GeoCloud status report – March 2013

Satellite Applications Technical Memo 10

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Contents

1. Introduction

Until recently, assimilation of cloud data into the convective-scale NWP models in the Met Office has been based primarily upon what are known as "MOPS" Cloud data. These data originate from the Post-Processing systems (i.e. UKPP and EuroPP) in the form of a three-dimensional cloud-fraction analysis product, derived from a combination of satellite data, surface reports and a precipitation-rate analysis. The Cloud Analysis is used within the Post-Processing systems for various downstream nowcasting applications, but a sub-set of this 3-d field is made available to the OPS, where the MOPS code is able to carry out various horizontal and vertical interpolation tasks on these data, before producing as output a series of vertical profiles of cloud fraction, together with an associated error profile (in terms of relative humidity), these profiles then becoming the contents of the MOPS Cloud "Varobs" file (see Renshaw & Francis, 2011 for more details).

In order to remove the dependence of the assimilation system on an intermediate nowcasting product, it has long been thought desirable to move the pre-processing of the satellite and surface cloud observations into the OPS. Work on the OPS pre-processing of satellite data has been carried out for a number of years under the name of GeoCloud. GeoCloud assimilation became operational in the UKV model at PS31 (December 2012), in place of MOPS Cloud assimilation. This report provides some details of the various tests which led to this decision being taken, includes some more recent results from the testing of further GeoCloud changes, and proposes some future work.

2. Testing by Gareth Dow for potential inclusion of GeoCloud in PS31

Although GeoCloud data have been assimilated alongside MOPS Cloud data in the NAE model since PS24 (i.e. the GeoCloud data are used outside the coverage area of the MOPS Cloud data), previous tests had failed to provide sufficient evidence that GeoCloud data should replace MOPS Cloud data completely. After some improvements to the quality of the Autosat cloud-top height product were introduced in April 2012, it was decided to carry out some new impact trials, to once more compare the relative impacts of MOPS Cloud and GeoCloud assimilation. These trials were carried out by

Gareth Dow (UK and Land DA group, DAE). More details of these trials are available at http://www-nwp/~frnl/UKV/PS31/PS31Trials.html, and some of the results are also presented in Figures 1 to 5 below. The intention had been to use equivalent settings to the then-operational MOPS Cloud assimilation settings, i.e. using observation errors that varied between 0.25 (fully overcast data) and 0.55 (clear-sky data), with the final observation error depending upon both the measured and background values of cloud-fraction (i.e. so-called symmetric observation errors). In fact, due to an oversight, these trials were actually run with observation errors of 0.4 (fully overcast) and 0.6 (clear-sky), with the final observation error depending only upon the measured cloud-fraction (i.e. asymmetric errors).

Figure 1 shows the verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the Jan/Feb 2012 trial period. Data in red are for no cloud assimilation, data in blue are for MOPS Cloud assimilation and data in green are for GeoCloud assimilation. In this case, we see that the MOPS Cloud assimilation verifies somewhat better than GeoCloud for fractional cloud cover, producing a smaller negative bias at short lead-times, and also a smaller RMS error, while both cloud assimilation methods improve upon the "no cloud assimilation" trial. For screen temperature verification, GeoCloud is seen to provide a slight improvement in RMS error for short lead-times, although MOPS Cloud generally shows a better impact on the bias.

Figure 2 shows an equivalent Figure for the March 2012 trial period. Looking at the fractional cloud cover first, we again see that the MOPS Cloud assimilation verifies somewhat better than the GeoCloud, with smaller negative bias and smaller RMS error at short lead-times. For screen temperature, GeoCloud generally verifies better than MOPS Cloud, showing a smaller bias and RMS error for most forecast lead-times. Figure 3 shows time-series of the T+1 hour verification for fractional cloud cover and screen temperature for the same trial, where it can be seen that the significant improvements relative to the "no cloud assimilation" case arise mainly from the early part of the trial (11-15 March), corresponding to a period of extensive low-level cloud cover over much of the UK, where both cloud assimilation methods help to correct significant errors in both fractional cloud cover and screen temperature.

Figure 4 shows verification of cloud and screen temperature for the July trial, as a function of forecast range. As before, we see that MOPS Cloud assimilation generally produces better results than GeoCloud for the cloud verification, whereas GeoCloud is generally better than MOPS Cloud for screen temperature.

It is interesting to look at the impact of the GeoCloud data on the resulting UK Index values for these trials. These are summarised in Figure 5, where the top row is for the Jan/Feb trial period, the middle row for March, and the bottom row for July. In this figure, the left-hand column shows the impact of the MOPS Cloud observations against the “no cloud assimilation” case, the middle column shows the impact of the GeoCloud observations relative to the MOPS Cloud trials, and the right-hand column shows the impact of GeoCloud relative to the “no cloud assimilation” trials (note the extended vertical scale for the March results, reflecting the very strong positive impact of cloud assimilation in this case). For all three trials, we see that GeoCloud produces a positive overall impact, insignificantly so for Jan/Feb, but slightly more positive for the July trial and very significantly so for the March period. In all three trials, the screen temperature is seen to be a key component of this positive impact, with visibility and 6-hour precipitation accumulation also providing some significant contributions for some of the trial periods. We also see, though, that the cloud verification scores are not improved by GeoCloud, which is consistent with the findings presented above. The overall impact of GeoCloud relative to the “no cloud assimilation” case is seen to be neutral to slightly negative for the Jan/Feb and July trials, and very strongly positive for the March trial.

3. Further testing prior to inclusion of GeoCloud in PS31

As stated in Section 2 above, the intention had been to use equivalent settings to the then-operational MOPS Cloud assimilation settings, i.e. using symmetric observation errors that varied between 0.25 (fully overcast data) and 0.55 (clear-sky data). Results from trials that were eventually run with this set-up are summarised in Figure 6, which shows the UK Index impacts of the updated settings (labelled “GC5”) relative to the trials presented in Section 2 above (labelled “GC control”). Overall, the change in impact is seen to be very small, especially for the Jan/Feb and March trials. For the July trial, a decrease in visibility and precipitation skills is offset by slight increases in skill for cloud and screen temperature.

Based on the results of the trials presented in Section 2 and 3, it was decided to implement this “GC5” set-up (i.e. 0.25/0.55 symmetric observation errors) in the UKV model at PS31, in place of MOPS Cloud assimilation.

4. Testing of additional GeoCloud changes for PS32 and beyond

In parallel with testing of the new SurfaceCloud data for possible inclusion in PS32 (described in http://www-nwp/~frpf/reports/SurfaceCloud_Report_v1.0.pdf), some further testing of various GeoCloud changes were also carried out, and these are briefly summarised below.

(a) Increasing the weighting of GeoCloud observations in VAR

Subjective assessment of differences between MOPS Cloud and GeoCloud during PS31 itself suggested that it might be beneficial to increase the weighting given to GeoCloud data in VAR. One way of doing this is to reduce the corresponding observation errors – a reduction in the observation errors of $\sqrt{2}$ corresponds to a doubling of the weighting. Results from some trials where the GeoCloud observations errors were reduced from 0.25/0.55 to 0.18/0.39 are summarised in Figures 7 to 10 below.

Figure 7 shows the verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the March 2012 trial period. Data in red are for the 0.25/0.55 "GC5" set-up (i.e. PS31 settings), and data in blue are for 0.18/0.39 observation errors (labelled "GC5W2"). There is little evidence of any significant impact on the screen temperature in the trial, but the fractional cloud cover bias and RMS error are seen to improve slightly with the increased weighting. This is also seen in the time-series of T+1 hour cloud fraction verification (Figure 8a), where there is an apparent decrease, on average, in the RMS error during the first half of the trial.

Figure 9 shows verification of cloud and screen temperature for the July trial period. In this case, the impact on cloud verification is not particularly significant, but there is a clear improvement in the screen temperature RMS error, albeit coupled with a slight worsening of the bias.

The impact of decreasing the GeoCloud observation errors on the resulting UK Index values is shown in Figure 10, where the top row is for the March trial period, and the bottom row is for July (a Jan/Feb trial was not carried out for this setting). In this figure, the left-hand column shows the impact of the decreased observation errors (labelled "GC5W2") relative to the "GC5" (PS31) case, and the right-hand column shows the impact of GC5W2 relative to the "no cloud assimilation" trials (again, note the extended vertical scale for the March results). There is little impact overall for the March period, whereas the July trial shows some reasonable positive impact overall, arising some small improvements in all elements.

On the basis of these results, it was recommended that these GeoCloud settings would be incorporated into the PS32 set-up for the UKV, alongside the new SurfaceCloud assimilation.

(b) Additional GeoCloud changes not included in PS32

Two further GeoCloud changes have been tested using the three trial periods discussed above. The first relates to the ability to allow non-unit Stable Layers cloud-fractions to be assimilated – see http://fcm1.metoffice.com/projects/OPS/ticket/3004. Until recently, all non-zero cloud fractions calculated on Autosat using the so-called "Stable Layers" scheme are reset to unity (and this is still the default behaviour), because (a) it was felt that the calculated cloud fractions were not reliable enough; and (b) trialling had shown a slightly more positive impact by doing so. However, recent changes to the Autosat scheme suggest that the calculated cloud fractions might now be more reliable, so it was decided to allow the option within OPS to use these values within VAR. The trial results from cases where the cloud fractions have not been re-set to unity are labelled as "GC2" throughout the remainder of this report.

The second change relates to some new Quality Control processing in the GeoCloud OPS code – see http://fcm1.metoffice.com/projects/OPS/ticket/3041. This new procedure was introduced by Richard Renshaw.

Figure 11 shows verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the March 2012 trial period, with these new settings introduced. Data in red are for the 0.25/0.55 "GC5" set-up (i.e. PS31 settings), data in blue (labelled "GC2") additionally allow non-unit Stable Layers cloud-fractions to be assimilated, data in green (labelled "GC3") include the effects of the additional GeoCloud quality control, and data in yellow (labelled "GC1") include both the GC2 and GC3 changes. In terms of the cloud cover verification, none of the new settings appears to improve the verification – all are seen to worsen the bias and slightly increase the RMS error relative to the GC5 control. In terms of screen temperature, there seems to be little significant impact for the March period.

The corresponding results for the July trial are shown in Figure 12. There is very little impact on the cloud verification for this season, either in terms of the bias or the RMS error. In terms of the screen temperature, both the GC2 and GC1 set-ups show a slight reduction in RMS error.

The Jan/Feb trial results are shown in Figure 13 – in this case only the combined GC1 trial was run (i.e. the GC2 and GC3 trials were not run individually). The GC1 results are plotted in blue in this Figure. There is some evidence of a very slight worsening of the cloud verification scores at short lead-times in this case, and little evident impact on the screen temperature verification.

The impact of these additional GeoCloud changes on the resulting UK Index values is shown in Figure 14, where the top row is for the Jan/Feb trial period (where only the combined GC1 case was run), the middle row for March, and the bottom row for July. In this figure, the left-hand column shows the impact of "GC2" settings (i.e. allowing non-unit Stable Layers cloud-fractions to be assimilated) relative to the "GC5" (0.25/0.55 symmetric observation errors) control, the middle column shows the impact of "GC3" settings (i.e. including the effects of additional GeoCloud quality control) relative to the GC5 control, and the right-hand column shows the impact of "GC1" (i.e. including both GC2 and GC3 changes) relative to the GC5 control. As indicated by the results shown in Figures 11 to 13, there is no strong impact on cloud scores from any of the changes, and a slight positive impact on screen temperature scores in the GC2 and GC1 set-ups. Also worth noting is the reasonable strong positive impact on visibility scores for all three seasons, and also a strong positive impact on the precipitation score for the July trial.

Due to the somewhat inconclusive nature of these results, neither of these changes was put forward for inclusion in PS32. Further testing will take place in due course, alongside the suggestions proposed in Section 5 below.

5. Issues to be considered for future GeoCloud testing

There can be significant differences between the impacts of MOPS Cloud and GeoCloud assimilation. These can be seen from comparisons of verification plots (e.g. the differences in fractional cloud cover verification apparent in Figures 1, 2 and 4), and may also be inferred from, for example, the routine inspection of charts during Parallel Suites. Significant differences in cloud fields were noted during the period covering PS31, although the situation was of course complicated in this instance because the change from MOPS Cloud to GeoCloud assimilation was only one of a number of changes (both UM and DA).

It is instructive to compare the Varobs data between the two data sources. Figure 15 shows Varobs from four UKV model levels (32, 27, 22 and 17), which, for the most part, covered the cloudy areas detected by the satellite data – the MOPS Cloud data are on the left-hand side, the GeoCloud data are on the right. In general, we see a reasonable correspondence between the two data sources (allowing for the obvious lack of any surface cloud reports in the GeoCloud data), although it does seem that the MOPS Cloud data are slightly more widespread in places. This arises from the fact that, as part of the vertical interpolation carried out by the MOPS OPS code in going from the Post-Processing system vertical levels to the UM vertical levels, the Post-Processing Cloud Analysis data tend to be spread out onto several UM vertical levels, whereas the GeoCloud OPS processing only ever populates the data structure for the one UM model level immediately below the observed cloud-top. This may be seen more clearly in Figure 16, where the same Varobs data are plotted, only this time for the consecutive models levels 26, 25, 24 and 23. For the MOPS Cloud data, we see essentially the same values at each of these four vertical levels, whereas data from the same areas of cloud are only ever seen at just one of the vertical levels in the GeoCloud case. This effectively means that the MOPS Cloud data are implicitly being given more weight in the VAR analysis (all other settings being equal), and also implies that the analysis is much more likely to produce a thicker cloud when using MOPS Cloud, compared with the GeoCloud case.

A specific example from some recent operational forecast runs is shown in Figure 17, with cloud fields from the (a) UK4 and (b) UKV runs from 03Z on 21st February 2013 being shown, together with corresponding SEVIRI (c) 10.8 micron and (d) 3.9 micron imagery. It is immediately apparent that the UK4's cloud field (which is still using MOPS Cloud assimilation) is significantly better than that of the UKV (using GeoCloud). These types of differences were evident over the course of several days during February 2013, where it was apparent that the UK4's data assimilation was able to add cloud to the analysis much more readily than the UKV. Obviously, there are many differences between the UK4 and the UKV, and it is far too simplistic to assume that these differences arise solely because of their differing cloud assimilation methods. Nevertheless, it does seem evident that we need to investigate ways of allowing the GeoCloud scheme to introduce cloud more readily in these situations.

In the short term, two sensitivity tests could easily be carried out. Firstly, to counter the fact that, in general, GeoCloud seems to have a negative cloud bias, we could look at the effects of widening the gap between the overcast GeoCloud observation error (0.25

at PS31, planned to be 0.18 at PS32) and the cloud-free observation error (0.55 at PS31, and planned to be 0.39 at PS32). This should allow GeoCloud to introduce more cloud to the analysis in general, by giving more weight to cloudy observations and less weight to clear-sky observations. Another sensitivity study would be to introduce some code changes to the GeoCloud OPS code, whereby rather than only populating the GeoCloud data structure for the one UM model level immediately below the observed cloud-top (as is currently the case), we look at the effect of populating two or more vertical levels with the same data, thereby mimicking the MOPS Cloud data more closely. The result of such a sensitivity study would be useful to guide the priority for developing any more robust and longer-term strategies for producing vertically-extended GeoCloud (and possibly SurfaceCloud) profiles.

References

Renshaw, R. & Francis, P.N., 2011: Variational assimilation of cloud fraction in the operational Met Office Unified Model. Quarterly Journal of the Royal Meteorological Society, Vol. 137, 1963-1974, doi: 10.1002/qj.980.

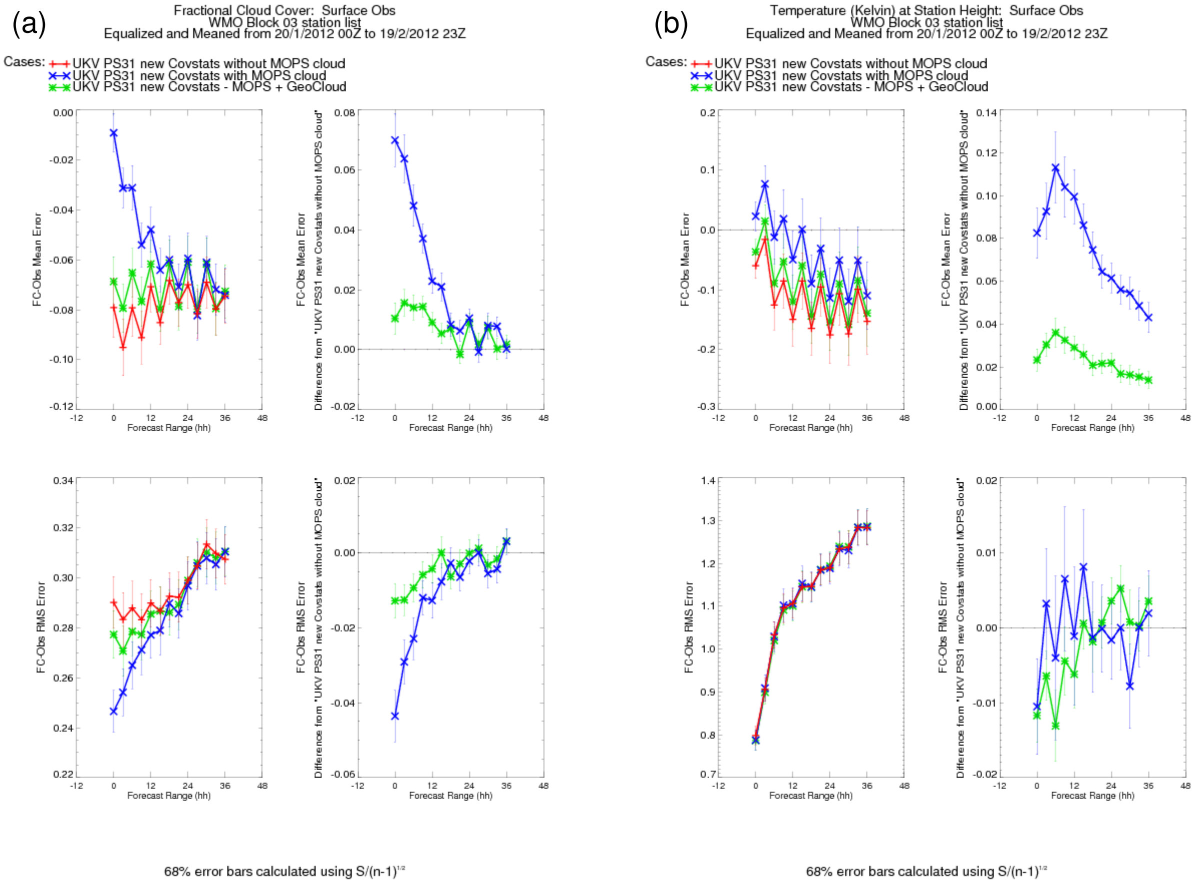


Figure 1: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the Jan/Feb 2012 trial period. Data in red are for no cloud assimilation, data in blue are for MOPS Cloud assimilation and data in green are for GeoCloud assimilation. Differences (right-hand side) are with respect to the "no cloud assimilation" case.**

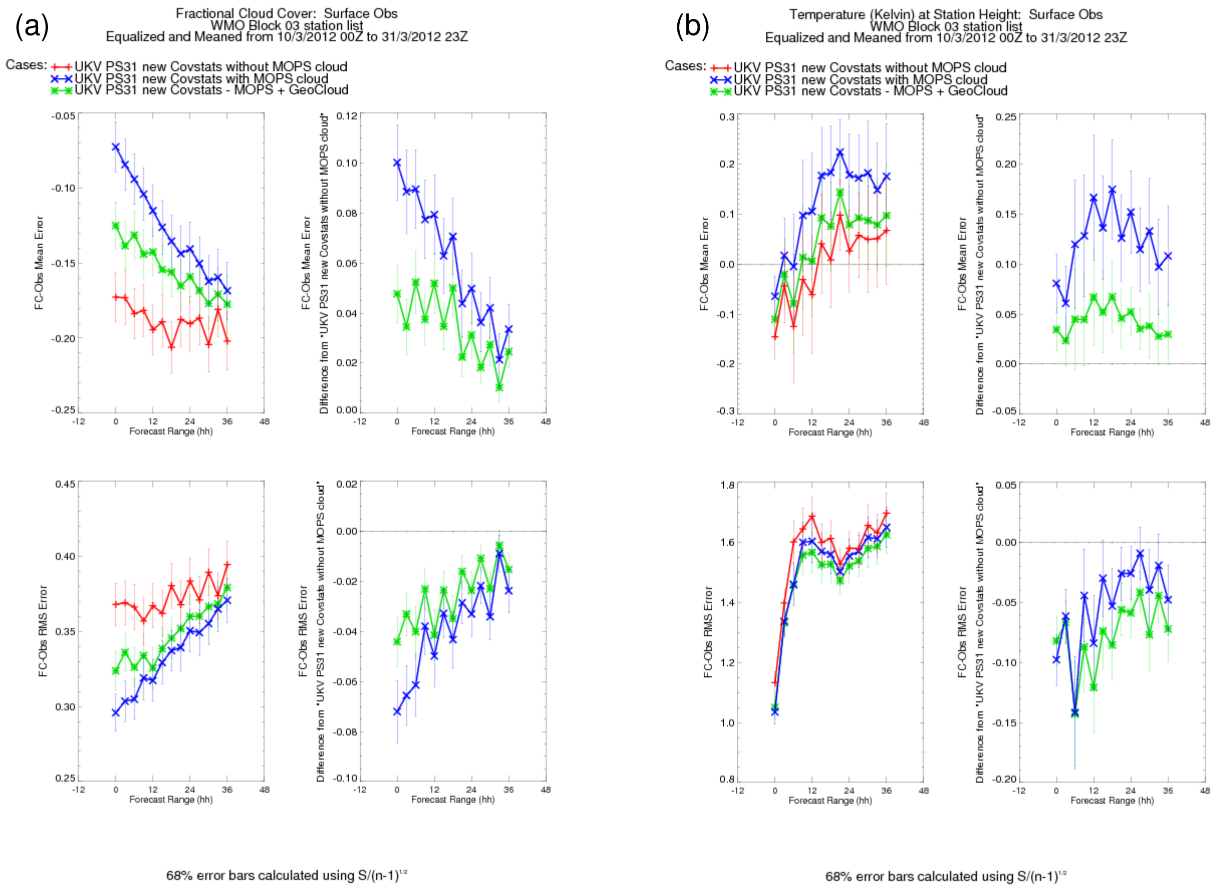


Figure 2: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the March 2012 trial period. Data in red are for no cloud assimilation, data in blue are for MOPS Cloud assimilation and data in green are for GeoCloud assimilation. Differences (right-hand side) are with respect to the "no cloud assimilation" case.**

(a)

(b)

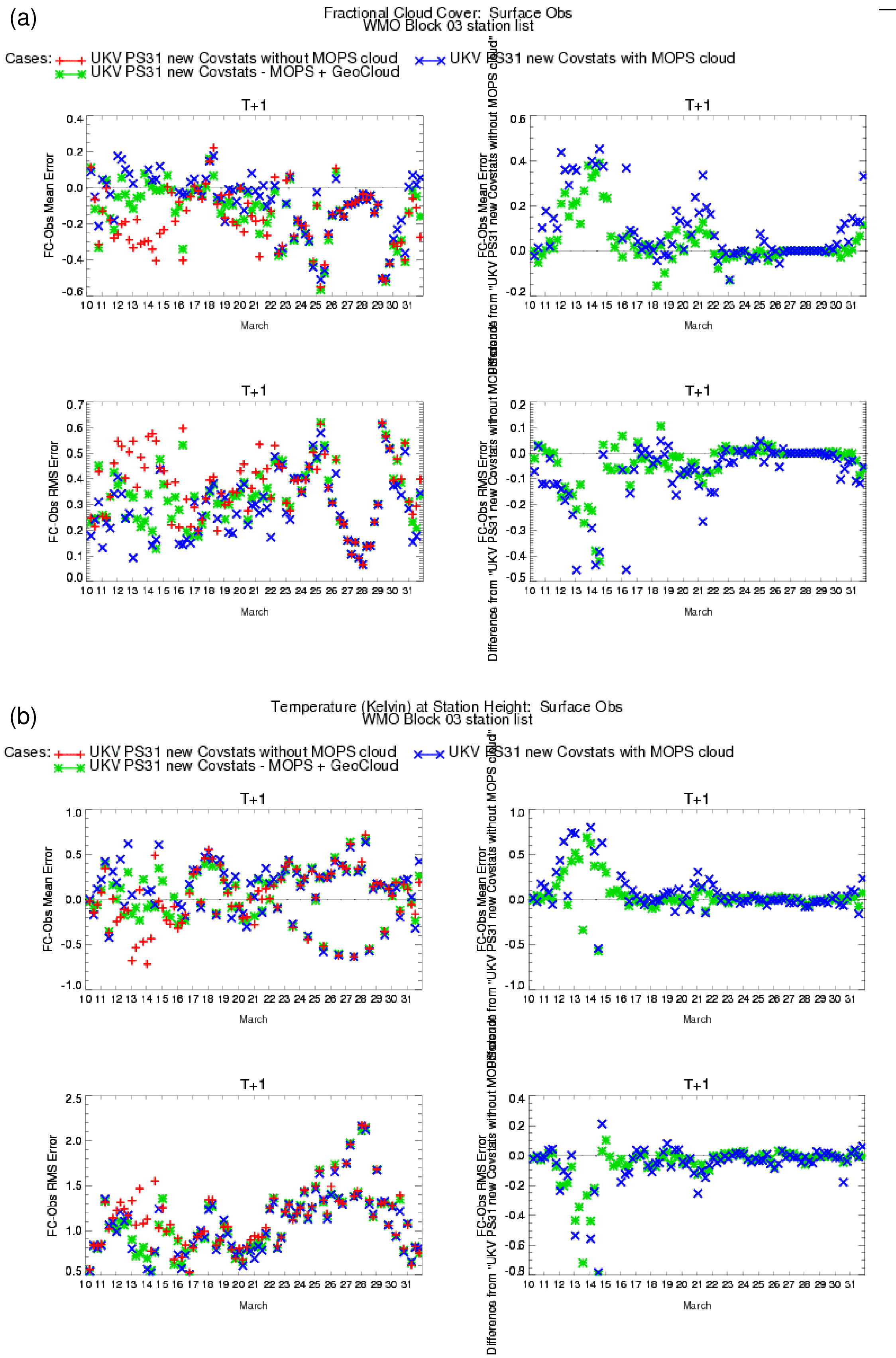


Figure 3: **Verification of (a) T+1 hour fractional cloud cover, and (b) T+1 hour screen temperature, as a function of time, for the March 2012 trial period. Data in red are for no cloud assimilation, data in blue are for MOPS Cloud assimilation and data in green are for GeoCloud assimilation. Differences (right-hand side) are with respect to the "no cloud assimilation" case.**

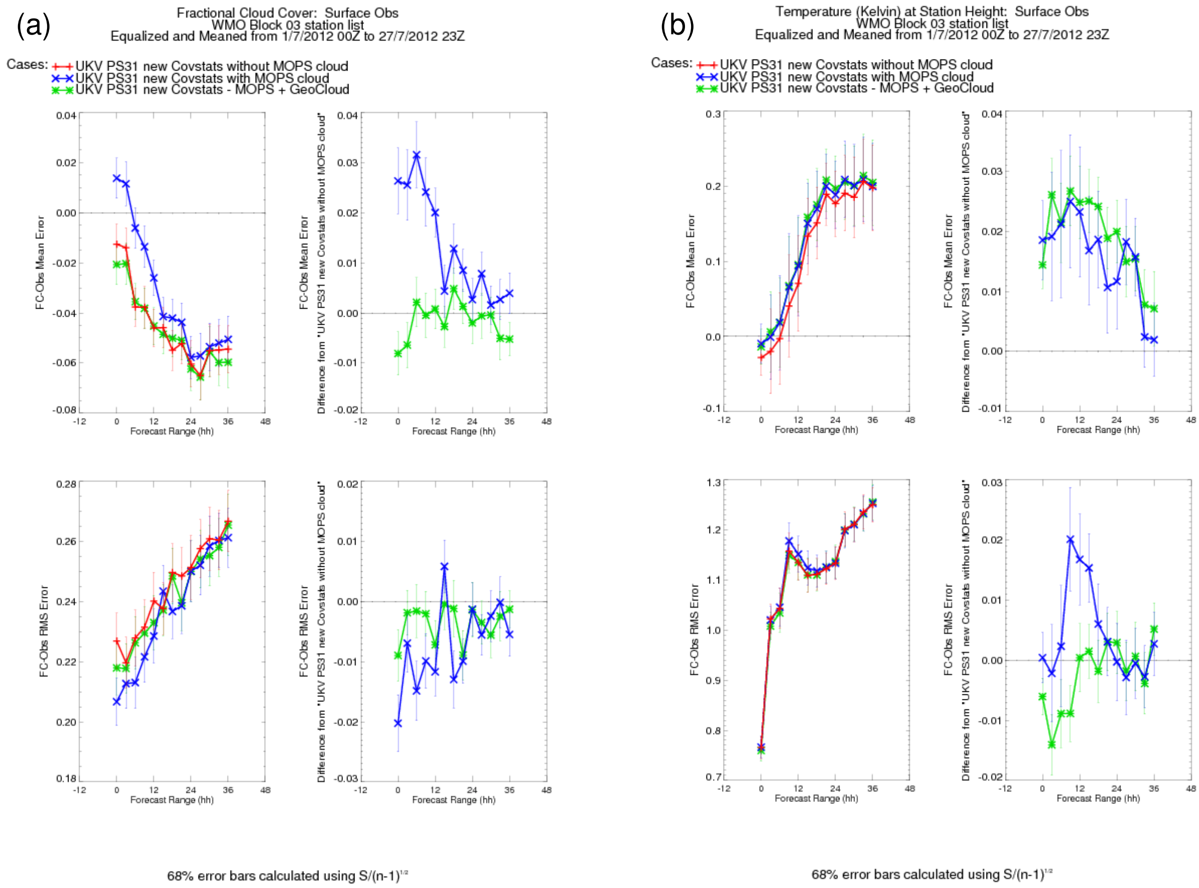


Figure 4: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the July 2012 trial period. Data in red are for no cloud assimilation, data in blue are for MOPS Cloud assimilation and data in green are for GeoCloud assimilation. Differences (right-hand side) are with respect to the "no cloud assimilation" case.**

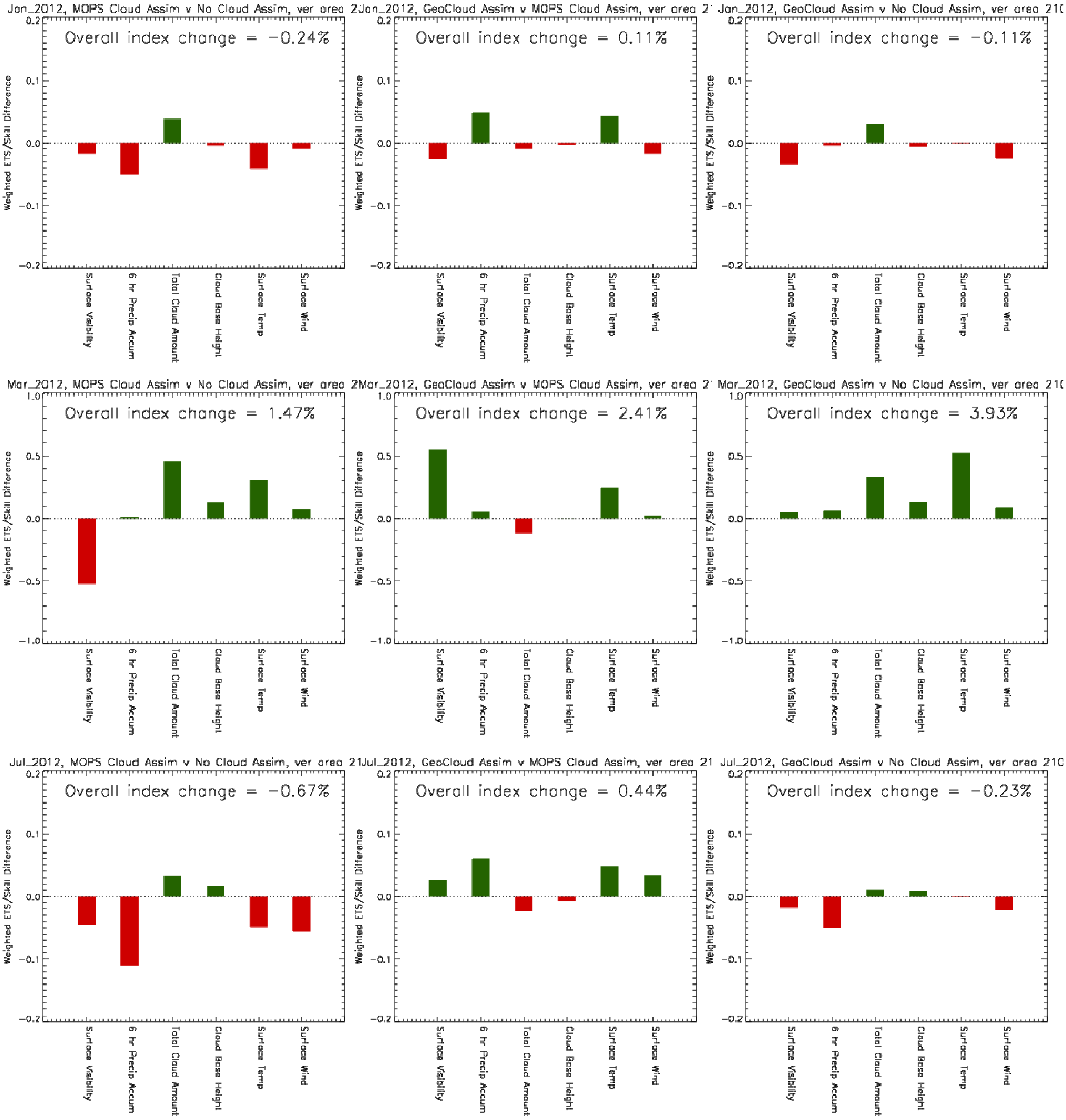


Figure 5: **UK Index impacts for various cloud assimilation trials. The top row is for the Jan/Feb 2012 trial period, the middle row for March 2012, and the bottom row for July 2012. The left-hand column shows the impact of MOPS Cloud assimilation relative to the "no cloud assimilation case, the middle column shows the impact of GeoCloud assimilation relative to MOPS Cloud assimilation, and the right-hand column shows the impact of GeoCloud assimilation relative to the "no cloud assimilation" case.**

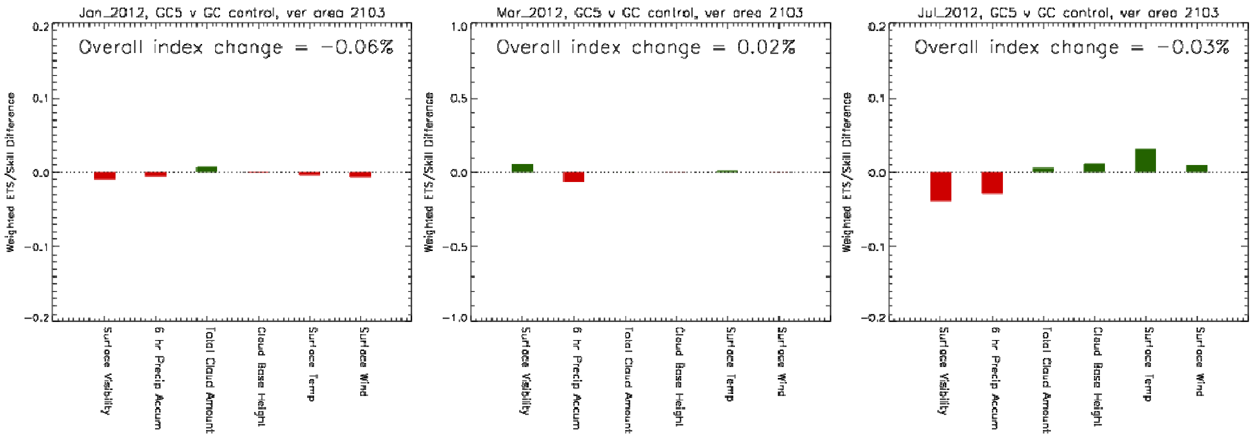


Figure 6: **UK Index impacts due to changes in the GeoCloud settings in VAR, for three seasons. The "GC control" results refer to the settings as used in Figures 1-5, where GeoCloud observation errors of 0.4 (overcast data) and 0.6 (clear-sky data) were used, and where this observation error depended only upon the measured value of cloud-fraction (i.e. asymmetric errors). The "GC5" results refer to updated settings, with GeoCloud observation errors of 0.25 (overcast data) and 0.55 (clear-sky data) being used, and where this observation error depended upon both the measured and background values of cloud-fraction (i.e. symmetric errors).**

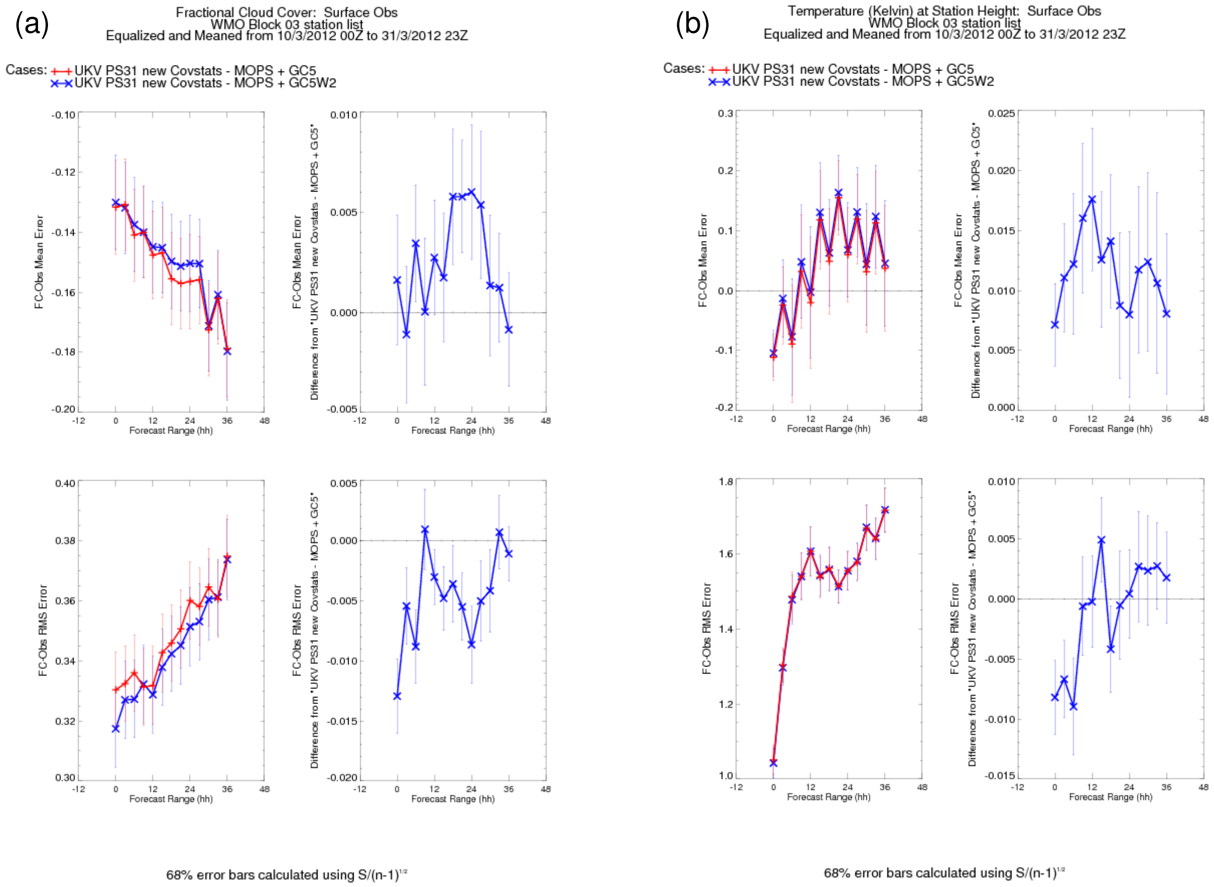
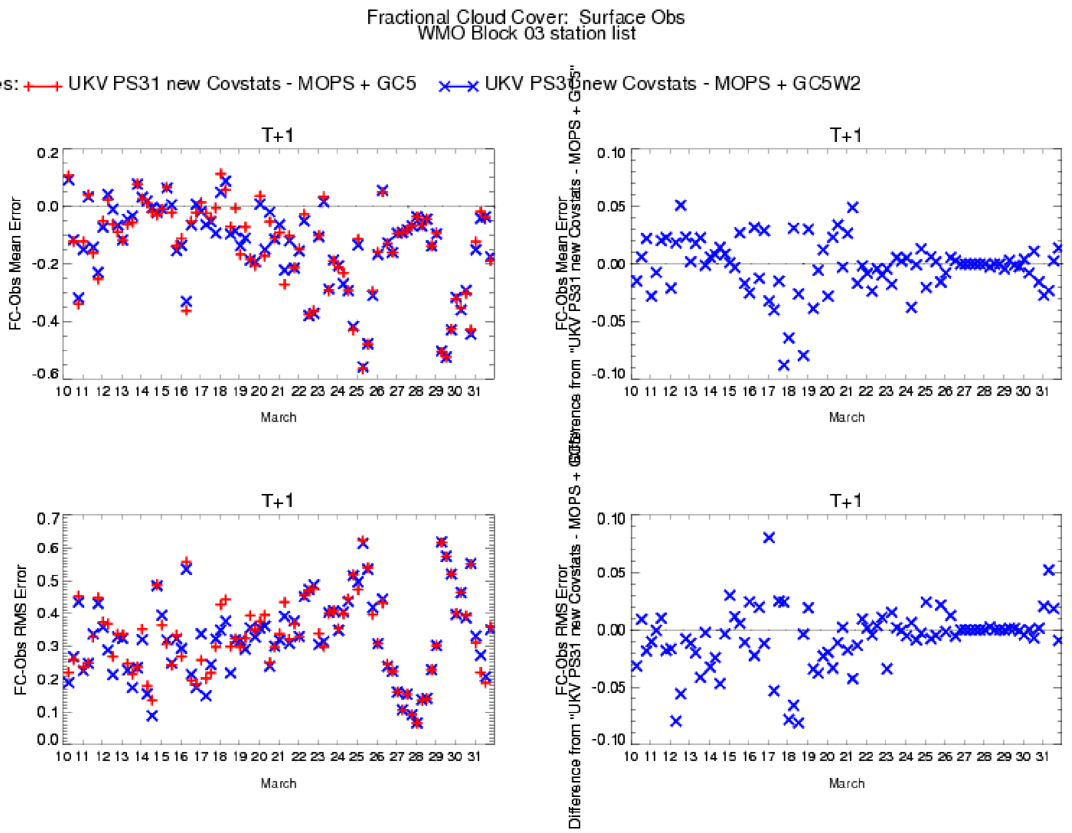


Figure 7: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the March 2012 trial period. Data in red are for the GeoCloud GC5 settings (i.e. 0.25/0.55 symmetric observation errors), data in blue are for 0.18/0.39 symmetric observation errors (i.e. effectively with doubled weighting in VAR). Differences (right-hand side) are with respect to the "GC5" case.**

(a)



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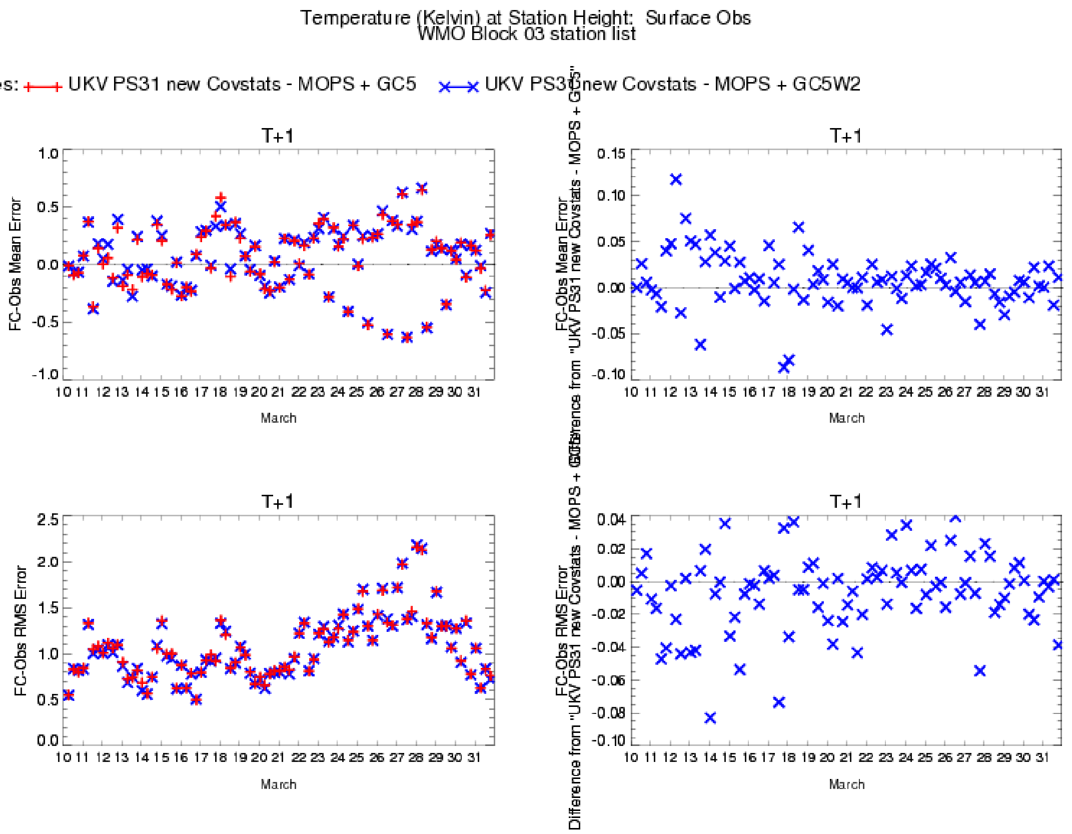

Figure 8: **Verification of (a) T+1 hour fractional cloud cover, and (b) T+1 hour screen temperature, as a function of time, for the March 2012 trial period. Data in red are for the GeoCloud GC5 settings (i.e. 0.25/0.55 symmetric observation errors), data in blue are for 0.18/0.39 symmetric observation errors (i.e. effectively with doubled weighting in VAR). Differences (right-hand side) are with respect to the "GC5" case.**

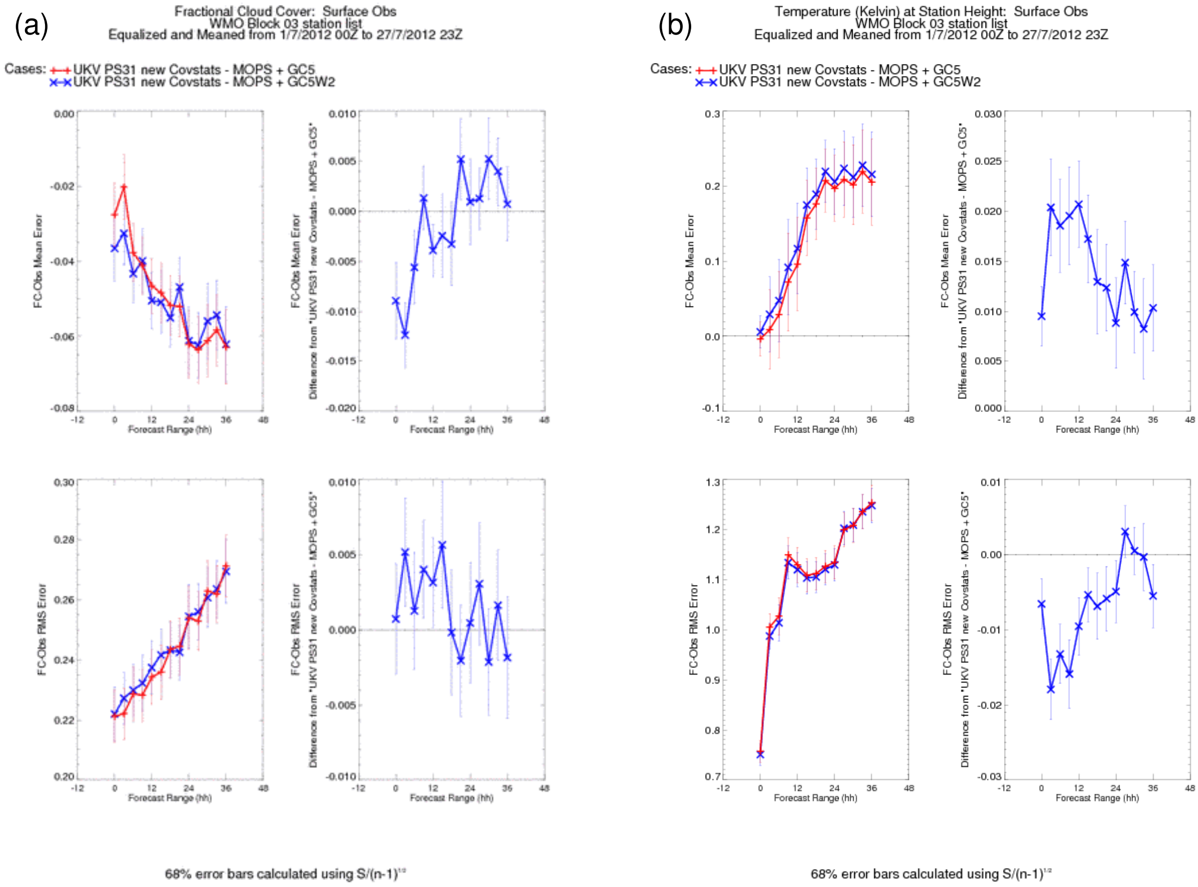

Figure 9: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the July 2012 trial period. Data in red are for the GeoCloud GC5 settings (i.e. 0.25/0.55 symmetric observation errors), data in blue are for 0.18/0.39 symmetric observation errors (i.e. effectively with doubled weighting in VAR). Differences (right-hand side) are with respect to the "GC5" case.**

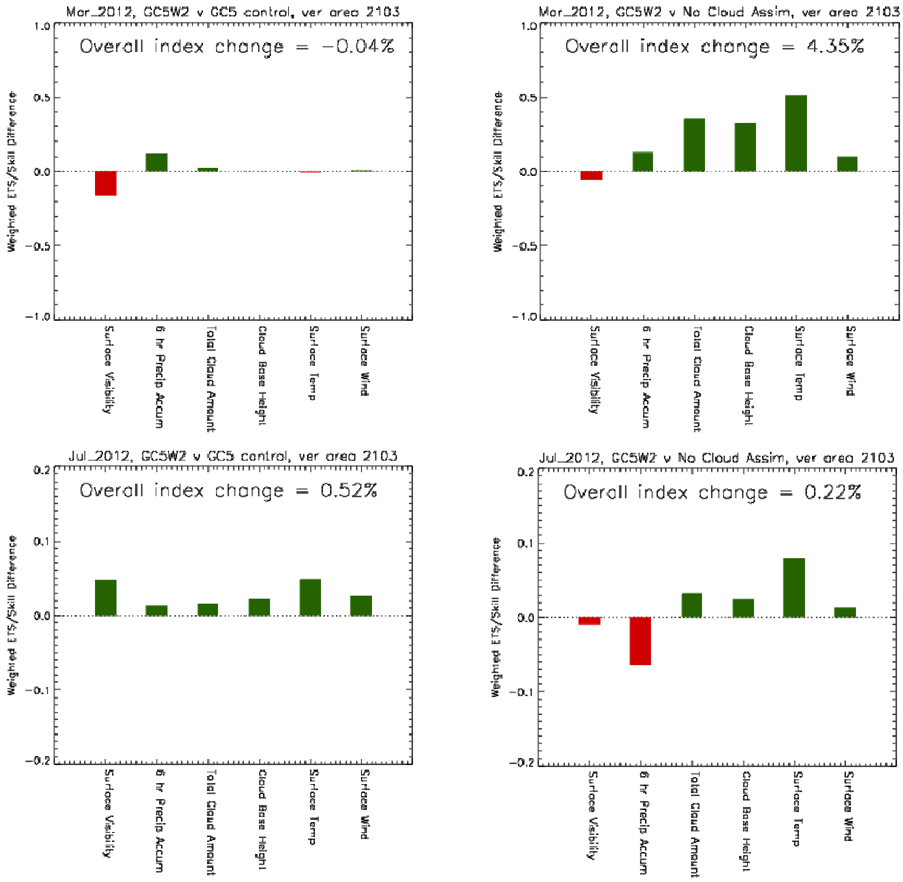

Figure 10: **UK Index impacts due to reducing the GeoCloud observation errors (i.e. increasing the weighting of GeoCloud in VAR), for two seasons. The "GC5 control" results refer to 0.25/0.55 symmetric GeoCloud observation errors, and the "GC5W2" results refer to 0.18/0.39 symmetric observation errors (i.e. effectively doubling the weighting of GeoCloud observations in VAR). The right-hand column shows the impact of the "GC5W2" set-up relative to the "no cloud assimilation" case.**

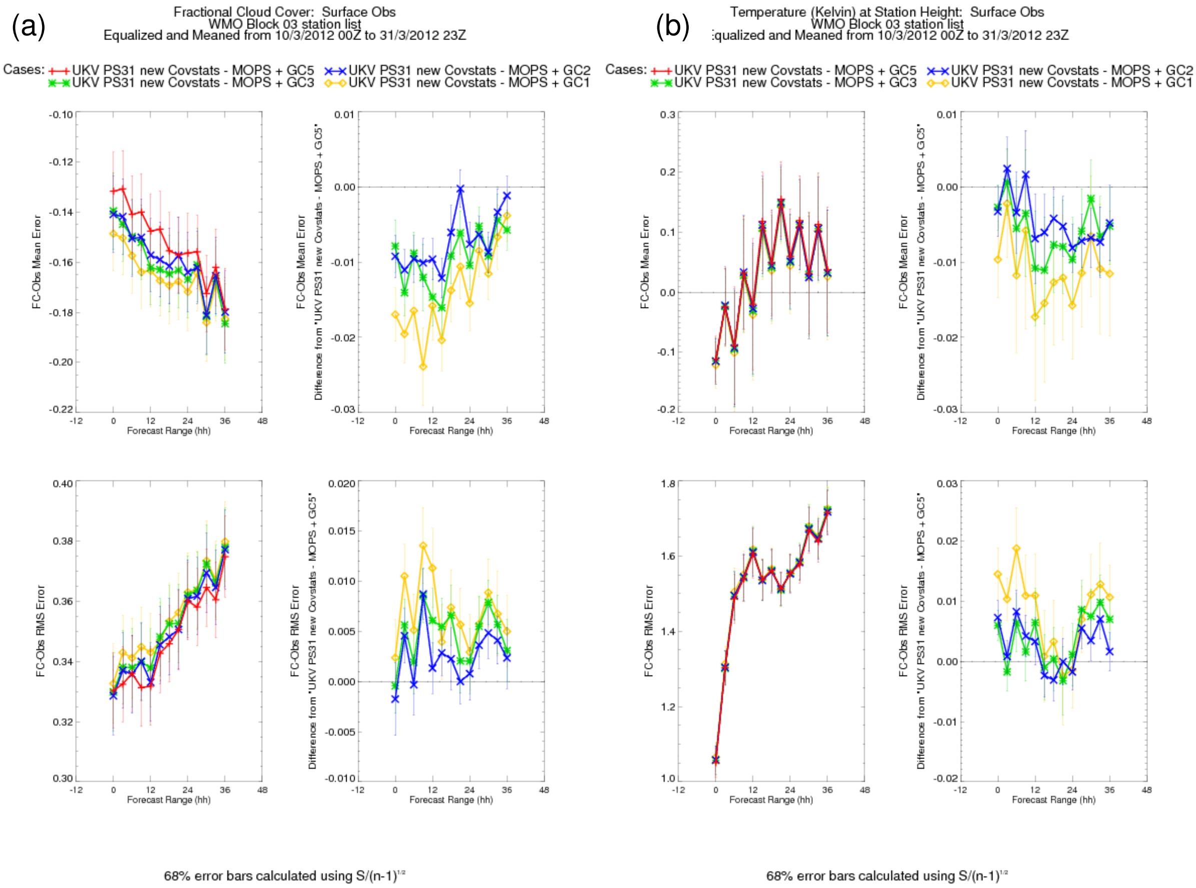

Figure 11: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the March 2012 trial period. Data in red are for the GeoCloud GC5 settings (i.e. 0.25/0.55 symmetric observation errors), data in blue (labelled "GC2") additionally allow non-unit Stable Layers cloud-fractions to be assimilated, data in green (labelled "GC3") include the effects of additional GeoCloud quality control, and data in yellow (labelled "GC1") include both GC2 and GC3 changes. Differences (right-hand side) are with respect to the "GC5" case.**

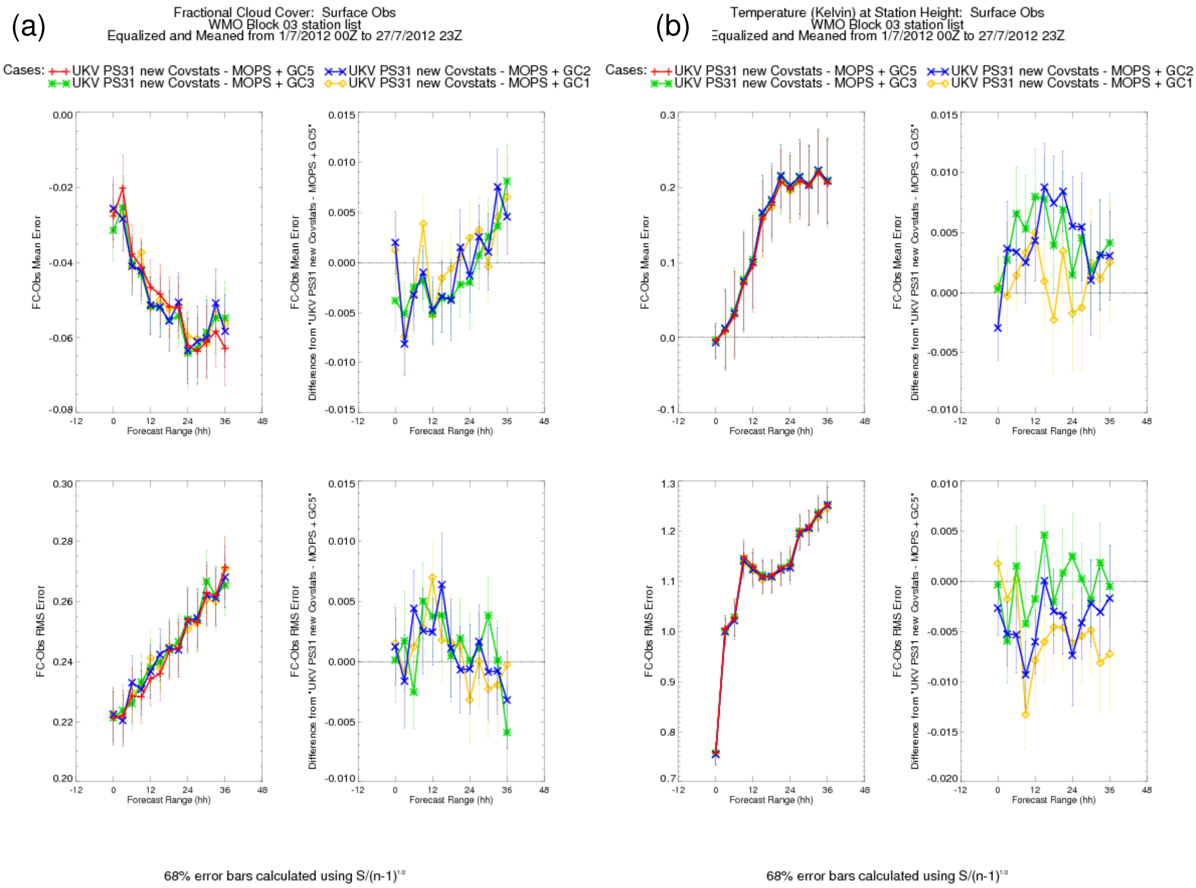

Figure 12: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the July 2012 trial period. Data in red are for the GeoCloud GC5 settings (i.e. 0.25/0.55 symmetric observation errors), data in blue (labelled "GC2") additionally allow non-unit Stable Layers cloud-fractions to be assimilated, data in green (labelled "GC3") include the effects of additional GeoCloud quality control, and data in yellow (labelled "GC1") include both GC2 and GC3 changes. Differences (right-hand side) are with respect to the "GC5" case.**

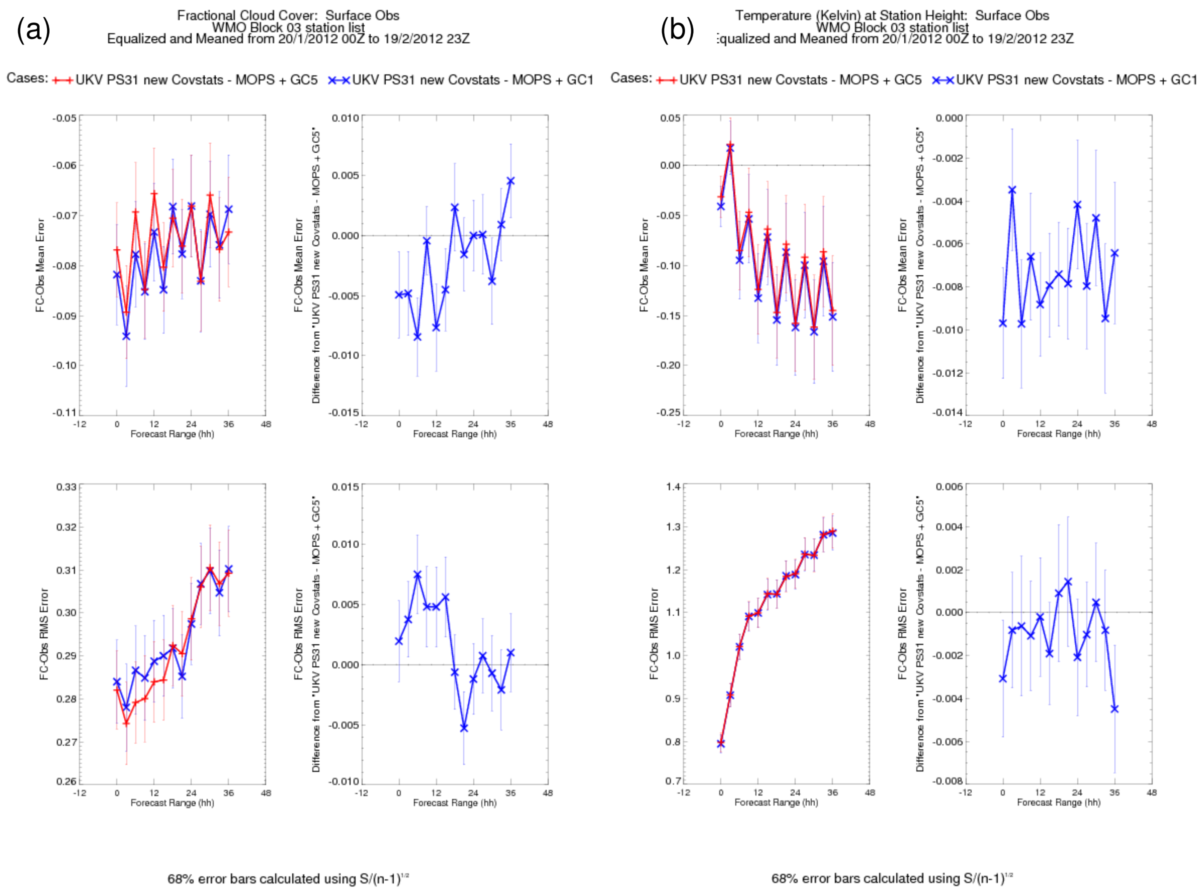

Figure 13: **Verification of (a) fractional cloud cover, and (b) screen temperature, as a function of forecast lead time, for the Jan/Feb 2012 trial period. Data in red are for the GeoCloud GC5 settings (i.e. 0.25/0.55 symmetric observation errors), and data in blue (labelled "GC1") include both GC2 and GC3 changes. Differences (right-hand side) are with respect to the "GC5" case.**

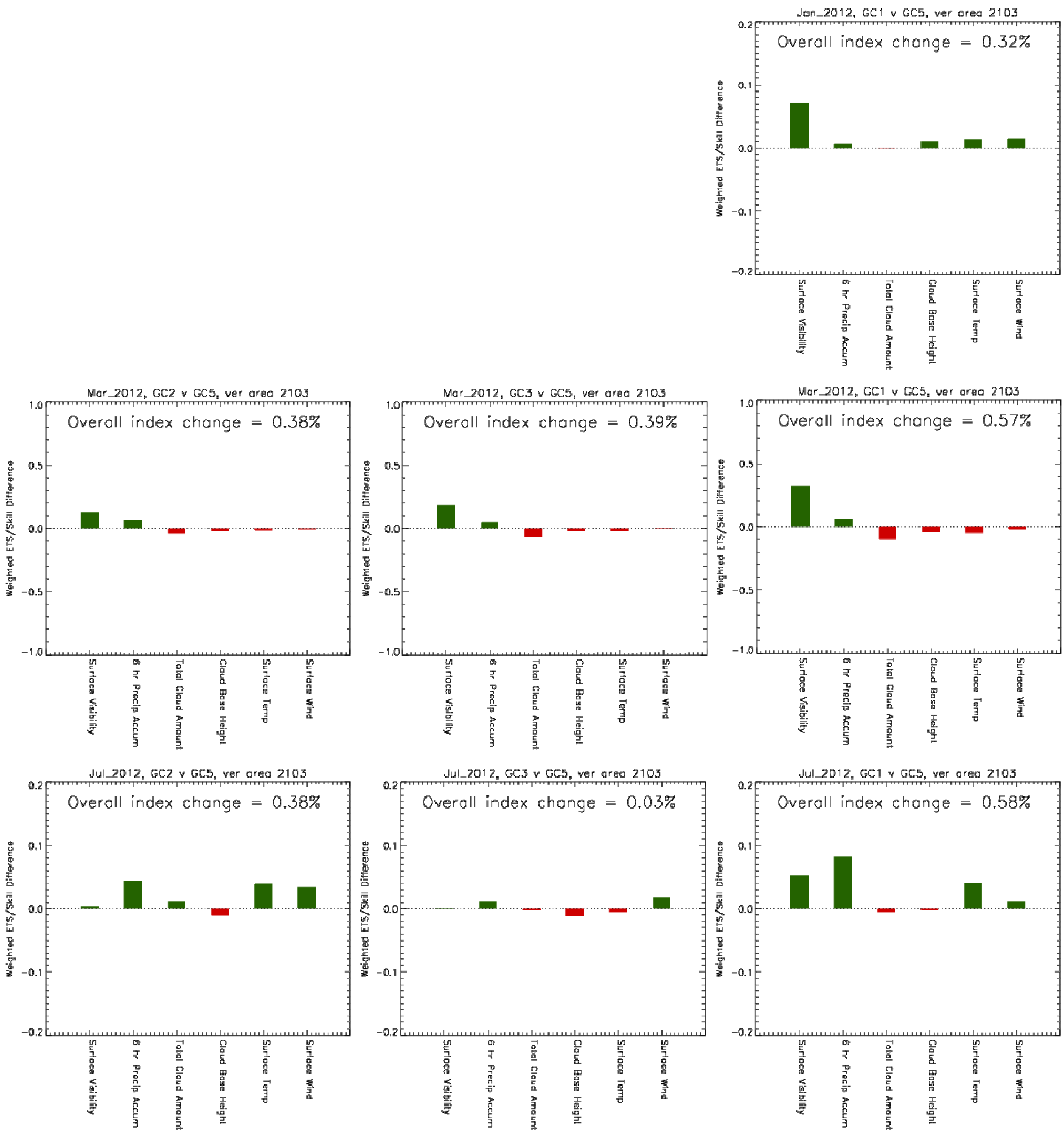

Figure 14: **UK Index impacts for various further cloud assimilation trials. The top row is for the Jan/Feb 2012 trial period, the middle row for March 2012, and the bottom row for July 2012. The left-hand column shows the impact of "GC2" settings (i.e. allowing non-unit Stable Layers cloud-fractions to be assimilated) relative to the "GC5" (0.25/0.55 symmetric observation errors) control, the middle column shows the impact of "GC3" settings (i.e. including the effects of additional GeoCloud quality control) relative to the GC5 control, and the right-hand column shows the impact of "GC1" (i.e. including both GC2 and GC3 changes) relative to the GC5 control.**

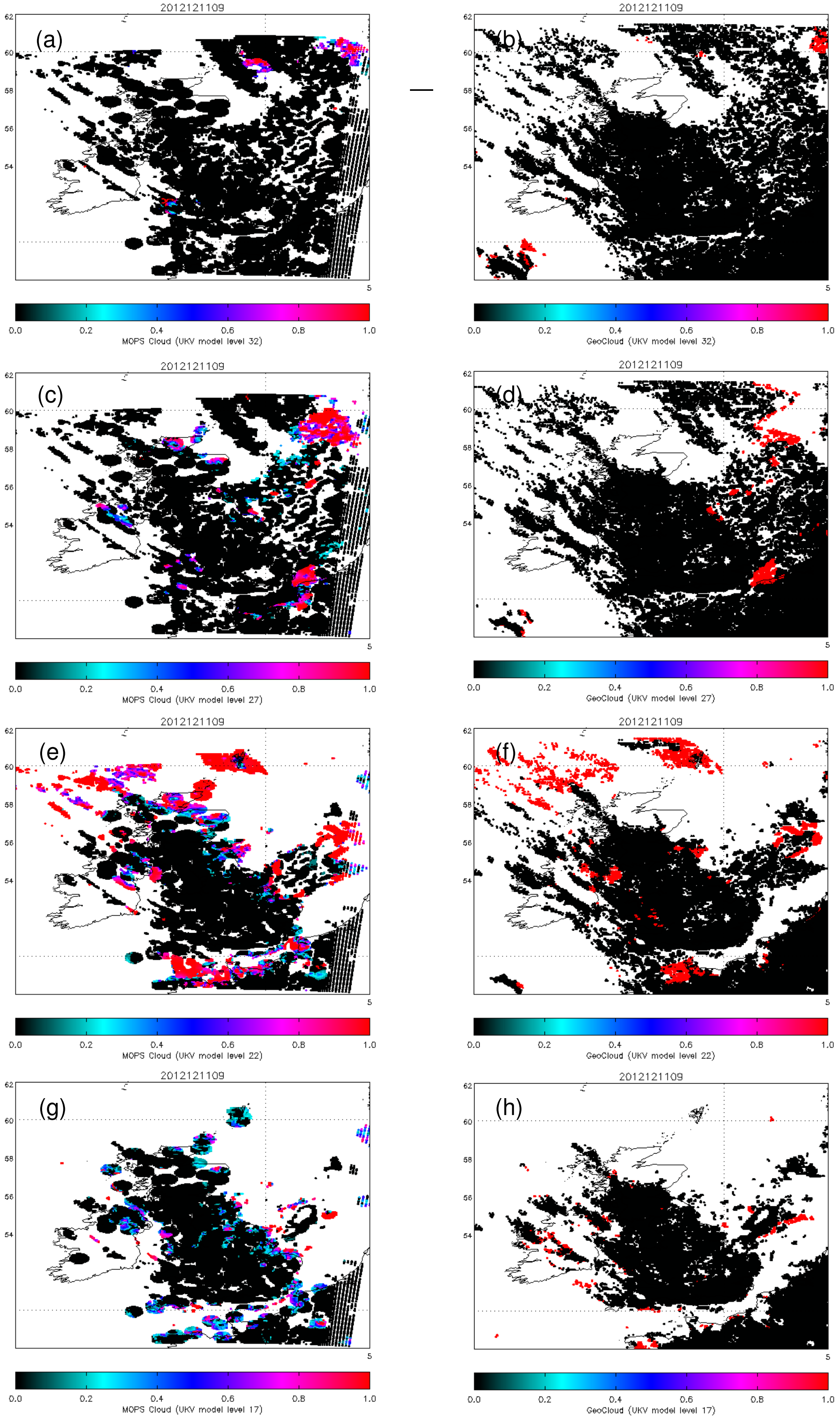

Figure 15: **Varobs cloud data for 09 on 11th December 2012. The left-hand column shows MOPS Cloud Varobs data at model levels (a) 32; (c) 27; (e) 22; and (g) 17. The right-hand column shows GeoCloud Varobs data for the same model levels. Both sets of data are from UKV runs, the MOPS data from the Operational Suite, and the GeoCloud data from the Parallel Suite.**

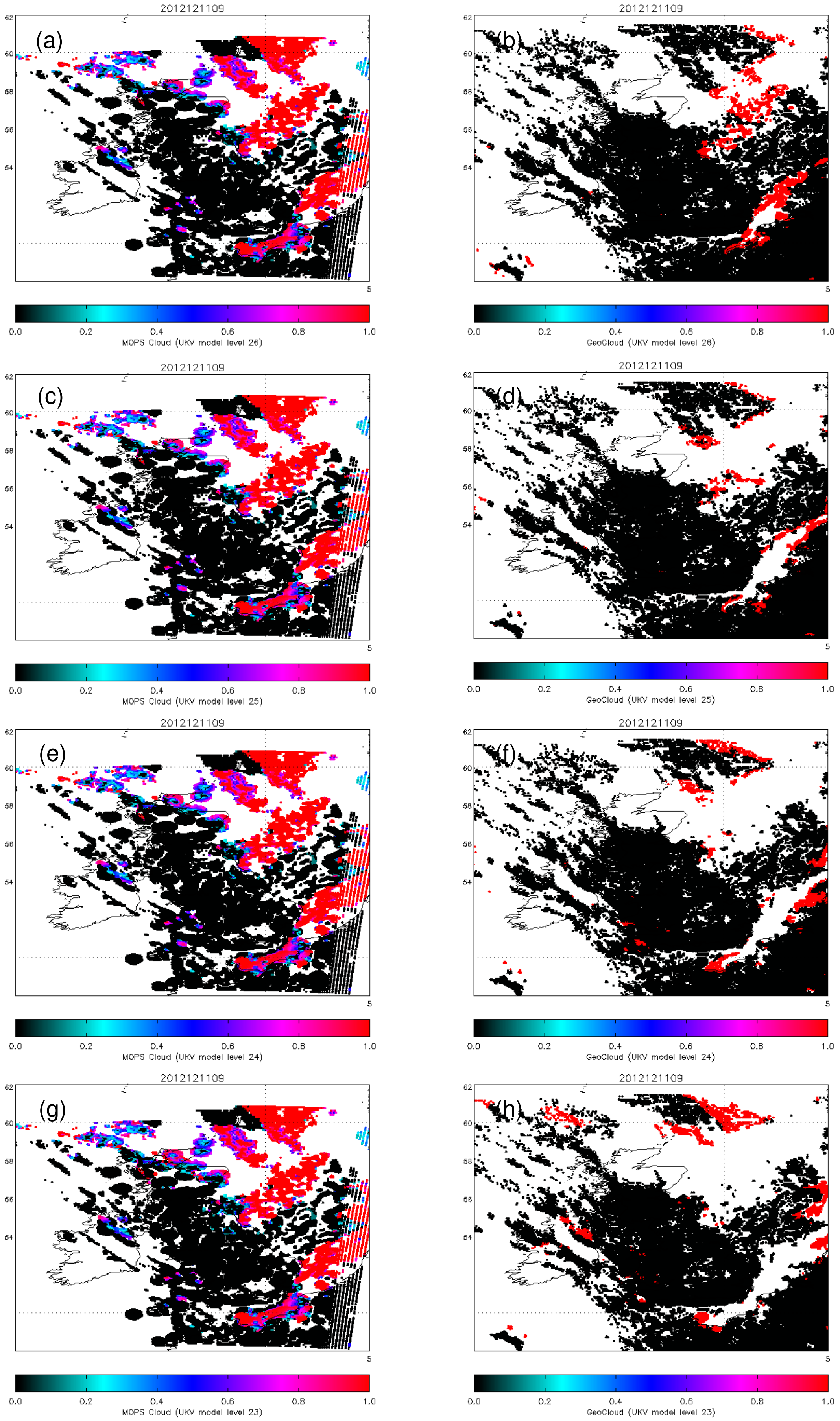

Figure 16: **As Figure 15, but for model levels (a, b) 26; (c, d) 25; (e, f) 24; and (g, h) 23.**

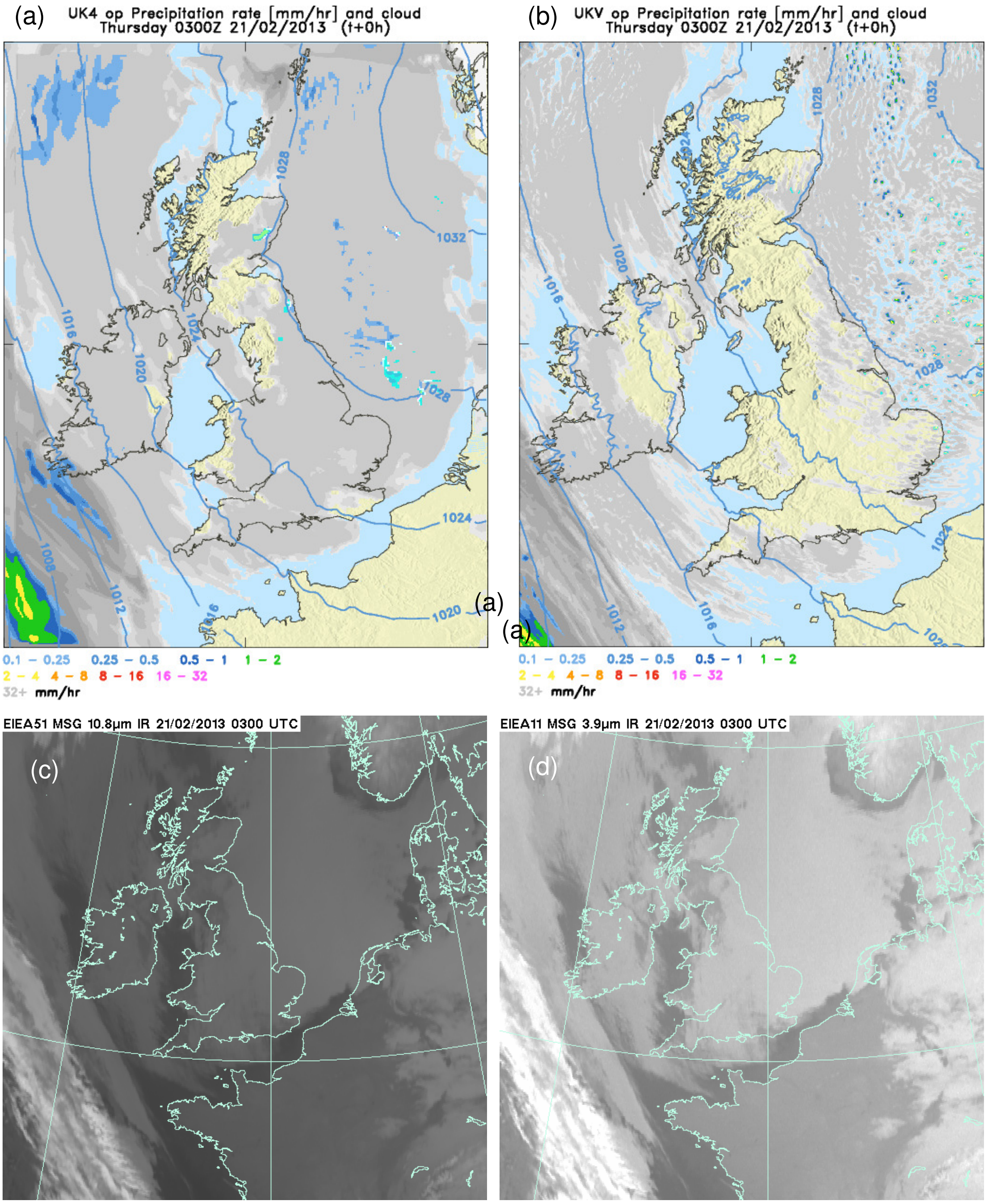

Figure 17: **(a) Cloud fraction (and precipitation rate) from operational UK4 run 03Z, 21st February 2013; (b) as (a), but for the UKV model; (c) 10.8 micron infrared image for 03Z on 21st February 2013; (d) corresponding 3.9 micron image.**

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