Operations Plan 2017

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ESSL Research and Training Centre
Wiener Neustadt, Austria

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Contents

Introduction and goals

1.1 ESSL Testbed Concept

The ESSL Testbed evaluates tools to forecast and nowcast convective high-impact weather and provides forecaster training to meteorologists. Within the Testbed, occurrences of high-impact weather across Europe will be investigated during one or more annual test periods of a number of subsequent weeks.

The Testbed's concrete aims are...

1. to assess the ability of new diagnostic products based on satellite measurements, numerical weather prediction, radar and standard weather observations to correctly indentify (upcoming) severe weather events (e.g. via subjective and objective verification procedures).
2. to obtain feedback from forecasters regarding these products, both with respect to their performance and to operational needs and constraints. This feedback helps the product developers to refine and optimize them, thereby accelerating their successful operational deployment.
3. to familiarize the forecasters of the European National (Hydro-)meteorological Services with the best use of the new products.
4. to enhance the forecasters' overall skills in forecasting of convective high-impact weather, by providing training by internationally known forecasting experts who teach scientifically-motivated forecasting techniques. The training is performed through remote learning in cooperation with EUMETCAL and "hands on" at the ESSL Training Centre.

An overall aim in the Testbed is to ***stimulate interaction between and among developers and forecasters*** which benefits the forecasting and warning process at European National Meteorological Services. The participants therefore include the persons from the following groups:

- weather forecasters from forecasting agencies worldwide and especially from Europe's National (Hydro-)Meteorological Institutes
- researchers/developers from these agencies and from international organizations such as EUMETSAT
- renowned experts on forecasting techniques

The Testbed is loosely modelled after its US counterpart, the Hazardous Weather Testbed Spring Experiment, an annual programme in which several branches of the National Oceanographic and Atmospheric Administration (NOAA) cooperate, including the Storm Prediction Center (SPC) and the National Severe Storms Laboratory (NSSL).

1.2 Facilities

Fig 1. The ESSL Training Centre in Wiener Neustadt, Austria

The ESSL Testbed is located in the ESSL Training Center in Wiener Neustadt, a historical imperial city 45 km south of Vienna and 60 km southeast of the Vienna International Airport. The main train station of Wiener Neustadt with frequent trains to Vienna and other Central European Destinations is only 300 m away, thus within walking distance.

The Testbed Centre is housed on the first floor of an Art Deco Style house (Fig. 1) near the town center of Wiener Neustadt. The Testbed and briefing rooms are situated on 150 m² including the secretariat and break rooms.

Operations

2.1 Overview

The operations include the following three fundamental components:

1. **Forecasting**
2. **Verification**
3. **Evaluation**

Within the forecasting activities, participants operationally use the experimental forecast products to generate a forecast. After the period for which the forecast was valid has passed, they are verified against observations. Finally, the use of the experimental forecast products is evaluated. Below, these activities are described in more detail.

In addition, there are presentations by experts on a forecasting topic or developers of the nowcast and forecast products under evaluation.

Within each daily online session, remote participants will receive a briefing of the forecasting, verification and evaluation efforts and are asked to provide feedback and questions. Subsequently, the “lecture of the day” will be transmitted online.

The daily Testbed programme is shown in the Tables 2 and 3, below.

Programme on Mondays

On-site registration at the welcome desk starts at 09:00 local time.

Time (local, UTC)		Activity	Description
10:00	0800	**Welcome Presentation**	Presentation of organizational and local matters. Introduction round.
10:15	0815	**Introduction to the Testbed**	Presentation of the concept of the ESSL Testbed.
11:00	0900	**Introduction to forecasting**	Brief introduction to scientific and ingredients-based forecasting. Concepts of moisture, instability and lift. Importance of wind shear to the storm type.
12:30	1030	Lunch Break	
14:00	1200	**Introduction to forecast products with hands-on exercise**	Introduction to the products used and evaluated during the Testbed and to the data interface.
15:30	1330	**Forecast Operations**	Day 2 forecast. Experimental probabilistic convective forecast for day 2. In case of imminent severe weather: Nowcasting. Short-range forecast and issuance of experimental watch for 2 hours at 14 and 15 UTC.
17:00	1500	End	

At 18:00 local time an optional free guided city tour is offered. End: about 19:30 local time.

Programme Tuesday – Friday*

Time (local, UTC)		Activity	Description
09:00	0700	**Verification**	Subjective verification of yesterday's experimental convective forecasts compared to ESWD severe weather reports, satellite and radar data. On Tuesday, verification session is skipped and programme starts with forecast operations.
09:20	0720	**Forecast operations**	The participants will be split into two groups, each dealing with a particular forecast period. Street Room: Day 1 forecast Experimental probabilistic convective forecast for the present day. Mountain Room: Day 2 forecast Experimental probabilistic convective forecast for day 2.
Part of programme with remote participation			
11:00	0900	**Weather briefing**	Discussion of the current weather and the forecasts that were made. Subjective evaluation with remote participants: summarizing new insights, preliminary findings, and issues needing further examination.
followed by		**Expert presentation**	Presentation on forecasting by developers of forecast tools or forecasting experts.
12:30		Lunch break	
14:00	1200	**Forecast tool evaluation**	Participants jointly discuss forecast tool performance, answer questions by their respective developers
followed by….		**Forecast operations**	Street Room: Nowcasting Short-range forecast and issuance of experimental watches for 2 hours at 13, 14 and 15 UTC. Mountain Room: Day 3 - 5 forecast Experimental probabilistic convective forecast for day 3 - 5. After the finished day 3 - 5 forecast the team can also switch to nowcast-mode. If the weather situation is unusually calm, the programme for both teams will be altered: Studies of past severe weather situations, or severe weather forecasting training by an expert.
1730	1530	end	End of forecast operations.

* On Friday the programme ends at 13:00 after a final weather briefing and product evaluation session. On-site participants are asked not to leave before 13:00, as this seriously disturbs the programme. There is no expert presentation on Friday.

Experimental convective forecasts

On a daily basis, participants will prepare experimental forecasts for severe weather. These forecasts differ in time range, validity time period, domain, and quantities to be forecast. They range from Nowcasts, that have a validity time of two hours starting at the moment the forecasts issuance, to Day 5 forecasts, that deal with the weather occurring four days ahead. The forecasts will be issued using a program with which areas can designated in which a particular probability of severe weather or lightning is expected. In addition, a short(!) text to explain the motivation for the forecast should be given.

Type	Deadlines (UTC)	Validity (UTC)	Forecast type The percentages refer to the probability of one or more events within 40 km of a point	Domain
Nowcast	1300 (1500 CEST) 1400 (1600 CEST) 1500 (1700 CEST)	1300 – 1500 1400 – 1600 1500 – 1700	warning with indication of expected severe weather type	selected sub-domain
Day 1	0855 (1055 CEST)	0900 – 0600 (next day)	thunder 15 % thunder 50 % level 1 (> 5% severe) level 2 (> 15% severe) level 3 (> 15 % extreme)	selected sub-domain
Day 2	0800 (1000 CEST)	0600 (next day) – 0600 (day + 2)	thunder 15 % thunder 50 % level 1 (> 5% severe) level 2 (> 15% severe) level 3 (> 15 % extreme)	selected sub-domain
Day 3	0855 (1055 CEST), on Mondays: 1300 (1500 CEST)	0600 (day + 2) – 0600 (day + 3)	level 1 (> 5% severe) level 2 (> 15% severe) level 3 (> 15 % extreme)	Europe
Day 4		0600 (day + 3) – 0600 (day + 4)		Europe
Day 5		0600 (day + 4) – 0600 (day + 5)		Europe

Table 4. Forecasts at the testbed.

Weather permitting a mobile nowcasting team may be formed that will drive by car to the storms and makes nowcasts on the way at the regular schedule. Participants can freely choose to join the mobile nowcasting team or stay with the regular team at the Testbed site in Wiener Neustadt. The possibility of having a mobile nowcasting team shall enhance the learning experience and will be announced the day before.

The forecasts are issued at fixed times and deal with a particular forecast domain. In the case of the Day 3, Day 4, and Day 5 forecasts, the domain is Europe, whereas the Nowcasts and Day1 and Day 2 forecasts are issued for a sub-domain that is decided based on the pre-conceived likelihood of severe weather occurring within that sub-domain. The subdomains can be seen in Figure 2. An example of a forecast is given in Fig. 3.

Many of the predictands of the various forecasts relate to the probabilities of severe weather and extreme weather which for the ESSL Testbed are defined as in Table 5.

Severe weather	**Extremely severe weather**
• hail 2.0 cm or larger in diameter • wind gusts 25 m/s or higher • any tornado • rainfall causing significant damage	• hail with 5.0 cm diameter or larger • wind gusts 32 m/s or higher • tornado F2 or higher
The quantities to be forecast in the Day 1-5 forecasts are the probabilities that lightning / severe / extreme weather occurs within a radius of 40 km of any given point.	

Table 5. ESSL Testbed criteria for severe weather.

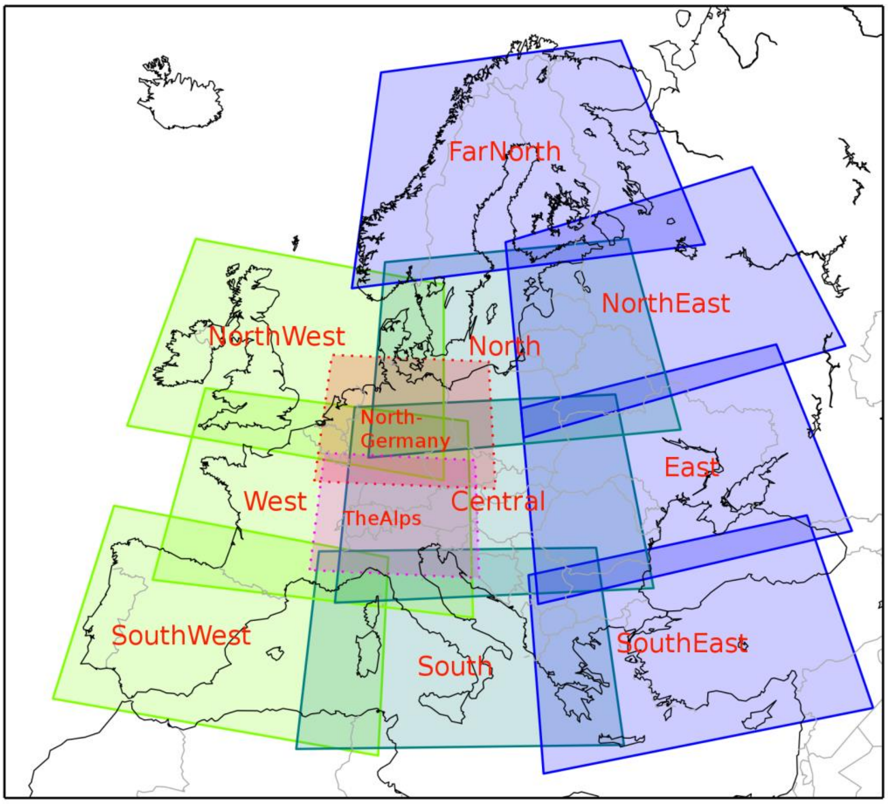


Fig. 2. The full ESSL Testbed domain (EU) and subdomains for which forecasts are to be made. The domains NorthGermany and Alps are to display COSMO and DWD nowcast products in detail; no forecasts or nowcasts are to be made for those domains.

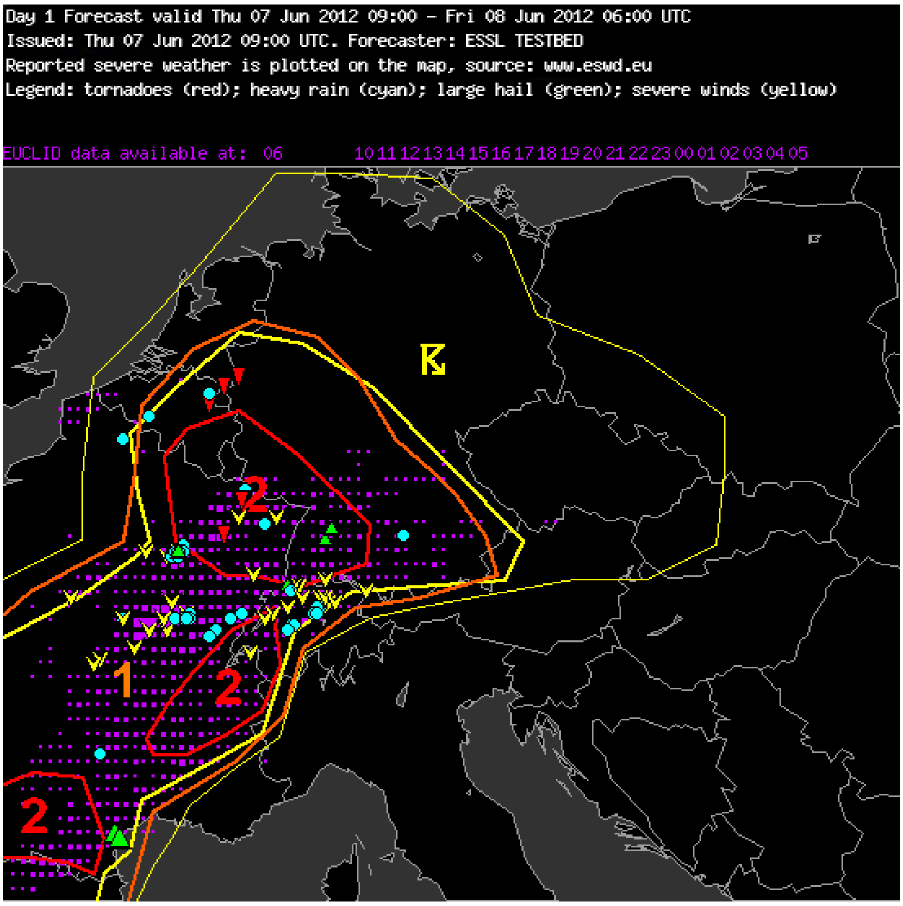


Fig. 3: Day 1 forecast map showing the areas drawn to depict low (15 – 50 %) thunderstorm probability (inside the thin yellow contour) and high (> 50%) thunderstorm probability (inside the thick yellow line), as well as a level 1 and 2 of severe weather threat (see the text and Tables 1 and 2 for definitions). The map also shows the data to verify the forecast, i.e. the observed severe weather reports from the European Severe Weather Database: heavy rain (blue circles), tornadoes (red triangles), yellow V's (severe wind > 25 m/s), and large (>= 2 cm) hail (green triangles), as well as lightning detected by the EUCLID network (purple).

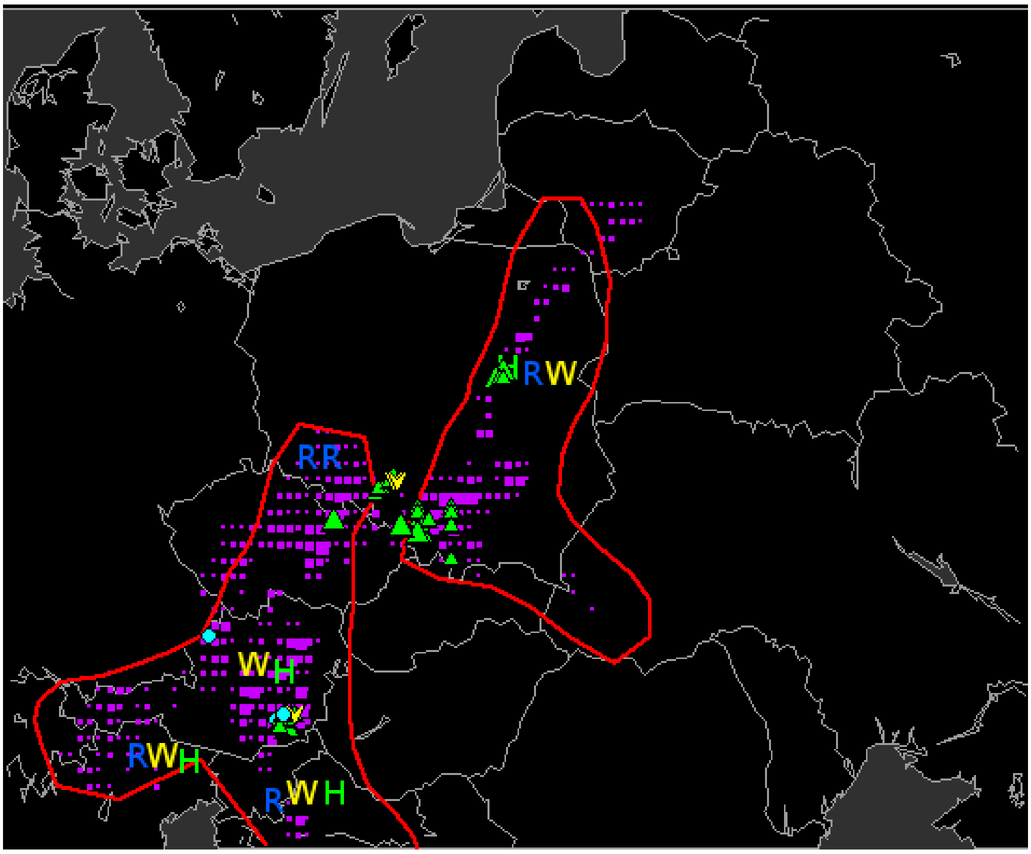


Fig. 4: Nowcast map with verification data. The map shows areas outlined by red contours within which thunderstorms are expected within the next two hours. The characters W, H, and R indicate that the main threat would be for wind, hail and extreme rainfall, respectively. The symbols, as in Fig. 3.a., denote the occurrence of such phenomena according to reports entered into the ESWD.

Nowcasts

During the afternoon session, starting at 14:45 local time, one or both of the Testbed teams will work on issuing severe weather warnings for smaller areas within the domain of the day. These are supposed to be warnings for severe weather issued two hours ahead of time.

Climatology

In case almost no convection is expected across the entire domain, the time slots for forecasting the current weather are used for studying historical cases, or for forecaster training sessions.

Fig 5. shows the coverage of high-impact weather during the Testbed period in previous years. The average number of monthly reports is approximately 1000. Considering that the domain covers the entire European continent (except for Islands and the extreme eastern parts), the weather is usually interesting enough somewhere over Europe.

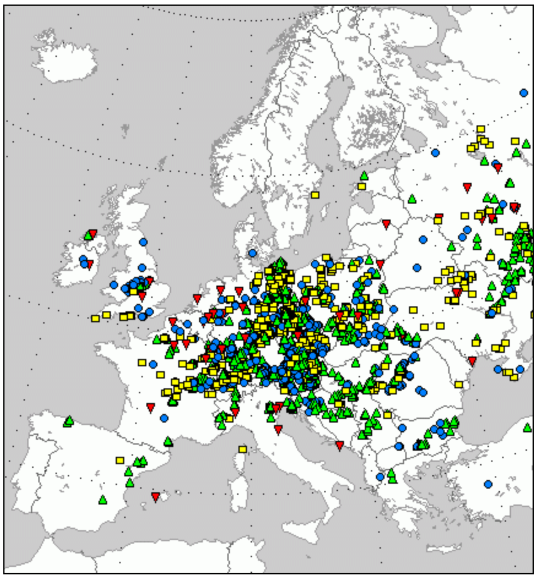


Fig. 5. Severe weather coverage during the Testbed period in 2012; yellow rectangles: severe wind gusts, red triangles: tornadoes, blue circles: flash floods, green triangles: large hail (source: ESWD, www.eswd.eu).

2.2 Forecast verification

During the *verification* slots, the forecasts will be verified subjectively against observed high-impact weather as collected in the European Severe Weather Database (ESSL) and against lightning data. Areas outside of the lightning detection network will be validated using satellite imagery as a proxy for the occurrence of convection. The outcome of the verification procedure is to establish how much forecast and observations differed and to identify possible causes. Such causes may be poor guidance by particular data, poor interpretation of the available data or other reasons.

2.3 Evaluation and reporting

In the evaluation sessions, the value of the individual products to the forecast will be assessed. These assessments result from discussions within the group of participants. At 14:00, typically, a plenary discussion will be held. In addition, participants are asked to report on the performance of a particular forecast-supporting product. There are three ways in which the feedback is collected:

Questionnaires

Questionnaires have been developed for each forecast-supporting product, in collaboration with the responsible researcher/developer. The answers given to these questions will be filled in during the evaluation session, at least once per group per week, but, preferably even more frequently. It is very important to document any feedback. The collected answers will be sent to the researcher/developer after the conclusion of the Testbed.

Testbed Blog

The Testbed blog is a web site (**www.essl.org/testbed/blog**) on which several texts with illustrations on the work at the Testbed will be posted on a daily basis, both by Testbed staff and participants. The posts discuss the forecasting, the products and their performance, as well as general impressions.

Direct communication with the developer

Almost every week some researchers/developers will be present at the Testbed. This gives the opportunity to directly interact, discuss and collect feedback on the forecast-supporting products.

2.4 Expert Presentations

The presentations 30 minutes in length (plus 15 minutes of question time) that will be disseminated online with support from EUMETCAL following the *Daily Briefing*, start approximately at 0930 UTC (1130 local time). The lecturers include experts on forecasting, modelling, remote-sensing or other relevant topics. They include scientists from European weather services and overseas, and from international organizations like EUMETSAT and ECMWF, as well as forecasters with a great expertise in the forecasting of convective high-impact weather. A list of speakers is available in **Appendix 2**. Since some changes occur, please visit the Testbed info page for the most current schedule: http://www.essl.org/testbed/info

2.5 Participation schedule

Testbed Groups

Participants to the Testbed consist of both forecasters and scientists/developers. Each Testbed week has up to 10 external participants, i.e. not including ESSL staff.

On-site and remote participation

It is recommended that participants first participate one week remotely, followed by a week on site at the ESSL Training Centre in Wiener Neustadt. All participants will, however, be able to take part in all online sessions. The online participation involves connecting to the Testbed through Saba Meeting teleconferencing system (provided by EUMETCAL) as well as participating in the Daily Briefing, and attending the *Lecture of the day.* These activities take place from 0900 UTC to approximately 1030 UTC. Participants of the first Testbed week will not have the possibility of prior remote participation, but are welcome to attend remotely later.

2.6 Standard tools at the Testbed

Testbed Data Interface

Data of all experimental products as well as conventional meteorological data are displayed through the Testbed Data Interface, which is a collection of intranet pages, that are accessed through a web browser: these pages include the *Multi-Model* and *Hi-Res Ensemble* pages that display output from several NWP models simultaneously, and the *Nowcast Display* page that allows the user to overlay several layers of satellite, radar, NWP, and observational data as well as various experimental products. For the 2016 Testbed, the data will be made available to remote participants through the internet and to the general public after the Testbed has ended. The web page to access is www.essl.org/testbed/data. Participants will receive a valid username and password to gain access from their home institution for the duration of the Testbed.

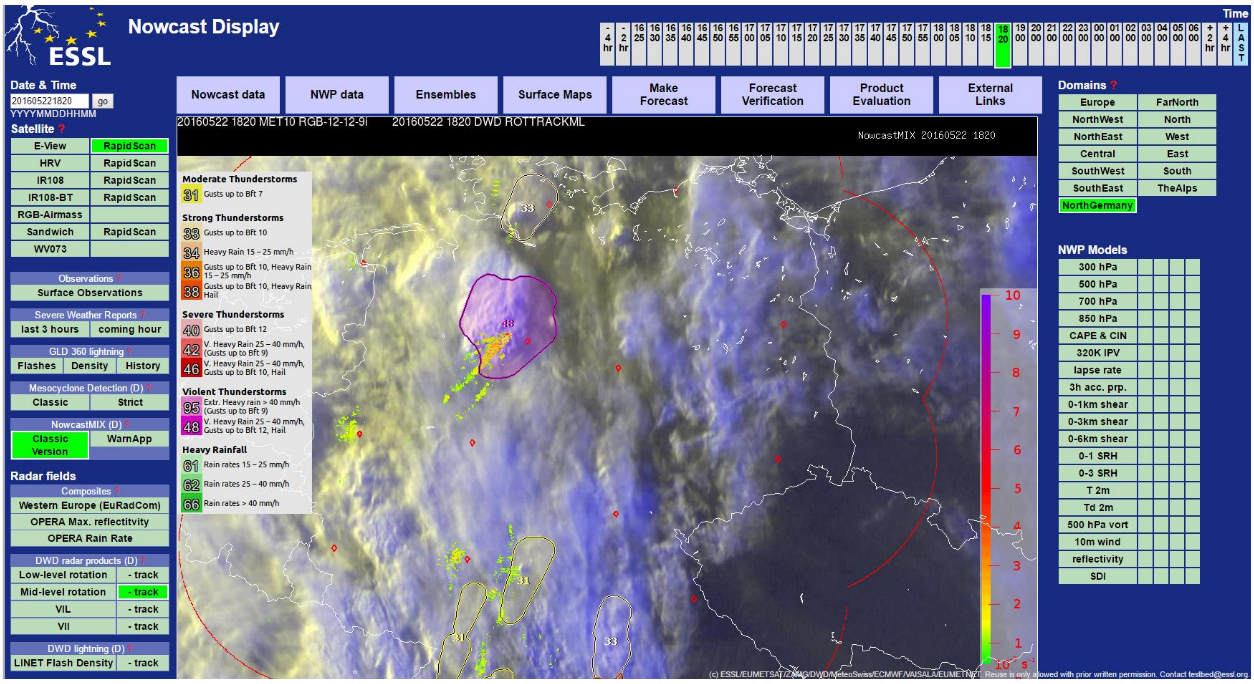


Fig. 6. Nowcast Display

Testbed Participant Page

On a dedicated web page, background information on the experimental products and techniques, beyond the information contained in this Operations Plan is gathered. The web page to access is www.essl.org/testbed/info.

Workstations and printing

ESSL's Research and Training Centre is equipped with 4 (and one spare) workstations that the participants will use to access the Testbed Data Interface. One of the pages of the Testbed Data Interface provides maps of surface observations, that can be printed in A3 format and analysed using provided colour pencils.

Available Standard Meteorological Data

In addition to the experimental products described in the following sections, the following "standard meteorological data" is available through the Testbed Data Interface:

2.6.1.1 NWP

Global:

- ECWMF IFS, provided by ZAMG
- GFS (source: NCEP)
- ICON-EU-EPS*

Regional:

- ICON-EU* (source: DWD)

Convection-permitting

- COSMO-DE* (source: DWD)

Convection-permitting-ensembles

- COSMO-DE-EPS* (source: DWD)

2.6.1.2 Satellite

From Meteosat 9 (available every 15 minutes):

- E-View, High Resolution Visible, IR-10.8, IR-10.8 (color enhanced), Airmass-RGB, WV-7.3

From Meteosat 8 RapidScan service (available every 5 minutes):

- E-View, High Resolution Visible, IR-10.8, IR-10.8 (color enhanced)

From these products, a “Sandwich Product” is created, both from Meteosat 9 and from MeteoSat8 RapidScan data.

- The majority of NOWCAST-SAF products*

Radar imagery

- The European radar composite OPERA is made available by ZAMG through an agreement with EUMETNET
- The West-European radar composite EuRadCom is provided by DWD

Observations

- Severe weather observations are available from the European Severe Weather Database.
- SYNOP and METAR surface observations of Europe
- Radiosonde data are available on the internet through the University of Wyoming and the University of Oklahoma

Lightning data

- The GLD360 product by VAISALA
- LINET lightning density product by DWD*

* part of the evaluation programme

3. Forecast-supporting products

A wide range of tools that support the forecaster in early operational or pre-operational stage (Forecast-Supporting Products) are evaluated at the ESSL Testbed. For example, new versions or configurations of numerical weather prediction models, new techniques to extract information from satellite, radar and other remote sensing data. This includes new visualizations and ways to combine different types of meteorological data relevant to the prediction of high-impact weather. The products up for evaluation are listed in Table 2, and described in the sections that follow.

Forecast-supporting Product	Developer	Description
3.1 NWC-SAF products	NWC-SAF	The Nowcast Satellite Application Facility (NWC-SAF) produces a range of products. A cursory evaluation of all products is scheduled, as well as an in-depth evaluation of the products “Convective Initation”, “Rapidly Developing Thunderstorm”, “High-Resolution Winds”, “Instability” and “Precipitable Water”
3.2 Mesocyclone Detection Algorithm	DWD	Radar-based algorithm to detect and assign severity levels to mesocyclones, based on Doppler velocity data from radars in the German national radar network
3.3 VIL (-Track)	DWD	Radar-derived vertically integrated liquid product.
3.4 VII (-Track)	DWD	Radar-derived vertically integrated ice product.
3.5 Rotation (-Track)	DWD	Doppler-radar-derived shear/rotation at several levels, and corresponding tracks.
3.6 Lightning density	DWD	LINET lightning density product
3.7 NowCastMIX	DWD	Grid-based system combining nowcast data from multiple sources using fuzzy logic
3.8 COSMO-DE and COSMO-DE-EPS (experimental setup)	DWD	COSMO-DE: Convection-permitting model for Germany and (wide) surroundings. COSMO-DE-EPS: Convection-permitting 20-member ensemble for Germany and (wide) surroundings. Both are Run 8 times a day out to 27 hours, and once per day out to 48 hours at 03 UTC. A number of new products for the assessment of severe potential have been added.
3.9 ICON-EU-EPS	DWD	DWD’s ensemble forecast system

Table 6. Forecast-supporting products.

3.1 EUMETSAT NWC SAF
Support to Nowcasting and Very Short Range Forecasting

NWC SAF consortium:

The key objective of the NWC SAF is to provide to National Meteorological Services, Scientific Institutions and in general meteorological users from EUMETSAT member states and worldwide, with an advanced, robust and reliable system to support both operational and research activities in Nowcasting and Very Short Range Forecasting, by means of:

- The production and provision of a software application for the near real time generation of a set of meteorological products to support Nowcasting activities, and
- The provision of support services to final users to allow the maximum exploitation and benefit of the software application and the transfer of knowledge from the NWC SAF consortium to its users.

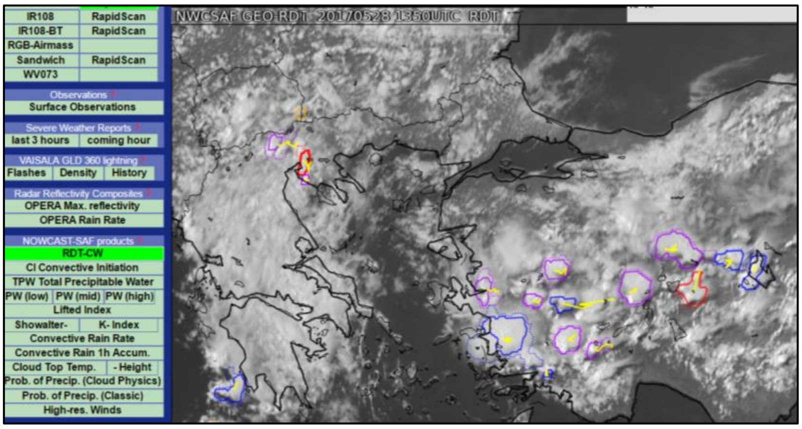
Products

NWC SAF offers a variety of products that are of potential interest for Nowcasting and Very Short Range Forecasting of severe convective storms. All products are explained in detail on the NWC SAF webpage:

http://www.nwcsaf.org/

The ESSL Testbed display provides integrated visualizations of most of these products from the geostationary orbit (NWC/GEO) with special focus on the products of main interest for deep convection. While we refer you to the NWC SAF webpage for detailed descriptions, we only present example screenshots of the Testbed displays together with very basic descriptions in this Operations Plan for the purpose of a quick overview.

RDT-CW: Rapid Developing Thunderstorms



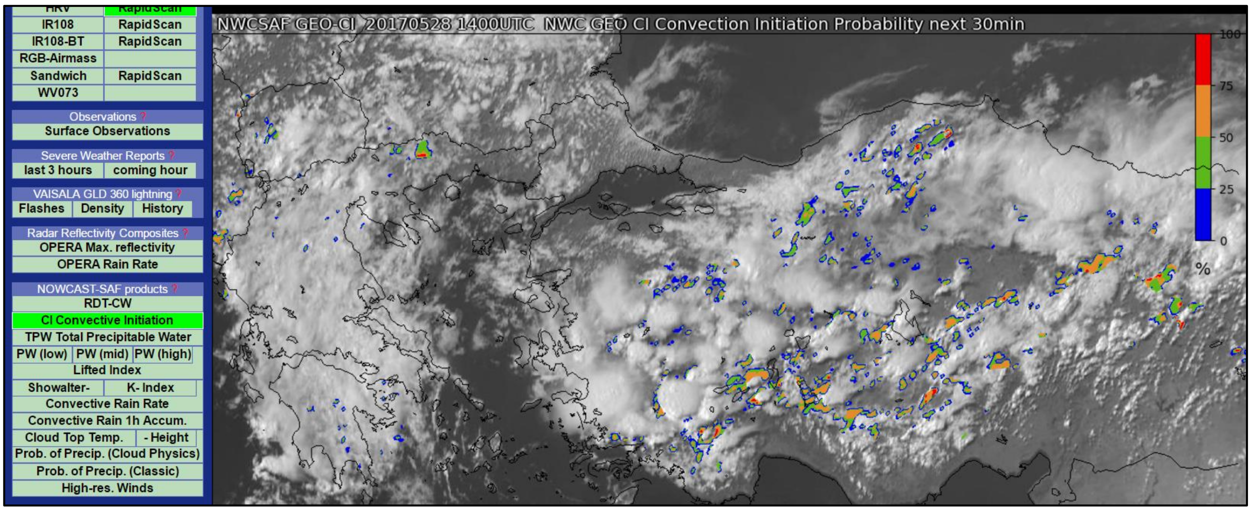
The product has been developed by Meteo-France in the framework of the EUMETSAT SAF in support to Nowcasting. Using mainly geostationary satellite data, it provides information on clouds related to significant convective systems, from meso-alpha scale (200 to 2000 km) down to smaller scales (few pixels).

The objectives of RDT-CW are:

- The identification, monitoring and tracking of intense convective system clouds
- The detection of rapidly developing convective cells
- The forecast of the convective cells

The object-oriented approach underlying the RDT product allows to add value to the satellite image by characterizing convective, spatially consistent, entities through various parameters of interest to the forecaster: motion vector, cooling and expansion rate, cloud top height … and their time series. It supports easy and meaningful downstream data fusion (surface observations, NWP fields, radar data...).

CI: Convective Initiation



The product has been developed by Meteo-France in the framework of the EUMETSAT SAF in support to Nowcasting. Using mainly geostationnary satellite data, it provides the probability for a cloudy pixel to become a thunderstorm in a given following period range. The product aims to catch the first steps of initiation of convection, when the first convective signs occur after the formation of clouds, or when those signs appear revealing a modification of environmental conditions.

Probability of the formation of a thunderstorm depends on evolution of local condition and on advection of clouds. For this second point, CI is unfortunately too scarce for a full object-approach that allows a good following of meteorological systems. CI is a pixel product. The process follows:

- The detection of cloud systems
- The tracking of cloud systems
- The discrimination of convective cloud objects
- The advection of convective cloud objects

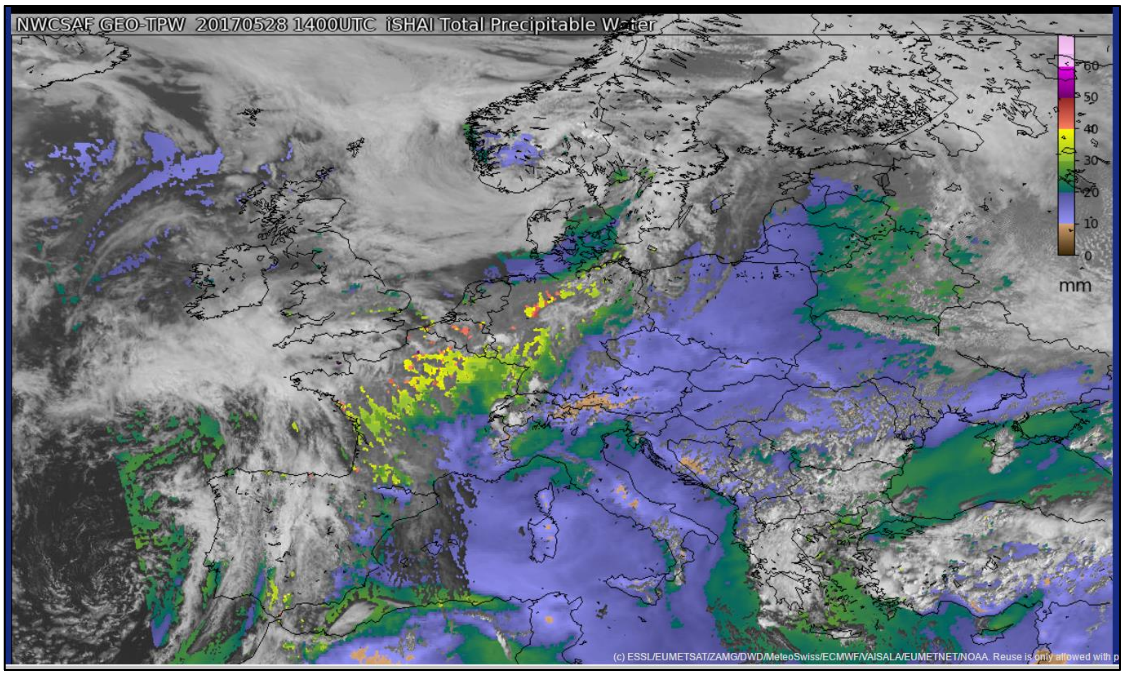
iSHAI products:

The GEO-iSHAI version 3.0 products aim to provide information about water vapour and instability distributions on clear air pixels using as main inputs MSG SEVIRI infrared channels and NWP fields. Products are generated at high spatial and temporal resolution to support real time meteorological applications. The iSHAI algorithm is a combination of one statistical and one optimal estimation algorithm and it has two main steps:

- In the first step, the iSHAI First Guess profile is built using a set of non-linear regressions from collocated background NWP temperature and humidity profiles and bias corrected SEVIRI BTs (brightness temperatures).
- In the second step, a physical retrieval algorithm (optimal estimation) is applied.

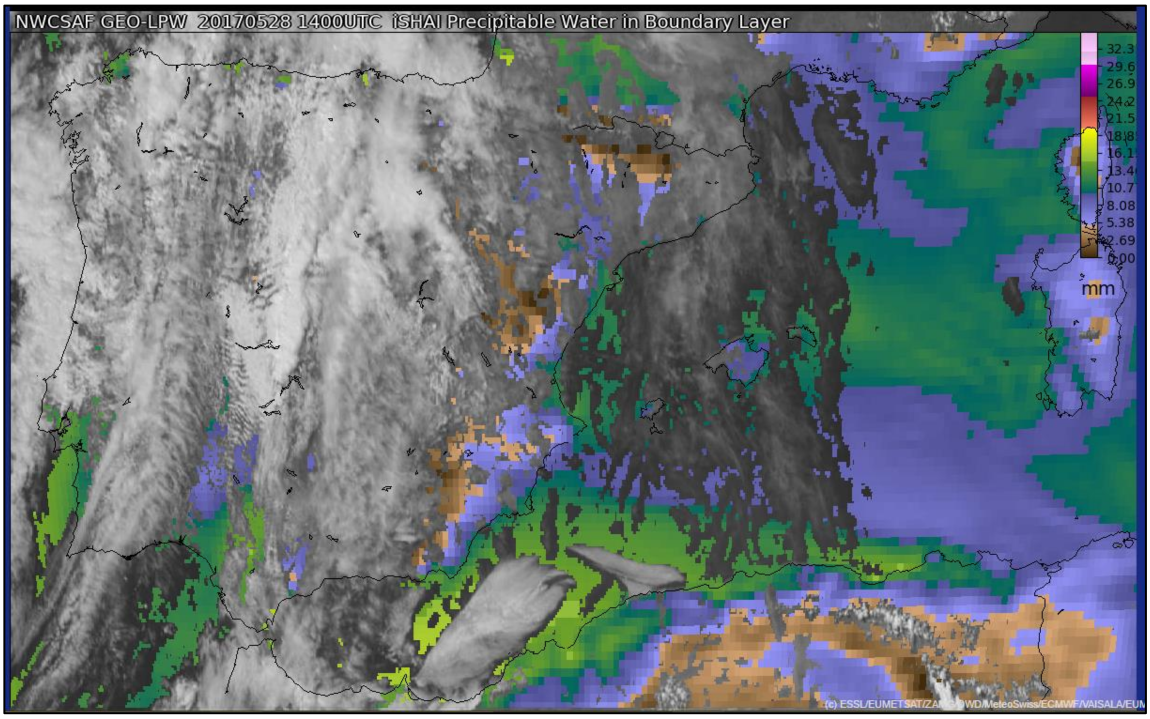
The following iSHAI products are available at the ESSL Testbed: TPW, Layer PW (low, medium, high), Satellite Humidity and Instability Stability Analysis Imagery (Lifted Index, K Index, Showalter Index).

TPW: Total Precipitable Water



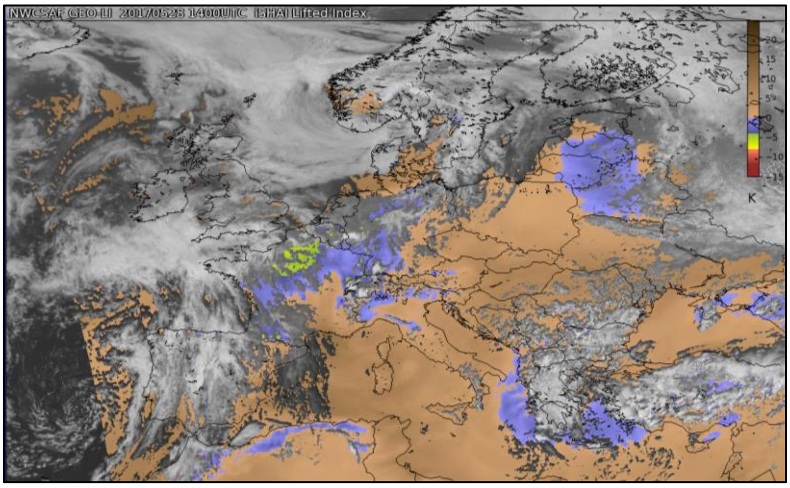
Example of TPW output.

PW (layer): Layer Precipitable Water (low, mid, high)



Example of PW (low) output.

Lifted Index, Showalter-Index, K-Index



Example of iSHAI output (Lifted Index)

Convective Rain Rate and Convective Rain 1h Accumulation

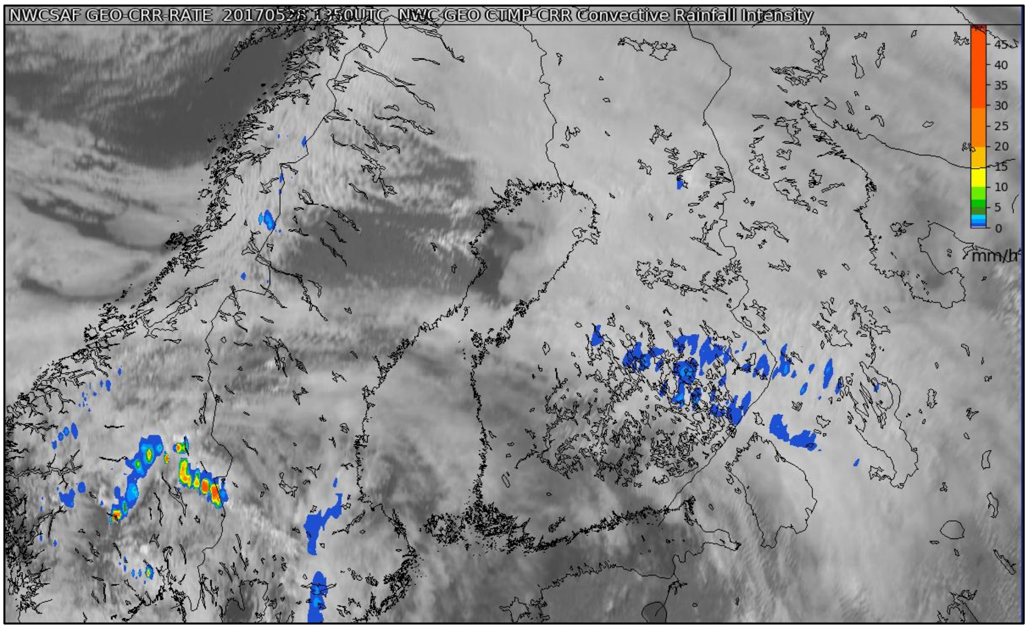
The objective of the CRR product is to estimate the precipitation rate associated to convective clouds. This product provides to forecasters complementary information to other NWC SAF products related to rain and convection monitoring as Precipitating clouds and Cloud type.

The algorithm assumes that clouds being both high and with large vertical extent are more likely to be raining, so that R = f(IR,VIS), being R the rainfall intensity expressed in mm/h. By other side, the IR-WV brightness temperature difference is a useful parameter for extracting deep convective clouds with heavy rainfall. The basic CRR mm/h value for each pixel is obtained from calibration functions. Calibration analytical functions are generated by combining SEVIRI and Radar data.

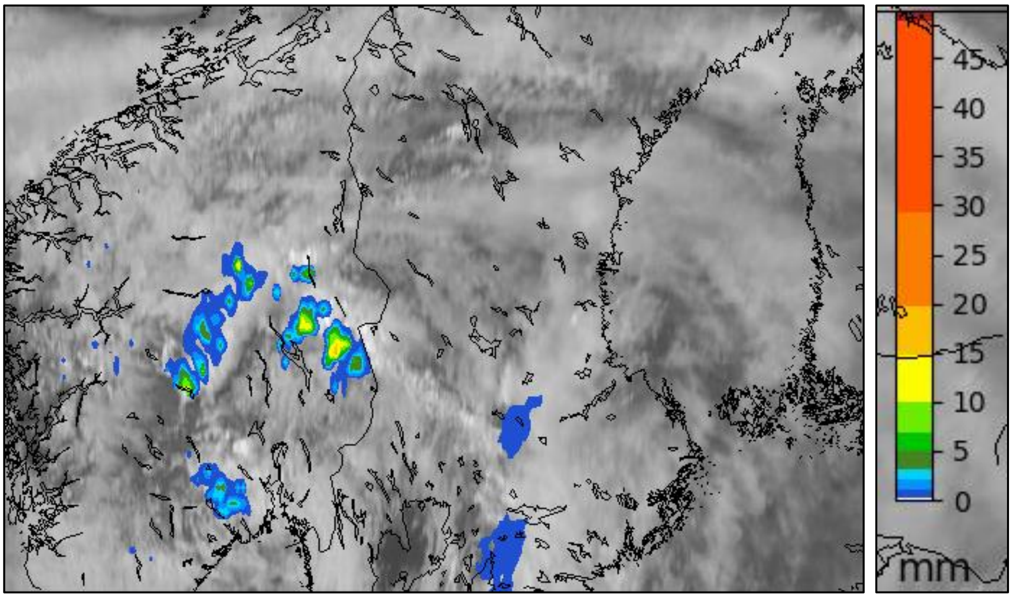
The calibration method, based on Rainsat techniques, tries to establish a statistical relationship between VIS reflectances, IR and WV temperatures and the rainfall rates derived from radar data. In summary, a composite radar data were compared pixel by pixel with a geographically matched MSG data in the same resolution and the total rain rate were calculated as a function of the two or three variables (IR brightness temperatures, IR-WV brightness temperature differences and normalised VIS reflectances). The radar data are used only for training the system and are not used directly as part of the output product.

In a second phase, a filtering process is performed in order to eliminate stratiform rain data which are not associated with convective clouds: the obtained basic CRR data are set to zero if all the nearest pixels in a grid of selected semisize (def. value: 3pix) centred on the pixel do not have an equal or higher value than a selected threshold (def. value: 3mm/h).

To take into account the temporal and spatial variability of the cloud tops, the amount of moisture available to produce rain and the influence of orographic effects on the precipitation distribution, several correction factors can be applied to the basic CRR value by the users. So that the possible correction factors are the moisture correction, the cloud top growth/decaying rates or evolution correction, the cloud top temperature gradient correction and the orographic correction.

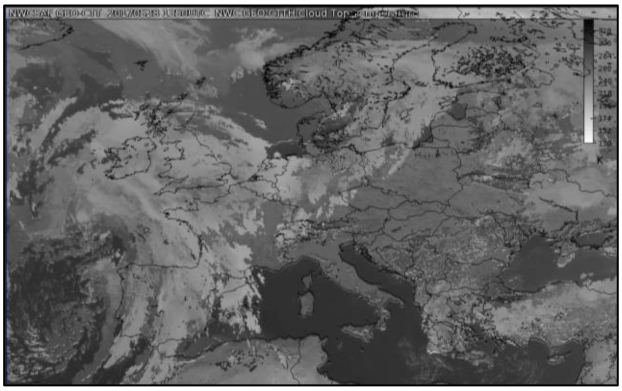


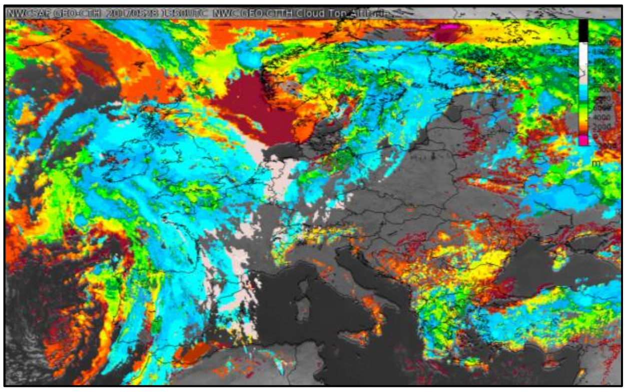
Convective Rain Rate Example



Convective Rain 1h Accumulation Example

Cloud Top Temperature and Height





This product contributes to the analysis and early warning of thunderstorm development. Other applications include the cloud top height assignment for aviation forecast activities. The product may also serve as input to mesoscale models or to other SAF NWC product generation elements. The CTTH product contains information on the cloud top temperature and height for all pixels identified as cloudy in the satellite scene.

RTTOV radiative transfer model is applied using NWP temperature and humidity vertical profile to simulate 6.2µm, 7.3µm, 13.4µm, 10.8µm, and 12.0µm cloud free and overcast (clouds successively on each RTTOV vertical pressure levels) radiances and brightness temperatures. This process is performed in each segment of the image (the size of the segment is defined by the user, the default value being 4*4 satellite IR pixels). The vertical profiles used are temporally interpolated to the exact slot time using the two nearest in time NWP fields input by the user. The techniques used to retrieve the cloud top pressure depend on the cloud's type

PoP: Probability of Precipitation (Cloud Physics)

PoP is defined as the instantaneous probability that a rain rate greater than or equal to 0.2 mm/h occurs at the pixel level. The PoP estimation is done using information on the cloud top microphysical properties, Effective Radius (Reff) and Cloud Optical Thickness (COT). The main limitation of this product is that only provides results during daytime. Using Reff and COT the Cloud Water Path (CWP) is computed. CWP means Liquid Water Path for water clouds and Ice Water Path of ice clouds. This parameter is computed using the following equation:

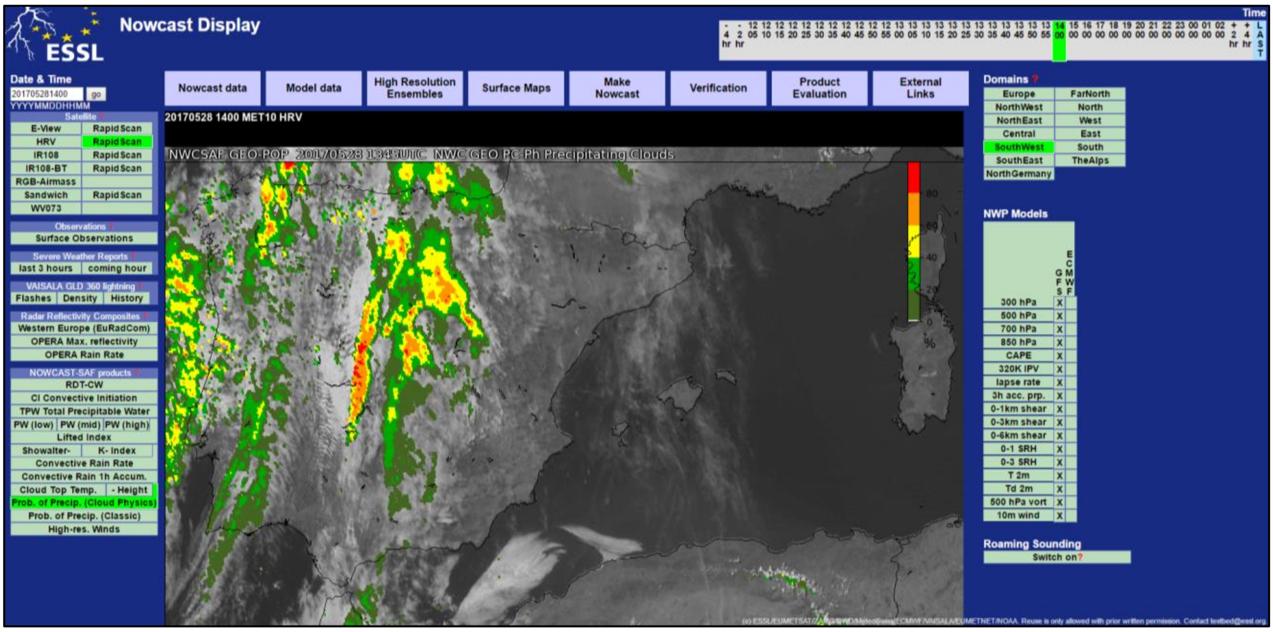
$$CWP = \frac{2}{3} * R_{eff} * COT$$

For the retrieval of the probability of precipitation, the Cloud Water Path (CWP) is used. The following relation between CWP and PoP has been obtained in order to assign a PoP to each satellite pixel:

$$RR = 2.0 * \exp\left(6 * 10^{-4}\left(CWP + 400.0\right)\right) - 3.02$$

Where PoP is the Probability of Precipitation occurrence (%) and CWP is the Cloud Water Path (gm-2).

Since the parameters used by this algorithm have a high dependence on illumination conditions, a study has been carried out in this sense. This study concluded that illumination conditions don't affect the quality of PC-Ph product. For a better PoP area location a parallax correction can be applied to this product. This option is chosen by the user through the product model configuration file and it is applied by default. When the Parallax Correction is working, a spatial shift is applied to every pixel with PoP greater than 0%.



PoP (cloud physics) example output in the ESSL Testbed Nowcast Display

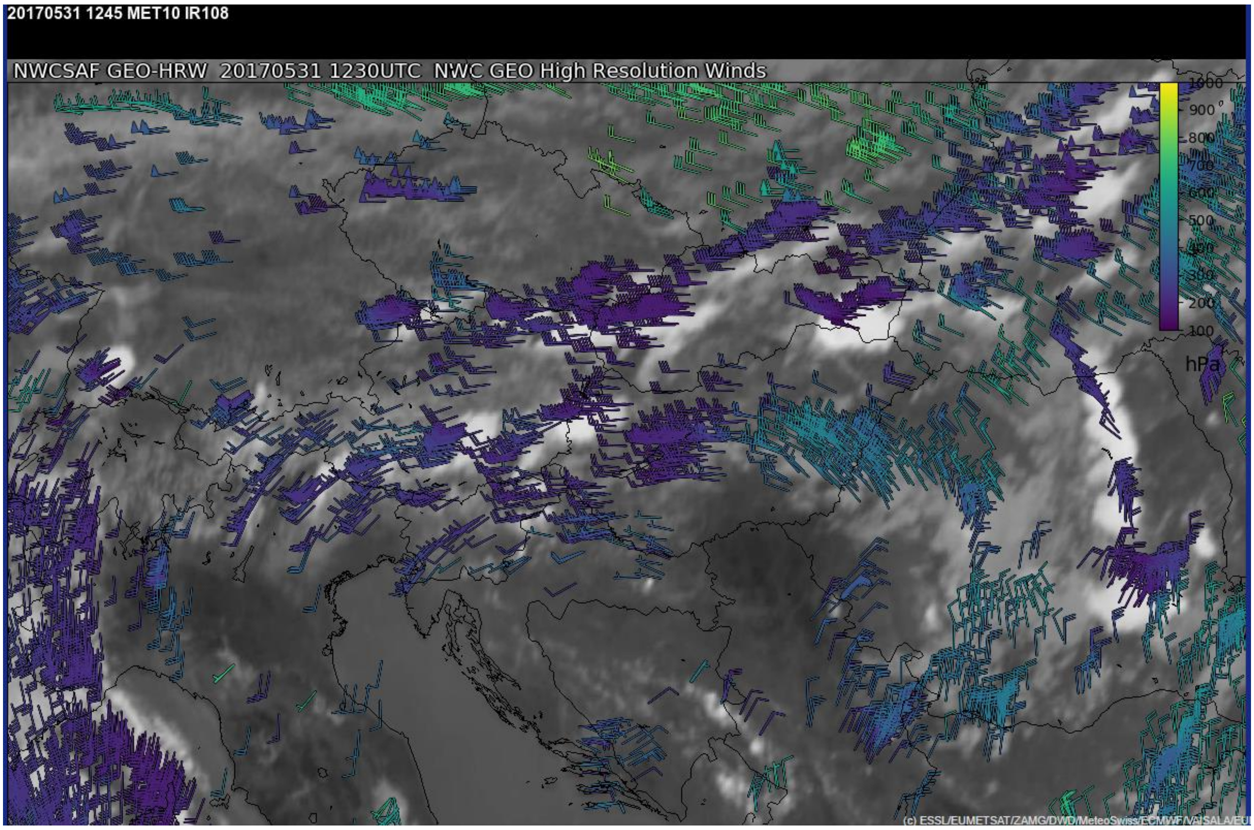
Probability of Precipitation (Classic)

In the same visualization the classic PoP product is made available:

The focus is on the delineation of non-precipitating and precipitating clouds and not on quantifying precipitation amount. Particular attention will be given to also identifying areas of light frontal precipitation. The product provides probability results for precipitation occurrence. It is not intended to provide information on the type of precipitation.

The precipitating clouds product gives the likelihood of precipitation. A linear combination of those spectral features, which have the highest correlation with precipitation, is used to construct a Precipitation index PI. For each value of the PI, the probability of precipitation in the respective classes is then determined from a comprehensive dataset of collocated satellite data, precipitation rates from surface radar and surface temperatures from NWP. Special attention has been given to spectral features in the visible, which implicitly contain information on cloud microphysical properties at the cloud top, such as optical thickness, effective radius and cloud phase. The algorithm to retrieve information on the presence of precipitation is based on the Cloud Type output. The algorithm relies much on the microphysical information available in both the 1.6 micron and 3.9 micron channels. For each algorithm a day and a night version exists.

High-res. Winds



NWC/GEO-HRW algorithm aims to provide detailed sets of Winds (Atmospheric Motion Vectors, AMVs) and Trajectories from up to seven MSG satellite series channels (HRVIS, VIS06, VIS08, IR108, IR120, WV062 and WV073), or from up to three GOES-N satellite series channels (VIS07, IR107 and WV065). These AMVs and Trajectories are calculated through the displacement of cloudiness features in successive images from all these channels, and of humidity features in successive images from the water vapour channels.

The AMVs and Trajectories can be calculated 24 hours a day, considering both "Nominal scan mode" conditions and "Rapid scan mode" conditions. The product includes pressure level information and a quality control flagging, giving some indication of its error in probabilistic terms. It has been developed by AEMET (the Spanish National Weather Service) in the framework of the EUMETSAT Satellite Application Facility on support to Nowcasting and Very short range forecasting (NWC SAF).

The AMVs and Trajectories can be calculated for up to two different scales at the same time: "Basic scale" and "Detailed scale". The corresponding dimension of the tracers to be tracked can be defined by the user, with a default value of 24 pixels for the "Basic scale". Many other processing parameters can also be configured, in particular the region and the MSG or GOES-N satellite channels to be processed for the AMV calculation.

This product can be useful in near real time applications including:

Nowcasting: Watch and warning of dangerous strong wind situations; Monitoring of the general flow, of convergence and divergence at low and high levels, or of small scale circulation and wind singularities.

Forecasting applications: Assimilation of HRW outputs in NWP models, or in applications where the real displacement of atmospheric structures is needed.

Detailed Information for all products

In the ESSL Testbed display for each product a direct link to the respective explanation page of the NWC SAF webpage is provided, that allows you to quickly access background information of the single products. A link “NowcastSAF Information” will lead you to these explanatory pages.

3.2 Mesocyclone Detection Algorithm

Thomas Hengstebeck (DWD)

Data basis

In the 5 min scan strategy of the DWD radar network 10 sweeps corresponding to 10 elevations ranging from 0.5° to 25° build up a 3D-volume for each radar site. The quality controlled basic data of this volume scan are provided as input for the MDA (Hengstebeck et al., 2011). The quality control includes the removal of spoke and ring artefacts, a clutter removal (static and dynamic clutter), an attenuation correction, the interpolation of “holes” within the reflectivity data and a speckle remover. A dual-PRF unfolding error correction is applied to the radial velocity data. The MDA uses the radial wind (Doppler wind) information of a volume as detection basis. The further classification of a detected mesocyclone, i.e. the severity estimation, is based on both radial wind and reflectivity information. A detected mesocyclone cell is assigned a time stamp corresponding to the time of the scan begin, the so-called reference time, which is 0, 5, 10, 15, etc. min after the full hour. The scanning of all 10 sweeps of the volume scan takes ca. 4.5 min.

Description of Algorithm

General remarks

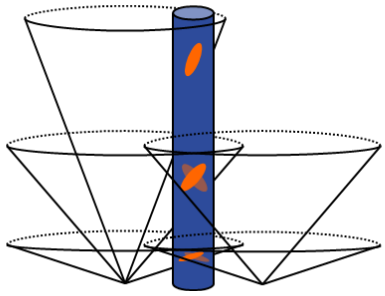
A mesocyclone (often found in connection with the updraft in supercells) is an atmospheric vortex field, which can be described by a so-called “Rankine Combined Vortex“-model (Zrnic et al., 1985). Here, one distinguishes between an outer and inner region of rotation. In the outer region, the rotation smoothly merges into the overall wind field. However, the inner region is characterized by rigid rotation and shows constant and high values of azimuthal shear. This region of high azimuthal shear – in the Doppler wind data visible as central part of the typical rotation dipole - is the signature that is searched for by the automatic mesocyclone detection algorithm. The algorithm follows the approach described in (Zrnic et al., 1985).

Pattern Vectors and Features

A so-called "pattern vector"-method is used for identifying regions of high azimuthal shear, i.e. in each radial wind sweep one tries to find contiguous azimuthal sequences of pixels with high azimuthal shear. The found pattern vectors are filtered with respect to the values of azimuthal shear and specific angular momentum and are grouped to so-called features (spatially correlated pattern vectors). The features are filtered according to symmetry criteria: Since a feature ideally resembles a complete rotation signature, it should have roughly equal extensions in range and azimuth directions. The "pattern vector-feature"-search is performed for each sweep of each volume (all radar stations) yielding a list of geo-referenced features (i.e. features with latitude / longitude coordinate pairs).

Mesocyclone-Objects

Within the above described list vertically aligned features, i.e. features with similar latitude / longitude coordinates, are searched for. A group of such features resembles a so-called mesocyclone-object (see Figure), which is classified as mesocyclone-cell with related severity level after validation. (In NinJo an upside down triangle symbol with color coding of severity index is visualized).



A vertically aligned group of geo-referenced features (orange patches) forms a mesocyclone object (depicted as blue cylinder).

Properties of the region of the detected mesocyclonic rotation like mean / max. reflectivity, cell-based VIL (vertically integrated liquid water), VIL density, height of lowermost detected rotation signature over ground, total height of rotational column and echo top height as well as max. rotational shear, max specific angular momentum and max. rotational velocity are calculated.

The severity level is determined by applying thresholds to these cell-characteristics (also called attributes). The thresholds given in table A1 are used, which put emphasize on the geometry of detection and the strength of the rotation. Basic thresholds on reflectivity related attributes are used as well. The thresholds for severity level 3 approximately follow the guide values given in the online resource “Radar Signatures for Severe Convective Weather” (see last entry in literature list).

The severity levels 1-5 imply mesocyclonic rotation with increasing strength and clearness. Severity-level 1 rather serves for test / tuning purposes, but may also give hints to early stages of rotation. The latitude / longitude-coordinate-pair of the mesocyclone-cell is determined as shear weighted mean of the lowest 3 km of the mesocyclone object.

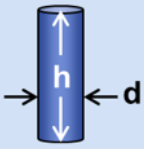
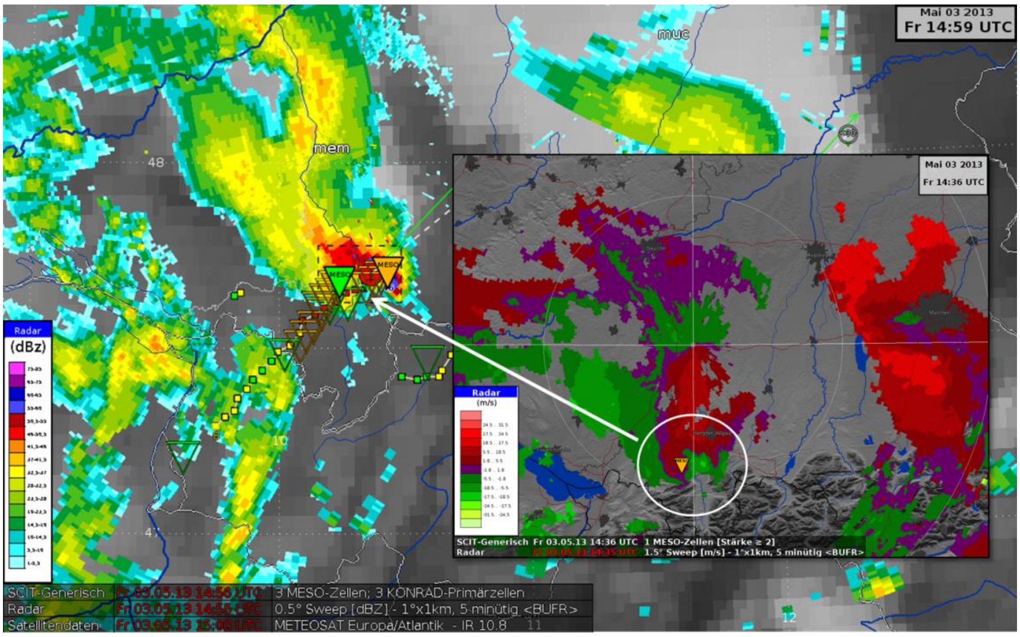
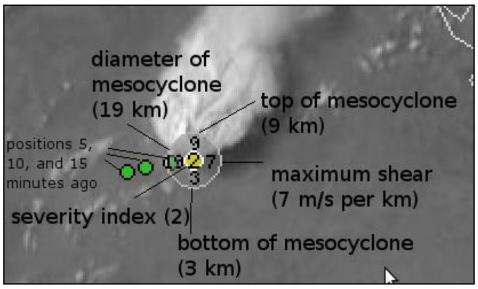
Mesocyclone Cell Attributes			Severity-Level				
			1	2	3	4	5
Reflectivity	*Max. Reflectivity [dBZ]*	≥	10				
	Avg. Reflectivity [dBZ]	≥	10				
	VIL [kg m^{-2}]	>	0				
	Echo Top Height [km]	>	2				
	VIL Density [g cm^{-3}]	>	1				
Geometry of detection 	*No. of features*	≥	1	1	2	2	2
	Height agl [km]	≤	5				
	Diameter d [km]	≥	3	3	5	5	5
	Meso-Height h [km]	>	1	2	3	6	8
Rotational Strength	*Rotational velocity [m/s]*	>	10 ⊗	12 ⊗	15 ⊗	20 ⊗	25 ⊗
	Max. Shear [m/s / km]	>	5	7	10	20	30
	*Max. Mom. [m/s * km]*	>	0				

Table A1: Strict thresholds for severity estimation. The "or"-symbol (⊗) in the rotational strength thresholds has the following meaning: E.g. for severity level 3 values of max. shear or rotational velocity must exceed the given thresholds of 15 m/s and 10 m/s/km, respectively.



Example of mesocyclone detections visualised by means of the NinJo workstation system at DWD. This weather case is addressed in the next two sections as well (VIL and rotation products).

For the ESSL Testbed, the algorithm has been integrated into the Nowcast Display. The figure explains which parameters are shown. Since the 2015 ESSL Testbed a further attribute has been added on top of the “top of mesocyclone” number. Here, the maximum rotational velocity is shown.



Visualisation of a mesocyclone detection in the Testbed Nowcast Display. On top of the “top of mesocyclone” a further number – the maximum rotational velocity - is displayed in the Nowcast Display since 2015.

In the Mesocyclone Detection menu of the Nowcast Display the user can choose between the options “All” (show all mesocyclone detections), “Intensity ≥ 2” (show detections with severity ≥ 2) and “Features ≥ 2“ (show detections where at least 2 features were detected). Choosing the last option will supress weak detections relying on just a single feature.

References:

Hengstebeck, T., D. Heizenreder, P. Joe and P. Lang (2011): The Mesocyclone Detection Algorithm of DWD, 6th European Conference on Severe Storms, 3-7 October 2011, Palma de Mallorca, Spain.

*Zrnic, D.S., D.W. Burgess and L.D. Hennington (1985): Automatic Detection of Mesocyclonic Shear with Doppler Radar, J. Atmos. Oceanic Technol., **2**, 425–438.*

Bureau of Meteorology, Commonwealth of Australia 2010: Radar Signatures for Severe Convective Weather,
URL: http://ftp.comet.ucar.edu/msanchez/W_modulos/radar/severe_signatures/print_supercell.htm

3.3 Vertically integrated liquid water (VIL) and VIL-Track

Thomas Hengstebeck (DWD)

Data basis

The quality controlled 3D-reflectivity data are used as input (see section 3.1).

Description of Algorithm

For the VIL calculation the following formula is used (Greene et al., 1972):

$VIL = \Sigma_i\ 3.44 \times 10^{-6}\ [(Z_i + Z_{i+1})/2]^{4/7}\ \Delta h_i$

Here, the sum is carried out over different height layers. Z_i and Z_{i+1} are the reflectivity at the bottom and top of the i-th layer with the thickness Δh_i. The units are as follows:

$[Z] = mm^6/m^3$

$[\Delta h] = m$

$[VIL] = kg/m^2$ or mm

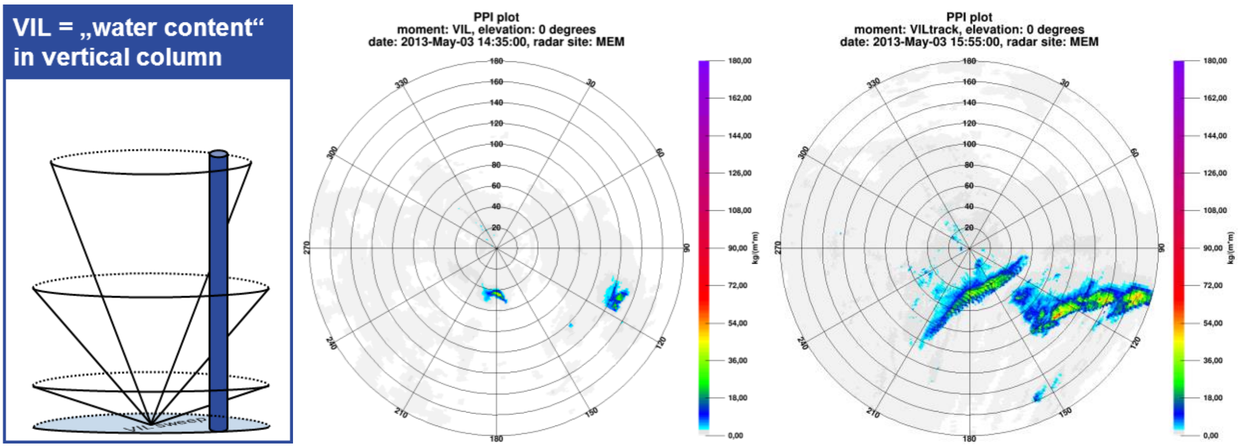
Above given formula indirectly contains a Z-R relation, the water equivalent is derived under the assumption of a Marshall Palmer drop size distribution. Details can be found in (Greene et al., 1972).

The VIL product at DWD is generated as Germany composite using the 3D-reflectivity volumes of all DWD radar stations (flatmap composite with 1950 x 1200 pixels, horizontal pixel size: 553.50 m - 699.67 m, vertical pixel size: 1000 m). For a given grid-cell of the composite a VIL value is calculated by integrating exactly vertical using above given equation. The reflectivities Z_i are taken from the intersected sweep data taking into account all sweeps of all radar stations which intersect with a vertical column above the grid-cell.

A so-called VIL Track is created by accumulating VIL composite products from a certain time interval, which should be chosen large enough to visualize tracks of moving cells. Currently, this time is set to 3 hours. In the accumulation procedure each pixel of the VIL Track composite is assigned the maximum value of all VIL values for this pixel in the corresponding VIL composite products.

Interpretation guidelines

VIL can be used for a classification of storm severity (Kitzmiller et al. 1995). VIL values exceed 10 kg/m^2 in convective events (thunderstorms); the higher the VIL, the more severe the storm. NowcastMix uses the VIL product as one of its input data sets. The VIL Track product is useful for depicting paths of moving cells. In case of cell splits two divergent VIL paths can be observed. It should be noted that VIL overestimates the “water content” when hail is present (especially water coated hail).



Left: VIL value calculation for a single pixel of a polar VIL sweep coordinate grid (actually a flatmap Germany composite grid is used, however the principle of the VIL calculation is unchanged). Observational data at DWD contains 10 sweeps for each radar site. Here, 3 sweeps are depicted for illustration purposes. Middle: VIL product as derived from observational data (see label for details). Right: Corresponding VIL Track.

In the VIL formula, as given above, the reflectivities are always interpreted as belonging to liquid hydrometeors. However, this overestimation pronounces severe storms, which make VIL a kind of “storm severity indicator”. In the VII (vertically integrated ice) product as described in the next section one tries to lift the lower integration limit in order to catch just the frozen hydrometeors, so that VII may be better suited to imply the presence of hail.

There are unavoidable geometrical influences, which should be taken into account when interpreting VIL values: In the vicinity of a certain radar site (< ca. 20 km) precipitation in larger heights is not captured by this site (so called cone-of-silence). The nearest radar sites are providing coverage filling the cone-of-silence. However, deterioration in vertical resolution may still occur, so that possibly too low VIL values are observed. On the other hand, for a location within the VIL composite, where the nearest radar site is situated at large distance (> ca.100 km) the spatial resolution of the radar scan is limited and precipitation close to ground may not be captured (overshooting precipitation). Furthermore, if vertical gradients of reflectivity are present the VIL algorithm produces positively biased values (overestimation) especially at large radar ranges. All these effects are mainly noticeable at the composite’s border regions and within the composite in case of single radar site’s data outages.

Greene, D.R. and R.A. Clark (1972): Vertically Integrated liquid Water - A New Analysis Tool*, Monthly Weather Review, **100**, 548–552.*

Kitzmiller, D.H., W.E. McGovern and R.F. Saffle (1995): *The WSR-88D severe weather potential algorithm, Weather and Forecasting, **10,** 141–159.*

Brown, R. A. and V. T. Wood, 1999: *Development of New WSR-88D Scanning Strategies for Convective Situations*, Final Report, NSSL, Norman, OK, fig. 17.

3.4 Vertically integrated ice (VII) and VII-Track

Thomas Hengstebeck (DWD)

Data basis

The quality controlled 3D-reflectivity data are used as input (see section 3.1). Furthermore, data from the COSMO-DE model with information about the height of the 0°C-layer h_0 is used.

Description of Algorithm

The algorithm works analogue to the VIL algorithm with the exception that the vertical integration is performed beginning at the -10°C-layer height h_{-10}, which is estimated from h_0 (COSMO-DE output) as follows:

$h_{-10} = h_0 + 1330$ m (assuming a temperature gradient of 7.5 K / 1000 m for convective situations)

REMARK: Actually, the calculation of VII involves a different factor (2.11 instead of 3.44 in the VIL equation) to account for the density of ice. However, this altered factor is *not* used. The only difference between VII and VIL is the lower integration limit. Thus, differences in the two products can unambiguously be traced back to the h_{-10} height.

Interpretation guidelines

The same considerations as for the VIL algorithm apply here. Additionally, uncertainties of h_0 (COSMO-DE model) influence the VII-product.

R. M. Mosier et al. (2011), Radar Nowcasting of Cloud-to-Ground Lightning over Houston, *Texas, Wea. Forecasting*, **26**.

3.5 Rotation and Rotation-Track

Thomas Hengstebeck (DWD)

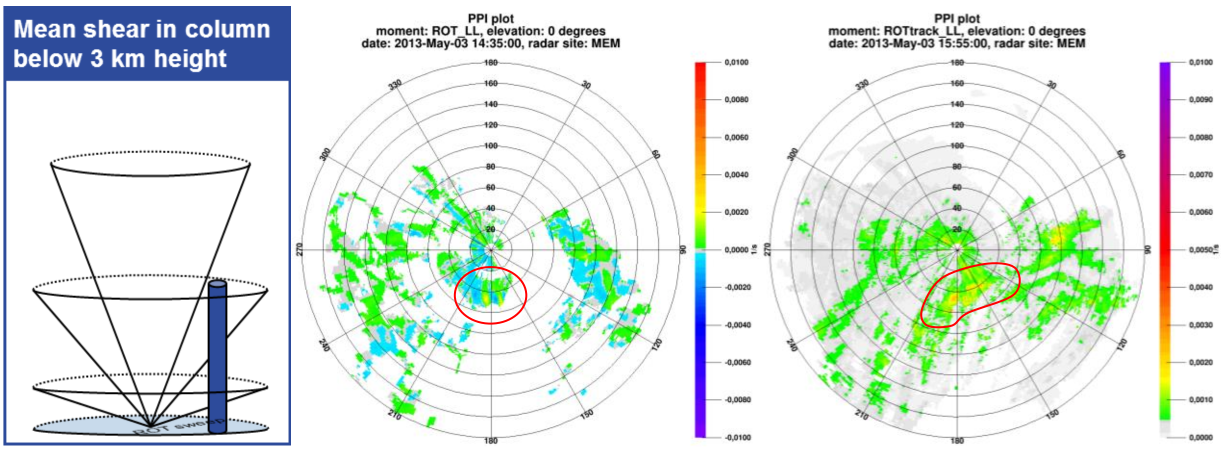
Data basis

The quality controlled 3D reflectivity and radial velocity radar data are used as input (see section 3.1).

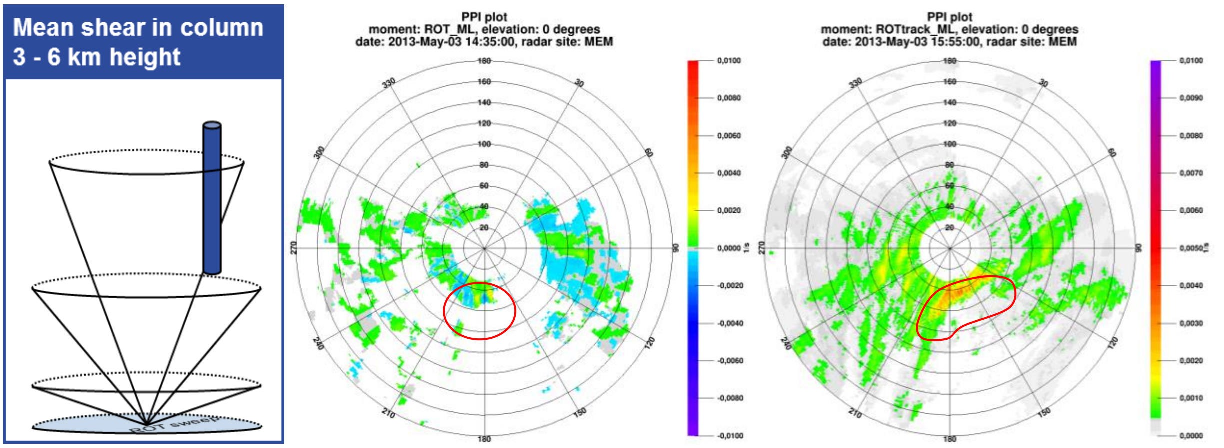
Description of Algorithm

The rotation product is meant for visualising the azimuthal shear connected with rotation in meso-(anti)cyclones. The data processing for the rotation algorithm starts by applying a smoothing filter to each radial velocity sweep of the 3D Doppler volume. Subsequently, the azimuthal shear is calculated pixelwise averaging over 3 azimuthally adjacent range bins.

The resulting 3D-volume of azimuthal shear sweeps is then further processed (see also the figures below). In analogy to the VIL product, a flatmap Germany composite is used (the same format as described in section 3.2 for the VIL-product). Each pixel (grid-cell) within this composite is assigned a value corresponding to the average azimuthal shear in the vertical column above the pixel. For the low level (LL) rotation product the column extends from 0 to 3 km above ground level (agl). In case of the mid level (ML) rotation product the column is ranging from 3 to 6 km height agl. A minimum reflectivity of 5 dBZ is necessary for a shear value to enter the averaging procedure.



Left: low level rotation (ROT-LL) value calculation for a single pixel of a polar "ROT" sweep coordinate grid (actually a flatmap Germany composite grid is used, however the principle of the ROT calculation is unchanged). Middle: ROT-LL sweep from observational data (see figure label for details). Right: ROT-LL Track (time interval for accumulation is 3 hours). Compare also figure in section 3.1 (mesocyclone detection). In this weather case, the rotation is more restricted to higher atmospheric layers as can be seen from the ROT-ML product (next figure).



Left: mid level rotation (ROT-ML) value calculation for a single pixel of a polar "ROT" sweep coordinate grid. Middle: ROT-ML sweep from observational data (see figure label for details). Right: ROT-ML Track (time interval for accumulation is 3 hours).

Both LL and ML rotation products show positive (cyclonic) and negative (anti-cyclonic) shear. The related track products are obtained by pixelwise accumulating the maxima from the LL and ML rotation products of the last 3 hours (which corresponds to 36 composite products due to the 5 min scan strategy), so that only positive shear is picked up.

The rotation and rotation track products are inspired by (Smith et al., 2004). However, it was found that picking up the maximum value in the column leads to noisy rotation products, so that finally the mean value was preferred.

In case of the track composite products only positive azimuthal shear is evaluated. The more frequently occurring cyclonic vortices are represented by an area of positive shear (centre of rotation) flanked on two sides by negative shear values (regions where the rigid rotation of the inner core merges into surrounding wind field). Accumulating both positive and negative shear values (by investigation of absolute value) would result in a complicated picture showing two negative rotation tracks beside each positive rotation track and vice versa.

Interpretation guidelines

Rotation and rotation track products should be used in addition to the mesocyclone detection as verification check. Moving rotating cells are expected to produce tracks of high azimuthal shear visible in the rotation track product. The low level and mid level rotation track products can help to distinguish between close to ground (implication for possible occurrence of tornadoes) and mid level atmospheric rotation.

A discussion of non-mesocyclonic signatures can be found in (Miller et al., 2012). Here it is stated that "significant vertical shear near the surface can cause false high azimuthal shear values very close to the radar" (Miller et al., 2012, p. 577) and that "bands of high azimuthal shear values associated with linear meteorological phenomena like outflow boundaries and bow echoes also appear in the rotation track fields" (Miller et al., 2012, p. 580).

Smith, T.M. and K.L. Elmore (2004): The Use of Radial Velocity Derivatives to Diagnose Rotation and Divergence, *11th Conference on Aviation, Range, and Aerospace Meteorology, 2004.*

Miller, M.L., V. Lakshmanan and T. Smith (2012): An Automated Method for Depicting Mesocyclone Paths and Intensities, *Weather and Forecasting, 2012*

3.6 Lightning density and lightning density track

Kathrin Wapler (DWD)

Data basis

Lightning stroke data measured by the Lightning detection NETwork (LINET, Betz et al. 2008) are used.

Description of the product

Lightning strokes are mapped on a grid. Based on recommendations from ESSL, the grid is three times coarser than the grid of the VIL and VII products, thus it has a spatial resolution of approximately 3km*3km. The lightning density product shows the number of lightning strokes per pixel for a 5 minute interval. The lightning density labelled 12:00 UTC contains the strokes that occurred between 12:00:00 and 12:04:59 UTC. This time slot is chosen to be comparable to the 3D volume radar data based products (see Section….).

A so-called lighting density track is created by accumulating the lightning density products from a certain interval. Currently, this time is set to 3 hours. Each pixel of the lightning density track product is assigned the total of all lightning density values for this pixel in the corresponding lightning density products. The lightning density track labelled 12:00 UTC contains the strokes that occurred between 09:05:00 and 12:04:59 UTC.

Interpretation guideline / product assessment

The products may be used for nowcasting as well as verification purposes. Intense convective storms tend to have higher lightning stroke densities. A so-called lightning jump, i.e. a rapid increase in the lightning stroke rate of a storm, has in many cases shown to be a precursor of severe weather (e.g. Wapler 2017).

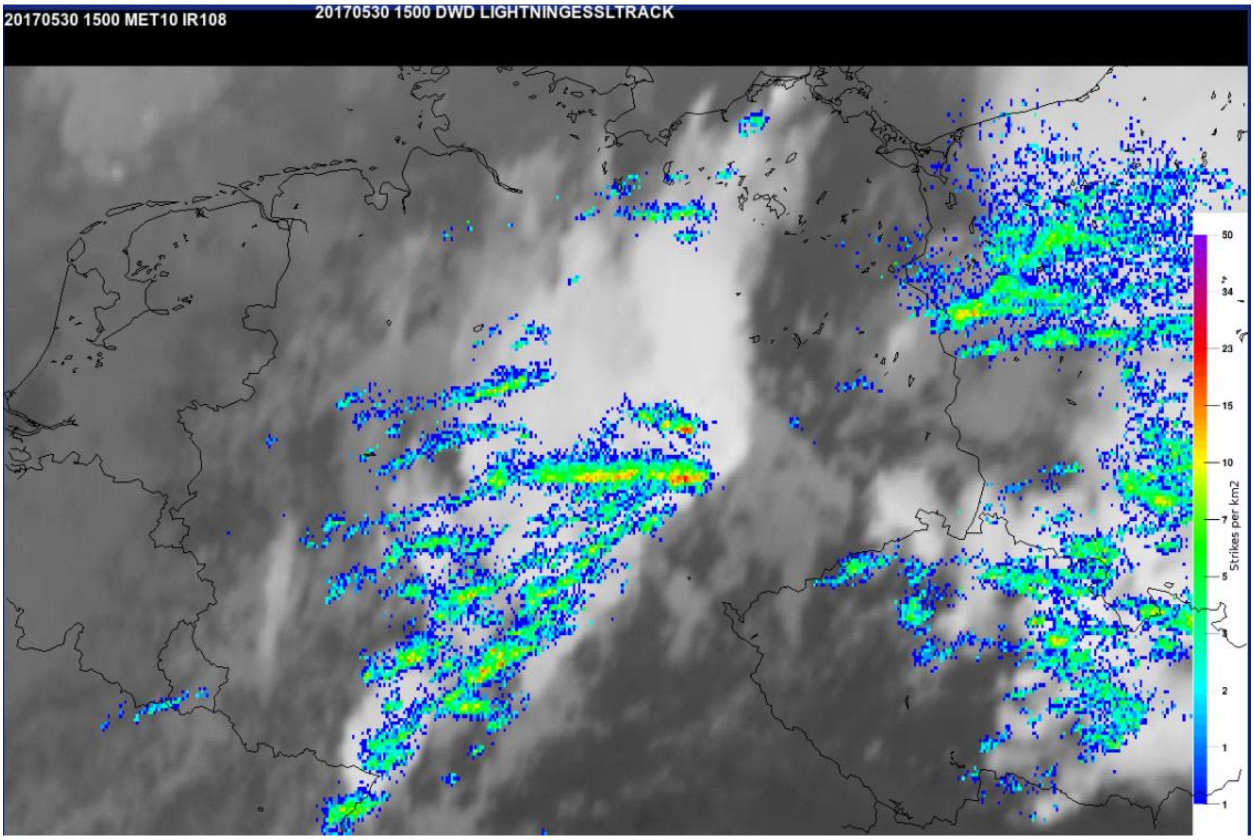


Figure: Example of lightning-track product as disaplayed at the Testbed. Note: The colorscale is logarithmic.

Reference:

Wapler, K. (2017): The life-cycle of hailstorms: Lightning, radar reflectivity and rotation characteristics. Atmospheric Research, 193, 60-72, http://doi.org/10.1016/j.atmosres.2017.04.009.

3.7 NowcastMix

Paul James (DWD)

The GermanWeather Service's AutoWARN system integrates various meteorological data and products in a warning decision support process, generating real-time warning proposals for assessment and possible modification by the duty forecasters. These warnings finally issued by the forecaster are then exported to a system generating textual and graphical warning products for dissemination to customers. On very short, nowcasting timescales, several systems are continuously monitored. These include the radar-based storm-cell identification and tracking methods, KONRAD and CellMOS; 3D radar volume scans yielding vertically integrated liquid water (VIL) composites; precise lightning strike locations; the precipitation prediction system, RadVOR-OP as well as synoptic reports and the latest high resolution numerical analysis and forecast data. These systems provide a huge body of valuable data on rapidly developing mesoscale weather events.

However, without some form of pre-processing, the forecasters could become overwhelmed with information, especially during major, widespread summer convective outbreaks. NowCastMIX thus processes all available nowcast data together in an integrated grid-based analysis, providing a generic, optimal warning solution with a 5-minute update cycle, combining inputs using a fuzzy logic approach.

The method includes optimized estimates for the storm cell motion vectors by combining raw cell tracking inputs from the KONRAD and CellMOS systems with vector fields derived from comparing consecutive radar images. Finally, the resulting gridded warning fields are spatially filtered to provide regionally-optimized warning levels for differing thunderstorm severities which can be managed adequately by the duty forecasters. NowCastMIX thus delivers an ongoing real-time synthesis of the various nowcasting and forecast model system inputs to provide consolidated sets of most-probable short-term forecasts. More information is given in James et al. (2011).

The NowcastMIX is available in two different visualizations. One is the 'classic' version that uses DWD's internal warning levels and the associated color scheme. It is provided to forecasters as part of DWD's AutoWARN system. An example is show in the figure below.

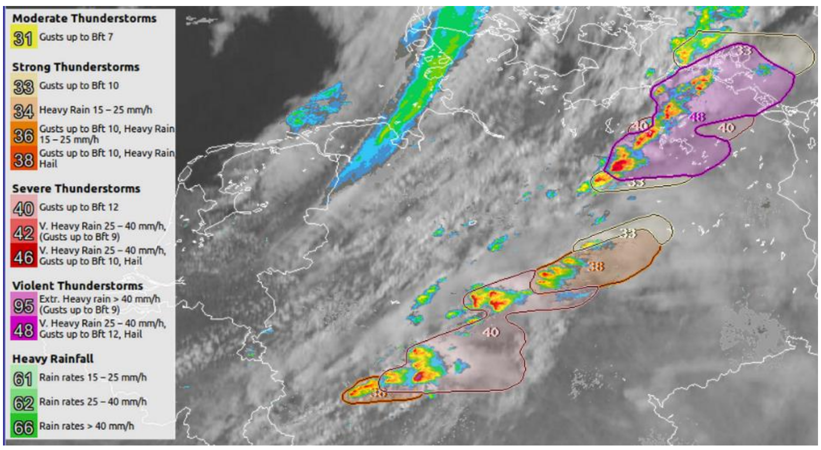


Figure. The "classic" visualization of DWD's NowcastMIX product.

The other version is one developed for DWD's app “WarnWetter”, that provides the general public with warning information. The polygons are similar to the classic product, but do not have a spatial filtering and fewer overlap within warning groups. The only distinction is within the severity levels indicated by a yellow, orange, red or violet colour. This means that severe thunderstorms are depicted sharper and smaller because of the lack of clustering. However, thinner filaments and residual polygons arise whenever two or more polygons overlap.

3.8 COSMO-DE and COSMO-DE-EPS

Ulrich Blahak (Deutscher Wetterdienst), Pieter Groenemeijer (ESSL) and others

COSMO-DE-EPS is an ensemble of the German Weather Service's high-resolution, convection permitting model COSMO-DE (COnsortium for Small-scale MOdelling - DEutschland).

Visualizations of the ensemble

Visualization of large volumes of ensemble data is a challenge. For example, in plotting the average and standard deviation of forecast quantities much information is lost. For a field like radar reflectivity such a display would not make much sense. In past years, ESSL has evaluated several visualization of high-resolution ensemble data. For several parameters the methods where by the most extreme value of any ensemble member at each location was plotted was compared to plotting contours of ensemble members exceeding a threshold and the pointwise probability of exceedance. As a logical next step, a 'probability of exceedance' will now be computed using the methods described by Ben Bouallègue and Theis (2013). These products called 'fuzzy' and 'upscaled'. The fuzzy method is a smoothing method that enlarges the ensemble sample size by including neighbouring forecasts and the upscaled method modifies the reference area of probabilities. At the Testbed, we will collect forecaster feedback on these products and compared them with the traditional pointwise or local probabilities.

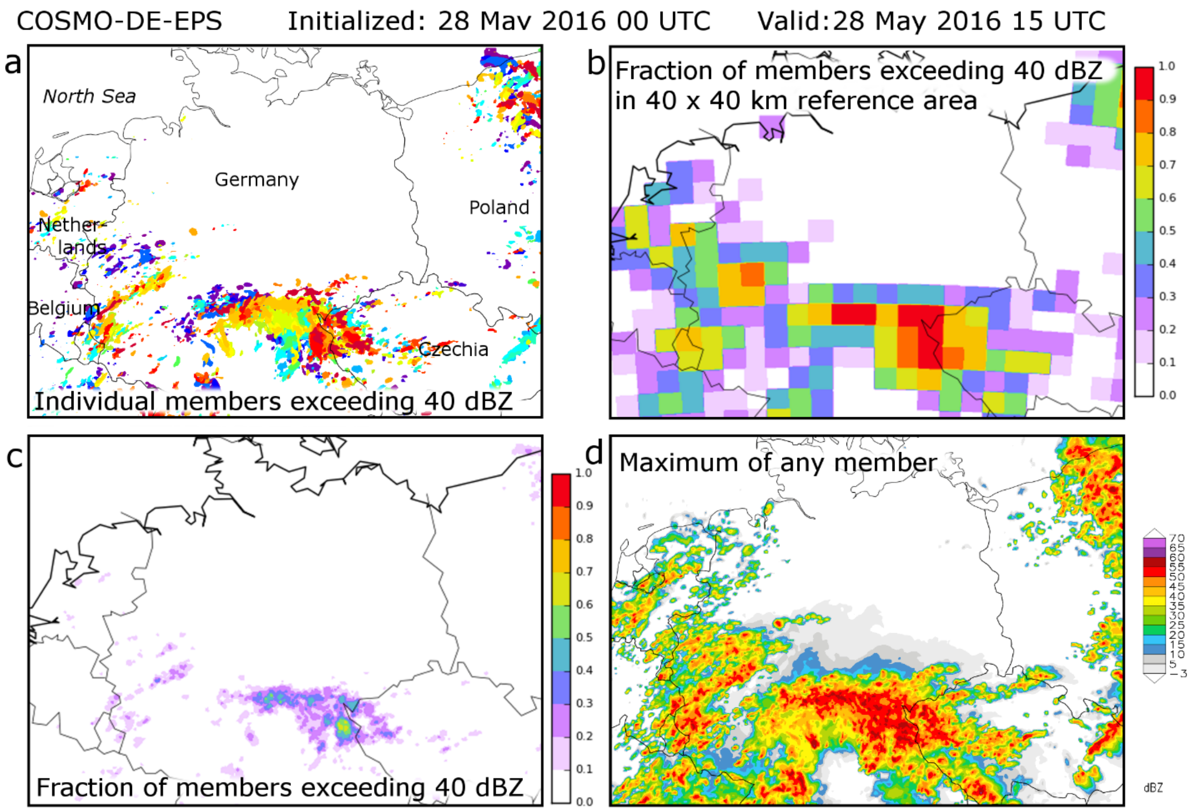


Figure: Four different visualizations of the same parameter in the same model ensemble. Which visualization is most useful? How does this depend on which parameter we are considering? Image from Groenemeijer et al, 2017 (Bulletin of the American Meteorological Society).

At an earlier Testbed edition it was noted that small-scale variations in convective parameters such as CAPE (Convective Available Potential Energy) and CIN are simulated by the COSMO-DE and COSMO-DE-EPS models, and that these may be relevant for the development and life cycle of convective storms. At this Testbed, we will visualize the distribution of CIN and CAPE and investigate whether they can benefit forecasting convective storms by characterizing the pre-convective environment more accurately than coarser models.

New diagnostic output parameters related to severe convective cells at the 2017 Testbed

Five new diagnostic 2-dimensional output fields are available from COSMO-DE and the ensemble COSMO-DE-EPS in hourly intervals, which contain the extreme values (minima/maxima) or the maxima of some quantities at each grid point during the last hour before the nominal time. These parameters are related to severe convective cells and are described briefly in the following subsections. By taking the extreme values at each grid point over time (between the nominal hourly output time steps), continuous cell tracks are visualized and simulated events between output time steps are not missed.

For the COSMO-DE-EPS, probabilistic products are provided in the same way as for the other available model parameters:

- **Extremum/Maximum of all members**
- **Fraction of members above a threshold**
- **Coarse-grained (40 x 40 km^2) fraction of members above a threshold**
- **Any member above a threshold (member indices in colors)**

Extreme value of Updraft Helicity (UH_MAX)

Extremum of absolute value (+ or -) of updraft helicity (UH) during the last hour for each grid point, in units of J/kg. UH is the vertical integral of updraft speed w times vertical vorticity ς between 2 km and 8 km height MSL. If orography > 1500 m MSL, the integration limits are raised to 0.5 km - 6.5 km AGL. Computation takes only updrafts into account This means that positive values indicate cyclonically rotating updrafts, while negative values indicate anticyclonic rotation:

$$\text{UH\_MAX} = \max_{t_{i-1} < t \le t_i} \left[\int_a^b \max[\, w(z,t), 0\,]\, \zeta(z,t)\, dz \right]$$

$$a = max\ [\,2\,\text{km}, 500\,\text{m AGL}\,]$$

$$b = a + 6\,\text{km}$$

$$t_{i-1}, t_i = \text{last and actual output time step of UH\_MAX}$$

Here the outer **max** over time denotes the extreme value (maximum of the absolute value combined with the true sign of the value). Severe rotation is indicated by absolute values above about +/- 100 J/kg and are often associated with long-lived supercells. This threshold has been chosen for the probabilistic products.

Extreme value of low level rotation (VORW_CTMAX)

Extremum of absolute value (+ or -) of low level rotation during the last hour, in units of 1/s. Low level rotation is defined here as the average vertical vorticity ς from the ground up to 3 km MSL or 1.5 km AGL, whichever is higher. Again, positive values indicate cyclonic rotation and negative values anticyclonic rotation:

$$\text{VORW\_CTMAX} = \max_{t_{i-1} < t \leq t_i} \left[\frac{1}{b-a} \int_a^b \zeta(z,t)\, dz \right]$$

$$a = 0\,\text{m AGL}$$

$$b = \max\,[3\,\text{km},\ a + 1.5\,\text{km}]$$

$$t_{i-1}, t_i = \text{last and actual output time step of VORW\_CTMAX}$$

Again the outer max over time denotes the extreme value. High absolute values indicate strong low level rotation and a certain potential for tornadoes. A threshold of above $10^{-3}\ s^{-1}$ has been chosen for the probabilistic products.

Max. of updraft speed (W_CTMAX)

Maximum updraft speed at each grid point from the ground to 10 km MSL and over time between output time steps, in units of m/s:

$$\text{W\_CTMAX} = \max_{\substack{t_{i-1} < t \leq t_i \\ 0\,\text{km} < z < 10\,\text{km}}} [\, w(z,t)]$$

$$t_{i-1}, t_i = \text{last and actual output time step of W\_CTMAX}$$

For the probabilistic products, a threshold of 15 m/s has been chosen.

Max. total condensate (TCOND_MAX)

Maximum total condensate between output time steps for each grid point, in units of kg/m^2. Total condensate is the integral of all hydrometeors except water vapor over the total model grid column. It is similar but not equal to the so-called VIL (vertically integrated liquid) from radar observations:

$$\text{TCOND\_MAX} = \max_{t_{i-1} < t \leq t_i} \left[\int_0^{Z_{top}} \rho(z,t)\ (q_c(z,t) + q_{rs}(z,t))\ dz \right]$$

q_c = cloud water mass fraction

q_{rs} = sum of all sedimenting hydrometeors

t_{i-1}, t_i = last and actual output time step of TCOND_MAX

For the probabilistic products, a threshold of 10 kg/m2 was chosen.

Max. total condensate above the -10°C isotherm (TCOND10_MX)

Similar to TCOND_MAX, but the vertical integration starts only at the -10-deg-C level upwards. It is similar but not equal to the so-called VII (vertically integrated ice) from radar observations:

$$\text{TCOND10\_MX} = \max_{t_{i-1} < t \leq t_i} \left[\int_{Z(-10^\circ\mathrm{C})}^{Z_{top}} \rho(z,t)\ \{ q_c(z,t) + q_{rs}(z,t) \}\ dz \right]$$

q_c = cloud water mass fraction

q_{rs} = sum of all sedimenting hydrometeors

t_{i-1}, t_i = last and actual output time step of TCOND10_MX

For the probabilistic products, a threshold of 10 kg/m2 was chosen.

General assessment of model performance

As at previous Testbeds, the ESSL team and the participants will monitor the overall performance of the COSMO-DE and COSMO-DE-EPS models, and will provide related feedback. Points of attention will include any tendencies to under- or overforecast convective initiation, the storm life cycle and secondary initiation of storms.

3.9 ICON-EPS: The global ICON Ensemble Prediction System

T. Heppelmann, M. Denhard, A. Fernandez del Rio, F. Fundel, M. Buchhold (DWD)

Since October 2015, the German Weather Service DWD runs an experimental ICON ensemble suite with 40 members and approx. 40km horizontal resolution on the global scale up to +180h lead time twice a day (00/12UTC). In the operational system (planned for autumn 2017) we will also run two additional forecasts at 06 and 18UTC up to +120h. The global grid contains a two-way nest over Europe with a grid resolution of 20km. The forecasts from the nest area are used to provide boundary conditions for the COSMO-DE-EPS operationally every 3 hours up to +30h lead time.

Ensemble Initialization

The ensemble is initialized by analyses from our ensemble data assimilation system (ICON EDA), a Local Ensemble Transform Kalman Filter (LETKF) with a cycle length of 3 hours. Kalman filters in data assimilation (DA) require covariance inflation to prevent the collapse of the uncertainty in the analysis ensemble. The climatological background error covariance from the 3dVar system (NMC Method) is added with a weight of 0.25 to the flow dependent Background error covariance from the LETKF and a multiplicative inflation factor is applied throughout the atmosphere. Moreover, the analysis states are to some extent relaxed to their priors and the SST's are perturbed by 1 K random perturbations with spatial correlations of 100km/1000km and correlations in time of 1 day. These perturbations mainly determine the spread skill properties of the system during the forecast. The flow dependent background error covariance matrix from the LETKF is used within a hybrid ensemble/variational DA system (EnVar) to generate the analysis for the high-resolution deterministic model at 13km horizontal resolution.

Verification and Evaluation

The ICON Ensemble forecasts are routinely verified against analyses and against observations based on feedback files. Feedback files contain information on the observation and of the model equivalent calculated by using explicit forward operators from the data assimilation system. At the moment, the verification includes surface verification against SYNOP data and upper-air verification against vertical TEMP data. It calculates monthly - and for periods with an unchanged model - probabilistic scores (e.g. spread/skill, continuous ranked probability score, etc.) for the global system and provides a comparison with the IFS-EPS from ECMWF. In terms of model evaluation, the forecasters have a detailed look at case studies and evaluate the ICON Ensemble against other forecasting systems as e.g. the IFS-EPS on the global scale, or on the regional scales e.g. the COSMO-LEPS and the COSMO-DE-EPS.

ICON Ensemble fields at the Testbed

Since the ICON Ensemble is still running as a pre-operational system, it is the first time of ICON Ensemble products to be part of the forecast evaluation at the ESSL Testbed. At the Testbed 2017, the following model fields of the ICON-EU Ensemble are provided: 6-hourly maximum wind gusts, 6-hourly accumulated precipitation, and 6-hourly Convective Available Potential Energy (CAPE) from the 00 and 12UTC forecast runs with a lead time of 72 hours. The nested ICON-EU grid has a resolution of 0.2° (~ 20km).

Notations and Challenges

In its current setup, the ICON Ensemble does not include any representation of model uncertainties. Physics parameter perturbations as well as stochastic schemes for the representation of the model error are still under development for the ICON Ensemble. Therefore, the challenge for the evaluation is, on the one hand, to provide an evaluation of the forecast quality and, on the other hand, to assess the extent to which the prediction error is described by the ensemble spread. Further, subjective evaluation should be made, at which lead times the model tends to over- or under-forecast the convective initiation. How many hits are produced by the system and how many false alarms? Is the ICON Ensemble able to simulate the storm life cycle properly? Predicted probabilities of exceeding certain thresholds could help to interpret hazardous weather events and derive meteorological warnings. Examples of forecast products are shown in the figures below.

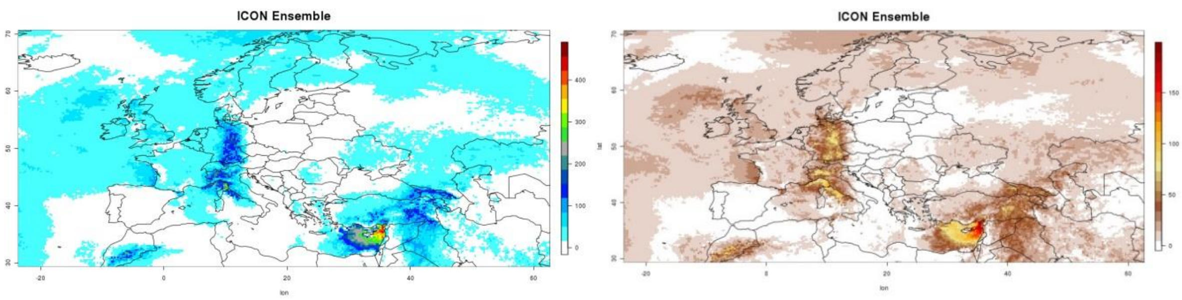


Figure: ICON-EU Ensemble +42h forecast example of CAPE, initialized at 20170518, 00UTC. (Left) 90%-percentile and (right) ensemble spread.

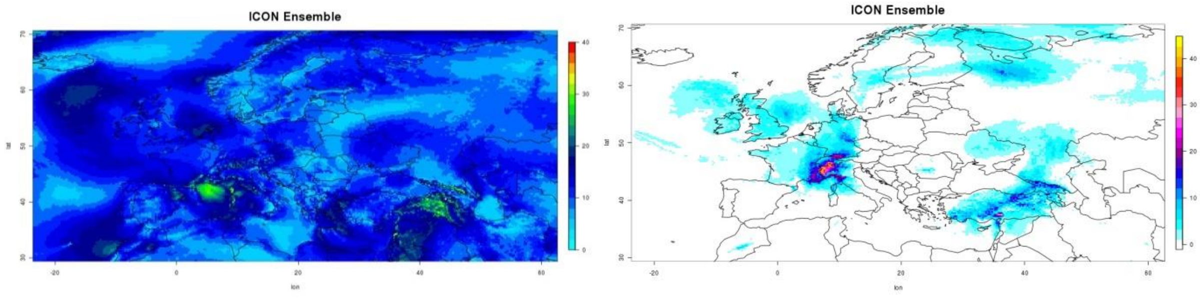


Figure: ICON-EU Ensemble +42h forecast example, initialized at 20170518, 00UTC (as previous figure). 90%-percentile forecasts of (left) the 6-hourly maximum 10 m wind gusts and (right) the 6-hourly accumulated precipitation.

Appendix 1: List of on-site participants

As of 31 May 2017

Week 1: 5 – 9 June

Javier Garcia Pereda – AEMET, Spain
Delia Gutierrez Rubio – AEMET, Spain
Claudia Riedl – ZAMG, Austria
Mariann Darányi – OMSZ, Hungary
Pauli Jokinen – FMI, Finland
Paavo Korpela – FMI, Finland
Jasnica Krulc – CroControl, Croatia
Ana Bago Tomac – CroControl, Croatia
John T. Allen – Central Michigan University, USA
Christoph Gatzen – ESTOFEX
Alois M. Holzer – ESSL
Pieter Groenemeijer – ESSL
Tomas Pucik – ESSL

Week 2: 19 – 23 June

Michaël Kreitz – Meteo France, France
Robert Hausen – DWD, Germany
Axel Barleben – DWD, Germany
Benito Elvira Montejo – AEMET, Spain
Javier Sanz de la Heras – AEMET, Spain
Martina Sadloňová – SHMÚ, Slovakia
Danijela Vlasic – DHMZ, Croatia
Biserka Francovic – CroControl, Croatia
Georgia Alexandropoulou, HNMS, Greece
Jana Stacke – CHMÚ, Czechia
Stavros Dafis – ESTOFEX
Matthew D. Parker Brown – North Carolina State University, USA
Thilo Kühne – ESSL
Alois M. Holzer – ESSL
Pieter Groenemeijer – ESSL
Tomas Pucik – ESSL

Week 3: 26 June - 30 June

Kathrin Wapler – DWD, Germany
Pedro Oria Iriarte – AEMET, Spain
Jaime Rey – AEMET, Spain
Martin Jonas – DWD, Germany
Kristiāns Pāps – LVGMS, Latvia
Matthias Gäßl – DWD, Germany
Urs Graf – MeteoSwiss, Switzerland
Natasa Puhalo Dragovic – CroControl, Croatia
Nikolina Leko – CroControl, Croatia
Joana Sanches – IPMA, Portugal
Tobias Heppelmann – DWD, Germany
Domenico Maione – Aeronautica Militare, Italy
Adam Clark – NOAA/NSSL/CIMMS
Thilo Kühne – ESSL
Alois M. Holzer – ESSL
Pieter Groenemeijer – ESSL
Tomas Pucik – ESSL

Week 4: 3 - 7 July

Susanne Lentner, ZAMG – Austria
Almudena Paul del Valle – AEMET, Spain
Francisco Diaz Bárcena – AEMET, Spain
Lars Kirchhubel – DWD, Germany
Elena Mirela Polifronie – NMA, Romania
Dennis Brüning, MeteoGroup – Germany
Christian Schubert – MeteoGroup, Germany
Jadran Jurkovic – CroControl, Croatia
Marko Zoldos – CroControl, Croatia
Martin Rempel – DWD, Germany
Katharina Amstler – MilMet, Austria
Helmut Laschan – MilMet, Austria
Darrel Kingfield – NOAA
Alois M. Holzer – ESSL
Pieter Groenemeijer – ESSL
Tomas Pucik – ESSL
Thilo Kühne – ESSL

Appendix 2: Expert Lectures

Expert lectures are daily returning lectures (Tue-Thu, 30-45 minutes plus some question time) on a specific topic. They start after the Daily Briefing at 11:00 l.t. / 0900 UTC has ended, approximately between 11:30 and 11:45 l.t. (0930-0945 UTC).

Expert lectures are intended both for the audience on site and for remote participants who can follow the presentation online. Please see http://www.essl.org/testbed/info for more information.

Day		**Speaker**	**Topic**
Tuesday	6 June	Kathrin Wapler (remotely)	DWD Lightning Detection
Wednesday	7 June	Javier García Pereda	NWC-SAF products
Thursday	8 June	John T. Allen	Convective Parameters
Tuesday	20 June	Ulrich Blahak (remotely)	COSMO-DE-EPS
Wednesday	21 June	Kathrin Wapler	DWD Lightning Detection
Thursday	22 June	Matthew D. Brown Parker	High-shear low-CAPE Severe Weather
Tuesday	27 June	Tobias Heppelmann	ICON-EPS
Wednesday	28 June	Paul James (remotely)	NowcastMIX
Thursday	29 June	Adam Clark	The NOAA/Hazardous Weather Testbed
Tuesday	4 July	Ulrich Blahak / Martin Rempel	COSMO-DE-EPS
Wednesday	5 July	Thomas Hengstebeck (remotely)	DWD Radar Products
Thursday	6 July	Darrel Kingfield	Identifying Thunderstorm Damage with Satellite Data