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VERIFICATION OF THE OPERATIONAL HIGH-RESOLUTION WRF FORECASTS PRODUCED BY WAVEFORUS PROJECT

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1. INTRODUCTION

The greater area of Thermaikos Gulf (Fig. 1b), which is located in Greece in northwestern Aegean sea, is an area of high economic and environmental significance. Weather and sea-state predictions are necessary in this region for marine transportation, fisheries, aquaculture, water sports, recreation and tourism as well as for scientific studies and environmental management and modeling. In the framework of WaveForUs project the most recent meteorological, storm surge, wave and coastal circulation models are combined in order to produce high-resolution operational weather and sea-state forecasts for Thermaikos Gulf and for dissemination purposes to end users and the public (http://wave4us.web.auth.gr; http://meteo.geo.auth.gr). Numerical weather predictions (NWPs) are not only produced for the Gulf of Thermaikos, but also for the Mediterranean sea. The state-of-the-art Weather Research and Forecasting model with the Advanced Research dynamic solver (WRF-ARW ver3.5.1; (Skamarock et al. 2008, Wang et al. 2013) is the core of the weather forecasting system. The goal of this article is to investigate the performance of the operational NWPs produced by WaveForUs project.

2. DATA AND METHODOLOGY

Three model domains, using 2-way telescoping nesting, cover Europe and the Mediterranean sea basin (D01), central and eastern Mediterranean (D02; Fig. 1a) and northern Greece – Thermaikos Gulf (D03; Fig. 1b) at horizontal grid-spacings of 15km, 5km and 1.667km, respectively. This setup and WRF version (3.5.1) are currently used operationally, while a smaller D02 and version 3.2.0 were originally used since the beginning of the project in 2013. The operational NCEP/GFS analyses and 3-hourly forecasts (0.5°x0.5° lat.-long.) are employed as initial and boundary conditions of the coarse domain. The forecast horizon is 96 hours and the initialization is performed at 1200 UTC daily. The SSTs are provided daily by NCEP at a horizontal increment of 1/12°x1/12° lat.-long., and remain fixed to the initial values throughout the forecast horizon. In the vertical, all nests employ 39 sigma levels (up to 50 hPa) with increased resolution in the boundary layer. The Ferrier scheme, the Betts-Miller-Janjic scheme, the RRTMG, the Monin-Obukhov (Eta), the Mellor-Yamada-Janjic and the NOAH Unified model represent microphysical processes, sub-grid scale convection, longwave and shortwave radiation, surface layer, boundary layer and soil physics, respectively.

Statistical evaluation is performed in the forecasts of D01 against the operational gridded ECMWF analyses and in the ones of D02 and D03 using the available stations of the WMO [up to 92 stations in D02, including the 17 stations of the Hellenic National Meteorological Service (HNMS; Fig. 1a)]. The ECMWF analyses are available at a regular grid with an increment of 0.15°x0.15° lat.-long. The errors are investigated as a function of the forecast time and the prevailing upper-air synoptic circulation. The period of the statistical evaluation is from March 2014 to February 2015.

The 10 upper-air synoptic circulation types of Karacostas et al. (1992), which describe the prevailing conditions over Greece, are used in the 6-hourly synoptic classification. These types are: 1) zonal flow (ZON), 2) northwest flow (NW), 3) open trough (OPTR), 4) closed low (CLOL), 5) cut-off low (CUTL), 6) southwest flow (SW), 7) open ridge (OPRG), 8) closed high (CLOH), 9) omega blocking (OME) and 10) undefined (High – Low) cases.

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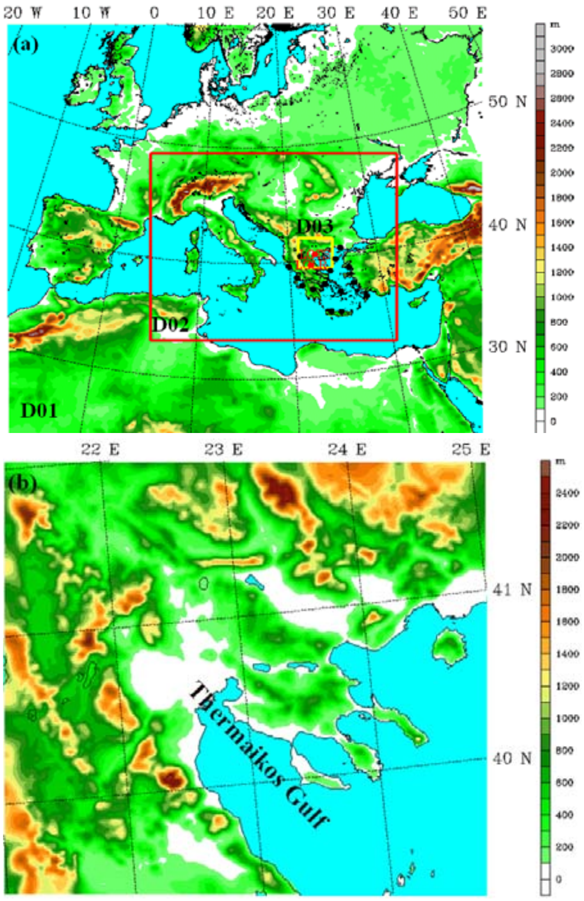

Fig. 1. The topography (m) of (a) the first – D01 and (b) the third – D03 nest used by WRF-ARW. On panel (a), D02 (red frame) and D03 (yellow frame) are illustrated. The utilized HNMS stations are indicated in black and the stations of Thessaloniki airport (LGTS) and Larissa airport (LGLR) are shown in red.

3. RESULTS

The Mean Absolute Error (MAE) of the mean sea-level pressure (mslp) forecasts of D01, relative to the ECMWF analyses, in Greece (Fig. 2) ranges from about 0.95 hPa at T+24 hours to 2.15 hPa at T+96 hours. The MAE of the 10m wind speed (WS10m) forecasts of D01 (Fig. 3) over Greece is about 1.6-1.8 m/s at T+24 hours and 2.2-2.3 m/s at T+96 hours. The WS10m errors exceed 3-3.5 m/s close to the boundaries of D01, indicating the improvement of the forecasts due to the use of the higher resolution WRF model and/or the 2-way nesting.

The fields of the mslp, WS10m, 2m air temperature (T2m), 2m relative humidity (RH2m) and total 12-hourly accumulated precipitation (06-18 & 18-06 UTC) are evaluated in D02 at the locations of all the available stations and at the 17 HNMS stations (Figs. 4, 5). It is noted that D02 and D03 are initialized at T+6 hours in order to reduce the model spin-up. Therefore, the scores are illustrated from the 12th forecast hour. The model underestimates the mslp and systematically overestimates WS10m up to about 2 m/s (Fig. 4). The maximum (minimum) daily temperatures are underestimated (overestimated) indicating a reduction of the daily temperature range. This behavior may be attributed to errors in the surfaces heat fluxes predicted by the soil and boundary layer parameterization schemes. In Greece, the WRF-D02 MAE of mslp ranges from about 0.8 to 2.1 hPa, the one of T2m varies between 1.6 and 1.9 K, the error of WS10m lies between 2.1 and 2.5 m/s, while that of RH2m is at about 9-12% (Fig. 4). These scores are in agreement with the ones that appear in the literature over the same area.

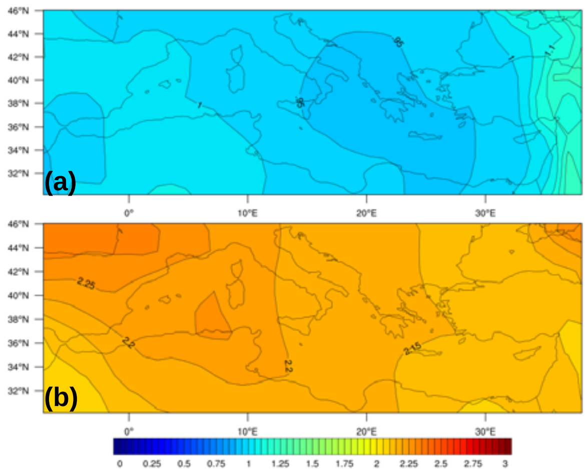

Fig. 2. The MAE (hPa) of the mslp forecasts of WRF-D01 at a) T+24 and b) T+96 hours against the operational ECMWF analyses (Mar 2014 – Feb 2015).

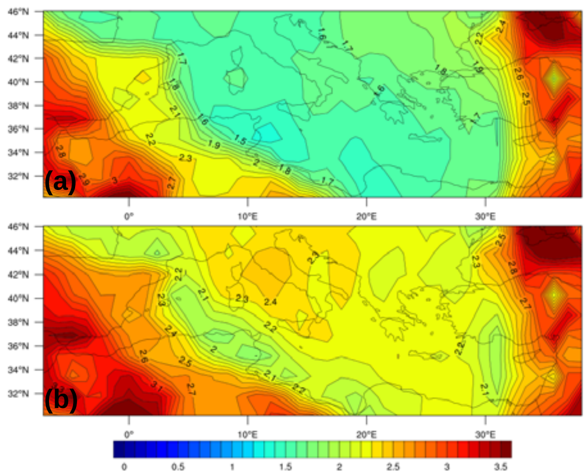

Fig. 3. The MAE (m/s) of the WS10m forecasts of WRF-D01 at a) T+24 and b) T+96 hours against the operational ECMWF analyses (Mar 2014 – Feb 2015).

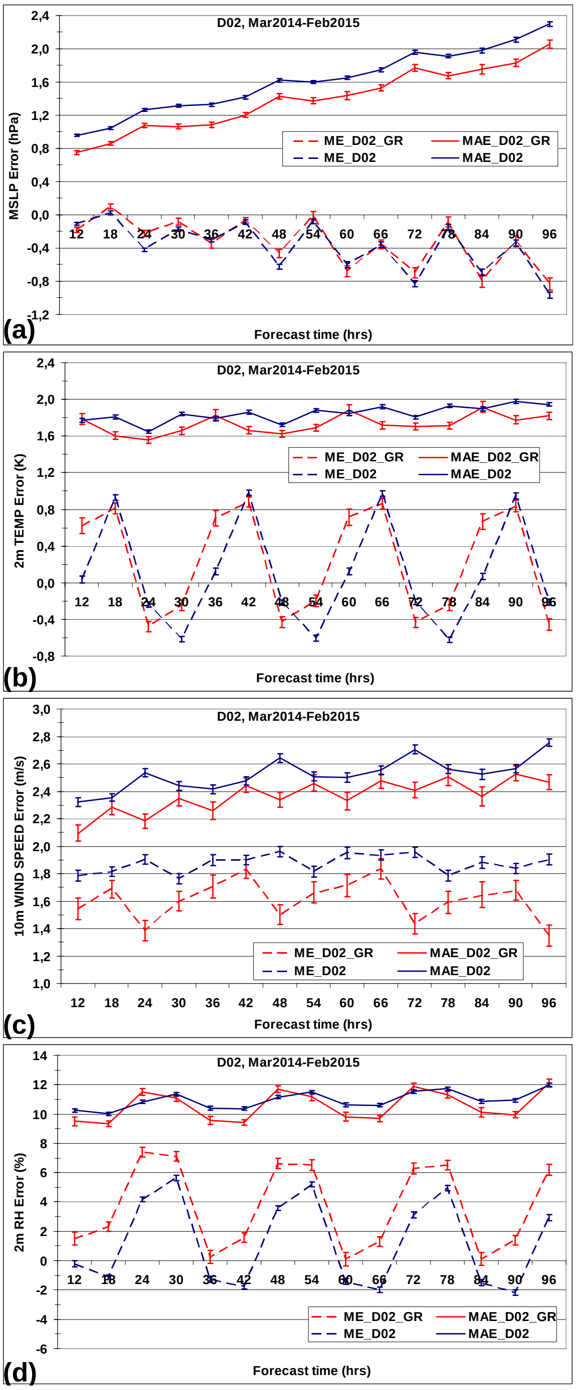

Fig. 4. The Mean Error (ME; WRF - observations) and the Mean Absolute Error (MAE) of a) mslp, b) T2m, c) WS10m and d) RH2m forecasts of WRF-D02 at the locations of all the available stations (D02) and the HNMS stations (D02-GR). The 95% confidence intervals are indicated.

The Heidke Skill Score (HSS) is a measure of the model accuracy relative to that of random chance. The HSS of the 12-hourly precipitation forecasts of D02, taking into account all the events (> 0.1mm/12hours), varies from 0.46 in the first forecast day to 0.35 at the end of the forecast horizon (Fig. 5). As far as the precipitation is concerned, the model performance in the whole D02 is the same or better than in Greece.

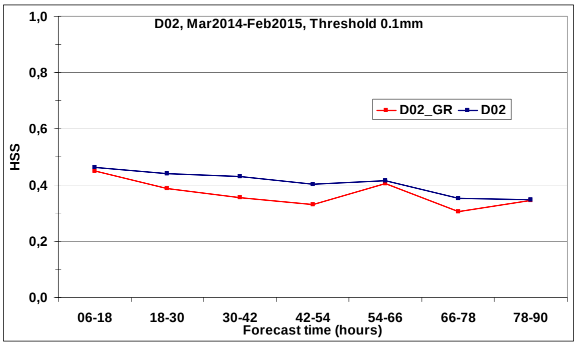

Fig. 5. The Heidke Skill Score of the 12-hourly precipitation forecasts of WRF-D02 at the threshold of 0.1mm at the locations of all the available stations (D02) and the HNMS stations (D02-GR).

At Thessaloniki airport (LGTS; in Thermaikos Gulf) and Larissa airport (LGLR; located about 40km SW of the gulf), the WRF-D03 systematically underestimates mslp and overestimates WS10m, but it also overestimates T2m at the vast majority of the forecast times (Fig. 6). The D03 MAEs of mslp, T2m, WS10m and RH2m at these 2 stations range between 0.7-2.3hPa, 1.7-2.0K, 1.4-2.1m/s and 9-12%, respectively (Fig. 6). The predictability of WS10m, T2m and RH2m appears to be maintained with forecast time similarly to D02.

Fig. 7 shows that the most frequently observed upper air synoptic type in Greece from March 2014 to February 2015 is the SW flow (25.3%). The largest average MAEs of mslp are associated with cut-off lows (1.5 hPa), followed by SW flow and closed lows, while the largest average MAEs of WS10m occur in SW flow (2.5-2.6 m/s).

4. SUMMARY - CONCLUSIONS

This study assesses the performance of the non-hydrostatic WRF-ARW model (ver 3.5.1), which is used operationally in the project WaveForUs in the Mediterranean sea, Greece and Thermaikos Gulf - northern Greece, from March 2014 to February 2015. The mslp is underestimated and the WS10m is overestimated in both inner domains. The model seems to maintain the predictability of WS10m, T2m and RH2m. Finally, the largest errors are associated with SW flow and cut-off lows during this period.

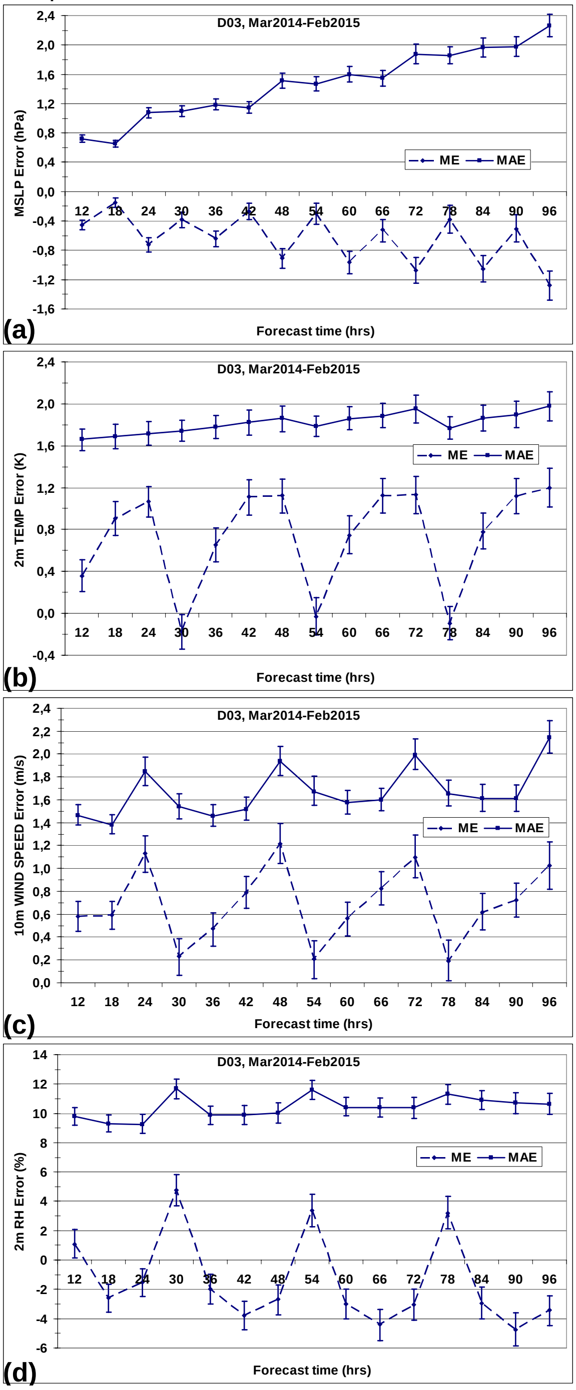

Fig. 6. ME (WRF - observations) and MAE of a) mslp, b) T2m, c) WS10m and d) RH2m forecasts of WRF-D03 at Thessaloniki (LGTS) and Larissa (LGLR) airports. The 95% confidence intervals are indicated.

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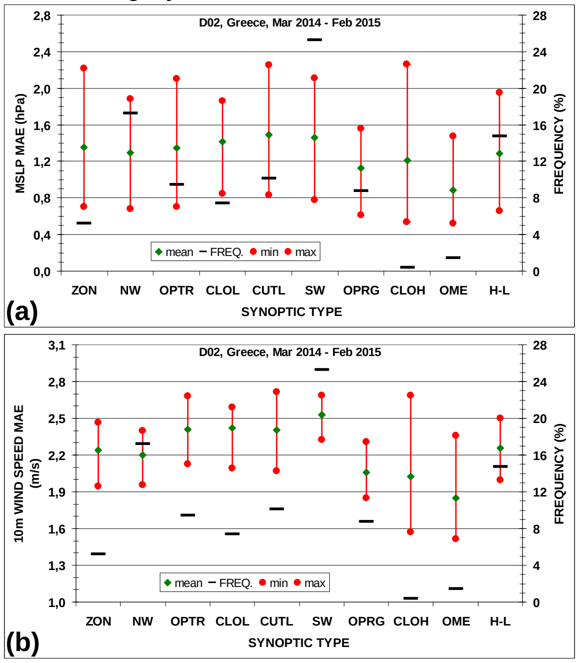

Fig. 7. The MAE of a) mslp (hPa) and b) WS10m (m/s) forecasts of WRF-D02 from T+12 to T+96 hrs at the 17 HNMS stations vs the synoptic type. The frequency (%) of each synoptic type is indicated.

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