

Interactive comment on “Optimal Transport for Variational Data Assimilation” by Nelson Feyeux et al.

Nelson Feyeux et al.

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a revised version of the paper is attached as a supplement

Reply to Referee 2

We would like to thank the referee for his/her extensive review on our paper and for giving us the opportunity to improve our paper.

We copied your commentary in *italics* below, we reply in normal font.

This is a very interesting paper, which introduces the use of optimal transport, and its metrics, in the world of data assimilation. The layout of the paper is very clear and appealing. For these reasons I strongly recommend the publication of this paper.

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However, the manuscript could benefit from the following remarks and suggestions:

NPGD

â€¢ The English could and should be significantly improved.

The paper has been read and corrected by a native English speaker.

â€¢ Clarifications are needed now and then, especially to help the reader who has little acquaintance with optimal transport.

Ok.

â€¢ There is a bit of a contradiction in the willingness to introduce, or not, the transference plan view on optimal transport. This should be clarified.

Ok.

â€¢ The authors could get rid of the mathematical remark style. In my opinion, it is not suited for NPG and is detrimental to the clarity of text. For the present manuscript, all the remarks can easily be naturally embedded in the text.

Done.

â€¢ For the sake of clarity, you should precisely define y_{obs} and x_b as mathematical objects.

It is done between equations (14) and (15).

â€¢ A recurrent question in data assimilation, which I believe many of your readers will have is: is there any probabilistic interpretation of the cost function defined with the Wasserstein distance? This is worth discussing it briefly.

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It is a very interesting question indeed, but we do not have any clear answer yet. We added a line on this topic in the conclusion.

NPGD

â€“ The paper would benefit from a more detailed discussion of the experiments, possibly another one with noise in the observation. There is room for it.

We added such experiment and a section commenting it

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Specific remarks, in connection, or not, to the previous remarks are:

1. Title: why the capital letters in the title?

Out of habit in some journals... Corrected.

2. p.1, l.5: "With appropriate choices...": of what? Unclear.

3. p.1, l.6: "Optimal-transport-based optimization..." → "Optimal transport-based optimization..."

4. p.1, l.6-7: "...to preserve the geometrical properties of the estimated initial condition.": this statement is too mysterious for an abstract. You should be more explicit.

Indeed that was cryptic. The abstract has been rewritten.

5. p.1, l.13: "to use so-called data assimilation methods" → "to use the so-called data assimilation methods" Ok

6. p.1, l.14: It is uncanny that the third author is reluctant to cite her own brand new book on data assimilation. :-) Done, thanks

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7. p.1, l.14-15: "They aim at finding either the initial/boundary conditions or some parameters of a numerical model.": not only! They can be used for parameter estimation, reanalysis, etc. Of course. Corrected.

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8. p.1, l.18: "comparison between the observations and their model counterparts.": a mathematical expression called the innovation in data assimilation. Yes, but actually the innovation is defined as the subtraction of the obs and their model counterparts, and here we talk about a comparison, which is not necessarily a subtraction. We tried to introduce the innovation here but it causes a problem later on because we really talk about distances between obs and model, and not only "norm of the innovation". So we decided with statu quo here.

9. p.1, l.19: "unperfect" → "imperfect" Ok

10. p.1, l.22: "More recently an hybrid of both approaches..." → "More recently hybrids of both approaches..." Ok

11. p.2, l.1-2: "model counterparts. A Tikhonov regularization is also added and so the distance between the control vector and a background state carrying the a priori information is added in the cost function.": needs to be rephrased. It could be instead: "A Tikhonov regularization term is also added to the cost function as a distance between the control vector and a background state carrying the a priori information." Ok

12. p.2, l.4: "aims to reach" → "aims at reaching" Ok

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13. p.2, l.4: "are smallest as possible." → "are as small as possible." Ok

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14. p.2, l.13: "...the desired localization." → "...the desired location." Ok

15. p.2, l.17: "...has been founded by Monge..." → "...has been pioneered by Monge..."
Ok

16. p.2, l.19: I would remove "quickly". Ok

17. p.3, l.1: "from pure mathematical analysis" → "from pure mathematical analysis
on Riemannian spaces" Ok

18. p.3, l.8: "...Wasserstein distance is to compare..." → "...Wasserstein distance to
compare..." Ok

19. p.3, l.9: "data assimilation Actual use of optimal transport" → "data assimilation.
Actual use of optimal transport". Better, you could start a new paragraph with "Actual
use...". Ok

20. p.3, l.15: "This particularly subtle mathematical consideration is indeed crucial for
the algorithm..." → "This particularly subtle mathematical considerations are indeed
crucial for the algorithm..." Ok

21. p.3, l.18: "...methods but it largely exceeds..." → "...methods, which largely ex-
ceeds..." Ok

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22. p.3, l.21: "required for the sequel" → "required in the following" Ok

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23. p.3, l.23-24: "Section 4 numerical illustrations are presented, choices for the gradients and the optimization methods are compared.": could be improved. Please rephrase. Ok

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24. p.3, l.24: "...and solutions proposed." → "...and solutions will be proposed.": the ellipsis could be avoided here. Ok

25. p.3, l.26: "The section..." → "This section..." Ok

26. p.3, l.27: "...materials...": principles?, facts?, properties? Ok: concepts, method, principles, main theorems.

27. p.3, l.28: "...production." → "...contribution." Ok

28. p.4: You could mention that the Euclidean distances are local metrics, as opposed to the Wasserstein distance. Ok, at the end of paragraph 2.1, just before we introduce the W2 distance.

29. p.4, l.6: "...term xb which contains..." → "...term xb , which contains..." Ok

30. p.4, l.6: "The actual cost function then writes..." → "The actual cost function then reads..." Ok

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31. p.4, l.15: "[0, 1]" → "the interval [0, 1]" since the notation is not really universal. Ok

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32. p.5, section 2.2.2: explain that the time t is fictitious, or you will puzzle many readers. Thanks! We added two sentences between eqs (5) and (6).

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33. p.5, l.9-11: Actually, I don't believe this is a necessary condition. There could non-zero fluxes of probability with a global balanced budget; see for instance Farchi et al. (2016). Thanks, it is indeed a sufficient condition, corrected.

34. p.5, l.18: Use "citep" for the citation to Benamou and Brenier (2000). Ok

35. p.5, l.21: "A remarkable point..." → "A remarkable property..." Ok

36. p.5, l. 22: Use citep for the citation to Ambrosio et al. (2008). Ok

37. p.6, l.4-5: "...like the primal-dual Papadakis et al. (2014) or the semi-discrete Mel'Arigot (2011)." I would be thrilled in meeting the primal dual Papadakis or discussing with the semi-discrete Mel'Arigot. . . Please rephrase.

We used citep instead.

38. p.6, l.7: "... the scalar product choice conditions the gradient value." → "... the scalar product choice is used to define the gradient value." Ok

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39. p.6, l.11: "...shall formally be defined by..." → "...is formally defined by..." Ok

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40. p.6, l.11: "(cf. Otto (2001))": use `citelp[]`. Ok

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41. p.6, Eq.(9): you probably should mention the set to which the Kantorovitch potential belongs.

This is now eq (10): we started the set with $\{\eta \in L^2, \text{ s.t. } \eta = -\text{div}(\rho_0 \nabla \Phi)\}$. We do not say more precisely where is Φ because Φ could be very general, its only requirement is to be so that $-\text{div}(\rho_0 \nabla \Phi)$ exists. As it would make the definition quite heavy we thought it best not to say anything about Φ . It's also quite complex to get information in the main litterature (Villani e.g.), we simply do not know what is, in general, the nature of Φ .

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42. p.6, l.15: This is not a proper sentence; you could merge it with the previous one.
Ok

43. p.6, l.23: "First we will consider..." → "First, we will consider..." Ok

44. p.6, l.24: "Second we will investigate..." → "Second, we will investigate..." Ok

45. p.6, l.24: "...we will investigate the role of the scalar product choice as well as the gradient descent method..." → "...we will discuss the choice of the scalar product as well as the choice of the gradient descent method..." Ok

46. p.7, l.5-6: another example, more accessible to the NPG readership, is the distance built in Farchi et al. (2016). Ok

47. p.7, l.11: "...belonging respectively to $P(\Omega)$ and $P(\Omega 0)$." → "...belonging to $P(\Omega)$ and $P(\Omega 0)$, respectively." Ok

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48. p.7, l.19: *The scalar product is not unique (and as a consequence the gradient), but there is a natural one induced by the norm used in the cost function (here Wasserstein's). This could be mentioned, as the statement could be slightly puzzling for the reader.*

Ok, we clarified at the beginning of 3.2.

49. p.7, l.26: *It is not clear at this stage why you would use the L2 inner product.*

Ok, we clarified at the beginning of 3.2.

50. p.8, l.24-25: *Two "thus" in a row.* Ok

51. p.9, l.19: *"...we will use after." → "...we will use in the following."* Ok

52. p.9, l.14-24: *You mentioned p.5, l.18-19 that the definition of optimal transport based on transference map is out of scope; and I am fine with it. I even think it was a clever choice. But, here, you finally use it and that seems important. This is quite frustrating for the reader, especially those who have little knowledge on optimal transport.*

Ok, we changed what was remark 3.4 and included a wide paragraph in Section 3.3 to explain the notation $\#$ as simply as we could, using geodesics.

53. p.10, l.5: *", but results are still satisfactory.": Please remove the statement. It does not make sense to give the conclusion beforehand.* Ok

54. p.10, l.8-13: *Why not consider, in addition, a case with observation noise;* you

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perturb the Gaussian parameters of the observation, which would be similar to some bias in satellite observation.

We added such an experiment (Section 4.3), it shows that the W2 distance is more robust to this type of noise than L2.

55. p.10, l.19: "is chosen a optimal": vague, please be more specific.

Line search, we clarified the text.

56. p.11, Eq.(26): I would explicitly write the wind field in the equation even if it is uniformly equal to 1. Ok

57. p.12, l.4: "...gaussians..." → "...Gaussians..." Ok

58. p.12, l.1: "The analyses $\rho_a, W, 2$ and $\rho_a, W, \#$ are different even if they arise from the same cost function JW , which highlights the need for a well-suited scalar- product.": that is one of the most interesting point of the experiment, but your comment is too short. You must elaborate. One would expect the numerical solutions to be the same, right? unless there is a convergence issue, which much be analysed and discussed and would fit nicely with what was laid in section 3.2.

Ok, a convergence figure has been added following referee1, and we discussed this point in Section 4.1 (+ added a few words about the minimizer uniqueness at the end of Section 3.1).

59. p.12, l.18: "Shallow-Water" → "shallow-water" Ok

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60. p.12, l.26: "Thanks to the wisdom gained..." → "Thanks to the experience gained...": My wisdom told me that norm-induced scalar product was the best one from the very beginning. Ok

61. p.13, Figure.4: please plot the observations, like you did for the first experiment. Ok

62. p.13, l.9: "...badly..." → "...poorly..." Ok

63. p.12, l.12: Please avoid inverting subject and verb as this is much less frequent in English than in French.

Ok.

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