Anonymous Referee #1

Few would have the patience to finish reading an overreaching manuscript that mumbles along.

Many thanks for the patience to read the manuscript and valuable comments.

Global climate change involves diverse aspects from the stratosphere to the ocean, from the polar region to the tropics, and from monsoon to severe storms. Each of these elements should be investigated independently in great detail, but their relationships to each other and their roles in global climate change also warrant investigation. Without the latter, we are unable to see the “big picture”. The goal of this study is to provide a framework for putting some of the pieces together by elucidating the connection between the tropical atmosphere and ocean.

We explained this in the introduction of revised paper and also modified the title as "Role of tropical lower stratospheric cooling in deep convective activity".

Major comments 1.

Fig. 6c. Zonal-mean vertical velocity change does not seem robust judging from the vertical structure and the relationship with OLR. (a) Vertical velocity change around 10N, where the authors identified a decrease in zonal mean OLR, changes signs three times within the troposphere. The vertical structure is inconsistent with the first-baroclinic mode structure that dominates the tropical troposphere (e.g., Fig. 6d). (b) Strong upward anomalies between the equator and 5S are inconsistent with overall positive OLR anomalies in the region (Fig. 6a). Something seems wrong here.

Convective activity is largely different according to the geographical situation. In fact, "Strange feature of three times change of signs" in zonal mean vertical velocity around 10° N resulted from a superposition of different structures over the continental and oceanic sectors. The northward shift occurs mainly over the continental sector, but over the oceanic sector, strengthening of vertical velocity occurs around 5° N-10° N without latitudinal shift.

"Strong upward anomalies between the equator and 5° S", is due to a low level convergence over the western Pacific–New Guinea region. This is produced as a pair with the change over the eastern Pacific, a part of the Walker circulation. To facilitate to seeing the association between the change over the western and the eastern Pacific, original Figs. 5 and 10 were merged together and the zonal wind component south of the Equator was added in the revised version.

Then, you may ask why we need the zonal mean. Because, if the forcing is zonal, the lower tropospheric responses largely depend on the underlying geography with zonally asymmetric characteristics. However, above the tropical propose layer (TTL), the zonal mean component of the response becomes significant. Therefore, to investigate the variation related to the stratospheric changes, analysis of the zonal mean field is necessary.

To respond the question, the following text and Fig. A1 (Fig. 8 in revised paper) was added in revised version.

"Therefore, meridional sections of "standardized" mean JAS 1999- 2016 anomalous pressure vertical velocity were calculated for different sectors (Fig. 8). In the case of standardized anomalies of 17-year mean as in Fig. 8, if one assumes a normal distribution, absolute values larger than 0.5 are statistically different from 0 at the 95% confidence level. Top panel shows the zonal mean field which can be comparable to that extracted by the SVD analysis in Fig. 7a. Contours indicate climatology. Middle panels are the same as the top panel, but divided into two parts: (left) African-Asian continental sector (30° W–130°E) and (right) Pacific-Atlantic oceanic sector (130° E–330° E). Strengthening of the upward velocity in the TTL and the lower stratosphere occurs in the continental sector adding to the northward shift in the troposphere, but over the oceanic sector, strengthening of vertical velocity occurs around 5° N-10° N without latitudinal shift. In the oceanic sector, upwelling is largest around 5° N–10° N, and strengthening of the upwelling occurs at the same location as the climatology. If we limit the sector only over the African continent (20° W–20° E) to exclude Indian Ocean influence, the abovementioned continental characteristics becomes further clear (bottom left). Over the oceanic sector, increase of the vertical velocity generally occurs around 5° N (bottom- right), but in the western Pacific sector (130° E– 170° E), upward velocity mainly develops south of the equator (10° S– 0°) (bottom- middle). We also note that in climatological vertical velocity in the western Pacific sector is confined practically in the lower troposphere over the equatorial SH (10° S– 0°). This feature can be attributed to the fact that the convergence of the air occurs over a warm ocean east of New Guinea island (Fig. 3c).

The above results indicate that in spite of the mixture of different profile according sectors, the zonal mean vertical field in the TTL mainly reflects the variation over African-Asian continental sector.

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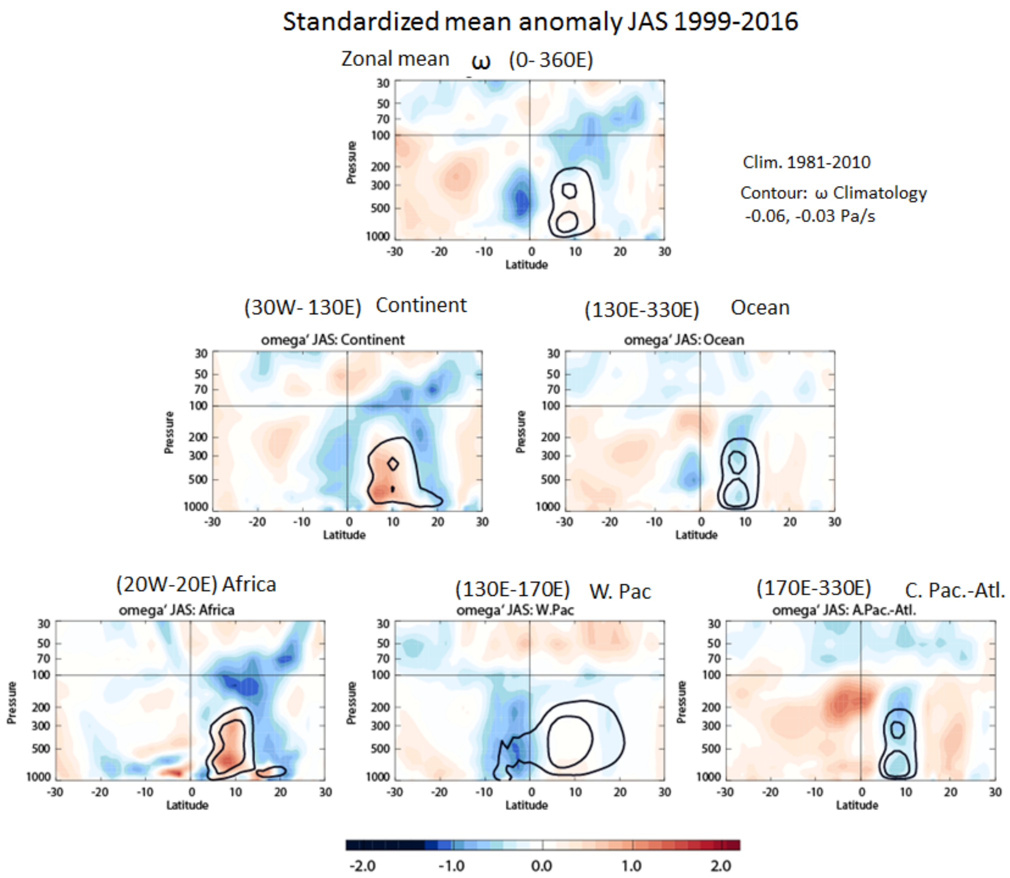

Fig. A1

The same problem applies to the SVD mode showing a strong trend in Fig. 8. The SVD mode with a strong trend features large OLR anomalies in the nonconvective subtropical regions (Figs. 8b,c), raising the question of to what extent the OLR pattern is associated with deep convection and deep vertical motion. Since the focus of the paper is on deep convection, I suggest using precipitation data throughout the paper, instead of OLR.

The reviewer didn't indicate the exact location of "nonconvective subtropical regions". Relatively negative correlation is found in two regions higher than 20° N in original Fig. 8c, one around Pakistan, and the other over Western Pacific (reproduced in the top panel of Fig. A2). It should be noted that strong convection events occur in these region: severe floods in Pakistan in summer 2010 is well known. In the case of western Pacific east of Philippine, deep convection associated with the tropical cyclone frequently occurs (Fig. A2 bottom). Unfortunately, long-term datasets to study the global occurrence frequency of the extreme deep convection does not exist. We will show in Part II of this paper that following a decrease of tropical lower stratospheric temperature, extreme deep convection increased over the western Pacific in association with a development of tropical cyclones.

There are advantages and disadvantages of using precipitation data. Large amount of precipitation is produced by low level convergence, which is of little concern in the present study. We are only interested in precipitation associated with deep convection. Also, direct measurements of global precipitation have limited data record. Thus, precipitation is derived by making use of some assumptions. In this sense, the OLR is better.

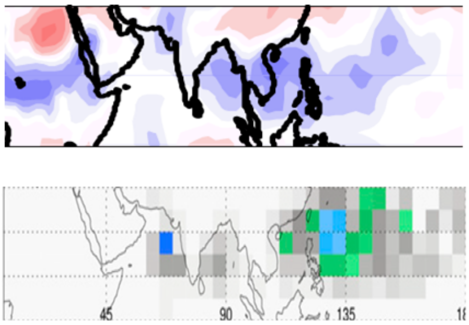

Fig. A2 (top) heterogeneous correction map of OLR, (Bottom) Fraction of deep convective updraft in tropical cyclones (from Fig. 4 of Jiang and Tao, 2014).

Jiang, H. Y., and C. Tao, (2014) Contribution of tropical cyclones to global very deep convection. J. Climate,27, 4313–4336, doi:10.1175/JCLI-D-13-00085.1.

The discussion of the seasonal transition in climatology (Fig. 6, right) is out of blue and the physical relationship to the multi-decadal change in deep convection is ambiguous at the best. I suggest deleting the discussion of the seasonal transition to avoid confusion and streamline the paper.

We agree with the comment, and the discussion on the seasonal transition has been removed.

2. The connection to the Brewer-Dobson circulation is dubious as it currently stands and should be deleted. ACP readers expect robustly tested results, not unsubstantiated speculations.

In this paper we showed a connection between the zonal mean vertical velocity in the tropical lower stratosphere and in the TTL around the rising branch of the Hadley circulation. The stratospheric zonal mean meridional circulation can be designated as Brewer Dobson circulation.

Figure 11 is bizarre: are the narrow bands in vertical velocity in Fig. 11a real, and the meridional dipole in the middle panel of Fig. 11b is averaged out in the meridional mean displayed in the upper panel of Fig. 11a. This is just one example that some speculations do not seem to hold water.

It is difficult to verify whether the narrow bands are real because there are no available observations. However, it is plausible that these features are related to the vertical velocity perturbations near convective overshooting clouds (COV), which penetrate into the TTL beyond the level of neutral buoyancy. Figure A3-top panels show the same vertical velocity field in the original Fig. 11, but the mean anomalous vertical velocity of 1999-2016 is compared with climatological (2007-2017) occurrence frequencies of COV. Increased vertical velocity mainly occurs over the region where COVs are frequent. This relationship is expected because convective overshooting occurs in extreme deep convective clouds, which penetrate into the TTL.

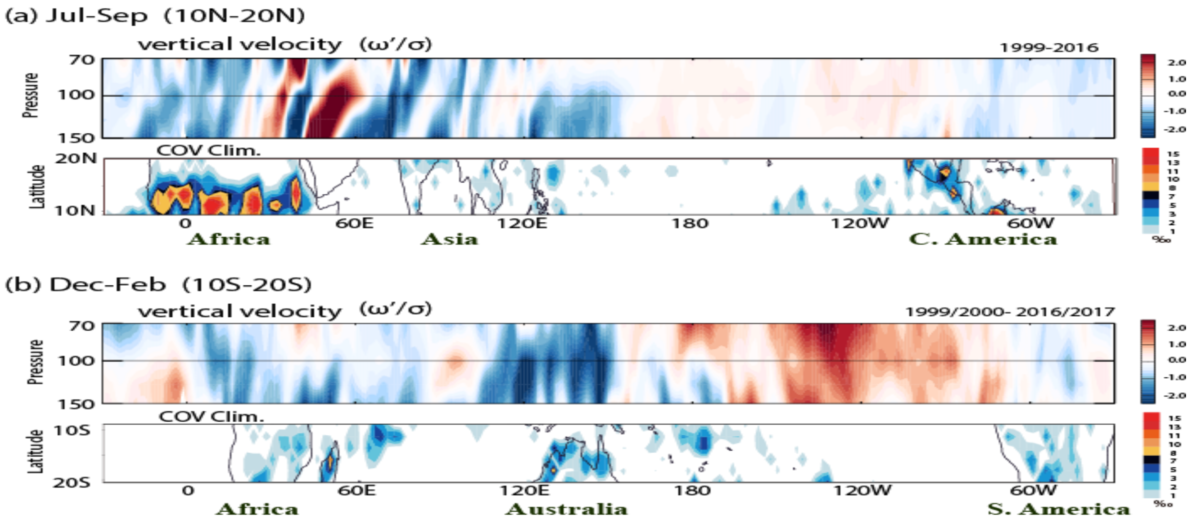

Fig A3

In a previous paper we showed that daily variation of occurrence frequency of the COV during boreal winter is correlated with the zonal mean vertical velocity in the lower stratosphere, while that of the OLR is correlated with the vertical velocity in the troposphere as in Fig. A4.

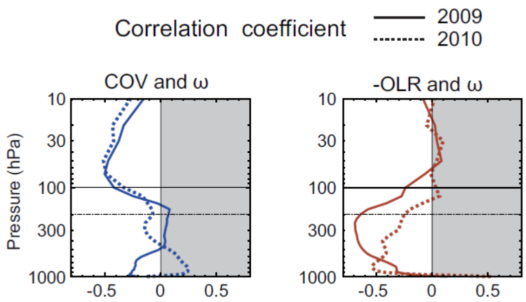

Fig A4 (left) Correlation coefficient between the pressure coordinate vertical velocity at each pressure level and the daily convective overshooting occurrence frequency (COV) averaged over the tropics. (right) Same as the (left) but for the correlation with OLR. [from Kodera et al. (2015), The role of convective overshooting clouds in tropical stratosphere–troposphere dynamical coupling Atmos. Chem. Phys., 15, 6767-6774]

Similar relationship can also be found in climatological field over Africa. Figure A5 compares JAS climatology (2007- 2017 mean) between (left-hand panels) the vertical velocity at 500 hPa and OLR and (right-hand panels) vertical velocity at 100 hPa and the occurrence frequency of the COV over North Africa. At 500 hPa, upwelling extends zonally along 10 °N latitude corresponding to the region of low OLR, whereas upwelling at 100 hPa is broken up in a couple of segments, which roughly corresponds to the region of frequent COV. Similar relationship may also hold on a decadal timescale.

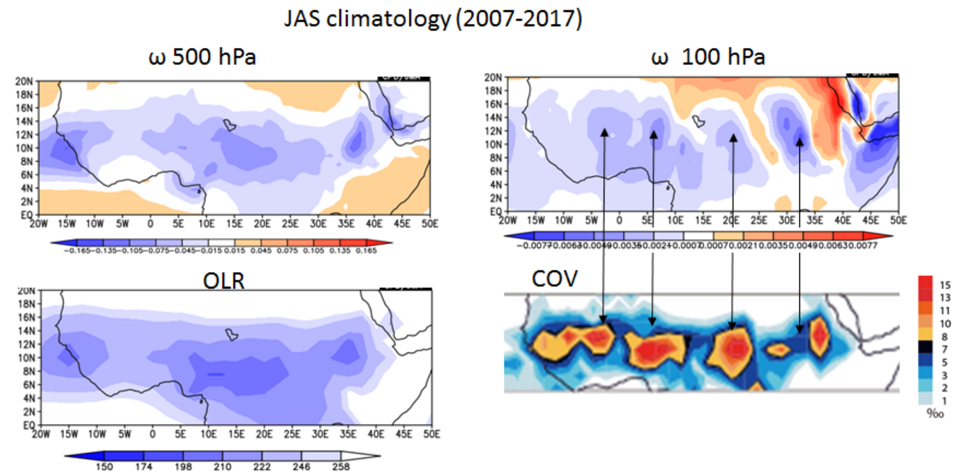

Fig A5

In recent paper, Taylor et al. (2017) reported an increasing trend in deep convective activity over Africa. They showed that the most intense Mesoscale Convective Systems (MCSs) with cloud top temperature lower than −70 °C (air temperature at ~150 hPa) exhibited the largest increasing trend; these MCSs represent clouds penetrating into the TTL. The evolution of these intense MCSs and the pressure vertical velocity at 150 hPa averaged over the similar area is compared in Fig. A6. Rectangles indicate the domains over which averages are calculated for the left panel. There is a quite good correspondence between the evolution of the vertical velocity at 150 hPa and the occurrence frequency of extreme deep convection over Sahel in Africa. It should be noted that the surface precipitation, and lower clouds do not show such clear increasing trend (Taylor et al., 2017). These evidence suggest that the vertical velocities shown in Fig. 11 appear to be related to perturbations induced by the distribution of extreme deep convection.

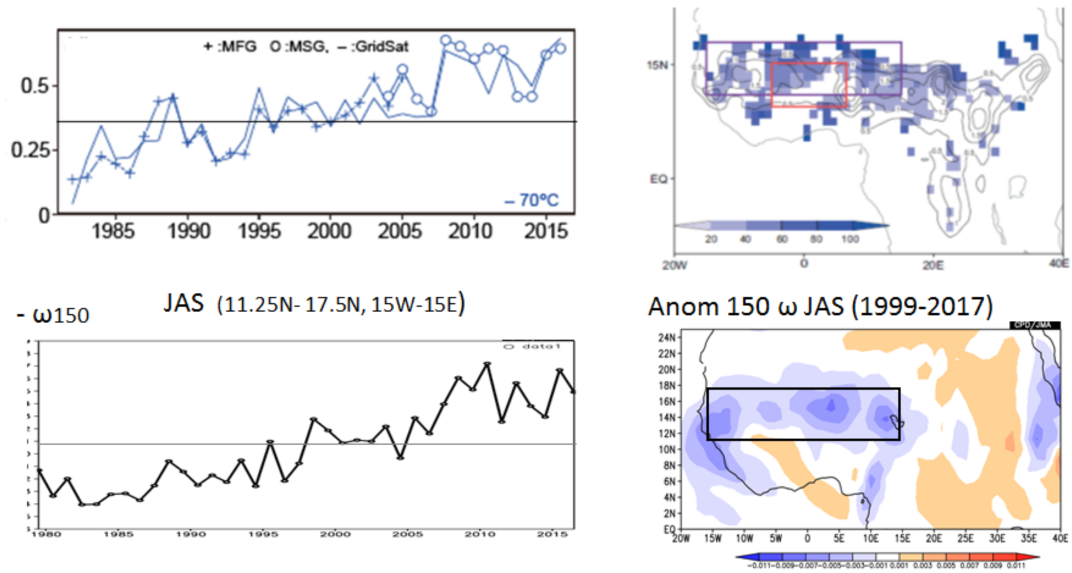

Fig. A6
Top panels: (left) MCS frequency of which cloud top temperature lower than -70 °C. (right) Region of significant trends. The purple rectangle denote the domains used in the left panel. (from Taylor et al., 2017). (Bottom) JAS mean vertical velocity at 150 hPa averaged over the area shown by rectangular in right-hand panel.

Taylor, C. M. et al, 2017: Frequency of extreme Sahelian storms tripled since 1982 in satellite observations. Nature, 544, 475–478.

According to the comment, original Fig. 11 was replaced by Fig. A3 (Fig. 9 in revised paper) and the text was modified as follows in revised version.

" While bottom panels show a distribution of climatological (2007−2017) occurrence frequency of the convective over shooting (COV) in the same latitudinal zone. Inspection reveals that increasing trend of the upwelling occurs over the continental sector, especially where COVs are frequent. This characteristics are commonly seen in both summer hemispheres. The contrast between the continental and oceanic sectors is clearer in the SH where the distribution of lands is simpler. Because the COV occurs in the deep convective clouds penetrating into the TTL beyond the level of neutral buoyancy, such the increased vertical velocity in the TTL over the region of frequent COV seems reasonable. It should also be noted that a connection between the COV and the vertical velocity in the tropical lower stratosphere in day-to-day scale has been shown in a previous study by Kodera et al. (2015)."

3. At the top of page 8, the authors admitted “a discussion of statistical significance : : : is practically impossible”. This may be true but the mutual physical relationship among different fields is a minimum test an analysis needs to pass. My major comment 1 questions whether some of the results are robust and physically consistent.

The results of above analyses can be schematically summarized in A7 (Fig. 11) . According to this, we selected 4 key variables which can be considered as fundamental in the recent tropical trends: (a) tropical lower stratospheric temperature in early summer (temperature at 70 h Pa averaged over 20° S–20° N from 16 July-16 August), (b) pressure vertical velocity at the bottom of the TTL (150 hPa) in August, (c) August-October mean "southward" winds south of the equator (10° S–0°) in the western hemisphere (180° W–0°) , (d) tendency in the SST, from the early summer (May-July) to late autumn (October–December) in the tropical Pacific west of South American continent (15° S–5° S, 100° W–80° W). Time series of these 4 variables (a–d) are displayed in A7 (Fig 11)–right.

When all 4 variables become negative (indicated by red dots), we define this as negative event. Similarly when all variables become positive (black dot), it is defined as positive event. All 6 positive events occurred within the first 14 years, while all 7 negative events appeared during the last 13 years. Chi-square test was conducted to examine whether such distribution of the events occurs by chance by dividing the whole 39 years to 3 equal period of 13-year. The result (χ^2 = 23) indicates that such distribution occurs by chance with less than 0.1% of probability. Therefore, there is a statistically significant tendency that negative events occur more frequently in recent decade.

The problem here is, however, whether there is a causal relationship among the variables. We introduced a seasonal variation for the selection of the variable from the stratospheric cooling at the end of July, to a cooling of ocean from summer to autumn. The time evolution tentatively suggests a causality among them, which can be used as working hypothesis, but definite causality needs to be proven in future study. More detailed analysis on selected events will be done to understand causal relationship between the stratospheric and tropospheric change in Part II of this paper.

We added the above text and Fig. A7 (Fig. 11 in revised paper) to revised version.

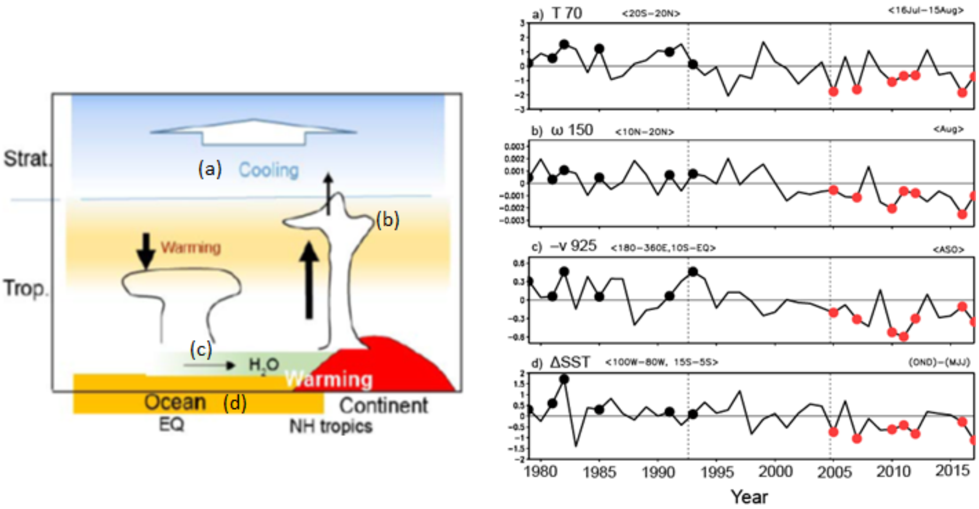

Fig. A7

4. Related to my major comment 1, JAS OLR change (Figs. 6 left, 8-9) is not zonally uniform; specifically the decrease in 10-20N is zonally confined in the African-western Pacific sector. This raises the question of whether the zonal mean even makes sense.

Please see our response to comment 1.

5. If the first three sections are hard to go through, section 4 (Summary and discussion) is impossible to comprehend, full of wild, poorly connected speculations. I urge the authors to summarize robust results that make physical sense first and only then, make some reasonable discussions that would be helpful for future research.

As mentioned earlier in this paper, we have tried to provide a framework for examining the different regions and variables simultaneously to better understand the present global change occurring in the atmosphere-ocean system.

Causal relationship is usually verified by numerical model simulations. However, this requires a model that is capable of realistically reproducing all key processes, none seems existing today. Here, we focused on the validation of one feature of one model - the effects of extreme deep convection on the vertical velocity in the TTL - which is a key element in addressing the present problem.

According to comment, we simplified the discussion section.