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Atmospheric Measurement Techniques Discussions

# *Interactive comment on* "Assimilation of GNSS radio occultation observations in GRAPES" *by* Y. Liu and J. Xue

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We are grateful for the reviewer' valuable comments and suggestions, which help us to improve the quality of the paper. Following are our replies:

1.For the general comments

We summarized the assimilation of radio occultation (RO) data in GRAPES. We prefer to emphasize the values of RO data in numerical weather prediction (NWP) by the assimilation and forecast impact experiments in GRAPES, although many NWP centers, for example ECMWF, UKMO and NCEP etc., have presented their results, all of which have shown the positive impact. But GRAPES is a developing model, whose performance is still not good, therefore, the impact of RO could be greater than any other



advanced assimilation system.

The definitions of coordinate, grid and variables in GRAPES are similar to that of Met office. Therefore, the expression of observation operator could be similar. Thank you for reminder. We indeed read the RO assimilation papers of Met. Office. In the revision, we have cited their papers where we referred to their method.

We have added an all observations impact experiment according to the reviewer's suggestion. We did not show the impact of RO in all observation, because we wanted to tell people that the RO was able to maintain the running of model even in an assimilation system with poor observations.

2.For the specific comments

1 ) Page 7614, line 23: A statement is made regarding the delay in exploiting RO for Earth-based meteorology. A reference is required here.

A: We have supplemented the reference.

2) Page 7615, line 18 onwards: The advantages of RO are described. The disadvantages should also be included for completeness (e.g. low horizontal resolution etc.).

A: we have described the disadvantages of RO data.

3) Page 7617: It is stated on line 4 that potential temperature is in the model but in equation (1) it does not appear in the state vector.

A: GRAPES is non-hydrostatic model, its forecast variables are Exner pressure, potential temperature, three components of wind field, and humidity variables. But we do not take the non-hydrostatic problem into account in GRAPES-VAR currently. We choose the Exner pressure $\pi$ as the state variable and the potential temperature $\theta$ as the derivative of $\pi$. Therefore, it does not appear in the equation (1).

4) Page 7617: The reason why the potential temperature is derived from the model Exner and geopotential height, rather than using the actual model potential tempera-

ture should be explained.

A: GRAPES-VAR is a hydrostatic balance assimilation system, and we choose the unbalance Exner pressure as control variable. Therefore, to keep the hydrostatic balance relationship, we use the derivation of potential temperature rather than the potential temperature from model forecast.

5) Page 7620: Is the bi-weight method applied to all observations in the window, or is it applied to the different instruments separately? This could affect the observations that pass/fail the QC.

A: The bi-weight method is applied to the different instruments separately in the preprocess not in the data assimilation. In fact, we only use bi-weight method to reject the outliers of RO and ATOVS data in GRAPES.

6) Section 3.3: The details of the observation operator, particularly the handling of model levels and the use of Exner-derived potential temperature, are very similar to the refractivity operator described in this report by Rennie (2008): 'The Assimilation of GPS Radio Occultation data into the Met Office global model' (http://www.metoffice.gov.uk/archive/forecasting-research-technical-report-510). Although the implementations are not identical, the similarities are striking, so the authors should make it clear that the operator is significantly based on previous work.

A: Thank you for reminder. I have cited this paper, and explained the calculation of model N in potential temperature level and the specified observation errors are refered to the method of Met office in the revision.

7) Page 7621: Vector quantities in equations (specifically x and y) should be bold.

A: We have corrected them.

8) Page 7222: The linear interpolation of Exner pressure could introduce systematic biases in the forward model. The reason for selecting this interpolation scheme should be stated.



A: Thank you for reminder. We will test other schemes in the future.

9) Page 7623: In equation (13) the value 0.608 should be expressed symbolically and its meaning as a physical constant described.

A: we have corrected it.

10) Page 7623: The vertical correlation of observation errors is not mentioned. For refractivity, these correlations are significant so they should be used in the assimilation. If they have not been, this decision should be explained.

A: we do not consider the vertical correlation of refractivity observation errors. To avoid their impact, we thin the RO data in the vertical direction. We only assimilate one RO observation nearest the model analysis level, and do not use the RO data nearest the model top.

11) Section 3.4: This section is well-written and the conclusions seem justified. However, results showing the impact of RO in a full system (i.e. with other satellite observations) are not presented here. If the authors have carried out any experiments to test this, then these results should also be included for completeness. If such experiments have not been carried out, I encourage the authors to at least provide a discussion of the issue, particularly with regard to anchoring the bias corrections of satellite radiance observations, and any plans they have to investigate this further.

A: Thank you for your suggestion. We have supplied the full observations impact experiment, and added related contents in the revision.

12. Page 7630: Part of the title of the Lanzante paper is listed as an author.

A: Thank you for you attention to the details. We have deleted them.

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Interactive comment on Atmos. Meas. Tech. Discuss., 7, 7613, 2014.