Interactive comment on “A characterization of thermal structure and conditions for overshooting of tropical and extratropical cyclones with GPS radio occultation” by R. Biondi et al.

Anonymous Referee #2
Received and published: 24 December 2014

General comments:
This paper examines thermal structure of the tropical cyclones (TCs) on different ocean basin using GPS radio occultation data (RO) temperature measurement. Based on the thermal structure (cold anomaly in the lower stratosphere) the cloud top height is estimated, and their statistics are compared and documented over different ocean basins and latitudes. Analyzing TCs influence in the upper troposphere and lower stratosphere (UTLS) region is a meaningful topic, and use of GPS RO data is very suitable for the purpose. Also, considering limited observation in TCs, utilizing temperature anomaly as a signature of deep convection (and overshooting) seems a reasonable approach, and the regional difference of TCs' overshooting convection is analyzed with a reasonably long record. The paper is generally well written, and recommended for publication in ACP.

>>> We thank the reviewer for the thorough review of our paper and for the helpful additional comments. Please find below our point by point response (in italics).

I have several minor comments and possible suggestions for the authors:

Specific comments (minor):

1. The major assumption here is the minimum temperature anomaly in the lower stratosphere (LS) corresponds with convective cloud top. The cold anomaly in the LS may not solely due to direct effect overshooting convection. The cold anomaly could also be formed by a large-scale dynamical response to latent heating below (e.g., Randel et al. 2003; Holloway and Neelin 2007), in this case, the cold anomaly is not necessarily correspond to convective cloud top. Although a reasonable agreement between these two properties are shown in Biondi et al. (2013) using CALIOP measurement (with limited number of profiles), additional discussion or physical reasoning on "robustness of this assumption" will be helpful for the future use (may be in the first paragraph of section 4.1).

>>> Biondi et al., 2011, 2012 and 2013 have already demonstrated and described the minimum temperature anomaly corresponding to the cloud top. We agree that the cold anomaly may not always be due to convection and that some uncertainties could be introduced by other phenomena. As suggested by the reviewer we added the following sentence in the first paragraph of section 4.1: "However, we note possible uncertainties regarding the cooling signature which may also be due to the presence of large-scale dynamical response to latent heating below the cold anomaly (Randel et al., 2003; Holloway and Neelin, 2007) or gravity waves originated by the TC (Tsuda et al., 2000; Kiladis et al., 2001; Kim and Alexander, 2015)."

2. The warm anomaly over Hcoldest and the double tropopause-like temperature anomaly in Figure. 6 could be a gravity wave signature (Kelvin wave, inertio-gravity wave; Tsuda

et al 2000; Kiladis et al 2001) in the UTLS. Because gravity waves are well trapped in the deep tropics, the wave-like signal may larger in the tropical profiles compared to extra-tropical profiles.

>>> We agree with the reviewer, and this is one of the uncertainties that we must take into account in such kind of studies. In Fig.6 we show mean temperature anomaly profiles, results of the average of hundreds (or thousands) of single profiles showing a double tropopause feature. Some of them could be due to gravity waves, but due to the fact that we are analyzing GPS RO co-located with TC most of the anomalies must be generated by the TC cloud top or by the two effects reinforcing each other (Randel et al., 2003). The discrimination of double tropopauses due to gravity waves is a topic of future work with the aim to include it in the algorithm for detecting the TC cloud tops.

3. In section 4.2, second paragraph proposes a mechanism of double tropopause formation. It is difficult to follow authors' interpretation because no actual double tropopause analysis is found in the manuscript, and the mechanism is different from the subtropical double tropopause formation (Rossby wave breaking and near-horizontal mixing in the subtropics; e.g., Pan et al. 2009; Wang and Polvani 2011). Further explanation and difference from the previously known mechanism would be beneficial.

>>> As reported above, In Fig.6 we show the mean temperature anomaly profiles, results of the average of hundreds (or thousands) of single profiles. The single profiles show the double tropopause, but they are all at different altitudes and the average smooths this variation. However, we decided to report also the panel b) explicitly for showing that the double tropopause is evident when we have a small number of samples (i.e. 3 samples for TC category 5). The detection of double tropopauses originated by the TC is not the objective of this paper since already reported in Biondi et al., 2011. In this manuscript we just use it as a tool for distinguishing different ocean basins characteristics and for detecting possible overshootings.

The overshooting is present when the tropospheric air is transported by the convection into the stratosphere and it remains there due to the stratospheric stability. We do not want to exclude that the tropopause uplift can create an overshooting: with a few hundred cases compared with CALIOP backscatter in the past (Biondi et al., 2012 and Biondi et al., 2013) we have never seen a temperature inversion associated with cloud top altitude higher than local tropopause. Thus we think that one possible explanation could be that the strong convection locally moves the tropopause upward (Fig. 1 below), creating a relatively small bubble where the tropospheric air ascends to stratospheric altitudes (Fig. 2 below). Once the storm is gone, the previous conditions are re-established, the air is trapped at stratospheric levels (Fig. 3 below) and moves laterally. Of course this depends on the stability and time scales so the process can be either stable or not, but it is a necessary condition for having an overshooting.

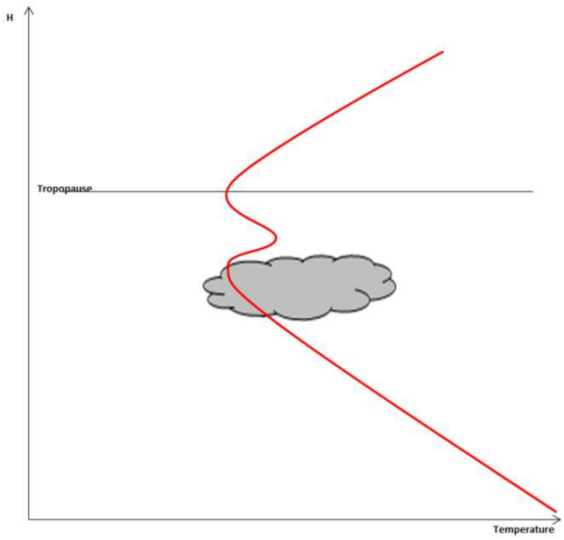

Figure 1. The double tropopause during convection: the lowest temperature inversion corresponds to the cloud top and the highest temperature inversion corresponds to the tropopause.

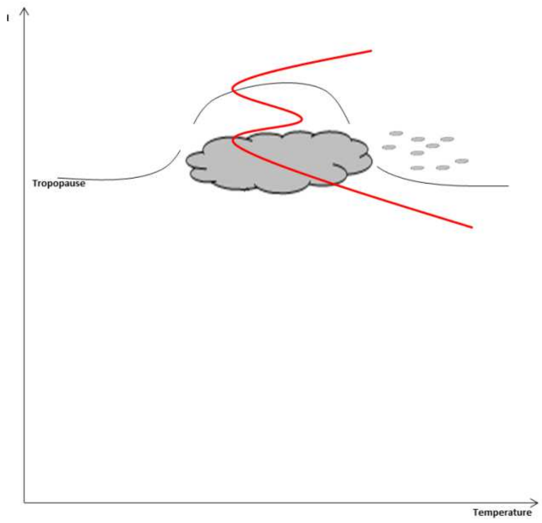

Figure 2. Temperature profile and tropopause altitude when the convection reaches the climatological tropopause altitude.

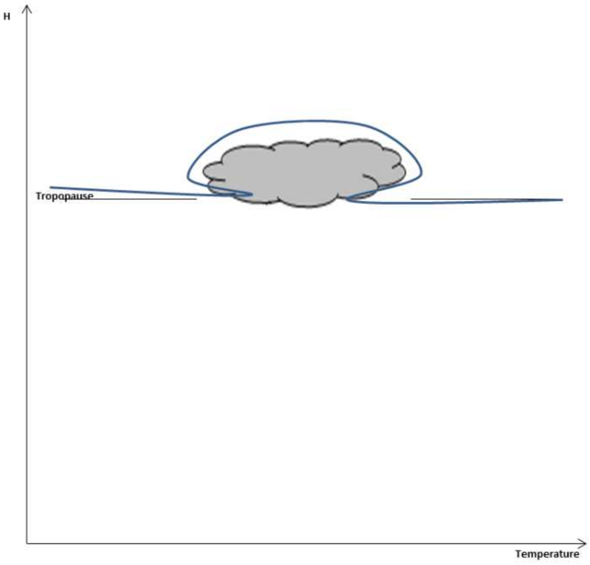

Figure 3. Once the convection is gone, the previous tropopause conditions are re-established.

Technical comments:

P.29400 L11: monthly mean => monthly climatology?
>>> *Done*

P.29401 L9: SD is used without definition
>>> *Done*

P.20702 L3-4: Hcoldest_std, Hcoldest_std+1 => Hcoldest, or
condition 1: Hcoldest > Hmm_trop + Hmstd_trop
condition 2: Hcoldest >
>>> *Done*

P.29403 L13: Since there is not any good => Since there is not enough
>>> *Done*

P.29403 L19: below => above?
>>> *We confirm it is actually below, we refer to the inversion creating the coldest point*

P.29403 L21: the minimum temperature => the minimum temperature (Hcoldest) ?
>>> *Done*

P.29404 L5: about 3 K (to my eyes it is 2-2.5 K)
>>> *We have corrected the value to 2.5 K*

P.29405 L17-19: Need to clarify
>>> *We have already replied to this in the specific comments. We added to this sentence the reference to Biondi et al., 2012 and Biondi et al., 2013.*

P.29407 L 4-11: Figure 11 only has description, but no discussion on it.
>>> *Fig.11 is just an example showing how the algorithm works, the discussion of Tab.3 is also related to this Figure. We added the following short description:*
“The distribution over the year shows that storms occur from April to December over the Western Pacific at 0°N to 20°N and mainly from July to October at 20°N to 40°N. Overshootings are found in each investigated latitude zone when storms occur. Hardly any overshootings are found from July to September in the Tropics (0° to 20°N).”

P.29407 L27: The sentence "A double tropopause characterizes a storm: : :" needs a proof (or supporting reference)
>>> *we added the references to Biondi et al., 2011. As reported above, an example of the evidence is the temperature anomaly profile of TC category 5 in Fig.6*

P.29407 L27: does "convection dynamics" means "gravity wave response?"
>>> *Convection dynamics in this case refers to the uplift of the tropopause in presence of strong convection. In some cases the dynamic could be due to the gravity waves as reported in the previous comments.*

P.29408 L3: The sentence "overshooting will overpass the climatological tropopause more deeply at extra-tropical latitude" doesn’t supported by analysis.
>>> *We referred the sentence to Tab.3 which clearly shows it corresponds to our results.*

References:

Biondi, R., Neubert, T., Syndergaard, S., and Nielsen, J. K.: Radio occultation bending angle anomalies during tropical cyclones, Atmos. Meas. Tech., 4, 1053–1060, doi:10.5194/amt-4-1053-2011, www.atmos-meas-tech.net/4/1053/2011, 2011.

Biondi, R., Randel, W., Ho, S. P., Neubert, T. and Syndergaard, S.: Thermal structure of intense convective clouds derived from GPS radio occultations, Atmos. Chem. Phys, 12, 5309-5318, doi:10.5194/acp-12-5309-2012, 2012.

Biondi, R., Ho, S. P., Randel, W., Syndergaard, S. and Neubert, T.: Tropical cyclone cloud-top height and vertical temperature structure detection using GPS radio occultation measurements, J. Geophys. Res. Atmos., 118, 5247-5259, http://dx.doi.org/10.1002/jgrd.50448, 2013.

Holloway, C. E., and Neelin, J. D.: The Convective Cold Top and Quasi Equilibrium. J. Atmos. Sci., 64, 1467–1487, doi:10.1175/JAS3907.1, 2007.

Kiladis, G., Straub, K., Reid, G., and Gage, K.: Aspects of interannual and intraseasonal variability of the tropopause and lower stratosphere, Q. J. R. Meteorol. Soc., 127, 1961–1983, doi: 10.1002/qj.49712757606, 2001.

Kim, J.-E., and Alexander, M. J.: Direct impacts of waves on tropical cold point tropopause temperature, Geophys. Res. Lett., 42, doi:10.1002/2014GL062737, 2015.