

Long-Term Monitoring of Mercury in Air and Rainwater in Taiwan

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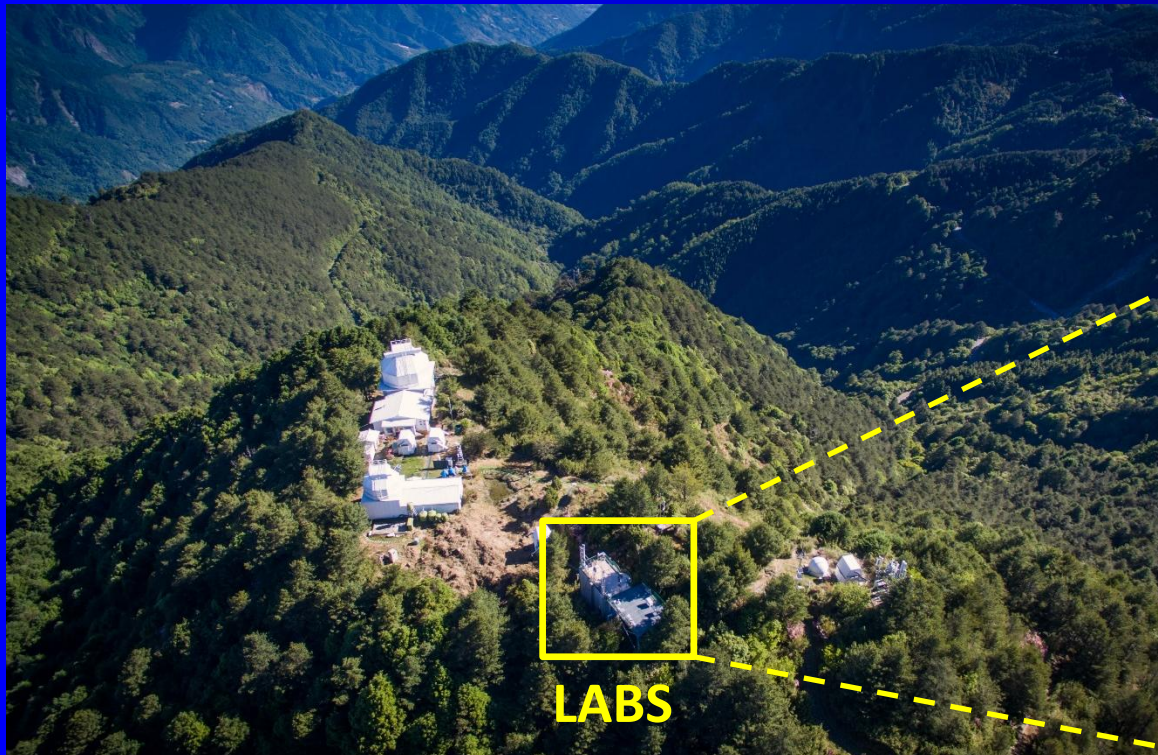
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Atmospheric Hg Monitoring Activities Supported by Taiwan MOENV and NSTC

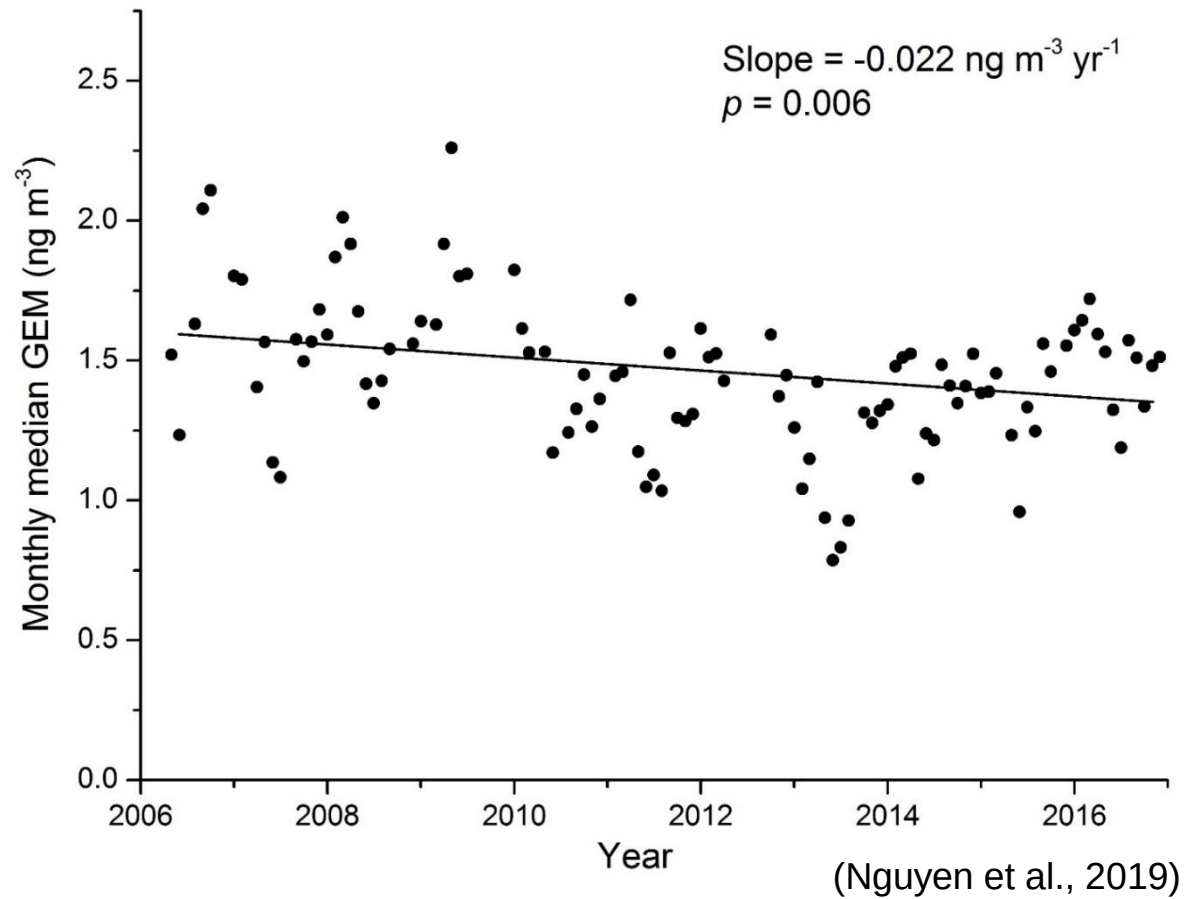
1. Continuous speciated atmospheric Hg monitoring since 2006 and wet Hg deposition monitoring since 2009 at Lulin Atmospheric Background Station (LABS)
2. Continuous speciated atmospheric Hg monitoring at National Central University (NCU) since 2016
3. Test and application of passive samplers since 2018
4. Mercury Wet Deposition Monitoring Network since 2008
5. Asia-Pacific Mercury Monitoring Network (APMMN) since 2016
6. Cloudwater Hg monitoring at Mt. Bamboo in 2004-2020
7. Regional atmospheric Hg Research with East/Southeast Asian countries

Lulin Atmospheric Background Station (LABS)

- LABS is located atop Mt. Front Lulin in central Taiwan, with an elevation of **2862 m** above sea level
- Location : **23.47°N, 120.87°E**
- **Atmospheric Hg monitoring** using Tekran 2537X(A)/1130/1135 began since **April 13, 2006**
- **Wet Hg deposition monitoring** began since 2009



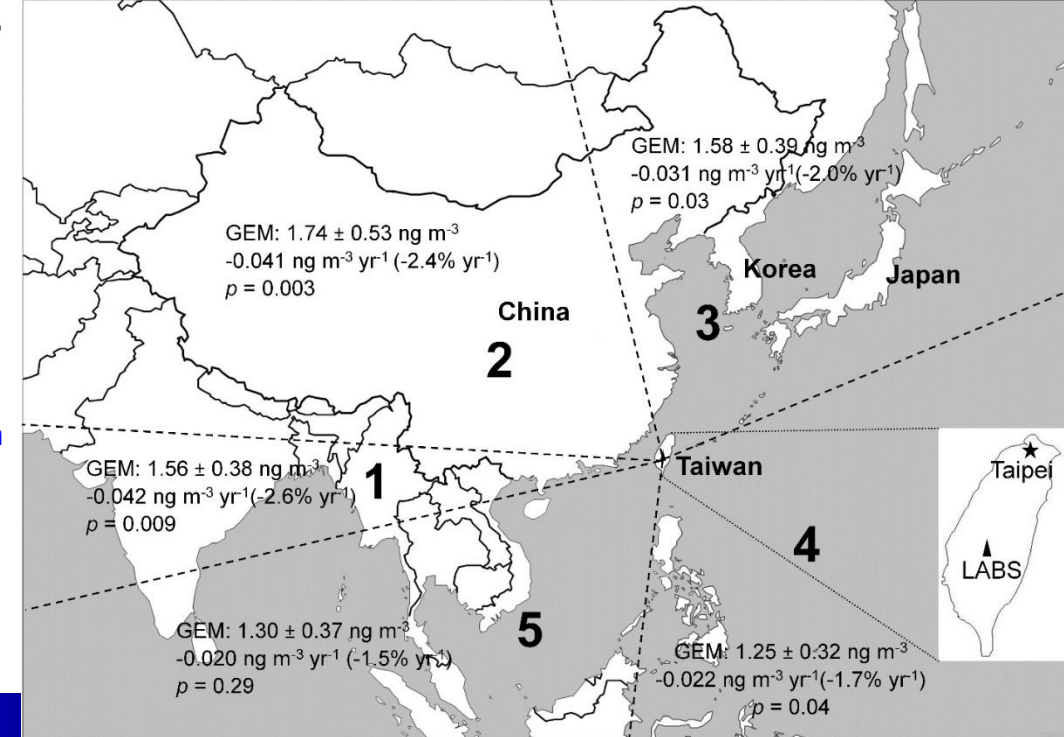
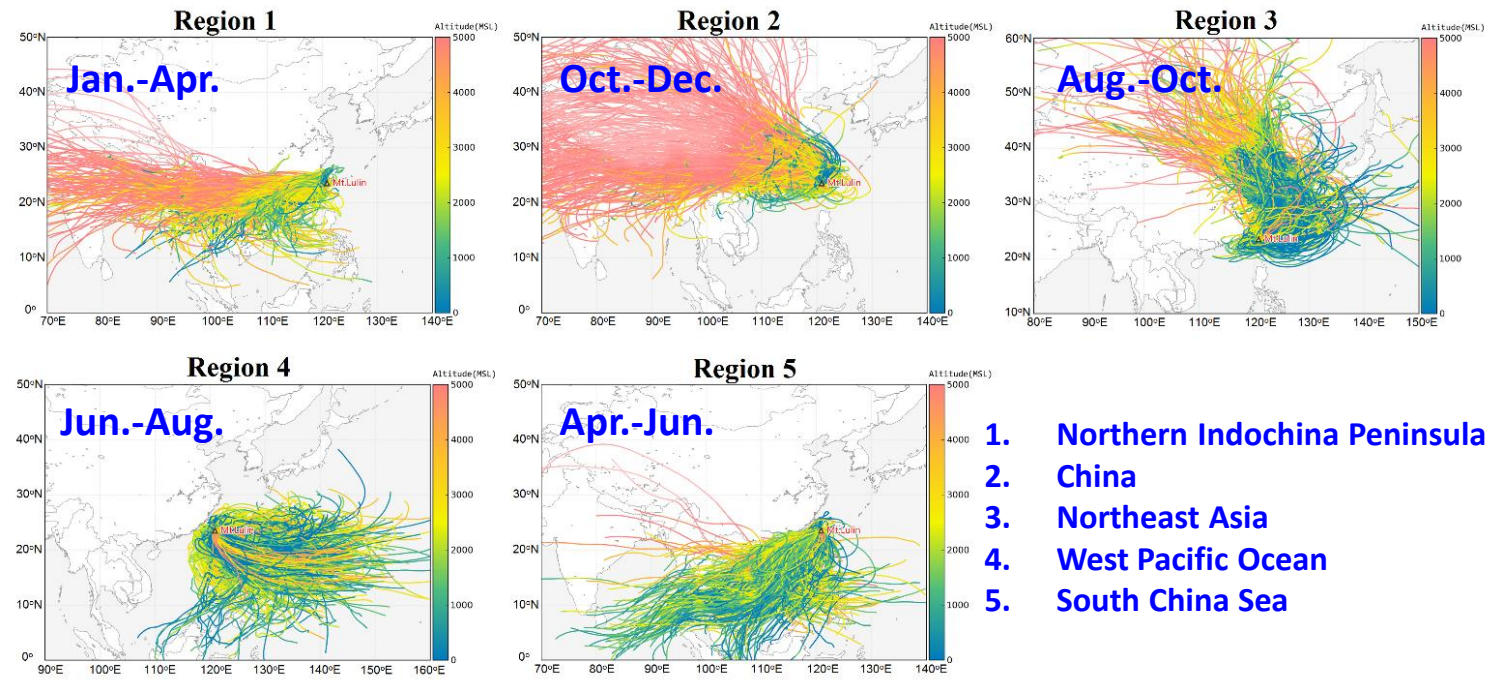
GEM Trend in 2006-2016



Location	Period	Trend ($\%\text{yr}^{-1}$)	References
Mt. Lulin (Taiwan)	2006 - 2016	- 1.5	Nguyen et al., 2019
Cape Hedo (Japan)	2007 - 2018	-2.1	Marumoto et al., 2019
Chongming Island (China)	2014-2016	-29.4	Tang et al., 2018
Cape Point (South Africa)	1996 - 2009	-2.5	Slemr et al., 2011
Mace Head (Ireland)	1996 - 2013	-1.3	Weigelt et al., 2015
EMEP (Europe)	1990 - 2011	-2.1	Zhang et al., 2016
11 sites in Canada	1995 - 2011	-0.9 to -3.3	Cole et al., 2014
NADP (USA)	1997 - 2007	-1.5	Weiss-Penzias et al., 2016
Cape Verde	2011 - 2015	-4.2	Read et al., 2017

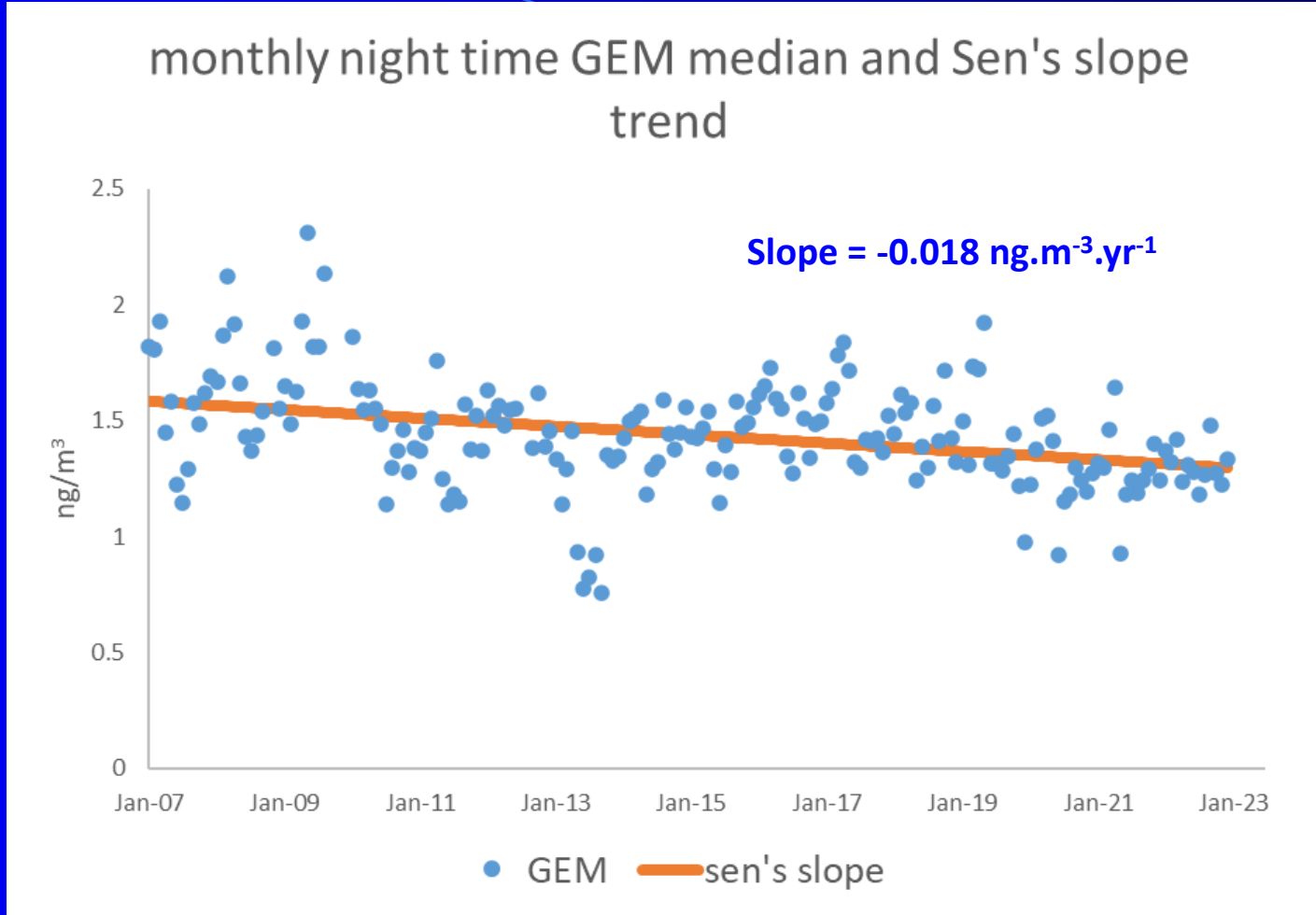
- Before the Minamata Convention entered into force in Aug. 2017
- Decreasing rate = $-0.022 \text{ ng.m}^{-3}.\text{yr}^{-1}$ or $-1.5\%.\text{yr}^{-1}$ ($p < 0.01$)

GEM Trend in Each Source Region in 2006-2016



- GEM concentrations decreased with air masses from every source region.

GEM Trend in 2007-2022



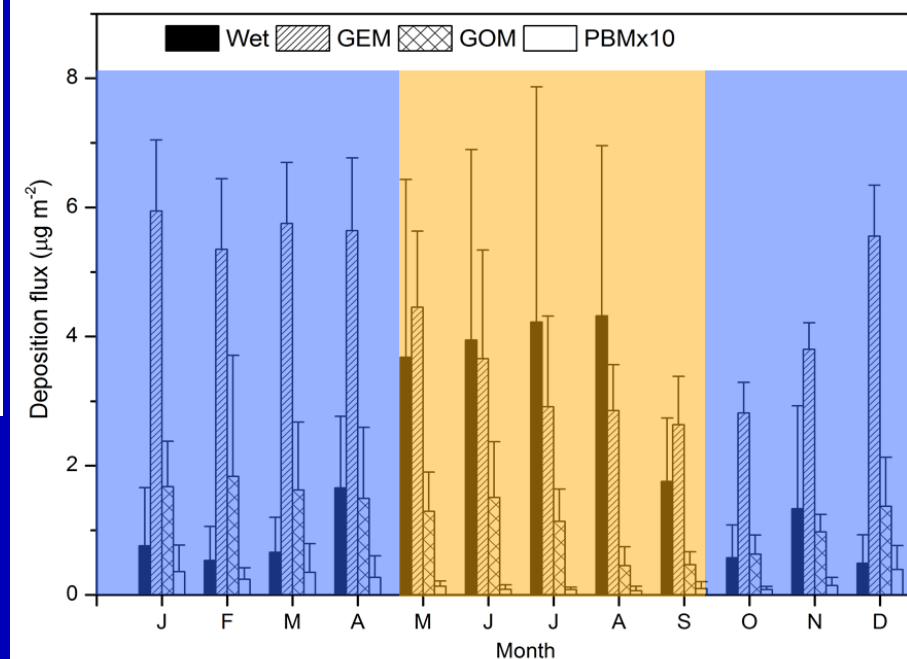
- Decreasing rate = $-0.018 \text{ ng.m}^{-3}.\text{yr}^{-1}$ or $-1.1\%.\text{yr}^{-1}$ in 2007-2022

Annual Deposition Fluxes in 2009-2016

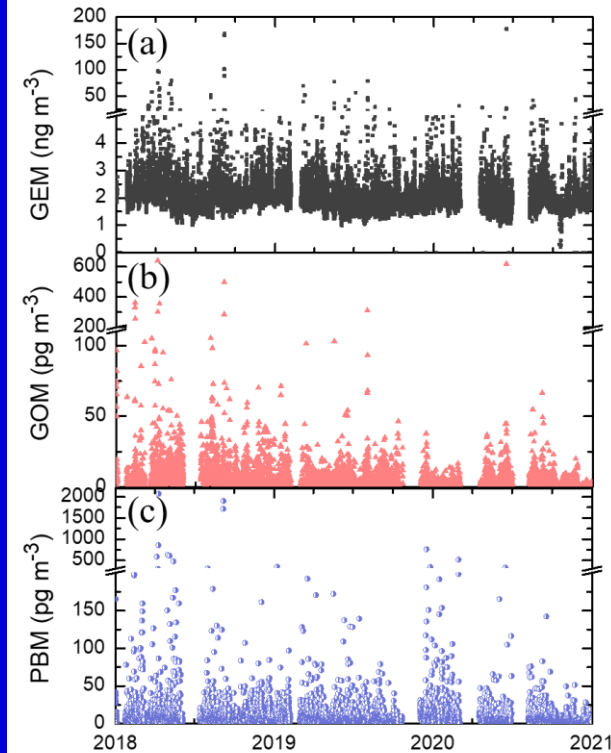
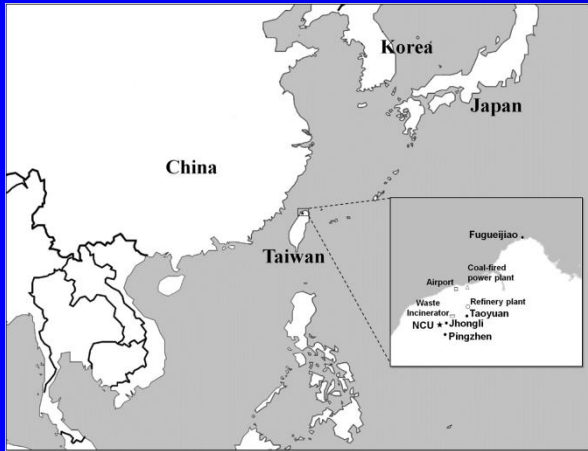
- Annual total (dry + wet) deposition ranged from 73.0 to 128.4 $\mu\text{g m}^{-2}$ with a multi-year average of 93.7 $\mu\text{g m}^{-2}$.
- Dry and wet deposition contributed about 70% and 30%, respectively.
- GEM deposition contributed 78% of the total dry deposition.
- Higher wet deposition in warm months.
- Higher dry deposition in cold months.

Table 1. Summary of estimated annual dry deposition ($\mu\text{g m}^{-2} \text{ yr}^{-1}$), volume weighted mean (VWM) rainwater Hg concentrations (ng L^{-1}), annual wet deposition ($\mu\text{g m}^{-2} \text{ yr}^{-1}$), and rainfall amount at LABS between 2009 and 2016.

	2009	2010	2011	2012	2013	2014	2015	2016
GOM + PBM	23.0	13.0	15.0	15.2	11.8	8.4	14.1	16.9
Net GEM	61.9	55.9	49.4	53.7	40.1	48.7	48.0	53.4
Total dry	84.9	68.9	64.4	68.8	51.9	57.1	62.1	70.3
VWM Hg conc.	8.7	9.6	7.7	13.1	7.0	6.6	5.0	6.5
Wet deposition	43.5	30.5	25.2	48.9	24.4	16.8	10.9	21.2
Total dry/wet	2.0	2.3	2.6	1.4	2.1	3.4	5.7	3.3
Rainfall amount	4991	3173	3271	3736	3503	2541	2161	3229



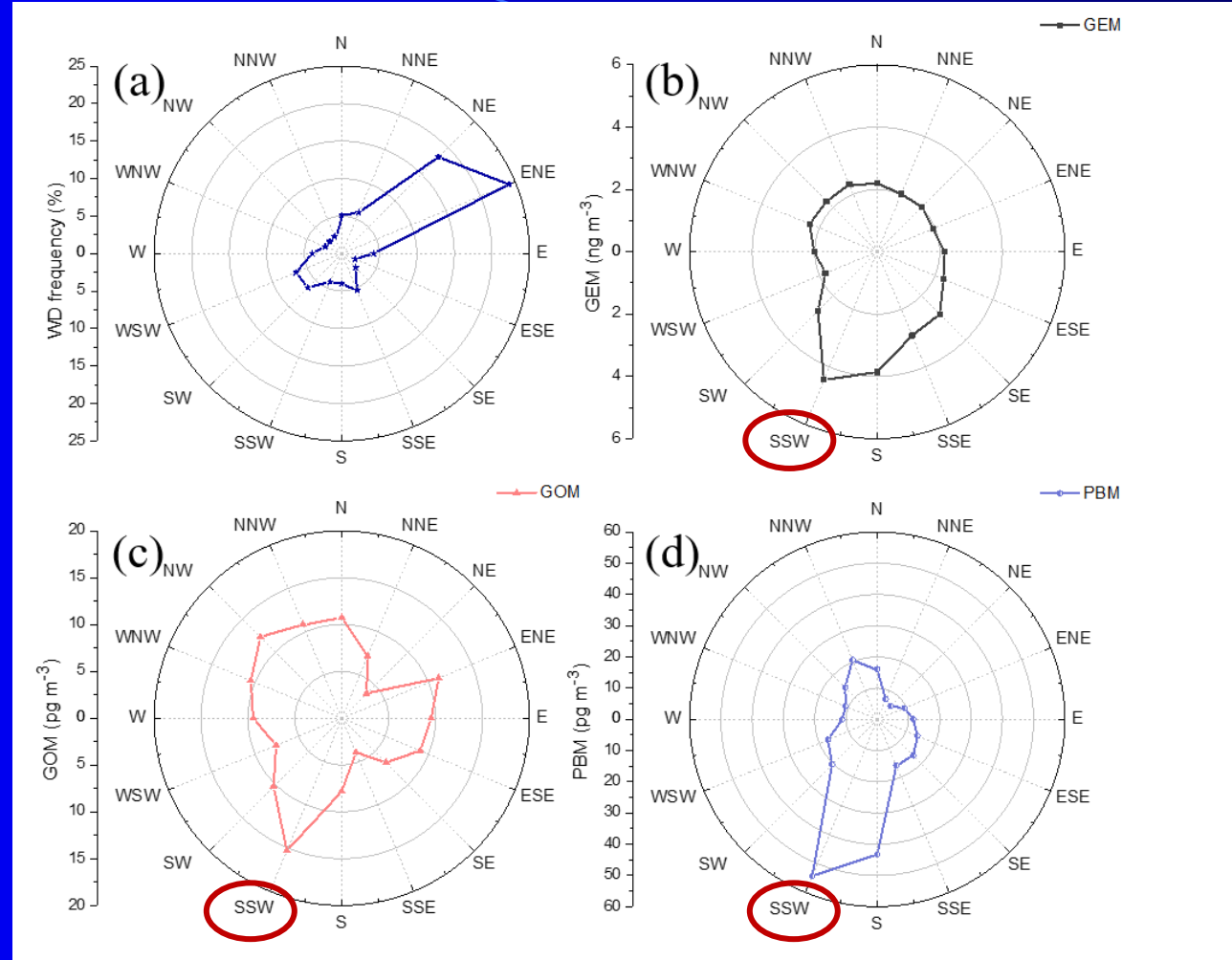
Atmospheric Hg Monitoring at NCU in 2018-2020



- Very high GEM, GOM and PBM values are observed sometimes, suggesting potential local emission sources.

	GEM (ng m ⁻³)	GOM (pg m ⁻³)	PBM (pg m ⁻³)
Mean ± S.D.	2.32 ± 4.60	7.1 ± 21.6	13.1 ± 51.4
Minimum	0.83	< MDL	< MDL
Median	1.97	1.5	5.7
Maximum	347.64	739.8	2073.7

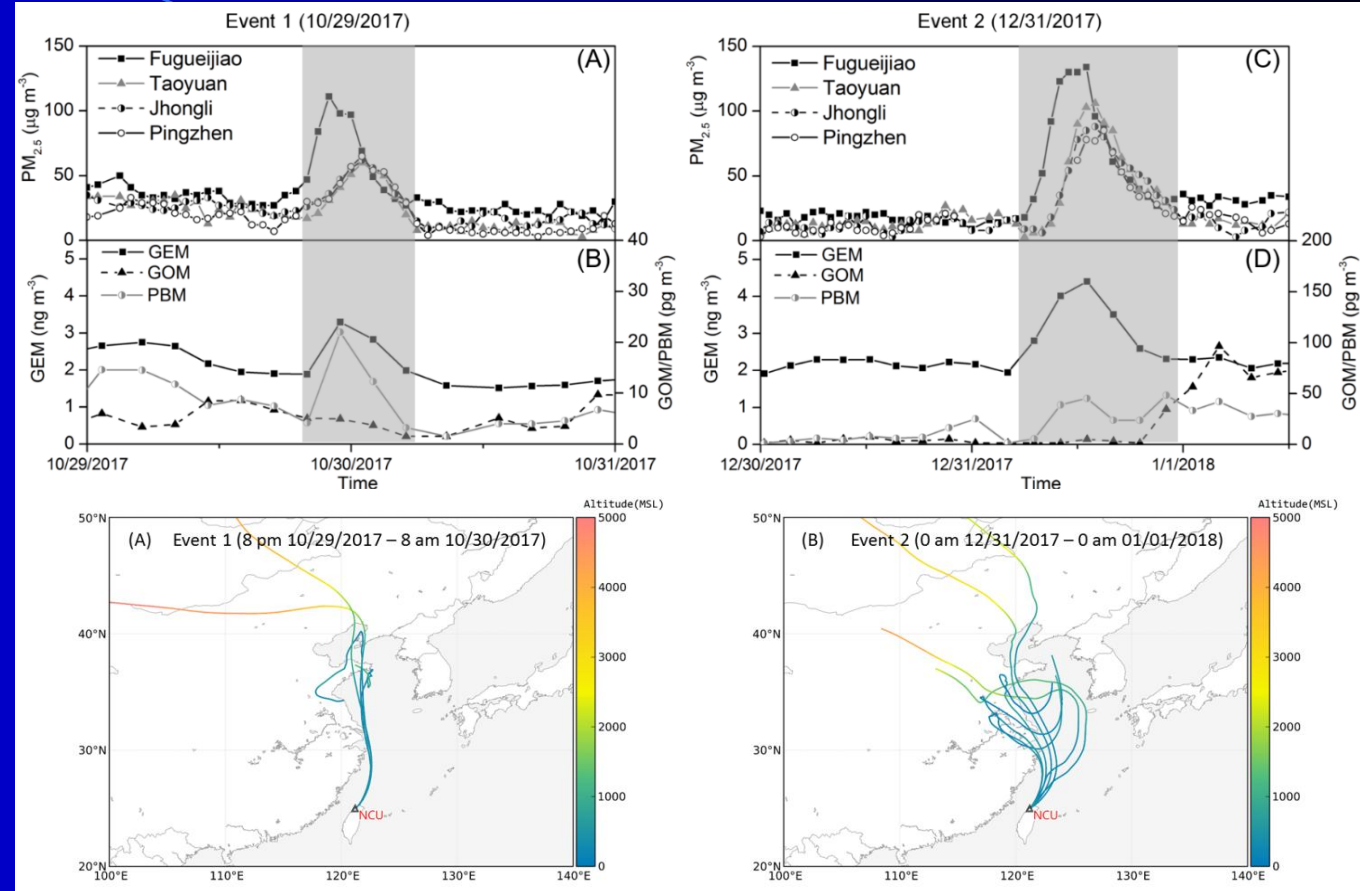
Atmospheric Hg Monitoring at NCU in 2018-2020



Unidentified but significant **local emission sources** located in the area between SSW and S of NCU.

Trans-Boundary Haze and Atmospheric Hg

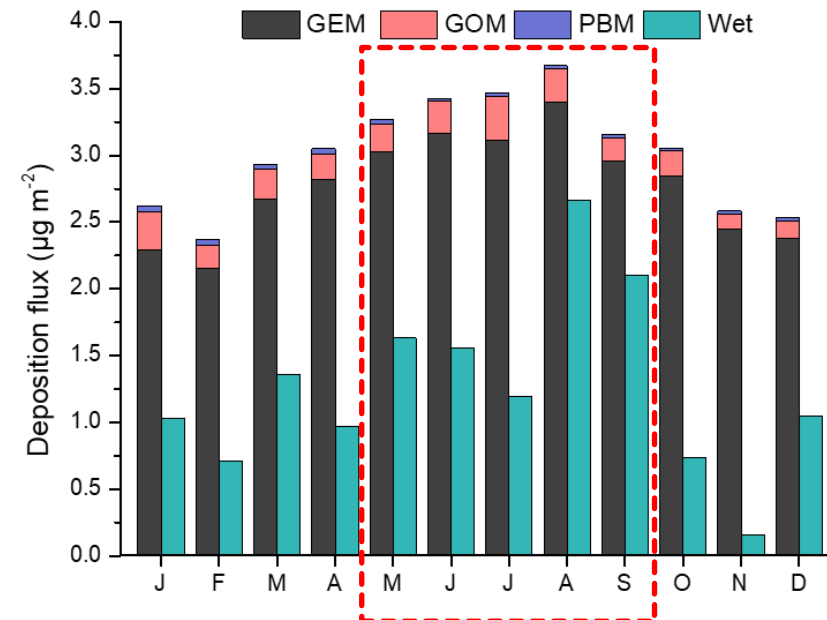
- Two trans-boundary haze events from China were encountered:
 - 2017/10/29
 - 2017/12/31
- Concentrations of GEM and PBM were enhanced on haze days, but GOM remained low.
- Yangtze River Delta and East China were the source regions for these haze events.



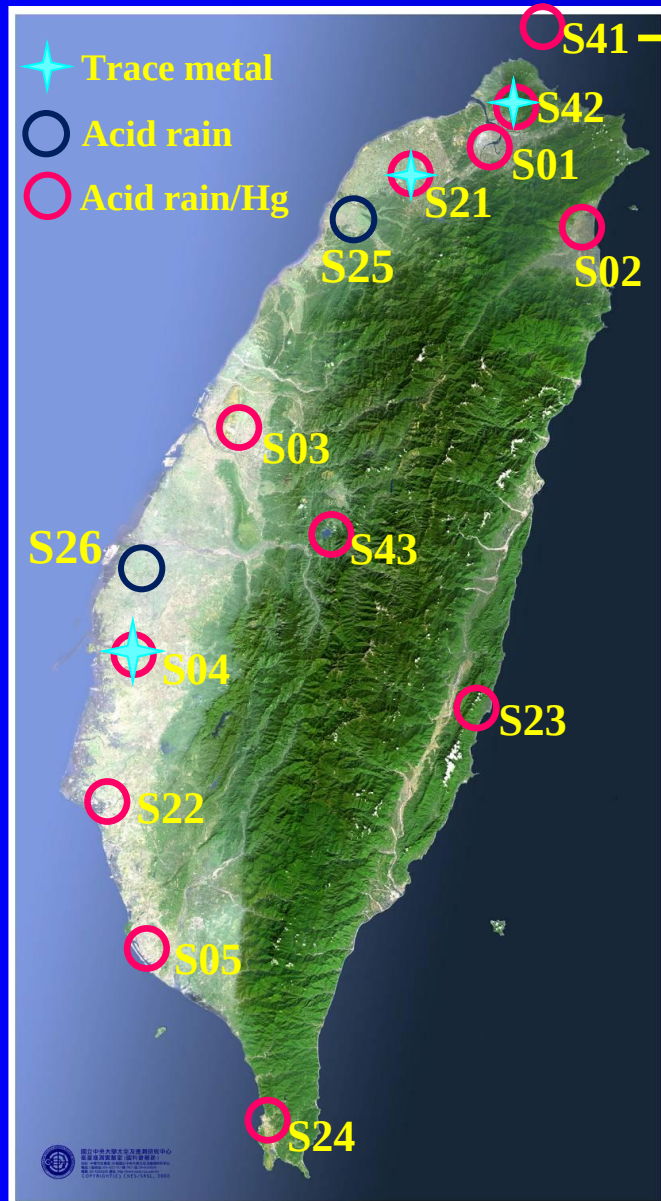
Mean Annual Deposition Fluxes in 2018-2020

- Mean annual total (dry + wet) deposition flux was **51.7 $\mu\text{g m}^{-2}$** .
- **Dry and wet** deposition contributed about **70% and 30%**, respectively.
- **GEM** deposition contributed **91.5%** of the total dry deposition.
- Higher dry and wet deposition in warm months.

GEM	GOM	PBM	Dry	Wet	Total	Dry/Wet
33.4	2.7	0.4	36.5	15.2	51.7	2.4



Wet Deposition Monitoring Networks of Acid Rain, Mercury and Trace Metals



- 14 sites for acid rain
- 12 sites for Hg in 2008-2022;
6 sites since 2023
- 3 sites for trace metals (2008-2018)



Site No.	Site Name	Charateristics	Altitude (m a.s.l.)
S01	Taipei	Urban	28
S02	Yilan	Urban	10
S03	Taichung	Urban	214
S04	Chiayi	Urban/Agriculture	27
S05	Kaohsiung	Urban/Coastal	17
S21	Jhongli	Suburb/Industrial	131
S22	Tainan	Suburb	17
S23	Chenggong	Suburb/Coastal	34
S24	Hengchun	Suburb/Coastal	22
S41	Pengjiayu	Remote/Island	102
S42	Anbu	Rural/Mountain	826
S43	Sun Moon Lake	Rural/Mountain	1018

Sampler and Hg Analyzer

A



B



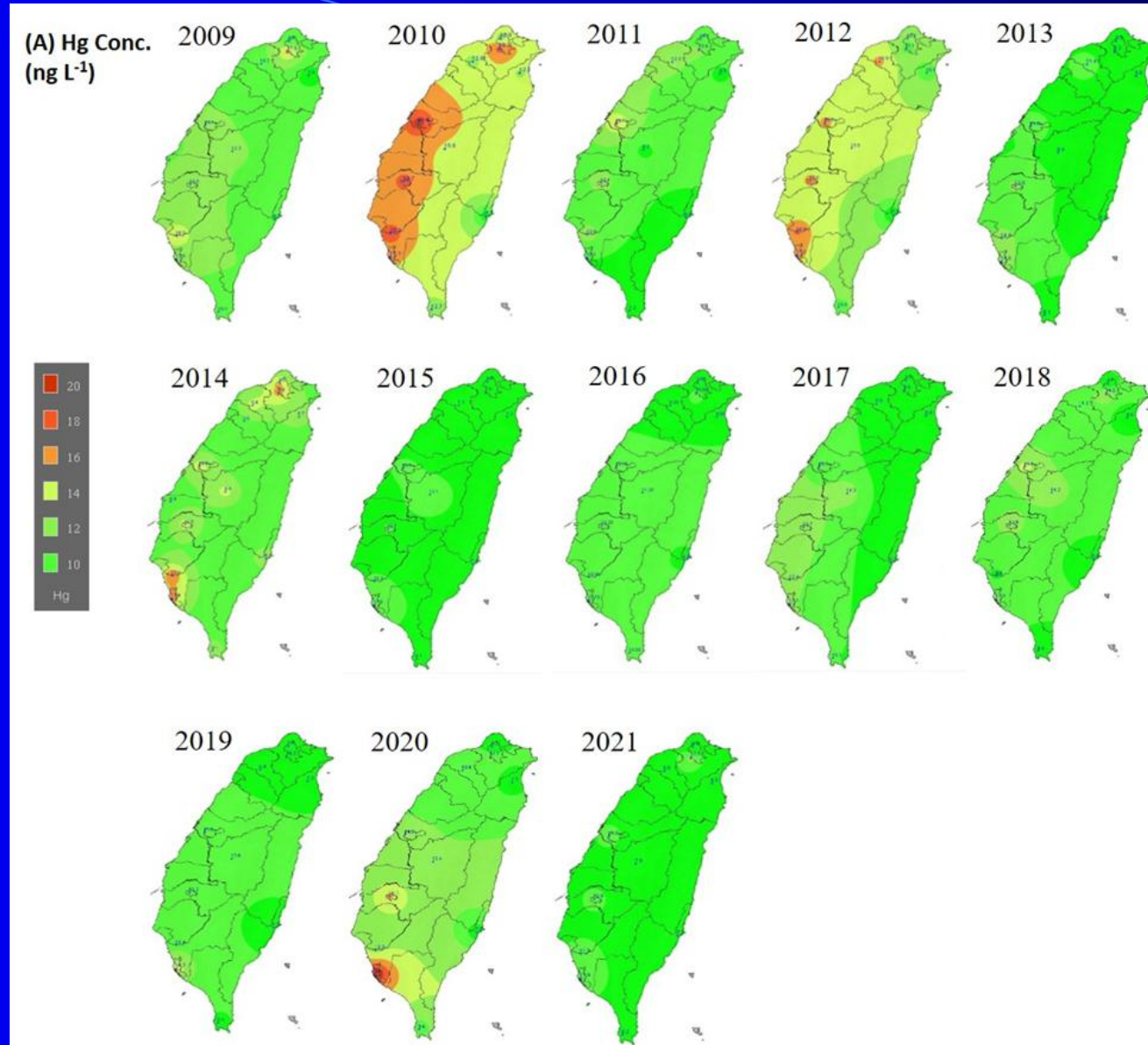
C



- Weekly samples were collected using MIC-B type automated wet-only precipitation collection systems.
- Acid-cleaned glass funnels and 1L Teflon bottles were used for the Hg collections.
- Sampling bottles and glassware were changed every Tuesday morning.
- Total Hg was quantified by dual amalgamation CVAFS after BrCl oxidation, $\text{NH}_2\text{OH} \cdot \text{HCl}$ neutralization, and SnCl_2 reduction (USEPA Method 1631, Revision E).
- Tekran 2600 Hg analyzers.

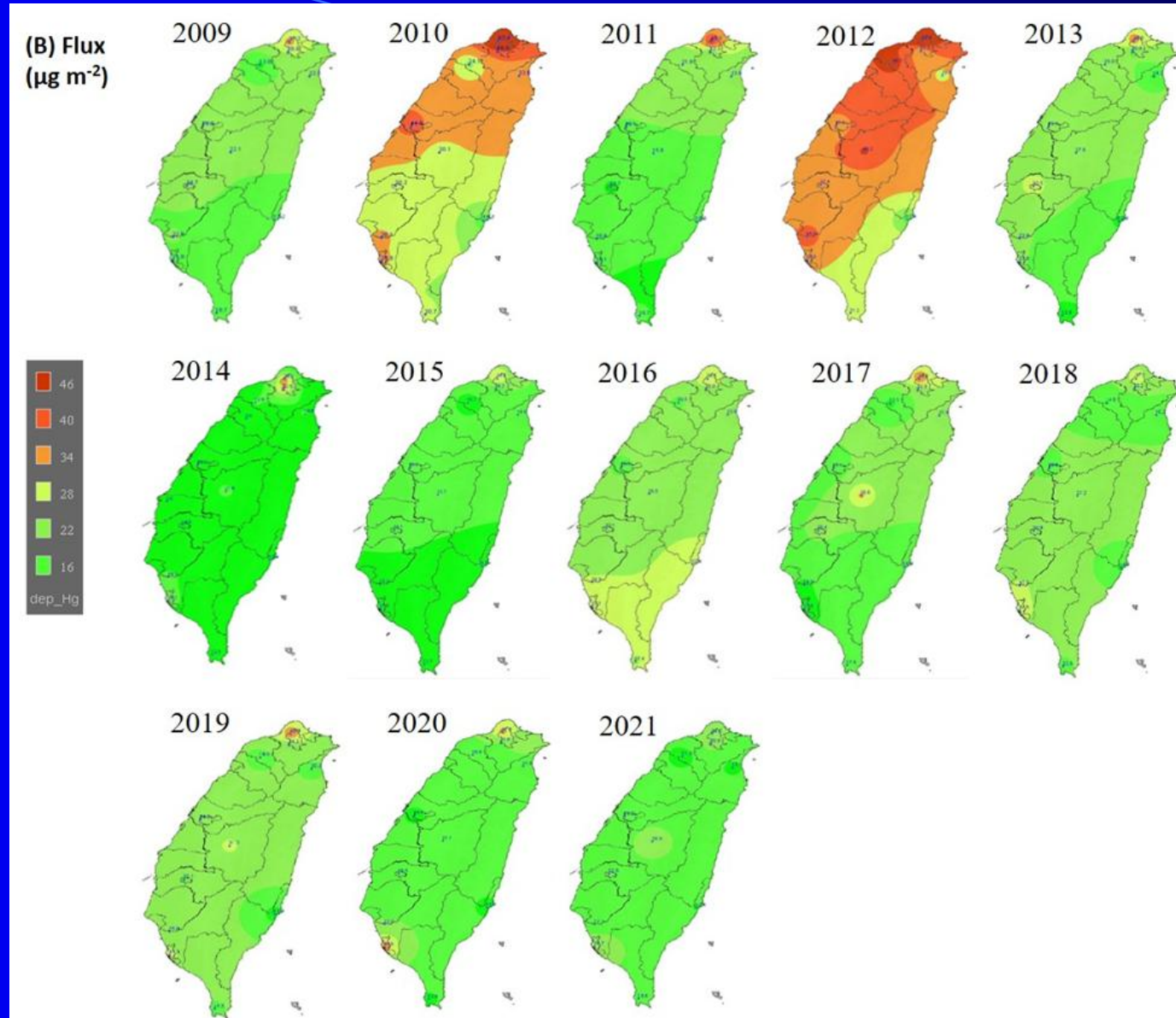


Rainwater Hg Concentrations in 2009-2021



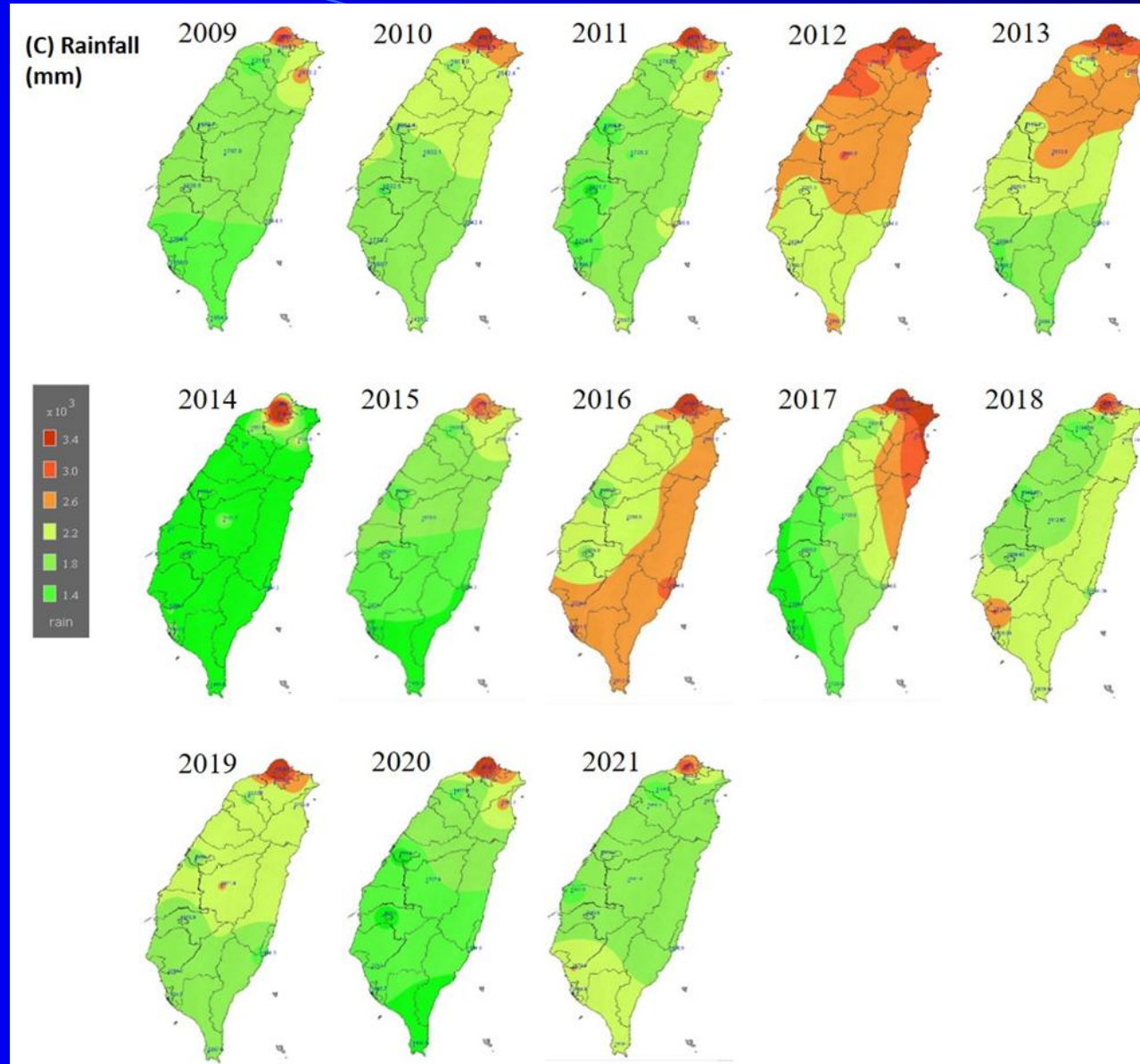
Higher rainwater Hg concentrations in western and southern Taiwan.

Wet Hg Deposition Fluxes in 2009-2021



Higher wet deposition flux of Hg in northern Taiwan.

Annual Rainfall in 2009-2021

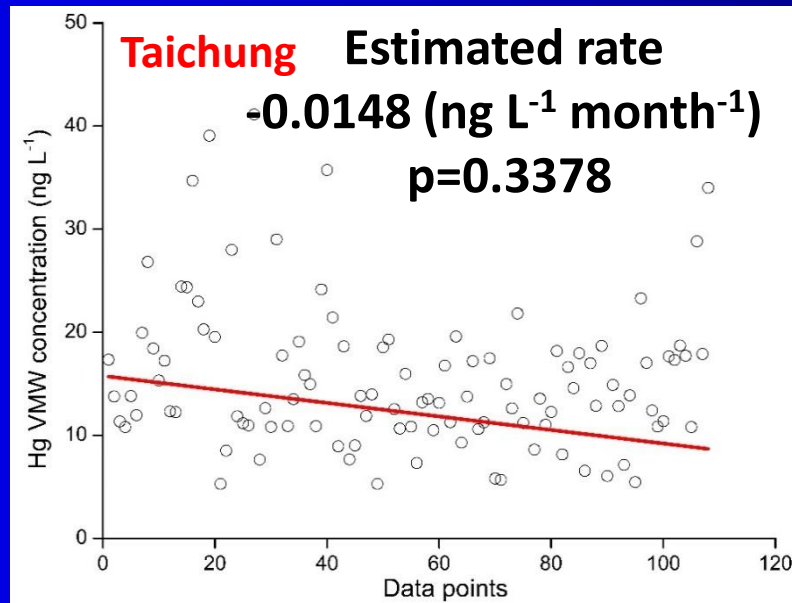
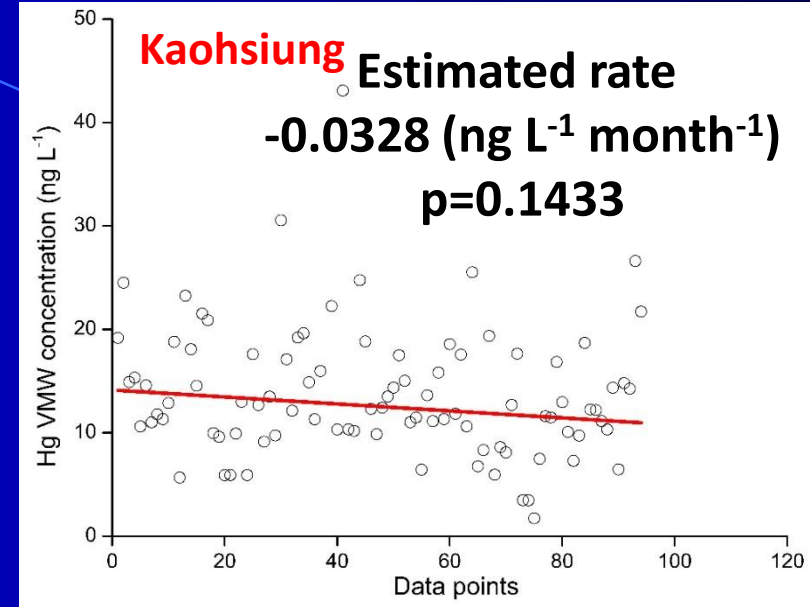
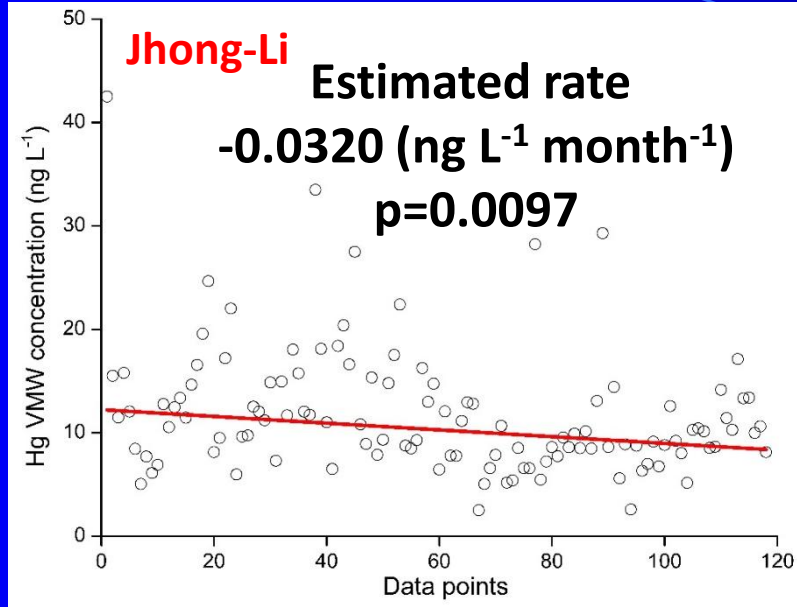


Higher rainfalls in northern Taiwan.

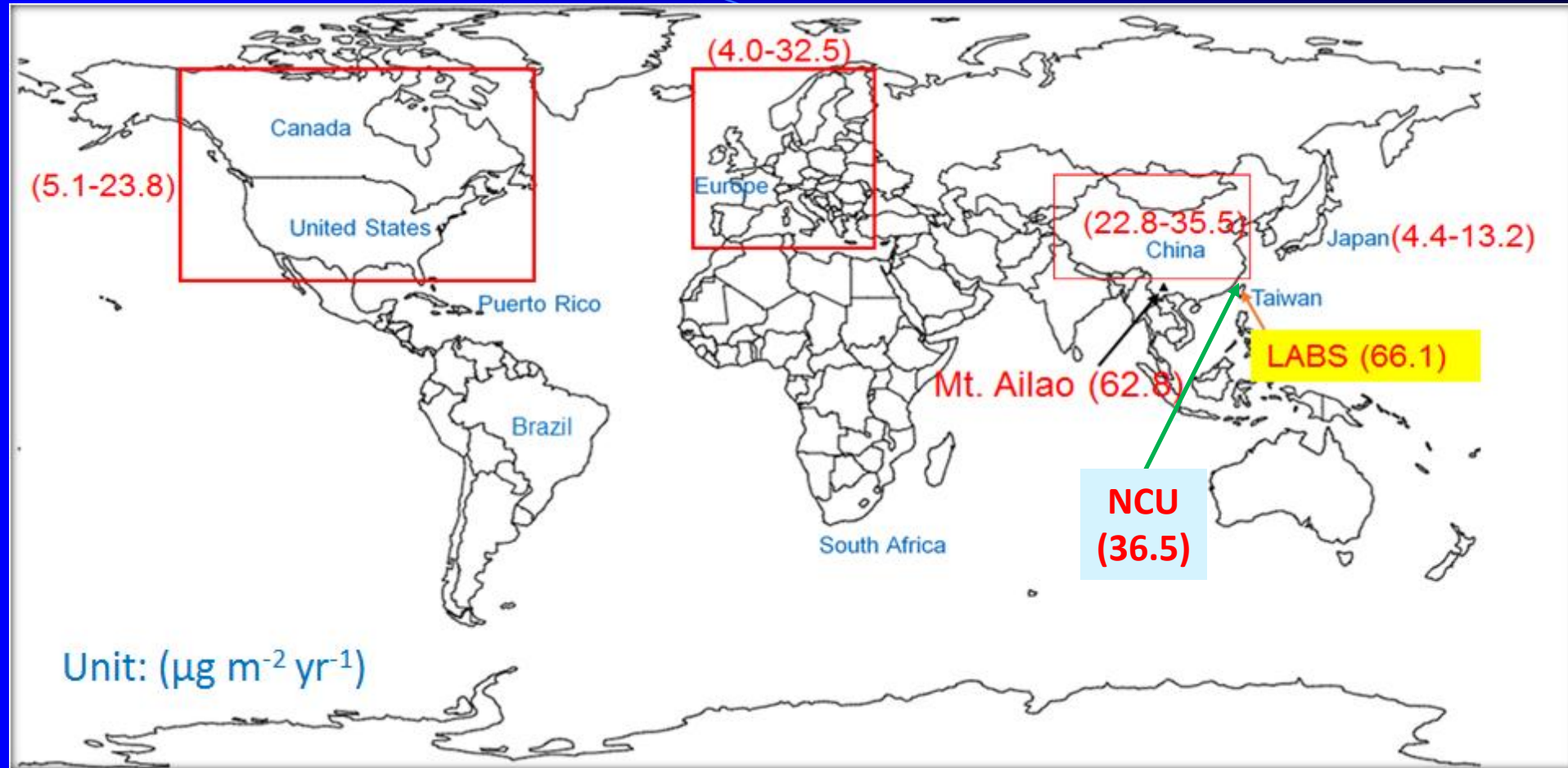
Comparison with NADP/MDN

Year	VWM conc. (ng L ⁻¹)		Wet deposition Flux (μg m ⁻² yr ⁻¹)	
	Taiwan	USA	Taiwan	USA
2021	6.5-13.5	3.2-16.7	11.3-29.7	2.8-16.7
2020	7.5-24.1	3.6-20.3	10.6-40.6	2.3-23.0
2019	7.3-16.2	3.7-16.6	11.2-40.9	3.0-28.1
2018	6.4-15.3	2.5-21.1	14.0-33.0	2.5-19.7
2017	6.6-14.3	2.1-21.4	13.1-39.4	3.7-21.3
2016	7.3-12.2	2.0-21.5	18.5-34.6	3.1-30.9
2015	7.0-12.1	3.8-15.3	8.9-34.5	2.6-19.8
2014	6.7-15.0	1.6-25.8	10.0-26.4	2.0-22.1
2013	5.6-14.0	2.7-31.8	11.7-38.0	2.7-22.1
2012	7.1-18.9	2.2-39.6	15.7-59.9	1.9-21.5
2011	6.8-16.7	1.5-26.1	11.0-49.3	2.4-20.2
2010	7.7-21.7	3.8-26.1	15.7-63.4	2.5-21.6
2009	7.6-17.2	1.7-34.1	12.6-37.2	1.2-22.9

Temporal Trends at Urban Sites in 2009-2018

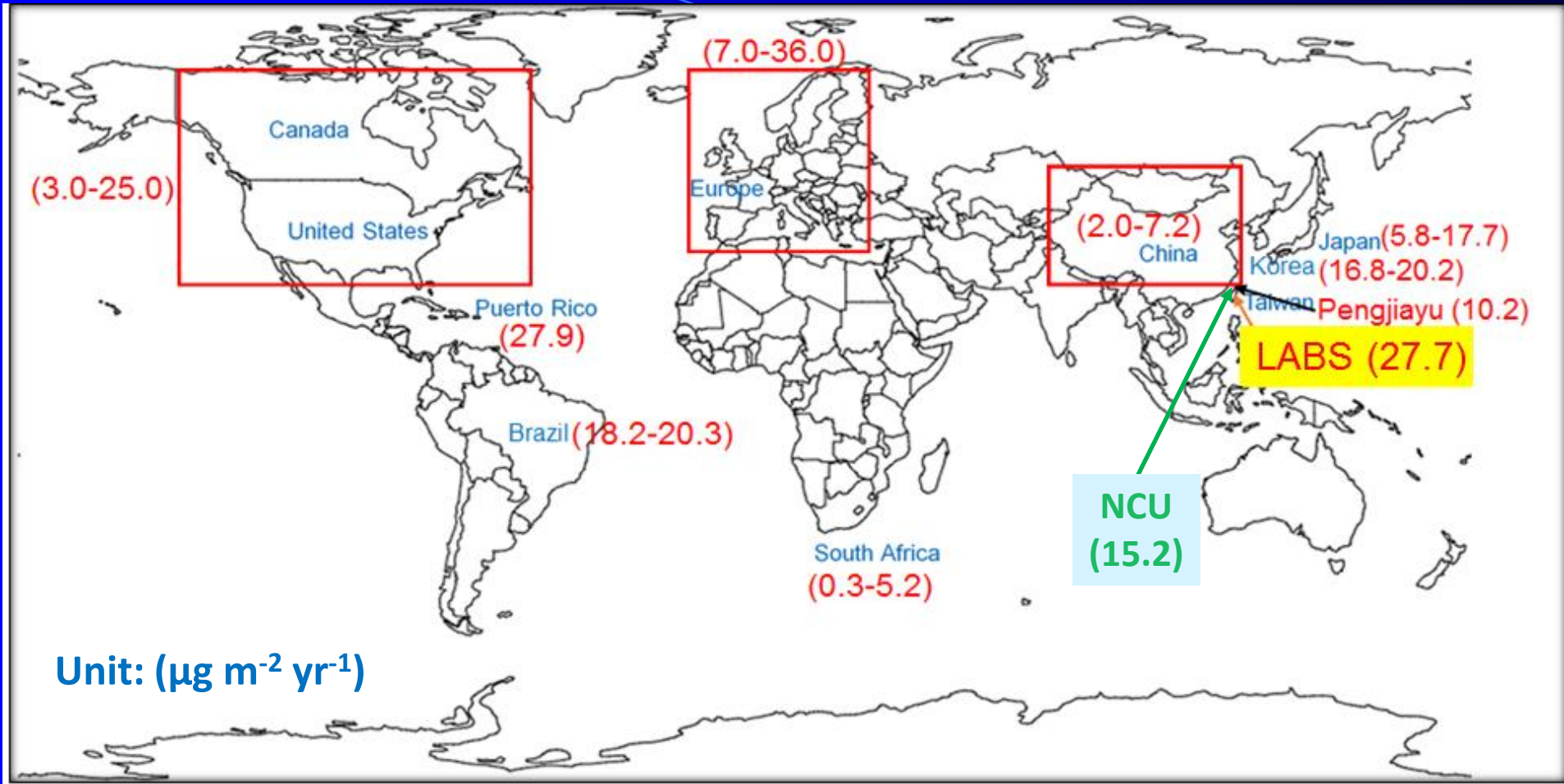


Spatial Distribution of Hg Dry Deposition



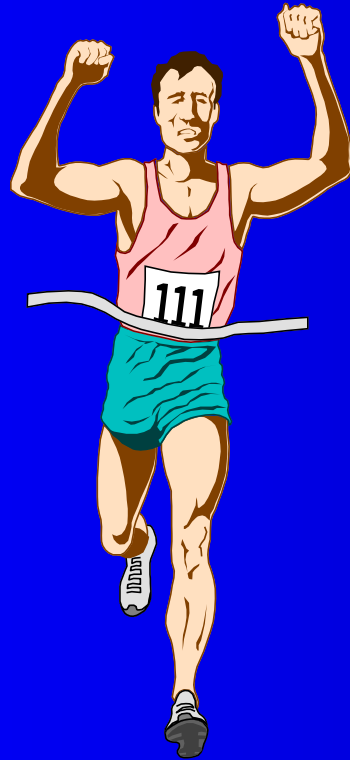
Dry Hg deposition to the mountain site in Taiwan is much higher than those of North America and Europe.

Spatial Distribution of Hg Wet Deposition



Wet Hg deposition to the mountain site in Taiwan is close to the higher-end values in North America and Europe.

**THANK
you!**



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