

Atmos. Meas. Tech. Discuss., referee comment RC2
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Comment on amt-2021-74

Anonymous Referee #2

Referee comment on "ALADIN laser frequency stability and its impact on the Aeolus wind error" by Oliver Lux et al., Atmos. Meas. Tech. Discuss.,
<https://doi.org/10.5194/amt-2021-74-RC2>, 2021

Review Summary

This paper provides a history and analysis of the on-orbit Aeolus frequency stability, its relationship to the satellite reaction wheel rotation velocities, and the impact on the wind measurements. It must have been very interesting to discover the relationship and to be able to clearly characterize it. The paper describes the relationship between specific reaction wheel speeds and laser frequency stability and follows the issue all the way through to the impact on different Mie and Rayleigh channel performance (accuracy and random error) for both atmospheric and ground returns. The paper conclusion section includes a summary of lessons learned and several important suggestions for mitigating this issue on future missions that require frequency stabilized lasers.

The paper is somewhat unusual for a scientific paper as there are few equations (143) and few variables, however the authors do a good job of explaining, with excellent graphics, what may be considered a complex issue for some readers. The paper includes a detailed description of the Aeolus instrument as well as information on the Mie retrieval, and Instrument Response Calibration step. One wonders whether this information is well covered in another paper in this special issue of AMT that could be referred here. If not, this paper will serve as a great reference for that material.

The paper is well organized, thorough, and provides an important contribution to the field. Thus, it is difficult to come up with any major issues or recommendations for improving the paper other than perhaps shortening it a bit. Some messages are relayed in multiple ways, likely in an effort to educate and convince the reader. Perhaps some of the graphics and corresponding explanation of the relationship between the reaction wheel speeds and laser frequency stability could be put into an appendix, but this is only necessary if the journal imposes page limitations.

While not necessary (and likely not appropriate) for this paper, it would be nice to know if a structural/modal analysis of the laser bench has been provided by the laser vendor that demonstrates the expected laser frequency stability levels at the reaction wheel speeds/frequencies where sensitivity was observed on orbit. Likewise, it would be interesting to know if there was any relationship between the reaction wheels and the performance of the interferometer spectrometers (or alignment between them), but again, this is not needed for this paper.

Overall, the paper is excellent and highly recommended for publication.

Line-by-line recommendations for minor changes (aimed at improving the document) are provided below.

Line 28-30: This sentence is confusing: "Hence, although the Mie wind bias is increased by $0.3 \text{ m}^2 \text{ s}^{-1}$ at times when the frequency stability is worse than 20 MHz, the small contribution of 4% from all wind results renders this effect insignificant ($<0.1 \text{ m}^2 \text{ s}^{-1}$) when all winds are considered. - What is the source of the 4%? "from all wind results"? All Mie winds or Mie and Rayleigh winds? Do the authors mean that the 0.3 m/s bias during frequency instability periods is dwarfed by other sources of random and accuracy errors?

Line 33-34: I found the meaning of this sentence difficult to pull out until reading the corresponding section, perhaps because of the term "sorts out"? Are the authors implying that, "Even if one considers only time periods of data with $> 20 \text{ MHz}$ frequency stability, the impact on accuracy of the Mie and Rayleigh ground velocities is still less than $0.15 \text{ m}^2 \text{ s}^{-1}$." (?)

Paragraph starting around line 60: Not all Doppler lidar and HSRL techniques require frequency stability. See Bruneau and Pelon 2021 (<https://amt.copernicus.org/articles/14/4375/2021/>) and Bruneau et al. 2013, <https://www.osapublishing.org/ao/abstract.cfm?uri=ao-52-20-4941>.

Line 68: Perhaps clarify "beyond" 1 Hz" as frequencies "greater than 1 Hz?"

Line 74-80: The authors might also consider including the work done for the GRACE-follow-on mission, <https://www.repo.uni-hannover.de/bitstream/handle/123456789/10524/PhysRevLett.123.031101.pdf?sequence=1>

Figure 1 – this is one of the better block diagrams/optical schematic that I've seen for

lidar systems. It is clear and helps the reader understand the optical path. It does seem familiar, however. If it has been used in other papers by this group, it may be good to reference the previous document in the caption as, "Figure after XXX et. al., 2019" (or whatever is appropriate).

Line 134-139: Suggest replacing "UV emit beam" with "transmitted UV beam" (keeping with "laser transmitter" on line 105-106). Likewise clarify laser radiation (vs. radiation) or use just one term (transmit beam).

Also – why 0.5%? Why not a smaller amount since it's being attenuated anyway?

Typically T0 reference beams are "leaked" through a 99.9% reflectivity mirror, and still require attenuation.

Line 182 – "on-ground" or "pre-flight" (On-ground could imply there's a ground-version of the laser being used for test).

Line 192-194 – What was the amplitude of the vibrations? (order of magnitude)

Line 230 – What is the "PD"? (is it the MO photodiode?)

Line 237 – May wish to say, ". *As of the writing of this paper*, the energy has remained above 60 mJ."

Line 271-272 – Just curious, why wasn't the more "agile" ramp-fire technique used on A2D also used on Aeolus?

Figure 4 – the colored dashed lines are a little difficult to see, especially the green one (I had to zoom in to see it after reading about it in the text). Can you make these slightly bolder?

Line 368 – how does "opacity" come into the display? Aren't all the dots opaque, with varying color from white to dark red?

Figure 5 and corresponding text –

- This is a good figure, demonstrating the information clearly in two different ways

- What is a “frequency step”? The term is only used in this figure caption, but not defined.
- Previous discussion used as 12 s analysis, what was the 24s?
- Here, and previously, the authors use phrases such as “standard deviation of the relative frequency on pulse-to-pulse level within this period” or “frequency stability in terms of the standard deviation of the relative frequency over the 540 pulses within that observation.” Perhaps back on line 268 the authors could introduce a variable name such as, “.the standard deviation of the relative frequency over one observation (540 pulses, 12 s), which we’ll refer to hereforth as $s_f(N=540)$.” Then they authors can use this term instead of the lengthy phrases

Figure 8 – This is a very interesting figure. It must have been an exciting discovery to see these results for the first time.

Line 452-453 (plus Tables 2,3 and surrounding text) – The authors state, “The variability in the center frequency of the common critical wheel speeds is on the order of 0.1 RPS which is comparable to the average width of the fitted peaks.” Is this actual variability in the reaction wheel speed, or is it uncertainty in the knowledge of the speed? Do the vendors provide an uncertainty on the knowledge of the reaction wheel speeds? This isn’t a critical point to be addressed, just a matter of curiosity.

Line 537-543 - this paragraph hints that there may be more to the magnetometer-laser frequency instability relationship than just an indirect relationship through the reaction wheel speeds, but the issue isn’t explored further. It comes up again in the conclusions, leaving the reader wondering if there might more to the story. Perhaps here the authors could clarify either that they have established there is not an expected impact of the magnetic fields on the laser frequency, or that this is an area open to further study.

Line 678 – Perhaps the authors could explain here why the Rayleigh wind accuracy is less impacted by the frequency stability? The question is briefly addressed in the conclusion (lines 825-830). Could the difference also be attributed to the number of Rayleigh (vs. Mie) observations that may average out biases?

Line 727-729: The authors may wish to explain briefly what is meant by “atmospheric contamination.” (Such a term seems ironic, given Aeolus’ mission to measure the speed of the atmosphere, but I digress). Presumably, it means that within a finite sized range bin they want the signal to be dominated by ground return, and so high albedo surface observations are chosen. That said, is there a concern about the impact of blowing snow over the arctic/Antarctic surfaces on the retrieval?

Lines 808-810 – see previous comment about the magnetometer discussion.

Lines 840-841 – Why was this technique implemented on Aeolus? If it was based on technology readiness for space, has that changed since launch?

Page 34 – When listing recommendations for mitigating the issue on future missions, do any future mission concepts include the ability to reference (adjust) the measurement on a pulse by pulse basis prior to pulse accumulation? I understand this is not feasible for the ACCD detection approach, but what about other future ESA-funded lidars?

General editing suggestions

While the paper is quite well written, the following is a list of suggestions that could be used to improve the grammar. They should not be considered necessary for paper publication.

- A comma belongs after use of “i.e.” or “e.g.”, (“e.g., as shown in this example”)
- Line 82: replace “...Spectrometers which allow to assess this...” with “...spectrometers that enable assessment of this...”
- Line 100: replace “This chapter will provide a brief description of the ALADIN instrument and its operating principle.” With, “This section provides a brief description of the ALADIN instrument and its operating principle.” The rest of the paragraph is in present tense, and the section (not a book chapter) is already providing the information.
- Line 109: It might not be clear to all readers what “switchable” means so I suggest replacing “The two fully redundant laser transmitters, referred to as flight models A and B (FM-A, FM-B), are switchable by a flip-flop mechanism (FFM).” with, “A flip-flop mechanism provides the ability to switch between the two fully redundant laser transmitters, referred to as flight models A and B (FM-A, FM-B).”
- Line 173-174: suggest replacing
 - “This is especially true, as the atmospheric backscatter signals from multiple outgoing laser pulses are accumulated to measurements before data down-link.” with
 - “This is especially true, as atmospheric backscattered signals from multiple outgoing laser pulses are accumulated on the CCD prior to digitization and data down-link.
- Line 303: Suggest replacing,
 - “Nevertheless, there is also a considerable amount of observations (19%) for which the frequency stability better than 5 MHz, i.e. comparable to the A2D laser performance” with
 - “However, there *are* also a considerable number of observation periods (19%) for

which the frequency stability *is* better than 5 MHz, i.e., comparable to the A2D laser performance”

- Line 425: “, which can be attributed to being located further away in the instrument” - do you mean RWA3 is located further away from the instrument or laser FMA is further away in the instrument?
- Line 431: suggest “...greater disturbing effect on one *laser* or another due to being located closer-by.”
- Line 535-516: suggest “As a result, the Allan deviation on the observation level is around (0.7 ± 0.1) MHz almost independent of enhanced noise periods.”
- Line 559-561: suggest “These included disturbing the laser transmitter with representative mechanical excitation spectra, thus identifying susceptibility in the 400 Hz to 600 Hz frequency band, as well as around 250 Hz.”
- Figure(12) – the term “frequency stability on measurement level” is used a few times in this figure (and supporting paragraph) –
- Line 739 AND 768: suggest replacing “In analogy to...” with “Analogous to...” or “By analogy with...”
- Line 832 – remove “In” from “In regions...” and start the sentence with “Regions...”