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Interactive comment on "In-situ sounding of radiation flux profiles through the Arctic lower troposphere" *by* Ralf Becker et al.

Anonymous Referee #1

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1 General remarks

The manuscript introduces a new tethered balloon sonde measuring solar and terrestrial up- and downward radiative flux densities. The sensors package is described, measurement uncertainties are briefly discussed and correction methods are presented. Some limited number of observations is used to illustrate the potential of this observation platform.

The new instrument package, the measured profiles of radiative flux densities and derived heating rates are within the scope of AMT and might contribute to improve our understanding of radiative processes in the lower clear sky and cloudy atmosphere. However, that manuscript is of poor quality which I will try to describe in detail below

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and, therefore, does not exhaust its full potential.

The methods applied to process the measurements are oversimplified and do not use state of the art methods, nor state of the art methods are compared or discussed. The methods applied in the manuscript and other details of data processing, simulations are not or inaccurately specified in many parts of the manuscript making it impossible to follow or reproduce the data processing and calculations. The performance of the instruments is not well characterized. Literature used for discussion is often not state of the art. Final uncertainties of the measurements are not given. Figures, style of presentation (structure, English, use of abbreviations, symbols, etc.), are below the quality level of AMT.

Therefore, the manuscript is far from a status that it can be published in a high quality journal like AMT. Because I like the measurement approach and see the potential of such observations, I only can recommend to revise the manuscript in all matters suggested below.

Below, I compiled a list of comments which have to be considered in a revised version of the paper. There might be some contradictory statements which result from my misinterpretation of the text when first reading the not well organized manuscript. I am sure the authors will know how to weight in such cases and how to improve the text to avoid misinterpretations by other readers.

2 Major comments

Tilt correction

There exist references which quantify the errors of a sensor tilt in high detail. e.g. Bannehr and Schwiesow (1993), Wendisch et al. (2001). Those are not included in the discussion of the manuscript but may easily point to the problem and magnitude of

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sensor tilt.

Also common correction methods frequently applied to airborne radiation measurements are not compared to the method presented here, nor are these methods discussed (e.g., Bannehr and Schwiesow, 1993). Instead, a rather simplified approach is used to correct for the sensor tilt. This approach is not well explained in the manuscript. Details are missing and assumptions like neglecting diffuse radiation or assuming the diffuse radiation to be height independent are questionable. Additionally, Figure 4 seems to have a bug. At least it show larger tilt errors for high Sun (zenith position) which does not follow theory. So I had problems following the method.

Only one example of measurements at a different location is shown, which certainly does not cover all possible conditions for which the correction needs to be applied. In the end it also was stated, that simulated downward irradiance were used for the analysis of the examples. Finally, I completely lost track of what had been done with the measurements to correct for the sensor tilt and how large the remaining uncertainty is after the correct. Some detailed comments and questions are here and in the list of comments below.

L149: Neglecting uncertainties of a sensor tilt for terrestrial radiation and upward solar radiation might be not acceptable. There should be uncertainties for 10°, which at least need to be quantified. Or a reference needs to be given discussion this problem. Can you estimate what error a 10° tilt would cause if a bright surface and a dark sky would be assumed. Should be possible to calculate from geometry.

L156, Figure 2: For what SZA this example holds? The effect of 5° tilt will be different if the Sun is in zenith. Therefore, I do not understand why this should be shown with a single measurement case. It is possible to calculate the effect from geometry for all possible geometries.

L162: Calculation of individual solar zenith angle: How this transformation is calculated? Provide the equations or a reference. However, it will not help to calculate the individual solar zenith angle if you want to analyse vertical profiles and compare two measurements with different tilt. I do not understand this approach.

L167-169: This assumption is highly risky in my point of view. Especially, if vertical profiles are to be analysed. Direct/diffuse fraction will change in dependence of altitude. Therefore, I recommend to use the analytical equations that can be used to correct for the sensor tilt. Only the direct/diffuse fraction needs to be known. This can be estimated by radiative transfer simulations.

L174: Which day? Which solar zenith angle? Is this example comparable to Arctic observations? Are the conclusions transferable to the Arctic?

Figure 4: I do not understand, why the misalignment error should be larger for low solar zenith angles (high Sun)? Cosine law tells, that changes for solar zenith angles of 0° (sun in zenith) are way less than changes of low sun, e.g., solar zenith angles of 80°.

$$\cos(0°) \cdot 1000\,\mathrm{Wm}^{-2} - \cos(3°) \cdot 1000\,\mathrm{Wm}^{-2} = 1\,\mathrm{Wm}^{-2}$$

$$\cos(77°) \cdot 1000\,\mathrm{Wm}^{-2} - \cos(80°) \cdot 1000\,\mathrm{Wm}^{-2} = 51\,\mathrm{Wm}^{-2}$$

To conclude: This correction scheme needs to be explained and tested in much more detail. In order to make the study shown in the manuscript more relevant, the correction approach needs to be explored for a general application to measurements in all potential conditions. Radiative transfer simulations are needed to support the approach. Two measurements at one location on a single can not be used to derive a parametrization for such a correction. Alternatively, the authors may apply common methods to correct for the sensor tilt.

"Lack of detail and discussion with respect to state of the art"

In almost all parts of the manuscript specifications of methods, instrument performance, etc. is missing. Day, time, solar zenith angle of observations is missing. Known methods reported in literature are not discussed. Therefore, the manuscript does not represent the state of the art of solar and terrestrial radiation measurements and analysis of vertical profiles of heating rates. Just to mention some references which need to be considered by the authors:

Bannehr, L. and Schwiesow, R. , 1993: A technique to account for the misalignment of pyranometers installed on aircraft, J. Atmos. Oceanic Technol., 10, 774– 777.

Freese, D. and Kottmeier, C.: Radiation exchange between stratus clouds and polar marine surfaces, Bound.-Lay. Meteorol., 87, 331–356, 1998.

Duda, D. P., Stephens, G. L., and Cox, S. K.: Microphysical and radiative properties of marine stratocumulus from tethered balloon measurements, J. Appl. Meteo., 30, 170-186, 1991.

Bucholtz, A., Hlavka, D. L., McGill, M. J., Schmidt, K. S., Pilewskie, P., Davis, S. M., Reid, E. A., and Walker, A. L.: Directly measured heating rates of a tropical subvisible cirrus cloud RID C-9570-2011, J. Geophys. Res., 115, D00J09, doi:10.1029/2009JD013128, 2010.

Saunders, R. W., Brogniez, G., Buriez, J. C., Meerkötter, R., and Wendling, P.: A comparison of measured and modeled broadband fluxes from aircraft data during the ICE'89 field experiment, J. Atmos. Ocean. Tech., 9, 391–406, 1992.

Gerber, H., S. P. Malinowski, A. Bucholtz, and T. Thorsen, 2014: Radiative cooling of stratocumulus. 14th Conf. on Atmospheric Radiation, Boston, MA, Amer. Meteor. Soc., 9.3. [Available online at https://ams.confex.com/ams/14CLOUD14ATRAD/webprogram/Paper248451.html.]

Curry, J. A. and Herman, G. F.: Infrared radiative properties of summertime Arctic stratus clouds, J. Climate Appl. Meteor., 24, 525–538, doi:10.1175/1520-0450(1985)024<0525:IRPOSA>2.0.CO;2, 1985.

Wendisch, M., D. Müller, D. Schell, and J. Heintzenberg, 2001: An airborne spectral albedometer with active horizontal stabilization. J. Atmos. Ocean. Tech., 18, 1856-1866.

Scientific presentation

The manuscript does not reach the standard of scientific writing required for AMT. Partly due to reasons given above, but also due to some general shortcoming.

Figures: Figures are of low standard. Labels are not precise and label boxes displaced from the main figure. Lines are partly not distinguishable. Figure captions do not explain, what is actually shown. Axis labels are incomplete or abbreviations not introduced before. Parametrizations are given in the figure instead of as equation within the text.

Quantities, units: Quantities are not used in a correct way, e.g. flux vs. irradiance (radiative flux density). Many quantities are given as abbreviations. Units are not written with exponentials. ° written as "deg". Date and time format is not consistent.

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3 List of comments

L15: "four times net" There are only two net radiative flux densities, solar and terrestrial.

L20: For which altitude the albedo from balloon observations is given? Why there are two values for surface albedo and albedo in flight level?

L20: Rather present albedo in [0,1]. Use of percentage is quite unusual.

L21: This sentence reads like a general finding, but this maximum is likely only valid for the specific location of the measurements (horizontal surface inhomogeneity).

L38: Which decades?

L39: Reference for IPCC report: Why 2007? There are new versions of the report. Does this statement still hold for the latest IPCC report?

L50: Stick to one unit. In the introduction $\mathrm{k\,day^{-1}}$ were used. My feeling is, that $\mathrm{K\,h^{-1}}$ is more useful for the low level clouds analyzed in this study.

L58 and whole manuscript: "Irradiation profiles", "fluxes": Be more precise or at least consistent with the radiation quantity measured. It is "radiative flux density" or "irradiance" to be correct. "radiative flux" as stated in the title already is incorrect. Unit of "radiative flux" is W while "radiative flux density" has a unit of $\mathrm{W\,m^{-2}}$.

L62-65: Reference to Siebert et al. (2003) does not fit here, when discussing radiation measurements as there had been no radiation measurements in Siebert et al. (2003). Rather use this reference as a general application of balloon borne measurements.

L66: Reference to Philipona et al. (2012) and Kräuchi and Philipona (2016). What is the difference of these studies to your measurement setup? Give some more details about what has been done in these references.

L68: A sonic is no satellite-based remote sensing technique. Also sonic is a ground-based observation and therefore already an in situ instrument. Rather discuss how ground-based and satellite remote sensing derived solar and terrestrial radiation profiles (general approach, remote sensing of atmospheric state and calculation of radiation based on radiative transfer simulation). What are the limitation compared to balloon borne observations?

L88: First introduce the sensor type, then give uncertainties.

L90: WMO (2008): This is not the latest edition of the WMO guide. And the reference does not tell about the uncertainty of the sensor used here. It only defines quality standards. Give the specific uncertainty of your instrument.

L93: "reduced sensitivity": specify!

L95: "secondary standard": Rather give numbers of uncertainties here.

L101: Radiation shields have been removed: How does this affect the uncertainties? Still "secondary standard"?

L106: Data loggers: Specify sampling frequency! Specify accuracy of the tilt sensor!

L108: "from 1 second to 1 minute": What was finally uses?

L110: CM11: I don't care about the CM11. Give range of CM22 used in your study.

L114: What is B? If that is a quantity then use italic letter.

L115: What is the ascent rate? Maybe restructure your manuscript and first introduce the balloon system then the sensors.

L116: I don't understand. What would it help to place the sensor into ambient conditions, when the ambient temperature will change during the ascent?

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L124: Filled with helium or hydrogen? What is the maximum lifting weight?

L128: "several sondes": Several? Are these mounted at the same time in different altitudes?

L131: What if time drift during the flight is strong? Simply state the uncertainty in time difference you assume for your system.

L139: "minimize mixing of temporal and spatial (vertical) change". Spatial vertical changes are what you are about to measure. So these should not be minimized.

L153: "high potential errors that need to be corrected" Why you can draw this conclusion? First provide the analysis which supports this conclusion.

L159: Give specification of inclinometer!

L162: How the wind vane of the radiation package can measure the wind direction? Is there a reading?

L164: Give a reference or justify why no correction is needed in overcast conditions.

L174: What steps?

L177: What is "quite similar"? To compare the slope of the plot, what is what you are looking for, the data first needs to be normalized.

L194: There are references which discuss that it is necessary to correct the measurements for the response time of the sensors in order to properly correct for the tilt of the solar irradiance measurements, e.g., Freese and Kottmeier (1998) or Ehrlich and Wendisch (2015).

L192: What level? Altitude z should be used as vertical coordinate instead of an index i.

L206, Eq. 3: What does the δ mean? Difference or derivative? If you use discrete altitudes (levels) you need to write the equation also for discrete levels.

L261-267: This section is rather something for the introduction.

L268: Of course it is. Radiative transfer processed always determine the solar irradiance, also in a 3D world, and for a large sensor footprint.

L274: This statement is too trivial. Remove.

L279: Why using simulations for downward irradiance? Wasn't downward irradiance measured? The discussion on the tilt correction suggested that there are measurements. Use measurements!

L280: "absence of insolation": Why analyzing solar radiation, if there is no solar radiation at all (no insolation = night)?

L287: Can you explain the maximum?

L292: Ceilometer might not be the best indicator of clouds disturbing the direct solar radiation. Clouds can be in front of the Sun, but not registered by the ceilometer in zenith.

L302: The horizontal drift will have an effect on the profiles of albedo presented before! A changing drift in different altitudes may bias the profiles or even produce artificial changes in the radiation profiles. How large was the effect for the measurements of albedo profiles?

L309: What is the benefit of measuring long time series of albedo? This is not clear from this section. Only the mean values are used to explain the effect of the balloon drift. No time series are needed for this effect.

L319: What is "May13 1"?

L319 and Figure 10: Introduce figure and what is plotted properly not only as a hint in some brackets.

Figure 10: Why showing potential temperature? Emission (Planck's law) depends

on air temperature. So to illustrate higher emission by higher altitudes, the real air temperature is needed, not the potential temperature.

L323-325: Why? If there is no impact on net radiation, where you will have a warming of the atmosphere leading to Arctic amplification? Does it has an effect on the surface?

L327: What do you mean with radiative effect? Radiative forcing of the cloud at surface? Specify!

L327: How do you compare cloudy case with clear sky case? Measurements of the same day, time? Same atmosphere profile? In best case, this needs to fixed (identical) in order to compare the impact of clouds on the radiation profile.

L336: UTC time? Use 24h format.

L349: "passing": This is not unambiguous. Passed from which side? Ascend or descend?

L348-365: Figure 13 is discussed in both sections. I suggest to reorganize this part in order to have the introduction and discussion in one section only.

L360: What signal? Irradiance is zero?

L364: There is no figure showing an albedo profile.

L366: "total net effect": What effect? Be more precise!

L371: The cloud layer indicated by the gray area in the figure is below the maximum of cooling rates. But cooling rates should be inside the cloud not above. Needs to be discussed and compared to literature.

L402: Repetition. Was already mentioned when introducing the table.

L407: The heating rate profile suggest, that cloud top was higher. I suggest to add the simulated profiles of heating rates into Figure 13.

L409: The different cloud top and cloud base altitudes for the single profiles need to be indicated in Figure 13 where only one altitude is shown.

L410: Cloud base warming strongly depends on the surface temperature (difference to cloud base temperature). What is used in the model, what was observed?

L413: How heating rates are derived from the model simulations? Heating rates strongly depend on the layer thickness considered in the calculations. On what vertical grid the simulations were performed and analyzed? To compare with the observations the same layer needs to be analyzed. Was this done?

L418: I suggest to use W m^{-2} instead of relative values for the comparison.

L431-432: The potential still needs to be shown! This is only speculative. I suggest to remove such statements.

Figure 1: Indicate which sensor is CM22 and which CG4. Where is the inclinometer mounted?

Figure 2: Labels: "Shortwave downward..." what? Write W m^{-2}. What is Sunzen? 130305 is this 13 March 2005 or 3 May 2013 or 5 March 2013? What does this equation in the label stands for? The equation does not use symbols for quantities introduced before. What is sz2? What is sz? What units do the coefficients of the equation own?

Figure 3: Similar to Figure 2: Incorrect quantities. What is GAP? What is GAP Sel, ZUG,...? Do not place parametrizations in the legend. Figure caption: The plot does not show "data fitting" it shows downward solar irradiance observed for different solar zenith angles.

Figure 4: Measurements and parametrization are only shown for 35-75° solar zenith angle. How you can calculate for 0° and 80°? Parametrization is not valid for these angles.

Figure 4: Label: What is "Diff" ? Give correct quantity. Caption is not stating what actually is shown.

Figure 5: Starting at low altitude over a bright snow surface I do not understand, how the reflected radiation can increase over the first 200 m. This increase looks like you started over a locally darker surface. How these profiles compare to the BSRN data at the surface?

Figure 6: Caption: What do you mean with range? Min and max?

Figure 7: Figure is not discussed in text. Therefore, there is no need to snow the time series of T and r.H. What is UT? "deg" as unit.

Figure 8: Merge with figure 9. This will allow to compare wind speed and direction with albedo.

Figure 10: Two lines are undistinguishable. What is LWD?

Figure 11: Give day, time of observations.

Figure 13: Give solar zenith angle! Differences between the profiles might result a from different solar position.

Figure 14: Label all symbols. What is total what is terrestrial cooling? What is LHR?

Figure 14: How large are the uncertainties of derived heating rates? Uncertainties etc. need to be given to illustrate the potential of the measurements.

4 References used in the review

Freese, D. and Kottmeier, C.: Radiation exchange between stratus clouds and polar marine surfaces, Bound.-Lay. Meteorol., 87, 331–356, 1998.

Ehrlich, A. and Wendisch, M., Reconstruction of high-resolution time series from slow-response broadband terrestrial irradiance measurements by deconvolution, Atmos. Meas. Tech., 8 , 3671-3684, doi:10.5194/amt-8-3671-2015., 2015

Wendisch, M., D. Müller, D. Schell, and J. Heintzenberg, 2001: An airborne spectral albedometer with active horizontal stabilization. J. Atmos. Ocean. Tech., 18, 1856-1866.

Bannehr, L. and Schwiesow, R. , 1993: A technique to account for the misalignment of pyranometers installed on aircraft, J. Atmos. Oceanic Technol., 10, 774– 777.

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