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Aircraft Turbulence Metrics:

A Study in the Australian Context

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Aircraft Meteorological DAta Relay 1



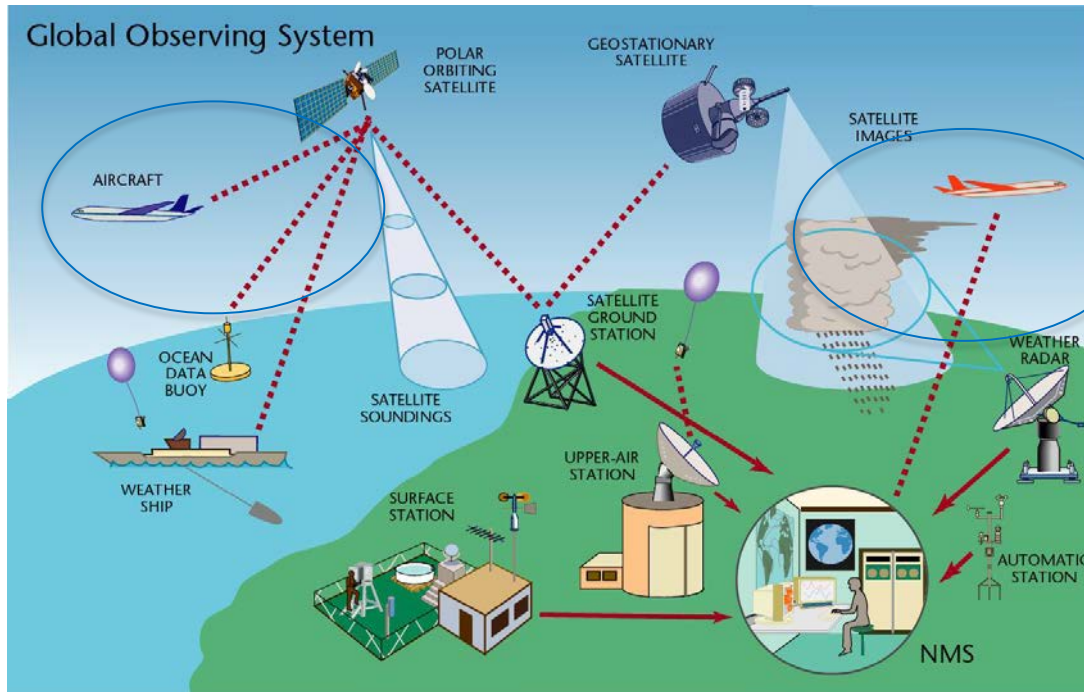
- Aircraft measure temperature + wind speed/direction + acceleration to assist with aircraft management.

- At time intervals/events data is downlinked via VHF or Satellite

- Reporting may be changed in flight by uplink to aircraft.



Aircraft Meteorological Data Relay 1



- Aircraft measure temperature + wind speed/direction + acceleration to assist with aircraft management.

- At

- time or pressure intervals
- in response to events

data is downlinked via VHF or Satellite and transferred to NMHS

- Reporting may be changed in flight by uplink to aircraft.

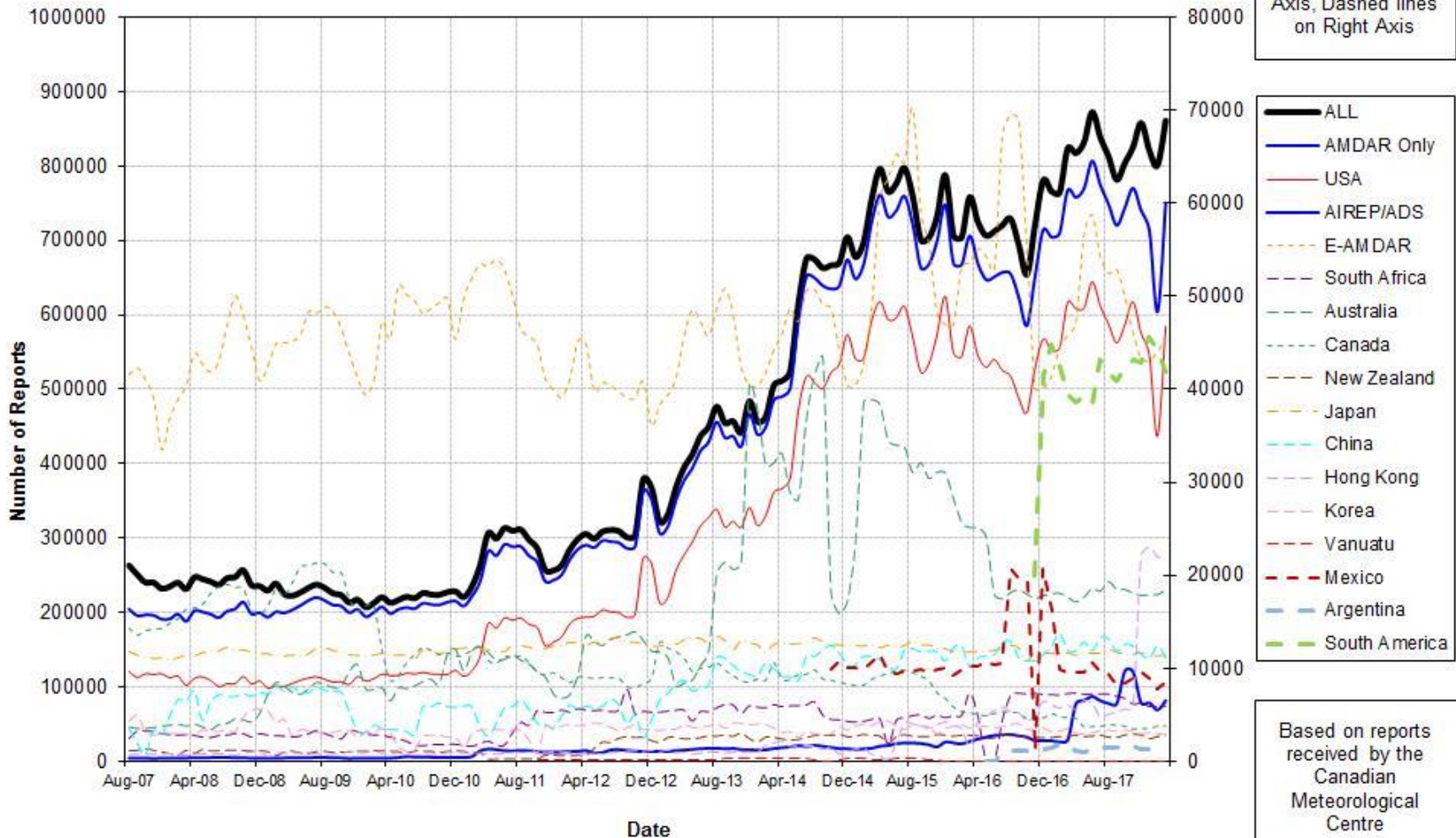


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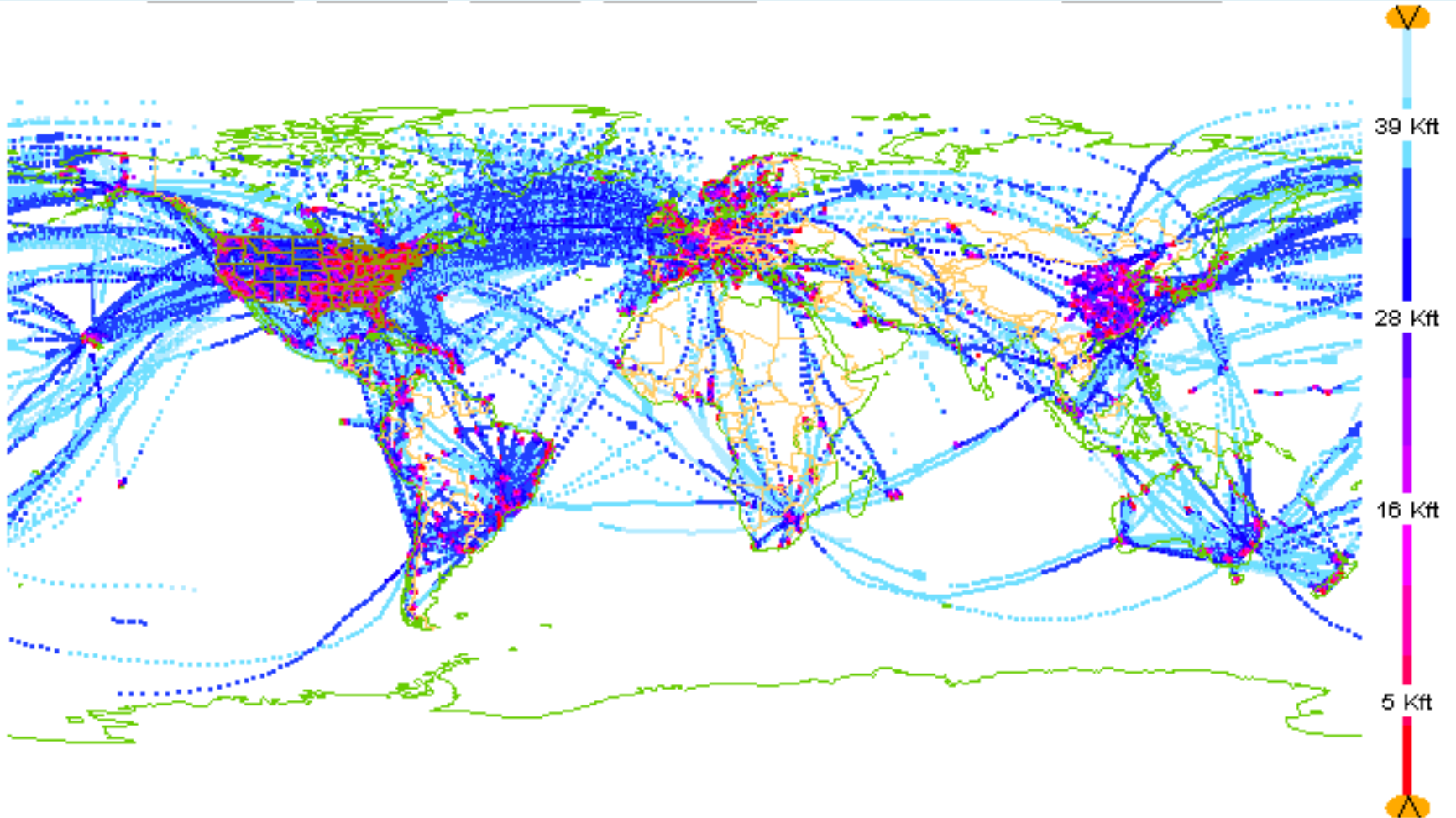
Aircraft Meteorological Data Relay 2

Aircraft Observations - Smoothed Monthly Average of Daily Report Totals





Aircraft Meteorological DAta Relay 3



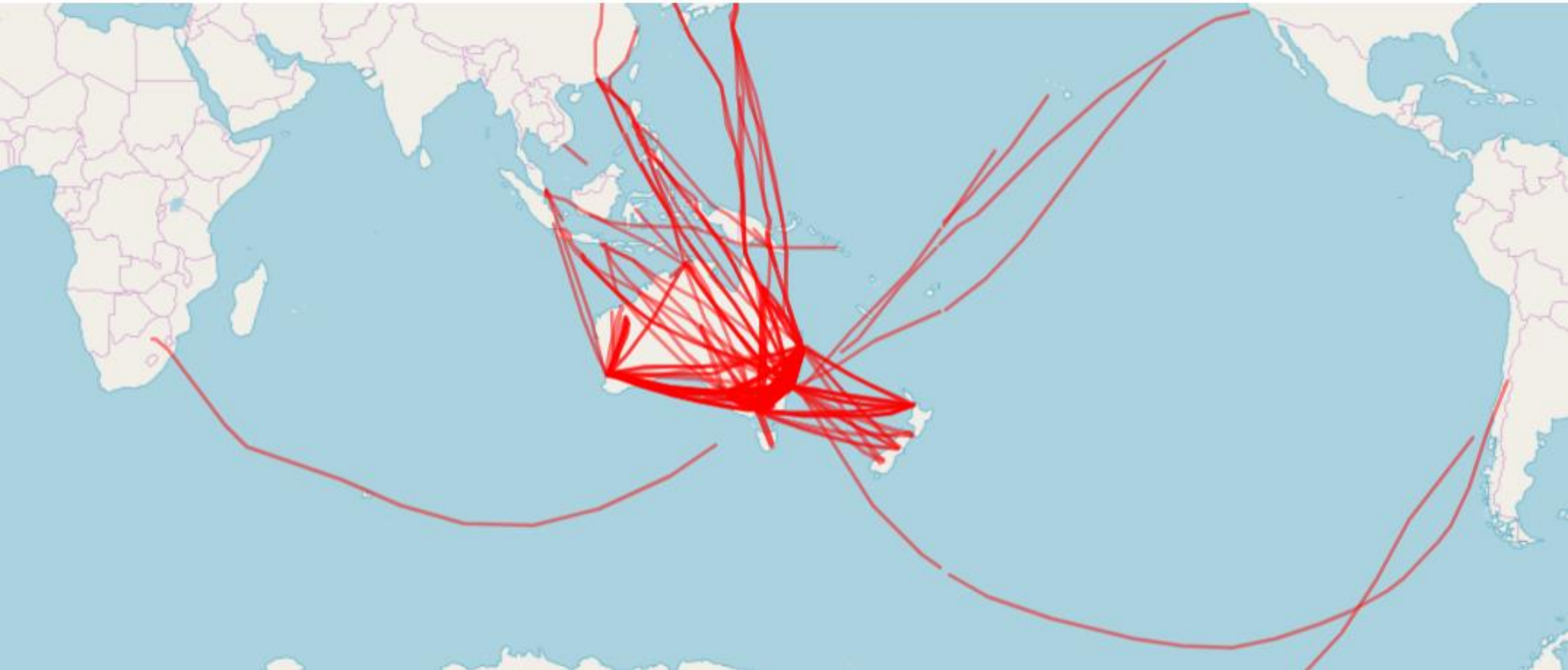
03-Oct-2018 00:00:00 -- 04-Oct-2018 00:14:30 (928243 obs loaded, 769976 in range, 27779 shown)



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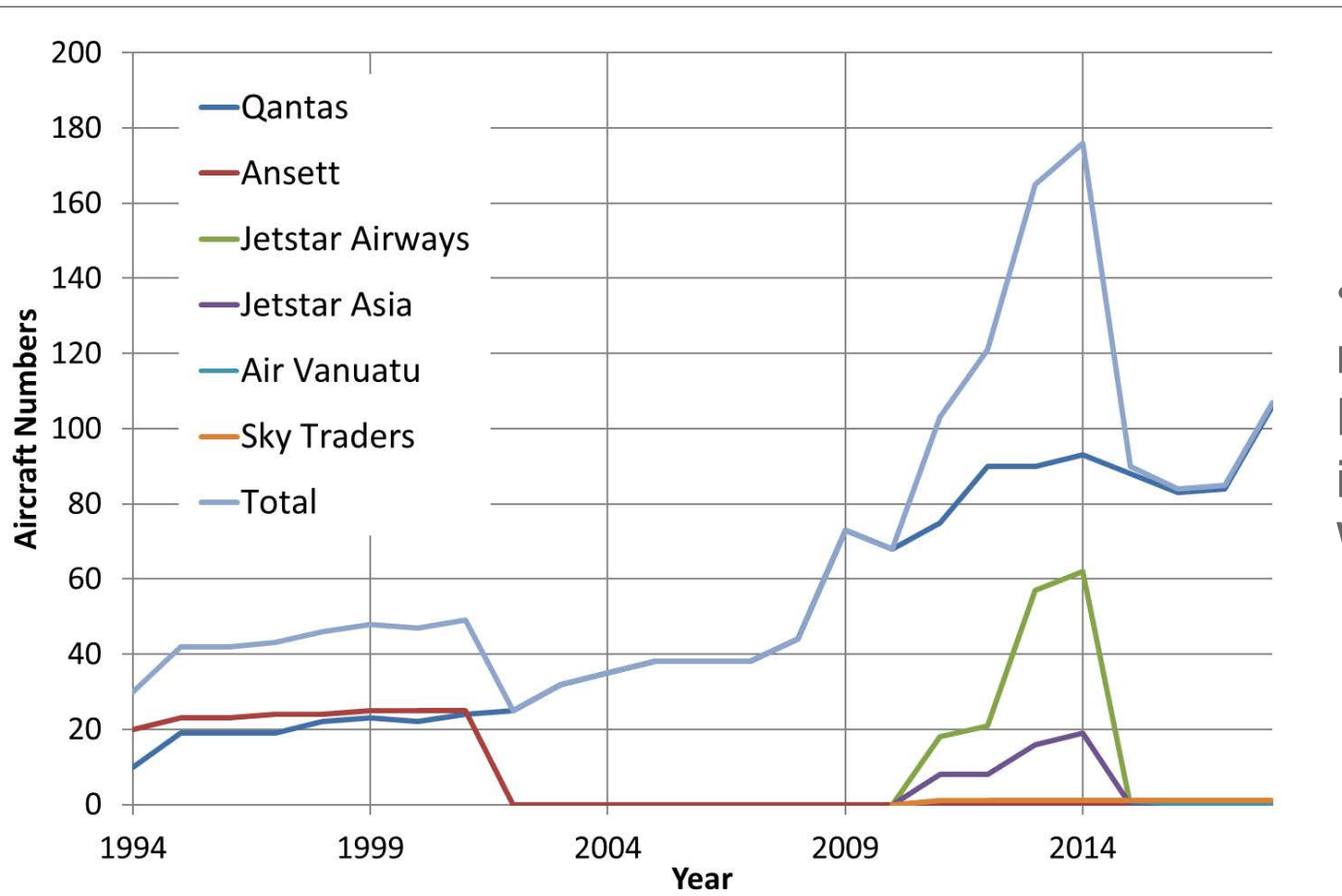
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AMDAR: 24 Hour Coverage





AMDAR: Australia Airlines

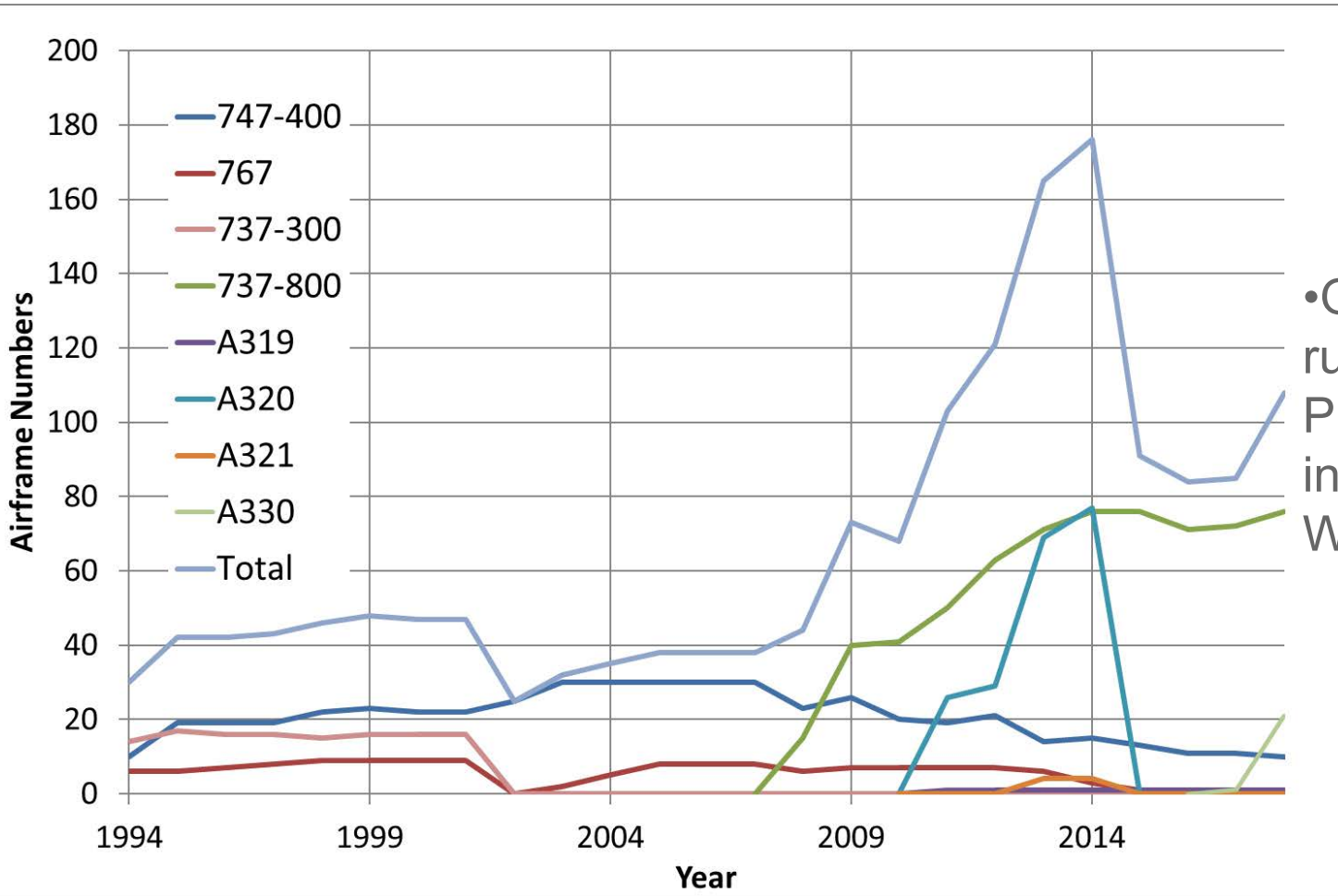


- One of the longest running Public Private Partnerships in the Global Weather Enterprise.

- In Australia, AMDAR started in late 1980s



AMDAR: Australia Airframes



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• In Australia, AMDAR started in late 1980s



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A Tale of 2 Turbulence Metrics: DEVG

- Derived Equivalent Vertical Gust (DEVG) [m/s]

- Definition: the instantaneous vertical gust velocity which, superimposed on a steady horizontal wind, would produce the measured acceleration of the aircraft.

- $$DEVG = \frac{Am|\Delta n|}{V}$$

- m = aircraft mass

- Δn = peak value of the deviation of the vertical acceleration from $1g$

- V = airspeed

- A = function of aircraft mass, altitude, empirical factors dependent on airframe



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A Tale of 2 Turbulence Metrics: EDR

- Eddy Dissipation Rate (EDR) [$m^{2/3}/s$]
 - Representative turbulence metric ICAO 2001
 - EDR proportional to the RMS vertical acceleration
 - A number of different methodologies available:-
 - Vertical Accelerometer based
 - Vertical Wind Based [NCAR2]
 - True Airspeed based



This Study: Introduction

- A number of studies [eg. S.H. Kim etal. 2017, Stickland 1998] recorded source values, then post calculated EDR/DEVG values.
- In this work, 16 A330-200 and 7 A330-300 aircraft belonging to Qantas configured to provide EDR and DEVG operationally.
- AMDAR (ACARS) messages used transmit data.
- Data: ~44k simultaneous comparisons [11 Feb – 2 Sep 2018]

GIA
AU0330C0NZAAYBBN
3ID50SZKR10,G5MJ-656Y360////91 2
3KWHIJ2 AKMJ,656Y350////91 1
7KFVJA: 51MJ.6D6,310////91 1221030IH
3KHBJ8E 5JMJ-6870320////91 5
3KXQIJF AKMJ-6A722:0////91 5
7KL1J2U 6MMJ-6D712,0////91 222103020;
3KBQJJK 3.MJ.6A732:0////91 2
3KV7IPS AKM0UAI6-2X0////91 G
7KJ,J5M 81LJ,F5752K0////91 62210J8/9W
3K5RJUB 2JLD.FN702H0////91 6

EDR Heartbeat
message

DEVG Observation

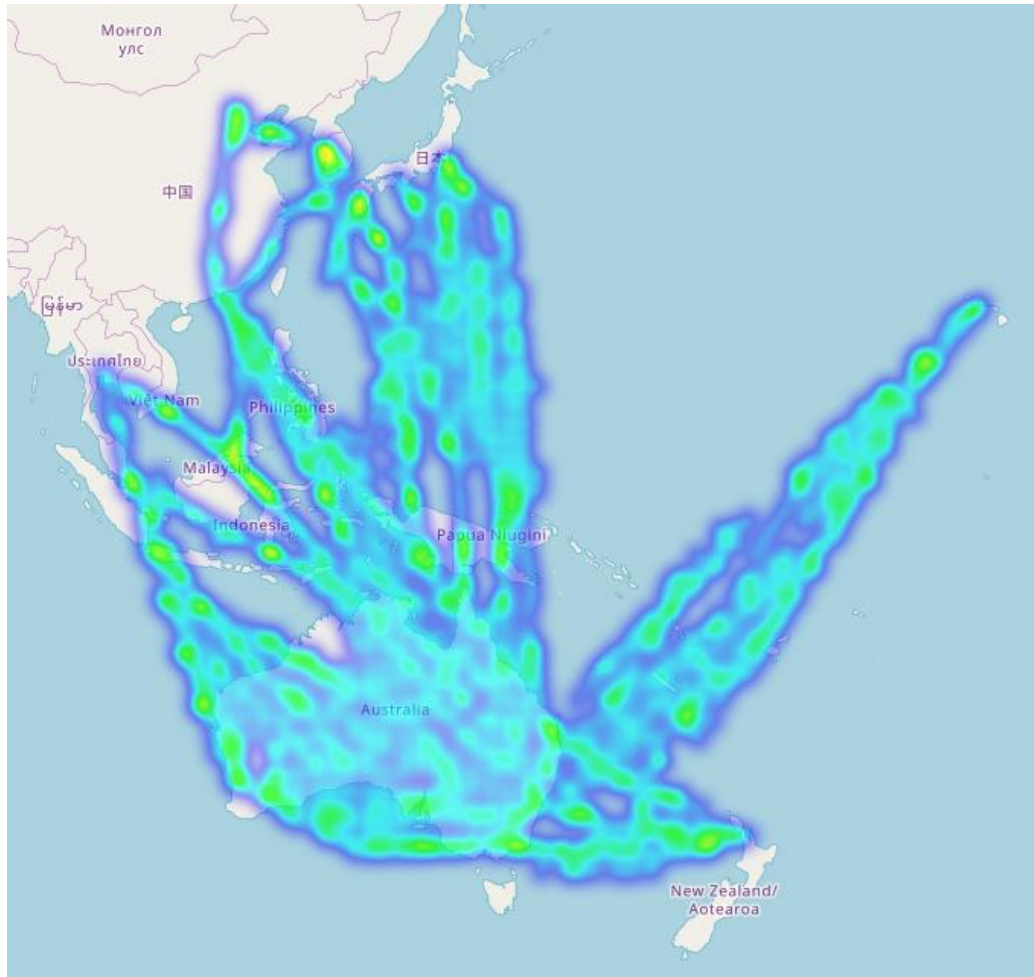
10 Observations



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Turbulence Geography

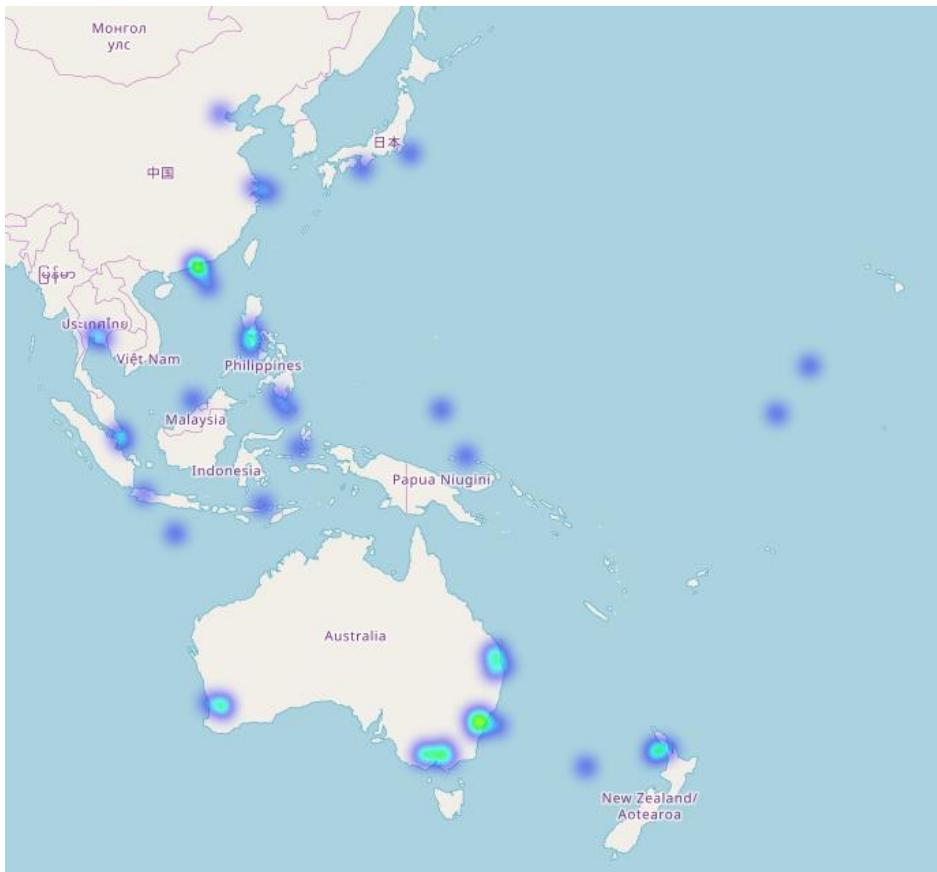


Density of A330 Observations

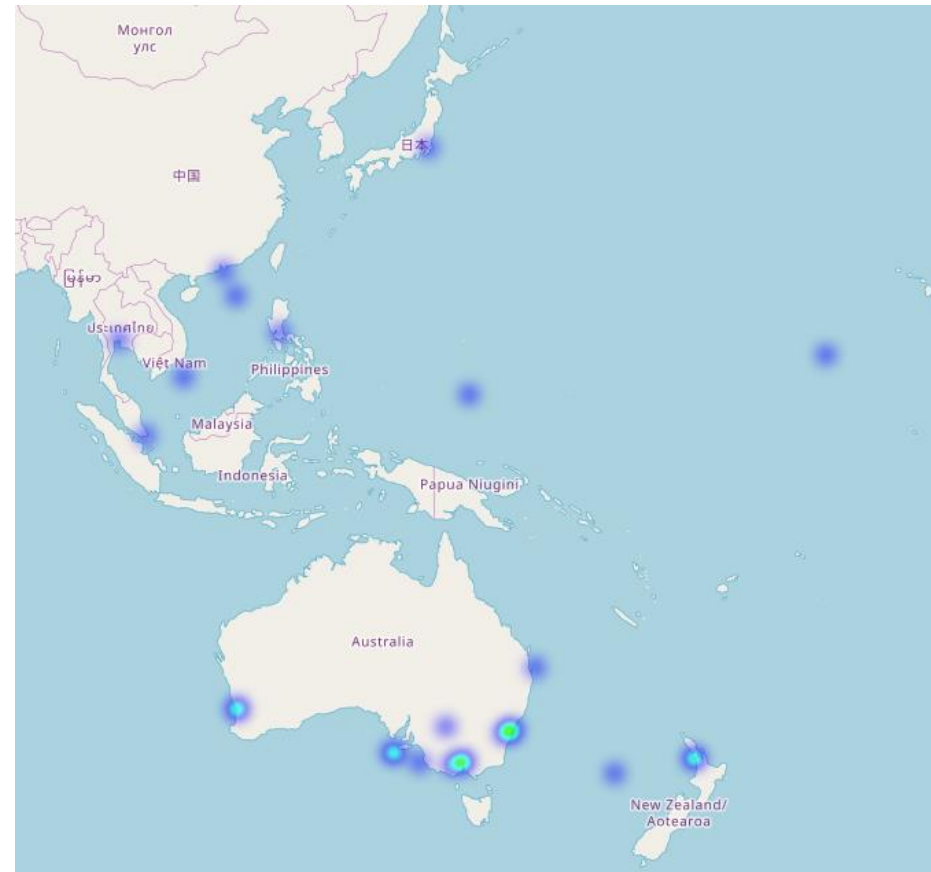


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Turbulence Geography



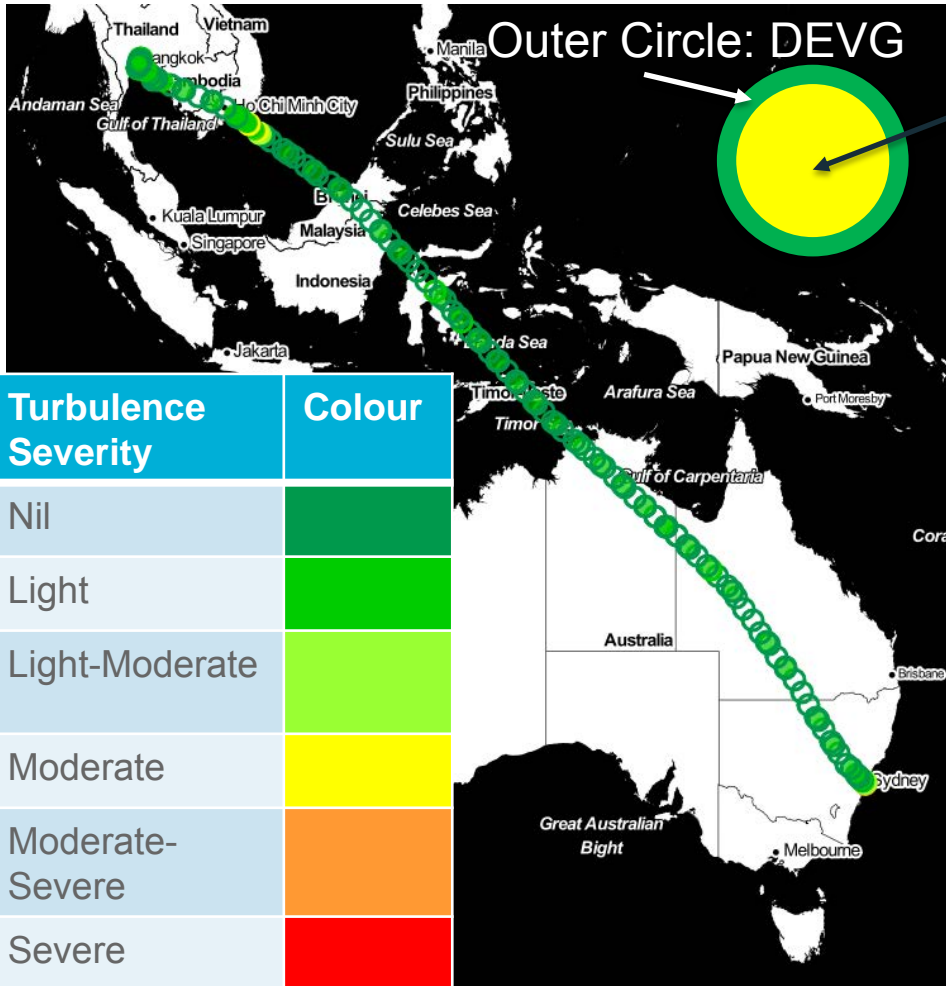
Density of Moderate/Severe DEVG Turbulence



Density of Moderate/Severe EDR Turbulence



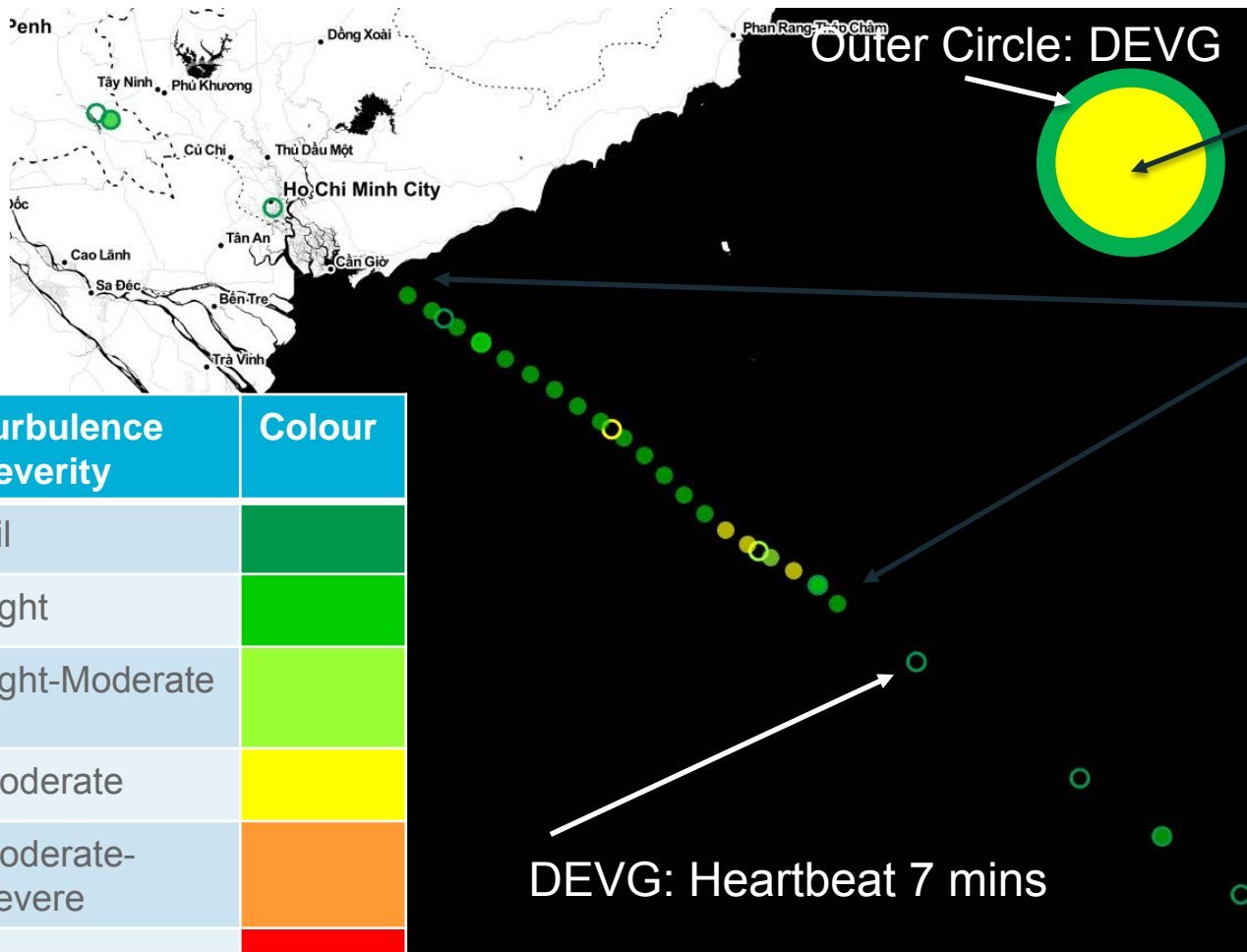
Comparing DEVG & EDR: An example



- Inner Circle: EDR
- VH-QPJ flight from Bangkok to Sydney on 15th August.
- DEVG follows 'AMDAR' reporting:
 - Pressure levels in ascent/descent
 - 7 mins during level flight
- EDR has 'heartbeat' and event reporting
 - 15 minute 'heartbeat'



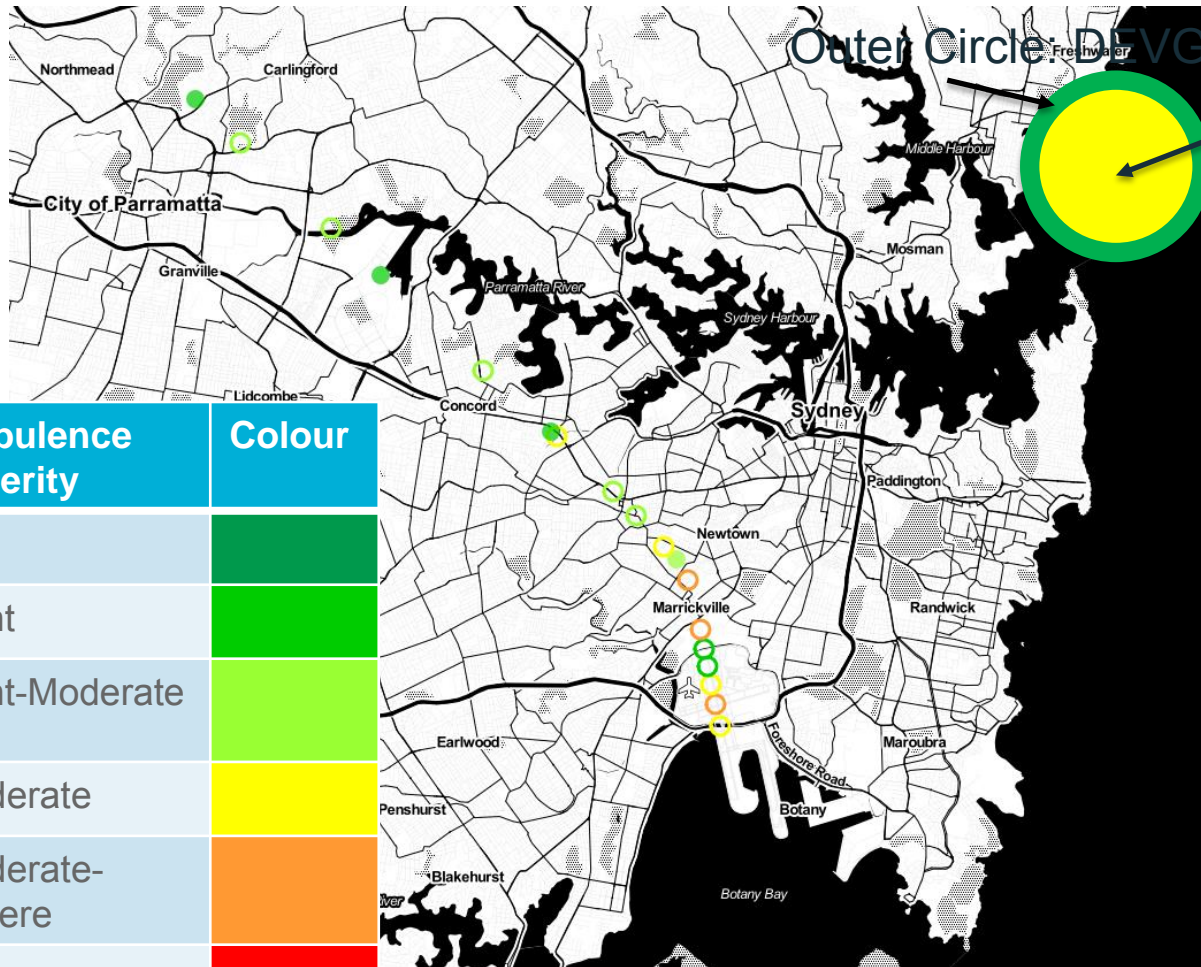
Turbulence Event



- EDR Event:
 - EDR above threshold [0.06/0.12/0.18]
 - Triggers up to 6 EDR Observations at 1 minute intervals following event



Turbulence Event



Inner Circle: EDR

- DEVG is known not to be able to determine Turbulence from aircraft manoeuvres

Turbulence Severity	Colour
Nil	Dark Green
Light	Light Green
Light-Moderate	Yellow-Green
Moderate	Yellow
Moderate-Severe	Orange
Severe	Red



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Turbulence Classification

Category	DEVG	Count	EDR	Count
Nil	$DEVG < 2$	40507	$EDR < 0.1$	41466
Light	$2 \leq DEVG < 4$	1020	$0.1 \leq EDR < 0.2$	390
Light-Moderate	$4 \leq DEVG < 6$	161	$0.2 \leq EDR < 0.3$	28
Moderate	$6 \leq DEVG < 8$	137	$0.3 \leq EDR < 0.4$	1
Moderate-Severe	$8 \leq DEVG < 10$	54	$0.4 \leq EDR < 0.5$	0
Severe	$DEVG \geq 10$	6	$EDR \geq 0.5$	0



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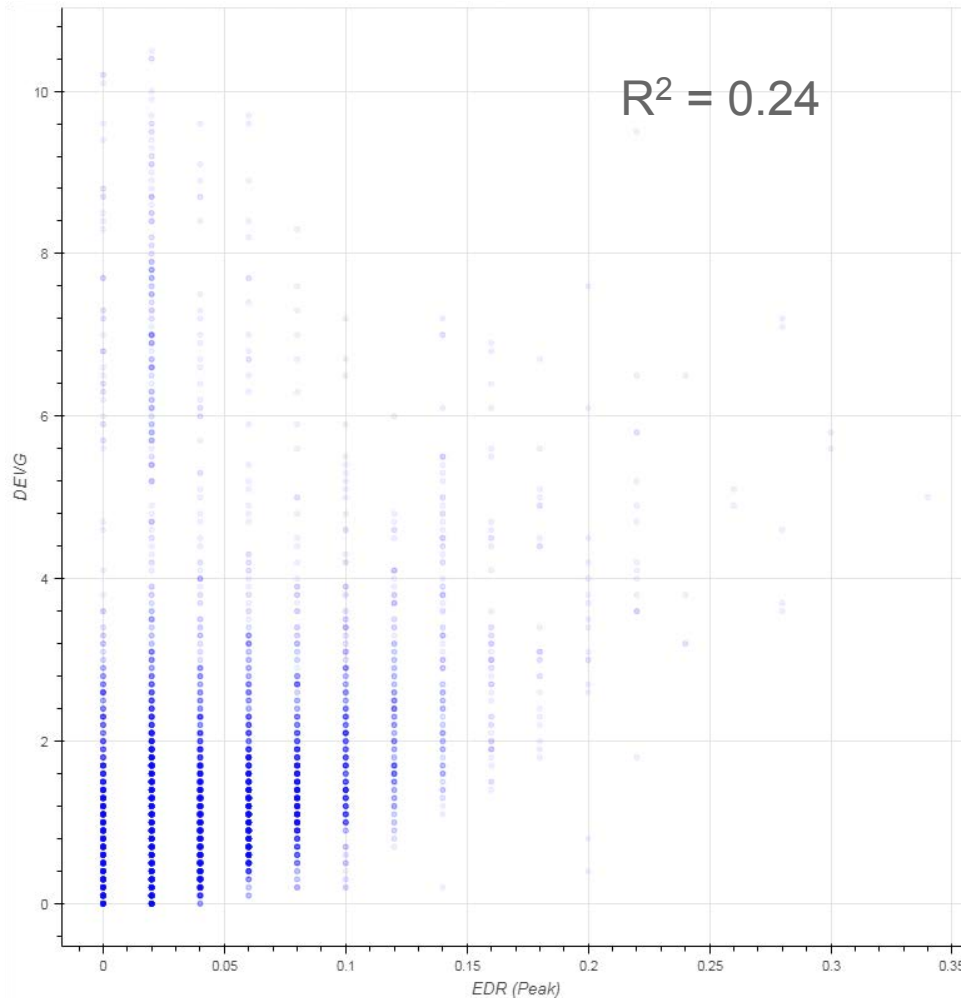


Turbulence Classification

	EDR						
DEVG	Nil	Light	Light-Moderate	Moderate	Moderate- Severe	Severe	
Nil	40365	141	1				
Light	821	189	10				
Light-Moderate	99	49	12	1			
Moderate	122	11	4				
Moderate- Severe	53		1				
Severe	6						



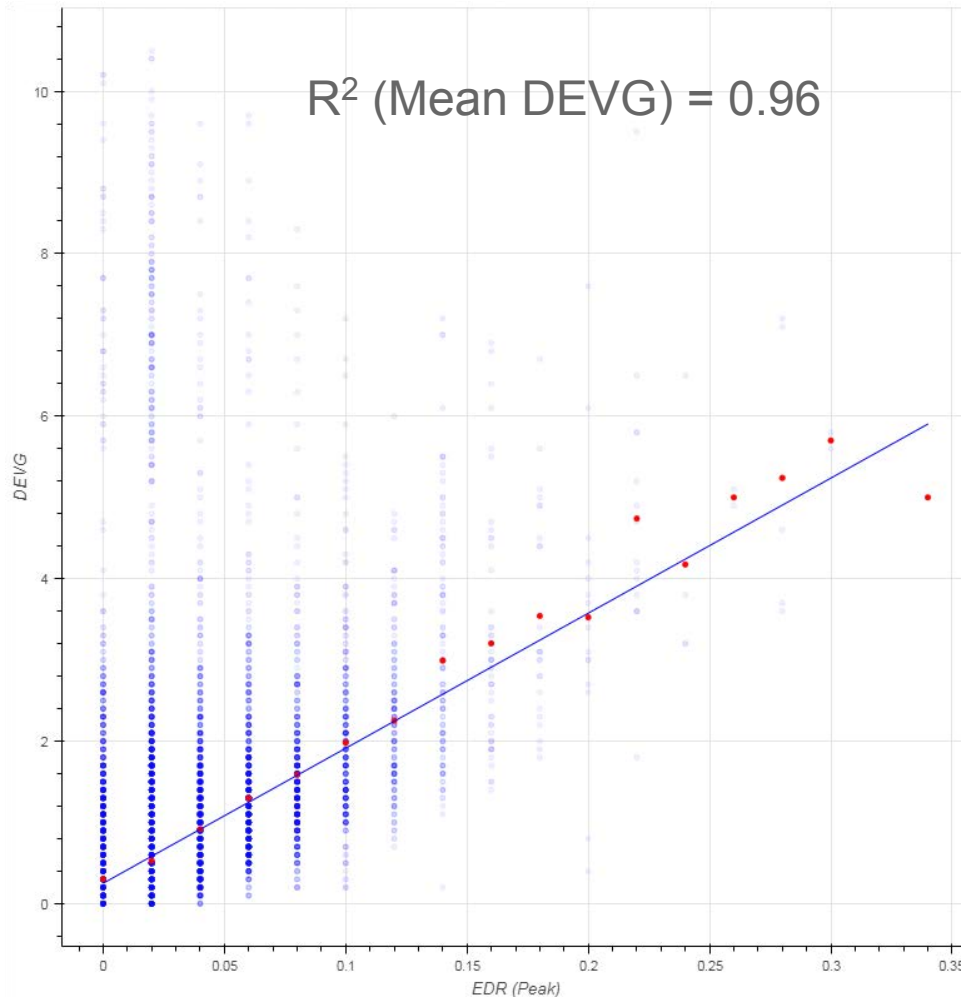
Correlation: DEVG to EDR



- No a lot of correlation apparent!



Correlation: DEVG to EDR



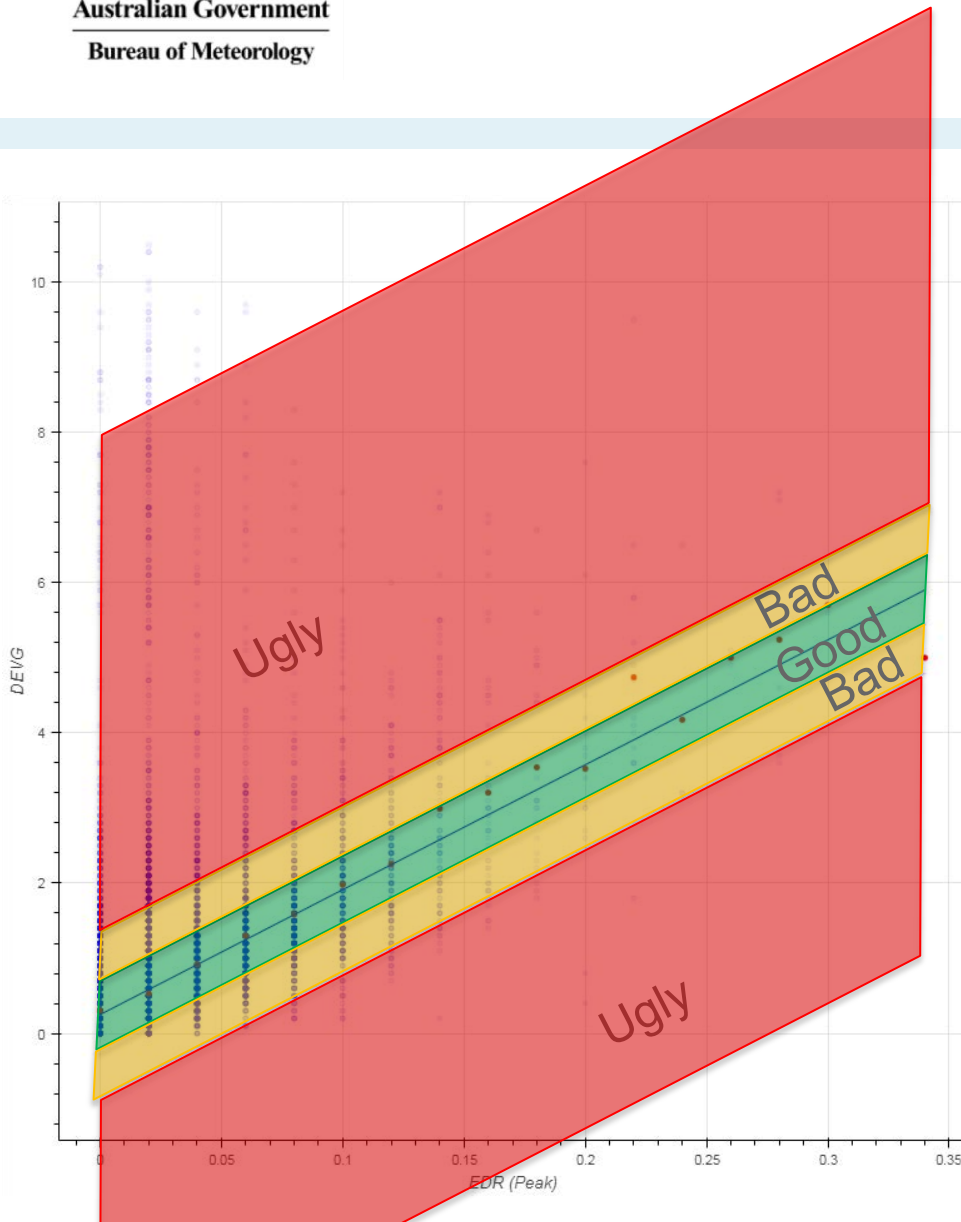
- No a lot of correlation apparent!
- However, if plot mean DEVG vs each EDR, shows a strong trend.



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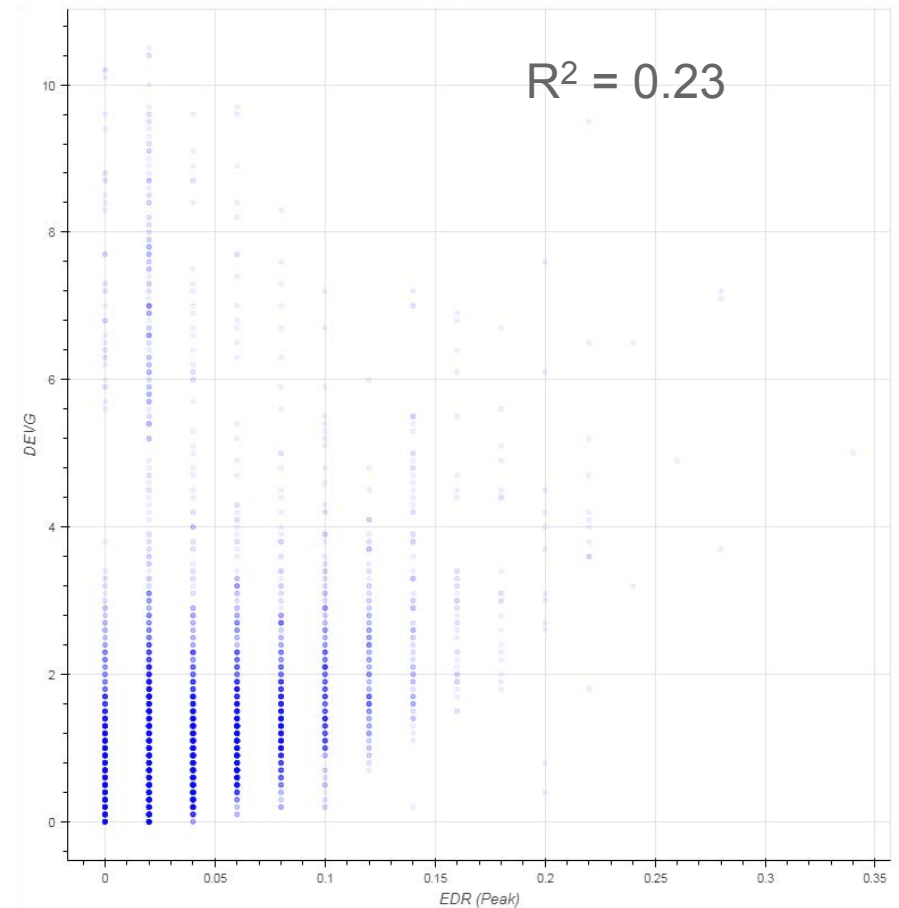
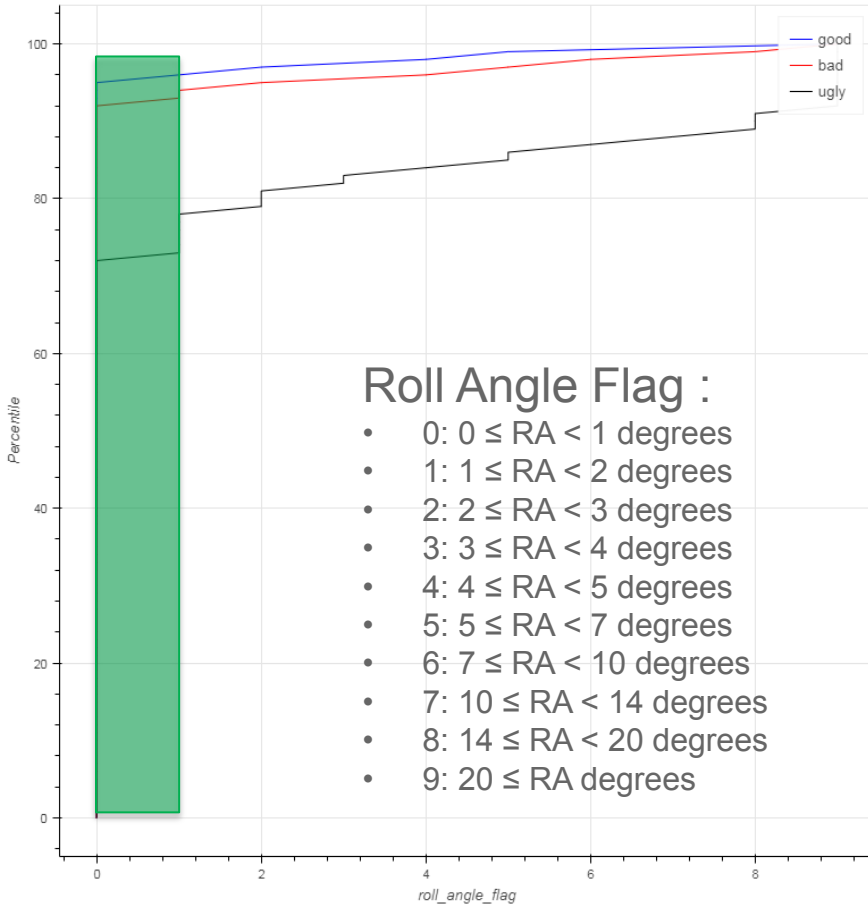
Correlation: DEVG to EDR



- No a lot of correlation apparent!
- However, if plot mean DEVG vs each EDR, shows a strong trend.
- Classify Data
 - Good: 50% Data around trend
 - Bad: 90% Data
 - Ugly: Remaining 10%
- Is it possible to use other observations to determine if DEVG is influenced by aircraft manoeuvres?



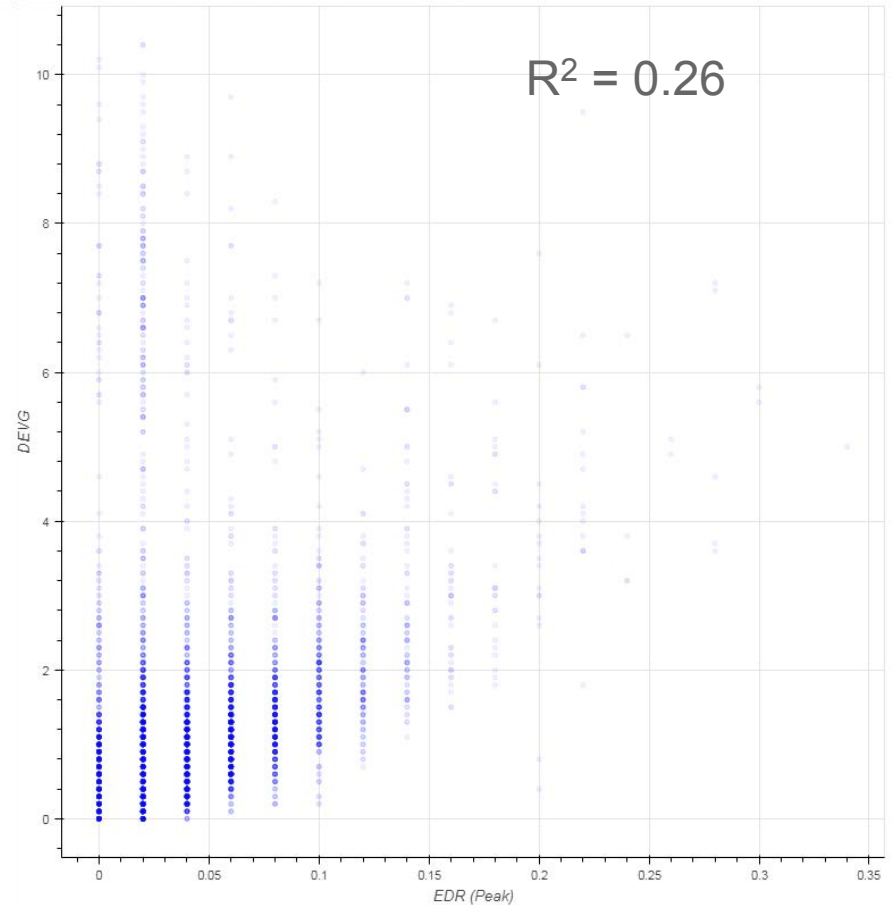
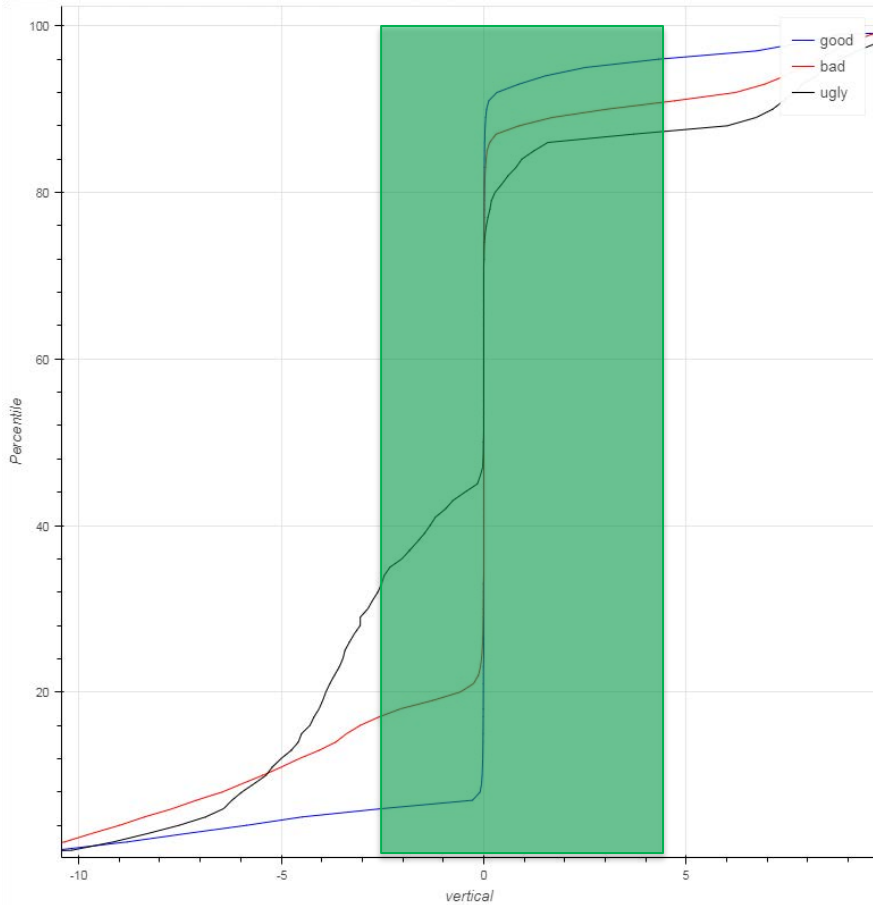
Factors in Turning: Roll Angle



- 90% Good: Roll Angle Flag ≤ 1



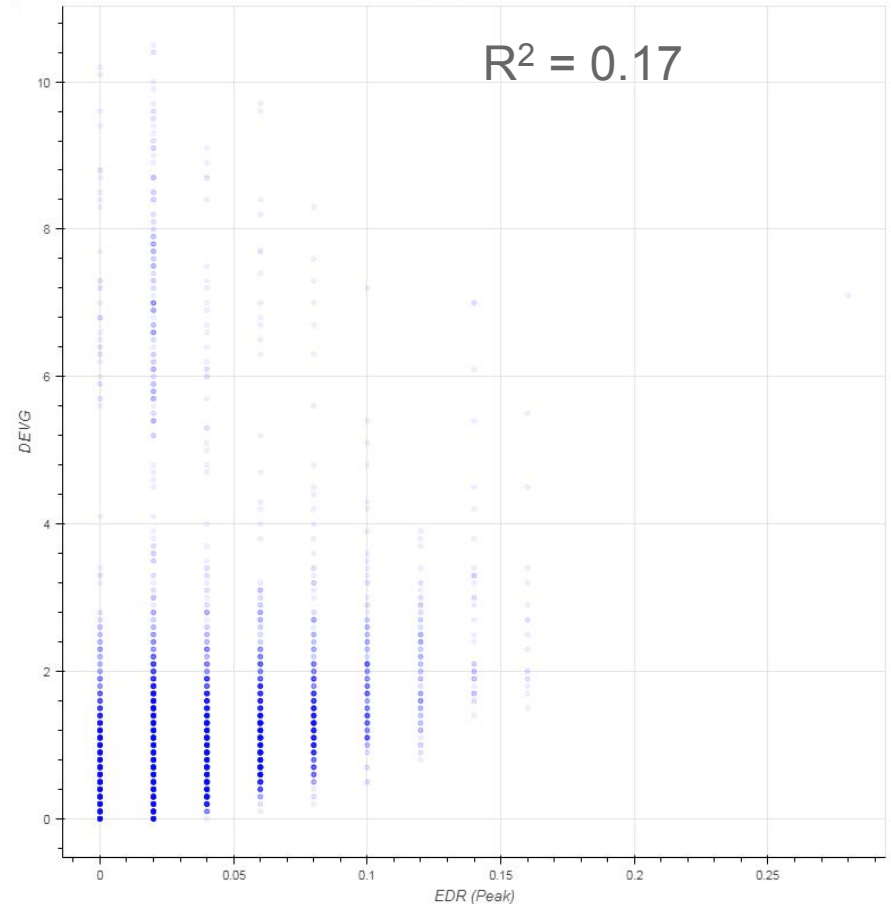
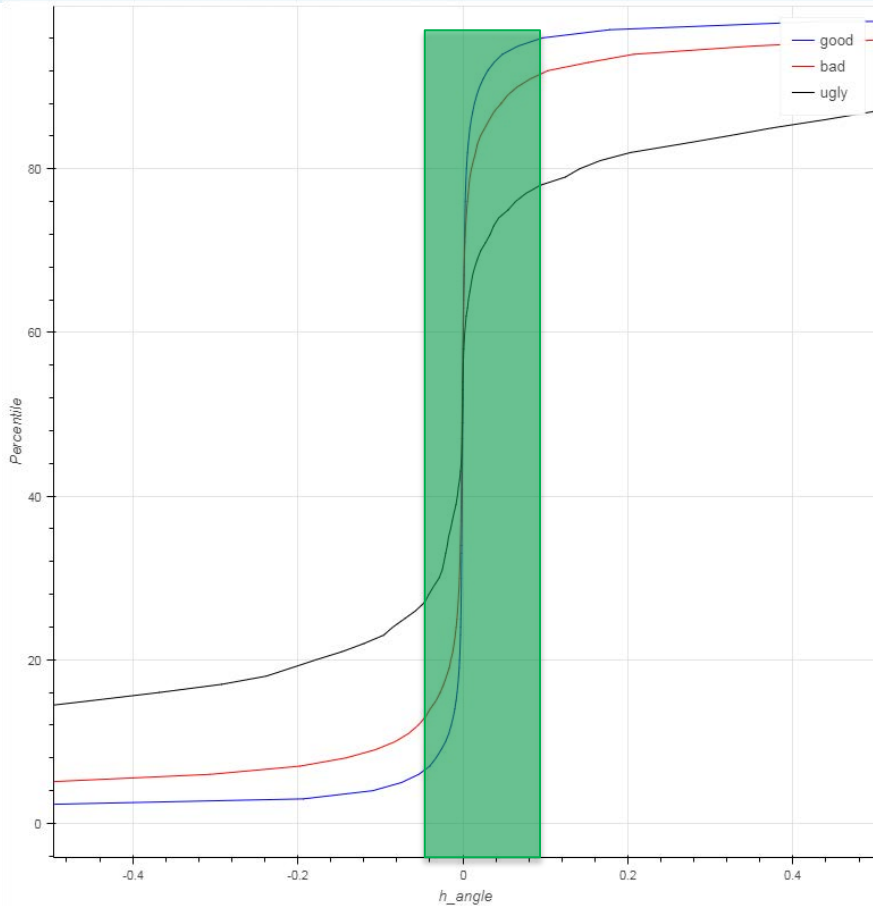
Factors in Turning: Vertical Velocity (m/s):



- 90% Good: Vertical Velocity $-2.5\text{m/s} \leq \text{VV} \leq 4.32$



Factors in Turning: Rotation (degrees/s)



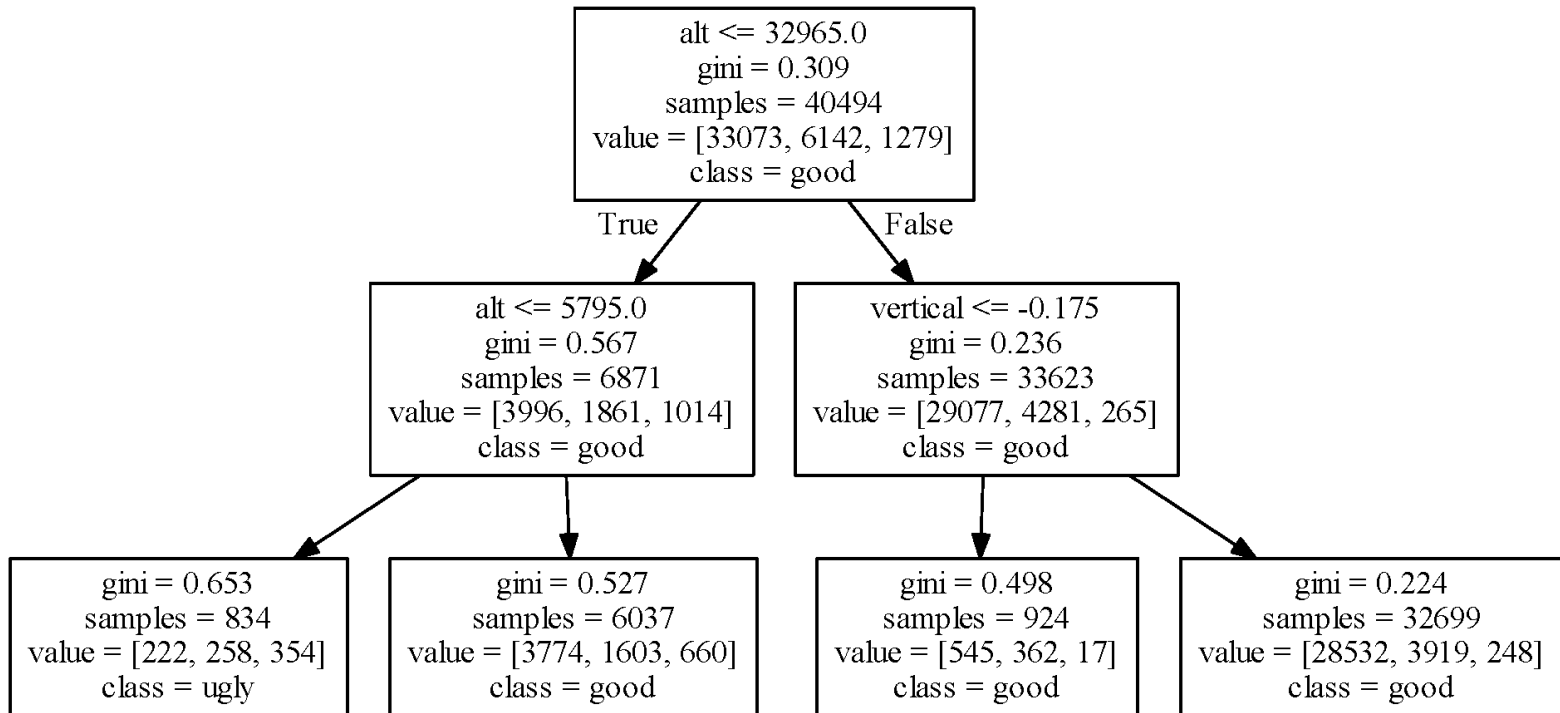
- 90% Good: Rotation $-0.05 \text{deg/s} \leq R \leq 0.1 \text{deg/s}$



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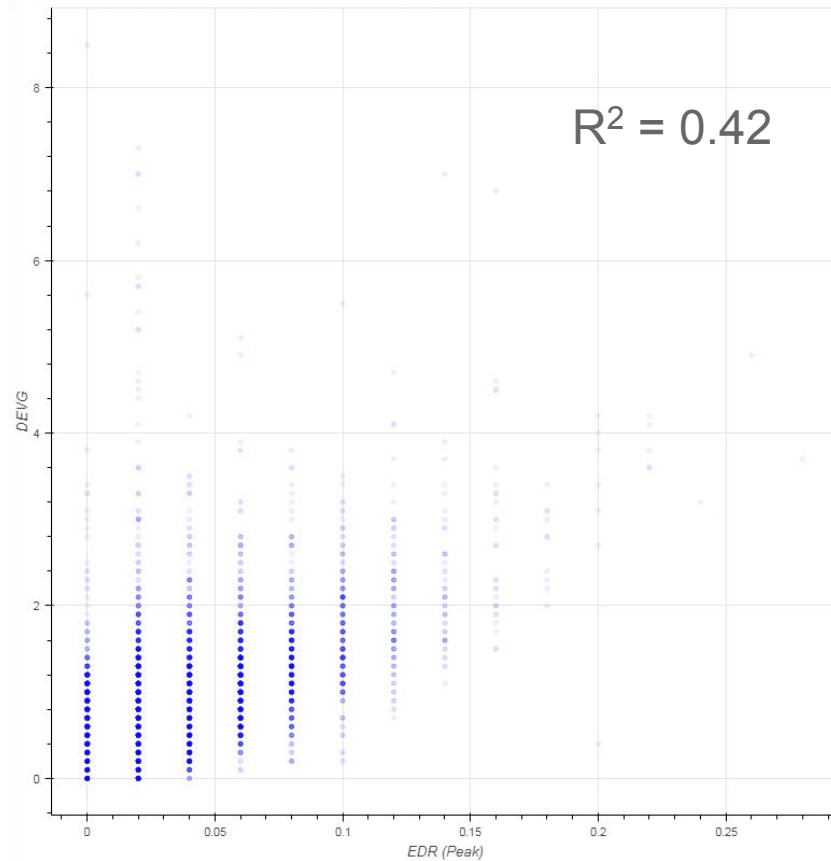
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Factors in Turning: Decision Tree





Factors in Turning: Decision Tree



- Altitude > 32965ft = Most effective Measure



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Now the why....

FAA Data: People injured due to turbulence

A serious injury is “any injury that (1) requires the individual to be hospitalized for more than 48 hours, commencing within seven days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second-or third-degree burns, or any burns affecting more than five percent of the body surface.”

Year	Passenger	Crew	Total
2002	35	12	47
2003	19	27	46
2004	6	11	17
2005	9	9	18
2006	6	8	14
2007	5	20	25
2008	14	14	28
2009	71	23	94
2010	41	14	55
2011	6	23	29
2012	9	16	25
2013	9	4	13
2014	22	9	31
2015	7	14	21
2016	32	12	44
2017	12	5	17

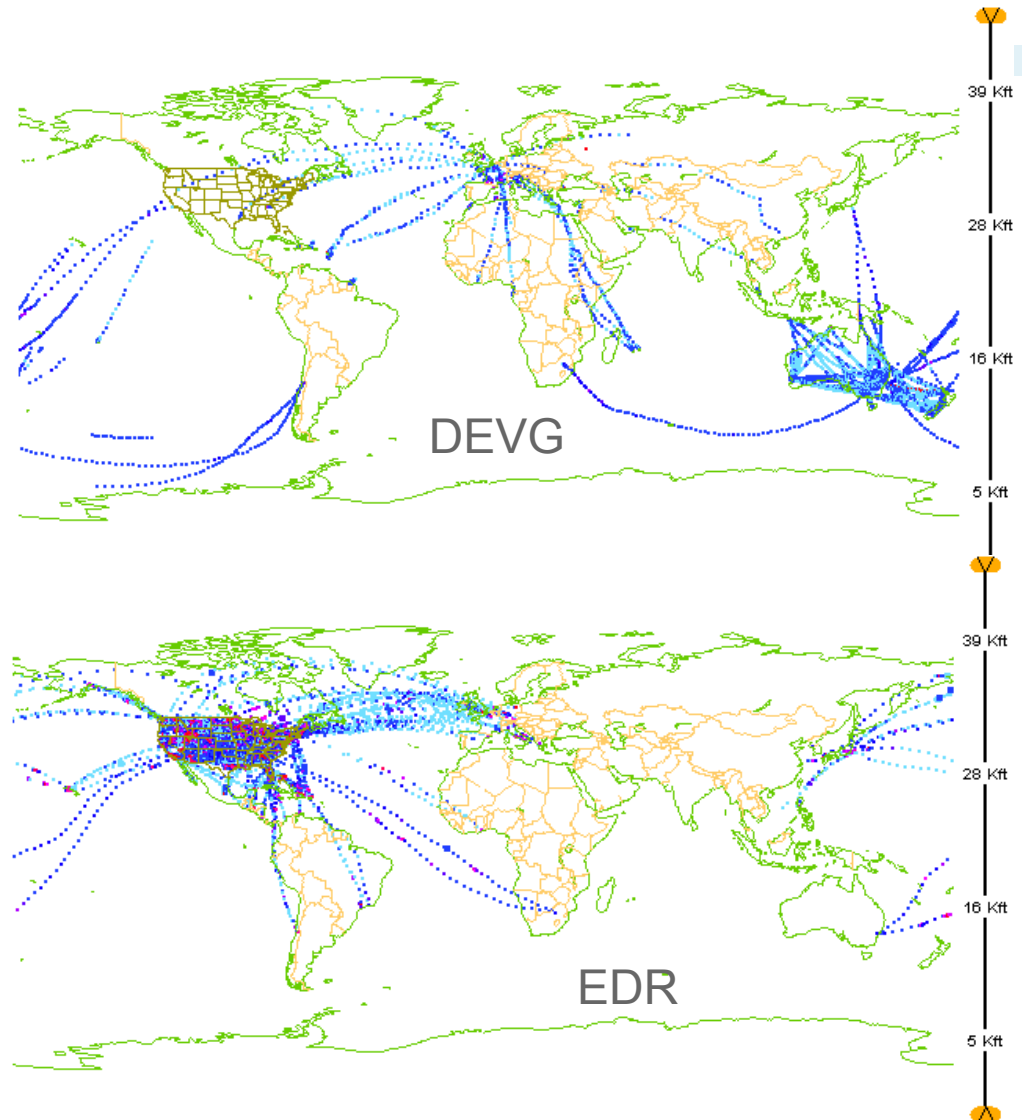


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Now the why....

- Better modelling/forecasting of Turbulence required.
- Need a way to use existing Turbulence data – what is 'real' and what is turning/maneuvering





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Thank you...

Presenter's name
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Email@bom.gov.au