Atmospheric Measurement Techniques Discussions

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Reply on RC2

Ryan Volz et al.

Author comment on "Four-dimensional mesospheric and lower thermospheric wind fields using Gaussian process regression on multistatic specular meteor radar observations" by Ryan Volz et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2021-40-AC6, 2021

Thanks for your detailed comments!

1. (More discussion of the prior wind mean) We concentrated on specifying and analyzing the prior covariance function because it is by far the more important component in the GPR specification, but we agree that more can and should be said about the prior mean function. The biggest effect of specifying a good mean function is that it improves the covariance function specification, allowing the amplitude and length scale hyperparameters to be smaller in general. This leads to smaller error bars on the wind estimates, but the wind estimates themselves (perhaps surprisingly?) don't change too much. We will be adding more discussion to the revised manuscript about how we specified the mean and its implications to the final estimates.

2. (Uncertainty in the meteor coordinates) Our current GPR method does not incorporate uncertainty in the meteor coordinates (space and time). We agree that it would be great to include this, but the GPR framework does not naturally incorporate this and adding it would be a significant project for future work. We expect this would entail leaving the closed-form solutions behind and numerically sampling from the distributions (e.g. MCMC). But for the analysis in this paper, we do try to limit the effect of coordinate uncertainty by throwing out low-quality detections. We will clarify what this entails in the revised manuscript. Overall the uncertainties for the high quality detections are small enough relative to the covariance length scales that the added estimation error is negligible.

3. (Poisson process for meteor occurrence in time) One must be careful to distinguish between the probability distribution of meteors occurrence/detection and the distributions used to model the winds. For the wind process, when and where the meteors occur is irrelevant; all we care about is that the meteors produce a set of measurements, and how those measurements are distributed does not factor into our assumptions about the wind processes. A practical effect of the Poisson distribution for meteor detections, however, does mean that our coordinate sampling of the winds is more grouped than it would be if the meteors were uniformly random. That just means that we'll get lower uncertainties for the wind estimates in those regions due to the abundance of samples. It may also be relevant to point out that we will be adding more discussion of the wind process distribution assumption in response to other reviewer comments.

4. (Further analysis of the covariance length scale hyperparameters) This comment matches our experience with the length scales: the fitted values are strongly driven by the density of meteor sampling within a particular dataset, so we might naturally want to use smaller values around 90 km and during the morning detection peak and larger values at low/high altitudes and during the evening detection valley. This is not currently considered in our GPR technique, since we are using constant values for the length scales that don't vary with location. We think that allowing the length scales to vary with location (e.g. altitude) would likely lead to better wind estimates, and we think that this would be a fruitful area for future work (and have already suggested this in the manuscript, if not quite as clearly).

5. (Confusion on mean error, figures 3 and 4) We intend to say "magnitude of the mean error of the horizontal wind vector" (averaged difference in the horizontal wind vector, including both u and v components) for the bias plot, and we intend to say "variance of the horizontal wind *error*" for the variance plot. Same for the vertical winds. We will be explicit and update the manuscript/figures to refer to the "magnitude of mean vector error" or "mean error" and "variance of the error" or "error variance".

6. (Computation in overlapping intervals) The overlapping estimation procedure is not a necessary component of GPR, but it is helpful for reducing the computational burden as long as care is taken. And by that we mean that we have only made estimates at times when at least 45 minutes of data both before and after are included, for a total time window of 90 minutes (with centered estimate). This window is wide enough, given the 15 minute time length scale for the covariance, to ensure that the estimates produced are only negligibly different from the result of if a wider time window (or the whole dataset) was used. We have verified this by comparing the 90-minute-window estimates to ones done with a 180 minute window. Thus, the smoothness of the wind estimates is not affected.

It is an astute observation that the overlapping estimation procedure could be used to apply different hyperparameters that are more tuned to different segments of the data. This is indeed the most straightforward way to apply that type of analysis for future work, even if it is not terribly elegant. This is also how we know that the density of meteor detections affects the hyperparameters: we have observed that the fitted length scales in particular change somewhat throughout the day (when fitted to these overlapping windows of data), seemingly in correlation to the density of meteor detections. Fortunately the estimates are not changed greatly by imposing constant conservative values throughout the day; it just means that we're not achieving quite the best resolution at times when the meteor density would support it, effectively smoothing over potentially-detectable features.

7. (Comparison to gradient method and estimation of mesoscale structures) Perhaps it is not totally fair to make this comparison and the claim that GPR shows mesoscale structure where the gradient method does not. It is definitely possible to perform an analysis with the gradient method (or other existing methods) that focuses on time and length scales similar to the GPR method, and thereby likely identify the same mesoscale structures. Such information is in the data, and we don't mean to claim that GPR performs some magic that unlocks it that is inaccessible to other methods. The benefit of GPR is not necessarily that it allows one to see these mesoscale structures, but that it provides a suitable framework and procedure for identifying those scales within the data and making them clear without manual data analysis.

8. (Vertical winds) In response to this and other discussion of the vertical winds and the figures, we have decided to remove the vertical wind component from the Figures 2 and 7 to improve clarity. Nevertheless, we will be adding more discussion of the vertical winds to the manuscript to address the questions raised in this and other reviews. The basic

conclusion is that the technique is agnostic to the prior assumptions the user wants to employ for the vertical winds, and it also provides the necessary uncertainty information on the wind estimates that will allow the user to assess the quality of the vertical wind estimates. Through the typical meteor observation geometries, there is much less information about winds in the vertical direction than the horizontal directions. The fitting procedure on the SIMONe dataset produced a prior variance for the vertical wind component of about 90 m^2/s^2 using a set mean of zero. This could be from actual instantaneous non-zero vertical wind values, but it could also be elevated due to errors in the Bragg vector direction and/or meteor location causing contamination from the horizontal winds. The values produced in the estimates conform to this prior distribution and the information added through the measurements, but the posterior error bars are still large enough that a zero or nearly-zero vertical wind is a plausible explanation, especially considering the possible role of horizontal contamination. Great care is still needed in this and any future analysis of vertical winds, but we think GPR will provide a useful new tool in performing that analysis.

9. (GPR resolution) The discussion of comment (7) is also relevant here. It is evident that we need to clarify the point we are trying to make with this discussion and conclusion. We will update the manuscript to better highlight the ease with which GPR enables analysis at finer scales.