Atmos. Chem. Phys. Discuss., 14, C11020–C11032, 2015
www.atmos-chem-phys-discuss.net/14/C11020/2015/

Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Evaluation of a regional air quality model using satellite column NO_2: treatment of observation errors and model boundary conditions and emissions" *by* R. Pope et al.

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Received and published: 9 January 2015

We thank the reviewer for his/her comments. These comments are repeated below surrounded by quotation marks. Our responses follow in normal text.

1. "In equations 1-3, y is a scalar, and A and x are vectors and the notation should be adapted accordingly (e.g. in boldface or with a vector sign)."

The A and x vectors will be changed to bold font.

2. "A discussion of why the kernel values over Dartmoor are lower than over London is missing. This should be explained. Kernels depend on a range of aspects: albedo, viewing geometry, clouds, and also location. So what do we see when kernels over Dartmoor and London are different? Are albedo, geometry and clouds all similar between those two locations, and do we see the effect of the different NO2 loading between Dartmoor and London?"

The retrievals have been filtered out for cloud cover under 20% over both London and Dartmoor. Therefore, cloud cover is unlikely to be causing the AK differences between the two sites. The viewing angle is unlikely to have a large affect on Dartmoor and London AKs as NO2 will be retrieved from the different locations at various viewing angles depending where OMI is in its orbit. We have looked at the surface albedo data from the OMI satellite files for 2006 and the patterns were noisy with no clear differences between the locations. Eskes and Boersma (2003) state that AKs are independent of trace gas distributions for optically thin absorbers (Eqn 15). However, for stronger absorbers they suggest that the AK depends on the true distribution of the tracer. Therefore, as London column NO2 is greater than that of Dartmoor, i.e. regions of optically strong and thin absorbers, and the AKs are more and less sensitive, respectively.

In the revised text in Section 2.1 (old pages 21755 and 21756) we will add a description of the properties influencing NO2 AKs and which we believe are dominating factors in our case study (i.e. NO2 loading and not cloud cover, viewing angle or surface albedo).

3. "More generally, it is unclear what the key message is for section 2.1 and Figure 1. The authors should reconsider this section and their discussion – what is the take-home message?"

The general purpose of section 2.1 is to discuss what an averaging kernel is, how it behaves with altitude and how it will modify the model NO2 profiles. In the revised paper the section will start with the following sentence to inform the reader what the section aims to communicate: "Model Transfer Functions (MTF), known as "averaging kernels", allow for direct comparison between model column NO2 and satellite retrievals. This section introduces how these MTF modify model vertical profiles and how they vary in season and location."

4. "On page 21757 it should be clarified what causes the systematic error in the slant column. Table 1 in Boersma et al. [2004] provides this information."

On page 21757, line 6, we will add the sentence "The sources of systematic error in the total slant column include the NO2 cross-section, spectral calibration, solar diffuser and temperature (Boersma et al., 2004).

5. "Related to this, the systematic error in the slant column should not be included in Eq. (6) as it does not propagate into a tropospheric column error. Any systematic error in the NO2 slant column density will be largely absorbed by the stratospheric assimilation procedure. Subtracting from the (biased) slant column a similarly biased stratospheric slant column results in a small tropospheric residual slant column. See e.g. Belmonte-Rivas et al.[2014]."

Having read Belmonte-Rivas et al. (2014), we have removed the σstrat term from Eqns 7-10. We will discuss the σstrat term in Eqn 6 and then explain why it needs to be removed stating the reasons described by Belmonte-Rivas et al. (2014) on page 21757. The σstrat term has been removed from the algorithm and this had a limited impact on the number of significant pixels in Figures 4-8 as it is a small term in the error budget. New versions of Figures 4-8 have been created to account for this limited effect on the number of significant pixels in the bias plots. They are attached below. The captions remain the same as they are in the ACPD manuscript.

6. "However, one problem in the way they present their results, is that what they define now as the systematic error (caused by errors in the AMF), is not a true systematic error in the sense that it is a persistent and always works in the same way. The authors use the notion that the retrieval error due to AMF errors is 40% of the tropospheric column

and systematic. But the AMF error changes in time (on day 1 albedo knowledge may be accurate and on day 2 albedo may be off by +0.02), and in space (for pixel 1 the cloud fraction may be underestimated, for pixel 2 it may be overestimated), and in practice at least part of these individual systematic errors may also cancel in a temporal or spatial average. The formulation in Eq. (10) leaves no room for this now, i.e. all AMF error is 40% and always proceeds systematically. The difficulty obviously is in estimating to what extent the systematic error cancels when averaging over time, but validation studies have provided some hints here (individual comparisons may be off by up to 40% but averaged over an ensemble the systematic differences are more on the order of 20%, e.g. Irie, Hains, Schaub-papers)."

We agree with the reviewer that the uncertainty in the AMF is not totally systematic and that an average ensemble of AMF uncertainties will reduce the overall error. However, we struggled to find the value in the "order of 20%" in the references suggested by the reviewer. We found how the uncertainties in multiple factors such as the NO2 profiles and surface albedo, that are used to calculate the AMF, lead to uncertainty in the vertical tropospheric column. However, these studies did not give any direct insight to the error associated in the AMF. The Irie et al., (2012) paper does discuss the 10-40% error quoted by Boersma et al., (2004), but we have already accounted for this here. Therefore, we feel that we should leave the AMF uncertainty as the conservative estimate of 40% in our study.

7. "In the revised manuscript the above concern should be taken into account, and the authors in their discussion of Figure 2 should also indicate the magnitude of the original errors (without subtracting the pure random contribution). There should also be a discussion of why the errors appear to reduce more over continental Europe than over Sea. And why is the reduction stronger in summer than in winter? Related to more samples in summer?"

In line with Reviewer 1's comments (3. Satellite error) on providing examples of average column NO2 errors we have added a second table, which describes the location (lat, lon), mean column NO_2, mean error and mean error with the random error comment reduced for London, the Benelux region, northern England, the Po Valley, North Sea and Scandinavia in summer and winter. This table is added as a figure below for the time being.

The average summer satellite retrieval error reduces more than winter because the samples are larger. As summer is more prone to clear sky conditions than winter, less retrievals are filtered out in summer, the sample is bigger, and there is a larger reduction in the random error component ($N_{summer} > N_{winter}$).

When looking at the frequency of pixels in grid box averages, the frequency is higher over the sea than land. Therefore, following the same argument for summer and winter, the larger samples over the sea result in lower average retrieval errors.

The following sentence will be added on page 21758, line 9, "The error in summer, compared with winter, and the error over sea in comparison to land, are smaller. We suggest that the larger sample size in summer and over the sea, when compared to winter and over the land, respectively, reduces the random error component further has N is larger."

8. "P21752, L1-2: how can models 'detect' shipping lanes?"

This line will be replaced with "Several of the regional models successfully simulated the shipping lanes seen by OMI."

9. "P21752, L18: 5-6% overall or per year?"

This is 5-6% per year and will be change to "5-6% per year" in the revised manuscript.

10. "P21754, L2-3: please clarify the statement here as there was not much of an OMI row anomaly in 2006."

We filter for the OMI row anomaly indirectly. All retrievals that are flagged as "-1" are of poor quality and not used in our analysis. This includes the influence of the OMI

row anomalies in some pixels and are automatically set to "-1" using the Braak (2010) algorithm during the quality control process. Therefore, we are not sure of the OMI row anomaly effect on the number of pixels filtered out of our analysis, but believe it to be small in this time period. We will add this to our discussion, page 21754 on line 3-4, to highlight to readers that this is accounted for when we filter out the poor quality pixels.

11. "P21754, L7-11: the Irie et al. [2008] citation is irrelevant here, since this concerns validation of another product than used here. The paper by Irie et al. [2012] is the appropriate paper that discussed the validation DOMINO v2.0 data."

In line with the reviewer's comments, the Irie et al., (2008) reference, stating "Irie et al. (2008) compared OMI and with ground based MAX-DOAS retrievals in the Mount Tai Experiment (2006). They found the standard OMI product (version 3) overestimated the MAX-DOAS measurements by approximately 1.6×1015 molecules $cm{-2}$ (20 %), but within the OMI uncertainty limits." will be replaced with the Irie et al., (2012) reference. The new text will read "Irie et al., (2012) compare SCIAMACHY, OMI and GOME-2 tropospheric column NO_2 with surface MAX-DOAS column NO_2 observations between 2006 and 2011. They found the instruments are biased by $-5 \pm 14\%$, $-10 \pm 14\%$, and $+1 \pm 14\%$, respectively, which the authors suggest are all small and insignificant.", on page 51754, line 7.

12. "P21754, L17-19: suggest to clarify 'the true vertical distribution'."

This refers to the real vertical profile of a tracer (e.g. NO_2) in the atmosphere.

13. "P21756, L4: 'with trap'?"

This will be corrected to "will trap".

14. "P21758, L8-10: how can the left-hand side of Eq. (8) become negative? The authors should explain in what sort of situations this happens, and why."

In Eqn 8, if the error in the tropospheric column NO_2 is small and either the N_{trop} or X_{total} terms are large, then the left hand side can be negative. The σ_{strat} term has been removed. As Xtotal is scaled by 0.03, this term is likely to be smaller than the σtropak term in most cases. However, there will be cases where the Ntrop, scaled by the AMF uncertainty value of 0.4, will to be sufficiently large, with low uncertainty, and the left hand side of Eqn 8 will become negative. From our analysis though, this is rare and the error is set to 50% as discussed with H. Eskes (2012) via personal communication.

The following text “(e.g. when Ntrop is large, but has small uncertainty - Xtotal is scaled by 0.03 so will be small compared to Ntrop)” will be added to page 21758, line 7, after “left hand side is negative”.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 21749, 2014.

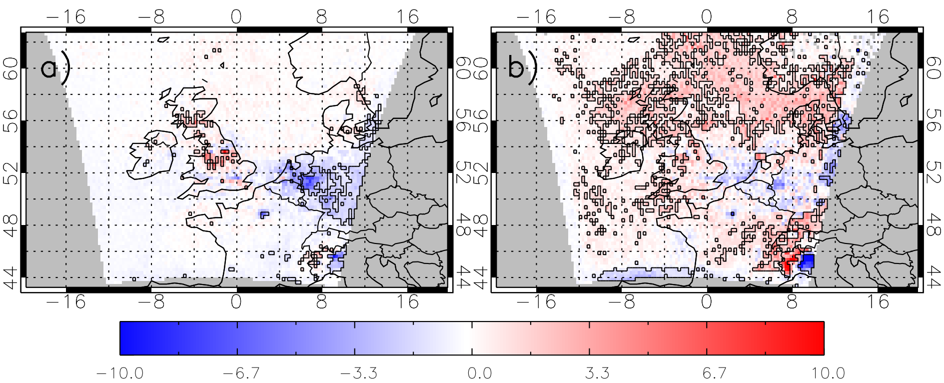

Fig. 1.

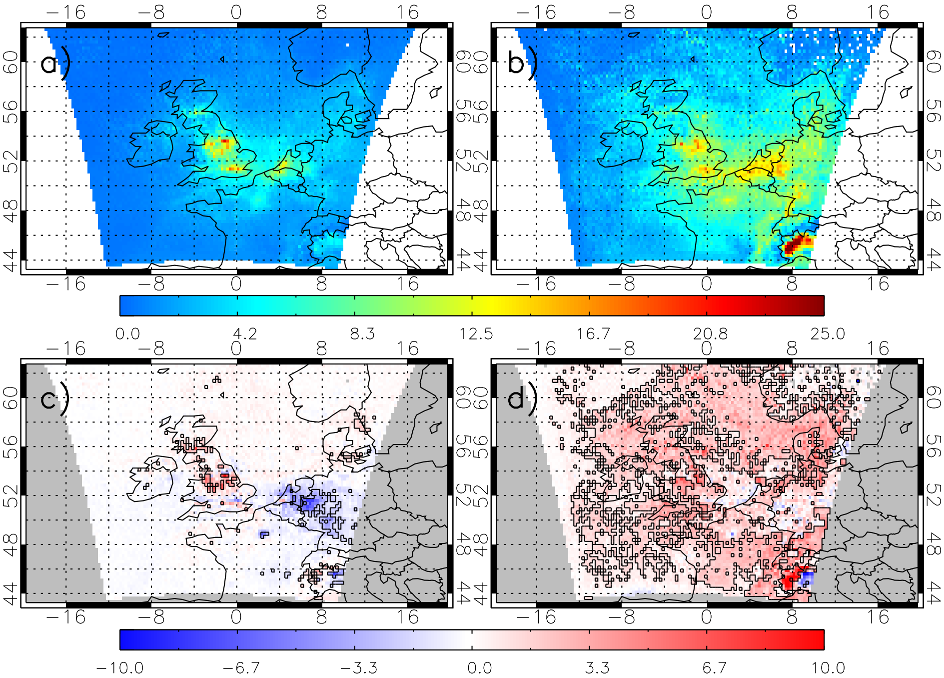
a)
b)
c)
d)
−16 −8 0 8 16
60 56 52 48 44
0.0 4.2 8.3 12.5 16.7 20.8 25.0
−10.0 −6.7 −3.3 0.0 3.3 6.7 10.0

Fig. 2.

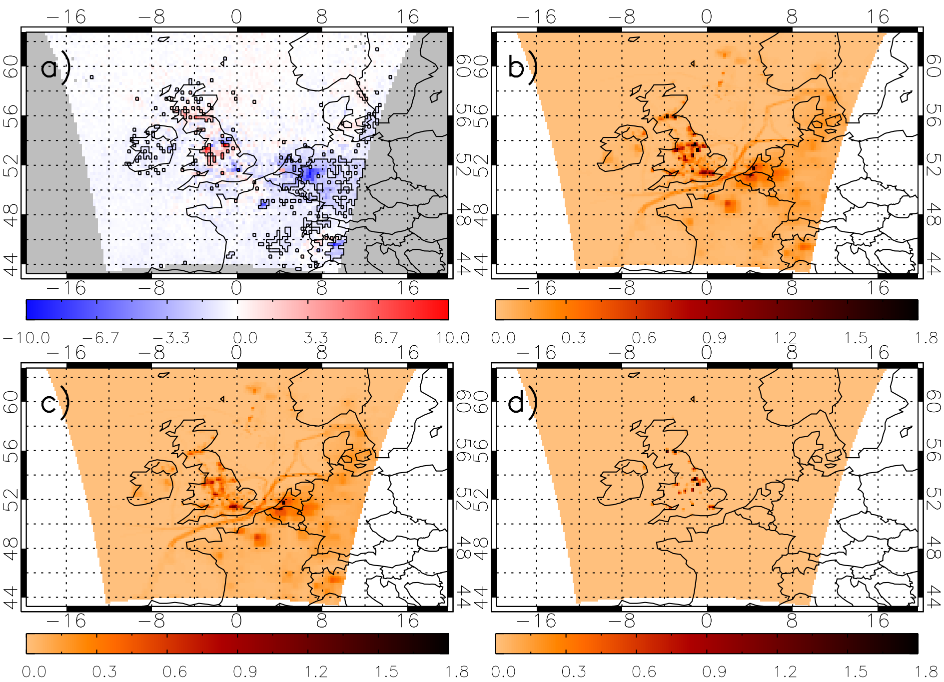
a)
b)
c)
d)
−16 −8 0 8 16
60 56 52 48 44
−10.0 −6.7 −3.3 0.0 3.3 6.7 10.0
0.0 0.3 0.6 0.9 1.2 1.5 1.8

Fig. 3.

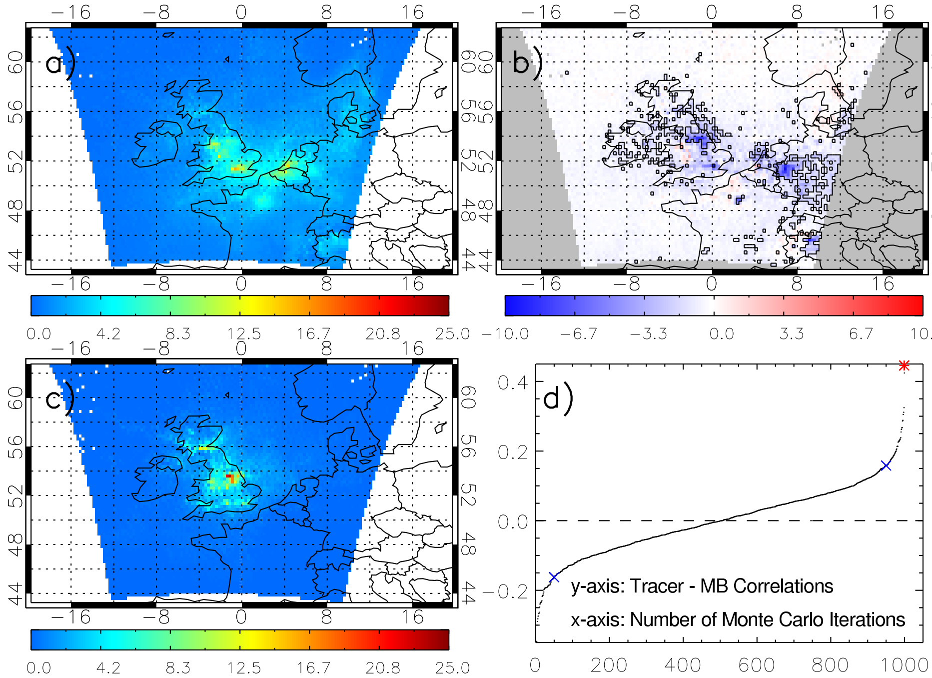
a)
b)
c)
d)
y-axis: Tracer - MB Correlations
x-axis: Number of Monte Carlo Iterations

Fig. 4.

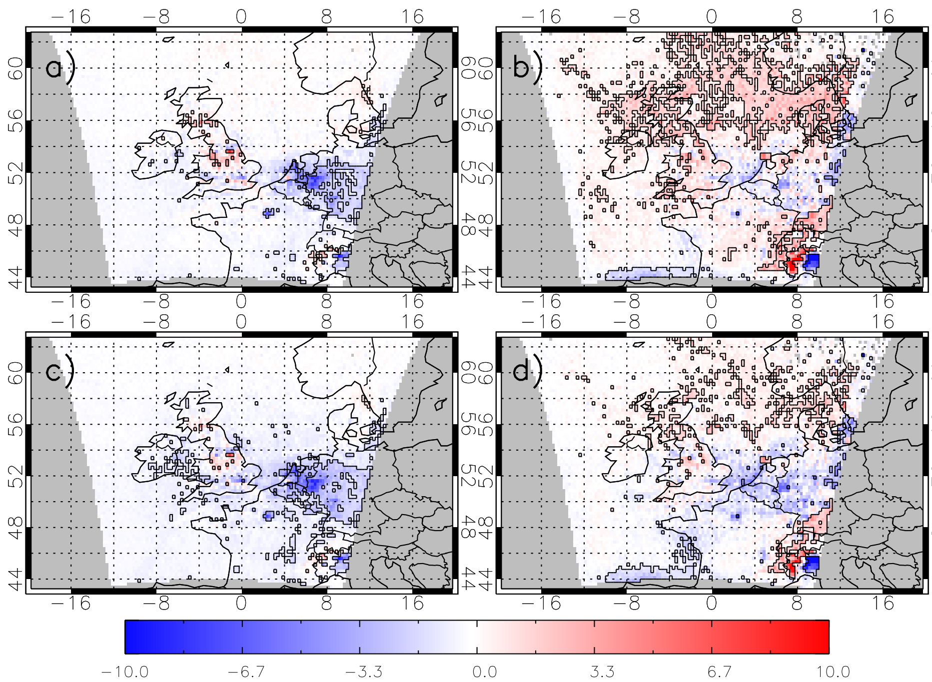
a)
b)
c)
d)

Fig. 5.

Place	Column NO_2		Column NO_2 Error		This Study	
	Summer	Winter	Summer	Winter	Summer	Winter
London 1°W-1°E, 51-51.5°N	9.86	1.07	9.68	9.13	4.24	4.52
Benelux 3-7°E, 50.5-52.5°N	9.57	11.4	7.09	9.24	3.98	4.82
Po Valley 7-9°E, 44.25-45.5°N	3.35	11.9	2.44	9.88	1.42	4.66
Northern England 3-0°W, 52.5-54°N	8.11	8.06	7.13	6.56	3.47	3.42
North Sea 0-8°E, 54-60°N	1.48	2.22	1.94	2.12	0.86	1.01
Scandinavia 6-16°E, 54-63°N	1.48	2.10	1.49	2.12	0.74	1.16

Fig. 6. The average column NO2, column NO2 error and column NO2 error calculated by this study for multiple locations across Europe in summer and winter (x10ˆ15 molecules/cmˆ2).