1 **Aerosol trace element solubility determined using ultrapure water batch leaching: an**

2 **intercomparison study of four different leaching protocols**

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Atmospheric
Measurement
Techniques
Discussions

23 **Abstract**

24 Solubility of aerosol trace elements, which determines their bioavailability and reactivity, is

25 operationally defined and strongly depends on the leaching protocol used. Ultrapure water

26 batch leaching is one of the most widely used leaching protocols, while the specific leaching

27 protocols used in different labs can still differ in agitation methods, contact time, and filter pore

28 size. It is yet unclear to which extent the difference in these experimental parameters would

29 affect the aerosol trace element solubility reported. This work examined the effects of agitation

30 methods, filter pore size and contact time on the solubility of nine aerosol trace elements, and

31 found that the difference in agitation methods (shaking vs. sonication), filter pore size (0.22 vs.

32 0.45 μm), and contact time (1 vs. 2 h) only led to small and sometimes insignificant difference

33 in the reported solubility. We further compared aerosol trace element solubility determined

34 using four ultrapure water leaching protocols which are adopted by four different labs and vary

35 in agitation methods, filter pore size and/or contact time, and observed good agreement in the

36 reported solubility. Therefore, our work suggests that although ultrapure water batch leaching

37 protocols used by different labs vary in specific experimental parameters, the determined

38 aerosol trace element solubility is comparable. We recommend ultrapure water batch leaching

39 to be one of the reference leaching schemes, and emphasize that additional consensus in the

40 community on agitation methods, contact time and filter pore size is needed to formulate a

41 standard operating procedure for ultrapure water batch leaching.

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Atmospheric
Measurement
Techniques
Discussions

1 Introduction

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45   Aerosol trace elements, originating from natural and anthropogenic sources, are of great

46 concerns, as they significantly impact marine and terrestrial ecosystems (Boyd and Ellwood,

47 2010; Dong et al., 2023; Mahowald et al., 2018), have adverse effects on human health

48 (Dahmardeh Behrooz et al., 2021; Fang et al., 2017; Gao et al., 2022; Wei et al., 2019), and

49 play important roles in atmospheric chemistry (Al-Abadleh, 2024; Alexander et al., 2009; Mao

50 et al., 2013; Martin and Hill, 1987; Wang et al., 2021). The dissolved fraction of aerosol trace

51 elements, instead of their total abundance, is considered to be bioavailable (Baker and Croot,

52 2010; Ito et al., 2012; Mukhtar and Limbeck, 2013) and more chemically reactive in the

53 atmosphere (Kebede et al., 2016; Mao et al., 2017). Dissolved trace elements are typically

54 referred to as the fraction of elements which can pass through a filter with certain pore size

55 (usually 0.2-0.22 or 0.45 μm) after aerosol particles are dissolved in certain aqueous solutions

56 (Boyd and Ellwood, 2010; Ito and Xu, 2014; Meskhidze et al., 2016; Myriokefalitakis et al.,

57 2018). Solubility (or fractional solubility, to be more precise), which is defined as the ratio

58 (in %) of the dissolved element to the total element (Baker et al., 2006; Sholkovitz et al., 2012),

59 largely determines the bioavailability and reactivity of aerosol trace elements.

60   A wide range in the solubility has been reported in the literature for a given trace element

61 in atmospheric aerosols, and for example, the reported solubility of aerosol Fe ranges from <1%

62 to >90% (Baker and Jickells, 2006; Sholkovitz et al., 2012). Such wide variabilities in aerosol

63 trace element solubility, on one hand, can be caused by difference in sources and aging

64 processes of aerosol particles examined (Ito et al., 2021; Meskhidze et al., 2019); on the other

65 hand, they also stem from various leaching protocols which were used by different studies

Atmospheric
Measurement
Techniques
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Discussions
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66   (Chen et al., 2006; Li et al., 2023; Upadhyay et al., 2011).

67   Various leaching protocols have been used in previous studies to extract dissolved aerosol

68   trace elements, as summarized in a recent paper (Li et al., 2023). In brief, available leaching

69   protocols broadly consist of two catalogues, including flow-through leaching and batch

70   leaching. Flow-through leaching is instantaneous and typically has a contact time (between

71   aerosol particles and the leaching solution used) of tens of seconds, and batch leaching usually

72   has a much longer contact time (tens of minutes or longer). Compared to flow-through leaching,

73   batch leaching is more widely used in atmospheric research. Furthermore, for batch leaching,

74   various leaching solutions were used in previous studies, such as ultrapure water, filtered

75   seawater, and formate/acetate buffers. Compared to filtered seawater and formate/acetate

76   buffers, ultrapure water is more widely used in atmospheric research due to its simplicity and

77   reproducibility (Li et al., 2023; Meskhidze et al., 2019); another important reason is that

78   ultrapure water leaching does not introduce any other chemical species (except water) and thus

79   can simultaneously extract water-soluble ions and organics for additional analysis.

80   Even for ultrapure water batch leaching, protocols used by different studies may still vary

81   in agitation methods, contact time, and filter pore size; nevertheless, the effects of these factors

82   on the reported solubility are not well understood. First, some labs use sonication to agitate the

83   leaching solutions (Chen et al., 2006; Kumar and Sarin, 2010; Liu et al., 2021; Longo et al.,

84   2016; Shi et al., 2020), and other labs use shaking (Baker et al., 2003; Gao et al., 2020; Hsu et

85   al., 2010; Li et al., 2022; Salazar et al., 2020). Sonication may cause changes in chemical

86   composition and formation of reactive oxygen species in the solution (Juretic et al., 2015;

87   Miljevic et al., 2014); however, it remains to be examined whether sonication will change the

Atmospheric
Measurement
Techniques
Discussions

88   solubility of aerosol trace elements. Second, filters with different pore sizes, including 0.2-0.22

89   and 0.45 μm (and 0.02 μm to a less extent), are employed to filter the leaching solutions,

90   contributing to the uncertainties in the reported solubility; however, the effects of filter pore

91   size have seldom been experimentally examined. Third, some studies (Li et al., 2023; Mackey

92   et al., 2015) suggested that contact time (2-8 h) could also influence the reported solubility.

93   In the present work, using aerosol particles collected at a suburban site close to the

94   coastline of the Northwest Pacific, we investigated to which extent different ultrapure water

95   batch leaching protocols would affect reported aerosol trace element solubility. In the first part

96   of this work, we examined the effects of agitation (shaking vs. sonication), filter pore size (0.22

97   vs. 0.45 μm) and contact time (1 vs. 2 h) on the reported solubility of nine aerosol trace elements.

98   In the second part, we compared solubility determined using protocols commonly adopted by

99   four labs. The four labs all use ultrapure water batch leaching, but the leaching protocols they

100   use differ in agitation method, contact time, and/or filter pore size.

2 Experimental section

2.1 Sample collection and distribution

103   We collected aerosol samples between 18 March and 22 April 2023 in Qingdao, a coastal

104   city in northern China, typically impacted by desert dust and anthropogenic aerosols in spring.

105   As described elsewhere (Zhang et al., 2022), aerosol sampling took place at a suburban site

106   which was about 1.3 km from the coast. A cumstom-made high-volume aerosol sampler (ASM-

107   1; flow rate: 1 m^3/min) was deployed on a building roof (about 20 m above the ground) to

108   collect PM_{10} samples. Aerosol sampling started at 08:00 am each day and stopped at 07:30 am

109   on the next day, resulting in a sampling volume of 1410 m^3. PM_{10} samples were collected onto

110   pre-cleaned Whatman 41 cellulose fiber filters (25 cm × 20 cm) which had very low

111   backgrounds for trace elements (Morton et al., 2013; Zhang et al., 2022). In total we collected

112   26 filter samples, 4 sampling blanks, and 3 lab blanks: lab blanks were defined as pre-cleaned

113   filters, and sampling blanks were defined as pre-cleaned filters which were placed in the aerosol

114   sampler for 2 h when the sampling flow was off.

115   After aerosol collection, each filter was folded inward and placed into a clean

116   polyethylene bag (12 inch × 9 inch, supplied by Sigma-Aldrich) which was used due to its low

117   background (Morton et al., 2013), and then stored at -20 °C. A titanium punch was used to

118   obtain 10 subsamples (47 mm in diameter) from each filter sample, and these subsamples were

119   stored at -20 °C.

120   **2.2 Measurement of total and dissolved trace elements**

121   **2.2.1 Total elements**

122   As shown in Table 1 and described below, for the 10 subsamples obtained from each

123   original filter sample, the first subsample was digested to determine total elements, another

124   eight subsamples were leached using different protocols to determine dissolved elements, and

125   the last subsample was reserved for any unforeseen purpose (but was not used at the end).

126   Subsample 1 was digested in a Teflon jar which contained a mixture of HNO_3-HF-H_2O_2,

127   using a microwave digestion system (Zhang et al., 2022). After digestion, we evaporated

128   residual acids in the Teflon jar, and filled it with 20 mL HNO_3 (1%). Subsequently, we filtered

129   the solution through a polyethersulfone membrane syringe filter (with a pore size of 0.22 μm),

130   and then used ICP-MS (inductively coupled plasma mass spectrometry, iCAP Q, Thermo

131   Fisher) to measure nine trace elements, including Fe, Al, As, Cr, Cu, Mn, Pb, V and Zn.

Atmospheric
Measurement
Techniques
Discussions

132

Table 1. Overview of protocols used to digest and leach subsamples examined in this work.

subsample	agitation	contact time (h)	filter pore size (μm)	Lab	References
1	digestion			GIG	
2a	shaking	2	0.22	GIG	Zhang et al. (2022)
2b	shaking	2	0.22	GIG	
2c	shaking	2	**0.45**		
2d	**sonication**	2	0.22		
2e	shaking	**1**	0.22		
3a	sonication	1	0.22	ZJU	Liu et al. (2021)
3b	sonication	1	0.45	OUC	Shi et al. (2020)
3c	sonication	0.5	0.20	NIO	Panda et al. (2022)

134

2.2.2 Dissolved elements

Subsample 2a was leached using the protocol adopted by the lab at Guangzhou Institute of Geochemistry (GIG) (Li et al., 2023; Zhang et al., 2022; Zhang et al., 2023). In brief, the subsample was shredded and then immersed in 20 mL ultrapure water for 2 h, stirred using an orbital shaker; subsequently, the solution was filtered through a polyethersulfone membrane syringe filter (with a pore size of 0.22 μm). After that, the solution was immediately acidified with a small volume of high-purity HNO_3 to contain 1% HNO_3, and then analyzed using ICP-MS to determine dissolved trace elements. Subsample 2b was leached using the same protocol as subsample 2a, and the purpose was to examine whether aerosol particles were homogeneously distributed on different subsamples, and to assess the repeatability of the GIG leaching protocol.

146   Subsamples 2c-2e were leached using protocols similar to that used to leach subsample

147   2a. As summarized in Table 1, the only difference to the protocol used to leach subsample 2a

148   was the filter pore for 2c (0.45 μm, vs. 0.22 μm for 2a), agitation method for 2d (sonication, vs.

149   shaking for 2a), and contact time for 2e (1 h, vs. 2 h for 2a). The purpose of using subsamples

150   2c-2e is to examine the effects of filter pore size (0.22 vs. 0.45 μm), agitation method (shaking

151   vs. agitation), and contact time (1 vs. 2 h) on the reported solubility.

152   Subsamples 3a, 3b and 3c were leached using the protocols typically used by ZJU

153   (Zhejiang University, China), OUC (Ocean University of China, China) and NIO (National

154   Institute of Oceanography, India), respectively, in order to compare solubility determined by

155   the GIG lab with those reported by the other three labs. Please note that subsamples 3c were

156   leached and analyzed by NIO, while subsamples 3b and 3c were leached and analyzed at GIG

157   (using the ZJU and OUC protocols, respectively).

158   Subsample 3a was leached at GIG using the ZJU protocol (Liu et al., 2021; Zhu et al.,

159   2020). In brief, each subsample was shredded and immersed in 20 mL ultrapure water, and the

160   aqueous mixture was sonicated for 1 h during which the water bath temperature was kept below

161   30 °C; after that, the aqueous mixture was filtered using a polyethersulfone membrane syringe

162   filter (pore size: 0.22 μm) and acidified for later ICP-MS analysis. Subsample 3b was leached

163   at GIG using the OUC protocol (Shi et al., 2020), which is very similar to the ZJU method: the

164   only difference is that the filter pore size was 0.45 μm for the OUC protocol and 0.22 μm for

165   the ZJU protocol.

166   Subsample 3c was leached and analyzed at NIO using the NIO protocol (Panda et al.,

167   2022). In brief, each subsample was shredded and placed into a pre-cleaned Savillex vial (50

168   mL); after that, the vial was filled with 20 mL ultrapure water, caped, and then sonicated for

169   30 minutes to agitate the aqueous mixture (but in 2 cycles with 15 min for each cycle, in order

170   to maintain the water bath at room temperature). The aqueous mixture was then filtered through

171   a Whatman PVDF syringe filter (pore size: 0.2 μm), and then acidified with HNO_3 (2% v/v)

172   for later high-resolution ICP-MS analysis (Nu Instruments, Attom ES).

173   **3 Results and discussion**

174   Subsamples 2a and 2b were identically leached using the protocol GIG normally uses, and

175   the paired *t*-test (α = 0.05) was employed to examine whether the difference in obtained

176   solubility was significant. As summarized in Table 2, the difference in obtained solubility was

177   not statistically significant between 2a and 2b for Fe, Al, As, Mn, Pb, and V; furthermore,

178   Figure S1 suggests good linear correlations in solubility between 2a and 2b for the six elements

179   (R > 0.99), and the corresponding slopes (0.98 to 1.02) were very close to 1. For the other three

180   elements (Cr, Cu and Zn), although the difference in solubility was found to be statistically

181   significant between 2a and 2b (Table 1), good linear correlations between the solubility were

182   found (R > 0.97) and the slopes (1.00-1.06) were close to 1; therefore, the difference in

183   solubility between 2a and 2b, if it existed, was small for Cr, Cu and Zn.

184   In summary, we conclude that the distribution of aerosol particles on a given original filter

185   was homogeneous and that the protocol GIG normally uses had very good repeatability.

186

187   **Table 2.** Summary of statistical analysis (paired-*t*-test, α = 0.05) which examined whether the

188   difference in solubility obtained for different groups of subsamples is statistically significant.

189   Solubility obtained for subsamples 2a is compared with those obtained for subsamples 2b, 2c,

190   2d and 2e, respectively. Y: the difference is statistically different; N: the difference is not

191   statistically different.

element	2a vs. 2b	2a vs. 2c	2a vs. 2d	2a vs. 2e
Fe	N	**Y**	**Y**	**Y**
Al	N	N	N	**Y**
As	N	N	**Y**	**Y**
Cr	**Y**	**Y**	**Y**	**Y**
Cu	**Y**	**Y**	**Y**	**Y**
Mn	N	N	**Y**	**Y**
Pb	N	**Y**	**Y**	N
V	N	N	N	N
Zn	**Y**	**Y**	**Y**	**Y**

192

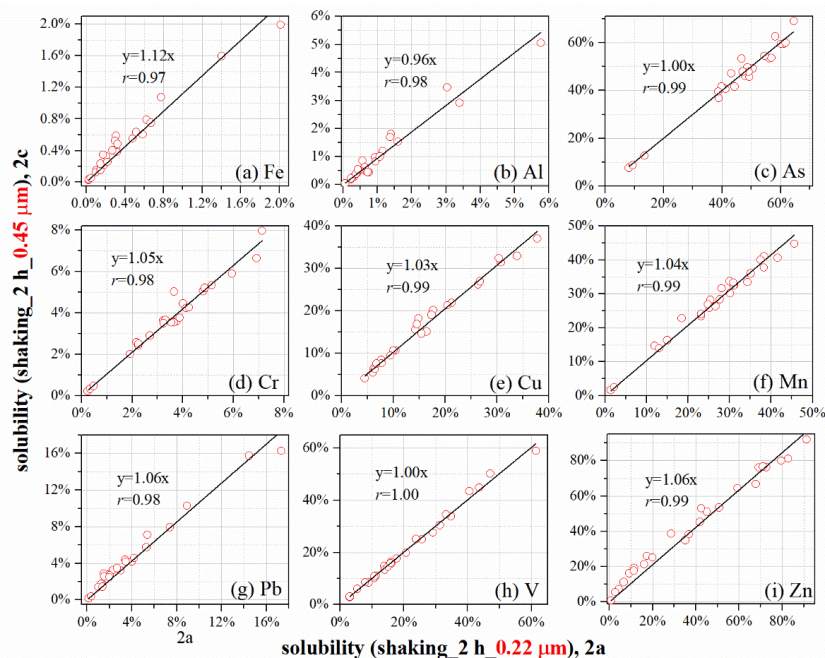### 3.1 The effects of filter pore size

194   To examine the effects of filter pore size on the reported solubility, subsamples 2a and 2c

195   were leached using very similar protocols, and the only difference is the pore size (2a: 0.22 μm;

196   2c: 0.45 μm) of filters used (Table 1).

197   The difference in obtained solubility was not statistically significant between 2a and 2c

198   for Al, As, Mn and V (Table 2); moreover, good linear correlations between 2a and 2c were

199   found for the four elements (Figure 1), with slopes (0.96-1.04) very close to 1. For the other

200   five elements (Fe, Cr, Cu Pb, and Zn), the difference in solubility between 2a and 2c was found

201   to be statistically significant; however, solubility between 2a and 2c was very well linearly

202   correlated (Figure 1), with slopes (1.03-1.12) close to or slightly larger than 1.

203   To conclude, among the nine elements we examined, the effects of filter pore size (0.22

204   vs. 0.45 μm) on reported solubility were found to be insignificant for four elements (Al, As,

205   Mn and V) and very smaller for the other five elements (Fe, Cr, Cu, Pb and Zn).

206

Figure 1. The effects of filter pore size (2a: 0.22 μm; 2c: 0.45 μm) on measured element

solubility. The only difference in protocols used to leach subsamples 2a and 2c is the filter pore

size (0.22 versus 0.45 μm).

210

3.2 The effects of agitation

212   As shown in Table 1, the only difference between the protocol used to leach subsamples

213   2a and that used to leach subsamples 2d is the agitation method used (2a: shaking; 2d:

214   sonication), and solubility obtained for subsamples 2a and 2d was compared to assess the

215   effects of agitation methods on reported solubility.

216   Table 2 shows that the reported solubility between 2a and 2d was not statistically different

217   for two elements (Al and V); in addition, good linear correlations between 2a and 2d were

11

218   found for the two elements (Figure 2), and these slopes (1.10 for Al and 1.05 for V) were quite

219   close to 1. With respect to the other seven elements (Fe, As, Cr, Cu, Mn, Pb and Zn), on one

220   hand, the difference in solubility between 2a and 2d was found to be statistically significant;

221   on the other hand, good linear correlations in solubility existed between 2a and 2d (Figure 2),

222   and these slopes were in the range of 0.94-1.21.

223
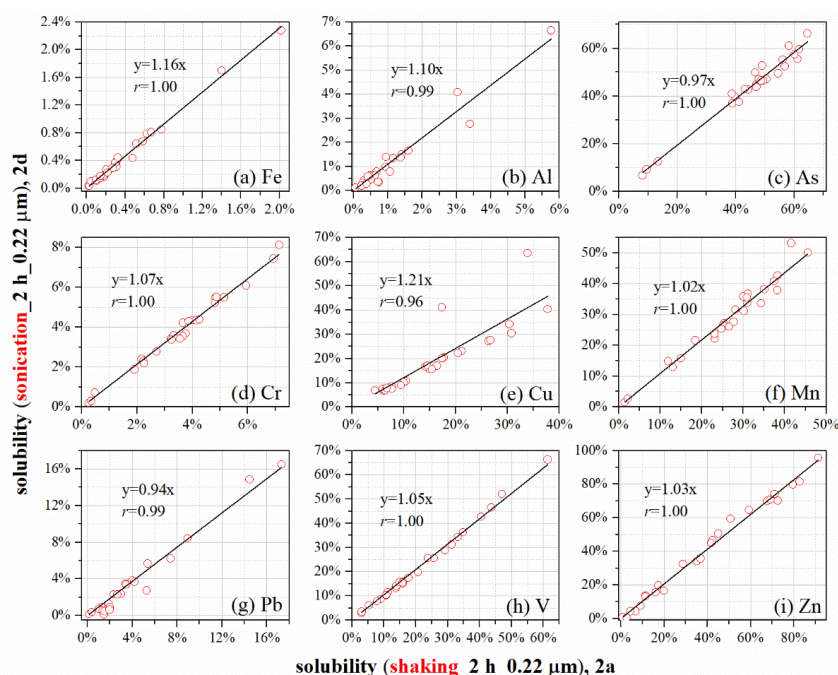
Figure 2. The effects of agitation (2a: shaking; 2d: sonication) on measured element solubility.

225   The only difference in protocols used to leach subsamples 2a and 2d is the agitation method

226   (shaking vs. sonication).

227

228   In summary, we found that the choice of agitation methods (shaking vs. sonication) had

229   no measurable (for Al and V) or small effects (for Fe, As, Cr, Cu, Mn, Pb and Zn) on the

230   reported solubility.

3.3 The effects of contact time

To assess the impacts of contact time on reported solubility, subsamples 2a and 2e were leached using very similar protocols, and the only difference was contact time (2a: 2 h; 2e: 1 h).

As shown in Table 2, the reported solubility were not statistically different between 2a and 2e for Pb and V; moreover, good linear relationships between 2a and 2e were found for the two elements (Figure 3), with slopes close to 1 (1.24 for Pb and 1.02 for V). For the other seven elements, their solubility was found to be statistically significant between 2a and 2e (Table 2); nevertheless, for each of the seven elements, the solubility reported for 2a was very well linearly correlated with that reported for 2e (Figure 3), and the slopes were close to 1 (in the range of 0.95-1.28).
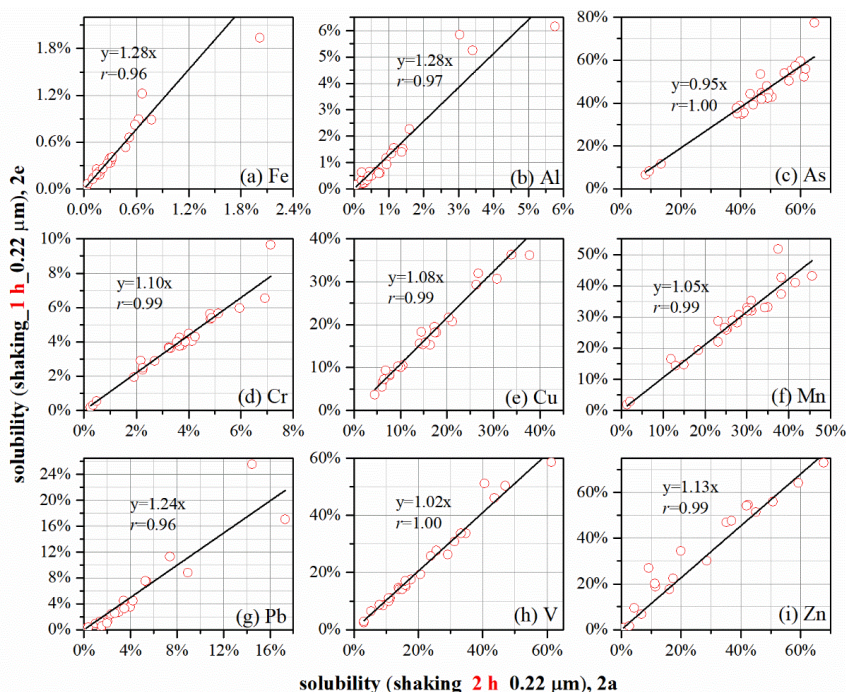
242 **Figure 3.** The effects of contact time (2a: 1 h; 2e: 2 h) on measured element solubility. The

243 only difference in protocols used to leach subsamples 2a and 2e is the contact time (1 h versus

244 2 h).

245

246 To summarize, our present work suggested that the increase in contact time from 1 h to 2

247 h would cause insignificant or small effects on reported solubility. Using a different set of

248 aerosol samples, our previous work (Li et al., 2023) compared the measured solubility obtained

249 with longer contact time (4 and 8 h) to that obtained with a contact time of 2 h. As shown in

250 Table S1, increase in contact time from 2 to 4 h would cause significant increase in solubility,

251 on average by a factor of ~1.3 for Zn to ~3.1 for As (Li et al., 2023). It is still not clear why the

252 increase in contact time from 1 to 2 h would not cause significant change in aerosol trace

253 element solubility while the increase in contact time from 2 to 4 h would.

254 **3.4 Comparison of solubility obtained using protocols commonly used by four labs**

255 We further compared solubility determined using the GIG protocol with those determined

256 using ZJU, OUC and NIO protocols, respectively. Table 3 summarizes the slopes obtained from

257 correlation analysis (Figures 4 and S2-S8). The NIO lab measured eleven elements, among

258 which five elements (Fe, Al, Cu, Mn, and V) were measured using the other three protocols; as

259 a result, the solubility of these five elements determined using the NIO protocol was compared

260 with those determined using the GIG protocol.

261

262 **Table 3.** Correlations between solubility determined using the GIG protocol and that

263 determined using ZJU, OUC and NIO protocols. Here only the slopes (k) are provided.

Atmospheric
Measurement
Techniques
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Discussions
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|	ZJU	OUC	NIO
	k	k	k
Fe	1.03	1.39	1.82
Al	1.09	1.19	1.80
As	0.96	0.87	--
Cr	0.96	0.97	--
Cu	1.06	1.04	0.99
Mn	0.99	0.98	1.09
Pb	0.97	1.01	--
V	1.06	0.99	1.05
Zn	0.97	0.94	--

264

265   With respect to Fe solubility, GIG results were very well correlated with ZJU results ($r =$

266   0.99, Figure 4a) and the slope was found to be 1.03, suggesting good agreement between GIG

267   and ZJU; GIG results were also well correlated with while overall larger than OUC results (r

268     $= 0.98$, Figure 4b), and the slope was determined to be 1.39; good correlation was also found

269   between GIG and NIO results ($r = 0.91$, Figure 4c), and the slope was determined to be 1.82,

270   indicating that Fe solubility determined using the NIO protocol was larger than that determined

271   using the GIG protocol. Similarly, with respect to Al solubility (Figure S2 and Table 3), the

272   GIG results were well correlated with ZJU, OUC and NIO results, and correlations were best

273   for ZJU ($r = 0.99$) and moderate for NIO ($r = 0.93$); in addition, the slopes were determined to

274   be 1.09, 1.19 and 1.80 for ZJU, OUC and NIO results, respectively.

275   With respect to Cu (Figure S5), Mn (Figures 4d-4f) and V (Figure S7), their solubility

276   determind using the ZJU, OUC and NIO protocols was well correlated with that determined

277   using the GIG protocol, and the slopes obtained from correlation analysis, which ranged from

278   0.98 to 1.09 (Table 3), were all close to 1.

279   Since As, Cr, Pb and Zn were not measured using the NIO protocol, we only compared

280   GIG results with ZJU and OUC results for these four elements. As shown in Figures S3, S4,

Atmospheric
Measurement
Techniques
Discussions
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281 S6 and S8, the solubility of As, Cr, Pb and Zn determined using ZJU and OUC protocols was

282 well correlated with that determined using the GIG protocol, and the slopes (0.87-1.01, as

283 summarized in Table 3) were close to 1.

284
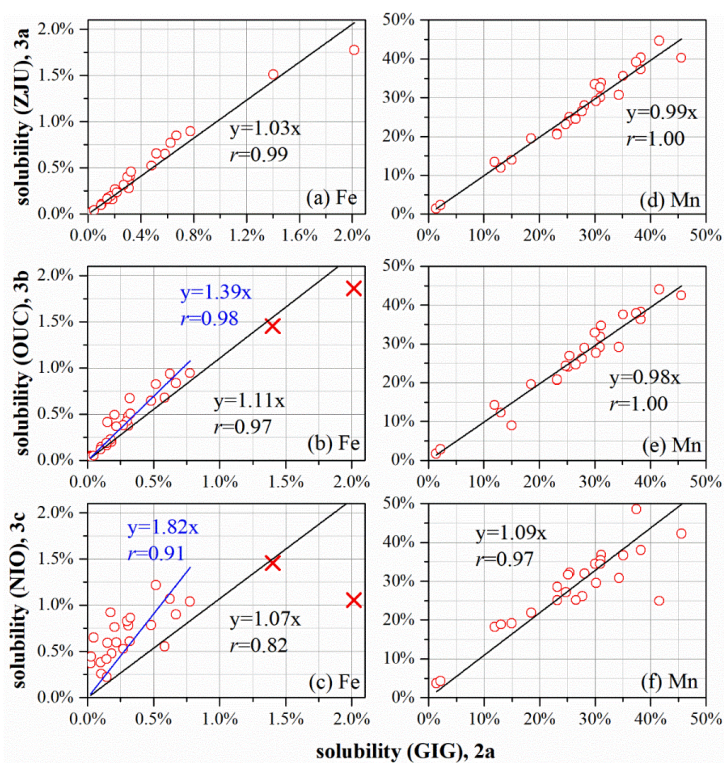
Figure 4. Solubility of Fe and Mn determined using the GIG protocol vs. those determined

using ZJU, OUC and NIO protocols: (a) Fe, GIG vs. ZJU; (b) Fe, GIG vs OUC; (c) Fe, GIG

vs. NIO; (d) Mn, GIG vs. ZJU; (e) Mn, GIG vs OUC; (f) Mn, GIG vs. NIO.

288

289 To summarize, although the four ultrapure water batch leaching protocols differ in

290 agitation method, contact time and/or filter pore size (GIG: shaking, 2 h contact time, 0.22 μm

291 filter pore size; ZJU: sonication, 1 h contact time, 0.22 μm filter pore size; OUC: sonication, 1

292 h contact time, 0.45 μm filter pore size; NIO: sonication, 1 h contact time, 0.22 μm filter pore

293   size), for the nine elements examined in this intercomparison study, their solubility determined

294   using the four protocols in general showed good agreement. This is consistant with the results

295   presented in Sections 3.1-3.3, where we found that the effects of agitation method (shaking vs.

296   sonication), contact time (1 vs. 2 h) and filter pore size (0.22 vs. 0.45 μm) were rather limited.

297   The solubility of Fe and Al determined using the NIO protocol deviated considerably from

298   those determined using the GIG protocol, probably because Fe and Al solubility was very low

299   (mostly <2%) and small change in leaching protocol may cause significant change in the

300   amounts of Fe and Al dissolved.

301   **4 Conclusion**

302   Ultrapure water batch leaching is widely used in atmospheric research to determine

303   aerosol trace element solubility, and the specific leaching protocols used in different labs can

304   still vary in agitation methods, contact time, and filter pore size. It is yet unclear to which extent

305   the difference in these experimental parameters would affect the reported aerosol trace element

306   solubility; in other words, it remains to be examined whether solubility reported by previous

307   studies which used different ultrapure water batch leaching protocols is comparable.

308   We examined the effects of agitation methods, filter pore size and contact time on the

309   reported solubility of nine aerosol trace elements, including Fe, Al, As, Cr, Cu, Mn, Pb, V and

310   Zn. It was found that the difference in agitation methods (shaking vs. sonication), filter pore

311   size (0.22 vs. 0.45 μm), and contact time (1 vs. 2 h) only led to small and sometimes

312   insignificant difference in the reported solubility. We further compared aerosol trace element

313   solubility determined using four widely used ultrapure water leaching protocols which differ

314   in agitation methods, filter pore size and/or contact time, and in general the solubility

315 determined using the four protocols was found to be in good agreement. Therefore, aerosol

316 trace element solubility determined in previous studies using ultrapure water batch leaching

317 may be comparable.

318   Aerosol trace element solubility is an operationally defined term (Baker and Croot, 2010;

319 Meskhidze et al., 2019), and strongly depends on the leaching protocol employed. A number

320 of leaching protocols have been used in previous studies to extract dissolved trace elements,

321 making it very challenging to compare solubility reported in different studies (Perron et al.,

322 2024). In order to reduce uncertainties in aerosol trace element solubility, it is necessary to

323 formulate standard operating procedures for frequently-used aerosol leaching protocols. Our

324 current work suggests that although ultrapure water batch leaching protocols used by different

325 labs vary in specific experimental parameters, the determined aerosol trace element solubility

326 showed good agreement; furthermore, ultrapure water batch leaching is operationally simple

327 and does not introduce any other chemical species which may interfer analysis of water-soluble

328 inorganic ions and organics. Therefore, we recommend ultrapure water batch leaching to be

329 one of the reference leaching schemes. Before a standard operating procedure can be

330 formulated for ultrapure water batch leaching, the community will need to reach consensus on

331 agitation methods, contact time and filter pore size, and further intercomparison studies,

332 preferentially with more labs involved, will be very helpful.

333

334 **Data availability.**

335 Data are available upon request (Mingjin Tang: mingjintang@gig.ac.cn).

336 **Author contributions.**

337 Rui Li: methodology, formal analysis, investigation, writing - original draft, writing - review

338 & editing; Prema Piyusha Panda: formal analysis, investigation; Yizhu Chen: investigation;

339 Zhenming Zhu: investigation; Fu Wang: investigation, supervision; Yujiao Zhu: resources; He

340 Meng: resources; Yan Ren: resources, supervision; Ashiwini Kumar: resources, writing -

341 review & editing, supervision; Mingjin Tang: conceptualization, methodology, resources,

342 writing - original draft, writing - review & editing, supervision.

Competing interests.

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Atmospheric
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Discussions

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