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Assessment of aerosol particles using a new index

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Abstract. Dry beds of lakes and surrounding areas play an important role in dust production. This work develops a new index called Aerosol Type Detection Index using the Extinction Coefficient and Depolarization Ratio. The developed index shows values between zero and 0.15 for desert dust and -0.3 to zero for polluted desert dust particles in two regions including the Aral Sea in Central Asia and Hamoun Lake in Sistan, Iran. Although the dried beds of these lakes are susceptible to strong winds, wind speed profiles show that north of the Aral Sea and northwest of Hamoun Lake can be dust storm sources in these regions.

1 Introduction

Dust particles, as an important part of the earth's atmosphere, have a significant impact on regional and global climate [1]. The Aral Sea in Central Asia and Hamoun Lake in Southeast Iran are among the areas that have suffered from droughts and shrinkage due to anthropogenic activities, improper management, excessive irrigation, and climate change [2]. The dried beds of the lakes can turn into aerosol sources and are susceptible to strong winds.

Recent studies used remote sensing tools and climate models to investigate dust storm occurrences and their relationship with human health, meteorological parameters, and climate change in different areas. Zhang et al. (2020) used the Multiangle imaging spectroradiometer (MISR) instrument on the Terra satellite to show that not only the occurrence of dust storms has increased 5 days in a year but also the intensity of these storms has significantly increased in recent years in the Aral Sea and Caspian Sea regions [3]. Rashki et al. (2012) showed that the dust events in the areas near Hamoun Lake are intense and highly dependent on wind speed. Their investigations showed an increase in PM10 concentration in Zabol atmosphere in dusty days, which could have adverse impacts on human health in the region [4]. In order to categorize aerosol types during dust storm activities, Yang et al. (2021) used Cloud and Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) to retrieve aerosol parameters such as Aerosol Optical Depth (AOD), Extinction Coefficient (EC), and Depolarization Ratio (DR). Their results showed that marine and desert dust are the most common aerosols in the North and South Poles and the Tibetan Plateau in Asia [5].

Many studies have used AOD and Ångström Exponent (AE) to determine aerosol types over different regions. Kumar et al. (2018) showed that the classification of particles based on these two parameters can vary in different geographical locations. They provided specific AOD and AE thresholds for distinct regions in China, India, and Pakistan to discriminate aerosol types such as marine, desert dust, polluted dust, continental, and industrial aerosol [6]. Since the particle type is an important factor in determining the source of aerosols and also assessing their impacts on hydrometeorology and human health, more precise physical parameters of the particles should be used in order to develop an index to identify the type of aerosols.

2 Study area

This study aims to evaluate changes in aerosol types and dust storm sources over the Aral Sea and Hamoun Lake. The Aral Sea in Central Asia is located on Kazakhstan and Uzbekistan border (Fig. 1a). The Aral Sea is one of the oldest natural lakes in the world that has experienced a great shrinkage and lost more than 70 percent of its water body over the last 20 years [7].

The second case of study is Hamoun Lake, which is located in the southeast of Iran near Afghanistan border (Fig. 1b). The lake plays an important role in the region's climate. During recent years due to human activities and climate change, the waterbody of the lake is extremely unstable during different seasons, which provides conditions for dust storms in Spring and Summer [7].

3 Dataset

This study uses Cloud and Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) to obtain Extinction Coefficient, Depolarization Ratio, and Aerosol Optical Depth at two wavelengths (532 & 1064 nm), available on a daily resolution at https://subset.larc.nasa.gov/calipso. CALIPSO is a joint

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project between NASA and the French Space Agency, which was launched into space on April 28, 2006. Daily wind speed data are collected from National Center for Atmospheric Research (NCAR), available at https://psl.noaa.gov. BTD (Brightness temperature difference) data are obtained from https://lpdaac.usgs.gov/products/modtbgav006 at both 11 & 12 µm.

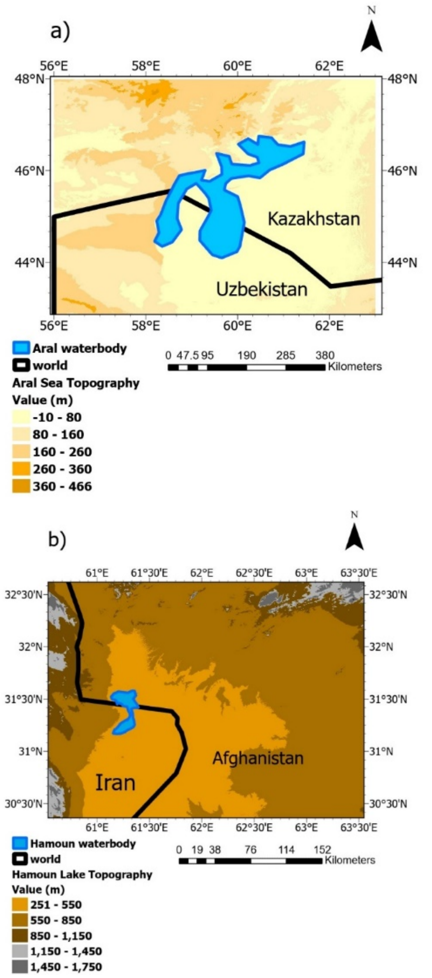

Fig. 1. Study areas including (a) Aral Sea and (b) Hamoun Lake.

4 Methodology

Past studies have used AOD and AE to determine the types of aerosols around the world. Although AOD can provide useful information about aerosol loading, it cannot solely determine the type of aerosols. In addition, it cannot analyze cloud coverage or aerosol-cloud discrimination. Lack of index to assess aerosol types/sources globally and discriminate aerosol and cloud particles indicates the necessity of developing more indices that can be used as complementary measures or comparison purposes. This study uses aerosol parameters including vertical-averaged EC and DR obtained from CALIPSO to analyze aerosol and clouds types. Radiation with a larger wavelength can usually pass through particles better than that of smaller wavelengths, which leads to a lower EC. In addition to the wavelength, type and size of the particles affect radiation transfer. Thus, in addition to the EC, other particle features defined by DR can be used to distinguish aerosol types and aerosol-cloud particle. Indeed, DR can be useful for distinguishing between spherical and non-spherical particles. Non-spherical particles (e.g. dust, ice crystals) change the polar state of the scattered radiation, while spherical particles (e.g., water droplets, polluted continental, smoke) would not change it. This study integrates the two particle parameters (EC & DR) to develop an index called Aerosol Type Detection Index (ATDI) to assess aerosol and cloud types as

$$ATDI = \frac{EC_{\lambda_1} - EC_{\lambda_2}}{EC_{\lambda_1} + EC_{\lambda_2}} * DR \quad (1)$$

where λ_1 and λ_2 are wavelengths at 532 and 1064 nm, respectively. The difference between EC at two wavelengths can provide information about the type of the aerosols. For instance, dust particles attenuate EC at small wavelengths more than large wavelengths, which leads to a higher EC at 532 nm and thus positive ADTI values. Similarly, for smoke or polluted dust particles with a higher EC at 1064 nm, ATDI tends to be negative. In addition, a specific range of the DR in cloud particles can help discriminate them from aerosols. Thus, considering DR in the equation can provide a better understanding of the shape of the particles. To calibrate and validate the developed dimensionless index, this study uses Kumar et al. (2018) aerosol categories based on AOD and AE for the Aral Sea and Hamoun Lake. Furthermore, BTD is considered for aerosol and cloud discrimination.

Table 1. Particle classification for (a) Aral Sea and (b) Hamoun Lake.

	Particle	ATDI	AOD	AE	BTD
(a)	Dust	0 – 0.15	> 1	0.5 – 1.5	0 – 1.5
	Polluted Dust	-0.3 - 0	---	-0.2 – 0.5	-0.2 – 0.5
	Smoke	-0.4 – -0.1	> 0.3	> 1	-0.5 – 0.5
	Cirrus/ Low-altitude Cumulus	> 0.2	---	---	< -0.5
(b)	Dust	0 – 0.15	> 0.5	< 0.4	0 – 1.5
	Polluted Dust	-0.3 - 0	> 0.1	> 0.7	-0.2 – 0.5
	Smoke	-0.4 – -0.1	> 0.1	> 0.7	-0.5 – 0.5
	Cirrus/ Low-altitude Cumulus	> 0.2	---	---	< -0.5

5 Results

To find proper thresholds for ATDI and modify initial assessments [7], [8], major aerosol events in April, May, June, and July in 2016 to 2020 are evaluated. These events calibrated and validated the ATDI based on AOD, AE, and BTD. Results are summarized in Table 1 for the Aral Sea and Hamoun Lake.

Table 1 shows proper ATDI thresholds for cloud and aerosol types. The values are based on particle's physical properties using the combination of EC and DR for each aerosol type. The equivalent AOD, AE, and BTD values can show the validity of the ATDI for each specific region. Indeed, many features are combined in ATDI as one index to provide useful information for distinguishing between different aerosol types and cloud particles.

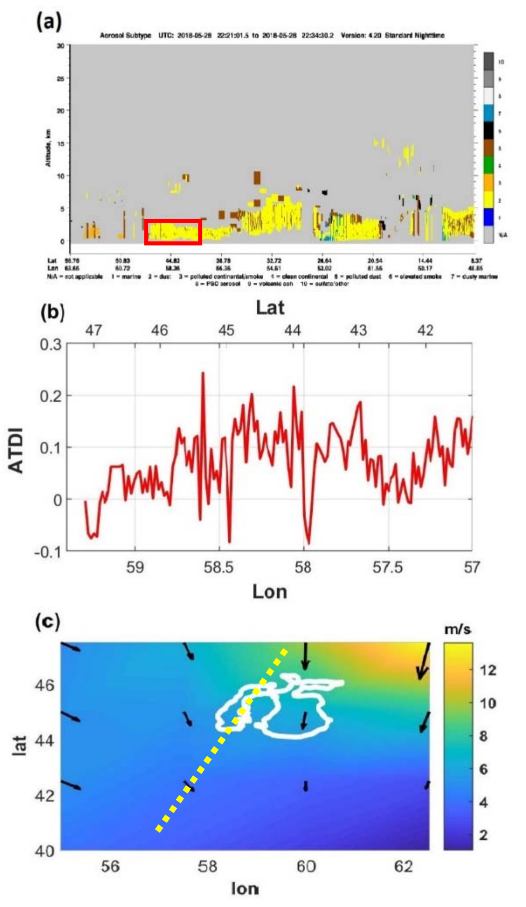

Fig. 2. Particle analysis: (a) CALIPSO Aerosol Type profile [9], (b) ATDI, (c) Wind speed on May 28, 2018 in Aral Sea.

To further analyze aerosol particles, the dust event on May 28, 2018 in the Aral Sea is assessed using CALIPSO (red rectangle in Fig. 2a). The ATDI values show that a large amount of desert particles with polluted desert particles and low-altitude scattered cumulus clouds can be found in this event (Fig. 2b). To address aerosol sources, the wind profile in Fig. 2c shows that the wind comes from north into the study area. The dashed yellow line in Fig. 2c illustrates the CALIPSO track over the Aral Sea. The north and northwest areas of the Aral Sea are desert-type and have a high potential for dust generation. The high-speed wind from north can transfer dust and other particles to the study area.

As another event, a strong aerosol-loading event is recorded on July 13, 2016 in the Hamoun Lake region (red rectangle in Fig. 3a). Desert particles, polluted desert particles, and low-altitude cumulus clouds in the area lead to a higher DR (above 0.4) than the event of solely desert particles. In addition, the largest EC is recorded at the wavelength of 1064 nm. These properties of particles are reflected in ATDI through EC and DR values (Fig. 3b). The ATDI changes between -0.1 and 0.1, which is due to the mixed desert, polluted desert, and cloud particles. Positive values smaller than 0.1 indicate desert particles in the region, and values closer to 0.1 at 60.8° longitude indicate the combination of cloud and aerosol particles in this region. Furthermore, the negative values of the index indicate polluted desert particles in the area. The CALIPSO track over Hamoun Lake is illustrated by the dashed yellow line in Fig. 3c. Furthermore, Figure 3c shows that the wind comes from the northwest into the study area. The north and northwest areas of Hamoun Lake are desert-type that are susceptible to the dust formation. A relatively high wind speed in most days of the year in this area with the dried bed and desert conditions around the lake can cause dust and particles transfer to the study area.

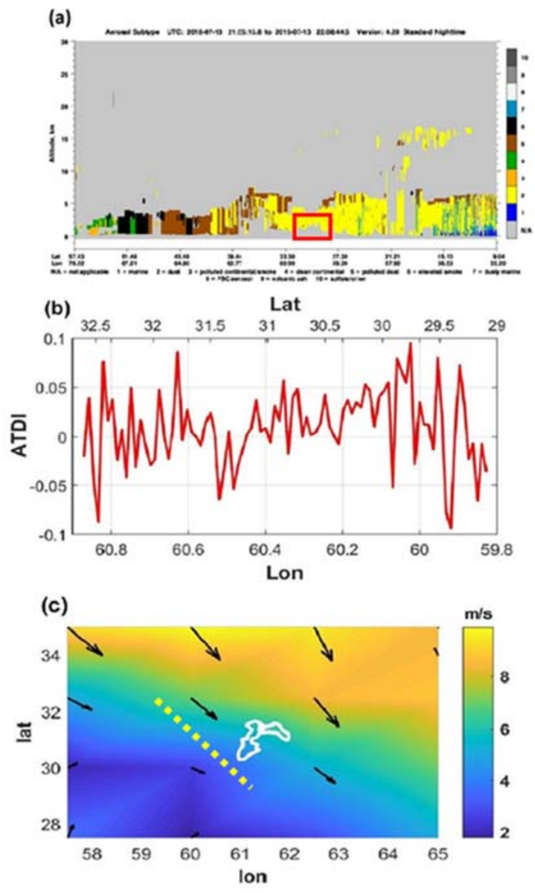

Fig. 3. Particle analysis: (a) CALIPSO Aerosol Type profile [9], (b) ATDI, (c) Wind speed on July 13, 2016 in Hamoun Lake.

6 Conclusions

An increase in the frequency and magnitude of dust formation in many regions and the decrease in the water body of the lakes due to human activities and climate change indicates the necessity of assessing dust events more closely and precisely using remote sensing and proper indicators.

This study used CALIPSO data to evaluate aerosol properties over the Aral Sea and Hamoun Lake. To derive a better understanding of aerosol particles and discrimination of aerosol and cloud particles in the atmosphere, a new index called ATDI is developed using EC and DR. Results show ATDI values between zero and 0.15 for desert particles and values between -0.3 and zero for polluted desert particles in both areas.

In addition, the developed index can provide information about cirrus or low-altitude cumulus clouds mixed with the aerosols. The wind speed profiles showed that north of the Aral Sea and northwest of Hamoun Lake are the main sources of the aerosol particles around the lake. The trend of drying Aral Sea with the changes in hydroclimatic parameters in the last 20 years can indicate that the impact of the Aral Sea on the region's climate is dramatically wide. Furthermore, shrinking of the Aral Sea could make the areas around the lake susceptible to the formation of the dust sources by reducing soil moisture, which can be further investigated through local measurements.

However, the scenario in Hamoun Lake, which is a seasonal lake, is different. Although the wind speed in the region is usually above 8-10 meters per second that can trigger dust storms in the region, the lake can reduce the aerosol particles in the region when it is full of water. On the other hand, most dust storm events have occurred when the lake's waterbody was at the lowest level. This can indicate the importance of Hamoun Lake to prevent and moderate extreme events in the region.

This study highlights the importance of proper indices to investigate different mechanisms of dust formation and aerosol particles in different geological locations and lakes' types. The efficacy of the ATDI can be further evaluated using varied Lidar ratios and a proper set of previous indices.

References

1. E. Proestakis, et al., Atmos. Chem. Phys. **18**, 1337–1362 (2018)
2. S. Sabetghadam, et al., Atmos. Environ. **246**, 118100 (2021)
3. X.X. Zhang, et al., Atmos. Environ. **238**, 117734 (2020)
4. A. Rashki, et al., Aeolian Res. **5**, 51–62 (2012)
5. Y. Yang, et al., Atmos. Chem. Phys. **21**, 4849–4868 (2021)
6. K.R. Kumar, et al., Int. J. Climatol. **38**, 320–336 (2018)
7. E. Goftari, *The investigation and tracking of dust particles over Hamoun Lake and the Aral Sea*, Sharif University of Technology, Tehran, Iran (2023)
8. E. Goftari, et al., International Congress on Civil Engineering at IUST 13 (2023)
9. CALIPSO, https://www-calipso.larc.nasa.gov/products/, last access: 2 April 2024