Anonymous Referee #2 Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-57, 2019. (Received and published: 31 May 2019)

Response to referee 2:

16th August 2019

We would like to thank the reviewers for their time taken to read and feedback very helpful advice and comments on our paper. Our responses are below.

We have added an extra figure (Figure 3) to illustrate the geometry of the CHAMP ascending and descending orbits, and the projection of the FPI wind vectors onto the CHAMP cross-track direction.

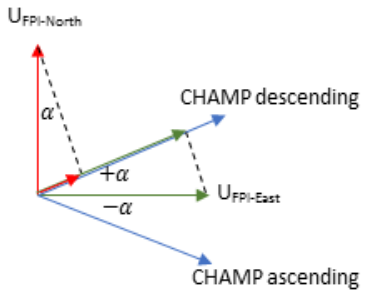

Figure 3: Geometry illustrating the projection of FPI look direction wind components onto the CHAMP cross-track direction for the ascending and descending tracks.

This is in response to both referees requesting that we do this projection for a fairer comparison with the CHAMP cross-track winds. This has required a renumbering of the figures as shown in the table below:

Original Figure Number	New Figure Number
1 CHAMP solar max 2001-2003 Longyearbyen	1 CHAMP solar max 2001-2003 Longyearbyen
2 CHAMP solar max 2001-2003 Kiruna	2 CHAMP solar max 2001-2003 Kiruna
3 CHAMP solar max 2005-2007 Longyearbyen	3 geometry for projecting FPI winds onto CHAMP cross-track direction
4 CHAMP solar max 2005-2007 Kiruna	4 CHAMP solar max 2005-2007 Longyearbyen
5 FPI solar max and min 2001-2003 Longyearbyen	5 CHAMP solar max 2005-2007 Kiruna
6 FPI solar max and min 2001-2003 Kiruna	6 FPI solar max and min 2001-2003 Longyearbyen
7 CHAMP vs HWM87 and HWM90 and FPIs measurements made by UCL + Alaska (1980)	7 FPI solar max and min 2001-2003 Kiruna
8 CHAMP vs FPI for 2- <= Kp < 4+ for Longyearbyen and Kiruna	8 CHAMP vs HWM93 and FPIs measurements made by UCL + Alaska (1980)
9 frequency distribution of CHAMP/FPI for solar max and both Longyearbyen and Kiruna	9 CHAMP vs FPI for 2- <= Kp < 4+ for Longyearbyen and Kiruna
10 CMAT2 model demonstration of effects of changing viscosity	10 frequency distribution of CHAMP/FPI for solar max and both Longyearbyen and Kiruna

11 height profiles of CMAT2 model zonal winds and comparison with the red line emission intensity profile.	11 CMAT2 model demonstration of effects of changing viscosity
12 frequency distribution of Kp	12 height profiles of CMAT2 model zonal winds and comparison with the red line emission intensity profile.
13 CMAT2 zonally averaged winds at Longyearbyen and Kiruna	13 frequency distribution of Kp
14 global maps of CMAT2 zonal winds comparing winds at 240 km with height integrated winds	14 CMAT2 zonally averaged winds at Longyearbyen and Kiruna
15	15 global maps of CMAT2 zonal winds comparing winds at 240 km with height integrated winds

Responding to Ref 1 comment 2 has also meant a re-numbering of the remaining equations:

Original Equation Number	New Equation Number
1	deleted
2	deleted
3	deleted
4	**1**
5	**2**
6	**5** (corrected original number which was out of order)
7	**3**
8	**4**

Some additional points we noted:

We noted that Figure 12 required some more explanation of the simulations of the height profile of the zonal winds (lines 633-645):

"Figure 12 illustrates how ground-based FPIs make measurements of the neutral winds at 240 km altitude. The left plot shows a height profile of the CMAT2 zonal mean zonal winds at the latitude of Longyearbyen. There are 6 simulations to demonstrate the effect on the height profile of the zonal mean zonal winds when changing the viscosity. CMAT2 uses a viscosity term that is the weighted mean divided by the scale height of two coefficients of viscosity: the molecular viscosity μ_m; and the turbulent viscosity μ_t. The simulations represent a comparison with the original molecular viscosity (dark blue). The other lines are for low (yellow - divided by 100) and high molecular viscosities (pink - doubled). The low and high turbulent viscosities are represented by the Prandtl numbers 0.7 (red) and 100 (green), where 2 is the default value used in CMAT2; which is relevant for the height at which gravity waves deposit momentum (Liu et al., 2013). The light blue line labelled "Mata" is an intermediate profile. As can be seen, the molecular viscosity dominates in the thermosphere above 100 km and at the altitudes where the FPI is measuring. The dark blue and yellow lines are representative of a vertical slice of Figure 11 left and right, respectively, for the latitude of Longyearbyen."

Replaced Nov-Jan with DOY 300-65 in abstract and line 424. This is the correct range of DOY used in the FPI selection criteria, as well as the CHAMP data.

Added the following:

i) an extra affiliation for MF
ii) data availability
iii) Co-author Rosie Hood's recently awarded PhD thesis as a reference

Moved and consolidated description of red line emission profile and winds with respect to height to follow Figure 12.

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This paper statistically compares upper thermospheric F-region winds measured by two high-latitude ground-based Fabry-Perot Interferometers (one located near Kiruna and other at Longyearbyen) and derived from in-situ accelerometer measurements onboard the CHAMP satellite. One of the ground-based stations is located in the auroral zone whereas the other one is in the polar cap. Results show that CHAMP winds are systematically 1.5-2 times larger than FPI winds. Further, the authors utilize the existing modeling tools for exploring the various possible reasons responsible for these systematic discrepancies in winds obtained from in-situ and optical techniques. Overall, this study can serve as an important reference for data users of these instruments.

In my view, the manuscript is loosely written. There is some repetitiveness of some of the text and the manuscript could be streamlined quite a bit. I would strongly recommend the authors to make clear, elaborate, and explain the following parts:

1. Please explain the purpose of having fist four figures (Figures 1-4). I think they are irrelevant and can be dropped without impacting the focus of the paper. Instead, it would help focusing this study on the core topic - FPI and CHAMP wind comparison.

The CHAMP figures 1-4 and FPI Figs 5-6 will be valuable to modellers to show phase and amplitude of the seasonal variation of thermospheric winds in the polar cap and auroral region for the European sector. Note these have been renumbered as in the table at the top. The FPI can only measure night-time winter winds. This is the reason why satellite measurements are so important.

2. Line 17: should be kinematic viscosity instead of viscosity?

Molecular viscosity dominates in the thermosphere, so this has been made explicit throughout.

3. Line 25: +-2 degrees in latitude, longitude, or both? Please explain.

The radial distance is the horizontal equivalent of +/- 2 deg in latitude (i.e. ~220km horizontal radius) at 240 km altitude.

4. Line 148: In Table 1 (column 4 and row 2), you mean 1.860 UT?

Yes, thank you. Corrected

5. Line 172: Emmert 2006a reference is not valid here because it is a climatological study.

Ok, thanks, point taken. Emmert ref removed

6. Lines 299-317: The simplest and most direct way to compare CHAMP and ground station winds would be to project ground station winds along the CHAMP cross track winds; it is doable because both the zonal and meridional winds exist for ground station FPIs.

This has been done for Figures 7 and 8 (renumbered 8 and 9) and to determine the ratios of CHAMP/FPI along the cross-track direction shown in the histogram in Fig 9 (renumbered 10).

7. Figure 5 and 6: Please keep the figure titles consistent. Subfigures a/b titles are not consistent with c/d titles: one shows Kp index in title and others not. In addition, please keep consistency when using plus or minus symbols in Kp values. For example, sometimes the manuscript uses Kp<2 and the other times Kp<2- [[or Kp<2o (line 367, 413, etc.) which may be a typo]]. Kp<2o is also present in Figures 6a and b. Moreover, I would suggest using an actual math symbol (ï˝C ˇc) instead of <=.

The <= has been replaced and the titles made consistent.

8. Lines 424-426 are referred to which figure/figures?

This is clarified in the text: ("The general trends seen in the northern winter CHAMP zonal winds (Figures 1-4, renumbered 1,2,4,5) are also seen in the FPI winds (Figures 5-6, renumbered 6-7). The phases match extremely well for both sites, however, there is a considerable difference in magnitude. The next 2 figures 7-8 (renumbered 8-9) show direct comparisons of CHAMP and FPI winds along the cross-track direction.")

9. Figure 7:
- This comparison is done for Kp 2-4, whereas earlier figures and discussion was focused on Kp 0-2. Same is true for Figure 8. Please explain the reason for this gear shift.

There is a lot of modelling effort into studying the active ionosphere-thermosphere, so we wanted to show this too. In particular it is relevant to the comparison with high latitude ion velocities discussed in section 6.4.

- Please explain why HWM87 and HWM90 were used instead of HWM14? HWM14 is the latest version of this empirical wind model.

HWM93 is used to replace HWM87 and HWM90

10. Figure 9: In addition to this figure, a plot showing CHAMP/FPI ratio as a function of UT or LT would be really helpful.

This is a very good idea, and has been added to Fig 9 (renumbered 10)

11. Lines 518-522: The major source of discrepancies could be the assumptions used when applying different wind extraction schemes as they can fail under different conditions.

Indeed, this is the point of sections 6.1-6.3. Sentence added to make this explicit just before section 6.1 (lines 554-555):

"With respect to hypothesis C – the assumptions of the FPI and CHAMP measurement techniques are discussed in the following sections 6.1-6.3."

12. Line 556: Please verify the viscosity expression.

The coefficient of viscosity is taken from Dalgarno and Smith (1962). Here it is given as

viscosity = $3.34 \times T^{0.71}$ micropoise

Equation 5 is the conversion to SI units. The Banks and Kockarts reference is removed.

13. Lines 715-722: Project FPI wind vector along the CHAMP cross track wind component.

Done, including an additional illustration of the geometry (figure 3). Words added, including (lines 752-754): ". To deal with this the UCL FPI zonal winds observed to the East and West are projected onto the CHAMP ascending and descending cross-track directions, and then averaged into 1-hour bins, thus replicating the CHAMP zonal wind averages (see Figures 7 and 8)."

14. Section 6.4: I did not get the motive of adding this section. So, please state explicitly the contribution of this section in this investigation.

This is a very important argument. At high latitudes the average neutral wind at high latitudes is expected to be smaller than the ion velocities, since the latter are driven by the magnetospheric dynamo. This is stated in the 2nd sentence of this section.