Reply to Reviewer 1

Jutta Vüllers et al.
(jutta.vuellers@kit.edu)

1 General Comments

I found this paper very important and interesting particularly the unique observations done in the DS area and described hear. I recommend to accept the paper after making a revision in light of the comments below.

Thank you for the very insightful review. Your comments helped to improve the paper. Responses to individual comments are provided below. Reviewer's comments are in italic.

2 Specific Comments

C1 - P1 l6 (page 1 line 6) "the mean maximum velocities of around 5m/s". Mean of the maximum is an exact number please give the exact value.
A) The sentence was changed to:
T) Type I has a duration of approximately 2-3 h and ~~mean maximum velocities of around 5~~a mean maximum velocity of 5.5 m s^{-1} and does not propagate far into the valley, whereas type II affects the whole valley, as it propagates across the valley to the eastern side. Type II reaches mean maximum wind velocities of 11 m s^{-1} and has a duration of about 4-5 h.

C2 - Section 3.1 It will be helpful if you will add some sentences describing the main differences between density and radiative driven flow, and their relation to potential temperature difference between the crest and bottom. What are the problems that the automatic mixture model deal with.
A) A short description of the differences and the relation to the potential temperature was added.
T)Density-driven flows are possible when the potential temperature of the upstream air mass crossing at crest height is equal or lower than the temperature in the valley. The air mass descends resulting in similar potential temperatures at the crest and in the valley. In contrast, radiative-driven downslope flows are triggered by radiative cooling of the air layer near the slope and the resulting temperature gradient between the air at the slope and the air at the same height in the valley centre (Whiteman, 2000). This leads to a stable stratification and therefore to a positive potential temperature difference between the crest and the valley ($\Delta\Theta = \Theta_{crest} - \Theta_{valley} > 0$).

C3 - p.6 line 5. The distinction between foehn and radiative flow are determined mainly by the potential temperature difference between the crest, Jerusalem 810 m and Masada, -7m p6l9 or Ein Gedi -427m p6l10. In Fig. 3 the temperature differences are shown. Please show the potential temperature differences instead. Also it looks like a mistake the positive temperature difference between Jerusalem and Ein Gedi, p6l13, Jerusalem is always cooler than Ein Gedi.
A) Thank you for this comment. The figure already shows the potential temperature difference, only the axes and the description was wrong. The potential temperature difference shown in the figure is $\Delta\Theta = \Theta_{crest} - \Theta_{valley}$. Thus, positive values mean potential temperature in Jerusalem is higher than Ein Gedi, in particular during radiatively-driven downslope flows, where a stable stratification occurs.

C4 - P7l16-l19 The west wind observed at least 2 hours earlier at 14:00. The height of the maximum west wind at 14:00 is at 1750m, and so at 16:00.
A) The description was not precise enough. What we meant is, that it started to penetrate into the valley at

16:00 LT. The text was changed.
T) Before the west wind reached the valley, an elevated west wind maximum just above crest height (~~1500~~1750 m agl) was observed ~~at~~ in the afternoon. At 16:00 LT, ~~which then penetrated~~ it started to penetrate down into the valley ~~over a time of about 2 h until it~~ and reached the valley floor at around 18:30 LT.

C5 - p8l19-26 The mixed events. At least in August 28 it is not clear to me why you call it mixed event and August 16 strong event. Comparing Fig. 5f after 20:00 and Fig. 6 after 21:00 the wind behaviour is similar and so both cases can considered as mixed events.
A) The difference is that in the case of the 16 August the foehn ceases at 21:00 completely. There is no foehn layer with the typical characteristics, such as the jet like structure observed anymore. Not in the valley, and also not at the slopes. In contrast, on August 28 the foehn first reaches far into the valley and after 21:00 it continues to be present with a well defined jet like structure, but only at the slope and at the foot of the slopes for nearly another 6 h (compare also Table 1 with the durations of the events). That's why we call August 28 a 'mixed event'. There are changes of the penetration distance into the valley and a change in intensity, but it keeps the typical characteristics of a well defined layer with a jet like structure for a total of 11:47h.

C6 - P9l10 Please note that from the ground up to 900m the stratification is unstable or neutral i.e. The strong vertical mixing from the ground to 900m discussed in, P9l18-20, is mainly due to the unstable layer close to ground, and not due to mechanical mixing.
A) We agree that the atmosphere is close to neutral at 9 LT and that there is of course convection and strong vertical mixing from the ground, but in our opinion strong vertical mixing from the ground would not lead to a secondary inversion and a temperature increase only in the upper part, between 500 and 900 m AMSL, which was observed in this case. The formation of this layered structure with two inversions is in our opinion due to mechanically induced downward mixing (Ri$<$0.25) of warmer air into the upper part of the boundary layer.

C7 - P9l16 It is not clear that the western wind is the return flow. I think it is the residual wind from the night.
A) During the night (00:00 - 07:30 LT) no west wind is observed in the valley. The wind profiles derived from the lidar show only north-easterly to easterly winds up to a height of 1100 m AMSL. Therefore, we assume that the observed westerly winds between 500 and 900 m amsl are the return flow of the lake breeze and not a residual flow.

C8 - P9l23-34 What was the resolution in COSMO-EU model, may be the not observed front is a consequence of the resolution. The flow field is not shown and could be very helpful in interpret the model results since the wind field play a major role in understanding the foehn. I recommend to add a figure o the flow field. Please also show the mixing ratio (q) instead RH fields in Fig. 11, since q is more relevant.
A) The resolution of the model is 7 km. As you suggested we now show specific humidity instead of relative humidity. Furthermore, we decided against showing the 2D flow field as the large scale near surface wind field can also be seen in Fig. 7, from the position of the isobars. However, we show the u-component of the wind along the cross section as we hereby also have the vertical information of the wind. Here you can see that a separation of a possible sea breeze from the large scale flow is not possible.

C9 - p10-11 Stage III. You combine observations, model results and interpretation, I suggest to note what based on observations what based on model and what is interpretation. I also suggest to add a model wind cross section at 21:00. The description of the hydraulic jump you refer looks like a sea breeze front/ gravity current head. You did not address one of the main questions: is this sea breeze front developed over the plains much earlier and propagates into the DS, or it developed in the valley. The formation of the foehn is not clear, since the authors claim that the source of the air is the Mediterranean and we would expect high q of this sea air relative to the inland air. Please explain the formation of the dry air. It is not clear if the hydraulic jump observed in the DS is formed there or maybe it is the sea breeze front formed over the plains

and mountains and propagates downslope into DS. If the hydraulic jump is the sea breeze front, this might explains the elevated foehn found in some cases since under certain conditions the front leave the mountain and propagates on isopycnicals.
A) Concerning your first point of clarification what results come from the model and what from the measurements: We rephrased some parts to hopefully make it clearer.
Your second question was, whether a sea breeze front propagated into the DS or not. In the discussed case of 16 August a propagation of a clear sea breeze front into the DS can not be observed in the COSMO-EU model data. Neither in the wind field (see also new cross sections which are added to the paper), nor in the temperature or humidity data. With a sea breeze front development, I would expect to see a strong temperature and humidity gradient at the sea breeze front head, propagating over the coastal plains and transporting moist air towards the mountains and in the valley. However, this was not seen in the data (Fig. 10). Of course synoptic large scale flow from west transports some maritime air towards the land, but no well defined sea breeze front with clear frontal structure or head is observed.
The foehn is triggered in the evening by the radiative cooling at the crest, as this starts earlier than in the valley. The intensification of the foehn, which results in the hydraulic jump in the valley, comes from the different development of the boundary layer over the plains, but not from the entrance of the sea breeze front into the valley.
In other cases the foehn is certainly connected to the sea breeze front entering the valley, which was already shown in several other papers, but not on 16 August.
We added an additional figure with cross sections of the wind. However, for the time you suggested (21 LT) we do not have model data. We do have model results for model time 20 LT this would correspond to 21:30 LT in reality as the events were predicted in the model too early. At this time, the event already ended. Therefore, and most likely also due to limited model resolution of 7 km, the hydraulic jump can not be seen in the model data.
T) At that time ~~the boundary layer inversion~~ model results show that the potential temperature at the CBL top increased by 4.1 K over the coastal plains and at the mountain ridge ~~strengthened to 4.1 K and~~ by 5.0 K~~, respectively, and the~~ [...] ~~In~~ Measurements in the valley and at the slope show that the mean wind velocity of the foehn increased to about 9 m s^{-1} at 18:30 LT, and the height of the foehn decreased to 350 m agl (Fig.5 e).

There, the height of the foehn layer increased to approximately 1000 m amsl and the air below was quite turbulent (see also animation of lidar measurements in the supplement).

Calculating the Froude numbers for the coastal plain (from model), mountain ridge (from model), and valley ~~conditions~~ (from measurements) results in $Fr_{plains} = 0.73$, $Fr_{ridge} = 1.06$, and $Fr_{valley} = 1.7$, which confirms the assumption of a hydraulic jump in the valley.

C10 - P12l7-12 The mixing is mainly due to convection from the unstable layer near the ground see my comment P9l10 above.
A) please see answer to comment C6.

References

Whiteman, C. (2000). Mountain Meteorology: fundamentals and applications. Oxford Univ. Press, New York.