We thank the referees for their kind investment of effort and feedback. We respond to all 3 referees in this one Author Comment. To facilitate the revision process we have copied the reviewer comments in black text. Our responses (Author Comments or **AC**) interspersed therein are in regular blue text. The revisions to our manuscript in response to referee comments are indicated in **bold blue text**, following a particular AC. All Figure references in Author Comments are the *new* figure numbers of the revised manuscript, unless otherwise noted. Old-New figure number cross-reference table is included below. Our revised manuscript, with Microsoft Word track-changes enabled, is included as a supplement. To reduce clutter, the track-changes do not include Figures or cross-references, thus displays as-revised appearance. An additional supplement presents the revised manuscript in final clean view.

Many of the plot graphics have been redone to AMT standards, but a few remain, which we will upgrade for the typesetting stage after acceptance of final revision.

Old vs New Figure Numbers

Old Figure Number	New Figure Number		New Figure Number	Old Figure Number
1	3		1	9
2	12		2	10
3	13		3	1
4	5		4	New
5	6		5	4
6	7		6	5
7	8		7	6
8	10		8	7
9	1		9	New
10	2		10	8
11	14		11	New
12	16		12	2
			13	3
			14	11
			15	New
			16	12

Anonymous Referee #1

Received and published: 31 March 2016

The present paper reports on novel application of zenith sky radiance measurements in the visible and near IR spectral ranges with the aim to infer the cloud optical depth (COD). In the core, the method appears sound although it apparently does not deliver unambiguous (and thus very accurate) results. A validation of the method with the AERONET based cloud optical depth retrieval is presented. As such the manuscript could be considered to become published in AMT. The present form the manuscript however comes short in couple of some major points which are outlined below. Therefore I only recommend it for publication after a major revision.

Major comments:

1. Structure of the manuscript: The structure of the manuscript largely deviates from the common form in scientific publishing, i.e. by having a.) a concise abstract, b.) an introduction, c.) a section describing the instrument, used methods and tools, followed by d.) a measurement section, and e.) a results and discussion section, and f.) a concluding section. In particular

AC: Our revision restructures the order of sections and content to comply with form suggested by RC1.

- The introduction (as it is) does not describe the state of art, nor does it motivates why a novel instrument and method for cloud optical depth retrievals is necessary or wanted, and what the potential applications are (beyond some very general and not referenced introductory remarks)

AC: Our introduction is substantially revised to address the deficits noted by RC1, namely discussion of motivations and contributions.

- The section describing the instrument, used methods and tools is dispersed over the manuscript so that for example the instrument description appears in a section 7 (rather than upfront in section 2. which could be called ‘Instrument description, or Methods&Tools et cetera

AC: Our revision restructures the order of sections and content to comply with form suggested above by RC1.

- . . ...

- Finally and in conclusion of 1., it becomes evident that the manuscript is a mixture of a technical description, a collection of some recipes, knowledge and wisdom not referred to existing scientific work, and a minor scientific part. Upgrading the later, however, would be decisive as to whether the paper is suitable to be published in scientific journal.

AC: We hope RC1 will be gratified by our revisions, which include new supporting material.

2. Physics et cetera

- Page 2, Line 12: The oxygen A-band is not free from absorption by other species. This is only true but for the spectral region at the lower wavelength end, but at the longer wavelength end water absorption plays role.

AC: Pfeilsticker justifies his use of the A-band as having little overlap in Pfeilsticker et al, (1998). The degree of water vapor absorption is minimal, as shown in the added Figure 11 and new discussion. But the more important point is that this minimal absorption does not impact our technique, since we are not attempting to retrieve *numerical* COD from the low-resolution A-Band EQW, as opposed to approaches employing high-resolution A-Band spectrometry.

The A-band is virtually free from absorption by other atmospheric constituents (Pfeilsticker et al, (1998)) except for aerosol and cloud continua extinction plus a very small amount of line absorption by water vapor (Figure 11).

{Figure 11 Caption} MODTRAN5 calculation of atmospheric transmittance for a ground-based zenith path to space. The Oxygen A-Band is virtually free of absorption by any other species except for aerosol and cloud continua extinction. At 0.1 cm^{-1} spectral resolution, H2O (water vapor) has a minimum transmittance of 0.9972 across the A-Band.

- Page 3, line 15: For zenith scattered light, the EQW of the oxygen A-band is known not to uniformly increase with COD. In fact it may even decrease with COD. Only low-lying and optically thick clouds increase the EQW (in the diffuse regime), while upper atmospheric and thinner clouds (cirrus) tend to decrease the EQW (since the optical path is shortened as compared to clear skies).

AC: See revised "nose" plot (Figure 12), where EQW is non-monotonic for COD~<1. We inexplicably swapped a low-fidelity notional nose plot into our original manuscript rather than Figure 12, which reflects our longstanding understanding of the points raised by RC1. Figure 12 now plots both measured data and a superimposed RT model-generated smooth-fitting "nose" curve.

COD is a two-valued function of up-looking spectral radiance while oxygen equivalent width is a monotonic function of COD for COD~>1. By plotting SR440 versus EQW as COD increases from no cloud to thick clouds one traces out a "nose-like" shape (Figure 12). For the very lowest COD values, EQW decreases with increasing COD and the slope is negative. Beyond about COD=1, the lower portion of the "nose" where the slope is positive corresponds to the optically thin regime; the upper portion where the slope is negative corresponds to the optically thick regime.

- Page 3, lines 29 to 32: Your 'Blueness factor' is often (mostly) called color index (google for respective references, there are 100s publications). Beyond this non-standard use of notion, no further motivation (for example by RT modelling, or by referring to previous work) is given how you arrive at the statement 'a threshold of 5' is sure indicator of optically thin clouds'. In a technical description of an instrument, this statement is probably ok without further explanation, but it is certainly insufficient for a scientific paper.

AC: We have renamed the Blueness factor the "**color index**".

The cloud optical thickness regime determination operates in two distinct radiance domains. When the COD is very low, e.g. COD<=1, the amount of radiation in the NIR is very small and the signal to noise ratio of the EQW is low (e.g. “clear sky” in Figure 3) and thus the nose plot slope is too low to resolve the thickness regime. The ratio of SR440 to SR870, termed the color index, has a much higher SNR and is more reliable in this regime. This, of course, is a simple consequence of the wavelength dependence of Rayleigh scattering. For low-moderate altitude water clouds, small-moderate SZA, and typical 440 nm ground albedos less than 0.2 (Figure 6), our data analyses have found a hard threshold of 4 to be a sure indicator of optically very thin clouds (e.g. “clear sky” in Figure 3) and a soft threshold of 2<index<4 to be a strong indicator (e.g. “COD<1” in Figure 3). When the color index is less than 2, the cloud’s optical thickness is not well correlated with the index, and we must rely on the nose plot slope.

- Why should the inferred COD (measured in the zenith sky for a certain FOV) tightly compare with the cloud mode AERONET data? For example how do the probed cloud areas compare? What are your expectations if they do not totally overlap? Finally why do the AERONET and TWST CODs correlate with a slope of 0.843? Again when digging into these questions, scientific work would actually start.

AC: In section 4.2.1: **Several conclusions follow from the very good agreement among TWST and AERONET spectral radiances. The first is the expectation of a COD comparison not influenced by TWST spectral radiance errors. As a corollary, the COD comparison should not be unduly influenced by different fields of view (1.2 ° for AERONET versus 0.5 ° for TWST) and zenith pointing (robotic control for AERONET versus fixed tripod with bubble level for TWST), given the close agreement over many different cloud conditions. The sensors were laterally displaced by about 3 m, and for a 1 km cloud base altitude their field of view footprints are 20 m and 8 m.**

Therefore the source of disagreement lies elsewhere. But we revisit the regression fits (section 4.2.2, with AC-added underline emphasis): **A linear fit of TWST to AERONET Cloud-Mode COD, for the 235 cases of thickness regime agreement, for fixed zero-intercept, found a slope of 0.843 (TWST reporting higher COD values) with an rms difference of COD 3.2. This was repeated while dropping the two high COD value outlier points (Figure 16), but the slope only changed by 1%. No evidence of a constant offset between TWST and AERONET Cloud-Mode was found. However, the sparsity of such evidence is due to the relatively few optically thin COD cases available from AERONET, due to the secondary mission status of its Cloud-Mode. (When skies are largely clear, AERONET executes its primary mission of aerosol optical depth and microphysical property retrieval measurements). Therefore, another linear fit, this time with free-intercept, found a slope of 0.905 and constant offset of -2.1.**

Now, given our better-supported albedo sensitivity findings, we can explain much of this disagreement (section 4.2.2): **The two primary candidates for causing the observed disagreements are differences in the TWST and AERONET Cloud-Mode lookup tables and effects from the trimmed mean process. There may also be some residual effects due to FOV and pointing differences, although these are not expected to be large due to the very good spectral radiance agreement (section 4.2.1). A partial explanation centering on the lookup tables is the difference in assumed ground albedos between the sensors. The TWST SR440-to-COD lookup table generated from MODTRAN used a weighted average of water, deciduous vegetation, dead pine, and sand albedos, resulting in an earth albedo at 440 nm of 0.078545. On the other hand, AERONET updates its ground albedo episodically every few days from MODIS data products or a (rolling) 16-day average MODIS historical database (Chiu et al, (2012)). For this dataset, the AERONET-employed albedos were lower than that assumed for TWST, varying between 0.02-0.04, 0.03 average. Most of the sample points are in the optically Thick regime, and according to our albedo sensitivity discussion (section 3.2.2), a *lower* than expected albedo implies TWST retrieval of *higher* COD values in the Thick regime, consistent with the linear fits. Figure 8 depicts an approximately constant relative COD retrieval error of about 10% per 0.1 albedo increment. The 0.05 average difference in assumed albedo therefore explains about half (0.05) of the difference between a slope of unity and the fitted slope (0.905).**

- Page 6, lines 20 to 27: Here the content is totally unclear. What is a bright point radiance, and what is interpolated (I guess the COD as function the maximum radiance in the nose curve?)

AC: This albedo sensitivity section has been substantially revised (and corrected). The (hopefully) improved explanation now depends on some development in prior sections. The findings are now supported by computations using asymptotic RT theory relations (King, (1987) and Melnikova et al, (2000)), so original Fig7 is now revised to new Figure 8 with new Figure 9. Hopefully, the following excerpts from the revised manuscript will indicate our responsive changes:

The plot in Figure 8(a) further explores this sensitivity, and shows the signed change in retrieved COD value for an unexpected increase in the ground albedo from 0.1 (for which the radiance-to-COD lookup tables are computed) to 0.2. Each curve, for either thick or thin cloud, is for some fixed percentage of the aforementioned 1DRT bright point radiance "Lbrt" (which varies with SZA, cf. Figure 4). These curves show that a higher than expected albedo implies retrieval of a lower (higher) COD in the Thick (Thin) regime.

And regarding 1DRT bright point radiance and (new) Figure 4, a prior section states:

The model used for generating 440nm radiance-to-COD look-up tables is the MODTRAN5 atmospheric radiative transfer code (Berk et al., 2006). MODTRAN employs the DISORT algorithm (Stamnes et al, 1988) for plane-parallel stratified media, i.e., idealized 1-

dimensional radiative transfer (1DRT). Calculations are done for a typical water stratus cloud above a stated ground albedo, for a stated nominal aerosol profile, over a grid of COD and solar zenith angles. Figure 4 is a graphical depiction of sample tables. For any solar zenith angle, there is a "bright point" radiance where the idealized 1DRT cloud radiance reaches a maximum, typically occurring for a COD between 2 and 8, as seen in Figure 4.

- Conclusions: Page 10, lines 27 – 31: Justify why the signal to noise (due to the photo electron shot noise) limits the COD detection? What are the limits of COD detection due to errors and uncertainties in the retrieval. Here you could consult the book of Rodgers 2000 (Inverse methods for atmospheric sounding, Singapore, New Jersey, London, Hongkong: World Scientific.)

AC: We eliminated the statement of relative COD error from instrument causes. As RC1 indicates, more substantial COD errors ensue from model and parameter uncertainties, as we have hopefully made clear in our new sections 3.2.1 titled "Radiative transfer construct" (discussing 1DRT vs 3DRT effects) and 3.2.2 titled "COD error sensitivity to radiative transfer parameter uncertainties".

3. Terms, notation, and description: Sometimes it becomes difficult to understand what is meant in the manuscript, since often the notation infers from 'laboratory slang'. Just a few examples (out of many).

- Title: My strong feeling is that the title of manuscript does not reflect the contents of the paper, since you only use the EQW of the oxygen A-band to provide 'useful information about whether a measurement is in the optically-thin or optically-thick regimes' (page 3 lines 15). In fact your method mostly relies on inspecting the measured zenith radiance at 440 nm (which is an ambiguous proxy for the COD).

AC: The title is now changed. The revised manuscript now attempts to make clear the RT foundations and precedents of the approach, which RC1 accurately indicates.

- Page 2, line 5: 'absolute power': In radiation physics it would properly be called spectral irradiance, or band integrated irradiance. . .

AC: The text in which that terminology appeared has been eliminated. Rather, elsewhere we simply refer to measuring the zenith spectral radiance.

- Page 2, line 11: are due to. . .constituents of the sun: These solar lines are called Fraunhofer lines.

AC: "**…Fraunhofer lines ~~constituents of the sun~~…**"

- Page 2, line 24: 'Cloud state'. Even though grammatically correct, the proper notation would be 'cloud cover' or 'type of cloud cover'. The notion 'cloud state' could also and easily (for experts) be confused with the thermodynamic state of the cloud particles, i.e. whether they are liquid, mix-phased and solid.

- Further, sometimes you refer to the 'cloud state' as optical state of the cloud (compare Page 2, line 24 with page 3, line 26). Changing the notion in scientific paper is very dangerous since

a.) in order to avoid confusion the same thing should always have the same notion properly defined early on in a manuscript, and

b) the notion optical cloud state is not unambiguous since many small cloud particles (polluted clouds) as compared to few but large cloud particles (pristine clouds) would lead to a different cloud color (white vs grey respectively), also a form an optical cloud state.

AC: We now employ the terminology "**cloud optical thickness regime**" or "**thickness regime**" when usage sense is clear.

- page 4, line 16: clouds to not 'switch' between think and thin states, but their optical thickness (and skylight radiance) has a deep routing in atmospheric dynamics, and thermodynamics.

AC: "**…for passing or evolving clouds spatially well-resolved within a narrow field of view, ~~we know that clouds do~~the thickness regime should not switch rapidly between ~~the~~ thick and thin ~~states~~ except possibly near the bright point (thick/thin regime boundary) where ~~the~~ a switch is inconsequential ~~anyhow~~to the retrieved COD.**"

- Page 5, line 5 – to 11: Define Lsc

AC: This (new) **section 3.2.3** has been re-written, eliminating the math symbols and equations, and instead describing the lookup table interpolation in graphical terms by referring to new Figure 4.

- Page 6, line 18: thin/thick duality: I guess you mean the ambiguity in skylight radiance at 440nm for thin and moderate thick cloud.

AC: replaced "duality" with "**ambiguity**".

- Page 6, line 30: What is a percent brightness?

AC: Deleted this erroneous/irrelevant statement.

- Page 5, line 19: What is a 'spectral agility'? (choice of wavelength)

AC: **This flexibility in the choice of wavelength is basis of the term "Spectrally-agile" within the TWST acronym.**

- Page 7, line 21: What is a 400nm long pass filter? (a band filter of a 400 nm wide band pass ? starting at?).

AC: Deleted this sentence and erroneous reference to filter.

- Page 9, line 21: What was averaged, and how?

AC: **A comparison of COD values between TWST and AERONET Cloud-Mode must recognize the time-sampling differences between them. For these comparisons only the 90 second average COD was available for AERONET Cloud-Mode, which is a form of trimmed mean based on up to ten instantaneous COD measurements during each measurement period (see Chiu et al, (2010) [sec.2.3]). … To attempt a comparison, each plot data point represents the average of the 90 instantaneous COD measurements produced by TWST during that same 90 second period for AERONET.**

- Page 10, lines 8 to 10: . . .. what is, and why prevented the secondary mission status of the (Aeronet) Cloud-Mode to infer COD of optically thin cloud covers?

AC: **No evidence of a constant offset between TWST and AERONET Cloud-Mode was found. However, the sparsity of such evidence is due to the relatively few optically thin COD cases available from AERONET, due to the secondary mission status of its Cloud-Mode. (When skies are largely clear, AERONET executes its primary mission of aerosol optical depth and microphysical property retrieval measurements).**

- Page 10, line 29: What is photon noise? (photo electron shot noise?)

AC: We omit mention of noise sources here (they are addressed in the instrument section, where we now use the term "**photo-electron shot noise**"), and merely summarize the SNR. We also omit the misleading COD error statement.

"**At peak signal, at a COD value of approximately OD 5, the SNR ~~due to instrumental and photon noise~~ is estimated to be 5,000:1 for 1Hz reports. ~~This peak occurs at a COD value of approximately OD 5, so the implied rms COD error is OD 0.001.~~**"

- . . ..

- Finally, including a flow chart appears to be necessary in order to understand the various steps involved in the data retrieval and reduction.

AC: We hope the clarity of the revised manuscript eliminates the need for a flow chart. The restructuring of sections, addition of figures, and replacement of maths with graphics hopefully facilitate understanding.

4. References The manuscript mostly lacks references to previous studies in the field. Some examples are given below:

- The introduction has no reference at all, which never occurred to me in the scientific literature.

- Page 4, Nose plot: Here you could easily refer to early work of King and Nakajima, or later studies of Marshak et al., and many others. Just inspect the list of reference in papers you cite or google for it. . ..

- Page 5. When dwelling into the sensitivity of the inferred COD as function of ground albedo certainly the early work Kattawar, Melnikova, Marskak, Chui and many others are worth to be cited. . .

- See above for Rodgers (2000).

AC: In response, notes on *new* references:

In our revised **Introduction**, for motivating the measurement of COD, (Kikuchi et al, (2006)) really does use COD per se (and not also requiring r_e) as the column-integrated constraint for "calibrating" profiling sensors (e.g. LWC or r_e profile). We cite Nakajima and King, (1990) for satellite-based COD retrievals. Liu et al, (2013) are cited as example of use of ground-based COD to validate satellite-based retrievals.

In our revised **Introduction**, we distinguish between retrievals of COD alone (as does TWST), and joint retrievals of COD and effective radius r_e. We cite Nakajima and King, (1990) on the use of dual wavelengths, absorbing and non-absorbing, to jointly retrieve COD and r_e. Citations to other ground-based COD sensors with dual-wavelengths: McBride et al, (2011): SSFR and SWS; Liu et al, (2013): ASD spectrometer; Fielding et al (2014): SAS-Ze.

In **section 3.2.2** we cite McBride et al, (2011) to support our finding of relative insensitivity of COD to r_e, based on their Fig3b and Fig7. We cite King, (1987) and Melnikova et al, (2000) for asymptotic RT theory used to support our albedo sensitivity findings.

Anonymous Referee #2

Received and published: 4 April 2016

The manuscript includes three major parts: 1) description of a cloud optical depth (COD) retrieval method that makes use of the zenith radiances at 440 nm, 870 nm and oxygen A-band. To do that, the authors first utilize the information from all the three bands to determine the atmospheric condition/state (clear, thin cloud or thick cloud); then retrievals are conducted using a 440nm zenith radiance look up table based on the atmospheric state; 2) Introduction to the zenith pointing radiometer developed by the authors for hyperspectral measurements that cover the bands needed for the COD retrieval; and 3) validation efforts, albeit brief, are presented. In general, the manuscript contains information and ideas that would be of interest to the community, but some of the fundamental justification for the technique and results, as described below, is missing from the current version; hence a major revision is needed before it's publishable.

AR: We respond to referee's specific comments below.

General Comments: 1. The determination of the atmospheric state, i.e. whether the atmosphere column contains thin or thick cloud, is the first and crucial step for the COD retrieval method presented. The authors used two techniques to do that 1) for ultra-thin clouds, the ratio of 440nm and 870nm zenith radiances is used and 2) for other situations the A-band equivalent width (EQW) vs 440 nm zenith radiance plot, which the authors call the "nose plot", is used. What is missing in the manuscript is the justification of both techniques.

AC: See comments immediately below on technique (1) and (2) justifications.

For example, why the EQW is a monotonic function of COD? How is Figure 2 generated? Is it from radiative transfer simulations? What are the inputs and which model is used?

AC: See revised "nose" plot (**Figure 12**), where EQW is non-monotonic for COD~<1, as pointed out by RC1. **Figure 12** now plots both measured data and a superimposed RT model-generated smooth-fitting "nose" curve.

COD is a two-valued function of up-looking spectral radiance while oxygen equivalent width is a monotonic function of COD for COD~>1. By plotting SR440 versus EQW as COD increases from no cloud to thick clouds one traces out a "nose-like" shape (Figure 12). For the very lowest COD values, EQW decreases with increasing COD and the slope is negative. Beyond about COD=1, the lower portion of the "nose" where the slope is positive corresponds to the optically thin regime; the upper portion where the slope is negative corresponds to the optically thick regime.

The nose plot in Figure 12 includes a smooth curve, based on MODTRAN5 computations but elastically stretched to fit the depicted data points over a 4 minute measurement where the COD varied strongly between blue sky, thin and thick regimes, as well as points deviating well away from the ideal 1DRT smooth curve. These deviating points are classified as either "3D Cloud" based on their SR440 exceedance of the 1DRT bright point radiance value (section 3.2.1) or as "Mixed" points attributed to heterogeneous cloud structure within the FOV, itself a 3DRT effect. The classification of the remaining data points into optically thin, thick or blue sky regimes was corroborated against coincident all sky camera video. Although the MODTRAN5 computed nose plot curve in Figure 12 supports these regime classifications, it is important to note that the TWST algorithm does not employ model-generated nose plot curves to guide its thickness regime determination. Indeed, the particular shape and slope of a computed nose plot curve varies, as it should, with the assumed (and unknown) physical cloud thickness. Instead, the algorithm exploits

the aforementioned positive-slope:thin, negative-slope:thick generic properties of the nose plot.

Also how was the threshold chosen for the 440nm and 870nm ratio (5 is used in the manuscript)? How does surface albedo/SZA affect the threshold? These are the physical basis of the retrieval method and a clear description would be essential.

AC: The "blueness factor" (i.e. the ratio of spectral radiances at 440 nm and 870 nm) is now renamed the **"color index"** in deference to RC1. Addressing justification for color index technique (relying on revised Figure 3):

The cloud optical thickness regime determination operates in two distinct radiance domains. When the COD is very low, e.g. COD<=1, the amount of radiation in the NIR is very small and the signal to noise ratio (SNR) of the EQW is low (e.g. "clear sky" in Figure 3) and thus the nose plot slope SNR is too low to resolve the thickness regime. The ratio of SR440 to SR870, termed the color index, has a much higher SNR and is more reliable in this regime. This, of course, is a simple consequence of the wavelength dependence of Rayleigh scattering. For low-moderate altitude water clouds, small-moderate SZA, and typical 440 nm ground albedos less than 0.2 (Figure 6), our data analyses have found a hard threshold of 4 to be a sure indicator of optically very thin clouds (e.g. "clear sky" in Figure 3) and a soft threshold of 2<index<4 to be a strong indicator (e.g. "COD<1" in Figure 3). When the color index is less than 2, the cloud's optical thickness is not well correlated with the index, and we must rely on the nose plot slope.

2. As the authors pointed out, the observed zenith radiation varies drastically and it is not likely that one can determine the atmospheric state without filtering the data. The authors developed a time varying hysteresis filter for the purpose (Section 5), which seems to have solved the problem, but what is missing is the results that shows that. A figure that shows how a data sequence, e.g. the data shown in Figure 3, is transformed before and after applying the filter would be good enough.

AC: As suggested by RC2, our new **Figure 13** shows a raw nose plot time sequence and the results of filtering. This figure is discussed in **new section 3.3.5 "Example operation of thickness regime filter"**. Also, the veracity of this filter is supported by new **Figure 15**, which shows a *time series* comparison of retrieved CODs between TWST and AERONET.

Specific Comments: 1. P2, Line 21: "This requires an accurate determination of the zero radiance level". It is not clear to me why this is the case. Please elaborate.

AC: We reword this as: "**The veracity of these calculations depends on accurate spectrometer dark current calibration and subtraction (discussed in section 2.3). Otherwise, a dark bias of the spectral radiance would falsely alter the computed transmittances and EQW value.**"

2. Page 15, Figure 1 caption: the abbreviation of TWST appeared before defined.

AC: TWST acronym now defined in **Abstract**.

3. Page 16-17, Figure 2 & 3: units of the axis missing.

AC: (now Figs 12 and 13) Will correct upon final acceptance.

4. Figure 10: description of each part missing in the caption.

AC: Added to caption (now Figure 2): "**See text for labeled component descriptions**".

Anonymous Referee #3

Received and published: 6 April 2016

General Comments: The manuscript "Application of Oxygen A-band Equivalent Width for Cloud Optical depth Measurement" presents a new technique for measuring Cloud Optical Depth (COD). This method is based on ground-based visible band zenith spectral radiance, similar to the AERONET Cloud-Mode sensors. Compared to the previous studies using the zenith spectral radiances measurements to derive COD, this paper used O2 A-Band to help determine COD. This method advances the measurement technique of COD. I recommend its publication in ATM after major revision.

According to this paper, the TWST Cloud optical depth sensor that used by the authors is a new instrument. Regularly, the instrument should be introduced firstly and in detail, which performance has direct impact on the accuracy of the measurement.

AC: In deference to RC1 and RC3 preferences, the instrument section now follows the introduction.

The authors can give more paragraphs to the introduction of this instrument. The core component of this instrument is the spectrometer, and more detailed information about it should be presented, e.g., the slit function (which shows the spectrum resolution and out-of-band rejection directly), the pixels number and size of the detector, spectral response of the detector and so on.

AC: We state in revised introduction section 1.3: "**The TWST sensor is a zenith staring narrow field of view (NFOV) VNIR spectral radiometer built around an inexpensive commercial compact grating spectrometer (CGS) with a nominal 2.5 nm resolution. The technological sophistication and robustness of the TWST instrument derives almost entirely from its commercial components; we neither depend upon nor make any remarkable claims about sensor design or suitability.**" We believe this point justifies excluding from presentation the internal details of the CGS. Nevertheless, we do agree that further instrument details and *performance* specifications deserve discussion:

"…sampling interval is ~0.3nm."

"With integral order-sorting filter, the stray light level is cited to be <0.1%."

"The spectrometer's silicon CCD detector outputs are susceptible to offset drift, typically driven by changes in ambient temperature. Although the detector array contains light-shielded dark-reference detectors intended to automatically track and subtract such drift,…"

Also, the wavelength and radiometric calibration are more thoroughly discussed (see below).

The other parameter is that whether the spectrum is stable when the environment temperature is changing, for example, does the spectrum shift in the detector with temperature? For the new instrument, radiation closure testing is often made before its data is used to do retrieval. For example, Min et al. (2014) developed a high resolution ground based spectrometer, it can detect both zenith and direct beam solar radiation with narrow field of view.

AC: **The TWST approach does not rely on resolving fine spectral features. The 440nm and 870nm spectral radiance levels, due to their shallow spectral slopes (Figure 3), and A-Band EQW value, due to its accumulation over many spectral bins, are relatively insensitive to foreseeable thermal shifting of the spectral sampling grid.**

The original manuscript mentions the mechanical shutter for measuring dark spectra. We expanded on that with the following discussion: "**The spectrometer's silicon CCD detector outputs are susceptible to offset drift, typically driven by changes in ambient temperature. Although the detector array contains light-shielded dark-reference detectors intended to automatically track and subtract such drift, TWST nonetheless employs a mechanical shutter for frequent collection of dark spectra, typically a 1-second dark spectrum every 60 seconds. The dark correction (offset subtraction) applied to each recorded spectrum is spline-extrapolated from earlier collected dark spectra.**"

Our manuscript shows a comparative radiative closure between the TWST sensor SR440 and AERONET SR440 in **Figure 14**, which we now reference in the revised instrument section. TWST 440nm spectral radiances are in excellent agreement with AERONET per **Figure 14** for a dataset over several weeks of coincident deployment at TCAP in early summer in Cape Cod, Massachusetts, USA, over a wide span of temperatures, as discussed in revised **sections 4.1 and 4.2.1**.

Min, Q., Yin, B., Li, S., Berndt, J., Harrison, L., Joseph, E., Duan, M., and Kiedron, P. (2014), A high-resolution oxygen A-band spectrometer (HABS) and its radiation closure, Atmos. Meas. Tech., 7, 1711-1722.

For the readers of this paper, they also hope to see some simple observation cases of this new instrument, such as different spectra (clear day case, thin cloud case, heavy cloud case, with similar SZA) in the same figure.

AC: As suggested by RC3, Figure 3 has been revised to show different spectra.

For Figure 2, if the authors can add the plots of spectra radiance@440 nm vs. COD, Equivalent width vs. COD, it will be better.

AC: Figure 4 shows SR440 vs COD.

Please also note the supplement to this comment:

http://www.atmos-meas-tech-discuss.net/amt-2016-67/amt-2016-67-RC3-supplement.pdf

AR: The supplement, other than for formatting, is identical in content to RC3, to which we responded above.