Revised quality control for radiosonde humidity

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1 Introduction

In July 2004, several soundings with strongly overestimated humidity values were issued by the radiosonde station Stuttgart. While the OI-based GME analysis scheme rejected at least some of these data, the operational nudging scheme of LM failed to detect these errors and assimilated the humidity observations. The impact on LM forecasts was rather limited and did not attract attention. In the assimilation cycle, however, it caused spurious rain of up to 200 mm in 24 hours (31 July − 1 August 2004, 6 UTC).

In the threshold quality control (QC) of the nudging, which is similar to a first-guess check of 3-D analysis schemes, it is assumed that the assimilating model run provides a fair estimate of the true atmospheric state. Hence, a relative humidity observation U_o can be considered erroneous and is rejected if it deviates from the model value U_b by more than a threshold value U_{thr} (i.e. if $|U_o - U_b| > U_{thr}$). In the operational LM, the threshold $U_{thr}(t_o)$ valid at observation time t_o is 70 % whereas for GME, it had been reduced to about 28 % for most data. In addition, the LM threshold is further enhanced with increasing distance to the observation time (by error up to 100 %). This leads to hardly any data ever being rejected.

Therefore, a modification to the quality control of upper-air humidity is required which is able to reject at least some of the bad data, including those leading to the 200 mm of spurious rain on 1 August 2004, but which at the same time accepts most of the good data. Note that near strong inversions in wintertime low stratus periods, good observations often deviate from the model values by (far) more than 50 % relative humidity since such inversions tend to be simulated poorly by the model. In order to meet these requirements to a satisfactory degree, it is found not to be sufficient to only modify the existing QC steps, i.e. the threshold QC for individual humidity observations and the multi-level check. A spatial consistency check for integrated water vapour is added for this reason.

2 Revisions to the quality control

Revised, stability-dependent thresholds in the QC for individual observations

In a first trial, the QC thresholds and multi-level check of the GME OI analysis were adopted. This, however, resulted in far too many observations being rejected (about 40 %) and initiated also a revision the GME QC by increasing the thresholds from about 28 % to 44 % for most data. These new thresholds are also used in the revised QC for LM:

$$U_{thr\,(1,3)}\,(t_o) \;=\; \min\left[\left({\sigma_0}^2 + {\sigma_b}^2\right)^{1/2}\;,\;2\,\sigma_b\right]\cdot c_{flag\,(1,3)}$$

where the observation error $\sigma_0 = 10\,\%$ ($15\,\%$ for $T_o < 233\,\mathrm{K}$, $20\,\%$ for $U_o < 20\,\%$), the background error $\sigma_b = 10\,\%$ ($15\,\%$ south of 30 N), and the constant $c_{flag\,(3)} = 3.1$ ($c_{flag\,(1)} = 1.8$ for flag 1 as used in the multi-level check).

In strongly stable situations and in particular at inversions, model errors are known to be increased often. In the revised QC for LM, the assumed background error σ_b is therefore enhanced by 2 terms selectively for those humidity observations at which the observed lapse rate β to the next humidity observation further above or below is $\beta > \beta_{crit} = -0.0065\,\mathrm{K/m}$:

$$\begin{aligned} \sigma_b \quad &\rightarrow \quad \sigma_b \cdot (1 + f_{stable} + f_{invers}) \\ f_{stable} \quad &= \quad 1/4 \cdot (1 - \min(\beta, 0) / \beta_{crit}) \cdot (1 + c_s), \qquad c_s = \Delta_\beta T / (1 + \Delta_\beta T) \\ f_{invers} \quad &= \quad 1/5 \cdot \max(\Delta T, 0) \cdot (1 + c_i), \qquad c_i = \min(2, \beta / 0.05) \end{aligned}$$

$\Delta T = T_k - T_{k-1}$, where T_k and T_{k-1} are the temperature observations at the humidity observation level k respectively at the next level $k{-}1$ further below. $\Delta_\beta T = T_k^\beta - T_{k-1}$, where T_k^β is T_k extrapolated to level $k{-}1$ with the lapse rate β_{crit} . Both terms f_{stable} and f_{invers} increase with increasing stability and with increasing thickness of the stable layer (given by the two successive humidity observation levels).

Finally, an upper limit of $70\,\%$ is imposed to the threshold $U_{thr}(t_o)$ at observation time. With increasing distance to the observation time, the threshold is enhanced linearly to a maximum of $77\,\%$ (with the temporal weight function used currently in the nudging).

Multi-level check

The revised multi-level check is analogous to that of the GME OI analysis (but not equivalent, due to the different, stability-dependent thresholds for flag ≥ 1 in the first guess check):

- Analysis layers are defined equal to the standard layers except below $700\,\mathrm{hPa}$, where the thickness of the analysis layers is reduced to $50\,\mathrm{hPa}$ and below $800\,\mathrm{hPa}$ to $25\,\mathrm{hPa}$.
- Criterion: If 4 or all consecutive standard layers contain humidity observations with flag ≥ 1 , then these standard layers are set to 'rejected'. Each analysis layer within those rejected standard layers is set to 'rejected' if it contains observations with flag ≥ 1 . All observations within these rejected analysis layers are rejected.

Spatial consistency check of integrated water vapour (IWV)

A spatial consistency check of integrated water vapour has been developed to detect a general bias in a radiosonde humidity sounding. As a first step, observation increments of IWV are derived from radiosonde humidity profiles and optionally also from ground-based GPS zenith path delay data. At the location of each IWV 'observation' Q_k , an IWV 'analysis increment' ΔQ_k^{ai} is then computed using only the neighbouring observations $Q_{j \neq k}$:

$$\Delta Q_k^{ai} \quad = \quad \frac{\sum_{j \neq k} \; w_{kj}^2 \cdot \frac{Q^{sat}(\mathbf{x}_k, t)}{Q^{sat}(\mathbf{x}_j, t)} \cdot \; (\, Q_j \; - \; Q(\mathbf{x}_j, t)\,)}{\max \left(\sum_{j \neq k} \; w_{kj}^2 \; , \; 1 \right)}$$

Here, $Q^{sat}(\mathbf{x}_k, t)$ is the IWV derived from the model temperature profile at the observation location assuming saturation. The Q^{sat} term scales the observation increment, mainly in order to account for differences in orographic height. The weight w_{kj} consists of a horizontal weight (equal to that used for the nudging of radiosonde humidity data at 850 hPa respectively for GPS data), and of a temporal weight (given by a linear function of time within $\pm\,2\,h$ respectively $\pm\,1\,h$ from the observation time).

The spatial consistency check of IWV is a revised first guess check, in which the model background is corrected by the above 'analysis increment' in order to obtain a better estimate of truth. The complete humidity profile of the sounding k is rejected if

$$\left| \, Q_k \; - \; \left(Q(\mathbf{x}_k, t) \; + \; \Delta Q^{ai}_{\,k}\right) \, \right| \quad > \quad Q^{ai}_{thr\,k}$$

This check corresponds to a first guess check of IWV if there are no neighbouring observations influencing the observation location $\mathbf{x}_k$. This usually applies approximately if GPS data are not used. The basic threshold $Q_{thr\,k}(t_o)$ depends on temperature and is set to (in [mm]):

$$Q_{thr\,k}(t_o) \quad = \quad \left(\, 1 \; + \; 0.15 \cdot Q^{sat}(\mathbf{x}_k, t)\right)$$

In the presence of many neighbouring IWV observations, however, the check addresses the spatial consistency between them. The more observations are used for the 'analysis increment', the more accurate the estimate of truth, and the smaller the threshold $Q^{ai}_{thr\,k}$ should be set. On the other hand, the larger the 'analysis increment' and hence the disagreement between model and observations, the more uncertain the estimate of truth, and the larger the threshold should be. Therefore, the following correction is applied to $Q_{thr\,k}$:

$$Q^{ai}_{thr\,k}(t_o) \quad = \quad Q_{thr\,k}(t_o) \cdot \left(\, 1 \; - \; 0.2 \cdot \min\left(0.2 \cdot \textstyle\sum_j w^2_{kj} \; , \; 1\right)\right) \quad + \quad \Delta Q^{ai}_{\,k}$$

3 Results

The revised QC for radiosonde humidity has been tested for 14 days in July 2004 and a 5-day wintertime low stratus period from 9 to 13 February 2003. The humidity profiles of radisonde Stuttgart, that lead to the strong spurious rain of 1 August 2004, are rejected successfully by the IWV check (not shown).

Figure 1 illustrates the negative effects if the QC is too strict. Subjective evaluation does not give any indication for errors in the radiosonde observations within the domain shown. Accepting all humidity data with the operational QC renders a fairly good analysis of low cloud for 13 February 0 UTC. Rejecting many data when using the small thresholds of the old GME OI version strongly degrades the analysis in the region around the Lyon and Payerne radiosonde stations. With preliminary stability-dependent but still too small thresholds (Figure 1, lower left), more data are accepted again, and most of the cloud around Lyon comes back. In this analysis, however, low cloud is missing in a large area around the Paris sounding, because the thresholds are still so small as to reject the moist data below the inversion, but large enough now to accept all the dry data above it. In the final revised QC, the introction of the IWV check allows to further relax the thresholds in the first guess and multi-level checks, so that for the case shown, almost all the relevant observations are accepted, and the low cloud analysis is as good as the original one.

In the whole 5-day low stratus period, the new QC rejects 4 % of the humidity profiles (completely, or partially from the top down to at least 700 hPa) in the multi-level check and another 1 % in the IWV check. Very few data are rejected additionally by the first guess check. About 80 % of the rejected profiles are relatively close (within 50 grid points) to the lateral boundaries of the LM domain. Some of them are rejected erroneously when the model fields are far too moist above the inversion, after this moisture has been advected from the lateral boundaries (see e.g. Figure 2). The latter reflect the GME OI analysis which often grossly overestimates moisture above inversions.

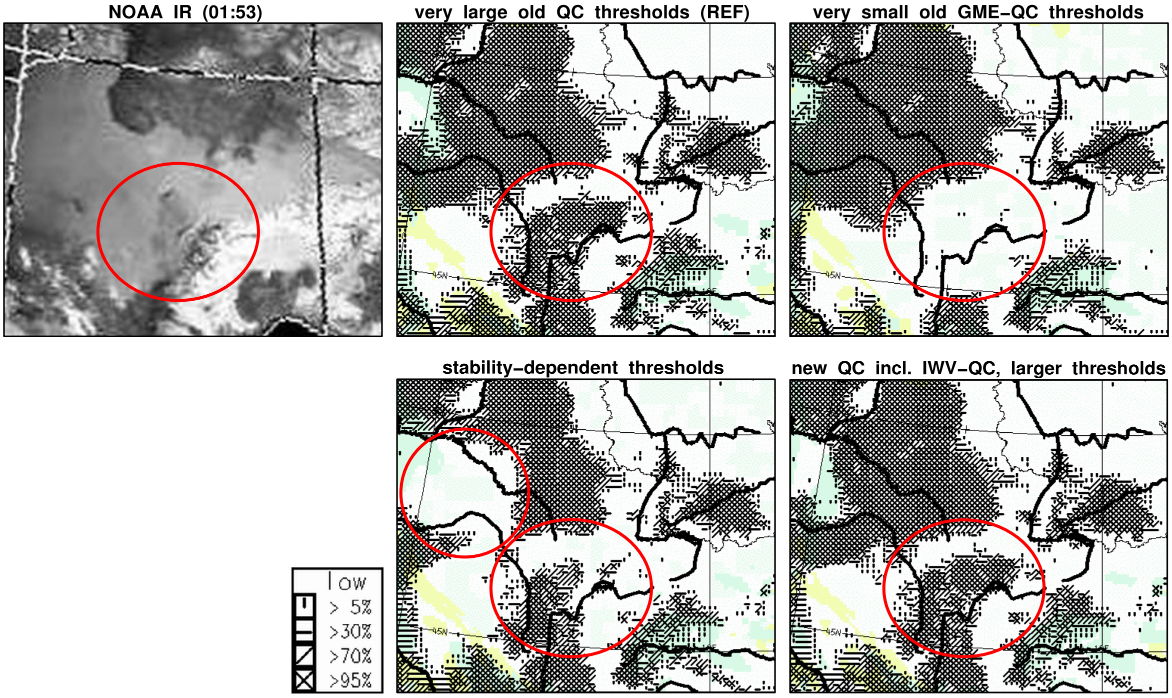


Figure 1: Cloud cover for southwestern Germany, northeastern France, and parts of the Alps on 13 February 2003, 00 UTC. Upper left panel: NOAA IR image (at 01:53 UTC); upper middle: reference LM analysis with old QC; upper right: LM analysis with QC thresholds as for operational GME; lower left: LM analysis with preliminary stability-dependent QC; lower right: LM analysis with new QC. In LM analyses panels, low cloud cover is displayed in black patterns as by the legend, middle and high cloud cover > 50 % in green and yellow shading. Red circles indicate areas of main interest.

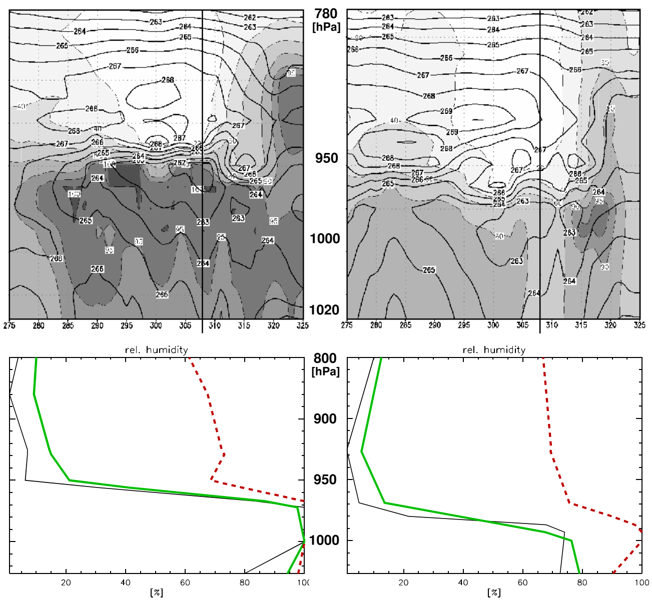
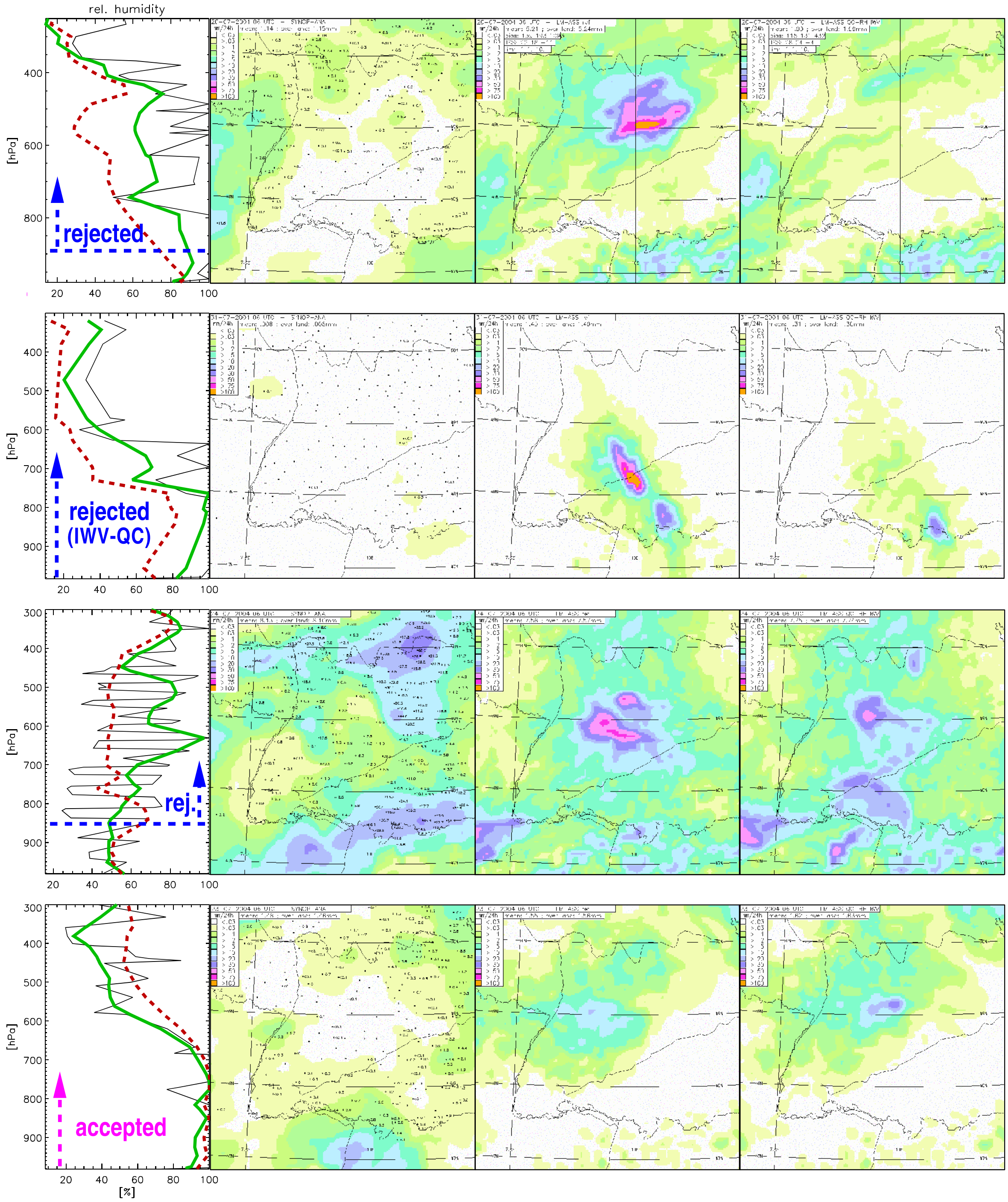


Figure 2: Upper panels: west-east vertical cross sections through the lowest 15 model levels (the numbers between the panels indicate the approximate pressure) and 50 horizontal LM grid points, which include the location of the Warsaw radiosonde station (indicated by the black vertical lines) and the eastern boundary of the LM domain (right boundary of panels). Solid black contours: temperature [K] of reference LM analyses with the old QC; grey shading and thin dashed contours (for 20, 40, 60, 80, 90, 95, 100 %): relative humidity. Lower panels: vertical profiles of relative humdity at Warsaw for 12 February 2003. Solid black line: observation; thick solid green line: reference LM analysis with old QC; red dashed line: LM analysis with new QC. Left panels: 00 UTC; right panels: 12 UTC.

In the 14-day period in summer 2004, significant spurious rain has occured with the old QC in 4 cases (shown in Figure 3, apart from the 1 August case that was used to tune the new QC). In the two most severe cases with spurious rain exceeding 100 mm, the revised QC is able to remove that rain (almost) completely, in the second case by means of the new IWV check. In the third case, it rejects the data of an erroneous profile only above 850 hPa. This does not eliminate the spurious rain but reduces its area and maximum amount (from 75 to 50 mm) and also tends to improve the rain patterns in the environs. It is the forth and least severe case only, where the revised QC completely fails to reject the erroneous data. In the whole period, 2 % of the profiles are (at least partially) rejected by the multi-level check and 1 % by the IWV check. 35 % of the rejected profiles are Stuttgart soundings.

4 Concluding Remarks

The quality control (QC) for radiosonde humidity has been revised. This includes a significant reduction of the general threshold in the 'first guess' check. Yet, a new stability-dependent enhancement to it allows to account for large model errors and observation increments near inversions. Furthermore, a spatial consistency check for integrated water vapour (IWV) derived from radiosonde humidity and optionally from GPS-derived zenith path delay has been developed. This check uses model-derived IWV as background information and is equivalent to a first guess check of IWV in the absence of neighbouring observations. The revised QC rejects about $2-5$ % of the humidity data, including most of the erroneous data from the radiosonde Stuttgart in July 2004, but it accepts most of the correct data near strong wintertime inversions. It is planned to become operational in LME at the beginning of 2006.



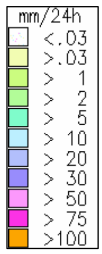


Figure 3: Left panels: Vertical profiles of relative humidity at Stuttgart on (from top to bottom) 19 July 2004 23 UTC, 30 July 23 UTC, 23 July 17 UTC, 22 July 23 UTC; solid black lines: observation; green thick solid lines: reference LM analysis with old QC; red thick dashed lines: LM analysis with new QC; horizontal blue dashed lines: approx. level above which all humidity data are rejected by the new QC.
Other panels: 24-hour sum of precipitation in southwestern Germany valid at (from top to bottom) 20, 31, 24, resp. 23 July, 06 UTC; panels from left to right: analysis from synop observations; reference LM analysis with old QC; LM analysis with new QC.