Review of *"JLH Mark2 – An Improved Opto-Mechanical Approach to Open-Path in situ Water Vapor Measurement in the Upper Troposphere / Lower Stratosphere,"* by R.L. Herman, et al., Egusphere-2024-4019

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This is an important contribution to the scientific literature, and AMT is an appropriate forum for publication. I recommend that the paper be published with minor revisions. The JPL group is uniquely positioned to get this information into the public domain. First, they pioneered this method for water vapor measurements from aircraft. Second, they showed the way forward that others have used. This paper documents a number of important features of the JPL aircraft instrument in various versions that are important for understanding their performance and accuracy. Although my comments are extensive, they are all straightforward for the authors to address, even the "most significant comments," and I trust them to decide how best to respond without the need for further review.

Most significant comments

[1] Line 217-220: There are important details in these improvements that could be explained more clearly. What, specifically, about the old components and methods resulted in more noise? Narrowing the scan presumably increased the dwell time on the main water absorption line, but this also comes at the expense of characterization of the background in the water continuum – maybe less important at very low pressures, but certainly important in the troposphere. Is it the case that changing from variable resistors to fixed resistors reduced noise, as opposed to drift in the gain? There is inherent "noise" from resistors, but I would think temperature stability is the bigger issue.

[2] Line 281-292: Although this is titled "Laser Calibration," I would suggest changing to "Laser Characterization" as it is more than calibrating. There is a lot to unpack in this short, but extremely important section that will be missed by most non-experts. It would help if the authors elaborated somewhat on why each of these matter. For example, "spectral purity" largely means how the emission of the laser is centered on a single wavelength and does not produce significant energy in "side bands." If this were to occur, there would be some residual power to the detector even when the water absorption is optically deep. There are other ways for this to occur, however. Light scattering by surfaces of the Herriott cell will reduce the effective path length even if 100% of the laser emission is in center of the water absorption line. So practically speaking, one has to estimate this contribution to scattering, which will depend on the optical depth of the absorption – i.e., it won't be the same for all concentrations of water because as the signal from the longest path is absorbed the contribution from signals from shorter paths become proportionally more important. I would suggest expanding this section a little bit to include some motivation behind each of the steps taken to characterize the laser, especially when the ultimate proof of accuracy will be a careful lab calibration that relies of some standard method for quantifying the water vapor mixing ratio over a wide range of pressures, temperatures, and water concentrations.

[3] Line 466-476: Please explain what you mean by "laser tuning rate." I assume this means the "wavelength versus time" or "versus index point." Also, why is this procedure necessary if you

are ultimately pinning your results to laboratory calibrations with known water vapor? I realize it is useful to know more about how the instrument operates, but the fact that "the response of the electronics is indeed slow, contributing to the observed somewhat large effective instrument linewidth" wouldn't seem to matter much at high pressures in the UTLS, whereas it might for a measurement at very low pressures. Maybe you can explain how RC filters, which are important for reducing high frequency electronic noise and, hence, are essential for the excellent precision you report in Figure 10, affect the accuracy of measurements at higher pressure – if at all.

[4] Line 518: What, specifically, about the "limited time response of the signal chain," causes the second negative lobe in the 2f spectrum to be "truncated?" From Figure 7 there appears to be a significant contribution from the Fabry-Perot fringe, which has a period of about 200 "index points." Or, put another way, is this "truncation" typical? Does the Fabry-Perot fringe wander with time or temperature? If this second lobe is always shifted upward, it could be the case that the phase shift in your 2f demodulation calculation is slightly off. Are you able to vary this value, or is this a non-adjustable feature of the code?

[5] Line 520-521: Do you know which "back reflection?" Is this the final reflection off the surface of the lens mounted to your detector? If so, is there a way to angle the detector or insert a wedge so that this can be minimized? Also, unless this fringe is stationary, it will contribute to your "error." Is this a significant source of uncertainty in your calculated H_2O at low mixing ratios? Or is the width of the fringe much greater than the width of the H_2O absorption?

[6] Line 559-561: The description of "laser drift" is a bit confusing. Are you saying that the actual temperature of the laser substrate is changing with ambient temperature for a fixed set point of the TEC control, in which case the wavelength of the laser will change? Or is it the case that with your lasers the output wavelength is determined mainly by the injection current, and the efficiency of conversion – i.e. output power versus injection current – increases with decreasing laser substrate temperature without impacting the output wavelength of the laser? Naively, I would expect the former to be the case, and you should be able to know this from the shift in the position of the absorption line.

[7] Line 577-588: The AIDA chamber demonstrations are an important "necessary" condition for the water vapor sensors that participated, meaning that one would expect the instruments to agree to within their stated uncertainties. In this case, you report "within 10% over a wide range of temperatures" which seems to be considerably larger than a back-of-envelope estimate of errors you note of 1% to 2% of various components of your careful analysis when added in quadrature. Because the JLH family of instruments are so critical to our understanding of stratospheric water, representing the only near-continuous record of in situ observations from aircraft spanning over three decades, it seems to me this paper is an excellent opportunity to "plant the flag" and make definitive statements about your best estimate for true uncertainty in the measurements without worrying about other methods which are much more difficult to "prove" from first principles. Although not required for this paper to be publishable, I think you should expand on this section, if only a little, – perhaps ½ to 1 page – to provide your best "sense" of what the true uncertainties in the water vapor mixing ratios are when the instrument is working properly. Hopefully at some point you will have a more rigorous analysis of

uncertainties, as this would be a very useful addition to the literature and historical record for JLH. Until then, would it be possible to make a summary statement about the largest sources of error in the JLH measurements and what they add up to in terms of accuracy over a typical range of pressures and temperatures for your flights?

[8] Line 590-594: This is also useful in the context of my statement about accuracy above. However, I believe the FLHYT instrument is a close relative of the JLH, having been designed and first built under the supervision of Randy May at SpectraSensors. It may be worth pointing this out, as one might expect these two instruments to yield similar results as dominant errors in them may share features that are common. Also, because JLH has a much longer optical path, it can measure to much lower mixing ratios in the stratosphere, whereas the FLHYT cuts off below 100 ppm, so it's value for UTLS measurements is somewhat limited.

Minor Comments

[9] Lines 16, 334, and 583: 'in situ' (no hyphen)

[10] Line 18-20: You could edit to read: "This instrument paper reports on the redesigned opto-mechanical structure of the instrument, new data retrieval algorithms, and updated data analysis procedures, along with recent laboratory and field performance and a comparison with other water vapor instruments."

[11] Line 16/22: The copy editor will know the correct style to use. You have "15 years" on Line 16 and "eight years" on Line 22.

[12] Line 29: should super saturated be one word?

[13] Line 31: "soot" may be a bit vague or too broad here, or is that your intent? For ice nucleation, I would guess metals, PAHs, others may be known better now from lab studies?

[14] Line 37: "UTLS" or "UT/LS"?

[15] Line 48: It might be helpful to state what year the mirrors were replaced.

[16] Line 64: How precisely do you know the path length, and is this invariant? In other words, is it to one part in 10,000 at all temperatures? Is it based on a ray trace or do you measure it somehow? You may want to explain in more detail – e.g.. "based on a ray trace…" and "this value is thought to be precise to one part in …" Also, accuracy matters, but I realize you calibrate the whole system with known water vapor, which effectively lumps the uncertainty in path length with the cross section of H2O.

[17] Line 84: "waterline?" Do you mean "water vapor absorption line?"

[18] Line 85-86: "28 VDC for de-ice" is a bit aircraft jargony. Maybe say "heated by a resistive element powered by 28 volts DC to reduce icing."

[19] Line 87: you will probably need to spell out ARINC somewhere – first use or in a list.

[20] Line 108: “loosely” may be too ambiguous. Maybe “approximately” is better, if you mean “we aren’t sure that the focal point is exactly at midpoint.”

[21] Line 117-119: Although the additional path after M0 represents only 0.8% of the total, a slowly purged volume of air in this “dead space” containing only 50 ppm could induce a +5% bias in the measurement. Is there a way to know what the H2O actually is in this dead space?

[22] Line 119-121: I realize this is getting into the weeds, but it would be useful to expand on this issue, which is critical for line-fitting at low pressures. A +/-0.01 degree shift of similar DFB lasers I have used is equivalent to xx cm-1 in wavelength, or about X5 of full-width at half-maximum. Depending on the rate of such a shift – i.e., during a scan or across multiple scans that are averaged into a single line shape profile, the gaussian shape can be distorted enough to effect “Beer-Lambert law” analysis.

[23] Line 162: It is obvious to me that “frequencies” refers to “data acquisition rates/speeds” etc., but maybe be more clear here to avoid any confusion with “frequency of laser emission.”

[24] Line 165: Might be simpler to just say “The laser current scan is produced as described in May (1998).” If you intend to keep this – which would be fine – it would help to elaborate, as it may be hardware specific for the digital-to-analog converters used. For example, in our “Teensy” version of a R.D. May-like instrument described recently, we also use direct memory access, but we don’t translate it using an audio codec. Rather, we can just output the stream with simple functions available in the Arduino library. So what matters isn’t the “codec” per se, but rather the bit resolution – e.g., 12 bits in our case – and the update rate.

[25] Line 166: Maybe rearrange to “sawtooth-shape current ramp…” and “at a repetition rate of 8 Hz” so that it isn’t confused with a wavelength specification. Also, maybe “water absorption line” instead of “feature.”

[26] Line 166-167: Very minor, but maybe say “measurement method” rather than “detection method.”

[27] Line 168: Perhaps “water absorbance is quantified by direct transmission (called “DC”).” And why “DC” and not “DT”?

[28] Line 170: I am admittedly “old school” when it comes to digital audio. 44.1 kHz is a “CD” quality data rate. In order to generate a 128 kHz sine wave and avoid Nyquist ratio issues, I would think you would need at least 1 Mhz update rates, which isn’t conventional “audio” – or is it? Maybe spell out the bit resolution and update rates specifically here, rather than saying “audio.”

[29] Line 202: Maybe give the exact part numbers for the Ampro PC-104 motherboards used? “Legacy” could mean many things.

[30] Line 204: Because this is such an important snapshot of an outstanding instrument, it might be useful to provide the exact part numbers for the Vicor DC-DC converters and ripple attenuator

modules as these have changed over the years as electronics have become smaller and more energy efficient.

[31] Line 205: A lot is buried in the "custom electronics board" that I am not sure what to recommend. There is probably some proprietary information, in which case it may not be possible to expand without legal implications. But if you could, it would be useful to describe how these "custom boards" work, in principle, as this was the "magic" of the early JPL/R.D. May-designed systems. Nothing too detailed is required here, so just general approach would be useful. For example, the operating system, information about ADC resolution and data rates, communication with the main Ampro computer, etc.? Is there any storage, or is it all done in volatile memory? Or, can you refer to a paper or technical publication that describes all of this? Similar for "flash card" – what kind? How large are the files? Information that might be useful for providing some historical context, as modern storage devices have become much faster and higher capacity.

[32] Line 209: Also nit-picky – what matters more is the temperature stability – i.e., +/- 10 degrees or +/- 1 degrees – rather than the way the resistive heating elements are powered. It might be more useful to give the approximate wattage and the controller – i.e., Minco model … and the range of temperatures observed – I think you have those housekeeping values, correct?

[33] Line 209-210: This might be a place where a more precise value would be very helpful. I would guess the wavelength stability of the laser is highly dependent on this "baseplate" temperature. Are you able to maintain that to +/- 5 degrees? +/- 1 deg? Even better?

[34] Line 211-212: This is where the temperature precision really matters. I presume it is the "0.01 C" that you refer to in Line 119-121. Maybe make that clear – or, if I am wrong, clarify what the stability actually is. Again, given how important this is to wavelength stability, I assume it is something that is known and/or measured.

[35] Line 212: Is it possible to provide a rough distance between the laser and thermistor? This is important for temperature hysteresis/control.

[36] Line 215: nit picky – "signal-to-noise ratio of the water vapor measurement…"

[37] Line 222: Why is there a new board to augment the one mentioned in Line 205, rather than replace it? Wouldn't a new board be able to handle the old control while adding new capabilities? Maybe explain the idea behind the decision to not just upgrade. Or maybe this is what you intend with Lines 236-239, in which case you could bring these lines up a bit or merge these two pieces.

[38] Lines 232: Does Interagency Working Group need a reference?

[39] Line 248-249: How does filtering remove the background? Or do you mean passing the A/C component of the signal and removing the slow ramp?

[40] Line 296: This is the third instance mentioning "128 kHz" modulation. I'm not sure the repetition is necessary, so it may make sense to find the natural spot for first use of this and only mention it again if there is a need to elaborate.

[41] Line 298: Why is it "critical to know the actual modulation amplitude in spectroscopic units?" Isn't it just the case that the value for the modulation amplitude in flight be the same as the value during lab calibrations? It seems that this quantity depends on many factors, including the initial DAC driving function of the laser, detector capacitance, filtering electronics, and wavelength stability of the laser – i.e., precision of TEC temperature control. It also depends on the nature of the DFB laser substrate, which is largely empirical, and differs from laser to laser. So even if one "knows" the amplitude, there is still much to be concerned about if the value isn't stable. Maybe elaborate on why, for JLH in particular, this value is critical – i.e., is the calibration matrix keyed to a value of modulation amplitude?

[42] Line 305-307: For small optical depths it is important to document that 99.9% of the light – I presume in a non-H_2O-absorbing region of the spectrum – is transmitted in the final pass of the Herriott cell. However, for large optical depths the relative contribution from scattered light from earlier passes with shorter pathlengths to the detector will increase. Did you estimate what these contributions might be? E.g., how close to "null" is the signal for an optically deep line at line center? This won't matter so much for stratospheric water, but it could become a systematic error with decreasing altitude in the UT.

[43] Line 364-365: It would be useful to describe why the smaller temperature dependence of the line at 7299.4311 cm-1 is "better." Either line would still need to use a measurement of T in order to convert from H2O concentration to mixing ratio using the Ideal Gas Law, meaning that errors in T will factor proportionally into errors in mixing ratio. Unless the T dependence of the line strength is significantly greater than "proportional to T" over the range of values encountered in flight, it would seem that the uncertainties in measurements using the two different absorption lines would be comparable, especially if you are ultimately tying down your results to HiTran parameters validated with laboratory calibrations. So why is a line with a smaller sensitivity to T "better?" Is it because temperature isn't known accurately enough? Or is it simply less convenient to add another parameter into the calculation of "mixing ratio?"

[44] Lines 370-460: Sections 4.1 and 4.2 report on details that are important to document and seem fairly clear. I have no additional comments.