CURRENT UTILIZATION OF ECMWF FORECASTS IN OPERATIONAL WEATHER FORECASTING AND HIGH-RESOLUTION NUMERICAL MODELLING AT IHMS

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Utilisation of ECMWF forecasting products

The main departments within our institution that utilize ECMWF products on a daily basis and whose work is primarily based on these products

- Department for Weather Analysis and Forecasting, Satellite and Radar Meteorology
- Department for Numerical Modeling

Department for Weather Analysis and Forecasting, Satellite and Radar Meteorology

- Faces a major problem - insufficient expert staff. Shifts run 4 a.m. to 4 p.m. with just one duty forecaster.
- The forecast area covers Montenegro and the southern Adriatic Sea.
- The primary source for forecast preparation is ECMWF.
- ECCharts and similar software solutions significantly facilitate the forecasters' work.

Department for Weather Analysis and Forecasting, Satellite and Radar Meteorology

The most commonly utilized medium-range forecast charts include:

- Mean sea level pressure & 850 hPa wind speed
- 500 hPa geopotential height & 850 hPa temperature
- Mean sea level pressure & 200 hPa wind
- Rain & mean sea level pressure
- Total cloud cover
- Wind & relative humidity (various levels)
- Precipitation type
- Total precipitation
- Snowfall in the last 6 hours

Department for Weather Analysis and Forecasting, Satellite and Radar Meteorology

For forecasting severe weather events, forecasters also utilize the Extreme Forecast Index (EFI), including:

- Multi-parameter EFI (24-hour period)
- EFI for 2-meter temperature
- EFI for wind speed
- EFI for wind gusts
- EFI for precipitation
- EFI for significant wave height

Another important type of visualization tools are:

- Meteograms

Department for Numerical Modeling

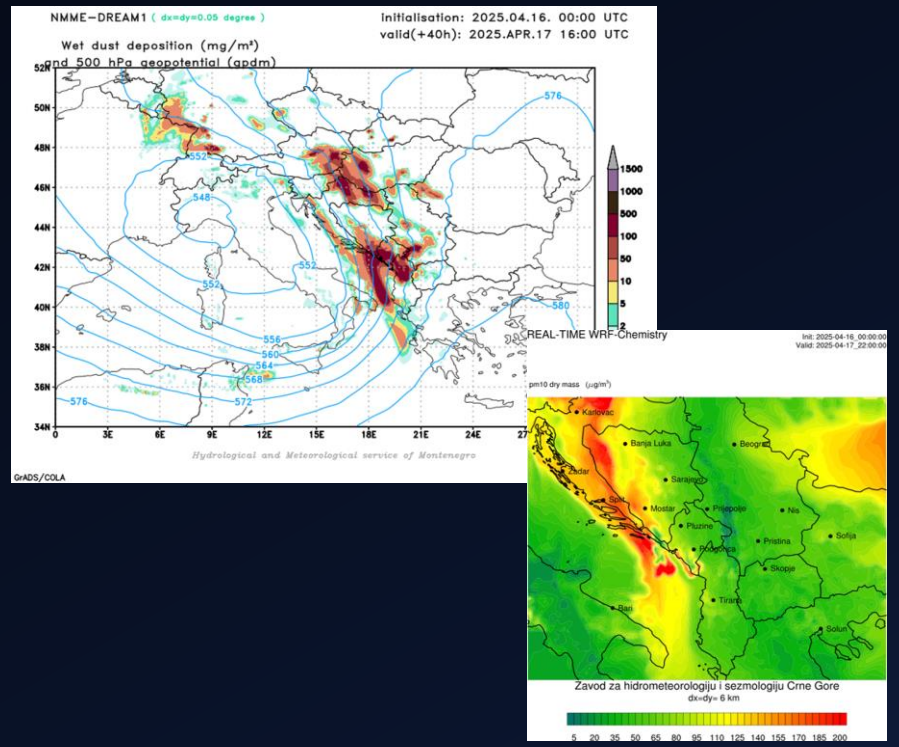
On a daily basis at the Department, the following model initializations are performed, each depending on ECMWF boundary conditions:

- WS-Eta_e25km (00 UTC), 0/72/3
- WRF-NMM_e3km (00 UTC , 12 UTC) , 0/144/1
- WRF-NMM_e1km (00 UTC, 12 UTC) , 0/144/1
- WRFChem (6 km i 2 km) (00 UTC, 12 UTC), 0/72/1
- NMME-DREAM (5km i 2km) (00 UTC), 0/72/1
- NMMB_3.5km (00, 12 UTC), 0/144/1
- WRF-NMM_e0.4 km (00 UTC) , 0/144/1 [Test phase]

Department for Numerical Modeling

All department products are available at the following links, with a limited archive spanning up to 2 to 3 months back.:

- Numerical forecast maps https://meteo.co.me/page.php?id=33
- Computing forecast https://meteo.co.me/page.php?id=34
- Meteograms http://nwp2.meteo.co.me/metgrams/oper1/index.php
- Dust deposition https://meteo.co.me/page.php?id=126
- nwp server: nwp1.meteo.co.me
- bckp nwp server: nwp2.meteo.co.me/nwp1/modeli/



Evaluating ECMWF Weather Forecast Products

- There is no real-time verification, nor direct verification available for the locations of ECMWF IFS or AIFS weather forecasts
  - Montenegro features highly complex terrain. Its coastal area is bordered by high mountains running from south to north; valleys, lakes, and canyons make weather forecasting extremely challenging
  - There is a tendency and ongoing experimentation to improve location-specific forecasts by combining real-time measurements and AIFS general synoptic forecasts, using machine learning approaches and nearest points forecasts corresponding to the desired locations.

- However, there are already verified Limited Area Model (LAM) High-Resolution (HRES) systems that are run using ECMWF boundary conditions:
  - The operational WRF_NMME_1km model
  - Wind speed and direction derived from the output of this model are used for site-specific forecast verification at the wind farm location.

Evaluating ECMWF Weather Forecast Products

Verification of temperature, wind and precipitation fields for the high-resolution WRF NMM model over the complex terrain of Montenegro *DOI: 10.3233/THC-229016*

- Model performance for key meteorological parameters (temperature, wind, precipitation) varies by time of day, season, station altitude, and surrounding terrain.
- For temperature, WRF NMM shows weakest skill for Bar and Žabljak, but is most reliable for Golubovci; largest RMSD (4.9°C) recorded in April for Žabljak.
- The model tends to be cooler than observations around midday and warmer during the evening.
- Wind forecasts are generally overestimated (except for Bar, April–September), with errors more pronounced in winter; wind skill is highest for Golubovci, likely due to more homogeneous surrounding terrain.
- Precipitation verification shows WRF NMM underestimates totals at all stations; best results for Bar, worst for Pljevlja.

Enhancing wind energy production estimation over Montenegro using modeled and observed wind speeds and synoptic weather patterns *DOI: 10.2298/IJGI2501033Z*

- The synoptic situations were analyzed to identify the underlying weather patterns that favour maximum and minimum energy production lasting most of the day. Maximum energy production was associated with a deep trough over western Europe extending in a northwest-southeast direction and a pronounced meridional meandering jet stream. A ridge or anticyclone over the Balkan Peninsula, a more or less zonal jet stream and strong warm air advection over Montenegro characterized the atmosphere during the periods of minimum energy production.

Evaluating ECMWF Weather Forecast Products

- However, our highly experienced forecasters mostly know when, where, and to what extent models will generate errors based on their accumulated operational experience.
- The most challenging meteorological variable to forecast—one that has the greatest impact on citizens as well as on energy, agriculture, and other economic sectors—is precipitation, particularly its intensity and spatial distribution.
- The subjective assessment of forecasters is that ECMWF overall tends to underestimate precipitation.
- Weather situations that are significantly missed by both global and local numerical weather models are documented and archived so they can be reanalyzed in order to identify the underlying causes, with the goal of implementing corrective measures for similar future synoptic patterns.
- Nevertheless, due to staff shortages and the low probability of recurrence of sufficiently similar synoptic situations, the archive awaits utilization by future generations of meteorologists.

Evaluating ECMWF Weather Forecast Products

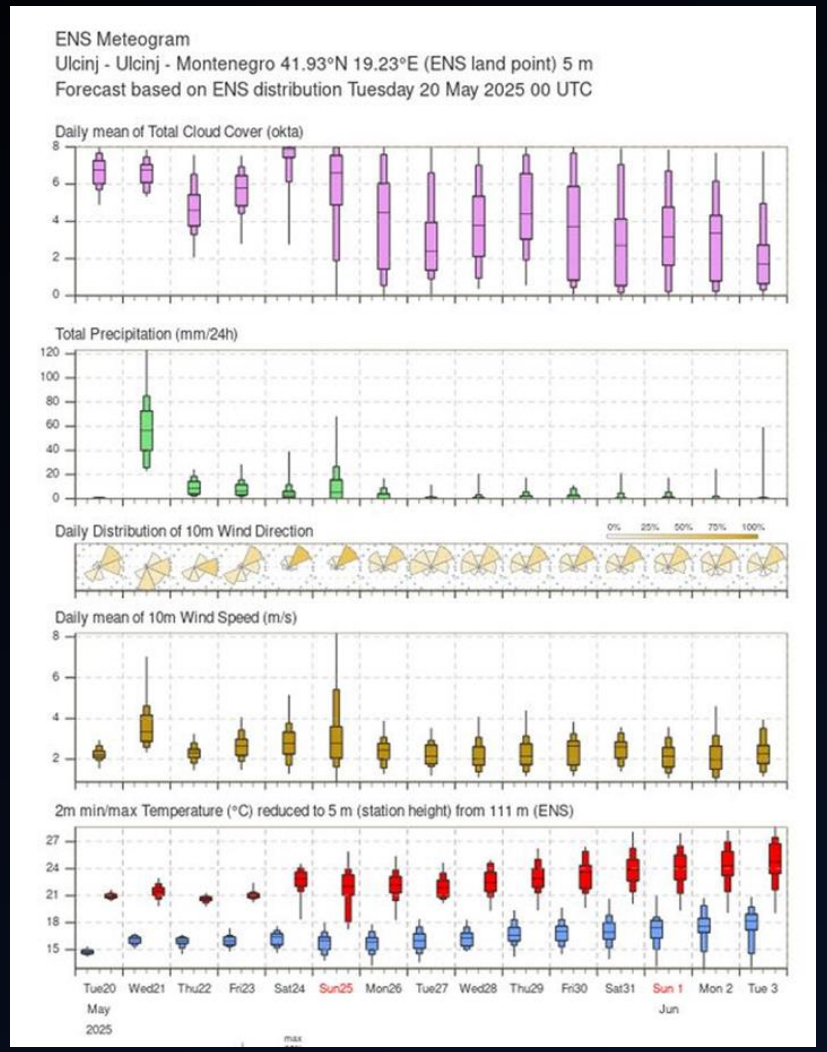
Poor forecast outcome our forecaster experienced at

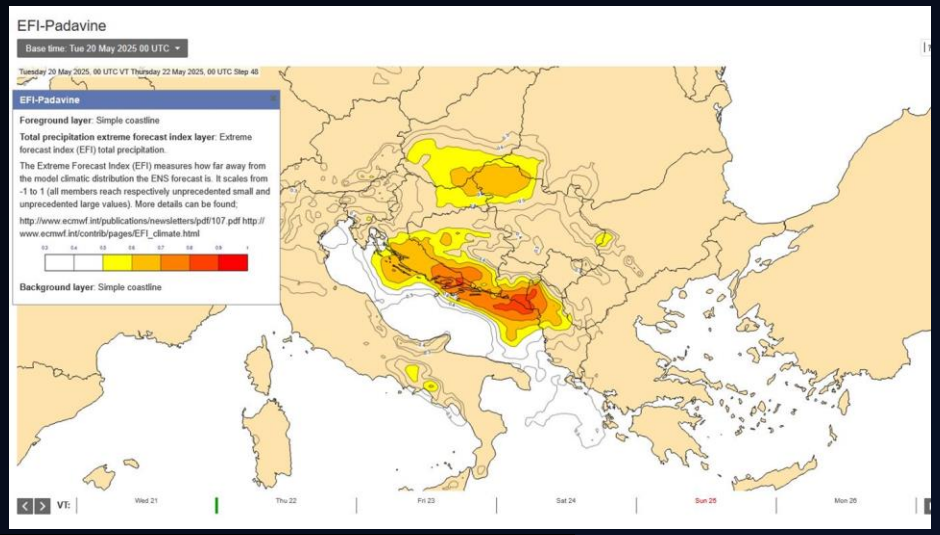
- **May 21st, 2025**
  - The forecast for Ulcinj predicted 60 mm of rain, but only 2 mm actually fell

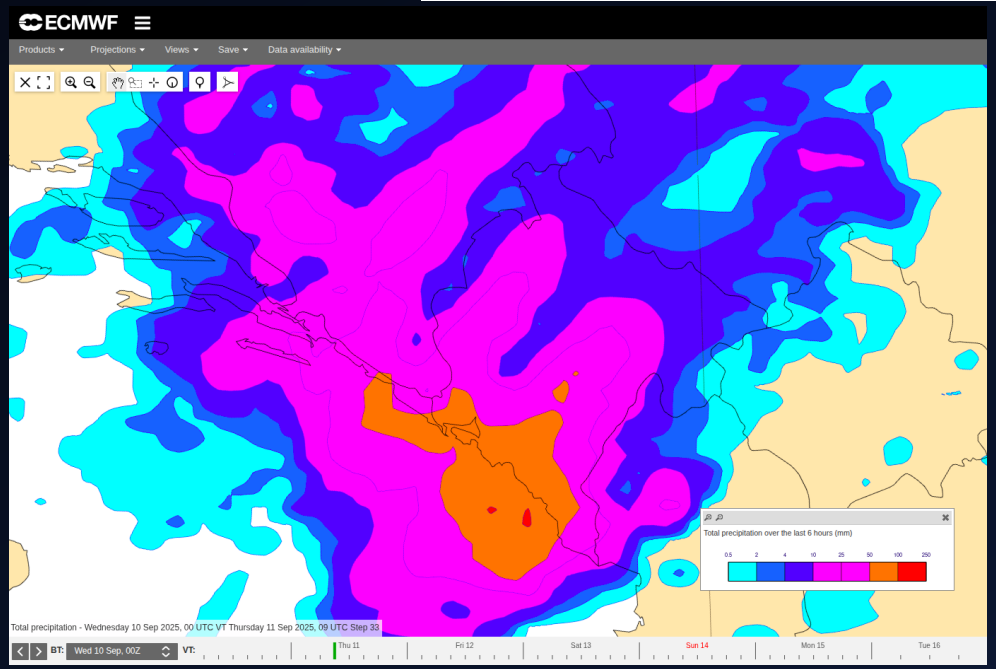
- **August 21st , 2025**
  - Based on the synoptic situation and the total precipitation forecast, we expected up to 100 l/m² (i.e., 100 mm) of rain in the coastal region. Although there was a lot of rain in the central part of Montenegro, none of the stations in the coastal region recorded any precipitation.

- **September 11th , 2025**
  - The forecast for Niksic municipality (central to west part of MNE) predicted less than 60 mm of rain, but 203 mm was actually measured at the main synoptic station in Niksic

Evaluating ECMWF Weather Forecast Products







Evaluating ECMWF Weather Forecast Products

There have also been forecasts with very good performance:

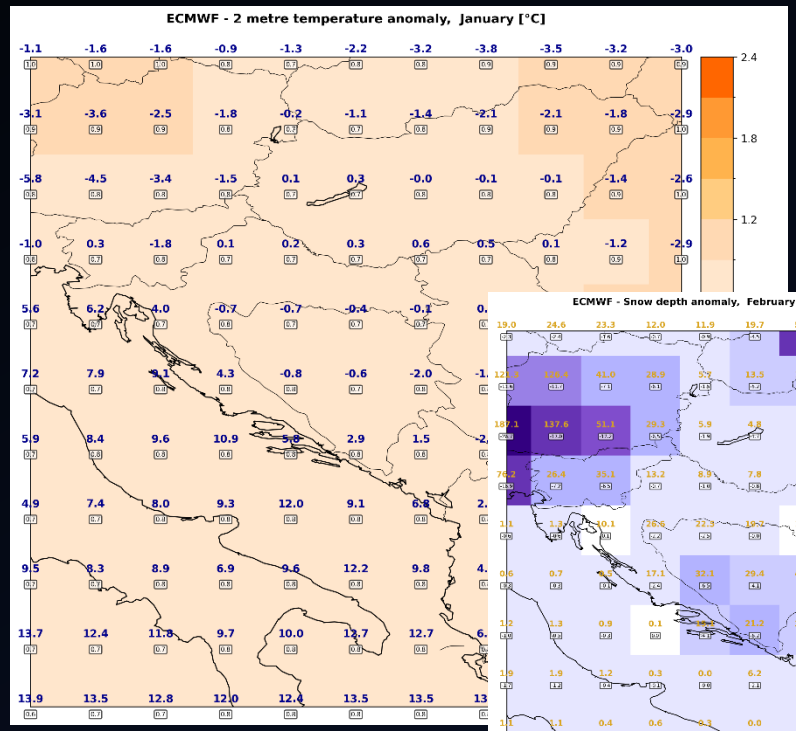
- We also had a well-performing forecast for an extreme weather event when more than 100 mm was predicted for the southwest of the country, and observations from many stations in that area confirmed the forecast performed well. This was a winter situation with a deep trough passing from the west, while Montenegro was under a southwesterly flow associated with it.

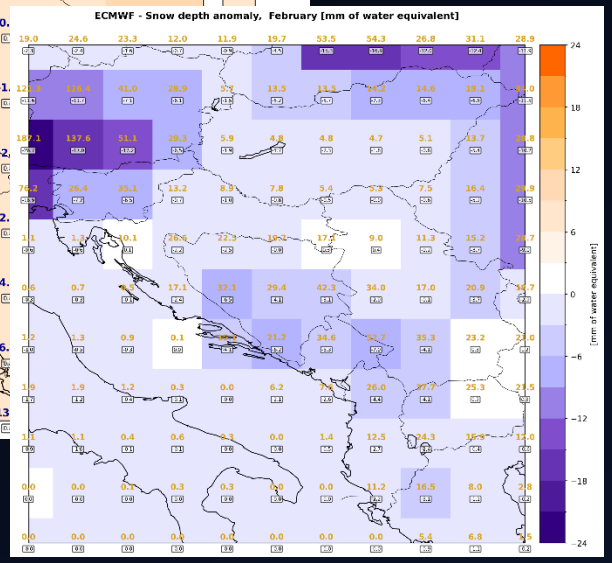
Joint activities in improving automated hail defense systems with meteorologists from RHMZ Serbia.

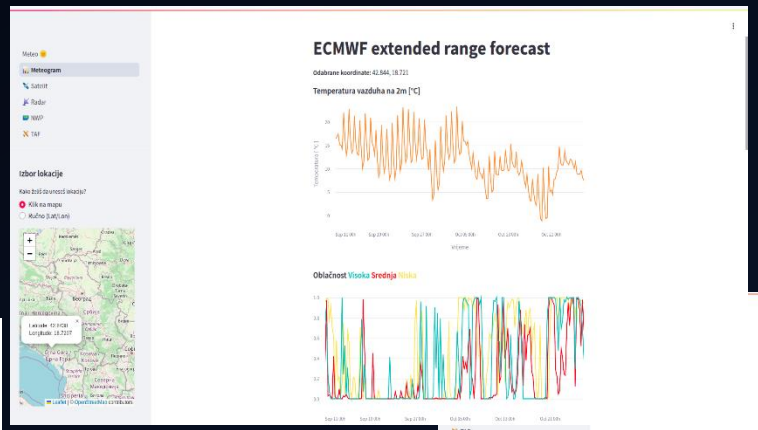
- IFS model (considered the most reliable global model) is used to achieve improved resolution of vertical profiles in the free atmosphere, especially in cases with large Cb clouds or several such clouds embedded in mesoscale convective systems (MCS).
- Accurate vertical temperature distribution in the free atmosphere is critical for effective hail suppression.
- Temperature profile decomposition from the IFS, which benefits from high-quality initial fields based on reanalysis, offers enhanced precision.
- Radiosonde observations and model forecasts are used to train a machine learning model that decomposes temperature fields using various observed and modeled meteorological parameters.
- Initial results are promising, with ongoing efforts to improve nowcasting of radar echoes, especially compared to existing approaches such as the PySTEPS package.

Use of Extended Range and Seasonal Forecasts

As an information source for various needs in the economy, energy sector, tourism, and water management.

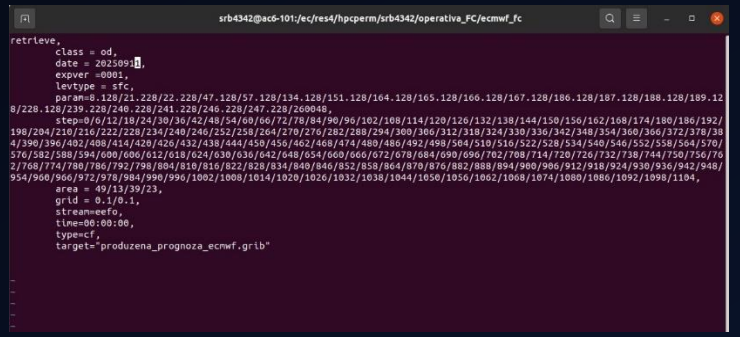


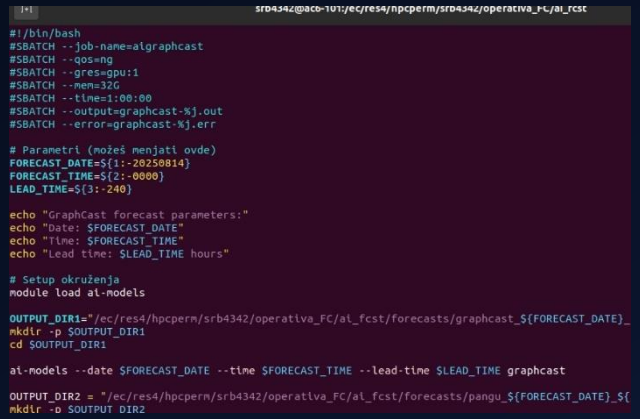




Benefits of utilizing ESS software solutions and computer resources

- Access to **HPC-ATOS** via university academic account as a PhD student provides significant benefits for learning how to organize computational workflows, run numerical models, perform post-processing, and gain practical experience in parallel programming and SLURM job scheduling.
- Access to the **MARS** archive enables retrieval of any forecast, reanalysis, and other meteorological or climate datasets without the need to create a local archive of these products.
- **EWC (European Weather Cloud)** provides additional storage and GPU resources to facilitate access, sharing, and processing of large meteorological datasets.
- **ecCharts** provides an interactive, web-based platform for visualizing and exploring extensive global weather forecast data—including surface and upper-air parameters, ocean wave forecasts, and ensemble-based products that illustrate forecast confidence. This functionality is essential for streamlining the workflow of forecasters working with limited staff, as every time-saving feature is critically important.

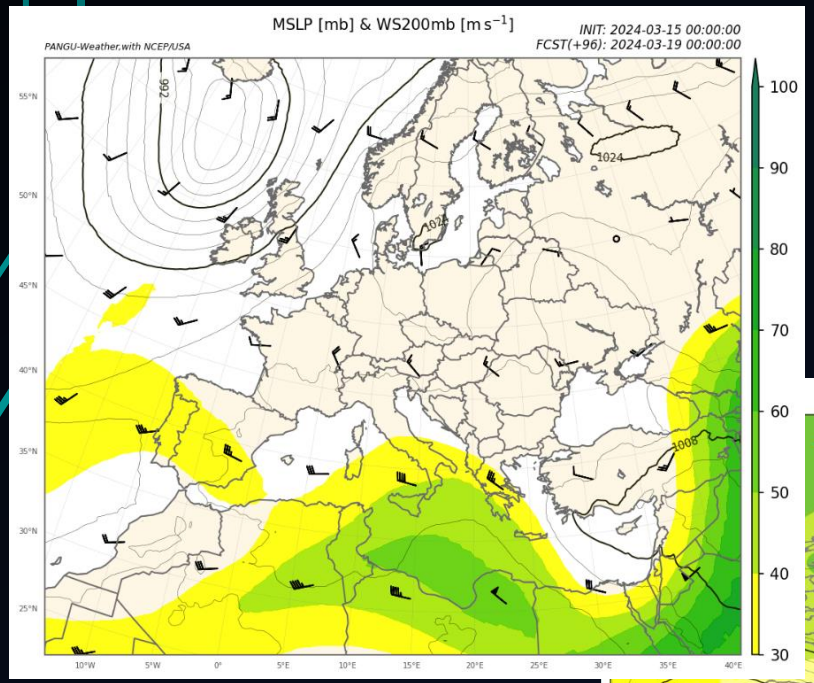


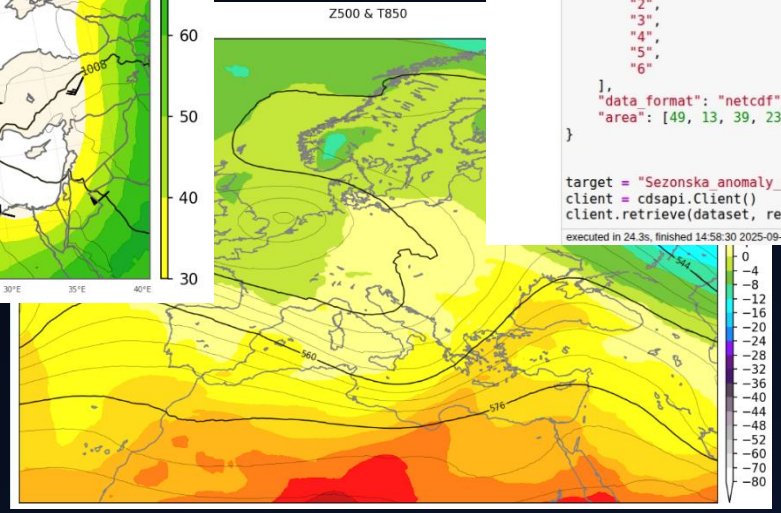


The repository of Python scripts and Jupyter Notebook examples, available at thehttps://github.com/ecmwf, significantly streamlines coding, decoding, and visualization of NetCDF4 and GRIB files, as well as practical AI model workflows. This facilitates faster analysis, easier data handling, and more efficient experiment cycles for applied meteorology and climate research.

ecCodes and ai-models are currently the two most frequently used packages in the operational work of IHMS.

cdsapi and adsapi are also highly valuable for formatting and post-processing various datasets prior to download, enabling efficient handling and customization of meteorological and climate data products.



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In [33]: import cdsapi

dataset = "seasonal-postprocessed-single-levels"
request = {
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        "soil_temperature_anomaly_level_1",
        "solar_insolation_anomalous_rate_of_accumulation",
        "surface_latent_heat_flux_anomalous_rate_of_accumulation",
        "surface_solar_radiation_downwards_anomalous_rate_of_accum
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        "total_precipitation_anomalous_rate_of_accumulation"
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        "2",
        "3",
        "4",
        "5",
        "6"
    ],
    "data_format": "netcdf",
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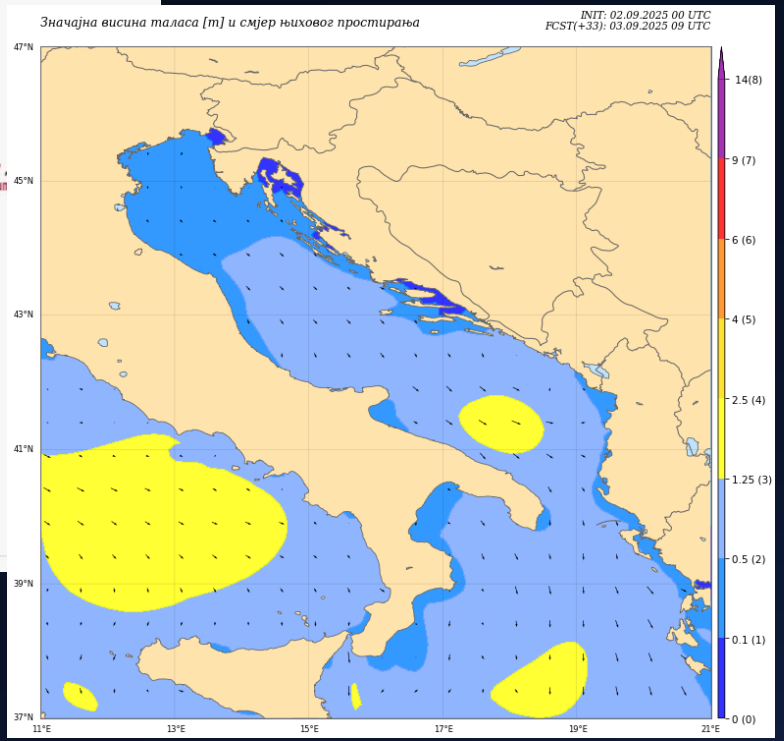
}

target = "Sezonska_anomaly_ensmean_ecmwf.nc"
client = cdsapi.Client()
client.retrieve(dataset, request, target)
```

executed in 24.3s, finished 14:58:30 2025-09-11



- We look forward to improvements in forecast accuracy and increased model resolution, closely monitoring developments in the implementation of AI techniques in weather prediction.

- The upcoming ERA6 reanalysis is expected to significantly enhance our understanding of atmospheric processes by providing improved data assimilation, which will advance AI-driven forecasting.

- We hope to achieve full membership and more active participation in ECMWF trainings, workshops, and conferences.

Thank you for your attention!

Questions or comments?

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