Monitoring rainfall accumulations

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OPERA Development Task OD11b

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Introduction

The OPERA Data Center (ODC) started the production of the OPERA composite in June 2011. Since then, the number of radars included in the composite increased considerably and some changes were implemented in the ODC processing.

Within OPERA 4, the development task OD11 aims at improving the harmonization of the OPERA network in terms of reflectivity and rainfall accumulations. OD 11 has been split into three sub-tasks which have been originally formulated as follows:

OD 11a : Monitoring and harmonization of reflectivity levels (DWD, 4 PM)

OD 11b : Monitoring of individual radar accumulations (RMI, 2 PM)

OD 11c : Gauge data for monitoring rainrates (UKMO, 2 PM)

It must be pointed out that single radar accumulations are not produced by the OPERA Data Centre (ODC). The ODC accumulation product is generated by summation of the 15-min rainfall composites. Generating a new ODC single radar accumulation product is beyond the scope of OD11. Therefore, we focus in the present study on the evaluation of rainfall accumulations based on the 15-min rainfall rate composite. The final goal is to develop monitoring tools allowing to evaluate and to improve the quality of the ODC composite. In OD11b, we investigate evaluation tools which do not make use of raingauge stations. The evaluation based on comparison with raingauge measurements is addressed in OD 11c and OD12.

The present report includes three sections:

1. synthesis of previous work

2. production and analysis of long-term accumulation maps based on ODC composite (several months to several years)

3. conclusions and recommendations for further work

1. Previous work

1.1 Evaluation of ODC composite at ECMWF

The OPERA composite has been evaluated at ECMWF by Philippe Lopez through comparisons with precipitation measurements from synoptic stations and with precipitation simulated by the ECMWF model. Similar evaluation has been performed for the NEXRAD composite produced by NOAA in the United States. The so-called "NEXRAD" composites are actually the NCEP Stage IV composites, which combine NEXRAD radar data but also some 1500 rain-gauge observations.

Fig. A1 shows the normalized bias of the 6-hour rainfall amounts from OPERA against synoptic stations for the period January-June 2016. The results show that the OPERA composite tends to underestimate rainfall amounts over most regions. Similar results are obtained from the evaluation against ECMWF model as shown in Fig. A2. Fig. A3 shows the evaluation of the NEXRAD composite through comparison with the ECMWF model. For both OPERA and NEXRAD composites substantial geographical variations of the normalized bias are found for the 6-month period considered here. The NEXRAD composite shows better verification results in the eastern part than in the western part of the United States. The most likely explanation for these differences is the presence of high rugged orography in the western part. The normalized bias values obtained over the western part of the NEXRAD composite are similar to those obtained with the OPERA composite. Over the eastern part the NEXRAD composite shows generally better agreement with ECMWF model than the OPERA composite over Europe. On the other hand, it must be pointed out that NCEP Stage IV precipitation composites are assimilated in ECMWF's 4D-Var system which might explain the lower mean differences between NEXRAD and the short-range model forecasts (0 to 24h range) in Fig.A3.
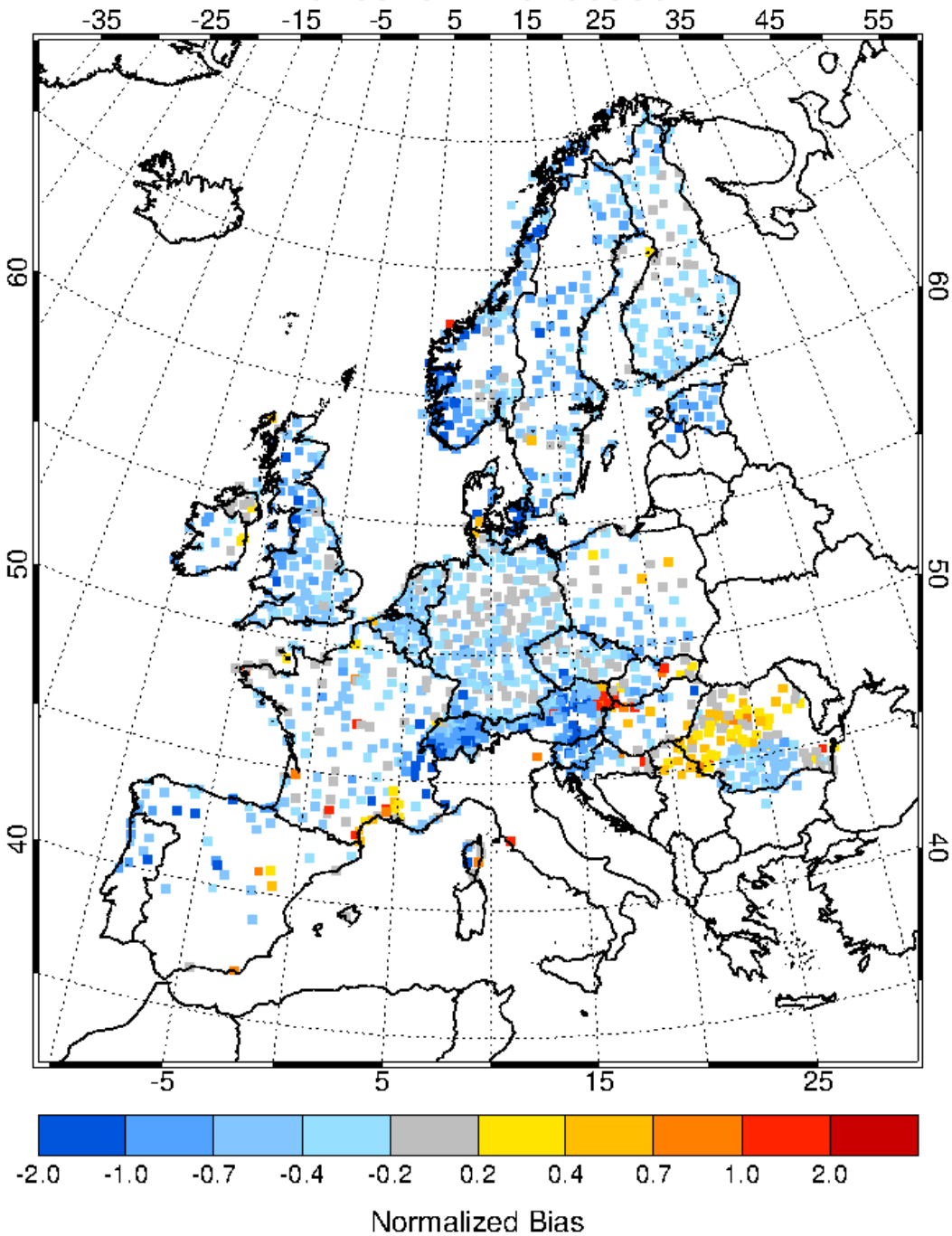
Fig. A1: Normalized bias of the 6-hour rainfall amounts from ODC composite against synoptic stations for the period January-June 2016 (courtesy of P. Lopez, ECMWF).
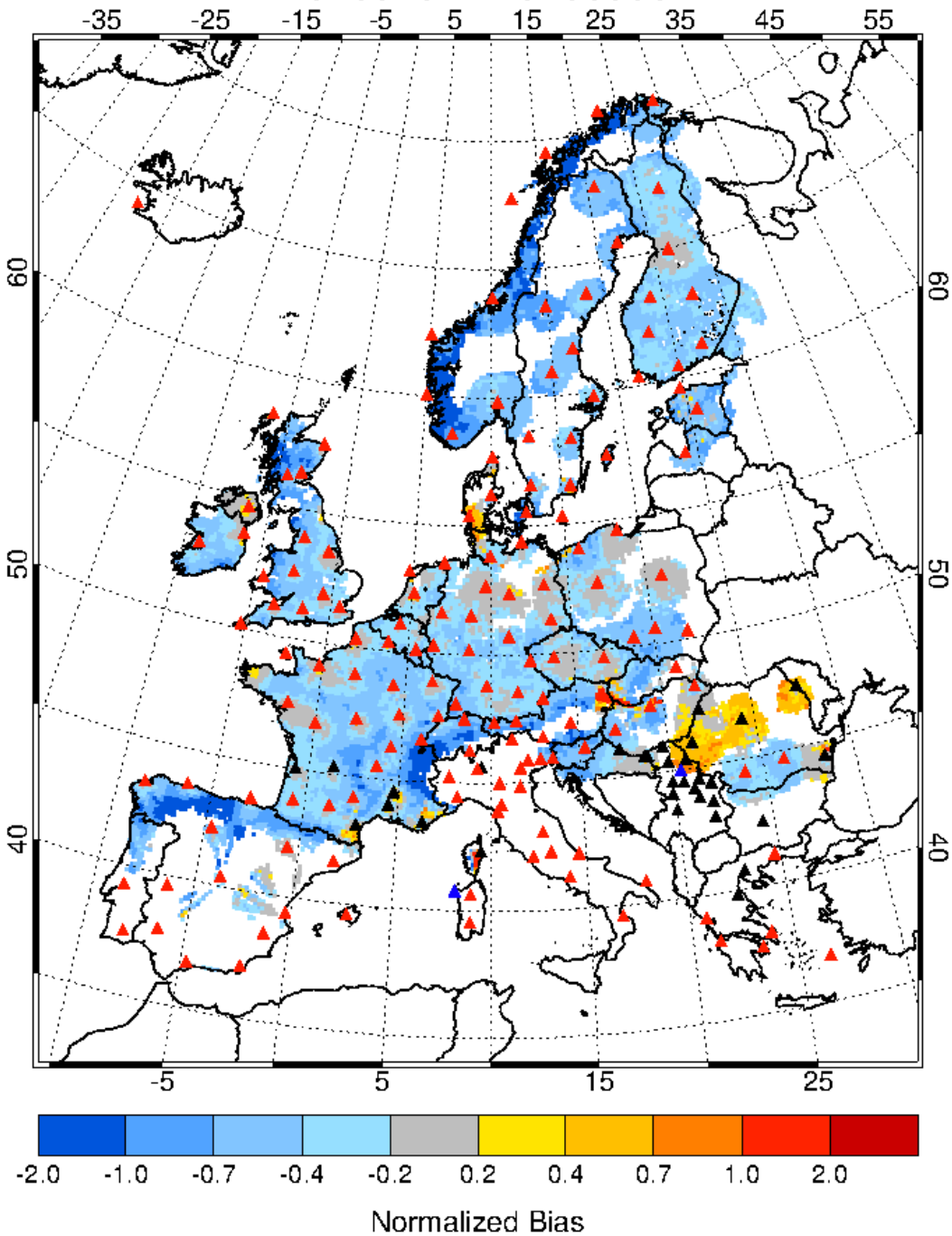
Fig. A2: Normalized bias of the 6-hour rainfall amounts from ODC composite against ECMWF model for the period January-June 2016 (courtesy of P. Lopez, ECMWF).
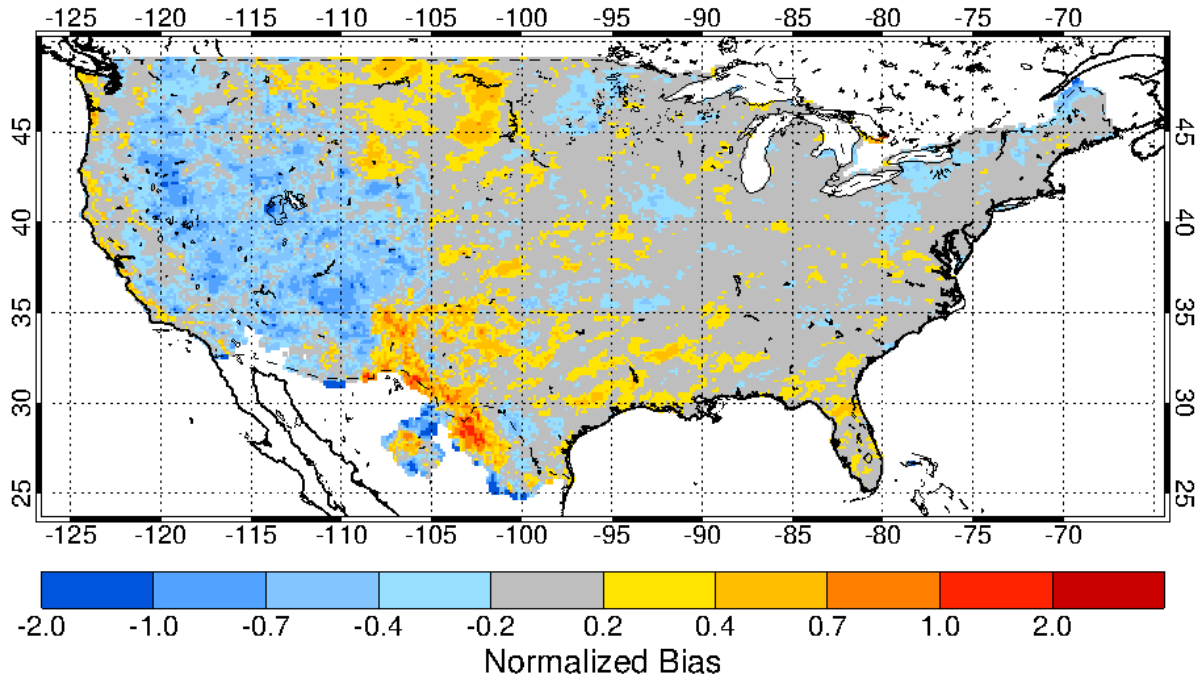
Fig. A3: Normalized bias of the 6-hour rainfall amounts from NEXRAD composite against ECMWF model for the period January-June 2016 (courtesy of P. Lopez, ECMWF).

1.2 Evaluation within ERICHA project

ERICHA (European Rainfall-InduCed Hazard Assessment; ericha.eu) is the third project of a trilogy of EC Civil Protection Prevention projects focusing on assessing and anticipating hazards triggered by intense precipitation. In the two previous projects, HAREN and EDHIT, a radar-based precipitation nowcasting system at European scale has been developed and demonstrated. In the ERICHA project, the nowcasting system is operationally implemented at the European Flood Awareness System (EFAS).

In the ERICHA system, the flash-flood hazard assessment is based on the nowcasts of accumulated precipitation generated from the OPERA radar composite. In the framework of this project the uncertainty of the radar precipitation input has been characterized. The results have been presented at the ERAD2016 conference by Park et al. (2016). Fig. A4 is extracted from this presentation. It shows the frequency of 10 dBZ reflectivity threshold exceedance and the monthly rainfall amount

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for May 2015. The figure shows realistic spatial variability of the monthly amounts but several artefacts like interference spikes or sharp discontinuities are visible. When the ODC composite is ingested in the nowcasting system such artefacts could perturb the identification of the precipitation motion field and the estimated rainfall intensity. An evaluation based on the comparison with synoptic observations has been carried out as well.
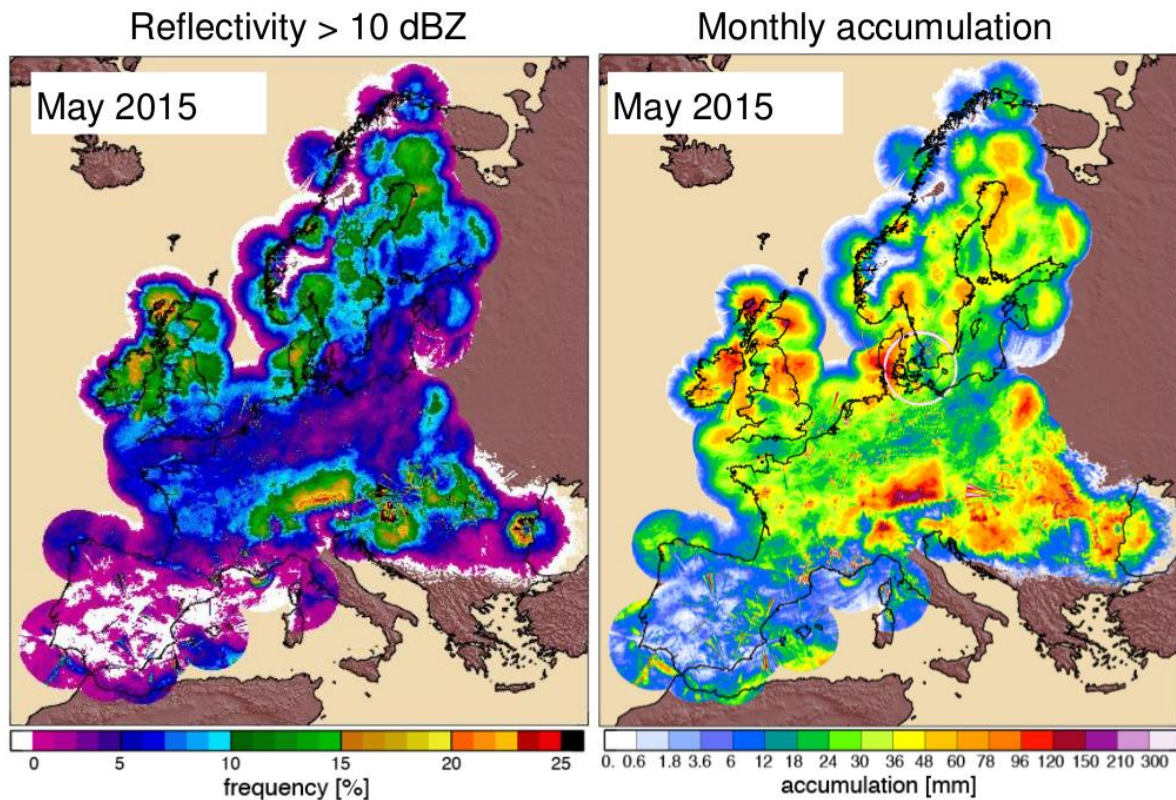

Fig, A4: Frequency of 10 dBZ excendance and monthly rainfall amount for May 2015 based on the ODC composite (courtesy of Shinju Park, UPC/CRAHI).

1.3 Evaluation within OPERA user group

The quality of the OPERA composite is an issue raised by several groups of users. Within the OPERA user group, a preliminary investigation of the quality based on averaged quantities over long periods has been performed by Klaus Stephan (DWD), the chairman of this group. The mean hourly precipitation amount (mm) over 6 months has been calculated (Fig. A5). The result shows the potential of producing such long-term statistics for identifying unrealistic precipitation patterns.

Another comparison concerns the rainfall values obtained from the ODC composite and from the EUCOM composite produced by DWD. The results have been presented by Klaus Stephan at OPERA ET2017a in Exeter. It has been found that the ODC composite exhibits substantially lower rainfall values than the EUCOM composite. These discrepancies can be at least partially attributed to the compositing scheme : weighting average performed in dBZ for ODC and maximum for EUCOM. The averaging in dBZ and not in Z values caused substantial underestimation. This has been recently corrected in the ODC processing.
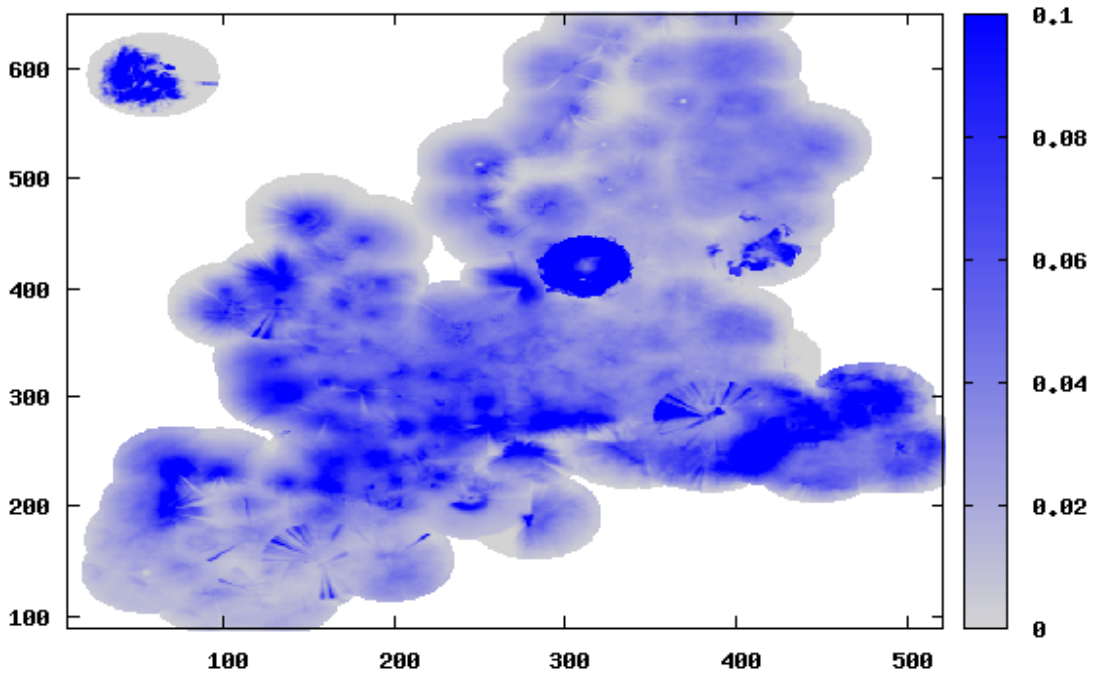

Fig.
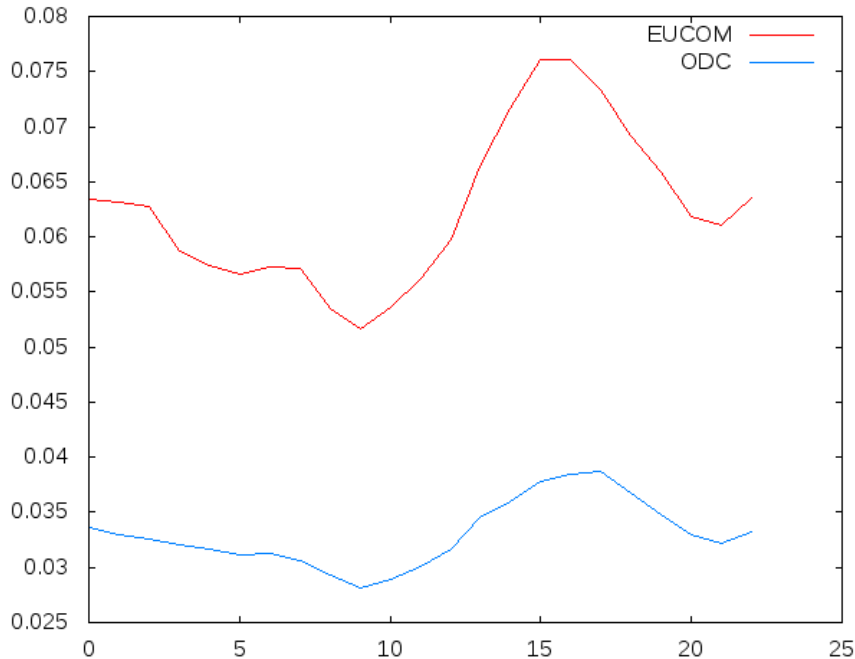Fig. A5 : mean hourly rainfall amount (mm) over 6 months. Courtesy of Klaus Stephan (DWD).

Fig. A6: Mean diurnal cycle of precipitation over Germany for the period September-October 2016 based on the ODC composite and the EUCOM composite produced by DWD.

2. Production and analysis of long-term accumulation maps

The production of the ODC composite started in 2011. The first full year is 2012. Three composites are generated every 15 minutes: (1) the surface precipitation rate composite (PAAH), (2) the maximum reflectivity composite (PABH), and (3) the hourly accumulation composite (PASH). The accumulation composite is based on the aggregation of 4 precipitation rate composites. The grid includes 2200x1900 pixels with a spatial resolution of 2 km.

The processing for generating the composite has changed in December 2015 in order to improve the removal of non-meteorological signals and to correct for beam blockage. The three following treatments have been incorporated:

1. Ground echoes removal using a clutter map updated every month
2. Clutter filtering based on satellite observations
3. Beam blockage correction

Based on long time series of the ODC composite it is possible to generate long-term rainfall accumulations over typically several months to several years. Various shortcomings which are not visible on 15-minutes products can be identified using such accumulations. Permanent ground echoes or interferences, spatial discontinuities or unrealistic spatial variations, gaps in spatial coverage are examples of shortcomings that can be identified. Next to rainfall accumulations, the frequency of threshold exceedance and the frequency of undetect and nodata values are also useful

to map. Monitoring tools can be used to identify and evaluate the impact of changes in the processing chain.

For a given time period, the following long-term maps are produced :

1. Frequency of nodata. The nodata value means "not measured" or "missing". This map allows to visualize the spatial coverage of the ODC composite.
2. Frequency of undetect. The undetect value means that the pixel was covered by the radar but no echo was received. This map is useful to identify areas contaminated by non-meteorological signals, even if these signals are very low in intensity.
3. Precipitation accumulation (mm). This map allows identifying various artefacts and unrealistic spatial variations.
4. Frequency of threshold exceedance. This map is typically generated for a threshold of 0.1 mm/h and allows indentifying areas that are contaminated by ground echoes strong enough to be wrongly interpreted as precipitation.

In order to identify the effect of the processing change in December 2015, we produce the maps for two 11-months periods: (1) January-November 2015 and (2) January-November 2016. In order to visualize the evolution with respect to the beginning of the ODC production period, the annual maps for 2012 have been produced as well. The year 2012 is the first full year of ODC production.

2.1. Frequency of nodata

Figure 1 shows the map of the frequency of nodata for 2016. The maps shows that Europe is very well covered by the ODC composite. The frequency of nodata is less than 2 % for most of the coverage. Areas with nodata frequencies larger than 2 % are generally at the boundaries of the covered areas, where observations from only one radar are available. In 2016, a substantial part of Germany shows frequencies between 8 and 10 %. This is due to changes in the DWD radar transmission software which caused interruption of the data flow to ODC.

A radar located in Corsica produces substantial nodata areas which seem to be associated with orography. This feature is present in 2015 and 2016, which means that the processing change in December 2015 is not responsible for the rejection of data contaminated by ground clutter in these areas. Nodata values are most probably already present in incoming polar volumes.

Figure 3 shows the nodata map for 2012. The comparison with figures 1 and 2 shows a substantial improvement of the OPERA composite coverage since the beginning of ODC operation.

2.2. Frequency of undetect

Figures 4, 5 and 6 show the frequency of "undetect" values for 2016, 2015 and 2012, respectively. Figures 7, 8 and 9 show the same maps but with another displayed frequency range (between 0 and 20 %). A frequency of 100 % means that no echo is received even if the area is within the radar coverage. A frequency of 0 % can be obtained if the area is outside radar coverage (nodata) or if the area is within coverage and an echo (or as signal coming from a source of interference) is continuously received. Around most radar locations lower "undetect"' frequencies are observed, which means that ground echoes are frequently observed. For many radars, the "undetect" frequency near the radar is lower than 10 % which means that clutter is observed more than 90 % of the time. The comparison between 2015 and 2016 shows that the clutter removal processing applied since December 2015 allows a substantial reduction of cluttered areas. Spikes usually caused by RLAN interferencies are also observed on the maps, for example in Spain. Again, a substantial improvement is observed in 2016 with respect to 2015. The maps let appear some discontinuities between countries which suggest different treatments of clutter applied by the National Meteorological Services in the raw polar data sent to ODC. With the current clutter removal processing at ODC the frequency of "undetect" is more than 25 % everywhere except around one radar in Island and over a few very localized areas in Corsica and in the north of Norway.

The comparison of undetect maps in 2012 and 2015 lets appear some differences, for example in The Netherlands and in France. These differences can not be attributed to changes in ODC processing and are probably related to changes in national processing chains.

2.3 Frequency of threshold exceedance

The frequency maps of 0.1 mm/h threshold exceedance are shown in Figures 10 to 15 for 2016, 2015 and 2012 and for two different frequency ranges. These maps are supposed to show the frequency of precipitation over Europe with a temporal sampling of 15 minutes. Large spatial variations are clearly visible on the maps. Some of them are caused by real weather phenomena while others are caused by radar artefacts. Some patterns can be clearly attributed to radar artefacts, for example interference patterns or sharp discontinuities at the maximum range of a given radar. Others are more difficult to interpret. The maps obtained for 2015 and 2016 can be compared to identify possible improvement produced by the new clutter removal processing. When comparing the maps it must be kept in mind that weather in Europe was not the same in 2015 and 2016. Therefore, it is not expected to get the same weather patterns. Compared to 2012, the maps obtained for 2015 and 2016 show better spatial homogeneity which is a consequence of the increase in ODC composite coverage.

Concerning radar artefacts, the visual comparison between 2015 and 2016 does not show a clear improvement produced by the new clutter filtering. In particular, artefacts caused by radio interferences are not substantially reduced. The new clutter removal is based on monthly clutter

maps and cloud observations from satellite. If the interference is not permanent and cloudiness is present, the removal scheme will not be able to eliminate interferences. Ground echoes are visible for the two years but the patterns are not exactly the same. Permanent ground clutter should be removed by the clutter filter but non-permanent clutter depending on the atmospheric propagation conditions will not be removed in cloudy conditions. This might explain the relatively low impact of the implementation of the new clutter removal scheme at ODC level. Nevertheless, some areas are visible with a reduction of clutter. A more careful analysis is required to analyse in detail the impact of the new scheme for various specific regions prone to ground clutter.

2.4 Precipitation accumulation

Figures 16, 17 and 18 show the rainfall accumulation maps for 2016, 2015 and 2012, respectively. It is clearly apparent that annual rainfall amounts over Europe are much better captured in 2015 and 2016 than in 2012. This improvement is due to the increase of the number of radars ingested by ODC and the subsequent extension of the composite coverage. It can also be related to a quality improvement of the incoming data to ODC.

The comparison between 2015 and 2016 exhibits various differences. In some regions and around some radars, it seems that non-meteorological signals (ground clutter and interferences) have been reduced in 2016 with respect to 2015. However, a careful inspection of the two maps show the opposite in some areas. Some improvement between 2015 and 2016 in the presence of non-meteorological signals can be expected from the change in the ODC processing but other factors, like the occurrence of abnormal propagation conditions and the frequency and intensity of RLAN interferences, may vary from year to another and also affect the contamination by non-meteorological signals. It must also be pointed out that the beam blockage correction can cause an intensification of the interference signals.

2.5 Statistics

Some statistics can be produced from the different maps that have been produced : frequency of nodata, frequency of undetect and frequency of threshold exceedance.

Four statistics representing fractions of the full composite domain (2200x1900 pixels; 16720000 km^2) have been produced.

(1) $F_{covered}$: fraction of the composite domain (or percentage of pixels) with a frequency of nodata less than 10 %. It shows the fraction of the domain which is well covered by the composite. It should be as large as possible. It must be noticed that a substantial part of the domain lies over the sea which implies that only a partial coverage of the domain can be achieved.

(2) $F_{clutter}$: fraction of the composite domain (or percentage of pixels) with a frequency of undetect less or equal than 20 %. It is the fraction of the domain where a signal is received more than 80 % of the time, which corresponds with quasi permanent clutter. It should be as low as possible.

(3) $F_{rain>60\%}$: fraction of the composite domain (or percentage of pixels) with a frequency of rainrate exceeding 0.1 mm/h larger than 60 %. Such frequency is unrealistic on annual basis and indicates wrong detection of precipitation generally due to contamination by clutter. It should be as lows as possible.

(4) $F_{rain<3\%}$: fraction of the composite domain (or percentage of pixels) with a frequency of rainrate exceeding 0.1 mm/h larger than 0 % and less than 3 %. Based on the European climatology, such frequency is supposed to be unrealistic on annual basis and indicates that substantial precipitation is not detected even if the pixel is covered by at least one radar. This fraction should be as low as possible.

Table 1 gathers the statistics obtained in 2012, 2015 and 2016. The evolution from 2012 to 2016 shows a substantial increase of the European radar coverage. The covered area increased from $6186400\ km^2$ (37 %) in 2002 to $7858400\ km^2$ (47 %) in 2016. A substantial decrease of the area affected by quasi-permanent clutter and wrong detection of precipitation is also obtained. Finally, the fraction of the domain with a very poor detection of precipitation is also significantly reduced.

	$F_{covered}$	$F_{clutter}$	$F_{rain>60\%}$	$F_{rain<3\%}$
2012	37 %	4.46 %	0.06 %	16 %
2015	45 %	4.72 %	0.02 %	13 %
2016	47 %	1.11 %	0.0001 %	6 %

Table 1: statistics based on frequency of nodata, undetect and threshold exceedance.

3. Conclusions and recommendations for future work

Long-term European maps have been produced for 4 quantities: the occurrence of nodata, the occurrence of undetect, the frequency of 0.1 mm/h threshold exceedance and the rainfall accumulation. These maps appear as a good tool for monitoring the quality of the ODC composite. It allows identifying contamination by ground echoes and interferences and pointing out spatial discontinuities or unrealistic patterns.

Such maps also allow visualizing the progressive extension of the composite coverage due to the progressive incorporation of additional radars. The comparison between the results obtained during the first year of ODC operation (2012) and those obtained in 2016 shows that the covered area has increased by 27 % (from $6186400\ km^2$ to $7858400\ km^2$). The quality of the radar coverage has increased as well, resulting in less pixels showing very poor detection of precipitation.

Long-term maps are also useful to identify and evaluate the impact of changes in the processing applied for generating the ODC composite from single radar data. The comparison between 2015 and 2016 maps of undetect frequency shows a significant impact of the clutter removal processing implemented in December 2015. It must be noted that some discrepancies have been found between National Meteorological Services practices for the attribution of the undetect value in the single radar data sent to ODC.

Identifying and evaluating the impact of the new processing on the threshold exceedance and accumulation maps is not straightforward since many factors are affecting these maps. Atmospheric conditions producing ground clutter may vary from one year to another and the presence of interference sources as well. In addition, some processing changes at national level also affect the quality of the ODC composite. Nevertheless, it can be pointed out that the fraction of the ODC domain with unrealistic values of the frequency of 0.1 mm/h exceedance has substantially decreased between 2012 and 2016.

Based on the work performed here we can formulate following recommendations:

- Long-term maps should be produced on a regular basis, for example every year or every 3 months, and each time a change in the ODC processing is implemented. Maps at seasonal timescale are particularly interesting to point out possible influence of the precipitation type, for example convective versus stratiform or rain versus snow.
- Some simple statistics can be produced for characterizing the quality of the ODC composite. In the present study, the thresholds used in those statistics, for example a 60 % threshold for the frequency of 0.1 mm/h exceedance, are uniform over Europe. However, large geographical variations of the precipitation climatology are found in Europe and the use of regional dependent thresholds would be more appropriate.
- A careful examination of the results should be performed for different sub-regions with the support of experts from National Meteorological Services having good knowledge of prevailing weather conditions and weather radars covering the area.
- Comparison with European-wide raingauge datasets should be performed. At first, 1-year rainfall accumulations estimated from ODC composite and measured by raingauges could be compared. SYNOP data and more denser climatological raingauge networks can be used. Access to raingauge datasets and comparison with gauges are covered by Tasks OD 11c and OD12. The use of external information from NWP, for example temperature information, would help to stratify the results for rainfall only and snowfall only situations.

Figures

OPERA radar network 01/01/2016 - 30/11/2016 in total 32003 files (100 %)

Fig.1: Frequency of nodata values for the period 01/01/2016-30/11/2016.

Fig.2: Frequency of nodata values for the period 01/01/2015-30/11/2015.
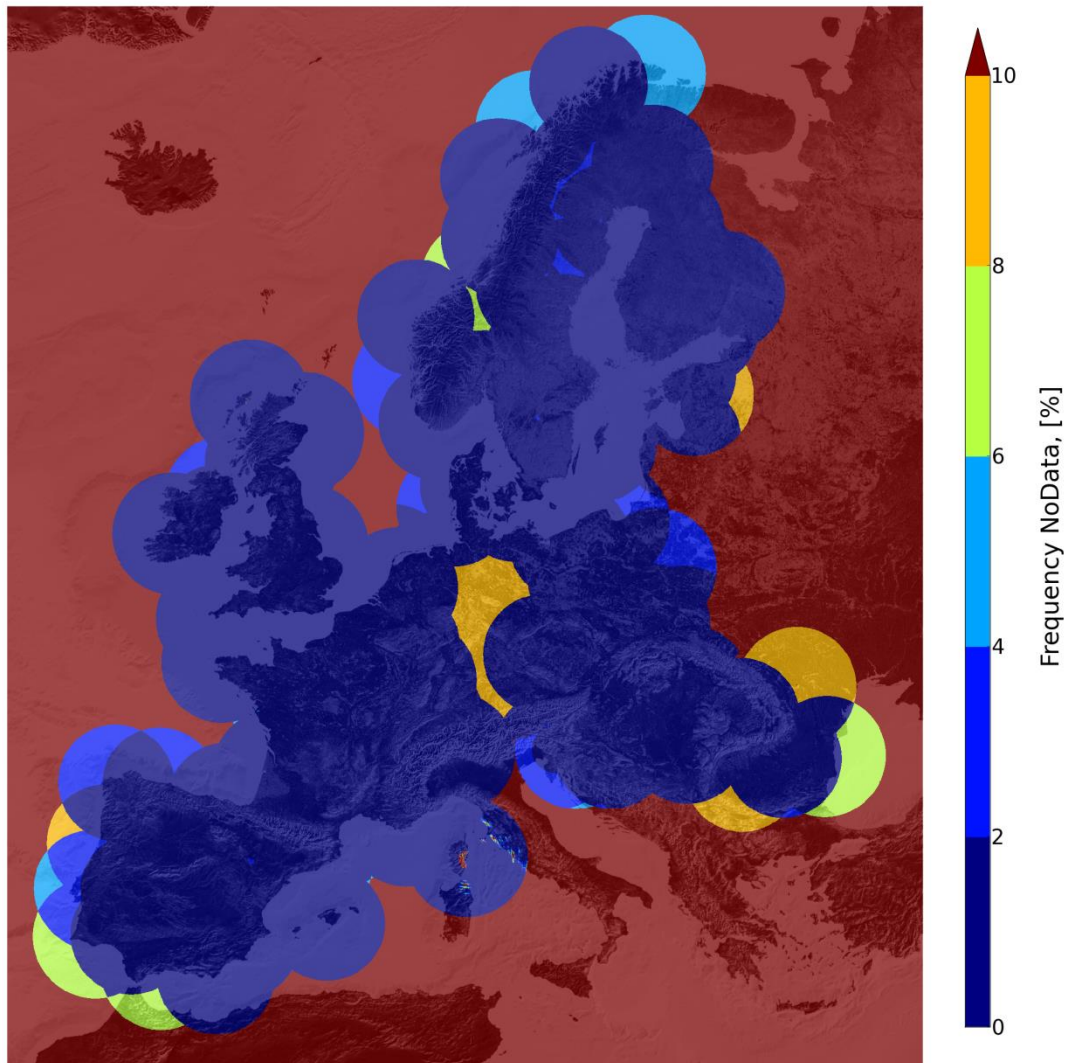
Fig.3: Frequency of nodata values for the period 01/01/2012-31/12/2012.

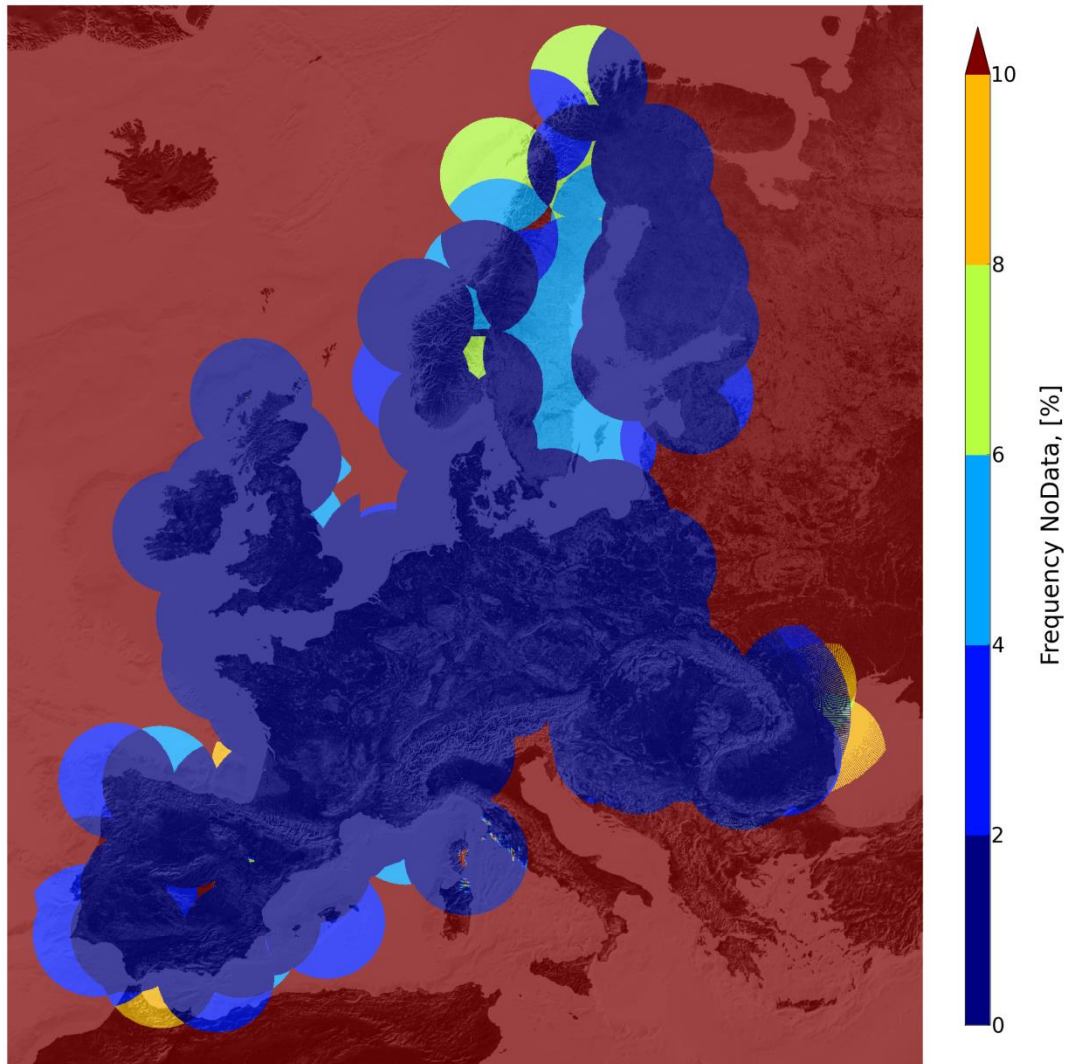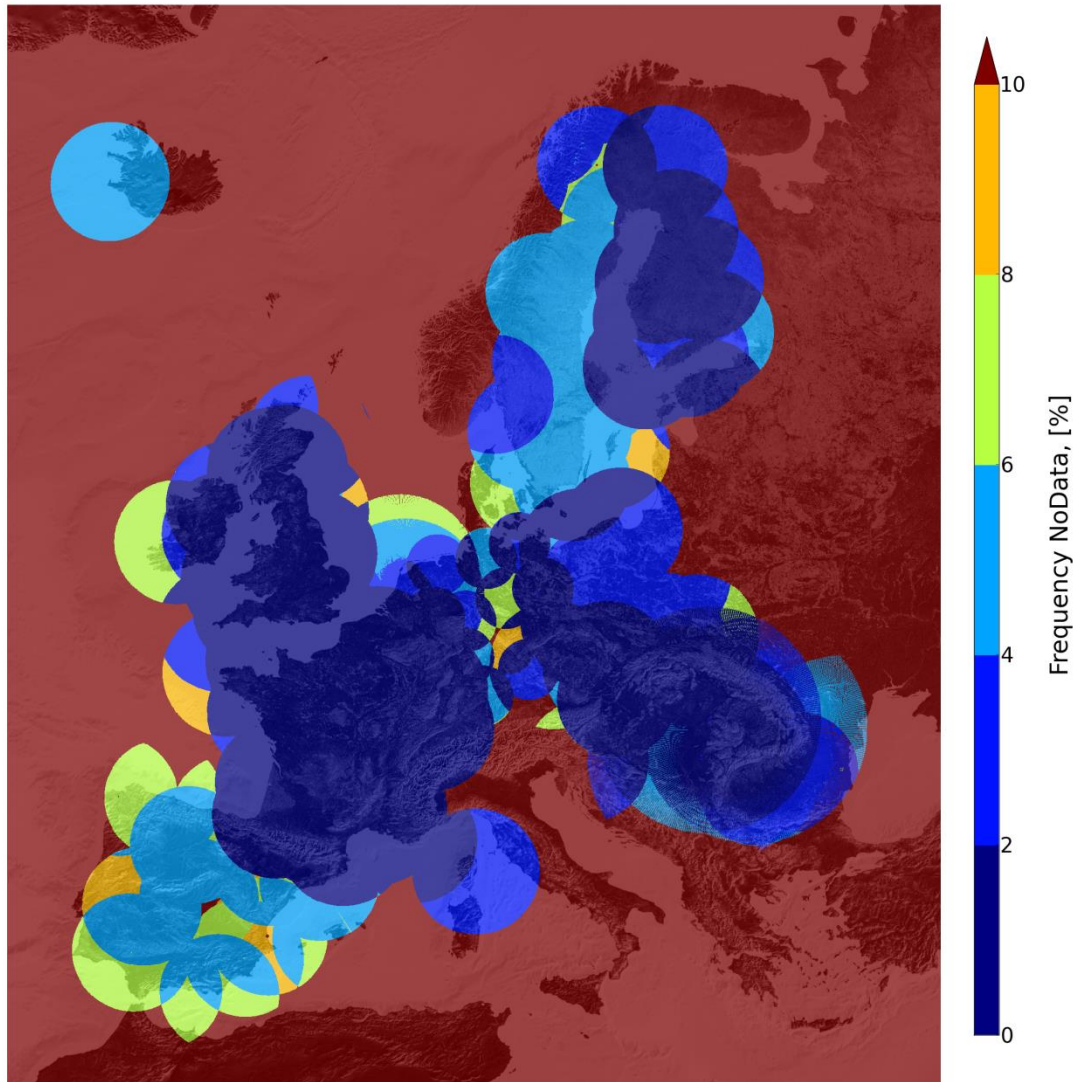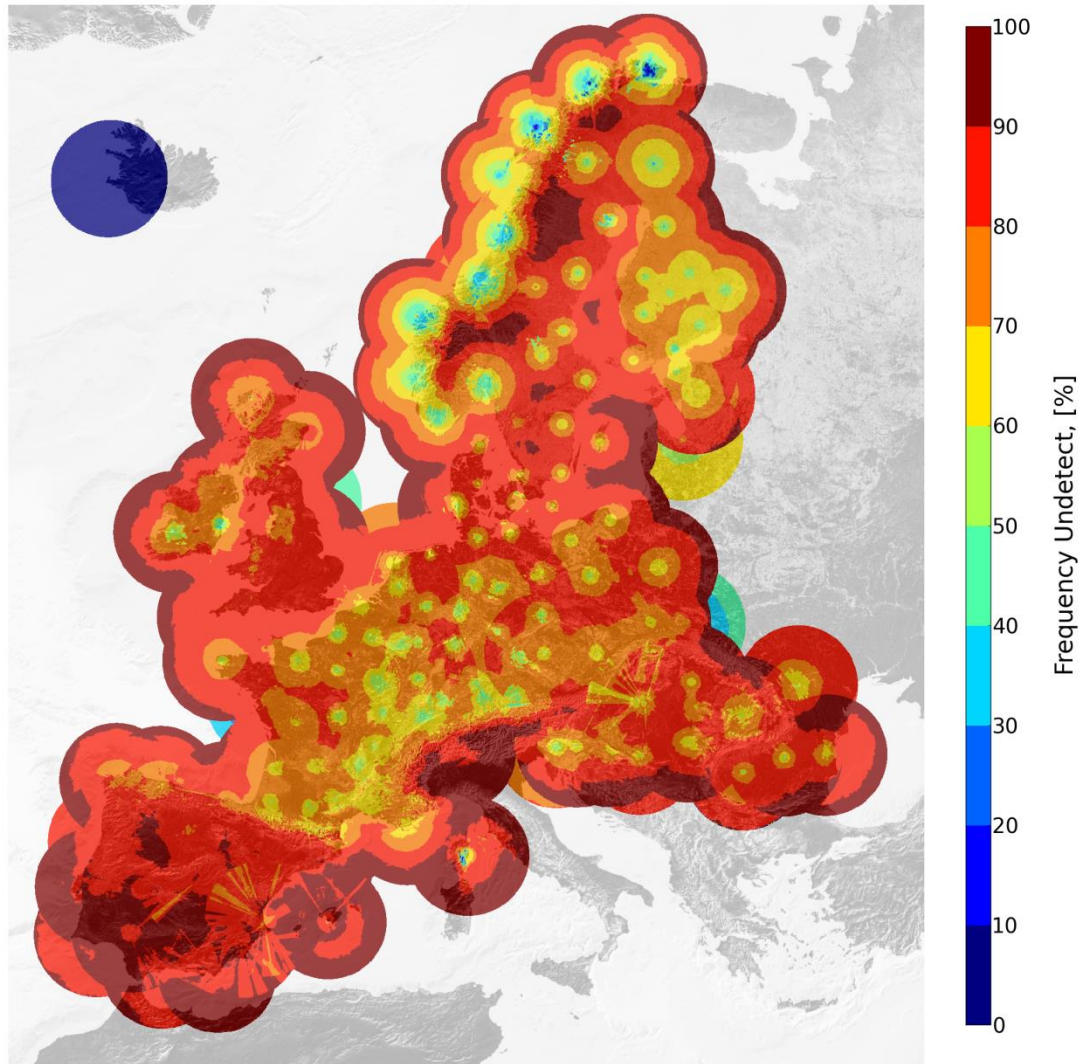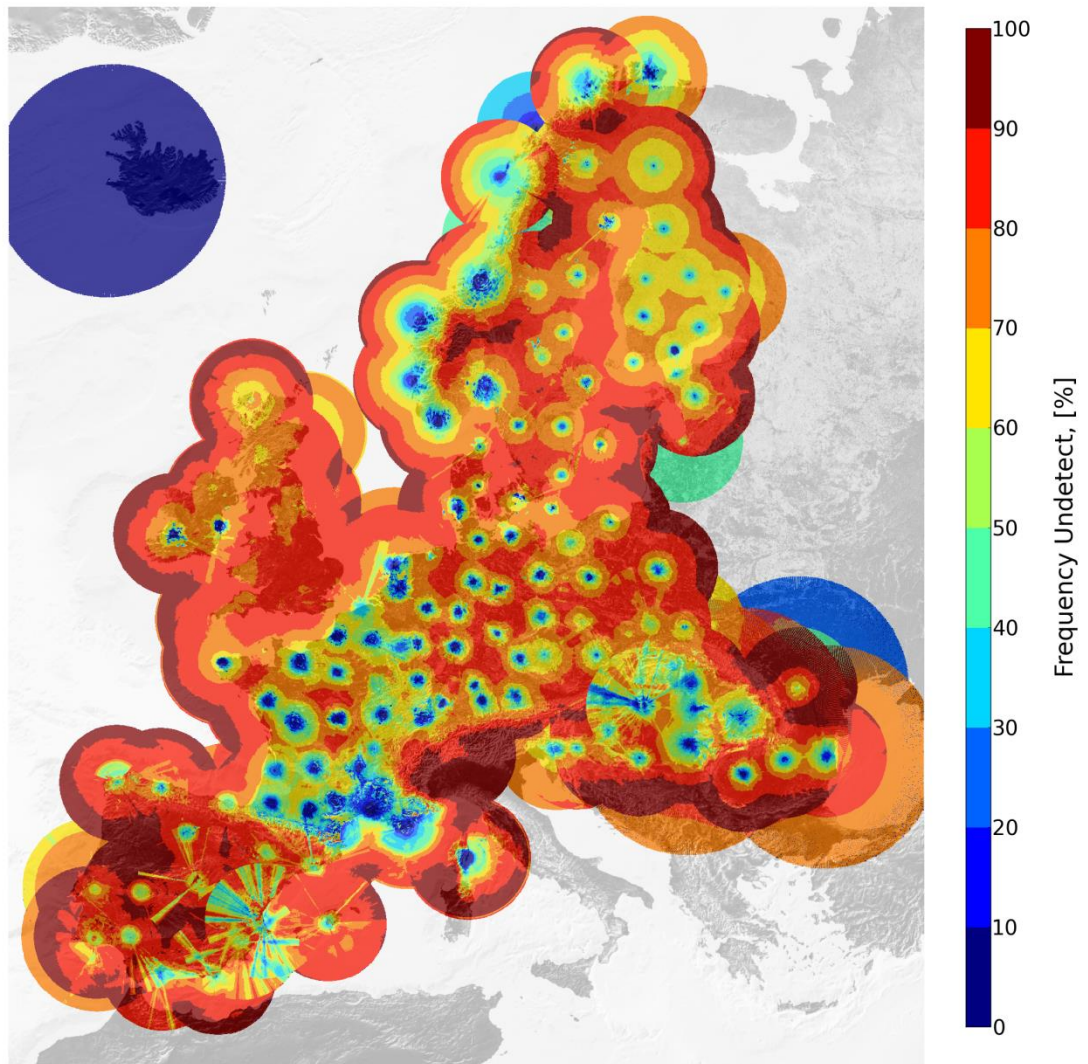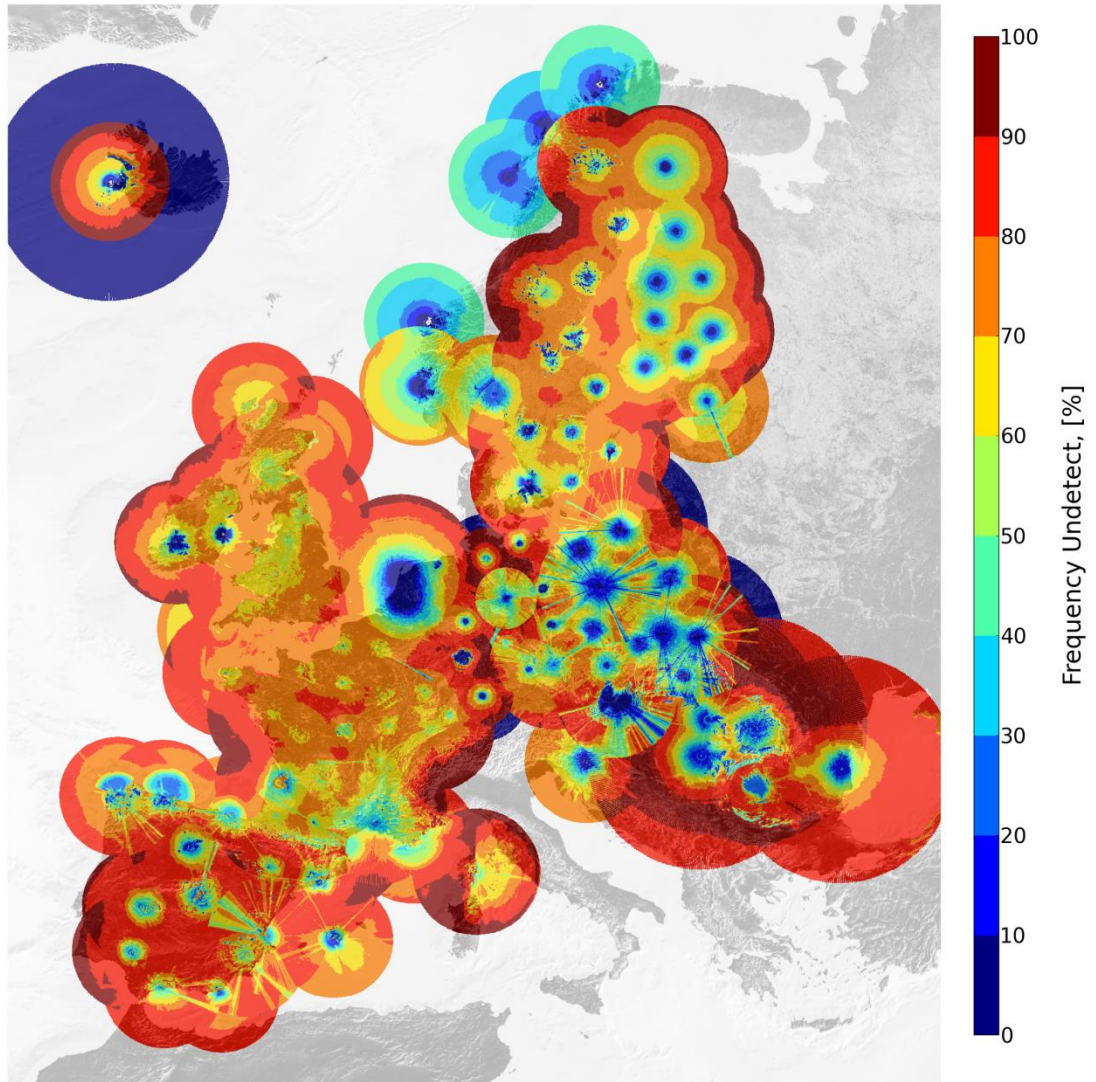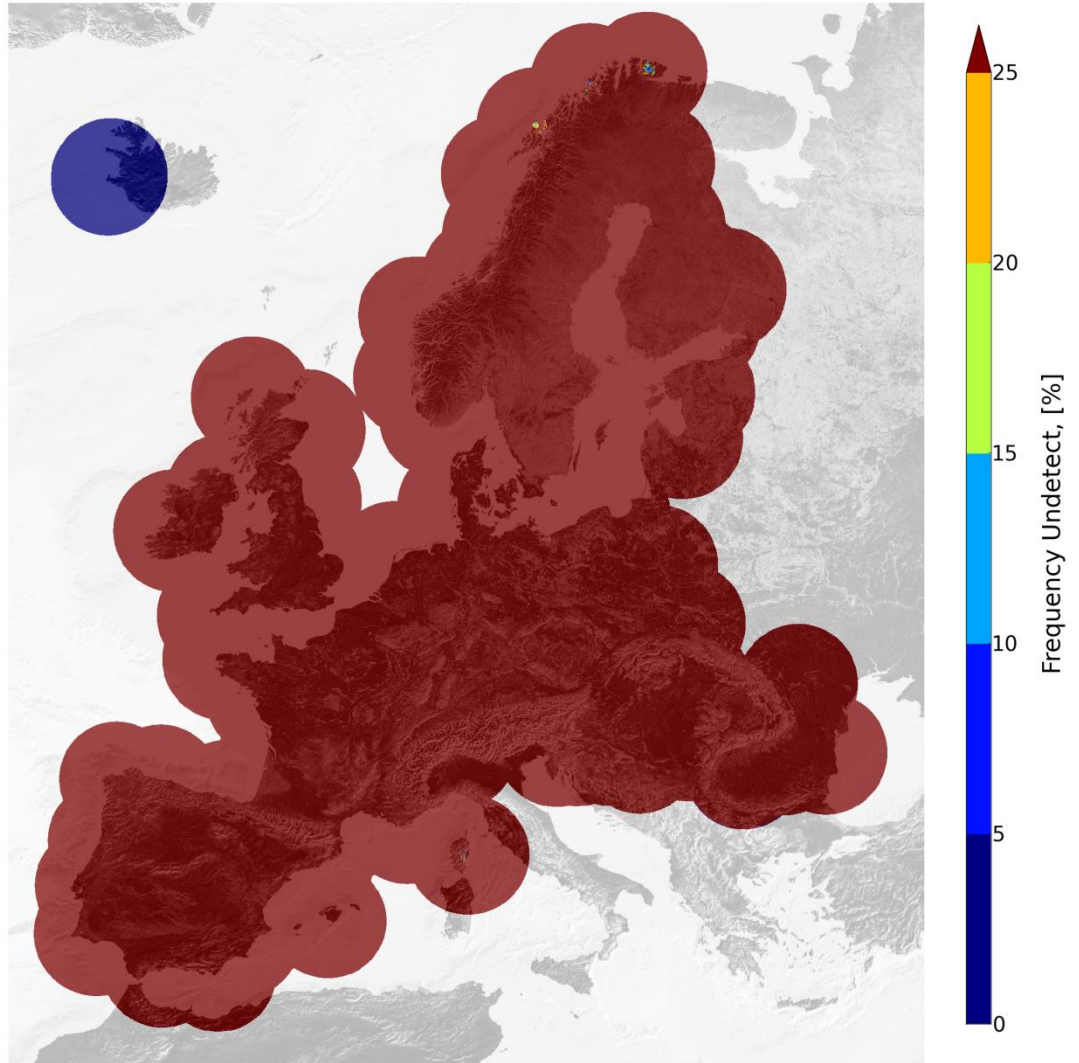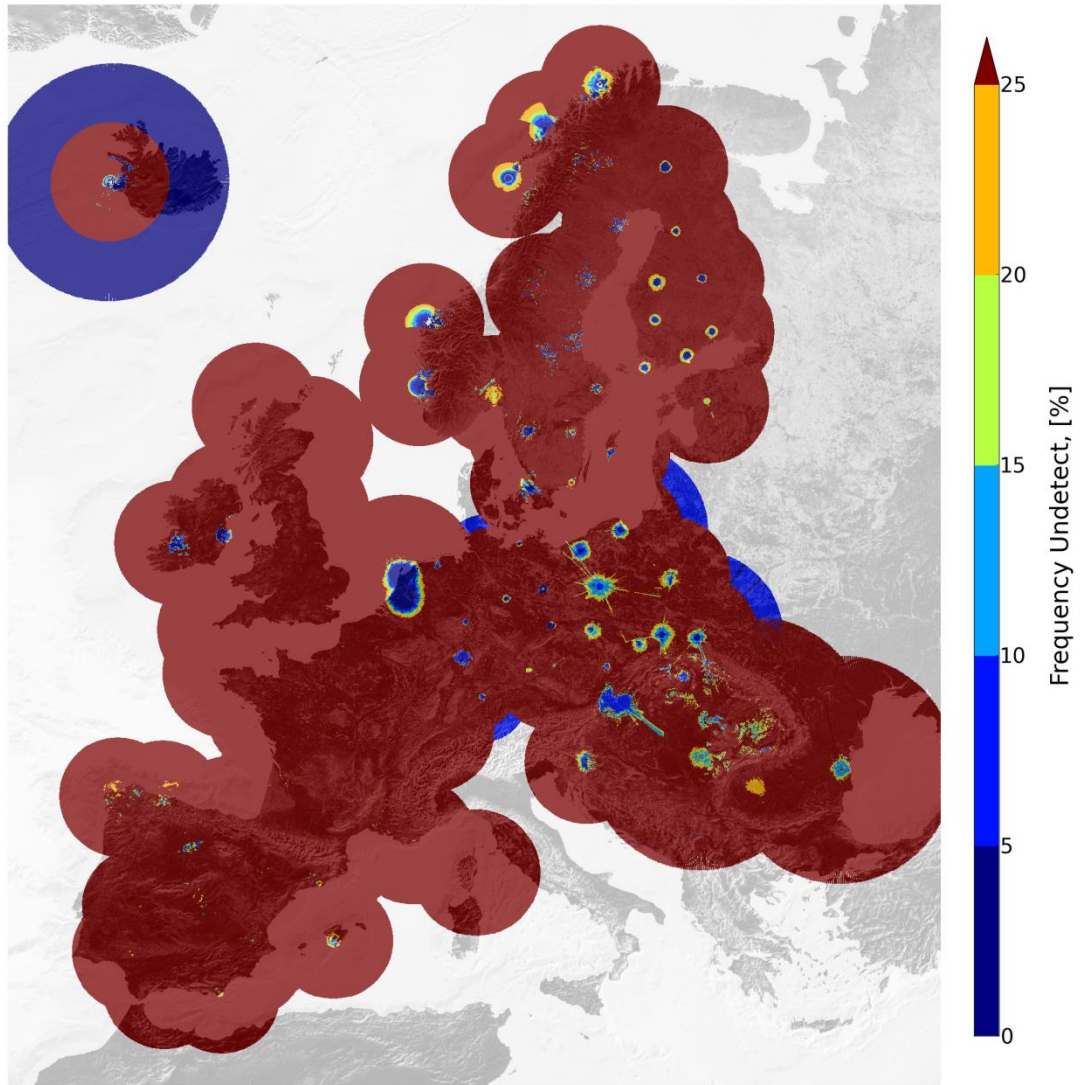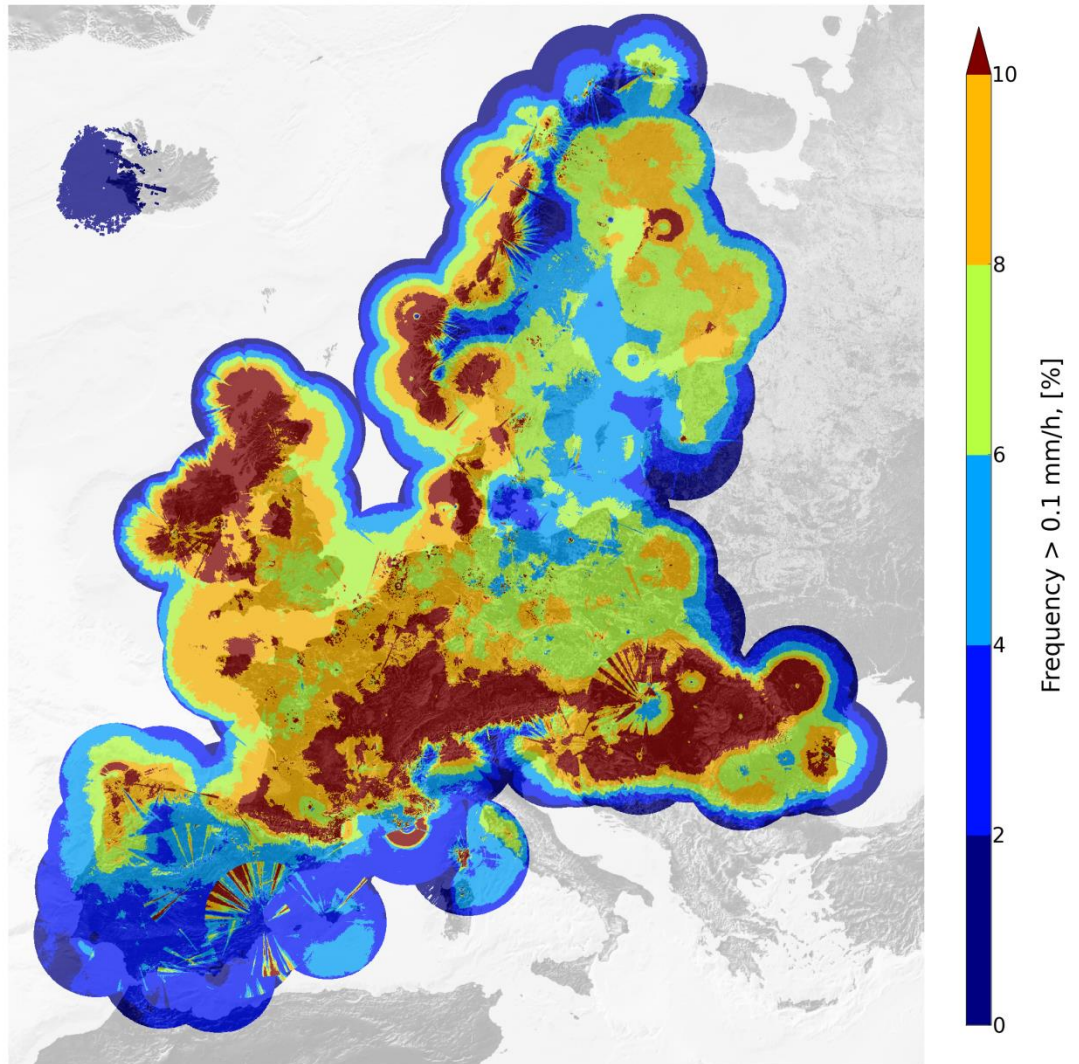OPERA radar network 01/01/2016 - 30/11/2016 in total 32003 files (100 %)

Fig.4: Frequency of "undetect" values for the period 01/01/2016-30/11/2016.

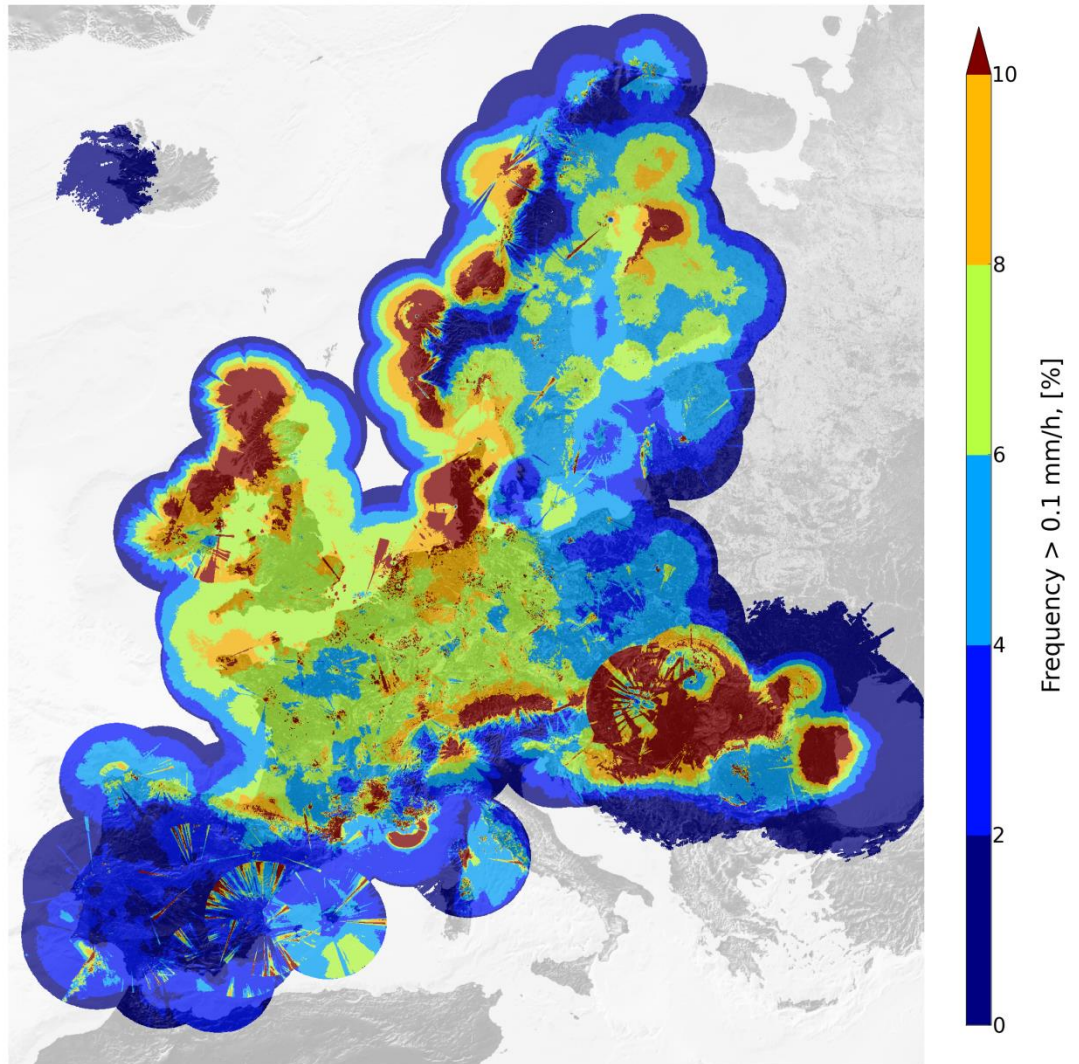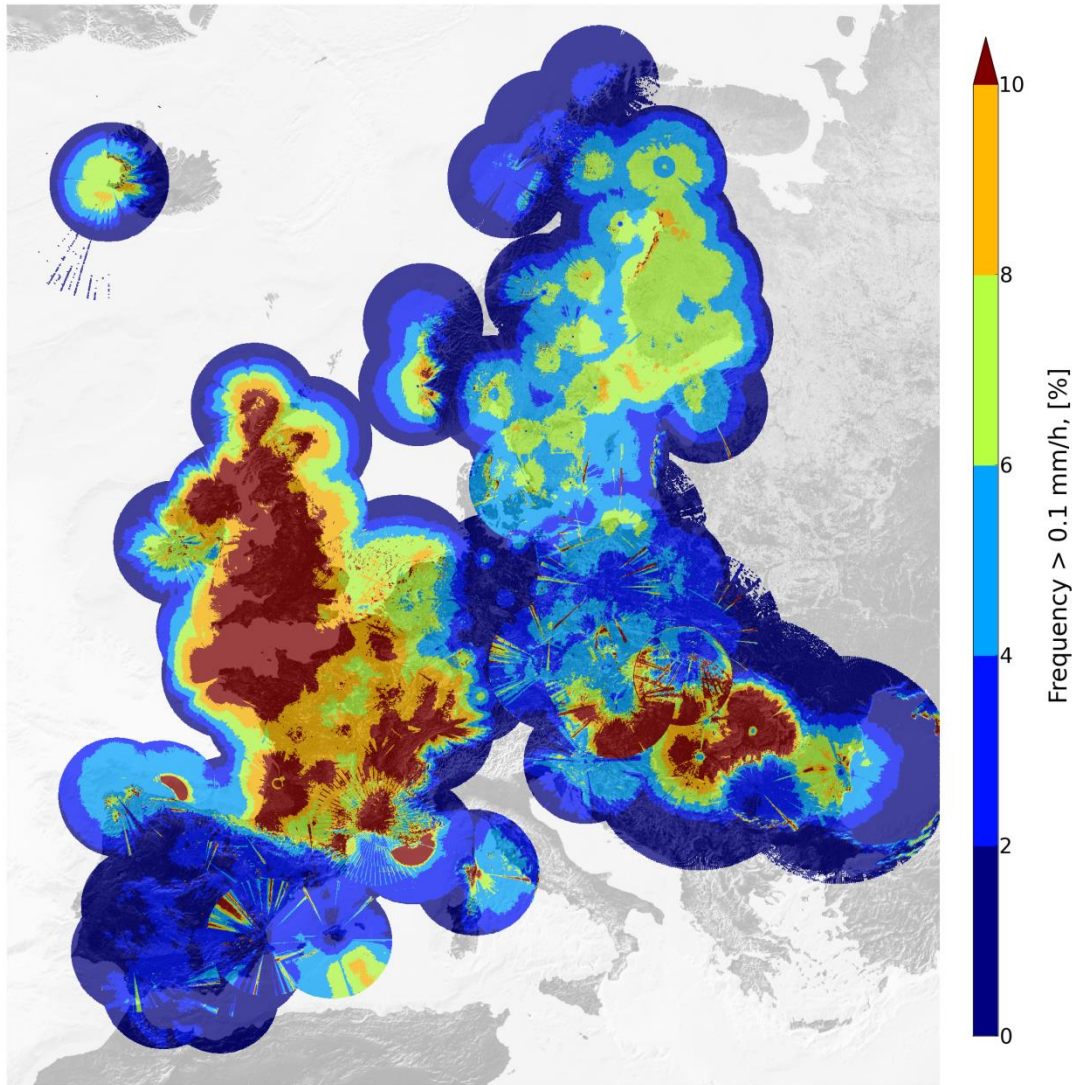OPERA radar network 01/01/2015 - 30/11/2015 in total 31988 files (100 %)

Fig.5: Frequency of "undetect" values for the period 01/01/2015-30/11/2015.

OPERA radar network 01/01/2012 - 31/12/2012 in total 32593 files (93 %)

Fig.6: Frequency of "undetect" values for the period 01/01/2012-31/12/2012.

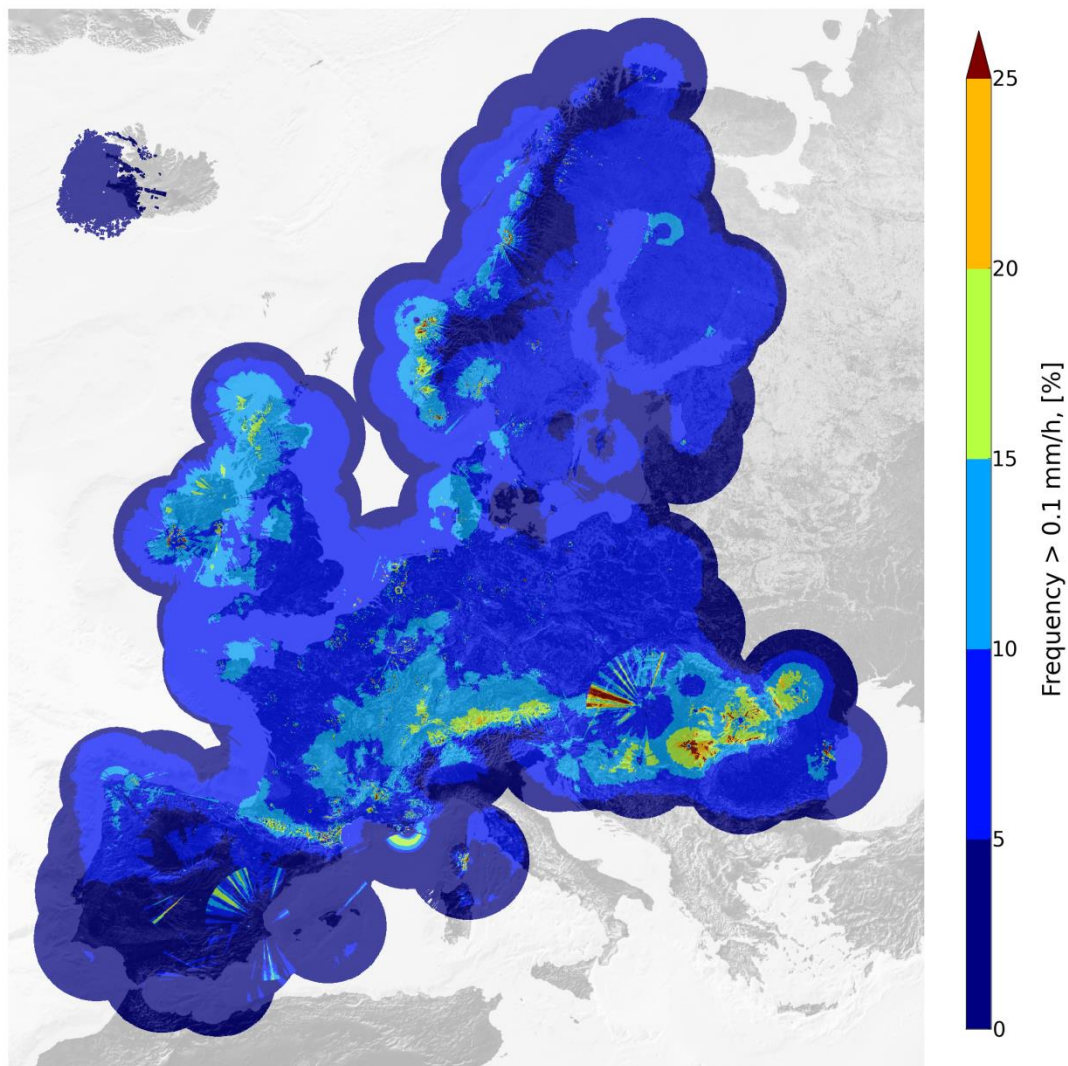OPERA radar network 01/01/2016 - 30/11/2016 in total 32003 files (100 %)

Fig.7: Frequency of "undetect" values for the period 01/01/2016-30/11/2016 (frequency range 0-25 %).
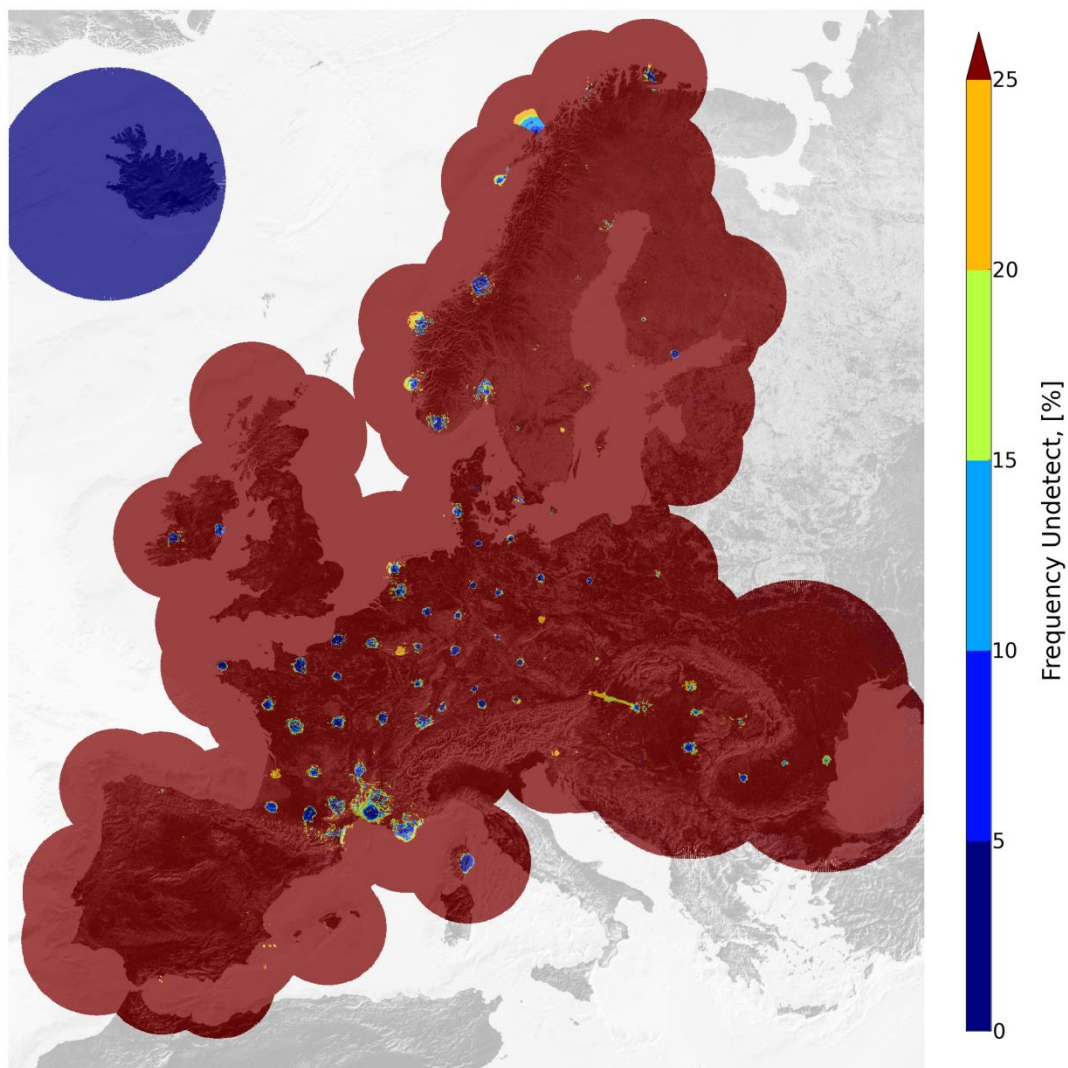
OPERA radar network 01/01/2015 - 30/11/2015 in total 31988 files (100 %)

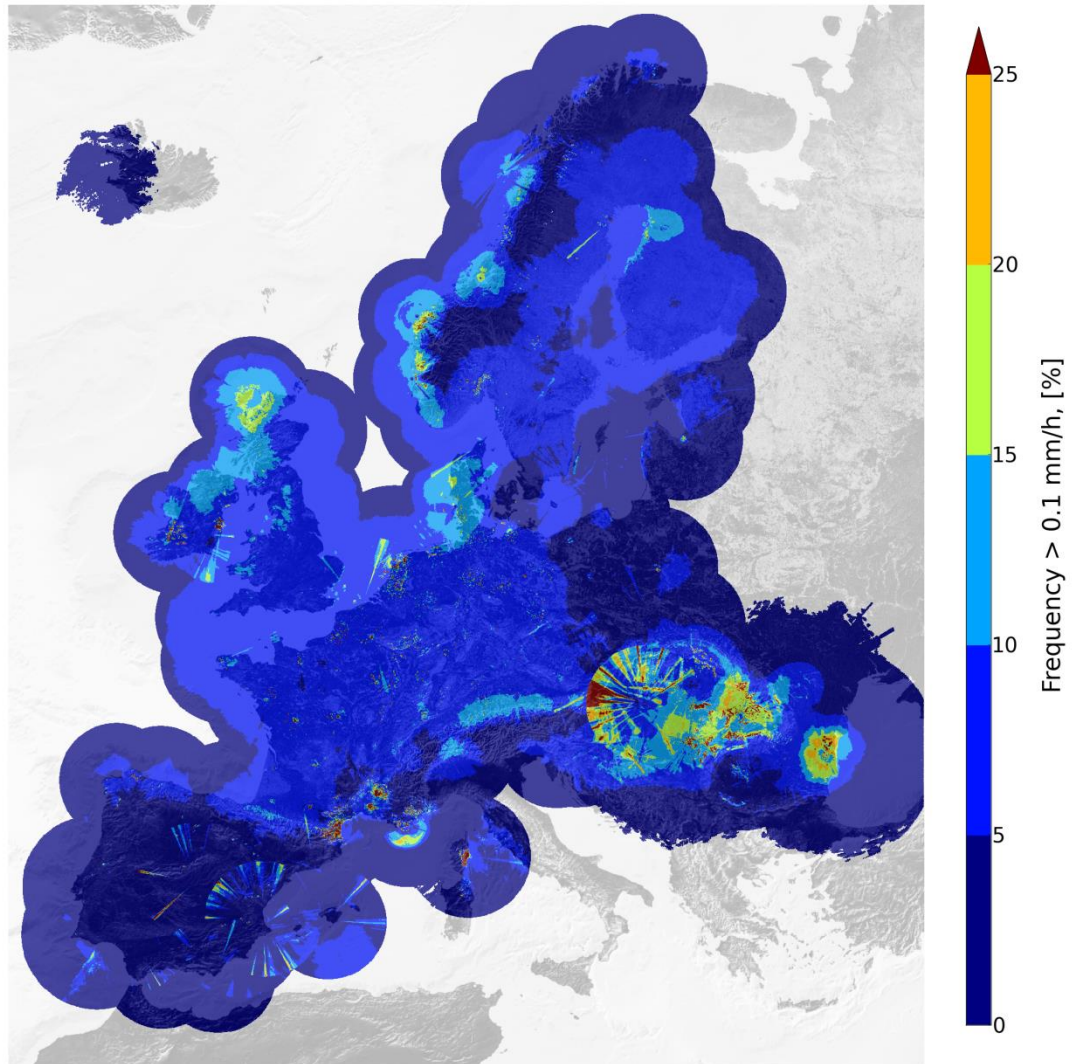Fig.8: Frequency of "undetect" values for the period 01/01/2015-30/11/2015 (frequency range 0-25 %).

Fig.9: Frequency of "undetect" values for the period 01/01/2012-31/12/2012 (frequency range 0-25 %).

OPERA radar network 01/01/2016 - 30/11/2016 in total 32003 files (100 %)

Fig.10: Frequency of 0.1 mm/h threshold exceedance for the period 01/01/2016-30/11/2016

Fig.11: Frequency of 0.1 mm/h threshold exceedance for the period 01/01/2015-30/11/2015

OPERA radar network 01/01/2012 - 31/12/2012 in total 32593 files (93 %)

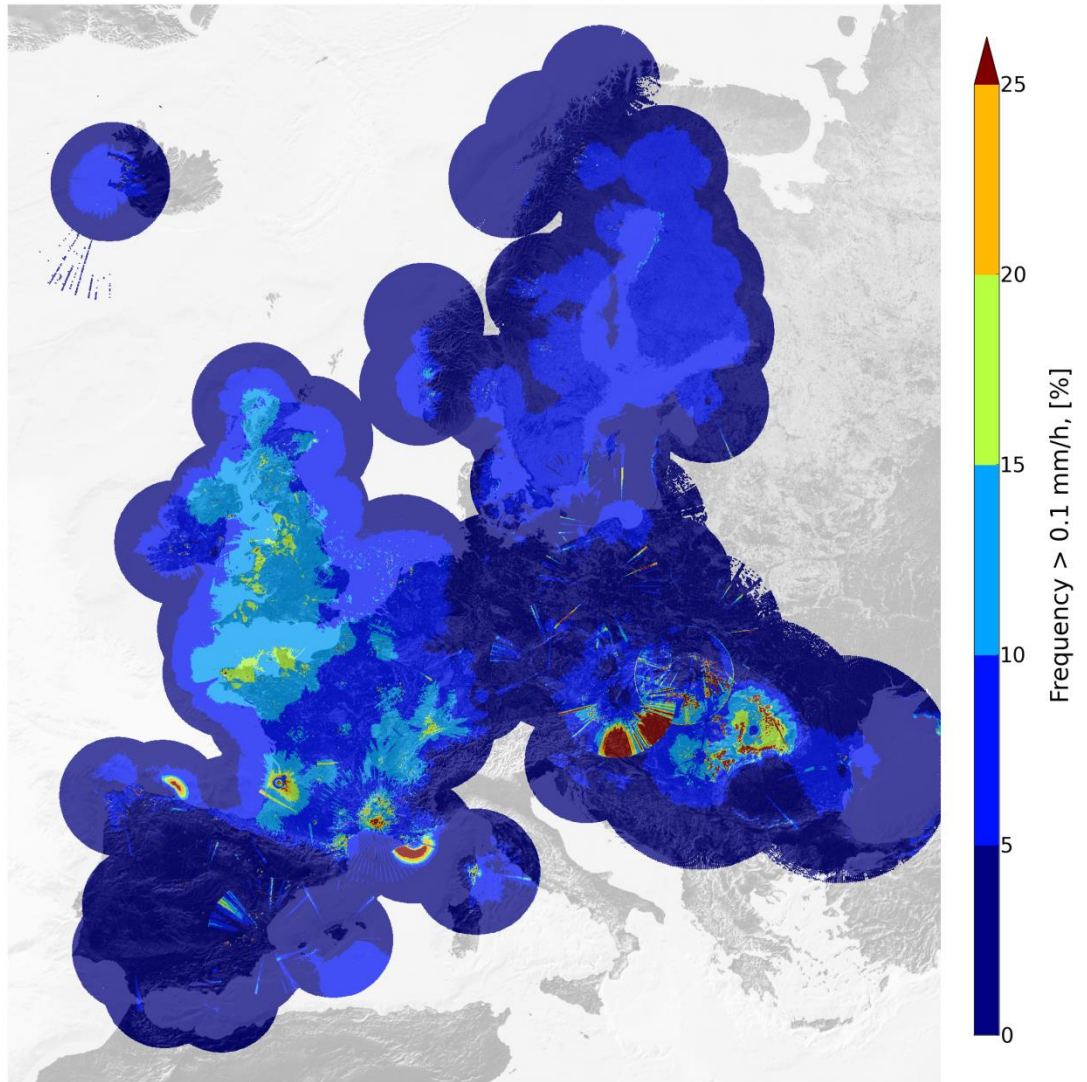Fig.12: Frequency of 0.1 mm/h threshold exceedance for the period 01/01/2012-31/12/2012

Fig.13: Frequency of 0.1 mm/h threshold exceedance for the period 01/01/2016-30/11/2016 (frequency range 0-25 %).

Fig. 14: Frequency of 0.1 mm/h threshold exceedance for the period 01/01/2015-30/11/2015 (frequency range 0-25 %).

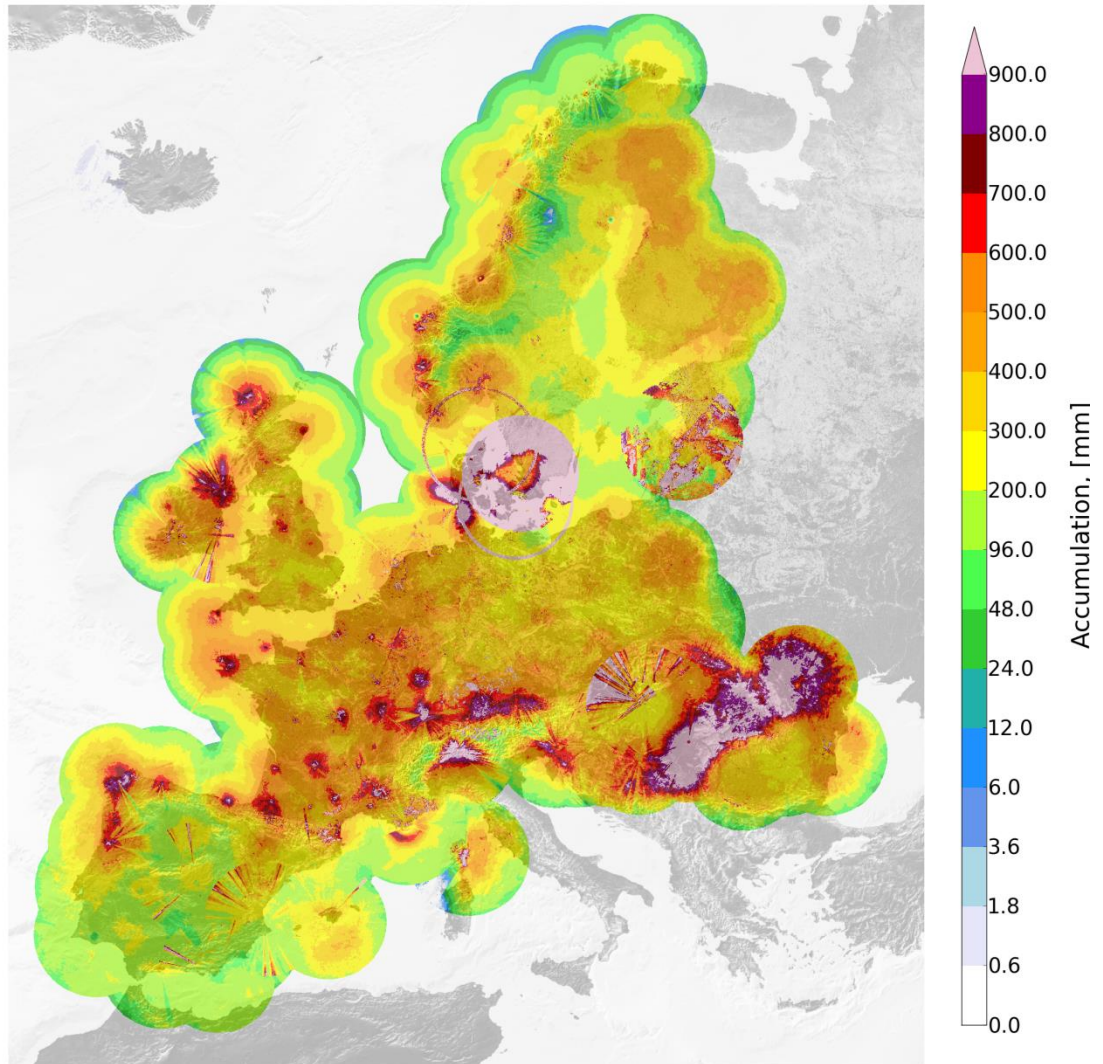OPERA radar network 01/01/2012 - 31/12/2012 in total 32593 files (93 %)

Fig.15: Frequency of 0.1 mm/h threshold exceedance for the period 01/01/2012-31/12/2012 (frequency range 0-25 %).

Fig.16: Rainfall accumulation for the period 01/01/2016-30/11/2016
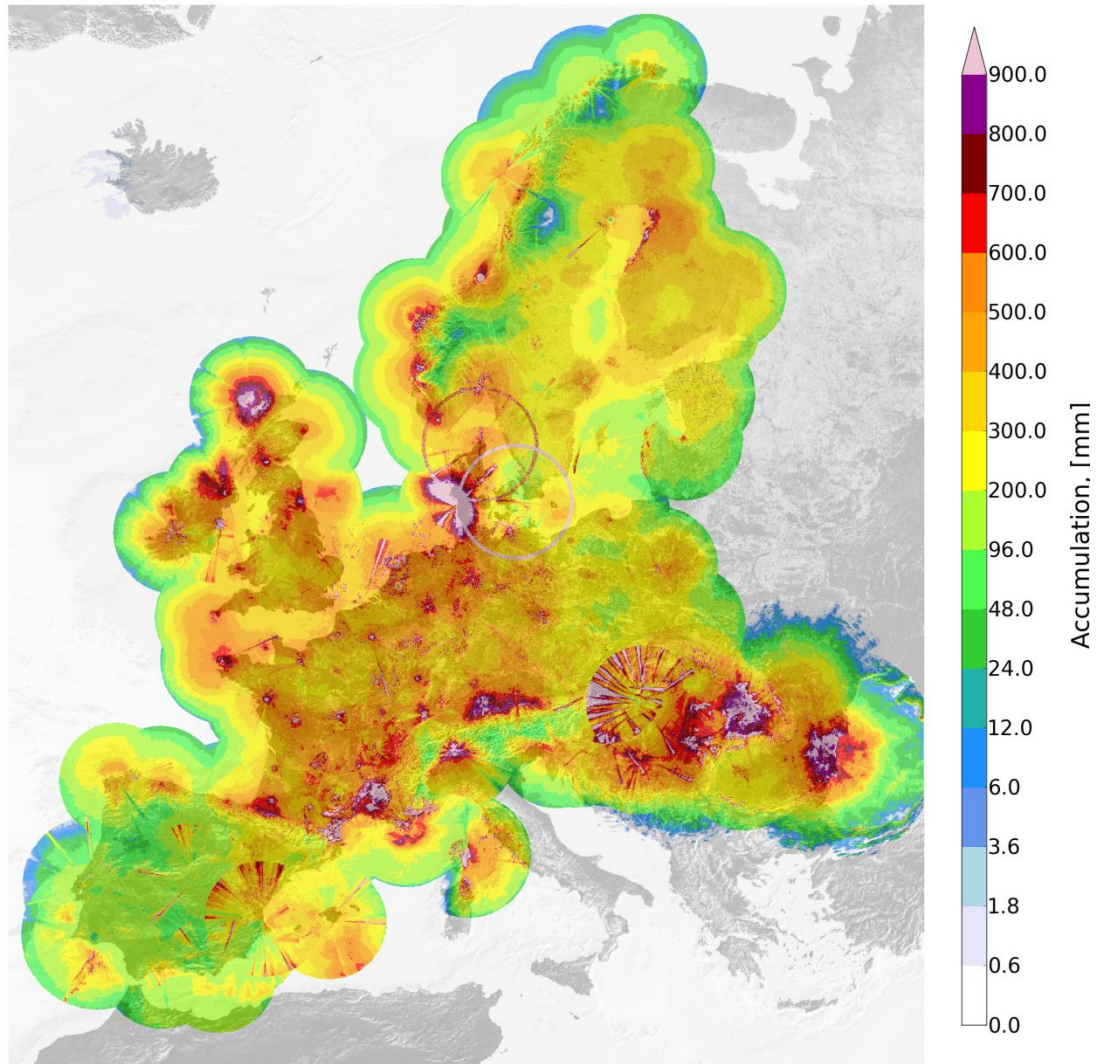
Fig.17: Rainfall accumulation for the period 01/01/2015-30/11/2015

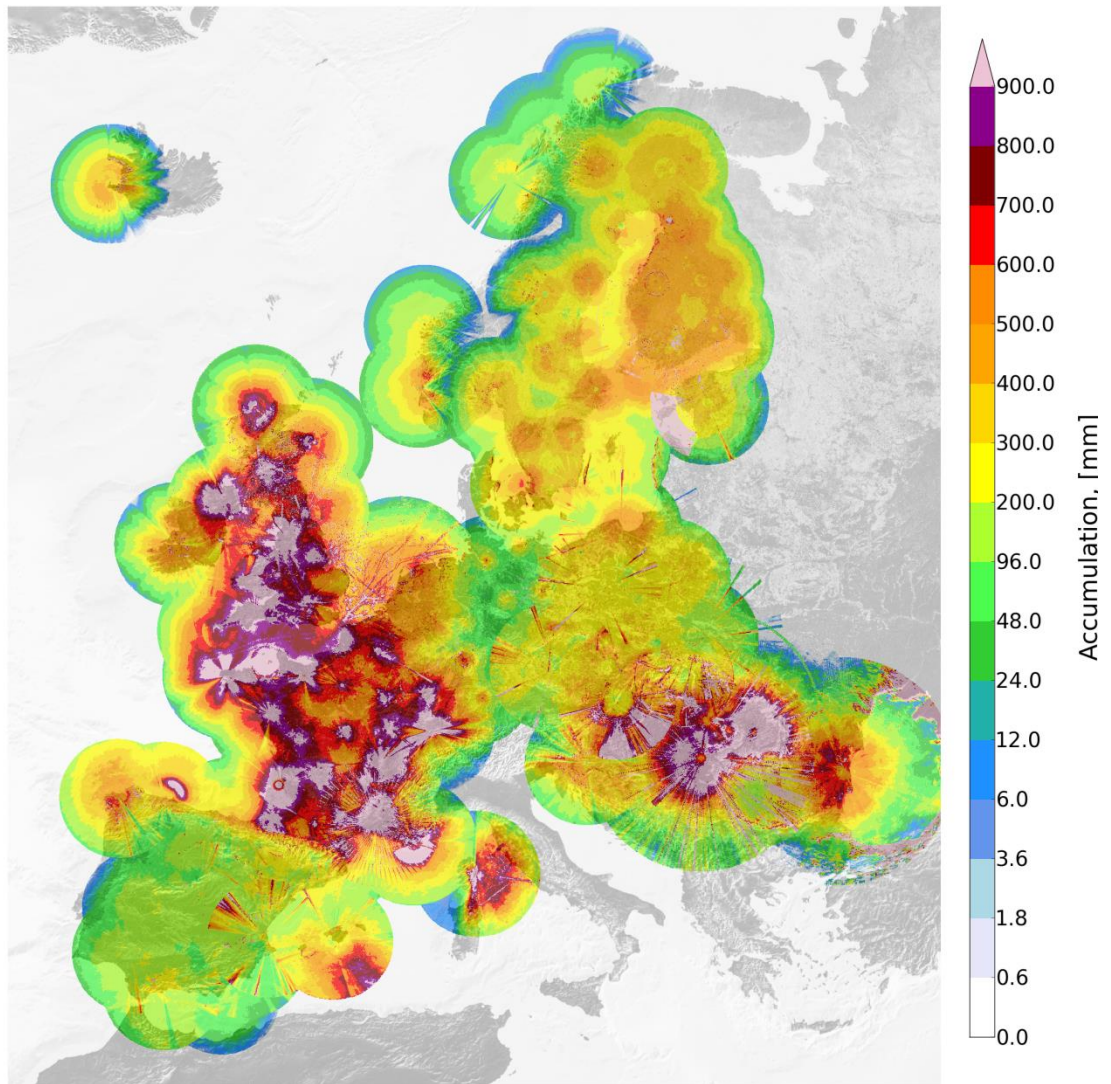OPERA radar network 01/01/2012 - 31/12/2012 in total 32593 files (93 %)

Fig.18: Rainfall accumulation for the period 01/01/2012-31/12/2012