Review of manuscript amt-2020-487

A new lidar design for operational atmospheric wind and cloud aerosol survey from space

By Didier Bruneau & Jacques Pelon

Summary and General Assessment

This paper builds on the decades of work performed and published by the authors (and their colleagues) on using Quadrature Mach Zehnder interferometry for wind and aerosol lidar systems. The paper represents an update on the QMZI approach and how it may provide an alternative to the Double Edge Fabry Perot an Fizeau spectrometers used on Aeolus, to simplify the mission, potentially without making changes in other areas. Using a radiometric model and interferometer receiver model, the authors demonstrate optimization of the system for full tropospheric coverage, resulting on a QMZ design with 3.2 cm OPD to optimize fringe contrast (and thus optimize wind retrievals) from molecular backscatter.

The authors have published data from similar QMZ systems (e.g. the LATMOS LNG airborne system) so the paper may benefit from a scaling of the performance of these systems to help demonstrate and further justify the potential for space-based operation.

The paper points out important advantages of the QMZ approach (e.g., a reduced need for frequency stability, high efficiency/optical throughput, and high angular acceptance/field of view) and its potential value for future wind mission systems. With minor edits, as listed below, I recommend this paper for publication in AMT.

General Editorial Suggestions

The paper has some confusing wording and sentence structure and would benefit greatly from editing by a native English speaker.

Most of the figures, at least in the version this reviewer was provided, have font that is too small or blurry to read (especially figures 3-11). Please replace with figures with higher resolution and/or larger font.

The paper presents a somewhat limited view of work done in the fields of wind lidar and HSRL. There is similar work being done in this field that the authors could use to further support and even enhance the important case that they are making in this paper. For example, presentations on OAWL at the Aeolus CalVal workshop have also supported the idea of using a short optical path difference QMZ interferometer for Aeolus and have demonstrated comparison with Aeolus data. While the interferometer implementation is different, the mathematical concept and listed advantages are quite similar.

A number of variables in the text (including italic font, subscripts, symbols) do not match those in the equations. This will presumably be caught in a more thorough editing process.

A few of the publications listed in the references section appear to be missing in the text: Baker, Benedetti, Lux, Reitebuch 2020, and Tucker. (Note, the text refers to Reitebuch 2019a, and Reitebuch 2019, but there is only one Reitebuch 2019 in the list of references. Perhaps one should be the Reitebuch 2020 reference?)

Detailed Comments

- Line 14: Might reword to say, "…wind profiler using a *single* fixed line-of-sight lidar from space." As some other proposed concepts have looked at fixed dual lines-of-sight.
- Line 19: "This ability is…" To what ability is the sentencing referring?
- Line 30: could clarify to say that, "… backscatter coefficients can be retrieved with uncertainties better than a few percent where backscatter levels exceed XX%, such as in the boundary layer and …."
- Lines 65-80: This is a limited list of HSRL approaches and could be expanded to include the OAWL approach as well as work being done by Fahua Shen:
    - Fahua Shen, Jie Ji, Chenbo Xie, Zhao Wang, and Bangxin Wang, "High-spectral-resolution Mie Doppler lidar based on a two-stage Fabry–Perot etalon for tropospheric wind and aerosol accurate measurement," Appl. Opt. 58, 2216-2225 (2019)
    - Tucker, S. and Weimer, C., 2018, October. Benefits of a quadrature Mach Zehnder interferometer as demonstrated in the Optical Autocovariance Wind and Lidar (OAWL) wind and aerosol measurements. In Remote Sensing of the Atmosphere, Clouds, and Precipitation VII (Vol. 10776, p. 107760E). International Society for Optics and Photonics.
- Line 123: DE-FP and Fizeau interferometers will have a "small" acceptance angle based on the finesse. Low Finesse etalons will have higher acceptance angles than higher finesse ones, but will provide poor frequency discrimination. Perhaps this can be clarified in the sentence by adding something like…, "*If they are providing high frequency discrimination*, both DE-FP and Fizeau interferometers will have small angular acceptance."
- Line 125: Don't the narrow interferometer fields of view (FOVs) *also* impose a high accuracy requirement on the alignment between the telescope and the receiver?
- Line 134: Could also include Grund 2008
    - Grund, C.J., Howell, J., Pierce, R. and Stephens, M., 2009, April. Optical autocovariance direct detection lidar for simultaneous wind, aerosol, and chemistry profiling from ground, air, and space platforms. In Advanced Environmental, Chemical, and Biological Sensing Technologies VI (Vol. 7312, p. 73120U). International Society for Optics and Photonics.
- Lines 149-153: The frequency stability is only required IF an accumulation detector is used for the observation. If a higher speed detector is used, such as a PMT or APD (e.g., CALIPSO detectors) then the reference can be updated every pulse, if needed.
- Line 161: 1.4 or sqrt(2)? Is this just for simplicity?
- Line 164-168: This may be due to the grammatical structure of the sentence, but it seems that the authors are implying that (because of the reflection from one edge of the Aeolus ALADIN DEFP is being used in the other edge) the Aeolus approach has a theoretical 1.4x advantage over the QMZI approach. However, it's unclear how it is possible to provide perfect efficiency through a double edge approach while maintaining the necessary frequency discrimination. Unlike with the QMZ approach, there will always be some molecular backscatter signal that is not allowed to pass through either edge filter and thus will be lost. I am aware the authors are quite familiar with how Aeolus (and DEFP) operates, so perhaps this was not the intent of the paragraph, but it's important to not lead other readers into an unintended comparison.
- Line 176-179: These statements could use a little bit of qualification. For example, *for short OPDs*, the particulate signal will be near unity, but not if the OPD is long compared to the laser linewidth. Perhaps just state that the discussion refers to the 3.2 cm OPD concept being presented here.

- Line 189: The term “emitter” is used here (and elsewhere in the paper, including Table 2) however the term “transmitter” is used in much of the Aeolus literature (e.g., Reitebuch, et al., 2009).
- Line 190: This point about “acceptance angle” (or “maximum field angle” or “range of field angles”) is an important point to make!
- Line 195: Suggest the wording “…can be mounted on the same plate, *as was done on CALIPSO*, and *boresight* mirrors….” (such language indicates heritage for the design)
- Line 220: perhaps add: “..to obtain a uniform illumination *and uniform field* distribution…”
- Line 225: Also successfully implemented and tested on the airborne OAWL system (which further supports your case!)
- Line 265: Do you mean that each spot fills an 8x8 pixel area?
- Line 261-270: The discussion is focused on using the same A-CCD as was used on Aeolus, however discussions of using a new ACCD or different type of detector are under consideration for Aeolus. Could the authors suggest what approach would be idea for a QMZ design? Perhaps ranging from more ACCD rows, to a different type of detector?
- Table 2: “Emitter Linewidth”: according to the text, the 200 MHz represents the allowed spectral jitter or drift over the 50 pulse (1/2 second) accumulation time and likely does not represent the laser linewidth. Perhaps clarify this by calling it “Accumulated Emitter Linewidth (1/2 s)” or even “Allowed laser linewidth”. Also, (see above comment on “emitter” vs. “transmitter”).
- Line 293: Clarify that “*For a 3.2 cm OPD*, the modulation by the molecular return….” For some longer OPDs, molecular return will provide NO modulation, just offset.
- Line 305: YES, this is true, however won’t there be a backscatter ratio below which the contrast difference is too small to clearly estimate?
- Line 330: Be sure to clarify that because of the *specific type* of field compensation used in this specific design, the OPD variation is only dependent on 4^{th} power of the source angle. There are other types of field compensation (e.g. cat’s eye) for which the OPD variation
- Line 331: Please provide a reference for the equation provided in this line.
- Line 340: Indeed, smaller incident angles on beamsplitters make it easier to balance reflection and transmission values.
- Line 355: The authors suggest using the laser in multimode operation to perform the amplitude (sensitivity parameter) calibration– but for many seeded lasers, running them multi-mode comes with a risk of damage due to modal interference.
- Line 337: modulation calibration can also be performed by allowing the laser to drift in frequency while remaining seeded. This can be achieved fairly easily by temperature tuning the seed laser source, or laser cavity.
- Line 369-374: Please indicate the wavelength for these profiles in the text for clarity. Have these profiles been validated in any sense using data from Aeolus and/or CALIPSO?
- Figure 4: Please increase the text font size and overall figure clarity. The text is too blurry to read. Sub figures (a) and (b) do not have titles indicating the wavelength, etc. Likewise, please indicate the wavelength for these profiles in the figure caption.
- Section 4.2: It’s nice to see this study on the impact of the horizontal light of sight angle on performance, though it would be interesting to compare it to previous studies done for Aeolus back when the mission was selected. This type of angle analysis shouldn’t be unique to this particular design, but if it is (for some reason this reviewer is missing) then please clarify. It indicates that the difference in 1/R^2 is less than the error in retrieving the horizontal LOS from a smaller pointing angle.

- Table 3: The authors may wish to clarify here that the total power is the same for the two systems. Aeolus requirements were based on a 2x higher laser pulse energy, and the QMZ approach is based on the as-operating Aeolus pulse energy but with a 2x pulse repetition frequency.
- Line 481: "where such an accuracy may be more acceptable than bias for assimilation purpose…" The terms "accuracy" and "bias" are often tied together. Do the authors mean that precision (or "uncertainty" or "random error") is more acceptable than bias?
- Line 508: The authors refer to a 10-3 relative error in the sensitivity calibration of each QMZ channel, however it might be good to clarify that this does (or does not) include the detector response sensitivity. For example, if one channel sees a high portion of the interferometric fringe during the outgoing pulse, will the detector response have any impact on returns for that channel?
- Line 564: the authors should clarify that "…the *short OPD* QMZ does not attempt to separate molecular…." There are long OPD QMZI designs that easily separate these two.
- Line 619-620: Is it possible to show a scaling of the performance of the UV HSRD-LNG airborne lidar to space-based operation (e.g., see Baidar et al. 2018).
- Appendix A: This is a good review of previous papers by the authors describing QMZ performance. Has data from the LNG system been used to validate this model and if so, how did they compare?
- Line 670-684: Why is 3 cm being used here for the OPD vs. the 3.2 cm chosen for the optimal system?
- Line 689: The assumption that the background can be measured over a long duration may meet challenges with highly varying cloud albedo over orbit.
- Appendix B: It's quite nice to see this analysis in a publication, showing the impact of OPD and maximum aperture driven by etendue and it would be nice to see this in the main paper, if room allows. It's important to clarify, however, that the analysis applies to QMZ structures using field compensation plates.
- Appendix C: Many of the points made in this section are really important in the argument for using a QMZ type system for an Aeolus follow-on. If possible, can more of this be moved into the main part of the document?

Example English edits (this is not an exhaustive list - please review further).

- Line 87: What is implied by "should take over"? Perhaps "will provide continuity for CALIPSO lidar and CloudSat radar observations for……."
- Line 98: What is meant by the phrase "….is ruled by…" ?
- Line 100: Only one reference is listed regarding the value of upper level winds to NWP, but there are many more that have been published.
- Line 107: "large efficiency detectors" should probably be "high efficiency detectors"
- Line 111: This line is awkward, perhaps the authors simply meant to say, "…the interferometer configuration has revealed operation and performance constraints."
- Line 119: "199b" should be "1999b" and "Witchas" should be "Witschas"
- Line 118: "requiring performing independent particulate…" is a bit awkward. Perhaps try, "requiring performance of independent particulate scattering…"
- Line 124: "implies…." could be replaced with "imposes a higher accuracy requirement on the laser pointing to maintain…"
- Figure 1: suggest: "receiver Telescope" (vs. "reception"), "boresight" vs. "steering"
- Line 240: suggest replacing "…we give here priory to.." with "…we give *priority* to…"
- 290: ODP should be OPD
- Line 367: "emitted the" should be "the emitted"
- Line 387: "…allied to a low reading noise." might be better as "…attributed to low read noise."

- Line 445: "…in the due…" ? Should that be "…in the PBL, due…"
- Line 542: "Witchas" should be "Witschas".
- Line 613-614: This sentence is confusing. Do the authors mean "…can be derived from meteorological analysis to provide products with the required accuracy."?
- Line 651: "celerity" is an unusual term for the usual "speed" of light terminology– but I guess it does apply here.
- Line 728: There is no Witschas 2008. Should that be 2010?