SPATIAL AND TEMPORAL ANALYSIS OF MIDDLE EASTERN TEMPERATURE CHANGES

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Abstract. The intense interest in the greenhouse effect has stimulated detailed studies of temperature records in North America, Europe, and Australia. In this investigation, the temperature records from the Middle East region (defined here as the land area extending from Morocco to Afghanistan) are investigated over the period 1950–1990. Results reveal a linear, statistically significant, temperature increase of 0.07 °C per decade over the study area that may or may not be associated with the concurrent rise in equivalent carbon dioxide from approximately 350 ppm to 430 ppm. Seasonal analyses reveal that most of this increase has occurred in the spring season, moderate amounts of warming occurred in the summer and fall seasons, and virtually no warming has occurred in the winter months. An analysis of spatial controls on these temperature changes reveals a general cooling effect associated with the atmospheric sulfate levels and a warming effect associated with the degree of human-induced desertification. The results of this study may prove useful to policymakers in the Middle East who are confronted with many difficult decisions regarding highly interrelated global warming and energy issues.

1. Introduction

Within the past few years, interest in climate change has increased due to the threat of significant warming from the anthropo-generated emissions of various greenhouse gases (Houghton *et al.*, 1990; 1992). In response to this interest, climate scientists from throughout the world have been analyzing local, regional, and global temperature records. Due largely to the availability of climatic data, much of this recent work at the regional scale has focused on the land air temperature records from North America, Europe, and Australia (e.g., Plantico *et al.*, 1990; Jones, 1991; Karl *et al.*, 1991; Balling and Idso, 1992). These regional studies generally have shown (a) only moderate warming in the period of instrumental records; (b) a relative increase in minimum temperatures when compared to maximum temperatures thereby yielding a substantial decline in the diurnal temperature range; and (c) an increase in cloudiness and precipitation (see Folland *et al.*, 1992). While scientists have attempted to demonstrate a connection between these observed changes and the buildup of greenhouse gases during the same time period, the linkage has been difficult due, in part, to the large natural variability in the climate system (Wigley and Barnett, 1990). Nonetheless, the detailed regional studies in

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North America, Europe, and Australia may be useful to the policymakers in those areas who are dealing with the greenhouse issue.

Despite the many papers published for these three highly-developed regions, surprisingly little research has been conducted on temperature changes in the Middle East. Given the obvious importance of energy and related greenhouse issues to policymakers in the Middle Eastern countries, it seems prudent to conduct relatively detailed analyses of climate change in this large land area of the planet. Accordingly, in this investigation, the recent temperature record for the Middle East region will be analyzed to determine not only the overall temporal trend during recent decades, but also to determine the influences that create spatial differences in the temperature changes observed in the region.

2. Data Requirements

The 'Middle East' may be defined on a variety of physical, social, and/or economic attributes; a review of the many potential definitions of the 'Middle East' lies well beyond the scope of this paper. In this investigation, we define the 'Middle East' as an area from Morocco on the west to Afghanistan on the east and from Turkey to the north to the Arabian Sea on the south (Figure 1). To represent various conditions in this region, four basic data sets are used in our analyses including the following:

1. The primary temperature data used in this study are taken from the gridded dataset prepared by Jones *et al.* (1986). Jones and his colleagues took station-specific temperature records, converted the validated monthly data in departures from normals, and then interpolated the temperature anomalies onto a 5° latitude by 10° longitude grid for the entire globe. The data are widely used in climatic research and are thought to accurately portray regional trends in temperature. Although a total of 25 of these 5° latitude by 10° longitude grid points are within our study area, four of the grid points had a large amount of missing data, and they were eliminated from further consideration. The remaining 21 grid points have temperature records that are over 90% complete during the 1950–1990 study period (Table I).

   Although urbanization may have influenced the station-specific temperatures in the study area, the use of the Jones *et al.* (1986) data largely eliminates the contamination from urban growth. Jones *et al.* (1989; 1990) have shown that these temperature records are not likely to have a century-long warming bias of more than 0.05 °C. In addition, Nasrallah *et al.* (1989) have shown that the heat island effect in this region may be less severe than in other parts of the world.

2. Satellite-based lower-to-mid-tropospheric atmospheric temperature measurements for 2.5° latitude by 2.5° longitude grid cells were collected for the period 1979–1990 (Spencer and Christy, 1990). These temperature measurements are made by a passive microwave sensor system that detects thermal

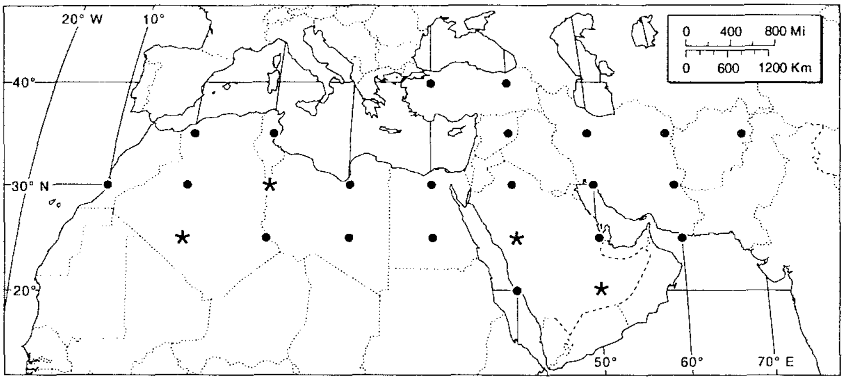

Fig. 1. Map of Middle East region study area; large closed circles are the 21 grid points from the Jones *et al.* (1986) temperature database.

TABLE I: Selected data for grid points used in the analyses

Latitude (°N)	Longitude (°E)	Country	Temperature change (°C/decade)	Desert-ification class	Sulfate ratio
40	30	Turkey	−0.06	1	14.0
40	40	Turkey	−0.08	0	12.0
35	0	Algeria	−0.04	3	6.5
35	10	Tunisia	0.12	3	8.0
35	40	Syria	−0.02	3	9.5
35	50	Iran	0.21	3	8.0
35	60	Iran	0.19	3	7.9
35	70	Afghanistan	0.07	0	7.5
30	−10	Morocco	0.03	0	2.6
30	0	Algeria	0.10	1	4.0
30	20	Libya	0.05	2	8.0
30	30	Egypt	0.03	1	8.0
30	40	Saudi Arabia	−0.09	1	8.3
30	50	Iran	0.09	3	7.4
30	60	Iran	0.18	3	6.0
25	10	Algeria	0.18	2	5.0
25	20	Libya	0.01	1	6.1
25	30	Egypt	−0.08	1	6.2
25	50	Saudi Arabia	0.07	2	6.1
25	60	Iran	0.23	3	4.0
20	40	Saudi Arabia	0.02	2	4.4

emission of molecular oxygen in the middle and lower troposphere. The resultant temperature readings are thought to be accurate to within ± 0.02 °C at the monthly time scale; however, as discussed by Trenberth *et al.* (1992) and Folland *et al.* (1992), these satellite-based lower-to-mid-tropospheric temperature measurements may not fully reflect trends from the near-surface air temperature measurements. The 21 grid cells that contain the 21 Jones *et al.* (1986) grid points were used in this study; there are no missing data over the 1979–1990 time period. The more homogeneous satellite-based temperature records were chosen in this investigation over the upper-air sounding data available in the region.

3. Recognizing that atmospheric sulfate levels could have a localized cooling effect on the temperature trends (Charlson *et al.*, 1990; 1991; 1992), we used the map originally drawn by Langer and Rodhe and reproduced by Watson *et al.* (1990) showing concentrations of sulfate at 900 hPa. The actual values used in this study are ratios of concentrations based on total emissions (natural and anthropogenic) divided by concentrations based on natural emissions. The spatial pattern shown on the map used in this study is quite similar to the spatial pattern of Charlson *et al.*'s (1991) global map of reflected flux to space due to tropospheric sulfate aerosols derived from anthropogenic sources. Although the sulfate ratio values do not reveal trends through our 1950–1990 study period, the results of Hameed and Dignon (1988) show an increase in sulfur dioxide emissions in the Middle East between 1966 and 1980. In our Middle Eastern study area, the sulfate ratios range from 14.0 in western Turkey to 2.6 in Morocco (Table I).
4. Balling (1991) has shown empirically that the severity of human-induced desertification can produce a statistically significant regional warming signal. In addition, a recent numerical modeling study by Franchito and Rao (1992) also showed a distinct warming effect associated with desertification. In order to represent the severity of human-induced desertification at each of the 21 Middle Eastern grid points, a map prepared for the United Nations by Dregne (1977) was employed. Only three of the 21 grid points are in no desertification class, six are in the 'slight' category, four are in the 'moderate' class, and eight are found in Dregne's 'severe' desertification class (Table I). Although the Dregne map is far from perfect in depicting conditions in the mid-1970s, we assume that the spatial pattern in desertification classes is a crude surrogate for trends in desertification that may have occurred during our 1950–1990 study period.

3. Analyses and Results: Temporal Patterns

A plot of raw and smoothed mean monthly temperature anomalies for the Middle East region for the period 1950–1990 is presented in Figure 2. The plot clearly shows high intermonthly variance with an underlying, statistically significant (0.95 level of confidence) linear trend of +0.07 °C (± 0.05 °C) per decade. The linear trend was established using a simple regression model with time as the independent variable and the monthly temperature anomaly as the dependent variable. Although the plot reveals some cooling from approximately 1960 to the mid-1970s and warming from the mid-1970s to the present, second- and third-order poly-

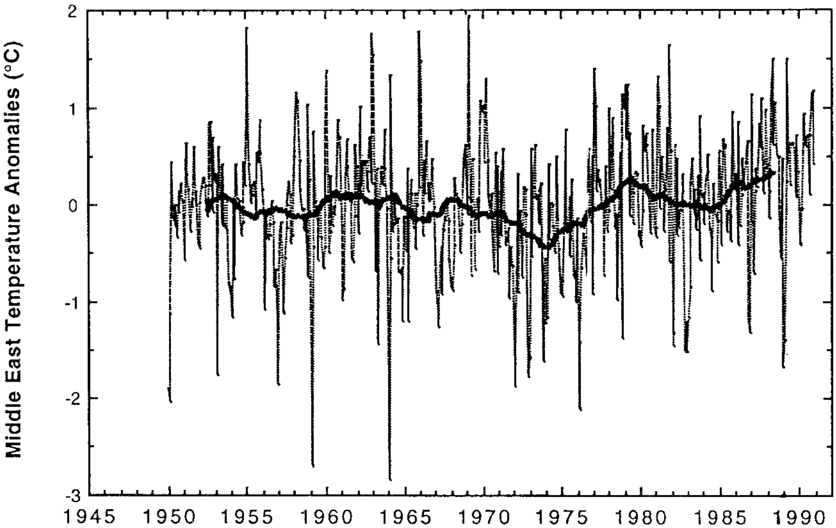

Fig. 2. Middle East region mean monthly temperature anomalies and 5-year smoothed anomaly values for the period 1950–1990; data are from an updated Jones *et al.* (1986) time series.

nomial curves did not statistically significantly increase the variance explained by the linear fit. Recognizing that the high inter-monthly variance could account for the lack of statistically significant improvement in the fit of higher-order polynomials, similar analyses were conducted on the annualized temperature values (Figure 3). In this case with annual data, the linear trend was +0.07 °C (± 0.09 °C) per decade and was not found to be statistically significant; again, higher-order polynomial curves did not significantly improve on the explained variance.

On a seasonal basis, winter months (DJF) showed a warming of 0.01 °C per decade, spring (MAM) warmed 0.13 °C per decade, summer (JJA) showed a temperature increase of 0.08 °C per decade, while the autumn months (SON) warmed 0.05 °C per decade. The summer and spring seasons were warming at a statistically significant rate, while the warming rates in the autumn and fall seasons were not statistically significant.

The observed linear warming on an annual basis of 0.28 °C during the 1950–1990 time period occurred as the global atmospheric concentration of equivalent carbon dioxide (CO_2 levels plus the effect of other anthropogenic greenhouse gases expressed in carbon dioxide equivalents) increased from approximately 350 ppm to 430 ppm (Houghton *et al.*, 1990, p. xx; Balling, 1992). Because investigators have been unable to confidently link the *global* temperature rise to the buildup of greenhouse gases (e.g., Wigley and Barnett, 1990), it is unreasonable to conclude that the regional temperature rise in the Middle East is directly caused by some greenhouse effect. Nonetheless, the Jones *et al.* (1986) temperature record certainly shows statistically significant warming in the Middle East in this 41-year period; the bulk of this warming was occurring in the spring and summer seasons.

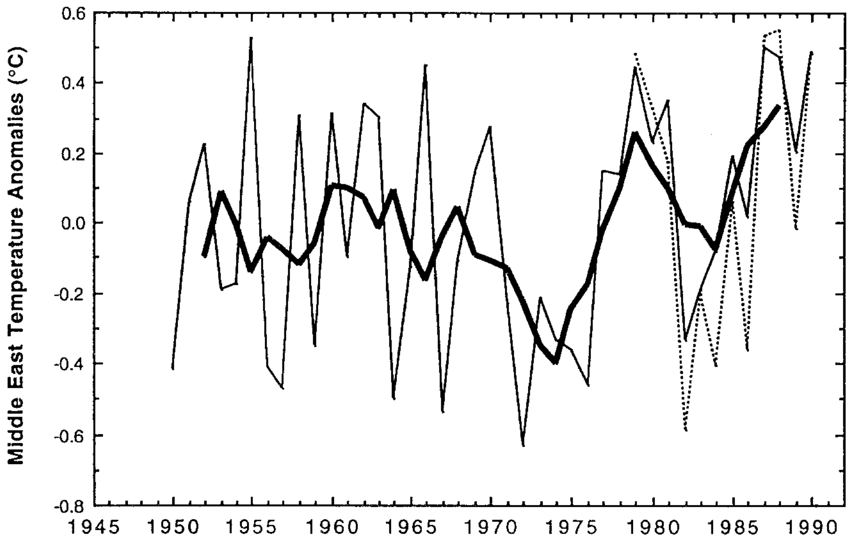

Fig. 3. Middle East region mean annual temperature anomalies (thin solid line) and 5-year smoothed anomaly values (solid thick line) for the period 1950–1990 from an updated Jones *et al.* (1986) time series. Satellite-based temperature anomalies (dashed line) are for the period 1979–1990 (from Spencer and Christy, 1990).

The satellite-based temperature record of Spencer and Christy (1990) was used as a check of the quality of the Jones *et al.* (1986) temperature data for the region. The correlation between the two area-averaged datasets was 0.72 on a monthly basis and 0.94 at the annual time scale. In addition, linear trend for the 1979–1990 period was +0.02 °C per year for both data sets. These results suggest that the Jones *et al.* (1986) data are adequately capturing the temperature patterns in the Middle Eastern region.

4. Analyses and Results: Spatial Patterns

The goal of this investigation was to not only examine the temporal trend in temperatures in the Middle East region, but also to analyze the spatial controls of any changes in temperature. To perform such an analysis, a new matrix was constructed containing 21 rows, one for each 5° latitude by 10° longitude grid points, and eight columns including latitude, latitude squared, longitude, longitude squared, the product of latitude and longitude, the sulfate ratio, the Dregne desertification category, and the change in temperature (Table I).

A stepwise multiple regression analysis was conducted on the annual and seasonal basis with the linear temperature change variable ($\Delta T/\Delta$decade) as the dependent variable. Independent variables could be added to the regression equations only if (a) the variable statistically significantly improved on the predictability of $\Delta T/\Delta$decade; (b) the variable was not statistically significantly related to other predictors already in the equation; and (c) the variable's regression coefficient was statistically significantly different from zero. The resulting equation for the annual data took the form:

$$\Delta T/\Delta\text{decade(Annual)} = 0.074 + 0.046(\pm 0.032) \times \text{Desert} \\ - 0.014(\pm 0.013) \times \text{Sulfate} \quad (1)$$

where 'Desert' represents the Dregne desertification class, and 'Sulfate' represents the sulfate ratio. The multiple R value equals 0.66 implying that 44% of the spatial variance in the $\Delta T/\Delta$decade values can be explained by these two independent variables (the correlation between the two predictor variables is −0.01). The Durbin-Watson statistic for the equation equals 1.98 showing no significant autocorrelation in the residual series. Finally, the standardized beta coefficients for Desert and Sulfate variable are 0.52 and −0.37, respectively.

Interpretation of the resulting multiple regression equation is relatively straightforward. The standardized beta coefficients imply that the level of desertification is the most important spatial control of the linear temperature change in the region followed by the sulfate ratio variable. The sign of the regression coefficients shows that, as expected, (a) warming tends to occur in areas with the higher desertification classes; and (b) higher sulfate loadings are associated with a cooling effect.

The positive relationship between $\Delta T/\Delta$decade is quite consistent with the findings of Balling (1991) who showed that around the globe, human-induced desertification tends to be associated with differential warming; the warming effect appears to be related to decreased soil moisture in overgrazed areas. The cooling effect associated with the higher sulfate ratios is very consistent with the findings of Charlson *et al.* (1990; 1991; 1992) who showed that increased atmospheric sulfate levels can act to reflect incoming solar radiation, brighten existing clouds, and lengthen the life-span of existing clouds.

On a seasonal basis, no statistically significant linkage could be determined between $\Delta T/\Delta$decade and the independent variables in the winter and spring seasons. However, in the summer months, a regression equation was determined as:

$$\Delta T/\Delta\text{decade(JJA)} = -0.071 + 0.088(\pm 0.078) \times \text{Desert} \quad (2)$$

where the R value equals 0.46, the standardized beta coefficient for 'Desert' equals 0.46, and the Durbin-Watson statistic equals 2.48 thereby indicating no autocorrelation in the residuals. In the autumn season, a regression equation was determined as:

$$\Delta T/\Delta\text{decade(SON)} = 0.173 + 0.069(\pm 0.046) \times \text{Desert} \\ - 0.035(\pm 0.020) \times \text{Sulfate} \quad (3)$$

where the multiple R value equals 0.75, the standardized beta coefficient for 'Desert' and 'Sulfate' equals 0.47 and −0.56, respectively, and the Durbin-Watson statistic equals 1.98 again indicating no autocorrelation in the residuals. These seasonal analyses reconfirm the results obtained for the annual data. In each case, statistically significant regression coefficients continue to show empirically the cooling effect of sulfates and the warming effect of desertification in the region.

5. Conclusions

As the interest in the global warming issue grows, scientists will continue to analyze local, regional, and global temperature records. In this investigation, temperatures from the Middle Eastern region are analyzed both temporally and spatially. Our results show a linear warming of near 0.07 °C/decade across the Middle East for the period 1950–1990; greatest warming is occurring in the spring season and the least amount of warming is occurring in the winter season. Analyses of spatial patterns of temperature changes reveal a statistically significant impact of both desertification and atmospheric sulfate loading. The severity of desertification is positively related to the linear change in temperature while the sulfate loading is negatively related to temperature change over the 1950–1990 period.

The results show that the Middle East region is warming during a time of an exponential rise in various greenhouse gases; the degree of causal linkage between the two is unknown at this time. However, the increase in these regional temperatures is statistically significant, and may well continue to occur in the immediate future. Policymakers in the Middle East should be aware of the facts presented in this study as they proceed with their deliberations regarding highly interrelated energy and global warming issues.

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