

Worringen et al. paper present the characterization of single-particle ice-nucleating, based on three different techniques. The paper is very interesting and a valuable contribution to the ice nucleation community; however, major corrections are needed before this manuscript can be accepted. Many sections of the paper are not clear and are written with not good flow, forcing reading the sections several times in order to understand it. It seems that different people wrote different sections and the writing is not uniform. That is why I will recommend the authors to rewrite so sections in order to increase their clarity and flow.

Details on the PCVI and CVI that were used in this work are missing, for example what type or model were used, what conditions were used in order to get cutoff sizes?

Detail on comparison between the three methods is missing, the authors mentioned that they were not measure at the same time, but do the authors know if all methods can see the same particles, and detect the same IN.

Where there any comparisons between these methods before the fieldwork to make sure they all see the same thing?

Each method had different artifact that should be mentioned with more details

It seem that the sampling with the different methos did not had any overlap, where each method used at different time, the author combine all the data to one data,

The author combine the data from all method at some part for the entire time period, does all days had the exact same conditions, is it possible to assume that some days had different IN types and the differences between the instrument come because of that?

Specific comments

Abstract:

The abstract is not clear I will recommend rewriting it again

Page 23029 lines1-8

The sentence is too long I will recommend to separate it to at least two sentences

Page 23029 line 2

I think using the two tern ice-nucleating particles (INP) and ice particle residuals (IPR) is a bit confusing for the reader, the term ice-nuclei residuals (INR) will be a better term since the analysis is for IN particles. If the author want to use both I will recommend on using ice crystal residuals (ICR) instead of IPR.

Page 23029 lines 11

Use the term January-February and not January/February

Page 23029 lines 12-19

Sentences are not clear

Page 23029 lines 14

I think it will be better to use the term FINCH+ PCVI then the term FINCH+IN-PCVI, it is obvious that the PCVI is used for IN residuals and that that FINCH was used for IN anlysis.

Page 23029 line 24

The choice of word yielded is not recommended I will replace it with something else

1 Introduction

The introduction is missing many things as the principle behind a PCVI or CVI method
Examples of laboratory and field works that used this technique not just for IN but also for CCN
Elementals that should be expected in IN particles

Tell the reader about previous IN measurement in the Jungfrauoch station.

Page 23030 line 17-18

I will recommend not to use the sentence as it is because it seem negative. Instead, I recommend the authors to use a sentence like this: although, in the last decade, large attention has been given to field studies at different parts of the world (e.g., Prenni et al., 2009a,c; Santachiara et al., 2010; Ardon-Dryer et al., 2011; Conen et al., 2012; Ardon-Dryer and Levin, 2014), these measurement covers small fraction of the world and many filed work are still needed.

Page 23030 line 20

I think this will be a better way (e.g. Hoose and Möhler, 2012, and references therein)

Page 23030 Line 24-26

The sentence is not clear and it should rewriting

Page 23030 line 26- page 23030 line1

Rewrite the sentences

Page 23031 line 4

Replace the word 'reached' with another word

Page 23031 lines 11-14

The authors should not include the FRIDGE in this part, since it is impossible to separate the activated particles from the non-activated ones in FRIDEG and FRIDGE samples the particles on a substrate.

Page 23031 lines 20-21

Use the term PCVI instead of pumped counterflow virtual impactor

Page 23031 lines 24-28

Rewrite the sentence it is cumbersome

2 Experimental

I suggest to separate this section to three parts sampling site, sampling the ice crystals (all CVI) and last section analyzing of the IN property (as microscope and laser) or combin it with the CVI part.

Page 23032 lines 1-10

Rewrite it, the flow of this paragraph is bad the description is bad, give more explanation on the station, why sampling there.

A figure with experimental set up will be very helpful for the reader; it might be even better then table 1.

2.1 INP/IPR differentiation

The whole section is not clear it will be better to use each section in the explanation of the chambers or setup instead here

Page 23032 line 12

Bundke et al., 2008 did not use a PCVI in this paper, rewrite it

Page 23032 lines 1-18

“Two-stage impactor system (see above)”, what does the author mean, not clear. The explanation seems to appear afterword is at line 20.

2.1.1 Coupling of FINCH and IN-PCVI

Page 23033 line 6

Use the word by, counted by an optical

Use the word was and not the word is, “The OPC used in this instrument was able”

Page 23033 lines 9-11

Not clear

Page 23033 line 13

There is not reference for this paper Schenk et al., 2014, there is one for Schenk, 2014

Page 23033 lines 12-15

Rewrite this sentence, say how they were separated with what, this is a suggestion for this sentence: The activated IN grow into an ice crystals. The ice crystals were separated from the non-activated particles and from the small-supercooled droplets by using the PCVI

Page 23033 lines 14-21

These sections are not clear at all

What does it mean: “This is realized by a counterflow that meets the FINCH output flow which is at the same time the IN-PCVI input flow”.

Does the authors mean that the flow from FINCH was the same as the input value that needed for the PCVI in order to get a cut off size of 4.5-8 micron, is this the 50% cut off?

What values were used for input and output for the PCVI that gave values of 4.5-8 micron? please write it.

2.1.2 Ice-CVI

The whole section is not clear, as setup figure would be helpful

Page 23033 line 24

Delete the words “so-called”

2.1.3 Ice Selective Inlet (ISI)

Well written, it is clear.

2.1.4 Laser Ablation Spectrometry (LA-MS)

Page 23035 lines 9-10

What is the meaning of 104h and 32h?

Perhaps this sentence will be better: Total of 1809 particles mass spectra were sampled with the LA-MS. A 1663 mass spectrum were when the Ice-CVI was in use and 146 when the ISI was in use.

2.2 Sample analysis by electron microscopy

Were only 46 particles analyzed or each sample contained many particles, please explain. In addition the author does not mention after which equipment this sampling were taken from.

2.3 Particle classification

Is this a combination of all the analysis methods if so say it?

Why there is a classification of droplets if the author mentioned that all droplets should evaporated or cut by the CVI? is there a sampling error, if so mention it before, which sampling method gave droplets?

Why there is definition of other with many elements? Are the materials are what the CVI built from or material of the grid itself, please explain.

Was there any compression between the different analysis methods? Or the author assume they are all measure the same parameters?

Page 23036 line 1

Use the word were and not the word are

3 Results

I will recommend to combined the result with the discussion it will be better to understand and will allow the author to make stronger points about their findings

3.1 Artifact particles

Information on the amount of artifact particles from the total particles that were sampled could tell the reader how this sampling methods had on the artifacts amounts

It will be clearer to mention what each CVI or chamber was built from and to state that some of the artifact could be due to that, the way it is written now is not clear.

3.1.2 Potential INP/IPR sampling artifacts

Can the author explain how or by with methods these particles were sampled, is it by all methods or just by some?

3.2 Composition of INP/IPR at the Jungfraujoch in winter

The author should mention in the text how many particles were sampled by each methods, and not just show it in figure 5

Why are the artifact part of the figure if the authors say that artifact are not an IN source and will not be shown (page 23037 line 21)

The comparison between the instruments (fig 7) is good because finally there are two samples that were taken at the same time, however perhaps some of the difference appear in Fig 7 are due to the different sampling methods, I think that the author should mention it in the text.

3.3 Size distribution of INP/IPR components

How was the size determined?

Are the artifact taken into account in this calculations?

More information and comparison with the literature will improve this section

3.4 Composition of total aerosol

Does the author think that such small sampling time represent the total aerosol type in that area for the entire period?

I think it would have been better to start and end every experiment by looking on the total aerosol composition and not just sample it for such small period.

Why only showing on Fig 9 the sample from the 16 and not all the times that were sampled?

4 Discussion

4.1 Which particle classes can be regarded as INP/IPR?

Page 23044 line 13

There is no need to writer Al- but only write Al unless the author wanted to say Al-rich

In addition, it is not clear if these are particle who only had these elements or perhaps they were parts of particles with other elements for example mineral dust particles contained many elements as Si, Al, Mg, K, Ca and Fe.

Page 23045 lines 12-13

I think this sentence is unnecessary in this part.

4.2 Relative ice nucleation ability of the different particle classes

I am not sure if it is correct to do this comparison since the total aerosol composition represent small period of time form this experiments.

Why should the author compare with dust particles as Feldspar when there is no dust event that were sampled and the chances for such particles to reach the station at winter is very low.

I am not sure if what written in page 23047 is relevant under this section, perhaps a better place will be under section 4.1

4.3 Comparison between FINCH+IN-PCVI, Ice-CVI and ISI

I think that this section is very important and it should be in an earlier part of the paper.

4.4 Comparison with other field experiments

The author have already compared some of these result in previous sections, I will recommend to combine all of it to one section

Page 23049 lines 12-16

I do not agree with combining all the data from the different methods due to their limitation of sampling at different times, but in any case, such information should have been included in the result section

Page 23049 lines 17-16

Perhaps a figure or a table with these comparisons will be clearer

Page 23050 lines 12-19

The author does not say much about the different days that were sampled therefore I am not sure if this paragraph is appropriate.

Page 23050 lines 20-28

The author already discuss about this point at an earlier stage I will recommend combining the two.

4.5 Comparison between scanning electron microscopy analysis and laser ablation mass spectrometry

I think this section should be in an early part of the paper, perhaps a better place will be to combine the result and the discussion to one part.

In addition, I do not think it is a good idea to compare something that was not measure in parallel because there could be many elements that could affect the comparison.

5 Summary and conclusions

I would recommend rewriting this part based on the artifact which should be taken out from all calculation. In addition, the author should say that although three methods were used they were not used in parallel.

Table 1

The freezing mechanism should not be included for IN-CVI or ISI since they both measure ice crystal after they nucleate

Figure 1

This figure is not clear, what are the gray or the colored marked represent.

Are the values of aerosol concentration, temperature, wind are they daily average, it will be good to mention it here and in the text as well.

Figure 3

This figure is not so clear and it seem that the effect of the artifact is too big, a different way of presenting this information might be better.

Figure 6-7

I would suggest to delete the artifact from these figures

Figure 9

This figure is very important and show the reader about the type of particle found in that area, however the author should mention that these particles were sampled on vary narrow time period, only on the February the 16 and for short period of time.

Figure 10

The author should mention at lease in the text which one is the current project and with one is the other for example “inuit- current project”

Reference:

- Ardon-Dryer, K. and Levin, Z.: Ground based measurements of immersion freezing in the Eastern Mediterranean, *J. Atmospheric ice nuclei in the Eyjafjallajökull volcanic ash plume*, *Atmos. Chem. Phys.*, 14, 5217–5231, doi:10.5194/acp-14-5217-2014, 2014.
- Ardon-Dryer, K., Levin, Z., and Lawson, R. P.: Characteristics of immersion freezing nuclei at the South Pole station in Antarctica, *Atmos. Chem. Phys.*, 11, 4015–4024, doi:10.5194/acp-11-4015-2011, 2011.
- Conen, F., Henne, S., Morris, C. E., and Alewell, C.: Atmospheric ice nucleators active $-12\text{ }^{\circ}\text{C}$ can be quantified on PM10 filters, *Atmos. Meas. Tech.*, 5, 321–327, doi:10.5194/amt-5-321-2012, 2012.
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- Santachiara, G., Di Matteo, L., Prodi, F., and Belosi, F.: Atmospheric particles acting as Ice Forming Nuclei in different size ranges, *Atmos. Res.*, 96, 266–272, 2010.