# International Geosphere-Biosphere Programme

## Introduction

The International Geosphere-Biosphere Programme (IGBP) is a research programme that studies the phenomenon of global change (www.igbp.net). IGBP addresses the interactive physical, chemical and biological processes that define Earth-system dynamics, the changes that are occurring in these processes and the role of human activities in these changes. IGBP contributes to produce new knowledge on climate change as well as many other global environmental change issues by: a) coordinating research activities through the IGBP core projects; and b) by organising workshops and synthesis activities that bring together scientists from a wide range of disciplines. The core projects under IGBP's stewardship study the land, the atmosphere, the oceans and the interfaces among these. They also address the carbon and water cycles as well as future and past global changes. IGBP works closely with the Intergovernmental Panel on Climate Change (IPCC).

## Research highlights

### A) Recent papers on climate extremes

**No pause in extremes**
The world's landmasses have had no respite from extremely hot days: the number of such days per year has continued to rise during the past three decades, according to a recent commentary published in *Nature Climate Change*. This is despite the apparent pause in the increase of global mean temperature during the past decade and half.

Several reasons – internal climate variability or heat uptake by the lower ocean, for example – were offered as possible explanations for the pause. The recent study points out that distinct temperature trends may nevertheless be discernible when different regions and seasons are considered. The analysis focused on warm extremes over land as these are the most relevant when considering the impact of climate change. It found that the area of land that experienced extremely hot days increased since 1979. The frequency of the hottest days has increased continuously and there was no slowdown during the past couple of decades.

The increasing frequency of the hottest days over land hints at positive feedbacks such as those arising from soil moisture deficits. Such feedbacks mean that the trends in temperature extremes might diverge from those in global mean temperature. The study thus cautions against overinterpreting the trend in global mean temperature as an indicator of the impacts of climate change.

Seneviratne S *et al*. (2014) *Nature Climate Change* 4: 161-163. doi:10.1038/nclimate2145.

**Climate extremes and the carbon cycle**
Recent IPCC assessments conclude that we can almost certainly expect more heat waves by the end of this century. Not only that, many regions will also experience an increase in the likelihood of heavy precipitation or droughts in the future. Climate extremes can affect the terrestrial carbon cycle: one example is the 2003 European heat wave, which released carbon that had accumulated over several years.

Two recent studies (Reichstein *et al*. 2013, Zscheischler *et al.* 2013) reported that disturbances to the carbon cycle led to around 3 Gigatons per year less carbon taken up by photosynthesis during the last decade; this is roughly equivalent to the annual net land carbon uptake in the last decade. At least 80% of these disturbances were related to climate extremes and their effects – droughts, heat waves, cold spells, heavy precipitation and fire – of which droughts were the most important. Events involving multiple stressors tended to have a disproportionally larger effect. 200 of the largest carbon-cycle disturbances, occupying only 8% of the surface area on average, explained more than 80% of the global interannual variability of carbon uptake by vegetation. Extreme events may influence the year-to-year variations in the rate of increase of atmospheric carbon-dioxide concentration. However the estimates are subject to considerable uncertainties; this calls for a concerted effort to understand climate extremes and their impacts.

As climate extremes increase in frequency, intensity or duration we may expect substantial reductions in the quantities of carbon dioxide taken up by photosynthesis. Previous work has shown that year-to-year changes in net carbon uptake are driven more by photosynthesis than by respiration: this implies a positive feedback whereby climate change leads to reduced carbon uptake, which in turn exacerbates climate change (including climate extremes). Interestingly, higher carbon-dioxide concentrations in a future world are likely to lead to more efficient use of water by plants, which might help to alleviate the effect of droughts.

Reichstein M *et al*. (2013) *Nature* 500: 287-295.
Zscheischler J *et al*. (2013) *Ecological Informatics* 15: 66-73.

**Carbon cycle sensitivity to tropical temperature variations**
The carbon cycle is sensitive to interannual temperature variability in the tropical regions. A recent study published in *Nature* reports an almost two-fold increase in this sensitivity during the past five decades. The study was undertaken by researchers associated with IGBP's Land Ecosystem–Atmosphere Processes Study (iLEAPS). Tropical regions are under the scanner as carbon sinks in these regions are considered to be vulnerable to climate change, particularly to an increase in warming and drought. But limited data prevent a comprehensive evaluation of future changes to the sinks. This study was an attempt to harness insights from an analysis of the past five decades' worth of data.

The researchers calculated the sensitivity based on the relationship between the interannual variations in the growth rate of atmospheric carbon dioxide and the tropical mean annual temperature. Alternative explanations for the sensitivity increase – the effect of climate extremes or precipitation, for example – were ruled out. The results indicated an increase in sensitivity from 2.6±0.5 petagrams of carbon per year per degree celcius during 1960-1979 to 4.8±1.0 petagrams of carbon per year per degree celcius during 1992–2011. Droughts have increased in tropical regions during the past decades, which might explain the increase in carbon-cycle sensitivity. The exact mechanism remains unclear, but changes in soil moisture might have contributed by affecting evapotranspiration.

The researchers found that most terrestrial carbon cycle models did not capture the measured increase in carbon-cycle sensitivity. This might be because the models do not adequately represent soil temperature and moisture or the response of ecosystem respiration to climate. Although this finding calls into question the ability of the models to predict future changes in the carbon cycle, it must be borne in mind that on longer timescales other processes such as changes in soil carbon stocks, for example, are important in addition to the interannual variability of the atmospheric carbon-dioxide growth rate.

Wang X *et al*. (2014) *Nature* 506: 212-215. doi: 10.1038/nature12915

## B) Other recent papers

**2013 carbon budget and carbon atlas**
The Global Carbon Project (GCP) provides a comprehensive policy-relevant understanding of the global carbon cycle, encompassing natural and human dimensions. Each year GCP publishes the global carbon budget. The budget receives widespread media attention. In 2013, GCP launched the budget with a new online data analytic tool for the public, scientists and policymakers – the Global Carbon Atlas.

The 2013 carbon budget, which covers the year 2012, reported that fossil fuel emissions grew to 9.7 Gigatons of carbon (GtC) per year, 2.2 % above 2011. This reflects a continued growing trend leading to the largest increase in atmospheric $CO_2$. It was estimated that fossil-fuel emissions in 2013 would be 61% above those in 1990. Global CO2 emissions were dominated by emission from China (27%), the USA (14%), the EU (28 member states; 10%) and India (6%).

GCP reported that global cumulative $CO_2$ emissions would reach about 535 ± 55 GtC for the period between 1870 and 2013, about 70% from fossil fuel and 30% from land use change (145 ± 50 GtC). During this period land and ocean sinks were stable or grew. Current trajectories of fossil fuel emissions continue to track some of the most carbon intensive emission scenarios used in the IPCC. The current trajectory is tracking the Representative Concentration Pathway 8.5 of the latest family of IPCC scenarios that takes the planet's average temperature to about 3.2°C to 5.4°C above pre-industrial times by 2100.

The Global Carbon Atlas, launched in November at the UNFCCC climate negotiations, received 25,000 unique visits in its first week. The atlas was designed to be one of the major interfaces between GCP research and three distinct audiences: the general public; policy makers, NGOs and the corporate world involved in climate-change policy and affairs; and researchers with model and other flux and pool carbon data.

Le Quéré C. *et al*. (2013) *Earth System Science Data* 5: 165-185. doi:10.5194/essd-5-165-2013.
Kirschke S. *et al*. (2013) *Nature Geoscience* 6, 813–823.

http://www.globalcarbonproject.org/carbonbudget/

**2013 methane budget**
In 2013 the Global Carbon Project published the most comprehensive study yet of global methane: the study, published in the journal *Nature Geoscience*, showed that human activities are emitting as much methane as all natural sources together, largely from fossil fuel extraction and processing, livestock and rice cultivation. Methane is also the second most important greenhouse gas, and is responsible for about 20% of the direct warming caused by long-lived gases since pre-industrial times.

Atmospheric methane was stable from the late 1990s to 2006, but the period after that has witnessed a renewed rise. The factors responsible for this trend had been unclear until recently. Dr Pep Canadell, a co-author on the study, said that the stabilization was “most likely due to decreasing-to-stable fossil fuel emissions, particularly industrial and mining fugitive emissions and emissions from rice cultivation, combined with stable-to-increasing microbial emissions. Since 2006 to the present, the rise in natural wetland emissions and fossil fuel emissions are likely to explain the renewed increase in global methane levels.

The study found that human sources of methane emissions account for 50–65% of total emissions. By including natural geological methane emissions such as seeps in the Arctic Ocean that were not accounted for in previous budgets, the fossil component of the total methane emissions such as those related to leaks in the fossil-fuel industry and natural geological leaks were estimated to amount to about 30% of the total methane emissions.

Long-term trends in methane emissions are dominated by trends in agriculture (largely rice cultivation and livestock) and landfills, now responsible for ~60% of all emissions from human activities, followed by emissions from fossil fuels at ~30%. Methane hydrates and permafrost soils are estimated to play a very small role in the global budget of methane, but their contribution can accelerate under global warming. Dr Canadell said the potential intensive exploitation of natural gas from shale formations around the world may lead to significant additional methane release into the atmosphere, although the potential magnitude of these emissions is still debated.

"Such additional emissions, and combustion of this “new” fossil fuel source, may offset mitigation efforts and accelerate climate change." In the longer term, the thawing of permafrost or hydrates could increase methane emissions significantly, and introduce large positive feedbacks to long-term climate change. A better quantification of the global methane budget, with regular updates as done for carbon dioxide, will be key to both embracing the opportunities and meeting the challenge," he said.

Kirschke S *et al*. (2013) *Nature Geoscience*, doi:10.1038/ngeo1955

Global Carbon Project (2013) Methane budget and trends 2013.
http://www.globalcarbonproject.org/methanebudget

**Ocean acidification summary for policymakers published**

IGBP and partners launched the Ocean Acidification Summary for Policymakers at the UN climate negotiations in Warsaw, November 2013. The summary is based on findings from the world's largest gathering of experts on ocean acidification: the 2012 Ocean in a High-$CO_2$ World symposium. Experts conclude that marine ecosystems and biodiversity are likely to change as a result of ocean acidification, with far-reaching consequences for society. Based on projections, the acidity of the world's oceans may increase by around 170% by the end of the century bringing potentially significant economic losses. People who rely on the oceans' ecosystem services – often in developing countries – are especially vulnerable.

Author and symposium chair Ulf Riebesell said: "What we can now say with high levels of confidence about ocean acidification sends a clear message. Globally we have to be prepared for significant economic and ecosystem-service losses. But we also know that reducing the rate of carbon-dioxide emissions will slow acidification."

One outcome emphasised by experts is that if society continues on the current high emissions trajectory, coldwater coral reefs, located in the deep sea, may be unsustainable and tropical-coral-reef erosion is likely to outpace reef building this century. However, significant emissions reductions to meet the two-degree target by 2100 could ensure that half of surface waters presently occupied by tropical coral reefs would remain favourable for their growth. The summary makes 21statements about ocean acidification with a range of confidence levels from "very high" to "low".

The report, supporting materials and graphics are available from http://www.ocean-acidification.net.

**Aerosols helped to ameliorate the greenhouse effect**

Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) models assess short-lived climate change drivers in present climate models, specifically those that include aerosols. By analyzing 10 ACCMIP models researchers found that aerosol effective radiative forcing masks a substantial percentage of late 20th and early 21st century global greenhouse forcing. Regionally this has resulted in negative net forcing over the majority of industrialized and biomass-burning regions through 1980, with strongly negative forcing over east and southeast Asia by the year 2000. The researchers further found strongly positive net forcing by 1980 over the Arctic and Australia as well as most deserts and tropical oceans. They discerned a subsequent trend in increased positive forcing globally, both in terms of magnitude and area.

Shindell D T (2013) *Atmospheric Chemistry and Physics*, doi: 10.5194/acp-13- 2939-2013.

**Changes to the nitrogen cycle during the last deglaciation**

The limited supply of nitrogen in bioavailable forms, most of which is $NO_3$, is the primary nutritional constraint on the marine ecosystem. As Earth started warming after the peak of the last ice age, 18,000 years ago, the ocean's nitrogen cycle began speeding up, eventually stabilizing 10,000 years later but at a faster rate. The result confirms the ocean is an effective self-regulator with respect to nitrogen, but reaching equilibrium after a disturbance can take hundreds or thousands of years – a concern given the scale and speed of current anthropogenic change. An international research group recently assembled nitrogen isotope data from surface sediments and sediment cores from around the world to construct a fuller picture of the perturbed nitrogen cycle and to compare the results with ocean biogeochemical models.

In the self-regulating global ocean, nitrogen fixation and denitrification must balance phytoplankton growth and the amount of dissolved oxygen that allows life to exist in the ocean interior. The new global data, published in the journal *Nature Geoscience*, show that denitrification picked up rapidly as the ice sheets started melting and climate warmed, requiring ecosystems to adapt to the gradually diminishing supply of nutrients and oxygen. But by the time the largest ice sheets were gone in the early Holocene, nitrogen fixation had sped up and compensated for the loss of nitrogen from denitrification. The ocean had apparently stabilised itself in its new, warmer state, in which the overall nitrogen cycle was running faster. The results suggest that the self-regulating ocean can balance the nitrogen cycle on the global scale, but that achieving the new balance takes many centuries to millennia.

Galbraith E D., Kienast M and NICOPP working group members (2013) *Nature Geoscience*, doi 10.1038/NGEO1832.

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