中国民用航空局
空中交通管理局
Air Traffic Management Bureau, CAAC

International Civil Aviation Organization (ICAO) Asia and Pacific (APAC)

(MET/ATM Seminar & MET/R WG/14)

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

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1 Characteristics of Aircraft Turbulence on Qinghai-Tibet Plateau Slope

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1

Characteristics of Aircraft Turbulence on Qinghai-Tibet Plateau Slope

1.1.1 Inter-annual Distribution

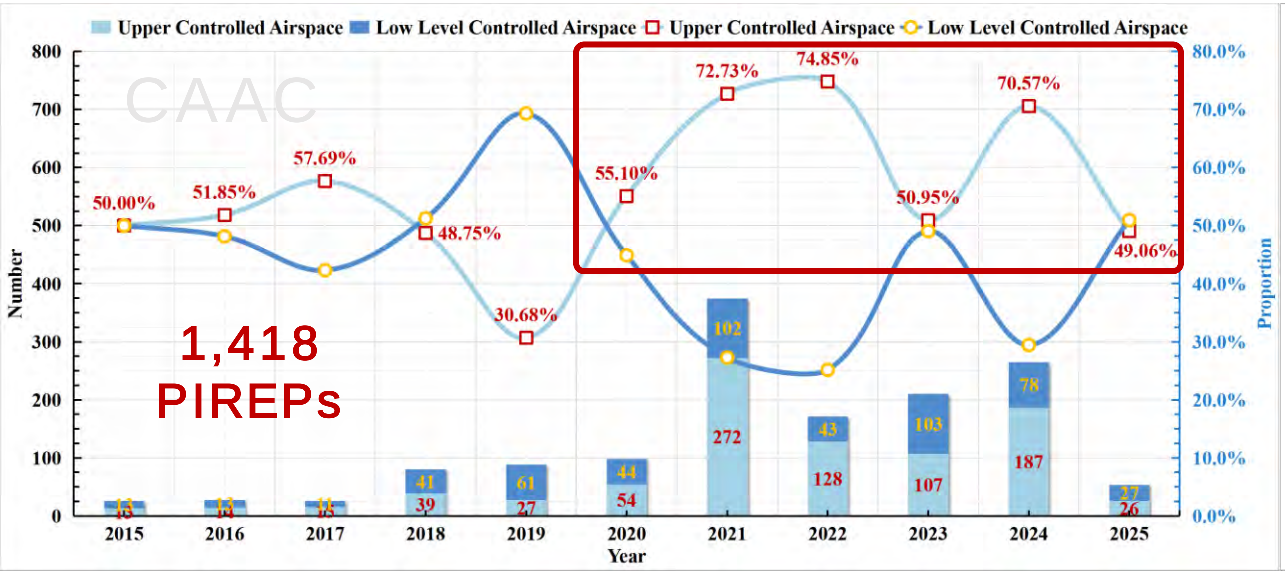


Fig.1.1 Inter-annual variation of aircraft turbulence events occured at different altitude

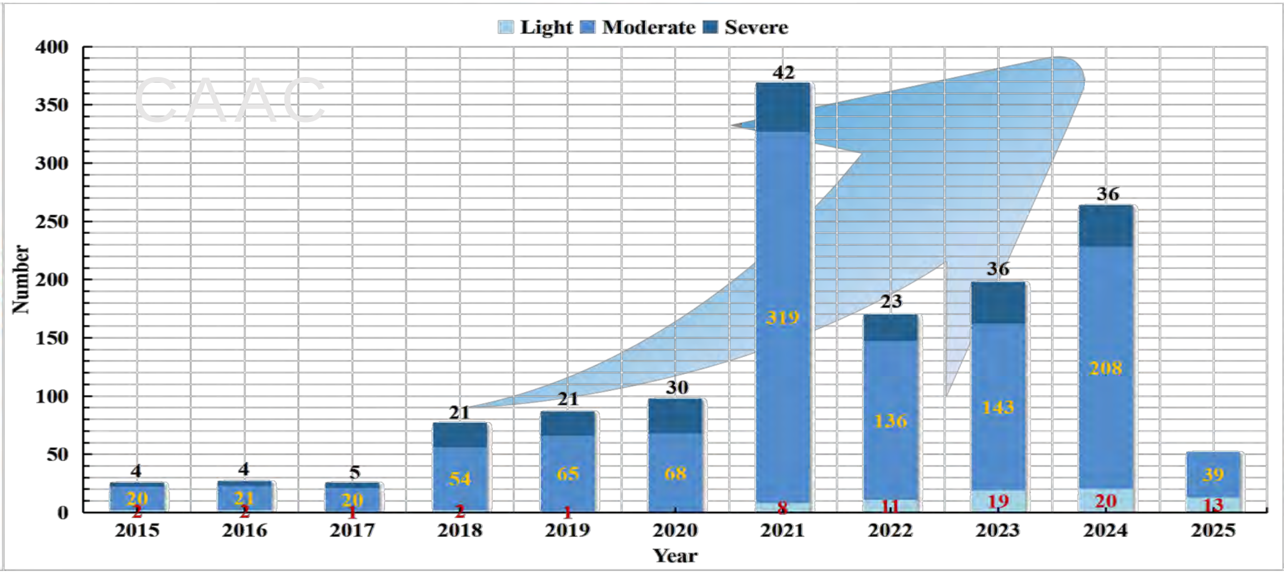


Fig.1.2 Inter-annual variation of aircraft turbulence intensity

- 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 occured more and more frequently.

1.1.2 Annual Distribution

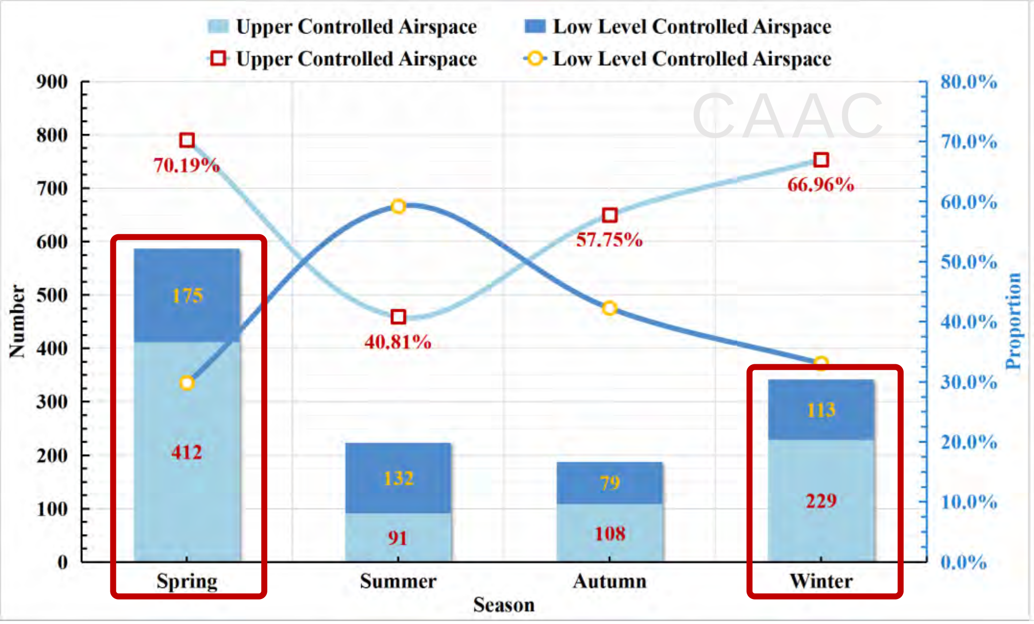


Fig.1.3 Seasonal variation of aircraft turbulence events occured at different altitude

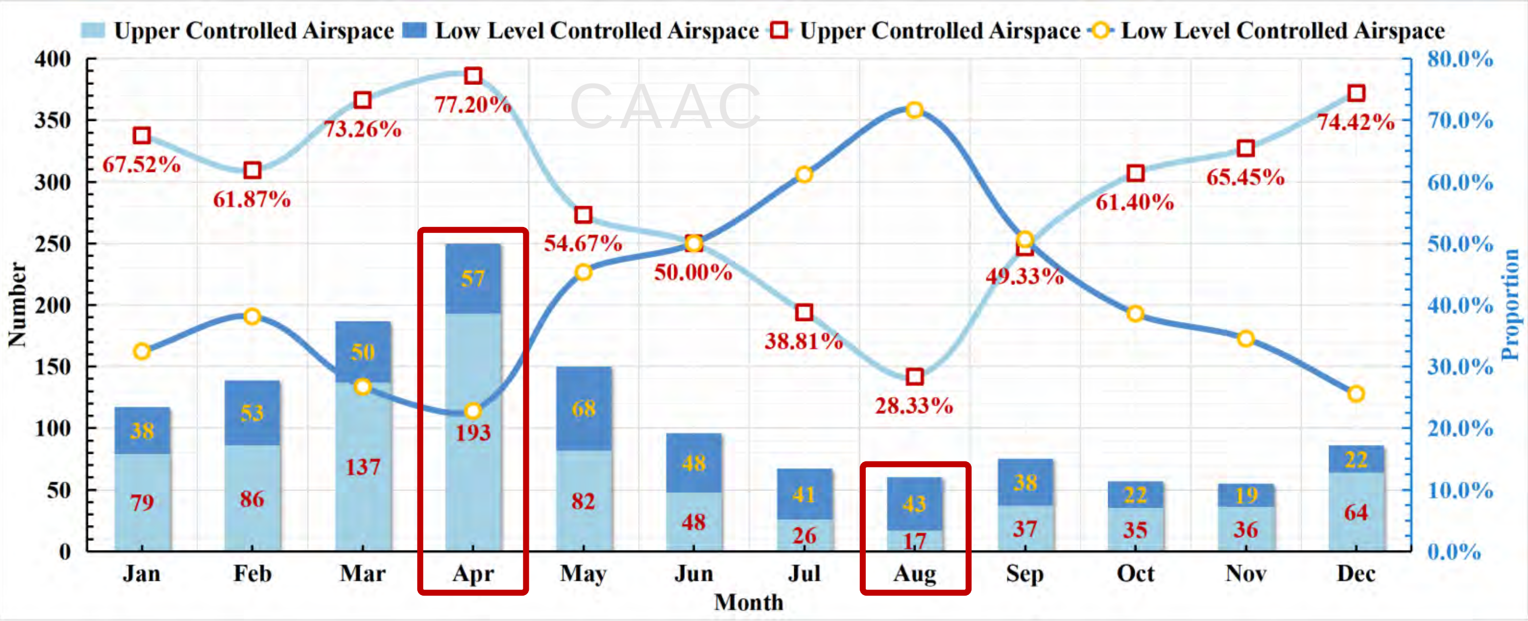


Fig.1.4 Monthly variation of aircraft turbulence events occured at different altitude

- 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.

1.1.2 Annual Distribution

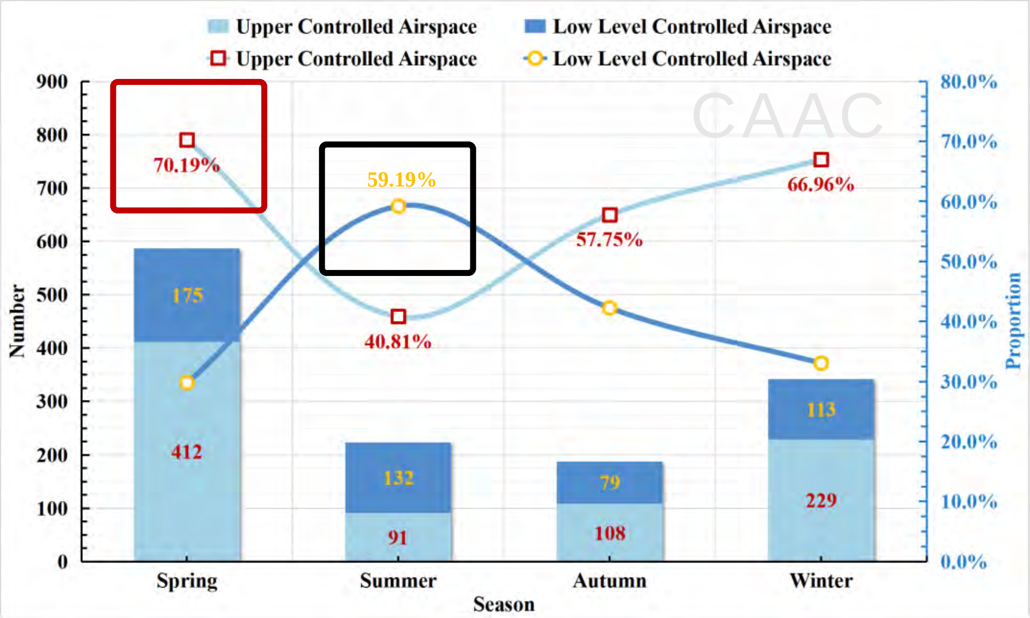


Fig.1.3 Seasonal variation of aircraft turbulence events occured at different altitude

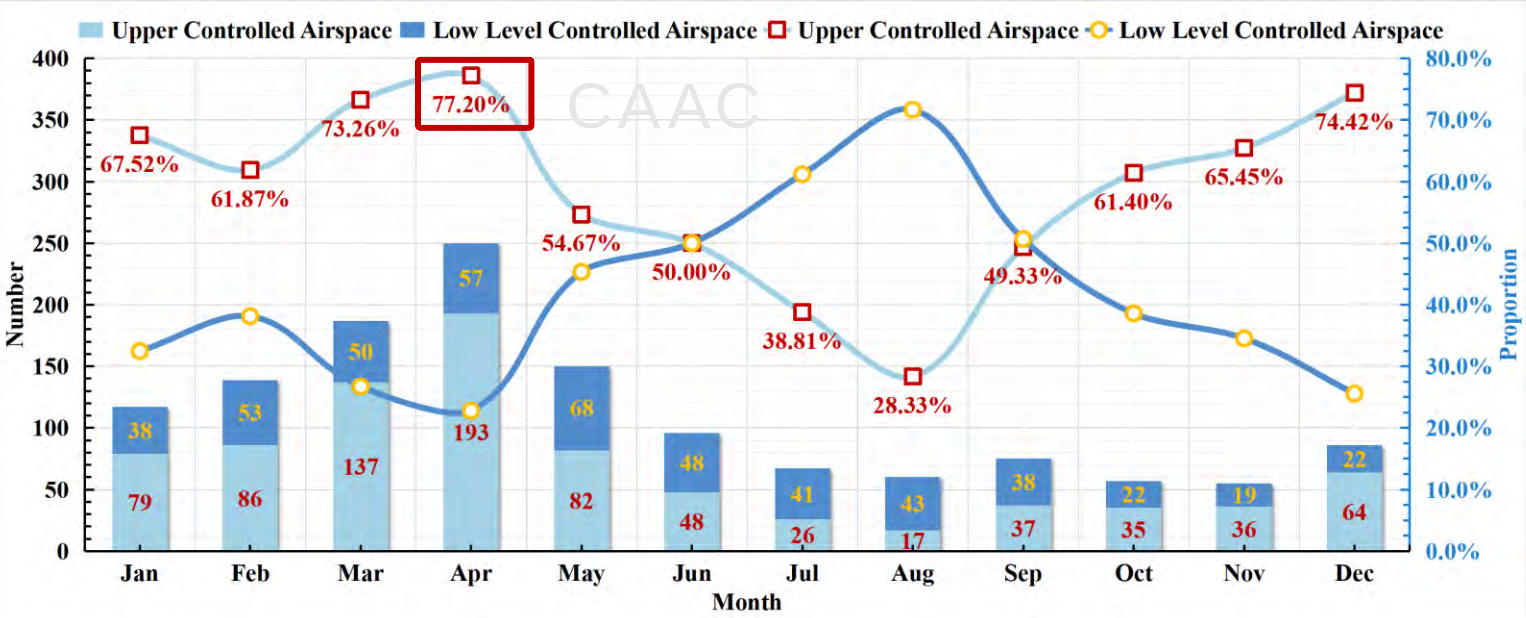


Fig.1.4 Monthly variation of aircraft turbulence events occured at different altitude

- **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

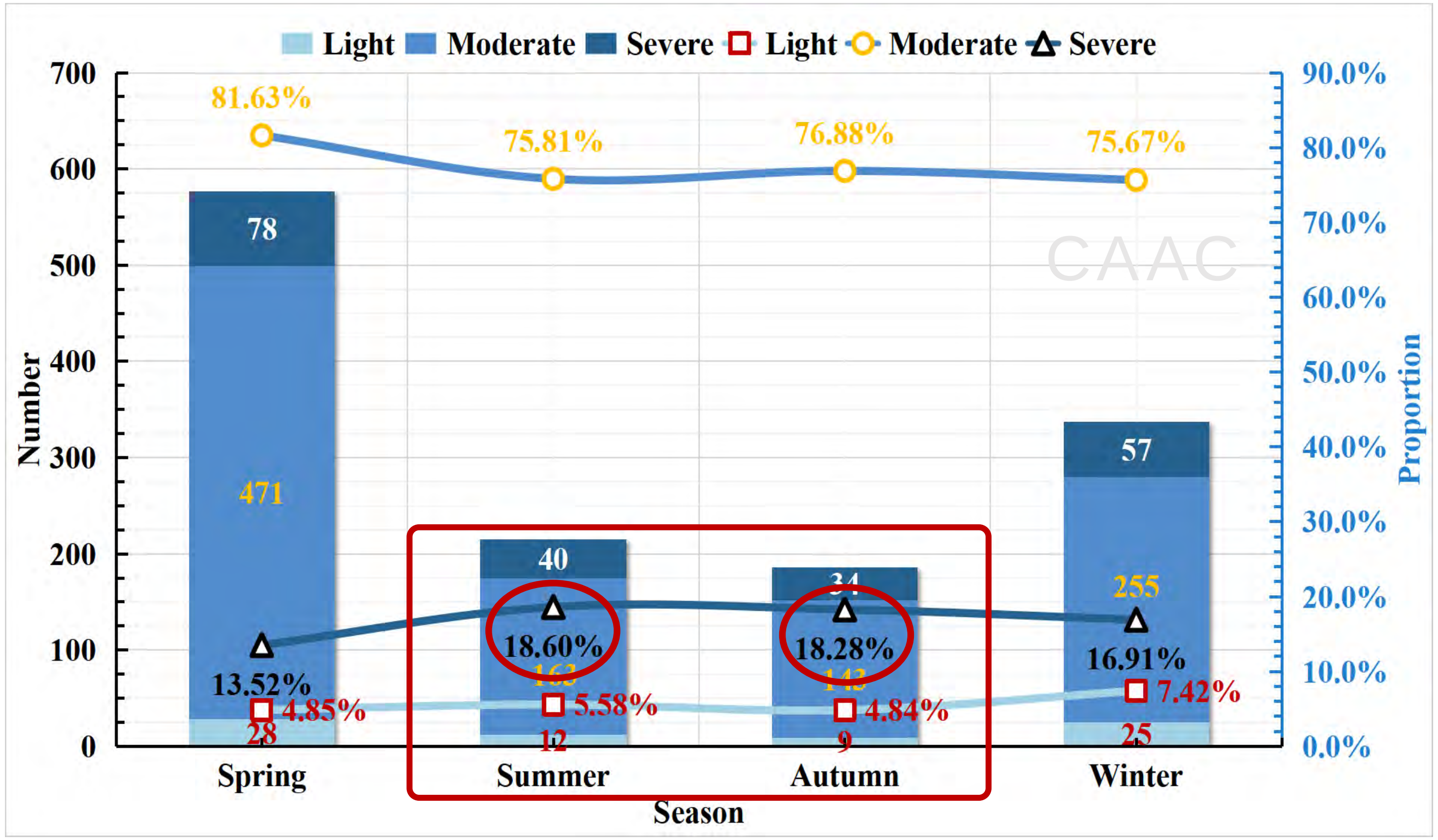


Fig.1.5 Seasonal variation of aircraft turbulence intensity

- 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%.

1.1.3 Daily Distribution

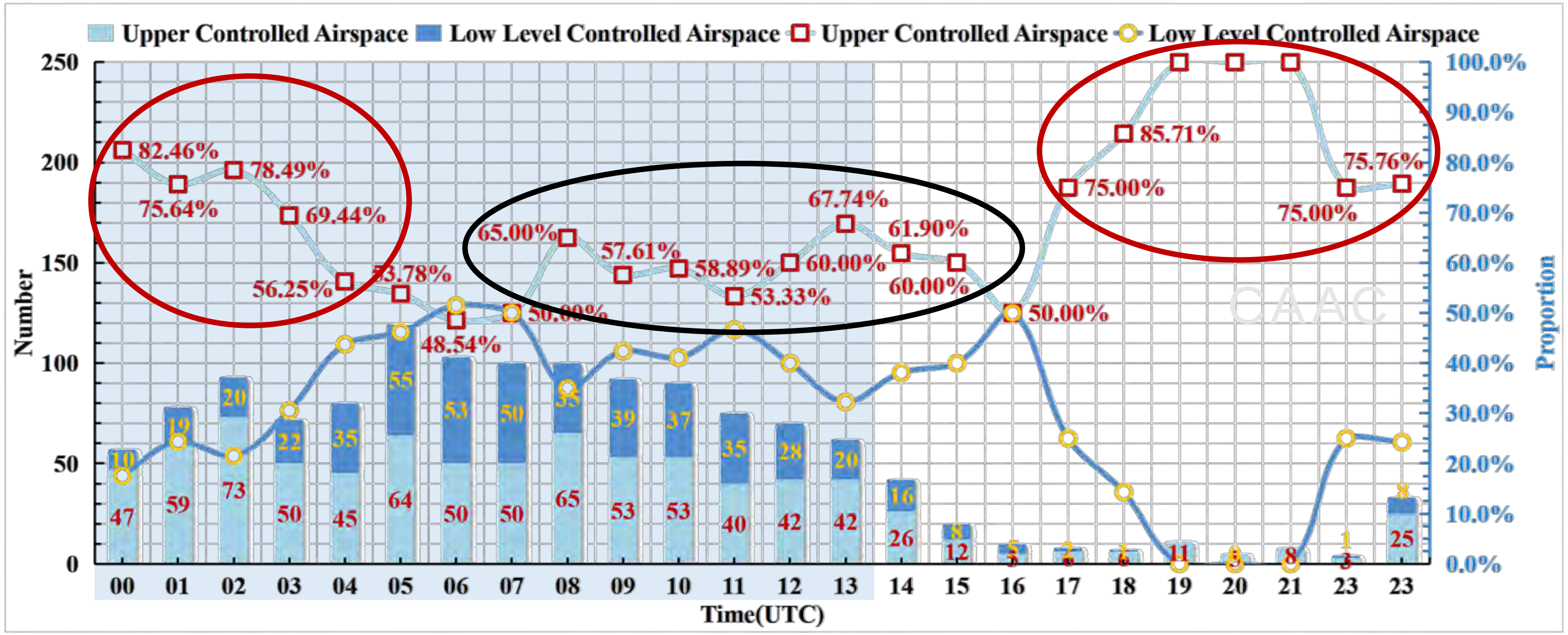


Fig.1.6 Daily variation of aircraft turbulence occured at different altitude

- 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

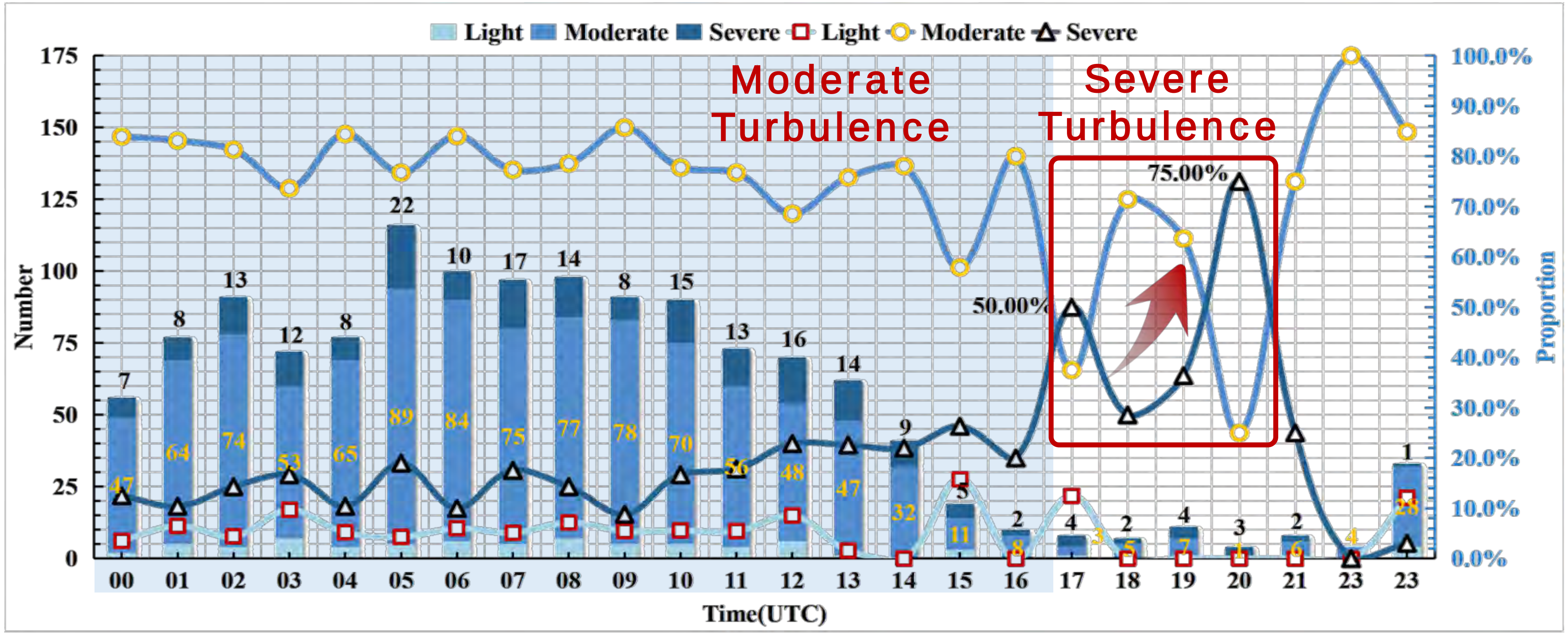


Fig.1.7 Daily variation of aircraft turbulence intensity

- 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

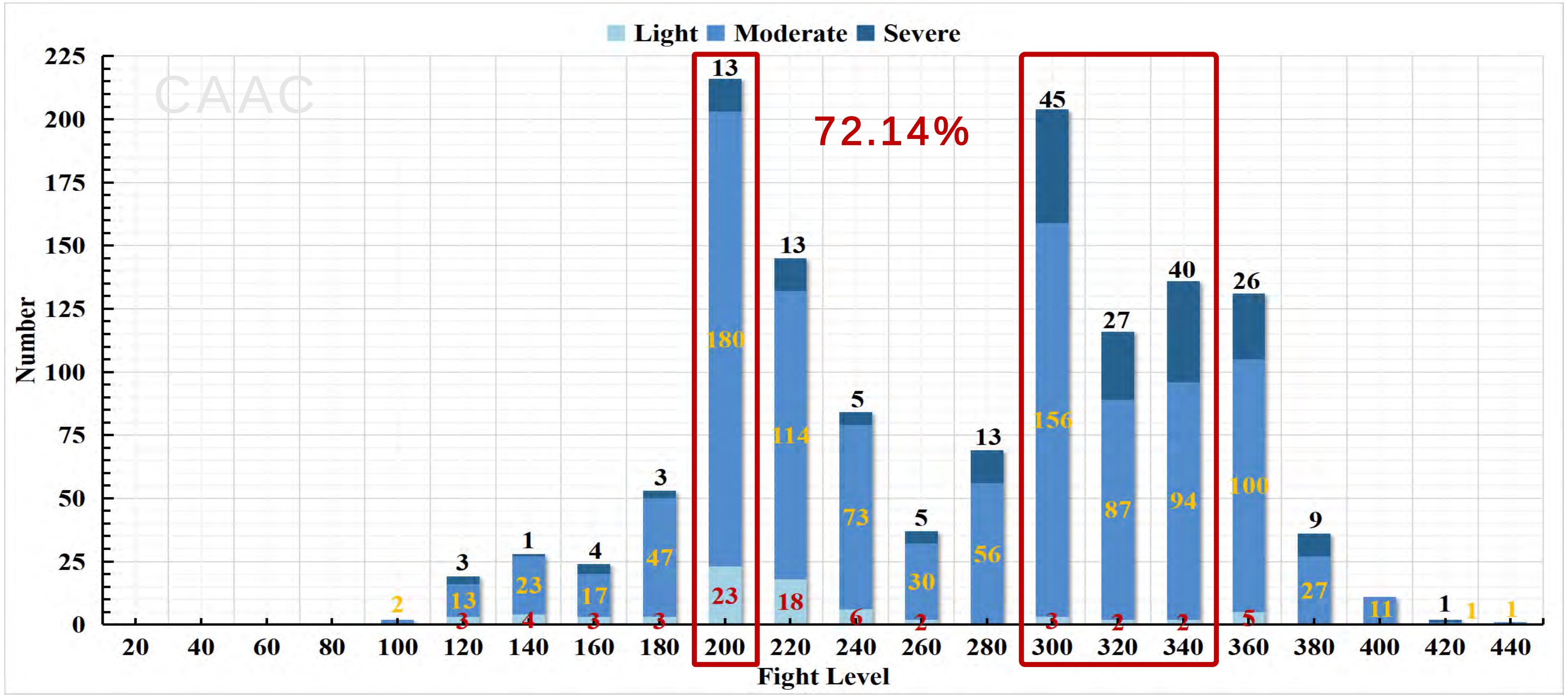


Fig.1.8 Vertical distribution of aircraft turbulence intensity

- 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 occured in the above flight levels accounted for 72.14% of the total.

1.2.2 Horizontal Distribution

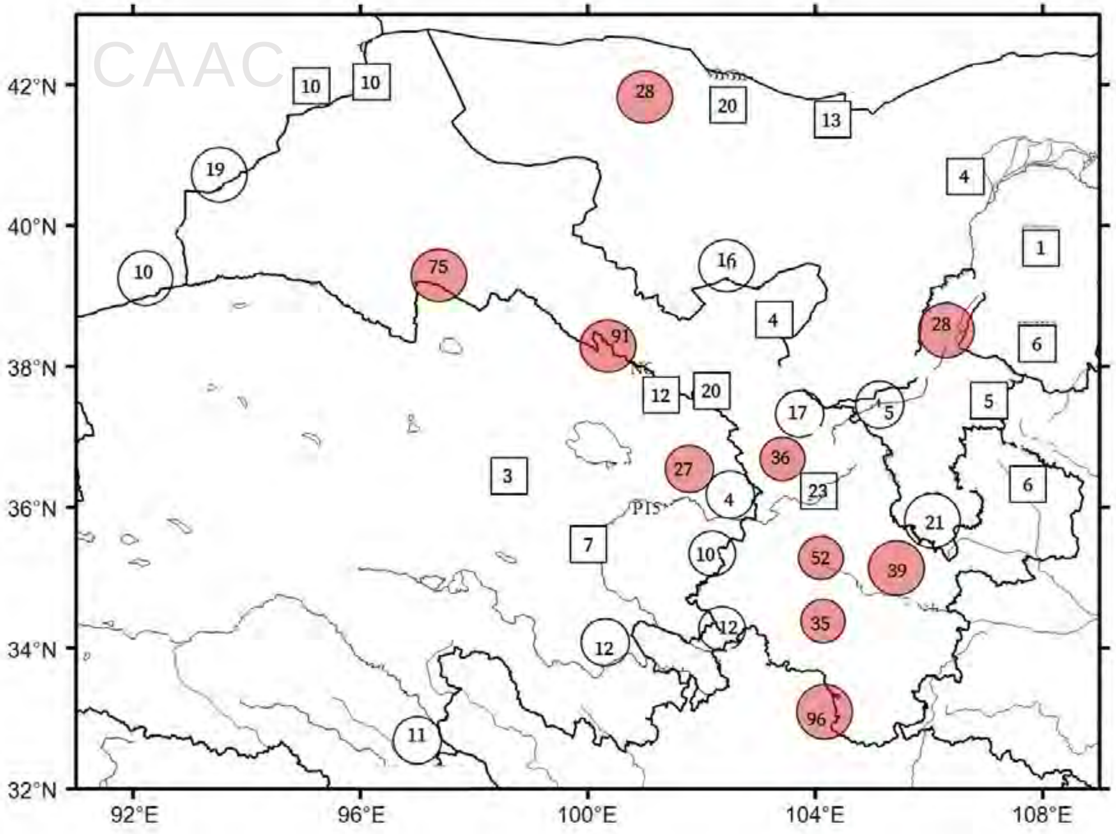


Fig.1.9 Horizontal distribution of high-alttude aircraft turbulence

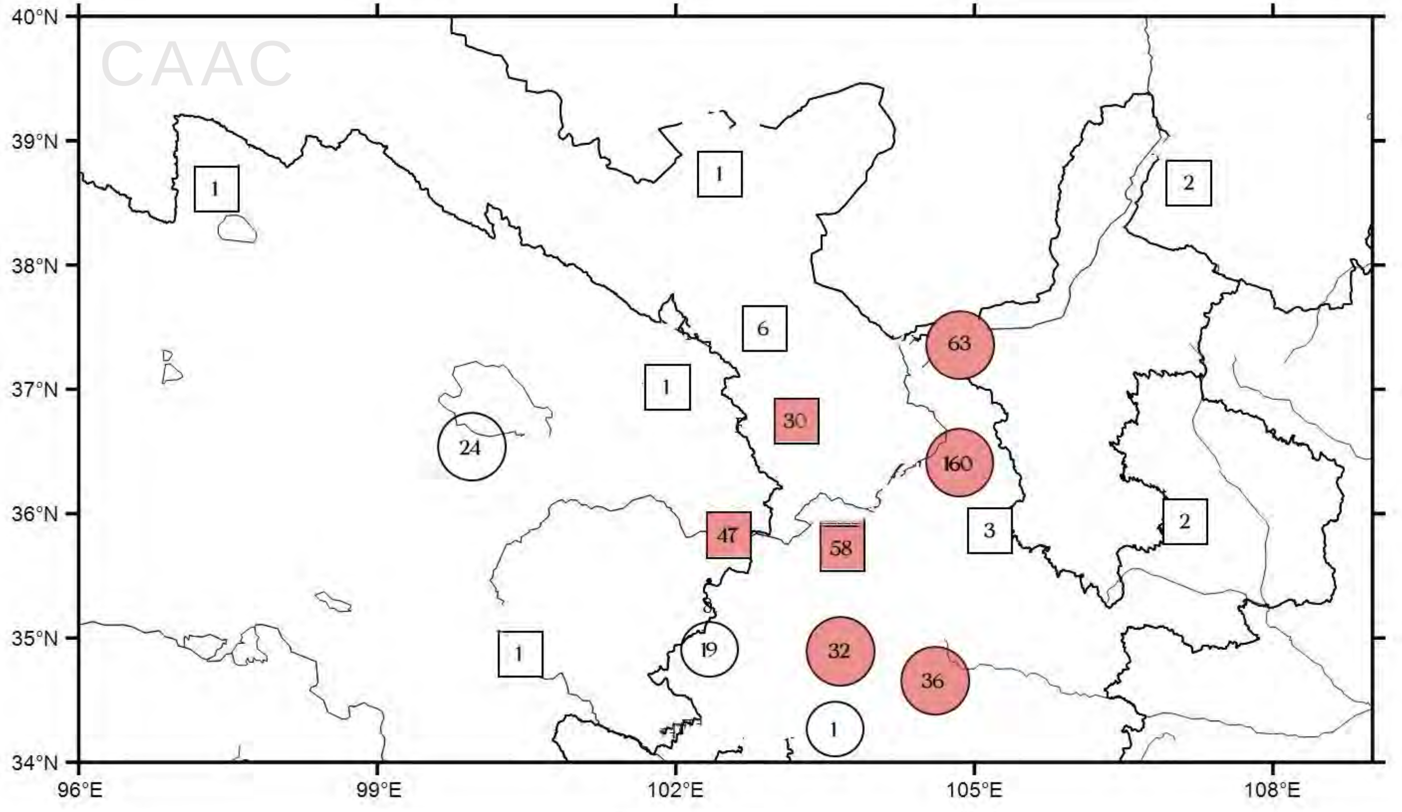


Fig.1.10 Horizontal distribution of low-medium altitude aircraft turbulence

- 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

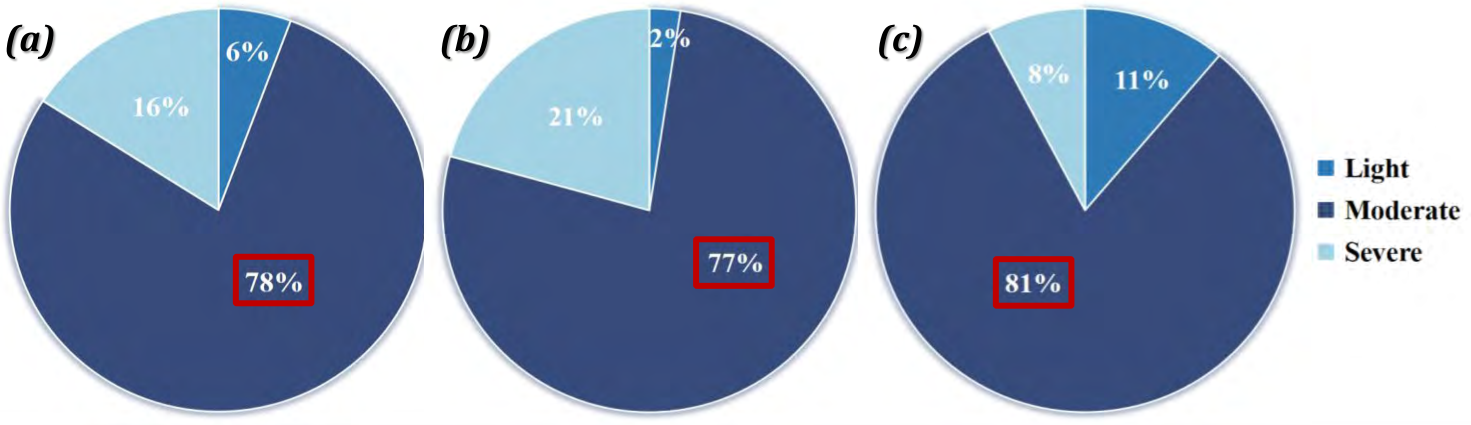


Fig.1.11 Proportion of turbulence intensity
(a) Total; (b) High-altitude; (c) Low level

- **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.

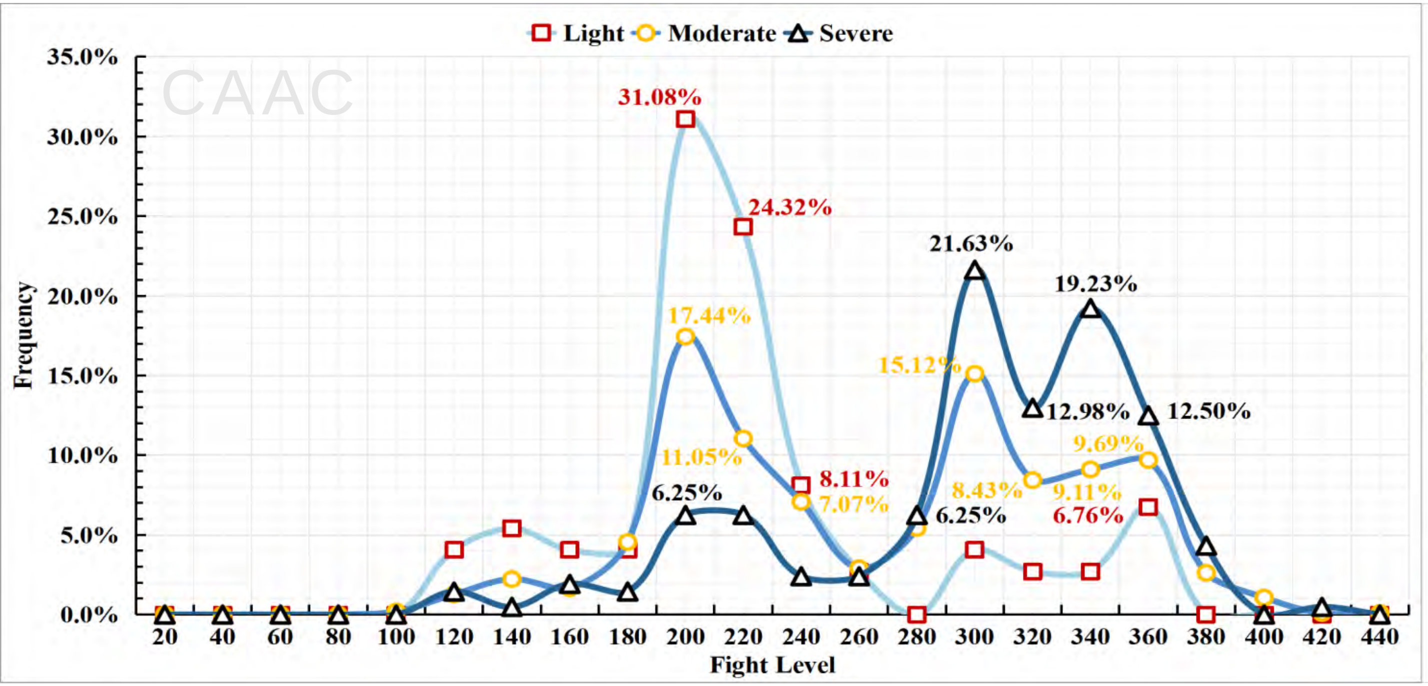


Fig.1.12 Vertical probability distribution of aircraft turbulence intensity

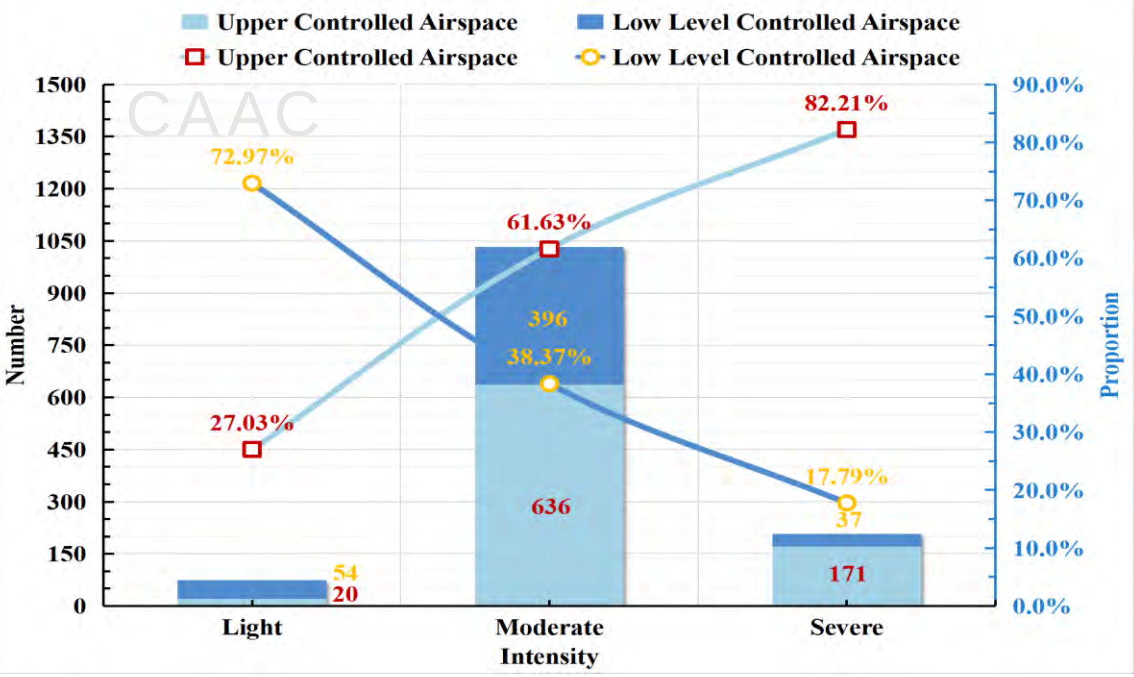


Fig.1.13 Vertical distribution of aircraft turbulence intensity

1.3 Turbulence Intensity

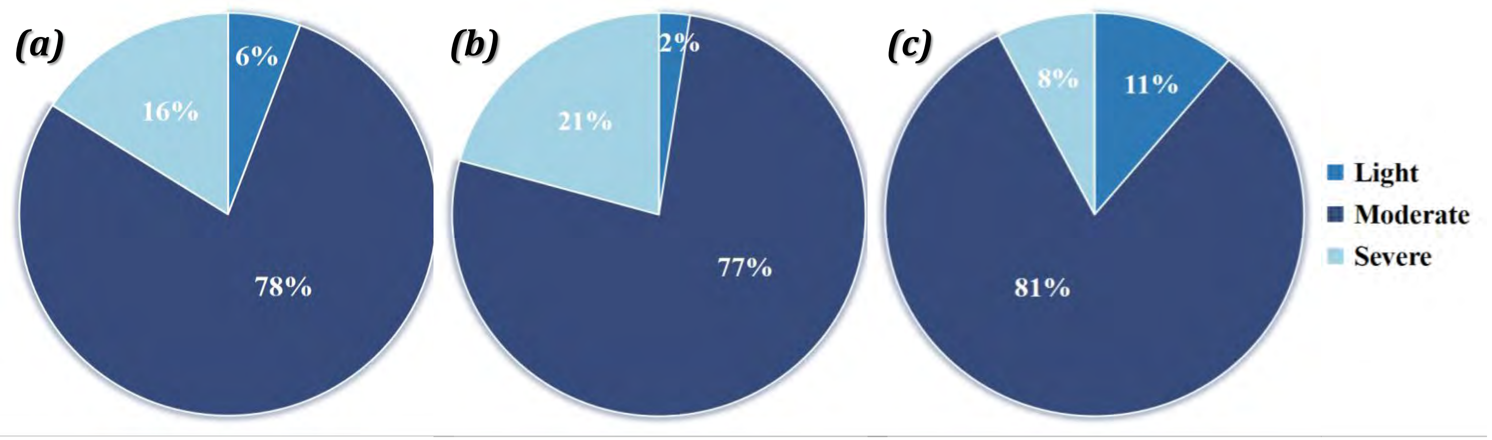


Fig.1.11 Proportion of turbulence intensity
(a) Total; (b) High-altitude; (c) Low level

- **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**.

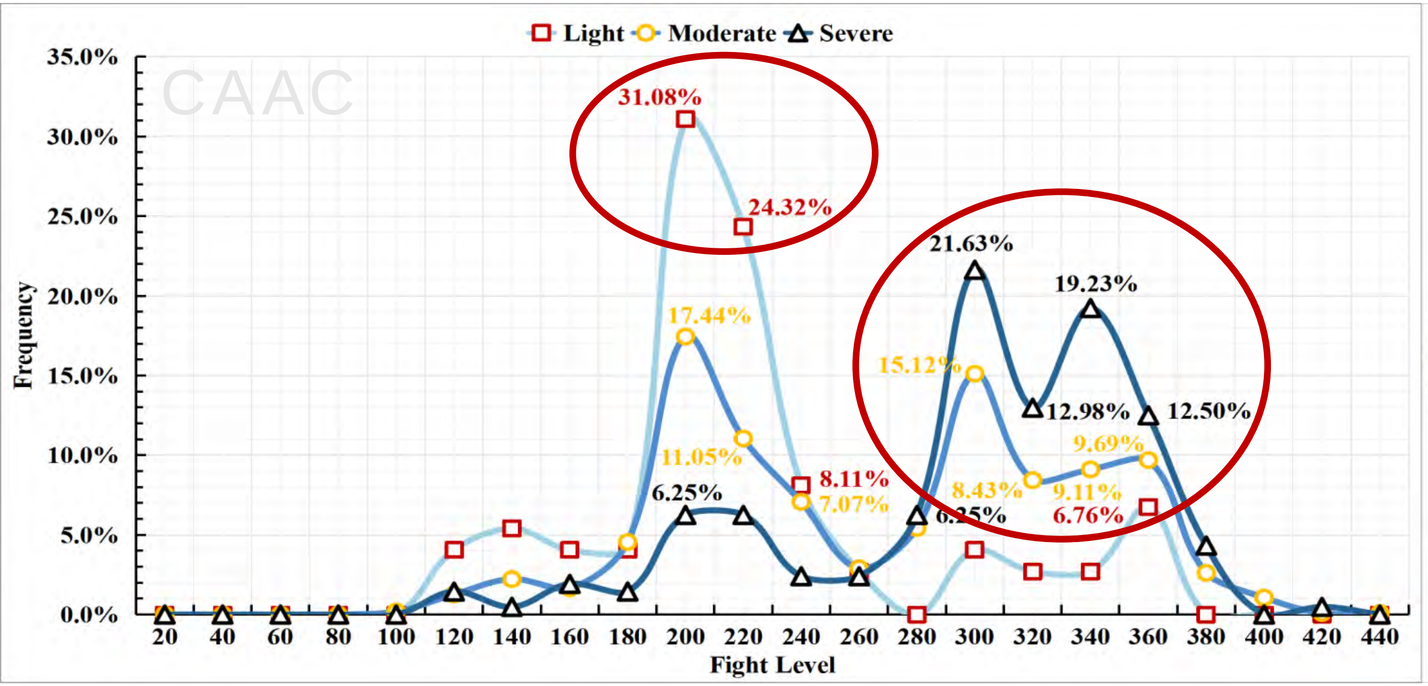


Fig.1.12 Vertical probability distribution of aircraft turbulence intensity

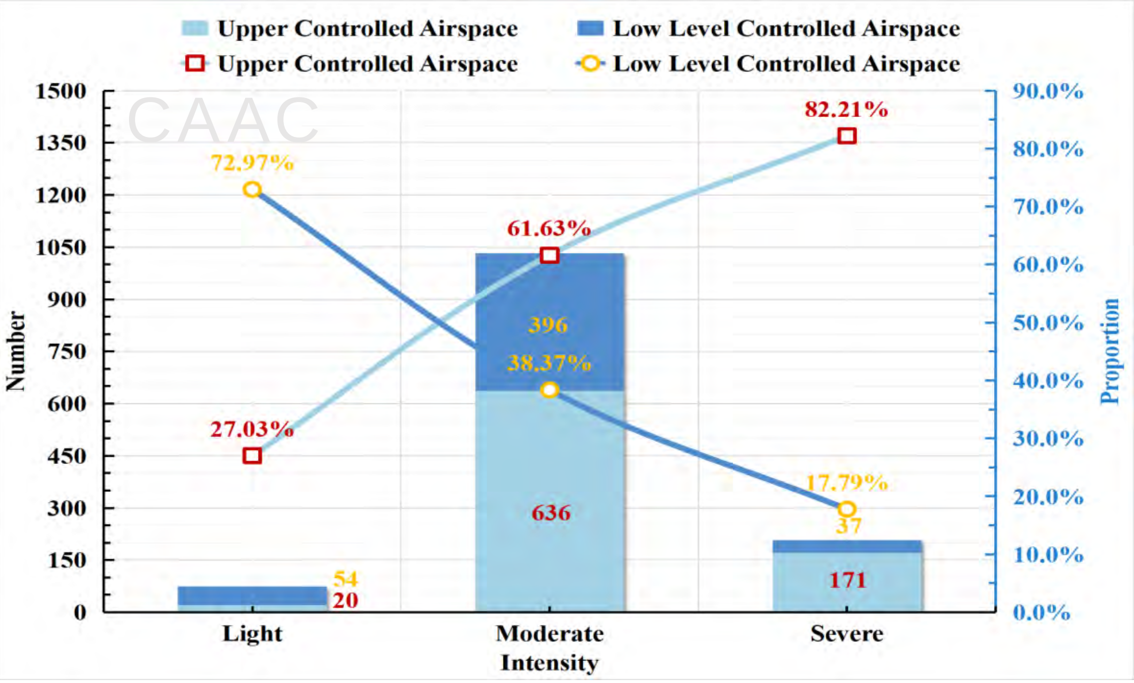


Fig.1.13 Vertical distribution of aircraft turbulence intensity

1.3 Turbulence Intensity

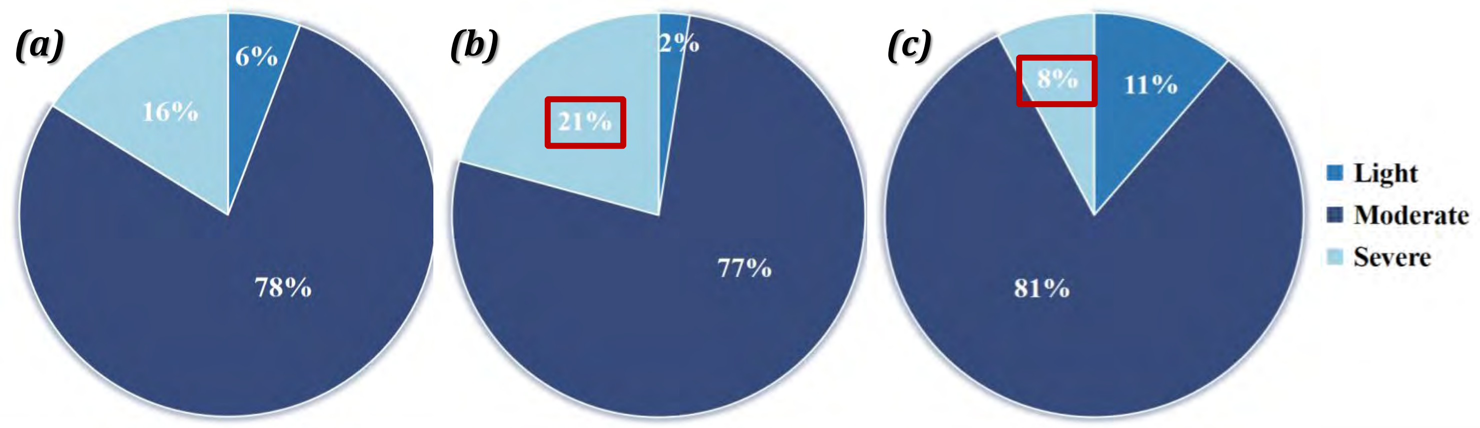


Fig.1.11 Proportion of turbulence intensity
(a) Total; (b) High-altitude; (c) Low level

- **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.

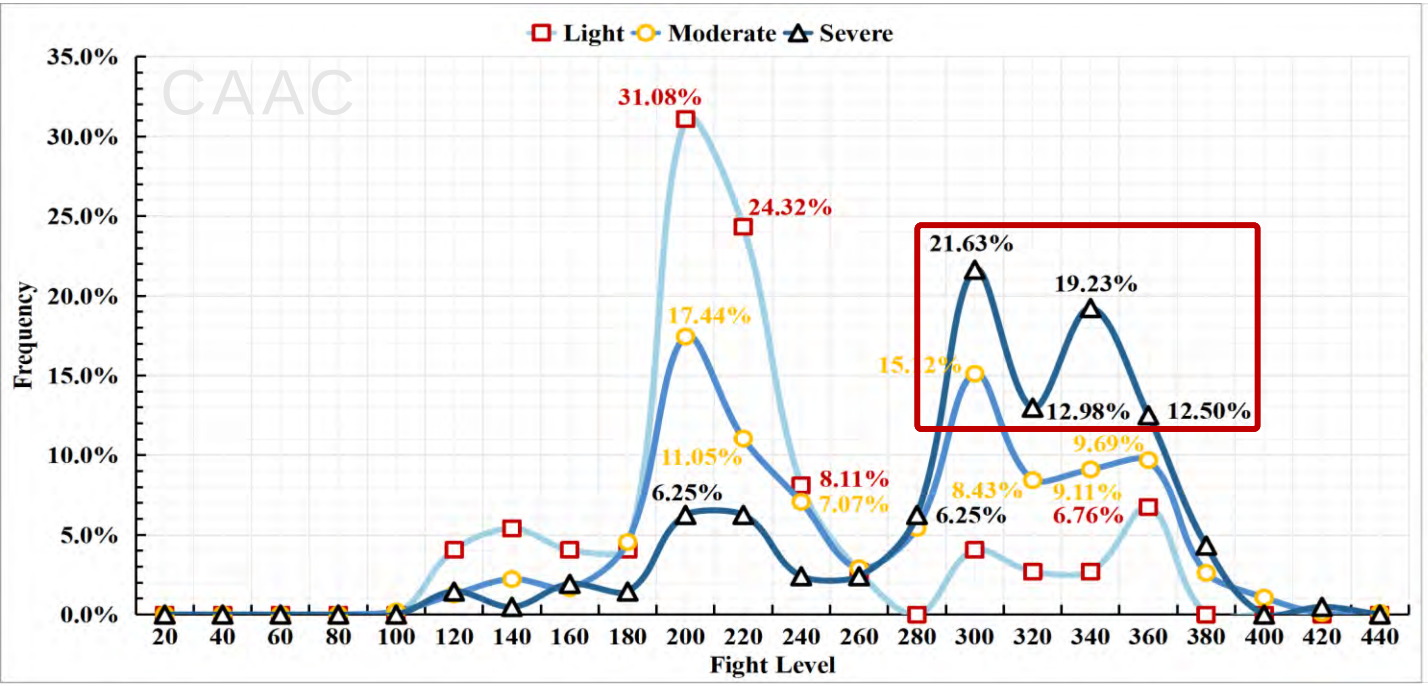


Fig.1.12 Vertical probability distribution of aircraft turbulence intensity

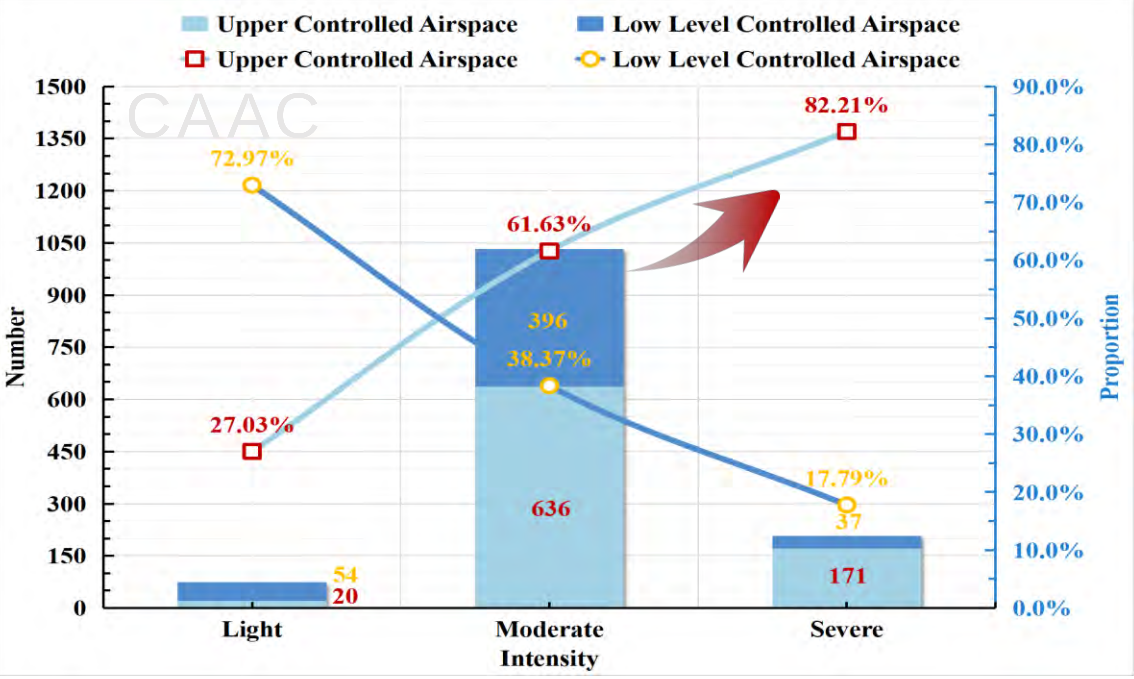


Fig.1.13 Vertical distribution of aircraft turbulence intensity

1.4 Causes of Turbulence

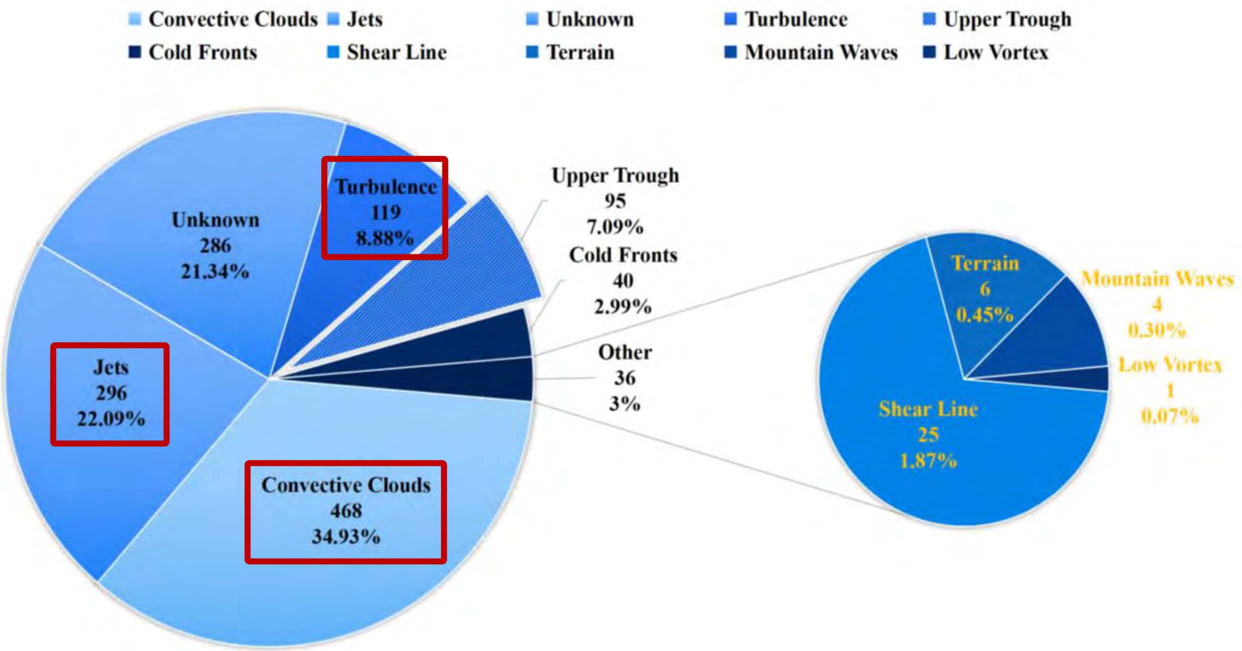


Fig.1.14 Causes of aircraft turbulence

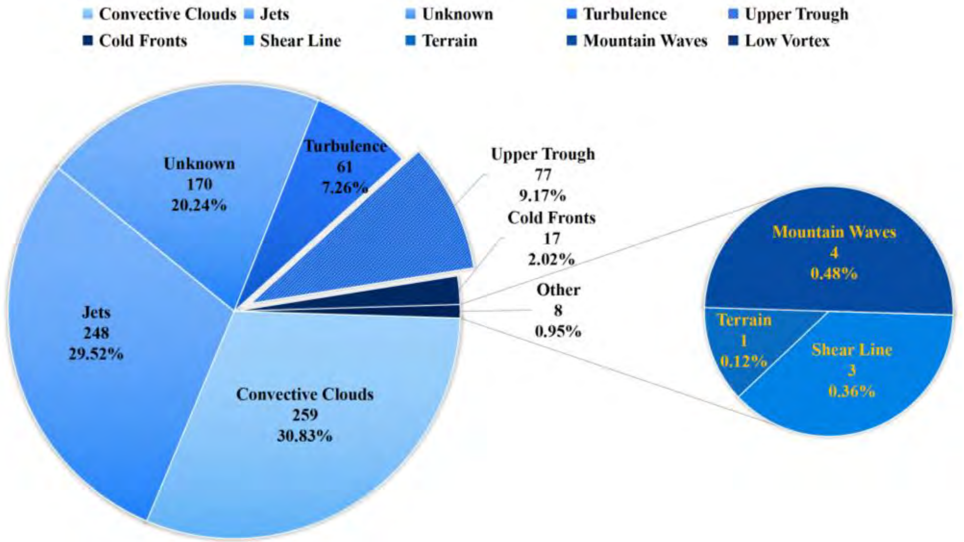


Fig.1.15 Causes of high-altitude aircraft turbulence

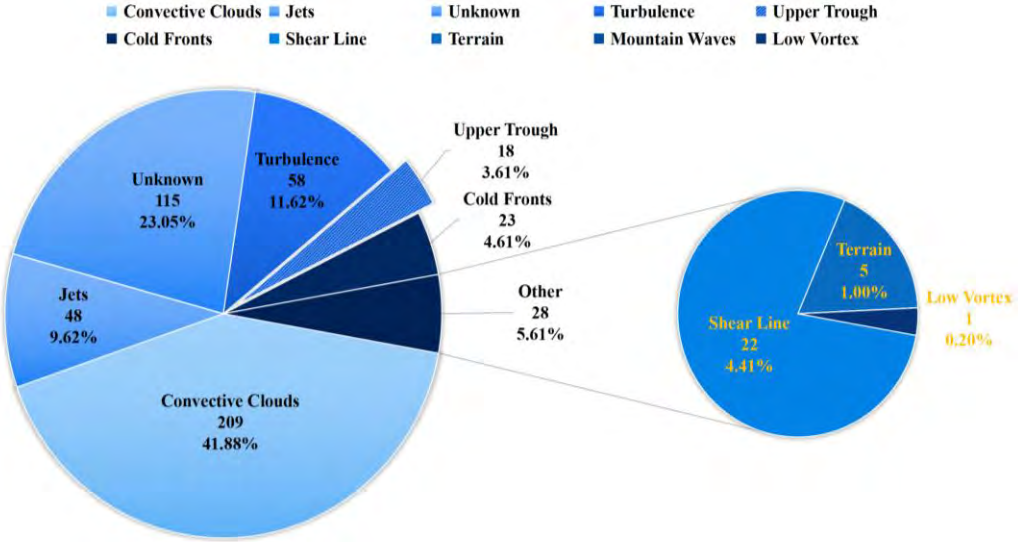


Fig.1.16 Causes of low-level aircraft turbulence

- 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.

1.4 Causes of Turbulence

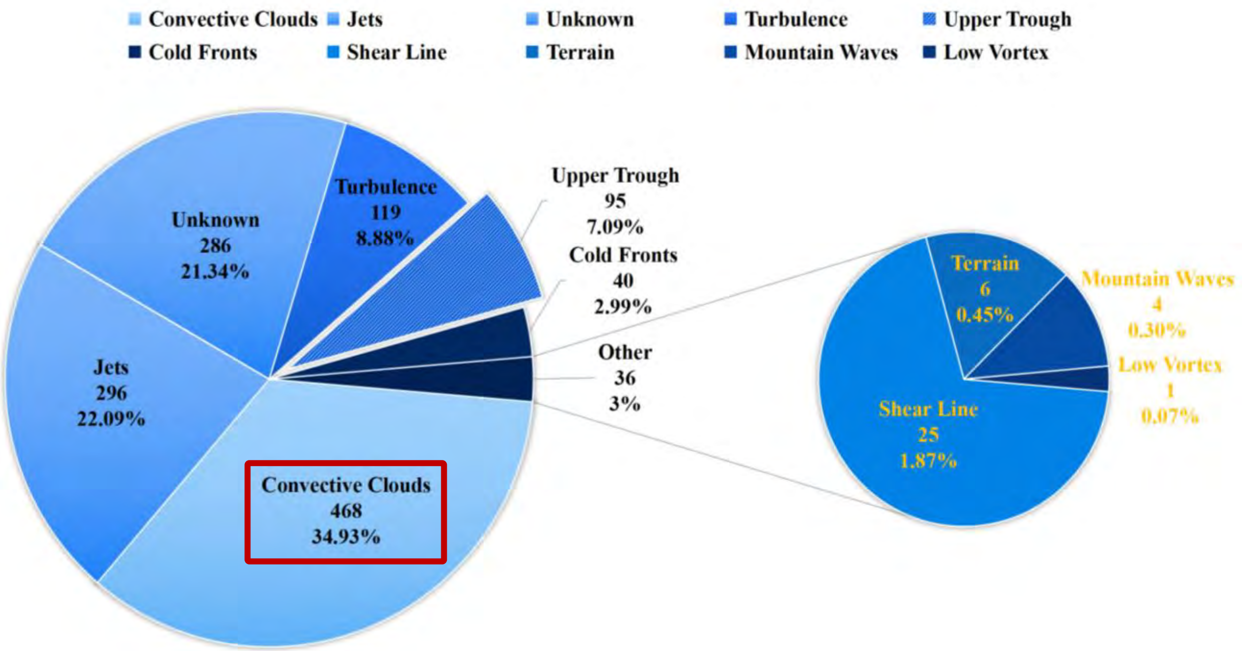


Fig.1.14 Causes of aircraft turbulence

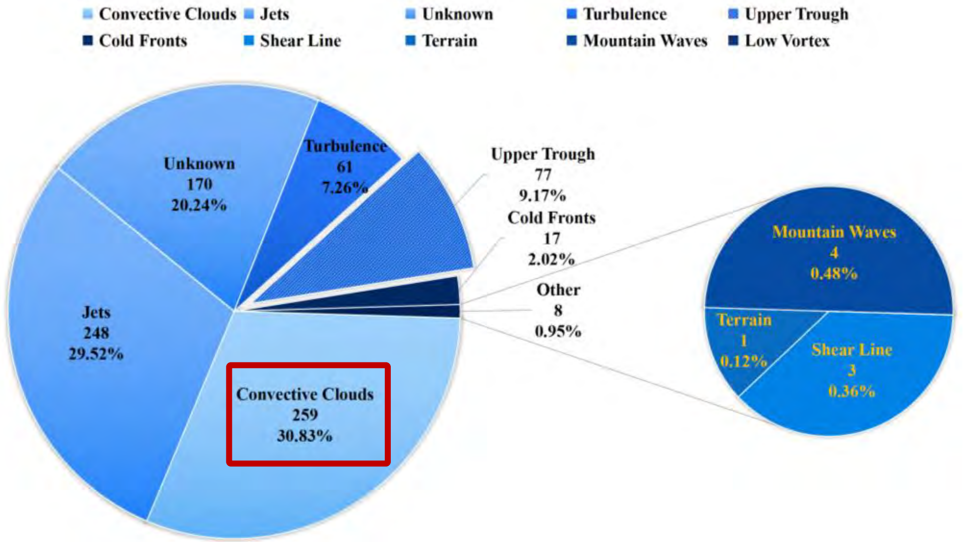


Fig.1.15 Causes of high-altitude aircraft turbulence

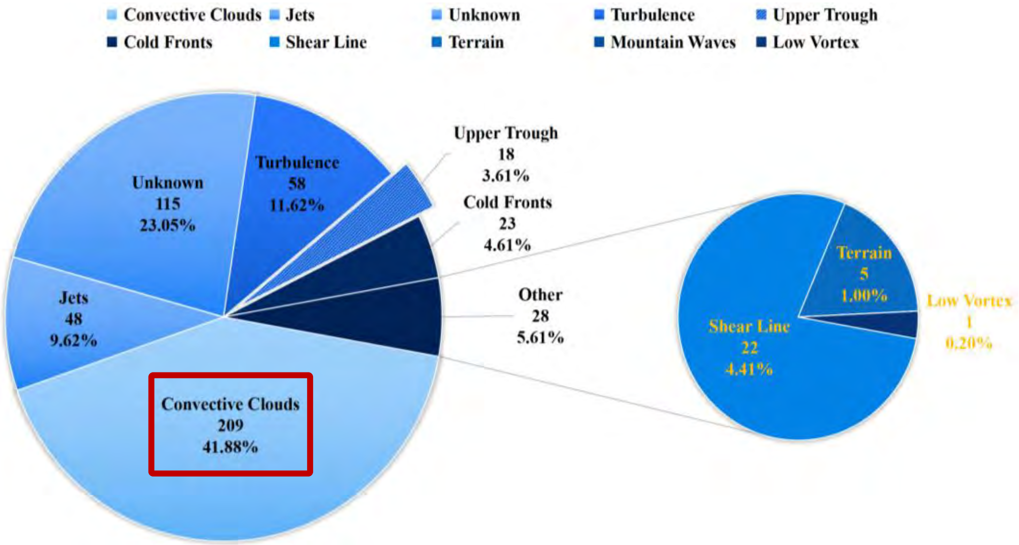


Fig.1.16 Causes of low-level aircraft turbulence

- **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.

1.4 Causes of Turbulence

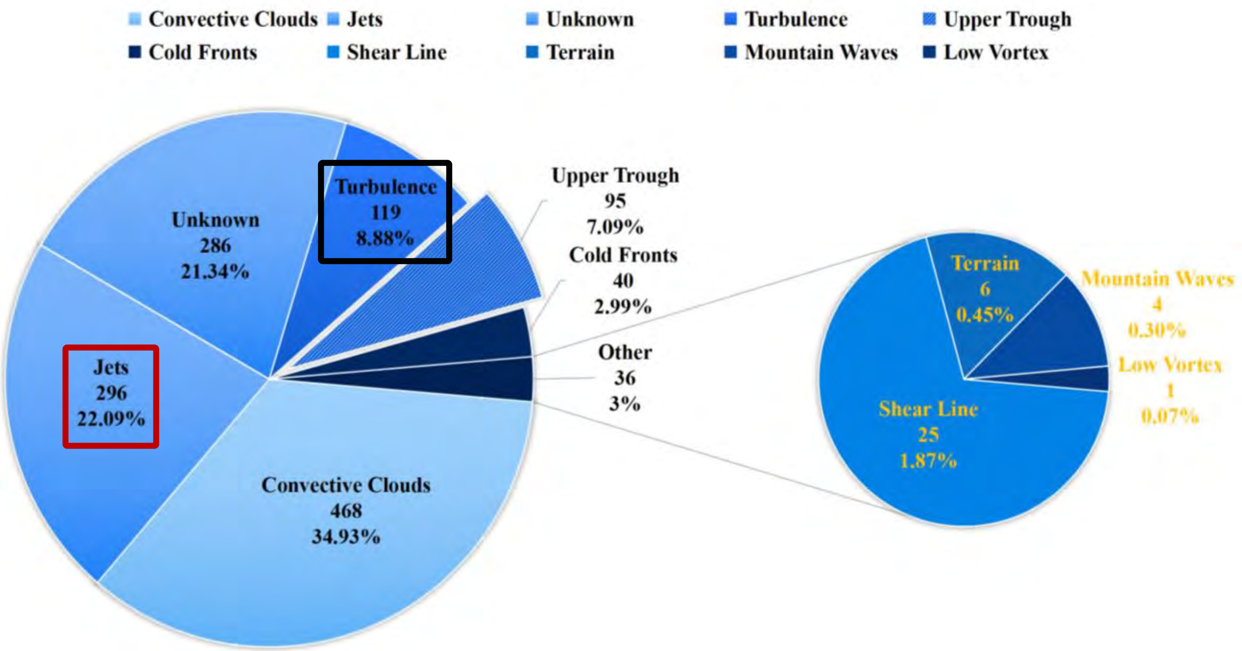


Fig.1.14 Causes of aircraft turbulence

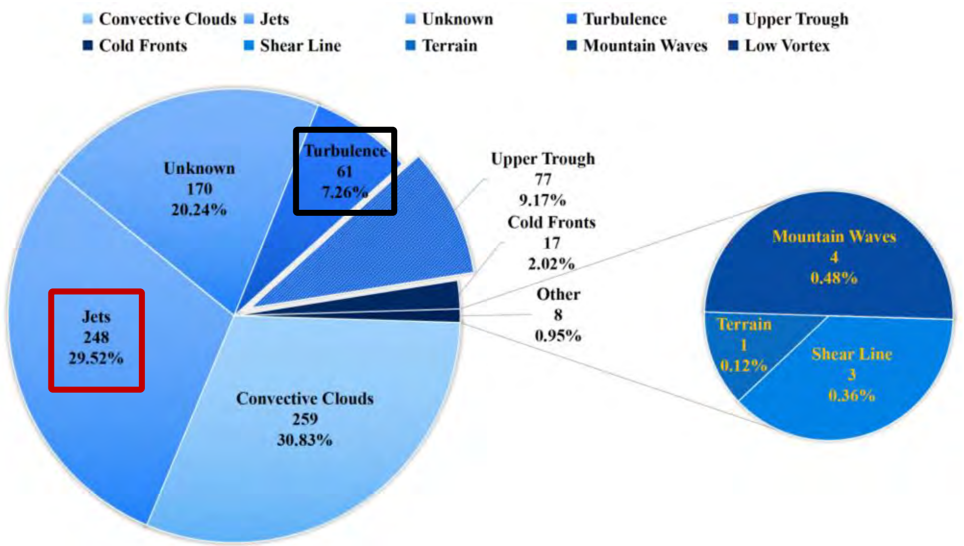


Fig.1.15 Causes of high-altitude aircraft turbulence

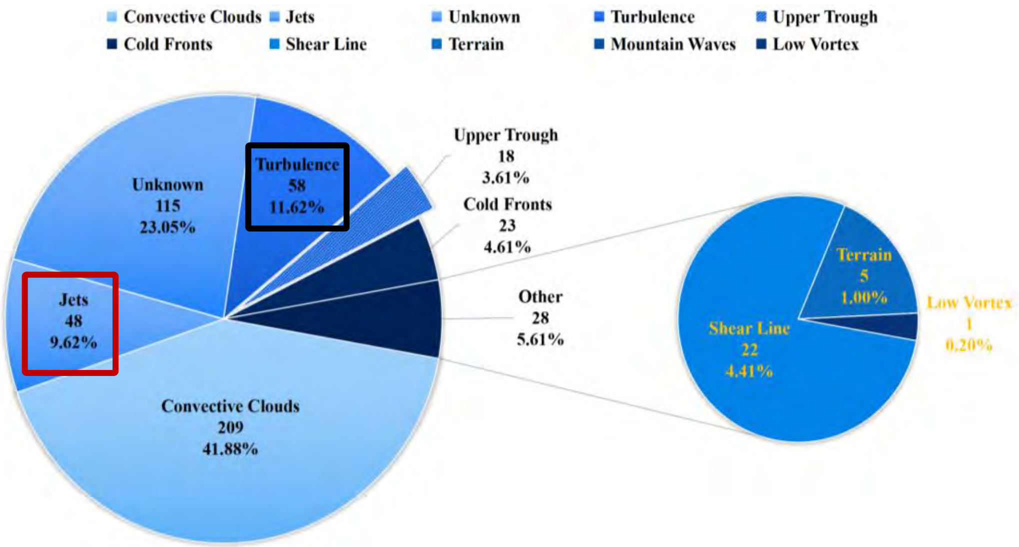


Fig.1.16 Causes of low-level aircraft turbulence

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

1.4 Causes of Turbulence

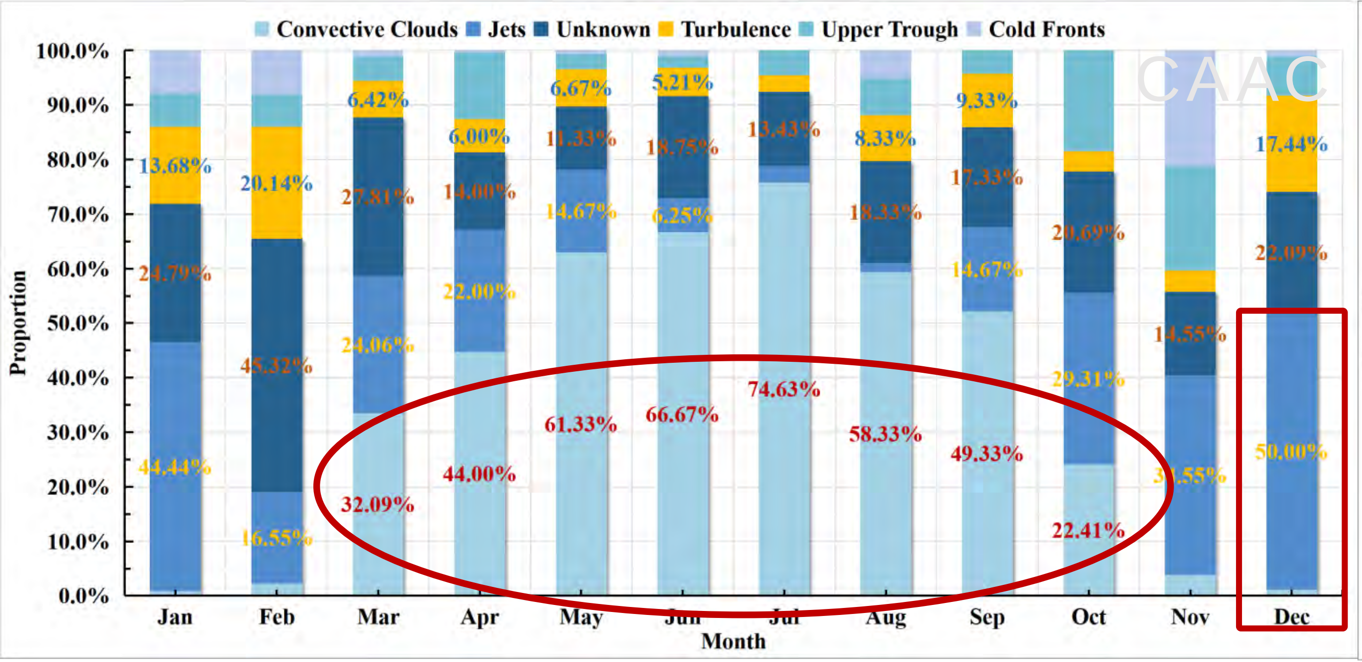


Fig.1.17 Monthly variation of different aircraft turbulence causes

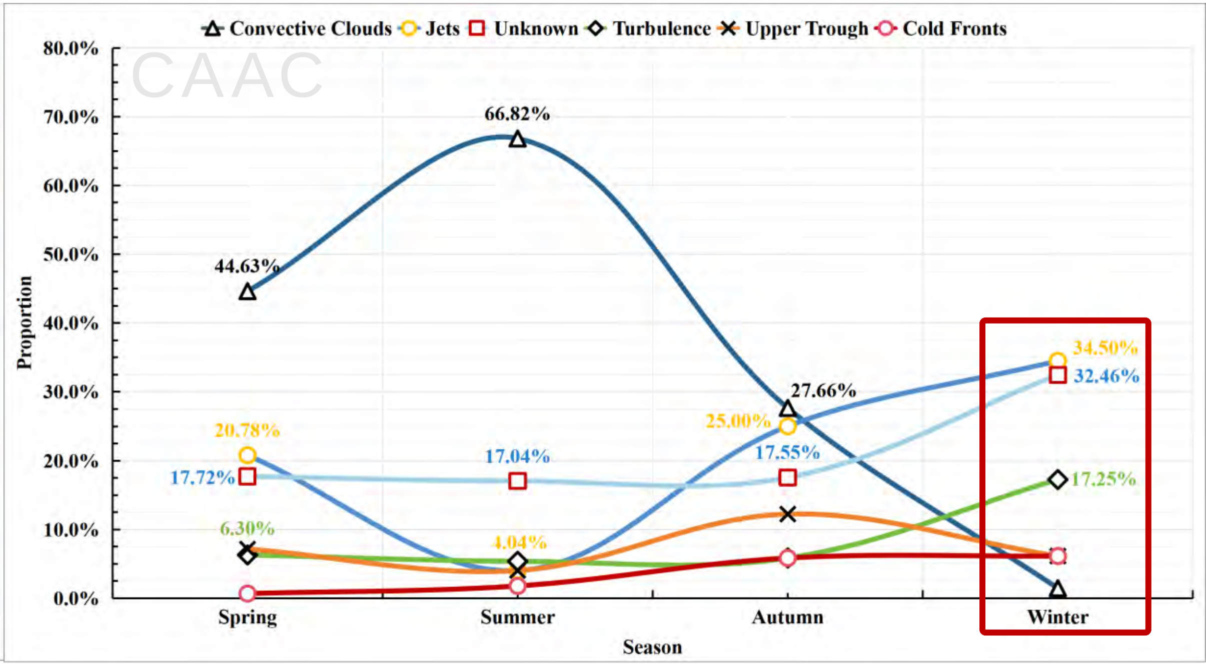


Fig.1.18 Seasonal variation of different aircraft turbulence causes

- **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

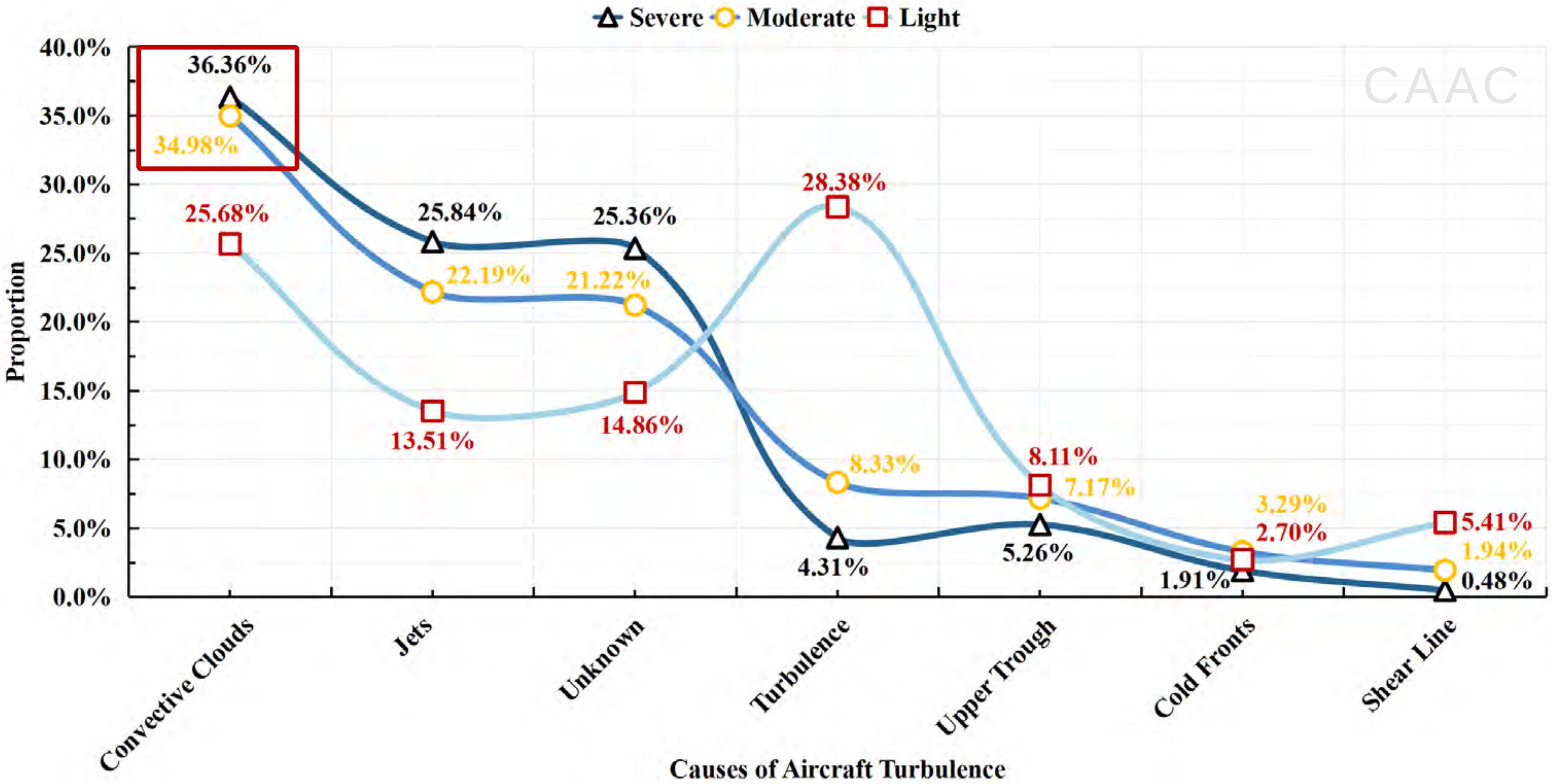
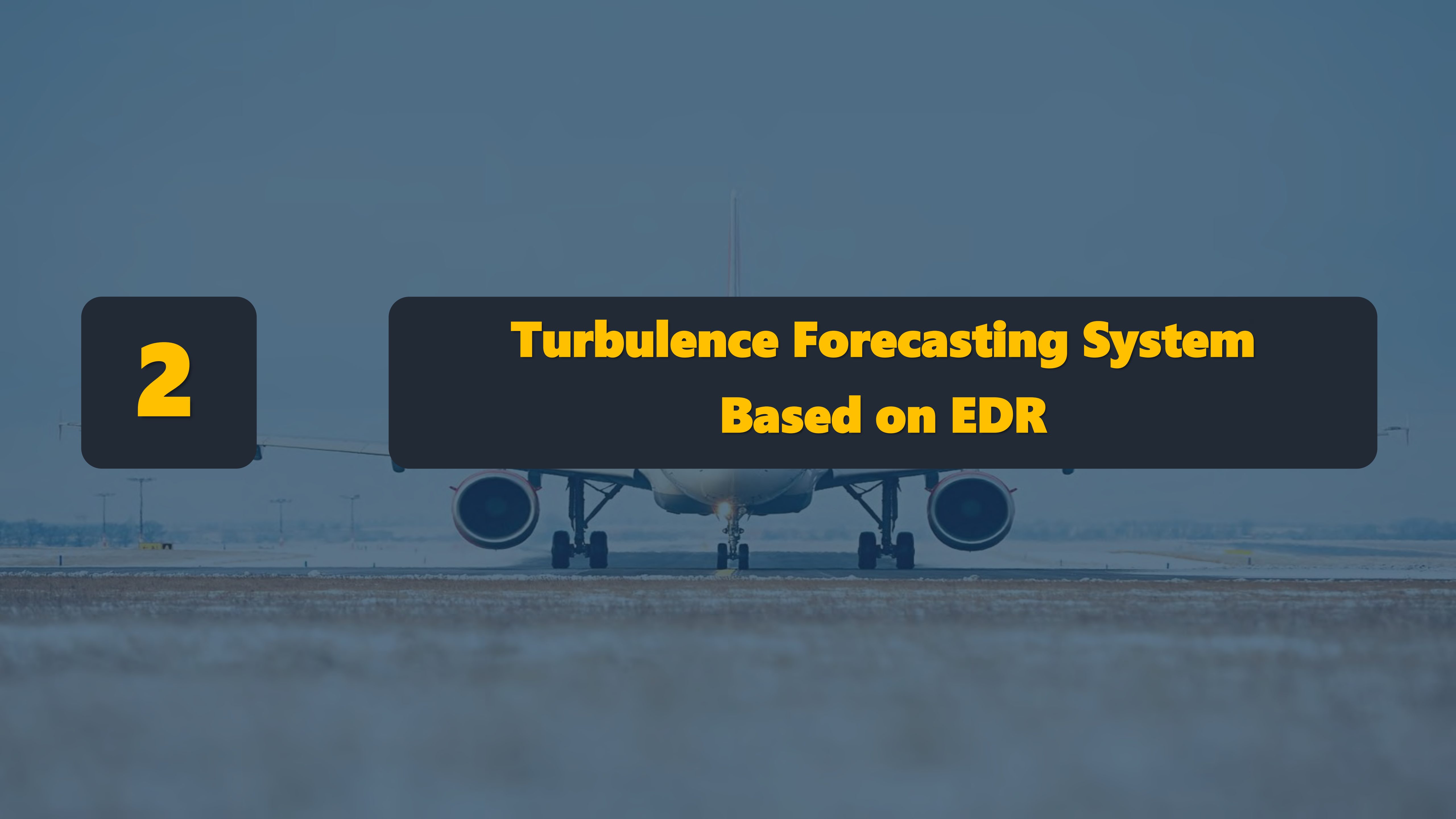


Fig.1.19 The distribution of aircraft turbulence intensity ratio caused by different reasons

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

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 EDR ≥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

2015 — Installed Algorithm

With the help of NCAR and Delta, in situ EDR algorithm was installed on 55 aircraft (B737) from Xiamen Airlines.

2016 — Decoded and Displayed

In situ EDR observation data was decoded and displayed on the map, with reminding in the flight plan.

2017 — Expanded Fleet Size

The number of aircraft (B737) installed in situ EDR algorithm increased to 120.

2019 — Developed Algorithm

Developed EDR forcast algorithm with China Meteorological Administration (CMA).

2020 — Business Operation

The EDR forecast algorithm and products based on CMA-Meso were put into business operation.

2025 — Continuous Verification

Verified the accurancy of the EDR forecast algorithm and products by comparing with in situ EDR observation, PIREPs and AMDAR.

2.3 Weather Risk Control System (WRC)

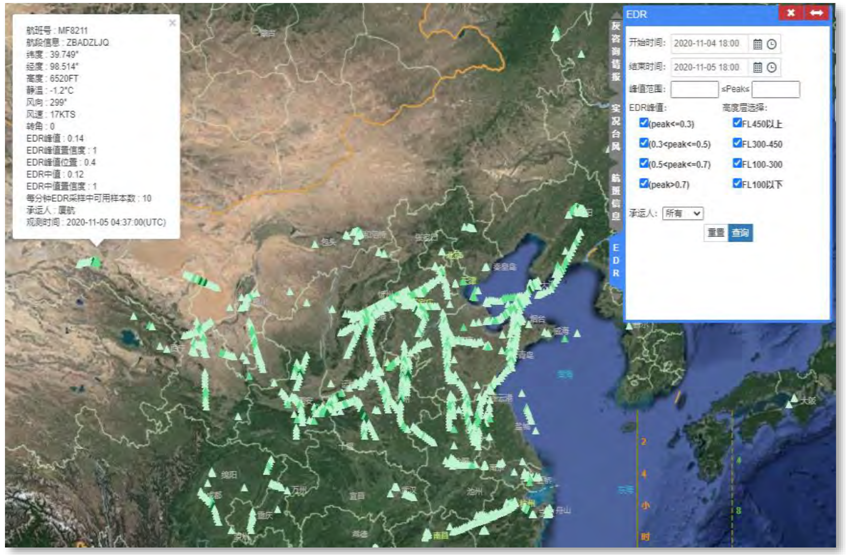


Fig.2.1 In situ EDR observation data

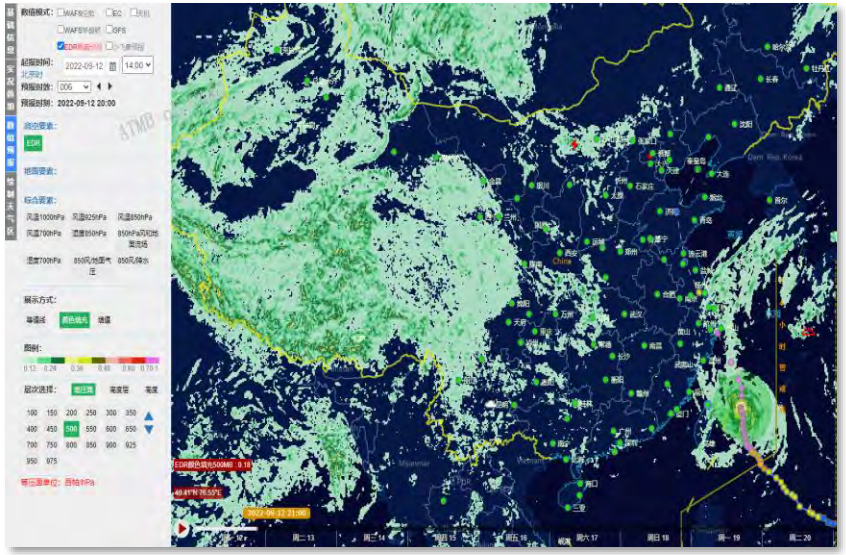


Fig.2.2 Grid EDR forecast product

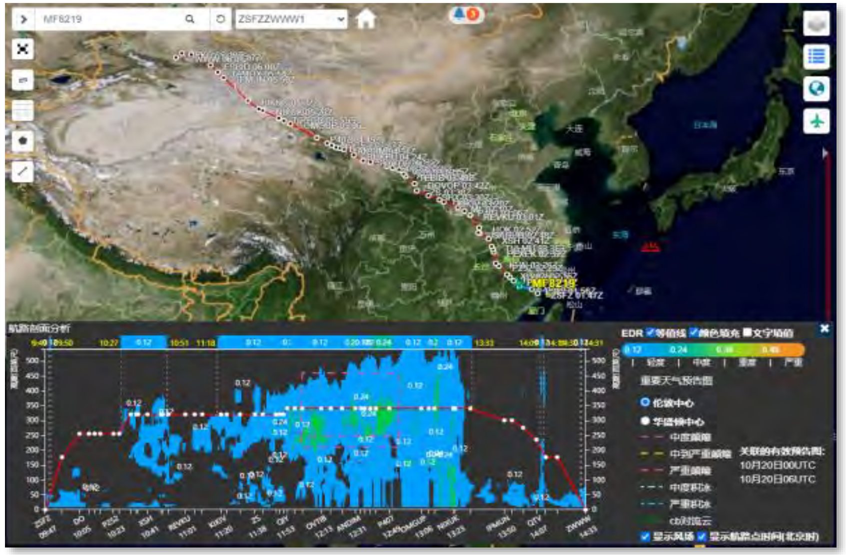


Fig.2.3 Vertical profile of EDR forecast in route

- 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-hoursly 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

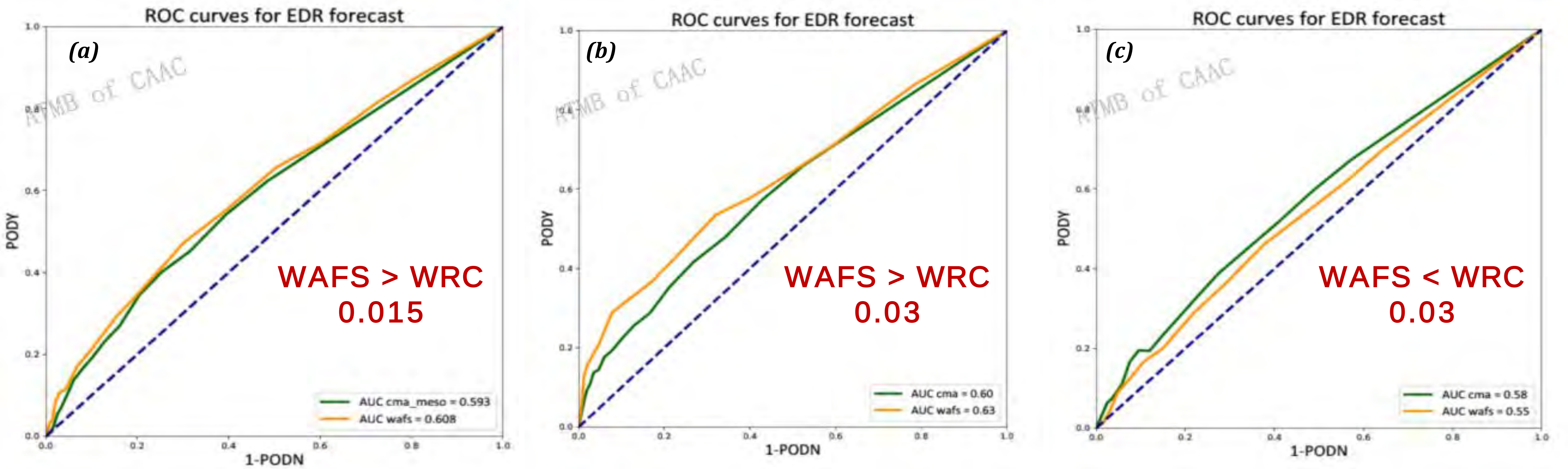


Fig.2.4 ROC curves for EDR forecast between WAFS and WRC from February to April in 2024
(a) February; (b) March; (c) April

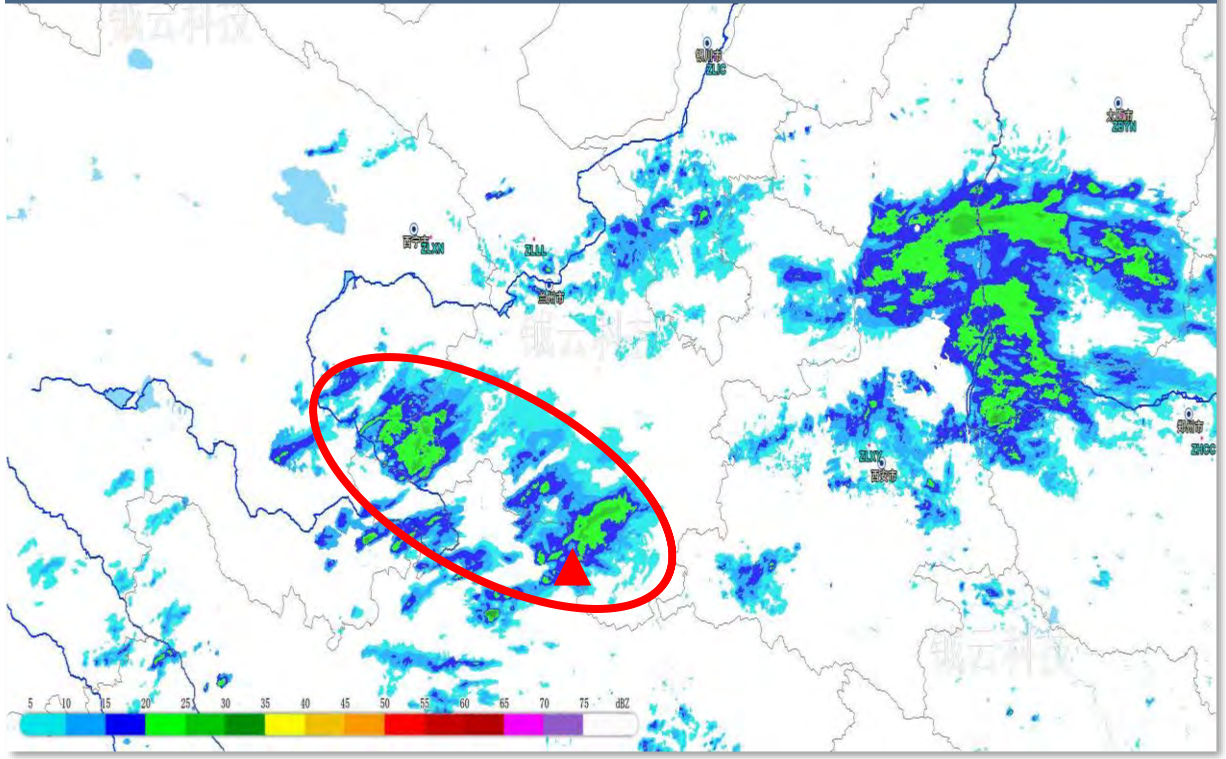
- The EDR forecast performance of WRC and WAFS were similar.
- Due to the higher temporal and spatial resolution of WRC, it could provide finer decision support to aviation forecasters, ATC, pilots and airlines.

2.5 Case Study - CIT

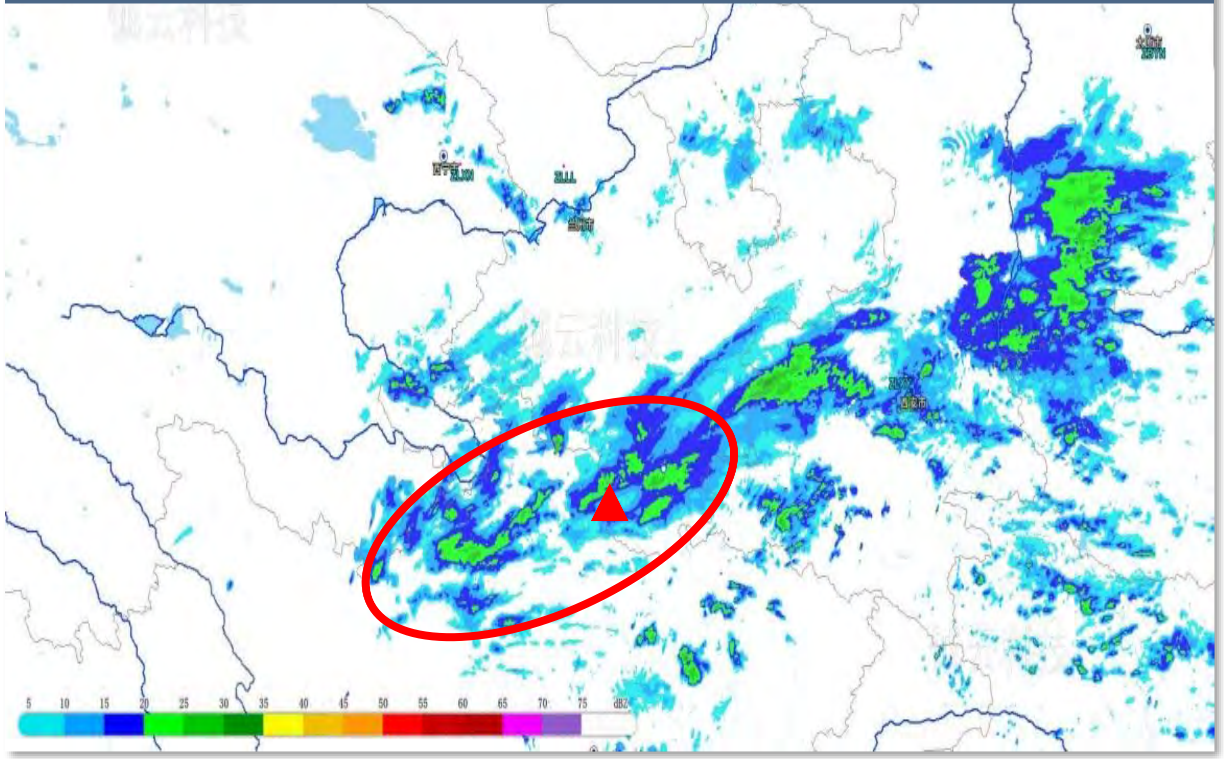
17 March 2024, 08-13 UTC, 7200-11000 Meters above Sea Level

Moderate - Severe Turbulence

10:10 (UTC) Radar Reflectivity



12:50 (UTC) Radar Reflectivity



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

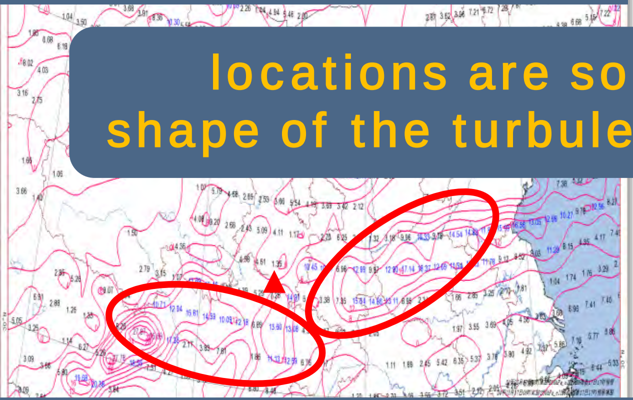
2.5 Case Study - CIT

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

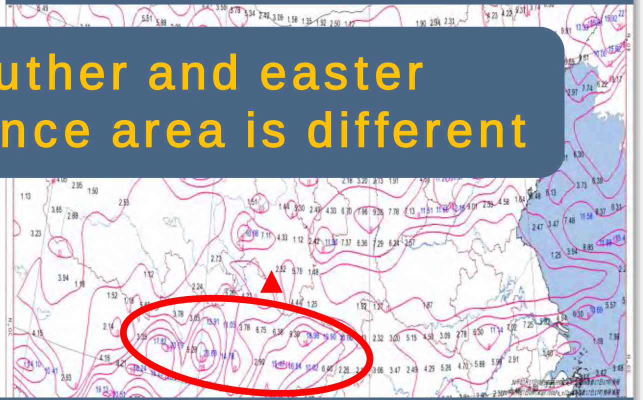
Moderate - Severe Turbulence

NCEP Ellord Forecast

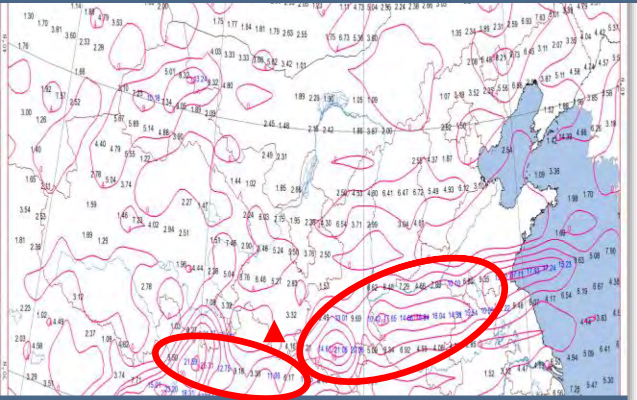
09 UTC, 250hPa



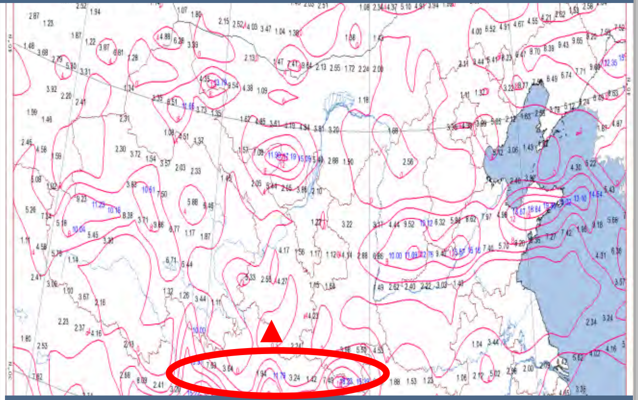
09 UTC, 300hPa



12 UTC, 250hPa

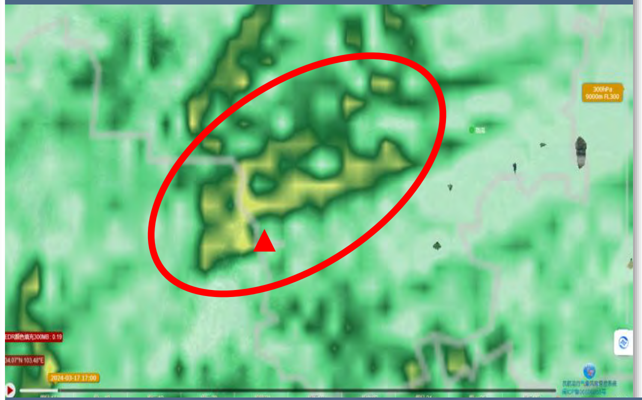


12 UTC, 300hPa



WRC EDR Forecast

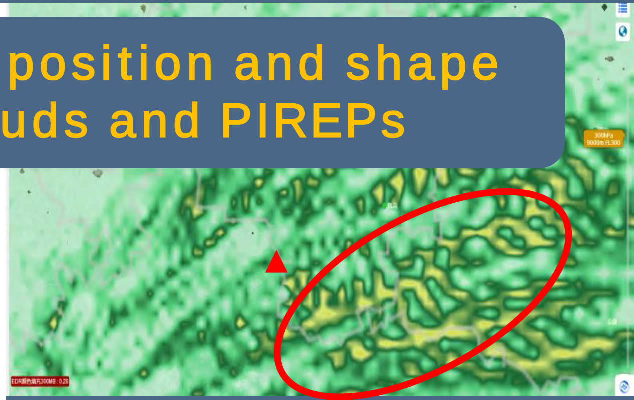
09 UTC, 9000 m



10 UTC, 10000 m

10 UTC, 7000 m

13 UTC, 10000 m



Thanks for listening!

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