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HONG KONG OBSERVATORY

EN-ROUTE TURBULENCE DETECTION USING ADS-B DATA AND SPECIAL AIR REPORTS

2025 MET-ATM Seminar

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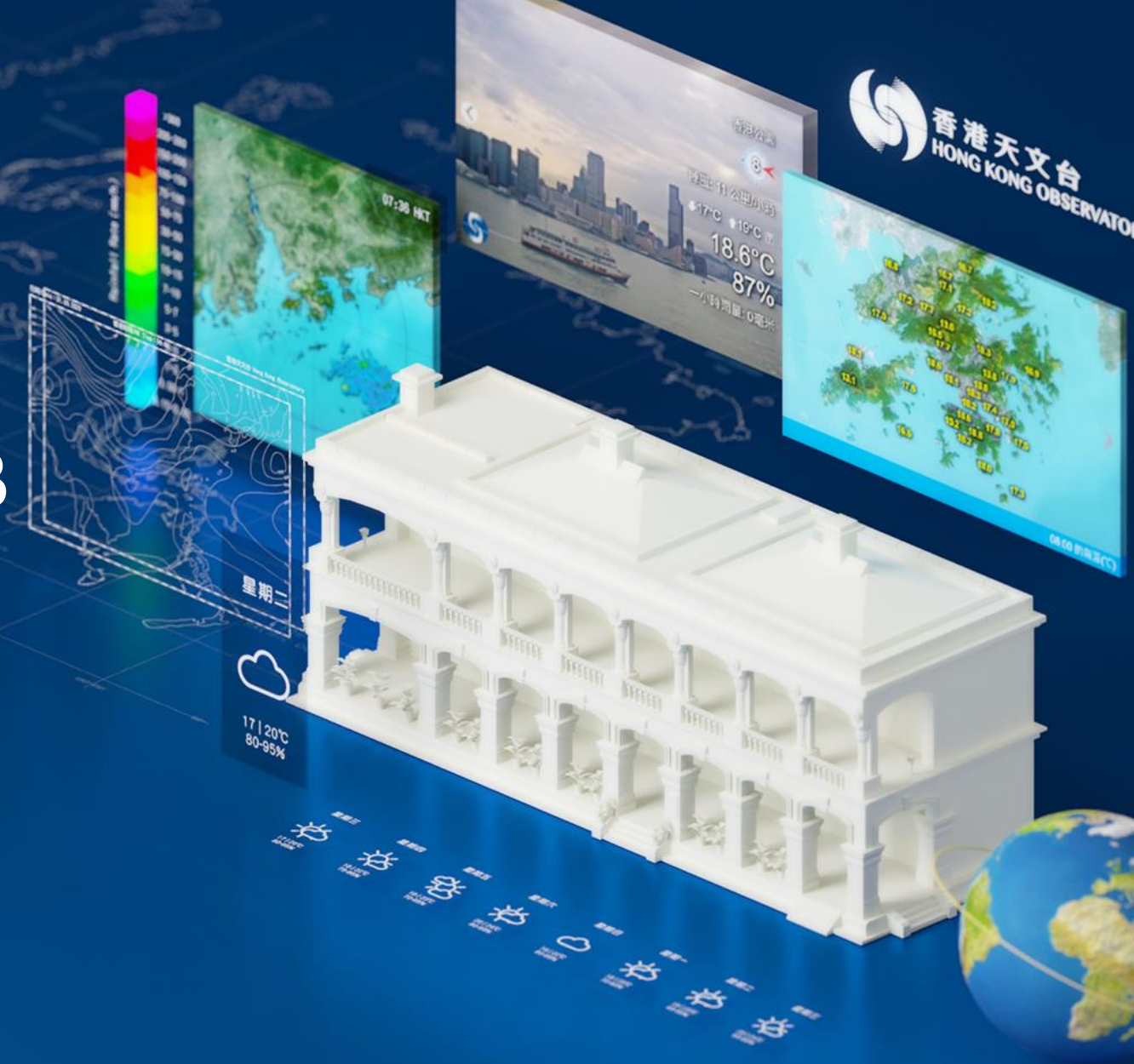
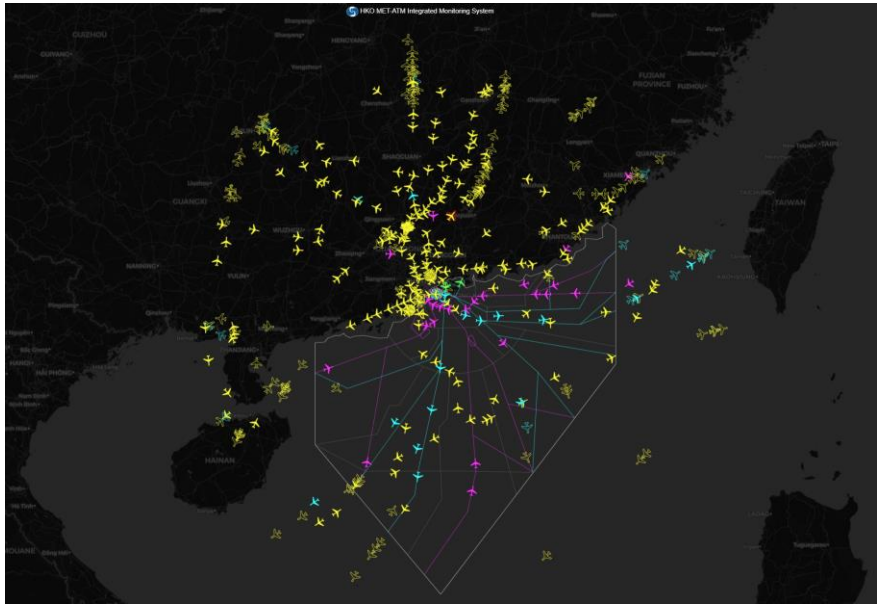


BACKGROUND

- The Hong Kong Observatory (HKO) installed an Automatic Dependent Surveillance–Broadcast (ADS-B) receiver at Tai Mo Shan Weather Radar Station since June 2016
- can receive aircraft information within an approximate range of 600 km

Data Item	Index in CAT021
Target Identification (callsign)	I180
Latitude, Longitude	I130
Flight Level	I140
Airborne Ground Vector (ground speed + track angle)	I160
Barometric Vertical Rate	I155
Geometric Vertical Rate	I157
Emitter Category (Aircraft type)	I020



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MOTIVATION

DETECTING TURBULENCE FROM ADS-B DATA

Vertical Acceleration (VA)

$$a = \frac{\bar{t}\bar{v} - \bar{t}\bar{v}}{(\bar{t})^2 - \bar{t^2}}$$

a : acceleration (ms^{-2})
v: vertical rate (ms^{-1})
t: timestamps (s)

- VA represents aircraft response to turbulence
- Calculate VA by differentiating vertical rate

Root-mean-square Vertical Acceleration ($\sigma_g/RMSVA$)

RMSVA (g)	Turbulence intensity
[0.1, 0.2)	LGT
[0.2,0.3)	MOD
[0.3,0.6)	SEV
[0.6,∞)	EXT

- RMSVA correlates to EDR (Sharman, 2016)
- Bowles (2009) categorizes RMSVA based on turbulence intensity

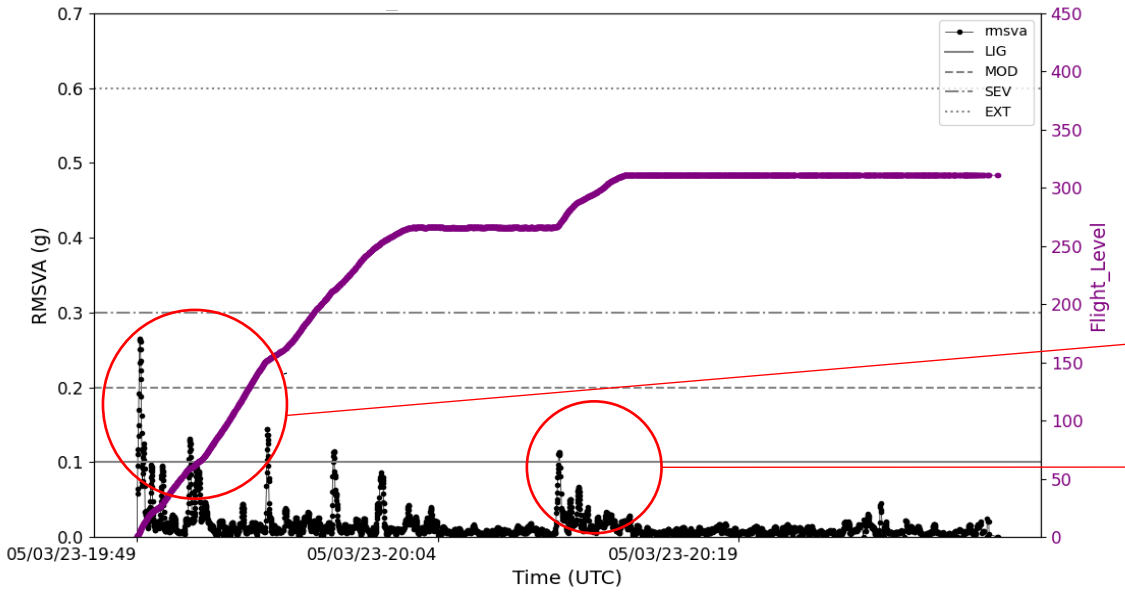
Reference:
Sharman, R. and Lane, T. (2016) Aviation turbulence. Springer International Publishing, Switzerland, DOI, 10, 978–3.
Bowles, R. L. and Buck, B. K. (2009) A methodology for determining statistical performance compliance for airborne doppler radar with forward-looking turbulence detection capability. Tech. rep.

MOTIVATION

- RMSVA increases in non-cruising phase, creating false alarms
- The study only focuses on the **cruising phase of the aircraft**

Remark

1. RMSVA (**black** line-plot)
2. Flight level (in **purple**)

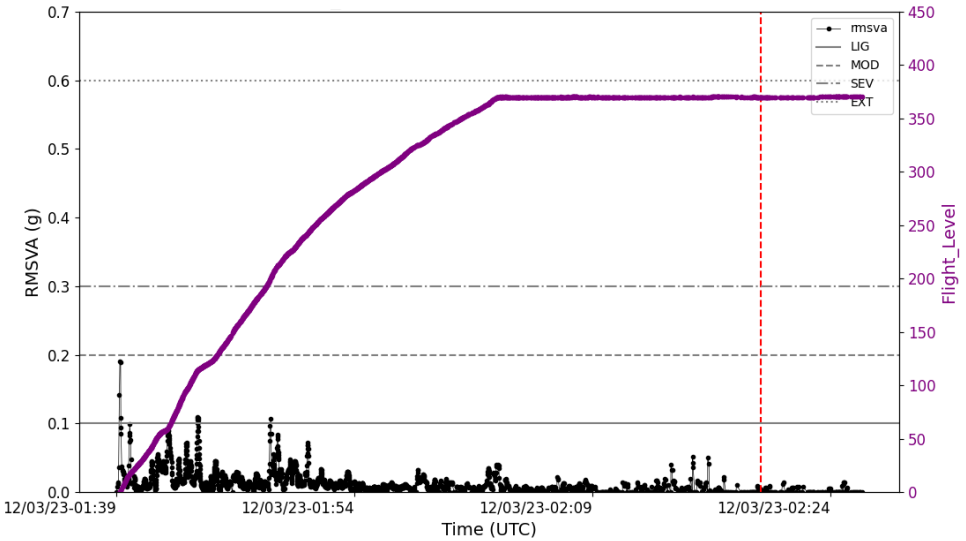


RMSVA > 0.2 when taking-off

RMSVA > 0.1 when climbing

IDENTIFYING CRUISING PHASE OF FLIGHT

1	2	3
Need to identify cruising phase automatically	Cruising is characterized by high ground speed, high altitude, and low rate of climb. **But how to define terms like 'high' and 'low'?**	Handle vagueness in definition using **fuzzy logic**



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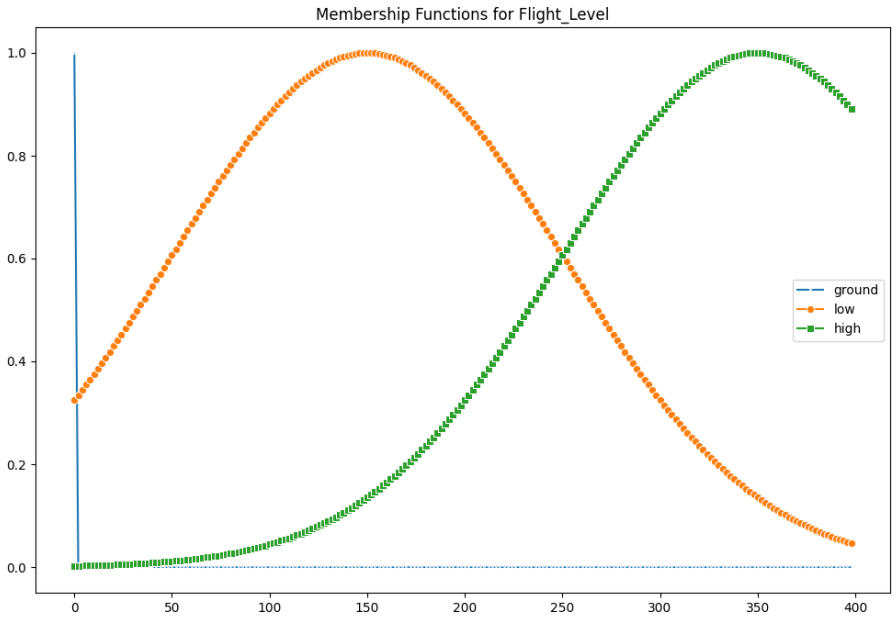
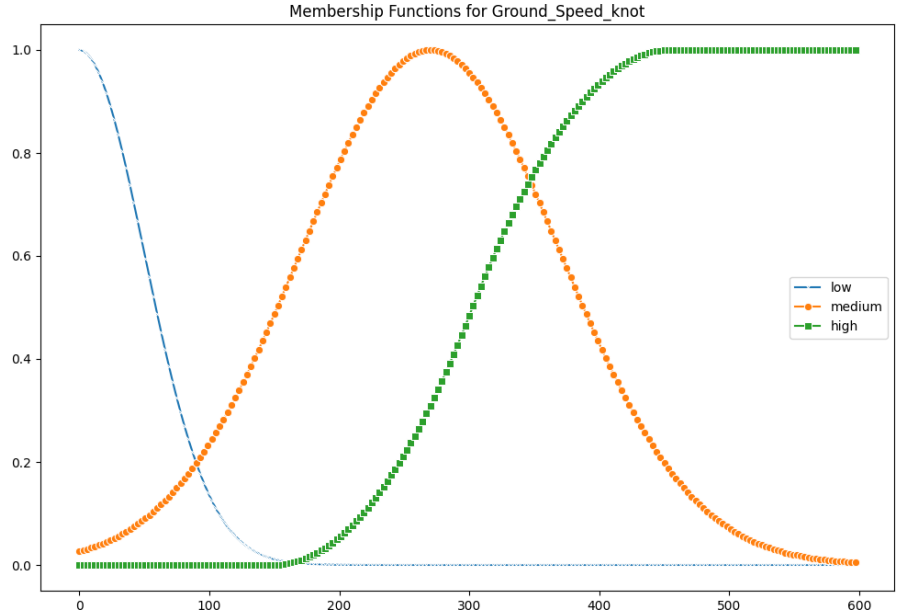
IDENTIFYING CRUISING PHASE OF FLIGHT

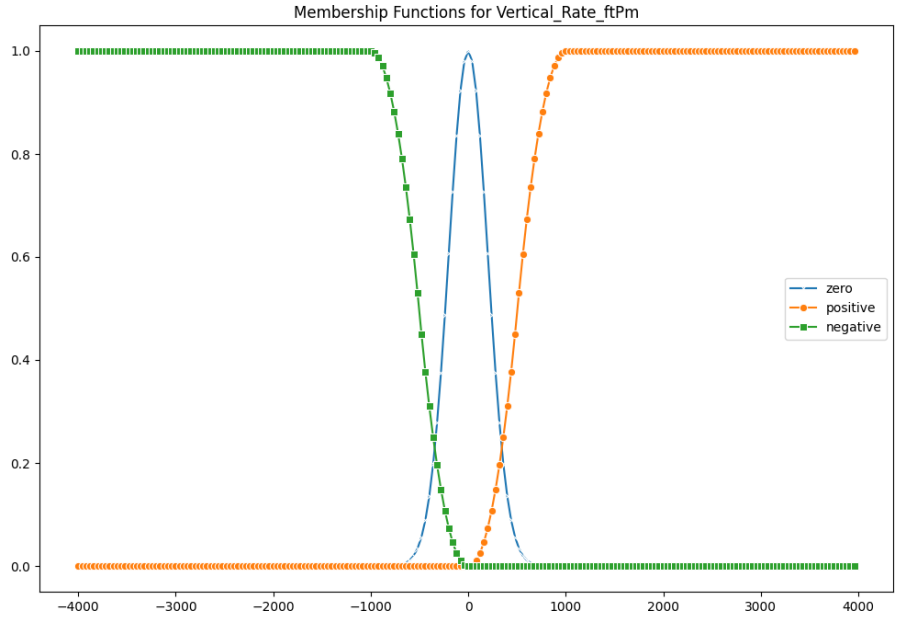
Concept of fuzzy logic:

Answer a yes/no question with an intermediate value





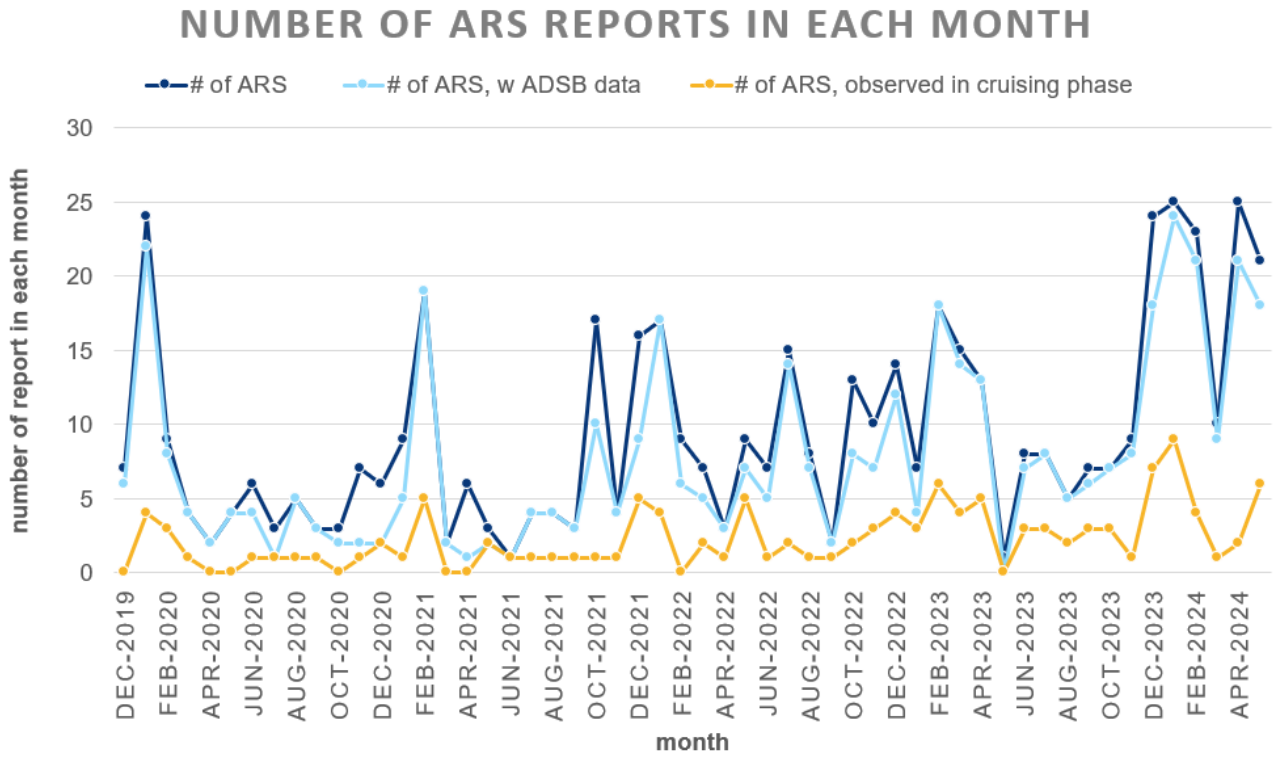
Cruising is characterized by high ground speed, high altitude, and low rate of climb.

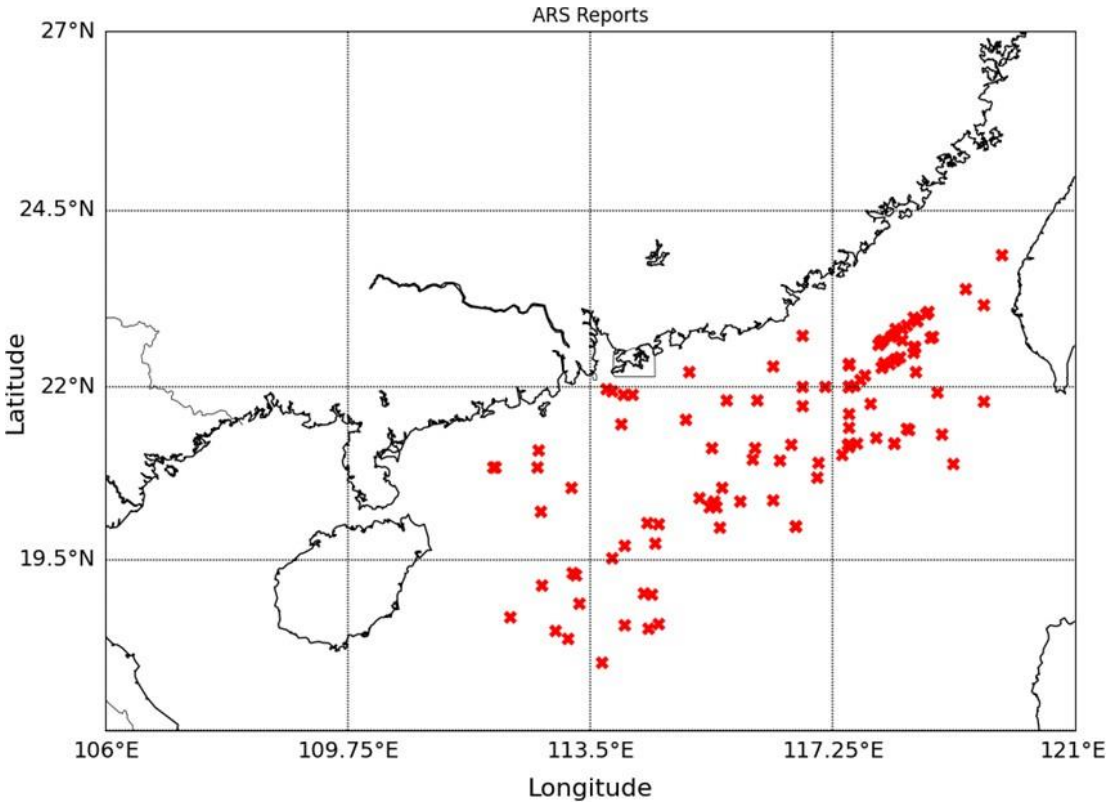


Reference: Flight Extraction and Phase Identification for Large Automatic Dependent Surveillance–Broadcast Datasets (Sun et al, 2017)

GROUND TRUTH

- The special air reports about turbulence are compiled as observations
- Study period: December 2019 to May 2024
- Total number of ARS reports: 122





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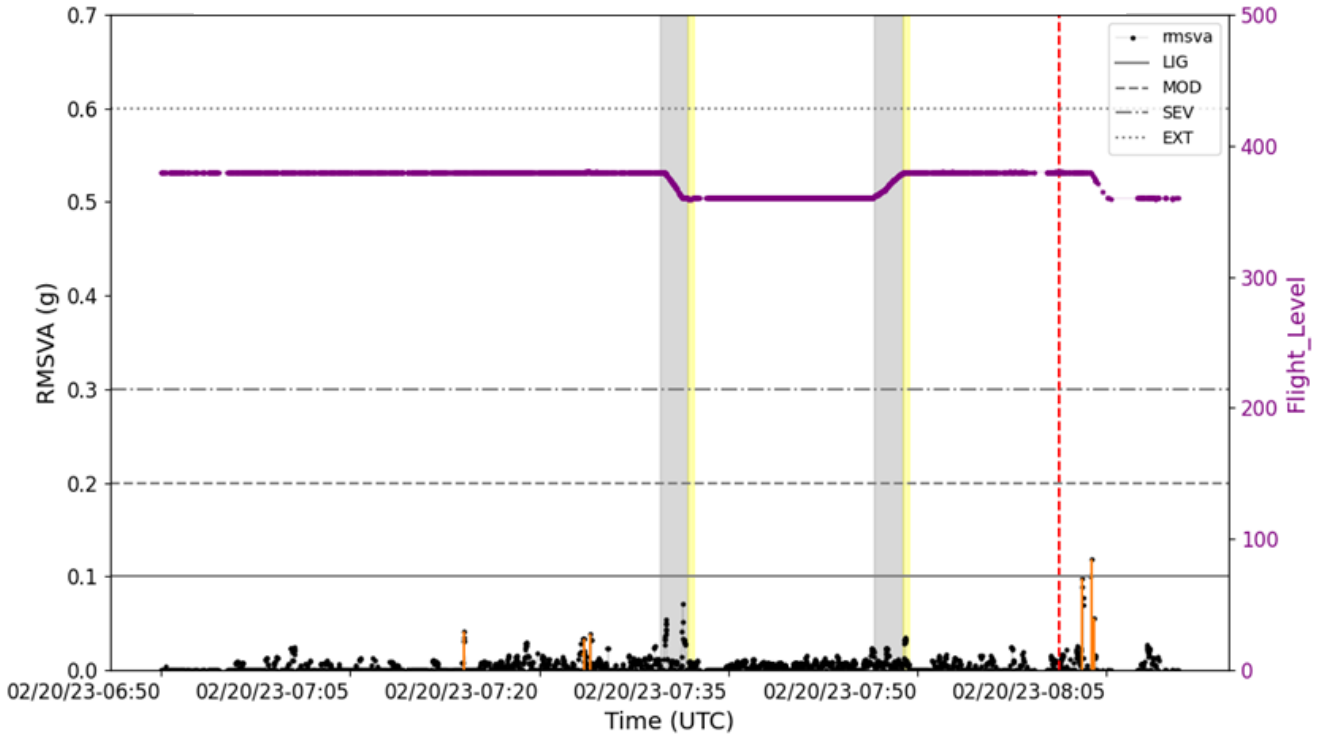
PROPOSED METHODOLOGY

- Identifying the spikes along the RMSVA time series
- Spike properties are extracted (including peak height, spike duration and spike count)

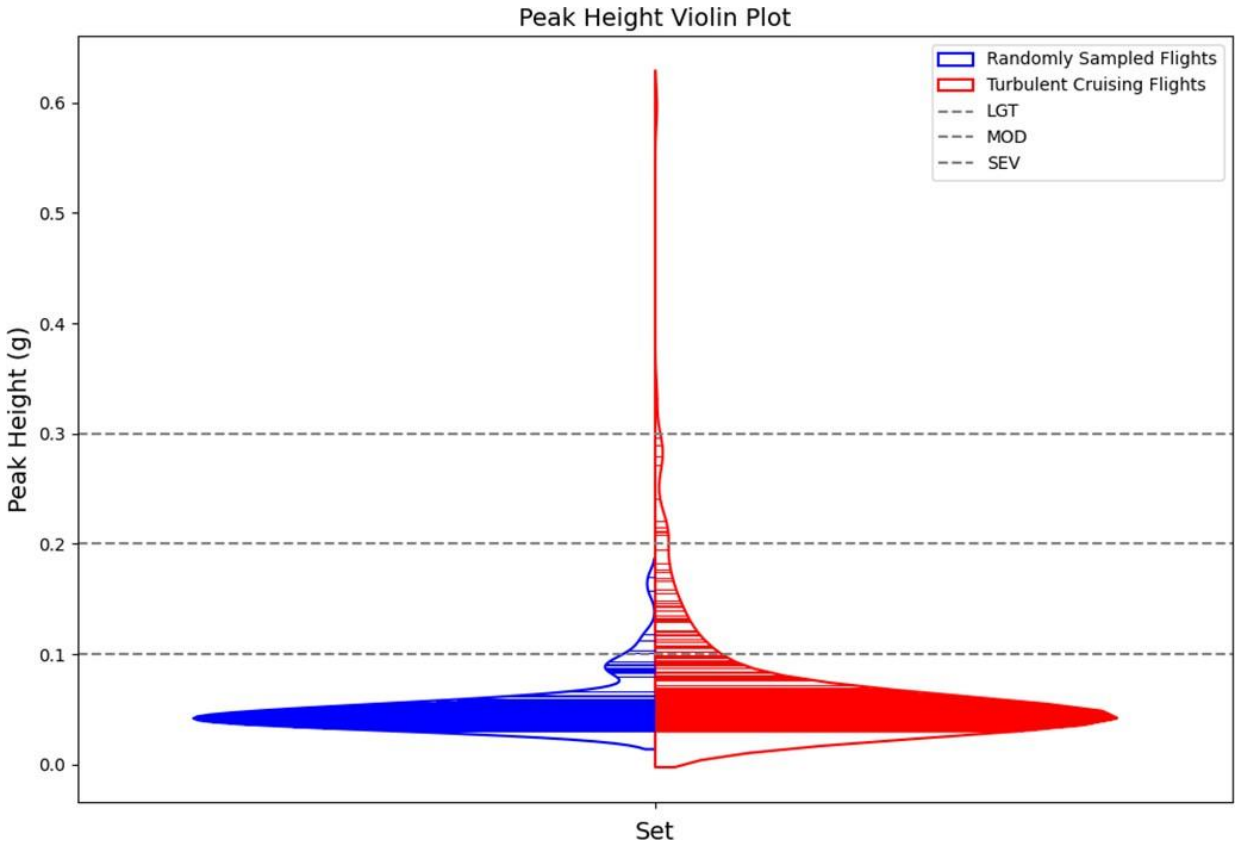


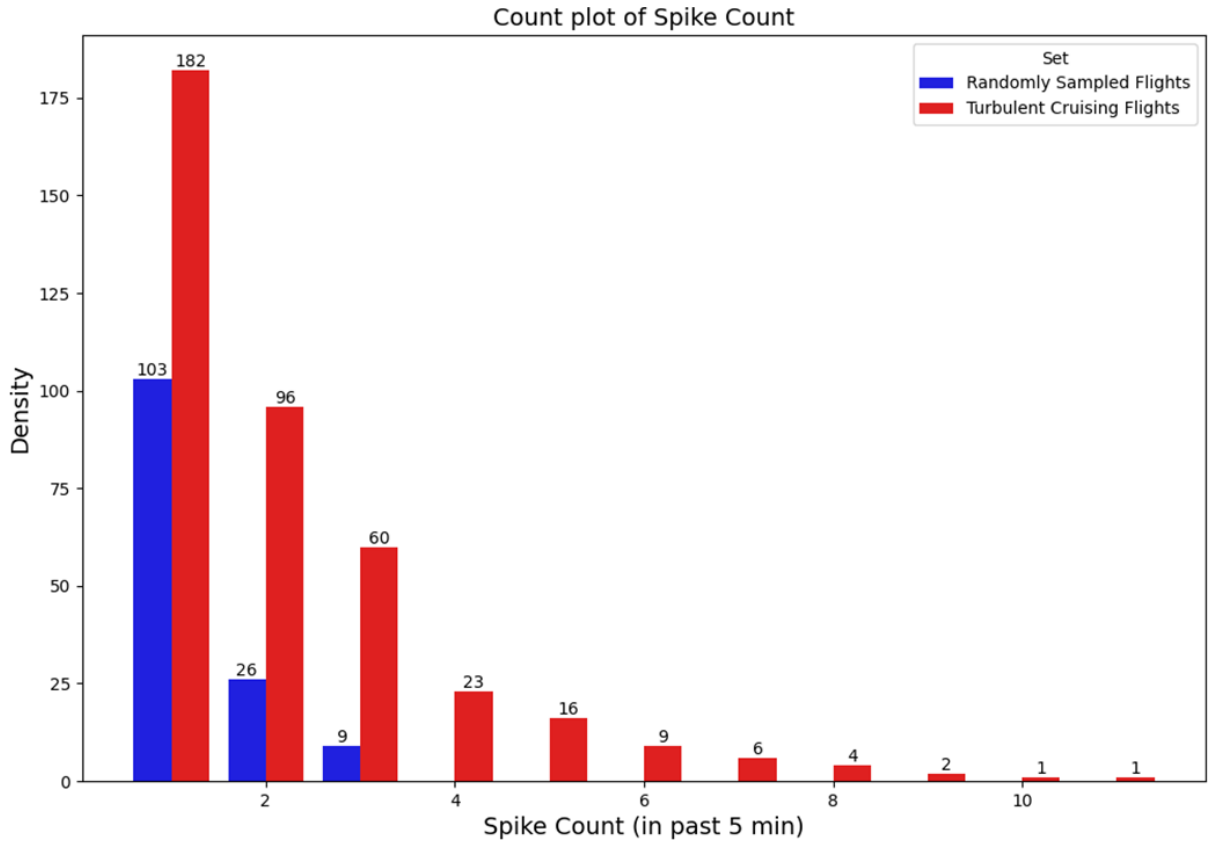
Orange lines are the spikes identified

Red line is where the turbulence reported

PROPOSED METHODOLOGY

- Comparative analysis are performed
  - Spike properties of turbulent flights vs randomly sampled flights

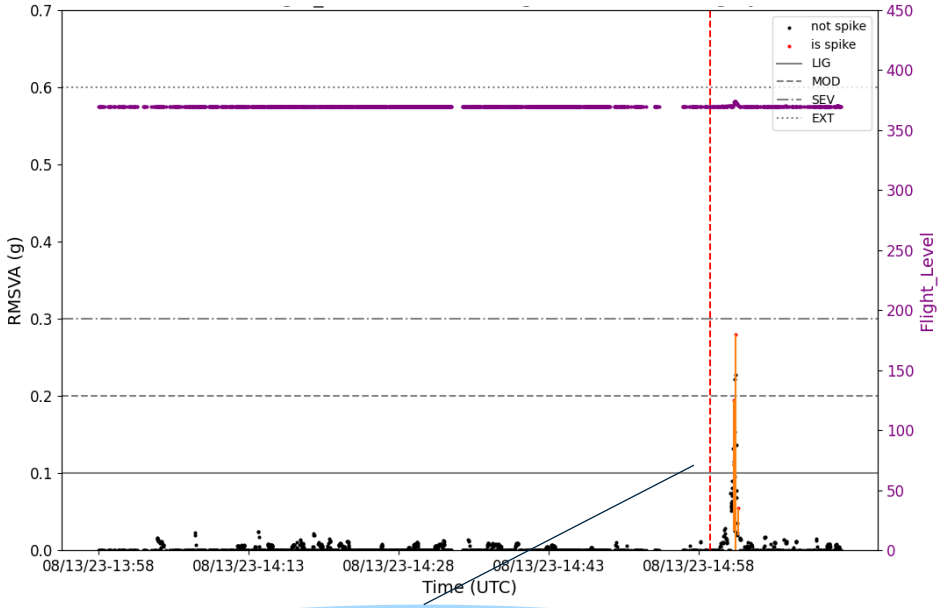




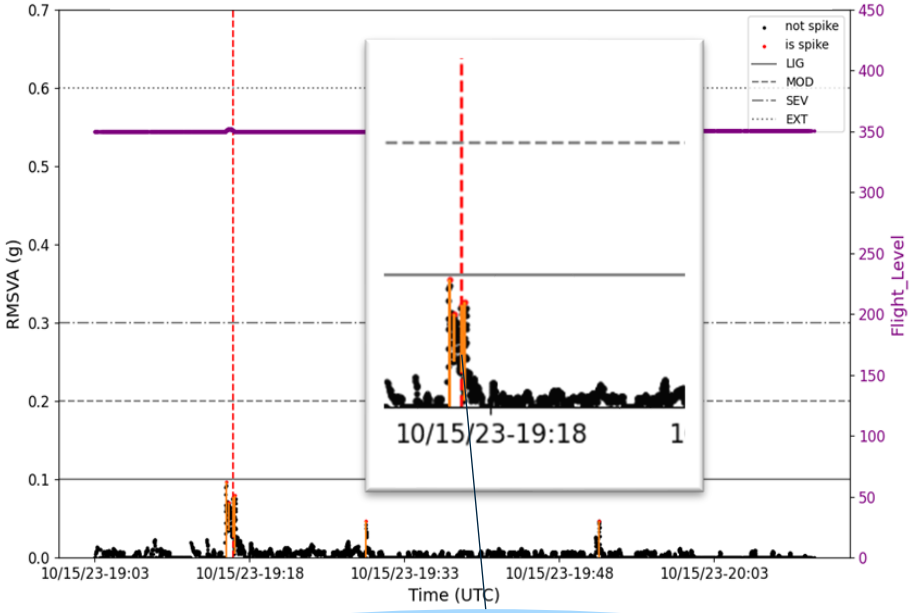
RESULTS

Following the thresholds from the documentation and also threshold identified from the comparative analysis,

	# of Turbulent Cruising Flights	# of Random Flights
Turbulence Detected	76	29
Turbulence Not Detected	46	93
	Probability of Detection = 62%	False Alarm Rate = 23%



Large spike, high spike count → Turbulence detected !



High Spike Count → Turbulence detected !

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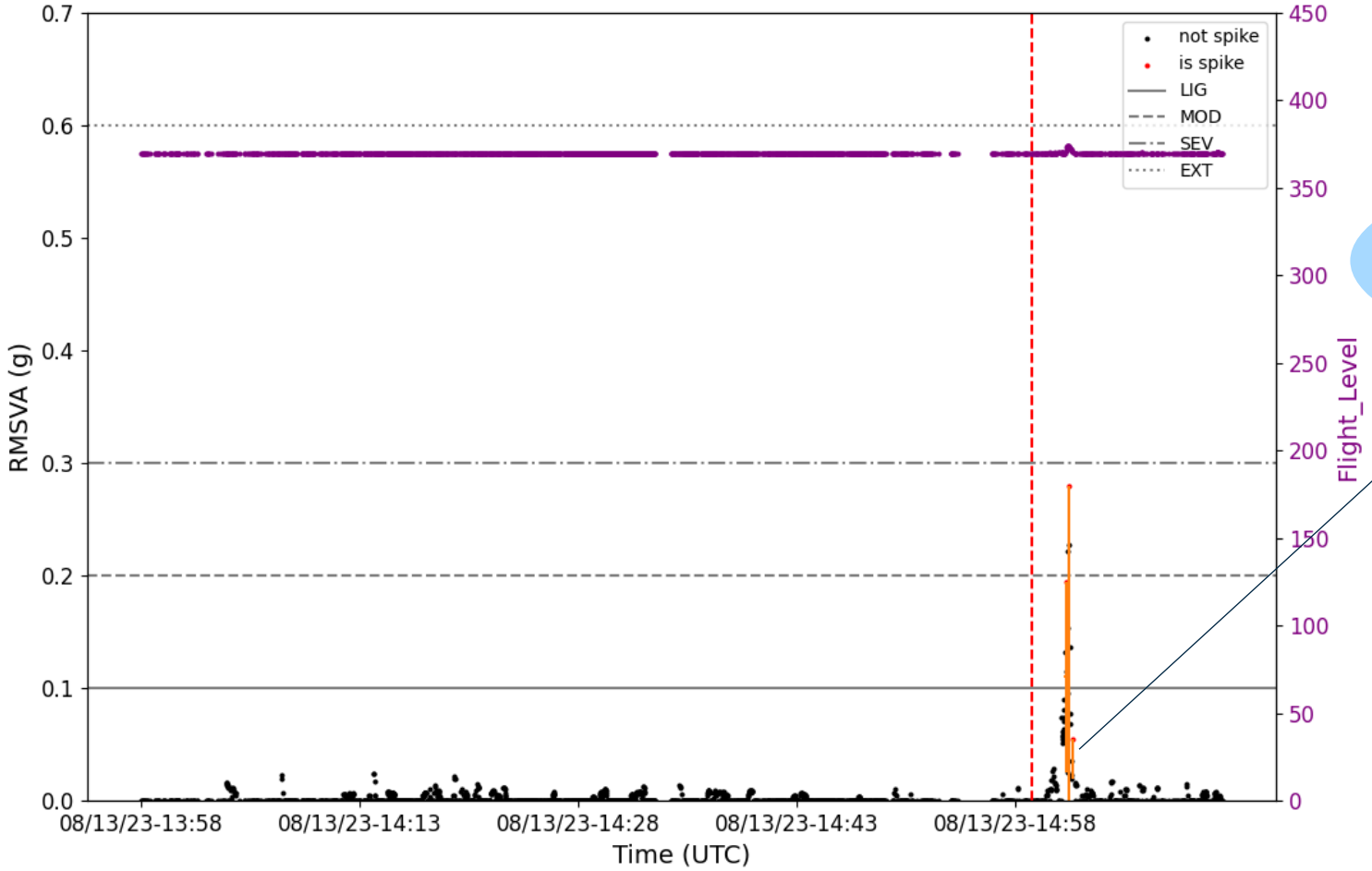
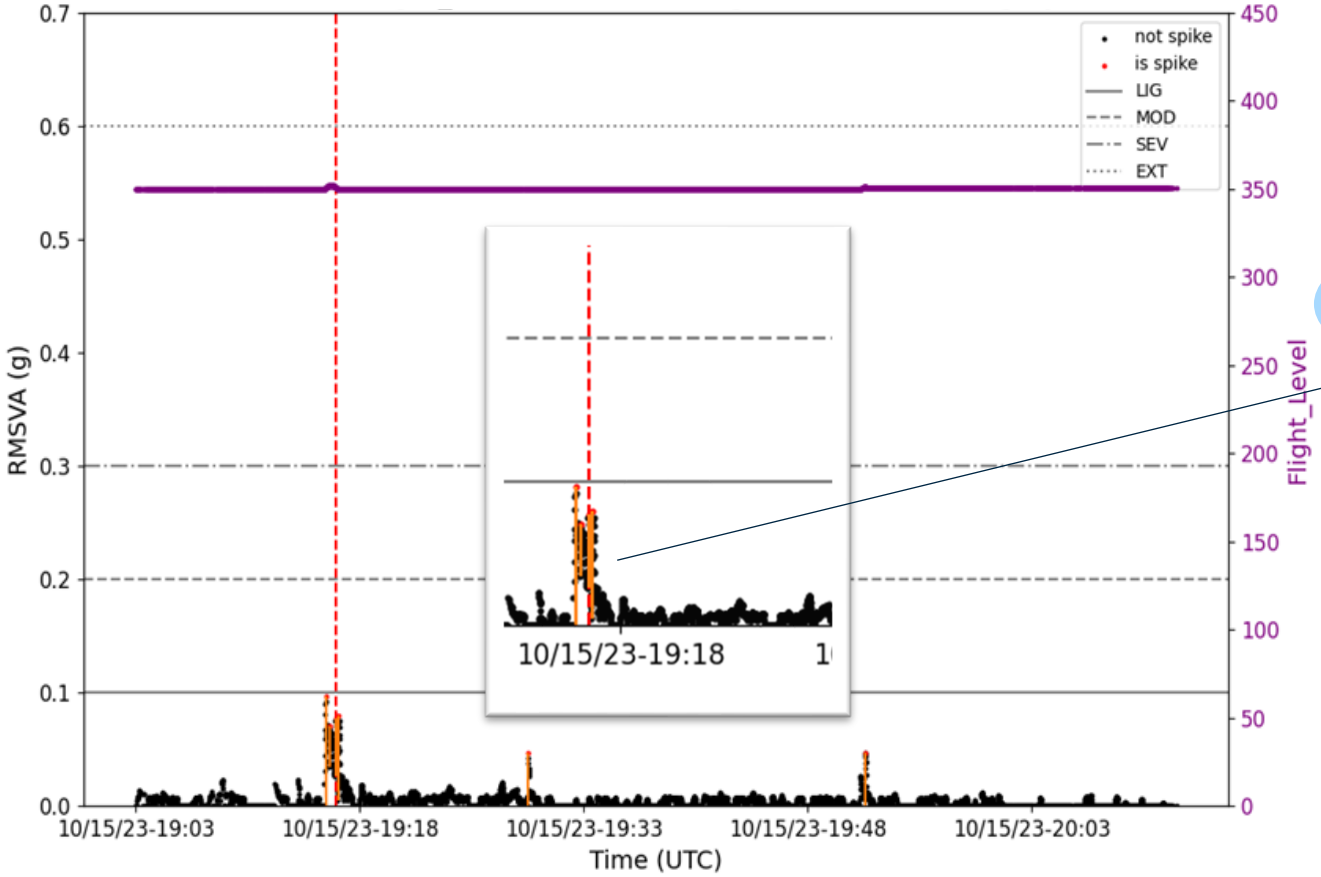
CASE



Large spike,
high spike count

Turbulence
detected !

CASE



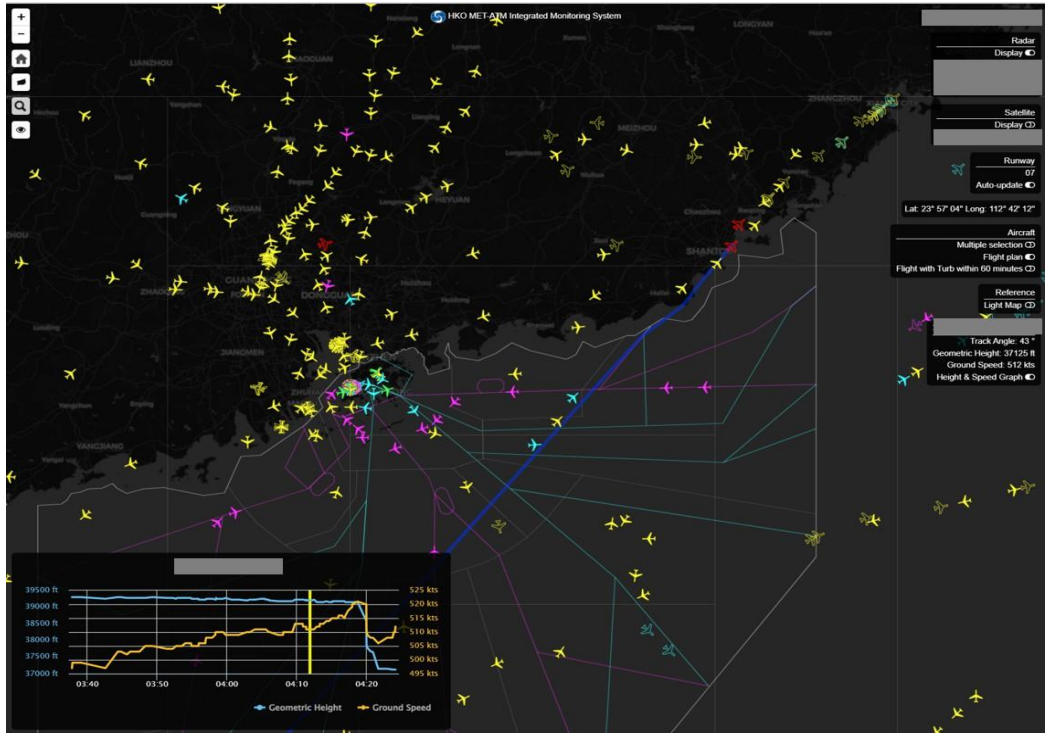
High Spike Count → Turbulence detected !

LIMITATIONS

- Special air reports (ARS) are sparse
- Reporting practice for ARS may vary for different airlines
- Number of ARS utilized in the study is small
- Some false alarm cases actually identified high peak height, but no ARS was reported
- Best to compare with Eddy Dissipation Rate (EDR) calculated from Quick Access Recorder data (however, not easy to obtain such information)

ROUTINE IMPLEMENTATION

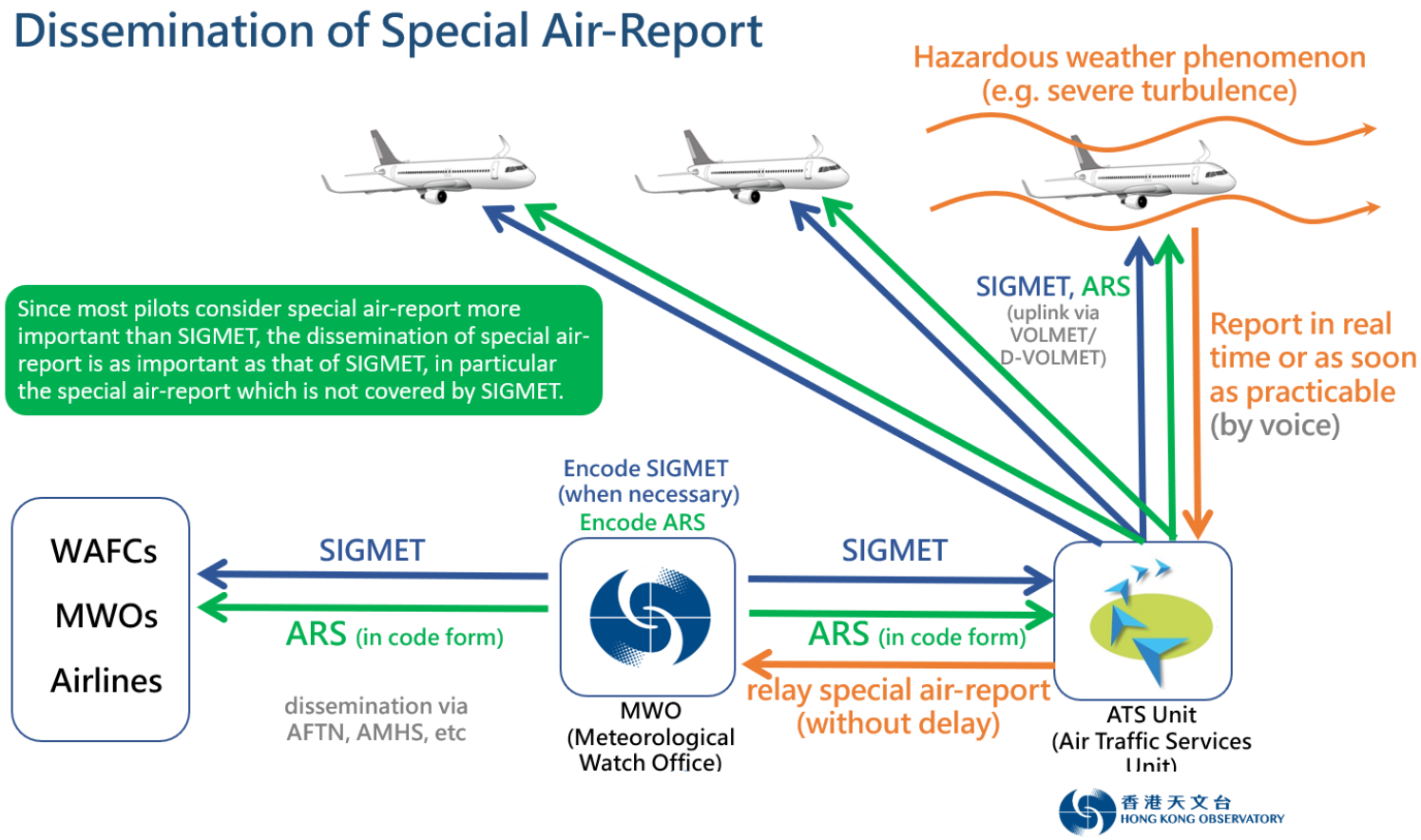
- Operational implementation started since November 2024
- Real-time detected turbulence is displayed on the HKO intranet page “HKO MET-ATM Integrated Monitoring System”, which allows aviation forecasters to monitor real time aircraft and turbulence information
- Further evaluation with the turbulence reported in January to February 2025, all the cases reported was detected by the proposed algorithm showing promising results

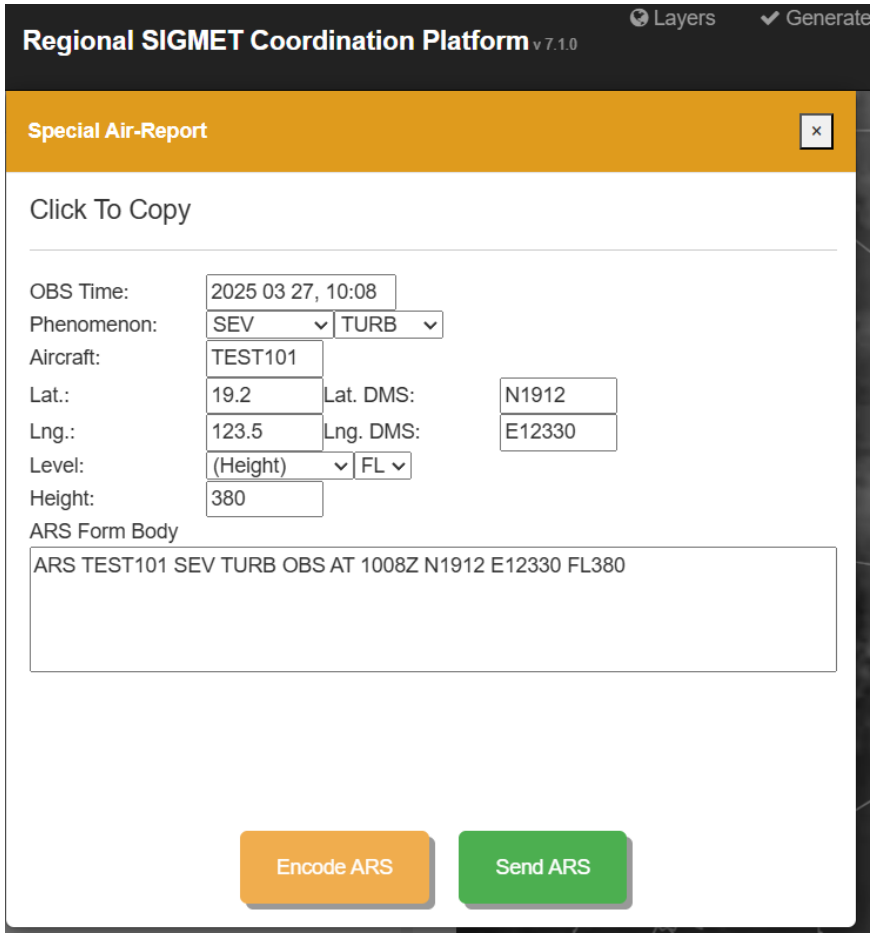


Time of occurrence	Phenomenon encountered	Height encountered	Time for ADS-B detected turbulence	Satisfied condition
2025-01-04 15:50Z	Severe Turbulence	FL280	2025-01-04 15:42Z to 15:43Z	spike count and spike duration
2025-02-09 14:10Z	Moderate Turbulence	FL380	2025-01-04 14:17Z	spike count
2025-02-10 04:53Z	Severe Turbulence	FL400	2025-02-10 04:32Z to 05:05Z	spike count and spike duration
2025-02-12 07:30Z	Moderate Turbulence	FL380	2025-02-12 07:30Z to 07:33Z	spike count

THE VALUE OF SPECIAL AIR REPORTS

- This reiterates the importance of having special air reports in different turbulence studies
- The dissemination of Special Air Reports involves a coordination of pilots, air traffic controllers and meteorological officers





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Further details of the study are submitted to peer-reviewed journal and the research article is currently under review. Interested readers may approach the author for sharing the publication once its published.

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