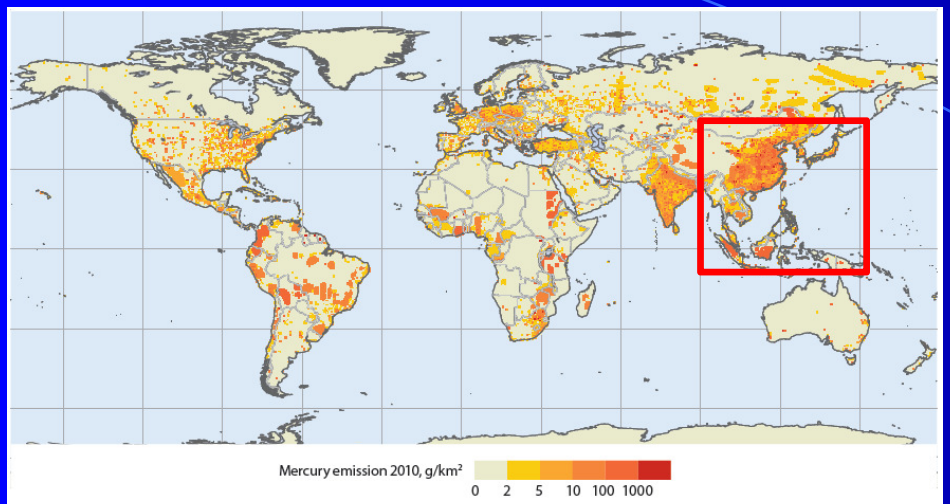
Overview of Mercury Measurements in East Asia and over the North Pacific Ocean

Guey-Rong Sheu

Department of Atmospheric Sciences
National Central University
Jhong-Li, Taiwan

Anthropogenic Hg Emissions in 2010

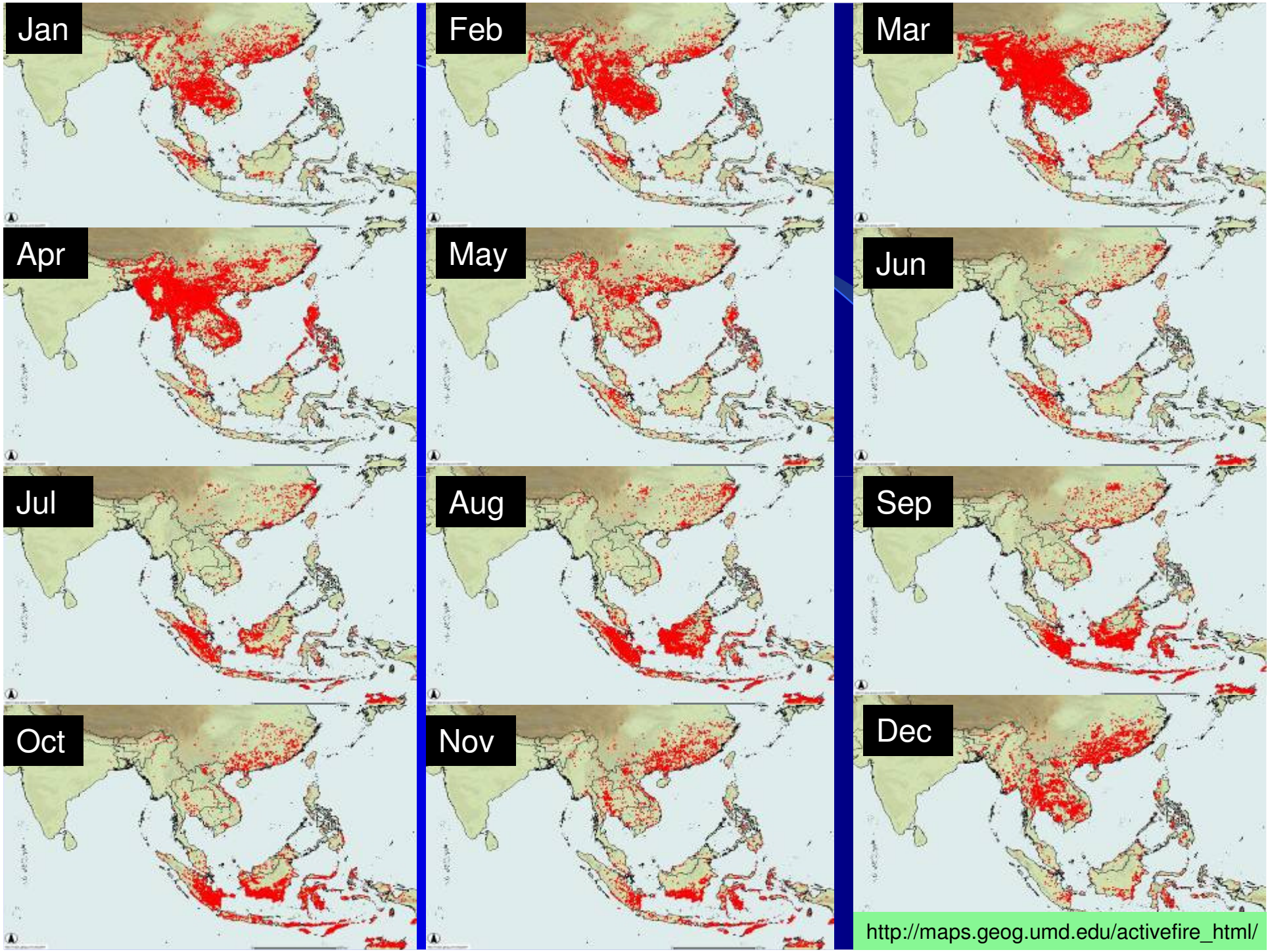


Global distribution of anthropogenic mercury emissions to air in 2010.

Region*	Emission (range), tonnes**	%
Australia, New Zealand & Oceania	22.3 (5.4 - 52.7)	1.1
Central America and the Caribbean	47.2 (19.7 - 97.4)	2.4
CIS & other European countries	115 (42.6 - 289)	5.9
East and Southeast Asia	777 (395 - 1690)	39.7
European Union (EU27)	87.5 (44.5 - 226)	4.5
Middle Eastern States	37.0 (16.1 - 106)	1.9
North Africa	13.6 (4.8 - 41.2)	0.7
North America	60.7 (34.3 - 139)	3.1
South America	245 (128 - 465)	12.5
South Asia	154 (78.2 - 358)	7.9
Sub-Saharan Africa	316 (168 - 514)	16.1
Undefined (global total for emissions from contaminated sites)	82.5 (70.0 - 95.0)	4.2
Grand Total	**1960 (1010 – 4070)**	**100**

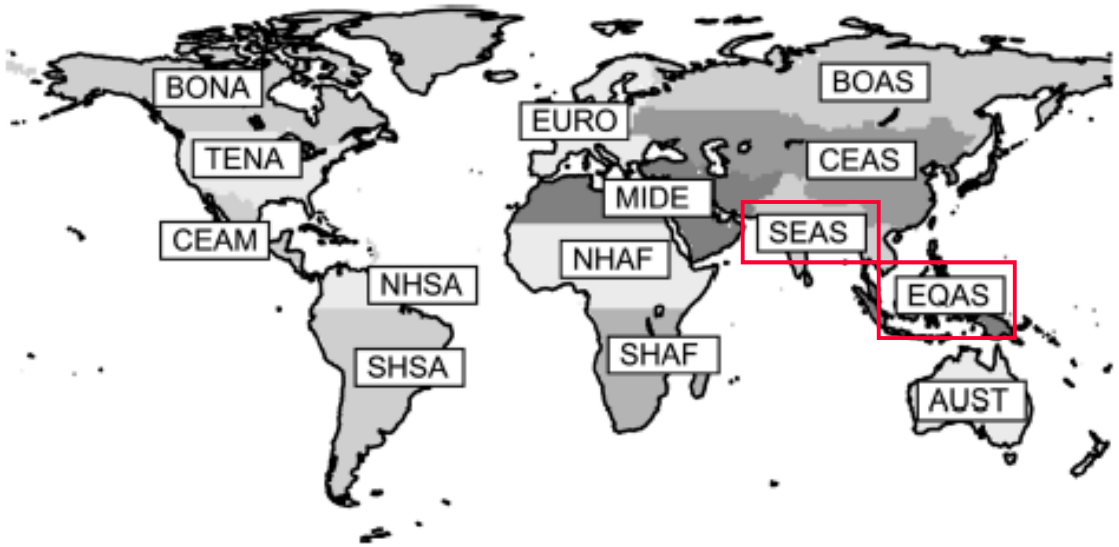
Country	Emission (tonnes)
Cambodia	3.9
China	575.2
Indonesia	78.2
Japan	17.2
Korea	7.1
Laos	1.3
Malaysia	6.1
Mongolia	6.9
Philippines	33.1
Singapore	0.9
Taiwan	5.5
Thailand	14.9
Vietnam	11.6

(UNEP, 2013)


Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
http://maps.geog.umd.edu/activefire_html/

Biomass Burning Hg Emissions in 2005



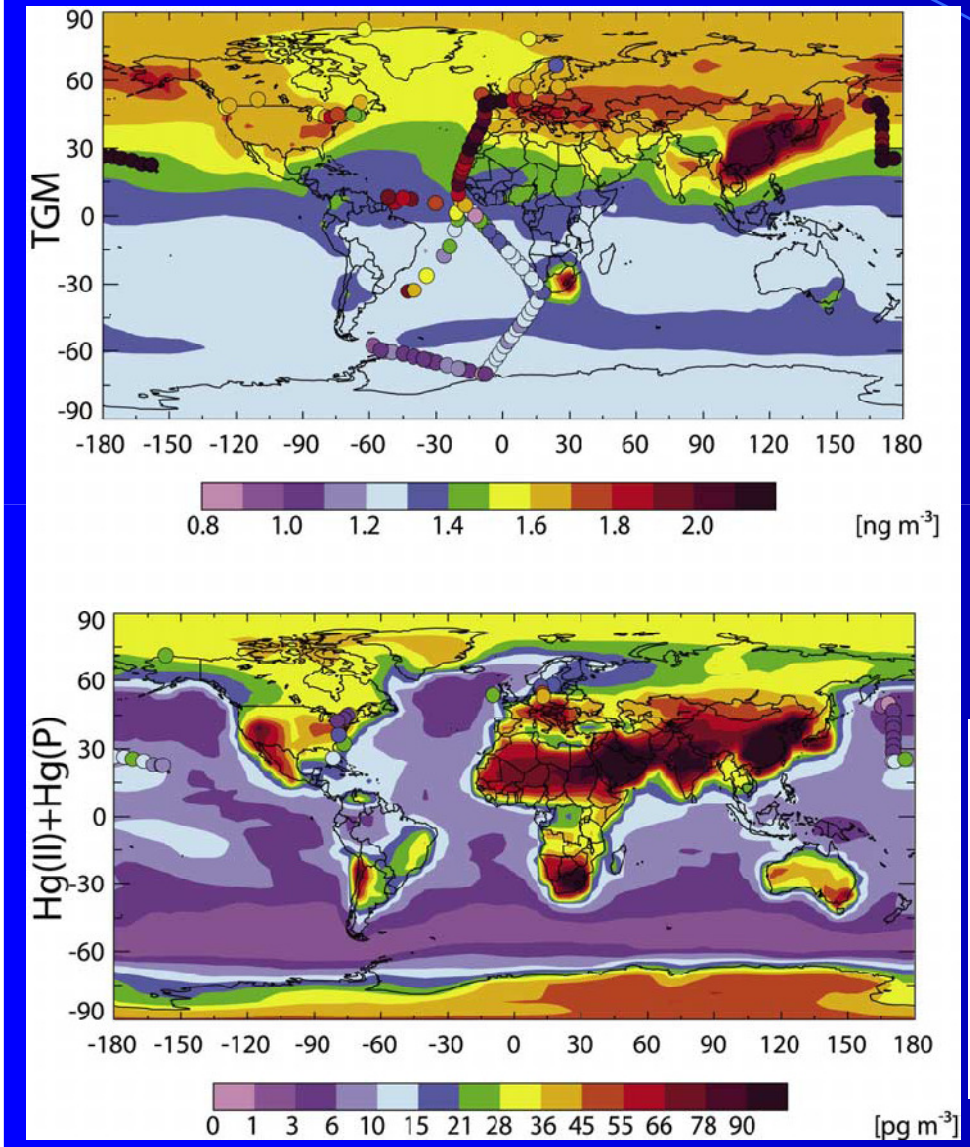


regions	Hg emissions Mg Hg/year mean	SD[a]
BONA	22	16
TENA	6	3
CEAM	22	25
NHSA	13	10
SHSA	95	39
EURO	2	1
MIDE	0	0
NHAF	83	13
SHAF	58	7
BOAS	99	83
CEAS	7	2
SEAS	57	35
EQAS	192	216
AUST	19	9
global	675	240
boreal[b]	121	85
temperate[c]	9	3
ROW[d]	545	224

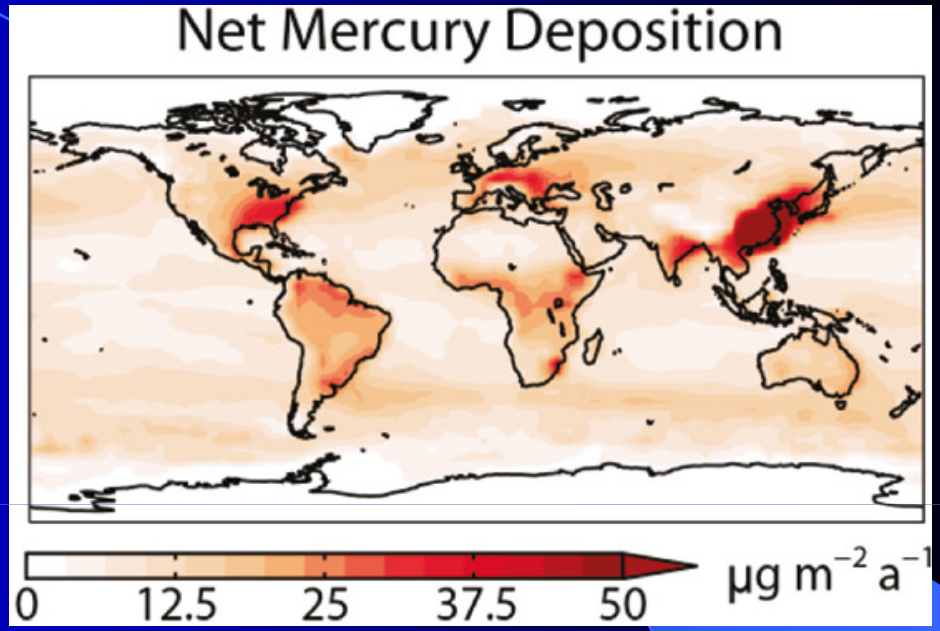
SEAS + EQAS = 249 Mg Hg/year

Friedli et al., 2009

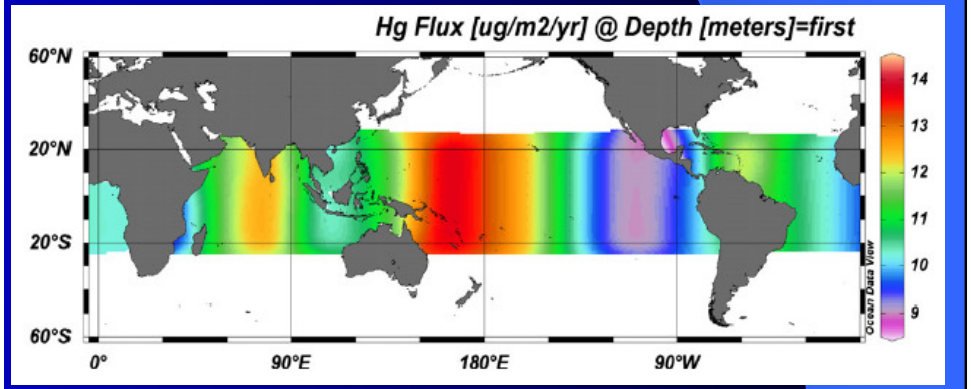
Distribution of Atmospheric Hg Concentrations and Deposition Fluxes: Modeling Results



Selin et al., 2007



Corbitt et al., 2011



Costa et al., 2012

Atmospheric Environment 78 (2013) 174–183

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Distribution of atmospheric mercury in northern Southeast Asia and South China Sea during Dongsha Experiment

Guey-Rong Sheu [a,*], Neng-Huei Lin [a], Chung-Te Lee [b], Jia-Lin Wang [c], Ming-Tung Chuang [b], Sheng-Hsiang Wang [a], Kai Hsine Chi [d], Chang-Feng Ou-Yang [c]

[a] Department of Atmospheric Sciences, National Central University, Jhongli 320, Taiwan
[b] Graduate Institute of Environmental Engineering, National Central University, Jhongli 320, Taiwan
[c] Department of Chemistry, National Central University, Jhongli 320, Taiwan
[d] Institute of Environmental and Occupational Health Sciences, National Yang Ming University, Taipei 112, Taiwan

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D17, 4529, doi:10.1029/2003JD003625, 2003

Reactive gaseous mercury formation in the North Pacific Ocean's marine boundary layer: A potential role of halogen chemistry

Fabien J. G. Laurier, Robert P. Mason, and Lindsay Whalin
Chesapeake Biological Laboratory, University of Maryland, Solomons, Maryland, USA

Shungo Kato
Department of Applied Chemistry, Tokyo Metropolitan University, Tokyo, Japan

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D06303, doi:10.1029/2009JD012958, 2010

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Mercury in the marine boundary layer and seawater of the South China Sea: Concentrations, sea/air flux, and implication for land outflow

Xuewu Fu,[1] Xinbin Feng,[1] Gan Zhang,[2] Weihai Xu,[3,4] Xiangdong Li,[4] Hen Yao,[1,5] Peng Liang,[1,5] Jun Li,[2] Jonas Sommar,[1] Runsheng Yin,[1,5] and Na Liu[1,5]

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 109, D19S25, doi:10.1029/2003JD004244, 2004

Mercury in the atmosphere around Japan, Korea, and China as observed during the 2001 ACE-Asia field campaign: Measurements, distributions, sources, and implications

Hans R. Friedli, Lawrence F. Radke, and Ryan Prescott
National Center for Atmospheric Research, Boulder, Colorado, USA

Pan Li, Jung-Hun Woo, and Gregory R. Carmichael
Center for Global and Regional Environmental Research, University of Iowa, Iowa City, Iowa, USA

Science of the Total Environment 408 (2010) 1295–1307

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The influence of long-range transport on atmospheric mercury on Jeju Island, Korea

Hang Thi Nguyen [a], Min-Yong Kim [b], Ki-Hyun Kim [a,*]

[a] Dept. of Earth & Environmental Sciences, Sejong University, Seoul, 143-747, Republic of Korea
[b] Seoul Metropolitan Institute of Public Health and Environment, Seoul, 137-734, Republic of Korea

Atmospheric Environment 44 (2010) 2393–2400

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Temporal distribution and potential sources of atmospheric mercury measured at a high-elevation background station in Taiwan

Guey-Rong Sheu [a], Neng-Huei Lin [a,*], Jia-Lin Wang [b], Chung-Te Lee [c], Chang-Feng Ou Yang [b], Sheng-Hsiang Wang [a]

[a] Department of Atmospheric Sciences, National Central University, Jhongli 320, Taiwan
[b] Department of Chemistry, National Central University, Jhongli 320, Taiwan
[c] Graduate Institute of Environmental Engineering, National Central University, Jhongli 320, Taiwan

Atmospheric Environment 77 (2013) 474–481

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Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Characterizations of wet mercury deposition to a remote islet (Pengjiayu) in the subtropical Northwest Pacific Ocean

Guey-Rong Sheu*, Neng-Huei Lin

Department of Atmospheric Sciences, National Central University, 300 Jhongda Road, Jhongli 320, Taiwan

Atmospheric Environment 45 (2011) 4454–4462

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Mercury in cloud water collected on Mt. Bamboo in northern Taiwan during the northeast monsoon season

Guey-Rong Sheu, Neng-Huei Lin*

Department of Atmospheric Sciences, National Central University, 300 Jhongda Road, Jhongli 320, Taiwan

Atmospheric Environment 43 (2009) 3267–3274

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Characteristics of atmospheric speciated mercury concentrations (TGM, Hg(II) and Hg(p)) in Seoul, Korea

Seung-Hee Kim [a], Young-Ji Han [b], Thomas M. Holsen [c], Seung-Muk Yi [a,*]

[a] Department of Environmental Health, School of Public Health, Seoul National University, Yeongon-dong, Chongro-gu, Seoul 110-799, Republic of Korea
[b] Department of Environmental Science, Kangwon National University, 192-1, Hyoja-2-dong, Chuncheon, Kangwondo, 200-701, Republic of Korea
[c] Department of Civil and Environmental Engineering, Box 5710, Clarkson University, Potsdam, NY 13699, United States

Water Air Soil Pollut
DOI 10.1007/s11270-007-9438-5

Monitoring of Atmospheric Mercury at a Global Atmospheric Watch (GAW) Site on An-Myun Island, Korea

Hang Thi Nguyen · Ki-Hyun Kim · Min-Young Kim · Sungmin Hong · Yong-Hoon Youn · Zang-Ho Shon · Jeong Soon Lee

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Atmospheric Environment 39 (2005) 3029–3038

ATMOSPHERIC ENVIRONMENT

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Export of atmospheric mercury from Asia

Daniel Jaffe [a,*], Eric Prestbo [b], Phil Swartzendruber [a], Peter Weiss-Penzias [a], Shungo Kato [c], Akinori Takami [d], Shiro Hatakeyama [d], Yoshizumi Kajii [c]

[a] Interdisciplinary Arts and Sciences, University of Washington-Bothell, Bothell, WA 98011 8246, USA
[b] Frontier Geosciences Inc. Seattle, WA, USA
[c] Applied Chemistry, Faculty of Engineering, Tokyo Metropolitan University, Tokyo, Japan
[d] Atmospheric Environmental Division, National Institute of Environmental Studies, Tsukuba, Japan

Atmospheric Environment 42 (2008) 7988–7996

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Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Reactive and particulate mercury in the Asian marine boundary layer

Duli Chand [a,b,*], Daniel Jaffe [a,b], Eric Prestbo [c], Philip C. Swartzendruber [a,b], William Hafner [a], Peter Weiss-Penzias [d], Shungo Kato [e], Akinori Takami [f], Shiro Hatakeyama [f], Yoshizumi Kajii [e]

[a] University of Washington-Bothell, 18115 Campus Way NE, Bothell, WA 98011, USA
[b] Department of Atmospheric Sciences, University of Washington, Seattle, WA, USA
[c] Frontier Geosciences, 414 Pontius Avenue N., Seattle, WA 98109, USA
[d] Department of Environmental Toxicology, University of California, 1156 High Street, Santa Cruz, CA 95060, USA
[e] Applied Chemistry, Faculty of Engineering, Tokyo Metropolitan University, Tokyo, Japan
[f] Atmospheric Environmental Division, National Institute of Environmental Studies, Tsukuba, Japan

The Science of the Total Environment 259 (2000) 231–237

the Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Man

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Background levels of atmospheric mercury in Kagoshima City, and influence of mercury emission from Sakurajima Volcano, Southern Kyushu, Japan

Takashi Tomiyasu*, Ayako Nagano, Hayao Sakamoto, Norinobu Yonehara

Department of Earth and Environmental Sciences, Faculty of Science, Kagoshima University, Kagoshima 890-0065, Japan

Environmental Pollution 157 (2009) 816–822

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Total gaseous concentrations in mercury in Seoul, Korea: Local sources compared to long-range transport from China and Japan

Eun-Mi Choi [a], Seung-Hee Kim [a], Thomas M. Holsen [c], Seung-Muk Yi [a,b,*]

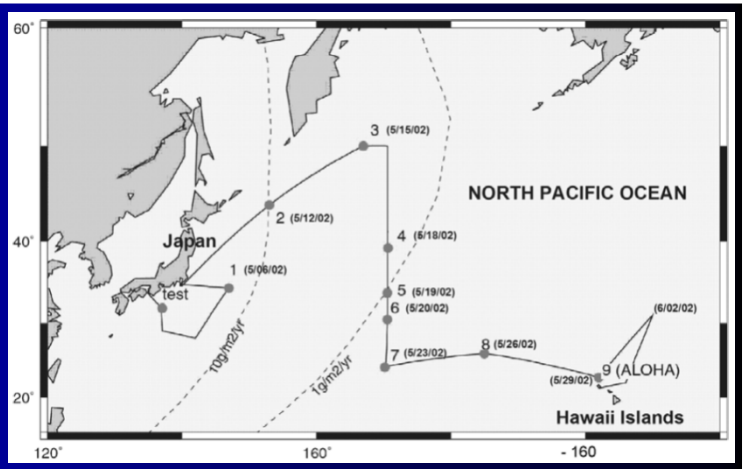
[a] Graduate School of Public Health, Department of Environmental Health, Seoul National University, Yeongon-dong, Chongro-gu, Seoul 110-799, Republic of Korea
[b] Institute of Health and Environment, Graduate School of Public Health, Seoul National University, Yeongon-dong, Chongro-gu, Seoul 110-799, Republic of Korea
[c] Department of Civil and Environmental Engineering, Clarkson University, Potsdam, NY 13699, USA

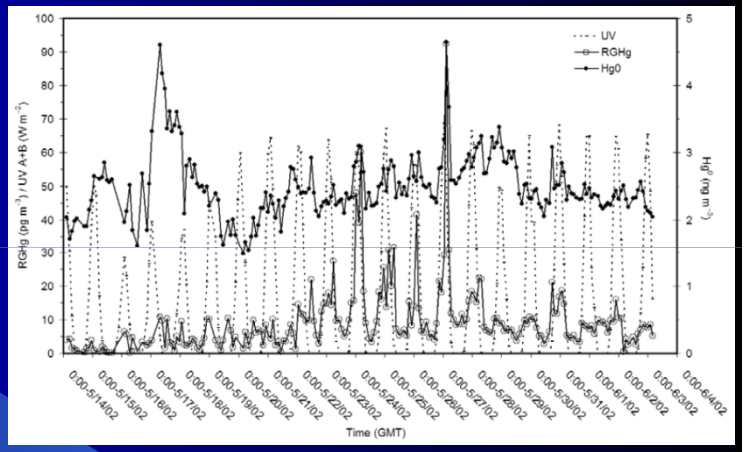
This study identified long-range transport from China and local sources of elevated TGM concentrations in Seoul, Korea using the relationship between ΔTGM and ΔCO.

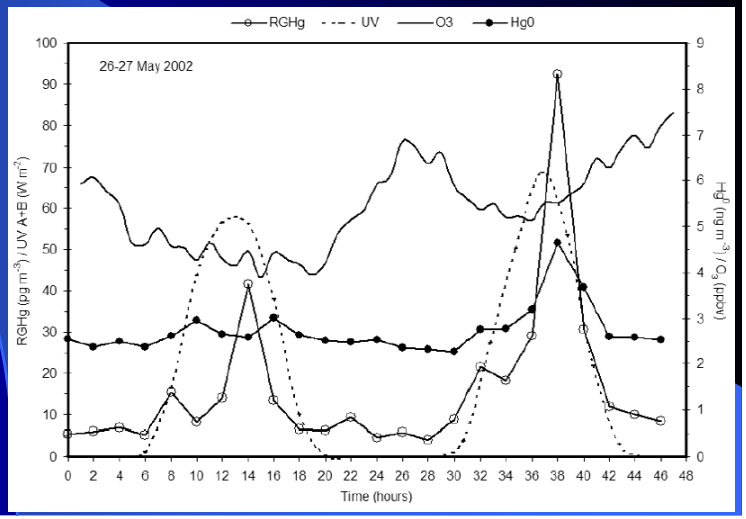
Mercury Speciation in the Marine Boundary over the North Pacific Ocean

(Laurier et al., 2003)

- GEM and RGM were measured using Tekran 2537A/1130 aboard a cruise from Osaka, Japan to Honolulu, Hawaii between May 1 and June 4, 2002.
- GEM ranged between 1.6 and 4.7 ng m^{-3} with an average of 2.5 ng m^{-3}.
- RGM ranged between 0.15 and 92.4 pg m^{-3} with an average of 9.5 pg m^{-3}.
- A distinct diurnal variation in RGM concentrations with maxima at midday suggests a photochemically driven oxidation of GEM in the marine boundary layer over the North Pacific Ocean.
- Enhanced RGM formation could be related to halogen chemistry.



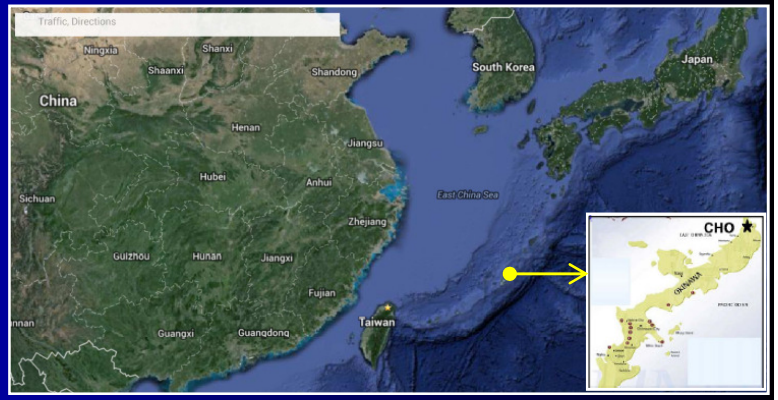




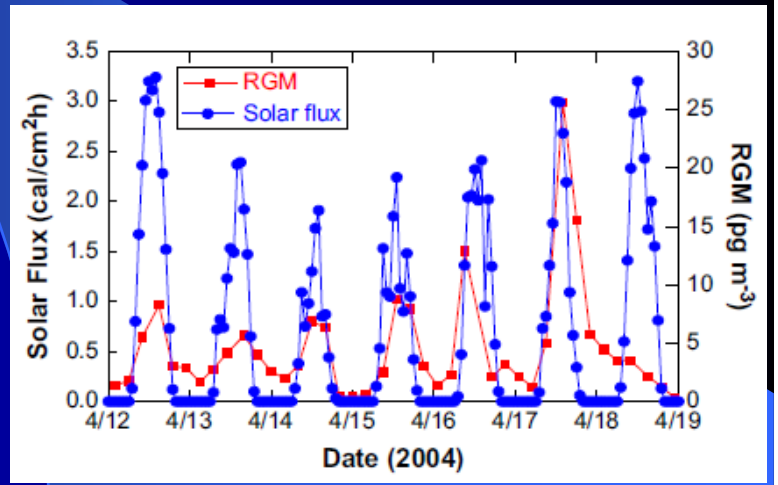
Mercury Speciation at Cape Hedo, Okinawa, Japan

(Chand et al., 2008)

- GEM, RGM and PHg were measured using Tekran 2537A/1130/1135 at the Cape Hedo Observatory between March 23 and May 2, 2004.
- Mean values of GEM, RGM and PHg were 2.04 ng m^{-3}, 4.5 pg m^{-3}, and 3.0 pg m^{-3}, respectively.
- In Asian outflow, most mercury export in the MBL is due to the GEM form, and direct outflow of RGM and PHg is low.
- RGM showed a diurnal cycle with a peak near local noon, suggesting photochemically driven oxidation of GEM.
- Air from China has a higher GEM concentration compared to the air coming from southern Japan.

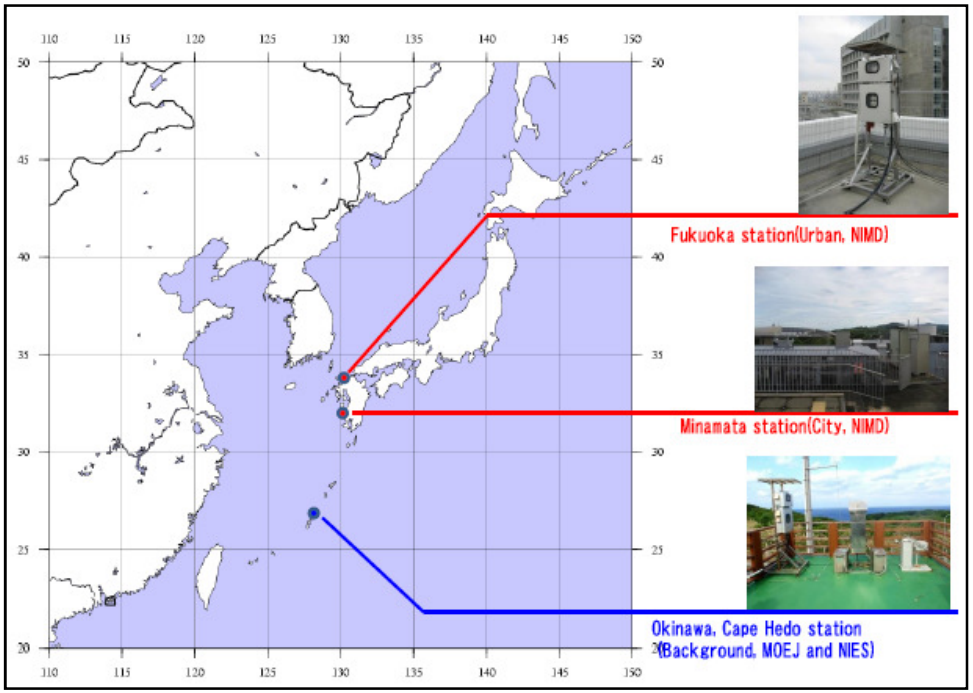


Event #	GEM vs CO Ψ1	R	PHg vs CO Ψ2	R	RGM vs CO Ψ3	R	% PHg export[a]	%RGM export[b]
Ev 1	0.0043	0.93	0.0067	0.14	0.0171	0.74	0.16	0.40
Ev 2	0.0056	0.99	0.0183	0.65	0.0011	0.10	0.33	0.02
Ev 3	0.0073	0.99	−0.0054	0.33	−0.0762	0.51	−0.07	−1.04
Ev 4	0.0051	0.88	0.0031	0.37	−0.0083	0.10	0.06	−0.16
Ev 5	0.0074	0.95	0.0436	0.77	0.0480	0.37	0.59	0.65
Ev 6	0.0036	0.96	0.0055	0.52	−0.0066	0.40	0.15	−0.18
Mean	0.0056	–	0.0120	–	−0.0042	–	0.20	−0.05
SD	0.0016	–	0.0173	–	0.0410	–	0.23	0.59
Min	0.0036	0.88	−0.0054	0.14	−0.0762	0.10	−0.07	−1.04
Max	0.0074	0.99	0.0436	0.77	0.0480	0.74	0.59	0.65



On-going Hg Monitoring Sites in Japan

Sites	Organizations	Hg speciation (GEM, GOM, PHg) In air	TGM	Hg in precipitation
Cape Hedo (Background)	MOEJ and NIES	Continuous (by Tekran)		Wet-only Weekly
Minamata (City)	NIMD	Manual sampling 1 week a month	Continuous	Wet-only Weekly
Fukuoka (Urban)	NIMD	Continuous (by Tekran)		Wet-only Weekly Since, Jun. 2013

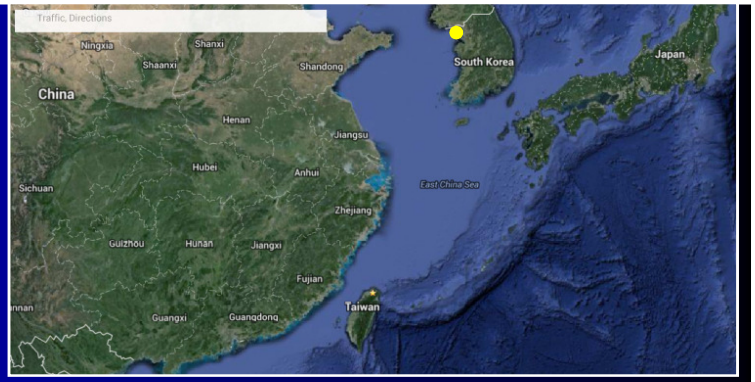


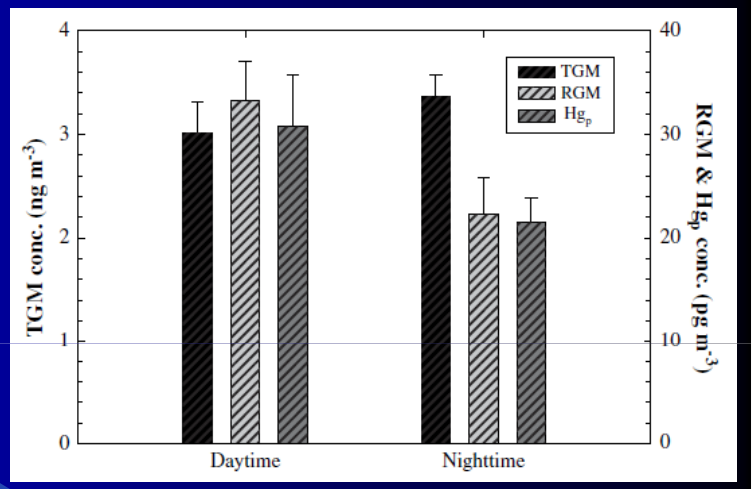
(Courtesy of Dr. Kohji Marumoto)

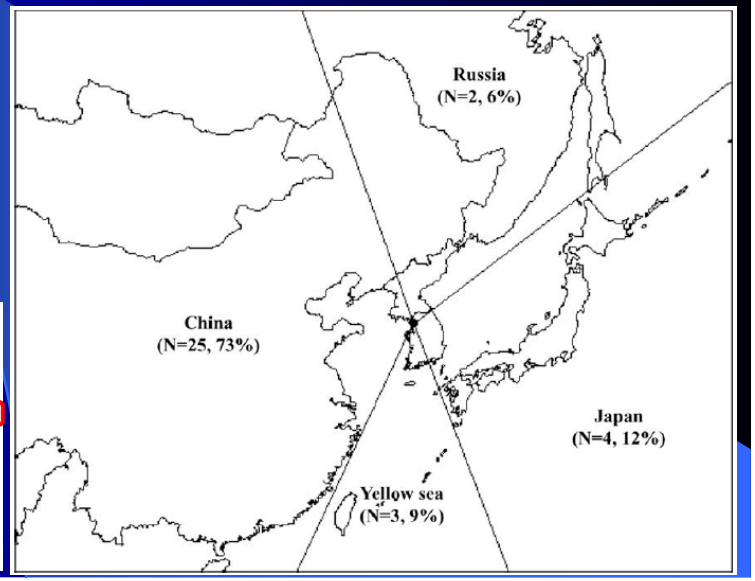
Mercury Speciation in Seoul, Korea

(Kim et al., 2009)

- TGM was measured using Tekran 2537A, whereas RGM and PHg were measured manually, in Seoul between Feb. 2005 and Feb. 2006.
- Mean values of TGM, RGM and PHg were 3.22 ng m^{-3}, 27.2 pg m^{-3}, and 23.9 pg m^{-3}, respectively.
- RGM and PHg were higher in daytime than at because of high photochemical activity.
- Long-range transport episodes with air from China has a higher TGM concentration compared to that of local episodes.







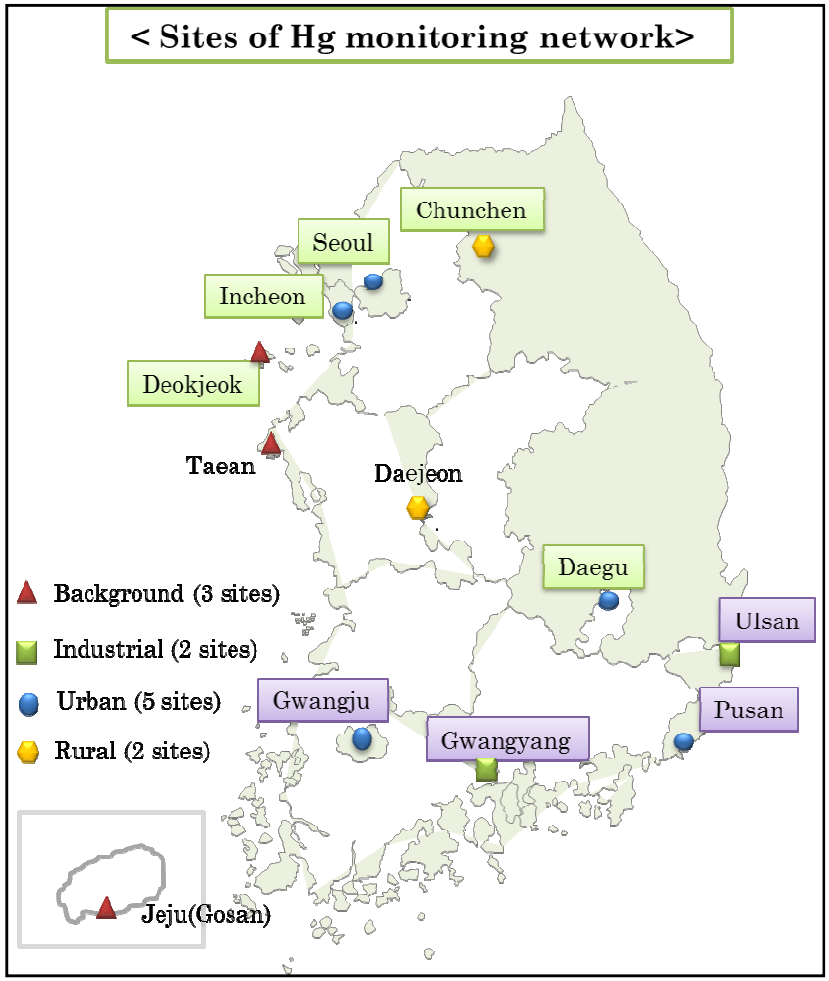
	Long-range transport episode					Local episode
	Total	China	Japan	Yellow Sea	Russia	
Episode (N)	34	25	4	3	2	36
Average duration (h)	17	18	15	14	9	20
TGM conc.(ng m^{-3})	4.42 ± 2.40	4.54 ± 2.50	3.67 ± 1.43	4.37 ± 2.45	4.42 ± 2.40	4.33 ± 1.97
CO conc. (ppbv)	780 ± 315	800 ± 306	603 ± 186	712 ± 222	988 ± 567	886 ± 422
ΔTGM/ΔCO (ng m^{-3} $ppbv^{-1}$)	0.0063	0.0055	0.0051	0.0078	0.0070	0.0011
r^2	0.64	0.60	0.56	0.62	0.77	0.13
Mixing height (m)	376 ± 164	383 ± 175	367 ± 139	350 ± 129	316 ± 38	406 ± 197
ΔO_3	21.2 ± 25.9	20.0 ± 22.9	28.6 ± 35.9	39.3 ± 39.0	−5.04 ± 22.12	13.9 ± 16.8
ΔNO_2	22.3 ± 8.4	22.1 ± 7.34	24.3 ± 9.42	24.3 ± 2.8	18.0 ± 26.6	30.5 ± 14.5
Pressure (hPa)[a]	1014.7 (+1.23)	1015.1(+1.7)	1013.45 (+0.1)	1013.7 (+0.3)	1016.6 (+3.2)	1012.5 (−0.9)

Atmospheric Mercury Monitoring Network of Korea

- **Objective**
  - To monitor the atmospheric mercury concentration levels in Korea
  - To evaluate the long-range transports of mercury between nations

- **Status**
  - Started from 2009 and currently operated at 12 sites to monitor TGM.
  - Operated by KECO (Korean Environmental Cooperation) and data are reported to NIER
  - Extended to the monitoring of wet mercury deposition at all sites and the monitoring of speciated mercury at 4 sites until 2015.

- **TGM monitoring methods**
  - Instrument : Teckran 2537
  - Sampling frequency : Every 5 mins.
  - Frequency of data report : Every 2 hours

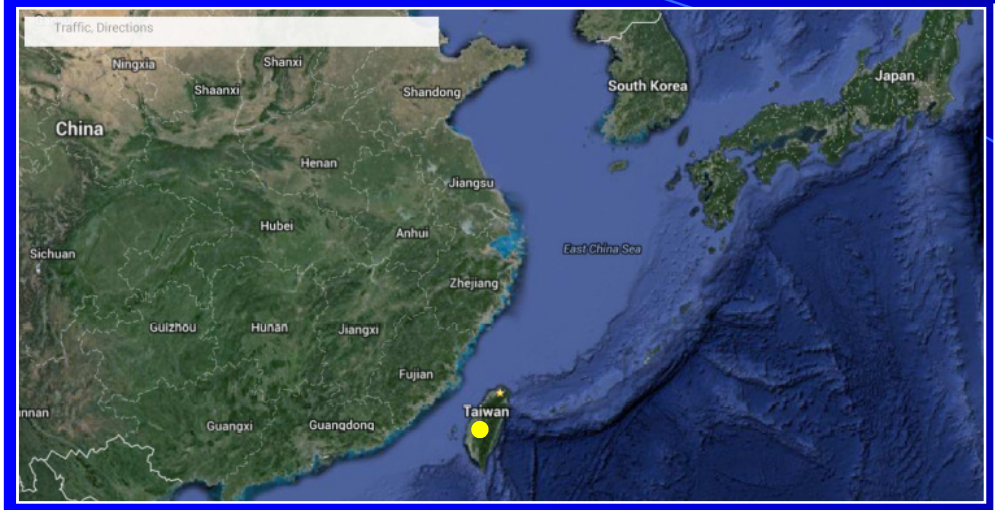


(Courtesy of Dr. Young-Hee Kim)

Mercury Speciation at the Lulin Atmospheric Background Station in Taiwan

(Sheu et al., 2010)

Lulin Atmospheric Background Station (LABS)









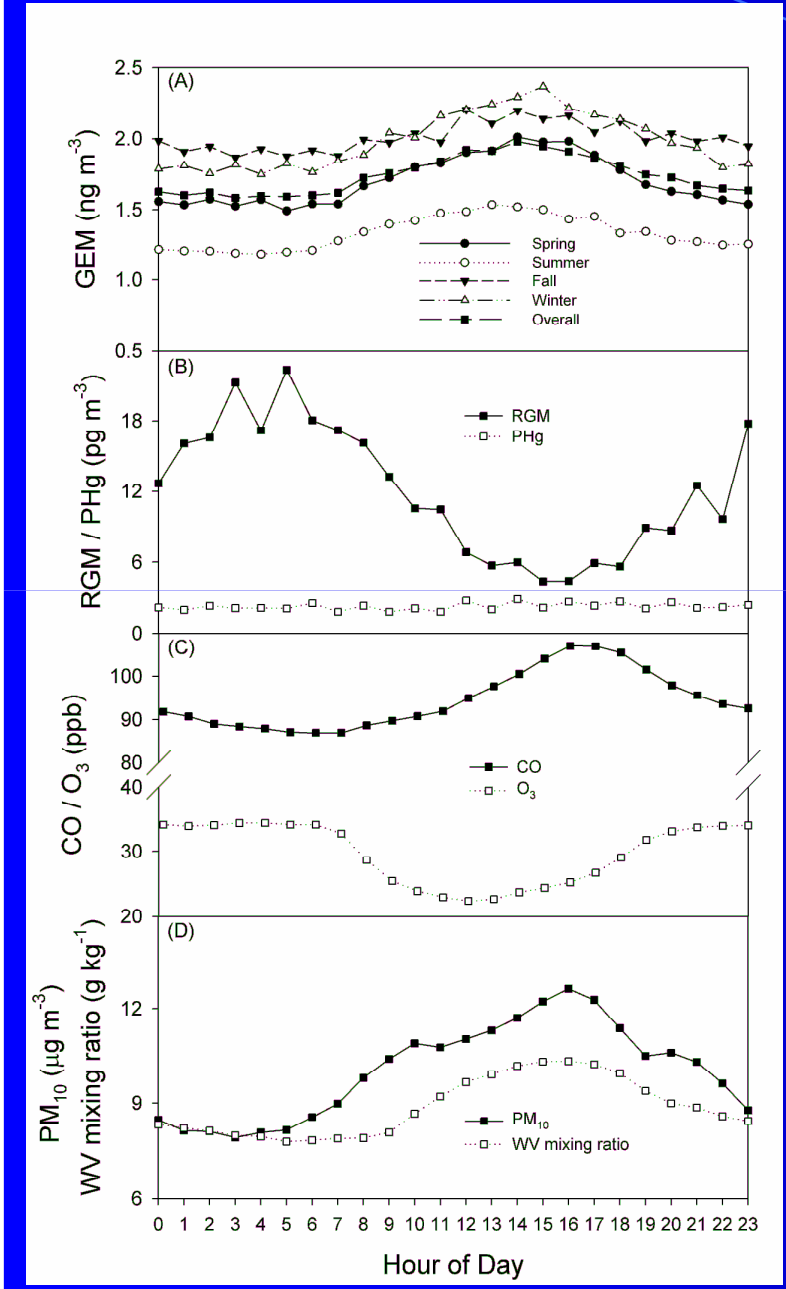
- LABS is located atop Mt. Front Lulin in central Taiwan, with an elevation of 2862 m above sea level.
- GEM, RGM and PHg have been measured using Tekran 2537A/1130/1135 at the LABS since April 13, 2006.

Summary of Atmospheric Hg in 2006/04-2013/11

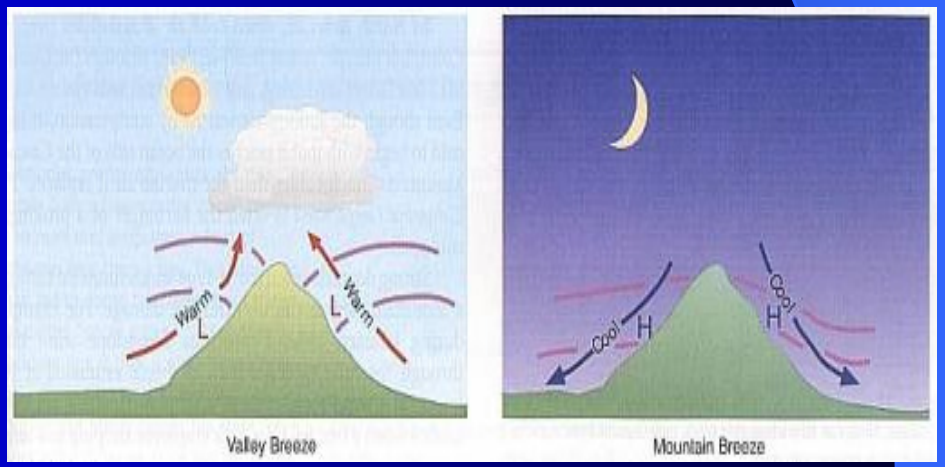
	GEM ($ng\ m^{-3}$)	RGM ($pg\ m^{-3}$)	PHg ($pg\ m^{-3}$)
Mean	**1.6**	**18.2**	**2.6**
S.D.	0.4	14.8	4.0

- GEM is the dominant atmospheric Hg species measured at LABS, constituting on average 98.7% of the total atmospheric Hg.
- Average GEM (1.6 ng m^{-3}) is within the Northern Hemisphere background value of 1.5-1.7 ng m^{-3} at sea level.
- However, about 30% of the GEM is greater than 2 ng m^{-3}, suggesting sources other than the background atmosphere are influencing the background station.

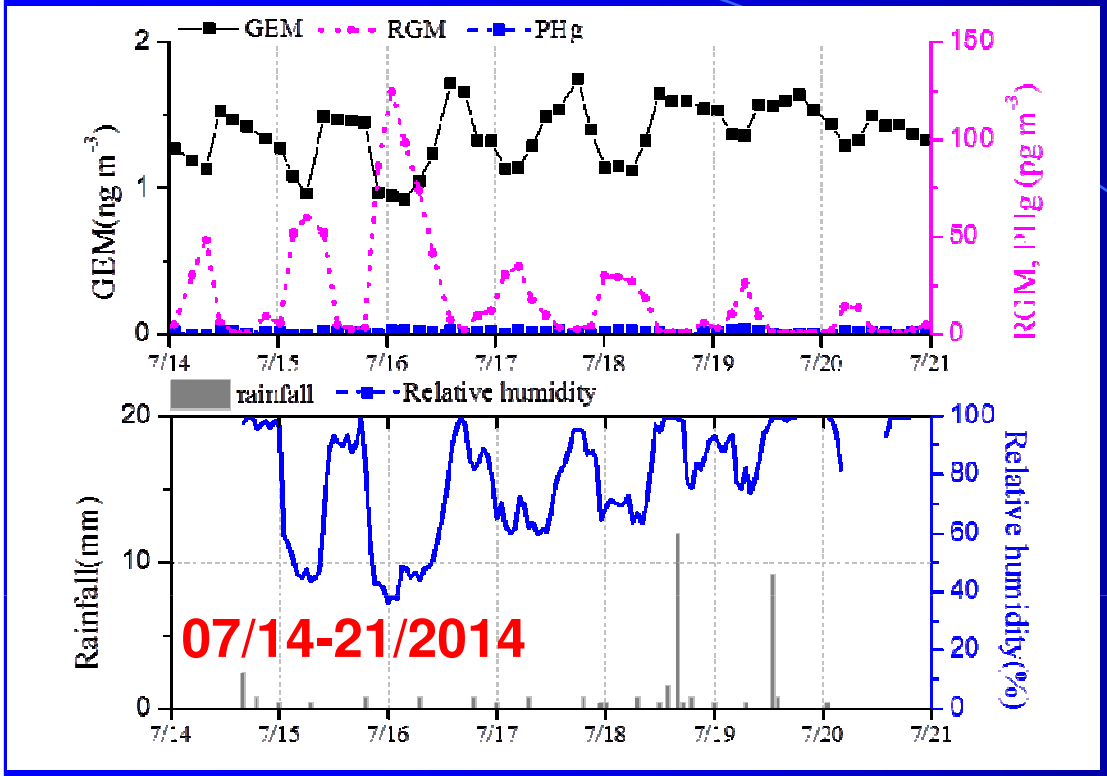
Diurnal Distribution of Hg and Other Chemicals

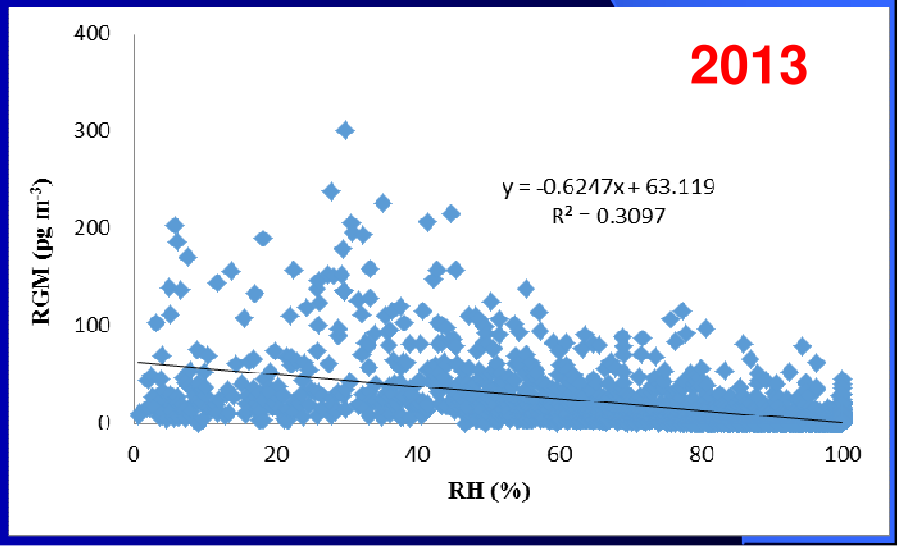


- Concentrations of CO, PM_{10} and WV mixing ratio all exhibited diurnal patterns similar to that of GEM.
- On the other hand, O_3 concentrations showed diurnal pattern similar to that of RGM.
- Upslope movement of boundary layer air in daytime and subsidence of free tropospheric air at night resulted in these diurnal patterns.

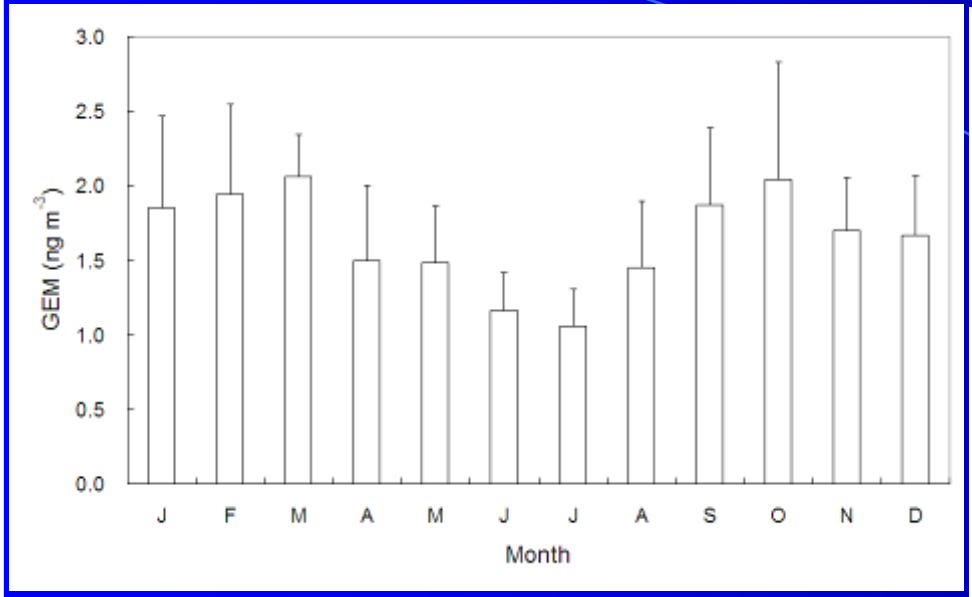


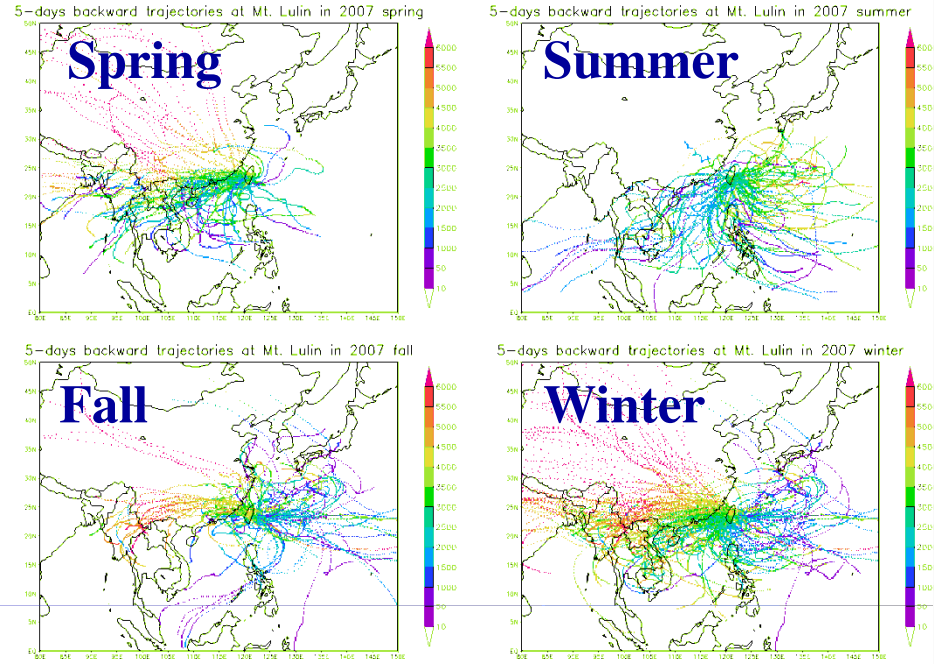
RGM and Humidity

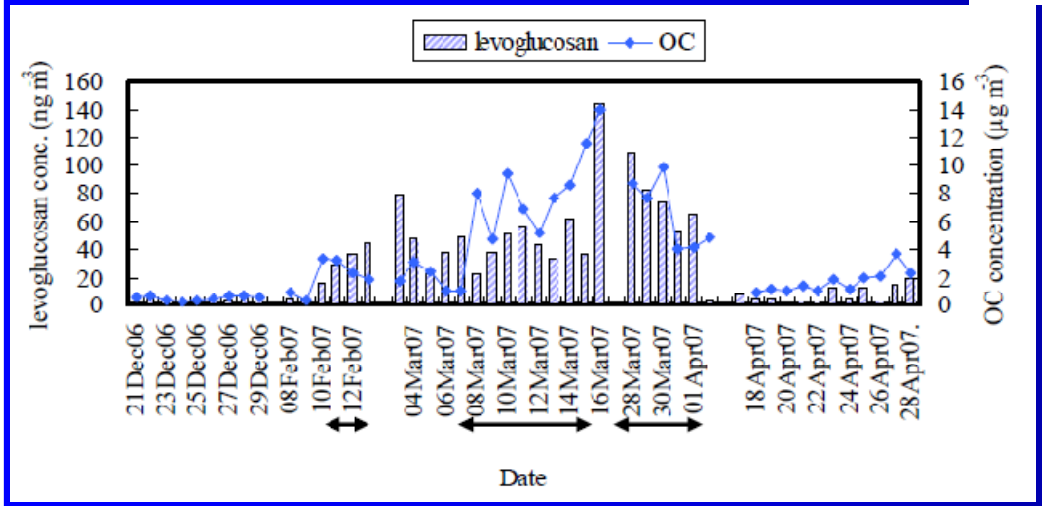


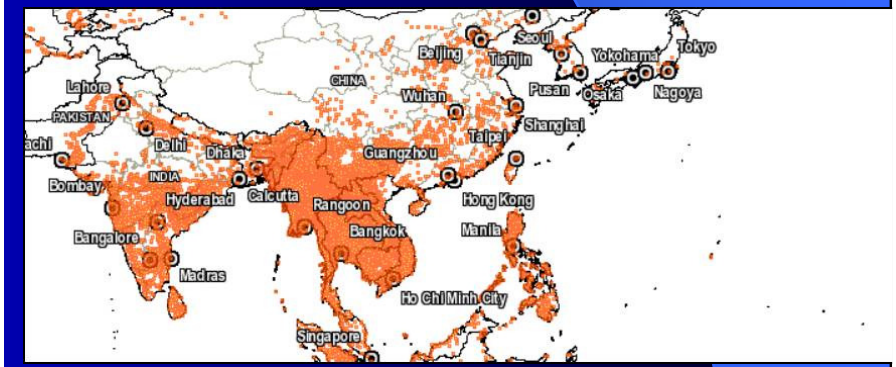


Seasonal Pattern of Nighttime GEM





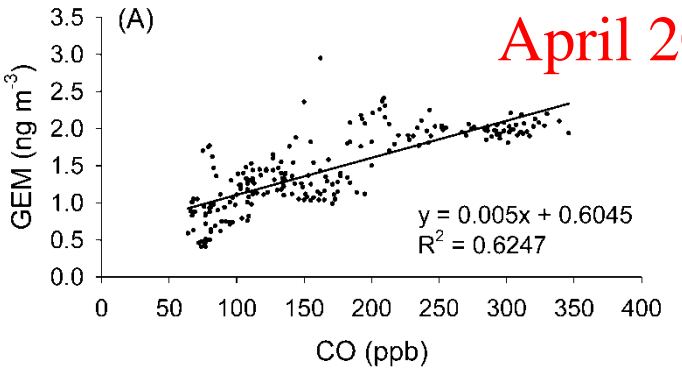




2007/03 MODIS fire detection

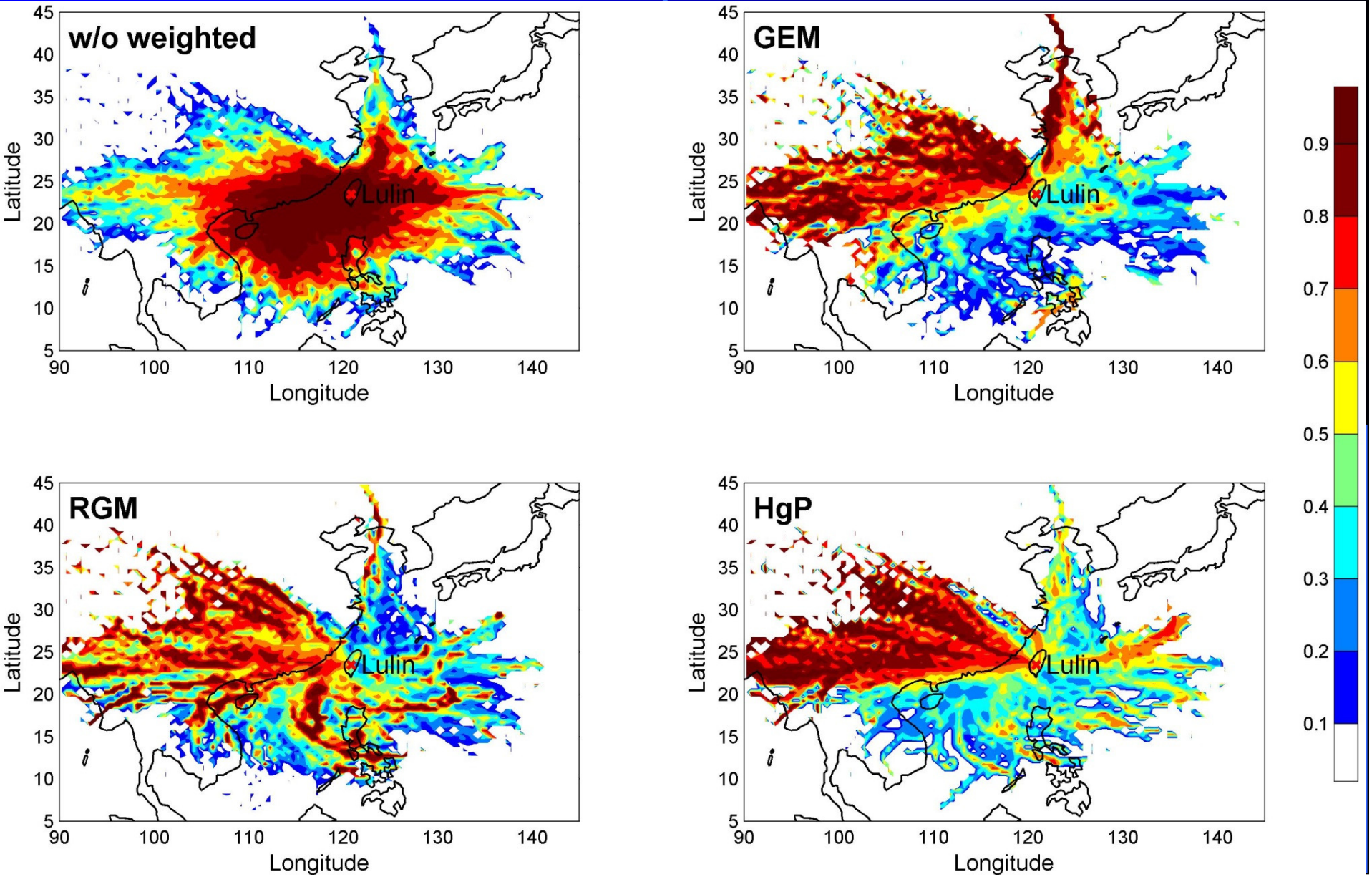
- LABS is the only site to observe Hg from anthropogenic emissions from China and biomass burning from Indochina Peninsula.

Correlation between GEM and CO

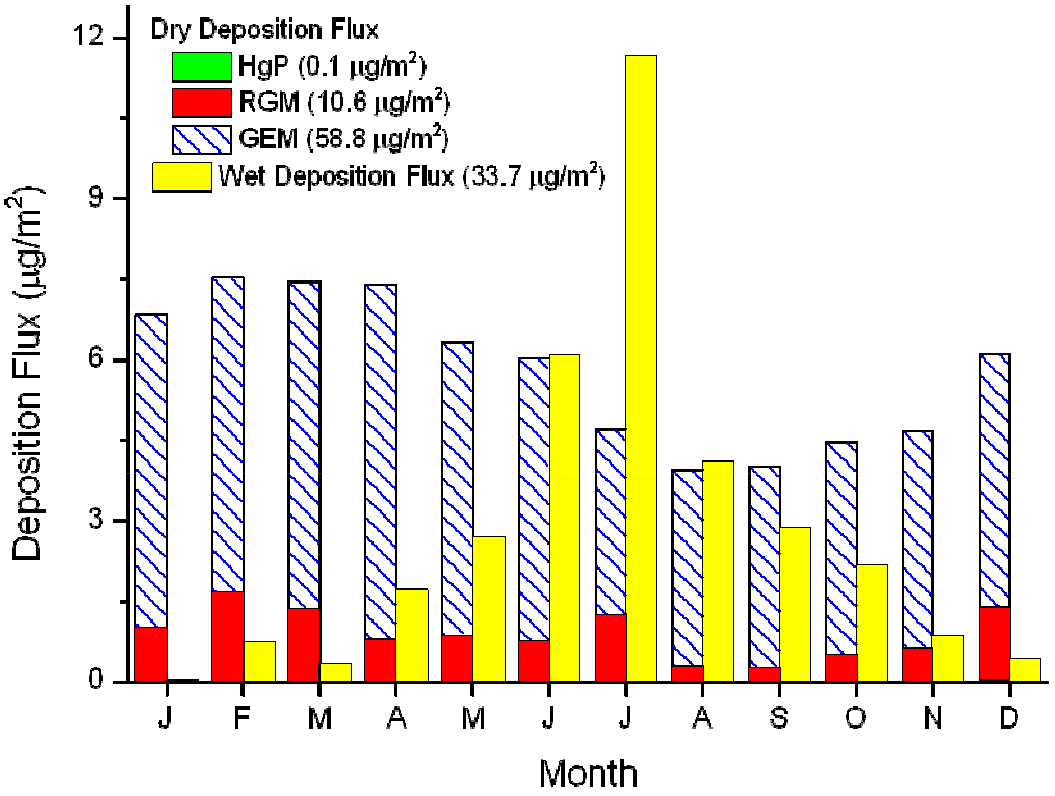


- Good GEM/CO correlations were observed in non-summer months, indicating influence of anthropogenic emission sources.
- GEM seasonal pattern, backward trajectory analysis and GEM/CO correlations indicated that air mass origins plays an important role in determining the GEM levels.
- These results also demonstrate the significance of East Asian Hg emissions and their long-range transport to downwind regions.

Source-Receptor Relatioship: Concentration-Weighted Trajectory



Wet and Dry Deposition Fluxes in 2010



Location	Site Type	GEM	RGM	PHg	Wet	Reference
LABS, Taiwan	Mountain	58.8	10.6	0.1	33.7	This study
AMNet, USA	Rural/urban	13-35	0.3-7.8	0.1-0.8	6-12.6	Zhang et al. 2012

Unit: μg m^{-2}

Summary

Location	Site Type	GEM (ng m^{-3})	RGM (pg m^{-3})	PHg (pg m^{-3})
Cruise over NPO	Ocean	2.5	9.5	
Cape Hedo, Japan	Ocean	2.0	4.5	3.0
Seoul, Korea	Urban	3.2	27.2	23.9
LABS, Taiwan	Mountain	1.6	18.2	2.6

- Higher atmospheric mercury concentrations at urban sites than in the marine boundary layer and free troposphere.
- RGM levels peak at noon at surface sites, likely due to *in situ* photochemical production. However, RGM peaks at night or in the early morning at high-elevation sites as a result of transport from higher altitudes.
- Lack of atmospheric mercury measurements in SE Asia.

THANK YOU!



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