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Atmospheric System Dynamics and Special Weather Environment over a sub-Himalayan Tropical Zone

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Abstract

Weather consists of complex systems when the convective heat transfer coupling process between the troposphere and the surface controls the vertical temperature profile, the vertically averaged troposphere temperature is controlled by radiative flux equilibrium at and near the tropopause. Further, tropical dynamics controlling the weather is more complex. Here, the convection forms an integral part of large-scale tropical motions and hence wet atmosphere associated with moist convective instability is likely to be an important issue related to the weather dynamics, along with precipitation scenarios that are generated from stratiform clouds of this system. Against this background, the paper takes the study of weather and its dynamics over a wet tropical zone of the NE part of India (Sub Himalayan terrain) where moisture is likely to play a determined role. Thus starting with the basic seasonal/diurnal features of the weather over the study area with precipitation as a significant member, a few anomalous events leading to a change in the weather scenario, are highlighted over main Guwahati (26° N, 92° E) a main focus location. Adopting model-based wind trajectory, radiosonde profiles, accumulated rain intensity over a day and week period, and an 830 mb wind magnitude & direction maps around the Bay of Bengal (BoB), the topography influence on seasonal weather status in this zone is highlighted. The paper deals then specific events of unexpected sudden warm spells of waves, where the solar geomagnetic hand on such modifications is examined by taking solar indices Rz, Kp, and respective DsT status on these days. Finally detailed analyses on humidity /temperature profiles & the lapse rate, up to the cold point tropopause (CPT) and the level of zero radiative heating, the result points to a decremental effect from convective cloud leading to excess humidity as one of the sources of sudden warming up of the environment contributed further by anthropogenic pollutants..
Keywords: Wind trajectory; topography; humidity & CPT ; solar variabilities; decremental effect.36

1. Introduction

The dynamics of the tropical zone are [Highwood and Hoskins 1998; Minschwaner and McElroy 1992; Holton 2004] relatively complex compared to the circulation system of the extratropical zone (above 30° latitudes). While in Extra Tropical Zone (ETZ) the primary source is potential energy leading to synoptical disturbances, in the Tropical Zone (TZ] because of the low-temperature gradient, the potential energy is low, to take the role in the dynamical system. Here latent heat release in association with convective clouds is the main source of energy leading to disturbances (mainly originating at lower latitudes/equator). Studies with climate models [Murphy et al., 2004; Klocke et al., 2011] have also shown that the mixing processes in cumulus convection are among the most sensitive ones. Further, stratiform clouds within this system generate precipitation in TZ. Therefore this zone experienced wide weather and climate over the years, heavy precipitation dry /moist environment, and sudden spells of unusual events. Added further, in the tropical zone, unlike ETZ, the maximum upward mass takes place from the troposphere to the stratosphere. This transition zone is significant as it couples thermally driven troposphere activities to the wave-driven stratosphere and can extend to several kilometers known as the tropical tropopause layer i.e., TTL [Holton et al., 1995; Fueglistaler et al., 2009]. Thus importance lies in the coupling dynamics of this zone mainly in Cold Point Tropopause (CPT) and TTL.

With this background, we aim to analyze the weather scenario of the SHT over a tropical location and to understand the relevant contribution of the terrain and atmospheric variabilities in the modification of weather scenarios over this zone. Especially rare events over this region that have been a study topic in the recent past [Devi et al., 2022], we will bring here such a case of sudden warm spells experienced on July 31 st and August 1, 2023, and to identify the dynamical background leading to this abnormal weather situation.

2. Analysis:

Starting with the basic seasonal weather feature over the NE zone of India we present in Figure 1 (the study area is marked by an ellipse) the representative one-day accumulated and weekly-accumulated precipitation profiles that configure the main component of weather over four seasons the Winter (Mid-

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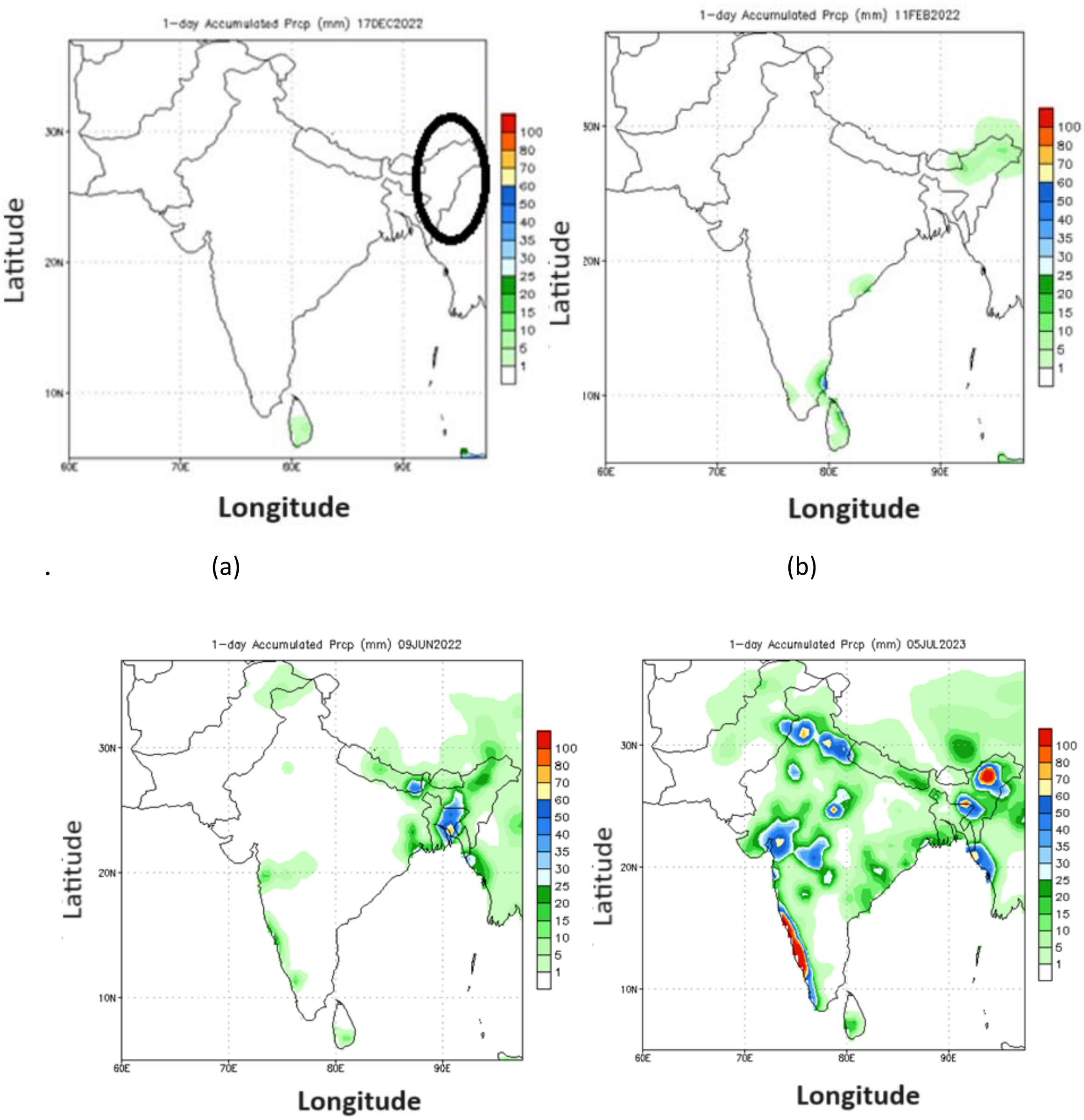
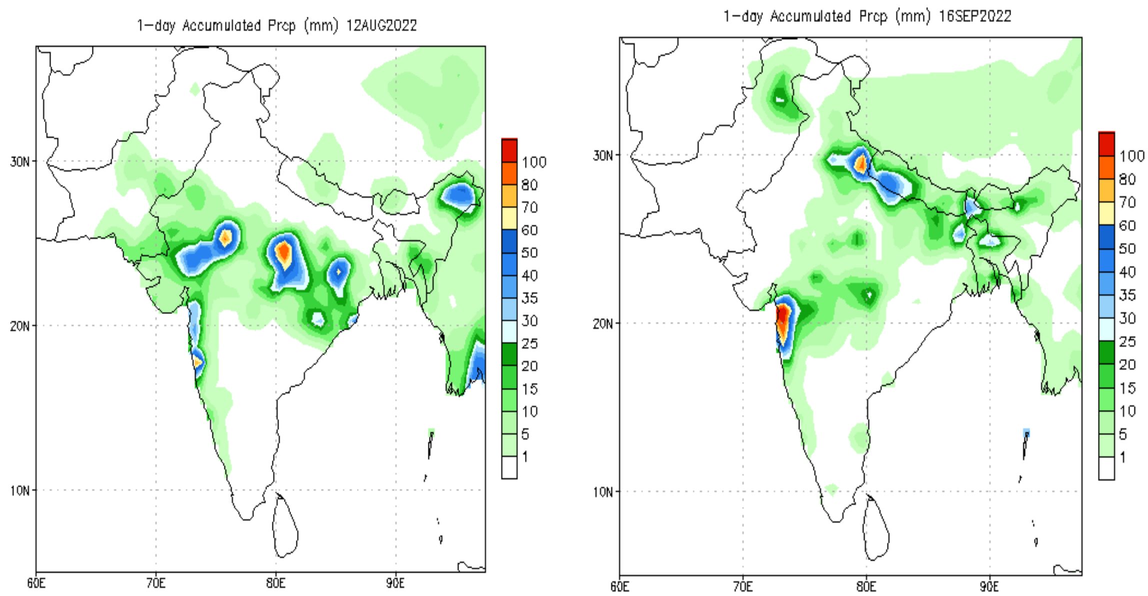
November to mid-March) Vernal equinox (Mid- March to May), Summer (June to August) and autumnal seasons (September to Mid-November).



. (a) (b)

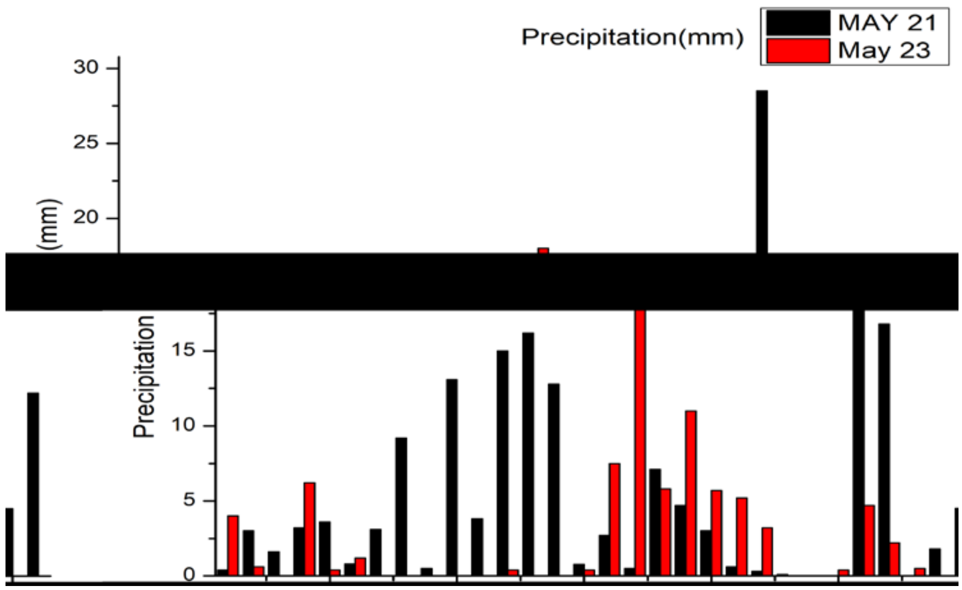
(c) (d)



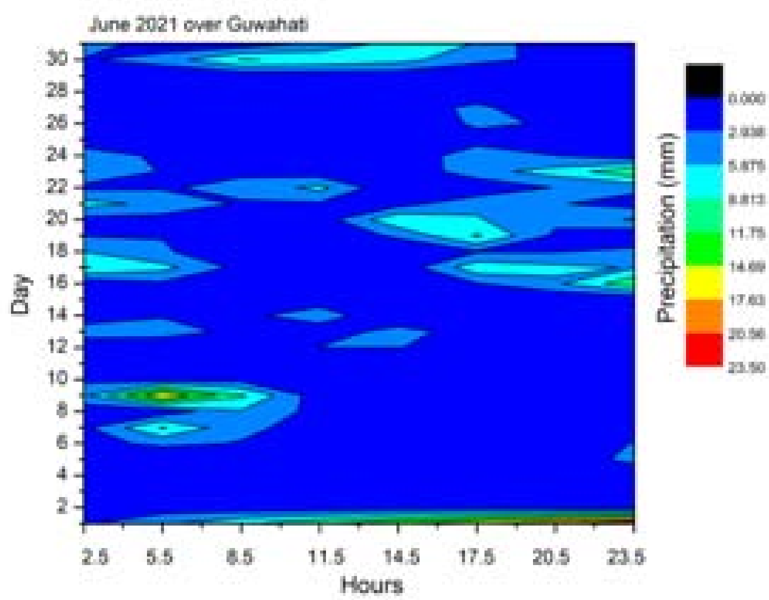
(e) (f)

Figure 1: Seasonal precipitation scenario over NE region of India: (a) Winter dry (b) early Vernal Equinox mild to moderate precipitation, (,d c) Heavy rain in Summer by the south-west Monsoon; (e,f) Moderate rain in Autumnal season by the retreating summer monsoon.

Figure 1 displays the Seasonal precipitation scenario, which is directly associated with the water vapor content of the atmosphere and dictates the weather pattern over this zone with (a) dry –winter,(b) mild to moderately wet Equinoxes, with precipitation, and (c) wet in Summer, by strong precipitation due to S-W Monsoon. There are year-to-year variations though, which are observed to be more pronounced in recent years as displayed in Figure 2, where we note drastic changes in one-day accumulated rain pattern between May 2021 and May 2023. Similarly, the precipitation pattern changes with years as of June 2021 and June 2023 as shown in Figure 2b and Figure 2c.


Precipitation(mm)
MAY 21
May 23
Precipitation (mm)
30
25
20
15
10
5
0

(a)


June 2021 over Guwahati
Day
Hours
2.5
5.5
8.5
11.5
14.5
17.5
20.5
23.5
Precipitation (mm)

(b)

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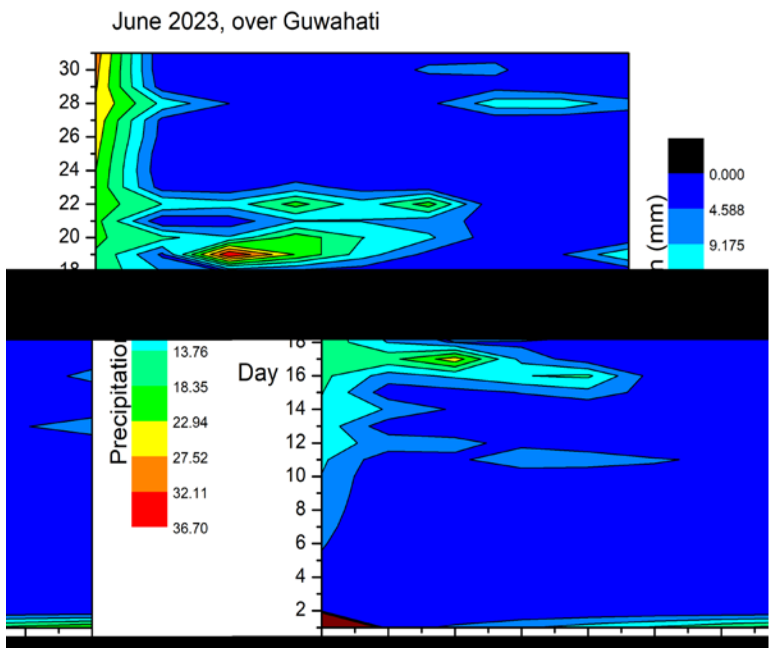
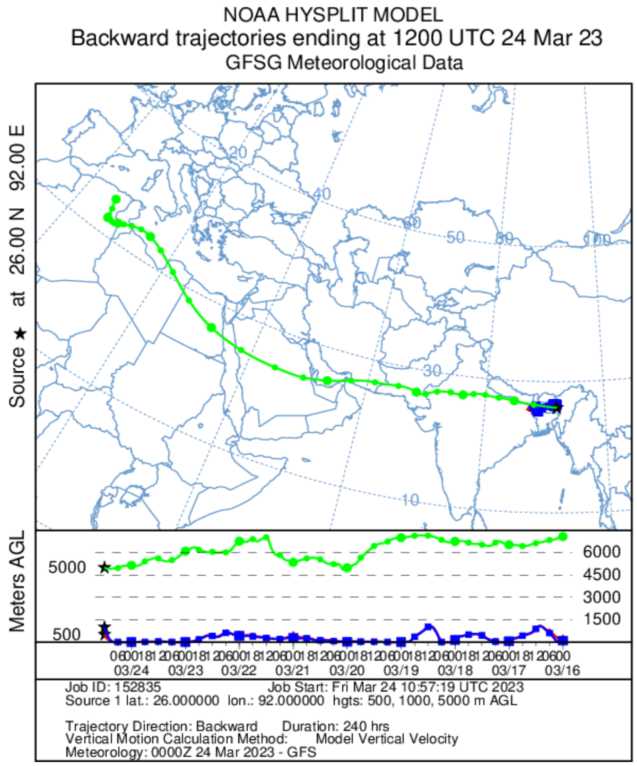


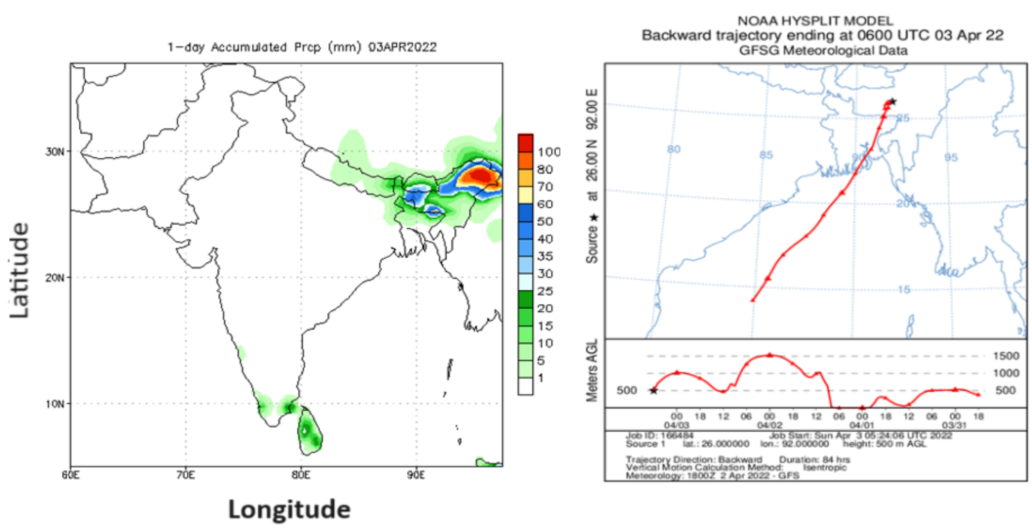
(c)

Figure 2: (a) May 2021 and 2023 one-day accumulated precipitation pattern ; (b) hourly accumulated rain pattern variation in June 2021 (Total 493.5mm) and (c) June 2023 (Total 682.1 mm), also note the change in diurnal precipitation features in these months.

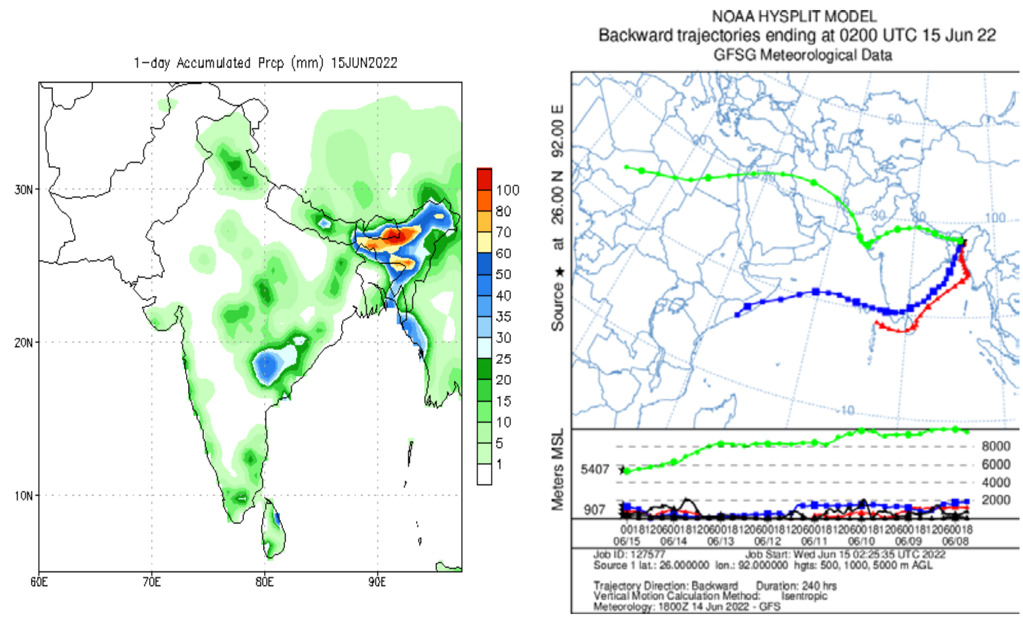
Thus precipitation leads to seasonal weather modification patterns. One of the sources of precipitation in the NE zone is the moisture-saturated air from the Bay of Bengal (BoB). In Figure 3 Hypersplit trajectory model shows that while during winter the wind is virtually localized with short hops around the NE (Figure 3a), with the entry to equinox season, the humid wind from SW/SE bringing precipitation to NE, and with the onset of SW monsoon during summer one can see significant changes in precipitation scenario with strong wet humid air enters mainly from BoB as well as a trajectory from the Arabian Sea.


NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 24 Mar 23
GFSG Meteorological Data
Source ★ at 26.00 N 92.00 E
Meters AGL
5000
500
6000
4500
3000
1500
03/24 03/23 03/22 03/21 03/20 03/19 03/18 03/17 03/16
Job ID: 152835 Job Start: Fri Mar 24 10:57:19 UTC 2023
Source 1 lat.: 26.000000 lon.: 92.000000 hgts: 500, 1000, 5000 m AGL
Trajectory Direction: Backward Duration: 240 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 24 Mar 2023 - GFS

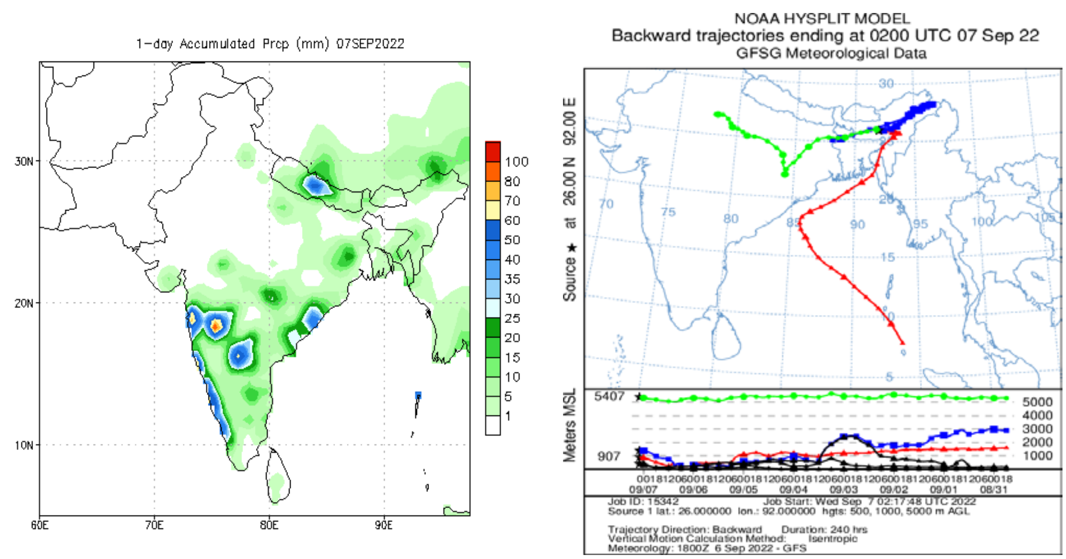
(a)


1-day Accumulated Prcp (mm) 03APR2022
Latitude
Longitude
30N
20N
10N
60E
70E
80E
90E
100
80
70
60
50
40
35
30
25
20
15
10
5
1
NOAA HYSPLIT MODEL
Backward trajectory ending at 0600 UTC 03 Apr 22
GFSG Meteorological Data
Source ★ at 26.00 N 92.00 E
Meters AGL
1500
1000
500

(b)



(c)



(d)

Figure 3: The precipitation pattern over NE and wind flow trajectory (a) Early Vernal equinox, (b) Mid Vernal equinox, (c) Summer solstice, and (d) Autumnal equinox.

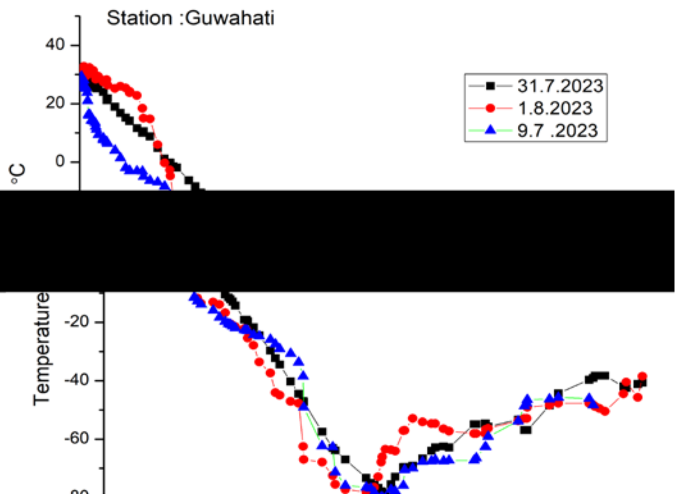
Thus, the overall normal weather over the study zone consists of a dry winter, mild to moderate wet with precipitation in equinoxes, and a heavy moisture-laden environment by South- West monsoon during summer, though there are shades of differences in year-to-year precipitation magnitude and its diurnal modulation as we present in Figure 2 and Figure 3, a feature more commonly noticed over the last 4/5 years, supposedly with the more abundance of anthropogenic pollution a topic we will deal separately.

Our interest now is on the special weather events of suddenly uncomfortable heat spells or unexpected hail storms (Devi et al., 2022) that disrupt the normal weather pattern. The situation in analysis now is unexpected uncomfortable warm and suffocating situations on July 31 and August 1, 2023, as a special case.

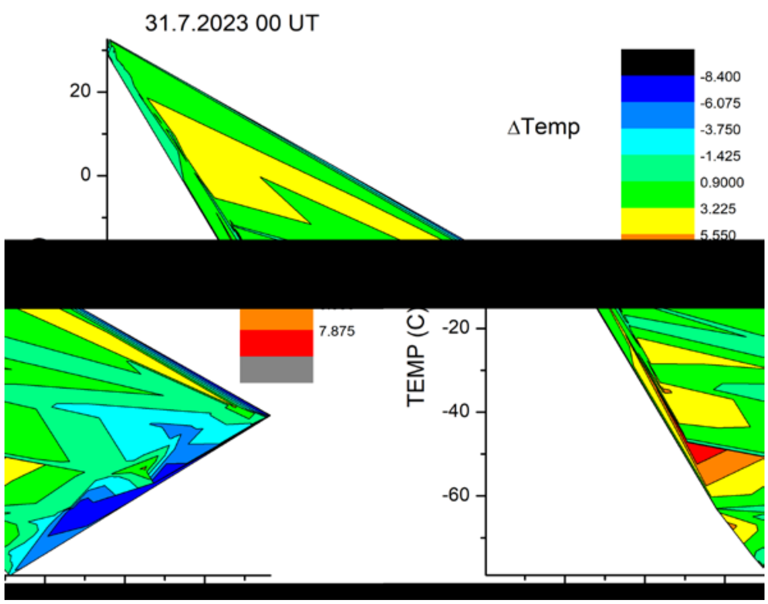
2.1 Special case: July 31st and August 1 unexpected sudden warm spell:

This is a special case when there were sudden uncomfortably warm environments built up on 31 July and August 1, 2023, with feeling going as hot as 40° C a situation far beyond normal status when the temperature in these seasons maintains a 30° C., so on these days too. So what could be the cause of such an abnormal situation, is the aim of this presentation.

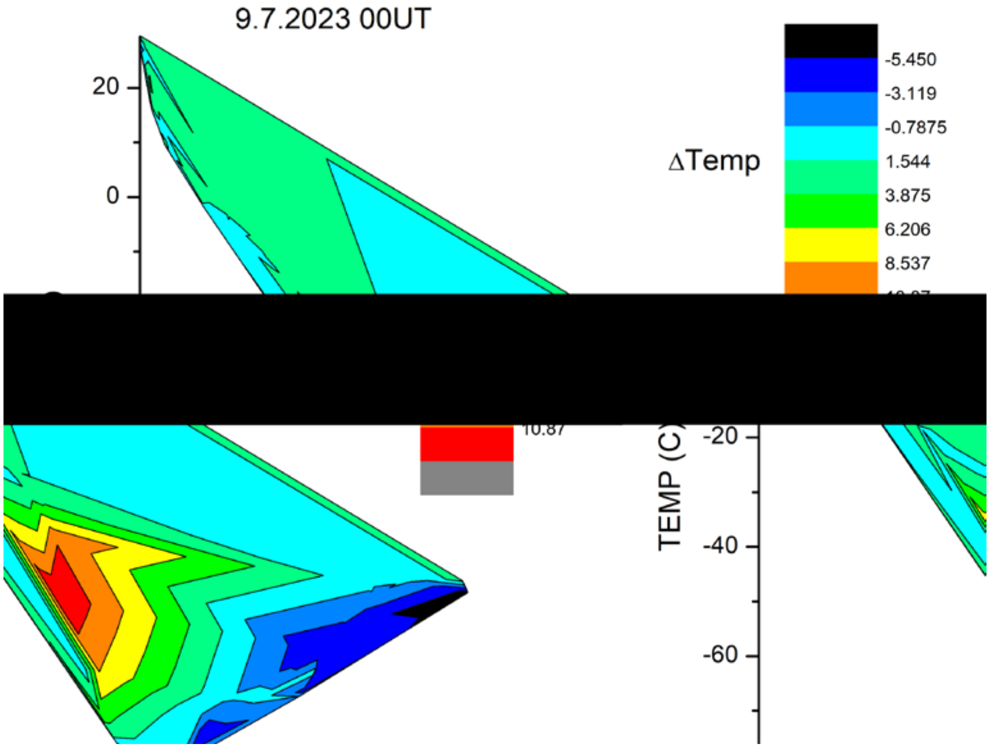
One of the parameters that need to be examined first is obviously the temperature profile from the surface to the CPT zone and beyond on these days, by comparing profiles with the ones on normal days. We take July 9 as a representative day to identify the inherent changes if any in temperatures on the abnormal days of July 31 and August. The result of Figure 4a apparently shows no significant change in profile pattern on these event days. But δTem i.e the change in temperature with altitude is 2 times lower on 31st July (Figures 4b) near the tropopause compared to that of no event day (Figure 4c) and also apparent is low in temperature gradient $\delta T/\delta h$ near tropopause on 31st July, and on August 1 compared to July 9 (Figure 4d).


Station :Guwahati
40
20
0
°C
[redacted]
Temperature
-20
-40
-60
31.7.2023
1.8.2023
9.7 .2023

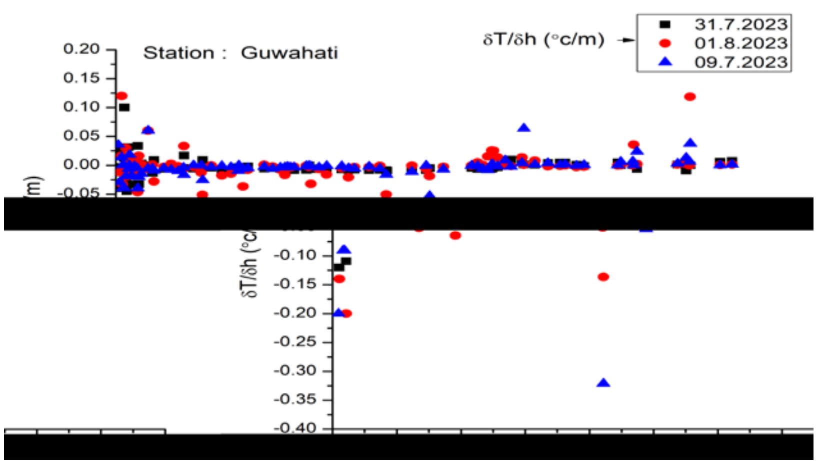
(a)


31.7.2023 00 UT
20
0
ΔTemp
-8.400
-6.075
-3.750
-1.425
0.9000
3.225
5.550
[redacted]
7.875
TEMP (C)
-20
-40
-60

(b)



(c)



(d)

Figure 4 : (a) Temperature profiles from the surface to CPT and beyond for July 9 (normal day), July 31, and August 1, 2023, the abnormal warm-spell days, (b) ΔTem with altitude on 31st July w.r.t. normal day, (c) same as of (b) but on no-event day of 9 July, (d) Temperature gradient with altitude 31.7.2023, 01.8.2023 and 09.7.2023.

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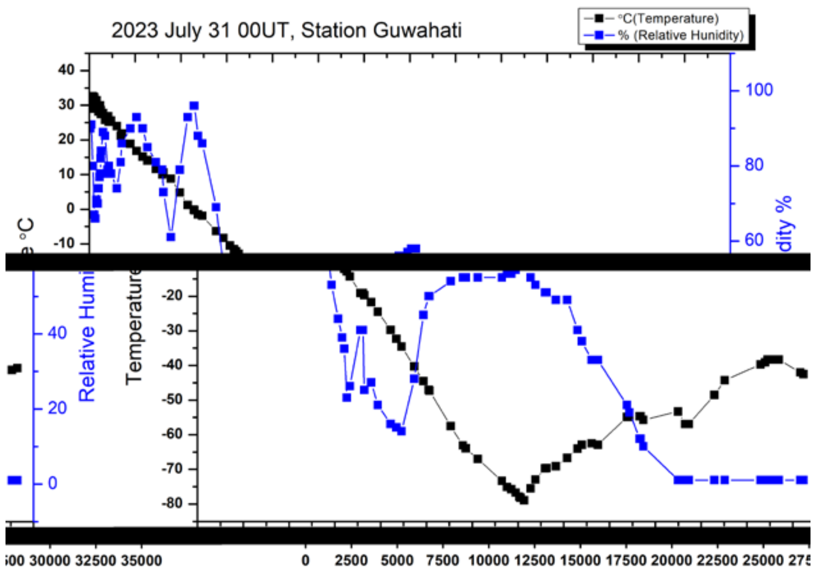
3. Discussion :

3.1 Humidity and the effect of entrainment and detrainment on the warm environment :

The associated parameter in this issue is humidity and its altitude variation near to CPT zone and beyond. An increase in sudden humidity content on these two days just before CPT (around 150mb) is clear compared to the normal humidity profile pattern (Figures 5a and 5b). The increase in humidity by 60% is abnormal when in a normal scenario it takes a C-shaped pattern decreasing to this point as in Figure 5 ©. The scatter matrix plots of humidity at 150 mb level over Guwahati (Figure 6a) between (i) 31st July and 1 August (Figure 6a) and (ii) 31st July and normal day of July 22, 2023 (Figure 6b), while provide similar humidity features between the two hot spell days (Figure 6a) and dissimilarity between normal and abnormal hot event days, directing humidity profiles get modified on these special events.



(a)

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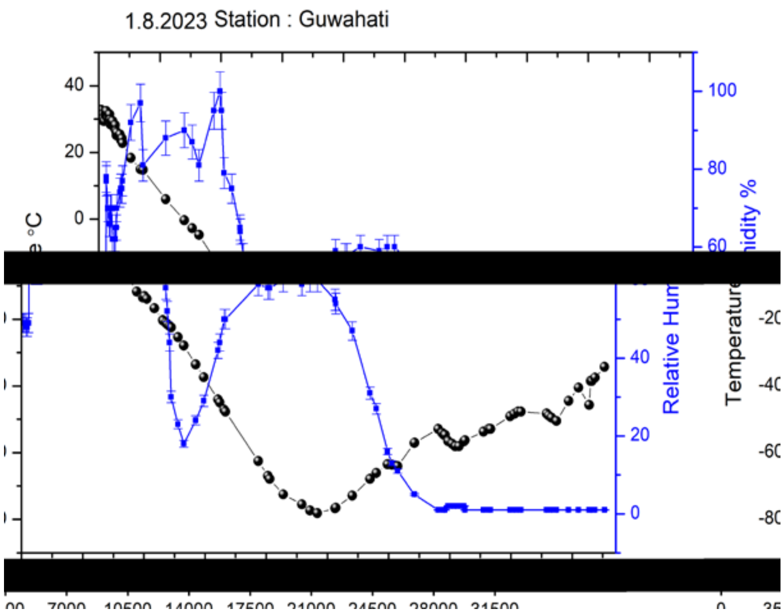
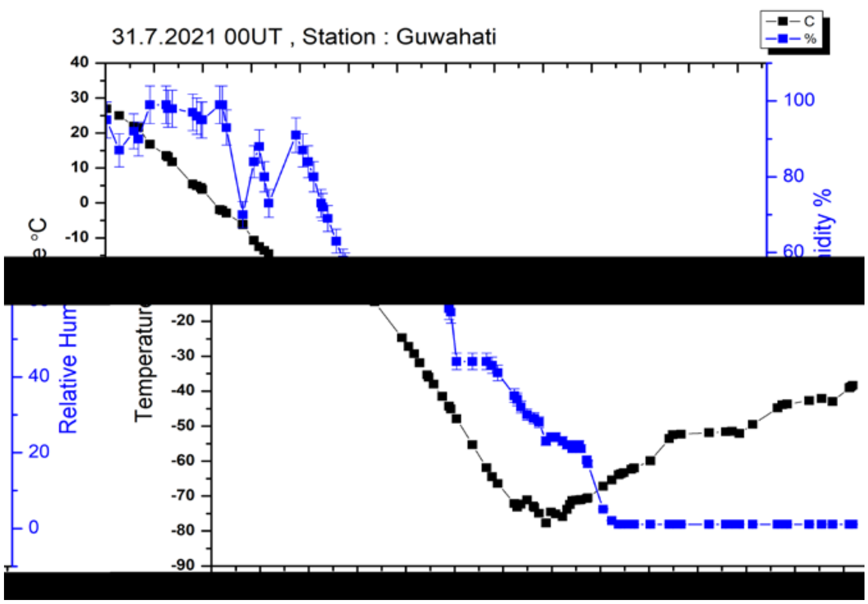
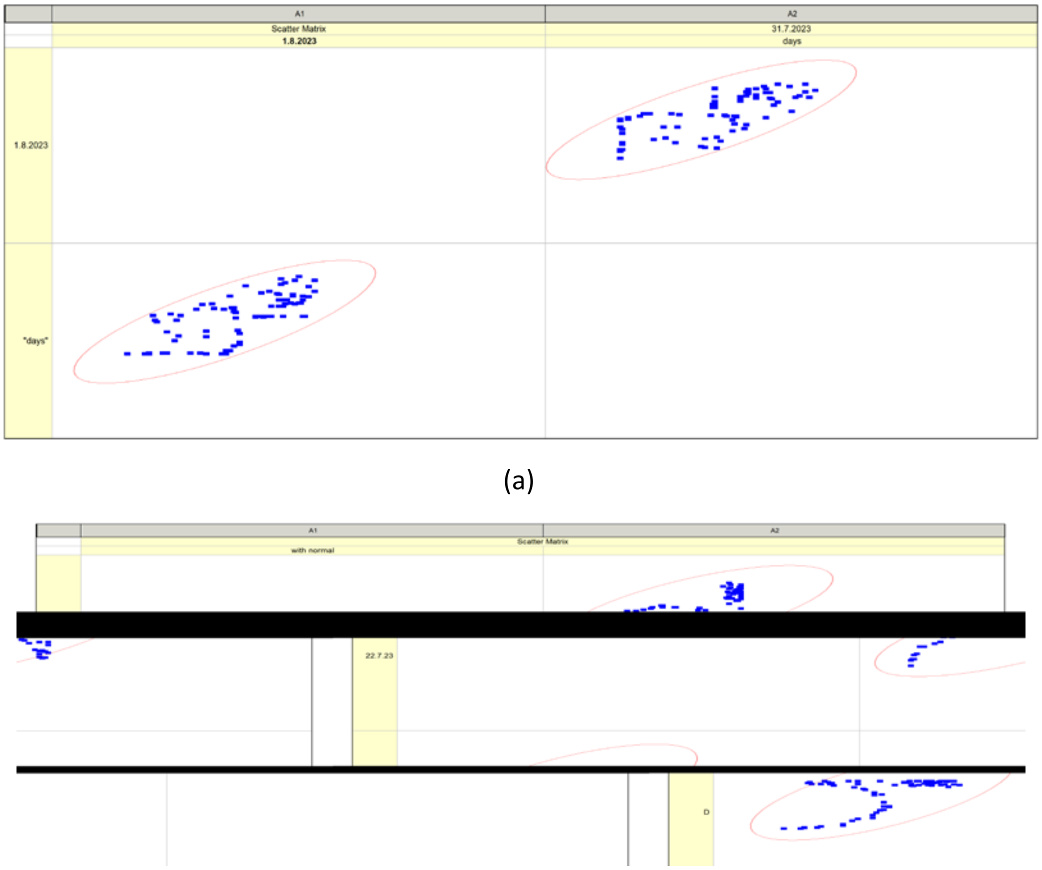


(b)



(c)

Figure 5 : (a) Altitude variation of humidity and temperature on (a) July 31st, 2023, (b) August 1, 2023, and (c) 31st July 2021, a normal day.

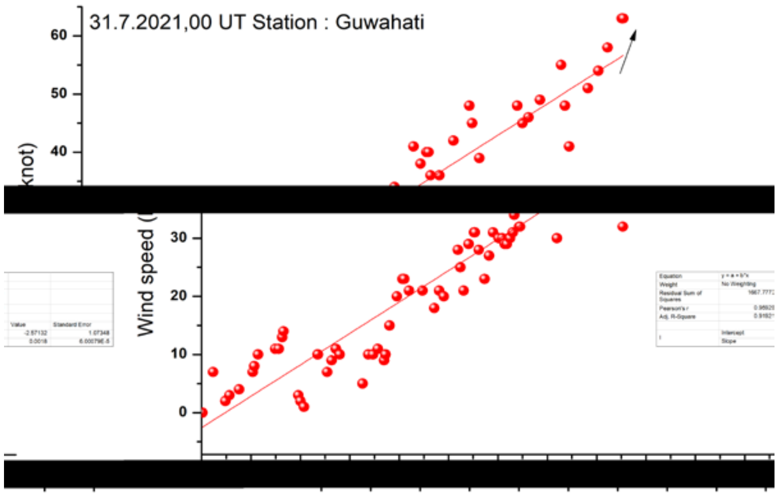


(a)

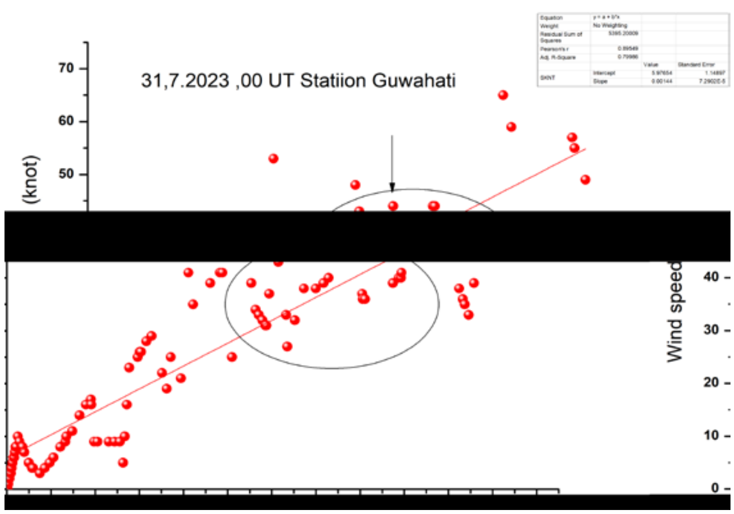
(b)

Figure 6: Scatter matrix plot of humidity : (a) 31st July 2023 and 1 August 2023 (hot spell days), (b) 31st July 2023 and normal day of July 22, 2023.

The phenomenon of uncomfortable warm spells of waves might have an association with excess water content present at higher altitudes near the TTL. One of the explanations is that in such a situation a free convective state of the atmosphere is modified around the zone as revealed by wind velocity on these days. Unlike a normal situation, when wind velocity speeds up (Figure 7 a) as it moves up to a free environment, here, wind retains at a stable velocity over this altitude zone on these days (Figure 7b), but beyond this slab-zone, the wind speed started increasing to reach the normal value of around 60 knots, confirming the presence of an abnormal state around 120-150 mb level.



(a)



(b)

Figure 7: Wind speed with altitude (a) Normal day of 31 July 2021 and (b) 31 July 2023, the hot spell day. Note a deviation in the profile of Figure 7b, at around 150 mb level (circled).

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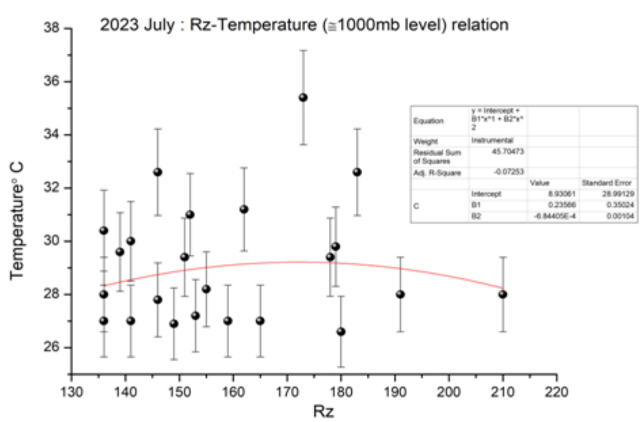
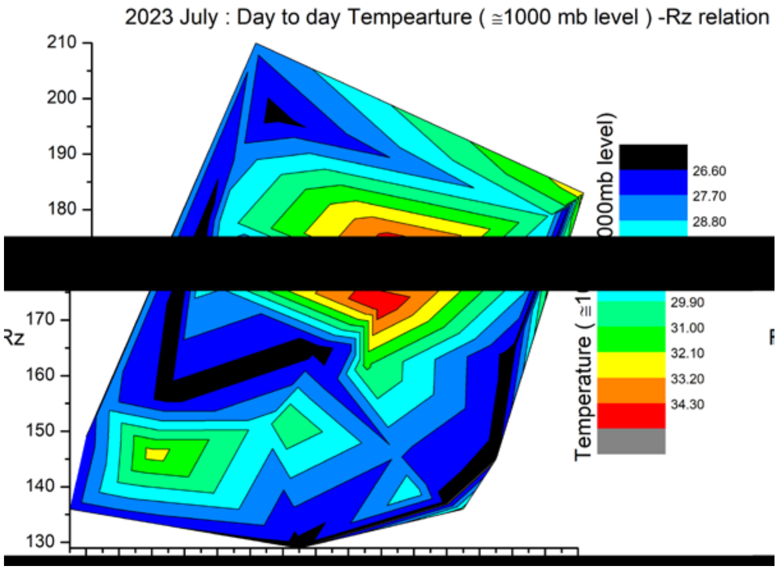
In such a situation [Figure 6(a)] this highly humid layer may act as a slab, and therefore the modifications imposed on the normally available free convective system (Figure 6b) (atmosphere) create a suffocating hot spell, more than the prevailing temperature could cause, as we experience in situations, especially in the warm season. Because the humidity profile shape provides the dynamics of the environment, the observed sudden increase in the rate of humidity at 150 mb (12-14 km) in the Rh –tem profile during warm spell days over Guwahati is an important issue to discuss its role on it. Such a profile could probably be influenced by the export of water from a source like BoB in a location like Guwahati, moistening through convective detrainment, unlike evaporation of water from falling ice, and flow from water-rich tropical zones [Pierrehumbert, 1998; Zhu et al., 2000; Sun and Lindzen1993] which generally lead to increase in humidity in non-tropical areas.

3.2 Solar geomagnetic variation and Temperature relation :

However, it is also relevant here to look for a relationship, if exists, between temperature, humidity, environment, and solar activity, as innumerable studies show the existence of such an association [Haigh 1996; Valev 2006; Haigh 2007; Zhen et al., 2018]. To identify the solar activity as an index finger in temperature changes, a brief analysis output of temperature and solar indices Rz and Kp relevant to these events is thus presented in Figures 8 (a,b, c).



(a)



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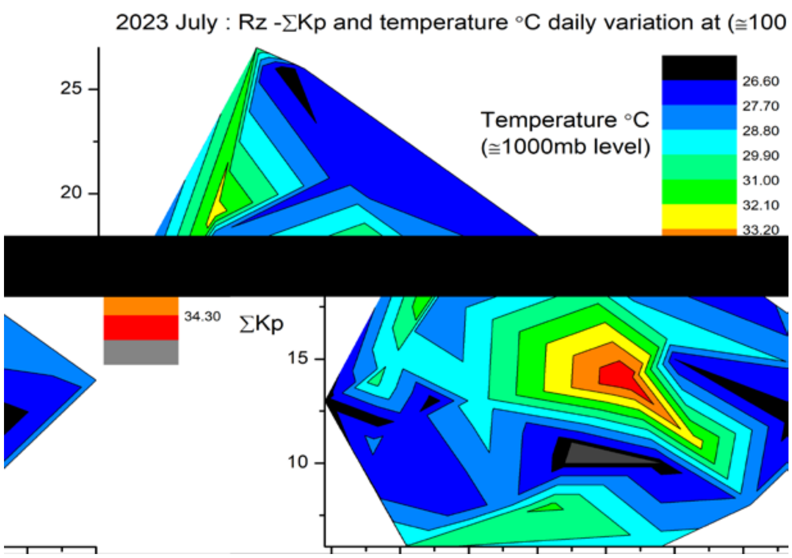

(C)

Figure 8: (a) Rz - temperature relation on July 2023 to 2nd August 2023,(b) day-to-day association between Rz and temperature of this period, and (c) Kp-Rz and temperature associations on the same month (all are at 1000mb level).

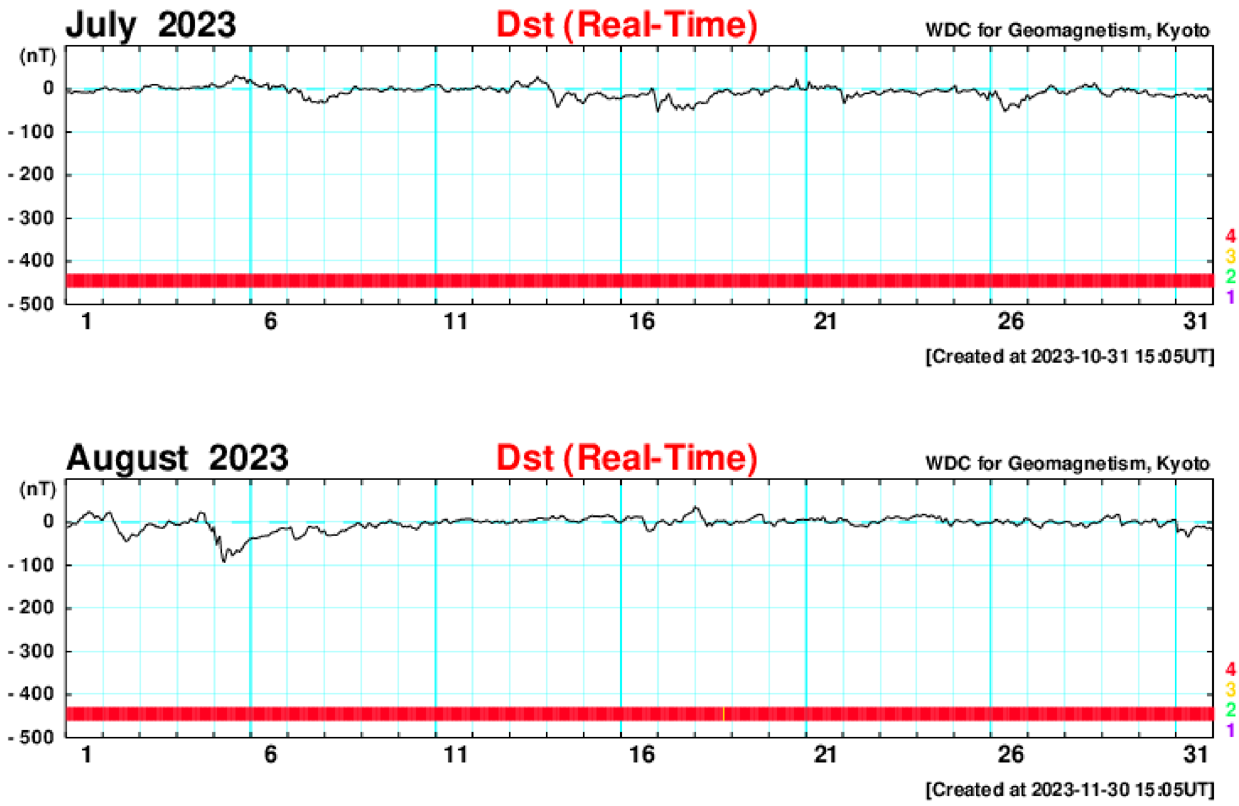

Figure 9: Day-to-day DSt values of July - August 2023.

The absence of a linear relation between temperature –and solar geomagnetic is apparent from these figures when temperature shows a maximum value of around 36 °C below peak Rz status (Figures 8a,b), and at a relatively low Kp background (Figures 8c,d). Also, we see that on the hot spell day of the 31st of July, the temperature of 30°C-31°C records a moderate value but does not reach the peak of 36°C with no Geomagnetic storm around (Figure 9). Thus the heat waves of July 31 and August 1, have no direct solar–geomagnetic influences.

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3.3 Source of high humidity and relevant explanation to the warm spell :

On examining the source of possible excess humidity, we draw the air trajectory to this location on these days (Figure 10). The trajectories show that the extra humidity was not likely to be transported from the Bay of Bengal, BoB (shown for July 31st and August 1 .2023), the main humid and precipitation air carrier source to this region. Neither surface precipitation (Figure 11) nor excess humidity at the surface (Figure 5) was observed on these days.

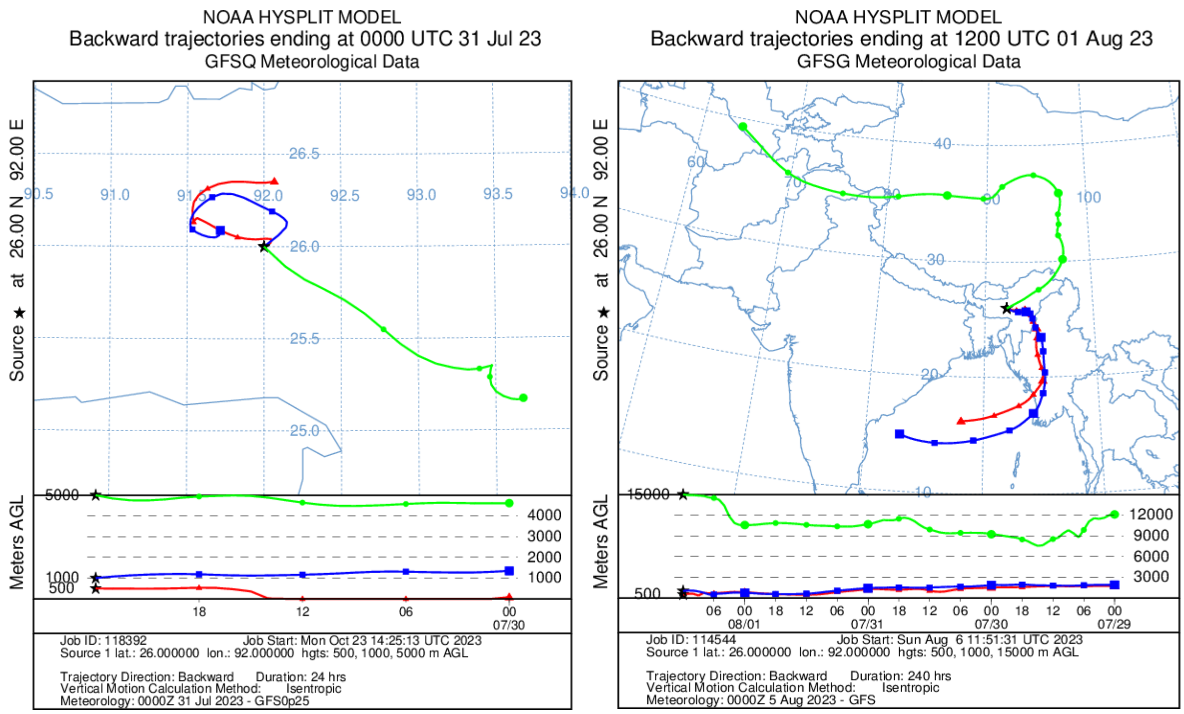

Figure 10: Wind trajectory to NE (a) 31st July 2023 and (b) August 1, 2023

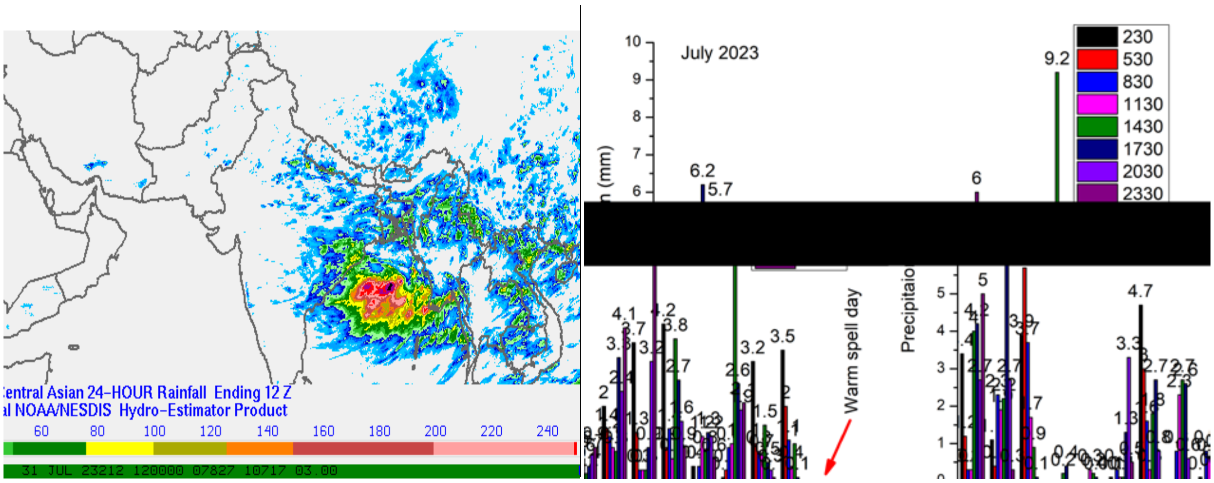

Figure 11 : (a.b) No precipitation at Guwahti on 31 July 2023

We, therefore, look for dynamical status of the troposphere-stratosphere transition zone as weather status is largely affected by this region and not only by the temporal and spatial structure of meteorological variabilities in the troposphere . We note then that the most significant feature that came out through this analysis is the large enhancement of moisture content at this transition level, the CPT. One of the important aspects of such issues is the types of clouds present and their abundances. The presence of convective clouds on these days is interesting when more than 50 % of clouds are at this 12-15 km level compared to the low-level clouds. Thus the presence of Cyrus cloud (at tropical zone average height 8 to 16 km) is significant at the TTL. Because such high-level clouds generally do not precipitate as we see Guwahati was precipitation-free [Figure 11] on July 31st, but such clouds influence modulating the background temperature as made up of ice crystals. There are suggestions that such clouds may increase the heating rate and may speed up the upwelling processes [Corti et al., 200]. Because, though not generally precipitating, such clouds could regulate the development process of a planetary boundary layer (PBL). and destabilize the lower troposphere as well as moisten the mid-troposphere [Betts and Jakob 2002] as seen in our case study here. Thus, the mixing processes between cloud (mainly convective) and environment come here which are generally described by the entrainment and detrainment and are respectively explained through the inflow of environmental air into the cloud and the outflow of cloudy air into the environment [Arakawa and Schubert, 1974; Derbyshire et al., 2004; Genio and Wu, 2010]. The highly humid feature can thus be explained with convective detrainment when the air may be moistened by the detrainment process of the convective clouds present on these days. It has been shown through models including couplings between the moistening effects of convective detrainment [Minschwaner and Dessler 2004], that the drying effects from clear-air subsidence, and radiative heating and cooling from water vaporate the sensitivity of water vapor in the tropical upper troposphere in changes in surface temperature is of increase in relative humidity, in above 250 mb level, is mainly determined by the level of zero radiative heating. Further, a transition from large-scale descent to the ascent of supersaturated air parcels as suggested by them may lead to an increase in the RH as observed by us, [Jensen et al., 1999]. Finally, high convective clouds present on these days form a detrimental effect on mixing with the environment at this level and enhance the background moisture level.

However such explanations are not simple to draw because the uplifting process or movement of air parcels is also a determined factor. Such movements in moist environments are complex and are to be discussed in terms of equivalent potential temperature, a situation beyond the scope of this work. But we see the lapse rate on these days is smaller compared to normal background suggesting the actual lapse rate on these days is less than the normal adiabatic lapse rate. in such a situation a parcel displacement is stable and more or less the situation we see at 120-150 mb level. Finally, the humidity anomaly around the 200mb/150 mb level is expected to affect radiative heating profiles, temperature, and wind, flow dynamics.

The consequence of such a phenomenon to the environment is that the excess water content present at higher altitudes makes the wind to attain a stable velocity over this altitude zone when the free convective system is modified (Figure 7b). In such a situation, this layer acts as a slab and therefore creates a suffocating warm spell under this background, more than the prevailing temperature could cause, as we experience in situations, especially in the warm season, a significant hazard to the environment and health.

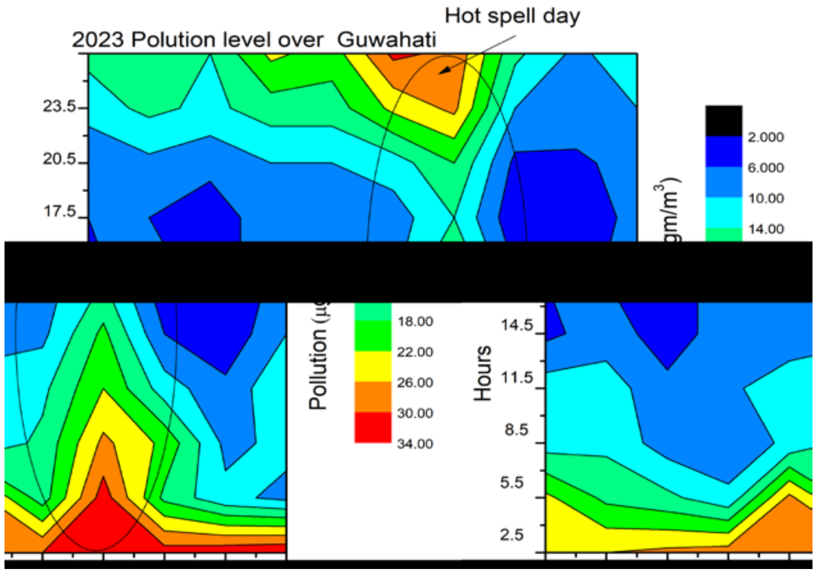

Figure 12: 2.5µm Pollution level (in µgm/m^3) around the warm spell days of July 31st and August 1, 2023

Pollution and Temperature /precipitation:

Anthropogenic pollutants are other main candidates associated with climate change /Global warming i.e. involved in the increase in temperature as the study shows [Lavitus et al., 2001; Fiore et al., 2015; He et al., 2017; Devi et al., 2021]. As a significant point of observation, we note that these two warm spell events occur in relatively high pollution environments, when particulates of size 2.5µm show a significant increase during 5 to 6 AM, the time when radiosonde profiles show strong humid growth at higher altitudes (Figure 12). Such pollutant backgrounds assist a parcel even with low humidity, to rise up. This situation is provided by the pollutant/ aerosol which generates higher cloud drop concentration but smaller mean cloud droplet size thus leading the parcel to a higher level and with the release of latent heat when water drop forms, but does not have enough to precipitate, the presence of a Cirus cloud on the day is thus a likely candidate. Also, an increase in CO_2 has a direct impact on climate change [Felix et al., 2022] and thereby on the enhancement of temperature [Gervais, 2016]. Further, as temperature and water vapor are entangled parameters the increase in the sudden concentration of water vapor could be associated with the sudden increase in pollution concentration as experienced over Guwahati on 31st and August 1. Therefore through such water vapor budgets, one can predict how the earth's climate will respond to the increasing concentrations of carbon dioxide/pollutants. In addition, surface temperatures might though be expected to continue to increase in response to higher levels of carbon dioxide, the magnitude of this increase will be strongly affected by the response of water vapor at these higher levels [Manabe and Wetherald, 1967].

4. Conclusion :

Finally, we come to the conclusion that while the overall weather over this TZ is controlled by wind flow from the Bay of Bengal and dry desert-filled air from the west (i.e. both Sea-atmosphere relation) , the topographical role dictated by SubHimalayan terrain is of equal significant. For sudden unexpected events like the warm spell, the detrimental effect from convective cloud around TTL adds extra humidity at 120 mb level making the wind flow pattern stable in this stratum and consequent contribution to an artificially wram state, which is further added by particulate pollutant present on this background.

Solar geomagnetic role on the temperature is not reflected when temperature shows a maximum not at the Rz peak but at a relatively low Rz status. We do not have any identified reasons for that, but the Forbush effect may be associated as an explanation when at maximum Rz, a part of the cosmic ray energy is not available for reaching the earth, and it results in modification of atmospheric pressure, cloud formation, and CCN growth [Usoskin and Kovaltsov 2008; Laken and Kniveton 2009], when temperature and humidity may show unexpected behaviour with solar strength . However, more case studies need to be conducted to determine the dynamics of the sudden onset of warm spells or increases in humidity at the TTL/CPT zone.

The importance of such a study is that the humidity contrast across /near tropopause is expected to control the radiative heating profile, gradients in temperature, and wind flow pattern, and its significant role is in the large-scale dynamics and thus in climate change [Pierrehumbert 1999]. In atmospheric model analysis, reanalysis, and forecast, moisture is one of the main features. as suggested by many [Trenberth 1997; Allan et al., 2002; Murphy et al., 2004; Minschwaner and Dessler 2004; Seager and Henderson 2013], hence lies its significance. More case studies are our future plans because the realization of the system physics during such events, cloud and its coupling dynamics to the atmosphere, along with topography influence on it, needs to be understood from multiple events.

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