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Wind Profiles in Peninsular Malaysia: A Comprehensive Upper Air Analysis
(Profil Angin di Semenanjung Malaysia: Suatu Analisis Komprehensif Udara Atas)

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ABSTRACT

Understanding the atmospheric properties and patterns is crucial in empowering Malaysia's national aerospace blueprint, national space, and legislation. While various policies have been enacted and implemented, there is a lack of information on the wind profile, specifically the upper air across Peninsular Malaysia. Realising the need to establish a standard guideline for national reference, future research, space-aerospace application, and legislation, this study was performed to develop the first wind profile analysis of upper air in Peninsular Malaysia. Relevant data from the Malaysian Meteorology Department was collected for analysis and evaluation. Specifically, a meteorology balloon attached with a sounding radiosonde was used to record data at 0000UTC (0800 h LT) and 1200UTC (2000 h LT) on the 15th day of each month for 7 years (from 2015 to 2021) at the KLIA and Kuantan Meteorology Stations for the wind profiling analysis. The daily overall data collection was recorded accurately once the balloon's rising rate stabilises from vertical air current (katabatic or anabatic winds). Subsequently, the collected data were evaluated in terms of the minimum, maximum, and average wind speeds for each year and time. Finally, the average wind speed of each year and time were combined to generate the Peninsular Malaysia wind profile. Based on the results, the projected wind profile for both stations identified three peaks of discrete sine wave flow type with low-speed wind profile in Peninsular Malaysia. The three peaks amplified the highest air velocity, whereby the 1st and 2nd peaks were located at the troposphere layer from 9,000 m to 12,000 m altitude (average wind speed of 10.8 ms^{-1}) and 12,000 m to 18,000 m altitude (average wind speed of 13.7 ms^{-1}). The 3rd peak was located at the stratosphere layer from 18,000 m to 32,000 m altitude (average wind speed of 15.2 ms^{-1}). Since East Malaysia is located on the same equatorial line, the wind profile is hypothetically the same and exhibits only slight differences. In short, the established wind profile of upper air in Peninsular Malaysia in this study would facilitate other future studies and assist long-term planning of Malaysia's airspace legislation.

Keywords: Meteorology; stratosphere; troposphere; wind profile; wind speed

ABSTRAK

Bagi memperkasakan pelan tindakan aeroangkasa negara, ruang angkasa lepas negara dan perundangan, memahami atmosfera menjadi penting bagi pereka bentuk, jurutera, penyelidik dan perundangan. Kerja ini bertujuan untuk menjana profil angin untuk Semenanjung Malaysia untuk rujukan negara, penyelidikan masa depan, aplikasi angkasa-aeroangkasa dan perundangan. Oleh kerana sumber yang sangat terhad untuk memahami atmosfera Semenanjung Malaysia, data udara daripada Jabatan Meteorologi Malaysia telah dimanfaatkan. Proses dijalankan menggunakan belon meteorologi dengan radiosonde bunyi di Stesen Meteorologi KLIA (Semenanjung Barat) dan Stesen Meteorologi Kuantan (Semenanjung Timur). Data telah dikumpul selama 7 tahun pada setiap hari ke-15 setiap bulan dari 2015 hingga 2021. Data udara ini telah dinilai dan dianalisis berdasarkan ketinggian. Hasilnya, unjuran profil angin bagi kedua-dua stesen telah mengenal pasti 3 puncak aliran gelombang sinus jenis profil angin kelajuan rendah secara diskret di Semenanjung Malaysia. Puncak Pertama dan Puncak Kedua terletak di lapisan Troposfera antara 9,000 m hingga 12,000 m ketinggian dengan purata kelajuan angin 10.8 ms^{-1} dan ketinggian 12,000 m hingga 18,000 m dengan kelajuan angin purata 13.7 ms^{-1} manakala Puncak Ketiga terletak di Stratosfera, lapisan antara 18,000 m ke ketinggian 32,000 m dengan kelajuan angin purata 15.2 ms^{-1}. Semenanjung Malaysia dan Malaysia Timur berada di garisan khatulistiwa, oleh itu, hasilnya secara hipotesis serupa untuk kajian pendekatan masa hadapan untuk penyelidik, jurutera dan perundangan.

Kata kunci: Atmosfera; kelajuan angin; meteorologi; profil angin; Semenanjung Malaysia

INTRODUCTION

The Malaysian Aerospace Industry Blueprint 2030 was established by the Malaysian Industry-Government Group for High Technology (MIGHT) as a long-term road map to develop the Malaysian aerospace industry by 2030. The inclusive policy set by MIGHT, which forms the Secretariat of the Malaysian Aerospace Council (MAC) under the Prime Minister's Department, covers various industrial activities related to the development, design, manufacturing, and construction, as well as the maintenance and disposal of aircraft, spacecraft, missiles, and rockets in the country. Meanwhile, the National Space Agency under the Ministry of Science, Technology and Innovation of Malaysia (MOSTI) effectively implemented the Malaysia Space Agency Act 2022 [Act 834] in 2023, which regulates certain space-related activities for security purposes, the registration of space objects, and to provide certain space-related offences and relevant issues. In view of these national guidelines, it is crucial to grasp a clear perspective of Malaysia's atmosphere system that may benefit space or aerospace studies, research, design, and legislation.

Malaysia is generally a maritime nation in southeast Asia just north of the equator. The country comprises two main territories, Peninsular Malaysia (West Malaysia) and Sabah and Sarawak (East Malaysia) on Borneo Island. The country occupies roughly 690 km^2 of land size, as shown in Figure 1.

Malaysia's wind profile is influenced by eight strong tropical cyclones over the Western North Pacific Ocean, which forms the Northeast Monsoon. The tropical cyclone coincides with the easter surge and enhances the convection caused by heavy rainfall across Malaysia, attributed to cross-equatorial wind flow (Fakaruddin et al. 2017). Apart from that, the Southwest Monsoon (or summer monsoon) affects Malaysia's wind profile and is generally characterized by westerly to southwesterly winds over the South China Sea, Indochina, and the northern maritime continent. The southwest monsoon also causes the rainy season in India and East Asia. In contrast, it is generally drier in Malaysia and its neighbouring regions during this season.

Readily available wind speed data used for developing wind resource atlases are measured 10 m above ground level, and the data shall not be predicted as constant throughout the days, months, and years (Lopez-Villalobos et al. 2022)the Monin–Obukhov similarity method was implemented to estimate the wind speed vertical profile within the surface boundary layer for a southeast Mexican site, considering seasonal and diurnal variations of the surface boundary layer stability parameters. Additionally, a power-law method was implemented where the wind shear exponent was set following the International Electrotechnical Commission (IEC. As a maritime nation, the wind source in Malaysia originates within 50 m altitude above sea level (a.s.l.), with a wind speed range of 1.0–3.0 ms-1 (Ahmad et al. 2018). Although several methods have been introduced to measure wind speed at certain altitudes using moderate requirements on logistics, facilities, and budget (Varentsov et al. 2021), high-altitude wind speed has not been profiled for wind power generation and energy production.

As illustrated in Figure 2, the high-altitude wind speed in Malaysia flow across the equatorial line and can be said to move away from the jet stream from the northern and southern hemisphere. Jet stream refers to the high-speed flowing, narrow, winding air near the tropopause altitude flowing from west to east. This supercritical wind speed may start, stop, split into two or more parts, combine into one stream, or flow in various directions, including opposite to the direction of the remainder of the jet. Thus, knowledge of the wind speed boundary layer and the vertical wind speed profile is vital to accurately estimating various meteorological and engineering practices, designing civil engineering structures, and developing wind power projects (He et al. 2022).

In this regard, it is essential to improve the understanding of numerous wind production profiles, the characteristics of extreme conditions produced by such turbulences due to surface terrain and roughness (land and sea), and the decay of this turbulence with distance and height over the sea surface under various atmospheric conditions (Abubaker, Kostić & Kostić 2018; Gryning et al. 2007; Martins, Carvalho & Sousa 2015; Svensson et al. 2019continuous-wave LIDAR is placed on an island in the central Baltic Sea with large open-water fetch, providing wind and turbulence profiles up to 300 m height. LIDAR and Weather Research and Forecasting (WRF). While recent studies have modelled the atmospheric momentum fluxes, which can simulate the vertical momentum distribution and determine the wind speed profile, the analysis is limited to a maximum jet level of 1,500 m altitude above the surface compared to over the sea simulation, which is naturally radioactive-cooled (Svensson et al. 2019)

WIND PROFILING

WIND PHENOMENON IN EARTH'S ATMOSPHERE

The worldwide wind formation is significantly contributed by the difference in air pressure between two regions within the Earth's atmosphere. Once the wind speed increases, the effect of the earth orbiting on its axis once a day takes place on the wind travelling along the isobars' direction. Additionally, local winds are generated due to several factors, such as airlifted by surface geographical features, lines of hills, or mountain ranges (orographic wind), the

FIGURE 1. (A) The map of Malaysia taken from Google Earth (4.21°N, 101.98°E) comprising the Peninsular (left) and Eastern (right) territories of Malaysia (Google Earth, n.d.) and (B) Malaysia wind flow map on May 2023 taken from Malaysia Wind Map,

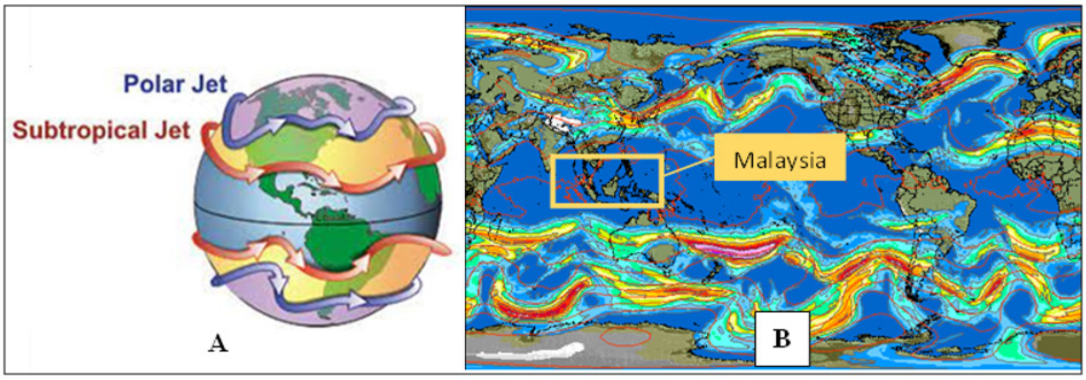

FIGURE 2. (A) The fastest winds of about 40–80 ms-1 are known as the Subtropical Jet (red line), while slower winds are known as the Polar Jet, which can travel over 50 ms-1 (blue line), and (B) The weather model from the Global Jet Stream shows that the subtropical jets do not affect the wind pattern in Malaysia

cold flow of air moving up (anabatic wind) and down (katabatic wind) the hills or mountains, and blowing wind in the form of sea-to-land (sea breeze) and land-to-sea (land breeze) owing to a temperature different (Jena & Gairola 2022 Svensson et al. 2019; Teneler 2011; Wind | SKYbrary Aviation Safety n.d.).

Furthermore, the strong up and downwind motion in the cumulonimbus cloud would potentially speed up the vector of gusts and occasionally generate microbursts to the surface. Low air pressure in tropical maritime regions could generate strong winds, such as tropical storms (Wind | SKYbrary Aviation Safety n.d.) and tropical cyclones (Fakaruddin et al. 2017). Therefore, wind production defined as the flow of large-scale atmospheric air as wind flows from high to low pressure. The change in wind speed and wind direction along specific altitude is called the wind shear (Teneler 2011). Although past research has reported that tropical storms exhibit a maximum wind speed of 18 ms-1 but the altitude remains unknown (Finocchio & Majumdar 2017)

Anemometer (Cup Anemometer) is a measuring device frequently used to determine surface wind speeds from 6 m above the open ground surface. The wind speed is measured by passing air velocity through the anemometer within a 2-minute average time. On the contrary, the pilot balloon with a theodolite visual-led setup is the simplest instrument for high-altitude wind speed measurements. Assuming a constant rising rate of a gas-lifted balloon, the elevation readings and azimuth angles of average wind speed and direction are periodically recorded based on the balloon position. Errors are interpreted when the balloon rising rate is not constant due to the local deployment's vertical winds (katabatic and anabatic winds). The readings and data collection are more accurate by installing a radiosonde to the balloon.

In recent years, meteorologists have employed rawinsonde with radiosonde to improve instrument capabilities for radar observation. Meteorology stations are often located more than 100 miles apart, and regular data recordings are sampled twice daily at 0700 h and after 1500 h as the temperature steadily decreases (Varentsov et al. 2021). Additionally, current research has utilised various drone technologies, including fixed-wing Unmanned Aerial Vehicles (UAVs), rotary-wing UAVs, and multirotor drones, such as the DJI Phantom 4 Pro drone to measure high-altitude air velocities but limited to 500 m altitude due to software capabilities (Varentsov et al. 2021). Furthermore, researchers have applied the millimetre Doppler radar to measure wind speed. However, the method often inaccurately measures the azimuth and elevation angle at 200–400 m height due to high-level interference from other networks and terrestrial movements (Sterlyadkin et al. 2017).

Previous studies have also verified that offshore wind and turbulence characteristics are generated by forcings compared to onshore meteorology. Typically, wind speed is naturally modified and turbulent flow routed to the Earth's surface. A recent study investigated these forcings over the sea within about a 5 km radius from land and limited to 1,000 m altitude on an island in the central Baltic Sea. Figure 3 illustrates the wind speed measurement using two methods with a difference of 3 ms-1 between both results (Svensson et al. 2019

Another study aimed to understand further the effect of varying heights on wind direction phenomena under monsoon and typhoon conditions. Based on the long-term wind measurements from the Doppler wind profiler and a surface weather station in Hong Kong, the veering was undetected up to 2000 m altitude, as depicted in Figure 4 (Shu et al. 2018)

Pietersen et al. (2015) conducted the Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) experiment approximately 40 km north of the central range of the Pyrenees mountains near Campistrous, France, on a plateau at the height of 600 m a.s.l. at the foot of the Pyrenees mountain range with heights of approximately 2,000–2,500 m. The result showed wind data up to 10 km altitude, where the boundary-layer properties and the lower atmosphere were extensively monitored, as shown in Figure 5.

The NASA/MSFC (Marshall Space Flight Centre) Sequential High-Resolution Jimsphere Wind Profile Measurement Program is one of the programs conducted at NASA's Kennedy Space Centre (KSC), Florida, in the early 1970s. The program measured wind speeds up to 18 km altitude over short periods, mainly at KSC and Point Mugu, in California. The Jimsphere and Automated Meteorological Profiling System (AMPS)/Radiosonde) was used to measure the wind speed at NASA's KSC launch site before the data was transmitted to NASA's Marshall and Johnson Space Centres. Figures 6 and 7 show the interesting wind and gust patterns recorded at NASA's KSC (Johnson & Vaughan 2017). Concurrently, the study defined the wind profile average up to 18 km altitude, as in Figure 8 (Johnson & Vaughan 2017).

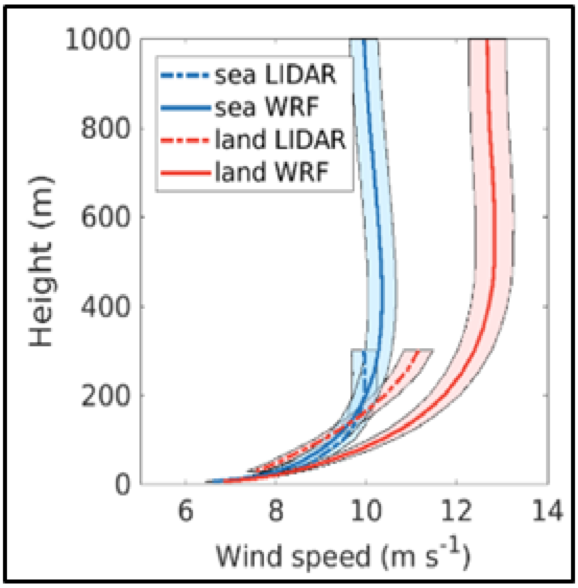

FIGURE 3. Mean wind speed profiles from Light Detection and Ranging (LIDAR) and Weather Research and Forecasting (WRF) divided into sea and land sectors during one full year. The filled area represents the standard deviation of the mean at each height (Svensson et al. 2019)

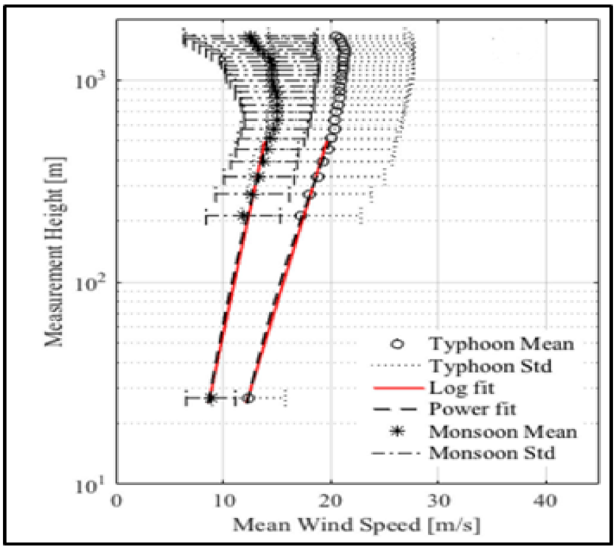

FIGURE 4. Vertical profiles of mean wind speed in Hong Kong showing the increase of wind speed with 10 ms-1 gradually along the increasing altitude using the Doppler wind profiler (Shu et al. 2018)

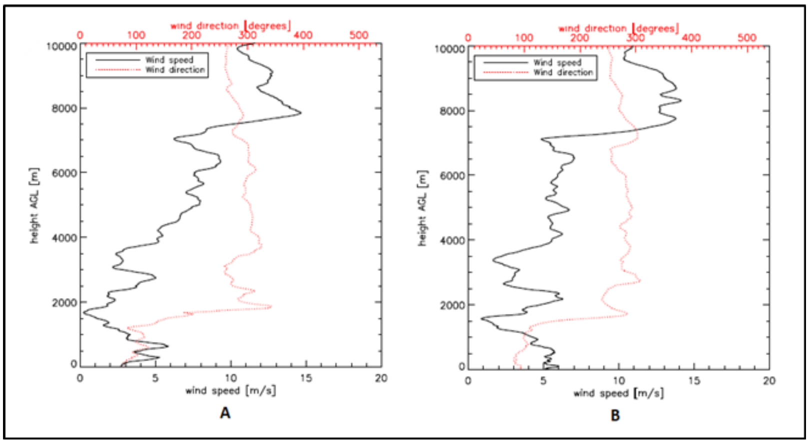

FIGURE 5. Wind profiles (speed and direction) of the lowest 10 km altitude in Campistrous, France, measured using the radiosondes: (A) 10:34 UTC and (B) 16:44 UTC (Pietersen et al. 2015)

Several research studies have identified the relationship between atmospheric wind speed and altitude increment. However, there is still a lack of information on this subject due to differences in geophysical atmosphere thermodynamic behaviour and geographical topologies. The insight into geography and geophysics thermodynamics is essential for researchers, scientists, and engineers to develop wind-based technologies and laws in Malaysia. Therefore, this study conducted a wind profile analysis of the upper air in Peninsular Malaysia to understand the wind characteristics and nature in Peninsular Malaysia with altitudes. Upper air data were obtained from the Malaysian Meteorological Department to process and analyse the wind profile in Peninsular Malaysia. The established wind profile from this study would be a reliable reference for various development of Malaysian airspace systems and technologies.

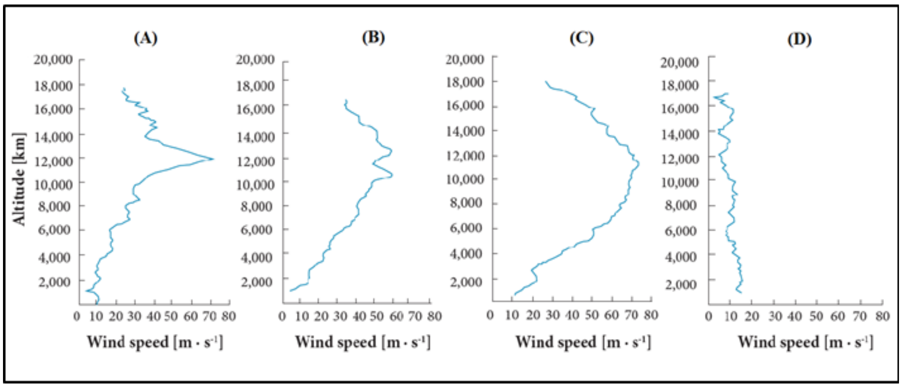

FIGURE 6. Type of wind patterns at NASA's KSC: (A) Example of jet stream winds; (B) Example of sine wave flow in the 10–14 km altitude region; (C) Example of high wind speeds over a deep altitude layer, and (D) Example of low wind speeds (Johnson & Vaughan 2017)

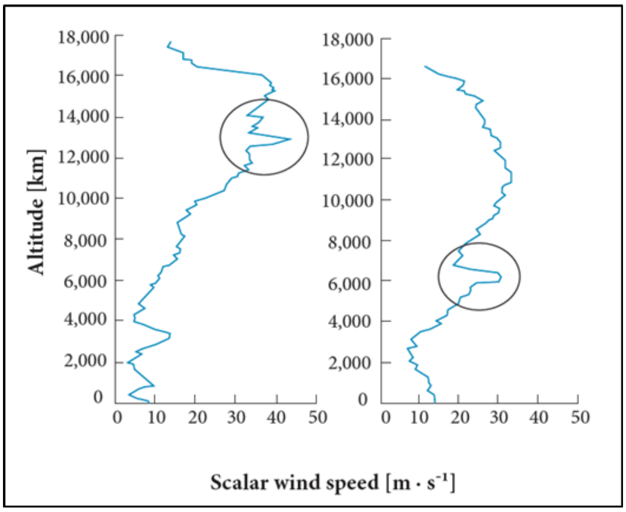

FIGURE 7. Examples of discrete gust patterns at NASA's KSC (Johnson & Vaughan 2017).

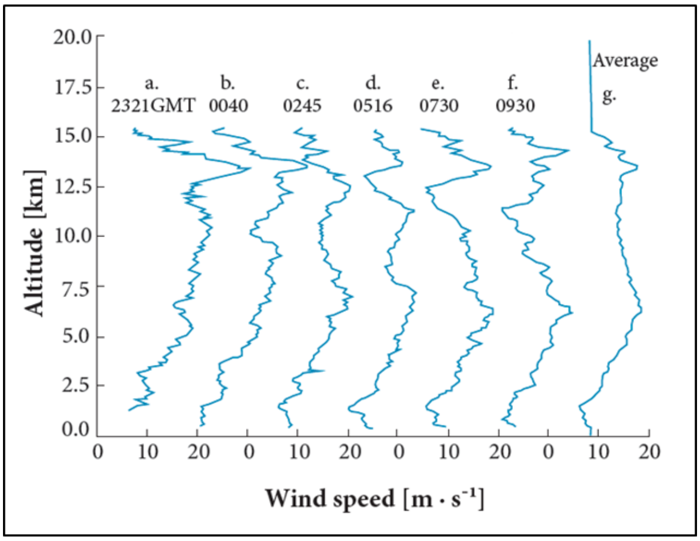

FIGURE 8. Sequential wind speed profiles measured at NASA's KSC (Johnson & Vaughan 2017)

MATERIALS AND METHODS

SAMPLING OF WIND PROFILE OF UPPER AIR IN PENINSULAR MALAYSIA

Peninsular Malaysia was selected as the focus for this study given its location near the equator line, surrounded by the South China Sea and the Strait of Melaka, and experiences Northeast and Southwest Monsoons annually. A formal favour-permission letter was submitted to the Malaysian Meteorology Department to request relevant data from 2015 to 2021 (7 years of data). The KLIA Meteorology Station (Latitude: 2°49’51”N, Longitude: 101°42’11”E, Elevation: 16.11 m) and Kuantan Meteorology Station (Latitude: 3°46’20”N, Longitude: 103°12’43”E, Elevation: 15.23 m) were chosen among the many meteorology stations in Malaysia due to data availability and that both stations have scheduled instrument deployment twice every day (Varentsov et al. 2021) at 0000UTC or 0800 h LT and 1200UTC or 2000 h LT. Figure 9 shows the location of both meteorological stations.

Current radiosonde instruments are equipped with sensors linked to a battery-powered radio transmitter that sends the information to a ground receiver to measure wind speeds. The direction of the wind flow is also determined by tracking the position of the radiosonde in flight via Global Positioning System (GPS). For this study, a Radiosonde DFM-17 developed by GRAW/Noris Group GmbH contains a temperature, barometric pressure (optional), and humidity sensor for upper air weather observations. The device also includes a GPS receiver for position tracking and calculating wind speeds. Table 1 provides a list of the instrument specification employed in this study.

Each station approved selected personnel to launch the meteorology instrument in accordance with the standard operating procedure. Figure 10 explains the step-by-step flow for the meteorology instrument launch at the Malaysian Meteorology Department. Note that hydrogen gas is harmful, and Personal Protective Equipment (PPE) is required to handle the gas properly.

PENINSULAR MALAYSIA WIND PROFILING

This method profiled and identified the average wind speed pattern from the troposphere and stratosphere layers in Peninsular Malaysia. The collected upper air data from KLIA and Kuantan Meteorology Stations were analysed based on the recorded air velocity during the meteorology balloon flight from ground level to the maximum flight altitude. The 7 years of data were taken on every 15th day of the month from 2015 to 2021 at KLIA and Kuantan Meteorology Stations and categorised into two groups, namely, 0000UTC (0800 h LT) and 1200UTC (2000 h LT,) to observe the different outcomes from both times. The meteorology balloons travelled vertically at an average of 33,000 m before losing altitude, signifying that the balloon could travel and record data up to the stratosphere layer. In the first stage, the raw data were sorted from lower to higher altitudes prior to processing. Figure 11 shows the upper air data sample collected by the GRAW Radiosonde DFM-17 at the KLIA and Kuantan Meteorology Stations.

For the second stage, the average of 7 years of wind profiles was processed by separating the 0000UTC (0800 h LT) and 1200UTC (2000 h LT) at each meteorology station. Subsequently, the pattern line of the wind profile was assessed to determine the different wind speeds at both times from 2015 to 2021. The third data processing stage

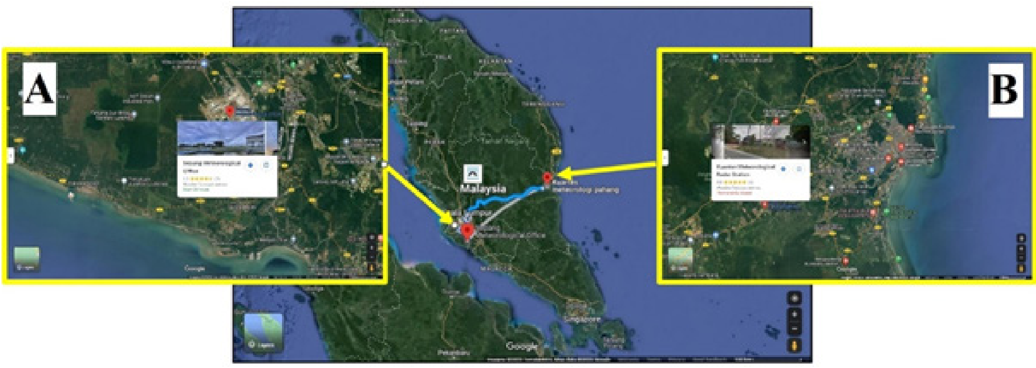

FIGURE 9. Locations of the (A) KLIA Meteorology station and (B) Kuantan Meteorology station (Sepang Meteorological Office to Kuartes Meteorologi Pahang - Google Maps, n.d.). The distance between the two stations is approximately 299.2 km

TABLE 1. Specification of the Radiosonde DFM-17 setup and its components for upper air data recording in this study

Component	Specification
Meteorology balloon	Brand: TOTEX (TOTEX Corporation/Meteorological Balloon, n.d.); Type: Sounding balloon; Colour: White; Weight: 350 g; Air charge: Hydrogen (Voss, Ramm & Dailey 2012)
Radiosonde	Brand: GRAW Radiosonde; Type: DFM-17 (Products | NORIS Group GmbH n.d.); Weight: 88 g; Measured range: Up to 40 km
Ground station	Brand: GRAW Radiosonde; Type: GS-E (Products | NORIS Group GmbH n.d.); Weight: 88 g; Receiving range: Up to 250 km
Computing software	Brand: GRAW Radiosonde; Type: GRAWMET (Products | NORIS Group GmbH n.d.)

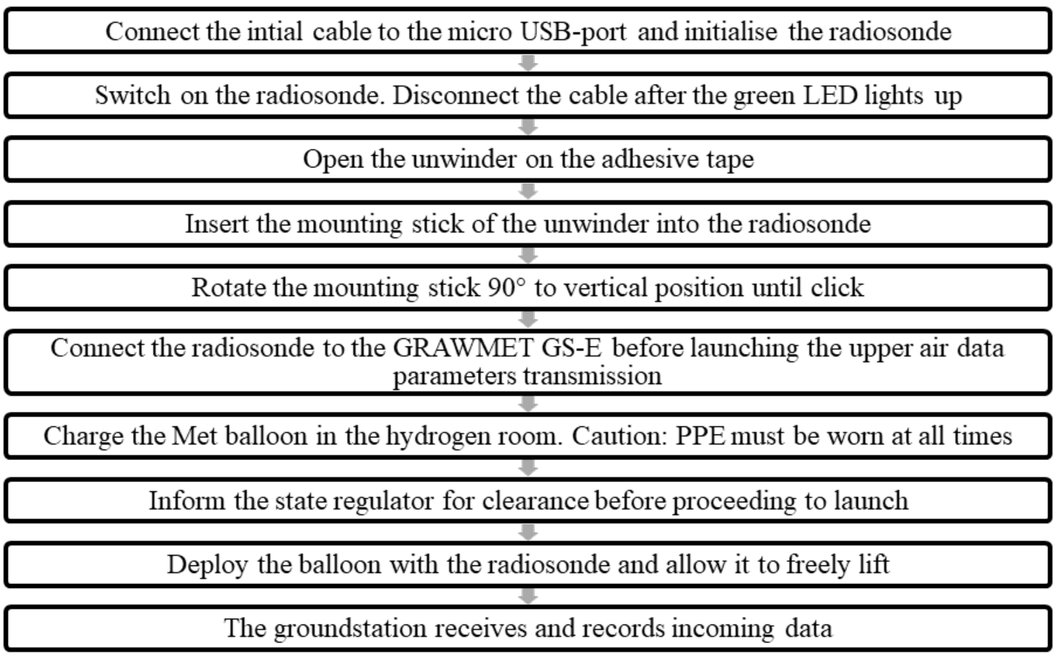

FIGURE 10. Upper air data collection procedures at the Malaysian Meteorology Department

A

JABATAN METEOROLOGI MALAYSIA
Records of Upper Air Data

Station: KLIA SEPANG | Record date: February, 2018
Latitude: 2° 43' 51" N | Hour: 0000 UTC
Longitude: 101° 42' 11" E | Level: Standard Level
Elevation: 16.11 m m

Day	Pressure (hPa)	Height (gpm)	Temp. (°C)	Humidity	Dew Point (°C)	Wind Dir.	Wind Speed
15	1000	124	25.2	77.6	21.1	90	1.0
15	925	808	21.8	77.7	17.8	325	2.6
15	850	1538	17.6	78.7	13.9	305	6.7
15	700	3175	8.8	72.2	4.1	280	7.7
15	500	5880	-6.5	32.4	-20.5	100	6.7
15	400	7600	-15.7	42.7	-25.7	70	3.6
15	300	9700	-31.7	37.9	-41.7	115	13.9
15	250	10960	-42.3	53.5	-48.3	140	22.1
15	200	12430	-53.7	61.1	-58.0	115	29.8
15	150	14230	-66.3	40.0	-73.3	105	11.3
15	100	16570	-82.7	57.8	-86.3	90	12.3
15	70	18600	-76.7			300	13.9
15	50	20560	-72.1			275	13.4
15	30	23610	-63.7			90	21.6
15	20	26110	-57.3			95	32.4
15	10	30590	-42.5			90	22.1

B

JABATAN METEOROLOGI MALAYSIA
Records of Upper Air Data

Station: KLIA SEPANG | Record date: February, 2018
Latitude: 2° 43' 51" N | Hour: 1200 UTC
Longitude: 101° 42' 11" E | Level: Standard Level
Elevation: 16.11 m m

Day	Pressure (hPa)	Height (gpm)	Temp. (°C)	Humidity	Dew Point (°C)	Wind Dir.	Wind Speed
15	1000	96	28.0	73.8	23.0	285	3.1
15	925	785	24.0	68.7	18.0	310	7.2
15	850	1520	18.8	79.8	15.3	335	3.1
15	700	3161	9.2	71.8	4.4	300	8.2
15	500	5880	-6.1	89.2	-7.6	75	4.6
15	400	7590	-15.7	46.7	-24.7	225	1.0
15	300	9700	-30.3	42.4	-39.3	140	12.9
15	250	10970	-40.9	39.1	-49.9	130	18.0
15	200	12440	-52.1	39.8	-60.1	110	27.8
15	150	14250	-65.1	30.8	-74.1	100	14.4
15	100	16600	-83.3	46.2	-88.3	125	9.3
15	70	18590	-80.5			315	7.7
15	50	20530	-76.3			270	18.0
15	30	23570	-64.5			85	26.8
15	20	26080	-59.7			80	31.4
15	10	30600	-44.3			85	21.6

C

JABATAN METEOROLOGI MALAYSIA
Records of Upper Air Data

Station: KUANTAN | Record date: February, 2018
Latitude: 3° 46' 20" N | Hour: 0000 UTC
Longitude: 103° 12' 43" E | Level: Standard Level
Elevation: 15.23 m m

Day	Pressure (hPa)	Height (gpm)	Temp. (°C)	Humidity	Dew Point (°C)	Wind Dir.	Wind Speed
15	1000	132	23.8	85.1	21.2	350	3.6
15	925	811	20.0	84.8	17.4	35	5.1
15	850	1539	17.8	59.1	9.8	325	4.6
15	700	3175	8.0	84.7	5.6	305	5.1
15	500	5880	-3.5	42.6	-14.5	85	4.1
15	400	7610	-15.7	46.7	-24.7	50	4.1
15	300	9700	-32.7	62.0	-37.7	130	8.7
15	250	10960	-42.1	62.8	-46.6	125	20.1
15	200	12430	-52.7	59.2	-57.3	115	31.4
15	150	14240	-65.7	40.2	-72.7	115	16.5
15	100	16590	-81.7	58.1	-85.3	100	11.3
15	70	18610	-75.1			305	11.8
15	50	20570	-72.7			260	10.3
15	30	23620	-64.1			80	23.7
15	20	26140	-56.3			95	34.0
15	10	30620	-43.5			95	25.2

D

JABATAN METEOROLOGI MALAYSIA
Records of Upper Air Data

Station: KUANTAN | Record date: February, 2018
Latitude: 3° 46' 20" N | Hour: 1200 UTC
Longitude: 103° 12' 43" E | Level: Standard Level
Elevation: 15.23 m m

Day	Pressure (hPa)	Height (gpm)	Temp. (°C)	Humidity	Dew Point (°C)	Wind Dir.	Wind Speed
15	1000	106	26.0	74.4	21.2	50	2.1
15	925	791	22.6	80.3	19.1	50	2.6
15	850	1523	18.0	86.8	15.8	300	5.1
15	700	3165	10.4	46.3	-0.6	5	3.1
15	500	5880	-4.5	21.6	-23.5	85	6.7
15	400	7610	-15.3	46.8	-24.3	30	3.1
15	300	9710	-31.3	62.3	-36.3	145	14.9
15	250	10980	-41.1	61.1	-45.9	140	21.6
15	200	12450	-52.5	39.7	-60.5	110	27.3
15	150	14260	-64.9	26.9	-74.9	115	13.4
15	100	16610	-83.1	39.5	-89.1	130	11.8
15	70	18600	-79.5			315	9.3
15	50	20550	-76.5			275	14.4
15	30	23580	-63.7			90	27.3
15	20	26100	-59.3			80	28.8
15	10	30630	-41.5			90	17.5

FIGURE 11. Sample of the upper air data collection on the 15th of February 2018 (A – 0000UTC) and (B – 1200UTC) from KLIA Meteorology Station; (C – 0000UTC) and (D – 1200UTC) from Kuantan Meteorology Station

involved combining the 0000UTC (0800 h LT) and 1200UTC (2000 h LT) for the yearly average at each meteorology station. The wind profile pattern is vital in this analysis phase since the latitude of both stations is in line with the Earth's equator. The final or fourth data processing stage summarised the average result of the combined 7 years average wind profile from both meteorology stations.

RESULTS AND DISCUSSION

WIND PROFILE FROM THE KLIA METEOROLOGY STATION

According to the upper air data, the KLIA Meteorology Station experienced a consistent wind profile from 0 m to 11,000 m altitude at 0000UTC and 1200UTC (referring to the troposphere-end layer and stratosphere-start layer) with an average wind speed of 11.3 ms^{-1} at 11,000 m. Meanwhile, the wind speed range of 2.1 ms^{-1} (minimum) to 20.2 ms^{-1} (maximum) was recorded from 11,000 to 15,000 m altitude. Although the meteorology balloon recorded an inconsistent rising rate in 2018 due to unstable vertical air currents that resulted in missing data at 11,000 m altitude, the overall data signify that the wind profile in Peninsular Malaysia was unaffected by the subtropical jet stream wind speed, which could reach a speed of 123 ms^{-1} or 443 kmh^{-1} (Jet Stream | National Geographic Society, n.d.). Furthermore, the 15,000–18,000 m altitude range, which is considered the maximum flight level altitude for jet engines operation and manned or unmanned airships operation, such as balloons, recorded the lowest, highest, and average wind speeds of 4.9 ms-1, 17.5 ms-1, and 11.7 ms-1, respectively.

The wind speed profile at 20,000 m is considered crucial as it is the maximum altitude for aircraft operation. Accordingly, the wind speed data obtained from KLIA Meteorology station (0000UTC) at 20,000 m altitude ranged from 10 ms-1 to 16 ms-1, with an average wind speed of 12.3 ms-1. Furthermore, the wind speed at 20,000–30,000 m altitude was considerably inconsistent due to the broad wind speed range from 7 ms-1 to 29.1 ms-1 in certain months. The fluctuating wind speed pattern was also affected by the vertical air current, where the balloons failed to record any data at 25,000 m altitude from 2016 to 2021. As the vertical air current at 30,000–32,000 m was inconsistent; only in 2021 was the wind speed not recorded. The obtained data within these altitudes showed minimum and maximum wind speeds of 7.7 ms-1 and 34 ms-1, respectively.

Comparatively, the wind profile from 0 m to 11,000 m altitude (the troposphere-end layer and stratosphere-start layer) at 1200UTC was similar to that of the 0000UTC. The average wind speed at 11,000 m was 8.7 ms-1, slightly lower than that of 0000UTC but significantly far from the jet stream hazard. The minimum and maximum wind speeds in the 11,000–15,000 m altitude range were 12 ms-1 and 21.5 ms-1, respectively. The minimum wind speed at 1200UTC was higher due to the rapidly decreasing temperature rate than at 0000UTC, while the maximum wind speed was relatively the same at both times. Meanwhile, the minimum, maximum, and average wind speeds within the operational flight altitude of 15,000–18,000 m were 6.2 ms-1, 17.8 ms-1, and 11.3 ms-1, respectively. The slight wind speed difference between both times was expected due to the decreasing temperate rate and increasing altitude.

Furthermore, the wind speed at 20,000 m altitude ranged from 10 ms-1 to 21 ms-1, with a maximum wind speed of 12.7 ms-1 for aircraft flight altitude. Inconsistent wind speeds at 20,000–30,000 m altitude were also detected at 1200UTC from 8 ms-1 to 28.4 ms-1, similar to that of 0000UTC. Additionally, vertical air currents at 30,000–32,000 m altitude were inconsistent as the balloons did not record any data in 2021 and 2020 due to the fluctuating rising rate of the balloons through the atmosphere. Figure 12 illustrates the KLIA Meteorology station wind profile at 0000UTC and 1200UTC.

WIND PROFILE AT KUANTAN METEOROLOGY STATION

The Kuantan Meteorology Station (Latitude: 3°46’20”N, Longitude: 103°12’43”E, Elevation: 15.23 m) experienced a wavy-like wind profile from 0 m to 11,000 m altitude (the troposphere-end layer and stratosphere-start layer) at 0000UTC, with an average wind speed of 11.8 ms-1 at 11,000 m. Meanwhile, the minimum and maximum wind speeds of 3.9 ms-1 and 21.5 ms-1 were recorded from 11,000 m to 15,000 m altitude. Nevertheless, the balloon rising rate was inconsistent at 14,000 m and 11,000 m in 2016 and 2018, respectively, due to unstable vertical air currents, resulting in missing data. Regardless, the available data verified that the upper air data in Peninsular Malaysia was unaffected by the jet stream hazard. Vertical air current was noticed from 15,000 m to 18,000 m as the meteorology

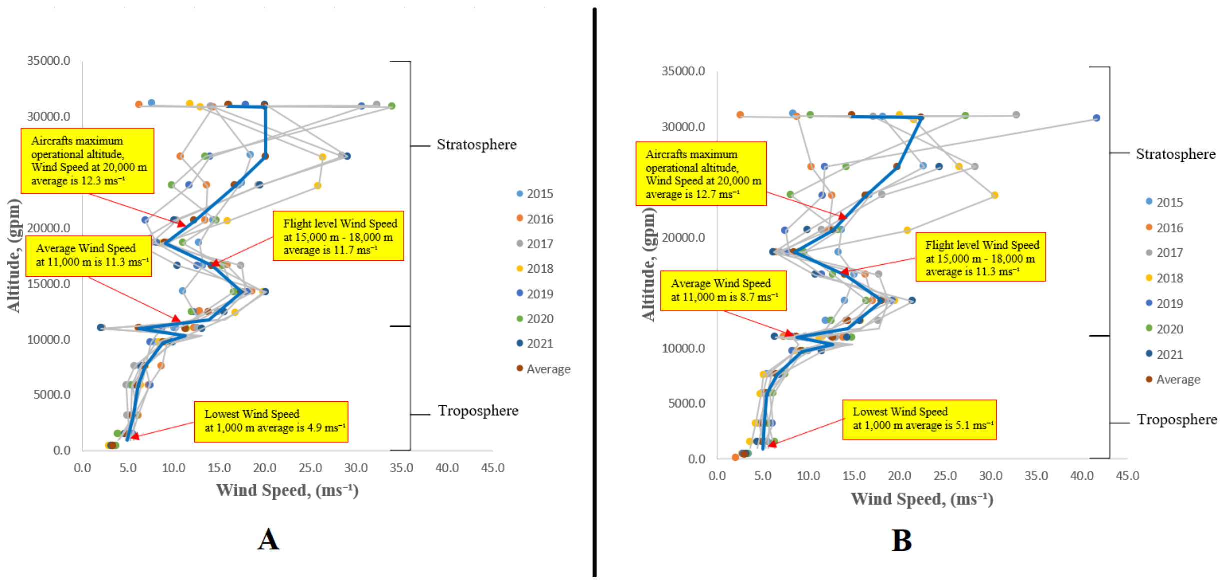

FIGURE 12. KLIA Meteorology station wind profile showing good pattern similarity and minimal differences between the two time zones at (A) 0000UTC and (B) 1200UTC

balloons failed to record data in 2015, 2017, 2018, 2019, 2020, and 2021. However, the average wind speed at 15,000 m was 11.5 ms^{-1}. At 20,000 m altitude (maximum flight operational altitude), the obtained data recorded a wind speed range of 6.8–16 ms^{-1} and an average wind speed of 11.9 ms^{-1} in 7 years. Besides, an inconsistent wind speed pattern was detected at 20,000–30,000 m altitude. This was supported by the missing data from the meteorology balloons, mostly at 25,000 m. The only data was recorded in 2015, as the vertical air current affected the rising rate of the meteorology balloons. The situation extended to 30,000–32,000 m altitude in 2015, 2016, 2017, and 2018, recording minimum and maximum wind speeds of 8.6 ms^{-1} and 30.4 ms^{-1}, respectively.

As expected, the wind profile from 0 m to 11,000 m altitude was similar at 1200UTC and 0000UTC as these regions are located at the troposphere-end and stratosphere-start layers. The data showed an average wind speed of 12.1 ms^{-1} at 11,000 m. However, the minimum wind speed of 7.4 ms^{-1} at 11,000–15,000 m altitude was slightly higher at 1200UTC compared to that at 0000UTC, while a minimal difference was observed between the two times, with a maximum wind speed of 20.9 ms^{-1}. Remarkably, the results showed that the upper air data in Peninsular Malaysia was unaffected by the jet stream air current. From 15,000 m to 18,000 m altitude (commercial flight level altitude), the average wind speed was 12.6 ms^{-1} within a range of 5.6–19.7 ms^{-1}. In contrast, an inconsistent pattern was detected from 2019 to 2021 at 20,000–30,000 m altitude with an average wind speed of 11.5 ms^{-1}. The outcome was attributed to the fluctuating rising rate of the meteorology balloons due to vertical air currents. A similar phenomenon was observed at 30,000–32,000 m altitudes, where data were not captured in 2019, 2020, and 2021, while data were missing at 32,000 m altitudes in 2018, 2019, 2020, and 2021. Nevertheless, the available data showed a wind speed range of 4.6–33.4 ms^{-1}. Figure 13 describes the Kuantan Meteorology Station wind profiles at 0000UTC and 1200UTC.

THREE PEAKS OF DISCRETE SINE WAVE FLOW TYPE WITH LOW-SPEED WIND PROFILE IN PENINSULAR MALAYSIA

The upper air data between the KLIA and Kuantan Meteorology Stations were compared for 0000UTC and 1200UTC. Figure 14 depicts the average wind profile pattern between both meteorology stations. Based on the results, the KLIA and Kuantan Meteorology Stations exhibit similar atmospheric geophysics properties and characteristics as both stations are located near the equatorial line in the tropical atmosphere with a small latitude and longitude difference of 1° and 2°, respectively, 1 m elevation, and a separating distance of 299.2 km between the two stations.

The average wind profile pattern from the KLIA and Kuantan Meteorology Stations in Figure 14 indicates a similar pattern line, confirming the minimal difference in wind profile at both meteorology stations in Peninsular Malaysia. Based on the three peaks of discrete sine wave flow type of low-speed wind profile (Johnson & Vaughan 2017) in Peninsular Malaysia, the 1st and 2nd peaks are located at the troposphere layer, where the 9,000–12,000 m altitude recorded an average wind speed of 10.8 ms^{-1},

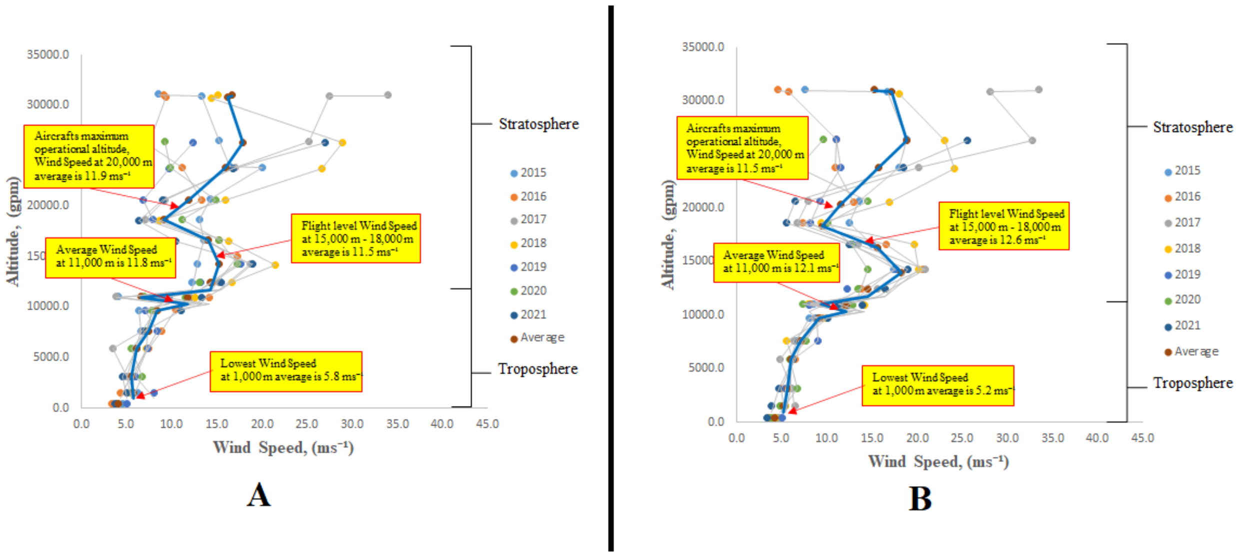

FIGURE 13. Kuantan Meteorology Station wind profile showing good pattern similarity and minimal differences with a slightly lower wind speed at 32,000 m between the two time zones at (A) 0000UTC and (B) 1200UTC

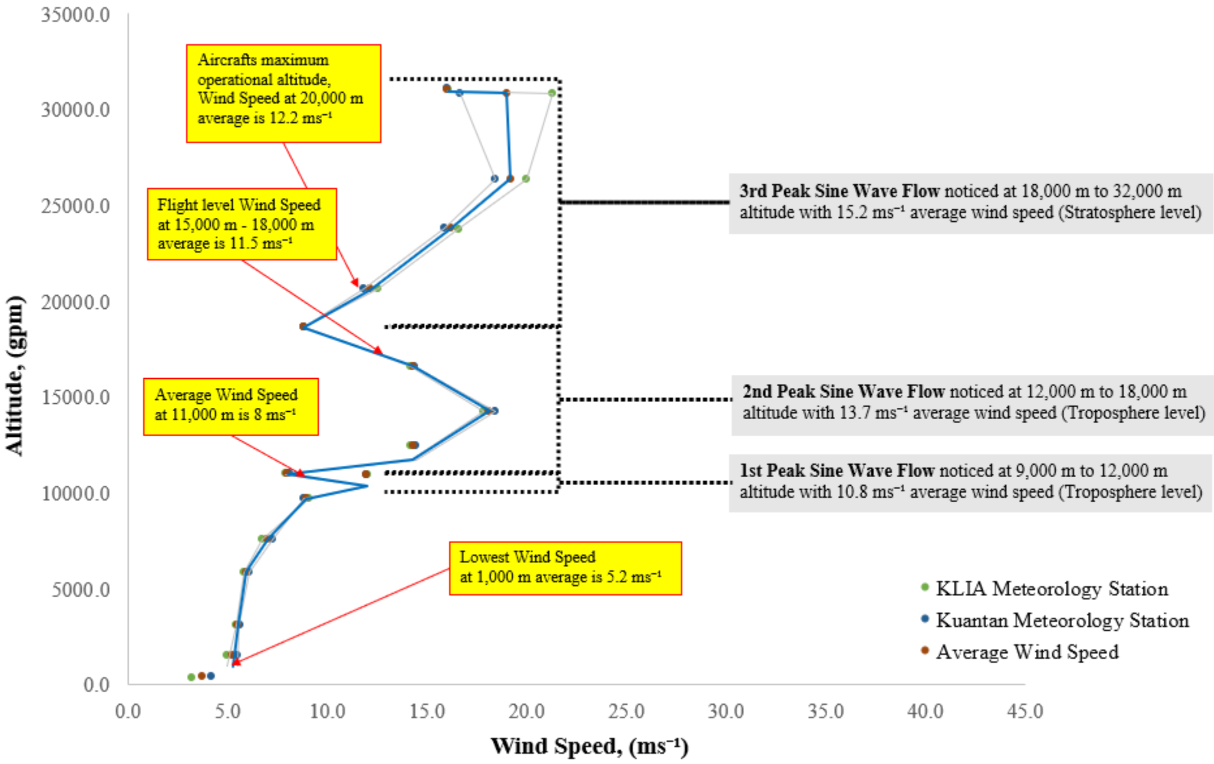

FIGURE 14. Wind profile at the KLIA and Kuantan Meteorology Stations from 2015 to 2021 highlighting the three peaks of discrete sine wave flow type with low-speed wind profile

while the 12,000–18,000 m altitude recorded an average wind speed of 13.7 ms^{-1}. The 3rd peak is located at the stratosphere layer, where the 18,000–32,000 m altitude showed an average wind speed of 15.2 ms^{-1}. Given that East Malaysia is located on the same equatorial line, the wind profile is hypothetically the same as that of Peninsular Malaysia, with only slight differences.

CONCLUSION

This work presented the first wind profile analysis of upper air in Peninsular Malaysia. The analysed data demonstrated a very exclusive wind profile in the troposphere to the stratosphere level (altitude up to 32,000 m) that can be used to develop wind power generation and provide input on cyclones and thermodynamic effects in urban areas. In particular, the three peaks of discrete sine wave flow type low-speed were identified from the wind profile in Peninsular Malaysia. The three peaks amplified the highest air velocity, whereby the 1st and 2nd peaks were located at the troposphere layer from 9,000 m to 12,000 m altitude (average wind speed of 10.8 ms-1) and 12,000 m to 18,000 m altitude (average wind speed of 13.7 ms-1). The 3rd peak was located at the stratosphere layer from 18,000 m to 32,000 m altitude (average wind speed of 15.2 ms-1). Since East Malaysia is located on the same equatorial line, the wind profile is hypothetically the same and exhibits only slight differences. Overall, the established wind profile from this study can be applied as preliminary data to assist engineers and researchers in evaluating future aircraft designs for better aerodynamic performance in Malaysian airspace, as well as other relevant applications, such as aerial and surveillance systems, flight mechanics, communication or broadcast bandwidth, and power systems. Finally, state authorities and regulators can use the data from this study to improve essential standard regulations (Civil Aviation Authority of Malaysia 2021b) for airspace boundaries (Civil Aviation Authority of Malaysia 2021a) in Malaysia's atmosphere.

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