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Atmospheric Measurement Techniques Discussions

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Interactive Comment

Interactive comment on "Retrieval of cirrus cloud optical thickness and top altitude from geostationary remote sensing" *by* S. Kox et al.

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Dear Referee, First of all thank you for your very helpful and interesting comments. In the following we will respond to your comments and provide answers to your questions.

You wrote: l. 24 "net radiative forcing" instead of "net forcing" (also I am missing a reference)

Our reply: Reference added, sentence is changed to: "High ice clouds hold an exceptional position within the large variety of clouds since they most probably generate positive net radiative forcing and therefore contribute to warming the Earth's atmosphere (Chen et al., 2000)."

You wrote: Introduction: The authors state that the Mecida algorithm has a lower optical depth limit of about 0.5 . It would be interesting to see the detection limits for the other methods listed (e.g. ISCCP, HIRS, TOVS) in order to understand if part of the differences arises from different detection limits.

Our reply: We changed the text in the introduction accordingly and added the detection thresholds for the listed methods. It reads now: "Since 1983 the infrared and visible radiances of imaging radiometers ....missed detections of very thin cirrus clouds (Wielicki and Parker, 1992). Rossow amd Schiffer (1999) state that for the detectable limit of cloud cover fraction (0.1 over ocean and 0.15 over land), the lower detection limits for clouds are approximately tau = 0.15 over ocean and tau = 0.25 over land. ...... were found by other polar-orbiting satellites. For example, the multispectral High Resolution Infrared Radiation Sounder (HIRS) ....[Wylie et al., 1998]....high clouds are less dominant in higher latitudes with values of less than 40 %. The threshold of HIRS to detect clouds appears to be tau = 0.1. .... Observational Vertical Sounder (TOVS) Stubenrauch et al. (2006) calculated a global averaged cirrus coverage of 27.3 % again with regional variations. Similar to HIRS the TOVS instrument is sensitive to clouds with low optical thickness (with a detection limit of $tau = 0.1$ (Stubenrauch et al., 2006, Wylie et al., 1995). This high variability is caused by the different detection sensitivities ...."

You wrote: II. 100ff: The near-infrared radiation in the Nakajima and King method also contains reflected sunlight. In the algorithm the authors refer to, which NIR channel is used (1.6μm, 2.2μm, 3.9μm)? If the information is from the 3.9μm channel, how is the separation between the reflected part and the thermally emitted fraction of the radiation done?

Our reply: In Bugliaro et al. (2011) the SEVIRI 1.6μm channel is used. Thus, no thermal radiation subtraction is needed as for the 3.9 mu channel. Therefore the text was changed to: “In order to characterize the properties of the detected cirrus clouds, MECiDA 2 is combined with a well-known method to retrieve the optical thickness of a cloud with passive remote sensing instrument, adapted from Nakajima and King (1990). It uses the properties of reflected sunlight in the visible and near infrared SEVIRI channels centred at 0.6 and 1.6 mu (APICS, Algorithm for the Physical Investigation of Clouds with SEVIRI, described in Bugliaro et al., 2011) and therefore cannot retrieve optical properties during night time."

You wrote: l. 108: It should be mentioned that the retrieval of cloud bottom height is only possible for optically thin clouds as the CALIOP signal otherwise saturates.

Our reply: Very good point. The text was changed to: "Based on different scene classifications and retrieval algorithms in combination with auxiliary datasets, CALIOP provides highly accurate measurements of different optical and physical properties of e.g. cirrus clouds from a polar orbit with a footprint of ....(Winker et al., 2002, Vaughan et al., 2004) with the typical limitations of a lidar. In case of CALIOP the vertical structure and therefore the retrieval of i.e. cloud bottom height is only possible if the cloud is optically thin and the lidar signal is not saturated."

You wrote: l. 172: I would suggest the term "quasi simultaneous" (as they stem from different satellites, the observations are not really simultaneous in a physical sense).

Our reply: The term was changed to "quasi-simultaneous".

You wrote: Section 3.2: : If I correctly understood the description, all clouds with ice particles at their top were called "cirrus" in the CALIOP dataset (l.334ff). Then I do not understand Fig.2, where the cumulative distribution function (evaluated from the histogram) approximates 1.0 at an optical depth of about 5-6. Does this mean that the number of "real cirrus" (optical thin) observations is so much larger then the observation of deep convective clouds, that the CDF would asymptotically approximate 1 at these optical depths, even if the x-axis would be expanded to higher values (e.g. 50 or 100)? Or does this mean that only CALIOP observations with optical depth lower than 6 have been evaluated, as the signals (both of CALIOP and of the SEVIRI TIR channels approach saturation for this optical depth? If so, a clear description of the saturation criterion and the selection rule is missing. I strongly suggest to describe the procedure how the training dataset was derived and which assumptions and constraints have been used in more detail, as this is very important information for the understanding and correct usage of the output product.

Our reply: As you correctly analyzed, the signal of CALIOP is limited to rather low cloud optical thickness, since the absorption of an aerosol or cloud layer increases until the signal gets totally attenuated and CALIOP fails to penetrate through the specific layer. In case CALIOP measures optically thick clouds with an optical thickness greater than 3 to 5 the lidar signal gets saturated (Winker et al. 2010). Therefore – depending on the quality of the measurement values higher than 8 are generally not found in the CALIOP dataset. The maximum values of optical thickness here refers to the cirrus-like top of a strong cumulonimbus cloud, if the CALIOP own quality flag (QC) is not taken into account (QC=All) and all measurements of optical thickness are accepted, Fig. 2. Your analysis in that case are absolutely correct, there are definitely no measurements of clouds with optical thickness of 50 or even 100. Since the focus of COCS is mainly set on the detection and retrieval of thin cirrus clouds only cirrus clouds with an optical thickness less equal 2.5 are taken into account for the training dataset. This selection was also driven by the constraints of the CALIOP own retrieval described in line 305-328, where I sorted the original text and added some missing parts: "During preliminary analysis, the cloud layer products in version 2.01 and 2.02 were found to contain some inaccurate classifications, where cirrus free parts of the atmosphere were labelled as cirrus clouds. Furthermore a well-known CALIOP retrieval behaviour had to be taken into account. In general the extinction quality flag is reported for each cloud layer, where an extinction coefficient was calculated by the CALIOP retrieval. This flag contains information whether the extinction retrieval is constrained or unconstrained, which is the case for example when the layer is elevated above a water cloud or like in case of the anvil of a cumulonimbus, where no spatial separation exists between the water and ice phase of the cloud. Furthermore it indicates if the lidar ratio was reduced or increased. Fig. 2 shows a histogram of the ice optical thickness of

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the 5 km cloud layer product with a bi -modal distribution. The right peak at tau $\sim$ 2.5 appears to be an artefact of the CALIOP retrieval algorithm, when the initial retrieval diverges and the lidar ratio is reduced in order to produce a convergent solution. In most cases this happens in totally attenuating, opaque clouds, when the true cirrus lidar ratio is significantly smaller than the initial value assumed by the algorithm [Atmospheric Science Data Center, 2011]. If the lidar ratio is kept unchanged the extinction quality flag is reported with values greater equal one. The absorption of an aerosol or cloud layer increases until the signal gets to totally attenuated and CALIOP fails to penetrate through the specific layer. This behaviour is observed for optical thickness greater than 3 - 5 (Winker et al., 2010)."

Concerning the filtering in order to retrieve a good training dataset, the following description was modified and updated in the original text accordingly:

"In order to remove these false alarms from the training dataset, the CALIOP data have been filtered according to the following criteria: A first criterion takes the accuracy of the retrieved cloud properties derived by the CALIOP algorithm into account, relying on the above described extinction quality flag. Only in case of an unconstrained retrieval the CALIOP results are taken into account. Furthermore and since the main focus of the COCS algorithm is on thin cirrus clouds the maximum value of the ice optical thickness of a cirrus layer can therefore be limited to tau = 2.5. Secondly the mid-layer temperature as a part of the CALIOP cloud layer product, which is calculated for each layer at its geometric midpoint, is used as another filter criterion. By testing and analysing the statistics of the CALIOP dataset an optimal threshold for the mid-layer temperature of the detected cirrus layer was found to be 243 K in order to achieve a low frequency of misclassification. Finally another threshold is applied that aims to prevent aerosol layers classified as cirrus clouds, which happens over tropical maritime regions at low altitudes. The threshold limittop is a simple approach based on the atmospheric temperature profile, depicted in Fig. 3. In high altitude regions it assumes that the cirrus cloud temperature of 243 K can be reached at altitudes of 4.5 km, while this

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altitude raises up to 9.5 km in tropical regions. Thus, only cirrus with cloud altitudes above ztop,min are taken into account. Therefore, for absolute values of latitude |lat| greater than 22° the minimum top altitude ztop,min of a cirrus can be calculated as: Formula (2) For latitudes with |lat| less equal 22° the threshold altitude is kept constant at a value of limittop(lat)=9.5 km."

You wrote: ll. 365ff.: What is the idea behing using the 13.4μm CO2 absorption band cannel of SEVIRI as input brightness temperature, but not as input for brightness temperature difference? As the 13.4μm channel has quite heigh relatove weight (Fig. 4) and the CO2 concentration has a strong annual cycle, does the CO2 signal influence on the cirus detection capabilities of COCS?

Our reply: In this context, the 13.4μm channel was used following the ideas of the CO2-slicing method (Menzel et al.,1983), which usually uses a combination of a CO2 (13.4μm) or water vapour (6.2 or 7.3μm) channel and an IR-window channel (10.8 or 12.0μm). This information can then be very helpful to determine the cloud top height, which is here done during the training, where you still have the single BT information of 7.3μm, 12.0μm, and 13.4μm which can be combined by the neural network to a "semi" CO2-slicing method. In the "common" CO2-slicing method you would use ratios to calculated BTs and differences. Since, the information context within the channel combination was rather high, the explicit BTD was not necessary. Another advantage of reducing the number of single BTs and BTDs is their influence on the training and therefore on the final result, as it is depicted in Figure 1. The more input information is used to train a neural network, the more hidden neurons and connections are needed, which again leads to an increased training time. Furthermore the application of COCS would be slower. Of course there is an influence of the diurnal CO2-cycle on the BTs of the 13.4μm channel, but the training dataset of CALIOP covers all seasons. Therefore the effect of the CO2 concentration in the atmosphere has no influence on the retrieval of cloud height or optical thickness.

You wrote: l. 385: should be changed to "minimum cirrus top altitude" in order to avoid

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confusion.

Our reply: I am very sorry, but could this be the wrong line? I am not sure, what should be changed to “minimum cirrus top altitude” here.

You wrote: ll. 395ff.: How large is the quantitative error introduces by the change of radiance definition if the wrong method would be used to calculate brightness temperatures?

Our reply: In fact the error caused by using the different definition to calculate the brightness temperature can lead to temperature differences of up to 0.5 K. Even higher in single cases. For some timeslots / full-discs the behaviour of COCS was tested using this “wrong” radiance definition leading to errors in the IOT of 0.05-0.1. The top altitude varies by around 100-200 meters in those cases. But a real quantitative error was not calculated in the framework of this paper.

You wrote: ll. 552f.: I would be careful with this interpretation. The period 1 is much longer (about 2 years, when I got the numbers right) than period 2, so the different sample size also could impact on the resulting accuracy. I would suggest to rephrase the sentence and at least mention the different sizes of the samples.

Our reply: Very good point. We changed the text accordingly: "COCS period 2 (right) may result in a higher accuracy possibly caused by EUMETSAT’s updated definition for measured radiances in order to retrieve brightness temperatures, but since both datasets (period 1 and 2) differ in size no final statement can be given here."

Once again thank you for your great and interesting question.

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 4123, 2014.