Comparison of Local and Transregional Atmospheric Particles Over the Urmia Lake in Northwest Iran, Using a Polarization Lidar Recordings

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Abstract. We have installed a scanning two-channel (532 nm) polarization lidar at the south-west coast of the hypersaline Urmia Lake since September 2018. Our measurements show dust layers are frequently transported to the region from sources like; Sahara, Mesopotamia, and Arabian Peninsula. Particles that are appearing at altitudes less than 2 km, have PDR < 25%, and mostly have local origins. From June to October, these lower altitudes atmospheric aerosols mostly are rising either from the dried lake bed or its coastal area. During cold months, atmospheric thermal inversion considerably increases the concentration of anthropogenic particles at altitudes less than 1 km AGL. Such particles possess PDR<10%. We haven't been able to detect dust or salt-dust particles that are originated from the lake bed and transported to altitudes above 3 km AGL.

Keywords: Urmia Lake, polarization lidar, dust, salt-dust.

1 Introduction

The Urmia Lake, a hypersaline lake, is in northwest of Iran. The lake is facing a serious drying scenario. Even though the lake has been recovered a bit during recent years, but still its surface is below the ecological level. The dried lake bed and its coastal area are covered with salt crusts, dust, and mixtures of salt and dust which we call the latter the salt-dust particles [1]. Therefore, such areas have the potential to become active sources of mineral particles and impact the neighboring and even distant lands to the lake. On the other hand, the Urmia Lake region like other areas in the west and northwest of Iran is considerably under the influence of dust sources in Mesopotamia, the Arabian Peninsula, and even North Africa [1-4]. It should be mentioned that more than 7 million inhabitants are living in the catchment area of the lake, and a considerable number of industries of different sizes are also active in this region. Therefore, urban-industrial particles also very frequently contaminate the atmosphere. To distinguish between different types of atmospheric particles that can be found in the atmosphere of this region, we have installed a polarization lidar at the southwest coast of the lake since 2018 [5].

In this paper, after introducing the lidar and measurements, we will discuss some recorded cases of different types of atmospheric particles including anthropogenic particles, dust and salt-dust from local sources, and transregional dust layers. An overview of all observed cases during the campaign will come after, and finally, the work is concluded in the last section.

2 Data Set and Measurements

The IASBS Scanning Polarization Lidar (ISPL) has been installed at the southwest coast of the Urmia Lake (37.3438 N, 45.2947 E, 1282 m AMSL) since September 2018, but in this work, we are reporting just measurements from July 2020 to March 2022 where the lidar was in operation for 65 days. The transmitter of ISPL is a frequency-doubled Nd:YAG laser (150/100 mJ/pulse at 1064/532 nm, 10 ns pulse duration) and it has just two cross-polarized receiving channels at 532 nm. Details of the ISPL's structure appeared in our previous work [5]. Even though the lidar can work both in azimuthal and zenith directions, here we are reporting measurements just in the zenith direction. To retrieve the particle backscatter coefficient (β) from the lidar data, the well-known Klett method [6] has been used and the particle depolarization ratio (PDR) has been calculated based on the work by Tesche, M. et. al. [7].

MODIS AODs' at 550 nm from Giovanni Deep Blue, and radiosonde data from Tabriz airport are other complementary data that have been used in this work. Also, the NOAA HYSPLIT model has been used to track back the detected layers of atmospheric particles.

3 Results and Discussions

In this section, we are presenting 3 sample cases of detected layers of atmospheric particles. The first two cases represent particles originating from the local sources in i.e., urban industrial pollution and salt-dust particles. The next case corresponds to transport of dust layers from Mesopotamia to the Urmia Lake region. The last part of this section is an overview of all recorded events during the campaign.

3.1 Case Studies

Case I: Local particles, 8-9 January 2022

Fig. 1a is the range corrected time-height series of the ISPL parallel channel at 532 nm from 17:20 UTC, 8 January 2022 to 07:20 UTC, 9 January 2022. The figure shows a dense layer of particulate matter extended from the surface up to ~1 km above the ground level (AGL). The recorded data for the time period specified by two red dashed lines in **Fig. 1a** is used to retrieve the β, and PDR. **Fig. 1b** depicts the obtained profiles of β (blue line) and PDR (red line). Their corresponding error values are shaded areas around the lines. **Fig. 1a** shows a very dense layer of atmospheric particles in the planetary boundary layer (PBL). **Fig. 1b** has more details of this layer. Just at the vicinity of the surface, β is ~ 5.5×10^{-5} $km^{-1}sr^{-1}$ but is decreasing with the altitude, and another layer appears at ~400 m AGL. At the vicinity of the surface, PDR is ~12% but for the layer at ~400 m AGL, it decreases to ~ 8%. The β-profile shows another layer at ~900 m AGL where its PDR is ~15 %. The potential temperature (θ) profile in **Fig. 1c** (12:00 UTC, 8 and 9 January 2022, Tabriz Airport) shows a very stable atmosphere below 500 m AGL on 8 January but this is not the case for the next day. The lidar time-height series in **Fig. 1a**, also shows how the boundary layer raised to altitudes above 600 m AGL on 9 January. Since the lidar station is just at the coast of the lake, we expect the increase of PDR just at the vicinity of the surface is due to existence of some wet salt or salt-dust particles but the dens layer at ~400 m AGL should be a concentration of the urban-industrial pollution in a stable atmosphere. It is expected that the aerosol layer at ~900 m AGL that has higher values of PDR, again had been originated from the lake bed. It should be mentioned that the obtained PDR values close to the surface and for the layer at ~900 m are in agreement with previously reported values of PDR for wet and dry salt particles [8], and CALIPSO recordings over the Urmia Lake [1, 9].

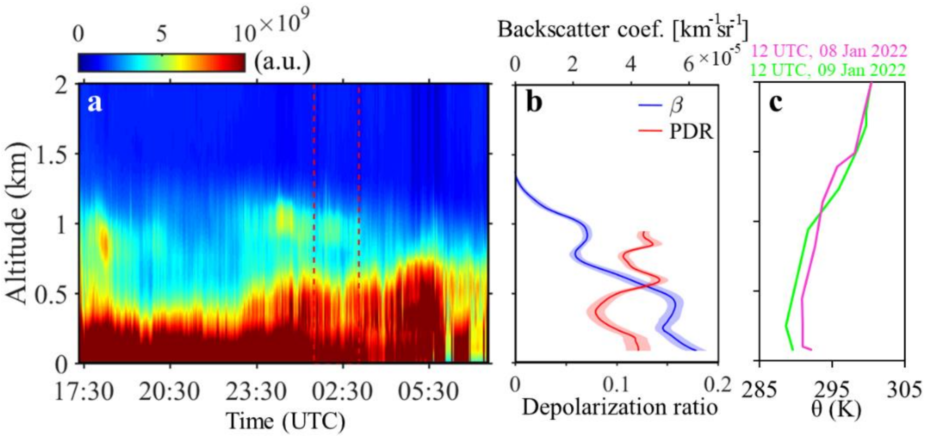

Fig. 1. (a) Parallel channel time-height series of range corrected lidar 8 – 9 January 2022. **(b)** β (blue) and PDR (red) profiles derived from lidar signals between two dashed red lines on (a), shaded areas are corresponding errors **(c)** potential temperature vertical profile at 12:00 UTC, 8 and 9 January 2022, Tabriz airport radiosonde. Altitudes are measured from the ground level.

Case II: Local particles, 19-20 August 2020

Fig. 2a shows the parallel channel time-height series of range corrected lidar signal at 532 nm from 15:30 UTC, 19 August to 11:50 UTC, 20 August 2020. Referring to **Fig. 2a,** it can be found that a thick atmospheric aerosol layer is extended from the surface up to ~3 km AGL. **Fig. 2b** depicts, for the part of the time series that is between two dashed red lines in **Fig. 2a**, β is almost constant up to ~2.0 km AGL but PDR is ~25% close to the surface then decreases to a local minimum of ~18% at 1.35 km AGL where β is maximum. The PDR has a local maximum of ~ 19% at an altitude of ~ 1.8 km AGL. β and PDR have other local maxima ~2.7 km AGL, where PDR is ~14%. **Fig. 2c** depicts 48 h HYSPLIT backward trajectories ending at the lidar station. It clearly shows, particle layers in **Fig. 2a** have local origins. PDR values in **Fig. 2b** indicate, near the surface some pure dust particles should exist but at higher altitudes, there should be a mixture of dust, salt, and salt-dust particles.

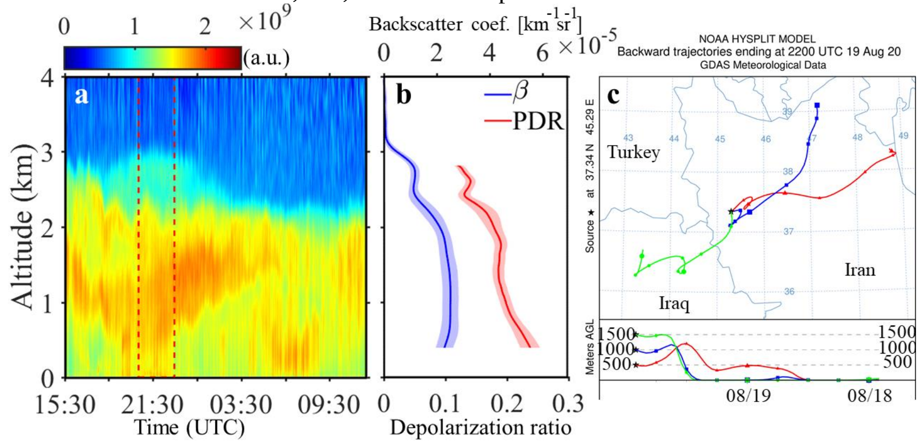

Fig. 2. (a) Parallel channel time-height series of range corrected lidar signal, 19 – 20 August 2020. **(b)** β (blue) and PDR (red) profiles derived from lidar signals between two red dashed lines on time-height series in **(a)**, shaded areas are corresponding errors. **(c)** 48 h HYSPLIT backward trajectories ending at the lidar station at 22:00 UTC on 19 August 2020. Altitudes are measured from the ground level.

Case III: Transregional dust layers, 22 and 23 July 2021

Fig. 3a and **3b** depict two dust layers originated from the north of the Mesopotamian region (**Fig. 3c**). The Aqua-MODIS AOD at 550 nm over the region on 21 July 2021 is shown in **Fig. 3c**. The first layer is extended from the surface up to ~2.5 km AGL and the altitude of the higher one is ~3 km AGL (**Fig. 3a**).

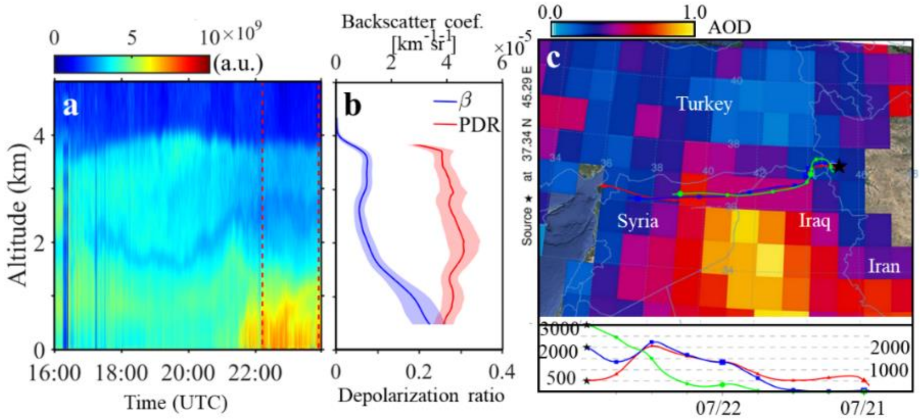

Fig. 3. (a) Parallel channel time-height series of range corrected lidar signal, 22 – 23, July 2021. **(b)** β (blue) and PDR (red) profiles derived from lidar signals between two red dashed lines on time-height series. **(c)** 48 h HYSPLIT backward trajectories ending at ISPL on 23:00 UTC 22 July 2021 overlaid on Aqua-MODIS daily deep blue AOD at 550 nm on 21 July 2021. Altitudes are measured from the ground level.

The retrieved PDR values for these layers vary from ~25 – 30%. Where lower values are for that part of the lower layer that is closer to the surface even it has higher β-values (**Fig. 3b**). It seems that when salt, and salt-dust particles, that have lower PDR values, are mixed with pure dust, the PDR of the mixture is decreasing.

3.2 Overall Behavior of Atmospheric Particles

Table 1 is an overview of all recorded events from 13 July 2020 to 8 March 2022. It should be mentioned that the reported PDR values are averaged over all layers originated from a specific source. It is noticeable that from all the recorded events 60% of them are from the sources inside the Urmia Lake catchment area and the rest 40% are from distant sources. When the particles are raising from the lake bed or its coastal area, the PDR is ~14 – 22%. However, in vicinity of the surface, for some cases like case II (**Fig. 2**) the PDR is getting close to that of pure dust [10]. From 39 events originated from local sources, only 5 (12%) of them correspond to anthropogenic particles. **Table 1** shows, the Mesopotamian region is the most influential distant source over the Urmia Lake and the Arabian Peninsula the least.

Table 1 An overview of all recorded events by the ISPL from 13 July 2020 to 8 March 2022

Source		Particle type	PDR averaged	Layer height (m)	Events Frequency	
					(days)	(%)
local	summer	Salt-dust	0.18 ±0.04	1900 ±600	18	28
	winter	Anthropogenic	0.11 ±0.01	500 ±250	5	7
		Salt-dust	0.17 ±0.02	800 ±350	16	25
Distant	Mesopotamia	dust	0.23 ±0.05	2500 ±850	20	31
	Africa	dust	0.24 ±0.04	4200 ±1800	5	7
	Arabian Peninsula	dust	0.23 ±0.03	900 ±200	1	2
Total					65	100

4 Conclusions

For the first time, we are reporting a comparison of atmospheric particles in the vicinity of the Urmia Lake in Northwest Iran using their particle depolarization ratio (PDR) retrieved from the recordings of a polarization lidar, ISPL. During a 21- month measurement campaign, we have recorded 65 days where different types of particles (salt, salt-dust, dust, anthropogenic) were contaminated the atmosphere. It is found that salt and salt-dust particles are the most dominant pollutant in this region (52% of all events). But distant sources also very frequently influence the region. Between them, the Mesopotamian region is the most influential one (31% of all events) but we even detected dust layers that had originated from North Africa and the Arabian Peninsula. We didn’t find any case where the raised particles from the lake bed got transported to altitudes above 3 km AGL. In the other words, based on these measurements, most probably the

Urmia Lake as a source of salt and salt-dust particles can't influence regions outside its catchment area.

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