TECHNICAL MEMORANDUM

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Improved Assimilation of Data from China's FY-3A Microwave Temperature Sounder (MWTS)

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Abstract

The FY-3A MWTS suffers from radiometer non-linearities and uncertainties in passband centre frequencies. Corrections have been developed, and are assessed here by comparing re-calibrated MWTS data with equivalent AMSU-A observations. The corrections are effective in improving the first guess departure statistics for MWTS, relative to the original un-corrected data, to values close to those for AMSU-A equivalent channels. In observing system experiments MWTS observations improve the first guess fits for AMSU-A observations. Forecast verification shows a systematic improvement by using the re-calibrated data, for example forecasts of 200 hPa geopotential are improved to Day 4 in the SH by approximately 1%.

1 Introduction

Over the next decade China's FY-3 series of seven polar orbiting meteorological satellites (Dong et al. (2009); Zhang et al. (2009)) will become an important component of the Global Observing System. The FY-3 suite of microwave and infrared sensors will provide data for applications including Numerical Weather Prediction (NWP), atmospheric reanalysis as well as climate studies. The preparatory platform (FY-3A) was launched on 27th May 2008 and has been evaluated at ECMWF (Lu et al. (2010)). A second platform (FY-3B) was successfully launched on 4th November 2010. Of particular interest for NWP applications is data from the Microwave Temperature Sounder (MWTS) as microwave sounding data currently delivers the largest positive impact on forecast accuracies in global NWP systems (Cardinali (2009)). The MWTS is a 4 channel radiometer with channels nominally centred at 50.3, 53.596, 54.94 and 57.29 GHz and is similar in specification to the Microwave Sounding Unit (MSU) carried on-board the Polar Orbiting Environmental System (POES) satellites TIROS-N to NOAA-14. The evaluation of the FY-3A MWTS showed data from the instrument is currently affected by two sources of bias. These biases are related to uncertainties in the centre frequencies of the passbands and radiometer non-linearities (Lu et al. (2011)). Corrections were developed for these biases and a re-calibrated dataset was generated for evaluation, both through comparison with observations from established microwave instruments (the Advanced Microwave Sounding Unit-A, carried on several operational platforms, see Goodrum et al. (2000)) as well as through observing system experiments in which the MWTS data was added to a full operational configuration of the ECMWF Integrated Forecasting System. The results of these investigations are described below.

2 Data Quality

As a first step in the assessment of data from new satellite instruments it has become standard practise at NWP centres to compare measurements with NWP model equivalents. In the case of radiance measurements (normally expressed as brightness temperatures) this involves a mapping of the model state, interpolated to the location of the measurements, to radiances using a fast radiative transfer model. This has proved to be particularly effective in the assessment of microwave temperature sounding radiances, for which the low sensitivity to cloud radiative effects, the high quality of NWP short range forecast fields and well characterised radiative transfer calculations result in highly accurate model equivalent radiances (Bell et al. (2008)). These modelled radiances can therefore be treated effectively as a proxy for the true radiances and differences in these modelled radiances with respect to the measured radiances can be used to estimate errors in the measurements. The high quality of the NWP fields results from the range of data types assimilated. Of particular importance for the ECMWF model in this context

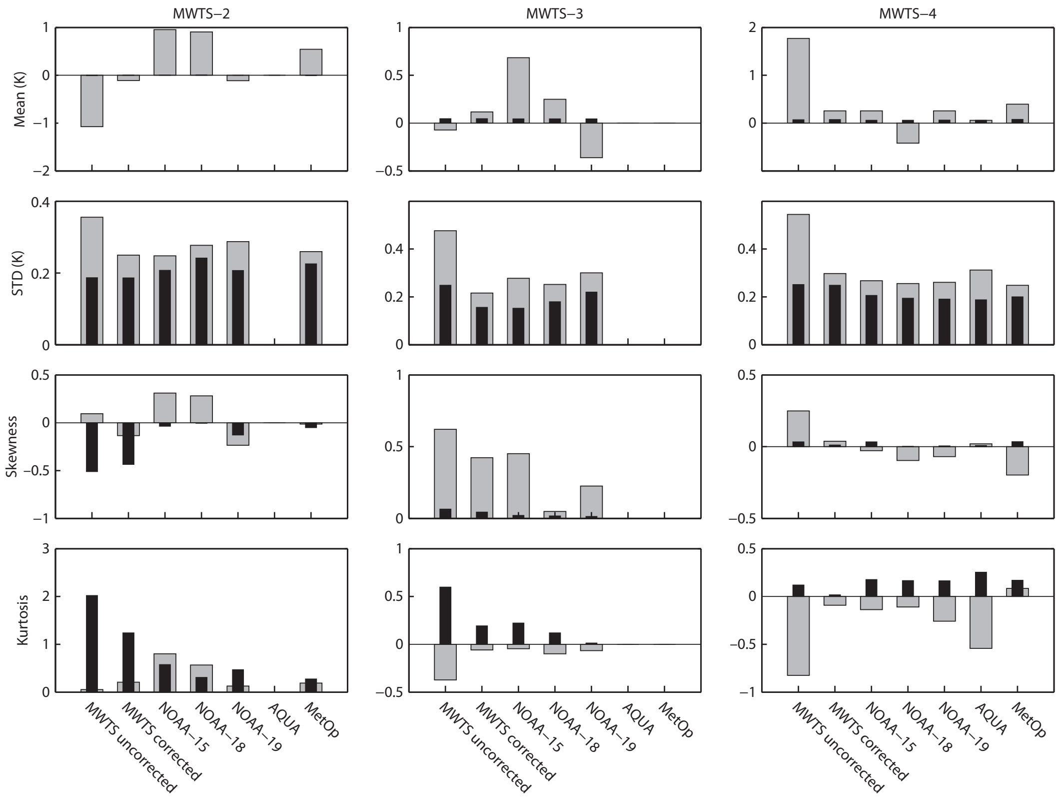

Figure 1: First guess departure statistics showing (from top to bottom) mean , standard deviations, skewness and excess kurtosis for MWTS data (channels 2-4, left to right) and AMSU-A data from NOAA-15,-18,-19, NASA's EOS Aqua and EUMETSAT's MetOp-A. The MWTS uncorrected *bars refer to the original MWTS data prior to passband optimisation and non-linearity correction. The light grey bars represent statistics for data prior to variational bias correction, the black bars represent data after variational bias correction.*

(Cardinali (2009)) are measurements assimilated from Advanced Microwave Sounding Unit-A instruments (AMSU-A) on-board five polar orbiting platforms, the Advanced Infrared Sounders (AIRS and IASI, see Challon et al. (2001) and LeMarshall et al. (2006)) and data from a constellation of Global Positioning Satellites (Healy and Thépaut (2006)). The global coverage of both measurements and model mean that errors can be assessed across the full measurement range of the instrument as well as a wide range of atmospheric conditions. This approach was used to good effect in detecting and correcting for radiometer passband mis-specification and non-linearities in the FY-3A MWTS.

As a quantitative measure of the fit of modelled radiances to measurements statistics can be computed and these in turn can be compared with those obtained from comparable well characterised instruments. Figure 1 shows the first four statistical moments for first guess departures for MWTS channels 2-4 compared with statistics from the five AMSU-A instruments currently used in ECMWF operations, for equivalent channels. Statistics are shown both prior to and after the re-calibration corrections described by (Lu et al. (2011)) and for both sets the statistics are shown before and after variational bias correction (Dee (2005)) of the data. The variational bias correction scheme for MWTS used eight predictors: a global offset, four thicknesses (1000-300 hPa, 200 hPa, 50 hPa and 10-1 hPa) and first, second and third powers of the satellite scan angle to model cross scan biases. Statistics were generated from data actively included in 22 consecutive assimilation cycles from 00Z on 1st June 2010 to 12Z on 11 June 2010.

Figure 1 shows that the passband and non-linearity corrections for MWTS are effective in significantly reducing the mean and standard deviation of the first guess departures for all channels, prior to variational bias correction. For all MWTS channels the re-calibrated data, prior to variational bias correction, is similar in quality to the equivalent AMSU-A data. The mean first guess departures for MWTS-2 and MWTS-3 are significantly smaller. Variational bias correction is effective in further reducing the means and standard deviations, with standard deviations for MWTS-2 ,-3 and -4 reduced by 30%, 28% and 17% respectively. The standard deviations of bias corrected data for channels MWTS-2 and MWTS-4 are similar whether or not the data is re-calibrated, indicating that the current bias correction scheme is very flexible in successfully reducing the impact of these instrument biases for these channels, however for MWTS-3 there is a benefit in correcting these errors in a re-calibration step. MWTS-1 and AMSU-A channel 3 (50.3 GHz), not shown here, are not actively assimilated in the ECMWF system but are used for screening data for cloud effects. The standard deviations for the re-calibrated and bias corrected data for MWTS- 2 and -3 are at or below the equivalent statistics for AMSU-A. For MWTS-4 the standard deviations (0.25K) are higher than those for the equivalent AMSU-A channel (0.20K). This is partially accounted for by the higher noise (NEΔT=0.19 K for MWTS-4 compared to 0.16K for AMSU-A channel 9) in the on-orbit MWTS data.

Higher order statistics (skewness and excess kurtosis respectively) for re-calibrated and bias corrected MWTS are similar to those for the AMSU-A equivalent channels for MWTS-3 and -4 and close to zero (skewness < 0.1 and excess kurtosis < 0.2 for both channels). MWTS-2 exhibits greater negative skewness and higher excess kurtosis than AMSU-A channel 5. This is most likely due to an unresolved inconsistency in the treatment of sea ice which results in larger negative departures at high latitudes for the MWTS channels with a significant contribution from the surface (MWTS-1 and MWTS-2), although as stated earlier MWTS-1 is not actively assimilated, but is used to screen other channels for cloud effects. These higher order moments give a clearer indication of the benefits of the re-calibration step as for all three channels shown here the first guess departures for re-calibrated data is closer to Gaussian than the original data. Overall, the re-calibration process has significantly improved the data and brought the MWTS data to a quality close to that of AMSU-A.

3 Observing System Experiments

Observing System Experiments (OSEs) were conducted to assess the relative benefit of the original MWTS data (ie based on the pre-launch measurements of the passband centres and with no non-linearity correction) with the re-calibrated data. The OSEs involved adding MWTS data to a full observing system which enabled an assessment of the benefit of the new re-calibrated MWTS data. The OSEs are summarised in Table 1 below.

The FULL SYSTEM contained all observational data sets used operationally in the ECMWF model (Radnoti et al. (2010)), with the exception of the microwave imager data (from F-15 SSMI and AMSR-E) which were omitted to reduce the computational cost of the experiments. It is not expected that the inclusion of this data would significantly change the conclusions presented here. The PRELAUNCH MWTS experiment used data prior to re-calibration, and the observation errors were derived by scaling the AMSU-A assumed observation errors by the ratio of the standard deviations of first guess departures as detailed in (Lu et al. (2010)). The HIOBSERR MWTS experiment used re-calibrated data, but maintained the inflated observation errors as used in PRELAUNCH MWTS. The LOWOBSERR MWTS experiment used the same observation errors as the AMSU-A equivalent channels, as justified by the data quality.

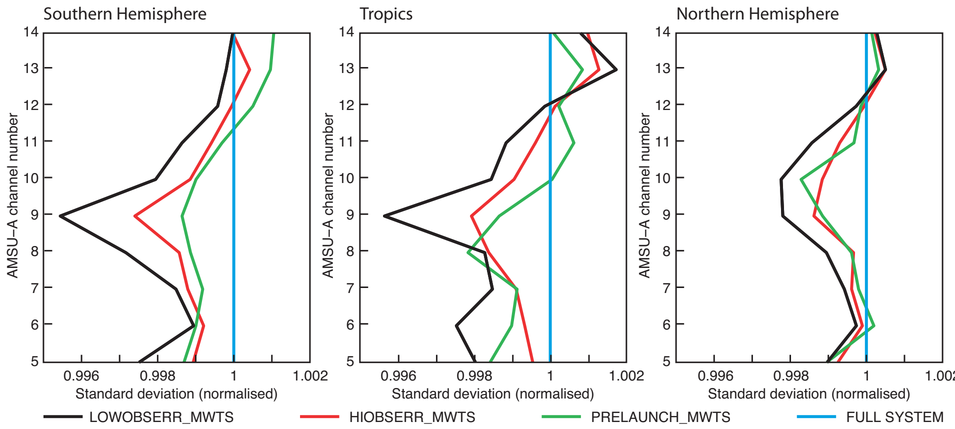

Figure 2: Normalised standard deviations of first guess departures for AMSU-A channels 5-14, aggregated over all actively assimilated AMSU-A's during the period 1 May 2010 - 30 July 2010. The normalisation is with respect to the standard deviations for the FULL SYSTEM OSE.

All experiments were run at T511 resolution (approximately 40 km grid resolution) over the period 1 May 2010 to 1 August 2010. Forecast fields were verified against the FULL SYSTEM analysis fields. An indication of the impact of the new data on the quality of analyses and short range forecasts is provided by the first guess fit (departures) to other observations. Figure 2 shows the first guess fit for all AMSU-A instruments currently assimilated in the ECMWF model (from NOAA-15,-18,-19, EUMETSAT's MetOp-A platform and NASA's Aqua platform). The standard deviations of first guess departures for both hemispheres and tropics are shown and have been aggregated over all sensors over the 3 month period of the OSE's. Typically 3-7 million actively assimilated observations for each channel have been aggregated over this period. The standard deviations are normalised with respect to the standard deviations from the FULL SYSTEM experiment. Error bars are not shown, but for sample sizes of 3-7 million observations, statistical uncertainties in these normalised standard deviations are expected to be in the range 0.10-0.15% (for 95% confidence).

From Figure 2 short range forecast fields show neutral to improved fit to AMSU-A radiances for channels 5-12 for all regions for the LOWOBSERR MWTS OSE. The impact is largest for AMSU-A channel 9 at approximately 0.4% in the SH and Tropics. This suggests an improvement in short range forecasts. The short range forecast fields are improved for the HIOBSERR MWTS and the PRELAUNCH MWTS

Table 1: Observing System Experiments.

Identifier	**Description**	**Assumed Observation Errors / K (MWTS-1,-2,-3,-4)**
FULL SYSTEM	Full Observing System	-
PRELAUNCH MWTS	Full + pre-launch MWTS	10 / 0.43 / 0.52 / 0.55
HIOBSERR MWTS	Full + re-calibrated MWTS with low weight	10 / 0.43 / 0.52 / 0.55
LOWOBSERR MWTS	Full + re-calibrated MWTS with high weight	10 / 0.35 / 0.35 / 0.35

experiments, but the improvement is smaller in magnitude than that obtained for LOWOBSERR MWTS and in some cases at the limits of statistical significance. An inspection of similar plots for AIRS and IASI are less conclusive as the higher radiometric noise levels for these instruments make the signal (of improved fit) difficult to discern. For other observations, there are no significant differences in the fit to short-term forecasts.

Figure 3 shows the normalised difference in geopotential RMS errors at 200, 500 and 700 hPa in the NH and SH for the three OSEs in which MWTS data is added. In the SH a steady improvement, albeit at the limits of statistical significance, is noted from PRELAUNCH MWTS to HIOBSERR MWTS to LOWOBSERR MWTS. Statistically significant improvements of 0.5-1.5 % are noted for forecasts to Day 3 for LOWOBSERR MWTS with the largest impacts at 200 hPa. In the NH impacts are close to neutral for forecast ranges from Day 1 to Day 8. Positive impacts are noted at T+12 hours, with the largest impacts at 200 hPa for LOWOBSERR MWTS.

Figure 4 shows the normalised difference in vector wind RMS errors for the SH, Tropics and NH at

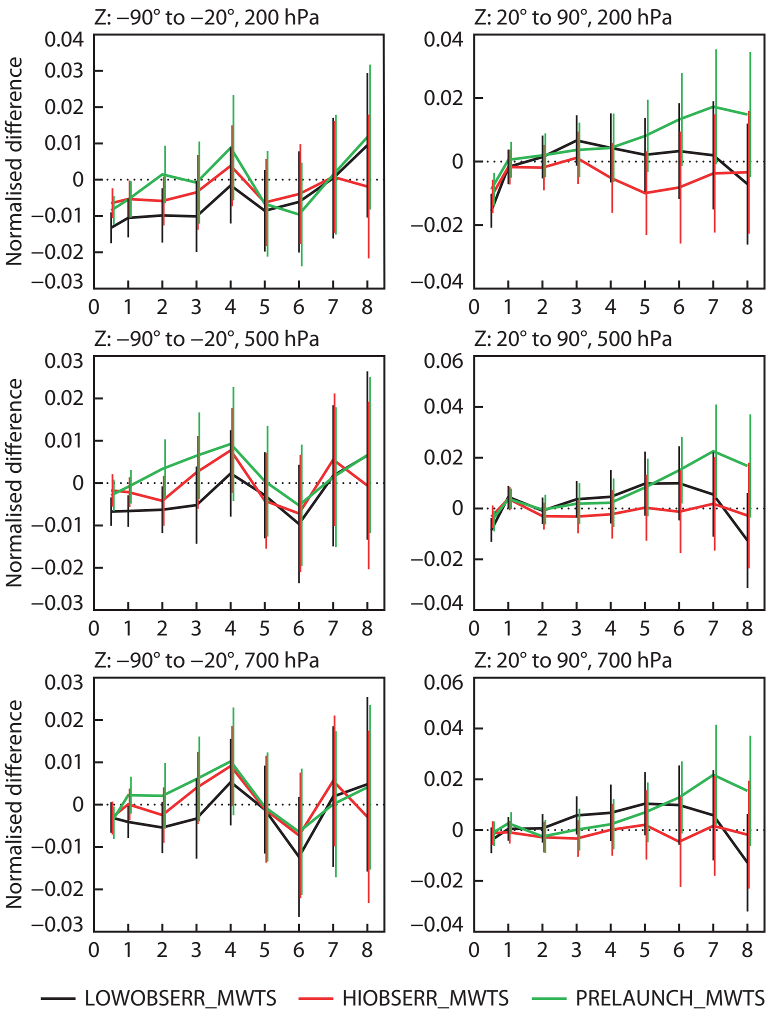

Figure 3: Normalised differences in RMS errors in geopotential for forecast days 0-8 (x-axis) in the SH (right colum) and NH (left column) for (top-to-bottom) 200 hPa, 500 hPa and 700 hPa levels. The normalisation is with respect to the FULL SYSTEM OSE. The error bars represent 90% confidence limits.

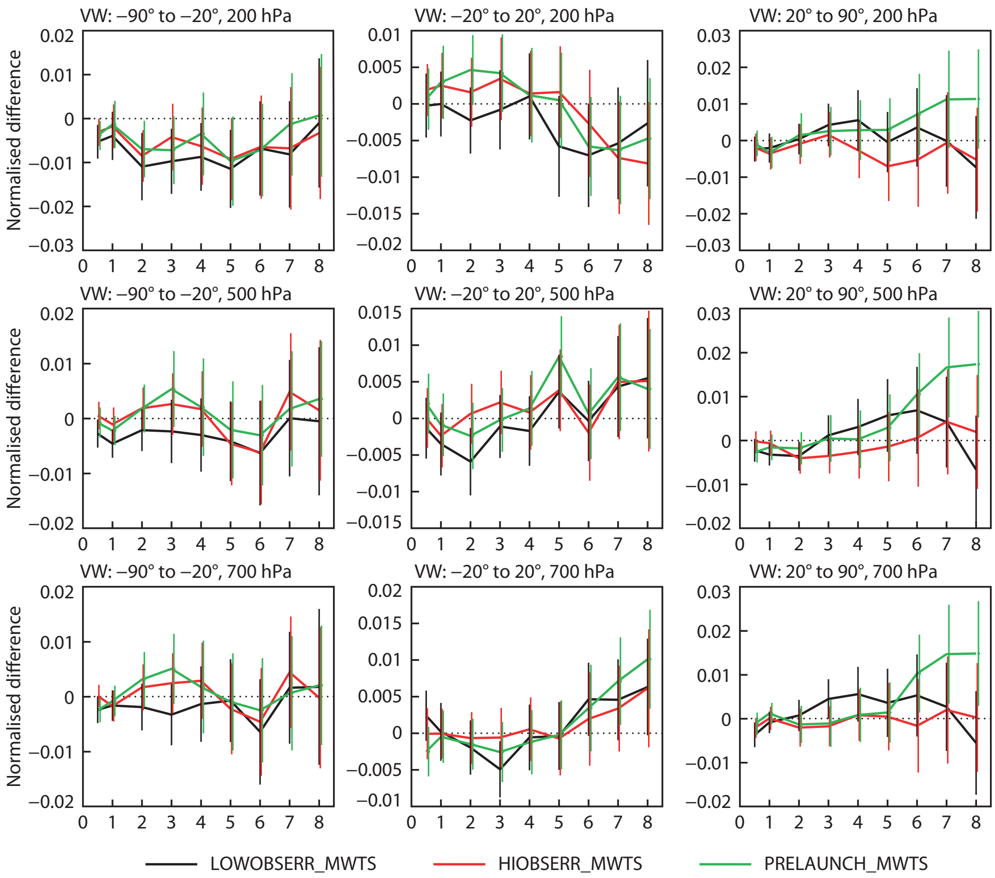

Figure 4: Normalised differences in RMS errors in vector wind for forecast days 0-8 (x-axis) in the SH (right colum) , Tropics (middle column) and NH (left column) for (top-to-bottom) 200 hPa, 500 hPa and 700 hPa levels. The normalisation is with respect to the FULL SYSTEM OSE. The error bars represent 90% confidence limits.

200 hPa, 500 hPa and 700 hPa. The results are broadly in qualitative agreement with those illustrated in Figure 3. The largest impacts are found in the SH at 200 hPa where winds are improved by approximately 1% for all forecast ranges to Day 5 and there is a systematic improvement in going from PRELAUNCH MWTS to HIOBSERR MWTS to LOWOBSERR MWTS. This trend is also observed in the Tropics but in the NH the picture is less clear. Indeed at 700 hPa, there is some indication of a small degradation (0.5%) in LOWOBSERR MWTS for the Day 3 and 4 forecasts. Smaller impacts are to be expected in the NH due to the denser network of non-satellite observations available in this region.

4 Results and Discussion

The aim of the work presented in this letter is threefold: firstly to assess whether the two physically based corrections described in (Lu et al. (2011)) are effective in improving the MWTS data quality; secondly to determine whether these corrections make a difference on forecast accuracy; and thirdly to assess the readiness of the FY-3A MWTS for active operational assimilation. With regard to the first aim a comparison of MWTS, both before and after re-calibration, with AMSU-A data has shown that the re-calibrated MWTS data is very similar in quality to the AMSU-A data. With regard to the second aim, the OSEs presented here show that there is some benefit in correcting for the passband shift and non-linearity in a re-calibration step rather than allowing variational bias correction to compensate for these errors. This was shown through an inspection of the short range forecast fits to AMSU-A observations as well as verification of longer range forecasts. In most cases the benefit is at the limits of statistical significance but appears coherent across forecast ranges and across a range of AMSU-A channels. The result also highlights the need to define an appropriate weighting of observations in the assimilation system, as the use of re-calibrated MWTS data is clearly improved through the use of revised (reduced) observation errors. Finally, in absolute terms, it has been shown that the inclusion of re-calibrated FY-3A MWTS data in 3 month full system OSEs results in improved forecast accuracy in the SH. Some issues with the screening of localised transient errors in the data remain however, which currently prevent active operational assimilation at ECMWF. These problems appear to be related to errors in the cold space views used for the radiometric calibration of the instrument and affect a small number of scan lines in occasional orbits. It is expected that these problems will be resolved soon. This work presents a picture of the FY-3A MWTS as a high quality radiometer capable of producing improvements in forecast quality when assimilated in a state-of-the-art NWP model. It also, however, illustrates the need for careful pre-launch characterisation, in this case of passband centre frequencies and radiometric non-linearities under on-orbit operating conditions. If these issues can be addressed successfully, then the FY-3 series of microwave temperature sounders is likely to be widely used for operational NWP, reanalysis and climate studies.

Acknowledgments

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References

Bell, W., et al., 2008: The Assimilation of SSMIS Radiances in Numerical Weather Prediction Models. *IEEE Transactions on Geoscience and Remote Sensing*, **46**, 884–900.

Cardinali, C., 2009: Monitoring the observation impact on the short-range forecasts. *Q. J. R. Met. Soc.*, **135**, 239–250.

Challon, G., F. Cayla, and D. Diebel, 2001: IASI: An Advanced Sounder for Operational Meteorology. *Proceedings of the 52nd Congress of IAF*, Toulouse, France.

Dee, D. P., 2005: Bias and Data Assimilation. *Q. J. R. Met. Soc.*, **131**, 3323–3343.

Dong, C., et al., 2009: An Overview of Chinese New Weather Satellite FY-3A. *Bulletin of The American Meteorological Society*, **90**, 1531–1544.

Goodrum, G., K. B. Kidwell, and W. Winston, 2000: NOAA KLM Users Guide. [Available online at http://www2.ncdc.noaa.gov/docs/klm].

Healy, S. and J.-N. Thépaut, 2006: Assimilation experiments with CHAMP GPS radio occultation measurements. *Q. J. R. Met. Soc.*, **132**, 605–623.

LeMarshall, J., et al., 2006: Improving Global Analysis and Forecasting with AIRS. *Bulletin of the American Meteorological Society*, **87**, 891–894.

Lu, Q., W. Bell, P. Bauer, N. Bormann, and C. Peubey, 2010: An Initial Evaluation of FY-3A Satellite Data. *ECMWF Technical Memorandum Number 631*, ECMWF, Shinfield Park, Reading, UK, ECMWF.

Lu, Q., W. Bell, P. Bauer, N. Bormann, and C. Peubey, 2011: Charactersing the FY-3A Microwave Temperature Sounder Using the ECMWF Model. *ECMWF Technical Memorandum Number 641*, ECMWF, Shinfield Park, Reading, UK, ECMWF.

Radnoti, G., P.Bauer, A. McNally, C. Cardinali, S. Healy, and P. de Rosnay, 2010: ECMWF Study on the Impact of Future Developments in the Space Based Observing System on Numerical Weather Prediction. *ECMWF Technical Memorandum Number 638*, ECMWF, Shinfield Park, Reading, UK, ECMWF.

Zhang, P., J. Yang, C. Dong, N. Lu, and J. Shi, 2009: General Introduction on Payloads, Ground Segment and Data Application of Fengyun 3A. *Frontiers of Earth Science in China*, **3**, 367–373.