Application and verification of ECMWF products 2018

Hellenic National Meteorological Service (HNMS)
Flora Gofa and I.Kouroutzoglou

1. Summary of major highlights

In order to determine the quality of the NWP products at the Hellenic National Meteorological Service (HNMS), a verification process is applied based on a tool that was developed through the **CO**nsortium for **S**mall-scale **MO**deling (COSMO). This operational conditional verification tool, known as **VER**ification **S**ystem **U**nified **S**urvey (VERSUS), the development of which was coordinated by the Italian Meteorological Service, is currently used by the HNMS for all verification activities concerning the weather forecast models. In the same time for spatial verification purposes, in a test case base, VAST (VERSUS Additional Statistical Techniques) software package, which was also developed by the COSMO consortium is employed as it offers a number of neighborhood verification tools (Gofa at al. 2018).

Daily verification is performed for the surface and upper-air fields of the IFS products as well as for the high-resolution limited area model (COSMO-GR at 4 and at 1km) that are used by the HNMS forecasters. In addition, the relative performance of the models is subject to intercomparison. The operational verification system at the HNMS has been expanded to include verification of ensemble forecasts derived by -range ensemble prediction systems as well as wave model forecasts.

2. Use and application of products

The medium-range weather forecasts at the HNMS are based primarily on the deterministic ECMWF forecast. Both the 00 UTC and 12 UTC cycles of the ECMWF forecasts are received daily in the current resolution. For short-range forecasting and for observation of local characteristics of weather patterns in Greece, the output of the limited area models is used in conjunction with the ECMWF products.

The EPS products (plumes, epsgrams, ensemble probability maps) are retrieved daily from the ECMWF website and are of particular value to the HNMS forecasters, especially the d+4 to d+7 forecast where the value of the deterministic forecasts is substantially reduced). An increasingly popular ECMWF product at the HNMS is the Extreme Forecast Index (EFI) for temperature and precipitation. As a measure of the distance from the climatological value (mean), the EFI maps are directly related to severe weather events. The monthly (and weekly) anomalies and seasonal forecasts are not used operationally but only for consultative or research purposes.

2.1 Post-processing of model output

2.1.1 Statistical adaptation

The HNMS implements a method improving the temperature minimum and maximum forecast values for 50 locations in Greece (position of the stations) on a daily basis. This method uses a Kalman filtering technique, which is based on non-linear polynomials, incorporating all available quality-controlled observations in combination with the corresponding NWP data of the IFS model as well as from the limited area model COSMO-GR. Application of the filter helps improve the temperature forecasts by eliminating possible systematic errors. The same technique is also used with the dew point temperature data (minimum and maximum) in order to correct biases related to relative humidity.

2.1.2 Physical adaptation

ECMWF model output provides the lateral and boundary conditions for the execution of the daily simulations of the HNMS limited area model (COSMO-GR, WAM). As an option, ECMWF model output can also be used to provide the necessary input for the MOTHY trajectory model.

MOTHY is a sea pollution model (e.g. Daniel, 1996), which is applied in cases of oil spills in the eastern Mediterranean Sea, that HNMS is responsible for. It is based on the numerical weather predictions of the ECMWF model, either the 00:00 UTC cycle or the 12:00UTC cycle. The data used as input are the surface wind speed and the sea surface pressure, (and the two meters temperature as an option). The model provides the possible trajectories (locations) of oil (or floating objects) transport as well as the percentage of the oil spill that will reach the coast or the seabed. The HNMS operates MOTHY as part of the Marine Pollution Emergency Response Support System (MPERSS) for the Marine Pollution Incident (MPI) Area III East, which includes the eastern Mediterranean Sea.

Finally, the ECMWF deterministic model provides the necessary initial conditions to drive a wave forecast model (WAM) as an alternative option to COSMOGR. The wave forecast of the HNMS is based on the ECMWF version of the WAM (CYCLE 4) model. It is a third generation wave model which computes spectra of random short-crested wind-generated waves and is one of the most popular and well tested wave models. Verification of the calculated wave height and direction has recently been implemented with the use of observations taking by the buoys positioned around the Greek Seas (POSEIDON system).

2.1.3 Derived fields

A wide range of derived fields are produced from the ECMWF model outputs (e.g. meteograms) for visualisation and other applications at the forecasting center.

2.2 Use of products

As mentioned above, the HNMS forecasting centre uses ECMWF products in conjunction with the products of its limited area models for the general 6-day forecast that is provided to the public as well as for the sea state forecast for the Eastern Mediterranean and, finally, the forecast for aeronautical purposes. The IFS forecast products are also consulted by the forecaster on duty and used to complete the awareness report for the European MeteoAlarm website.

3. Verification of products

The forecasted values of weather parameters are compared with synoptic meteorological data from the HNMS operational network of stations and a range of statistical scores is calculated on a daily, monthly and yearly basis. The surface verification is performed by using the SYNOP data from the most reliable surface stations, every 3 or 6 hours.

The continuous variables that are routinely verified are the 2m temperature, 2m dew point temperature, Mean Sea Level pressure, wind speed and cloud cover. For dichotomic parameters such as precipitation, the 6-, 12- and 24h-hour precipitation amounts are verified using indices from the respective contingency tables for the 72-hour forecast horizon. The thresholds for the precipitation amounts range from 0.2mm up to 30mm, accumulated in different time ranges. Only a small selection of statistics is presented in the current report and correspond to the four seasons.

3.1 Objective verification

3.1.1 Direct ECMWF model output (both deterministic and EPS)

The ECMWF deterministic forecasts are verified against the synoptic observations. The RMSE and Bias scores are calculated for every forecast cycle, every 6 hours from the t+6 to the t+120 forecast hour (here presented up to 72h) for every synoptic station, indicating the degree to which the forecast values differ from the observations. The scores, which are averaged over all stations, are presented below. The verification was performed for every season (when available for JJA2017-MAM2018), ECMWF/IFS statistics are represented with the orange lines and the main findings are as follows:

Mean Sea Level Pressure: For MSLP (Fig. 1), a slight propagation of the error (RMSE) with forecast time is evident for almost all seasons but JJA and more during winter months. The ME error values exhibit an underprediction for almost all seasons.

2m Temperature: A clear diurnal cycle of the Bias values is a characteristic of all seasons (Fig. 1). The model underpredicts the temperature values in all seasons to up to 1.2˚C with higher underprediction during fall. The average error for all periods is approximately 2.5 ˚C.

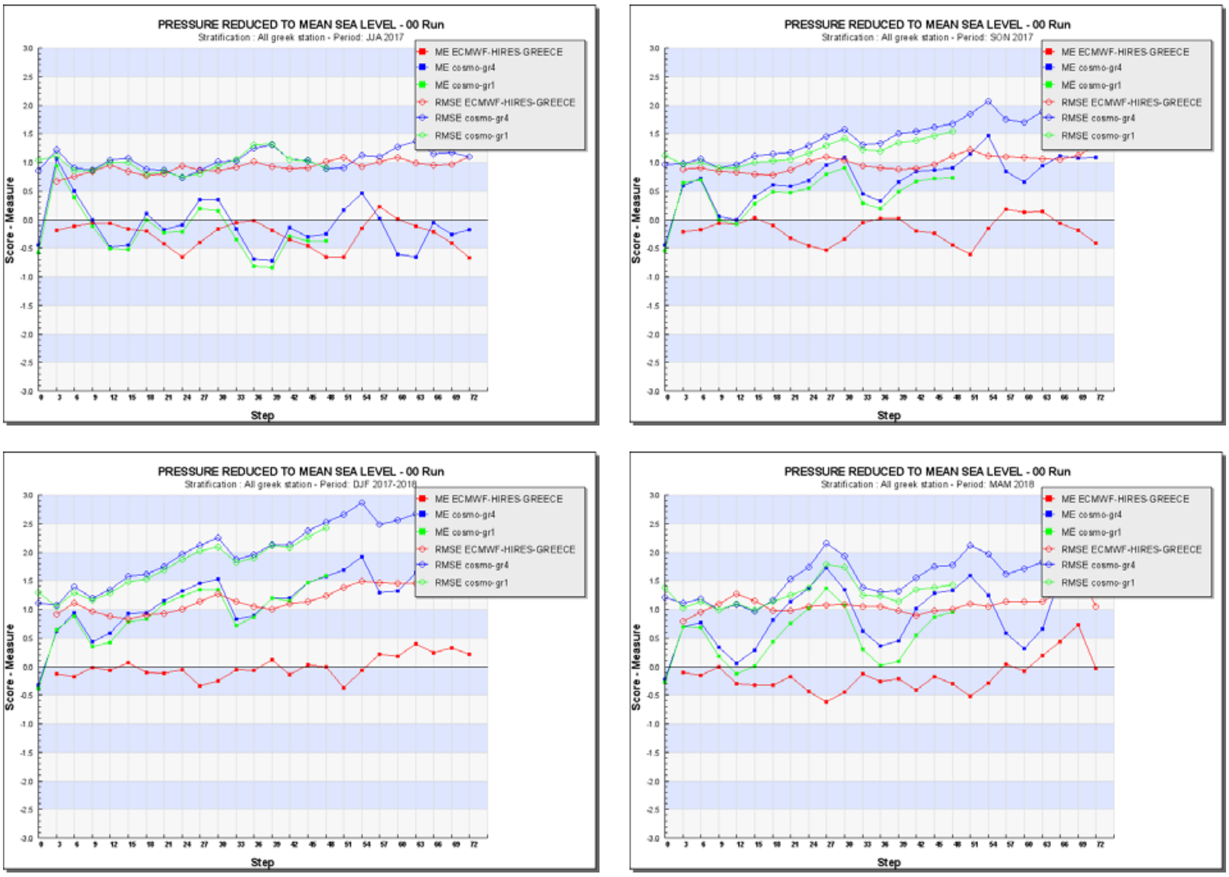
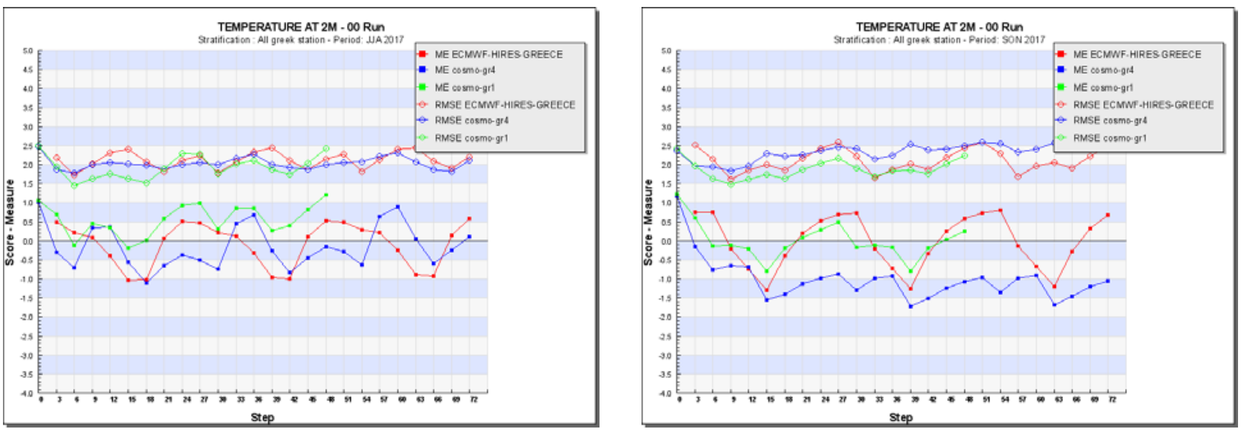
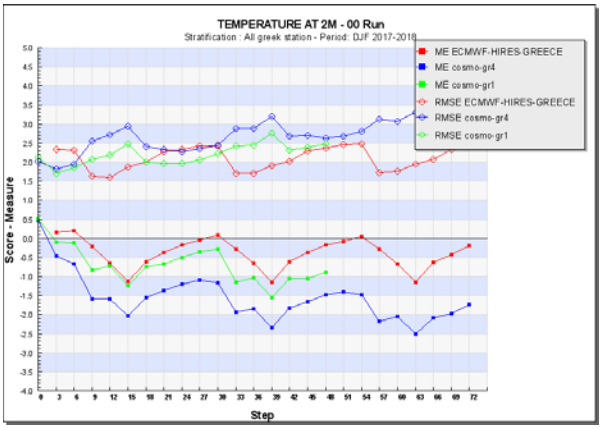
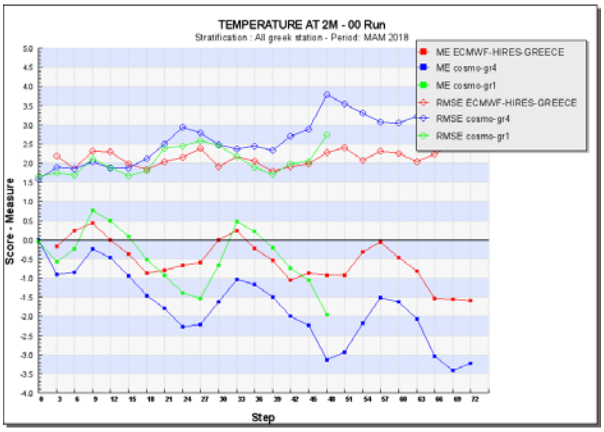
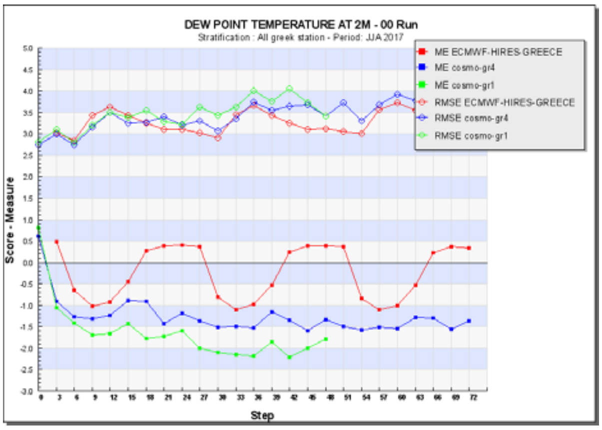


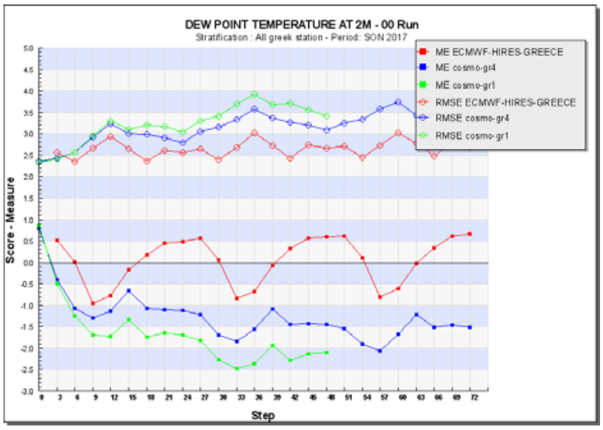
Fig.1: RMSE and Bias scores for MSLP (above) and 2m Temperature (below) from all models (00UTC run) calculated and presented for every season

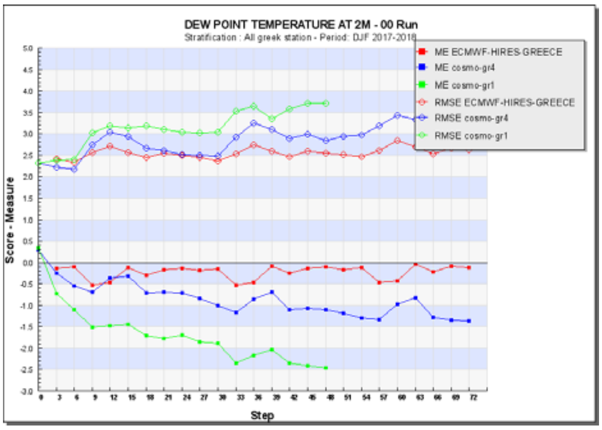



TEMPERATURE AT 2M - 00 Run
Stratification : All greek station - Period: DJF 2017-2018
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


TEMPERATURE AT 2M - 00 Run
Stratification : All greek station - Period: MAM 2018
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


DEW POINT TEMPERATURE AT 2M - 00 Run
Stratification : All greek station - Period: JJA 2017
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


DEW POINT TEMPERATURE AT 2M - 00 Run
Stratification : All greek station - Period: SON 2017
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


DEW POINT TEMPERATURE AT 2M - 00 Run
Stratification : All greek station - Period: DJF 2017-2018
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
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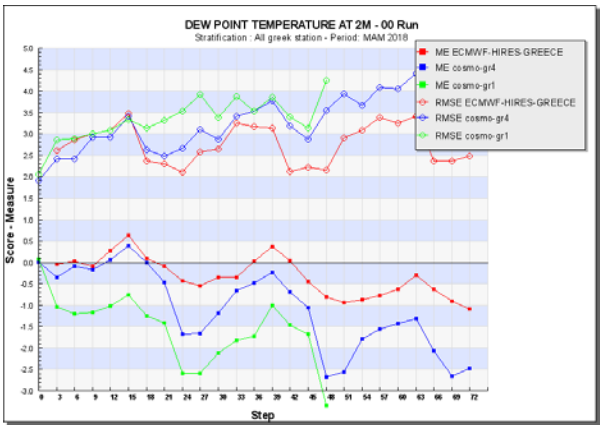
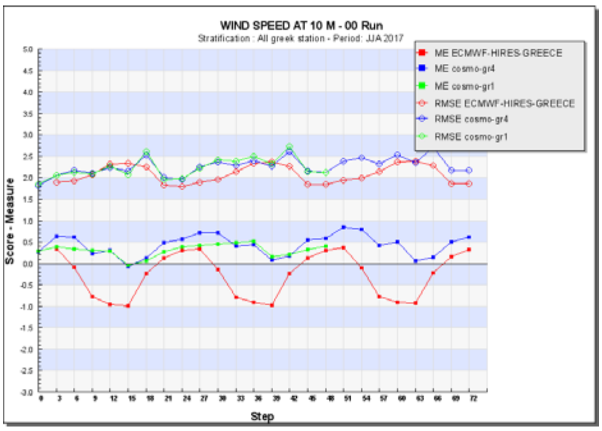
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


DEW POINT TEMPERATURE AT 2M - 00 Run
Stratification : All greek station - Period: MAM 2018
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


WIND SPEED AT 10 M - 00 Run
Stratification : All greek station - Period: JJA 2017
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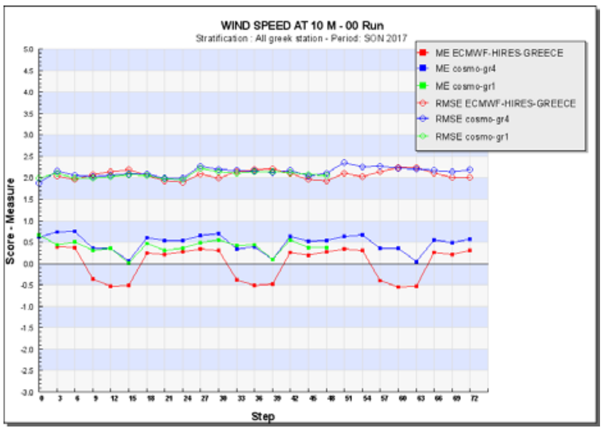
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step


WIND SPEED AT 10 M - 00 Run
Stratification : All greek station - Period: SON 2017
ME ECMWF-HIRES-GREECE
ME cosmo-gr4
ME cosmo-gr1
RMSE ECMWF-HIRES-GREECE
RMSE cosmo-gr4
RMSE cosmo-gr1
Score - Measure
Step

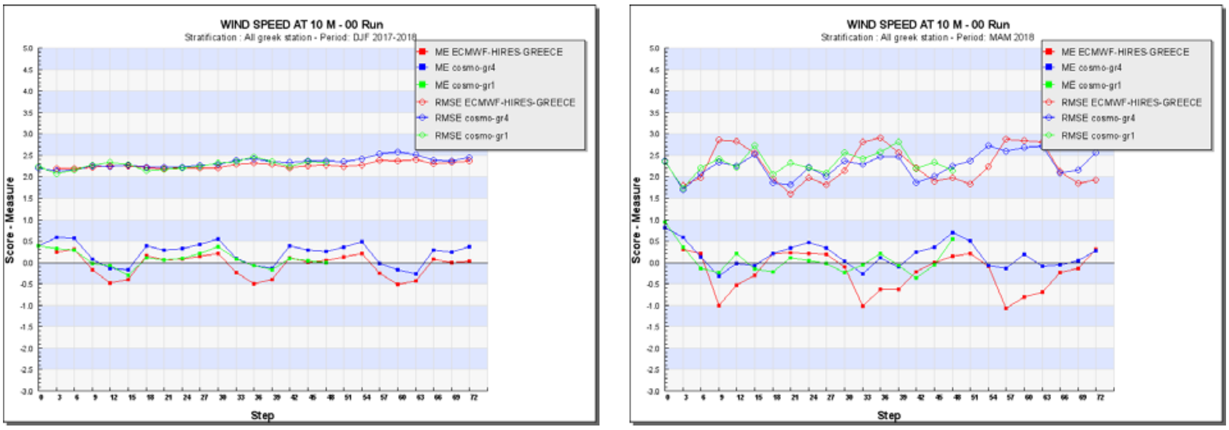


Fig.2: RMSE and Bias scores for 2m Dew Point Temp (seasonal) and 10m Wind speed from the all models (00UTC run)

Fig.3: RMSE and Bias scores for Cloud Cover from all models (00UTC run)

2m Dew Point Temperature*:* The DPT is mainly underestimated the warm hours of the day especially in the summer and spring. The diurnal cycle is evident in the Bias values. Large RMSE values for the summer and spring periods (Fig. 2).

10m Wind Speed: RMSE behaviour and values are almost constant for all seasons with values around 2.5-3 m/s with a clear daily cycle in the Bias values (Fig. 2).

Cloud Cover: A general underestimation of cloud cover percentage from IFS model is apparent in all seasons as well as a clear daily cycle of the ME. The RMSE values were quite high with a much better performance during the summer season when weather conditions are more stable and cloud cover amount is in general decreased (Fig.3).

Precipitation:

Precipitation is commonly accepted as the most difficult weather parameter to correctly predict in terms of its spatial and temporal structure due to its stochastic behaviour and any connection with specific weather systems is greatly appreciated by forecasters. The 12h-hour precipitation amounts were verified for this study and the thresholds for the precipitation amounts ranged from 0.2mm up to 10mm accumulated over 12h time interval. For each threshold a number of scores were calculated that provide insight into model behaviour, but the representation chosen for this report are the FBI (Bias), the ETS (Equitable Threat Score) and FAR (False Alarm Ratio). Scores are presented for 12UTC (Fig.4) and for 48UTC (Fig.5) for all seasons (columns).

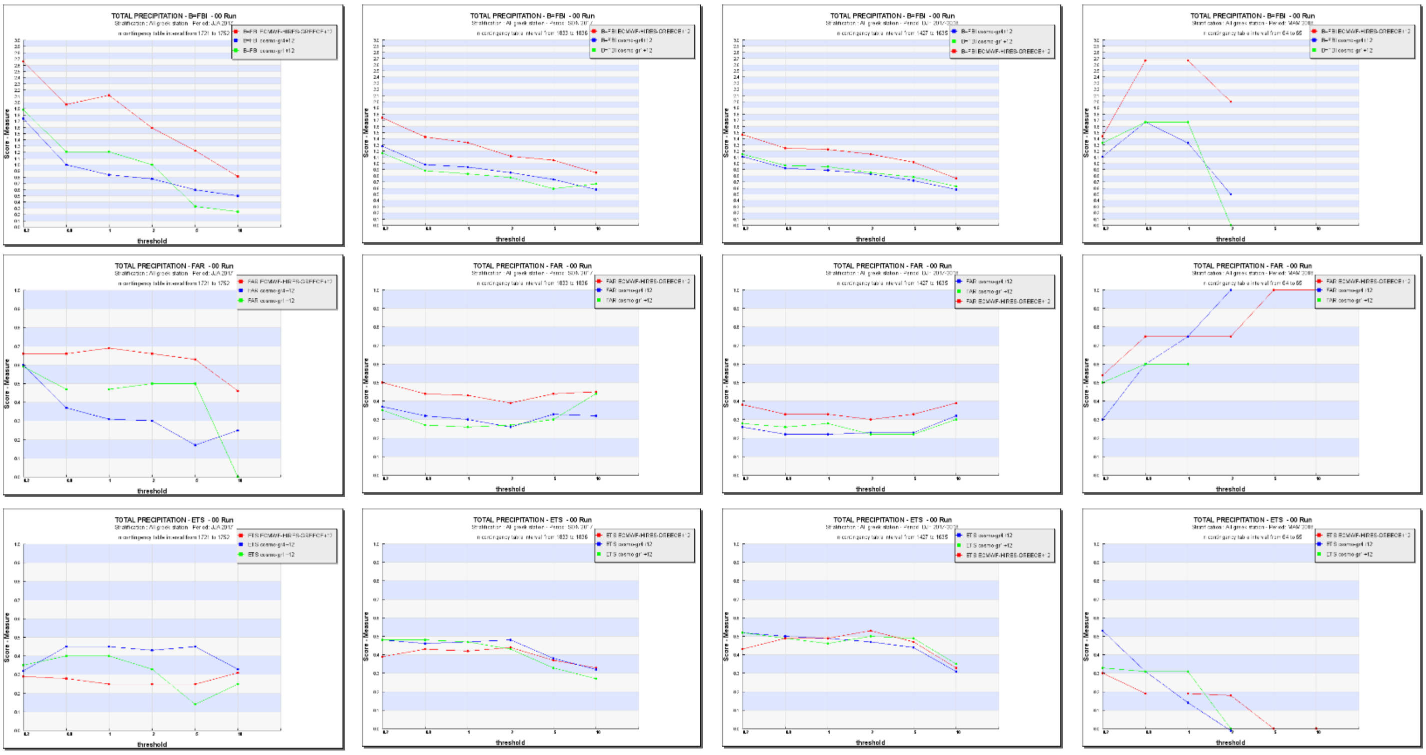


Fig.4: Rows: FBI, FAR, ETS scores for 12h precipitation for forecast time12UTC for all seasons (columns)

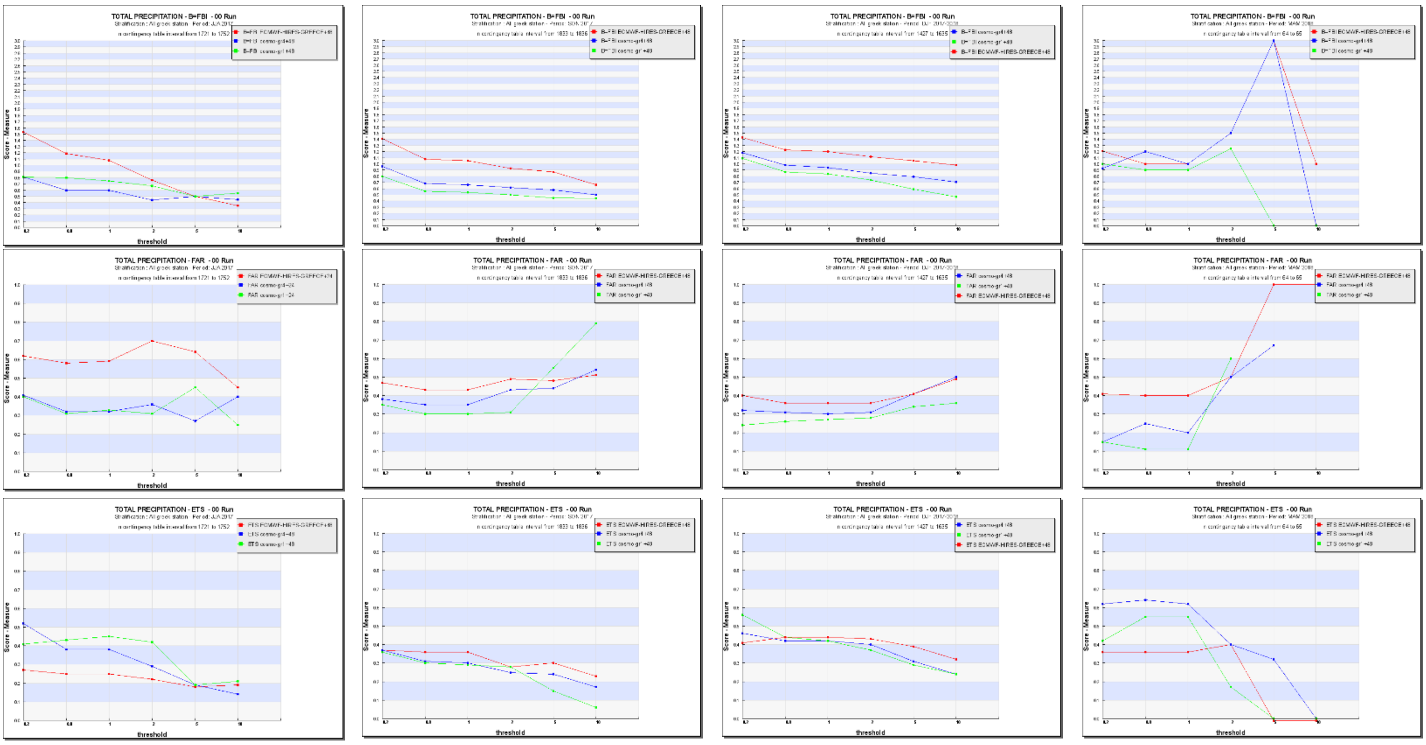


Fig.5: Rows: FBI, FAR, ETS scores for 12h precipitation for forecast time 48UTC for all seasons (columns)

The results indicate that the IFS model performs better for the thresholds corresponding to small amounts of precipitation, but it fails to accurately predict large rainfall events. FBI plots exhibit an elevated overestimation of precipitation amounts for small thresholds compare to limited area models

(COSMO).FAR values are higher for all thresholds and for all seasons for both forecast times for IFS model.

3.1.2 ECMWF model output compared to other NWP models

An unusually strong precipitation event that occurred on the 16-17th of July 2017 was selected as a test case. The event, which was a combination of both dynamic and convective activity was accompanied by relatively low temperatures for the season and affected a large part of the country, causing hailstorms, flooding, property damage and unfortunately loss of human life. The event was preceded by a series of relatively warm days with 850hPa temperatures around 15-20°C. On 17/04 00UTC, a trough centered over Russia covering all of Eastern Europe moved southwards toward Greece, resulting in cold air masses (-15°C) at 500hPa (Fig 6a) moving slowly E-NE. The trough was accompanied by a low pressure system at the surface, which moved from west to east (Fig 6b). Initially, convective precipitation was observed over northern and western Greece which extended to the central and eastern parts of the country by the afternoon. This was accompanied by lightning (Fig 6c) and hail at several locations on the mainland.

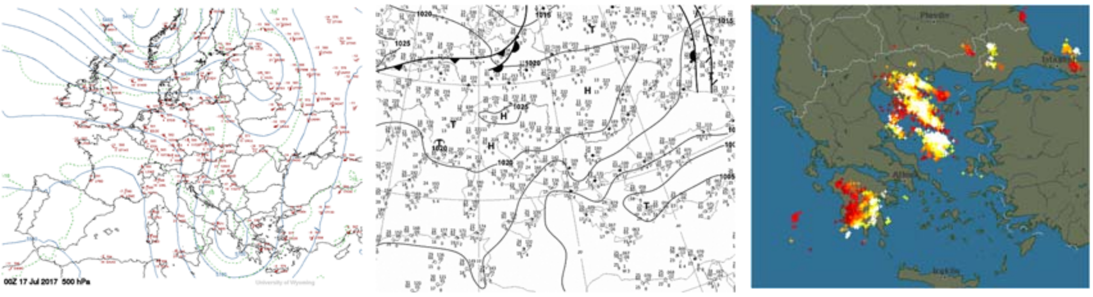
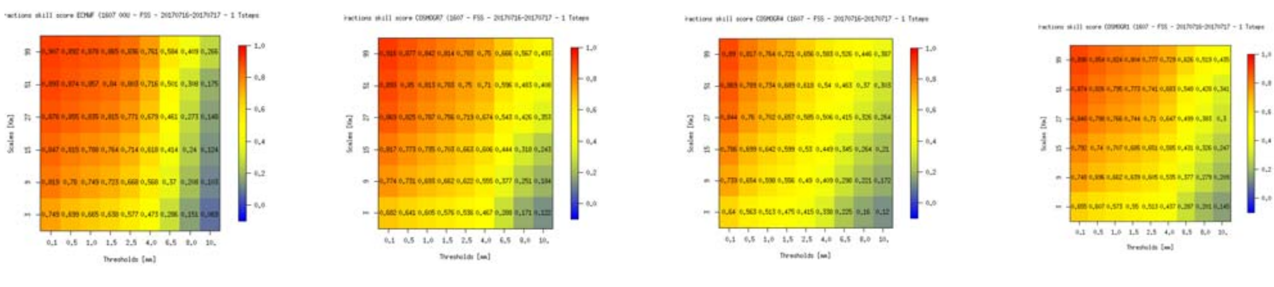


Fig. 6a. (left): 17/04 00UTC 500hPa (source: University of Wyoming), 6b. (center): Surface Analysis (source: UK Met Office), 6c. (right) Lightning activity at 10UTC (http://el.blitzortung.org) with dots indicating the location of lightning strikes where the color refers to the age of the strike (20 min intervals)

A selection of the evaluation plots for July 17th applying neighborhood methods to the various models and resolutions is presented in Fig 7. (time lead 1600 UTC). The scores are plotted as intensity-scale diagrams, where the intensity threshold and spatial scale averaging increase along the x and y axes respectively, and the color shade gives an indication of the value of the score (also plotted explicitly). By evaluating the color intensity (darkness), scales and thresholds at which a particular model system performs best, it is possible to evaluate model performance without focusing on the absolute value of each colored window.
The forecast skill (as represented by the FSS score) does not differ significantly between models, but it does increase as window size (<15km) and precipitation thresholds (<3mm/3h) decrease. For high precipitation thresholds, on the other hand, forecast skill decreases.

ETS (Equitable Thread Score) index diagrams (Practically perfect Hindcast decision method) show that the forecast quality is better for window sizes <50km and thresholds 0.1-0.2mm. The indices for COSMO-GR1 and COSMO-GR4 are slightly better than those of ECMWF-IFS. However, significant differences appear in the Bias score (upscaling method) as ECMWF-IFS has the tendency to overestimate both the low thresholds (0.1-3mm) and high thresholds (>10mm/3h) while underestimating the remaining thresholds. The COSMO model generally overestimates rainfall for windows up to 27km for all thresholds, except for COSMO-GR7 which underestimates only the high thresholds. The POD (Probability of Detection) and FAR (False Alarm Rate) (calculated using the Anywhere in the Window method) show that ECMWF-IFS had more successful hits (dark red) but also more false alarms (dark blue).

ECMWF-IFS **COSMOGR-7** **COSMOGR-4** **COSMOGR-1**



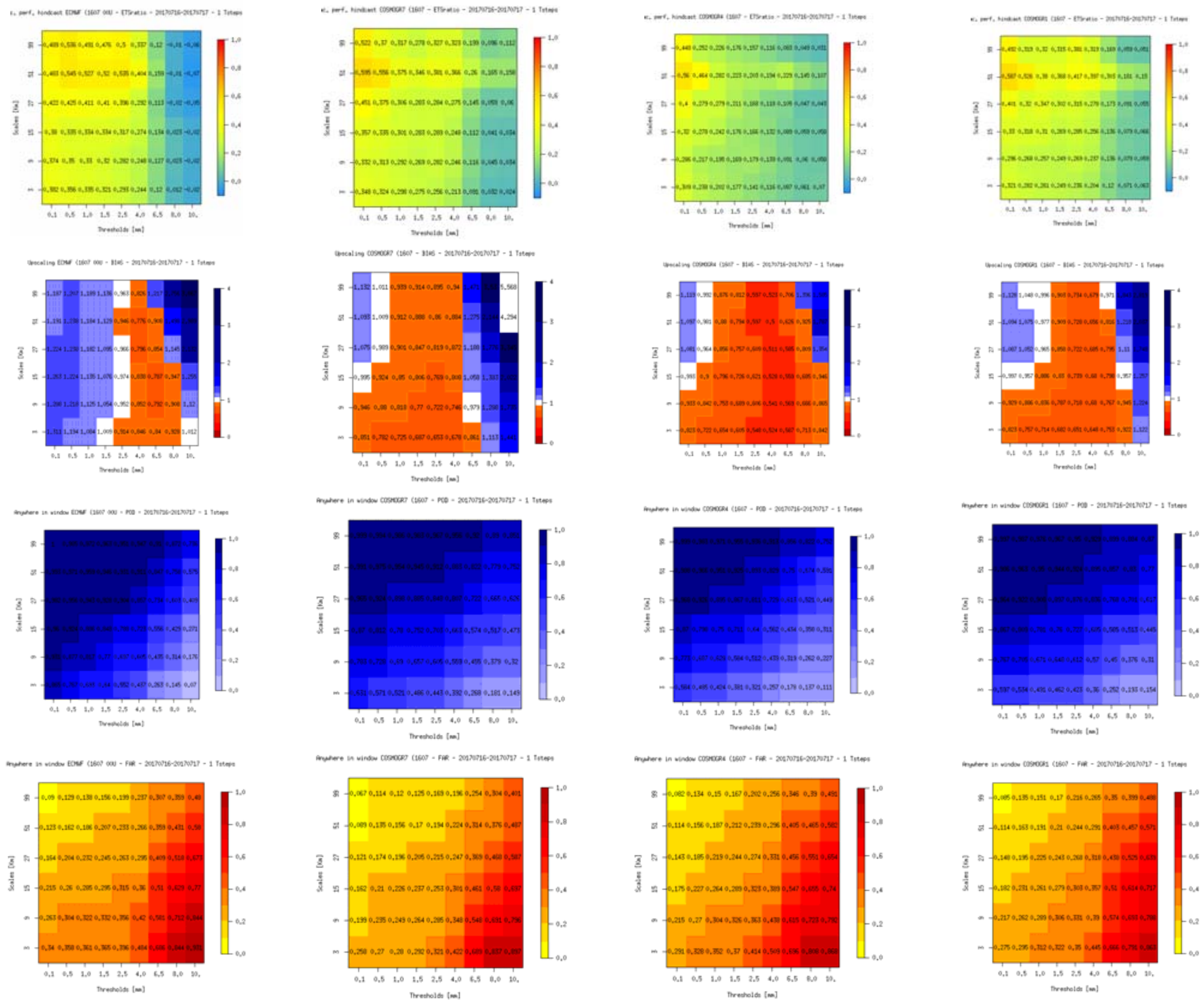


Fig. 7. Neigborhood method plots for lead time 16/07 00 UTC derived for the various model setups. From top to bottom: FSS (Fractions Skill Score), ETS (Equitable Thread Score), Bias, POD (Probability of Detection) and FAR (False Alarm Rate)

Neighborhood verification results showed that for high rainfall rate thresholds and large spatial windows, the forecast skill and quality decreased for all models used in the study. Differences between the COSMO and ECMWF-IFS models at different scales and thresholds are mainly evident in Bias and ETS scores, with the latter model tending to overestimate precipitation for low thresholds and consequently producing more false alarms.

3.1.3 Post-processed products

e.g. Kalman-filtered products, calibrated ENS probabilities, etc.

3.1.4 End products delivered to users

3.2 Subjective verification (by I. Kouroutzoglou)

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

3.2.2 Case studies

<u>In general, systematic errors experienced by HNMS staff:</u>

a) Underestimating of precipitation totals over Eastern –windward parts of Greece:

i. when the 500 hPa prevailing flow is SW, or

ii. a cold front crosses the country from the west and mainly SW, considering that the orography of continental Greece distorts the thermodynamic structure of the low level frontal activity

iii. Extensive low level baroclinic zones without necessarily be combined to organized frontal activities, mainly from Northern Africa,

b) On the contrary, overestimating of precipitation totals snowfall, in particular over NE mainland Greece,

c) Often unsuccessful tracking of the movement of extensive, quasi-stationary cut-off lows (500hPa), situated over a wide area in the Central - Eastern Mediterranean - secondary upper level cyclogenesis. For example when a warm upper level anticyclone forms in the Atlantic or the Western European area and upper level downstream development rejuvenates the pre-existed quasi-stationary cut-off low under the effect of a mobile polar front jet streak and the strengthening of the respective transverse ageostrophic circulations,

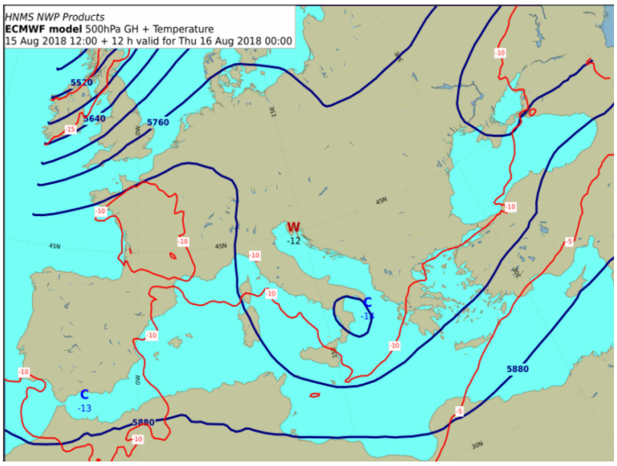
d) Unsuccessful simulation of diabatic heating in the form of surface sensible and latent heat fluxes from the sea during the transitional time periods between warm and cold sea,

e) Unsuccessful simulation of the transformations of surface frontal activities in cases where the absence of organized conveyor belts and wind component perpendicular to the frontal activities does not allow the surface depression to follow the typical life cycle of a mid-latitude surface depression from the incipient to the mature stage, for example the typical life cycle described in Shapiro and Keyser (1990). In these cases the dissipation of the cyclone's warm front and the formation of comma clouds or occluded fronts with persistence over a specific area, being steered by a stationary or quasi-stationary upper level cyclone, lead to problematic forecasts of the surface front's movement,

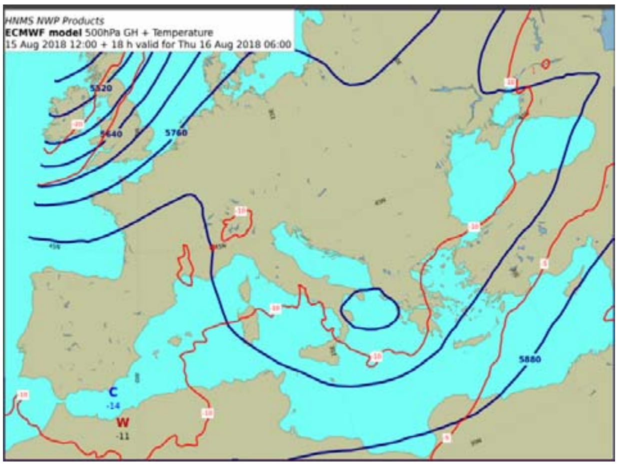
f) The general synoptic behavior of June and July 2018 over the Mediterranean area, allows us to expand the comment of paragraph (d) for the period of cold sea, as well. The increased frequency of establishment of upper level blocking anticyclones in the Atlantic or Western Europe and the resultant shift of the atmospheric circulation from zonal to meridional, allowed the southward propagation of upper level deep cyclonic circulations (often detected even in the 850hPa isobaric level) towards the southern parts of Mediterranean area, including the Eastern Mediterranean and Greece. Despite the fact that climatologically the air-sea interaction does not favor instability over the Eastern Mediterranean Sea surface during summer, lighting activity and thunderstorms were observed over the Ionian and the Aegean Sea during the above mentioned episodes between June and July 2018, implying that upper level dynamic forcing managed to overcome the tendency of a stable low level stratification over the sea surface. In the majority of these cases the ECMWF forecast precipitation failed to simulate effectively the cloudiness and the precipitation amounts over the sea and especially over the southern parts of the Aegean and Ionian Seas. Nevertheless, it is also a question whether the sign of the heat fluxes from the sea is reversed (from negative – instability to positive – stability), except the influence of the above mentioned upper level forcing. Although the air-sea interaction does not favor climatologically the instability over the Eastern Mediterranean Sea during summer, this does not mean that in any synoptic type Tair – Tsea >0. For example, in cases of surface and low level NW flow over Greece (existence of surface cyclogenesis and probably frontogenesis over the Eastern Europe and the Black Sea), the temperature of the surface air mass advected from the Eastern Balkans towards the Aegean Sea will probably be smaller than the SST over the Aegean Sea (especially during the night hours). In these cases both the upper level dynamic processes and the respective surface and low level diabatic ones, will positively operate in order to have $\omega < 0$ over the sea surface and the combination of potential and convective instability.

A case of particular interest which was representative of the comments in paragraph (f) was the one affecting Greece during the period between 15/08/2018 to 16/08/2018, focusing on the rainfall on 16/08/2018 in the Ionian Sea. A deep large scale upper level cyclonic circulation propagated from Italy towards Greece distorting the 850hPa temperature field in the form of a low level baroclinic zone (without generating organized surface frontogenesis) and the result was the formation of a comma cloud structure with strong thunderstorms over the Southern Italy and the Ionian Sea. The HRES ECMWF forecast 6hr total precipitation was not satisfactory.

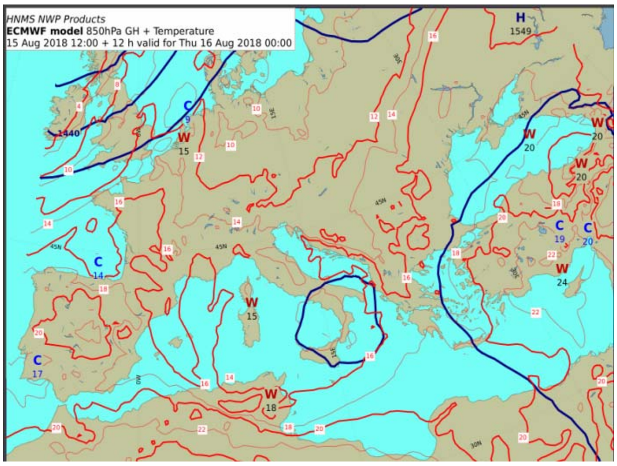
500hPa GH-T forecast for 16-08-2018 00UTC



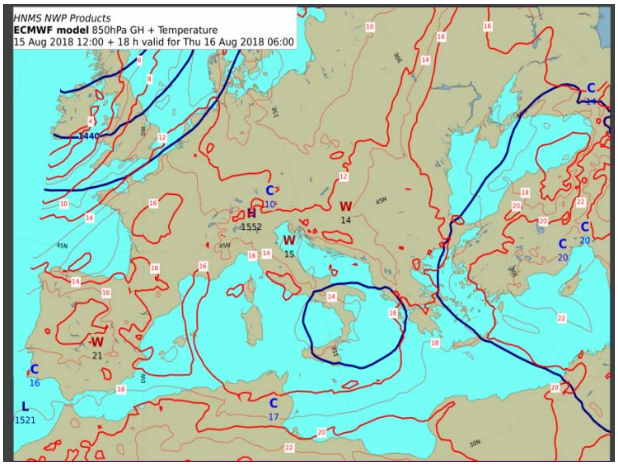
500hPa GH-T forecast for 16-08-2018 06UTC



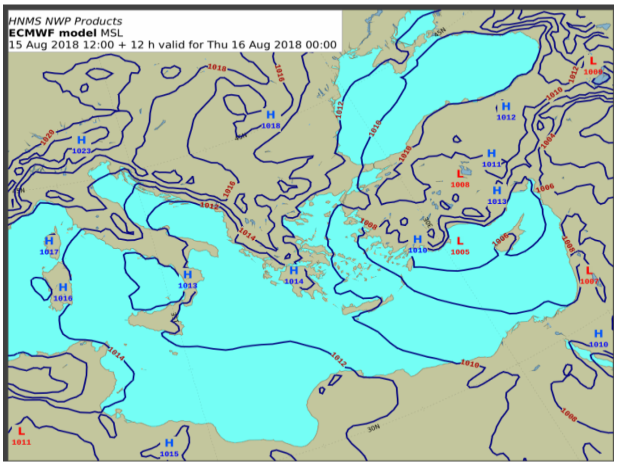
850hPa GH-T forecast for 16-08-2018 00UTC



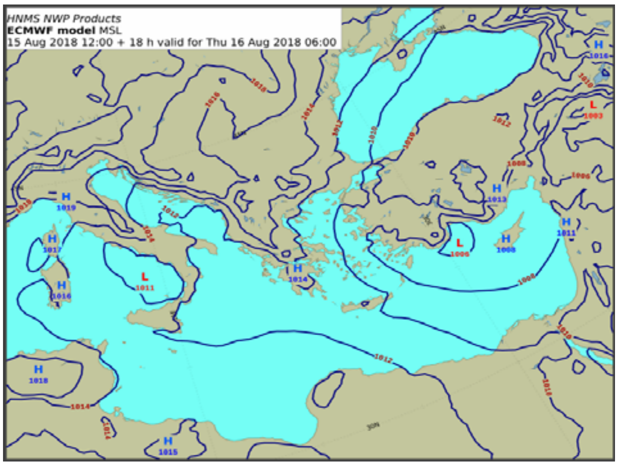
850hPa GH-T forecast for 16-08-2018 06UTC



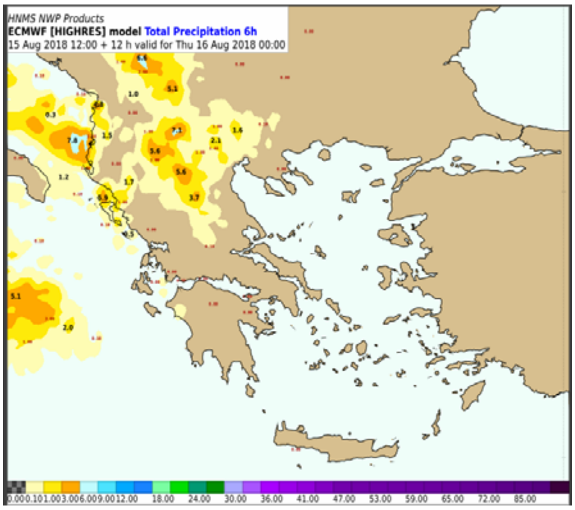
MSLP forecast for 16-08-2018 00UTC



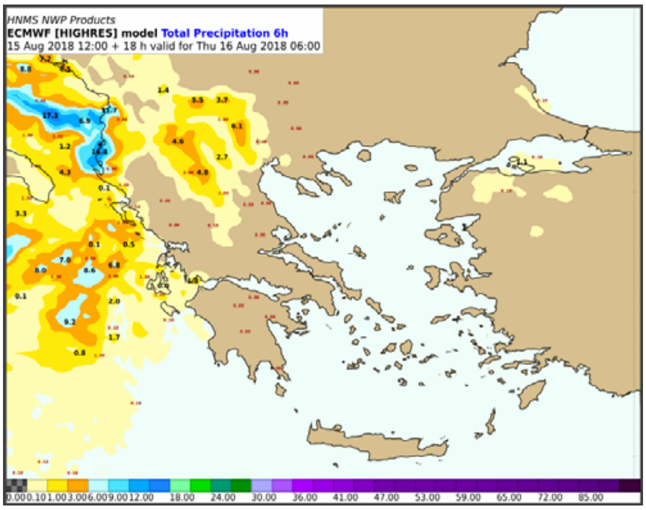
MSLP forecast for 16-08-2018 06UTC



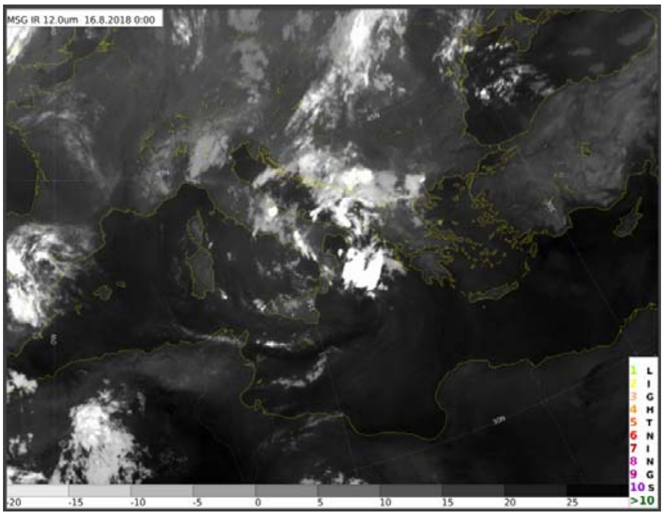
6HR TOTAL PRECIPITATION FORECAST FROM HRES ECMWF FOR 16-08-2018 00UTC



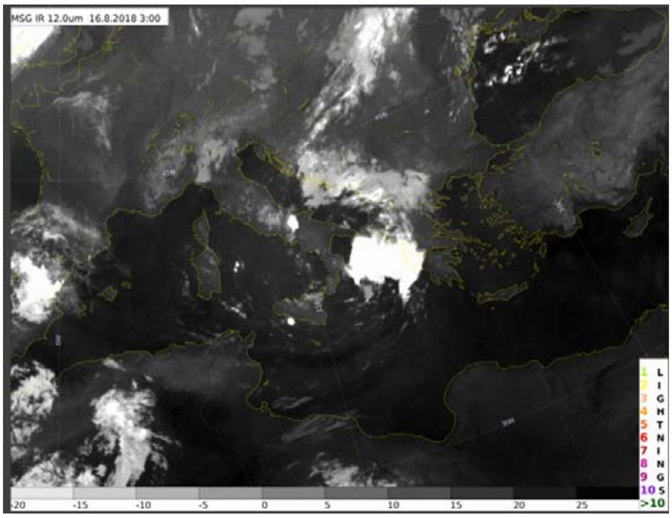
6HR TOTAL PRECIPITATION FORECAST FROM HRES ECMWF FOR 16-08-2018 06UTC



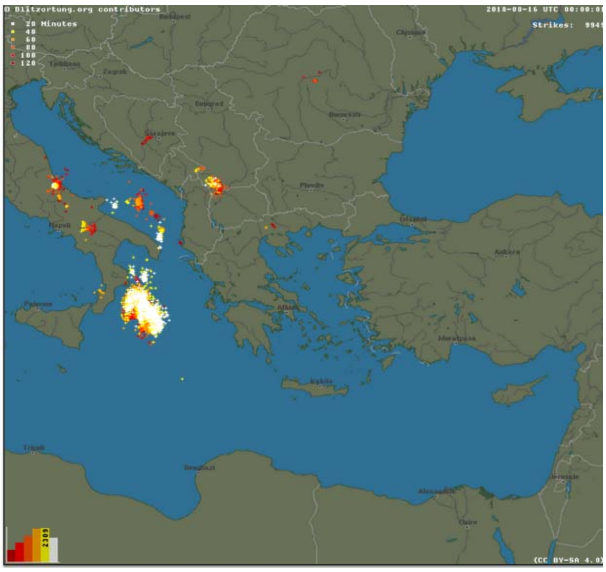
MSG IR IMAGE FOR 16-08-2018 00UTC



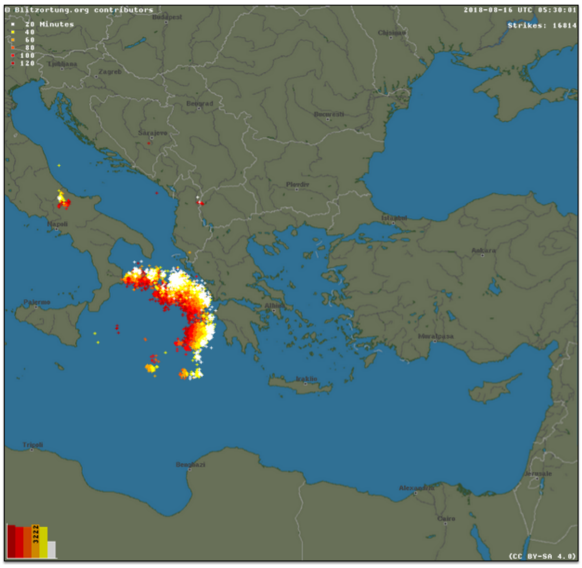
MSG IR IMAGE FOR 16-08-2018 03UTC



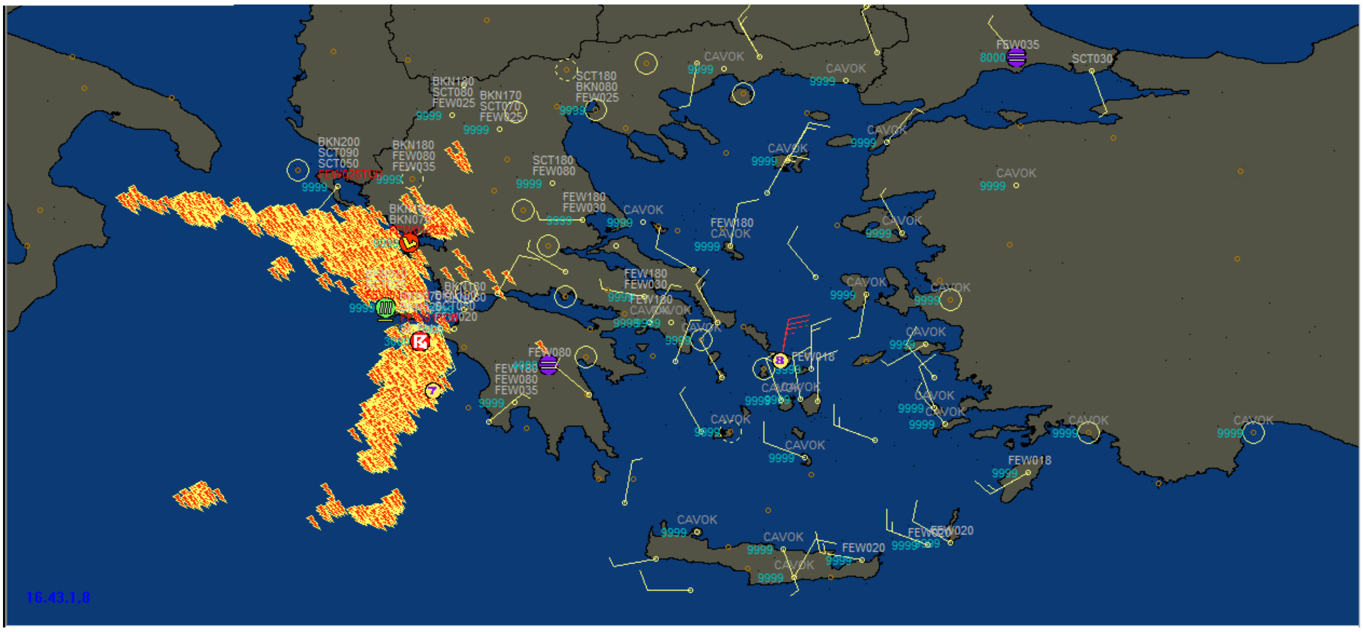
LIGHTINGS ACTIVITY FOR 16-08-2018 00UTC



LIGHTINGS ACTIVITY FOR 16-08-2018 0530 UTC



REAL TIME WEATHER FOR 16-08-2018 05:45 UTC



4. Feedback on ECMWF “forecast user” initiatives

5. References to relevant publications

Gofa F, Boucouvala D, Louka P Flocas HA (2018) Spatial verification approaches as a tool to evaluate the performance of high resolution precipitation forecasts, Atmospheric Research, Volume 208, 2018, 78-87

Gofa F, Pytharoulis I, Andreadis T, Papageorgiou I, Fragkouli P, Louka P, Avgoustoglou E, Tyrli V (2008) Evaluation of the operational numerical weather forecasts of the Hellenic National Meteorological Service. Proc. 9th COMECAP Conference of Meteorology, Thessaloniki, Greece, 51-58