Application and Verification of ECMWF Products 2019

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1. Summary of major highlights

ECMWF HRES and ENS forecasts play a very important role for all ZAMG activities related to weather and environment. These include forecasting and warning activities, the generation of products for internal and external users and research and operations of local numerical models. Almost all Limited Area Models operated by ZAMG are coupled to ECMWF HRES and/or ECMWF ENS. ECMWF monthly and seasonal forecast products are still used just occasionally. An overview of the application of ECMWF products is given in the following sections.

2. Use and application of products

2.1 Direct Use of ECMWF Products

A variety of ECMWF products is used as the main source for operational weather forecasts, warnings and the generation of (derived). ECMWF HRES runs are heavily used, information from ECMWF ENS is then used as additional information, in particular in critical weather situations.

ECMWF HRES and ENS gridded data is transferred to ZAMG and visualized with the local software (see Fig. 1). In addition some products available via ecCharts are used by forecasters.

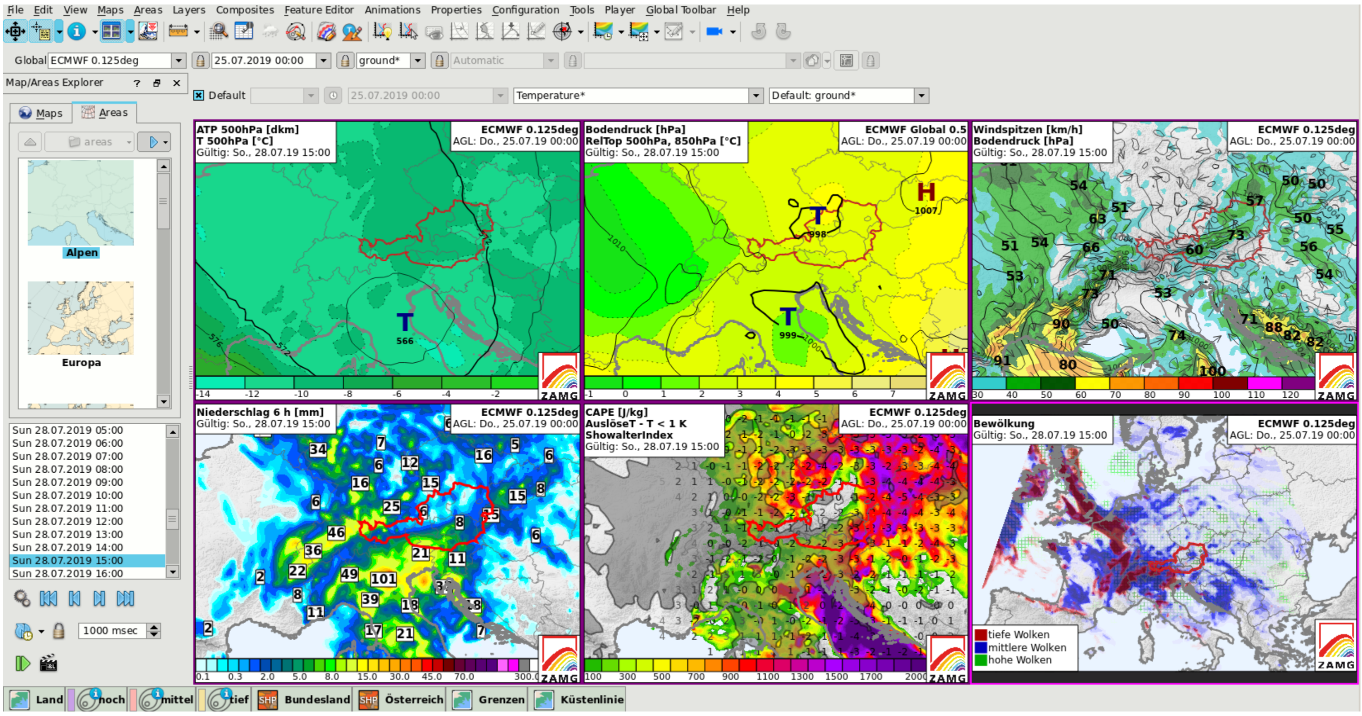

Fig.1 Example for ECMWF HRES data being visualized for operational forecasting purposes with the local visualization software

Selected products derived from ECMWFs monthly and seasonal forecast systems are available in ZAMG intranet. These include anomaly maps (Figure 2) and “Klimagrams” for selected points in Austria. The main purpose is to try to react on occasional requests by media or customers (“Is it going to be a hot summer?”, “Will we have a lot of snow this winter”).

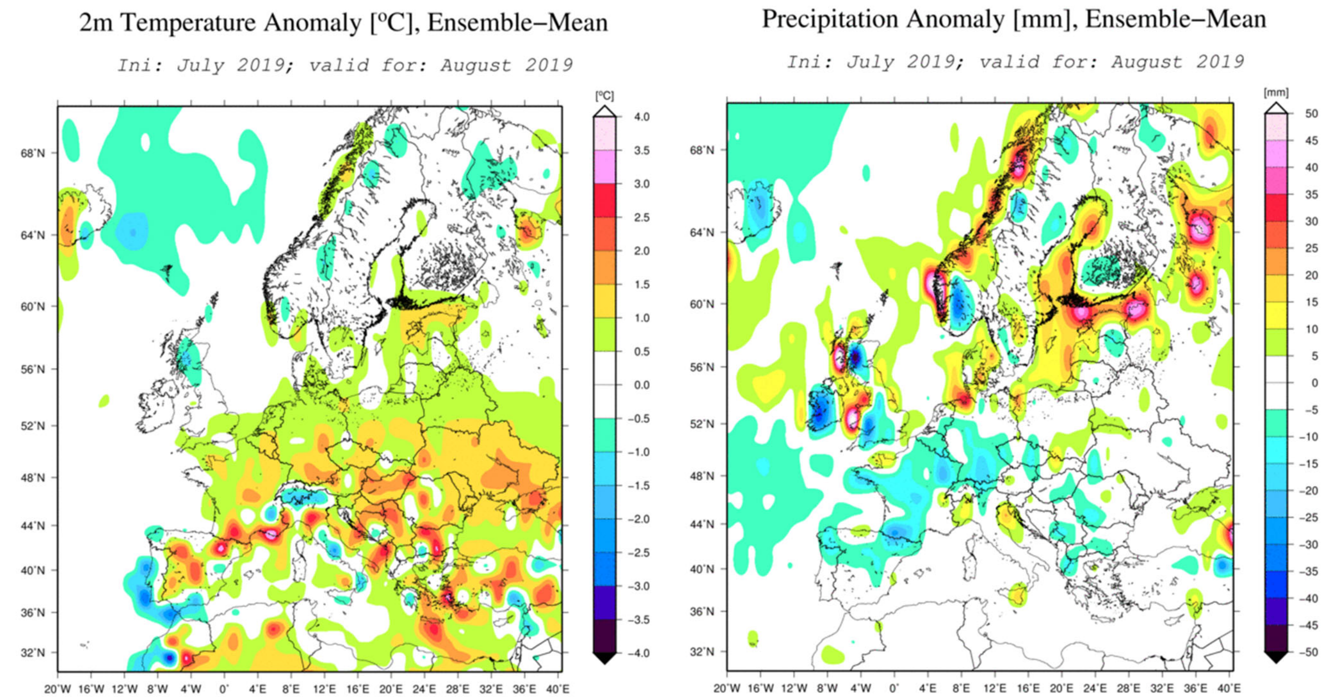

Fig.2 Example for a visualization of ECMWF seasonal forecasts as temperature (left) and precipitation (right) anomalies.

2.2 Other uses of ECMWF output

2.2.1 Post-processing

A model output statistics system (AUSTROMOS) is run operationally at ZAMG, using ECMWF HRES forecast fields as input. This MOS covers a forecast range up to five days for ~200 points in Austria and Europe using 37 predictands. Three different types of predictors are used: (i) direct model output (DMO), (ii) derived quantities, such as relative vorticity or a baroclinicity index, (iii) previous observations. The AUSTROMOS system is adapted from time to time by re-calculating its statistics.

A statistical calibration procedure is applied on 2-m temperature and 10-m wind speed forecasts of the ECMWF ENS in order to reduce systematic deviances of the first (ensemble mean) and second moment (ensemble spread). The method of non-homogeneous Gaussian regression (NGR, Gneiting et al. 2005) is used to derive calibrated PDFs of temperature and wind forecasts up to 10 days ahead.

ZAMG is currently implementing a statistical post-processing of ECMWF ensemble forecasts based on standardized anomalies, the so called standardized anomaly model output statistics (SAMOS). Therefore, the idea of Dabernig et al. (2017) will be applied on ensemble forecasts and the INCA analysis. The standardized anomalies are calculated from ensemble forecasts and INCA analysis at every grid point individually and afterwards only one non-homogenous regression is necessary to post-process the whole domain (~ 250000 grid points) simultaneously. The INCA analysis has a spatial resolution of 1 km which is also the resolution of the SAMOS forecasts. The post-processing is at the moment still under development but the plans are to integrate SAMOS into the operational services. The idea of standardized anomalies could also include the deterministic ECMWF forecast but it is not yet decided in which setting it will be operationalized. A forecast example for temperature is shown in Figure 2.

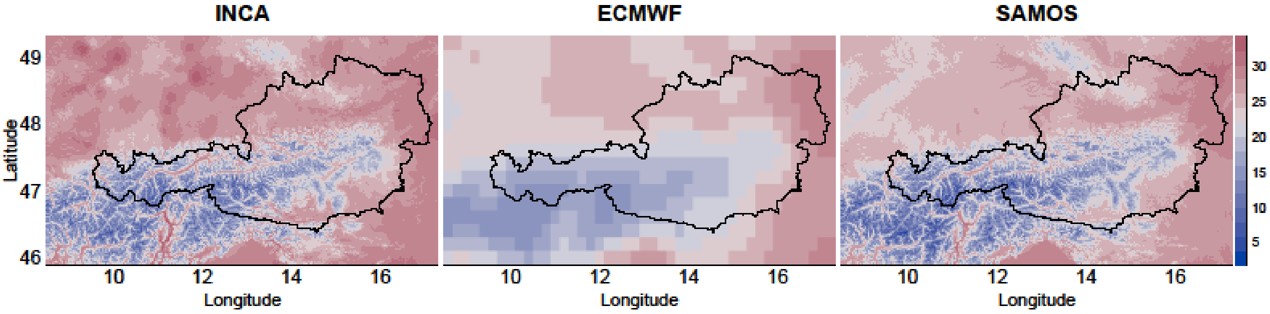

Fig.3 A SAMOS forecast example for temperature from July 1st 2016 lead time +15 h, with the analysis on the left, the raw ECMWF ensemble mean forecast in the middle and the post-processed SAMOS forecast on the right.

2.2.2 *Derived fields*

There are several products derived on clustering of ECMWF ENS data available for the ZAMG forecasters. An example is given in Fig. 4 where ATP500hPa and T500hPa for 4 clusters are shown. Figure 5 shows the corresponding probability of precipitation exceeding a certain threshold valid for cluster 1.

A large number of products based on ECMWF HRES and ECMWF ENS are available for the forecasters. An example recently added is the so called "SweetSpot" chart indicating areas with favourable conditions for hail, heavy rain and strong (convective) gusts (Figure 6). It is an empirically derived parameter computed from several ECMWF HRES forecast parameters like e.g. CAPE, vertical wind shear, showalter index, etc.

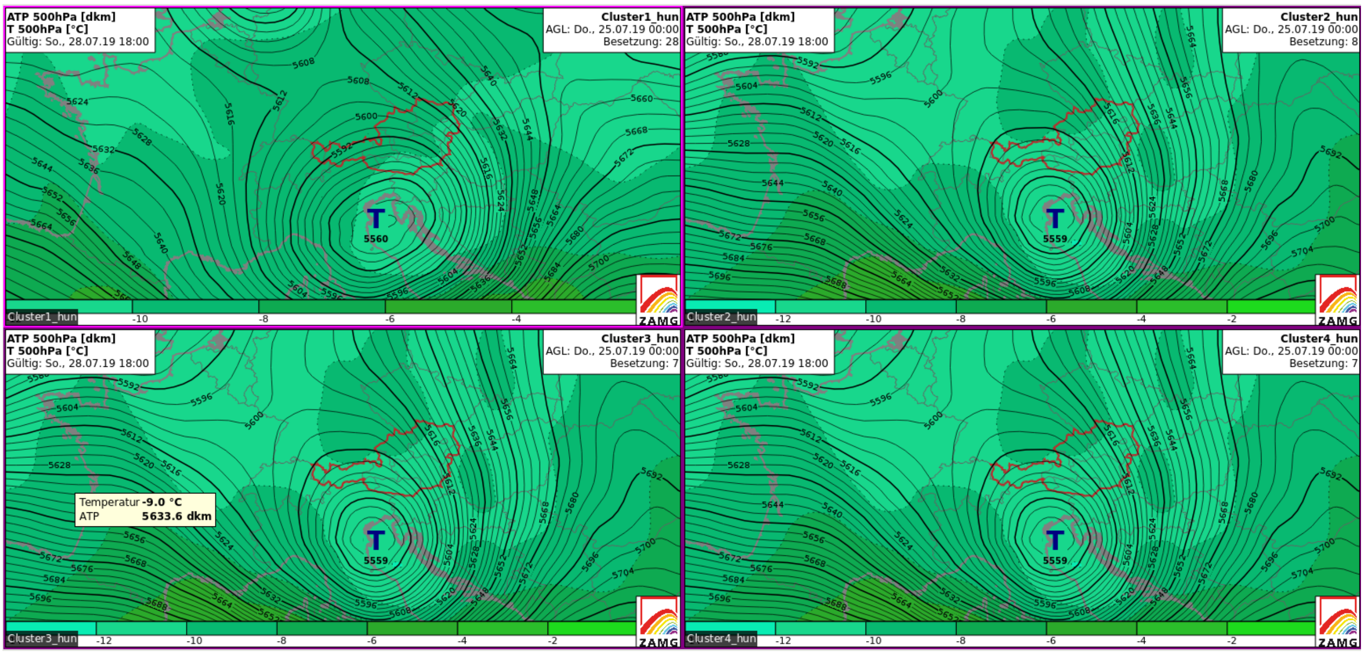

Fig.4 Visualization of cluster means for ATP and T in 500hPa including the number of cluster members: 28 (cluster 1), 8 (cluster 2), 7 (cluster 3) and 7 (cluster 4).

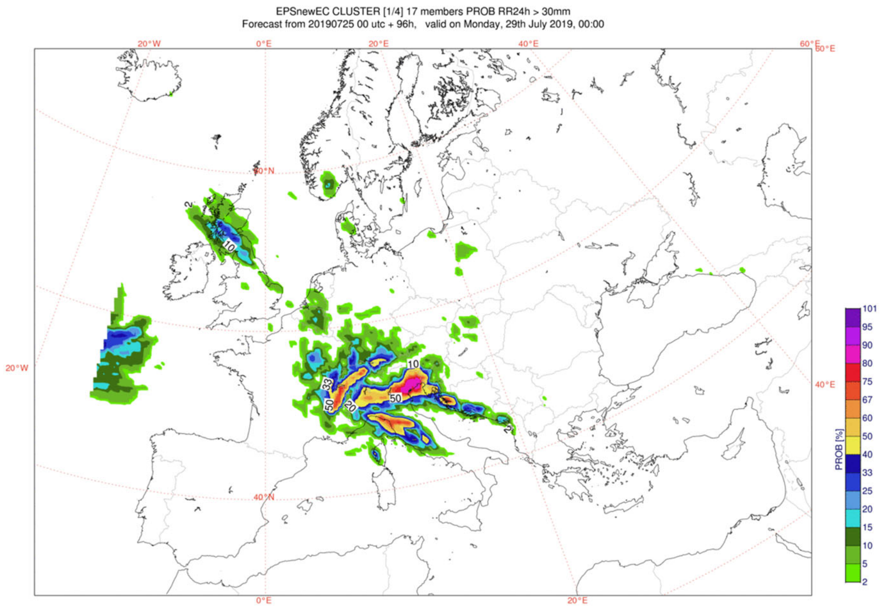

Fig.5 Probability of precipitation exceeding 30mm in 24h based on the members in cluster 1.

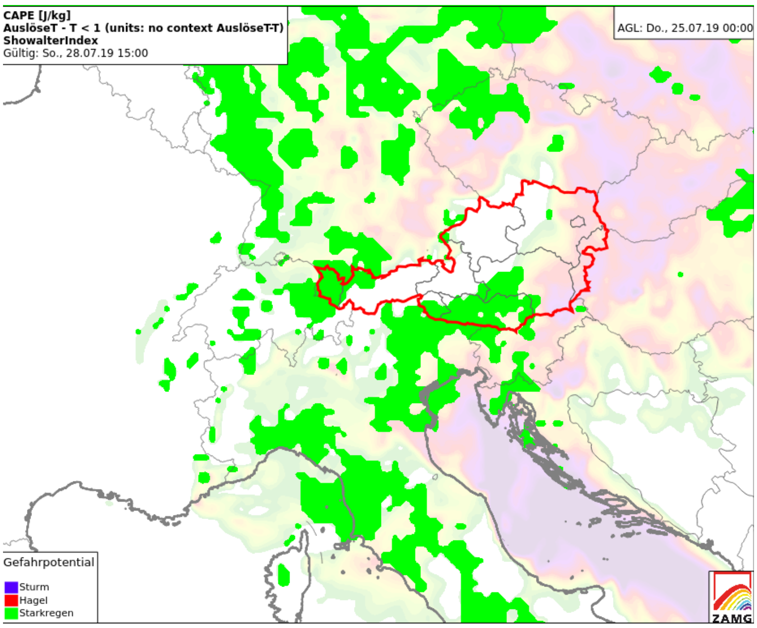

Figure 6: Sweetspot Index to identify regions with favourable conditions for hail (red), high wind gusts (violet) and heavy rain (green) based on difference ECMWF HRES model fields (CAPE, wind shear, etc.)

2.2.3 Modelling

ECMWF products (HRES and ENS) are used as Lateral Boundary Conditions (LBC) and partially also as Initial Conditions (IC) for several model applications at ZAMG:

1. The current deterministic forecast system AROME-Aut (2.5kmL90, 8 runs per day) is using hourly LBC from ECMWF HRES runs (00, 06, 12 and 18). Initialization is done with a local 3DVAR/OI system for atmosphere/soil. LBCs are used in so-called "time-lagged" mode, e.g. AROME-Aut 00 UTC run is coupled to ECMWF HRES 18 UTC run as there are some time constraints in terms of AROME-Aut product availability and the ECMWF HRES 00 UTC would be too late for the AROME-Aut 00 UTC run.

2. The second deterministic forecast system ALARO-Aut (4.8kmL60, 4 runs per day) is using 3-hourly LBC from ECMWF HRES runs (00, 06, 12 and 18). Initialization of atmosphere is done using HRES products as well while for the surface a OI assimilation system is used. ALARO-Aut will be switched off by the end of 2019.

3. The current LAM ensemble forecast system ALADIN-LAEF (Wang et al 2011; 1kmL45, 16+1 member, running at ECMWF HPC) is using 6 hourly LBC data from ECMWF ENS runs (first 16 members + control). Similar as for AROME-Aut the coupling is done in time-lagged mode .

4. Till the end of 2019 ALADIN-LAEF is replaced by a new systems called C-LAEF (Convection permitting Limited Area Ensemble Forecast) system. C-LAEF (2.5kmL90, 16+1 member, 4 runs per day) is using LBCs from the ECMWF ENS runs, again in time-lagged mode.

5. WRF-Chem is operated to conduct daily Air Quality forecasts. It is coupled with ECMWF HRES input data which is used as initial- and lateral boundary conditions. WRF-Chem is operated over a European- (12 km resolution) and Central European domain (4 km resolution) which covers Austria and uses data from local emission inventories. The modelling system provides daily forecasts of Ozone NO2 and Saharan dust (see Figure 7), as well as an Air Quality index for Austria (Figure 7).

6. The Environmental section at ZAMG operates the Atmospheric Transport and Dispersion (ATD) Modeling System TAMOS (Pechinger et al., 2001) as part of the Austrian National Crisis and Disaster Management and has been a (RSMC) for supporting the Comprehensive Nuclear-test-ban Treaty Organization (CTBTO) with atmospheric backtracking products (e.g. (backward) tracer concentrations at a global 0.5x0.5 degree grid) since July 2011. For the generation these products, forecasts of the ECMWF HRES model is used as driver for the atmospheric transport and dispersion modelling system.

7. The emergency response system in RSMC Vienna is currently based around the atmospheric transport model FLEXPART, a Lagrangian particle dispersion (LPD) model and FLEXTRA, a trajectory model. The meteorological input for FLEXPART and FLEXTRA is derived from the output of the ECMWF HRES model using 3hourly data from 00 and 12 UTC runs up to a forecast range of 96 hours. These data are interpolated to a global 0.5 degree longitude-latitude grid at 3-hourly output steps with 137 model level on a hybrid coordinate system. Additionally, NWP data are converted to a 0.2 degree longitude-latitude grid for a European region. The LPD model FLEXPART has been extensively used in this configuration to support the PTS of the CTBTO in the framework of the WMO CTBTO atmospheric backtracking response system.

8. Ensemble dispersion modelling becomes more and more used in atmospheric transport modelling due to increasing availability of computational and storage capabilities. The benefit of ECMWF ENS driven FLEXPART runs compared to ECMWF HRES driven ones for typical CTBTO applications were tested. Global ECMWF ENS data was retrieved for the period Dec., 1st to 15th, 2018. North hemispheric hindcast ensembles have been re-produced with the help of ECMWF experts for the period March, 11th to 25th, 2011 (period after the Fukushima accident), because model level data was no longer available for this products.

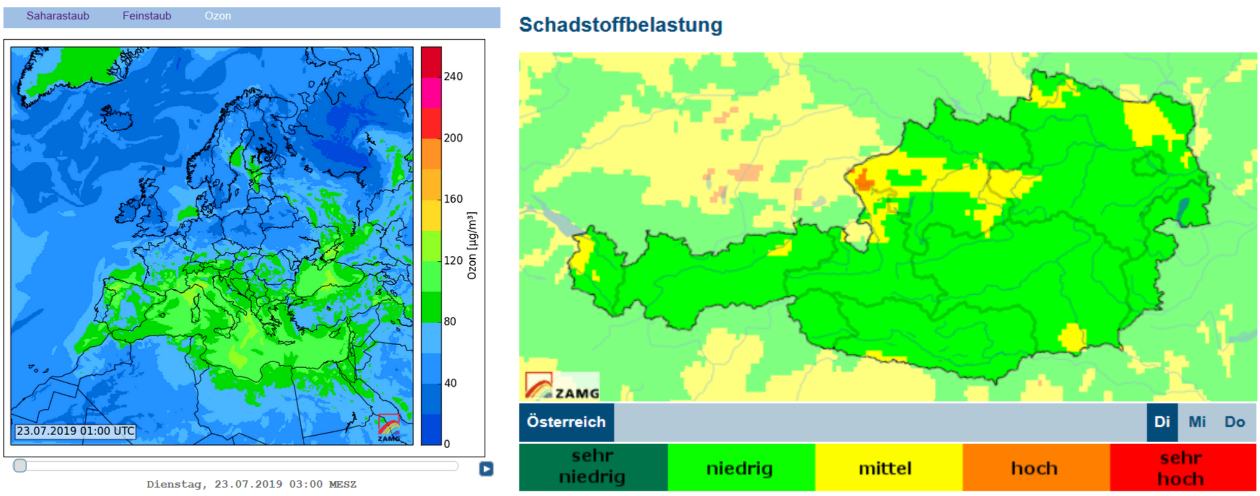

Figure 7: Ozone forecast for Europe (left) and Air quality index (very low, …, very high) for Austria is provided by the modelling system ECMWF-WRF-Chem

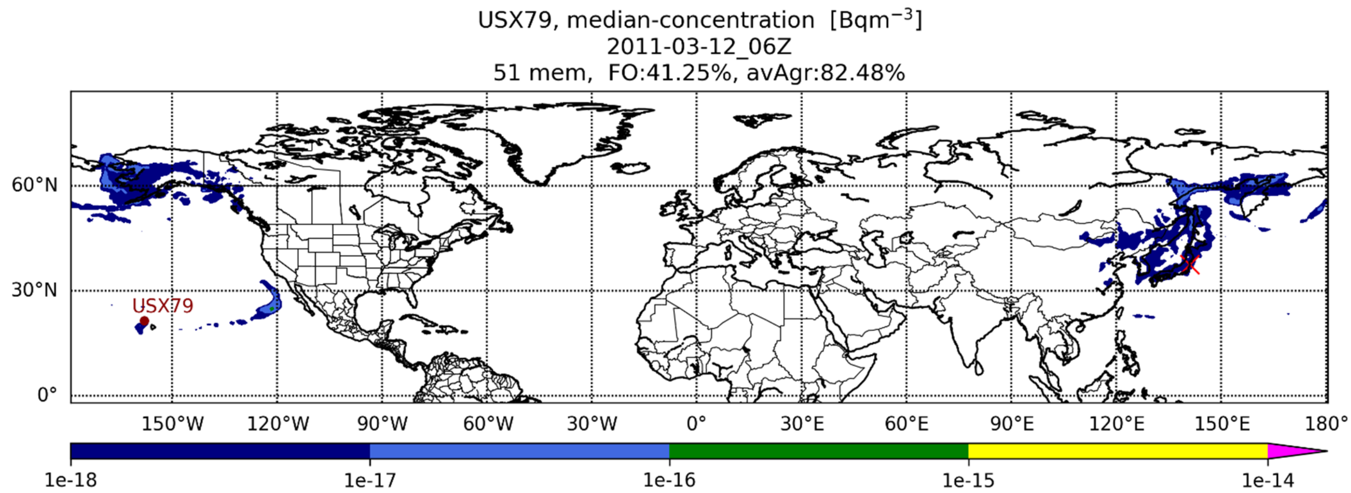

Figure 8: Median Source Receptor Sensitivity (SRS) backward field for species Xe-133 and a sample from the CTBT US International Monitoring Station (IMS) USX79 (Oahu) based on the FLEXPART runs driven with the full ECMWF-ENS ensemble.

3. Verification of ECMWF products

3.1 Objective verification

In general, NWP models (including ECMWF) are verified using different methods for deterministic and probabilistic forecast systems. These methods include:

- Point verification for meteorological standard parameters on screening level height (e.g. temperature, humidity, wind, …) and for vertical profiles
- Grid point based using 1) scores based on contingency tables (e.g. HR, FAR, ETS) and 2) Fraction Skill Score and 3) SAL.
- Verification based on area means

ECMWF products (HRES and ENS) are used as some kind of “benchmark” when comparing forecast quality to ZAMG LAMs. In addition to ECMWF some other global models are usually included in the model comparison (GFS, ICON, UM). Selected verification results are shown in the following section.

3.1.1 Direct ECMWF model output (both HRES and ENS), and other NWP models

ECMWF HRES vs. local LAMs

<u>2m Temperature:</u>

Figure 9 shows the BIAS for 2m temperature for a summer and winter season and for stations with differing location characteristics (all vs. flatland vs. mountainous area > 1000m) as a function of lead time. The computation of BIAS includes a simple height correction of DMO using a standard height gradient (0.6 degree /100m). Considering the upper row, we can see that in summer ECMWF HRES has a significant positive bias during night/morning and a cold bias during afternoon. This behaviour is visible both for flatland stations and for the ones with higher altitude while for AROME forecasts this is indicated just for flatland stations. During winter time, a diurnal cycle in the BIAS evolution is visible as well, but shifted when compared to summer. A positive bias is indicated during the day while it is (slightly) negative during night time. AROME forecasts show a similar behaviour overall, except for flatland stations where the diurnal cycle in terms of BIAS is just weakly pronounced.

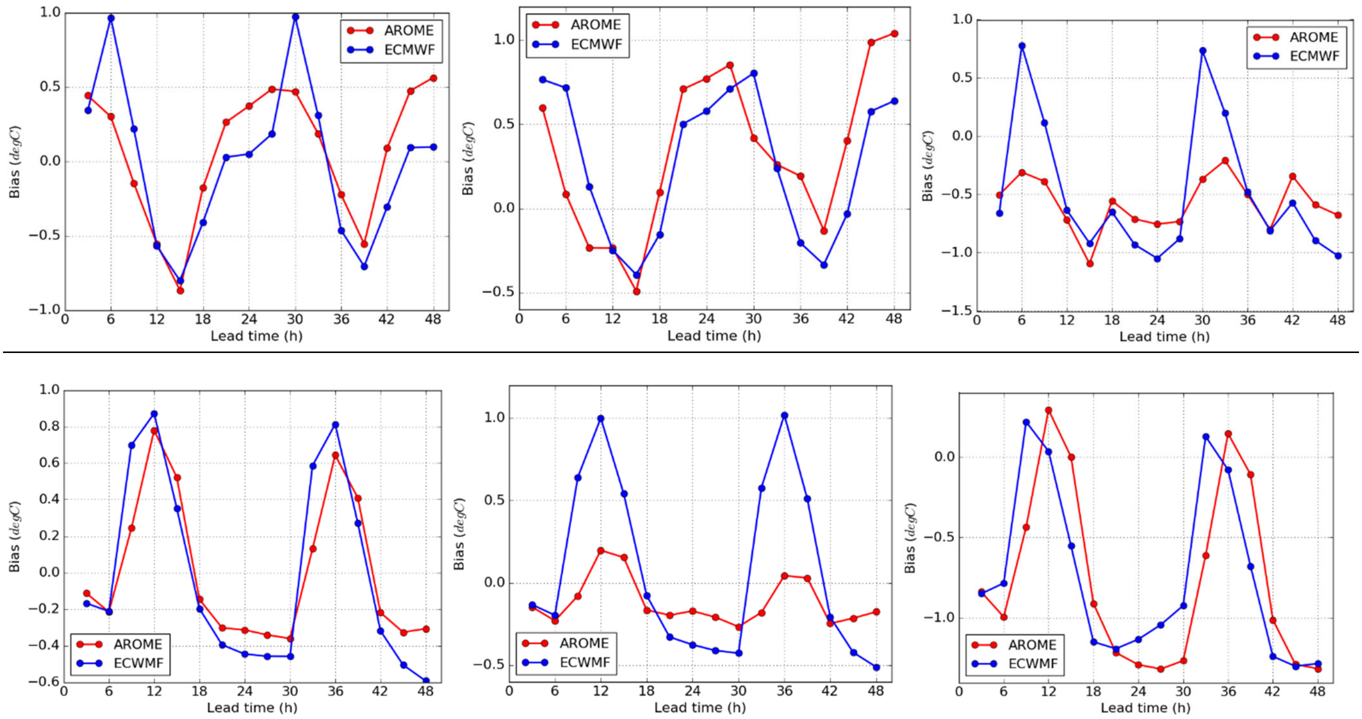

Figure 9: 2m Temperature BIAS for summer 2018 (upper row) and winter (bottom row) for ECMWF HRES and AROME-Aut for all (left) Austrian stations, for flatland stations with altitude < 500m (middle) and for stations with altitude > 1000m (right).

<u>Precipitation:</u>

In 2018 a further, bit more “user oriented” approach for precipitation verification was implemented. This is done using small areas (0.2 x 0.2 degree) for which the mean forecasted and observed (INCA analysis; Haiden et al. 2011) precipitation values are compared. Figure 10 shows approx. 100 areas spread over Austria, which represent areas corresponding to major cities and popular touristic places. Fig 11 show the results as tables for HR (Hit Rate), FAR (False Alarm Ratio), MR (Miss Rate) and ETS for different weather types, thresholds and lead times for a two month summer period. For example, the upper left table in Figure 11 shows the scores for all events with observed (area mean) precipitation > 0.0mm / 6 hours for +18h forecasts initialized at 00 UTC - summed up for all areas shown in Fig 10. There are 3 entries in each table, representing the scores for different weather types (0XXX: weak gradient situations, 3XXX: south-westerly flow, 4XXX: north-westerly flow). It can be seen that e.g. HR is 95 percent for ECMWF HRES forecasts to get events > 0.0mm/6hours correct in weak gradient situations while it is reduced to 85 percent when considering days with a prevailing north-westerly flow. This characteristics is also visibly for stronger events (>1mm/6hour areal mean) ad higher lead time (+42h shown). Compared to AROME, ECMWF HRES achieves higher scores for low thresholds but lower ones for stronger events (not shown).

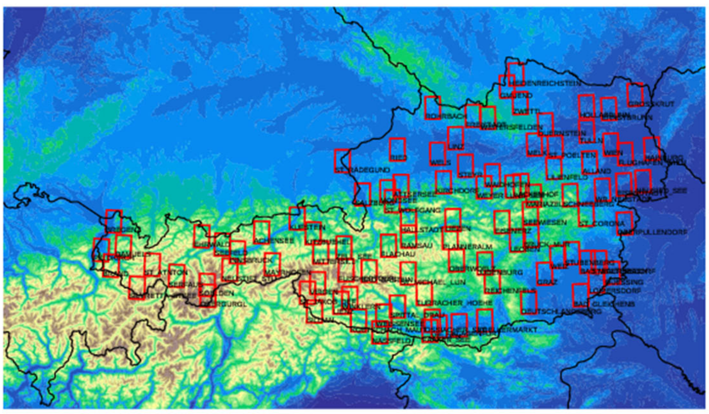

Figure 10: 0.2x0.2 degree areas used to evaluate forecast and observed (INCA analysis) precipitation means for different thresholds and weather types.

INIT: 00 + 18
EVENT THRESHOLD: 0.0 mm / 6 h

exp_name	hr	far	mr	ets
ECMWF_0XXX_00	0.95	0.20	0.05	0.45
ECMWF_3XXX_00	0.87	0.25	0.13	0.38
ECMWF_4XXX_00	0.85	0.19	0.15	0.46

#events (min): 296

INIT: 00 + 18
EVENT THRESHOLD: 1.0 mm / 6 h

exp_name	hr	far	mr	ets
ECMWF_0XXX_00	0.83	0.27	0.17	0.48
ECMWF_3XXX_00	0.79	0.42	0.21	0.37
ECMWF_4XXX_00	0.67	0.41	0.33	0.33

#events (min): 162

INIT: 00 + 42
EVENT THRESHOLD: 0.0 mm / 6 h

exp_name	hr	far	mr	ets
ECMWF_0XXX_00	0.88	0.15	0.12	0.47
ECMWF_3XXX_00	0.88	0.28	0.12	0.35
ECMWF_4XXX_00	0.85	0.18	0.15	0.47

#events (min): 296

INIT: 00 + 42
EVENT THRESHOLD: 1.0 mm / 6 h

exp_name	hr	far	mr	ets
ECMWF_0XXX_00	0.79	0.33	0.21	0.40
ECMWF_3XXX_00	0.77	0.48	0.23	0.30
ECMWF_4XXX_00	0.69	0.42	0.31	0.33

#events (min): 162

Figure 11: ECMWF HRES score tables (including HR, FAR, MR and ETS) for all events with > 0.0mm observed area mean (left) and > 1.0mm (right) for different weather types (0XXX: low gradient, 3XXX: south-westerly flow, 4XXXX: north-westerly flow). Scores are averaged over all areas shown in Fig. 10

Total cloudiness:

Verification of (total) cloudiness is more difficult than for other parameters. At ZAMG verification of total clouds is done both on station basis using synop observations (not shown) and for selected areas (with a size approx. 100x100km) using INCA cloudiness analysis (derived from a combination of satellite data and synop global radiation observations). The evolution of total cloudiness forecasts for a 100 day period is shown for a flat (Fig 12 left) and an Alpine area (Fig 12 right) in Austria in. The score used to measure forecast performance is the A component of the SAL tool adapted for cloudiness (A: Amplitude score; 0 = perfect; >0 overestimation; <0 underestimation). Each point in Fig 12 represent a computed A value for a +12h forecast initialized at 00 UTC while the solid lines represent 7d running means. The small box in the upper left additionally gives information about MAE, BIAS and sigma of the A score computed for the full 100d period. It is evident that all models (ECMWF, ALARO-Aut = ALA_O and AROME-Aut = ARO_O) have a tendency to over predict total cloudiness in both areas, but the overestimation is significantly more pronounced in the flatland area. There are mainly two aspects that may help to explain this behaviour: 1) similar as for precipitation diurnal cycle of (convective) cloudiness is shifted in the model towards too early triggering, probably resulting in general overestimation at 12 UTC; 2) models seem to have bit less problems to predict the cloud cover over mountains than in flatland areas thanks to the strong orographic forcing producing clouds at more or less similar locations every during typical (calm) summer days. Overall the differences between ECWMF HRES and local LAMs are rather small with bit lower MAE and BIAS overall for ALA_O.

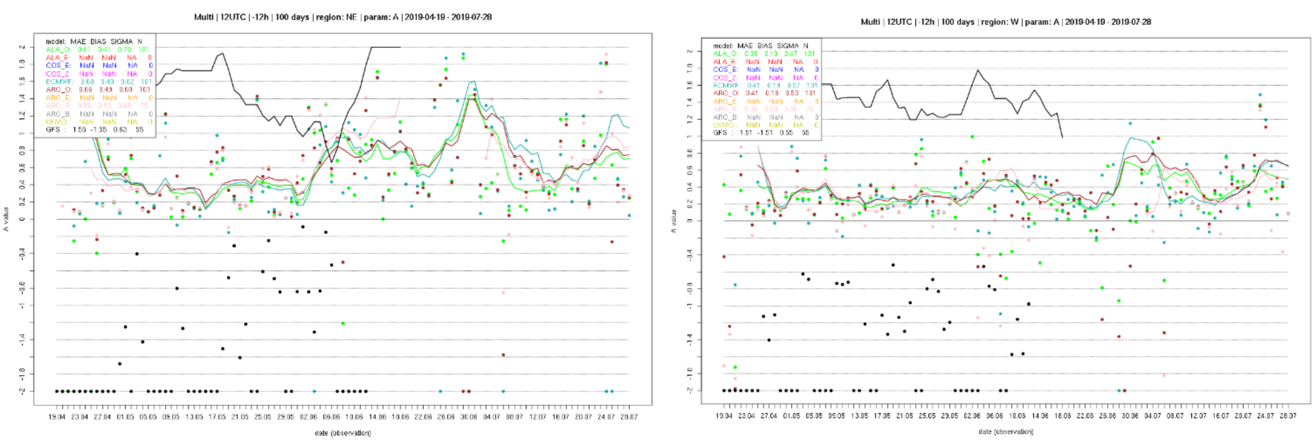

Figure 12: Amplitude (A) component for total cloudiness for a 100d period showing the evolution of the total cloud cover forecast for a flat (left) and Alpine area (right) in Austria. Points: single A values for a +12h forecast initialized at 00 UTC, lines: 7d running means.

ECMWF ENS vs. local LAMEPS

Fig 13 shows the RPS (ranked probability score; upper right) and Brier Score for different thresholds: 0.3mm/h (upper right), >3mm/h (bottom left) and >5mm/h (bottom right) calculated for a 1-month summer period for ECMWF ENS and C-LAEF 00 UTC runs. The benefit of the high resolution C-LAEF system is clearly visible, but for higher thresholds the differences are more limited to the period of the day with strongest convective activity (approx. 15 – 20 UTC). The score are based on all grid points of the 1x1km observation grid (INCA precipitation analysis including rain gauge + radar) to witch C-LAEF and ECMWF EPS forecasts are interpolated. Solid line represents the median value for RPS / BS based on the values for all grid points, shaded area denotes the 25%-75% scope.

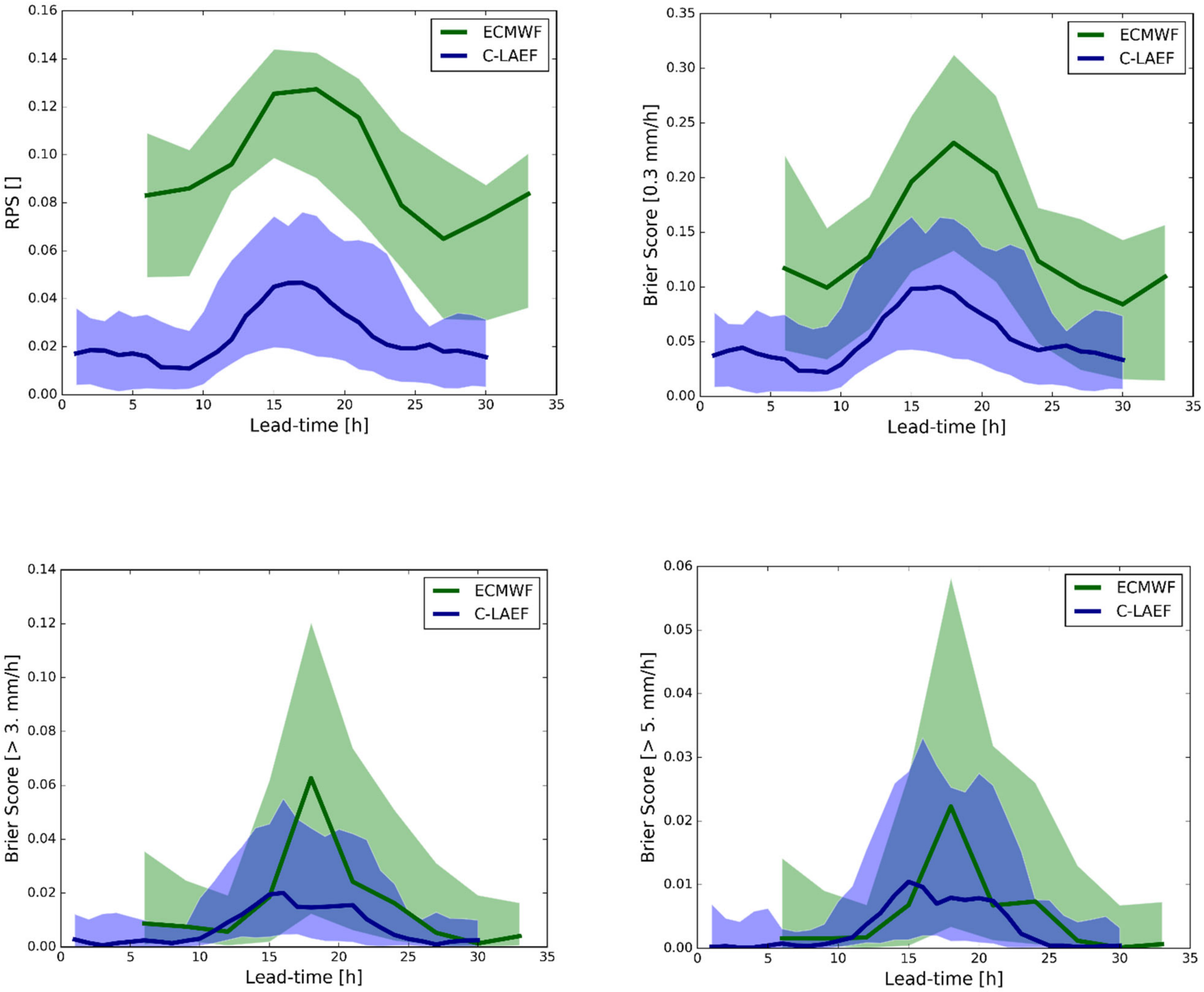

Figure 13**:** Amplitude Median (solid) and IQ-range (shaded) for C-LAEF (blue) and ECMWF EPS (green) for RPS (upper left) and BS (three thresholds shown) for 1 month (201607) based on the grid points of a 1x1km grid covering Austria; INCA precipitation analysis (rain gauge + radar) are used as observations

3.1.2 Post-processed products and end products delivered to users

3.1.3 Monthly and Seasonal forecasts

3.2 Subjective verification

3.2.1 Subjective scores (including evaluation of confidence indices when available)

3.2.2 Case studies

Critical weather situations (when red warnings are issued by ZAMG), are usually evaluated in detail by forecasters and modellers. An example is given in Fig. 14. A “red warning” was issued for a 4-day period in October 2018, indicated high precipitation amounts in the southwestern part of Austria. Some stations registered precipitation amount exceeding 500mm for this period (locally even up to 700mm). The event was well indicated by the models (ECMWF HRES and ENS, local models AROME-Aut and ALARO-Aut) as an extreme event in advance. According to Fig 11, ECMWF HRES (middle) forecasted maxima up to 400mm / 72h and ALARO-Aut (bottom) up to 600mm / 72h. This reveals the typical situations, although ECMWF HRES has significantly improved over the years, there is still an underestimation for orographic enhanced precipitation events in the Alpine region.

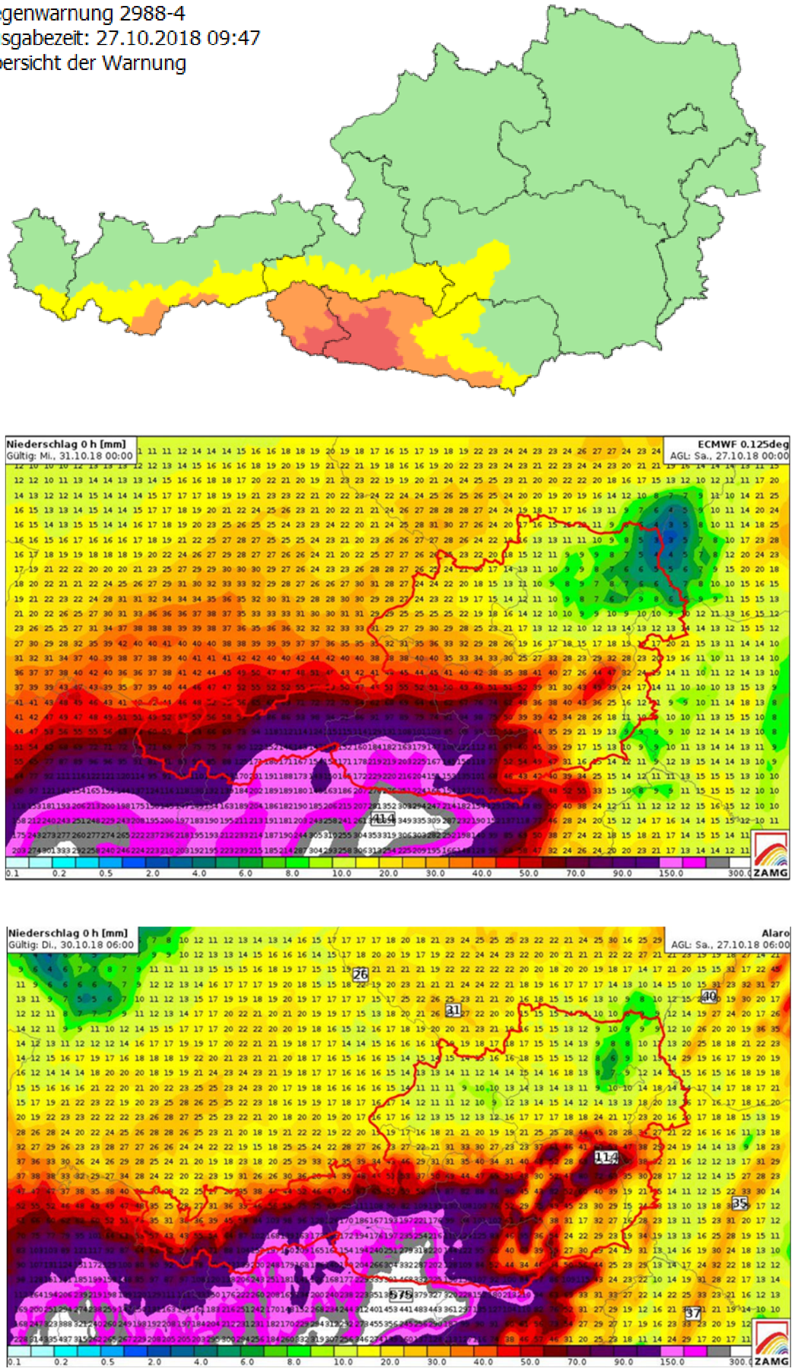

Figure 14: A ZAMG “red warning” for precipitation (top) and the corresponding model forecasts (mm/72h) for ECMWF HRES (middle) and ALARO-Aut (bottom). Period 20181027 – 20181030.

4. Requests for additional output

The ECMWF HRES and ENS products currently available are already seen as very comprehensive. There are no particular requests at the moment.

5. Feedback on ECMWF "forecast user" initiatives

6. References to relevant publications

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