Application and verification of ECMWF products 2016

Hellenic National Meteorological Service (HNMS)
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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.

Daily verification is performed for the surface and upper-air fields of the IFS products as well as for the two high-resolution limited area models (Eta/Skiron, COSMO-GR at 3 and at 7km) 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.

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 JJA2015-MAM2016), ECMWF/IFS statistics are represented with the red 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 all seasons but JJA. 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 error values reach up to 3.0 °C during winter, while the average error for the other periods is approximately 2.5 °C.

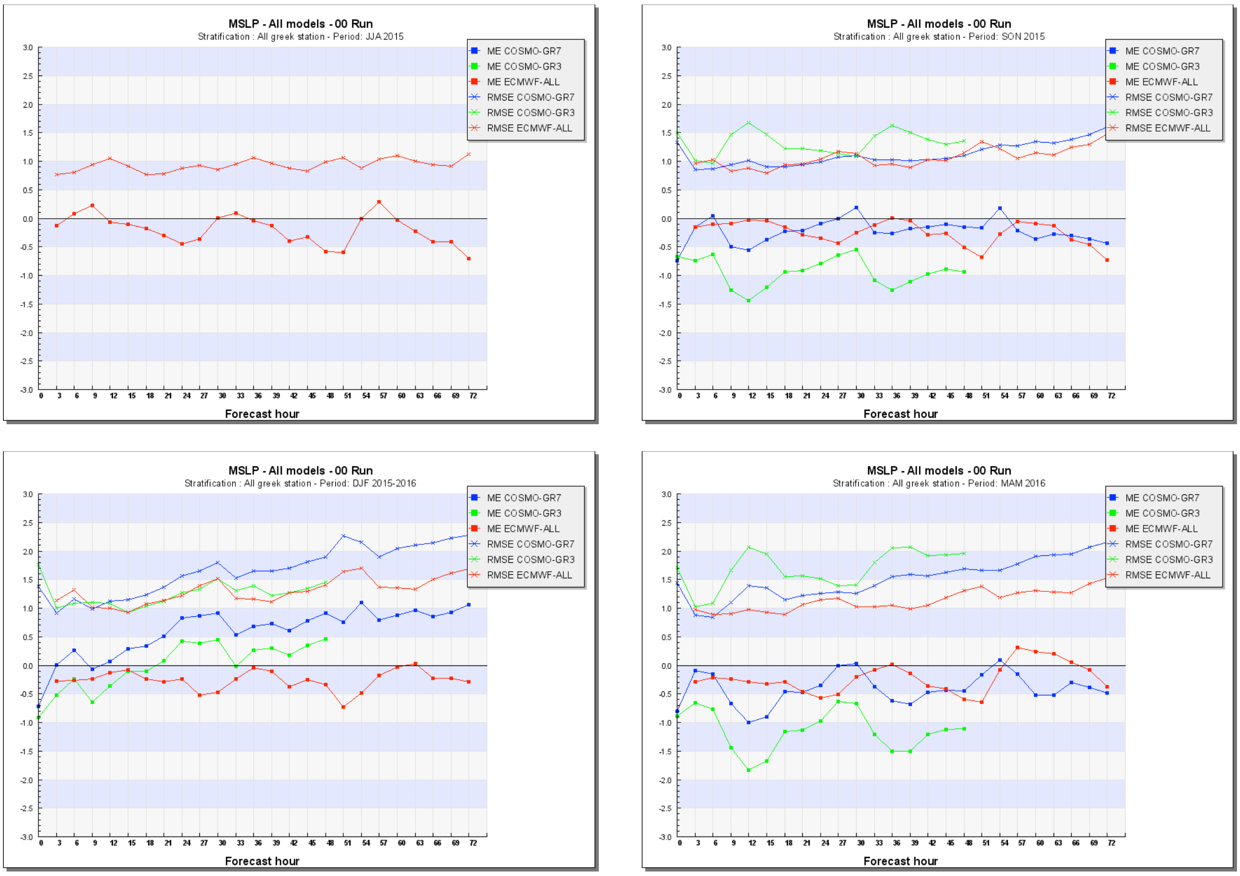
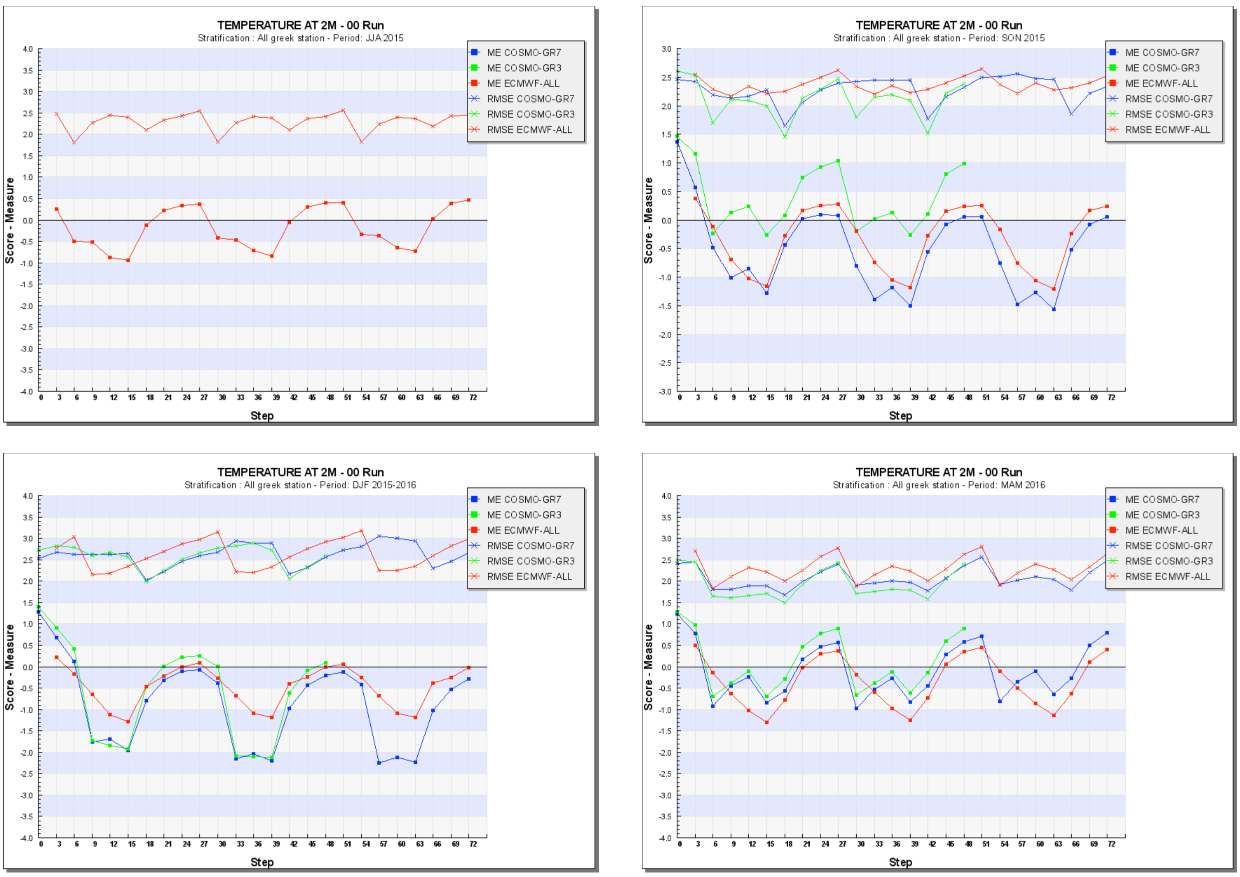


Fig.1: RMSE and Bias scores for MSLP (above) and 2m Temperature (below) from all models (00UTC run) calculated and presented for every season



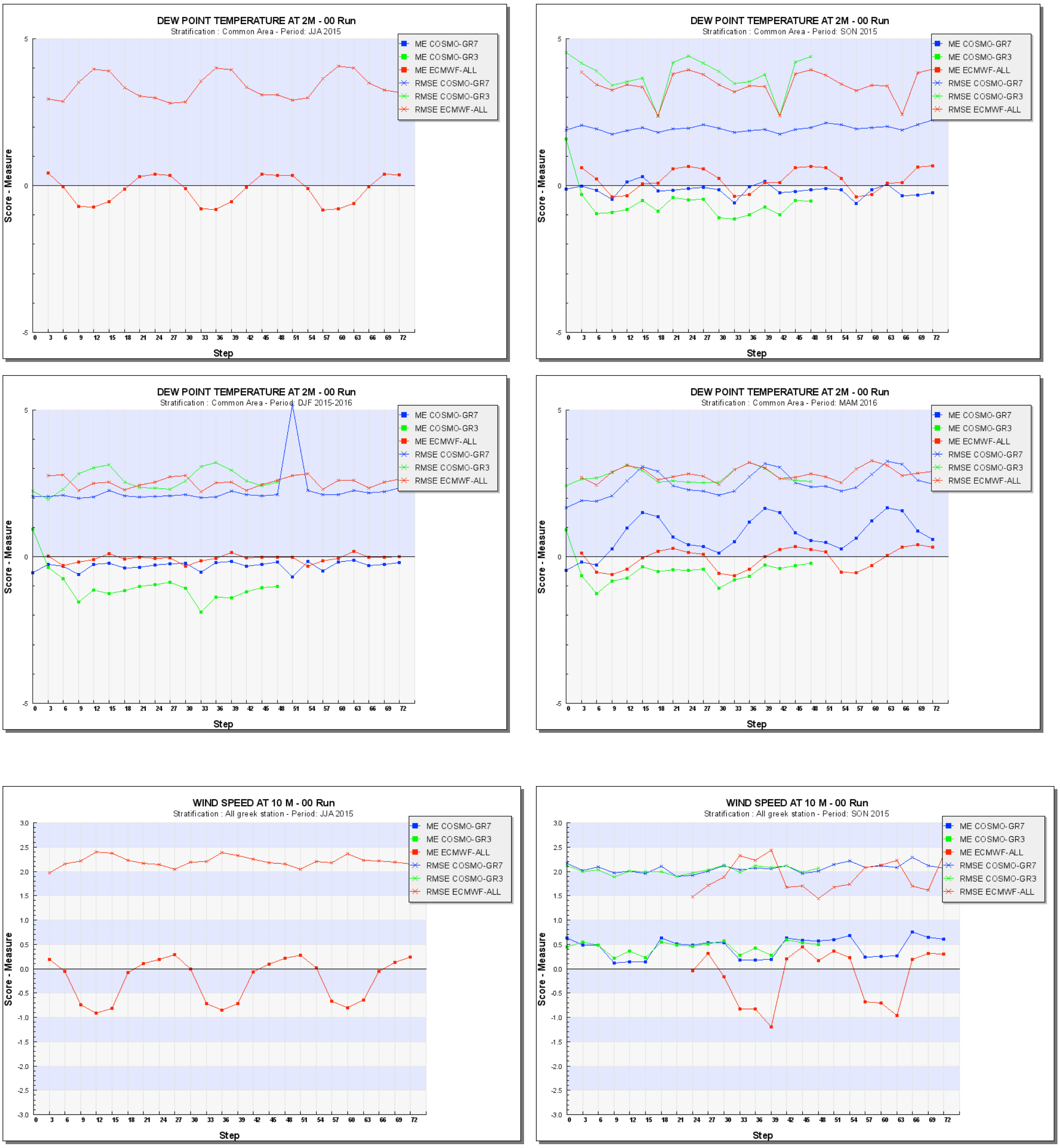
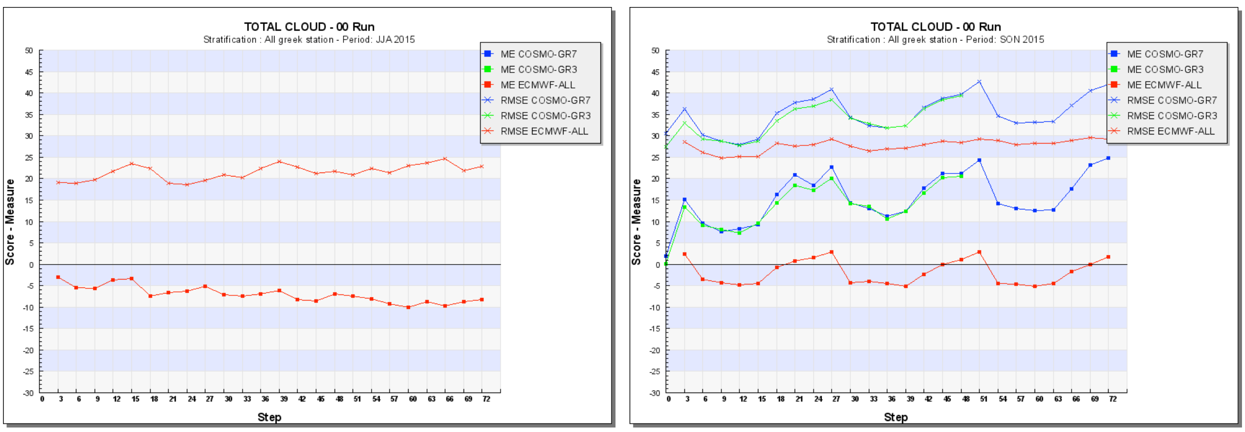


Fig.2: RMSE and Bias scores for 2m Dew Point Temp (seasonal) and 10m Wind speed (only two seasons due to missing data) from the all models (00UTC run)



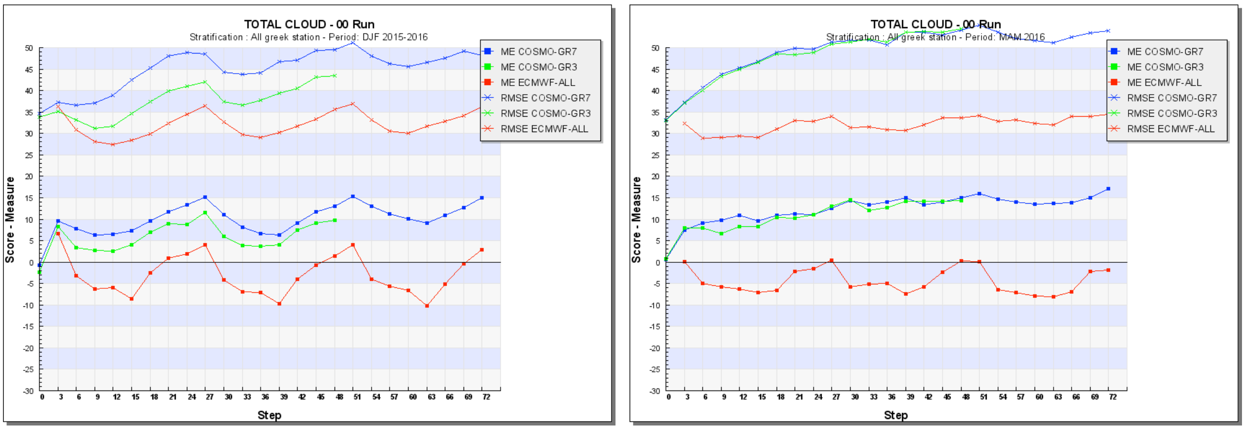


Fig.3: RMSE and Bias scores for Cloud Cover from the IFS model (00UTC run) – Fall and Winter (above)

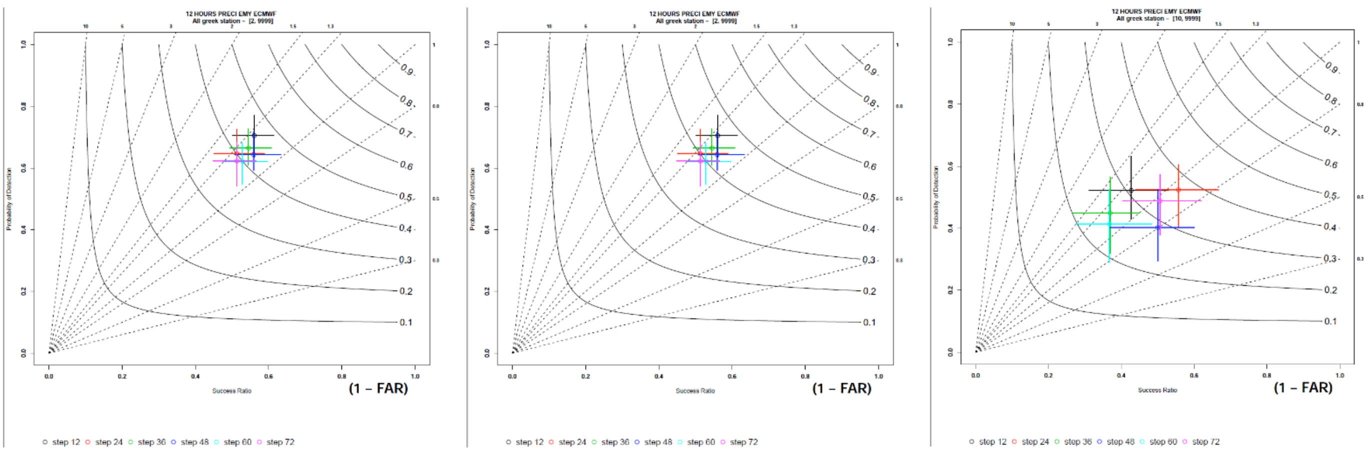
2m Dew Point Temperature: The DPT is mainly underestimated the warm hours of the day especially in the summer and spring. The diurnal cycle is evident in he Bias values. Very large RMSE values for the summer (Fig. 2).

10m Wind Speed: The data series for this parameters was not available so only two seasons are presented..The 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). The slight overestimation of wind is also apparent in the Time Series (TS) plots of obs-fcst pairs and of the statistical scores (Fig.4).

Cloud Cover: A general underestimation of cloud cover percentage from IFS model (opposite from limited area models) 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 30mm accumulated over each 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 Performance Diagrams (PD). PD summarizes the SR (that is FAR-1), POD, FBI, and TS. Dashed lines represent bias scores with labels on the outward extension of the line, while labelled solid contours are TS. Sampling uncertainty, if any, is given by the crosshairs. A perfect, or better, forecast will lie on, or towards, the upper right corner of the diagram.



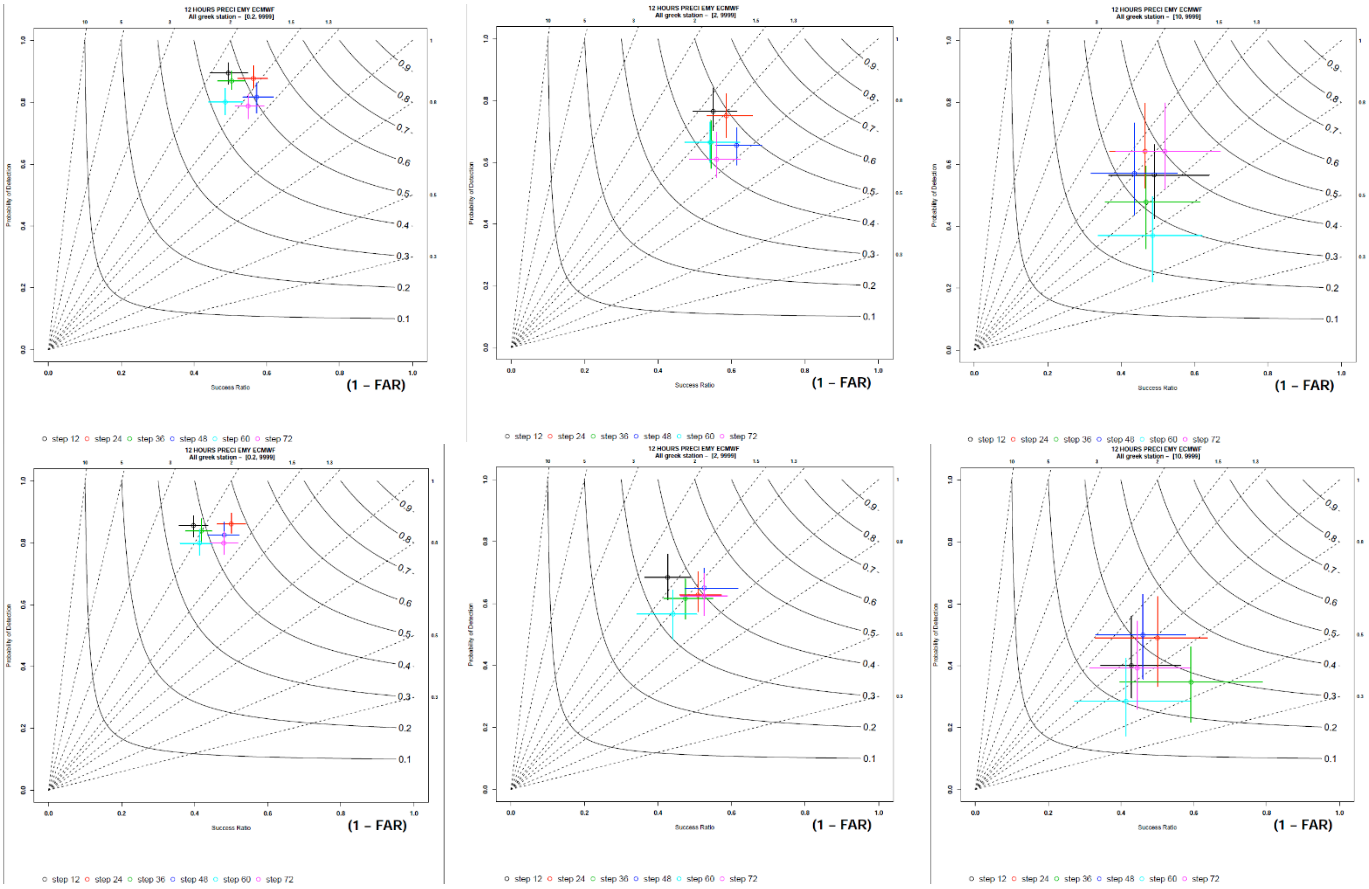


Fig.4: Performance diagrams: Fall-Winter-Spring (up to down) for thresholds >0.2mm (left), >2mm (middle), >10mm/12h (right)

The results indicate that the IFS model performs well for the thresholds corresponding to small amounts of precipitation, but it fails to accurately predict large rainfall events. PD graphs indicate that there is an overprediction for the lower thresholds meaning that the model was giving more often precipitation than truly occurred. On the other hand, the model underforecasts precipitation during heavy rainfall events (>10mm). In general, the performance of IFS model deteriorates with increasing precipitation threshold.

3.1.2 ECMWF model output compared to other NWP models

The HNMS operates two high-resolution Numerical Weather Prediction (NWP) systems (COSMO-GR and Eta/Skiron) that provide detailed deterministic forecasts for an extended area around Greece on a daily basis. The operational domain of COSMO-GR7 covers an area with a longitude range of 45^{o} and a latitude range of 24.5° with 35 vertical levels and a horizontal resolution of 0.0625° (~7 km). More recently, a higher resolution version of the model is also operated (~2.5 km), providing a more detailed forecast (COSMOGR3).

Comparison of the performance of the ECMWF model with the COSMO-GR7 and COSMO-GR3 is done on a regular basis. Average statistical indices over every season are calculated and presented in this report (Fig1,2,3). For MSLP, the IFS model gives lower errors and less propagation with time as for the two local models. On the other hand, IFS performs worse with respect to 2m temperature, and with the highest values of error in different timesteps than the two COSMO models that as expected have similar behaviour.

SEEPS is a precipitation score designed to be as insensitive as possible to sampling uncertainty and equitability and most important adapts to the climate of the region in question. A matrix comprised of climatological probabilities for ‘dry’ and ‘light’ conditions is derived from 30 years of observations data (1980- 2009) for each station (disseminated by GTS) where high values have been excluded by a quality control mechanism based on the latitudinal dependence of upper limit values. The station climatology was provided by ECMWF while the code to calculate SEEPS was developed at HNMS. The score includes three categories; ‘dry’, ‘light precipitation’ and ‘heavy precipitation’. The boundary between the light and heavy categories is dependent on the relevant climatology for the station. The resulting SEEPS index matrix was calculated as the scalar product of the SEEPS weights matrix and the contingency table of total available model/observation pairs for each station averaged over the number of the days of the month. The SEEPS index matrix elements are HD (modelled Heavy-observed Dry), LD (modelled Light, Observed Dry), LH (modelled Light, observed Heavy), DH (modelled Dry, observed Heavy). The sum of these individual components determines the total SEEPS value for each month. The monthly values were averaged for each season and for the whole observing period. A perfect forecast has a SEEPS score of 0. The expected score increases linearly with the unskilled component of the forecast towards a maximum value of 1. A dataset of 24h accumulated precipitation values for 18 months (December 2013 to May 2015) was used for 19 Greek stations. The data was compared with precipitation forecasts from the operational regional model COSMO 7km and the global ECMWF model.

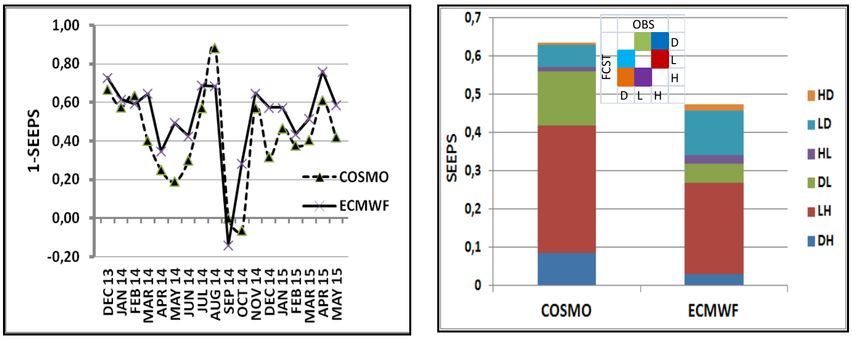


Fig.6: Left: Monthly variation of 1-SEEPS during the observational period SEEPS for COSMO and ECMWF models. Right: Decomposition of SEEPS for the period December 2013 to May 2015 for COSMO and ECMWF models.

Because of its linearity, the SEEPS score can be broken down into individual contributions from the six off-diagonal elements of the 3×3 contingency table, providing insight into the source of error and facilitating a comparison of the strengths and weaknesses between models. Both models have their largest SEEPS error contribution from predictions for the 'light' category when 'heavy' was observed (orange in Fig. 2). This is apparent in the corresponding graphs of SEEPS attributes for each season (Fig. 3). For stations with moderate-to-dry climatologies (p1>0.5), such as Greece, predicting 'light' rainfall when 'heavy' is observed is penalized considerably more than predicting 'light' when 'dry' is observed (blue). For the ECMWF model, SEEPS is mainly connected with LD and LH categories, indicating that it has the tendency to smooth out precipitation forecasts. On the other hand, the COSMO model is penalized for LH and DL categories, leading to the conclusion that its forecast is usually 'drier' than that of the ECMWF model, and that the SEEPS score is strongly influenced by this attitude. As anticipated, SEEPS scores are generally better in DJF, while for the specific period examined in the context of this study, the COSMO model scores were worse in JJA-SON.

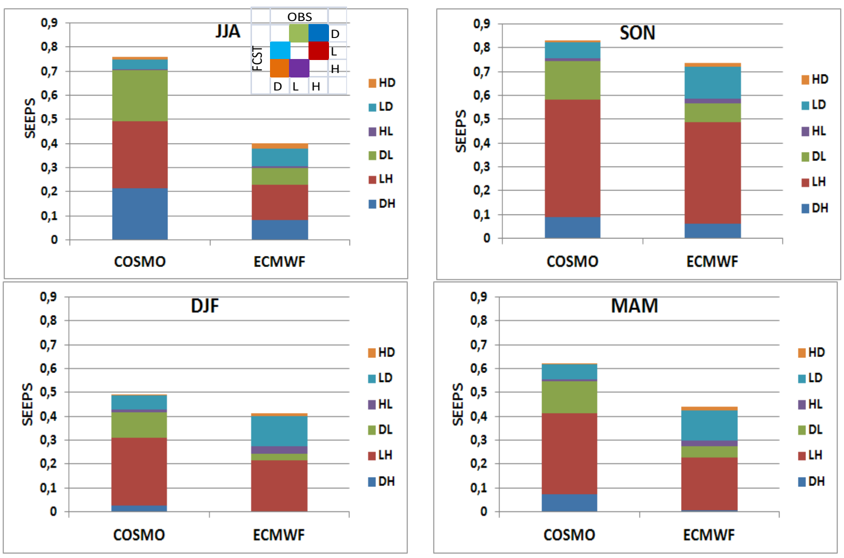


Fig. 7: Seasonal decomposed SEEPS score for COSMO and ECMWF models

3.1.3 Post-processed products

3.1.4 End products delivered to users

3.1.5

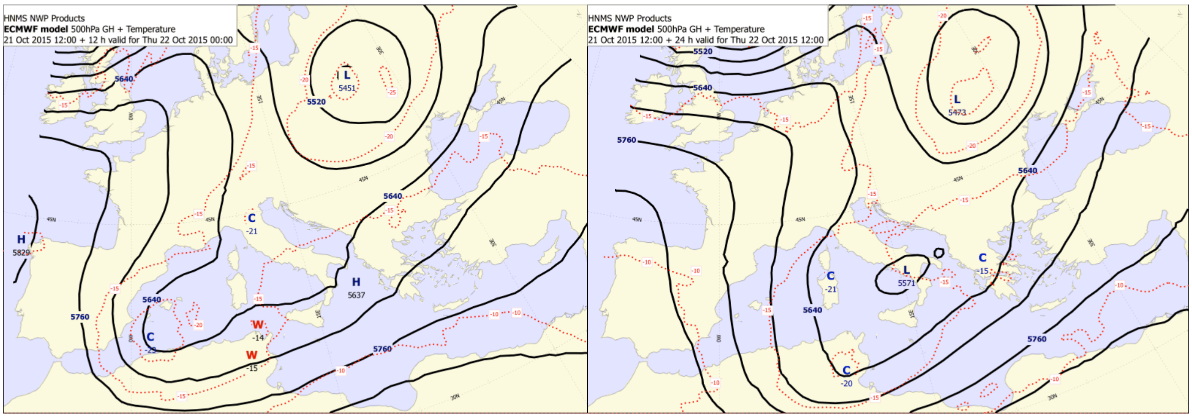
3.2 Subjective verification

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

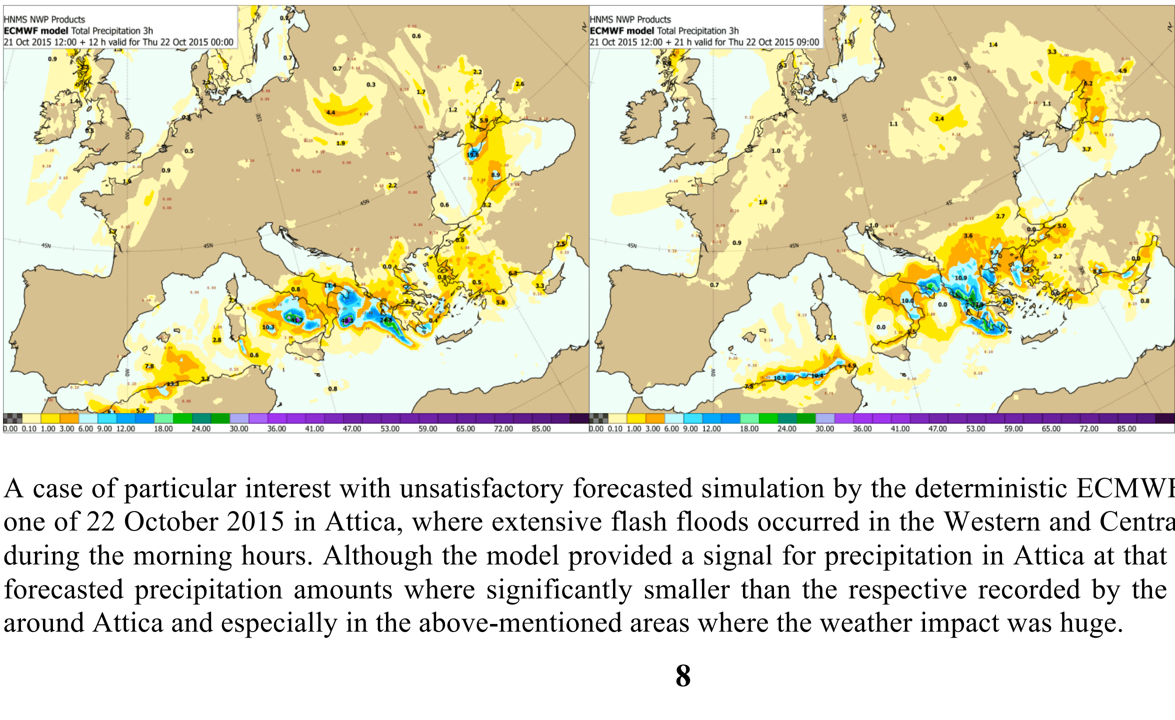
3.2.2 Case studies: (I.Kouroutzoglou, HNMS)

The following systematic errors are experienced by HNMS staff:
a) Underestimating of precipitation totals over Eastern–windward parts of Greece:
i. *500hPa prevailing flow from SW*
ii. Cold front crosses the country from the SW
iii. Presence of extensive low level baroclinic zones without necessarily to be combined to organized frontal activities, mainly from Northern Africa
b) Overestimation 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.

500hpa GH-T 21/10/2015 12UTC t+12 500hpa GH-T 21/10/2015 12UTC t+24



TP 21/10/2015 12UTC t+12 TP 21/10/2015 12UTC t+21



A case of particular interest with unsatisfactory forecasted simulation by the deterministic ECMWF model was the one of 22 October 2015 in Attica, where extensive flash floods occurred in the Western and Central parts of Attica during the morning hours. Although the model provided a signal for precipitation in Attica at that time period, the forecasted precipitation amounts where significantly smaller than the respective recorded by the surface stations around Attica and especially in the above-mentioned areas where the weather impact was huge.

Real-time weather situation

22/10/2015 0700B

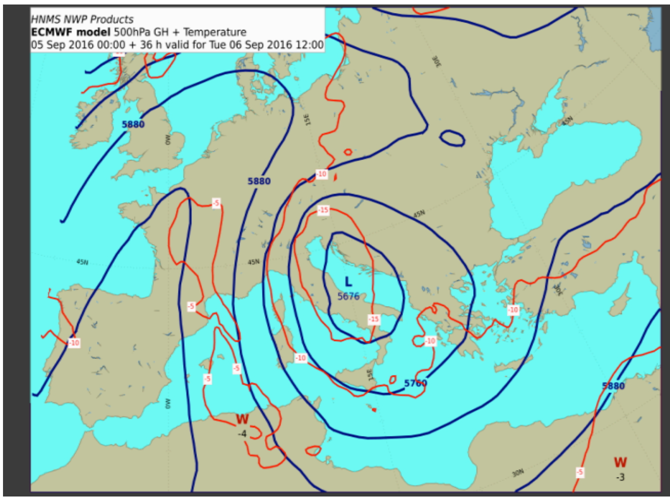
22/10/2015 0800B

22/10/2015 0830B

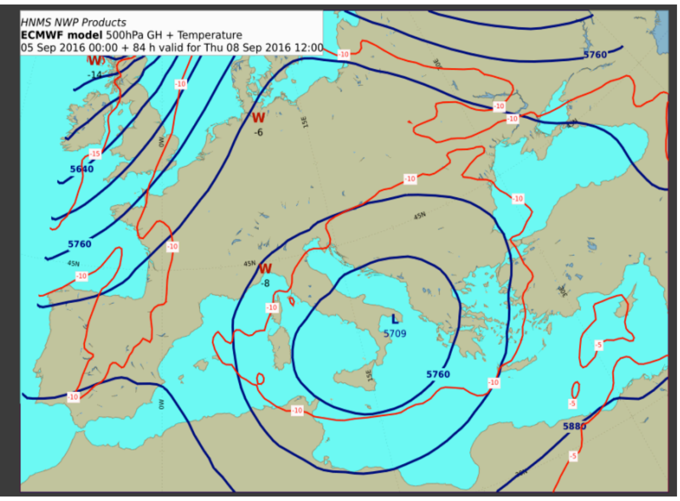
22/10/2016 0900B

A second and more recent case with also significant interest, since it consists part of synoptic category of cyclogenetic events affecting the Eastern Mediterranean area including Greece, was the one that occurred during the period 03-13 September 2016. Severe weather affected the continental parts of Greece and mainly the western parts of Greece, accompanied by huge damages and life losses in the latter areas. The model failed to effectively predict the persistence of the upper level dynamic processes that favored the re-enforcement of the upper level cyclone. At the beginning of the event (06 September 2016), the model predictions showed an improvement of the weather conditions after the 8th of September 2016, while the next model runs although simulated effectively the kinematic characteristics of the large scale upper level cyclonic activity after the 8th of September 2016, the respective model predicted precipitation was weaker than the observed by the surface stations.

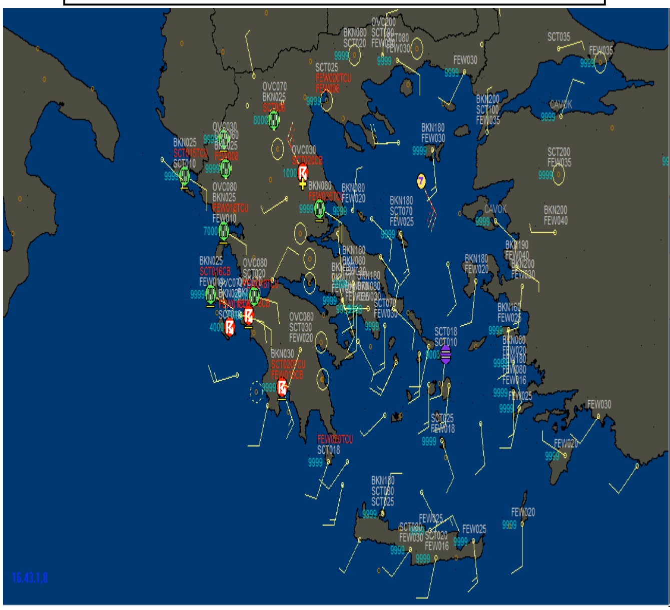
500hPa FORECASTED SIMULATION



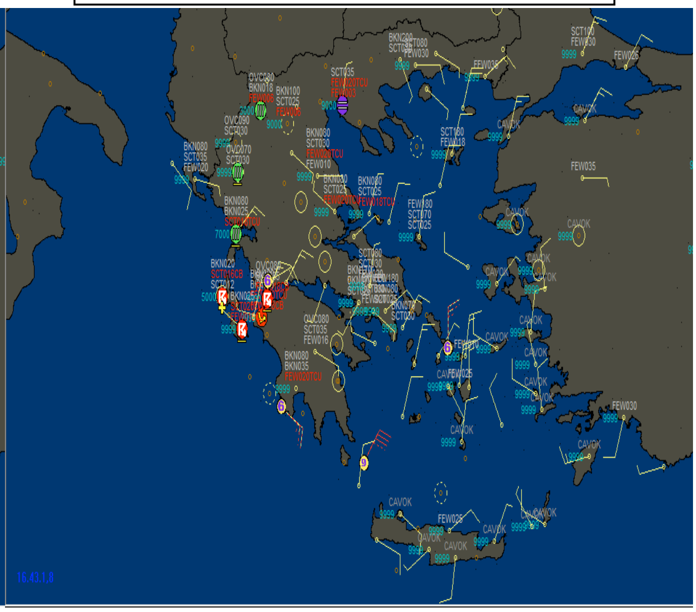
500hPa FORECASTED SIMULATION



REAL TIME VISUALIZATION
06 SEPTEMBER 2016 12UTC



REAL TIME VISUALIZATION
08 SEPTEMBER 2016 10UTC



4. Feedback on ECMWF "forecast user" initiatives

Please comment on whether you use the following, on how useful you find them, and on any changes you would like to see. The "known IFS forecast issues" page –(see: https://software.ecmwf.int/wiki/display/FCST/Known+IFS+forecasting+issues) and the "severe event catalogue" (see: https://software.ecmwf.int/wiki/display/FCST/Severe+Event+Catalogue).

5. References to relevant publications