8th CJK IMBeR Symposium

Atmospheric Deposition of ^{7}Be, ^{210}Pb and ^{210}Po during Typhoons and Thunderstorm in Shanghai, China and global Data Synthesis

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Introduction

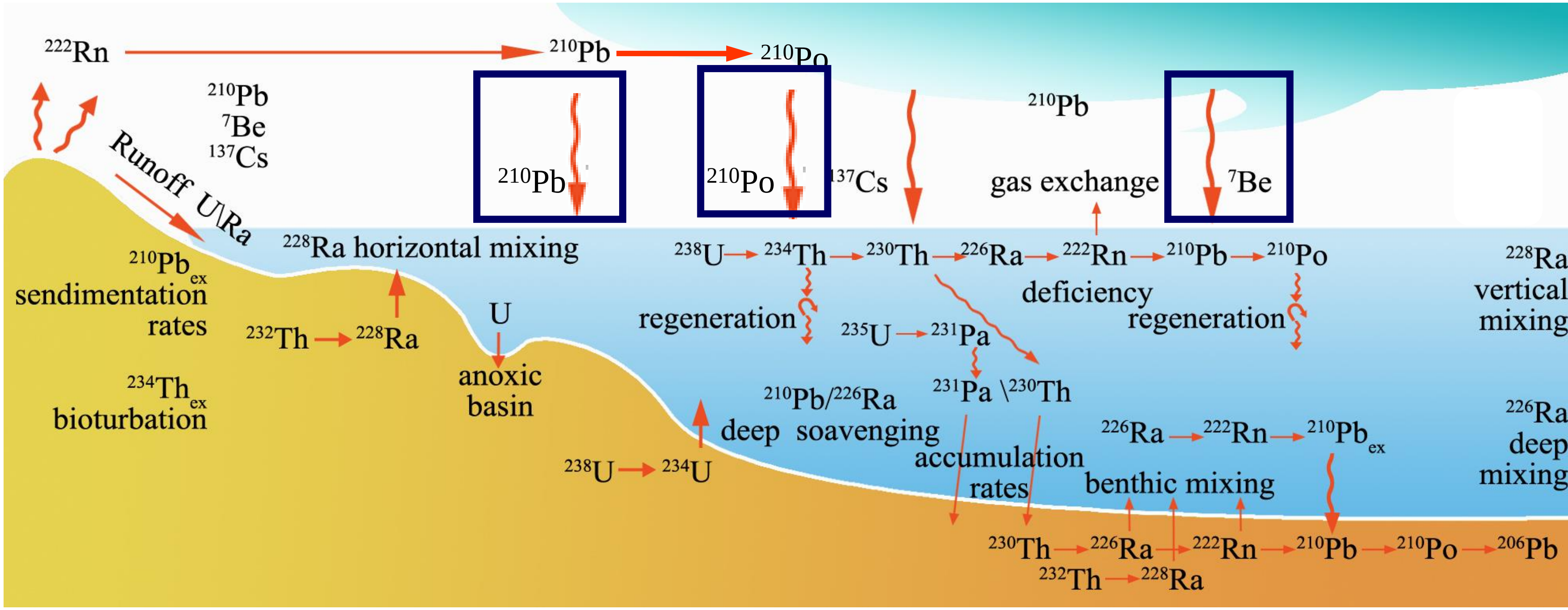


Figure 1. The application of radionuclides in the estuarine and costal area.

- Beryllium-7 (^{7}Be, half-life, $T_{1/2}$ = 53.3 d), a typical cosmogenic radionuclide, is produced in the stratosphere and upper troposphere.
- Lead-210 (^{210}Pb, $T_{1/2}$ = 22.3 y) and polonium-210 (^{210}Po, $T_{1/2}$ = 138.4 d) are both the progenies of ^{222}Rn ($T_{1/2}$ = 3.82 d), which emanates primarily from the rocks and minerals on the earth's upper crust and embarks on its journey in the atmosphere via advection and diffusion.

Introduction

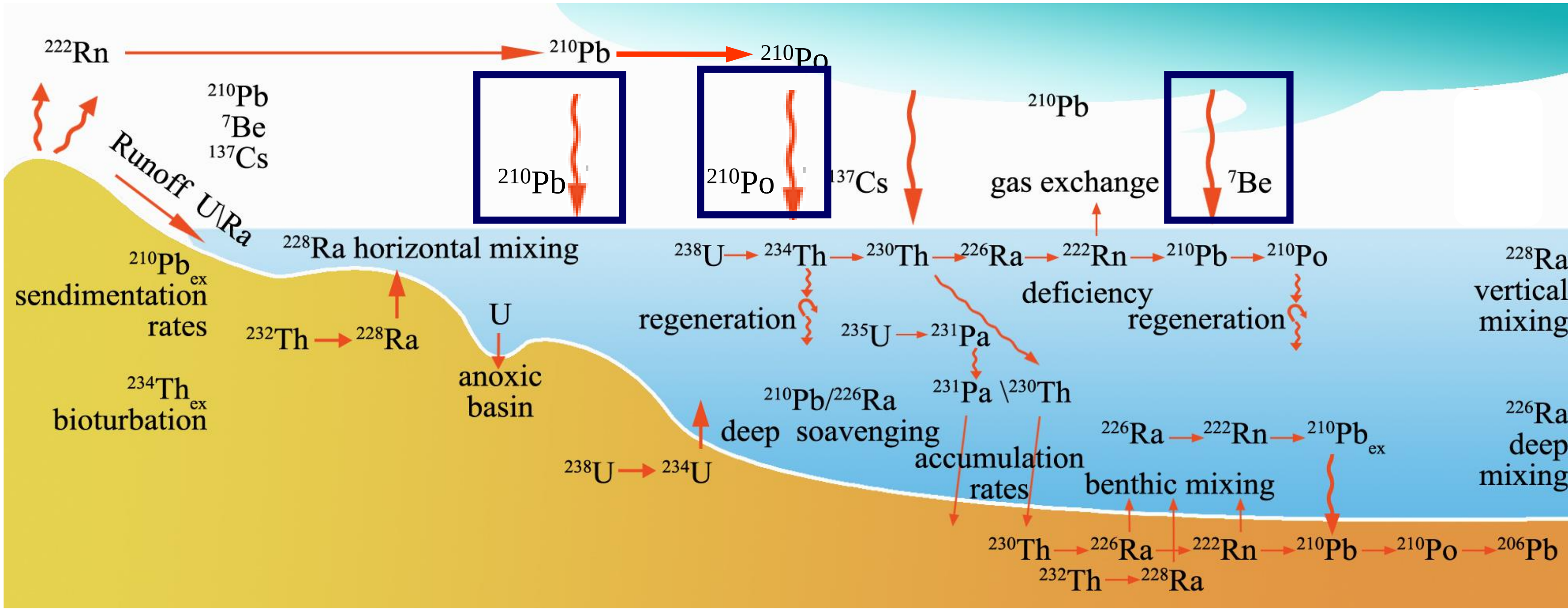
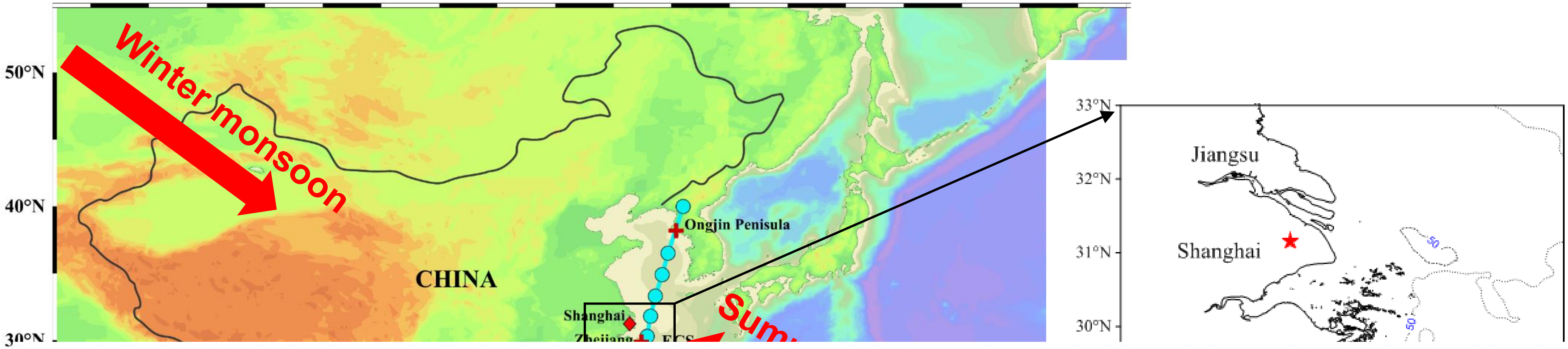


Figure 1. The application of radionuclides in the estuarine and costal area.

- ^{7}Be, ^{210}Po and ^{210}Pb are all partical-reactive and primarily removed by wet perecipitation from the atmosphere, these three radionuclides have been widely used as tracers for studying atmospheric and surface earth processes such as **time scales of atmospheric mixing (both horizontal and vertical), stability, and removal/transport of air masses, source tracking, rates of soil erosion and sediment accumulation/mixing in aqueous systems** (e.g. Baskaran, 1995; Chen et al., 2016; Du et al., 2008, 2015; McNeary & Baskaran, 2007; Moore et al., 1973; Pham et al., 2011; Poet et al., 1972; Turekian & Graustein, 2003).

Study area-Shanghai



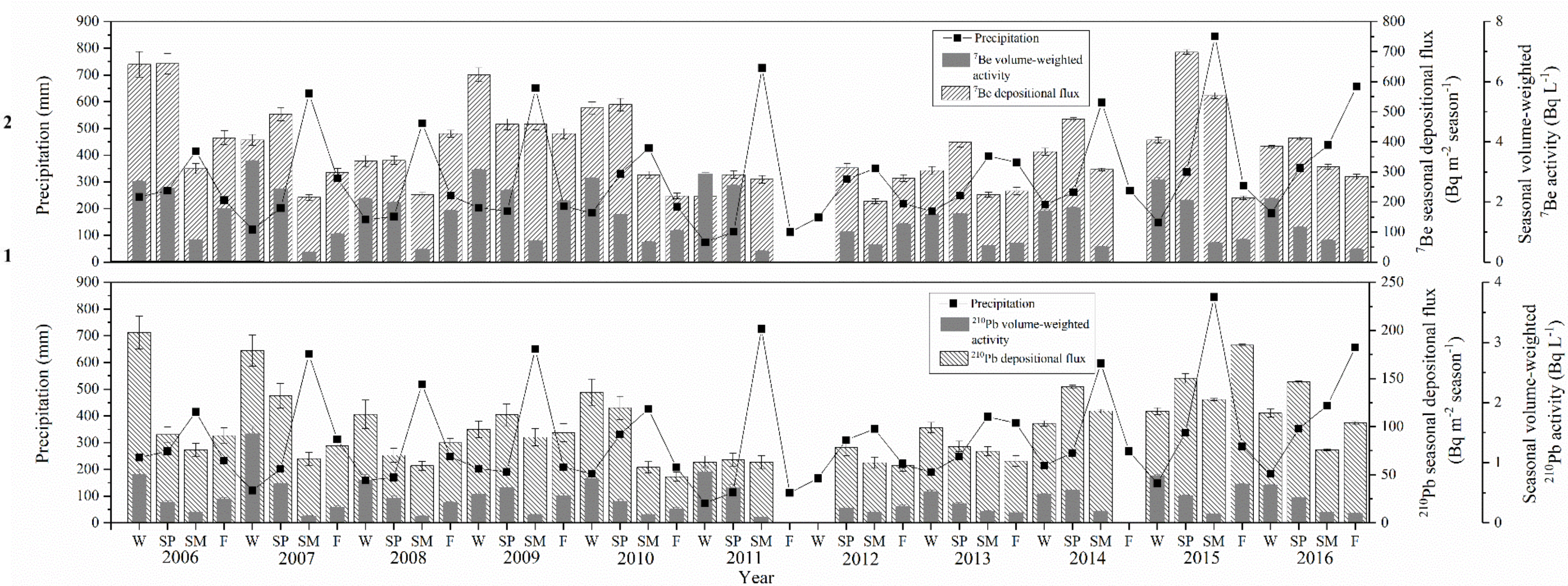


Figure 3. Seasonal precipitation, depositional fluxes, and volume-weighted activities of ^{7}Be and ^{210}Pb in Shanghai from 2006 to 2016.

^{222}Rn-depleted maritime air masses.

134 mm of precipitation amount.

- ➢ Annual precipitation in Shanghai is usually ~1100 mm of which ~50 % takes place during the raining season (June – August).

- ➢ Typhoon Dujuan (9/28-9/30/2015): the 21st named storm of the 2015 Pacific typhoon season, 55 mm of precipitation amount.

Sample information

RE-I: Thunderstorm: 6/25-6/28/2015, totally 3 samples.

RE-II: Typhoon Chan-hom: 7/11/2015, totally 7 samples.

RE-III: Typhoon Dujuan: 9/28-9/30/2015, totally 3 samples.

Table 1. Deposition fluxes and activities of ^{7}Be, ^{210}Pb and ^{210}Po measured in three rainout events in Shanghai, China in 2015.

Sample ID	Sample collection nterval[a]	Central pressure (hPa)[b]	Time in hour (Precipitaion)[c]	^{7}Be Flux (Bq m^{-2} d^{-1})	^{7}Be (Bq L^{-1})	^{210}Pb Flux (Bq m^{-2} d^{-1})	^{210}Pb (Bq L^{-1})	^{210}Po Flux (mBq m^{-2} d^{-1})	^{210}Po (mBq L^{-1})	$^{7}Be/^{210}Pb$ AR	$^{210}Po/^{210}Pb$ AR
RE-I	20:00, 25 Jun-18:30, 26 Jun, 2015	-	22.5 (39.2)	26.8±2.2	0.64±0.05	4.32±0.56	0.10±0.01	348 ±8	8.50±0.17	6.21±0.55	0.082±0.012
	18:30, 26 Jun-19:20, 27 Jun 2015	-	22.5-48.3 (9.0)	11.5±1.0	1.37±0.11	3.04±0.42	0.15±0.01	282 ±8	13.3±0.8	3.77±0.71	0.095±0.007
	19:20, 27 Jun-16:20, 28 Jun 2015	-	48.3-69.3 (78.4)	19.5±1.3	0.22±0.02	5.23±0.75	0.06±0.01	432±20	4.83±0.17	3.74±0.32	0.083±0.015
RE-II	15:05, 10 Jul-9:00, 11 Jul, 2015	925	17.9 (27.4)	325±27	8.84±0.74	19.1±2.2	0.52±0.06	1650±17	50.7±0.5	17.0±1.5	0.096±0.012
	9:00 -11:10, 11 Jul 2015	935	17.9-20.1 (11.8)	154±13	1.18±0.10	15.0±1.8	0.12±0.01	1405±50	10.8± 0.3	10.3±0.9	0.094±0.014
	11:10 -13:00, 11 Jul 2015	945	20.1-21.9 (9.4)	32.9±2.7	0.27±0.02	13.5±1.8	0.11±0.01	1200± 48	9.67± 0.33	2.43±0.20	0.088±0.007
	13:00 -16:00, 11 Jul 2015	945	21.9-24.9 (15.7)	36.4±3.4	0.29±0.03	6.69±0.94	0.05±0.01	628± 27	5.00± 0.17	5.44±0.46	0.094±0.015
	16:00 -18:00, 11 Jul 2015	955	24.9-26.9 (14.9)	31.4±2.9	0.18±0.02	4.17±0.66	0.02±0.01	223± 12	1.83±0.17	7.54±0.63	0.079±0.013
	18:00 -22:00, 11 Jul 2015	955	26.9-30.9 (17.6)	39.0±3.4	0.37±0.03	3.35±0.51	0.03±0.01	303± 13	2.83± 0.17	11.6±1.0	0.089±0.010
	22:00, 11 Jul -7:30, 12 Jul 2015	960	30.9-40.4 (37.2)	89.2±7.4	0.95±0.08	5.64±0.97	0.06±0.01	620± 8	5.83±0.17	15.8±1.3	0.097±0.005
RE-III	16:15, 28 Sep-10:40, 29 Sep 2015	935	18.4 (11.8)	15.3±1.4	1.00±0.09	3.83±0.69	0.25±0.05	267±20	17.3±1.3	4.00±0.43	0.069±0.009
	10:40-21:55, 29 Sep 2015	990	18.4-29.5 (11.8)	41.5±3.2	1.73±0.15	2.84±0.52	0.12±0.02	255±17	10.2±0.7	14.6±1.4	0.086±0.012
	21:55, 29 Sep-8:40, 30 Sep 2015	1005	29.5-40.4 (31.4)	31.8±2.7	0.45±0.04	9.22±1.63	0.13±0.02	840±67	11.8±1.0	3.45±0.29	0.090±0.011

Results and discussion

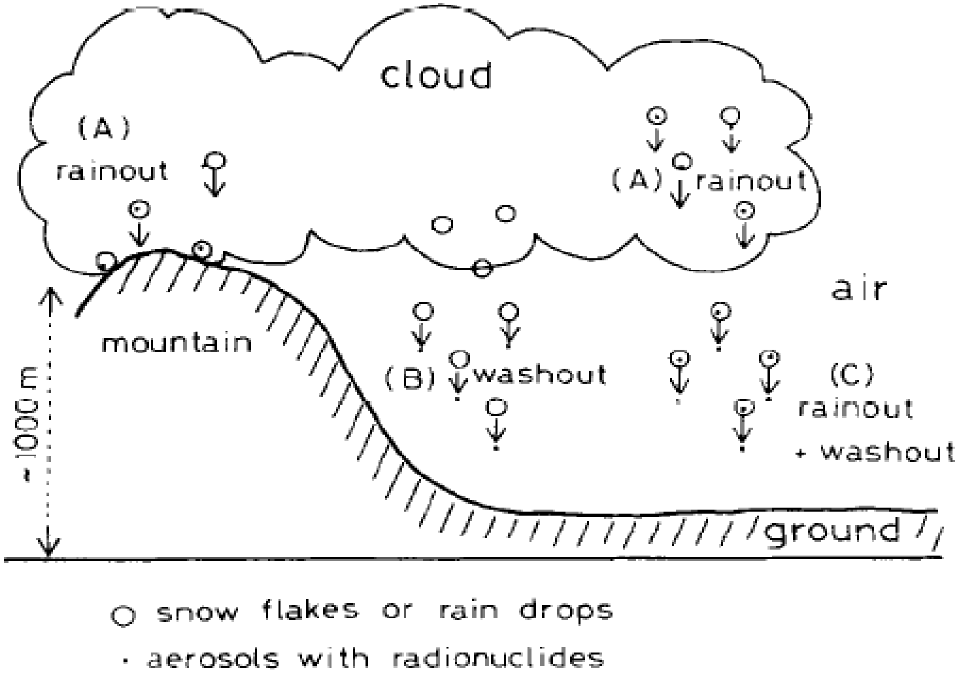


Figure 3. A pictorial model of aerosol scavenging by precipitation (snow flakes or rain drops). (A) Scavenging by rainout only, (B) by washout only and (C) by both rainout and washout. (Ishikawa and Murakami, 1995)

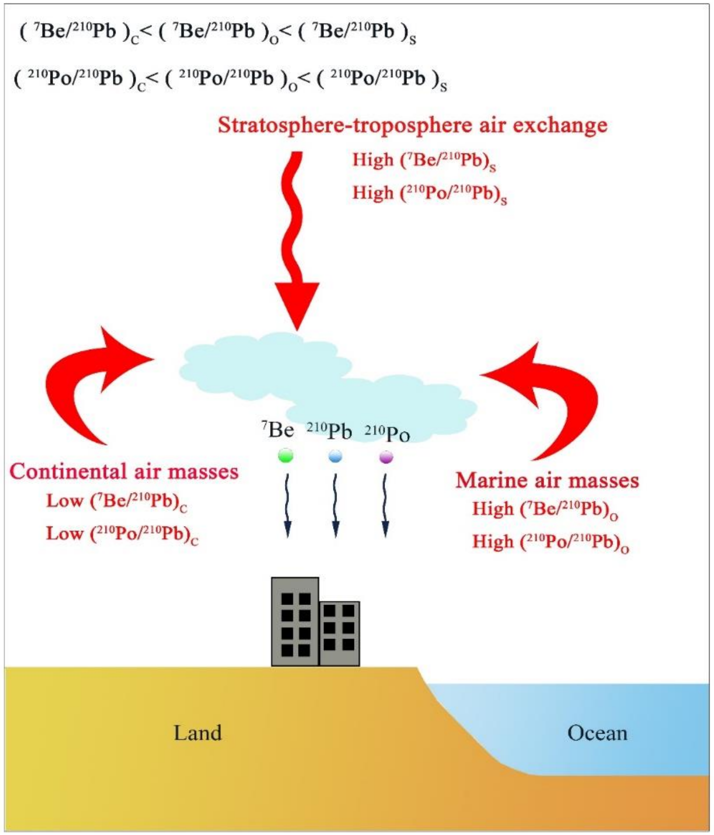


Figure 4. The schematic diagram of air masses intrusions into the condensing cloud at the coastal area.

- The radionuclides are removed from the atmosphere through both by washout and rainout processes.
- The activities ^{7}Be, ^{210}Pb and ^{210}Po in rainwater are generally higher in the early stage of and subsequently decreased due to dilution effect.
- If a certain air mass is undergoing condensation without any additional input from the surrounding air masses via lateral injection and/or from upper troposphere – lower stratosphere, the specific activities of all three radionuclides in one rainout event are anticipated to decrease systematically from the beginning.

Results and discussion

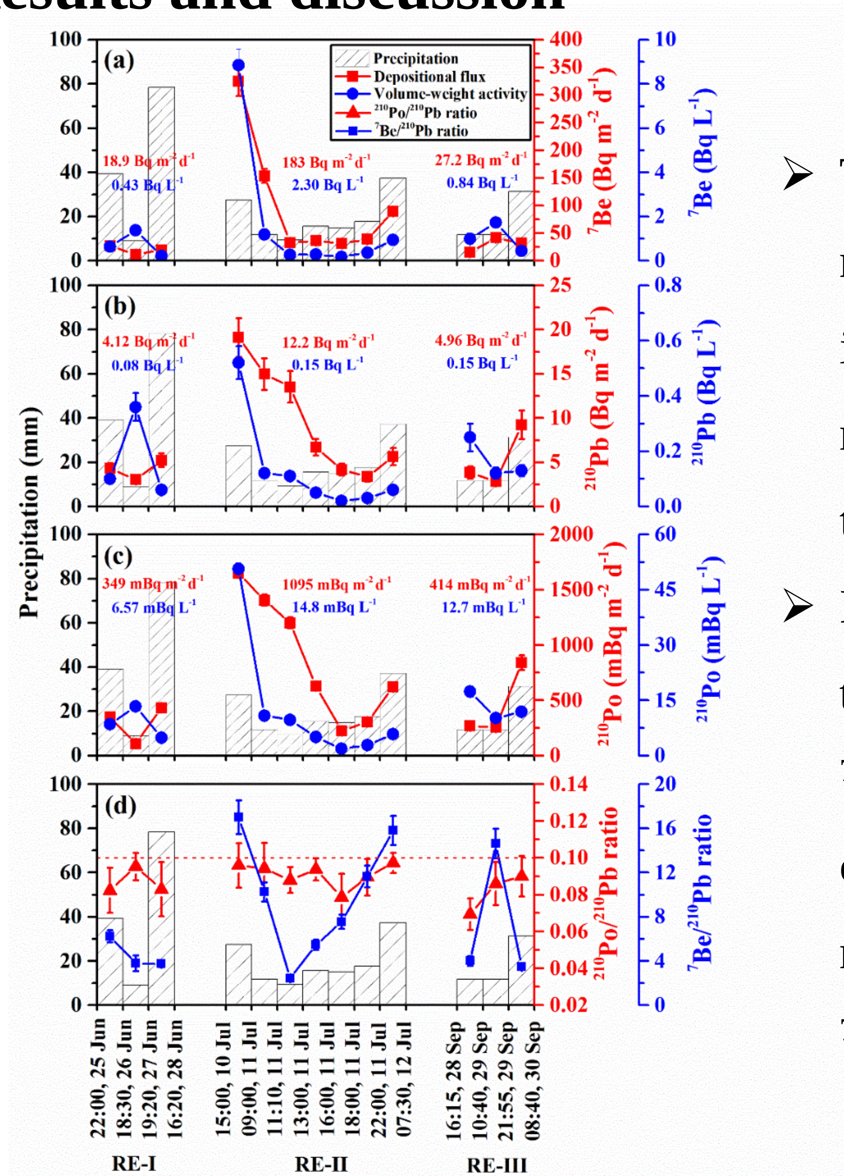


Figure 5. Depositional fluxes and activities of (a) ^{7}Be, (b) ^{210}Pb and (c) ^{210}Po during three rainout events in summer 2015 (RE-I, RE-II and RE-III) in Shanghai, China. (d) $^{210}Po/^{210}Pb$ ratios and $^{7}Be/^{210}Pb$ ratios during three rainout events. The red dash line in (d) represents for $^{210}Po/^{210}Pb$ is 0.10. The numbers represent the bulk depositional fluxes and the specific activities of the three radionuclides in three rainout events.

- The obvious variations of the $^{7}Be/^{210}Pb$ activity ratios can be observed in all three rainout events, indicating the change of the relative fraction of maritime and continental air masses drawn into the typhoon's low pressure system.
- In RE-I, prior to the onset of rainfall, it appears that upper air mass downdraft resulted in higher ^{7}Be (relative to ^{210}Pb) in aerosols below cloud condensation height. Once those excess ^{7}Be are removed by first precipitation, then, the $^{7}Be/^{210}Pb$ ratio had remained constant .

Results and discussion

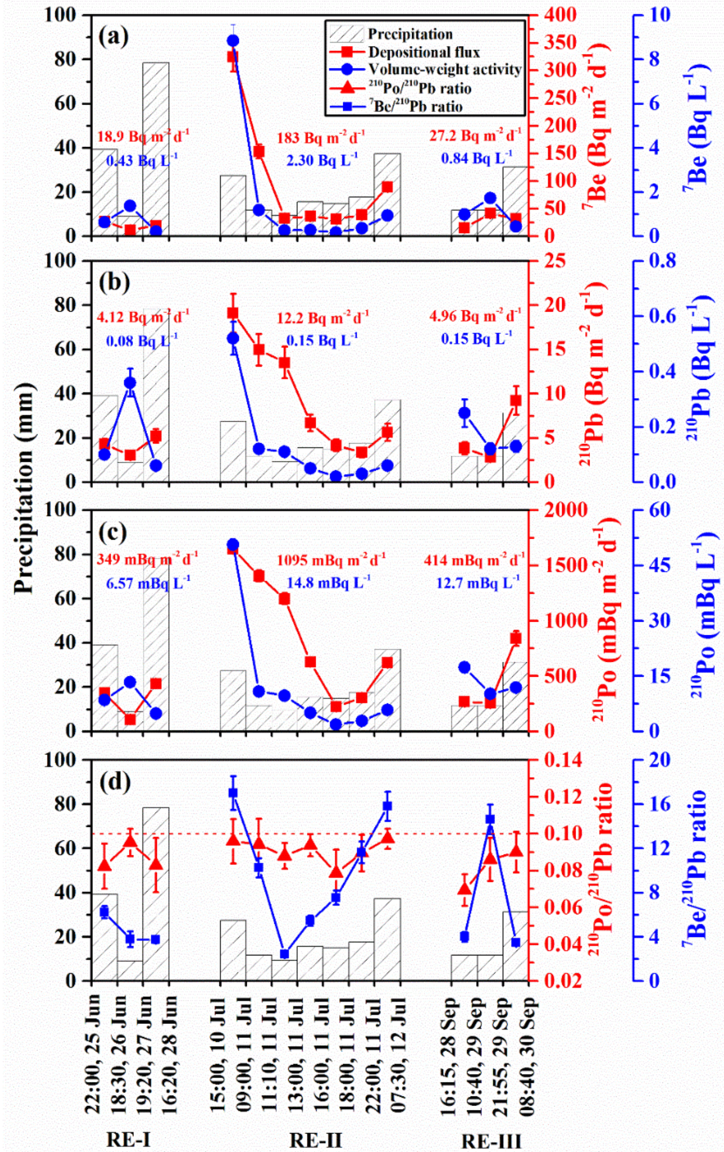


Figure 5. Depositional fluxes and activities of (a) ^{7}Be, (b) ^{210}Pb and (c) ^{210}Po during three rainout events in summer 2015 (RE-I, RE-II and RE-III) in Shanghai, China. (d) ^{210}Po/^{210}Pb ratios and ^{7}Be/^{210}Pb ratios during three rainout events. The red dash line in (d) represents for ^{210}Po/^{210}Pb is 0.10. The numbers represent the bulk depositional fluxes and the specific activities of the three radionuclides in three rainout events.

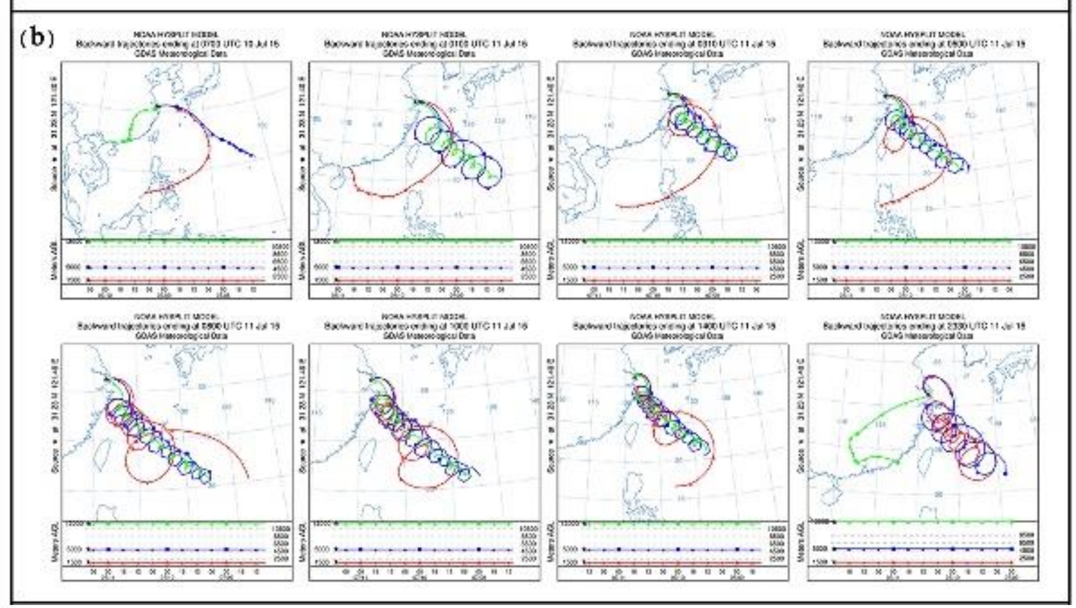


Figure 6. Air masses backward trajectory analyses of the RE-II.

- At the beginning of the RE-II, the typhoon Chan-hom hadn't impacted Shanghai deeply. The source of air masses at 12 km height were still from the inland area. Thereafter, typhoon Chan-hom brought ^{210}Pb-depleted air masses from the Pacific Ocean (PO) to Shanghai, leading to the decrease of ^{210}Pb and ^{210}Po.
- The depositional fluxes of ^{7}Be and ^{210}Pb as well as the ^{7}Be/^{210}Pb AR indicate the injection of extraneous air masses into typhoon and the intrusion of variable fractions of continental and maritime air masses to Shanghai.

Results and discussion

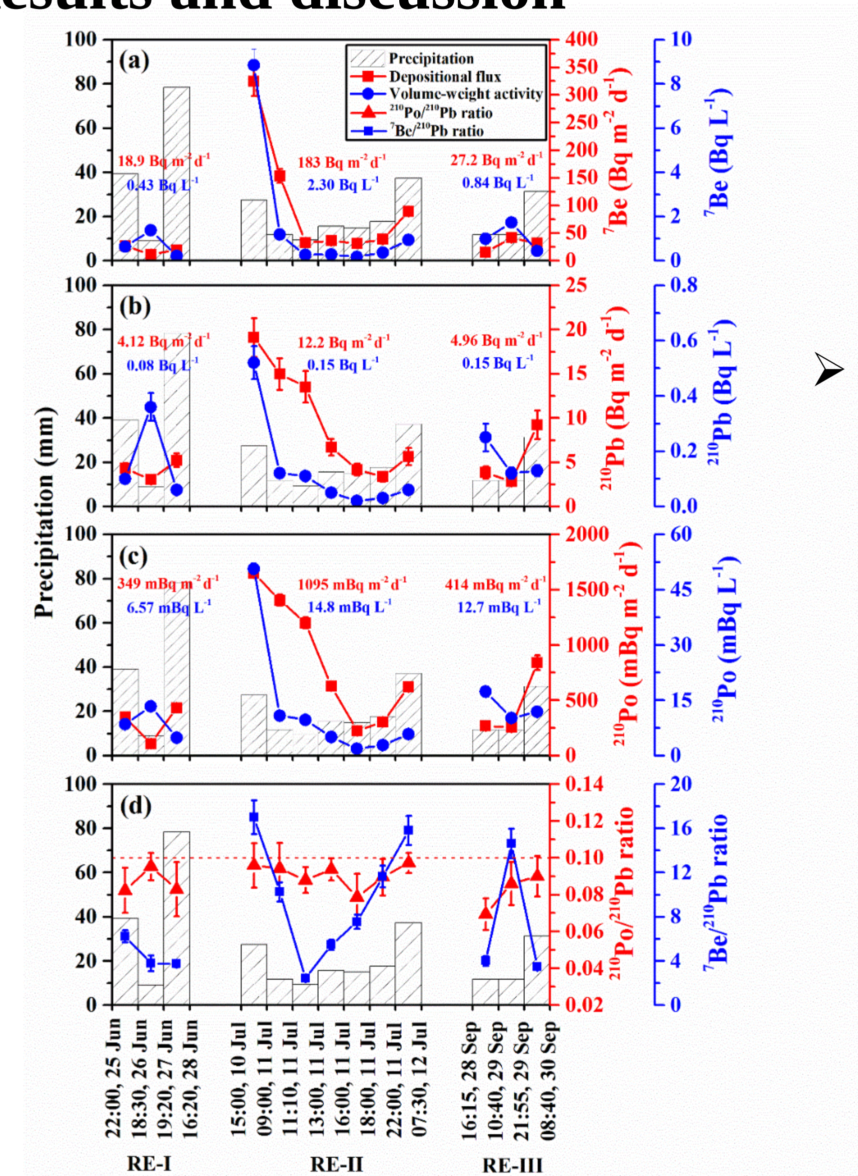


Figure 5. Depositional fluxes and activities of (a) ^{7}Be, (b) ^{210}Pb and (c) ^{210}Po during three rainout events in summer 2015 (RE-I, RE-II and RE-III) in Shanghai, China. (d) $^{210}Po/^{210}Pb$ ratios and $^{7}Be/^{210}Pb$ ratios during three rainout events. The red dash line in (d) represents for $^{210}Po/^{210}Pb$ is 0.10. The numbers represent the bulk depositional fluxes and the specific activities of the three radionuclides in three rainout events.

- In RE-III, the ^{7}Be activity decreased by 79% but both the ^{210}Pb and ^{210}Po activities were almost constant from the second to the third sample, suggesting the continuous intrusion of air masses bringing ^{210}Pb and ^{210}Po below the condensation cloud.

Results and discussion-Global Data Synthesis

- The bulk depositional fluxes of ^{7}Be in RE-I, RE-II and RE-III were 18.9, 183 and 27.2 Bq m^{-2} d^{-1} , respectively;
- The bulk depositional fluxes of ^{210}Pb in RE-I, RE-II and RE-III were 4.12, 12.2 and 4.96 Bq m^{-2} d^{-1} , respectively;
- RE-I, RE-II and RE-III together brought 18.6% of the total annual precipitation, but deposited about 28% and 11% of the total annual bulk depositional fluxes of ^{7}Be and ^{210}Pb, respectively.

Table 2. Percentages of bulk depositional fluxes and precipitation-normalized enrichment factors (α) of ^{7}Be and ^{210}Pb during pulse rainout events.

Location	Sample	Percent of Annual precipitation	^{7}Be Percent of annual flux	^{7}Be α	^{210}Pb Percent of annual flux	^{210}Pb α	References
Detroit, USA	RWB 1	5.8%	15.8%	2.72	8.6%	1.48	McNeary & Baskaran, 2003
	RWB 10	7.5%	9.6%	1.28	5.4%	0.72	
	RWB 16	6.3%	5.0%	0.79	3.9%	0.62	
	RWB 20	3.6%	3.3%	0.92	4.4%	1.22	
	RWB 21	9.4%	6.6%	0.70	7.6%	0.81	
	RWB 25	5.0%	2.9%	0.58	6.9%	1.38	
Ansan, korea	5 heavy rainfalls with more than 50 mm precipitation amount in 1992	6.5%	2.2%	0.34	4.7%	0.72	Kim et al., 1998
		6.6%	3.9%	0.60	2.0%	0.30	
		11.4%	8.3%	0.73	8.9%	0.78	
		10.5%	0.6%	0.06	1.9%	0.18	
		8.2%	2.0%	0.24	1.5%	0.18	
Xiamen, China*	11 heavy rainfalls more than 50 mm precipitation amount from 2004 to 2005	5.1%	31.2%	6.10	3.7%	0.72	Chen et al., 2016; Jia et al., 2003
		5.3%	5.1%	0.97	6.6%	1.26	
		5.6%	11.2%	2.00	4.0%	0.72	
		5.8%	18.6%	3.20	8.3%	1.44	
		6.0%	4.7%	0.80	3.8%	0.63	
		6.2%	2.4%	0.39	1.1%	0.18	
		6.6%	4.2%	0.64	4.2%	0.63	
		6.9%	25.7%	3.71	14.3%	2.07	
		7.1%	3.8%	0.54	3.8%	0.54	
		9.9%	1.7%	0.17	0.9%	0.09	
		12.8%	28.8%	2.25	4.6%	0.36	
California, USA	Typhoon Melor in 2010	17.9%	9.2%	0.51	-		Conaway et al., 2013
	6 extra-tropical storms in 2010	3.1%	5.2%	1.68	-		
		7.0%	6.3%	0.90	-		
		9.2%	9.9%	1.07	-		
		3.2%	3.8%	1.18	-		
		5.8%	3.7%	0.65	-		
		5.8%	4.2%	0.73	-		
Nankang, Taiwan*	Rainfalls caused by typhoon during 9 year time series from 1996 to 2005	31.0%	16.0%	0.52	12.0%	0.39	Huh et al., 2006
	Rainfalls in plum season during 9 year time series from 1996 to 2005	8.0%	7.0%	0.88	7.0%	0.88	
Ahemedabad, India	5 heavy rainfalls with more than 50 mm precipitation amount in 2000 and 2001	7.0%	-		6.5%	0.93	Rastogi & Sarin, 2008
		7.0%	-		1.7%	0.24	
		7.5%	-		2.7%	0.36	
		14.0%	-		20.5%	1.47	
		14.0%	-		7.0%	0.50	
San Luis, Argentina	3 heavy rainfalls with more than 50 mm precipitaiton amount in 2007 and 2008	7.7%	8.1%	1.05	-	-	Ayub et al., 2009
		7.9%	10.1%	1.28	-	-	
		8.1%	10.5%	1.30	-	-	
Shanghai, China	RE-I	7.5%	3.7%	0.50	3.3%	0.44	This study
	RE-II	7.9%	21.0%	2.66	5.6%	0.71	
	RE-III	3.2%	3.1%	0.96	2.3%	0.70	
	5 heavy rainfalls with more than 50 mm precipitaiton amount in 2010	4.9%	2.1%	0.43	1.6%	0.33	Kong, 2012
		5.0%	3.6%	0.72	0.9%	0.18	
		5.5%	0.9%	0.17	0.2%	0.04	
		6.2%	8.8%	1.42	6.9%	1.12	
		6.2%	2.1%	0.34	3.7%	0.59	

- A summary of the percentages the total annual rainfall, bulk depositional fluxes of ^{7}Be and ^{210}Pb during pulse rainout events (≥ 50 mm precipitation from single rainout event) around the world are summarized, it can been seen that these pulse rainout events significantly contributed to the annual depositional fluxes of both ^{7}Be and ^{210}Pb, especially the rainout events caused by typhoon.

Results and discussion-Global Data Synthesis

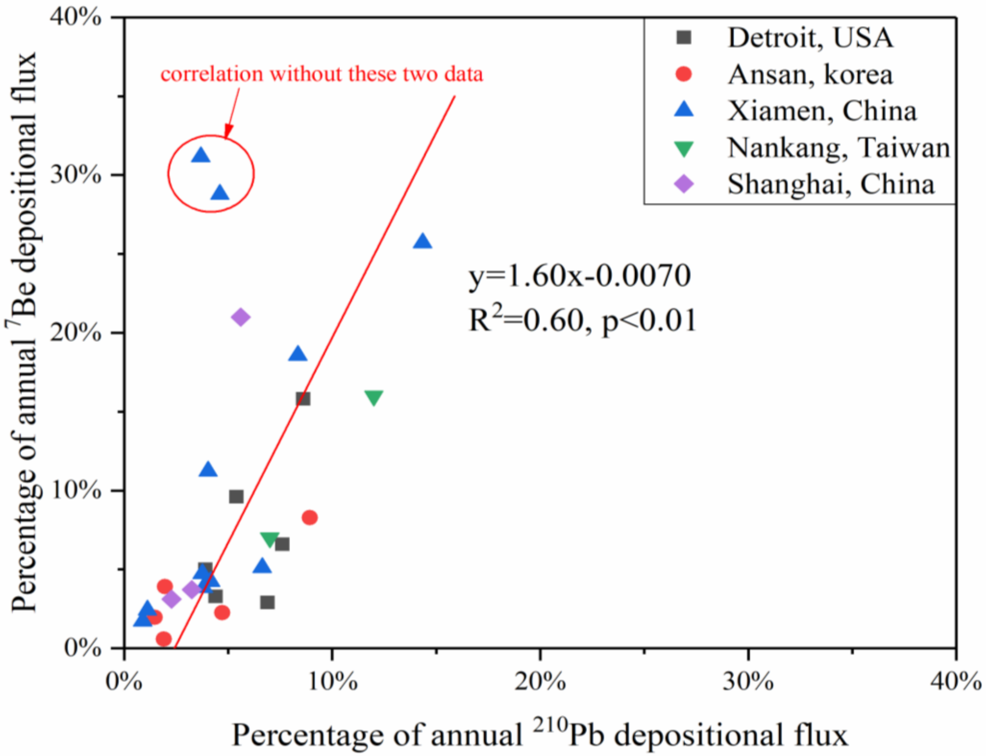


Figure 7. Percentages of annual ^{7}Be depositional flux plotted against percentages of annual ^{210}Pb depositional flux.

- A strong linear correlation between the percentages of annual ^{7}Be depositional flux and the percentages of annual ^{210}Pb depositional flux in the pulse rainout events is observed (R^2=0.60, $p<0.01$);
- The slope of 1.60±0.27 indicates that these pulse rainout events brought more ^{7}Be than ^{210}Pb, suggesting a relatively enhanced convective mixing or stratosphere-troposphere exchange during these rainout events.

Results and discussion-Global Data Synthesis

- To quantify the variations in the depositional fluxes of ^{7}Be and ^{210}Pb in pulse rainout events, the precipitation-normalized enrichment factors (α) were calculated in this study (Baskaran, 1995):

$$\alpha = P_{\mathrm{f}} / P_{p}$$

- where P_{f} and P_{p} are the percentages of annual depositional flux and amount of precipitation for single pulse rainout events, respectively.
- Values of $\alpha > 1.0$ indicate that the depositional fluxes were higher than expected from the amount of precipitation;
- $\alpha < 1.0$ indicate depletion of the depositional fluxes of the nuclides.

Results and discussion-Global Data Synthesis

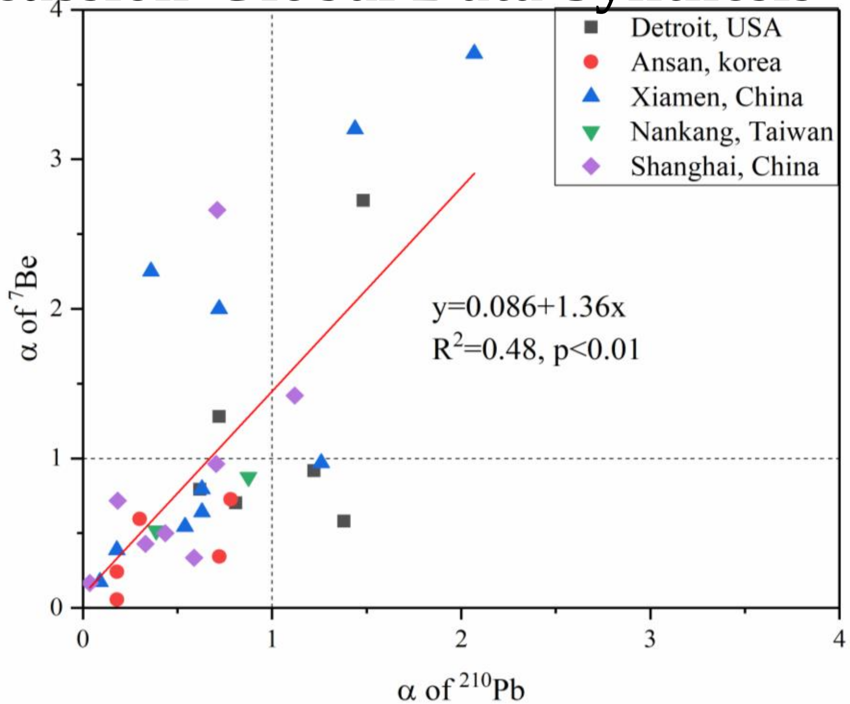


Figure 8. The precipitation-enrichment factors of ^{7}Be plotted against the precipitation-enrichment factors of ^{210}Pb for the pulse rainout events.

- In 27 out of 42 and 28 out of 36 pulse rainout events had α values < 1.0 for ^{7}Be and ^{210}Pb, respectively, indicating that in the most pulse rainout events, the depositional fluxes of ^{7}Be and ^{210}Pb were lower relative to the amount of precipitation due to the dilution effect by the large amounts of precipitation.
- The α value > 1.0 for both radionuclides could still been found in some stations, showing that there were enrichments of ^{7}Be or ^{210}Pb in some pulse rainout events, which might have been caused by the intrusions of air masses (vertical or horizontal transportation) during the rainfall.

- The study of continuous time-series samples can help us better understanding the variations of air masses intrusions during rainfall, but more studies during pulse precipitation in coastal and deep oceanic stations, as well as time-series measurements of $\delta^{18}O$ and $\delta^{2}H$ are needed to better understand the intrusions of these air masses.
- This study has been submitted to the Journal of Geophysical Reasearch.

Thank for your attention!