Geosci. Model Dev. Discuss.,
doi:10.5194/gmd-2016-108-AC1, 2016

Geoscientific Model Development Discussions

Interactive comment on "A robust gap-filling method for Net Ecosystem Exchange based on Cahn–Hilliard inpainting" *by* Yufeng He and Mark Rayment

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Received and published: 6 July 2016

We are delighted that the referee found this paper well written and thanks for his/her valuable comments. We understand the major concern raised by the referee and see that it lies in the interpretation of results 3.1, which leads to some confusions in the subsequent analysis where we have tried to gap-fill the de-noised NEE signals. Substantial revisions have been made to the result section of the manuscript, including adding a 14-day scenario (see Fig. 2-4, Table 2), and we have made major corrections to the narrative of results 3.1 (see attached file for a revised version of the manuscript). The detailed responses (with the referee's comments quoted) are as follows:

1) About artificial gap length

Reviewer's comments: "The comparison of the two method is based on artificial gaps of up to 7 days; this is definitely a period too short to challenge the IIP method. In fact, as also the authors say, the drivers used by the MDS method add noise in the performances and for this reason on short gaps it is expected that methods based only on NEE interpolation will work better (the Mean Diurnal Variation (Falge et al 2001) is also bases only on NEE data and will probably perform well in these conditions). The effect of changed environmental conditions will be probably visible on a longer time interval and for this reason the IIP should be evaluated on gaps of 2-3 weeks."

Response: We agreed on challenging the IIP at a longer gap length and we have included a 14-day scenario in the manuscript. The results still show little difference between IIP and MDS in gap-filling a 14-day scenario (please refer to the attached manuscript for a revised result 3.1 and Fig. 3&4). Despite the reviewer's concerns that a long gap would challenge IIP, this was not the case - 1) Smoothly filling the gaps (by IIP) did not necessarily performed less well in terms of the estimation accuracy; 2) Large gaps did not significantly affect the gap-filling performance for either method. (Falge et al 2001) reported that "With the data at hand, we were unable to answer which methods compared best with the artificially removed data, and under what conditions (day, night, functional group, climatic conditions). The residuals between artificially removed and filled data of various sites, methods and gap percentages could not be distinguished by ANOVA". It seems that both methods and (very likely) other methods largely "failed" to recover the nuances of the original signal. This is exactly the reason that drives us to investigate the effects of noise on gap-filling performance in the subsequent analysis.

2) About de-noising the NEE signal

Reviewer's comments: "The discussion on the noise on the NEE data is interesting and largely correct. However the conclusions related to the study are somehow expected and not proving the goodness of the IIP method. In fact as the authors assert the IIP is an "highly smoothness estimator" and for this reason is it expected that its

performances in the image re-construction will dramatically improve is the image is "smoothed" and simplified. It is also expected that with an "oversimplified" NEE time-series the effect of the short term variability of the meteorological drivers for the MDS can only add noise to the result (the potential short term relation driver-output is broken by a filtering applied to the output; for example the fast pulse effect on respiration due to precipitation or the fast reaction of photosynthesis due to cloudy periods)."

Response: We are delighted that the reviewer recognises that this discussion on signal noise is interesting and correct. As far as we know, no studies have been found in analysing the noise of NEE in such details. First, it is not easy or trivial to find a "highly smoothness estimator" while maintaining the main variations of signals. For example, replacing the gaps with a single value of the mean value is the smoothest way, but the temporal variations will be totally lost. In fact, IIP, as a highly non-linear estimator, has the ability to "learn" the pattern of signal and then implement the reconstruction. The problem raised in the reviewer's previous comment (and our response) is that ***we would not be able to distinguish the gap-filling performance in artificial gaps even with a highly smooth estimation***. Based on these results, we speculate that random process embedded in the NEE signal ultimately determine the gap-filling performance – a fair explanation for these observations. Secondly, the de-noise method based on Fourier Transform is justifiable. We have showed that the full signal can be decomposed into two parts, one of which is a "close to a zero" mean superposed with a symmetric (e.g. Gaussian) distribution (i.e. features typical of noise). IIP can reconstruct the de-noised signal quite well and one should notice that the de-noised signal conserves the main information of temporal variations (see Fig. 5). In fact, all gap-filling methods are technically smoothness estimators and work by modelling patterns (structures) in the signal pattern (e.g. by drawing a single curve through a scatter of points in regression or by averaging (Mean) Diurnal Variation), to maintain the main trends while discarding fluctuations. As we have pointed out in the Discussion, the accuracy of IIP as a completely unsupervised process for filling data gaps, particularly when coupled with a de-noising algorithm, may contribute to bringing into focus underlying ecological

and meteorological mechanisms not identifiable a priori.

3) **Reviewer's comments**: "Some of the results interpretation are subjective and not justified. For example the fact that the reconstruction of the larger gap in summer in the DE-Gri site (figure 3) by the IIP is something to be positively evaluated because smoother and less noisy respect to MDS (page 5) needs to be proved. It is possible that the correct reconstruction is the one from the MDS method. . . only artificial (long) gaps can say which method is more close to the original measured data."

Response: We have made major corrections to the interpretation of result 3.1. We agree that only through using artificial gaps can we say whether either method is better. In our studies, little difference was found between methods.

To conclude, 1) IIP, despite being compact and completely unsupervised, shows a gap-filling performance at a same level of MDS when applied to the original NEE signal; 2) IIP outperforms MDS on de-noised NEE data. Either way, IIP is a robust gap-filling method for any structured data, including NEE.

Reference: Falge et al. (2001) Gap filling strategies for defensible annual sums of net ecosystem exchange, Agricultural and Forest Meteorology 107, pp. 43–69