NEWS & VIEWS

CARBON CYCLE

Harvest of the century

Emilio Mayorga

A century-long record of levels of inorganic carbon in the Mississippi, extracted from the water-treatment plants of New Orleans, documents the changes wrought by shifting agricultural practices in the river's basin.

Concerns about the effects of increasing levels of atmospheric carbon dioxide on climate and ocean acidity have intensified the study of how carbon is exchanged between the atmosphere, land and oceans — especially how CO_2 is removed from the atmosphere and transferred into long-term storage (sinks). The rates of removal into terrestrial and ocean sinks seem to be slowing down[1], highlighting the need for improved data on the individual sinks, their controls and likely future behaviour, and their relationship to other carbon fluxes.

In the global carbon cycle, rivers are a fundamental, multi-faceted link between atmosphere, land and ocean[2,3]. Five years ago, a study[3] of the Mississippi River in the United States found a large increase in the export of dissolved inorganic carbon to the ocean during the past 50 years, a result of the enhanced dissolution (weathering) of rock minerals. Links to changing agricultural practices and crop management, as well as to increased precipitation, were found, but the mechanisms remained unclear. On page 449 of this issue, Raymond *et al.*[4] revisit this topic using a remarkable, century-long data set and more robust approaches. They conclude that direct effects from changes in land use outweigh the indirect influence of climate change.

The chemical weathering of rock material in soils typically consumes CO_2 of atmospheric origin through reactions with carbonate and silicate minerals. These reactions are controlled by factors including climate, mineral type, the availability of acids (particularly carbonic acid) and physical erosion[5]. The resulting bicarbonate ion (HCO_3^-) is the dominant form of dissolved inorganic carbon in most rivers, and does not exchange readily with atmospheric CO_2. Instead, it is transported by water run-off to rivers and, ultimately, to the ocean, where it contributes to the ocean's alkalinity — and so its capacity to absorb CO_2 and buffer changes in acidity.

The weathering of silicate rocks such as basalt and granite results in complete conversion of consumed CO_2 to bicarbonate in soils and groundwater, and the weathering of carbonates such as limestone converts one molecule of mineral CO_2 to bicarbonate for each molecule of atmospheric CO_2 consumed[5]. Overall, chemical weathering is a sink of CO_2 on land, and represents a transfer of atmospheric carbon and buffering capacity to the ocean at timescales relevant to human activity (hundreds to thousands of years). But in all this, human alterations of weathering fluxes through land management had typically been neglected in large-scale assessments.

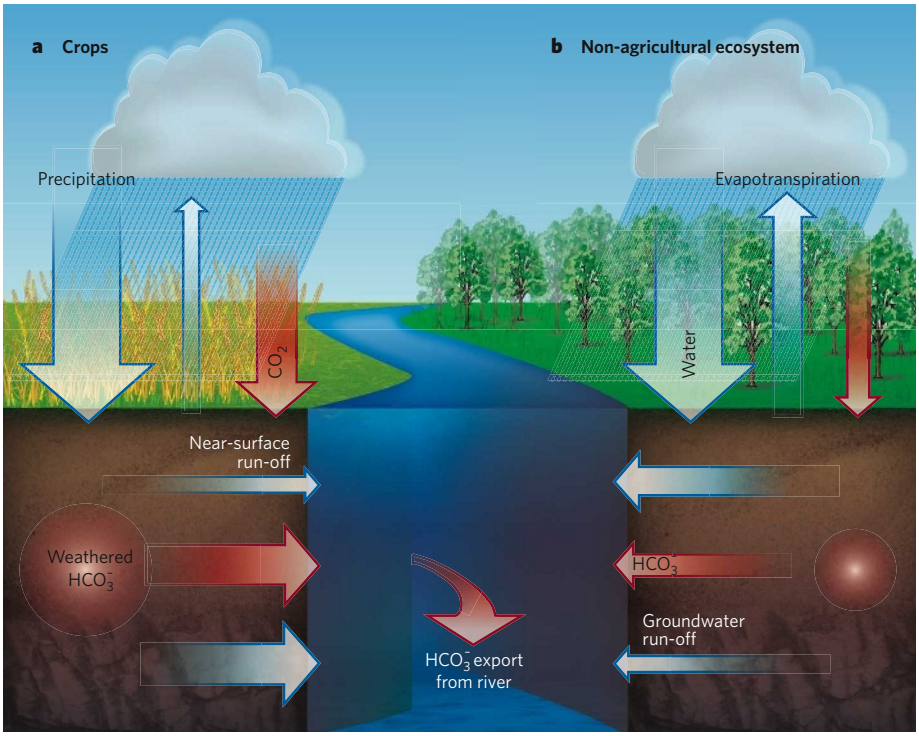

Figure 1 | Carbon exchange and land-use change. Even with similar soil types and well-buffered (mineral-rich) bedrock material, water and CO_2 fluxes through soils in cropland (**a**) and non-agricultural ecosystems (**b**) can be very different. For the same precipitation rate, certain agricultural conditions (including drainage systems, crop type and tillage practice) result in a greater fraction of annual water flows occurring as groundwater run-off and a lower fraction occurring as evapotranspiration. The increase in groundwater run-off results in larger export to rivers of bicarbonate (HCO_3^-) derived from the consumption of atmospheric CO_2 during chemical weathering, as demonstrated by Raymond and colleagues' 100-year Mississippi time series[4]. Agricultural practices such as lime application might also increase the concentration of bicarbonate in soils and groundwater.

Raymond *et al.*[4] exploit alkalinity measurements taken at the water-treatment plants that supply the city of New Orleans with drinking water drawn from the Mississippi. Combined with information about river discharge from the US Geological Survey, these data provide an extraordinary 100-year record of monthly variability in water and bicarbonate export from North America's largest river. They show little change before the 1950s, but confirm the approximately 40% increase in bicarbonate export over the past 50 years previously assessed using an independent record[3].

To investigate the factors driving this increased annual flux, Raymond *et al.* separate out two possible mechanisms. First, there are increases in water discharge that increase total amounts of bicarbonate export, but imply no change in bicarbonate concentration.

Second, there are increases in bicarbonate flux at equivalent discharge values, representing net increases in mean bicarbonate concentration. The authors assess this second effect by normalizing annual bicarbonate flux to the long-term mean annual water discharge. They conclude that more than 60% of the increased bicarbonate flux results from increased concentrations, and not mainly from increased water discharge as was previously thought[3].

Alterations in how the watersheds of the Mississippi basin work seem to have driven the increased bicarbonate discharges of the past 50 years. This period coincides with agricultural intensification, and changes in crop type and land-management practices in the basin. One must bear in mind, however, that the data from New Orleans, near the mouths of the Mississippi, provide only a highly aggregated picture. So Raymond *et al.*[4] turn to an extensive sub-watershed data set of bicarbonate discharge, land use and precipitation distribution to probe the role of cropland extent, changes in hydrology and increased precipitation.

They find that increases in discharge in agricultural — but not grassland or forested — watersheds outpaced increases in precipitation. This conclusion agrees with recent hydrological studies[6] that found that agricultural changes in the Mississippi basin, especially the expansion of soya-bean row crops, might be reducing evapotranspiration and increasing the fraction of precipitation that reaches the groundwater and flows to streams (Fig. 1). Together with practices such as liming soil to neutralize acidity, this enhanced flow through deeper mineral-rich soils results in increased bicarbonate exports from agricultural areas. The authors suggest that more than 50% of the total increase in bicarbonate export in the past 50 years results from the direct effect of land-use changes. The influence of precipitation increase and CO_2 fertilization from atmospheric CO_2 increase is comparatively small. Agriculturally driven hydrological alterations will, however, magnify the effect of precipitation increases.

Does enhanced weathering tip croplands into becoming a net sink of atmospheric CO_2 in comparison with the situation in pristine ecosystems such as forests or grasslands? The answer is complex. First, the acceleration of weathering reported by Raymond *et al.*[4] is probably limited to mineral-rich soils and particular agricultural practices. More importantly, other direct human pressures must be considered. Besides the removal of biomass during conversion from pristine ecosystems, agricultural activities commonly lead to enhanced erosion of soils and loss of associated organic carbon, providing a potential source of CO_2 to the atmosphere through oxidation downstream[2]. Sedimentation in the reservoirs that are often built to support irrigation can, on the other hand, serve as a long-term sink for eroded-soil organic carbon[2]. Consequently, the net global effect of agricultural soil erosion on atmospheric CO_2 remains contentious[2,7]. Land-management effects on river-carbon exports should be considered in parallel with the more extensively studied effects on nutrient exports. The Mississippi basin represents a notable example of both[8].

An intensification of groundwater flow and bicarbonate flux analogous to, but of smaller magnitude than, that highlighted by Raymond *et al.* seems to be occurring in some Arctic basins. Here, it is an effect of climate change on freeze–thaw cycles and permafrost coverage[9]. Thus, changes in chemical weathering caused both by direct human alterations and by the indirect effects of climate change seem to be a more significant component of regional and global perturbations of the carbon cycle than was thought.

This latest study[4] adds to mounting evidence that the levels of carbon export from developed watersheds today might not be representative of conditions before pressures such as intensive agriculture and acid deposition from industrial emissions became widespread[10]. Long biogeochemical time-series such as that from the New Orleans water-treatment stations are invaluable tools for discerning what the dominant controls on river-carbon exports are, and how they respond to large-scale human activities. ■

Emilio Mayorga is at the Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Road, New Brunswick, New Jersey 08901-8521, USA.
e-mail: emiliomayorga@gmail.com

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HIV/AIDS

Virus kept on a leash

Heinrich G. Göttlinger

Without its Vpu protein, the AIDS-associated virus HIV-1 becomes stuck to the surface of the human cell in which it has replicated. The mysterious factor that tethers HIV-1 is probably a cell-membrane protein.

Mammals have evolved various mechanisms to thwart the spread of intracellular pathogens. Thus, even if the infectious agent breaches the first lines of defence, the infected cells express restriction factors that suppress its further dissemination. One such restriction factor prevents HIV-1 from leaving infected cells and is counteracted by an accessory viral protein called Vpu. On page 425 of this issue, Neil and colleagues[1] characterize this factor and provide tantalizing clues about how it functions*.

To escape the infected cell, HIV-1 buds through the cell surface (thus becoming wrapped in an envelope derived from the host cell membrane) (Fig. 1a) and pinches off. But even if the virus reaches this stage of release, Vpu-deficient HIV-1 particles tend to remain trapped at the cell surface. What keeps them there has been a mystery.

The effect of Vpu on virus release has been perplexing, as it seems to be unrelated to the protein's other function of reducing cellular levels of CD4, the HIV-1 receptor on T cells of the immune system. Also, Vpu's effect on release does not seem to require other HIV-1 components, and its importance for virus release varies widely among cell lines.

*This News & Views article and the paper concerned[1] were published online on 16 January 2008.

It has emerged[2,3] that Vpu counteracts a human antiviral factor that suppresses HIV-1 release by tethering mature viral particles to the cell surface after they have completely pinched off. Such retention of HIV-1 particles at the surface of infected cells can also be induced by human interferon-α, a protein that 'jump-starts' a cell's antiviral defences[4]. Moreover, in an earlier study[5], Neil and colleagues found that Vpu counteracts the effect of interferon-α on HIV-1 release.

The authors now identify[1] an interferon-α-induced human protein that fulfils all the criteria for the tethering factor antagonized by Vpu. The protein, which they aptly name tetherin, is expressed only by cells that require Vpu for HIV-1 release. Decreasing tetherin levels in cells that normally produce this protein allows the release of Vpu-deficient viruses. Furthermore, tetherin expression in cells that normally lack this protein selectively inhibits the release of Vpu-deficient HIV-1. Neil and colleagues' findings suggest that tetherin is highly potent, with only minute quantities being enough to efficiently inhibit HIV-1 lacking Vpu.

How can tetherin entrap outgoing viral particles with such efficiency? Little is known about this small protein, but one aspect is clear — both ends of tetherin are inserted in the cell