

Temporal and Spatial Characteristics of Aircraft Turbulence on Qinghai-Tibet Plateau Slope and Turbulence Forecasting System Based on EDR

Lijing Chen

*Gansu Branch of Northwest Air Traffic Management Bureau of CAAC
Low-level Wind Shear Laboratory of CAAC*

Bangkok, Thailand

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Based on EDR**

A large commercial airplane is shown from a low angle on a runway. The image is overlaid with a semi-transparent blue filter. On the left, a dark rounded square contains a large yellow number '1'. To its right, a dark rounded rectangle contains the title text in yellow. The background shows the aircraft's engines, landing gear, and the runway surface.

1

Characteristics of Aircraft Turbulence on Qinghai-Tibet Plateau Slope

A 1.1.1 Inter-annual Distribution

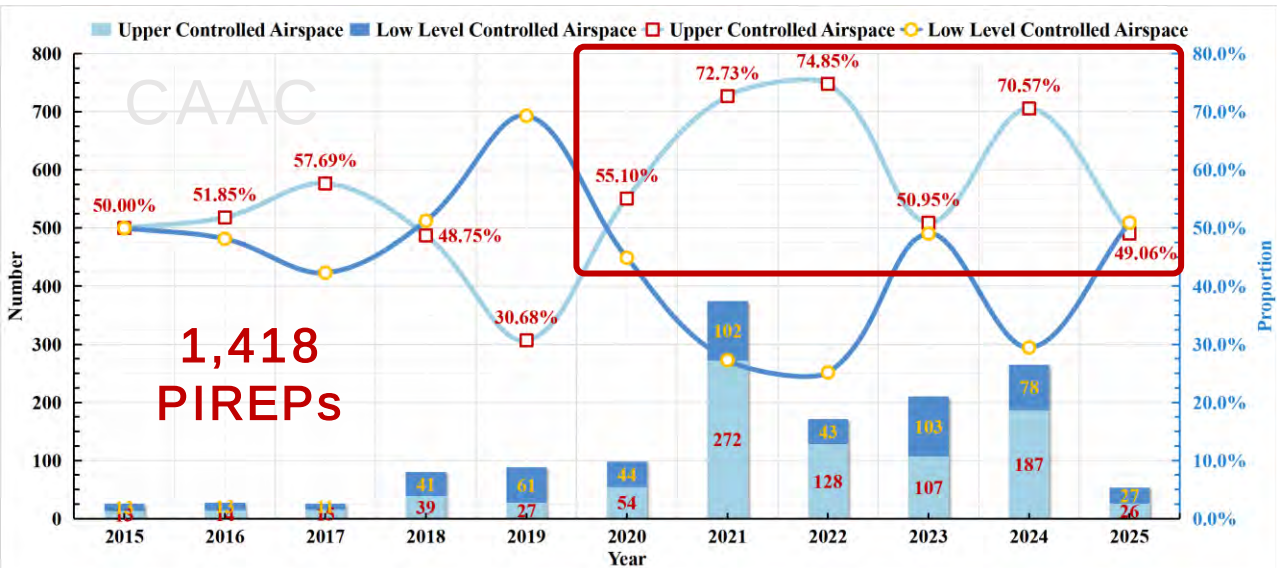


Fig.1.1 Inter-annual variation of aircraft turbulence events occurred at different altitude

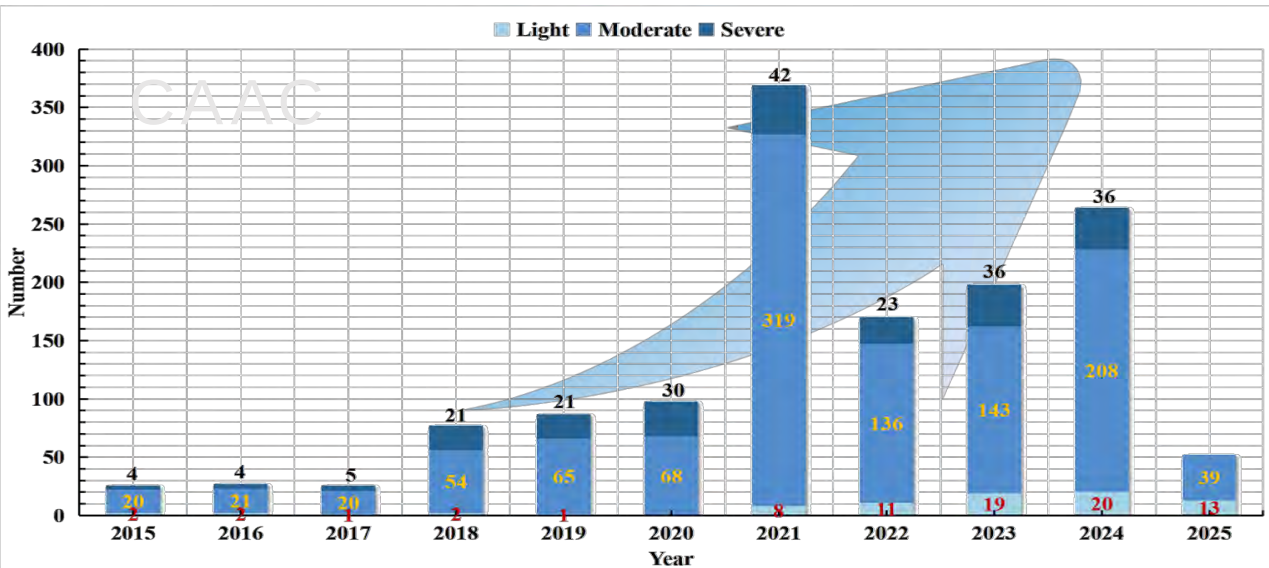


Fig.1.2 Inter-annual variation of aircraft turbulence intensity

- 882 cases accounting for **62.20%** of all above **6,600 meters (including)**.
- Since 2020, the aircraft turbulence occurred at **high altitude** had consistently accounted for over 50% of annual turbulence reports, peaking at **74.85%**.
- The intensity of aircraft turbulence also showed an increasing trend, the frequency of **moderate to severe turbulence** was increasing.

- Under the background of global climate change, the atmosphere became more and more unstable.
- With the rapid increase of flights, aircraft turbulence occurred more and more frequently.

A 1.1.2 Annual Distribution

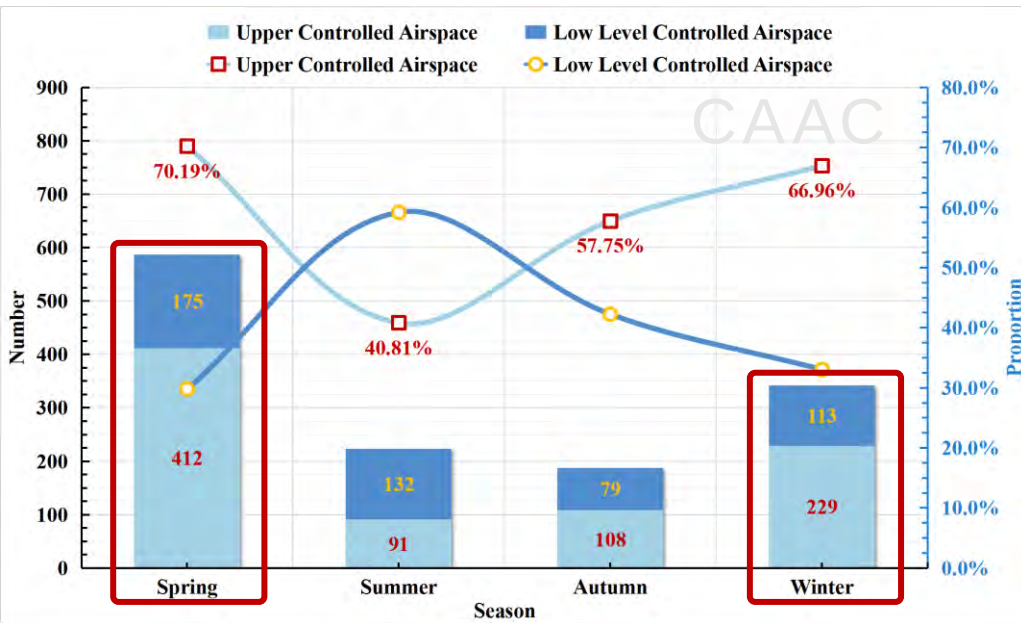


Fig.1.3 Seasonal variation of aircraft turbulence events occurred at different altitude

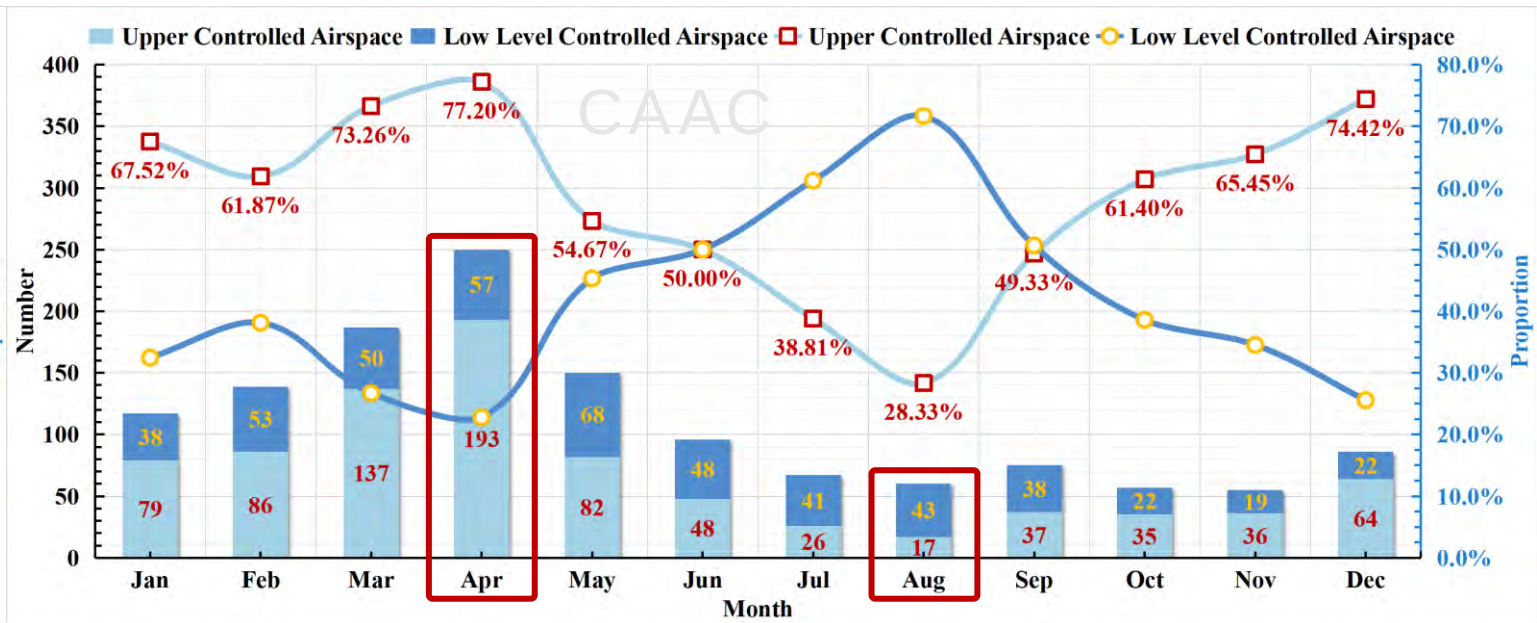


Fig.1.4 Monthly variation of aircraft turbulence events occurred at different altitude

- The number of aircraft turbulence events in **winter (December, January, and February)** and **spring (March, April and May)** was twice than that in summer (June, July and August) and autumn (September, October and November), which accounting for **69.38%** of the whole year.
- **Spring** was the season with the highest frequency of aircraft turbulence occurrences, accounting for about **43.84%** of all turbulence events.
- **April** was the peak month, and **August** was the valley month with only a quarter of the reports in April.

A 1.1.2 Annual Distribution

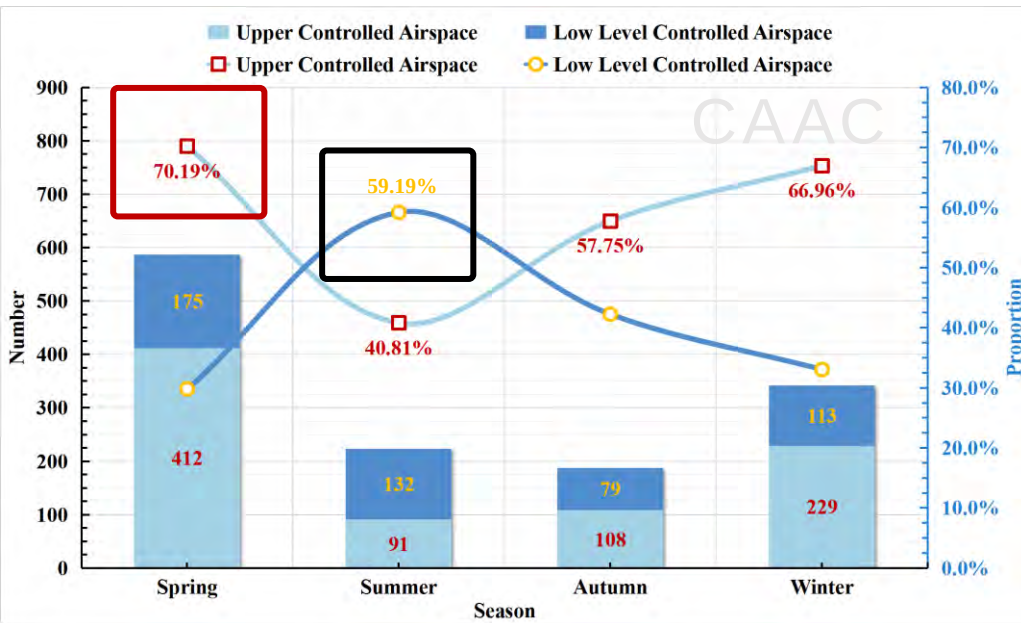


Fig.1.3 Seasonal variation of aircraft turbulence events occurred at different altitude

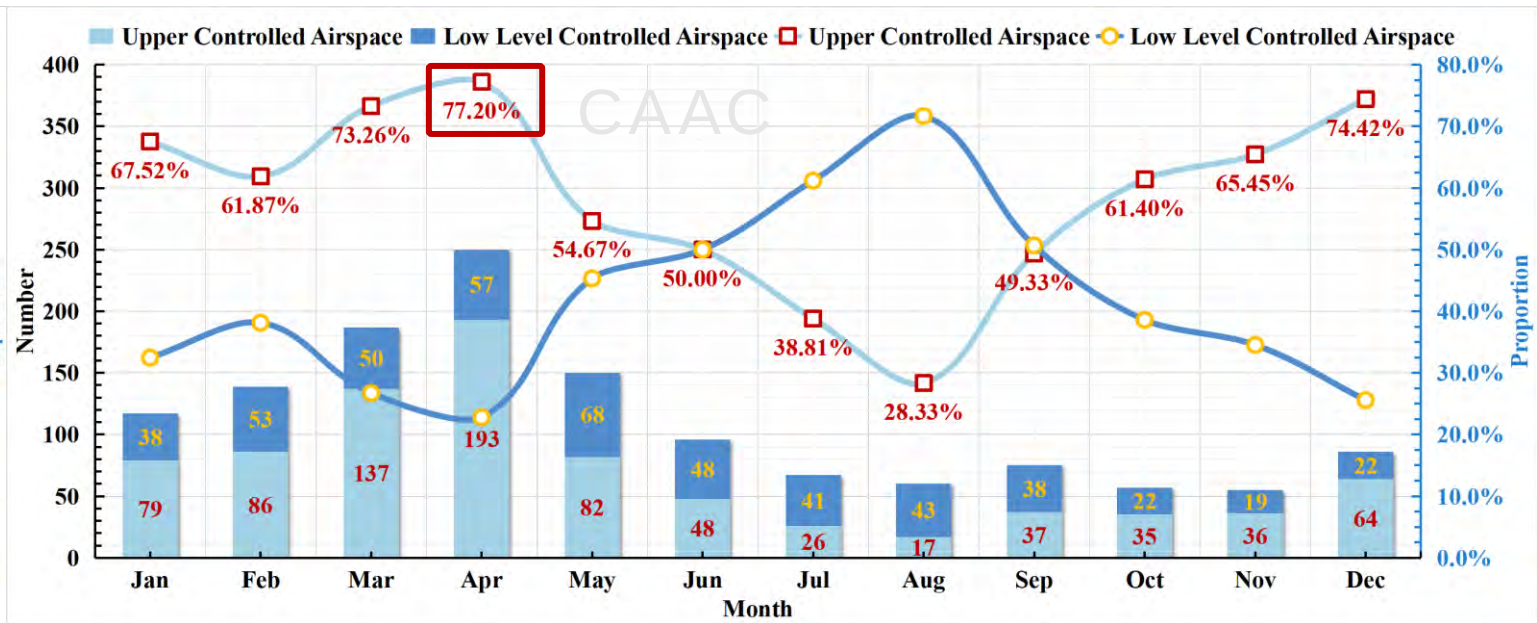


Fig.1.4 Monthly variation of aircraft turbulence events occurred at different altitude

- **Spring** had the highest proportion of **high-altitude aircraft turbulence**, which was up to **70.19%**.
- **April** was the peak month for **high-altitude turbulence**, with **77.20%** of the turbulence events occurring above 6,600 meters.
- There were **59.19%** of aircraft reports received in **low-level controlled airspace** in **summer**, which had the highest proportion of low-level altitude turbulence.
- Pilots can avoid convectively induced turbulence actively at high altitude during cruising, but can't avoid it during take-off and landing.

1.1.2 Annual Distribution

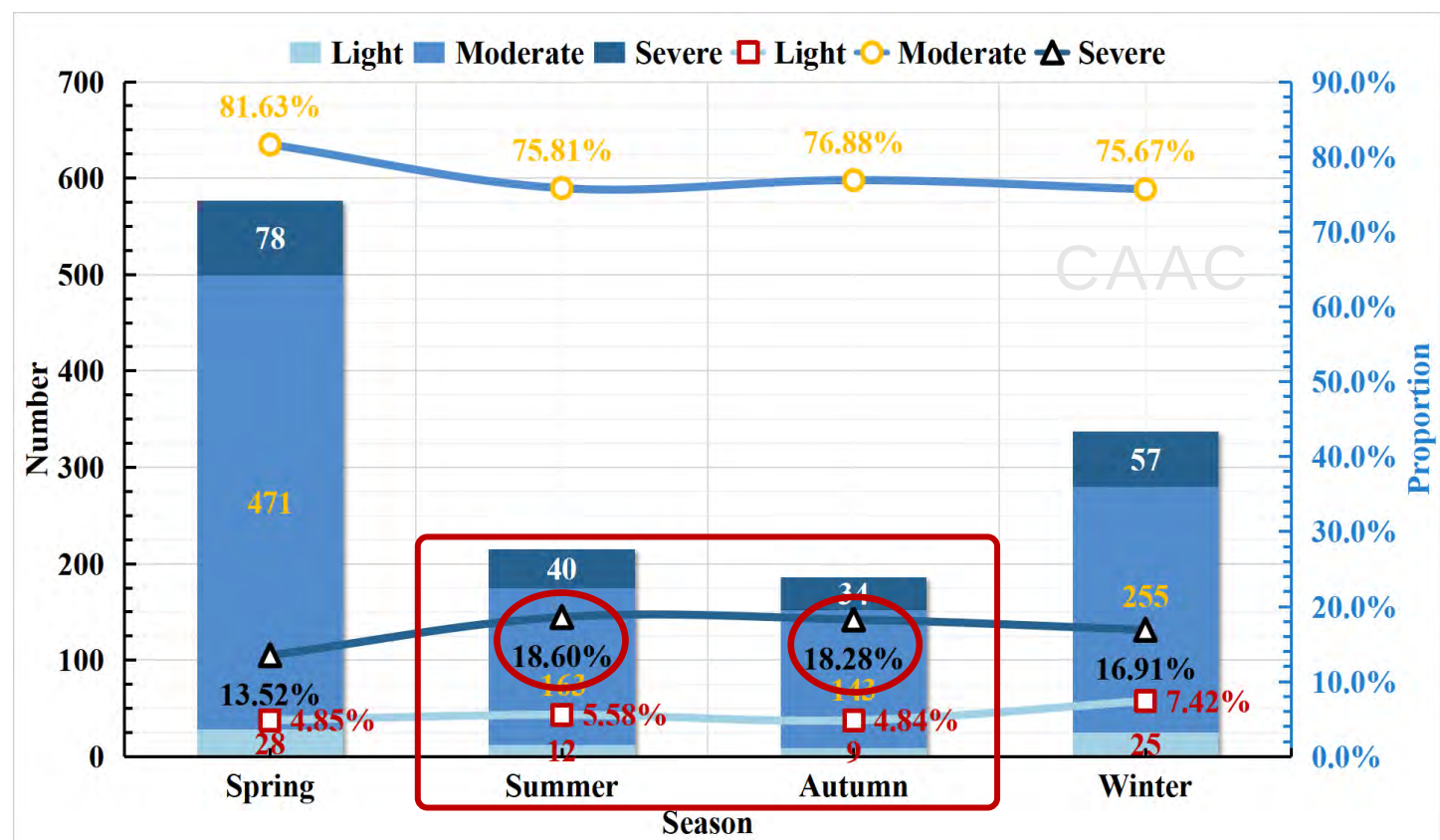


Fig.1.5 Seasonal variation of aircraft turbulence intensity

- There were the least aircraft reports of turbulence received in **summer** and **autumn**, which accounting for only **30.50%** of the whole year.
- Due to strong atmospheric convection, the proportion of **moderate to severe turbulence** remained significant.
- Especially in **summer**, the proportion of **severe turbulence** was the highest in the whole year, which was up to **18.60%**.

A 1.1.3 Daily Distribution

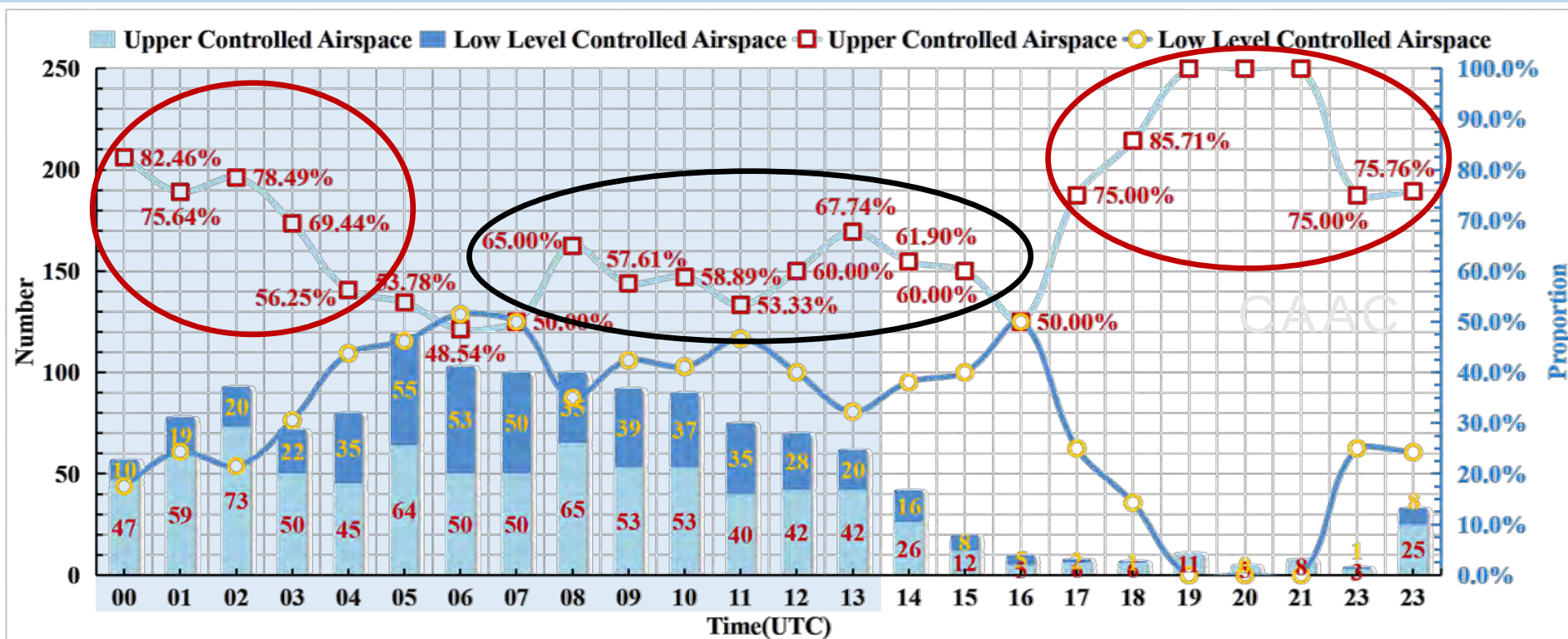


Fig.1.6 Daily variation of aircraft turbulence occurred at different altitude

- The aircraft turbulence events were mostly concentrated from **00:00 to 13:00 (UTC)**, which accounting for **88.95%** of the whole day.
- **05:00 (UTC)** was the daily peak hour.
- From **16:00 to 05:00** the next day, it was mainly **high altitude turbulence**; **low-level turbulence** was mainly concentrated in **05:00-16:00**.

Weather
Conditions



Flight
Schedules

1.1.3 Daily Distribution

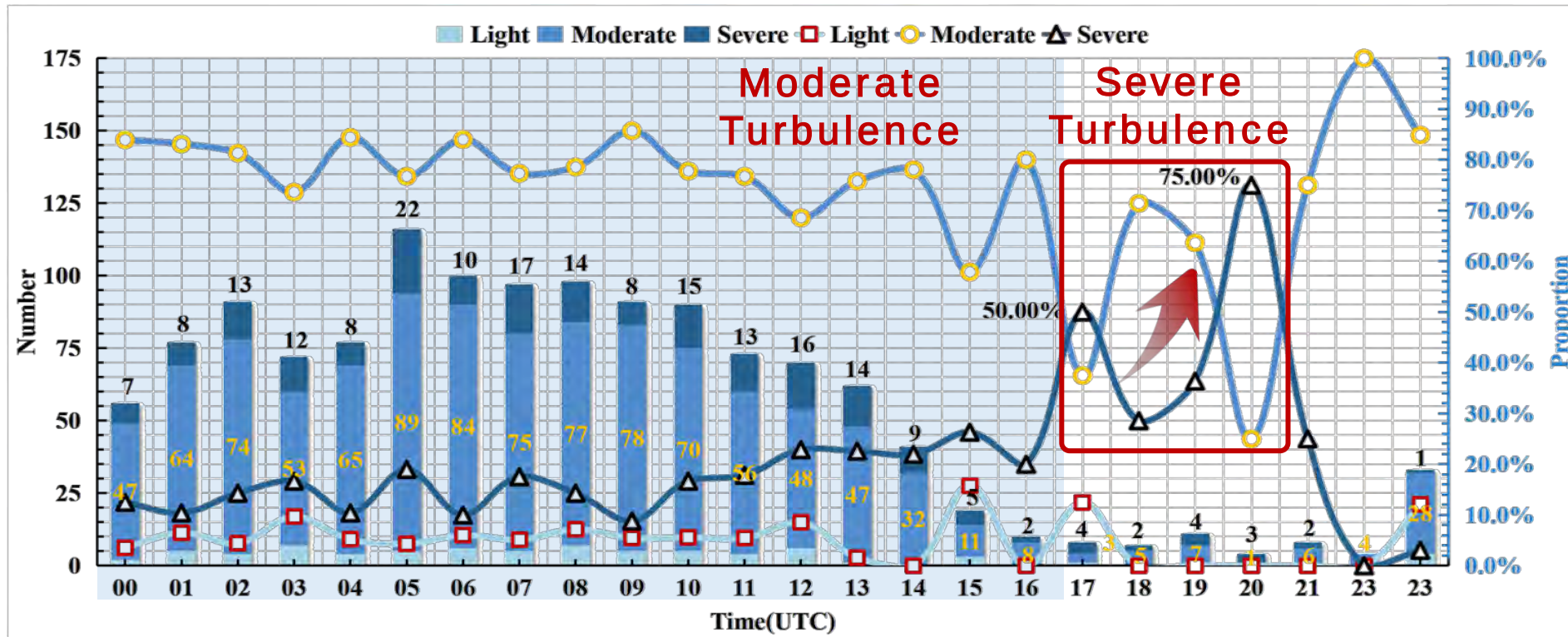


Fig.1.7 Daily variation of aircraft turbulence intensity

- During the **daytime**, **moderate turbulence** predominated.
- After **dusk**, especially after 17:00 (UTC), the frequency of **severe turbulence** increased significantly.
- It peaked at **20:00 (UTC)**, with **75%** of aircraft reporting **severe turbulence**.



- Therefore, enhancing weather monitoring and aviation services for **high altitude turbulence** was necessary at **nighttime**.

1.2.1 Vertical Distribution

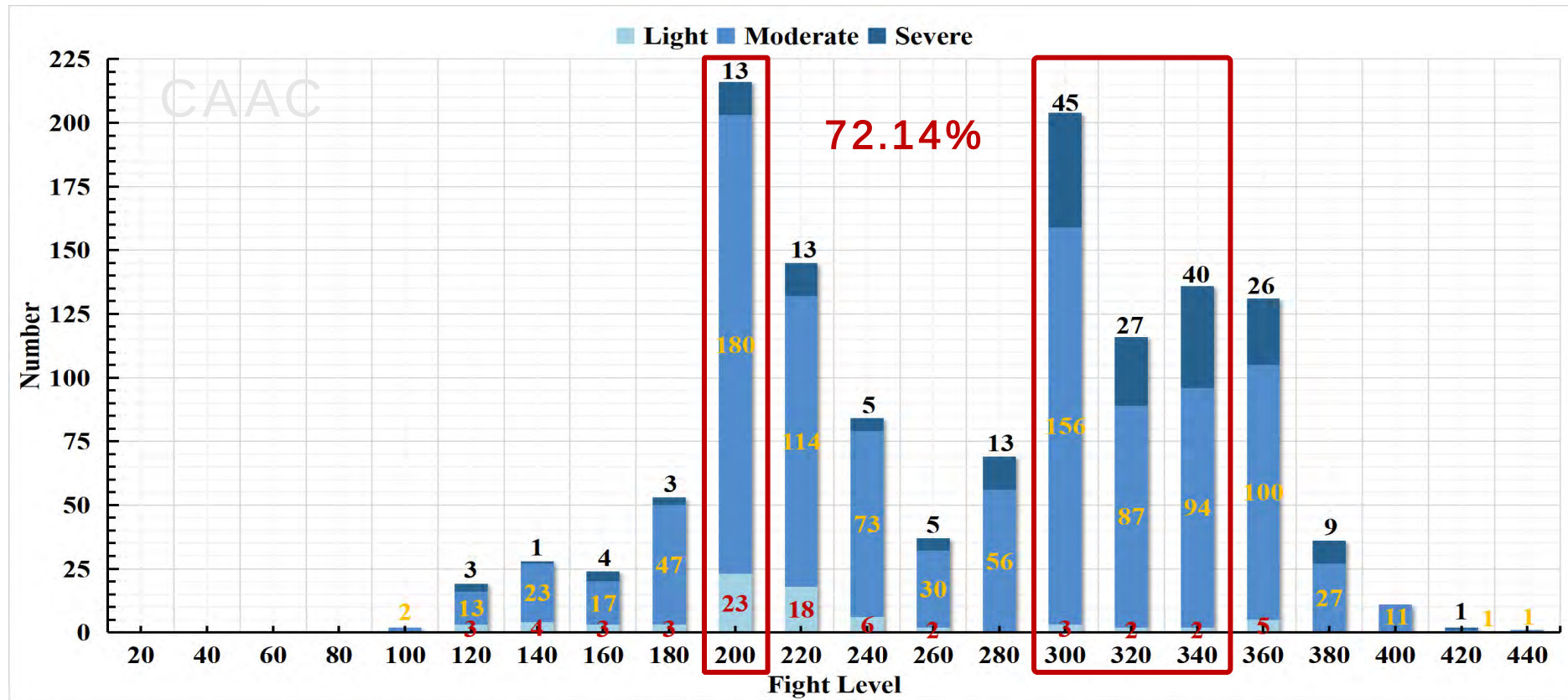


Fig.1.8 Vertical distribution of aircraft turbulence intensity

- The vertical distribution of aircraft turbulence showed a "double-peak" structure.
- The low-to-medium altitude turbulence was mainly concentrated during **FL180-FL200**, the high-altitude turbulence was mainly distributed in **FL280-FL360**, with **FL280-FL300** being the most frequent.
- Aircraft turbulence occurred in the above flight levels accounted for **72.14%** of the total.

1.2.2 Horizontal Distribution

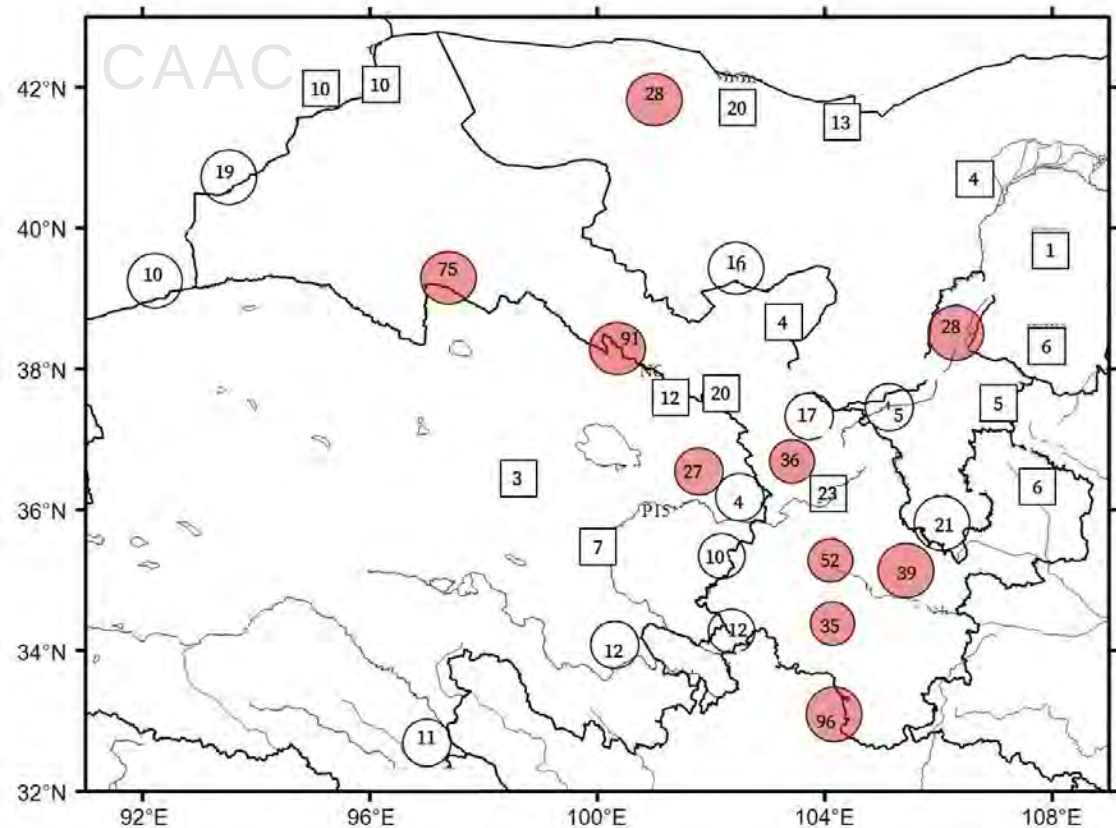


Fig.1.9 Horizontal distribution of high-altitude aircraft turbulence

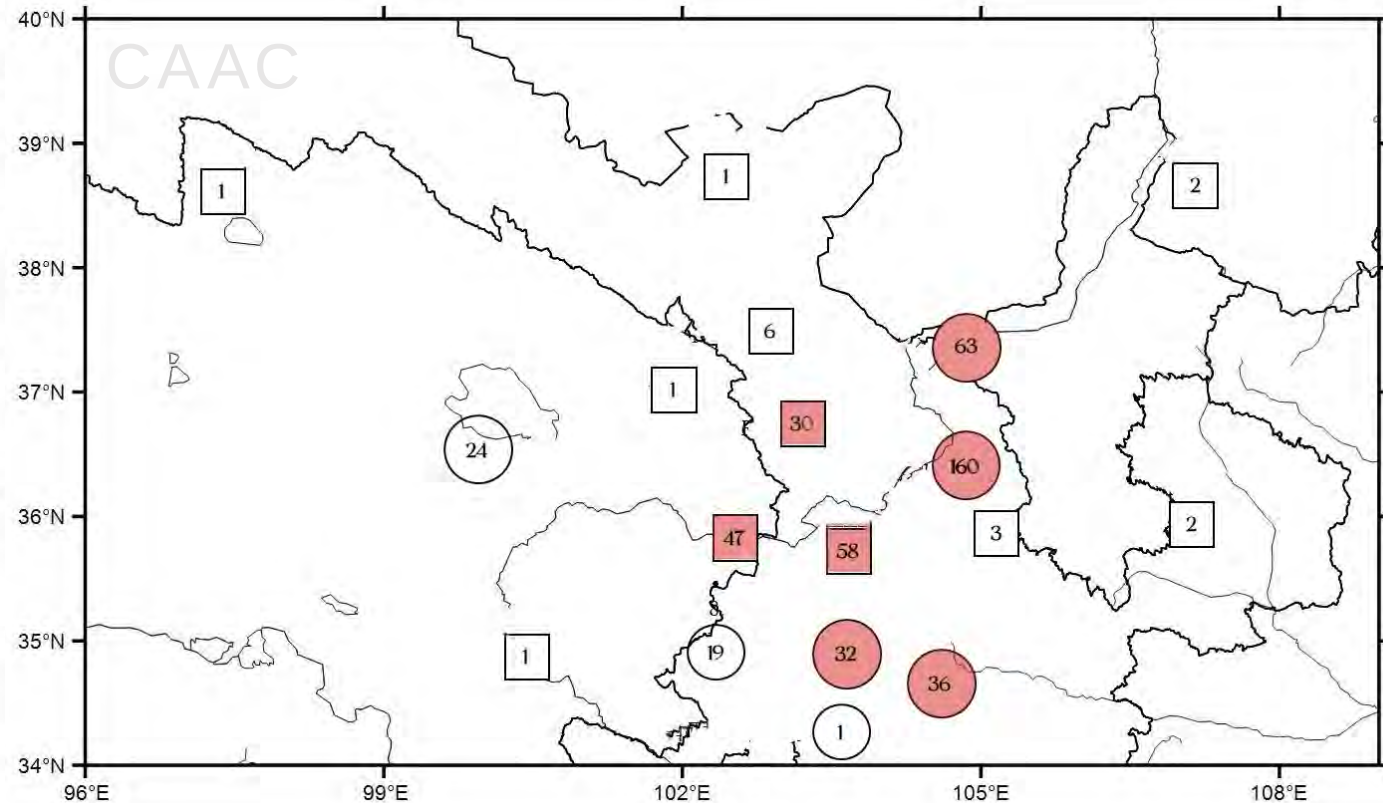


Fig.1.10 Horizontal distribution of low-medium altitude aircraft turbulence

- The **high-altitude** aircraft turbulence was mainly distributed along the plateau slope, especially on the **northeast** and **southeast** sides of the slope where the steepest terrain was.
- The **low level** turbulence clustered **east and south of Lanzhou Airport** and the **southeast** of plateau slope.

1.3 Turbulence Intensity

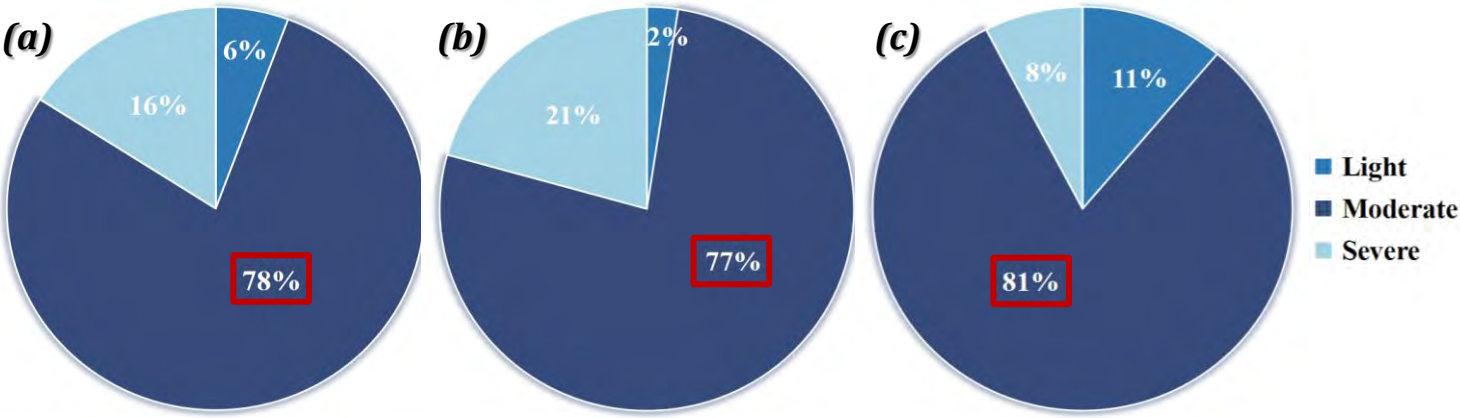


Fig.1.11 Proportion of turbulence intensity
(a) Total; (b) High-altitude; (c) Low level

- **94.37%** of the turbulence occurred on the slope of Qinghai-Tibet Plateau was above moderate intensity.
- The **moderate turbulence** events were the most common, accounting for **78.54%** of all.

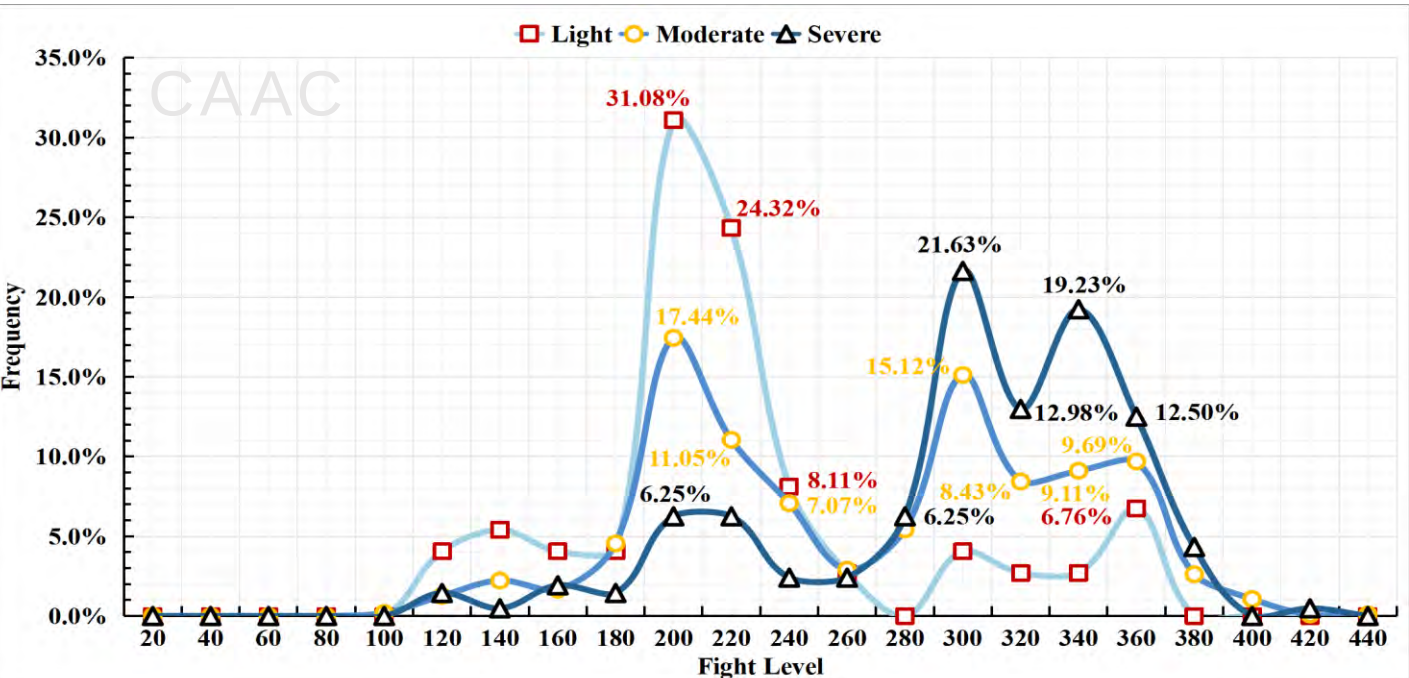


Fig.1.12 Vertical probability distribution of aircraft turbulence intensity

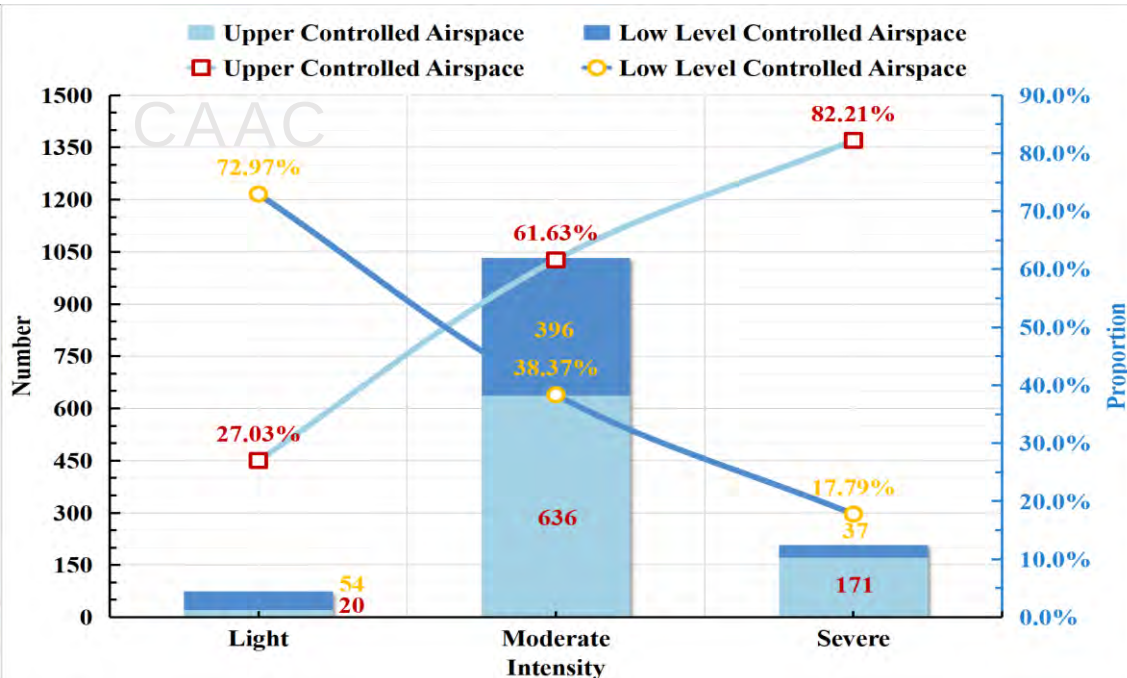


Fig.1.13 Vertical distribution of aircraft turbulence intensity

1.3 Turbulence Intensity

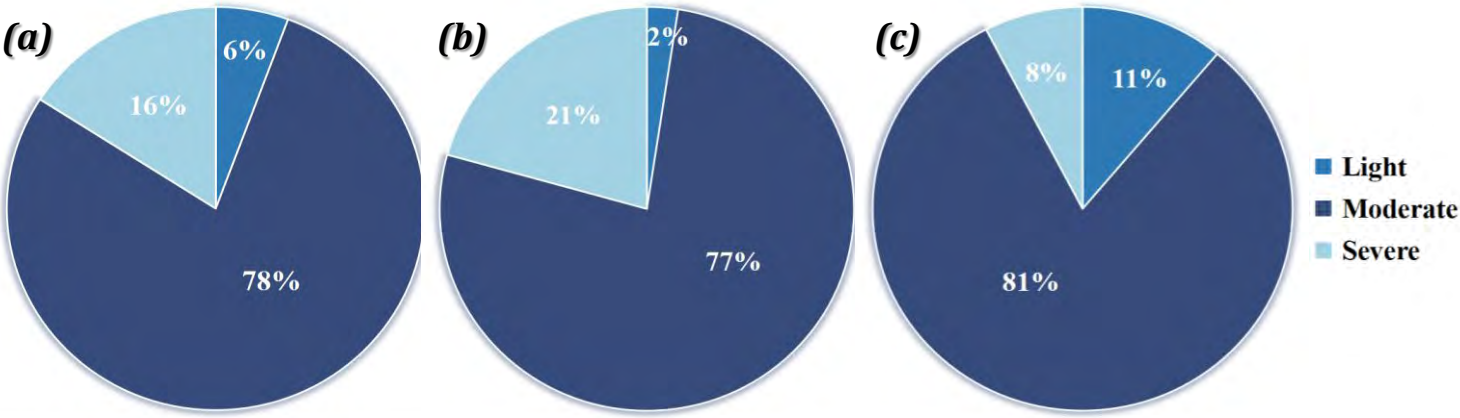


Fig.1.11 Proportion of turbulence intensity
(a) Total; (b) High-altitude; (c) Low level

- **Light turbulence** was mainly distributed between **FL180-FL220**.
- **Moderate to severe turbulence** also showed a **"double-peak"** structure, mostly between **FL180-FL200** and **FL280-FL300**.

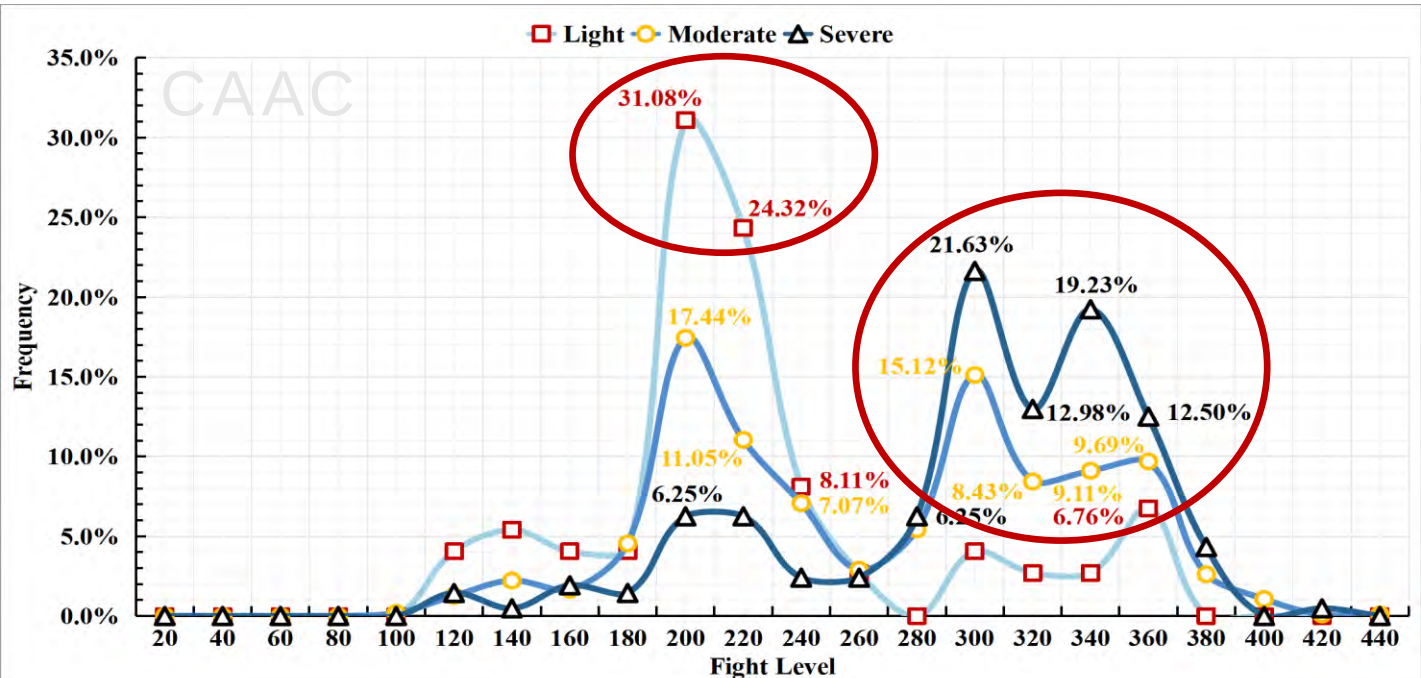


Fig.1.12 Vertical probability distribution of aircraft turbulence intensity

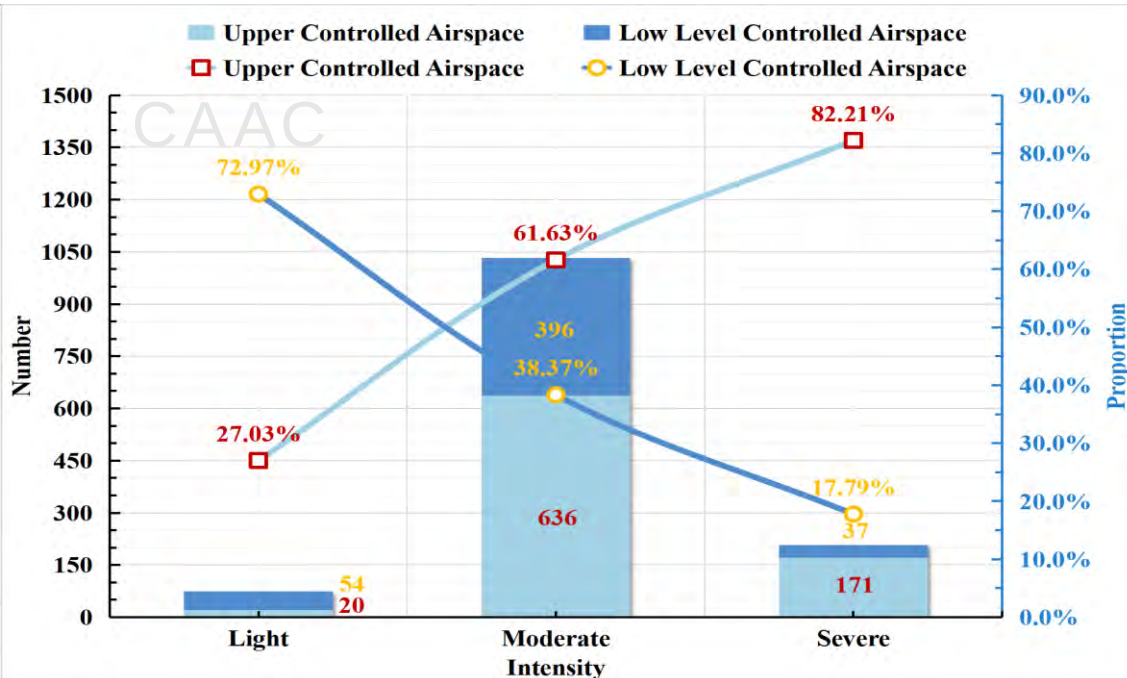


Fig.1.13 Vertical distribution of aircraft turbulence intensity

1.3 Turbulence Intensity

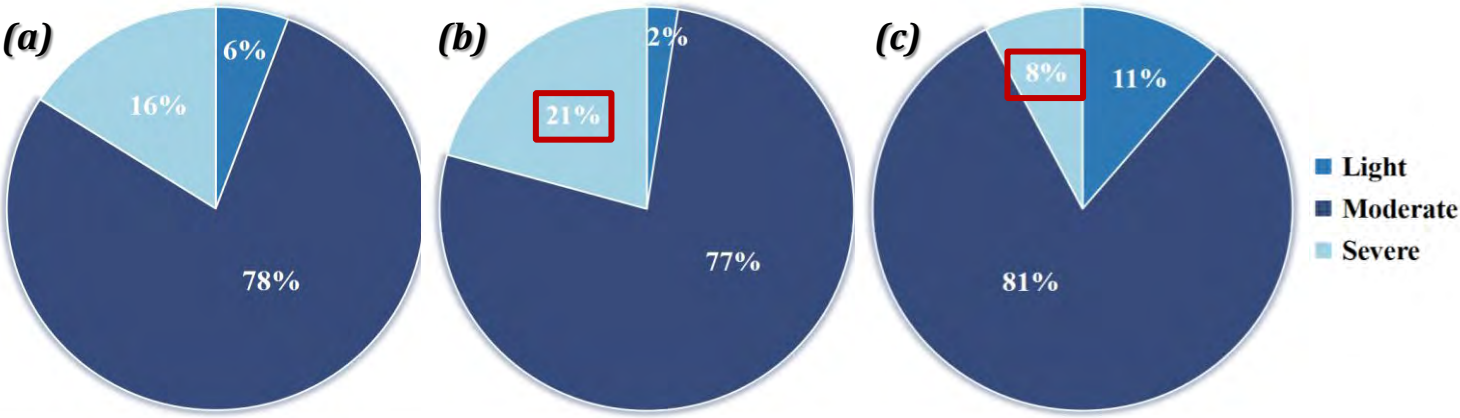


Fig.1.11 Proportion of turbulence intensity
(a) Total; (b) High-altitude; (c) Low level

- **Severe turbulence** accounted for 8% at low altitude but increased to 21% at high altitude, which mainly concentrated in **FL280-FL360**.
- It indicated that the higher altitude, the greater probability of severe turbulence.

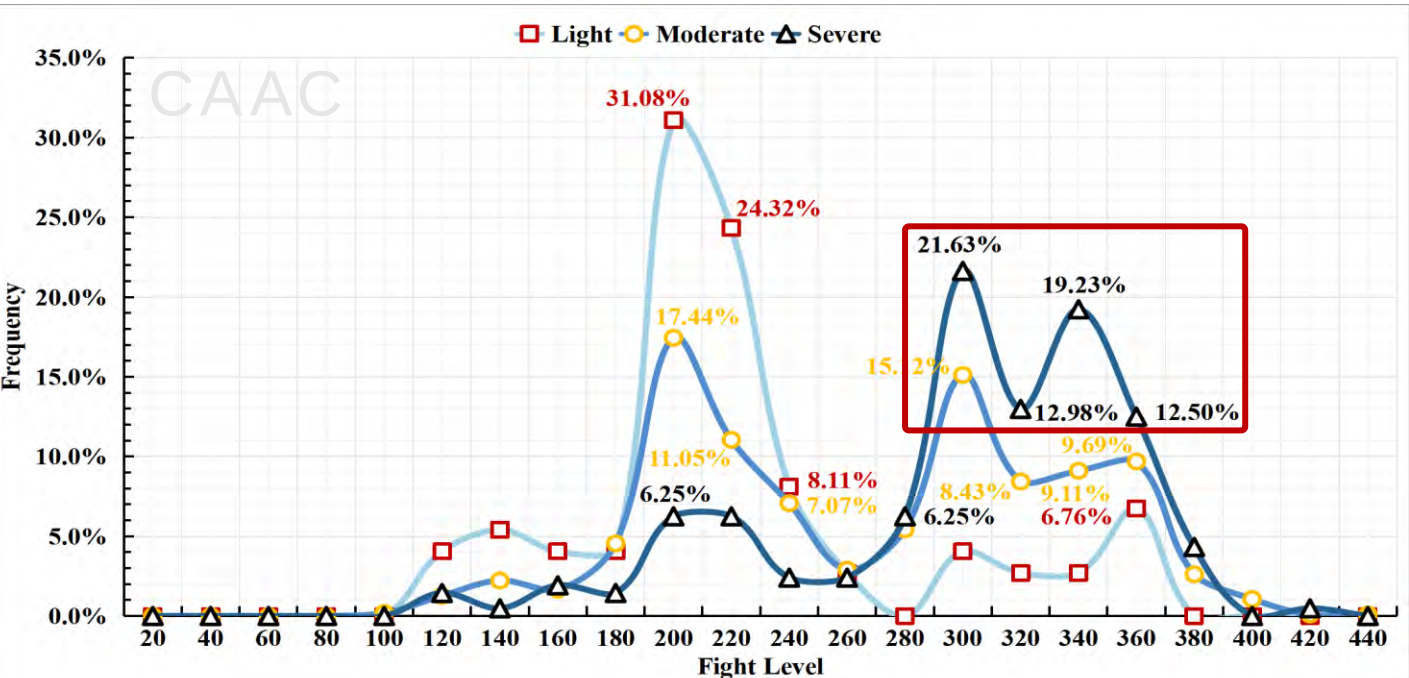


Fig.1.12 Vertical probability distribution of aircraft turbulence intensity

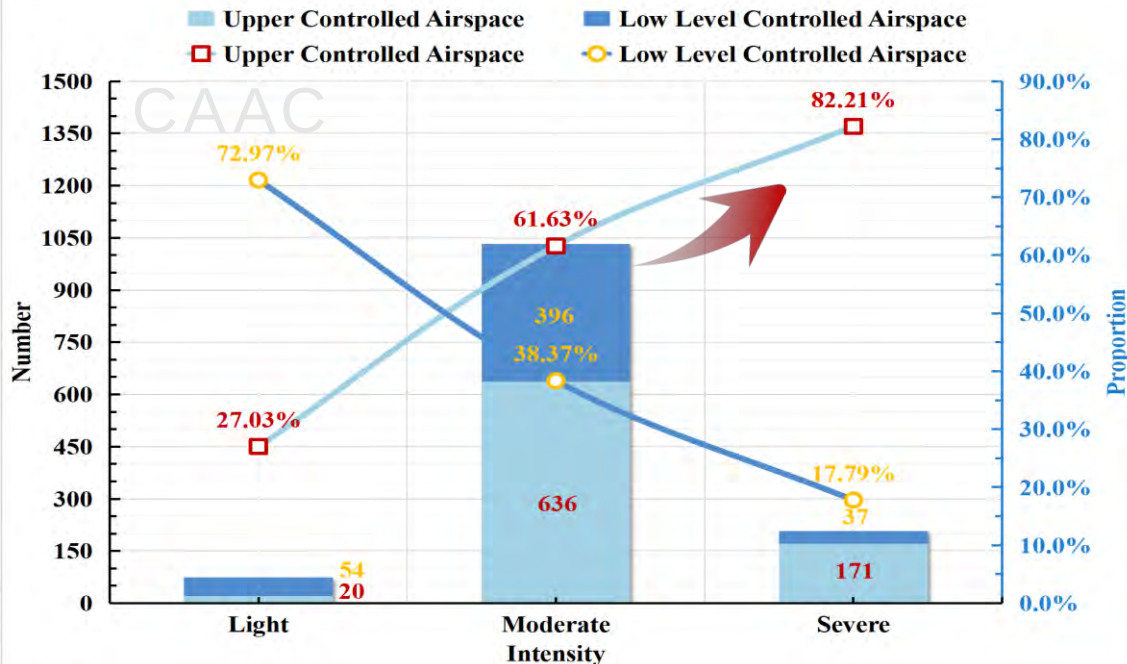


Fig.1.13 Vertical distribution of aircraft turbulence intensity

A 1.4 Causes of Turbulence

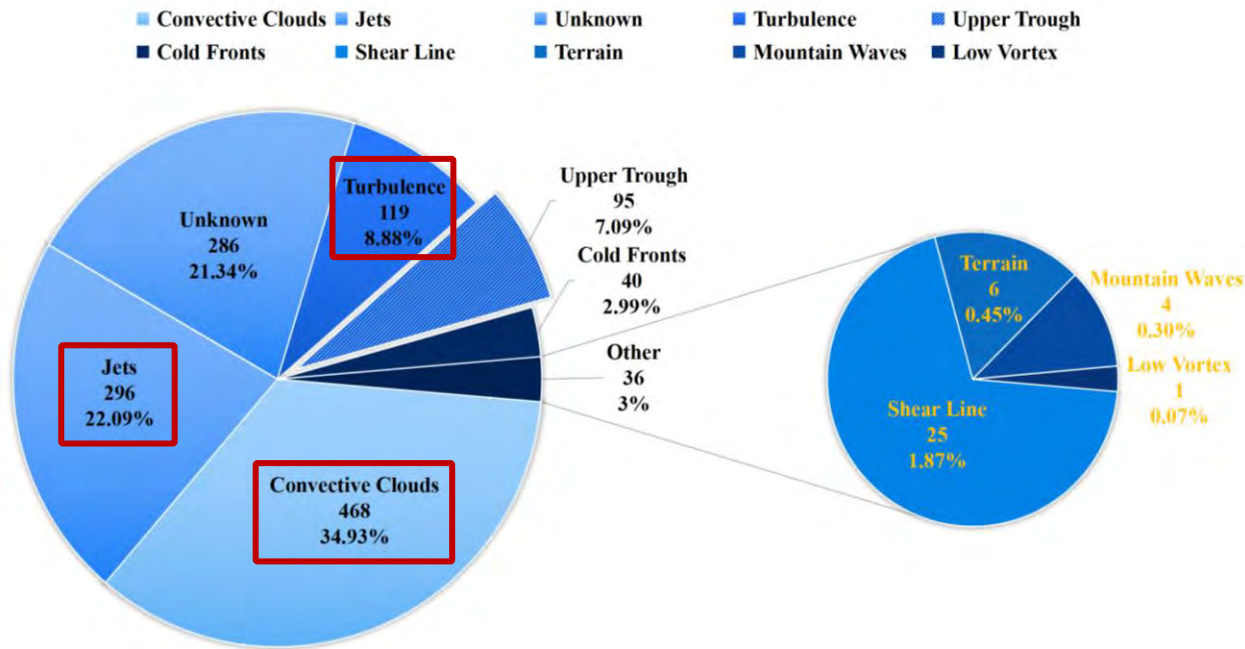


Fig.1.14 Causes of aircraft turbulence

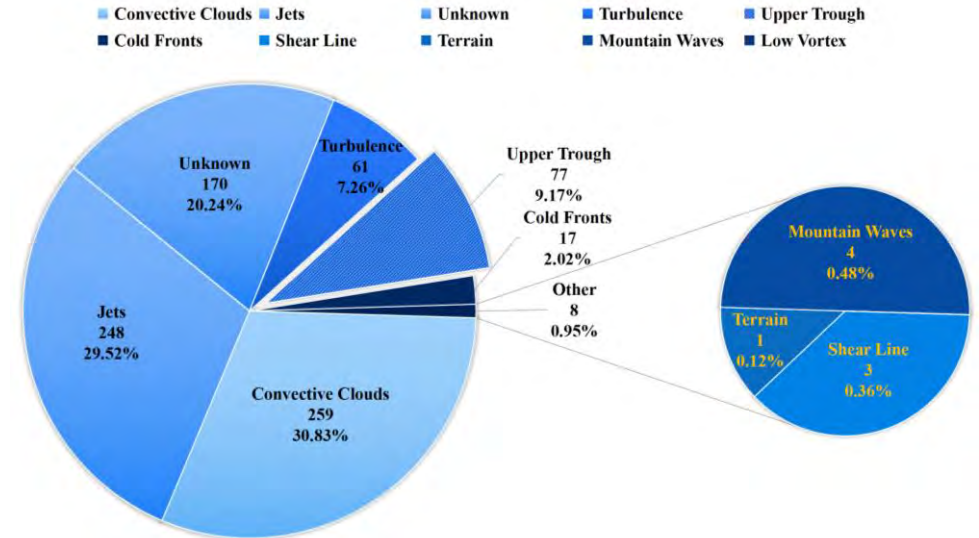


Fig.1.15 Causes of high-altitude aircraft turbulence

- **65.90%** of aircraft turbulence events were attributed to **convective clouds**, **jet streams**, and **atmospheric turbulence** — the three primary causes over the slope of Qinghai-Tibetan Plateau.

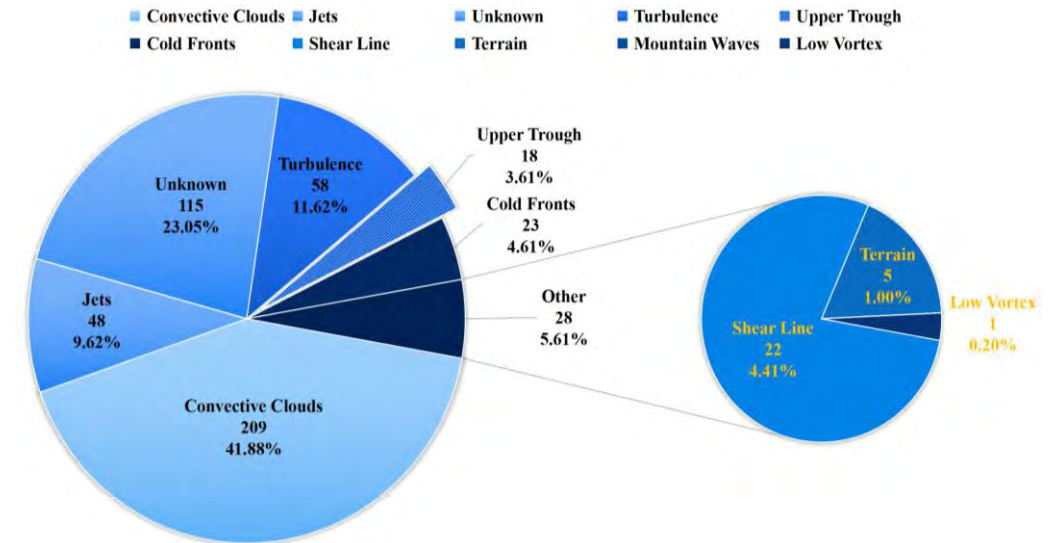


Fig.1.16 Causes of low-level aircraft turbulence

A 1.4 Causes of Turbulence

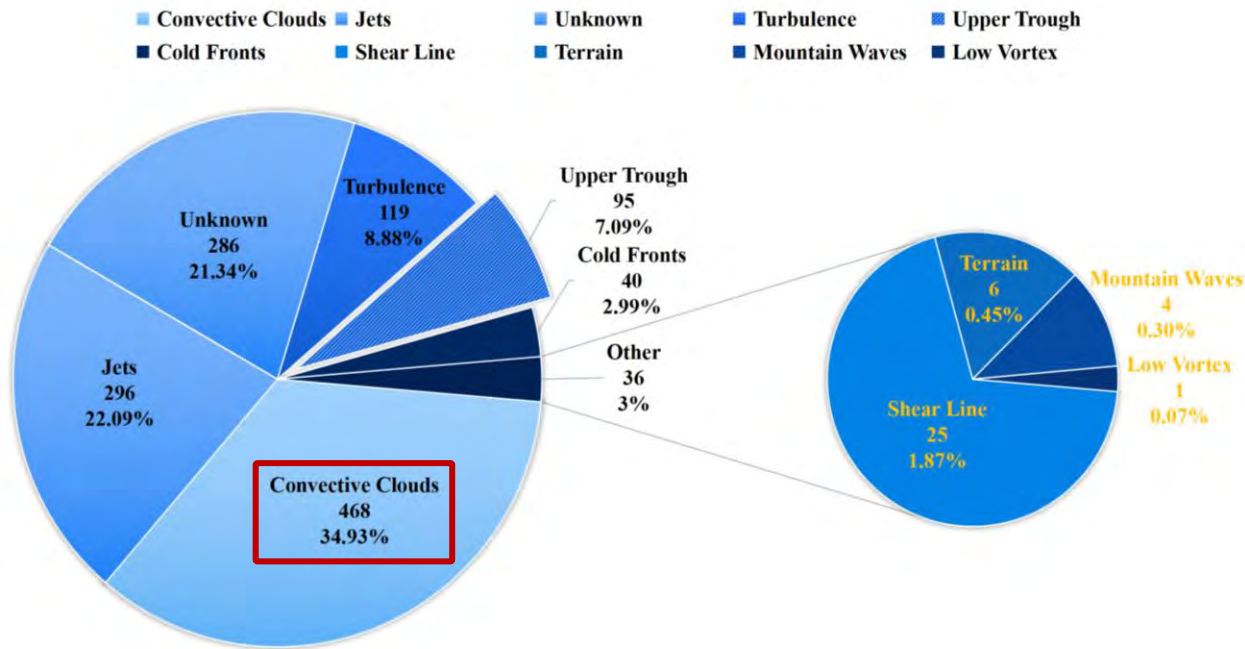


Fig.1.14 Causes of aircraft turbulence

- **Convective clouds** had the largest range of influence. They affected both high and low altitudes, especially **low-altitude flight**.
- **41.88%** of aircraft turbulence occurred below 6,600 meters were caused by convective clouds.

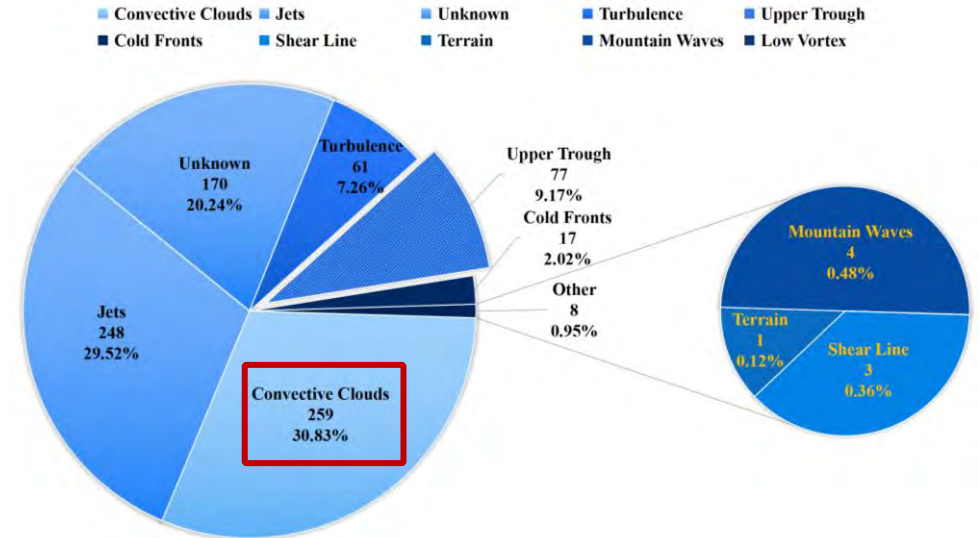


Fig.1.15 Causes of high-altitude aircraft turbulence

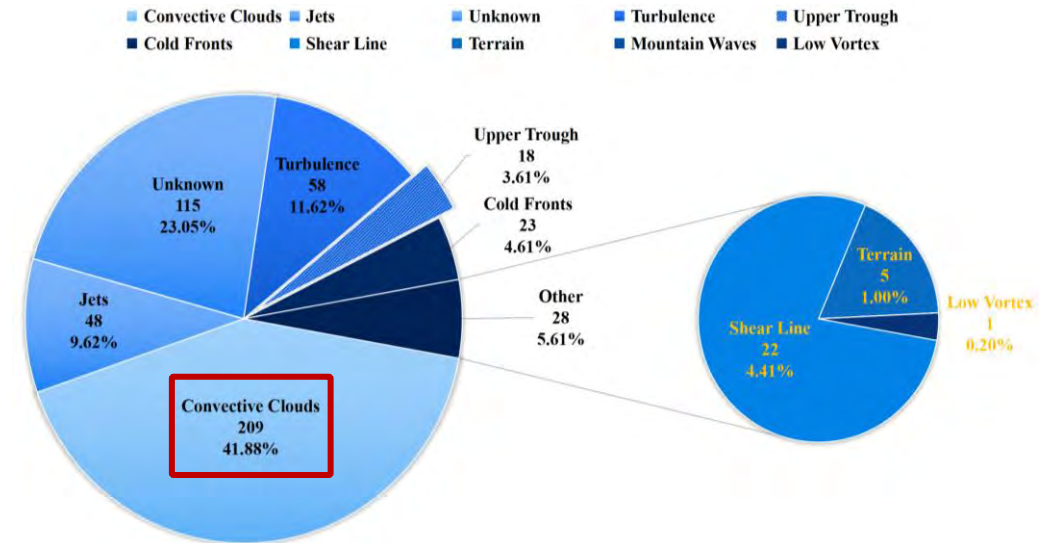


Fig.1.16 Causes of low-level aircraft turbulence

1.4 Causes of Turbulence

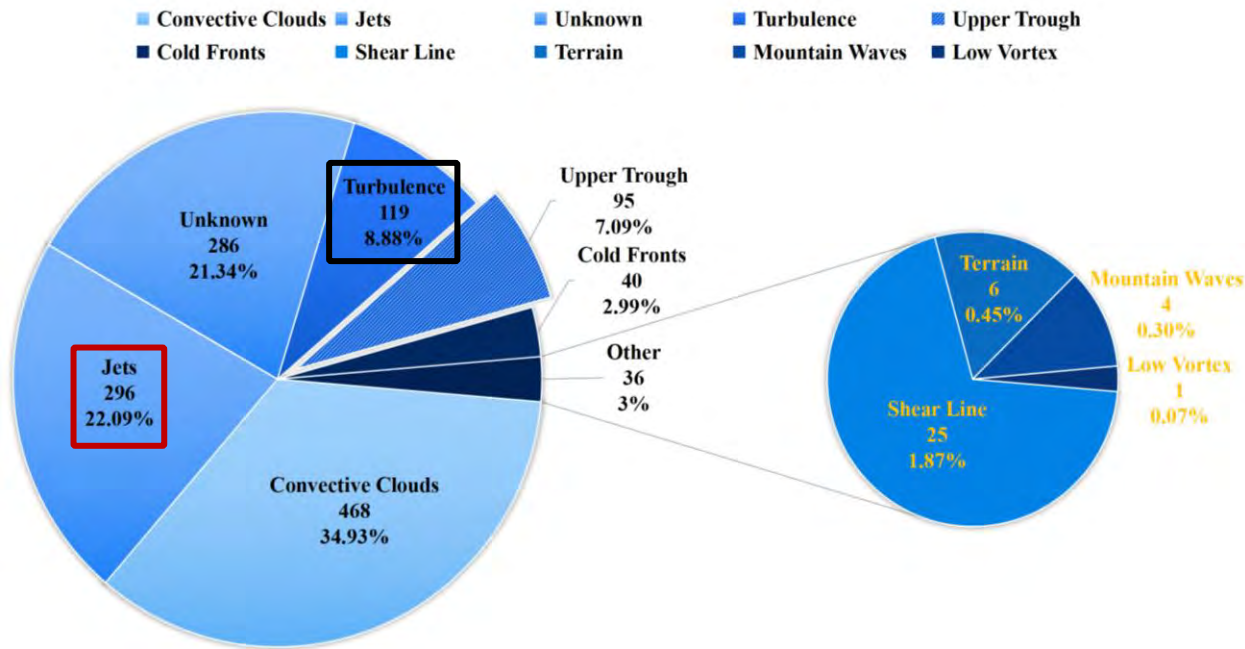


Fig.1.14 Causes of aircraft turbulence

- **Jet streams** primarily influenced **high altitude** flight.
- Affected by terrain and other factors, **atmospheric turbulence** was also mainly concentrated at **low altitude**.

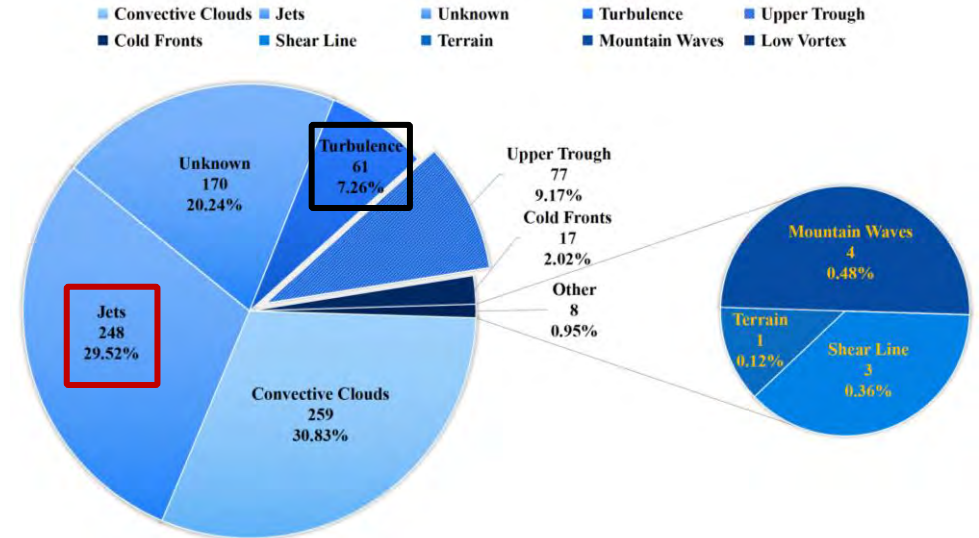


Fig.1.15 Causes of high-altitude aircraft turbulence

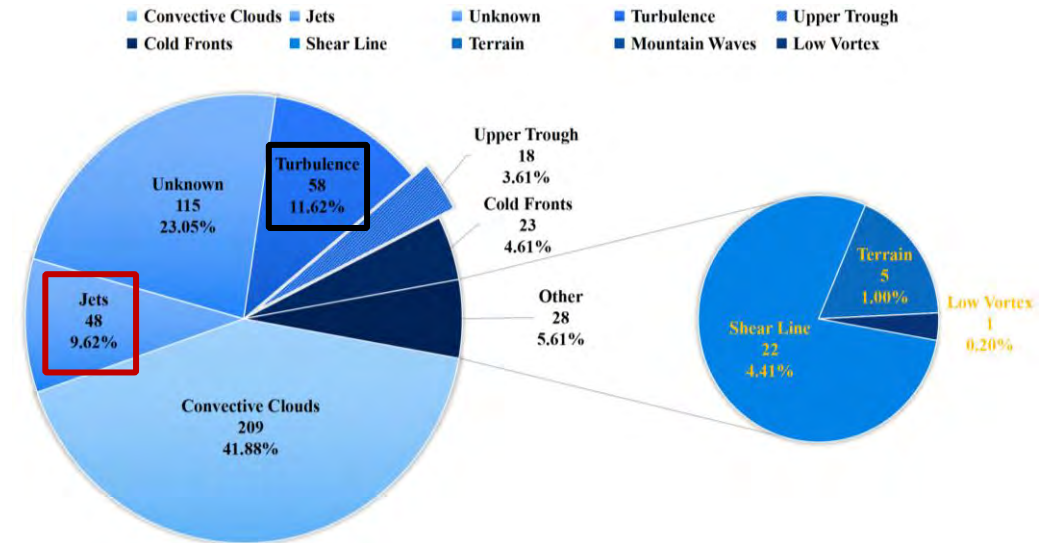


Fig.1.16 Causes of low-level aircraft turbulence

1.4 Causes of Turbulence

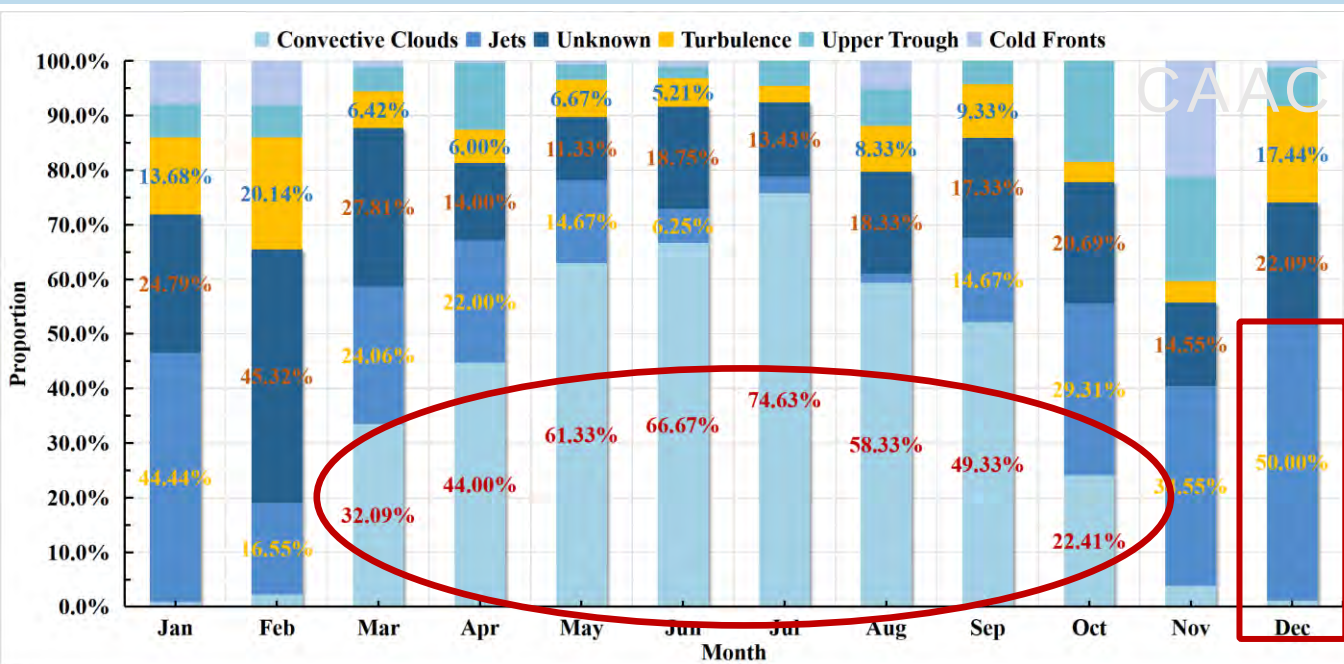


Fig.1.17 Monthly variation of different aircraft turbulence causes

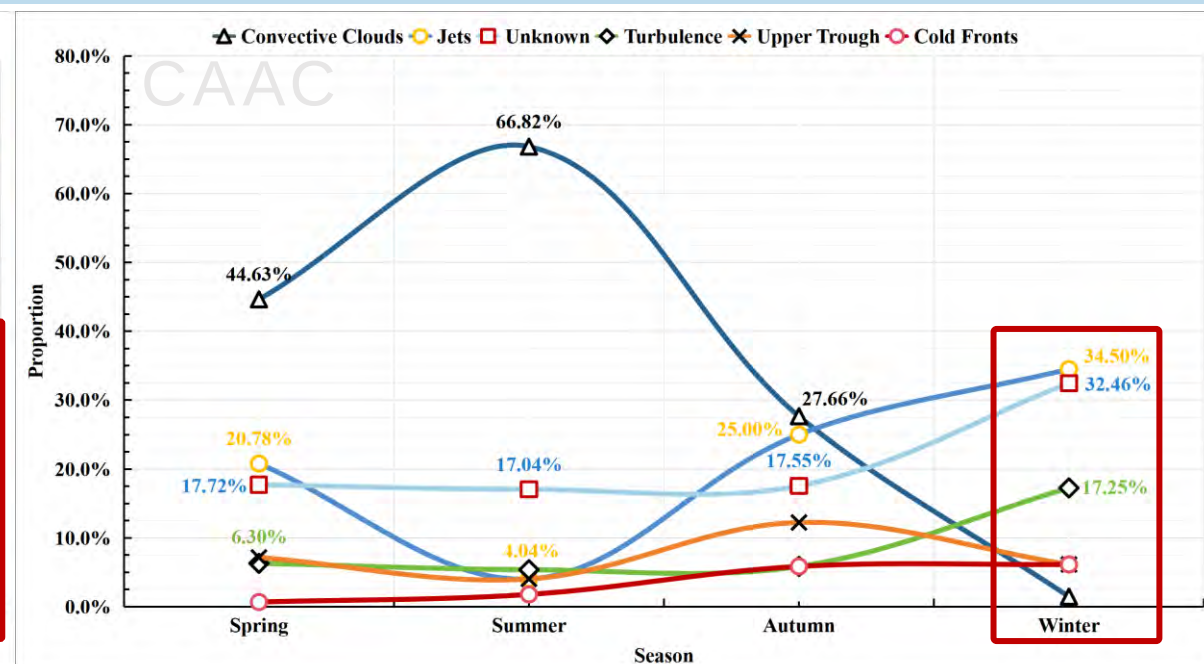


Fig.1.18 Seasonal variation of different aircraft turbulence causes

- **Convective clouds** were the main cause of aircraft turbulence in **spring** and **summer**, especially **from March to September**. Particularly in **July**, **74.63%** of turbulence were caused by them.
- **Jet streams** was **weakest in summer** and **strongest in winter**, especially in **December**, when 50% of turbulence events were caused by them.
- In autumn and winter, the influence of jet streams, atmospheric turbulence, and upper-level troughs was gradually prominent.

1.4 Causes of Turbulence

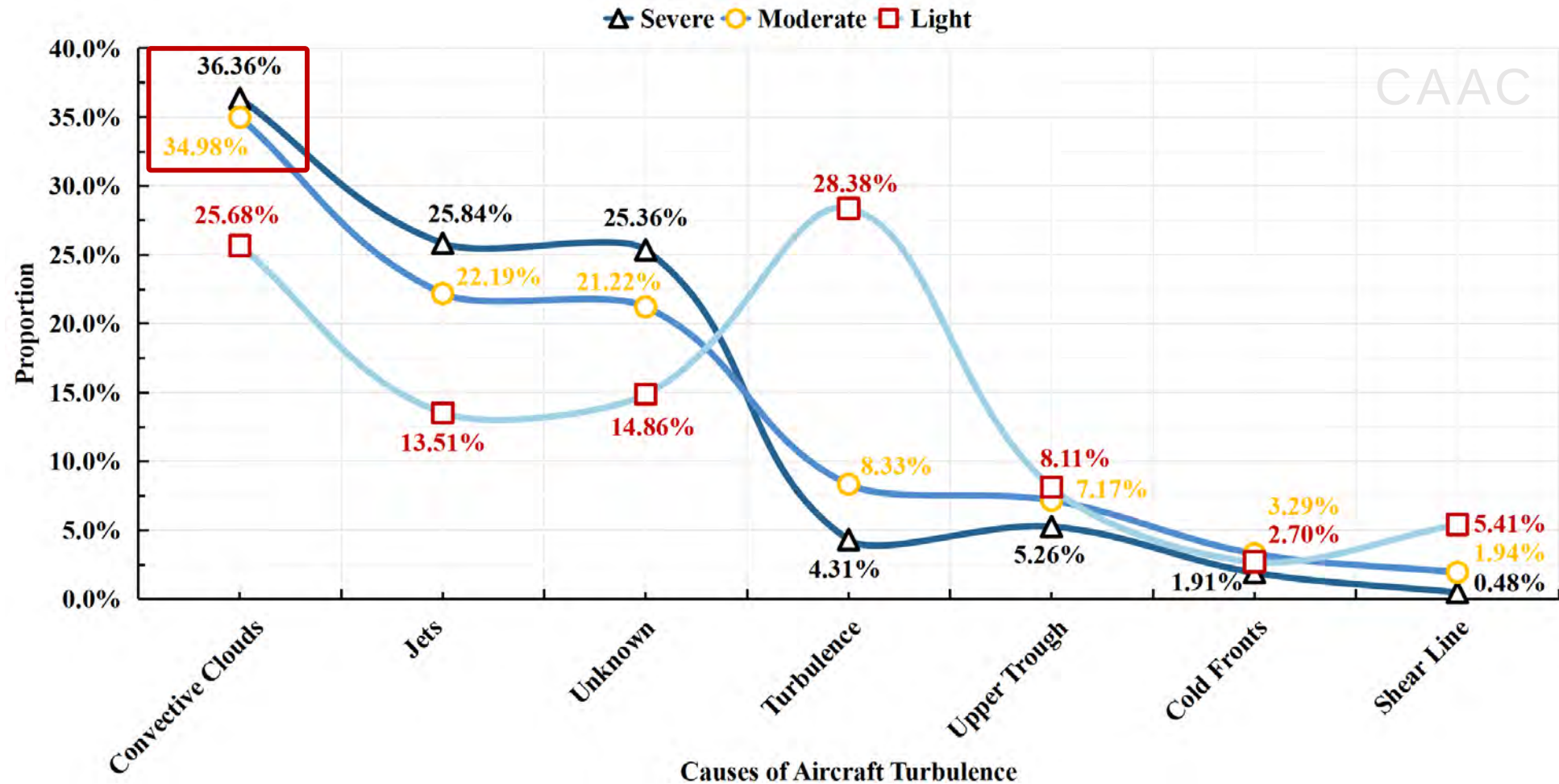
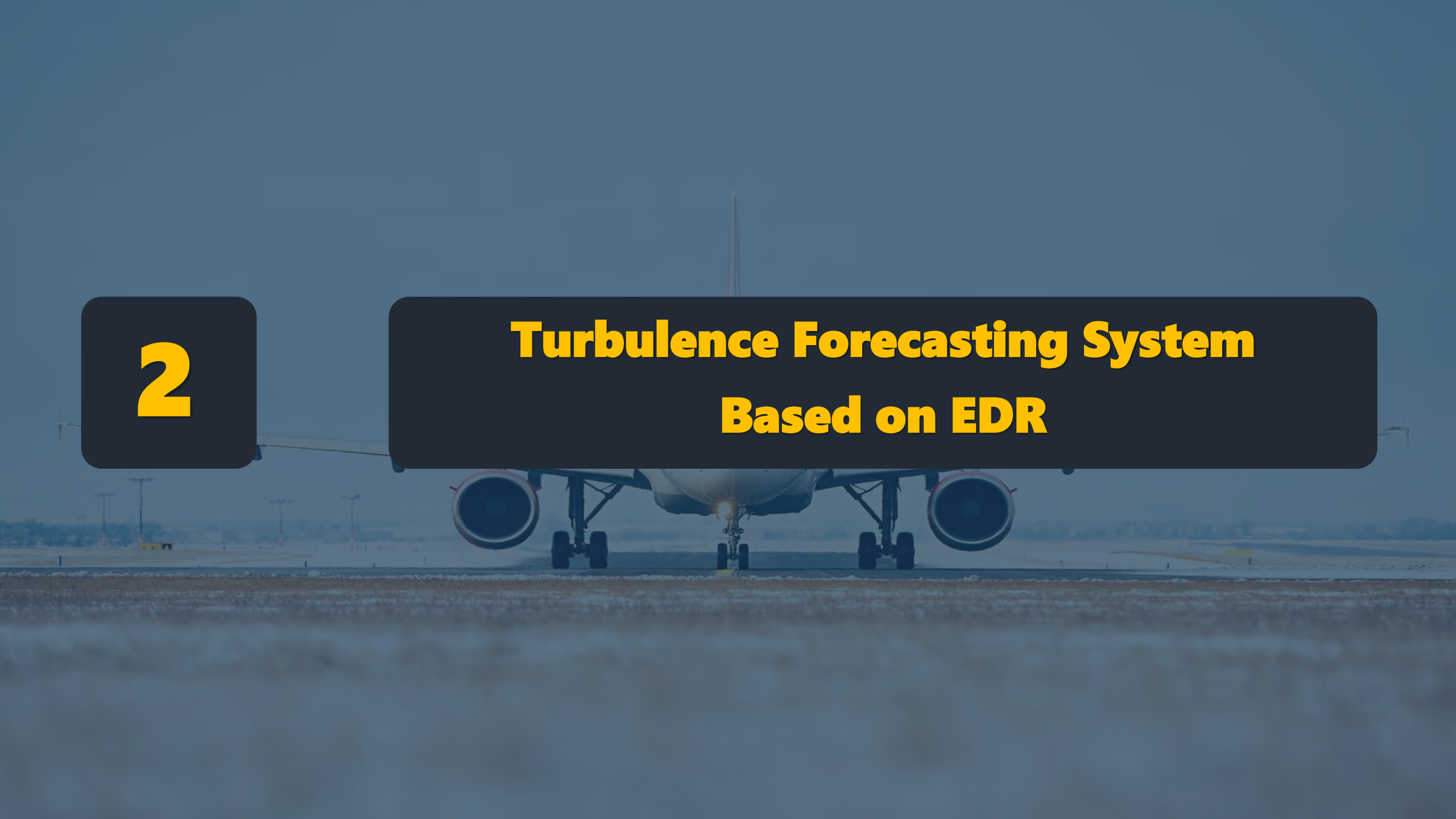


Fig.1.19 The distribution of aircraft turbulence intensity ratio caused by different reasons

- **36.36% of severe turbulence** were caused by **convective clouds**, which were the most likely reason to cause moderate to severe turbulence.

A large commercial airplane is shown from a low angle on a runway. The image is overlaid with a semi-transparent blue filter. In the center, there is a dark blue rounded rectangle containing yellow text. To the left of this rectangle is a smaller dark blue rounded rectangle containing a large yellow number '2'.

2

Turbulence Forecasting System Based on EDR

2.1 Eddy Dissipation Rate (EDR)

- The **eddy dissipation rate (EDR)** expressed in m^2/s^3 is the rate at which turbulence energy dissipated in the atmosphere, which can represent the **intensity of atmosphere turbulence**.
- The values range **from 0 to 1**, the higher the value, the faster the energy dissipation, and the stronger the turbulence.
- EDR is an **objective, aircraft-independent, universal** measure and parameter of turbulence.
- ICAO and WMO regard it as the official atmospheric and aircraft turbulence intensity metric.

Table.2.1 Classification of aircraft turbulence intensity based on EDR

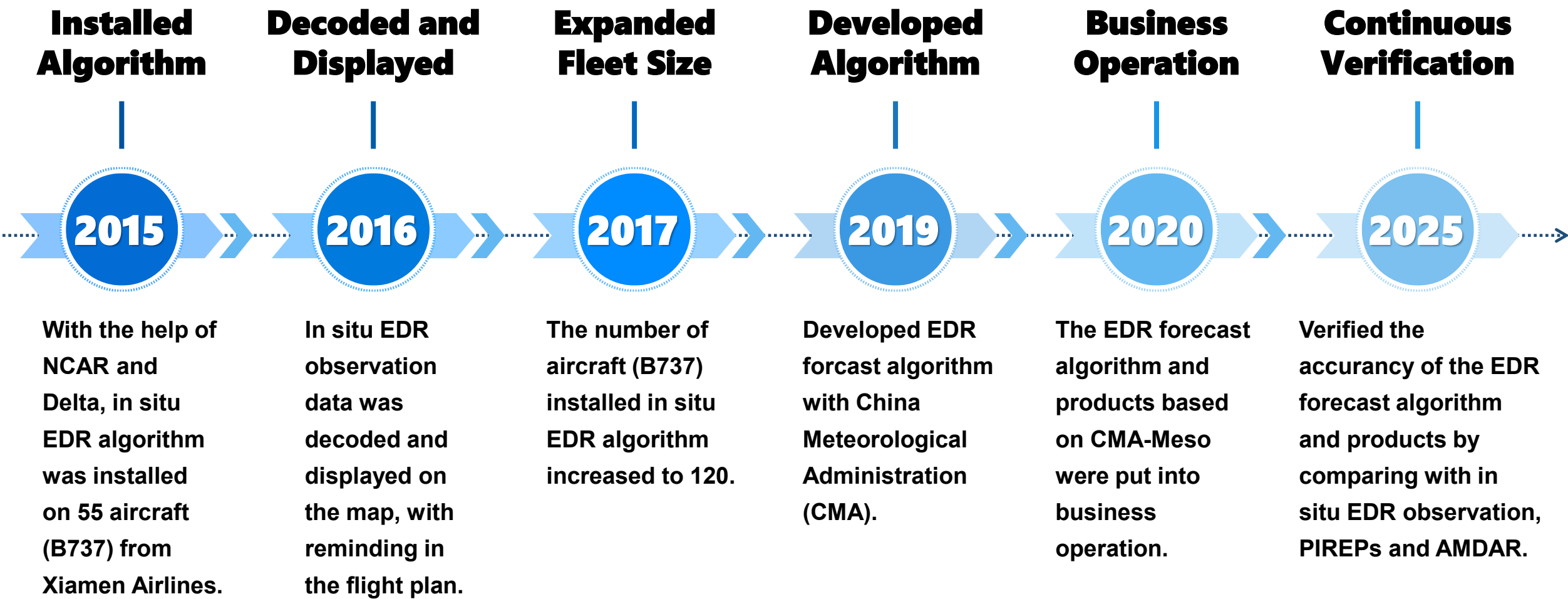
Aircraft Weight Class \ EDR	Light	Moderate	Severe
Light	0.17-0.24	0.24-0.54	0.54-0.96
Medium	0.15-0.20	0.2-0.44	0.44-0.79
Heavy	0.13-0.16	0.16-0.36	0.36-0.64

From Annex 3 (Appendix 4):

- Turbulence for medium-sized aircraft (e.g. B-737):
- Severe: peak value of $\text{EDR} \geq 0.45$
- Moderate: peak value of EDR between 0.20 to 0.45
- Light: peak value of EDR between 0.10 to 0.20

Although EDR provides a turbulence measurement that is not based on any particular aircraft, the relationship between the EDR value and the perception of turbulence is a function of aircraft type and the mass, altitude, configuration and airspeed of the aircraft. For example, an EDR of 0.24 will be moderate turbulence for an A320 but light turbulence for a B777.

2.2 Development History



2.3 Weather Risk Control System (WRC)

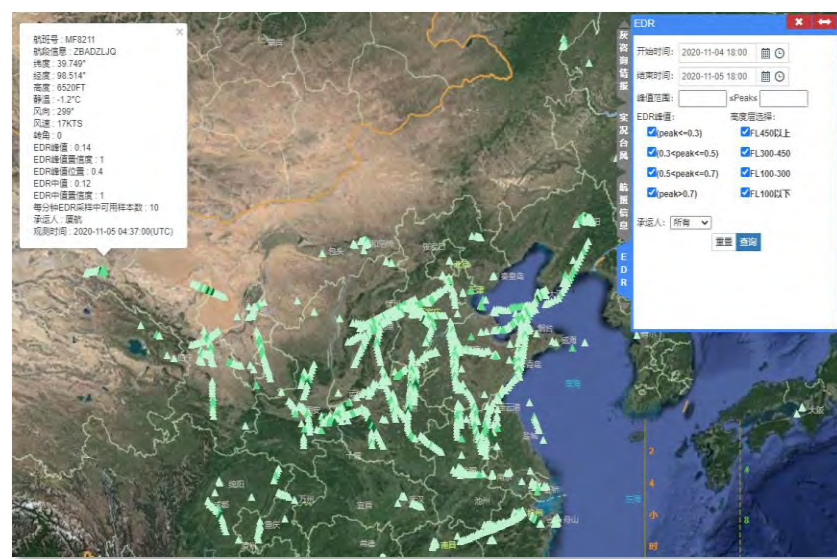


Fig.2.1 In situ EDR observation data

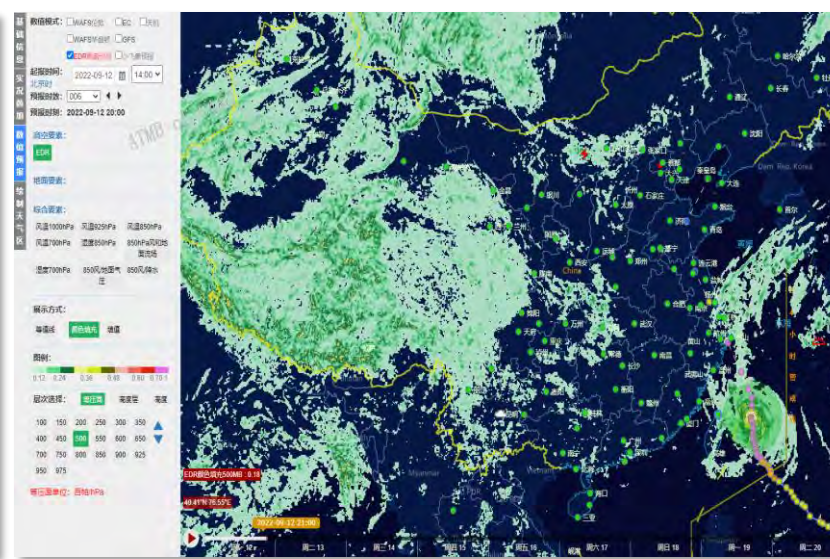


Fig.2.2 Grid EDR forecast product

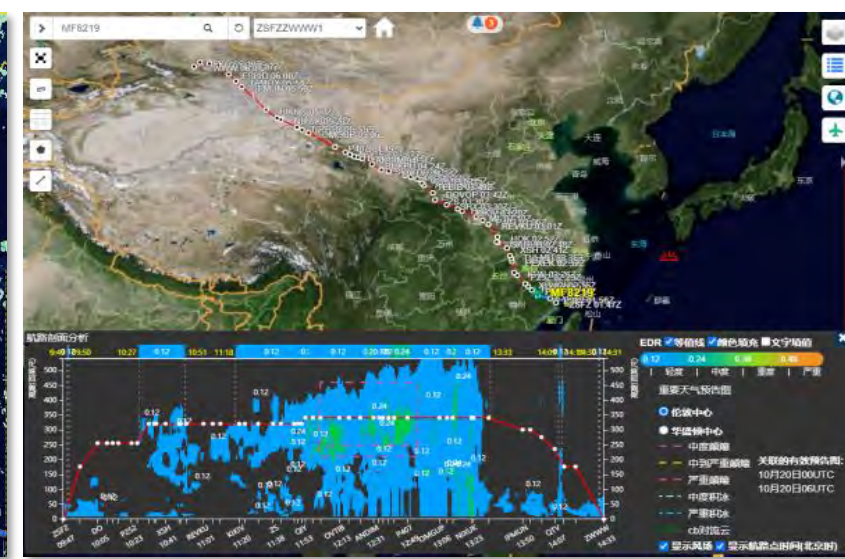


Fig.2.3 Vertical profile of EDR forecast in route

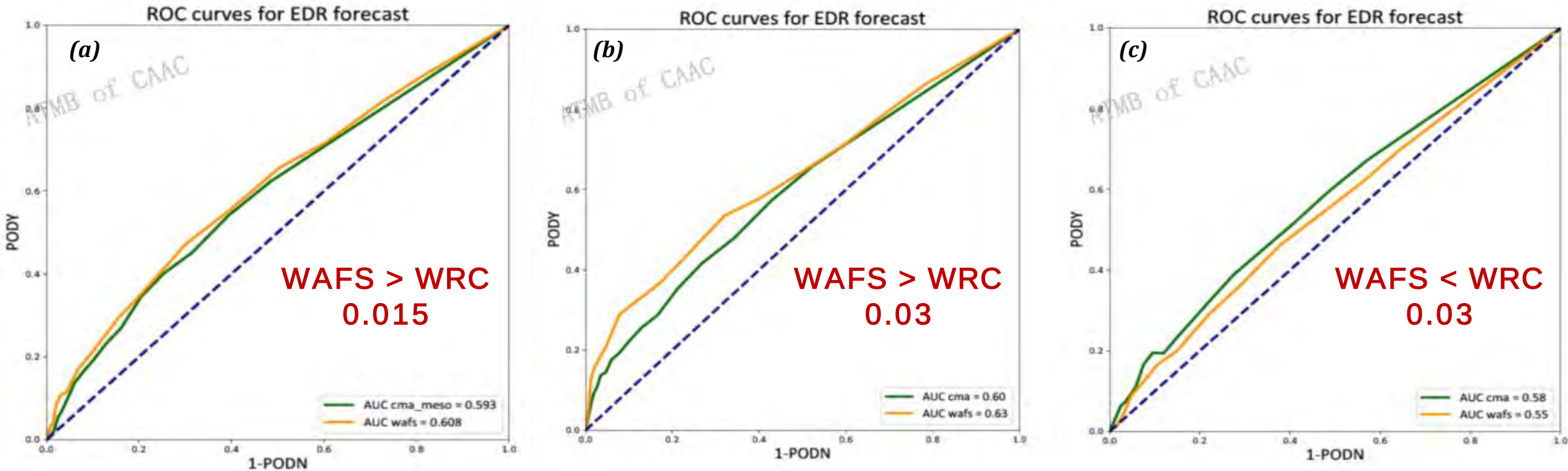
- WRC is based on the **3km CMA-MESO** (China Meteorological Administration Meso-scale weather forecast system) model.
- It updates **every 6 hours** and produces **hourly forecasts through 36 hours**, the products are available at **1000hPa, 975hPa and every 50hPa from 950hPa to 100hPa**.
- It produces forecasts of **clear air turbulence (CAT)**, **mountain wave turbulence (MWT)**, and **convectively induced turbulence (CIT)** which are expressed in terms of **EDR**.

2.3 Weather Risk Control System (WRC)

Table.2.2 Comparison between GTG and WRC

	GTG3	GTGG/WAFS	WRC	GTGN
Defination	Forecast System	Forecast System	Forecast System	Nowcast System
Domain	CONUS (Continental United States)	Global	China East Asia	CONUS (Continental United States)
Horizontal Resolution	13 km	0.25°(28 km)	3 km	13 km
Vertical Resolution	(36 levels) every 1000 ft from FL100 toFL450	(41 levels) every 1000 ft from FL100 toFL500	(20 levels) 1000hPa, 975hPa every 50hPa from 950hPa to 100hPa	(36 levels) every 1000 ft from FL100 toFL450
Updating Cycle	1 hour	6 hours	6 hours	15 minutes
Valid Time	18 hours	48 hours	36 hours	next 15 minutes
Temporal Resolution	T+3 at 1-hourly intervals T+6 to T+18 at 3-hourly intervals	T+24 at 1-hourly intervals T+27 to T+48 at 3-hourly intervals	1 hour	15 minutes
Forecast Model	13-km Rapid Refresh (RAP) numerical weather model	13-km Global Forecast System (GFS) and UKMET model	CMA-MESO	13-km Rapid Refresh (RAP) numerical weather model
Inputs	-	-	-	GTG3 short-term forecasts PIREPs In situ EDR reports NTDA
Outputs	CAT, MWT, LLT	CAT, MWT	CAT, MWT, CIT	CAT, MWT, CIT

2.4 Comparative Verification



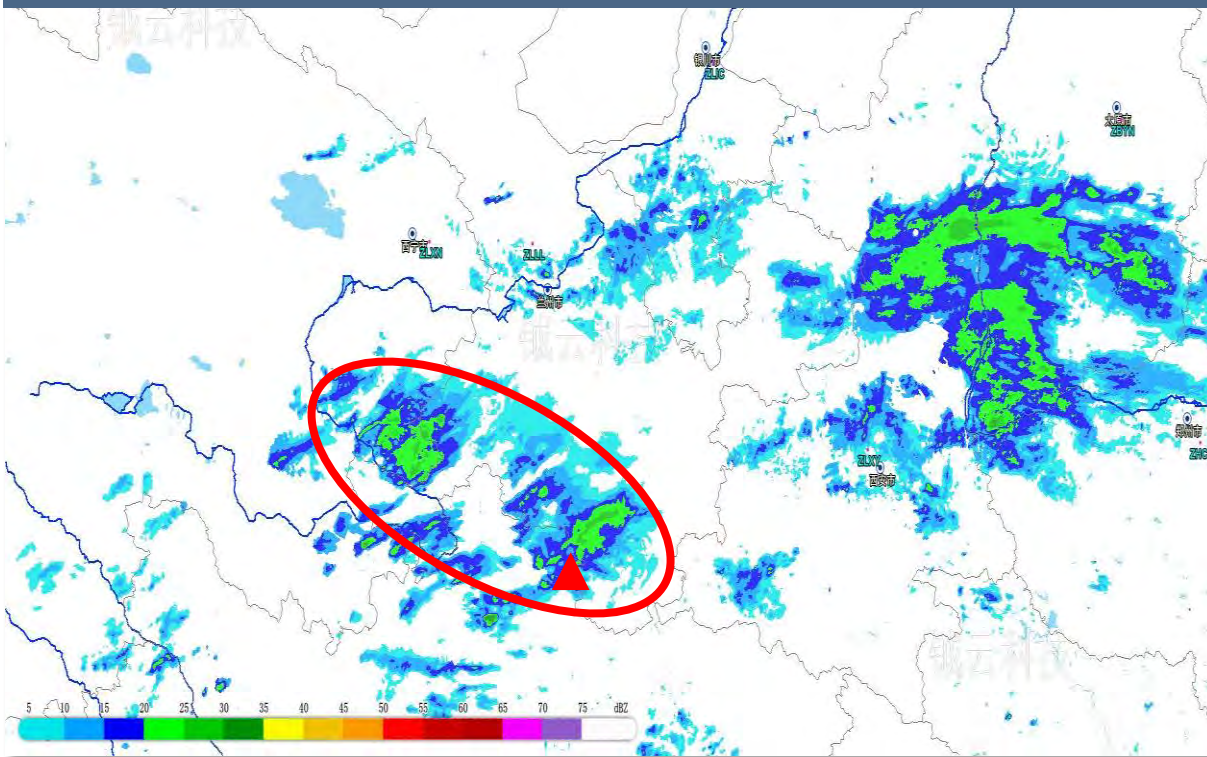
*Fig.2.4 ROC curves for EDR forecast between WAFS and WRC from February to April in 2024
(a) February; (b) March; (c) April*

- The EDR forecast performance of **WRC** and **WAFS** were similar.
- Due to the **higher temporal and spatial resolution of WRC**, it could provide **finer decision support** to aviation forecasters, ATC, pilots and airlines.

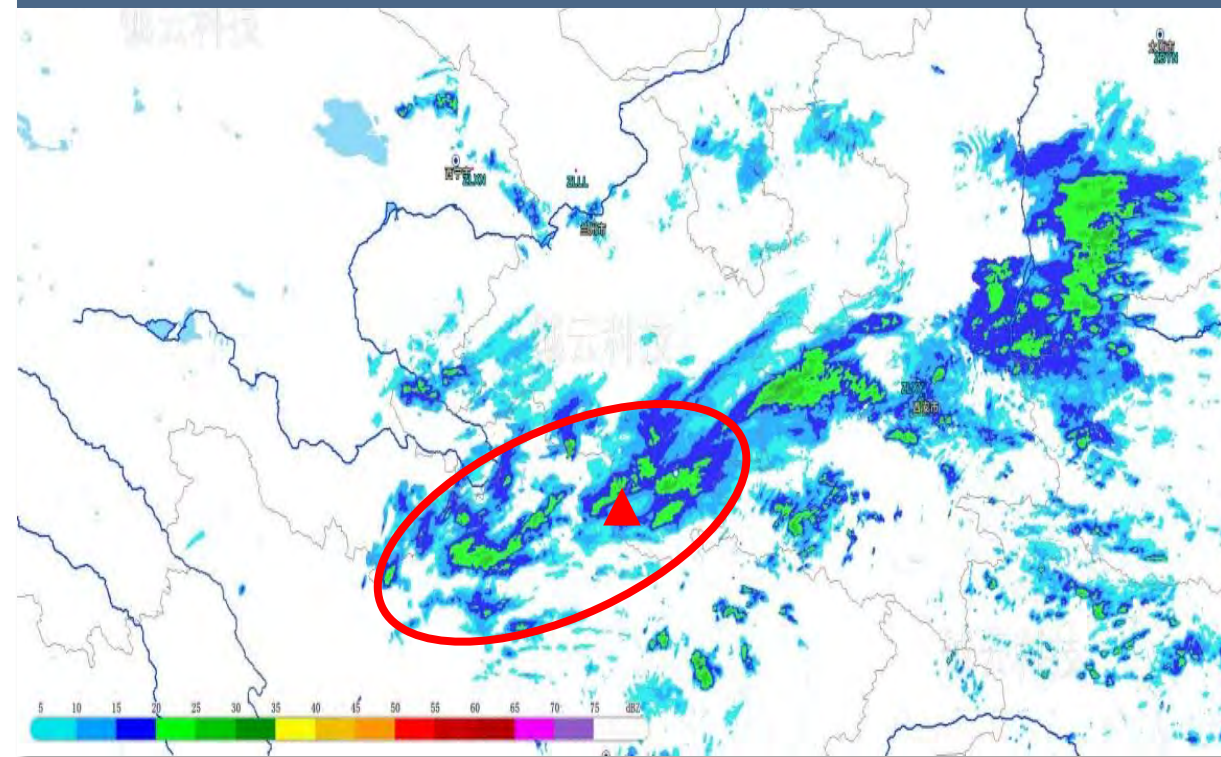
2.5 Case Study - CIT

17 March 2024, 08-13 UTC, 7200-11000 Meters above Sea Level
Moderate - Severe Turbulence

10:10 (UTC) Radar Reflectivity



12:50 (UTC) Radar Reflectivity



- Embedded weak convective clouds induced moderate - severe aircraft turbulence.

2.5 Case Study - CIT

17 March 2024, 08-13 UTC, 7200-11000 Meters above Sea Level

Moderate - Severe Turbulence

09 UTC, 250hPa

09 UTC, 300hPa

locations are souther and easter
shape of the turbulence area is different

09 UTC, 9000 m

10 UTC, 10000 m

NCEP Ellord Forecast

WRC EDR Forecast

12 UTC, 250hPa

12 UTC, 300hPa

10 UTC, 7000 m

13 UTC, 10000 m

horizontal, vertical position and shape
agreed with clouds and PIREPs

Thanks for listening!

Lijing Chen

chenlj_1991@163.com

Bangkok, Thailand

2025.04