Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454

Vol. 22 | No. 3 | pp. 1447-1455 | 2023

Original Research Paper

https://doi.org/10.46488/NEPT.2023.v22i03.030

Open Access Journal

Determination of the Dynamics of Thunderstorms Through the Dry Adiabatic Lapse Rate and Environmental Lapse Rate

Shiemaa A. Hashim*, Jasim H. Kadhum*, Zainab M. Abbood*, Osama T. Al-Taai*† and Wedyan G. Nassif*

*Department of Atmospheric Science, College of Science, Mustansiriyah University, Baghdad, Iraq

†Corresponding author: Osama T. Al-Taai; osamaaltaai77@uomustansiriyah.edu.iq

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 28-01-2023
Revised: 05-03-2023
Accepted: 10-03-2023

Key Words:
Thunderstorms
Weather factors
Cloud formation
Lapse rates

ABSTRACT

This research aims to determine the types of thunderstorms formed in the thickness of the cloud (determine the Dry adiabatic lapse rate (DALR) and Environmental lapse rate (ELR)) in the case of precipitation during the day. Data were taken by Temperature, Dew point, Atmospheric Pressure, and Height from re-analysis by the (ECMWF) for the heights (0-18000) m, the levels of pressure (1000-100) mbar, low cloud cover data, and the characteristic days ((18, 24, 27) February, 28 April, and 25 November) of the year 2018 for Baghdad station were chosen to obtain the largest possible number of clouds and their diversity to use them in calculating the cloud cover and weather stability in terms of calculating the daily change, temperature, dew point in addition to calculating the low cloud cover with altitude and atmospheric instability. The Sigma Plot program was used in this research to determine the base of clouds and thunderstorms. The change in temperature, Dew point, clouds base, and altitude was determined, then the cloud thickness, types, and classification were calculated. The clouds found are strong thunderstorm clouds characterized by thickness and height, such as the clouds of Nimbostratus (Ns) and Cumulonimbus (Cb).

INTRODUCTION

A thunderstorm is a turbulence in the atmosphere. It is a single or multiple electric discharge that reveals itself with a flash of light and a Sharpe or bruising sound like thunder. Thunderstorms accompany clouds of load and are often accompanied by precipitation from those that reach the Earth through showers of rain, snow, snowballs, or cold (Tompkins 2003). Strong winds usually accompany them and produce heavy rain and sometimes snow, sleet, or hail, but some thunderstorms produce little precipitation or no precipitation (Abbood & Al-Tai 2018a, 2018b, 2020). As the warm, moist air moves upward, it cools, condenses, and forms a cumulonimbus cloud reaching over 20 kilometers (Al-Taai & Abbood 2020a). As the rising air reaches its dew point temperature, water vapor condenses into water droplets or ice, reducing pressure locally within the thunderstorm cell. Any precipitation falls a long distance through the clouds toward the Earth's surface. As the droplets fall, they collide with other droplets and become larger (Al-Taai & Abbood 2020b, Sun et al. 2000).

ORCID details of the authors:

Osama T. Al-Taai: https://orcid.org/0000-0002-4747-214X

Cloud Formation

The process of forming clouds, or condensation in the air, is very delicate and subject to several physical laws. This difference is responsible for the formation of different types of clouds, such as stratified and cumulative clouds, and it is also responsible for the difference in the height of the rules of the clouds and the difference in thickness (Tompkins 2003, Al-Taai et al. 2021a). Accordingly, the decrease in air temperature decreases in three forms. The first form is called the normal laps rate, which varies according to the times of the day, seasons, and locations, but in general, it is 6.3 percent per 1000 meters. The second, this decrease is at a percentage of 9.8 per 1,000 meters up, and the third is called the Moist Adiabatic Lapse Rate, which equals 6.4 percent per 1,000 meters upwards (Yamashita et al. 2004, Nassif et al. 2021a). The decrease in air temperature by elevation depends on Poisson's law (Which states that a mass of air rising vertically upwards gradually loses part of its temperature).

On this basis, the decrease in air temperature first is subject to Poisson's law until it reaches a certain height and its temperature decreases below the dew point. At this temperature, condensation occurs as clouds form. (Eastman et al. 2011, Al-Taai et al. 2021b).

MATERIALS AND METHODS

The Atmospheric Stability

Clouds are formed when the air contains as much water vapor (gas) as possible. This is called the saturation point (Hartmann 2013, Tierney et al. 2001). The lifting condensation level (LCL) is formed when the temperature reaches the dew point. It is the level at which condensation can occur through uplift. At the lifting condensation level, the base of the cloud is formed. Then the air is saturated (the air retains the largest amount of water vapor at a certain temperature), and the relative humidity is 100% (Cooper et al. 2003, Bryan & Fritsch 2000). When determining the high base of the cloud at the intersection point between the temperature of the antenna ejection temperature curve and the temperature of the dew point temperature curve symbolized by the symbol zb and determining the temperature of the upper cloud at the point of divergence of the temperature curve of the dew point temperature curve symbolized by the symbol zt, a thickness of the cloud (Δzc) can be determined using the following equation (Hartmann et al. 2013 & Nassif et al. 2022):

$$\Delta zc = zt - zb \qquad ...(1)$$

The Δzt can be calculated using the Hypsometric equation (Sun et al. 2000 & Nassif et al. 2021b):

$$\Delta zt = Rd \frac{Tv}{g} \ln \frac{P_1}{P_2} \qquad ...(2)$$

Where:

Δzt**:** The thickness of the cloud in km.

Rd**:** specific gas constant for dry air (287.1 $J.kg^{-1}. k^{-1}$).

Tv: Virtual temperature of the cloud in □k.

g: ground acceleration (9.8 $m.sec^{-2}$).

P_1: The pressure at the base of the cloud in mbar.

P_2: Pressure at the top of the cloud in mbar.

The air moves up or down within the atmosphere. It is affected by this process (Sun et al. 2000). The air parcels that do not contain clouds (are not saturated) cool at the dry adiabatic lapse rate (DALR) as they rise through the atmosphere (Sun et al. 2000). The DALR not only applies to absolutely dry air parcels but also parcels containing water vapor, so long as the relative humidity (RH) < 100%.

The parcel of non-saturated air will rise at a rate of cooling given by the dry adiabatic lapse rate where Cp is 1007 $J.kg^{-1}$. K and Γd are 9.8 $°C.km^{-1}$ (Hartmann 2013, Al-Taai & Wedyan 2020) as the following equation:

$$\Gamma d = \frac{g}{C_p} \qquad ...(3)$$

Where Γd is the dry adiabatic lapse rate, g is the Earth's gravity = 9.8 $m.sec^{-2,}$ and the Cp is the specific heat capacity. The atmosphere is highly variable in air temperature distribution. For dry air, it ranges as shown in Fig. 1 and Table 1 (Abbood et al. 2021, Mahdi et al. 2021).

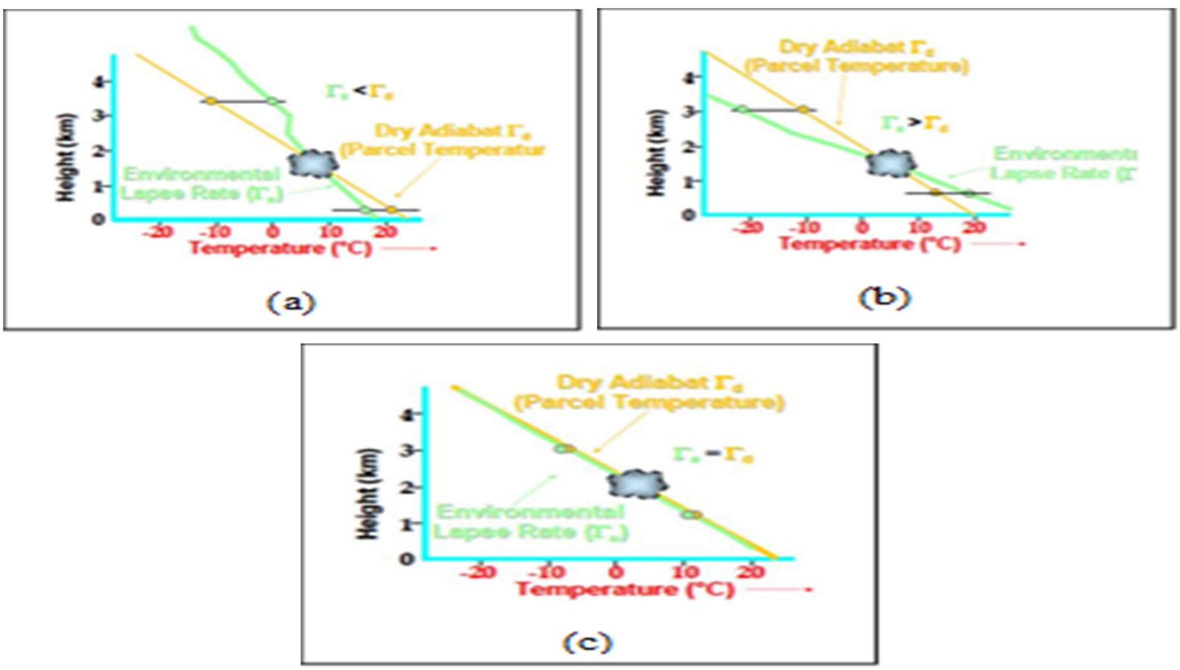

Fig. 1: The formation of clouds, in this case, is a) Stable, b) Unstable, and c) Neutral (Tierney et al. 2001, Buell 1943).

Table 1: The characteristics of ten cloud types (Nassif et al. 2021c).

Cloud Type	Symbol	High cloud base (km)	Temperature cloud base °C	Thickness (km)	Case of water in the clouds	rising airspeed ($m.sec^{-1}$)
Cirrus	Ci	10-5	70-,30-	2-0.5	Ice	0.3-0.1
Cirrostratus	Cs	10-5	40-,25-	2-1	Ice	0.3-0.1
Cirrocumulus	Cc	12-5	40-,25-	0.3-0.1	Liquid or mixed	1-0.3
Altostratus	As	8-3	30-,10-	3-1	Ice or mixed	0.3-0.1
Altocumulus	Ac	8-2	30-,10-	1-0.1	Liquid or mixed	1-0.3
Nimbostratus	Ns	2-0.5	20-,10-	10-2	Ice or mixed	1-0.3
Stratus	St	2-0	20-,10-	0.5-0.1	Liquid	0.3-0
Stratocumulus	Sc	2-0	20-,10-	2-0.1	Liquid or mixed	1-0.1
Cumulus	Cu	4-1	5,25-	4-0.5	Liquid	3-0.3
Cumulonimbus	Cb	4-1	5,25-	20-2	Mixed	30-3

Data Source

The work was carried out using the average hourly values of temperature and dew point temperature for selected days of the year 2018. Dataset values were obtained from the European Center for Medium-Range Weather Forecasts (ECMWF), https://www.ecmwf.int/en/forecasts/datasets (Berrisford 2009, Nassif et al. 2021d), for Baghdad city, located at ….33.375°N latitude, 44.375°E longitude, and 34.0m altitude in the center of Iraq. The determination of thunderstorms depends on weather factors such as temperatures, relative humidity, and dew point temperature over Baghdad City (Nassif et al. 2021a).

RESULTS AND DISCUSSION

The Temperature Changed with the Height

The behavior and temperature change at each pressure altitude how it changes with the height over Baghdad city for the year () 2018. For the daily change in temperatures, it occurs in temperatures during the Day and night, and this is due to the rotation of the Earth around itself and this change in temperature due to latitude; the temperature decreases as we move from the equator towards the poles due to the decrease in solar radiation. Also, as the temperature changes with the height in the first layer of the troposphere, the layer in which different weather phenomena occur. The higher the temperature, the air expands and rises to the top, its density decreases, and its pressure decreases. If the temperature drops, the air shrinks, and the density increase, then the drop to the bottom increases the air pressure. The range of pressure that you adopted in your study ((100-1000) mbar) of the daily temperature changes over Baghdad city during 2018 (Fig. 2).

Dew Point Temperature Change with the Height

The Dew point varies depending on the amount of water vapor in the air, with more humid air resulting in a higher dew point than dry air. Furthermore, the higher the relative humidity, the closer the dew point to the current air temperature, with 100% relative humidity meaning that the dew point is equivalent to the current temperature. When the air pressure increases, the dew point will increase. This means that if the pressure increases, the mass of water vapor in the air must be reduced to maintain the same dew point. The relationship between pressure and the dew point is direct; the higher the atmospheric pressure, the greater the dew point score, and vice versa. The range of pressure that you adopted in your study ((100-1000) mbar) of the daily temperature changes over Baghdad city during 2018 (Fig. 3.)

Calculations of the Daily Changes

The daily report of February 2018 for Baghdad station provides data on the thickness, height, type, and classification of the clouds and the weather stability of the cloud base and under the cloud base. Fig. 4 and Table 2 present the data of Baghdad station for 18th Feb. 2018. The state of instability of the daily cloud cover is determined at the Baghdad station, and it found that the clouds at low altitudes are unstable and clouds at high altitudes of 750 mbar were below or at ELR level, the cloud base being at 750 mbar pressure, either above or at the DALR level. The temperature at the base of the cloud in this form at the ELR level is 275 K, while the temperature at the highest level of DALR is 202 K. As for dew point temperature at the cloud base and the ELR level, it reached 274 K, as for the DALR height, it is 208 K, and we notice that the clouds were of a kind (Cb) and its classification is due to the vertical development clouds.

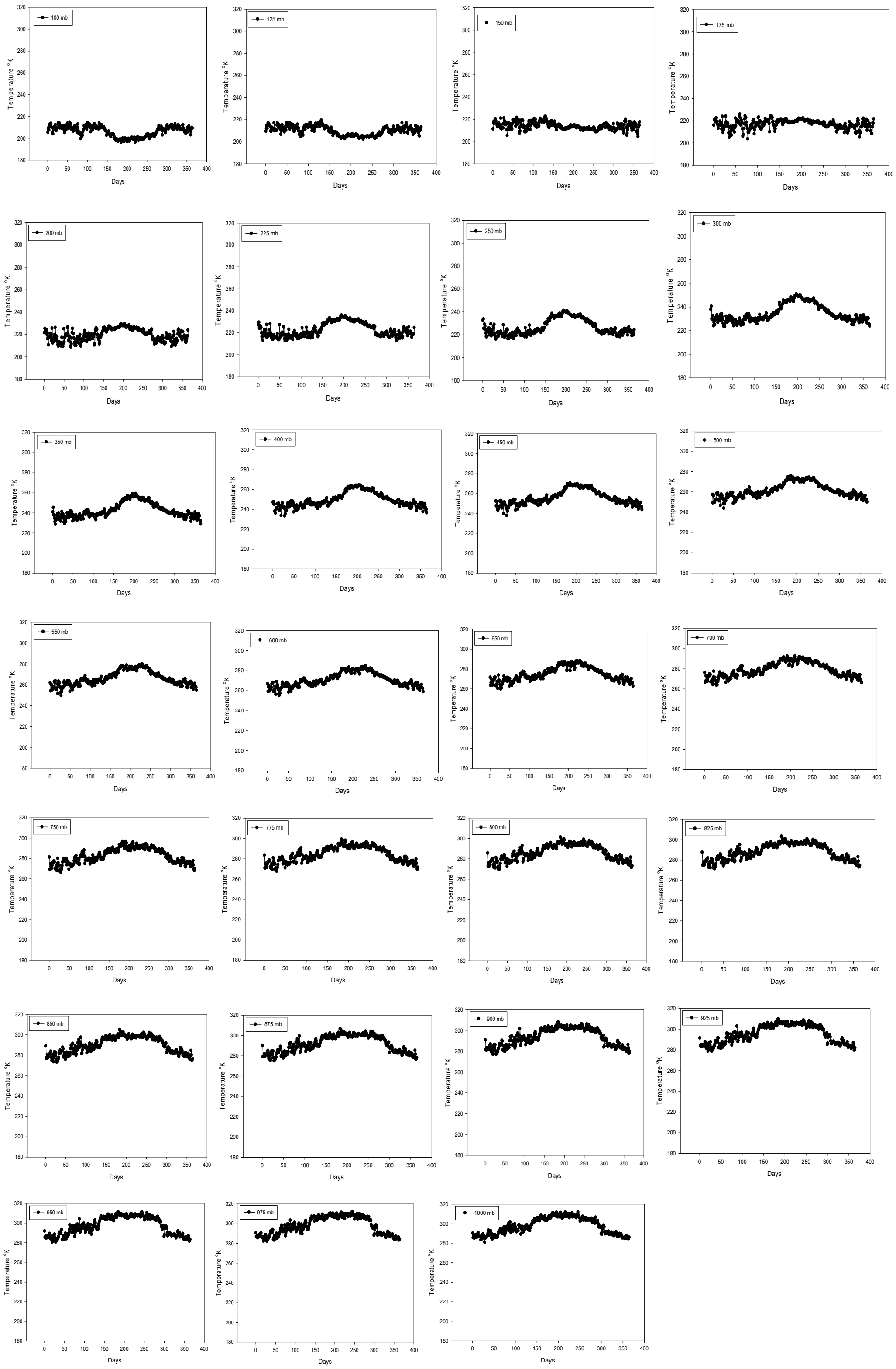

Fig. 2: The daily change of temperature at pressure from (100-1000) mbar for the year 2018 of Baghdad city.

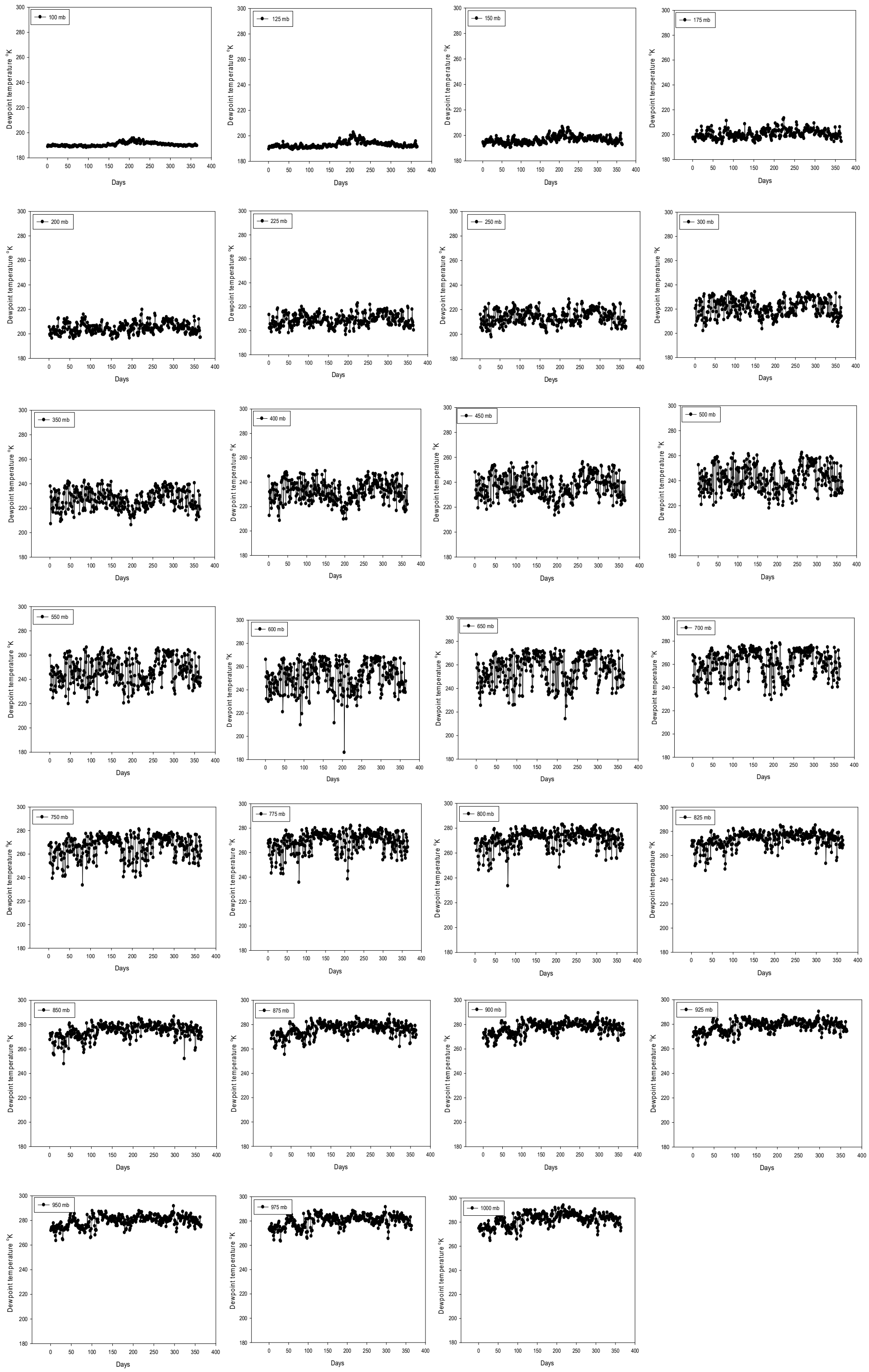

Fig. 3: The daily change of dew point temperature at pressure from (100-1000) mbar for the year 2018 of Baghdad city.

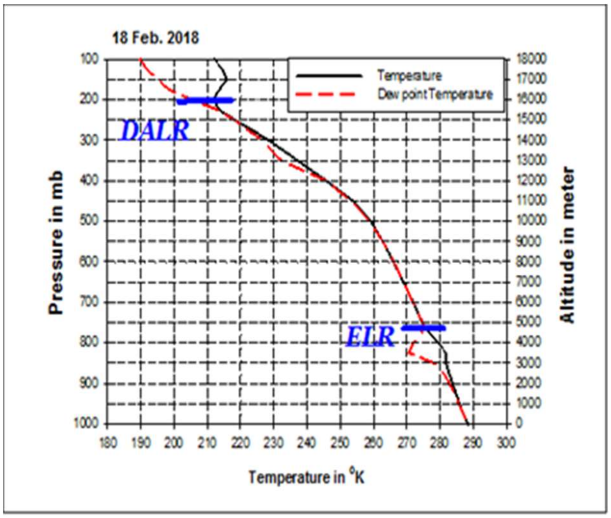

Fig. 4: Determine thunderstorms from the DALR and ELR levels for the day (18 Feb. 2018) in Baghdad city.

Table 2: Information on the weather (18 Feb. 2018).

Baghdad station data	18 Feb. 2018
Pressure base [mbar]	760 mbar
High base [m]	4900 m
The temperatures of the base [ºK]	275 K
Dewpoint the base [ºK]	274 K
Pressure top [mbar]	200 mbar
High-top [m]	16000 m
The temperatures of the top [ºK]	212 K
Dew point the top [ºK]	208 K
Thickness [m]	12000 m
Cloud type	Cb
Cloud classification	Low Clouds
Stability state	Instability
Pressure under the base [mbar]	750 mbar

Fig. 5 and Table 3 present the data of Baghdad station for (24 Feb. 2018). The state of instability of the daily cloud cover was determined at the Baghdad station, the environment laps rate gradual fall, and the decrease of an atmospheric variable with height where below or at ELR level is the cloud base being at 700 mbar pressure, either above or at the DALR level the cloud beings to fade at latitude 15800 m and with your thickness 6000. The temperature at the base of the cloud in this form at the ELR level is 270 K, while the temperature at the highest level of DALR is 219 K. As for the dew point temperature at the cloud base and the ELR level, it reaches 269 K, as for the DALR height, it is 204 K, and we notice that the clouds were of a kind (Ns) and its classification is due to the low clouds.

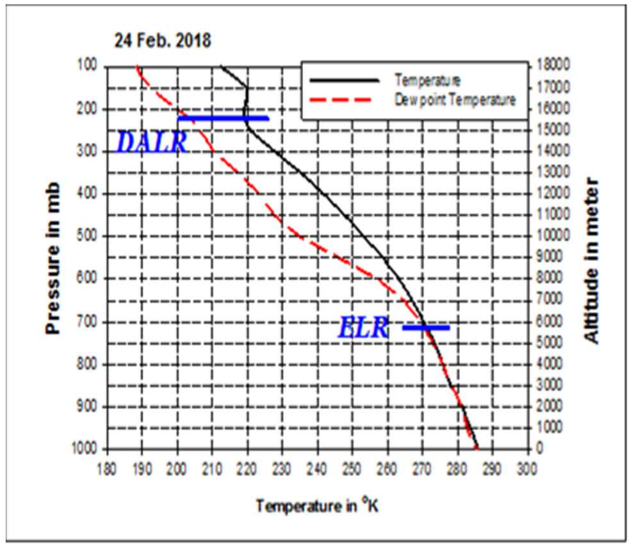

Fig. 5: Determine thunderstorms from the DALR and ELR levels for the day (24 Feb. 2018) in Baghdad city.

Table 3: Information on the weather (24 Feb. 2018).

Baghdad station data (hpa)	24 Feb. 2018
Pressure base [mbar]	710 mbar
High base [m]	5900 m
The temperatures of the base [ºK]	270 K
Dewpoint the base [ºK]	269 K
Pressure top [mbar]	220 mbar
High-top [m]	15800 m
The temperatures of the top [ºK]	219 K
Dew point the top [ºK]	204 K
Thickness [m]	10000 m
Cloud type	Ns
Cloud classification	Vertical Clouds
Stability state	Instability
Pressure under the base [mbar]	700 mbar

Fig. 6 and Table 4 present the Baghdad station data (27 Feb. 2018). The instability of the daily cloud cover is determined at the Baghdad station, which shows the daily behavior of the low cloud cover in Baghdad station. In this case, the convective condensation level (CCL) occurs, which leads to a significant increase in the rate of thermal decrease in the lowest layer of air.

Hence, this is the level at which the cumulus cloud rules exist. To confirm the atmospheric instability of the cloud where below or at ELR level is the cloud base being at 940 mbar pressure, either above or at the DALR level, the cloud beings to fade at an altitude of 14000 m and with your thickness of 1800. The temperature at the base of the cloud

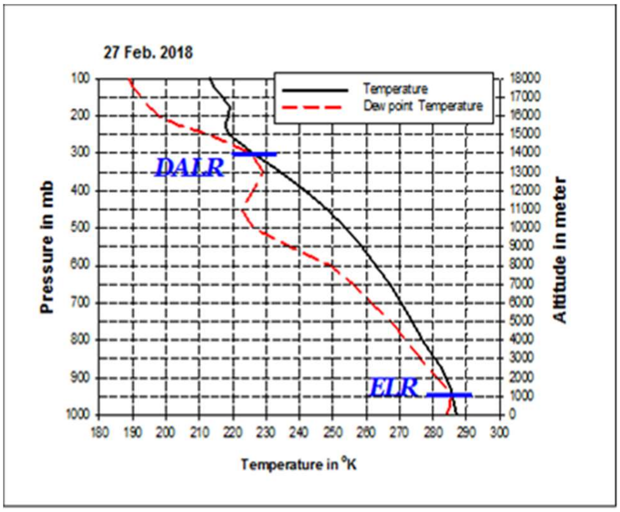

Fig. 6: Determine thunderstorms from the DALR and ELR levels for the day (27 Feb. 2018) in Baghdad city.

Table 4: Information on the weather (27 Feb. 2018).

Baghdad station data	27 Feb. 2018
Pressure base [mbar]	950 mbar
High base [m]	1000 m
The temperatures of the base [°K]	286 K
Dewpoint the base [°K]	284 K
Pressure top [mbar]	300 mbar
High-top [m]	14000 m
The temperatures of the top [°K]	227 K
Dew point the top [°K]	125 K
Thickness [m]	14000 m
Cloud type	Cb
Cloud classification	Low Clouds
Stability state	Instability
Pressure under the base [mbar]	940 mbar

in this form at the ELR level is 286 k, while the temperature at the highest level of DALR is 227 K. As for dew point temperature at the cloud base and the ELR level, it reached 284 K, whereas for the DALR height, it is 125 K, and we note that the clouds were of type (Cb), and its classification is due to the vertical development clouds.

Fig. 7 and Table 5 present the Baghdad station data (28 April 2018). The state of instability of the daily cloud cover is determined at the Baghdad station. When drawing pressure levels in this Fig., the dew point temperature change with height, and for each pressure level and the pressure level at the base of the cloud is about 950 mbar at the height of 1000 m, either above or at the DALR level the cloud at altitude 14000 m and with your thickness 1000.

The temperature at the base of the cloud in this form at the ELR level is 289 K, while the temperature at the highest level of DALR is 228 K. As for the dew point temperature at the cloud base and the ELR level, it reaches 288 k, whereas for the DALR height, the temperature was 223 K, and we notice that the clouds were of a kind (Cb) and its classification is due to the vertical development clouds.

Fig. 8 and Table 6 present the Baghdad station data (25 Nov. 2018). The state of instability of the daily cloud cover is determined at the Baghdad station. Where we notice a severe thunderstorm, starting at the pressure level at the base of the cloud, about 860 mbar at the height of 2700 m, and with a thickness of 3000, then it began to decay at the DALR level at the height of 14000 m and a pressure of 300 mbar. The temperature at the base of the cloud in this form at

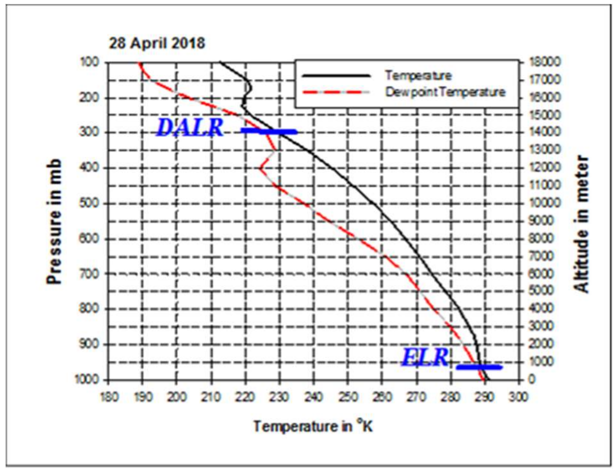

Fig. 7: Determine thunderstorms from the DALR and ELR levels for the day (28 April 2018) in Baghdad city.

Table 5: Information on the weather (20 April 2018).

Baghdad station data	20 April 2018
Pressure base [mbar]	960 mbar
High base [m]	900 m
The temperature of the base [°K]	289 K
Dew point the base [°K]	288 K
Pressure top (mbar)	300 mbar
High top [m]	14000 m
The temperature of the top [°K]	228 K
Dew point the top [°K]	223 K
Thickness [m]	14000 m
Cloud type	Cb
Cloud classification	Low Clouds
Stability state	Instability
Pressure under the base [mbar]	950 mbar

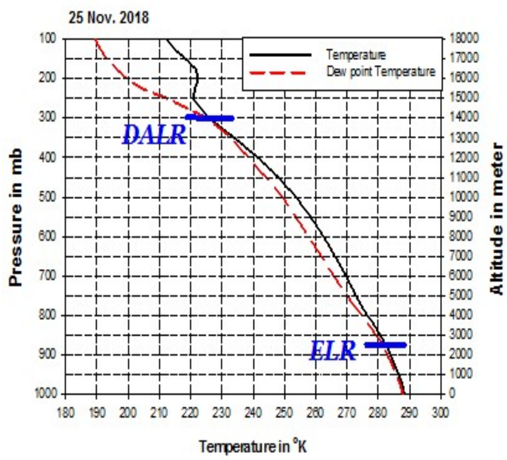

Fig. 8: Determine thunderstorms from the DALR and ELR levels for the day (25 Nov. 2018) in Baghdad city.

Table 6. Information weather on the day (25 Nov. 2018).

Baghdad station data	25 Nov. 2018
Pressure base [mbar]	870 mbar
High base [m]	2700 m
The temperatures of the base [ºK]	283 k
Dewpoint the base [ºK]	282 k
Pressure top [mbar]	300 mbar
High-top [m]	14000 m
The temperatures of the top [ºK]	226 k
Dew point the top [ºK]	125 k
Thickness [m]	12000 m
Cloud type	Cb
Cloud classification	Low Clouds
Stability state	Instability
Pressure under the base [mbar]	860 mbar

the ELR level is 283 K, while the temperature at the highest level of DALR is 226 K. As for the dew point temperature at the cloud base and the ELR level, it reached 282 K, as for the DALR height, it is 125 K, and we notice that the clouds were of a kind (Cb) and its classification is due to the vertical development clouds.

CONCLUSIONS

The change in the daily average temperature with an altitude in the troposphere at the pressure levels 1000 mbar and 950 mbar. The average daily temperature changes with altitude, as the temperature increases with the increase in altitude above ground level until it reaches its lowest possible level at the pressure levels of 150 mbar and 100 mbar. The daily average dew point temperature is similar and consistent with the behavior of changing the daily average temperature. That is, the form of the relationship between dew point temperature and temperature is a positive correlation. The thickness of the low clouds was determined for the selected days with the highest daily rains. Depending on these determinations, it had found that there were clouds of Nimbostratus (Ns) and Cumulonimbus (Cb) types.

Determine the clouds of Nimbostratus (Ns) and the Cumulonimbus (Cb) by setting the height of the Dry Adiabatic Lapse Rate (DALR) and the height of the Environmental Lapse Rate (ELR). The amount of precipitation in the (Nimbostratus (Ns) and Cumulonimbus (Cb) clouds was so high. The clouds found were strong thunderstorm clouds characterized by thickness and height, such as those of Nimbostratus (Ns) and Cumulonimbus (Cb).

ACKNOWLEDGMENTS

We extend our thanks and gratitude to Mustansiriyah University and our thanks to the European Center for Medium-Range Weather Forecast Dataset for providing the data used in this manuscript.

REFERENCES

Abbood, Z.M. and Al-Taai, O.T. 2018a. Calculation of absorption and emission of thermal radiation by clouds cover. ARPN J. Eng. Appl. Sci., 13(24): 9446-9456.

Abbood, Z.M. and Al-Taai, O.T. 2020. Data Analysis for cloud cover and rainfall over Baghdad City, Iraq. Plant Arch., 20(1): 822-826.

Abbood, Z.M., Al-Taai, O.T. and Nassif, W.G. 2021. Impact of wind speed and direction on low cloud cover over Baghdad city. Curr. Appl. Sci. Technol., 21(3): 590-600.

Abood, Z. and Al-Taai, O.T. 2018b. Study of absorbance and emissivity solar radiation by clouds, aerosols, and some atmospheric gases. J. Appl. Adv., 3(5): 128-134.

Al-Taai, O.T. and Abbood, Z.M. 2020a. Analysis of convective available potential energy by convective and total precipitation over Iraq. Indian J. Ecol., 47: 263-269.

Al-Taai, O.T. and Abbood, Z.M. 2020b. Analysis of the convective potential energy by precipitation over Iraq using ECMWF data for 1989-2018. Sci. Rev. Eng. Environ. Sci., 29(2): 196-211.

Al-Taai, O.T. and Wedyan, G.N. 2020. Impact rainfall on the aerosol optical thickness over selected stations in Iraq. IOP Conf. Ser. Mater. Sci. Eng., 928(7): 072053.

Al-Taai, O.T., Abbood, Z.M. and Kadhum, J.H. 2021a. Determination stability potential energy of thunderstorms for some severe weather forecasting cases in Baghdad city. J. Green Eng., 11(1): 779-794.

Al-Taai, O.T., Hashim, S.A., Nassif, W.G. and Abbood, Z.M. 2021b. Interference between total solar radiation and cloud cover over Baghdad City. J. Phys. Conf. Ser., 2114(1): 012070.

Berrisford, P. 2009. The ERA-interim archive. ERA Rep. Ser., 1: 1-16.

Bryan, G.H. and Fritsch, J.M. 2000. Moist absolute instability: The sixth static stability state. Bull. Am. Meteorol. Soc., 81(6): 1207-1230.

Buell, C. 1943. The determination of vertical velocities in thunderstorms. Bull. Am. Meteorol. Soc., 24(3): 94-95.

Cooper, C.S., Sudarsky, D., Milsom, J.A., Lunine, J.I. and Burrows, A. 2003. Modeling the formation of clouds in brown dwarf atmospheres. The Astrophysical Journal, 586(2), 1320.

Eastman, R., Warren, S.G. and Hahn, C.J. 2011. Variations in cloud cover and cloud types over the ocean from surface observations, 1954–2008. J. Clim., 24(22): 5914-5934.

Hartmann, D.L. 2013. Observations Atmosphere and Surface, Climate Change 2013: The Physical Science Basis. Working Group I Contribution To The Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, MA, pp159-254.

Mahdi, Z.S., Abbood, Z.M. and Al-Taai, O.T. 2021. Thunderstorm dynamic analysis based on total precipitation over Iraq. J. Eng. Sci. Technol., 16: 62–70.

Nassif, W.G., Al-Ramahy, Z.A. and Al-Taai, O.T. 2021a. Impact of rainfall and temperature on the frequency of dust storms for the period (1985-2018). AIP Conf. Proceed., 2372: 030005.

Nassif, W.G., Al-Taai, O.T., Mohammed, A.J. and Al-Shamarti, H.K.A. 2021b. Estimate probability distribution of monthly maximum daily rainfall of Iraq. J.Phys. Conf. Ser., 1804(1): 012078.

Nassif, W.G., Jaber, S.H., Naif, S.S. and Al-Taai, O.T. 2021c. Estimate of the dynamical change of air temperature, relative humidity, and dew point temperature for some selected station in Iraq. IOP Conf. Ser. Earth Environ. Sci., 910(1): 012010.

Nassif, W.G., Jasim, F.H. and Al-Taai, O.T. 2021d. Analysis of air temperature, relative humidity, and evaporation over Iraq using ECMWF reanalysis. Indian J. Ecol., 48(2): 446-452.

Nassif, W.G., Lagenean, F.H.S. and Al-Taai, O.T. 2022. Impact of vegetation cover on climate change for different regions in Iraq. J. Agrometeorol., 24(2): 138-145.

Sun, B., Groisman, P.Y., Bradley, R.S. and Keimig, F.T. 2000. Temporal changes in the observed relationship between cloud cover and surface air temperature. J. Clim., 13(24): 4341-4357.

Tierney, H.E., Jacobson, A.R., Beasley, W.H. and Argo, P.E. 2001. Determination of source thunderstorms for VHF emissions observed by the FORTE satellite. Radio Sci., 36(1): 79-96.

Tompkins, A. 2003. Impact of temperature and humidity variability on cloud cover assessed using aircraft data. Quart. J. Royal Meteorol. Sco., 129(592): 2151-2170.

Yamashita, M., Yoshimura, M. and Nakashizuka, T. 2004. Cloud cover estimation using multitemporal hemisphere imageries. International Archives of Photogrammetry Remote Sens. Spat. Inform. Sci., 35(7): 826-829.