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Half-hearted engineering

Climate warming is not the only consequence of rising levels of atmospheric greenhouse gases. The only way to counter all effects, including those on rainfall and ocean acidity, is to remove carbon from the climate system.

Arguably, some of the most immediate impacts of a warming climate will result from shifts in global rainfall patterns. The potential threats are diverse, and include water scarcity in the lush Amazonian rainforest; increased drought in the already parched southwestern United States; rainfall replacing snow in low-latitude mountain regions; and a rise in flooding in temperate climates. Whatever the exact outcome of these threats, the stability of the world's economy and ecosystem both depend on maintaining precipitation patterns more or less as they are today.

Yet a number of geoengineering schemes discussed in the Commentary on page 722 of this issue are directed at countering greenhouse warming only, ignoring the potential ramifications for the hydrological cycle. Geoengineering proposals come in two flavours: those that suggest ways of taking carbon out of the climate system, and those that seek to reduce only the Earth's incoming solar radiation, and hence the warming at the Earth's surface. But far from stabilizing current precipitation patterns, the latter schemes actively disturb them in their attempt to constrain global temperatures.

At the root of the problem lies the fact that any engineered change in incoming solar radiation cannot totally compensate the effects of increasing levels of greenhouse gases. Even on a global mean basis, a change in incoming solar radiation that exactly offsets the warming effect of greenhouse gases is expected to overcompensate their effect on the hydrological cycle (*Proc. Natl Acad. Sci.* **105,** 7664–7669; 2008). So if temperature is brought back to pre-industrial levels, rainfall — expected to increase in a warming climate — will decline well below the levels of the early nineteenth century.

In addition, geoengineering measures such as the insertion of sulphur into the stratosphere cannot be applied uniformly over the globe for obvious logistic reasons. But regional changes in climate forcing will lead to changes in regional precipitation. The Asian and African summer monsoons on which billions of people's livelihoods rely are one potential geoengineering hotspot (*J. Geophys. Res.* **113,** D16101; 2008).

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Rice paddies need the monsoon rains to flourish.

Worryingly, changes in rainfall are particularly difficult to predict in detail: precipitation patterns are simulated with only moderate confidence in general circulation models. It would therefore be very hard to assess the impacts of insolation-altering schemes on precipitation patterns by using modelling studies in advance of a scheme's implementation.

Together these three factors — the economic and environmental importance of current precipitation patterns, the difficulty of manipulating both temperature and rainfall to the desired extent, and the uncertainties associated with hydrological predictions — make it virtually impossible to design a radiation-based geoengineering scheme that will not have first-order negative impacts on people's lives, at least regionally.

But in order to be at all defensible, a purposeful (and presumably costly) engineering action with the sole aim of averting the consequences of anthropogenic greenhouse gas emissions must not harm those who have contributed little or nothing to the problem. By this criterion, any geoengineering scheme that may have detrimental effects on the African and Asian monsoon systems is unacceptable.

Of course, the acidification of the world's oceans resulting from increased dissolution of atmospheric carbon dioxide in sea water is not even considered in attempts to manipulate the Earth's radiation budget. Current projections suggest that considerable areas of the world's oceans will become corrosive to corals and shell-forming organisms by the end of this century. As discussed at a recent symposium (http://www.highco2world-ii.org), it is unlikely that this particular climatic fallout will be prioritized by those who design engineering schemes if it is left out of the post-Kyoto negotiations next year.

If we are to modify the Earth system to compensate for human-induced carbon dioxide emissions, solutions should be sought as close to the source of the problem as possible. Ideally, anthropogenic carbon dioxide would never enter the atmosphere, and instead would be removed from power plant and cement factory exhausts before they leave the chimney. If the technical problems can be overcome, atmospheric carbon capture could still do the trick.

The current economic crisis is demanding all the attention of policy makers and the general public at this time. But once the market turbulence has settled, money needs to be spent on developing solutions to the climate problem. Adaptation, alternative energies, energy-saving technologies and geoengineering schemes all beg further investigation. But we need to keep in mind that the technologically most spectacular proposals — such as mimicking a volcanic eruption — are not necessarily the best.