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WIND NOWCASTING TO SUPPORT CONTINUOUS DESCENT APPROACHES

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1. INTRODUCTION

The UK Met Office has been providing predictions of upper air wind and temperature to support Continuous Descent Approaches (CDA) into Stockholm Arlanda airport in Sweden.

The forecasts are provided on a grid covering an area of radius up to 160 Nm around Arlanda.

From September 2007 forecasts have been generated for certain specific transatlantic flights. These flights arrive early in the morning, Swedish time. Forecasts generated are for up to 80 minutes ahead.

For many approaches into busy airports, step-wise descent profiles are standard practice (Figure 1). For approaches into particularly busy airports such as Heathrow in England, it is very common for aircraft to join “stacks” in which there are alternating phases of level and descending flight. However, it is recognised that continuous descent approaches allow considerable fuel savings (with associated reductions in CO2 emissions). In addition the noise footprint is considerably reduced and the chances of encountering a wake vortex from another approaching aircraft are reduced.

The WAFTAGE (Winds Analysed and Forecast for Tactical Aircraft Guidance over Europe) nowcasting tool is being used. WAFTAGE ingests measurements of wind and temperature, in this case from AMDAR equipped aircraft. In addition to generating forecasts, the work described includes verifying the forecasts against later AMDAR reports.

2. CONTINUOUS DESCENT APPROACH

Normally aircraft use step-wise descents at busy airports.

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Figure 1 shows the difference between a typical continuous descent approach (green flight path) and stepped approach (red flight path). When aircraft use the stepped approach, they join ‘stacks’ at different levels. The CDA method removes the need for stacks, and therefore reduces the chances of the aircraft encountering wake vortices from other approaching aircraft.

During the descent, the noise pollution comes from two different places. The engines deliver high power when the plane is manoeuvring near the ground and the aerodynamic noise from the flaps on the trailing edge of the wing gets worse during manoeuvres. When the manoeuvres are carried out at higher altitudes, the noise pollution is reduced. Aircraft using CDA carry out their manoeuvres at high altitudes, and then maintain a steady angle of descent with minimal corrections. In a study done at Louisville International Airport in Kentucky (Clarke 2004), it was found that near the airport, the noise dropped between 3.9 and 6.5 decibels when using a continuous rather than stepped approach.

In addition, the fuel consumption is reduced with CDA, which reduces emissions of CO_2 and other pollutants. In the same study, approximately 200 kilograms of fuel were saved on each landing. The CDA starts from cruise level at around 100 Nm from the airport and a constant angle of descent is maintained. A stepped approach can start from as far out as 400 Nm from the runway. The fuel consumption increases at lower altitudes.

Swedish aviation company AVTECH have requested accurate meteorological data for the area around Stockholm Arlanda airport to assist with continuous descent approaches.

Met Office vector wind and temperature forecasts are being supplied to AVTECH on an inverted conical grid centred on Arlanda airport. At the base the cone has radius 55Nm with data every 1000ft up to 43 000ft. At the highest level the data is on a disk of radius 160Nm.

The meteorological data is assimilated by AVTECH using their NowCast system together with predicted flight path information from an aircraft. Wind information is then uplinked to the aircraft for descent.

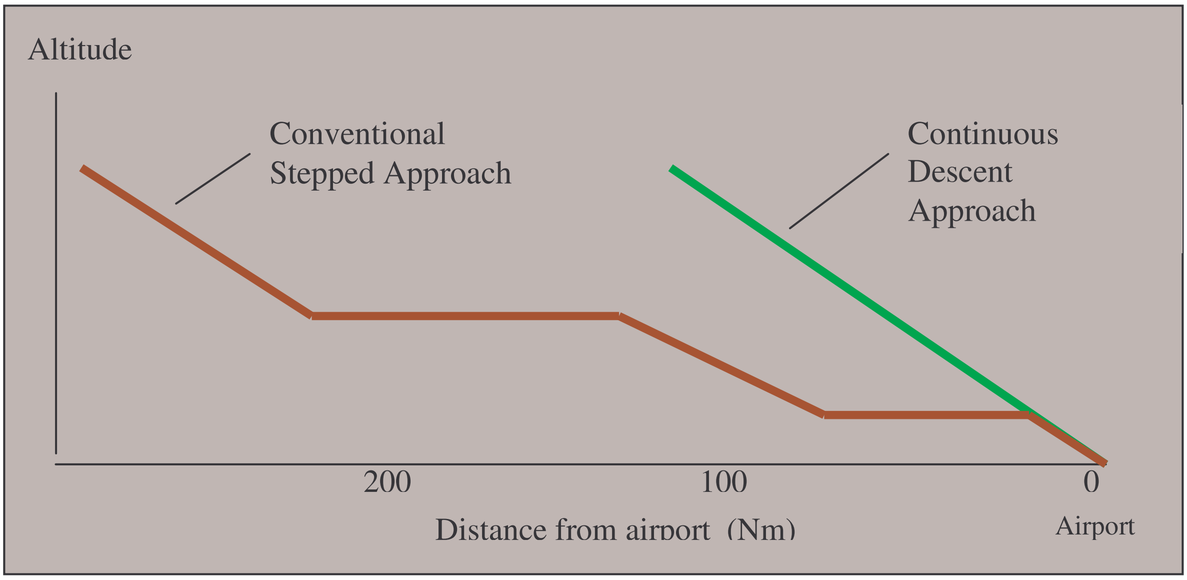

Figure 1 Flight path for continuous descent and stepped approach

3. WAFTAGE

Although NWP model forecasts are continually increasing in accuracy there is always a delay between the time the model forecast is run and the time that the forecast is available.

WAFTAGE is a nowcasting system that works by updating a model forecast with the latest observations available just before the validity time of the forecast. It was originally developed by Dharssi and Forrester (Dharssi and Forrester 1992) and uses a successive correction algorithm which can be summarised by the following equations.

The successive correction algorithm modifies each of the n x m lat-lon grid points on all of the k vertical pressure levels.

$$a_p = b_p + \sum_{i=1}^{N} B_{grdpi} q_i^{(u)} \qquad (1)$$

where

$$q_i^{(u+1)} = q_i^{(u)} + \frac{(o_i - b_i) - \sum_{j=1}^{n} (B_{ij} + O_{ij}) q_j^{(u)}}{\sum_{j=1}^{n} (|B_{ij}| + |O_{ij}|)}$$

Is Newton's iterative method to find $q_i^{(u)}$ where $q_i^{(0)} = 0$ and $u = 25$.

In equations (1)

o_i is the input observation value (eg AMDAR reports)

b_i is the background value of the model forecast interpolated in 4D to the location of o_i

a_p is the output analysis value (ie the WAFTAGE nowcast) at grid point p

b_p is the corresponding background value of the model forecast at WAFTAGE grid point p.

B_{ij} is an element of the matrix of covariances of background errors at the location of observations i and j.

O_{ij} is an element of the matrix of covariances of observation errors at the location of observations i and j.

N is the total number of observations used by the WAFTAGE successive correction algorithm.

B_{grdpi} is the matrix of covariances of background errors between the position of observation i and WAFTAGE point p

Error covariances describe how the change in a variable at one location influences the change of another variable at a different location. In WAFTAGE the error covariance functions are represented by Gaussian functions (Sharpe 2005).

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WAFTAGE currently takes the UK Met Office NAE (North Atlantic European Model) forecasts as the background model, and updates them using the most recent measurements of wind speed and temperature from AMDAR equipped aircraft. The NAE model currently has a horizontal resolution of 12km and 38 vertical levels. Figure 2 shows the NAE domain with the WAFTAGE domain inside. Figure 3 shows AMDAR data over the Stockholm Arlanda area. The runway is marked with a blue cross. Each red cross represents the position of an AMDAR report. The data was collected during a 24 hour period.

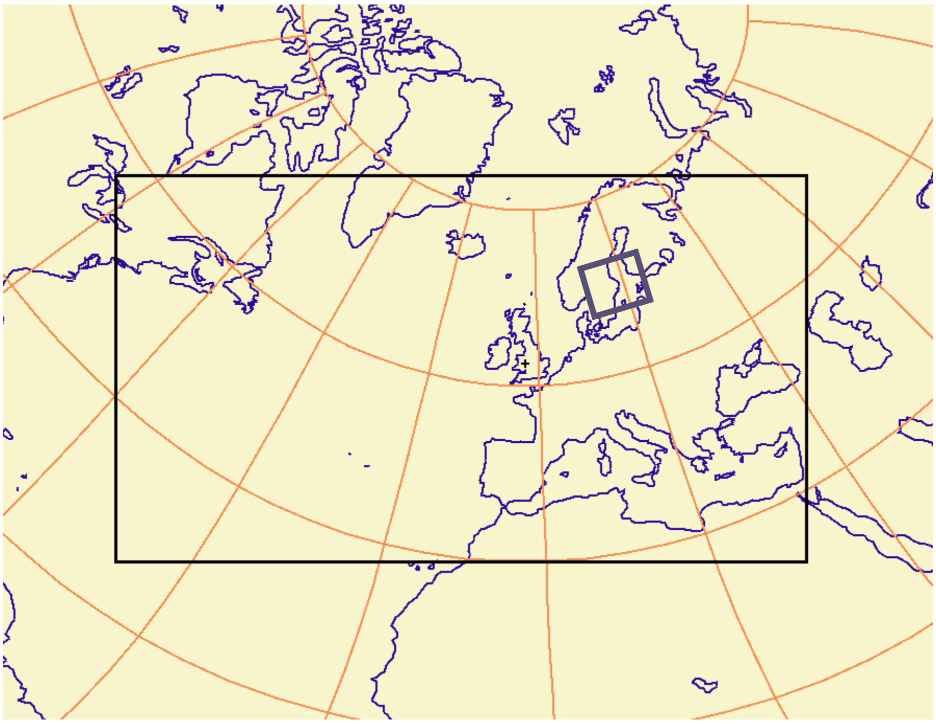

Figure 2 UK Met Office NAE model and WAFTAGE Domains

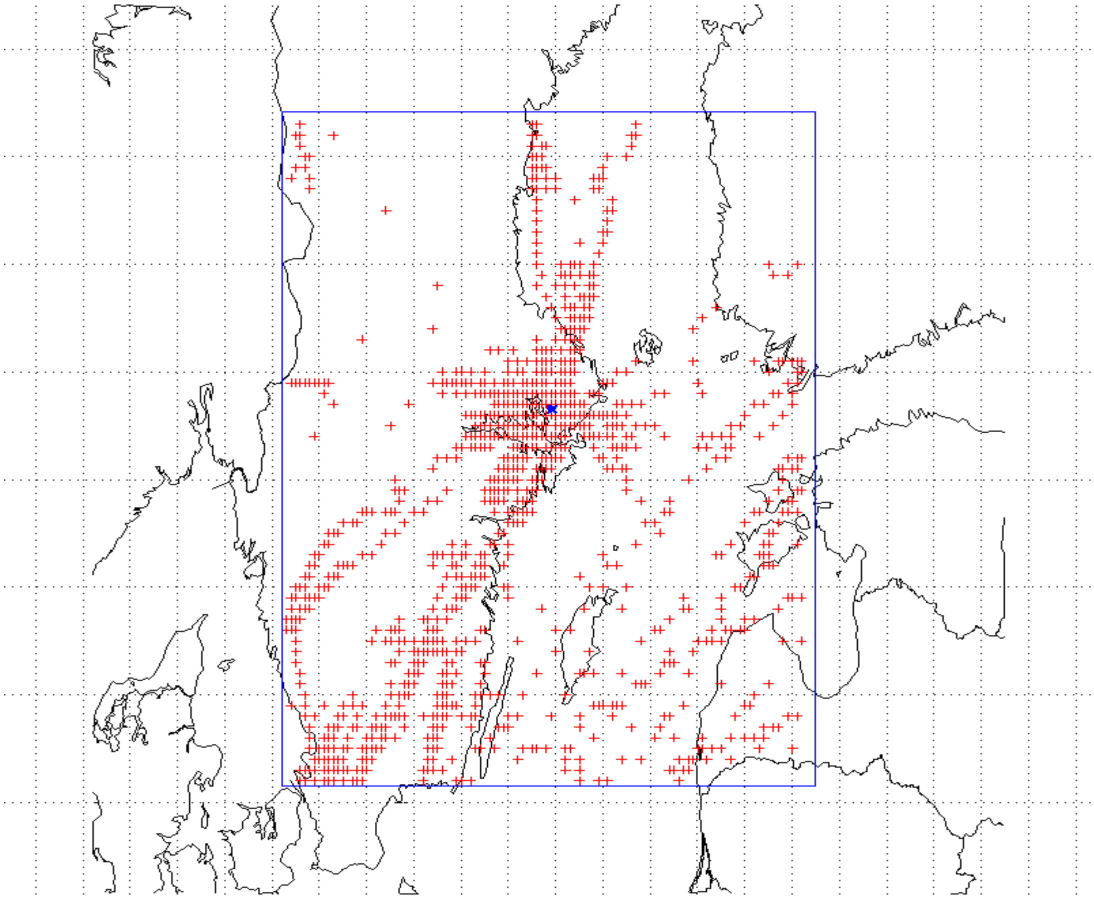

Figure 3 WAFTAGE area around Stockholm Arlanda with AMDAR reports

Figure 4 shows a schematic diagram of the way WAFTAGE is currently being run. The NAE model forecast is run at 00, 06, 12 and 18z. This is used as the model input to WAFTAGE with a forecast range of between 4 and 11 hours. Any observations that are available in the 40 minutes immediately preceding runtime are ingested into WAFTAGE to produce forecasts with forecast ranges in 20 minute intervals out to T+80 minutes. WAFTAGE is currently being run every hour and typically takes around one minute to produce the updated forecasts.

The size of the area around Stockholm Arlanda that has been investigated is 12.2E to 23.5E and 57.25N to 60.22N, on 45 vertical levels at 1000 ft intervals up to 44000ft . The grid consists of 62x70 lat-lon pts.

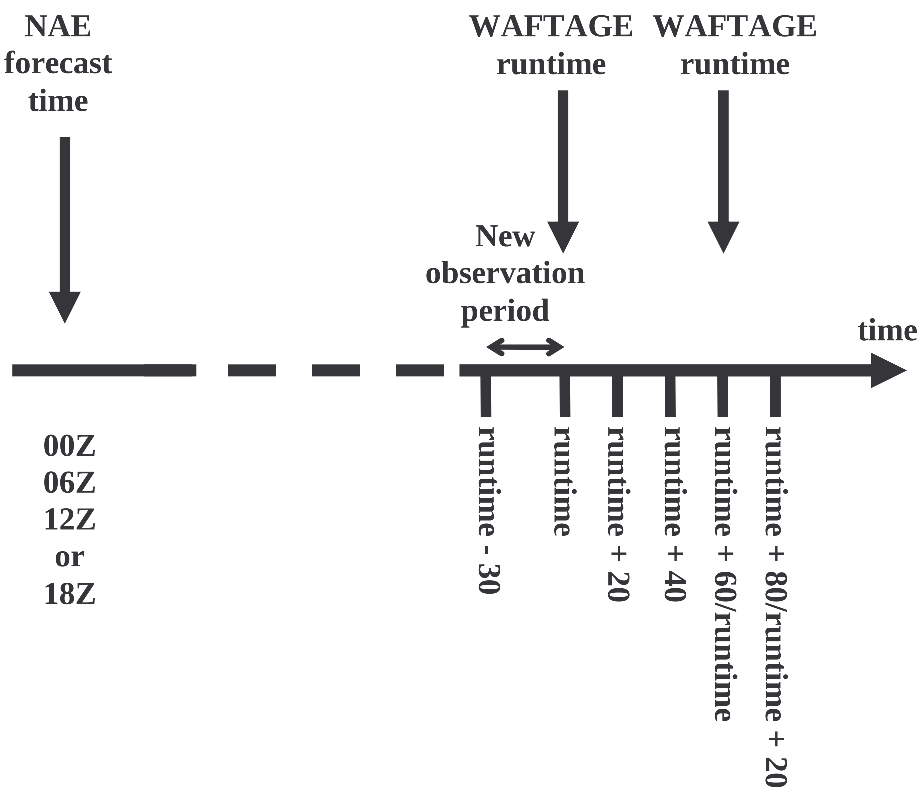

Figure 4 Diagram of the WAFTAGE system

An example of a WAFTAGE forecast can be seen in Figure 5 this shows a vertical latitudinal cross section through Arlanda of the u component of the wind speed. This would correspond to the cross winds that would be experienced for a northerly approach into Arlanda at varying altitudes. Figure 6 shows the horizontal wind shear on a lat-lon plot at approx 30000ft

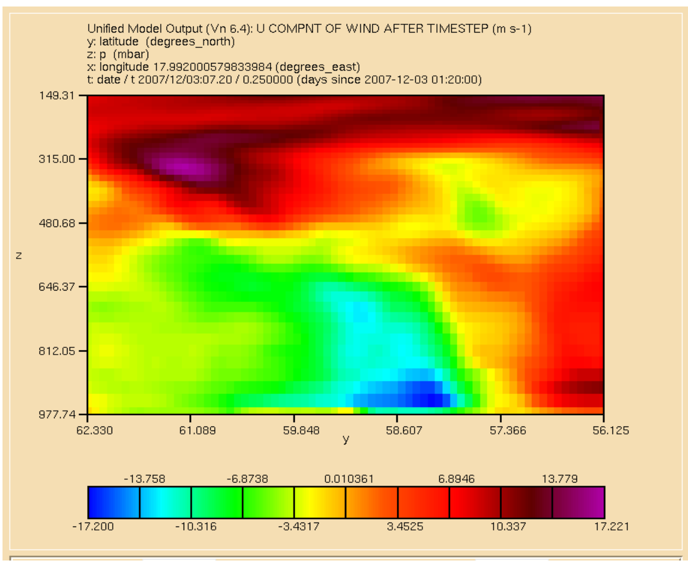

Figure 5 WAFTAGE vertical latitudinal cross section plot through Arlanda

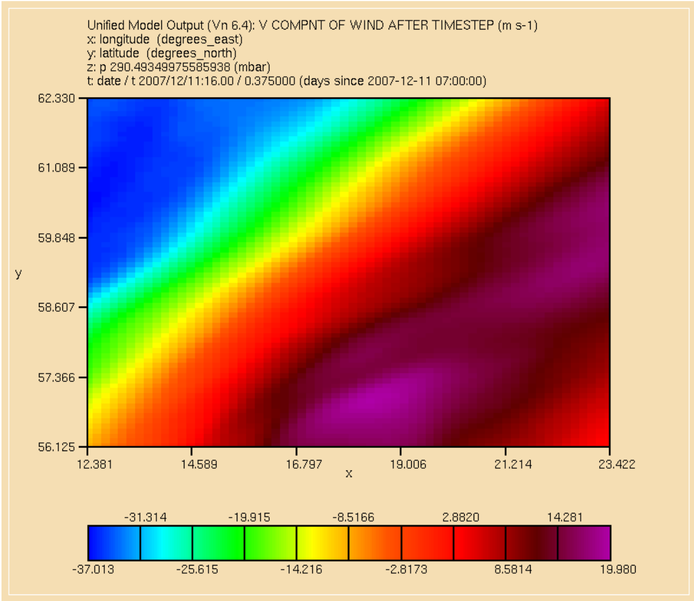

Figure 6 WAFTAGE lat-lon plot

4. RESULTS

4.1 *Verification of WAFTAGE forecasts*

Verification of the WAFTAGE forecasts against AMDAR observations is carried out routinely. Observations within 10 minutes either side of the validity time of the forecast are used. Choosing the observations in this way means that no observation is used more than once in the verification.

To avoid using observations of poor quality checks are carried out before they are used. A regularly updated list of blacklisted aircraft is used to remove observations from potentially unreliable sources. Checks are also carried out against the background for gross errors. Again any observations that are flagged as having gross errors are removed from the verification.

Forecasts are verified by creating a grid, and choosing one observation point in each grid box. By doing this it removes the bias of a number of observations all in the same area. The WAFTAGE and background results are then compared with the observation points to verify the data. The grid used for the verification is the same as the grid used for WAFTAGE.

Linear interpolation is used in all three spatial dimensions to calculate the forecast value at the position of each observation. Time interpolation is not currently used on the forecasts.

Mean and root mean square (RMS) error statistics were calculated for each WAFTAGE run by calculating the difference between the observation and forecast and summing the results.

4.2 *Analysis of results*

	Number of observations	RMS T error	RMS U error	RMS V error	Mean T error	Mean U error	Mean V error
Background	19407	1.0307	2.7864	2.8868	-0.1775	-0.6659	0.0103
WAFTAGE	19407	0.9186	2.5746	2.6260	-0.1615	-0.4163	0.0605

Table 1 Verification statistics for WAFTAGE and the background model.

The WAFTAGE verification scores in Table 1 cover the two week period between 20/12/2007 and 08/01/2008. The RMS scores shown in figure 7 show that WAFTAGE is clearly producing an improved forecast from the background model field.

The scatterplots in figure 8 show the RMS error of the WAFTAGE forecast plotted against the RMS error of the associated background model field. Only forecasts that have been updated with at least 50 observations are used here. It can be seen from these scatterplots that most of the points lie above the line which means that the WAFTAGE forecast has improved on the original background model forecast.

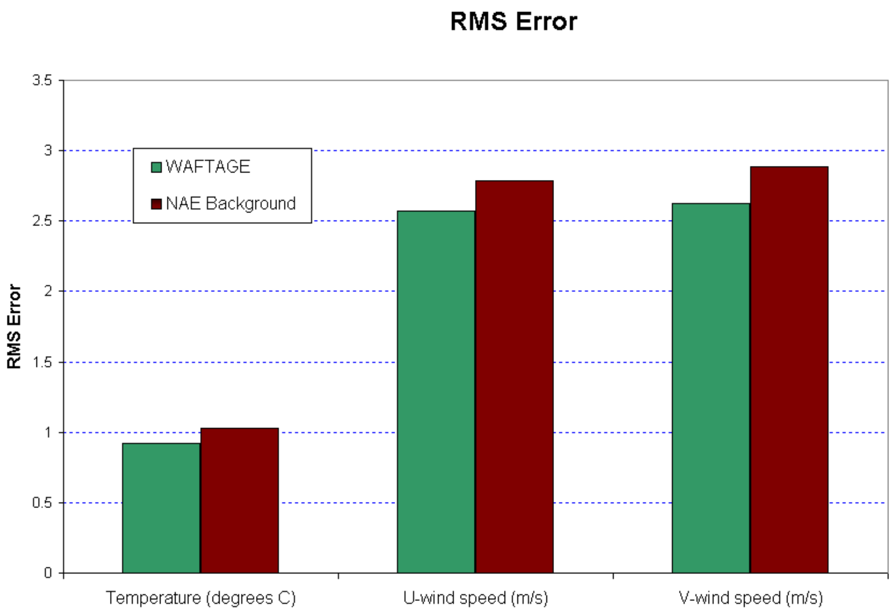

Figure 7 WAFTAGE and background model RMS errors

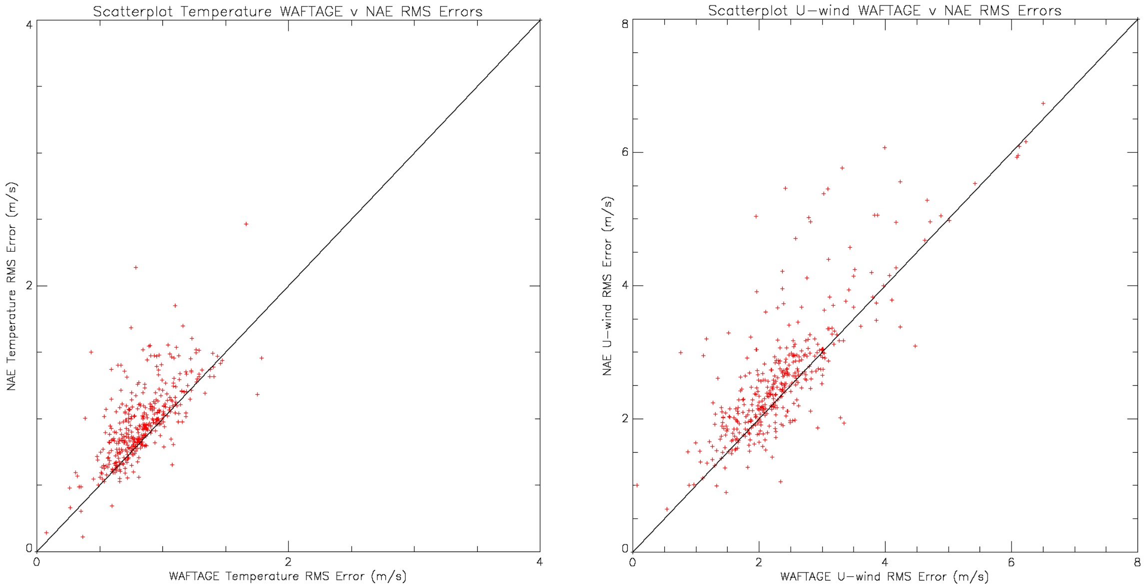

Figure 8 Scatterplots for temperature and wind RMS errors

5. FURTHER WORK

Extensive will be carried out over the next few months and further development work to the WAFTAGE system is planned.

The scheduled resolution upgrade to the UK Global Model in 2008 should increase the accuracy of WAFTAGE to be run anywhere in the world.

Increased accuracy could be obtained by running WAFTAGE at a higher resolution and at shorter time intervals. Currently WAFTAGE is run every hour, this could be reduced to 20 minutes with forecasts being available every 10 minutes. As the background models increase in resolution, WAFTAGE should also be run at a finer resolution.

6. REFERENCES

Clarke, J-P B; Ho, N T; Ren, L; Brown, J A; Elmer, K R; Tong, K-O; Wat, J K 2004, Continuous Descent Approach - Design and Flight Test for Louisville International Airport, Journal of Aircraft. Vol. 41, no. 5, pp. 1054-1066.

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