The storage and controlling factors of mercury in the soils and permafrost of the Tibetan Plateau

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Introduction

- Mercury (Hg) is a toxic heavy metal that is associated with cardiovascular effects in adults and neurocognitive defects in fetuses。
- Soil serves both as a source and sink of Hg in the atmosphere in the global biogeochemical cycling of Hg.
- The Hg concentrations in soil are largely influenced by soil organic carbon(SOC) content and atmospheric input.
- The Tibetan Plateau, known as the “Third Pole”, is sensitive to anthropogenic impacts, like the input of Hg transported from nearby populous and industrialized regions in Indiaand the deposition from the Northern Hemispheric background air from long-range sources.

Methods

Mercury analysis:

- Sample Sites: the Tibetan Plateau
- Collecting Time: July and August) of 2013 and 2014
- Analyzer: a Direct Mercury Analyzer (DMA-80 with T660, Milestone Srl, Italy)
- The instrument detection limit (IDL) :0.0005 ng total Hg

Atmospheric models:
GEOS-Chem nested-grid Hg

- Time: during 2015-2016 （2014： spin-up）
- Domain: 15–55°N and 70–140°E
- Met data: GEOS-FP
- Resolution: 0.25° × 0.3125° with 47 vertical layers.

Dataset:

- Tibetan Plateau:144 points
- Over China:920 points
  agricultural fields：491 points
  urban regions ： 95 points
  mining areas ： 97 points

Results and discussion

1.Concentrations, distribution of soil mercury in the Tibetan Plateau

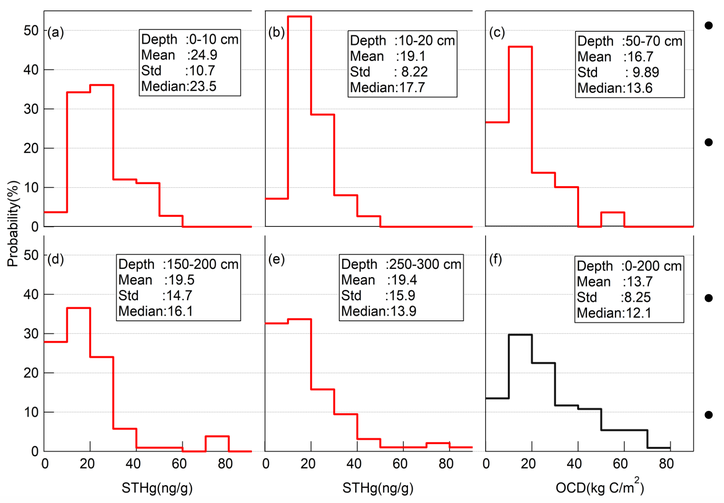


Fig1. Probability functions showing the fraction of values as a function of STHg (a-e) and OCD((f)0-200 cm).

- The STHg concentrations in the Tibetan Plateau are 19.9±12.4 ng/g.
- The probability distribution of STHg and OCD are both **right-skewed** with higher means than medians.
- About 60 % of the STHg data at different depths are between 10 and 30 ng/g.
- Occasionally, there are samples with concentrations greater than 60 ng/g and with OCD less than 10 kg C/m² in deep layers (> 50 cm)

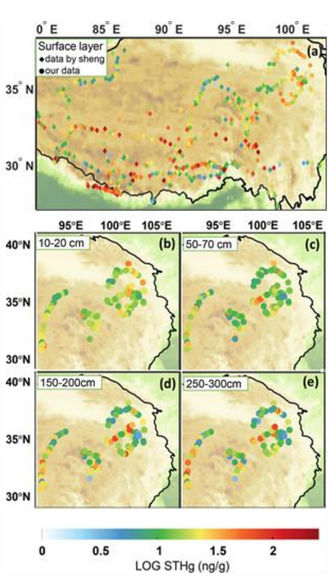


Fig2. Measured STHg for different depths in the Tibetan Plateau. (◆: data collected by Sheng, Map color represents altitudes)

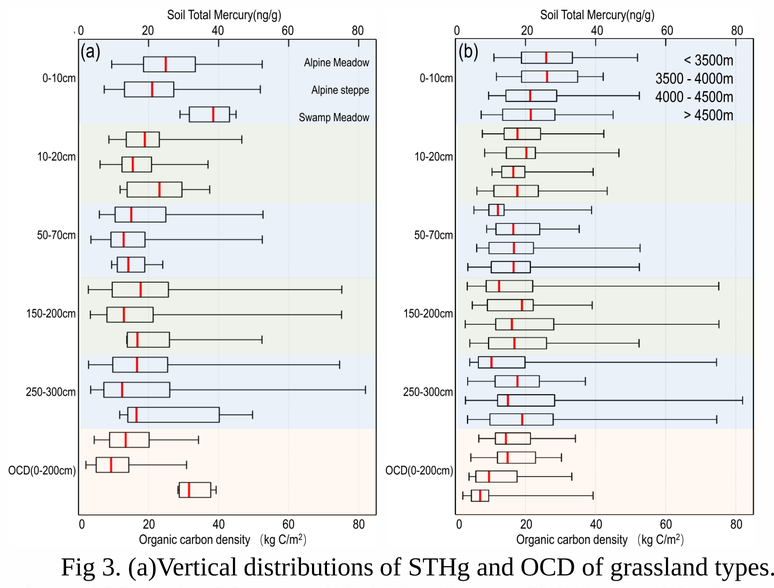


Fig 3. (a)Vertical distributions of STHg and OCD of grassland types. (AM: Alpine Meadow; AS: Alpine Steppe; SM: Swamp Meadow)
(b) Vertical distributions of STHg and OCD of altitudes. (altitude <3500 m, 3500-4000 m, 4000-4500 m, >4500 m)

- The STHg exhibits large spatial variability in surface layer of TP and is higher in the south and lower in the north(Figure 2a).
- The distribution of STHg in the deep layers mimics the surface layer: higher in the south than the north (Figure 2b-e).
- The STHg concentrations decrease with depth in the top three layers (0-70 cm) and remain almost unchanged in below(Fig 3).
- The STHg and OCD in SM are the largest among the three grasslands(Fig 3a).
- Temperature is not an important controlling factor for STHg in the frozen soil, as the microbial activity is paused under low temperature and STHg is fixed in the deep soil(Fig 3b).

2. Storage of soil mercury in the Tibetan Plateau

We calculate the R^{HgC} of our samples and find a mean R^{HgC} of 5.5 ± 5.1 μg Hg/g C. Ding estimated organic carbon stock in alpine grasslands in the Tibetan Plateau is 12 Pg (0-200cm). This results in an estimated STHg of 67 Gg in alpine grasslands in the Tibetan Plateau.

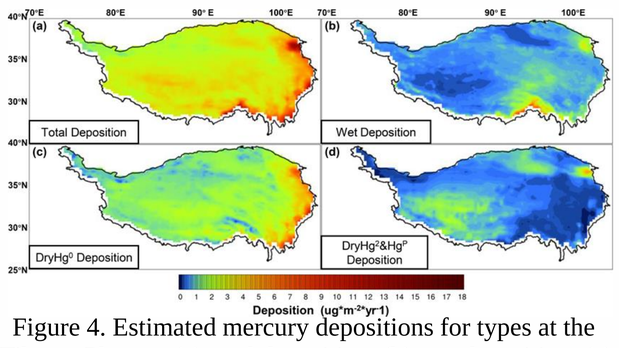


Figure 4. Estimated mercury depositions for types at the Tibetan Plateau. (a) total deposition, (b) wet deposition, (c) dry deposition of hg^0, (d) dry deposition of hg^2 and hg^p.

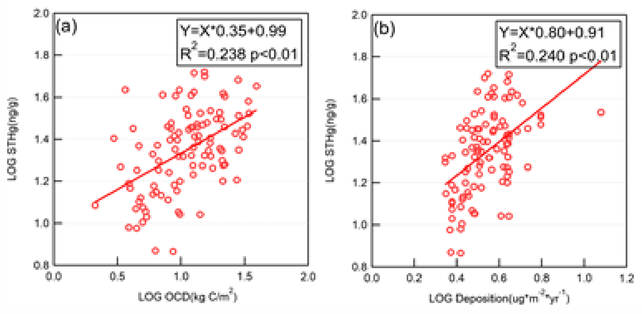


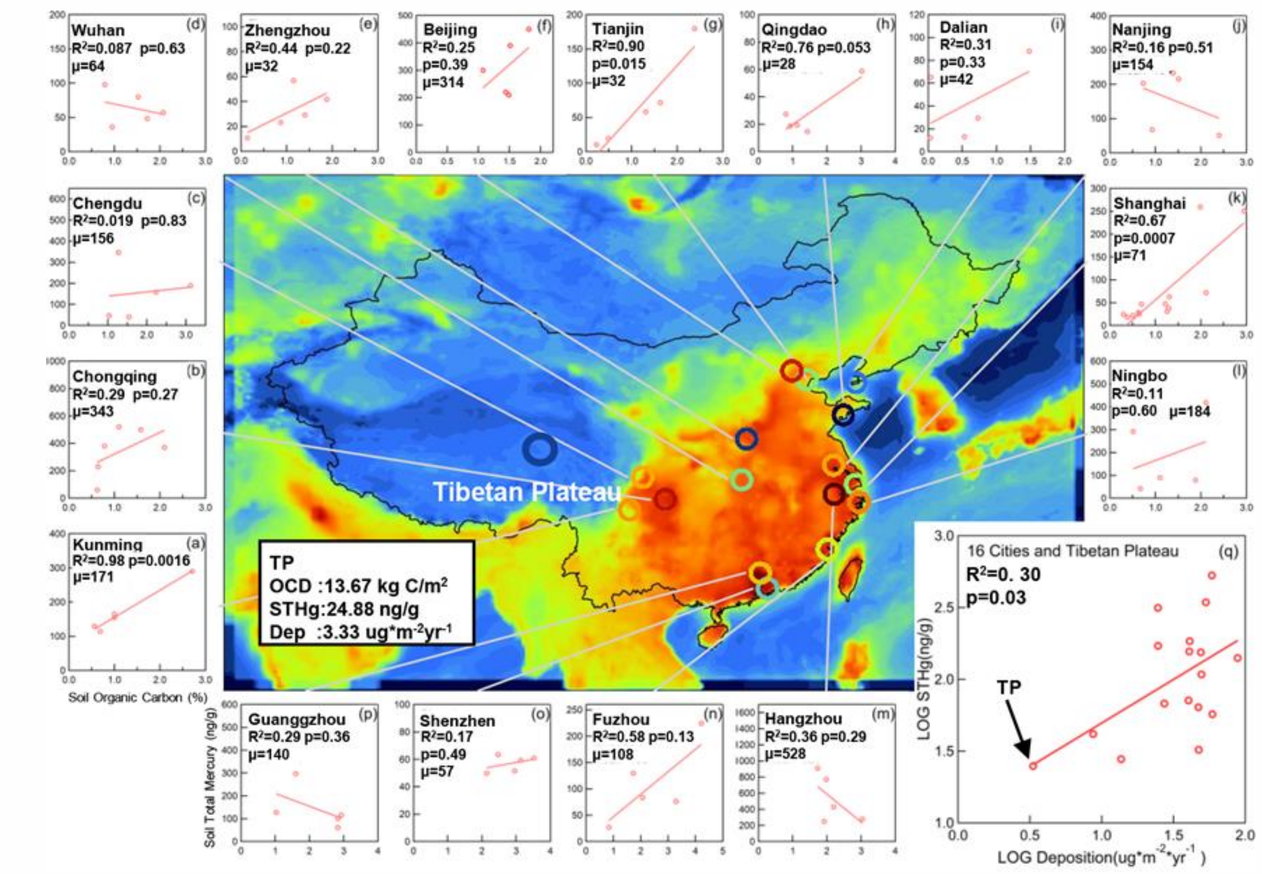
Figure 5. (a) Relationship of STHg and (in log scale);
(b) Relationship of STHg and atmospheric deposition(in log scale).

[Soil organic carbon]: a correlation between OCD and STHg (Figure 5a,log-transformed): Log (STHg) = 0.35log (OCD) + 0.99, R^2 = 0.238, F-test: p <0.01

[Atmospheric deposition]: a correlation between STHg and atmospheric deposition (Figure 5b, log-transformed, R2 = 0.240, F-test: p <0.01).

3. Controlling factors of mercury

- The total atmospheric deposition in the TP ranges 0-18 ug*m^{-2}yr^{-1}(Fig4a).
- The average deposition flux of Hg is 3.3 ug*m^{-2}yr^{-1} with 57% contributed by dry deposition of Hg^0, followed by dry deposition of Hg^{II} and Hg^P (19%) and wet deposition (24%) (Fig4b-d).
- Dry deposition and wet deposition show different spatial distribution patterns, especially in the southwestern Tibetan Plateau.
- The wet deposition is higher in the southern and northeastern parts of the plateau, but is very low over the western region (even low to zero ug*m^{-2}yr^{-1} at some locations).



[Atmospheric deposition, SOC and STHg throught China]:

- At smaller spatial scale (i.e. cities or regions), there are strong correlation and linear relationship between STHg and SOC [Figure 6(g, h, k, a)].
- Cities [Figure 6(p,d)] with weaker relationship between STHg and SOC. The sample sizes are small for these cities, and the high STHg concentrations associated with high atmospheric input -- these sites are close to industrial regions, roadsides or power plants.
- The average STHg concentrations for each city correlates well with the average atmospheric Hg deposition (R^2 = 0.29, Figure 6q) ---- Regions with very different atmospheric input, different STHg values are observed for sites even with similar SOC.

Conclusions

- Total Hg concentrations in 114 Tibetan Plateau grassland soil columns were measured.
- The mean Hg:C ratio of the samples is 5.5± 5.1 μg Hg/g C and the estimated Hg mass is 67 Gg in alpine grasslands in the Tibetan Plateau.
- Soil organic carbon content and atmospheric deposition both control the spatial distribution of soil Hg concentrations.

References

Ding, J.; Li, F.; Yang, G.; Chen, L.; Zhang, B.; Liu, L.; Fang, K.; Qin, S.; Chen, Y.; Peng, Y.; et al. The Permafrost Carbon Inventory on the Tibetan Plateau: A New Evaluation Using Deep Sediment Cores. Glob. Chang. Biol. 2016, 22 (8), 2688–2701.