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Investigation of Precursor from Low Level Jet Stream for Indian Summer Monsoon from Mascarene High Near Madagascar Island

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***Abstract** A major driver of the Indian Summer Monsoon (ISM) is the cross-equatorial low-level jet (LLJ), whose maximum intensity is usually found around 850 hPa, corresponding to an altitude of nearly 1.5 km. This monsoon system exhibits substantial intra-seasonal variability between June and September. At its onset, the LLJ gains strength from the Mascarene High near Madagascar, channeled via the Somali Current, which in turn triggers wind reversal over the Indian subcontinent. The present work is entirely data-driven, utilizing radiosonde and rawinsonde (RSRW) upper-air observations from the University of Wyoming. Atmospheric profiles at 925 hPa, 850 hPa, and 700 hPa were analyzed for temperature, humidity, and wind parameters during March of the years 2021–2025. North–south moisture flux components were calculated, revealing that a reversal occurs near Seychelles (station FSSS, WMO 63985; 4.66°S, 55.53°E), approximately three months before the ISM onset in India. The influence of El Niño on this variability was also detected. Findings suggest that moisture flux reversal over Seychelles can act as a precursor for long-range monsoon forecasts.*
***Keywords:** Low Level Jet, Mascarene High, Somali current, RSRW, Moisture Influx, Scale Height, ELNINO.*

I. INTRODUCTION

India mainly depends on agriculture for its economy, with a substantial portion of its population directly or indirectly dependent on agriculture for livelihood. The performance of agriculture in India is critically linked to the Indian Summer Monsoon (ISM), which supplies about 75–80% of the annual rainfall. Despite advancements in digital infrastructure and technology, agricultural productivity and the overall development of India still hinge heavily on the behavior of the monsoon. Consequently, accurate prediction and monitoring of monsoon patterns remain a central focus for planning and risk mitigation in agriculture.

The southwest monsoon, which typically arrives in early June and lasts till September, is a complex meteorological phenomenon influenced by several large-scale atmospheric systems. Among these, the Heat Low, Monsoon Trough, Mascarene High, Tibetan High, Low-Level Jet (LLJ), and Tropical Easterly Jet (TEJ) play pivotal roles. The evolution, intensity, and position of these systems govern the onset, distribution, and intensity of monsoonal rainfall across the Indian subcontinent.

The Heat Low, a thermal low-pressure system, forms over the Indo-Pak region before the monsoon and is closely tied to the monsoon's vigor. The Monsoon Trough, extending southeastwards from the Heat Low, steers rainfall patterns across the Indo-Gangetic plains. The Mascarene High, located in the southern Indian Ocean, regulates the flow of moist air towards India. The Tibetan High, a dominant upper tropospheric feature, significantly influences monsoon progression, while the Tropical Easterly Jet (TEJ), at 150–100 hPa, is associated with enhanced convection over the Indian region. Among these, the Low-Level Jet (LLJ)—a strong westerly wind current at around 850 hPa over Peninsular India—has received special attention for its strong correlation with monsoon rainfall. Studies by Joseph and Raman (1966), Findlater (1969), and others have confirmed the role of LLJ in transporting moisture from the equatorial Indian Ocean to the Indian mainland. These winds, often part of the Somali Jet, are known to influence the timing, intensity, and spatial distribution of monsoon rainfall, particularly over western and peninsular India. The variability in strength and frequency of LLJs is often reflected in the rainfall patterns, making them a valuable diagnostic tool in monsoon forecasting. Despite its importance, comprehensive observational studies on the LLJ, especially using high-resolution atmospheric sounding data, remain limited. In particular, detailed analyses based on multi-year atmospheric sounding datasets over cross-equatorial regions are scarce, especially those that quantify moisture flux associated with LLJ dynamics.

In this context, the present study aims to investigate the behavior of the cross-equatorial Low-Level Jet (LLJ) and its associated moisture flux over the Indian Ocean during the southwest monsoon season using five years (2021–2025) of upper-air atmospheric sounding data from the Seychelles (FSSS, WMO station code 63985), located near Madagascar.

The analysis focuses on the vertical wind profile from 925 hPa to 700 hPa, with particular attention to the 850 hPa level, the typical core height of the LLJ. Moisture flux components have been computed using directional wind data and relative humidity to quantify the northward transport of moisture, which fuels the Indian monsoon.

By examining the interannual variations of LLJ and moisture influx during the pre-monsoon and monsoon months, this work seeks to enhance understanding of LLJ dynamics as a predictive tool for monsoon performance. This is crucial for early drought prediction and agricultural preparedness, reaffirming the centrality of atmospheric diagnostics in supporting India's food security and climate resilience strategies.

II. DATA & METHODOLOGY

The observatory collects Radio Sonde Radio Wind (RSRW) data as per WMO norms. These RSRW data containing pressure, temperature , Humidity, wind speed and wind direction starting from surface to different layers of upper atmosphere with the help of a hydrogen gas field big balloon . the on board balloon containing sensors of pressure, temperature, humidity . with the help of a radio transmitter, signals of sensors are transmitted to the ground based radio receiver. Then received signal then modulated to corresponding said parameters. Wind speed is calculated by triangulation method. As still now , low cost small robust reliable wind sensors are not available . For this reason , now a days , GPS sonde are being replaced by RSRW. In this piece of work, atmospheric sounding data from the website of the University of Wyoming have been utilized for five years the years 2021, 2022, 2023, 2024 and 2025 respectively. It is to be mentioned here that we have utilized 00 gmt and 12 gmt dataWe examined the southwest monsoon flow through the cross-equatorial low-level jet (LLJ), extending from the 925 hPa to the 700 hPa pressure levels, which corresponds to a height of nearly 3 km within the local atmospheric scale height. The jet's core was identified at approximately 850 hPa, or about 1.5 km above the surface. Our study is based on five years of data (2021–2025) collected from the Seychelles station (ICAO code FSSS, WMO 63985; 4.66°S, 55.53°E), located at an Air Force base near Madagascar. The meridional (south-to-north) component of cross-equatorial moisture transport was estimated along the 180° direction. Wind direction values were interpreted following WMO conventions, allowing the southward flux component to be expressed as relative humidity multiplied by the cosine of (DDD – 180). These flux values, derived for both pre-monsoon and monsoon months, were then plotted as time series against calendar dates.For this study, we used sounding data from the University of Wyoming upper-air database:
http://weather.uwyo.edu/upperair/sounding.html

Table 1 provides a summary of atmospheric parameters in dataset while Table2 provides sample of the data of year 2025, 000 Gmt, Station Seychelles latitude: -4.66 longitude: 55.53.

Code	Variable Measured	Unit of Measurement
PRES	Pressure at observation level	hPa
HGHT	Height above mean sea level (geopotential)	m
TEMP	Air temperature	°C
DWPT	Dew point temperature	°C
FRPT	Frost point	°C
RELH	Relative humidity	%
RELI	Humidity relative to ice	%
MIXR	Mixing ratio of water vapor	g/kg
DRCT	Wind direction	degrees (true north reference)
SKNT	Wind speed	knots
THTA	Potential temperature	K
THTE	Equivalent potential temperature	K
THTV	Virtual potential temperature	K

Table 1: Description of the used data column

Date	Time	PRES	HGHT	RELH	DRCT	…
2025-05-19	12Z	925.0	760	84	175	…
2025-05-19	12Z	850.0	1495	43	185	…
2025-05-19	12Z	700.0	3148	24	100	…
2025-05-30	00Z	925.0	787	95	155	…
2025-05-30	00Z	850.0	1520	86	150	…
2025-05-30	00Z	700.0	3167	62	195	…

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Table 2: Sample of the data of year 2005, 000 Gmt, Station Seychelles latitude: -4.66 (Southern Hemisphere) longitude: 55.53.
To calculate the northward moisture flux, we used the wind direction (DRCT) and relative humidity (RELH) values from the RSRW data.
The cosine component of wind direction (toward north) is computed as:

$$\cos\theta = \cos\left(\frac{\pi}{180} X\ (DRCT - 180)\right) \qquad \ldots(1)$$

Then the northward component of relative humidity flux is calculated as:

$$RH\_flux_{cos} = RELH\ X\ \cos\left(\frac{\pi}{180} X\ (DRCT - 180)\right) \qquad \ldots(2)$$

Here,
DRCT= wind direction in degrees
RELH = Relative Humidity (in %)
RH_flux_{cos} = Component of relative humidity flux in the north-south direction

III. RESULT AND DISCUSSION

The present study examined the northward moisture flux and onset of northerly winds at Seychelles (Station FSSS, WMO code 63985) for five consecutive years (2021–2025), covering the pre-monsoon and early monsoon period (March to May). The analysis is based on daily averaged values derived from atmospheric sounding data at 925 hPa, 850 hPa, and 700 hPa pressure levels, using observations at both 00Z and 12Z.

A. Moisture Flux Trends

Figures 1 to 5 present the time series plots of northward moisture flux (RH_flux_cos) for each year from 2021 to 2025. In all five cases, a consistent pattern of increasing positive flux is observed beginning in the first or second week of March, indicating the onset of cross-equatorial flow.
Key observations:

- In 2021, 2022, and 2024, the increase in northward moisture flux started around 5th March.
- In 2023, it began slightly earlier on 4th March.
- In 2025, the onset was slightly later, around 9th March.

This northward moisture transport is a key component of the Low-Level Jet (LLJ), which plays a significant role in bringing moisture from the southern Indian Ocean toward the Indian subcontinent.

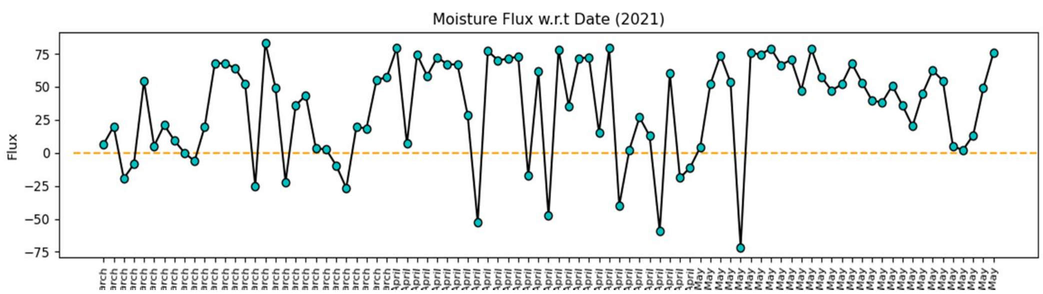

Figure-1: Representation of Moisture flux along North-South direction at Seychelles (2021)

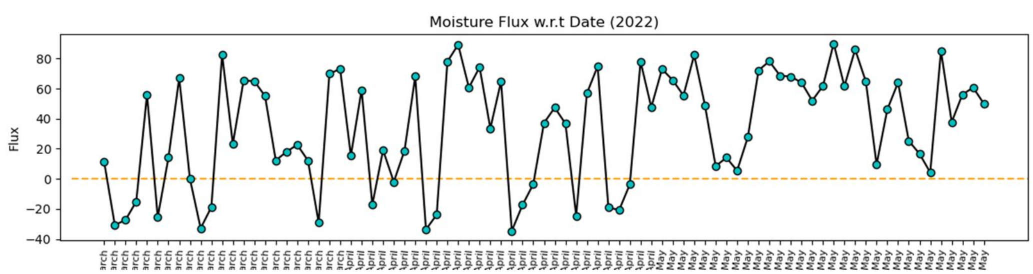

Figure 2: Representation of Moisture flux along North-South direction at Seychelles (2022)

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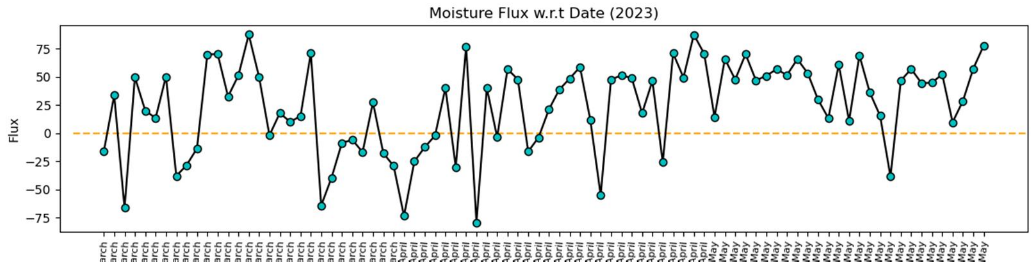

Figure 3: Representation of Moisture flux along North-South direction at Seychelles (2023)

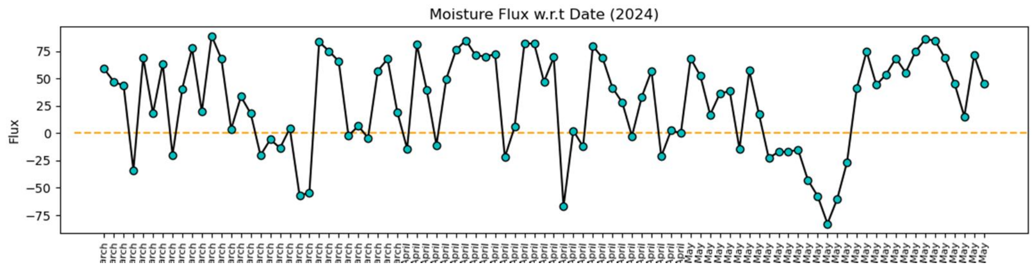

Figure 4: Representation of Moisture flux along North-South direction at Seychelles (2024)

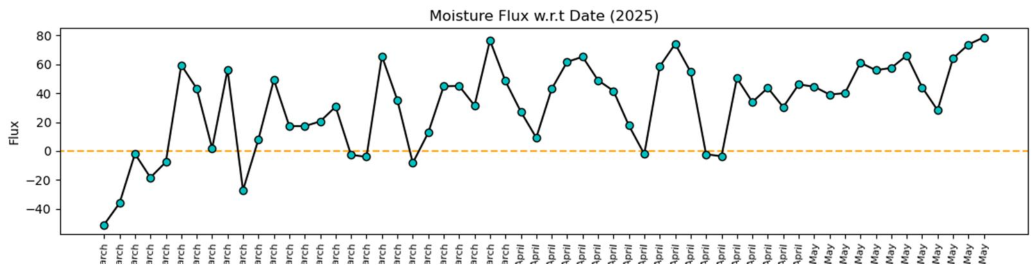

Figure 5: Representation of Moisture flux along North-South direction at Seychelles (2025)

B. Comparison with Monsoon Onset Dates in India

The official monsoon onset dates over India for the same years were:3rd June (2021), 29th May (2022), 8th June (2023), 30th May (2024), 24th May (2025). It is being found from the above depicted results that there is always a consistent advance signature received of about 80–90 days between the start of northerly winds/moisture flux at Seychelles and the onset of the Indian Summer Monsoon. This clear and repeated time gap supports the idea that the onset of northerly winds at Seychelles serves as an early precursor to the Indian Summer Monsoon.

C. Implications

This finding suggests that monitoring wind direction and humidity data at Seychelles can provide valuable early signals for predicting the timing of monsoon onset in India. This could be particularly useful for long-range weather forecasting, drought preparedness, agricultural planning and crop sowing at different parts of India.

In an agriculture-based country like India, where rainfall patterns have a direct impact on food production and rural livelihood, early detection of monsoon behaviour can greatly enhance climate resilience and decision-making at both policy and farm levels.

IV. CONCLUSION

Based on the analysis, several conclusions can be drawn:

1) The timing of the southwest monsoon onset over different parts of India can be anticipated by monitoring the preceding northward moisture flux at those locations.
2) The onset is not uniform; it varies from region to region across the subcontinent.
3) Tracking changes in moisture incursion also provides insights into the advancement and temporary stagnation of the monsoon.

Since moisture transport signals appear well before the actual establishment of monsoon circulation, they can serve as a reliable precursor for long-range forecasts. Despite advancements in irrigation infrastructure, India's agricultural output and economic stability remain highly sensitive to rainfall distribution. Therefore, using moisture flux variability as an early diagnostic tool can significantly strengthen seasonal forecasting and agricultural planning.

V. ACKNOWLEDGEMENTS

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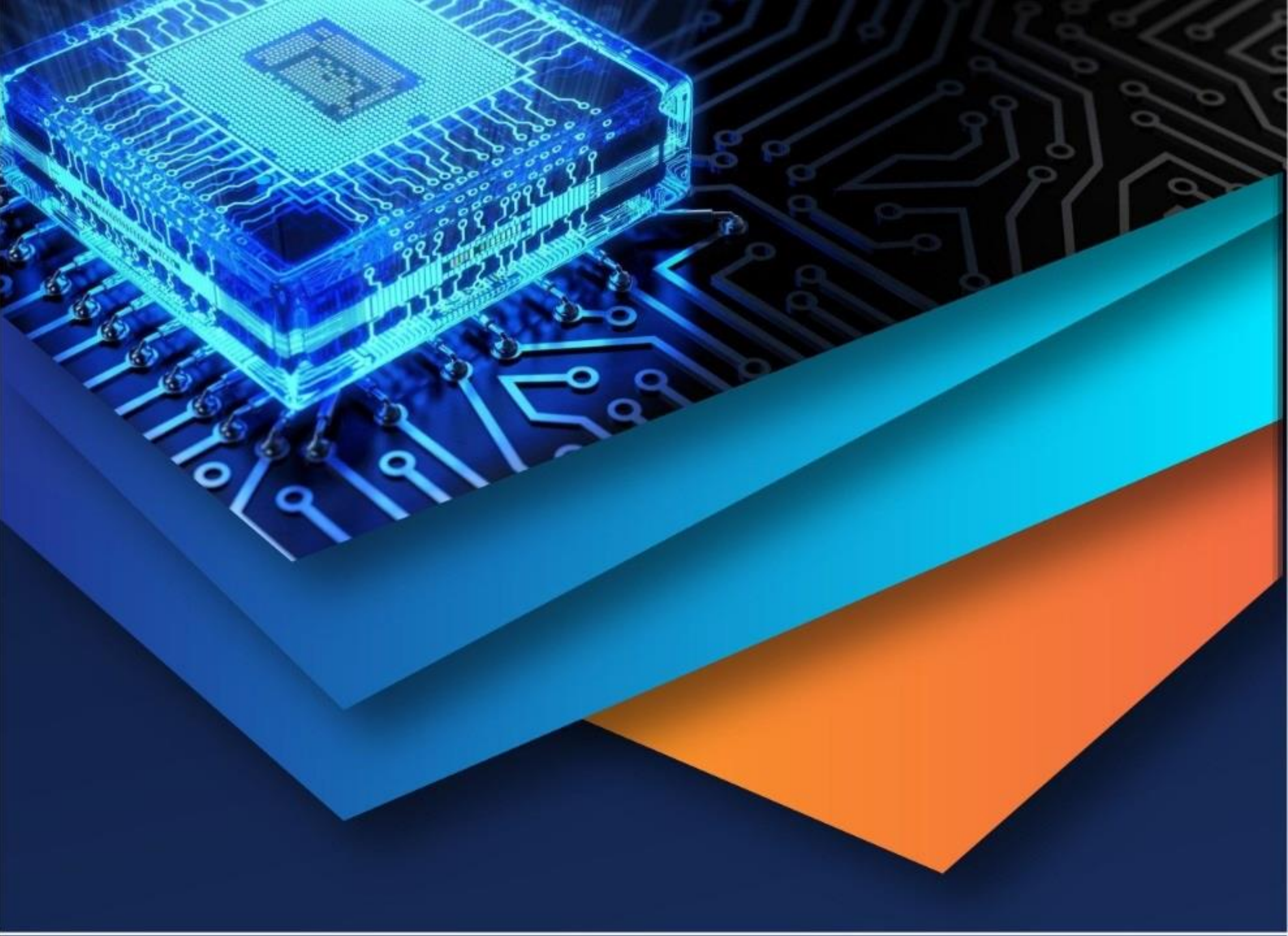

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