Studies of Local Climate Change in United Arab Emirates Using Satellite Data

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ABSTRACT: This paper presents a case study of 10-years of satellite data relating the atmospheric and land surface variables to the desertification in the United Arab Emirates. These studies demonstrate the usefulness of long-term, spatially continuous data sets for studies in the field of global warming. The analysis of the data between 1989 to 1999 shows that the anomalies exhibit a greater degree of variability in the second five year period, 1994-1998 as compared to the 1989-1993 periods. Increase in variability is an indicator of global change. These results should be interpreted as a precursor to a longer and more definitive study.

INTRODUCTION

The global climate is ever evolving. However, global warming does not imply that every point on the surface of the earth has undergone an increase in surface temperature. There is a need to study climate on local spatial scales in order to understand their variability in time. This change would be an integrated effect of natural climate variability and human-induced changes.

Previous studies on feedback between land surface and precipitation have resulted in quantification of this feedback mechanism. Convective precipitation in the HAPEX-Sahel is enhanced by the presence of wet soils (Taylor and Lebel, 1997; 1998). These studies follow observations by Anthes (1984), which demonstrate the connection between vegetation and mesoscale convective activity. A certain pattern of vegetation in semi-arid regions can induce precipitation events due to convection resulting from evapotranspiration. Both sets of studies point to a sustainability of wet soils in semi-arid regions by local convection.

Global change can result in feedback between mesoscale and local systems. Figure 1 demonstrates the translation of regional meteorlogical phenomenon to local hydrology. Changes in precipitation and air temperature on meso-, continental scale affect changes in the local soil moisture and surface temperature. This impacts the availability of water resources for human consumption.

An understanding of these interactions and feedbacks help us evaluate the availability of water resources of the present day as well as forecast for the future.

In order to use satellite data we must ensure that these data sets are unbiased when compared to surface measurements. In reality, the surface data are very difficult to ascertain. Satellite sensors obtain observations at a considerably coarser spatial resolution than ground sensors. When the variables in question contain significant spatial heterogeneity at a scale finer than that of the ground observations, errors in scaling up to the satellite sensor resolution are introduced. Modelers are often forced to interpret observations from a ground network as the average

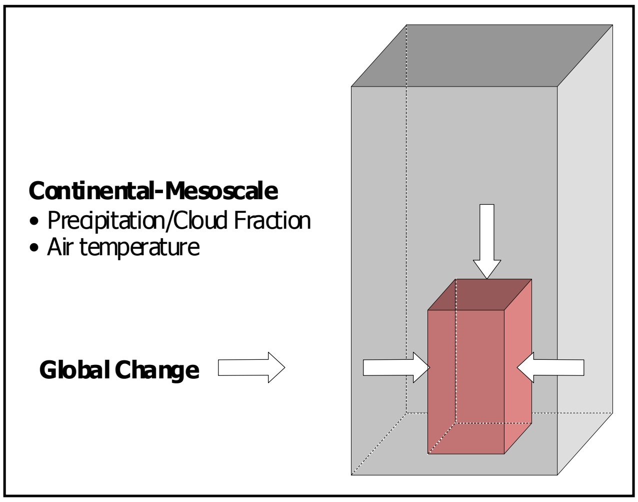

Figure 1. Impact of regional meteorology on local water and energy budgets.

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over the satellite sensor field-of-view, even when such errors are known to exist, due to the lack of more detailed information on spatial behavior. There have been numerous studies comparing land surface variables derived using satellite sensors with surface observations. These include studies over forest canopies (Czajkowski et al., 1997; Prince et al., 1998). Grasslands have been investigated by Prince et al. (1998), Sugita and Brutsaert, (1993), Kalluri and Dubayah, (1995), Goetz et al. (1995), Jin et al., (1997). Other studies over mixed scrub vegetation and trees (Andersen, 1997, Xiang and Smith, 1997, Prince et al. 1998, Lakshmi and Susskind, 2000) and at airports (Lakshmi and Susskind, 1998). These studies carried out detailed analyses of the difference between satellite-derived land surface variables and the ground observations of the same variables over varying climatic regions, spatial extents and time periods. The ground observations are by necessity acquired for small areas, as a part of large interdisciplinary field experiments (Sugita and Brutsaert, 1993; Prince et al., 1998), or routinely observed at airports (Lakshmi and Susskind, 1998).

DATA AND METHODS

The TIROS Operational Vertical Sounder (TOVS) contains two instruments: the High Resolution Infra-Red Sounder (HIRS2) and the Microwave Sounding Unit (MSU). The TOVS has been operated on NOAA satellites from TIROS-N since 1978 to the present. Radiance data from the TOVS has been used to derive surface meteorological variables such as land surface temperature, air temperature, specific humidity, atmospheric profiles of air temperature, water vapor and ozone burden, and cloud fraction and height (Susskind et al., 1997). These variables are calculated separately for each (instantaneous) overpass (230am, 730am, 230pm and 730pm) and gridded to global 1^o X 1^o spatial resolution (land and ocean). The derived variables are aggregated into pentad (5-day) and monthly averages. The air temperature and water vapor profiles are calculated using an initial guess from the Goddard Earth Observing System (GEOS) general circulation model (GCM) as input to a radiative transfer scheme (Susskind et al., 1984). The atmospheric profiles are adjusted so that the channel radiances calculated at the satellite equal observed channel radiances for the cloud free portions of the scene. Canopy air temperature and surface specific humidity are obtained by extrapolating the air temperature and water vapor profiles to the surface pressure. Land surface temperature is calculated directly using observations in the thermal and infrared regions (channels 8, 18 and 19; 11.14µm, 3.98µm, and 3.74µm respectively) and inversion of the Planck function. Surface emissivity values of 0.95 (channel 8) and 0.85 (channel 18, and 19) were assumed for the surface temperature calculations. The atmospheric vapor pressure was calculated using surface specific humidity and surface pressure.

We have used the monthly, 1^o X 1^o, gridded data for our analysis. In order to have a minimum effect of time of observation (230am/pm versus 730 am/pm), we have chosen the period 1989 to 1998 for our analysis. This period has both the morning (730am/pm) and the afternoon (230am/pm) satellite. Therefore, the satellite observations of any two years are identical with respect to each other. Furthermore, we have used monthly averages in our study. The average of all available daily observations for a month has been used to construct a monthly average. The climatological average is subtracted from the monthly value to obtain the anomaly.

Our analysis has focused on three distinct regions in United Arab Emirates (UAE). These are: 23^o - 24^oN, 53^o -54^oE – the coastal region with influence from the Gulf in the form of dews and oil fields (coast + oil fields) 22^o -23^oN, 54^o -55^oE – the inland region without coastal influences and without human intervention (native) 24^o -25^o N, 55^o -56^o E – the foothills of the mountains with runoff influences (mountainous + wet)

The use of three different regions helps in detecting affects of human intervention on changes in the local water and energy budget variables.

RESULTS AND ANALYSIS

Figure 2 shows the variation of precipitation, cloud fraction, surface and air temperature for the three different regions for the 10-year period. The precipitation for the mountainous plus wet region depicted by the green line is larger than the coast plus oil fields and the native regions. This is expected as the mountainous region has a precipitation mechanism dictated by the orography. There are certain months when the native region has a higher precipitation than the mountainous plus wet region. The cloud fraction follows the similar trend to the precipitation. Larger precipitation is accompanied by greater cloud fraction. The surface temperature and air temperature follow similar trends. However, the seasonal range in the surface temperature is 5K larger than that of air temperature.

The trends of anomalies in Figure 3 show similar trends. The mountainous plus wet region shows the largest swing from negative to positive in the cloud fraction as well as precipitation. Anomalies of surface and air temperature are correlated. It is seen that the first 5-year period, 1989 to 1994, has a much

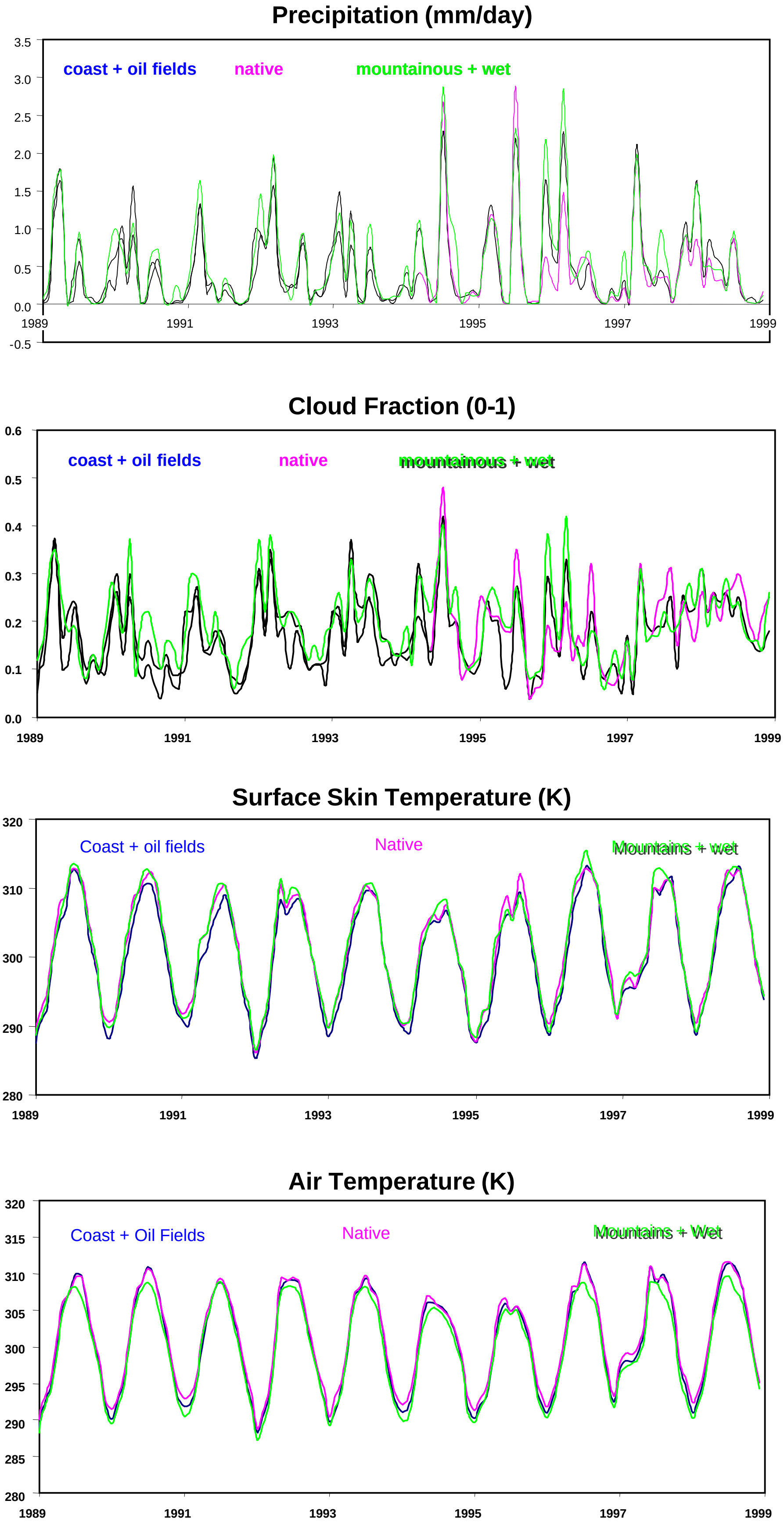

Figure 2. Precipitation, cloud fraction, surface and air temperature for the three regions in United Arab Emirates between 1989 to 1998.

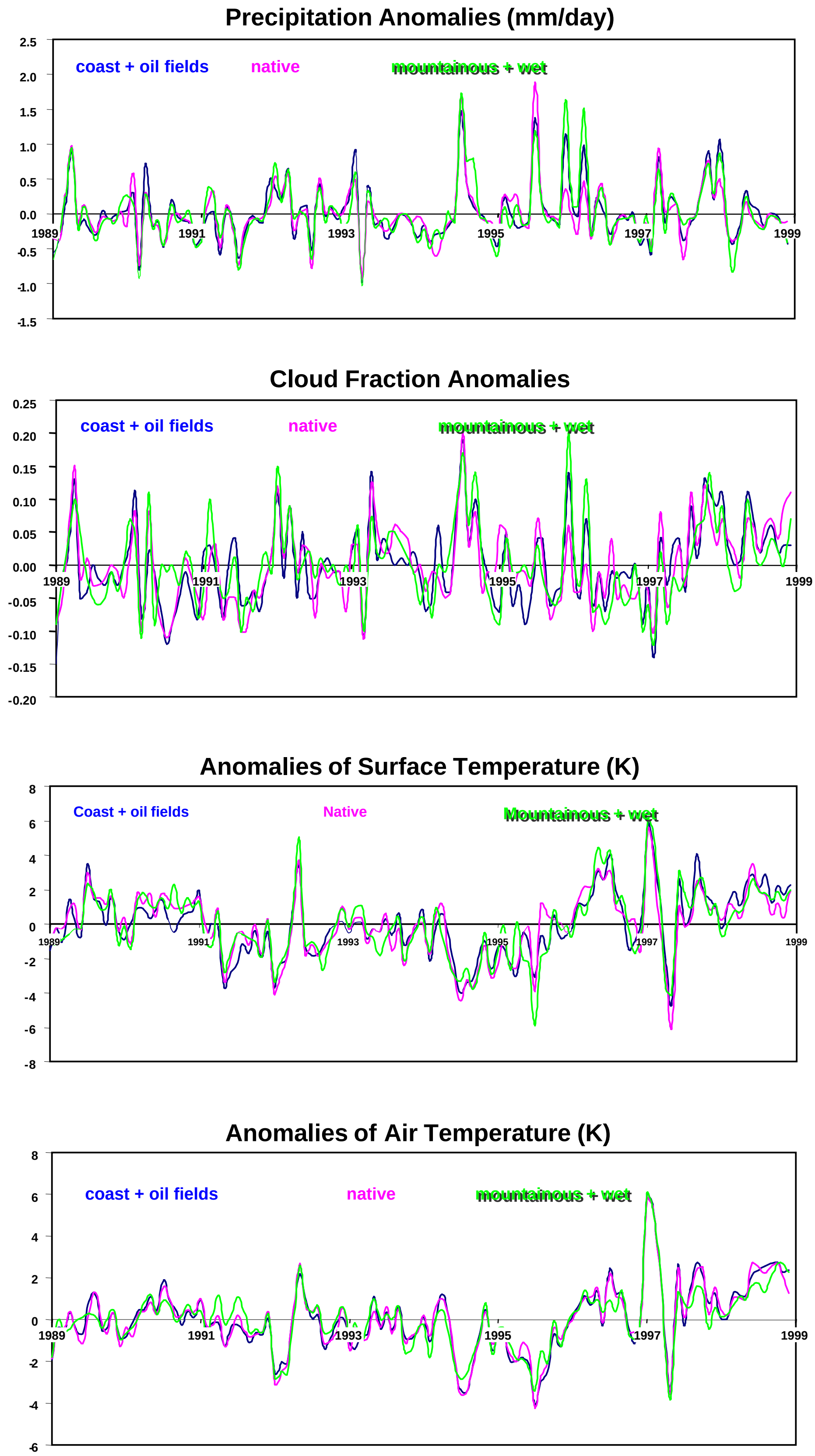

Figure 3. Anomalies of precipitation, cloud fraction, surface and air temperature for the three different regions of the United Arab Emirates for 1989 to 1998.

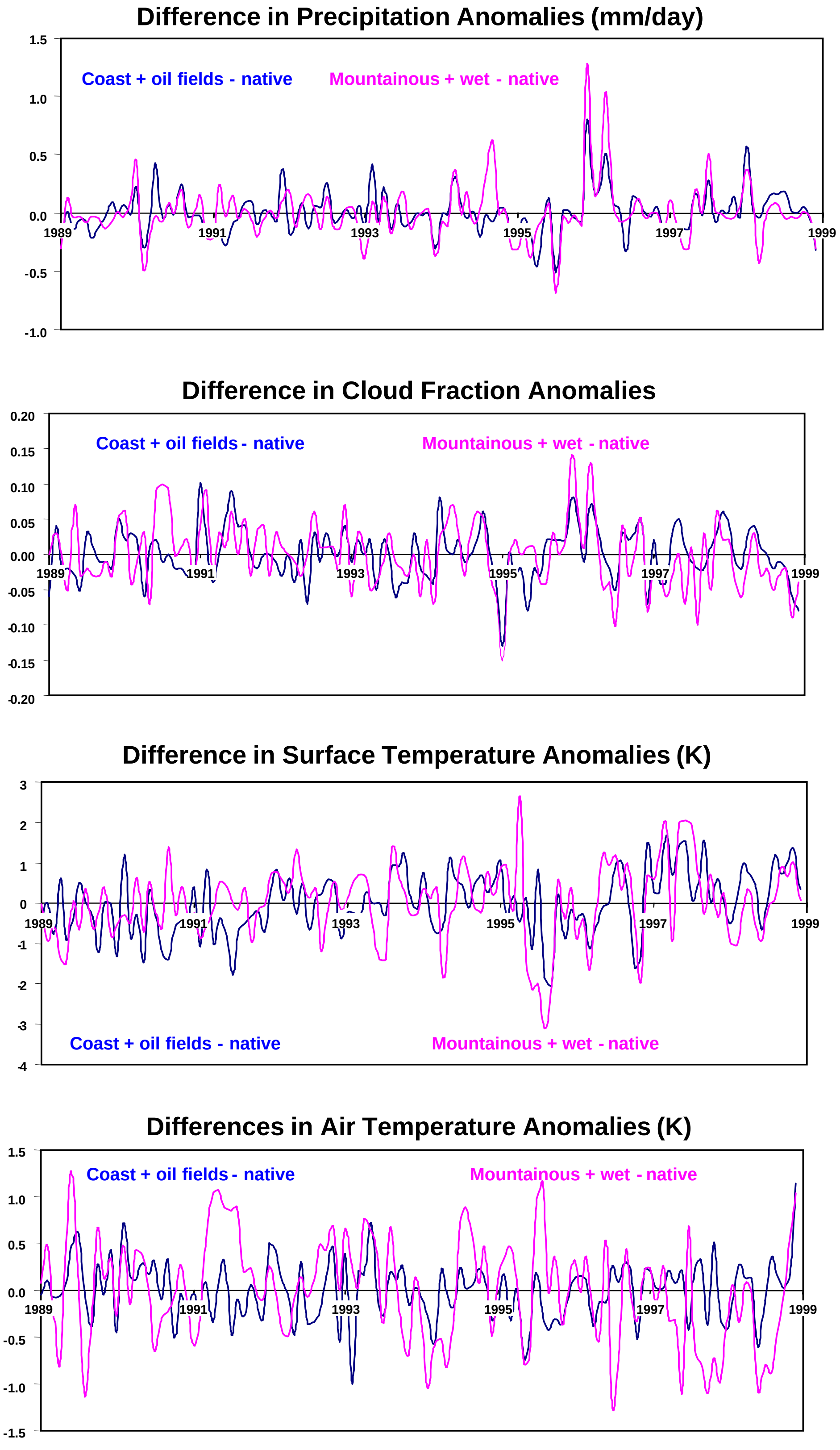

Figure 4. Differences between the coast plus oil fields and native; mountainous plus wet minus native for precipitation, cloud fraction, surface and air temperature for the three regions of United Arab Emirates for 1989 to 1998.

smaller range in anomaly (maximum minus minimum anomaly) compared to the second 5-year period, 1994 to 1998. The range in the precipitation anomaly increases from 1.97 to 2.71 mm/day between 1989 to 1994 and 1994 to 1998. The case for cloud fraction is 0.26 to 0.34, for surface temperature it is 9.01 to 12.08K, for air temperature, and this is 5.66 to 10.29K for the first and the second 5-year period. It is clearly seen that there is an increase in the range of the extremes. Furthermore, in line with our previous observation, the range for surface temperature is greater than the corresponding values of air temperature. This result is along lines of our initial hypothesis that the local response to global change is an increase in the frequency and intensity of extremes.

The difference between the coast plus oil fields and native and the mountainous plus wet minus native anomalies shows and interesting relationship between the different variables. This is depicted in Figure 4. It is seen that the mountainous plus wet region has a larger precipitation anomaly than the native region. This is especially true for the second 5-year period. In addition, the range of these differences (maximum minus minimum) is larger for the second 5-year period than the first 5-year period. This shows similarity to the observation we have made about the range in the anomalies of the precipitation signal. The signal of the difference between the coast plus oil fields and native anomalies of precipitation, shows a smaller range. This observation holds good for the other three variables – cloud fraction, surface and air temperatures.

DISCUSSION AND CONCLUSIONS

This paper outlines a simple study of three different regions and the inter-relationships of the variables for water and energy budgets.

It is our hypothesis based on this study of a 10-year period, 1989 to 1998 of precipitation, cloud fraction, surface and air temperature over three regions in UAE, that there is no definite change in the signal. However, the variability of the anomalies shows a higher degree of variation for the second 5-year period, 1994 to 1998 as compared to the first 5-year period, 1989 to 1994.

The anomalies in these hydrological variables have been studied to understand their trends. Positive anomalies in precipitation indicate wetter than normal season and correspond to a negative anomaly in surface temperature (cooler surface than normal). The heat fluxes are derived using these satellite variables. Sensible heat flux is proportional to the difference between the surface and air temperature. Latent heat flux is proportional to the difference between the saturation vapor pressure corresponding to the surface temperature and the surface vapor pressure. Ground heat flux is proportional to the difference between the surface temperature and the deep soil temperature (derived using minimum air temperature). The temporal variability of the fluxes has given us a very good indication of the changes in the water and energy budgets of the land surface. In other words, the changes in the last 20 years in terms of rearrangement of various heat and energy components – evaporation, precipitation, infiltration, sensible heat and ground heat can be accounted for. This paper harnesses the potential of satellite remote sensing, land surface physics and dynamics using the hydrological cycle and the studies of global change. Technical advances will come in the way of using and interpreting satellite, GCM and reanalyses data, singly or in conjunction with each other to understand the land-atmosphere system.

Further studies will help in defining the amount and consumption of water resources in arid regions. This will involve computing the water and energy budget quantities. The water budget involves calculation of the total precipitation and total evaporation on a monthly or annual basis. The energy budget requires the calculation of incoming and outgoing total radiation and the partitioning into latent, sensible and ground heat fluxes. Understanding how the various quantities in the budget have varied over the past 10 years will allow us to quantify the local affect of global change on UAE.

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