Atmos. Chem. Phys. Discuss., 7, S816–S823, 2007
www.atmos-chem-phys-discuss.net/7/S816/2007/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Diurnal variation of upper tropospheric humidity and its relations to convective activities over tropical Africa" *by* E. S. Chung et al.

E. S. Chung et al.

Received and published: 28 March 2007

We would like to thank the referee for detailed comments on the paper.

1) The abstract should emphasize the new results in this study, that is, EOF analysis and similarity/difference between Eulerian and Lagrangian frameworks.

In the revised version, we emphasized new results from EOF analysis and Lagrangian approach. Following sentence is added in the abstract: "The EOF analysis indicated that these diurnal variations over the African continent seem to be closely related to continental-scale daytime solar heating and topography. On the other hand, advection effect on the diurnal variation appeared to be minor because of the similar patterns shown in both Eulerian and Lagrangian approach."

2) Page 353, line 2: Although there are significant variations in the diurnal phase over the oceans, it has been well established that the oceanic deep convection generally peaks in the early morning, especially over the open waters. As I understand, the various hypotheses referenced by authors mainly aim to explain the early morning maximum in the oceanic deep convection instead of the regional variations of the diurnal cycle. Some literatures, such as Yang and Slingo (2001), Mapes et al. (2003), and Tian et al. (2005), do discuss the regional variations of the diurnal cycle.

Following the comments we change the sentence and it now reads “Previous studies commonly show that the amplitude of the diurnal variation is larger over the land than over the open oceans, and that most land regions exhibit diurnal maxima during the afternoon-evening period. By contrast, it has been reported that there exist significant differences in the timing of diurnal maxima over the ocean, leading to various hypotheses for explaining the early morning maxima in association with deep convection (e.g., Gray and Jacobson, 1977; Randall et al., 1991; Chen and Houze, 1997) and studies examining regional differences in diurnal maxima (e.g., Yang and Slingo, 2001; Tian et al., 2005; Yang and Smith, 2006).”

3) Page 353, line 13: Should it be clear-sky OLR?

The influence of UTH on the OLR is most significant over the cloud-free area. In addition, the UTH variation is also important for the OLR variation in the cloudy area because of indirect water vapor - cloud interactions (e.g., Sohn et al., 2006). In order to clarify the meaning, we rephrase the sentence as “despite its importance in regulating/modulating outgoing longwave radiation for both clear sky and cloudy sky.”

4) Page 353, line 28: There is a phase lag, although small, between deep convection, high cloud, and UTH over land in Soden (2000).

Thanks for the careful examination. With our careful reading, we found typos and misinterpretation of results in Soden (2000). We correct those and cite correctly as follows: “Soden (2000) reported a similar phase relationship between land and ocean.

ACPD
7, S816–S823, 2007

EGU

The UTH maxima in both land and ocean appeared to lag 3-4 hours behind the upper tropospheric cloud maxima."

5) Page 354, line 6: What does 'more comprehensive measurements' really mean here? Is it referring to high temporal and spatial resolution of Meteosat-8 (15 minutes and 3 km)?

This expression was used to indicate higher spatiotemporal resolution of Meteosat-8. We make it clear by adding 'in space and time domain'. Now it reads "In this research, extending these studies with more comprehensive measurements of the European Meteosat-8 satellite (Schmetz et al., 2002b) in space and time domain, ..."

6) Page 356, line 21: Any reference for MTH algorithm?

Algorithm for MTH is same as in UTH except for coefficients. We made the MTH algorithm clear.

7) Page 357, line 7: Define diurnal amplitude and phase which are mentioned later.

The diurnal amplitude denotes a half of the value from trough to crest in the first diurnal harmonic and the diurnal phase is defined as the local time showing maximum value. More information regarding the decomposition of diurnal cycle is found in Tian et al. (2004).

8) Page 357, line 17: Should we discuss the methodology for Lagrangian framework in this section?

Following your suggestion, we add a brief introduction of Lagrangian approach given below. "Conventionally Eulerian approach has been used for the diurnal variation study. But it is often observed that cloud and humidity features propagate following the large scale circulation, and thus it is of much interest to examine the diurnal variation in Lagrangian framework. Detailed explanation for the Lagrangian approach is given in section 4."

ACPD

7, S816–S823, 2007

9) Page 358: The discussion of harmonic analysis and diurnal anomalies in section 3.1 should be significantly reduced because most results here are consistent with those reported by earlier studies, such as Tian et al. (2004).

Our results in section 3.1 are generally consistent with previous studies such as Soden (2000) and Tian et al. (2004). However, the local times of maxima and the phase-lag relations are slightly different to each other as shown in Table 1, probably due to the different satellite data, sample size, and analysis domain. Compared to diurnal variation studies in the precipitation and cloud parameters, diurnal variations of UTH are much less completed. Furthermore, most previous studies are geographically confined within the tropical Americas and their surrounding oceans where GOES observations were available (e.g., Udelhofen and Hartmann, 1995; Soden, 2000). Therefore it is still worthwhile to document UTH variations over the other regions and compare with other results in order to better understand the diurnal variation of UTH and its relations to deep convection and high cloud.

10) Page 358, line 17: Duplicate what are stated on page 357, line 10.

We restated those sentences to help readers interpret Fig. 2 and Fig. 3. Following your comment, however, those sentences will be removed in the revised manuscript.

11) Page 360, line 23: Diurnal anomalies should be in different section because they do not belong to harmonic analysis.

We agree that diurnal anomalies are different from harmonic analysis results. Thus, following your suggestion, we now separate the diurnal anomalies from the harmonic analysis, letting the section 3 consist of 3.1 Harmonic analysis, 3.2 Diurnal anomalies, and 3.3 EOF analysis.

12) Page 361, line 14: The claim that the diurnal cycle of precipitation is not directly related to deep convection is not right. The different phase between PI and DCC is due to their different definition. By definition, PI takes more account of colder clouds (such

ACPD
7, S816–S823, 2007

as TB11<215K), while DCC weighs all clouds above 230K equally. It is well known that there is a strong diurnal phase lag among clouds at different levels especially over ocean (e.g., Fig. 6 in Tian et al. 2004). Thus, the diurnal phase lags among PI, DCC, and CAC shown in Fig. 4 is not totally unexpected. If the authors change the TB threshold to 210 or 215K for DCC definition, the agreement of PI and DCC will be much better.

You are right. In contrast to the vertically aligned PI and DC over the land which can bring in a coherent phase, a distinct vertical phase lag is noted for the oceanic high clouds (Soden, 2000; Tian et al., 2004). Precipitation peak associated with the coldest clouds is in the early morning while warmer clouds in the upper troposphere exhibit their maxima in the afternoon. Thus, we agree that the different phase between PI and DC over the ocean is attributed to their different definition. Following your comment, we correct the sentence and it now reads: "The DC shows a maximum around 14:00 LT with a secondary maximum around 07:00 LT. Soden (2000) and Tian et al. (2004) examined the time variations of DCs colder than 230 K and noted that upper (colder) and lower level (warmer) DCs are coherent with time over land while upper level DCs appear earlier than lower level DCs over the ocean. Thus, over the ocean, the precipitation peak associated with coldest clouds occurs in the early morning while warmer DCs exhibit their maxima in the afternoon. Because of the vertical time lag of DC over the ocean, the different phase between PI and DC in Fig. 4 is attributed to the different definition of DC."

13) In any case, I would suggest to delete DC and HC in all figures and the authors should focus their discussions on PI, CAC, and UTH (maybe MTH too) only.

From Fig. 6 in Tian et al. (2004) we found that a phase lag exists between colder clouds (i.e., DC) and warmer clouds (i.e., CAC) in the upper troposphere and that the time variation of UTH is more coherent with warmer clouds. But, diurnal variations of UTH have been examined in conjunction with HC in previous studies. Thus, it is necessary to examine diurnal variations of HC for the comparison with other studies.

ACPD
7, S816–S823, 2007

EGU

Since HC is composed of DC and CAC, diurnal variation of DC was also included in this study.

14) Page 362, line 5: The afternoon peak of PI in January case is kind of surprising to me. This does not seem to be supported by the map in Fig. 3. When the authors calculated the diurnal anomalies over land and waters, did they use the area-weighted average?

The afternoon peak of oceanic PI in Fig. 5 is not an artifact, but a true signal consistent with the map in Fig. 3. Examination of diurnal harmonics over offshore regions of southwestern coast of Brazil and Madagascar indicates that PI peaks in the afternoon. Although the morning peak is observed over the open oceans, the amplitude is smaller than that over those offshore regions. The afternoon peak over those offshore regions is generally consistent with results from TRMM observations – see Fig. 15a in Yang and Smith (2006).

15) Page 362, line 18: It is clear to me that there is a phase lag between PI (deep convection), CAC and UTH in Fig.4. Of course, the phase lag is small over land and much larger over ocean. This is consistent with the results of Tian et al. (2004) based on the 3-hourly IR data over the whole Tropics. Thus, it seems to me that the authors' claim 'the same trend occurs between CAC and UTH' might not be true. As a result, their conclusion that the evaporation of ice particle from CAC plays only a small role in moistening the upper troposphere is not very convincing. These comments also apply to their discussion in other parts of the paper: abstract (page 353, lines 14-17), section 3.2 (page 365, line 1), and conclusion (page 368).

Figure 8 in Tian et al. (2004) indicates that UTH lags high clouds by about 6 hours over land. Similar phase lag (between UTH and HC) is also noted in our study. By contrast, the phase lag between CAC and UTH is much smaller (about 1 to 2 hours), indicating that anvil spreading and upper tropospheric moistening occur almost simultaneously. Furthermore, if the evaporation of condensates plays an important role in moistening

ACPD
7, S816–S823, 2007

EGU

the upper troposphere, the UTH maximum is likely observed around the time of CAC minimum. However, it is noted that the UTH maximum precedes the CAC minimum by about 10 hours, implying that the upper troposphere is also moistened by other physical/dynamical processes beside the evaporation of CAC condensates.

16) Page 363, line 13: The spatial pattern of the EOF analysis is very interesting. The 1st mode of PI seems to be related to the land-sea contrast. It is well known that the diurnal cycle is strong over land and weak over oceans. Thus, the smaller values over oceans are expected. The authors may want to increase the contour levels over water to highlight the spatial pattern.

We replotted the figure showing more detailed spatial patterns especially over the ocean.

Fig. 6: Spatial patterns of two leading EOF modes: (a) precipitation index, (b) deep convective cloud, (c) cirrus anvil cloud, and (d) UTH. Sold and dashed lines denote positive and negative contours, respectively. Contour interval is 4 except 1 for values between -2 and 2.

17) Page 369, line 5: Gray and Jacobson (1977): Diurnal Variation of Deep Cumulus Convection. Monthly Weather Review, Volume 105, Issue 9, pp. 1171-1188.

Thanks for pointing out the mistake. We corrected.

References

Sohn, B. J., Schmetz, J., Stuhlmann, R., and Lee, J. Y.: Dry bias in satellite-derived clear-sky water vapor and its contribution to longwave cloud radiative forcing, J. Clim., 19, 5570-5580, 2006.

Tian, B., Held, I. M., Lau, N.-C., and Soden, B. J.: Diurnal cycle of summertime deep convection over North America: A satellite perspective, J. Geophys. Res., 110, D08108, doi:10.1029/2004JD005275, 2005.

ACPD

7, S816–S823, 2007

Yang, G.-Y. and Slingo, J.: The diurnal cycle in the tropics, Mon. Wea. Rev., 129, 784-801, 2001.

Yang, S. and Smith, E. A.: Mechanisms for diurnal variability of global tropical rainfall observed from TRMM, J. Clim., 19, 5190-5226, 2006.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 351, 2007.