Application and Verification of ECMWF Products 2021

1. Summary of major highlights

For ZAMG, ECMWF HRES and ENS products play a very important role for all ZAMG activities related to weather and environment: Operational forecasting and warning activities, the generation of products for internal and external users, providing boundary conditions for 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 on occasional basis, but interest is significantly growing. An overview of the application of ECMWF products is given in the following sections.

2. Use and application of products

A variety of ECMWF products is used as the main source for operational weather forecasts, warnings and the generation of (derived) products. While ECMWF HRES runs are heavily used and represent the main source for operational weather forecasts, information from ECMWF ENS is then used as additional information mainly in critical weather situations. ECMWF HRES and ENS gridded data are transferred to ZAMG and visualized with the local software (see figure 1).

2.1 Direct Use of ECMWF Products

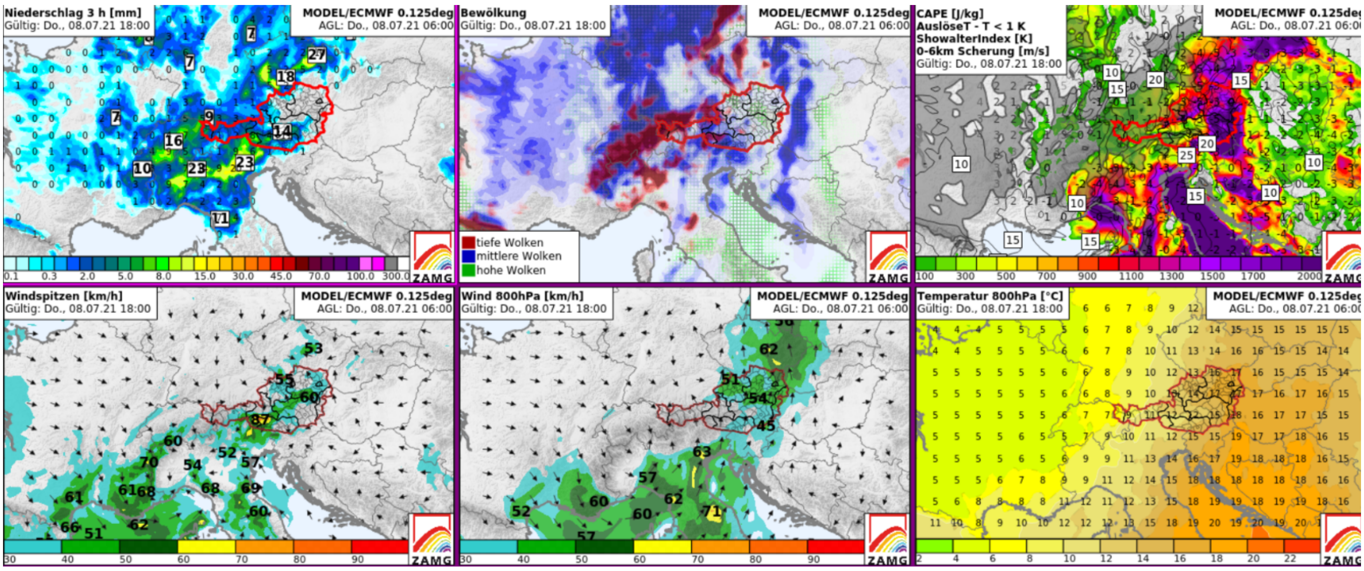

Figure 1: Selected products/plots generated from ECMWF HRES with the local visualization (from upper left to lower right: precipitation, cloudiness, CAPE, wind gusts, wind 800hPa, temperature 800hPa).

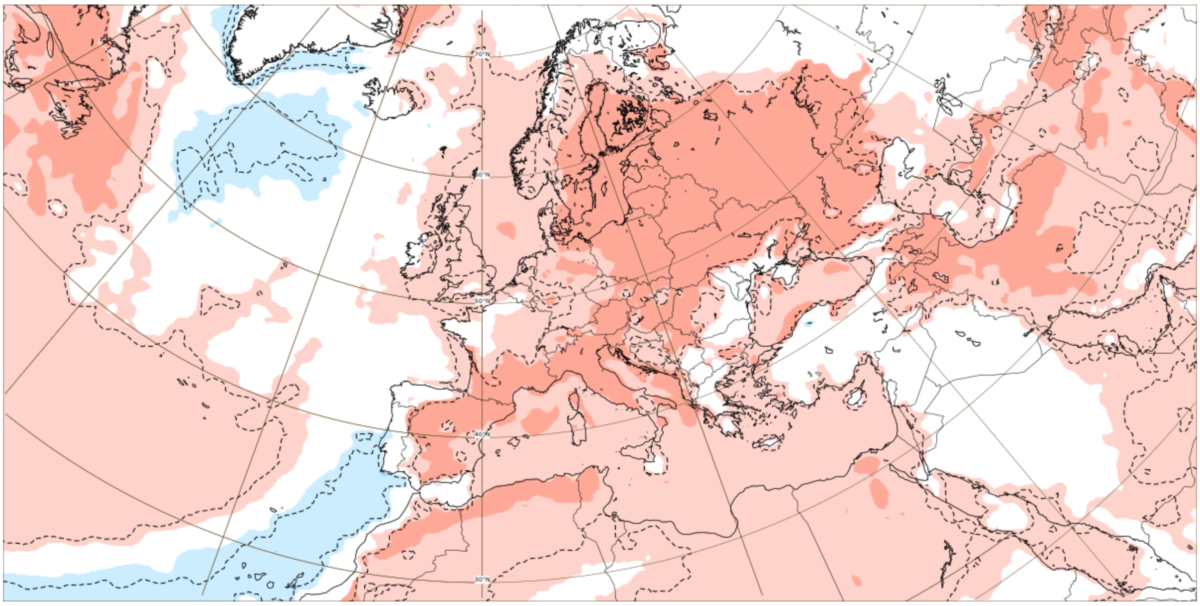

Figure 2: Temperature anomalies derived from the ECMWF ENS (extended) system available via OpenCharts

Open Charts is used on occasional basis so far as most of the products needed for operational forecasts are produced with the local visualization software. But so far Open Charts was found very useful, in particular for products from ECMWFs monthly and seasonal forecast systems (see figure 2).

2.2 Other uses of ECMWF output

2.2.1 Post-processing

ZAMG has implemented a statistical post-processing method based on standardized anomalies model output statistics (SAMOS, Dabernig et al. (2020)). Therefore, the deterministic and the probabilistic ECMWF models are used in combination with the different AROME realisations at ZAMG. As gridded observation, INCA analyses are used which allows to produce a spatial post-processed product with a resolution of 1 km. Currently, SAMOS is available for temperature as a pre-operational product. An example of SAMOS is shown in figure 3. Additionally, INCA and the raw models (not all shown) are presented to demonstrate the necessity for post-processing in Alpine regions. While AROME-RUC would almost resemble the spatial resolution of INCA, the ECMWF models are important to provide information especially for forecast projections beyond the lead time of the AROME model.

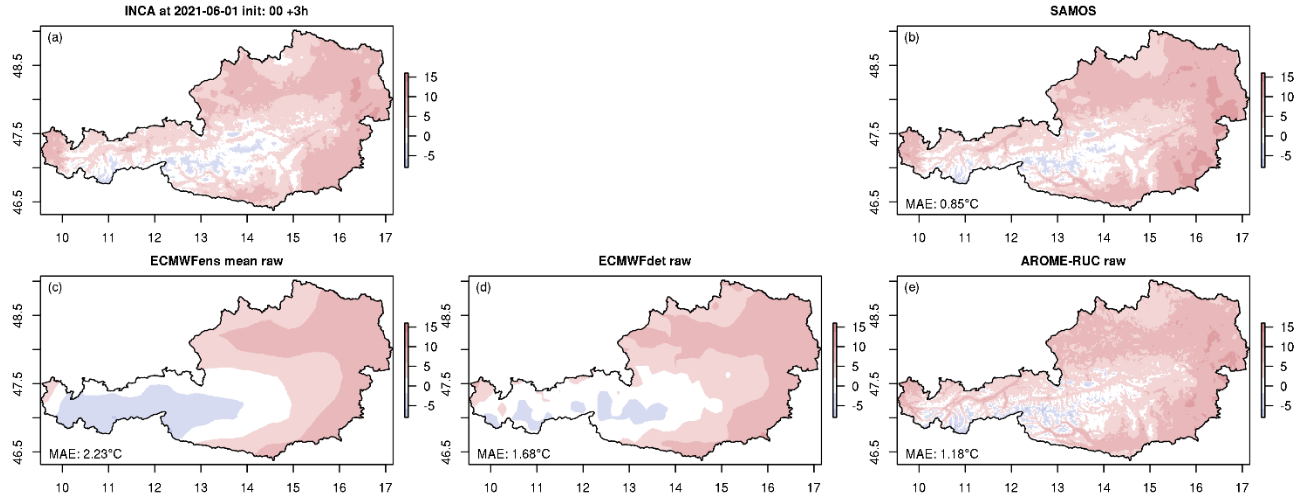

Figure 3: Temperature forecast of SAMOS (b) and the raw model forecasts of ECMWF ensemble mean (c), ECMWF deterministic (d) and AROME-RUC (e) in comparison with INCA analysis (a) for May 1st 2021 at 3 UTC. In the lower left corner the MAE averaged over all Austria for the different model is displayed.

The meteogram of Wien/Hohe Warte in Figure 4 shows the post-processed forecast with the uncertainty in red and the corresponding INCA analysis as solid black line. Although the AROME models are only provided until +12 h (RUC) or +60 h (AROME / C-LAEF), no jumps are visible at the transitions to only ECMWF which results in a seamless temperature forecast for forecasters and end users.

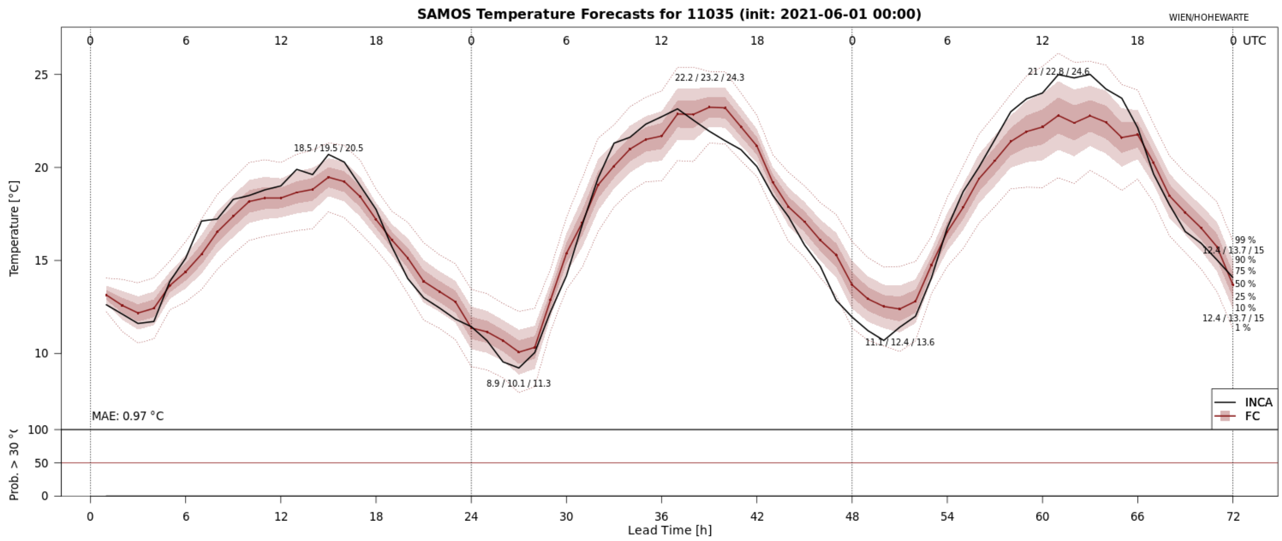

Figure 4: Meteogram from May 1st 2021 initialised at 00 UTC for Wien/Hohe Warte with the post-processed temperature forecasts in red as percentiles and the INCA analysis as black solid line.

Dabernig, M.,I. Schicker, A. Kann, Y. Wang, M. Lang, 2020: Statistical Post-Processing with Standardized Anomalies Based on a 1 km Gridded Analysis. – Meteorol. Z.29, 265–275, DOI:10.1127/metz/2020/1022.

2.2.2 Derived fields

For ECMWF ENS 00 and 12 UTC runs we perform clustering of the ensemble members based on the ECMWF approach, according to L.Ferranti and S. Corti 2011, with some adaptations. Since many years we plot representative members for each of the clusters. Additionally, in order to support shift forecasters severe weather warning issues we additionally compute exceedance probabilities for a list of significant parameters. Some variables are different between winter (from November to April) and summer (May until

October). Here is the full list of parameters: Minimum temperature at 2m, maximum temperature at 2m, total rainfall within 24 hours, total rainfall in 48 hours, total rainfall in 72 hours, wind gust, snow depth.

Figure 5 (maximum temperature >35) indicates threshold probabilites for very high maximum temperatures for two different clusters, where cluster 1 contains 21 and cluster 2 just 16 out of 50 members from the full ensemble. Focusing on Austria, there is an even stronger signal for very high temperatures in cluster 1 than in cluster 2.

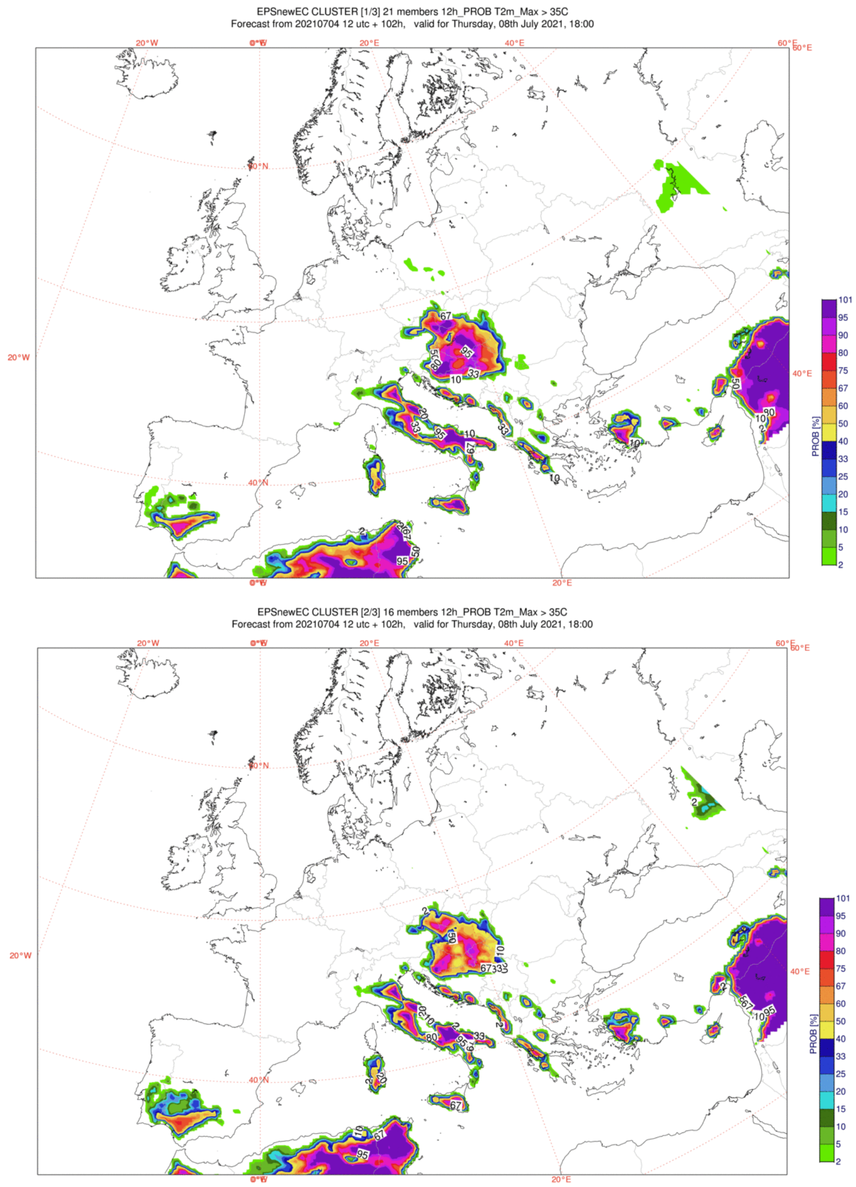

Figure 5: Probability [%] of T2m maximum greater 35°C valid 8 Jul 2021, 18 UTC 4 Jul 2021, 12 UTC +84h for cluster 1 (top, 21 members) and cluster 2 (bottom, 16 members)

Another, somewhat more typical example for the use of cluster derived probabilities at ZAMG is shown in Figure 6. This example illustrates the challenging task to forecast (mainly convectively induced) summertime precipitation about 5 days ahead. There are quite different probability patterns indicated across Central Europe, with maximum likelihood of severe rainfall in Cluster 2 for western Austria and northern Switzerland and - on the other hand a complete shift of the maxima regions in Cluster 3, covering especially lowlands around the Alps and north of Slovenia.

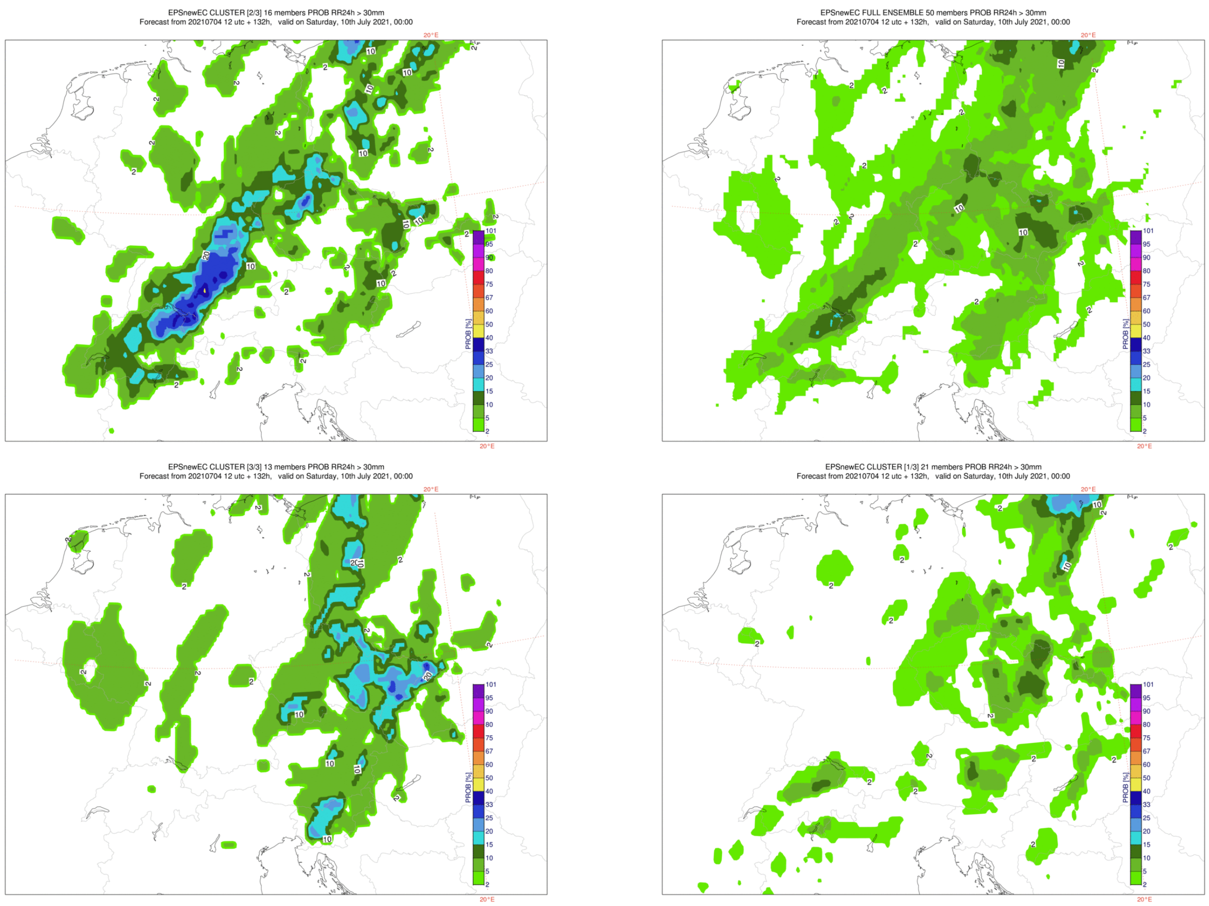

Figure 6: Probability [%] of total precipitation greater 30mm/24h valid 10 Jul 2021, 00 UTC 4 Jul 2021, 12 UTC +132h for cluster 1 (upper left, 21 members), cluster 2 (upper right, 16 members), cluster 3 (bottom left, 13 members)

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:

Weather models:

- 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.

- The current LAM ensemble forecast system C-LAEF (Wastl et al 2020; 2.5kmL90, 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.

Air Quality models:

The responsibilities of ZAMG as the national weather service of Austria include the support of the federal provinces and the public, providing advice and counselling services, as well as expert opinions, in areas related to the protection of the environment. ZAMG operates the WRF-Chem chemical transport model system to conduct operational air quality forecasts covering Europe (12 km resolution) and the nested Alpine region with Austria at a finer (4 km) resolution. The 72-hour forecasts of the most relevant pollutants (e.g., PM10, O3, NO2, Sahara dust) are made available to the public. Meteorological fields used as initial and boundary conditions are derived from the European Centre for Medium-range Weather Forecasts (ECMWF).

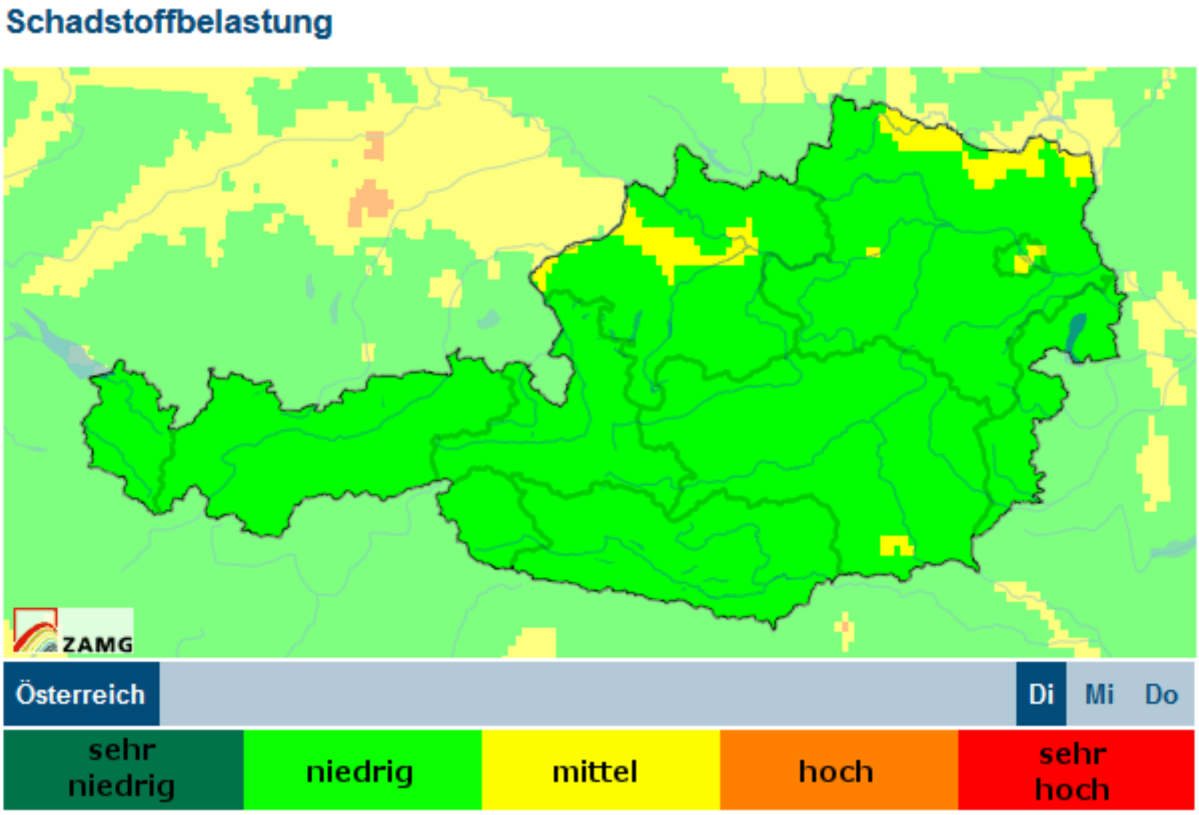

Figure. 7: Air quality index (O3, NO2, PM10, PM2.5, SO2) predicted for the next 3 days for Austria (https://www.zamg.ac.at/cms/de/umwelt/luftqualitaetsvorhersagen/caqi/oesterreich/heute).

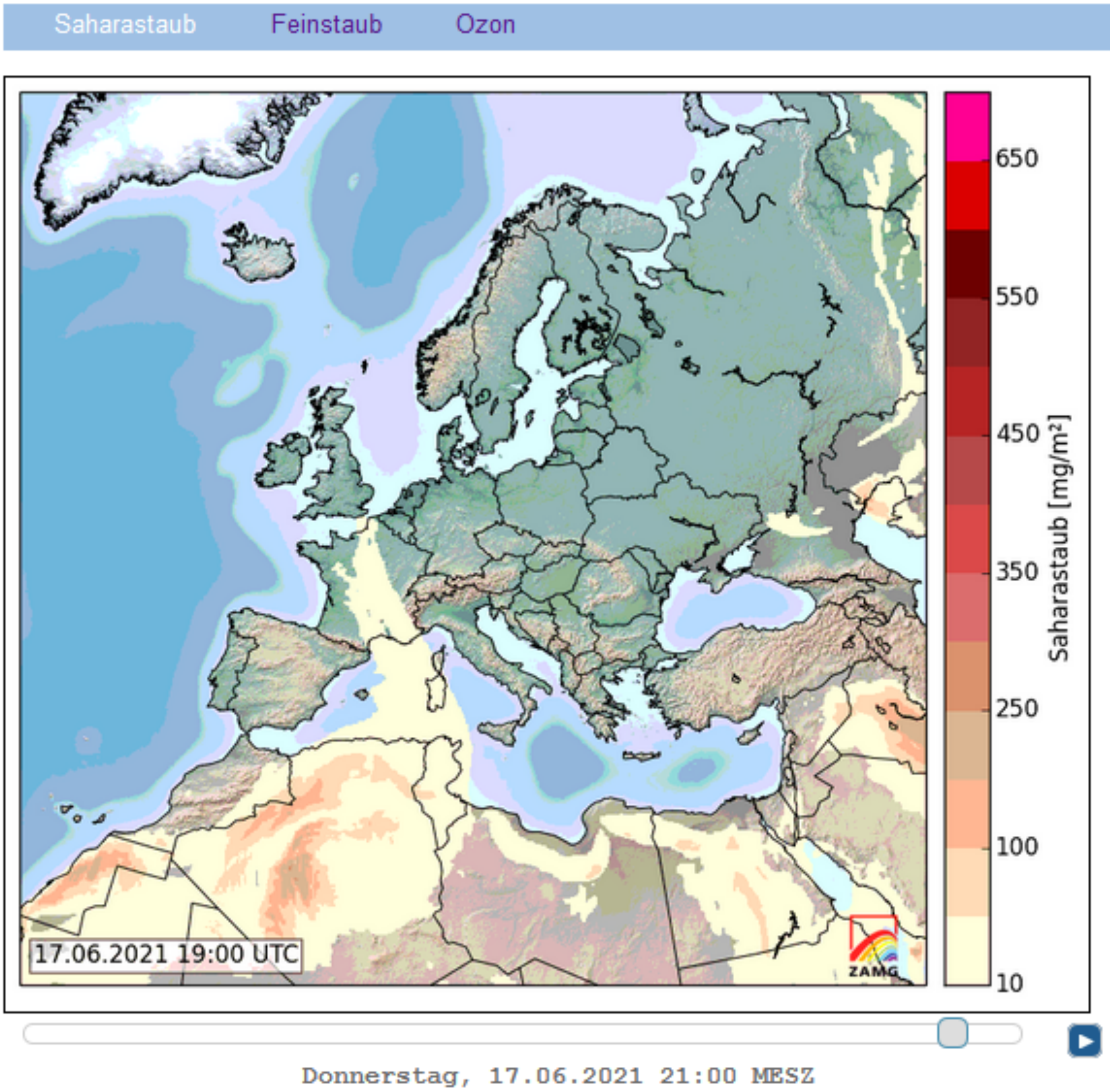

Figure. 8: Forecast of Saharan dust transport for the next 3 days (https://www.zamg.ac.at/cms/de/umwelt/luftqualitaetsvorhersagen/schadstofftransport/?imgtype=0). ZAMg also provides large scale PM10 and O3 predictions.

Based on the above mentioned existing applications the following interfaces to the EU Copernicus programme (and previous projects like MACC) will be maintained. ZAMG will provide downstream services for end users in Austria based on:

- Chemical boundary conditions from global forecast: ZAMG uses the operational pollution forecast from the global forecasting system provided by the Copernicus Atmosphere Monitoring Service as boundary conditions for the chemical transport model.
- Emission inventory from TNO: European emission data is an important input data for the chemical transport model at ZAMG. The latest data is provided by TNO and integrated into the modelling system at ZAMG.

Volcano tool:

In Austria to complement the VAACs authoritative information and to provide tailored services to Austro Control (air navigation services provider for Austria), a specific IT and modelling platform was developed at ZAMG to facilitate the triggering, modelling and visualization of volcanic ash and SO2 clouds. Once a volcano erupts an alert will be issued, e.g. based on the VAACs GTS system or the SACS system, and a model simulation is started. Depending on a few parameters that can be adjusted the dispersion of the ash or SO2 plume is calculated and results are automatically sent to Austro Control. The ZAMG-VT makes use of pre-defined emission databases but also has the possibility to use a specific source term provided by the end user. Output of the dispersion calculations is interpolated to flight levels, either globally or for a region of interest (e.g. Europe). As meteorological input global ECMWF data is used and prepared for the FLEXPART model that simulates the dispersion. Results are visualized either by the tool itself or, since output can be produced in the standard NetCDF format, by any other visualization tool able to digest the aforementioned format.

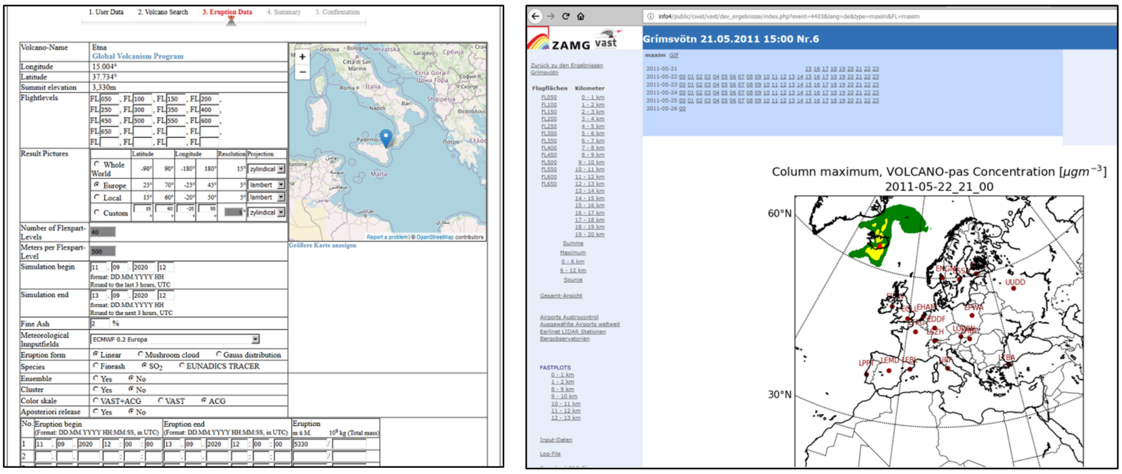

Figure 9: Web-Interface of the ZAMG-VT for launching a dispersion run (left) and browsing the results of a dispersion run (right).

3. Verification of ECMWF products

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, ...) . Selected verification results are shown in the following section.
- For events extreme events ("red warning level") detailed analysis of available models is conducted.

3.1 Objective verification

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

Verification of the Austrian ensemble system (C-LAEF; Wastl et al., 2021) has been made for a summer (August + September 2019) and winter (February+ March 2020) test period in comparison to the ALADIN-LAEF system (Wang et al., 2011) and the ECMWF ENS.

Some results of the surface verification can be found in the following figures – more information on this is given in the C-LAEF system paper (Wastl et al., 2021).

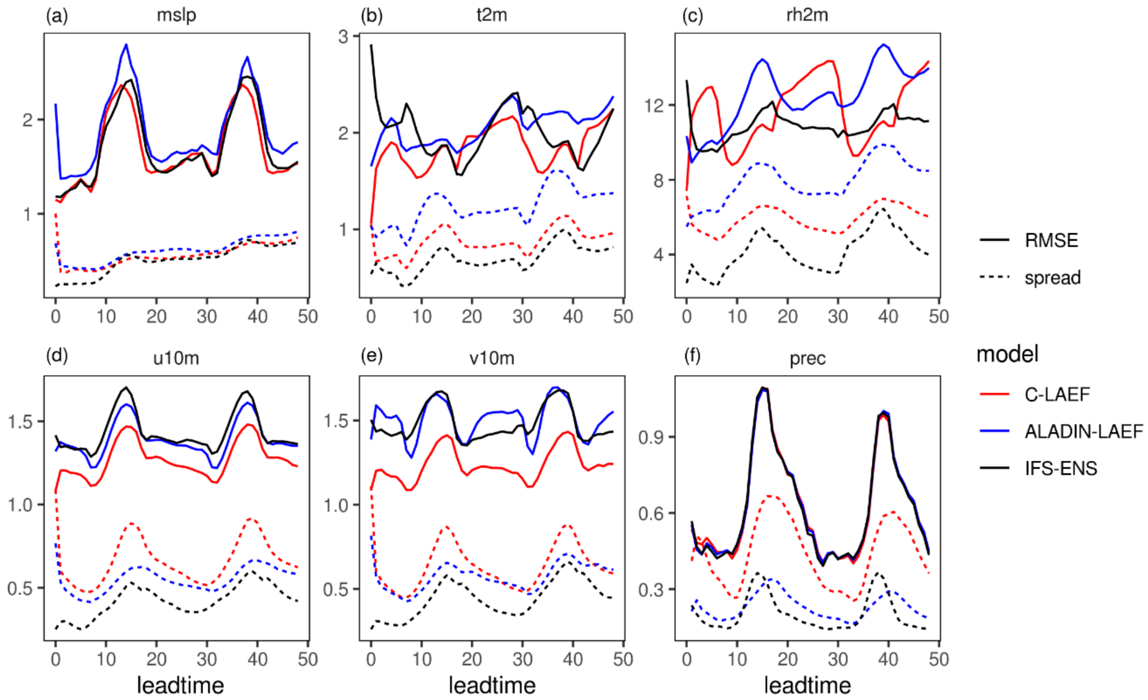

Figure10: RMSE of the ensemble mean (solid lines) and ensemble spread (dashed lines) as a function of lead time for (a) mean sea level pressure (hPa), (b) 2 m temperature (K), (c) 2 m relative humidity (%), (d) u and (e) v component of 10 m wind (m s-1) and (f) 1-hourly accumulated precipitation (mm) in the summer period.

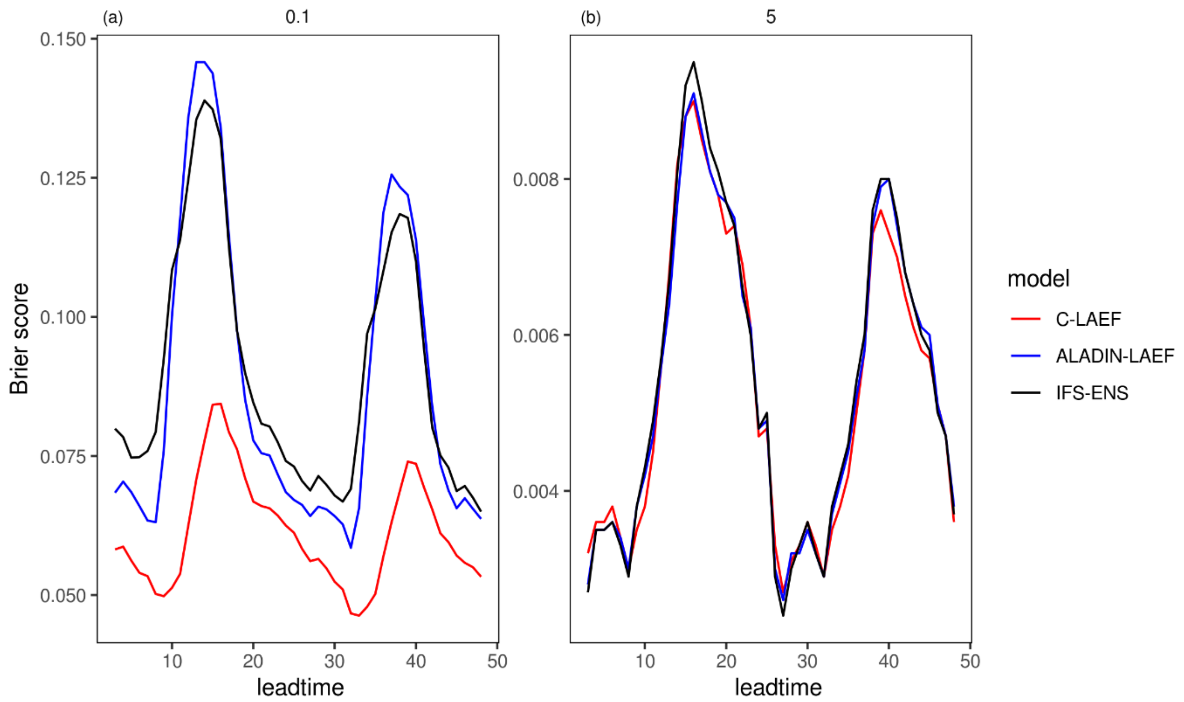

Figure 11: Brier score as a function of lead time for 1-hourly accumulated precipitation in the summer period for the thresholds (a) 0.1 mm/h and (b) 5 mm/h.

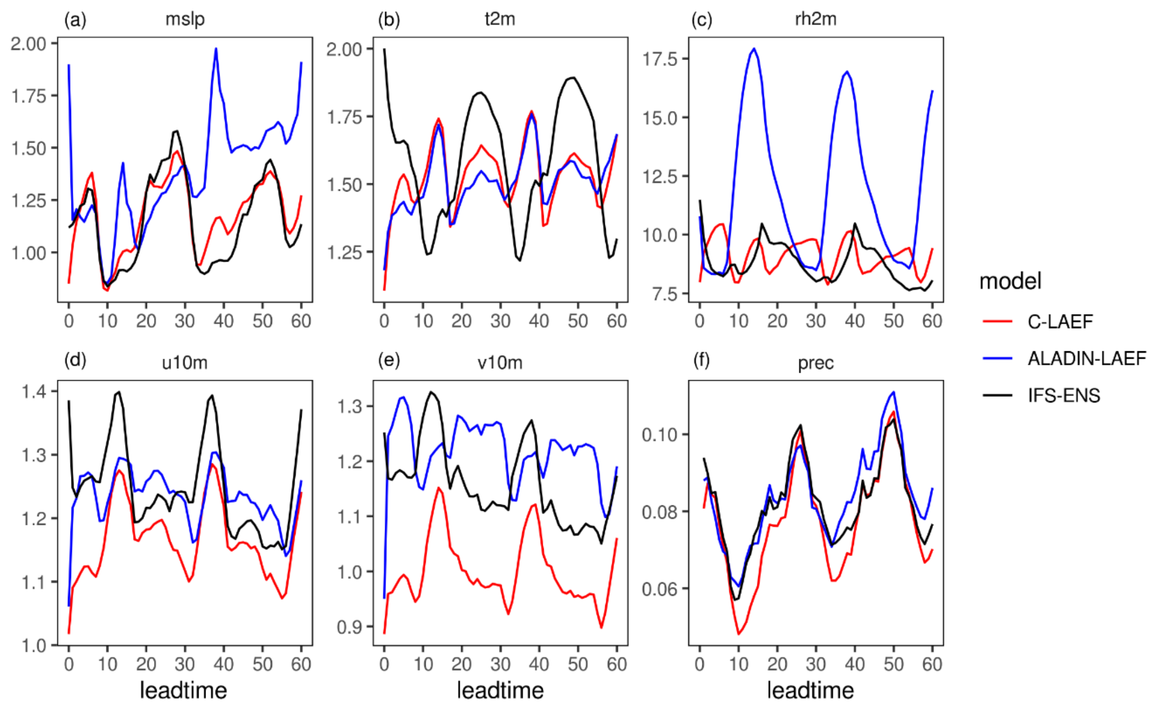

Figure 12: CRPS as a function of lead time for (a) mean sea level pressure (hPa), (b) 2 m temperature (K), (c) 2 m relative humidity (%), (d) u and (e) v component of 10 m wind (m s-1) and (f) 1-hourly accumulated precipitation (mm) in the winter period.

3.2 Subjective verification

5. References to relevant publications

Dabernig, M.,I. Schicker, A. Kann, Y. Wang, M. Lang, 2020: Statistical Post-Processing with Standardized Anomalies Based on a 1 km Gridded Analysis. – Meteorol. Z.29, 265–275, DOI:10.1127/metz/2020/1022.

Wang, Y., Bellus, M., Wittmann, C., Steinheimer, M., Weidle, F., Kann, A., Ivatek- Šahdan, S., Tian, W., Ma, X., Tascu, S. and Bazile, E. (2011) The Central European limited-area ensemble forecasting system: ALADIN-LAEF. Quart. J. Roy. Meteor. Soc. 137, 483–502. https://doi.org/10.1002/qj.751

Wastl C., Y. Wang, A. Atencia, F. Weidle, C. Wittmann, C. Zingerle, E. Keresturi, 2021: C- LAEF: Convection- permitting Limited- Area Ensemble Forecasting system. Quart. J. Roy. Meteor. Soc. 147, 1431– 1451. https://doi.org/10.1002/qj.3986