, information about HIW events can be obtained at the spatial resolution level of a few square km, starting from continental, *via* country, to sub-country (city) scale.

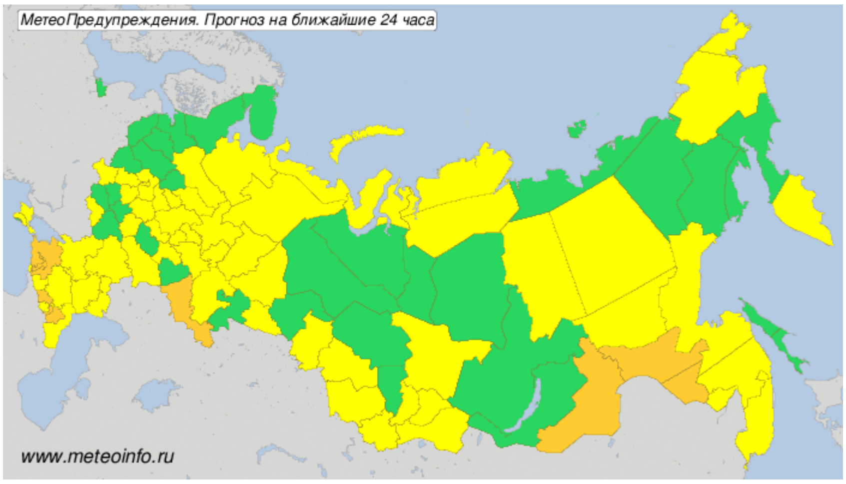


a. Meteoalarm main page

b. Warnings for selected country



c. Detailed warning for city/small region



d. Alert map in Russia similar to Meteoalarm

Figure 7. Meteoalarm systems

One important difference is that this portal only allows you to check alerts (forecasts). However, later, for verification, one can compare the data from this webpage with e.g. the data from ESWD/ESSL. For this reason, this webpage should also be considered valuable.

Conclusions

- Combining all available datasets is usually the best choice
- The usefulness of data strongly depends on the particular case. For example, during the stormy season, all methods can be equally useful, as well as their combination.
- For individual cases of thunderstorms, LDN seems to be the best to determine their intensity and location. Supplementing LDN results with radar data would give a full picture of the situation.
- Data quality and data uncertainty assessment: usage of multiple data sources
- Introducing uncertainty information in applications – one of the implicit ways: spatial verification methods
- Closer cooperation with nowcasting, where products for high-impact weather detection are developed

And one final note, definitely written in time and under the influence of the state of the outbreak. In the CoVid-19 era, strangely enough, the number of available data may significantly decrease – as a result of data limitation, e.g. from cancelled flights or sea cruises. That is therefore so important to make the best use of the available data.

References

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