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Short communication

Effect of meteorological variables on evaporation duct height (EDH): A case study in Basra, Iraq

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Propagation of electromagnetic waves (EMW) in the atmosphere is affected by refraction absorption and scattering by particles and aerosols. Abnormal refraction such as super refraction, negative refraction and trapped refraction can cause abnormal propagation of EMW. Part of the EMW under conditions of trapped refraction, is captured within the atmosphere and propagates back and forth between the lower and upper layers, like waves propagating in a metal tube; The regions of the atmosphere that cause this type of propagation are called atmospheric ducts. There are four kinds of atmospheric ducts: surface ducts, surface-based ducts, elevated ducts, and evaporation ducts. The evaporation duct (ED) is a weather phenomenon that often occurs in marine environments and affects the operation of shipborne radar. The most important evaluation parameter is the evaporation duct height (EDH). Forecasting the EDH and adjusting the working parameters and modes of the radar system in advance can greatly improve radar performance (Hitney, 2002).

The ground penetrating radar (GPR) is an effective geophysical tool for assessing subsurface soil properties, such as moisture, root structure, and other properties, by transmitting electromagnetic waves into the ground and analyzing the feedback signal (Lombardi, *et al.,* 2022). The presence of this duct can have a profound effect on electromagnetic propagation over the water surface in the microwave range. In coastal areas, the radar signal is affected by the evaporation duct, which causes the refraction of electromagnetic waves and affects the accuracy of the feedback signal information (Yang, *et al.,* 2022). As a result of the sporadic meteorological phenomena, the evaporation duct heights are subject to significant spatial and temporal changes, which is a phenomenon related to the weather (Ivanov *et al.,* 2007). Mai *et al.,* (2020) developed a new method for diagnosing and predicting the EDH on the sea surface, which has a certain reference significance for the study of ED. A machine learning technique (Ji *et al*., 2024) and deep neural network (Jiang, *et al.,* 2022) is used to improve the accuracy, which contributes to ensuring the stable operation of radio systems. Chiao, *et al.,* (2024) used radiosonde data to study the evaporation duct (ED) and evaporation duct height (EDH). The study showed that the EDH experienced diurnal variations. Present study has therefore, been aimed to study the EDH and relate it with the fluctuations in weather parameters.

Study area

The study area is Basra region situated in Iraq, which extends between latitudes 29°–37° N and longitudes 38°–48° E, with a total area of 437072 km^2 (Al-Lami *et al*., 2024). Al-Faw is one of Iraq's major cities coastal, located in the far southeast of Basra Governorate, between longitudes 48°27′30" and 48°29′10" east, and latitudes 29°57′30" and 29°59′10" north. The region overlooks the Shatt al-Arab River to the east, overlooks the northeastern coast of the Arabian Gulf, and enjoys significant geographical and strategic importance on Iraq's coast, which is characterized by high temperatures and high levels of solar radiation. The region is also subject to multidirectional winds, the most important of which are northwesterly, southeasterly, and southwesterly winds (Abdalamer and Daham 2024).

Evaporation duct height (EDH) calculation

Daily weather data of the Al-Faw station, located in Basra city in southern regain of Iraq from January 1 to December 31, 2020 comprising of relative humidity (%), wind speed (m s^{-1}), air temperature (^{0}C) and atmospheric pressure (hPa) were obtained from the Iraqi Meteorological Organization and Seismology Basra, Iraq, to compute evaporation duct height (EDH). The formula developed by NASA Marshall-Smith model (Marshall and Smith, 1997) was used to calculate the EDH, as given below:

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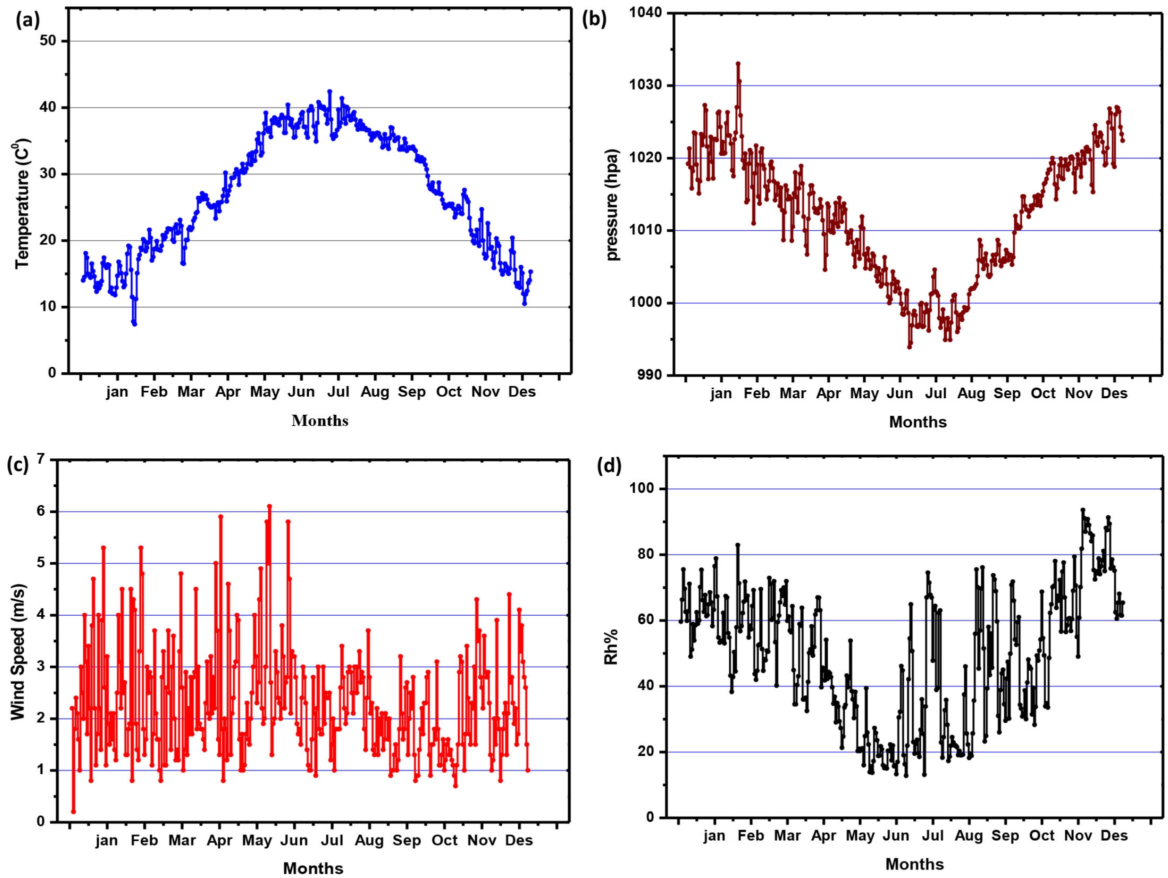

Fig. 1: Daily variations of (a) air temperature (°C), (b) atmospheric pressure (hPa), (c) wind speed (m s^{-1}) and (d) relative humidity (%)

$$H = (T - Td) \times \left\{0.024 \times \left(\frac{P}{1013.23}\right)\right\}^{0.5} \times \left[1 + 0.0536 \times \left(\frac{WS}{100}\right)^{0.56}\right]$$

where H is the evaporation duct height in meters, T is the air temperature in Celsius, Td is the dew point temperature in Celsius, P is the atmospheric pressure in millibars, and WS is the surface wind speed in meters per second.

The relation between weather parameters and EDH were developed. The relationship between two variables was tested for its significance using a t-test, the value of t was compared with the table value of t (tc). If the value of t > tc, the relationship is significant, and vice versa.

Variation in weather variables during the year

Fig. 1 shows the daily variations in weather parameters during the year 2022. Fig. 1(a) shows the daily variation in the air temperature value during the year. The air temperature increases from about 15 ^{0}C during January to more than 40 °C during June and July and then decreases continuously and reaches to less than 10°C during December. Fig. 1(b) presents the behavior of atmospheric pressure (hPa) during the year, the trend of which is in reversal of air temperature. The lowest atmospheric pressure (less than 1000 hPa) was recorded during June and July, while the highest value (more than 1020 hPa) was recorded during winter season (November to February). The wind speed has been highly fluctuating during the year, without any seasonal pattern (Fig. 1 c). The daily variations in relative humidity (Fig. 1d) also show highly fluctuating but with a seasonal variation being higher in rainy and winter seasons and lower humidity during summer season (May June).

Evaporation duct height and frequency

Fig. 2(a) shows the changes in the evaporation duct height (EDH) value during January to December 2020; the height of the evaporation duct increases during the summer season and peaks during July and August, with the EDH reaching a height of 6 meters. The height decreases in winter, reaching its lowest value during December and January, with a minimum of less than 0.5 meters. This variation is due to the influence of atmospheric variables that are presented in Fig. 1. Fig. 2(b) shows that the highest frequency for evaporation duct height is at 2m, where it is 125 times; frequency of 3 m EDH is 70 times, followed by frequency of 1 m EDH as 60 times. The EDH of 5m high has frequency of 50 times, and the least frequency (20 times) was EDH of 6m high. Thus, the most common evaporation duct height occurs at a height of 2 m and often does not exceed 6 m.

Relation between atmospheric variables and EDH (m) values

Fig. 3 (a) shows a linear correlation between EDH values and temperature, where each increase in surface temperature leads to increasing EDH values. The correlation coefficient for this relationship reaches R = 0.75, which indicates a strong linear correlation. The increase in temperature leads to an increase in the height of the atmospheric boundary layer (AL-Khuwaylidee

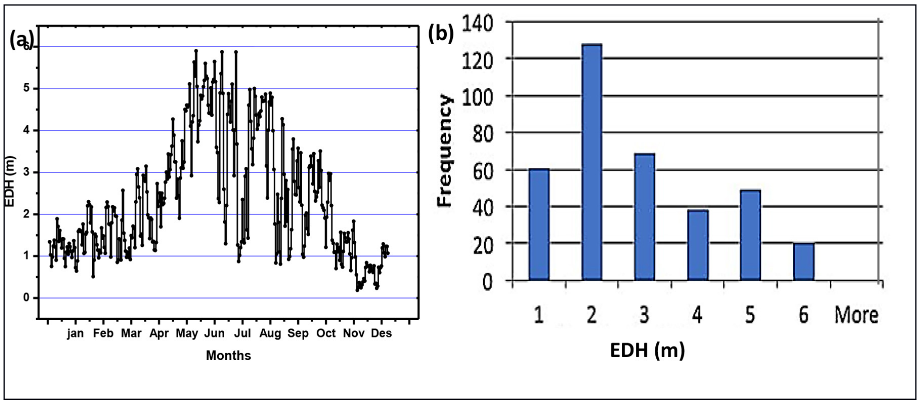

Fig. 2: (a) Evaporation duct height (EDH) during 2020 and (b) frequency distribution of EDH

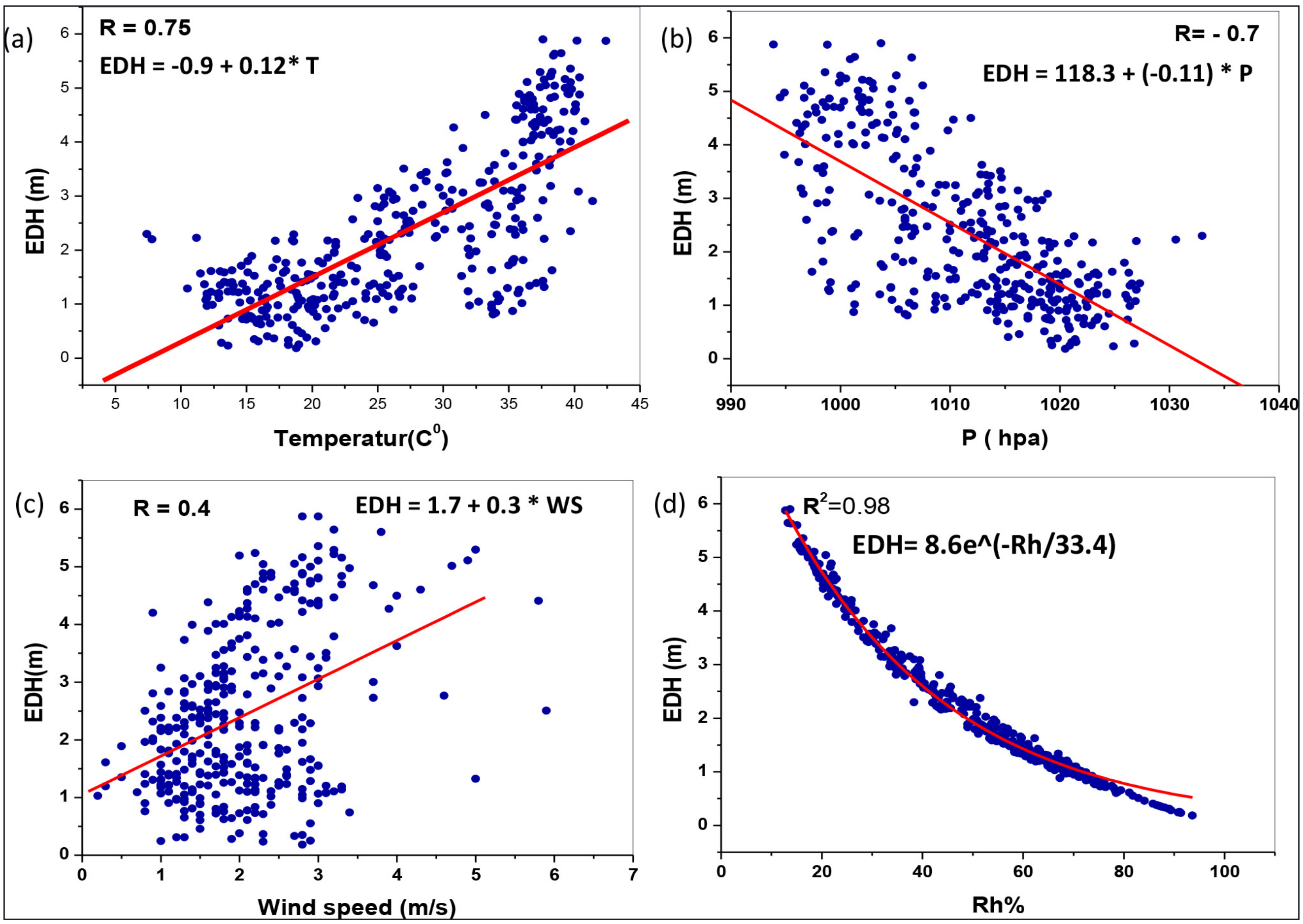

Fig. 3: Relation between the evaporation duct height (EDH) (m) and (a) air temperature (C°), (b) atmospheric pressure (hPa), (c) wind speed (m/s) and (d) relative humidity (%)

et al., 2023). This is reflected in all the secondary layers in the atmospheric boundary layer, such as the macro layer and the surface layer. Thus, it is clear why temperature affects the behavior of EDH, considering that it is part of the surface layer. The result was t= 14 > tc, where tc=1.660. Based on this result, the correlation has a significant value. Fig. 3(b) shows the linear relationship between EDH and atmospheric pressure. The linear correlation between the two variables is evident, with a correlation coefficient of R = 0.7, indicating a strong correlation between the variables.

As shown in Fig. 3 (c). There appears to be a weak direct proportional relationship between EDH (m) and wind speed, where the increase in wind speed contributes to increased EDH values due to increased evaporation from the sea surface, which increases the thickness of the ED layer. The correlation coefficient (R) for this relationship was 0.4. This value indicates a weak correlation. However, the correlation coefficient was significant at the 0.05 significance level. The result was t= 4 > tc, where tc=1.660. Based on this result, the correlation has a significant value. Finally, Fig. 3 (d) presents the correlation between EDH values and relative humidity. It is a decay exponential relationship, and the coefficient of determination, R^2, has a value of 0.98, indicating a strong effect of relative humidity on EDH values. Increasing relative humidity will reduce evaporation from the sea surface, and the inverse effect of relative humidity on temperature also plays a role in affecting EDH values. Based on this result, the correlation has a significant value.

Thus, the analysis revealed that EDH values along the coast near Basra ranged from less than 1 meter to 6 meters, with an altitude of 2 meters being the most frequent throughout the year. Temperature has a positive effect on EDH values, increasing them as BLH increases. Relative humidity, on the other hand, works in the opposite direction to temperature. Increased relative humidity reduces evaporation from the surface due to the formation of a saturated layer above the sea surface, which inhibits evaporation and thus slows the growth of ED. Atmospheric pressure also works, as high pressure reduces EDH by making BLH thinner than usual, increasing thermal inversion in the surface layer, and increasing the movement of vertical currents downward. The effect of surface winds is considered weak; however, they play a significant role in displacing saturation from the near-surface layer, allowing for more evaporation, thus increasing EDH values.

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