



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 research addresses the interactive physical, chemical and biological processes that define Earth-system dynamics, changes that are occurring in these processes and the role of human activities in these changes. IGBP contributes to new knowledge on climate change, as well as many other global environmental change issues, by coordinating research activities through the IGBP core projects and by organising workshops and synthesis activities that bring together scientists from a wide range of disciplines. The eight core projects of IGBP address processes on land, in the atmosphere and oceans, and at the interfaces between these. The projects include two integrative crosscutting projects that address future and past global changes. Many IGBP activities have considerable collaboration with other partner programmes.

Research highlights

Ocean acidification through geological time

A recent study suggests that the oceans may be acidifying faster today than they did in the last 300 million years. Based on a review of hundreds of paleoceanographic studies, the study found evidence for only one period in the last 300 million years when the oceans changed nearly as fast as today: the Paleocene-Eocene Thermal Maximum.

About 56 million years ago, a surge of carbon into the atmosphere warmed the planet and turned the oceans corrosive. In about 5,000 years, atmospheric carbon dioxide doubled to 1,800 parts per million (ppm), and average global temperatures rose by about 6°C, and ocean acidity – its pH – may have fallen by as much as 0.45 units. As many as half of all species of benthic foraminifera, a group of one-celled organisms that live at the ocean bottom, went extinct, suggesting that deep-sea organisms higher on the food chain may have also disappeared.

In the last hundred years, rising carbon dioxide from human activities has lowered ocean pH by 0.1 unit, an acidification rate at least 10 times faster than 56 million years ago. The Intergovernmental Panel on Climate Change (IPCC) predicts that pH will fall another 0.2 units by 2100, raising the possibility of substantial changes in marine ecosystems.

Hönisch B et al (2012) The geological record of ocean acidification. *Science* 335, 1058

See also the following publication for a synthesis of the latest knowledge on ocean acidification:

Ocean Acidification, edited by JP Gattuso and L Hansson, Oxford University Press

Synthesis of the most recent information about the consequences of ocean acidification to inform both future research agendas and marine management policy.

Erosion along the Arctic coasts

A new classification of the Arctic Ocean coastline, published recently, assembled information on 1315 coastline segments totaling more than 100,000 km. The mean erosion rate was found to be about 0.5 m/year, with high local and regional variance, and rates as high as 30 m/year were reported in some places. Erosion rates show a weak positive correlation with volumetric ground ice content ($r^2=0.23$). The highest mean erosion rates in the Arctic Ocean occur in the Beaufort Sea, the East Siberian Sea and the Laptev Sea. Rapid warming, loss of sea ice and potential for increased wave energy in the Arctic suggest a high potential for more rapid coastal erosion, particularly on ice-rich coastal plain shores, threatening the stability of built infrastructure in coastal communities and the integrity of coastal ecosystems supporting subsistence economies.

Lantuit, H et al (2011). The Arctic Coastal Dynamics database: a new classification scheme and statistics on Arctic permafrost coastlines, *Estuaries and Coasts*. DOI information: 10.1007/s12237-010-9362-6, published on-line 2011-02-01.

Related reference:

Forbes, D.L. (editor) (2011): *State of the Arctic Coast 2010: Scientific Review and Outlook*. International Arctic Science Committee (IASC), Land-Ocean Interactions in the Coastal Zone (LOICZ), Arctic Monitoring and Assessment Programme (AMAP), International Permafrost Association (IPA). Helmholtz-Zentrum, Geesthacht, Germany, 178 p. <http://arcticcoasts.org>.

REDD+ implementation in Africa

Several challenges will need to be overcome to pave the way for effective implementation of the UN-sponsored Reducing Emissions from Deforestation and forest Degradation (REDD) initiative in Africa, according to a recent analysis. Among the challenges are the existence of a number of redundant and parallel initiatives, and weak technical and institutional capacities.

REDD+ goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. According to the report, REDD+ implementation in Africa faces challenges from the prevalent socio-political context. Western notions of property rights, improved governance, local participation and sustainable development have at times proven to be contentious. Land tenure is a particularly tricky issue, for the complexity in Africa is incompatible with the conventional concept of property rights and there is little clarity about who – the state, local/traditional government and individuals – partake of the perceived benefits accruing from the implementation of REDD+ schemes. The report's authors state that the regulations and expectations associated with REDD+ need to better reflect the ground realities in Africa.

Mbow C *et al.* (in press) Challenges and Prospects for REDD+ in Africa: Desk Review Of REDD+ Implementation in Africa. *GLP Report 5*. GLP-IPO, Copenhagen.

Co-benefits of reducing black carbon and tropospheric ozone precursors

The harmful health effects of black carbon and tropospheric ozone are well known, as is the adverse effect of the latter on crops. But their climate effects are complex and less well understood. A study published in *Science* now suggests that cutting down on black carbon and methane – a precursor of tropospheric ozone – could prove to be a win-win solution. Besides leading to obvious health benefits, it could reduce global mean warming by around 0.5°C by the middle of this century.

The research team first used a model to test the effectiveness of hundreds of pollution control measures. Based on the climate impact of the measures, they came up with a list of measures that both improve air quality as well as reduce warming. Of the top 14 measures that together achieve most of the reduction in warming, 7 address black carbon and 7 address methane. The team's analysis suggests that if implemented simultaneously with substantial reductions in

carbon-dioxide emissions, it might be possible to limit global warming to $<2^{\circ}\text{C}$ during the coming 60 years.

Whereas the benefits in terms of reduced warming would be spread more or less evenly around the world, the benefits for health and improved crop productivity would be particularly marked in certain parts of the world. For example, hundreds of thousands of premature deaths could be avoided in India and China, and along with the United States, these countries could also witness large increases in crop yields. The study's authors state that the co-benefits of reducing black carbon and methane emissions could provide strong incentives for appropriate policies.

The study emerged from the UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone.

Shindell D et al. (2012) Simultaneously mitigating near-term climate change and improving human health and food security. *Science* 355: 183-189.

Link between nitrogen and climate probed

Human perturbations of the nitrogen cycle cause adverse health and environmental effects but might have a positive short-term impact on Earth's climate (small net cooling) suggests a synthesis of recent work initiated by IGBP. There are many complicating factors, however, and the report resulting from this activity points out that current knowledge is insufficient to fully quantify the complex links between nitrogen and climate.

During pre-industrial times, the nitrogen and carbon cycles were in a state of equilibrium. But since humans began converting atmospheric nitrogen into reactive forms to make fertilisers, the nitrogen cycle has been profoundly altered. An effect on the carbon cycle, and thus climate, was to be expected. The direct effects include warming due to the release of nitrous oxide, a potent greenhouse gas, whereas indirect effects include stimulating the growth of terrestrial vegetation that sequesters carbon, thereby causing cooling. A key challenge is to quantitatively evaluate whether the overall effect is one of warming or cooling. The answer might depend on the timescales considered: cooling in the short term and warming in the long term.

Erisman J W et al (2011). Reactive nitrogen in the environment and its effect on climate change. *Current Opinion in Environmental Sustainability* 3: 281–290.

Research relevant to greenhouse-gas emissions and removals from coastal and marine ecosystems

Carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are among the most important greenhouse gases associated with coastal and marine ecosystems. Coastal and marine ecosystems are diverse and there are many region-specific characteristics; the vast amount of literature on these environments is difficult to summarise briefly. Nevertheless, below we first provide a quick overview, followed by a couple of examples from recent research findings from IGBP's Surface Ocean-Lower Atmosphere Study (SOLAS) project.

After considerable research during the past years, we now know with increasing certainty that on a global scale the margins of continents – the sites of coastal ecosystems – are net sinks of CO_2 , absorbing approximately 0.36 Pg C per year (Chen 2010 and references therein). However, it is important to bear in mind that there is considerable spatial and temporal variation. For example, many estuaries and mangrove ecosystems are net sources, although the areas involved are much smaller than the continental margins as a whole.

In contrast, continental margins tend to be net sources of CH_4 (approximately 0.1×10^{12} moles per year) to the atmosphere (Chen 2010 and references therein). The most important source of the methane is the fermentation of organic-rich sediments along the continental shelf.

However, methane hydrate deposits can also serve as important sources in certain regions. Recent observations from the Arctic (Shakhova et al., 2010) show that methane is leaking out of reservoirs in the seabed along the East Siberian Arctic Shelf, aided by thawing of permanently frozen ground due to exposure to warming in the region. Methane is a potent greenhouse gas and large deposits are predicted to occur in the seabed in the Arctic region. In view of increasing warming of the Arctic, methane emissions might increase considerably in the future and it is important to monitor this region carefully.

Continental margins also release N₂O to the atmosphere (net sources), a process that is expected to intensify as nitrogen from agriculture and energy production is transported by rivers to coastal regions. Globally, N₂O emissions from estuaries roughly doubled between 1970 and 2000 (from 0.14 to 0.28 Tg N/yr) due to increased river N loading from anthropogenic sources (Kroeze et al., 2010). The open waters of continental shelves are also a source of N₂O, releasing about 0.6 Tg N per year to the atmosphere associated primarily with natural inputs of N from the open ocean. However, rivers inputs also contribute.

Emissions of N₂O from estuaries and continental shelves can also increase as a consequence of the spread and intensification of eutrophication and hypoxia (Codispoti 2010). Both N loading and increasing temperature are associated with the expansion of hypoxia. However, increases in N₂O emissions associated with the expansion of hypoxia are not well quantified. A recent review suggests that N₂O production in oxygen-deficient zones is globally significant (especially in the open ocean), but awaits quantification (Naqvi et al. 2010). For the open ocean, atmospheric deposition of reactive nitrogen due to human activities is estimated to lead to N₂O emissions of 1.6 Tg N per year in the year 2000 (Duce et al. 2008). Those estimates are very preliminary and are in the process of being refined.

Codispoti L A (2010). Oceans. Interesting times for marine N₂O. *Science* 327:1339-1340.

Kroeze C, Dumont E and Seitzinger S P (2010). Future trends in emissions of N₂O from rivers and estuaries. *Journal of Integrative Environmental Sciences* 7: 71-78.

Chen C-T A (2010). Cross-boundary exchanges in of carbon and nitrogen in continental margins. *In: Liu K.-K et al (eds), Carbon and Nutrient Fluxes in Continental Margins. Global Change – The IGBP Series. Springer-Verlag Berlin Heidelberg 2010. 561-574 pp.*

Shakhova N et al (2010). Geochemical and geophysical evidence of methane release over the East Siberian Arctic Shelf. *Journal of Geophysical Research* 115: C08007, doi:10.1029/2009JC005602.

Seitzinger S P and Kroeze C (1998). Global distribution of nitrous oxide production and N inputs in freshwater and coastal marine ecosystems. *Global Biogeochemical Cycles* 12: 93.

Duce R A et al. (2008). Impacts of atmospheric anthropogenic nitrogen on the open ocean. *Science* 320: 893-897.

Naqvi S W A et al (2010). Marine hypoxia/anoxia as a source of CH₄ and N₂O. *Biogeosciences* 7: 2159–2190.

Arctic coastal waters a net sink of CO₂

Annual air–sea exchange of CO₂ in Young Sound, NE Greenland was estimated using *p*CO₂ surface-water measurements during summer (2006–2009) and during an ice-covered winter (2008). All surface *p*CO₂ values were below atmospheric levels indicating an uptake of atmospheric CO₂. The observation that the surface water is undersaturated in *p*CO₂ in both summer and winter implies that Young Sound is a sink for atmospheric CO₂ on an annual scale. The average annual uptake of atmospheric CO₂ was estimated at 2.7 mol CO₂/m² per year for the study area, which is lower than estimates from the Greenland Sea.

A warmer future climate is expected to increase the amounts of melt water, which would act to lower surface-water $p\text{CO}_2$ levels. As these main factors identified to cause low surface-water $p\text{CO}_2$ levels all respond to warming, it is highly likely that annual air-sea CO_2 exchange in Young Sound, and potentially the East Greenland coastal region, will change in response to global warming.

Sejr, M. K., Krause-Jensen, D., Rysgaard, S., Sørensen, L. L., Christensen, B. P., Glud, R. N., 2011. Air-sea flux of CO_2 in Arctic coastal waters influenced by glacial melt water and sea ice, *Tellus B.*, 63B, pp.815-822.

<http://solas-int.org/aboutsolas/organisationaandstructure/solasnetwork/reportsdenmark/DenmarkJan2012.pdf>.

Carbon exported from Nordic Seas to deep North Atlantic

A recent study shows that the dominant exchange of carbon in the Nordic Seas region takes place across the Greenland-Scotland Ridge. The Nordic Seas are the ocean area connecting the North Atlantic with the Arctic Ocean. Horizontal transport of carbon in the region is almost two orders of magnitude larger than the uptake from the atmosphere: 12.3Gt of carbon is imported annually and 12.5Gt carbon is exported. An annual export of about 0.09Gt anthropogenic carbon (excess carbon resulting from perturbations of the “natural” carbon cycle) is expected from the Nordic Seas to the deep North Atlantic. This is a crucially important pathway for removing the climatically important CO_2 from the atmosphere to the interior ocean and thus helps moderate the potential global warming of global fossil fuel combustion and land-use change.

Jeansson, E., Olsen, A., Eldevik, T., Skjelvan, I., Omar, A. M., Lauvset, S. K., Nilsen, E. Ø. R., Bellerby, G. J., Johannessen, T. and Falck, E., 2011. The Nordic Seas carbon budget: Sources, sinks and uncertainties. *Global Biogeochemical Cycles*, doi: 10.1029/2010GB00396.

<http://solas-int.org/aboutsolas/organisationaandstructure/solasnetwork/reportsnorway/NorwayJan2012.pdf>.

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