FOG FORECASTING, DETECTION AND MONITORING IN THE UAE USING SEVIRI-MSG DATA

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ABSTRACT

The UAE location on the edge of a very warm sea and hot and dry desert create the optimal conditions of inland fog forming. The afternoon sea breeze, which is almost a daily event in UAE coastal areas, transports moisture inland, then at clear sky conditions at night, the large surrounding desert radiates heat very efficiently and temperatures fall quickly. The rapid cooling of accumulated inland moisture during the night represents the optimal conditions for fog development. Fog detection and monitoring algorithms from remote sensing data have been developed during the last two decades. Retrieval of fog-related information from geostationary platforms has matured into applications at operational level in many national weather service programs in the USA, Europe and more recently in China. In this study, a satellite-based tool developed at EIAST for fog detection and monitoring in the UAE will be presented. Data collected by SEVIRI instrument onboard of the European Satellite Meteosat Second Generation (MSG) were the main source of spatial data. The development approaches and the preliminary results will be presented and discussed in this paper.

Index Terms— *UAE, remote sensing, fog detection, METEOSAT SEVIRI.*

1. INTRODUCTION

The American Meteorological Society (AMS) Glossary defines fog as water droplets suspended in the atmosphere in the vicinity of the earth's surface that affects visibility. There are several types of fog. The most dominant is the radiation fog that occurs when radiational land cooling at night reduces the air temperature to its dewpoint. This is the most occurring type of fog in the UAE. Radiation fog forms typically under clear sky conditions, high moisture in the surface layer and lack of air turbulence [1]. Soil conditions (moisture content and vegetation cover) affect soil thermal conductivity which plays the major role in radiation fog forming [2]. There are several factors that affect thermal conductivity including; soil type and porosity, moisture content and organic matter content of the soil. In addition the previously sited parameters, the high thermal conductivity of silty and sandy soils, which are very common in the UAE, create the optimal conditions of inland fog forming.

Satellite remote sensing is an important tool in the detection and nowcasting (short range forecasting) 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, while visible imagery helps to monitor the extent and density of fog after sunrise. Satellite remote sensing is widely used in the United States in detecting and nowcasting fog events. The temperature difference between two infrared bands (11 µm and 4 µm) forms the basis for fog detection and classification. These two frequencies, available in the US geostationary satellite GOES, are widely used in fog detection and monitoring in North America. Similar data currently acquired by the European satellite METEOSAT/SEVIRI and covering the Gulf region will be used in this project.

Several fog detection and monitoring algorithms from remote sensing data have been developed during the last two decades. Retrieval of fog-related information from geostationary platforms has matured into applications at operational level in many national weather service programs in the USA, Europe and more recently in China [3-12]. The ability of satellites to provide large observations at high temporal frequency has made them the primary tool for the fog forecasting and monitoring.

The temperature difference between two infrared bands (11 µm and 4 µm) forms the basis for fog detection and classification [15]. These two frequencies, available in the European geostationary satellite Meteosat-MSG, are widely used in fog detection and monitoring in both Europe and Asia [16]. Fog could be identified according to its spatial distribution and time of formation. In this study, both coastal fogs (over water) and land fogs (over land) are considered including night-time and daytime occurrences. Fog detection

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systems differ according to their functionality, where there are systems that operate automatically and other that need a human interaction. In observer-based systems, the detection approach focuses on rejecting clear areas from some preselected scenes with high fog coverage. This methodology is mostly used for daytime fog detection. In other hand, the automatic systems mainly focus on detecting and discriminating fog from other types of clouds. This type of systems is mostly used for night-time detection [13].

The simplest method used in automatic fog detection systems is the use of one spectral band. Another method is comparing the sky radiance to the IR images. Moreover, the most common method is by using the min and max thresholds matched by a spatial variance test. However, these approaches are very limited in distinguishing between surfaces. Another approach that was sought is combining one visible band and one IR band by looking into spectral similarities. In this study, we propose to use an advanced neural-network-based approach in the three sub-algorithms.

2. METHODOLOGY

Fog forecasts will be first generated before sunrise using thermal imagery collected at night. The predicted maps will be then corrected and updated with the first visible images received and processed as soon as the sun rises.

It has been demonstrated from previous studies that fog thickness is proportional to brightness temperature difference in the two IR channels (for cloud layers <1 km thick). After sunrise, the brightness difference between the fog and surrounding cloud-free areas can also help estimate dissipation time. Dry soil warms up faster than moist soil after sunrise, resulting in faster clearing of fog. Conversely, fog that overlies a cold surface such as sea water tends to dissipate more slowly [13].

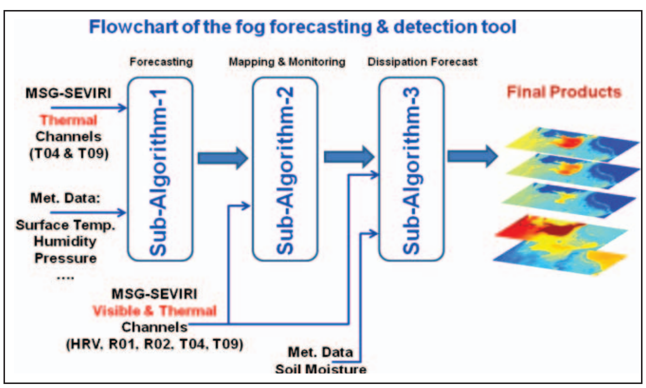

Figure 2: Algorithm Flowchart

The ultimate objective of this study is to produce web-base forecasts and near-real time fog monitoring tool. To achieve this objective, three sub-algorithms will be developed and tested: (1) Forecasting; (2) Mapping and Monitoring; and (3) Dissipation Forecasting. A flowchart of these sub-algorithms is presented in figure 2. A brief description of these units is presented below:

- **Sub-Algorithm 1** (Forecasting): Fog forecasts will be first generated before sunrise using thermal imagery collected at night. The forecasting tool will be operated from midnight (local time) to one-hour before sunrise. This tool will be "feeded" with thermal bands received each 15 minutes from the European Geostationary Satellite Meteosat. 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 fogs and clouds at night.
- **Sub-Algorithm 2** (Mapping and Monitoring): 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.
- **Sub-Algorithm 3** (Dissipation Forecasting): Soil moisture has been tested in some studies in the United States, in addition to standard meteorological data, to improve the prediction of fog dissipation time. Daily soil moisture product will be used. A statistical study will be performed to evaluate the contribution of soil moisture information in improving the prediction of fog dissipation time.

MODIS sensors on NASA's Earth Observation System (EOS) Aqua and Terra platforms provide superior quality images for fog detection due to their high spatial resolution (1km). However, due to infrequent sampling (6-hourly at mid-latitudes), and since most of fog events dissipate in the morning hours, only MODIS on board of terra satellite (which passes over the UAE daily around 10:30 am local time) will be used in this project. The images presented in figure 3 show the same fog event observed by MODIS sensor on the polar orbiting satellite Terra (left) and by the SEVIRI instrument on board of the European satellite Meteosat.

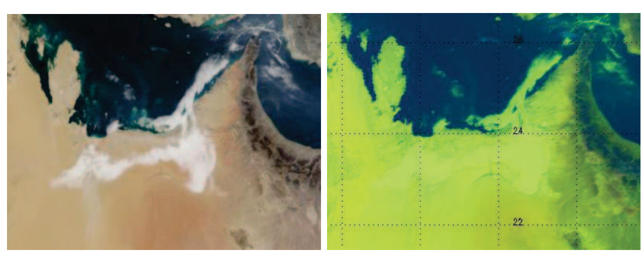

Figure 3: Recent fog event over the UAE observed by both MODIS (terra) and Meteosat satellites.

These images were acquired on December 31, 2008 10:30 am UAE local time (10:15 am for Meteosat).

Soil moisture information has been recently explored to improve fog dissipation forecasting. In fact, dry soil warms up faster than moist soil after sunrise, resulting in faster clearing of fog. An early-morning Soil moisture product generated from different passive microwave sensors will be used in this project. The soil moisture information will be used as additional input to the third sub-algorithm.

An accurate knowledge of the spatial distribution and the type of land cover over the study area will help to better understand the contribution of land surface on measured reflectances and temperatures. In fact, under the same atmospheric conditions, a desert pixel will have lower night temperature compared to urban pixel. This variation is mainly due to the different radiation behavior of the two land covers. Similar variations are also observed in measured reflectances during day light where bright bodies (i.e. deserts) reflect more energy than dark bodies (i.e. roads, buildings and vegetation). Indeed, rigorous assessments of land cover contribution to the measured signal will make the developed tool less sensitive to land cover variations and will certainly improve the fog forecasting accuracy.

In order to account for land cover contribution, an averaged Normalized Difference Vegetation Index (NDVI) will be derived from MODIS data and added, as extra input, to the neural network model. The NDVI is the most used product in land cover parameterization. It was used in similar applications such as cloud detection and precipitation detection tools.

3. DATA ANALYSIS

The satellite data analysis started with a visual interpretation of the MSG channels for some foggy and no-foggy days. The maps presented in figure 4 shows how the temporal evolution of one dense fog event can be seen by MSG HRV channel.

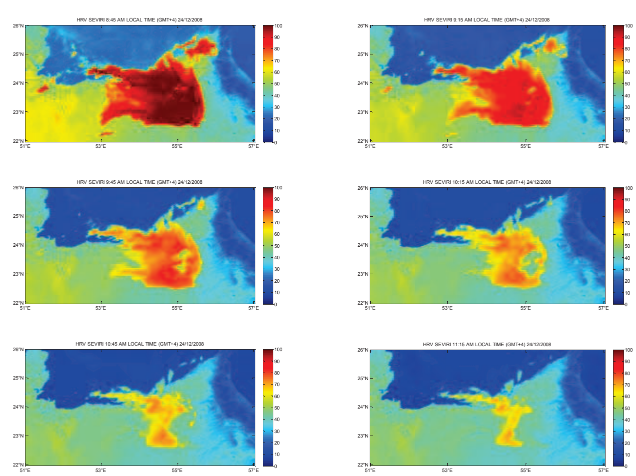

Figure 4: Reflectance values measured in the high resolution visible channel (HRV) of SEVIRI-MSG

Six scenes are presented at 30-minute intervals form 8:45 am until 11:15 am (UAE local time). This dense fog event occurred over the UAE on December 24, 2008.

The second analysis step is to evaluate the temporal behavior of thermal difference (T04 –T09) averaged over a subsetted area with recurrent fog occurrences. The average of thermal differences was calculated over the subsetted area for four foggy and four not foggy days. As shown in Figure 5, 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 -5 ºK. Furthermore, there is a thermal peak at sunrise that decreases gradually until sunset.

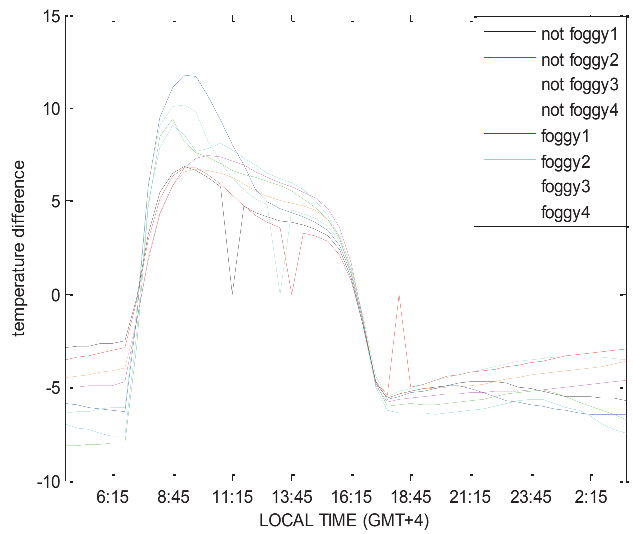

Figure 5: Thermal difference (T04-T09)

The temporal variation of T04-T09 shows that foggy events can be detected from the early night hours. Furthermore, it was observed that the desert emits a thermal difference that is similar to the fog signature, which would increase the number of false fog alarms in the forecasting system if only thermal channels are used.

A simple discrimination threshold of -5 ºK has been then tested to evaluate if it can be used to detect fog occurrences before sunrise. It was found that in some days there was an overlap in thermal differences for foggy and not foggy pixels. To overcome this confusion, a separability index (SI) technique has been tested. SI technique has shown much better accuracy in discriminating between foggy and not foggy pixels.). SI treats similarities in probability distribution using statistical pattern classification. The following equation has been used to retrieve SI [14]:

$$\frac{|\mu_R - \mu_n|}{\sigma_R + \sigma_n} \quad (1)$$

Where (μ) refers to the average and (σ) refers to the standard deviation of the difference between the two MSG thermal channels, (R) for an input from a random day and (n) for an input of one of six reference days (3 foggy and 3 not foggy) Figure 6 shows the SI computed for two random days (foggy and not foggy) compared to preselected reference days. Very low SI (less than 2) was obtained when similar events were compared (fog to fog; not fog to not-fog) and high SI was obtained when differed events were compared (fog to not-fog; not-fog to fog).

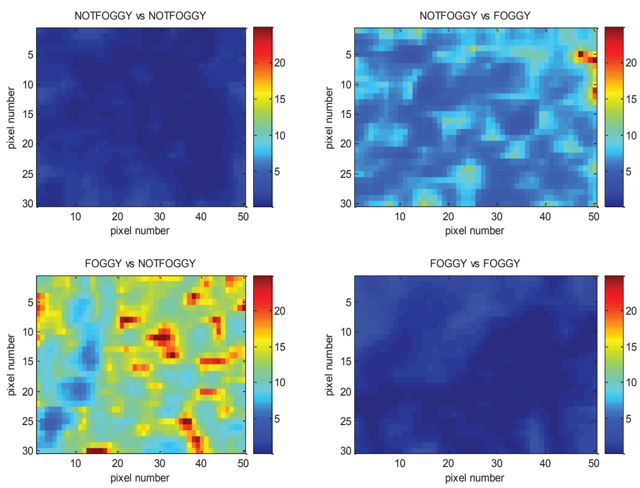

Figure 6: Output of the SI-based technique

4. CONCLUSIONS

The preliminary results have shown that the use of thermal difference between the two MSG channels (T04 and T09) give a good indication of fog presence. The analysis of thermal data measured at night has shown that the thermal difference T04-T09 ranges between -5 and -8 degree Kelvin under dense fog conditions, while it ranges between -2 and -5 degree Kelvin under clear sky conditions. However, more confusion was observed for light fogs. At his stage, a simple threshold of -5ºK between T04 and T09 was used to detect the presence of dense fog before sunrise.

The forecasting capabilities can be improved by adding land-cover-related information to the discrimination tool. A system of neural networks that takes into consideration other meteorological and land-cover-related parameters is being developed. The developed system will be used for fog forecasting and monitoring at night.

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