Numerical Weather Prediction Sensitivity to Sea-Surface Temperatures

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The numerical weather prediction system WRF-ARW is used in order to investigate the sensitivity of 3-day forecasts to sea surface temperatures (SSTs). WRF is integrated in three domains covering Europe, Greece and Northern Greece using telescoping nesting with grid spacing of 15km, 5km and 1.667km, respectively. In the control experiment NCEP SSTs with grid spacing of 1/12°x1/12° are used, kept constant throughout the forecast. In the 2nd experiment the initial SSTs are the same with the control run, but vary during the forecast according to the predicted meteorological conditions, using the Zeng and Beljaars model. In the 3rd experiment, very high-resolution SSTs (provided by JPL/NASA with grid spacing of 0.01° x 0.01°) are employed. The experimental period covers January 2012 which was characterized by strong synoptic activity. The use of time-varying SST forcing seems to improve the model forecasts, but not significantly.

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1 Introduction

Over the last decades, there is a growing appreciation of the importance of surface conditions for weather and climate. Yamamoto and Hirose (2007) showed that the numerical simulation of a developing depression was sensitive to the definition of the SSTs (reanalysis, satellite) and this was due to their mesoscale features. A numerical case study suggested that lightning episodes associated with thunderstorm activity at central Macedonia in June 2009 were sensitive to the SSTs and their temporal evolution (Pytharoulis et al. 2012). Using a three-dimensional cloud model, Tompkins and Craig (1999) found that in the absence of large scale flow, convection is not sensitive to changing SSTs. The surface heat fluxes were important for the development of a hurricane-like cyclone (medicane) that appeared in the Mediterranean Sea in January 1995 (Pytharoulis et al. 2000). On the contrary, the Mediterranean bomb of January 2004 was strongly affected by the upper air dynamics, but not by the surface heat fluxes (Lagouvardos et al. 2007, Katsafados et al. 2011). Therefore, the SSTs and the surface fluxes seem to affect the meteorological conditions in different ways.

In the framework of WaveForUs project, the Laboratory of Meteorology and Climatology (http://meteo.geo.auth.gr) of the Aristotle University of Thessaloniki provides to the partners and the public, operational numerical weather predictions for Europe, Greece and mainly Thermaikos Gulf, which is the target area. The goal of this article is to investigate the sensitivity of the operational numerical weather predictions to the SSTs, aiming to improve the model performance.

2 Data and Methodology

The nonhydrostatic Weather Research and Forecasting model with the Advanced Research dynamic solver (WRF-ARW Version 3.2.0; Skamarock et al. 2008, Wang et al. 2010) was utilized in the numerical experiments. Three model domains, using 2-way telescoping nesting, covered Europe and northern Africa (D01), the central and a large part of eastern Mediterranean sea, including Greece and the Aegean sea (D02; Fig. 1a) and the wider region of Macedonia - Thermaikos Gulf (D03; Fig. 1b) at horizontal grid-spacings of 15km, 5km and 1.667km respectively. Fine-resolution data (30’’ x 30’’) were used in the definition of topography and land use. GFS analyses and 3-hourly forecasts (0.5°x0.5° lat.-long.) of the 1200 UTC cycle were employed as initial and boundary conditions of the coarse domain and the production of 3-day forecasts. The two inner domains were initialised 6 hours after the coarse domain (D01) in order to reduce the model spin-up. In the vertical, 39 sigma levels (up to 50 hPa) with increased resolution in the boundary layer were used by all nests. The Ferrier scheme, the Betts-Miller-Janjic scheme, the RRTMG, the Monin-Obukhov (Eta), the Mellor-Yamada-Yanjic and the NOAH Unified model represented microphysical processes, sub-grid scale convection, longwave and shortwave radiation, surface layer, boundary layer and soil physics, respectively.

(a) (b)

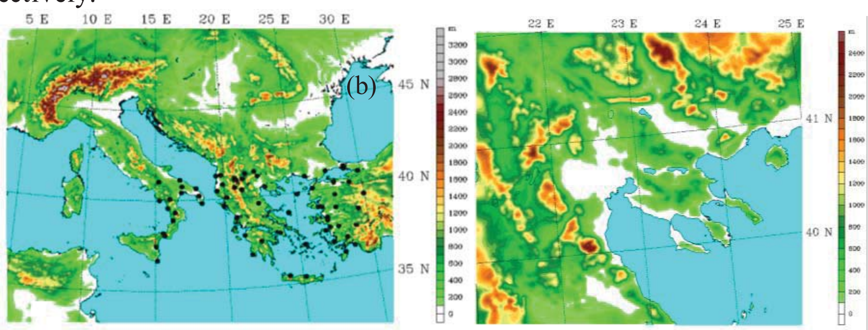

Fig. 1. The topography of (a) the second – D02 and (b) the third – D03 nest used by WRF-ARW in the numerical experiments. The locations of the utilized WMO stations are indicated on D02.

The three SST datasets/configurations employed in the experiments were:

1) The daily NCEP (National Centers for Environmental Prediction) SSTs, with a grid-spacing of 1/12°x1/12° lat.-long., that were kept fixed throughout each simulation (hereafter exp1). The NCEP SSTs are produced on a daily basis through the assimilation of the most recent 24-hours sea-surface observations and satellite SST measurements (http://polar.ncep.noaa.gov/sst/ophi/),

2) The daily NCEP SSTs of exp1 in the initial conditions, allowed to vary with time (hereafter exp2) according to the WRF forecasts, following the model of Zeng and Beljaars (2005),

3) The daily JPL (Jet Propulsion Laboratory/ NASA) SSTs, with a grid-spacing of 0.01°x0.01° lat.-long (Chao et al. 2009), that were kept fixed throughout each simulation (exp3). These analyses use multi-sensor satellite data and in situ observations from buoys.

All the experiments were performed at operational forecast mode, which means that the boundary conditions were based on GFS forecasts and the initial SSTs were valid one day before the initial time of WRF. Three-day forecasts were performed for each day of January 2012. The impact of the different SSTs on the meteorological forecasts was evaluated using 68 stations of the World Meteorological Organization network (WMO; Fig. 1a).

3 Results

The experiments were performed for January 2012 which was characterized by strong synoptic activity and low temperatures (associated with cold air intrusions) that affected most of the country, including Thermaikos Gulf. The deepest cyclone appeared on January 6th and exhibited a minimum mean sea-level pressure of 980 hPa over Chalkidiki. According to the NCEP reanalysis, the anomaly of the mean monthly geopotential height at 500 hPa (temperature at 850 hPa), relative to 1961-1990, was -20 to -50 gpm (-2 to -3 K) over Greece. Intense winds were frequently observed over the Greek seas due to the developed strong pressure gradients. At Thessaloniki airport, the 10-minute wind speed at 10m reached 15.5 m/s (near gale force) with gusts up to 20.6 m/s on 6 January.

The SST difference of exp1 and exp3 in January 2012 is illustrated in Fig. 2. The JPL SSTs are generally warmer than the ones of NCEP in the Mediterranean, reaching deviations of 1.5-2 K locally. It is noted that the very high-resolution of JPL SSTs allows the representation of coastal features such as the well-defined cold anomalies near estuaries. These are likely to play an important role in the modeling of mesoscale phenomena under certain meteorological conditions.

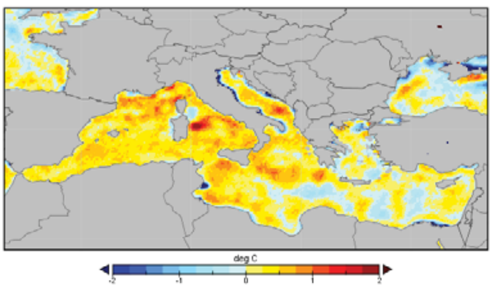

Fig. 2. The average SST difference (exp3-exp1 in K) of NCEP (exp1) from JPL/NASA (exp3) SSTs in January 2012, zoomed over the Mediterranean sea region.

The 31 forecasts produced at each experiment were statistically analysed. Fig. 3 shows the mean absolute error (MAE) of the WRF forecasts from the domain D02 at the locations of the 68 WMO stations of Fig. 1a. These stations were chosen because they are located in Greece and the nearby regions. It is important to investigate the effect of the different SSTs in this area and not only in Thermaikos Gulf, because in WaveForUs project WRF provides the forcing to the ocean models that operate in the Mediterranean sea, the Aegean sea and Thermaikos.

The MAE of mean sea-level pressure (mslp) ranges from about 1.3 to 3 hPa, the one of 2m temperature varies between 1.6 and 2.9 K while the error of 10m wind speed lies between 2.6 and 3.25 m/s. These errors were expected to be near the upper limit of the ones that appear in the literature since January 2012 was characterized by large variability in this region and therefore meteorological conditions more difficult to predict. Regarding the mean error (not shown), the mslp was systematically underestimated, while the temperature and the wind speed were overestimated by the model. The mean error signs of mslp and wind speed forecasts are consistent with the WRF-NMM forecasts of Katsafados et al. (2012) for January 2009 in the Mediterranean basin.

Fig. 3 indicates that exp2 (with the time-varying SSTs) provides the best forecasts of mslp, air temperature and wind speed, mainly after the first forecast day. The SSTs affect the atmosphere by destabilizing the boundary layer through the surface latent and sensible heat fluxes. However, the latter also depend on the surface wind speed and the thermodynamic state of the near surface layers. Thus, the effect of SST changes on the mesoscale or synoptic circulations is not immediate. The improvement of exp2, relative to the control run (exp1), reaches 3% (at T+72) in the mslp and 3.8% (at T+48) in the temperature. These values are not large, but the fact that they are associated with different synoptic conditions at various locations and monthly timescale suggests that the effect of the time-varying SSTs may be more important in smaller spatiotemporal scales. Indeed, this was indicated in the case study of Pytharoulis et al. (2012) in Macedonia.

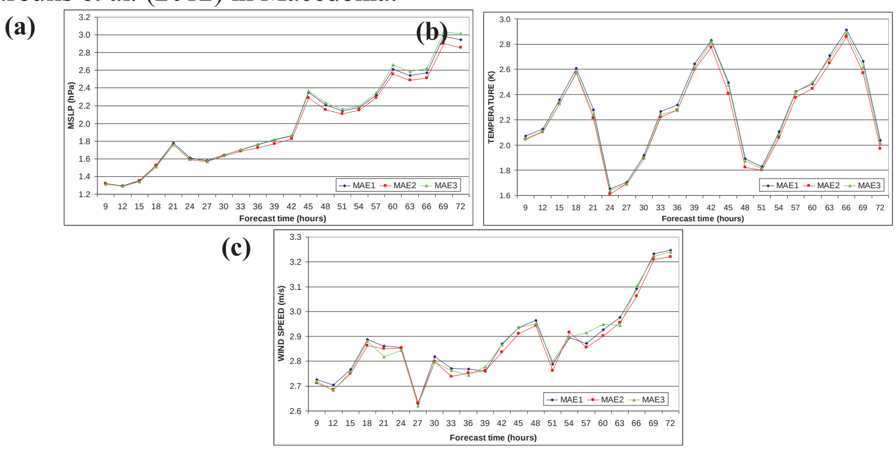

Fig. 3. The Mean Absolute Error of a) mean sea-level pressure, b) 2m air temperature and c) 10m wind speed forecasts of WRF-D02 in the three experiments of January 2012 at the 68 locations indicated in Fig. 1a.

The frequency Bias and Heidke Skill Score (HSS) of 12-hourly WRF-D02 precipitation forecasts at the locations of the same 68 WMO stations (Fig. 1a) is depicted in Fig. 4, using the thresholds of 0.1 and 5.0 mm. The time-varying SSTs (exp2) result to slightly smaller overestimation of the total number of precipitation events and slightly better HSS values. Regarding stronger events (≥ 5.0 mm), the exp2 bias is close to unit and has better values than exp1, exp3 in the last forecast day. However, exp3 has generally the highest HSS at these stronger events.

Fig. 5 shows the performance of WRF-D03 experiments at Thessaloniki airport (at Thermaikos Gulf) and Larissa airport (located about 40 km SW of the gulf). The MAE of mslp, 2m air temperature and 10m wind speed varies between 1.2-4.0hPa, 0.9-3.4K and 1.3-2.2m/s, respectively. Exp2 systematically exhibits smaller MAE in mslp than exp1 (up to 4%) and exp3. As far as temperature is concerned, exp3 generally provides the best forecasts (up to 10% smaller MAE than exp1), while no clear conclusion can be drawn for 10m wind speed.

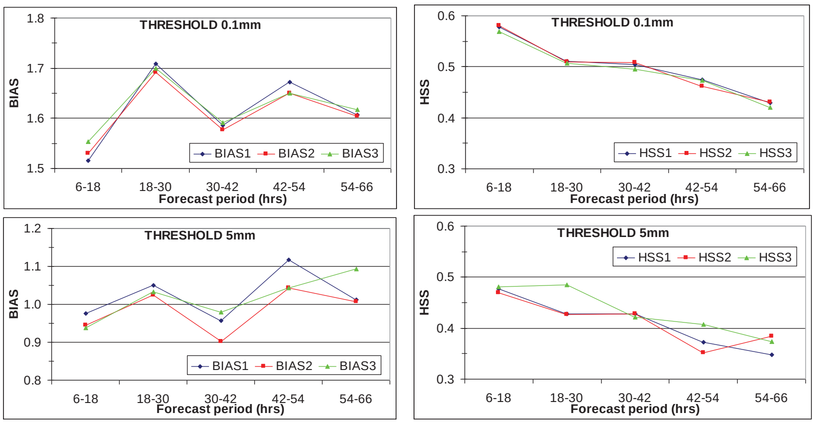

Fig. 4. Frequency Bias (BIAS) and Heidke Skill Score (HSS) of 12-hourly precipitation forecasts of WRF-D02 in the three experiments of January 2012 at the 68 locations indicated in Fig. 1a**.**

(a)

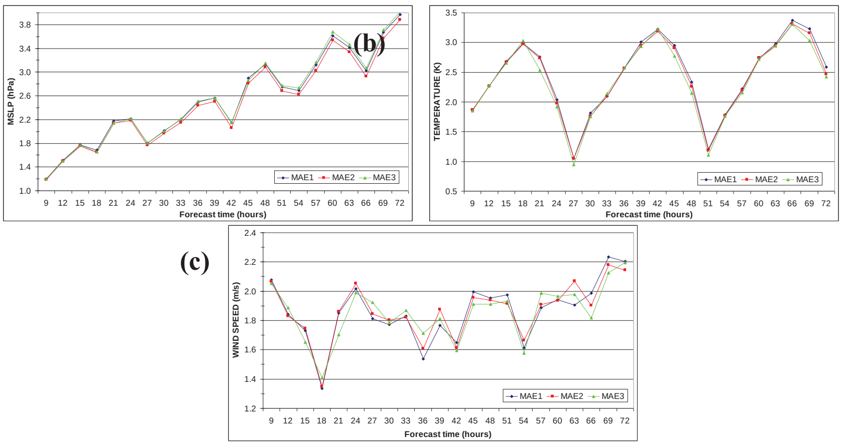

Fig. 5. MAE of a) mean sea-level pressure, b) 2m air temperature and c) 10m wind speed forecasts of WRF-D03 at Thessaloniki and Larissa airports in the 3 experiments of January 2012.

4 Conclusions

This study investigated the sensitivity of WRF-ARW forecasts on different SST datasets and configurations in the wider Greek area in January 2012. The use of a parameterization that allows the SSTs to vary according to the predicted meteorological conditions resulted to slightly, but systematically, better forecasts of mslp, 2m temperature, 10m wind speed and 12-hourly precipitation frequency. In the region close to Thermaikos Gulf the abovementioned SSTs and the very high-resolution JPL SSTs produced the best surface forecasts. These conclusions correspond to the mean results of a whole winter month. Future work must include further analysis of more months (at different seasons) as well as case studies.

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