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Atmospheric Measurement Techniques Discussions

Interactive comment on "A variational regularization of Abel transform for GPS radio occultation" *by* Tae-Kwon Wee

Anonymous Referee #1

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Overall, the paper is clear and concise and presents a case where using a variational technique can be used to improve the retrieval of a refractivity profile from GNSS-RO. The math and application of the technique all appear sound. However, the improved refractivity profile is acquired by the assimilation of ECMWF forecasted atmospheric profiles. This then poses a fundamental question as to the goal of GNSS-RO, is it to solely obtain the best refractivity profile, or to gain atmospheric state information such as temperature and moisture from the profile? If it's the latter there may then be an incestuous relationship where if the ECMWF model were to ingest these refractivity profiles, they would be ingesting forecast data from their own model. Does this technique then need to be applied for each NWP model independently, and the background error covariance calculated for the NWP model it is going to be applied to? Further, in

the technical description, I could use a little more detail on the computation particularly of the error covariances. The vertical coordinate is never discussed for these matrices and should be described. And though a reference is stated for the control-variable transform its application seems to merit a sentence or two. Lastly, the abstract of the paper itself never mentions that the regularization method will ingest ECMWF model forecast data, or more generically, NWP model forecast data, for input to the method. This is a key point, and obviously impactful on the final result and should be mentioned plainly in the abstract. Considering these points, revisions are required before publication can be considered, though minor revisions, they are fundamental and need to be addressed.

One last philosophical point, the paper should try to address the question as to what is the benefit of the final result of such a technique. The antagonist would say that in a full data assimilation system, would you acquire the same result assimilating bending angle or refractivity profile which utilizes the traditional AI approach, with appropriate observation error, and then also assimilating the ECMWF forecast model profiles? The benefit to the VR refractivity profiles is coming from the ECMWF model data, so if they are available why not just assimilate the ECMWF model data directly as proxy radiosondes? To address this concern, you could start by clearly stating that the goal or focus of this study is on creating the highest quality refractivity profile and what the benefits of such a dataset may be. Then follow up in the final summary and conclusions with a discussion about what may be the next steps in advancing this technique. It would seem that the logical extension would be to formulate a way to create a new forward operator for the bending angle profiles in the observation height coordinate which uses the NWP systems background (forecasts) to create an adjusted bending angle and PHD, and then subsequently transforms this back into innovations and Jacobians in the model space which can be used in the full solver minimization. It could be thought of as something similar to a 1D-Var step which would be embedded before passing information onto the main DA solver.

Typos and grammatical changes: Multiple times in the paper, data assimilation(s) is used. The final "s" is not needed as it can already be considered plural. One could use data assimilation methods/systems is you wanted to add another word, but it is perfectly adequate to leave this out. For example: Page 1, line 13: In contrast to variational data assimilation, VR holds ... Page 1, line 17: ... purposely corrupted synthetic sounding with a known true solution. Page 7, line 1: This differs from meteorological data assimilation of in-situ observations, where state variables are usually the same as those of the prediction model. — The original statement was not correct as currently the majority of observational data in meteorological data assimilation originates from satellite radiances which are not in state space, but need a forward operator similar to GNSS-RO. Please note my addition of "in-situ" but revise as you deem appropriate. Page 7, line 3: ... the location of the state-vector elements is represented in relation ... Page 7, line 4: For this reason, ... Page 7, line 33: The method attempts to separate forecast and observation errors from the variance of y – H(x), using the assumption that ... Page 9, line 4: Question, does the sampling rate of 1 second correspond to 4 meters throughout the entire occultation or just in the lower troposphere. Please clarify, "4 meters though the depth of the occultation" or "4 meters in the lower troposphere" as appropriate. Page 10, line 8: On the other hand, regularization methods include the penalty term, which acts like a filtering and invokes a reverse ... Page 11, line 10: Note, the total cost function in complex systems often does not always monotonically decrease. It can occur but often requires aggressive pre-conditioning to be applied and appropriate conjugate gradient descent methods chosen. You may want to preface that you have seen this behavior which can be attributed to the small order and general simplicity of the problem. Page 12, line 1: ... Monte Carlo approach is larger than ... Page 12, line 4: Data assimilation methods/systems are similar ... Page 12, line 32: The slope is indeed the critical refractivity gradient, GC, ... (This abbreviation was not defined, but subsequently used). Page 13, line 24: ... actual RO events and compare these results with ... Page 14, line 16: ... above the ECMWF model top up to a height of 2,000 km. Page 15, line 20: ... does not always deviate discernibly from

ORD. Page 16, line 20: ... RO and FCST is crucial to allow for VR to reduce the bias. Page 18, line 10: ... observations on average at the tropical HVRRD stations than the tropical ORD stations. Page 18, line 12: At the tropical HVRRD stations, RO observations are assumed to be more accurate, while the (simulated refractivities?) from the model background are less reliable. – I did not follow the use of "background sounding" so please be explicit here.

Figure 2: It would maybe help to have the "key" for the lines shown explicitly for figure 2a (true and measured), and figure 2b (smoothed and measured). Figure 3: I believe the x-axis in Figure 3a should be "Climatological B [N,%]" Figure 4: The purple and black lines are very hard to distinguish particularly in figure 4b. Figure 8: Similar to figure 4, the black and purple lines in figure 8b are very hard to distinguish.

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