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## Reply on RC2

Abdellatif Benchafaa et al.

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Author comment on "Simulation of Gravity Wave D-region disturbance and its effect on the LWPC simulated VLF signal" by Abdellatif Benchafaa et al., Ann. Geophys. Discuss., <https://doi.org/10.5194/angeo-2020-68-AC2>, 2021

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### Summary:

This paper describes simulations of the D-region ionosphere response to a simulated gravity wave perturbation, and with the VLF response via simulation of the sub-ionospheric VLF signal. Results show that the imposed disturbance modifies both the neutral density and electron density, and specifically, when the neutral density increases, the electron density decreases, and vice versa. The VLF signal response is then simulated, and shows measurable changes in amplitude and phase of about 0.5 dB in amplitude and 5-10 degrees of phase.

### Overall Impression:

I do not feel that this paper is sufficient for publication in Annales Geophysicae. First, the paper simply does not provide a significant result worthy of publication. Second, what is described in the paper has some serious issues or missing information. One of the main issues is that the neutral density and electron density are negative in Figures 2 and 3, which is not physical and therefore highly suspect. There are various other issues that I comment on below.

On the question of significance, the paper provides simulations and model predictions of the D-region response to a gravity wave, and the VLF signal response. But these simulations are not grounded in any real data. There are no examples provided of VLF observations of gravity waves to compare the simulations to. The gravity wave perturbation that is imposed on the D-region (Equation 1) is not backed up with any data. In fact, there is no simulation of the gravity wave from the ground to the D-region, similar to Marshall and Snively (2015); here, the disturbance is imposed directly at 80-90 km altitude. Without justification of the size, shape, and evolution of this disturbance, it is not really a believable gravity wave. I will address these and other issues in more detail in the line-by-line comments below.

### Answer

**In our simulation we imposed the shape and form of the gravity wave disturbance to the neutral atmosphere in similar way to Brissou et al as described in the text. Our choice is justified since the GW disturbance is used as a disturbance term source in the simulation code and not as the main objective of the simulation. This is in similar way of the X-ray solar flare disturbance which was widely studied and simulated in order to get the electron density perturbation without need to simulate the solar flare itself. We stated in the text**

**some papers which show observations of the VLF signal perturbations due to different sources such as the gravity wave some of them was done by our group. In this new version we added a plot of some VLF signal perturbations observed by our VLF receiver in the NAU-Algiers path during Karl storm in the Atlantic Ocean since it was chosen as the VLF GCP in our simulation. A new figure of the geometry is added in this new version of the paper.**

**We agree with the reviewer that in Marshall and Snively (2015), the authors simulated the disturbance due to acoustic wave starting from 10km above thunderstorm till the D region. But what is different in our case is that the gravity wave has several sources such as the earthquake, tsunami, holographic and cyclone as stated in the text. Thus, in our case the source of the gravity wave was supposed due to meteorological system such as cyclone or tropical storm which is different from Marshall and Snively case. Additionally, in the comparison with the recorded perturbation due to Karl storm, clear correspondence between the response of the measured signal perturbations and the simulated amplitude. This was clearly stated in the text.**

Line-by-line Comments:

Line 13: the "ionization rate" should not be affected by chemistry. The ionization rate is  $q$ , also called production, which at nighttime is just the cosmic ray ionization source. I think you mean "electron density" here.

**Answer**

**Yes what we mean is the electron density, thank you for bringing attention.**

Line 21: the ellipsis makes it seem like this sentence is incomplete. Ellipses are not used in formal writing. Same on line 31.

**Answer**

**We changed the sentence in 21 and 31 according to the reviewer remark.**

Line 25: The citation to NaitAmor (2010) is fine, but there are many more earlier papers that show similar results. It is a disservice to previous authors to leave those out and suggest that NaitAmor (2010) is the first to show the geometry of VLF perturbations. See numerous papers by the Stanford VLF group on early/fast and LEP events going back to the early 1990s.

**Answer**

**In this new version we reformulate the sentence.**

Line 28: Similarly, it has long been known that an increase in  $N_e$  below the reflection height will lead a lower reflection height. This paper did not discover this phenomenon.

**Answer**

**We reformulated the sentence to show the important information given in that paper.**

Line 29: "people are attracted" - this statement is unsubstantiated; references are needed to justify this claim.

**Answer**

**Thanks for the remark, we modified the sentence.**

Line 35: Of critical importance, Marshall and Snively did not just conduct simulations, but used simulations to explain real data of a VLF perturbation associated with a thunderstorm. This is much more powerful than simulation alone, without data.

**Answer**

**We added to this new version example of observed signal perturbations due to the GW observed by our VLF receiver due to Karl storm (see NaitAmor et al 2016) and compared to the simulation results.**

Line 42: It is not clear which paper the "wavelet analysis" is referring to.

**Answer**

**Thank you to your comment, we rewrote the sentence to be clear.**

Line 45: Why is the ambient reflection height of 87 km chosen?

**Answer**

**As we explained above, our objective is to show the response of the VLF signal to the modification of the D region due to GW by means of LWPC code. In the LWPC**

**code, the nighttime reference height, which is also considered as reflection height of the VLF signal, is fixed at 87km. Thus any altitude which contains electron density equals to  $N_e$  at 87km will be considered as a new reference height in the LWPC simulation.**

Line 55-56: Equation 1 describes the disturbance to the D-region at 80-90 km altitude. The equation is similar (nearly identical) to the gravity wave simulated in Marshall and Snively; however, in that paper, the disturbance was at 10 km, where the storm occurs. What is the justification for the same analytical form of the disturbance at 80-90 km altitude? Most simulations of gravity waves show considerably different structure once the disturbance reaches the mesosphere. See numerous papers by Snively, Heale, and many others.

**Answer**

**As we explained above, we are not interested on the simulation of the gravity wave propagation from the bottom (near the source) to the D region as in the work of Marshall and Snively (2016) who studied the acoustic wave driven disturbance in the lower ionosphere and not the GW. The Gaussian formalism is widely used in different scientific domains. Additionally, this mathematical formalism ensures the symmetry of the disturbance in space and time. The difference between our case and Marshall and Snively is in the fixed parameters of the disturbance spatial size, frequency and speed of the disturbance in the horizontal direction which is not considered in their work since they studied a stationary thunderstorm. The novelty in our simulation by considering the moving disturbance is to see the effect of interferences on the recorded VLF signal which was not done before. The damping of the disturbance during the time is also justified because in the fluid simulation of the neutral atmosphere disturbances, the collision and friction forces are considered as damping forces in the momentum equations.**

**Considering a more complicated form of the gravity wave starting from the bottom near the source to the D region is important but also will takes more computational time. But taking one parameter fixed, like the neutral disturbance form since it is not important in the goal of our paper, will reduces the computational time much more and the results will be also consistent and describe what is observed by ground receivers.**

Line 58: How is the wind speed imposed, mathematically? I would expect this to be incorporated into equation 1.

**Answer**

**The wind speed is also a fixed parameter introduced in the code.**

Line 65: Most uses of the GPI model now use the 5-species version, updated by Lehtinen and Inan (2007), which includes heavy negative ions. The authors should justify the use of the four-species model, which is somewhat outdated.

**Answer**

**Thank you to your comment. In the paper of Lehtinen and Inan the new equation is added because they were interested to the ionization enhancement below 70 km due to Gigantic Jet which is not our altitudes of interest. But in this new version we added the fifth species and re-run the program and updated the plot which showed similar results as for 4-GPI equations system.**

Line 100-101: The LWPC simulation setup is not clear. Is the new reference height,  $h'$ , used everywhere along the LWPC path, or only in the disturbance region? Only the latter makes physical sense, but it's not clear from the paper.

**Answer**

**The modified  $H'$  and beta parameters due to GW are used inside the disturbed zone only and the other locations between the transmitter and the receiver the parameters take the ambient values as presented in the plots of the LWPC parameters. Text is modified accordingly.**

Line 110-112: It makes sense that as neutral density increases, collisions increase, and

therefore electron loss by recombination goes up, reducing electron density. This will track the gravity wave disturbance if the gravity wave variation (frequency  $\omega$ ) is slow compared to the electron recombination time. The paper should compare these two timescales.

**Answer**

**We stated in the text that the  $t=4000s$  and we fixed  $\omega=0.015$  rad, so the time scale is sufficiently below the characteristic times of the chemical reaction loss and production terms and thus is enough to track the gravity wave. An explanation sentence is added in the text.**

Figure 1: The top panel should show a map, or at the very least a scale in km. No dimensions are given.

**Answer**

**We changed the figure 1.**

The second and third panels show variations in the neutral density which at some times become negative. How can the neutral density be negative?? From the figures and the text, it seems clear that this plot shows the neutral density and not the change in neutral density; so it makes no physical sense to be negative. This makes the entire simulation seem unbelievable, since this neutral density is critical to the entire paper.

Figure 2: Again, the electron density becomes negative at various points. The chemistry model should even be able to output negative values!

**Answer:**

**The problem is that in the code we missed to added the ambient neutral density and electron density to the GPI system. Now the system is completed and the new plots show positive values.**

Figure 3:  $h'$  values are good to show vs time and distance, but the authors should also show changes to beta. The D-region electron density disturbance can be fit to give a best estimate of beta near the reflection height, which would be valuable information.

**Answer**

**We agree with the review that beta parameter is also important. In this new version the parameter beta was determined form the fit of the electron density as function of altitudes and then introduced in the LWPC simulation. New plots are then generated. Thanks!**

Figure 5: the authors should comment on the 360-degree phase difference after 2400 km. This likely requires a phase-wrapping correction.

**Answer**

**Thank you for the comment, we did wrapping of the phase and we updated the figures accordingly.**

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