New WAFC SIGWX Verification

When developing the new automated WAFS SIGWX forecasts, checks have been made to ensure that the forecast areas of cumulonimbus cloud, icing and turbulence provided within these forecasts have a good level of accuracy and are at least as good as, if not better than, the manually drawn T+24 SIGWX forecast charts that they will replace.

It is important to note that the manually drawn T+24 SIGWX forecasts are not considered to be "the truth" and the new SIGWX forecasts aren't trying to be identical to them, instead both are verified against observational data sets to assess their performance.

Jet stream information is not verified individually, it is based on the WAFC gridded wind data sets which are verified separately. This information can be found here: https://www.metoffice.gov.uk/services/transport/aviation/regulated/wafc-london-performance-indicators

After the initial verification of each of the features described below, the output is "tuned" and the verification re-run to see if the performance improves. This process happens multiple times to determine the settings that give the best forecast performance.

This document explains the verification carried out on the turbulence, icing and cumulonimbus part of the SIGWX forecasts.

Turbulence Objects

Verification of the SIGWX turbulence forecasts uses IATA Turbulence Aware data as it provides Eddy Dissipation Rate measurements. To process the aircraft turbulence data everything below 28000ft is filtered out, and the observations are mapped to the nearest model level in order to be used in the verification process.

It should be noted that the IATA Turbulence Aware data doesn't indicate whether the turbulence was clear air (CAT), orographic or convective in nature, and the SIGWX turbulence areas forecast include only CAT and orographic types. It should also be noted that the coverage area for the IATA Turbulence Aware data is heavily biassed towards the United States and is sparse in other areas. This is shown in the figure 1 and does have an impact on the verification scores.

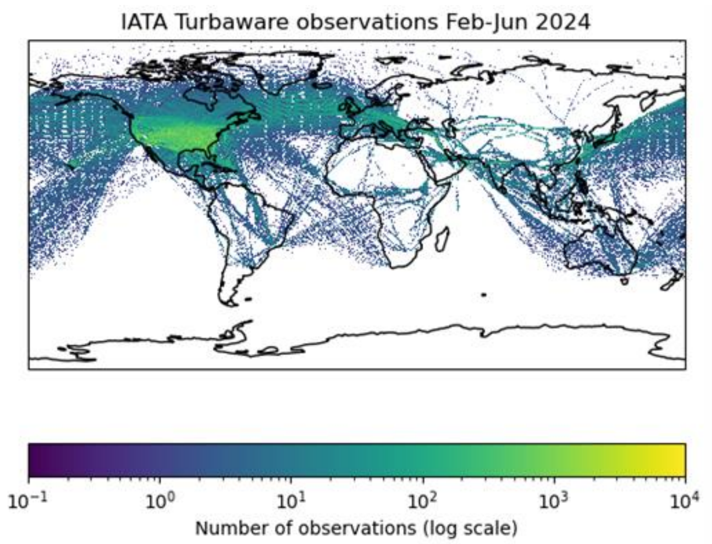


Figure 1 – coverage area of IATA Turbulence aware plots

The forecast SIGWX objects are mapped to a 0.25-degree grid by finding grid points inside the hazard polygons, and then assessed against observations to determine the "hit rate" and "false alarm rate". These results can be plotted as a Relative Operating Characteristic (ROC) Curve. The further the plotted curve lies above the diagonal line the higher the level of skill.

Figure 2 below shows the results of the turbulence SIGWX verification. The new SIGWX forecast is indicated by the blue line, orange is the manual SIGWX currently produced by WAFC London, and the green is the manual T+24 SIGWX produced by WAFC Washington.

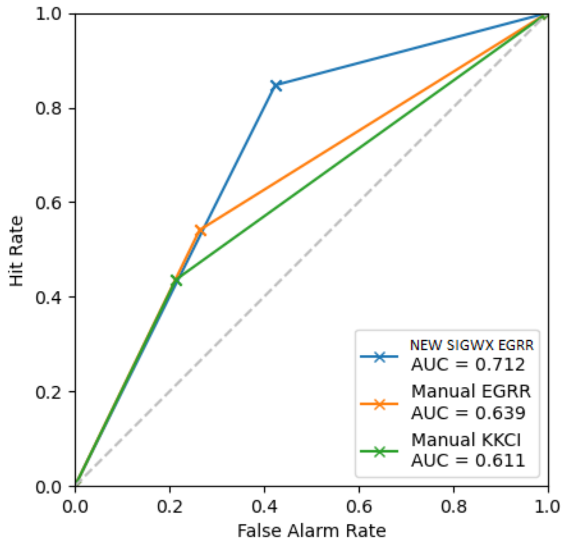


Figure 2 – Old and new SIGWX ROC plot. AUC stands for Area under the curve. Hit Rate and False Alarm Rates are only calculated for areas where IATA turbulence data is available (as shown in Figure 1)

It is important to note the following:

1.1 The new SIGWX forecasts include Clear air Turbulence (CAT) and orographically generated turbulence, whilst the manual T+24 SIGWX only includes CAT. Therefore, the new SIGWX areas can be expected to cover more of the world. Increasing the forecast area will increase the false alarm rate as well as the hit rate

- Areas of observed turbulence are only likely to cover a small area of the forecast turbulence area. In other words, you wouldn't expect to experience turbulence continuously throughout the marked turbulence area. This contributes to the false alarm rate.

- There is no, or very limited air traffic in some areas where turbulence areas are forecast (as illustrated in Figure 1), and for those areas it is not possible to assess the Hit Rate or False Alarm Rate.

- The IATA Turbulence Aware data includes turbulence caused by severe convection which we are not trying to forecast, and this results in a reduced hit rate score.

Figure 2 shows that the hit rate for the new SIGWX turbulence areas is higher than the current T+24 CAT areas, but it also indicates a higher false alarm rate. The ratio between the hit rate and false alarm rate is the same for both versions. Therefore, we are confident that the new SIGWX turbulence areas are at least as good as the manual forecasts.

A comparison of the turbulence areas on a manually drawn T+24 SIGWX forecast and those generated by the new SIGWX for the same forecast validity is shown in Figures 3 and 4.

Looking at Figure 3, it is evident that there are more marked turbulence areas in the new SIGWX forecast (Figure 3b) compared to the manually drawn SIGWX (Figure 3a). Many of these can be attributed to orographic turbulence. The jet stream over the Himalayas has a more extensive and severe turbulence forecast compared to turbulence area 1 on the manually drawn forecast In addition, the new SIGWX has turbulence areas over East Africa (numbered 8, 10 and 14) caused by the easterly wind flow over the mountains in that area, Georgia/Azerbaijan due to the Caucasus Mountains, and even in the area that stretches from Switzerland up across Scandinavia.

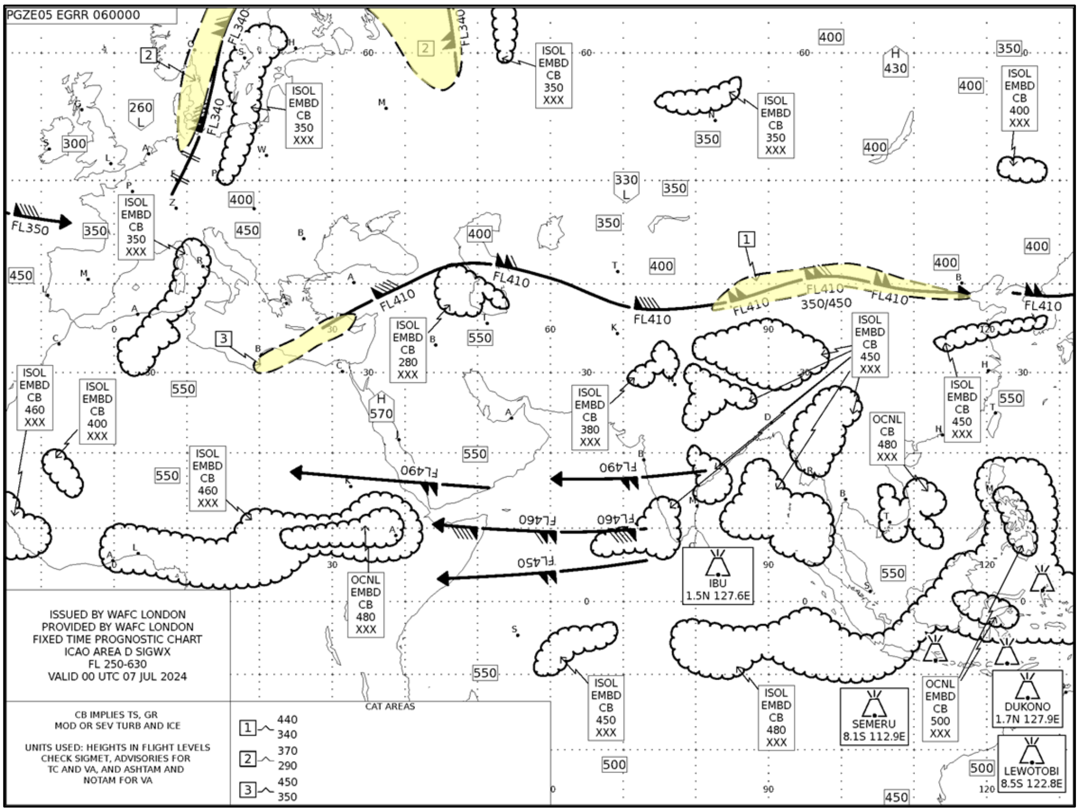


Figure 3a – manually drawn T+24 SIGWX with turbulence areas highlighted in yellow.

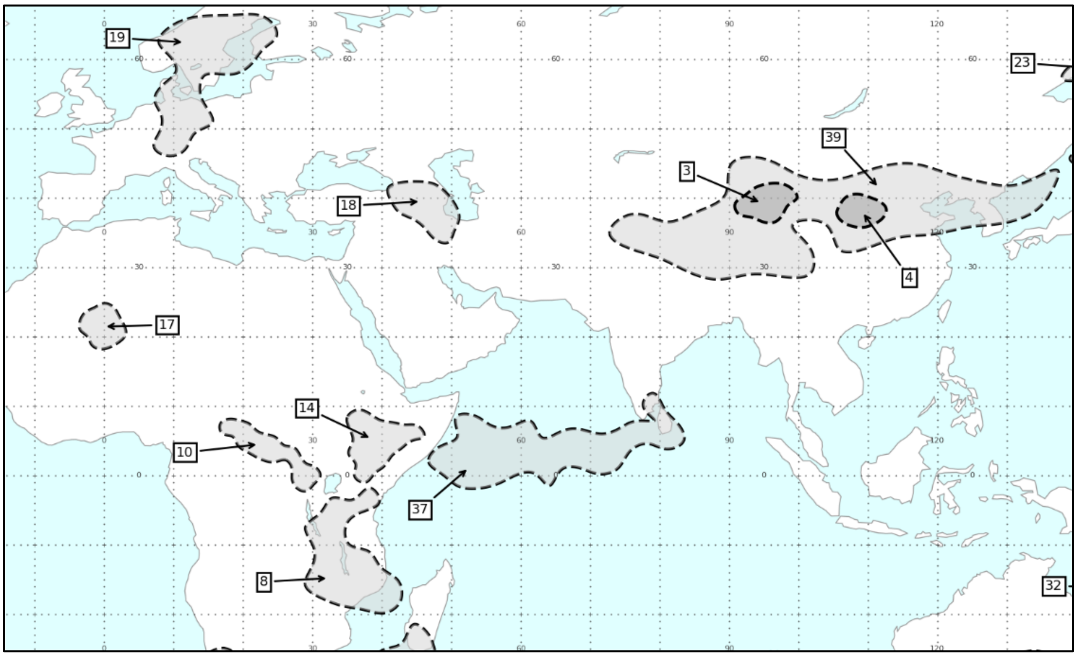


Figure 3b - T+24 produced by the new SIGWX with SEV turb shown in the darker grey colour.

Both 3a and 3b are valid at the same date and time.

Looking at Figure 4, it can be seen that both the manual T+24 SIGWX (Figure 4a) and the new SIGWX (Figure 4b) forecast turbulence is associated with the jet stream that is crossing the southern part of the Pacific Ocean and across Australia as well as to the southeast of New Zealand. The new SIGWX has also forecast more severe turbulence intensities in the area close to the Great Australian Bight where there is a splitting jet stream.

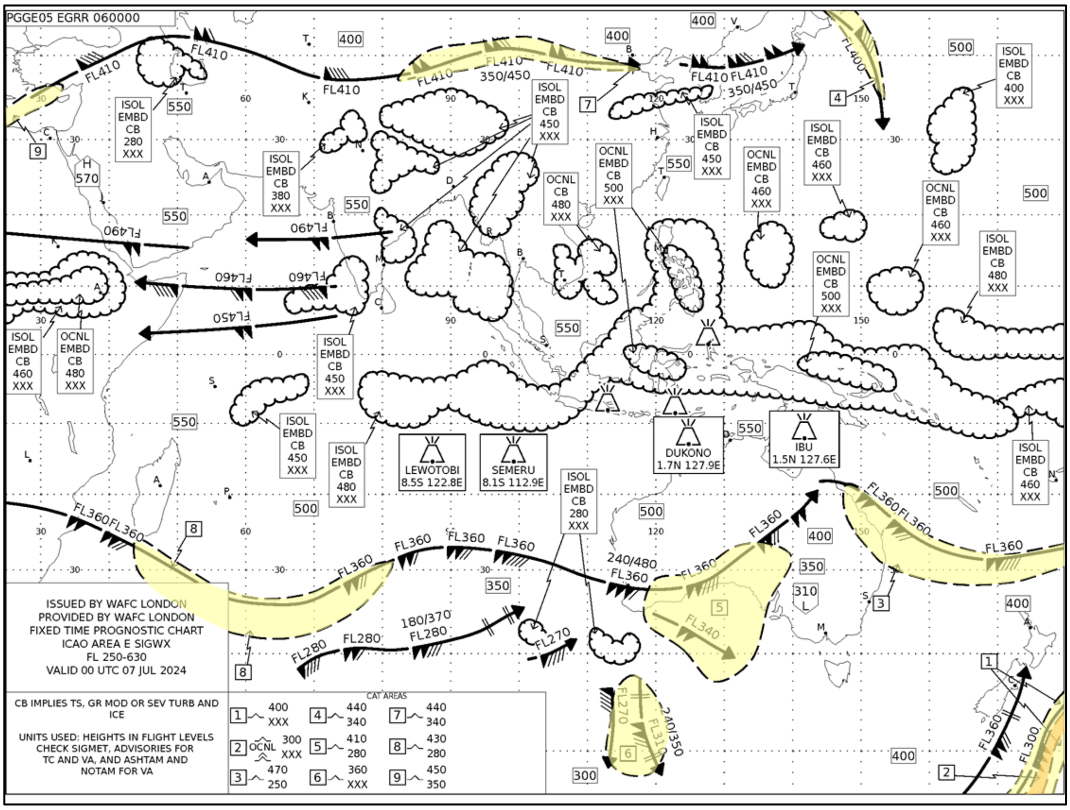


Figure 4a – manually drawn T+24 SIGWX with moderate turbulence areas highlighted in yellow and severe turbulence in orange.

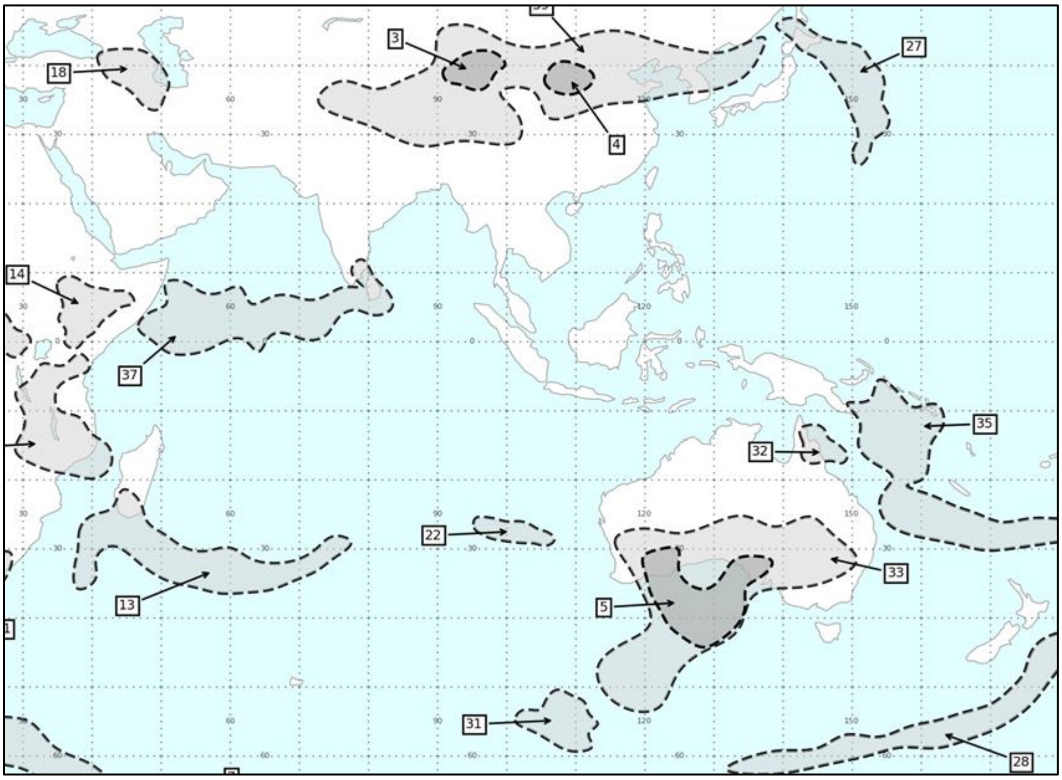


Figure 4b, T+24 produced by the new SIGWX with severe turbulence shown in the darker grey colour.

Both 4a and 4b are valid at the same date and time.

Icing

The manually drawn SIGWX icing forecasts are only created for part of the globe, and therefore it is not possible to provide a full and direct comparison against the new SIGWX icing areas which do have global coverage. Icing verification uses process satellite imagery determination of icing areas. For this reason, the focus of the verification has been to look at the performance of the new SIGWX T+24 icing areas.

An object-based verification approach was undertaken using the Method for Object-Based Diagnostic Evaluation (MODE: Davis, 2006a,b; Brown et al., 2007; Bullock et al., 2016) approach. For this, "objects" are defined from a chosen circular radius and threshold, and this is carried out for both the observed and forecast data.

Two thresholds were used to assess the forecast of moderate icing (a threshold of >0.5) and severe icing (a threshold of >1.5). A range of radii were also assessed (5, 7 and 9 grid points where a grid point is 0.25 degrees of latitude and longitude). The verification scores are displayed on a Roebber plot in Figure 5. Information to assist with interpreting these plots is included underneath the diagrams.

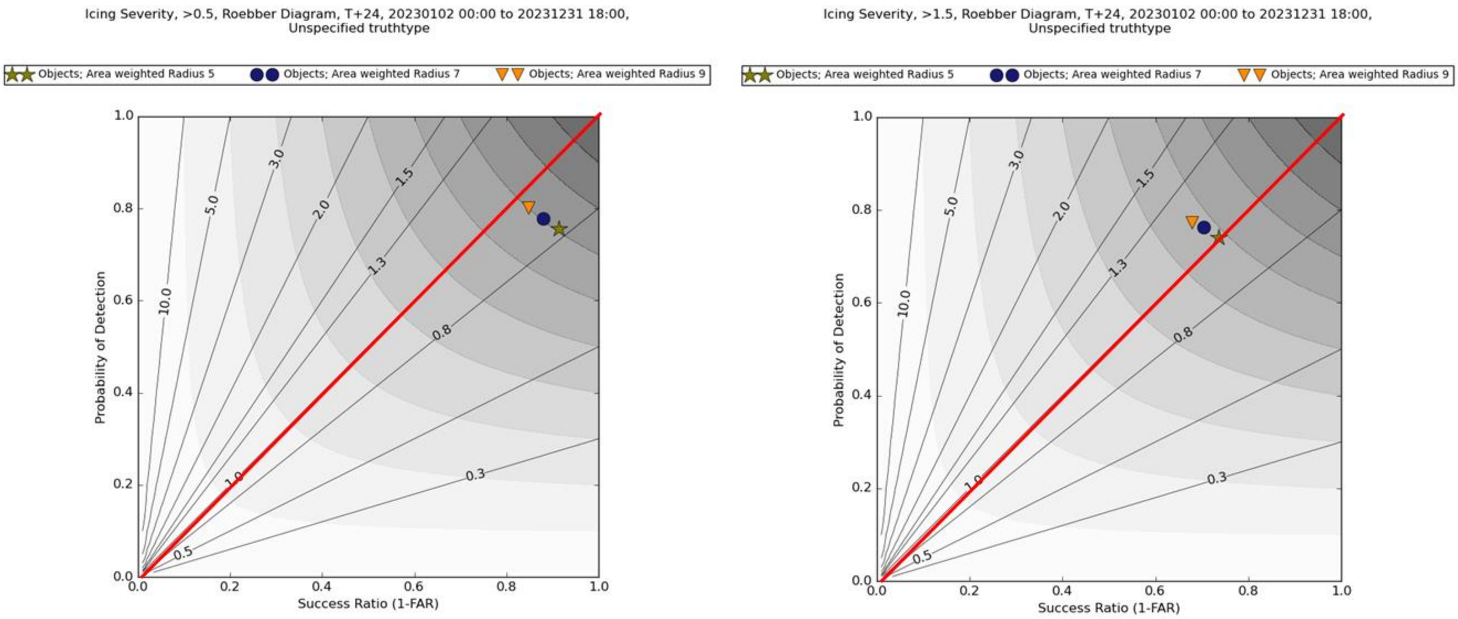


Figure 5 - Left: threshold of ≥0.5, representing "any icing". Right: threshold of ≥1.5 representing moderate or greater amounts of icing.

Interpretation information: Probability of detection represents the "hit rate" of the forecasts, and Success Ratio is "1-False Alarm Rate". The straight lines indicate the values of frequency bias, and the red diagonal line is the "perfect" forecast where the hit rate and false alarm rate are balanced. To the left of this line (i.e. a frequency bias >1) indicates too many objects were forecast , whilst to the right (i.e a frequency bias <1) would indicate too few objects were forecast. The top right hand corner indicates a perfect forecast (the highest possible Critical Success Index).

Figure 5 shows that the new WAFS SIGWX icing forecasts are well matched to the observations. There is a slight under-forecast of lower severity threshold and slight over-forecast of higher threshold icing (expected). Therefore, we are confident that the new SIGWX icing areas are at least as good as the manual forecasts.

A visual comparison of the icing areas on a manually drawn T+24 SIGWX forecast and those generated by the new SIGWX for the same forecast validity is shown in Figure 6. It is important to note that the WAFS gridded icing forecast used by the new SIGWX includes areas of icing within layer cloud and convective cloud.

Looking at Figure 6, the icing areas in the new SIGWX (Figure 6b) forecast are a little more extensive that what is drawn on the manual T+24 SIGWX forecast (Figure 6a), but largely covers the same geographical areas. Areas of more severe icing intensity in the North Sea and in the Black Sea/Moldova correspond to where thunderstorms with potential severe turbulence are expected (shaded darker blue).

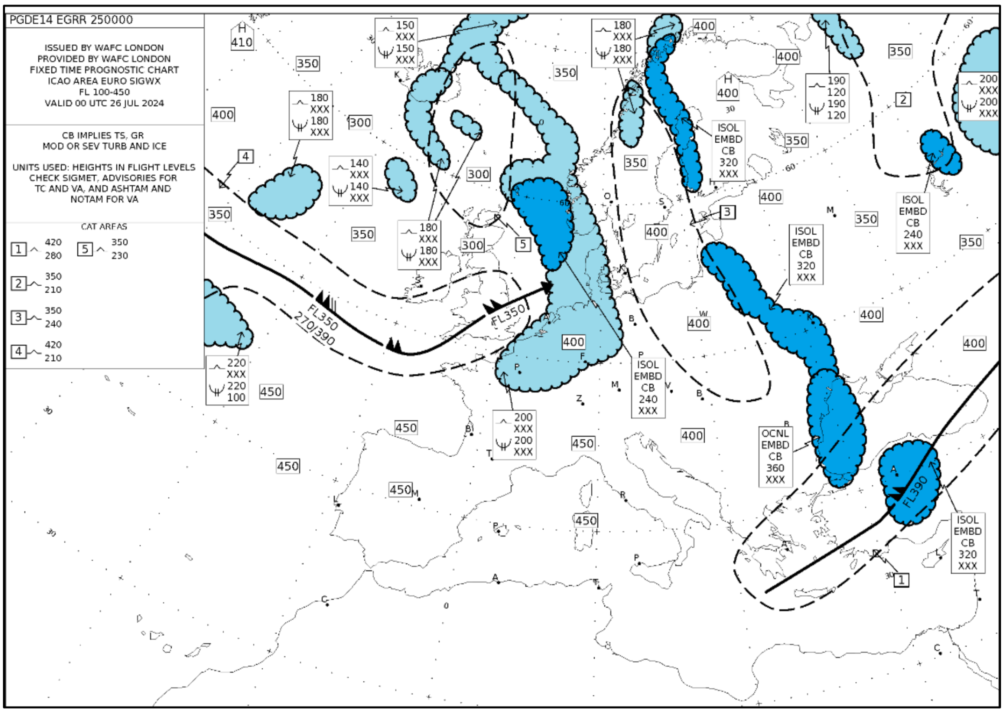


Figure 6a –manually drawn T+24 SIGWX with icing areas highlighted in light blue, and more severe icing areas associated with cumulonimbus cloud highlighted in dark blue.

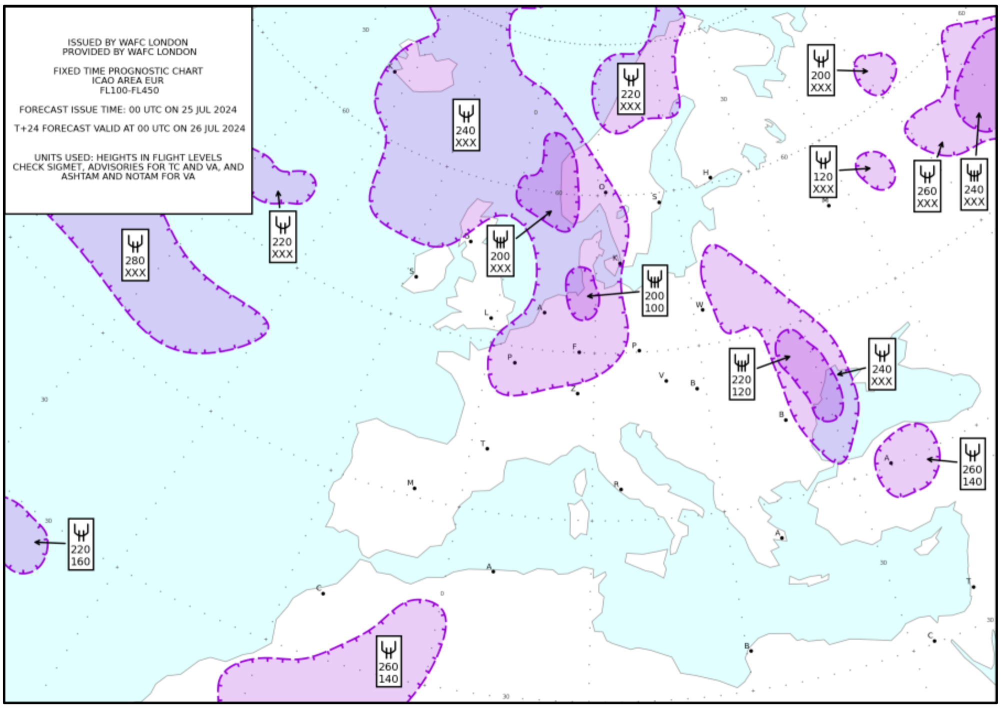


Figure 6b - T+24 produced by the new SIGWX. The darker purple colour indicates areas of Severe Icing.

Both 6a and 6b are valid at the same date and time.

Cumulonimbus

Comparison of the manually drawn SIGWX cumulonimbus (CB) areas and the new SIGWX CB areas is more difficult as once again there are differences in what each forecast includes.

The manually drawn SIGWX contains areas of ISOL EMBD (embedded CB with <50% spatial coverage), OCNL EMBD (embedded CB with 50% to <75% spatial coverage), FRQ EMBD, OCNL and FRQ CB. “ISOL” coverage is less than 50% of the marked area, “OCNL” is from 50% to less than 75% coverage of the marked area, and “FRQ “ greater than 75% of the marked area.

The new SIGWX does not include forecasts of areas of embedded (EMBD) CB which most notably means there will be no ISOL EMBD CB areas. It is important to note that in the new SIGWX many of the areas that might have been marked as ISOL EMBD CB on the manually drawn charts are actually forecast as OCNL CB areas instead.

Traditionally, verification of CB extent is carried out using geostationary satellite imagery data and lightning location data, however this process is not able to diagnose whether the CB is embedded or classify the CB areas as ISOL, OCNL or FRQ in their horizontal extent.

A new approach has been used instead that uses Geostationary Lightning Mapper (GLM) data on the GOES-16 and GOES-18 satellites to create a new verification observation data set. The area GOES-16 and GOES-18 GLMs cover is shown in Figure 7 below. At the current time equivalent data covering the rest of the world is not available.

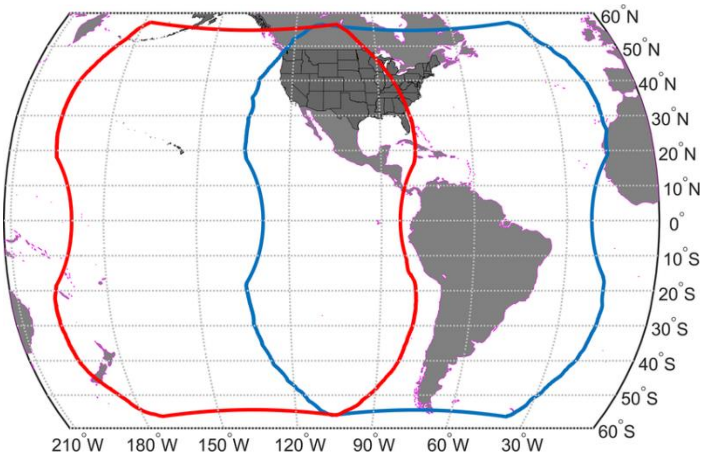
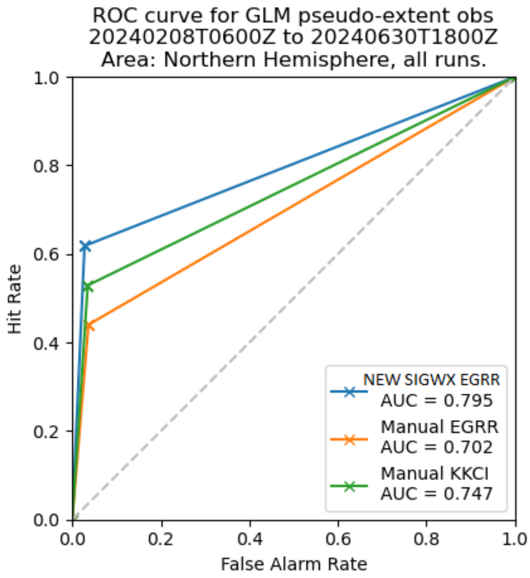


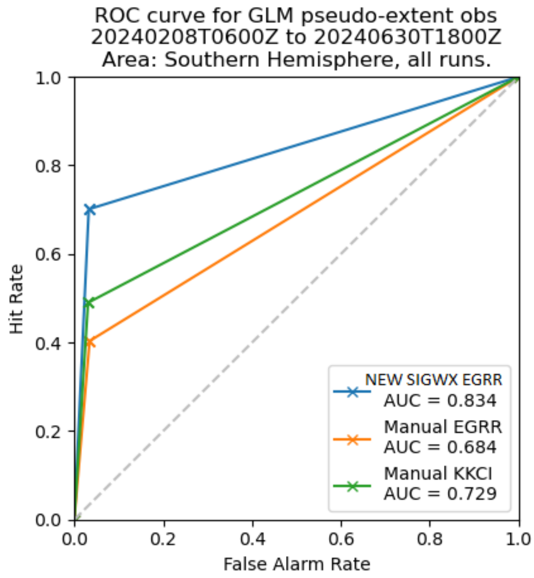
Figure 7 – GOES-18 (red) and GOES-16 (blue) field of view. For the CB verification process GLM data is has been restricted to a box which covers 187°W to 25°W and 50°S to 50°N.

The density of satellite detected lightning strikes received over a window 1.5 hours either side of the forecast validity time can be used to infer CB extent by splitting the area into 0.1° boxes, spreading the areas out to directly adjacent boxes (to account for movement of the CB’s) and then counting the number of 0.1° boxes with activity within 1.0° to infer CB extent. For the manual SIGWX the ISOL EMBD CB areas are excluded from the process to give a more direct comparison.

The verification dataset is created by reading in GLM flashes for a 3-hour window, 1.5 hours either side of the valid time of the forecast. Flash data is then split into 12 15-minute “chunks” (to account for moving storms) and processed into a 2D histogram on a 0.1° grid. Grid boxes with counts of flashes over a certain threshold (~5) are then counted as "active".

The number of active grid boxes is then converted into a CB extent by setting any grid boxes directly adjacent to an active grid box from the previous step to also be active (to account for the size of cumulonimbus clouds extending beyond the area of lightning strikes, then counting the number of active filtered grid boxes per 1.0° box, and applying a threshold to this for ISOL or OCNL activity. The results are shown in Figures 8.





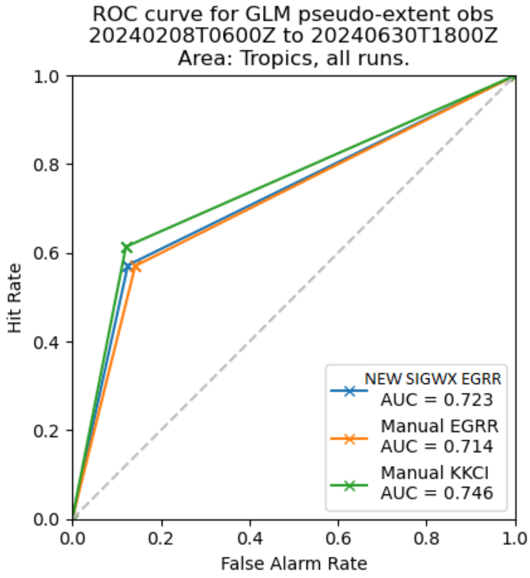


Figure 8 – ROC plots comparing the manually drawn SIGWX forecasts from WAFC London (orange) and WAFC Washington (green) with the new SIGWX (blue).

Top left – Northern Hemisphere area (187°W to 25°W and 00°N to 50°N)

Top right – Southern Hemisphere area (187°W to 25°W and 50°S to 00°N)

Bottom left – Tropics (187°W to 25°W and 30°S to 30°N)

The plots in Figure 8 show that in the Northern Hemisphere and Southern Hemisphere the new SIGWX has a better performance (higher hit rate and slightly lower false alarm rate) than the manually produced SIGWX. Some of the lower hit rate in the manually produced SIGWX can be attributed to the forecasters labelling areas of cumulonimbus that are really "OCNL" in nature as "ISOL EMBD" instead. In the Tropics performance of the new SIGWX and manual SIGWX is very similar.

It is important to note that these performance plots are not for the whole globe as they only extend from 187°W to 25°W, but they are expected to be broadly representative of the whole globe. Therefore, we are confident that the new SIGWX cumulonimbus areas (for OCNL/FRQ areas) are at least as good as the manual forecasts.

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A comparison of the cumulonimbus areas on a manually drawn T+24 SIGWX forecast and those generated by the new SIGWX for the same forecast validity is shown in Figures 9 and 10.

Looking at Figure 9 it can be seen that there are many more areas of OCNL cumulonimbus cloud marked, and many of these correspond to ISOL EMBD CB areas drawn on the manual T+24 SIGWX, particularly across Africa, Asia and the Indian Ocean. This also suggests that in those areas the forecaster drawing the chart is under-estimating the spatial coverage of the cumulonimbus clouds. In Scandinavia and Poland/Slovakia/Hungary this is not the case, and the threshold for OCNL CB has not been met for including in the new SIGWX.

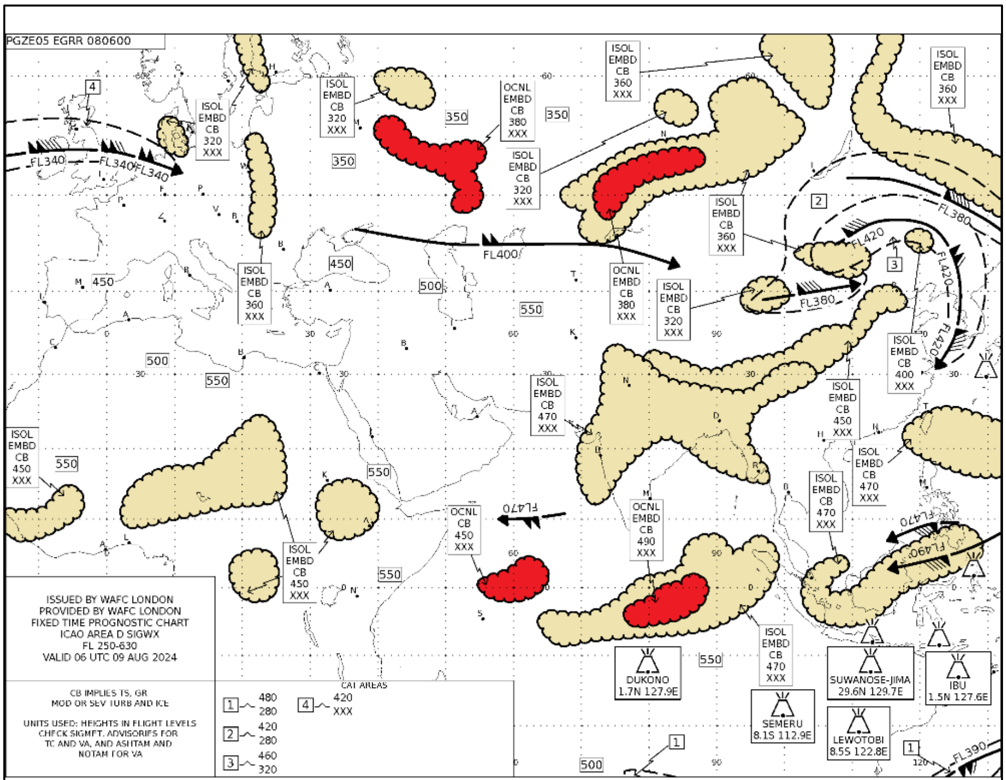

Figure 9a – manually drawn T+24 SIGWX OCNL areas of cumulonimbus cloud highlighted in red and ISOL EMBD areas of cumulonimbus highlighted in yellow.

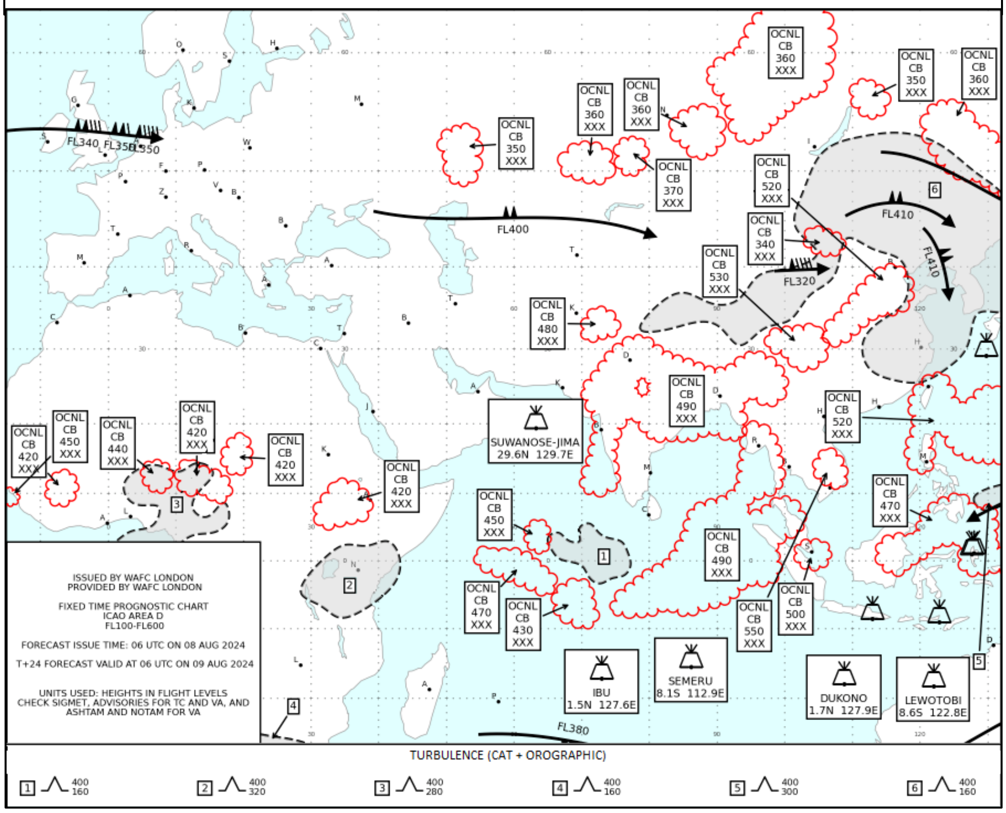

Figure 9b - T+24 produced by the new SIGWX.

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Both 9a and 9b are valid at the same date and time.

Figure 10 is valid for the same date/time as those in Figure 9 and allows the area over North America and the Caribbean to be seen. Once again it can be seen that there are many more areas of OCNL cumulonimbus cloud marked and that many of them correspond to areas marked as ISOL EMBD CB on the manual T+24 SIGWX chart.

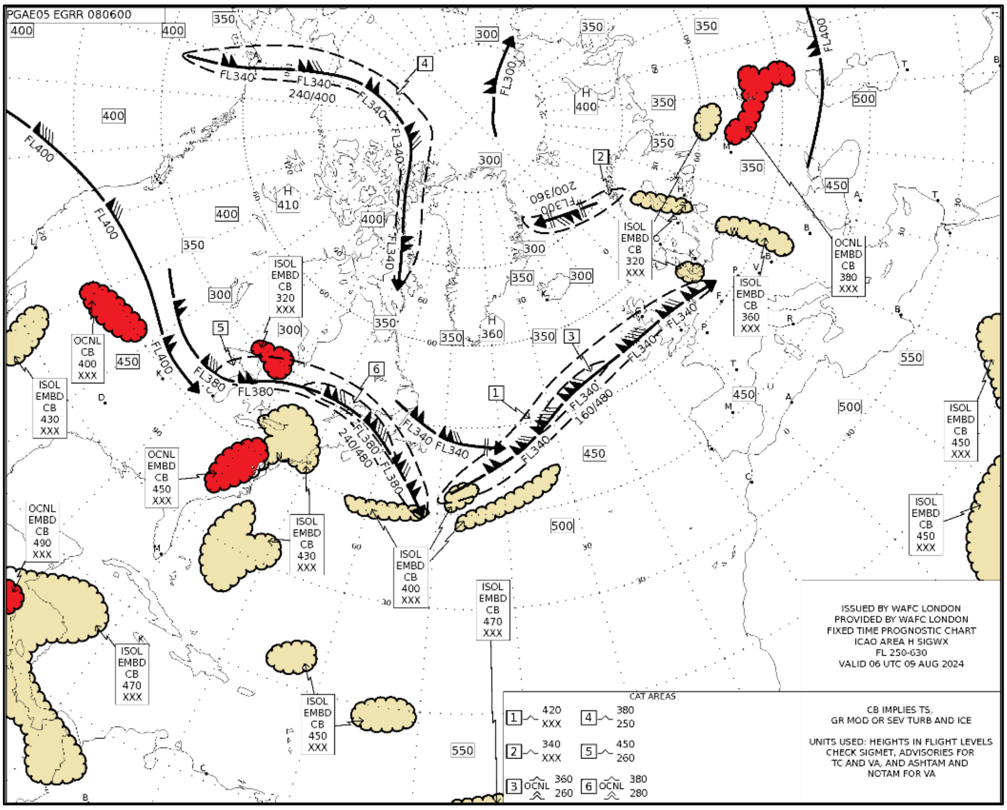

Figure 10a – top, manually drawn T+24 SIGWX OCNL areas of cumulonimbus cloud highlighted in red and ISOL EMBD areas of cumulonimbus highlighted in yellow.

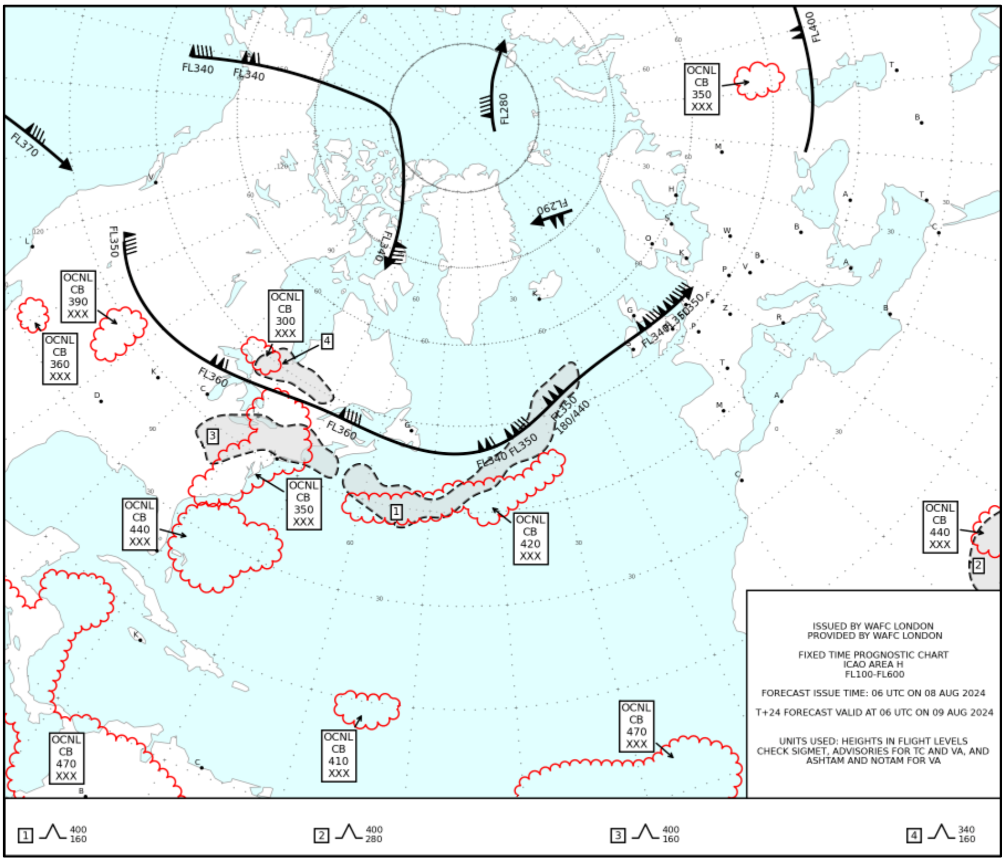

Figure 10b - T+24 produced by the new SIGWX. Both charts are valid at the same date and time.