

INVESTIGATION OF THE DAILY URBAN COOLING ISLAND (UCI) IN TWO COASTAL CITIES IN AN ARID ENVIRONMENT: DUBAI AND ABU DHABI (U.A.E)

Corinne M. Frey *, Gergely Rigo, Eberhard Parlow

Institute of Meteorology, Climatology and Remote Sensing Department of Geosciences University of Basel
corinne.frey@stud.unibas.ch, (gergely.rigo, eberhard.parlow)@unibas.ch

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ABSTRACT:

Variations of surface temperature, albedo, emissivity and net radiation in different urban and rural classes in an arid area were investigated. Four ASTER satellite scenes with channels from the very near infrared to the thermal infrared were analyzed. For a better understanding of the spatial coherences a land use classification was built. The classes were then spatially and temporally compared. The investigations show a distinct daily cool island for Dubai and daily cooling areas of Abu Dhabi city and its surrounding mangrove areas. Net radiation is mainly controlled by the albedo. Therefore the net radiation is higher in the urban areas, where the albedo is lower than in the bright desert areas. The surface temperatures behave contrary to the net radiation and are mostly correlated with the availability of water. This work describes part of the urban-rural climatologically complex and contributes particularly to the different situations of coastal cities in an arid environment.

KURZFASSUNG:

Es wurden in verschiedenen urbanen und ruralen Klassen in aridem Gebiet Oberflächentemperatur-, Albedo-, Emissivitäts- sowie Strahlungsbilanzvariationen untersucht. Dazu wurden vier ASTER Satellitenbilder mit Kanälen vom nahen bis zum thermalen Infrarot analysiert. Um die räumlichen Zusammenhänge besser zu verstehen, wurde eine Landnutzungsklassifikation erstellt. Die Landnutzungsklassen wurden anschliessend räumlich und zeitlich verglichen. Die Untersuchungen zeigten eine ausgeprägte tägliche Kälteinsel in Dubai und tägliche Kältegebiete in Abu Dhabi und den umliegenden Mangrove-Gebieten. Die Strahlungsbilanz wird hauptsächlich durch die Albedo kontrolliert. Deshalb ist die Strahlungsbilanz in urbanen Räumen mit niedriger Albedo höher. Die Oberflächentemperaturen verhalten sich invers zur Strahlungsbilanz und sind v. a. mit der Verfügbarkeit von Wasser korreliert.

1. INTRODUCTION

While cities in temperate zones often show an urban heat island, cities in semiarid and arid areas in contrast have the possibility to act as daily urban cool islands (UCI). The interest in urban climate is huge; proven by the increasing number of publications. However, very few investigations to the UCI were made. Saaroni et al. (2004) show for the Kibbutz Mash'abei-Sadeh, a rural farm settlement within the Negev Desert, an oasis effect. Garcia-Cueto et al. (2003) investigated urban/rural radiation balance for Mexicali. Dimoudi and Nikolopoulou (2003) worked on the impact that urban vegetation has on the microclimate of urban settlements. The Middle East region as a field of remote sensing study is quite new and apart from military applications, a significant amount of remote sensing work has not been completed to date.

In this paper the urban climate of two cities in 'tropical semi desert and desert climate' shall be introduced. These cities present a better and improved urban living comfort relative to their natural environment.

1.1 Area under investigation

Dubai and Abu Dhabi are fast growing and modern, coastal cities in desert climate, situated at the northwest coast of the United Arab Emirates (U.A.E.). Looking at the climatologically conditions the Arabian Peninsula is one of the most hostile places on Earth. Extremely high summer temperatures, consequently high evaporation rates in combination with limited amounts of freshwater make the area a harsh environment. However due to their coastal location the climates of Dubai and Abu Dhabi are modified. Humidity rates are high, especially during night and in wintertime.

2. DATA

For both towns two ASTER satellite scenes including surface reflectance, surface kinetic temperature and surface emissivity were downloaded and geo-referenced using differentially corrected GCP taken during a field work in the UAE. The RMS (Root Mean Square) values were smaller than 0.4 pixels for all four scenes. After warping and re-sampling, the scenes were cut into quadratic pictures. To obtain the surface radiances, the DN were multiplied by a scaling factor and added to the same factor. The scaling factor is given by the NASA. The surface

* Corresponding author

kinetic temperature and the surface emissivity data had only to be multiplied ten-fold.

As the ASTER products already include an atmospheric correction, the satellite data did not need any more pre-processing.

Using the field records different land use classes for Dubai and Abu Dhabi were defined. Firstly, 'Water' and 'Not water' was separated. Secondly, 'Not water' was distinguished into its final classes. Input-channels for the classification routine were 14 ASTER channels as well as eight co-occurrence measures and the NDVI. The co-occurrence measures were necessary to identify highly structured urban classes. Almost impossible was to recognise the seashore and the beaches. Therefore a small buffer zone of 2 pixels (30m resolution) was laid around the water areas to mask out these values.

Using the GCP with its associated heights an absolute DEM was produced. As both satellite scenes contain large regions of water pixels (Dubai 35.66%, Abu Dhabi 54.28%), these areas were masked out of the DEM and manually set to a given level got by sea level data from two neighboured sea ports. As the resulting DEM still showed some perceptible deviations, such as false uprisings on a flat artificial island, a 3x3 median filter that excluded the GCP and the water pixels was programmed. The filter was run iteratively until the differences between the new calculated and the altered pixels were less than a set value. This procedure smoothed the surface and improved the height through the additional information of the GCP.

To calculate the net radiation the shortwave irradiation (I), the shortwave reflection (R), the atmospheric counter radiation (A) and the thermal emission (E) were modelled. The net radiation (R_n) is:

$$R_n [W/m^2] = I - R + A - E \quad (1)$$

The broadband shortwave irradiation was computed by the SWIM (ShortWave Irradiation Model) (Parlow, 1996b).

Shortwave reflection was calculated from the spectral surface reflectance and the swim output. To obtain the broadband albedo the following formula was used (Liang et al., 2003):

$$A = 0.484 \cdot b_1 + 0.335 \cdot b_3 - 0.324 \cdot b_5 + 0.551 \cdot b_6 + 0.305 \cdot b_8 - 0.367 \cdot b_9 - 0.0015 \quad (2)$$

$$A = \text{Broadband albedo} \\ b_{1,3,5,6,8 \text{ and } 9} = \text{Corresponding ASTER bands}$$

The longwave counter radiation was computed with an empirical formulae from Brutsaert (Brutsaert, 1982):

$$C = 0.552 \cdot e^{\frac{1}{7}} \cdot \sigma \cdot T^4 \quad (3)$$

$$C = \text{Longwave counter radiation [W/m}^2\text{]} \\ e = \text{Water vapour pressure [hPa]} \\ \sigma = 5.67 \cdot 10^{-8} \text{ (Stefan Boltzmann constant) [W/m}^2\text{K}^4\text{]} \\ T = \text{Air temperature [K]}$$

Longwave emission was calculated using surface kinetic temperature and surface emissivity. To obtain the broadband surface emissivity values, a broadband conversion was performed using formula (Ogawa et al., 2002):

$$e = 0.035 \cdot b_{10} + 0.072 \cdot b_{11} + 0.118 \cdot b_{12} + 0.381 \cdot b_{14} + 0.380 \quad (4)$$

$$e = \text{Broadband surface emissivity} \\ b_{10,11,12 \text{ and } 14} = \text{Corresponding ASTER bands}$$

Surface kinetic temperature was calculated already by NASA.

3. RESULTS

3.1 Land use classification

Calculating the land use classification was done under the precondition that the land use classes are contiguous areas that may consist of single pixels that belong to another class. The class 'Residential area' for example possesses a lot of vegetation pixels or mixed vegetation-building pixels that nonetheless were classified as 'Residential area' as the aim of this classification was to map and retrieve surface fluxes of a whole area; and not making statements on a single pixel basis. Even this complicated the land use classification the use of co-occurrence measures improved the classification results highly and helped to lead to good classification accuracies. The controlling ROIs (Region Of Interests) for calculating the accuracies were chosen different from the input ROIs and were spread over the whole image as much as possible.

The accuracy of the land use classification in the Dubai scene is 97%, in the Abu Dhabi scene it is 91%. The single land use classes show also good results. They range from 80- 100%. Only one class lies outside of an accepted value (58 %) (Frey, 2004). As table 1 and figure 1 show, classes with less good results only cover little percentage of the whole area.

Table 1
Producer accuracy and proportion of pixels for Dubai

Class	Producer accuracy (%)	Proportion of pixels (%)
Agriculture	96.18	2.11
City	81.33	2.06
Industry	85.54	5.01
Mangrove	100	0.19
Parks and golf courses	82.71	1.09
Residential area	96.18	6.29
Residential area in construction	96.44	9.41
Salty sand	99.24	7.71
Sand	99.62	26.04
Streets	80.79	4.21
Water	100	35.09
Total percent		100
Average producer accuracy	92.55	

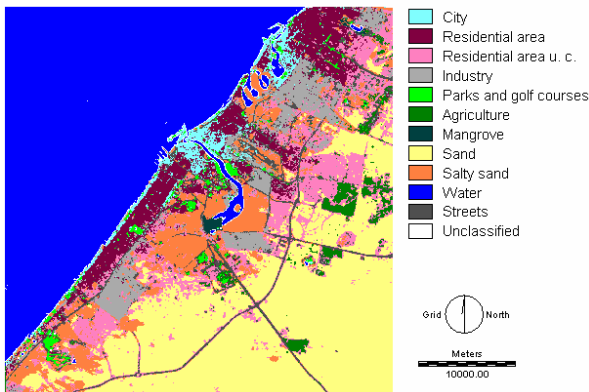


Figure 1. Land use classes Dubai

3.2 Surface temperatures

The sea surface temperatures (SST) of the scene Dubai 2nd February 2002 and of the scene Abu Dhabi 4th June 2003 portray a gradient towards the coast. This seems to be logical, as shallow waters heat up faster. But the SST of Dubai 27th November 2000 and Abu Dhabi 18th November 2000 scene show an inverse gradient. The first can be explained by prevailing southern offshore winds in November.

Human settlements and agriculture emerge from the hot desert ground. Even non-vegetated industrial areas have lower surface temperatures than sand. Wet sand and mangrove areas show similar temperatures to those of human settlements. Inside the settlement areas there are some cooling spots, represented by parks and golf courses. Water possesses the lowest surface temperatures.

To compare the surface temperatures of the newer and the older scenes, the SST were subtracted from each others land use classes. Next, the differences of the newer and the older scene were calculated. In Dubai no large differences were found. Both scenes are in wintertime. The mean difference is 0.52°C. Else in Abu Dhabi: While the land use class 'Mangrove' has a difference between the two scenes of about 4 °C, the class 'Industrial area under construction' differs by 9 °C. Mean difference in Abu Dhabi is 6.43°C. One scene of Abu Dhabi is in wintertime, the other in summertime. The availability of water in a class dictates the difference in surface heating. This effect intensifies with increasing temperatures.

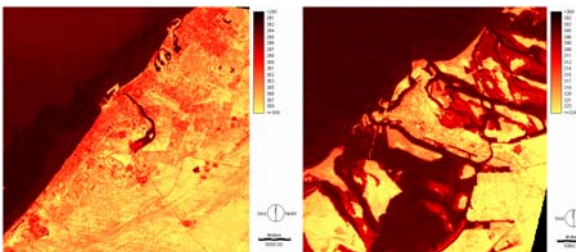


Figure 2. Surface temperatures [K] of Dubai, 2nd February 2002 and Abu Dhabi, 4th June 2003

To examine the differences between urban and rural temperature two classes were constructed: 'Urban' and 'Rural'. The first class includes the temperature values from 'City', 'Industry', 'Parks and golf courses' and 'Residential area' for Dubai and Abu Dhabi; the second class 'Agriculture', 'Mangrove', 'Salty sand' and 'Sand' in Dubai, and 'Mangrove',

'Salty sand', 'Sand and mangrove' and 'Wet sand' in Abu Dhabi. The classes 'Residential areas under construction' and 'Streets' were omitted.

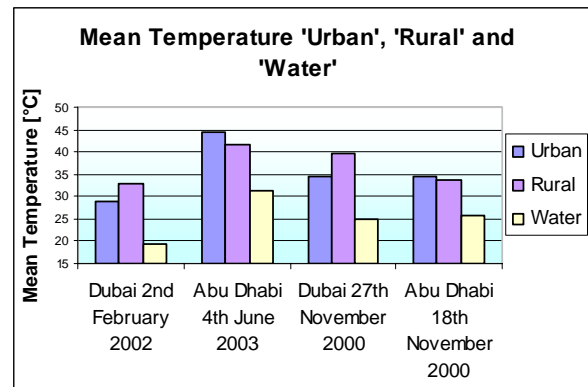


Figure 3. Mean temperatures of 'Urban', 'Rural' and 'Water' classes

Figure 3 shows the mean temperatures of 'Urban', 'Rural' and 'Water' classes. In Dubai the 'Rural' class has because of its large areas of sand higher temperatures than the 'Urban'. In Abu Dhabi the 'Rural' class shows lower temperatures than the 'Urban' class due to the large mangrove and wet sand areas included in that class. Water possesses always the lowest temperatures.

The cities Dubai and Abu Dhabi are daily surface cool islands (UCI) relative to their dry desert environments. Abu Dhabi city shows similar surface temperatures to that of mangrove and mud areas (Frey, 2004).

3.3 Albedo

The desert shows very high albedo values. Particularly in the Dubai scene, human settlements emerge from the natural background with the Central Business District as a low reflection zone. Agriculture and shallow water show similar albedo values like the settlements. Most albedo values do not change greatly between the two scenes of both Dubai and Abu Dhabi. Exceptions are the classes 'Water' and 'Mangrove' in both cities and 'City' only in Abu Dhabi (0.05 to 0.1 in difference).

The lowest albedo is found in the land use class 'Water'. There is a remarkable difference between the classes of Dubai and Abu Dhabi. While in Dubai the mean albedo of water is 0.045, the Abu Dhabi mean albedo is 0.164. The water depth there is quite shallow and high levels of reflection from the sand from the sea basin are visible and increase the water's albedo. Another reason for this is the especially high albedo values on 4th June 2003. Due to the high temperatures during the summer the production of marine phytoplankton must have been stimulated, what on their part helped to increase the waters albedo.

Differences between similar land use classes from both cities are smaller than 0.11. The best matches were the classes 'Residential area' and 'City' in 2000 with a difference of only 0.02. Generally the Abu Dhabi scene shows higher albedo values. These results were expected as in 'tropical semi desert and desert climate' seasonal changes in land cover are not as large as in temperate zones.

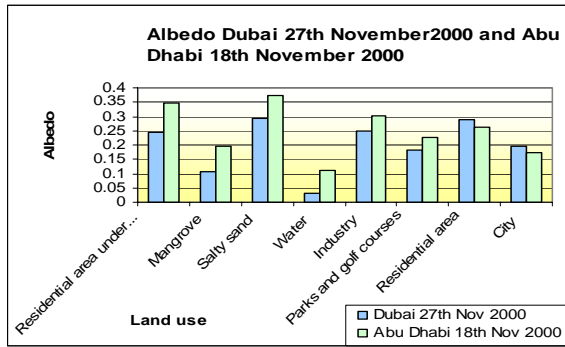


Figure 4. Albedo of Dubai 27th November 2000 and Abu Dhabi 18th November 2000

Urban classes show in all cases a lower albedo than the rural ones. In Dubai the rural albedo is 0.07 higher than the urban albedo, a 77% rise. In Abu Dhabi it is 0.08 higher, a 75% rise. The two cities behave almost identically, contrary to their surface temperature differences. A higher albedo reduces the net radiation and therefore the available energy for the heat fluxes. However, areas with a high albedo also have high surface temperatures, whereas settlement areas with a lower albedo, and thus more available energy, show lower surface temperatures (Frey, 2004).

3.4 Net radiation

Irradiation and counter radiation stay almost the same in all land use classes. The longwave emissions show some variations; particularly in the Abu Dhabi 4th June 2003 scene; net radiation and shortwave reflection have an inverse relationship. Only in the Abu Dhabi 4th June 2003 scene is the smooth relationship between the shortwave reflection and the net radiation disturbed by the longwave emission.

Comparing the two scenes Dubai 27th November 2000 and Abu Dhabi 18th November 2000, the two mean values of 'Water' differ only by 1 W/m². Classes with different characteristics such as 'City' or 'Mangrove' show larger variations (141 and 130 W/m²).

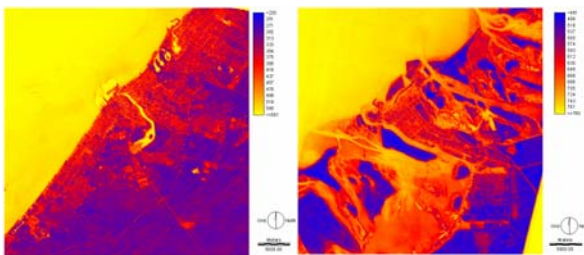


Figure 5. Net radiation [W/m²] of Dubai 2nd February 2002 and Abu Dhabi 4th June 2003

Variations in net radiation between urban and rural classes are mainly due to the sizable differences in shortwave reflection and secondly because of the varying surface temperatures that control the longwave emission. In the rural class the albedo, surface temperature, shortwave reflectance and the longwave emission are higher than in the urban class.

The way the human settlements stand out from their natural terrestrial background is different for cities in temperate zones.

Whilst in these cities and rural sites roughly the same energy is available (Parlow, 1996a), in settlement areas of Dubai and Abu Dhabi more energy has to be processed. The higher net radiation in settlement areas is a result of the high albedo in the desert and the lower albedo in settlement areas. Artificial greening of the city highly strengthens this effect. But even in non-vegetated industrial areas the net radiation is higher than in their surroundings.

Variations in net radiation between urban and rural classes are mainly because of the large difference in shortwave reflection and secondly due to the different surface temperatures that control the longwave emission. In Dubai 2nd February 2002 the difference between urban and rural classes averages to 69 W/m². On 27th November 2000 it is 61 W/m². In the rural class, the albedo, the surface temperature, the shortwave reflectance and the longwave emission are higher than in the urban class. In Abu Dhabi, the difference of net radiation between rural and urban land use classes is 58 W/m² in the 4th June 2003 scene, and 42 W/m² in the 18th November 2000 scene. While shortwave reflection in Abu Dhabi is also higher in rural areas, longwave emission is higher in urban classes due to the aspects discussed in the temperature chapter (Frey, 2004).

3.5 Regression

The implementation of multiple regression analysis for the surface temperatures showed the best regression coefficient r^2 of 0.58 for Dubai and 0.78 for Abu Dhabi. The inputs for the regression analysis were the land use classes, the NDVI and an extra layer showing the distance to the sea. The latter input layer produced very good results, particularly in Abu Dhabi. The water - land distribution is very complex in Abu Dhabi and the surface temperature often changes with leaps. The distance to water therefore provides a good explanation for that distribution.

In the Dubai scene of 2nd February 2002 the surface temperatures could be explained by the distance to sea with an r^2 of 0.33, the scene of 27th November 2000 with an r^2 of 0.30. In the Abu Dhabi scene of 4th June 2003 the surface temperatures could be explained only by the distance to sea factor with an r^2 of 0.48, the scene of 18th November 2000 with an r^2 of 0.50.

Input scenes	Dubai		Abu Dhabi	
	02.02.02	27.11.00	04.06.03	18.11.00
NDVI	0.41	0.35	0.24	0.40
Distance to water	0.33	0.30	0.48	0.50
NDVI + Distance to water	0.47	0.41	0.52	0.61
Land use classes + NDVI + Distance to water	0.58	0.49	0.76	0.78

Table 2

Values of r^2 of NDVI and 'Distance to water' and the land use classes

Together the 'Distance to water' and the NDVI explained the surface temperatures with a correlation of 41 to 61 %. The input of land use classes improved these results even more. In Dubai all land use classes, the NDVI plus the distance to sea layer showed for the 2nd February 2002 scene an r^2 of 0.58, for the 18th November 2000 scene an r^2 of 0.49. In Abu Dhabi the multiple regressions with the NDVI, the 'Distance to water' and the land use classes produced an r^2 of 0.76 / 0.78 (Frey, 2004).

4. CONCLUSIONS

The comparison between the temperature and the net radiation analysis shows that there is no direct relationship between them. The net radiation is firstly controlled by the albedo, secondly by the longwave emission. It provides the available energy for the heat fluxes, but the main controlling factor of the surface temperature is the evaporation, the latent heat flux. The dependence on the latent heat flux is very high. In settlement areas where the net radiation is high, temperatures are lower - due to the vegetation that allows evaporation - compared to desert areas where less energy is available but no water supply feeds the latent heat flux.

The regression of surface temperatures with the NDVI showed that there is a relation between the NDVI and the surface temperatures. Anyhow, the correlation is not so good, that a parameterisation of surface temperatures only from the vegetation index is possible. Input of the 'Distance to water'-layer and the land use classes were necessary to improve the correlation.

The investigations highlighted the importance, especially in an area of hyper-aridity, of vegetation for a more bearable climate. The kind of vegetation, artificially planted or naturally grown does not make a large impact on surface temperatures. The investigations showed the daily urban surface cool island in Dubai. And they showed the daily surface cooling of urban and mangrove areas in Abu Dhabi.

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