

Review of ESSD-2016-24

Nishina et al.: Reconstruction of spatially detailed global map of NH₄ and NO₃ application in synthetic nitrogen fertiliser

The manuscript describes a global 0.5 x 0.5 degree data set of total N fertiliser application for the period 1961 to 2010, including distinction of NO₃ and NH₄ contributions to the the total N applied as synthetic fertiliser. Its key features seem to derive from time series for all countries and from the separate accounting for NO₃ and NH₄.

Its methods start from FAO country data, proceed through a data imputation step to fill gaps in that country data, downscale that improved country data to gridded fields using global crop type and area data (from a source different than FAO), and then anchor the fertiliser inputs in time by referencing the fertiliser application date to the sowing or transplanting date for each crop for each year. The authors deliberately include multicrop patterns, regionally and temporally. Whether one agrees with the specific data sources and tools - particularly the imputation tools - one must admit that the authors have documented a very systematic approach.

Based on request from the topical editor, I also looked at ESSD-2016-35. I make some comparison comments below in several sections but I believe the topical editor should compile my comments with any other comments received about the two data sets and use his or her discretion to post a uniform set of comments to both sets of authors. E.g. I hope for a fair bilateral approach, in which each group of authors gets identical recommendations relative to both data sets.

Overall, I believe this data set will prove very useful to many users. Although I raise questions and issues below, throughout the manuscript, I believe the authors have done a very good job of documenting sources, processing steps, assumptions, and intercomparisons. The addition of NO₃ and NH₄ data adds valuable information about change in usage patterns with time. I also like the comparisons with N deposition.

Specific comments:

The link to FAOSTAT, which necessarily occurs early and prominently through the manuscript, does not resolve. This represents a major barrier to all readers and users. We need a more reliable and permanent link. Either the authors need to convince FAO to deposit a fixed snap shot of the relevant version under a doi at a reliable site (perhaps too much to ask of any specific users) or the authors should include a version of the FAOSTAT data that they used as a component of the Pangaea resource or deposited under some other data authority. Seriously, it makes no sense to cite this source, and almost the entire paper becomes moot, if a reader has no reliable mechanism to start from the same sources. The FAO link must work reliably now and again two years from now. (As a comparison, the links to FAOSTAT global fertiliser data in ESSD-2016-35, which those authors do not represent as their primary source, do work!)

Likewise, the Pangaea link at the bottom of the abstract does not resolve. The link at the end of the narrative (page 10 lines 306, 307) does resolve but leads to a registration page. This reviewer finds such a registration step as a considerable barrier, very unusual for Pangaea data sets. Have these restrictions come from the authors? Do they derive from the FAO data source? Do they pertain for some initial period, with fully open access thereafter? We need all the Pangaea links working and we need some explanation of the unusual registration step, e.g. the reason for the moratorium.

Ironically, the link to the IFA data base, which these authors mention but do not use (e.g. on page 8 line 230), does work.

P3L90-92 This statement implies that FAOSTAT includes time series of farmer data (number of farmers?, number, size and types of farms?) at sub-national resolution to allow the authors to

successfully manage the changes in national frameworks. We need more information here, to document what the authors used and how the process worked.

P4 Description and application of the Amelia data imputation package. The authors provide a careful and useful description of what they assumed and how they proceeded. This user also found the documentation for the Amelia R package adequate and helpful. One wonders, however, whether the application of the imputation idea generally and the specific Amelia code to geographic and temporal patterns of fertiliser data represents a unique and creative solution or a misuse. One could argue that fertiliser application data in fact represent social data (a deliberate human intervention) and therefore the use of Amelia seems quite appropriate? Do the authors know of any other applications of Amelia to these types of more geophysical data sets?

P4L112 - What are 'panel' data and why do they fit better with the Amelia assumptions?

P4L115 - 'EM' I suppose this acronym refers to expectation-maximization (as in line 98, same page) but the authors should have defined it there or here?

P4L119 - Do each of these covariants also come from FAOSTAT?

P4L122 - "in each was" in each what? Nation?

P4L124 - dividing the fertiliser consumption data for each nation for each year by the maximum fertiliser consumption value for that country for the entire period? (Also, I understand why the authors did this scaling but I believe this manipulation to give only lower than existing values from the imputation process deserves mention as part of the processing uncertainties later.)

P5 Section 2.3 - Here the authors provide a useful description of their process for downscaling and for dealing with double cropping. The final statement of the Section, e.g P5L149 seems vague. Do they mean that they applied the double crop weighting for each appropriate crop region for the entire 1961 to 2010 time period or for each time period of double cropping as specified in the SAGE data base?

P5L152 - millet oats should be millet, oats?

P6L162 - second fertiliser application set to 30 days after initial. However, in Figure 1 on page 16, the authors clearly say 45 days after first fertiliser. The difference of 15 days probably does not make an impact on annual fertiliser usage but the authors should clarify?

P6L171 - "one digit inflation for just one year" Does these mean what we might otherwise call 'order of magnitude', e.g. plus or minus a factor of 10?

P7L194 - I do not know what the authors mean by "peaky" in this context. Can they give a more precise description?

P7 Section 3.1 - Here the authors should provide readers and potential users with a more thorough assessment of strengths and weaknesses of imputation approach and of use of Amelia imputation tool. On the one hand, only 16% of countries had missing data and fertiliser use by those countries accounted for an even smaller fraction of total global use. For these reasons the authors conclude that the outcome of the imputation process seems "reasonable". On the other hand, we know that the authors deliberately constrained the imputation process to only produce univariate outcomes - values lower than existing. And we know, as the authors admit and as Figure 3 clearly demonstrates, that missing data did not occur randomly, either in time or geographically. Under these operational constraints, did the large number of iterations (1000) and the use of independent co-variants (GDP, population) in the imputation process reduce or offset the non-random or univariate biases? We need some assurances, or at least a more quantitative assessment, from the authors. Perhaps they know of other applications of Amelia to real world examples that can

help us understand the reliability of the outcomes in this case? Reliable outcomes for “all countries”?

P7,8 Section 3.2. The authors provide a careful, detailed and very useful comparison with Potter 2010 based on year 2000. I note that authors for ESSD-2016-35 made a very similar comparison. This section would represent a very good place for the authors of ESSD-2016-24 to compare their outcomes to ESSD-2016-35? On first glance, the total numbers for N use seem very comparable? (As mentioned earlier, I believe ESSD editors should ensure that this request to authors of ESSD-2016-24 should apply equally to authors of ESSD-2016-35.)

P8, Section 3.3. How does or should the inclusion of these NO₃ and NH₄ data improve our understanding of temporal and geographic patterns of N fertiliser use. The authors of ESSD-2016-24 could make a few clear statements of the value of NO₃ and NH₄ data compared to total N approach in ESSD-2016-35?

P8L261 to P9L264. The textual description of temporal changes in NO₃ and NH₄ use seem substantially in contradiction to Figure 6, and Figure 6 seems inconsistent with Figure 10. From the text here and Figure 10 we learn that “the total amount and fraction of NH₄ increased consistently”. But looking at Figure 6, and particularly at the global average portrayed in Figure 6, we must conclude that the ratio of NH₄ input to total N input has stayed above 0.8 for the entire 1961 to 2010 period and with only a very narrow variation across those decades? Has this reviewer interpreted the text or the figures incorrectly? Do we in fact have a contradiction inherent in the data as presented?

P9L269 - Technically, Figure 11 does not show these total numbers, unless one can integrate the latitudinal data by eye. The authors might consider adding the totals to each panel of Figure 11. In both Figure 10 and Figure 11 the authors should make clear that the values represent the cumulative sum of N inputs while the colours indicate the proportions of NH₄ and NO₃. I find this overall section quite interesting but the authors might add a sentence or two about the implications of this comparison, to better explain to users why they the users should take an interest in these two sources of reactive nitrogen?

P9L290 - I think the authors mean that few other sources exist for these kinds of global N data sets. Here the authors might mention ESSD-2016-35 as a comparison?

P9L292 - Yes, these N data come from national consumption data mapped to crop area, but the process as the authors have described seems quite far from simple.

P10L298 - I think the authors have understated the utility of the NH₄ and NO₃ data. Those data provide much additional information about national sources and about the time history of use of various forms of N fertiliser.

P10L300 - Yes, the nationally-provided data have uncertainties, but can the authors provide a quantitative estimate to that uncertainty? How do those uncertainties affect the total cumulative use data, e.g. 110 Tg N as in Figure 10. Plus or minus 10%? 20%? In all the figures that follow, only Figure 3 displays error bars and then only because the imputation run over such a large number of iterations provides statistical uncertainty information. Either here or in the prior discussion the authors should provide their best estimates of cumulative uncertainty from all sources: original data, the imputation process, the crop area estimate, etc. These uncertainty estimates would prove very helpful for users, especially modellers. The statement here about inverse modelling would absolutely require such uncertainty estimates? I find this overall conclusion weak compared to the large effort the authors have put in to assembling and describing this data set. The authors should emphasise the utility of these data for inverse modelling studies, and perhaps compare the strengths (times series, 0.5 degree resolution) and uncertainties in these numbers to the uncertainties around atmospheric N concentrations. There remains a long and somewhat hidden gap between these N input data and the N₂O emissions data used in Thompson

et al. Also, Winiwarter, cited earlier in the section, addresses uncertainties in nationally reported greenhouse gas inventories. How do those uncertainties apply or compare here? We need a better summary of uncertainties from all sources.

P16 Figure 1 - The authors should provide explicit reference to the sources of their crop area data, doubling cropping data, etc. Or link more explicitly to the text where they provide those descriptions? This figure needs better documentation.

P17 Figure 2 - For the US, fertiliser application rates rise but total crop area stabilises or declines so total N fertiliser consumption falls slightly - that make sense. But for China, during a time of expanded crop area and increased fertiliser application rates the total fertiliser consumption appears to fall behind, at least for some years? Have I interpreted this plot correctly? Do the authors have an explanation? Mention the similarity to or emphasise the contrast with Figure 3 in ESSD-2016-35?

P18 Figure 3 - Very interesting plot. I believe it conveys a sense of the importance of the co-variants because in several cases shown the imputation values clearly do NOT fit the local country time series. The 95% confidence intervals seem quite large in all cases even though of course, by design, they can not exceed values of 1.0; in most cases those 95% CI cover essentially the full range of relative N consumption. Instead of, or in addition to, these specific country examples, could the authors provide a summary of the average error for the 16% of imputation-filled data? This information should help inform the larger uncertainty discussion suggested above?

P19 Figure 4 - Not very impressive as log-log plots go. The correlation coefficient and RMSE numbers look good and provide sufficient information. Do we need this plot if we have those numbers in the text or in a small table?

P20 Figure 5 - All these numbers presented as absolute, with no uncertainties in either these data or those of Potter 2010?

P21 Figure 6 - I mentioned already the apparent discontinuity between this data and those presented in the text and in Figure 10. The figure includes some smoothing for each regional data time series, but not explained? Why do so many open circles occur, and why so far above the average, for the North American data which one supposes has reasonably accurate reporting? Explain the boxes: mean plus SE or SD plus max min or quartiles or ...?

P22 Figure 7 - The authors could add a global average number to each panel that should correlate with global data in Figure 6? This figure suggests the small average changes of Figure 6, not the dramatic changes of Figure 10? Pakistan, designated as a hot spot of N use in ESSD-2016-35, does not show up here as particularly important in terms of fraction of NH₄ use?

P23 Figure 8 - Would we expect to see an offset but repeat pulse in double cropped areas (e.g. of North America or Eurasia) or are the data too smoothed or the application dates too varied? The caption should read "Values represent average NH₄ N applied over all crops across each grid cell"?

P24 Figure 9 - Same question as above about repeat pulses of N inputs observed in areas of double crops, perhaps evident here in April / May (first pulse) and August / September (second pulse) for areas of North America and Eurasia? The caption should read "Values represent average NO₃ N applied over all crops across each grid cell"?

P25 Figure 10 - Make clear that this represents cumulative (NO₃ plus NH₄) total N with fractions of NO₃ and NH₄ shown by colours. Explain the differences, if any, between data shown here and data shown in Figure 6.

P26 Figure 11 - Make clear that this represents cumulative (NO₃ plus NH₄) total N with fractions of NO₃ and NH₄ shown by colours. Authors could add a cumulative number to each panel to give readers a sense of the integrated totals?