MOGREPS ensemble-based Clear Air Turbulence products

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Introduction

The Met Office MOGREPS ensemble forecasting system became formally operational in September 2008, having already run for several years in trials. It runs twice daily with 24 members at a resolution of 24 km over the North Atlantic and Europe (MOGREPS-R). A global model (MOGREPS-G) runs twice daily at a resolution of 90 km to provide lateral boundary conditions. This global model also runs out to 15 days as the Met Office contribution to the THORPEX-TIGGE project (MOGREPS-15). Ensemble based products can also be produced from ECMWF and NCEP data . All these products can be used by our forecasters in their assessment of the most likely outcomes and risks of high impact weather.

Clear Air Turbulence

- Clear Air Turbulence (CAT) is one of the main weather related hazards to en-route aircraft.
- The main causes of CAT are wind-shear, mountain-waves and convection.
- There are a number of predictors currently in use to produce operational forecasts of wind-shear induced CAT.
- The two World Area Forecast Centres currently use the Ellrod TI1 index to produce deterministic gridded forecasts of CAT.

Ellrod TI1 = Vertical Wind Shear x Deformation

MOGREPS ensemble products

Ensemble member output can be combined together to produce plots of the probability of exceeding a certain threshold. In Figure 1, the probability of Ellrod TI1 exceeding 1.6×10^{-6} is produced from MOGREPS-R on 2/1/2007. Figure 2 shows another example where ensemble members are reduced to "postage stamps" so that they can be viewed on one plot.
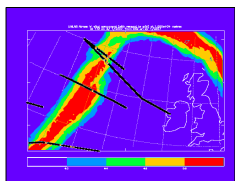

Figure 1. T+36 hours forecast of the probability of Ellrod TI1 > 1.6×10^{-6} on 2/1/2007. Aircraft tracks are overplotted in black and turbulent events in orange.
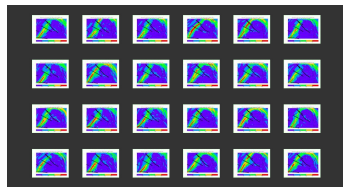

Figure 2. T+36 hours postage stamp figures for Ellrod TI1 forecasts from individual ensemble members on 2/1/2007.

CAT forecast trial

- Four-month trial from February to May 2009.
- Forecasts produced over MOGREPS-R region covering North Atlantic and Europe.
- Forecasts produced twice a day at forecast ranges from 3 to 54 hours in 3 hour time steps.
- Forecasts produced on nine vertical levels between 400 to 150 hPa.

Verification

Forecasts assessed using objective verification against automated aircraft observations from the Global Aircraft Dataset (GADS) comprised of high resolution data from the fleet of British Airways B747-400 aircraft. The distribution of aircraft data can be seen in Figure 3.

Derived Equivalent Vertical Gust (DEVG) used as an observational measure of turbulence.

Each aircraft track split up into 10 minute sections and assigned as a turbulent or non-turbulent observed event, depending on whether DEVG exceeds the 2m/s threshold representing slight turbulence at any time in the flight section.

Each track assigned as a forecast turbulent or non-turbulent event by interpolating the forecast to the position of the maximum observed value of DEVG in each flight section and comparing with a threshold (6.0×10^{-7} for probabilistic forecast and 5.0×10^{-7} for deterministic forecast).

2x2 contingency tables used to accumulate scores over each section of every flight within the sample. Figures 5 and 6 show the totals from all flights in the trial.

From the contingency tables verification statistics can be calculated, by plotting hit rate against false alarm rate a Relative Operating Characteristic (ROC) curve can be constructed and used as a measure of skill to assess both the probabilistic and deterministic CAT forecasts (Figure 4).

Deterministic	CAT Forecast	No CAT Forecast
Turbulence observed	191	247
No turbulence observed	13256	42283

Figure 5. Contingency table – deterministic

Probabilistic (20% threshold)	CAT Forecast	No CAT Forecast
Turbulence observed	190	248
No turbulence observed	10911	44528

Figure 6. Contingency table – probabilistic
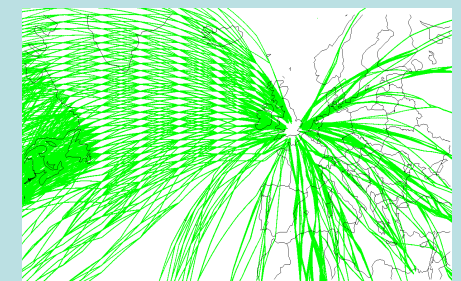
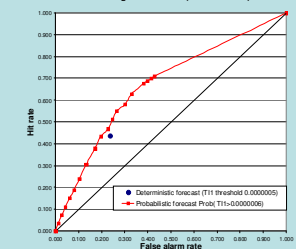**Figure 3.** Distribution of GADS aircraft data over 10 days

Figure 4. ROC curve Deterministic v Probabilistic

Conclusions and further trials

- MOGREPS probabilistic CAT forecasts have shown greater skill than deterministic CAT forecasts.
- Probabilistic forecasts give a measure of confidence in the forecasts.
- Further trials will use moderate or greater turbulence threshold rather than the slight turbulence threshold.
- Use verification results to calibrate forecasts in terms of reliability.
- Use of MOGREPS-G to give global forecasts following resolution upgrade to approximately 60 km horizontal resolution and 70 vertical levels in 2010.