Update to Reviews:

We thank the reviewers for their patience to receive the modified manuscript. We tried hard to follow the suggestions of both reviewers to be more concise and clear regarding the conventions and terminology for relations between Θ and N_2O. Therefore we applied some clarifications after the first response to the reviewers had been submitted. These clarifications all only relate to the terminology, but do not concern methods or data analyses.

We added below these updated final comments with the respective changes to the text as they appear in the revised manuscript to assure consistency between the revised manuscript and our response. The comments below refer to those four comments of both reviewers which are affected as indicated below.

Overall Remarks:

Updated authors response:

We thank the reviewer for the careful reading and the constructive suggestions to improve the accessibility to a broader community. We tried to follow most of the suggestions and hope to have satisfied the criticism.

The major changes are a s follows:

1) We included a definition section to the manuscript to clarify the terminology. We checked the manuscript for a consistent wording particularly of the multi-word expressions.

We included a definition paragraph to the introduction as given below and adopted the text accordingly

2) We removed Fig. 1 and included the wind information into the former Fig. 2 as suggested.

3) We checked the terminology of the N_2O-Θ relationship and the expressions referring to slopes and ratios. We thereby kept our original idea to just use one way of expression to quantify slopes and ratios. This is directly deduced from the intuitively native way of analyzing vertical profiles with potential temperature as y-axis (similar to the discussion of temperature profiles, which are commonly shown as temperature on the x-axis and Θ or altitude as y-axis). We therefore wanted to keep the emerging quotient throughout the manuscript with N_2O in the denominator and Θ in the numerator. We think this facilitates to follow any discussions instead of introducing inverted relationships. This is consistently done through the paper, independent of the analysis which relates N_2O to Θ. The reader does not need to link the ratio to a specific analysis step or Figure. We think, this facilitates the thinking. We added a note on this, when first introducing the scheme in Fig. 8 *(former Fig. 9)*, see new text in comment to page 13, line 1 below.

Specific Comments line-by-line:

Comment Page 13 Line 1: It should be stated much earlier in the text that cross-isentropic fluxes are diabatic. 1 and onward: the text refers to species gradients as d(X)/d(theta), yet the plotted gradient in Figure 11 appears to be inverted as d(theta)/d(X). Because the text indicates that the tracer slope changes as a function of theta (instead of saying the theta slope changes as a function of the tracer), it would be much clearer to plot d(X)/d(theta) rather than d(theta)/d(X).

Updated changes to manuscript: The decrease of N_2O in the lowermost stratosphere with respect to Θ is schematically shown in Fig. 7 *(former Fig. 8)*. For the following analysis we will use the following conventions: we will express the slope as ratio of the anomalies Θ'/N_2O' (according to Eqn. 4) to be consistent with the profile view (as in Fig. 7 and Fig. 8 *(former Fig. 8 and Fig. 9)*). We will apply this convention with Θ in the numerator and N_2O in the denominator throughout the following analyses below. We will further use the following terminology:

The term Θ-N_2O-relation refers to general aspects of their relation, the term Θ'/N_2O'-ratio (associated with a slope) will be used when referring to the specific measurements further below. A change of this ratio is directly linked to the change of the vertical gradient with respect to Θ ($\partial N_2O/\partial\Theta$).

Comment Page 14 Line 9-10 (also reviewer 2): The use of the word “steeper” is confusing in this case - due to the orientation of the axes in Figure 8, the downstream slope looks “steeper” to the eye than the upstream slope because the plot is oriented to show the dependent variable (theta) on the y axis rather than the x axis. To avoid confusion, it would be clearer to say the gradient d(X)/d(theta) is larger upstream. As suggested above, this would be easier to see visually if the diagram in Figure 8 shows d(X)/d(theta) vs theta or altitude rather than theta vs N2O.

Updated changes to manuscript: Thus, in case of gravity wave induced turbulent mixing during flight FF09, we expect a ~~steeper vertical N_2O-Θ gradient in the inflow region upwind the mountains (i.e. a smaller Θ' / N_2O' ratio) than at the downstream side of the mountain ridge~~ more rapid decrease of N_2O with increasing Θ in the inflow region upwind the mountains than at the downstream side of the mountain ridge as an effect of turbulent mixing. The vertical N_2O profile with respect to Θ is modified from upstream to downstream due to turbulent mixing.

Comment Page 15 Line 4: change “corresponding to the hypothesis described above” to “consistent with our hypothesis that d(X)/d(theta) will be reduced in regions impacted by gravity wave induced mixing”. See General Comments above regarding the use of consistent wording.

Updated changes to manuscript: As evident from Fig. 8 *(former Fig. 9)* different ~~slopes of N_2O versus Θ~~ relations between Θ and N_2O appear on the upstream side, downstream side and above the mountains ~~corresponding to the hypothesis described above~~. The different relations are consistent with our hypothesis that the relationship between Θ and N_2O (and consequently the vertical gradient $\partial N_2O/\partial\Theta$) will be changed in regions impacted by gravity wave induced mixing.

Comment Page 18 Lines 7-9 (also reviewer 2): It is confusing to identify the slope behavior at “larger wavelengths” and then refer to these dynamics as “at small scales” in the next sentence, as the greatest downstream slope modulation from the upstream slope occurs for the largest averaging times in the figure (i.e., the largest spatial scales). Please use consistent terminology, as referring to the same scale range as both “larger” and “small” from one sentence to the next is needlessly confusing.

Updated changes to manuscript: The downstream impact ~~This~~ is evident from the different Θ'/N_2O'~~slope~~ -ratio at larger wavelengths at the ~~lee~~ downwind side compared to the upstream ~~slope~~ ratio. ~~The transition between the upstream and downstream ratios occurs at scales <3 km above the mountains.~~ Therefore we conclude that during FF09 mountain waves modified the ~~slope N_2O-Θ~~ Θ'/N_2O'-ratio by the generation of turbulence at small scales ~~and induced cross-isentropic turbulent mixing~~. They induced cross-isentropic turbulent mixing leading to changes at large scales downwind the Alps as evident from the Θ'/N_2O'-ratio and finally the vertical gradient $\partial N_2O/\partial\Theta$ (Fig. 6 *(former Fig. 7)*).

Comment Page 19 Lines 12-14: Please provide more detailed explanations in the text from lines 3-11, as I do not follow how this conclusion is supported by the analysis of Figure 12.

Updated changes to manuscript: ~~We therefore conclude that for wave periods with low coherence and the breakdown of the phase above the mountains the relationship between N_2O and Θ is the result of gravity wave induced mixing leading to the observed N_2O-Θ slope change at the downstream side, where a modified slope establishes.~~ We therefore conclude that above the mountains the low coherence and the breakdown of the phase relationship at short wavelength were an effect of the gravity waves which produced turbulence and led to cross-isentropic mixing. Therefore, the change in the Θ'/N_2O'-ratio from the upwind to the downwind side is the result of gravity wave induced mixing. Since the mixing is cross-isentropic this changed the Θ'/N_2O'-ratio, which is evident at the downstream side, where a modified ratio establishes (compared to the upwind side).