Reply to referee #1

We are grateful to the thorough reading and constructive comments on our manuscript. We believe we have incorporated all aspects pointed out. The detailed description on the revision follows:

Major issues

1. *The comparison between the sonde temperatures and winds with ECMWF is interesting and important, however the question is whether the sonde data and ECMWF are independent needs to be answered. Are these wind and temperature observations used in the ECMWF analysis?*

> Reply: All radiosonde data compared with ECMWF analysis in Figs. 3, 4 and 5 are independent from ECMWF analysis as they are not submitted to GTS network since they were taken during SOWER campaigns. One sentence has been inserted at the end of the paragraph ending in line 12, page 25843, which reads:

> Note that ECMWF does not include SOWER data in the analyses and thus the sets to be compared in the following are mutually independent.

2. *The Trajectory analysis is based on different versions of the ECMWF analyses. This may introduce avoidable differences that would not be there when using the re-analysis ERA-Interim data that is available for the full time span. If the time and effort is not too large, it would be nice to if the results change with taking this updated meteorological data set. This would be interesting since Schoeberl et al (ACP, 2012) report differences between different meteorological analyses.*

> Reply: Our results from the trajectory analyses depend on the choice of dataset and we are aware that the latest reanalyses such as ERA-Interim are superior to the previous ones in several aspects. For our specific purpose of studying the TTL dehydration, on the other hand, fine vertical resolution in the TTL is quite important because the temperature perturbations and wind shear associated with large scale atmospheric waves could play a key role in the TTL dehydration. This is why we use 91-model-level operational dataset. Before February 2006, however, the number of model levels in ECMWF operational analysis and ERA-40 reanalysis we currently rely on was 60. As it is the same in ERA-Interim, it must be better to use ERA-Interim for the analysis before February 2006. Unfortunately we are still on our way of switching to ERA-Interim and the results are not yet available. Admitting the reviewer's concern arising from the inhomogeneity is reasonable, we still value more on the fine resolution model-level dataset since our present study does not deal with the long-term change. The description has been modified in lines 20-22, page 25851. Some more arguments are made in response to the comments from another reviewer. The revised sentences are:

> Although growing numbers of global analyses have emerged with notable differences (e.g. Liu et al., 2010; Schoeberl and Dessler, 2011), our use of the high-resolution model-level ECMWF analysis is based on our recognition that fine vertical resolution in

the TTL is important for our study as the temperature perturbations and wind shear associated with large scale atmospheric waves could play a key role in the TTL dehydration. On the other hand, there is a clear limitation as can be seen from the comparison between the analysis field and sonde data as seen in Fig. 4. Fortunately the wind biases in the TTL are mostly confined to zonal wind between 375 K and 390 K, while the spatial scale of variabilities becomes larger in this altitude range than in the lower TTL thus the impact of wind bias on the estimates of SMRmin is more limited. A mean temperature bias of 2 K on the potential temperature surfaces at 355 K and 360 K (but not at 365 K and above), on the other hand, needs to be considered in the estimation of SMRmin. Our present approach is to assume a 2 K constant bias in the ECMWF temperature field and add 2 K to the temperature along the trajectories without considering any change in the trajectories themselves. This is over simplification of the problem, but provides a better estimate of SMRmin making the judgement of the encounter with deep convection more realistic. As is expected, the points have moved to the righthand side and come closer to the dashed line in Fig. 14 as compared to those without taking this bias into account (not shown). It is interesting to see the uneven shift at potential temperatures 360 K and 365 K does not go far beyond the dashed line suggesting that the supersaturation along the trajectories does not greatly exceed the homogeneous nucleation limit. One of the possible ways ...

3. *The authors report a very large RH$_{ICE}$ value at temperatures near 180K within cirrus (page 25848, line 17ff and abstract line 12f) and comment that they are much higher then reported by Krämer et al. (2009). However, this is not the case, since at temperatures below about 186 K the RH$_{ICE}$ climatology also reports values above the homogeneous freezing threshold in a few cases (compare fig. 7 of Krämer et al.). It should rather be stated that the observations are in accordance with Krämer et al. The request of further needed observational evidence in the abstract should be left out (line 12f). At least the authors have convinced this reviewer about the credibility of their data.*

Reply: Revised as suggested.

The abstract p. 25835, l. 12:
Although further observational evidence is needed to confirm the credibility of such high values of RHice, the evolution of TTL dehydration is evident from the data in isentropic scatter plots between the sonde-observed mixing ratio (OMR) and the minimum saturation mixing ratio (SMRmin) along the back trajectories associated with the observed air mass.

The sentence in p. 25848, l.18:
The RHice value of 179 ± 14 % within the cirrus is extremely high, although similar values have been reported previously (Krämer et al., 2009).

The sentence in p. 25852, l.5:
This value is one of the highest among those observed in cirrus clouds (Krämer et al., 2009).

Minor Points

figs 8 and 12: Ozone is shown in these figures but there is little deduced from these data.

Reply: One sentence is inserted for Fig. 8, and one sentence is modified mentioning the structure of TTL:

p. 25846, top:
... 2008 at Biak. The lower boundary of TTL, implied by the upward ozone increase from its tropospheric value of about 25 ppbv, is found at around 360 K.

p. 25848, l. 10:
The former, sitting just below the TTL lower boundary with a marked ozone increase and a sudden drop of frostpoint temperature, is not discussed here ...

page 25839 line3 / fig.1: Mention the source of the wind and temperature data (ECMWF...)

Reply: One sentence and figure caption have been modified:

p. 25838, bottom:
The latitude-longitude distributions of the horizontal wind components (arrows) and temperature (colour) on the 370 K isentropic surface are derived from the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analyses and are shown as an average over the campaign period in Fig. 1.

Caption of Fig. 1:
... during four SOWER campaigns deduced from ECMWF operational analyses.

25840-42: The response times of the different experiments are discussed, e.g. for SW for temperatures of -30 and -60 degrees C. However, it would be also interesting to mention the response time for lower temperatures down to -90 degrees that are relevant for the dehydration process.

Reply: No such value could be given for SW hygrometer since it does not work under extreme coldness such as -80 degrees C. One sentence has been inserted for SW. For CFH, one sentence has been modified:

p. 25840, after l. 18:
This is one of the reasons we do not use SW in this study.

p. 25840, l. 21-23:
However, in the upper troposphere and lower stratosphere, as is discussed later, τ could be much longer than the sampling interval of about 7 s for TMAX-C and 1.4 s for V2C systems that transmit telemetry data to the ground station.

25844.20: There may be bifurcations and saddle points in the calculation of advection, however, I don't see those in the cited figure.

Reply: Bifurcations are seen at around 10 degrees in latitude south of Tarawa in the bottom panel of Fig. 1 of Hasebe et al. (2007). The sentence has been modified:

... to wind shear and the bifurcation of the trajectories at the saddle point encountered along the advection (e.g. south of Tarawa in the bottom panel of Hasebe et al., 2007, Fig. 1).

25844.27: Mention the number of trajectories per bundle.

Reply: The number of trajectories, 81, has been inserted in the text.

25845.4/ fig. 7: It is not clear, how the ECMWF SMR is calculated here. Is it calculated from ECMWF H2O and temperature or from observed H2O and ECMWF temperature?

Reply: The second word in line 5 "filed" is a typographic error of "field." Atmospheric water content is not necessary to calculate SMR and our estimation here and in Fig. 7 is made from the ECMWF temperature field using the Goff-Gratch equation, which is inserted in the text:

p. 25845, l.3-5:
Those on the top panel are colour-coded by the saturation mixing ratio (SMR) for the advected air parcel estimated from the ECMWF temperature field using the Goff-Gratch equation.

25845.11: Some explanation/reference about what geostationary satellites should be given here.

Reply: Geostationary Operational Environmental Satellite-9 (GOES-9) and Multi-functional Transport Satellite-1 Replacement (MTSAT-1R) are used, which is inserted in the text.

25845.14/ figures 7&11: The purple colour is hardly to distinguish from blue and black. If I read the color scale correctly it is from about -7 to -14 K. I don't think that this is a special range. So either the sentence needs to be rephrased or the color scale needs to be adjusted.

Reply: The text has been modified so as not to restrict dark colours to purple:

p. 25845, l. 14:
The dark colours such as purple indicate that ...

25847.1: "This is due..." It is not clear what is meant by this statement.

Reply: The sentence has been replaced:
This is due to the general tendency of the isentropes in the TTL, e.g. 360 K, to be higher in the tropics than in midlatitudes.

25847.28, figures 7, 10 and 11: To understand this statement it would be good to include longitude (and latitude) values on the axes of the plots.

Reply: Longitude-latitude values are put on these figures.

25849.14ff: Does that mean that the trajectories that encounter temperatures $T<T_{bb}+12$ K are excluded from this plot?

Reply: Such trajectories are not excluded in whole but only those portions of them before the last of such events as to meet $T<T_{bb}+12$ K are excluded in the estimation of SMR_{min}. The sentence has been modified.

p. 25849, l. 17-18:
In case where an intrusion of deep convection is suspected, SMRmin has been sought only from those portions of trajectories after the last of such events.

25849.27: Mention "about 60%" as the homogeneous nucleation threshold is temperature dependent

Reply: The sentence has been modified.

p. 25849, l. 27-28:
(60-75 % for homogeneous nucleation of ice at temperatures characteristic of the western Pacific cold point tropopause; see Koop et al., 2000, for detailed temperature dependence), the OMR might be a factor of 1.6-1.75 higher than SMRmin without ...

25851.12: change to "...stratospheric value of response time adopted..."

Reply: The sentence has been changed as indicated.

Typographical corrections

25835.2 & 25838.20: balloon-borne

Corrected.

25844.1: There are some…

    Corrected.

25850.4: leads

    Corrected by modifying the sentence.

25852.9: do not correspond

    Corrected.

figures 3, 8 and 12: type ○C instead of C as temperature unit

    Corrected.
    Oppositely allocated left and right panels in Fig. 3 are also corrected.

figure 8b: replace "/" by "," to avoid confusion as this is no division

    Corrected.

Other revision:
    Fig. 2 has been rewritten by plotting the descending profiles first and ascending data later
    so that masking due to overlapping error bars be minimal.