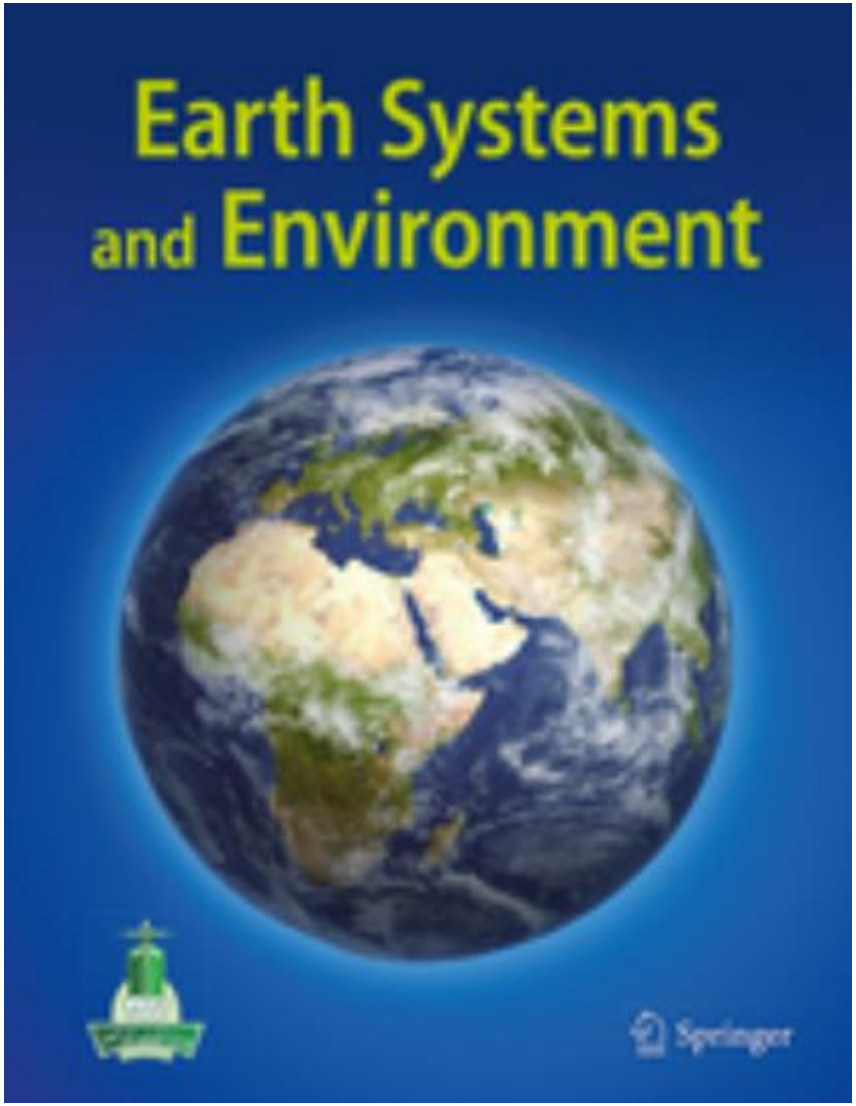
Standard aerosol optical depth index (SAODI) and application in the Middle East

International Journal of Global Warming

Zekâi Şen
Istanbul Medipol University
Climate Change Excellency Center – Medipol (CERC – Medipol)

Turkish Water Foundation
Climate Change Research and Development Center (CLERDEC)



Editor-in-Chief : Zekâi Şen

Dünyanın kurak bölgeleri
Dry lands of world
مناطق القاحلة في العالم

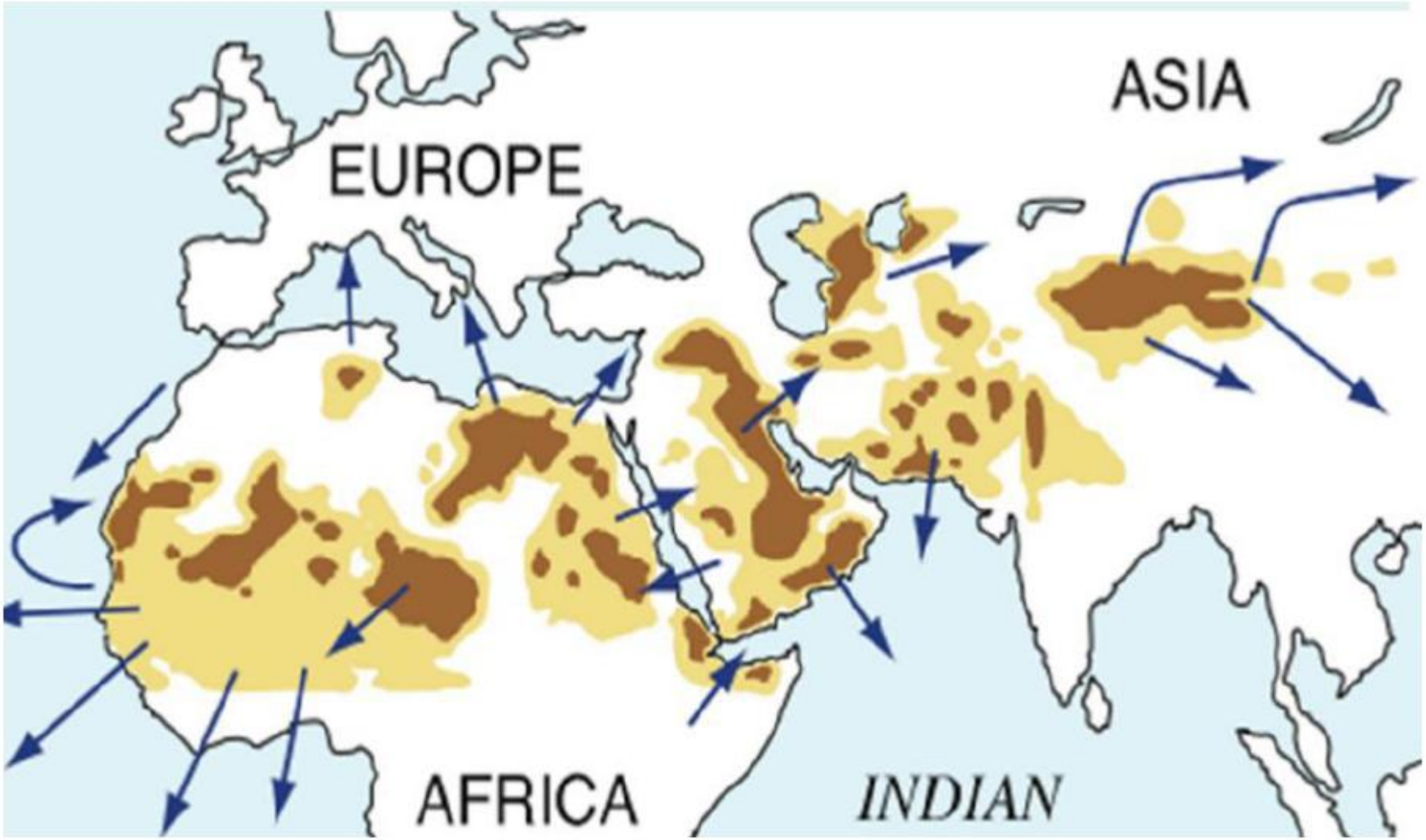


Figure 1 Dust sources in the Middle East, North Africa and WAR


Turkey-SE
Syria-Iraq
Ilam-
Kirmansah
Iraq-
West
Ahwaz
Mar
shes
Saudi
Arabia
Saudi Arab.
U.A.E.
Umman
B. Abbas
Sistan
Belucis
tan
Middle East
NAHCIVAN
AZERBAYCAN
TURKMENISTAN
Aşkabad
Tahran
İRAN
Beyrut
Şam
LÜBNAN
Amman
ÜRDÜN
Bağ
KUVEYT
Kuveyt
BAHREYN
Manama
KATAR
Doha
Abu Dabi
Maskat
Basra Körfezi
Umman Körfezi
30°
45°
60°

AOD Index for classification in the literature

Aerosol Optical Depth (AOD)

AOD : $\overline{AOD} + \sigma_{AOD} < 0$ → Negligible

AOD : $0 < \overline{AOD} + \sigma_{AOD} < 2$ → Normal

AOD : $2 < \overline{AOD} + \sigma_{AOD} < 4$ → Strong

AOD : $\overline{AOD} + \sigma_{AOD} > 4$ → EXTREME (DUST)

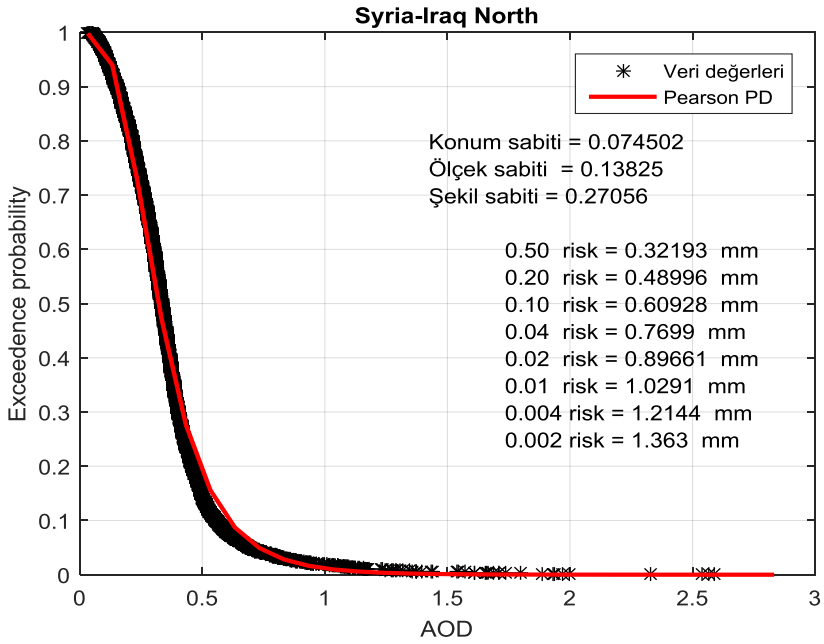
Is this classification methodology dependable? NO WHY? Are the probability distribution models the same? NO, they are different

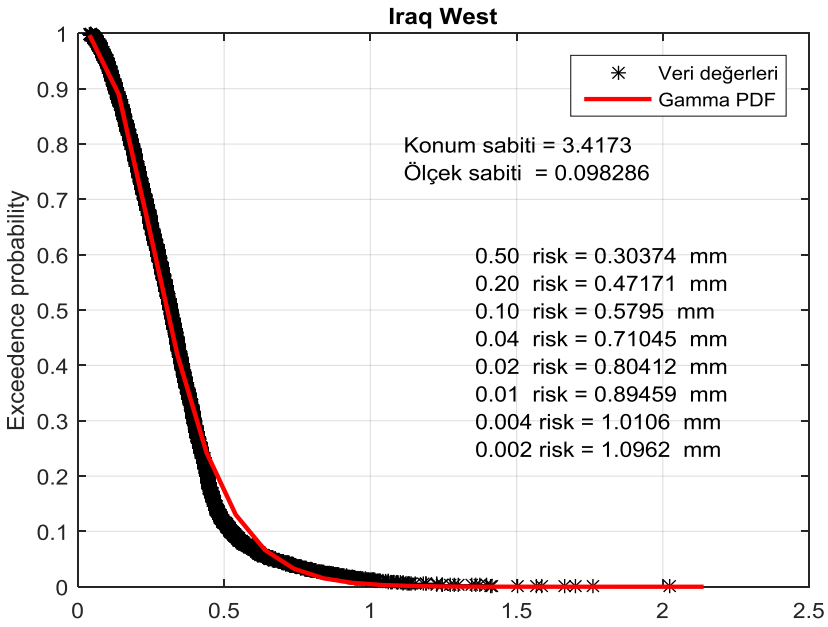
The literature classification has has the following assumptions and drawbacks.

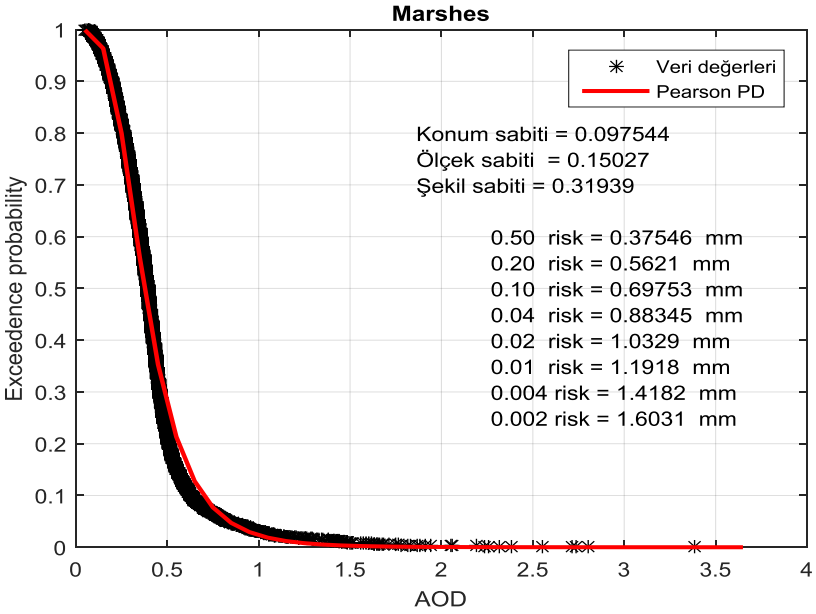
AOD records abide with the same PDF, which is not possible in all cases,

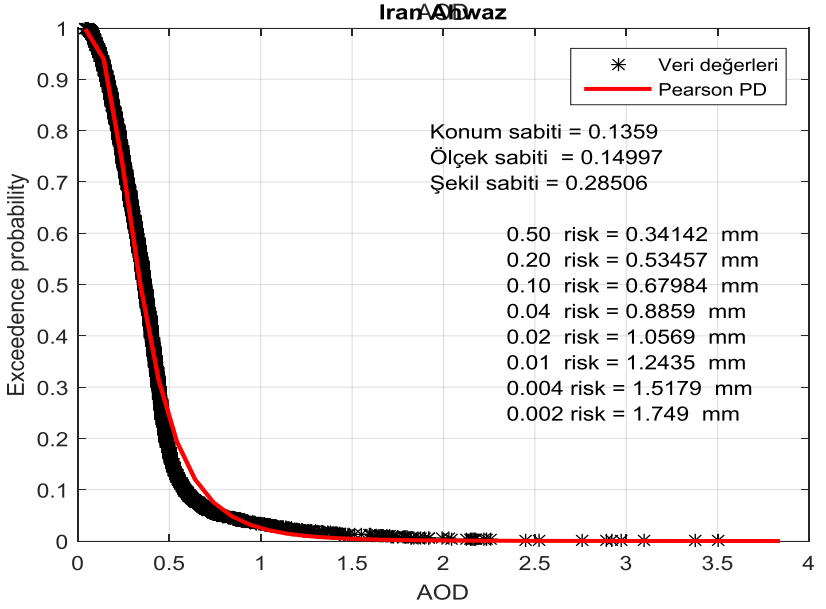
Two statistical parameters (μ_{AOD} and σ_{AOD}), imply a symmetric PDF for the PDF of AOD records, because the skewness coefficient is not taken into consideration,

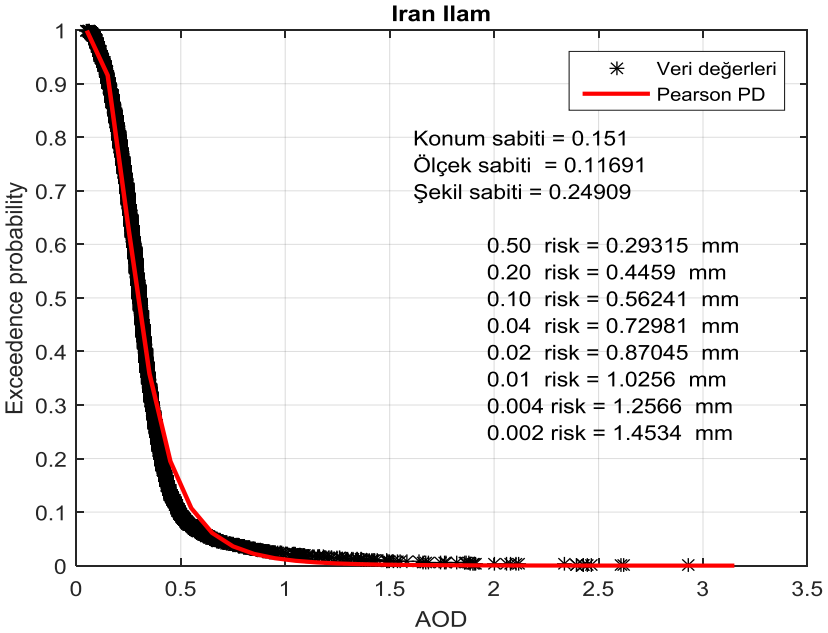
These two parameters might be affected by extreme values, which lead to biased threshold levels.

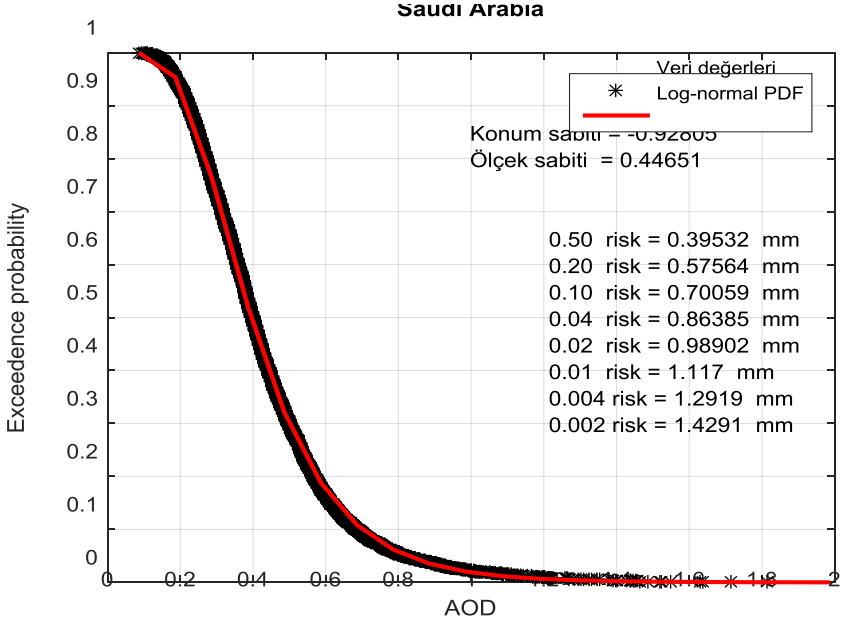

Syria-Iraq North
Veri değerleri
Pearson PD
Konum sabiti = 0.074502
Ölçek sabiti = 0.13825
Şekil sabiti = 0.27056
0.50 risk = 0.32193 mm
0.20 risk = 0.48996 mm
0.10 risk = 0.60928 mm
0.04 risk = 0.7699 mm
0.02 risk = 0.89661 mm
0.01 risk = 1.0291 mm
0.004 risk = 1.2144 mm
0.002 risk = 1.363 mm
Exceedence probability
AOD

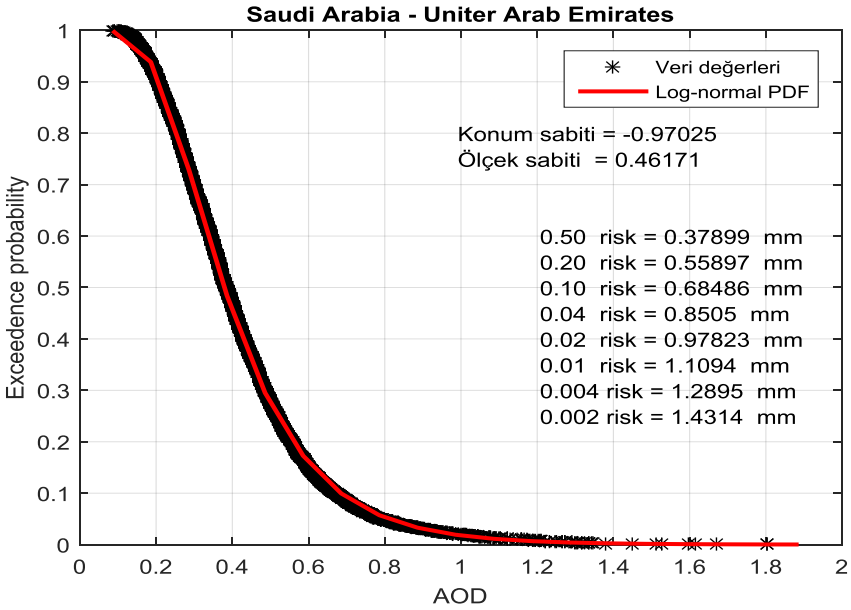

Iraq West
Veri değerleri
Gamma PDF
Konum sabiti = 3.4173
Ölçek sabiti = 0.098286
0.50 risk = 0.30374 mm
0.20 risk = 0.47171 mm
0.10 risk = 0.5795 mm
0.04 risk = 0.71045 mm
0.02 risk = 0.80412 mm
0.01 risk = 0.89459 mm
0.004 risk = 1.0106 mm
0.002 risk = 1.0962 mm
Exceedence probability


Marshes
Veri değerleri
Pearson PD
Konum sabiti = 0.097544
Ölçek sabiti = 0.15027
Şekil sabiti = 0.31939
0.50 risk = 0.37546 mm
0.20 risk = 0.5621 mm
0.10 risk = 0.69753 mm
0.04 risk = 0.88345 mm
0.02 risk = 1.0329 mm
0.01 risk = 1.1918 mm
0.004 risk = 1.4182 mm
0.002 risk = 1.6031 mm
Exceedence probability
AOD


Iran Ahwaz
Veri değerleri
Pearson PD
Konum sabiti = 0.1359
Ölçek sabiti = 0.14997
Şekil sabiti = 0.28506
0.50 risk = 0.34142 mm
0.20 risk = 0.53457 mm
0.10 risk = 0.67984 mm
0.04 risk = 0.8859 mm
0.02 risk = 1.0569 mm
0.01 risk = 1.2435 mm
0.004 risk = 1.5179 mm
0.002 risk = 1.749 mm
Exceedence probability
AOD


Iran Ilam
Veri değerleri
Pearson PD
Konum sabiti = 0.151
Ölçek sabiti = 0.11691
Şekil sabiti = 0.24909
0.50 risk = 0.29315 mm
0.20 risk = 0.4459 mm
0.10 risk = 0.56241 mm
0.04 risk = 0.72981 mm
0.02 risk = 0.87045 mm
0.01 risk = 1.0256 mm
0.004 risk = 1.2566 mm
0.002 risk = 1.4534 mm
Exceedence probability
AOD


Saudi Arabia
Veri değerleri
Log-normal PDF
Konum sabiti = -0.92805
Ölçek sabiti = 0.44651
0.50 risk = 0.39532 mm
0.20 risk = 0.57564 mm
0.10 risk = 0.70059 mm
0.04 risk = 0.86385 mm
0.02 risk = 0.98902 mm
0.01 risk = 1.117 mm
0.004 risk = 1.2919 mm
0.002 risk = 1.4291 mm
Exceedence probability
AOD


Saudi Arabia - Uniter Arab Emirates
Veri değerleri
Log-normal PDF
Konum sabiti = -0.97025
Ölçek sabiti = 0.46171
0.50 risk = 0.37899 mm
0.20 risk = 0.55897 mm
0.10 risk = 0.68486 mm
0.04 risk = 0.8505 mm
0.02 risk = 0.97823 mm
0.01 risk = 1.1094 mm
0.004 risk = 1.2895 mm
0.002 risk = 1.4314 mm
Exceedence probability
AOD

Standard AOD Index (SAODI)

1) Sort the given AOD_i record (i = 1, 2, 3, . . . ,n) into ascending order with rank attachments (r = 1, 2, 3, . . . , n), and the new sorted sequence is labelled as AOD_r $(r = 1, 2, 3, \ldots, n)$,

2) Calculate the empirical probability value, p_r, for each AOD_r record according to the following frequently used formulation,

$$p_r = \frac{r}{n+1} \qquad (2)$$

3) Plot AOD_r versus p_r to have the empirical cumulative PDF scatter points, which appear in the form of non-decreasing and non-linear form,

4) Determine the most suitable cumulative PDF (CDF) that matches the scatter points in the best possible manner. In practical applications, most often normal (Gaussian), Gamma, Log-normal, Pearson or Weibull PDF are applicable,

5) After determination of the theoretical CDF for each site the AOD_r values are standardized. Herein, standardization means the conversion of different PDFs to a common normal (Gaussian) PDF with zero mean and unit variance. For this purpose, the execution of the following steps is necessary.

a) Calculate the theoretical probability values for each $\mathrm{AOD_r}$ record by means of the most suitable PDF,

b) Enter these probability values into the standard normal (Gaussian) PDF, to calculate the standardized AOD_{sr} values,

c) Plot the time series of the standardized $\mathrm{AOD_r}$ values.

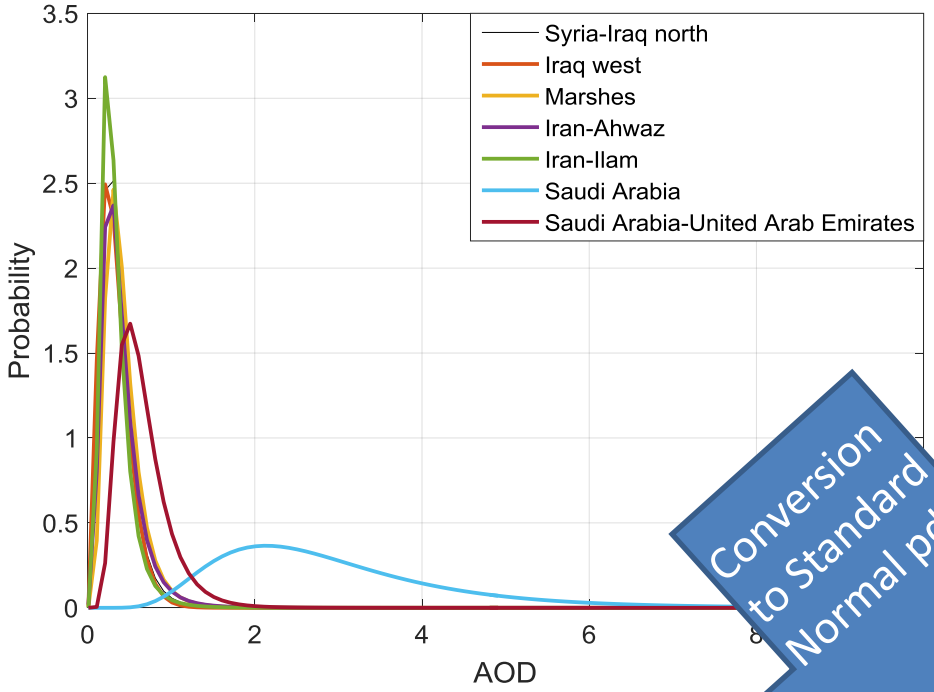
d) On the basis of the standard normal PDF four categorizations are suggested for classification.

"Extreme" aerosol episodes, if $AOD_{sj} > 4$,

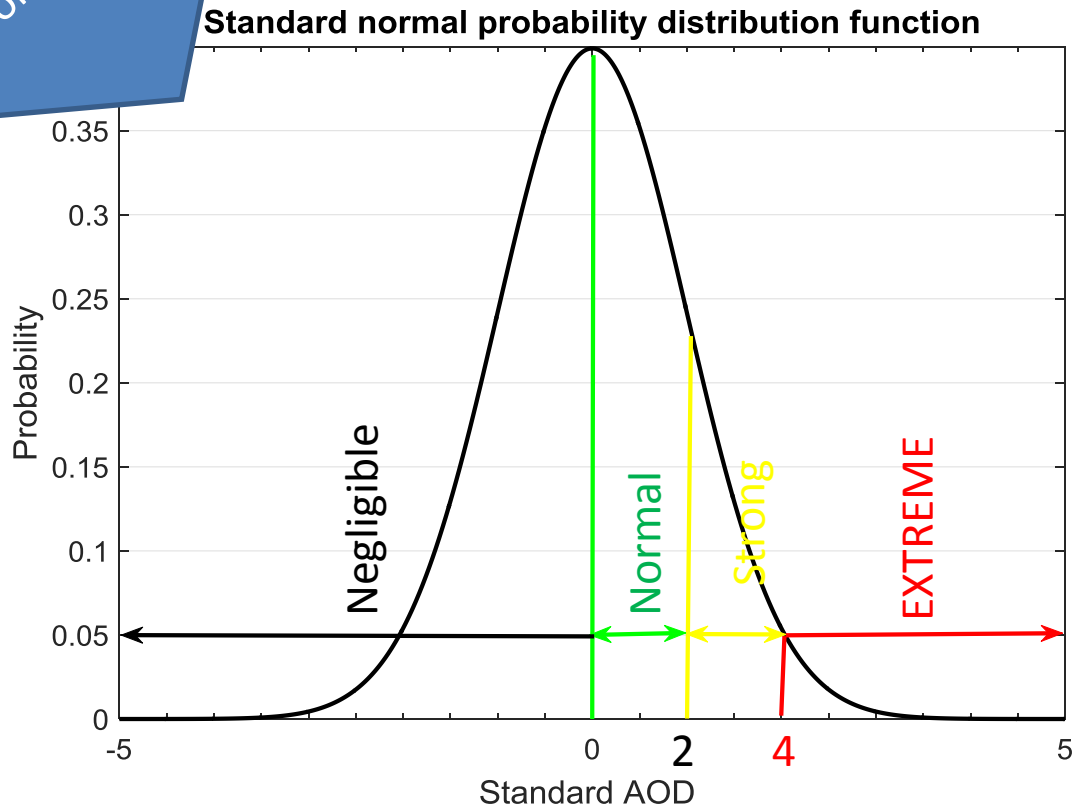
"Strong" aerosol episodes, if $2 < AOD_{sj} < 4$,

"Normal" aerosol episodes, if $0 < AOD_{sj} < 2$,

"Negligible" aerosol episodes, if $AOD_{sj} < 0$



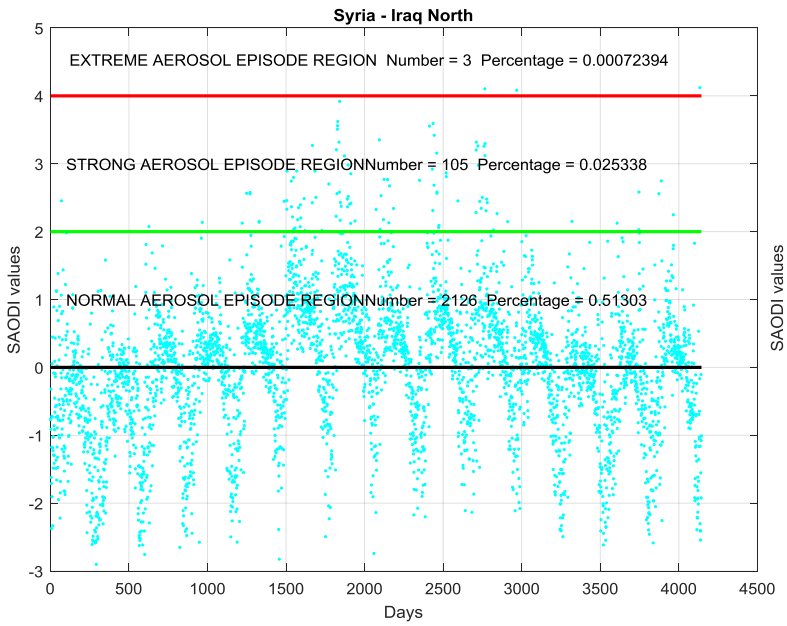
Conversion to Standard Normal pdf

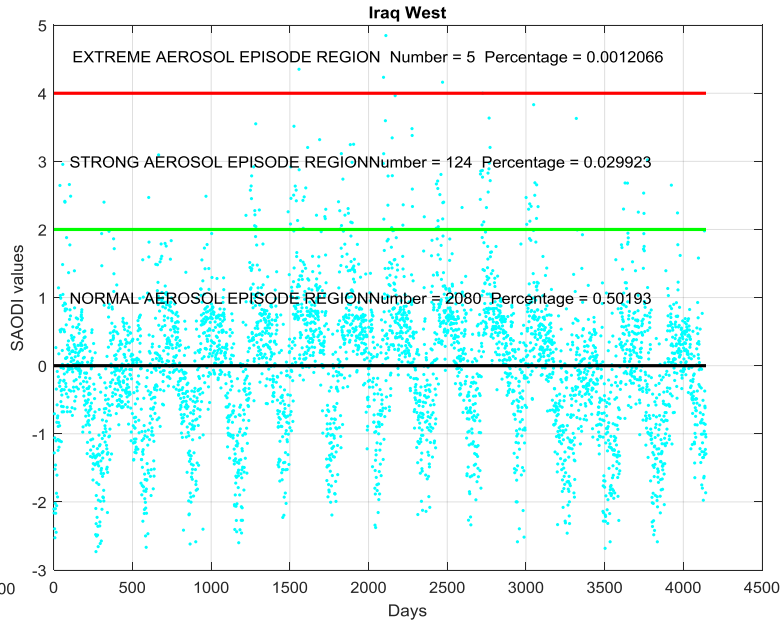


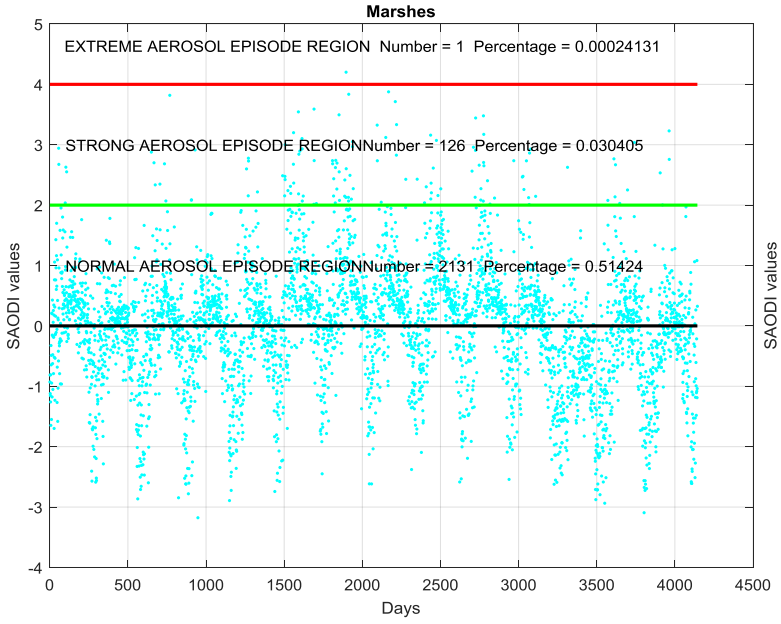
In practice, 10% risk level is adapted for design purposes. On this percentage level Iraq West and Iran Ilam sites have the least AOD values and therefore, these sites are safer than other sites in the region.

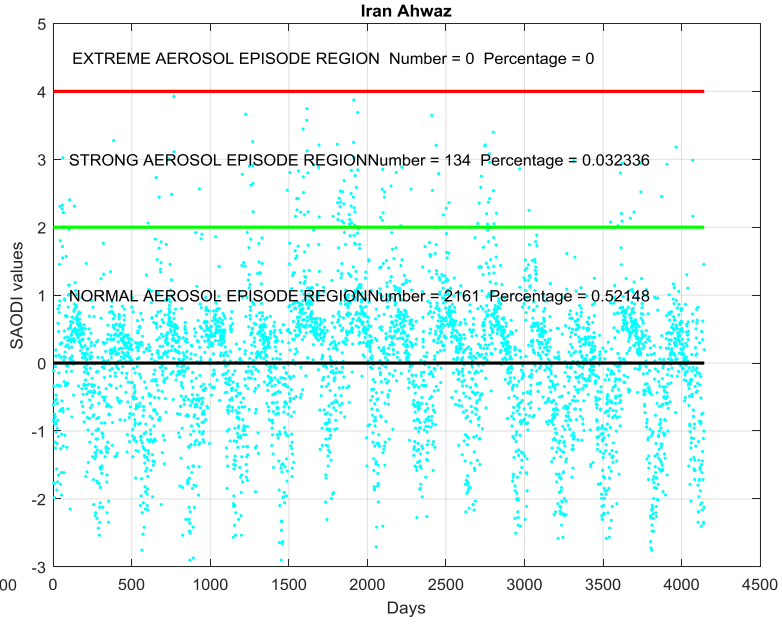
AOD amounts at different risk levels

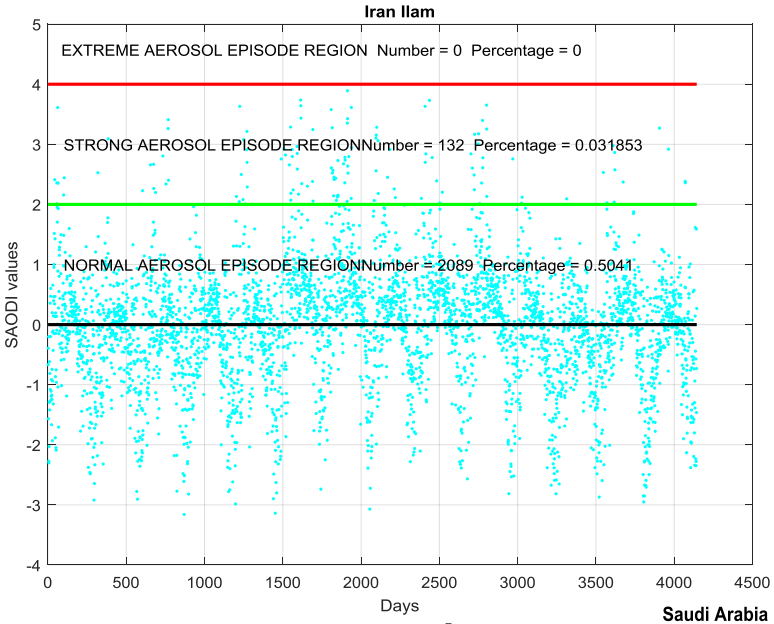
Location	Aerosol episode risk levels							
	0.50	0.20	0.10	0.04	0.02	0.01	0.004	0.002
Syria-Iraq West	0.32	0.48	0.60	0.76	0.89	1.02	1.21	1.36
Iraq West	0.30	0.47	0.57	0.71	0.80	0.89	1.01	1.09
Marshes	0.37	0.56	0.69	0.88	1.03	1.19	1.41	1.60
Iran Ahwaz	0.34	0.53	0.67	0.88	1.05	1.24	1.51	1.74
Iran Ilam	0.29	0.44	0.56	0.72	0.87	1.02	1.25	1.45
Saudi Arabia	0.39	0.57	0.70	0.86	0.98	1.11	1.29	1.42
Saudi Arabia-U.A.E. border	0.37	0.55	0.68	0.85	0.97	1.10	1.28	1.43

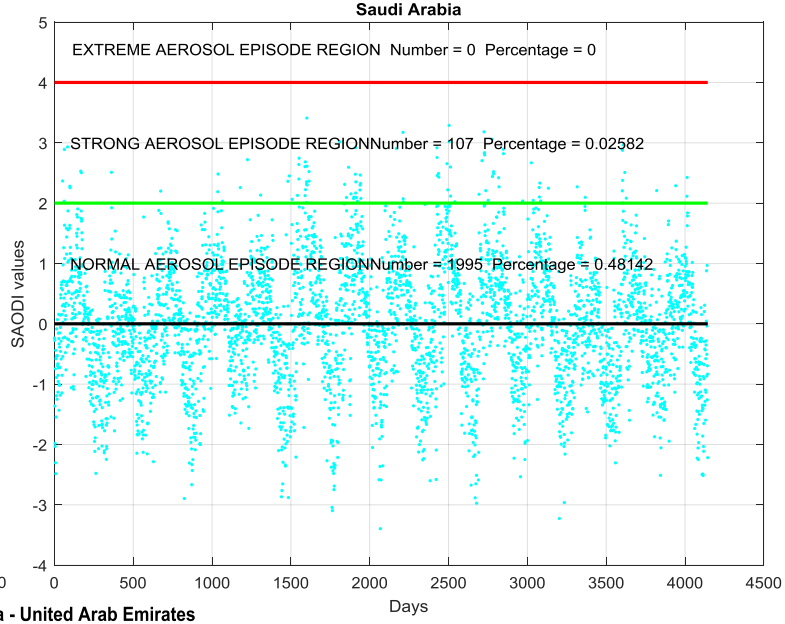

Syria - Iraq North
EXTREME AEROSOL EPISODE REGION Number = 3 Percentage = 0.00072394
STRONG AEROSOL EPISODE REGIONNumber = 105 Percentage = 0.025338
NORMAL AEROSOL EPISODE REGIONNumber = 2126 Percentage = 0.51303
SAODI values
Days

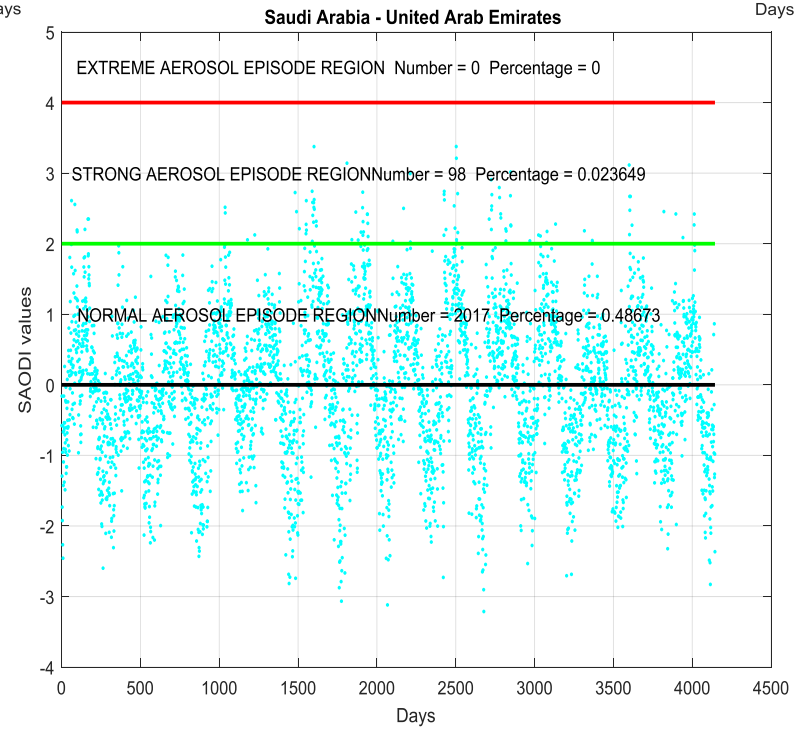

Iraq West
EXTREME AEROSOL EPISODE REGION Number = 5 Percentage = 0.0012066
STRONG AEROSOL EPISODE REGIONNumber = 124 Percentage = 0.029923
NORMAL AEROSOL EPISODE REGIONNumber = 2080 Percentage = 0.50193
SAODI values
Days


Marshes
EXTREME AEROSOL EPISODE REGION Number = 1 Percentage = 0.00024131
STRONG AEROSOL EPISODE REGIONNumber = 126 Percentage = 0.030405
NORMAL AEROSOL EPISODE REGIONNumber = 2131 Percentage = 0.51424
SAODI values
Days


Iran Ahwaz
EXTREME AEROSOL EPISODE REGION Number = 0 Percentage = 0
STRONG AEROSOL EPISODE REGIONNumber = 134 Percentage = 0.032336
NORMAL AEROSOL EPISODE REGIONNumber = 2161 Percentage = 0.52148
SAODI values
Days

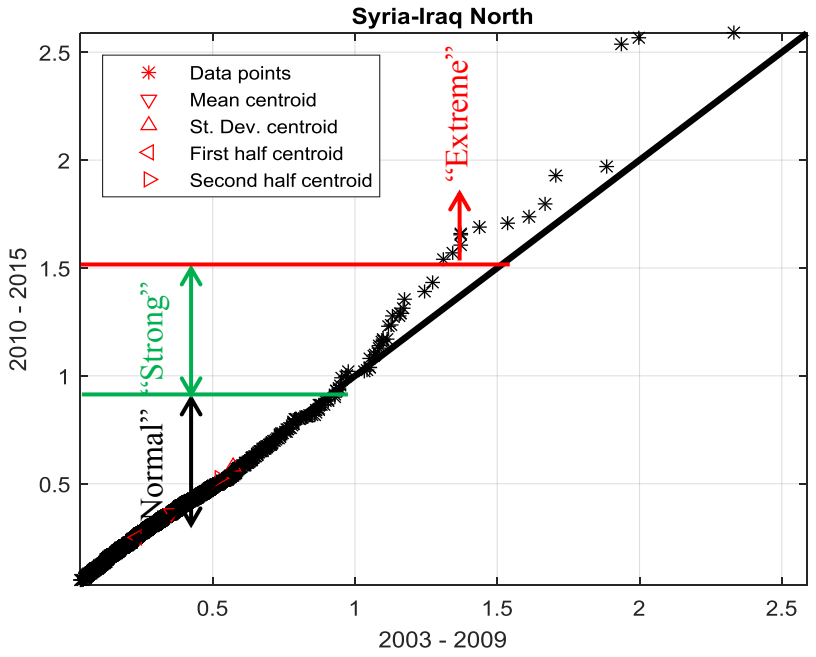

Iran Ilam
EXTREME AEROSOL EPISODE REGION Number = 0 Percentage = 0
STRONG AEROSOL EPISODE REGIONNumber = 132 Percentage = 0.031853
NORMAL AEROSOL EPISODE REGIONNumber = 2089 Percentage = 0.5041
SAODI values
Days

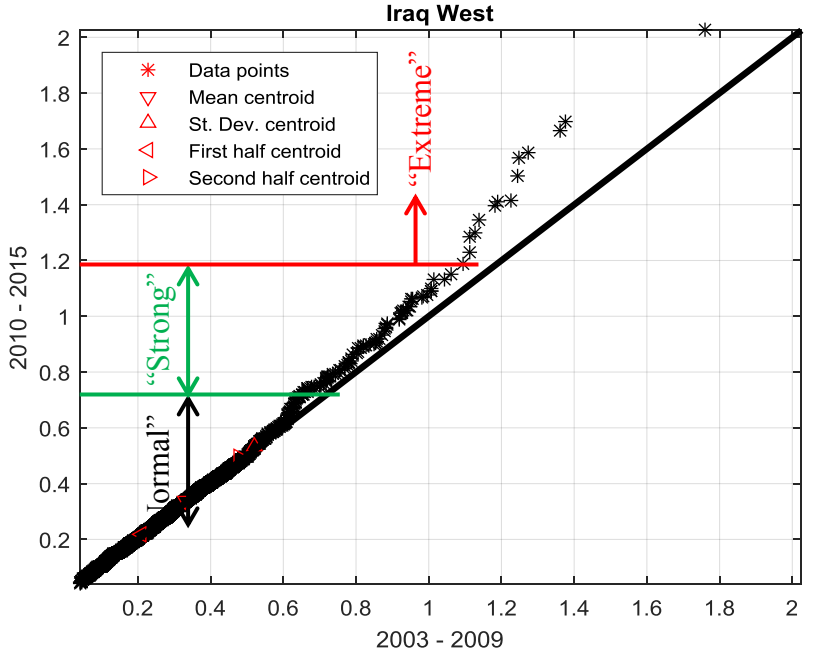

Saudi Arabia
EXTREME AEROSOL EPISODE REGION Number = 0 Percentage = 0
STRONG AEROSOL EPISODE REGIONNumber = 107 Percentage = 0.02582
NORMAL AEROSOL EPISODE REGIONNumber = 1995 Percentage = 0.48142
SAODI values
Days

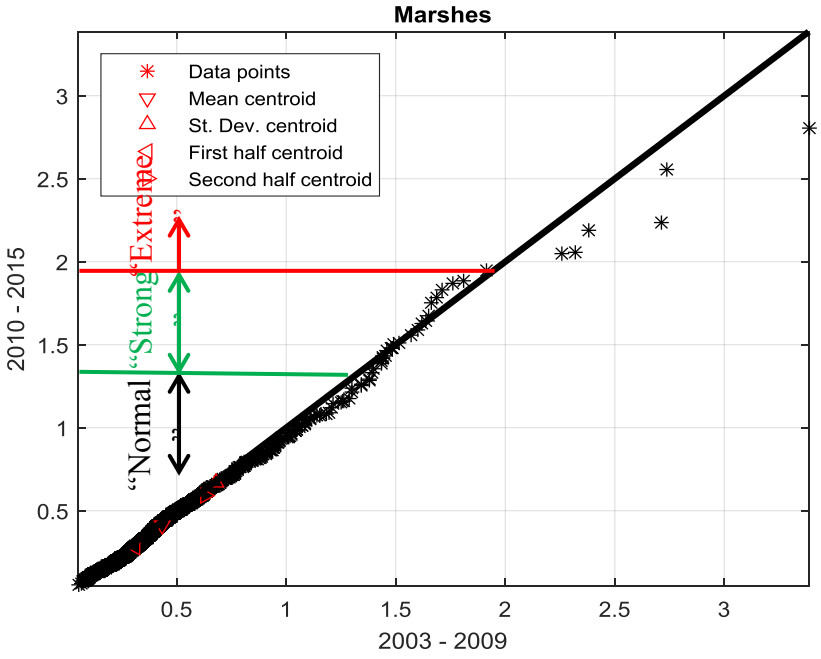

Saudi Arabia - United Arab Emirates
EXTREME AEROSOL EPISODE REGION Number = 0 Percentage = 0
STRONG AEROSOL EPISODE REGIONNumber = 98 Percentage = 0.023649
NORMAL AEROSOL EPISODE REGIONNumber = 2017 Percentage = 0.48673
SAODI values
Days

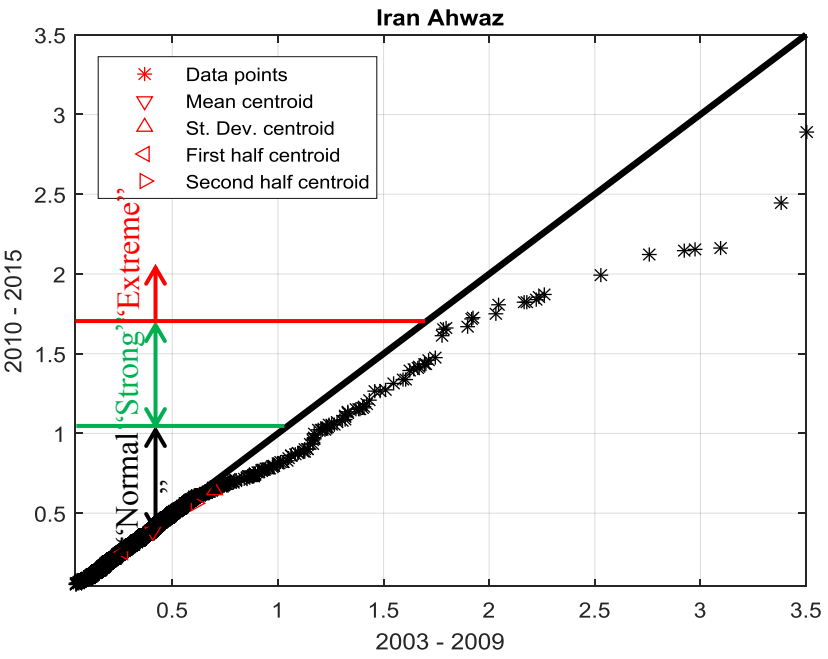
SAODI classifications

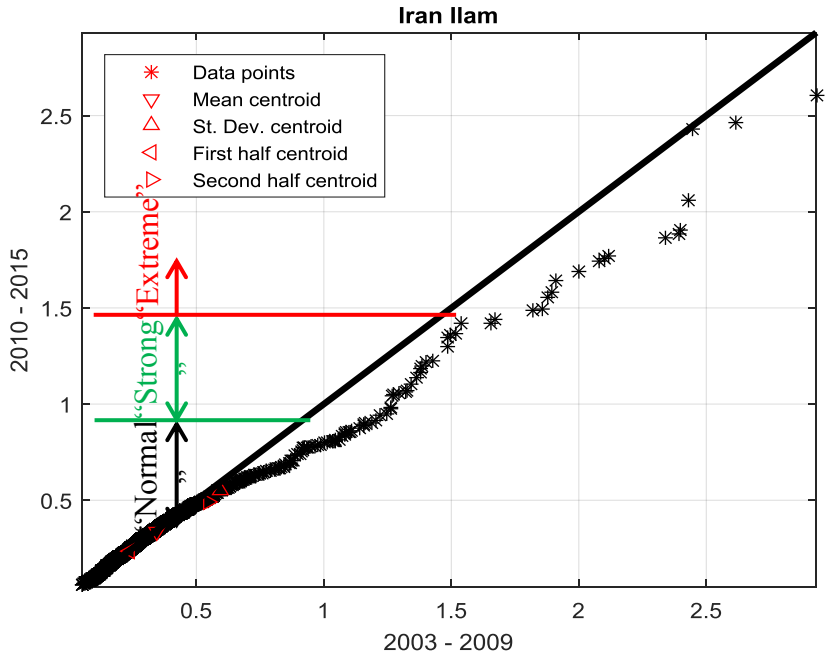
Location	Aerosol episodes		
	Extreme	Strong	Normal
Syria-Iraq West	3	105	2126
Iraq West	5	124	2080
Marshes	1	126	2131
Iran Ahwaz	0	134	2161
Iran Ilam	0	132	2089
Saudi Arabia	0	107	1995
Saudi Arabia- U.A.E. border	0	98	2017

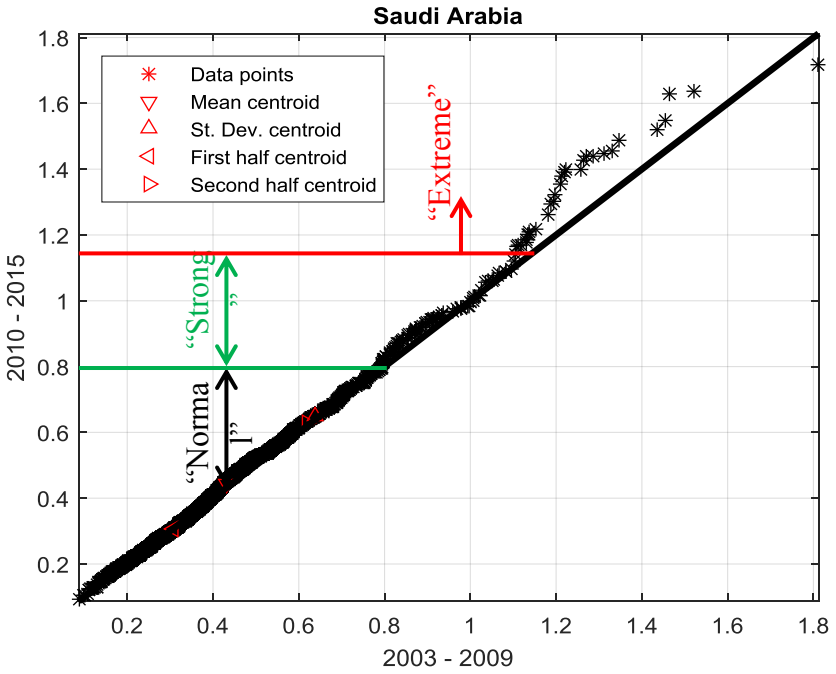

Syria-Iraq North
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

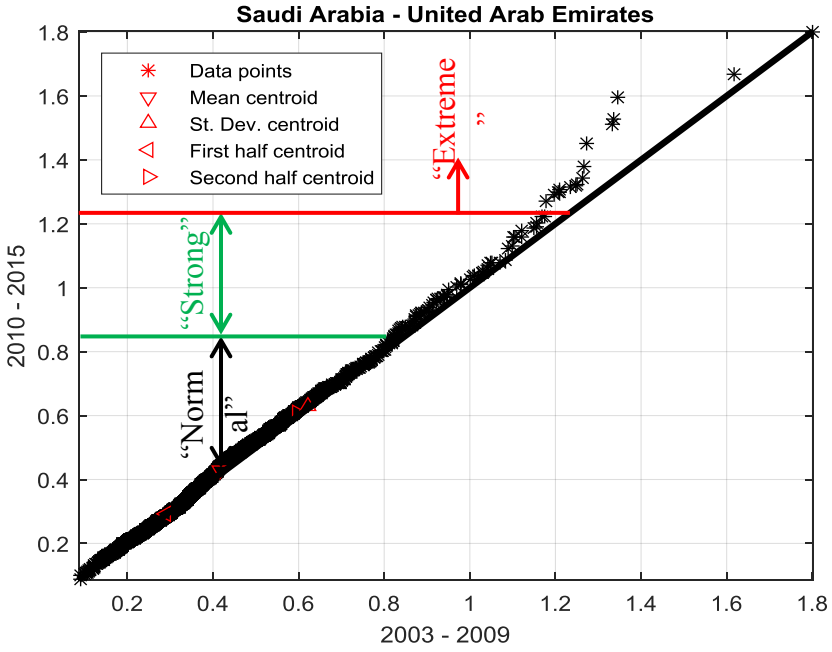

Iraq West
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

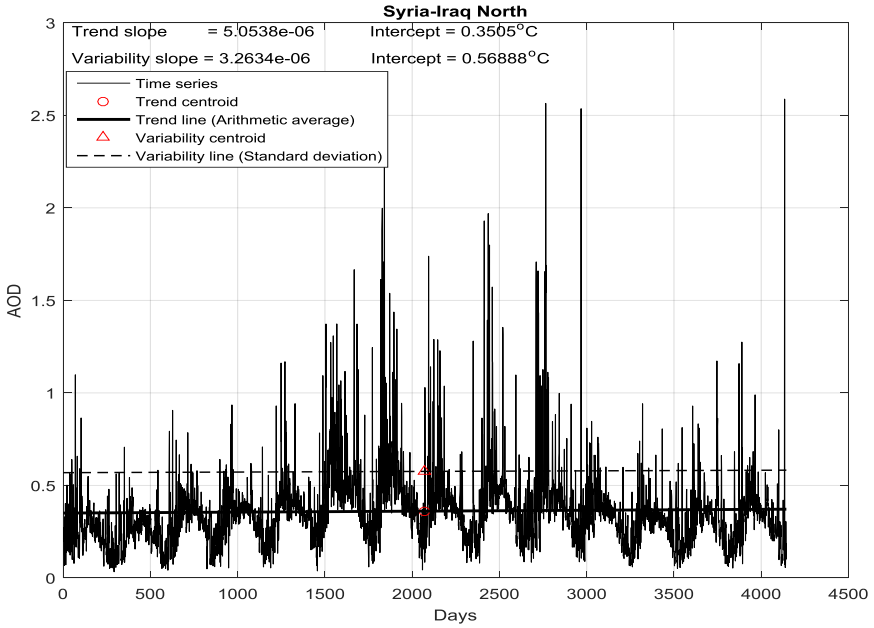

Marshes
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

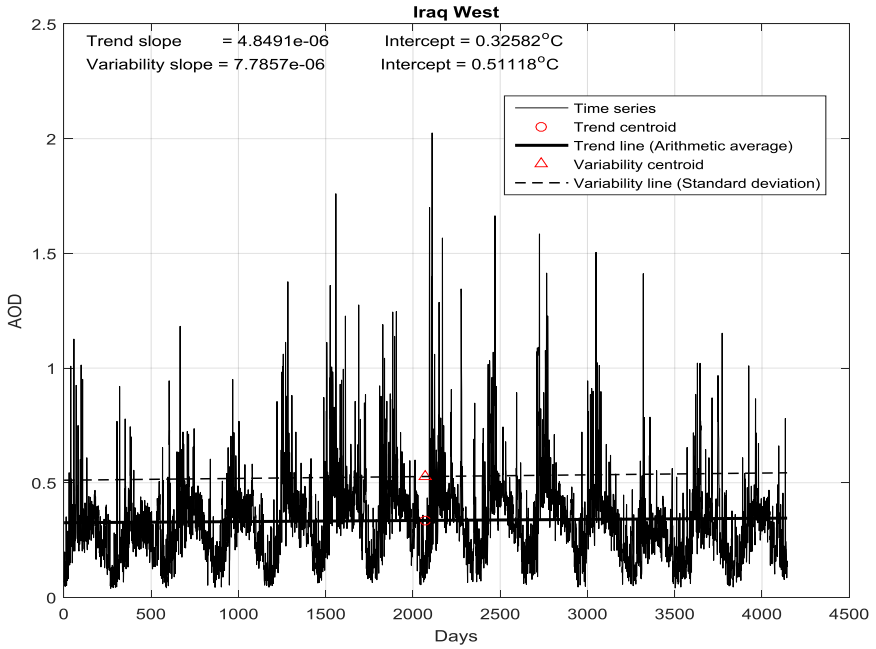

Iran Ahwaz
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

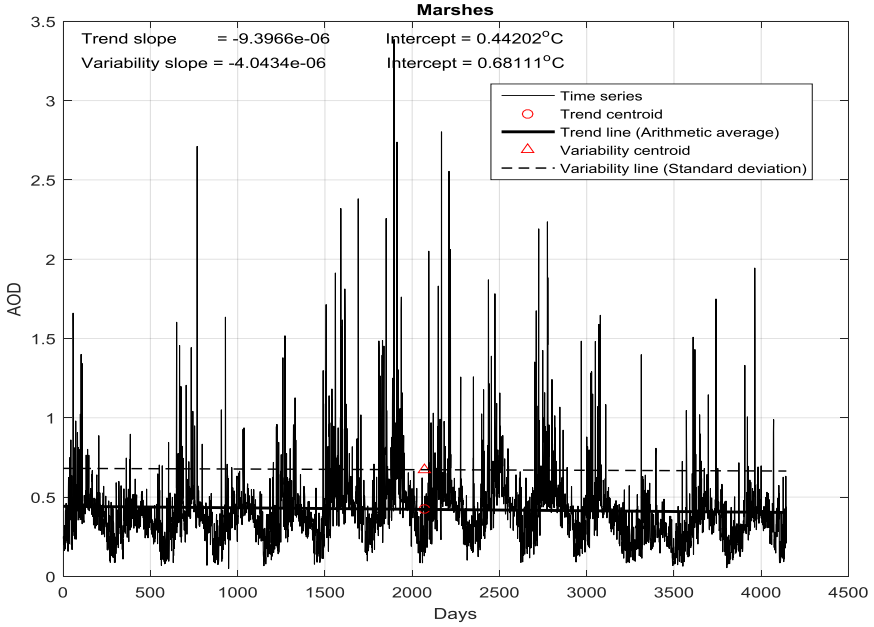

Iran Ilam
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

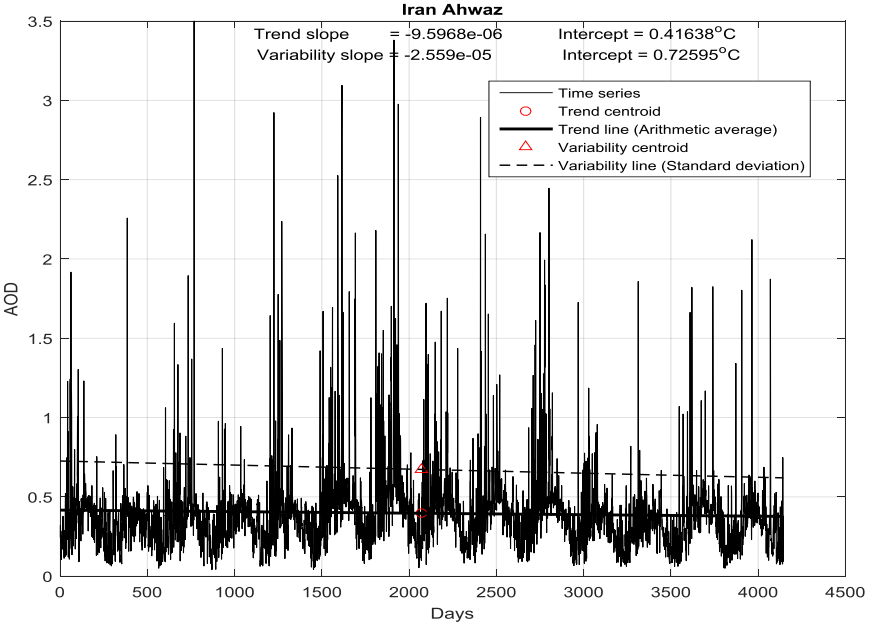

Saudi Arabia
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

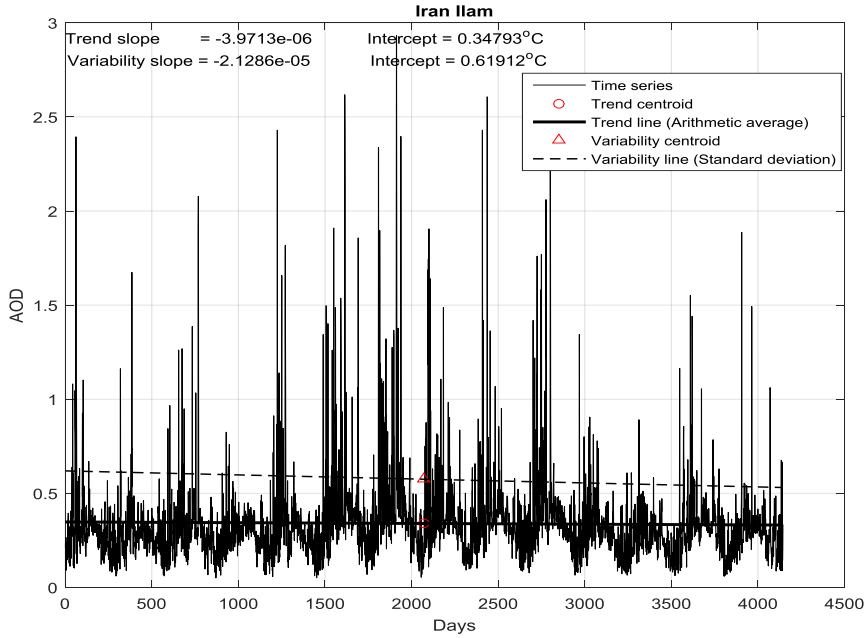

Saudi Arabia - United Arab Emirates
Data points
Mean centroid
St. Dev. centroid
First half centroid
Second half centroid
"Extreme"
"Strong"
"Normal"
2010 - 2015
2003 - 2009

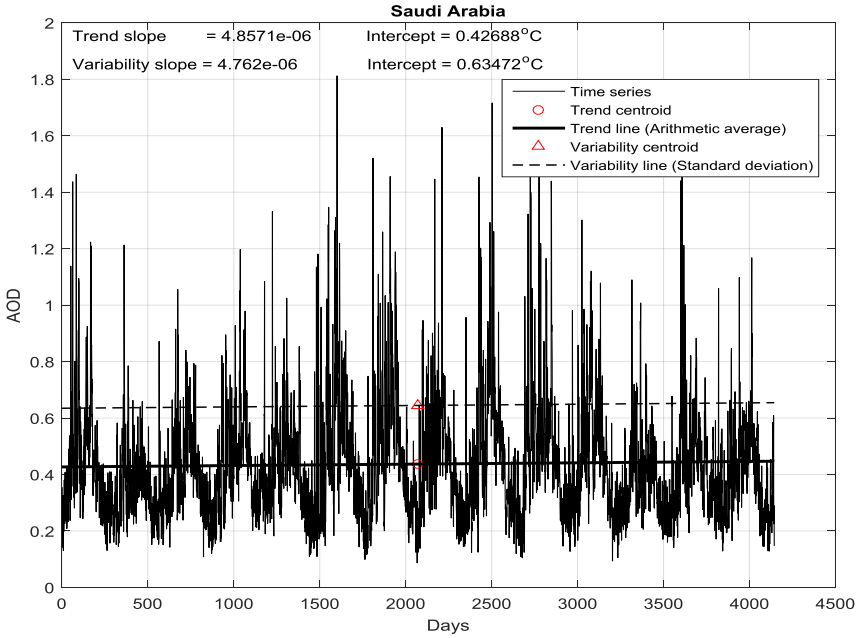

Syria-Iraq North
Trend slope = 5.0538e-06
Intercept = 0.3505°C
Variability slope = 3.2634e-06
Intercept = 0.56888°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days

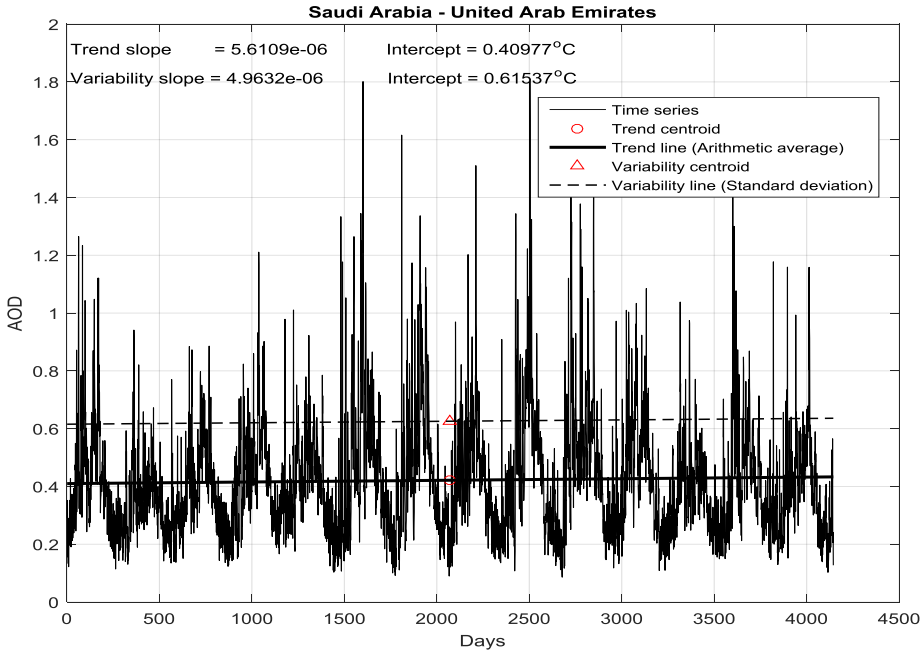

Iraq West
Trend slope = 4.8491e-06
Intercept = 0.32582°C
Variability slope = 7.7857e-06
Intercept = 0.51118°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days


Marshes
Trend slope = -9.3966e-06
Intercept = 0.44202°C
Variability slope = -4.0434e-06
Intercept = 0.68111°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days


Iran Ahwaz
Trend slope = -9.5968e-06
Intercept = 0.41638°C
Variability slope = -2.559e-05
Intercept = 0.72595°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days


Iran Ilam
Trend slope = -3.9713e-06
Intercept = 0.34793°C
Variability slope = -2.1286e-05
Intercept = 0.61912°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days


Saudi Arabia
Trend slope = 4.8571e-06
Intercept = 0.42688°C
Variability slope = 4.762e-06
Intercept = 0.63472°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days


Saudi Arabia - United Arab Emirates
Trend slope = 5.6109e-06
Intercept = 0.40977°C
Variability slope = 4.9632e-06
Intercept = 0.61537°C
Time series
Trend centroid
Trend line (Arithmetic average)
Variability centroid
Variability line (Standard deviation)
AOD
Days

Trend slopes and intercepts

Location	Arithmetic average		Standard deviation	
	Slope ($x10^{-6}$)	Intercept (^oC)	Slope ($x10^{-6}$)	Intercept (^oC)
Syria-Iraq Wets	+ 5.05	0.35	3.26	0.56
Iraq North	+ 4.84	0.32	+ 7.78	0.51
Marshes	- 9.39	0.44	- 4.04	0.68
Iran, Ahwaz	- 9.59	0.41	- 25.59	0.72
Iran, Ilam	- 3.97	0.34	- 21.28	0.61
Saudi Arabia	+ 4.85	0.42	+ 4.76	0.63
Saudi Arabia-U.A.E. border	+ 5.61	0.40	+ 4.96	0.61

CONCLUSIONS

Aerosol optical depth (AOD) measurements provide numerical information about the local weather and climate conditions in addition to environmental circumstances.

The Middle East is very prone to aerosol, and especially, dust events, because of surrounding huge deserts in Africa and Arabian Peninsula and also dry and arid conditions of the Middle East.

In the literature, the assessment of AOD measurements is achieved statistically by means of the arithmetic mean and standard deviation parameters. In this paper, more general standart AOD index (SAODI) is suggested based on the probability principles.

Each measurement site has different AOD measurement theoretical probability distribution function (PDF). The SAODI method transforms AOD records at different sites to a common PDF, which is a standard normal (Gaussian) PDF with zero mean and unit variance.

The SAODI helps to categorize the data into four classes as “negligible”, “normal”, “strong” and “extreme”. Furthermore, innovative trend template (ITT) is applied for trend possibility identification in each class.

Finally, timewise monotonic trends are identified on the arithmetic average and standard deviation (variability) levels.

The application of the methodology is presented for seven different sites in the Middle East region with 13-year daily AOD records from 2003 to 2015, inclusive.

It is noticed that Marshes site in Iraq and Iranian sites (Ahwaz and Ilam) have decreasing trends on the average and standard deviation levels.

As a result of research in this paper, it is recomended that local aerosol problems may be reduced to a significant extend by a systematic groundwater explotation, revival of wetlands, reforestation and local mulching.