Response to Referee #1

We thank the reviewer for the useful suggestions to improve the paper. The comments of the referee are repeated in bold letters while our response is given in normal text.

According to the comments of both referees, we changed to title of the paper, replaced X by [X], and added error bars to the TIMED/SABER observations in Fig. 1-5.
We further carried out sensitivity runs with different sets of Einstein coefficients and included a new Figure 2. We also increased the uncertainty of the Einstein coefficients and added uncertainties of SABER temperature, SABER OH(9-7)+OH(8-6) VER, and SABER O3, resulting in larger total uncertainties of [O(3P)] and [H]. The discussion of potential error sources of [O(3P)] was also extended.
The rate of OH(v=8)+O(3P) was reduced in order to obtain physically allowed [O(3P)] values, which are slightly lower than in the previous paper version.
Finally, a detailed comparison between the [O(3P)] derived here and [O(3P)] from other studies is also included in the section "Conclusions" and we explicitly state that out [O(3P)] should be regarded as an upper limit.

General comments:

I know it's a bit persnickety, but throughout the paper you need to be careful distinguishing between X and [X], as is done in the equations. X is not being derived, you are deriving X densities, or deriving [X].
Done, we changed X to [X] throughout the paper.

If O3 is also a variable in the airglow model, could you not compare the resulting O3 with SABER values as a further constraint, in addition to the SABER VER? Either way, it would be interesting to see how the best fit model O3 compares to the SABER values, since those are not related to OH (although if it is expected that SABER O3 values are too large, maybe this wouldn't work. Or could you compare to SABER O3 1.27 µm data?).
No, O3 is not a variable in this paper and was obtained from SABER observations at 9.6 µm. Comparisons with SABER O3 at 1.27 µm are not possible since these measurements are not available during night. Recent comparisons between SABER night-time O3 with MIPAS night-time O3 showed that these two data sets agree within the corresponding error bars in the altitude region 80-100 km over the equator region (Lopez-Puertas et al., 2018, their Fig. 8 and 10). Thus, at least to our knowledge there is no conclusive evidence stating that SABER night-time O3 is generally too large or too low. The corresponding sentences in the paper were rephrased and an uncertainty of about 10 % of SABER O3 (Smith et al., 2013) was considered when estimating the total error of derived [O(3P)] and [H] profiles.

Thus, we added (l. 166-167):
"There are also SABER O_3 measurements at 1.27 µm but these observations are not available during night."

rewrote l. 211-216:

"Finally, rewriting Eq. (1) enables the derivation of [H] while [O(^{3}P)] is calculated by substituting Eq. (3) in Eq. (1) and rewriting the resulting term as follows:

$$[H] = \frac{OH(9-7) + OH(8-6)\ VER}{G\,k_1\,[O_3]} \quad ,$$

(4a)

$$[O(^3P)] = \frac{OH(9-7) + OH(8-6)\ VER}{G\,(k_3\,[O_2][M] - k_2\,[O_3])}\ .$$

(4b)

Air temperature and air pressure from SABER were used to calculate [M], [O$_2$] (VMR of 0.21), and [N$_2$] (VMR of 0.78) as well as to convert SABER O$_3$ VMR into [O$_3$] via the ideal gas law."

and added l. 549-554:

"Recent comparisons between MIPAS O$_3$ and SABER O$_3$ derived at 9.6 µm were performed by Lopez-Puertas et al. (2018). The authors showed that night-time O$_3$ from SABER is slightly larger than night-time O$_3$ obtained from MIPAS in the altitude region 80-100 km over the equator (their Fig. 8 and 10) but these differences are within the corresponding errors. Thus, at least to our knowledge there is no conclusive evidence stating that SABER night-time O$_3$ is generally too large. Nevertheless, we considered an uncertainty of O$_3$ of about 10 % (Smith et al., 2013)."

Also, please comment on how initial conditions of the target species affect the results of the model, i.e. have you tested this, what are the scale of any uncertainties the first guesses can add?
The target species [O(3P)] and [H] were derived by Eq. 4a and 4b, solely depending on OH airglow, [O3], [O2], [M], and several rates of chemical and physical processes involved (k1, k2, k3, G).

$$[H] = \frac{OH(9-7) + OH(8-6)\ VER}{G\,k_1\,[O_3]} \quad , \qquad (4a)$$

$$[O(^3P)] = \frac{OH(9-7) + OH(8-6)\ VER}{G\,(k_3\,[O_2][M] - k_2\,[O_3])}\ . \qquad (4b)$$

During our sensitivity runs, we used different [O(3P)] and [H] values based on different assumptions of the chemical and physical rates involved.
But we did not assume any a priori information of [O(3P)] and [H] to calculate these two target species, and consequently there are no "initial conditions" of the target species [O(3P)] and [H] influencing the model results.

Thus, we rephrased (l. 220-222):
"It is apparent from Eq. (4a-b) that any changes applied to the input parameters (G, O$_2$, O$_3$, M, k$_1$, k$_2$, k$_3$) are balanced by the derived values of [O(^{3}P)] and [H], without assuming any a priori information of [O(^{3}P) and [H]."

Specific comments:

Abstract should specifically indicate that the [O] and [H] profiles derived in this study are from the SABER observations using an OH model informed by SCIAMACHY and SABER observations.
We rewrote the beginning of the Abstract as follows (l. 10-16):
"Based on the zero dimensional box model CAABA/MECCA-3.72f, an OH airglow model was developed to derive night-time number densities of atomic oxygen ([O(^{3}P)]) and atomic hydrogen ([H]) in the mesopause region (~75-100 km). The profiles of [O(^{3}P)] and [H] were calculated from TIMED/SABER satellite OH airglow emissions measured at 2.0 µm. The two target species were used to initialize the OH airglow model, which was empirically adjusted to fit four different OH airglow emissions observed by the satellite/instrument configuration TIMED/SABER at 2.0 µm and at 1.6 µm as well as measurements by ENVISAT/SCIAMACHY of the transitions OH(6-2) and OH(3-1)."

L27: "high" should be "large" (as to not confuse with altitude)
Sentence was rephrased.

L39 and onward: What is meant by "OH(v)"? Do you mean vibrationally excited OH? It should be defined when it is first used as "vibrationally excited OH" or "OH(v>0)".
We rephrased l. 38-39 and adapted the text onward:
"This chemical reaction additionally leads to the production of vibrationally excited hydroxyl radicals (OH(v>0)) up to the vibrational level v=9, …"

L63: "last decades" sounds ominous. Should be specific, i.e. last three to four decades.
Done. Was changed as suggested by the referee.

L69: "of" should be "from"
Done.

L79: "individually" doesn't sound right. Maybe, "Both airglow emissions were used to derive separate data sets of O(3P) profiles"?
and
L80: "profiles" makes it sound as if only one profile was retrieved for each airglow feature. Should probably be "data sets".
Done. Sentence was changed to:
"Both airglow emissions were used to derive separate data sets of [O(^{3}P)] and the best agreement between these two [O(^{3}P)] data sets was obtained …"

L89: should be OH(v=9). Or define that OH(x) means OH(v=x).
Done, the notation of OH(x) was changed to OH(v=x) throughout the paper.

L140: please fix the significant digit mismatch for "837.5-848"
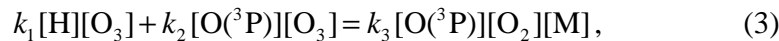Done, was changed to: "837.5-848.0".

L183: by "issues" do you mean uncertainties?
We changed "issues" to "uncertainties".

L205-208: should specify that the three-body reaction is the production of O3.
Was changed to:
"In the second step, chemical equilibrium of O_3 during night is assumed as follows:
$$k_1[H][O_3] + k_2[O(^3P)][O_3] = k_3[O(^3P)][O_2][M], \qquad (3)$$
meaning that O_3 loss due to H and $O(^3P)$ (left side) is balanced by O_3 formation via the three-body-reaction $O(^3P)+O_2+M$ (right side)."

L209: M is not the total density of air, M represents an air molecule. [M] is the total density.
Was changed to:
"while M being an air molecule and $[M]$ being the total number density of the air."

L215-216: The wording makes it sound as if the SABER O3 was derived via the ideal gas law. Did you mean to say that you're using SABER derived O3?
Yes, we meant that the O3 volume mixing ratios from SABER were converted into O3 number densities.

Thus, we rephrased this sentence to:
"Air temperature and air pressure from SABER were used to calculate $[M]$, $[O_2]$ (VMR of 0.21), and $[N_2]$ (VMR of 0.78) as well as to convert SABER O_3 VMR into $[O_3]$ via the ideal gas law."

L234-235: would suggest "well suited" as opposed to "very suited".
Done.

L248-250: the way this sentence is worded means that the equation should be v=9. If that's not the case, it should read something like "OH at all vibrational levels v≤9"
The sentence was rephrased to:
"The reaction $H+O_3$ can populate $OH(v)$ at all vibrational level $v \leq 9$ and the nascent distribution of $OH(v)$ was taken from Adler-Golden (1997)."

L264: I assume that by "added" you mean "applied" and not literally added.
Yes, you assumed right. Since a factor cannot be added, we replaced "added" with to "applied".

Figures 1-5: Why are there no error bars on the SABER observations?
We added error bars of OH(5-3)+OH(4-2) VER in Fig.1-5 and a short description
as follows (l. 176-181):

"The total uncertainty of SABER OH airglow data used here comprises three different error sources. Since we used climatology of the measurements (see Sect. 2.2), there are sufficient samples that the random noise component of the total uncertainty is essentially zero. The remaining two major terms are the absolute calibration error (<5 %) and the "unfilter" factor error (<3 %). Assuming a root-sum-square propagation of the individual uncertainties, this results in a total uncertainty of about 6 % for all data points presented in this study."

L396: "probably" is not needed
Was deleted.

L402: They also seem to match within the error bars above ~92 km.
and
L402-404: I believe this sentence is missing an altitude value and a very important comma. Are you intending to say, "The model still overestimates the measurements in the altitude region above xx km, which might be related to O(3P) quenching."?
This section was rephrased as follows (l. 400-404):
"This new model is referred to as "O_2 SD model" and the corresponding results are displayed in Fig. 3 as red lines, showing that the simulated OH(6-2) VER matches the observations within the error bars below 85 km and above ~92 km. The model still overestimates the measurements in the altitude region ~90 km, which might be related to O(^{3}P) quenching (see Sect. 3.3)."

R8: this claims that you're only considering $0 \leq v' \leq v-5$, for $v \geq 6$. If that were the case, then the branching ratios for 8-4, and 7-3 should be 0, which, according to Table 2, they are not. Should it be $0 \leq v' \leq v-4$?
This is a typing error. It has to be "$v' \leq 5$" and not "$v' \leq v-5$".
Thus, we corrected R8 to: OH($v \geq 6$)+$O_2 \rightarrow$ OH($v' \leq 5$)+O_2

L432: "Including R10b in the model…" is confusing.
In the v-4 scenario, are you including R10a and R10b, or are you including only R10b and not R10a. If it's the former, that would seem to imply that v'=v-4 can't occur at all (for $v \geq 6$), and then, again, the branching ratios for 8-4, and 7-3 should be 0. If it's the latter, then I agree that the implication is that v'=v-5 (and not v'=v-4) is the predominant pathway, which fits with the values in Table 2. Please make the explanation of this case clearer. (It's even more confusing in the context of R8, which already says this pathway isn't being considered.)
We meant the latter case, in which R10a is substituted by R10b.
Thus, we rephrased the sentence to: "Replacing R10a by R10b in the model…"

L460: Should be "that implied" instead of "which implied".
Also, "implied" is somewhat vague and makes it sound like you might not be sure (same with "seems reasonable").
Done. We changed "which implied" to "that showed" and "seems reasonable" to "is reasonable".

Table 3: Reactions 11a-d seem to indicate that k11 doesn't entirely decrease with v, which goes against what's written in the text. This is touched on a bit later, but not explicitly stated.

The rate of $OH(v=8)+O(^3P)$ was reduced and the corresponding explanation in the text was extended as follows (l. 473-486):

"The assumption that $k_{11}(v)$ decreases at lower vibrational levels is supported by the overall rate of $OH(v=7)+O(^3P) \rightarrow OH(v')+O(^1D)$ at mesopause temperature which is suggested to be on the order of $0.9\text{-}1.6 \times 10^{-10}$ cm^3 s^{-1} (Thiebaud et al., 2010; Varandas, 2004). At least to our knowledge, the total rate of $OH(v=8)+O(^3P) \rightarrow OH(v')+O(^1D)$ was not measured. Nevertheless, results reported by Mlynczak et al. (2018) and Panka et al. (2017, 2018) indicate that this rate might be slower than the value of 2.3×10^{-10} cm^3 s^{-1} suggested by Sharma et al. (2015). This is also in agreement with our findings here, because applying 2.3×10^{-10} cm^3 s^{-1} for $k_{11}(v=9,8)$ results in non-physical $[O(^3P)]$ values above 90 km. The corresponding value of $[O(^3P)]$ e.g. at 95 km is about 1.25 times larger than SABER $[O(^3P)]$ 2013 (Mlynczak et al., 2013a) which in turn is about 1.15 times larger than the upper limit of $[O(^3P)]$ (Mlynczak et al., 2013b, their Fig. 4). This results in a factor of $1.15 \times 1.25 = 1.44$ (=44 %) above the upper limit and cannot be explained by the uncertainty of the $[O(^3P)]$ profile derived here (40 %, see Sect. 3.4). In order to obtain reasonable $[O(^3P)]$ values, it was necessary to lower the rate of $k_{11}(v=8)$ to 1.8×10^{-10} cm^3 s^{-1}, and we therefore recommend $k_{11}(v=8) \leq 1.8 \times 10^{-10}$ cm^3 s^{-1} as an upper limit to derive physically allowed $[O(^3P)]$ values."

L528: "higher" should be "larger" as not to be confused with the discussion of altitude.
Done.

Figure 6: These plots would be much easier to read with boxed axes (ticks on the top and right).
Done.

Also, this would be a good spot to compare O3 and show that the model O3 is (presumably) lesser than SABER values.
As explained above, O3 was not a variable in this study. The [O3] used here was calculated from SABER O3 VMR.

L632-635: Have you considered doing a similar study incorporating OH(9-4), (8-3), and (5-1) band VERs from OSIRIS?
Not yet because our project is focused on SCIAMACHY observations. Comparisons between SCIAMACHY and OSIRIS might be hard since both instruments are on board of two different sun-synchronous satellites. The Odin satellite crosses the equator at 18 LT while ENVISAT crosses the equator at 22 LT. Thus, there might be a few co-location measurements but only at high latitudes. But replacing SCIAMACHY data by OSIRIS data should be possible and it would be very useful to compare the corresponding results to the results of this study.

Thus, we added in the text:
"Including additional OH transitions, like OH(9-4), OH(8-3), and OH(5-1) from the Optical Spectrograph and InfraRed Imager System (OSIRIS) on board the Odin satellite, might result in other values and deactivation schemes. This could be a subject of a future study."

Summary: needs a bit more description at the end of how [O] and [H] compare to the SABER results and explaining the differences.

We added (l.653-663):

"The [H] derived here is systematically larger by a factor of 1.5 than SABER [H] reported in Mlynczak et al. (2018) which is primarily attributed to their slower $OH(v=8)+O_2$ rate. Our $[O(^3P)]$ values in the altitude region below ~87 km are in agreement within the corresponding errors with the results found in Mlynczak et al. (2018) and Zhu and Kaufmann (2018) but are lower than the values presented in Panka et al. (2018). However, we think that the results of the latter study are too large because the authors falsely assumed too fast $OH(v)+O_2$ rates. In the altitude region above ~87 km, the $[O(^3P)]$ shown here is generally larger than the values reported in these three studies up to a factor 1.5 to 1.7. These differences are attributed to the faster rates and different deactivation channels of $OH(v)+O(^3P)$. Therefore, it is indicated that we might overestimate $[O(^3P)]$ above >87km and we suggest that our results should be interpreted as an upper limit. However, a final conclusion cannot be drawn at this point due the large uncertainties of the rates assumed to derive $[O(^3P)]$."