Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2018-872-RC2, 2018

Interactive comment on "Mesospheric nitric oxide model from SCIAMACHY data" *by* Stefan Bender et al.

We thank the reviewer for the careful review of the manuscript. We have marked our replies in blue and changes made in the paper in green .

Anonymous Referee #2

Received and published: 19 December 2018

General comments

In this paper, Bender et al. describe the empirical model for NO that they have developed, based on SCIAMACHY limb measurements of mesospheric NO. This model relates the daily zonal means of NO number densities to the Lyman-α and AE indices, as proxies for the solar irradiance and geomagnetic activity, respectively.

Such a model is very useful, both to provide an estimate of the NO concentrations and to indicate regions where certain processes dominate. It is a good complement to other existing empirical models for NO in the MLT. These models can be used to validate or constrain atmospheric models, or as a tool to help compare different observational data sets with each other.

I recommend the publication of this article in ACP after consideration of the few revisions suggested below. My only significant comment is about the way the non-linear model is defined. The methodological choices could be described in a more accurate way. The comparison with the linear version of the model, as it is presented in the paper, is not convincing enough.

We address the issues raised in our replies to the specific comments below.

Specific comments

p.1, l.18-20: Variations in solar and geomagnetic activity do not affect the atmosphere only above 100 km. This is what one can understand when reading these few lines. Please reword this paragraph to make it clearer.
We changed the sentence to:
"The atmosphere above the stratosphere ($\gtrsim$ 40 km) is coupled to solar and …"

p.2, l.4-5: SSW events do not always result in a strong downward transport of air from the mesosphere to the upper stratosphere. The formation of an elevated stratopause is generally needed for that to be observed.
We refer to our reply to reviewer #1 on the same issue

p.2, l.10: Odin/SMR NO measurements are actually available from 35 to 115 km (Pérot et al., 2014). As explained by Kiviranta et al. (2018), only a part of the available altitude range has been used to develop SANOMA model.
The altitude range mentioned is not stated in that reference, although the figures presented therein cover a pressure range from 9 hPa (≈ 32 km) to 0.003 hPa (≈ 90 km). The level 2 data available on http://odin.rss.chalmers.se/level2 (referred to by Kiviranta et al., 2018) cover the pressure range from 1 hPa (≈ 48 km) to 1e-5 hPa (≈ 133 km). There the official denoted altitude range is 45 to 115 km and we changed the numbers in the text to that altitude range.

p.3, l.11: NO is produced by particle precipitation at auroral latitudes under sunlit conditions too.
We agree that the used expression is misleading, the text has been changed, see reply to reviewer #1 on the same point.

p.3, l.14-15 and l.19: There is a mistake in the dates of the SNOE mission. According to Marsh et al. (2004), the instrument was operational for only two years, from 1998 to 2000.
The SNOE mission lasted longer, until December 2003 (Bailey, 2005), but only part of the data have been used by (Marsh et al., 2004) to develop the NOEM model. We corrected the SNOE data period on which NOEM is based to 03/1998–09/2000, and we changed. "three years" to "two and a half years".

p.4, l.22-23 and l.30: The Lyman-α index is a proxy for solar irradiance and the AE index is a proxy for geomagnetic activity, but both exhibit long- and short-term variations. Please reword your description of the proxies.
We changed the beginning of the section according to our reply to the same point raised by reviewer #1. In addition we changed the beginning of the second paragraph to read:
"In the same manner as for the irradiance variations, the"right" geomagnetic index to model particle-induced variations of NO is a matter of opinion."

p.4-5, Sec. 2.2: Please indicate the source for the proxy data used in your study.
We added the sources for the proxy data to the "Code and data availability" paragraph:
"The solar Lyman-α index data were downloaded from `http://lasp.colorado.edu/lisird/data/composite_lyman_alpha/`, the AE index data were downloaded from `http://wdc.kugi.kyoto-u.ac.jp/aedir/`, and the daily mean values used in this study are available within the aforementioned data set."

p.5, l.1: I agree with referee 1 about the fact that "questioned" seems too strong. Hendrickx et al. (I guess that you meant 2015, and not 2017) showed that the AE index correlates better with NO concentrations measured by SOFIE. One cannot draw a conclusion from one study based on one instrument. As mentioned in Kiviranta et al. (2018), the Kp index correlates better than the AE index with Odin/SMR NO observations.
Our work relates more closely to (Hendrickx et al., 2017), but indeed, the motivation to use AE for SOFIE NO data is discussed in more detail in (Hendrickx et al., 2015). We changed the text to read according to our reply to the same point raised by reviewer #1, also changing the reference to (Hendrickx et al., 2015). The (Kiviranta et al., 2018) study uses Odin/SMR NO above 85 km, where Kp may be better suited. In our case AE resulted in better fits and Kp may not be really suited because of its non-linearity. The effect

of using other indices is discussed in the original manuscript in the paragraph below the mentioned place. However, in addition to the aforementioned change, we changed "Kp" to "Kp (or its linear equivalent Ap)" in the following paragraph.

p.5, l.25: "We then omit the harmonic parts in the model." Why? Please explain this choice.
We refer to our reply to reviewer #1 on the same issue.

p.9, l.10-11: "At high southern and low latitudes, the improvement over the linear model is less evident." How do you explain that the improvement is clearer in the NH than in the SH?
We added the following explanation after the mentioned sentence:
"At low latitudes, the NO content is apparently mostly related to the eleven-year solar cycle and the particle influence is suppressed. Since this cycle is covered by the Lyman-α index, both models perform similarly, but the non-linear version has one less parameter. At high southern latitudes, the SCIAMACHY data are less densely sampled compared to high northern latitudes (see (Bender et al., 2017)). In addition to the sampling differences, geomagnetic latitudes encompass a wider geographic range in the Southern Hemisphere (SH) than in the Northern Hemisphere (NH), and the AE index is derived from stations in the Northern Hemisphere. Both effects can lower the NO concentrations that SCIAMACHY observes in the Southern Hemisphere particularly at the winter maxima. The lifetime variation that improves the fit in the NH is thus less effective in the SH."

Fig. 1-2 - following my previous comment: For high southern and low latitudes, it is difficult to see any clear difference between the linear and non-linear models in the residuals but, looking at the upper panels, it actually seems that the linear model reproduce better the seasonal variations of the data. That would mean that the non-linear model is not better in all regions. That could be due to the fact that, in your non-linear version of the model, you do not take into account seasonal variations which are not related to EPP. Please comment about that.
One should be careful when comparing the upper panels in Figs. 1 and 2 because the blue line can be misleading. We therefore presented the residuals on which the judgement should be based. The mentioned apparent traces of residual seasonal effects in the non-linear fit are minor compared to the overall lower residuals, keeping in mind that the non-linear model has one parameter less than the linear version. We added the following note to the discussion of the non-linear fit quality (including the footnote):
"In both regions the residuals show traces of seasonal variations that are not related to particle effects. The linear model appears to capture these variations better than the non-linear model. However, by objective measures including the number of model parameters,[1] the non-linear version fits the data better in all bins (not shown here)."

p.10, l.1-2: How do you explain the observed decrease in the Lyman-α parameter distribution between 80 and 90 km?
We refer to our reply to reviewer #1 on the same issue where we extended the discussion about the Lyman-α

[1] Past and recent research in model selection provides a number of choices on how to compare models objectively. The results are so-called information criteria which aim to provide a consistent way of how to compare models, most notably the "Akaike Information Criterion" (AIC, (Akaike, 1974)), the "Bayesian Information Criterion" or "Schwarz Criterion" (BIC or SIC, (Schwarz, 1978)), the "Deviance Information Criterion" (DIC, (Ando, 2011; Spiegelhalter et al., 2002)), or the "Widely Applicable Information Criterion" (WAIC, (Vehtari et al., 2016; Watanabe, 2010)). Alternatively, the "Standardized Mean Squared Error" (SMSE) or the "Mean Standardized Log-Loss" (MSLL) (Rasmussen and Williams, 2006, Ch. 2) give an impression of the quality of regression models with respect to each other.

parameter morphology.

p.10, l.2-3: “The Lyman-α coefficients are all negative below 65 km.” Please mention that the coefficients are negative at high northern latitudes too.
We added the following statement and short discussion after the mentioned sentence:
“We also observe negative values at high northern latitude at all altitudes and at high southern latitudes above 85 km. These negative coefficients indicate that NO photodissociation or conversion to other species outweighs its production via UV radiation in those places. The north–south asymmetry may be related to sampling and the difference in illumination with respect to geomagnetic latitudes, see Sect. 5.1.”

p.11, l.5: “The amplitude also increases with decreasing altitude.” This is not always true. At high northern latitudes, the amplitude actually decreases with decreasing altitude between 75 and 90 km. Please make the description of this figure more accurate and comment about this observed distribution (in Sec. 5.4).
The results for the highest northern latitude bin should be taken with caution. We changed the line in question:
“The amplitude also increases with decreasing altitude below 75 km at middle and high latitudes and with increasing altitude above that. The increasing annual variation at low altitudes can be the result of transport processes …”
We then added the following statement to the discussion (Sect. 5.4):
“Note that the results (in particular the large annual variation) in the northernmost latitude bin should be taken with caution because this bin is sparsely sampled by SCIAMACHY and the large winter NO concentrations are actually absent from the data.”

p.12, l.16-17: “We observe negative Lyman-α coefficients […] at high northern latitudes above 80 km.” How do you explain that such a pattern is observed only in the NH?
This remark is related to the point raised above referring to p.10, l.2-3 and the explanation is similar. We added the following text to the end of that paragraph:
“At high southern latitudes these negative Lyman-α coefficients are not as pronounced as at high northern latitudes. As mentioned in Sect. 5.2, this north–south asymmetry may be related to sampling and the difference in illumination with respect to geomagnetic latitudes, see also Sect. 5.1.”

p.13, l.2: “Production rate” I agree with referee 1 on this point. AE coefficients do not represent the NO production rate, but rather the NO response to changes in the AE index.
We refer to our reply to reviewer #1 on the same issue.

p.13, l.17-18: “the increasing photochemical lifetime at low solar zenith angles.” This sentence is unclear. According to Sinnhuber et al. (2016, Fig.7b), the photochemical lifetime of NO is lower for low solar zenith angles than for high SZAs. Did you mean “the increasing photochemical lifetime with decreasing altitude, at low SZAs”? In any case, this does not explain why the annual variation of your lifetime parameter increases from 75 to 90 km in the highest northern latitude bin.
The “low solar zenith angles” is a typo, we changed “low” to “large”.
The issue with the northernmost latitude bin is addressed in our reply above (p.11, l.5).

Technical corrections

Fig.1 and 2: These figures are not easy to read, especially because the dots representing the data are hidden by the error bars. Maybe you could represent the error bars in a different way (other colour for example) in order to make the plots clearer.

We thinned the error bars and changed their colour to gray. However, due to the high density of data points, this approach helps only a little, but we hope that the quality improved so that the data variations are visible better.

p.9, l.17-19: This sentence is unclear (too long). Please reword.

We changed the last two sentences in that paragraph to read:

"Since we require the geomagnetic index and constant lifetime parameters to be larger than zero (see Table 1), these sampled distributions are sometimes skewed towards zero even though the 95% credible region is still larger than zero. Excluding heavily skewed distributions avoids those cases because the "true" parameter is apparently zero."

p.18, l.1: "Versick, S" has been written twice.

Fixed.

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-872, 2018.

Akaike, H.: A new look at the statistical model identification, IEEE Transactions on Automatic Control, 19(6), 716–723, doi:10.1109/tac.1974.1100705, 1974.

Ando, T.: Predictive bayesian model selection, American Journal of Mathematical and Management Sciences, 31(1-2), 13–38, doi:10.1080/01966324.2011.10737798, 2011.

Bailey, S. M.: Observations of polar mesospheric clouds by the Student Nitric Oxide Explorer, J. Geophys. Res., 110(D13), D13203, doi:10.1029/2004jd005422, 2005.

Bender, S., Sinnhuber, M., Langowski, M. and Burrows, J. P.: Retrieval of nitric oxide in the mesosphere from SCIAMACHY nominal limb spectra, Atmos. Meas. Tech., 10(1), 209–220, doi:10.5194/amt-10-209-2017, 2017.

Hendrickx, K., Megner, L., Gumbel, J., Siskind, D. E., Orsolini, Y. J., Tyssøy, H. N. and Hervig, M.: Observation of 27 day solar cycles in the production and mesospheric descent of EPP-produced NO, J. Geophys. Res., 120(10), 8978–8988, doi:10.1002/2015JA021441, 2015.

Hendrickx, K., Megner, L., Marsh, D. R., Gumbel, J., Strandberg, R. and Martinsson, F.: Relative Importance of Nitric Oxide Physical Drivers in the Lower Thermosphere, Geophys. Res. Lett., 44(19), 10, 081–10, 087, doi:10.1002/2017gl074786, 2017.

Kiviranta, J., Pérot, K., Eriksson, P. and Murtagh, D.: An empirical model of nitric oxide in the upper mesosphere and lower thermosphere based on 12 years of Odin SMR measurements, Atmos. Chem. Phys., 18(18), 13393–13410, doi:10.5194/acp-18-13393-2018, 2018.

Marsh, D. R., Solomon, S. C. and Reynolds, A. E.: Empirical model of nitric oxide in the lower thermosphere, J. Geophys. Res., 109(A7), A07301, doi:10.1029/2003JA010199, 2004.

Rasmussen, C. E. and Williams, C. K. I.: Gaussian processes for machine learning, MIT Press, Cambridge, MA. [online] Available from: http://www.gaussianprocess.org/gpml/chapters/, 2006.

Schwarz, G.: Estimating the dimension of a model, The Annals of Statistics, 6(2), 461–464, doi:10.1214/aos/1176344136, 1978.

Spiegelhalter, D. J., Best, N. G., Carlin, B. P. and Linde, A. van der: Bayesian measures of model complexity and fit, Journal of the Royal Statistical Society: Series B (Statistical Methodology), 64(4), 583–639, doi:10.1111/1467-9868.00353, 2002.

Vehtari, A., Gelman, A. and Gabry, J.: Practical bayesian model evaluation using leave-one-out cross-validation and WAIC, Statistics and Computing, 27(5), 1413–1432, doi:10.1007/s11222-016-9696-4, 2016.

Watanabe, S.: Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory, Journal of Machine Learning Research (JMLR), 11, 3571–3594 [online] Available from: http://www.jmlr.org/papers/v11/watanabe10a.html, 2010.