Interactive comment on "Predicting cloud ice nucleation caused by atmospheric mineral dust" by Slobodan Nickovic et al. Anonymous Referee #1

General Comment:

My main concern is that at this stage the authors compare model ice nuclei with observations of ice water path which are not directly comparable. It would be more appropriate to calculate the corresponding modeled cloud properties and use them for model evaluation. Model results with the old version of the model should be also presented for comparison.

We agree, it would be more appropriate to compare the model against the observed cloud ice. However, in the current stage of our work, we do not predict the cloud ice but calculate the ice nuclei concentration (n_{IN}) *and therefore compared* n_{IN} *against the observed ice water. Although the two variables are not directly comparable as the Referee #1 correctly noticed, they are linked through the continuity equation for cloud ice and we assumed the two variables should be correlated. Our results indeed confirm that* n_{IN} *in general well compares against the observed cloud ice water.*

In our next paper which will represent as continuation of the current study, we will use n_{IN} *as a prognostic input in the cloud microphysics scheme of our dust-atmosphere modelling system. Based on above considerations, we propose to the Editor replacement of the current manuscript title with: 'Cloud ice caused by atmospheric mineral dust - Part 1: Parameterization of ice nuclei concentration in the* NMME-DREAM model'**.** *This also takes into account the Referee's suggestion in his/her first Specific Comment to change the article title. The second part of the current in that case will be a paper titled as: 'Cloud ice caused by atmospheric mineral dust - Part 2: Parameterization of ice water in the* NMME-*DREAM model'***.**

Specific Comments:

Page2, Line 28: To our knowledge, this is the first time that all ingredients needed for cold cloud formation by dust are predicted in the operational forecasting mode within one modeling system. Please provide more support for this statement since a variety of coupled dust-ice models seem to be already available (e.g. Zhang et al.,2012; Liu et al., 2012; Atkinson et al., 2013).

This is true there are numerous coupled dust-ice models. Articles the suggested by the Referee #1 (Zhang et al.,2012; Liu et al., 2012; Atkinson et al., 2013) are focused on studying nucleation effects in general, rather than on using dust-ice parameterization to improve numerical weather prediction. For example, n_{IN} *is not online prognostic variable in none of the operational dust models within the largest two international dust forecasting projects: the WMO Sand and Dust Warning and Assessment System https://www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html; and the ICAP Multi-Model Ensemble (ICAP-MME) http://icap.atmos.und.edu/ ; Sessions et al, 2015). Differently from those dust models, we perform prediction of* n_{IN} *at every model time step to be used as input to a microphysics scheme.*

We added in the text the following clarification:

... Such new parameter will be used in our future study as an input to a microphysics scheme, expecting improve the operational prediction of cold clouds and associated precipitation. Currently, n_{IN} is not used as online prognostic variable in eider of the operational dust models of two largest international dust forecasting networks: in the WMO Sand and Dust Warning and Assessment System (SDS-WAS) (://www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html) and in the ICAP Multi-Model Ensemble (ICAP-MME) (http://icap.atmos.und.edu/). Unlike dust models of these networks, our modelling system predicts n_{IN} at every model time step which will be used as input to a microphysics scheme in the study of our forthcoming paper...

Page 4, Line 14 : In this study, dust concentration, atmospheric temperature and moisture as predicted by the atmospheric component of the coupled model are used to calculate. The parameterization consists of two parts applied to warmer and colder glaciated clouds. The vertical wind component is a crucial parameter for CCN/IN activation processes. Do you consider w in your calculations?

We wanted to implement the most recent parameterizations available in the community for dust-induced IN (DeMott et al., 2015; Steinke et al., 2015). These schemes require temperature, relative humidity and dust concentration as input parameters, but not vertical velocity. We added the following text:

The schemes of DeMott et al. and Steinke et al. require temperature, relative humidity and dust concentration as input parameters, but not vertical velocity as it is used in some other microphysical schemes (e.g. Wang et al, 2014) .

Page 5, Line 20: to identify the different aerosol types (Papagiannopoulos et al., 2015) taking advantage of the large number optical properties they are able to provide, i.e. lidar ratio at two wavelengths, the Angstrom exponent, the backscatter-related Angstrom exponent, and linear particle depolarization ratio. This aerosol typing capability allows to classify the aerosol type acting Nin, and especially to separate mineral dust from other types of aerosol Please add Papagiannopoulos et al., 2015 in your Reference list. Also check carefully your references and edit your list in ACP format.

The reference by Papagiannopoulos et al. has been replaced by the following two as more appropriate:

Groß, S., Freudenthaler, V., Schepanski, K., Toledano, C., Schäfler, A., Ansmann, A., and Weinzierl, B.: Optical properties of long-range transported Saharan dust over Barbados as measured by dual-wavelength depolarization Raman lidar measurements, Atmos. Chem. Phys., 15, 11067-11080, doi:10.5194/acp-15-11067-2015, 2015.

Burton, S. P., Ferrare, R. A., Vaughan, M. A., Omar, A. H., Rogers, R. R., Hostetler, C. A., and Hair, J. W.: Aerosol classification from airborne HSRL and comparisons with the CALIPSO vertical feature mask, Atmos. Meas. Tech., 6, 1397-1412, doi:10.5194/amt-6-1397-2013, 2013.

Page 6, Line 15: The model resolution has been set to 25km in the horizontal. Could you please justify how you resolve cloud-scale features at this resolution?

We added the following text as a clarification:

At the horizontal model resolution used in our study (which relates to the hydrostatic type of thermodynamics), clouds are resolved by the following schemes: the parameterization of grid-scale clouds and microphysics (Ferrier et al., 2002); and the parameterization of convection clouds (Janjić, 1994, 2000).

Page 7, Line 4. On the other hand, a visual inspection shows considerable similarity between NL and the IWPL patterns (columns (B) and (C)) with respect to their shapes and locations. These two quantities are not directly comparable. Could you please show what is the NMME predicted IWP? Also show the difference between the control run (without IN parameterization) and the new run.

See please above our reply to the General Comment of the Referee #1

Figure 2. If I interpret correct the plots in Figure 2, it seems that the model predicts IN even at areas without dust. If your only aerosol source is dust (Eq.1, Eq.2) could you please explain more on this?

We think the Referee #1 is reporting to Figure 1, not to Figure 2.
Figure 1 shows maps of dust C and IN integrated vertically (columns A and B respectively). The maps for same valid times indeed do not fully match because C and IN are not linearly proportional (Eq.1, Eq.2), neither their loads. However, according to Eq.1 and Eq.2 even for small C concentration there is some n_{IN} *if thermodynamic conditions permit it. With the used color palette scales in maps, load of small dust concentrations cannot be shown even if* n_{IN} *is displayed.*

Page 7, Line 29: The forecasts are translated horizontally over the observations until the minimum squared error (MSE) is achieved Please explain.

Figure 3 was referred by mistake to the CRA method instead to the Method for Object-based Diagnostic Evaluation - MODE. We added in the article the following correct explanation:

Additional evidence on matching between our forecasts and satellite observations has been made by applying the Method for Object-based Diagnostic Evaluation - MODE (Davis et al., 2006a; 2006b; 2009) which is based on a fuzzy-logic algorithm and which has been originally developed to quantify the errors related to spatial patterns and location of precipitation which considers various attributes of rain patterns (e.g. orientation, rain area). Factors as the separation of the object (pattern) centroids, minimum edge separation between modeled and observed patterns, model/observed patterns orientation angles relative to the grid axis, the ratio of the areas of the two objects, and the fraction of area common to both objects. MODE is used here to indicate the level of matching between NL and IWPL for a selected day of 11 May 2010. Figure 3 shows that MODE has identified three precipitation objects: two (green and red colored) showing good matching, and one (blue) with no matching.

Page 8, Line 8: Anyhow, in order to predict IWC we need to incorporate predicted Nin into a cloud microphysics scheme, which is a future task of our project. Therefore, the comparison using a semi-quantitative approach is the only available at the current stage of the analysis. Why don't you incorporate the NMME microphysics scheme? Please show also the modeled IWC.

See please above our reply to the General Comment of the Referee #1. Incorporating the NMME microphysics scheme will be the subject of the forthcoming Part 2 of the paper, as we have indicated above.

Page 8, Line 14: Most of the ice, observed by the cloud radar below 4.0-4.5 km above ground level (AGL), is not predicted by the model. Is there any dust at these layers? If there is no dust in the model and your only IN source is dust, this could make sense.

IN could be absent not only because dust missing but also because the other, thermodynamic conditions are not fulfilled. However, we assume that IN for lower mixed clouds is predicted because the DeMott scheme could not be extrapolated for T warmer than -36°C. See please also our detailed answer to the similar question of the Referee #2 on the same issue.

Page 8, Line 23: Moreover, like for the case of May 2010, the model tends to under-predict the lowest ice water layers observed with the radar below 4.5 km AGL. Again it is a little confusing when you refer to IN and when you refer to ice water. Also to me it looks like there is no IN below 6km which means that the model fails to represent half of the clouds in this cross-section.

We made corrections to avoid confusion when using model IN and ice water (following the Referee's comment.

We also included discussion addressed to the fact that the model failed to represent lower cold clouds.

Inability of the model to predict n_{IN} at lower elevations can be explained by the fact that the DeMott et al. (2015) parameterization is valid for temperatures in the interval (-20°C – -36°C). We extended this scheme to work in the interval (-5°C ; -20°C) as well but our experiments showed that lower mixed clouds could not be predicted. This result is consistent with the statement of DeMott et al. (2015) that the parameterization is weakly constrained at temperatures warmer than -20°. As these authors also claimed, this is the temperature regime that may be dominated by organic ice nucleating particles such as ice nucleating bacteria, which is aerosol not included in our parameterizations.

Page 8, Line 27 and Figure 5 caption. Replace upper and lower panel with left and right

We did it.

Page 9, Line 18: On the contrary, in South Italy, the volcanic layer, observed at Potenza up to an altitude of about 8 km above sea level Please provide some evidence for this argument

The paragraph at page 9 has been modified by citing the sources that can provide the requested evidence for this argument. The information has been extended also to match the most recent published version of the lidar analysis of the observation collected in 2010 freely available in the relational database at www.earlinet.org. which extend the content of the local analysis performed at the CIAO EARLINET station in Potenza to the results achieved by the whole EARLINET at the European scale. This database contains all information about volcanic layers (base, top, center of mass) and correspondingly mean and integrated values. According to what discussed above, the new paragraph has been modified as follows:

In the period between 13-15 May 2010, both DREAM and back trajectories analysis showed that, while the transport of volcanic aerosol from Iceland (due to the Eruption of volcano Eyjafjalla 2010) was still ongoing, dust contribution was not negligible (Mona et al., 2012). In this period, the volcanic aerosol was mainly 5 transported across the Atlantic Ocean, passing over Ireland and west UK, and then transported to the west off the Iberian Peninsula before reaching the Mediterranean Basin and Southern Italy. Satellite images and ground-based measurements confirmed the presence of volcanic particles in the corresponding regions (not shown). A detailed description of the volcanic layers as observed by EARLINET (European Aerosol Research Lidar NETwork) during this period is reported in Pappalardo et al., 2014. EARLINET volcanic dataset is freely available at www.earlinet.org (The EARLINET publishing group 2000-2010; (2014): EARLINET observations related to volcanic eruptions (2000-2010); World Data Center for Climate (WDCC). http://dx.doi.org/10.1594/WDCC/EN_VolcanicEruption_2000-2010).Moreover a devoted relational database freely avialable at www.earlinet.org contains all information about volcanic layers (base, top, center of mass) and correspondingly mean and integrated values.

The Iberian Peninsula, France and South Italy were the regions more significantly affected by the presence of volcanic aerosol (sulphate and small ash) during the considered period. For the purpose of our modelling study this might induce an underestimation of the IN (since IN due to dust only is modeled) in the above mentioned regions and can be responsible of part of the discrepancies between modeled IN and IWP provided by SEVIRI. This is particularly true for Iberian Peninsula where volcanic aerosol concentrations were quite relevant. The comparison of model predicted IN and SEVIRI IWC on 13 May shows differences that might be correlated to a larger availability of IN of volcanic origin.

On the contrary, in South Italy, the volcanic layer, observed at Potenza up to an altitude up to 15.8 km above sea level, did not enhance the formation of cold clouds due to unfavourable dry conditions in the free troposphere; this is also confirmed by the Potenza cloud radar which did not observed? clouds for the whole day (Figure 4). The absence of cold clouds over most of South Italy, including Potenza region, is also shown by the IWC reported for 13 May in Figure 1.

Page 9 Line 20: did not observed? Typo - observe

corrected

Page 9, Line 29 : The model has been validated .Avoid the use of the term validation (here and elsewhere in the text) since you are only referring to specific case studies. A validation process would require much more comparisons with observations and for a much longer time period until the model could be verified to produce validated products.

accepted and reformulated

Page 9, Line 32: wormer negative temperatures Typo - warmer

corrected

Page 10, Line 6: What do you mean by “unified modelling system”

The word 'unified' is redundant and we removed it.

Throughout the text Please check again the text for grammar and spelling and provide an improved manuscript.

We made effort and improved the language with the assistance of a native English colleague.

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