13.4 VERIFICATION OF MET OFFICE GLOBAL ICING POTENTIAL FORECASTS USING SATELLITE OBSERVATIONS

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1. INTRODUCTION

In-flight icing is a major hazard to aviation, occurring when aircraft fly through cloud at sub-freezing temperatures due to the accretion of super-cooled liquid water. To ensure worldwide aviation safety, the World Area Forecast System (WAFS) provides global gridded forecasts of major meteorological hazards to aviation: in-flight icing, turbulence and cumulonimbus clouds.

This study investigates the use of satellite derived observations of icing potential as a source of truth data to verify the WAFS icing forecasts. The challenges and assumptions made in order to develop the most appropriate methodology are discussed. Objective verification assesses the skill and reliability of the WAFS UK icing diagnostic over the North Atlantic region.

2. WAFS ICING FORECASTS

As a World Area Forecast Centre (WAFC), WAFC London produces forecasts of mean and maximum icing potential on a 1.25 degree global grid. These forecasts are combined with icing potential forecasts issued by WAFC Washington to produce harmonised forecasts available to the global aviation community (ICAO 2012). Icing potential forecasts indicate the potential for the presence of icing, with values ranging from 0 to 1 (Figure 1). Forecasts are produced operationally 4 times a day at 6 levels (300, 400, 500, 600, 700 and 800 hPa) and at 3 hourly forecast ranges (T+6 to T+36). The UK icing algorithm calculates an icing potential based on relative humidity where cloud is present and temperature is between 0°C and -20°C.

3. SATELLITE OBSERVATIONS

Recent instrument developments to the geostationary Meteosat Second Generation (MSG) and Japan Meteorological Agency (JMA) Himawari-8 satellites provide additional information about cloud properties to help identify areas conducive to icing. The Met Office uses this information to produce a satellite icing potential product (Francis, 2007) to aid forecasters in predicting in-flight icing. Icing potential satellite observations are updated every 30 minutes on a 0.25 degree grid with current coverage over Europe, North Atlantic, Africa and Asia (Figure 2). The gridded field contains icing potential values, ranging from 0 to 1, based on the algorithm developed by Minnis et al. (2005).

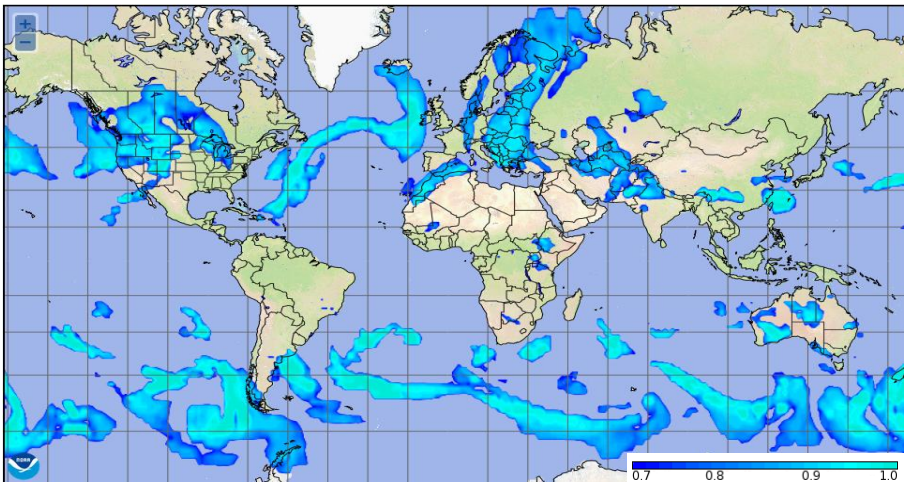

Figure 1: Unofficial display of WAFS global grids: harmonised icing forecast at 600hPa on 19/02/2016 0Z T+24.

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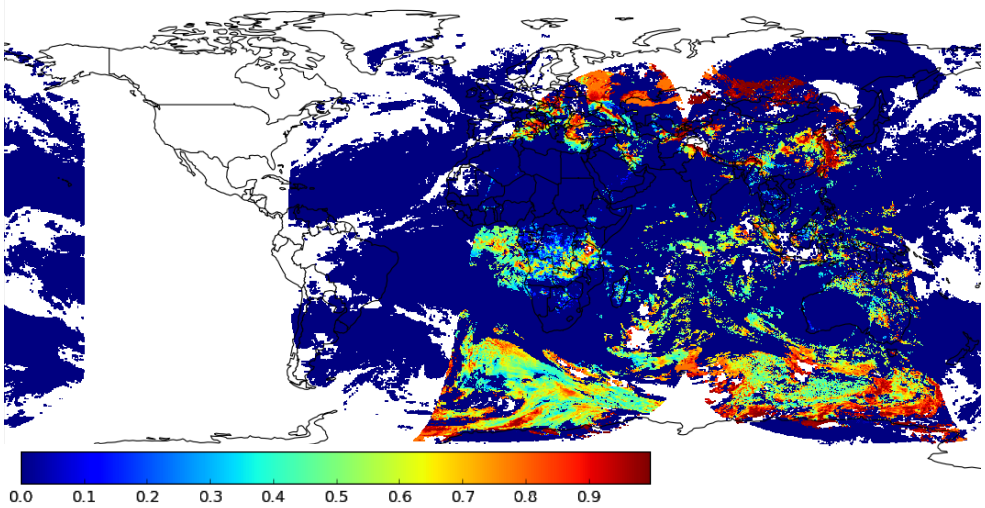

Figure 2: MSG and Himawari-8 satellite coverage for the icing potential satellite product valid 11/02/16 0730Z.

4. CHALLENGES AND ASSUMPTIONS

In order to produce verification, the forecasts and observations must be matched appropriately to allow a fair comparison. The biggest challenge is that the forecasts are for 6 different pressure levels (corresponding to flight levels) and the satellite observations are a single field of values as observed by the satellite. The satellite only detects the highest level of cloud, and therefore icing potential, so any icing closer to the Earth's surface but below a layer of higher cloud would go undetected. To best replicate the satellite observations a method to process the forecasts from 300 hPa down to 800 hPa has been developed and applied. This requires a threshold which represents the smallest forecast value with a potential for the presence of cloud, which will prevent the detection of any icing below it. WAFS documentation (ICAO, 2012) states 0.1 indicates trace icing, so a threshold of 0.1 is applied when processing the forecasts into a single field.

Other implications of using satellite observations as truth data that need to be considered are:

- Satellite icing observations are limited during night-time hours. Only the presence of cloud can be detected, therefore if no cloud is present an icing potential of 0.0 is recorded, otherwise the icing potential is unknown.

- To calculate certain verification statistics an observed icing event, in terms of the satellite icing potential, needs to be defined. Minnis et al. (2005) categorised Icing potential into low, medium and high probabilities of icing. Given icing potential less than 0.4 is classified as a low probability of icing, this has been applied as the event threshold.

- The verification regions cover large areas, particularly the North Atlantic region (Figure 3) where longitudes range 80W to 5E. Therefore, times when the whole domain is in daylight, allowing non-zero icing potential observations, are limited. In order to obtain the maximum data all 3 hourly validity times are included in the verification.

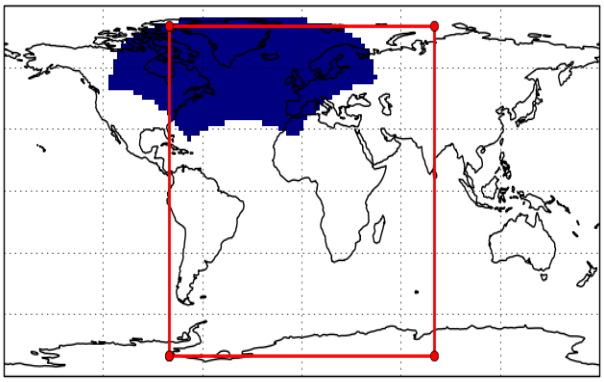

Figure 3: Verification area covering North Atlantic region. Solid blue area is verification Area 2 domain, red boxed area is the coverage of the MSG satellite.

- Both the WAFS icing forecasts and the satellite icing potential observations produce values on a scale of 0.0 to 1.0. However these scales are not calibrated, so an icing forecast of 0.7 is not necessarily the same icing severity or likelihood as a satellite icing potential of 0.7. For the purpose of this verification they are assumed to be comparable but not exact.

- The satellite observations are on a 0.25 degree grid, whereas the WAFS forecasts are on a coarser 1.25 degree grid. To compare the two gridded fields the satellite data is scaled down to a 1.25 degree grid so the finer detail in the observations is lost.

5. INITIAL VERIFICATION RESULTS

Initial categorical verification focuses on forecasts of mean icing over a 13 month period, January 2015 to January 2016 inclusive. During this period only the MSG satellite produced icing potential observations. Therefore, forecasts over the North Atlantic region and Europe were assessed, where both forecast and satellite data was available.

Relative Operating Characteristic (ROC) plots display the corresponding hit rate and false alarm rate for a range of forecast icing potentials. This verification plot demonstrates the skill of the forecast at discriminating between icing events and non-events. The ROC curve for the mean icing forecasts at a lead time of 24 hours in the North Atlantic region is shown in Figure 4. The forecasts show skill at forecasting icing events, with minimal decrease in skill at longer lead times.

Reliability plots assess how well the predicted icing potentials correspond to their observed potential frequencies. Figure 5 displays the reliability of the forecasts in the North Atlantic region at a lead time of 24 hours; it shows consistent over-forecasting of icing events. These are forecasts of mean icing potential so are not directly related to probabilities, but the trend of increasing icing potential with observed frequency should be evident. These results highlight the scope for forecast calibration as forecasts of 1.0 should be observed correctly more frequently than on 30% of occasions. The bar plot indicates the rarity of icing events, with the majority of forecasts in the 0.0 forecast bin.

6. DEVELOPED METHODOLOGY

In addition to objective verification, case studies of observed high icing potential over the UK have been assessed. On both the 11th February 2015 and 19th March 2016, satellite icing potentials of over 0.8 were observed across the UK. On initial assessment neither of the events were predicted by the UK diagnostic. However, after examining the corresponding cloud top heights associated with the icing, in both cases the majority of icing occurred at low levels (less than 1km). As the purpose of the WAFS forecasts is to detect in-flight aviation hazards, the base of the lowest level at which icing is forecast is FL050 (5000ft or 1.52km). Therefore these observed icing events occurred lower than the WAFS forecast domain and so are not expected in the forecast.

Not accounting for this in the satellite observations means that when low level icing events occur, the number of missed events will be greater in the verification results. This will incorrectly negatively impact the hit rate and observed frequency of icing events. To improve the verification methodology

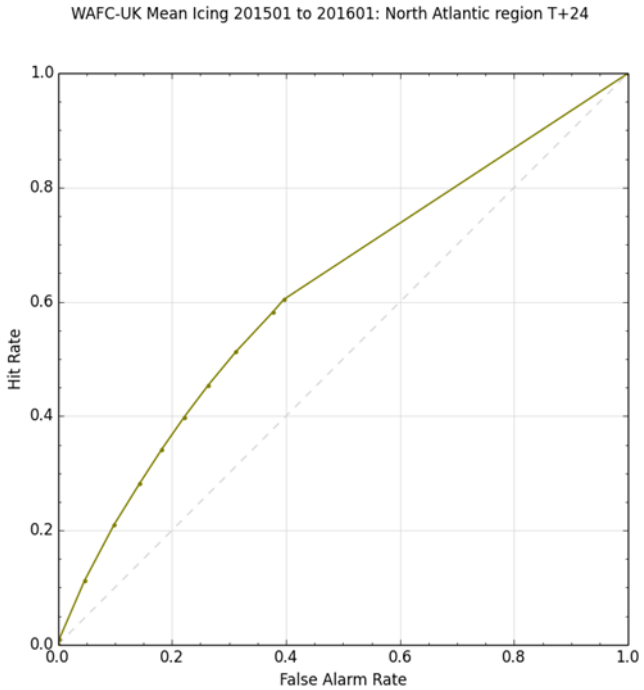

Figure 4: ROC plot for the T+24 UK WAFS mean icing forecasts over the North Atlantic region.

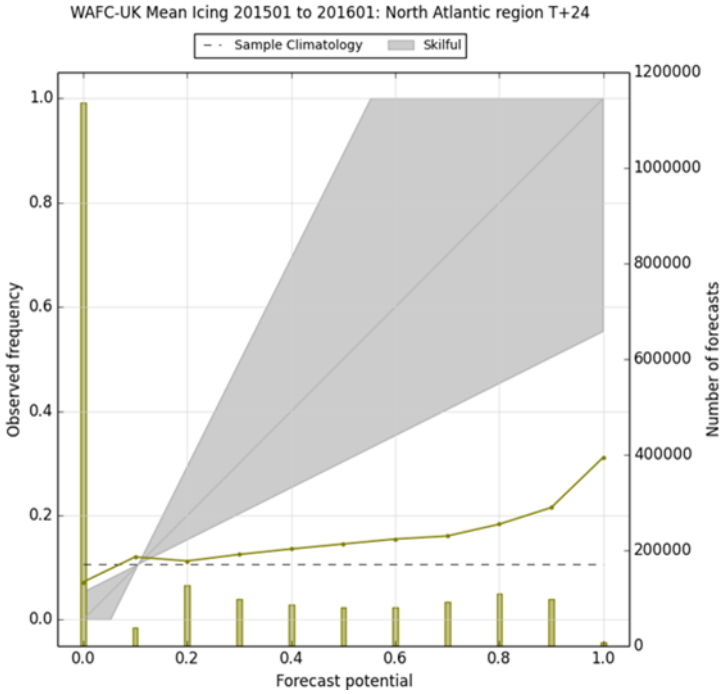

Figure 5: Reliability plot for the T+24 UK WAFS mean icing forecasts over the North Atlantic region.

the satellite cloud top height observations are now utilised in processing the satellite icing potential. If the observed cloud top height is lower than 1.52km the icing potential is amended to 0.0. This applies the assumption that if the cloud top is below a given level no icing will be present above it.

Since the satellite icing potential observations update every 30 minutes, but the forecast are issued 3 hourly, the initial verification uses the single observation field valid at the forecast validity time. However, given the detail of icing potential observations is dependent on daylight hours and that the forecasts are valid over a 3 hour period, verifying using a large window of observations has been investigated. Three observed icing potential fields have been combined: the original field valid at the forecast validity time and the fields from the preceding and following half hour intervals. The verification using this combined observation window will be compared to the single observation window, with the aim of improving the forecast reliability without degrading the forecast skill.

Observations from the JMA Himawari-8 satellite increase the icing potential coverage to include Asia and Australasia from February 2016. Therefore, these new regions have been added to the verification using the developed methodology.

7. CONCLUSIONS AND FUTURE WORK

Overall this method of verifying the UK WAFS icing forecasts has produced interesting results, demonstrating the potential to develop a broad assessment of WAFS icing forecasts. Both processing the forecasts to best replicate the satellite observations and categorising an observed icing event as icing potential greater than 0.4 have proved reasonable assumptions. Initial verification of forecasts over the North Atlantic show skill but indicate significant over-forecasting.

The verification of icing forecasts using satellite observations is still a developing area of research. Future work will investigate further the most appropriate use of icing potential satellite observations for verification, including evaluating the use of combined observation windows.

The launch of the Himawari-8 and GOES-R satellites will expand the coverage of icing potential observations, allowing verification over Asia and North America. In the years to come, forecast and satellite data will accumulate and hence provide a more substantial verification dataset. This method of verifying icing forecasts will also be used to assess and monitor developments to the UK icing algorithm.

8. REFERENCES

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