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The spatial and temporal variability of aerosol optical depths in the Mojave Desert of southern California

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Abstract

The Mojave Desert of southern California is under constant pressure from anthropogenic influences on atmospheric pollutants and land management. Previously, the spatial, temporal, and source characteristics of aerosols over the Mojave Desert have been examined using in situ observations; however, in situ observations lack spatial coverage, and the only long-term measurements of aerosol optical depth (AOD) needed for aerosol impact studies on the local climate and biota is the AERONET site at Rogers Dry Lake. In this study, we provide the first moderately high spatial resolution (17.6×17.6 km^2) study of AOD over the Mojave Desert of southern California using satellite data from the Multi-angle Imaging SpectroRadiometer (MISR) for the period of March 2000 to October 2005. We have demonstrated the seasonality of AOD over the entire Mojave Desert, and the spatial and temporal variability of AOD from the average AOD at national parks, military installations, and dry lakes and playas. Statistically significant differences from the Mojave Desert mean AOD can be attributed to proximity to urban sources (e.g., Rogers Dry Lake is near the Los Angeles metropolitan area) and local sources (e.g., mineral extraction at Bristol Dry Lake). The western Mojave, generally around Rogers Dry Lake and Harper Dry Lake exhibited the most sustained pattern of seasonally high aerosol optical depths throughout the year. As a result, the AERONET site at Rogers Dry Lake should not be used as a site representative of the aerosol conditions over the entire Mojave Desert of southern California.

Keywords: Aerosol optical depth; Mojave Desert; MISR

1. Introduction

The ecosystem of the Mojave Desert of southern California is constantly under threat because of anthropogenic influences on atmospheric pollutants and land management (e.g., Hunter et al., 2003; Lovich & Bainbridge, 1999). The amount of dust and other particulate matter has been shown to be increasing, where approximately one half of the current atmospheric dust is estimated to be anthropogenic in origin as a result of soil degradation by agriculture, overgrazing, and deforestation (Miller & Tegen, 1998). The impact of aerosols, both anthropogenic and natural, are of particular concern because of their role in degrading visibility, in reducing sunlight at the surface and the resultant consequences on the local climate and biota, and in the health of the local inhabitants. The spatial, temporal, and source characteristics of aerosols over the Mojave Desert have been examined using in situ observations (e.g., Green, 1992; Reheis & Kihl 2002; Trijonis et al., 1987). However, in situ observations lack spatial coverage, and the only long-term measurements of aerosol optical depth (AOD) needed for aerosol impact studies on the local climate and biota is the AERONET site (Holben et al., 1998) at Rogers Dry Lake. In this study, we provide the first moderately high spatial resolution (17.6×17.6 km^2) study of AOD over the Mojave Desert of southern California using satellite data from the Multi-angle Imaging SpectroRadiometer (MISR) for the period of March 2000 to October 2005. The MISR data are described in Section 3 and the results of our analysis are shown in

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Section 4. Some of the spatial and temporal characteristics observed in the MISR AOD data are similar to the spatial and temporal characteristics found in surface-based estimates of aerosol concentrations (or related measures of aerosol concentration) reported in the literature, which are reviewed in Section 2. In addition, we take advantage of the spatial coverage from MISR and relate the spatial characteristics of AOD as a function of season to local sources. Further discussions on the results are given in Section 5.

2. The Mojave Desert

The Mojave Desert of southern California covers approximately 73,880 km^2 in areal extent (Fig. 1). The Mojave Desert is surrounded on the north by the Sierra Nevada range, on the west by the Tehachapi and San Gabriel mountains, and to the south by the San Bernardino and Little San Bernardino mountains. These imposing mountains alter local wind patterns and intercept moisture derived from the Pacific Ocean, producing a rain-shadow effect and arid conditions on the lee side of the mountains. Within this part of the Mojave Desert, approximately 75% of the desert is under federal ownership, with 10% of that under the Department of Defense, 21% in national parks, and 44% managed by other federal agencies, primarily the Bureau of Land Management. The remainder of the desert land is under control of state entities (3%), and private ownership (22%). Historically, this region has been used for military training, off-highway recreation, and cattle grazing (Lovich & Bainbridge, 1999). These activities tend to reduce the amount of vegetation cover and create potential sources for mineral dust in the atmosphere. Dust mobilization is extremely sensitive to a range of factors that include the composition of soils, moisture content, disturbance of the surface, and wind velocity (e.g., Reheis & Kihl, 2002).

The Mojave Desert contains a large number of features that are potential sources of mineral dust (Figs. 1 and 2). In the east-central part of the Mojave Desert are Death Valley National Park and the Mojave National Preserve, both of which contain large deposits of mineral salts and fine alluvial sediments within playas at Badwater Basin and Soda Dry Lake. Larger particles in sand dunes can be found at Mesquite Flat and Kelso Dunes. In the southeast, Cadiz Valley contains large playas at Bristol Dry Lake, Cadiz Dry Lake, and Danby Dry Lake. There are additional sand dunes further south and east.

Dust mobilization from these sources can occur naturally by way of wind or through human activities. Of the dust mobilization caused by wind in the continental U.S., approximately 65% of the dust flux is due to dust devils or larger scale convective plumes (Gillette & Sinclair, 1990). In the desert southwest, dust mobilization from dust devils and large convective plumes is largest during the late morning through later afternoon hours between May and July (e.g., Metzger, 1999; Snow & McClelland 1990).

There are many human factors that may cause dust mobilization. For example, Bristol Dry Lake is an active mineral extraction site where bulldozers plow mineral salts into piles for drying and extraction. There is approximately 196 km^2 of off-road recreational areas at Johnson Valley, Rice Valley Dunes, Jawbone Canyon, Rasor, Dumont Dunes, Spangler, Dove Springs, El Mirage, Olancha and Stoddard Valley. Of particular interest are the four large military installations found within the Mojave Desert of southern California. They are the National Training Center at Ft. Irwin, China Lake Naval Weapons Facility, Edwards Air Force Base, and the Marine Corp Air Ground Combat Center. The National Training Center and the Marine Corp Air Ground Combat Center are training facilities where tracked and wheeled vehicles routinely drive through the open desert, contributing to mineral dust in the atmosphere (Anderson et al., 2005).

Another significant source of aerosols and other pollutants in the Mojave Desert comes from airflow from the Los Angeles Basin, primarily through passes at Soledad Canyon and Cajon Pass, and from the San Joaquin Valley through Tehachapi Pass (e.g., Green, 1992; Pryor et al., 1995; Rosenthal et al., 2003; Smith et al., 1997; Trijonis et al., 1987). Many of these aerosols and pollutants are anthropogenic in origin, ranging from industrial pollutants from the Los Angeles Basin to agricultural pollutants from the San Joaquin Valley. They have been blamed for the century-long deterioration in visibility over a large part of the Mojave Desert including Federal Class I air quality areas, such as Joshua Tree National Park, as well as several military installations (Smith et al., 1997; Trijonis et al., 1987). The meteorological conditions that lead to the seasonally and diurnally varying wind patterns causing the transport of aerosols and other pollutants into the Mojave Desert are well described in Green (1992) and Rosenthal et al. (2003).

3. MISR AOD data

MISR is onboard the EOS-Terra spacecraft orbiting the Earth at a nominal altitude of 705 km. The orbit is sun-synchronous with a descending node equator crossing time of ~10:45 a.m. LST. The MISR Level 2 aerosol product reports regional mean aerosol optical depths at 17.6 km × 17.6 km resolution over the ~380 km swath of each MISR orbit (Martonchik et al., 2002). We used the 558 nm regional mean AOD for the period ranging from March 2000 to October 2005. The MISR 558 nm regional mean AOD has been extensively validated over desert regions. Martonchik et al. (2004) and Christopher and Wang (2004) found that the MISR AOD falls within ±0.07 of coincident AERONET values at sites over desert locations in Africa and China. The only AERONET site over the Mojave Desert is at Rogers Dry Lake. AERONET AODs from this site have been compared to Version 12 of the MISR regional mean AODs by Kahn et al. (2005) and Liu et al. (2004). Both these studies show that MISR overestimates the AOD relative to AERONET by ~0.04.

Because of the reprocessing schedule of the MISR Level 2 aerosol product that takes place at the Atmospheric Sciences Data Center at the Langley Research Center, Versions 15, 16, and 17 were available for different periods between March 2000 and October 2005 at the time our analysis took place. The

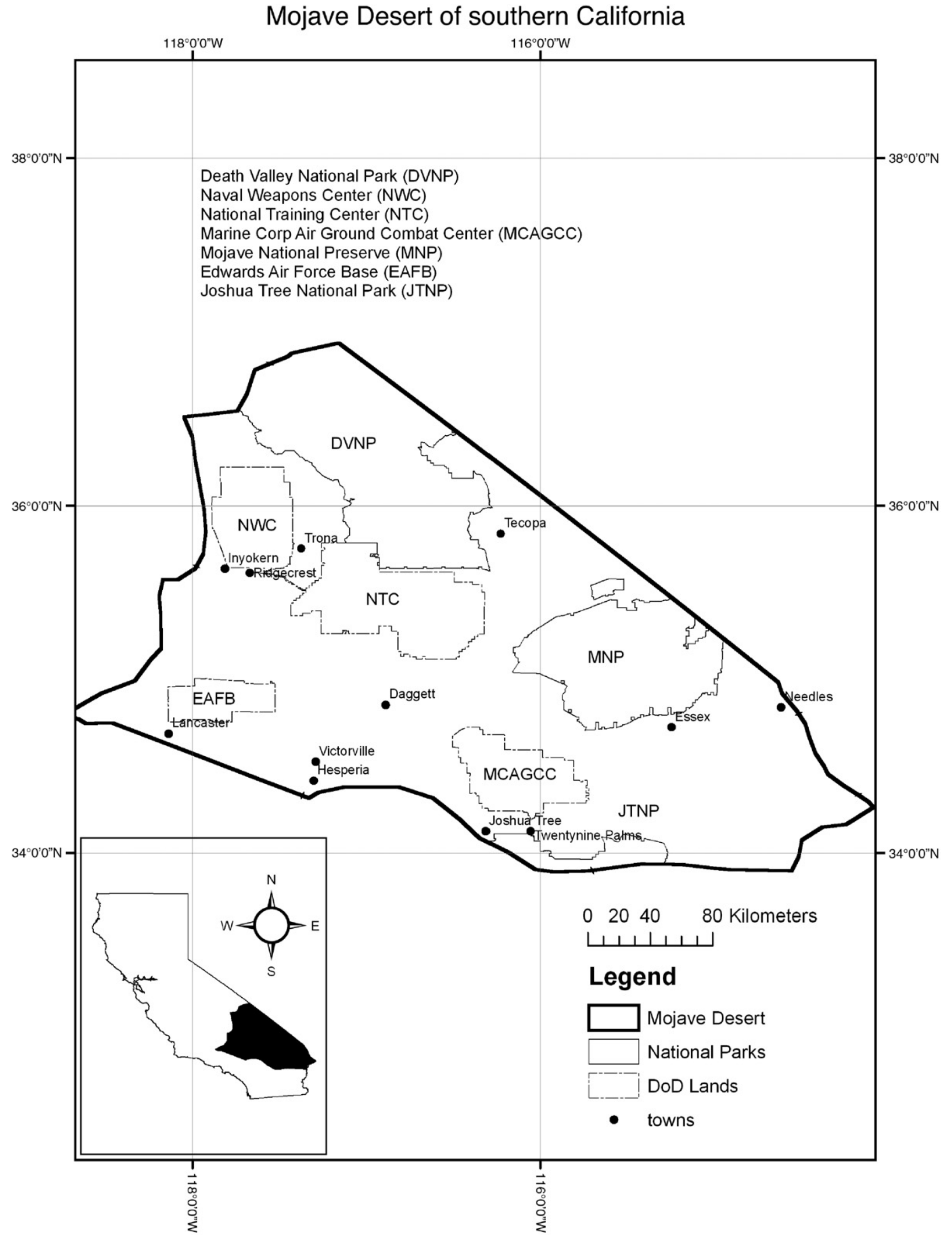

Fig. 1. The Mojave Desert of southern California and the location of study sites (towns for reference only) for the analysis of MISR aerosol optical depths.

changes made from one version to the next can be found at http://eosweb.larc.nasa.gov. The only changes that would impact the results of this study are changes in the ancillary files that contain the aerosol particle properties used in the MISR AOD retrieval. To verify the impact that this may have on our analysis, we have compared the MISR AOD from the later versions of the software to the AERONET AOD values for Rogers Dry Lake for mean monthly AOD, as shown in Fig. 3. The number of AERONET observations per month vary widely by month and year, as do the number of MISR scenes used to construct the AOD imagery, so there will be some random differences associated with the observation frequency.

However, a clear bias is observed in Fig. 3, with a mean bias ∼0.04 across all months, with MISR reporting higher aerosol optical depths than was measured from AERONET. When stratified by version, the mean biases for Versions 15, 16, and 17 are 0.04, 0.03, and 0.03, respectively. Thus, the differences in the quality of the MISR 558 nm regional mean AOD between versions are small, with results similar to those found in Kahn et al. (2005) and Liu et al. (2004). However, if the bias depends on aerosol type, and the type of aerosol varies seasonally (below the AOD is shown to be seasonal), then any analysis of seasonal

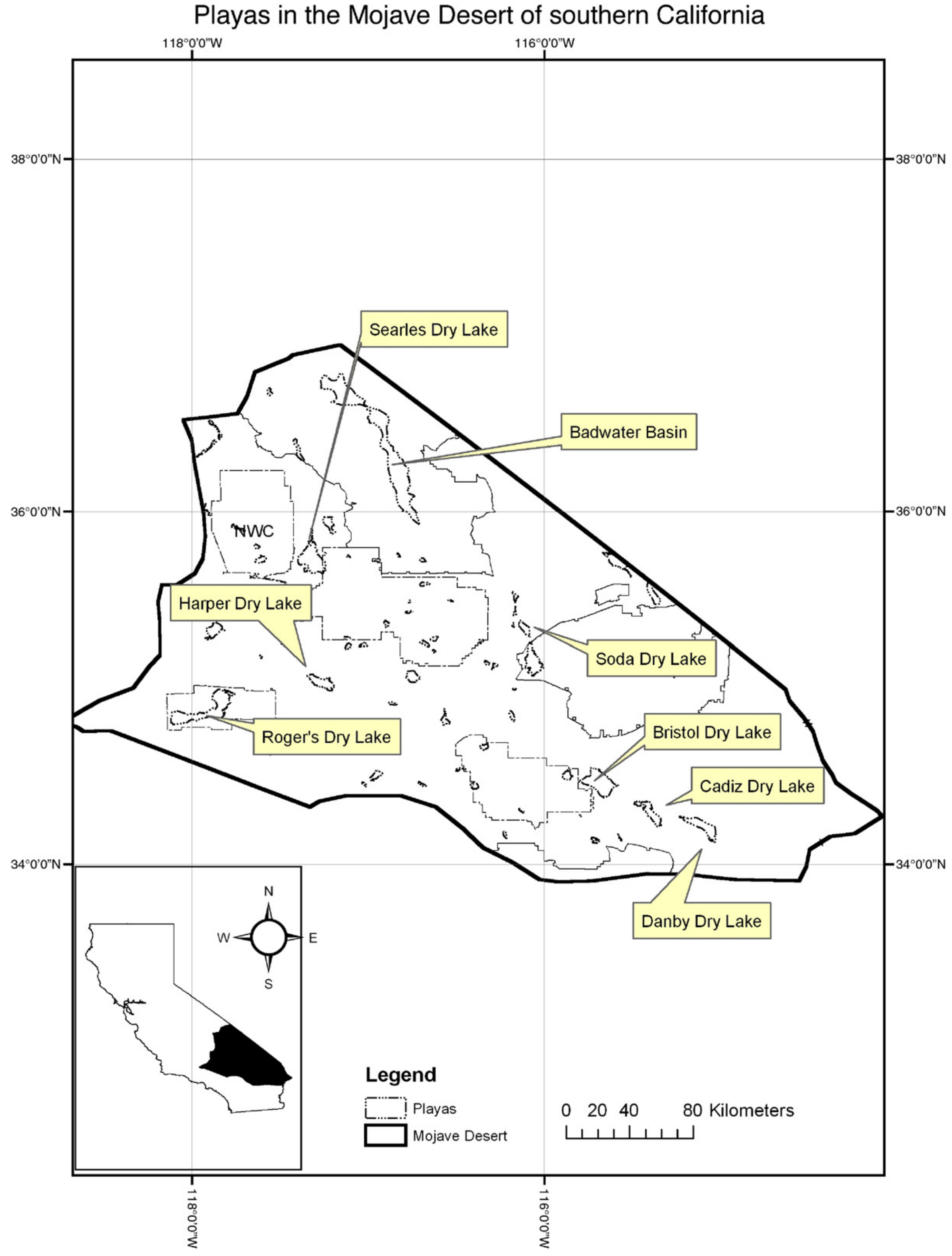

Fig. 2. Location of major playas in the Mojave Desert of southern California.

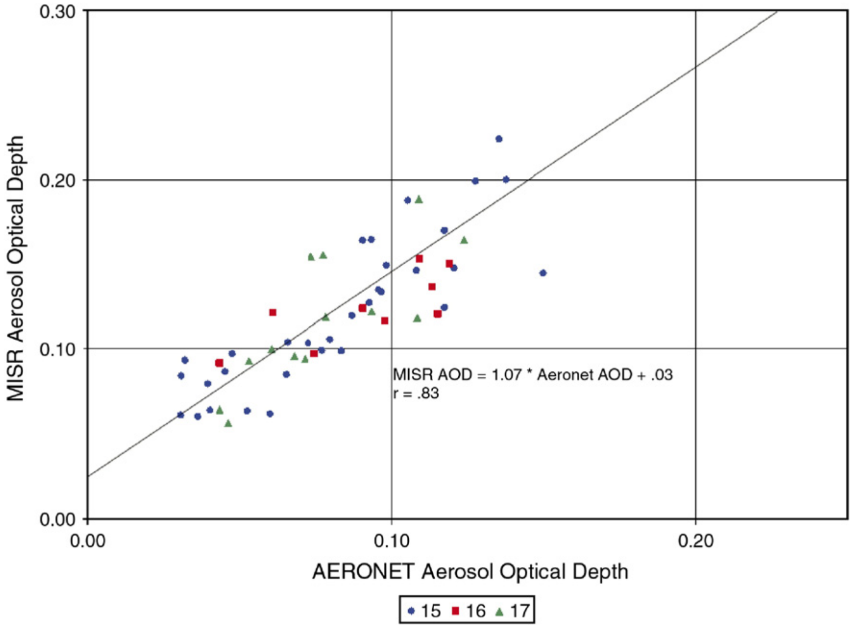

Fig. 3. Mean monthly MISR and AERONET aerosol optical depths were averaged from March 2000 through October 2005 at Rogers Dry Lake, California. MISR versions included 15, 16, and 17, which are differentiated by symbol and color.

cycle of AOD must take this into account. Fig. 4 shows the mean monthly AOD averaged over our 6-year period. The figure shows that the bias is not seasonally dependent.

4. Results

The average 558 nm AOD in the southern California region of the Mojave Desert was calculated for each month from March 2000 through October 2005 (Table 1). The orbital characteristic and swath width of MISR allows for only four or five overpasses per month for any 17.6 × 17.6 km^2 region in the Mojave Desert, not all of which have AOD values due to, for example, cloud cover.

Averaged over the entire Mojave Desert of southern California and time period of this study, the mean AOD was 0.10 with a standard deviation of 0.04. Fig. 5 shows the mean monthly AOD as a function of time, revealing a clear seasonal pattern with higher AOD values during the spring and summer months, and lower AOD values during the winter months. This is also reflected in Fig. 4. The same seasonal pattern has been observed in surface-based estimates of aerosol concentration (or other related measures of aerosol concentration) and other

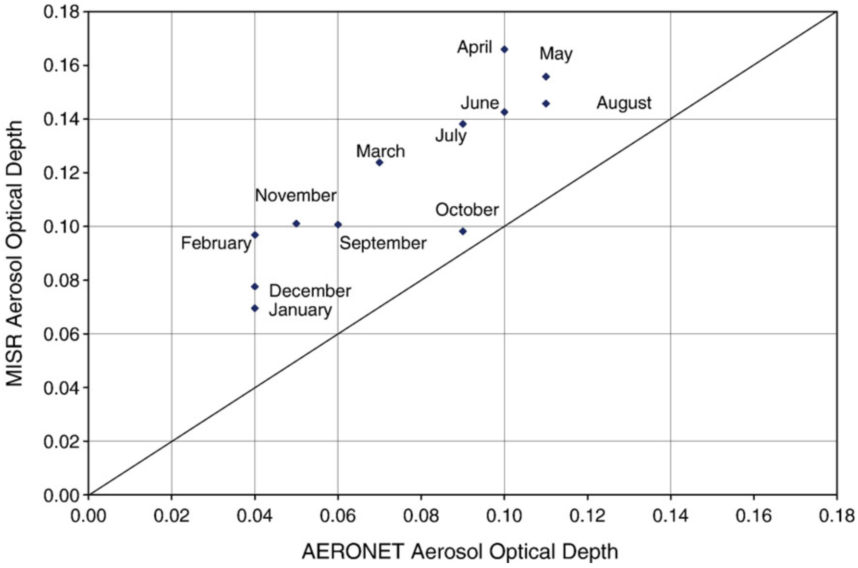

Fig. 4. Mean monthly aerosol optical depths at Rogers Dry Lake AERONET site and MISR mean monthly aerosol optical depths were averaged over 6 years of data from 2000 to 2005. The average AOD difference was .04.

Table 1
Inter-annual variability of mean monthly aerosol optical depth for the Mojave Desert of southern California derived from MISR from March 2000 to October 2005

Year	January	February	March	April	May	June	July	August	September	October	November	December
2000			0.10	0.12	0.14	0.12	0.19	0.10	0.08	0.06	0.04	0.03
2001	0.08	0.07	0.11	0.17	0.18	0.13	0.12	0.13	0.08	0.07	0.07	0.02
2002	0.02	0.05	0.09	0.13	0.12	0.11	0.15	0.16	0.08	0.07	0.03	0.04
2003	0.04	0.05	0.08	0.12	0.16	0.15	0.14	0.12	0.08	0.06	0.04	0.03
2004	0.03	0.06	0.08	0.15	0.13	0.12	0.12	0.11	0.08	0.06	0.04	0.04
2005	0.06	0.08	0.11	0.17	0.15	0.15	0.15	0.13	0.07	0.07	N/A	N/A
Mean	0.05	0.06	0.10	0.14	0.15	0.13	0.15	0.13	0.08	0.07	0.04	0.03
SD	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.00

ground-level atmospheric pollutants (e.g., Green, 1992; Metzger, 1999; Rosenthal et al., 2003), as well as in the "absorbing aerosol index" of the Total Ozone Mapping Spectrometer satellite dataset (Prospero et al., 2002). This seasonality is largely explained by the seasonality in atmospheric motions over the region. During the spring and summer months, weather conditions are generally dominated by flow from high pressure located over the Pacific towards a thermally generated low pressure over the desert interior, bringing pollutants from the Los Angeles Basin and San Joaquin Valley into the Mojave Desert (Section 2). In addition, these are also the seasons when dust mobilization due to dust devils, larger convective plumes, and high wind speeds is at its highest (Section 2). However, during the winter, synoptic conditions are more variable, winds speeds are at their lowest, and deep convective plumes are much less frequent (e.g., Cover et al., 1989; Green, 1992; Rosenthal et al., 2003).

The seasonality of mean monthly aerosol optical depths apparent in Fig. 5 led to an analysis of mean seasonal aerosol optical depths. Further interpretation of Fig. 5 (or Table 1) in terms of year-to-year variability for a given month is difficult given the small differences observed for most months, the sampling errors that arise (but difficult to quantify) due to the small number of overpasses per month, and any artifacts (albeit small in our case) caused by using different versions of MISR aerosol product for different time periods. To avoid such problems, MISR mean monthly aerosol optical depths were averaged over the 6 years of data for fall (September, October, November), winter (December, January, February), spring (March, April, May), and summer (June, July, August). The Mojave Desert exhibited higher means ($\bar{x}$) and standard deviations (σ) during the spring ($\bar{x}=0.11$, $\sigma=0.05$) and summer seasons ($\bar{x}=0.12$, $\sigma=0.05$), and lower values during the fall ($\bar{x}=0.06$, $\sigma=0.03$) and winter ($\bar{x}=0.04$, $\sigma=0.03$) (Table 2). Edwards Air Force Base stands out with high mean values during all four seasons, where the other military installations only had high mean values during the spring and summer. The Mojave National Preserve and Death Valley showed the same

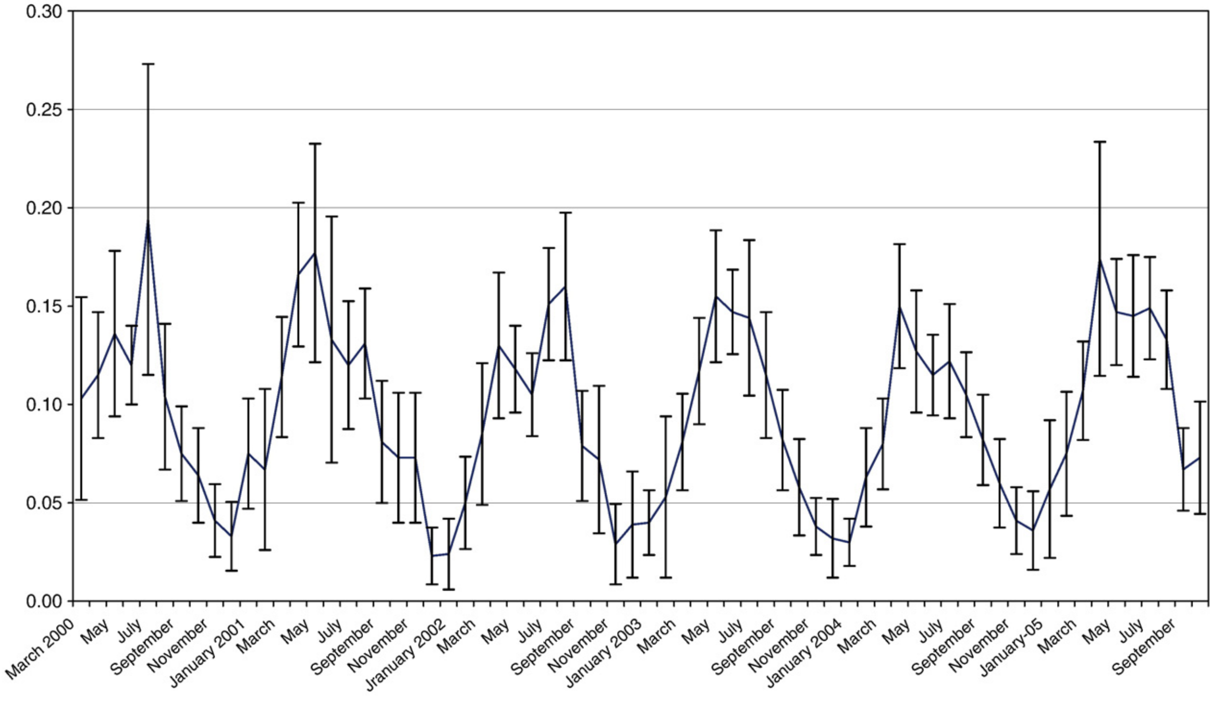

Fig. 5. Mean monthly aerosol optical depths for the Mojave Desert of southern California were derived from MISR Level 2 aerosol product from March 2000 through October 2005. Error bars represent 1 standard deviation from monthly means.

Table 2
Mean ($\bar{x}$) and standard deviation (σ) of seasonal aerosol optical depth derived from MISR from March 2000 to October 2005 in the Mojave Desert of southern California

Study sites	Seasons							
	SON		DJF		MAM		JJA	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Mojave Desert average	.06	.03	.04	.03	.11	.05	.12	.05
Military installations								
Edwards Air Force Base	.10	.03	.08	.04	.14	.06	.10	.08
Marine Corp Air Ground Combat Center	.06	.03	.05	.02	.13	.02	.13	.03
National Training Center, Ft. Irwin	.06	.02	.05	.02	.13	.02	.14	.01
Naval Weapons Center, China Lake	.06	.03	.04	.02	.12	.04	.12	.04
National parks								
Mojave National Preserve	.04	.02	.03	.02	.12	.03	.13	.03
Death Valley National Park	.06	.04	.03	.02	.10	.06	.11	.06
Joshua Tree National Park	.03	.03	.04	.04	.06	.06	.07	.08
Playas and sand dunes								
Cadiz Dry Lake and sand dunes	.04	.03	.07	.01	.10	.05	.17	.07
Rogers Dry Lake	.10	.02	.08	.01	.15	.02	.14	.02
Harper Dry Lake	.09	.01	.08	.01	.15	.02	.14	.01
Soda Dry Lake	.05	.01	.06	.01	.14	.02	.15	.01
Bristol Dry Lake	.07	.04	.07	.01	.13	.02	.15	.16
Searles Dry Lake	.06	.02	.05	.01	.13	.01	.14	.01
Death Valley playa	.08	.04	.04	.02	.13	.06	.13	.06
Danby Dry Lake and sand dunes	.05	.03	.02	.03	.12	.02	.11	.01

Seasons: DJF – December through February. MAM – March through May. JJA – June through July. SON – September through November.

pattern. However, four playas, Rogers Dry Lake, Harper Dry Lake, Bristol Dry Lake and Death Valley playa had high mean values during all four seasons. The others had spring and summer high mean values.

Mean seasonal aerosol optical depths were mapped for the 6-year period between 2000 and 2005 (Fig. 6A–D). The maps depict the anticipated low aerosol optical depths throughout most of the Mojave Desert during the fall and winter, and higher values during spring and summer. Letters A through G refer to locations described on Fig. 6A–D.

In the southwestern Mojave, there was a high mean summer aerosol optical depth on the western edge of Rogers Dry Lake (A) at Edwards Air Force Base (Fig. 6D). The high spring aerosol optical depths in this area expanded closer to Tehachapi Pass, an event that could be associated with dust coming from agricultural fields being plowed and harvested in the San Joaquin Valley (e.g., Green, 1992; Smith et al., 1997). Just to the northeast (B) were two of the highest mean summer aerosol optical depths, associated with a playa rich area that is a significant source of dust which spreads to the north and east during summer months (Prospero et al., 2002). The dust season begins in April, reaches a maximum in May–June, and ends in August. A third region of high summer mean aerosol optical depths occurred near the southern extent of Death Valley National Park (C). This site was associated with alluvial deposits and mineral salts coming from the saltpan on the valley floor during high spring and summer winds and convection. The aerosol optical depths dropped quickly though to the east and southeast of the Death Valley boundary. The fourth significant location of high mean summer aerosol optical depths occurred at the extraction site at Bristol Dry Lake immediately east of the Marine Corp Air Ground Combat center, and south of the town of Amboy (D). Southeast of Bristol Dry Lake was an extensive array of playas in Cadiz Valley, which constituted the fifth source of high summer seasonal aerosol optical depths, with the highest summer values at Cadiz Dry lake (E) and Danby Dry Lake and sand dunes (F). The other two high aerosol optical depths occurred at Searles Dry Lake (G) and Soda Dry Lake (H).

Desert land managers are responsible for assuring compliance with federal air quality standards. Managers are responsible for specific national parks, military installations, or public rangelands. They want to know how their facilities compare to other facilities within the Mojave Desert, and to the Mojave Desert in general. Paired *t*-tests between mean monthly AOD for the military installations, national parks, and playas, and Mojave Desert mean monthly AOD were conducted to provide this comparison (Table 3). The expectation was that military installations would have higher than average aerosol optical depths because of off-highway training; national parks, which restrict off-highway vehicle use would have lower aerosol optical depths, and playas would have the largest difference because they are a primary source of mineral dust and salts. This test provided a way to determine which locations in the Mojave Desert were significantly different over the 6-year period, and whether they were higher or lower than the Mojave Desert average.

Edwards Air Force Base had a significantly higher mean monthly aerosol optical depth than the Mojave average (Table 3). The low *p*-values and high positive *t*-values indicated aerosol optical depths were much larger for this site. The National Training Center was not statistically different, but the higher *t*-values indicated this site had higher aerosol optical depths than the Mojave in general. The Naval Weapons Center at China Lake was also statistically different, yet the optical depths were lower than the Mojave Desert average (negative *t*-values). The Marine Corp Air Ground Combat Center was not statistically different from the Mojave Desert average. Joshua Tree National Park and Death Valley National Park were not statistically different, however the positive *t*-value indicates that Joshua Tree National Park had higher AOD than the Mojave mean AOD. The Mojave National Preserve was significantly different from the Mojave Desert, with a large negative *t*-value that indicated lower AOD than the Mojave mean.

Five of the eight playas were significantly different from the Mojave Desert mean monthly aerosol optical depth. Three playas, Rogers Dry Lake, Harper Dry Lake, and Bristol Dry Lake had large positive *t*-values, which indicated that aerosol optical depths were much higher than the Mojave average. Two dry lakes though had significant negative *t*-values, Danby Dry Lake and Death Valley playa. Soda Dry Lake, Cadiz Dry Lake, and Searles Dry Lake were not significantly different from the mean monthly Mojave values.

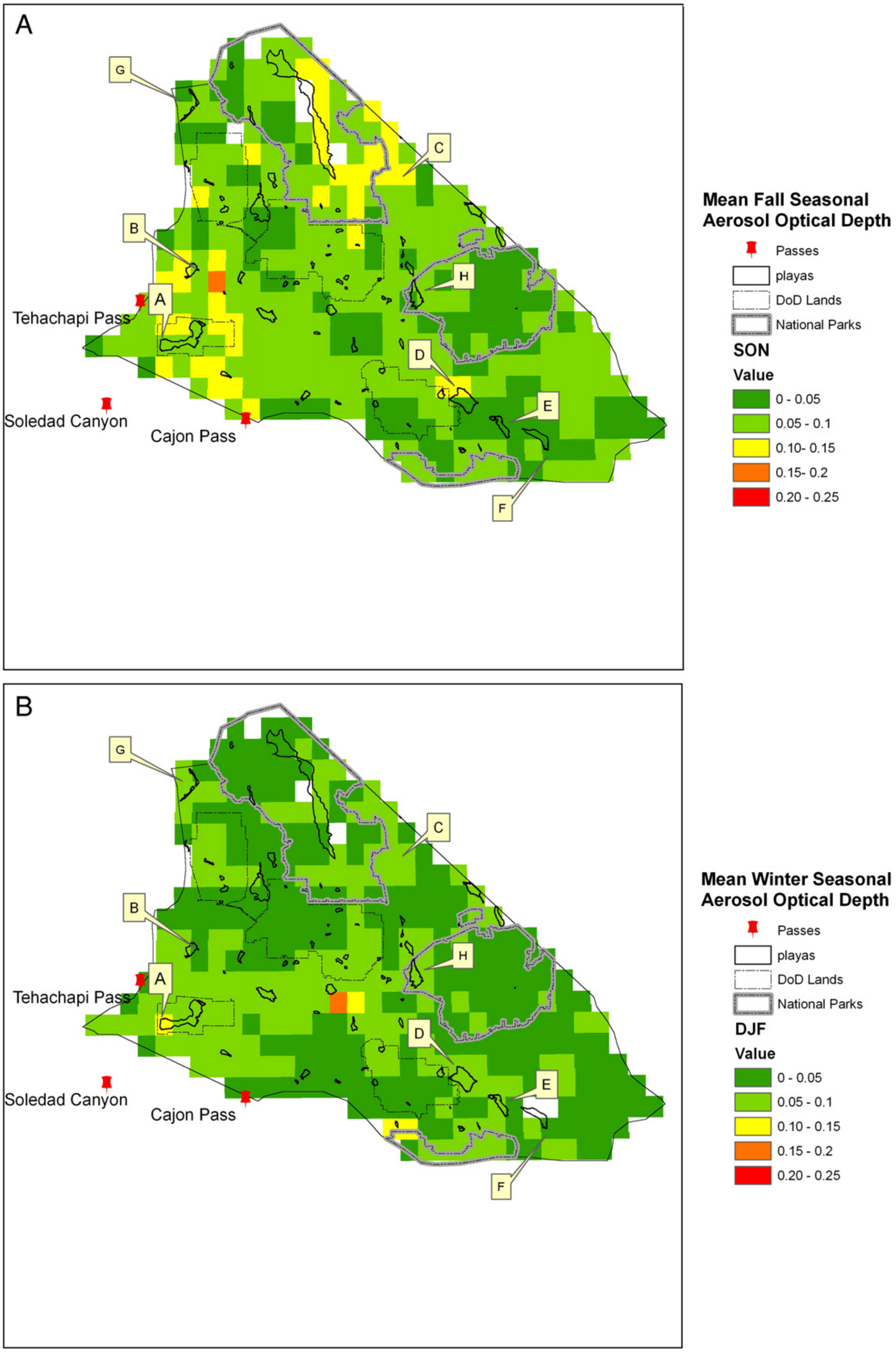

Fig. 6. (A) MISR Level 2 mean fall seasonal aerosol optical depths for the Mojave Desert of southern California. (B) MISR Level 2 mean winter seasonal aerosol optical depths for the Mojave Desert of southern California. (C) MISR Level 2 mean spring seasonal aerosol optical depths for the Mojave Desert of southern California. (D) MISR Level 2 mean summer seasonal aerosol optical depths for the Mojave Desert of southern California.

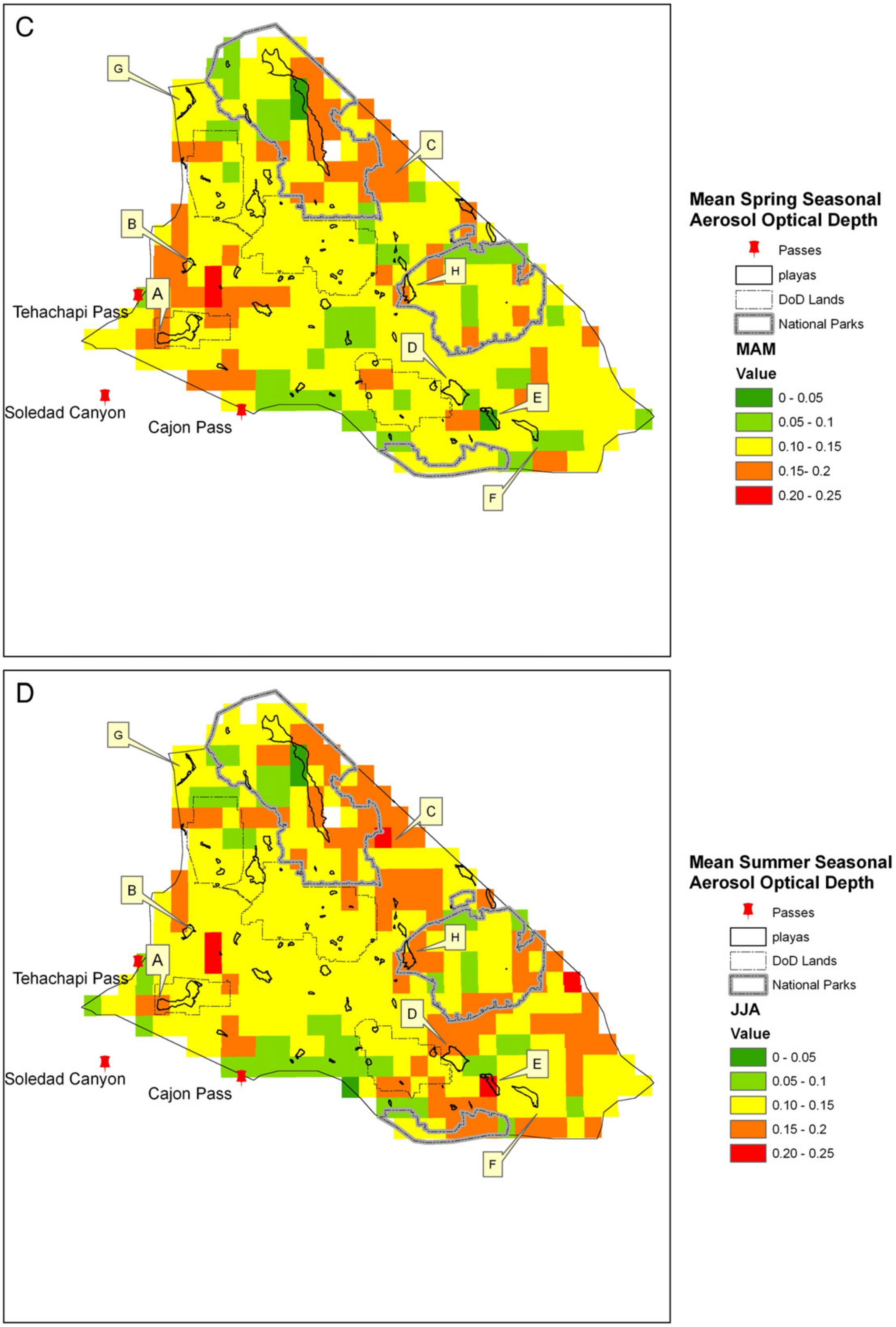

Fig. 6 (*continued*).

Paired *t*-tests between the Mojave Desert mean seasonal averages and each of the study sites was conducted to determine the statistical significance of the patterns depicted on the maps (Table 4). The *t*-test was conducted with values for each month in each season, not the seasonal means. Although the maps show where the higher aerosol optical depths occur by season, few of the patterns were statistically different from the mean values in the Mojave as a whole during those seasons. During

Table 3
Results of paired *t*-test between MISR mean monthly aerosol optical depths for four military installations, three national parks, and eight playas, and the mean monthly aerosol optical depth of the Mojave Desert of southern California

Study sites	*t*	*p*	*r*
Edwards Air Force Base	4.73	.00	.79
National Training Center, Ft. Irwin	1.74	.08	.93
Marine Corp Air Ground Combat Center	0.28	.80	.88
Naval Weapons Center, China Lake	−3.22	.00	.90
Joshua Tree National Park	1.55	.30	.81
Death Valley National Park	−1.21	.23	.95
Mojave National Preserve	−3.13	.00	.93
Rogers Dry Lake	5.93	.00	.74
Harper Dry Lake	3.38	.00	.48
Bristol Dry Lake	2.32	.02	.73
Soda Dry Lake	0.59	.55	.75
Searles Dry Lake	−1.51	.14	.83
Danby Dry Lake and sand dunes	−2.00	.05	.68
Cadiz Dry Lake and sand dunes	−0.83	.41	.27
Death Valley playa	−2.14	.04	.91

t=t-value. $p<.05$ indicated sample means were statistically different from Mojave Desert means. Positive t-value indicates site aerosol optical depth was greater than Mojave Desert mean. r=correlation coefficient.

the fall, only three sites had statistically significant higher AOD; Edwards Air Force Base, Rogers Dry Lake and Harper Dry Lake. During winter, these three sites and Bristol Dry Lake emerged as having higher AOD. By spring though, only Edwards Air Force Base and Rogers Dry Lake were different, and by summer none of the sites were statistically different than the Mojave Desert average.

5. Summary

Our maps of aerosol optical depths over the Mojave Desert of the southern California are the first maps of aerosol optical depth over the desert region collected over multiple years. Previous studies reviewed in Section 2 that used in situ measurements of aerosol concentration (or related measures of aerosol concentration) at the surface had described numerous contributing factors – climatic, physical, geographic, and anthropogenic – help explain the general nature of these aerosol distributions. For the Mojave Desert in general, it was apparent from Fig. 5 that climate was the underlying factor that caused the seasonal cycle of aerosol optical depths. Higher wind speeds, the larger number of dust devils and larger-scale convective plumes, and the thermal low over the desert in spring and summer causing aerosols from the Los Angeles Basin and the San Joaquin Valley to flow into the desert were all contributed to the higher aerosol optical depths observed in the spring and summer peaks in Fig. 5 (e.g., Green, 1992; Metzger, 1999; Snow and McClelland, 1990). In addition, the Mojave Desert annual precipitation cycle shows two distinctive patterns that approximately divide the region along the 117°W meridian. A bi-seasonal pattern prevails to the east, whereas a winter dominant pattern is typical to the west. May through June are consistently dry, accounting for less than 5% of annual rainfall (Hereford et al., 2005). Cool season precipitation is the most important and extensive source of rain in the desert region, however, occasional convective thunderstorms due occur in the warm season. The wetter cool-season may also contribute to lower aerosol optics depths in fall and winter (Fig. 6) through wet deposition.

Secondary factors, such as land use, available source materials, and proximity to urban areas help to explain the spatial variability of aerosol optical depth within the Mojave Desert (Tables 2, 3 and 4). Analysis of mean seasonal aerosol optical depths showed that all four military installations, all eight playas, and two of the three national parks had high values

Table 4
Results of paired *t*-test between MISR seasonal aerosol optical depths for four military installations, three national parks, and eight playas, and the seasonal aerosol optical depth of the Mojave Desert of southern California

Study sites	SON			DJF			MAM			JJA		
	t	*p*	*r*	*t*	*p*	*r*	*t*	*p*	*r*	*t*	*p*	*r*
EAFB	5.68	.00	.57	3.76	.00	.50	3.16	.01	.79	−0.35	.73	.42
NTC	1.75	.10	.84	1.46	.16	.92	0.50	.62	.71	0.54	.59	.73
MCAGCC	−1.36	.19	.83	−0.18	.85	.76	0.79	.44	.75	0.22	.82	.66
NWC	−2.45	.03	.84	−1.15	.27	.91	−1.53	.14	.71	−1.91	.07	.63
JTNP	0.66	.52	.85	1.85	.08	.82	−0.87	.39	.84	0.85	.41	.71
DVNP	2.87	.01	.95	−4.30	.00	.91	−1.46	.16	.90	−0.25	.81	.65
MNP	−8.23	.00	.72	−2.92	.01	.77	−0.22	.83	.92	0.37	.72	.63
Rogers DL	4.69	.00	.30	4.28	.00	.50	4.21	.00	.73	0.87	.39	.31
Harper DL	6.13	.00	.40	2.51	.03	.33	0.54	.59	.16	0.78	.45	.45
Bristol DL	0.40	.69	.18	3.63	.00	.72	0.02	.98	.60	1.40	.18	.60
Soda DL	−2.76	.01	.41	0.85	.41	.57	0.98	.34	.49	1.36	.19	.34
Searles DL	−1.04	.31	.64	0.00	.99	.69	−0.87	.39	.72	−1.00	.33	.51
Danby DL	−2.56	.02	.32	−4.86	.00	.32	0.05	.96	.48	−1.30	.21	.76
Cadiz DL	N/A			−1.89	.08	.55	−1.78	.09	.23	0.09	.93	.11
DVNPP	4.43	.00	.94	−3.20	.01	.71	−1.45	.16	.90	−0.25	.81	.65

$p<.05$ indicated sample means were statistically different from Mojave Desert means. Positive t-value indicated site aerosol optical depths greater than Mojave Desert mean.

Edwards Air Force Base – EAFB. National Training Center at Ft. Irwin – NTC. Marine Corp Air Ground Combat Center – MCAGCC. Naval Weapons Center – NWC. Joshua Tree National Park – JTNP. Death Valley National Park – DVNP. Mojave National Preserve – MNP. Death Valley playa – DVNPP.

N/A insufficient number of month with aerosol optical depths to derive statistics.

during the spring and summer months, but low values during the cool-season (Table 3). Only Joshua Tree National Park had a relatively low value during the warm seasons. Four sites, primarily located west of the 117°W meridian, demonstrated seasonal high aerosol optical depths throughout the year (Edwards Air Force Base, Bristol Dry Lake, Harper Dry Lake, and Rogers Dry Lake). The western Mojave, generally around Rogers Dry Lake and Harper Dry Lake exhibited the most sustained pattern of seasonally high aerosol optical depths, and even had a high winter season value at the western edge of Rogers Dry Lake (Fig. 6B). This indicates that seasonal AODs from the AERONET site at Rogers Dry Lake are not representative of the Mojave Desert as a whole.

During the fall season, only three of the regions had high aerosol optical depths; Edwards Air Force Base (and Rogers Dry Lake bed within), nearby Harper Dry Lake, and the playa at Badwater Basin in Death Valley (Fig. 6A). The winter season exhibited the lowest aerosol optical depths in general, yet four of the playas were the exception (Fig. 6B). Bristol Dry Lake (mineral extraction), Rogers Dry Lake and Harper Dry Lake (proximity to urban areas), and Cadiz Dry Lake (large playa surface) maintained high aerosol optical depths. Although our analysis found that many sites were not significantly different from the Mojave Desert in general, these sites are still particularly high in aerosol distributions; the Mojave Desert in general having high aerosol optical depths.

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