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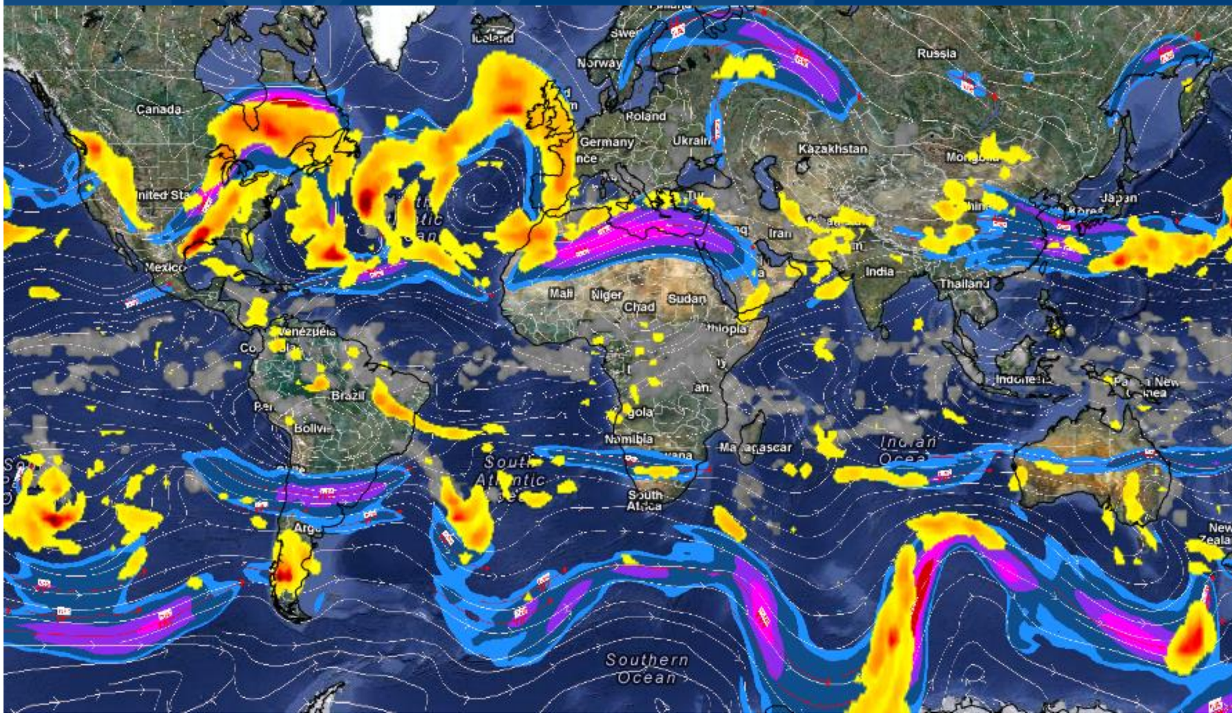

Guidance on the Harmonized WAFS Grids for Cumulonimbus Cloud, Icing and Turbulence Forecasts.

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Contents

1. Introduction

1.1 The World Area Forecast System (WAFS) provides global gridded model forecasts of wind, temperature, relative humidity, turbulence, icing and cumulonimbus (Cb) cloud. The wind, temperature and relative humidity forecasts are available via SADIS 2G, Secure SADIS FTP and WIFS. The Cb cloud, icing and turbulence forecasts are available via Secure SADIS FTP and WIFS. Of these, the temperature and wind forecasts have been operational (through various GRID and GRIB formats) since 1983. Relative humidity was added in 2001. Cb cloud, icing and turbulence forecasts have been operational with effect from November 2013 as part of Amendment 76 to ICAO Annex 3 – Meteorological Service for International Air Navigation.

1.2 This user's guide has been developed by the World Area Forecast Centre (WAFC) Provider States (the United Kingdom and the United States) to provide WAFS users with a general overview of the how the harmonized WAFS GRIB2 data for Cb, icing and turbulence is calculated, and how it can be used.

2. General Description of Data

2.1 The data are made available in WMO GRIB2 format. Details on the format are available via the WAFC London WAFS Upper Air Forecast GRIB2 Dataset Guide, which can be found online.

http://www.icao.int/safety/meteorology/WAFSOPSG/Pages/GuidanceMaterial.aspx

2.2 The target time for availability for wind, temperature and humidity forecasts is 4 hours and 20 minutes after the model data time. For example, the 1200 UTC model data delivery target time is 1620 UTC. For SADIS 2G, which has a slower data rate, the target for delivery is 5 hours after model data time. So, for 1200 UTC model data, the delivery target is 1700 UTC.

2.3 For the forecasts of Cb cloud, icing and turbulence, the target time for the availability of the harmonized forecasts is 4 hours and 35 minutes after the model data time (1). For example, the 1200 UTC model data delivery target time for these parameters is 1635 UTC. To allow for rare occasions where it is not possible for one of the WAFCs to harmonize data, a cut-off time of 4 hours 50 minute will be applied. After that time, un-harmonized data will be issued by the affected WAFC.

2.4 For turbulence and icing, the value associated with a specific flight level (FL) should be considered applicable to the associated vertical layer. For example, a turbulence forecast at 300 hPa (FL300), would also be valid throughout the 50 hPa thick layer centered at 300 hPa, which extends from 325 hPa to 275 hPa.

Table 1 identifies the availability of the Cb cloud, icing and turbulence forecasts by flight level. A full list of all WAFS GRIB2 forecast parameters can be obtained via the WAFSOPSG web pages http://www.icao.int/safety/meteorology/WAFSOPSG/Guidance%20Material/WAFS%20GRIB2%20Specification%20(V5.0).pdf .

[1] Note, this exceeds the requirement in ICAO Annex 3 for delivery of WAFS gridded forecasts to be completed no later than 6 hours after model data time.

Flight Level	Pressure level (hPa)	Mean/Max CAT (50hPa depth, centered at level given)	Mean/Max in-cloud turbulence (100hPa depth, centred at level given)	Mean/Max Icing (100hPa depth, centred at level given)	Height of Cb base/top, and horizontal extent
FL050	850	No	No	No, but base of lowest icing layer starts at this level	N/A, existence at a grid point above the earth's surface will be indicated by the horizontal extent parameter, with height of base and top provided in the Cb base/top fields.
FL060	800	No	No	yes, covering 850-750hPa	
FL100	700	No	yes, covering 750-650hPa	yes, covering 750-650hPa	
FL140	600	No	yes, covering 650-550hPa	yes, covering 650-550hPa	
FL180	500	No	yes, covering 550-450hPa	yes, covering 550-450hPa	
FL240	400	Yes, covering 425-375hPa	yes, covering 450-350hPa	yes, covering 450-350hPa	
FL270	350	Yes, covering 375-325hPa	No, but top of lower layer and base of higher layer meet at this level	No, but top of lower layer and base of higher layer meet at this level	N/A, existence at a grid point above the earth's surface will be indicated by the horizontal extent parameter, with height of base and top provided in the Cb base/top fields.
FL300	300	Yes, covering 325-275hPa	yes, covering 350-250hPa	yes, covering 350-250hPa	
FL320	275	No, but top of lower layer and base of higher layer meet at this level	No, but highest in-cloud turbulence layer includes this level	No, but highest icing layer includes this level	
FL340	250	Yes, covering 275-225hPa	No, but this level is the top of the highest in-cloud turbulence layer	No, but this level is the top of the highest icing layer	
FL360	225	No, but top of lower layer and base of higher layer meet at this level	No	No	
FL390	200	Yes, covering 225-175hPa	No	No	
FL450	150	Yes, covering 175-125hPa	No	No	
FL530	100	No	No	No	

Table 1 Availability of the Cumulonimbus Cloud, Icing and Turbulence parameters by flight level

3. Description of Data Values

3.1 **Clear Air Turbulence (CAT)** – is derived via an algorithm that is based on the Ellrod Index. The index is calculated from the product of horizontal deformation and vertical wind shear derived from numerical model forecast winds aloft. The resulting values provide an objective technique for forecasting clear-air-turbulence (CAT). The theoretical limit to the data range is zero to 99, but over 98 percent of the values will be below 11, and they will rarely exceed 40. The numbers are not a probability, but are instead a potential of encountering turbulence of any severity.

3.2 It is difficult to establish universal thresholds to use when using the gridded data that are applicable to all aircraft types, as aircraft response and pilot perceptions differ greatly.

3.3 However, the limited range of values, combined with verification scores and comparisons to forecaster experience suggests that a value of 6 should be considered as a threshold for moderate or greater turbulence. It is recommended that users develop their own set of thresholds for their specific applications, much the same way that users have unique thresholds for other weather variables, such as surface crosswind components for landings and takeoffs.

3.4 **In-Cloud Turbulence –** The in-cloud turbulence algorithms are based on 1) the model indicating the presence of a cloud, and 2) the change in potential energy with height, which is a measure of instability. There have not been any studies that suggest thresholds to use for these grids. The range of values in the data is from 0 to 1 and are a potential for encountering in-cloud turbulence.

3.5 **Icing** – The icing algorithms are based on a combination of cloud condensate (ice and water), temperature, relative humidity and vertical motion parameters that predict the presence of super-cooled liquid water. The values range from 0 to 1 and are a potential for the presence of icing.

3.6 Values have not been calibrated to the probability of icing, but one study(2) does suggest that 0.1 should be used as a threshold for trace icing which could be used for Extended Diversion Time Operations (EDTO) (formally known as ETOPS) fuel use planning. This is because it provides a better determination of icing, with a lower false alarm rate than the alternative (traditional) method of using greater than 55 percent relative humidity with a temperature range from 0 to minus 20 degrees Celsius.

3.7 **Cumulonimbus Clouds** – the Cb cloud algorithm gives information relating to base, top and horizontal extent (coverage) of any expected Cb clouds. The horizontal extent component is expressed as a value between 0 and 1, representing the fraction of sky covered by Cb cloud within a grid cell. Where a Cb cloud is forecast to exist, a base and a top of the Cb cloud is represented by a height that can be converted into a flight level. The algorithm is based on convective rainfall rates.

4. Grid Interpolation

4.1 The WAFS gridded forecasts outlined at 1.1 above are provided on a 1.25 degree regular grid, which gives a 75 x 75 nautical mile grid box at the equator, with the grid boxes becoming progressively smaller towards the poles. The WAFS grid boxes are comparatively much larger than the grid box sizes from the native global models from which the WAFS data is generated. Therefore, the native global model data must be interpolated to fit into the larger grid box size of the WAFS grid.

Although greatly simplified, the process can be visualized by considering the 2 dimensional schematic below, representing a 1.25 degree grid box, with smaller grid boxes inside it from the native global model.

5	7	5	2	0
7	10	7	5	0
5	7	5	2	0
2	5	2	0	0
0	0	0	0	0

[2] http://www.icao.int/safety/meteorology/WAFSOPSG/WAFSOPSG%20Meetings%20Metadata/WP%2014.pdf

In the above schematic, the mean value for the WAFS grid box would be 76 divided by 25, or 3.04 which is rounded to 3. The maximum value for the WAFS grid box would be 10.

5. Description of the Harmonization Process

5.1 The Cb cloud, icing and turbulence forecasts actually consist of harmonized versions of the individual forecasts produced by each WAFC. This methodology is an example of an ensemble approach that has proven to improve WAFS forecast quality by combining output from different models.

5.2 Both WAFCs use the same process to harmonize the WAFC gridded forecasts. The raw forecasts (i.e. raw model output) for Cumulonimbus cloud, icing and turbulence in GRIB2 format are exchanged by the WAFCs as soon as they are available. These forecasts are:

- Mean CAT potential
- Maximum CAT potential
- Mean icing potential
- Maximum icing potential
- Mean in-cloud turbulence
- Maximum in-cloud turbulence
- Cb horizontal extent
- Cb cloud top height
- Cb cloud base height

5.2.1 The harmonization process is performed for these parameters at the applicable pressure levels and all forecast time steps (i.e. T+6 to T+36 at 3-hour increments). The method for harmonizing the forecasts is different depending on the parameter that is being combined, as explained below.

5.3 Mean forecasts (CAT, icing, in-cloud turbulence)

5.3.1 The harmonized mean clear-air turbulence (CAT), icing and in-cloud-turbulence forecasts are derived by taking the 'mean of the mean' values of the WAFC London and WAFC Washington forecasts for each grid box.

5.4 Maximum forecasts (CAT, icing, in-cloud turbulence)

5.4.1 The harmonized maximum clear-air turbulence (CAT), icing and in-cloud-turbulence forecasts are derived by taking the higher value of the maximum values from each of the WAFC London and WAFC Washington forecasts for each grid box.

5.5 Cb forecasts

5.5.1 The Cb horizontal extent forecasts are harmonized by taking the higher value of the WAFC London and WAFC Washington forecasts for Cb horizontal extent at each 1.25 degree grid.

5.5.2 The Cb base height forecasts are harmonized by taking the lower value of the WAFC London and WAFC Washington forecasts for Cb base and height at each grid box.

5.5.3 The Cb top height forecasts are harmonized by taking the higher value of the WAFC London and WAFC Washington forecasts for Cb top height at each grid box.

6. <u>Explanation of differences between the WAFS gridded forecasts for CB cloud, icing and turbulence and the WAFS significant weather (SIGWX) forecasts</u>

6.1 Users will notice that maximum values in the CB cloud, icing and turbulence forecasts will not always correlate one-to-one with the equivalent parameters included in the graphical WAFS significant weather (SIGWX) forecasts. Reasons for such differences are:

- WAFS SIGWX forecasts, prepared by WAFC forecasters, are for a single validity time (based on T+24 data) and are released about 17 hours before validity; whereas the WAFS gridded forecasts for CB cloud, icing and turbulence covering a period of 6 to 36 hours are re-generated after every model run. As a consequence, the WAFS gridded forecasts are likely to deviate, to some degree, from the equivalently time-stamped WAFS SIGWX forecast that was based upon a single earlier model run.

- The WAFS GRIB2 forecasts for icing and turbulence are provided for discrete layers of the atmosphere and those discrete layers may exhibit distinct differences. The available capabilities of the WAFS SIGWX forecasts, prepared by WAFC forecasters, means that the representation of areas of moderate and/or severe icing and turbulence have to be simplified to a certain extent, particularly in the vertical.

- WAFS SIGWX forecasts and WAFS gridded forecasts for CB cloud, icing and turbulence are actually different types of forecasts. The WAFS SIGWX forecasts are a deterministic forecast. As such, they are simply a binary 'yes' or 'no' forecast as to the expected presence of adverse conditions. Whereas, the WAFS gridded forecasts are similar to a probabilistic forecast that gives the user a measure of the potential for encountering the parameter.

- The WAFS gridded forecasts do not indicate the severity of the parameter. Intuitively, the higher the gridded potential value, the more likely that the parameter could be severe. However, more detailed study is needed before potential can be directly related to severity.

- WAFS SIGWX forecasts represent Cb, icing and turbulence differently than the WAFS gridded forecasts. The WAFS gridded forecasts contain forecasts of all Cb cloud, icing and turbulence. The WAFS SIGWX forecasts have a more restrictive set of criteria to determine the extent to which a parameter is included in the forecasts. The differences are described in the tables below.

Clear Air Turbulence (CAT)	
CAT as identified in WAFS SIGWX forecasts	**CAT as identified in WAFS gridded forecasts**
MOD CAT	Provides numerical value indicating 'potential' for clear air turbulence
SEV CAT	

Table 2 Differences between representation of CAT in WAFS SIGWX forecasts and in WAFS gridded forecasts (WMO GRIB 2 code form)

In-Cloud Turbulence	
In-cloud turbulence as identified in WAFS SIGWX forecasts	**In-cloud turbulence as identified in WAFS gridded forecasts**
MOD/SEV TURB in CB cloud (implicit)	Provides numerical value indicating 'potential' for in-cloud turbulence
MOD TURB in non-CB cloud	
SEV TURB in non-CB cloud	

Table 3 Differences between representation of in-cloud turbulence in WAFS SIGWX forecasts and in WAFS gridded forecasts (WMO GRIB 2 code form)

Icing	
Icing as identified in WAFS SIGWX forecasts	**Airframe Icing as identified in WAFS gridded forecasts**
MOD/SEV ICE in CB cloud (implicit)	Provides numerical value indicating 'potential' for icing conditions.
MOD ICE in non-CB cloud	
SEV ICE in non-CB cloud	

Table 4 Differences between representations of Icing in WAFS SIGWX forecasts and in WAFS gridded forecasts (WMO GRIB 2 code form)

Cumulonimbus Cloud	
Cumulonimbus cloud forms identified in WAFS SIGWX forecasts	**Cumulonimbus cloud as identified in WAFS gridded forecasts**
ISOL EMBD CB	Provides numerical value representing fraction of sky covered by CB cloud
OCNL CB	
OCNL EMBD CB	
FRQ CB	

Table 5 Differences between representations of Cumulonimbus cloud in WAFS SIGWX forecasts and in WAFS gridded forecasts (WMO GRIB 2 code form)

7. Suggested usage of WAFS gridded forecasts for Cb cloud, icing and turbulence

7.1 General principles

7.1.1 Verification studies and comparison with forecaster tools, conducted by the WAFCs, have resulted in some suggested threshold values that can be used to minimize the risk of encountering an aviation hazard such as CB cloud, icing and turbulence. Such threshold values should be used only for identifying potential areas of the hazard parameter during the flight planning process, since the coarse resolution of the WAFS gridded forecasts excludes them from use as a tactical decision aid during flight. An example of their short comings as a tactical decision aid was demonstrated by a study undertaken by Hong Kong, China in 2011 and 2012[3], which demonstrated how the WAFS gridded forecasts only give a general location of turbulence, and can fail if used pixel by pixel to evaluate turbulence, especially if the turbulence is not jet stream related.

[3] Reported to the 16th Meeting of the ICAO Asia-Pacific Planning and Implementation Regional Group Communication, Navigation and Surveillance/Meteorology Sub-Group (APANPIRG CNS/MET SG/16)

The following sections will discuss the usage for the various types of WAFS gridded forecasts. They will also provide visualization examples and verification, where available.

7.2 **Use of the WAFS Clear Air Turbulence (CAT) gridded forecast**

7.2.1 Verification studies conducted by the WAFCs show that the max grid has more skill than the mean grid, so it is recommended that the max grid be used for planning purposes, and the mean grid (which is an average of the WAFC London and WAFC Washington grid) be used to ascertain confidence in the max grid. For example, the closer the mean is to the max, the higher the level of confidence a user should have in the max, because this shows that the WAFC London and WAFC Washington grids are similar. The data distribution noted above, when combined with verification scores noted in figure 2 suggest that a threshold between 4 and 6 should be used for the general location of moderate or greater turbulence. This value also subjectively compares well with forecaster tools used to help prepare the WAFS SIGWX forecasts. Table 6 provides contingency table data relating to WMO North Atlantic Area 2 for T+12 harmonized Maximum CAT forecasts for April 2013 to March 2014 inclusive. Users can access harmonized CAT contingency tables for a range of WMO Areas for T+12, T+24 and T+36 via the WAFC London Performance Indicators Website - http://www.metoffice.gov.uk/public/weather/aviation-wafc/#?tab=wafcPerformance. The 'drop down' boxes permit selection of parameter and timestep. Simply select CAT-Maximum from the 'Parameter' menu.

Contingency Tables for North Atlantic - Area 2

Threshold	Hits	False Alarms	Miss	Correct Rejection	Hit Rate	False Alarm Rate
10.99882984	61	13398	150	496266	0.2891	0.0263
8.96586037	88	26795	123	482869	0.4171	0.0526
7.85658979	107	40193	104	469471	0.5071	0.0789
7.11425018	124	53590	87	456074	0.5877	0.1051
6.58549976	137	66988	74	442676	0.6493	0.1314
6.15693998	144	80385	67	429279	0.6825	0.1577
5.80721998	151	93783	60	415881	0.7156	0.1840
5.51400995	156	107181	55	402483	0.7393	0.2103
5.25961018	161	120577	50	389087	0.7630	0.2366
5.03885984	162	133975	49	375689	0.7678	0.2629
4.83832979	163	147372	48	362292	0.7725	0.2892
4.65993023	166	160770	45	348894	0.7867	0.3154
4.49637985	170	174170	41	335494	0.8057	0.3417
4.33997011	173	187565	38	322099	0.8199	0.3680
4.19832993	177	200963	34	308701	0.8389	0.3943
4.05902004	182	214359	29	295305	0.8626	0.4206
3.91680002	184	227762	27	281902	0.8720	0.4469
3.77750993	188	241154	23	268510	0.8910	0.4732
3.60706997	190	254553	21	255111	0.9005	0.4995
3.35284996	190	267949	21	241715	0.9005	0.5257
3.02640009	191	281347	20	228317	0.9052	0.5520
2.65439010	193	294744	18	214920	0.9147	0.5783
2.25264001	196	308143	15	201521	0.9289	0.6046
1.84303010	196	321538	15	188126	0.9289	0.6309
1.44335997	197	334936	14	174728	0.9336	0.6572
1.05280018	199	348332	12	161332	0.9431	0.6835
0.70931005	199	361729	12	147935	0.9431	0.7097
0.42120001	202	375129	9	134535	0.9573	0.7360
0.16807993	204	388526	7	121138	0.9668	0.7623
0.00000014	206	401923	5	107741	0.9763	0.7886

Table 6 Verification scores (in the form of a contingency table) for a range of thresholds of harmonized maximum CAT, assessed against accelerometer readings on aircraft encountering moderate or greater turbulence. Note: Users should always refer to the data provided on the verification website – the above is provided for illustrative purposes only.

7.2.2 Users should also note that the algorithm will perform best near strong jet streams. Figure 1 is a visualization example of CAT and the jet streams, with the CAT visualization beginning at a CAT potential of 6.

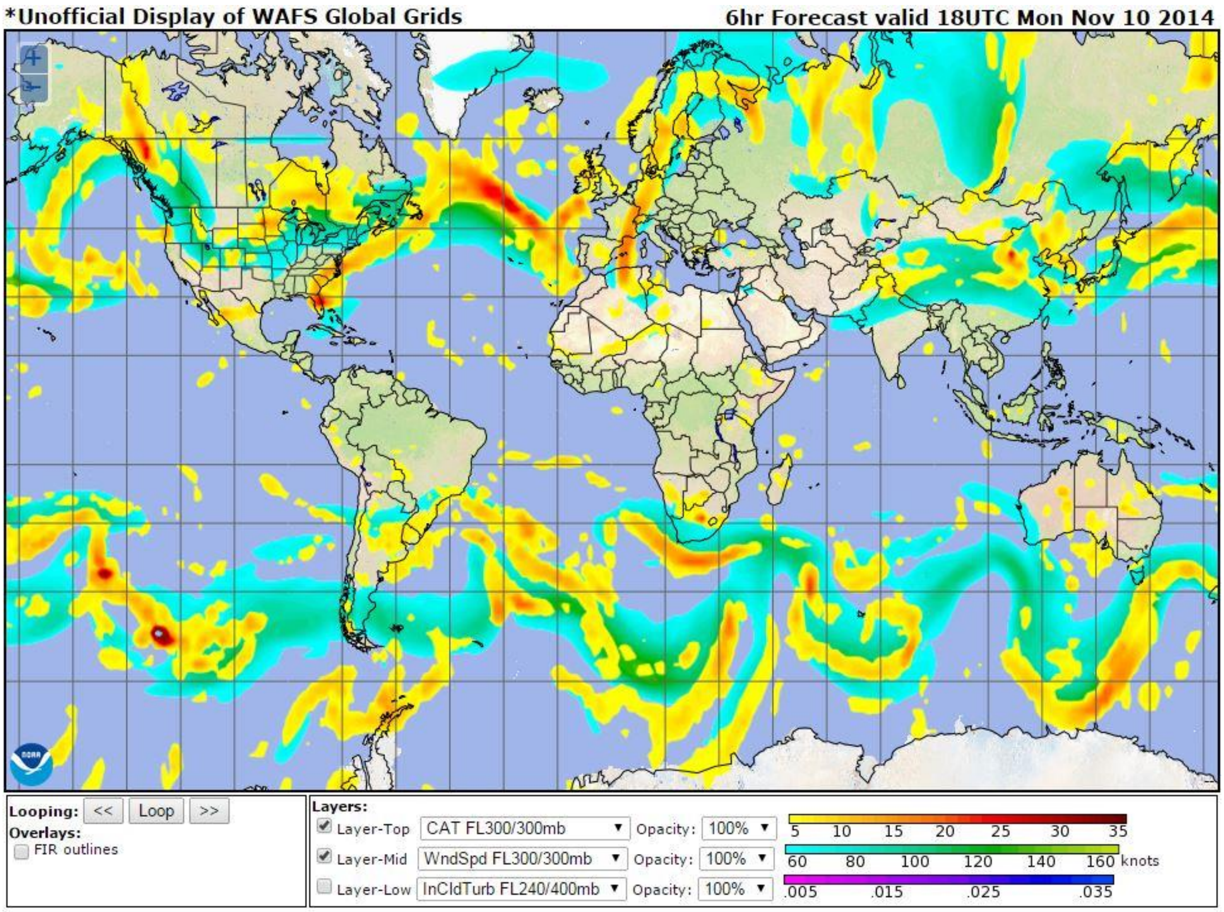

Figure 1 Example of WAFS gridded forecast for clear air turbulence and jet stream locations

7.3 Use of the WAFS icing gridded forecast

7.3.1 The WAFS icing gridded forecast has a range from 0 to 1. It varies by flight level selected, but at FL100, the global data distribution is such that around 70% of the values are zero, 73% of them are less than 0.1, and 92% of them are less than 0.7. The data distribution is skewed farther towards zero as the flight level increases, because the occurrence of icing is less frequent at higher altitudes.

7.3.2 The WAFCs have recommended the use of a threshold of 0.1 in the maximum icing field for the avoidance of icing for EDTO planning. This was based on verification studies, conducted by the WAFCs that indicated this threshold performed better than a traditionally used threshold of 55 percent relative humidity combined with a temperature of zero to minus 20 Celsius. Since presentation of that first study to the WAFSOPSG/6 meeting, further verification studies have been conducted for other thresholds. A threshold of approximately 0.7 will subjectively compare well with the moderate icing areas included by WAFC forecasters in WAFS SIGWX forecasts.

7.3.3 Users should use the verification website at http://www.emc.ncep.noaa.gov/gmb/icao/ to help select thresholds for other uses. An example of the icing gridded forecast is shown in Figure 2.

Contingency Tables for Australia/NZ

Threshold	Hits	False Alarms	Miss	Correct Rejection	Hit Rate	False Alarm Rate	Bias
blndmean							
0.10	6465	29278	87	100826	0.9867	0.2250	5.46
0.20	6307	23054	245	107050	0.9626	0.1772	4.48
0.30	6038	17920	514	112184	0.9216	0.1377	3.66
0.40	5546	12656	1006	117448	0.8465	0.0973	2.78
0.50	4560	7216	1992	122888	0.6960	0.0555	1.80
0.60	2788	2882	3764	127222	0.4255	0.0222	0.87
0.70	837	689	5715	129415	0.1277	0.0053	0.23
0.80	200	119	6352	129985	0.0305	0.0009	0.05
0.90	15	5	6537	130099	0.0023	0.0000	0.00
blndmax							
0.10	6545	45411	7	84693	0.9989	0.3490	7.93
0.20	6543	43086	9	87018	0.9986	0.3312	7.57
0.30	6539	40829	13	89275	0.9980	0.3138	7.23
0.40	6529	38500	23	91604	0.9965	0.2959	6.87
0.50	6517	36440	35	93664	0.9947	0.2801	6.56
0.60	6490	33640	62	96464	0.9905	0.2586	6.12
0.70	6397	29968	155	100136	0.9763	0.2303	5.55
0.80	6122	24530	430	105574	0.9344	0.1885	4.68
0.90	5351	16981	1201	113123	0.8167	0.1305	3.41

Table 7 Verification scores for a range of thresholds of harmonized maximum icing centered at FL100 at T+24 over the Australia/New Zeeland region for the months of May through July, 2015. Note: Users should always refer to the data provided on the verification website – the above is provided for illustrative purposes only.

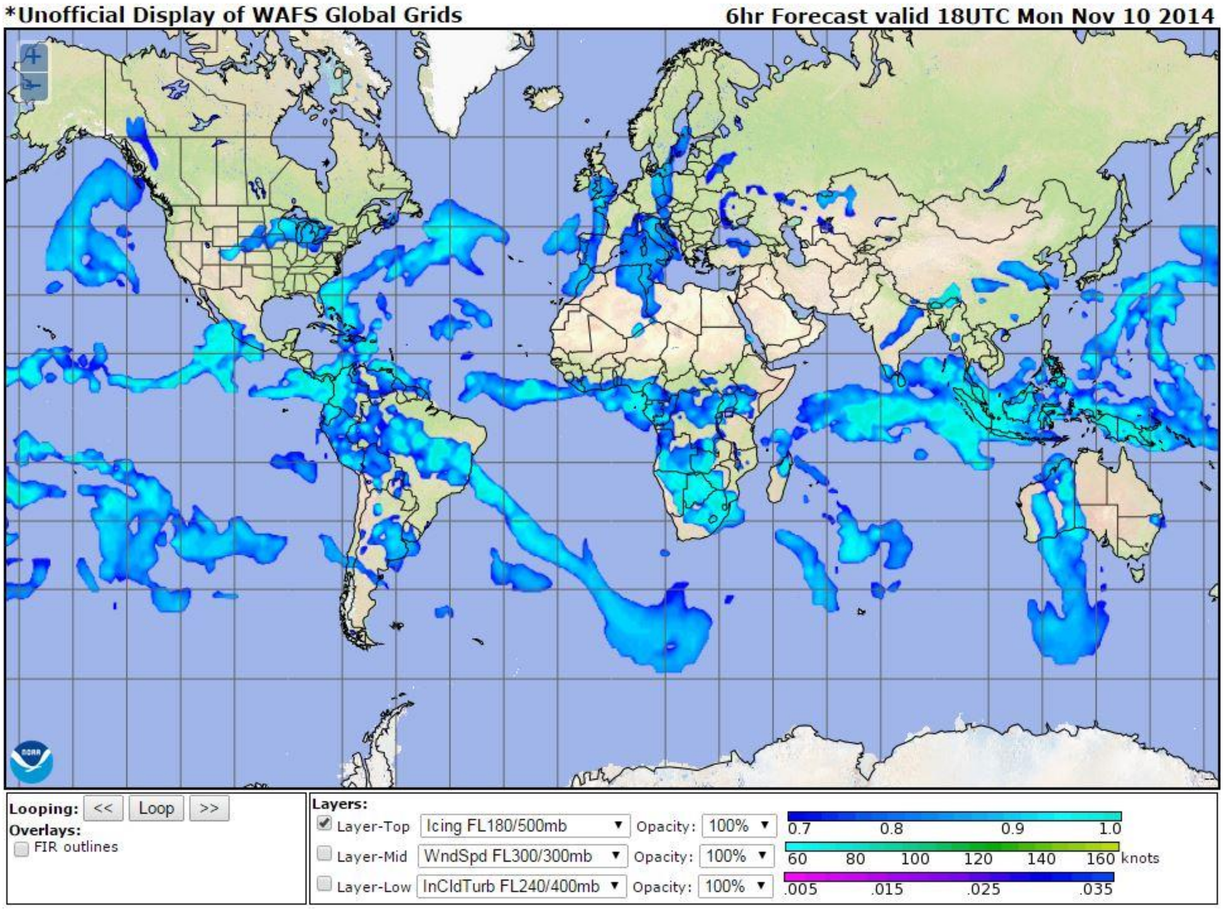

Figure 2 Example of WAFS gridded forecast for icing.

7.4 Use of the WAFS Cb cloud gridded forecasts

7.4.1 The WAFS Cb cloud gridded forecast has a range of zero to 1 for horizontal extent. The global distribution of data is such that about 89 percent of the values are zero and 90 percent of them are below 0.1. About 92 percent of them are below 0.4, about 99 percent of them are below 0.5, and values above 0.7 are extremely rare. The infrequent high values are at least partially due to the size of the WAFS grid boxes (at 1.25 degrees regular grid) being so much larger than the comparative size of a thunderstorm.

7.4.2 The verification scores in Table 8 indicate a hit rate of 60 percent and relatively low false alarm rate of 5 percent for the threshold of 0.1.

7.4.3 Users can access harmonized Cb Horizontal Extent contingency tables for a range of WMO Areas for T+12, T+24 and T+36 via the WAFC London Performance Indicators Website - http://www.metoffice.gov.uk/public/weather/aviation-wafc/#?tab=wafcPerformance. The 'drop down' boxes permit selection of parameter and timestep. Simply select CB Extent from the 'Parameter' menu.

Contingency Tables for North Atlantic - Area 2

WAFC Blended Cb Extent T+12
CB verification results meaned over period 1st July 2013 to 30th June 2014
Forecast 1200
Area 2 : Rectangular model domain

Threshold	Hits	False Alarm	Miss	Correct Rejection	Hit Rate	False Alarm Rate
0.00	49388	3112959	0	0	1.0000	1.0000
0.05	29520	174149	19868	2938810	0.5977	0.0559
0.10	29520	174149	19868	2938810	0.5977	0.0559
0.15	29032	168714	20356	2944245	0.5878	0.0542
0.20	29009	168486	20379	2944473	0.5874	0.0541
0.25	26768	138957	22620	2974002	0.5420	0.0446
0.00	26316	136009	23072	2976950	0.5328	0.0437
0.35	24143	110414	25245	3002545	0.4888	0.0355
0.40	22331	103344	27057	3009615	0.4521	0.0332
0.45	6437	15787	42951	3097171	0.1303	0.0051
0.50	3593	8671	45794	3104287	0.0728	0.0028
0.55	1406	3196	47982	3109762	0.0285	0.0010
0.60	418	1155	48970	3111804	0.0085	0.0004
0.65	96	287	49292	3112672	0.0019	0.0001
0.70	38	119	49350	3112840	0.0008	0.0000
0.75	7	28	49381	3112931	0.0001	0.0000
0.80	2	18	49386	3112941	0.0000	0.0000
0.85	0	0	49388	3112959	0.0000	0.0000
0.90	0	0	49388	3112959	0.0000	0.0000
0.95	0	0	49388	3112959	0.0000	0.0000
1.00	0	0	49388	3112959	0.0000	0.0000
>1.0	0	0	49388	3112959	0.0000	0.0000

Table 8 Verification scores in the form of a contingency table for a range of thresholds of harmonized maximum Cb cloud horizontal extent. Note: Users should always refer to the data provided on the verification website – *the above is provided for illustrative purposes only.*

Subjective comparison of the Cb cloud gridded forecasts to tools used by WAFC forecasters preparing WAFS SIGWX forecasts indicates that a threshold of 0.5 equating to 50 per cent coverage will approximate the areas of occasional Cb cloud (OCNL CB) that the forecasters include in WAFS SIGWX forecasts. Figure 3 is an example of a WAFS Cb cloud gridded forecast.

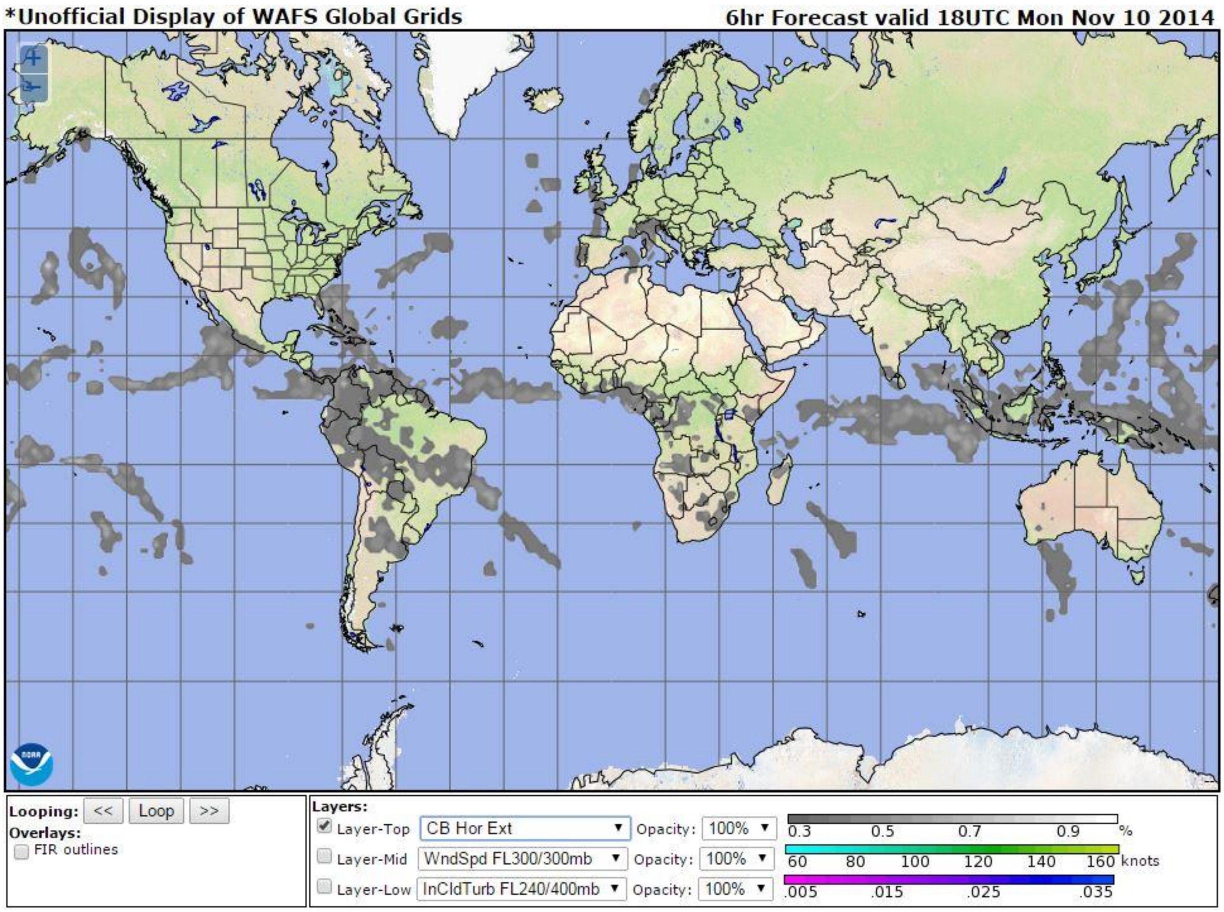

Figure 3 Example of WAFS gridded Cb cloud forecast

8. <u>Quality control and continuous improvement</u>

8.1 The suggested thresholds for WAFS gridded forecasts are based on both WAFC forecaster experience and WAFC empirical studies of observational data. These empirical studies are limited by a lack of observational data on the global scale. The WAFS user community is encouraged to provide the WAFCs with pilot reports and automated sensor readings of parameters such as icing and turbulence, since these will greatly help the WAFCs fine tune thresholds by geographic area and by season. The WAFCs will update this user guide to reflect regional and seasonal thresholds as they are developed. Meteorological service providers can help this process by contributing their own studies to the WAFSOPSG.

8.2 Observational data will become even more important for the development of future generations of WAFS gridded forecasts. Assigning weights to various parameters based on the parameters' past performance will likely be used to derive such forecasts. Any weighting system applied will be impossible without observational data.

1. Appendix: Cumulonimbus Cloud, Icing and Turbulence Value Ranges and Missing Data Indicators

The table below indicates the theoretical range of values for each of the parameters. It will provide a guide to users regarding the full extent of all possible values. It also indicates the values representing 'missing data'. Missing data can be due, for example, to grid points being below the land surface (such as with the Himalayan mountain range), and do not necessarily indicate that there are errors contained in the provided data.

Note - this table does not provide guidance on how the values should be interpreted in relation to 'severity' of phenomena (icing, turbulence).

Parameter name	Expected range of values	Missing data indicator
Maximum/Mean CAT potential	Values in the range 0 to 99, with higher values representing greater potential of CAT.	-0.5
Maximum/Mean in-cloud turbulence potential	Value between 0 and 1, with higher values representing higher potential.	-0.004
Maximum/Mean icing potential	Value between 0 and 1, with higher values representing higher potential.	-0.01
Cb horizontal extent	Value between 0 and 1, representing fractions of sky covered by Cb cloud. If greater than 0, values for height of Cb base and top will also be available (see below)	-0.1
ICAO height at Cb base	Values in the range 100 m-20000 m indicating the height of the base of the Cb cloud (given that Cb cloud is forecast to exist - see Cb horizontal extent)	-1.0
ICAO height at Cb top	Values in the range 300 m-20000 m indicating the top of the Cb cloud (given that Cb cloud is forecast to exist - see Cb horizontal extent)	-1.0

Table A1: Theoretical ranges of cumulonimbus cloud, icing and turbulence parameters in harmonized WAFS gridded forecasts in the WMO GRIB 2 code form

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