Quantifying The Improvement In Reanalysis Accuracy Due To Hobbyist Weather Stations

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Submitted to the “Observations” track of the 5th International Conference on Reanalysis
(Rome, Italy; 12 - 17 November 2017)

Abstract
ArabiaWeather has, over time, created a large network of hobbyist weather stations distributed to volunteers around the Middle East and North Africa region, in an effort to cover areas that are too distant from traditional sources of observational data. Due to the sparsity of existing weather stations, the region makes for a good case study regarding the improvement in reanalysis accuracy gained by increasing the number of weather stations at the surface level. In this project, we attempt to quantify the accuracy improvement versus the amount of weather stations added, and also quantify the plateau effect that occurs once we reach a saturating point in terms of stations added. We also attempt to geospatially visualize this increase in weather station density versus accuracy improvement, and quantify the relationships between distance, density, and accuracy. Finally, we propose a method to optimally choose locations for future weather stations in such a way that would maximize gained accuracy improvement.

Methodology
Our proposed methodology to determine the accuracy improvement is to perform a simple reanalysis technique on surface ambient temperature. We assume temperature measurements from official weather stations (such as those from airports in the region) to be ground truth. In our methodology, all ground truth stations in our region of interest are removed from the reanalysis input. Interpolation between hobbyist station observations and the GFS forecasting model is performed. The ground truth is then compared to the reanalysis output to determine accuracy. Additional tests were also performed on other surface parameters, including humidity and wind speed, and similar results were produced.

Relationship Between Density and Accuracy
After performing an interpolation of the temperature deviations between our observations and model data, a geospatial grid of deviations is obtained. Our first experiment involves empirically determining a relationship between the coverage (density) of a certain point, and the increase in accuracy of our reanalysis estimate for that point. This relationship is outlined in Figure 4. Our second experiment involves empirically determining a relationship between the number of additional stations added within our reanalysis boundary and the respective average increase in reanalysis estimate accuracy for all points of interest. This relationship is outlined in Figure 2 and 3.

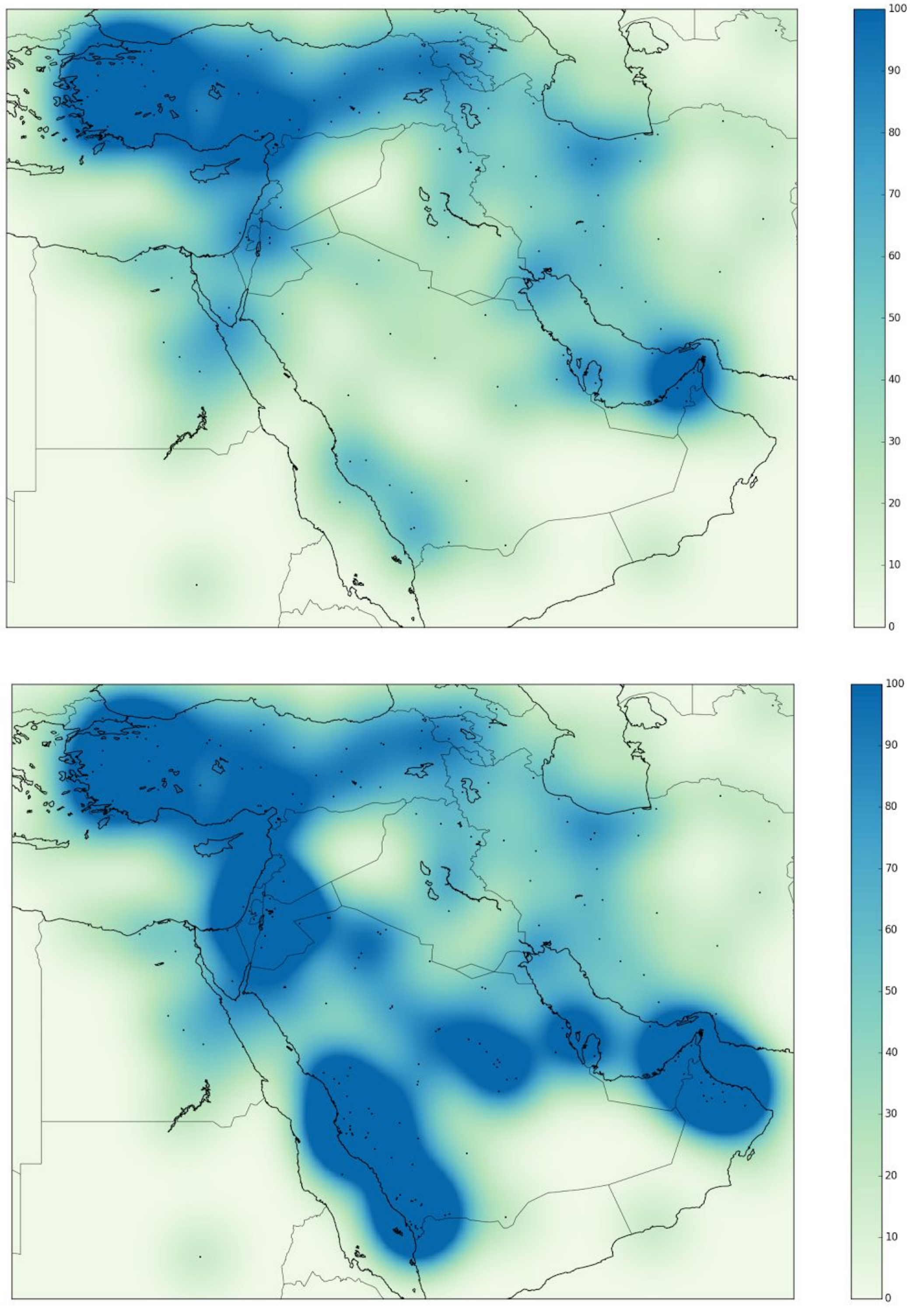

Figure 1: The two heat-maps above show the geospatial coverage (as a percentage) that was available before (top) and after (bottom) utilizing our hobbyist weather station network. The heatmap before the network shows that true (~100%) geospatial coverage was only present in Turkey and the UAE. Following the distribution of approx. 100 stations, we were able to achieve similar true coverage in Jordan, parts of Saudi Arabia, and most of the UAE and northern

Oman. The heat-maps also show ideal positions for the distribution of new stations. This optimal selection of weather stations is used in conjunction with a peak finding algorithm that works on the background (model) deviations grid.

Optimally Choosing Station Location

In order to maximize gained accuracy improvement from an additional weather station, we propose a method that optimally chooses locations based on the previously derived deviations grid. Using a two-dimensional peak finding algorithm, we determine the geospatial locations of local minimas or maximas in our derived deviation grid. This algorithm is used in conjunction with a two-dimensional Gaussian coverage algorithm, and an example of this algorithm's result is shown in Figure 1. A local minima/maxima in the deviation grid indicates a very large deviation of the reanalysis estimate from the model (initial guess for the reanalysis). Our results show that areas of large model deviation, that lack observations, are the most optimal for placing observations, as opposed to locations with low model deviation.

Quantifying the Accuracy Improvement

There currently exists a large uncorrectable inaccuracy in most available weather forecasting models for the Middle East region, when compared with what we considered to be ground truth observations coming from traditional weather stations. Additionally, the poor geographical coverage of the area with weather stations creates inaccurate reanalyses for the region. From our results, we find a significant improvement in reanalysis accuracy for multiple parameters. Given the relatively small cost of this method, and the ease of deployment over a large geographical area, this case study strengthens the role of of hobbyist weather stations in reanalysis.

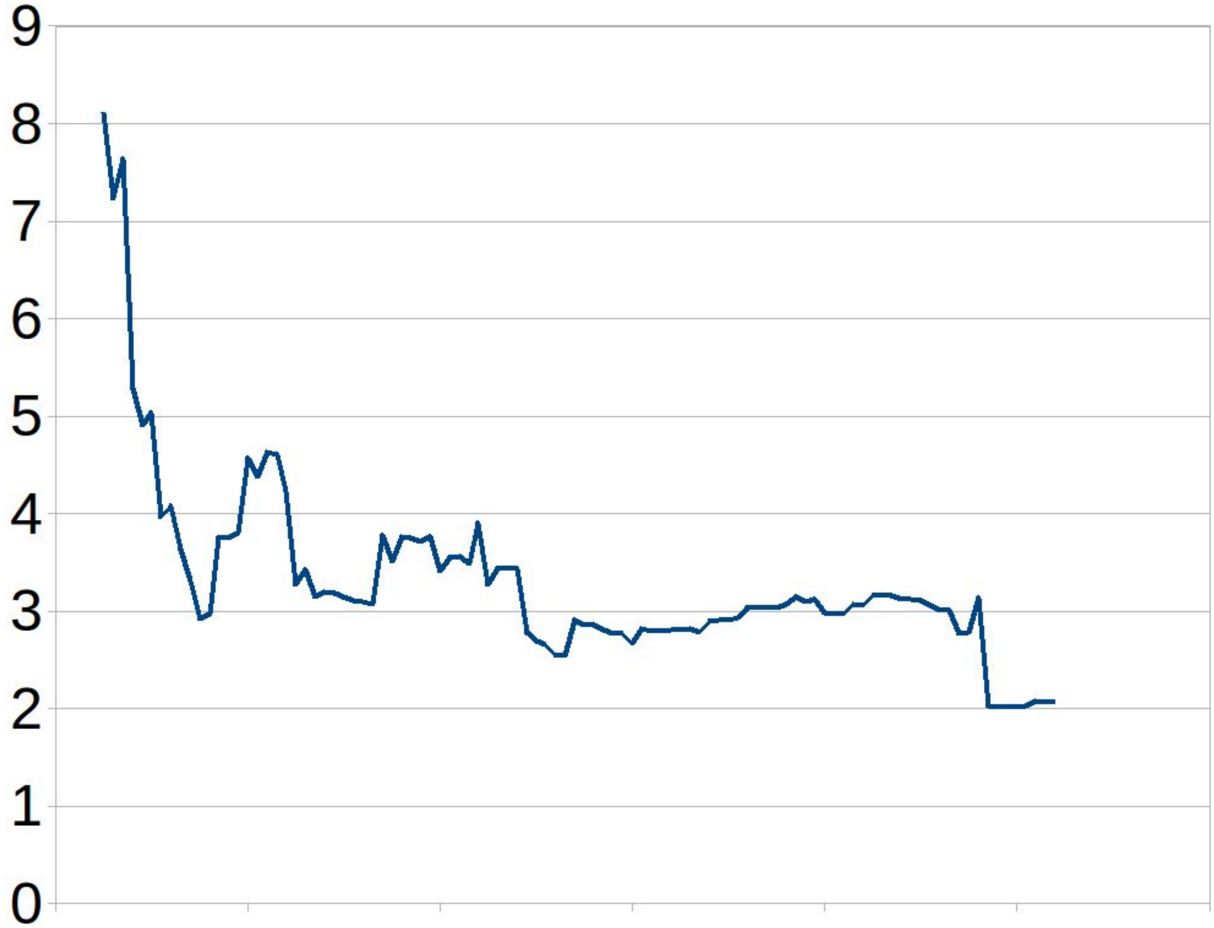

Figure 2: The graph shows the percentage of ground truth station estimates from the reanalysis that have improved versus the number of hobbyist stations added to the reanalysis. A ground truth estimate is said to have improved if it the estimate is a significant improvement compared to the background (model). Results show that the addition of approx. 100 stations improved approx. 73% of ground truth station estimates.

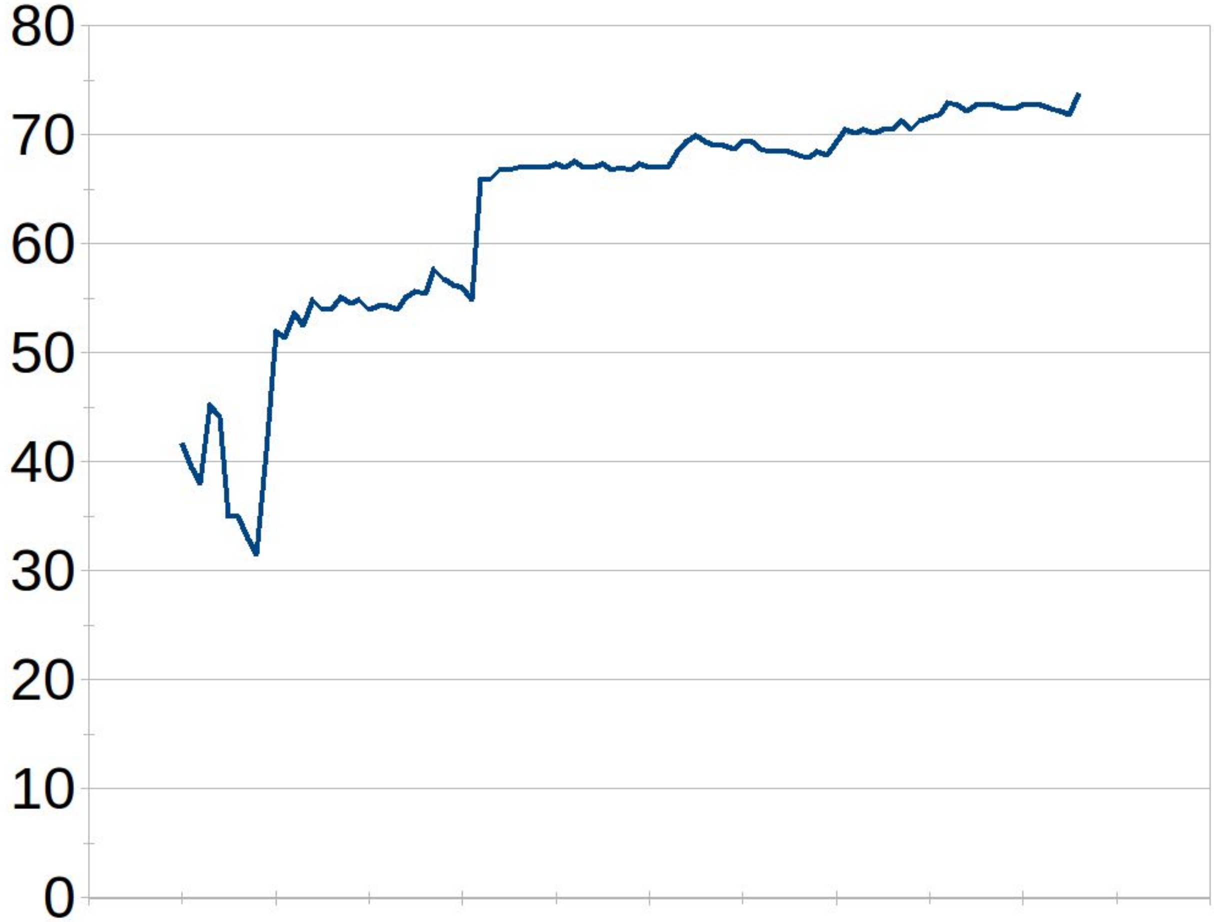

Figure 3: The graph shows the decrease in mean absolute error in the estimate of ground truth stations in degree Celsius versus the number of hobbyist stations added to the reanalysis. Results show that the mean error dropped from approx. 8 degree Celsius (using only the background as an estimate) compared to approx. 2 degree Celsius (when using optimal interpolation between approx. 100 station observations and the background).

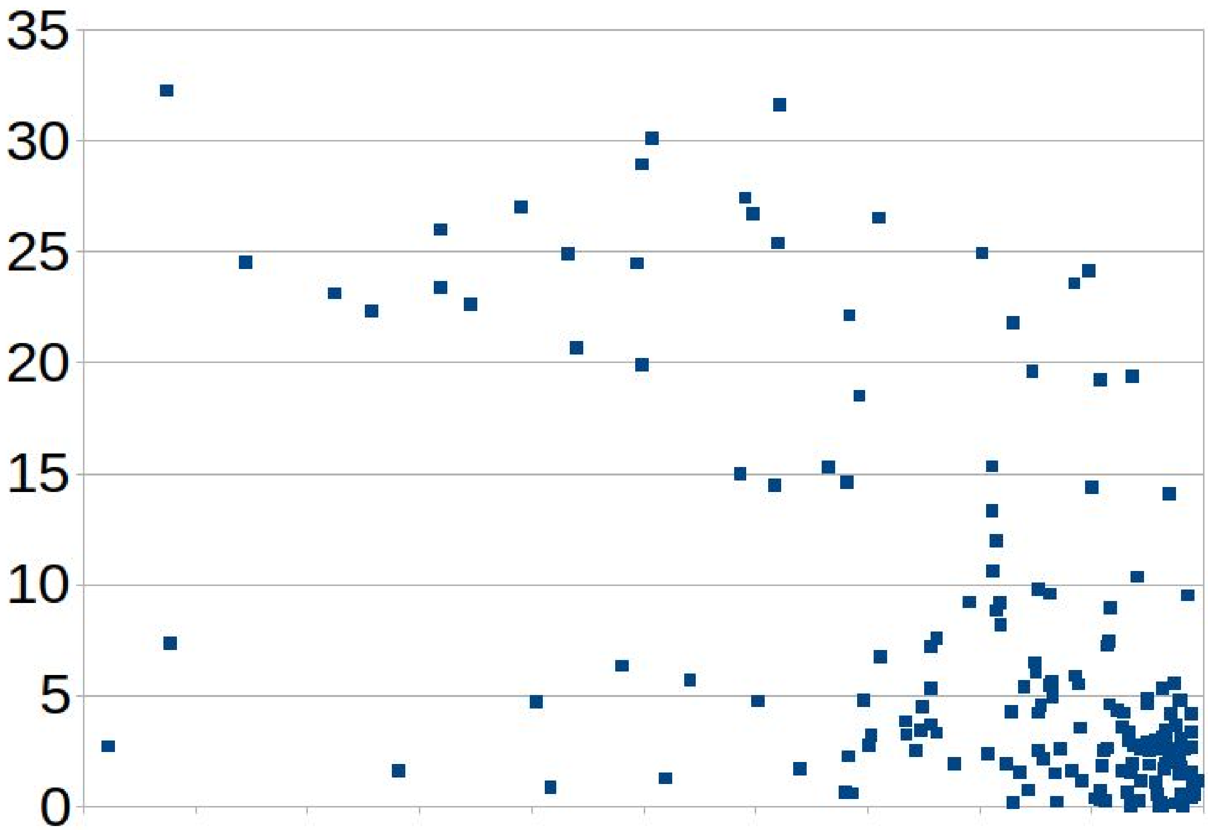

Figure 4: The graph shows the decrease in mean absolute error in the estimate of ground truth stations in degree Celsius versus the coverage of the station point by the hobbyist weather station network (coverage is on a logarithmic scale, as a percentage). Results show that the increase in coverage by the station network tends to lead to a decrease in the mean absolute error of the reanalysis estimate.

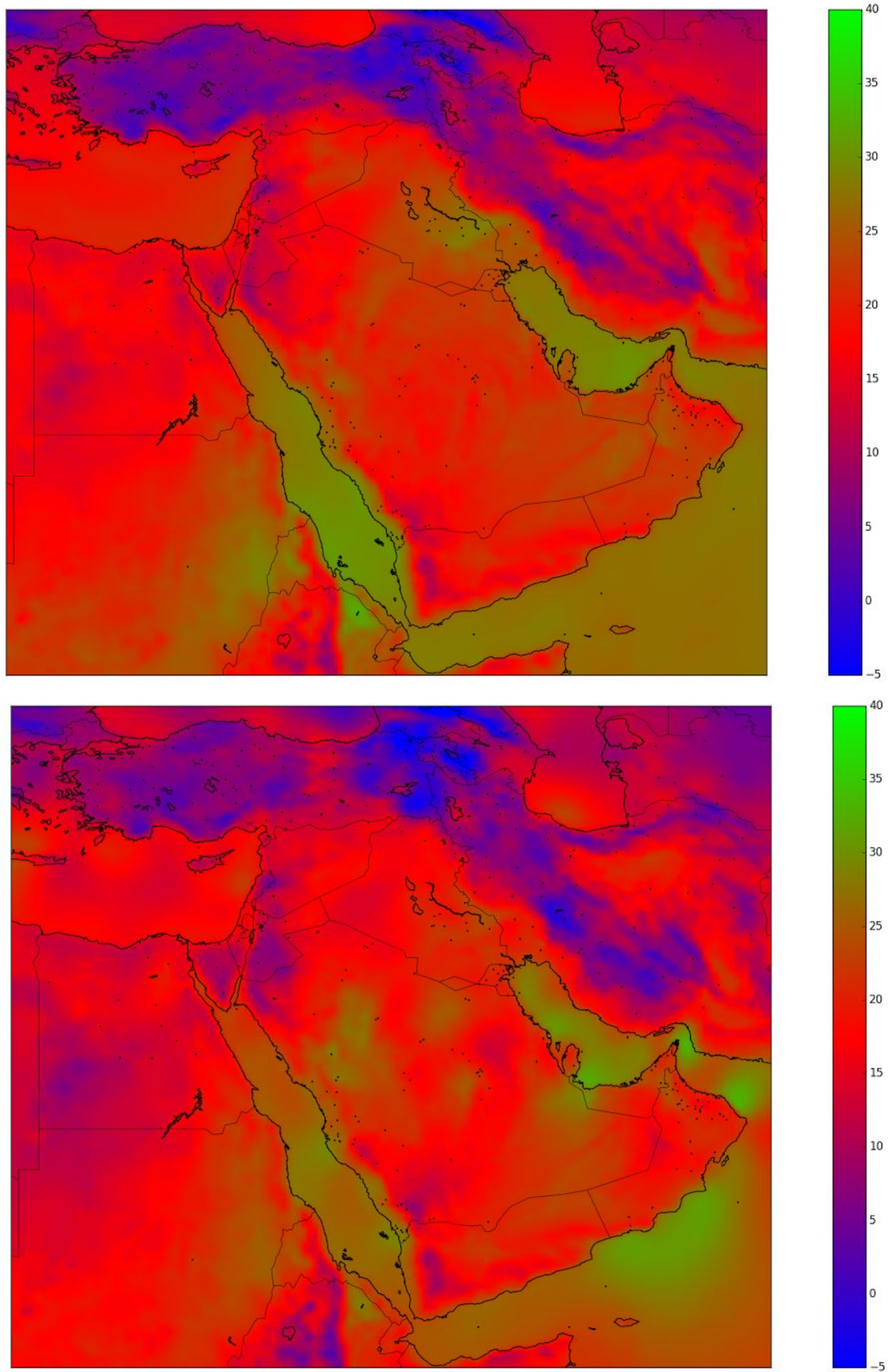

Figure 5: An example of the reanalysis before (top) and after (bottom) using the stations to modify the background. The initial guess (top) of surface temperature is taken from the GFS model only.

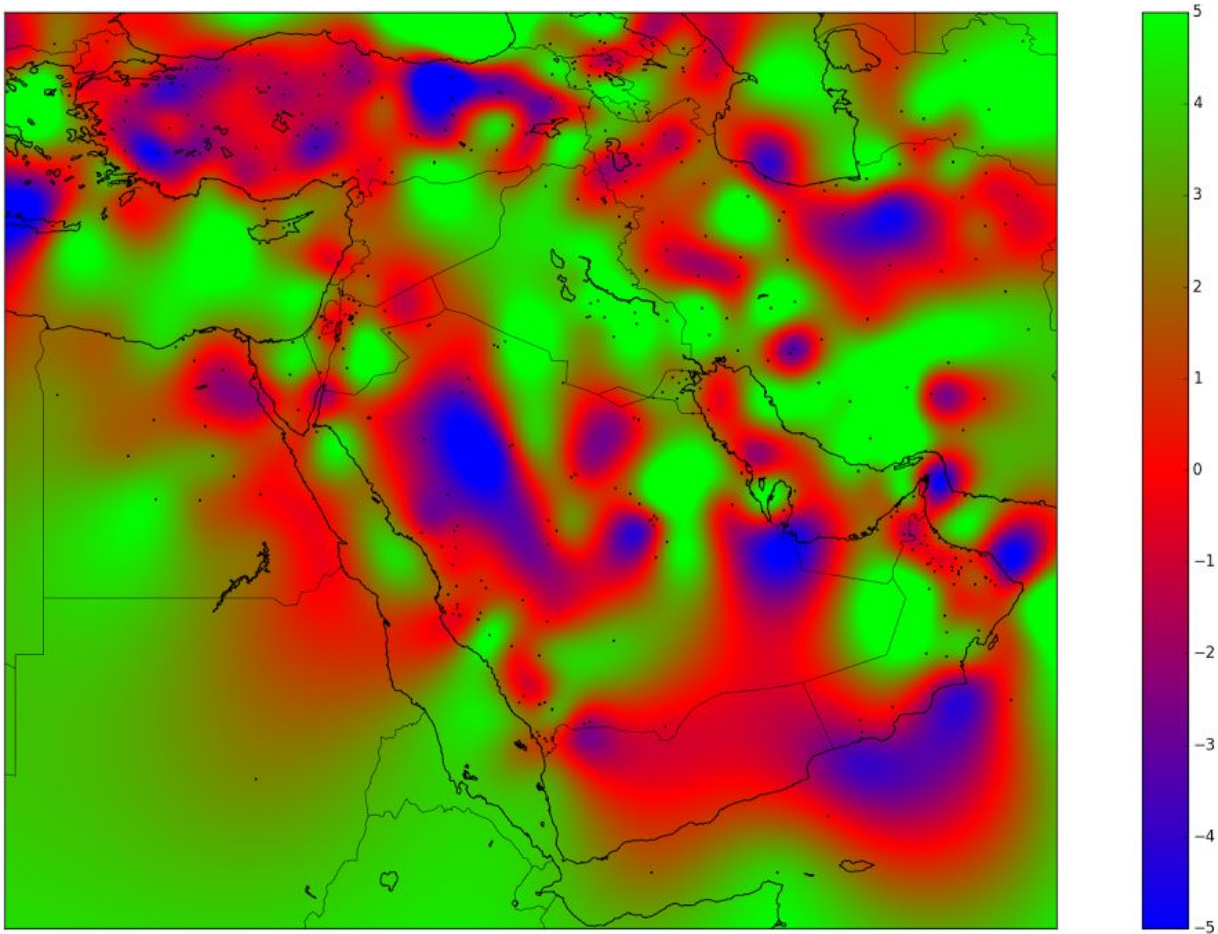

Figure 6: An example of the deviations grid that results from interpolation between the background (model) and the station observations. Following data sanitization, deviations range between -5 and +5 degrees Celsius for most of the Middle East region.