Interactive comment on "Predicting cloud ice nucleation caused by atmospheric mineral dust" by Slobodan Nickovic et al. Anonymous Referee #2

Page 2 line 28: To our knowledge, this is the first time that all ingredients needed for cold cloud formation by dust are predicted in operational forecasting mode within one modeling system. Please give more evidence.

Please see our reply to the General Comment of the Referee #1

Page 4 line 25: the spread of errors in predicting IN concentrations at a given temperature has been reduced from a factor of 1000 to 10. Please give some evidence or support for this conclusion.

This statement is based on results shown Fig 3 in DeMott et al (2010); see the reference below. The spread of predicted/observed n_{IN} *points range from 0.001 to 10 (*L^{-1}*) in the older approach of Meyers et al.(1992); in the DeMott et al (2010) article, it ranges approximately from 0.001 to 0.1 (*L^{-1}*). We introduced in the article corresponding reference of DeMott et al, 1010.*

Page 4 line 29: Why do you choose -5C, since the underlying measurements were taken at temperatures lower than -9C. Moreover, you set the temperatures for C1 warmer clouds range -36C to -10C (page 4 line 17). Please give more discussion.
and
Page 8 line 14-15: Why the model can't predict the ice below 4-4.5km while the cloud radar can detect? Due to the temperatures you set in section 2.3 (-10 – -36C) , the vertical distribution of dust aerosols, or any other reason? You should give more discussion.

Although the DeMott et al. (2015) parameterization is for temperatures (-20°C – -36°C) we extrapolated their scheme to work in the interval (-5°C – -20°C)as well, with intention to include prediction of the occurrence of warmer mixed clouds. Our experiments however showed that the scheme could not predict such clouds. Probable reason for that is that the parameterization is weakly constrained at temperatures at temperatures warmer than -20°C as stated by DeMott et al. (2015). As these authors claimed, this is the temperature regime that may be dominated by organic ice nucleating particles such as ice nucleating bacteria. In the article we added the following text:

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 5 line 9: Dust is ice nucleation active surface linked to dust concentration. As we know that dust aerosols lifted to the mid and upper troposphere can serve as ice nuclei, here you use the surface value of dust. Will it affect the model results?

We wish to clarify that *surface* *is not addressed to the dust concentration on surface but to the ice-active surface site density* S_{dust} $[m^{-2}]$ *(see also the definition of* S_{dust} *in e.g. Connolly et al., 2009; Niemand et al., 2012).* S_{dust} *describes the ability of a dust particle to freeze the cloud water. We added a clarification in the text.*

Page 5 line 12-13: Please give some related evidence.

In our IN modelling, we transit from DeMott et al., (2015) to Steinke et al., (2015) parameterization at T= -36°C. Although one might expect some discontinuity to occur at this transitional temperature threshold, in practice a rather continuous behavior of n_{IN} *at this boundary has been achieved, thus not additional smoothing has been required. The following clarification has been introduced in the article in response to the Referee's request:*

Although based on two different parameterizations, the resulting n_{IN} has a smooth transition across the temperature boundary of -36°C between DeMott et al. (2015) and Steinke et al. (2015) schemes. At this transitional temperature, we have not applied any mathematical smoothing.

Page 5: paragraph 1 on section 3, please give details description for the ground observe instruments.

The paragraph 1 on section 3 has been extended in the new version of the manuscript to provide a more detailed description of the ground based instruments employed in the presented study. The new paragraph is reported below for your convenience:

The model capabilities to predict vertical features of dust and cold clouds have been evaluated using vertical profiles of the aerosol and cloud properties routinely measured at the CNR-IMAA Atmospheric Observatory (CIAO) at Tito Scalo (Potenza), Italy, using several ground-based remote sensing techniques, such as lidar, radar and passive techniques. MUSA (Multiwavelength System for Aerosol) is a mobile multi-wavelength lidar system based on a Nd:YAG laser equipped with second and third harmonic generators and on a Cassegrain telescope with a primary mirror of 300 mm diameter. The three laser beams at 1064, 532 and 355nm are simultaneously and coaxially transmitted into the atmosphere in biaxial configuration. The receiving system has 3 channels for the detection of the radiation elastically backscattered from the atmosphere and 2 channels for the detection of the Raman radiation backscattered by the atmospheric N2 molecules at 607 and 387 nm. The elastic channel at 532 nm is split into parallel and perpendicular polarization components by means of a polarizer beam-splitter cube. The calibration of depolarization channels is made automatically using the ±45 method. The typical vertical resolution of the raw profiles is 3.75 m with a temporal resolution of 1 min. It is worth to stress that multi-wavelength Raman lidar measurements allow the user not only to monitor the dynamical evolution of aerosol particles in the troposphere, but also to identify the different aerosol types (Burton et al., 2013; Groß et al., 2015) taking advantage of the large number of 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 the user to classify the aerosol type acting n_{IN}, and especially to separate mineral dust from other types of aerosol.

CIAO, as one of the Cloudnet stations (www.cloud-net.org), applies the Cloudnet retrieval scheme to provide vertical profiles of cloud types. Cloudnet processing is based on the use of ceilometer, microwave radiometer and cloud radar observations. For the CIAO station (Madonna et al., 2010; Madonna et al., 2011), the Cloudnet processing involves observations provided by the VAISALA CT25k ceilometer, the Radiometrics MP3014 microwave profiler, and the METEK millimetre-wavelength Doppler and polarimetric cloud radar MIRA36. In particular, MIRA36 It is a mono static magnetron-based pulsed Ka-Band Doppler radar for unattended long term observation of clouds properties. In the configuration operative at CIAO, linear polarized signal is transmitted while co- and cross polarized signals are received simultaneously to detect Doppler spectra of the reflectivity and Linear Depolarization Ratio (LDR). The reflectivity is used to determine the density of cloud constituents while LDR helps to identify the target type. The radar has a 1 m diameter antenna and emits the microwave radiation at 35.5 GHz with a peak power of 30 kW, a pulse width of 200 ns and a pulse repetition rate of 5 KHz. The antenna beam width is 0.6° x 0.6° (gain 49 dBi) and the radar sensitivity is -40.3 dBZ at 5 km (0.1 sec time resolution) while the Doppler velocity resolution is 0.02 m/s. The linear depolarization ratio (LDR) accuracy is within +/- 2.0 dB. The receiver calibration is within an accuracy of less than +/- 1 dB. This system is able to provide high accurate measurements of the reflectivity factor with a vertical resolution up to 15 m, though the current configuration is set to a vertical resolution of 30 m. The radar is a 3D scanning system, but Cloudnet processing makes use of zenith pointing observations only.

Finally we add that the reference reported in the paragraph by Papagiannopoulos et al. has been replaced by the following two because more appropriate:

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.

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.

Page 8 line 27: The position for the pictures in Fig.5 should be left and right.

Corrected

Page 9 line 20: there is a redundant question mark.

Corrected

Figure 1: The color bar and coordinate are unclear. The compared results for the second case should also be given and discussed.

We replaced the figure with its vector image format in which the color bar can be checked by enlarging the image.

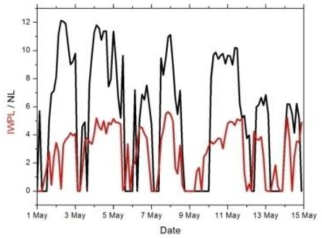
Comparison against SEVIRI for the second case: We did not include comparison model NL against SEVIRI IWPL because unfortunately EUMETSAT CN SAF products are available for the period (2009-01-01 - 2012-02-29) *and do not cover September 2012. See: https://wui.cmsaf.eu/safira/action/viewProduktDetails?id=11467_14338_16270_16283_16906*

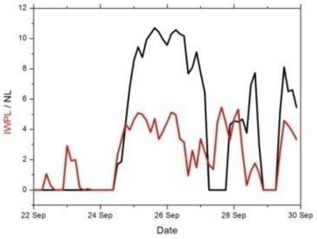
Figure 3: Please give the meaning for each color and the title for x-y coordinate.

We added the explanation for the meaning of each color and the meaning of x-y coordinate.

Figure 5: For the first case, the mean values of IWPL are mainly greater than NL. However, for the second case, the mean values of IWPL are mainly less than NL. Please give more discussion.

IWPL vs. NL: This is due to our mistake in inserting wrong image on the right, see graphs below which are now correctly included in the article.





There are some research discuss dust aerosols effect on clouds and precipitation, please discuss more about the relationship between dust and clouds in Section 1.

The following was added in reply to the Referee's request.

Another study indicates that desert dust has the ability to glaciate the top of developing convective clouds, creating ice precipitation instead of suppressing warm rain; also dust invigoration effect would enhance precipitation (Rosenfeld et al., 2008). On the other hand, Teller et al. (2012) conclude from their modelling study that the presence of mineral dust had a much smaller effect on the total precipitation than on its spatial distribution, which indicates that quantification of dust effects to precipitation is still uncertain because dust could modify cloud properties in many complex ways (Huang et al., 2014); therefore impacts of dust on cloud processes requires further research.

References:

Wang, W., J. Huang, P. Minnis, Y. Hu, J. Li, Z. Huang, J. Ayers, and T. Wang, Dusty cloud properties and radiative forcing over dust source and downwind regions derived from A-Train data during the Pacific Dust Experiment, Journal of Geophysical Research, 115 (2010), D00H35, doi:10.1029/2010JD014109.

Huang, J., P. Minnis, B. Lin, Y. Yi, S. Sun-Mack, T. Fan, and J. Ayers, 2006: Determination of ice water path in ice-over-water cloud systems using combined MODIS and AMSR-E measurements, Geophysical Research Letters, 33 (21)L21801, doi:10.1029/2006GL027038.

Huang, J., P. Minnis, B. Lin, Y. Yi, M. Khaiyer, R. Arduini, A. Fan, and G. Mace, 2005: Advanced retrievals of multilayered cloud properties using multispectral measurements, Journal of Geophysical Research, 110 (D15) (2005), D15S18, doi:10.1029/2004JD005101.

DeMott, P.J., Prenni, A. J., Liu, X., Petters, M. D., Twohy, C. H., Richardson, M. S., Eidhammer, T., Kreidenweis, S. M., and Rogers, D. C., b: Predicting global atmospheric ice nuclei distributions and their impacts on climate, P. Natl. Acad. Sci. USA, 107, 11217–11222, 2010.

Meyers MP, DeMott PJ, Cotton WR (1992) New primary ice-nucleation parameterizations in an explicit cloud model. J Appl Meteorol 31:708–721.

Connolly, P. J., O. Möhler, P. R. Field, H. Saathoff, R. Burgess, T. Choularton, and M. Gallagher, 2009: Studies of heterogeneous freezing by three different desert dust samples. Atmos. Chem. Phys., 9, 2805–2824, doi:10.5194/acp-9-2805-2009.

Niemand, M., Moehler, O., Vogel, B., Vogel, H., Hoose, C., Connolly, P., Klein, H., Bingemer, H., DeMott, P., Skrotzki, J., and Leisner, T.: Parameterization of immersion freezing on mineral dust particles: An application in a regional scale model, J. Atmos. Sci., 69, 3077–3092, 2012.

Teller, A., Xue, L., and Levin, Z.: The effects of mineral dust particles, aerosol regeneration and ice nucleation parameterizations on clouds and precipitation, Atmos. Chem. Phys., 12, 9303-9320, doi:10.5194/acp-12-9303-2012, 2012.