COMBING MSG THERMAL CHANNELS WITH METEOROLOGICAL DATA FOR FOG FORECASTING AND MAPPING OVER DESERT AREAS IN THE UAE

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ABSTRACT

Satellite remote sensing is an important tool in the detection and short range forecasting (*nowcasting*) of fog events. Fog over land develops primarily during the late-night and pre-dawn hours, infrared remote sensing is indispensable in observing fog formation at night, while visible imagery helps to monitor the extent and density of fog after sunrise. Satellite remote sensing is widely used in the United States and Europe in detecting and nowcasting fog events. The temperature difference between two infrared bands (11 µm and 4 µm), available in geostationary satellites, forms the basis for fog detection and classification [1].

In this study an algorithm for now-casting, detecting and monitoring fog events in the United Arab Emirates was developed. The major approach is based on developing a neural-networks system in MATLAB, mainly using METEOSAT SEVIRI data and local meteorological data. The final developed tool is named UAE-FAD (Fog Automatic Detector) and will provide real-time information for further research and development as well as for public and civil services.

Index Terms— *UAE, remote sensing, fog, METEOSAT SEVIRI, UAE-FAD and nowcasting.*

1. INTRODUCTION

On March 11, 2008, a thick fog occurred along the highway between Dubai and Abu-Dhabi. Regardless that most of the national weather stations reported less than 100-meter visibility, this fog event caused horrific chain-reaction accidents that killed and injured many people and burned more than 200 vehicles.

The UAE coastal area is located on the edge of a very warm sea and a hot and a dry desert creating the optimal conditions of an inland fog forming. The afternoon sea breeze, which is almost a daily event in UAE coastal areas, transports moisture inland. At clear sky condition at night, the desert environment radiates heat very efficiently and temperatures fall quickly. The rapid cooling of accumulated inland moisture during the night represents the optimal condition for fog development [1]. In this study, fog occurrences and coverage over the UAE were observed and recorded in the last three years (2008-2010). Data compiled from these observations has shown an average of 45 occurrences of dense fog events each year. The annual distribution of fog occurrences over the UAE is shown in the figure below (Figure 1).

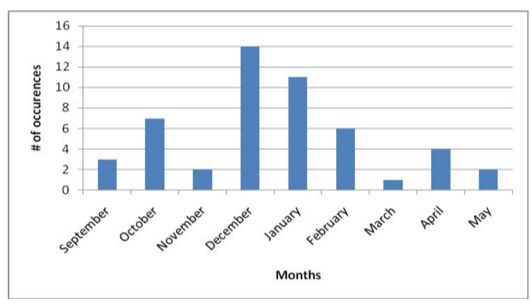

Figure 1: Fog occurrences over the UAE for 2008/2009 season

This paper deals with the development of a satellite-based tool for nowcasting, detecting and monitoring fog events in the United Arab Emirates. The developed algorithm uses a system of neural networks trained with METEOSAT SEVIRI channels and gridded meteorological data as inputs. Fog over land develops primarily during the late-night and pre-dawn hours. Therefore infrared and thermal channels were used in detecting fog formation at night, while visible channels were used to monitor the extent and density of fog after sunrise. The temperature difference between the two infrared bands (11 µm and 4 µm) forms the basis for fog detection and classification [1]. Neural networks were selected as primary tool due to the complex and non-linear relationship between the multisource inputs (satellite and meteorological data) and the system output (fog presence and fog density). Additionally, neural networks can be easily converted to an automatic detection tool that can be operated without the need for human intervention (after rigorous calibration and validation) [2].

Fog forecasting and detection require the analysis of thermal images from the early night hours. This data is provided by SEVIRI-MSG sensor at 15-minute interval. Also, the detection approach has to take into account the dynamic behavior of fog by considering all resources available (ground-based and satellite-based measurements). Indeed, it was proved in numerous studies that the addition of ground-based measurements of meteorological parameters to satellite-based measurement increases the accuracy of prediction and detection models [3-7].

2. ANALYSIS

The analysis started with a visual interpretation of the MSG channels for the foggy events. Reflectances measured by the High Resolution Visible Channel (HRV) are shown in figure 2 for one foggy and one no foggy days. The top-left image was collected at 08:45 am local time (GMT+4) on the 24th of December 2008 and compared to a not-foggy day (top-right). Furthermore, it can be noticed how the reflectance might reach a maximum value of 100% (bottom-left) in a foggy day, where in a clear day (bottom-right) the reflectance maximum value will not exceed 60% over bright surfaces such as desert.

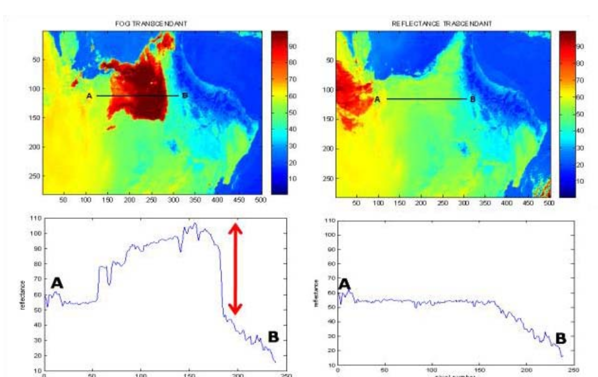

Figure 2: HRV Reflectance Transcendent

The focus of the analysis was over the behavior of the fog thermal difference and the spatial distribution of the fog coverage. As shown in Figure 3, the thermal difference starts (first scene starts 04:15 local time) with a negative value, however, it can be seen that all of the foggy days (bluish lines) are below a certain value (-5). Furthermore, there is a thermal peak at sunrise that decreases gradually until the sunset period, where the degradation reduces, after that a thermal drop occurs representing the night time period.

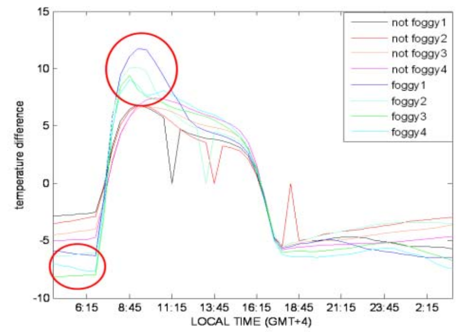

Figure 3: Thermal Difference Mean

2.1. Analysis Summary

A visual interpretation of the difference between the two thermal channels T04 and T09 has shown how the foggy events could be detected from the early night hours. Moreover, it was noticed how the readings of the satellite sensor gives a false reading due to the low solar angles and sun glint after sunrise. Furthermore, it was observed that the desert emits a thermal difference that is similar to the fog signature, which could lead to an increase in false alarms if the detection system will only rely on thermal channels for fog detection.

The threshold function of the thermal difference is a dynamic function that changes according to the satellite solar angle [8]. As can be noticed in Figure 3, the thermal difference during foggy days ranges between -5 and -10 Kelvin before sun rise, while after sun rise the fog albedo increases to reach a range of 10 to 15 Kelvin.

3. METHODOLOGY

Fog nowcasting was performed before sunrise using multi-temporal thermal imagery collected at night. The thermal-based nowcasting algorithm was operated from midnight to one-hour before sunrise. The algorithm is fed with thermal bands images received at 15-minutes interval from the European Geostationary Satellite Meteosat-SEVIRI. The satellite images will not be enough to build a proper fog warning system. Therefore, meteorological data provided by some local weather stations spread over the UAE was gridded and used in the nowcasting phase. It was found that, during foggy days, the humidity doesn't fall below 80% and the visibility doesn't exceed 0.5 km/m.

In order to avoid any spatial extrapolation of meteorological data during the gridding process, the study area selected for neural network training and calibration was located between three weather stations (◆) as shown in Figure 4. These stations are located in Dubai, Al-Ain and Abu Dhabi. A total of 10 neural networks were trained and calibrated with different sets of foggy and non-foggy scenes.

In order to avoid the randomness of a single net output, the final system decision is based on the outcome of all 10 nets.

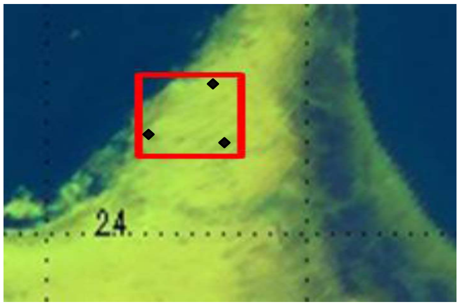

Figure 4: Study Area

The optimum objective of this study was to produce a web based nowcasting system that will provide hourly forecasting of fog events through UAE-FAD tool. In order to achieve this objective, two sub-algorithms were developed and tested: (1) Night-Detection and (2) Day-Detection algorithms. A flowchart of these two sub-algorithms is presented in Figure 5. A brief description of these units is presented below:

Sub-Algorithm 1 (Night-Detection): Fog nowcast will be first generated before sunrise using thermal imagery collected at night beside the meteorological data from the local weather stations. The nowcasting tool will be operated from midnight (local time) to one-hour before sunrise. At each new scene, the likelihood of fog occurrence will be calculated and updated. As was mentioned earlier, thermal bands have been used in similar applications and have shown great potential in discriminating between fog and clouds at night.

Sub-Algorithm 2 (Day-Detection): The fog maps produced by the first algorithm will be corrected and updated with the first visible images received and processed as soon as the sun rises. Spatial fog coverage and fog physical properties will be generated in near-real time.

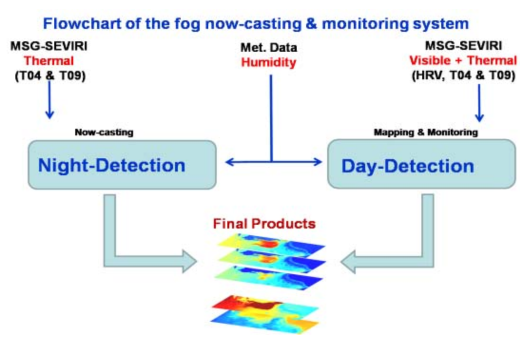

Figure 5: Algorithm Flowchart

As was shown in similar studies, neural network with one hidden layer is enough to solve a non-linear problem, which is the case for this study [5]. Moreover, the number of nodes in the hidden layer can be twice or three times the number of nodes in the input layer. In this study, a hidden layer with twice the nodes in the input layer was chosen in minimize the neural network weight. Therefore, choosing one hidden layer and keeping the number of nodes to the minimum keeps the system within a suitable range to operate in term of simulation time as shown in Figure 6.

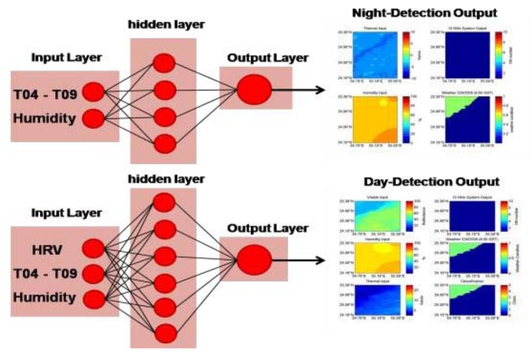

Figure 6: System Structure

Furthermore, the topology that was chosen is the Perceptron feed forward network for its simplicity. The sigmoid hyperbolic (*tansig*) was selected as activation function, since it's considered as the most widely used function in the remote sensing field [9]. The topology of the network and the function were chosen based on the nature of the application, since the system should be operated continuously on an hourly basis and should provide the user with the prediction of dissipation based on the thickness of the fog (gradual range of thickness). The output of the system starts with a binary output that indicates whether there is fog or not then a group of ten additional neural networks goes through the same process and the final decision will be taken based on the majority classification for the pixel. Afterwards, a pixel-based test was carried out on the Night and Day-Detection sub-systems and the results will be presented in the form of confusion matrices as presented in Table 1.

Table1: Pixel-Based Performance Test of the NN System

(a)Night detection accuracy

10 NNs	Fog	Not-Fog
Fog	95.7	4.3
Not-Fog	5.7	94.3
Accuracy	95	

(b)Day detection accuracy

10 NNs	Fog	Not-Fog
Fog	96.4	3.6
Not-Fog	4.6	95.4
Accuracy	95.9	

4. RESULTS

The system was tested under different weather conditions: foggy days, clear days, foggy days with the presence of clouds and clear days with the presence of clouds. Furthermore, the Night-Detection system (0:00 to 7:00 GST) displays as follow: on the top-left is the thermal difference input and on the bottom-left is the gridded humidity level, where on the top-right is the 10 NN's output and on the bottom-right is the final decision that gives zero for clear pixels and one for foggy pixels. Moreover, as shown in figures 7 and 8, the Day-Detection system (8:00 to 13:00 GST) displays inputs as follow: on the top-left is the visible input followed by the thermal difference input on middle-left and on the bottom-left is the interpolated humidity level. On the other hand, the Day-Detection system displays outputs as follow: on the top-right is the 10 NN's output followed by the final decision image (middle-right) and a classification output (bottom-right) that gives zero for clear pixels and assign a value from 3.5 to 5 for the foggy pixels based on the thickness of the event.

Afterwards the system was tested under different four weather conditions: foggy day (30th of December 2008) Figure 7, clear/cloudy day (19th of November 2008) Figure 8.

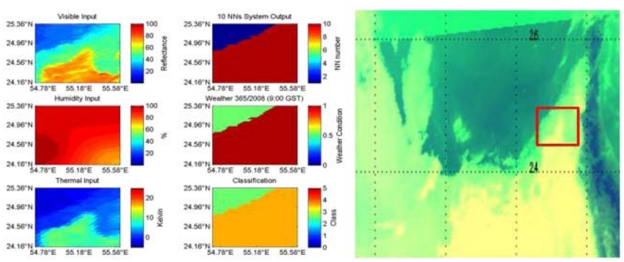

Figure7: Foggy Weather Condition 365/2008

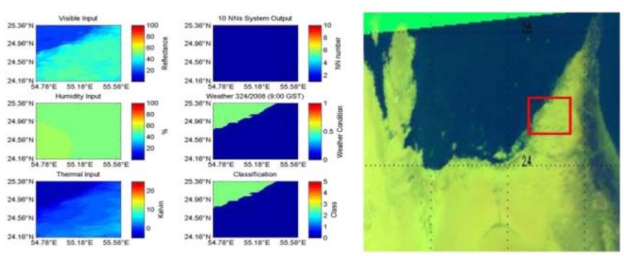

Figure8: Clear Weather Condition 324/2008

Finally, the system was tested under 25 random days and the system Probability of Detection (POD) was calculated using the following equation:

$$POD = \frac{D_{CC}}{D_{CC} + D_{FC}} * 100 \qquad (1)$$

where D_{cc} stands for correctly classified detection and D_{fc} stands for falsely classified detection.

5. CONCLUSIONS

After the analysis of the fog events over different parameters (T04-T09 and HRV) it was clear that the thermal difference is the main contributing parameter to detect fog from normal clouds. After further analytical and visual analysis of the collected data, it was obvious that thermal difference alone will not be sufficient to detect fog over bright surfaces as desert where small sand particles give a similar thermal pattern as for fog.

The addition of ground-based measurement of surface humidity to visible and thermal channels inputs has shown to have a significant effect on the overall accuracy with a POD of 88%. However, it's worth to mention that the 12% False Alarm Ration (FAR) observed in three days with a rare weather conditions in the UAE, since there was a blowing sand coming from Al-Ain (South-West) toward a rainy area (Dubai and Abu-Dhabi), which has produced high visible readings due to clouds (white color), a high humidity values due to the rain and a similar thermal signature to the fog event due to the presence of small (sand) particles in the air.

6. REFERENCES

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