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Interactive Comment

Interactive comment on "Validation of the Swiss methane emission inventory by atmospheric observations and inverse modelling" *by* S. Henne et al.

Anonymous Referee #1

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Review of "Validation of the Swiss methane emission inventory by atmospheric observations and inverse modelling" by Henne et al.

Henne et al. present a comprehensive analysis of 2013 Swiss methane emissions using atmospheric observations from the new CarboCount-CH measurement network. They perform a suite of inversions using different specifications of the uncertainty, definitions of the background, and inversion frameworks. Importantly, they find emissions that are consistent with the Swiss Greenhouse Gas Inventory (SGHGI). This is an excellent manuscript. It is well written, uses state-of-the-art inversion techniques, the figures are high quality, and demonstrates that well-informed bottom-up inventories can

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Interactive Discussion
Discussion Paper

accurately represent the emissions. This manuscript should be published in ACP. The only comments I have are, seemingly, minor.

1 Minor comments:

Best inversion?
It could be useful for the authors to suggest a “best” setup. This would help inform others doing similar atmospheric inversions. The authors may want to perform an additional inversion using the “best” setup. They currently say the best estimate is the mean over all sensitivity inversions (Page 35452, Lines 19-21). However, this seems a little odd because it means they don’t actually have a map of their “best emissions”. It seems like they could try one additional inversion using the setups that performed best (extKF, ML method, COSMO transport, seasonality, all sites, MAIOLICA, and Grid baseline).

Also, why don’t the extended Kalman Filter inversions have Skill scores for FRU and GIM in Table 4?

Unidentified source in north-eastern Switzerland
Page 35456, Lines 23-26: The authors mention that different manure management methods could lead to slight variations in emission factors. However, the differences due to manure management can be dramatic. Owen & Silver (2014) find orders of magnitude differences in the methane emission rate between anaerobic lagoons, slurry tanks, and manure piles (see their Fig. 3; Anaerobic lagoons emit at a rate about 35$\times$ larger than manure piles!). They also include a revised liquid manure slurry manure conversion factor that’s about 2$\times$ larger than what’s currently used by the European Union.

Have there been changes in the regional manure management practices (maybe due to a shift to more concentrated animal feeding operations)?

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Discussion of US ruminant and natural gas emissions

In Section 4.2 (Page 35454, Lines 23-25) and Section 5 (Page 35459, Lines 5-7), the authors mention that the findings of reduced ruminant emissions are in contrast to studies from the USA (Miller et al., 2013; Wecht et al., 2014; Turner et al., 2015). It's not clear to me that these results are actually inconsistent. Miller et al. (2013), Wecht et al. (2014), and Turner et al. (2015) all find that US methane emissions from ruminants are underestimated. However, the Turner et al. (2015) shows little-to-no change throughout Europe (see their Fig.3) in their coarse global inversion. Another paper (Alexe et al., 2015) also find a a large increase in US emissions and a decrease in the emissions across Europe (see their Fig. 6). This would imply that Swiss ruminant emissions are not underestimated (in agreement with the finding from Henne et al.). It seems that it may just be different regional features, not something pervasive in inventories (which would make sense because countries have different reporting requirements).

The authors present a similar argument in Section 4.2 (Page 35455, Lines 2-5) and Section 5 (Page 35459, Lines 16-20) for natural gas emissions from the distribution sector. The authors claim their findings are in contrast to studies from the USA, "This is in contrast to recent studies from the USA where a large underesimation of fugitive emissions was established in the inventories for different metropolitan areas (Wennberg et al., 2012; McKain et al., 2015) and fractional loss rates between 2.5 and 6% were established." However, the fractional loss rates from Wennberg et al. (2012) and McKain et al. (2015) are probably not representative of the average US leak rate. Wennberg et al. (2012) examined emissions from Los Angeles, a city with a lot of oil and gas activity (the Aliso Canyon leak is, anecdotal, evidence of this), and McKain et al. (2015) examined emissions from Boston, an old city with a lot of cast-iron pipes. So these studies are not necessarily indicative of a pervasive problem in the inventory, as implied by Henne et al.

Consider adding a brief discussion of Zavala-Araiza et al.

I feel like one of the biggest strengths of this paper is demonstrating the consistency

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between a well-informed bottom-up inventory and the top-down estimates. This was the main point of the recent paper: Zavala-Araiza et al. (2015). It seems that this paper could be another one that demonstrates this point.

Implementation of the inversion

On Page 35430 the authors state, "In our implementation of the inverse of $\mathbf{S} = (\mathbf{MBM}^T - \mathbf{R})$, a $L \times L$ matrix, was calculated using LU factorisation (function DGESVX in LAPACK)." This seems like it may be an inefficient implementation. The DGESVX routine in LAPACK is for dense linear algebra. However, the matrices in atmospheric inversions are typically sparse (usually less than 1% of the elements are non-zero). I've found that I get a 31$\times$ speedup and use 17$\times$ less memory by just switching from dense to sparse matrices for large atmospheric inversions ($K_E > 2,000,000$). There are also routines that allow for efficient solutions to large inverse problems with covariance matrices that can be represented as a Kronecker product (cf. Yadav & Michalak, 2013; they provide source code for the routines). The authors could also look into some of the multi-scale state vector design methods from Bocquet et al. (2011). Bocquet et al. (2011) presented methods for optimally designing a multi-scale state vector that allowed information to transfer across scales.

These are merely suggestions for future code development that may allow the authors to expand the scale of the problem (Increase the number of observation sites? Estimate monthly emissions? Expand the inversion domain?). The implementation presented here is sufficient to tackle the problem they are interested in.

2 Specific comments:

Pages 35421-35422, Lines 29-1: Should add a reference to Zhao et al. (2009), Jeong et al. (2012), Jeong et al. (2013), and Ganesan et al. (2015).

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Page 35425, Line 9: Is this an issue if wind direction changes? 3hr seems like a long time.

Page 35426, Lines 9-30: How are the PBL heights? I didn't see any mention of evaluating them.

Page 35428, Lines 8-13: Why are you using a fixed height? Shouldn't it be the mixed layer height? It seems that using a percentage of the PBL height would be more reasonable.

Page 35429, Line 21: I think it should be "$K_E \approx 1000$", not "$J_E \approx 1000$".

Page 35430, Line 9: How many observations? I'm assuming $L < K$ since you're using the L-form.

Page 35431, Line 17: What is f_E? I didn't see it in the table. What is the resulting grid-scale uncertainty? Is there a floor on the uncertainty?

Page 35432, Line 25: Are observations only correlated for a given site or all sites?

Page 35435, Line 10: Spent a lot of time explaining the Bayesian, maybe give the equation for the extKF or explain how $\mathbf{Q}$ was specified.

Page 35437, Line 1: How? How is summing diagonals with 30% uncertainty giving you a smaller uncertainty (16%) at the national scale (without anti-correlations in the off-diagonal)?

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Page 35438, Line 15: Should say “separated”, not “separating”.

Page 35438, Line 16: Should say “ensure”, not “assure”.

Page 35438, Line 19: Should say “ensures”, not “assures”.

Page 35448, Line 15: Should say “distinct”, not “destinct”.

Page 35448, Line 27: Should say “sensitivity”, not “sensititivy”.

Page 35453, Line 15: Should cite Ganesan et al. (2014).

Page 35454, Line 21: Should say “inferred”, not “infered”.

Colorbars: Some of the numbers on the colorbar are hard to read (Fig. 2c, 6a-d, 7, 8a, and 9a).

3 References:

Alexe *et al.*: Inverse modelling of CH_4 emissions for 20100–2011 using different satellite retrieval products from GOSAT and SCIAMACHY. *Atmos. Chem. Phys.* **15**, 113-133, 2015.

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Bocquet *et al.*: Bayesian design of control space for optimal assimilation of observations. Part I: Consistent multiscale formalism. *Quarterly Journal of the Royal Meteorological Society* **137**, 1340-1356, 2011.

Ganesan *et al.*: Characterization of uncertainties in atmospheric trace gas inversions using hierarchical Bayesian methods. *Atmos. Chem. Phys.* **14**, 3355-3864, 2014.

Ganesan *et al.*: Quantifying methane and nitrous oxide emissions from the UK and Ireland using a national-scale monitoring network. *Atmos. Chem. Phys.* **15**, 6393-6406, 2015.

Jeong *et al.*: Seasonal variation of CH_4 emissions from central California. *J. Geophys. Res.* **117**, D11, 2012.

Jeong *et al.*: A multitower measurement network estimate of California's methane emissions. *J. Geophys. Res.* **118**, 19, 2013.

Owen & Silver: Greenhouse gas emissions from dairy manure management: a review of field-based studies. *Glob. Chang. Biol.* **21**, 2, 2014.

Yadav & Michalak: Improving computational efficiency in large linear inverse problems: an example from carbon dioxide flux estimation. *Geosci. Mod. Devel.* **6**, 583-590, 2013.

Zavala-Araiza *et al.*: Reconciling divergent estimates of oil and gas methane emissions. *Proc. Natl. Acad. Sci.* **112**, 15597-602, 2015.

Zhao *et al.*: Atmospheric inverse estimates of methane emissions from Central California. *J. Geophys. Res.* **114**, D16, 2009.

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