Characteristics of cloud liquid water path from SEVIRI on the Meteosat Second Generation satellite for several cloud types

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Overall recommendation

This paper presents an analysis of diurnal cycles of liquid water path retrievals from SEVIRI during daytime. The authors analyze for different region the temporal variations in LWP. Although studies on diurnal cycles are described in several other papers, there are few papers that use observations from geostationary satellites for this purpose, which makes the topic of the paper of interest.

In general the paper is well written, and the work has to potential to be of interest to users in the model community. However, the authors need to better explain the setup of their study (cases, assumptions, etc). The analysis can be improved and made more interesting for the reader. Instead of analyzing diurnal cycles for a mixture of meteorological conditions, it would be more interesting to focus on specific conditions (e.g. land convection, land stratiform, ocean stratocumulus, ocean trade cumulus, etc). Moreover, the comparability would be improved if the diurnal cycles should be constrained to local solar times or, when the area is large or different seasons are analyzed, that these cycles are normalized between sunrise and sunset. Some figures are not clear and need to be explained better or presented in a different manner.

Concluding, the manuscript needs some major and but mainly minor revisions before it can be published. The major points of criticisms are given followed by a chronological list of minor points of criticisms.

Major issues

Point A: Selection of the cases
An analysis of land versus ocean cycles for cloud fraction and LWP would be interesting. Apart from the analysis over Namibia, the authors decided to study their cloud parameters over large regions with different meteorological conditions. For modelers this will not provide much new insight. It would be more useful if the authors could confine their analysis more to specific meteorological conditions. Especially over the northern hemisphere distinction between land and ocean would be useful. Over land they could then select a region that is known to have different meteorological conditions during different months, such as the typical convective conditions during Central European summer and stratiform conditions during Central European winter. ITCZ would also be interesting, but since the authors concentrate on water clouds outside of the scope of this paper.

Point B: Diurnal cycle analysis
The diurnal cycle analysis can be improved.
First, it is better to constrain the analysis to more pure cases, and not mix the diurnal cycles of different cloud conditions.
Second, in the Figures the diurnal cycles are presented for observation times between 5 and 15 (is this local solar time, if so why is it then not from 7 till 17?). The pixels in the observation domain (Europe or

full disk) will have, due to their latitude, different sunrise and sunset times. Therefore, it would be more useful to normalize the diurnal cycles to a sunrise and sunset cycle.
Third, in the present analysis for the larger domains (full disk, northern hemisphere) the full diurnal cycle will have different lengths at different latitudes. By merging diurnal cycles of different locations together (as in Figure 6) much information on the typical diurnal behavior of these clouds is lost or, at least, diminished.
Fourth, instead of only presenting only the diurnal cycles, it would be interesting to provide information on other statistics of the cycle, such a time of maximum and minimum, and amplitude. See references to the following papers in which some of these types of analysis are used.

Roebeling R.A., and E. van Meijgaard, 2009: Evaluation of the daylight cycle of model predicted cloud amount and condensed water path over Europe with observations from MSG-SEVIRI, J. Climate, 22, 1749-1766, doi: 10.1175/2008JCLI2391.1

Thomas J. Greenwald and Sundar A. Christopher, 2000: The GOES I–M Imagers: New Tools for Studying Microphysical Properties of Boundary Layer Stratiform Clouds, BAMS

Wood R., C. S. Bretherton, and D. L. Hartmann, 2002: Diurnal cycle of liquid water path over the subtropical and tropical oceans. Geophys. Res. Lett., 29, 2092, doi:10.1029/2002GL015371.

Point C: Effect of excluding ice clouds from the analysis
On Page 6, line 190 the authors indicate that they only perform their analysis for water clouds. This is valid in case the cloud phase at the locations analyzed is only (or predominantly) water. In case there is a diurnal cycle in phase (e.g. morning water and afternoon ice) the diurnal cycles found will not be representative, and won't say much about the cloud behavior at that location. Please explain how the target areas were selected, to what extend the decision to limit the analysis to water clouds has been taken into account in this selection process, and how the diurnal cycles in cloud phase are taken into account/corrected for. Please comment and examine if the effect of diurnal cycles in cloud phase can be quantified for the cases studied in this paper, for example by providing information of the diurnal cycle of cloud phase as additional information.

Point D: Clarity of the Figures
Some figures are not clear or may be improved. Since it is a general issue I highlighted it as a major issue. Below some points that stick out, more details are given in my minor comments.
- Figure caption are not always clear. Please indicate for all figures which month and which area is analyzed.
- Figure 4 is unclear. I have been looking at it several times and reading the associated text, but could not figure out what is exactly presented and what conclusions can be drawn from this figure. There seem to be several horizontal clusters of points, where do they come from? (minor see general comment on this).

Minor issues

- Sometimes the diurnal cycles represent cloudy and cloud free conditions, other times only the cloudy conditions. Please be clear with this choice and explain in the manuscript why this choice is made.

Section 1: Introduction

- *Line 35*: Refer here also to the comparisons that are being done in the framework of the cloud retrieval evaluation workshops (CREWs)
- *Line 40:* the authors refer to few papers in which diurnal cycles of LWP have been studied. Since the analysis of diurnal cycles (daylight only) plays an important role in this paper a more extensive overview on the current state of the literature with respect to studying diurnal cycles would be good. In this overview the author may want to concentrate on studies based on microwave observations and those using passive imaging instruments (polar and geostationary satellites), and shortly summarize their main findings. In addition, the authors may want to broaden this review to studies on the cycles of cloud fraction and cloud phase as well.

  Cairns, B., 1995, Diurnal variations of cloud from ISCCP data. Atmos. Res., 37, 133-146.

  Stubenrauch, C.J., A. Chédin, G. Rädel, N. A. Scott, S. Serrar. (2006) Cloud Properties and Their Seasonal and Diurnal Variability from TOVS Path-B. Journal of Climate 19:21, 5531-5553

  Wylie, D. (2008) Diurnal Cycles of Clouds and How They Affect Polar-Orbiting Satellite Data. Journal of Climate 21:16, 3989-3996

- Reference to Painemal et al., 2012 is missing in the reference list.

Section 2: Generation of LWP and CTY from SEVIRI measurements

- *Line 175:* The authors mention here the validation of the cloud phase product by Meirink et al. 2013b. Since cloud phase plays a crucial role in the analysis of high opaque liquid water clouds the reader needs to be informed how accurate this validation is, and then especially for the high opaque water clouds. Can the authors confirm that the algorithm is accurate enough to depict these clouds?

Section 3: Analysis

- *Line 353 "The local time of the individual data points was taken into account by sorting the pixel into time zones"*
  Are the times presented in the figures local solar times? If this is the case, it is not clear why all diurnal cycles are between 5 and 15 hr, and not between 7 till 17. Please clarify this in the Analysis section and in the axis (or caption) titles of the figures.

- The authors should introduce more clearly how their analysis is set up. After reading the manuscript several times, and checking the boxes in Figure 1, the reader can figure out that the cases analyzed in the paper are:
  1. Full disk analysis (analysis per cloud height class, land only and ocean only, 4 months in 2009)
  2. European analysis (heterogeneous land and ocean, October 2009)
  3. Namibian coast analysis (ocean stratiform, 4 months in 2009)
  4. Northern Hemisphere (heterogeneous land and ocean, October 2009)

  Please present this more clearly, by introducing all cases at the beginning of the "Analysis" section and by providing information on region and time period considered in the Figure captions.

3.1 General characteristics of distributions and statistical properties

- Explain the cloud layer cases more clearly, and how they are selected (low, middle and high)

- *Figure 2 and Figure 3:* the authors analyze low, middle and high clouds. How are these cloud cases selected? How meaningful is it to present statistics for high opaque water clouds while the majority of these clouds will be ice clouds are excluded from the study? Please explain.
- *Page 8, line 240,* please indicate for the pairs of LWP values which one represent the ocean values and which one represents land values.
- *Page 9, line 275:* the authors write "the illumination hours were taken as weighting factor". This is not clear, please explain.
- *Figure 4, upper panel.* This figure shows the relationship between LWP values and times. Although the reader may get a clue that the different lines of pixel-pairs represent different observations hours, this is not clear from the figure. Please use different symbols (or lines) for different observation hours.
- *Page 9, line 290:* In the CPP algorithm the CTT retrieval method corrects for cloud semi-transparency using the cloud optical depth as an estimator of the infrared emissivity (see eq. 2 in Roebeling et al. 2006). Please correct for this.
- *Section 3.1.1,* The notes on the cloud phase introduced here could be better presented round line 195, where the authors indicate that their analysis is restricted to water clouds.

3.2 Diurnal cycle

- *Figure 6 (page 11):* Indicate in the figure caption that this analysis is done for N Hemisphere.
- *Figure 9 (page 12):* Indicate in the main text and figure caption for which region these cycles were derived. Further, in the right panel individual cycles are presented. It is not clear how these individual lines are calculated. Please clarify in the text and figure caption.
- *Figure 10:* Indicate in the figure caption observation area.
- *Figure 10:* This figure gives some good clues on how the diurnal cycles of the other regions could have been presented as well, i.e.,
  1. Relative diurnal cycle LWP including zeros (left panel)
  2. Relative diurnal cycle LWP excluding zeros (right panel intrinsic variability)
  3. Relative diurnal cycle fraction water clouds (right panel cloud fraction variations)

  Would be useful if we could see that information for the other regions as well.
- *Figure 11:* related to major comment B, here it needs to be clarified how the authors were able to derive a diurnal cycle from 5 till 15 hr over the northern hemisphere during all the 4 month. During January the pixels that contribute to these diurnal cycles are mainly from southern latitudes. Depending on the solar local time, the pixels that contribute to the average LWP at a certain time will differ considerably during the day.

Section 4: Conclusions

- *Line 475:*
- *Line 490:* The authors correctly mention here, but earlier in the manuscript as well, that viewing geometry conditions may affect the accuracy of the retrievals of cloud detection and cloud liquid water path. Please complement these statements with some references to papers on this topic. For example:

  Minnis, P., 1989: Viewing zenith angle dependence of cloudiness determined from coincident GOES East and GOES West data. J. Geophys. Res., 94 (D2), 2303–2320.

  Várnai, T., and A. Marshak, 2007: View angle dependence of cloud optical thickness retrieved by Moderate Resolution Imaging Spectroradiometer (MODIS). J. Geophys. Res., 112, D06203, doi:10.1029/2005JD006912.

Editorial

There are several editorial issues that need to be addressed. The authors are advised to carefully check their manuscript on spelling and grammatical errors once more. Without the intention to be complete, some examples are given below:

- Reference to Painemal et al (2012) is missing
- Not all abbreviations are introduced (e.g. CTY, ERA, CPP, NWC SAF) or only in abstract but not in main text (e.g. LWP, CM SAF), or not the first time they are used (e.g. CPH).
- Not consistent use of abbreviations (e.g. CMSAF and CM SAF)
- Line 264 and 265 "*the year 2009*" should be " *the months during 2009*"
- Line 310: "*Rosenfeld and Woodley*" should be "*Rosenfeld and Woodley (2000)*"
- Line 327: "*greater than*" should be "*warmer than*"
- Line 358: "*Octobre*" should be "*October*"
- Line 429: "*all pixel"* should be "*all pixels"* (applies at more places in the manuscript)