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Atmospheric Measurement Techniques Discussions

Interactive comment on "A novel gridding algorithm to create regional trace gas maps from satellite observations" *by* G. Kuhlmann et al.

G. Kuhlmann et al.

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We thank the reviewer for the careful review of our manuscript and the valuable comments, suggestions and commentary. We replied to the comments below. The updated manuscript has been attached as supplement. The changes are highlighted in red for changes based on reviewer #1, in green for changes based on reviewer #2 and blue for changes based on comments from both reviewers.

Main comments

1) The problem of producing detailed maps is essentially two-dimensional. The missing

part in the paper is insufficiently detailed description of the algorithm in 2D. In Section 2.4.4, the authors state that the surface spline can be computed uniquely using 1D splines with the reference on the paper by Kobza and Mlcak (1994). As this procedure is very important, a short description of the algorithm (in order to get the idea) would be very useful.

I found also unclear in the 1D descriptions, why the error term appears only in along-track formulation? (This seems to be not the case for 2D case).

An estimate of numerical efficiency for using 1D splines compared to 2D- spline method would be also useful in Section 2.4.4. This would justify the selection of the proposed method.

Reply: Section 2.4.4 has been rewritten to have a more detailed description of the 2D algorithm (see supplement to this comment). A short description of the computational efficiency as been included, as well.

In the 1D descriptions, the penalty term has been introduced to obtain the parameter in along-track direction, where the inclusion of matrix $\mathbf{M}$ makes the inverse problem ill-posed. From this perspective, no penalty term is required in across-track direction.

2) For any measurement, its uncertainty is nearly as important as the measurement itself. However, the uncertainty characterization for the data fields, which are created by the proposed method, is completely missing in the paper.

Reply: The propagation of measurement noise has been extensively studied using Monte Carlo simulations (Sect. 3). These results can also be used to estimate the uncertainty of trace gas map. To state this more clearly, the following paragraph has been added to Sect. 3.2.4:

3.2.4 The surface spline: performance and propagation of measurement uncertainty
[...]
The results can also be used to the estimate the measurement uncertainty of the trace gas map. For CVM, grid cell values are given by averaging overlapping pixels and thus the propagation error can be computed easily (Wenig et. al. 2008). For PSM the computation of the error is more complex and out of the scope of this study. However, if the propagation error is dominant ($\delta_\varepsilon \geq 25\%$), Fig. 6 shows that l_2 errors for CVM and PSM are similar. Therefore, the error distribution obtained by CVM can also be used to estimate the errors of trace gas maps created by PSM.

Detailed comments

P. 7873 l. 4: "For a push broom scanner, we can neglect the x dependency" Please explain why.
Reply: In across-track direction, the instrument function is given by $\exp(-cx^4)$. This function is nearly constant within the pixel boundaries and drops rapidly towards zero outside the pixel. Therefore, the sensitivity does not change in x direction within a single pixel.

P. 7873, l. 13: "Since the FWHM changes are small within a pixel..." According to Fig.3, this is not true for the nadir case.
Reply: At nadir the FWHM is about 14 km and changes not more than 0.015 km within the 24 km-width of a pixel in across-track direction. At the swath edge, the FWHM changes about 2 km along the 160 km wide pixel ($< 2\%$). Therefore, the change of the FWHM is small within a pixel. Fig. 3 shows the instrument function in along-track direction.

P. 7877, Eq. (13) Please provide direct expression for f_i'. (They seems to be differences, not derivatives, right?)
Reply: f_i' is the first derivative of the i-th polynomial. To make this clearer, we changed the sentence before Eq. (13): "by requiring continuity of the first derivative of the spline f' at each knot x_i. This is written as ..."

P. 7885, l. 15: "10% smaller" $\rightarrow$ 10 times smaller?
Reply: This is correct. Changed.

P. 7887, l. 24 "The reason is that the movement of the lattice between samples improves the parameterization of the distribution" This is true only for a constant source.
Reply: The paragraph discusses the behaviour of the gridding algorithms for averaging measurements from different orbits. Because our test distributions are modelled as a mean distribution with random noise, shifting the lattice position between "measurements" improves the parametrisation. In general, any distribution, which can be divided into a mean value and a variance, has this behaviour. In particular, the existence of such a mean value is the necessary requirement for computing an average.

P. 7888, 1st paragraph. It is worth to add a note at the end of the paragraph that uncertainties are included in the matrix B.
Reply: The suggestion has been included:

> The penalty term is scaled using the inverse of matrix $\mathbf{B}$, which is proportional to the measurement uncertainty δ_ε and ρ_{est} (Eq. 29). ρ_{est} is set to one. Using this scaling, l_2 and l_{max} have minimum values at similar γ independently of the measurement uncertainty δ_ε (Fig. 7).

P. 7894, l. 12 "high-resolution maps". I think it is worth to mention here that the actual resolution is still limited due to the resolution of measurements. This is also related to

the uncertainty/resolution characterization (see main comments).
Reply: The following sentences have been included in the conclusion:

> Application to OMI NO_2 column densities suggests that PSM is more suitable than CVM to create high-resolution maps. It should be understood that the best possible resolution is fundamentally limited by the spatial resolution of the satellite instrument. However, a well-chosen gridding algorithm may be able to detect small-scale features at this limit, which are missed otherwise. The use of PSM in satellite validation studies is being planned for in the future.
> The general approach described in this study...

Suggestions for figure improvements

Fig. 3: Please add scale on the vertical axis.
Reply: The vertical axis shows the (normalised) instrument function $W_i(y)$, for which a scale is, in our opinion, not required. The caption has been changed to emphasise this:

> Normalised instrument functions, as described by Eq. (3), of six consecutive pixels..."

Fig. 5: Please arrange subplots in a different way (e.g., 2 x 2) for better visibility. Pink line is practically invisible.
Reply: Done.

Figs. 6 and 10: Yellow shading is overlapping with pink one and is invisible. Please use a more contrast color (grey, for example).

Reply: Done.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/6/C3390/2013/amtd-6-C3390-2013-supplement.pdf

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Interactive comment on Atmos. Meas. Tech. Discuss., 6, 7867, 2013.