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Key Points:

- Dubai regional climate change
- MODIS albedo and temperature changes
- Coastal anthropogenic activities

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Impact of coastline-intensive anthropogenic activities on the atmosphere from moderate resolution imaging spectroradiometer (MODIS) data in Dubai (2001–2014)

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Abstract This paper illustrates the potential impact of large or the largest anthropogenic surface activities on the future of Earth's near-surface climate due to constructions performed in Dubai within just about 14 years. Dubai's massive constructions in the outstanding form of both artificial islands and coastal urbanization areas during 2001–2014 are rated among the top global growth rates. While earlier studies in the Dubai area focused mainly either on the sea or the land impacts, here, we examine the atmospheric dynamic effects in an extended area including both land and sea. Temperature increases along with albedo decreases were observed in most recently urbanized areas, while the opposite occurred over the big artificial islands, all based on moderate resolution imaging spectroradiometer data. Temperature changes in both land and sea are also associated through the coastal breezes with humidity and wind speed changes that are analyzed against several meteorological stations. Surface observations show humidity increases in all stations, while the wind speed changes are varying between the different stations.

1. Introduction

The coast of Dubai witnessed some dramatic anthropogenic land and sea constructions over the past 2 decades [*Gardner and Howarth*, 2008]. A description of these anthropogenic activities follows below. Earlier studies investigated the impact of those constructions on the marine environment [*Sheppard et al*., 2010] as well as on the sea currents [*Cavalcante et al*., 2012]. Investigation of the atmospheric parameters characterizing the Dubai area was mostly focused on collected data recorded at the Dubai metrological station. Conca et al. found a positive increasing trend in temperature in the time period of 1982–2009. More specifically, a sharp increase was exhibited in Dubai since 2005, in contrast to the nearby Abu Dhabi and Al Ain [*Conca et al*., 2010]. In a regional study on climate change in the Arabian Peninsula, it was found that Oman and Dubai are the two cities with the highest statistically significant mean annual warming trends [*AlSarmi and Washington*, 2011]. Here, we extend the previous investigations to an integrated study including data from both stations and remote sensing in order to explore human activities' effects on albedo, temperature, humidity, and wind speed. For instance, albedo spatial changes and their potential influence on temperature and rainfall were studied extensively over the south Israel Negev desert, including albedo aircraft measurements [*Ben-Gai et al*., 1998].

Over the past few years, remote sensing (RS) has become a valuable tool in estimating atmospherics dynamics and trends (from aerosols to temperature). Moderate resolution imaging spectroradiometer (MODIS) has become a most useful platform for such RS studies. For example, MODIS was previously used to investigate the effect of urbanization of temperature in mega cities in Asia [*Tran et al*., 2006] as well as in global-scale [*Clinton and Gong*, 2013] studies. Dubai serves as a good case study for a rapid urbanized area as its annual urban growth rate is among the world's highest [*Nassar et al*., 2014; *Ghoneim*, 2009]. Moreover, over the last four decades, its annual urban growth rate was about 10%, where the majority of it occurred after the year 2000, with a peak of around 13% in 2003–2005. The rapid anthropogenic and population growth in Dubai was also reviewed by *Pacione* [2005] until 2004, while here, the focus is given to the more recent period covered by the MODIS data since 2001.

The Dubai coastline area demonstrated a high growing rate, highlighted by the ongoing construction of artificial islands including Palm Jumeirah, Palm Jebel-Ali, Deira Island, The World, and Dubai Waterfront as well as the development of the surrounding coastal area (e.g., Dubai marine, hotels etc.). The massive

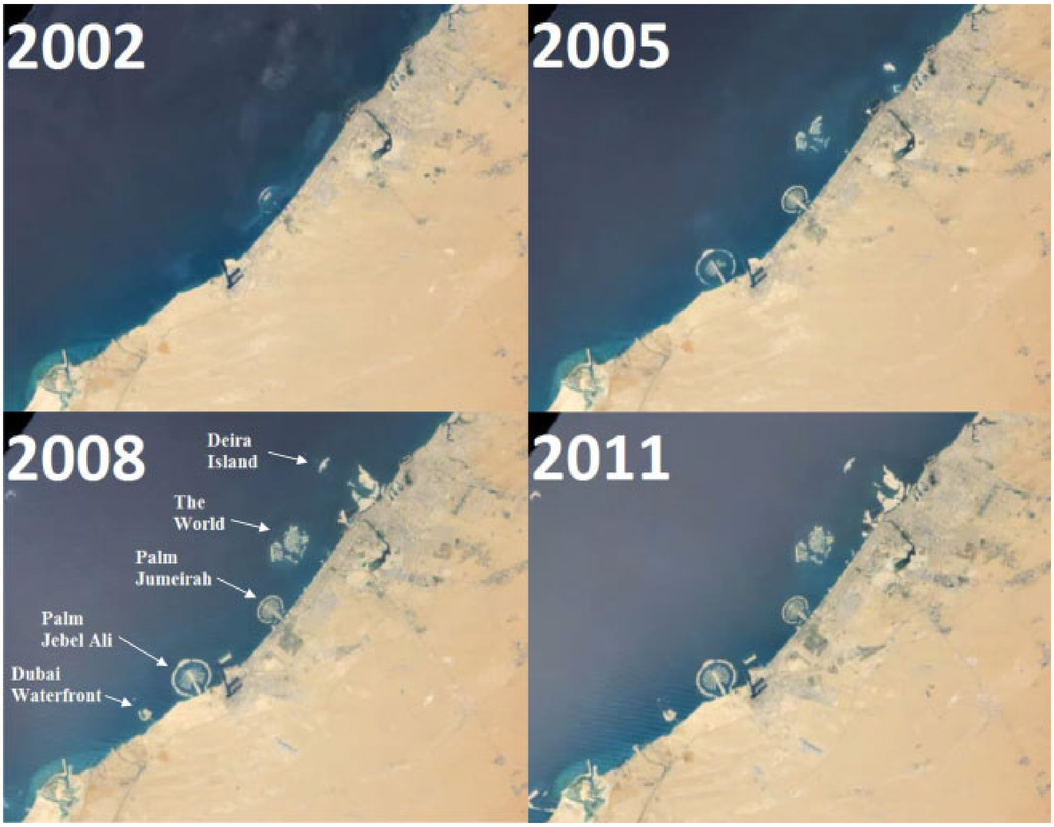

Figure 1. Rapid constructions of the Dubai coastline area over the years 2002–2011 as seen from Landsat pictures for the years 2002, 2005, 2008, and 2011. Each frame shows the area 24.75–25.45°N, 54.60–55.60E, with approximate dimensions of ~72x92km and is constructed from a year of Landsat satellite data of the Earth at 30-meter resolution. Landsat satellite data obtained from the Google Earth Engine in March 2015. The main constructions along the coast from north to south are Deira Island, The World, Palm Jumeirah, Palm Jebel Ali, and Dubai Waterfront.

changes in the Dubai coastline landscape could be observed from space; see Figure 1. The major changes seen over the years are the construction of the artificial islands and the urbanization of the Dubai coastline (darker areas along the coastline). In this way, one could monitor the constructions' progress, which can also be verified by the timeline of the constructions (see Figure 2). For example, the first signs of Palm Jumeirah were spotted in 2002, and as of 2005, the island seems mostly complete.

2. Data

Here, the Dubai rapid urbanization impact on temperature, albedo, and other variables was investigated. First, the detailed urbanization of the Dubai area is described. Later, albedo, temperature, and other parameters, changes, and trends in the time period of 2001–2014 are evaluated. The introduction of Dubai urbanization was illustrated by the Landsat satellite images obtained by the Google Earth Engine. [*Google Earth Engine Team*, 2015] This was followed by the evaluation of albedo and temperature trends obtained by MODIS MAIRS (Monsoon Asia Integrated Regional Study; website: gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id = mairs_8day).

In addition, surface temperature, humidity, and wind speed data from local meteorological stations were obtained from Tutiempo Network, S.L.; website: en.tutiempo.net

2.1. MODIS Data

All data was extracted from MODIS MAIRS 8 day and monthly data products for the month of January. The following are some of the data details employed here: for the albedo (8-Day MCD43C3.005 product)—8d data, horizontal grid of 5.6-km, black-sky albedo (BSA), Visible, MODIS of both Terra and Aqua; for the MODIS Land surface temperature (Monthly MOD11C3.005 product)–monthly data, 5.6-km, night time and MODIS

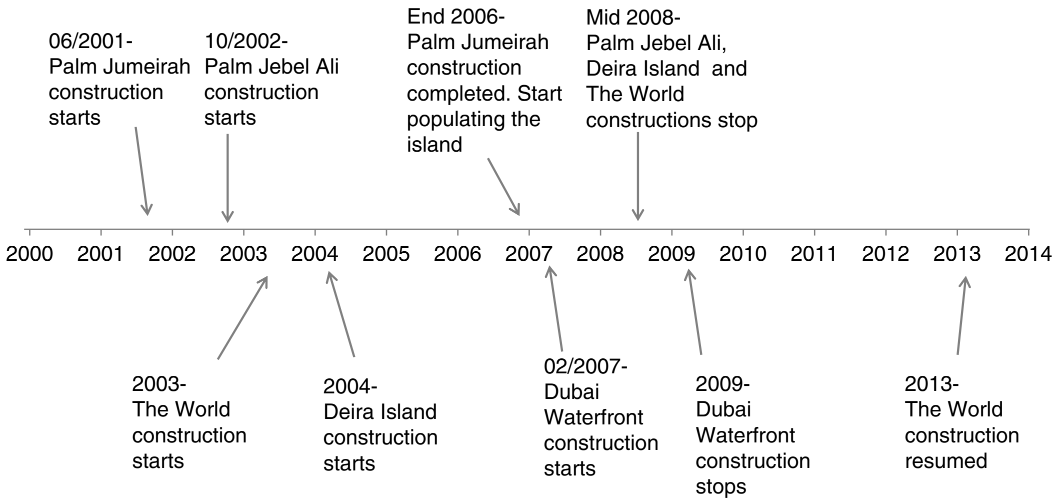

Figure 2. Timeline of Dubai's artificial islands construction during 2001–2014 based on Wikipedia.

Terra; and for the sea surface temperature (Monthly MAMO_NSST_4km.CR product) – monthly data, 4-km, 11 μ night, MODIS Aqua.

2.2. Maps

Landsat images: Each frame was constructed from a year of Landsat satellite data, constituting an annual 1.7-terapixel snapshot of the Earth at 30-meter resolution. Data was obtained from Google Earth Engine in March 2015.

Coastline map for plotting albedo and temperature changes was obtained from the National Geospatial-Intelligence Agency, from the following website: msi.nga.mil/NGAPortal/DNC.portal?_nfpb = true&_pageLabel = dnc_portal_page_72

3. MODIS Albedo and Temperatures Changes

As previously noticed, the albedo is an efficient tool in distinguishing urban versus rural regions over the Dubai area as they influence the net radiation and temperature [*Frey et al*., 2007]. Moreover, albedo serves as another component in atmospheric dynamics; in cases of albedo decrease where there is more energy available from the sun, this energy could be translated, for example, to wind speed. Hence, the MODIS albedo changes during 2001–2014 are plotted, Figure 3a. Most inland areas (mainly desert) show slight decreases of the albedo, probably due to some anthropogenic activities. However, high albedo decreases (up to about −0.05 or −50 in the figure's units) are clearly noticed in the areas that were significantly urbanized along the coast at a distance of up to 25 km. Among those regions are the Dubai Marina (25.08°N, 55.14°E), Media city (25.09°N, 55.15°E), Internet city (25.09°N, 55.15°E), International city (25.16°N, 55.40°E), Khalifa city (24.42°N, 54.56°E), AlShakma (24.38°N, 54.70°E), and Mussafah (24.35°N, 54.49°E) (in Abu Dhabi). The sea area albedo shows mostly low increases, where high increasing albedo is exhibited mainly in Deira Island (25.30°N, 55.28°E) and Palm Jebel Ali (25.00°N, 55.00°E). One could expect such increasing albedo in a sea area that was turned into land. This positive albedo trend is also noticed in Palm Jumeirah (25.11°N, 55.13°E) but mainly in the early period (a jump from 0.017 to 0.062 was observed between 2001 and 2002) and, therefore, has not strongly influenced the overall trend shown in Figure 3a.

The temperature changes are shown in Figure 3b. The sea mostly shows temperature decreases (less than −0.2), whereas the desert land shows temperature increases. The newly urbanized areas are characterized by the highest increases (up to 2 degrees). Those increases are higher than the ones exhibited in most inland desert rural areas; thus, those high trends may be stronger than the regional climate change and can also be related to decreased albedo and increases in the net radiation. The big artificial islands mainly show temperature decreases of less than −0.5° (notice that Palm Jumeirah at 25.1°N, 55.1°E shows some temperature increases, but during its construction in 2001–2006, decreasing temperatures were observed but are not shown here).

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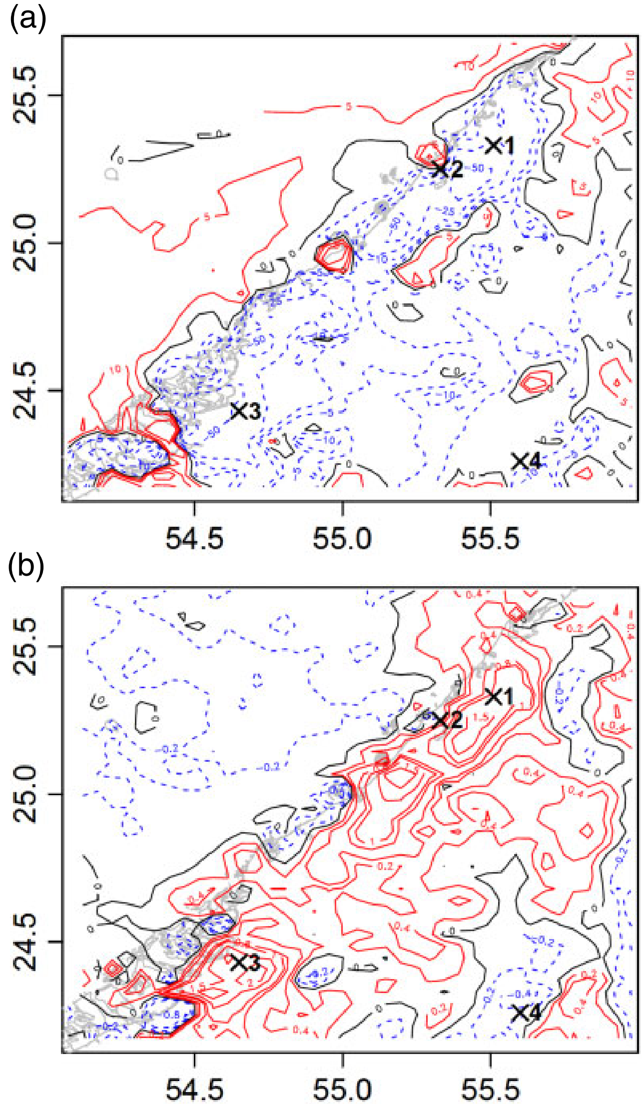

Figure 3. MODIS albedo (a) and temperature (b) changes in January during 2001–2014. The changes were calculated according to the annual linear trend multiplied by the number of years (for albedo and land temperature, 14 yr and 12 yr for the sea temperature). Panel (a) summarizes the albedo changes multiplied by 1000 (i.e., −50 value represents a total albedo change of −0.05 during the 14 yr). Bottom panel (b) shows the temperature changes in both land and sea. The temperature map (Figure 3b) is composed of two different datasets: land surface temperature and sea temperature (2003–2014). X1–X4 represent the locations of the meteorological stations: X1 - Sharjah, X2 - Dubai, X3 - Abu Dhabi, X4 - Al-Ain.

4. Evaluation of January MODIS Temperature Trends against Surface Observations

Recorded MODIS temperatures are lower than those measured on the tested meteorological stations (as seen in Figure 4). This is mainly due to the fact that MODIS data is at night time, while the available station data is a daily average. Another reason is that the station is close to the ground (World Meteorological Organization standard of 2 m), while MODIS integrates the surface value over a horizontal plane of 5.6 × 5.6 km. Night time MODIS data and data in the month of January were chosen for our present preliminary trends study because of the assumption that these data are less noisy. Trends in Dubai (X2) and Sharjah (X1) are similar to the same positive trend, while in Abu Dhabi (X3) and Al-Ain(X4), the trends are different. Again, this might be a result of the comparison of night time MODIS data with the stations' daily average data. The correlation between the station daily average and MODIS night time values was found to be good in all four stations, with calculated values of 0.8–0.9.

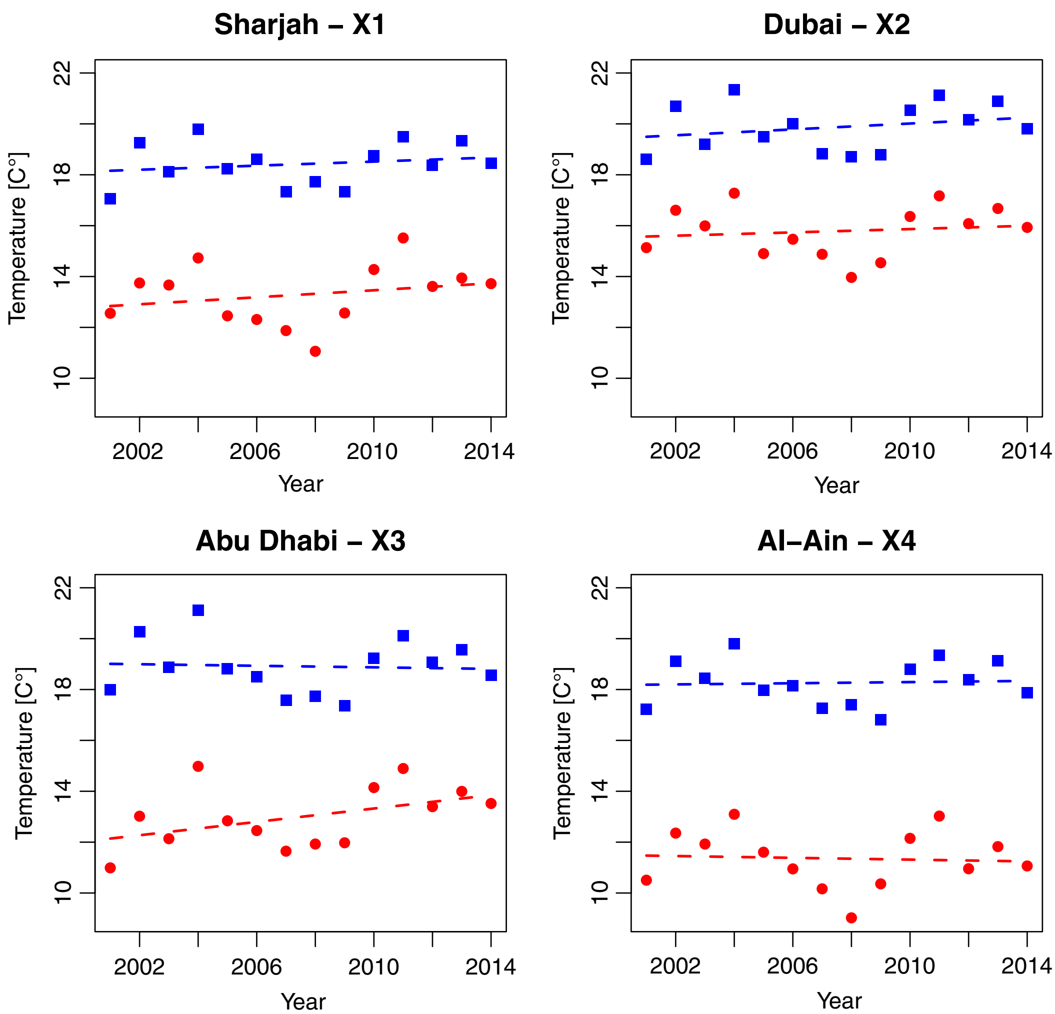

Figure 4. Observed January temperatures at local meteorological stations (blue squares) and MODIS (red circles). Information recorded at four stations: Sharjah (X1 at 25.33 N, 55.51°E), Dubai (X2; 25.25°N, 55.33°E), Abu Dhabi (X3; 24.43°N, 54.65°E), and Al-Ain (X4; 24.26°N, 55.60°E). All stations are positioned within airports. The plotted monthly temperature is an average of the 31 January days' daily averages (on the Sharjah station, data from 13 January 2003 was missing — the 2003 data point was averaged over 30 days). MODIS data was extracted from MAIRS (Monsoon Asia Integrated Regional Study) monthly products. The data were extracted for 5.6 km^2 frames surrounding each station.

The short time period that is available from MODIS (14 years), combined with the variability due to synoptic inter-annual changes, prevent the trends from reaching high statistical significance.

5. Variations in Temperature and Other Variables During 2001–2014

Changes in temperature between areas of sea and land will change the gradient and lead to a potential trend in the wind speed. A positive temperature trend on land accompanied with a negative trend at sea may indicate an increase in wind speed (Figure 5, X1, X3). Similar results showing opposite changes in temperature gradients associated with decreasing winds [*Alpert and Mandel*, 1986; *Pielke et al*., 1993] were discussed but with emphasis on vegetation, which may also be partially relevant here due to enhanced planting in the Dubai region, such as newly constructed parks. This was observed at the Dubai station and also in the non-urban Al-Ain station, which is further inland (Figure 5, X2, X4).

Relative humidity (RH) changes were also investigated, and all stations show increasing trends that can be expected due to the extensive urbanization. All stations show trends of nearly 0.2%/yr except Dubai, which shows lower increases (Figure 5). A summary of the temperature (in black), RH (blue), and wind speed (red) trends is given in Figure 5b.

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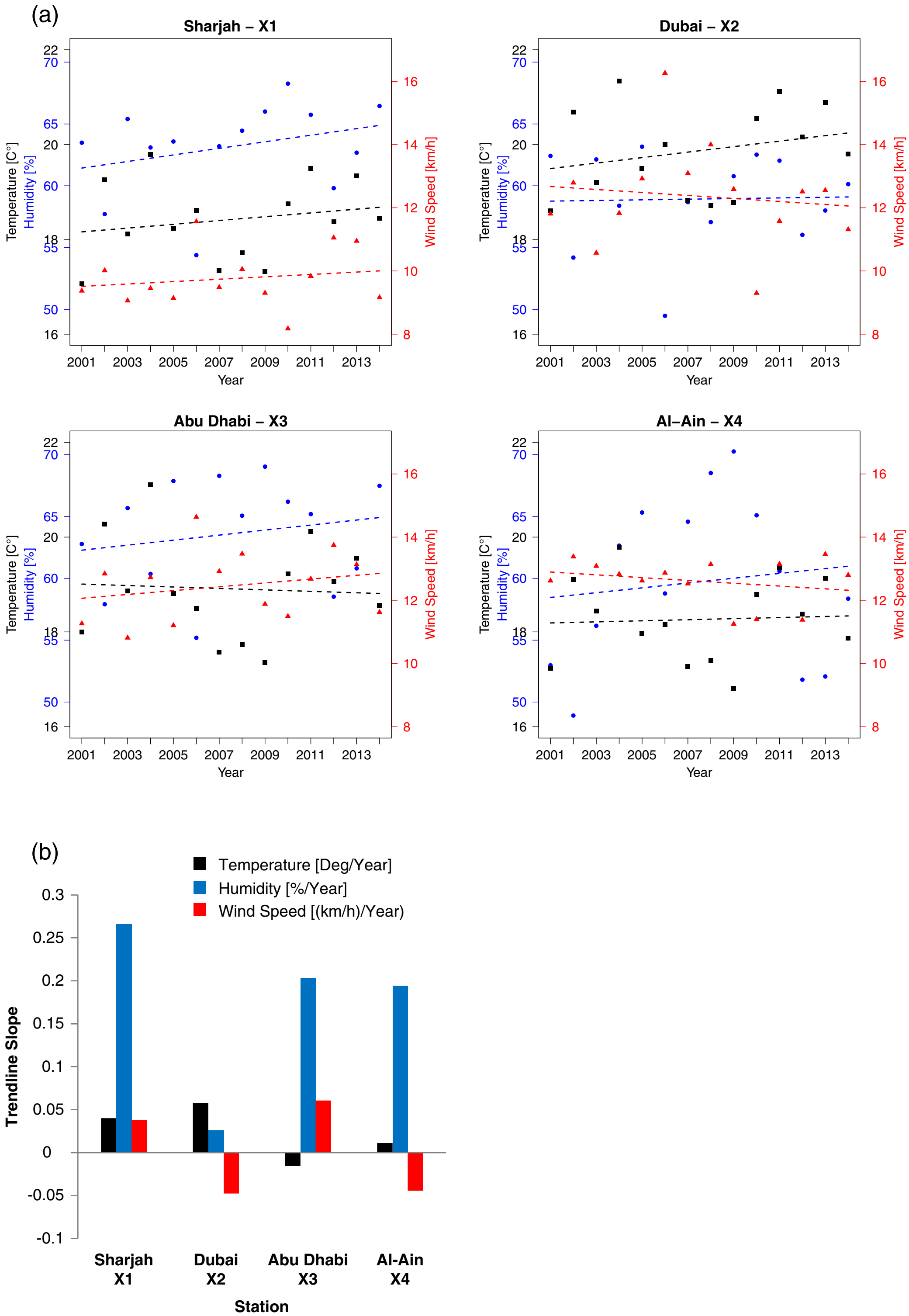

Figure 5. January temperature, RH, and wind speed observed at local meteorological stations X1–X4 during 2001–2014 (a). The plotted data is an average of 31 daily averages of the above parameters (in the Sharjah station, data from 13 January 2003 was missing—the 2003 data point was averaged over 30 days). The dashed lines describe the linear trend lines. The bottom plot (b) is the summary of all slopes for linear trend lines.

6. Discussion and Conclusions

Dubai's massive constructions in the outstanding form of both artificial islands and coastal urbanization areas during 2001 – 2014 are rated among the top global growth rates and are investigated here. In contrast to earlier studies in this area, which partly focused on the sea or land, here, we examine the atmospheric effects in an extended area including both land and sea. Temperature increases along with albedo decreases in the urbanized areas are pronounced, while the opposite occurred on the artificial islands. Analysis was based on MODIS data. Changes in the temperature patterns were also associated with humidity and wind changes as analyzed in four surface stations.

It should be noted that as the stations are not located in the cities' centers but in airports, which are adjacent to the centers, the urban effect is not so pronounced in the surface observations and could be also biased by extended air traffic as previously pointed out [*Conca et al*., 2010]. On the other hand, the areal MODIS pictures do show, for the first time, very significant trends in both albedo and temperatures, which fit the Dubai anthropogenic activities described in detail in the Introduction (Section 1) and Figures 1 and 2.

Analysis was also done in other near-by stations, including Sharjah, Abu Dhabi, and Al-Ain, which are not the focus of this study. Indeed, the observed coastal temperature increases over the land urbanized area along with the temperature decreases over the sea due to the artificial islands, both should contribute to stronger sea breezes by the increased and/sea temperature and pressure gradients. However, the increased roughness in the cities which influences the near by stations positioned in the airports may contribute to wind speed decreases. It is therefore probable that the two processes sum up with the observed opposing trends in the 4 stations wind speeds. The MODIS sea temperature dataset included very small land areas, especially due to the artificial islands and a very small area in Abu Dhabi. In addition, the MODIS land temperature dataset included very small sea areas, including some of the artificial islands and all of the Abu Dhabi area.

This preliminary study focuses on the winter month of January for 2001 – 2014, and this may explain why an earlier study focused on 1996 – 2008 annual averages shows RH decreases in Dubai and Abu Dhabi. Both studies show RH increases in the Al Ain station [*Conca et al*., 2010, Figure 4]. However, this is a yearly average, while we focused on January.

Future extended studies may include higher spatial and temporal resolutions, including monthly and diurnal variations. Also, mesoscale high-resolution modeling to investigate sensitivity to surface anthropogenic studies similar to what we have done earlier in other regions is required [*Perlin and Alpert*, 2001; *Hirsch-Eshkol et al*., 2014].

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