USGS and various other organizations are investigating the connection between the deposition of mercury and its uptake in ecosystems by tracing known amounts of mercury added to a watershed ecosystem. Results of the experiment, known as METAALICUS (U.S. Geological Survey, 2007), show that recently added mercury is more likely to be converted to methylmercury and taken up in organisms than mercury that is already present in the ecosystem. This finding indicates that a reduction in the input of anthropogenic mercury to the atmosphere could decrease the occurrence of fish consumption advisories in some environments. In an effort to reduce atmospheric emissions of mercury in the United States, the U.S. Environmental Protection Agency (USEPA) has adopted a plan to limit mercury emissions from coal-fired utility power stations, the largest unregulated anthropogenic mercury source in the United States. The plan, consisting of the USEPA Clean Air Interstate Rule (U.S. Environmental Protection Agency, 2007b) and the USEPA Clean Air Mercury Rule (U.S. Environmental Protection Agency, 2007c), would ultimately result in a 70-percent reduction in mercury emissions from this source by 2018.

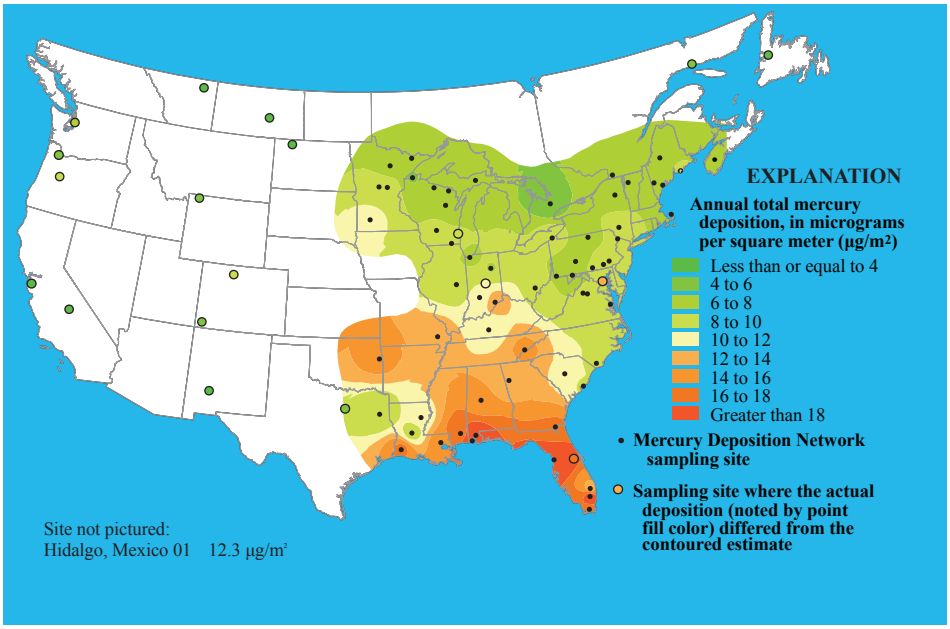

Figure 2a. Map showing location of Mercury Deposition Network sampling sites and contours of 2005 total annual mercury wet deposition. Map shows that wet deposition of mercury is greatest along the Gulf Coast and in Florida. (From National Atmospheric Deposition Program, 2007)

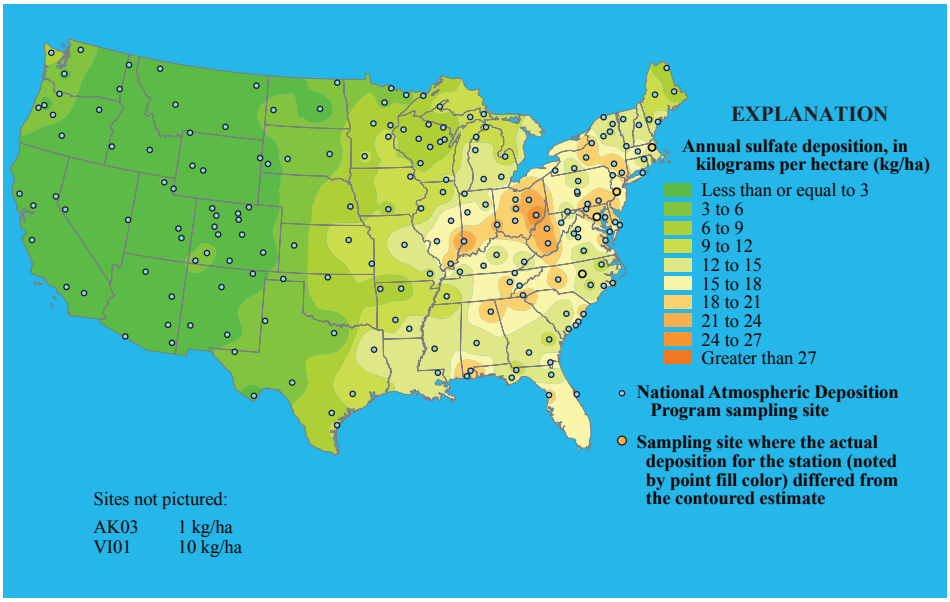

Figure 2b. Map showing 2005 contours of sulfate-ion (SO_4^{2-}) deposition, which reflect the distribution of sulfur-emitting sources such as coal-fired utility power stations. This distribution is distinctly different from that for total wet mercury deposition (shown in figure 2a). (From National Atmospheric Deposition Program, 2007)

Measuring Deposition of Mercury from the Atmosphere

In the mid-1990s, the Mercury Deposition Network (MDN) of the National Atmospheric Deposition Program was begun to provide weekly estimates of the amount of mercury deposited in the United States from precipitation and the concentration of mercury in that precipitation (National Atmospheric Deposition Program, 2007). The MDN, a cooperative effort of many agencies and participators, consists of nearly 100 sampling stations concentrated primarily in the eastern United States, where rainfall amounts, and the proportion of mercury-emitting point sources, are high. Recent MDN results (fig. 2a) show that wet mercury deposition is greatest in the southeastern United States and the Gulf Coast states; however, the density of coal-fired utility power stations and the proportion of atmospheric contaminants derived from coal combustion, such as sulfur dioxide, are greatest in the Ohio Valley, Mid-Atlantic, and northeastern states (fig. 2b). Possible explanations for this discrepancy include (1) the MDN does not measure mercury that is deposited when there is no rainfall (dry deposition); (2) reactions may be occurring in coal-fired power plant plumes that convert most of the mercury to the elemental form, which is less easily deposited; and (or) (3) there may be unique conditions or sources of mercury in the southeastern states, or near coastal settings, that contribute to high rates of mercury deposition there.

Deployment of the USGS Mobile Mercury Laboratory to Measure Atmospheric Mercury

In order to improve understanding of the pattern of mercury wet deposition, especially in the southeastern United States, the USGS mobile mercury lab was deployed to sites in Alabama and South Carolina in 2005 and 2006, respectively (fig. 3). These sites were chosen to study the interaction of atmospheric mercury from sources on land with air masses

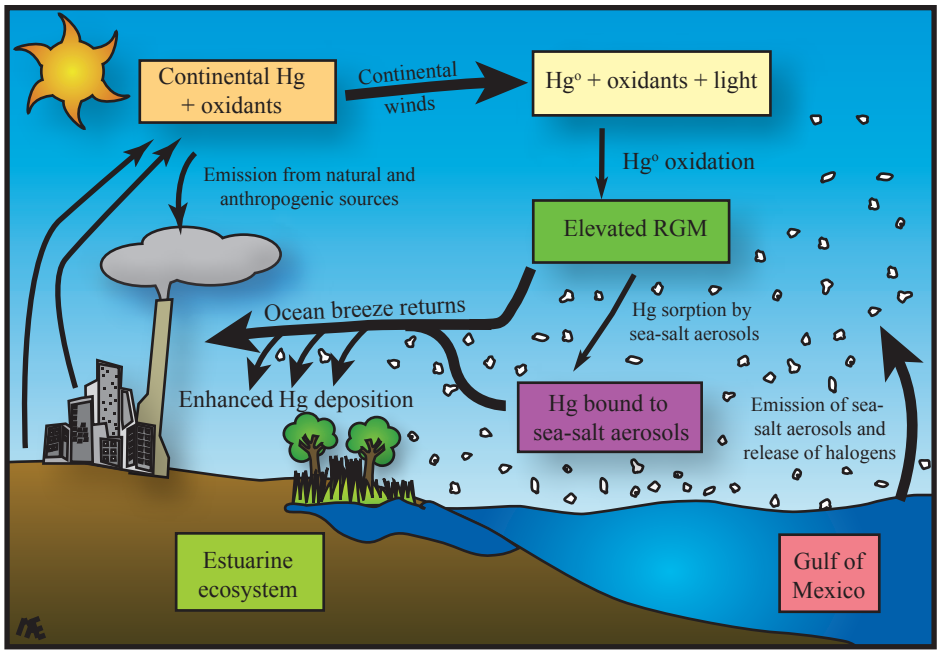

Figure 5. Conceptual model for enhanced mercury (Hg) deposition along the Alabama Gulf Coast, based on results from atmospheric sampling with the USGS mobile mercury lab and separate aerosol samplers. Model shows formation of sea-salt aerosols, primarily by action of wind on the ocean, and release to the atmosphere of halogen elements such as chlorine, a major component of sea salt. Wet deposition of mercury in coastal areas may be enhanced by formation of reactive gaseous mercury (RGM) from elemental mercury (Hg^o) and oxidants derived from sources on land, and return of mercury onshore as RGM and mercury adsorbed onto sea-salt aerosols that are easily dissolved.

onshore as ocean breezes. On days when air masses coming off the land return onshore in the form of ocean breezes or come directly off the ocean into the RGM-rich nearshore environment, some of the RGM and (or) Hg^o appears to be scavenged and incorporated onto large aerosol particles, which contain sea salt from the ocean air. Combining mercury and air contaminant sources on land with onshore ocean breezes that are warm and humid and contain sea salt provides an environment that may allow for enhanced deposition of mercury along the Gulf Coast compared to inland areas or sites over the open ocean (fig. 5).

Other Research Sites

Additional studies with the mobile mercury lab are planned to test the effect of ocean temperature and sampling-site location on the model developed for the Gulf Coast by deploying the lab at more northerly coastal sites in the Mid-Atlantic region and possibly New England. Our overall hypothesis is that the marine boundary layer (the intrinsic characteristics of the atmosphere overlying the ocean) interacts with atmospheric mercury in near-coastal settings to enhance mercury deposition, and the strength of this interaction depends on factors such as ocean temperatures and wind patterns. Thus, the marine boundary layer is hypothesized to have a smaller effect on mercury deposition in cooler oceanic settings such as the Mid-Atlantic or New England states than at the warmer Gulf Coast and southeast Atlantic sites.

At existing air-quality-monitoring sites, the capabilities of the mobile mercury lab can be nearly duplicated by adding an analyzer that measures forms of atmospheric mercury to the instruments that are already in place. This approach was taken in 2006 at Shenandoah National Park-Big Meadows in Virginia and in 2007 in western Pennsylvania and is planned for other study areas. Studies at these inland sites are intended to illustrate what is happening in the atmosphere nearer to mercury sources such as coal-fired utility power stations, in order to understand the factors that control the reactivity of atmospheric mercury and the mechanisms by which mercury begins to separate from other atmospheric constituents derived from coal combustion.

Summary

Mercury deposited from the atmosphere is added to aquatic ecosystems, where it can be converted to toxic organic forms such as methylmercury and taken up in the food web, ultimately resulting in unsafe levels for human consumption of fish. Our work in coastal Alabama shows that, in some cases, air masses containing mercury derived from the land mix with marine air masses, generating high concentrations of reactive gaseous mercury that can be deposited directly or possibly adhere to sea-salt particles that are deposited or dissolved in precipitation. This reactive gaseous mercury and particulate mercury is available to be deposited in mercury-sensitive coastal ecosystems, which may explain in part why mercury deposition is greater along the Gulf Coast than in the Ohio Valley, even though coal use for power generation is much more prevalent in the Ohio Valley than along the Gulf Coast.

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