Response to SC1 by Richard Essery :

a) Tuzet et al. use a sophisticated model to investigate the direct and indirect effects of light absorbing impurities on the melt of snow. The conclusion that the direct effect dominates over the season is expected, but it is interesting to see it demonstrated and quantified. I have some minor corrections and suggestion.

The authors are grateful to the referee for the positive global feedback on the work presented in the manuscript. The comments and additional grammar corrections have been helpful to improve the manuscript and are addressed point to point hereafter.

b) Page 3, explain briefly why radiative forcing increases as SSA decreases.

The radiative forcing increases as SSA decreases because the SSA decrease induces a decrease in the NIR reflectance of snow. This is due to the fact that a lower SSA is associated to a lower surface to mass ratio and, thus, a lower ratio between scattering and absorption.

Line 16 page 3 was then modified as follows: '… First, snow albedo in the near-infrared decreases with SSA (even in absence of LAI due to a decrease in the ratio between scattering and absorption coefficients ; e.g. Warren; 1982). '

c) page 5, It is not correct that LAI deposition fluxes measured in the field are used in this study.

Indeed, measured deposition fluxes are not used. The following corrections have been done:

Page 5 Lines 31-33 : In this study, the Crocus model takes typical meteorological driving data required for land surface models measured in the field, complemented by time series of LAI deposition fluxes (BC and dust) extracted from simulations with the ALADIN-Climate atmospheric model (Nabat et al. 2015). Our recent developments on the Crocus model were evaluated for the snow season 2013-2014 at the Col de Porte experimental site (Morin et al. 2012).

d) Page 7, Equation (2) seems to use subscript i twice for different purposes: D_i for deposition of impurity type i as in equation (1), and z_i for layer i. zi is missing from the numerator. (Why?)

In the revised manuscript, the subscript 'i' is used for impurity type and 'l' and 'k' for the layers. The changes are enlightened in all the equations of the revised manuscript (pages 6 to 8).

e) Each layer is affected the depth value of its center" is unclear.

Page 7 lines 6-8 have been modified has follows: **'**Here z_l is the depth of the layer l and z_k is the depth of the layer k, N being the total number of Crocus layers. We assume the depth value of a layer to be the distance between the snowpack surface and the middle of this layer.'

f) Mi and SWEi in equation (3) should be Mo and SWEo.

Section 2.1.2 page 7 has been modified accordingly.

g) Is impurity content really stored on the ground after the snowpack has melted, and not just discarded by the model?

In this study, the impurity content of the basal layer is discarded when it melts.

Page 7 Line 25 has been modified accordingly : ' If the disappearing layer is the basal one, its impurity content is discarded by the model**'.**

h) Page 8 Equation (4) should really have subscripts for both impurity type and layer.

Done, please refer to the response to comment d).

i) Page 9

Is there a reference for ATMOTARTES?

There is no reference for ATMOTARTES. This manuscript is the first reference to it.

What difference would also considering low cloud make?

Since ATMOTARTES is only used to compute the spectral distribution of the solar irradiance, the difference between low clouds and high clouds would not significantly impact the results in terms of snow evolution.

Explain what SBDART is.

p9 line 23 has been modified accordingly: '… winter profiles from SBDART (Santa Barbara DISORT Atmospherice Radiatiave Transfer - Richiazzi et al., 1998). SBDART is a plane-parallel radiative transfer model for the atmosphere under clear and cloudy conditions. The solution of the radiative transfer equation is based on DISORT, so is more sophisticated and time consuming than the two flux method used in ATMOTARTES. '

j) page 11, It is not correct to say that C5 is not included in the model evaluation; it can be seen in Table 2 and Figures 3, 4, 5 and 7.

Indeed, C5 is included in the model evaluation.

The corresponding sentence (Page 11 Line 20) has been removed.

k) Page 13, While pointing out that C1 has the largest RMSE for snow depth, it should be noted that it has the smallest bias (and both the smallest bias and RMSE for SWE).

Page 13 Line 1 has been modified accordingly: Over this period, the maximum RMSE is 8.0 cm (C1). It is to note that C1 has also the smallest bias because the underestimation of snow depth along the season (similar to all the other configurations) is compensated by a large overestimation of snow depth from May 20 onward.

Page 13 Line 12 The seasonal RMSE between measured and simulated SWE is 90.2 kg m^{-2} for C0 and around 80.0 kg m^{-2} for the other configurations**.** The minimum RMSE (71.6 kg m^{-2}) and bias (64.2 kg m^{-2}) are obtained for C1 configuration.

l) Page 13, Why is the size of the bias between manual and automatic SWE measurements so large? Morin et al. (2012) stated that the instrument is calibrated to manual measurements.

The automatic SWE measurement is calibrated using the weekly SWE manual measurement sites located immediately close to this instrument (SWE_North, SWE_South, see Morin et al., 2012). Here SWE measurements from the snowpit SWE measurement site are also used, exhibiting systematic deviations to the SWE measurements performed near the automatic SWE measurement site. Snow depth measurements are located at a third location, more or less in-between the SWE automatic sensor and the snowpit sensor.

m) Page 15, Transport of BC from Grenoble to Col de Porte could be suppressed by persistent winter inversions.

Small scale winter inversions (frequently observed in Grenoble) could indeed prevent BC transport from Grenoble to Col de Porte. This might be an explanation for the BC deposition overestimation by ALADIN-Climate because this model can not represent this small-scale phenomenon. The authors are grateful for this hypothesis, which has been added to the discussion Page 15 Line 15 :

Moreover persistent winter inversions are frequently observed in Grenoble. These phenomena could lead to accumulation of BC emissions in the lower part of the atmosphere, preventing significant transport to Col de Porte. ALADIN Climate can not represent these winter inversions because of their relative small-scale compared to the model resolution. This may also partly explain the overestimation of BC deposition fluxes predicted by the model.

n) Rather than using remote observations of dust in snow for the February event and none for the April event, why not scale ALADIN-Climate deposition in C5 to be closer to local BC equivalent measurements?

Using deposition values scaled to reproduce the measurements would lead to unrealistic dust contents and could mask some model limitations. Indeed it is currently not possible to state whether there is not enough dust in the snowpack simulation or if dust impact is overestimated by the model because of modeling uncertainties. For these reasons, we decided to use realistic values found in the literature.

However, scaling ALADIN-Climate to be closer to local BC equivalent measurements is an interesting approach as well because it makes it possible to evaluate the performance of the model forced with the "optically correct" amount of impurities. An additional simulation has been performed to better reproduce BC equivalent measurements. Smaller RMSE/bias in terms of SSA and of shortwave albedo are observed (the albedo bias is reduced to 0.049) but the results in terms of snowdepth and SWE are deteriorated. Possible explanations for this deterioration and subsequent modifications in the manuscript are discussed in response to the comment f) of RC1.

o) page 16 Albedo measurements are available at Col de Porte and could be compared with the simulations.

The evaluation of the new developments using albedo measurements has been added to the revised manuscript. Please refer to the response to the comment f) of RC1 for more details.

p) Figure 3 contradicts the assertion that C2, C3 and C4 improve the simulation at the end of the season compared to C1.

It is true that the assertion is valid only for snow depth and melting rate and not for SWE.

Page 16 – line 10 has been modified accordingly : "The atmospheric deposition fluxes provided by ALADIN-Climate (C2,C3 and C4) improve melting rate at the end of the season compared to C1 simulation although SWE is simulated more accurately using C1, probably due to a bias at the beginning of the season''.

q) Table 2, The 20% scavenging is in the wrong column for C4

The mistake has been corrected in Table 2.

r) Figure 3, Why are the configuration lines broken in the upper panel and solid in the lower?

It was a mistake, the configuration lines are now broken for both panels for mote readability.

Additionnal grammar corrections :

page 1

6
referred **to as** Crocus

10
the Col de Porte experimental site

14
The model simulates snowpack evolution **reasonably**

15
comma deleted

16
from **the** ALADIN-Climate model

18
advances **by** 6 to 9 days

page 3

12
Lais radiative impact on snow → **the radiative impact of LAIs on snow**

15
accelerating near-surface SSA decrease

20
gathered information~~s~~

21
Lais radiative impact → the radiative impact of LAIs

22
absorption by LAIs

23
LAI content

34
referred **to as** dust outbreaks

page 4

1
drop significant amounts

2
the vertical profile of snowpack impurity content

4
LAI impacts

10
relative

12
the presence of LAIs

22
wavelength range**s**

28
the deposition and fate of LAIs

page 7

7
most of the LAIs are initially deposited in the uppermost layer

page 8

2
that some LAI types

7
pore volume

page 9

4
an upper bound ... a lower bound

5
the values of Warren and Brandt

28
the Col de Porte experimental site for the 2013/2014 snow year

31
radiation

page 10

11
spectral albedos were measured

18
the top centimetres

20
from the Crocus top layer

21
BC in the snow

31
while configurations

page 11

5
in mid-February

6
struck the Alps

11
the Italian Alps

19
The C5 simulation

28
In this way

page 12

27
Once this initial snowpack has melted

page 13

6
advances by 6 to 9 days

page 14

1
where → when

7
for the configurations implementing LAIs
almost the same

17
periods during which SWE is less than 50 kg m-1

18
increases through the season

page 15

3
which cannot represent

6
but small scale phenomena

9
affected by high levels

11
Grenoble**'s** impact

17
computed from simulations

22
the April dust outbreak

24
fit the measurements well before April 3

31
for the 2013-2014 snow season

32
advances by 6 to 9 days

page 16

4
the initial version is in agreement with the observations

8
When using the TARTES radiative transfer model

12
compared to the C1 simulation

16
which worsens

23
15% of the LAI radiative forcing comes from

24
for the C2 configuration

26
similar characteristics to Col de Porte

page 17

9
a physically based liquid water parameterization

19
LAI impacts in TARTES

27
a user-defined number

31
the Col de Porte experimental site

page 18

4
simulates LAI acceptably

6
in the presence

9
by 6 to 9 days

11
in this particular season

18
at different sites

22
LAI impacts

26
the Col de Porte experimental site

31
nutrient evolution

33
Crocus is now capable of tracking thin layers ... and representing the discontinuity induced in terms of

References:

Morin, S., Lejeune, Y., Lesaffre, B., Panel, J.-M., Poncet, D., David, P., and Sudul, M.: A 18-years long (1993 - 2011) snow and meteorological dataset from a mid-altitude mountain site (Col de Porte, France, 1325 m alt.) for driving and evaluating snowpack models, Earth Syst. Sci. Data, 4, 13–21, doi:10.5194/essd-4-13-2012, 2012.

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