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Dear Dr Paciorek and Dr Sykulski,

Thank you for taking the time to read and examine my thesis "Bayesian spatio-temporal methods for small-area estimation of HIV indicators". I attach my response to the minor corrections you have suggested.

With kind regards,

Adam Howes

Thesis corrections for "Bayesian spatio-temporal methods for small-area estimation of HIV indicators"

Adam Howes (ath19@ic.ac.uk)

Contents

1 Dr. Christopher Paciorek

Thank you for the thorough discussion of the thesis, both during the defense and in the provided corrections. I have addressed the corrections point by point, as follows.

1.1 General comments

1.1.1 Chapter 4

> *I'd like to see some more context relating the potential shortcomings to the public health setting (you have a bit of this in Section 4.1.3). For a public health analyst, when might they be most concerned about using the Besag model? What kinds of areal arrangements/neighborhood structures/types of data might be most prone to concern? E.g., one might be concerned about cases like Canadian provinces where their populations are so concentrated right near neighboring US states and most of the provincial area is sparsely populated. And as we discussed, I'd like for you to see if you can drill down into the localized results of the simulation to give some insight into where the smoothing is sub-optimal in the simulations. Relatedly would you expect the features highlighted by your vignettes to occur in reality in public health settings?*

Not yet resolved.

1.1.2 Chapter 5

> *I'd like to see the chapter initially clearly lay out the overall goal, the quantitative representation of that, the various pieces of the analysis and how they fit together, and the data available, as well as what components you can estimate uncertainty for. In particular the notion of "reaching" the population needs to be clearly spelled out initially. And as we discussed, please make clear how prevalence is needed.*

Not yet resolved.

> *Model 5.11 omits various interactions. Focusing on the category-area-age interaction, which seems like the omitted interaction most likely to have substantial variation in reality, some effort to come up with some "residual" type diagnostic to assess model mis-specification in this regard would be helpful (e.g., perhaps some sort of variogram type analysis of some sort of age-group specific "working residuals" to borrow a GLM framing). Or you mentioned fitting the model with the interaction for one country. If that is not too burdensome that would also be a reasonable approach here.*

Not yet resolved.

> *The distinct differences between the CPO and information criteria (IC) results (and the very structured pattern in the surprising IC results) suggest the possibility of a bug somewhere, as we discussed. Getting the observation-specific values from INLA might help to better understand this.*

Not yet resolved.

1.1.3 Chapter 6

> *Chapter 6 extends standard INLA computation in two ways. For the first, I'd like to see more clarity in how this differs from the Stringer et al. (2022) approach (i.e., that you go beyond the Gaussian mixture over the quadrature points, as we discussed in the defense) and the details of the software implementation (e.g., giving an overview in the chapter describing what someone would need to do to make use of your code/approach).*

Not yet resolved.

> *As we discussed in the defense, I'm concerned about any case where one draws from marginals, implicitly assuming no dependence, either at the hyperparameter level or the latent process level,*

and then does inference on a derived quantity that depends on more than one input. You should be clear anytime you do this that this is problematic (and try to avoid as much as possible).

Not yet resolved.

Relatedly, assuming I'm understanding correctly, there is an important tradeoff between using Laplace marginals for improved accuracy for latent marginals and using the Gaussian mixture over the quadrature points, which allows one to make draws and do inference on any derived quantity in a way that takes account of posterior dependence between and amongst hyperparameters and latent process values. If that's the case, I think it's worth pointing this out and discussing when one can use the Laplace marginals in a public health context and when one might need to use the Gaussian mixture.

Not yet resolved.

1.2 Minor comments

1.2.1 Chapter 2

4: "develop into a stage" -> "Infection with HIV can"

Changed to "If untreated, infection with HIV can develop into a more advanced stage known as acquired immunodeficiency syndrome (AIDS).".

6: "to result a reduction"

Changed to "found complete surgical removal of the foreskin to result in a reduction".

11: "Both DHS and PHIA surveys collecting"

Changed to "Both DHS and PHIA surveys collect demographic, behavioural, and clinical information.".

12: individual disclosure: error may come from them not knowing status

Good point, I have added the sentence: "Furthermore, individuals may be unaware of their HIV status.".

14: "UNAIDS process"

Apologies for this stub! This has been been corrected as follows: "Indeed, careful validation of data by country teams is a crucial part of the yearly UNAIDS HIV estimates process.".

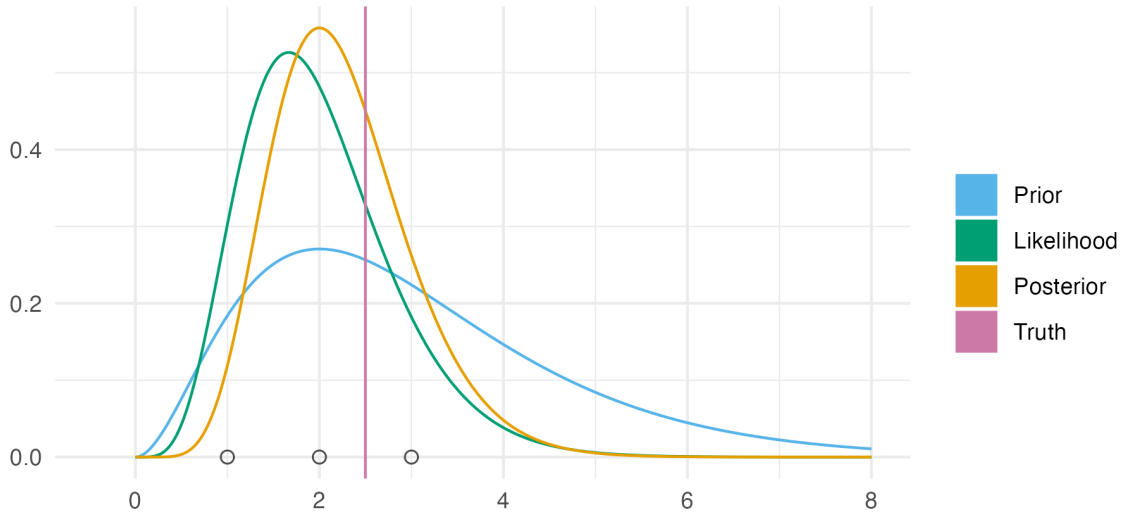
1.2.2 Chapter 3

16 (and elsewhere): Please look up usage of "that" vs. "which" so you can join me in the grammar police. "Models which do not produce" -> "Models that do not produce"

Thank you for the pointer, I have fixed this issue and look forward to joining the good fight.

Fig 3.1: I suggest that you also show the likelihood.

I have now included the likelihood in this figure as follows:



17: Beyond just p(y) even if you know the full form of p(phi|y) what do you do with it in non-trivial dimensions? You have to be able to either draw from it or estimate expectations of interest. the issue is rather broader than just the unknown normalizing constant.

Good point! I have added the sentence: "Further, even given a closed form expression for the posterior distribution, if $\boldsymbol{\phi}$ is of moderate to high dimension, then it is not obvious how to evaluate expressions of interest, which usually themselves are integrals, or expectations, with respect to the posterior distribution.".

19. You haven't defined 'convergence' when you dive into diagnostics.

I have altered the text to read: "After running an MCMC sampler, it is important that diagnostic checks are used to evaluate whether the Markov chain has reached its stationary distribution. If so, the Markov chain is said to have converged, and its samples may be used to compute posterior quantities. Though it is possible to check poor convergence in some cases, we may never be sure that a Markov chain has converged, and thus that results computed from MCMC will be accurate.".

21. I'd frame this as deterministic approximations need to focus on approximating expectations of interest. I think of Laplace as approximating an integral over part of parameter space (often > random effects') to be able to work with a smaller-dimensional space, such as for maximization.

Not yet resolved.

23. "data is" -> "data are" (also p 66 and perhaps elsewhere)

I have corrected to "data are" in these instances, and searched through the thesis for other incorrect uses of "data is".

30. You distinguish ELGM from LGM with having defined eta for LGM or been explicit about 1:1 relationship of x and y.

Good point. In an LGM, it is that there is a one-to-one relationship between $\mathbf{y}$ and $\boldsymbol{\eta}$. I have added the sentence: "In an LGM, like the more general GLMM case as given in Equation (3.6), there is a one-to-one correspondence between observations y_i and elements of the linear predictor η_i.".

Sec 3.4: worth commenting on additivity of these measures that treat each obs as a unit of information given you are in a spatial setting.

Note connection to SLOO-CV in Chapter 4.

35. (3.30) should be for π_{2hj}.

Thank you for spotting this! Corrected.

37. "difficultly"

Corrected to "problem difficulty".

37. "arrived at using by"

Corrected to "arrived at by estimating the variance of".

1.2.3 Chapter 4

41. Might be worth including the variance piece raised to the power `n-c`.

I imagine this relates to Equation (4.4) and the equation for the probability density $p(\mathbf{u})$.

41. "recommended against": passive, and by who?

Altered the text to read: "Directly using the Besag model as described in Section 4.1.1 has several practical limitations in applied settings. To overcome these limitations, @freni2018note recommend three best practices:".

42. Why is unit variance correct?

Yes that's a good point, what I mean to say is that the singletons have unit variance in the "structure matrix" sense. I have corrected the text to read that $p(u_i) \sim \mathcal{N}(0, \tau_u^{-1})$.

47. tau_v an d tau_w are not orthogonal - what does this mean?

Not yet resolved.

48. Is convolution the right term here?

Not yet resolved.

55: what is meant by "model is implemented in arealutils"?

Not yet resolved.

56: need citation for v being hard to estimate

Not yet resolved.

56: have Li vary with size?

Not yet resolved.

56: effect -> affect

Change made.

57: "and the calibration"

Not yet resolved.

57: What parameter is shown in Figs 4.7-4.9 - it's not clear you're assessing the latent process values. And in that case you should be clear the CRPS is averaged over locations.

Not yet resolved.

59: Explain that mean CRPS is mean over the simulations.

Not yet resolved.

63: Table 4.4 has no standard errors.

Not yet resolved.

64: "resulted wide"

Changed to "resulted in wide".

64: surprisingly

Changed.

67: "This chapter used of area-level models to for point-level data throughout". I can't parse this. You can only use point level model if have point level data.

Not yet resolved.

67: "measures are disaggregated by area" - not sure of the point here.

Not yet resolved.

1.2.4 Chapter 5

71: FSW is not defined in Table 1 caption.

Changed to "female sex workers (FSW)".

71: In Table 1 why does High risk group IRR not vary with local incidence?

Not yet resolved.

71: Purpose of Table 1 is not clear. Nor how IRR is to be used.

Not yet resolved.

Tables sometimes appear earlier than they should (e.g., 5.1 and 5.2).

Not yet resolved.

77: Table 5.2: phi_{ik} should be u_{ik}.

Good spot! Thank you, fixed.

80: Mention country-specific vs single models earlier.

Not yet resolved.

82: I would say clearly that model structure for q_ia is discussed next.

Not yet resolved.

85: First paragraph of 5.3.3 is a bit hard to follow.

Not yet resolved.

86: The bio-marker survey data and disaggregation model is unclear. How are risk groups known for individuals in the survey?

Not yet resolved.

88: Section 5.4.3 is hard to understand. I don't understand how it relates to 5.4.2. "Reach" is not clearly defined nor is it clearly discussed how it is quantified based on the various modeling pieces.

Not yet resolved.

91: Not clear what the quantities are in the statement about "in most districts adolescent girls aged 15-19 were not sexually active". Is this an across-district or within-district quantity?

Not yet resolved.

95: does the approach presented allow identification of actual people or just targeting efforts to reach more such people collectively

Not yet resolved.

96: "Accounting for the 0% of new infections"?

Not yet resolved.

1.2.5 Chapter 6

106: Not sure what you mean by "log p(y|x,theta) is small". This is the likelihood...

Not yet resolved.

116: "in which, which"

Changed to "in which, similar to extended latent Gaussian models".

122: "Method" in Table 6.1 a bit terse.

Not yet resolved.

122: Is "Gaussian, EB" the same as frequentist Laplace approx (up to hyperparameter prior)? If so, probably worth saying.

Not yet resolved.

130: Somewhat unclear how the quadrature is implemented, wrapped around the TMB-based Laplace approximation. Is your code in R? (Sorry, this may be because I didn't have time to look through appendices.)

Not yet resolved.

131: Using same number of iterations with stan (full posterior, including latent values) vs tmbstan (hyperparameters, much lower-dimensional space) seems odd.

Not yet resolved.

132: Fig 6.7 is just grid/AGHQ, not EB? If so, why present EB method?

Not yet resolved.

132: Why surprising tmbstan faster than rstan - what are the different computations involved - having to compute Laplace vs doing HMC over higher dimensional space. I expect it would vary with I expect it would vary with hyperparameter and latent dimensions.

Not yet resolved.

136: "kridge" -> "krige"

Changed to `gstat::krige`.

137: "this" in "this difference" is unclear.

Not yet resolved.

143: "survey weighting increases variance" - what about effect of increasing precision in small strata? Are you talking about influence of complex survey design or somehow about weighting scheme?

Not yet resolved.

149: INLA uses CCD for d>2, right? Would this not work for this setting?

Not yet resolved.

151: (6.97) has 'd' instead of 'm'

Agree, fixed swapping d to m.

154: "closet"

Changed to "posterior contraction was very close to zero.".

154: Did you use MAP for theta when looking at Hessian eigenvalues?

Not yet resolved.

156: "Figure ??"

Fixed, thank you.

156: "far fewer than full 24" - is this a problem?

Not yet resolved.

156: "point estimates" "distributional quantities" - need "and"

Not yet resolved.

157: Need caption to describe the green

Thank you, I have updated this caption to read "The grey histograms show the 24 hyperparameter marginal distributions obtained with NUTS. The green lines indicate the position of the 6561 PCA-AGHQ nodes projected onto each hyperparameter marginal. For some hyperparameters, the PCA-AGHQ nodes vary over the domain of the posterior marginal distribution, while for others they concentrate at the mode.".

165: What went wrong with tmbstan?

(Note to self that this is in regard to "Preliminary testing of this approach, using `tmbstan` and setting `laplace = TRUE`, did not show immediate success but likely could be worked on.")

2 Dr. Adam Sykulski

Thank you for providing a paper copy of the thesis annotated with suggested typographical changes. I have made these changes, and additionally thoroughly proofread the thesis as requested.

References