

Ramal cyclone its impact on NE Environment and Atmospheric Dynamics

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Article history : Ist received, April 22, 2025 ; Final, June 5, 2025

Abstract

. The work addresses several aspects-of the modifications induced by the Ramal Cyclone (May 24-28, 2024) to the environment and atmosphere, while its track entered the North Eastern (NE) zone of India. The basic parameters taken as inputs to this study are temperature from the lower troposphere to the TTL height, precipitation (in its accumulated magnitude, daily, weekly, and anomaly amounts), as well as the deepening or sinking of tropopause heights. The system instability was examined through lapse rate, and the paper discusses how cyclone-induced water vapour and anthropogenic components trigger the atmospheric system from a stable (super moist adiabatic) to an absolutely unstable stage. The contributions of the cyclone to the environment of the NE zone are brought into the ambit of discussions.

Key words : Ramal Cyclone: Precipitation anomaly: Lapse Rate ;Atmospheric stability , Aerosol & environment

1. Introduction

A brief background:

Cyclone Ramal has a relatively short lifespan. As the basic processes of growth of a cyclone, it also started with a low depression on May 23, 2024, in the Bay of Bengal (BoB) and intensified into a cyclonic storm on May 24, 2024, as *Remal*. On 26 May, Remal further strengthened into a severe cyclonic storm with 3-minute sustained winds of 95 km/h, and made its landfall as a cyclonic storm on the same day, in the Sundarban area of West Bengal, India. It continued to weaken and dissipated on May 28 over Northeast India, as shown in the track (Figure 1).

Ramal intensified in a favourable environment with relatively high SST over the north BoB and low wind shear as the other cyclone in the BoB. However, this cyclone in the category of a severe storm was weaker in comparison to many of its predecessors, as detailed below in the list. The strength of a cyclone is dictated mainly by the low-pressure magnitude at its eye and sustained wind speed; thus, a comparative assessments of the intensity of Ramal are presented with four other storms, Fani, Nragis, and Amphan, which originated in the BoB:

Ramal : 1 minute sustained wind speed of 100 km/h and with lowest pressure of 978 hPa, it formed into a cyclone on May 24, 2024. On 26 May, it strengthened into a severe cyclonic storm with 3-minute sustained winds of 95 km/h, and made landfall on the same day. It dissipated on May 28.

Fani: Extremely Severe Category 5-equivalent tropical cyclone formed on 26 April 2019 with 3-minute sustained highest winds of 215 km/h and the lowest pressure of 932 hPa (mbar). Fani attained 1-minute sustained highest winds of 280 km/h and the lowest pressure of 900 hPa (mbar). It was a long-lasting cyclone, dissipating on 5 May 2019.

Nargis: An Extremely Severe, Category 4, cyclonic storm was formed on 27 April 2008 with 3-minute sustained winds of 165km/h and a lowest pressure of 962 hPa. It attained 1-minute sustained speed of 215 km/h and a lowest pressure of 937 hPa and dissipated on May 3, 2008.

Amphan: A Super Cyclone Category equivalent storm, formed on 16 May 2020 with 3-minute sustained wind of 240km/h and lowest pressure of 920 hPa. It attained 1-minute sustained speed of 270km/h with the lowest pressure of 901 hPa and dissipated on 21 May 2020.

Under this background, the Ramal is a short-lived severe cyclone; the rest mentioned above are of the extremely severe and super cyclones. With the severity of a Cyclone, the destruction caused by the cyclone hits hard at the landfall region, generating floods, causing heavy landslides, and loss of life, not to speak of huge damage to infrastructure. However, one can study the contributions of greenhouse components, aerosols of different dimensions, water vapour, that a cyclone track brings

with it as inputs for understanding atmospheric modifications and hence relevant consequences to weather and meteorological systems, which otherwise is not possible or difficult to create artificially .

The aim of this work is to examine the modifications imposed to the environment and atmosphere by this severe cyclone Ramal, while its track entered the NE region of India (Figure 1)



Figure 1a :Track of the Ramal cyclone and its entry in to the NE zone

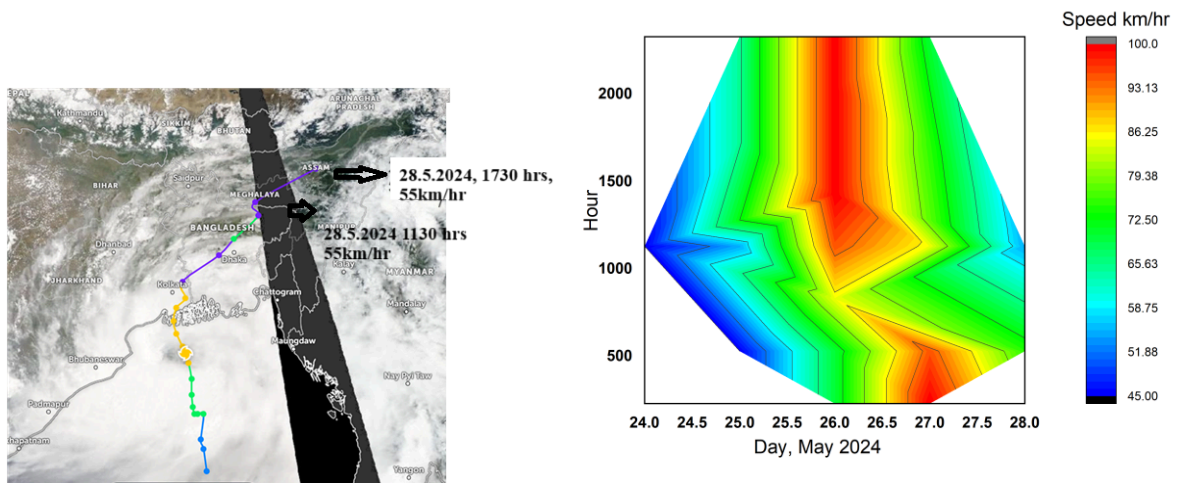


Figure 1b: Track of the Ramal cyclone entering Meghalaya at 1130 hrs and Guwahati at 1730 hrs on 28.5.2024, and 1c: the decrease of wind speed after attaining maximum on May 26

2. Observations

2.1 Cyclone induced modifications on Atmospheric/Meteorological Parameters:

(i) Precipitation: Accumulated magnitudes Daily & Weekly and Anomalous Status

We present here an overall effect on the meteorological parameters brought in by the humid air along the cyclone track over the NE zone. The heavy precipitations to this zone and Myanmar as presented in Figure 2 are the contributions of the Ramal cyclone. The more detailed precipitation scenario is presented in Figure 3, with one-day and weekly accumulated observations over Guwahati (26°N, 92°E). The one-day accumulated rain shows how Ramal changed the precipitation scenario from practically no rain (Figure 3ai) to heavy, intense precipitation (Figures 3aii and 3aiii) till it dissipated and lost strength (Figure 3aiv). Similar scenario for weekly accumulated precipitation pattern is also emerged, when with 5-10 mm of intensity before the cyclone track entered this zone (Figure 3b(i)), its intensity went up to 100mm (Figure 3b(ii)) and 125 mm (Figure 3b(iii)) in the next consecutive two weekly accumulated status. These are the consequences of the humid air brought in by the Ramal cyclone to this area.

Similarly, the one-week accumulated precipitation anomaly drastically reversed the status from a deficiency of -75% to -100% (Figure 3c(i)) to an excess of 75% to 100% as the cyclone track entered this NE region (Figure 3c(ii)).

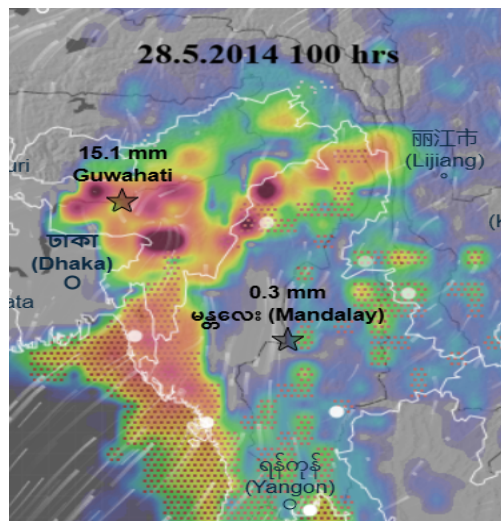
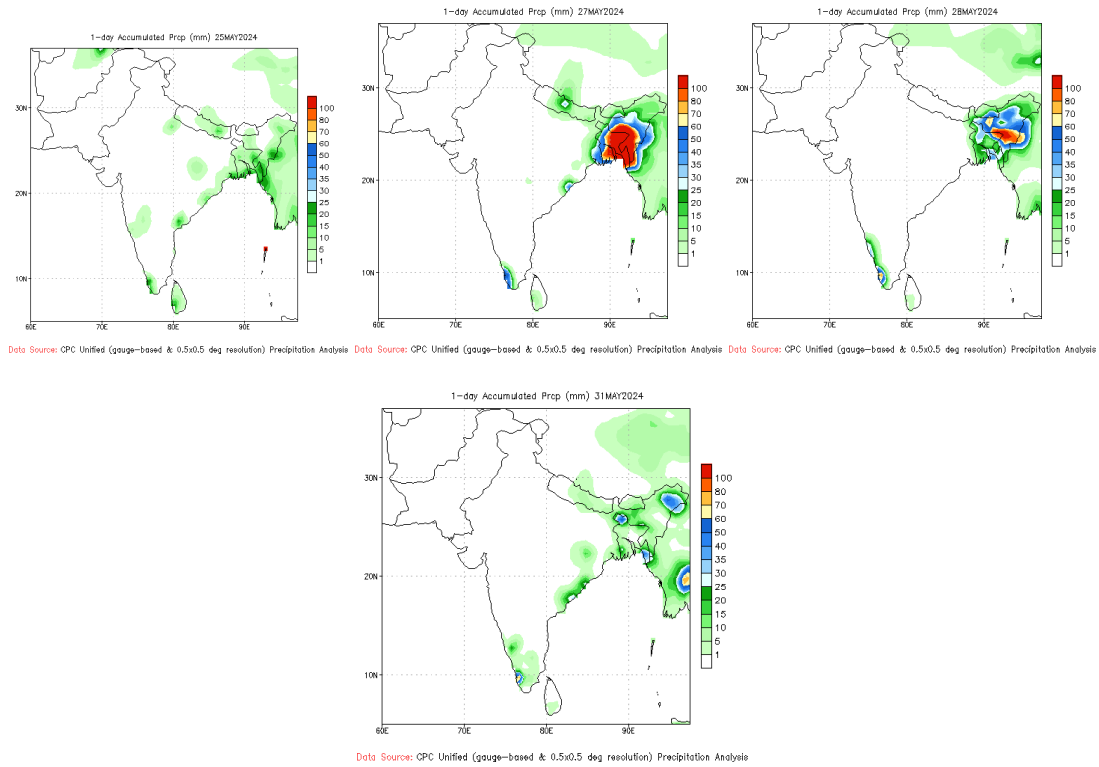
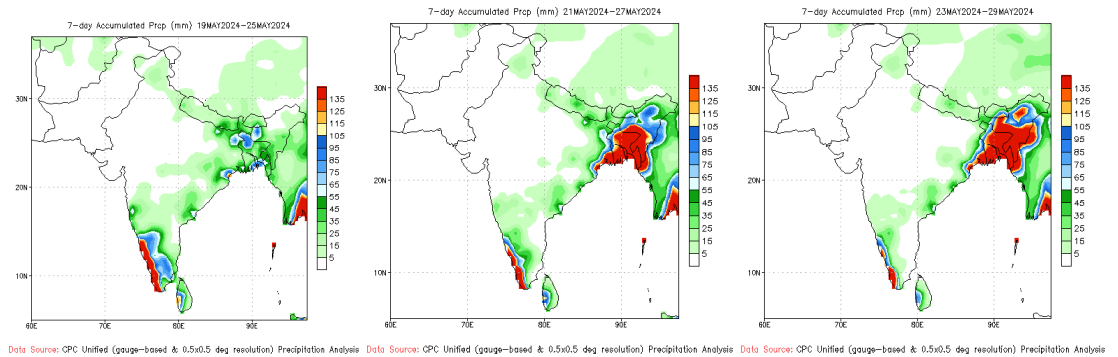


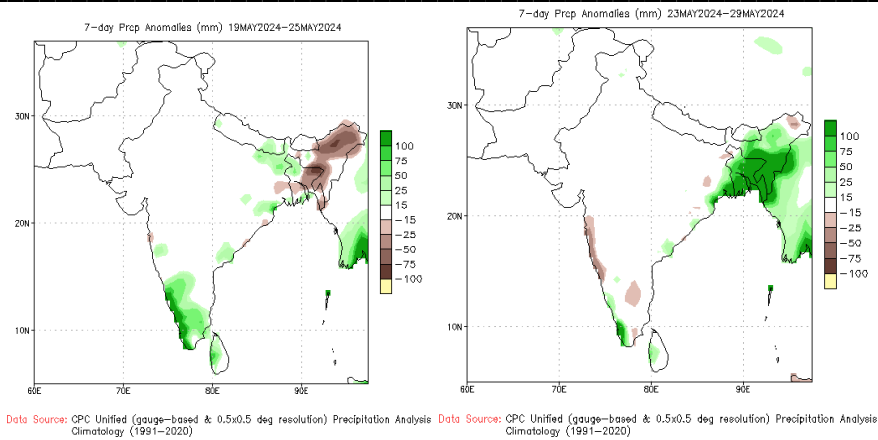
Figure 2: The cyclone Ramal carrying humid air (28.5.24) bringing heavy precipitation in the NE zone along its track (Figure 1)



a (i to iv) : One day accumulated rain May 25, 27, 28 and May 31, 2024



b (i to iii): Weekly accumulated precipitation (i) May 19 - 25; (b) May 21 - 27 and (iii) May 23-30

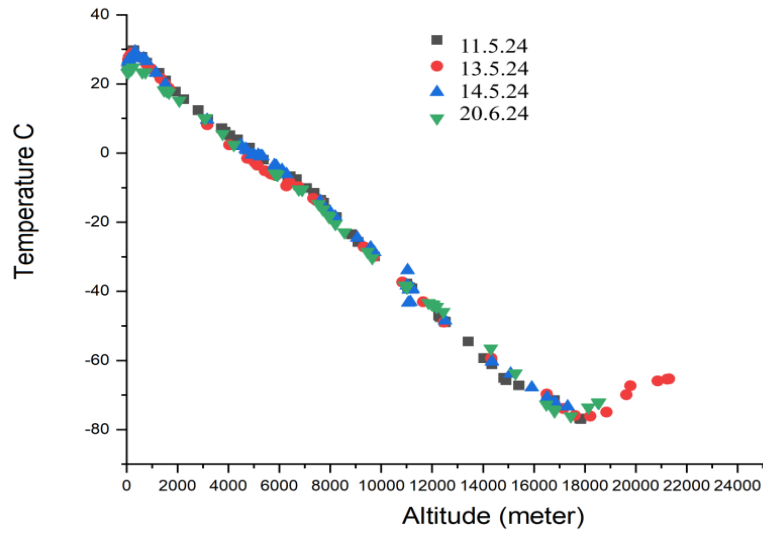


C :Precipitation anomaly (i) deficit rain before the Ramal track entered the zone (ii) Excess of precipitation brought by Ramal air along with its track

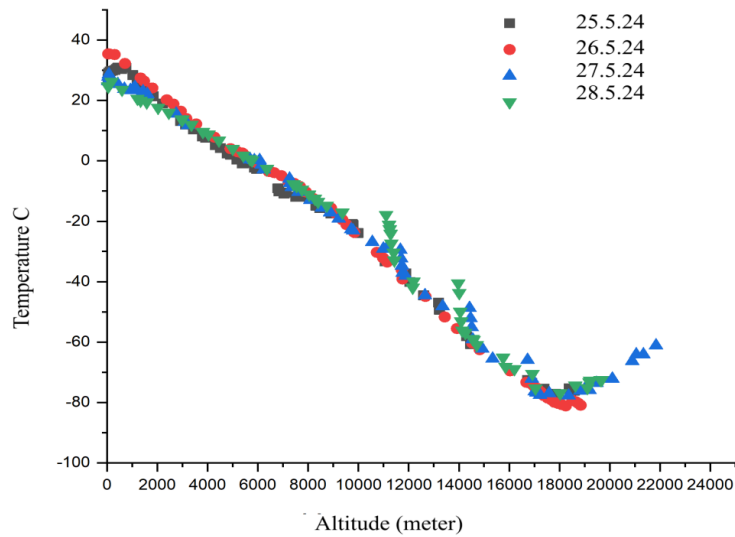
Figure 3: a(i to iv): One day accumulated rain: May 25, 27, 28, and May 31, 2024. Note heavy precipitation in the NE along the track of the Cyclone during May 27-28, 2024; b(I to iii): Weekly accumulated precipitation (i) May 19 to 25; (ii) May 21 to 27, and (iii) May 23 to 30, 2024. Note the increase in intensity of rain caused by the entry of Ramal, and (c) shows the Precipitation anomaly (i) deficit rain before the Ramal track entered the zone, (ii) Excess of precipitation brought by Ramal cyclone .

(ii) Temperature profiles and tropopause height

Temperatures are largely affected by cyclone winds, like the precipitation. In Figure 4, two groups of profiles (a) before and (b) after the cyclonic track entered the NE are shown. There are no appreciable modifications in the profile characters by cyclone, as one sees; however, two features that are come out are (i) changes in tropopause height and (il) tropopause temperature that varies from -74°C at normal situation (Figure 4a) to -79°C (Figure 4b) during cyclone time. The temperature gradient, dT/dh parameter, however, shows significant changes. In normal environment the gradient maintained at a $6.4^{\circ}\text{C}/\text{km}$ from 500m to 10km and $6.2^{\circ}\text{C}/\text{km}$ from 10km to near tropopause, a relatively uniform average rate from lower troposphere to TTL height and beyond, but then the gradient shows wide variations from $4.0^{\circ}\text{C}/\text{km}$ to around $9.0^{\circ}\text{C}/\text{km}$ within 500m to the tropopause, by the entry of cyclone induced wind to this zone. These aspects have a direct association with atmospheric stability, which will be our point of analysis in the following articles related to the lapse rate.



(a)



(b)

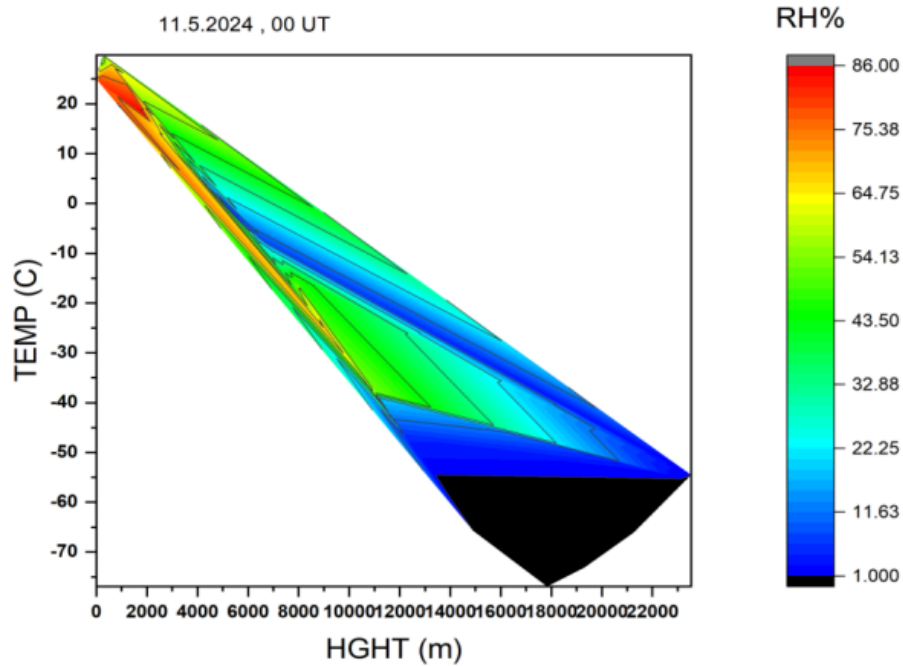
Figure 4 : Temperature profiles (a) Normal-day and (b) Cyclone-time

(iii) Tropopause height modulation and its significance :

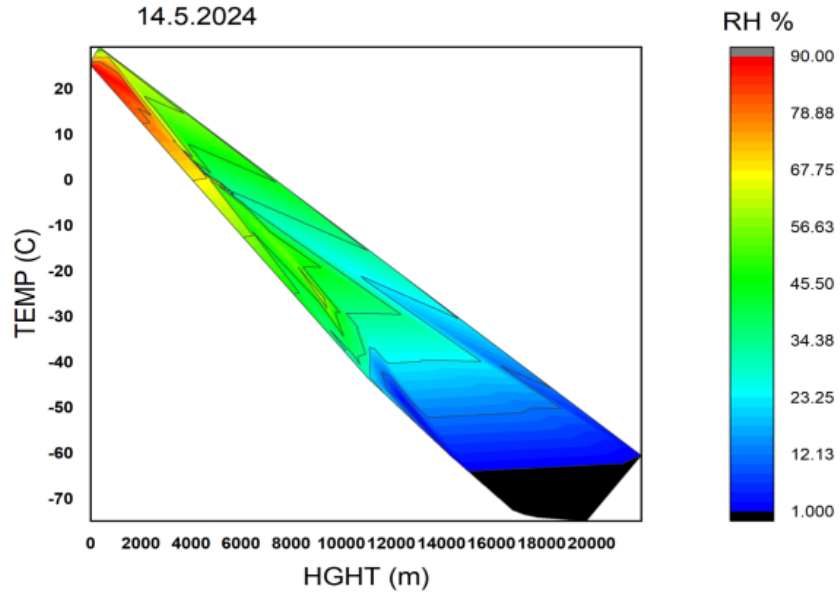
We recorded little modifications of an average of 1.2 km in tropopause height and small temperature changes, varying from -74°C in normal situations to -79°C during cyclone, suggesting the effect of

Ramal-induced deepening of the height. The decrease in tropopause temperature has a direct role in the consequent coupling dynamics between the stratosphere and troposphere. This observation, with no appreciable changes as we have recorded, is, however, significant for a short-lived severe cyclone like Raman's, but for understanding the troposphere-stratosphere coupling dynamics, more involved modulation beyond the TTL height is expected. This aspect will be the future course of our study .

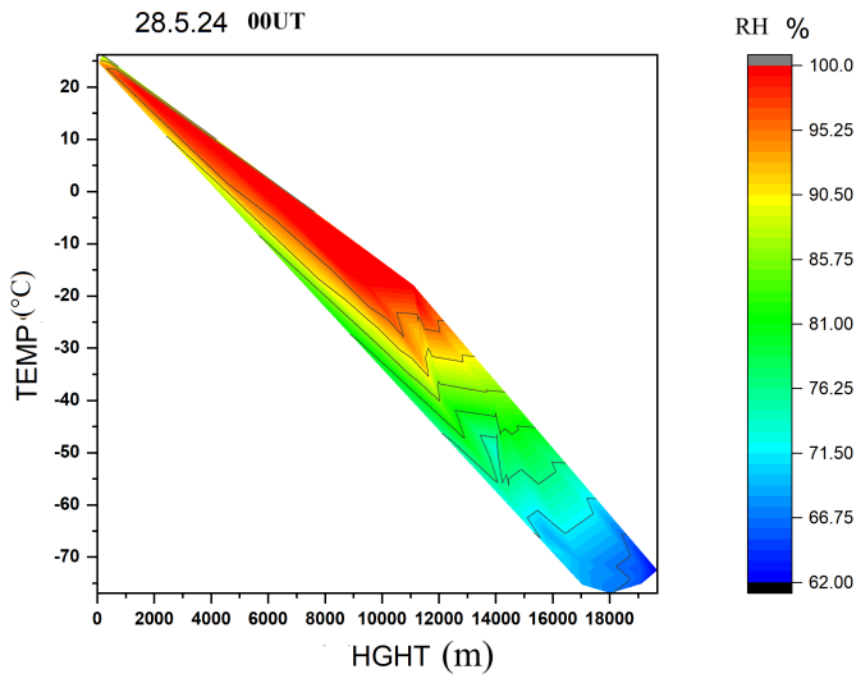
(iv) Humidity (RH %) from the lower troposphere to the TTL and above :



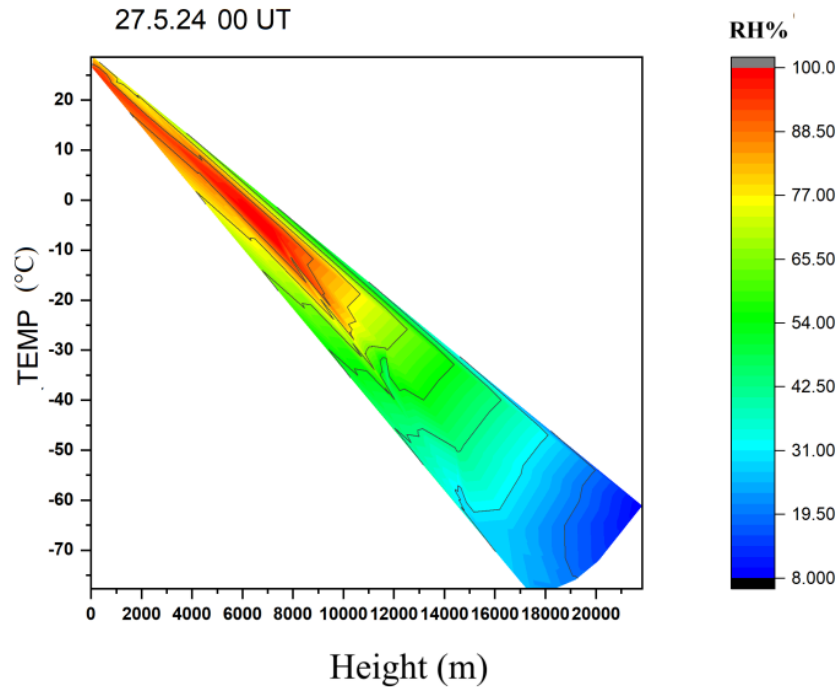
(ai)



(aii)



(bi)



(bii)

Figure 5 :Relative Humidity-Temperature - altitude profiles: (a) normal environment (b) the effect of Ramal wind

2.2 Wind flow pattern and pressure variation at the source :

May is a pre-monsoon month, when precipitation sources of the NE are the humid winds from the BoB. But, the modulation in the wind profiles that are significantly developed from May 27 to 29, along with the growth process of the Ramal cyclone, disappeared on May 30 with its dissipation (Figure 6), bearing the direct association with the cyclone time pressure variations developed in the BoB, as displayed in Figure 7. This sharp decrease in the pressure from the formation of the Cyclone to its maturity is an index of the growth of high clouds (thunder-associated) as recorded with its 100% coverage over the NE zone on these days and also its consequent effects of heavy precipitation (Figure 3).

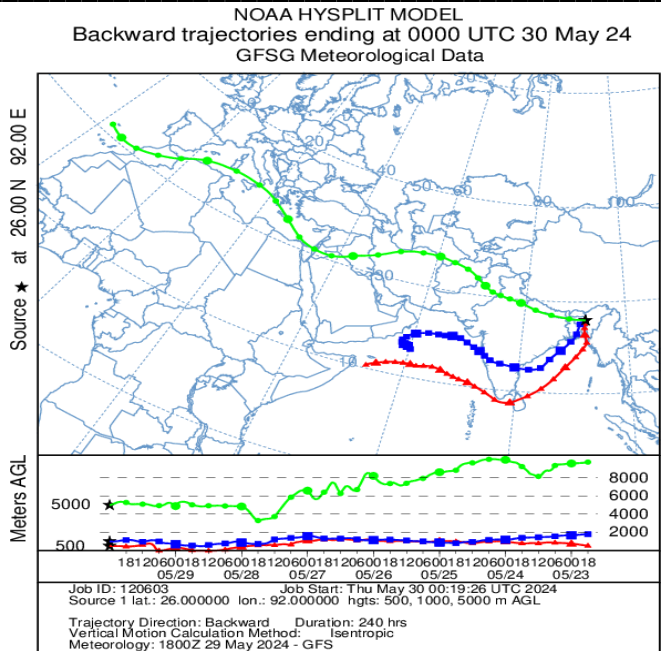


Figure 6: Wind trajectories to Guwahati, during May 27,28 29 and 30 ,2024

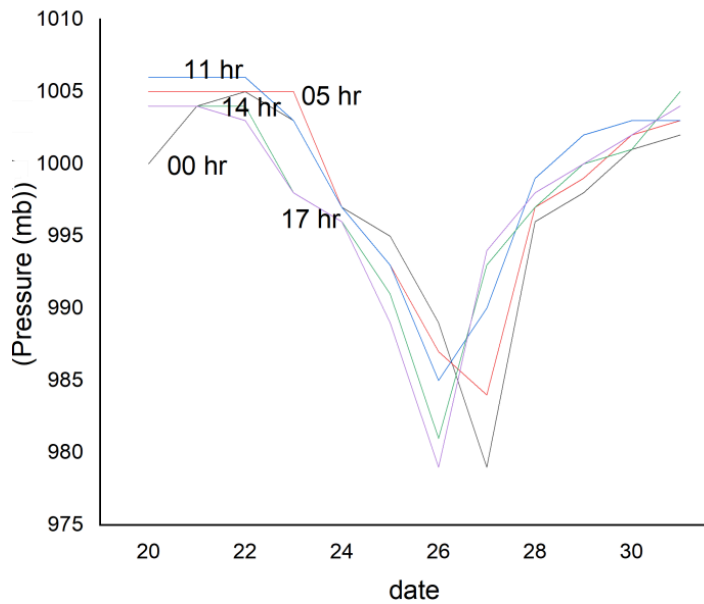


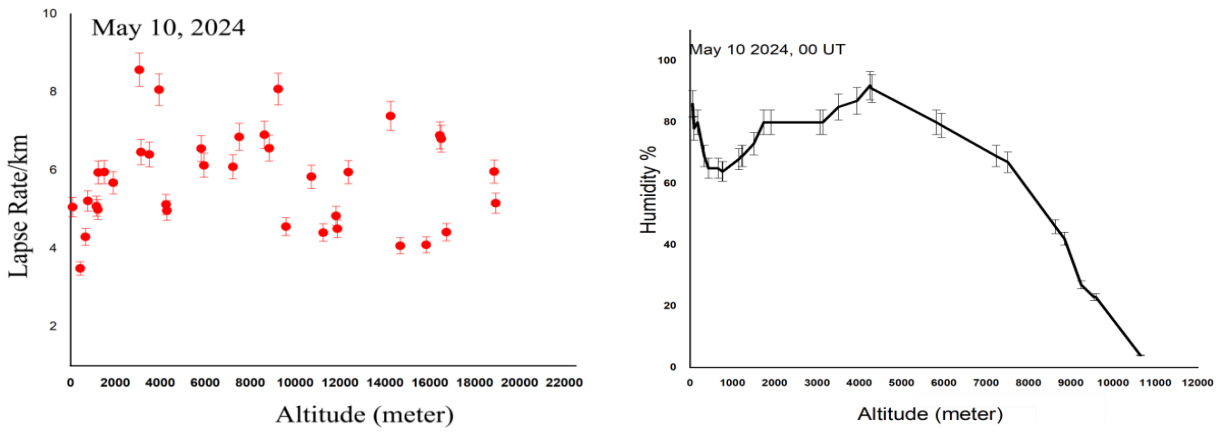
Figure 7 : Pressure in the BoB with date and hours , Note sharp decrease its values from May 26 to 29 , 2024

2.3 Lapse rate :its importance :

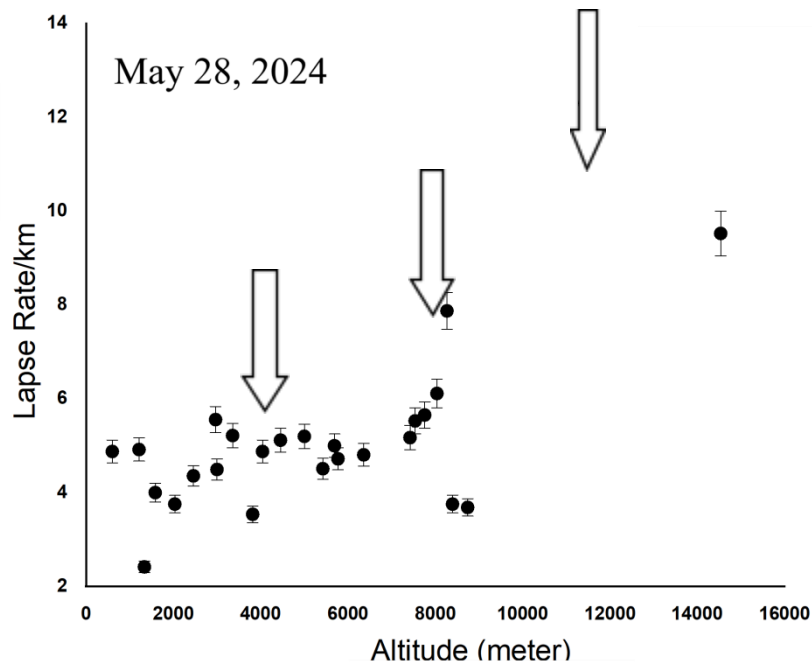
The Lapse Rate (LR) is the decrease of temperature with height i.e $LR = -dT/dz$, and is an important parameter in troposphere as it provides the status of stability or instability of the system. It is a highly variable parameter affected by radiation, convection condensation . In normal status this value is 6.5 °C/km in the lower troposphere . But lapse rate varies significantly and depending on the state of water vapour content these are termed as dry or moist .

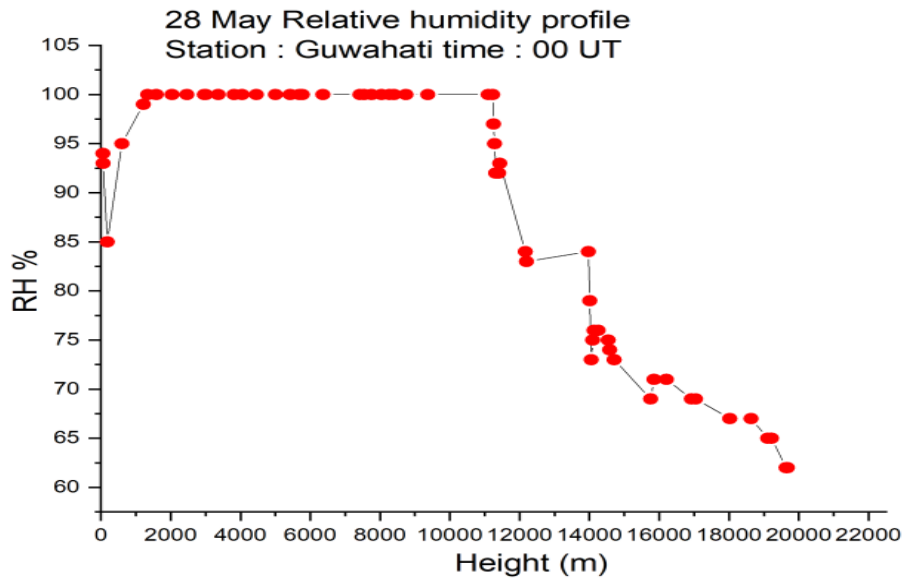
In Figure 8 (a) we present a normal-day profile of a lapse rate over Guwahati (May 10, 2024), that shows an average variations from 5.5 °C/km to 7 °C/km at different altitudes maintaining the mean value of 6.4 °C /km , an usual wet adiabatic LR . This LR value is expected under the relative humidity background of the troposphere prevailing at that time as displayed in Figure 8(b). The average RH varies within 79 % to 80%, from lower tropospheric level to around 5 Km, then starts decreasing with altitude reaching almost zero level at 12 km (near TTL height) . . Beyond that altitude with practically no humidity in the background, the average LR value still maintained at around 6 °C/km though with an initial increasing tendency. However significant changes in the lapse rate character of the cyclone affected day of May 28, 2024 are evident from Figure 8(b), when . the profile presented three levels of LR values with average from 4.4°C/km , 6.1°C/km and finally to a value of LR >9 °C/km as altitudes increase . The relative humidity profile also indicated wide variation from a normal day status when RH attained and maintained saturation level from 2 km to 12 km (beyond TTL) , though it started decreasing then , the RH still retains a high of 60% beyond tropopause . This modifications are the consequences of the fall out of Ramal induced humid air to this zone and effective to the LR modifications.

It is a significant that such difference between the normal lapse rate in the atmosphere and the dry and moist adiabatic lapse rates determines the vertical stability of the atmosphere and it is one of the important parameters that reflects the dynamical situation of a zone and we will deal with this aspect in the article on system dynamics , to be followed.



(a) Lapse rate on May 10 2014 and corresponding humidity (RH%) profile





(b) Lapse rate on May 28 and humidity profile

Figure 8 : Lapse rate profile with humidity status with altitude (a) May 10 , normal environment , and (b) May 28 , on entering the Ramal cyclone track to the NE

3. Discussion :

The atmosphere is considered to be a continuous fluid medium, the dynamics of which are controlled by physical quantities like pressure, temperature, and density, but the situation turns out to be complex with anthropogenic components brought in by the wind, whatever be their sources of generation. One such source is cyclonic induced wind carrying aerosols, water vapour, resulting in modifications of meteorological parameters (Chauhan et al, 2018, 2020, 2021a,b) and the environment. Devi et al (2021) have shown how the Amphan wind carrying pollution-free air (due to the pandemic lockdown) to the NE zone had purified the environment. Singh (2024) also pointed out that the Cyclonic effect from the BoB and ARB to the NE zone will have a strong impact in the near future on its environment and weather modification. Similarly, the unexpected buildup of severe hailstorms and snowflakes in NE locations is attributed to wind flowing from the Himalayan range (Devi et al., 2022). Thus, whatever be the origin of sources, wind has a great role to play over the NE region with the Himalayan range in the north and the BoB on the south, though it is virtually a land lock zone .

Wind involves intricate processes related to the coriolis force, pressure/temperature gradient, specially in situation like cyclones, therefore their role to atmospheric modifications is complex to comprehend, but at the same time the wind carrying parameters provide strong inputs for understanding atmospheric dynamics in the situations which are difficult to achieve artificially, a brief presentation in this issue is followed

.On System dynamics contributed by the cyclone :

One of the most important aspects in atmospheric dynamics is its stability (or otherwise) and one of the parameters to understand such a situation is Lapse Rate (LR) .The significant changes of LR character before and during cyclone track entered the NE region, as observed in this study, is worth mentioning here .

The fundamental aspect of LR can be briefed as LR could be placed in different categories specially Dry Adiabatic LR (DALR) and Wet/Moist Adiabatic LR(WALR). The Dry Adiabatic Lapse Rate (DALR) is that the temperature of unsaturated air decreases as it rises in the atmosphere, and its value is approximately 9.8°C per kilometer in general.

The Wet Adiabatic Lapse Rate is defined as:

$$WALR = (9.8 \text{ C/km}) / (1 + (L/c_p) * (dW_{sat}/dT))$$

Here, 9.8°C/km is DALR

L=Latent heat of condensation = 2.5×10^6 JJ/kg

C_p =The heat capacity at constant pressure of air = 1005 J kg⁻¹ K⁻¹

dW_{sat}/dT Rate of change of saturation mixing ratio with temperature

Therefore, humidity has a strong contribution to the LR, and the WADLR will always be smaller than the DALR.

The environmental lapse rate is thus highly variable. In this analysis what we note is that in normal situation before the cyclone induced anthropogenic contributions (water vapour) affected the environment, the average value of LR maintained at around 6.5 °C /km., a normal wet adiabatic lapse rate as presented in Figure .8a. However, effect of cyclone with high humidity in the environment (



Figure 5b) the LR got modified, and dramatic modification in LR from a low of 4.8 to as high as of 9.0 C/km (Figure 8b) is seen. The three-level LR values are marked in the figure.

Considering the humidity status during this period (Figures 5b and 8b), the LR of 4.08, a value 50% lower than the dry adiabatic situation, supports the moist adiabatic lapse rate of the parcel of wet air. However, an increase in LR near the TTL is significant, which is a result of the fact that when a saturated water vapor parcel rises, the water vapor condenses, releasing latent heat and allowing the parcel to cool slowly. However, during the process of condensation, the parcel loses moisture, and the lapse rate increases, eventually reaching almost the adiabatic lapse rate of 9°C/km. whereas in the normal environment, LR is maintained at an average, with background RH displayed in Figure 8a.

The difference between the normal lapse rate in the atmosphere and the moist adiabatic lapse rate determines the vertical stability of the atmosphere. The LR values of around 4.5 °C/km, in the lower troposphere on May 28, signify saturated moist adiabatic status representing a “stable “condition, while the values greater than 9.8 °C/km, provides "dry" adiabatic status at the TTL and beyond and is considered an "volatile" unstable situation. In between these two values, lapse rates > 6.5 are considered "conditionally unstable.", as we noted in Figure 8b.

Thus, the wind carrying humid air from the BoB generates a highly unstable situation, resulting in the formation of high clouds and precipitation, as observed. This is supported by 100% coverage of High Cloud (8 km to 18 km) on this day . In addition, at the TTL level, the instability may result due to tropopause deepening,

This system status information contributed by the cyclone Ramal is summarized in Table I

Table I : The system status induced by the Ramal cyclone

Height	Lapse Rate °C/km Environmental	Result	Remark
1000m to 8km	4.1	Saturated moist adiabatic condition	System stable
8 km to 10-11km near TTL	6.5	Moist adiabatic condition	Conditionally unstable
10km to tropopause	9.0	Dry adiabatic condition	Absolutely unstable

4. Environment modification by Cyclone to the NE environment :

The wind from the BoB is the main source of precipitation (Figure 6) to this region and specially during a cyclone. The wind thus provides information in understanding system dynamics in situations that are dynamically important but difficult to generate artificially. The contribution of cyclone induced wind may increase the pollution level or may clean the environment as the track enters a zone. In cases when watersoluble aerosol (WSOA) is present, the humid air that brings heavy precipitation washes away the aerosol making the environment clean as we see from decrease of aerosol AOD after the track enters this zone. as displayed in Figure 9 . There are reports showing that WSOA on average accounted for 55 % of OA, cities like Kanpur India (Chakraborty et al. 2017) and . 60.3 % (Ge et al. 2017) in Yangtze River Delta, China. Zhang, .et al (2022) showed that WSOA consists of 59 %. While analyzing characterization of WSOA in PM2.5 during the transition season from autumn to winter in Beijing China . The existing pollution over the study zone are the sources of fossil burning, a large contributor to WSOA , thus the cyclone induced heavy precipitation brought the relief from the contaminated air .

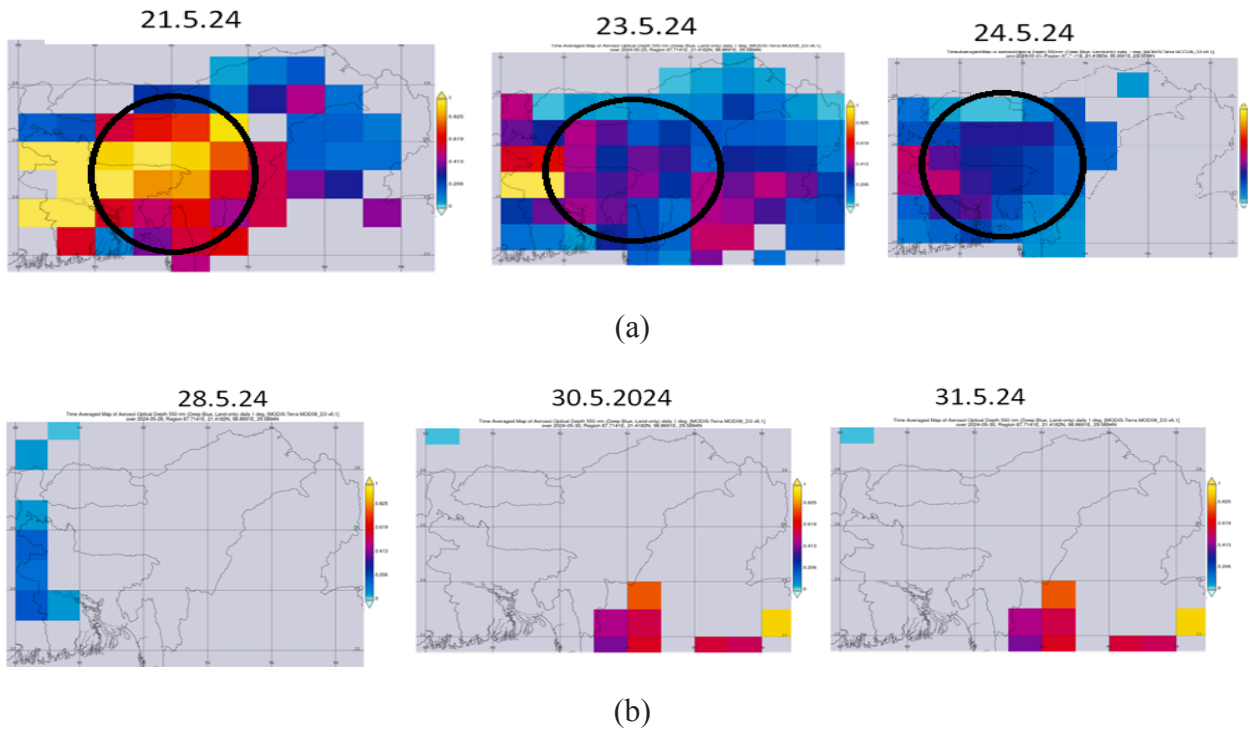


Figure 9 : Aerosol AOD over the study zone (a) before and (b) cyclone track effect

But the untold devastation it caused to the environment is its negative impact . One such picture, presented in Figure 10 , shows the huge landslide when the cyclone wind track enters this location (in Mizoram , Figure 10b), bringing moisture-laden air.

5. Conclusion :

The Ramal, though a short-lived super cyclone, brought changes in the atmospheric parameters by the wind it carried through its track. These parameters play a vital role here, in understanding system dynamics induced by the anthropogenic components when sudden changes in precipitation anomaly, temperature lapse rate had a role in modifying the system stability from stable to an absolutely unstable situation. One of the significant positive aspects is the washing away of pollution (aerosol) as the humid air brought heavy precipitations However, its devastating effect on the environment is the serious negative impact.

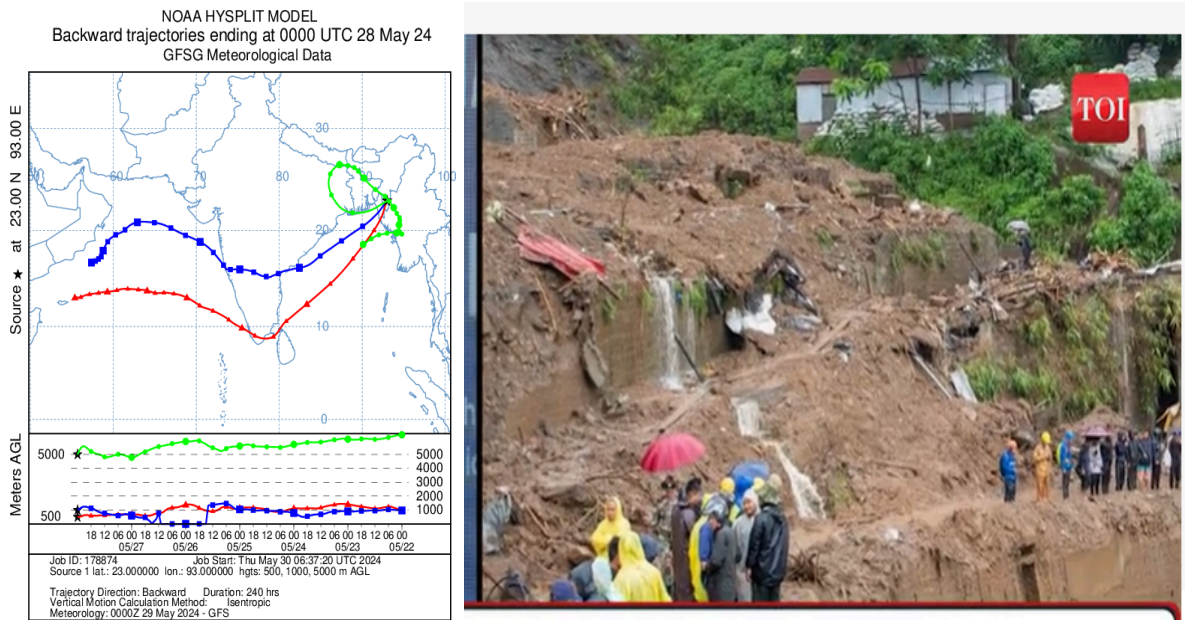


Figure 10 : Wind Track of Ramal to Mizoram and environmental devastation (courtesy TOI)

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