ABO Workshop

Turbulence Monitoring

ECMWF, Reading UK

12-13th February 2020

Stewart Taylor

Technical Co-ordinator

EUMETNET-Aircraft Based Observations (E-ABO)

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Presentation Content

1. Overview of turbulence,
2. Brief summary of turbulence measurements,
3. Current data coverage,
4. EDR data monitoring and product production,
5. Planned implementations.

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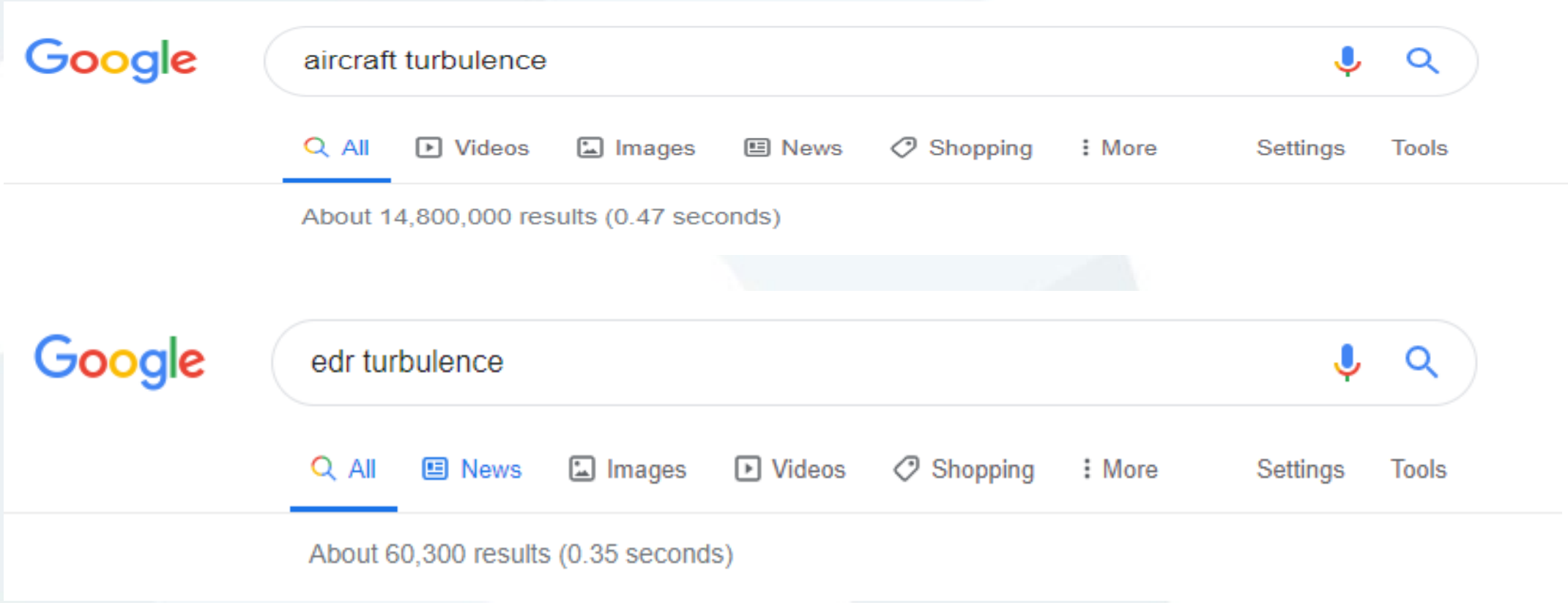
Overview of turbulence 1



Turbulence is one of the most unpredictable of all the weather phenomena and although aircraft are built to withstand turbulence there is still a big impact to operations – crew/passenger safety, routing and associated fuel costs and aircraft structural damage…

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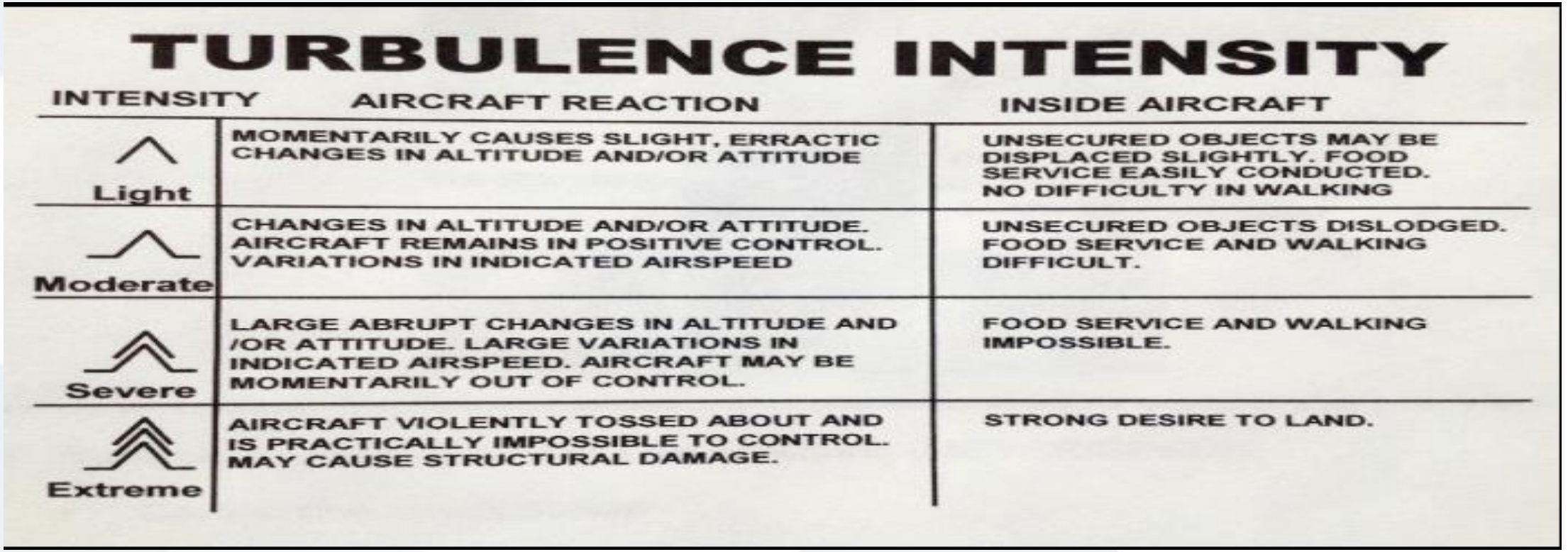
Overview of turbulence 2



TURBULENCE INTENSITY

INTENSITY	AIRCRAFT REACTION	INSIDE AIRCRAFT
Light	MOMENTARILY CAUSES SLIGHT, ERRACTIC CHANGES IN ALTITUDE AND/OR ATTITUDE	UNSECURED OBJECTS MAY BE DISPLACED SLIGHTLY. FOOD SERVICE EASILY CONDUCTED. NO DIFFICULTY IN WALKING
Moderate	CHANGES IN ALTITUDE AND/OR ATTITUDE. AIRCRAFT REMAINS IN POSITIVE CONTROL. VARIATIONS IN INDICATED AIRSPEED	UNSECURED OBJECTS DISLODGED. FOOD SERVICE AND WALKING DIFFICULT.
Severe	LARGE ABRUPT CHANGES IN ALTITUDE AND /OR ATTITUDE. LARGE VARIATIONS IN INDICATED AIRSPEED. AIRCRAFT MAY BE MOMENTARILY OUT OF CONTROL.	FOOD SERVICE AND WALKING IMPOSSIBLE.
Extreme	AIRCRAFT VIOLENTLY TOSSED ABOUT AND IS PRACTICALLY IMPOSSIBLE TO CONTROL. MAY CAUSE STRUCTURAL DAMAGE.	STRONG DESIRE TO LAND.

These classifications of turbulence intensity are “subjective” and a need for “objective and quantifiable” i.e. measured turbulence is required.

https://edition.cnn.com/videos/us/2019/06/18/airplane-turbulence-flight-attendant-mxp-vpx.hln

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Turbulence measurements 1

- The *eddy dissipation rate* (EDR) first suggested in 1964 as a metric of turbulence intensity.
- In 1985, the Australians implemented a turbulence reporting system (as part of AMDAR), based on the Derived Equivalent Gust Velocity (DEVG),
- FAA sponsored National Center for Atmospheric Research (NCAR) to develop an “in-situ” turbulence measurement using existing sensors, avionics and communications networks.
- In 1997, UAL implemented RMS-g based EDR algorithm developed by NCAR.

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Turbulence measurements 2

- GADS (DEVG) database started in the 1990s.
- ICAO adopted EDR as standard metric for atmospheric turbulence reporting (2001)
- 2005, EDR was implemented on the NWS Experimental ADDS (Aviation Digital Data Service).
- 2006, EDR incorporated into GTG2 (Graphical Turbulence Guidance product, vers. 2).
- Operational in 2010.
- 2008, DAL deployment of NCAR's wind-based EDR algorithm.
- EDR in-situ measurements "remove the subjectivity of manual PIREPs"
- Development of forecast products/verification tools.

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Turbulence measurements 3

- EDR is the index-based metric for reporting aircraft turbulence,
- Is included in Annex 3 - *Meteorological Service for International Air Navigation* since Amendment 72 (2001),
- EDR values were revised for Amendment 74 (2007) as an improved algorithm had been developed - results indicated that the EDR thresholds for reporting turbulence should be revised,
- Scientific studies of over 100 million aircraft turbulence reports have shown that EDR values in Annex 3 require another revision .

MEETING OF THE METEOROLOGY PANEL (METP)

FOURTH MEETING

Montréal, 10 to 14 September 2018

Agenda Item 6: Meteorological Operations Group
4.4: World area forecast system

PROPOSED REVISION TO EDDY DISSIPATION RATE (EDR) VALUES IN ANNEX 3

(Presented by Colin Hord – Rapporteur MET Operations Group)

SUMMARY

This paper presents revised values of eddy dissipation rate (EDR) for aircraft turbulence within Annex 3 to be consolidated with other changes for Amendment 79 to Annex 3 (applicable November 2020).

Action by the METP/4 is in paragraph 4.

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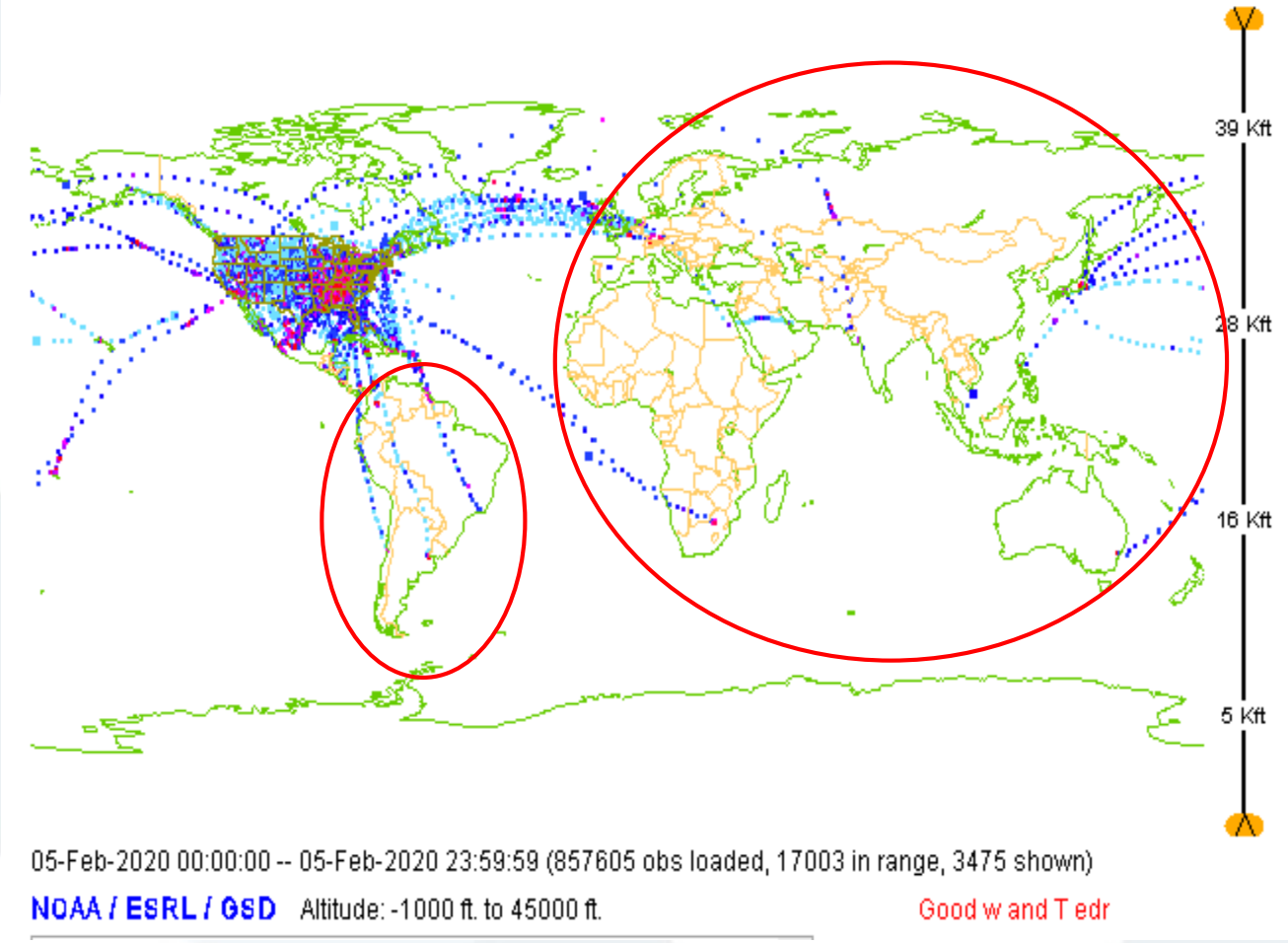
Data coverage 1



- There are 200+ aircraft reporting worldwide and an average of ~17,000 reports per day.
- Continued development and “buy-in” from airlines will assist in further data coverage.

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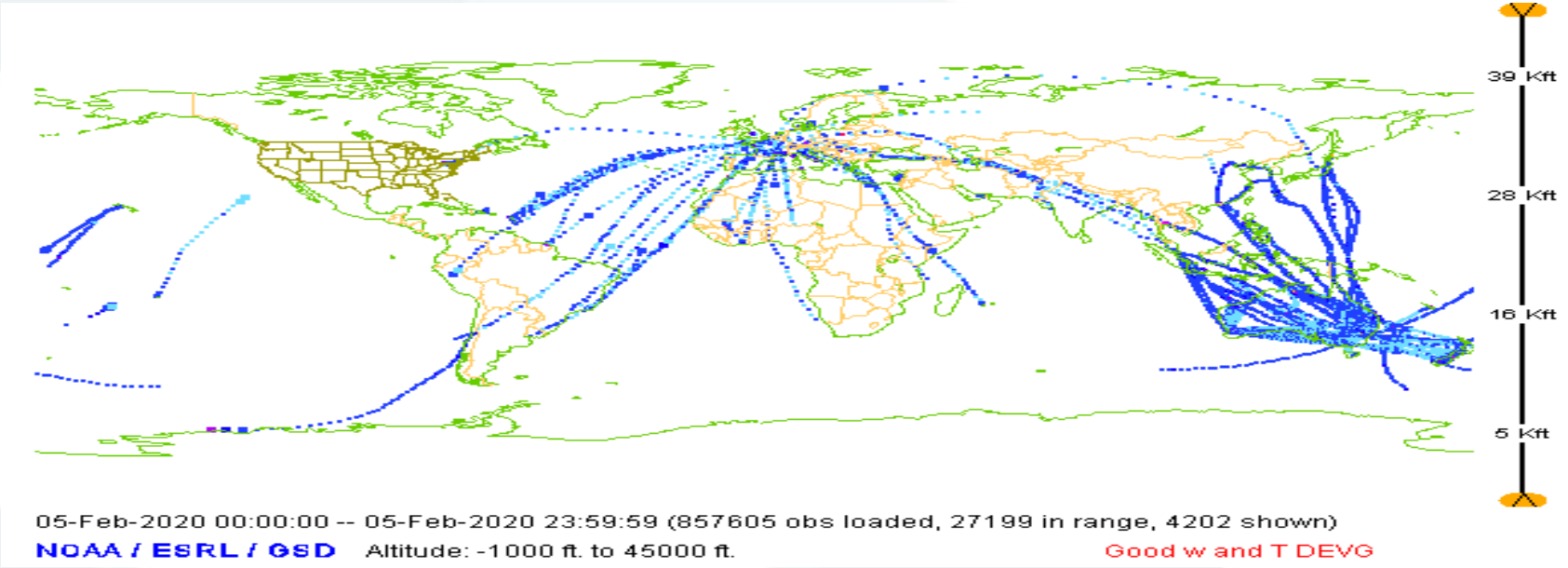
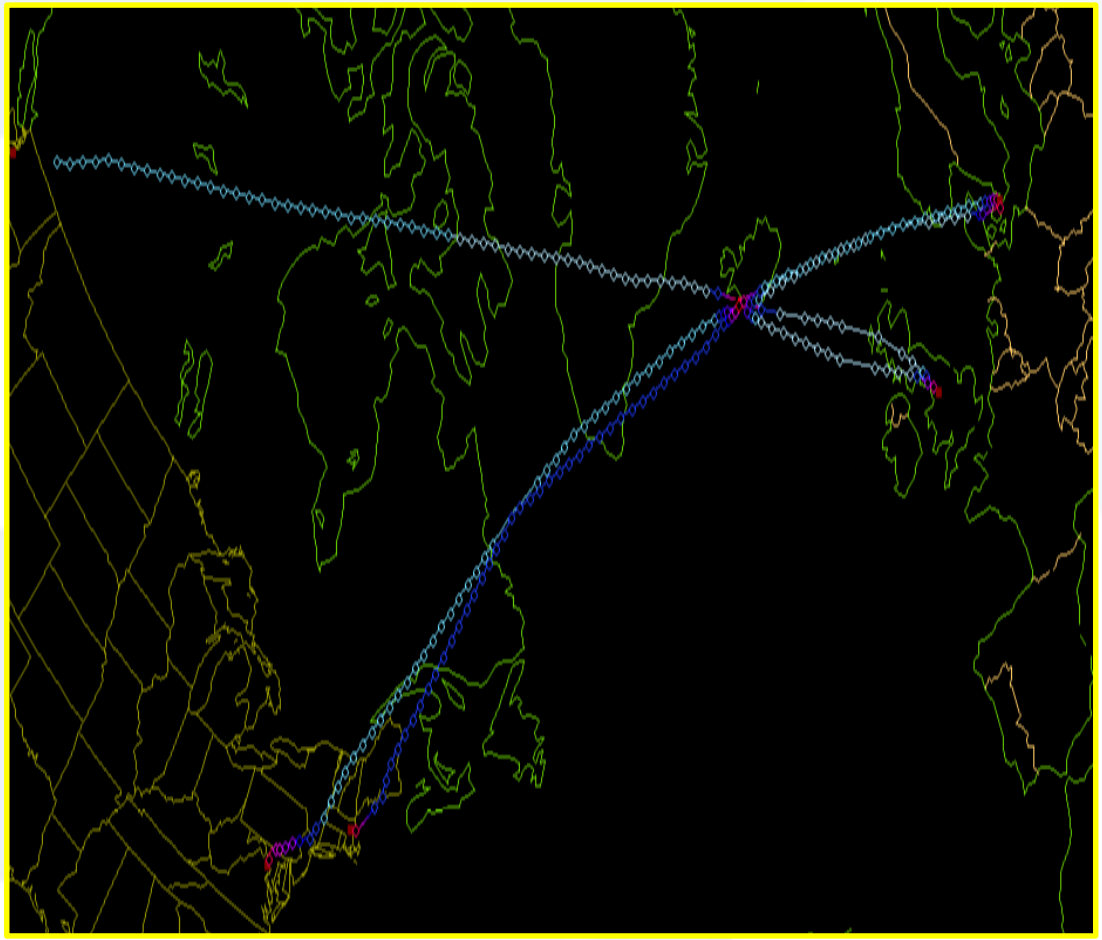
Data coverage 2

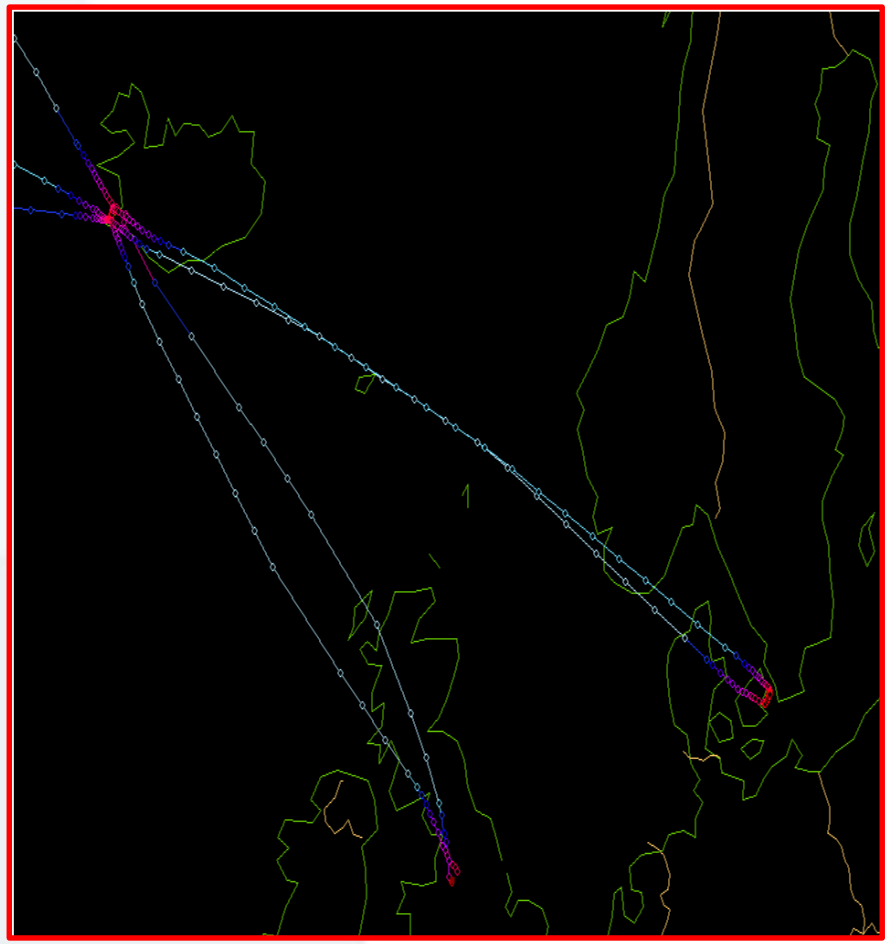


- Another turbulence metric is *derived vertical gust* (DEVG), defined as the instantaneous vertical gust velocity which, superimposed on a steady horizontal wind, would produce the measured acceleration of the aircraft. The effect of a gust on an aircraft depends on the mass and other characteristics, but these can be taken into account so that a gust velocity can be calculated which is independent of the aircraft.

- There are currently ~350 aircraft reporting DEVG worldwide and an average of ~20,000 reports per day.

Data coverage 3





TAMDAR – several airlines globally reporting EDR as part of the sensor array e.g Icelandair B757

Data coverage 4

EDR reporting airlines:

Delta Airlines:

Teledyne ACMS -916: B737NG, B767-300/400 [work done by Delta]

Boeing ACMS AIMS-2: B777 [work done by Boeing]

Southwest Airlines:

Teledyne -916 B737NG [work done by Teledyne]

United Airlines:

Boeing ACMS AIMS-2: B777, B787 [work done by Boeing]

Xiamen Airlines:

Teledyne ACMS -916: B737NG [work done by Delta and Xiamen]

Current list of compatible avionics:

Boeing AIMS-2

Teledyne ACMS -916

Honeywell ACMS -50x

Current compatible aircraft types:

B737NG (Teledyne -916; Honeywell -50x)

B767-300/400 (Teledyne -916)

B777 (Boeing AIMS-2)

B787 (Boeing AIMS-2)

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Data monitoring and products 1

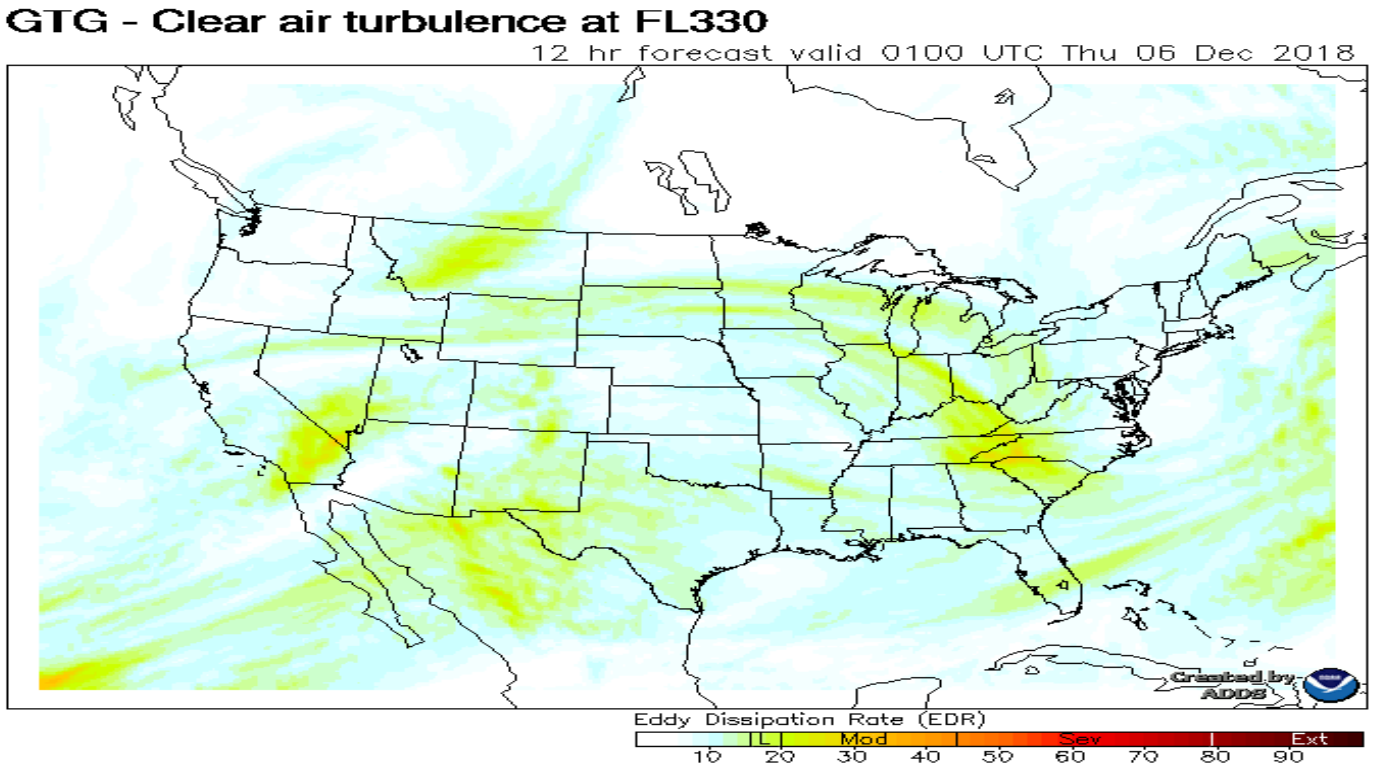
GTG: Graphical Turbulence Guidance (NOAA)

AVIATION WEATHER CENTER
NOAA NATIONAL WEATHER SERVICE

Local Forecast Go HOME ADVISORIES FORECASTS OBSERVATIONS TOOLS NEWS SEARCH ABOUT USER

Current GTG Forecast Turb. Home GTG Forecast Info

Aircraft: Medium Plot: CAT Vert. level: FL330 Time: 12hr - 01Z 06 Dec



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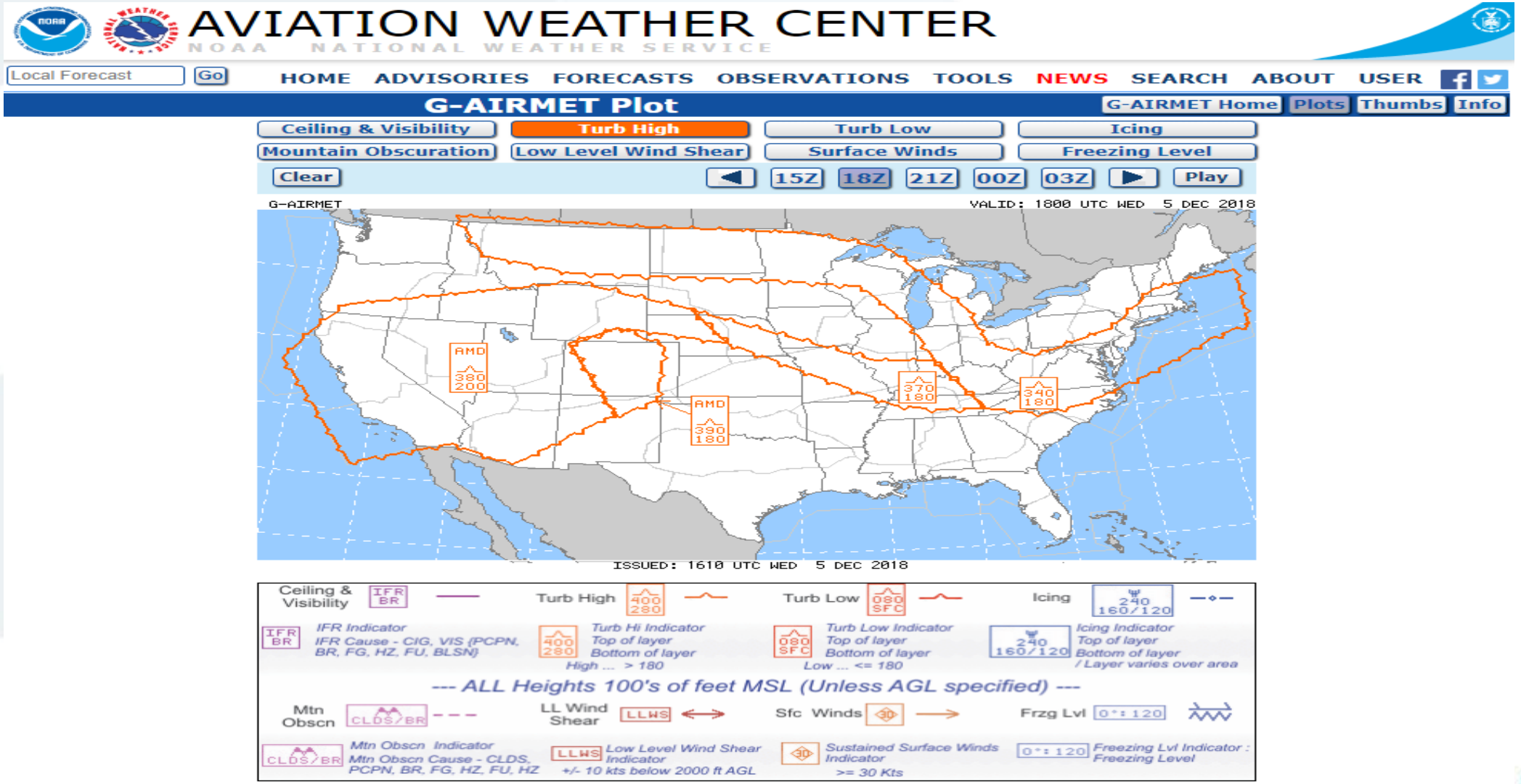
Data monitoring and products 2



Data monitoring and products 3

DRAFT COPY

Met Office

WAFC turbulence nowcasting using EDR observations

March 28, 2018

2.2 EDR Observations

The EDR observations are provided to the Met Office by Airbus, taken from approximately 24 EasyJet aircraft based out of Switzerland. The data spans from 23^{rd} Jan 2017 to 21^{st} Dec 2017 and data interval is roughly every 10 seconds. Figure 1 shows the spatial coverage of the data set. There are 3899718 out of 9124064 records within the useful range of $100 - 450\ hPa$.

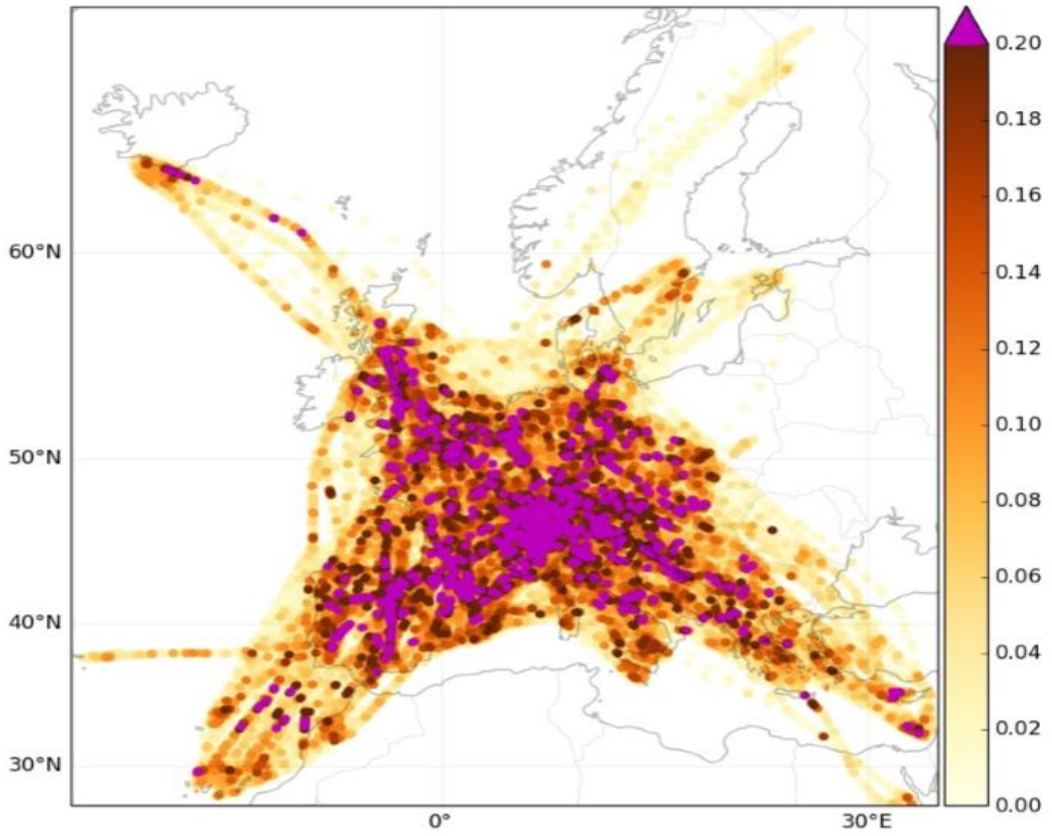


Figure 1: Spatial coverage of EDR observations $[m^2 s^{-3}]$.

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Data monitoring and products 4

ENSEMBLE TURBULENCE FORECASTING TRIAL

- Turbulence can come from different sources, those included in this trial are wind shear and convection
- Wind shear indicators – Ellrod TI (Figure 4), Ellrod TI2, Brown, Dutton, Lunnon
- Convection indicators – Convective rainfall rate, Convective rainfall accumulation, Richardson number
- Climatology – light and moderate turbulence
- 12-month trial from November 2010-October 2011.

Photos © P Gill

- Included objective verification of deterministic and probabilistic model forecasts
- Global verification to assess T+24 MOGREPS-G forecasts of turbulence
- Verification against automated aircraft observations from the Global Aircraft Data Set (GADS) Figure 5

GADS

- British Airways fleet of Boeing 747-400 aircraft
- Global coverage, but flight mainly over northern hemisphere
- Automated aircraft observations available every 4 seconds

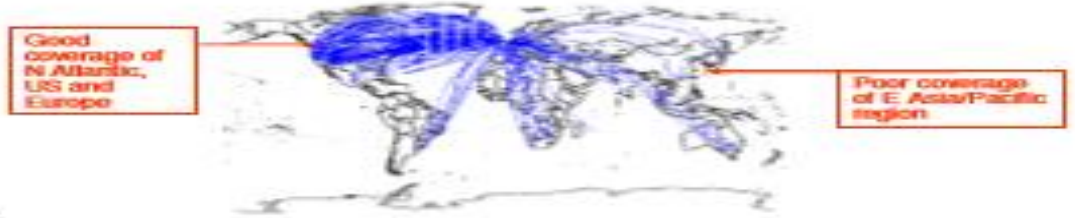

Figure 3. Coverage included in GADS – 10-19 Jan 2009

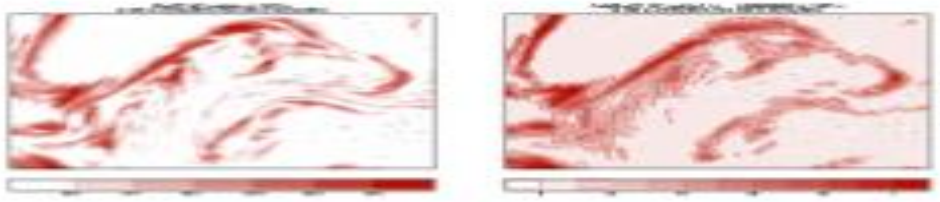

Figure 4. Forecasts for Ellrod TI indicator – deterministic left, probabilistic right

Data monitoring and products 5

ENSEMBLES

- The atmosphere is a chaotic system: *"… one flap of a seagull's wing may forever change the future course of the weather"*, (Lorenz, 1963)

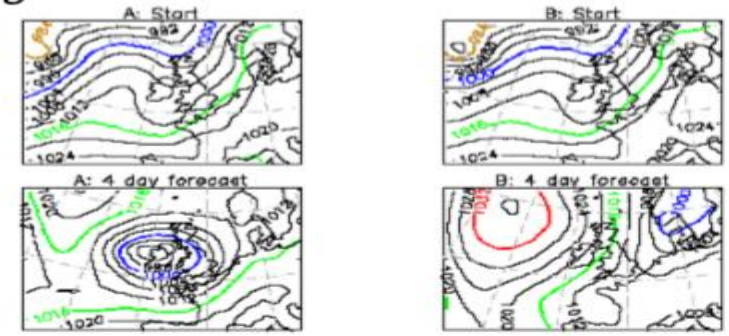

Figure 1. Two forecasts with similar initial conditions

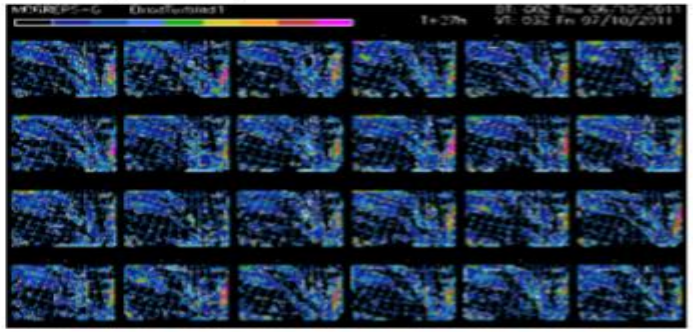

Figure 2. Ensemble postage stamps

- Tiny errors in how we analyse the current state of the atmosphere lead to large errors in the forecast – the two forecasts in Figure 1 are both equally valid 4-day forecasts!
- Ensembles produce probability distributions to try and understand the uncertainty in forecasts by perturbing the initial conditions of a finite set of ensemble members

TRIAL CONFIGURATION

- The Met Office Global and Regional Ensemble Prediction System is used for this trial with regional model MOGREPS-R run twice daily with 24 members (Figure 2 shows member 'postage stamps') at a resolution of 24km over the North Atlantic and Europe
- The global model, MOGREPS-G, is used to provide lateral boundary conditions, run twice daily at a resolution of 90km, 70 levels T+72h

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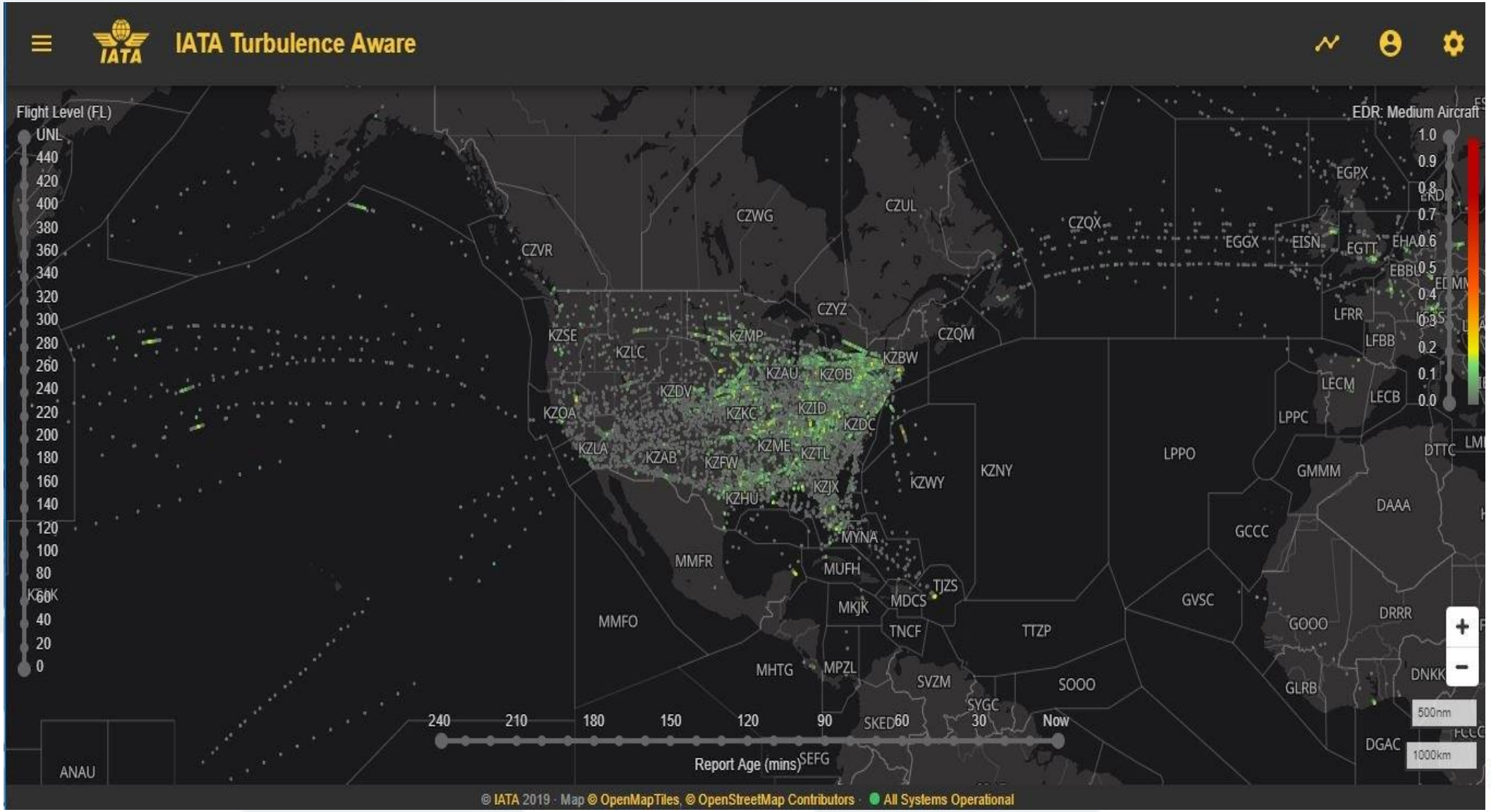
Data monitoring and products – IATA Turbulence Aware Platform 1



Data monitoring and products – IATA Turbulence Aware Platform 2

EDR is calculated using six inputs:

- true airspeed,
- angle of attack,
- pitch,
- pitch rate,
- roll and vertical velocity,
- measured eight times per second.

A detailed report about each data point, including peak EDR values, is then aggregated by a central database maintained by IATA, using Snowflake Software's Laminar Data private cloud.

Access accurate, objective, aircraft-generated data

With objective, automated, in-situ turbulence reports, dispatchers, pilots and cabin attendants can:

- Know exactly where turbulence and smooth air are, and take appropriate action
- Be able to reassure passengers and cabin attendants
- Optimize fuel burn

Contribute to better situational awareness for all

By contributing objective, automated, in-situ turbulence reports, commercial and business aviation can:

- Help provide a more complete picture of atmospheric turbulence
- Improve the accuracy of turbulence data at different altitudes
- Work towards increasing global coverage and eliminating blind spots

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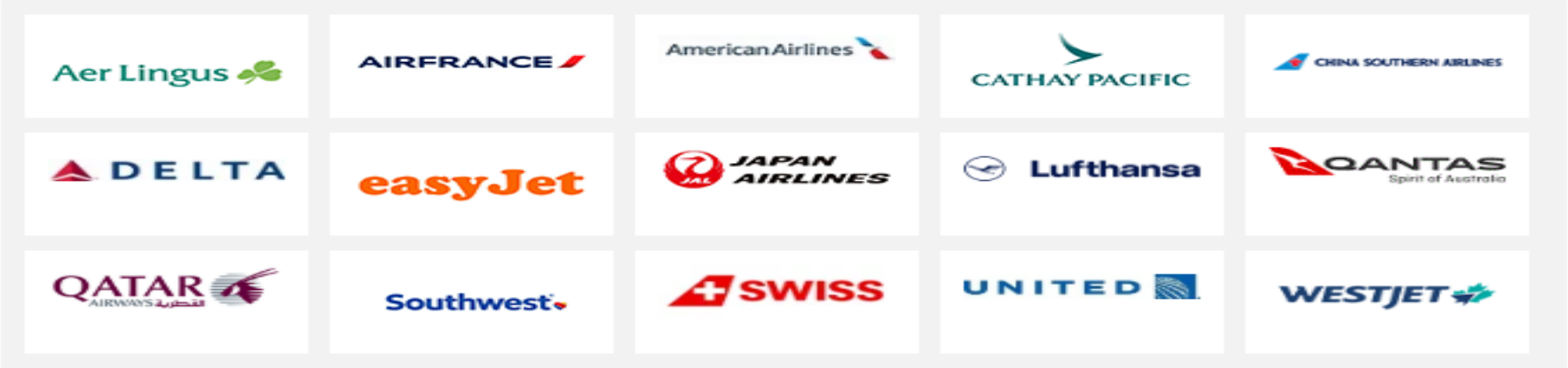
Data monitoring and products – IATA Turbulence Aware Platform 3

Airlines Involved



Boost efficiency and your brand

- **Protect passengers and crew from injury and aircraft from damage** – Accurate information enables pilots and dispatchers to choose optimal flight paths
- **Keep fuel costs down** – Optimal flight altitudes use fuel efficiently
- **Enable continuous improvement of flight operations** – Archived data can be used to carry out strategic, data-driven evaluation of processes and procedures
- **Preserve and improve your reputation** – Smooth flights have a positive impact on the passenger experience and brand perception

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Planned implementations/developments 1

- Air France:
  - Boeing ACMS AIMS-2: B787 and plan to migrate B777 DEVG to EDR
- Delta Airlines:
  - Teledyne ACMS: A321, A330 [work done by Delta]
- Qantas:
  - Teledyne ACMS: A330 [work done by Quantas/AirDatec/Teledyne]
  - EDR implemented on 16 A330-200 and 7 A330-300 aircraft
  - both routine and event EDR and for the routine EDR, DEVG is also being calculated.
  - Not yet on GTS but available soon.
- Lufthansa:
  - EFBs: A330 and/or B747.
  - Project with DWD on WVSS and data communications…
- Aer Lingus:
  - EFBs: A320 and/or A330
- Boeing:
  - Airlines may purchase a Technical Transfer Package (Boeing/Teledyne)
- Other E-AMDAR Airlines:
  - Finnair – airline and NMHS discussions
  - Possibly British Airways…

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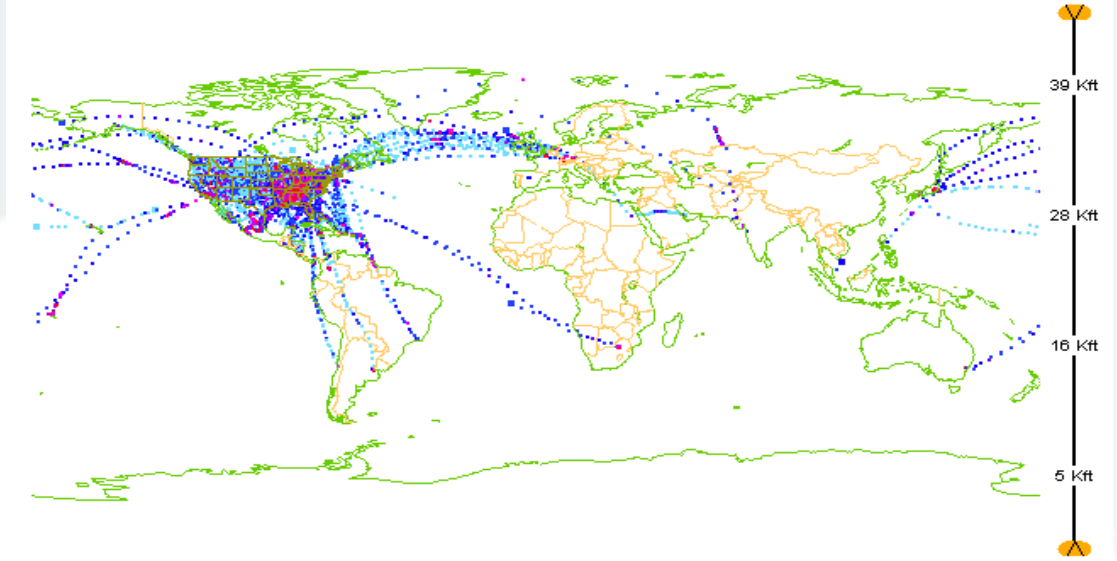
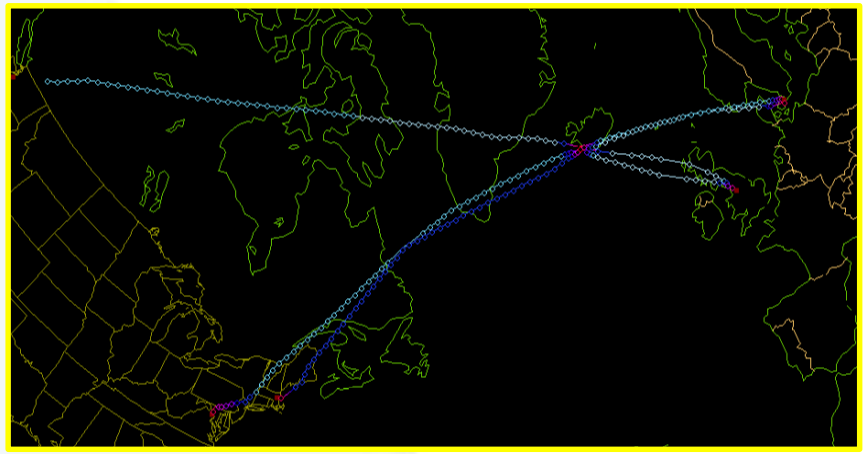
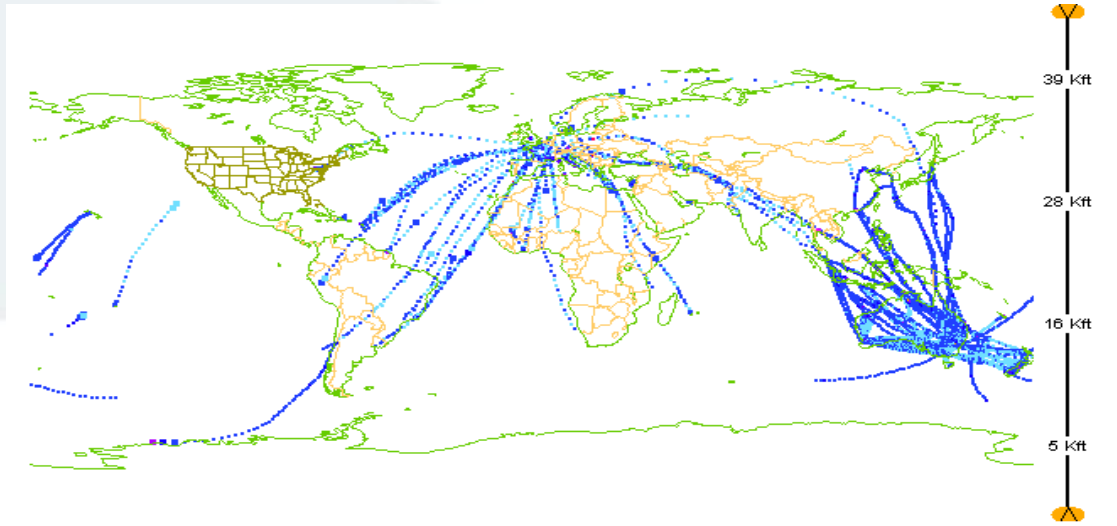
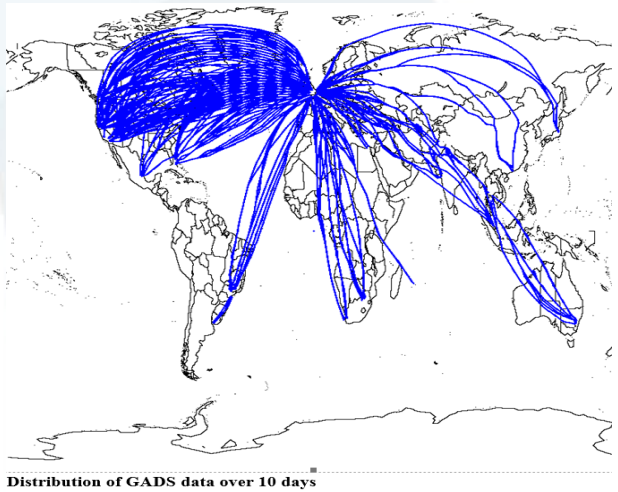
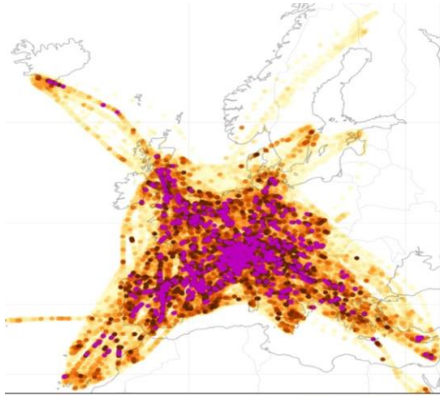
Recap – coverage of turbulence reporting








Distribution of GADS data over 10 days



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