CORRECTION OF ERRORS IN THE SIMULATION OF AMSU-A OBSERVATIONS

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Abstract

The radiative transfer model plays a crucial role in radiance assimilation as it is used in the estimation of the optimal state of the atmosphere to fit the analysis to the measured radiances. The radiative transfer absorption coefficients for AMSU-A channels 5 to 8 on NOAA-15, NOAA-18 and AQUA are currently scaled at ECMWF by a factor, termed gamma, of the order of a few percentages, while the radiative transfer calculations for the same instrument on NOAA-18 and on METOP-A do not have such a correction factor applied.

To harmonise the treatment of radiance data over the different platforms, we have estimated the value of an absorption coefficient correction for all the 7 AMSU-A instruments currently assimilated, following a previous work done in 2004 by P. Watts and A. McNally. The new values of gamma compare well with the old ones for the AMSU-A sensors that had already a correction applied, suggesting that they are modelling radiative transfer errors or errors in the instrument characterisation rather than model errors. Assimilation experiments show that scaling the absorption coefficient by a factor smaller than 1.05 reduces significantly the air-mass dependent component of the bias in AMSU-A channel 5 to 8 departures from model estimates.

INTRODUCTION

The radiative transfer absorption coefficients for AMSU-A channels 5 to 8 on NOAA-15, NOAA-18 and AQUA are currently scaled at ECMWF by a factor, termed γ, of the order of a few percentages, while the radiative transfer calculations for the same instrument on NOAA-18 and on METOP-A do not have such a correction factor applied. Here we calculate a correction for the absorption coefficient of AMSU-A channels 5 to 8 of NOAA-19 and MetOp-A (and update the correction factors for the other AMSU-A instruments) using a physically-based model which follows the work of Watts and McNally (2004).

CORRECTION FACTOR CALCULATION

Watts and McNally (2004) have shown that biases commonly observed between observed and FG-simulated radiances for some channels can be modelled through a scaling factor γ for the optical depth. We estimate the values of the correction γ to the the optical depth $\sigma(p)$ in the AMSU-A channel transmittance $\tau(p)$ from pressure level p to space, such that

$$\tau(p) = e^{-\gamma\sigma(p)}. \quad (1)$$

The γ-correction provides a more physically-based approach than the variational bias correction scheme, VarBC (Dee 2004), to correcting some commonly observed air-mass dependent biases. VarBC is an adaptive scheme employing a linear bias model that includes for AMSU-A a global constant, scan and air-mass dependent predictors. The predictor coefficients are estimated in the variational analysis together with the optimal state of the atmosphere.

The γ-correction accounts for constant errors in the optical depth calculations, that is errors in the absorption coefficient due for example to inaccurate channel response function or line strength. Calibration errors or variable errors in the assumed gas concentrations have to be corrected differently.

Let us suppose that AMSU-A radiance systematic errors can be modelled by a global constant offset δ plus the bias due to an incorrect absorption coefficient in the radiative transfer as follows:

$$mean[Obs - FG] = \delta + mean[FG_{\gamma} - FG], \quad (2)$$

where Obs is the radiance measurement, FG is the corresponding model first guess (the simulated radiance from the model state; FG used without subscript implies that no γ-correction is applied in the radiative transfer, i.e. $\gamma = 1$), and γ is the absorption coefficient correction used in the calculation of FG_{γ}. The constant offset in this case corrects for global average values of all biases not attributable to an absorption coefficient error.Then, under a linear assumption for γ (see Watts and McNally 2004), equation 3 can be written as

$$mean[Obs - FG] = \delta + \beta(\gamma) mean[FG_{\gamma^*} - FG], \quad (3)$$

where γ^* is a given fixed value and β is a linear function of γ.

We have run experiments, both in the summer and winter season, with a 5% increment in the absorption coefficient ($\gamma^* = 1.05$) of the AMSU-A channels in order to calculate FG_{γ^*}. We have used an equivalent increment for the sensors which had already a correction γ_0 applied, so that equation 4 becomes:

$$mean[Obs - FG_{\gamma_0}] = \delta + \beta(\gamma) mean[FG_{\gamma_0 + .05} - FG_{\gamma_0}]. \quad (4)$$

The experiments were run in a 'monitoring mode' (i.e. without the assimilation of the observations) with the short-term forecast taken from a control experiment: the first-guess FG_{γ^*} (or $FG_{\gamma_0+.05}$) and FG in equation 4 (or 5) were calculated from the same short-term forecast, respectively with and without the 5% increment in the absorption coefficient. The control experiment used the same γ corrections as in operations: $\gamma \neq 1$ for NOAA-15, NOAA-18, Aqua, and $\gamma = 1$ for NOAA-19 and MetOp-A. The ECMWF 4D-Var assimilation system used for the experiments was Cy36r3 at a T255 resolution and with version 9 of the fast radiative transfer model RTTOV (Saunders et al. 1999). We have estimated β (and hence a new value of γ) from equation 4 (and 5) for all AMSU-A channels. The updated values of γ are in Table 1, together with the values used currently in operations for the tropospheric channels 5 to 8. For the higher peaking channels the γ-correction model performs poorly in correcting air-mass biases due to larger model biases in the higher part of the atmosphere, as also stated in Watts and McNally (2004).

The new values of γ compare well with the old ones for the AMSU-A sensors that had already a correction applied (NOAA-15, NOAA-18 and Aqua), suggesting that they are modelling radiative transfer errors rather than model errors (as the forecast model went through numerous changes since the previous γ calculations in 2004). Only channel 5 shows slightly bigger differences consistently for the three above sensors. This is likely due to the recent change in the emissivity calculations (Krzeminski 2008) which has modified the bias of channel 5 since the previous γ calculations were performed.

ASSIMILATION EXPERIMENT SETUP

We have tested the updated values of the γ-correction (the fourth column of Table 1) in the ECMWF 4D-Var assimilation system. We have run an experiment ("gamma experiment") with a γ correction for

Table 1: Values of γ used in operations and new estimates

Satellite	Channel	Operational γ	New γ
NOAA-15	5	1.0500	1.0419
	6	1.0500	NA
	7	1.0339	1.0321
	8	1.0400	1.0386
NOAA-18	5	1.0420	1.0344
	6	1.0180	1.0204
	7	1.0390	1.0370
	8	1.0350	1.0414
NOAA-19	5	1.0000	1.0348
	6	1.0000	1.0199
	7	1.0000	1.0309
	8	1.0000	1.0430
Aqua	5	1.0500	1.0305
	6	1.0390	1.0297
	7	1.0450	NA
	8	1.0460	1.0438
MetOp-A	5	1.0000	1.0322
	6	1.0000	1.0165
	7	1.0000	NA
	8	1.0000	1.0436

all AMSU-A tropospheric channels 5 to 8: updated values were used for the satellites that had already a correction. The current setting for VarBC were left unchanged. Additionally we have run an experiment with no γ-correction ("no-gamma experiment") for any AMSU-A instruments. The current operational setup ("ctl experiment") is a mixture of the two above experiments with a γ correction applied only to some of the satellites. The ECMWF 4D-Var assimilation system used for the experiments was Cy36r3 at a T255 resolution, and experiments were run from 20 July 2009 to 31 October 2009. A description of the three experiments is in Table 2.

Table 2: Experiment description

Experiment name	Experiment id	γ-correction for AMSU-A ch 5 to 8
"gamma experiment"	fgkh	new $\gamma \neq 1$ for all AMSU-A
"no-gamma experiment"	ffv3	$\gamma = 1$ for all AMSU-A
"ctl experiment"	ffwz	old $\gamma \neq 1$ for NOAA-15, NOAA-18, Aqua, $\gamma = 1$ for NOAA-19, MetOp-A

RESULTS

Departure statistics of the first guess and analysis

Mean and standard deviation of the FG-departures (i.e. the differences between the observations and the model first guess) are computed for the observing system over the period 1 August 2009 to 31 October 2009. Correcting the absorption coefficient errors removes to a great extent the air-mass dependent biases for AMSU-A channels 5 to 8. As an example we show in Figure 1 the mean first guess departures before (VarBC) bias correction of AMSU-A channels 5 and 8 on NOAA-19, in the "gamma experiment" (where a γ-correction equal to 1.035 and 1.043 is used respectively for channel 5 and 8) and in the "ctl experiment" (where no γ-correction is applied to AMSU-A on this satellite). In the "gamma experiment" location-dependent biases are significantly removed and channel 5 to 8 radiances are fed into the assimilation system with a much more flat bias. This is a positive aspect, as it means that VarBC has to do less work to correct the residual biases. Note that in the case of channel 5 the γ-correction produces different biases over land and sea in the first guess departures before the VarBC bias correction is applied. This is likely a result of different methods being used to estimate the surface emissivity over land and sea, leading to different biases in the emissivity. For this reason VarBC uses different scan bias predictors over land and over sea for the correction of channel 5 which is the lowest-peaking among the assimilated AMSU-A observations. Without a γ-correction the air-mass dependent bias appear to compensate for the difference in bias over different surfaces. Departure statistics after the VarBC bias

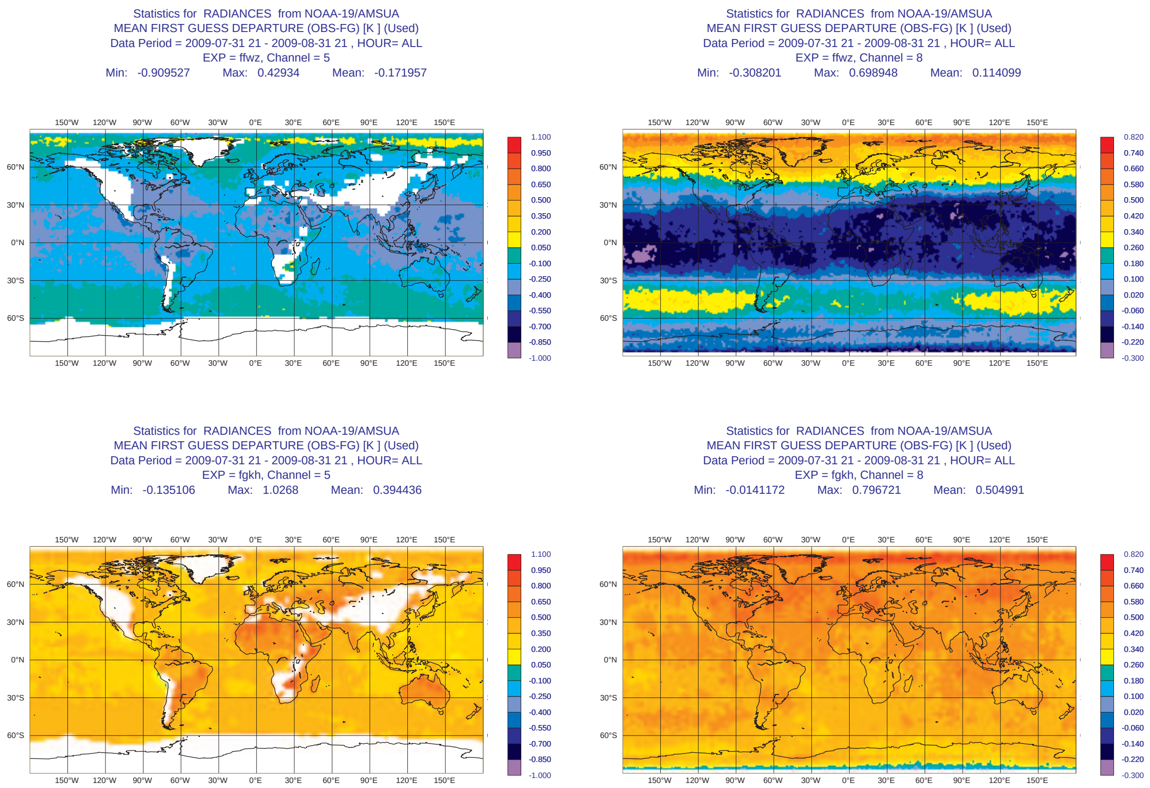

Figure 1: Mean first guess departures for AMSU-A channel 5 (left) and channel 8 (right) on NOAA-19 before bias correction for the "ctl experiment" (ffwz) (top) and for the "gamma experiment" (fgkh) (bottom). Note that in the"ctl experiment" AMSU-A on NOAA-19 has no γ-correction applied, while in the "gamma experiment" a correction equal to 1.035 and 1.043 is used respectively for channel 5 and 8.

correction show that VarBC is able to correct well for the air-mass dependent component of the bias and compensate for the correction of the absorption coefficient performed by γ for the channels that do not have a γ-correction applied. Figure 2 shows the mean first guess departures after bias correction for the same channels and experiments of Figure 1. The mean first-guess departures are comparable with or without a γ-correction, with the exception of channel 5 where the γ-correction produces slightly higher biases over land. For this reason, we are currently investigating further the γ-correction of channel 5 and the impact that the higher biases and standard deviations over land have on the forecast.

The fit to other observations like radiosonde temperature and GPS radio occultation measurements suggest that the γ-correction produces a better first-guess in the higher part of the atmosphere. Figure 3 shows for example the improvement in the stratospheric bias of the first-guess and analysis for the "gamma experiment" versus the "no-gamma experiment". The improvement is less obvious when the

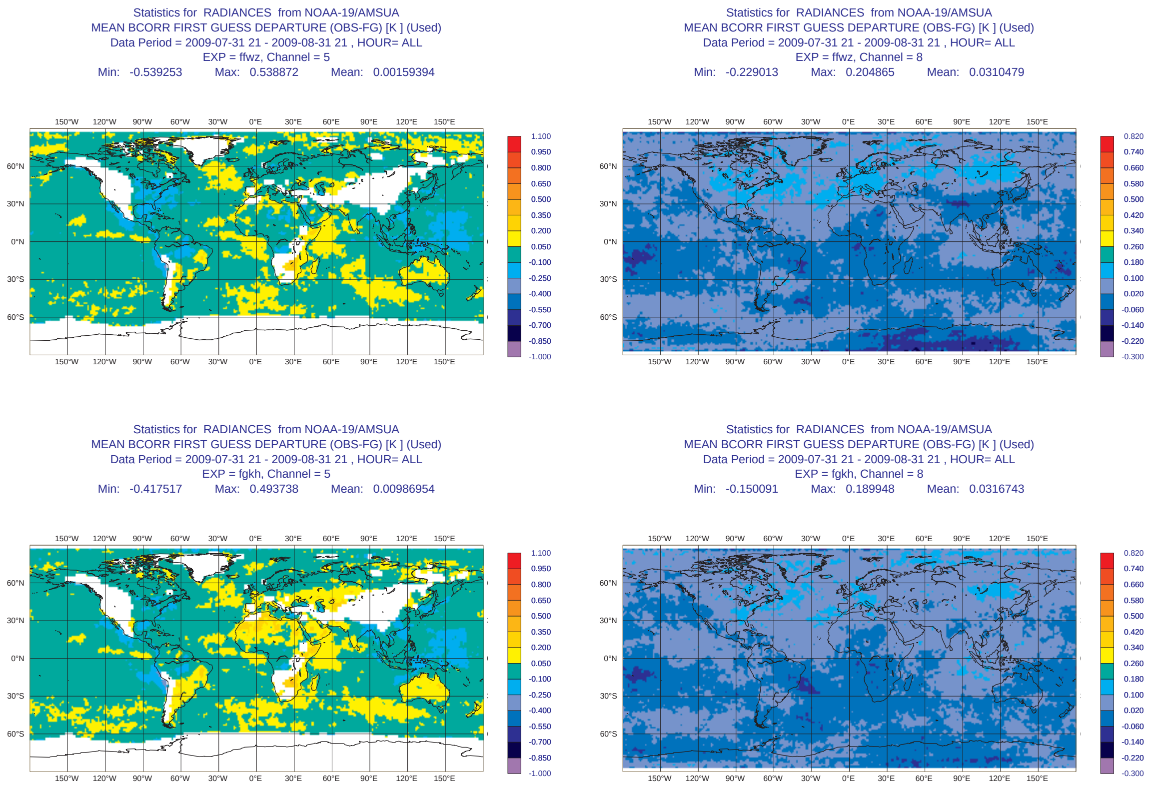

Figure 2: Mean first guess departures for AMSU-A channel 5 (left) and channel 8 (right) on NOAA-19 after bias correction for the “ctl experiment” (ffwz) (top) and for the“gamma experiment” (fgkh) (bottom). Note that in the“ctl experiment” AMSU-A on NOAA-19 has no γ-correction applied.

“gamma experiment” is compared to the “ctl experiment” as there three out of five AMSU-A have a γ-correction applied in both experiments.

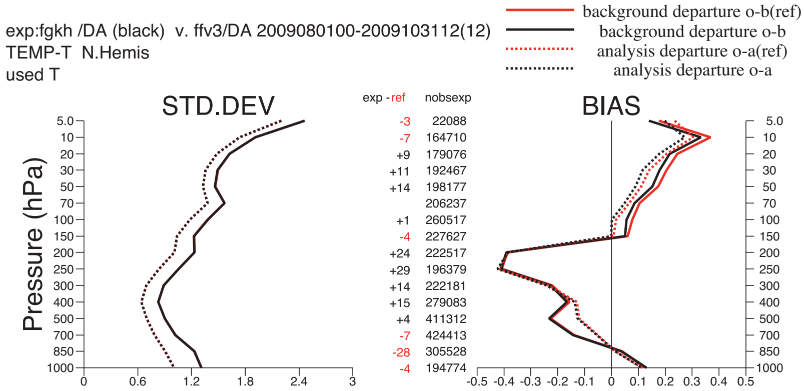

Figure 3: Radiosonde temperature departure statistics for the “gamma experiment” (fgkh) (black) and the “no-gamma experiment” (ffv3) (red) for the Northern Hemisphere.

Forecast impact

The impact of the γ correction on the forecast is studied for different variables and regions. Forecast results are computed for 92 days of assimilation experiments. The forecast impact of the “gamma experiment” versus the “no-gamma experiment” is not uniformally in favour of one or the other experiment (see for example Figure 4 for the forecast of the geopotential). This result is coherent with the small differences in departure statistics of the first guess and analysis after the bias correction. As shown earlier, the VarBC air-mass predictors are able to correct location-dependent biases as efficiently as the off-line γ-correction.

CONCLUSIONS

We have calculated a correction for the absorption coefficient of AMSU-A channels 5 to 8 of NOAA-19 and MetOp-A (and updated the correction factors for the other AMSU-A instruments) using a physically-based model which followed the work of Watts and McNally (2004). Assimilation experiments show that the γ-correction reduces significantly the air-mass dependent component of the bias and leaves VarBC with an easier (more flat) bias to correct.

The new values of gamma for channels 5 to 8 do not differ much from the values computed in 2004, suggesting that the biases they correct are likely due to radiative transfer errors or errors in the instrument characterisation rather than model errors. When no γ-correction is applied, VarBC is however able to correct the systematic differences between the observations and the model. Correcting systematic errors off-line prior to the application of VarBC is however preferable as the γ-correction is less likely to correct effects which are not radiative transfer biases, while VarBC can erroneously attribute model errors to observation bias.

Depending on the actual sources of the bias, there might be alternatives to the correction. Work is going on at ECMWF to partition bias in spectroscopy errors and instrument characterisation errors. Estimates of passband shifts as estimated at ECMWF by Qifeng Lu and William Bell (Lu et al. 2011) for the FY-3A instrument might provide an alternative correction to the simulation of AMSU-A channel 5 to 8.

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REFERENCES

Watts, P. and A. P. McNally, (2004), Identification and correction of radiative transfer modelling errors for atmospheric sounders: AIRS and AMSU-A. In Proceedings of the ECMWF Workshop on Assimilation of High Spectral Resolution Sounders in NWP. ECMWF, Reading, UK.

Dee, D. P. (2004), Variational bias correction of radiance data in the ECMWF system. In Proceedings of the ECMWF Workshop on Assimilation of High Spectral Resolution Sounders in NWP. ECMWF, Reading, UK, 97112.

Krzeminski, B et al. (2008), EUMETSAT Fellowship first year report, ECMWF (available from the authors).

Qifeng Lu, W. Bell, P. Bauer, N. Bormann and C. Peubey, Characterising the FY-3A Microwave Temperature Sounder Using the ECMWF Model, Accepted by Journal of Oceanic and Atmospheric Technology, March 2011, doi: 10.1175/JTECH-D-10-05008.1.

Saunders, R.W.,M.Matricardi and P. Brunel, (1999), An improved fast radiative transfer model for assimilation of satellite radiance observations. Q. J. R. Meteorol. Soc. 155, 1407-1425.

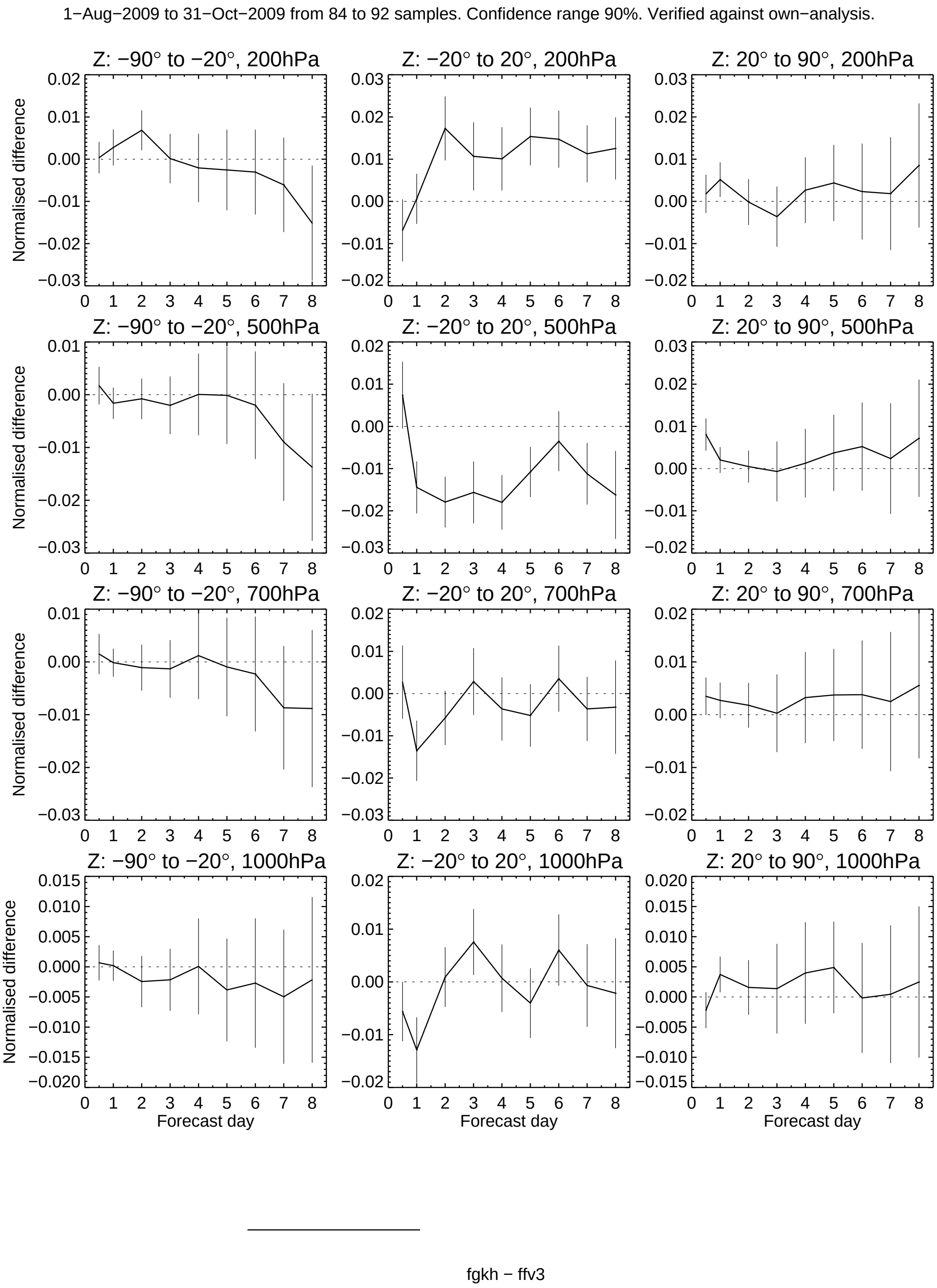

Figure 4: Normalised differences in the root mean squared forecast error between the “gamma experiment” (fgkh) and the “no-gamma experiment” (ffv3) for the 0Z forecast of the 200 hPa, 500 hPa, 700 hPa and 1000 hPa geopotential. Verification is against the experiment own-analysis.