INSTIITUTE OF ACCELERATING SYSTEMS AND APPLICATIONS, ATHENS, GREECE
WP10 Coordinator

MEDITERRANEAN OCEAN FORECASTING SYSTEM: TOWARD ENVIRONMENTAL PREDICTION

MFSTEP

Project Deliverable Report
D10

WP10: Atmospheric Forcing and Air-Sea Interaction Studies

Project title	**MEDITERRANEAN OCEAN FORECASTING SYSTEM: TOWARD ENVIRONMENTAL PREDICTION**					
Project acronym	**MFSTEP**					
Contract number	**EVK3-CT-2002-00075**					
Deliverable number	**D10**					
Deliverable title	**LAM2 simulations with predicted SSTs**					
Work package	**WP10 Atmospheric Forcing and Air-Sea Interaction Studies**					
Name of WP10 Coordinator	**Prof. George Kallos Institute of Accelerating Systems and Applications, Athens, Greece**					
Date of delivery	**May 2006**					
Report status		**Draft**		**Final**	**X**	
Project home page	**http://www.bo.ingv.it/mfstep/**					
WP10 home page	**http://forecast.uoa.gr/mfstep/**					

1 Introduction

This report describes the work performed by IASA and UAT under the scopes of deliverable 10 (subtask 10220) of WP10. This WP contained the necessary activities to create and deliver the atmospheric surface fields to the WP8 and WP9 ocean modeling community, to examine the sensitivity of atmospheric response to sea surface temperatures, to study the air-sea interactions and to implement higher resolution limited area models in Mediterranean sub-regions. Moreover, its aim was to define and perform the Scientific Validation Period (SVP) inter-comparison of atmospheric models.

Currently, the atmospheric numerical models utilize a fixed SST field throughout their simulation or forecast period. The aim of this sub-task (deliverable 10) is the implementation of the high-resolution predicted SSTs of OGCM or Alermo model in SKIRON/Eta model and the assessment of the importance of 2-3 days SST variability on the quality of the atmospheric forecast. This study will try to indicate whether the amount of extra information provided by predicted (contrary to fixed) SSTs improves the atmospheric forecasts in the Mediterranean sea at basin scale. Therefore, it was decided to utilize the predicted SSTs of OGCM model that covers the whole Mediterranean sea and not the products of Alermo that focuses only over Eastern Mediterranean.

2 The predicted OGCM SSTs

High-resolution SST forecasts were produced operationally by OGCM model (INGV) and they became available to the partners of subtask 10220 in order to be implemented in SKIRON/Eta model (LAM2). The horizontal resolution of this dataset is 1/16° x 1/16° (longitude-latitude) which is equivalent to about 5.5-6 km in our area of interest. Similarly to the high-resolution satellite SSTs, the high-resolution predicted SSTs were expected to represent the spatial variability of the sea-surface temperatures in the Mediterranean Sea more accurately than the 0.5x0.5 degrees operational SSTs.

2.1 Description

The high-resolution SSTs were available in daily files in Netcdf format for the whole TOP period. These files contained daily mean fields averaged from 1200 UTC on one day to 1200 UTC on the next day. The potential temperature forecasts were available at all OGCM model levels, but in this study only the output at the uppermost model level were utilized. This level is at a depth of about 1.47m. Operational SSTs at a resolution of 0.5x0.5 degrees were also available for the same period allowing their use in data void regions.

The domain of the disseminated high-resolution predicted SSTs extended from 6°W to 36.25°E and from 30.25°N to 46°N. The predicted SSTs which were valid from 1200 UTC on 30/11/04 to 1200 UTC on 1/12/04 at the original resolution (1/16°x1/16°) for the entire dissemination domain that became available by WP8 appears in Figure 1. Similarly Figure 2 presents the same SST field zoomed over Greece. It is obvious that this dataset provides significant details about the spatial variability of SSTs in the Mediterranean Sea. However, there is lack of data in a number of seas, such as the Black Sea, the Red Sea, the Vosporos Straits, as well as in various areas near the coastline and in the lakes. Moreover, the domain of the high-resolution SSTs is smaller than the computational domain of the operational SKIRON/Eta modeling system (LAM2) that extends from 24.38°N to 51°N and from 21.04°W to 51.04°E.

The above analysis shows that the new product is likely to provide significant information about the SST patterns in our area of interest, but, it also needs further pre-processing before it is utilized by SKIRON/Eta model.

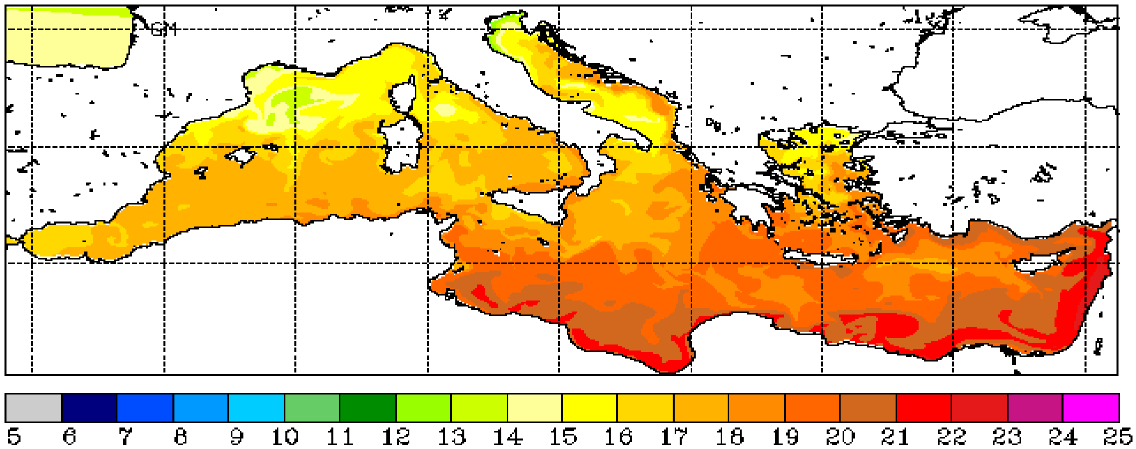

Figure 1. *The high-resolution OGCM predicted SSTs (1/16°x1/16°) valid from 1200 UTC on 30/11/04 to 1200 UTC on 1/12/04 in the entire dissemination domain. Units: °C.*

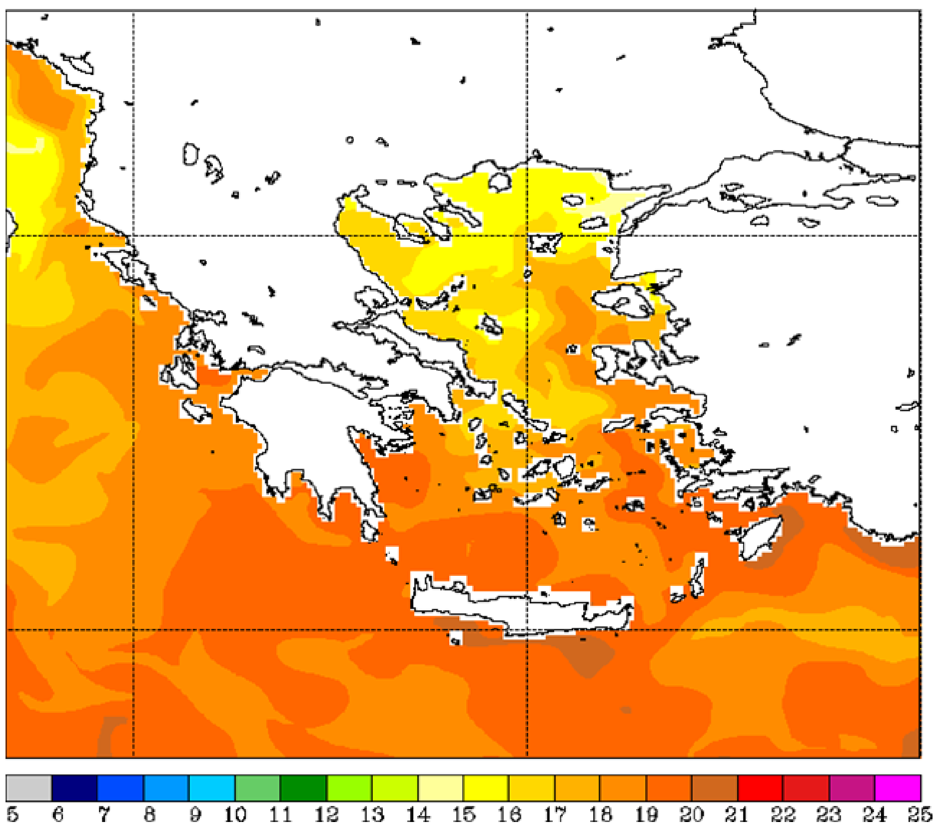

Figure 2. *The high-resolution predicted OGCM SSTs (1/16°x1/16°) valid from 1200 UTC on 30/11/04 to 1200 UTC on 1/12/04 focused over Greece. Units: °C.*

2.2 Implementation in SKIRON/Eta

The influence of the high-resolution predicted OGCM SSTs on the atmospheric predictability was studied using the SKIRON/Eta modeling system. The SSTs were firstly decoded from the original Netcdf format and then they were interpolated into the E-grid of the operational model domain. In the development of the pre-processing algorithms, special attention was given in the calculation of the SSTs near the coastline.

Figure 3a shows the SST field of Figure 1 interpolated into the E-grid of the operational SKIRON/Eta domain. The horizontal resolution of the E-grid is 0.1°x0.1°. Despite the fact that the SSTs are interpolated into a grid with horizontal resolution coarser than that of the original dataset, no loss of information is observed. This happens because the two resolutions (0.1° and 1/16°~0.0625°) do not differ significantly. Moreover, the lack of SSTs in several regions of the domain is obvious. The operational SSTs (Figure 3b) were used in data void regions because the atmospheric numerical models require full meteorological fields in the initial conditions. Thiebaux et al. (2003) showed that their use by ETA model resulted to improved forecasts of storm track and precipitation over Eastern US. The operational SSTs were also used in the Biscay Gulf.

Figure 4 illustrates an example of the final SST product that resulted from the combination of the SSTs of Figure 3a and 3b and was used for the initialization of SKIRON/Eta hindcasts on 1 December 2004. Similarly combined fields were used to initialize SKIRON/Eta in the experiments of MFSTEP subtask 10220.

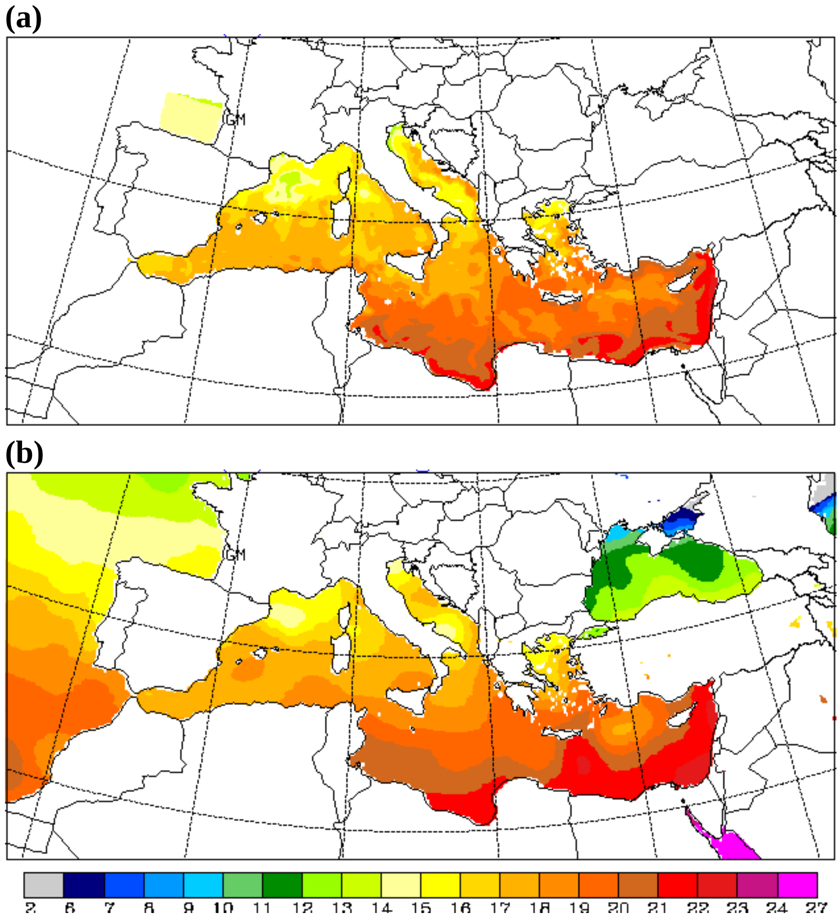

Figure 3. *a) The high-resolution predicted SSTs and b) the operational SSTs interpolated into the 0.1°x0.1° E-grid of the operational SKIRON/Eta domain on 1 December 2004. Units: °C.*

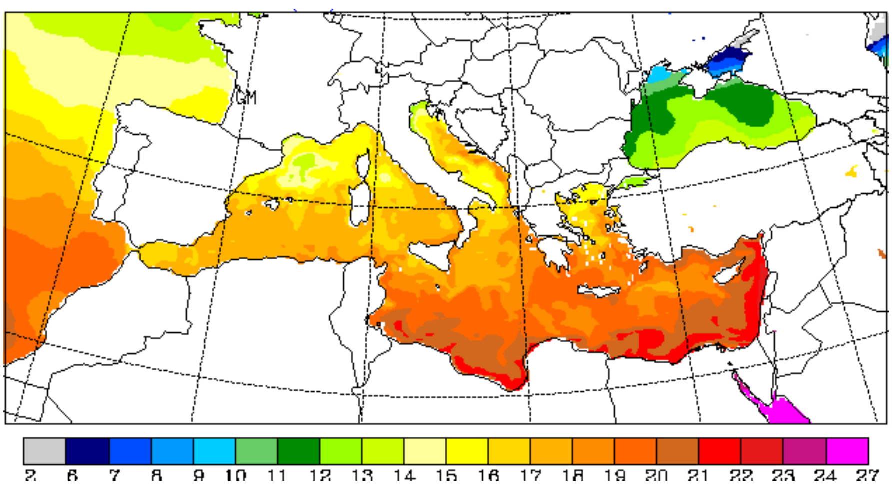

Figure 4. *The SSTs that resulted from the combination of the predicted and the operational SSTs and were used to initialize SKIRON/Eta hindcasts on 1 December 2004. Units: °C.*

2.3 Spatiotemporal variability

Investigation of the spatiotemporal evolution of the OGCM SST predictions with time showed that the significant SST changes are often localized (e.g. Figure 5) and they may exceed 0.5°C. However, in some cases significant SST changes are predicted by OGCM in large regions of the Mediterranean after 4-5 days (Figure 6). The SST changes do not always follow the same pattern in the whole basin and dipoles of positive-negative differences (corresponding to warming-cooling respectively) appear quite often.

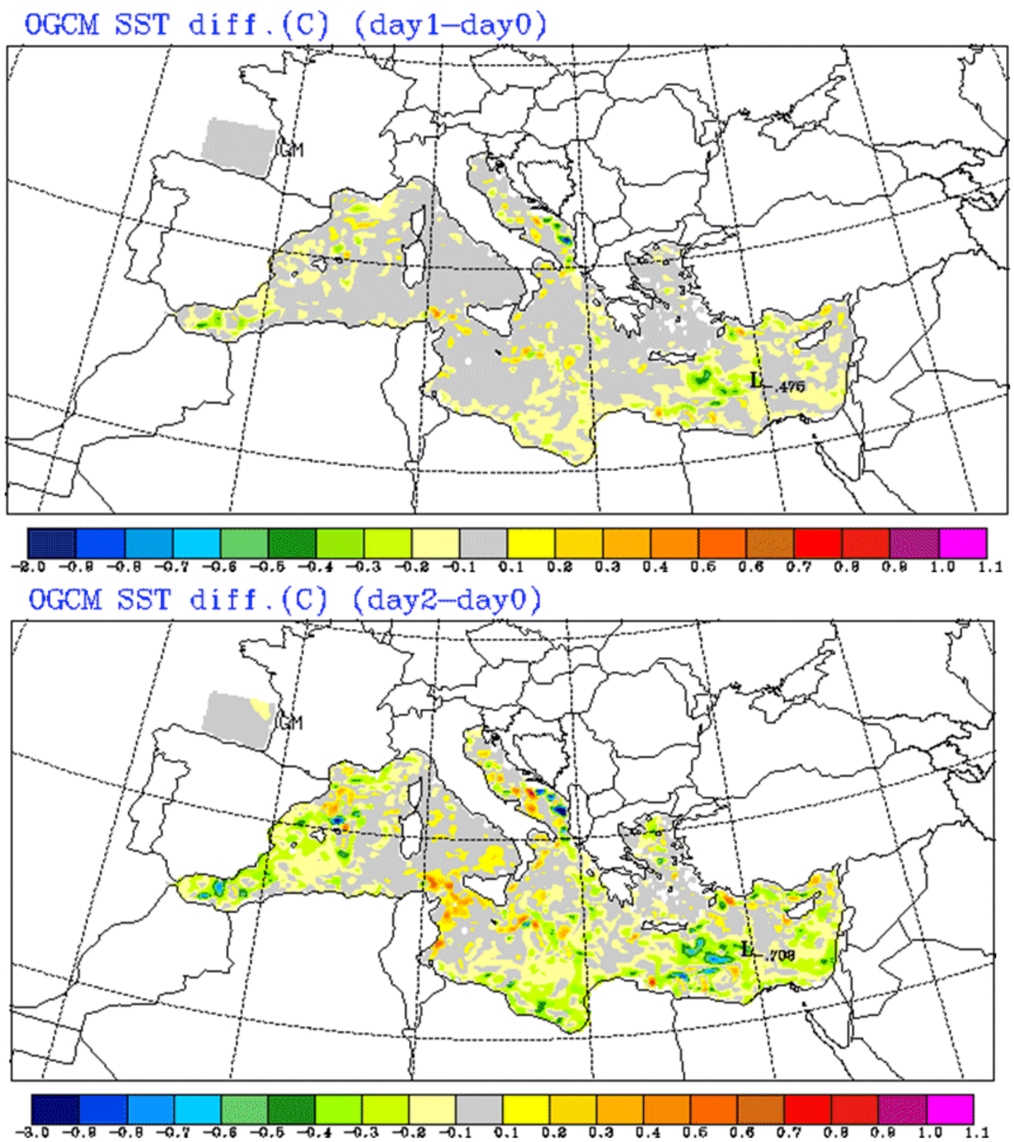

Figure 5. *The SST differences (°C) between the initial time and each consecutive day in the hindcast that was initialized at 0000 UTC, 1/12/04.*

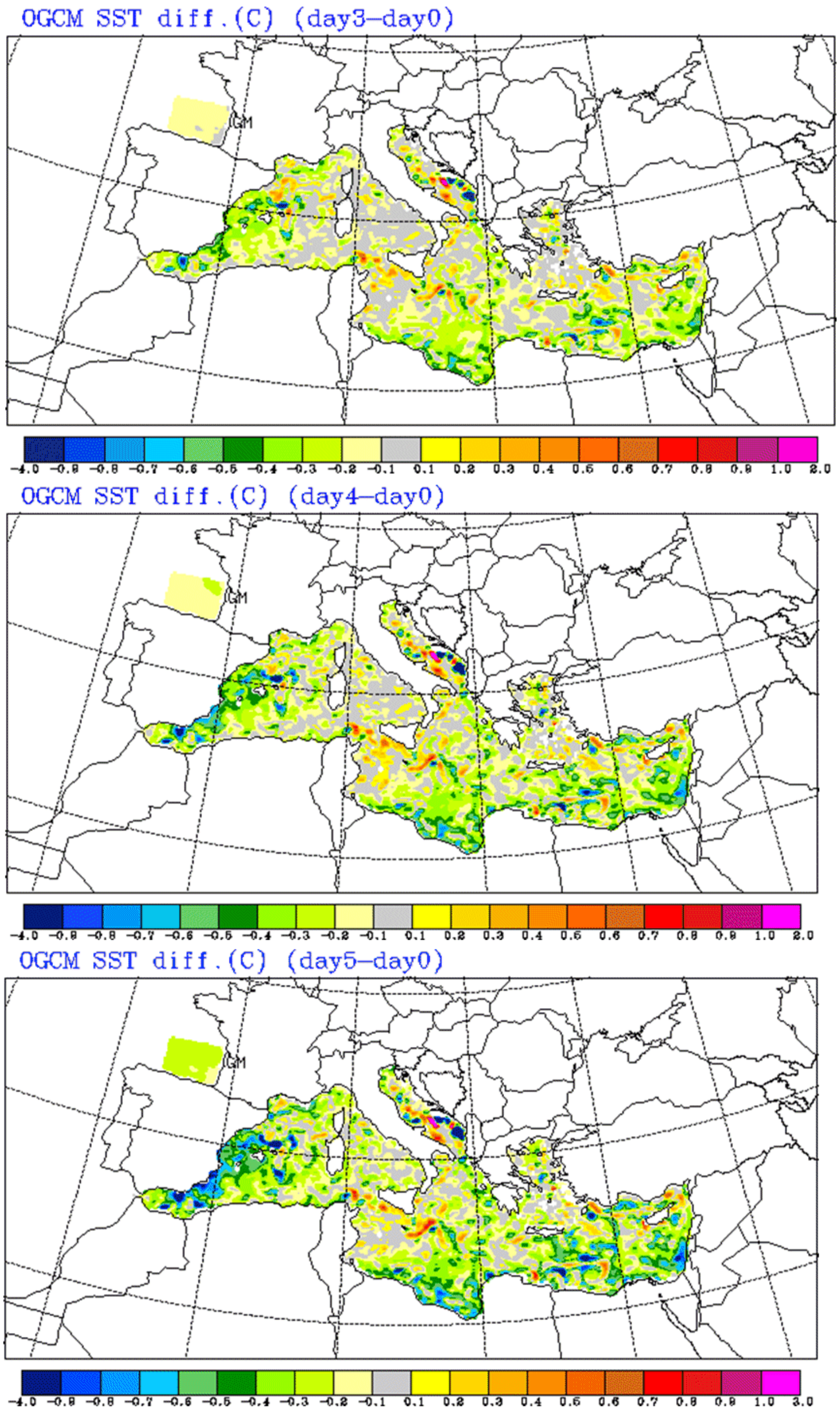

Figure 5. *Continued*

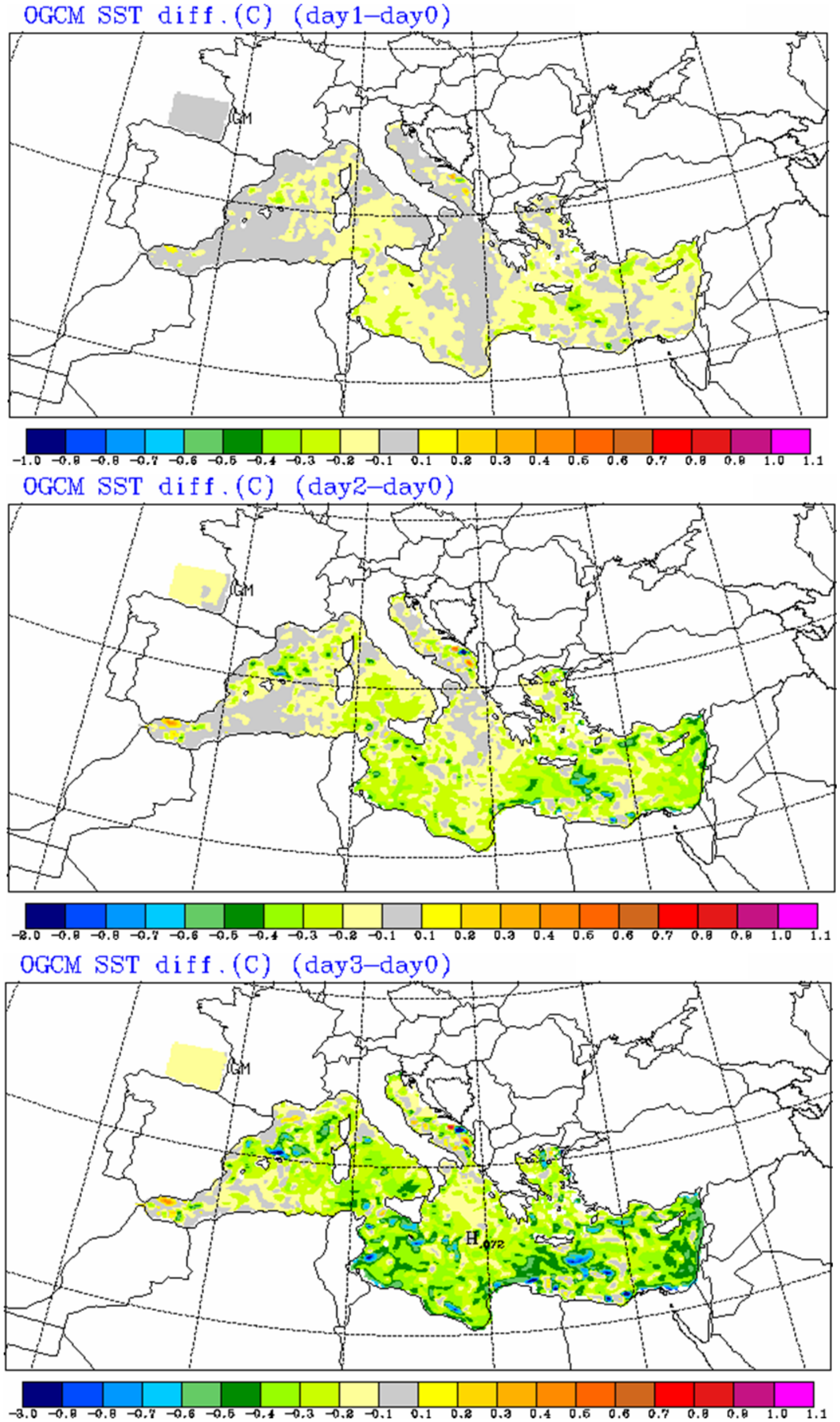

Figure 6. *The SST differences (℃) between the initial time and each consecutive day in the hindcast that was initialized at 0000 UTC, 15/12/04.*

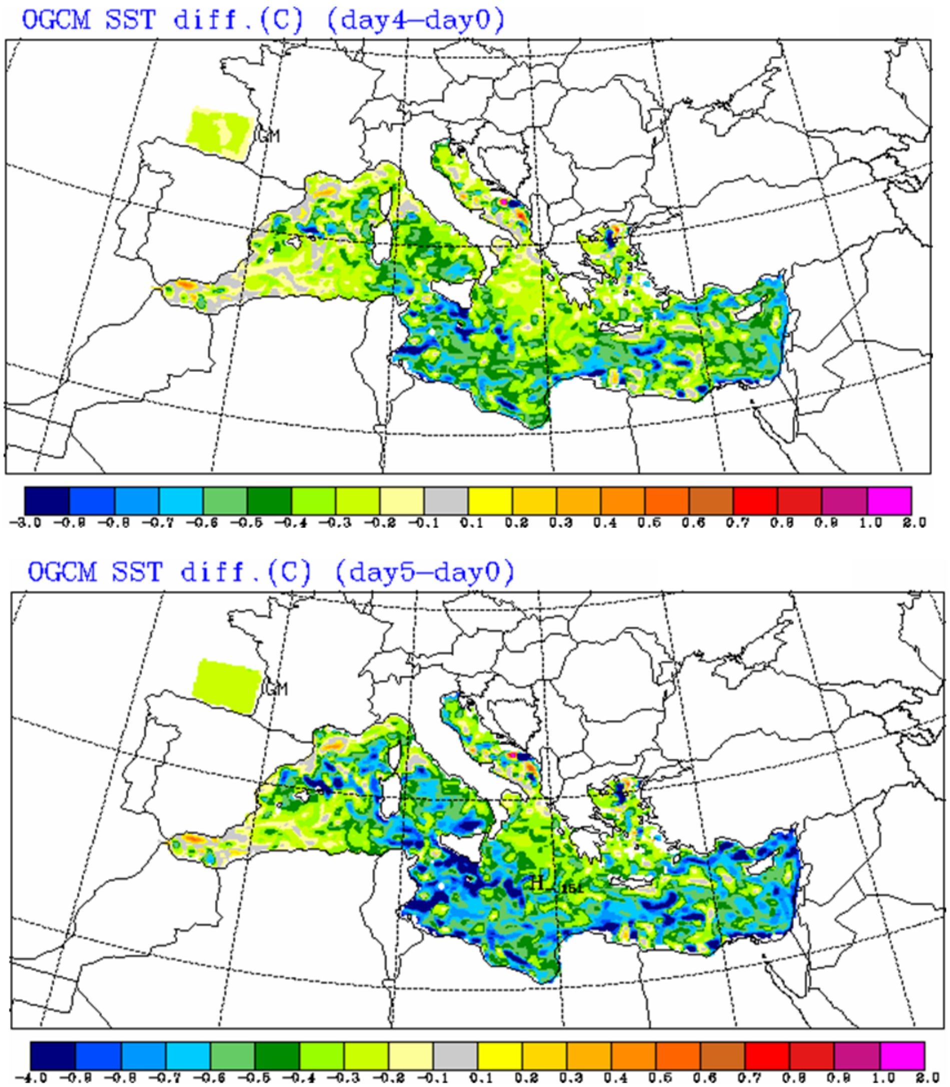

Figure 6. *Continued*

3 Experimental setup

According to the Description of Work (DoW), a three month period during the TOP should be repeated in subtask 10220 with the usage of the predicted SST fields. The main criteria for selecting this period were: a) the existence of significant weather in the Mediterranean basin and b) the existence of significant SST changes with time. Following the above criteria, the period of December 2004, January and February 2005 was chosen for sensitivity experiments. The initial time of these runs was every Wednesday at 0000 UTC, since the TOP runs were also initialized every Wednesday at

0000 UTC. Contrary to the DoW, the TOP runs were repeated with a forecast horizon 120-hour and not only for 2-3 days.

Two 5-day simulations were produced for each one of the 13 cases[1] (of the above period) utilizing ARPEGE initial and lateral boundary conditions. The model resolution and domain were identical to those used during TOP. The TOP setup is described in deliverable D4 of MFSTEP-WP10. In both sets of simulations the atmospheric initial and lateral boundary conditions as well as the initial SSTs were identical. However, in the one simulation of each case the SST field was kept fixed throughout the run, while in the other simulation the daily average (OGCM) predicted SSTs were introduced in SKIRON/Eta at specific intervals. The predicted OGCM SSTs of a specific day corresponded to the daily average prediction from 1200 UTC on that day to 1200 UTC on the following day.

A schematic representation of the schedule followed for the update of the SST field is illustrated in Figure 7. The valid dates of the simulation appear in the upper row. The second row shows the corresponding forecast hours from T+0 to T+120. Finally, the last row (i.e. SST day0, SST day1 etc.) indicates the utilized OGCM SST files and the time period that each one of these fields was used as lower boundary condition during the run.

The weather conditions during the selected periods covered the typical weather regimes (Varinou 2000) that appear in the Mediterranean during winter. The weather patterns that prevailed in the sensitivity experiments include transient depressions originating in the Gulf of Genova or near the Atlas mountains or in the Cyprus region, strong winds in the Gulf of Leon, cold-air advection associated with convective activity and cold fronts associated with low-pressure centers over Europe that extend into the Mediterranean.

[1] 13 runs were performed during TOP in the three month period December 2004-February 2005

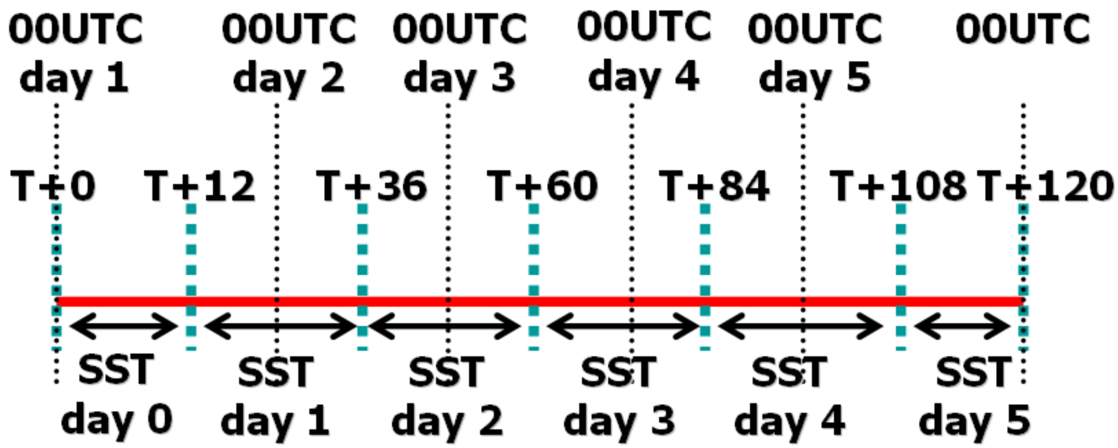

Figure 7. *Schematic representation of the schedule followed for the update of the SST field. In the second row the forecast time is in hours and T+0 corresponds to the initial time.*

4 Analysis of model output

The assessment of the influence of predicted SSTs on atmospheric predictability was performed with the use of well-known and widely accepted statistical methods. In this task the maximum available near shore surface observations (METAR and SYNOP) from reliable meteorological stations were used (Figure 8). The data measurements were retrieved from the ECMWF database.

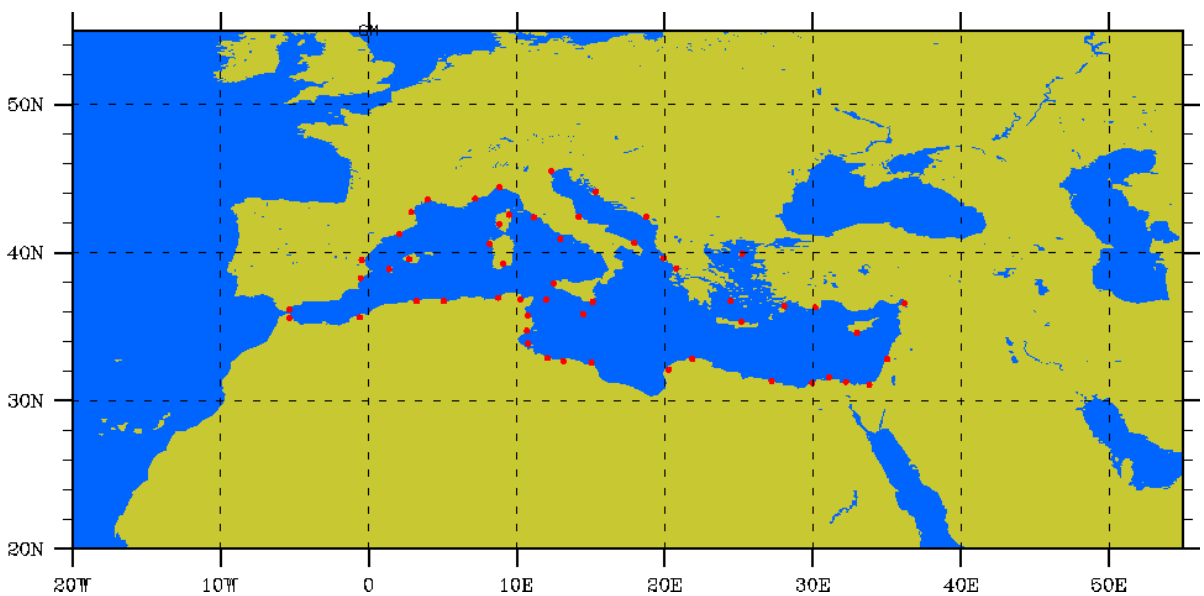

Figure 8. *The network of the coastal surface weather stations that provide observations to the Global Telecommunication System and were used in this study.*

The methodology of statistical analysis allows the examination of the model response in the quality of lower boundaries conditions providing significant conclusions about the impacts of high-resolution SST forcing in models' forecasting capabilities.

4.1 Statistical methods

The statistical analysis exhibits some differences depending on whether the meteorological variables are discrete or continuous. Discrete variables are allowed to take on only a finite number of values, whereas continuous variables may take on any of the infinitely many real values within their range. The rainfall, snowfall and the cloud cover are considered to be discrete variables, while the temperature, the wind speed and the mean sea-level pressure are continuous variables. On the surface of the earth, the forecasts and the observations of continuous meteorological variables result from a finite number of discrete values.

IASA and UAT chose a number of statistical methods to provide a robust validation of the models. The statistical methods that were used in order to validate the model performance are described below:

Continuous meteorological fields (Surface and upper air):

The surface fields that were examined here are the 2m temperature and 10m wind speed. The proposed statistical methods, applied to discrete variables, are the bias (BIAS) and the root mean square error (RMSE).

Bias (BIAS):

The bias estimates the correspondence between the mean value of the forecast (F) and the observation (O). This measure calculates the sum of the differences in a total of N values:

$$bias = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i) = \overline{F} - \overline{O}$$

If *bias*<0 (>0), the model underestimates (overestimates) the specific variables.

Root Mean Square Error (RMSE):

This measure is considered to be one of the most popular in the estimation of the forecast accuracy (Wilks, 1995; Katsafados, 2003 and others). It is mostly used in grid-point fields and it is expressed by:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$$

RMSE takes values greater than or equal to zero. This value is not dimensionless but it exhibits the same units as the validated field. It is an important measure as it provides a quantitative measure of the model performance.

<u>Discrete meteorological fields (Precipitation)</u>:

The validation of discrete meteorological variables, such as the accumulated precipitation, is based on an I×J contingency table of absolute frequencies, or counts, of the I×J possible combinations of forecast and event pairs. Every element of this table represents the number of cases where the predicted and the observed value of precipitation (for example) exceed the predefined precipitation amounts in the same time periods. In the case of precipitation IASA proposes the use of the predefined values of 0.5, 2, 4, 6, 10, 16, 24, 36 mm per 12 hours. Figure 9 illustrates the essential equivalence of the contingency table and the joint distribution of forecasts and observations for the simple, I=J=2, case.

		Observed		
		Yes	No	
Forecast	Yes	a	b	a+b
	No	c	d	c+d
		a+c	b+d	n=a+b+c+d

Figure 9. *The contingency table for discrete meteorological variables. The letters a to d correspond to all the possible pairs Forecast/Observation. (After Wilks, 1995).*

The term “a” defines the number of cases where the predicted and observed values exceed a predefined precipitation amount, and it corresponds to a successful forecast. The term “b”, corresponding to false alarm cases, represents the number of cases where only the predicted value (and not the observation) exceeds a predefined precipitation amount. The term “c” represents the number of cases that the observed value (and not the predicted) exceeds a predefined amount, and it corresponds to missed cases. The total number of combinations is n=a+b+c+d.

The contingency table is the base for the use of statistical tests for discrete variables and it will be used in the evaluation of precipitation forecasts. The proposed statistical methods, applied to discrete variables, are the bias (B), the root mean square error (rmse), and the Equitable Threat Score (ETS).

Bias (B):

The bias, or comparison of the average forecast with the average observation, of categorical forecasts, is usually represented as a ratio. The bias is simply the number of ‘YES’ forecasts to the number of ‘YES’ observations. In terms of Figure 9, the bias ratio is:

$$B = \frac{a+b}{a+c}$$

Unbiased forecasts exhibit B=1, indicating that the event was forecast the same number of times that it was observed. Bias greater (less) than one indicates that the event was forecast more (less) often than observed.

Equitable Threat Score (ETS):

This measure can be used as an index of the model ability to predict a predefined precipitation amount. In terms of figure 9, the Equitable Threat Score is:

$$ETS = \frac{a - a_r}{a+b+c-a_r}$$

where $a_r = \frac{(a+b)\cdot(a+c)}{a+b+c+d}$ defines the random frequency of successful predictions that exceed a predefined precipitation amount (Schaefer, 1990).

The Equitable Threat Score takes values between –1 and +1 (included). In the case of perfect forecasts ETS=1, while ETS is near 0 in constant or random forecasts.

Root Mean Square Error (rmse):

This statistical measure quantifies the range of the differences between the predictions and the observations that exceed a predefined precipitation amount (Colle et al. 1999, 2000) when it is applied to discrete variables. The rmse is expressed by the equation

$$rmse = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - X_i)^2}$$

where P_i and X_i are the predicted and observed precipitation amount in a total number of N observations that exceed the predefined value. The importance of this measure lies on the fact that it provides a quantitative measure of the model performance although it cannot indicate overestimates or underestimates of the forecasts.

4.2 Statistical analysis

The BIAS and RMSE of predicted temperature at 2 m and wind speed at 10 m for the whole 3 month period exhibited very small differences (to infinitesimal) between the runs performed with fixed SSTs and updated SSTs. This implies that these two fields are not generally affected significantly in short-to-medium forecast ranges by changes in the lowest boundary forcing over the sea. In order to allow the visualization of any differences between the two techniques the BIAS and RMSE of a few selected simulations (and not of the whole 3-month period) are presented.

Figures 10, 11 show the BIAS and RMSE of 2m temperature for the hindcasts initialized at 0000 UTC on 1/12/04 (case 1) and 15/12/04 (case 2). These 2 cases exhibited different characteristics. In the first case the SST changes during the 5-day period of the run were generally small and localized (Figure 5), while in the second case significant SST changes (above 0.5°C) appeared after 4-5 days in large parts of the Mediterranean sea (Figure 6). The differences of BIAS and especially those in the RMSE scores in the first case were very small and they appeared in the last 2 days of the hindcasts. In the other case, the RMSE error differences were slightly larger, but certainly not significant. In this case the use of updated SSTs resulted to small improvement of the forecasts.

Figures 12 and 13 that present the BIAS and RMSE of 10m wind speed for the same hindcasts (initialized at 0000 UTC on 1/12/04 and 15/12/04) result to the same conclusion. The influence of the small SST changes in the 1st case resulted to infinitesimal differences in 10m wind speed. Discernible, but small, improvements (up to 0.1-0.2 m/s) appeared in the whole Mediterranean basin in the 2nd case that was characterized by large SST changes. It is noted that in both cases strong synoptic flow existed in various parts of the basin (a few examples appear in Figures 14, 15).

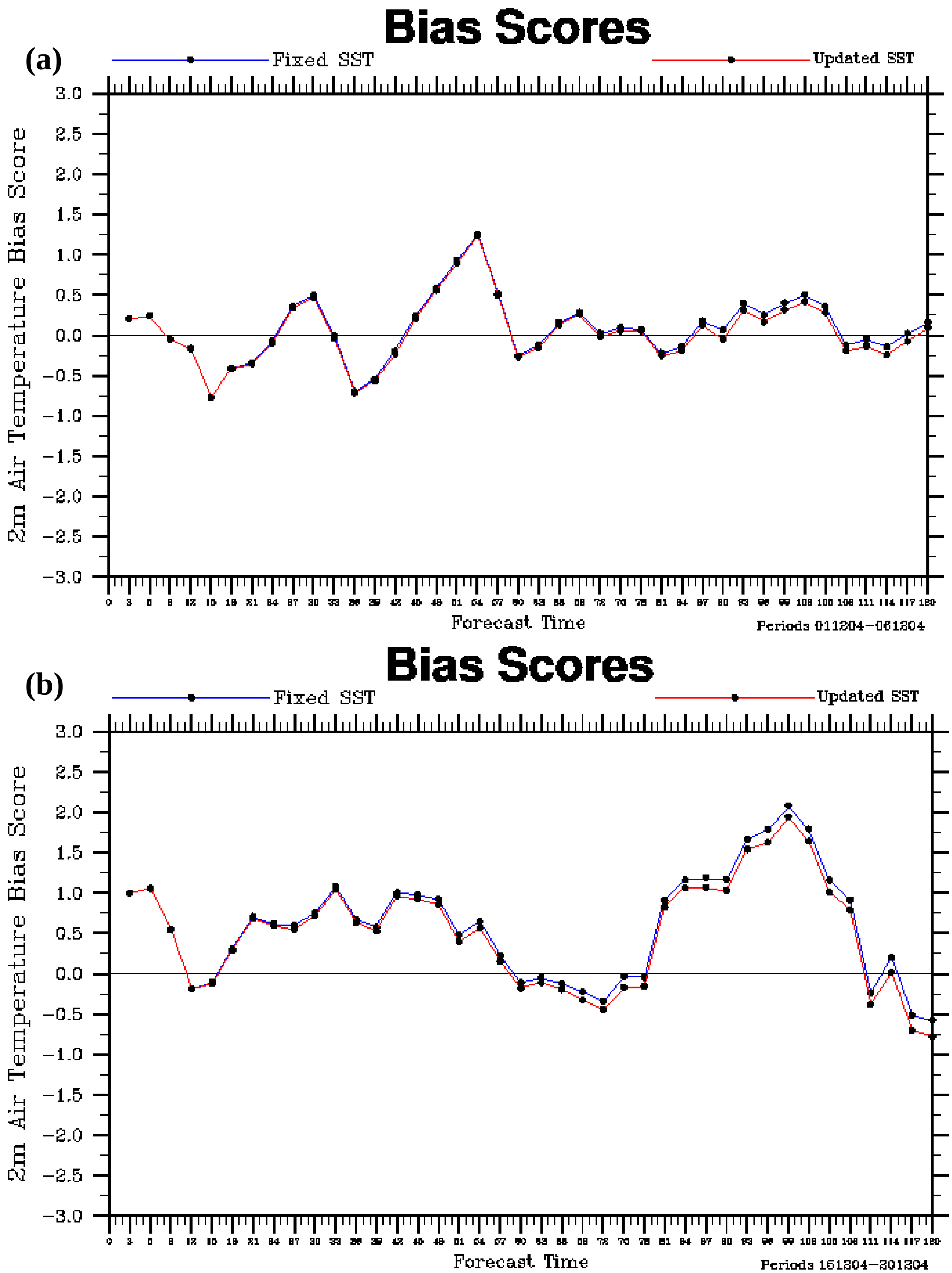

Figure 10. *BIAS of the 2m air temperature (C) for simulations forced by fixed SSTs (blue line) and updated SSTs (red line) for the 5-day runs initialized at a) 0000 UTC, 1/12/04 and b) 0000 UTC 15/12/04.*

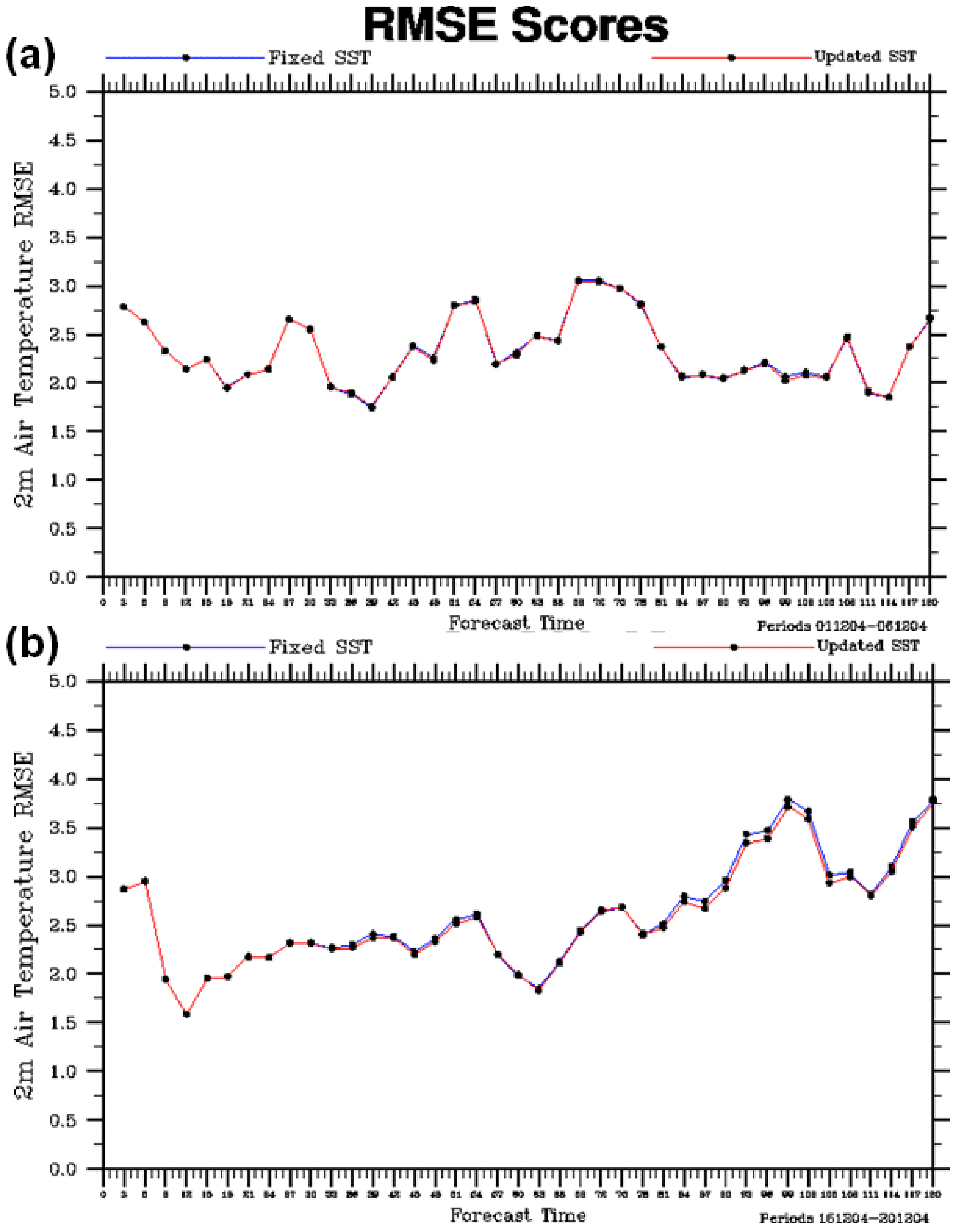

Figure 11. *Root Mean Square Error (RMSE) of the 2m air temperature (C) for simulations forced by fixed SSTs (blue line) and updated SSTs (red line) for the 5-day runs initialized at a) 0000 UTC, 1/12/04 and b) 0000 UTC 15/12/04.*

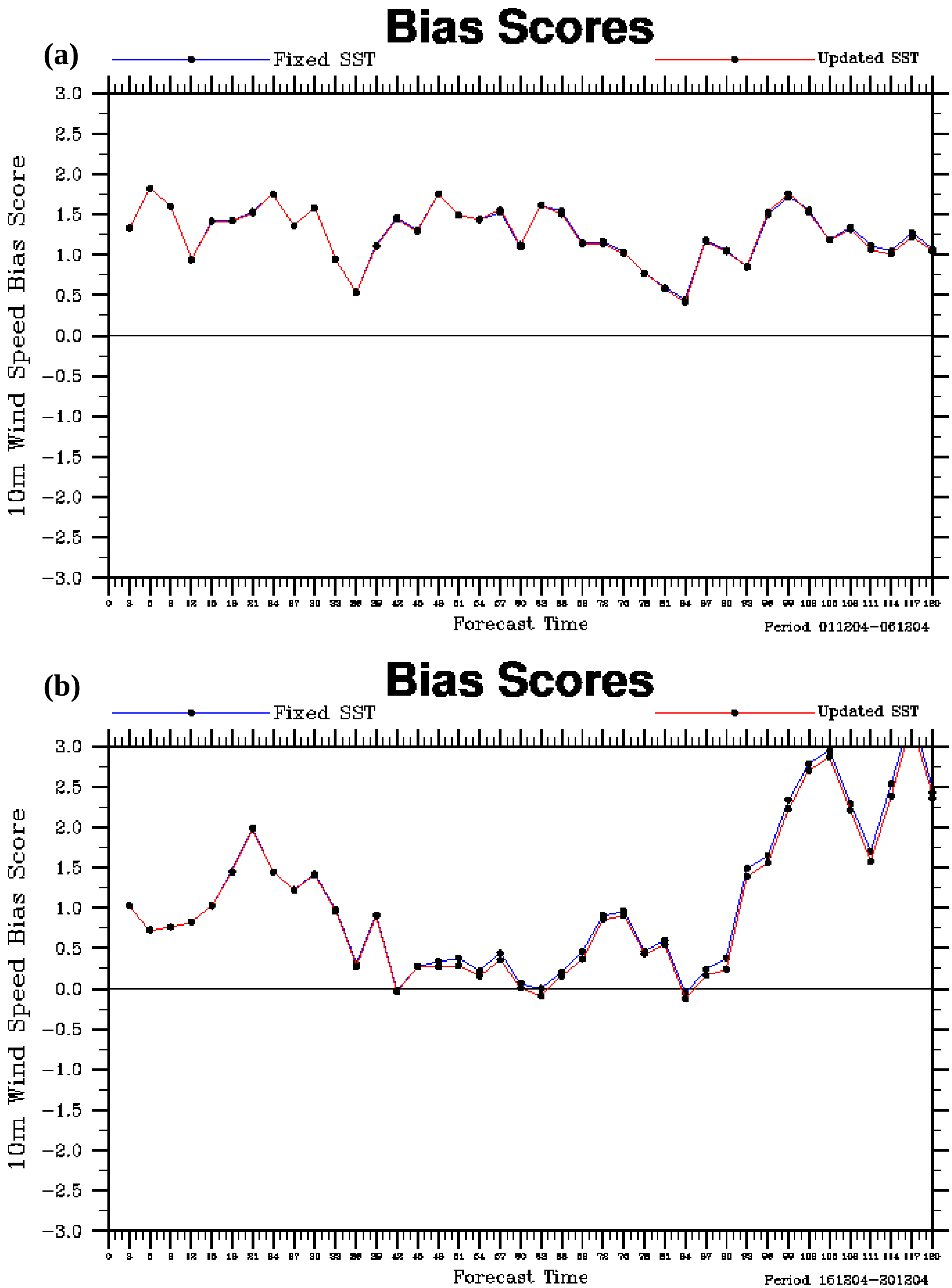

Figure 12. *BIAS of the 10m wind speed (m/s) for simulations forced by fixed SSTs (blue line) and updated SSTs (red line) for the 5-day runs initialized at a) 0000 UTC, 1/12/04 and b) 0000 UTC 15/12/04.*

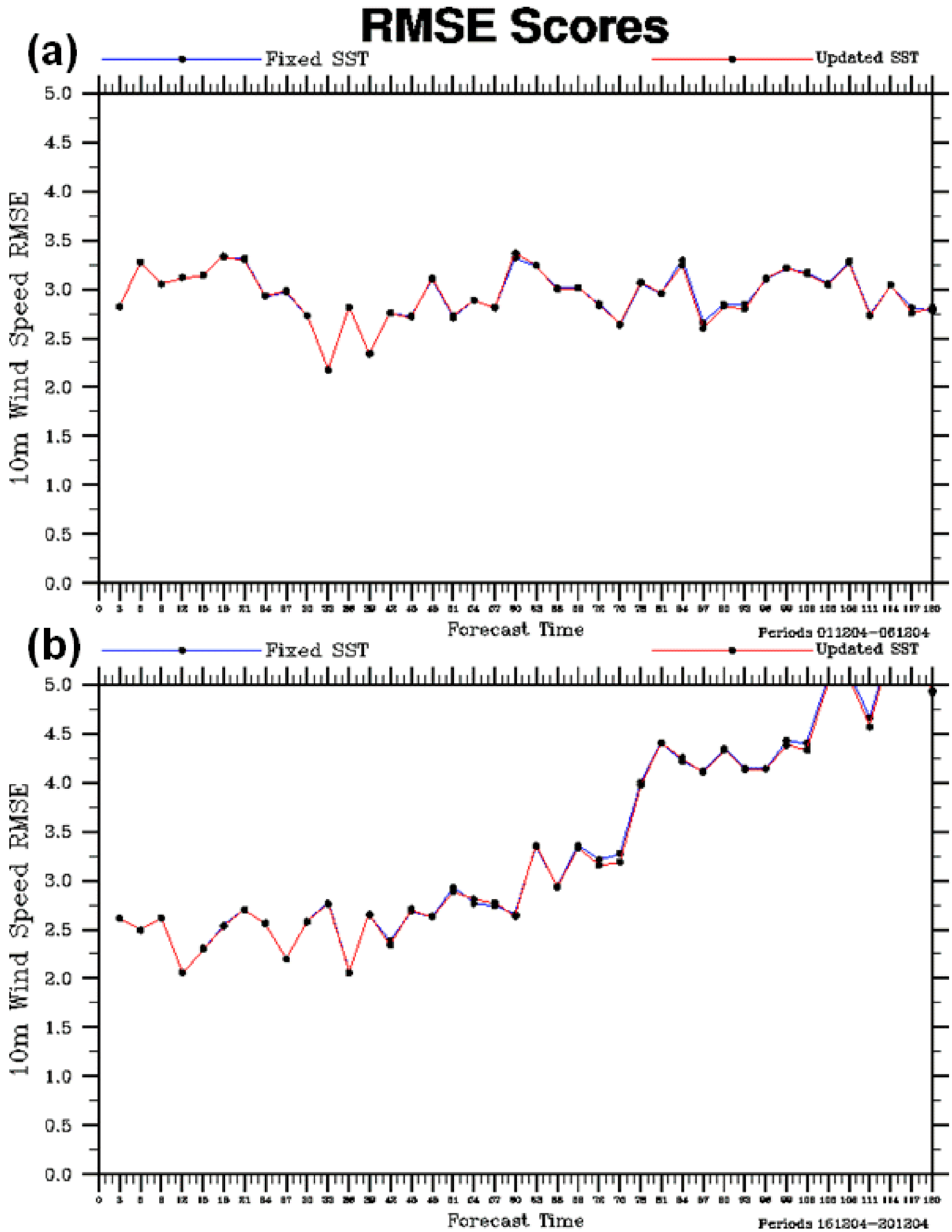

Figure 13. *Root Mean Square Error (RMSE) of the 10m wind speed (m/s) for simulations forced by fixed SSTs (blue line) and updated SSTs (red line) for the 5-day runs initialized at a) 0000 UTC, 1/12/04 and b) 0000 UTC 15/12/04.*

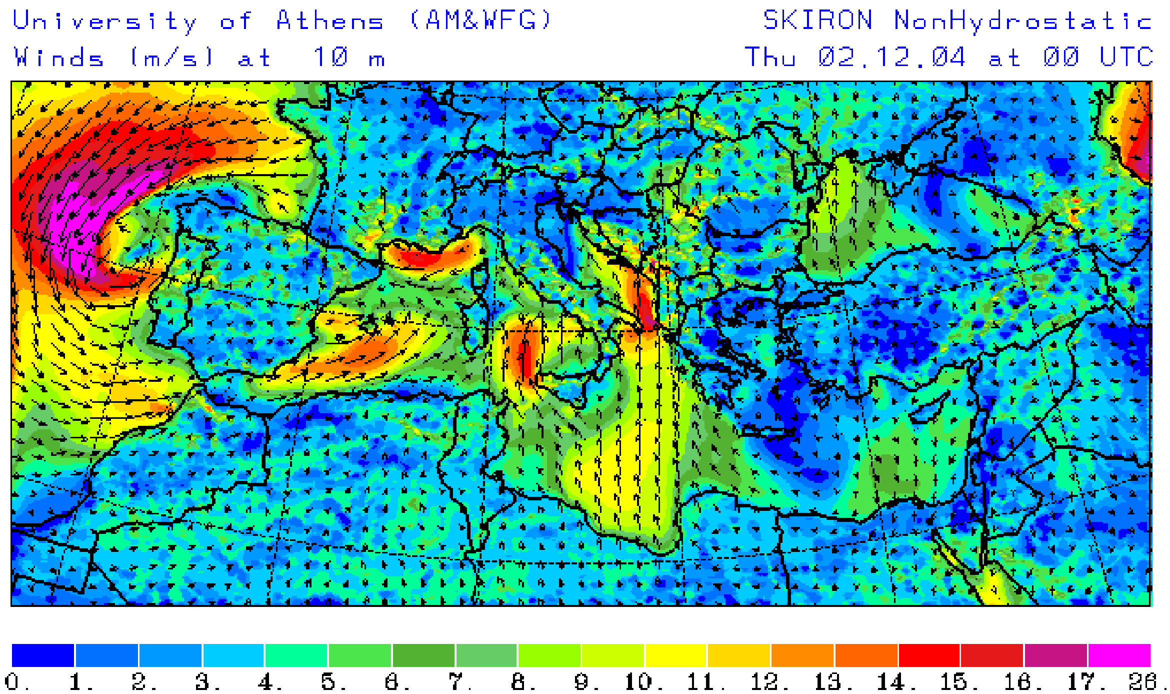

Figure 14. *10m wind speed (m/s) and direction predicted by SKIRON/Eta at T+24 from the hindcast that was initialized at 0000 UTC on 1/12/04.*

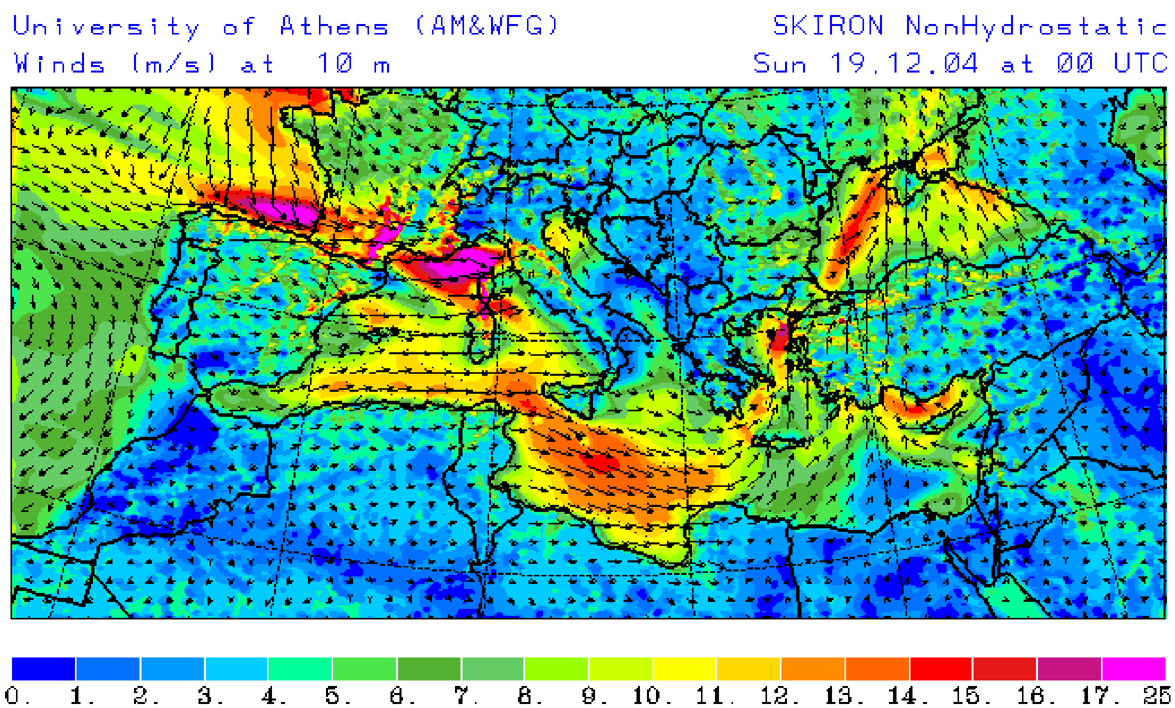

Figure 15. *10m wind speed (m/s) and direction predicted by SKIRON/Eta at T+96 from the hindcast that was initialized at 0000 UTC on 15/12/04.*

Similarly to the 2 m temperature and the 10 m wind speed, the BIAS and RMSE scores of 12-hourly total accumulated precipitation exhibited very small differences between the two kinds of hindcasts. These scores are presented for the whole 3-month period (Dec. 04 – Feb. 05) for the precipitation. Figure 16 shows that the scores of precipitation do not change significantly in the 3rd day of the hindcasts (from T+54 to T+66). A smaller overestimation appears in the BIAS of the hindcasts with updated SSTs (Figure 16a), but minor differences appear in the RMSE. In the last day of the hindcasts (T+102 to T+114; Figure 17) the RMSE differences have increased, especially in relatively strong precipitation rates (of 6-16 mm per 12 hours), but they are still small (up to 0.5-1 mm in 12 hours).

The Equitable Threat Scores in the above forecast periods (from T+54 to T+66 and from T+102 to T+114) showed a small deterioration in very weak precipitation rates (up to 2 mm per 12 hours) in both forecast ranges (Figure 18). However, the ETS scores of precipitation exhibit a small, but clear, improvement in the prediction of stronger precipitation rates in both forecast ranges, due to the use of updated SSTs. Finally, the case study analysis of precipitation forecasts (Figures 19, 20) indicated the existence of spatiotemporal differences in the distribution of precipitation from the use of fixed and updated OGCM SSTs, with the precipitation amounts to remain similar.

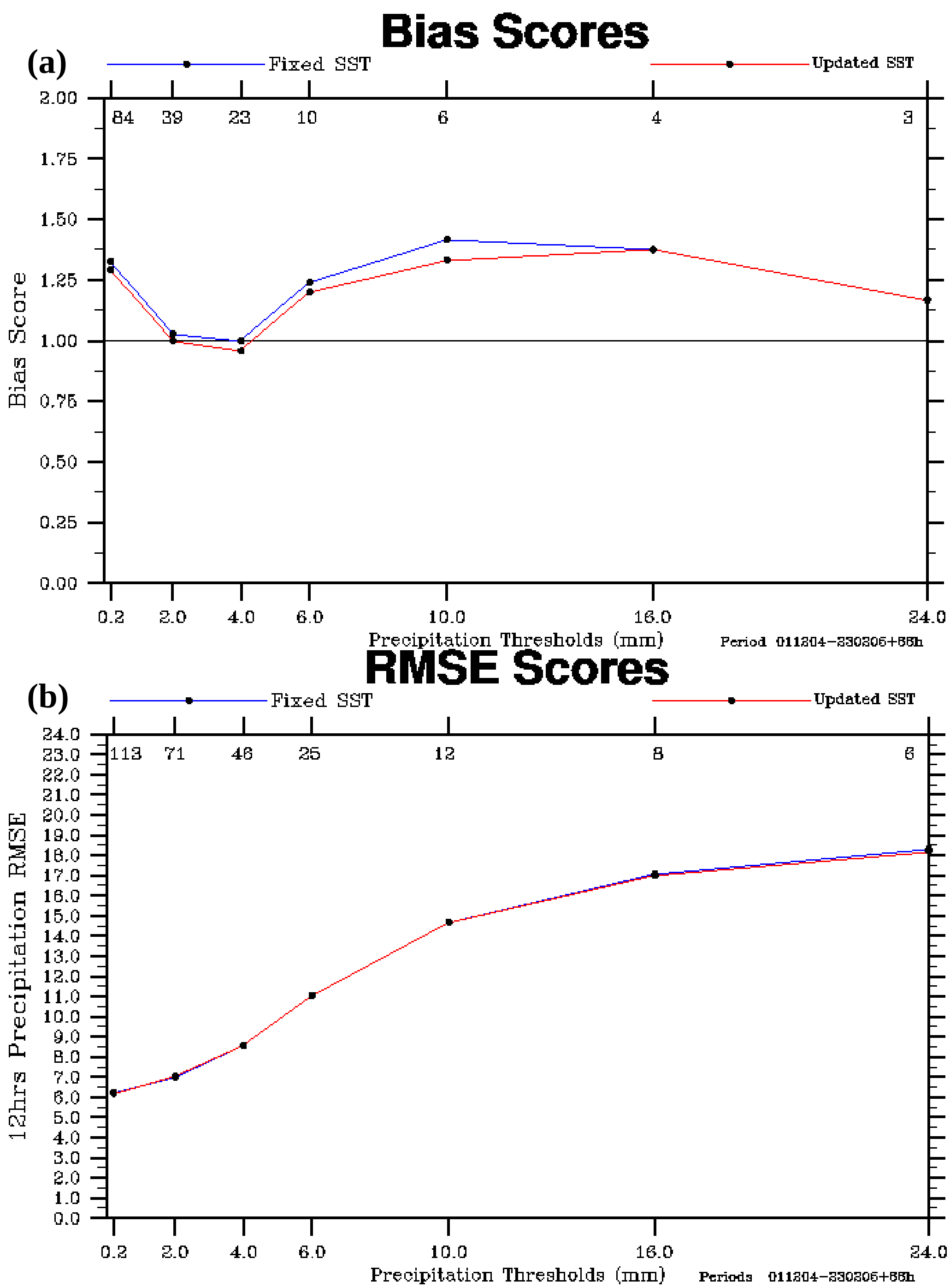

Figure 16. *a) BIAS and b) RMSE of 12-hourly precipitation predicted by SKIRON/Eta from T+54 to T+66 for the whole 3-month period (Dec. 04 – Feb. 05), in the hindcasts with fixed SSTs (blue line) and updated SSTs (red line).*

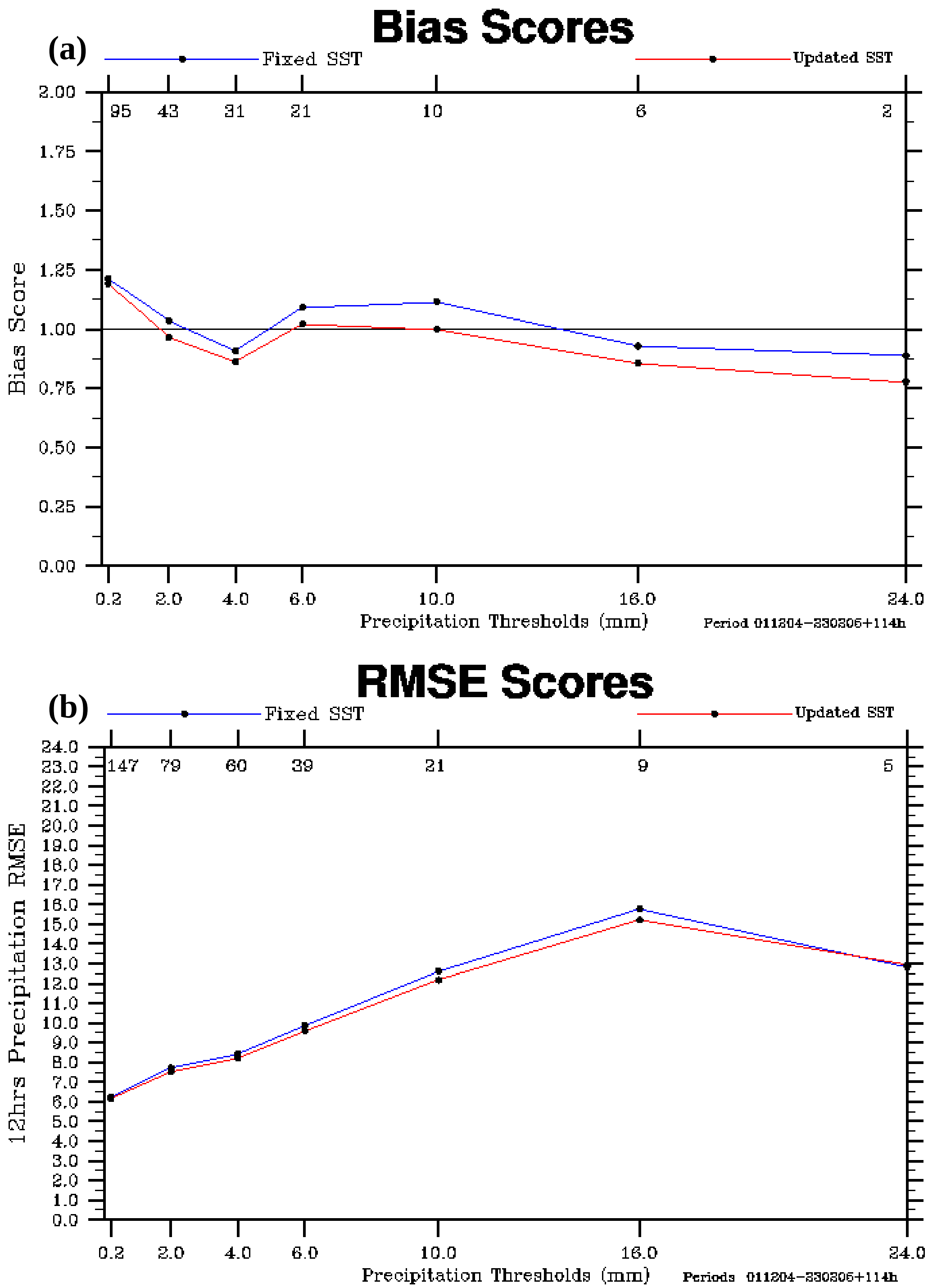

Figure 17. *a) BIAS and b) RMSE of 12-hourly precipitation predicted by SKIRON/Eta from T+102 to T+114 for the whole 3-month period (Dec. 04 – Feb. 05), in the hindcasts with fixed SSTs (blue line) and updated SSTs (red line).*

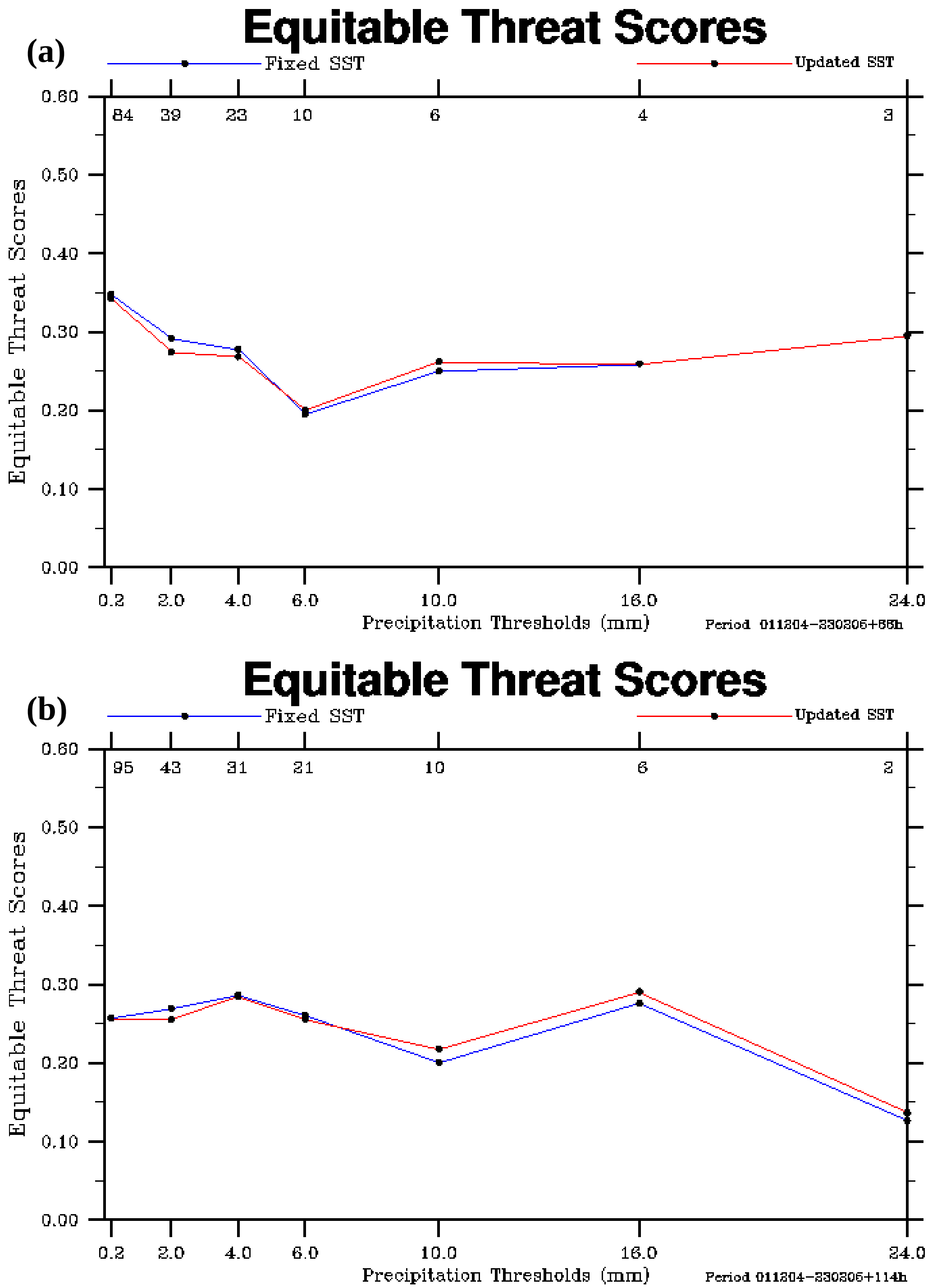

Figure 18. *Equitable Threat Scores (ETS) of the total 12-hour accumulated precipitation predicted by SKIRON/Eta a) from T+54 to T+66 and b) from T+102 to T+114, for hindcasts forced by fixed SSTs (blue line) and updated SSTs (red line) in the period from December 2004 to February 2005.*

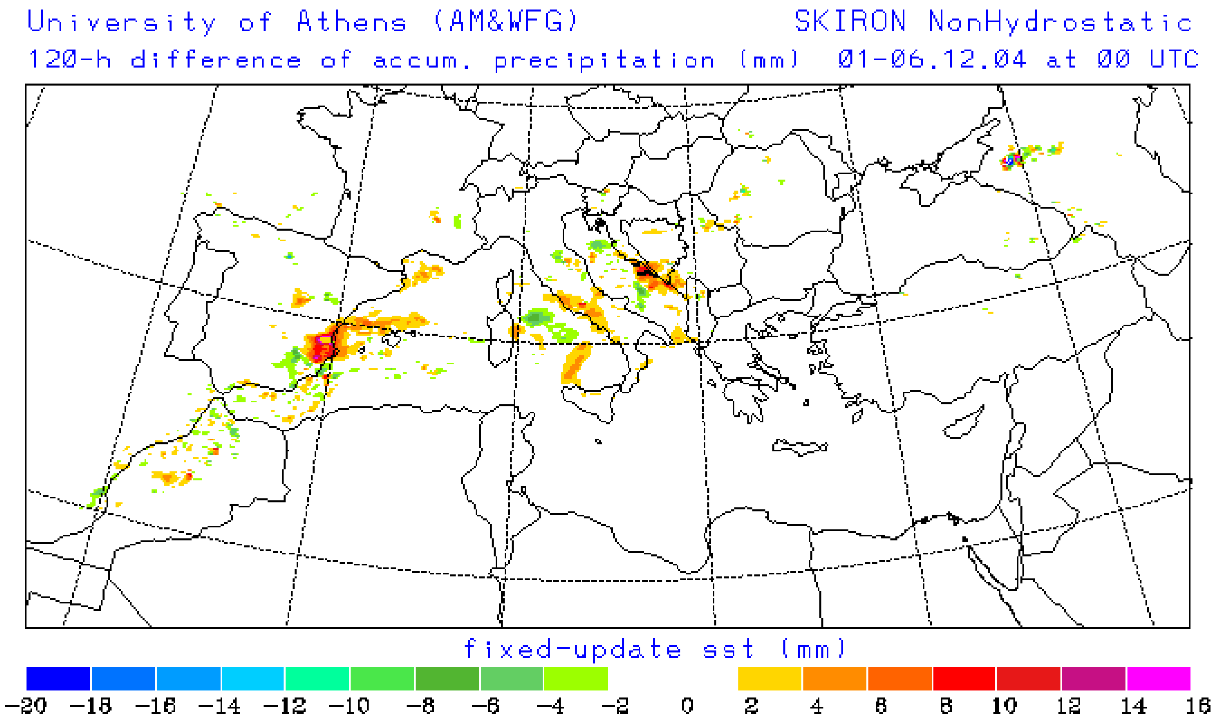

Figure 19. *The differences of the 120-hour total accumulated precipitation (mm) between the runs with the fixed and the updated SSTs. Initial time at 0000 UTC 1 December 2004.*

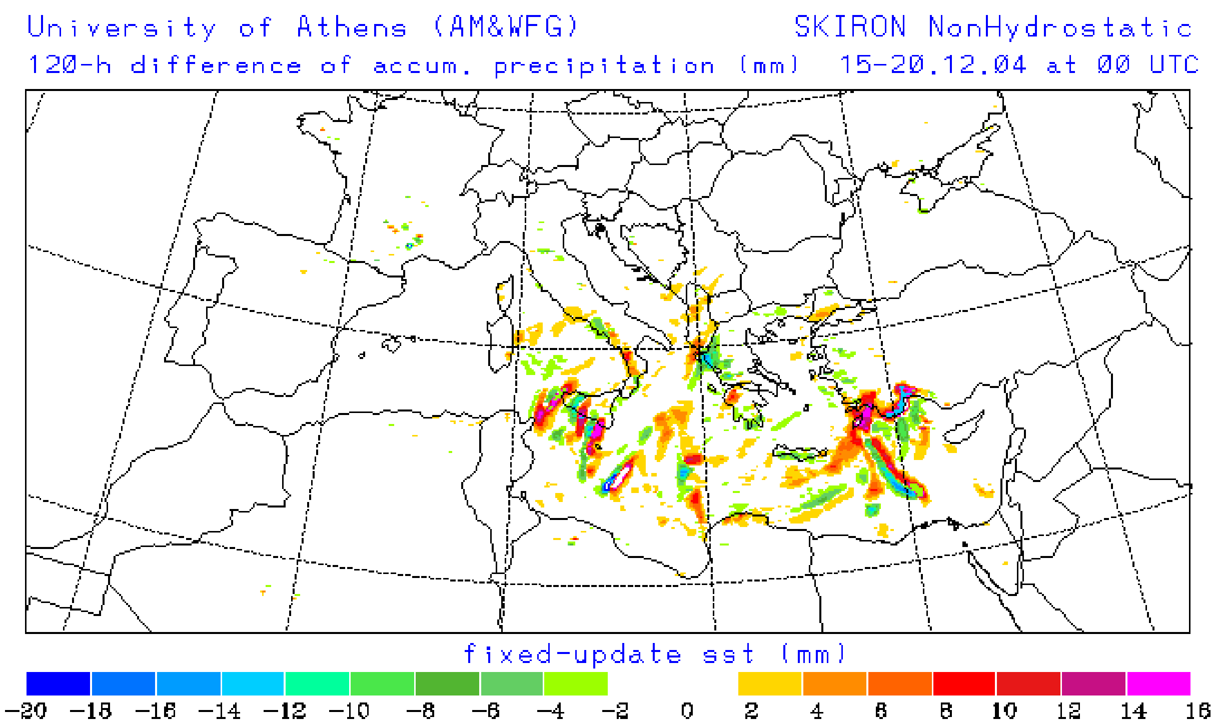

Figure 20. *The differences of the 120-hour total accumulated precipitation (mm) between the runs with the fixed and the updated SSTs. Initial time at 0000 UTC 15 December 2004.*

5. Conclusions

This study showed that the short to medium range forecasts are sensitive, in local scales, to changes in the underlying SSTs in the presence of significant weather. The impact of the predicted SST forcing in the SKIRON/Eta forecasts for the whole Mediterranean basin appears to be very small in the 2m Temperature and the 10m wind speed. However, a minor improvement appears in the basin scale due to the use of updated SSTs. There are spatiotemporal differences in the distribution of precipitation from the use of fixed and updated OGCM SSTs, and the statistical scores indicate a small improvement in the prediction of strong precipitation rates especially in medium range forecasts. However, the precipitation amounts remain similar.

References

Colle, B. A., K. J. Westrick, and C. F. Mass, 1999: Evaluation of MM5 and Eta-10 Precipitation Forecasts over the Pacific Northwest during the Cool Season. *Wea. Forecasting*, **14**, 137–154.

Colle B.A., C.F. Mass and K.J. Westrick, 2000: MM5 precipitation verification over the Pacific Northwest during the 1997-1998 cool seasons. *Wea. Forecasting*, **15**, pp. 730-744.

Katsafados, P., 2003: Factors and parameterizations that determine the performance of limited area models in long-range weather forecasts. PhD Thesis, Dept. of Physics, Univ. of Athens, Athens, Greece. pp. 257 (in Greek).

Schaefer, J.T., 1990: The critical success index as an indicator of warning skill. *Wea. Forecasting*, **5**, pp.570-575.

Thiebaux, J., E. Rogers, W. Wang, and B. Katz, 2003: A new high-resolution blended real-time global sea surface temperature analysis. *Bull. Amer. Meteor. Soc.*, **84**, 645-656.

Varinou M. 2000: Characteristic scales of dispersion and photochemical transformation of pollutants in Northeastern Mediterranean. PhD. Thesis, School of Physics, University of Athens, Greece. (in Greek)

Wilks, D.S., 1995: Statistical Methods in the Atmospheric Sciences, Academic Press NY, pp. 467.