The nature of boundary scavenging in the North Pacific Ocean

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The radionuclides ^{231}Pa and ^{230}Th are useful tracers in the ocean of chemical scavenging, or the process of removal from the water column by adsorption onto sinking particles. This is because of their well-known and uniform source from the decay of U. The residence time of ^{231}Pa in the water column (50-200 yrs) is roughly five times greater than that of ^{230}Th (10-40 yrs), and thus their combined distributions provide information on scavenging processes occuring over different timescales. The increase of the ^{231}Pa/^{230}Th ratio in surface sediments toward ocean margins has been used as evidence that ^{231}Pa is laterally transported (to a greater degree than ^{230}Th because of its longer residence time) by diffusive fluxes from areas of low scavenging intensity to areas of high scavenging intensity [1]. This process is termed boundary scavenging [2] and potentially affects all scavenged elements whose residence time is long enough to allow basin-wide isopycnal diffusion. Little data exist, however, to support this phenomenon on the basis of ^{231}Pa/^{230}Th in the water column. Along lateral gradients in scavening intensity, the theory predicts inversely corresponding lateral gradients in [^{230}Th] (high scavenging, low [^{230}Th] and vice versa), and smaller lateral gradients for [^{231}Pa], reduced by isopycnal transport.

From the Innovative North Pacific Experiment (INOPEX) cruise of 2009, profiles of dissolved ^{230}Th and ^{231}Pa situated along strong lateral productivity gradients in the subarctic Pacific show virtually no lateral concentration gradients for either radionuclide, at odds with the traditional boundary scavenging explanation. From the subarctic to subtropical and tropical North Pacific, based on published data from this area, much larger lateral gradients in [^{231}Pa] and [^{230}Th] exist, even over lateral productivity gradients of similar magnitude to those within the subarctic. From subtropics to subarctic, in the upper 2.5 km, the lateral gradient is larger for [^{231}Pa] than for [^{230}Th], exactly the opposite of the expectation based on their residence times. We link this behavior to the geographical distirbution of biogenic opal, a strong scavenger of Pa. Below 2.5 km depth, however, ^{231}Pa has a more uniform distribution across the North Pacific, whereas ^{230}Th displays a relatively large contrast primarily between areas north and south the subarctic front. While more water column data are needed to determine the influence of inflow from the South Pacific, it is suggested that in deep waters isopycnal diffusion dominates over the lateral gradient in scavenging intensity for ^{231}Pa. The sensitivity of ^{230}Th and ^{231}Pa to differences in scavenging intensity across gyes but not within them suggests a new biogeographic dimension to boundary scavenging that deserves more attention.

[1] Bacon (1988) *Philos. T. Roy. Soc. A.* **325**, 147-160. [2] Spencer et al. (1981) *J. Mar. Res.* **39**, 119-138.

Global warmth during the Pliocene: a CO_2 paradox?

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Multiple sources of geological proxy data indicate higher than modern surface temperatures, relative to present-day, during intervals of the Pliocene. Recently there has been a suggestion that the increase in global annual mean temperature of the planet for the Pliocene (~2 to 3°C) is inconsistent with CO_2 forcing alone, since it would require a very high climate sensitivity. Other mechanisms that are not currently, or only poorly, represented in climate models have been invoked as a means to provide a significant contribution to Pliocene warmth, in addition to CO_2.

This argument is based upon the premise that we define climate sensitivity during the Pliocene in the same way that we define climate sensitivity in response to a CO_2 doubling during this century. This premise may be invalid because in the deep palaeo proxy records provide evidence for the response of climate to a carbon cycle perturbation over far longer timescales than are used to understand 21st century climate sensitivity. Over such timescales feedback s from slow responding components of the climate system (e.g. vegetation and ice sheets) have the ability to enhance any surface temperature rise caused by CO_2.

Here we demonstrate this concept through the presentation of a suite of climate model simulations using the Hadley Centre Coupled Climate Model Version 3, in which fast and longer term feedbacks to a CO_2 rise to 400 ppmv are considered. The direct climate response in the short-term indicates a climate sensitivity in line with the best estimates of the IPCC for the coming century (~3°C). Feedbacks from vegetation and ice sheets to the CO_2 forcing (probably in response to orbital forcing as well) are able to significantly increase the total change in global mean temperature. Our results are corroborated by initial model outputs produced by the Pliocene Model Intercomparison Project.

Overall we conclude that the Pliocene paradox can easily be resolved when different timescales of environmental response to a given carbon cycle perturbation are considered.